The LHCb Upgrade

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for the US LHCb Groups

Intensity Frontier Workshop

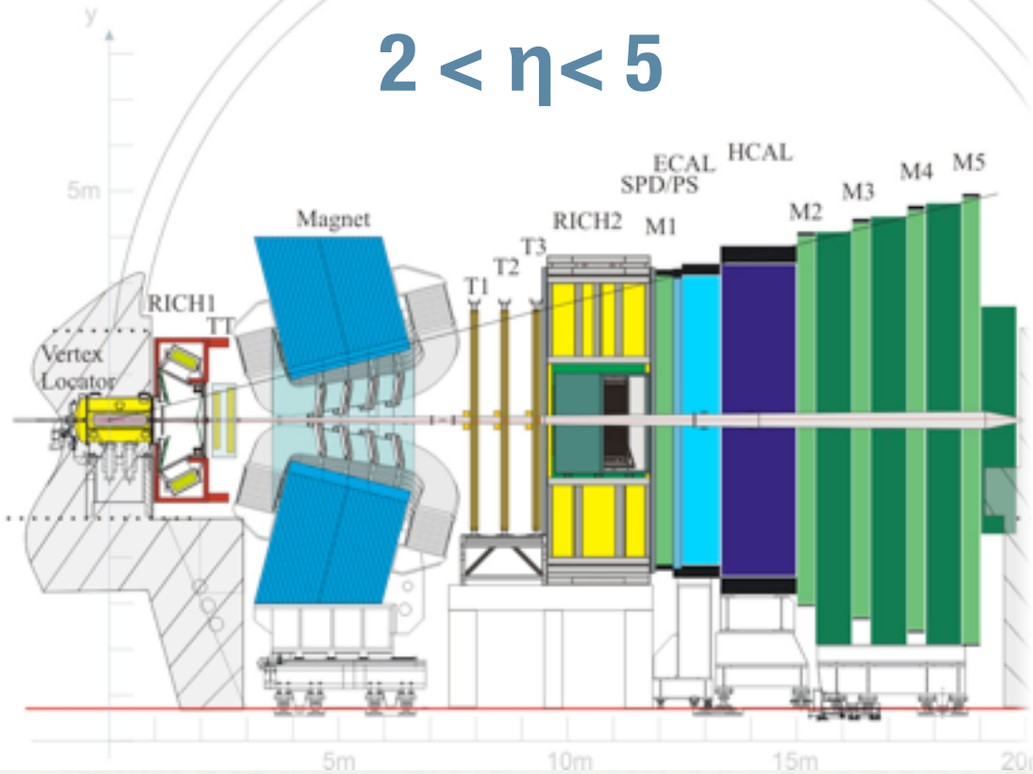
ANL

26 April 2013

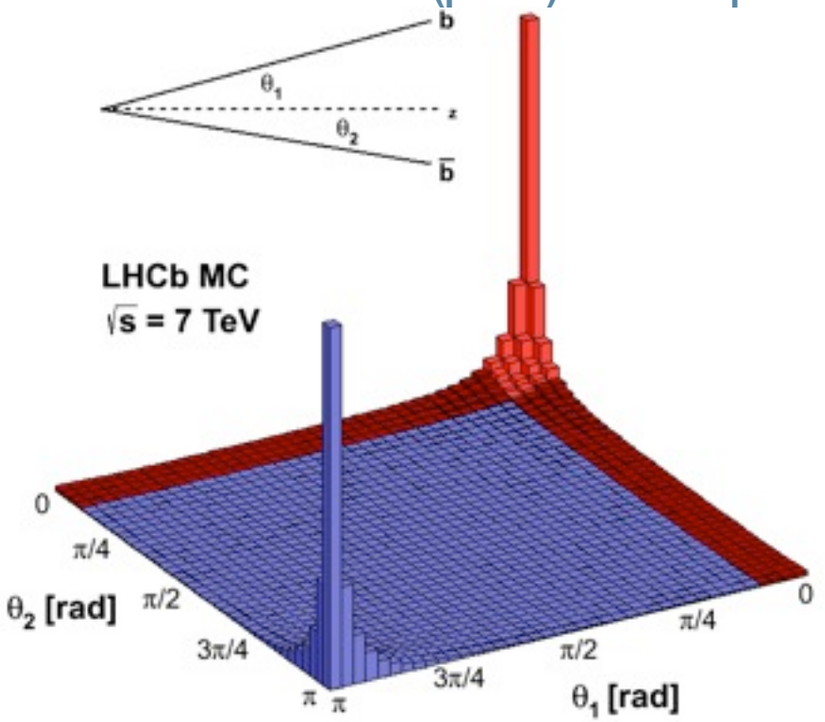
The LHCb Detector

FORWARD-ARM SPECTROMETER

2 < η< 5



27%(25%) Of B Quarks (pairs) In Acceptance



At LHC, $b\bar{b}$ pairs produced at lower p_t, with highly boosted parton CM frame

At 7 TeV:

$\sigma_{inel} \sim 70$ mb

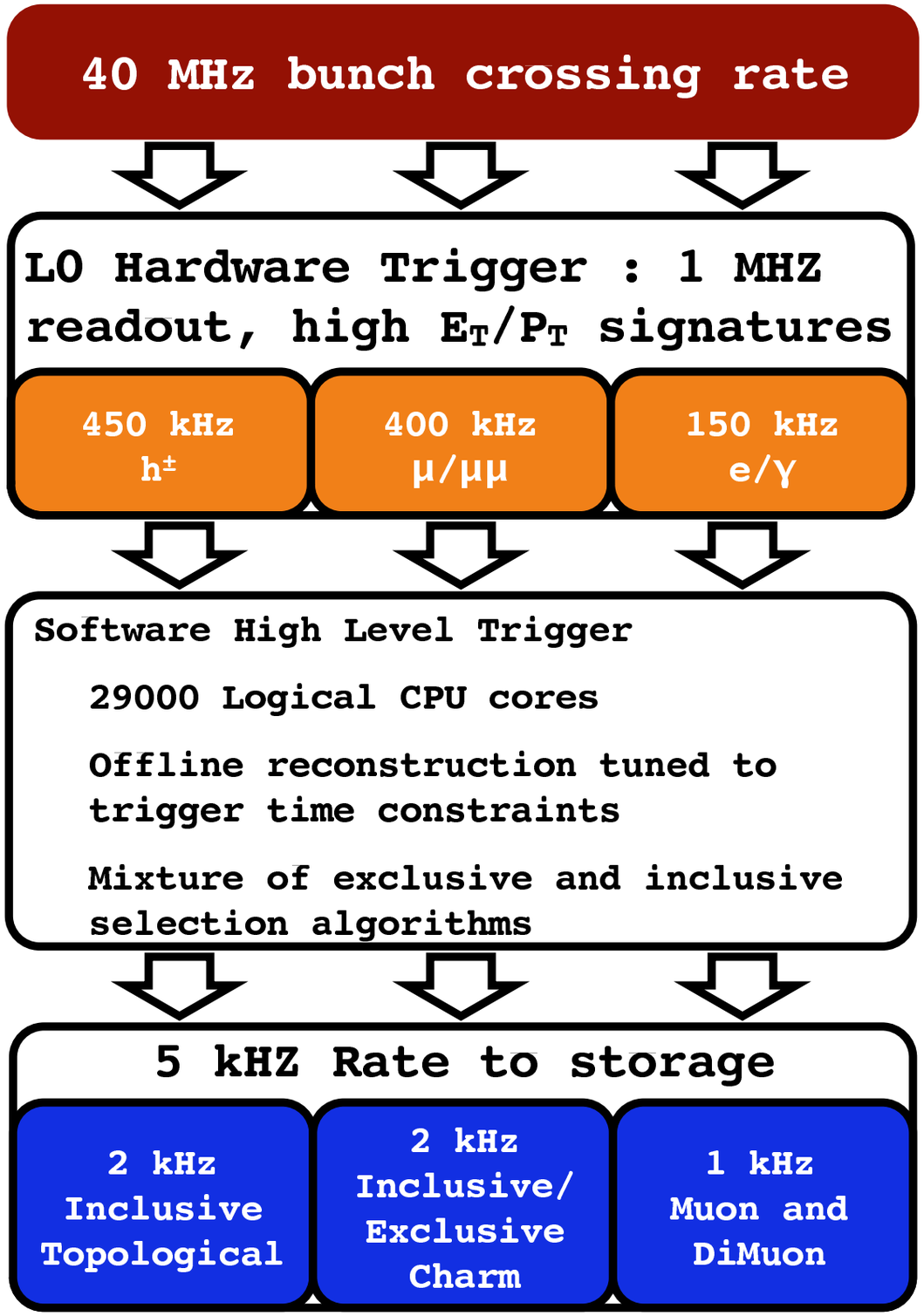
$\sigma_{c\bar{c}} \sim 6$ mb

$\sigma_{b\bar{b}} \sim 280$ μb

- B physics performance:
  - **Trigger efficiency**: 93% for $J/\psi X$, ~30% for all-hadronic channels
  - **Tracking**: $\sigma_p/p \sim 0.40\%$, $\sigma_{ip} < 20\mu m$ (high-p_T tracks)
  - **Vertexing**: $\sigma_\tau \sim 45$fs for $B_s \rightarrow J/\psi\phi$
  - **PID**: 95% $K^\pm$ ID efficiency for 5% $\pi \rightarrow K$ misID, 97% μ ID for 1-3% $\pi \rightarrow \mu$ misID

