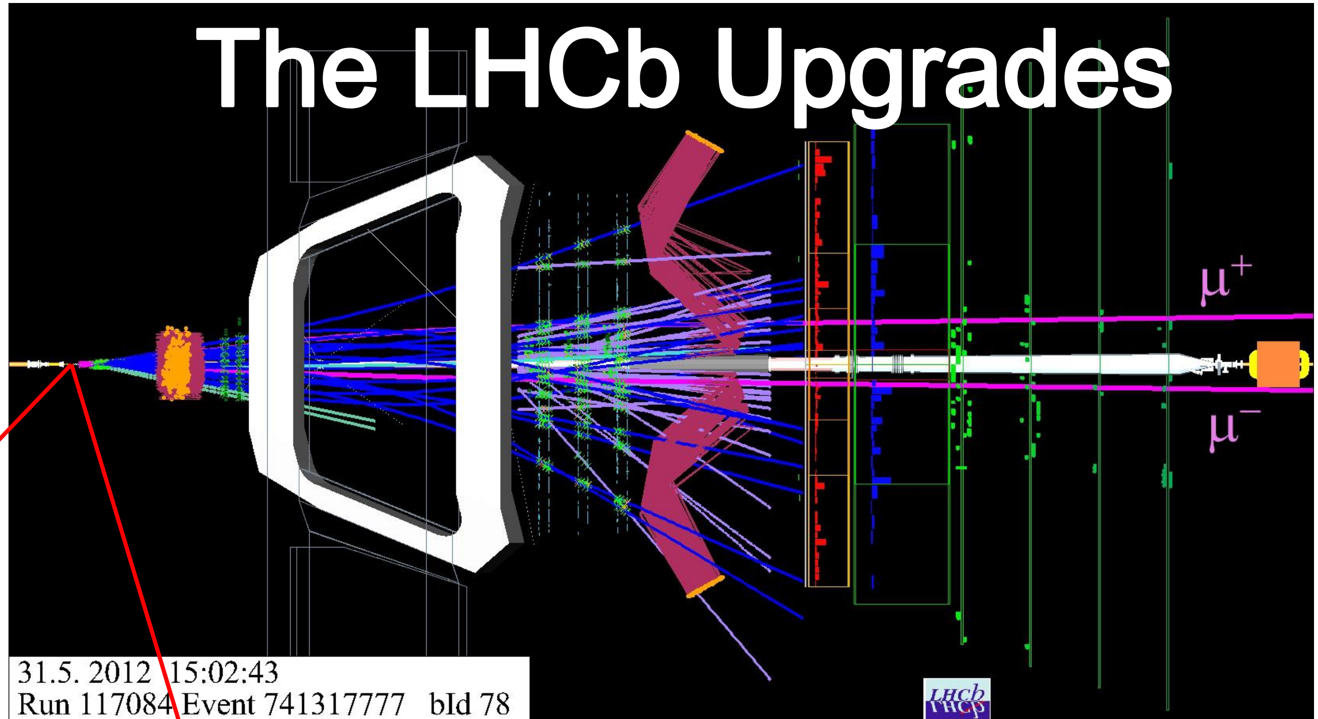
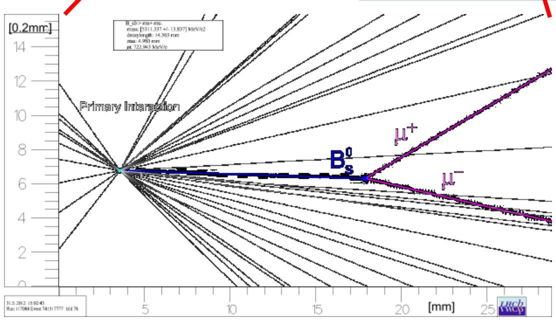
The LHCb Upgrades





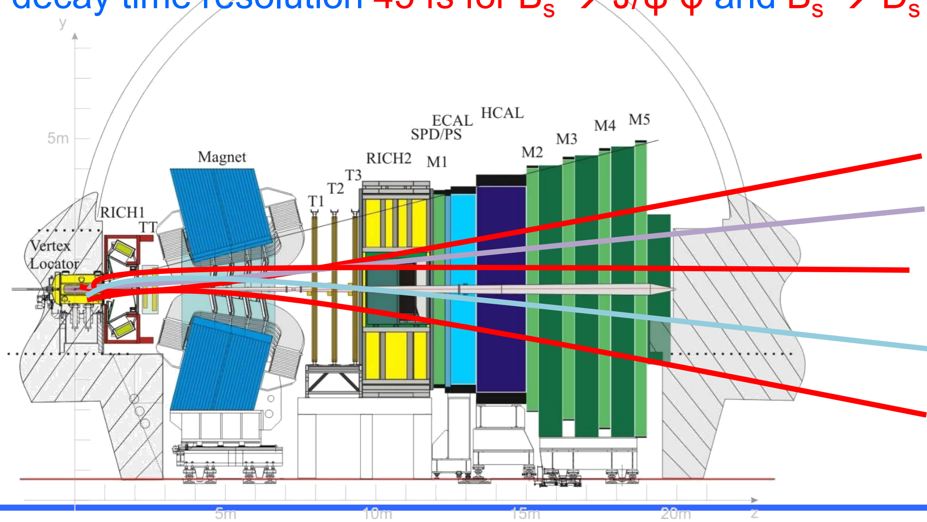
An Alpine LHC Physics Summit (ALPS 2017)
17-21 April 2017,
Obergurgl, Austria

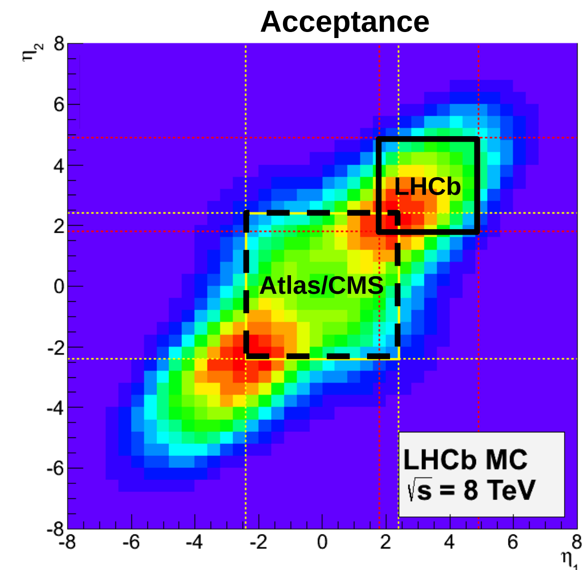
Federico Alessio, CERN
on behalf of the LHCb Collaboration

