The LHCb Upgrade

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on behalf of the

LHCb Collaboration

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Outline

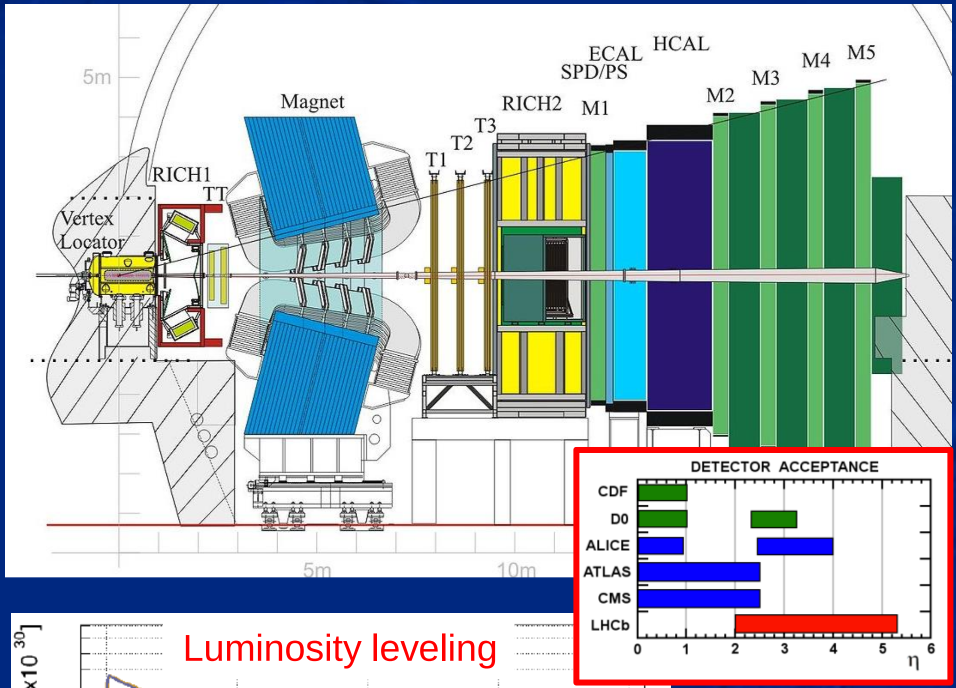
- Introduction to LHCb
  - Design
  - Performances
- The LHCb upgrade
  - Motivations
  - Trigger & DAQ
  - Detector
- Summary

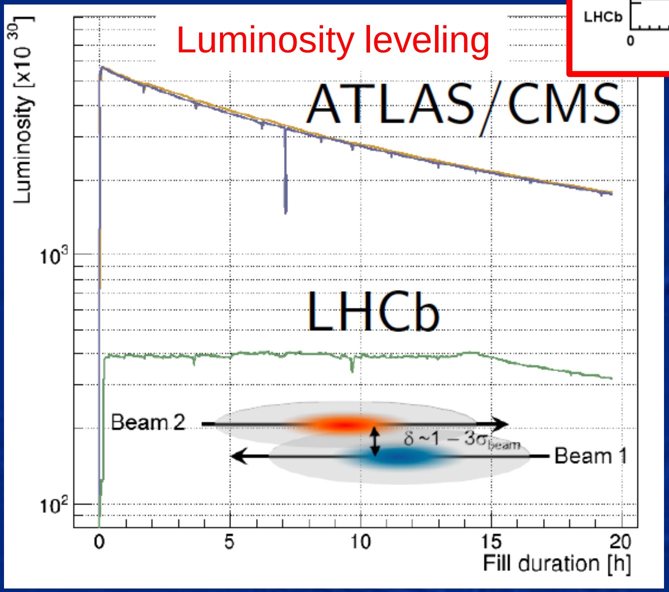
What is LHCb?

- It's a dedicated heavy flavor experiment at LHC, designed to:
  - measure the CP-violation in *b* sector
  - study rare *b*- and *c*- hadron decays
  - perform indirect searches for New Physics

- It's a forward spectrometer exploiting the huge production of beauty-pairs at small angles → 27% of b-pairs produced at 7 TeV collision energy are in the LHCb acceptance (2<η<5)

- Operates at fixed instantaneous luminosity

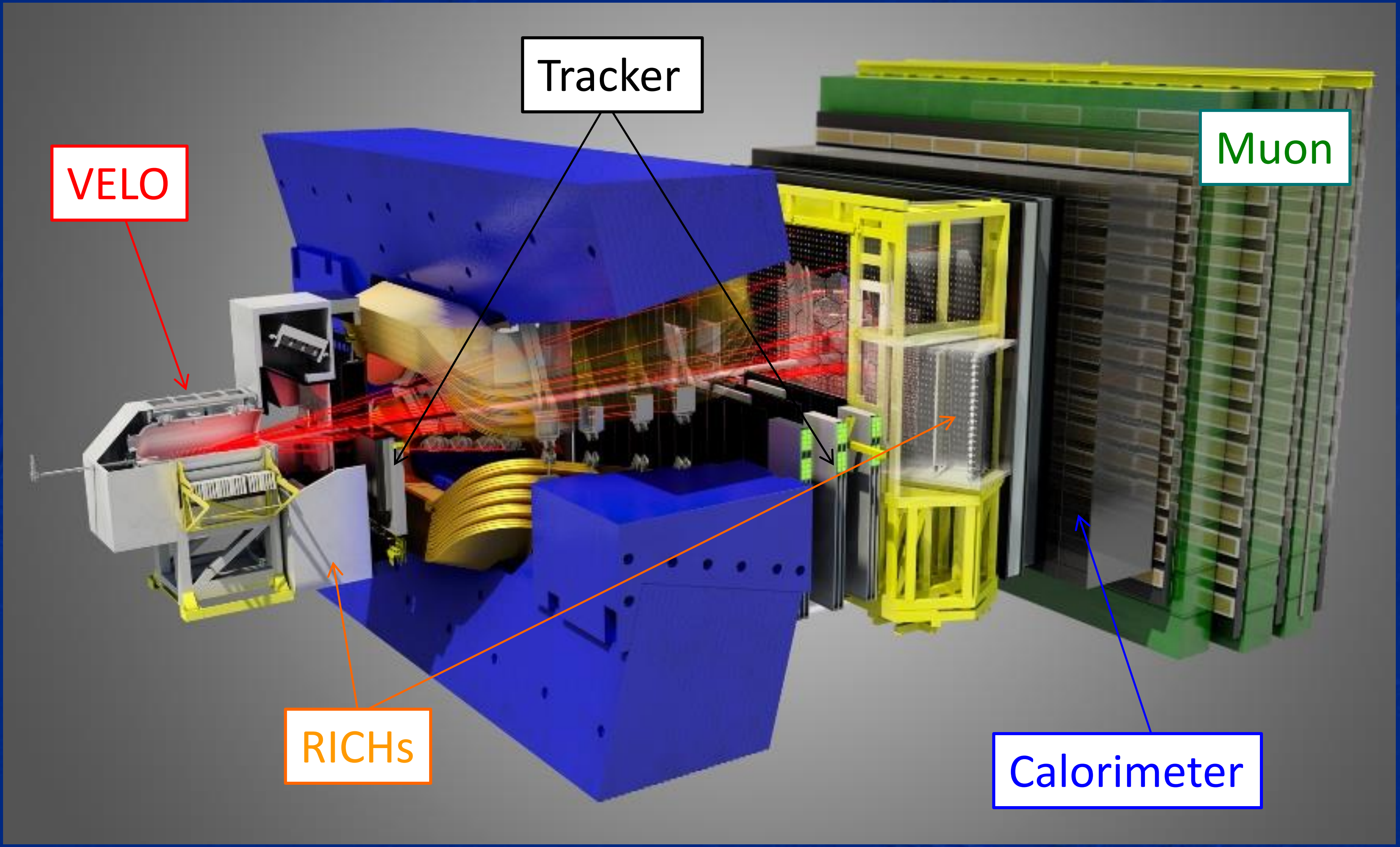




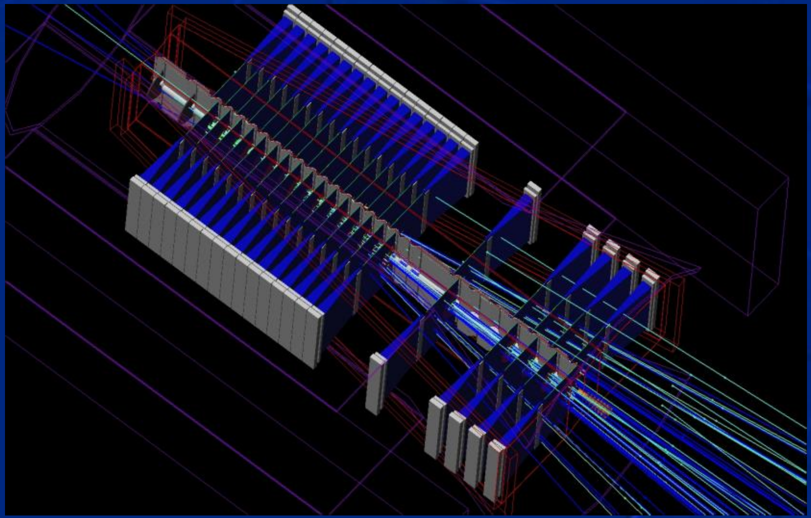
LHCb requirements

- Separate secondary decay vertices from primary production vertex → 20μm impact parameter resolution for high–p_t tracks
- Excellent momentum resolution: as low as 0.35% at 5 GeV/c (and still 0.55% at 100 GeV/c), which provides a mass resolution of 10 – 25 MeV/c^2
- Excellent particle identification capabilities, to unambiguously identify photons, electrons, muons, pions, kaons, protons in the b-meson decay chain, essential to select rare beauty and charm exclusive decays
- Efficient multi-stage trigger for leptonic and hadronic final states

