LHCb Upgrade Detector

G. Passaleva

INFN – Florence and CERN

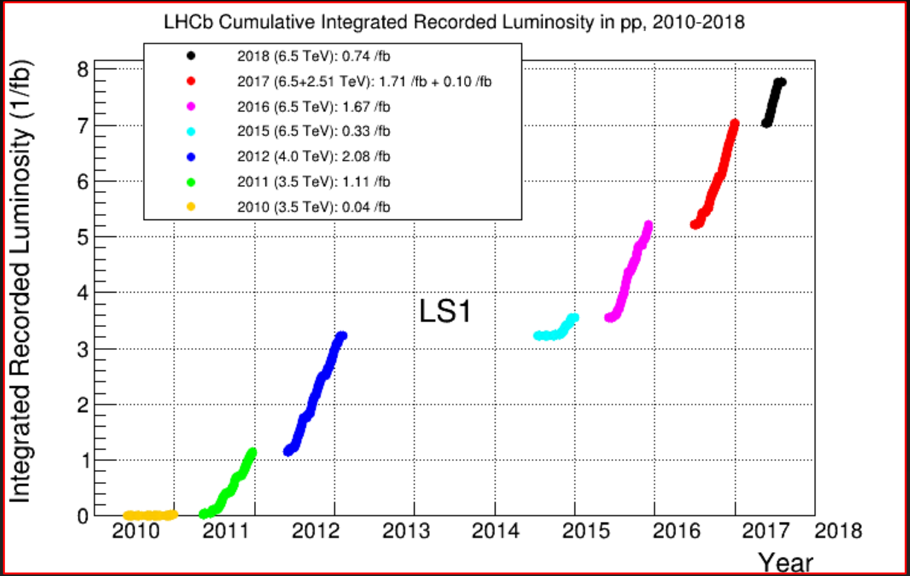
On behalf of the LHCb collaboration

ICHEP2018 – 07/07/2018

LHCb physics: a gourmand menu

LHCb has a very rich and diverse physics programme

- CKM mechanism and CP Violation
  - ★ γ,sin2β, ϕs, mixing in B,D decays,...
- Rare decays
  - ★ $B^0_{d,s} \rightarrow \mu\mu$ b $\rightarrow$ sll,...
- Spectroscopy
  - ★ Ξ_{cc}^{++}, tetraquark, pentaquark,...
- EW, QCD, direct searches
  - ★ Z^0,W,top,dark-photons ,LLP...
- Heavy ion, fixed target
  - ★ Heavy flavour production and nuclear effects in pA,AA



- ~8 fb^{-1} collected until now
- Expect to collect >9 fb^{-1} by the end of Run 2

Precision on many key flavour physics observables already remarkable but still statistically limited e.g. $\sigma(\gamma) \sim 4^\circ$ by end of Run 2.

The LHCb upgrade

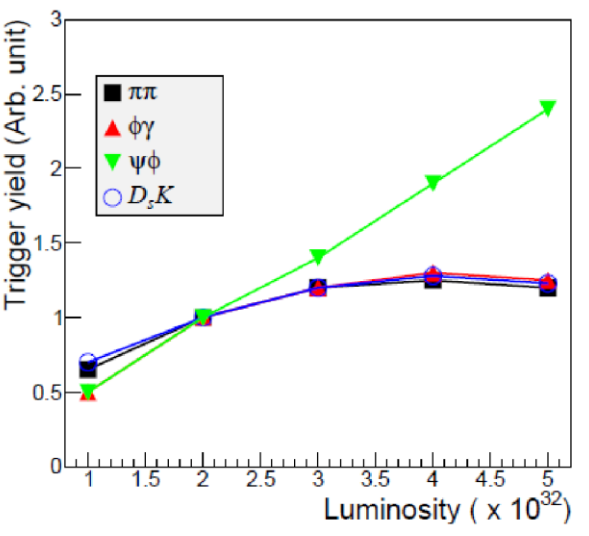
[LHCb-PUB-2012-010]

- Need more satistics!
  - ★ An LHCb Upgrade is scheduled, with installation in 2019-2020 (LHC LS2) and first data-taking in Run 3 (2021-2023).

- Raise operational luminosity by factor five to 2 x $10^{33}cm^{-2}s^{-1}$
- Remove present hardware trigger limitations
  - ★ ☞ Full software trigger running at 40 MHz input rate!

