The LHCb upgrade

- Setting the scene
- Running conditions
- Upgraded sub-systems

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LHCb physics goals

LHCb designed for flavour physics measurements :

→ associated with many open questions of the SM

- # of generations - hierarchy of masses - CKM matrix

→ very sensitive to new physics effects :

probe new states via virtual production in loop diagrams

↘ LHCb phase 1 - up to 2018 (8-10 fb^{-1}) :

→ find or rule out "large" new physics effect

Yet, it is already clear that NP effects are small

→ need to go deeper with more precise measurements

need more statistic

↘ LHCb phase 2 (50 fb^{-1}): UPGRADE

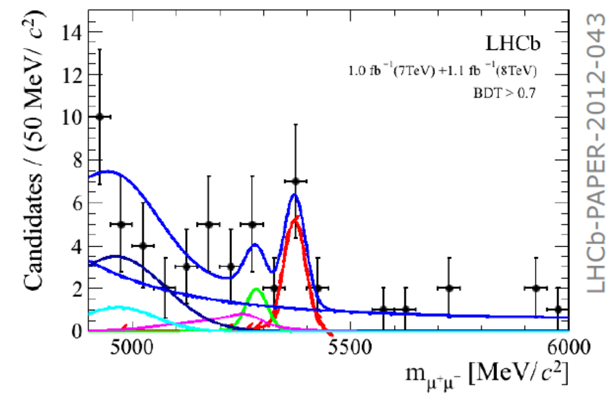
→ increased precision on quark flavour physics observables

- aim at experimental sensitivities comparable to theoretical uncertainties

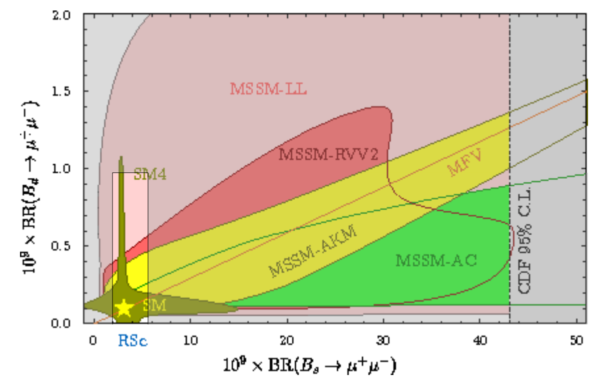
→ enforce LHCb as a general purpose forward detector

- lepton flavour physics (lepton FV decay $\tau^- \to \mu^-\mu^+\mu^-$)
- electroweak physics ($\sin^2\theta_{eff}^{lept}$ from measuring A_{FB} of leptons in Z decays)