Current LHCb detector

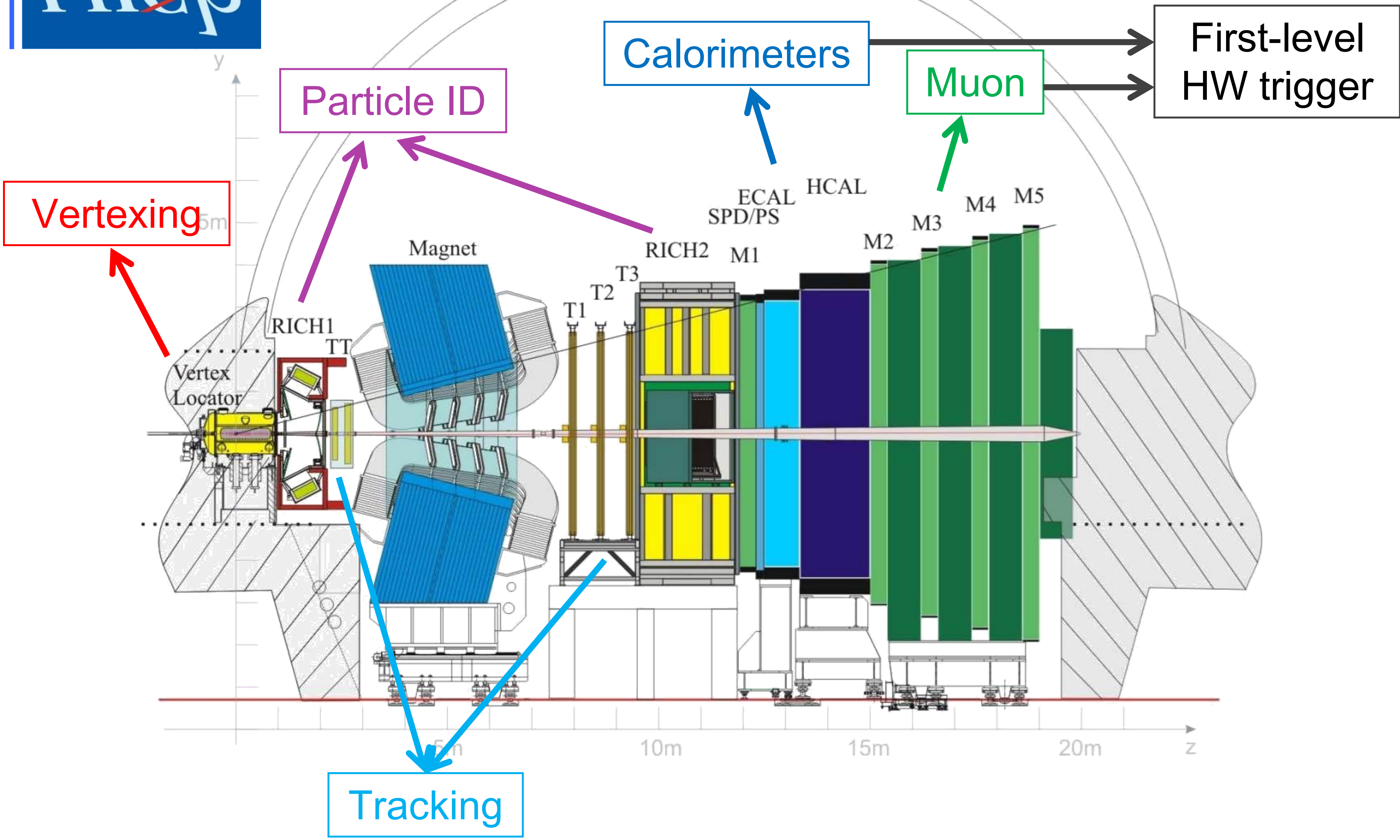
LHCb proved itself to be the Forward General-Purpose Detector at the LHC:

- forward arm spectrometer with unique coverage in pseudorapidity (2 < η < 5, 4% of solid angle)
- catching 40% of heavy quark production cross-section
- precision measurements in beauty and charm sectors
    - ✓ Δp / p = 0.4% at 5 GeV/c to 0.6% at 100 GeV/c
    - ✓ impact parameter resolution 20 μm for high-pT tracks
    - ✓ decay time resolution 45 fs for $B_s \rightarrow J/\psi\ \varphi$ and $B_s \rightarrow D_s\ \pi$

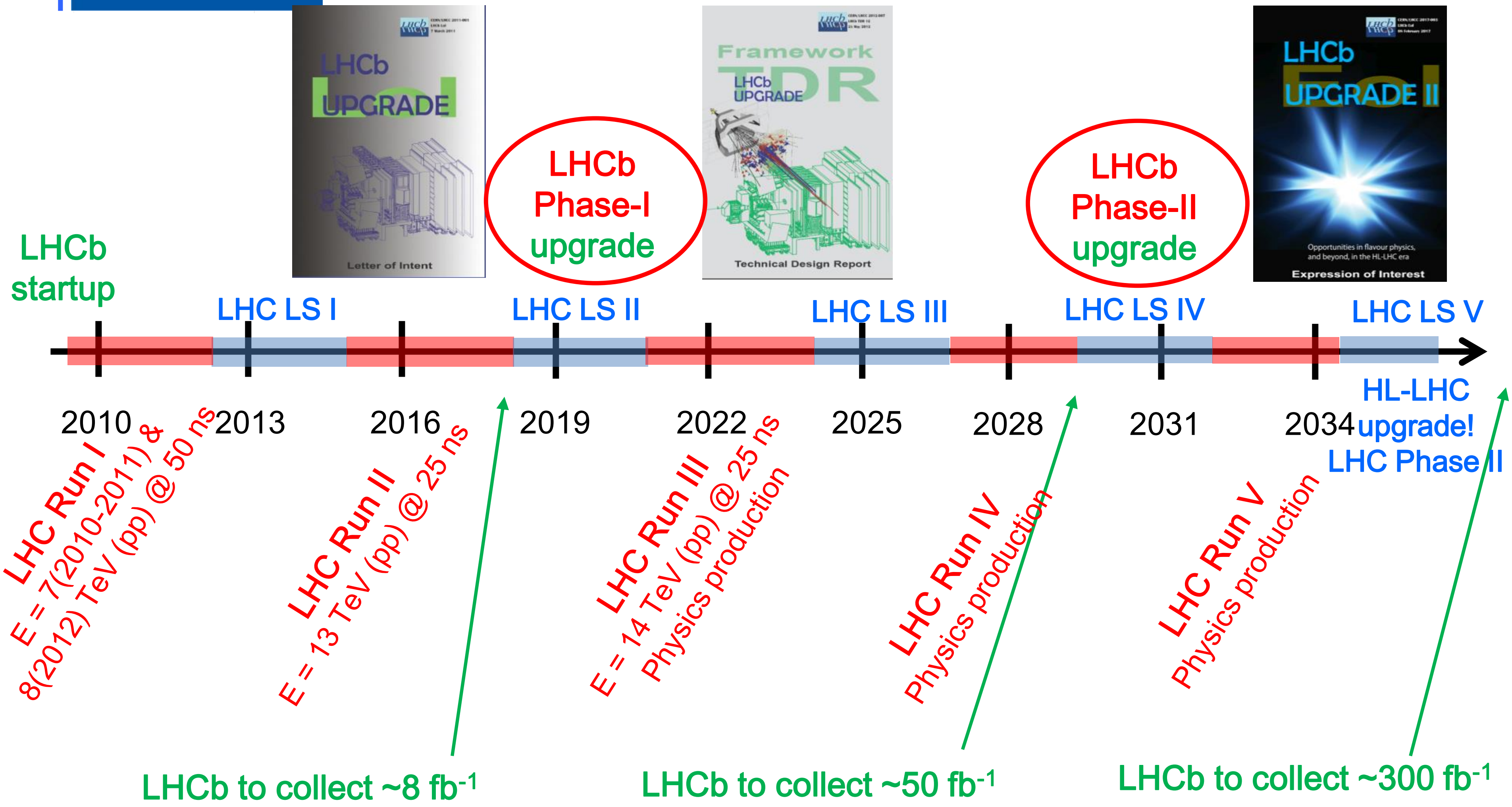




Current LHCb detector



LHCb long-term plan



Phase-I Upgrade of LHCb

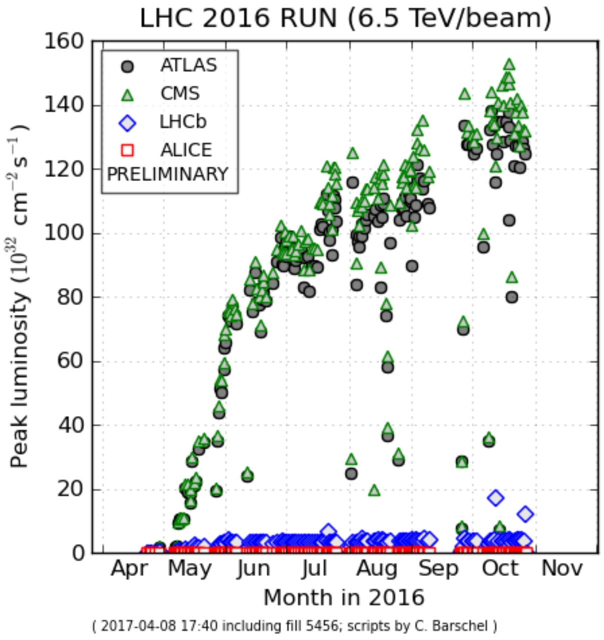
The amount of data and the physics yield from data recorded by the current LHCb experiment is limited by its detector.