- Necessitates redesign of several sub-detectors and overhaul of readout (40 MHz readout rate)

- Huge increase in precision expected in many cases. (See for example Eur. Phys. J. C 73 (2013) 2373)

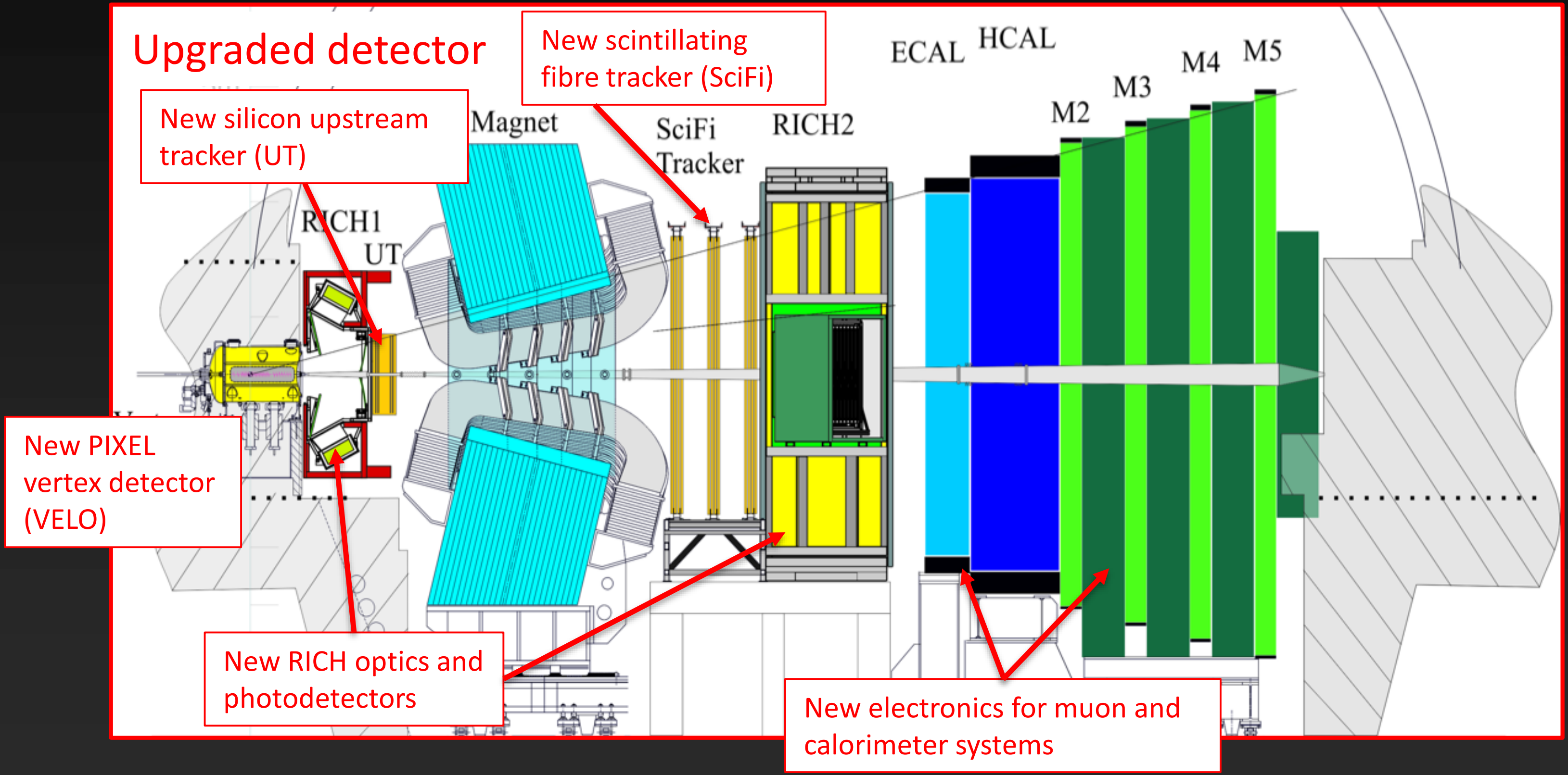


Present L0 hardware trigger (max rate 1 MHz) saturates at high luminosity for hadronic final state modes

The LHCb upgrade in a snapshot

[CERN-LHCC-2012-007]