ex: $B_{s/d}$ BR measurement and constraint on new physics models

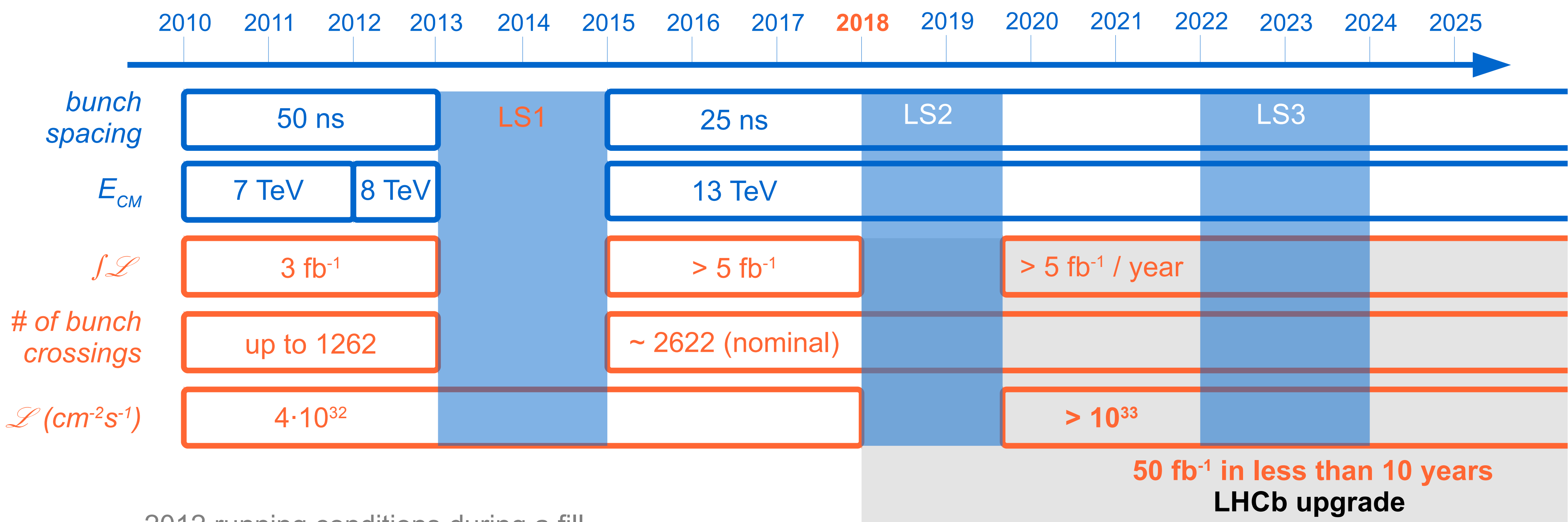


$B(B_s \to \mu\mu) = (3.2^{-1.2}_{+1.5})\times10^{-9}$
$B(B_d \to \mu\mu) < 9.4\times10^{-10}$ @ 95%CL



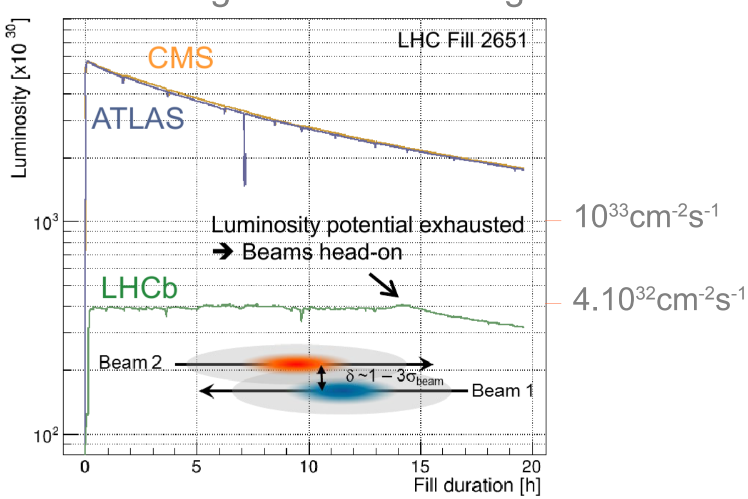
$\sigma(B_s \to \mu\mu)$
- LHCb-upgrade: ~ 0.15×10^{-9}
- theory: ~ 0.3×10^{-9}

LHC time-line & LHCb running plans



2012 running conditions during a fill

R. Jacobsson, Proc. IEEE NPSS-MIC 2012



LHCb specificities

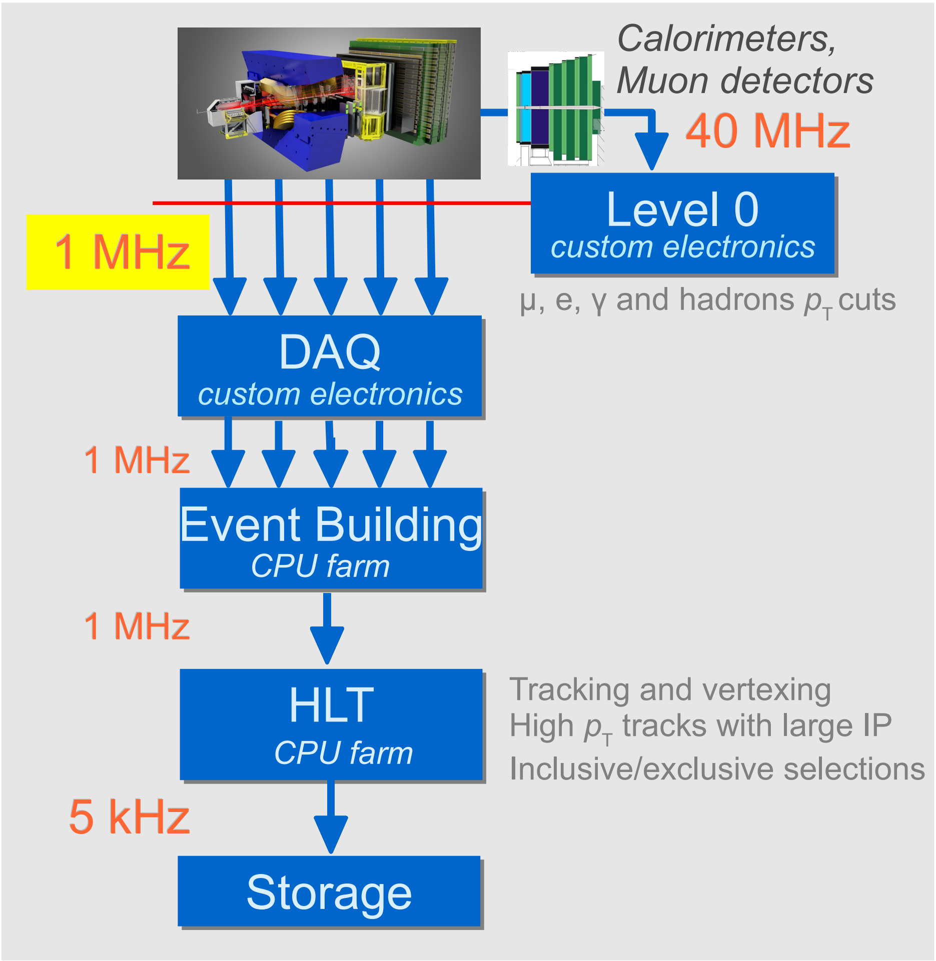
- → luminosity lower than ATLAS & CMS
  - 4·10^{32} cm^{-2}s^{-1}
- → no luminosity decay during a fill

Upgrade

- → stable luminosity > **10^{33}** cm^{-2}s^{-1}

↘ What prevents us from running at higher luminosity already ?

