LHCb upgrade: Plans and physics potential

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LHCb upgrade

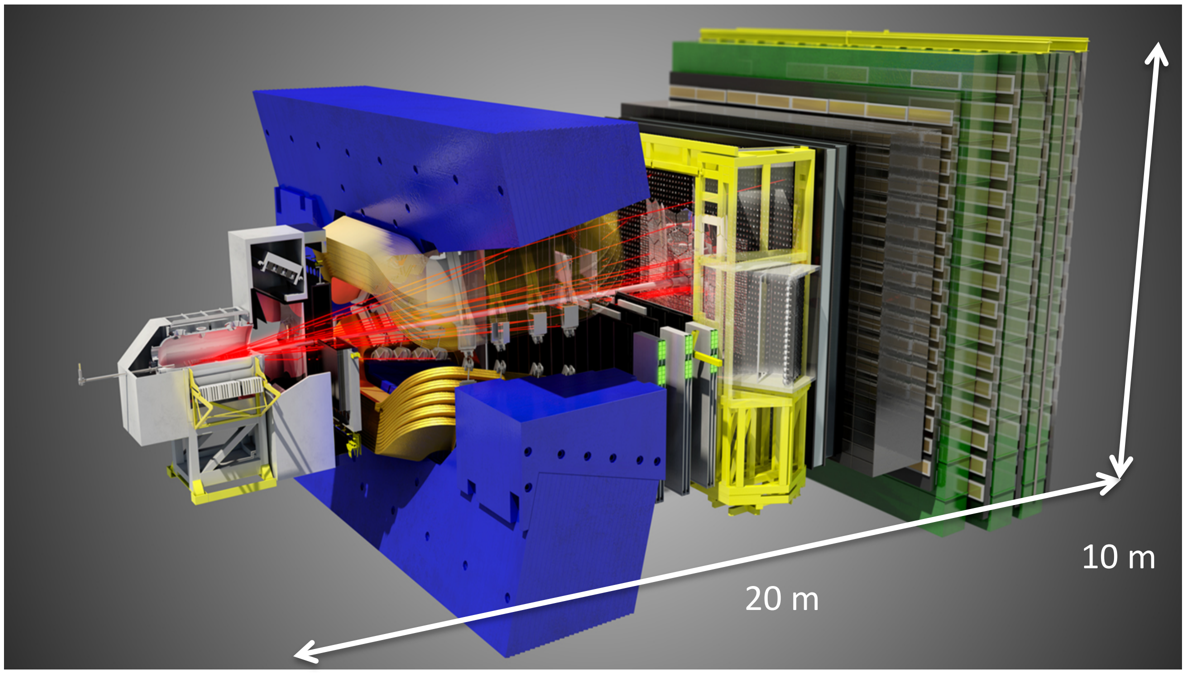
- The upgrade of the LHCb detector and DAQ system aims to enable the collaboration to run the experiment at a luminosities 5 times greater than presently:

  $L_1 = 4. \times 10^{32}\ cm^{-2}\ s^{-1} \rightarrow L_2 = 2. \times 10^{33}\ cm^{-2}\ s^{-1}$

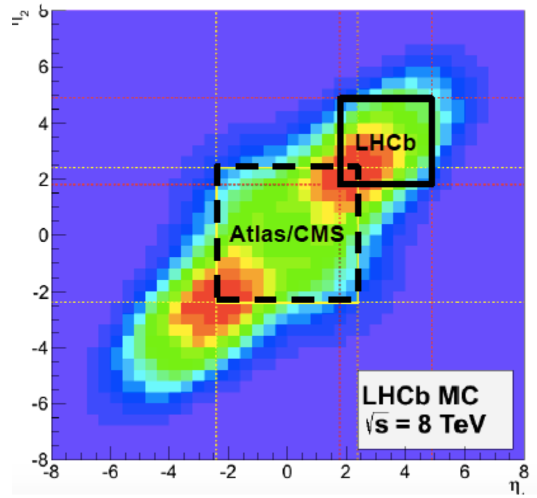
- **Goals**:
  - Double the present yield: collect 5 fb^{-1}/y in run 3 and run 4
  - Improve considerably the trigger efficiency on hadronic channels ($B_s \rightarrow \phi\phi$) and on rare decays.
  - Expand the scope to the lepton flavor sector, electroweak physics, QCD and exotics searches.
- The upgrade (phase I) will take place during the LS2, foreseen in the years 2019 – 2020.

Single arm forward spectrometer

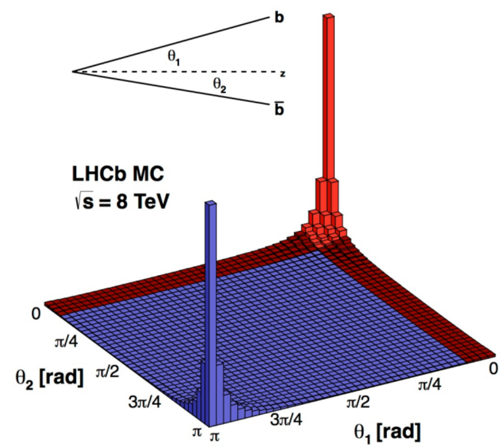
Covering about 4% of the solid angle the detector captures 40% of the beauty and charm cross-sections.



Acceptance $2 < \eta < 5$



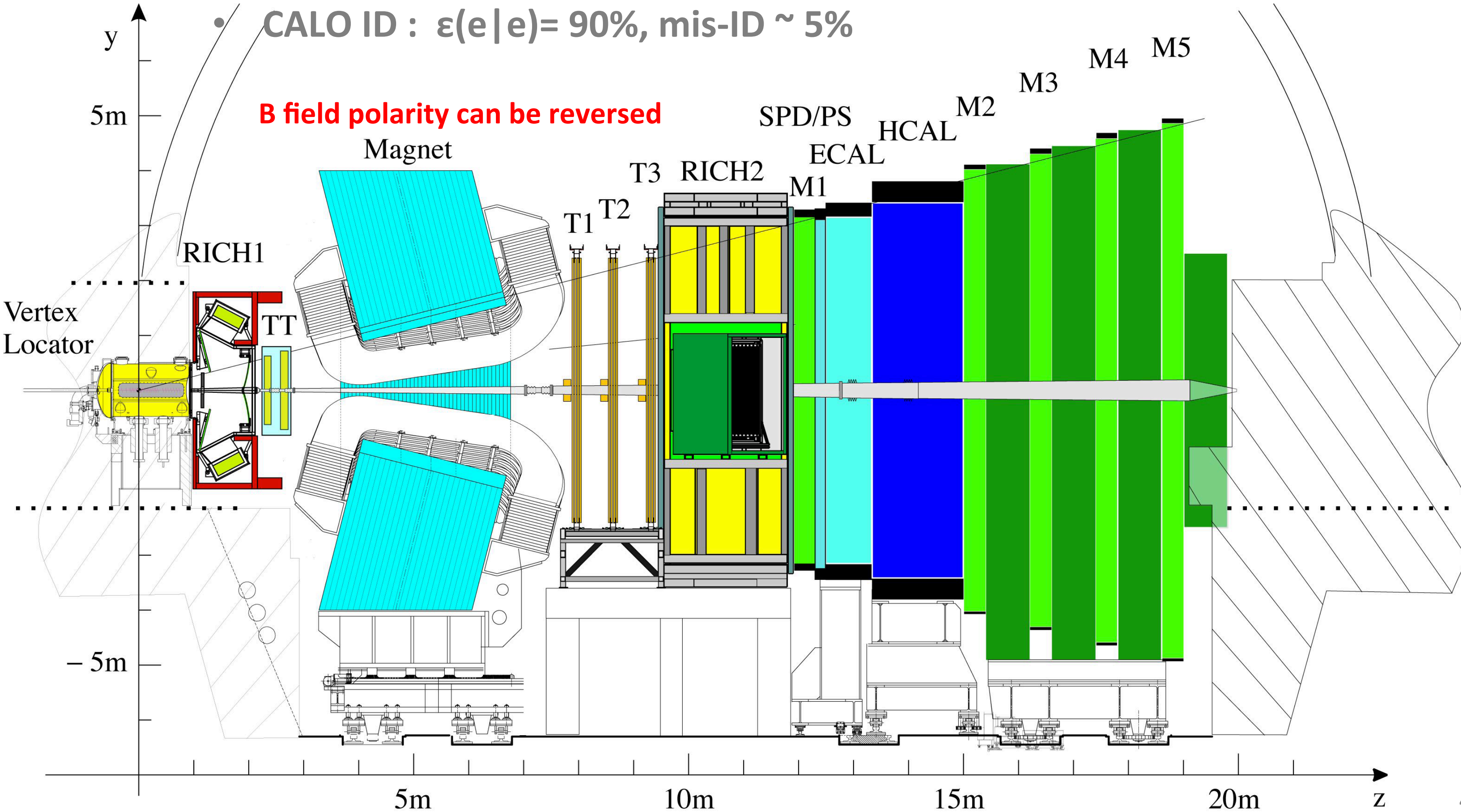
differential cross-section



- LHCb measured σ_{beauty} = 75 μb at √s = 7 TeV in acceptance.
- Charm cross section is ~20 times more.
- Cross sections scale linearly with √s.

Present detector performance

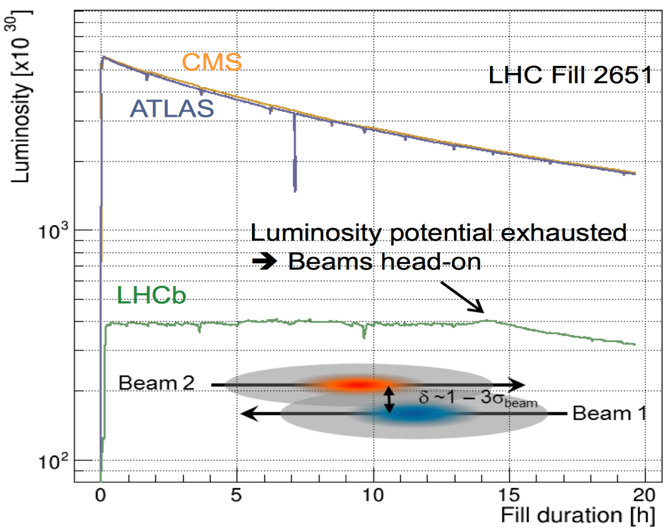
- Decay time resolution Δt: 30-50 fs
- Δp/p = 0.5-1.0% in the range 5 – 200 GeV/c
- Muon ID : ε(μ|μ) = 95%, ε(π|μ) ~ 1%
- RICH ID : ε(K|K) = 95%, ε(K|π) ~ 5%
- CALO ID : ε(e|e)= 90%, mis-ID ~ 5%



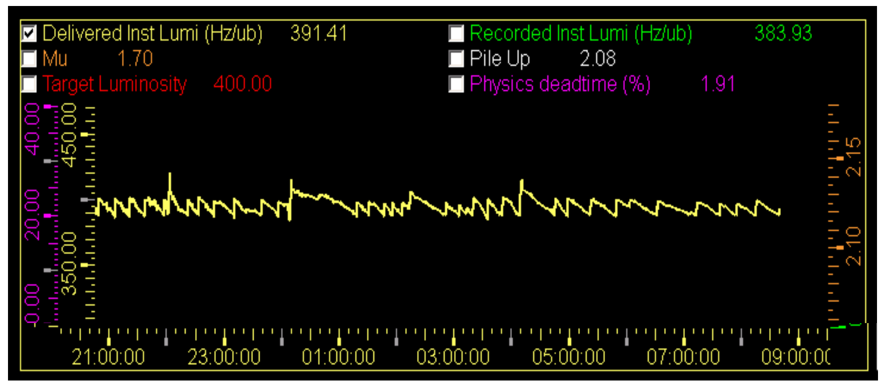
"The LHCb Detector at CERN"; The LHCb Collaboration, JINST 3, S08005 (2008)
LHCb detector performance, Int. J. Mod. Phys. A30 (2015) 1530022, arXiv:1412.6352.