All sub-detectors read out at 40 MHz for a **fully software trigger**

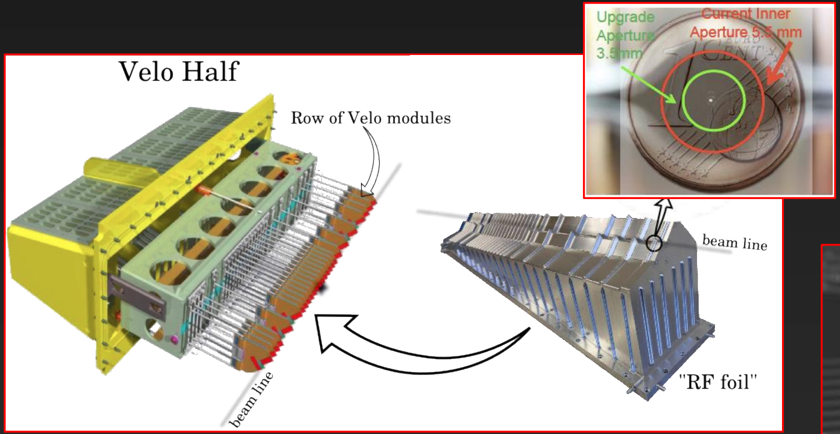


Tracking system: Vertex Locator (VELO)

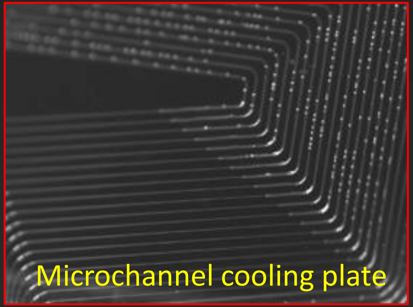
[CERN-LHCC-2013-021]

Talk by Stefano De Capua

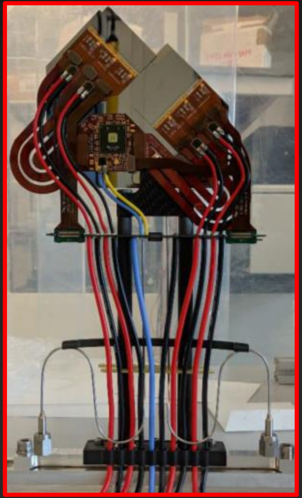
- Silicon pixel detector, 55 x 55 μm^2 pixels.
- In secondary vacuum, retractable.
- Closest pixels at 5.1 mm from the beam line.
- Aluminium foil to protect the Velo without interfering with the beam ("RF-foil").
  - ★ 250 μm tickness, option to go to 150 μm with chemical etching.
  - ★ Low material budget.



- High and non-uniform irradiation: 8 x10^{15} n_{eq}/cm^2 with a $r^{-2.1}$ profile.
- ☞Cooling @ < -20°
  - Evaporative CO_2 thorugh silicon microchannel substrate



CO_2 bubbles

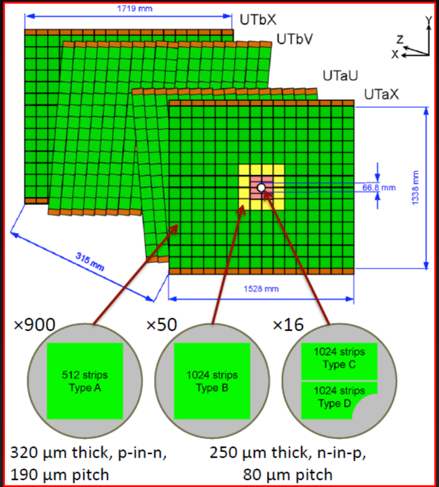


VELO module

Tracking system: Upstream Tracker (UT)

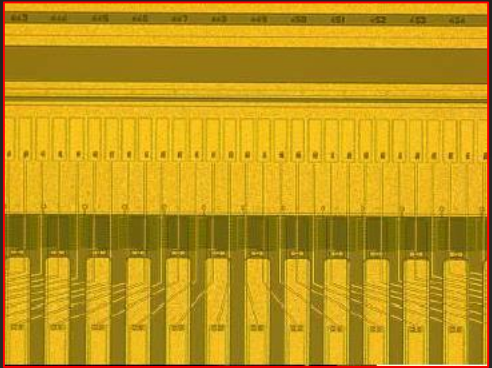
- 4 stations with x-u-v-x layers of silicon microstrip detectors.
  - ★ 4 sensor design, one with circular cut-out around the beam-pipe.
- Sensors with embedded pitch adapter
  - ★ Mounted on low material budget staves

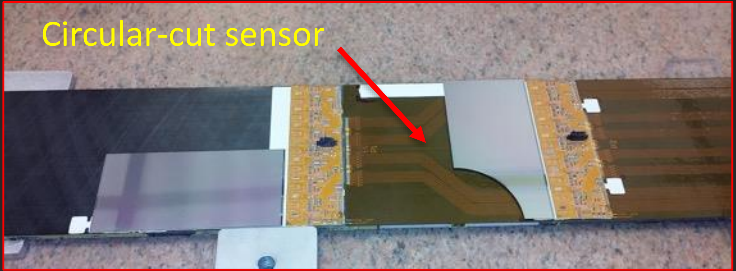
[CERN-LHCC-2014-001]

