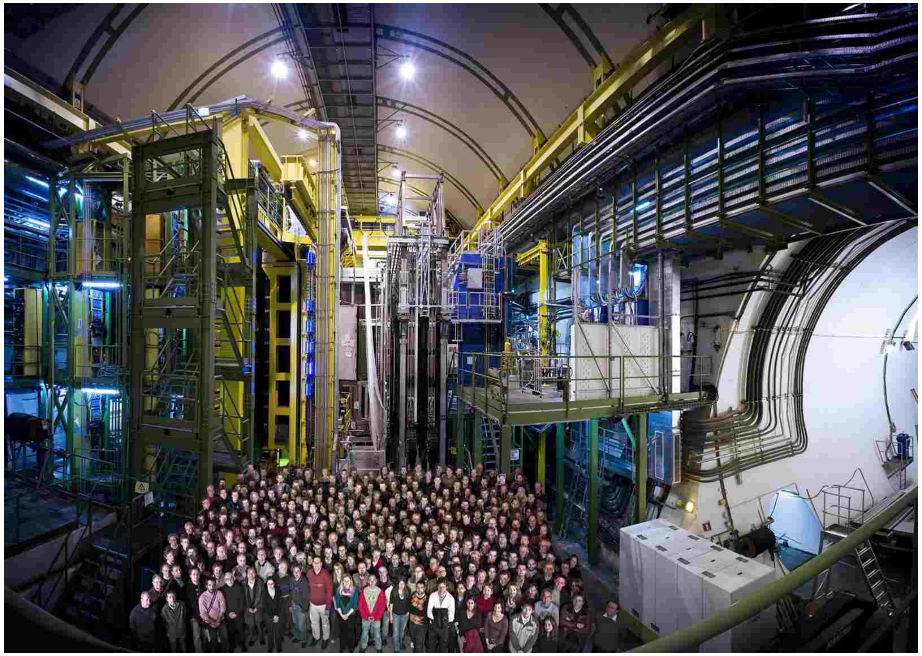
The Upgrade of the LHCb Detector



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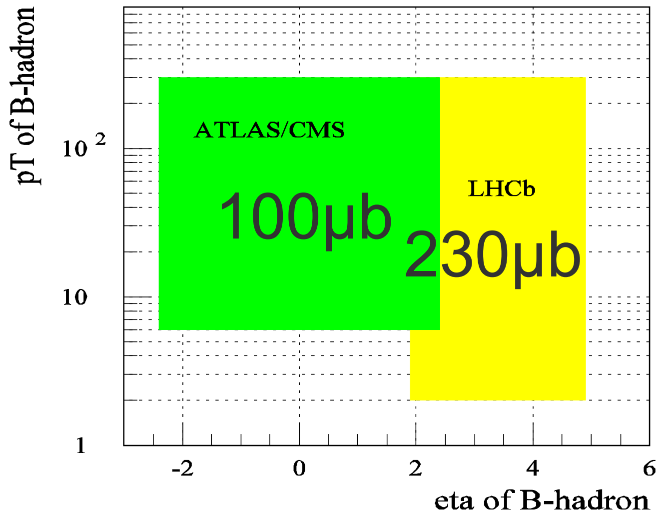
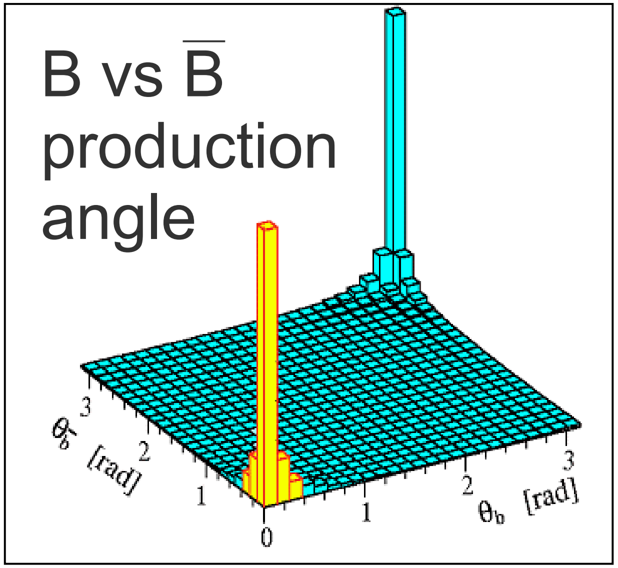
Laboratoire de l'Accélérateur Linéaire
France

LHCb/CERN

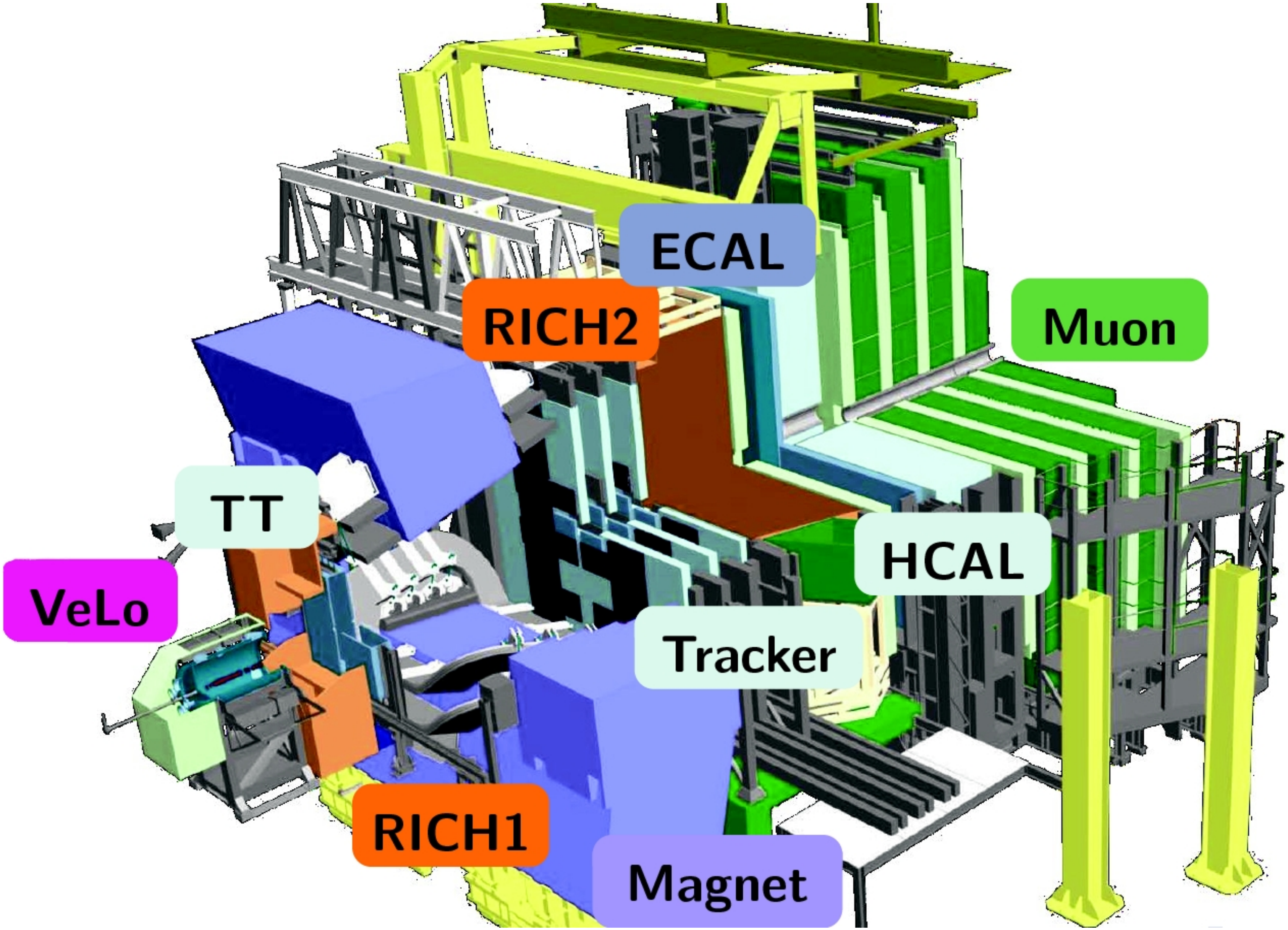
LHCb

- LHCb is a collaboration of more than 700 people from 54 institutes of 15 countries
- LHCb is the dedicated B physics experiment at LHC devoted to precision measurement in CP violation and rare decays
- LHCb seeks to find the evidence of new particles via their interferences in b and c quarks decays
- b/anti-b production at LHC is very large especially in the forward region of the interaction points
- LHCb is a single-arm forward spectrometer
  - $1.9<\eta<4.9$
  - $\sigma_{b\bar{b}} \sim 230\ \mu b$ in detector coverage
  - Production of B^0, $B^{+/-}$, B_s, B_c, b-baryons
  - B's have a large momentum
    - Hadrons with both b and $\bar{b}$ in the acceptance
    - Large displaced vertices
- Present "nominal" luminosity is $2x10^{32}cm^{-2}.s^{-1}$
  - At $L=10^{33}cm^{-2}.s^{-1}$, $5x10^{12}$ B-hadrons produced per year (10^7s)





