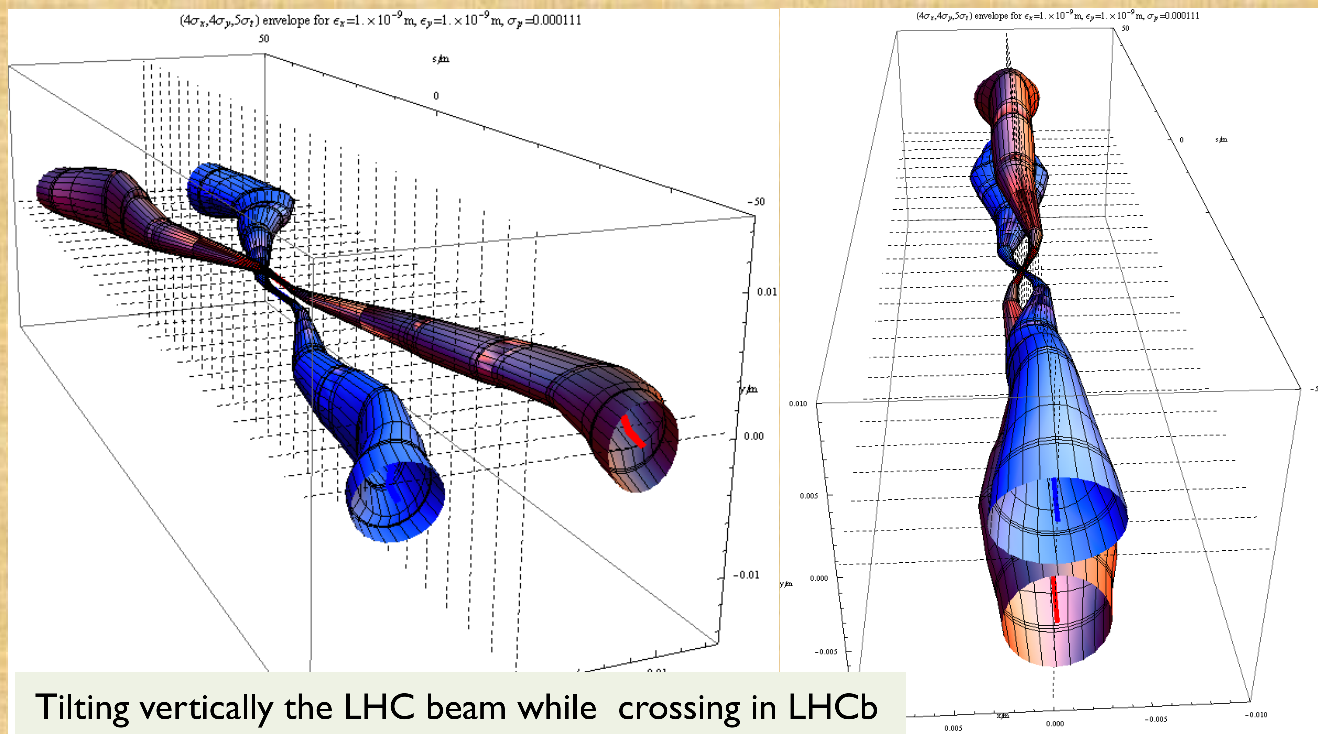
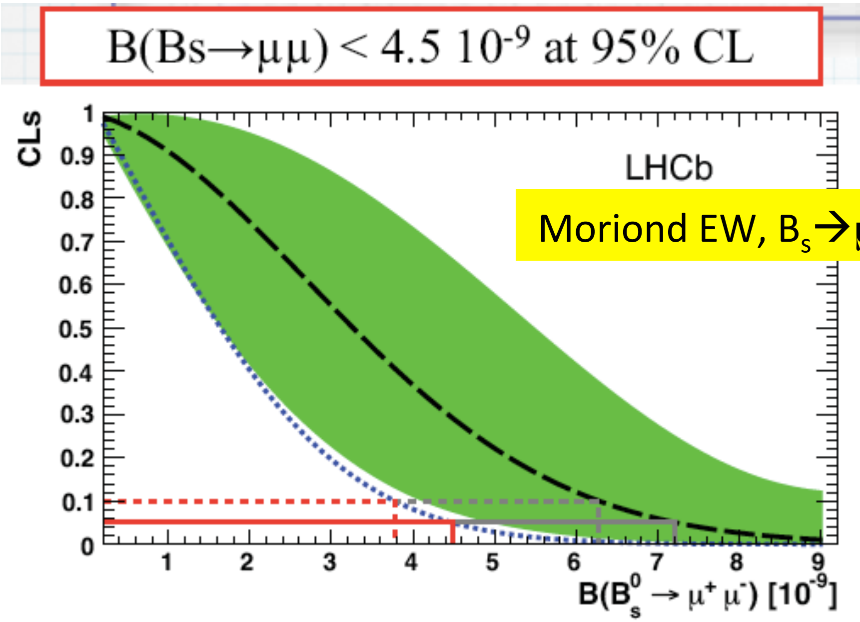
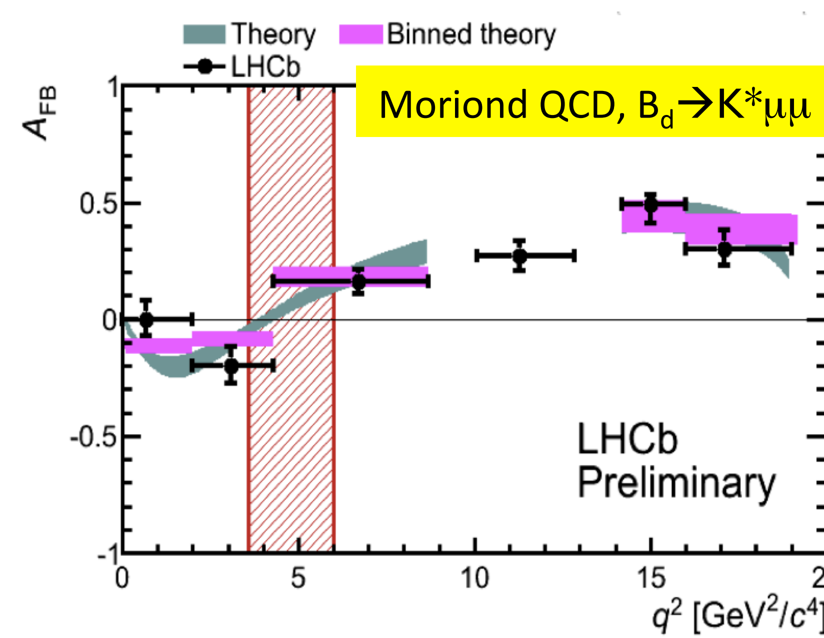
Status of the LHCb Experiment

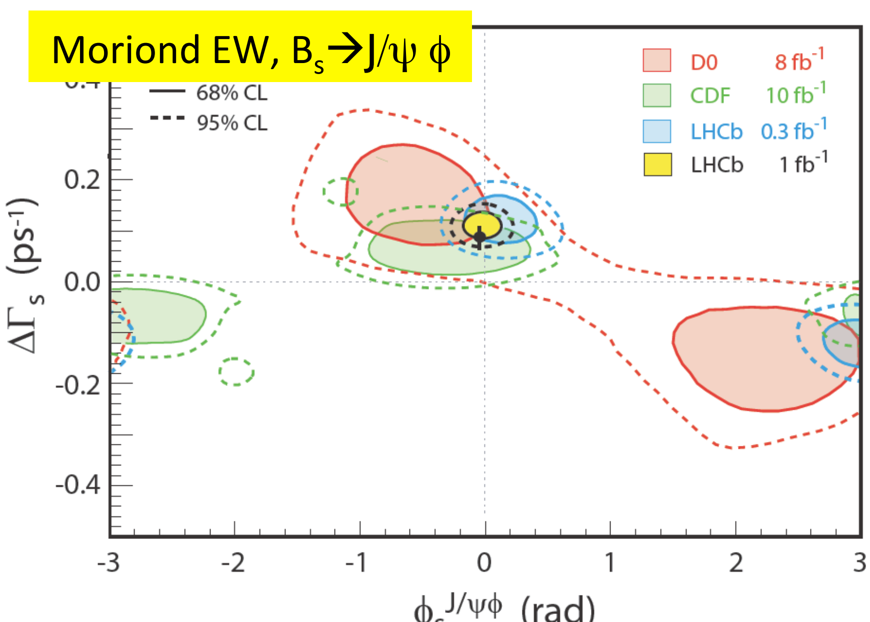


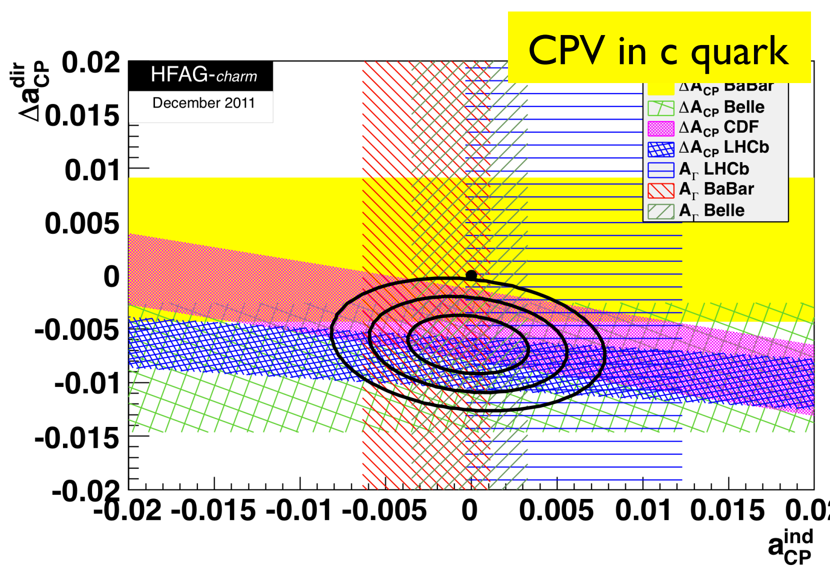
Tilting vertically the LHC beam while crossing in LHCb

Highlights of LHCb results from 2012 Winter Conferences (1)



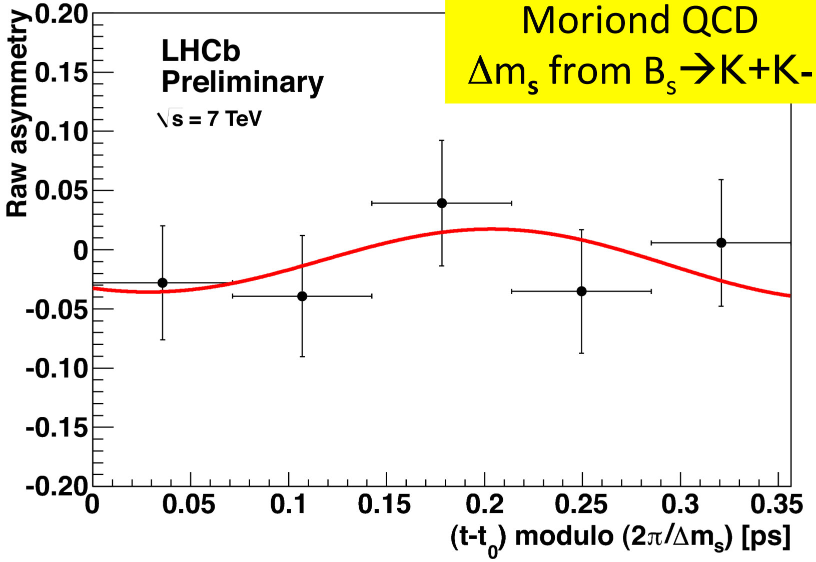




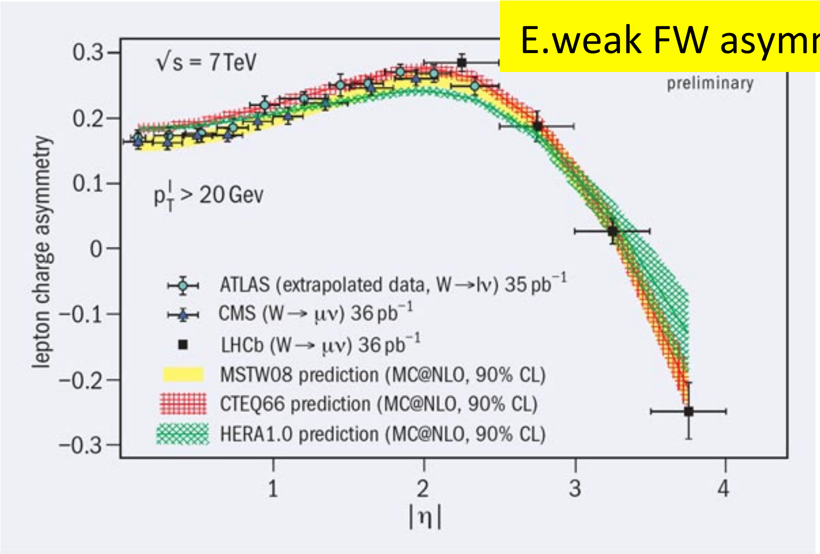


Highlights of LHCb results from 2012 Winter Conferences (II)

