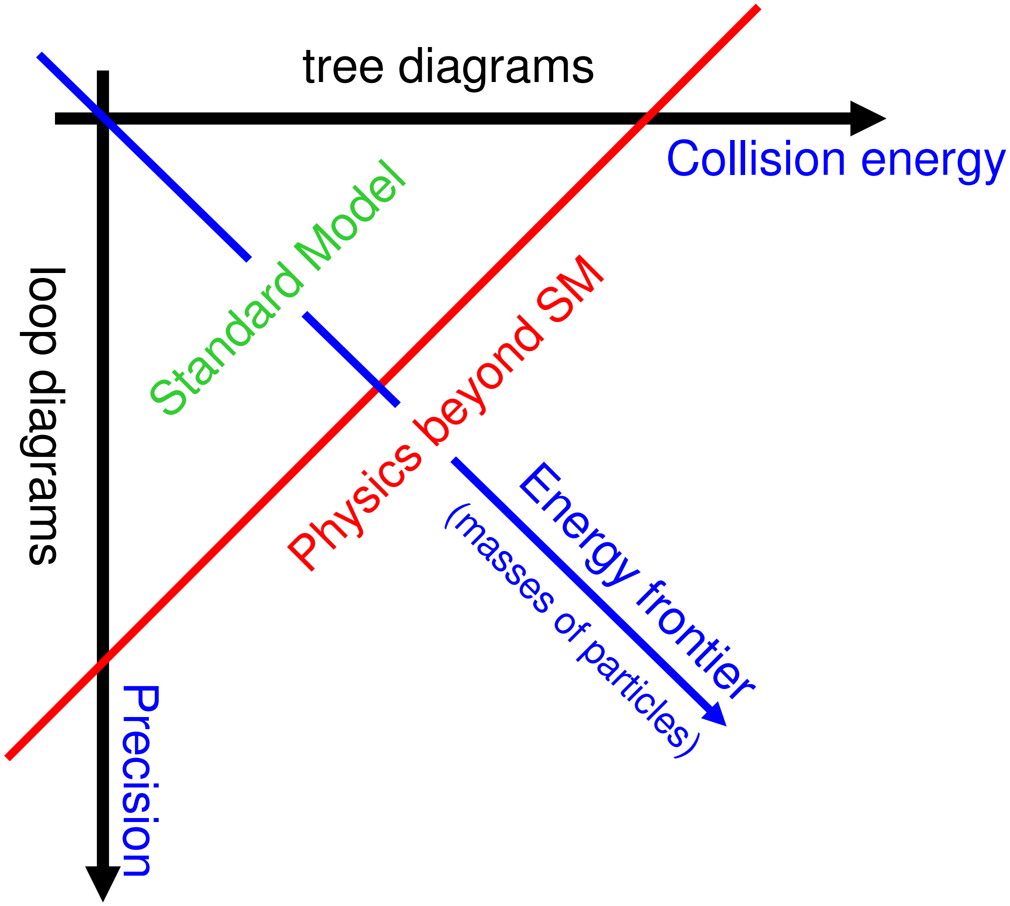
Future b and c experiment with hadron machine

Tomasz Skwarnicki

Representing LHCb collaboration

Two ways of advancing "energy frontier"



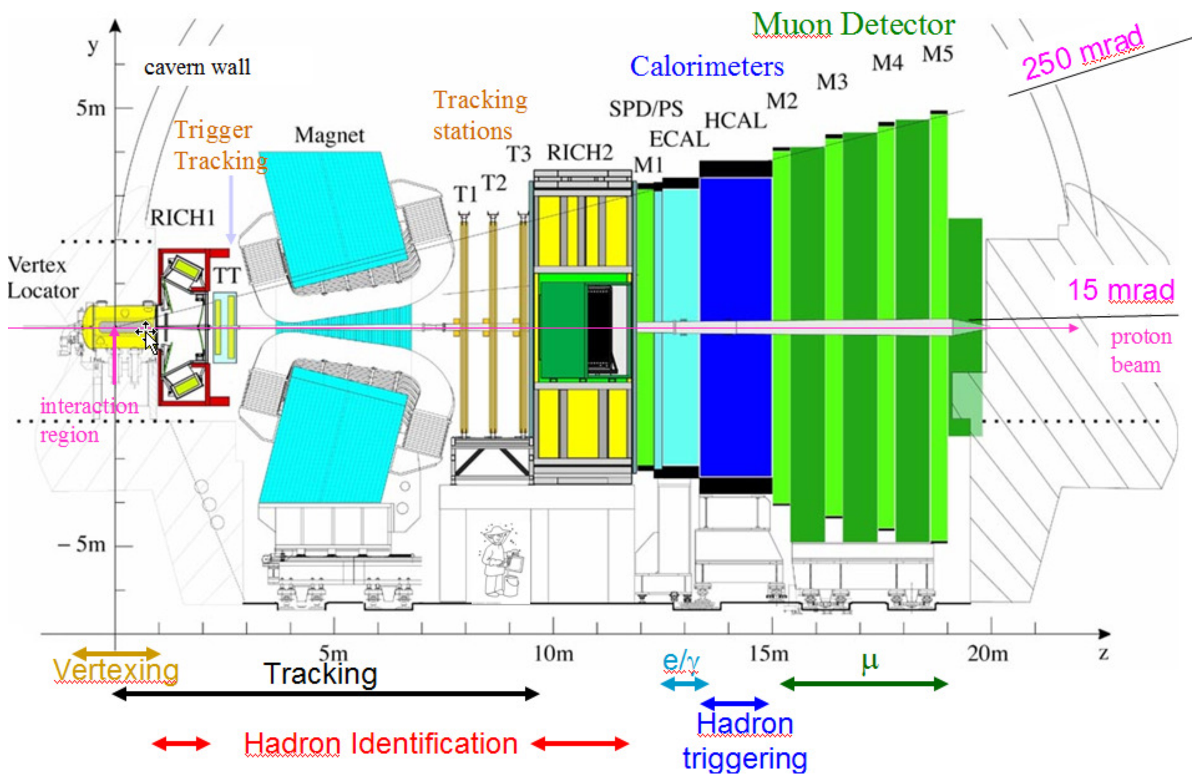
- Flavor physics offers many loop processes to study (FCNC, mixing, CPV):
  - Some spectacular successes in the past (existence of charm quark, 3rd generation, top quark mass)
  - Very existence of flavor sector with puzzling hierarchy hints NP
- Advancing precision of flavor experiments (statistics & systematics) and advancing collision energy for direct NP searches are complementary:
  - Both must continue

