LHCb Upgrade Physics Case

Patrick Robbe, LAL Orsay, 19 Feb 2013

Introduction

- LHCb Physics program for the upgrade: precision tests of the Standard Model and search for New Physics in the Flavour Sector.
- First LHCb data have demonstrated that a dedicated detector at an hadron collider can have a major impact on New Physics searches (See talks of yesterday and today).
- This can be significantly improved by the upgrade of the detector.

Principles

- Exploit two features of flavour physics in the Standard Model:
  - No Tree Level Flavor Changing Neutral Current
  - Quark mixing described by CKM matrix with a single source of CP violation
- Deviations from these via heavy (virtual) particles in loop corrections could be a sign of ~TeV massive particles.
- Complementary to direct searches of new heavy particles by ATLAS and CMS.
- Upgrade:
  - Improvement of the precision of the existing measurements down to theory uncertainties
  - New ideas, new modes to increase the physics reach potential

Classes of observables

- Large set of observables sensitive to New Physics are obtained from the study of:
  - Rare decays, in flavour changing neutral currents, with branching fractions small in the Standard Model and where new heavy particles could enhanced notable these fractions
  - CP violation in *B* meson decays, where strong experimental and theory constraints provide a solid framework in the Standard Model to compare with.
  - CP violation and mixing in charm.
- Numbers of other analyses where LHCb data collected in the forward region can help significantly.

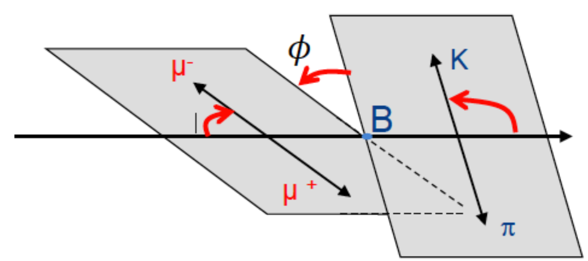
Upgrade conditions

- In the following, sensitivities of the upgraded LHCb detector will be shown, based on:
  - « Implication of LHCb measurements and future prospects », arXiv: 1208.3355
- Assuming (conservatively):
  - The detector performances will be equal to the current ones except the trigger efficiencies which will be twice the current ones for hadrons, photons and electrons (unchanged for muons)
  - D and B production cross-sections will double at 14 TeV compared to 7 TeV.
  - Instantaneous luminosity in LHCb will be 10^{33} $cm^{-2}.s^{-1}$ with 25ns bunch crossings (μ=2).
  - 50 fb^{-1} of data will be collected in 10 years.
- Statistical uncertainties only

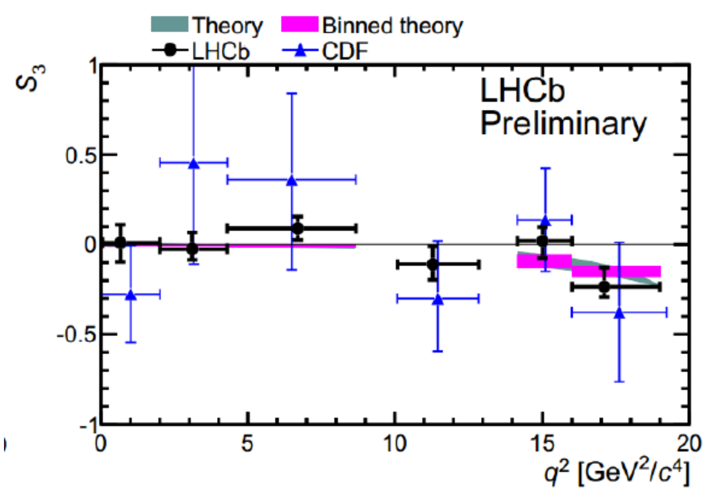
$B^0 \to K^{*0}\,\mu\,\mu$

- Semi-leptonic decays are a rich laboratory for new physics contribution searches.
- Study of Flavor Changing Neutral Currents to access Wilson coefficients that can be affected by New Physics Contributions.
- Angular analysis of the decays $B^0 \to K^{*0}\,\mu\,\mu$ or $B_s^0 \to \phi\,\mu\,\mu$ to access $C^{(\prime)}_7$, $C^{(\prime)}_9$ and $C^{(\prime)}_{10}$.

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}\,\mathrm{d}q^2} = \frac{9}{16\pi}\Big[F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) \, - \\ F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) \; + \\ \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) \; + \\ S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} \; + \\ \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell \; + \\ A_{Im}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big]$$



$B^0 \to K^{*0} \mu \mu$



	Current precision	LHCb in 2018	Upgrade	Theory
$S_3(1<q^2<6$ GeV$^2)$	0.08	0.025	0.008	0.02
A_{FB} crossing point	25%	6%	2%	7%

- Isospin asymmetries between $B^+ \to K^+ \mu^+\mu^-$ and $B^0 \to K_s^0 \mu^+ \mu^-$ (challenging because of the K_s^0 reconstruction):