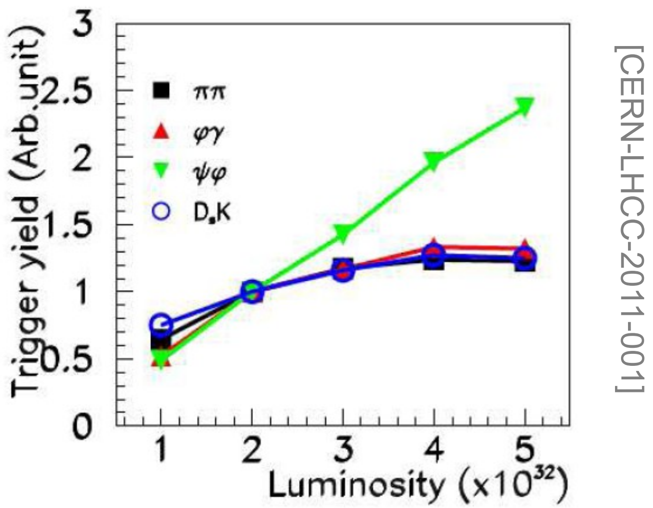
Current data acquisition and trigger limitations



Performances at 8 TeV in 2012 (L0xHLT)

- B decays with μμ : ε ≈ 90 %
- B decays with hadrons : ε ≈ 30 %
- Charm decays : ε ≈ 10 %

Saturation of the Yields :

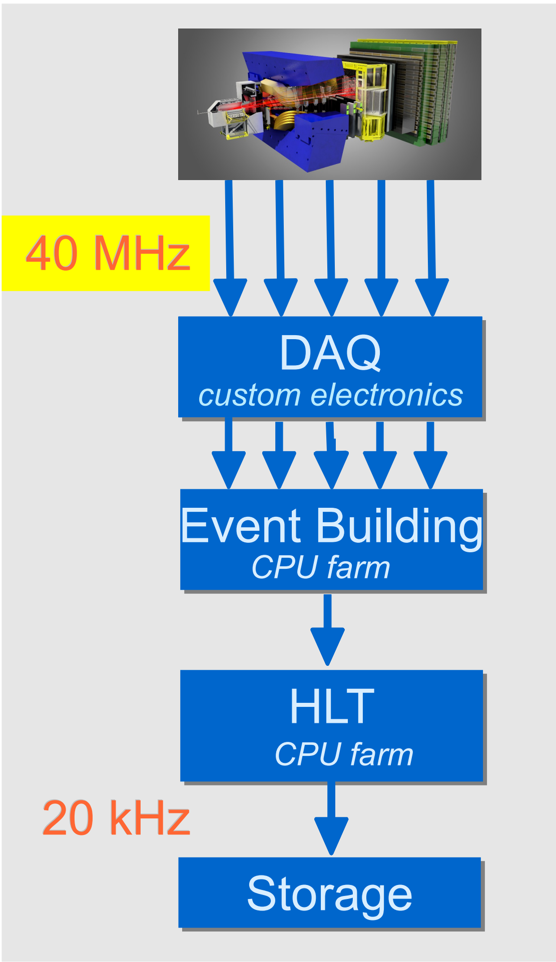


- p_T cuts must be raised to cope with the 1 MHz read-out rate
- no gain beyond 2-3 10^{32} $cm^{-2}s^{-1}$ for hadronic modes

↘ To benefit from high luminosity :

- remove L0 bottleneck
- read-out full detector at 40 MHz
- use fully software trigger

Upgrade strategy and consequence



Full detector readout at 40 MHz up to CPU farm

- → replacement of all front-end and back-end electronics
- \- detectors with embedded electronics need to be replaced
- → fast high-level software trigger

For sub-detectors which need to be replaced :

- → optimize geometry and granularity to allow fast full reconstruction
- → allow to increase instantaneous luminosity up to $2 \cdot 10^{33}$ $cm^{-2}s^{-1}$
- → sustain increased radiation dose