While LHC accelerator will keep steadily increasing …

- energy / beam (3.5 → 4 → 6.5 TeV → 7 TeV)
- luminosity (peak 8×10^{33} → 2×10^{34} $cm^{-2}s^{-1}$ → HL-LHC)

… but LHCb will stay limited in terms of

- data bandwidth: limited to 1.1 MHz / 40 MHz max
- physics yields for hadronic channels at the hardware trigger
- detectors degradation at higher luminosities

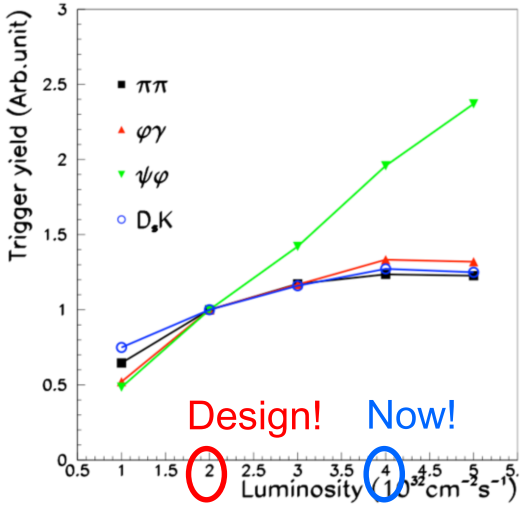


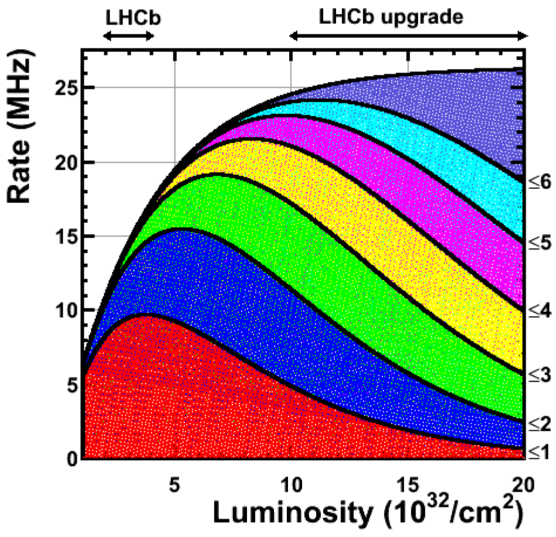
Factor ~40 between LHCb and ATLAS/CMS instantaneous luminosity!

Current limitations

First-level hardware trigger is limited at higher luminosities for hadronic channels:

- almost a factor 2 between di-muon events and fully hadronic decays
- due to trigger criteria based on p_T and E_T to reduce trigger rate to the bandwidth limited to 1.1 MHz





At higher luminosities → harsher cuts on p_T and E_T

- waste luminosity while not retaining amount of data
- increases complexity of track reconstruction
  - higher computational times in processing farm
- ageing and fast degradation of sub-detectors
  - designed to operate 5 yr at 2×10^{32} $cm^{-2}s^{-1}$
  - currently reaching 5 years at $>3 \times 10^{32}$ $cm^{-2}s^{-1}$ and still two years to go…

Physics motivations

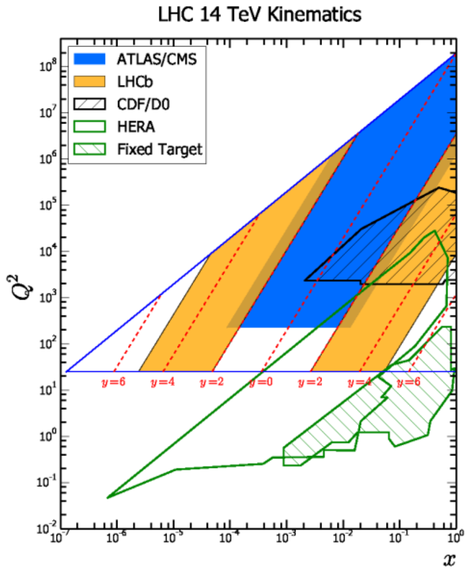
Beyond Flavour Physics:

from exploration studies → to precision studies

- *BR*($B_s \rightarrow \mu^+\mu^-$) down to ~10% of SM
- CKM γ angle to <1°
- $2\beta_s$ to precision <20% of SM value
- charm CPV search below 10^{-4}

but also beyond heavy flavour physics:

- search for lepton-flavour violating tau decays
- low mass Majorana neutrinos
- electroweak physics
- long-lived new particles
- QCD



Even more important to maximize the possibility of discovery of NP by studying flavor observable to highest precision possible!

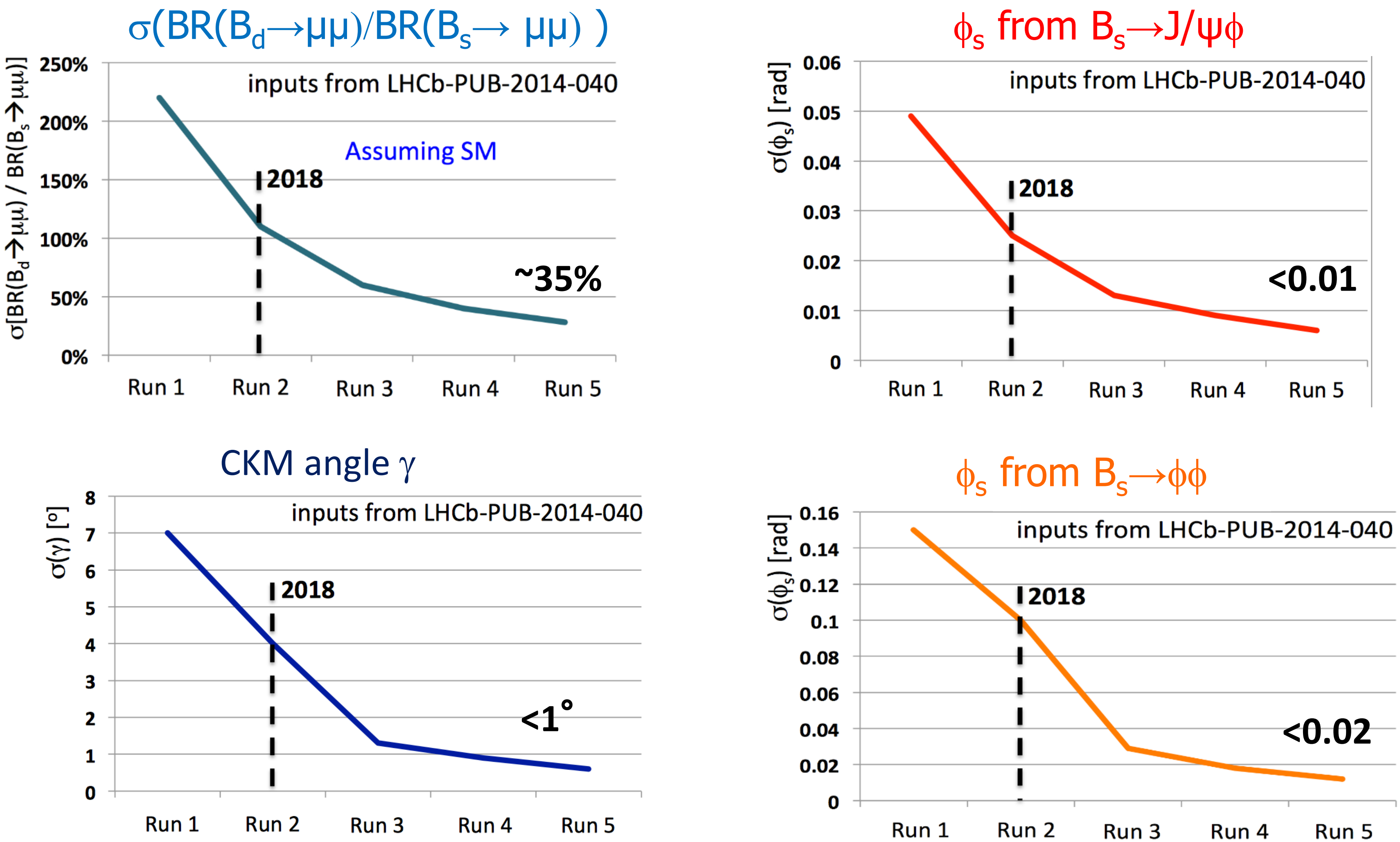
LHCb physics prospects for a Phase-I upgrade

Expect to collect a total of ~8 fb^{-1} of data up to 2018 and 50 fb^{-1} of data after 2018
→ moving towards theory precision measurements!