LHCb Trigger

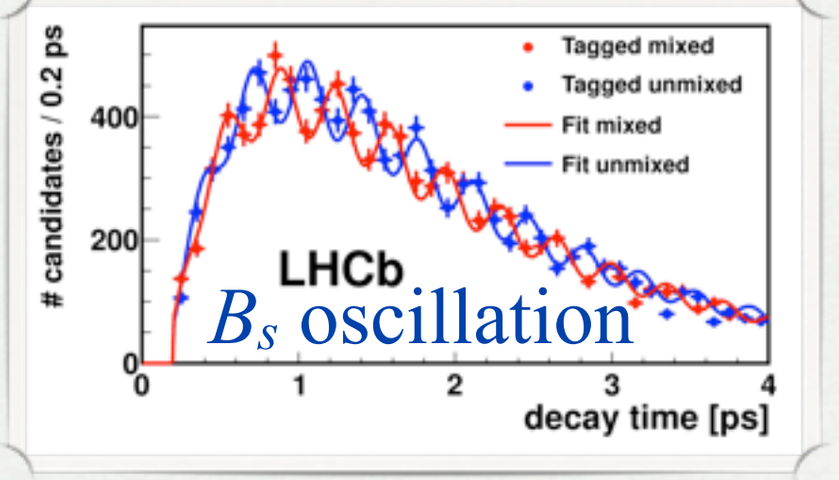
- Need to cleanly extracting heavy flavor production events from LHC collisions with high efficiency. Requires very fast online reconstruction!
  - **L0 hardware** trigger
    1 MHz out
  - **HLT1**: software trigger, partially-reconstructed events (high p_t objects)
    ~50 kHz out
  - **HLT2**: reconstruct tracks and vertices to pick out heavy flavor events inclusively + exclusively
    ~5 kHz out
- Bottlenecks at 1MHz L0 and 5 kHz to disk

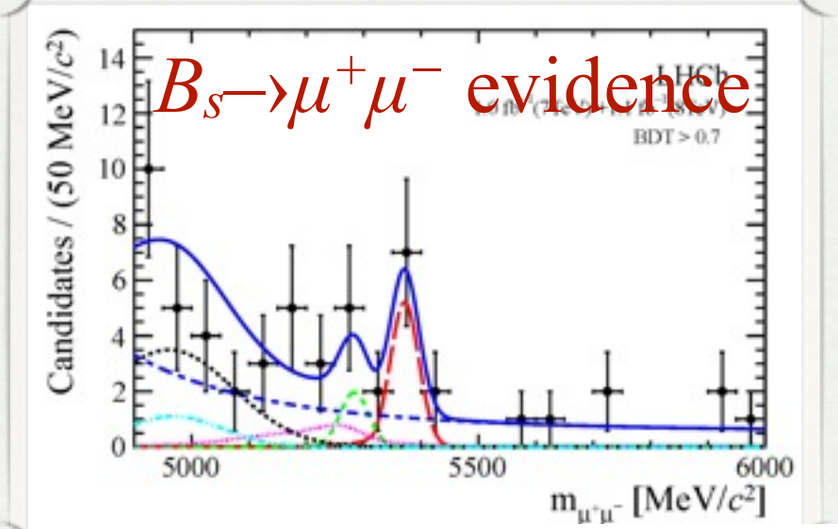


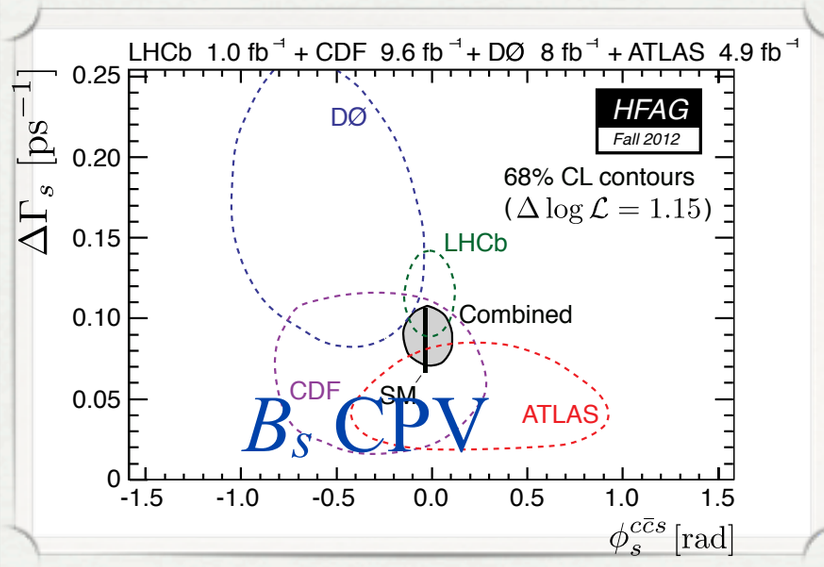
2011-2012 Datasets

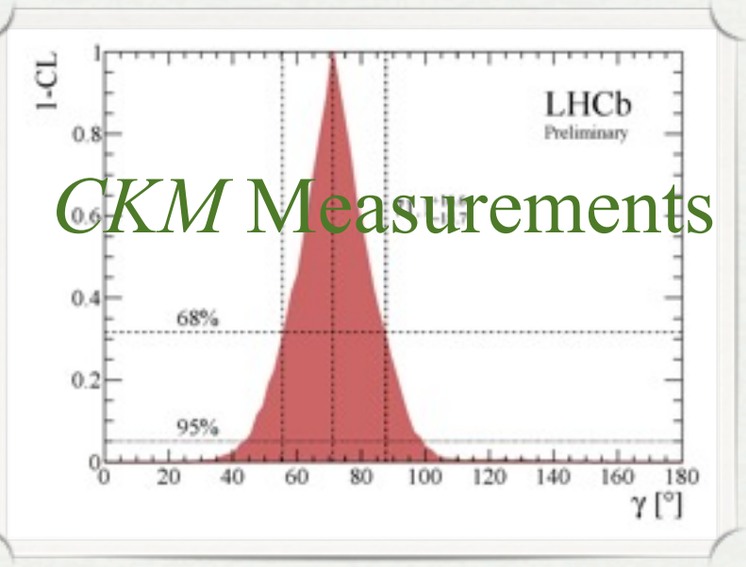
- 2012: 2 fb^{-1} @ 8 TeV
  2011: 1.0 fb^{-1} @ 7 TeV
  ‹μ› = 1.7 (visible interactions per crossing)

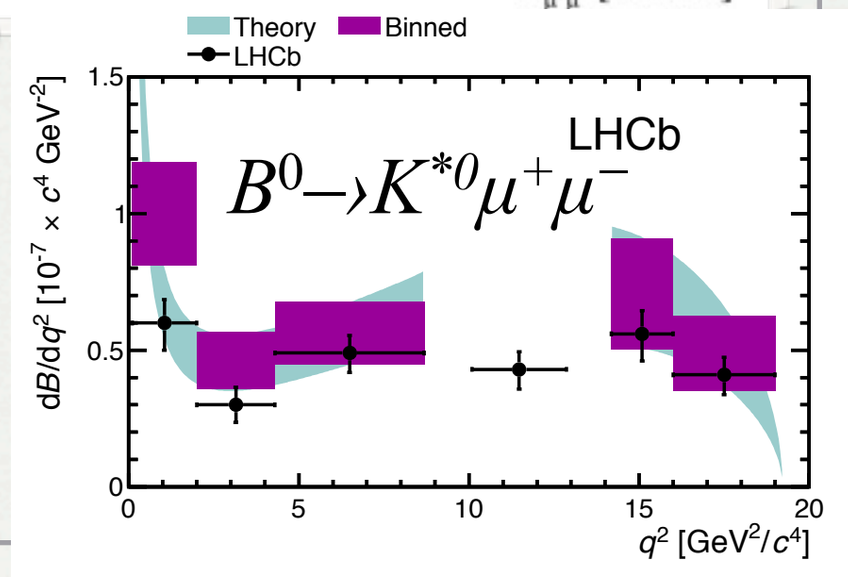
- Many results across different physics topics: neutral meson mixing, flavor-changing neutral current decays, CP violation, penguin decays etc









