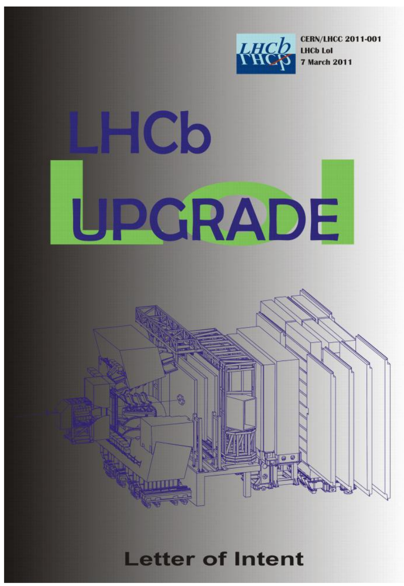
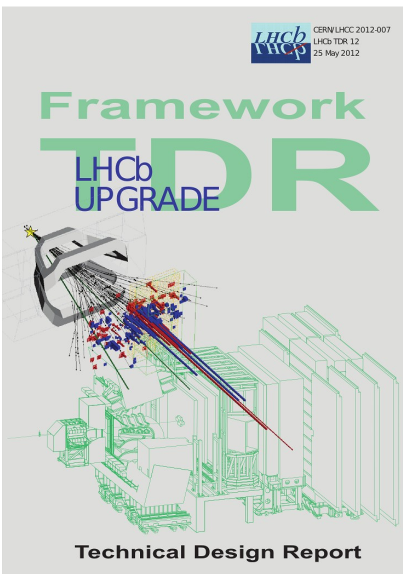


CERN-LHCC-2011-001



CERN-LHCC-2012-007

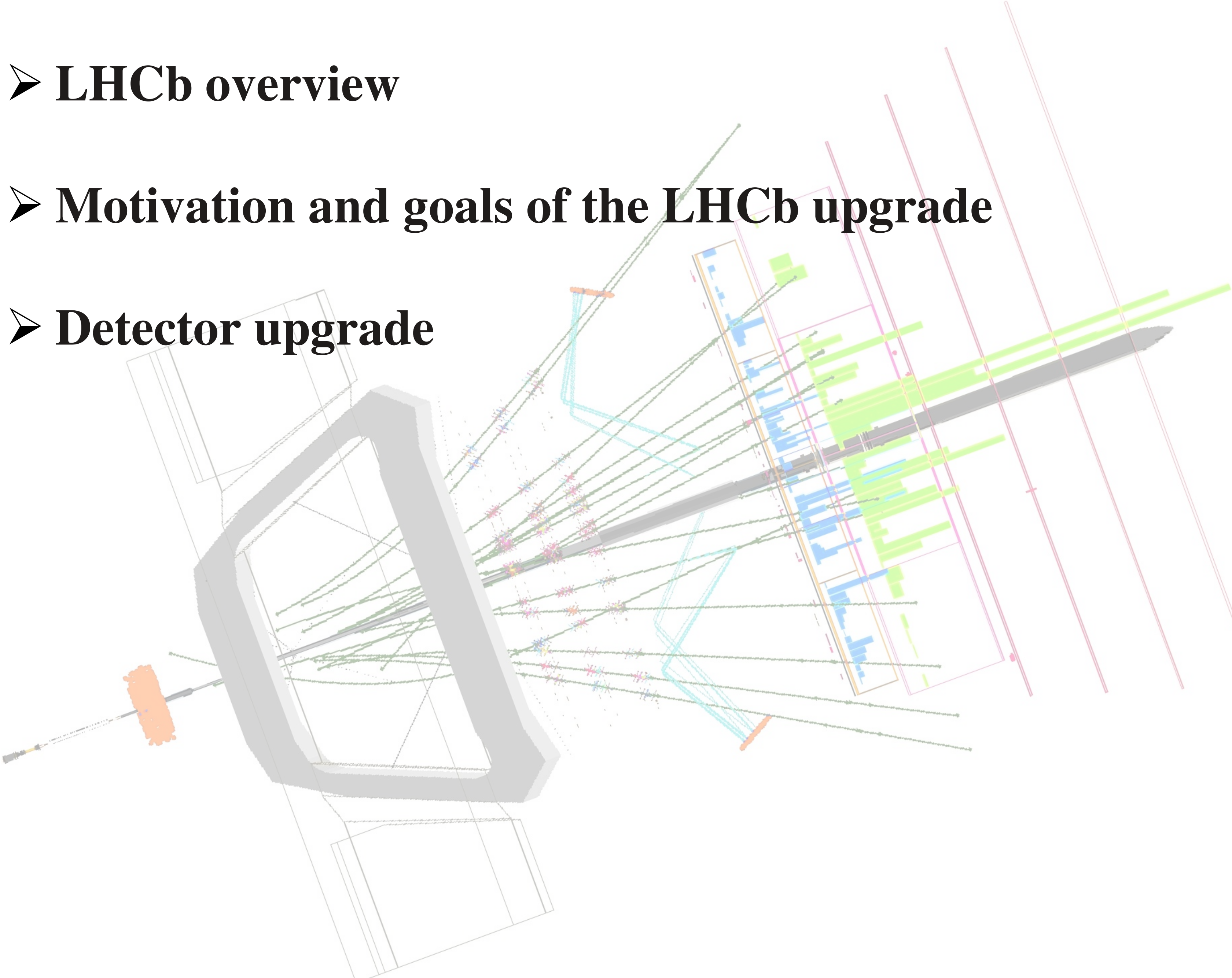
The LHCb Upgrade

Plamen Hopchev, LAPP (Annecy) & CERN
on behalf of the LHCb Collaboration

International Conference on New Frontiers in Physics

10-16 June 2012 Kolymbari, Crete, Greece

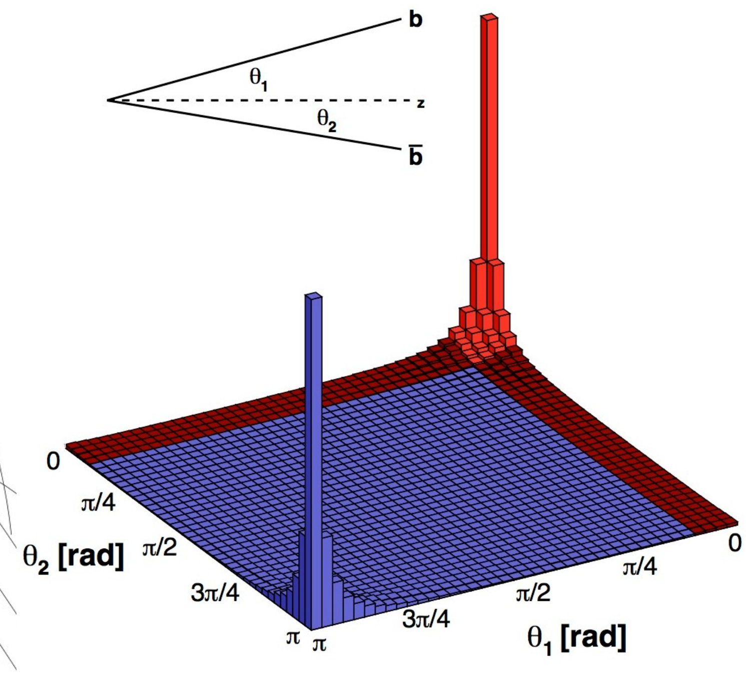
- LHCb overview
- Motivation and goals of the LHCb upgrade
- Detector upgrade