The LHCb Detector



Introduction

- The present picture we have is very consistent with the Standard model
  - Still there many unanswered questions → New physics

- We may expect that NP will be seen at LHC
  - The first run (5/6 fb^{-1}, until 2015) could already give some hints
  - This is especially true in the heavy flavour sector (LHCb)

- If there are hints of NP after 5/6 fb^{-1}
  - Physics sensitivity is not sufficient
    to distinguish between different models

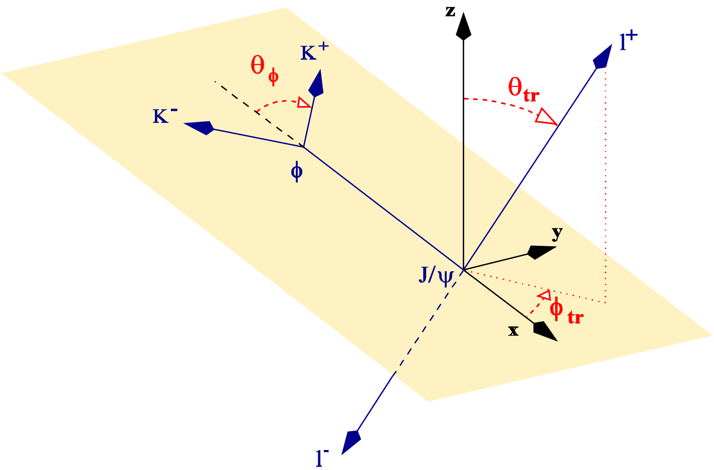
- Present operation of LHCb is very satisfactory
  - See the talk from Franz Muheim on Tuesday

- Upgrade done in 2 phases matching the LHC schedule

- Goal of first phase
  - Improve the trigger efficiency on b hadron (factor 2)
  - To accumulate 10 times more statistics (>50fb^{-1})
  - Be flexible to be ready for the exploration of NP if found

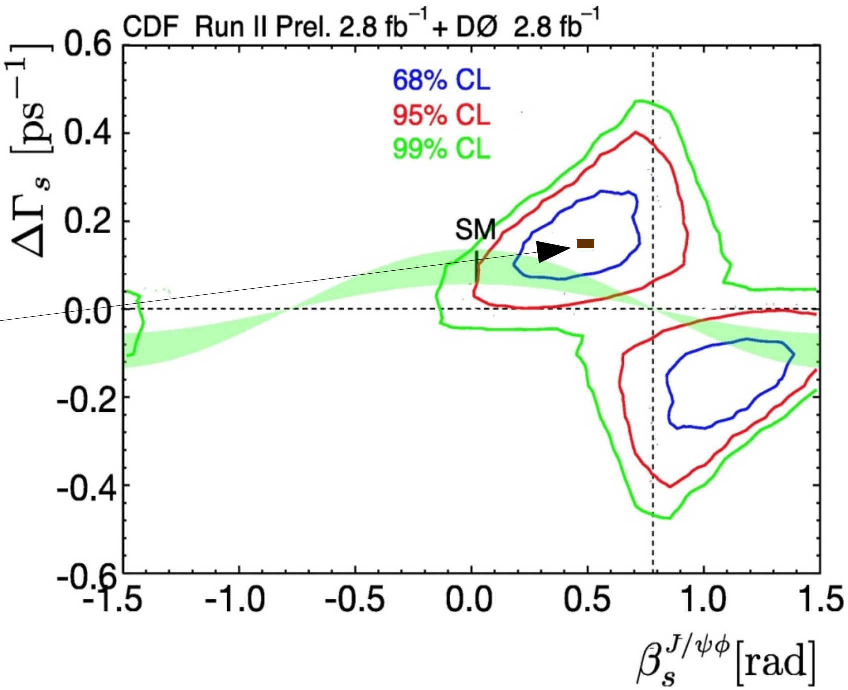
CP asymmetry in $B_s \to J/\psi\ \Phi$

- $B_s \to J/\psi\ \Phi$ measures the B_s mixing phase $-2\beta_s$ as $B \to J/\psi\ K_s$ provides the CPV phase 2β



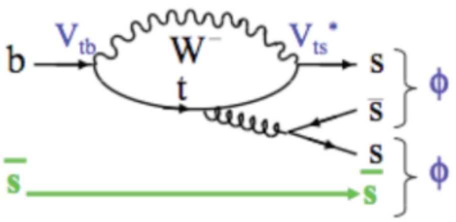
- $B_s \to J/\psi\ \Phi$ is a vector-vector final state
  - Angular analysis required
  - $\Delta\Gamma_s/\Gamma_s$ is a parameter of the fit

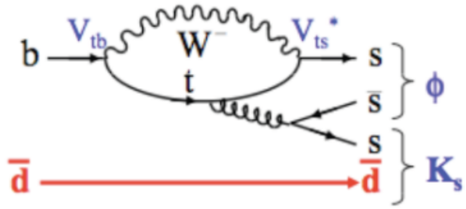
- LHCb should get 655k events in $10fb^{-1}$
  - Projected errors
    - $2\beta_s \sim +/- 0.010$
    - $\Delta\Gamma_s/\Gamma_s \sim 0.005$



- With $100fb^{-1}$ errors on $2\beta_s$ is reduced to $+/-0.004$ (Extrapolation – Stat. errors only)
  - May imagine to distinguish among several supersymmetry models

- $B_s \to \Phi\Phi$ is similar to $B \to \Phi K^0_s$



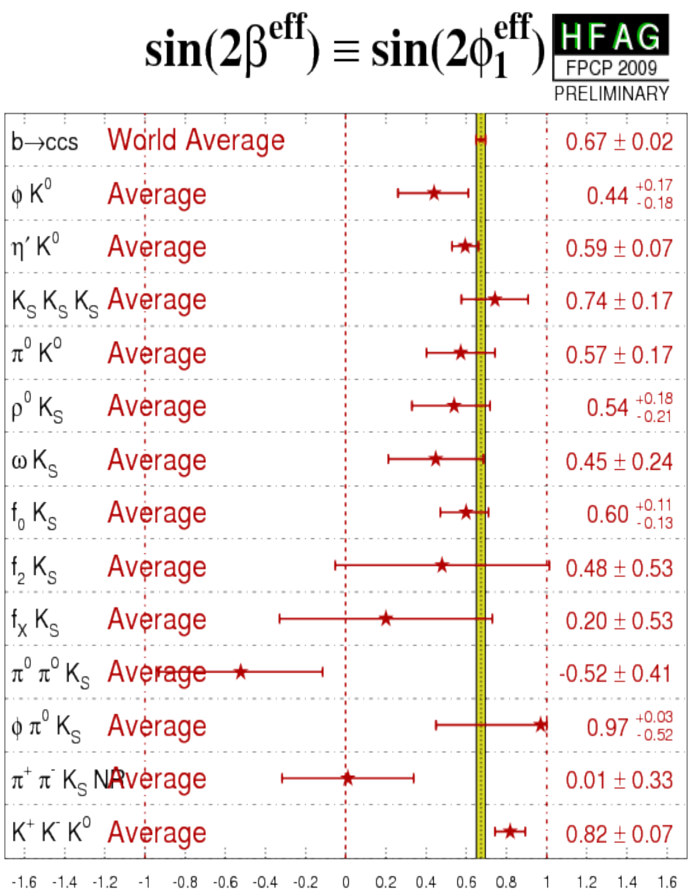


- Decay is dominated by penguins
  → very sensitive to NP

- SM predicts the decay phase cancels the mixing phase → this should be a “null measurement”

- $B_s \to \Phi\Phi$ is a vector-vector state
  - angular analysis is more difficult