Luminosity

- **Constant luminosity**: stable running conditions and selection criteria



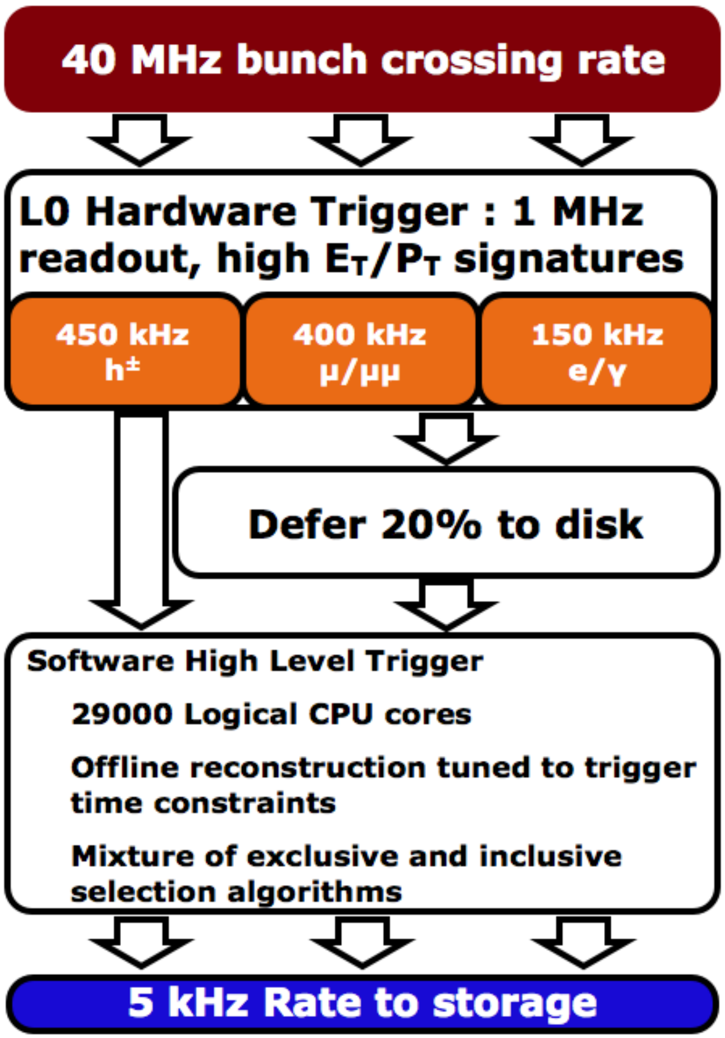
monitoring

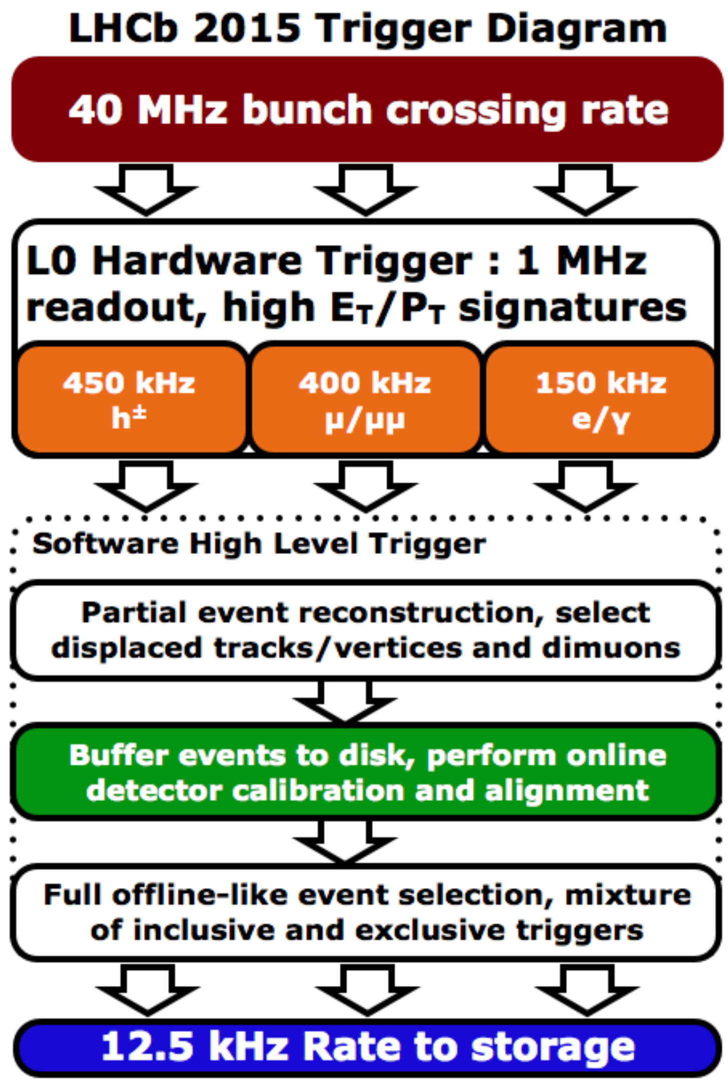


±3% around the target value

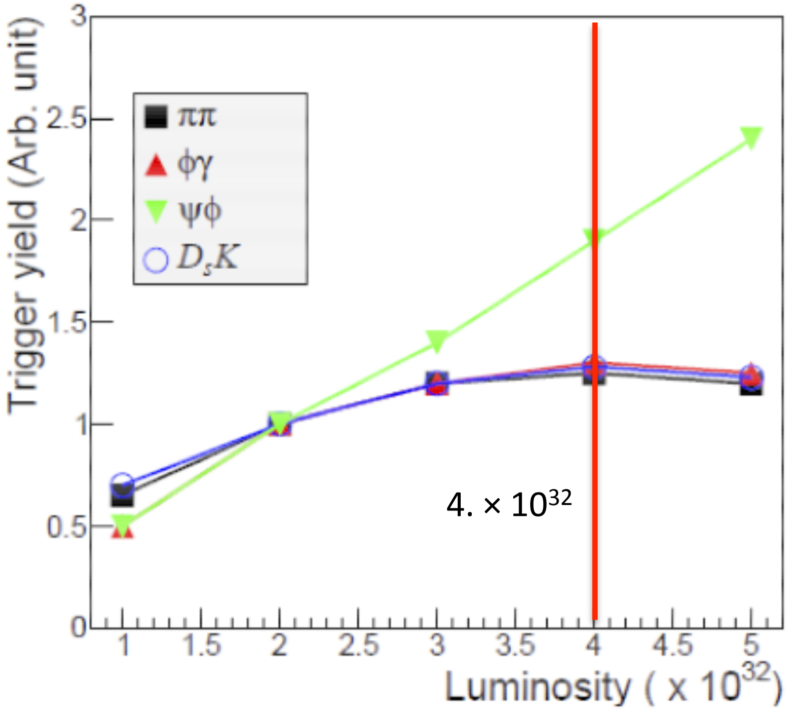
- LHCb was designed to operate with a single collision per bunch crossing, running at **2. × 10^{32} cm^{-2} s^{-1}**, with **25 ns** bunch spacing and **2700** circulating bunches.
- We run at **4. × 10^{32} cm^{-2} s^{-1}**, with **1262** colliding bunches, and **50 ns** time spacing: **4 times more collisions per crossing than planned in the detector design.**

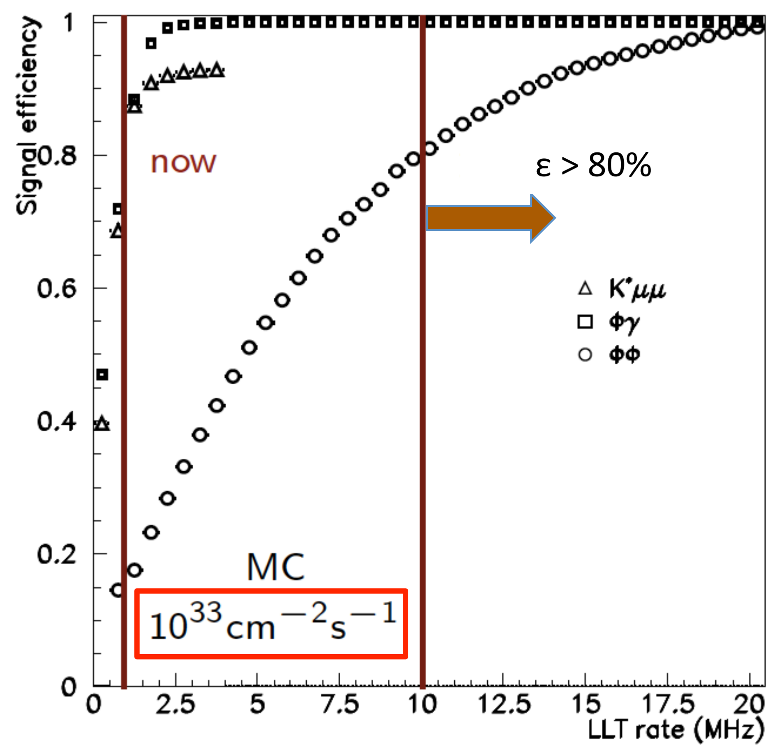
Trigger evolution





The 1 MHz readout rate limitation





- Due to the available bandwidth and the limited discrimination power of the hadronic L0 trigger, LHCb experiences the **saturation of the trigger yield on hadronic channels** around 4. $\times 10^{32}$ cm^{-2}s^{-1}
- Increasing the first level trigger rate considerably increases the efficiency on the hadronic channels.

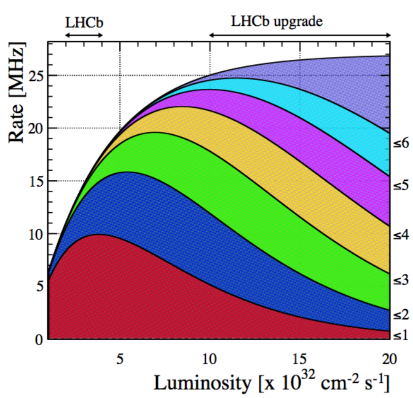
"Framework TDR for the LHCb Upgrade: Technical Design Report"; The LHCb Collaboration,CERN/LHCC-2012-007, LHCb-TDR-12 - 2012

Upgrade main concepts

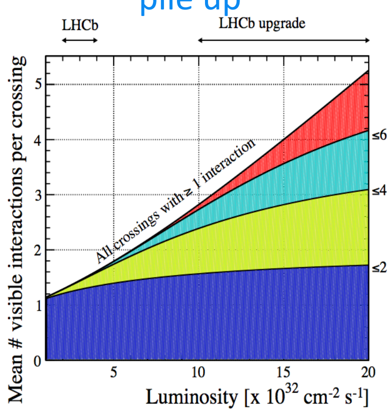
Requirements

- Readout the whole detector at 40 MHz.
- Event selection performed by means of the HLT software trigger only.
- Luminosity of 2. × 10^{33} $cm^{-2}s^{-1}$
  - pp interaction rate: 27 MHz
  - Average visible interactions: μ = 5.2
    Poisson mean: ν = 7.6

interaction rate



pile up

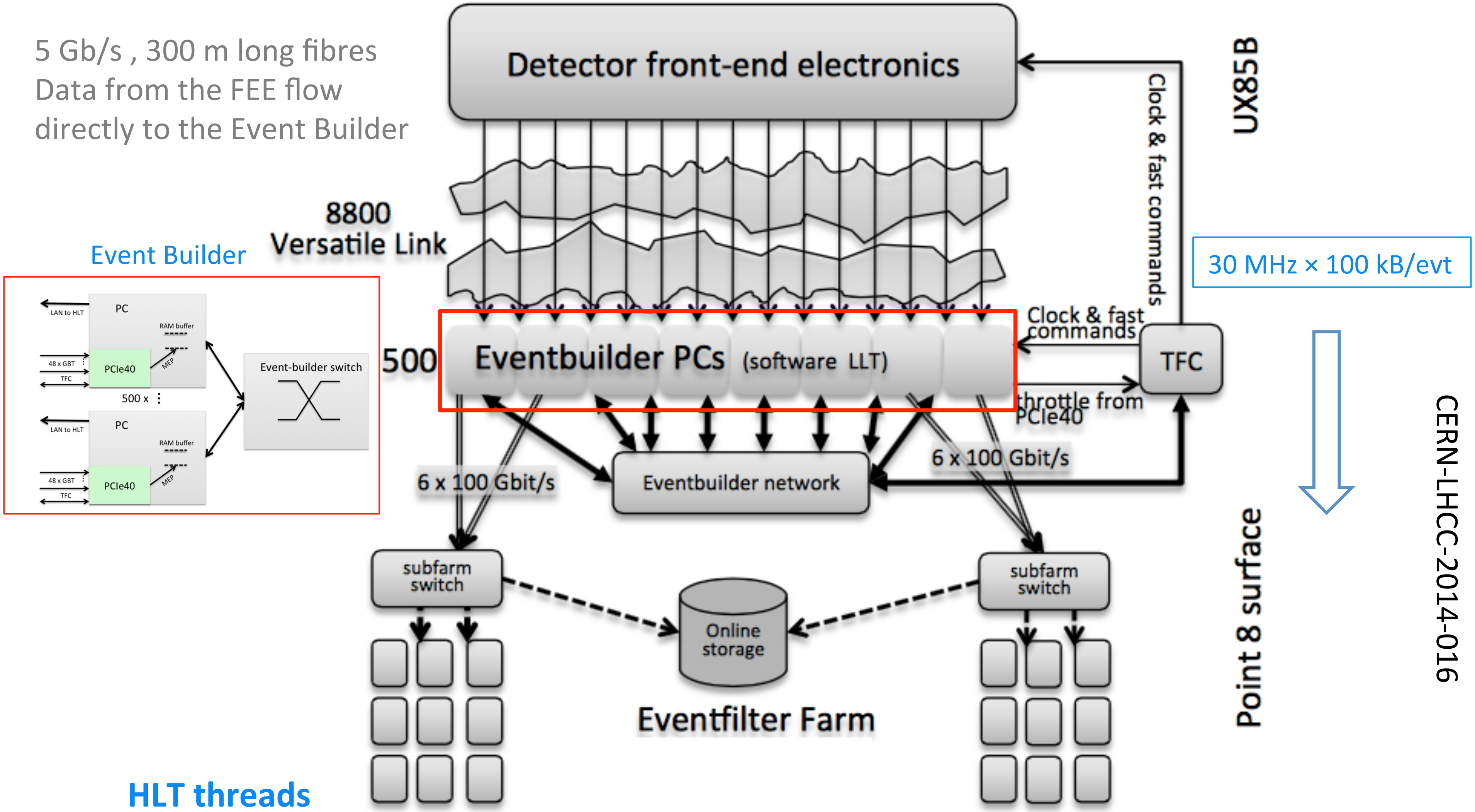


Consequences

- **The detector front-end electronics has to be entirely rebuilt** because of the new readout requirement.
- **New HLT farm and network**
  new LAN technologies and need of powerful many-core processors.
- **Rebuild the trackers**
  finer detector granularity to reduce channel's occupancy.
- **Consolidate sub-detectors**
  Let them stand the foreseen higher luminosity.