Final output bandwidth at ~20 kHz

The 40 MHz detector

VELO
radiation dose and occupancy
→ replace sensors

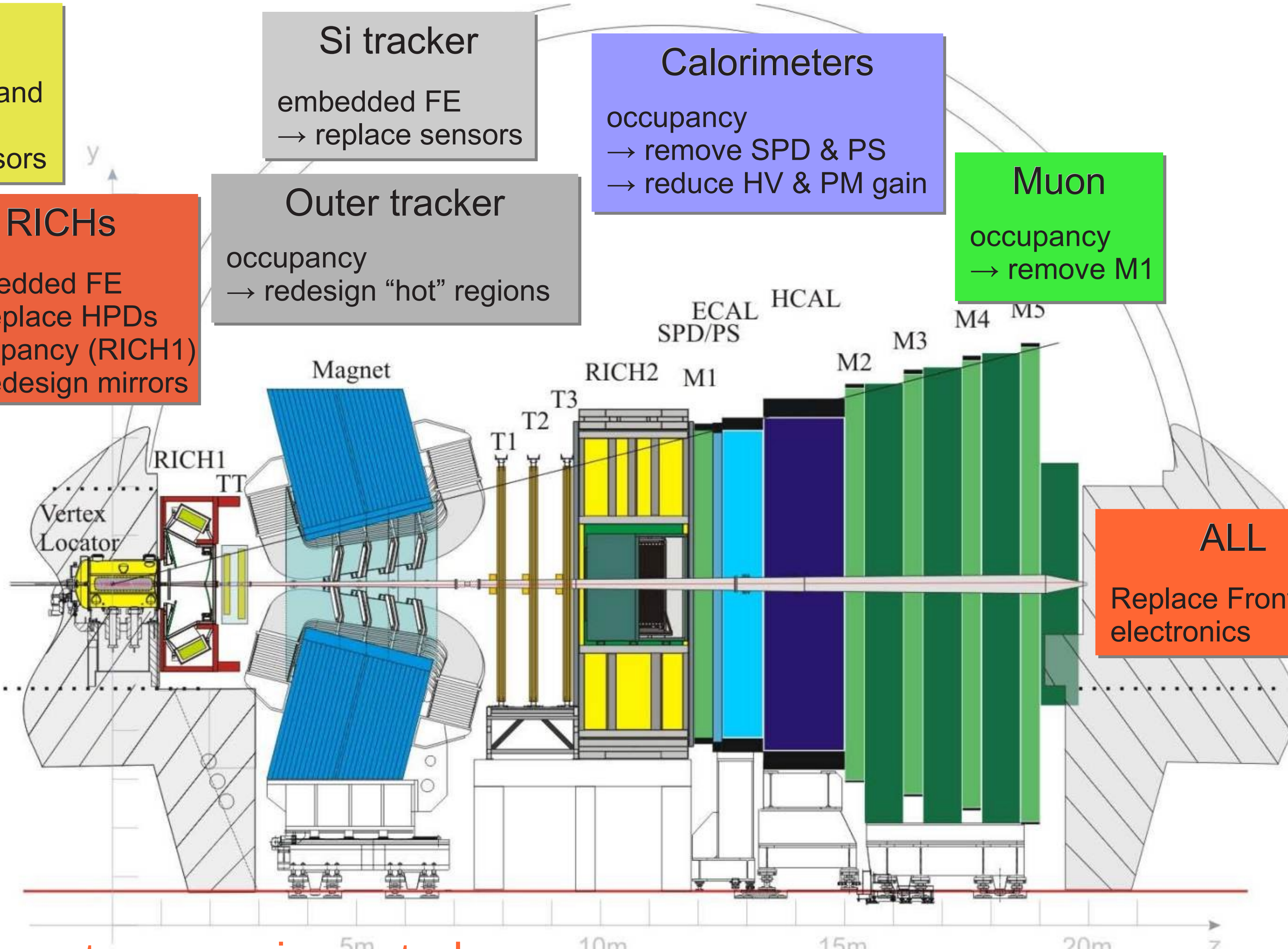
Si tracker
embedded FE
→ replace sensors

Calorimeters
occupancy
→ remove SPD & PS
→ reduce HV & PM gain

RICHs
embedded FE
→ replace HPDs
occupancy (RICH1)
→ redesign mirrors

Outer tracker
occupancy
→ redesign "hot" regions

Muon
occupancy
→ remove M1



ALL
Replace Front-end electronics

↘ all subsystems are impacted

Upgrading the vertex locator (VELO)

Current detector :

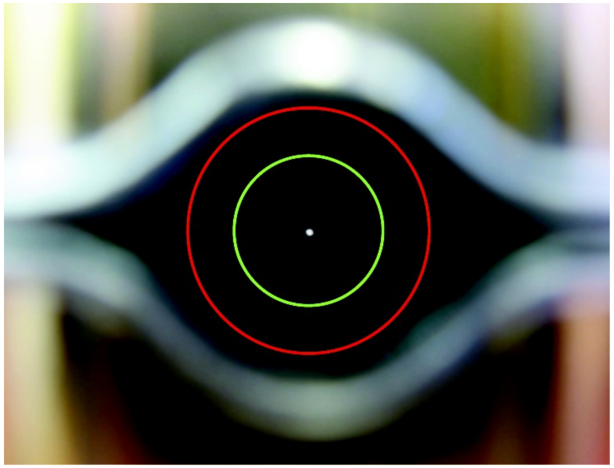
- microstrip sensors (R,Φ)
- operated in vacuum with movables halves