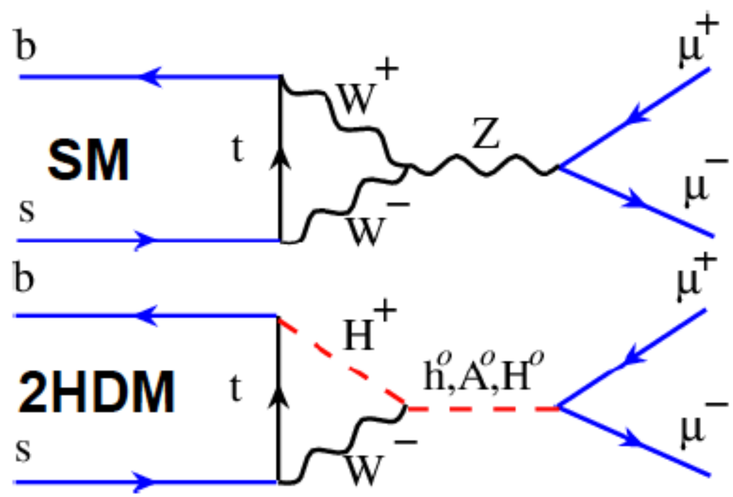
	Current precision	LHCb in 2018	Upgrade	Theory
$A_{isospin}$	0.25	0.08	0.025	0.02

- Mesurement of the suppressed $B^+ \to \pi^+ \mu^+ \mu^-$

$B(B\to\pi\mu\mu)/(B\to K\mu\mu)$	25%	8%	2.5%	10%

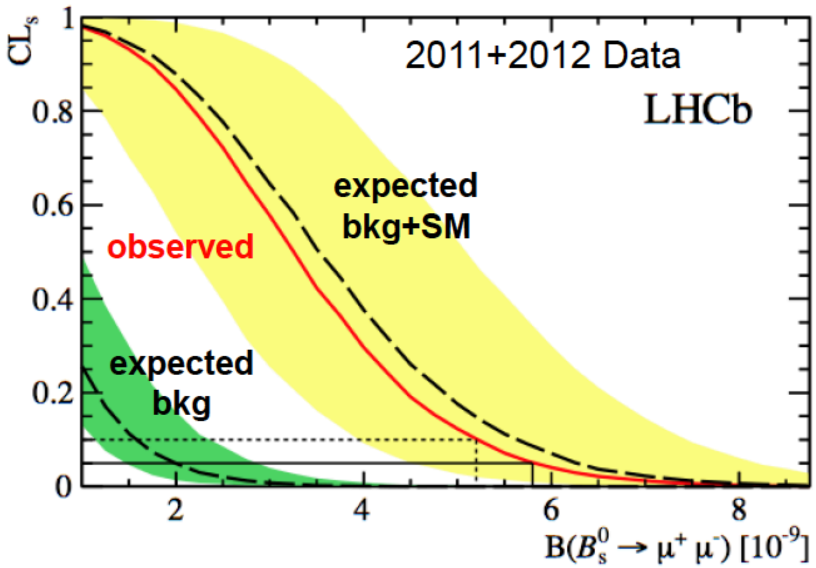
$B_{(s)}{}^0 \rightarrow \mu^+ \mu^-$

- Test possible new particles in loops comparing with precise SM predictions.



- Comparison of $B^0 \rightarrow \mu\mu$ to $B_s{}^0 \rightarrow \mu\mu$ allows to probe Minimal Flavour Violation.

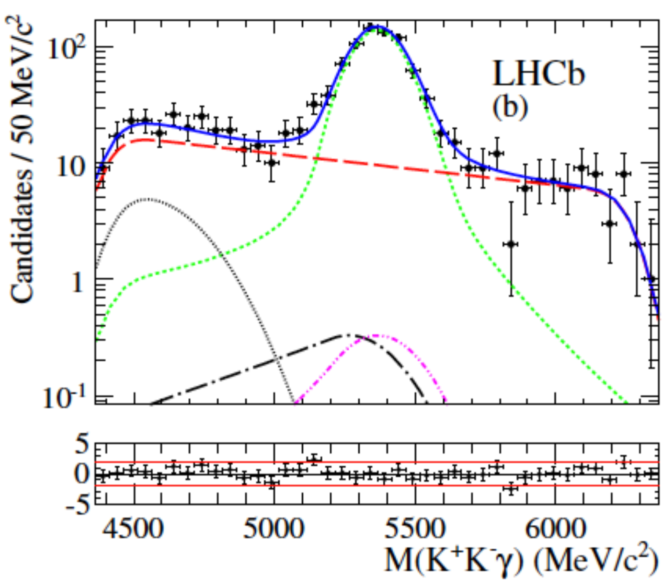
$B_{(s)}{}^0 \rightarrow \mu^+ \mu^-$



	Current precision	LHCb in 2018	Upgrade	Theory
$B_s \rightarrow \mu\mu$	1.5×10^{-9}	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
$B_d \rightarrow \mu\mu$/ $B_s \rightarrow \mu\mu$		~100%	~35%	~5%