DAQ Upgrade: 40 MHz PCIe based readout

5 Gb/s , 300 m long fibres
Data from the FEE flow
directly to the Event Builder



n ~ 30 MHz × **20 ms** ~ 6 × 10^5

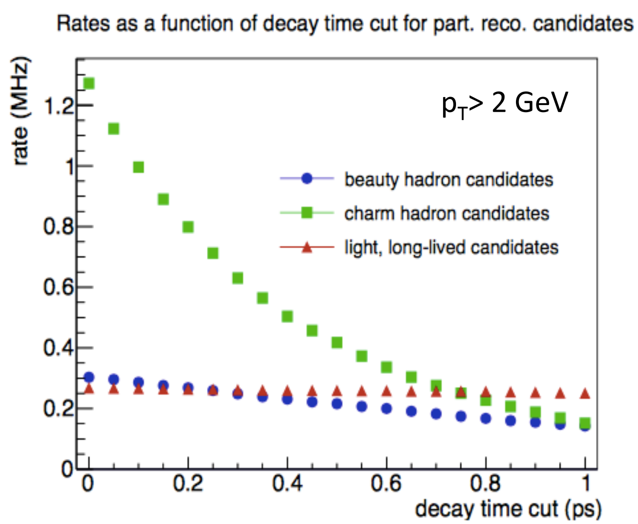
HLT output rate

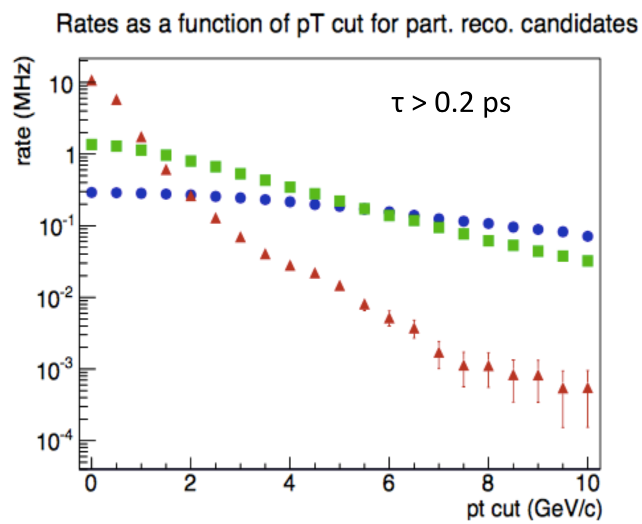
Effective input rate: 30 MHz, event size = 100 kB

MB events	b-hadrons	c-hadrons	light, long-lived hadrons
Reconstructed yield	0.032 ± 0.001	0.118 ± 0.001	0.406 ± 0.002
$\epsilon(p_{\mathrm{T}} > 2\,\mathrm{GeV}/c)$	$85.6 \pm 0.6\%$	$51.8 \pm 0.5\%$	$2.3 \pm 0.1\%$
$\epsilon(\tau > 0.2\ \mathrm{ps})$	$88.1 \pm 0.6\%$	$63.1 \pm 0.5\%$	$99.5 \pm 0.1\%$
$\epsilon(p_{\mathrm{T}}) \times \epsilon(\tau) \times \epsilon(\mathrm{LHCb})$	$27.9 \pm 0.3\%$	$22.6 \pm 0.3\%$	$2.2 \pm 0.1\%$
Output rate	$27\ \mathrm{GB\,s^{-1}}$	$80\ \mathrm{GB\,s^{-1}}$	$26\ \mathrm{GB\,s^{-1}}$

Candidates which had at least two tracks from which a vertex could be produced.

Challenge

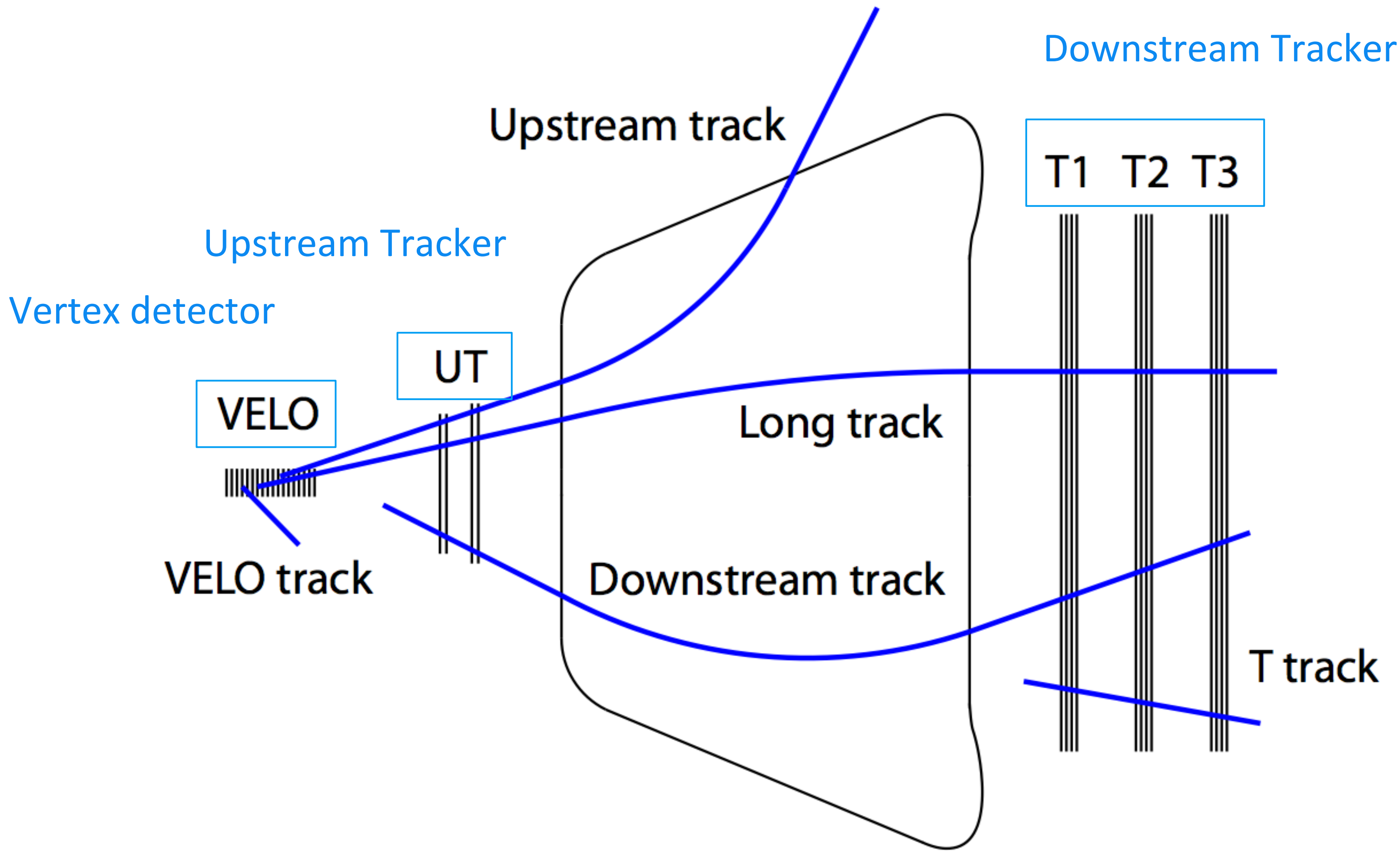




LHCb-PUB-2014-040

How to limit the HLT output rate? downscale signals, reduce the event size.

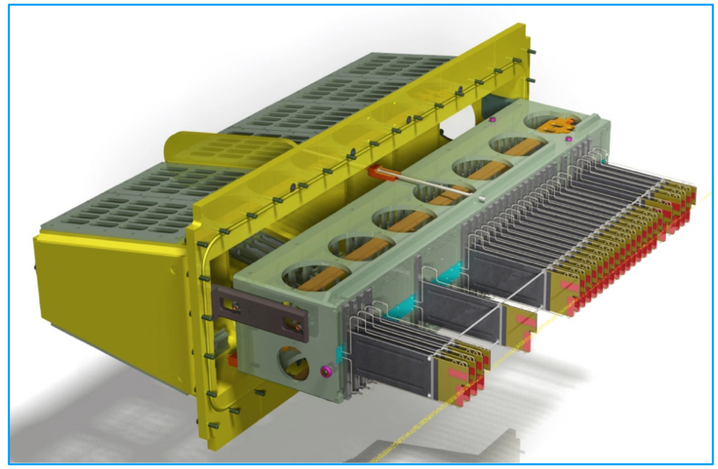
Upgrade of the tracking system



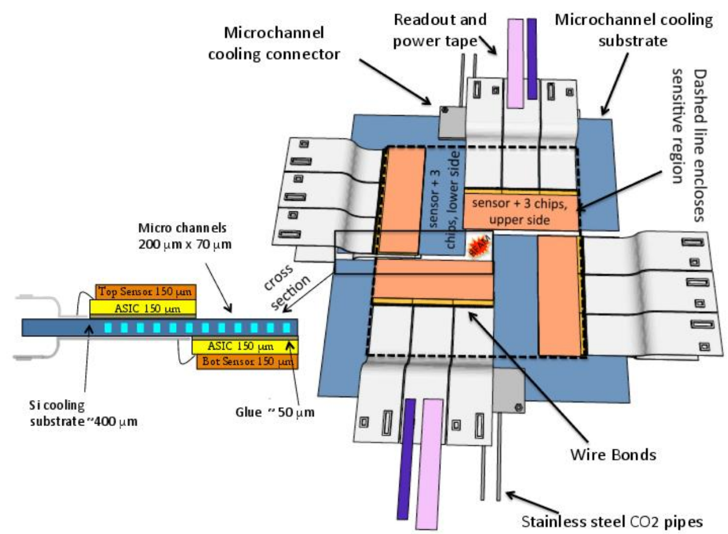
VELO upgrade

- **Silicon pixels for higher granularity and improved resolution**
  - Pixels of surface area 55 × 55 μm^2
- **Reduced material** **budget:**
  - Sensor thickness: 300 µm → 200 µm
  - Aluminum foil: 300 µm→ ≤ 250 µm
- **Enlarged acceptance:**
  - Edge of detector closer to beam 8.2 mm → 5.1 mm
  - 26×2 modules, in two retractable halves.
- **New readout chip** VeloPix with CMOS 130 nm technology
  - Sustain ~400 MRad
  - Close to beam ~10^{16} $n_{eq}cm^{-2}$ for 50 fb^{-1}
- **Cooling**
  - Cool to -10°C to -15°C to prevent thermal runaway, by using micro-channel CO_2 cooling

One of the retractable halves



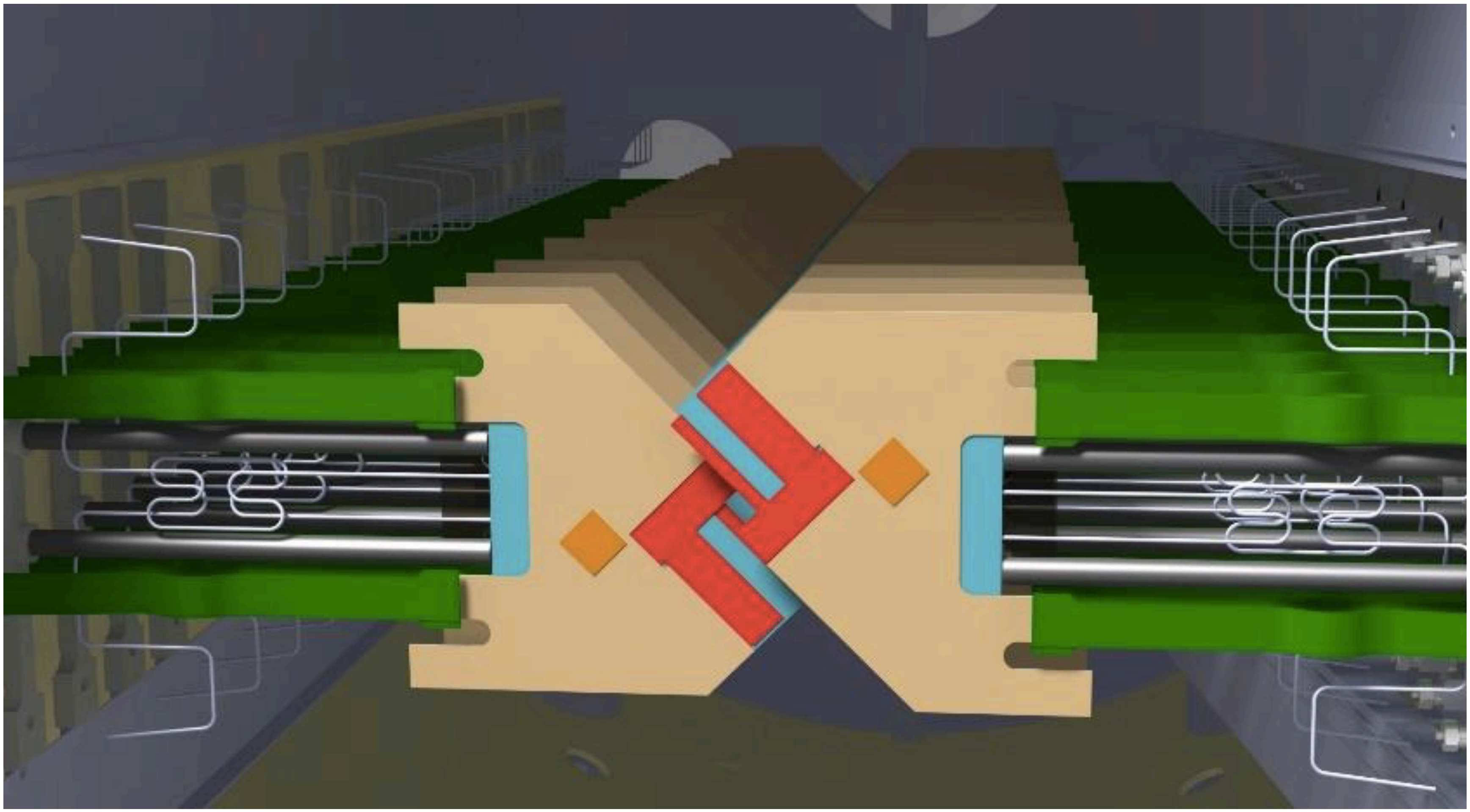
VELO module



http://cds.cern.ch/record/1624070/files/LHCB-TDR-013.pdf

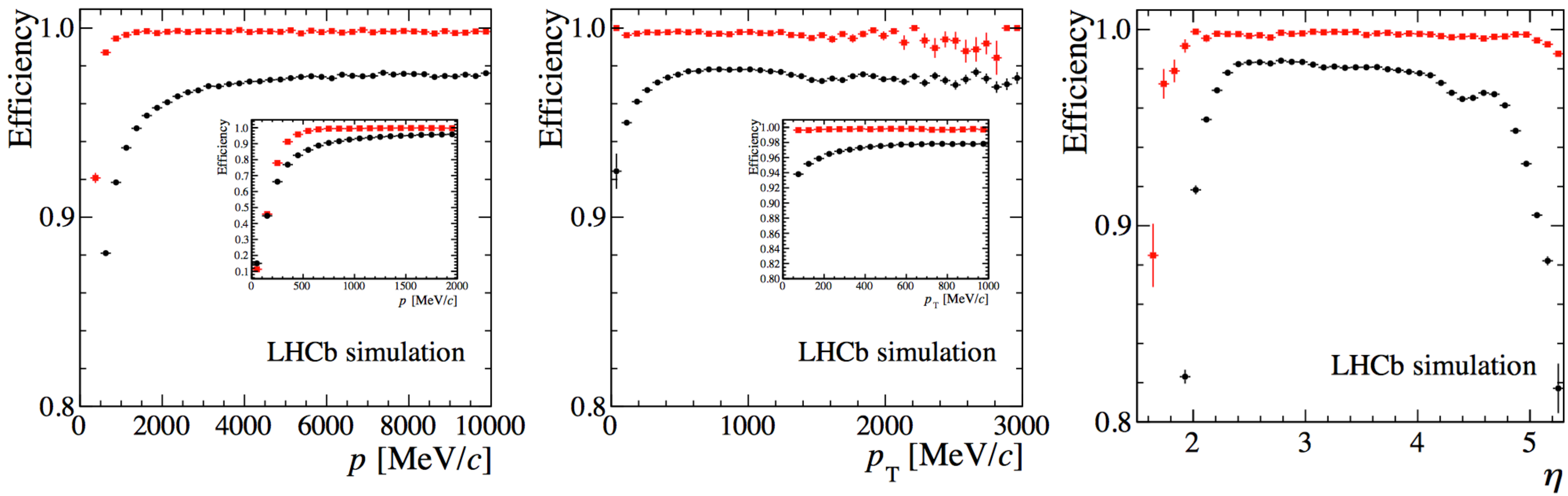
Velo Upgrade (II)

