Il Programma di Upgrade di LHCb

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On behalf of the LHCb Collaboration

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Outline

- Introduction to LHCb
- LHCb upgrade
  - Physics motivation
  - Trigger upgrade
  - Detector upgrade
    - Tracking
    - Particle identification
- Conclusions

Introduction

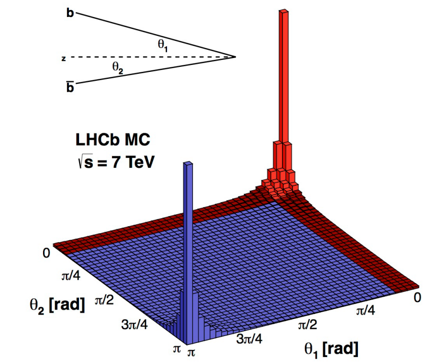
- LHCb is a precision experiment devoted to the search for New Physics beyond the Standard Model (SM)
  - Study CP violation and rare decays in b and c quarks
  - Search for deviations from the SM due to virtual contributions of new heavy particles in loop diagrams
  - Sensitive to new particles above the TeV scale not accessible to direct searches

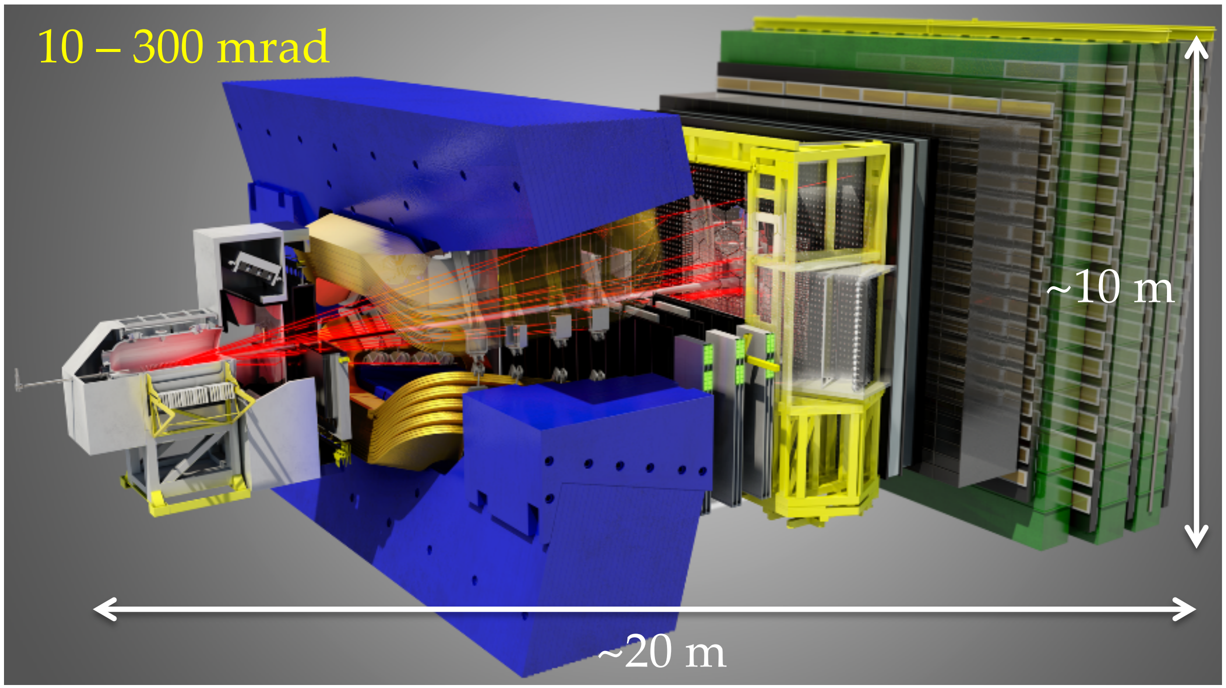
LHCb Collaboration

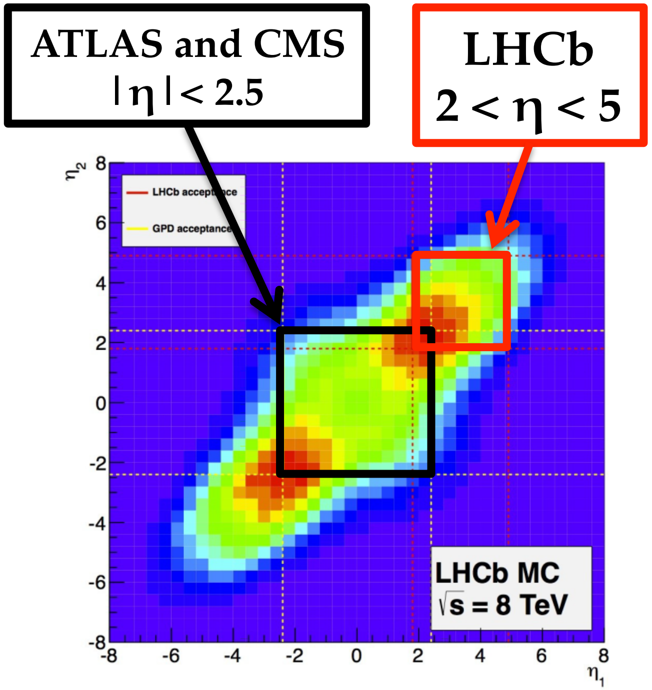
- ~900 participants
- 64 institutes
- 16 countries

The LHCb Experiment

- Single arm spectrometer
- Flavor factory
  - $b\bar{b}$ cross section $\sigma_{b\bar{b}} \sim 300\ \mu b$ at 7 TeV
  - $c\bar{c}$ cross section $\sigma_{c\bar{c}} \sim 20\ \sigma_{b\bar{b}}$



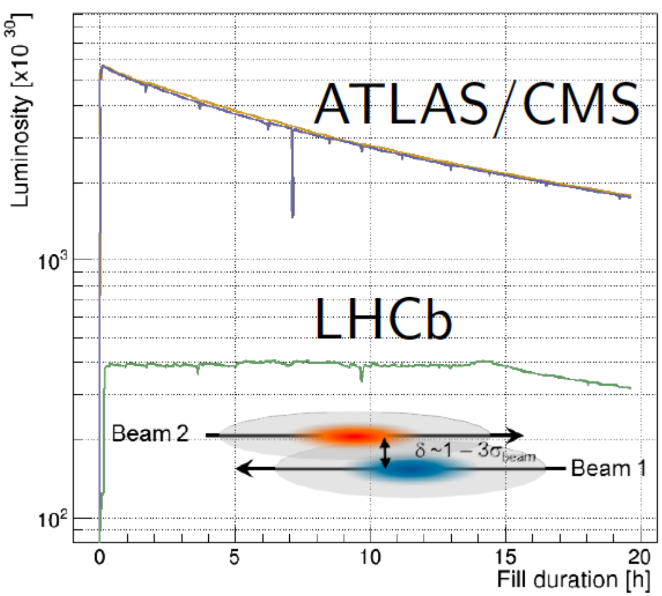


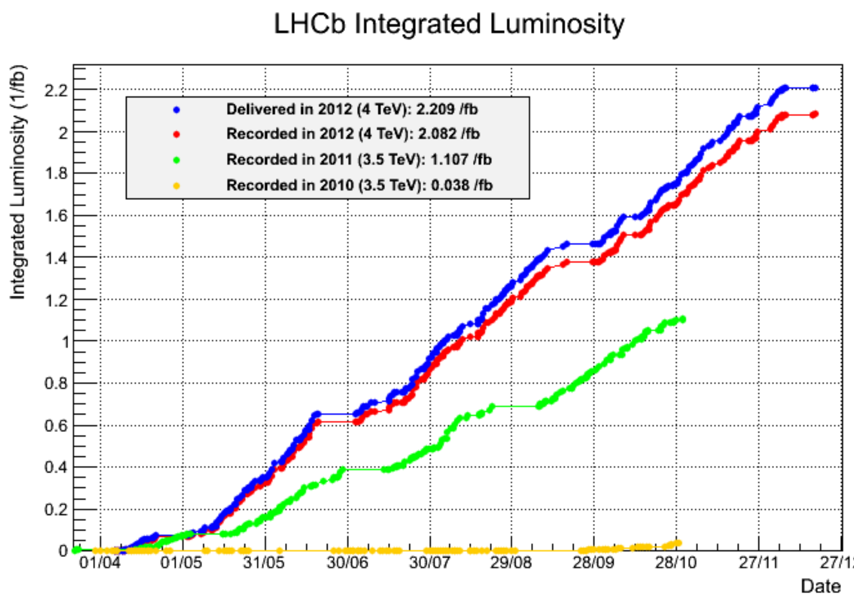


Run 1

- Very successful Run 1
- LHCb operated at tunable leveled luminosities up to ~4×10^{32} cm^{-2}s^{-1} (μ=1.6)
  - 2× higher than design value (μ=0.4)
- Recorded $\int L dt \sim 3$ fb^{-1}

2012	**8 TeV**	**2.1 fb^{-1}**
2011	**7 TeV**	**1.1 fb^{-1}**
2010	**7 TeV**	**0.04 fb^{-1}**





Run 2 and Upgrade

- LHC Run 2
  - LHCb should collect ~5 fb^{-1}
  - 7, 8 TeV → 13 (14) TeV nearly doubles $b\bar{b}$ and $c\bar{c}$ production cross section

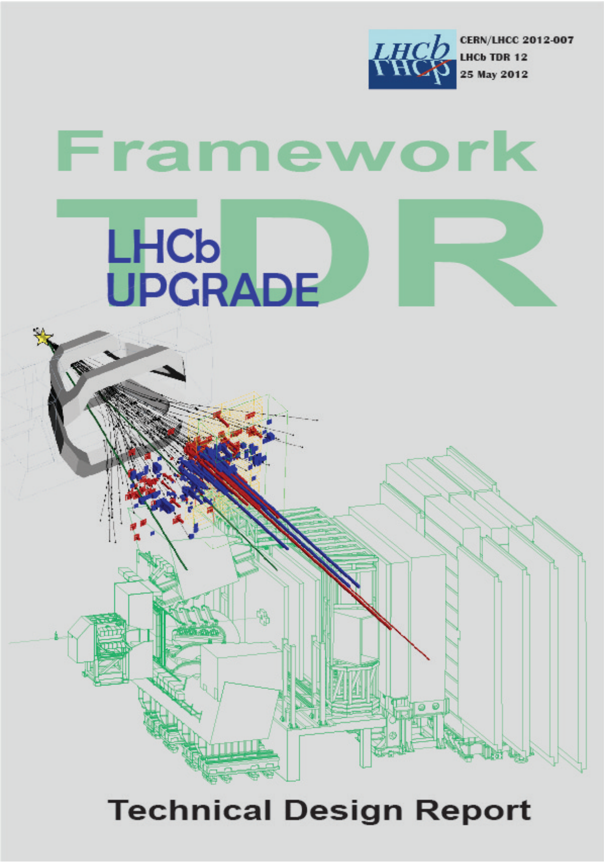
LHC era		HL-LHC era		
Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-23)	Run 4 (2025-28)	Run 5+ (2030+)
3 fb^{-1}	8 fb^{-1}	~25 fb^{-1}	~50 fb^{-1}	~100 fb^{-1}