- Estimated error in CP violating asymmetry
  - $B \to \Phi K^0_s$ for 100 fb^{-1}, +/-0.019-0.045 (20000 events)
  - $B_s \to \Phi\Phi$ for 100 fb^{-1}, +/-0.017 (0.6M events)
    (Extrapolation – Stat. errors only)



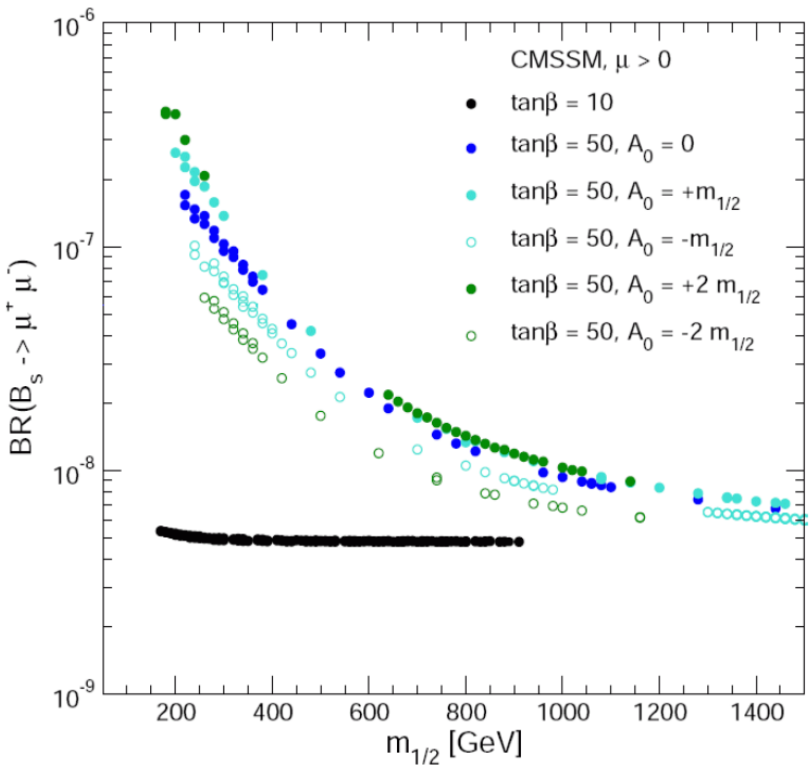
Not yet a clear picture
Precision is needed

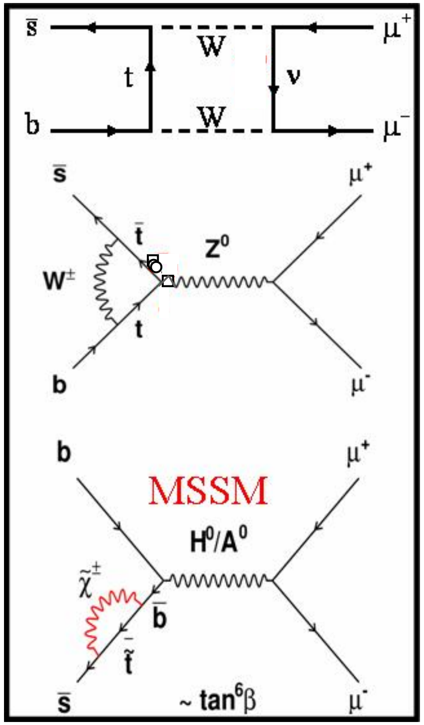
$B_s \to \mu\mu$ (I)

- Standard model prediction for BR is precise and small
  - $Br(B_s \to \mu\mu) = (3.35 +/- 0.32) \times 10^{-9}$

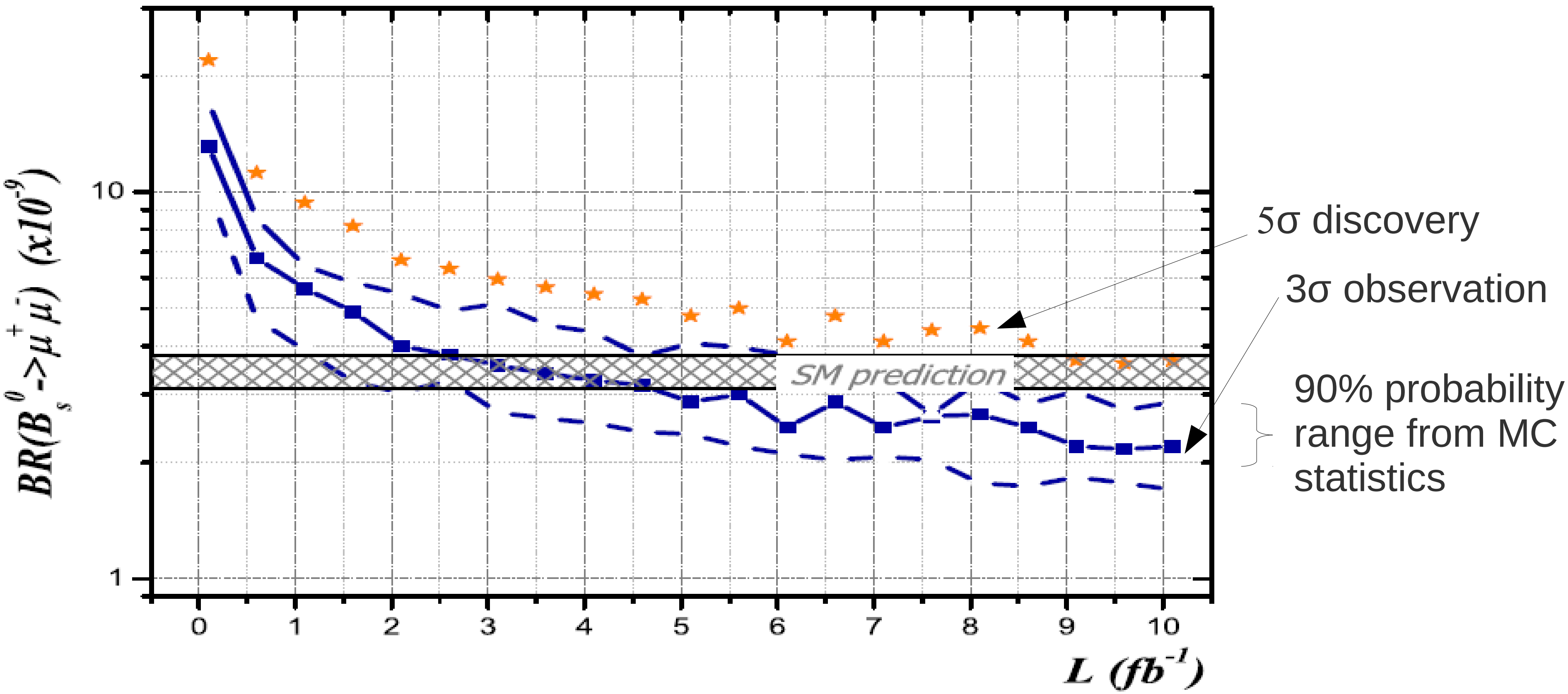
Blanke et al. JHEP 0610:003, 2006

- But BR is very sensitive NP
  - example of MSSM → goes as $\tan^6\beta$





$B_s \to \mu\mu$ (II)



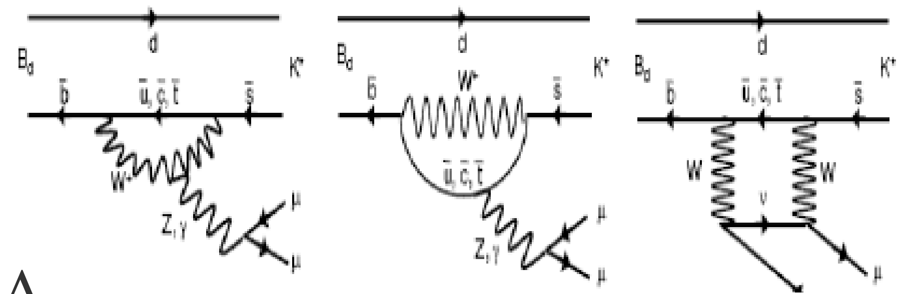
- SM Br will be reached with 10 fb^{-1}
- Br may be measured sooner if NP enhancement
- But certain models may also lead to BR suppression depending on phases
- Rate of ($B_d/B_s \to \mu\mu$) is tightly constrained (distinction of SM and MFV)