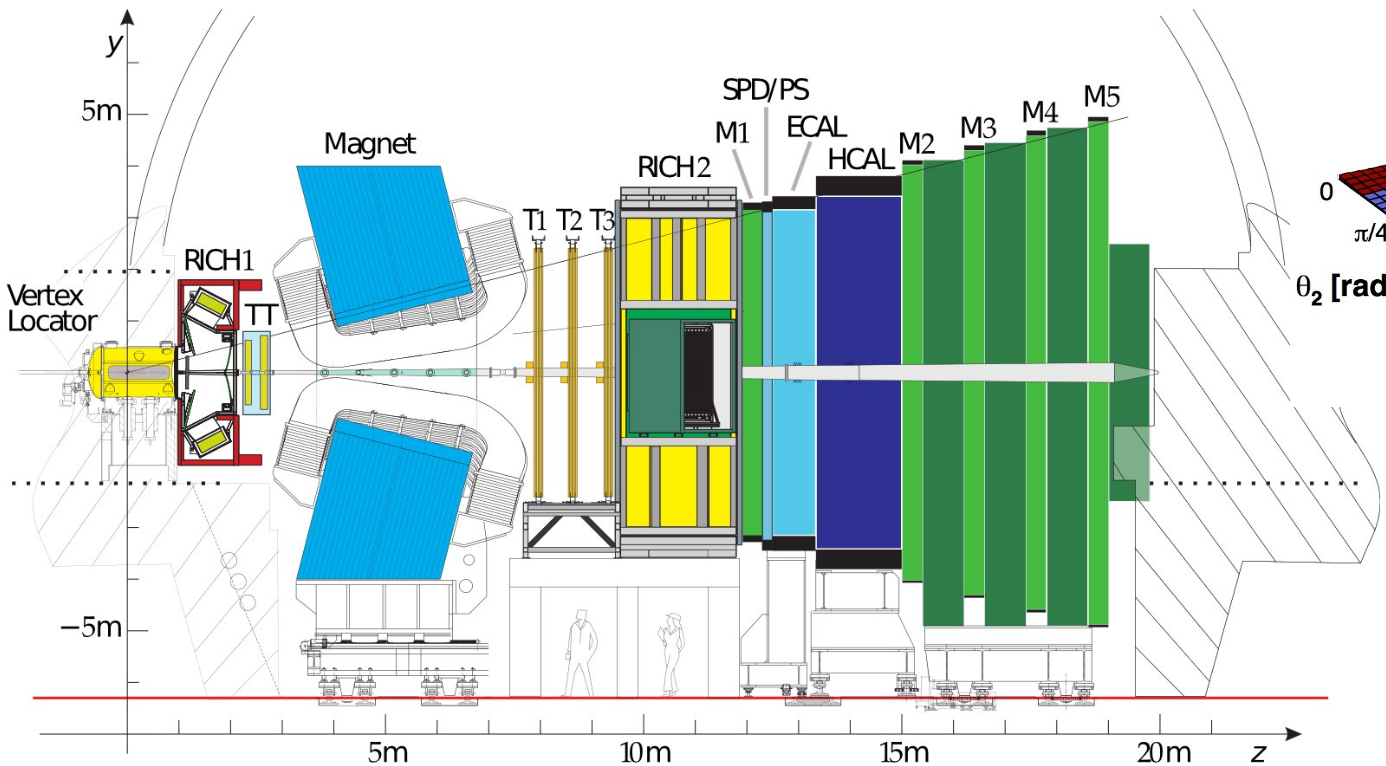


LHCb – a brief introduction

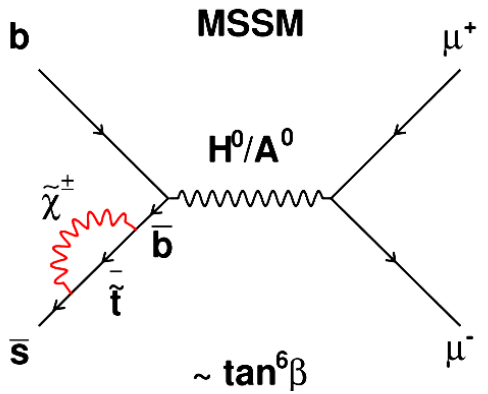
- **Precision CP violation and rare decay measurements of charm and beauty hadrons:**
  - Test the Standard Model
  - Indirect search for New Physics
- **Forward spectrometer: $2 < \eta < 5$**
  - Detect a large fraction of the $b\bar{b}$-pairs
  - Complementary to ATLAS/CMS ($|\eta| < 2.5$)

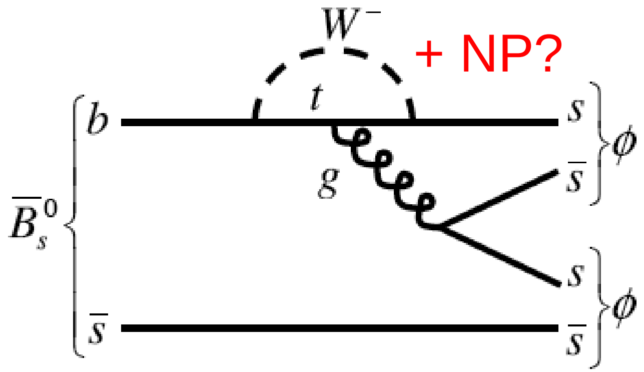
LHCb overview: see talk of U. Egede

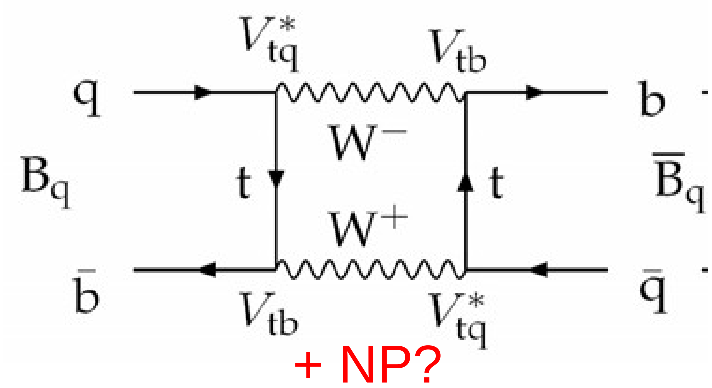




- **Search for the effects of New Physics in CP-violation and rare decays using FCNC processes**
  - New Physics enters through loop diagrams (boxes and penguins)
- **Improve the precision of CKM parameters, using tree and loop processes**







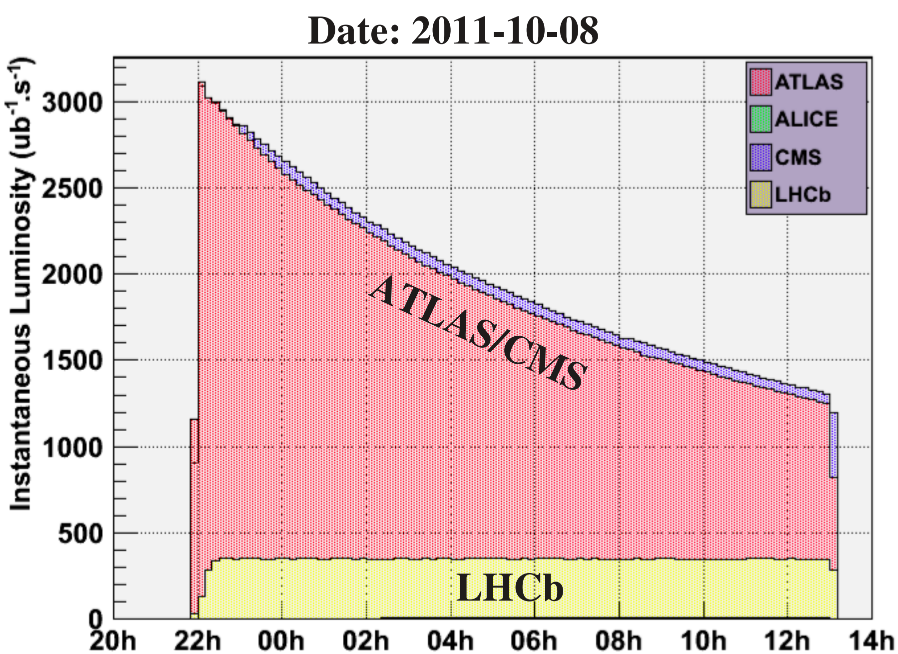
- **CP-violation** *see talks of N. Lopez March and A. Martens*
  - B_s oscillation phase φ_s
  - CKM angle γ in trees and loops
  - CP asymmetries in charm decays
- **Rare decays** *see talk of B. Sciascia*
  - Helicity structure in $B_d \to K^*\mu\mu$, $B_s \to \varphi\gamma$
  - FCNC in loops: $B_{d,s} \to \mu\mu$, $D \to \mu\mu$