$B_s \to \phi\,\gamma$

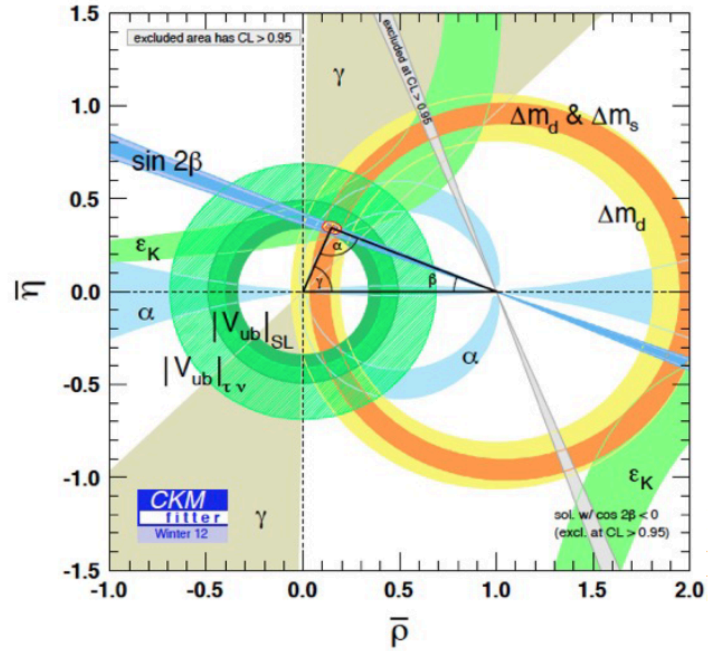
- CP asymetries in $B \to K^{*}\gamma$ can bring important constraints but is extremely difficult to measure at an hadronic collider (tagging + reconstruction of $K^{*0} \to K_s^0\,\pi^0$)
- However, the same measurement in $B_s \to \phi\gamma$ is reachable by LHCb.
- Other interesting ideas using $\Lambda_b \to \Lambda\gamma$ or $B \to \phi K\gamma$.



	Current precision	LHCb in 2018	Upgrade	Theory
$2\beta_s^{eff}(B_s^0 \to \phi\gamma)$		0.09	0.02	<0.01
$\tau^{eff}(B_s^0 \to \phi\gamma)/\tau(B_s^0)$		5%	1%	0.2%

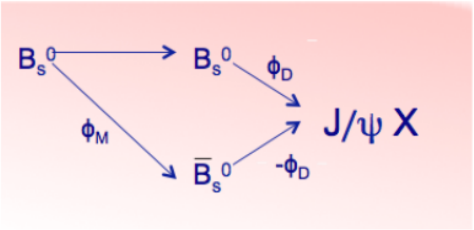
CP violation

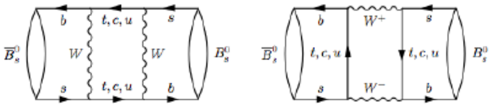
- CP violation in the Standard Model is fully described by CKM mechanism.
- Other sources of CP violation could come from New Physics.
- Large CP violation effect in *B* decays in the Standard Model, at tree level. Corrections in loops could modify it.
- Experimental and theoretical knowledge of the CKM parameters in the Standard Model are best summarized in Unitarity Triangle fits. Consistency within the Standard Model tested to O(10%).

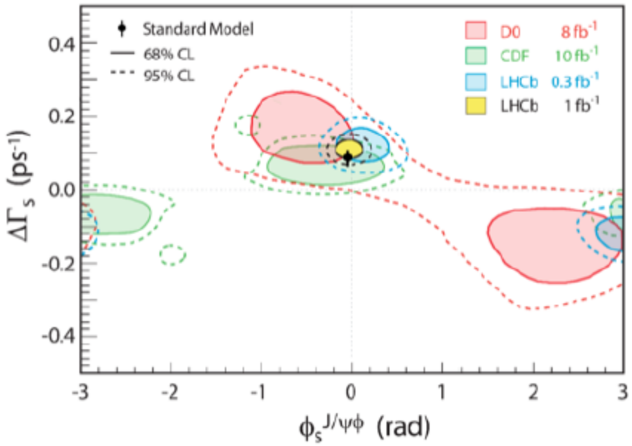


ϕ_s with $B_s^0 \to J/\psi\ \pi$

- Mixing phase can be modified if presence of heavy particles in the box diagrams