- LHCb Upgrade
  - Upgrade detectors to be able to readout at 40 MHz
  - Operate detector at luminosities of $\sim 2\times10^{33}\ cm^{-2}s^{-1}$
  - Install upgraded LHCb during long shutdown 2 (2019-20)

Motivation for the Upgrade

- Present experimental status:
  - Flavor changing processes are consistent with the CKM mechanism
  - Large sources of flavor symmetry breaking are excluded at the TeV scale
- Why is the LHCb upgrade important:
  - Measurable deviations from the SM are still expected, but should be small
  - Need to go to high precision measurements to probe clean observables
- LHCb upgrade essential to **increase statistical precision** significantly

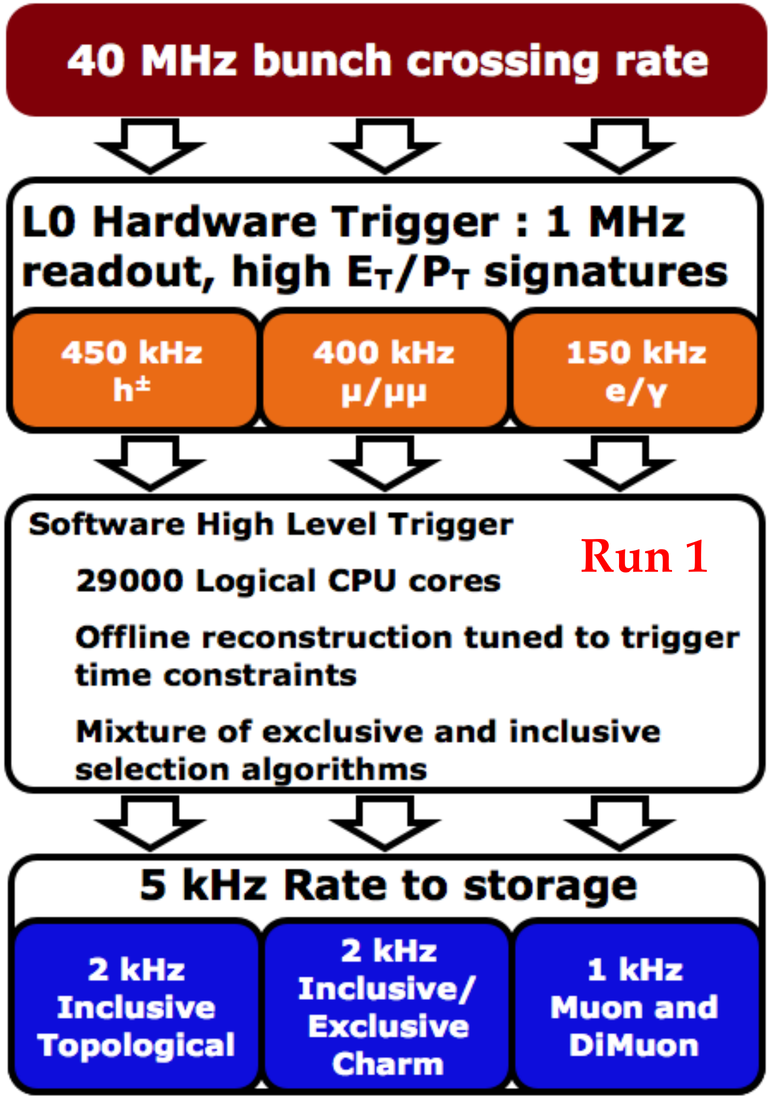
LHCb Upgrade



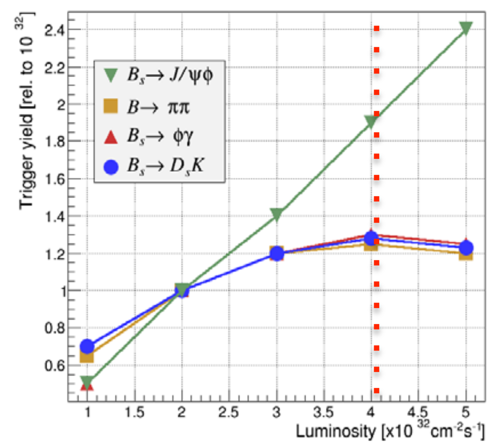
CERN-LHCC-2011-001

CERN-LHCC-2012-007

LHCb Trigger

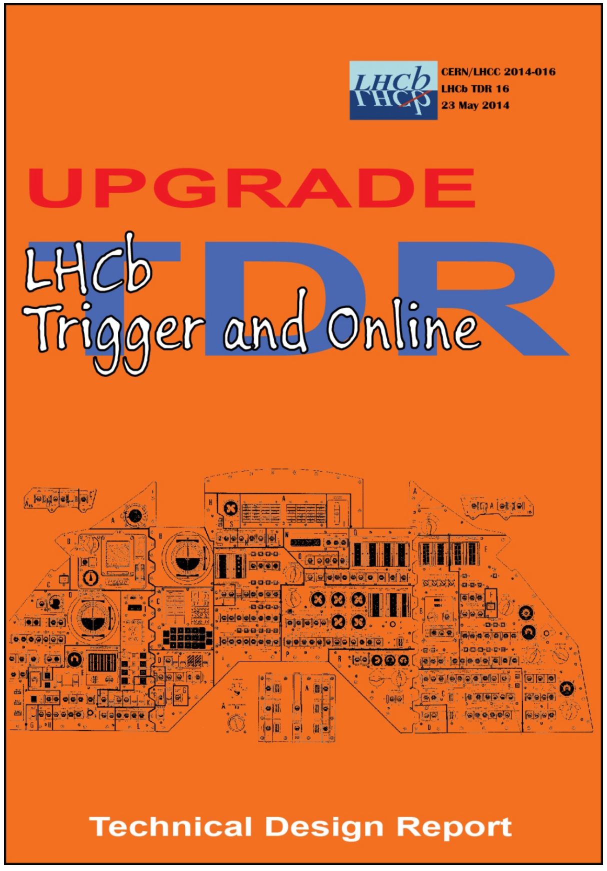


- Current limitation: front-end readout time 900 ns → 1.1 MHz maximum L0 trigger rate
- L0 event yields saturate for hadronic channels