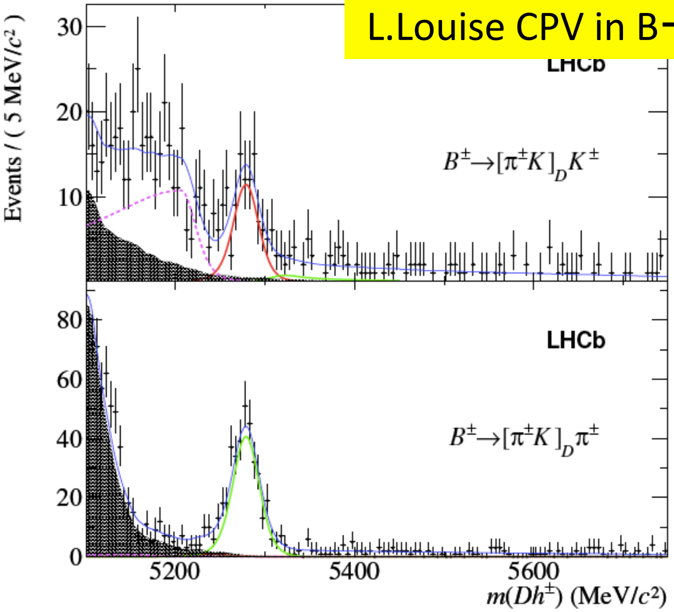
Moriond QCD
Δm_s from $B_s \to K+K-$



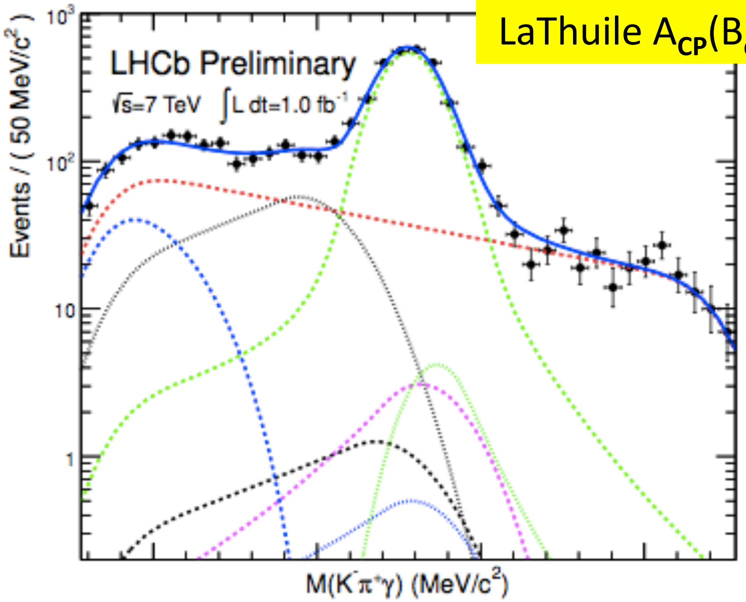
E.weak FW asymm.



L.Louise CPV in $B \to DK$



LaThuile $A_{CP}(B_d \to K^*\gamma)$



Shutdown activities (infrastructures)

- Consolidation of Electrical Network

~ 5 km cable - 2x2MVA new transformers
New switchboards
→ More Redundancy, flexibility, reliability
→ Max down time in case of EBD or EXD failure: 1h

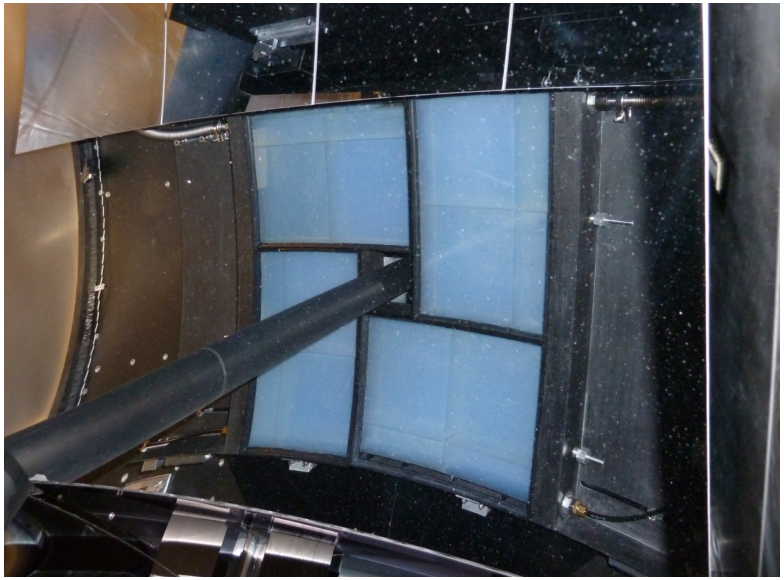
- Consolidation of detector cooling plants

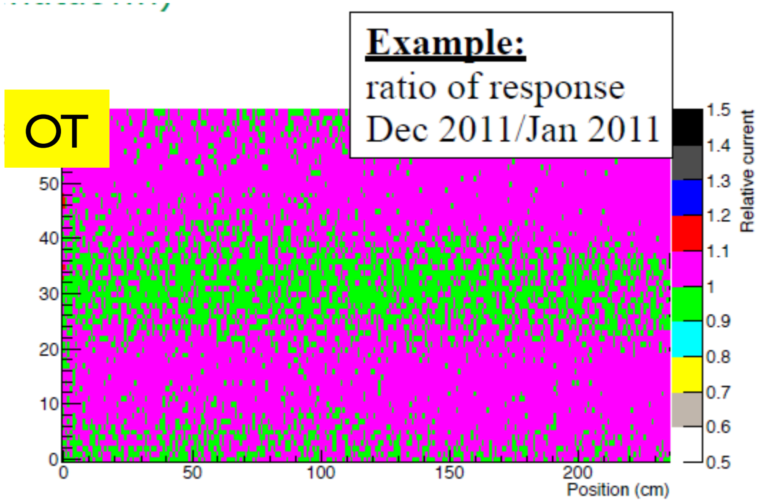
- Consolidation of IT & TT fridges

- Radioprotection survey

- Start preparing LS1 (with several maintenances but also in view of upgrade)

Shutdown activities (detectors)





Aerogel – installation of gas tight box to prevent C_4F_{10} contamination

TT - Electrostatic shielding improvement

IT – Survey with and w/o magnetic field, VCSEL exchange

OT – General maintenance and source scans for aging studies (NO AGING)

RICH – HPD exchange (37 in total)

CALO – Usual maintenance (PM and electronics)

Muon – New shielding (partial) for M5 chambers + general maintenance (chambers and electronics)

Online - +10% in CPU and upgraded disk space (for deferred trigger)

+ radiation tolerance & shielding upgrade studies (SiPM, SciFi, Ecal/Hcal modules)

Prospects for LHCb data taking in 2012

LHC running conditions

- $\sqrt{s}$ = 8 TeV (b-bbar cross section increases +15%)
- L ~ 4 10^{32} $cm^{-2}s^{-1}$ (in LHCb)
- Bunch spacing 50 ns (ok, this level of pileup is not an issue for LHCb)
- LHC crossing angle in LHCb in the vertical plane (fully symmetric with magnet swaps)

  → useful for the future (when spacing=25 ns)

LHCb running conditions

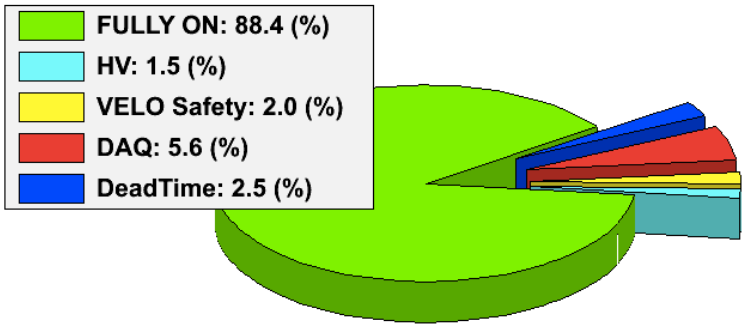
- Keep detector efficiency and data quality high
- L0 output ~ 1 MHz (maximum allowed)
- HLT output ~ 4.5 kHz (with upgraded farm [+10%] and better HLT trigger)

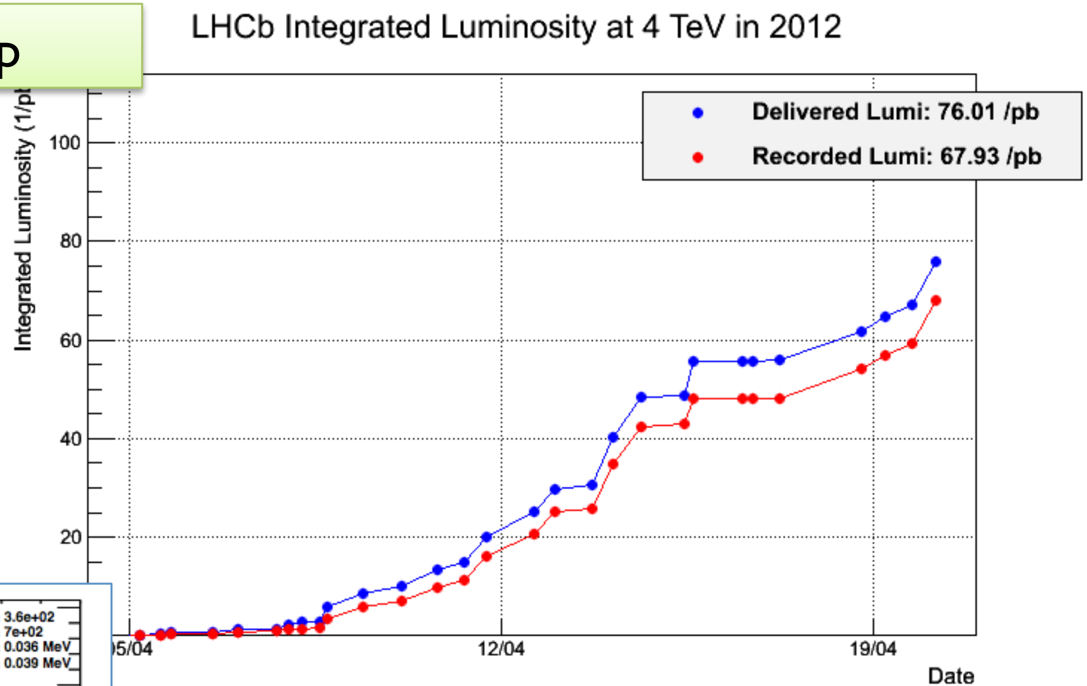
  → increase in yields of charm (K_s in HLT1) and in b-hadronic channels
- Deferred HLT event processing during LHC inter-fills (planning to gain at least another 10% in CPU power)