Future (beyond first round of LHC experiments)

- Physics beyond Standard Model will have or will not have been observed in direct searches at LHC at a TeV energy scale
- In either case flavor physics experiments must carry on:
  - To reveal flavor structure of NP observed in direct searches
  - To probe for NP in multi-TeV range if no NP observed in direct searches
- Future b and c experiments:
  - At e^+e^- collisions: Super-KEKB, Super-B (previous talks)
  - At hadronic collisions: LHCb upgrade (this talk)

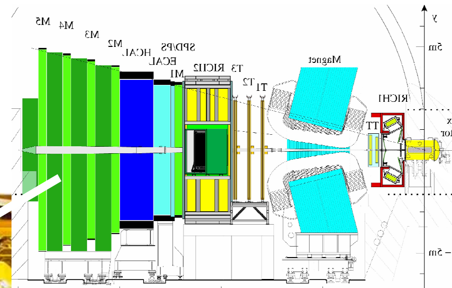
Existing LHCb detector

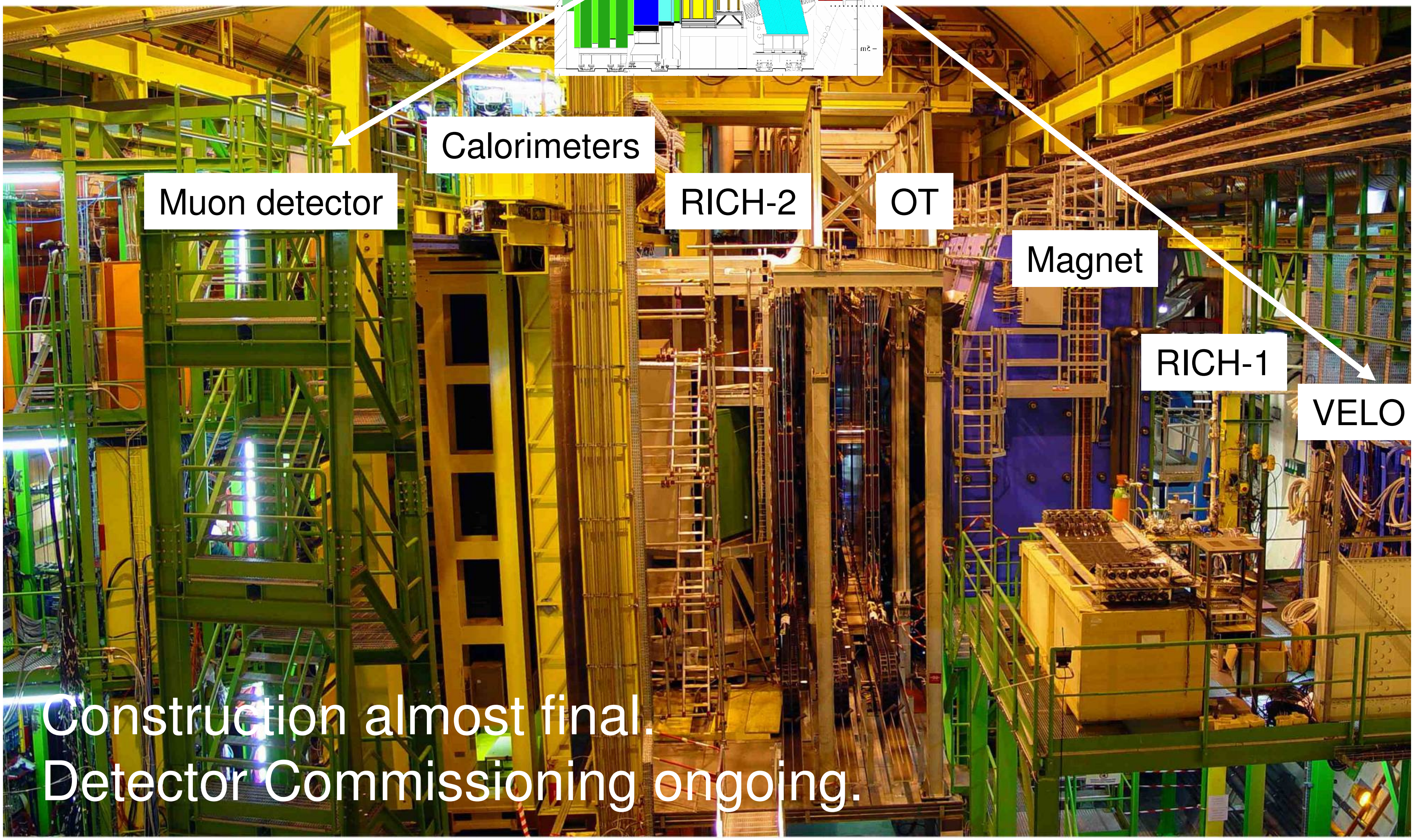
- Forward geometry:
  - 10^{12} bb/2 fb^{-1} produced
  - both B hadrons in acceptance for tagging
  - excellent proper time resolution (40 fs)
  - Space for RICH detectors (K/π separation 2-100 GeV)
- Adjustable luminosity:
  - (2-5) x 10^{32} $cm^{-2}s^{-1}$ i.e. factor 50-20 below peak luminosity of LHC to limit:
    - number of interactions per bunch crossings
    - radiation dose
    - data rates in trigger