- HLT: full software trigger running on processors farm

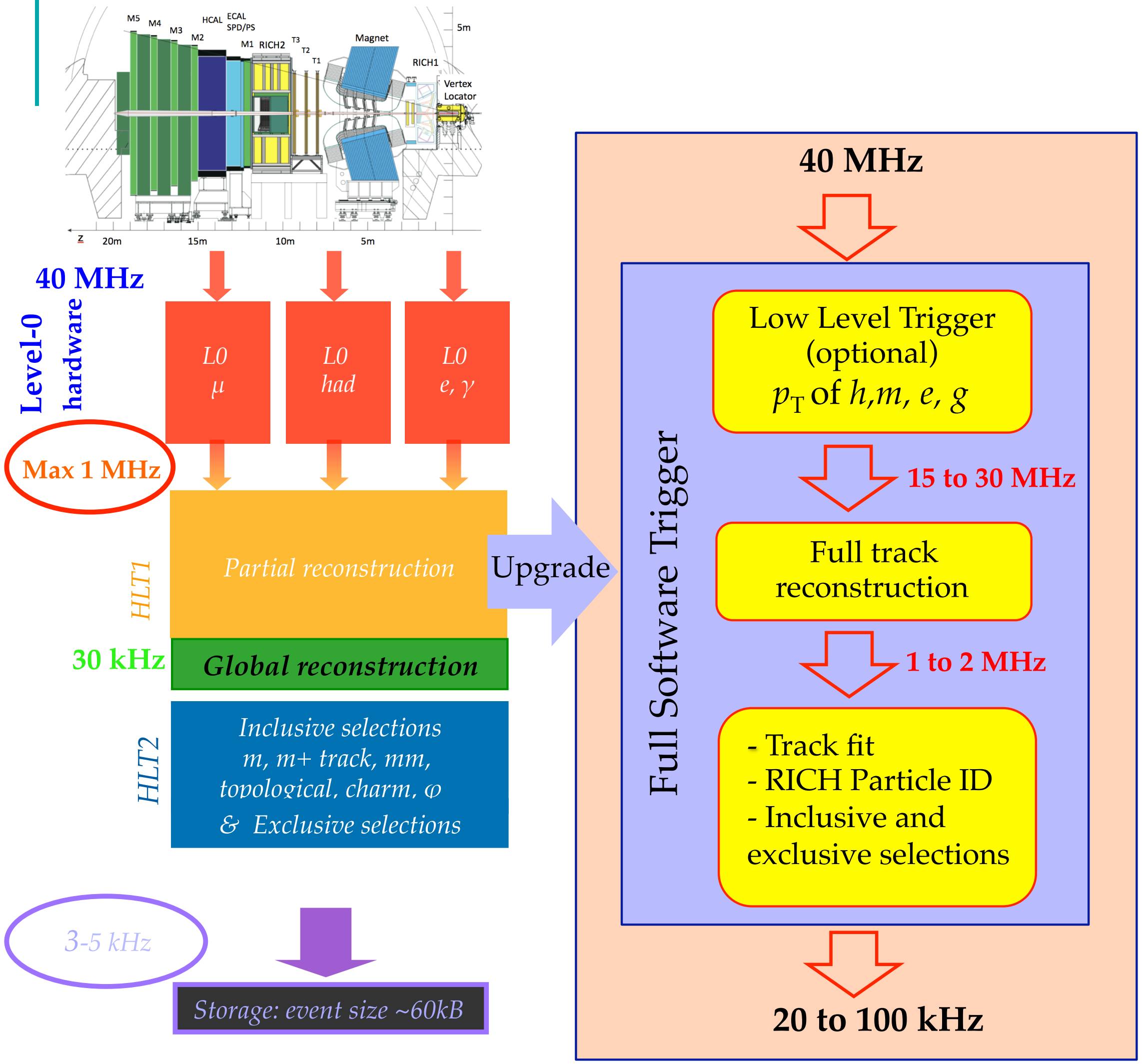
Trigger Upgrade



CERN-LHCC-2014-016

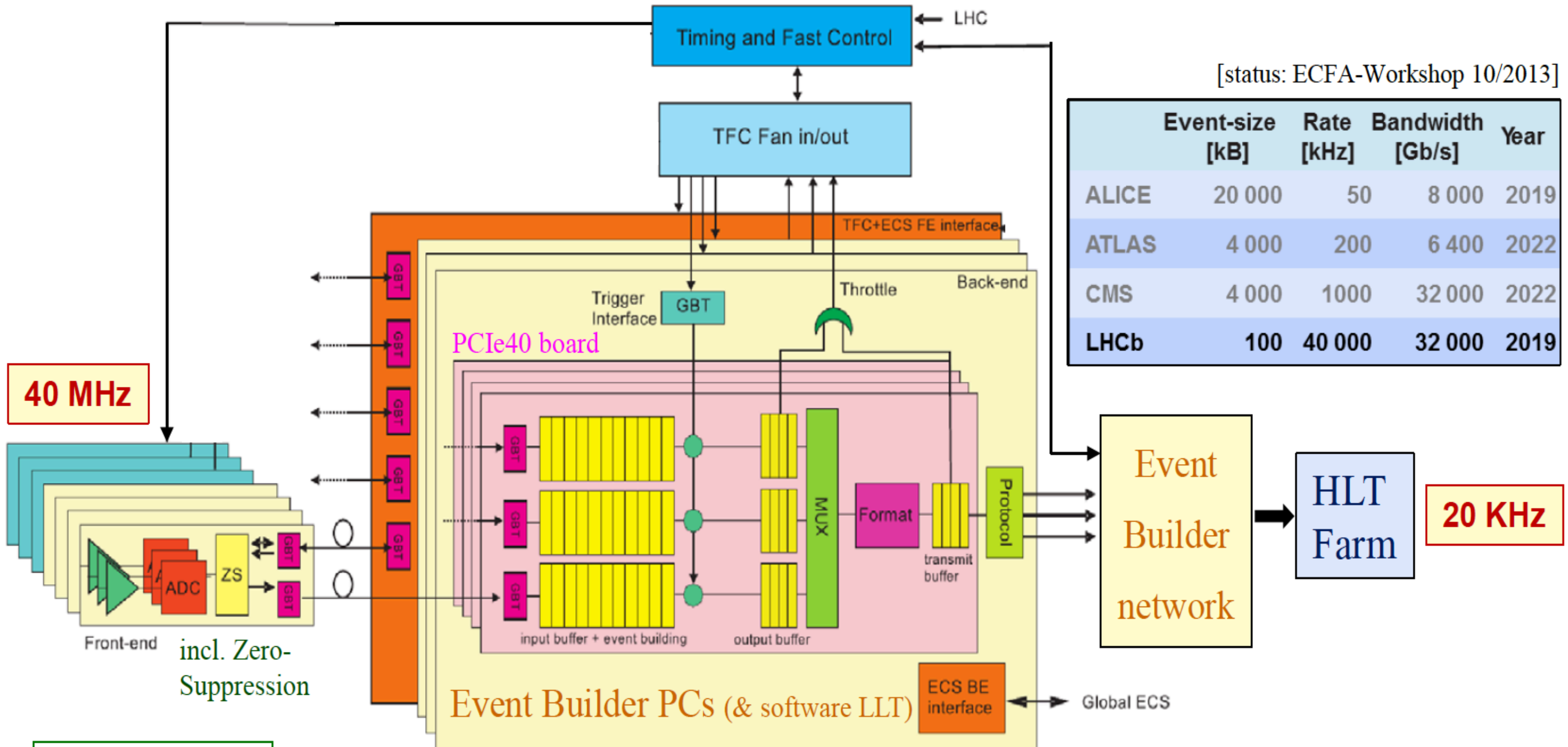
- Remove L0 Trigger
- Replace all front-end and back-end for 40 MHz full read-out to CPU farm
- Implement a fast HLT based on full topology
- Final output bandwidth at >20 kHz
- Ultimate trigger flexibility to adjust to physics scene

LHCb Trigger Upgrade



- 40 MHz readout rate
- Full software trigger, 20 kHz output rate
- Efficient and selective use of all detectors information
- Low Level Trigger (LLT) foreseen in early stage
- LLT output rate increases as trigger farms grows

40 MHz read-out architecture



[status: ECFA-Workshop 10/2013]

	Event-size [kB]	Rate [kHz]	Bandwidth [Gb/s]	Year
ALICE	20 000	50	8 000	2019
ATLAS	4 000	200	6 400	2022
CMS	4 000	1000	32 000	2022
LHCb	**100**	**40 000**	**32 000**	**2019**

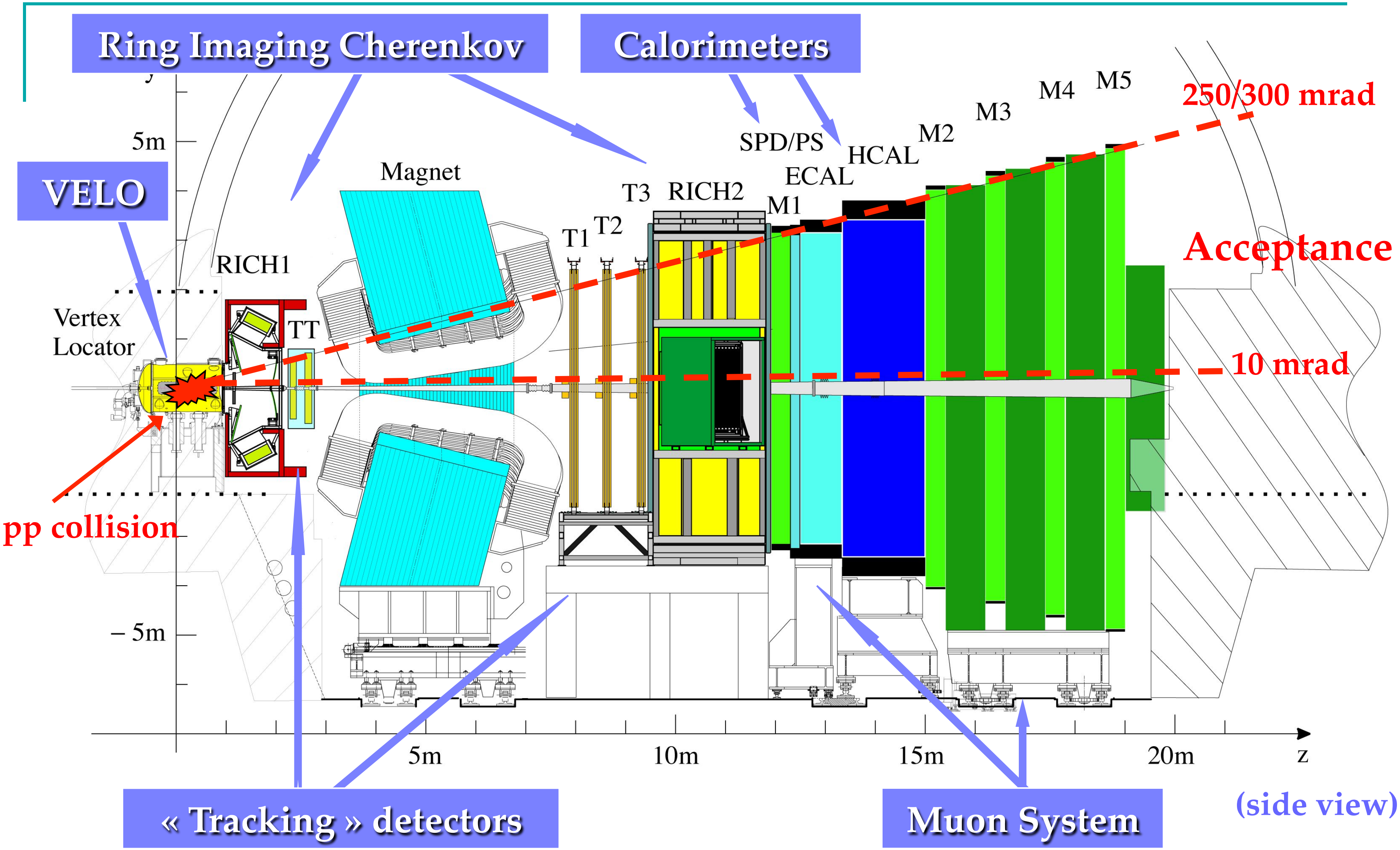
individual sub-systems Front-End electronics → optical link via GBT → PC servers with PCIe40 R/O LLT and Event Building → pure software trigger

underground — ~300m — on surface

Detectors Upgrade

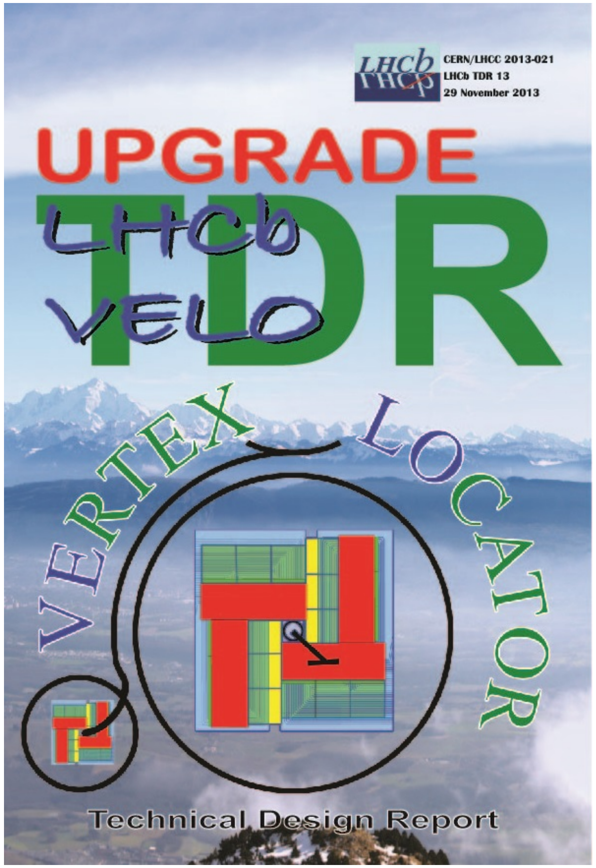
- Objective:
  - Upgrade all sub-systems front-ends to 40 MHz
  - Adapt sub-systems to increased occupancies due to higher luminosity
  - Keep excellent performance of sub-systems with 5 times higher luminosity
- Detectors
  - Vertex Locator (VELO)
  - Tracking system
    - Upstream tracker + Fiber tracker
  - Particle Identification (PID)
    - RICH + Calorimeters + Muon

LHCb Detectors



(side view)