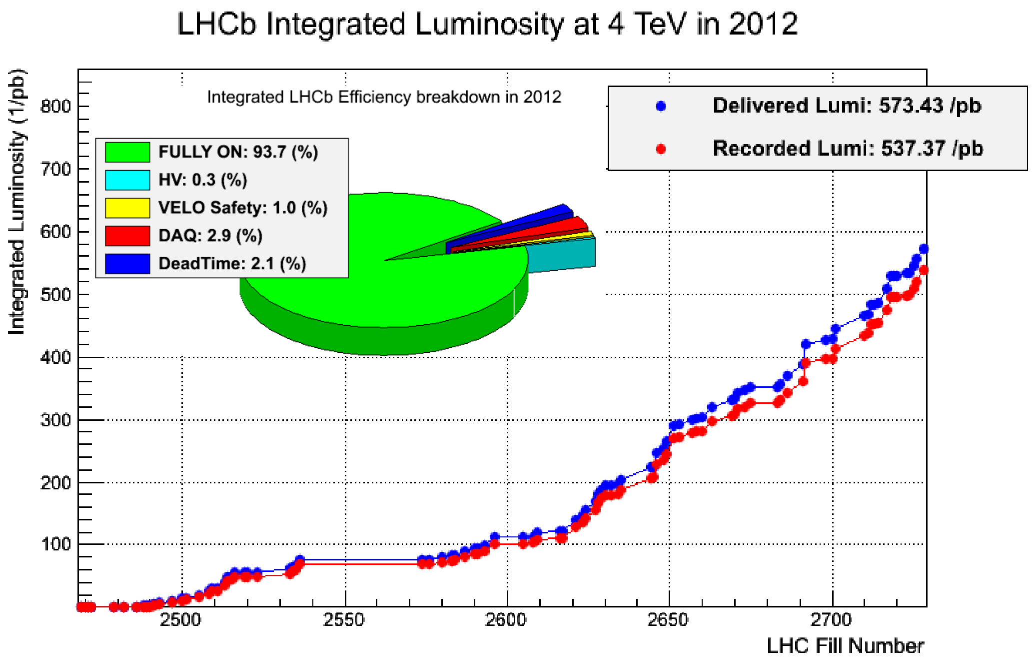
see talk of A. Contu

- **Particle production studies, EW & QCD physics, exotic searches (long-lived particles, hidden valley, Majorana neutrinos, …) and more**

- **In 2011 and 2012 operate at L ~ 4×10^{32} $cm^{-2}s^{-1}$** (nominal L: 2×10^{32} $cm^{-2}s^{-1}$)
  - Luminosity leveling
  - Stable trigger and pile-up ~ 1.5 (nominal pile-up: 0.4)
  - About 99% of the detector channels operational
  - Data taking efficiency > 90%
  - Ageing of detector as expected

	2011	2012
L0 output [MHz]	0.85	1.0
HLT output [kHz]	3	4.5
Recorded luminosity [fb^{-1}]	1.0	Until 10/06: 0.5 Goal: 1.5





Motivation for the LHCb Upgrade

- **Overall: great performance of LHC and LHCb**

- **Plan to collect ≥ 5 fb^{-1} before 2018 (LHC LS2)**
  - Sufficient to perform *many* (more) world-best measurements

- **However, up to now no striking deviations from the SM**
  - Will need even better precision for optimal comparison with the theoretical predictions **→ can be achieved with more statistics (many measurements not limited by systematics)**

- **Design limitations of current detector**
  - Read-out network (1 MHz readout)
  - Tracking performance at larger pile-up

- **Note: LHC has demonstrated great flexibility, providing the operation conditions needed by LHCb**