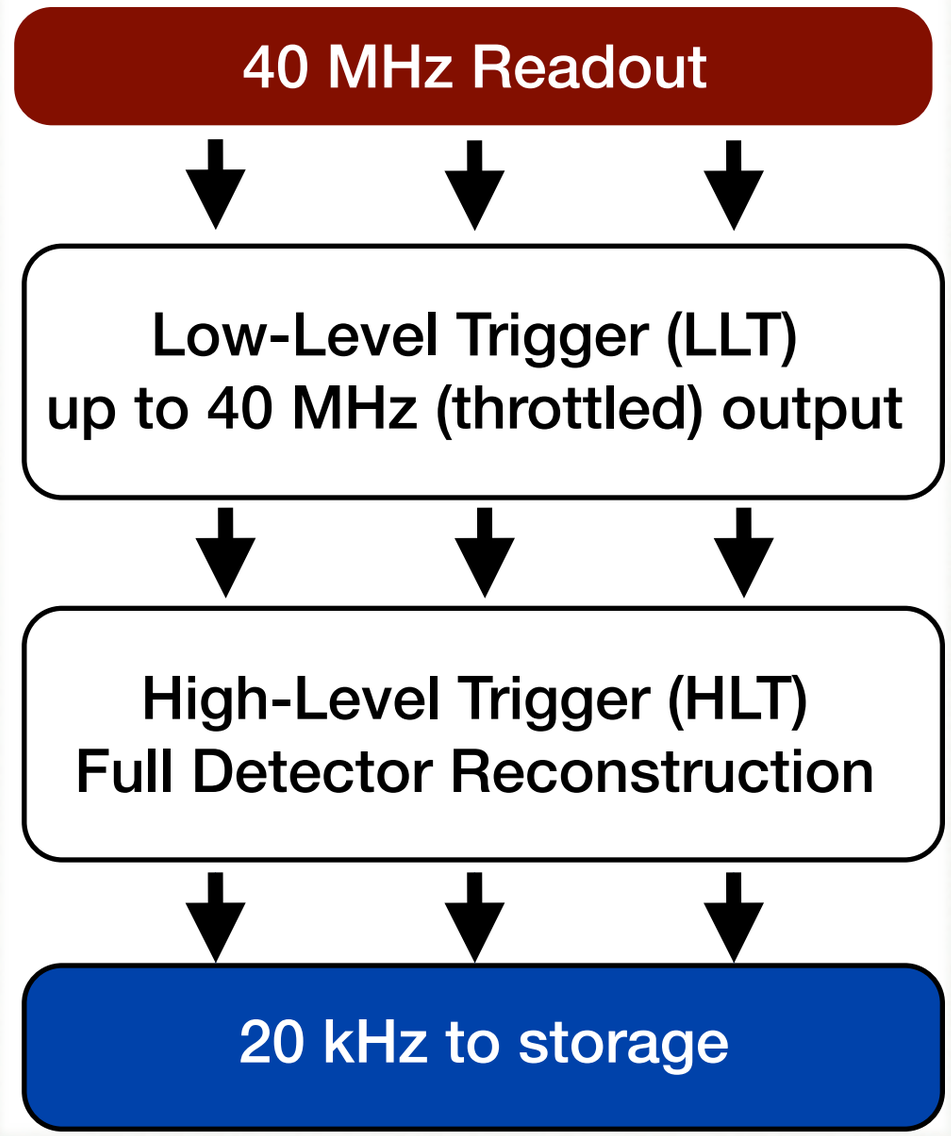


Prospects for Run 2 and Beyond

- Additional 5-7 fb^{-1} by 2018:
  13 TeV running at ~4×10^{32} $cm^{-2}s^{-1}$
  - Heavy flavor cross sections scale roughly linearly with $\sqrt{S}$ –› 60% higher signal rates at 13 TeV
  - Changes to software trigger planned to use prompt calibration to exploit more information for smarter triggering (e.g. PID info)
- Beyond 2018:
  To continue to improve precision as rapidly as possible, must upgrade detector so that 50+ fb^{-1} can be collected running at ~2×10^{33} $cm^{-2}s^{-1}$

Beyond 2018 - All-Software Triggering

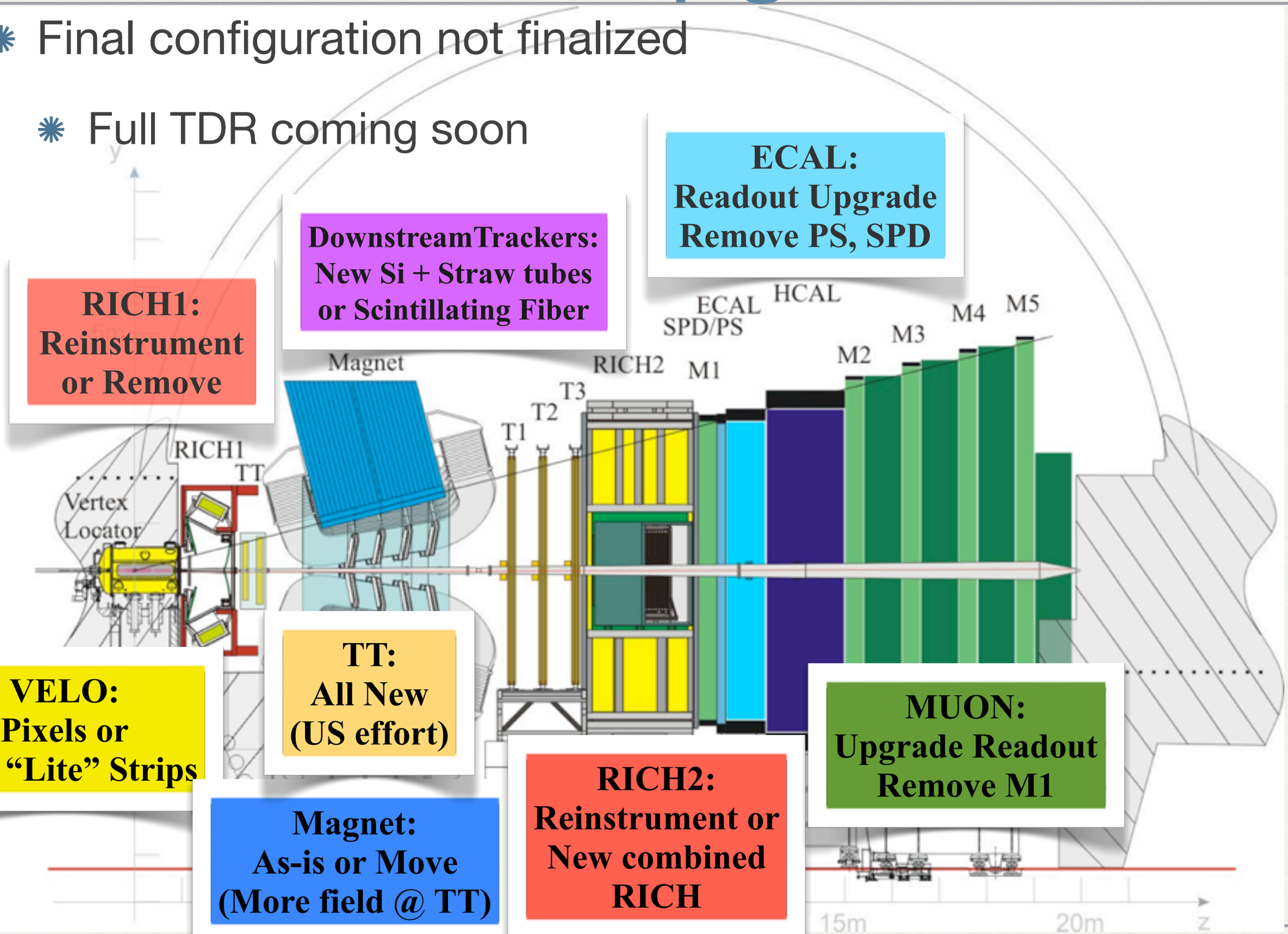
- Goal: Remove 1 MHz L0 bottleneck + improve signal efficiency
- Upgrade:
  - Front-end read out at up to 40 MHz (synced with 25 ns LHC)
  - All-software trigger
    - **L**ow **L**evel **T**rigger: limited reconstruction to enrich in interesting events
      - Similar to L0, but output rate ≳10 MHz and is tunable
    - HLT: Full detector information as before



- Improve hadronic channel efficiency by ~2× and simultaneously cope with 10× data rate

Subdetector Upgrades

- Final configuration not finalized
  - Full TDR coming soon



LHCb Schedule

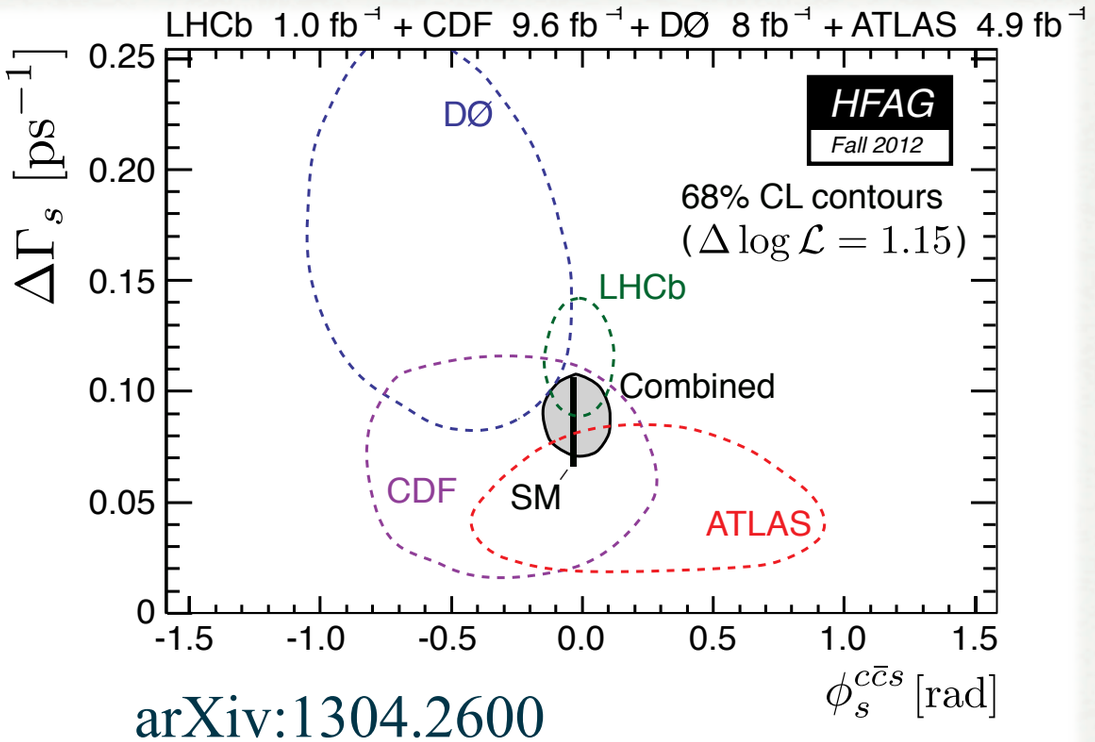
- Operations:
  - End of LS1-2017: accumulate 5-7 fb^{-1} (13 TeV)
  - Install upgrade in 2018
  - Upgrade data taking 2018 (14 TeV) until 50 fb^{-1} are acquired
- Upgrade work:
  - 2013: R&D, Technological choices,
    Submit subsystem TDRs
  - 2014-2016: Funding/procurements and production
  - 2017: Quality control
  - 2018: Systems tested and ready for installation