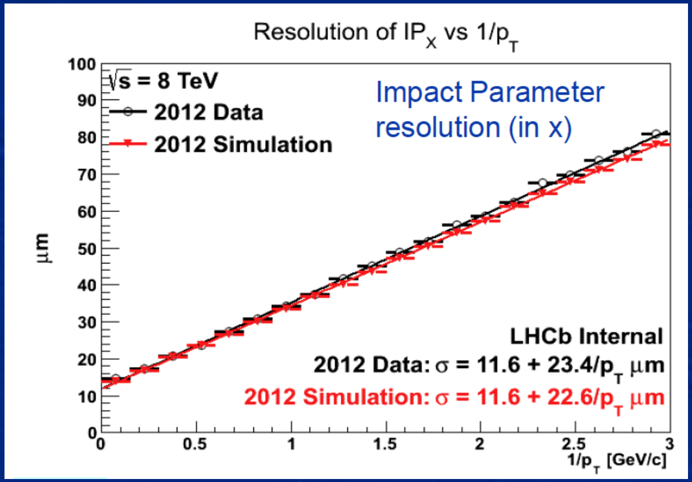
LHCb subsystems overview

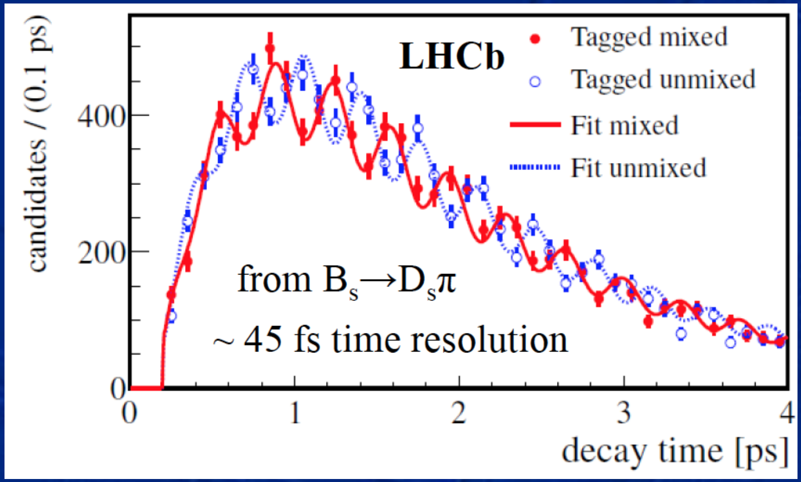


VErtex LOcator

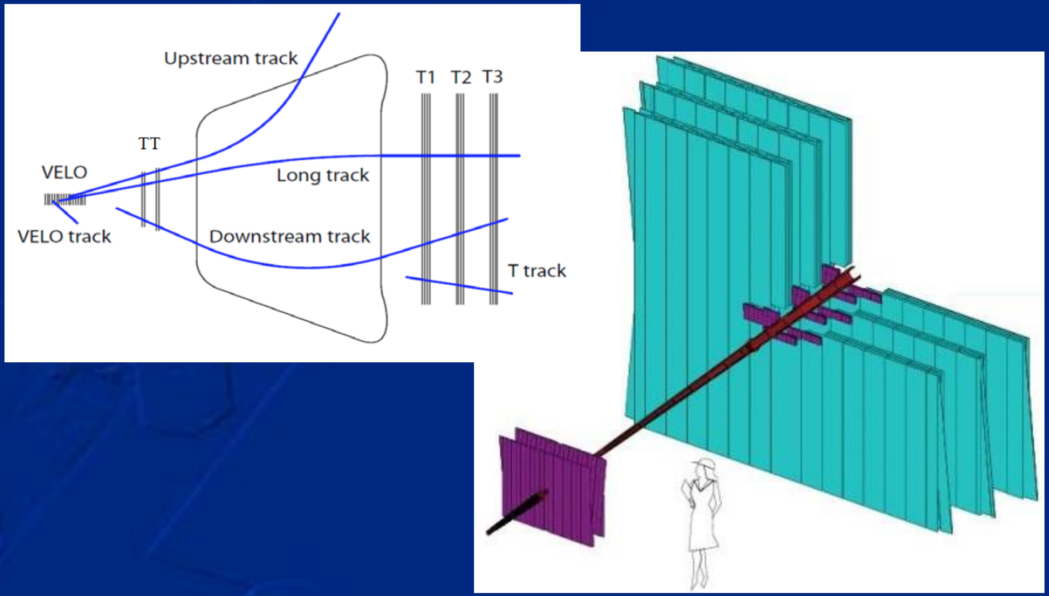


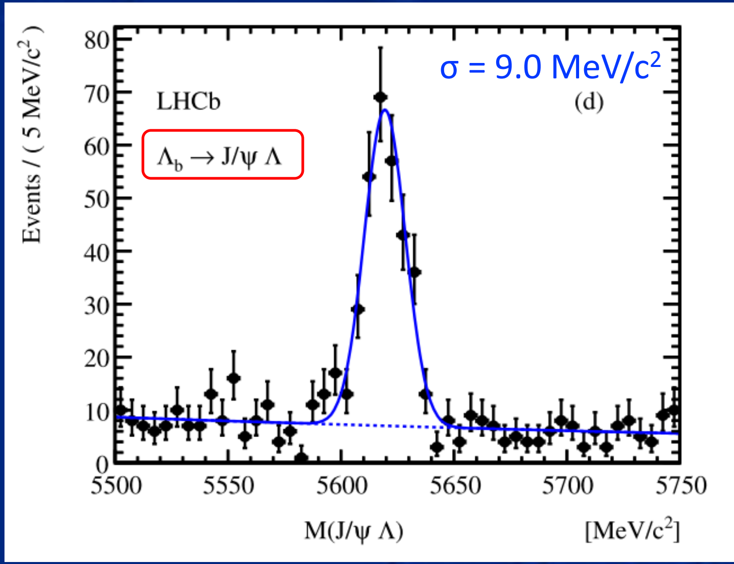
Microstrips sensors with rϕ strips – closing around beam during data taking

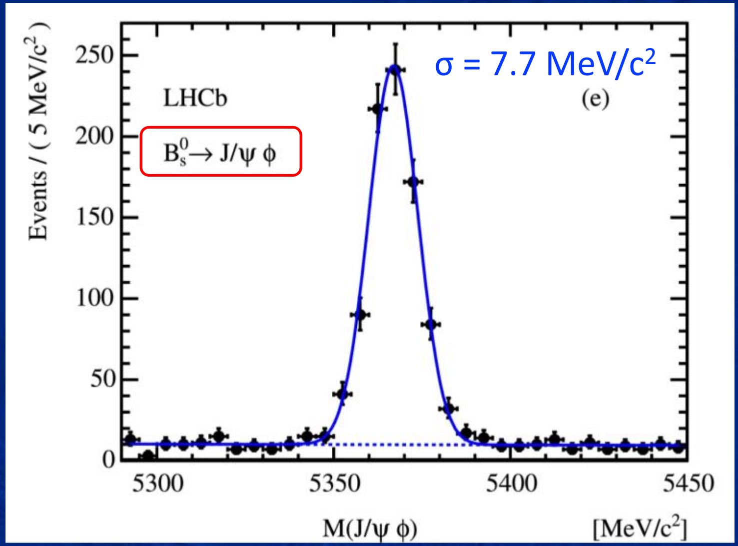




Tracking system





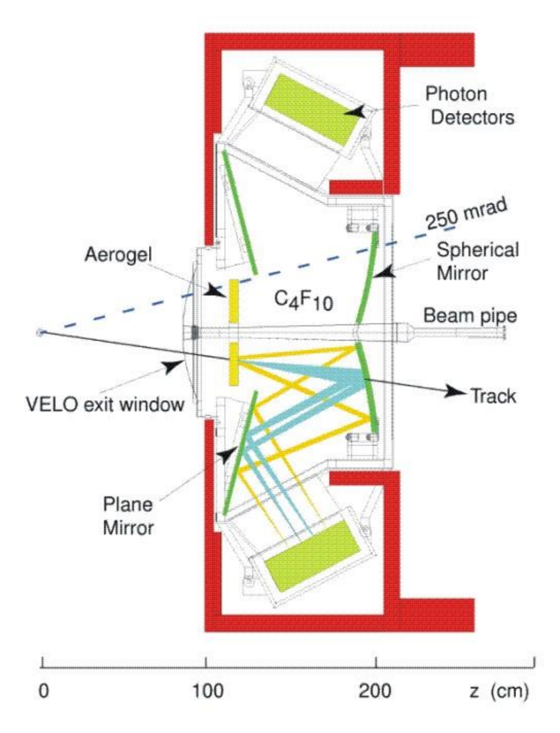


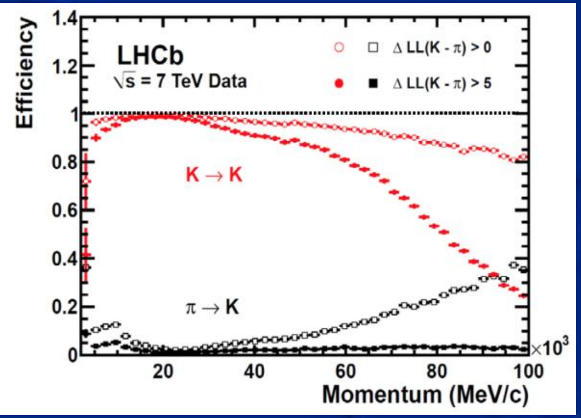
Various tracking stations (Si microstrips, straw tubes) and dipolar magnetic field of 4 Tm provide:

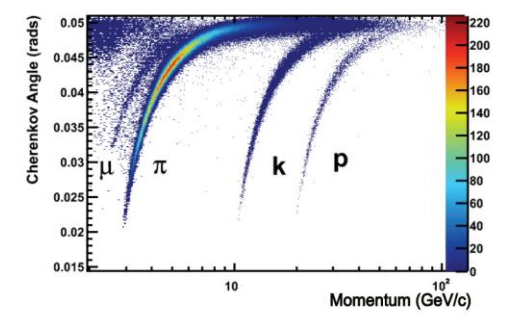
- Excellent mass resolution
- World's best mass measurements

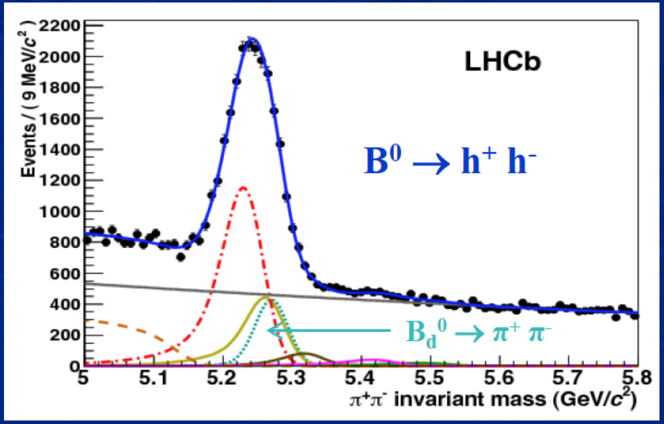
RICH

- 2 RICH detectors in LHCb
- Cherenkov light readout by photon detectors located outside geometrical acceptance
- Hybrid Photon Detectors readout with embedded 1 MHz R/O ASIC

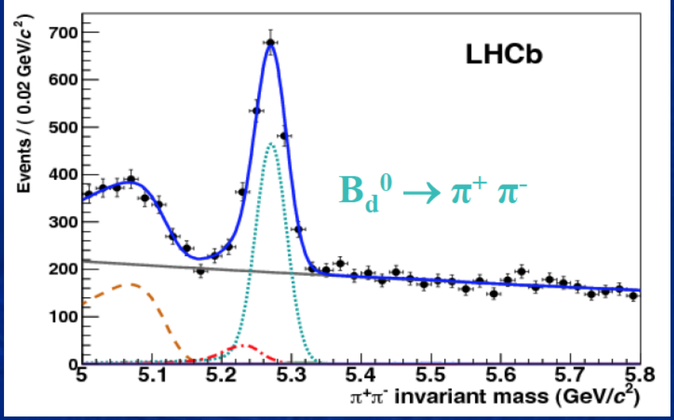




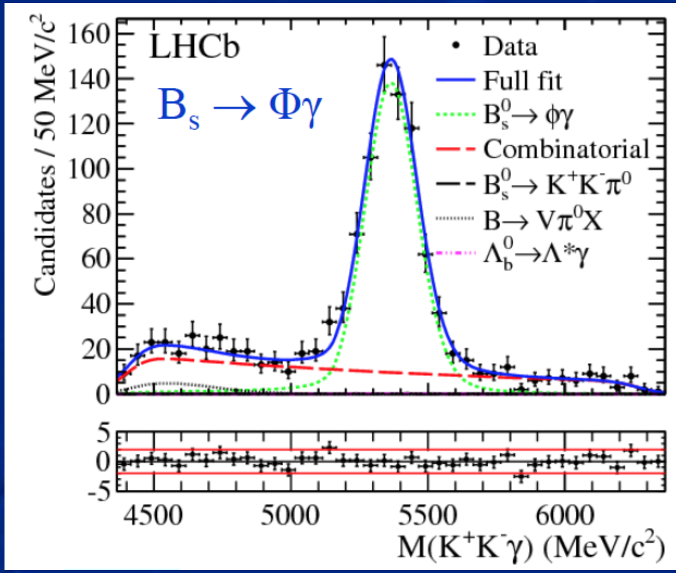




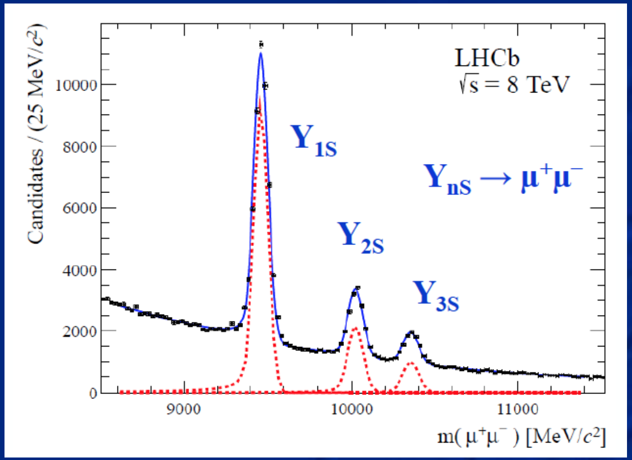
Using RICH information

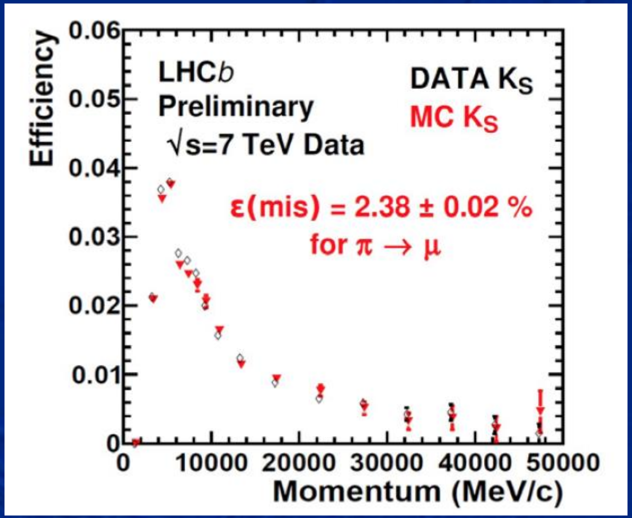


Calorimeters and Muon System



World best BR measurement: $(3.5 \pm 0.4)\ 10^{-5}$
with invariant mass resolution of about 94 MeV/c^2