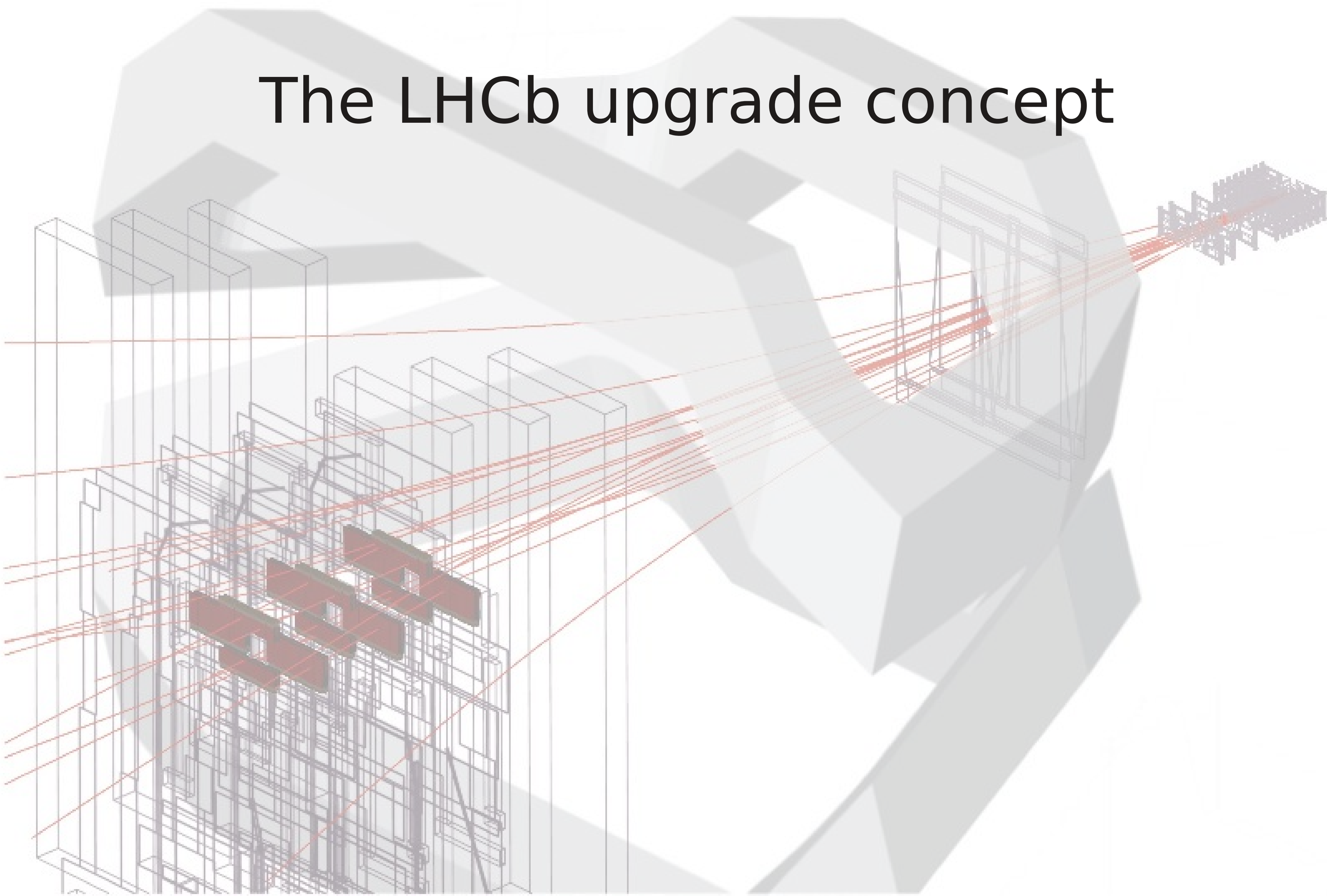
Goals of the LHCb Upgrade

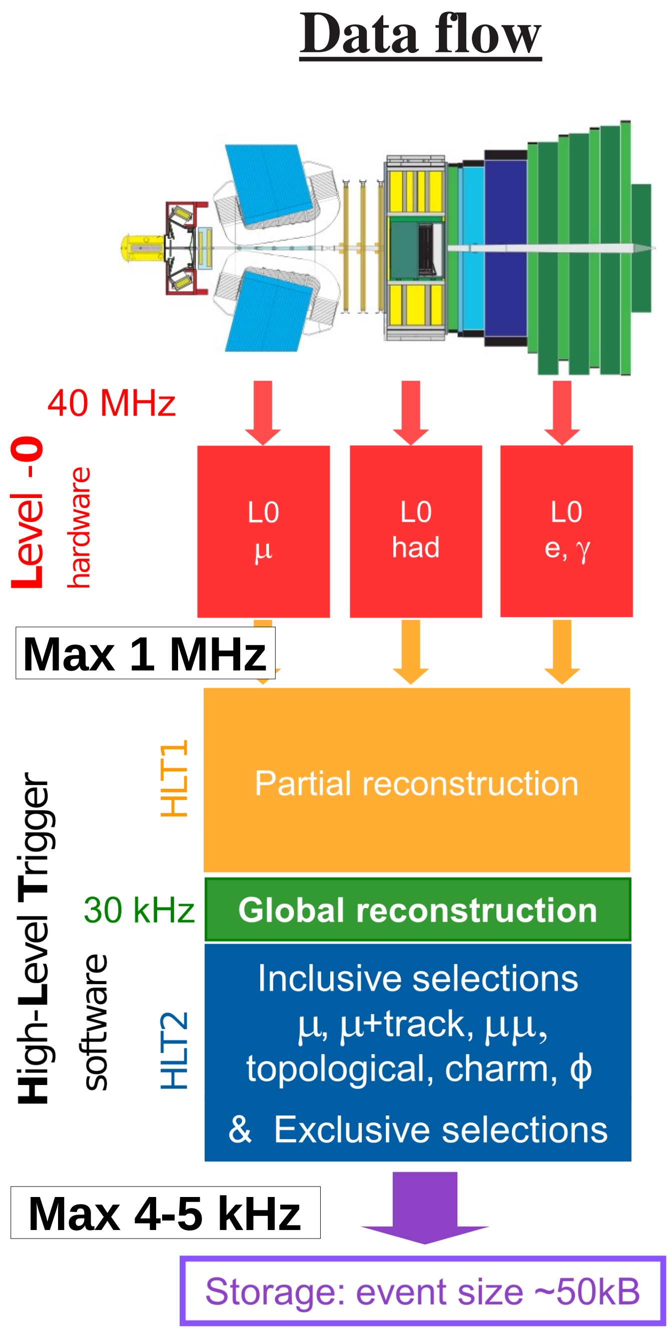
- **Reach experimental precision in key observables comparable to the theoretical uncertainty**
  - Increase the annual yield: x10 for leptonic and x20 for hadronic channels (wrt 2011)
  - Collect > 50 fb^{-1} at L~$1x10^{33}$ $cm^{-2}s^{-1}$ (detector able to sustain L up to $2x10^{33}$ $cm^{-2}s^{-1}$)
- **Enlarge core physics programme (new collaborators welcome!)**

Projected sensitivities (stat. errors only) [LHCb Framework TDR]

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}	–

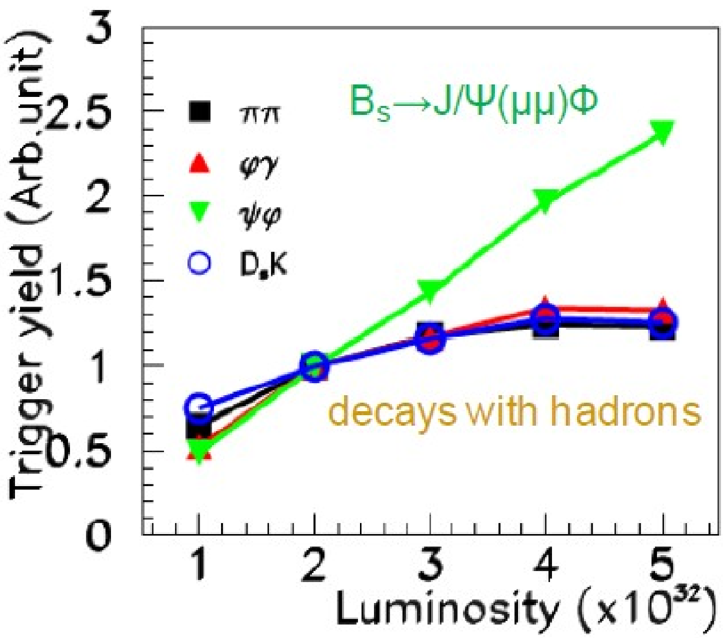
The LHCb upgrade concept





- **Only Calorimeter and Muon data is available at L0**
  - Use E_T / p_T cuts to select signal and reduce background
- **The full event data of up to 1 MHz of events is read-out and sent to the HLT**
- **At the HLT more refined selections are made**
- **Up to 4-5 kHz of events can be written to disk**

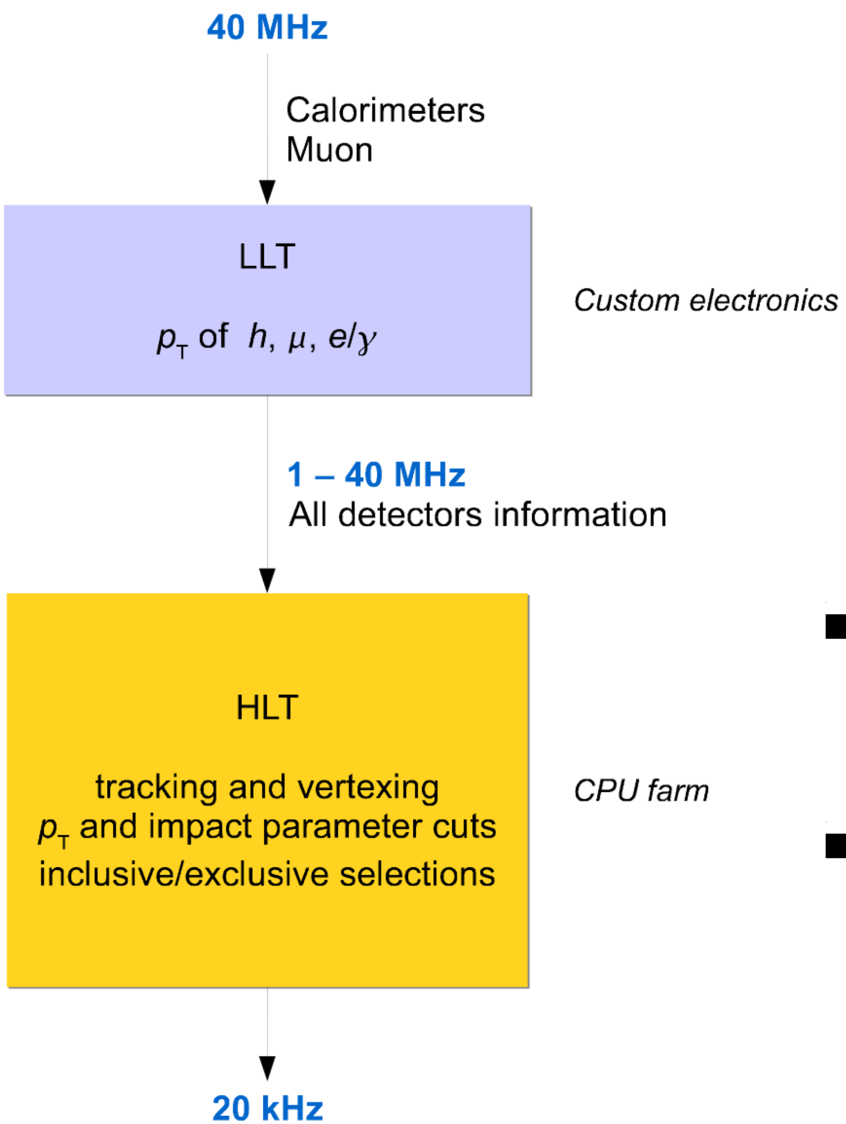
- **At higher luminosity need to increase the L0 E_T / p_T thresholds to stay within the allowed 1 MHz**