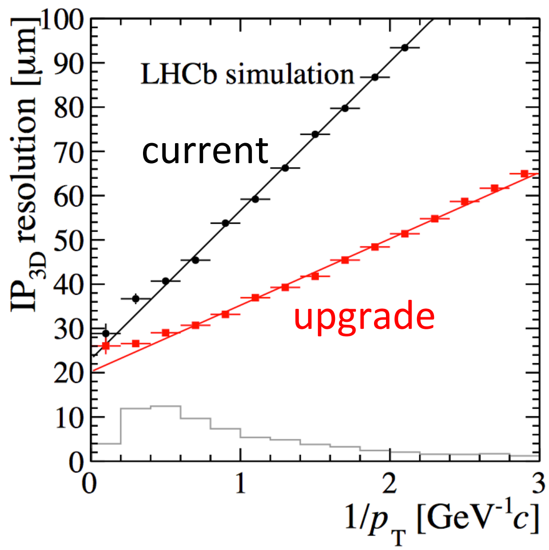
Velo halves in running position



VELO upgrade performance

Tracking efficiency





ν: pp interactions per crossing	Existing VELO [%] $\nu = 2$	Existing VELO [%] $\nu = 7.6$	Upgraded VELO [%] $\nu = 7.6$
Ghost rate	6.2	25.0 (strip)	2.5 (pixel)
Clone rate	0.7	0.9	1.0
Reconstruction efficiency			
VELO, $p > 5$ GeV/c	95.0	92.7	98.9
long	97.9	93.7	99.4
long, $p > 5$ GeV/c	98.6	95.7	99.6
b-hadron daughters	99.0	95.4	99.6
b-hadron daughters, $p > 5$ GeV/c	99.1	96.6	99.8

Expected output data rate: 3 Tb/s

current: current technology with upgrade condition

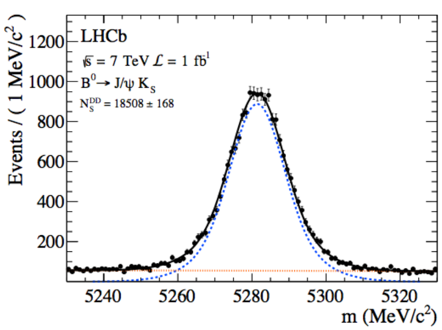
Upstream Tracker

- **Reconstruct downstream tracks** of particles decaying after the VELO ($K_S \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi$, etc.)
- **Reconstruct upstream tracks**: slow momentum particles that bend out of the acceptance.
- **Improve momentum resolution and signal purity** of long tracks.
- **p_T estimate of charged tracks for fast trigger tracking**
  - $\sigma(p_T)/p_T$~15% in the p_T range of 0.5-10 GeV/c.

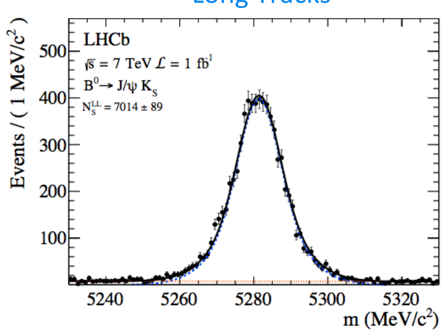
CERN-LHCC-2014-001 ; LHCB-TDR-015.-2014.

$B_d \rightarrow J/\psi\ K_S$

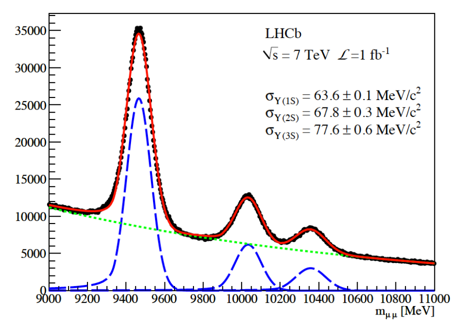
Downstream Tracks

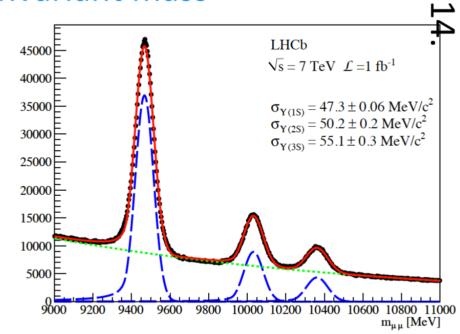


Long Tracks



muon pairs invariant mass

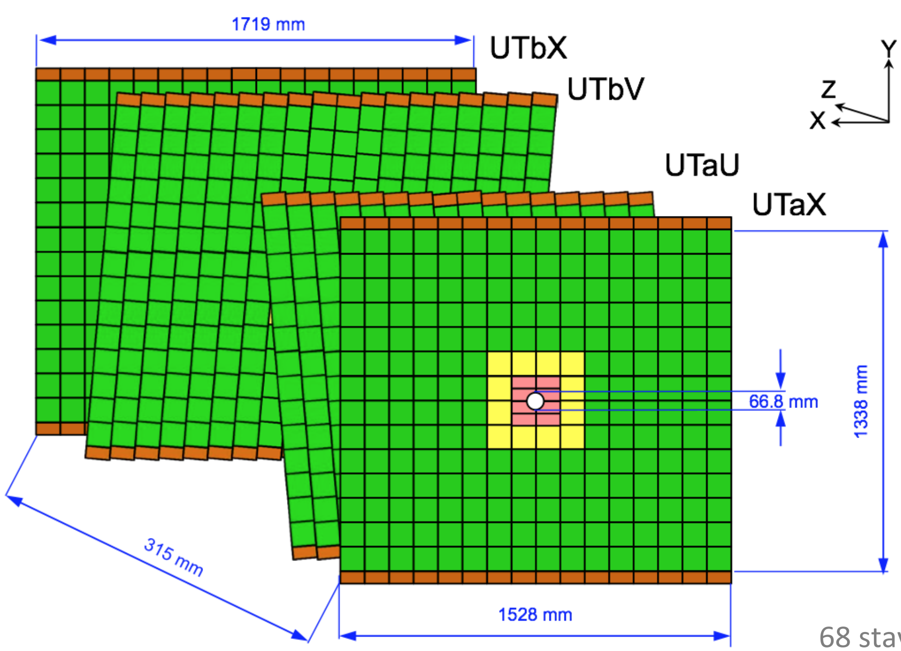




mass resolution improves by about 25%

Upstream Tracker (II)

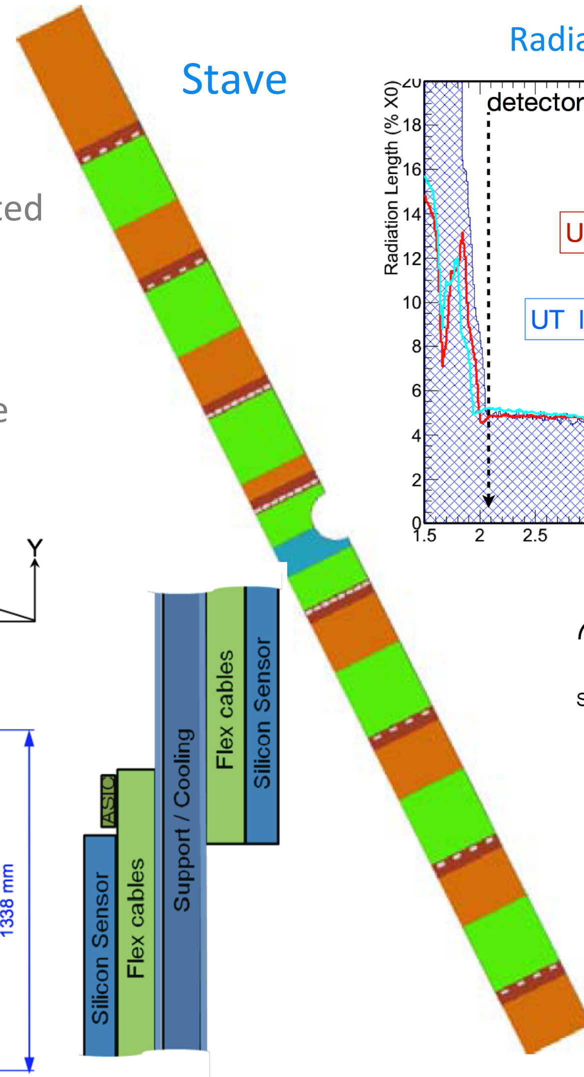
- Material budget kept to minimum: ~1% X_0 per plane. Light mechanics and cooling system.
- Single-sided silicon strip sensors 250 µm thick instead of 500 µm. Strip pitch and length adapted to the particle flux depending on the position.
- Single-hit resolution of 50 µm.
- Improved coverage by overlapping sensors.
- Closer to beam pipe to improve the small-angle acceptance.



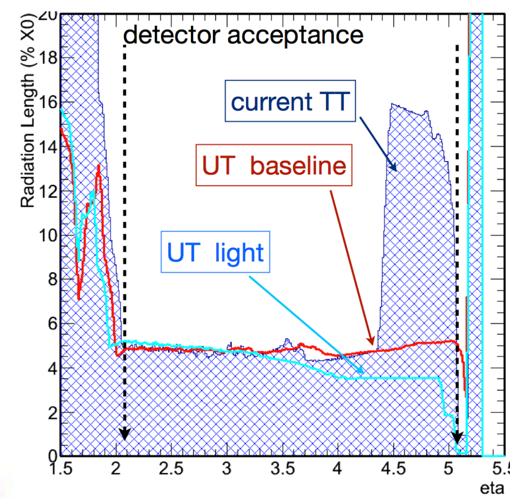
Strip pitch and length

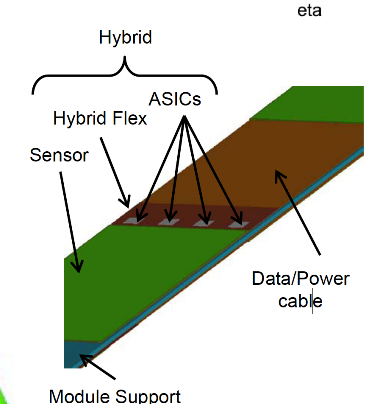
98 mm 190 µm 512 strips | 98 mm 95 µm 1024 strips | 49 mm 95 µm | 49 mm 95 µm

Stave



Radiation Length





Sensors will be operated at a temperature of -5°C
Bi-phase CO_2 cooling in stave support

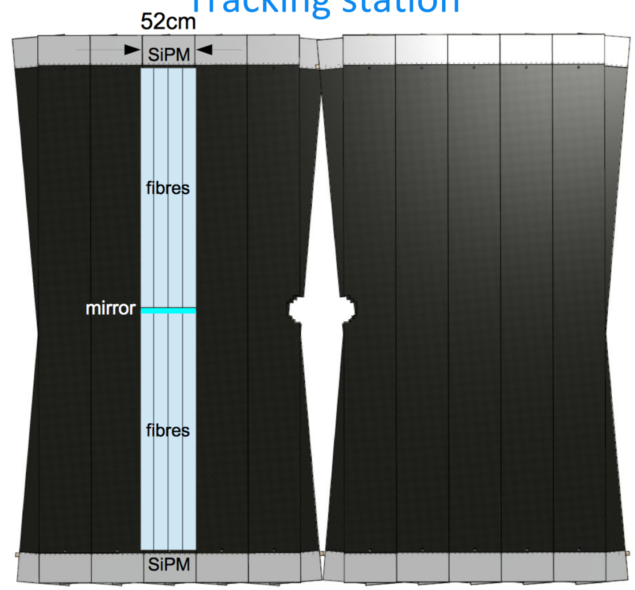
68 staves, staggered 10 mm in z to provide overlap in x

CERN-LHCC-2014-001 ; LHCB-TDR-015.-2014.-196p. (Technical Design Report LHCb ; 15)

SciFi: the Downstream Tracker

- Scintillating Fibre Trackers covering the full acceptance: $5 \times 6\ m^2$
- A SciFi detector module is made of multiple layers of 2.5 m long scintillating fibres of 250 μm diameter.
- Very light and uniform material distribution: $X/X_0 = 2.6\%$ per station.
- The fibres are read by SiPM.
  - The SiPMs need to be cooled to -40°C to mitigate radiation damages.
- Expected 60 – 100 μm spatial resolution.

