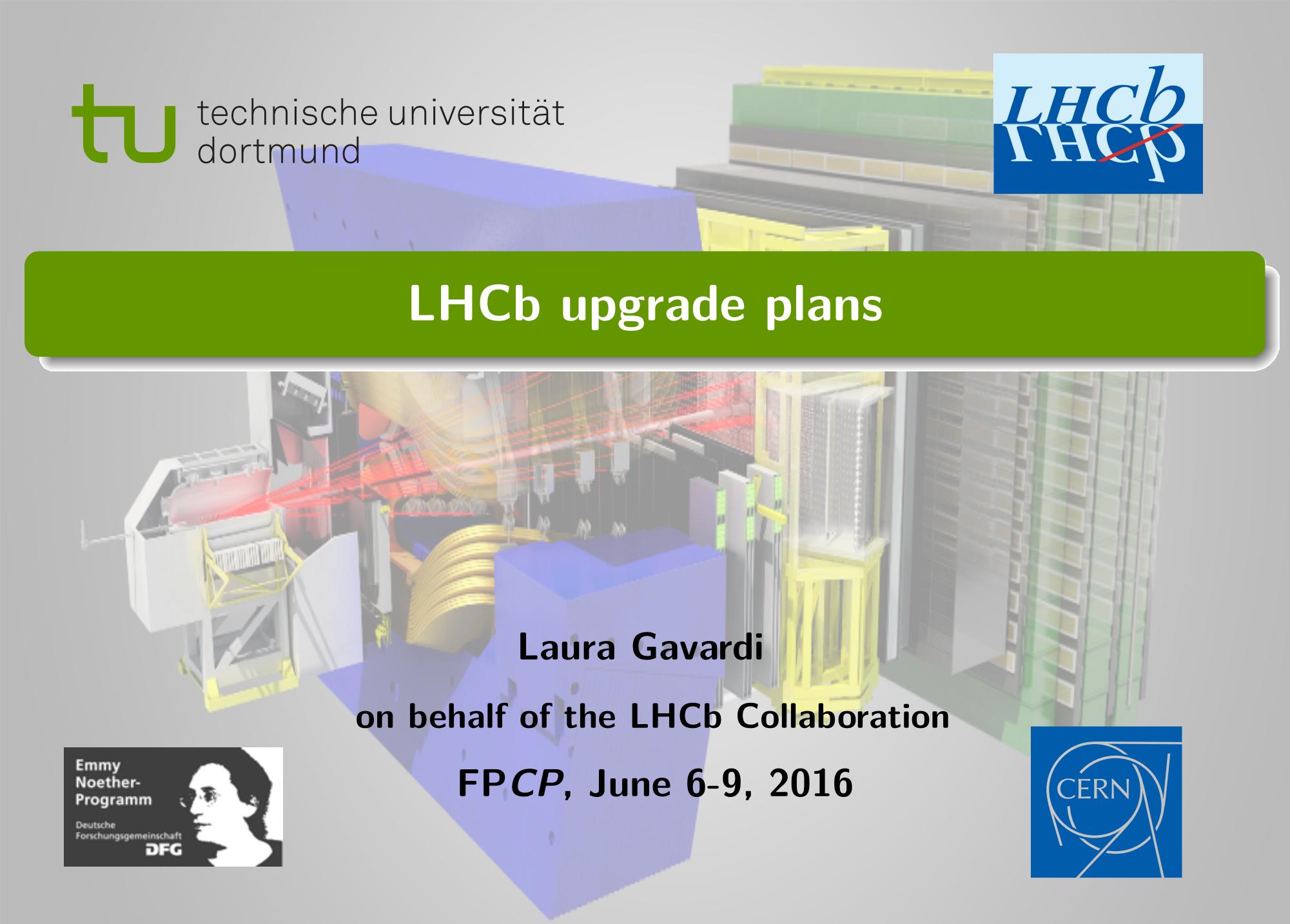
technische universität
dortmund



LHCb upgrade plans

Laura Gavardi

on behalf of the LHCb Collaboration

FP*CP*, June 6-9, 2016

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

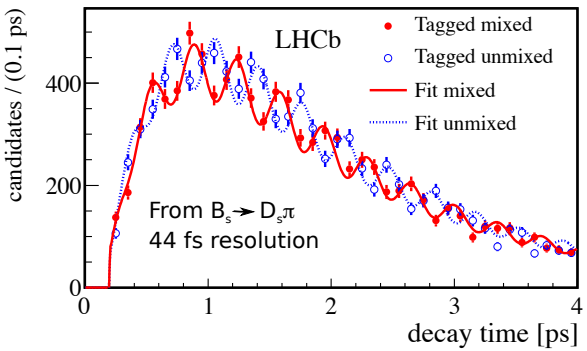
CERN

Highlights of the LHCb physics program

LHCb is a high precision experiment dedicated to the search for Physics beyond the Standard Model

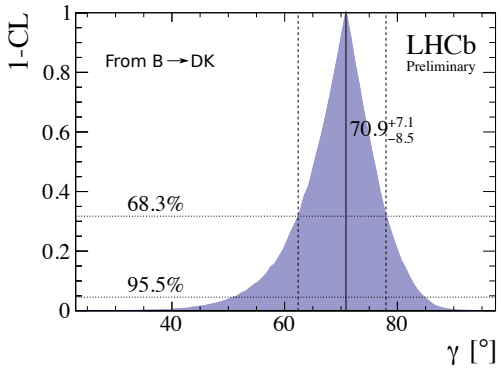
B_s oscillation frequency

New J. Phys. 15 (2013) 053021



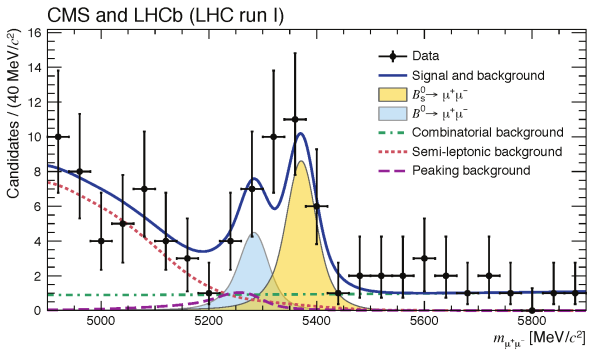
Best measurement of γ

LHCb-CONF-2016-001



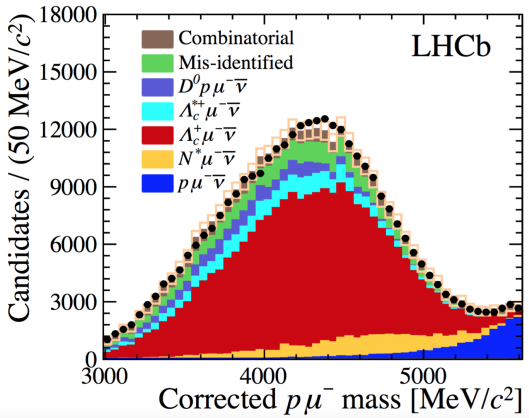
Observation of $B_s \to \mu\mu$

Nature 522,68-72(2015))



$|V_{ub}|$ from $\Lambda_b \to p\mu\nu$

Nature Physics 10(2015)1038



Summary of LHCb upgrade physics reach

Type	Observable	LHCb 2018	**Upgrade** ($50\ \text{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.025	0.008	~0.003
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.045	0.014	~0.01
	a_{sl}^s	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \to K^{*0}\overline{K}^{*0})$	0.13	0.02	< 0.02
	$2\beta^{\text{eff}}(B^0 \to \phi K_S^0)$	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 penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\ \text{GeV}^2/c^4)$	0.025	0.008	0.02
	$s_0 A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\ \text{GeV}^2/c^4)$	0.08	0.025	~0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	8 %	2.5 %	~10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	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	$\gamma(B \to D^{(*)}K^{(*)})$	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	0.65×10^{-3}	0.12×10^{-3}	–