- Hardware & software triggers:
  - Hardware L0: high Pt μ, charged hadron, and e/γ triggers (10 MHz$\rightarrow$1 MHz)
  - Software High Level Triggers (large CPU farm):
    - HLT1: confirm L0 seeds with the tracking detectors, add Impact Parameter cuts
    - HLT2: full event reconstruction and off-line like selections to reduce rate to **2 kHz**

LHCb Status





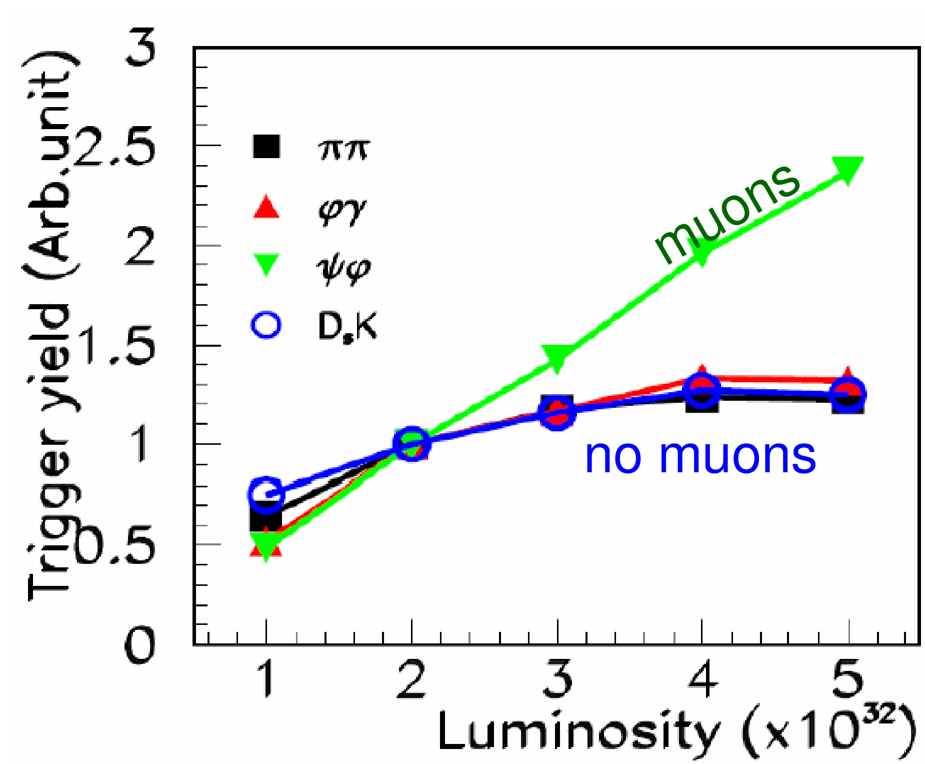
Construction almost final.
Detector Commissioning ongoing.

LHCb physics program

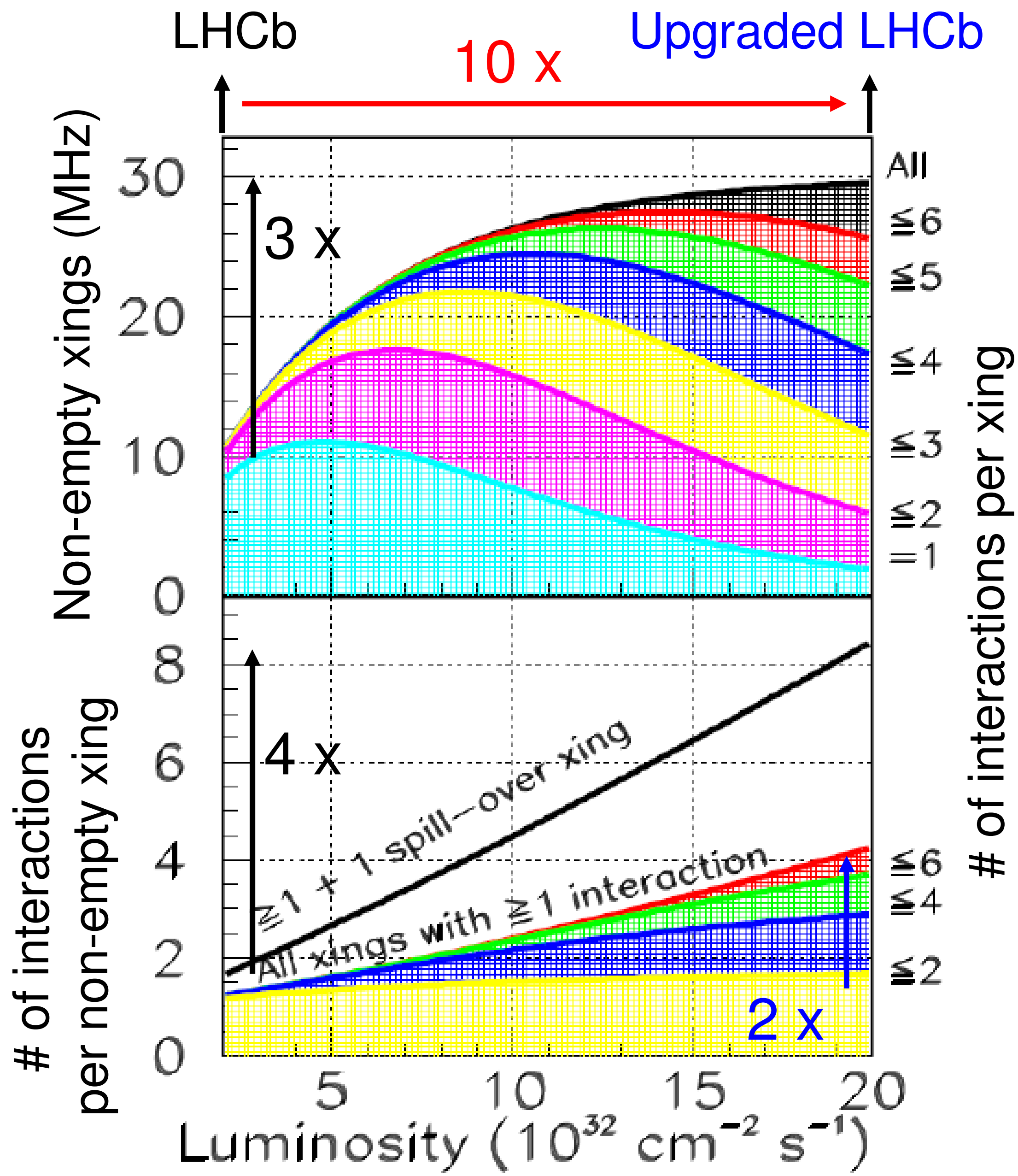
- By 2013 LHCb expects to accumulate 10 fb^{-1}. Allows for wide range of analyses, with high sensitivity to new physics.
- Some highlights:
  - Observation of $B_s \to \mu\mu$ at SM value
  - B_s mixing phase measured with uncertainty of 0.01 rad (SM expectation: -0.036±0.003)
  - $B \to K^*\mu\mu$: '0-point' of FB asymmetry measured to 7%
  - Precise determination of γ
    - tree-level value known to ~2°
    - NP-sensitive measurements with Penguin modes (eg. $B \to hh$)
  - Search for NP CPV in gluonic penguins, e.g. $B_s \to \phi\phi$
  - D^0 mixing measurements & searches for charm CPV to 10^{-3}