Physics Prospects

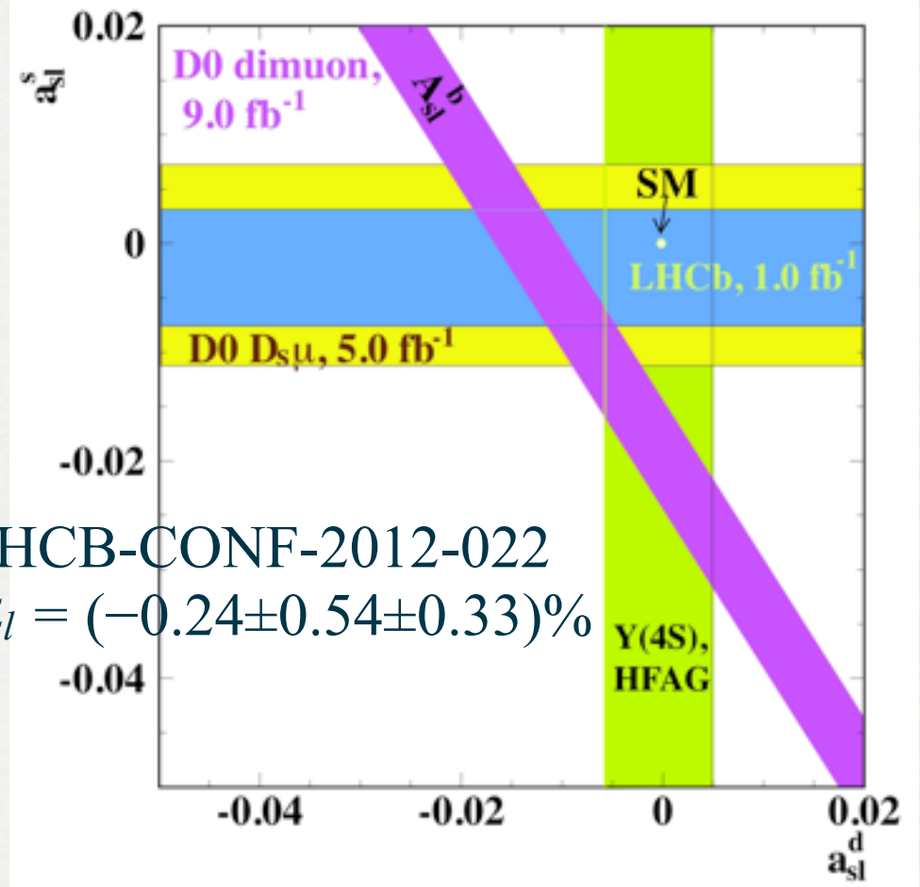
LHCb Program

- Strengths of the LHCb program:
  - Dominant in B_s^0 physics
  - Large statistical power for exclusive charged channels
    - Complimentary to e+e– super flavor factory's coverage of inclusive and neutral modes
- Key targets for upgrade (statistical uncertainties):
  - B_s^0: $2\beta_s$, a_{sl}^s
  - $B_{(s)}^0 \to \mu^+\mu^-$
  - Angular observables in $B^0 \to K^{*0}\mu^+\mu^-$
  - Exclusive $b \to s\gamma$ and photon polarization
  - Unitarity triangle angle γ with B^0 and with B_s^0
  - Improved reach on charm CPV

B_s Physics & CPV



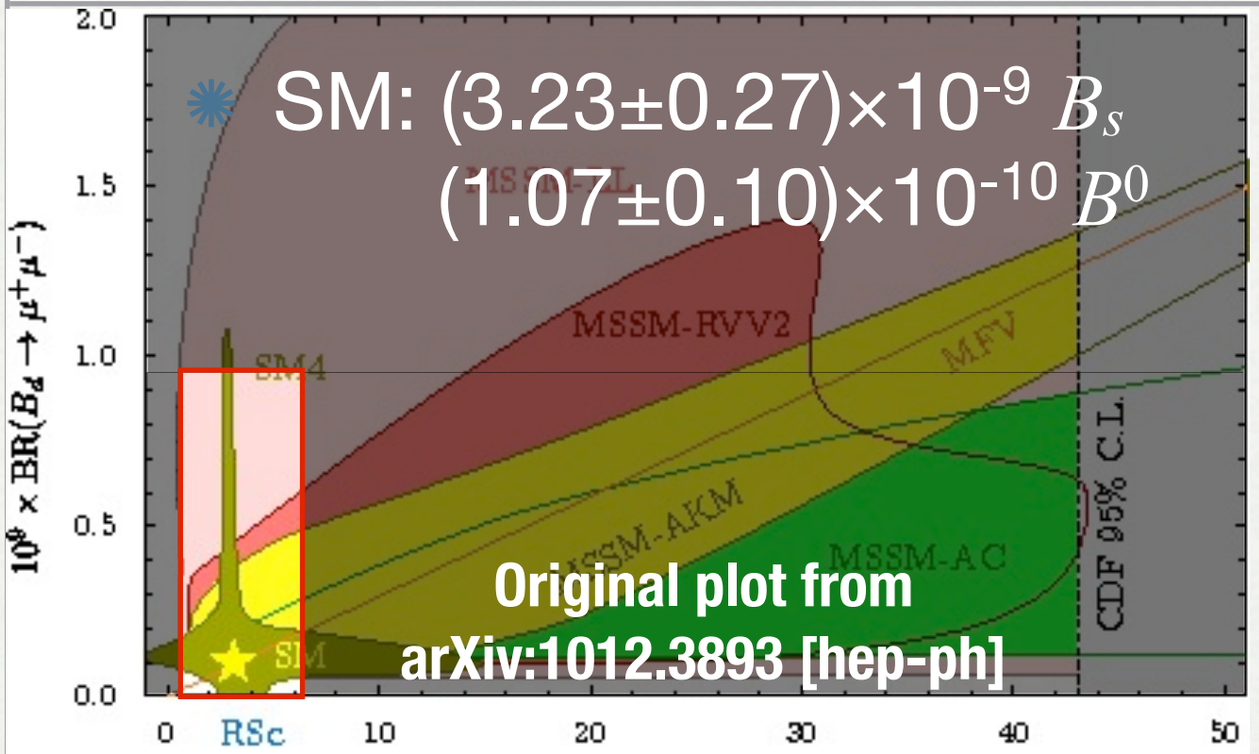
arXiv:1304.2600
ϕ_s ($-2\beta_s$ in SM)=0.01±0.07±0.01 rad
$\Delta\Gamma_s$=0.106±0.011±0.007 ps^{-1}

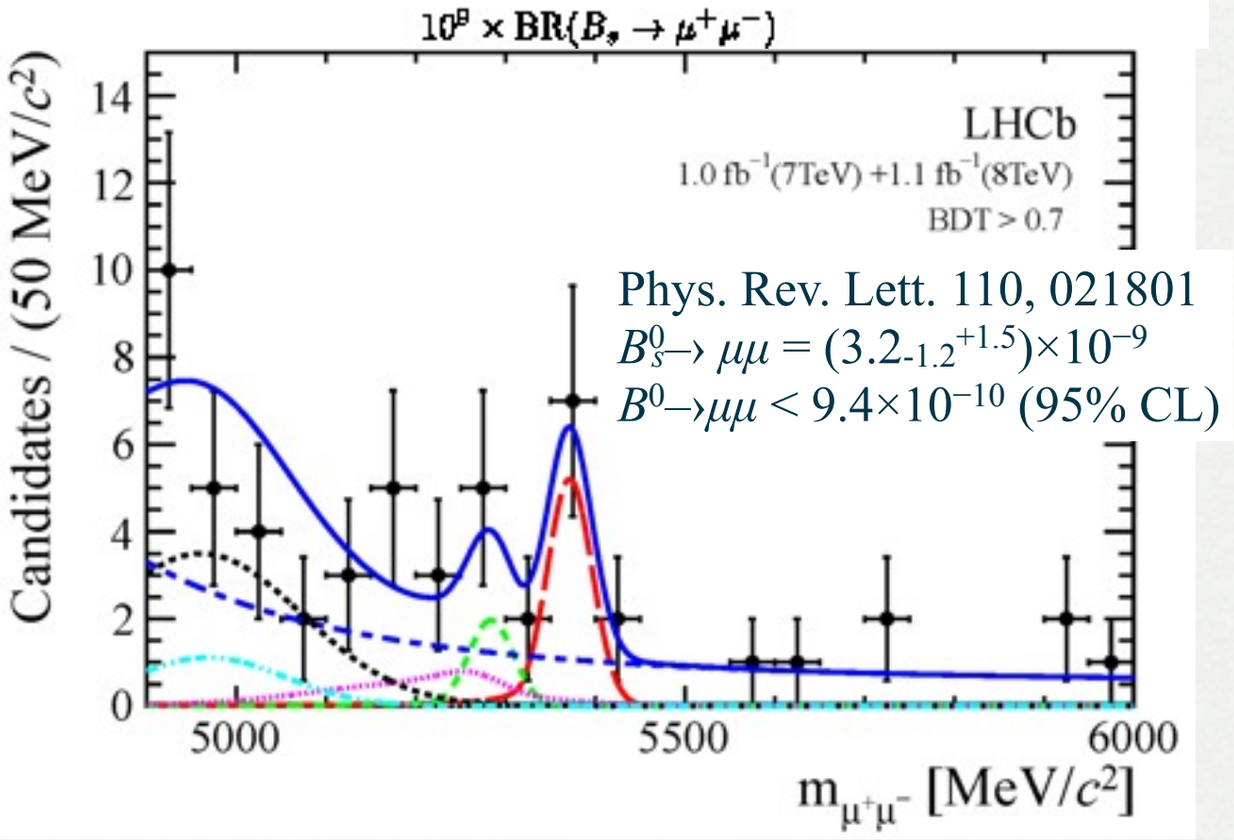


LHCB-CONF-2012-022
$a^s_{sl} = (-0.24\pm0.54\pm0.33)\%$

- $-2\beta_s$ from $B^0_s \to J/\psi(K^+K^-/\pi^+\pi^-)$ (SM: 0.0364±0.0016 rad)
  - K^+K^-: CP eignestates from angular analysis, $\pi^+\pi^-$: Dominated by CP-odd
- a^s_{sl} measured in $B^0_s \to D^-_s\mu^+\nu$ channel, currently to 0.54%
  - Additional opportunities in $B^0_s \to D^-_s(\to K^-K^+\pi^-)\pi^+$
- **Upgrade**: a^s_{sl} precision of 0.02% ,
  $2\beta_s$ precision of < 0.01 radians in $B^0_s \to J/\psi$ (SM ϕ_s = 0.04)