Tracking station

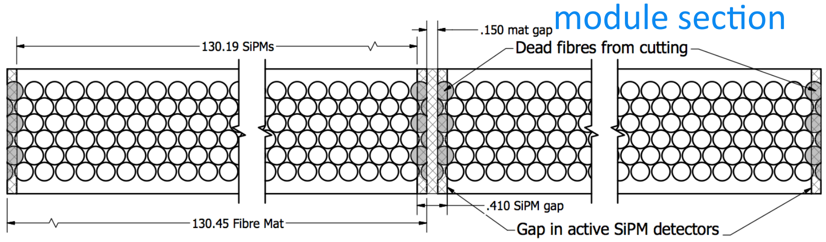


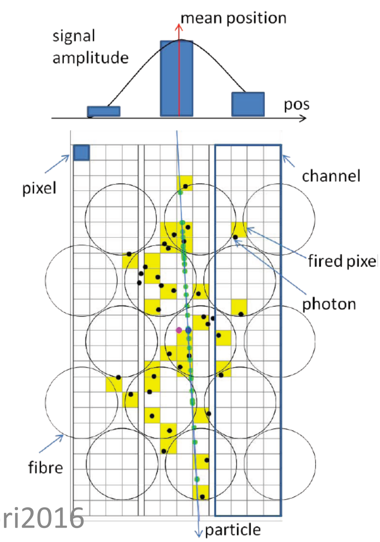
modules

X U V X

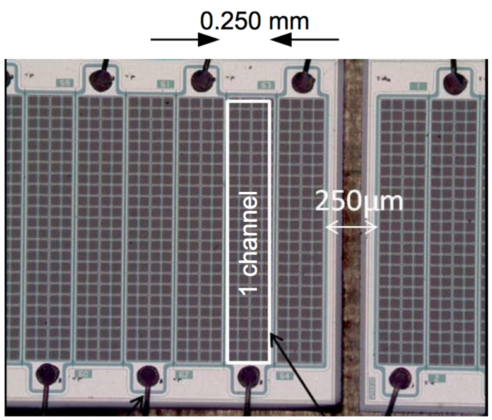
U & V at 5°

module section





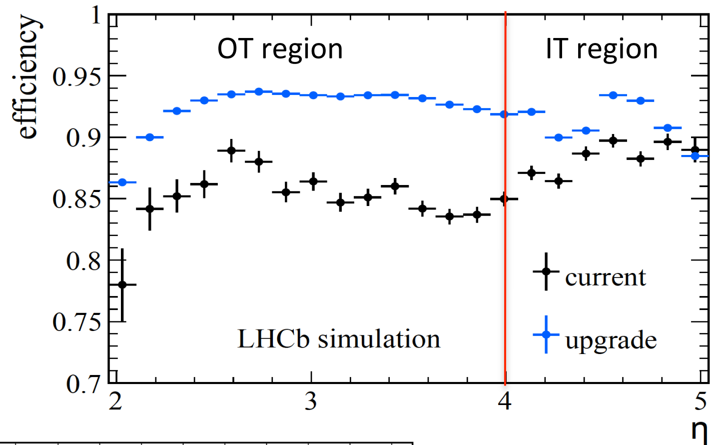
Array of SiPM



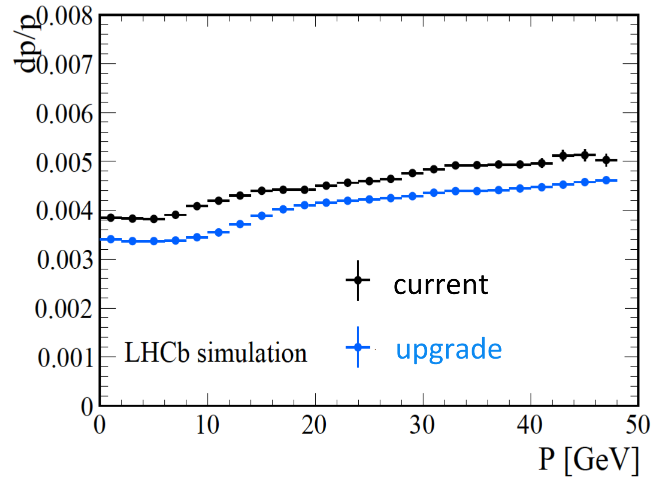
CERN-LHCC-2014-001 ; LHCB-TDR-015.-2014.-196p. (Technical Design Report LHCb ; 15)

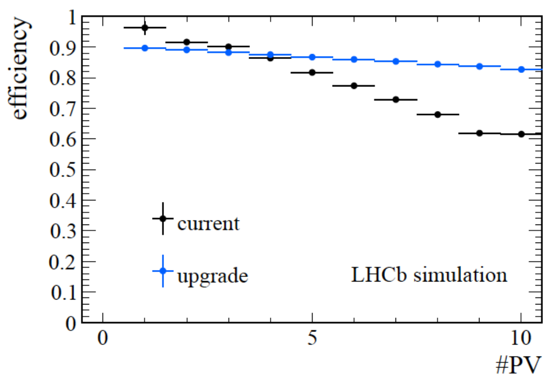
Tracking performance

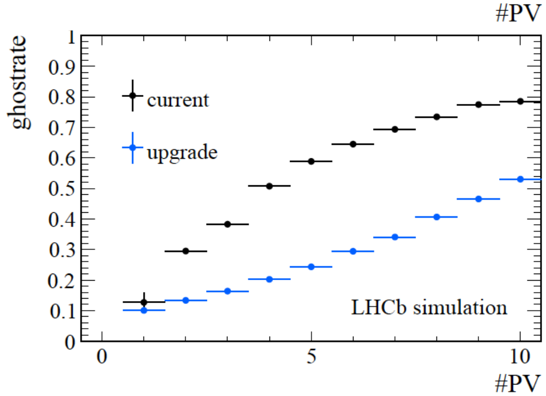
efficiency as function of η



momentum resolution







current: current technology with upgrade condition

Performance as function of primary vertices

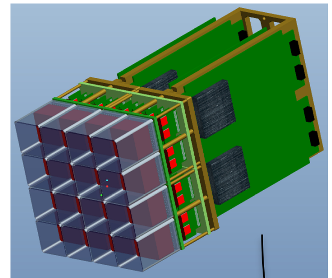
	Current LHCb [%]	Upgrade LHCb [%]	
	$\nu = 2$	$\nu = 3.8$	$\nu = 7.6$
Ghost rate	13.1	14.7	25.5
Reconstruction efficiency			
long	90.9	86.9	84.5
long, $p > 5\,\text{GeV}/c$	95.4	92.9	91.5
b-hadron daughters	93.9	91.9	90.6
b-hadron daughters, $p > 5\,\text{GeV}/c$	96.1	95.1	94.2

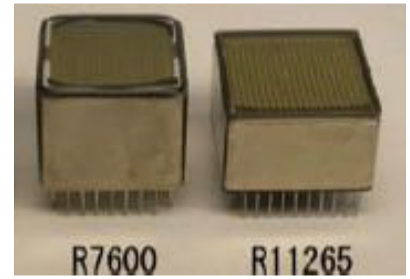
$4. \times 10^{32}$ cm^{-2}s^{-1} $\quad$ 2×10^{33} cm^{-2}s^{-1}

CERN-LHCC-2014-001 ; LHCB-TDR-015.-2014.-196p. (Technical Design Report LHCb ; 15)

RICH detector

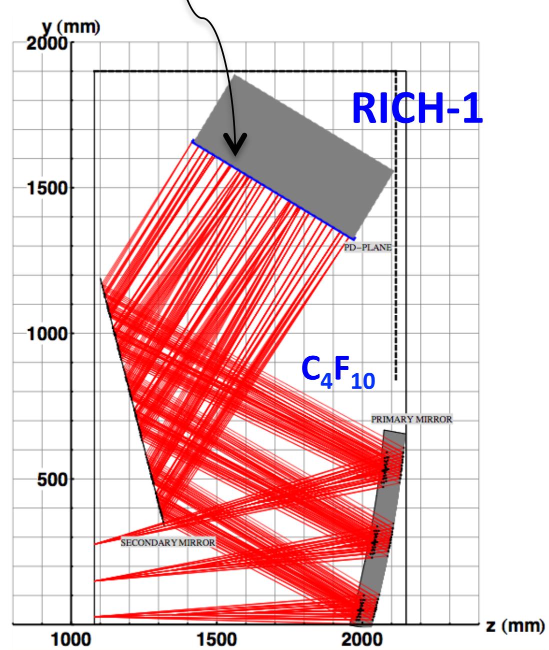
- The overall structure of RICH-1 and RICH-2 unchanged.
- HPD photon detectors will be replaced with MaPMT
  - 1920 MaPMT in RICH-1 and 2560 in RICH 2
- The optical layout of RICH 1 has to be modified to reduce the hit occupancy.
  - Increasing the focal length of the spherical mirrors halving the occupancy.
- Remove the Aerogel radiator in RICH-1.
  - ~3.5% of X_0
  - The K and π threshold in C_4F_{10} are 9.3 GeV/c and 2.6 GeV/c .





PDM size of 116 × 116 mm^2

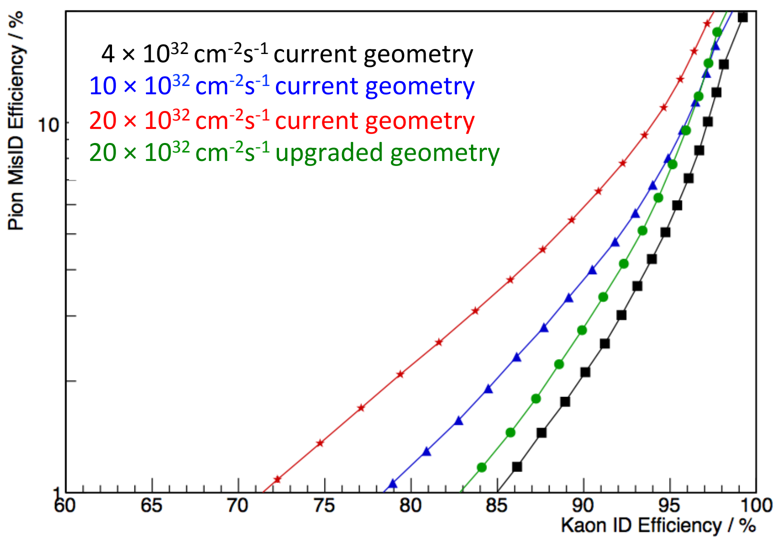
R11265 MaPMT from Hamamatsu.

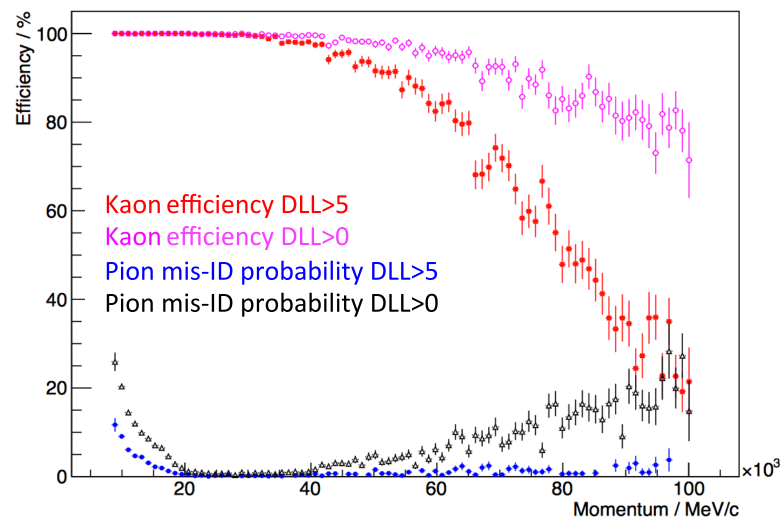


RICH PID performance

Running the full simulation and reconstruction chain in $B_s \rightarrow \phi\phi$

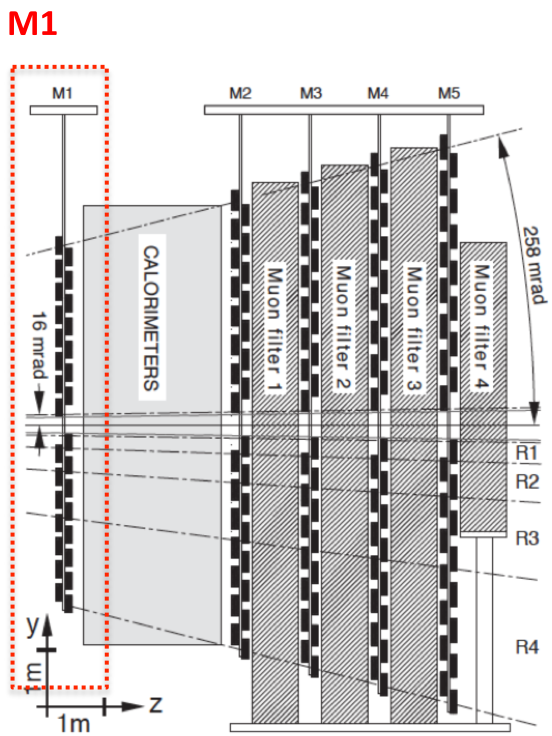
Compare upgraded with current geometry



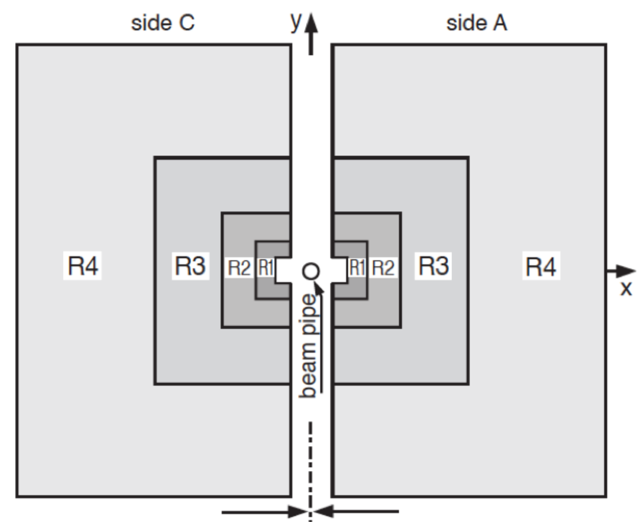


Performance of the LHCb RICH detector at the LHCThe European Physical Journal CMay 2013, 73:2431
CERN-LHCC-2013-022 ; LHCB-TDR-014. - 2013.