Why LHCb upgrade?

- Many important measurements will be statistics limited in 10 fb^{-1}
  - Aim at ~100 fb^{-1} for a significant gain in sensitivity
- LHCb statistics is not limited by the LHC luminosity but by the detector itself:
  - Radiation damage (spec was <20 fb^{-1})
  - No gain from increased luminosity for channels relying on L0 hadron trigger
  - Significant problems with spill-over in straw tracking stations



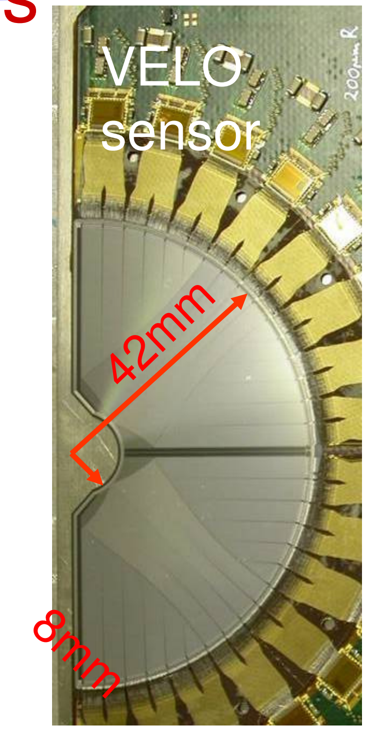
Choice of luminosity

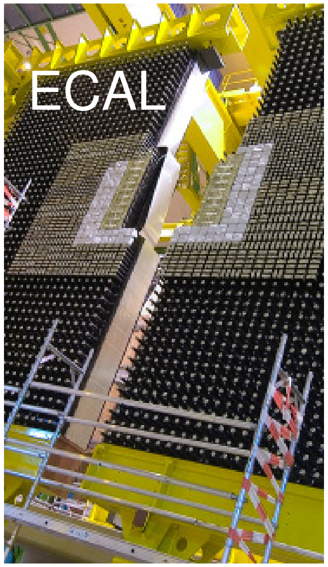


- Instantaneous luminosity to be increased by a factor of 10
  - Bunch crossing rate with at least 1 visible pp-interaction up by a factor of 3
  - Number of pp-interactions per non-empty bunch crossing up by a factor of 2 (4 including spillover)
- This luminosity upgrade does not require any changes to the LHC. It is also compatible with SLHC proposed for ATLAS & CMS.

Upgraded detector – radiation hardness

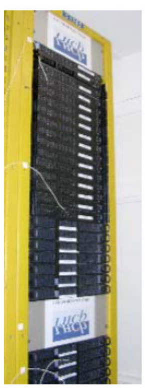
- Present vertex detector (VELO) has long R & ϕ strips and is not particularly radiation hard.
  - We are planning to replace it after ~6 fb^{-1} even without an upgrade.
- Short strips (strixels) or pixels are needed.
  - This will also help pattern recognition and enable stand-alone momentum measurement if magnetic field is generated in the vertex detector area (presently no field, would help moving IP requirements to the lowest trigger level)
  - Number of different technologies are being considered. The R&D program has started.
  - Other possible improvements: removing RF foil (50% of present X_0 budget), moving VELO closer to the beam (presently at 8mm which is conservative)
- Possibly replace inner region of EM calorimeter:
  - With the same technology (shashlik) but smaller segmentation
  - With rad hard crystals (would improve energy resolution)
- Possibly may also have to replace MWPC in the inner region of the first muon superlayer
  - by triple GEM-detectors (already in use in parts of the detector)