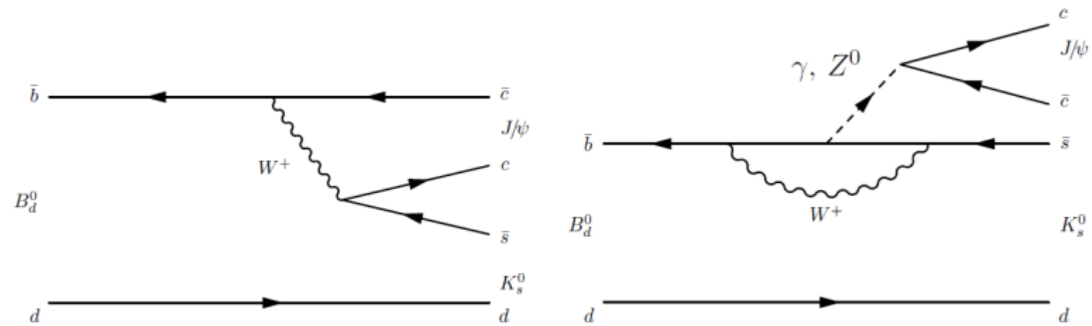




	Current precision	LHCb in 2018	Upgrade	Theory
$2\beta_s(B_s^0 \to J/\psi\phi)$	0.1	0.025	0.008	0.003
$2\beta_s(B_s^0 \to J/\psi f_0)$	0.17	0.045	0.014	0.01

β

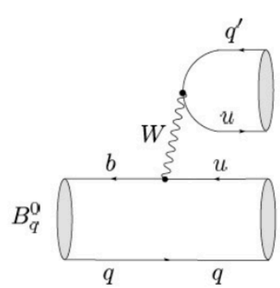
- Precise measurements of β_s but also β will be obtained.
- With this level of precision, penguin contaminations in these measurements cannot be ignored, and can be controlled from other measurements.

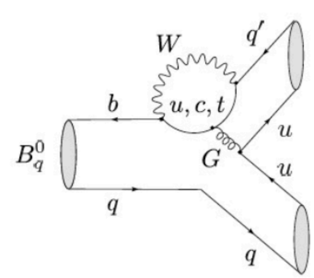


	Current precision	LHCb in 2018	Upgrade	Theory
β	0.8◦	0.6◦	0.2◦	Negligible
$2\beta_s^{eff}(B_s^0 \rightarrow \phi\phi)$		0.17	0.03	0.02
$2\beta_s^{eff}(B_s^0 \rightarrow K^{*0}K^{*0})$		0.13	0.02	<0.02
$2\beta^{eff}(B^0 \rightarrow \phi K_s^0)$	0.17	0.30	0.05	0.02

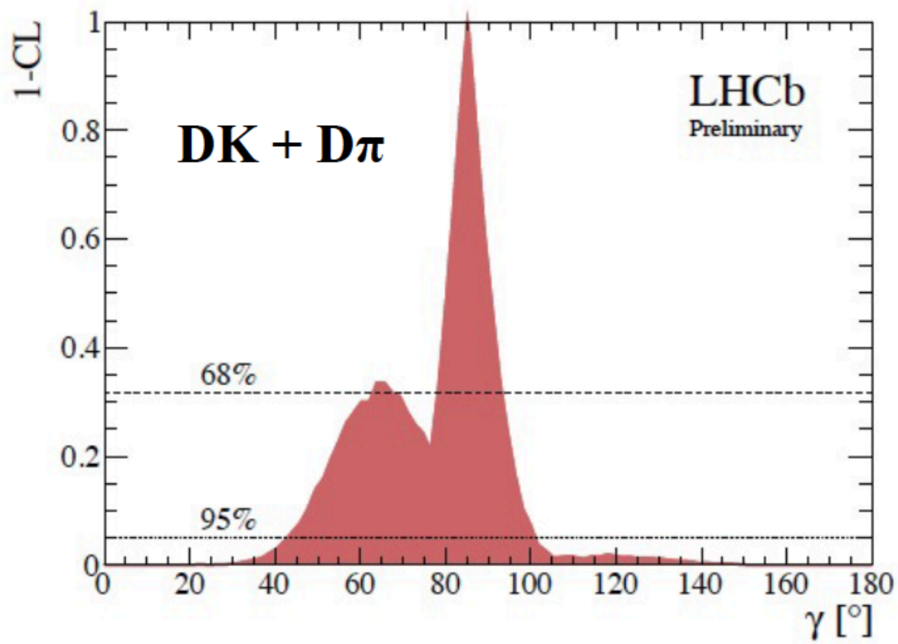
γ angle

- The least well know angle of the UT, with an uncertainty of 10° on the combined experimental measurements.
- Also the only angle which can be measured with tree only processes, through:
  - Asymmetries in $B \to D^{(*)}K^{(*)}$ decays,
  - Taged time-dependent analysis of $B_s^0 \to D_s K$
- Provide a reference measurement of γ in the Standard Model that can be compared to measurements where loop diagrams contribute: charmless 2 or 3 body decays.