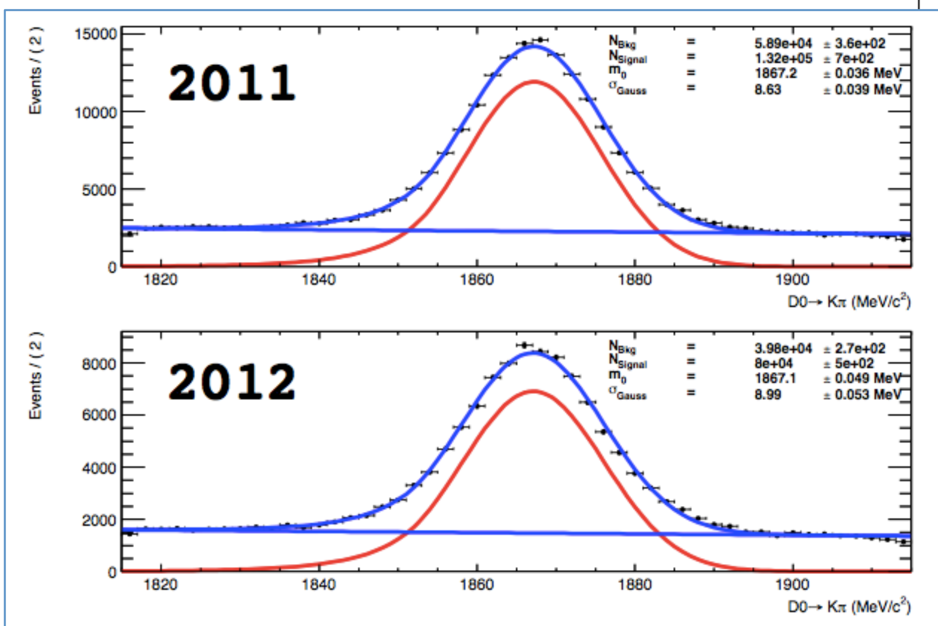
Considering the experience of 2011 → target of ≥ 1.5/fb on tape in 2012

- Expected increase in event yields in 2012
- Energy (better S/B) + improved HLT + more CPU ~ +20-30% (mainly had. decays)

2012 data taking startup







HLT-online reconstructed charm 2-body: same S/B, increased yield (amount under study)

Good startup of data taking: ~90% eff.
~60/pb of usable data collected

First week of collisions useful to:

- test vertical collision scheme in LHCb (delicate, but successful)
- L0 & HLT tuning (8 vs 7 TeV)
- test successfully HLT deferred trigger (at level of 10% CPU gain)

Performance w/o & during deferring

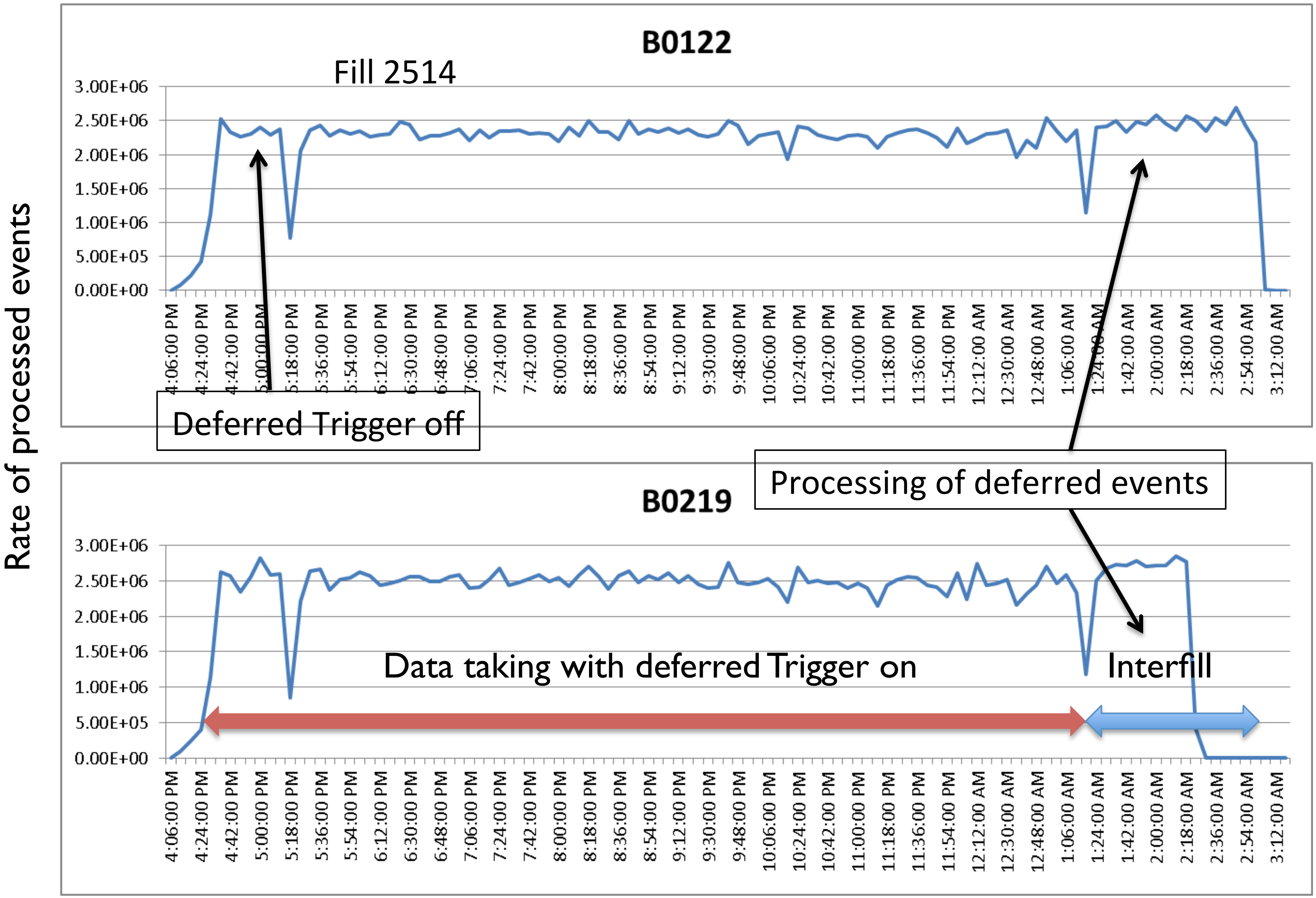


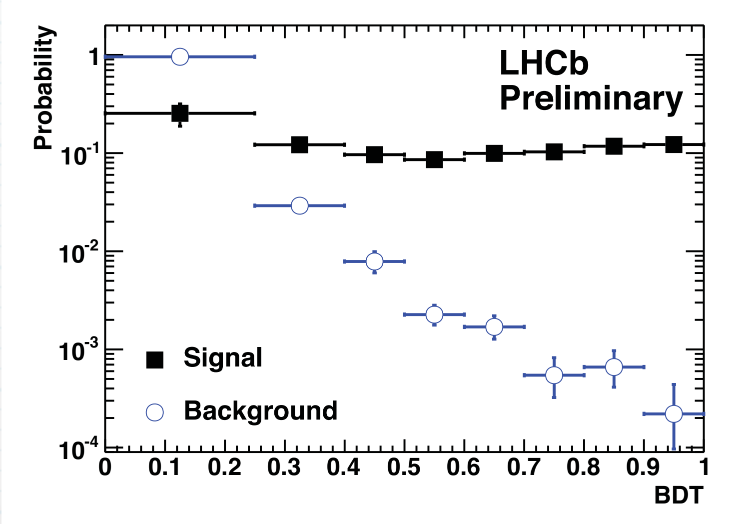
PHOTO CREDIT: D.M.STRAUB

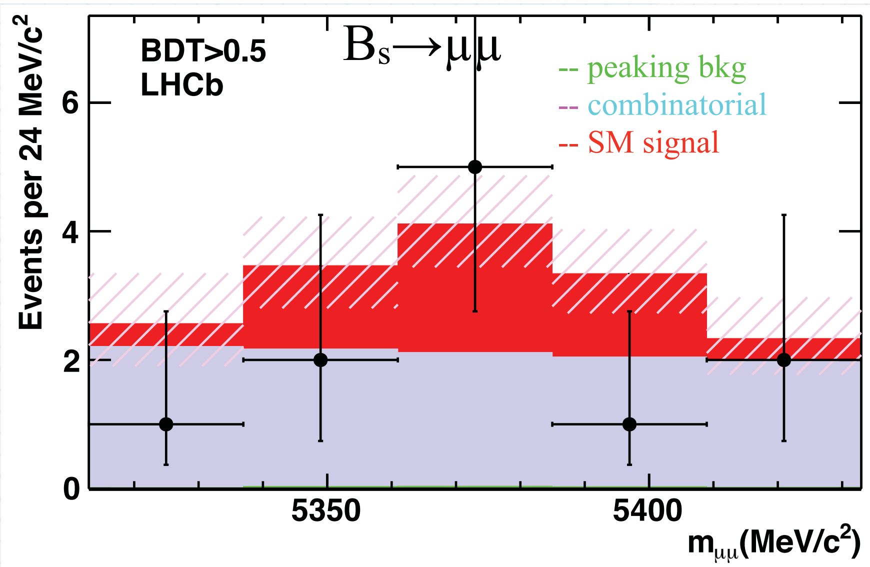
B mesons Rare Decays

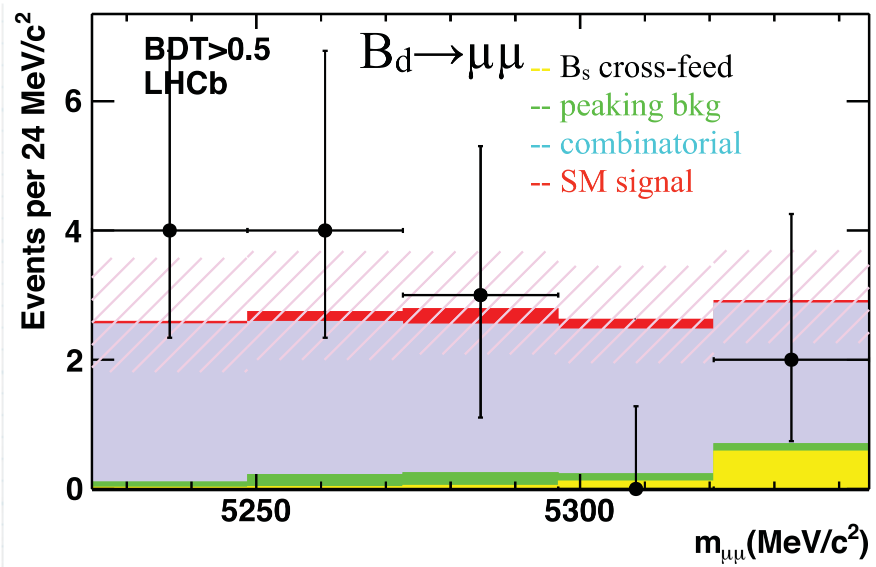
$B_{(s)} \to \mu\mu$

arXiv:1203.4493

- A multivariate discriminant BDT:
  - kinematical and geometrical variables
  - signal uniformly distributed [0,1]
  - trained with MC
  - estimated with data:
    - signal $B \to hh$ trigger unbias
    - background: $B_s \to \mu\mu$ sidebands