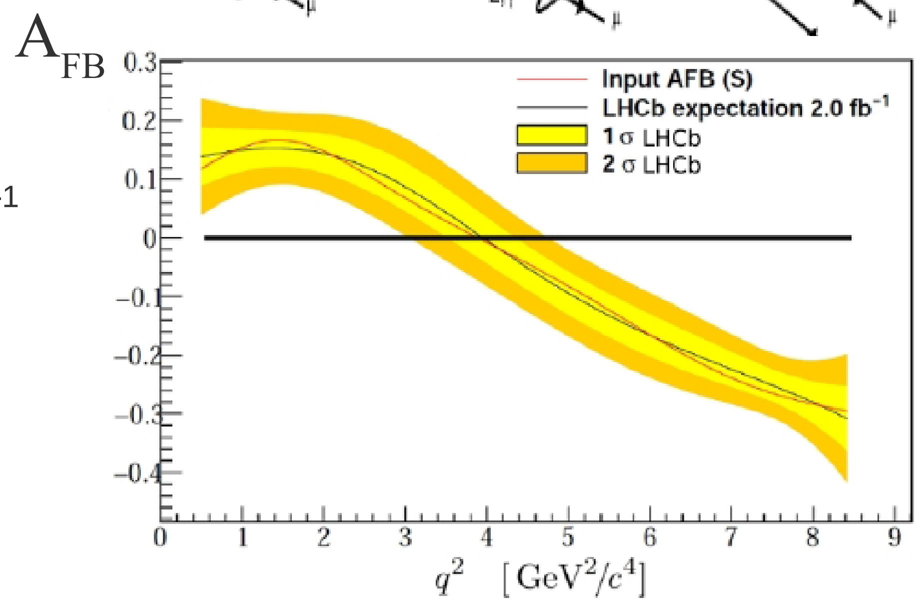
Buras: hep-ph/060450

- Can we hope to see $B_d \to \mu\mu$ at the upgraded LHCb ?

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

- Observable : forward-backward asymmetry of the angle between lepton and B in the di-lepton rest frame
- Position of zero asymmetry crossing point will be measured by LHCb
- LHCb measures 0 to +/-0.22 GeV^2 in 10 fb^{-1}



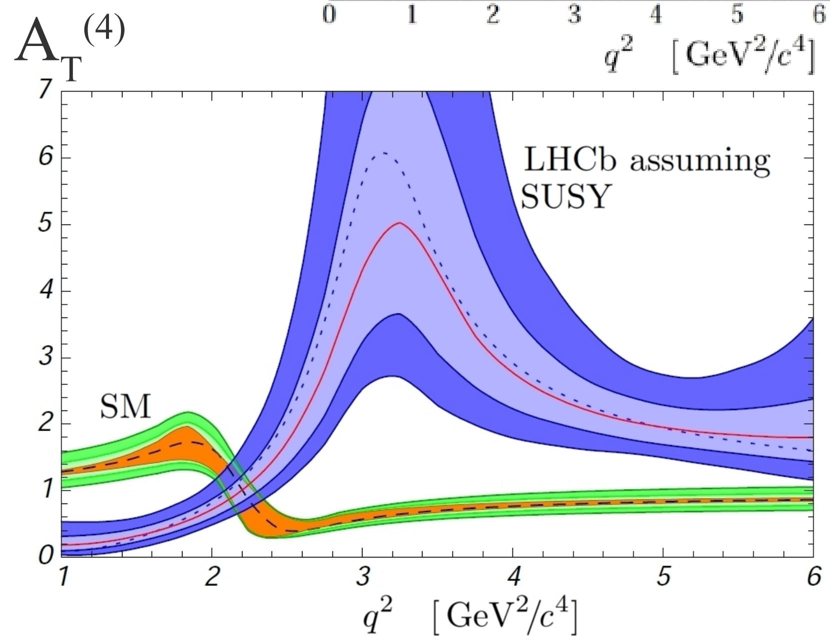


- Other clean theoretical observables can only be extracted with more than 10fb^{-1}
  - Transverse polarization functions

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2},$$

$$A_T^{(3)} = \frac{|A_{0L}A^*_{\parallel L} - A^*_{0R}A_{\parallel R}|}{\sqrt{|A_0|^2|A_\perp|^2}},$$

$$A_T^{(4)} = \frac{|A_{0L}A^*_{\perp L} - A^*_{0R}A_{\perp R}|}{|A^*_{0L}A_{\parallel L} + A_{0R}A^*_{\parallel R}|},$$



- 0.35 M yield at upgrade 100fb^{-1}

$B_s \to \Phi\gamma$: Right-handed currents

- SM predicts no right-handed currents

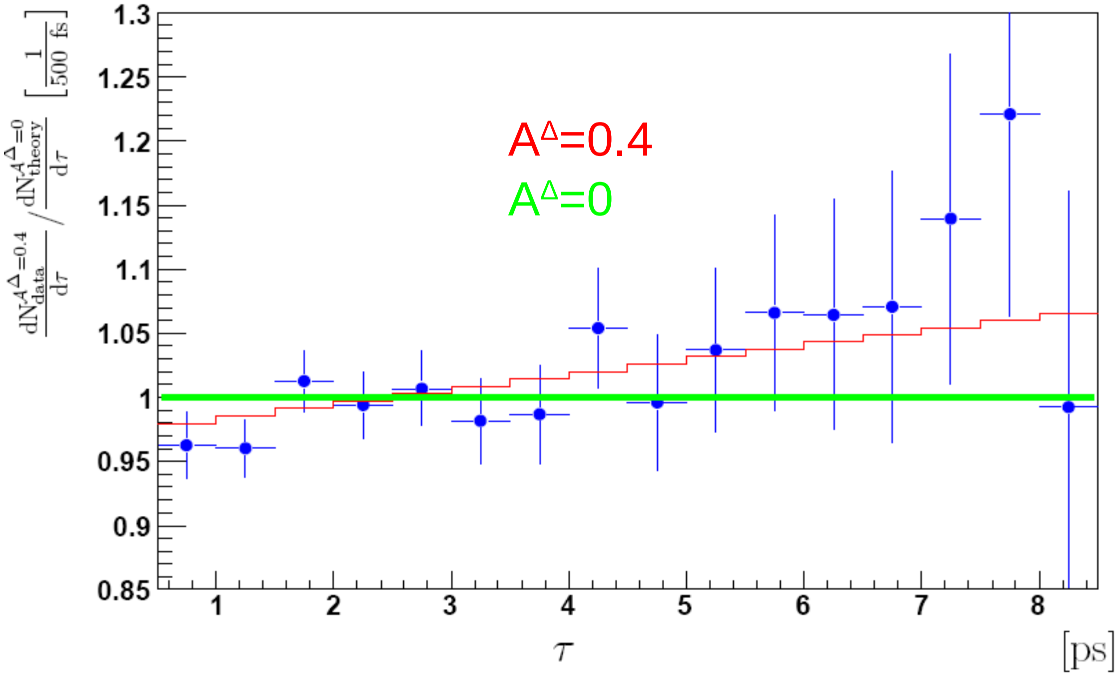
$$\tan\psi \equiv \left|\frac{\mathcal{A}\left(\bar{\mathrm{B}}_{(s)} \to \Phi^{\mathcal{CP}}\gamma_{\mathrm{R}}\right)}{\mathcal{A}\left(\bar{\mathrm{B}}_{(s)} \to \Phi^{\mathcal{CP}}\gamma_{\mathrm{L}}\right)}\right|$$ is null

$$\Gamma_{\mathrm{B_s^0}\to\Phi^{\mathcal{CP}}\gamma}(\mathrm{t}) \approx |\mathrm{A}|^2 e^{-\Gamma_s t}\left(\cosh\frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2}\right)$$

$$\Gamma_{\bar{\mathrm{B}}_s^0\to\Phi^{\mathcal{CP}}\gamma}(\mathrm{t}) \approx \Gamma_{\mathrm{B_s^0}\to\Phi^{\mathcal{CP}}\gamma}(\mathrm{t})$$, Where $A^{\Delta}=\sin 2\psi$

- Sensitivity to A^{Δ} (assume $\Delta\Gamma_s/\Gamma_s \sim 0.12$)
  - $\sigma(\sin 2\psi) = 0.22$ (2 fb^{-1})
  - $\sigma(\sin 2\psi) = 0.02$ (100 fb^{-1})

(Extrapolation – Stat. errors only)