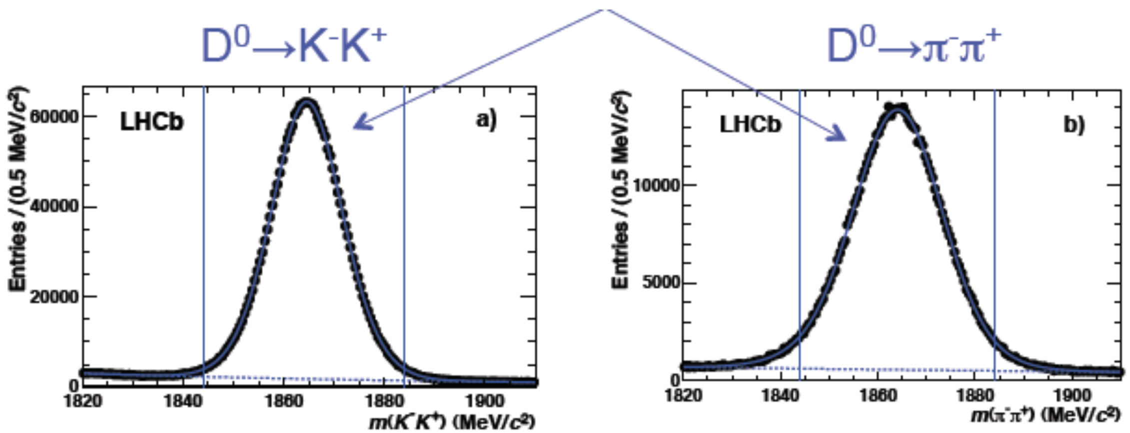
γ angle



	Current precision	LHCb in 2018	Upgrade	Theory
$\gamma(B \to D^{(*)}K^{(*)})$	10∘	4∘	0.9∘	Negligible
$\gamma(B_s^0 \to D_sK)$		11∘	2∘	Negligible

CP violation in D

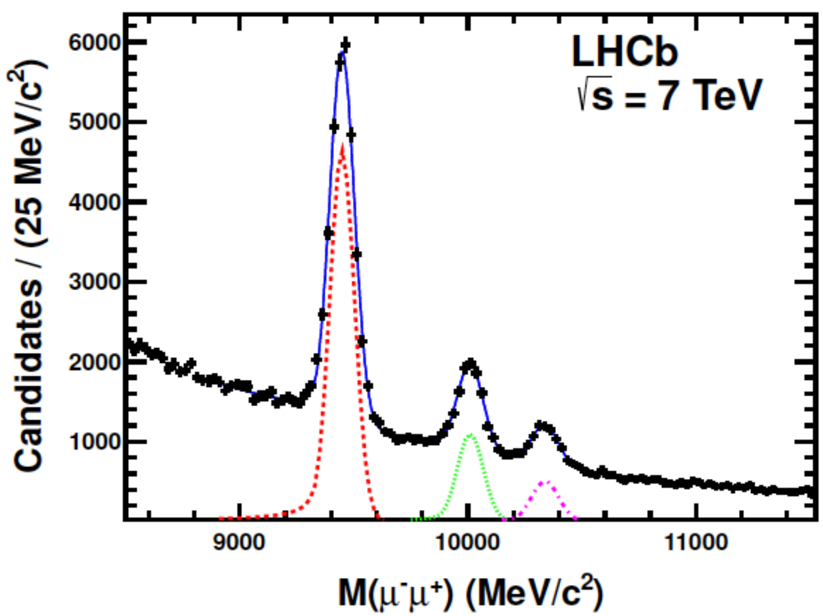
- The charm sector also provides interesting oportunities to test the Standard Model, in particular in studying CP violation and mixing. Complementary constraints with respect to *B* sector (up quarks <-> down quarks)
- Huge statistics: requires precise control of systematic uncertainties



	Current precision	LHCb in 2018	Upgrade	Theory
$A\Gamma$	2.3×10^{-3}	0.4×10^{-3}	0.07×10^{-3}	-
ΔA_{CP}	2.1×10^{-3}	0.65×10^{-3}	0.12×10^{-3}	-

Spectroscopy

- LHCb can also contribute significantly in other fields.
- For example, study of the exotic quarkonium-like states, using the huge di-muon available sample.
- Charmonium-like sector currently under detailed investigation, bottomonium counter part could be studied also in the upgrade, thanks to the good $\Upsilon(nS) \to \mu\mu$ reconstruction performances.



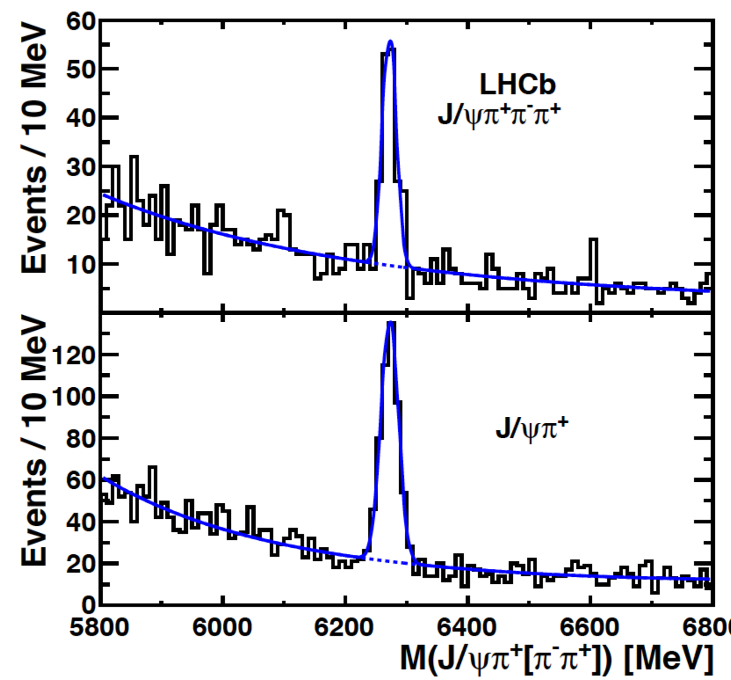
B_c

- Unique meson: formed with two different heavy flavours. Nice laboratory where precision of mass and lifetimes could help reducing uncertainties in QCD parameters affecting B physics predictions.