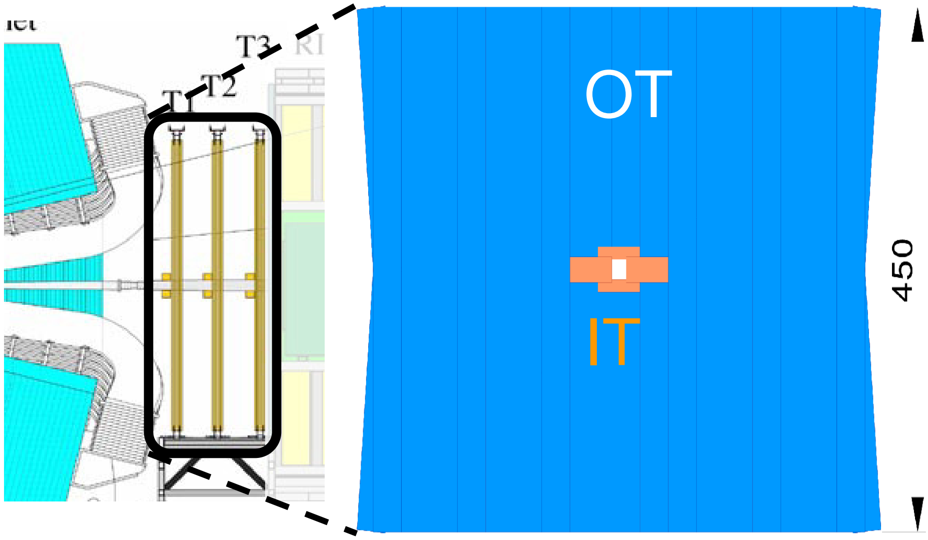
Upgraded detector – trigger & FE

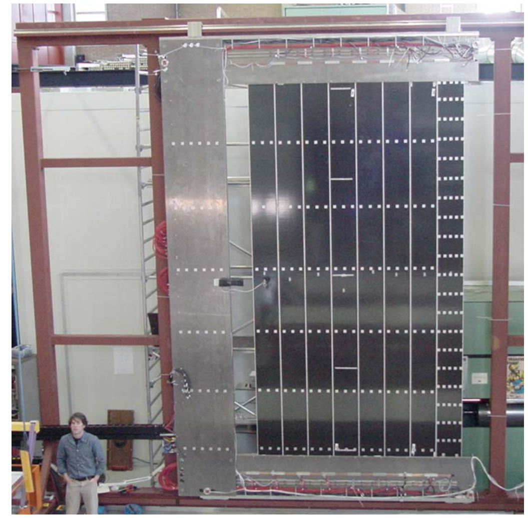
- Present Front End & trigger electronics:
  - limit readout from detectors not included in L0 trigger (all tracking detectors, RICHes) to 1MHz
  - limit L0 decision time to a few μs
- As the luminosity is increased by a factor of 10, the trigger must become more selective
  - visible bb cross-section alone will reach ~0.4 MHz (total ~30 Mhz)
  - the present L0 trigger scheme breaks down.
    - The efficiency (especially for modes with no muons) decreases wiping out the luminosity gain.
  - more selective trigger requires use of tracking information early on and longer decision time (latency):
    - On top of sustaining higher luminosities can improve trigger efficiency for hadronic modes by a factor of 2
- Solution is to readout all detectors synchronously at 40 MHz (bunch crossing frequency) and make all trigger decisions in the CPU farm:



  - All FE electronics must be replaced!
  - Requires new photo-detectors in RICH detectors, since present HPDs cannot be readout at this rate

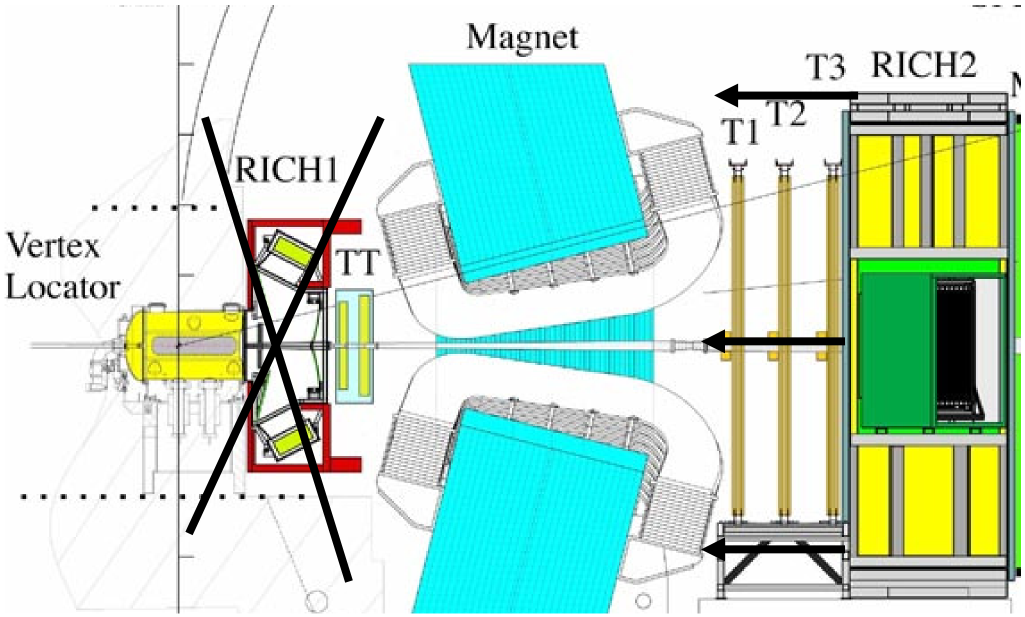
Upgraded detector – Outer Tracker





- Tracking stations behind the magnet consists of straw tubes (OT) and silicon strips in the inner part (IT)
- Spill over increases occupancy in OT by a factor of 4 with significant degradation on tracking performance (lower efficiency, higher ghost rate)
- Possible solutions:
  - Faster gas to reduce spill over
  - Increase IT area, decrease OT area
  - Replace straws by new technology (Scintillating Fiber tracker?)

Upgraded detector – PID options



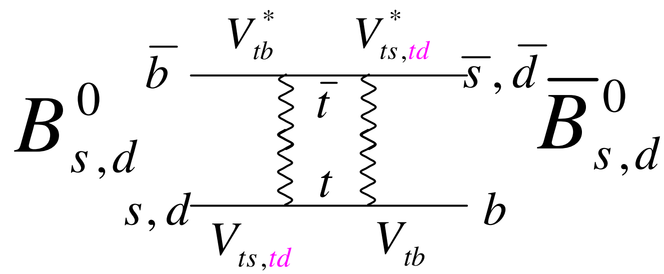
HPDs

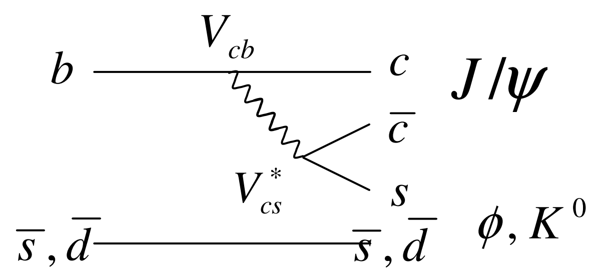
- Since RICH photo-detectors must be replaced, contemplate (optional) more drastic redesign of hadron ID system:
  - Remove RICH1 significantly reducing dead material in the tracking system (improves momentum resolution, e/γ detection)
  - RICH2 then must also be replaced to cover lower particle momenta:
    - Its aperture must be increased by enlarging & moving closer to the interaction point
    - Requires integration with the tracking devices