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 [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	γ $(B \to D^{(*)}K^{(*)})$	~ 10–$12°$ [19, 20]	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° [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}	–

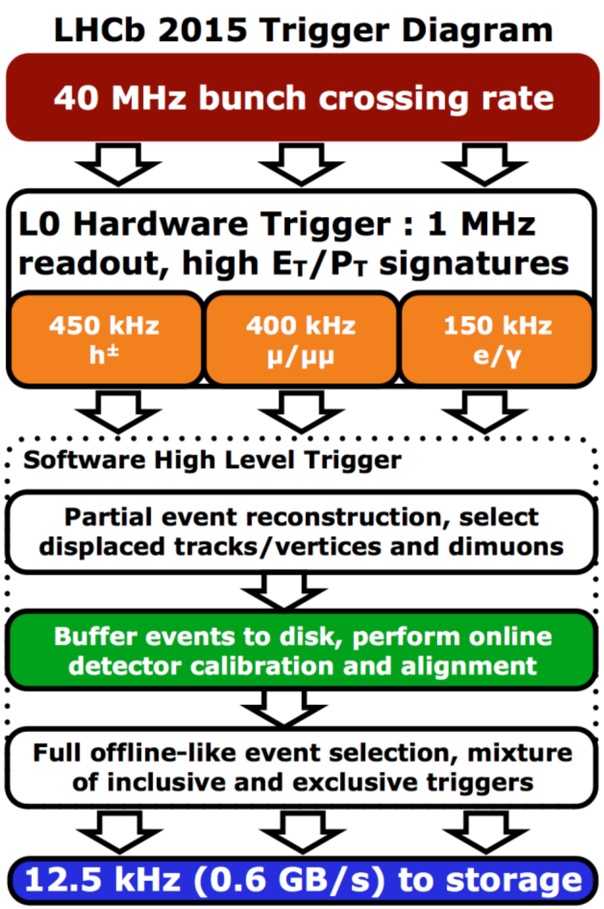
- Outdated estimations, already doing better (γ at ~7° already…)
  - For more up-to-date results, see F. Muheim presentation @ ALPS2017

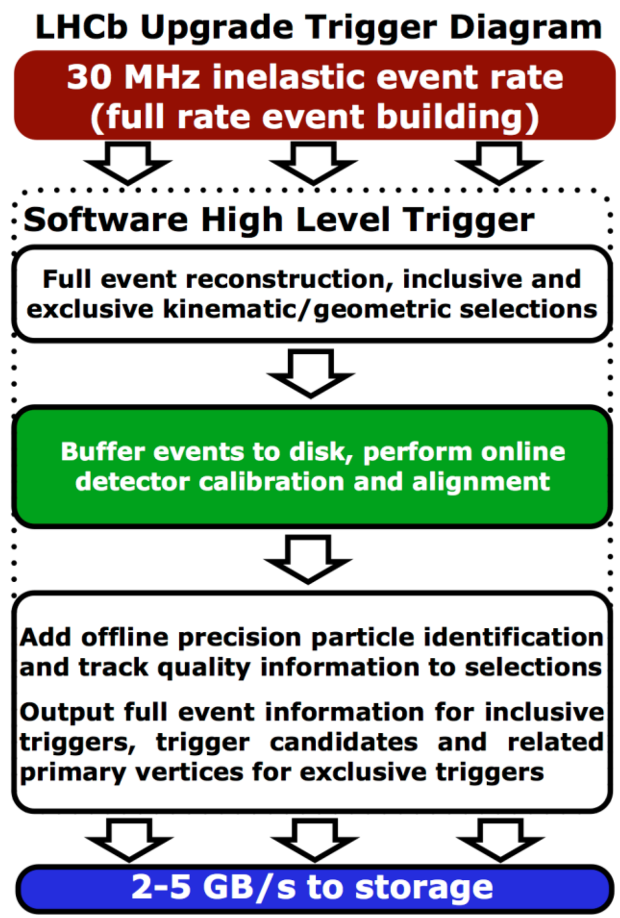
LHCb physics reach with a Phase-I upgrade