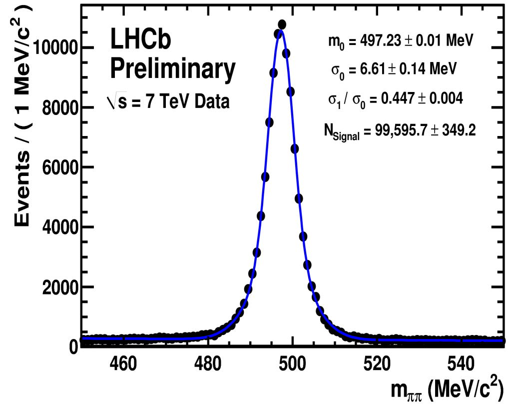
LHCb upgrade : the detector requirements

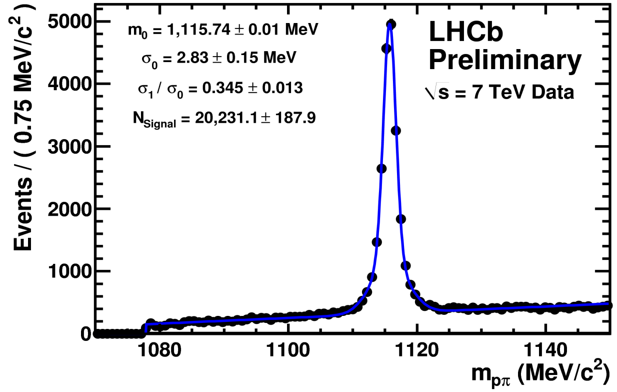
- The modern heavy quark experiments rely on
  - Favourable physics conditions
    - Essential to produce a large rate of (anti)b hadrons in the apparatus solid angle
  - Vertexing
    - Measure the displaced decay points, reduce background (*)
  - Particle identification
    - Kinematic constraints often do not permit to remove background contributions from other decay modes
  - Triggering
    - Need to select the interesting events with a high efficiency/purity (*)
  - Data acquisition and processing
    - The aim is to collect a large statistics

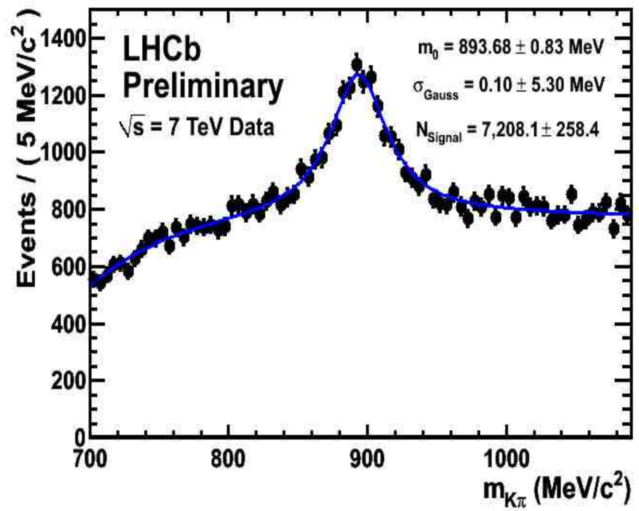
(*) vital for hadron colliders !

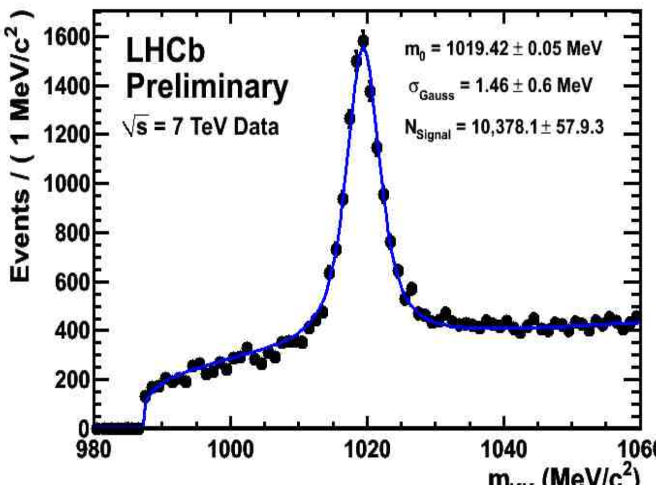
- LHCb was built to fulfil those requirements
- LHCb started to operate in very satisfactory conditions
  - The detector runs as expected
  - The present aim is to
    - consolidate the detector operations,
    - achieve fine calibrations and better understand LHCb
    - And of course : collect as much data as we can !