Physics with the upgraded LHCb detector

Mixing phases

- *No dedicated physics studies yet; all numbers come from results of LHCb 10 fb^{-1} simulations scaled by factor of 20 for hadronic channels, and 10 for channels with muons.*
- CPV phase in $B_s \to J/\psi\phi$:
  - Mixing and decay phases are both small in SM.
  - Good place to look for NP in mixing diagram.
  - Large value would exclude MFV hypothesis.
  - LHCb will hopefully see beyond-SM phase.
  - Upgraded LHCb will make precise measurement.

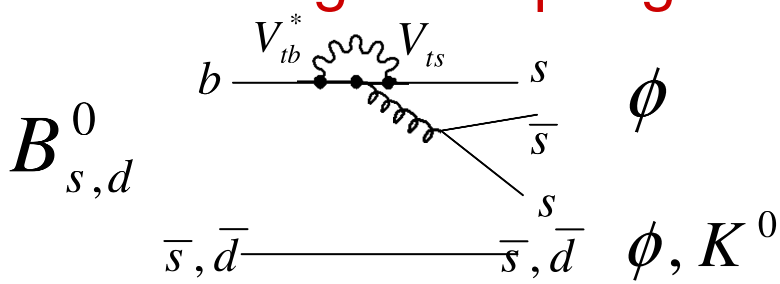




	LHCb		Upgraded LHCb	ϕ_s - SM expectation
Luminosity	2 fb^{-1}	10 fb^{-1}	100 fb^{-1}	
$S(B_s \to J/\psi\phi)$	±0.02	±0.01	±0.003	-0.036±0.003

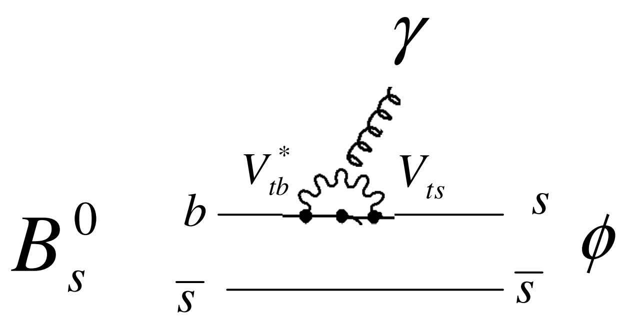
- Similar precision in CPV phase in $B_d \to J/\psi K_s$ (sin2β).
  - Vast statistics will permit understanding of systematics (e.g. from tagging).
  - Mixing phase is large in SM.
  - Not likely to reveal NP by itself.
  - Providing constraints for interpretation of other measurement.

CPV phases and gluonic penguins



- Decay channels mediated by penguin diagrams can peak up additional phases from NP in the loops
- Hint of disagreement between mixing phase measured in trees and loops with the present data (Belle & BaBar):
  - $S(B_d \to \phi K_s) - S(B_d \to J/\psi K_s) = 0.29 \pm 0.17$ (expect ≈ 0 in SM, since each ≈ $\sin 2\beta$)
  - Sensitivity of (LHCb) upgraded LHCb with ($10 fb^{-1}$) $100 fb^{-1}$:
    $S(B_d \to \phi K_s)$ to (± 0.1) ± 0.025
- Even better to look for extra phases of penguin diagrams in B_s sector, since the mixing phase is small:
  - Golden mode: $B_s \to \phi\phi$:
    - In SM mixing and decay phase (both small) approximately cancel each other, thus expect $S(B_s \to \phi\phi) \approx 0$.
    - (LHCb) upgraded LHCb with ($10 fb^{-1}$) $100 fb^{-1}$ can measure:
      $S(B_s \to \phi\phi)$ to (± 0.05) ± 0.01

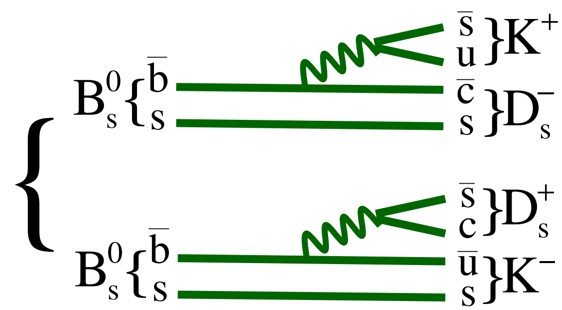
CPV phases and radiative penguin



- $B_s \to \phi\gamma$ is particularly sensitive to right-handed currents:
  - (LHCb) upgraded LHCb sensitivity: $S(B_s \to \phi\gamma)$ to (±0.05) ±0.02
  - Additional sensitivity via hyperbolic-sine term in decay width: $A^{\Delta\Gamma} \sinh(\Delta\Gamma\, t / 2)$:
    - $\Delta\Gamma$ Negligible in B_d decays
    - (LHCb) upgraded LHCb sensitivity: $A^{\Delta\Gamma}$ to (±0.1) ±0.03
    - Reach the level of theoretical uncertainties with the upgraded detector