MUON system



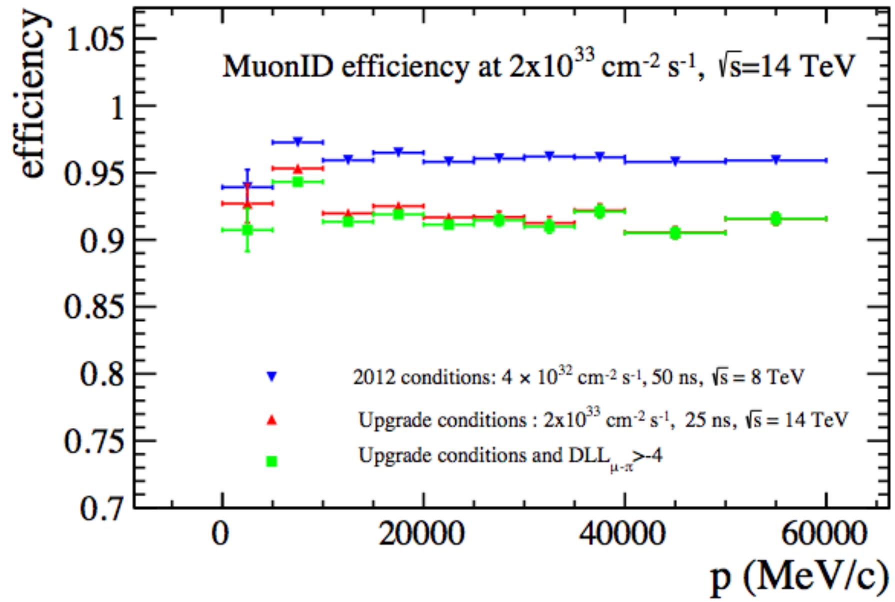
Anode-pad triple-GEM detectors for the R1 regions, MWPCs for the external regions.



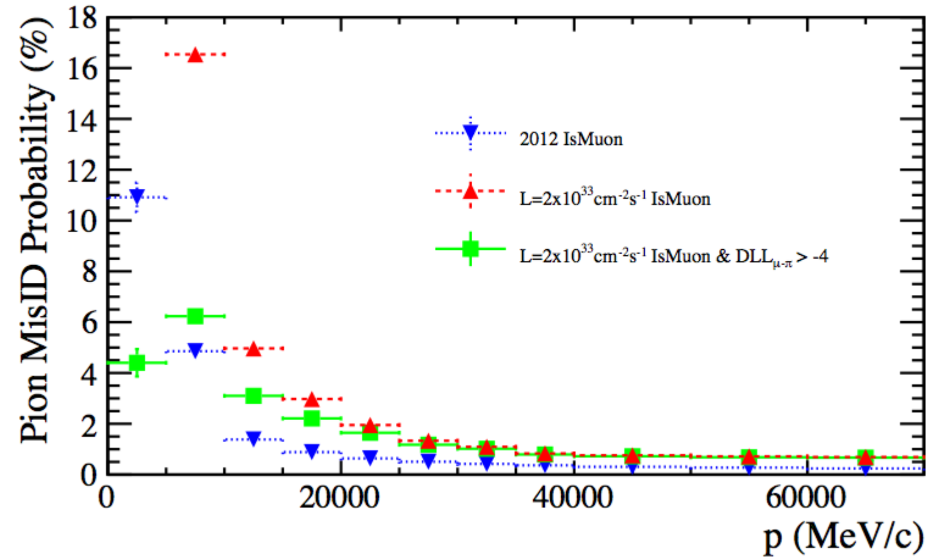
- M1 will be removed: currently used by the L0 trigger.
- High particle flux in the innermost regions of station M2.
  Shielding will be installed around the beam-pipe, behind the HCAL, to reduce the occupancy in these regions.

MUON ID Performance

Efficiency



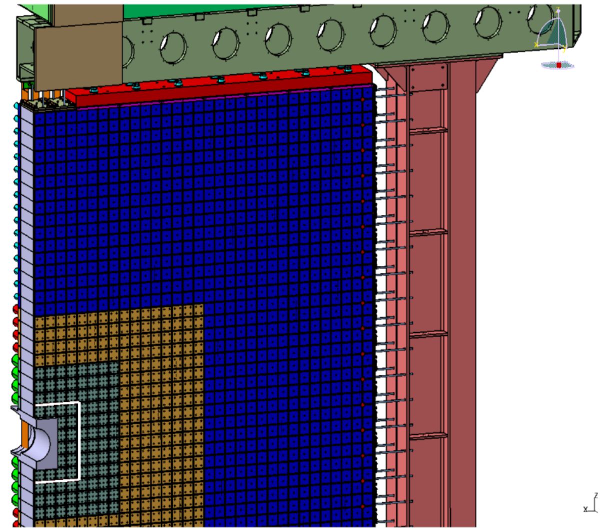
Pion MisID



- The upgrade and current performance are obtained from a simulated sample of $B_s \rightarrow \mu^+\mu^-$ events and are evaluated for single muon.
- $DLL_{\mu\pi}$ variable: is based on the distance of matching hits from the extrapolated track in the muon stations, combined with the information coming from RICH and calorimeter detectors.

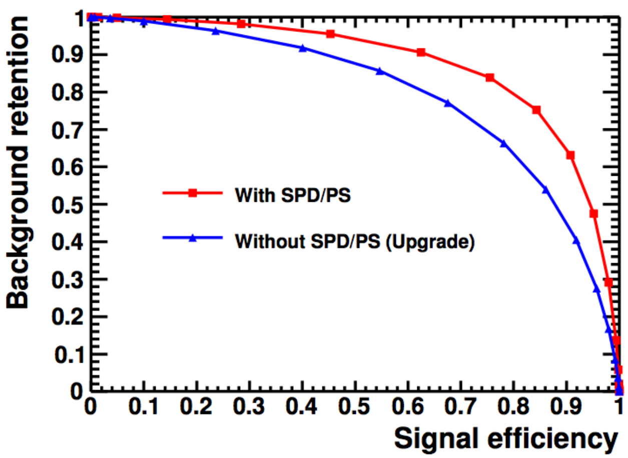
Calorimeters

- The scintillating pad detector (SPD) and the pre-shower (PS) will be removed.
- Very little effect for the higher electron momentum: p > 10 GeV/c
- A reduction of 10 to 15% in the efficiency is expected at a fixed background retention for lower momenta.

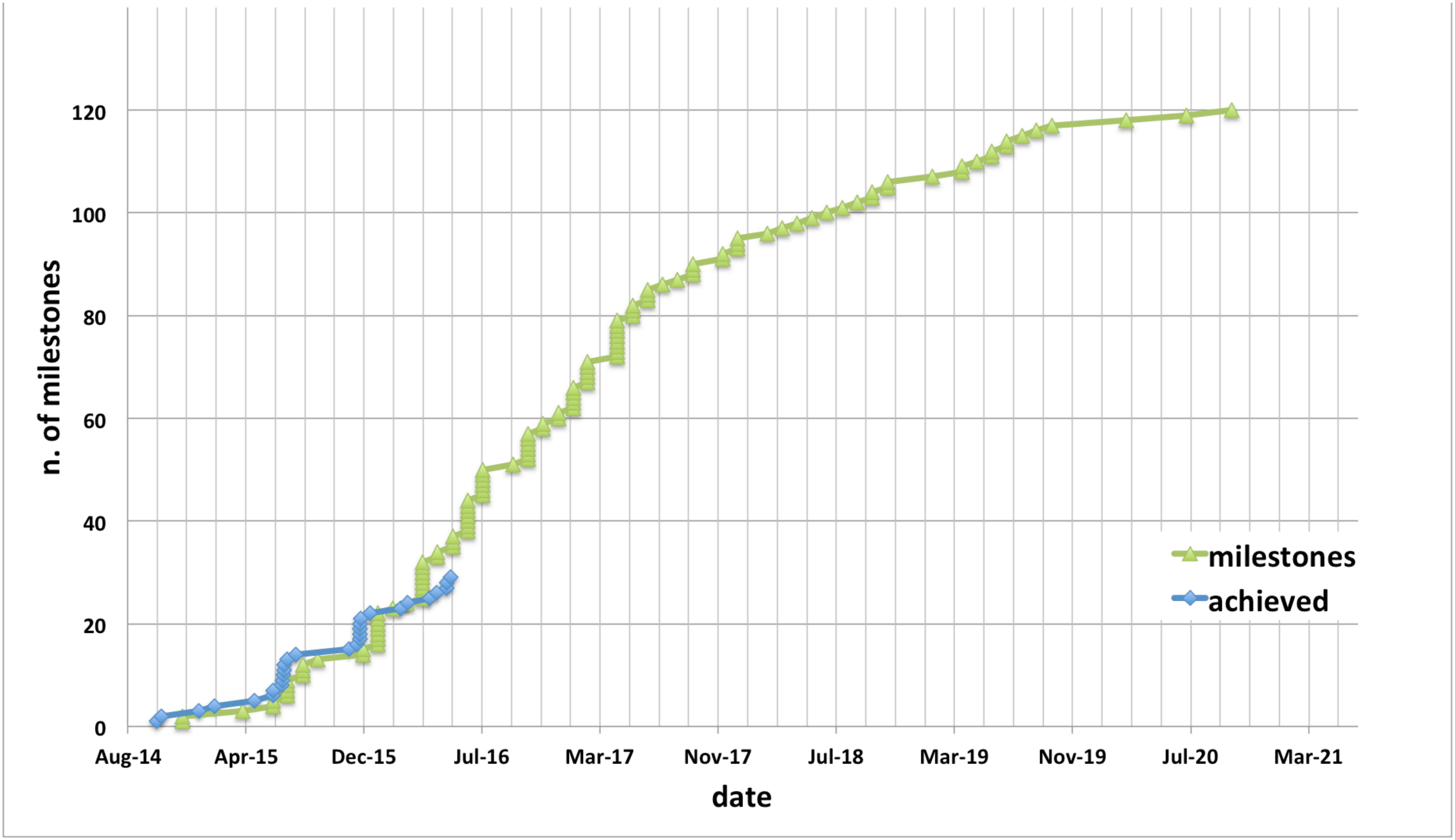


Momentum (GeV/c)	SPD/PS $\nu = 7.6$	no SPD/PS $\nu = 7.6$
Selection efficiency 80%		
$0 < p < 10$	3.2	9.0
$p > 10$	0.29	0.32
Selection efficiency 90%		
$0 < p < 10$	12	18
$p > 10$	1.3	1.4

Photon selection



Upgrade milestone evolution



LHCb upgrade beyond 2023

- **Upgrade phase Ib: Run 4, 2027 – 2030**
  - Run still at 2. × 10^{33} $cm^{-2}s^{-1}$, with an improved detector.
- **Upgrade phase II: Run 5, beyond 2031**
  - Run at 2. × 10^{34} $cm^{-2}s^{-1}$, v~40 to collect ~300 fb^{-1}
  - Implies a radical change of the detector.
  - 4D tracking with timing pixel
- "Beyond the LHCb phase 1 upgrade"
  Theater of Dreams, Manchester 6-7 April 2016

Phenomenological
and
Theoretical Contributions

Physics benchmarks beyond LS4	*Vincenzo Vagnoni*	
Bragg Lecture Theatre, Schuster Laboratory, University of Manchester	09:00 - 09:20	
Searches for NP in CP violation	*Luca Silvestrini*	
Bragg Lecture Theatre, Schuster Laboratory, University of Manchester	09:25 - 09:55	
Searches for NP in rare decays	*Gino Isidori*	
Bragg Lecture Theatre, Schuster Laboratory, University of Manchester	10:00 - 10:30	

Sensitivity prospects

Type	Observable	LHC Run 1	LHCb 2018	LHCb upgrade	Theory
B_s^0 mixing	$\phi_s(B_s^0 \to J/\psi\,\phi)$ (rad)	0.049	0.025	**0.009**	~ 0.003
	$\phi_s(B_s^0 \to J/\psi\, f_0(980))$ (rad)	0.068	0.035	**0.012**	~ 0.01
	$A_{\rm sl}(B_s^0)$ (10^{-3})	2.8	1.4	**0.5**	0.03
Gluonic penguin	$\phi_s^{\rm eff}(B_s^0 \to \phi\phi)$ (rad)	0.15	0.10	**0.018**	0.02
	$\phi_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$ (rad)	0.19	0.13	**0.023**	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$ (rad)	0.30	0.20	**0.036**	0.02
Right-handed currents	$\phi_s^{\rm eff}(B_s^0 \to \phi\gamma)$ (rad)	0.20	0.13	**0.025**	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5%	3.2%	**0.6%**	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.04	0.020	**0.007**	0.02
	$q_0^2\, A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	10%	5%	**1.9%**	$\sim 7\%$
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.09	0.05	**0.017**	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	14%	7%	**2.4%**	$\sim 10\%$
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ (10^{-9})	1.0	0.5	**0.19**	0.3
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	220%	110%	**40%**	$\sim 5\,\%$
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	7°	4°	**0.9°**	negligible
	$\gamma(B_s^0 \to D_s^{\mp}K^{\pm})$	17°	11°	**2.0°**	negligible
	$\beta(B^0 \to J/\psi\, K_S^0)$	1.7°	0.8°	**0.31°**	negligible
Charm *CP* violation	$A_\Gamma(D^0 \to K^+K^-)$ (10^{-4})	3.4	2.2	**0.4**	–
	ΔA_{CP} (10^{-3})	0.8	0.5	**0.1**	–

LHCb-PUB-2014-040

- Before the upgrade (8 fb^{-1})
- After the upgrade (50 fb^{-1})
- Theory uncertainty (as far as we know today)

The extrapolations assume:
- Precisions scale as √L.
- Gain ×2 on fully hadronic decays
- HLT and analysis performance as in Run I
- Backgrounds as in Run I.