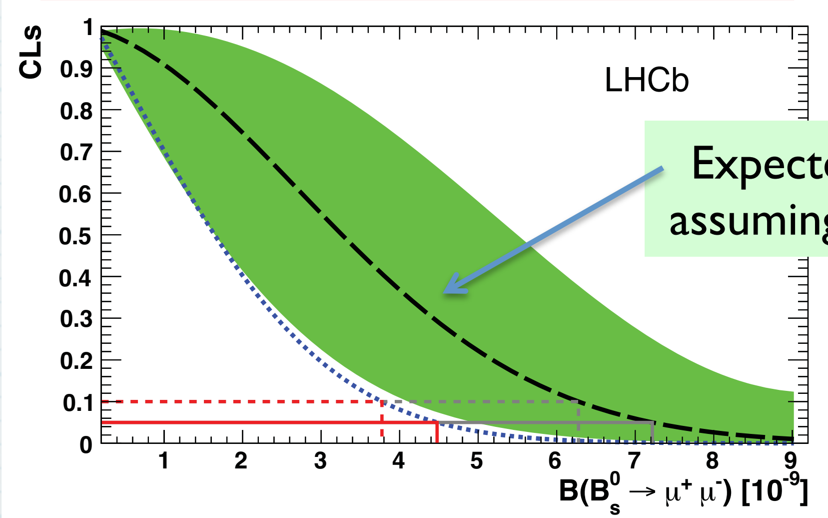




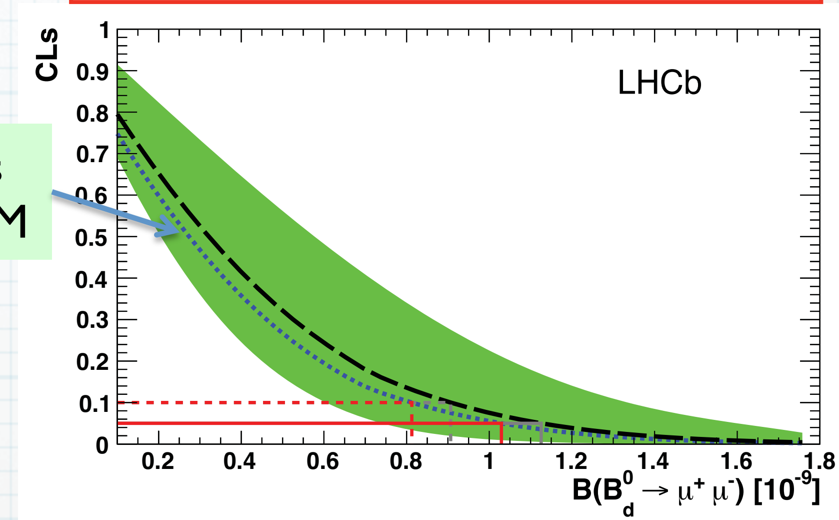


Events expected in the most sensitive region (BDT>0.5): 5.3 ($B_s \to \mu\mu$), 0.6 ($B_d \to \mu\mu$)

$B(B_s \to \mu\mu) < 4.5\ 10^{-9}$ at 95% CL



$B(B \to \mu\mu) < 10.3\ 10^{-10}$ at 95% CL



Expected limits assuming bck+SM

Mode	Limit	at 95 % CL
$B^0_s \to \mu^+\mu^-$	Exp. bkg+SM	7.2×10^{-9}
	Exp. bkg	3.4×10^{-9}
	Observed	4.5×10^{-9}
$B^0 \to \mu^+\mu^-$	Exp. bkg	1.1×10^{-9}
	Observed	1.0×10^{-9}

Observed limit is stronger than expected: if (true) BR equals SM, under-fluctuation of the signal

With 2.5/fb (expected at the end of 2012), still able to observe SM signal at 3 sigma

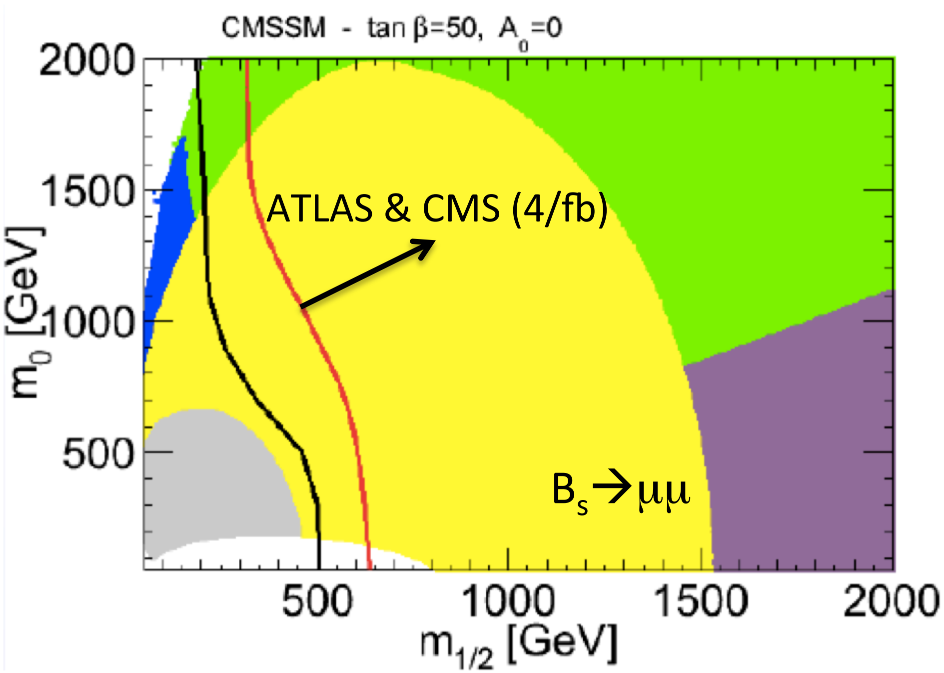
BR estimation:

simultaneous unbinned LL fit to the mass to the 8 BDT bins

$B(B_s \to \mu\mu) = (0.8^{+1.8}_{-1.3})\ 10^{-9}$

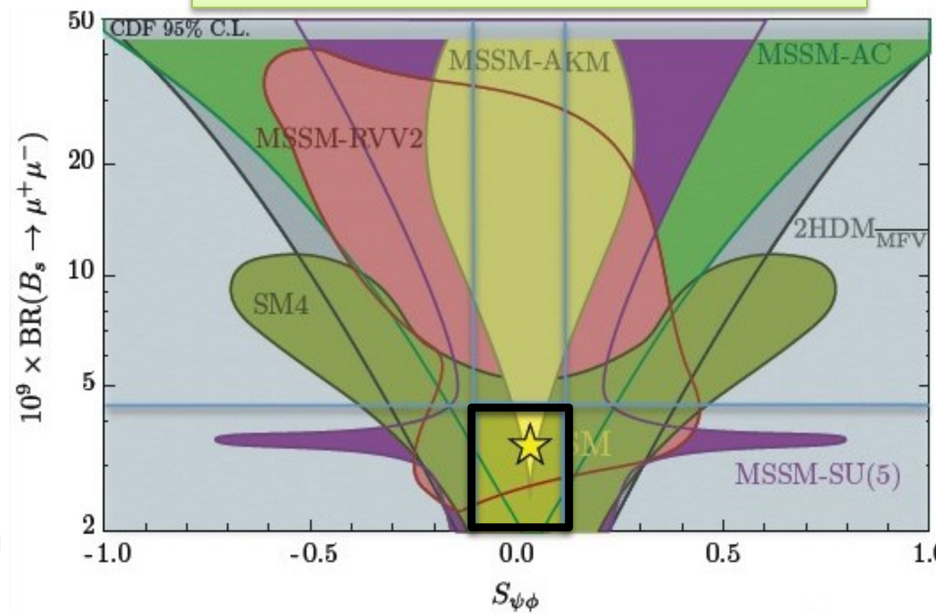
LHCb flavor results constraining New Physics

BR($B_s \to \mu\mu$) puts strong bounds on mass scale (at least in high *tan β* models), complementary to direct searches; LHCb results enter the SUSY fits and moreover put severe bounds on several models



N. Mazhoudi, Moriond QCD2012

Allowed region from $B_s \to \mu\mu$ and ϕ_s



D. Straub [arXiv:1107.0266]

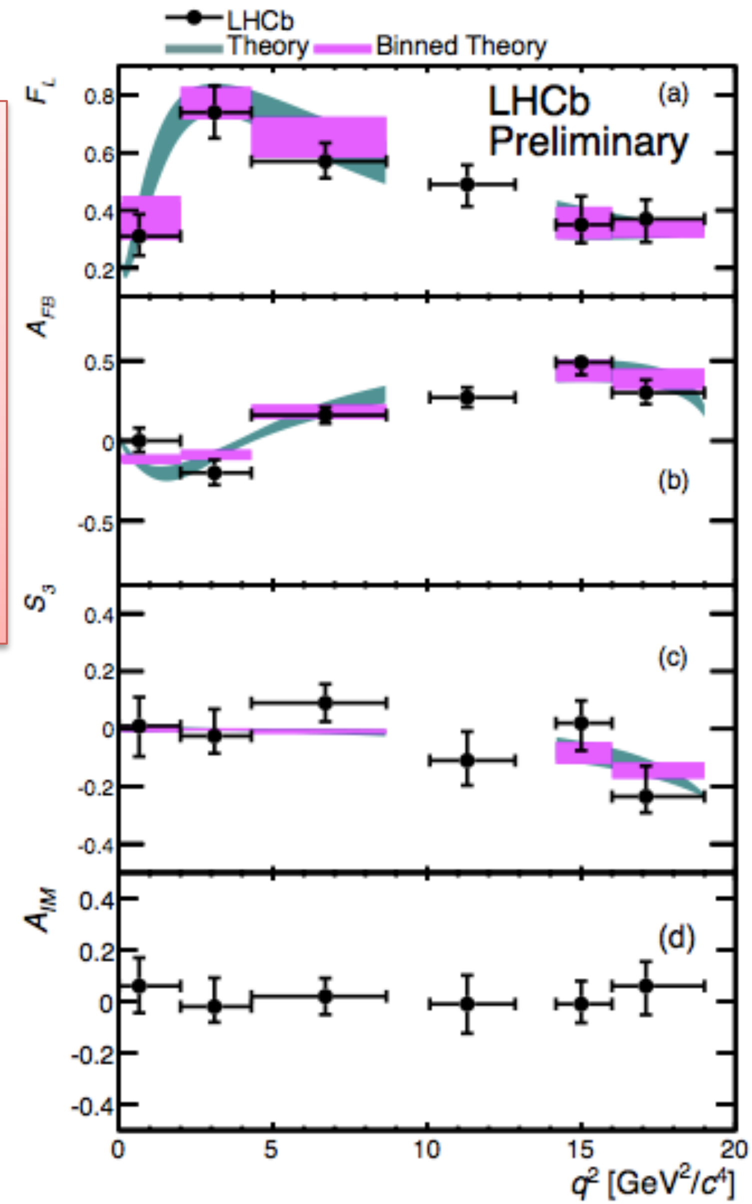
$B^0 \to K^{*0}\mu^+\mu^-$ Angular Analysis Results

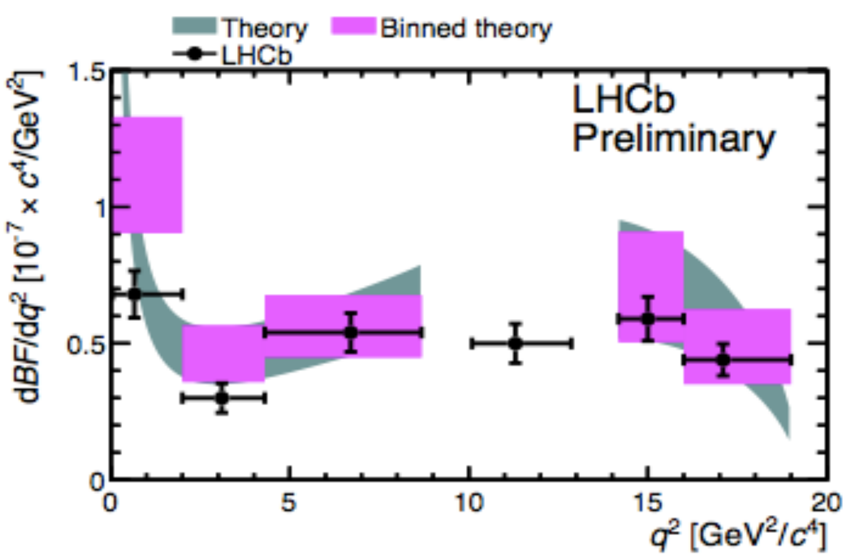
LHCb-CONF-2012-008

Several angular variables can be fitted to search for NP in a clean theoretical environment:

- F_L , fraction of K* longit. polar.
- A_{FB} the forward backward asymmetry
- S_3 the asymmetry in K* transv. polar.
- A_{IM} a T-odd CP asymmetry

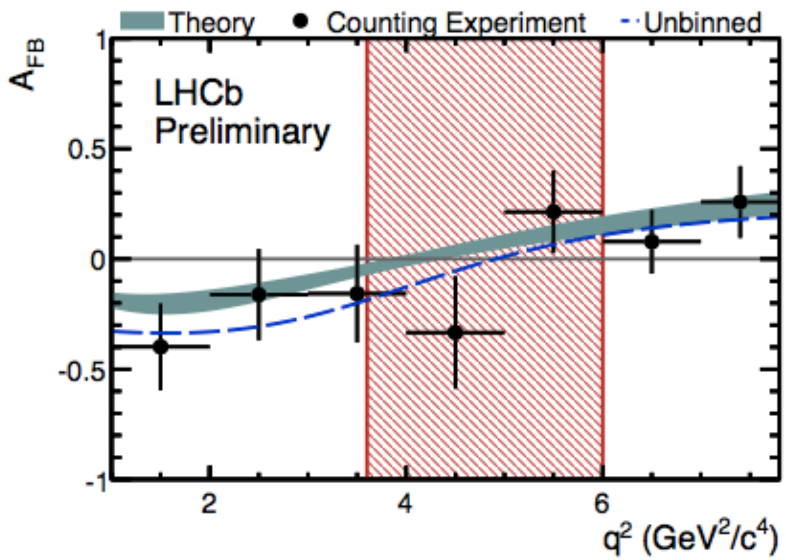
Strong agreement (so far) with SM, also for the differential branching ratio (*dBF/dq*^{2})





$B^0 \to K^{*0}\mu^+\mu^-$ A_{FB} zero-crossing point

- The SM predicts A_{FB} to change sign at a well defined point in q^2
- This zero-crossing point q_0^2 is largely free from form-factor uncertainties
- Extracted through a 2D fit to the foward- and backward-going m_{B^0} and q^2 distributions

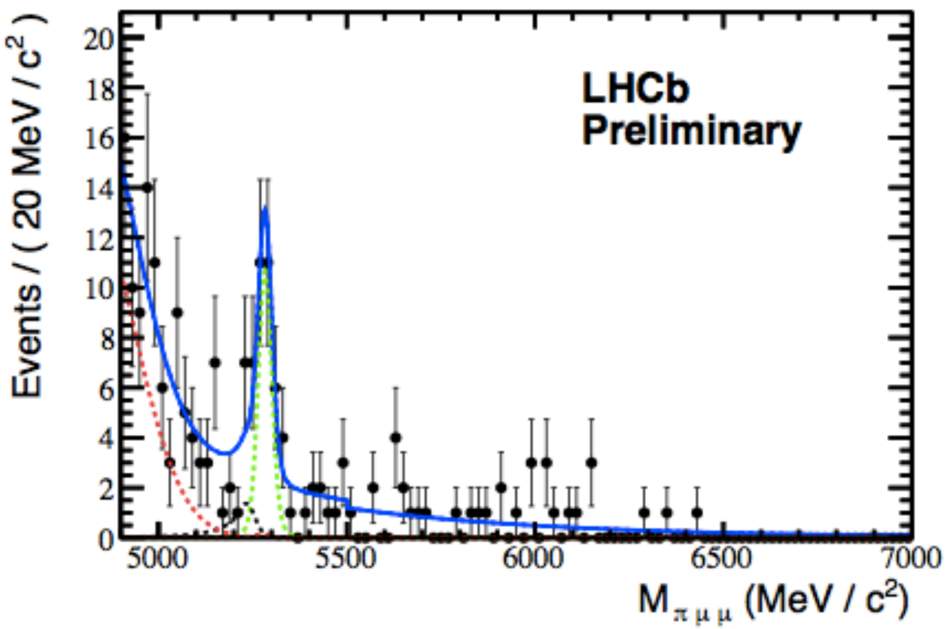


- The worlds first measurement of q_0^2, at $q_0^2 = 4.9^{+1.1}_{-1.3}\ \mathrm{GeV}^2/c^4$ [preliminary]
- This is consistent with SM predictions which range from $4 - 4.3\ \mathrm{GeV}^2/c^4$ [2, 3, 4]

First observation of $B^+ \to \pi^+\mu^+\mu^-$

LHCb-CONF-2012-006

- This is the first observation of a $b \to d\ell\ell$ transition
- LHCb(1.0 fb^{-1}) : $B^+ \to \pi^+\mu^+\mu^-$: $25.3^{+6.7}_{-6.4}$ signal events
  - 5.2σ excess above background
- The measurement is consistent with the SM prediction

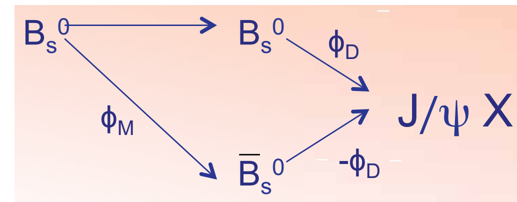


- $\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-) = (2.4 \pm 0.6(stat) \pm 0.2(syst)) \times 10^{-8}$ [preliminary]
- The rarest B decay ever observed

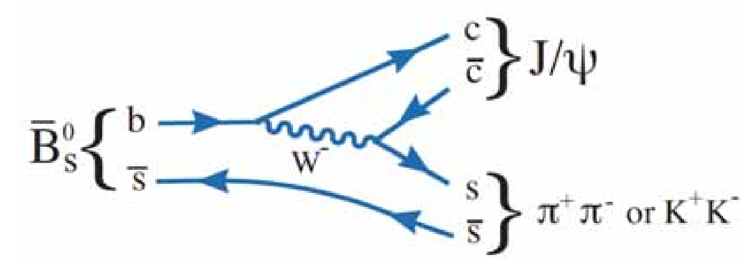
CP violation in B meson decays

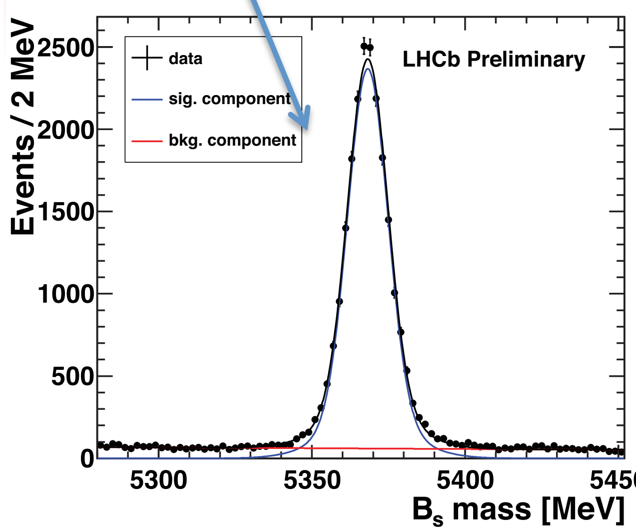
Results on CP Violation in B_s Mixing [measurements of ϕ_s and $\Delta\Gamma_s$]

- Measure relative phase difference[1]
  $\phi_s = \phi_M - 2\phi_D$ between two "legs"

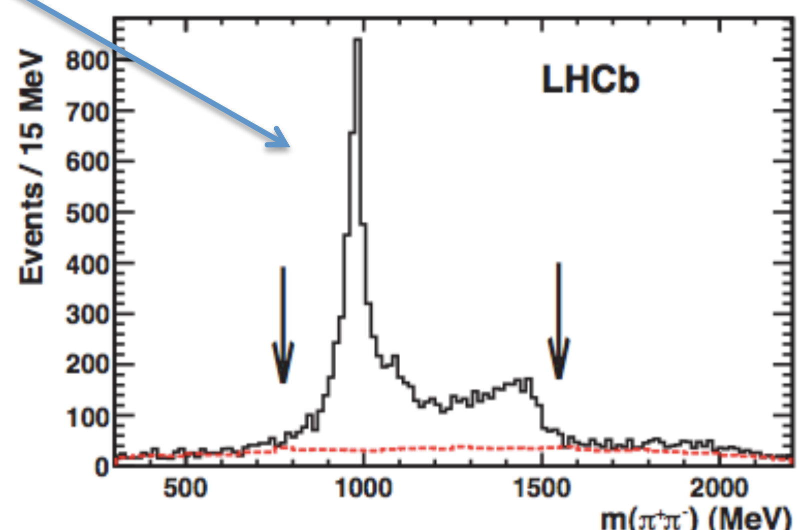


- $B_s \to J/\psi\Phi$ and $B_s \to J/\psi\pi\pi$ are very clean decays



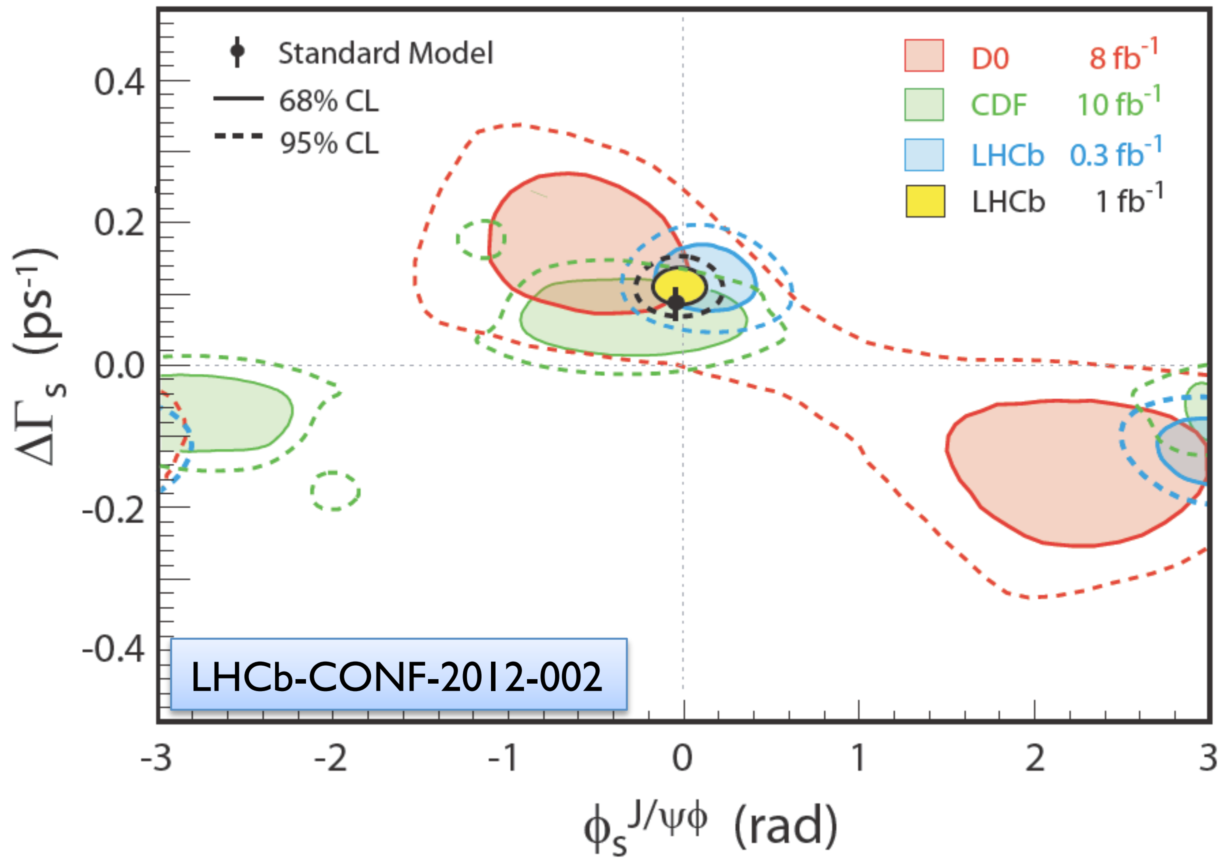


CP odd & even (angular analysis)