Decays with muons: linear gain

Fully hadronic decays: saturation

LHCb trigger – Upgrade



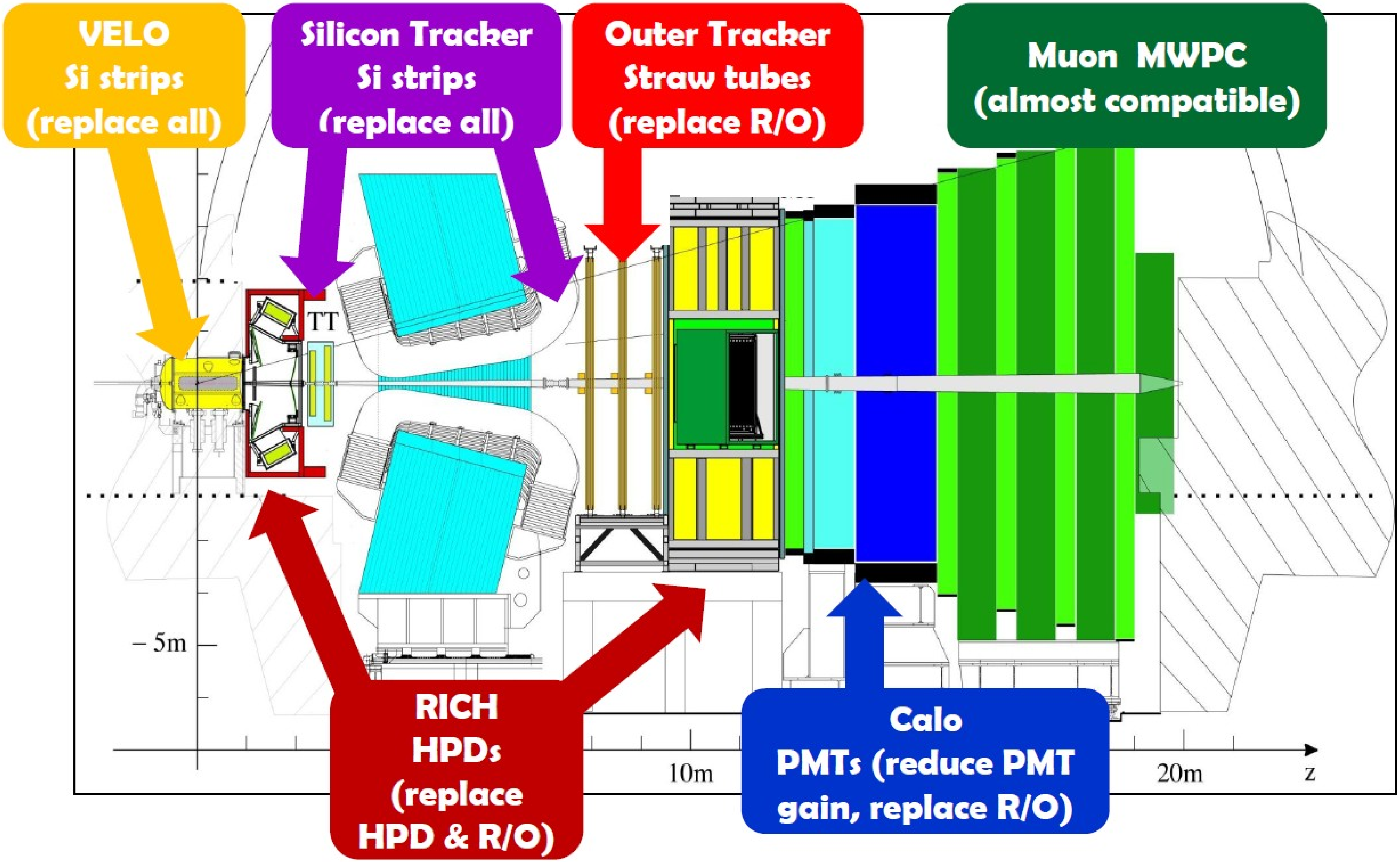
- **To be able to fully profit from higher luminosity:**
  - **Upgrade the complete detector read-out to 40 MHz**
  - **Use software-only trigger**
    - foresee ~10 MHz of LLT with an initial (smaller) CPU farm
  - **Increase the output rate to 20 kHz**

➡ Challenging requirements to the detectors FE electronics and the read-out infrastructure

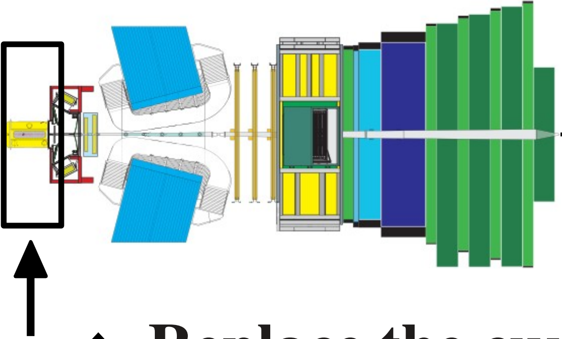
➡ Expected improvement to signal efficiencies with the upgraded trigger, assuming L=1x10^{33} cm^{-2}s^{-1}

LLT-rate (MHz)	1	5	10
$B_s \to \phi\phi$	0.12	0.51	0.82
$B^0 \to K^*\mu\mu$	0.36	0.89	0.97
$B_s \to \phi\gamma$	0.39	0.92	1.00