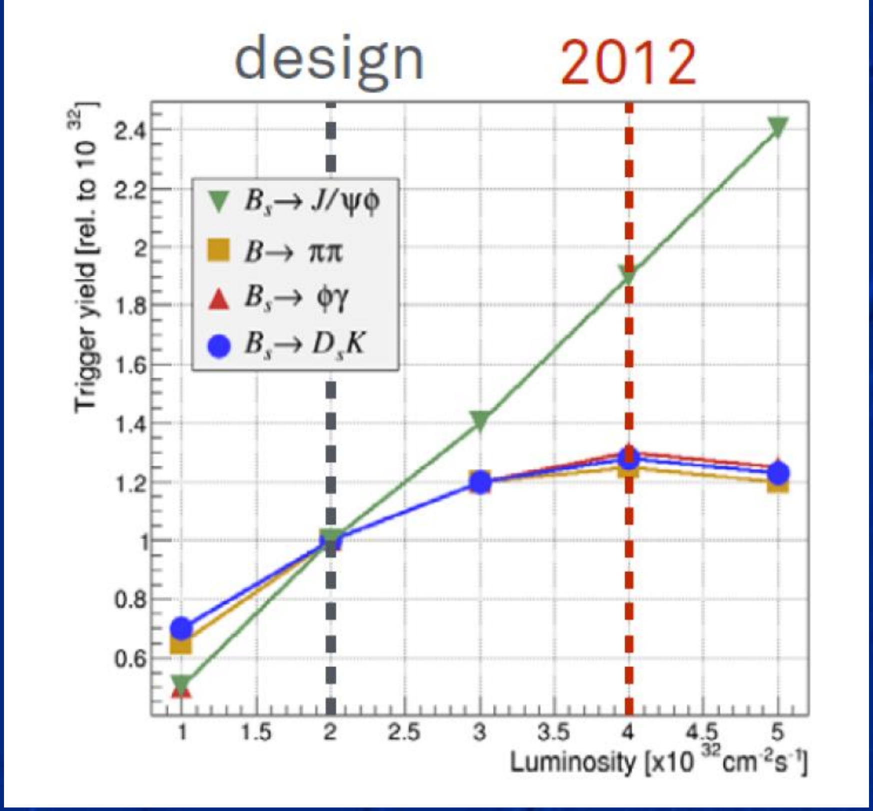
- Calorimeters
  - 4 subsystems (PS, SPD, ECAL, HCAL)
  - Scintillating tiles + lead (ECAL) or iron (HCAL)
  - PMT readout
  - Input to high E_t trigger
- Muon System
  - 5 muon stations, multi-wire proportional chambers
  - High muon detection efficiency (97.3%) with low misidentification (only 2.4% pions identified as muon)
  - Input to level-0 high-P_t muon trigger

Why upgrade?

- No evidence for New Physics in Run1
  - ➔ Look for tiny deviation from SM predictions
  - ➔ more (x10) data required, aiming at experimental sensitivities comparable to theoretical uncertainties

- <u>The current 1 MHz level-0 trigger output is a severe limitation!</u>

- If we increase the luminosity
  - – trigger yield of hadronic events saturates
  - – need harder cuts on P_t and E_t due to the 1 MHz bandwidth limit
  - ➔ there's not a real gain in statistics
  - ➔ ~5 fb^{-1} in Run2



- Note that our upgrade <u>does not depend LHC upgrade</u>, we use a fraction of the available luminosity

… and how?

- Remove the level-0 hardware trigger
  - Readout an event every bunch crossing (40 MHz)
  - New front-end electronics (on-chip zero suppression)
  - New DAQ system
- Use an efficient fully software trigger accessing complete event information, running at the bunch crossing rate
- The high instantaneous luminosity of 2 $10^{33}/cm^2/s$ implies higher occupancies in all subsystems → redesign several detectors to adapt them to new conditions
- Install by LS2 in 2018-2019

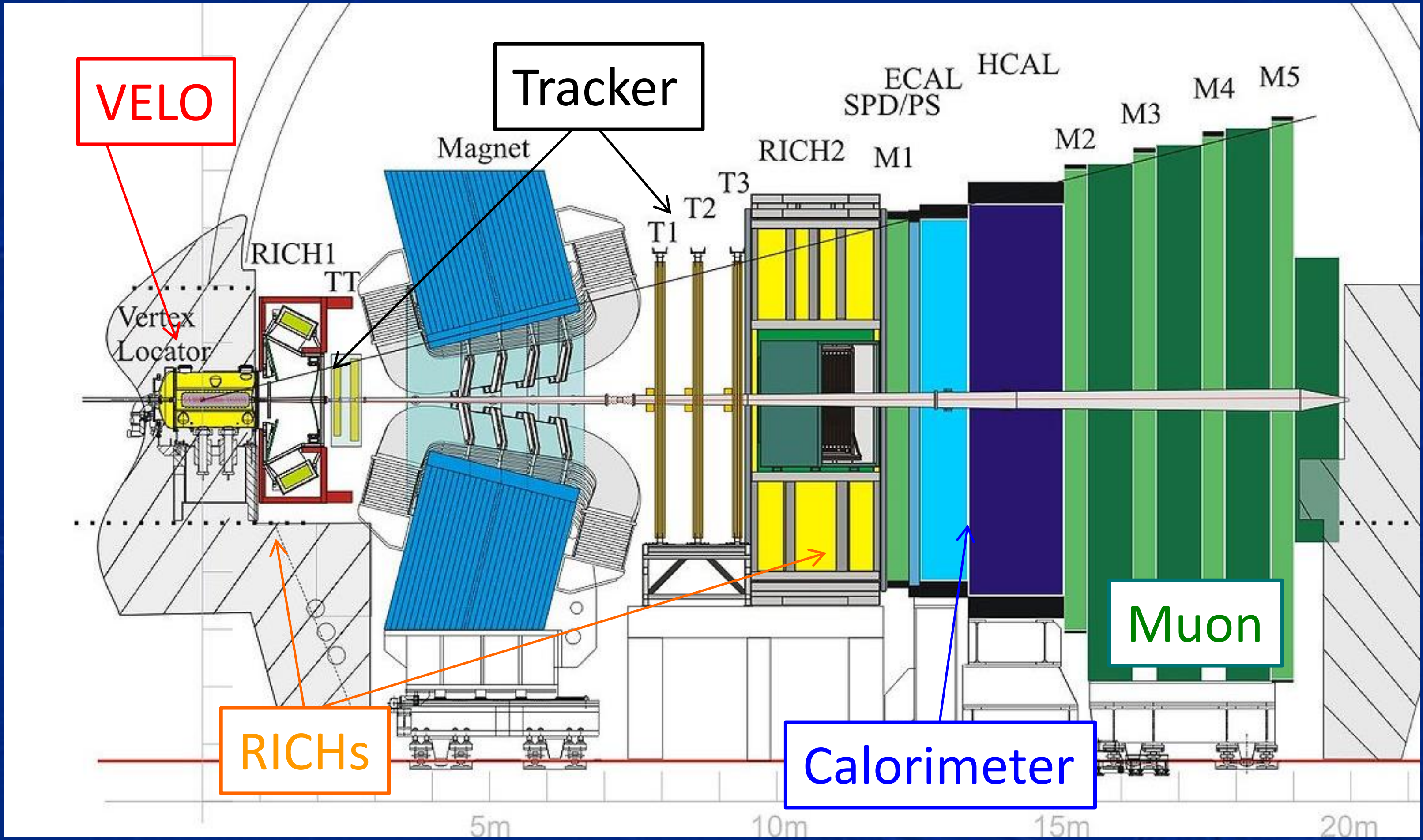
Upgrade scenario

- Data taking conditions
  - Leveled instantaneous luminosity of $2 \cdot 10^{33}/cm^2/s$
  - 30 MHz collisions
  - 20-100 kHz to disk
  - ➔ ~5 fb^{-1} per year

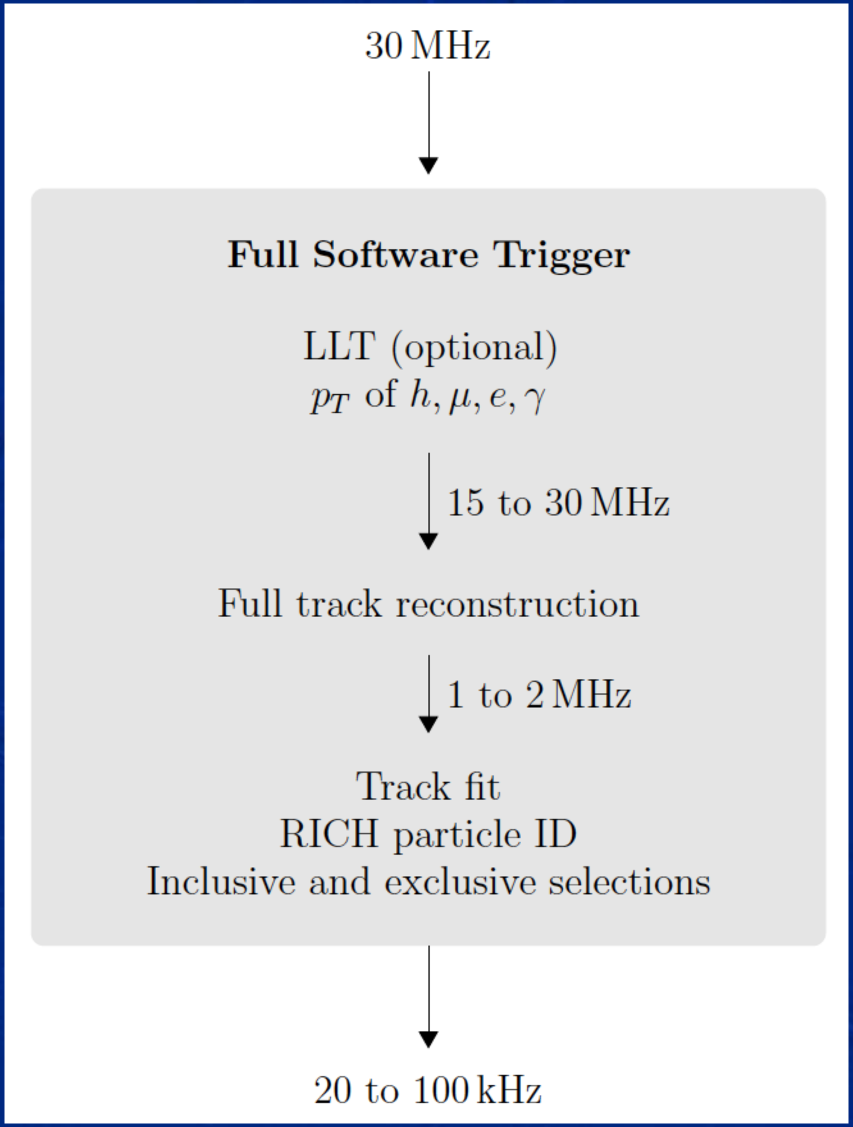
- Challenges
  - High pile-up
  - Large occupancies
    - event reconstruction is more difficult
    - more difficult PID
  - Radiation damage