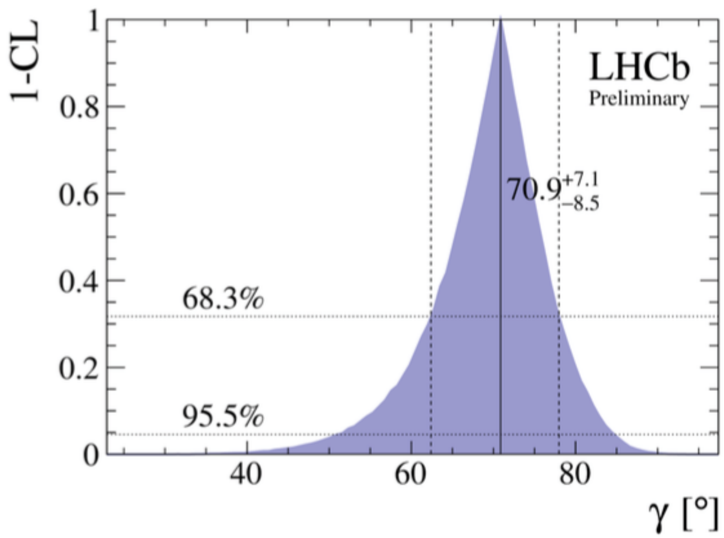
γ from trees

- Combining several independent decay modes is the key to achieve the ultimate precision.

LHCb measurement	Type/ Dataset	Reference
$B^+ \to DK^+$ $D \to 2h,4h$	ADS/(q-)GLW ($3fb^{-1}$)	arXiv:1603.08993
$B^0 \to DK\pi$	Dalitz ($3fb^{-1}$)	arXiv: 1602.03455
$B^0 \to DK^*$ $D \to K_S\pi\pi$	GGSZ MD ($3fb^{-1}$)	arXiv: 1605.01082
$B^+ \to DK^+$ $D \to hh\pi^0$	ADS/q-GLW ($3fb^{-1}$)	PRD 91(2015) 112014
$B^+ \to DK\pi\pi$, $D \to 2h$	ADS/GLW ($3fb^{-1}$)	PRD 92 (2015) 112005
$B^0 \to DK^*$ $D \to 2h$	ADS ($3fb^{-1}$)	PRD 90 (2014) 112002
$B^+ \to DK$ $D \to K_s hh$	GGSZ MI ($3fb^{-1}$)	JHEP 10 (2014) 097
$B^+ \to DK$, $D \to KsK\pi$	ADS ($3fb^{-1}$)	PLB 733 (2014) 36
$B_s \to D_sK$, $D_s \to hhh$	Time dep ($1fb^{-1}$)	JHEP 11 (2014) 060

Only B→DK – like results included

LHCb- CONF-2016-001



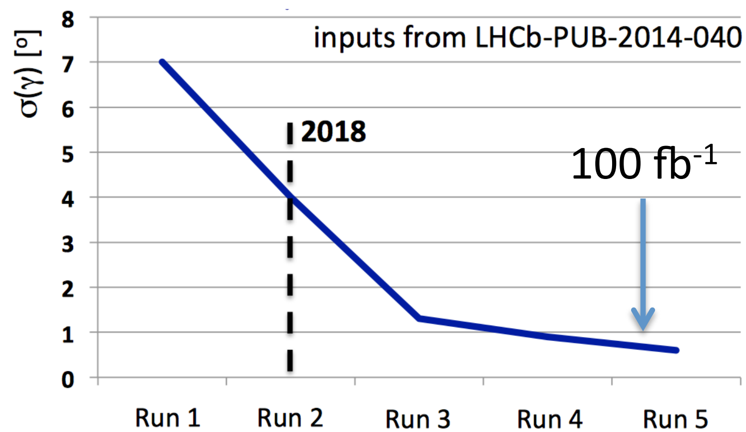
LHCb combined result

LHCb: $\gamma = (70.9^{+7.1}_{-8.5})^\circ$

BaBar : $\gamma = (69^{+17}_{-16})^\circ$ PRD 87 (2013) 052015

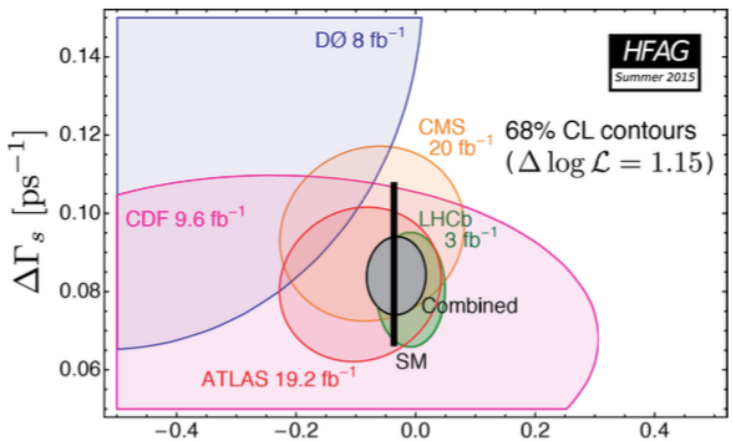
Belle: $\gamma = (73^{+15}_{-14})^\circ$ arXiv:1301.2033

σ(γ)≈4° by 2018 and sub-degree precision by the end of the experimental programme



CP violation induced by B_s mixing: ϕ_s

ϕ_s(SM) = -36.4 ± 1.6 mrad

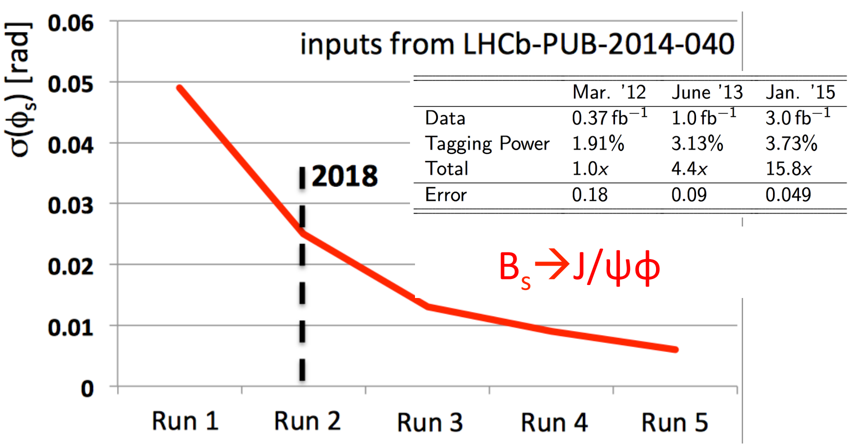


HFAG average: ϕ_s = -34 ± 33 mrad

- LHCb results with 3 fb^{-1}
- **$B_s \to J/\psi K^+K^-$**, ϕ_s = -58 ± 49 ± 6 mrad
  - Phys. Rev. Lett. **114** (2015) 041801
- **$B_s \to J/\psi \pi^+\pi^-$**, ϕ_s = 70 ± 68 ± 8 mrad
  - Phys. Lett. **B736** (2014) 186
- $B_s \to D^+_s D^-_s$ = 20 ± 170 ± 20 mrad
  - Phys. Rev. Lett. **113** (2014) 211801

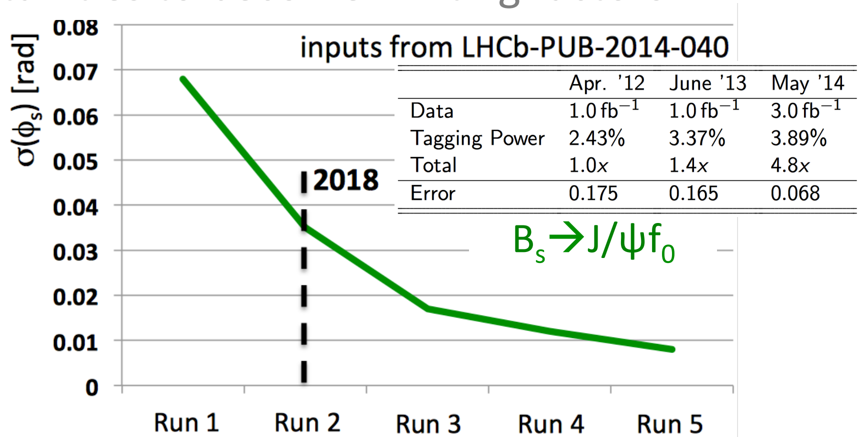
LHCb average: ϕ_s = – 10 ± 40 mrad

We don't envisage systematic uncertainties to become limiting factors



	Mar. '12	June '13	Jan. '15
Data	0.37 fb^{-1}	1.0 fb^{-1}	3.0 fb^{-1}
Tagging Power	1.91%	3.13%	3.73%
Total	1.0x	4.4x	15.8x
Error	0.18	0.09	0.049

$\sigma(\phi_s)$ ~4 mrad with 300 fb^{-1}



	Apr. '12	June '13	May '14
Data	1.0 fb^{-1}	1.0 fb^{-1}	3.0 fb^{-1}
Tagging Power	2.43%	3.37%	3.89%
Total	1.0x	1.4x	4.8x
Error	0.175	0.165	0.068

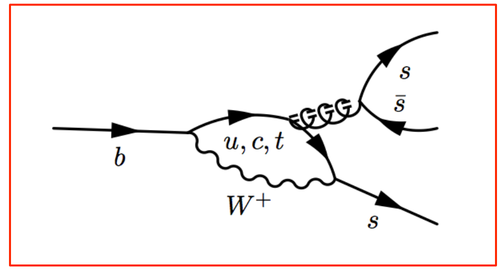
$\sigma(\phi_s)$ ~5 mrad with 300 fb^{-1}

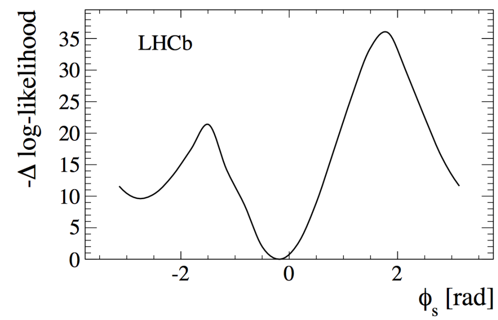
CP violation in $B_s \to \phi\phi$

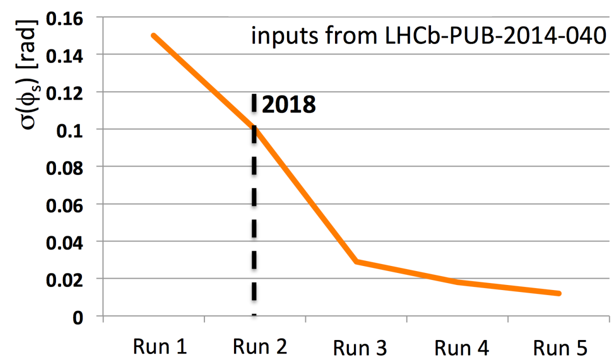
Interference between B_S-$\underline{B}_S$ mixing and the loop-induced decay amplitude.

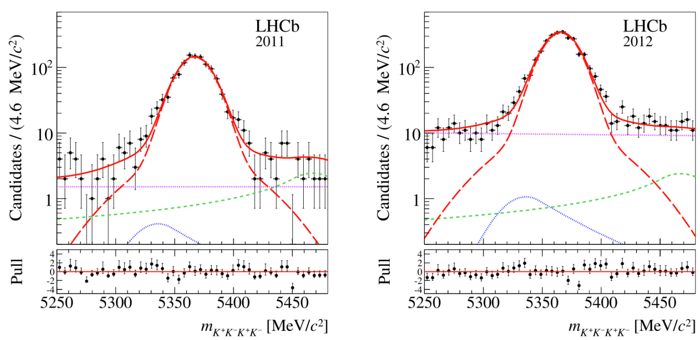
- **FCNC gluonic $b \to s\underline{s}s$ penguin**
  - Provides an excellent probe of new heavy particles entering the penguin quantum loops.
- LHCb result with full Run 1 data set ($3fb^{-1}$), with approximately 4000 events:

  ϕ_s= (- 170 ± 150 ± 30) mrad
- Overall precision comparable to golden $b \to c\underline{c}s$ modes.
- No sign of discrepancy.







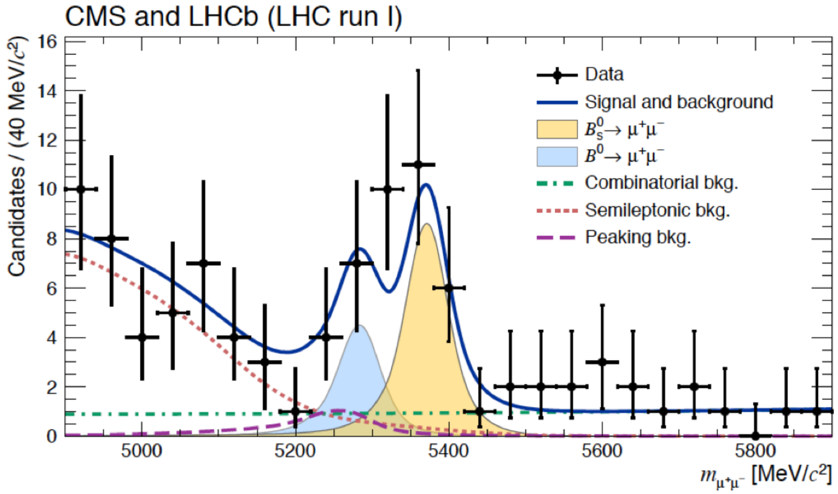


σ(ϕ_S) ~7 mrad at 300 fb^{-1}

Phys. Rev. D90 (2014) 052011, arXiv:1407.2222

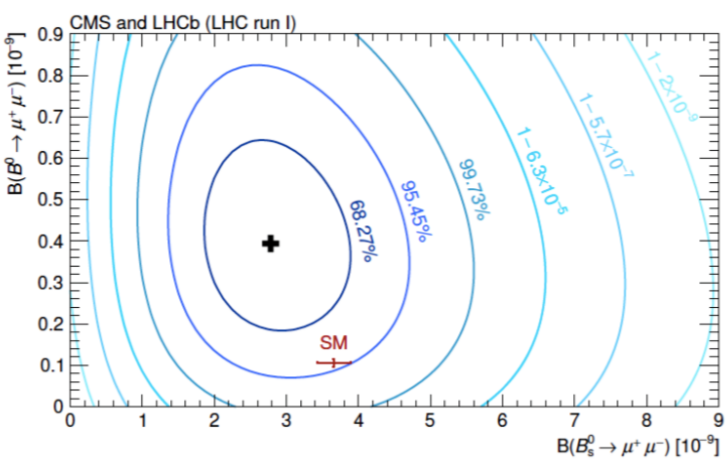
$B_{d,s} \to \mu^+\mu^-$

CMS & LHCb



$$\mathcal{B}\left(B_s \to \mu^+\mu^-\right) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$$

$$\mathcal{B}\left(B^0 \to \mu^+\mu^-\right) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$$



Significance of $B_s \to \mu\mu$ at 6.2σ

– First observation

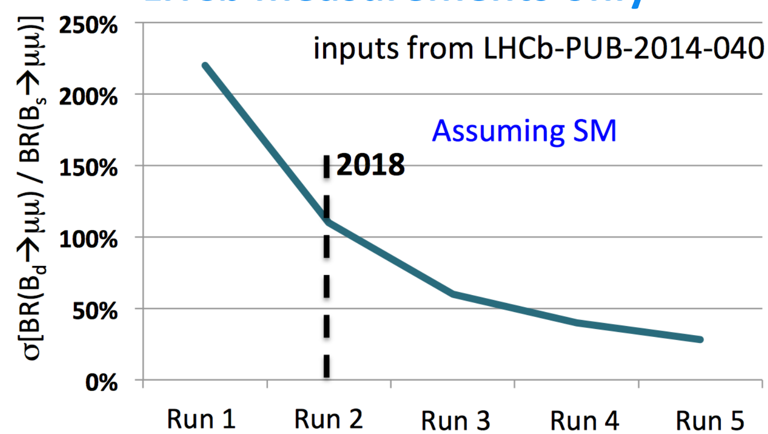
– Compatibility with the SM at 1.2σ

$B^0 \to \mu\mu$ hypothesis:

– Excess of events at the 3σ level observed with respect to background.