- Most of its properties still not known with precision, because of its low production rate.

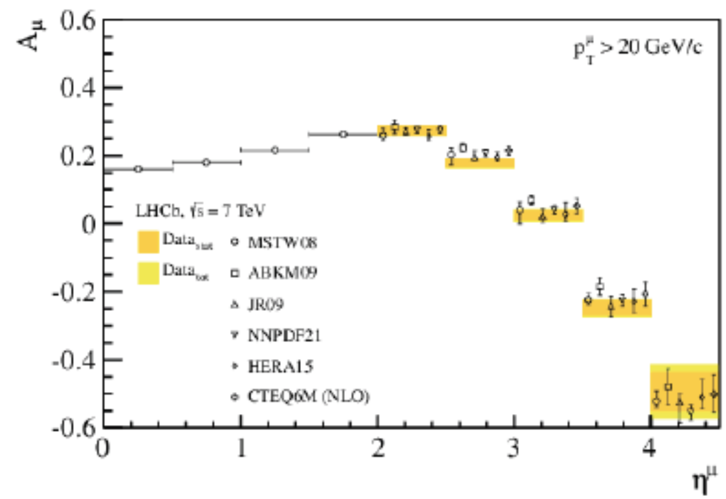
- New decay modes discovered with LHCb data and first measurement of mass.

- Large B_c samples could allow also exploring CP violation in original places ($B_c^+ \rightarrow D_{(s)}^+ D^0$) or exotic states in $B_c^+\pi(\pi)$ spectra

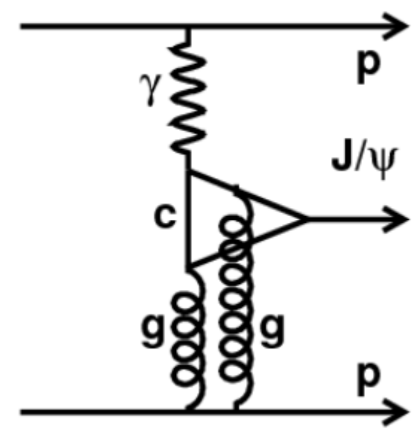


Forward and exclusive physics

- Precise measurement of W^+/W^- production asymmetry can give strong constraints on Parton Density Functions for better knowledge of them



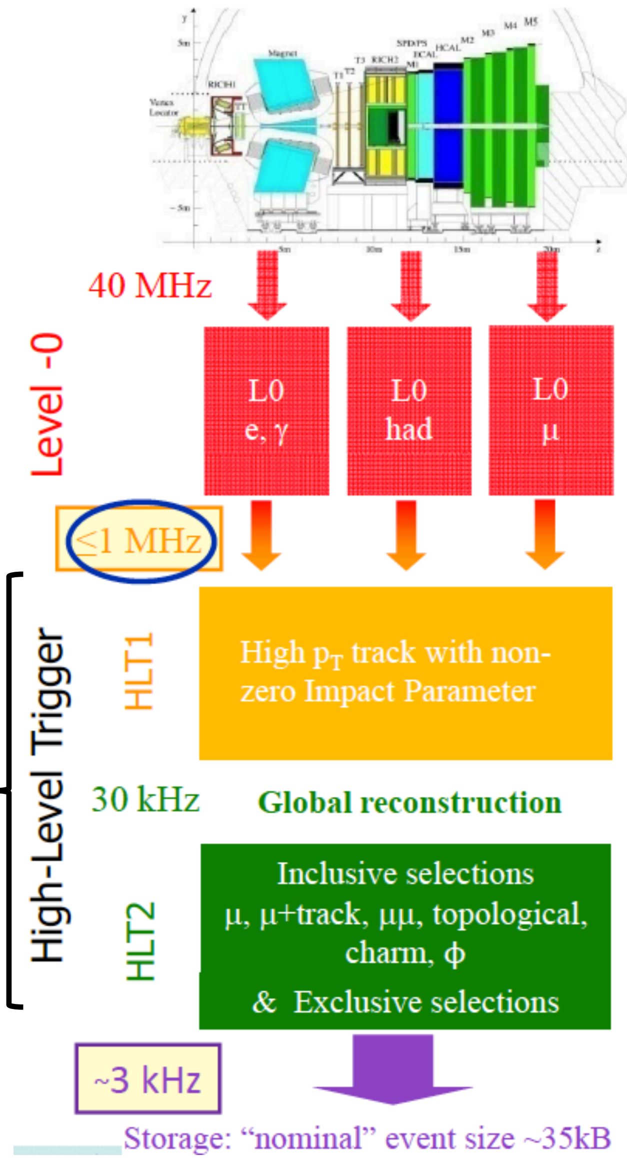
- Central exclusive production (J/ψ, heavy quarkonium, …) via photon and pomeron exchanges.
- Clean environment for the study of quarkonium or exotic states.