The LHCb Upgrade

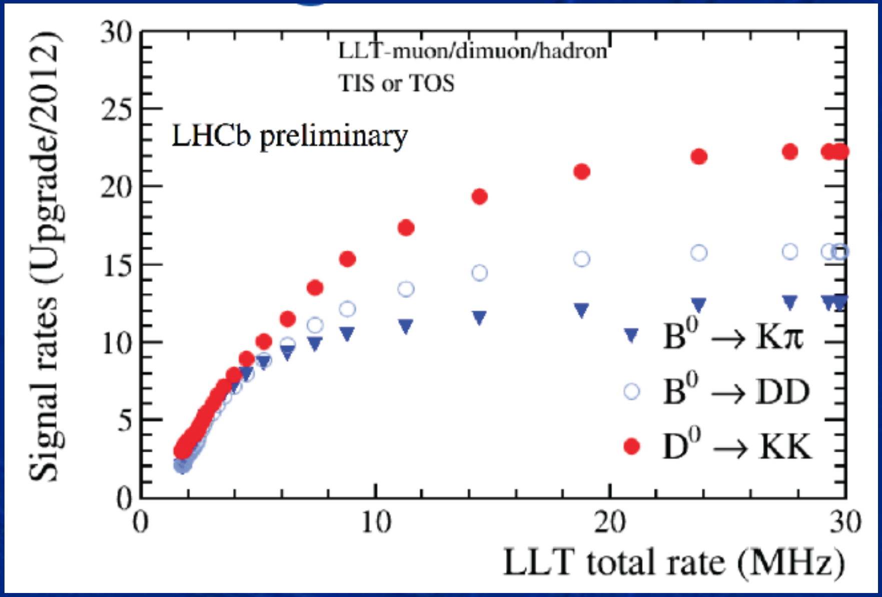
Fully software trigger + new DAQ + …



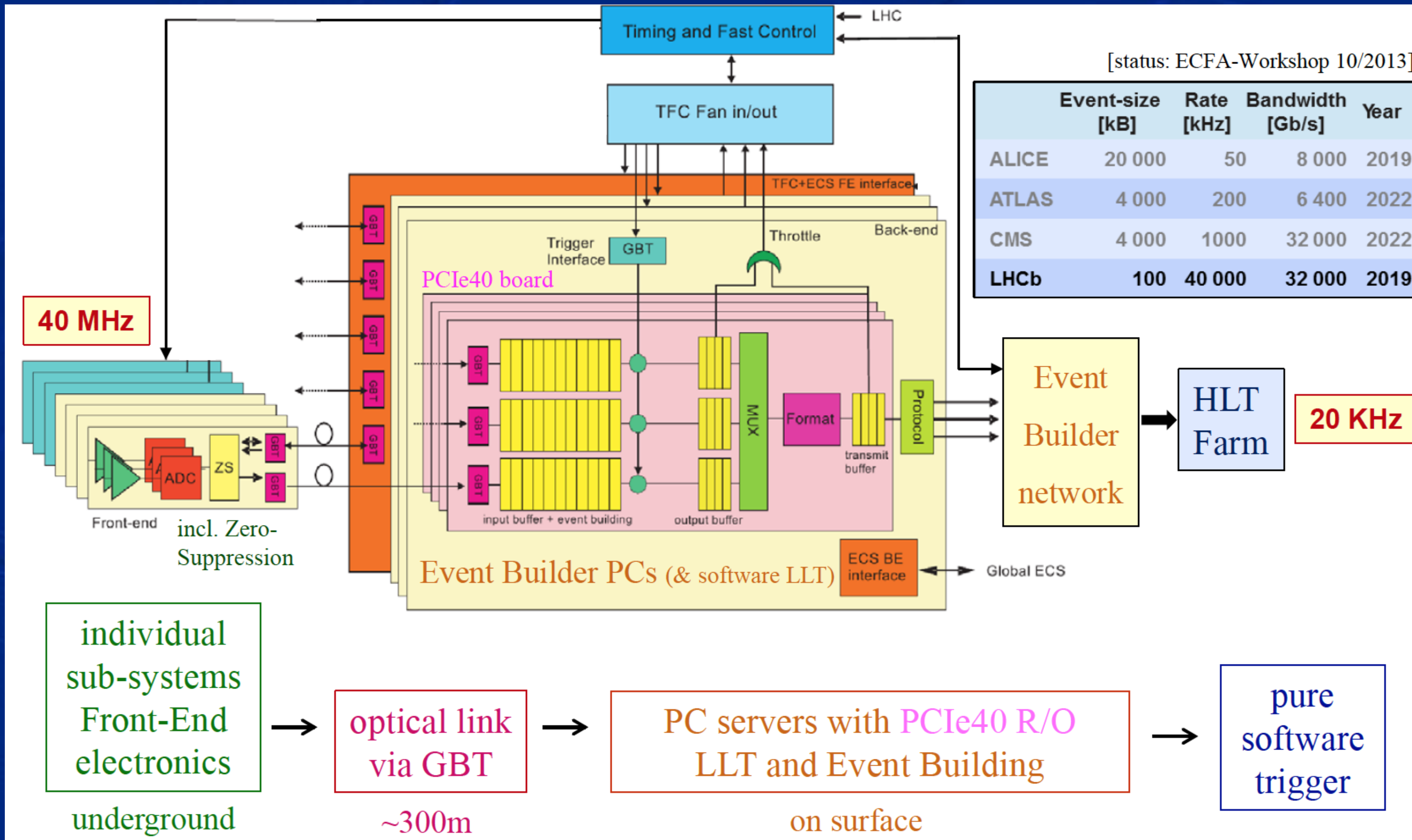
The software trigger



- Trigger farm: 50k logical CPU cores
- Offline-like reconstruction tuned to available time constraints
- Mixture of exclusive and inclusive selection algorithms
- LLT output rate progressively increases as trigger farms grows



The 40 MHz R/O architecture

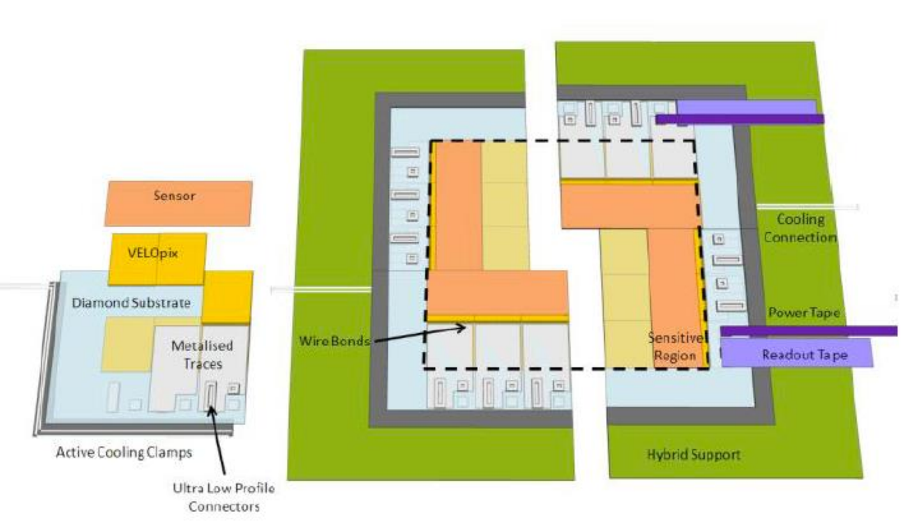


[status: ECFA-Workshop 10/2013]

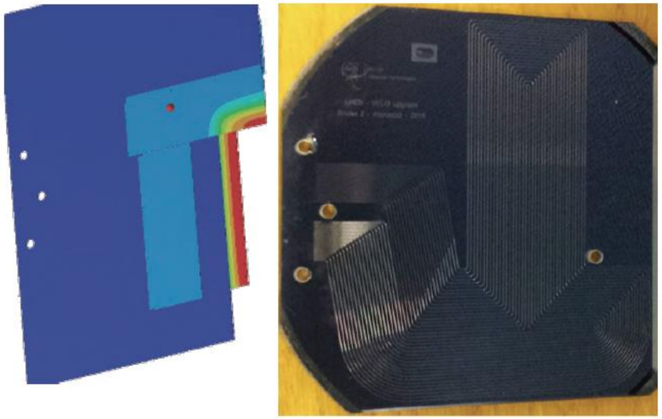
	Event-size [kB]	Rate [kHz]	Bandwidth [Gb/s]	Year
ALICE	20 000	50	8 000	2019
ATLAS	4 000	200	6 400	2022
CMS	4 000	1000	32 000	2022
LHCb	**100**	**40 000**	**32 000**	**2019**

Upgraded VELO

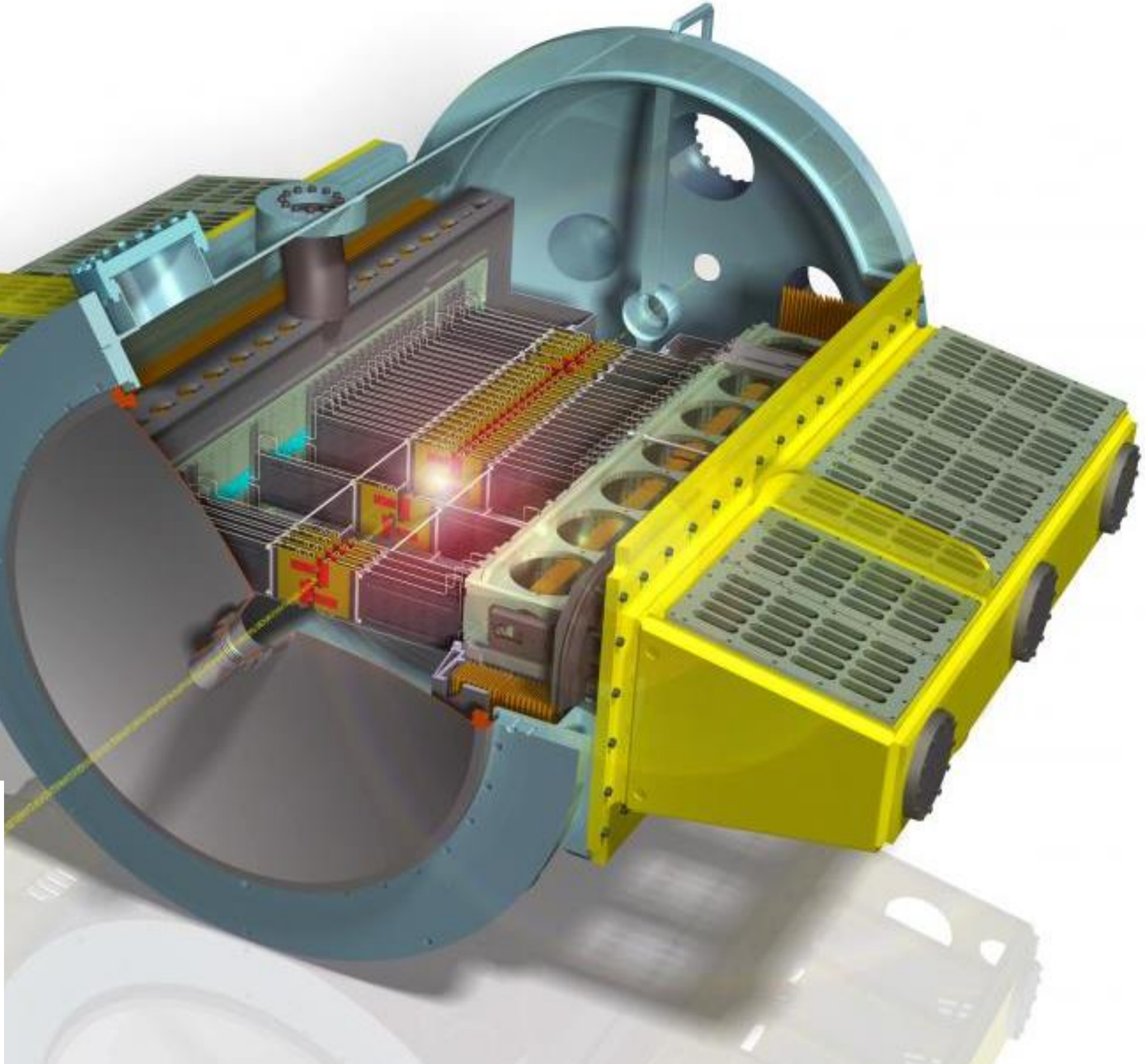
- Challenges
  - Very high particle rates
  - Large data volumes: 20 Gbit/s/ASICs
  - Highly non-uniform radiation damage (up to $8\ 10^{15}\ n_{eq}/cm^2$ for 50 fb^{-1})
  - Reduce material budget
  - Bring detectors closer to the beam axis: 13.6 mm → 8.5 mm
- Technical choices
  - 256x256 pixels matrices, with 55 x 55 μm^2 pixels
  - Micro-channel CO_2 cooling
  - FE: Velopix (Timepix3 evolution, x8 faster)