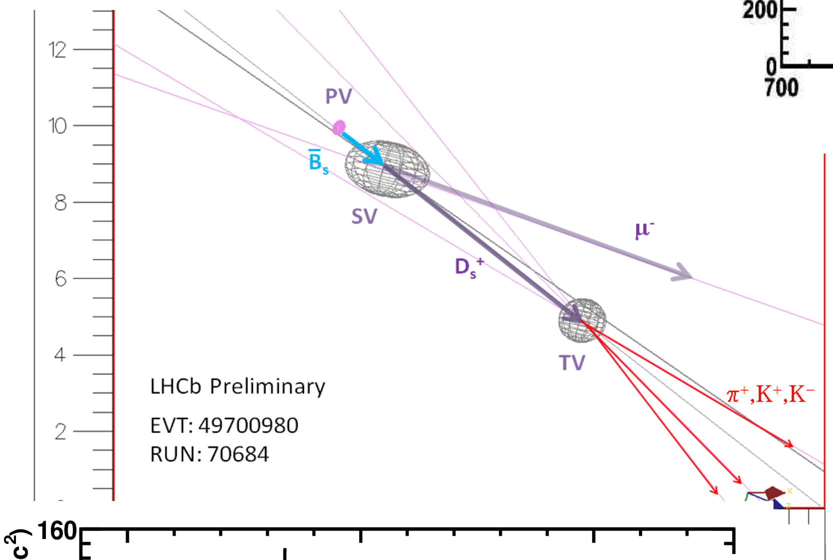
A flavour of the present LHCb

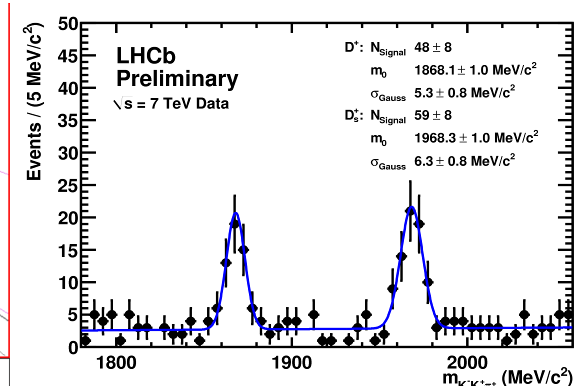


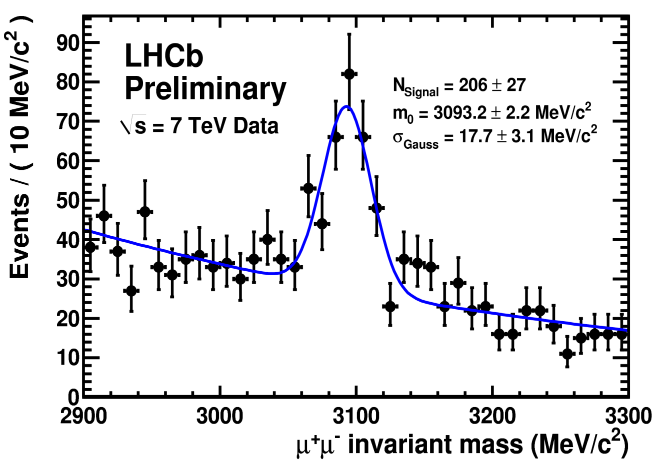


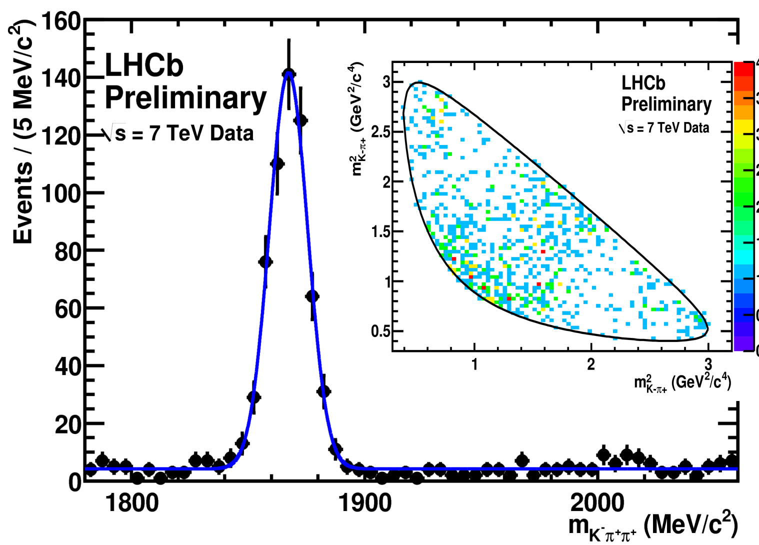


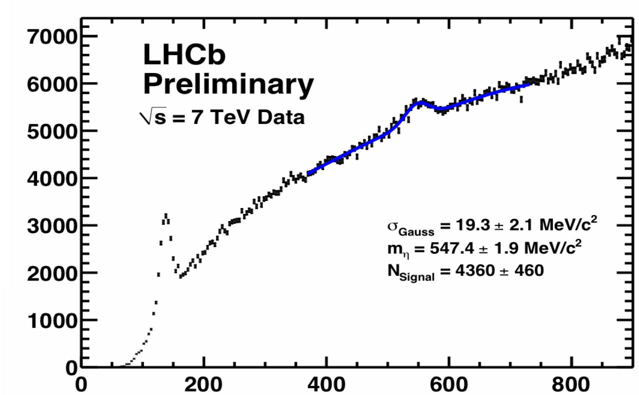












How can we upgrade ?

- The goal is to collect up to 5 / 6 fb^{-1} during the present LHCb “first run” → 2015
  - We may expect to get first hints for new physics
  - The upgraded LHCb should adapt to new physics

- Upgrade is strongly coupled to the LHC schedule → 2 Phases

(1) LHC long shutdown in 2015/2016

- Increase the instantaneous luminosity from $2x10^{32}$ to 10^{33} $cm^{-2}.s^{-1}$
- Complete re-design of the trigger scheme
- New VELO
- RICH photon detectors replacement
- TT & IT replacement
- New electronics for OT, calorimeter and muon system

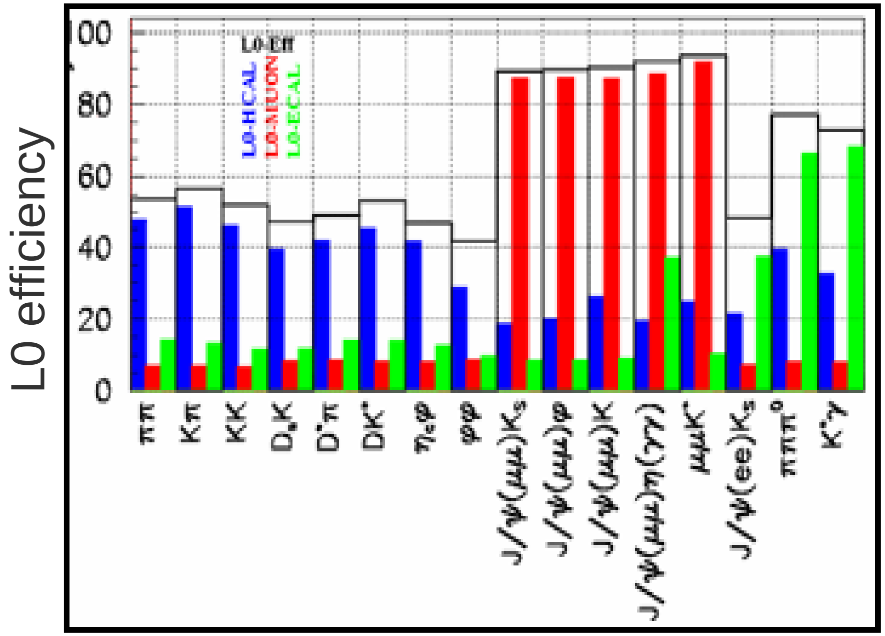
} Focusing on this phase

(2) Second phase of the upgrade

- Torch / Super-Rich detector
- Better ECAL segmentation ?

New Trigger Scheme (I)

- Only 1% of the inelastic cross-section is b production
- Not all the b hadrons are interesting
  - Present trigger is based on
    - L0 : fully hardware trigger selecting events, 4µs latency, readout at 1MHz
      - high Pt muons
      - high Et hadrons, photons, electrons
      - Veto on multiple interactions
    - HLT : software trigger
      - L0 confirmation
      - Impact parameter, full tracking, ...
      - Exclusive decays

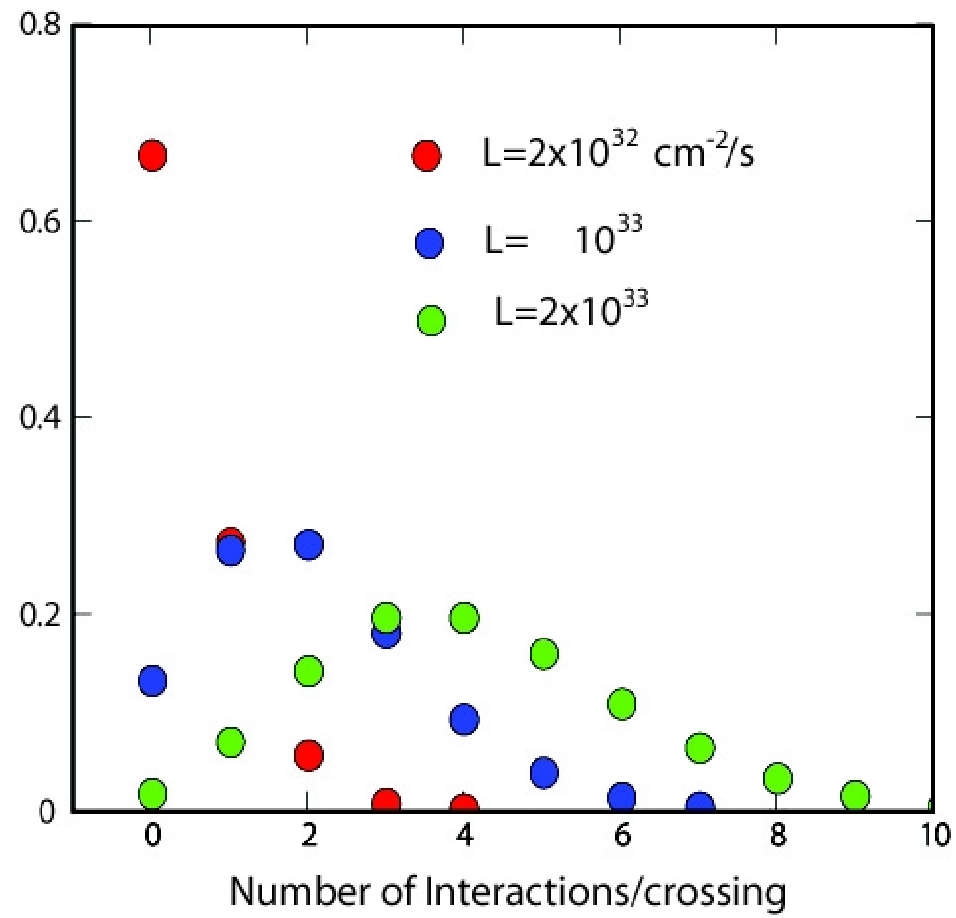


- Upgrade would consist in reading out the entire detector at 40MHz
  - Full software trigger
- The goal is to increase the current yield by a factor 5 to 10 in dileptonic and hadronic channels
  - Present D_sK^- channels efficiency ~ 25%
    - L0 efficiency ~ 50%
    - HLT 1 / 2 : ~ 60% / 85% in D_sK^-