Vertex Locator Upgrade



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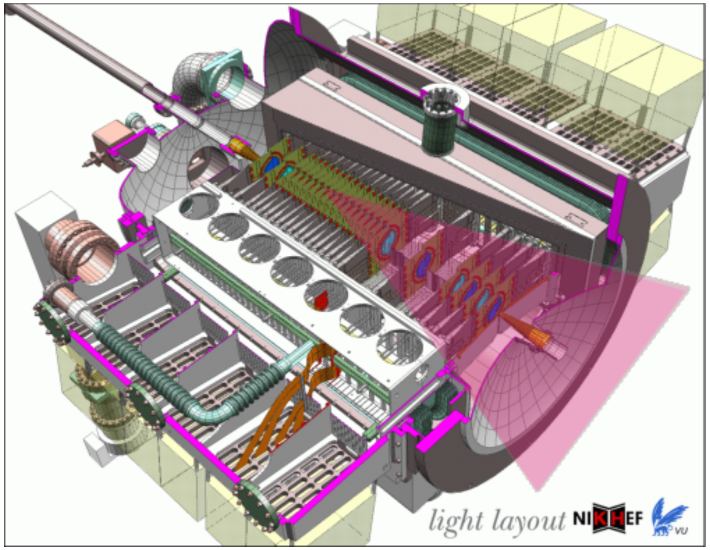
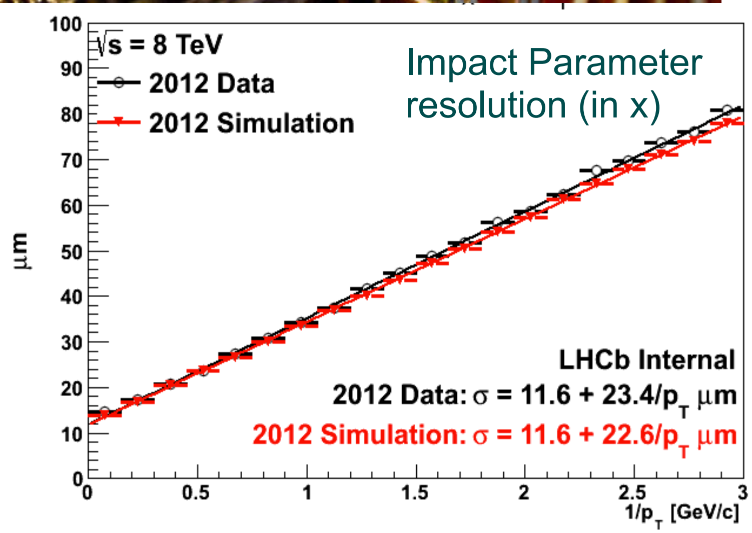
Current VELO

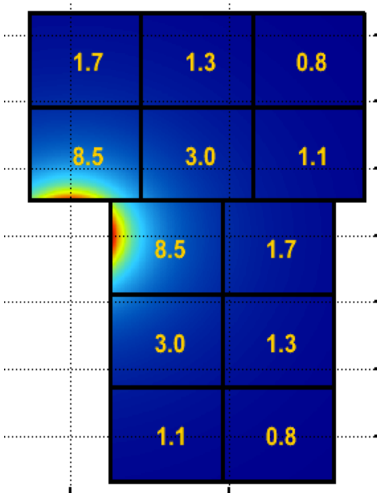


- Two retractable halves
- 5.5 mm from beam when closed
- 30 mm during injection
- Operates in secondary vacuum
- 300 μm Al-foils separate detector from beam
- 21 R/Φ modules per half
- Silicon micro-strip sensors
- Pitch 38-101 μm

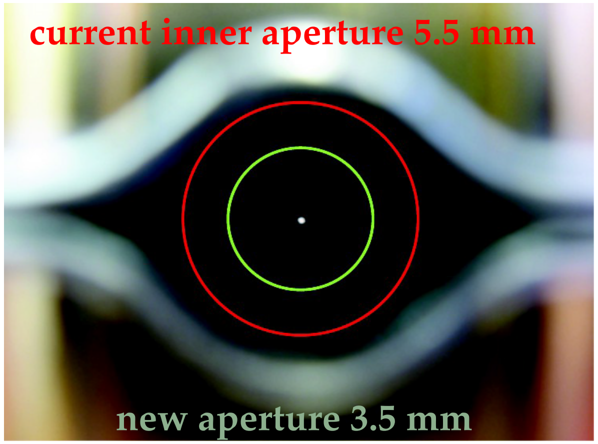


VELO Upgrade (1)

- Upgrade challenge:
- Withstand increased radiation (highly non-uniform up to $8 \times 10^{15}\ n_{eq}/cm^2$ in 10 years)
- Handle high data volume
- Keep (improve) current performance
  - Lower materiel budget
  - Enlarge acceptance
- Move closer to the beam
  - Reduce inner aperture from 5.5 mm to 3.5 mm

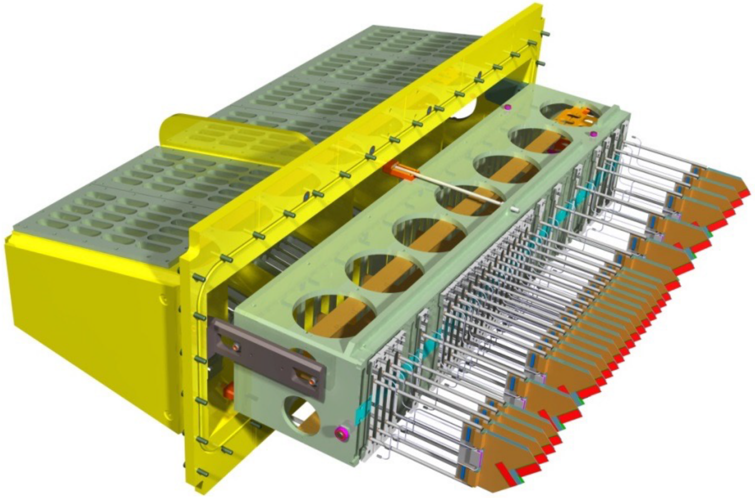


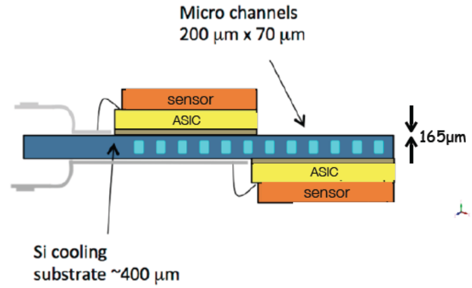
tracks/chip/event at $L = 2 \cdot 10^{33}\ cm^{-2}s^{-1}$

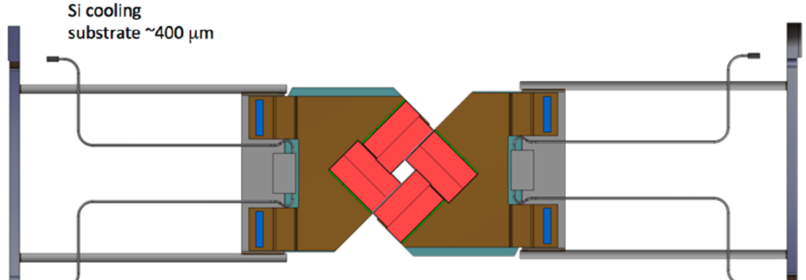


VELO Upgrade (2)

- Technical choices:
  - 55×55 μm^2 pixel sensors with micro channel CO2 cooling
  - 40 MHz VELOPIX (evolution of TIMEPIX 3, Medipix)
    - 130 nm CMOS to sustain ~400 MRad in 10 years
  - Replace RF-foil between detector and beam vacuum
    - Reduce thickness from 300 μm to ≤ 250 μm



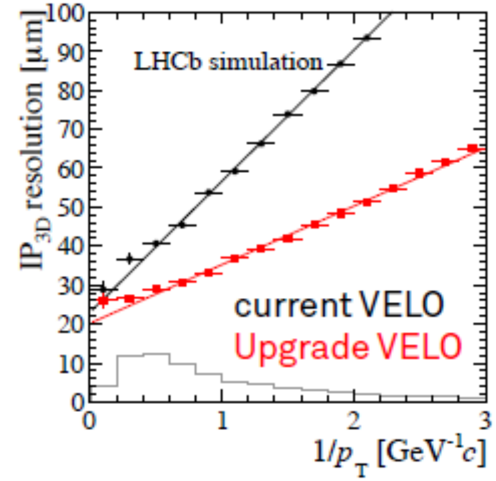


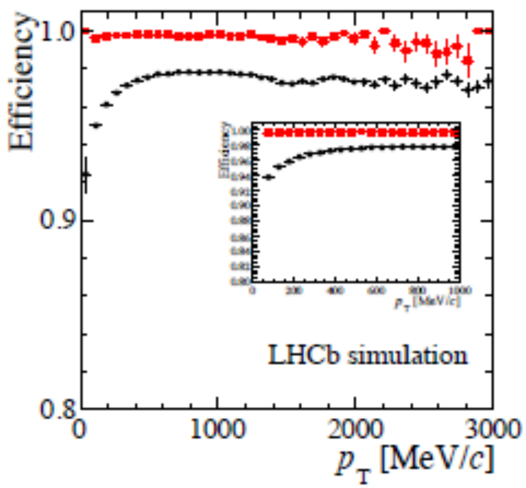


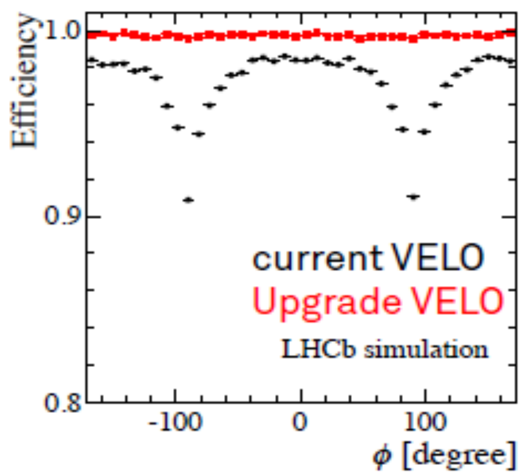
projected view of sensors

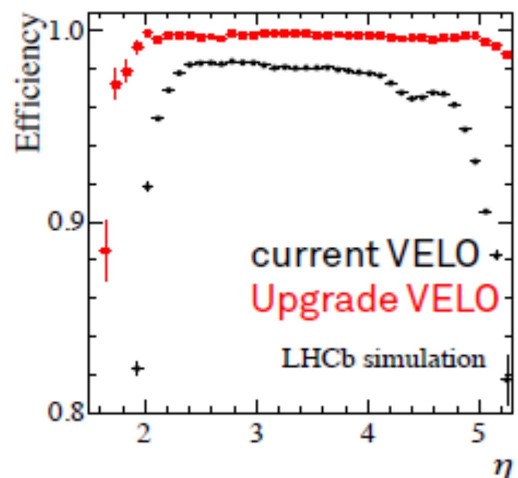
VELO Upgrade Performance

- Better impact parameter resolution due to reduced material budget
- Reduced ghost rate
- Improved efficiency over p_T, ϕ, η