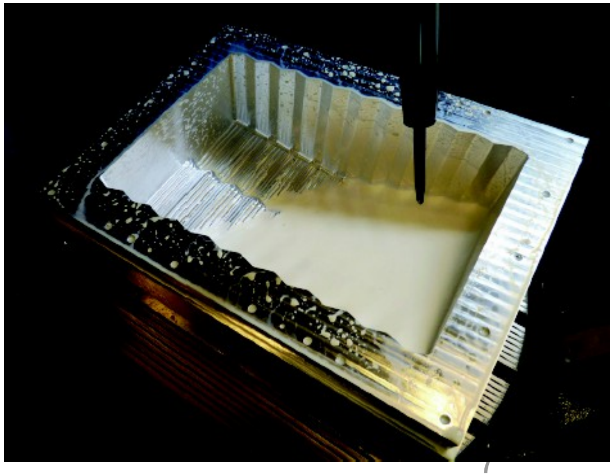
Upgrade challenge :

- withstand increased radiation
- high data volume
- keep or improve current performance
  - lower materiel budget
  - enlarge acceptance

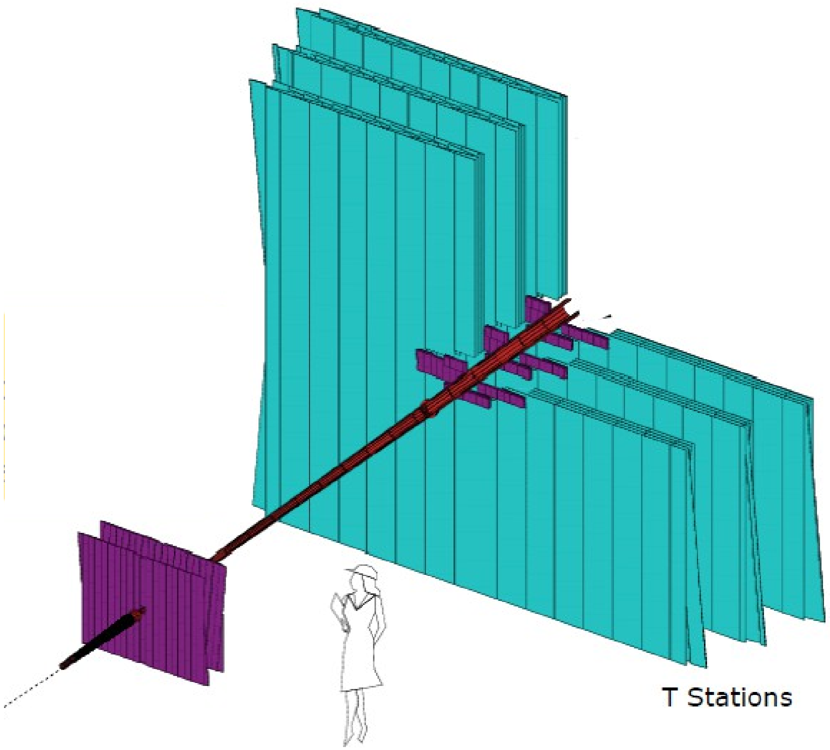
Technical choice :

- pixel sensors with micro channels CO_2 cooling
- replace RFoil between detector and beam vacuum :
  - thickness 300 µm → 150 µm
- move closer to the beam :
  - inner aperture 5.5 mm → 3.5 mm





Upgrading the tracker



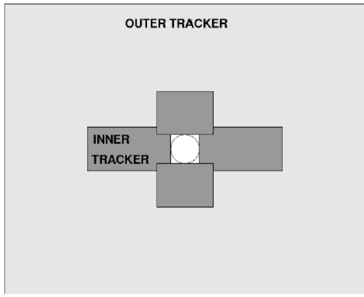
TT → UT : replace all modules

- Si strip detector
- Enlarge acceptance at high η
- Improve granularity along y

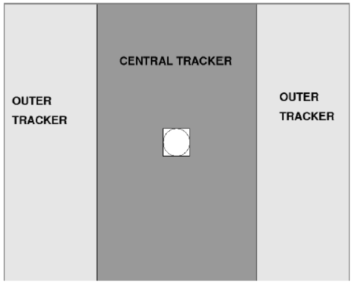
OT occupancy too high in the inner regions

2 options under development :