Phase-I upgrade strategy

Straightforward idea: remove the first-level hardware trigger

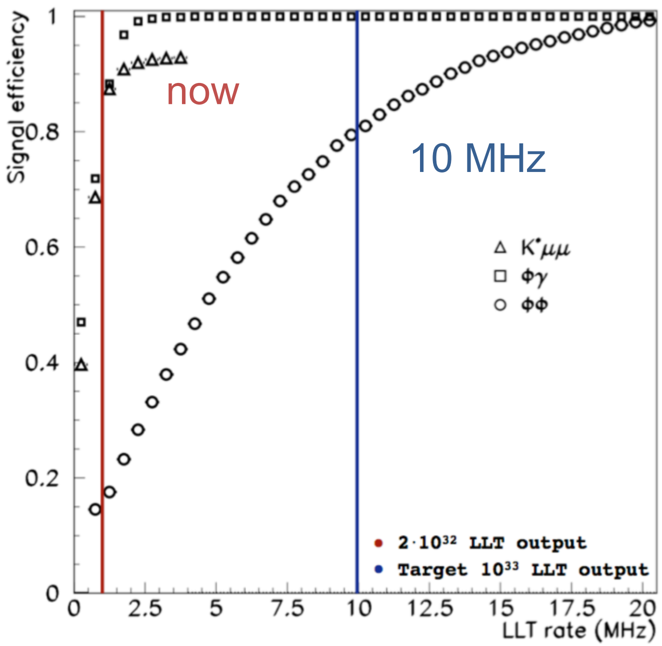




Implications of upgrade strategy

Removal of first-level hardware trigger implies

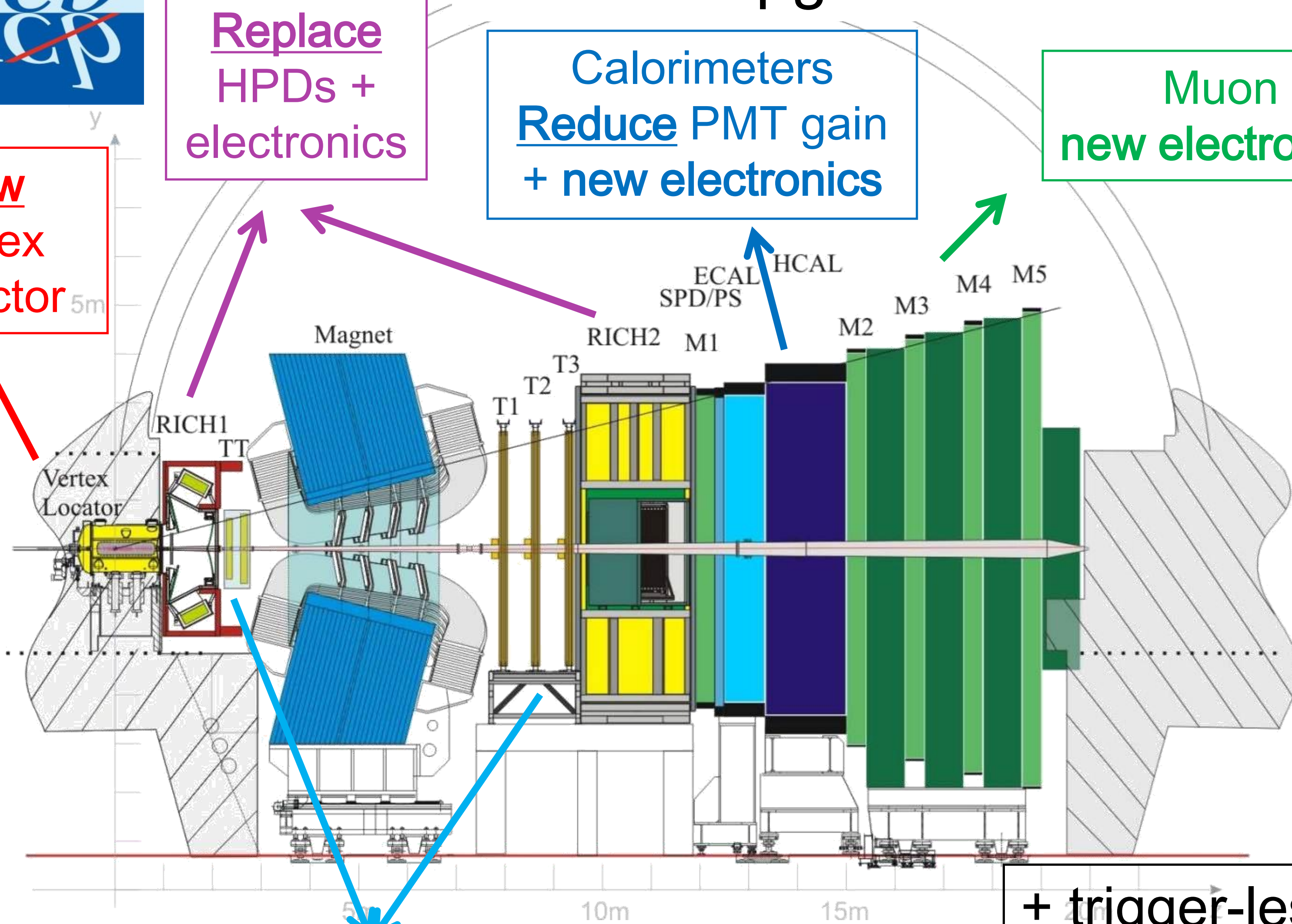
- read out every LHC bunch crossing
  - trigger-less Front-End electronics
  - multi-Tb/s readout network
- fully software flexible trigger
  - full event information available to improve trigger decision
  - maximize signal efficiencies at high events rate



→ higher luminosities: redesign (incompatible) sub-detectors for a **peak luminosity of $2x10^{33}$ $cm^{-2}s^{-1}$** (x5-x10 more than today)

→ more data by increasing bandwidth: redesign readout architecture to record 40 MHz events

Phase-I upgraded LHCb detector



New Vertex Detector

Particle ID
Replace HPDs + electronics

Calorimeters
Reduce PMT gain
+ **new electronics**

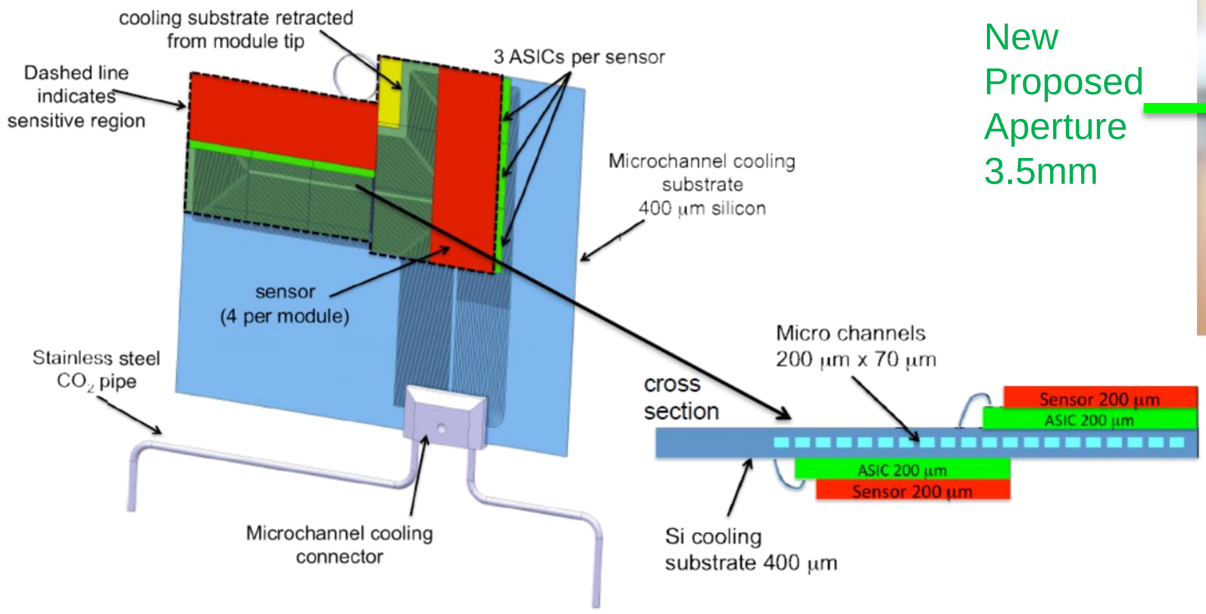
Muon
new electronics

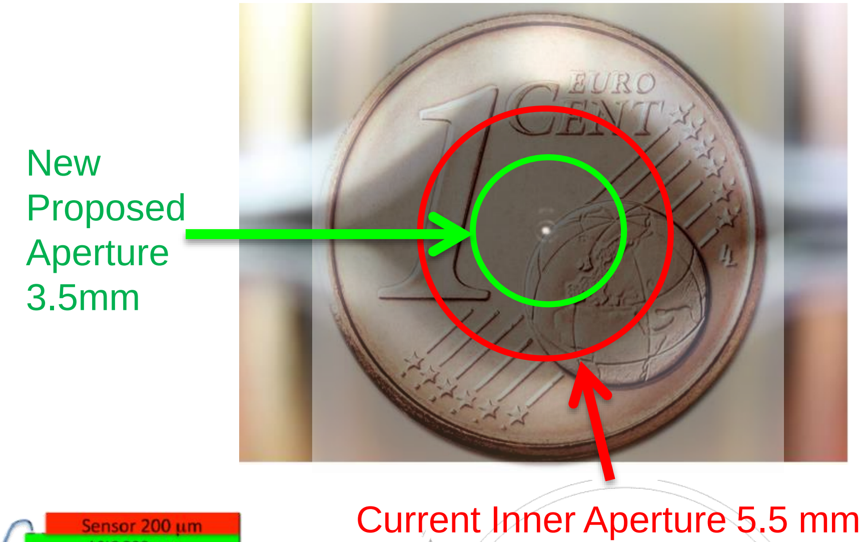
New Tracking stations

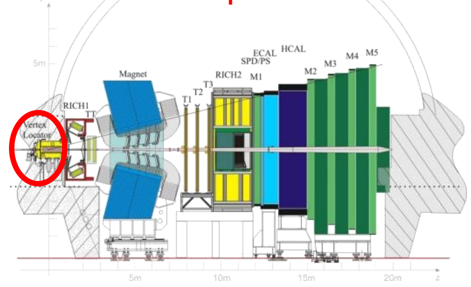
+ trigger-less readout system

New LHCb Vertex Detector

- Pixel Silicon detector modules cooled down with fluid (bi-phase CO_2) which passes under the chips in etched microchannels (ΔT = 4-7 ˚C between fluid and sensor)
- Getting closer to beam to improve IP resolution!