~ CP odd in the whole mass range

$B_s \to J/\psi\ \phi$ and $B_s \to J/\psi\ \pi\pi$ combined result



ϕ_s= -0.002 ± 0.083 ± 0.027 rad

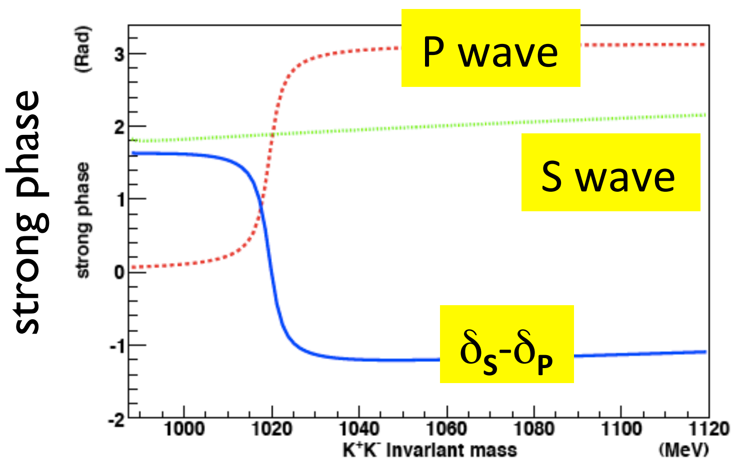
Γ_s = 0.6580 ± 0.0054(stat.) ± 0.0066(syst.) ps^{-1}

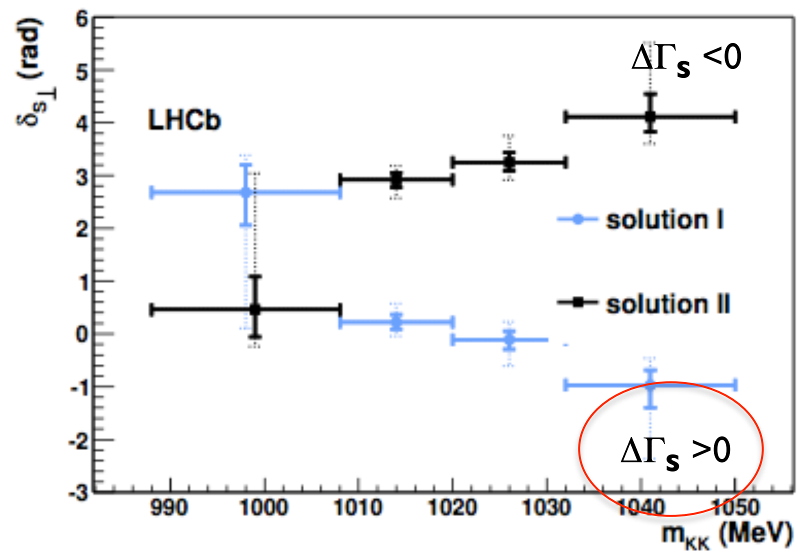
$\Delta\Gamma_s$ = 0.116 ± 0.018(stat.) ± 0.006(syst.) ps^{-1}

arXiv:1202.4717

Removing the ambiguity: the sign of $\Delta\Gamma_s$

- There are two ambiguous solutions related by $\phi_s \Leftrightarrow \pi - \phi_s$ and $\Delta\Gamma \Leftrightarrow -\Delta\Gamma$
- We can disambiguate using the P-Wave ⇔ S-Wave interference (strong phase of KK)





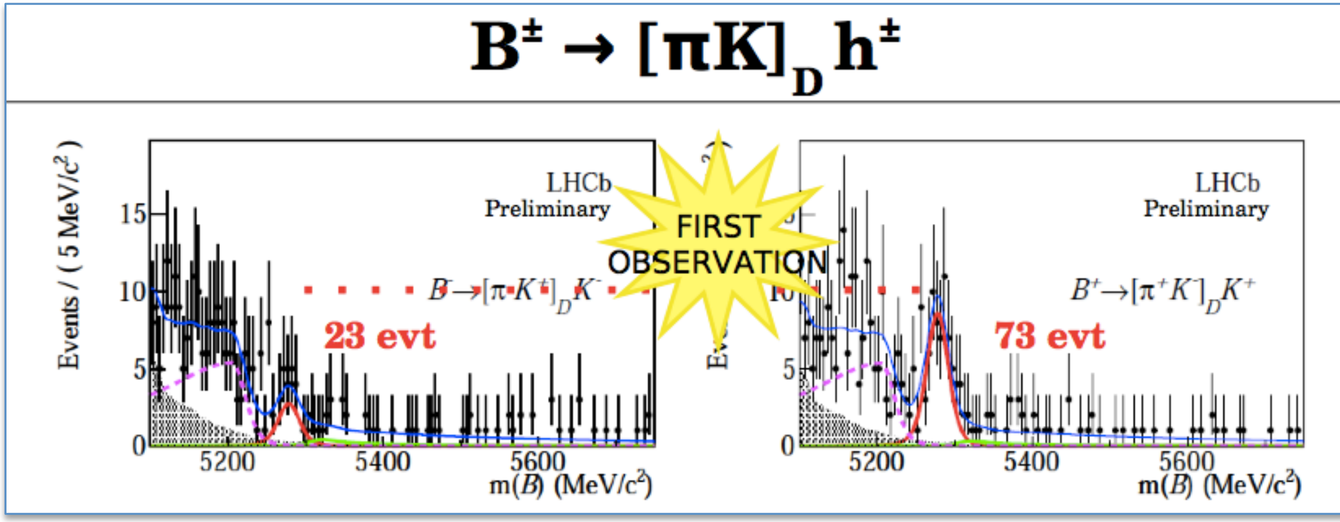
- $\Delta\Gamma_s = \Gamma_L - \Gamma_H > 0$: solution I (the correct one) shows the lighter B_s mass eigenstate is aligned with CP=+1 and is decaying faster
- Analogy with the K_L - K_S system

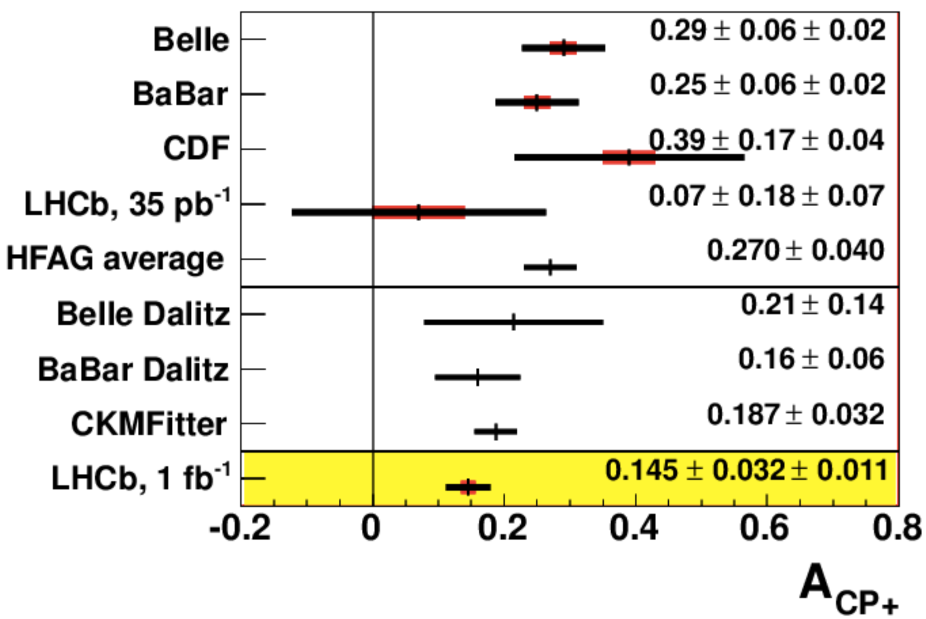
arXiv:1203.3662

Observation of CP violation in $B^{\pm} \to DK^{\pm}$ decays

ADS suppressed modes

Very rare transitions:
BR ~ 10^{-7}





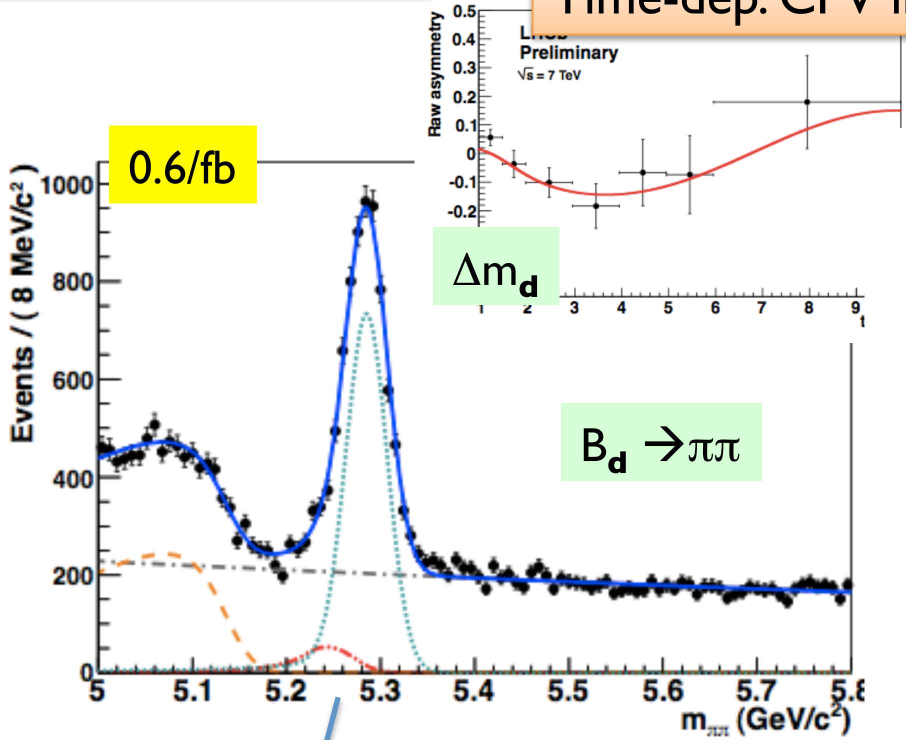
Combining all B→DK decays,
CPV in $B^{\pm}$ observed with 5.8 σ