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

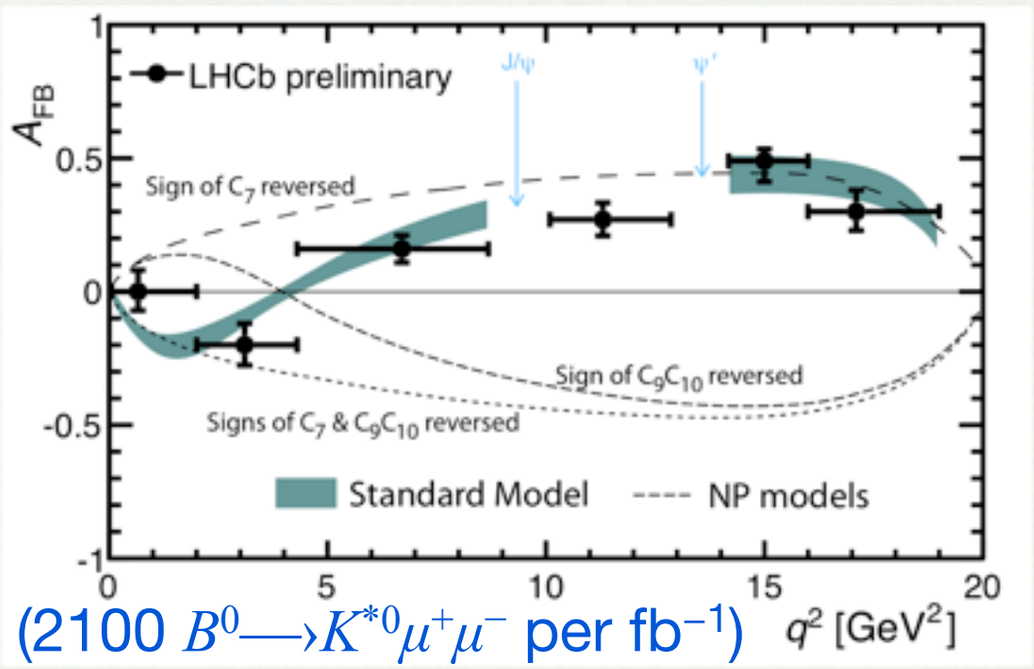




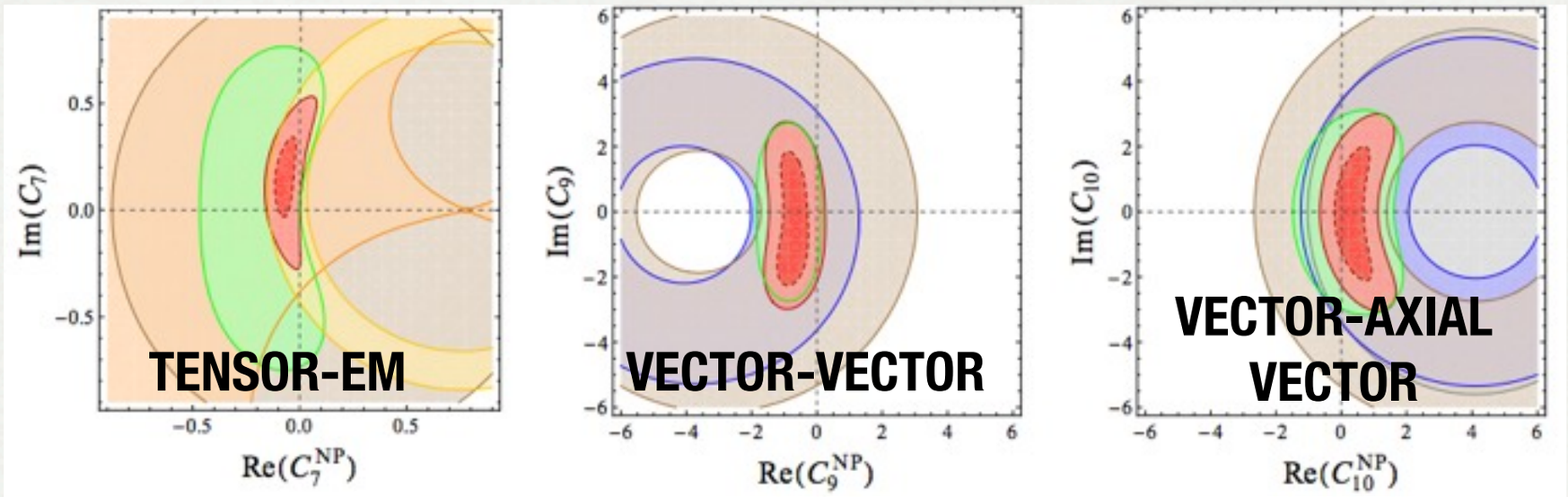
- Constrains flavor-sector behavior of NP: any deviation from MFV is interesting, as is no deviation from MFV
- **Upgrade**:
  - Measure B_s^0 channel with uncertainty below 10% level
  - Achieve sensitivity to B^0 channel down to standard model rate
  - Measure ratio of branching fractions $B^0 \to \mu^+\mu^- / B_s^0 \to \mu^+\mu^-$ to a precision of ~35%

Electroweak Penguins

- $B^0 \to K^{*0}\mu^+\mu^-$ will remain a powerful probe for the effects of NP
  - s_0 (zero-crossing of A_{FB} vs q^2) is cleanly predicted in the SM → $4.36^{+0.33}/_{-0.31}$ GeV^2
  - NP Wilson coefficients already strongly constrained by $B^0 \to K^{*0}\mu^+\mu^-$ observables
- **Upgrade**:
  - 2% statistical precision (beyond current theory precision) on s_0 A_{FB} is just the beginning! Will pursue full angular information
  - Explore even rarer related decays, eg $K^+\mu^+\mu^-$, $K_1^+\mu^+\mu^-$, $K_2^{*0}\mu^+\mu^-$, etc



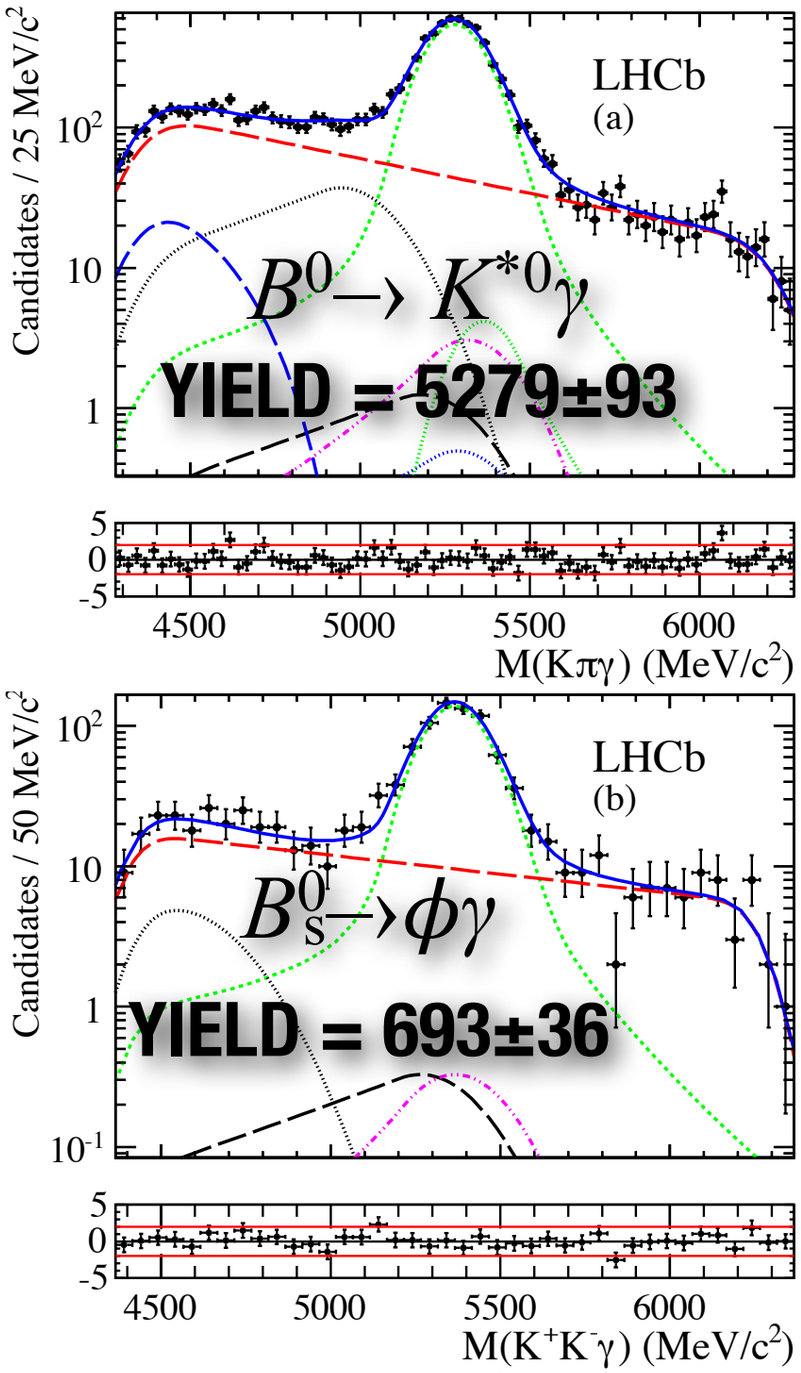
(2100 $B^0 \to K^{*0}\mu^+\mu^-$ per fb^{-1})



arXiv:1304.6325
s_0=4.9±0.9 GeV^2 (New!)