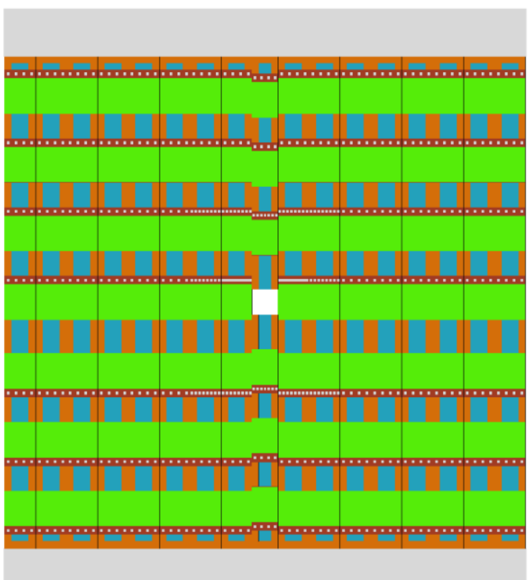


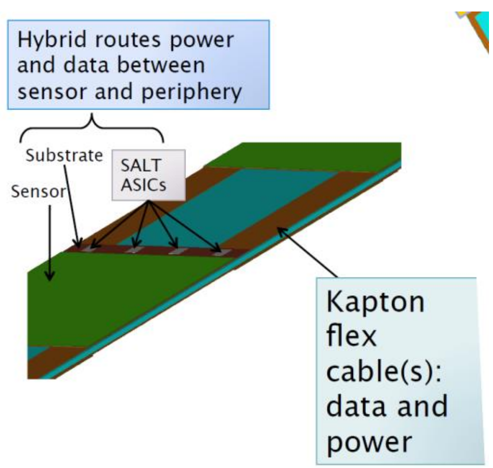


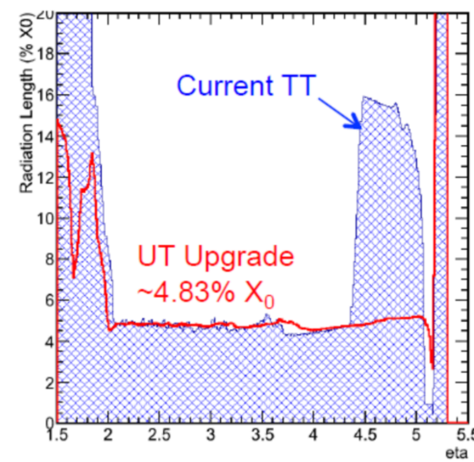
New Upstream Tracking Stations

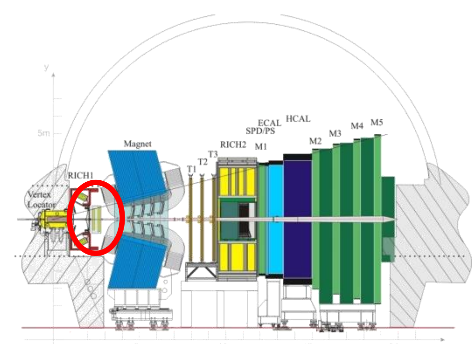
R&D upstream:

- Replace current TT with UT (*Upstream Tracker*) , also based on Si-strips
  - reduced thickness
  - finer granularity
  - improved coverage (innermost cut-out at 34 mm)
  - much less material budget (<5% X_0)

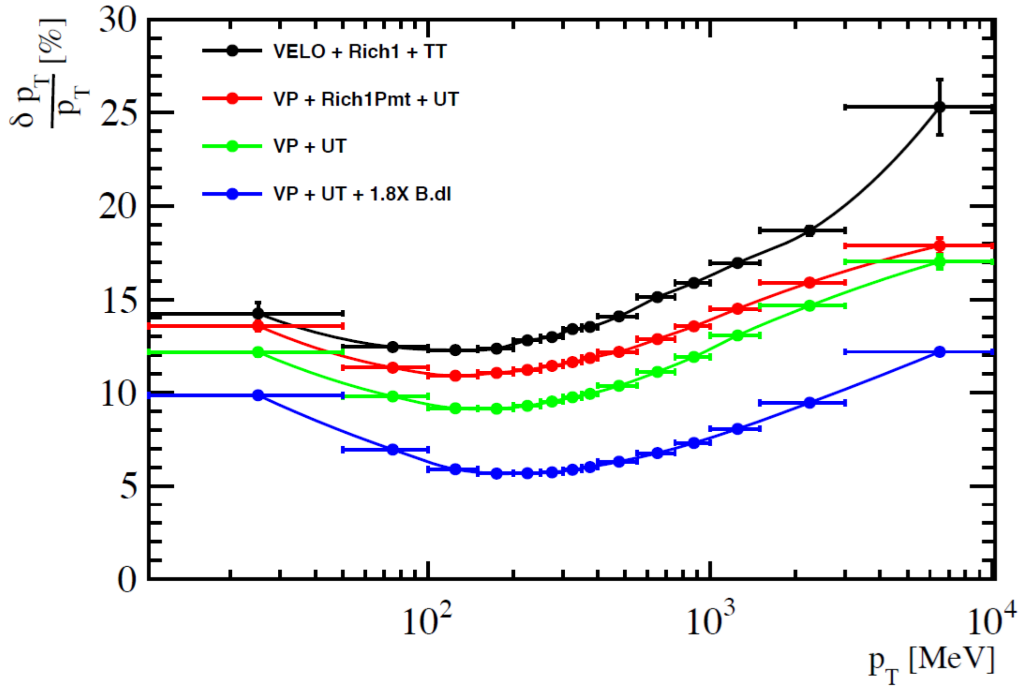






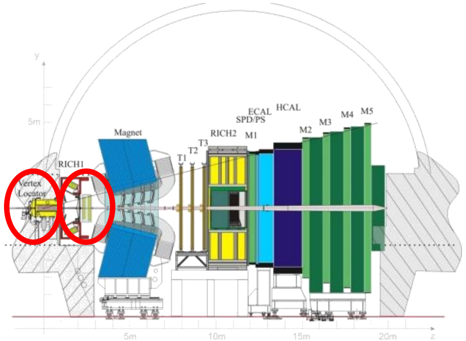


New UT + New VELO



better p_T resolution
+
drastic reduction in ghost rate
+
large gain in reconstruction time!

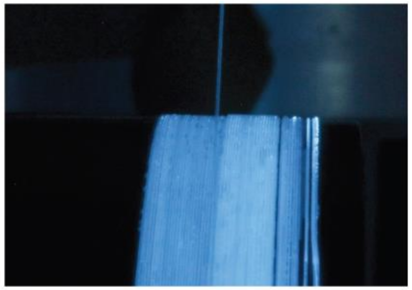
	$\epsilon(\%)$	$GR(\%)$	t(ms)	err	range	min_{p_T} (MeV)
No p-estimate	96.3	52.1	25.7			1100
$\delta p/p = 0.0$	96.7	2.9	3.0	0.06	60	1245
$\delta p/p = 0.1$	96.7	3.4	5.2	0.17	60	1000
$\delta p/p = 0.2$	96.7	4.9	8.2	0.28	60	750
$\delta p/p = 0.3$	96.7	7.2	16.6	0.39	60	500