Detector Upgrade Overview

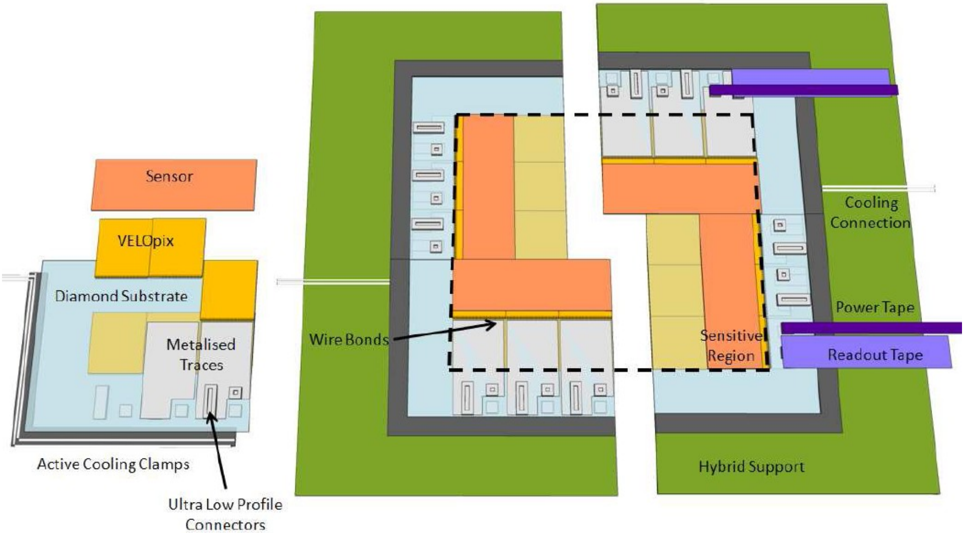


+ New front-end electronics and read-out network

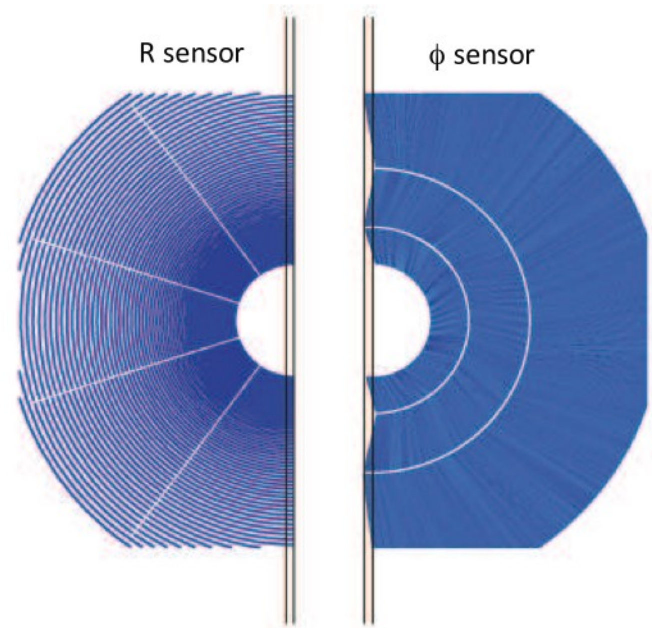


VELO

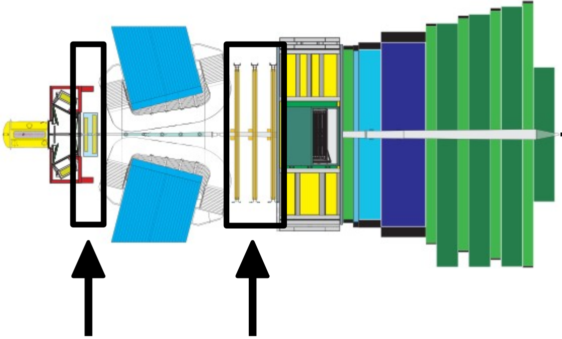
VELO "straw-man" module



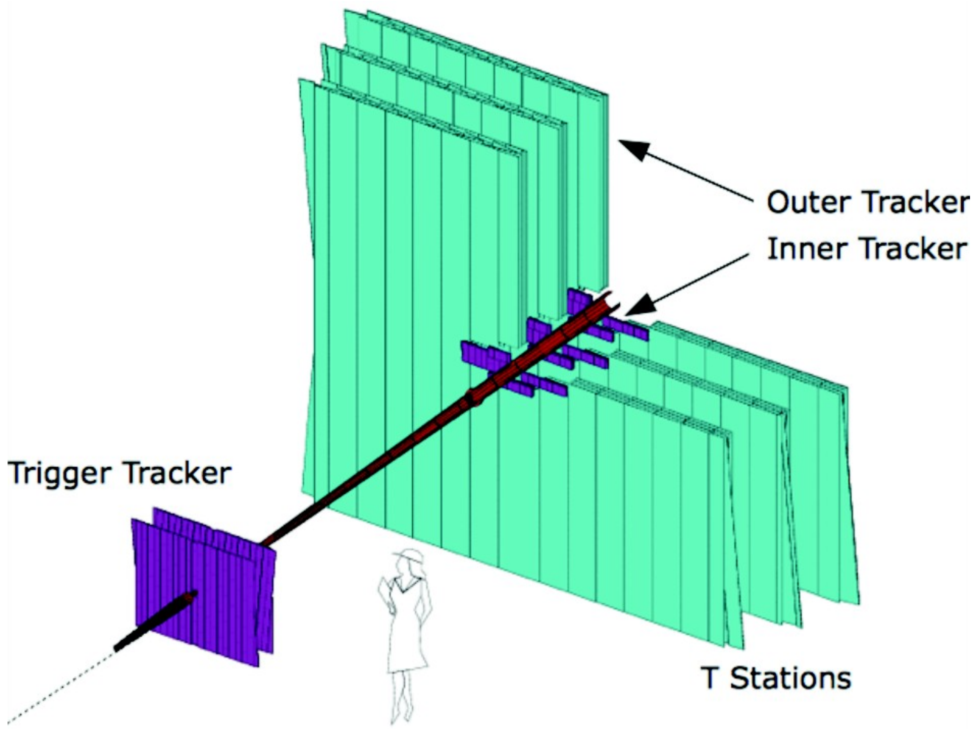
- **Replace the current detector**
  - Requirements: segmentation, data rate, rad. hardness, material budget
- **Two options under investigation**
  - Pixels: "VELOPIX" chip with 55x55 μm pixels
  - Strips: Proven design, reduced strip pitch (~30 μm), more strips



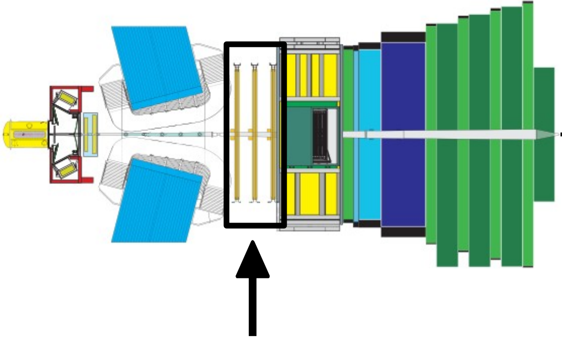
- **R&D programme:**
  - Module layout and mechanics
  - Sensor material: planar or 3D Si, diamond cooling substrate
  - Front-end electronics



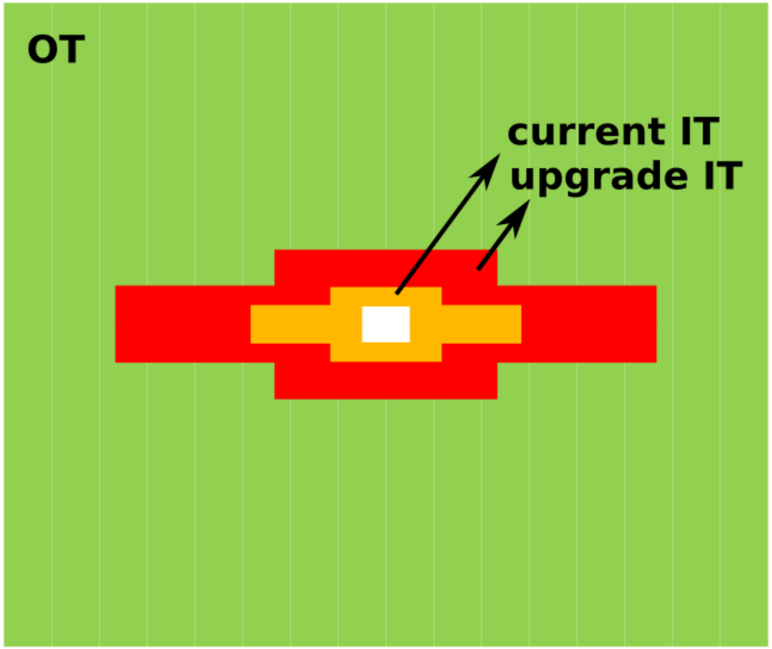
Downstream Tracking Detectors (1)



- **TT and IT:**
  - Must be replaced as the FE electronics are "integrated" with detector
  - TT: for optimal operation in upgrade environment consider smaller inner radius and better vertical segmentation
- **Two options under consideration:**
  - Continue using Si-strips
    - Long experience & proven
    - Share FE chip with VELO strips option
  - Scintillating fibres + SiPM
    - Main advantage: material budget (cooling and electronics outside acceptance)
    - Can develop common readout electronics with RICH
- **OT: can keep existing detector, except in the region closest to the beam-line. Needs new FE electronics (40 MHz readout).**



Downstream Tracking Detectors (2)



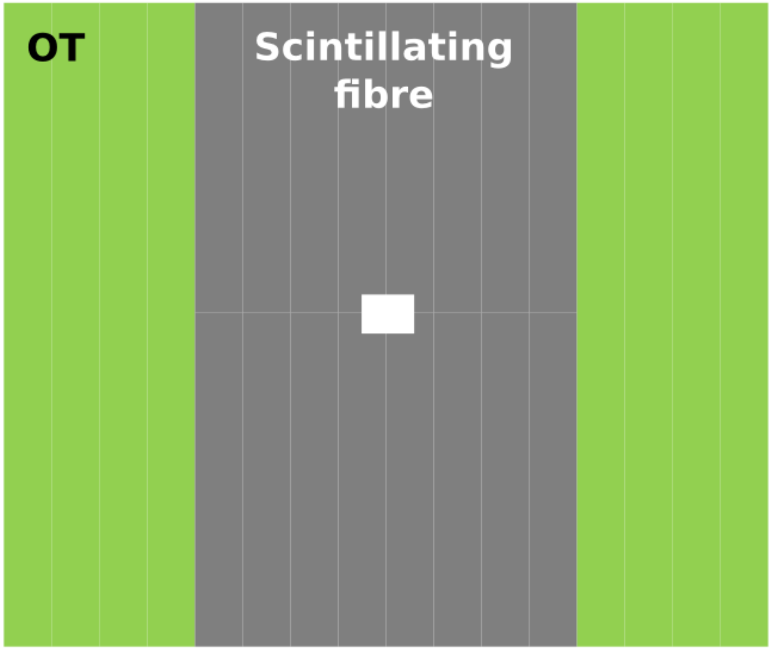
<u>Two possible layouts of the T-stations</u>

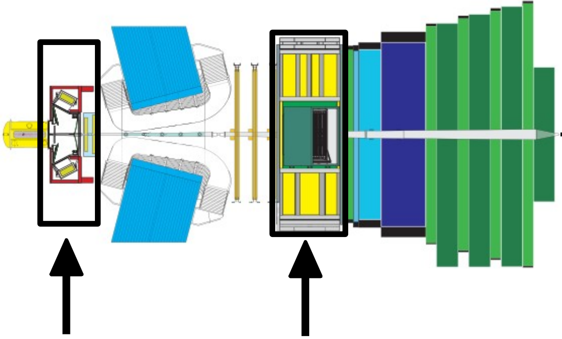
I. Larger (than current) IT

II. Scintillating fibres at the central part

- Fibres with diameter 0.25 mm
- 128-channel SiPM at top/bottom of the detector
- Active R&D programme under way
  - Module construction
  - Radiation hardness of fibres and SiPM