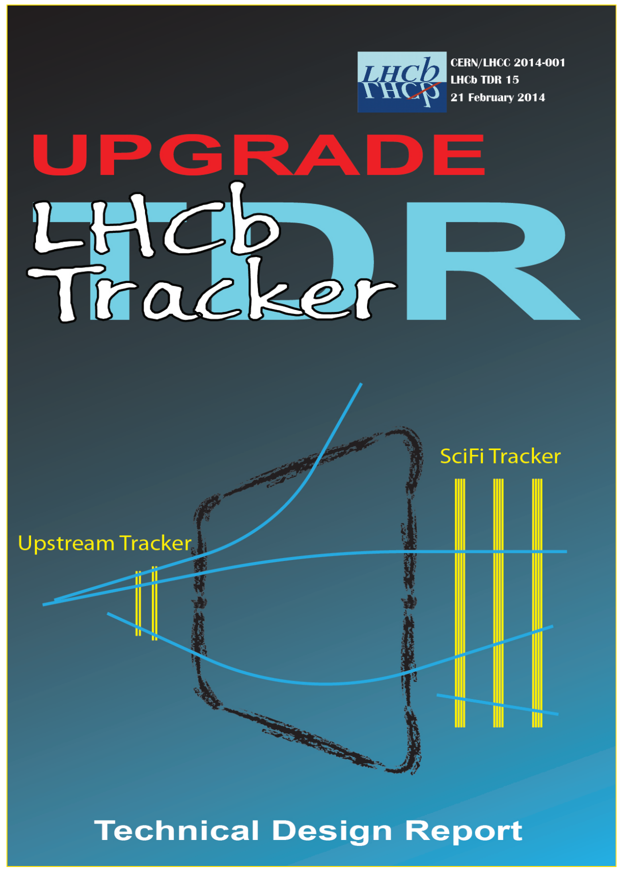








Tracker Upgrade



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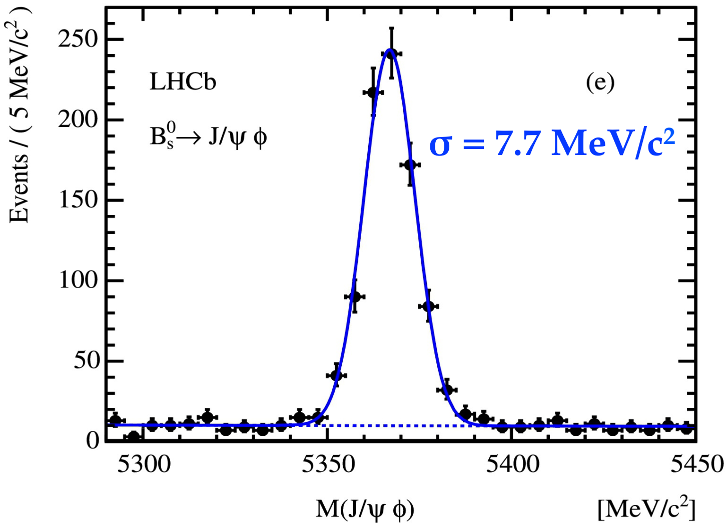
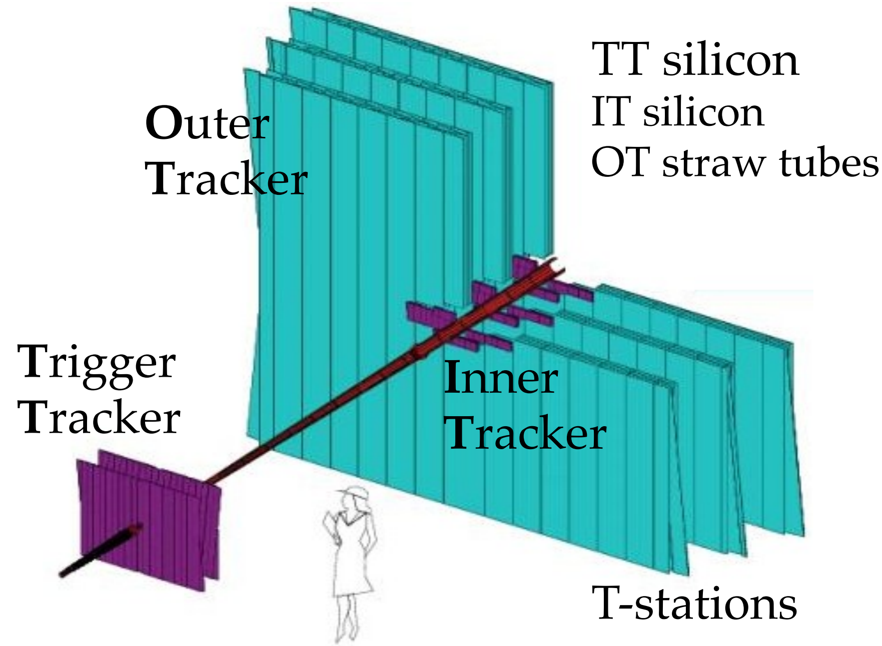
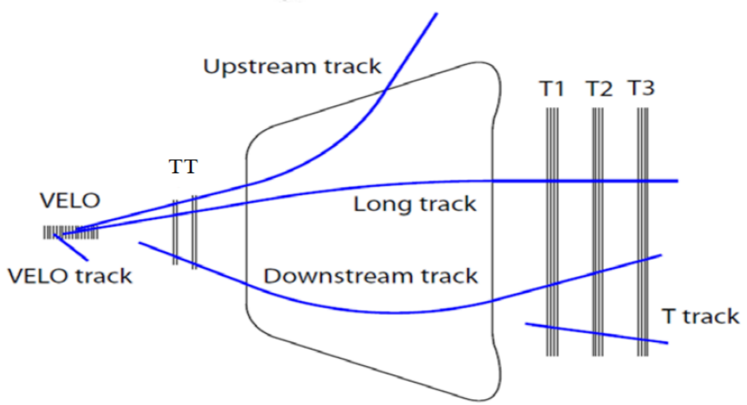
Present tracking system



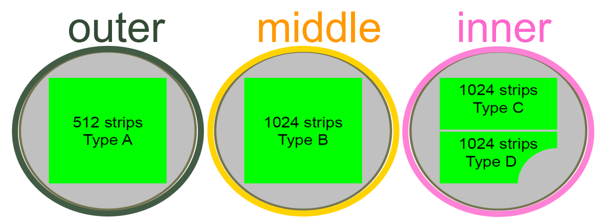


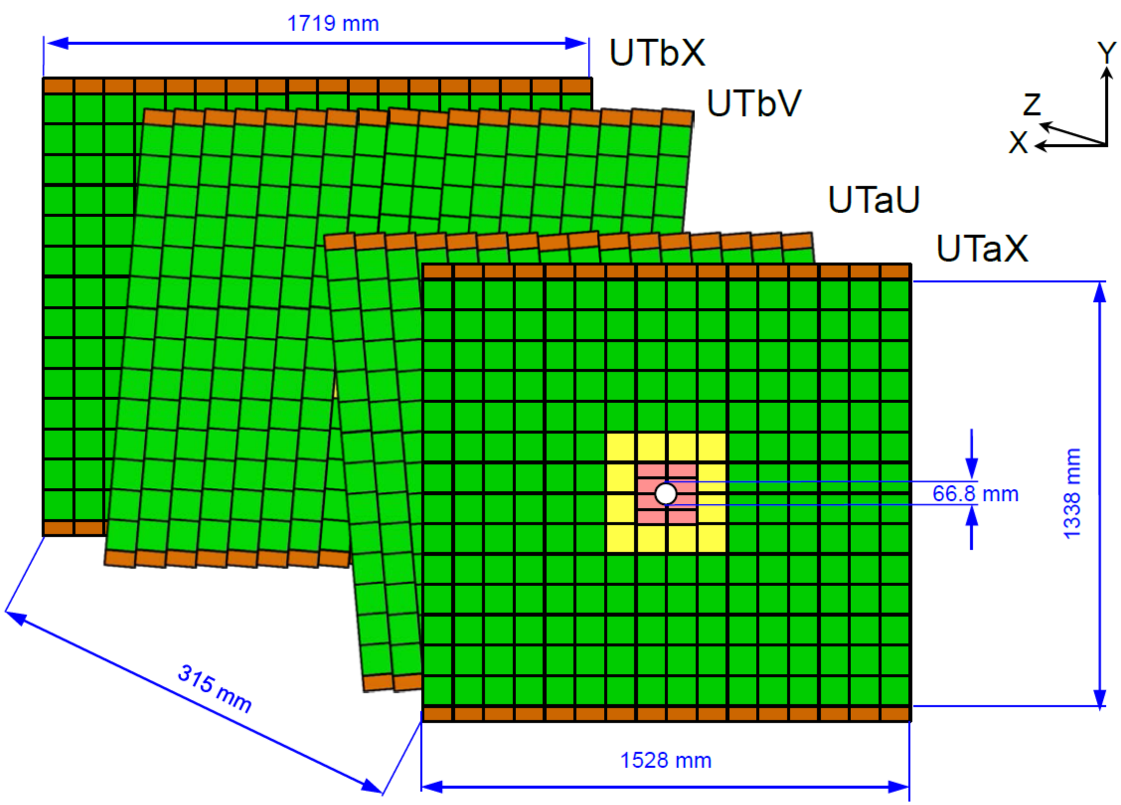


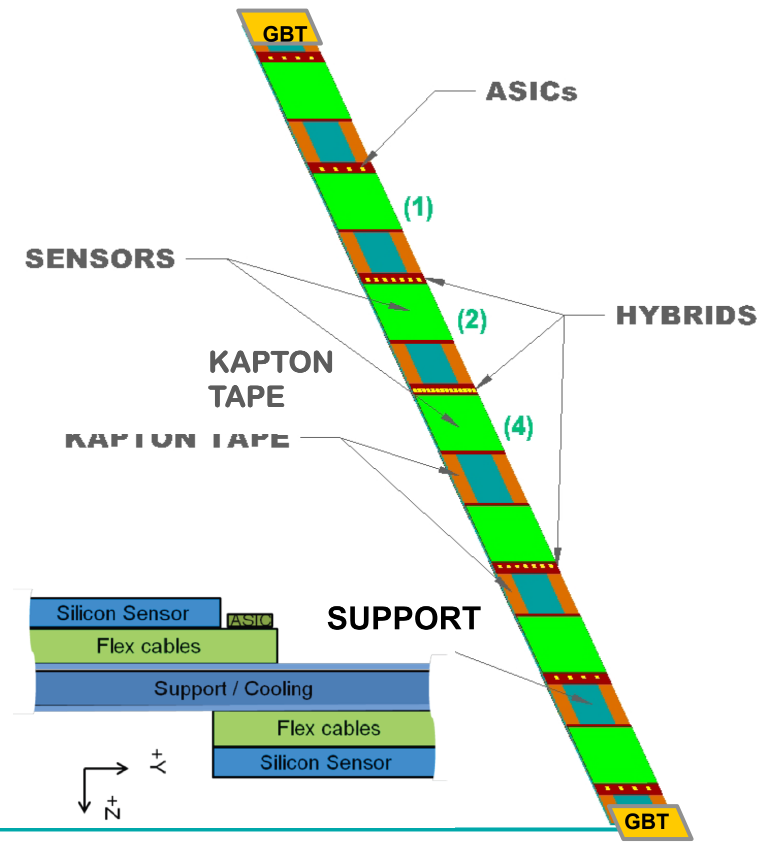
- Three subsystems: Trigger Tracker, Inner Tracker, Outer Tracker
- Different technologies: silicon strips for TT and IT, straw tubes for OT
- Dipolar magnetic field of 4 Tm provides excellent mass resolution
- World's best mass measurements [PLB 708 (2012) 241]

Upstream Tracker (UT)

- TT upgrade: silicon strip detector
- Adapt segmentation to varying occupancies
  - 98-49 mm long strips, 190-95 μm pitch, p+-in-n n+-in-p
- 40 MHz silicon strip read-out (SALT chip)