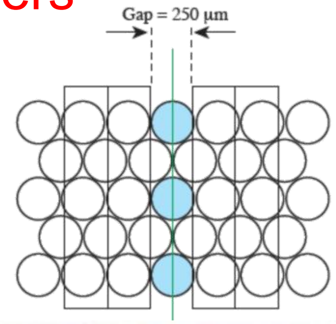


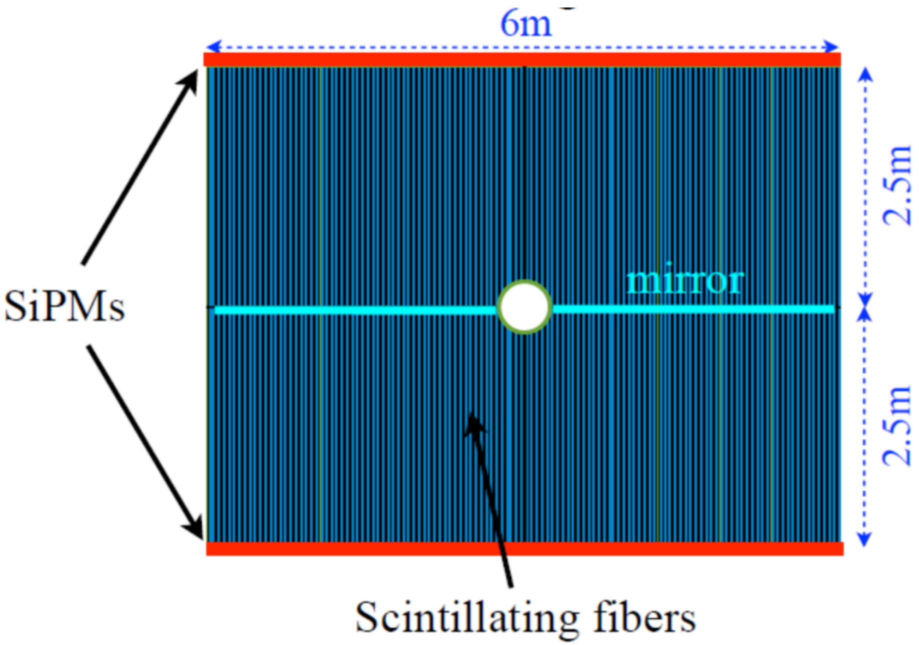
New LHCb Sci-Fi detector

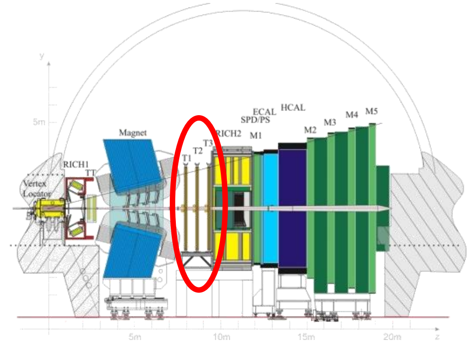
Build a completely new detector based on Scintillating Thin Fibers

- Blue-emitting multi clad fibers, laid down as a mat
- 2.5m long, 250 um diameter (2.8 ns decay time)
- 12 layers of modules in different layout (x-u-v-x)
- read out with SiPM (at -40C): new trigger-less FE









Upgraded Particle ID

Present Ring-Imaging Cherenkov (RICH) detector will be upgraded:

- Current RICH1 (aerogel C_4F_{10}) + RICH2 (CF_4) to maintain excellent Particle ID!

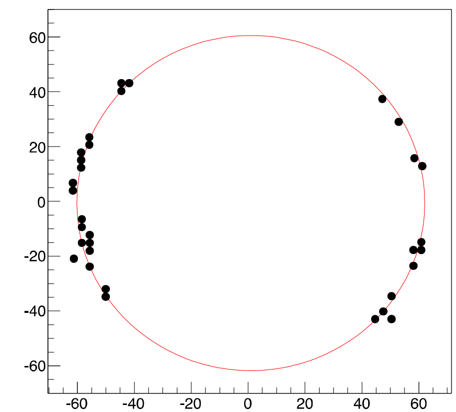
Main changes:

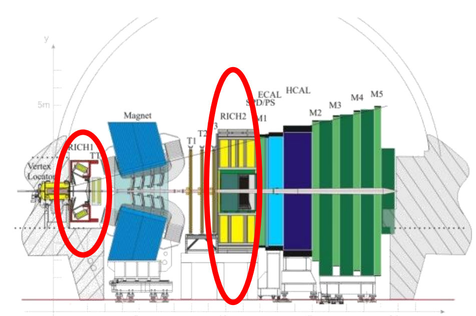
Exchange Hybrid-PhotoDetectors (HPD) with Multi-AnodePMTs

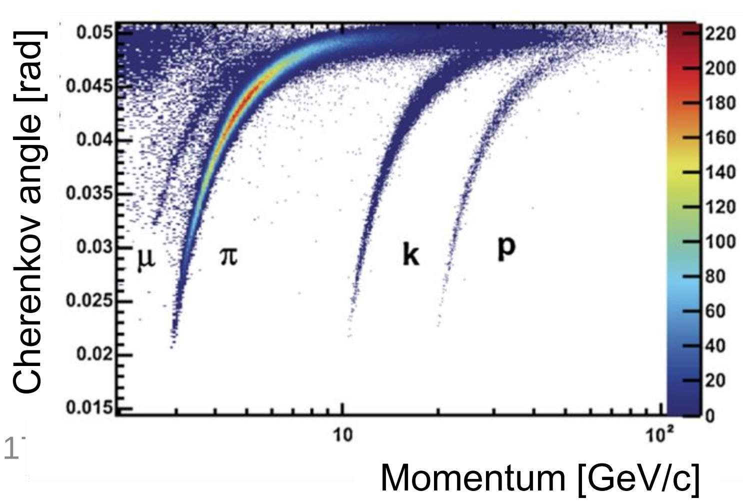
- Hamamatsu R11265 with 80% active area

+ new Front-End electronics at 40 MHz

Testbeam Cherenkov Ring







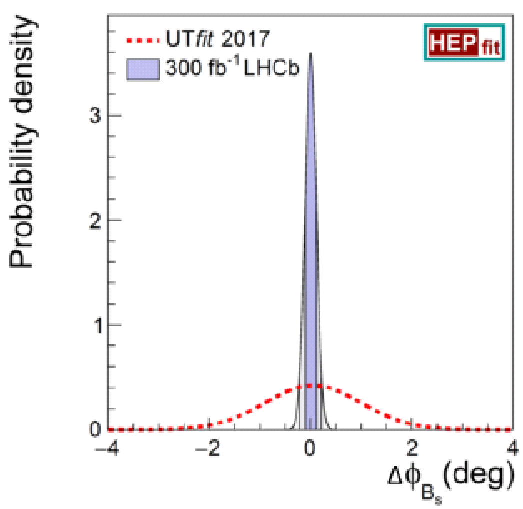
LHCb Phase-II upgrade

Just recently submitted an EoI to install an upgraded LHCb detector that can operate up to a peak instantaneous luminosity of **2×10^{34} cm^{-2}s^{-1}**

- between x50-x100 more than today and x10 more than Phase-I upgrade
- to be ready for LHC Run V and to fully exploit HL-LHC

Improve even more the Phase-I LHCb precision:

- Comprehensive measurement programme of observables in a wide range of b->s l^+l^- and b-> d l^+l^- employing both muon and electron modes
- Measurement of the CP-violation phases γ and ϕ_s with a precision of 0.4° and 3 mrad



NP contribution to ϕ_s

(dark blue 68%, light blue 95%)