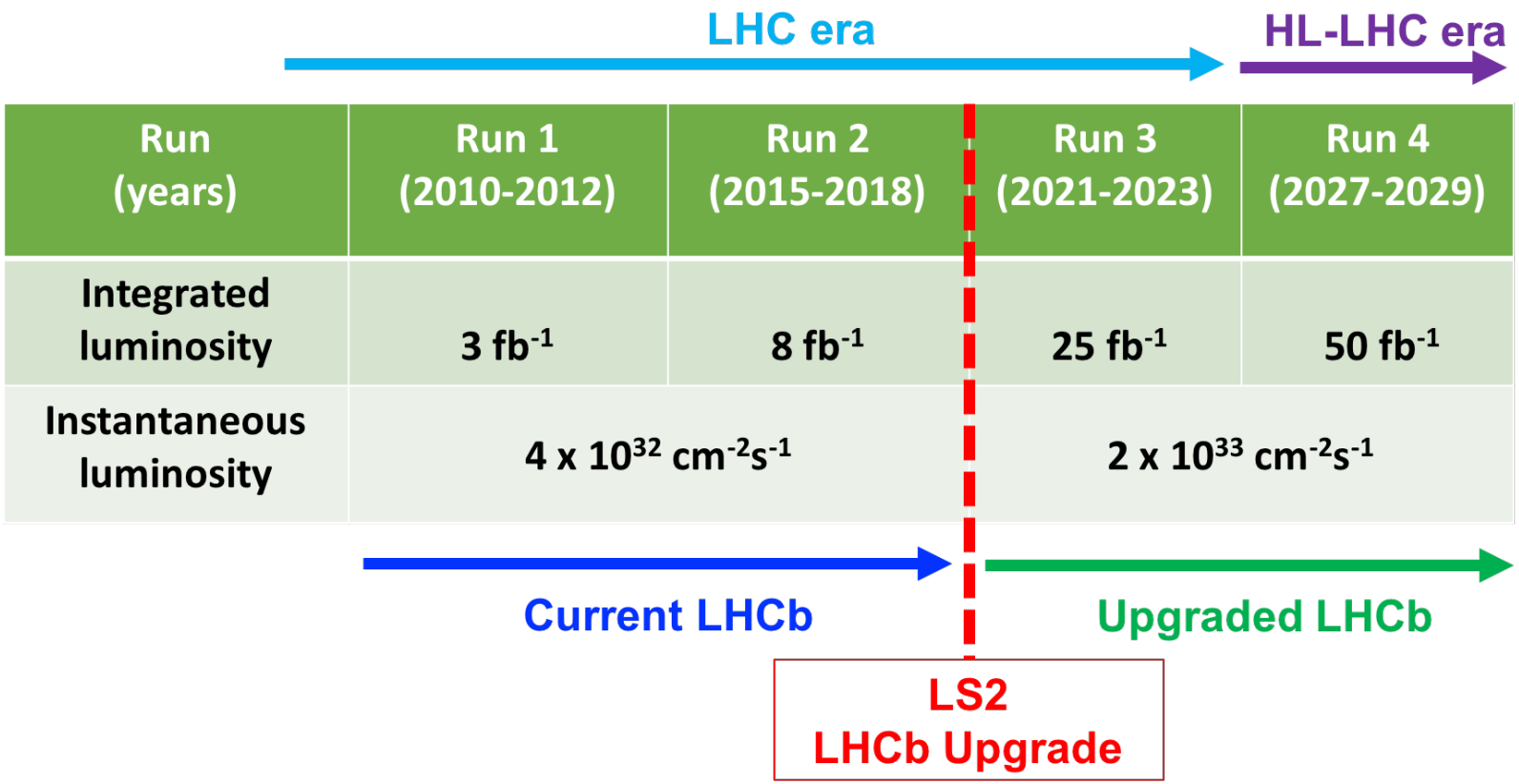
Eur. Phys. J. C (2013) 73:2373

Summary of LHCb upgrade physics reach

Type	Observable	LHCb 2018	**Upgrade** ($50\ \text{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.025	0.008	~0.003
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.045	0.014	~0.01
	a_{sl}^s	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \to K^{*0}\overline{K}^{*0})$	0.13	0.02	< 0.02
	$2\beta^{\text{eff}}(B^0 \to \phi K_S^0)$	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 penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\ \text{GeV}^2/c^4)$	0.025	0.008	0.02
	$s_0 A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\ \text{GeV}^2/c^4)$	0.08	0.025	~0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	8 %	2.5 %	~10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	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	$\gamma(B \to D^{(*)}K^{(*)})$	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	0.65×10^{-3}	0.12×10^{-3}	–

Eur. Phys. J. C (2013) 73:2373

Schedule and luminosity evolution



- The upgraded LHCb detector is expected to take physics data for an integrated luminosity of at least 50 fb^{-1}

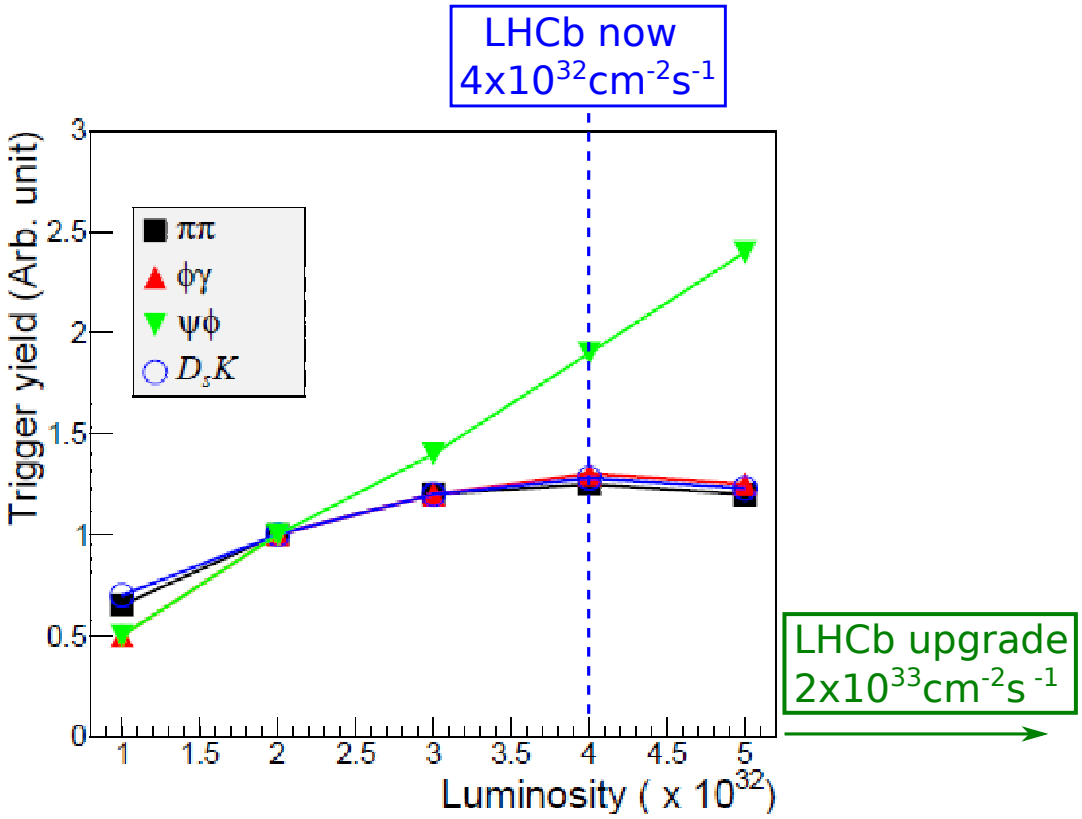
Increasing LHCb statistics

Current detector

- First selection: Hardware trigger (L0) based on E_T and muon P_T
- L0 limited to a max. readout rate of 1.1 MHz

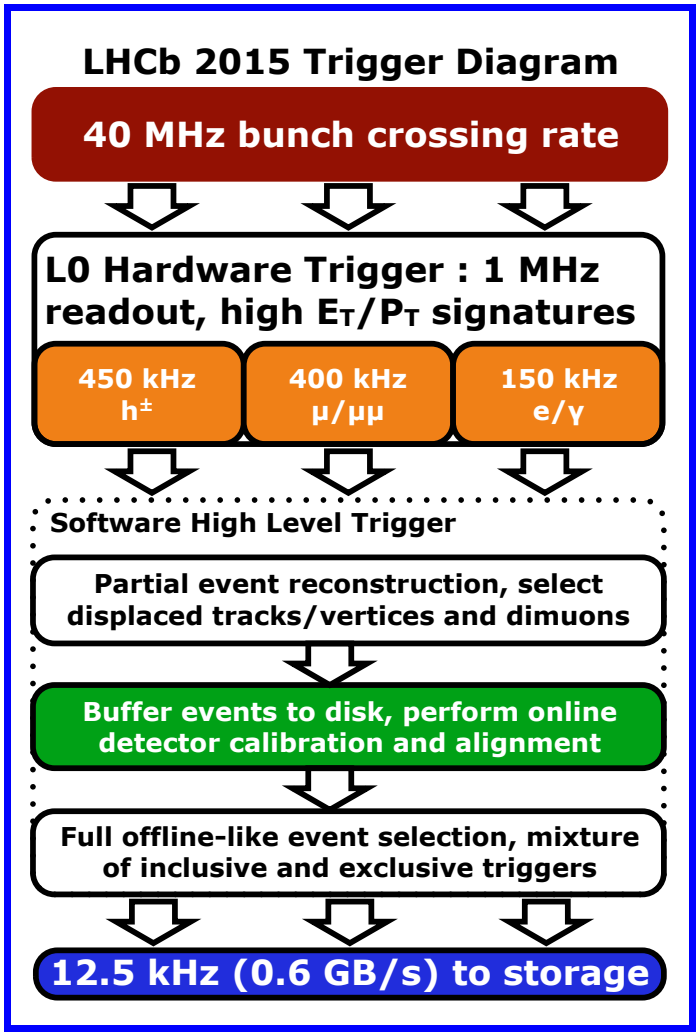
Upgrade to a full software trigger

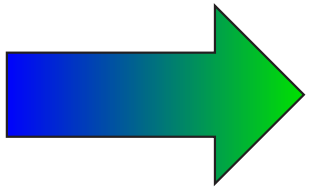
- Readout at 40 MHz
- Full event reconstruction (IP, tracks, PID)