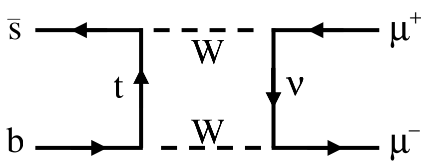
Measurements of γ

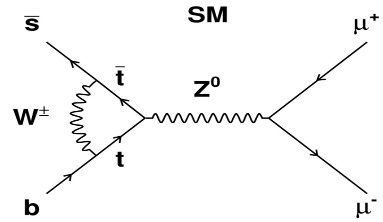
- Determined via tree-level processes ($B^{\pm}\rightarrow D^0 K^{\pm}$, $B_s\rightarrow D_s^{\mp}K^{\pm}$), thus serves as another "standard candle" for constraints on unitarity triangle parameters.
- LHCb with 10 fb^{-1} will measure γ to $\pm 2.5^o$.
- Very large statistics with upgraded LHCb (examples):
  - 620,000 $B_s\rightarrow D_s^{\mp}K^{\pm}$ (interference via B_s mixing, very clean way to measure $\gamma+\phi_s$)
  - 500,000 $B^{\pm}\rightarrow D^0 (K_s\pi\pi) K^{\pm}$
  - 5,600,000 $B^{\pm}\rightarrow D^0 (K\pi) K^{\pm}$



- Statistical uncertainty in several modes below 1^o
- Systematic uncertainties largely uncorrelated, and often can be measured in control samples
- Upgraded LHCb will allow γ determination to < $\pm 1^o$

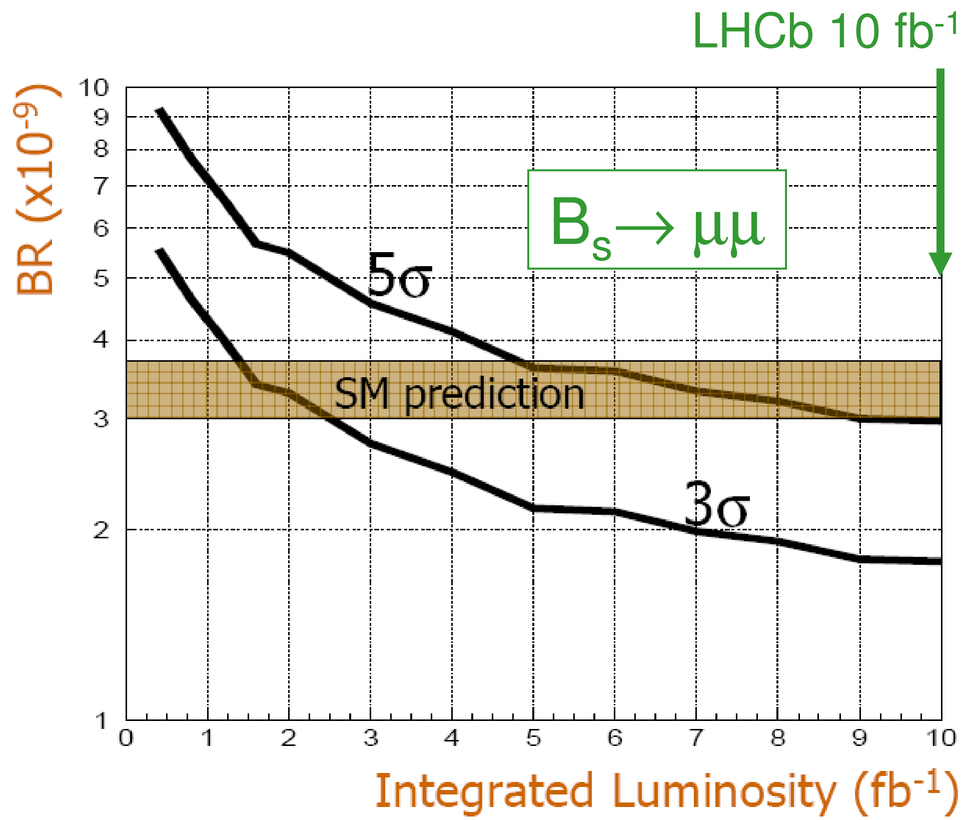
$B_{s,(d)} \to \mu\mu$





- Loop decays very sensitive to many extensions of SM.
- LHCb will hopefully detect beyond-SM signal in $B_s \to \mu\mu$
- To lower experimental error below the theoretical uncertainty on SM prediction (10%), upgraded LHCb will be needed

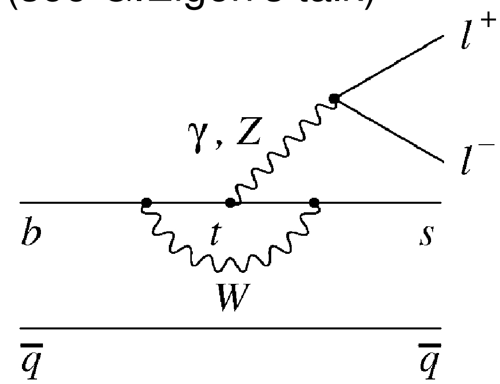
Expected limits from CDF,D0 with ~6 fb^{-1}:
BR < ~(2-3) x 10^{-8} (see Donati, Tsybychev)



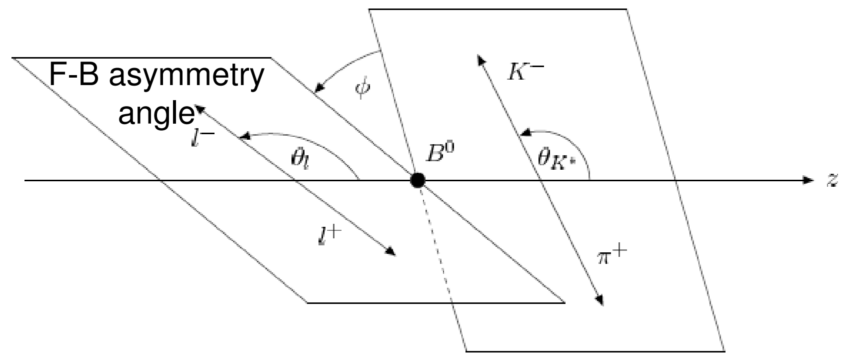
- With upgraded LHCb it should also be possible to observe $B_d \to \mu\mu$ at SM level (~1 x10^{-10})

$B_d \rightarrow K^{*0}\mu\mu$

(see G.Eigen's talk)

