The LHCb Upgrade

Silvia Borghi on behalf of the LHCb Collaboration

Motivation

- The flavour sector offers a very rich programme to search for physics beyond the Standard Model in a complementary way to the direct particle searches carried out at ATLAS and CMS
- Recent LHCb results have shown the potential of flavour Physics at LHC and the excellent performance of the detector
- LHCb can exploit the full range of B hadrons, including unique NP prospects in B_s decays
- A broad charm physics programme is carried out at LHCb
- LHCb thanks to its forward geometry covers a complementary pseudo-rapidity range to the one of ATLAS and CMS
- LHCb upgrade would allow to fully exploit flavour physics potential and extend the programme to be a general purpose detector for the forward region

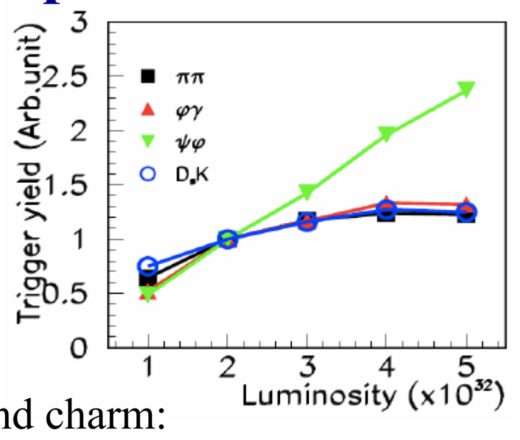
LHC schedule

Integrated luminosity @ LHCb

- 2009: LHC startup, $\sqrt{s}$ = 900 GeV
  - $\sqrt{s}$=7-8 TeV, L=4×10^{32} cm^{-2}s^{-1}, bunch spacing 50 ns — ~2.5 fb^{-1}
- 2013 (LS1): Go to design energy, nominal luminosity
  - $\sqrt{s}$=13-14 TeV, L~4×10^{32} cm^{-2}s^{-1}, bunch spacing 25 ns — ~6 fb^{-1}
- 2018 (LS2): Injector and LHC Phase-1 upgrade to full design luminosity & **LHCb upgrade installation**
  - $\sqrt{s}$=14 TeV, L~1-2×10^{33} cm^{-2}s^{-1}, bunch spacing 25 ns — ~20 fb^{-1}
- 2022 (LS3), 2023 ….. 2030?: HL-LHC Phase-2 upgrade, IR, crab cavities?
  - $\sqrt{s}$=14 TeV, L~5×10^{34} cm^{-2}s^{-1}, luminosity levelling — ~60 fb^{-1}