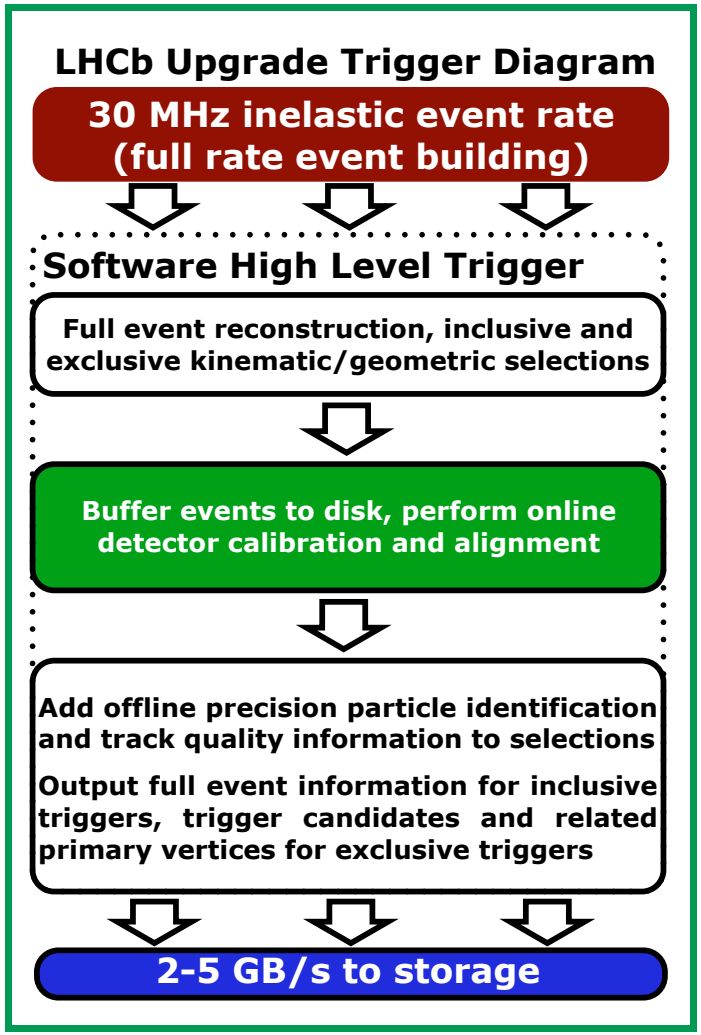


CERN/LHCC 2011-001

Trigger upgrade

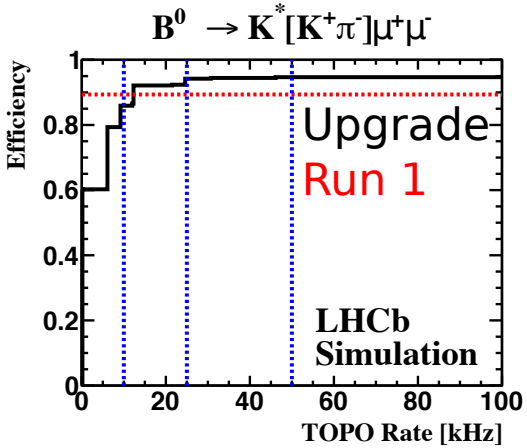


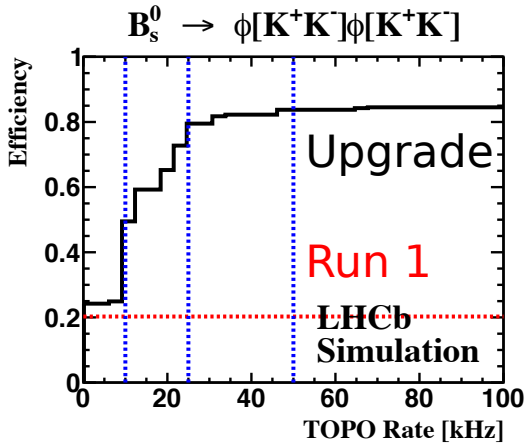


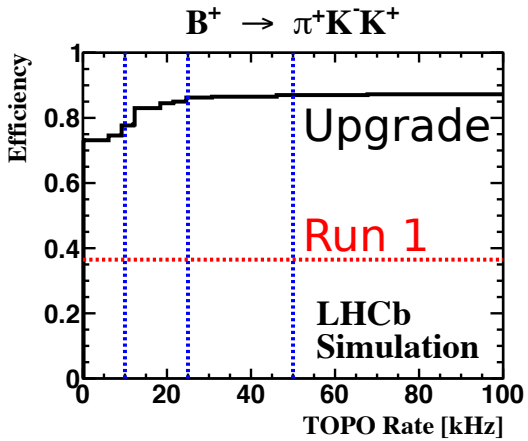


Performance of the upgraded trigger

- Full software trigger $\longrightarrow$ efficient triggering on both leptonic and hadronic final states



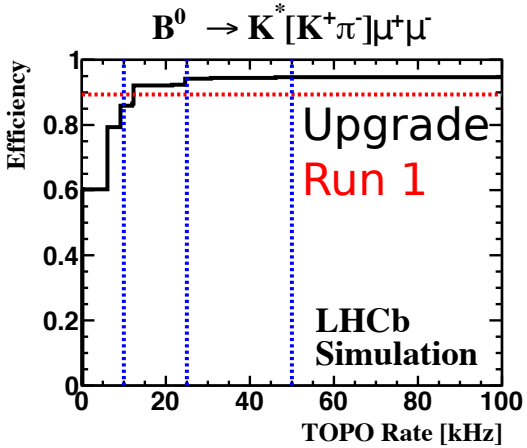


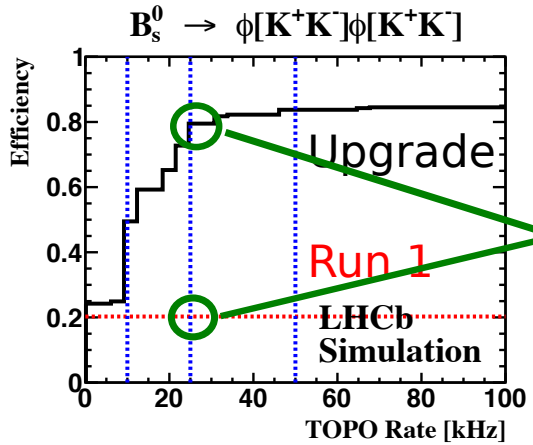


CERN/LHCC-2014-016

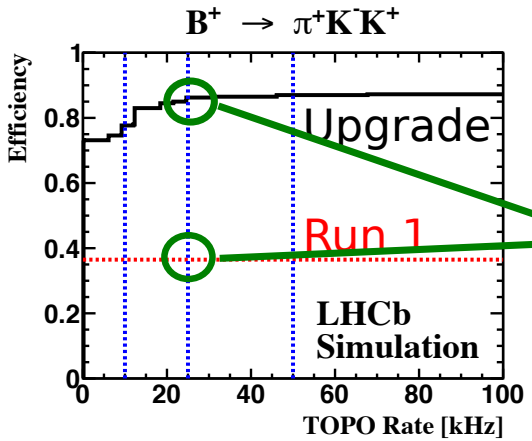
Performance of the upgraded trigger

- Full software trigger $\rightarrow$ efficient triggering on both leptonic and hadronic final states