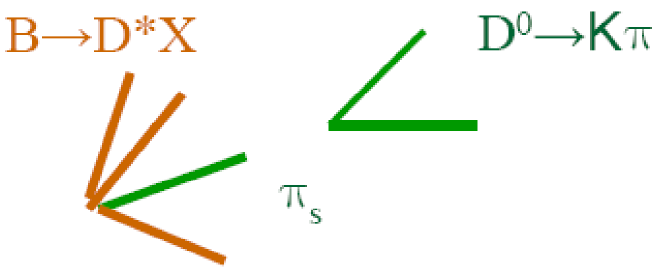


- Sensitive to NP in small tanβ range.
- Zero point of forward-backward asymmetry in $M_{\mu\mu}^2$ will be measured to (±0.3) ±0.07 GeV^2 with (LHCb-10 fb^{-1}) upgraded LHCb-100 fb^{-1}.
- The latter exceeds present theoretical uncertainty on SM predictions.

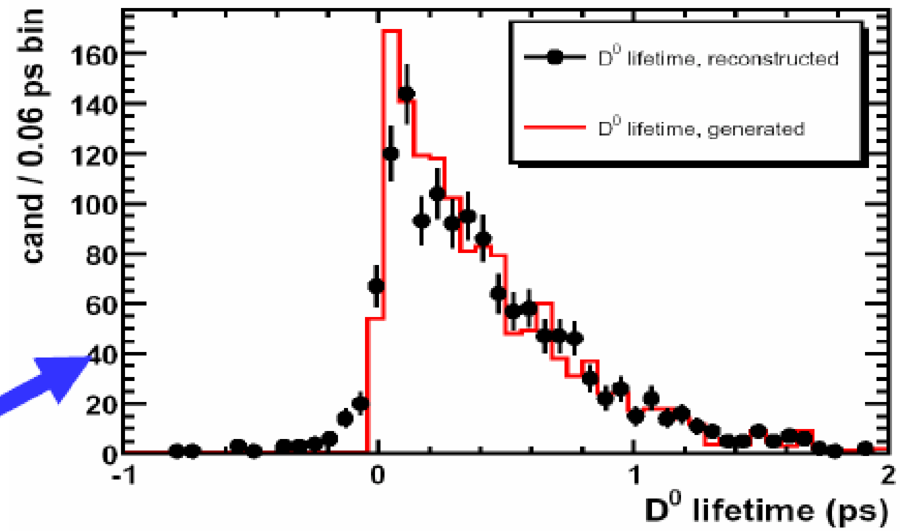


- Additional sensitivity via transversity amplitudes (analysis of full angular correlation)
- Measurement of ($|A_\perp| - |A_\parallel|$) / ($|A_\perp| + |A_\parallel|$) for theoretically preferred region ($M_{\mu\mu}^2$<6 GeV^2) to (±0.2) ±0.06 for (LHCb) upgraded LHCb vs theoretical error of ±0.003
- We will also study $B_d \rightarrow \rho(\omega)\mu\mu$ and $B_s \rightarrow \phi\mu\mu$, $B_s \rightarrow K^{*0}\mu\mu$

D^0 mixing and CPV



Partially reconstruct B decay vertex to find birth position of D^0 - gives good proper time resolution



- From wrong sign $K\pi$ measure:
  - x'^2 to $\pm 2\times10^{-5}$
  - y' to $\pm 3\times10^{-4}$
- From KK measure:
  - y_{CP} to $\pm 1.5\times10^{-4}$

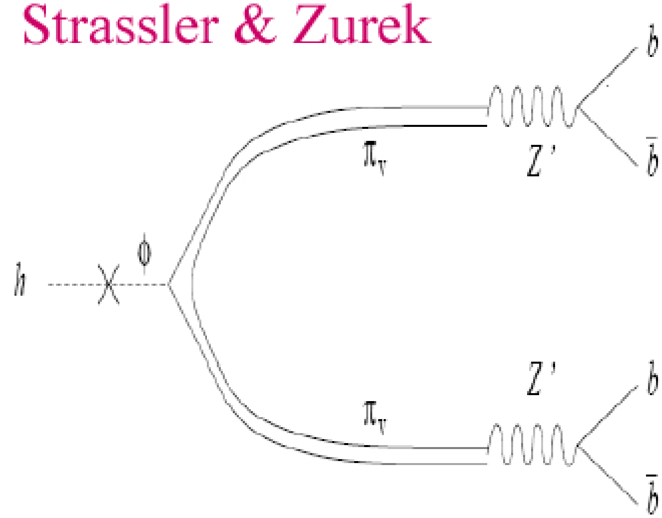
Other selected topics

- Lepton flavor violating decay $\tau \to \mu\mu\mu$.
  - $BR(\tau \to \mu\mu\mu)$ sensitivity 2×10^{-9} *(preliminary estimate)*
- Sensitivity to long-lived (vertex detector is 1m long) NP particles decaying to $b\bar{b}$.
  - For example, "hidden valley" model

$$\text{Higgs} \to \pi^0_v\,(b\bar{b})\,\pi^0_v\,(b\bar{b})$$

where π^0_v are new v-flavored particles

Strassler & Zurek



Conclusions

- LHCb about to take over the baton of flavor physics.
  - 10 fb^{-1} expected by ~2013: wealth of exciting discoveries and measurements in store.
- Require upgraded flavor experiment to capitalize on what is learnt at early LHC, and to exploit fully enormous b production cross-section and access to B_s sector:
  - Updated readout, trigger and vertex detector will be critical in upgrade.
  - Significant changes needed elsewhere (e.g. RICH photodetectors)
  - Experiment compatible with, but not reliant on, machine upgrade.
  - General physics capabilities clear; details under study.
- EOI recently approved by the collaboration and submitted to LHCC (CERN/LHCC/2008-007, April 22, 2008)
  - Aim at upgraded LHCb detector to start taking data in 2015
  - 100 fb^{-1} collected by 2020
  - Starting detector R&D