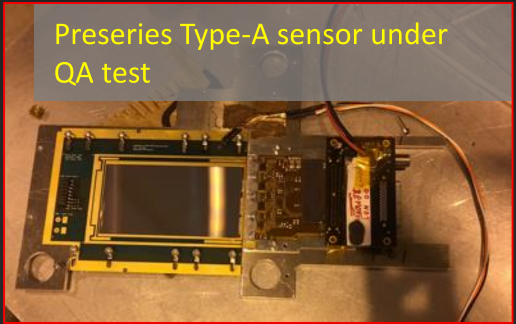


stave construction

Detail of embedded pitch adapter




Circular-cut sensor

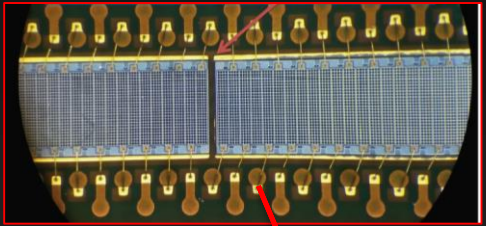

Preseries Type-A sensor under QA test

Tracking system: Scintillating fibre tracker (SciFi)

[CERN-LHCC-2014-001]
Talk by anine Müller

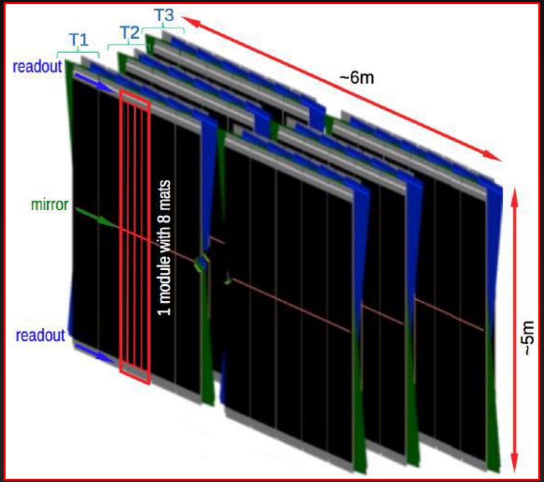
- 11000 km of Ø250 μm scintillating fibers with silicon photo-multipliers (SiPM) readout.
- 3 planes of x-u-v-x modules.
- SiPM cooled down to -40° to reduce the dark count rate due to radiation damage.

Module construction



Detail of a SiPM array

Cold Box to keep SiPM at -40° in construction



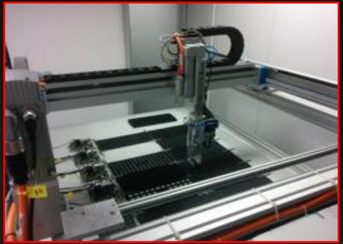
PID detector system: RICH, Muon, Calorimeters

[CERN-LHCC-2013-022]
Talk by Michele Piero Blago

- RICH:
  - ★ New photo-detectors and readout chain.
  - ★ 6x6 and 2.9x2.9 mm^2 pixels multi-anode photo-multipliers (MaPMTs).
  - ★ Modified optics and mechanics to reduce RICH1 occupancy.

- Calorimeters:
  - ★ Electromagnetic (ECAL) and hadronic (HCAL) calorimeters remain identical
  - ★ New readout electronics.
  - ★ ECAL inner modules replaced in LS3.

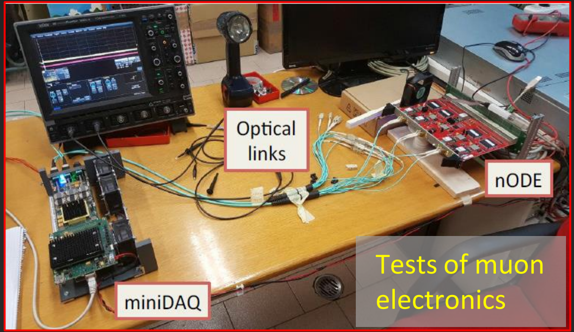
- Muon Stations:
  - ★ New readout electronics and increased granularity.