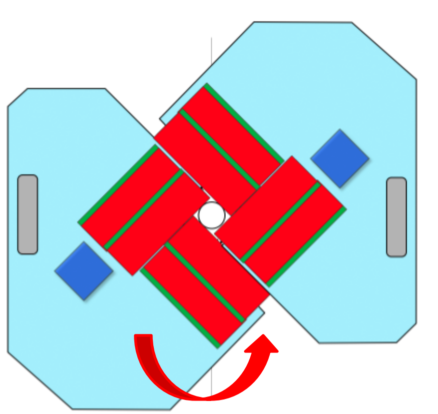


Micro-channel



CO_2 passes through channels etched in a silicon plate

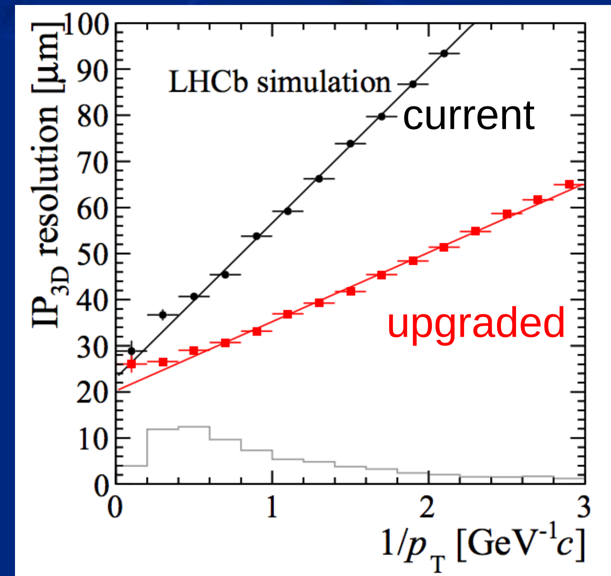


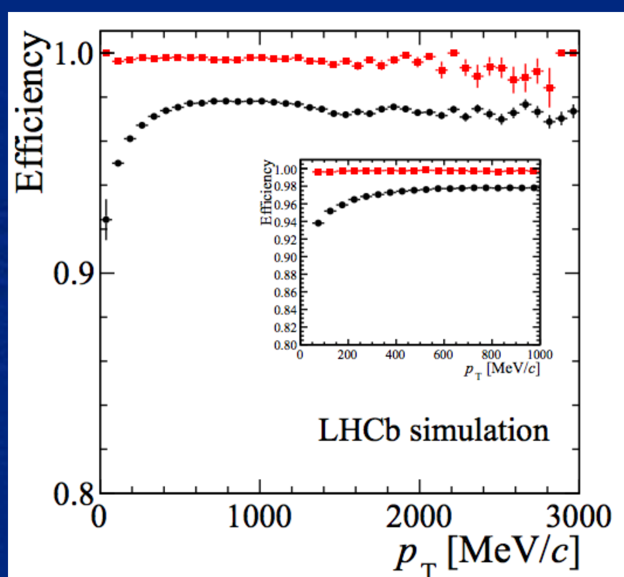


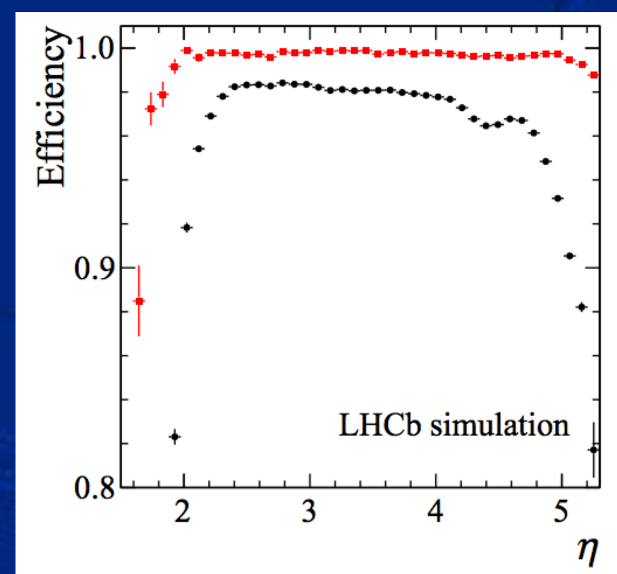
45 deg. rotated new VELO option under discussion

New VELO Performance

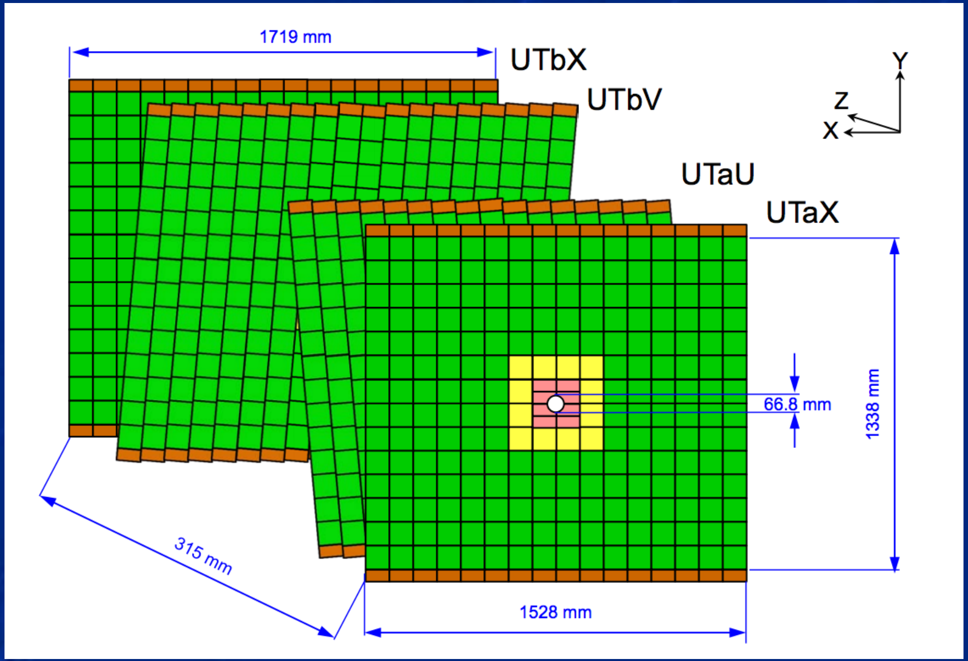
Predicted performances at $2 \cdot 10^{33}/cm^2/s$ are superior in almost every aspect with respect to the current VELO operating at high luminosity

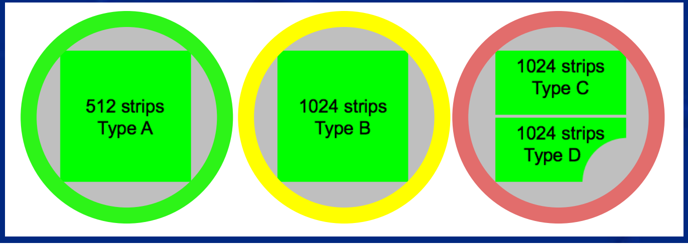






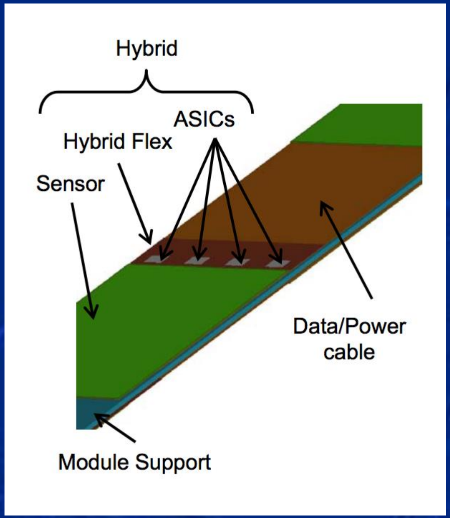
TT upgrade: Upstream Tracker (UT)

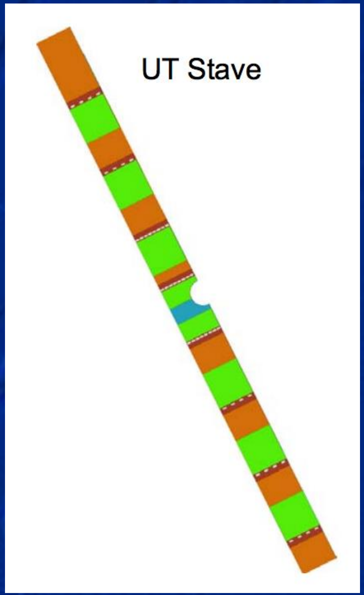




Property	Sensors B,(C,D)	Sensors A
Technology	n^{+}-in-p	p^{+}-in-n
Thickness	250 µm	250 µm
Physical dimensions	98 mm X 98 (49) mm	98 mm X 98 mm
Length of read-out strip	98 (49) mm	98 mm
Number of read-out strips	1024	512
Read-Out strip pitch	95 µm	190 µm
Sensor number (needed)	48 (16,16)	888

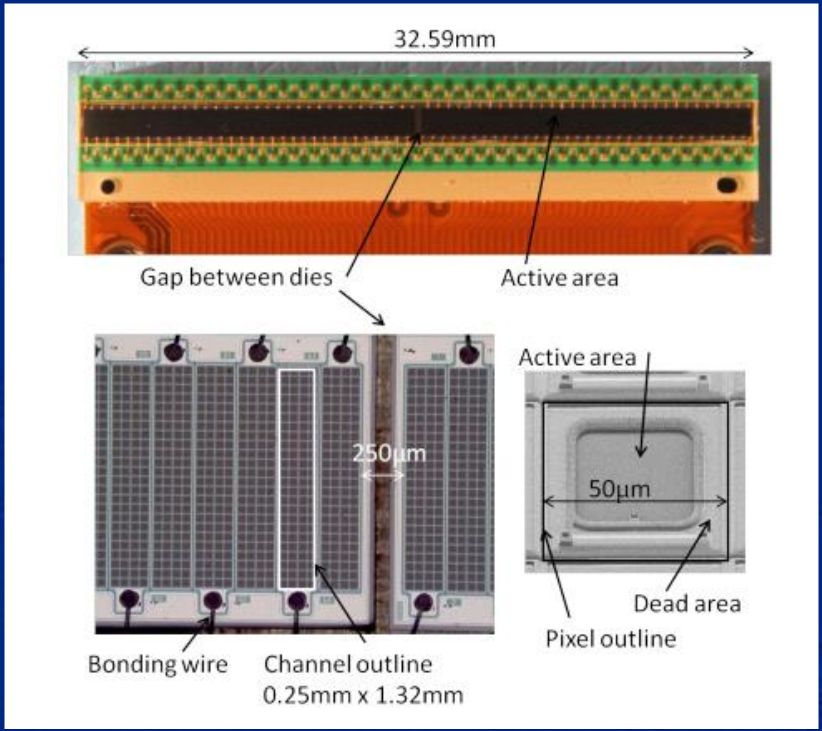
- 4 detection planes, stereo
- Silicon strip detector, 250 µm thick
- Segmentation and technology depends on expected dose and occupancy
- 40 MHz R/O via SALT ASIC