x4 higher efficiency

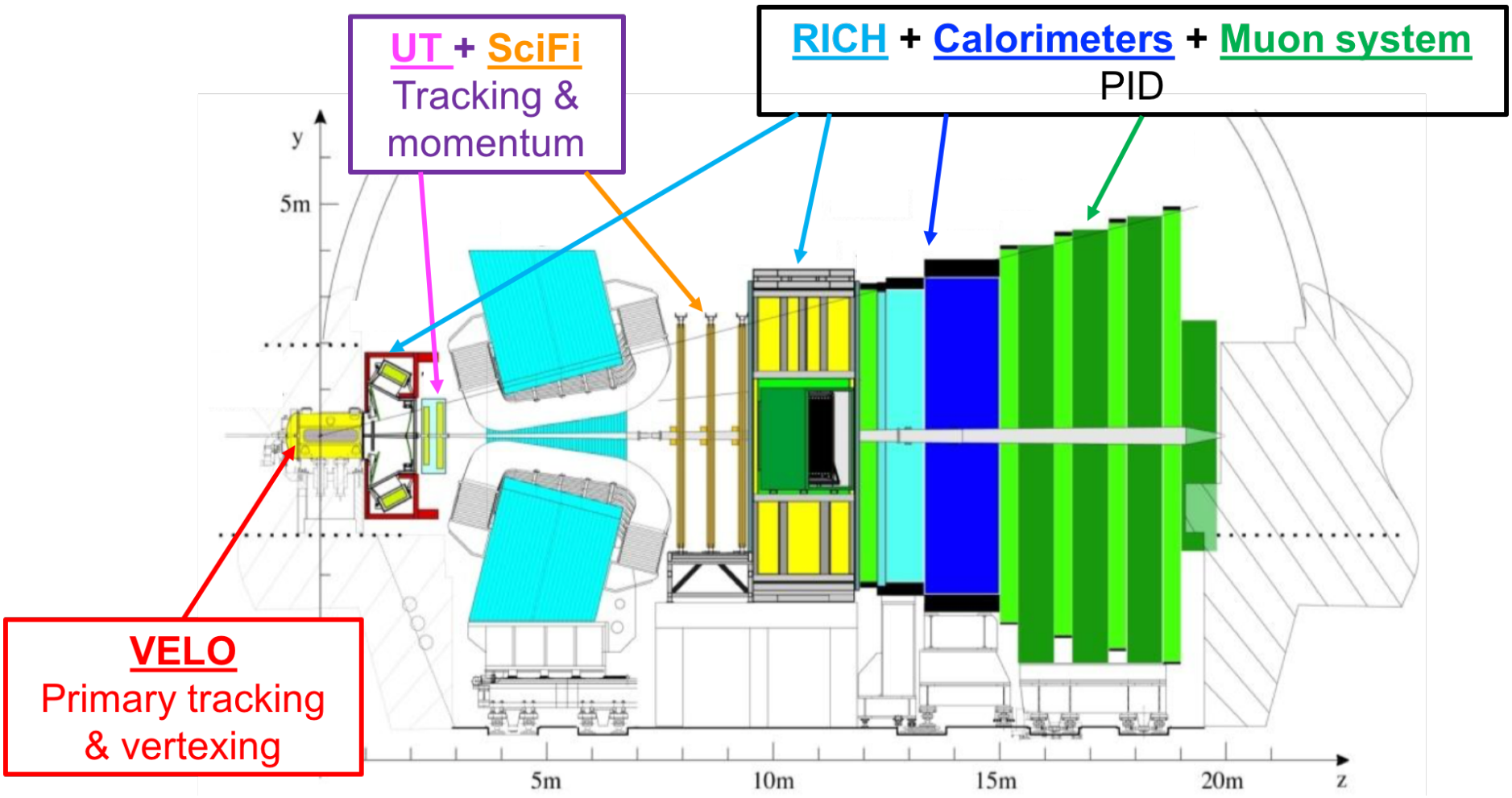


x2 higher efficiency

CERN/LHCC-2014-016

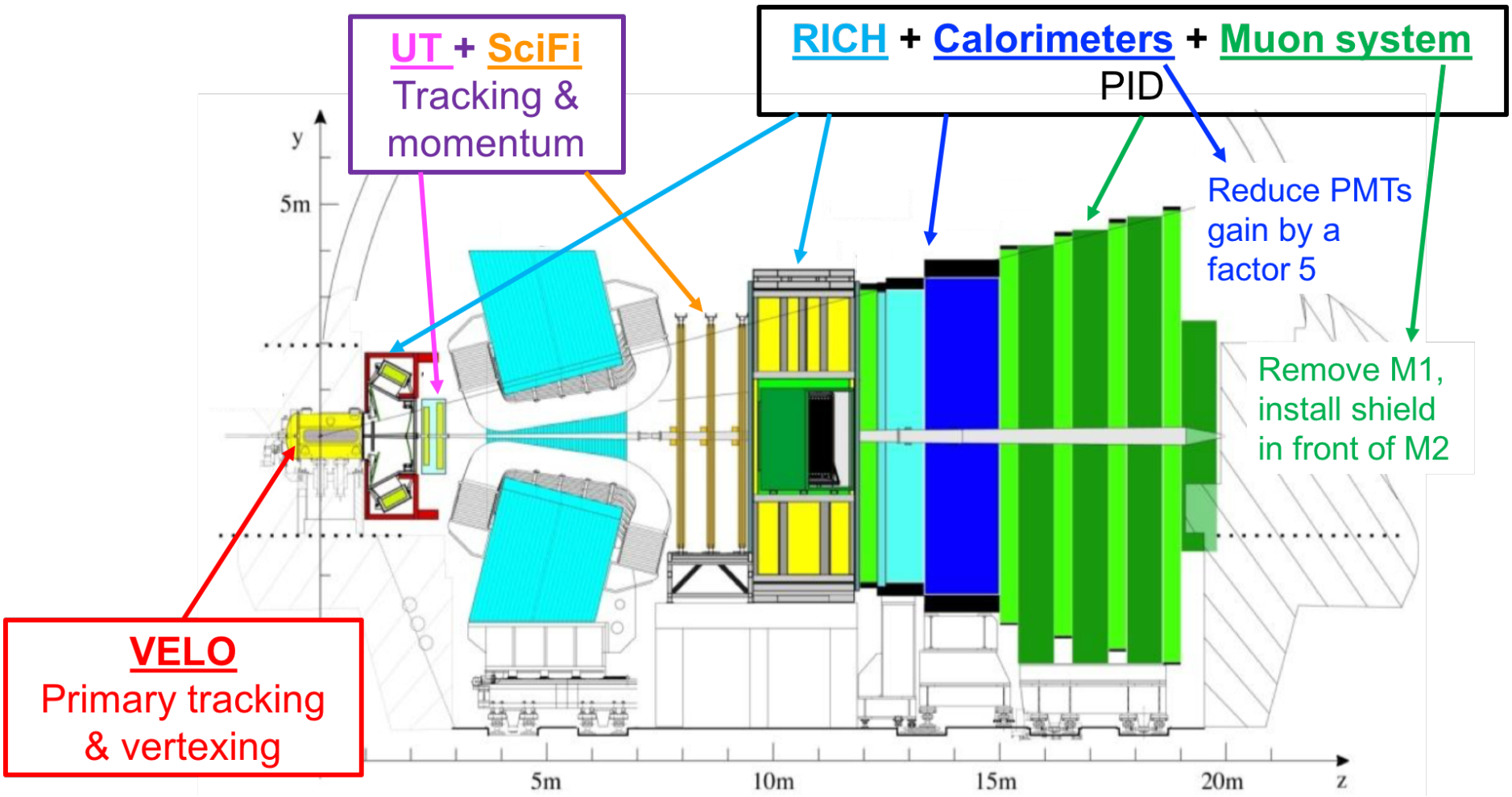
Upgrade strategy

- Readout at 40 MHz $\Longrightarrow$ replace front-end electronics



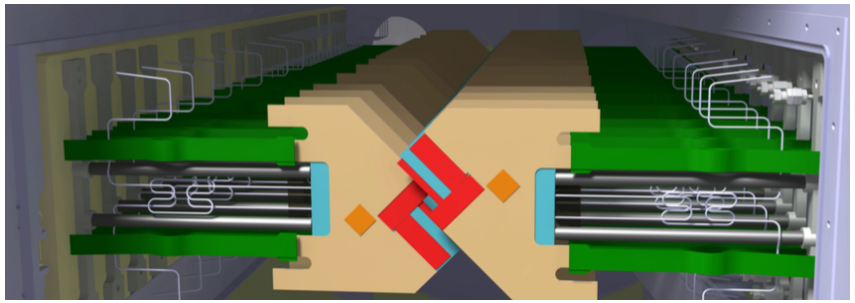
Upgrade strategy

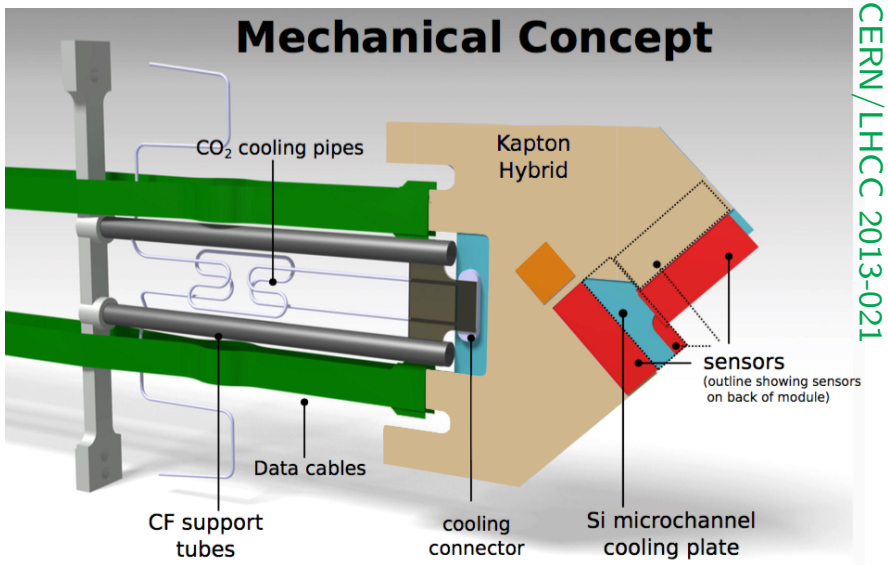
- Readout at 40 MHz $\Longrightarrow$ replace front-end electronics



The VErtex LOcator (VELO) upgrade

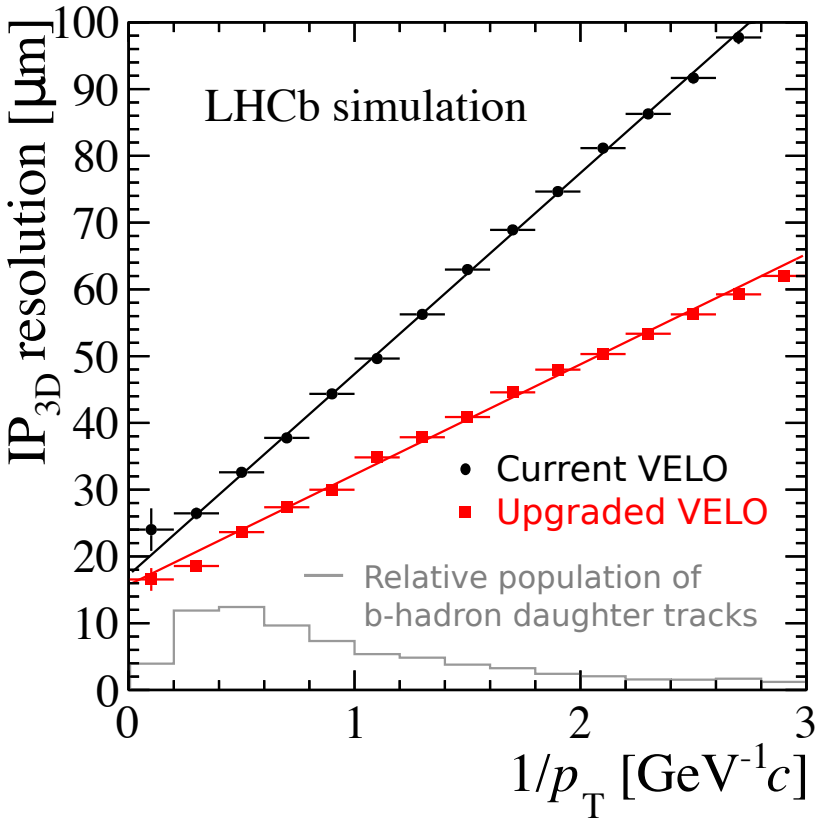
- Two moveable halves in vacuum tank
- Replace Si strips with pixel sensors
- Active region @ 5.1 mm from beam (instead of 8.1 mm as in the current VELO)
- Rad. in the innermost region: $8 \cdot 10^{15}$ n_{eq}/cm^2 after 50 fb^{-1}
- Readout at 40 MHz
- Tot. power consumption>2 kW
- CO_2 micro-channel cooling





CERN/LHCC 2013-021

VELO performances



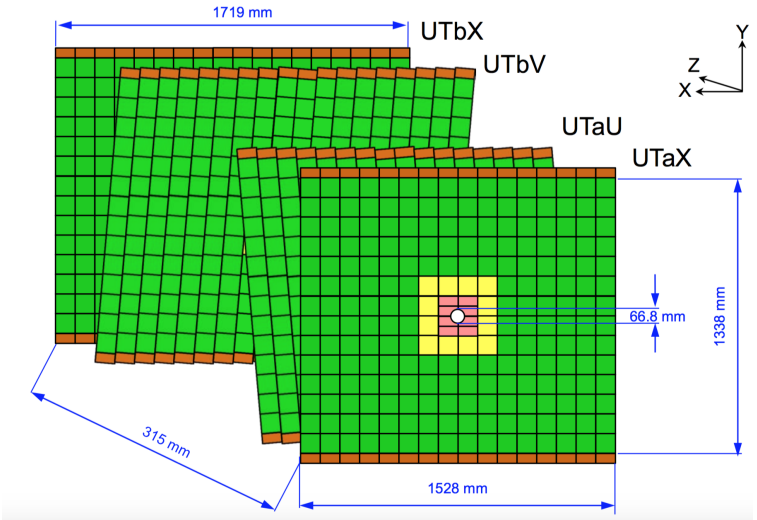
← 3D Impact Parameter resolution at $\mathcal{L} = 2 \cdot 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

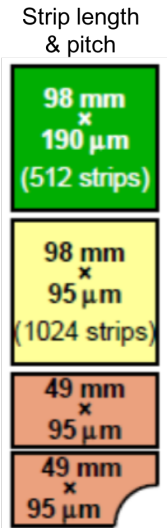
CERN/LHCC 2013-021

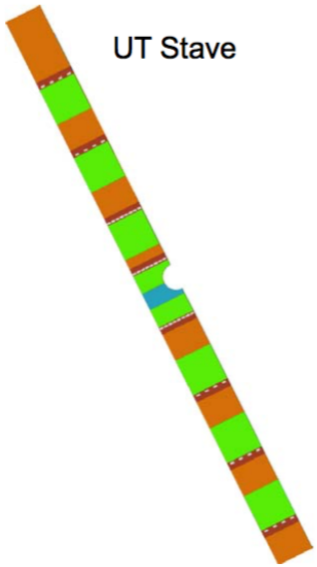
Decay time resolution [fs]		
	$B_s^0 \to \phi\phi$	$B^0 \to K^{*0}\mu^+\mu^-$
Current VELO	48.3 ± 0.5	41.2 ± 0.5
Upgraded VELO	43.4 ± 1.6	35.3 ± 0.3

The Upstream Tracker (UT)

- Four planes (x-u-v-x) of Si strips sensors (250 μm thick)
- Staves staggered $\rightarrow$ overlap in x
- Closer to the beampipe $\rightarrow$ improve small-angle acceptance
- Finer granularity $\rightarrow$ reduce occupancy
- Strip pitch and length adapted to the particle flux depending on the position
- New FE electronics $\rightarrow$ readout at 40 MHz
- Bi-phase CO_2 cooling in stave support