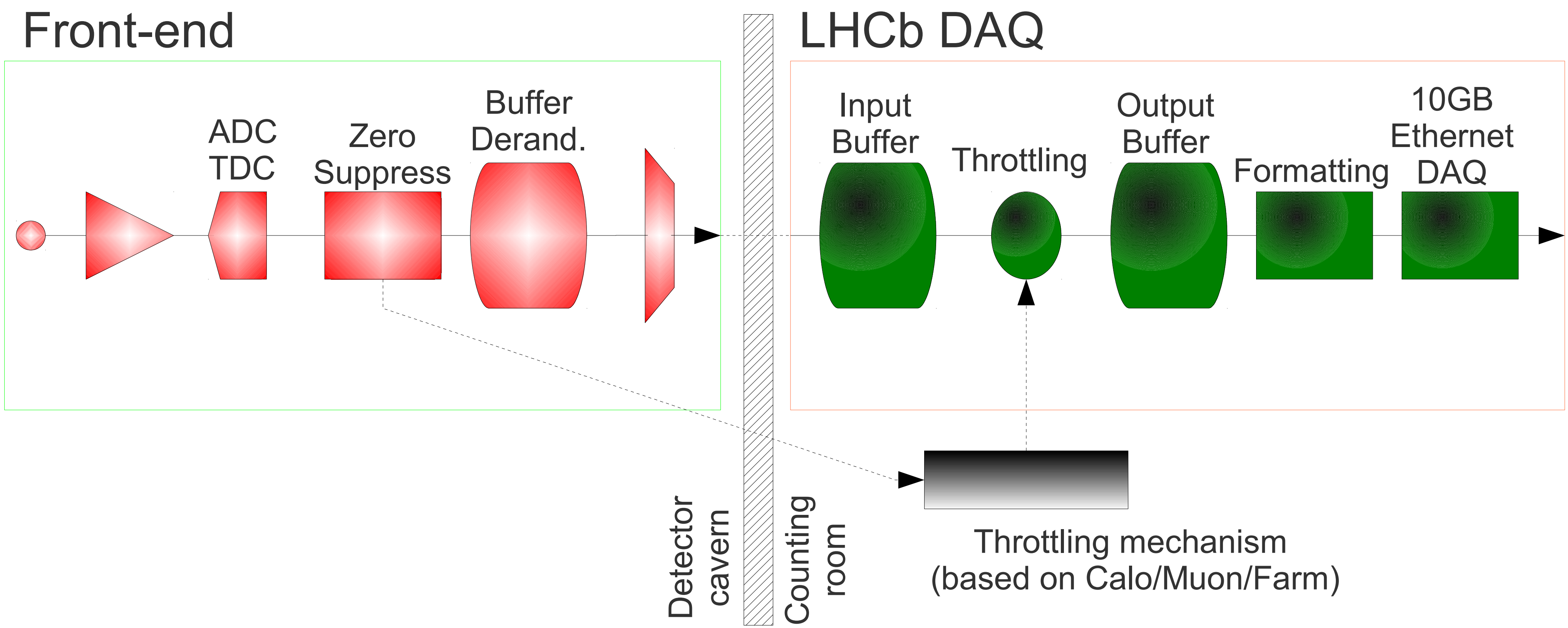
Room for improvement especially in Hadronic channels → x2

New Trigger Scheme (II)

- At 2×10^{32} $cm^{-2}.s^{-1}$ (nominal conditions)
  - 30 MHz of crossings
  - Most crossings have no interaction
  - L0 reduces data to 1MHz
  - HLT output is 2kHz → on tape
- At 10^{33} $cm^{-2}.s^{-1}$
  - On average 2.3 interactions/crossings
- Software trigger
  - 16000 processors in the farm
    - 25nsx16000=0.4ms on average to
      - Reduce background
      - Maximize the signal efficiency
  - Aim is
    - ~20kHz on tape
    - Reduction factor of 100000 on min-bias
    - Hadronic trigger efficiency ~ 50%



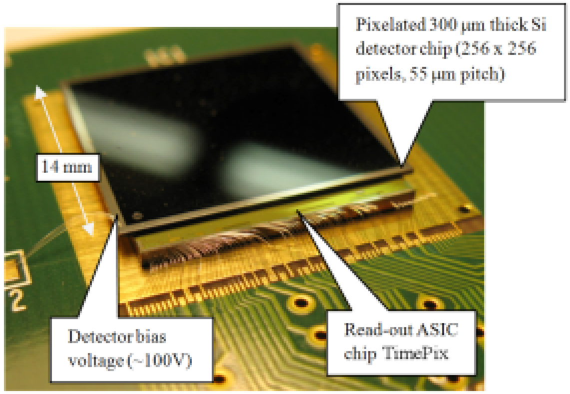
Electronics and readout

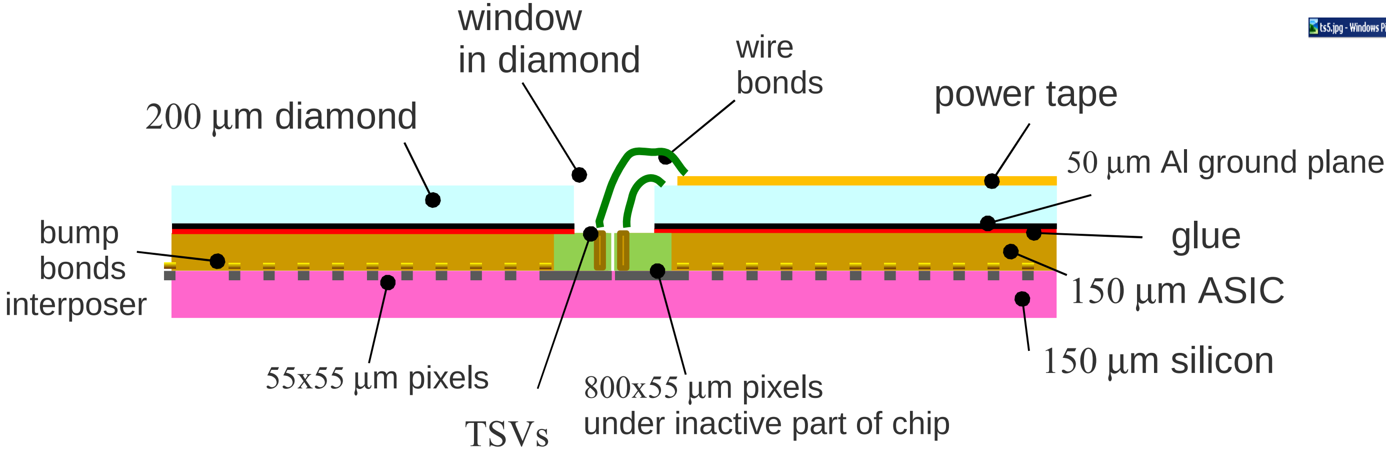


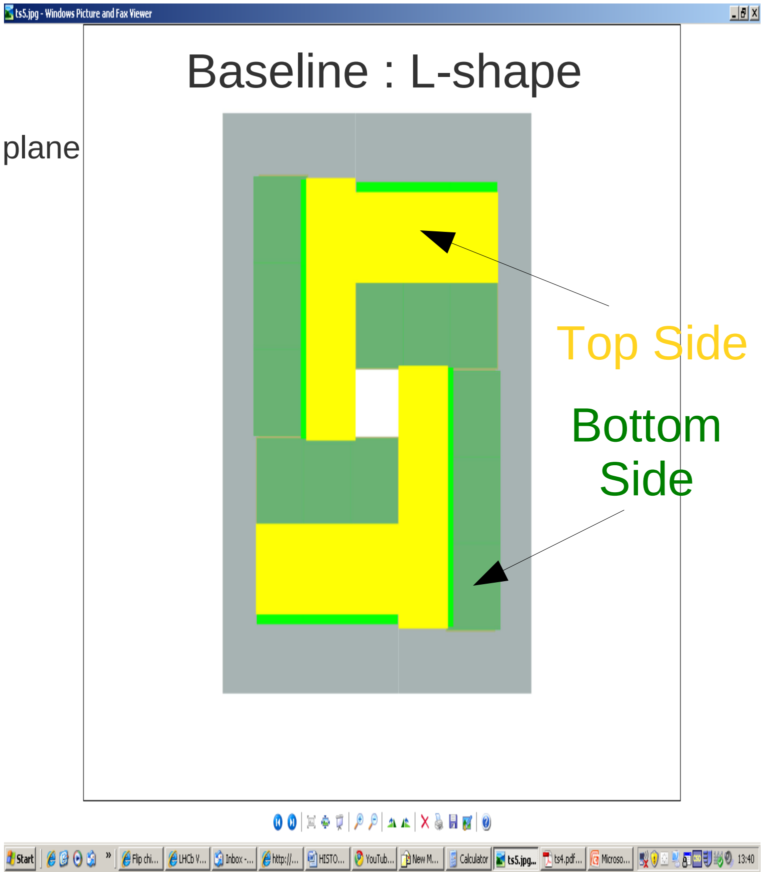
- Electronics and readout completely re-design to permit readout @ 40MHz
- The events are zero-suppressed / packed at the front-end level
- The GBT technology is used to send the data from the FE to the readout syst.
- The readout boards are common to all the sub-detectors
- A throttling mechanism (Calo/Muon/Farm) is implemented to cope with
  - A staged DAQ which cannot handle the full rate
  - Unexpected high occupancies which prevent a full readout