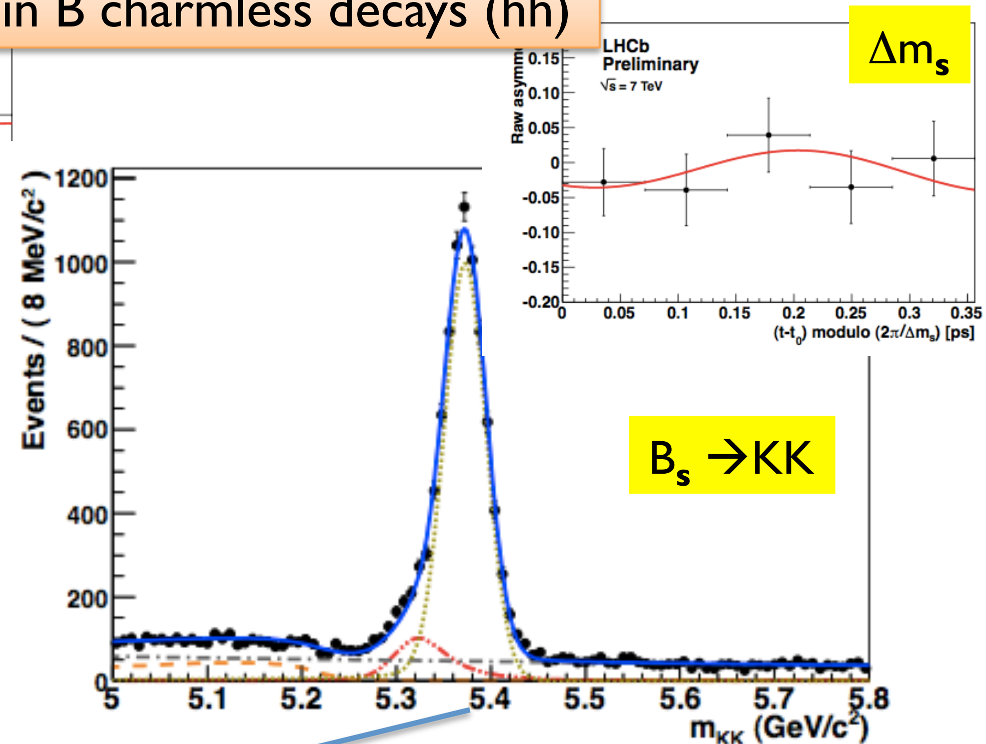
First steps toward measurement of γ with tree decays

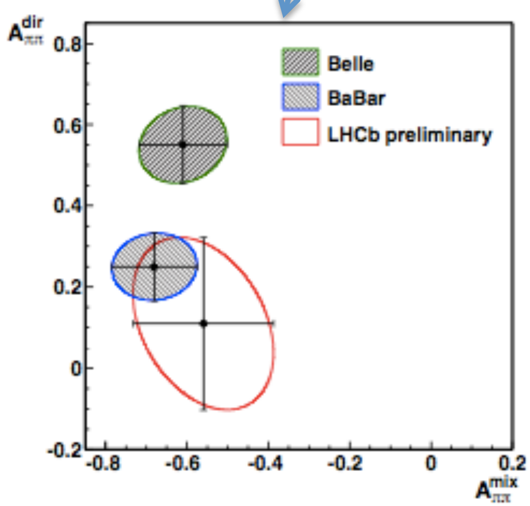
Significant impact on determination of γ expected

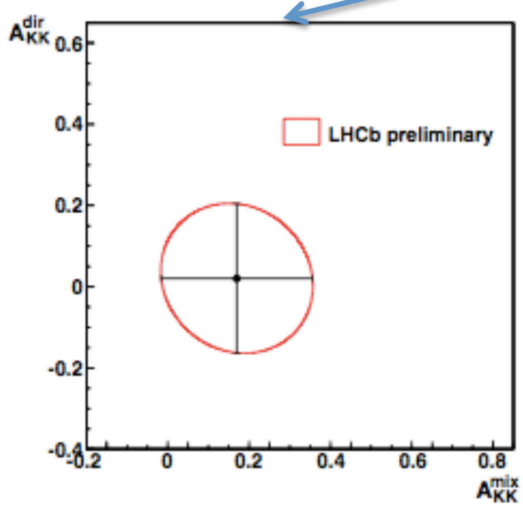
LHCb-CONF-2012-007

Time-dep. CPV in B charmless decays (hh)





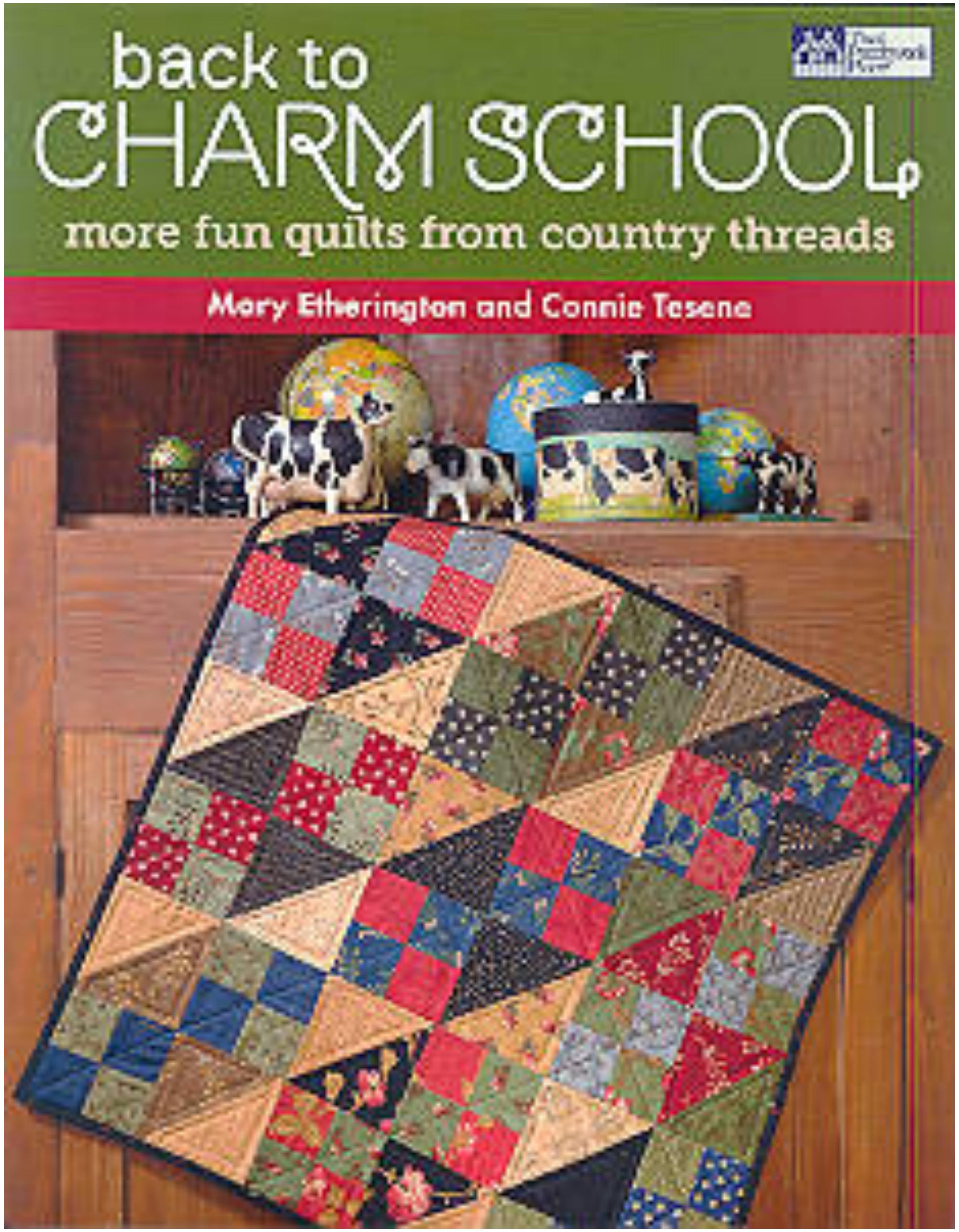




First measurement of time dependent CP asymmetries with $B_s \rightarrow KK$

First step toward the measurement of γ with loops

CP violation in Charm decays



CP violation in charm decays

Measure CP asymmetry in Time Integrated single Cabibbo suppressed $D^0 \rightarrow hh$ decays

$$A_{CP}(f) = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\overline{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\overline{D}^0 \rightarrow f)}$$

f = KK or ππ
D^0 tagged by $D^* \rightarrow D^0 \pi_{soft}$

$$A_{raw}(f) = A_{CP}(f) + \cancel{A_D(f)} + A_D(\pi_s) + A_P(D^{*+})$$

- $A_{CP}(f)$: Physics CP asymmetry
- $A_D(f)$: Detection asymmetry of D^0
- $A_D(\pi_s)$: Detection asymmetry of "slow" pions
- $A_P(D^{*+})$: Production asymmetry

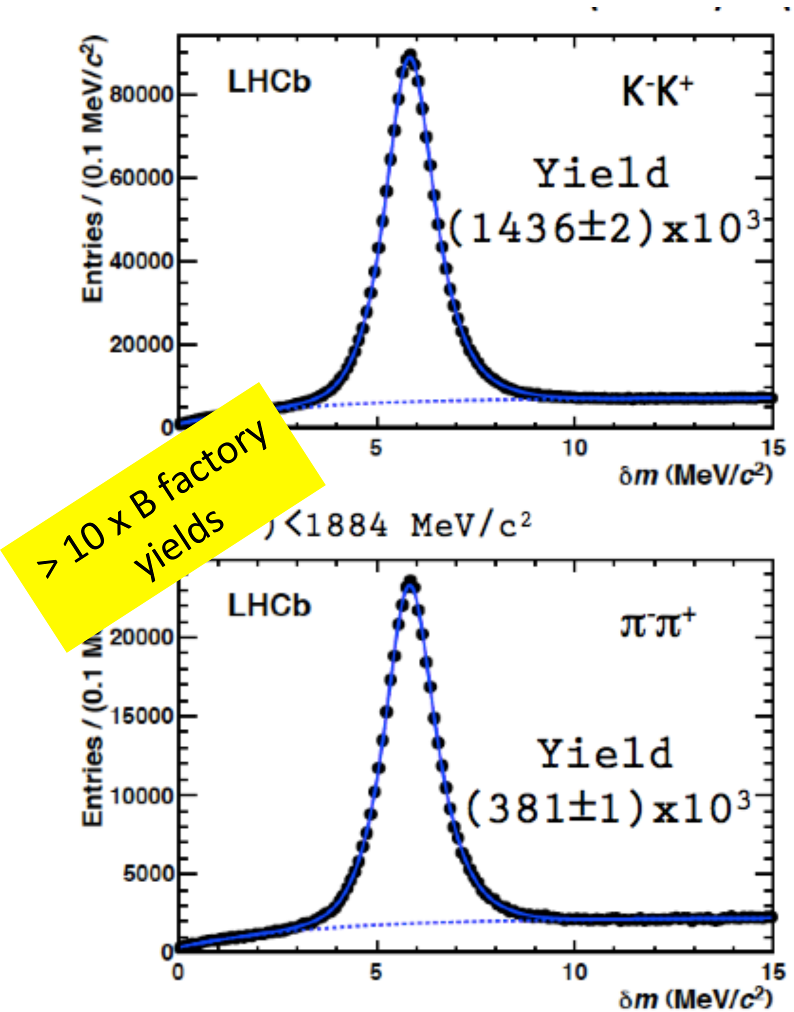
$$\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$

In the difference $A_{raw}(KK)-A_{raw}(\pi\pi)$ the production and the π_{soft} asymmetries cancel (at 1st order)

arXiv:1112.0938

In first approximation, measuring ΔA_{CP} at LHCb, means measuring direct CPV

$$\Delta A_{CP} = [a_{CP}^{dir}(K^-K^+) - a_{CP}^{dir}(\pi^-\pi^+)]$$



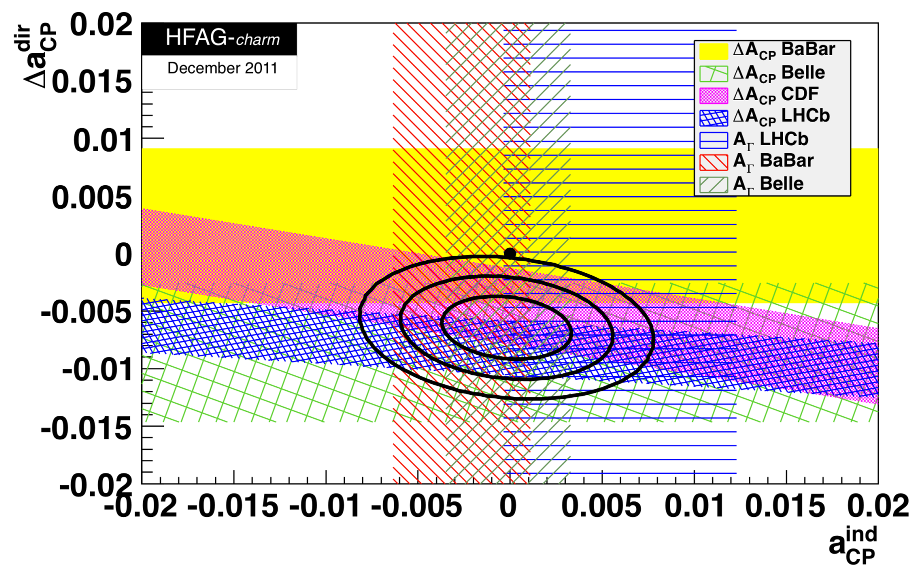
The analysis (~0.6 /fb) takes into account
- Pt spectrum of π_{soft}
- η and L/R detector acceptance
- magnet polarities swaps
- run blocks, etc..