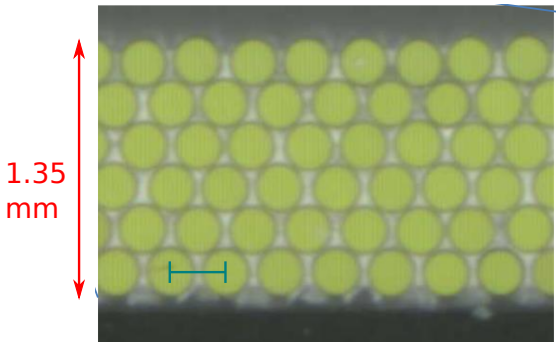




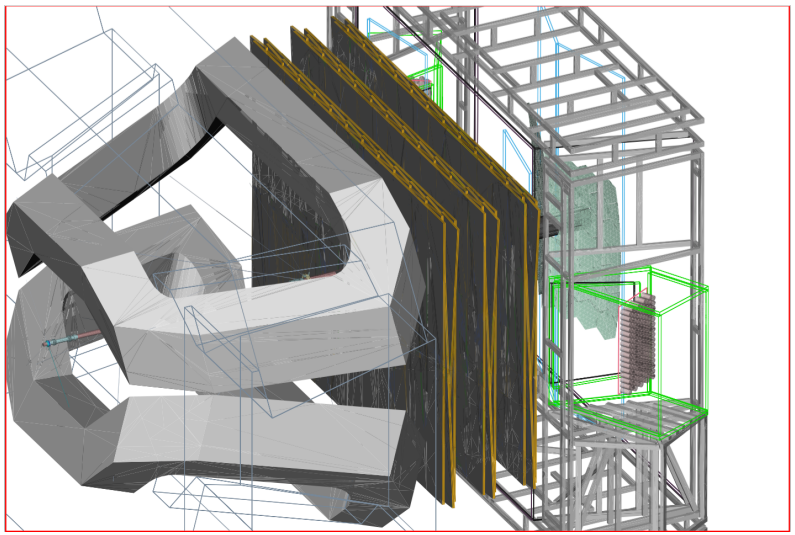
CERN/LHCC 2014-001

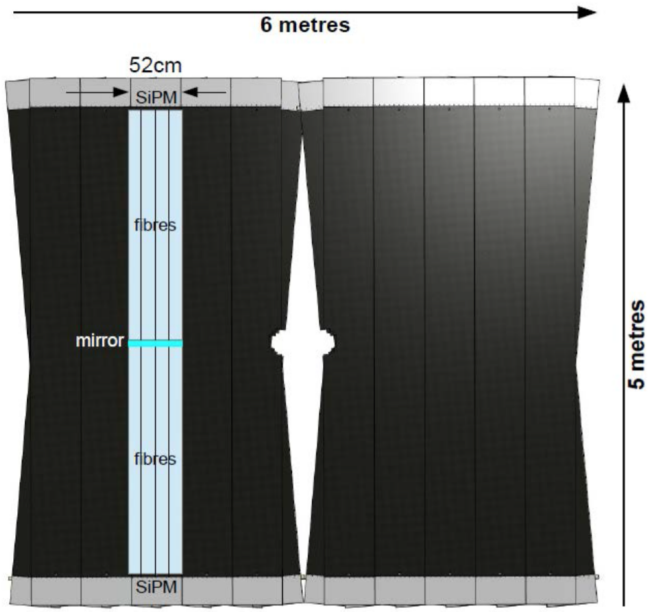
The Scintillating Fibres Tracker (SciFi)

- Active detector element: scintillating fibres ($\varnothing = 250\ \mu\mathrm{m}$)
- 3 stations with 4 detection layers (x-u-v-x)
- $2 \times 2.5\ \mathrm{m}$ long modules with mirror in the middle
- Readout with SiPMs at the outer edges



Fibre pitch 275 µm

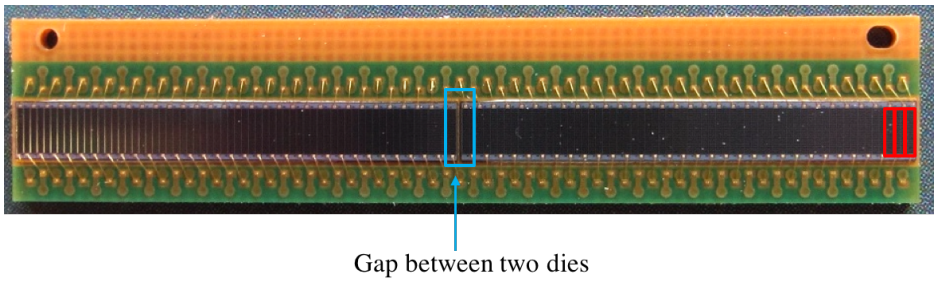


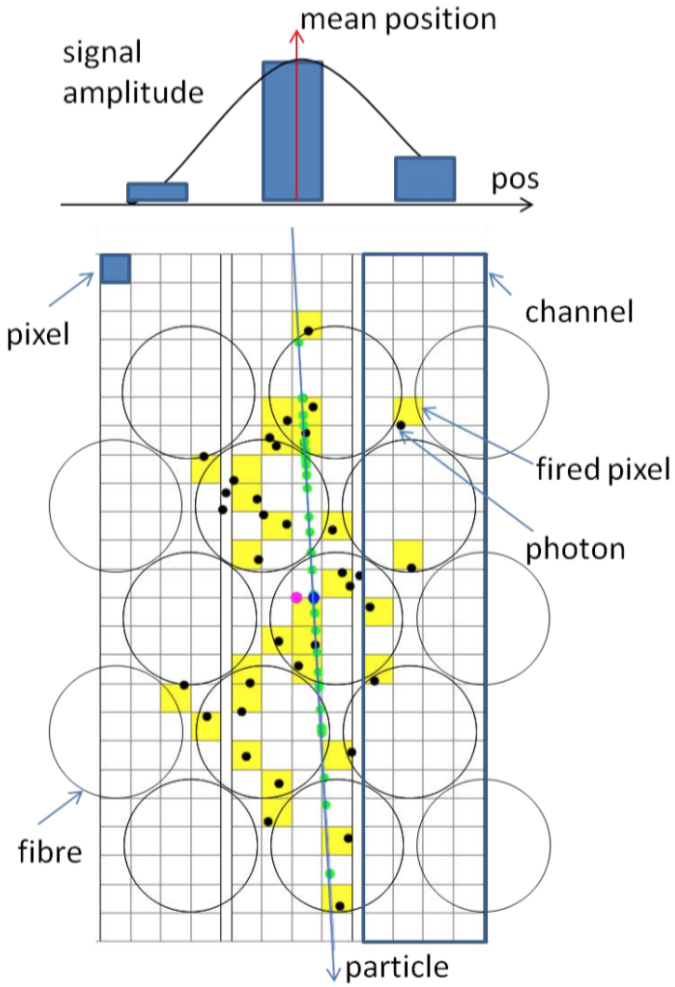


CERN/LHCC 2014-001

The Scintillating Fibres Tracker (SciFi)

- Attenuation length ≥ 3 m
- SiPM array:
  - 128 channels on two dies
  - customised channel size
    250 μm x 1.625 mm (HxW)

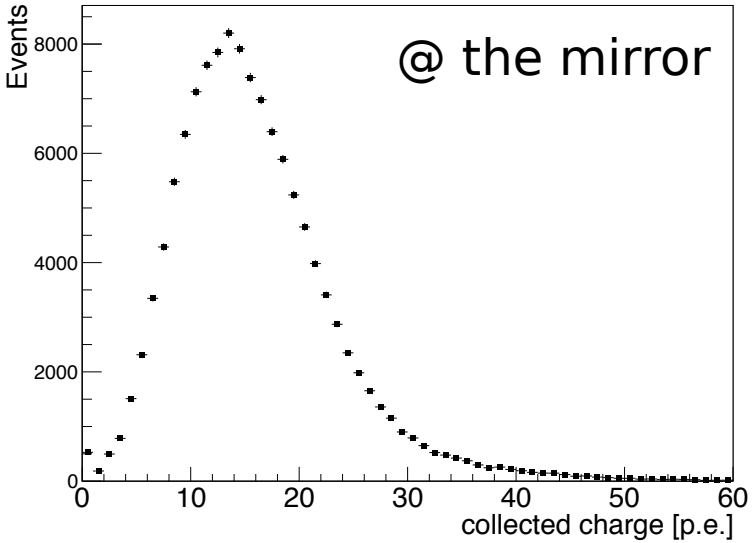


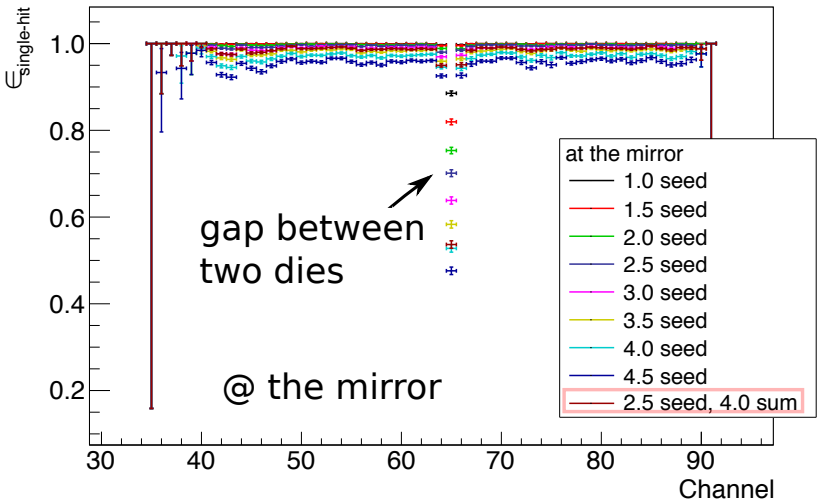


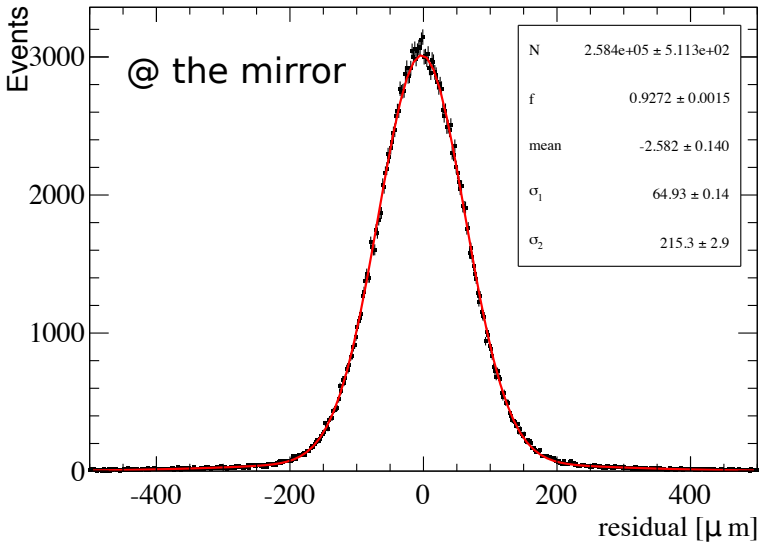
CERN/LHCC 2014-001

SciFi Tracker performances

- Light yeld:
  16 p.e. @ the mirror
- x-position resolution:
  $\sim 80\ \mu\mathrm{m}$
- High hit detection efficiency
  ($\geq 99\%$)