Data taking prospect

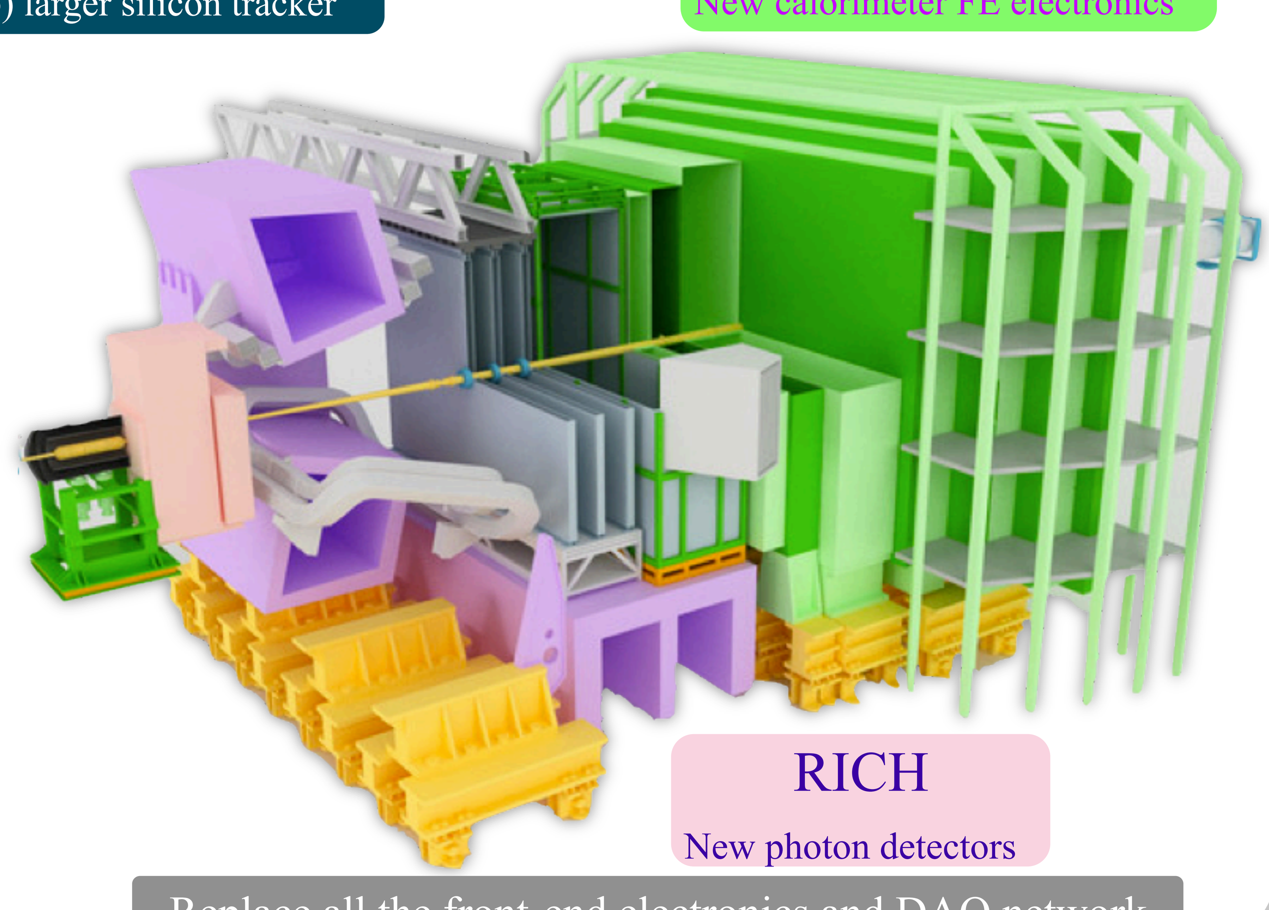
- Collect 50 fb^{-1}
- Increase annual yield:
  - Leptonic channels: ×10
  - hadronic channels: ×20
- Reach experimental sensitivities for many observables comparable or better than theoretical uncertainties
- Physics programme beyond beauty and charm:
  - Lepton flavour violation (Majorana neutrino, LFV in τ decays)
  - Electroweak physics ($\sin 2\theta_{eff}^{lept}$, M_W)
  - Exotic searches (hidden valleys, ...)
  - QCD (central exclusive production, ...)