– Compatible with SM at 2.2σ

LHCb measurements only



By the end of Run 4 measurements will still be dominated by experimental uncertainty. Uncertainty <10% on the ratio BR(Bd)/BR(Bs) is at reach with 300 fb^{-1}

New observables: effective lifetime,...

arXiv:1411.4413 Nature (2015) doi:10.1038/nature14474

Conclusions

- **LHCb has performed very well in Run 1**
  Confirming to date the Standard Model predictions.

- **Improvements of LHCb results are expected in Run 2**
  Additional 5-6 fb^{-1} expected by 2018, to be collected with the present detector, with improved trigger capabilities.

- **The LHCb upgraded detector shall start taking data in 2020**
  New PCIe based read out and full HLT software trigger at 40 MHz.
  Optimized tracking system and still good PID.
  The preparation of the upgrade is progressing well.

- **LHCb prospects look excellent**
  Heavy flavour physics has still large room for improvements.
  Key measurements are far from being limited by systematic uncertainties.
  LHCb has great potential of discovering indirect evidence of NP in future measurements.

The End

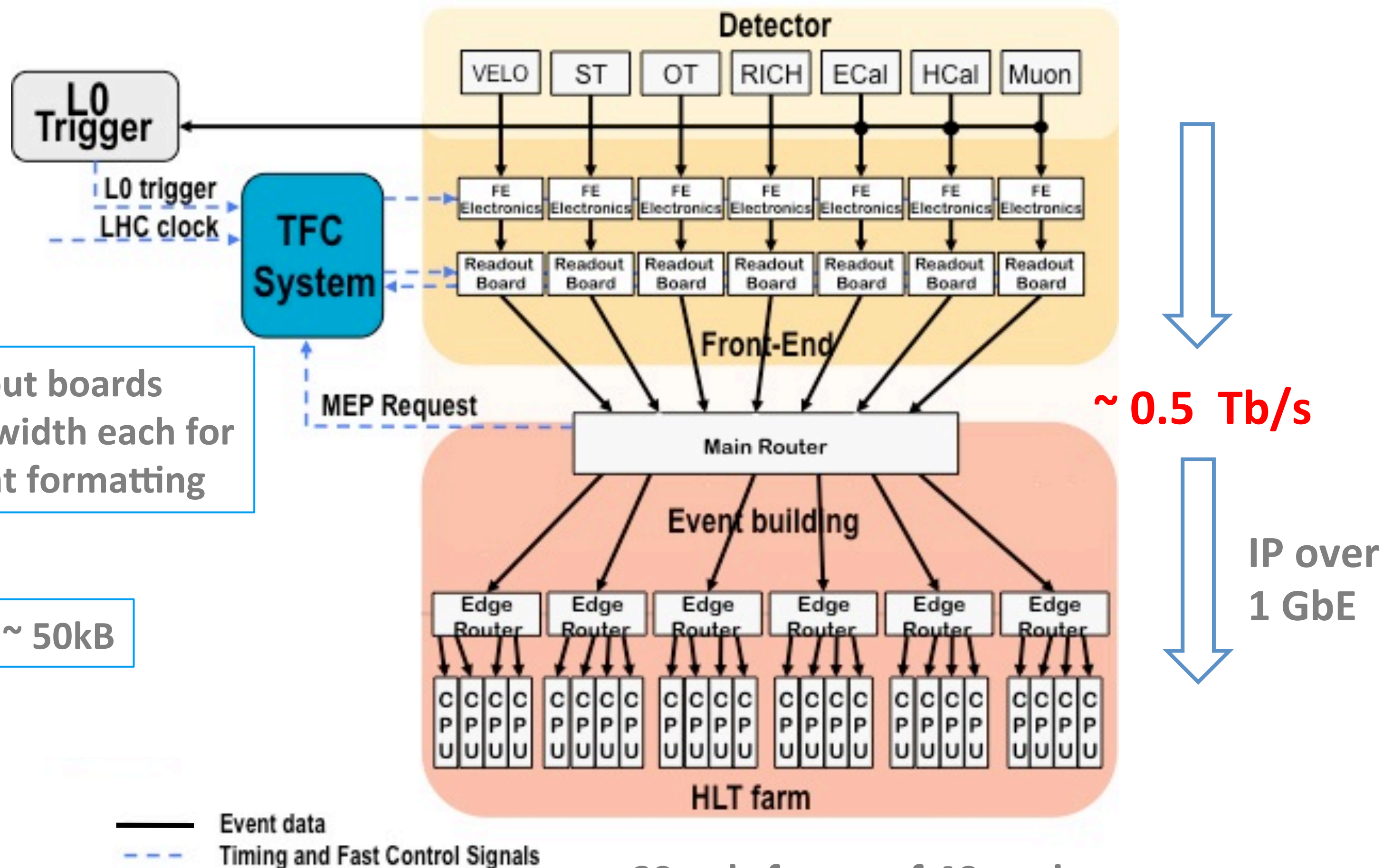
Present 1 MHz DAQ system

Push-protocol with centralized flow-control

L0 trigger rate
1.1 MHz

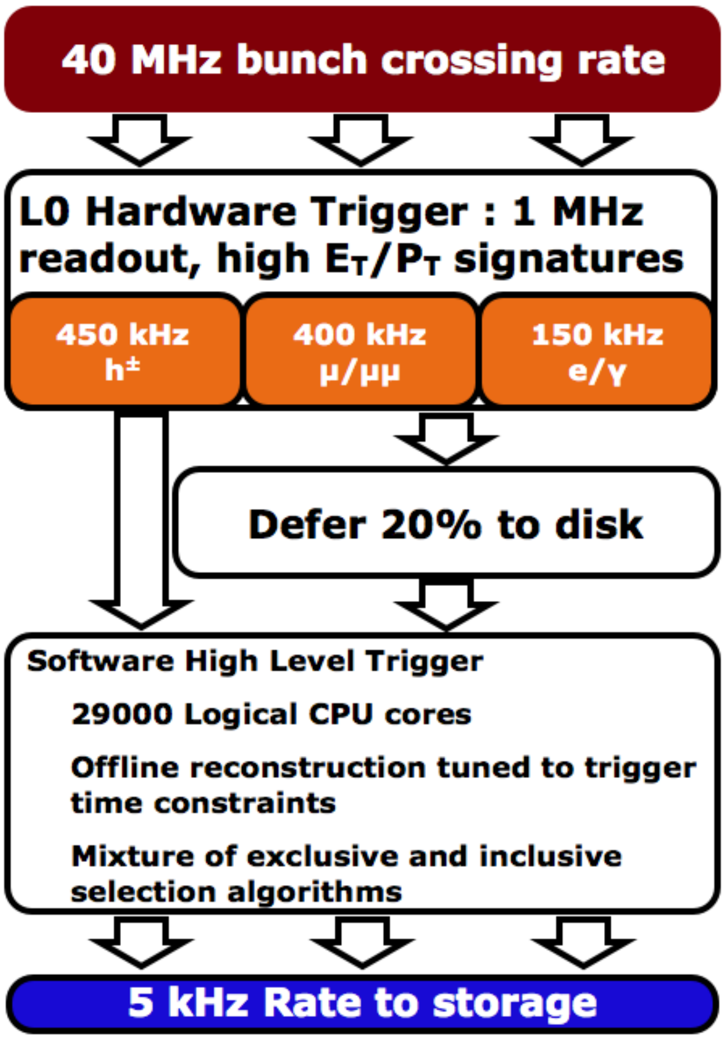
300 TELL1 readout boards
4 Gb/s output bandwidth each for buffering and event formatting

Event size ~ 50kB



60 sub-farms of 40 nodes
HLT event processing

Trigger in Run1



- **L0 Trigger: 40 MHz → 1MHz**
  - ECAL, HCAL and MUON detectors read out at 40 MHz
  - **20% to disk: deferred processing**
- **HLT: 1MHz → 5 kHz**

HLT1

- Reconstruct VELO tracks and primary vertices
- Select events with at least one track matching p, p_T , impact parameter and track quality cuts.

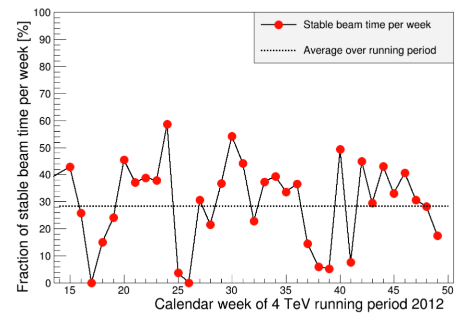
HLT2

- At around **100 kHz** performs inclusive or exclusive selections of the events.
- Full track reconstruction, without particle-identification.
- Total accept rate to disk for offline analysis is around **5 kHz**.

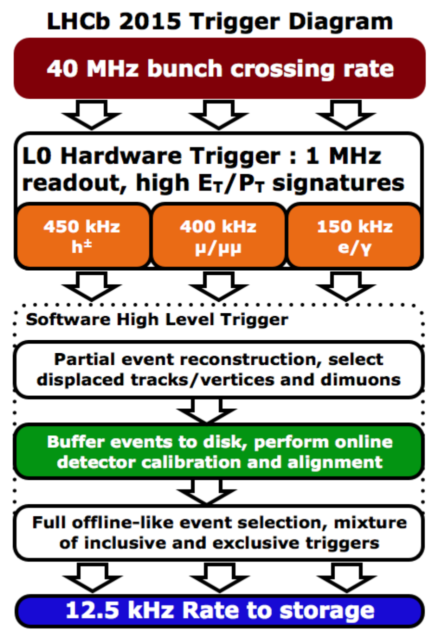
R. Aaij et al. The LHCb trigger and its performance in 2011. *JINST*, 8:P04022,2013

Trigger evolution in Run2

- **LHC stable beams during 30% of the running period**: 70% of the time the CPU of the HLT farm would be idle.
- **Real-time HLT1**
  HLT1 selects events that are temporarily stored on 5.2 PB of the farm servers.
  - Buffer 10 days of continuous data taking.
  - Staging after the HLT1 filter occurs at a rate of about 100 kHz instead of 1 MHz.
  - **HLT1 time budget ~50 ms**
- **Deferred HLT2**
  Performs the final event filtering, relying on up-to-date calibration constants, with offline quality.
  - HLT2 time budget: ~800 ms
  - Trigger algorithm: ~350 trigger lines
  - Output rate ~**12.5 kHz**.
  - 2.5 kHz processed as Turbo Stream (no more raw data recorded)

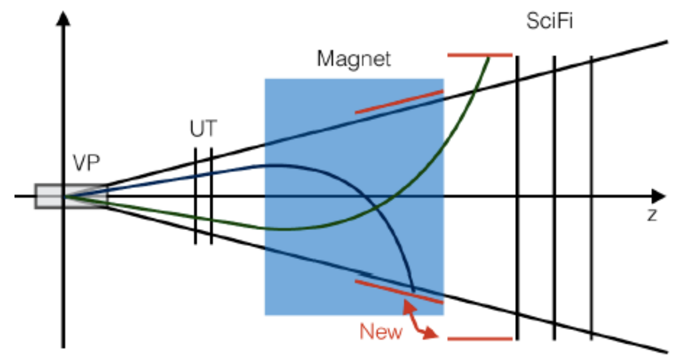


stable beam 30% of the time in average



With the increased time allowed trigger's reconstruction can be brought into line with the quality achieved offline

Upgrade phase Ib



- Spectroscopy and CP-violation studies are increasingly focused on high multiplicity final states
- Extend the tracking acceptance of the tracking stations by instrumenting the internal sides of the magnet, and possibly outside the magnet.
- Improve RICH performance: replace part of the MaPMT with SiPM to increase the granularity to 1 mm from the present 3 mm.
- Performance with π^0 and γ are still far behind analyses with charged tracks
  - $B \rightarrow D\ K \rightarrow (K\ \pi\ \pi^0)_D\ K$
- Neutral reconstruction will be even worse at 2×10^{33} $cm^{-2}s^{-1}$: Baseline is to replace the innermost part of ECAL, above 20 fb^{-1} Think to different ECAL technology?
  - Scintillator-W based ECAL
  - CALICE-type ECAL