Robotised test of calorimeter front-end electronics

RICH module equipped with MaPMTs

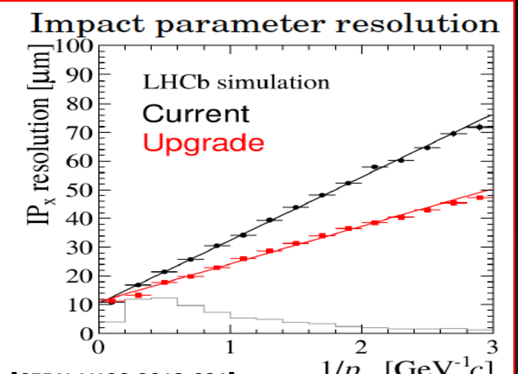
Tests of calorimeter electronics



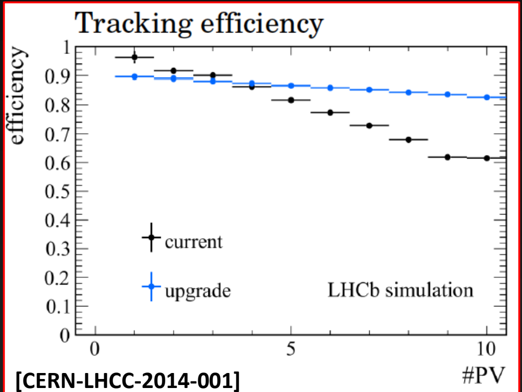
Tests of muon electronics

Expected detector performance

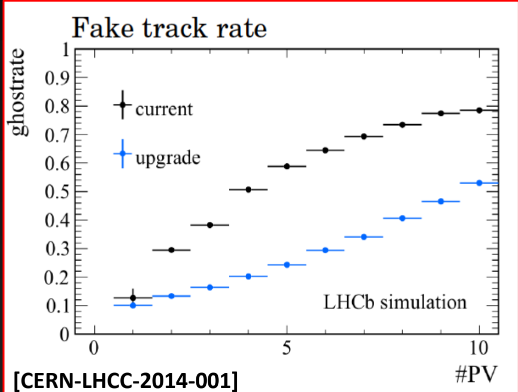
- Comparing upgraded LHCb and current LHCb in upgrade consitions



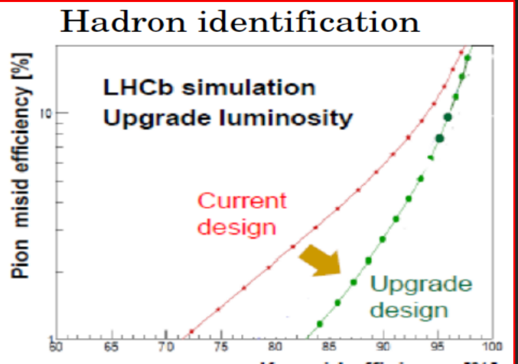
[CERN-LHCC-2013-021]



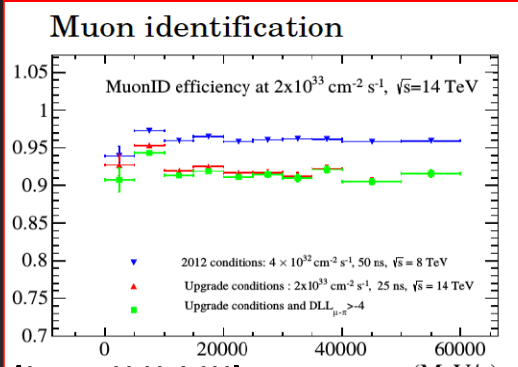
[CERN-LHCC-2014-001]



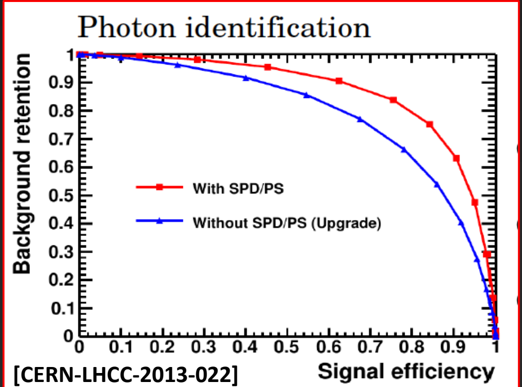
[CERN-LHCC-2014-001]



[CERN-LHCC-2013-022]



[CERN-LHCC-2013-022]