Tracking
Reduce straw coverage +
a) fiber tracker
b) larger silicon tracker

Calorimeter+Muon
Remove M1, SPD, PS
New calorimeter FE electronics

VELO
a) New pixel detector
b) Improved strip detector

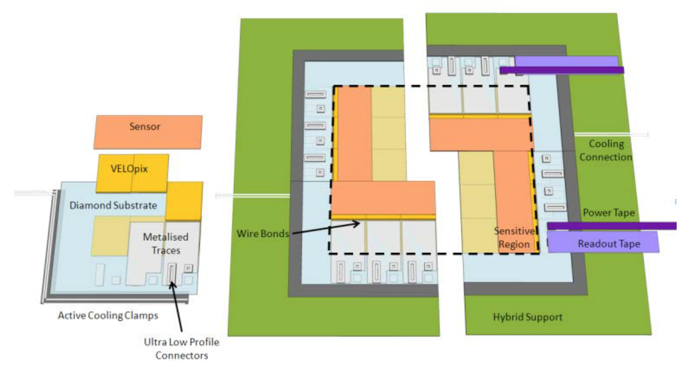


RICH
New photon detectors

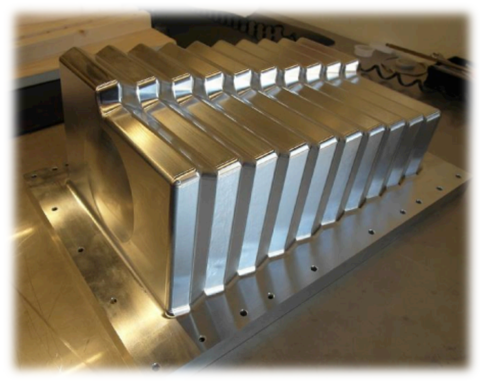
Replace all the front-end electronics and DAQ network

VELO upgrade

- Requirements
  - To deal very high data rate ≥ 12 Gbit/s/asic
  - High radiation level of ~370 Mrad or 8×10^{15} n$_{eq}$/cm^2
- Pixel detector
  - VELOPIX based on Timepix chip
  - 55 μm × 55 μm pixel size, 256 × 256 matrix



- Alternative option based on strips
  - Similar to existing detector: R/ϕ geometry
  - Increased number of strips, smaller pitch and strip length
- R&D programme
  - Module structure (X_0)
  - Sensor options: Planar Si, Diamond, 3D
  - RF-foil of vacuum box



Trigger upgrade

2012

40 MHz — read out Pileup, Calorimeter, Muon

Level 0
p_T of h,μ,e,γ

1 MHz — Full detector readout

High Level Trigger
Full event reconstruction:
tracking and vertexing
p_T and impact parameter cuts
inclusive/exclusive selections

to storage

4.5 kHz

Upgrade

40 MHz — Full detector readout

Fully flexible software trigger

High Level Trigger
Full event reconstruction:
tracking and vertexing
p_T and impact parameter cuts
inclusive/exclusive selections

to storage

20 kHz

Tracking performance

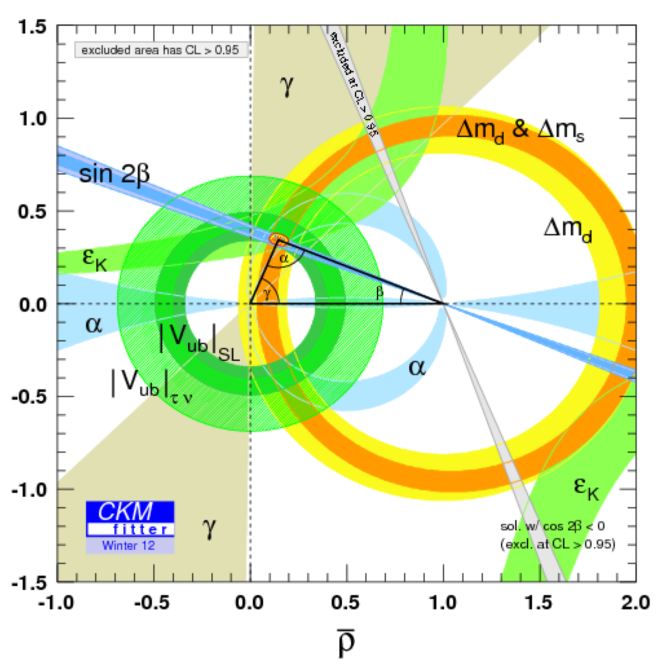
Challenge to maintain current performance level:

- High momentum resolution ➔ Δp/p = 0.4% - 0.6%
- High tracking efficiency ➔ ~96% for p>5 GeV
- Low ghost rate ➔ ~15% without any selection
- Fast processing time in HLT ➔ ~30ms
- Low material budget ➔ similar to current