‹–LHCB-PUB-2012-009
Green are constraints from $K^{*0}\mu^+\mu^-$

Radiative Penguins



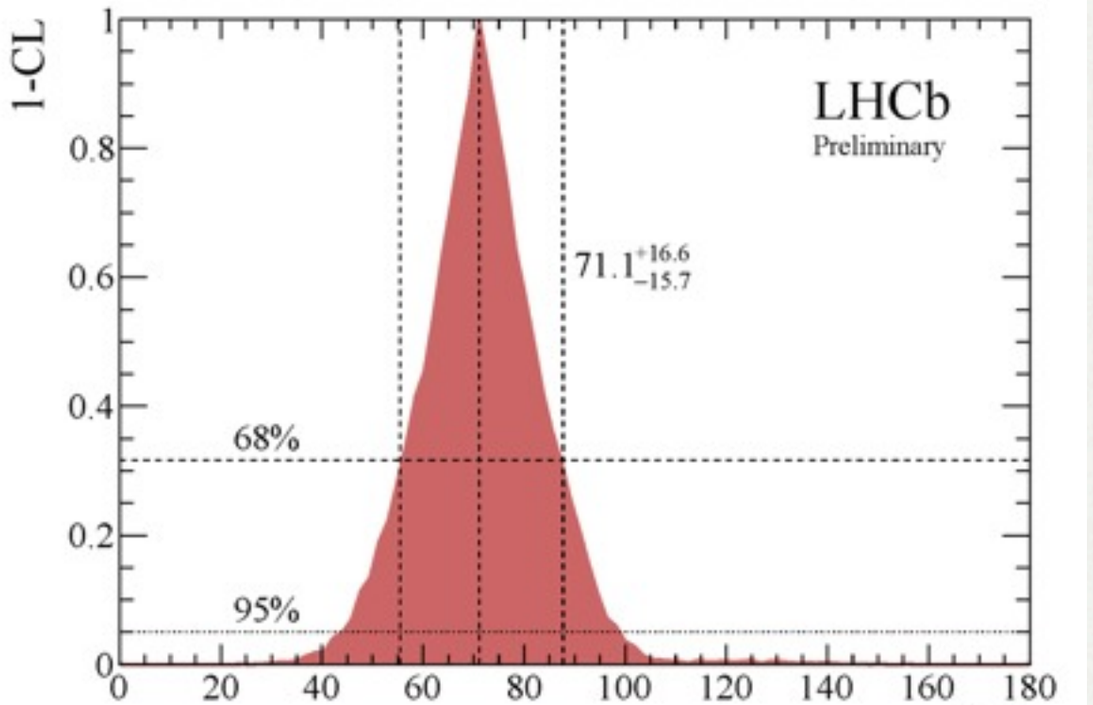
- $b \to s\gamma$ is another testbed for the SM.
  Prediction: predominantly $b \to s\gamma_L$
- Probe γ polarization via time-dependent CPV:
  - $2\beta_s^{\text{eff}}$ and τ_{eff} depend on polarization, different dependence on β_s
- B-factories: $B^0 \to K^{*0}(\to K_S\pi^0)\gamma$
  $(S_{K^{*0}\gamma} = -0.15 \pm 0.22)$
  LHCb: $B^0_s \to \phi\gamma$ - potentially very powerful mode for this
- 2012: O(700) events in 2011 data (with selection), hope to collect 40,000+ such decays with 50 fb^{-1} and the improved trigger
- **Upgrade**:
  - $2\beta_s^{\text{eff}}$ to ±0.02 radians
  - τ_{eff} to 1%

  → 1% polarization precision

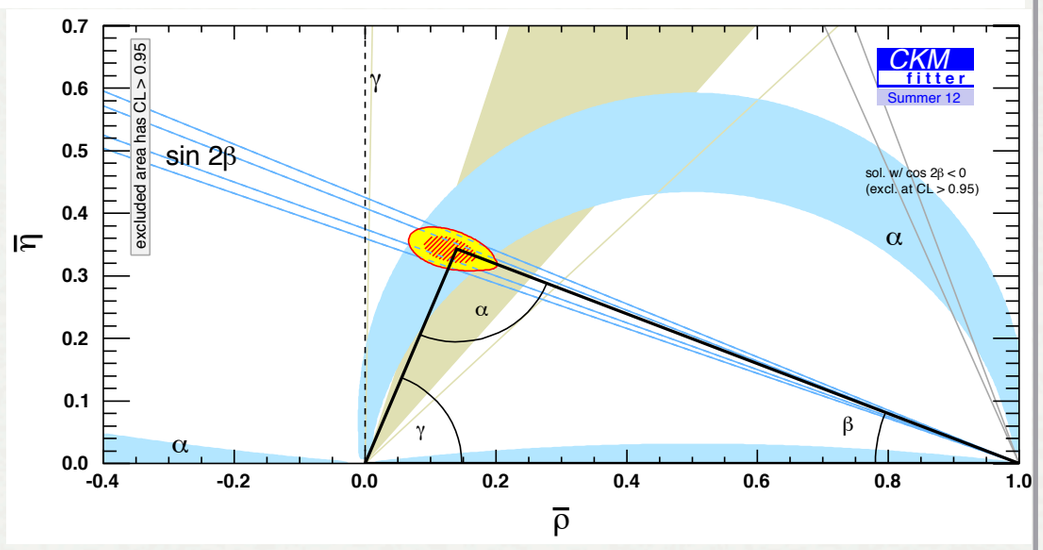
Nucl. Phys. **B** 867 (2012) 1-18 (1 fb^{-1})
$A_{CP}(B^0 \to K^{*0}\gamma) = (0.8 \pm 1.7 \pm 0.9)\%$
$B(B^0 \to K^{*0}\gamma)/B(B^0_s \to \phi\gamma) = 1.23 \pm 0.06 \pm 0.04 \pm 0.10$

γ measurements

- Can be measured with tree-level processes, yet is relatively poorly measured (γ=66±12 degrees [CKMFitter combination])
- UT angle γ currently measured to 15 degrees or so at LHCb
  - Comparable to individual B factory results:
    BaBar combination = $69^{+17}/_{-16}$
    Belle $68^{+15}/_{-14}$
  - Expect ~5 degrees by 2018 with B–›DK and ~11 degrees with B_s–›D_sK
- **Upgrade precision**:
  - 0.9 degrees with B–›DK and
    2 degrees with B_s–›DK



LHCB-CONF-2012-032



Summary Table

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\text{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [30]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [32]	0.045	0.014	~ 0.01
	$a_{\rm sl}^s$	6.4×10^{-3} [63]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$	0.17 [63]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.08 [64]	0.025	0.008	0.02
	$s_0\, A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [64]	6 %	2 %	7 %
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.25 [9]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [29]	8 %	2.5 %	~ 10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [4]	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	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–12° [40, 41]	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° [63]	0.6°	0.2°	negligible
Charm	A_Γ	2.3×10^{-3} [63]	0.40×10^{-3}	0.07×10^{-3}	–
CP violation	ΔA_{CP}	2.1×10^{-3} [8]	0.65×10^{-3}	0.12×10^{-3}	–

Table 1: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with $50\,\text{fb}^{-1}$ by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities. Note that the current sensitivities do not include new results presented at ICHEP 2012.