The VErtex LOcator

- Present VELO has to be replaced (radiation)
- Precise measurement of the vertices
  - Aim is pattern recognition for the trigger
- The baseline is VELOPix, based on Medipix/TimePix readout chip
  - 256x256 pixels, 55μm square
  - 3 side buttable chip
  - TSV (Through Silicon Via) → dead side may be reduced to 0.8mm (Medipix3)





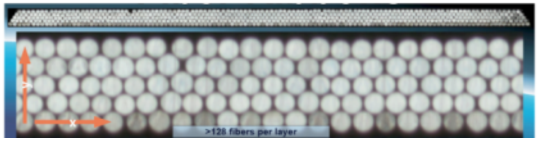


- Benefit from the 3D information
  - Less combinatorial for tracking reconstruction
- Very low occupancy of the detector
- But very high data rate (15Gbit/s/chip)

Tracking

- Running at $2x10^{33}$ is not acceptable for the present Outer tracker
  - Too high occupancy
  - Decide to limit the luminosity to 10^{33} for phase I of upgrade (2016)

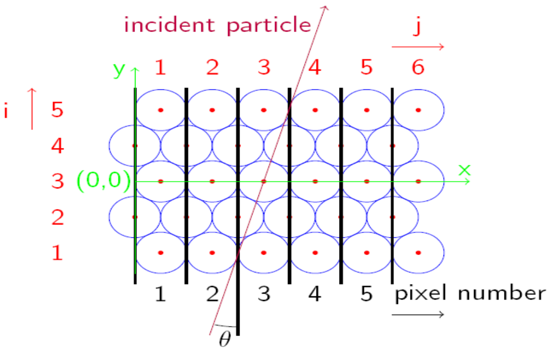
- Still the OT electronics has to be changed to cope with the 40MHz readout
  - First prototypes are being designed

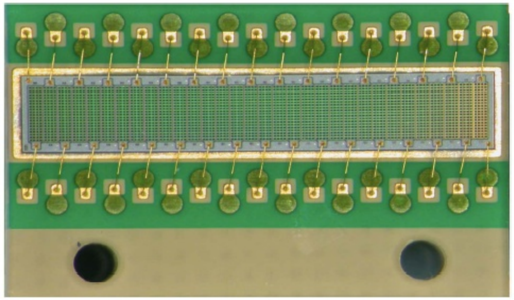


- Two options are still envisaged for the ST (TT and IT)

  (1) Si options
    - Keep the existing modules unchanged
      - Need re-equip them with an upgraded electronics
      - Development of a new rad-hard FE chip @ 40MHz
    - Build new modules identical to the existing ones

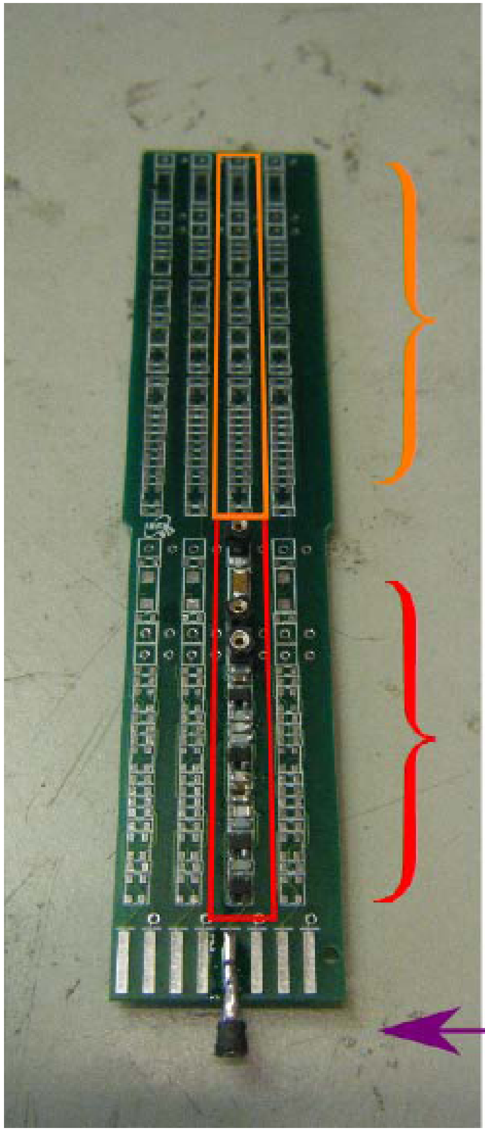
  (2) Fiber option
    - Several layers of scintillating fibers
    - Light collections with SiPM
    - Electronics is out of the acceptance (rad. tolerance)
    - First simulations show equivalent performances as Si
    - Requires important R&D but several labs are interested





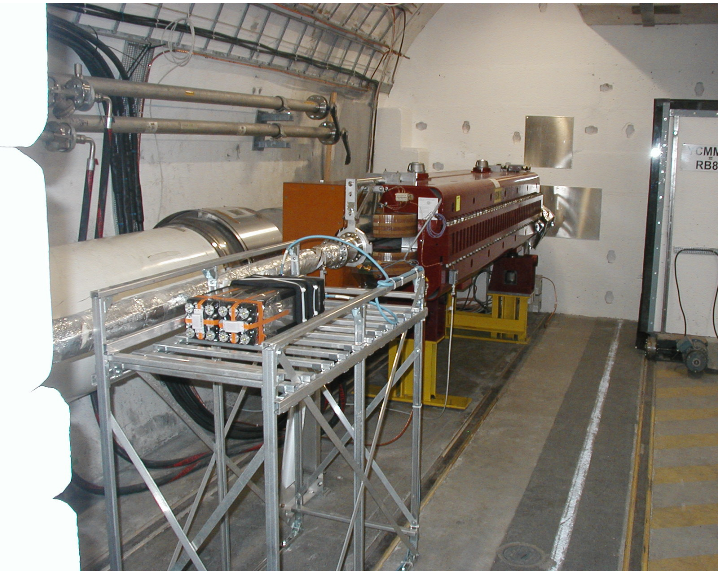
Rich (+TOF)

- Rich HPD tied to 1MHz readout → must be replaced
- Baseline candidate is the MA-PMT (Hamamatsu)
  - 8x8 pixels (of 2.0x2.0 mm^2)
  - Characterisation of the chip shows good properties
    - Single photon response,
    - Uniformity,
    - Cross-talk,
    - Dark current.
  - Behaviour under magnetic field still to be checked
  - Temperature
- A front-end electronics is being designed
  - Target is
    - no pile-up (25ns)
    - Low consumption
- TOF (Torch)
  - TOF measurement could be coupled to the RICH for PID
  - 1 cm thick quartz plate at z=12m
  - 30ps resolution
  - Probably for the second upgrade phase



Calorimeter and Muon system

- The front-end electronics of the calorimeter to be replaced (40MHz readout)
  - The PMT have to be operated at lower gain
  - The electronics will compensate but need to maintain the same noise as before
    - 2 directions : ASIC and discrete components → prototype being delivered
  - The L0 uses calo information (40MHz)
    - Plan is to keep on providing this to the farm to help software trigger (seeds)
- Radiation tolerance of the calorimeter inner modules
  - 2 modules irradiated at Protvino (Russia) and 2 other in the LHC tunnel



- Muon front-end electronics can basically be kept (already @ 40MHz)
  - The M1 chamber should be removed (background and upgraded L0)
  - The interface to the common readout has most probably to be adapted
  - The muon system should provide information to the throttling mechanism
    - Based on the present L0

LHCb

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Conclusion

- LHCb is being operated in very satisfactory conditions since day 1
- LHCb physics program is largely not affected by the present running conditions
- Physics sensitivity for LHCb gives good chance of seeing NP after 5 or 6 fb^{-1}
  - But we need high precision to
    - understand NP
    - Distinguish between different models
- We want a flexible trigger (software) to be able to study any kind of NP signal
- The phase I upgrade is mainly a trigger and readout upgrade
  - Better trigger performances (fully software trigger)
  - Readout @40MHz
  - and a new VELO, a new RICH photo-detection
- The letter of intent should be sent to the LHCC this year

The LHCb detector