Physics Prospects at LHCb Upgrade

Some of the core measurements in the beauty sector

- Measurement of the CP-violating phase ϕ_s in B_s decays
  - Phase I: observe NP in ϕ_s if larger than 3×SM
  - Upgrade: beyond SM precision measurement
- Rare penguin decay topologies sensitive to NP: charmless hadronic B-decays
  - Phase I: direct CP violation in B_s and Λ_b, time dependent CPV in $B_s \to K^+K^-$
  - Upgrade: precision time dependent CP violation in penguin dominated $B_s \to K^{*0}K^{*0}$, $B_s \to \phi\phi$
- Measurement of CKM angle γ using different ways
  - Phase I: precision to few degrees
  - Upgrade: precision better than 1 degree



Sensitivity to various flavour observables

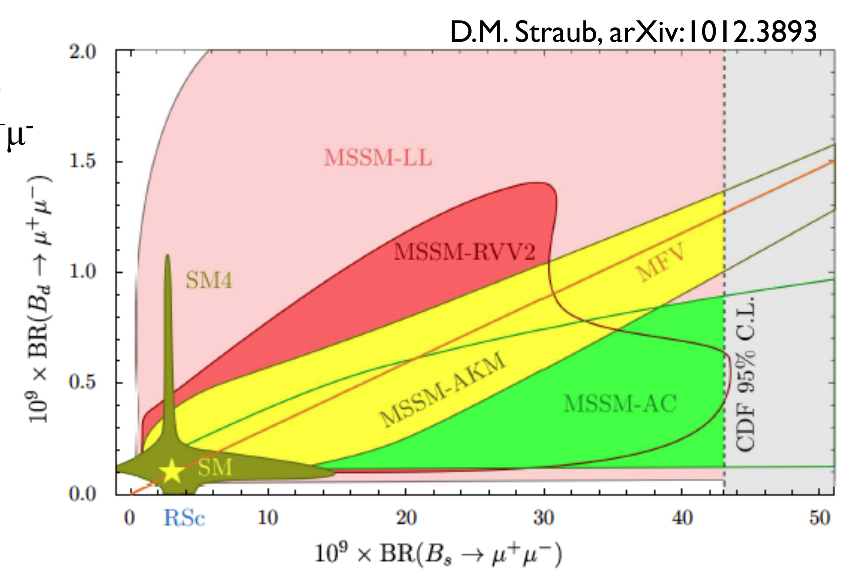
Type	Observable	Current precision	LHCb 2018	**Upgrade** (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [10]	0.045	0.014	~ 0.01
	$A_{fs}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{eff}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,GeV^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\ A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_I(K\mu^+\mu^-; 1 < q^2 < 6\,GeV^2/c^4)$	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	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–12° [19, 20]	4°	0.9°	negligible
	γ ($B_s^0 \to D_sK$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\ K_S^0$)	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}	–

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 fb^{-1} by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities.

[Framework TDR for the LHCb Upgrade, CERN-LHCC-2012-007. LHCB-TDR-012]

Rare decays

- $B_{s,d} \to \mu^+\mu^-$
  - Phase I: search for new physics in $B_s \to \mu^+\mu^-$
  - Upgrade: evaluation of $BR(B_{s,d} \to \mu^+\mu^-)/(B_d \to \mu^+\mu^-)$ and the correlation between $B_{s,d} \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$ to distinguish the theory predictions
- $B_{s,d} \to K^{*0}\mu^+\mu^-$
  - Phase I: measure A_{FB} and other observables
  - Upgrade: precise full angular analysis to study further observables (transverse asymmetries) sensitive to NP
- $D^0 \to \mu^+\mu^-$
  - Current limit 10^5× larger than SM prediction
- Radiative decays: $b \to s\gamma$: $B_s \to \phi\gamma$
  - Study of the photon polarisation



Mixing and CPV search in the charm sector

- Measurements of mixing parameters with several decays (WS, CP eigenstates, 3-body decays)
  - Phase I: measurement of mixing at >5 σ
  - Upgrade: precision better than 0.1×10^{-3}
- Search of direct and indirect CP violation
  - Phase I: precision of ~0.5×10^{-3}
  - Upgrade: precision of ~0.1×10^{-3}