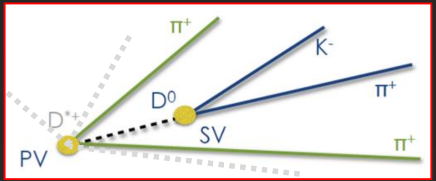


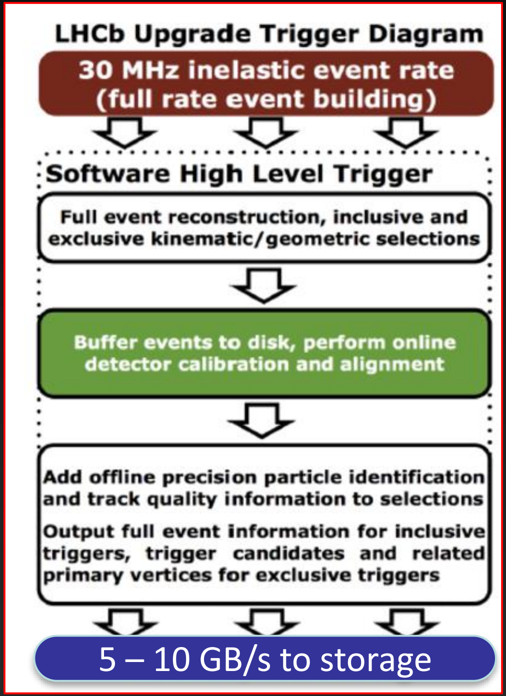
[CERN-LHCC-2013-022]

The upgrade full software trigger

[CERN-LHCC-2018-007]
Talk by Mark Withehead

- Must fully process events at 30 MHz
- Events stored in buffer, for online alignment, calibration
- Full reconstruction and physics analysis in real time
  - ★ No further reprocessing offline
- Use the «TURBO» scheme:
  - ★ Save only part of the event, e.g. primary vertex + secondary vertex and daughter tracks of triggered signal





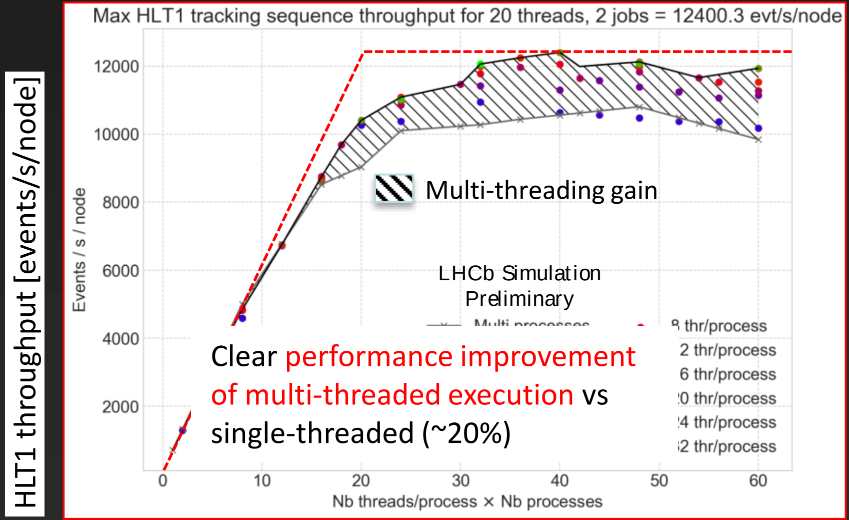
Currently writing ~0.7 GB/s

LHCb upgrade: full software trigger development

[CERN-LHCC-2018-007]

- Upgrade HLT will process data at 30 MHz – challenging !
  - ★ Need software modernization
  - ★ Need proper software engineering
  - ★ Exploit modern CPU features (multi-threading, vectorization)
  - ★ Huge effort ongoing, substantial progress in many areas

Tracking algorithm optimization



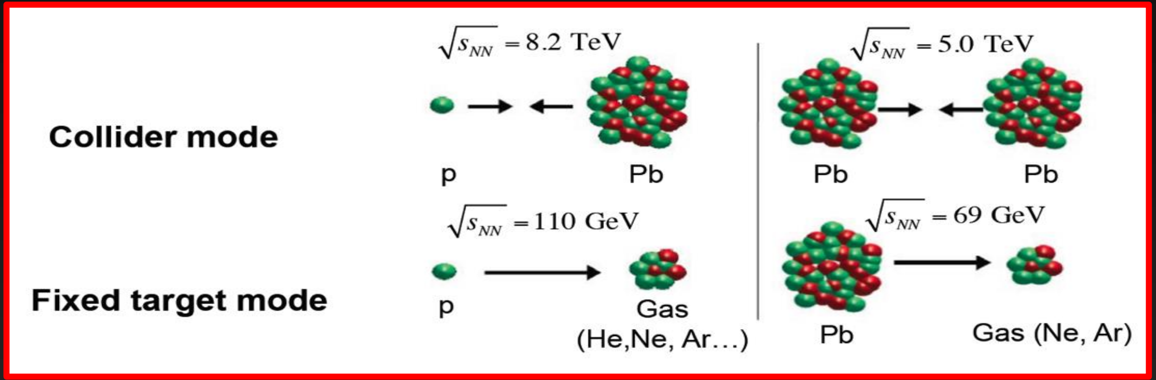
		SSE4		AVX2	
		time (s)	Speedup	time (s)	Speedup
double	scalar	233.462		228.752	
double	vectorized	122.259	1.90	58.243	3.93
float	scalar	214.451		209.756	
float	vectorized	55.707	3.85	26.539	7.90