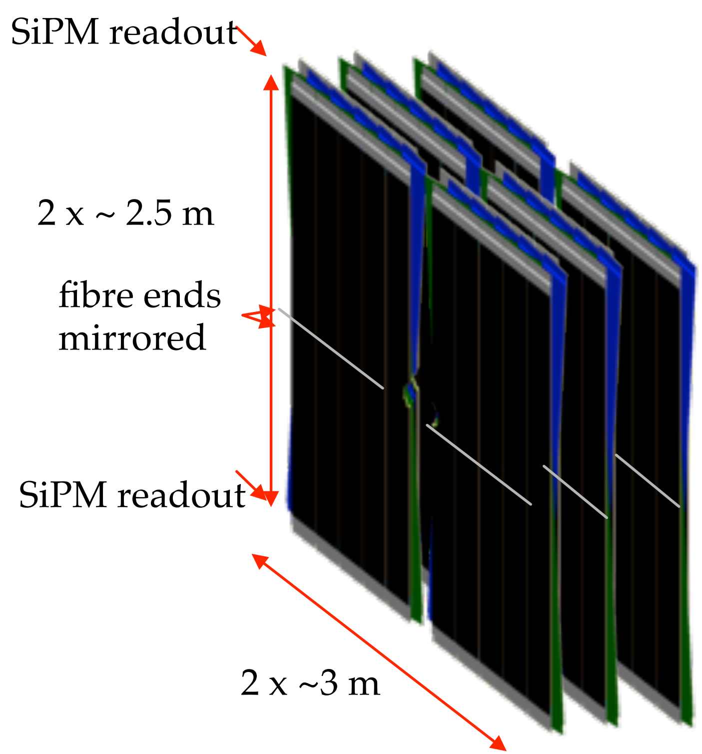


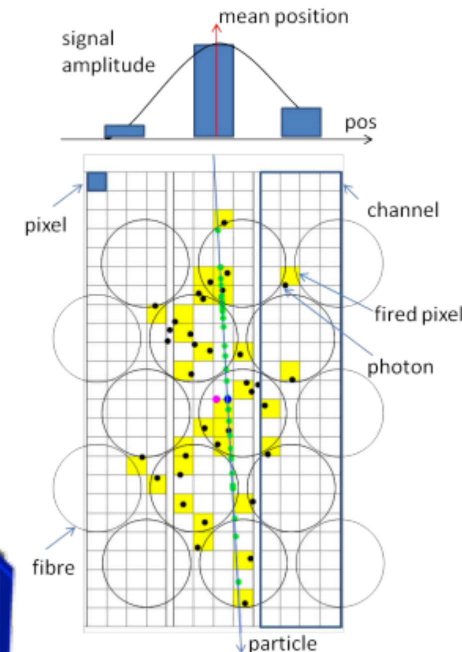




Fiber Tracker

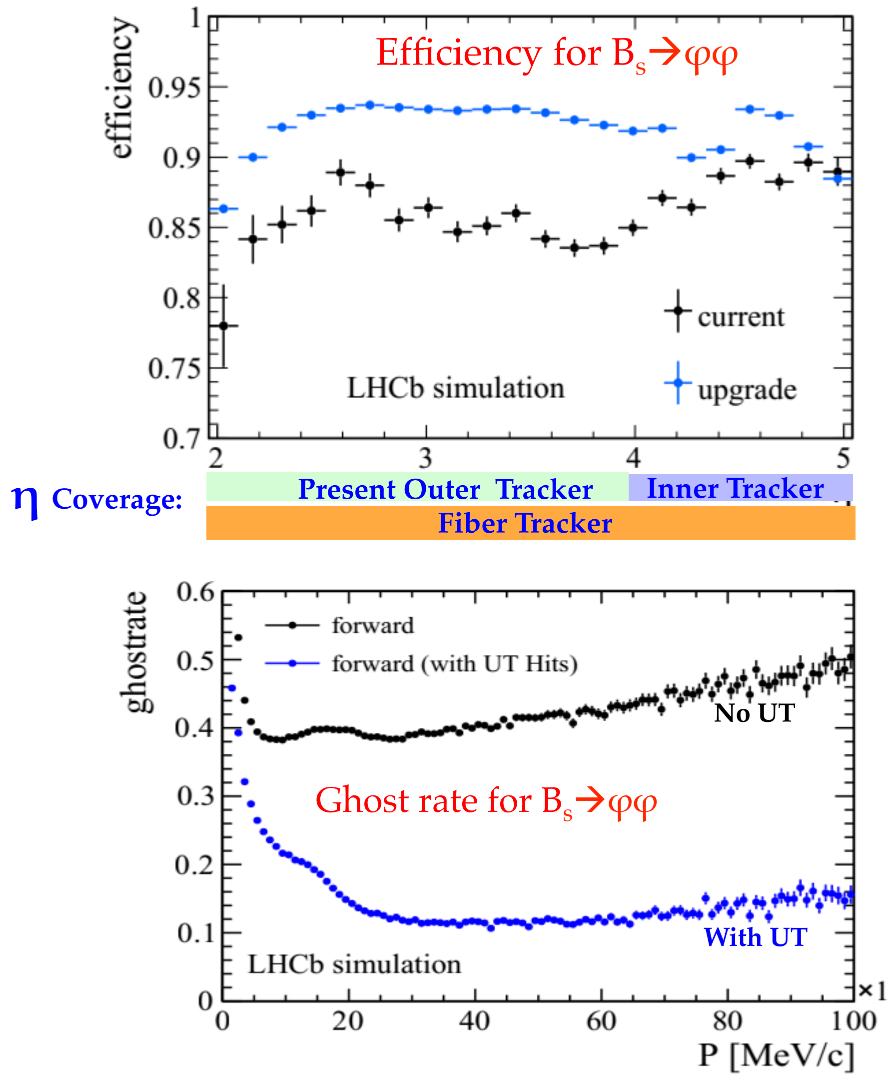
- Three X-U-V-Y stations
- Each plane made by a stack of round 250 μm scintillating fibers
- Light converted via Silicon Photo-Multiplier array readout at 40 MHz by PACIFIC ASIC
- X position resolution of 50-75 μm
- SiPM cooled at -40 °C to maintain good performances with radiation



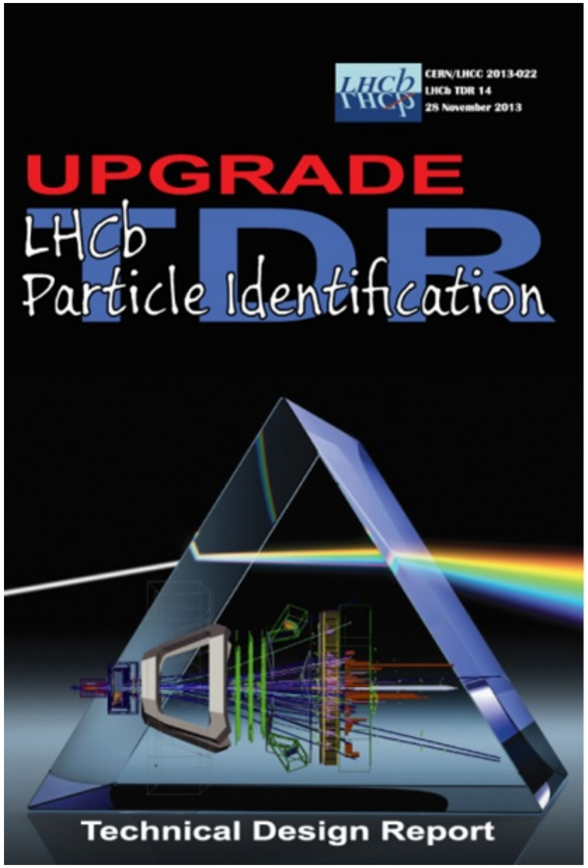


Tracker Performance

- Full η coverage with a single technology
- Improved tracking performance at upgrade luminosity with Fiber Tracker
- Ghost rate significantly reduced using Upstream Tracker information



Particle ID Upgrade



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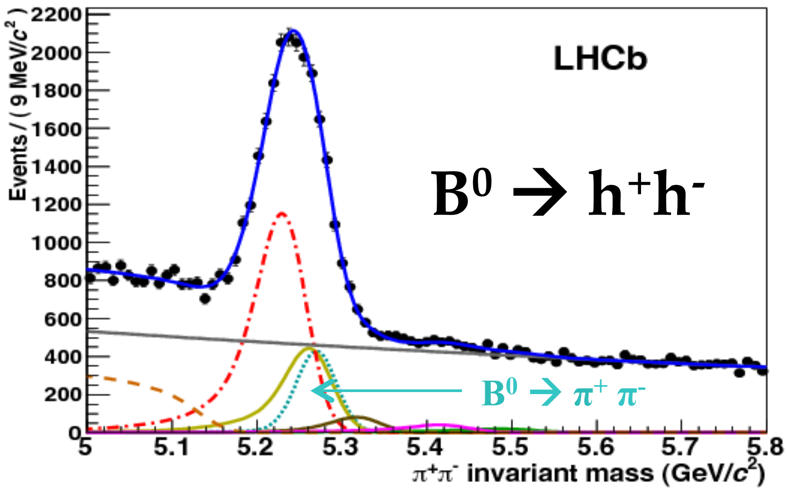
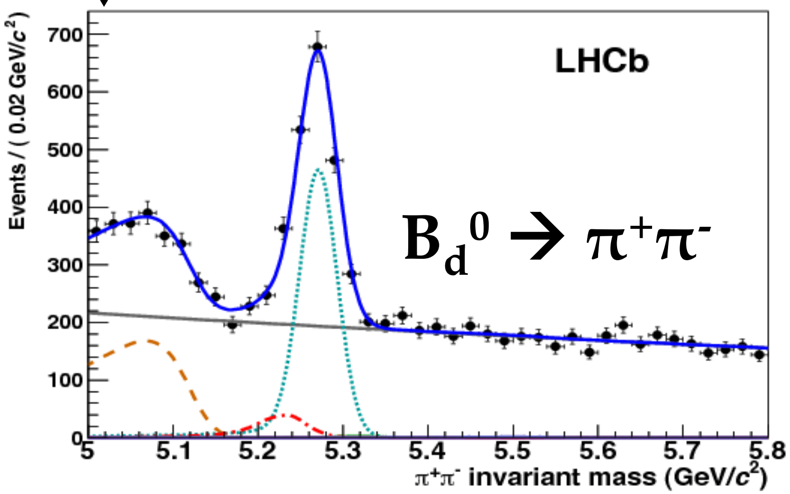
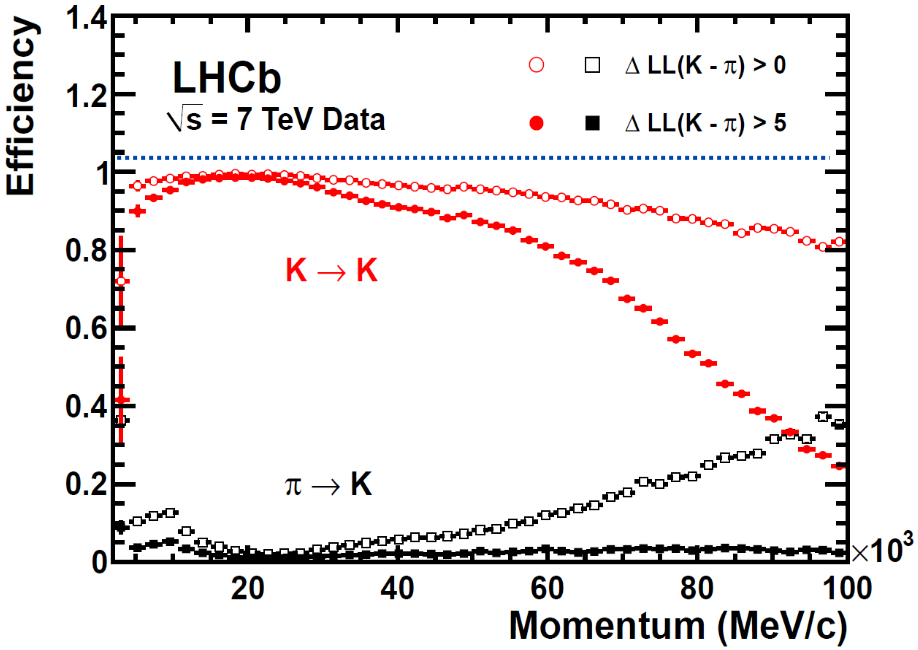
RICH Particle ID



particle identification of 2π
$BR(B \rightarrow \pi^+\pi^-) = 5 \times 10^{-6}$!