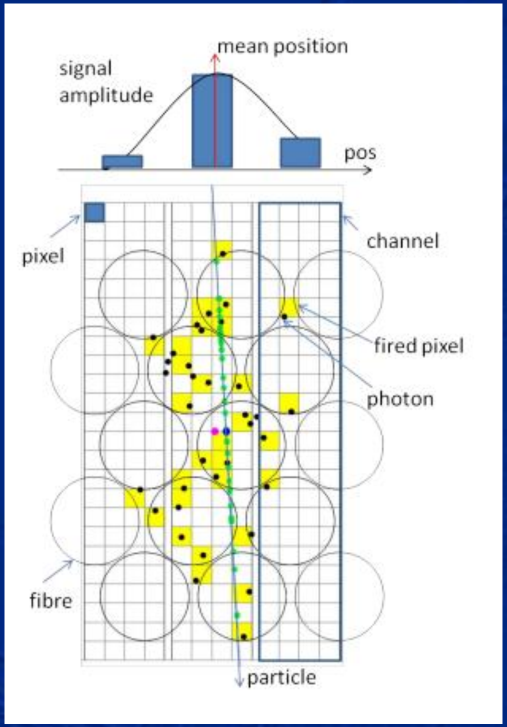




Fiber Tracker (FT) technology

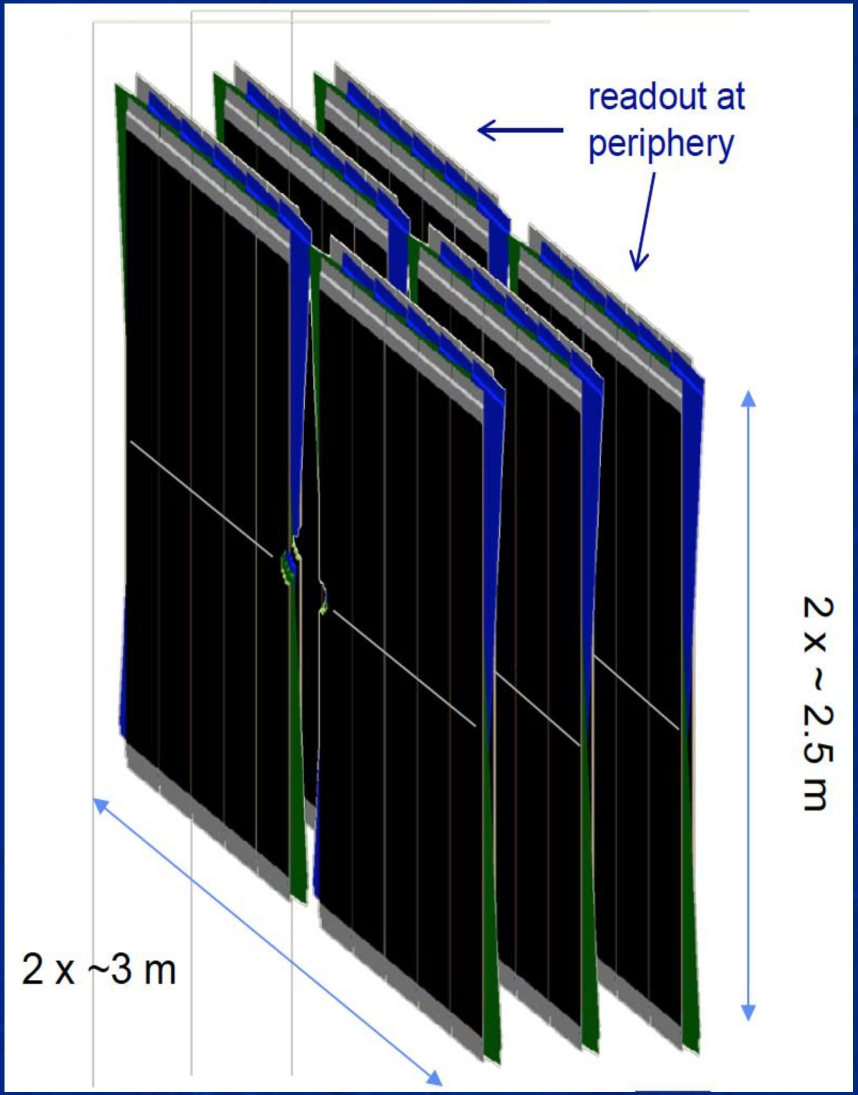
- Scintillating fiber mat (5-6 fibres thick)
- 250 µm diameter scintillating fibres
- R/O via 2x64 channel silicon photomultiplier (SiPM) array
- R/O by dedicated 128 channels 40 MHz PACIFIC ASIC





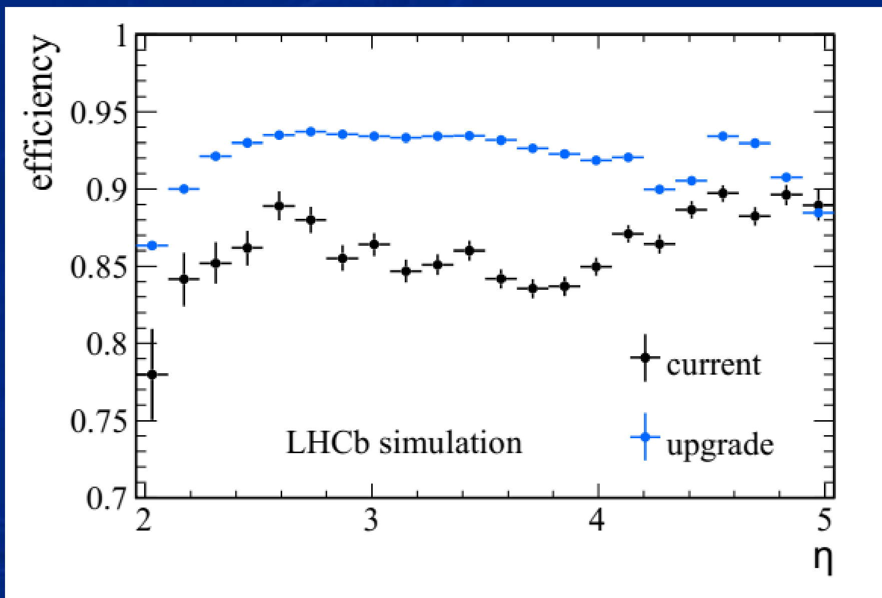
FT Design

- 12 detection layers in 3 stations
- Each station has *XUVX* layers (*U,V*: ±5°)
- Advantages
  - Single technology easy to operate
  - High granularity (250 µm) gives excellent x-position resolution (50-75 µm)
  - Uniform material budget
  - SiPM & R/O outside acceptance
- Challenges
  - Radiation damage to fiber → tested, ok
  - SiPM rad. damage → operate @ -40° C

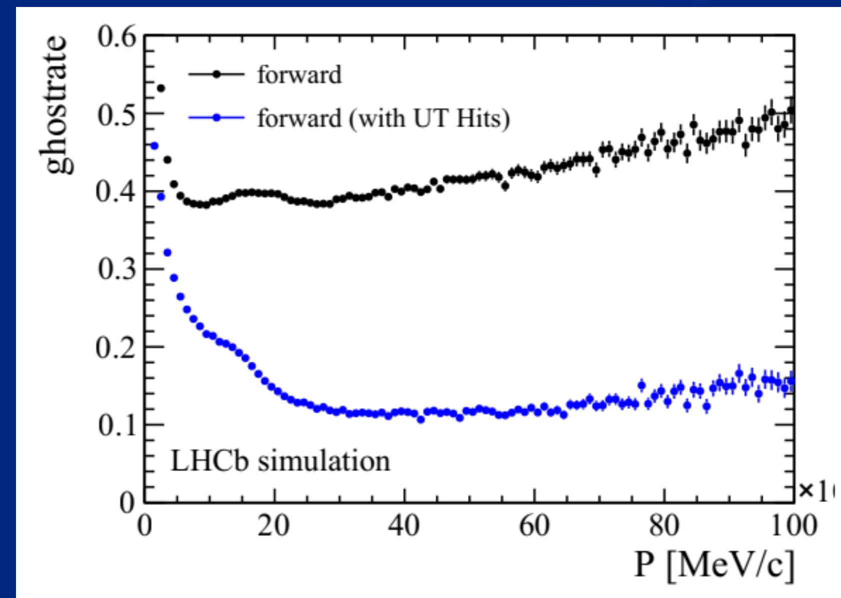


Upgraded Tracker Performance

Efficiency for $B_s \rightarrow \phi\phi$



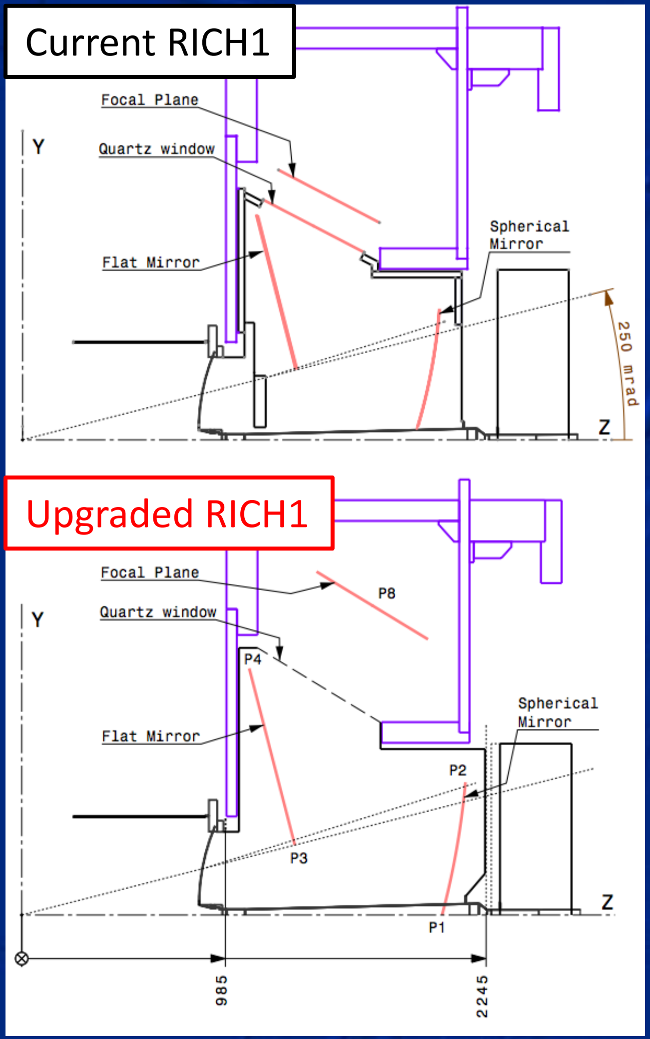
Ghost rate (long tracks) for $B_s \rightarrow \phi\phi$

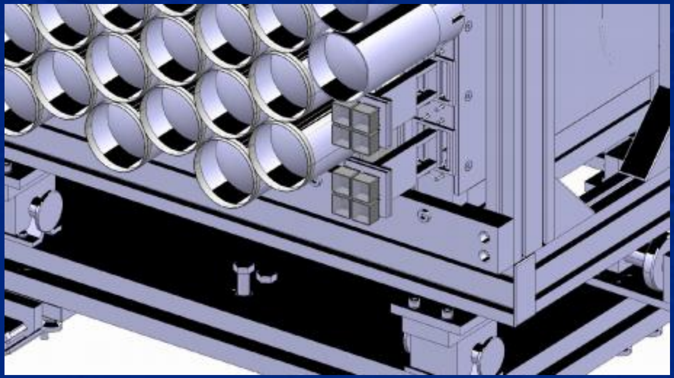


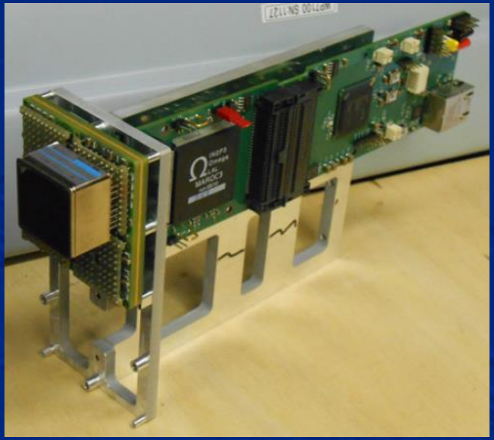
- FT ➔ Improved tracking efficiency
- UT ➔ Improved background rejection