- Enlarged IT area : Si strips
  - → Si strips (IT) + straw tubes (OT)
  - \- increase IT acceptance to keep the OT occupancy below 20 %



- Central tracker (CT) : scintillating fibres
  - → 250 μm diameter, 2.5 m long fibres
  - \- degradation with radiation dose : OK
  - → 5 layers / module
  - → 5 m long modules
  - \- module flatness ?
  - → read-out by multi-channel SiPM outside the acceptance
  - \- neutron fluence : OK (shielding + cooling -40°C)



↘ Decision on technology → soon

Upgrading the RICHs

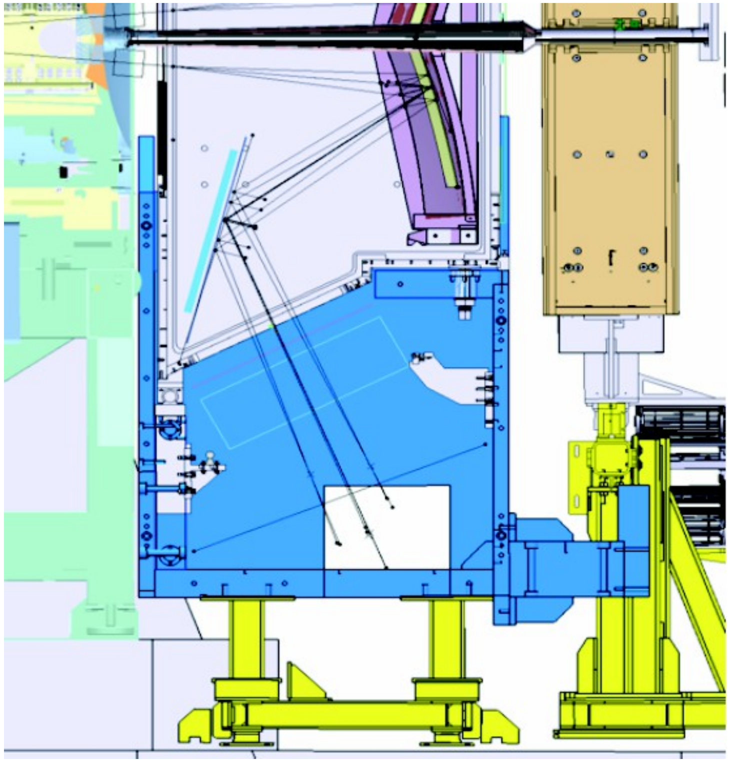
RICH1 occupancy to high :

- → remove aerogel radiator
- CF_4 in RICH1 & C_4F_{10} in RICH2
- → optic redesign to spread out the rings

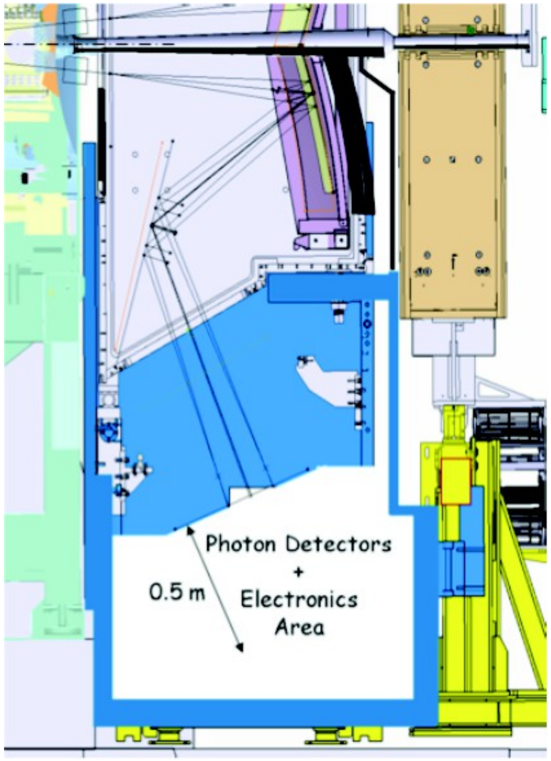
RICH1 and RICH2 :