Table 3.3: Performance of vectorized Rich's Ray Tracing

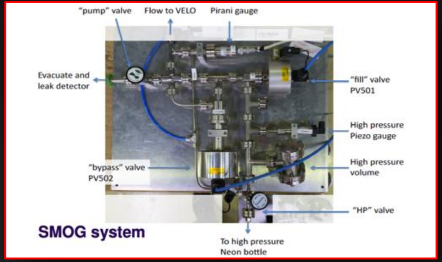
Vectorization can give up to an ideal x8 speed-up factor

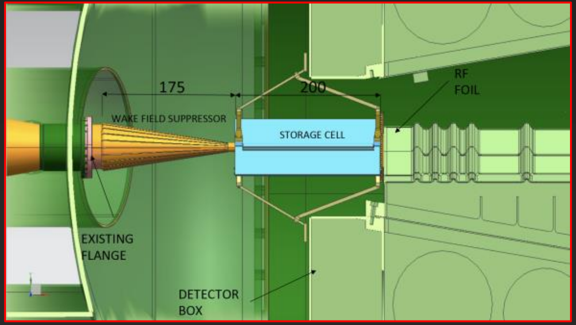
LHCb fixed target program evolution

- LHCb can operate in collider mode, fixed target mode or both in parallel!
  - ★ Fixed target is obtained by injecting gas inside the beam pipe at VELO position (SMOG system)



Nucl. Instrum. Meth. A 553 388
JINST 9 (2014) P12005

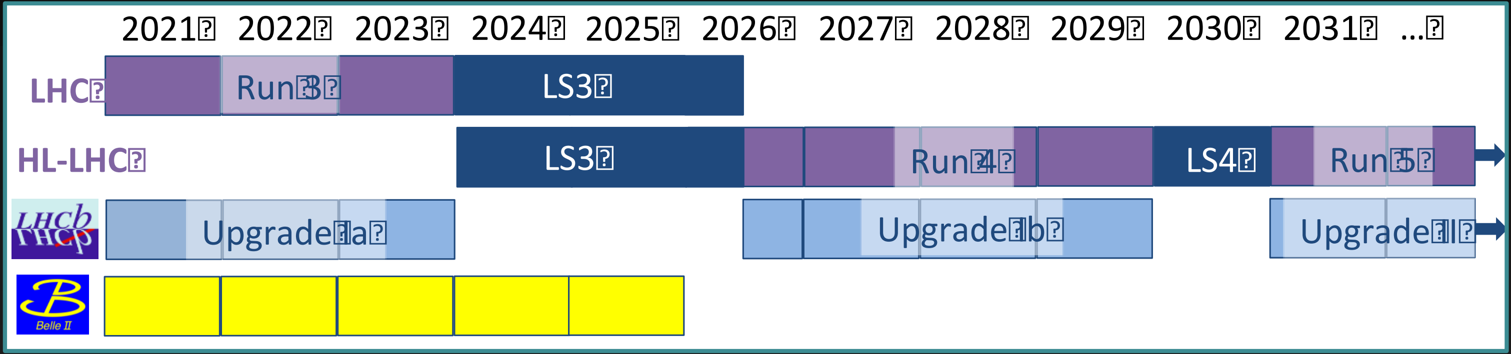




- An upgrade of the gas injection system comprising a gas storage cell is actively pursued
  - ★ Higher gas density; possibility to inject more gas types
  - ★ Better knowledge of gas volume and gas pressure => higher precision in luminosity measurement