LHCB-PUB-2012-009

Conclusion

- LHCb is a powerful general-purpose experiment in the forward direction
  - Many interesting topics in the physics program not in the scope of this session
- The LHCb upgrade will be a powerful super flavor experiment which will dominate Bs and charged exclusive channels
  - Flexible all-software trigger working on 40 MHz readout is key to continued improvement in hadronic modes
- Expect 5-7 fb^{-1} pre-upgrade, then 50 fb^{-1} of upgrade data at $\gtrsim$ 5 fb^{-1}/year
- TDRs for the upgrade due this year, work begins in 2014, installation in 2018

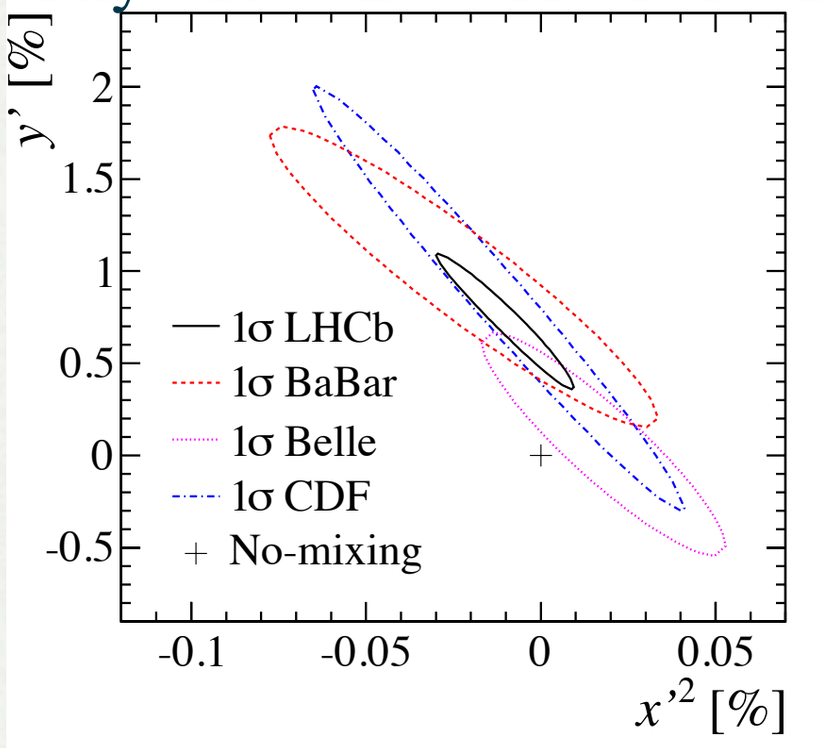
END

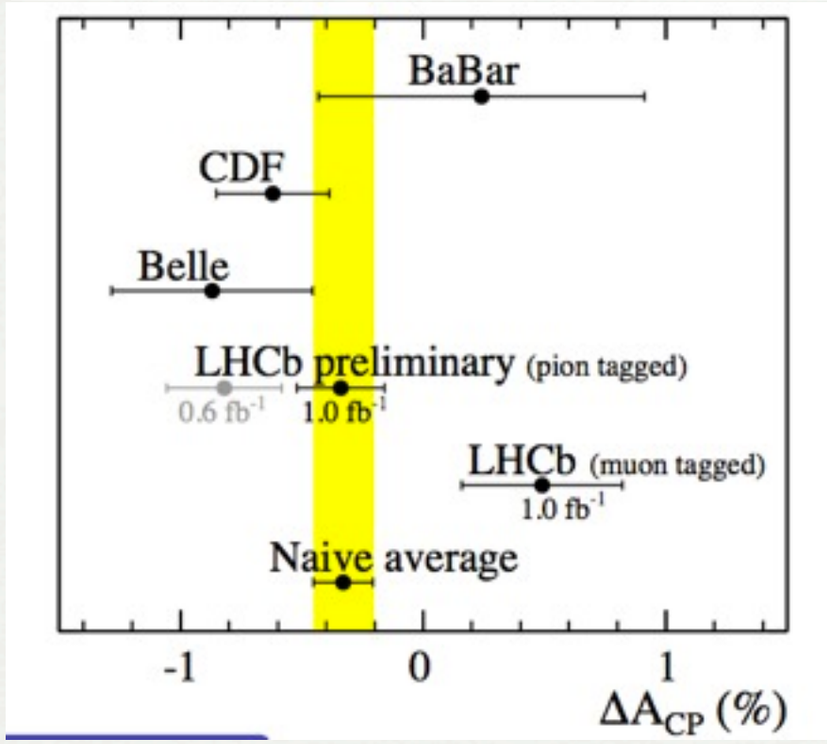
Charm CPV

- Combinations of previous measurements had established D^0 mixing at high significance
  - D^0 mixing now cleanly observed in a single channel at LHCb
- $\Delta A_{CP} = A_{CP}(D \to K^+K^-) - A_{CP}(D \to \pi^+\pi^-)$ very clean due to cancellation of production, detection asymmetries
- **Upgrade**:
  ΔA_{CP} to sub-10^{-4} precision
  Lifetime asymmetries to few×10^{-5}

  LHCB-TALK-2013-055
  LHCB-PAPER-2013-003
  LHCB-CONF-2013-003
  $\Delta A_{CP} = 0.49 \pm 0.30 \pm 0.14$ (SL)
  $\Delta A_{CP} = -0.34 \pm 0.15 \pm 0.10$ (Preliminary Prompt)