- → replace photo-detector due to their embedded FE
- HPDs → Multi-anode PMTs

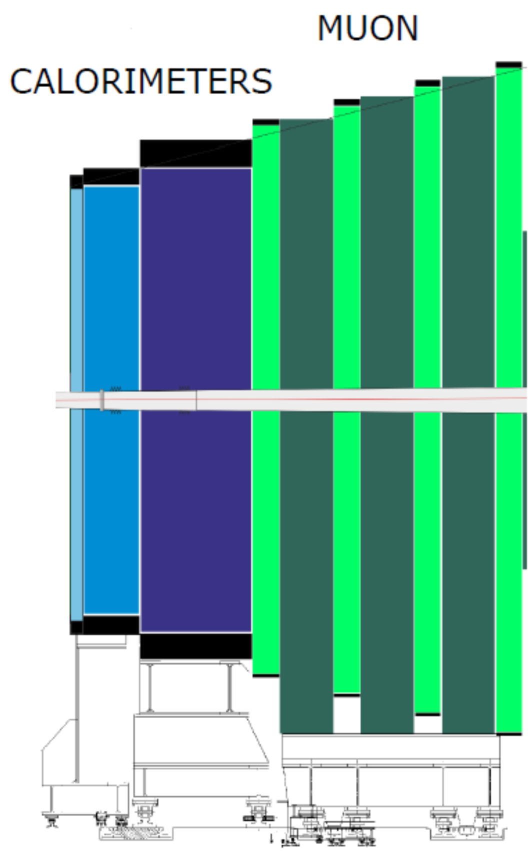
Current RICH1



RICH1 with new optics



Calorimeters and muon detectors



M1, SPD,PS removed

Calorimeters

→ Replacement of FE electronics

→ Keep current modules

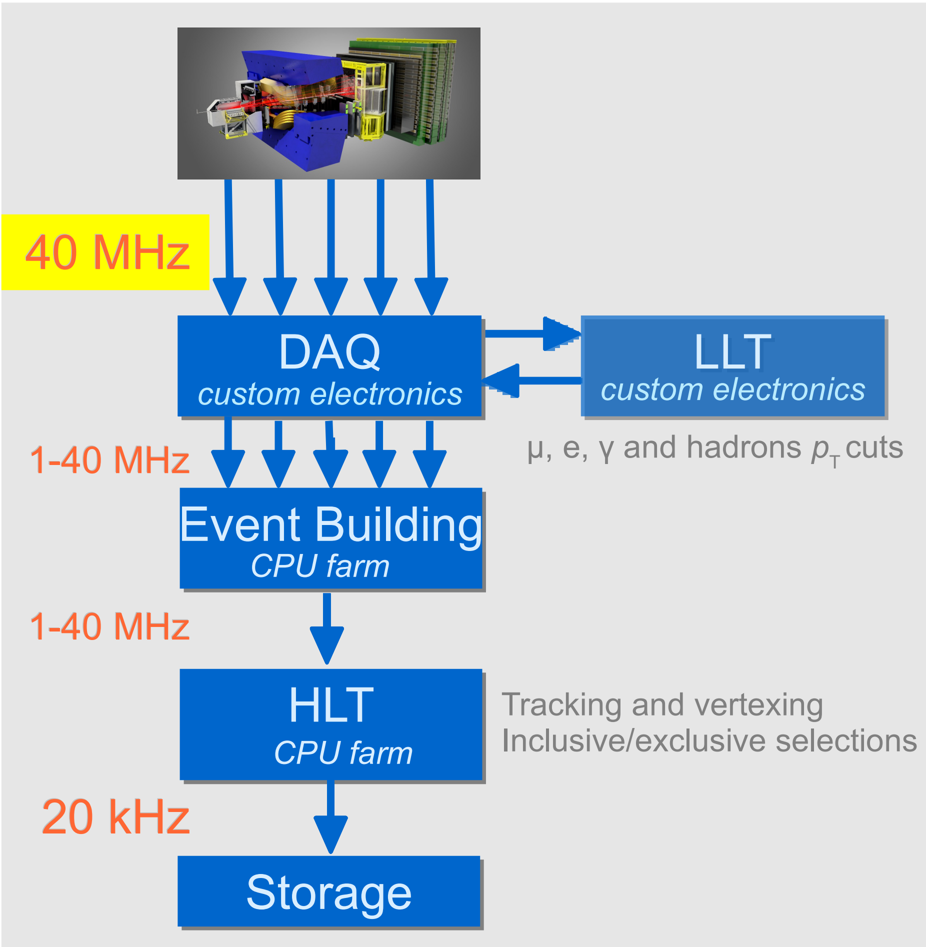
- lower HV and PMT gain to reduce ageing

Muon

→ Replacement of FE electronics

→ Possible installation of higher granularity detectors at later stage

Upgrading the data acquisition and trigger



DAQ :

→ common read-out boards with different firmwares

→ exploring :

- merging read-out units and event builder in a single entity
- Ethernet / Infiniband / PCIe technologies
- use of co-processors like GPUs or FPGAs

Low Level Trigger (possibly) :

→ at early stage :

use of a Low Level Trigger to allow staging of the CPU farm capacity

HLT :