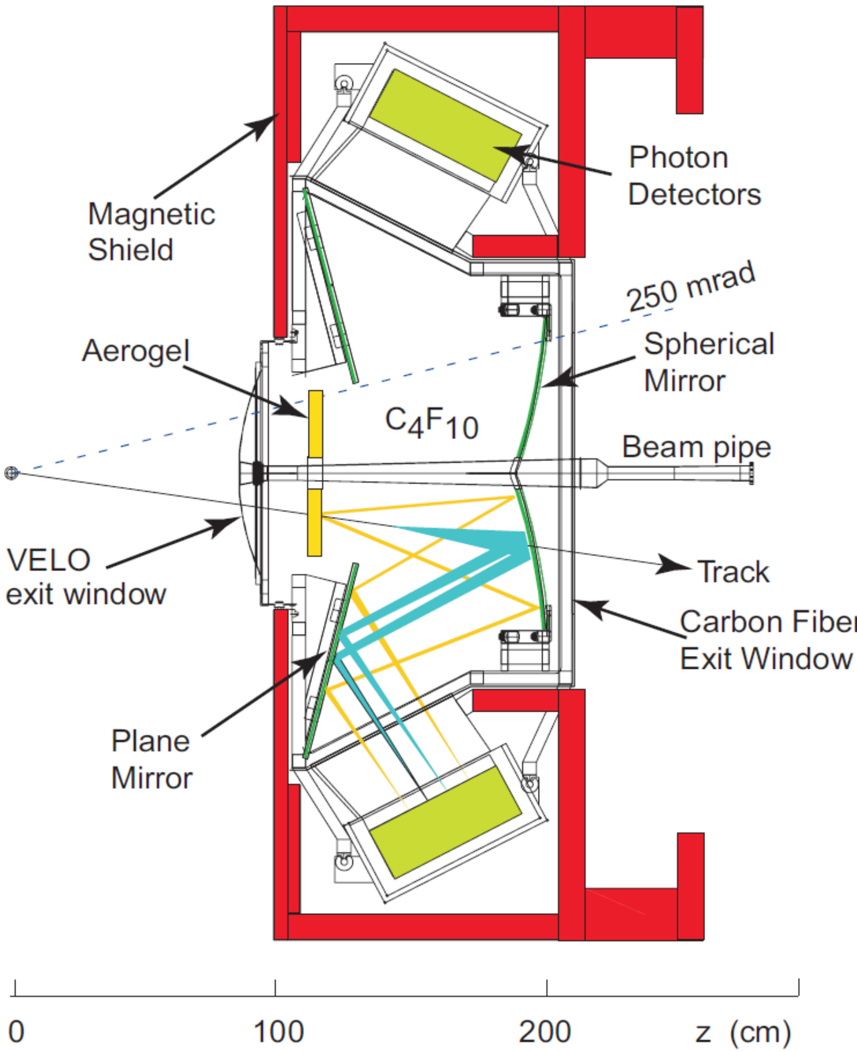
❖ In addition: a part of OT can be replaced by Sci. Fi modules with thick (1mm) fibres





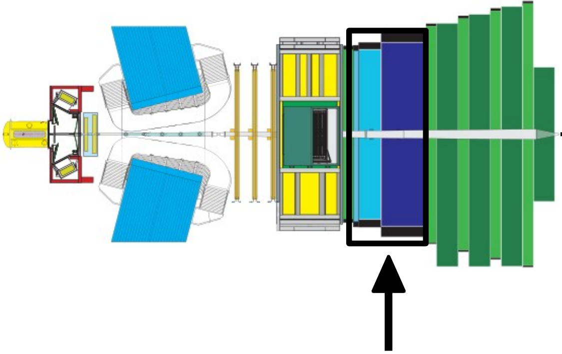
Particle ID Detectors

RICH-1 layout

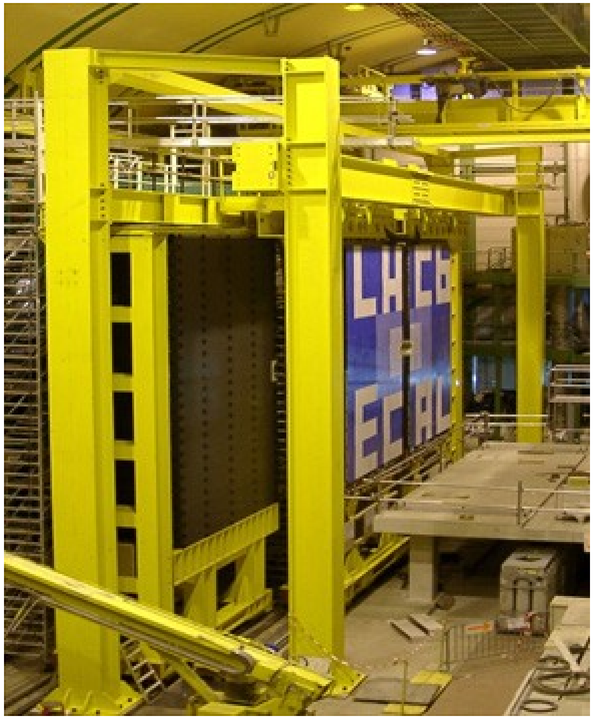


- **Essential for the reconstruction of hadronic decay modes**
- **Keep the current RICH detectors**
  - Need to replace photon detectors (40 MHz readout). Two options:
    - MaPMTs (baseline): consider square-shaped photon detectors
    - new HPDs with external readout

MaPMTs (Hamamatsu)

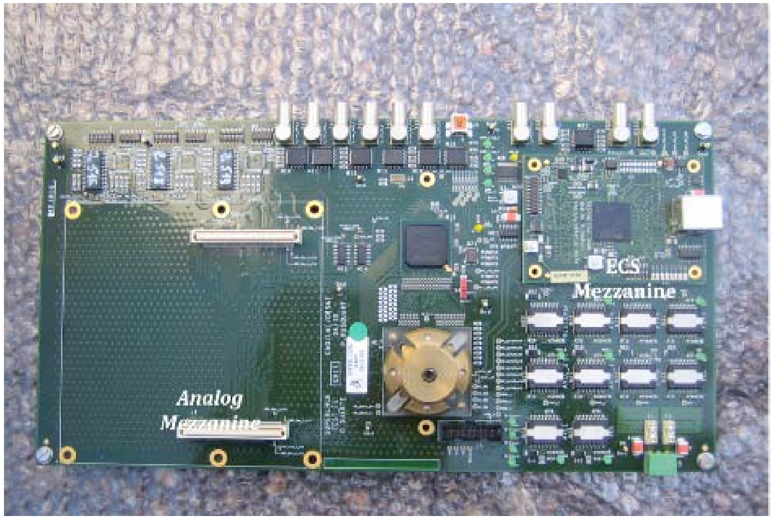


Calorimeters

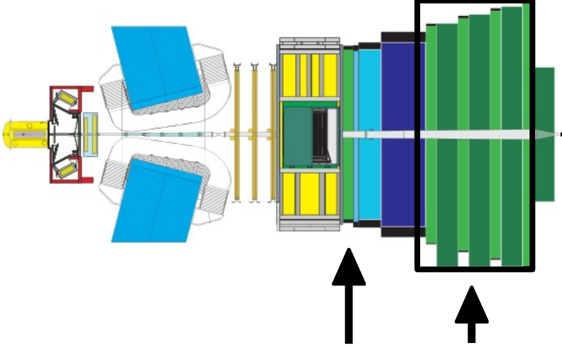


- **Keep the current ECAL and HCAL detectors**
  - Modules in the inner region of ECAL may need to be replaced (radiation damage)
  - PM gain will be reduced (higher Luminosity)
- **Preshower and Scintillating Pad Detector will be removed**
  - In the HLT the e/γ separation will be done using the full event information