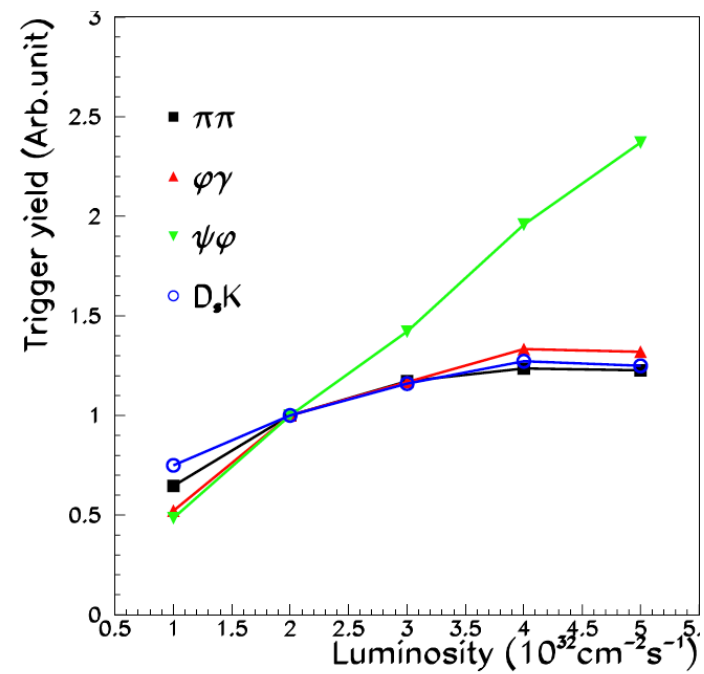


How to reach these goals

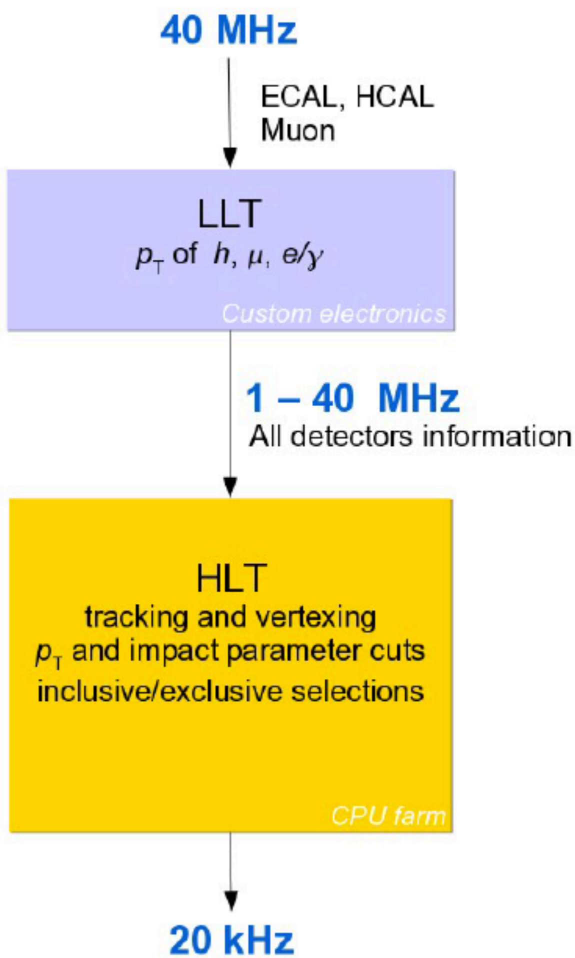
- The DAQ of the current detector is limited to 1 MHz readout rate by design.
- Rate reduction to 1 MHz is obtained with a hardware trigger looking for high p_T objects (muons, hadrons, électrons, photons)
- This 1MHz constraint limit the efficiency of hadronic channels at higher luminosity.