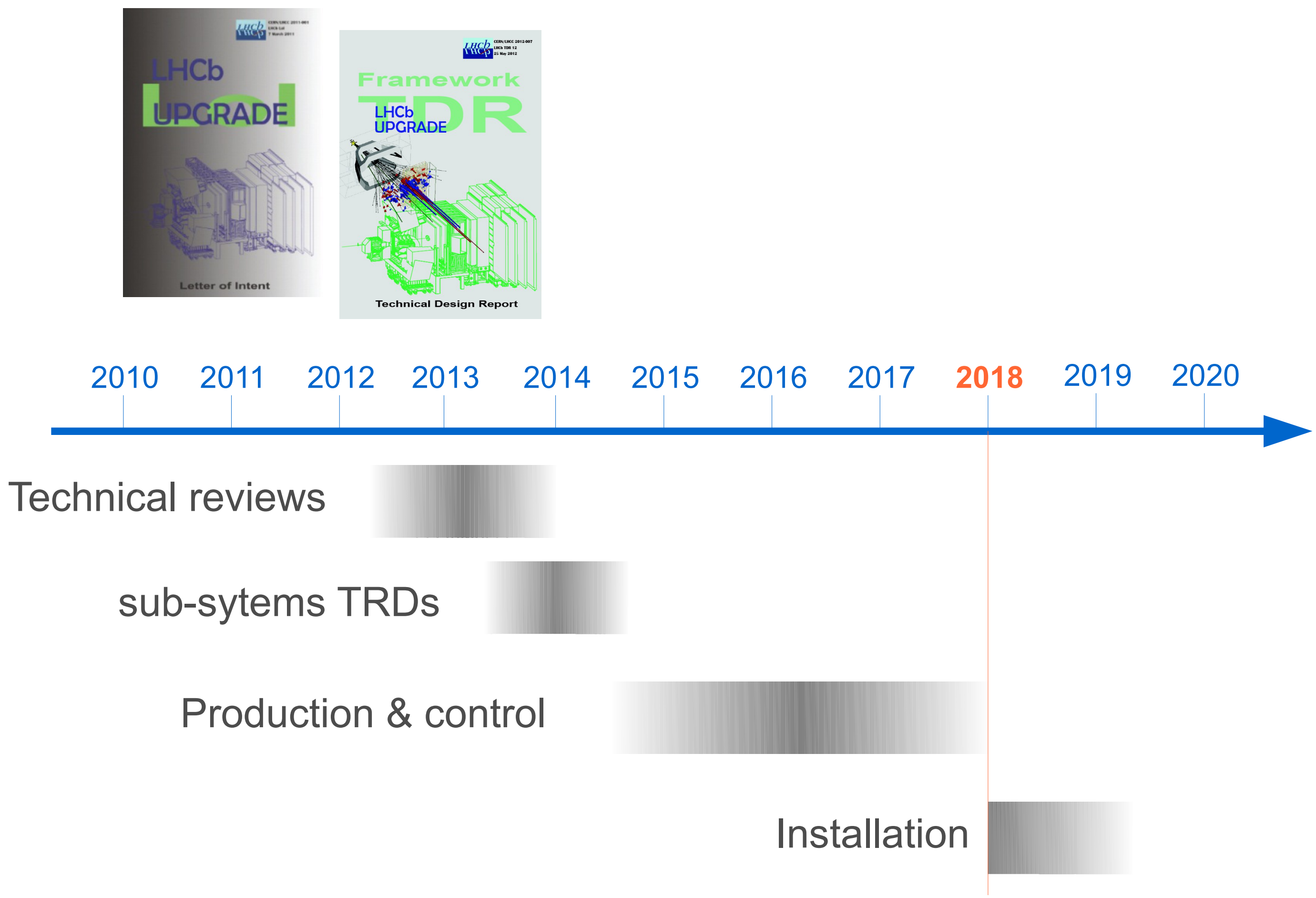
→ output rate limited to 20 kHz

→ full and fast reconstruction

encouraging progress

↘ Decision on technology → towards end of 2013

Upgrade roadmap



Conclusion

The LHCb upgrade has been fully approved by CERN

- LHCb will be upgraded in 2018 to start the phase 2 of its physics program
  - → high precision measurements will allow to understand better the flavour structure of the SM and possibly reveal new physics, e.g. :

$$\sigma(\gamma) \leq 1° \; ; \; \sigma(2\beta_s^{eff}(B_s \rightarrow \Phi\Phi)) \approx 0.003 \text{ rad} \; ; \; \sigma(\Delta A_{CP}(D \rightarrow KK, \pi\pi)) \approx 1.2\ 10^{-4}$$

- The upgraded LHCb is based on a trigger-less readout running at 40 MHz
  - → full software trigger
- Extensive R&D program going on
  - → new VELO and RICH technologies have been chosen
  - → technical choice for readout and fiber tracker to be taken towards the end of the year

Sensitivity of LHCb to key observables

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 [9]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\text{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\text{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\text{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\ A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	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–$12°$ [19, 20]	$4°$	$0.9°$	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	$11°$	$2.0°$	negligible
	$\beta\ (B^0 \to J/\psi\ K_S^0)$	$0.8°$ [18]	$0.6°$	$0.2°$	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

[Framework TDR for the LHCb Upgrade, CERN-LHCC-2012-007]