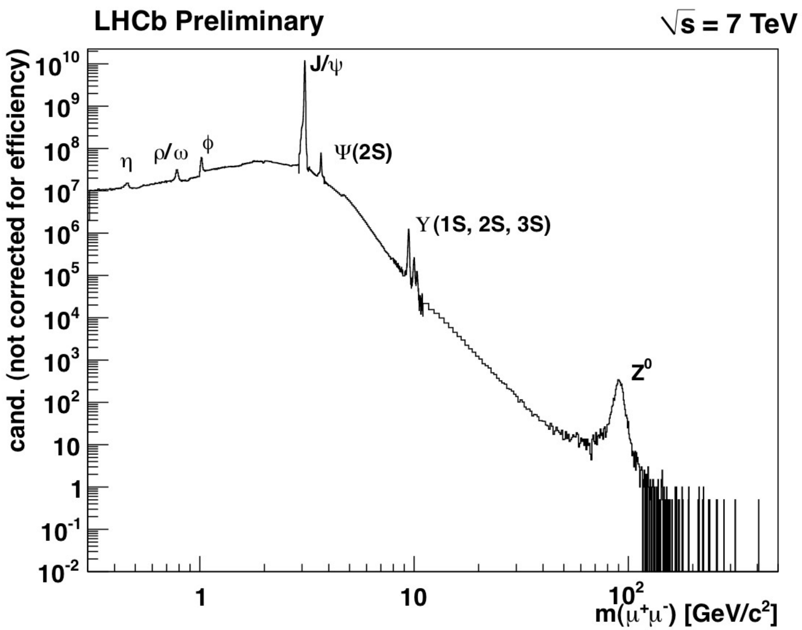
- **Prototype of the new FE electronics running at 40 MHz is ready**

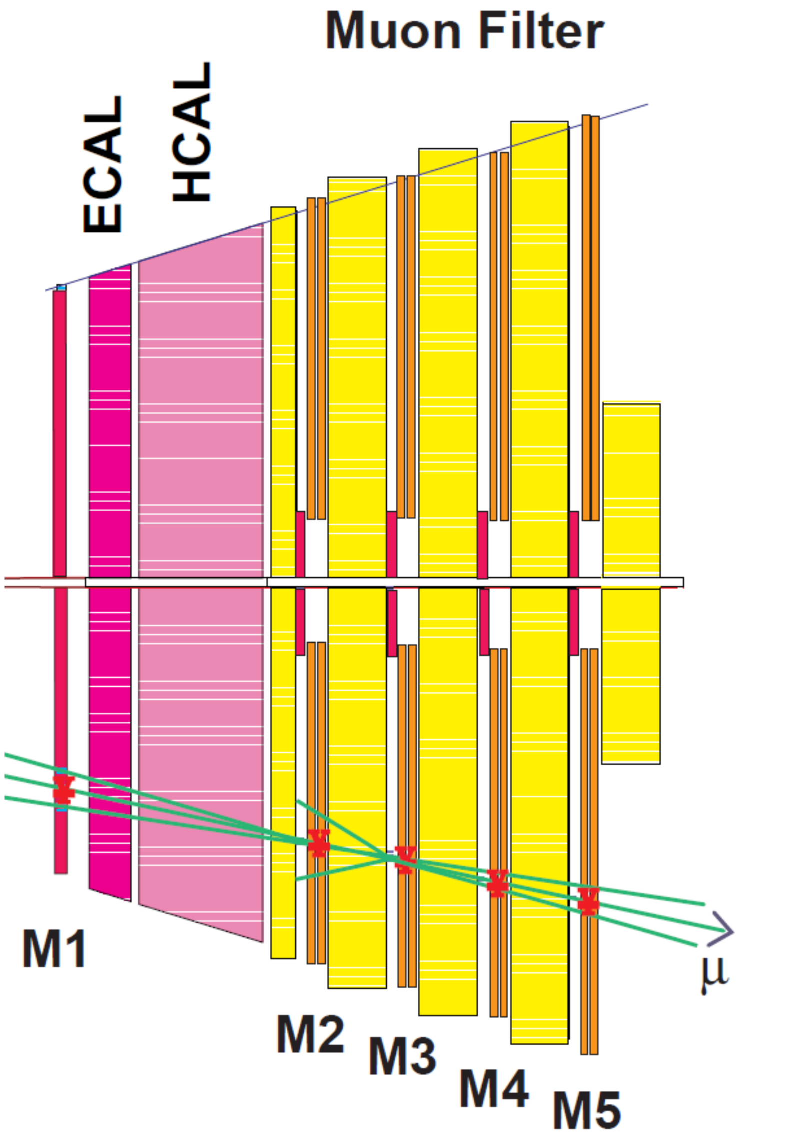


Muon Detectors



- **Muon detectors are already read out at 40 MHz in current L0 trigger**
  - Front-end electronics will be kept
  - Remove the muon station in front of Calorimeters (M1)
- **High-occupancy performance and ageing under study**





Approximate Timeline

Year	Phase	LHC*	LHCb data taking	LHCb Upgrade activities
2009		Startup		
2010–2012		$\sqrt{s}$ = 7-8 TeV L up to 6x10^{33} cm^{-2}s^{-1} Min. bunch spacing: 50 ns	L_{max}=4x10^{32} cm^{-2}s^{-1} Up to 1.5 fb^{-1}/year	**2011 – 2013** - Detector R&D - Prepare TDRs - Secure funding
2013–2014	LS1	Magnet splice repair – go to 13-14 TeV		
2015–2017		$\sqrt{s}$ = 13-14 TeV L up to 1x10^{34} cm^{-2}s^{-1} Min. bunch spacing: 25 ns	L=4x10^{32} cm^{-2}s^{-1} ≈1.5 fb^{-1}/year	**2014 – 2017** Detector construction: VELO, IT/TT, RICH
2018	LS2	Injectors and LHC "Phase I" upgrade →		**2018 – 2019** Installation and commissioning of the upgraded detector
2019–2021		$\sqrt{s}$ = 14 TeV L up to 2x10^{34} cm^{-2}s^{-1} Min. bunch spacing: 25 ns	L≈1-2x10^{33} cm^{-2}s^{-1} ≈5 fb^{-1}/year	
2022	LS3	HL-LHC ("Phase II") upgrade		
2023 … 2030?		$\sqrt{s}$ = 14 TeV L up to 5x10^{34} cm^{-2}s^{-1} Min. bunch spacing: 25 ns	L≈1-2x10^{33} cm^{-2}s^{-1} ≈5 fb^{-1}/year	

** Adapted from M. Nessi, Chamonix 2012*

Summary

- **LHCb has a firm plan to upgrade by 2018**
  - Aim at reaching the ultimate theoretical uncertainties in key flavor observables and to search for new phenomena in the forward region: 50 fb^{-1} needed
  - Envisage to readout the entire detector at 40 MHz with a fully software-based trigger and replace some of the major detector components
  - Independent of the LHC luminosity upgrade

- **The LHCb Upgrade is taking shape**
  - The LoI submitted in March 2011 was well received by LHCC
  - The Framework TDR, released in May 2012, provides updated physics performance, schedule and cost estimates
  - Subdetector R&D is in progress, TDRs will follow in 2013

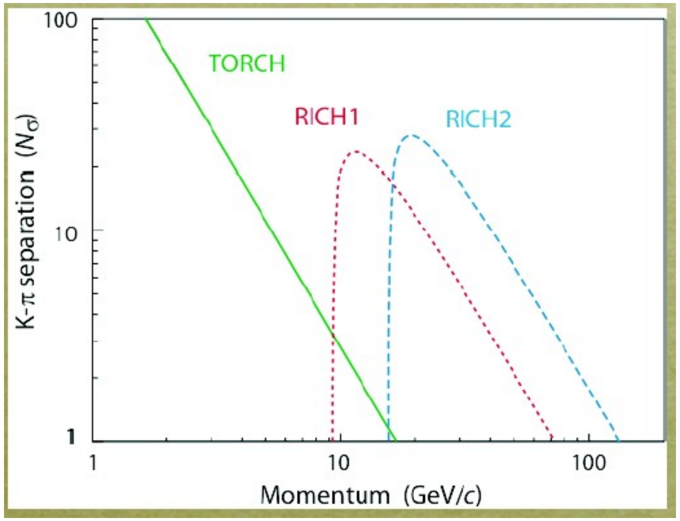
- ***Great opportunity to join the LHCb Collaboration!***

BACKUP SLIDES

PID with TORCH

- There is a proposal to add a Time-of-Flight (ToF) detector based on a 1 cm quartz plate, combined with DIRC technology:
  - TORCH (Time Of internally Reflected CHerencov light)
  - Measure photon flight time and direction in a standoff box
  - Measure ToF of tracks with ~15ps resolution
  - Could be installed after 2018

PID at low momentum important for tagging



TORCH detector layout