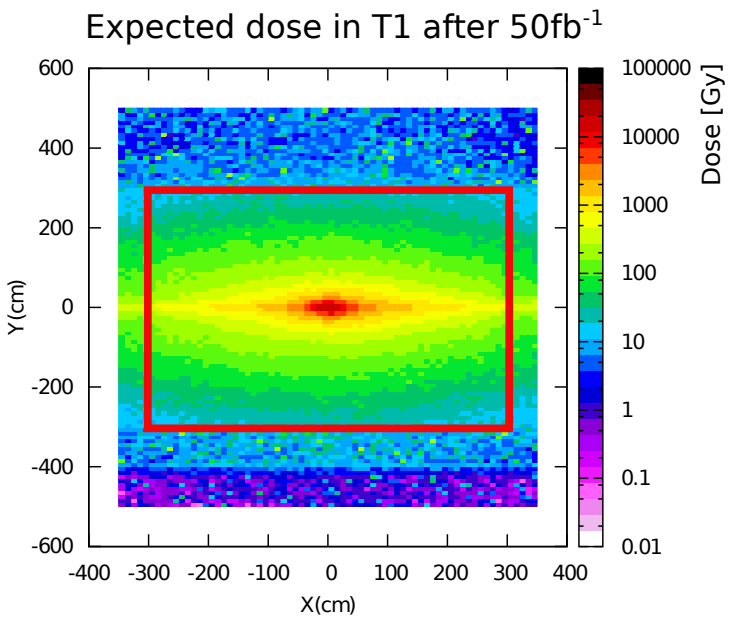


LHCb-PUB-2015-008

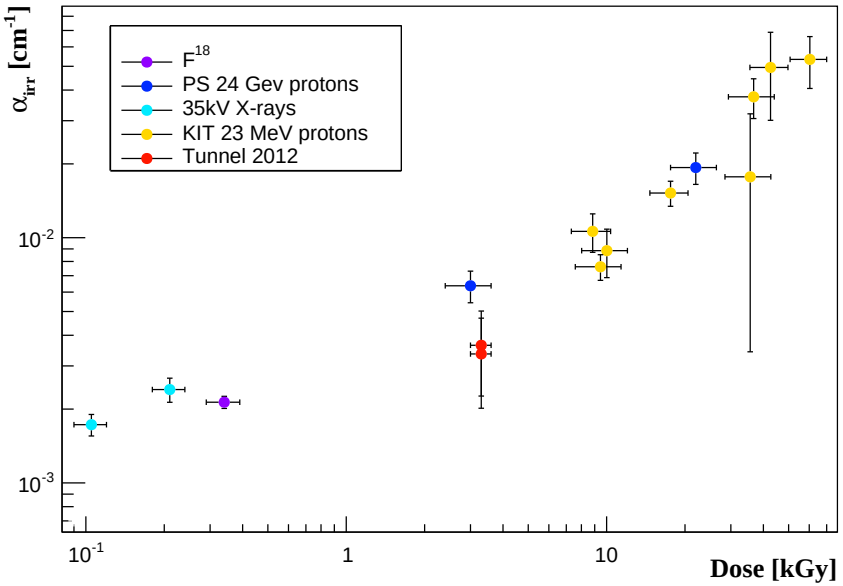
The Scintillating Fibres Tracker (SciFi)

Absorbed dose after 50 fb^{-1}:

- 35 kGy close to the beam pipe
- 50 Gy at the SiPMs



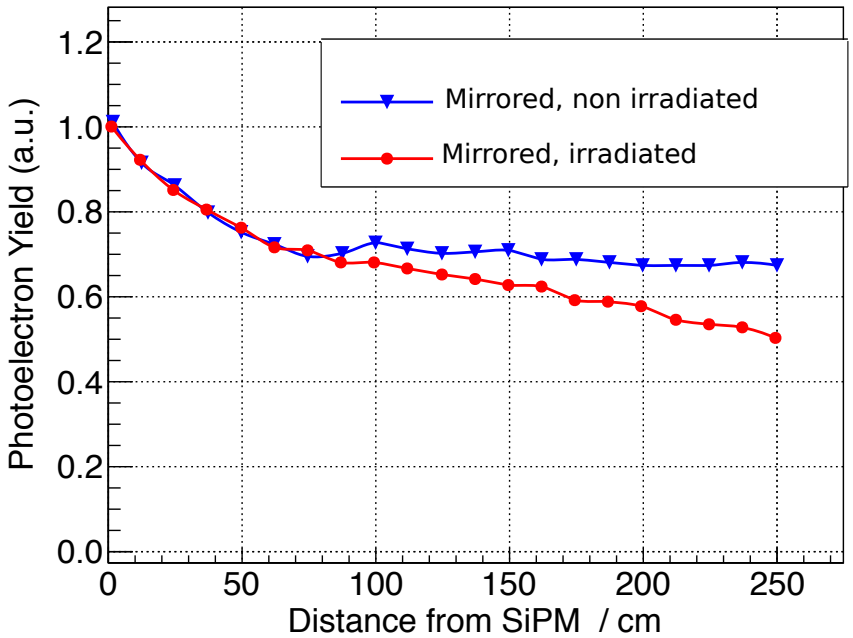
Additional absorbtion coefficient due to irradiation



CERN/LHCC 2014-001

The Scintillating Fibres Tracker (SciFi)

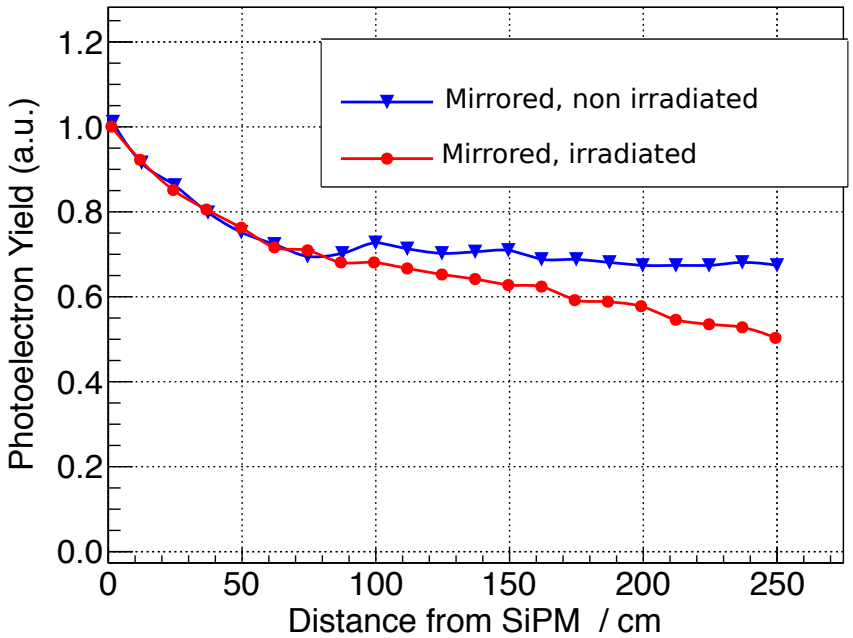
- Light loss @ the mirror: $\sim$ 30-40% after 50 fb^{-1}



CERN/LHCC 2014-001

The Scintillating Fibres Tracker (SciFi)

- Light loss @ the mirror: $\sim$ 30-40% after 50 fb^{-1}

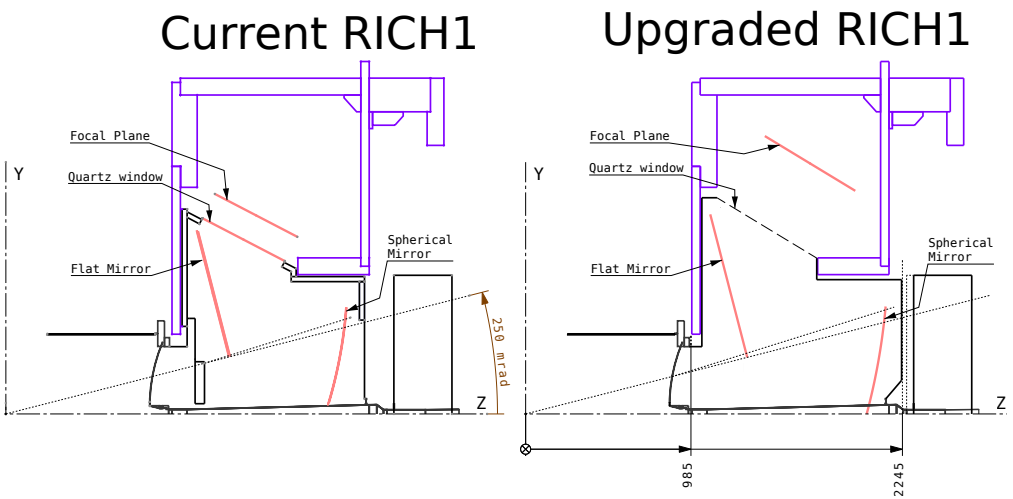


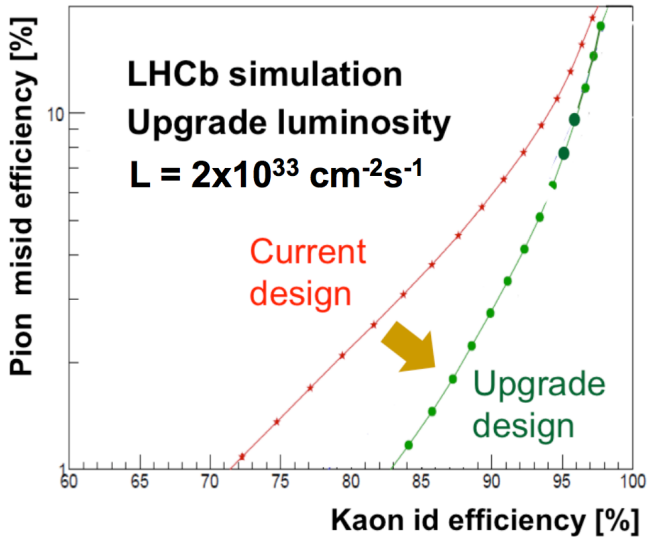
- Neutron damage to SiPMs ($6 \cdot 10^{11}$ $\mathrm{n_{eq}cm^{-2}}$)
  $\longrightarrow$ operate at -40°C

CERN/LHCC 2014-001

The RICH upgrade

- RICH system (RICH1 + RICH2) $\rightarrow$ PID of charged hadron over the range $10 < p < 100$ GeV/c
- HPDs photodetectors have embedded readout electronics $\rightarrow$ Replacement with MaPMTs with external readout electronics
- Large hit occupancy in RICH1 $\rightarrow$ modification of the optical layout





CERN/LHCC 2013-022

Summary

- LHCb has produced world-leading results
- Most results on key observables sensitive to Physics beyond the Standard Model are statistically limited. A detector upgrade is needed to significantly go further in precision
- The upgraded detector will be installed during LS2. New technologies:
  - VELO detector: Si pixel sensor
  - UT: Si strips sensor
  - SciFi Tracker: scintillating fibres
  - RICH detector: new layout
- Full reconstruction of all events at 40 MHz input rate with a full software trigger
- LHCb is expected to collect a total dataset of 50 fb^{-1} at $\mathcal{L} = 2 \cdot 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- The LHCb upgrade is fully approved and is in the production phase