Fit of ΔA_{CP} value in 216 "kinematic" bins
→ 3.5 σ effect (compatible with HFAG data)

$$\Delta A_{CP} = [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})]\,\%$$

Next steps:
- Update analysis with 1/fb
- Complementary analysis with B→D semileptonic tagging
- Search for CPV in other charm decays

CPV in charm: theoretical framework



LHCb result generated a strong interest among theoreticians

CP violation in charm was expected to be very small: O(0.1%) or less: a larger value would have implied NP

Deeper analyses of current constraints (eg D mixing) suggest less strong statements. SM could still explain the current result, re-evaluating penguin contributions

Theorists have suggested several channels that we can study to try to confirm or disprove if the effect can be accomodated in the SM

Explanations of the LHCb result in SM, and in NP models:

- Isidori et.al. arxiv:1103.5785 ⇒ NP explanation in a model independent way
- Brod et.al. arxiv:1111.4987 ⇒ Large $1/m_c$ suppressed amplitude
- Rozanov et.al. arxiv:1111.5000 ⇒ Large penguin in sequential 4th generation model
- Pirtskhalava et.al. arxiv:1112.5451 ⇒ Badly broken $SU(3)_F$ symmetry
- Cheng et.al. arxiv:1201.0785 ⇒ Large weak penguin annihilation contribution
- Bhattacharya et.al. arxiv:1201.2351 ⇒ CP conserving NP in penguin
- Giudice et.al arxiv:1201.6204 ⇒ Left-right flavour mixing via chromomagnetic operator
- Altmannshofer et.al. arxiv:1202.2866 ⇒ Chirally enhanced chromomagnetic penguins
- Brod et.al. arxiv:1203.6659 ⇒ In SM via s- and d-quark penguin contraction

.........many more

… and many more other results

- Inclusive Low mass Drell Yan production in the forward region (LHCb-CONF-2012-013)
- Search for $B_{(d,s)} \rightarrow \mu\mu\mu\mu$ (LHCb-CONF-2012-010)
- Search for $D^0 \rightarrow \mu\mu$ (LHCb-CONF-2012-005)
- B_s decays in double charm final state (LHCb-CONF-2012-009)
- CP asymmetry in $B_d \rightarrow K^*\gamma$ decay (LHCb-CONF-2012-004)
- $B_s \rightarrow \phi\mu\mu$ decays (LHCb-CONF-2012-003)
- $B_s \rightarrow KK$ lifetime (LHCb-CONF-2012-001)
- Measurement of $\sigma(\chi_{c2})$ / $\sigma(\chi_{c1})$ of prompt χ_c mesons (arXiv 1202.1080)
- Y production (arXiv 1202.6579)

+ searches for Majorana neutrinos, exotic states, quarkonia, etc…

As of today, **49** LHCb physics papers (+ **9** final drafts in circulation in the Collaboration)
(at last RRB we had 15 papers, > 200% increase)

LHCb data taking perspectives and its upgrade

Based on 2011 experience LHCb can collect ~ 1.5/fb per year

- 2012 @8 TeV and 2015-16-17 @13 TeV

By the end of 2017 ≥ **5/fb** collected

Reaching ultimate theory precision in flavor variables will need more statistics

Current LHCb limitation: trigger rate capability. Upgrade plans:

- **1 MHz → 40 MHz readout**
- **Full software trigger**
- **Up to L ~ 2 10^{33} $cm^{-2}s^{-1}$** to collect **50/fb**

Expected annual physics yields increase:

- **x5** in muonic channels
- more than **x10** in hadronic channels ($B_s \rightarrow \phi\phi$, DK, charm, etc...)

Installation of upgraded LHCb during **LS2** (**2018**)

LHCb Upgrade: the formal steps

- *March 2011, "Letter of Intent for the LHCb Upgrade" submitted to LHCC*
  → Endorsement of physics case. Review of proposed trigger concept (40 MHz)

- *June 2011, Positive peer review of trigger concept*
  → LHCC endorses the LOI, green light for TDR preparation

- *June 2012, Submission of "Framework TDR for the LHCb Upgrade" to LHCC*
  (intermediate document describing the plan, cost and resources needed for the upgrade)

- *September 2012, Approval of "Framework TDR" expected*

- *October 2012, Presentation of "Framework TDR" to RRB and to Funding Agencies*
  → Start of negotiations for signing the "Addenda to MoU for the LHCb Upgrade"

- *Fall 2013, Submission of LHCb subsystems TDRs to LHCC*

The *"Framework TDR"* will address the schedule, a first (reasonably accurate) evaluation of CORE costs and of interests of institutes
→ working document to the FA for R&D funding and for "cost envelopes" definition

The schedule for the LHCb Upgrade

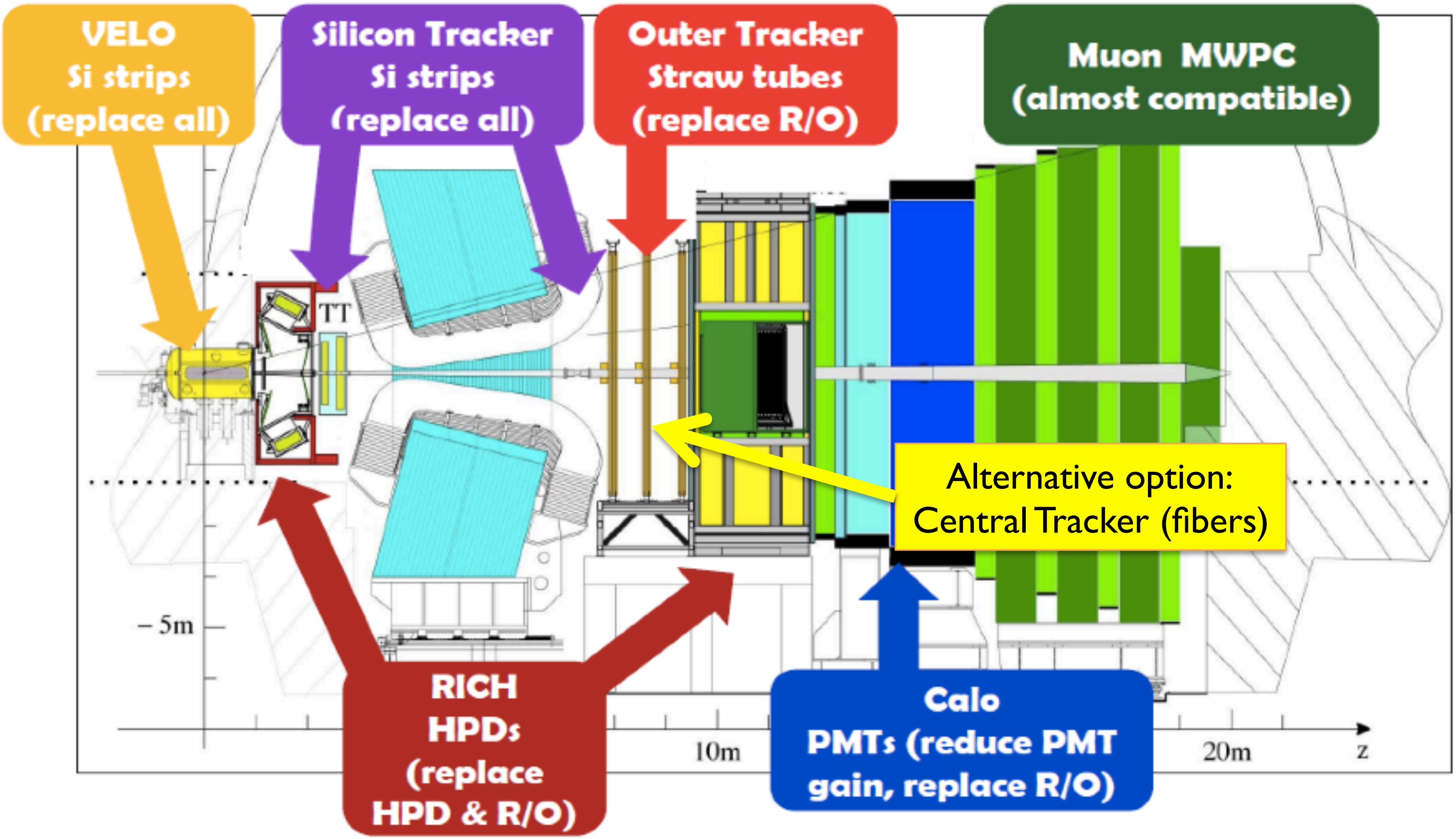
2012	LHCb data taking (8 TeV)
2013-14	LHC LS1 / LHCb maintenance, first infrastructures for upgrade
2015-17	LHCb data taking (13 TeV → 14 TeV)
2018	**LHC LS2 / LHCb upgrade installation**
2019-21	LHCb data taking
≥ 2022	LHCb data taking @ HL-LHC*

LHCb Upgrade preparation

2012-13	R&D, technology choices, subsystems TDRs
2013-14	Requests for approval/Funding/Start of productions
2015-18	Construction & installation

* Coord. Committee between LHC-HL and experiments, setup by CERN management
"To agree upon a common and coherent set of goals, parameters and plans for the HL-LHC project, while providing a forum for official information transfer on the status of the project."

LHCb detector modifications for the upgrade



LHCb Upgrade in brief
(more detailed info in the coming FTDR)

"40 MHz" upgrade scheme:

- new vertex detector (VELO)
- new tracking systems (TT, CT, OT)
- new photo sensors and FEE on RICH
- front end and readout electronics upgrade for OT – CALO – MUON
- software trigger (efficiency for hadronic channels ~ double)

Preliminary evaluation of upgrade cost ~ **57 MSF**

- CORE cost for upgraded detectors ~ 41 MSF
- CORE cost for Common Projects ~16 MSF (Online, Common Electronics, General Infrastructure)

Collaboration matters

- Cincinnati University (Babar - interests in charm physics, HLT and upgrade) has become LHCb associate member. Host institute: Syracuse.
  Grant application for funding to NSF submitted in October.
- Lahore University (interests in b physics) has become LHCb associate member. Host institute: Syracuse.
- Negotiations ongoing with several other institutes (strong commitment to enlarge the Collaboration, also in view of the upgrade)

Conclusions

LHCb performed well in the 2012 data taking startup (a particular thank to LHC team for the careful tuning of vertical crossing !)

A lot of activities and very good perspectives for "world record" measurements (several already achieved) with 1 fb^{-1} in CPV in b and c decays, CKM angle γ , rare decays + a very large spectrum of other physics items

Looking forward to increase the statistics in 2012 and later in 2015-17

Standard Model remains "un-cracked" but still large room for New Physics:
LHCb is complementing ATLAS & CMS searches for Supersymmetry
Charm CPV is a nice surprise ! Further experimental and theoretical study required

Upgrade goal: reaching ultimate theoretical errors in flavor variables and search for unexpected phenomena in the forward region: 50/fb needed

"Clock for LHCb Upgrade has started (Framework TDR)" (quote from LHCC chairman)