RICH Upgrade

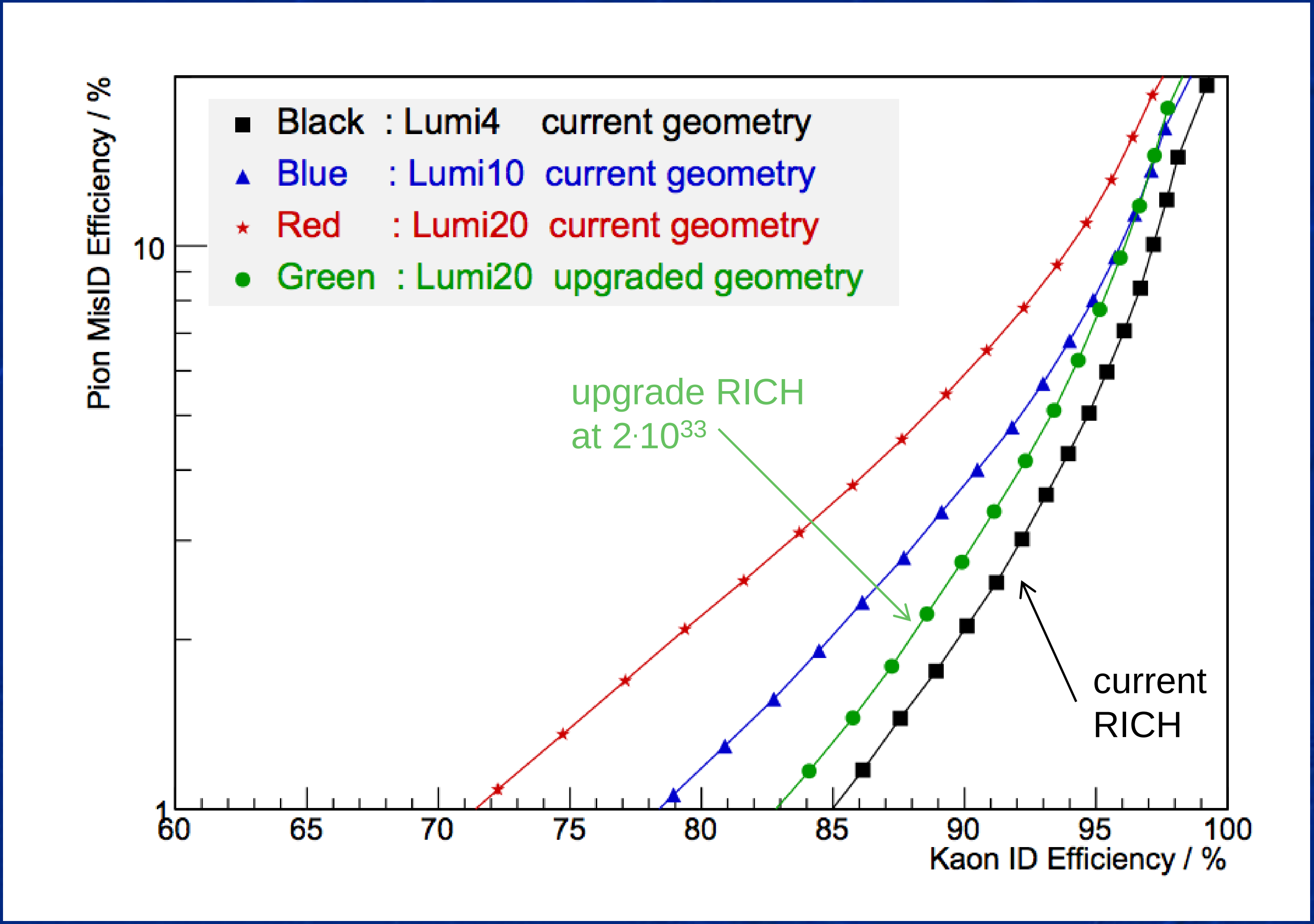
- New R/O: 64 channel multi-anode PMTs
- 40 MHz CLARO front-end ASIC
- In addition, for RICH1:
  - Remove aerogel
  - improve optics to spread out Cherenkov rings on the focal plane







Upgraded RICH comb. performance

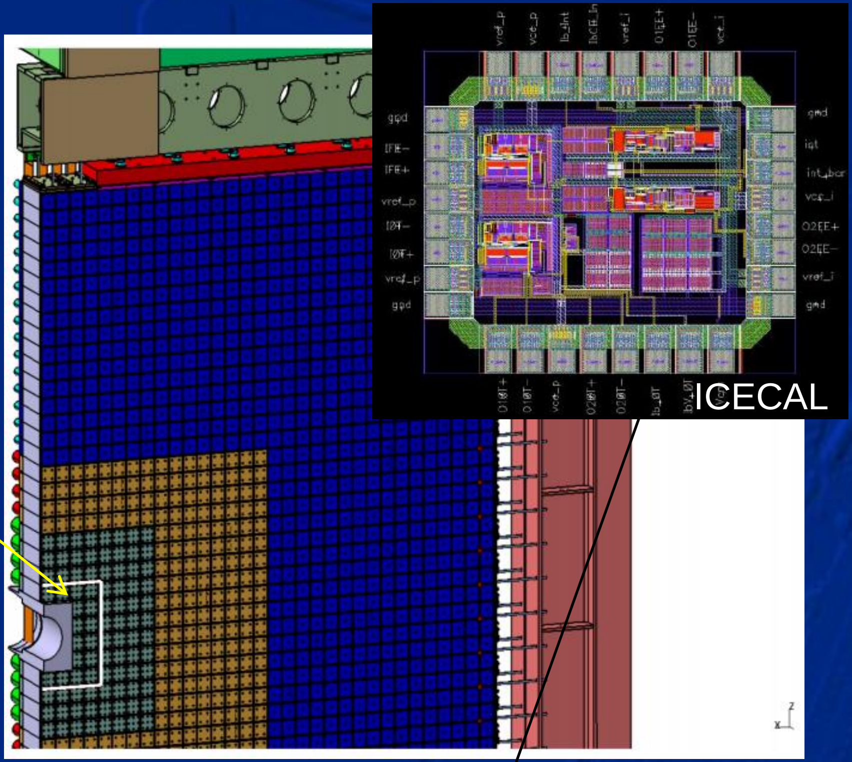


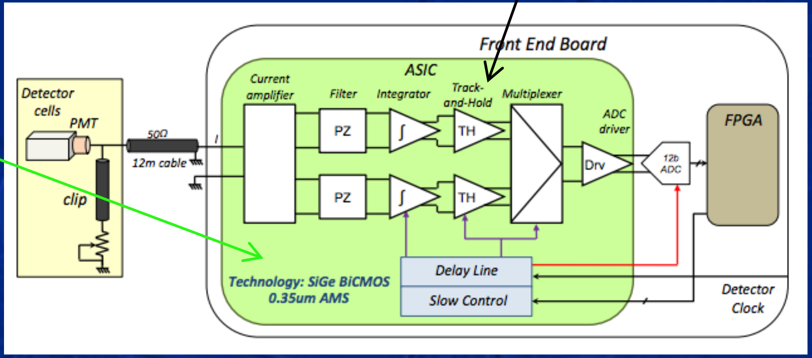
Upgraded RICH performance at $2 \cdot 10^{33}$ close to current one

Calorimeter System Upgrade

Occupancy and radiation issues

- Pre-shower and SPD will be removed (no more L0 calorimeter trigger)
- ECAL expected to be fine up to 20fb^{-1}, inner ECAL cells could be replaced at LS3
- HCAL OK up to 50 fb^{-1}
- Lower PMT gains to guarantee extended operation at HL
- New front-end electronics: ICECAL
- New back-end electronics, calculating ECAL and HCAL 2x2 cell energy for LLT

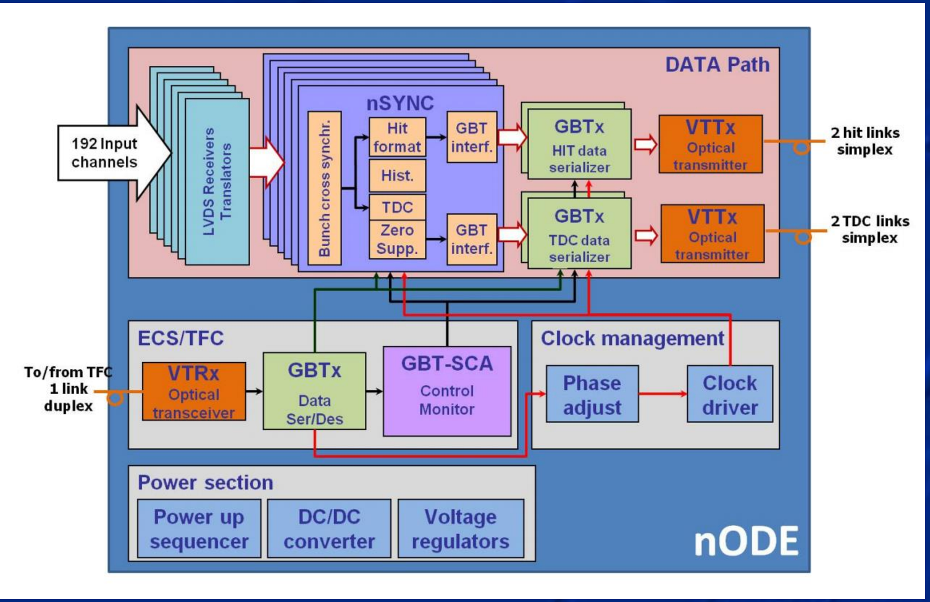


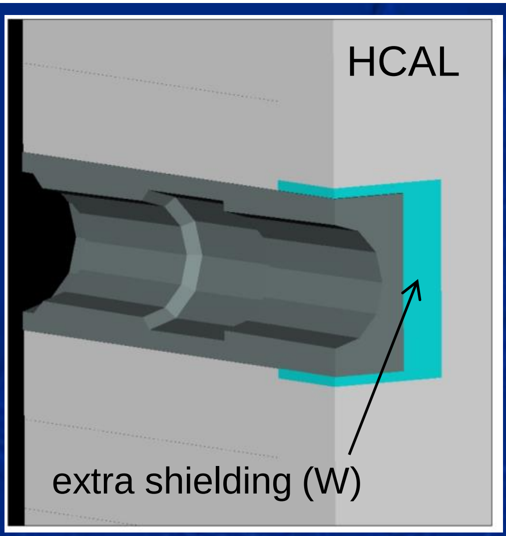


Muon system Upgrade

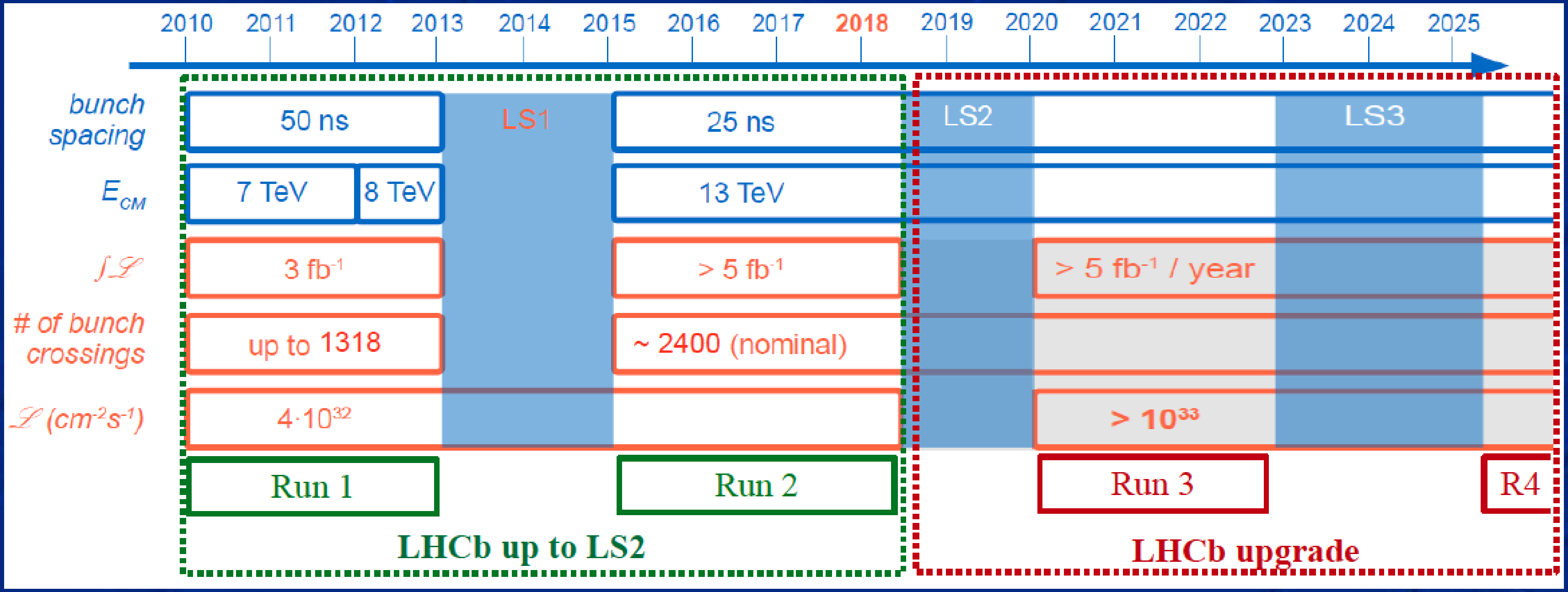
R/O and occupancy issues

- Muon detector front-end CARIOCA already operating at 40 MHz
- New off-detector board for efficient readout via PCIe40 common R/O boards
- Remove M1
  - no muon level-0 muon trigger
  - Very high occupancies
- Additional shielding behind HCAL to reduce rate in inner regions of M2
- Possible replacement of M2/M3 inner region detectors under study





The next years



- Run2 starts in 2015, the aim is to collect 5 fb^{-1}
- LS2: 18 months for full LHCb upgrade
- Then: collect ~5 fb^{-1}/year