Outlook - Beyond the upgrade

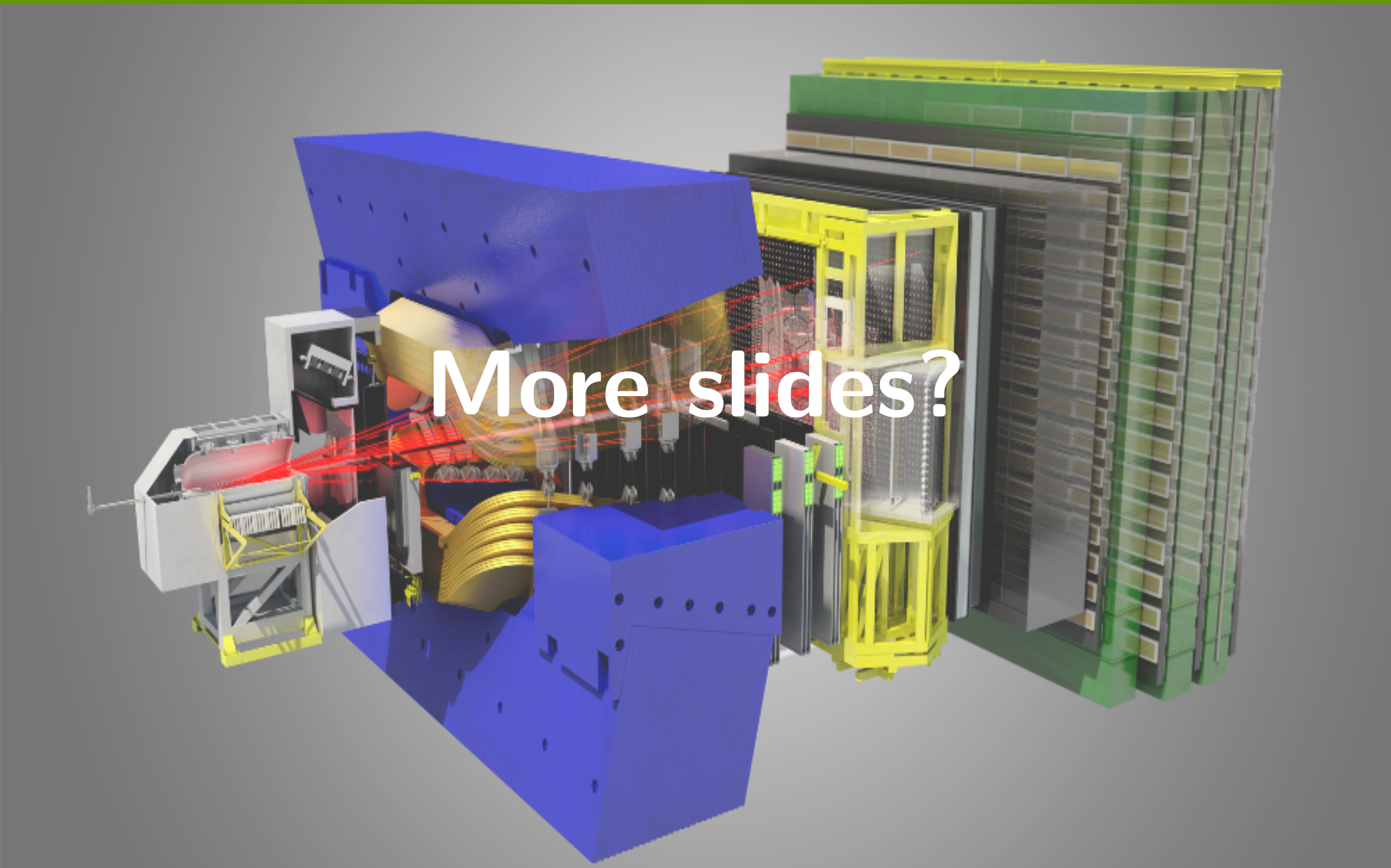
From the LHCb public website:

11 April 2016: Theatre of Dreams: LHCb looks to future

80 physicists gathered in Manchester on April 6th and 7th to discuss the future of the LHCb experiment. The LHCb collaboration is currently constructing a significant upgrade to its experiment which will be installed in 2019/2020. The workshop in Manchester, entitled "Theatre of Dreams: Beyond the LHCb Phase I Upgrade", explored the longer term future of the experiment in the second-half of the coming decade, and thereafter. The image below shows the Workshop participants at the University of Manchester museum.

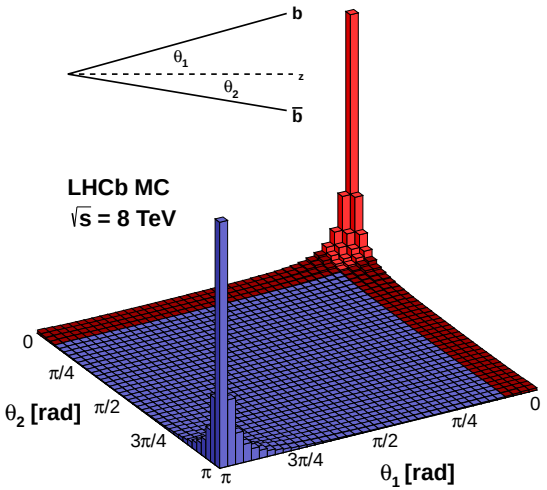
In the mid-2020s the LHC will be upgraded for higher luminosity operation. At this time the ATLAS and CMS experiments plan to undertake major phase II upgrades of their experiment. These works will necessitate a long-shutdown of at least 2.5 years duration. The meeting discussed enhancements to the LHCb experiment, dubbed a Phase Ib upgrade, that could be installed at this time. Although relatively modest, these improvements could bring significant physics benefits to the experiment. These include an addition to the particle Identification system using an innovative time of flight system based on Cherenkov light; placing detector chambers along the sides of the LHCb dipole to extend the physics reach by reconstructing lower momentum particles; and replacing the inner region of the electromagnetic calorimeter with new technology, thus extending the experiment's measurement programme with photons, neutral pions and electrons.

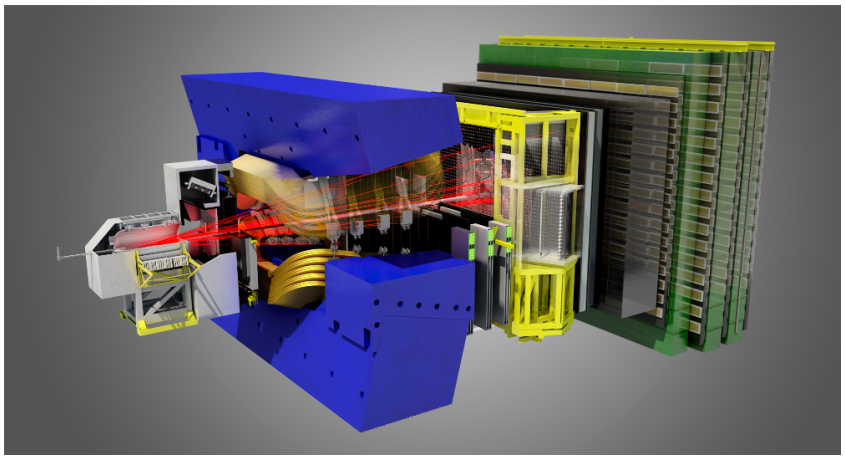
Backups



The LHCb detector

- Dedicated to Beauty and Charm physics
- Single-arm forward spectrometer
- η coverage: $2 < \eta < 5$
- Cross section at $\sqrt{s} = 7$ TeV in LHCb acceptance:
  - $\sigma_{\text{beauty}} = 75\ \mu\text{b}$
  - $\sigma_{\text{charm}} = 1419\ \mu\text{b}$





Detector performances

Decay time resolution: $\Delta t = 30$-50 fs

$\sigma(\text{IP}) = 20\ \mu$m for high-$p_T$ tracks

$\Delta p/p = 0.4$-0.6%

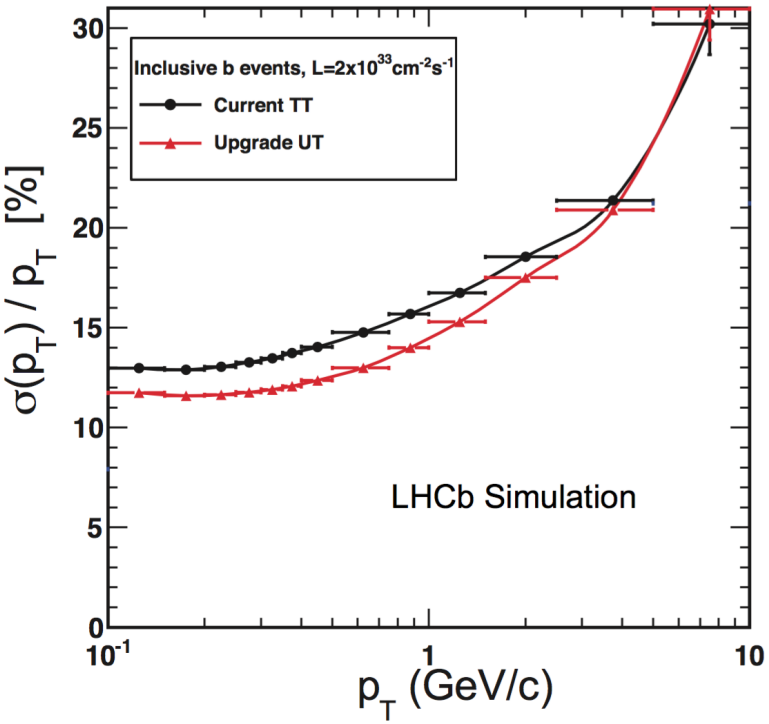
$\varepsilon(\mu/\mu) = 97\%, \varepsilon(\pi/\mu) = 1\%$