- Efficient particle ID of π, K, p essential for selecting rare beauty and charm decays

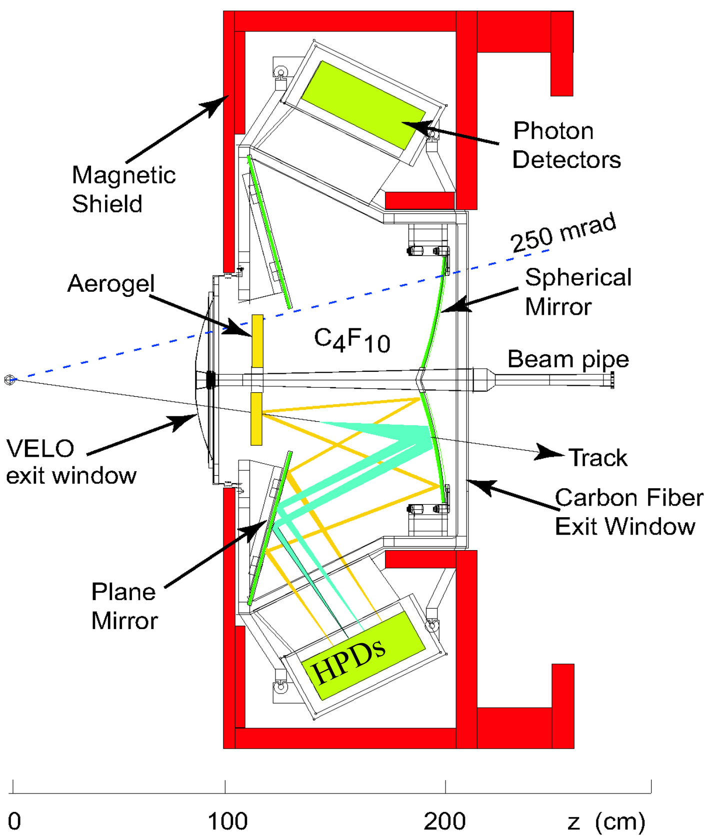


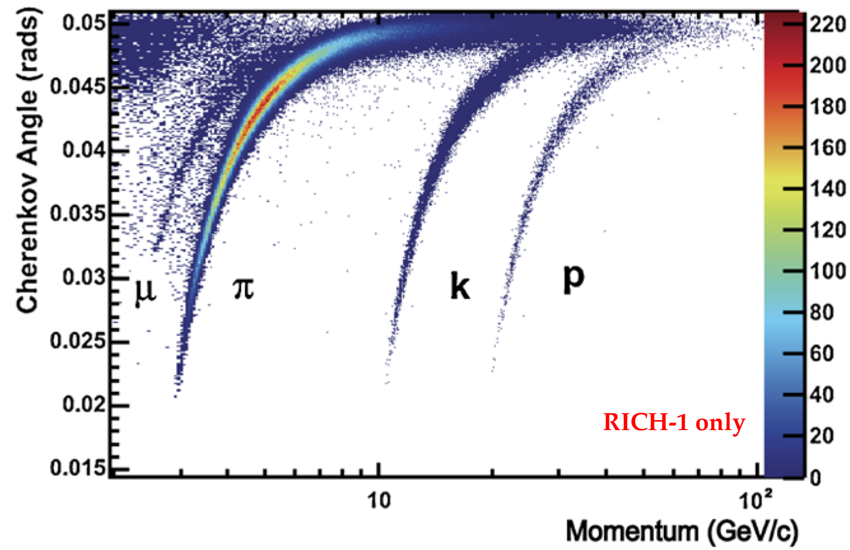
K-identification and π-misidentification efficiencies vs. particle momentum

Current RICH

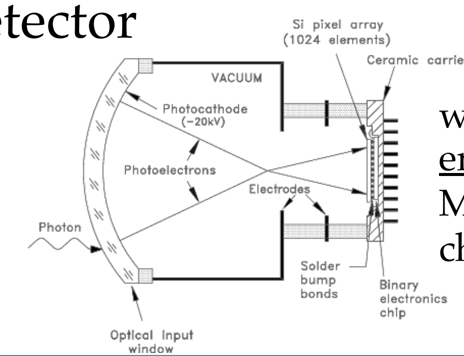
- Particles produce Cherenkov light rings on an array of Hybrid Photo-Detectors located outside the acceptance

RICH 1



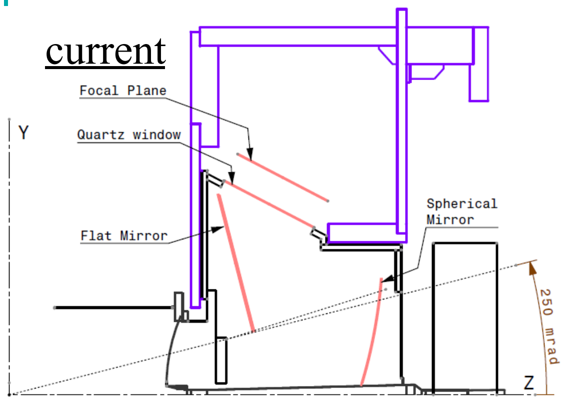


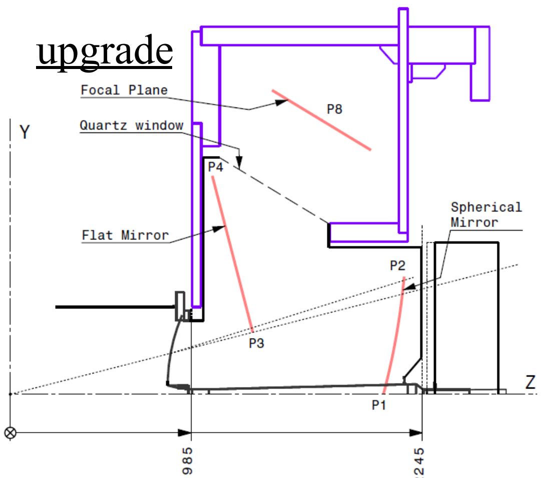
Hybrid Photon Detector



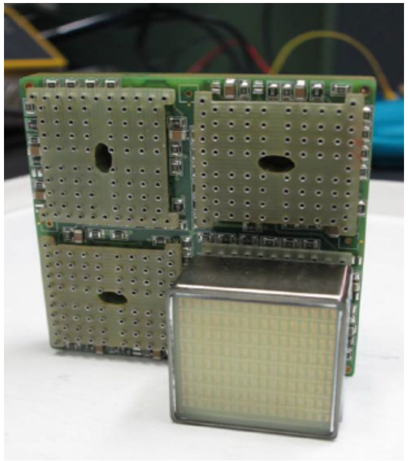
with embedded 1 MHz R/O chip

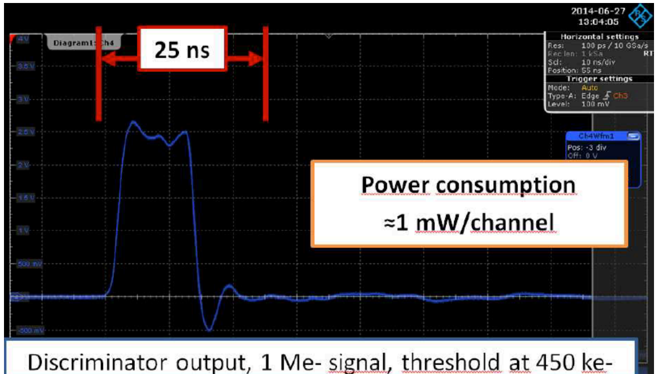
RICH Upgrade





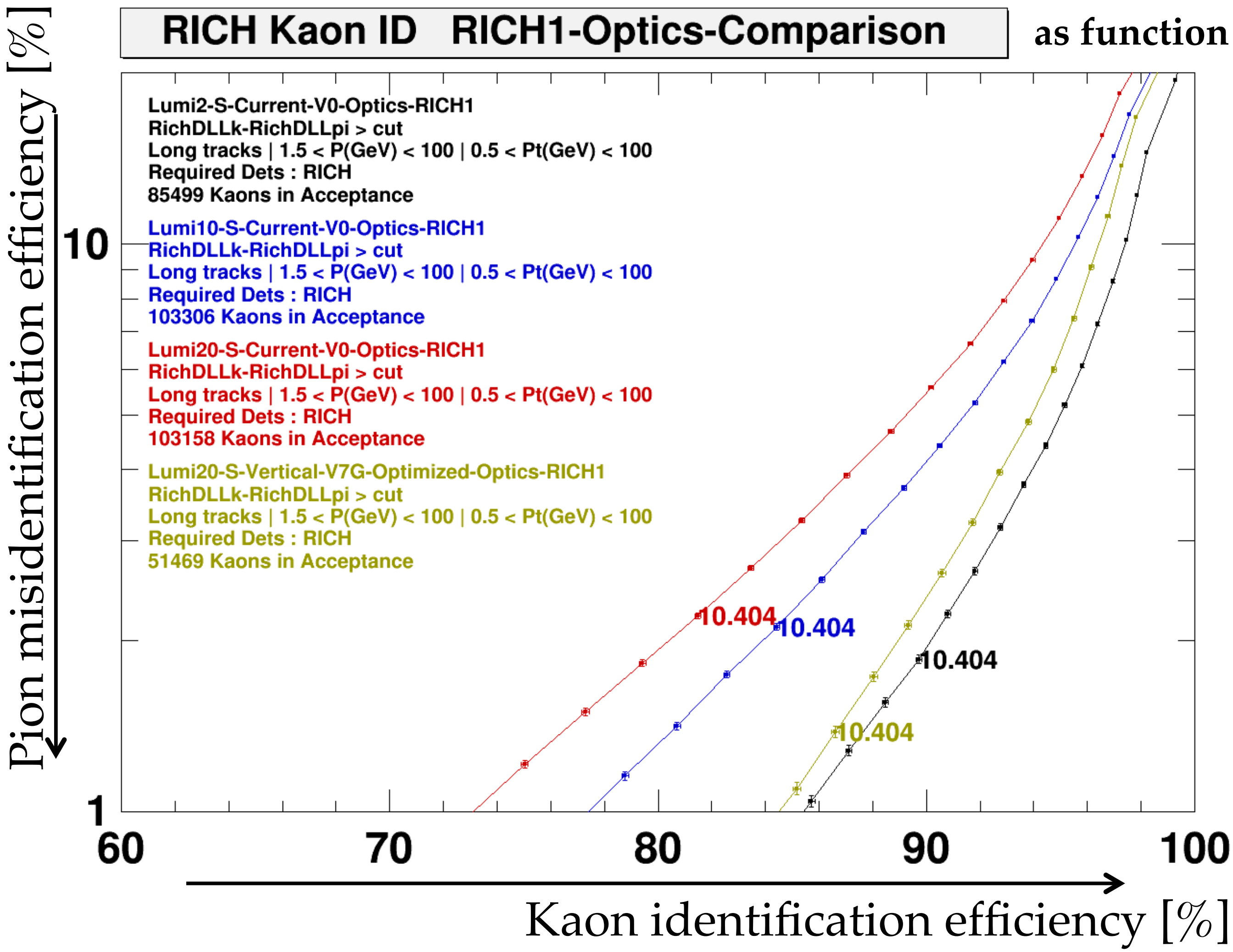
- Adapt to higher luminosity
  - Aerogel radiator removed
  - RICH1 optics modified to spread out Cherenkov rings
- 40 MHz readout → replace HPDs
  - 64 ch. multi-anode PMTs
  - 40 MHz Front-End: CLARO chip