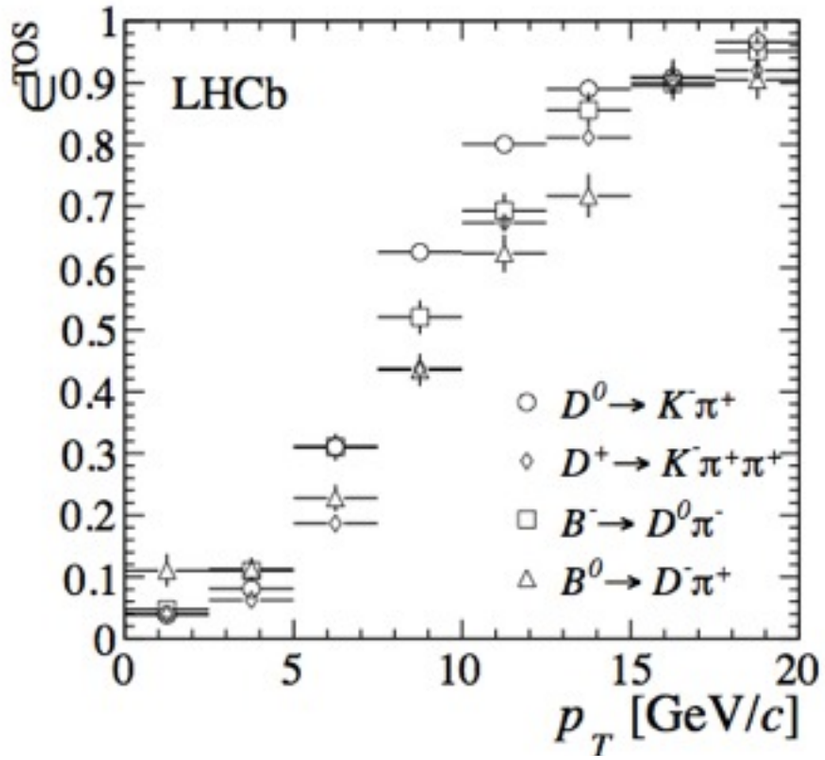
Phys. Rev. Lett. **110** 101802



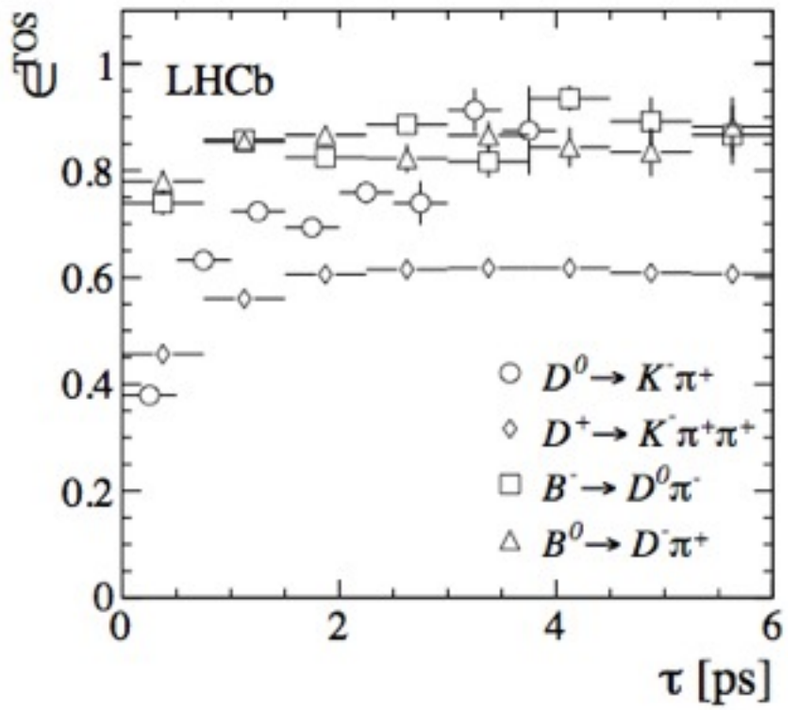


Triggering in $B \to D\pi$

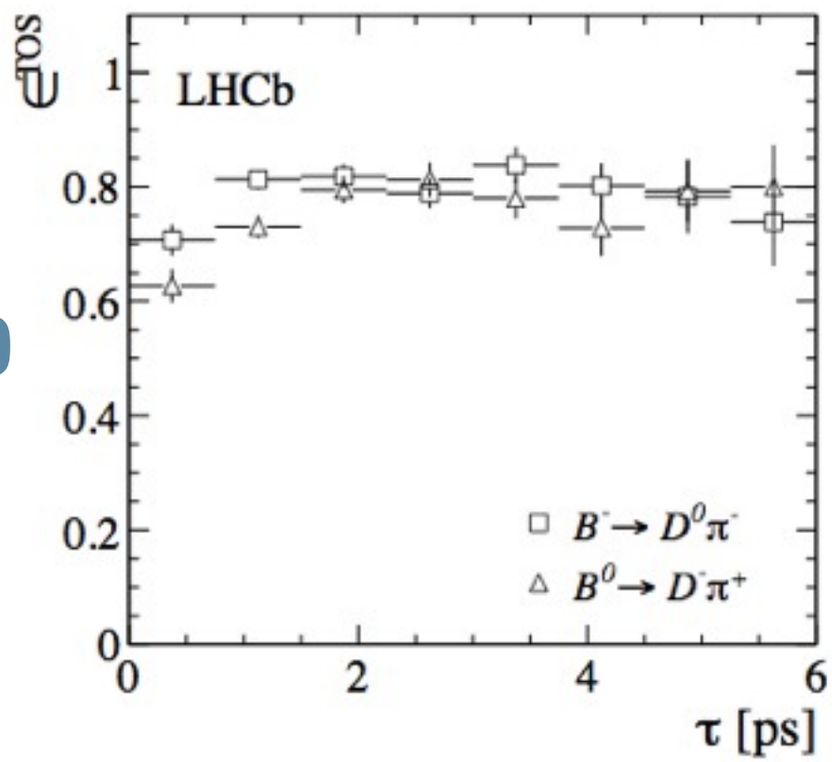
LOHADRON



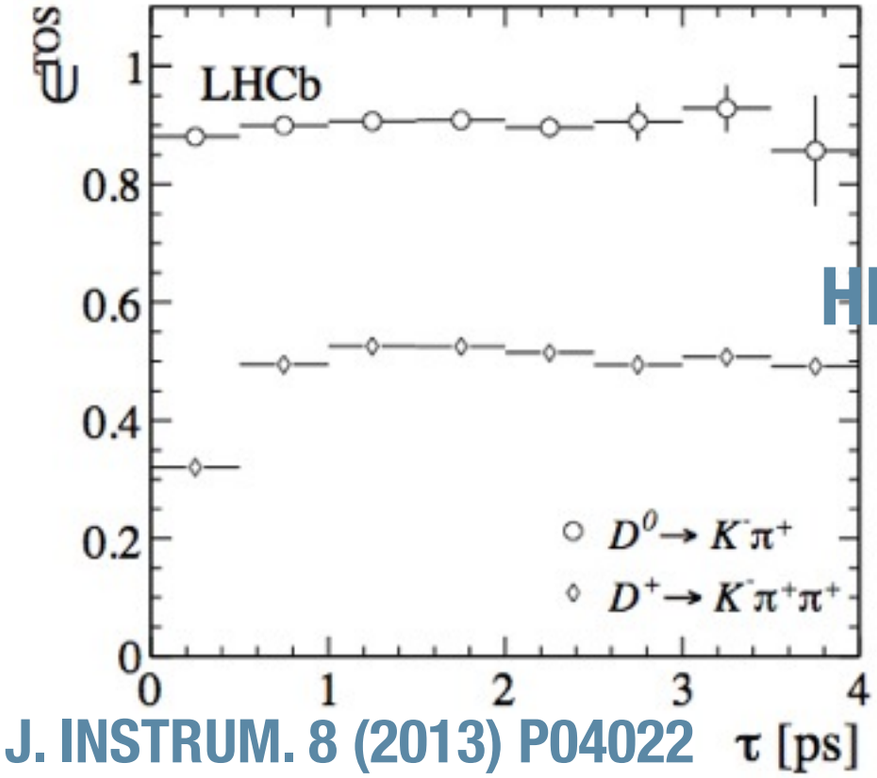
HLT1



HLT2 TOPO

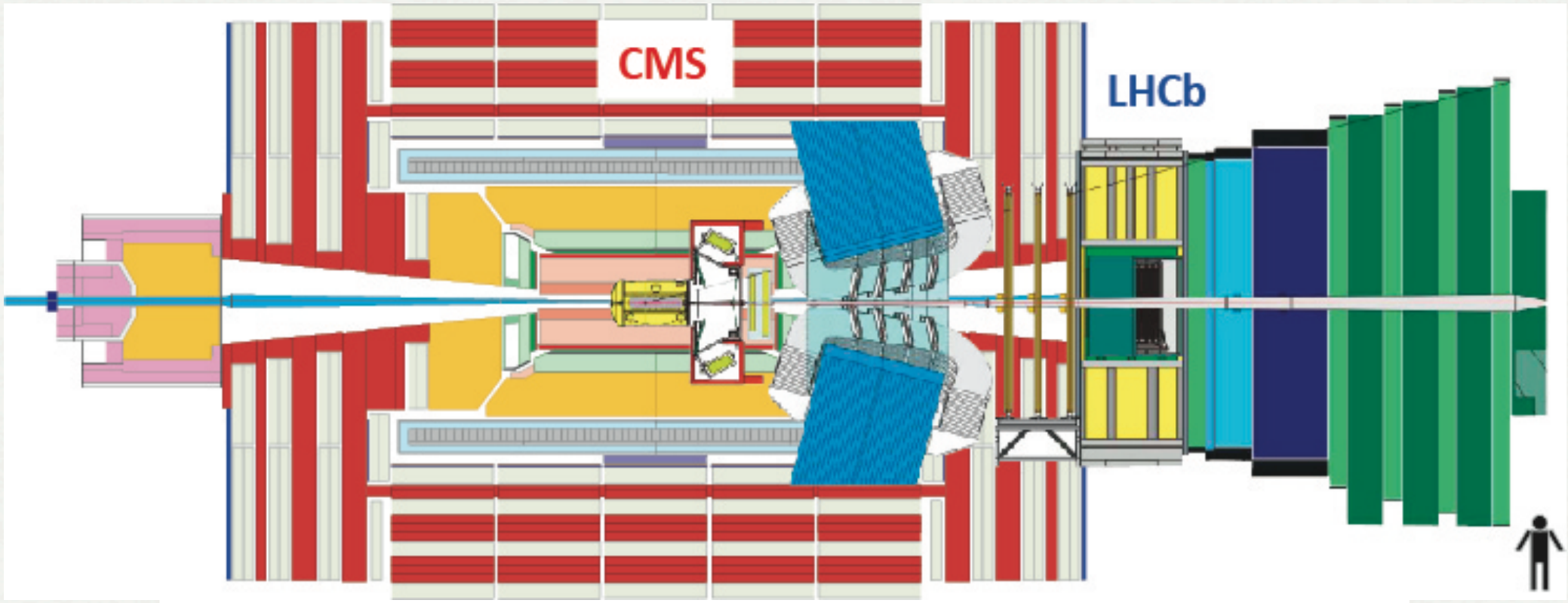


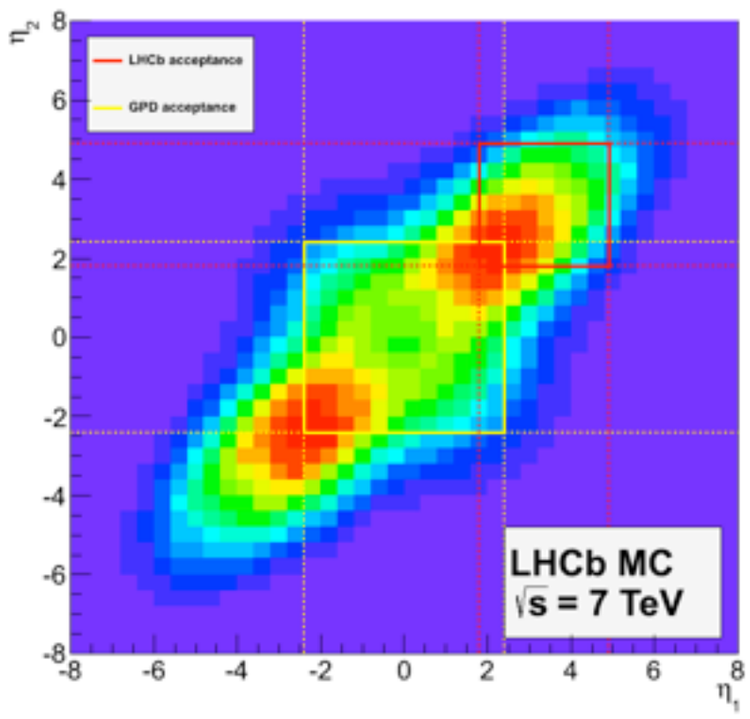
HLT2 CHARM

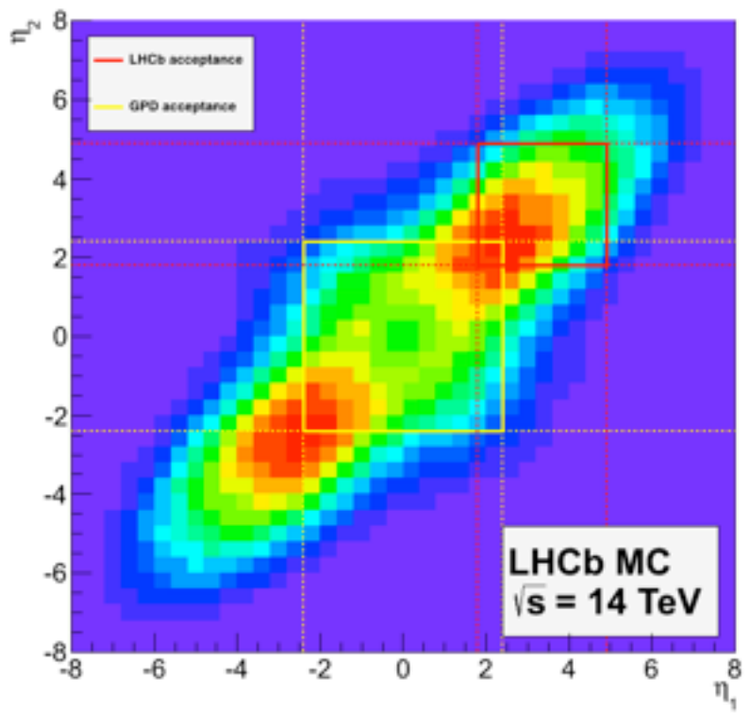


J. INSTRUM. 8 (2013) P04022

LHCb vs CMS


CMS
LHCb


LHCb acceptance
GPD acceptance
LHCb MC
√s = 7 TeV
η1
η2


LHCb acceptance
GPD acceptance
LHCb MC
√s = 14 TeV
η1
η2