Software trigger 29000 CPU cores running quasi-offline reconstruction software

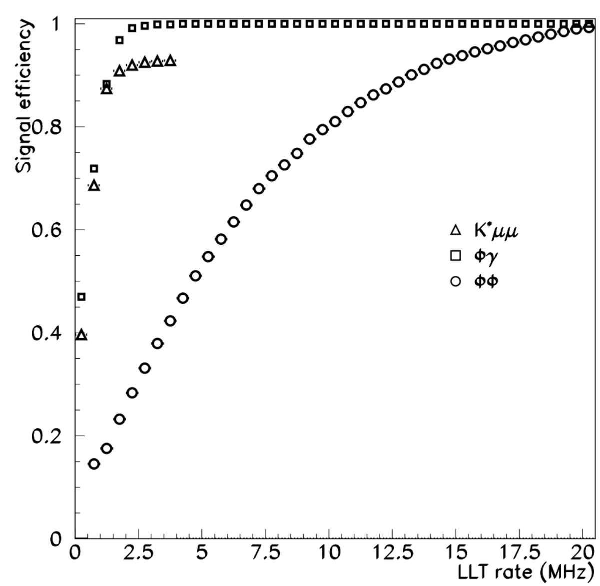




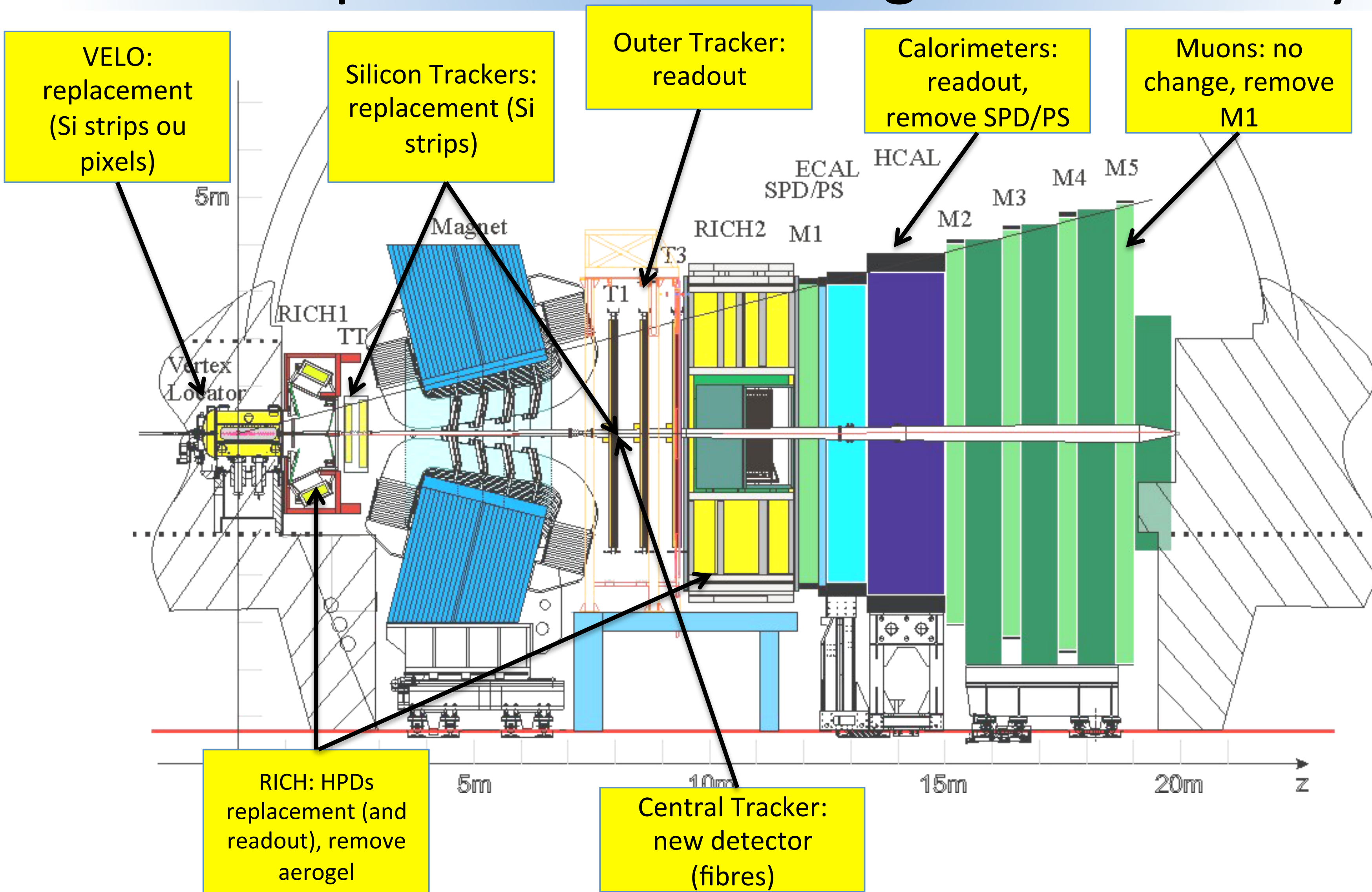
Trigger for the upgrade



- Replace the readout electronics to read the full detector information at 40MHz !
- Trigger hardware (LLT, Low Level Trigger) will adjust the readout rate but will progressively be removed:
  - Higher efficiencies on hadronic channels
  - Full software trigger which allows maximum flexibility: data analyses are not limited and trigger software can be modified to explore particular interesting decay modes.



Detector modifications: 40 MHz readout and improvements for higher luminosity



Conclusions

- LHCb proven capabilities of studying B and D physics at the LHC can be extended to obtain precision flavour physics measurements comparable to theory uncertainties.
- → LHCb Upgrade, based on full software trigger reading out the detector information at 40 MHz: exciting challenge, crucial to reach the necessary flexibility and perfomances.