$\varepsilon(K/K) = 95\%, \varepsilon(\pi/K) = 5\%$

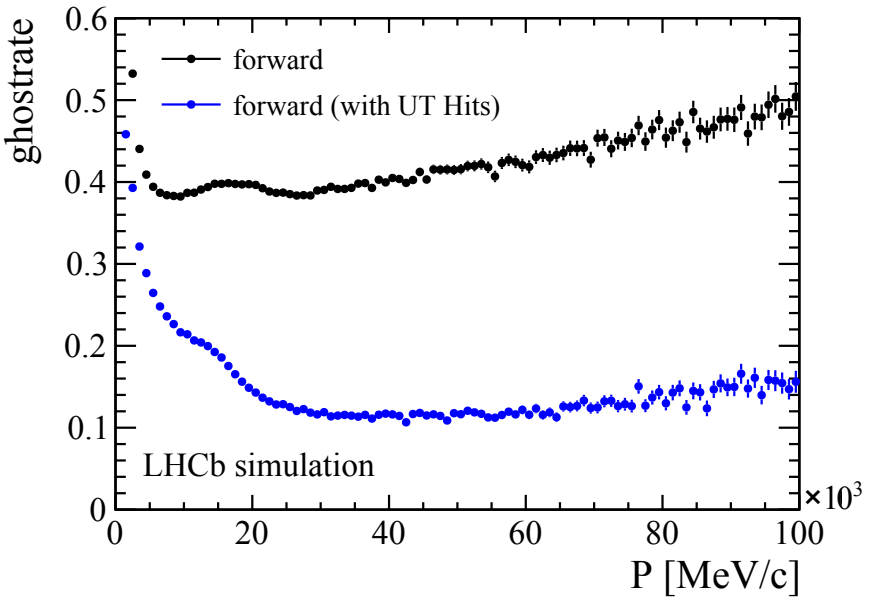
$\varepsilon(e/e) = 90\%, \varepsilon(e/h) = 5\%$

UT performances

p_T resolution
at upgrade conditions



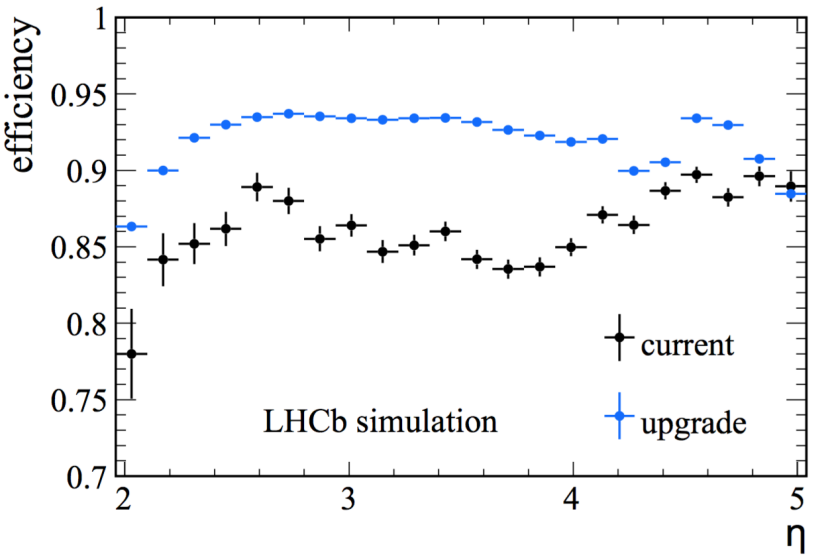
Ghost rate with and
without UT hits
at upgrade conditions

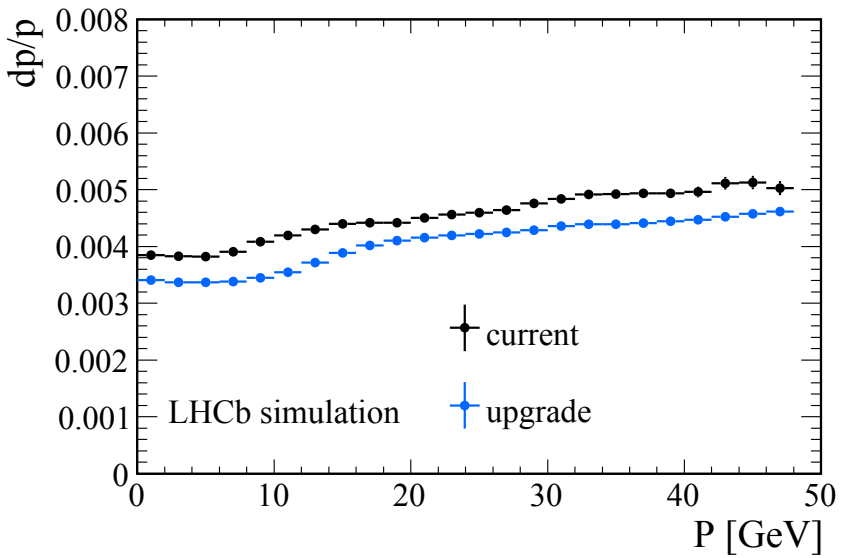


CERN/LHCC 2014-001

Tracking performance

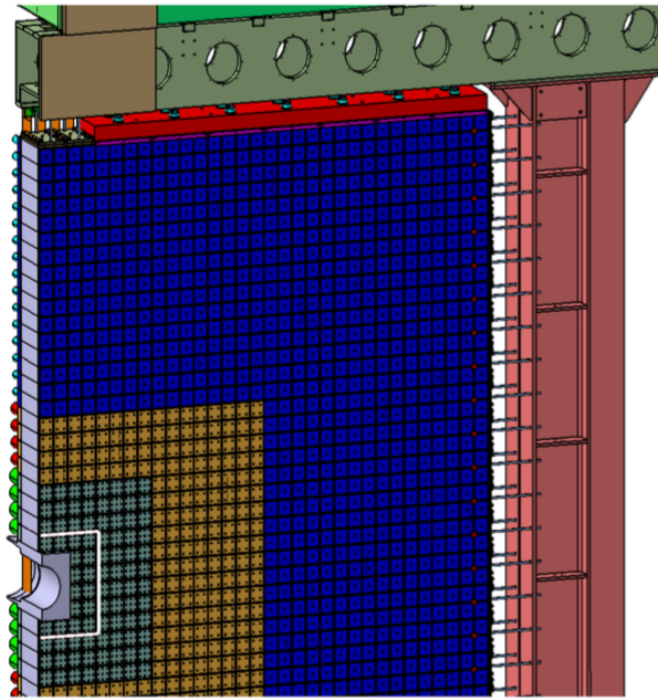
- Tracking performance (VELO + UT + SciFi) at upgrade conditions

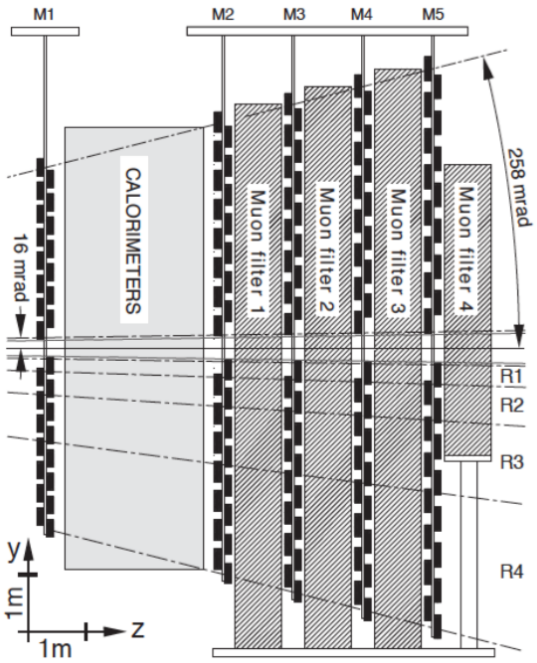
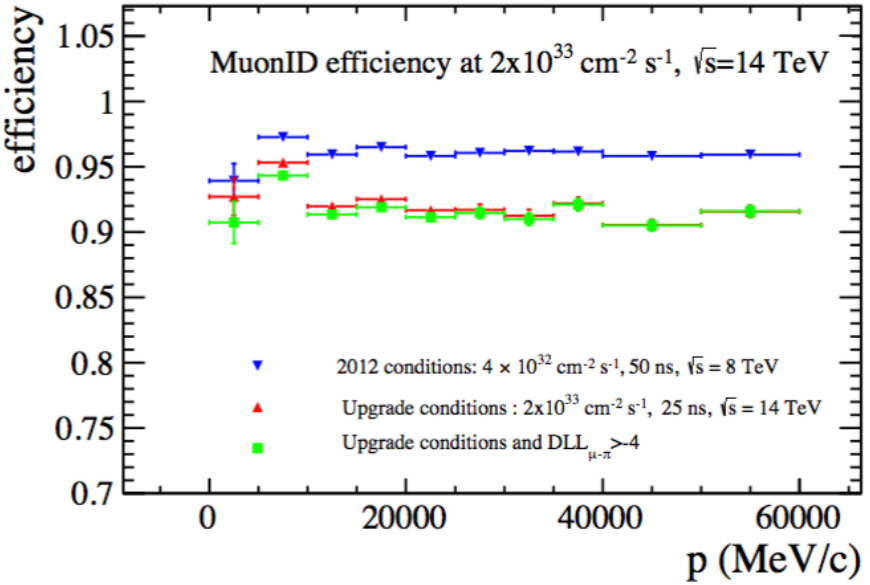
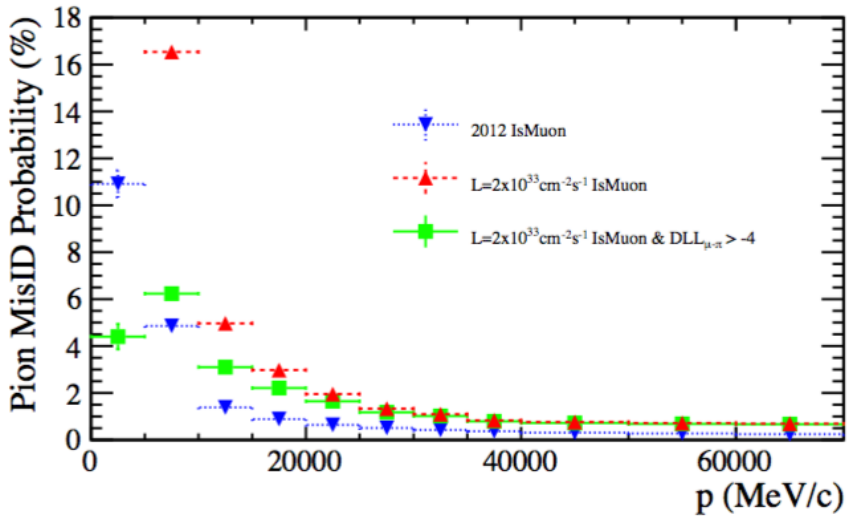




The calorimeters (ECAL + HCAL) upgrade

- Remove SPD and PS
- Readout at 40 MHz $\rightarrow$ Replace FE and BE electronics
- Increase in luminosity $\rightarrow$ Reduce gain of PMTs by a factor 5
- Irradiation campaignes and simulations showed:
  - HCAL modules ok up to 50 fb^{-1}
  - ECAL innermost modules will be replaced during LS3



The muon stations upgrade

- Remove M1
- Install shielding in front of M2
- Replace off-detector electronics