- Other FT proposals submitted to LHCb under scrutiny

LHCb Upgrade II



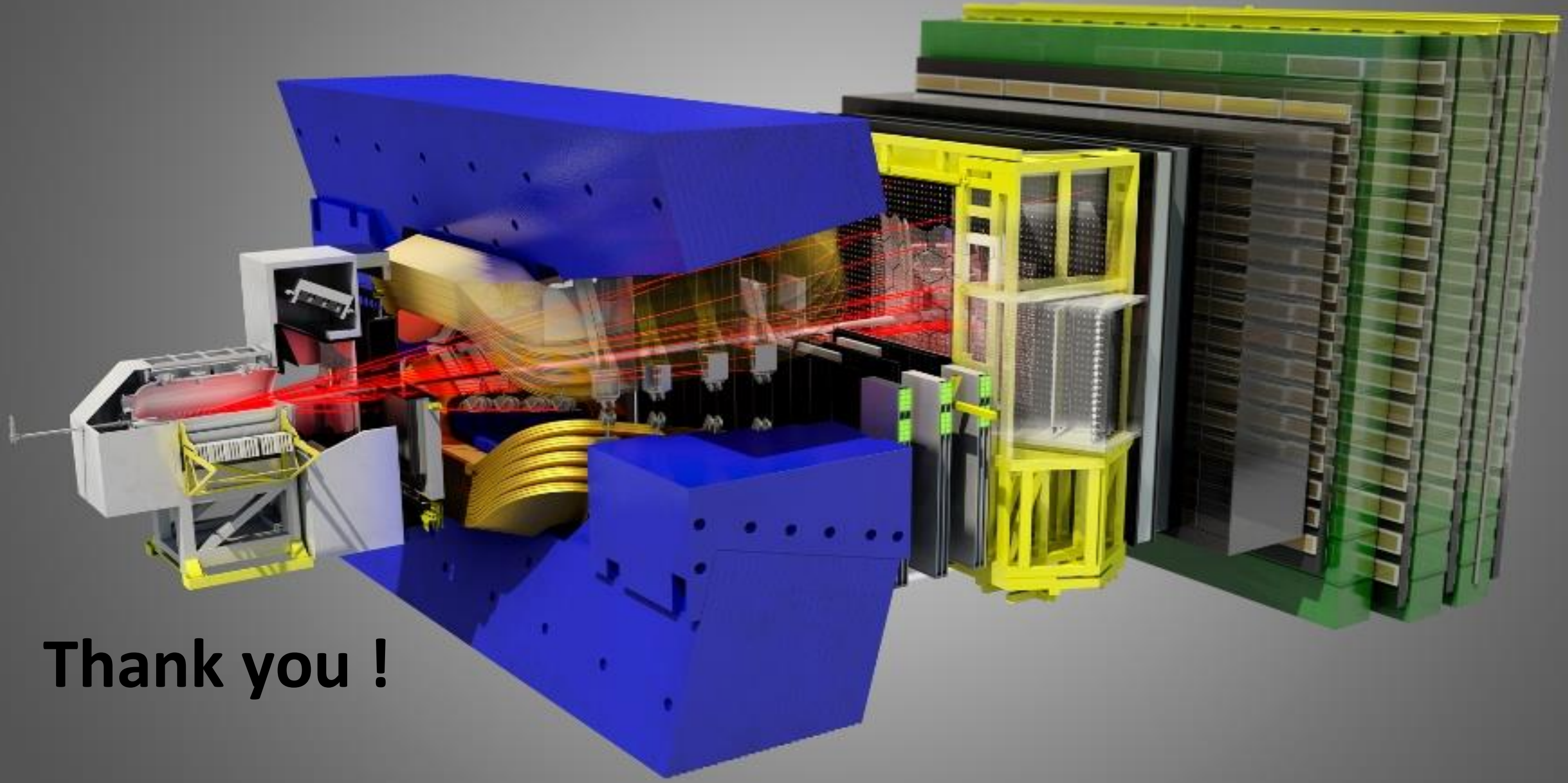
[CERN-LHCC-2017-003]

Talks by
Chris Parkes
Marco Poli-Lener
Thomas Blake

- Aim to fully exploit HL-LHC for flavour physics and other opportunities in the forward direction
- Aim to collect > 300 fb^{-1} at L = $2x10^{34}$, x10 with respect to Upgrade I
- Consolidate in LS3, Major upgrade in LS4
- Expression of Interest issued in 2017
- Feasibility study performed by LHC experts
- Physics case in preparation

Conclusions and outlook

- A major upgrade of the LHCb experiment is under construction
- Many challenges for detectors, readout electronics and trigger
- Detector construction in full swing, installation starts in 6 months !
- Looking into the far future:
  - ★ Expression of Interest for future upgrades submitted
  - ★ Preparing a physics case document
  - ★ A lot of opportunities !



Thank you !

BACKUP SLIDES

Statistical sensitivities of the LHCb upgrade to key observables

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

Table 16: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with 50 fb^{-1} by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities. Note that the current sensitivities do not include new results presented at ICHEP 2012 or CKM2012.

Type	Observable	Current precision **(in 2012)**	LHCb 2018	**Upgrade** (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [138]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [214]	0.045	0.014	~ 0.01
	$a_{\rm sl}^s$	6.4×10^{-3} [43]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$	0.17 [43]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.08 [67]	0.025	0.008	0.02
	$s_0\ A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [67]	6 %	2 %	7 %
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.25 [76]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [85]	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	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–$12°$ [244, 258]	4°	0.9°	negligible
	γ ($B_s^0 \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\ K_S^0$)	0.8° [43]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [43]	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–