Amplitude/Time measurement	Current	+Peak	-Peak	μ (Avg)	RMS	σ (S-dev)	Event count	Wave count
Rise time	1.9473 ns	2.1418 ns	1.8535 ns	1.949 ns	1.9496 ns	48.407 ps	1067	1067
Fall time	1.4484 ns	1.6184 ns	1.3941 ns	1.4572 ns	1.4577 ns	39.381 ps	1067	1067
Pos. pulse	11.908 ns	12.017 ns	11.738 ns	11.889 ns	11.889 ns	48.743 ps	1067	1067
Delay to trigger	22.065 ns	22.117 ns	22.002 ns	22.048 ns	22.048 ns	20.134 ps	1067	1067

RICH Upgrade Performance



as function of luminosity

Current RICH1
- $2 \cdot 10^{32}\ cm^{-2}s^{-1}$
- $10 \cdot 10^{32}\ cm^{-2}s^{-1}$
- $20 \cdot 10^{32}\ cm^{-2}s^{-1}$

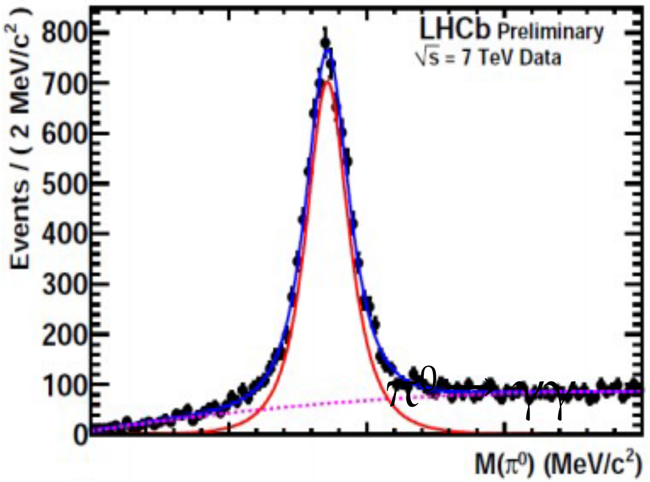
RICH1 upgrade
- $20 \cdot 10^{32}\ cm^{-2}s^{-1}$

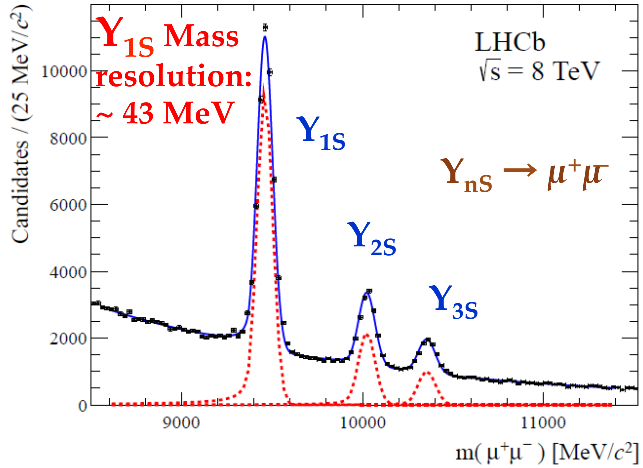
note:
full GEANT MC with standard LHCb simulation framework

Calorimeters and Muon

- Calorimeters
  - 4 subsystems: PS, SPD, ECAL, HCAL
  - Scintillating tiles + lead (ECAL) or iron (HCAL)
  - PMT readout
- Muon System
  - 5 stations, 1368 Multi-Wire Proportional Chambers + 12 GEM chambers
  - High muon detection efficiency (~97%) with low misID (~2% pions identified as muon)

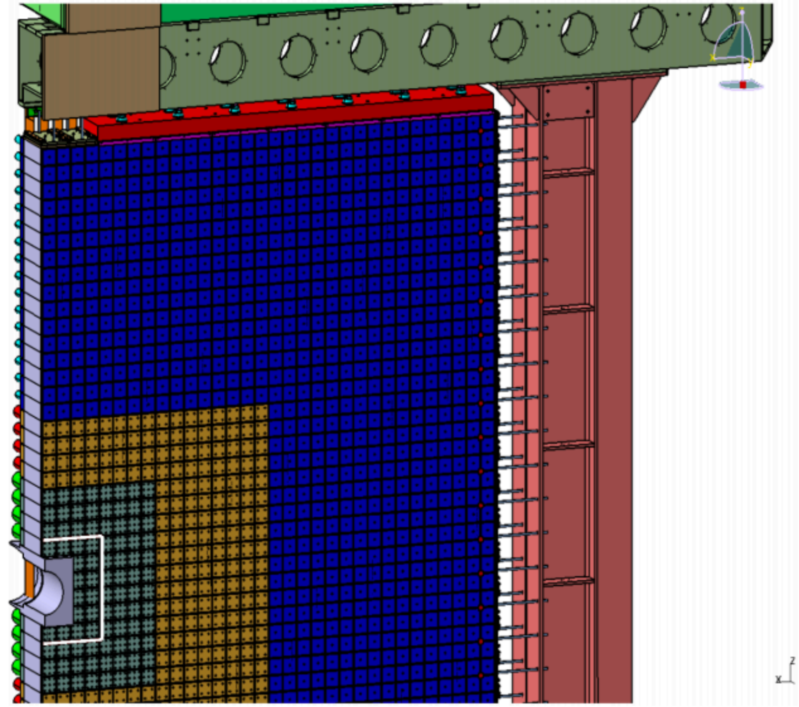
Typical π^0 mass resolution ~7-10 MeV / c^2

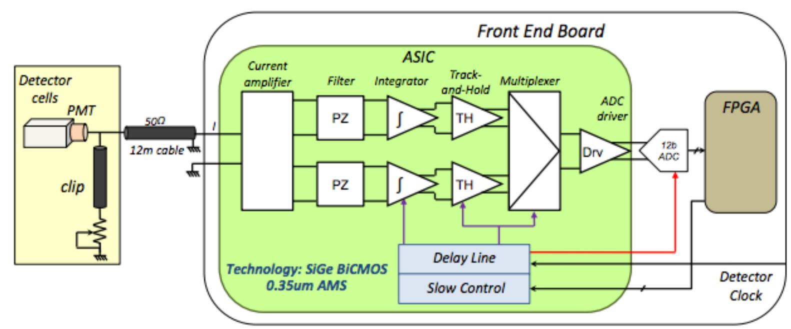




Calorimeter Upgrade

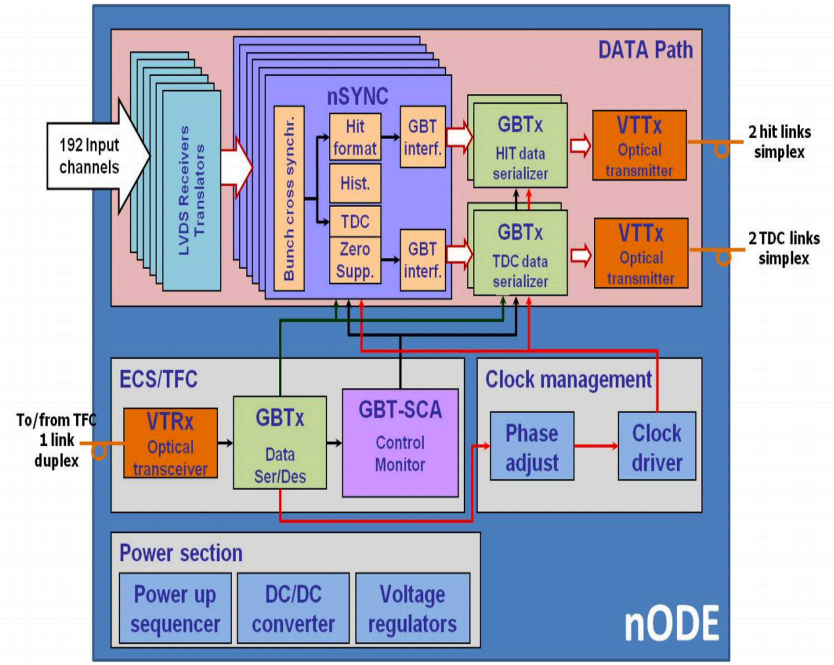
- Pre-shower and SPD removed (no more L0 calorimeter trigger)
- ECAL expected to be fine up to 20 fb^{-1}, inner ECAL cells could be replaced at LS3, HCAL OK up to 50 fb^{-1}
- Lowered PMT gains to guarantee extended operation at $2x10^{33}$ $cm^{-2}s^{-1}$
- New front-end electronics: ICECAL
- New back-end electronics





Muon Upgrade

- Muon detector front-end CARIOCA already operating at 40 MHz
- New Off-DEtector board for efficient readout via PCIe40 common readout boards
- Remove M1
  - No L0 muon trigger
  - Very high occupancies
- Additional shielding behind HCAL under study to reduce rate in inner regions of M2



Conclusions

- Thanks to its excellent performance LHCb is producing world best measurements in the b- and c-quark sector
- The Upgraded LHCb trigger-less read-out scheme will allow to read the whole detector at 40 MHz and collect 5 fb^{-1}/year, with a leveled luminosity of 2×10^{33} $cm^{-2}s^{-1}$
- The LHCb upgrade is mandatory to reach experimental precisions in the order of the theoretical uncertainties
- The LHCb Upgrade is fully approved
  - Installation is foreseen during LS2 (2019-2020)

Extra Slides

LHCb upgrade physics reach

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}	–

- Getting close to the theoretical uncertainties