Physics reach after the upgrade

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 [139]	0.025	0.008	~0.003
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.17 [219]	0.045	0.014	~0.01
	a_{sl}^s	6.4×10^{-3} [44]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{eff}(B_s^0 \to K^{*0}\overline{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{eff}(B^0 \to \phi K_S^0)$	0.17 [44]	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 penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [68]	0.025	0.008	0.02
	$s_0 A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [68]	6 %	2 %	7 %
	$A_I(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [77]	0.08	0.025	~0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [86]	8 %	2.5 %	~10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	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° [252, 266]	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° [44]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [44]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–

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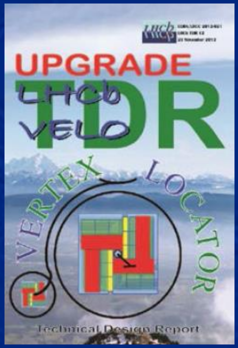
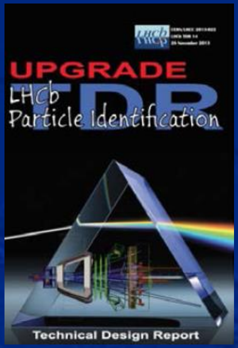
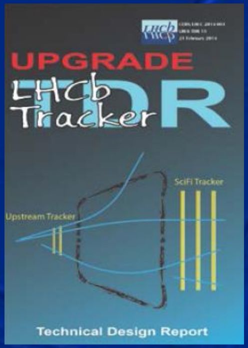
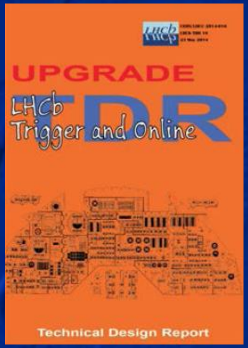
Summary

- Thanks to its excellent performance LHCb is producing world best measurements in the beauty and charm sector
- The Upgraded LHCb trigger-less scheme, guaranteeing event processing at 40 MHz, will allow to collect 5 fb^{-1} per year
- The upgrade will be performed in 2018-19 during LS2; data taking will start in 2020
- The LHCb upgrade is mandatory to reach experimental precision of the order of theoretical uncertainties
- The LHCb upgrade is fully approved





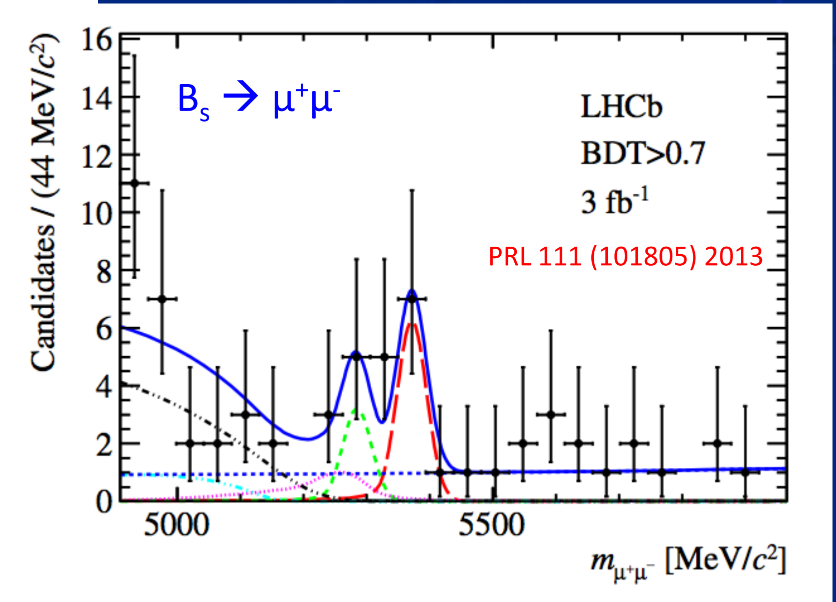


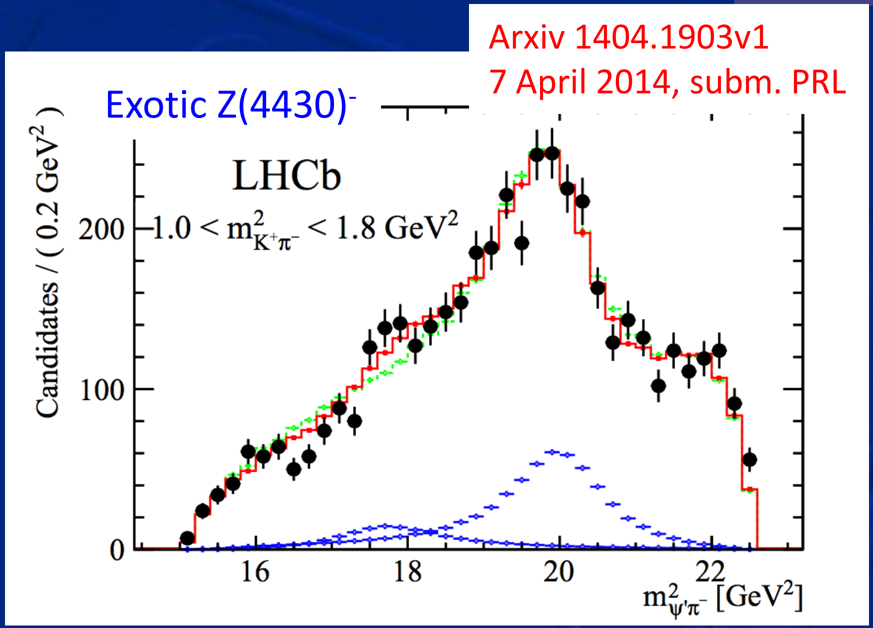


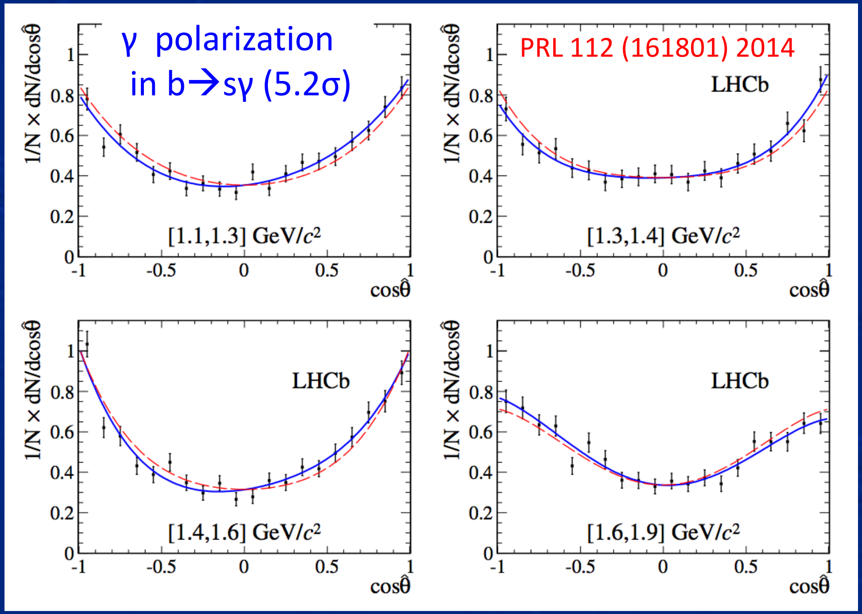
4π view from Arthur's Seat (yesterday, ~06:00 am)

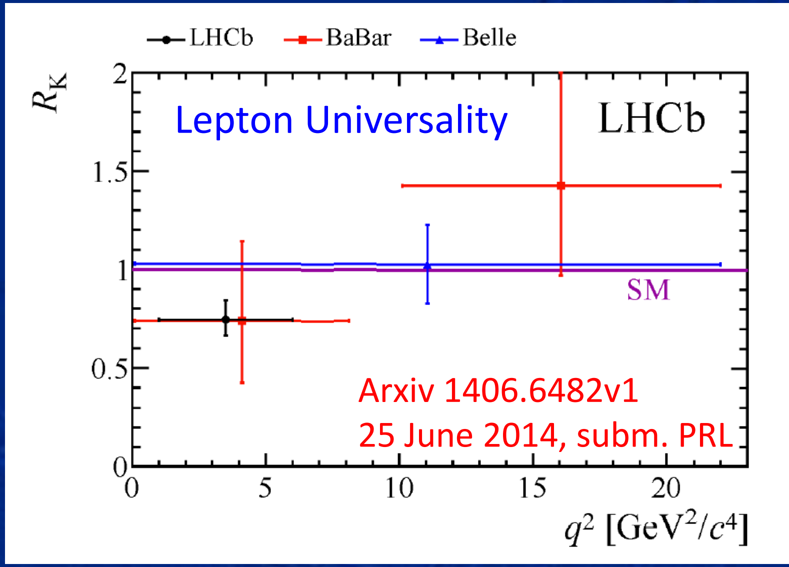
Spare slides

A few physics highlights

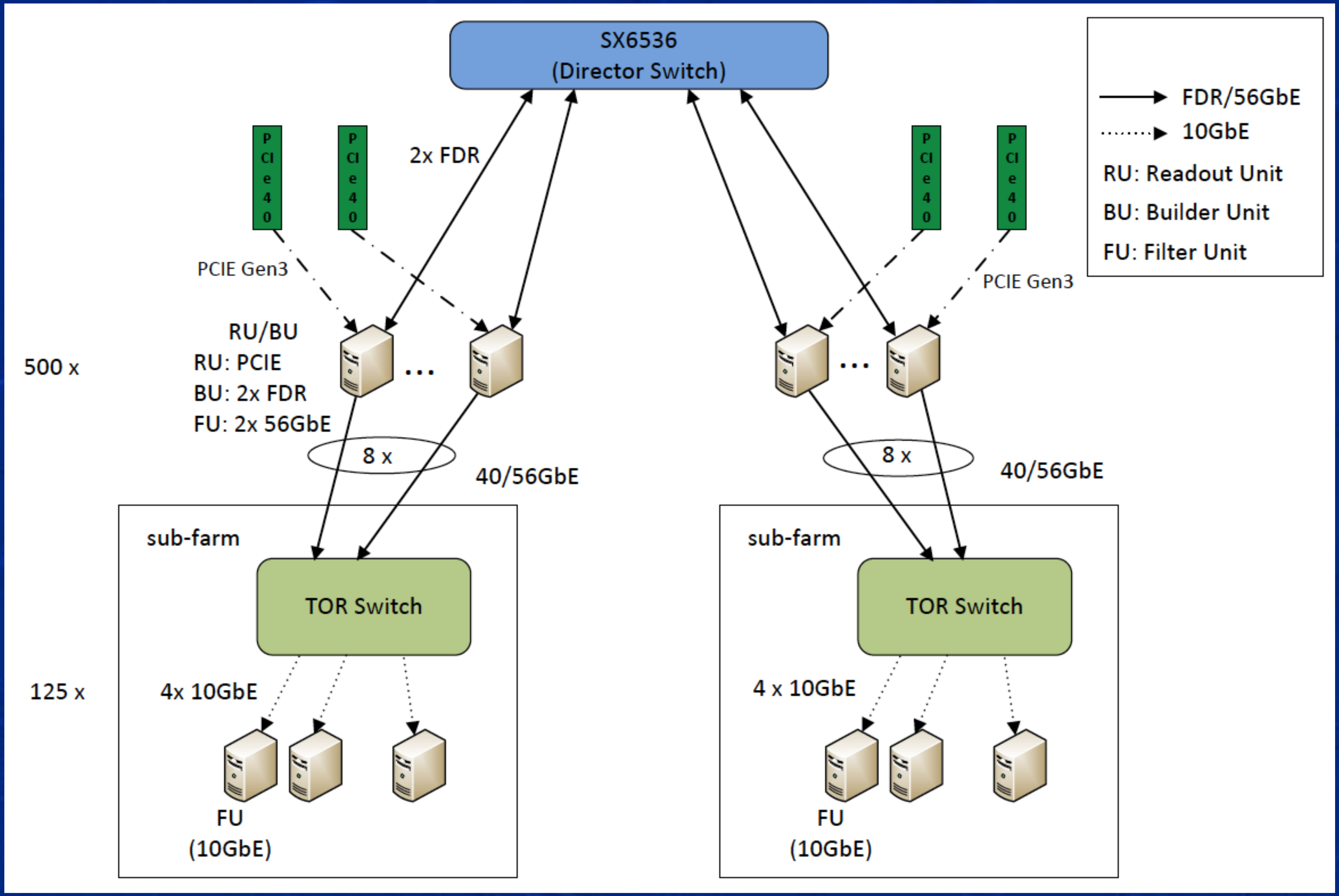








The new DAQ



Bidirectional event-building scheme uses FDR Infiniband for event-building and Ethernet for event distribution