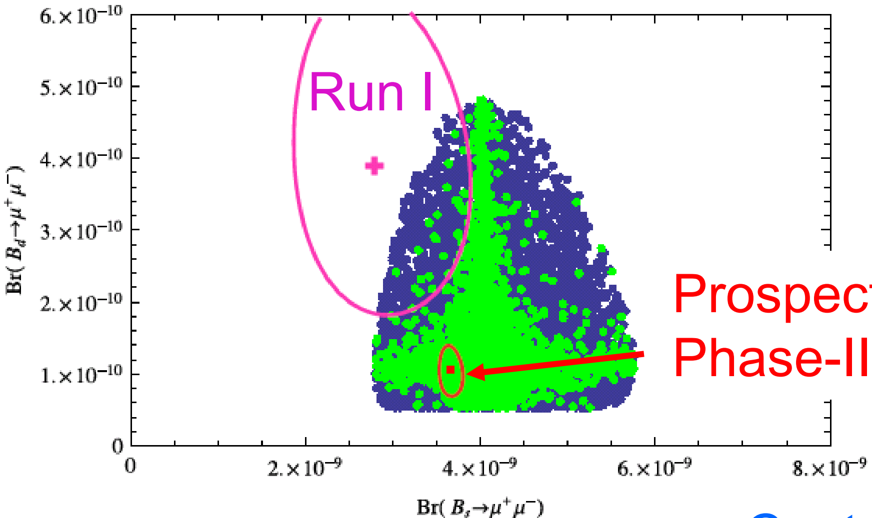
LHCb Phase-II upgrade

For an exhaustive list see CERN-LHCC-2017-003

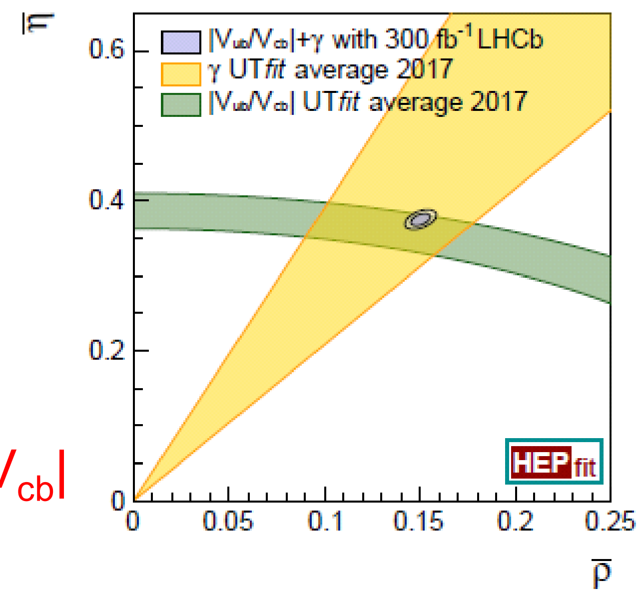
Improve even more the Phase-I LHCb precision:

- Measurement of B ($B^0 \to \mu^+\mu^-$) / B ($B_s \to \mu^+\mu^-$) with 20% uncertainty
- CP-violation studies in charm with 10^{-5} precision
- Exotica searches, dark photons?

Close up on $B^0 \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$ with 14% precision on ratio



Contribution to knowledge of $|V_{ub}/V_{cb}|$



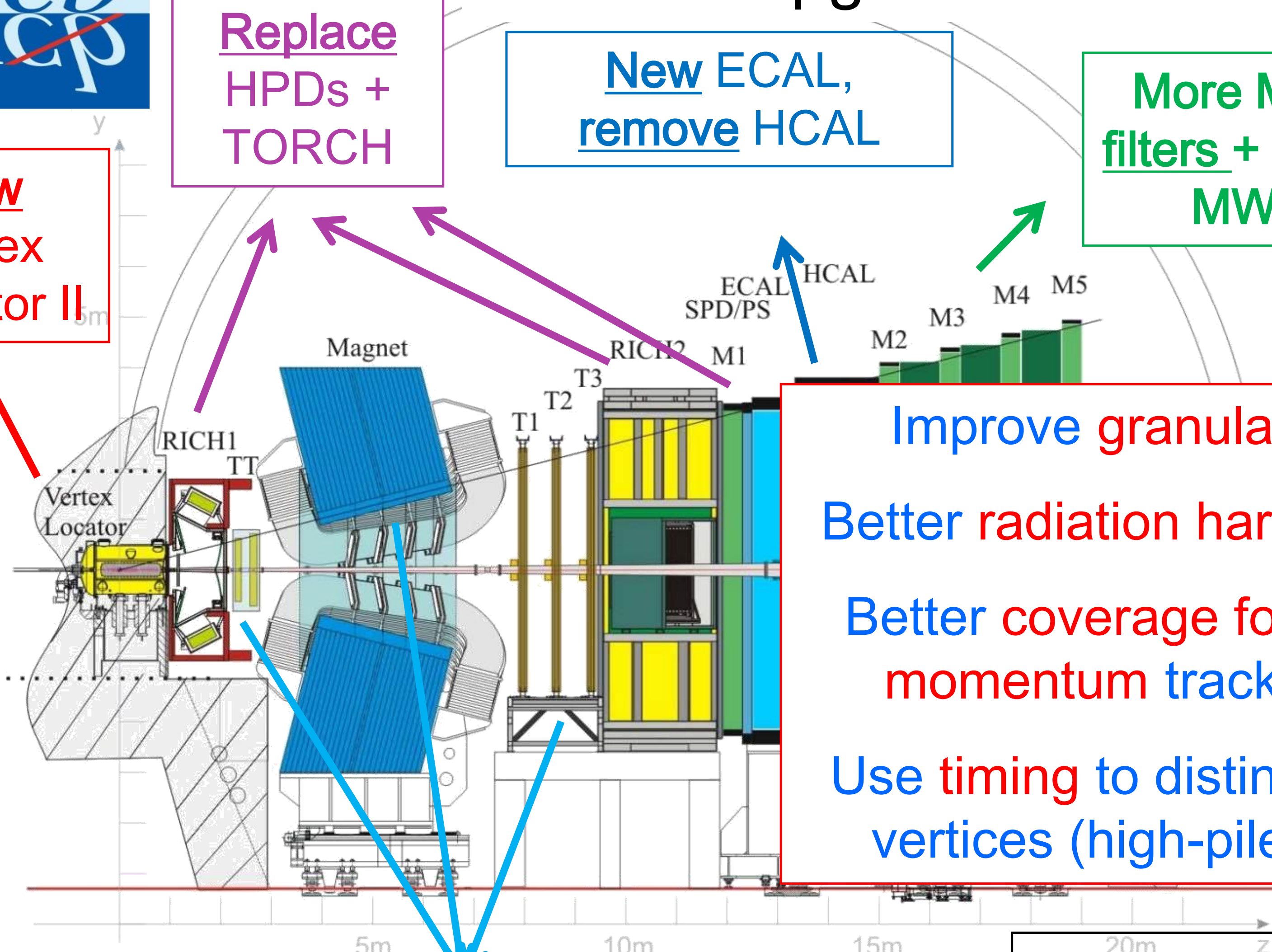
Phase-II upgraded LHCb detector

New Vertex Detector II

Particle ID
Replace HPDs + TORCH

New ECAL, **remove** HCAL

More MUON **filters** + **replace** MWPC



Improve granularity

Better radiation hardness

Better coverage for low momentum tracking

Use timing to distinguish vertices (high-pileup)

Additional Tracking stations

+ keep trigger-less readout

Conclusion

LHCb is currently taking data successfully and efficiently

- Well-earned title as Forward General Purpose Detector at the LHC

Two upgrade plans are set out to increase the amount of data and physics yields

- Phase-I upgrade aim at collecting 10x more data with 20x more hadronic events
- Phase-II upgrade aim at collecting 100x more data with particular emphasis in muon channels, time resolution and efficient/challenging pileup discrimination

Both upgrades are technologically challenging

- But LHCb can shine light in many areas in flavour physics to extreme and world-leading precision

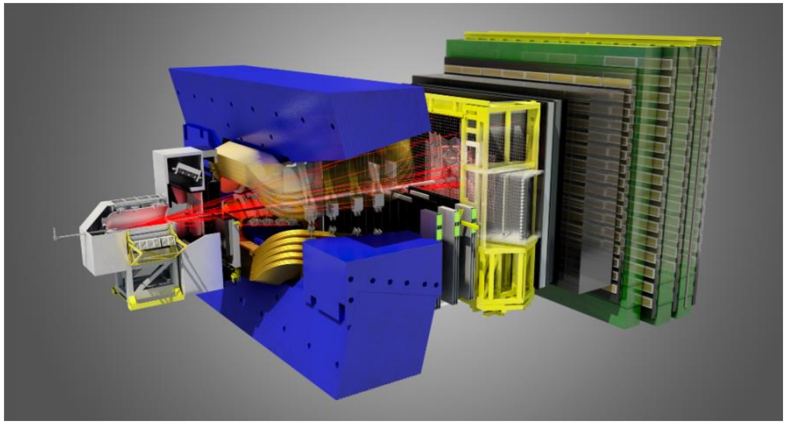
We have exciting times ahead in LHCb!

Thank you for your attention!

Backup

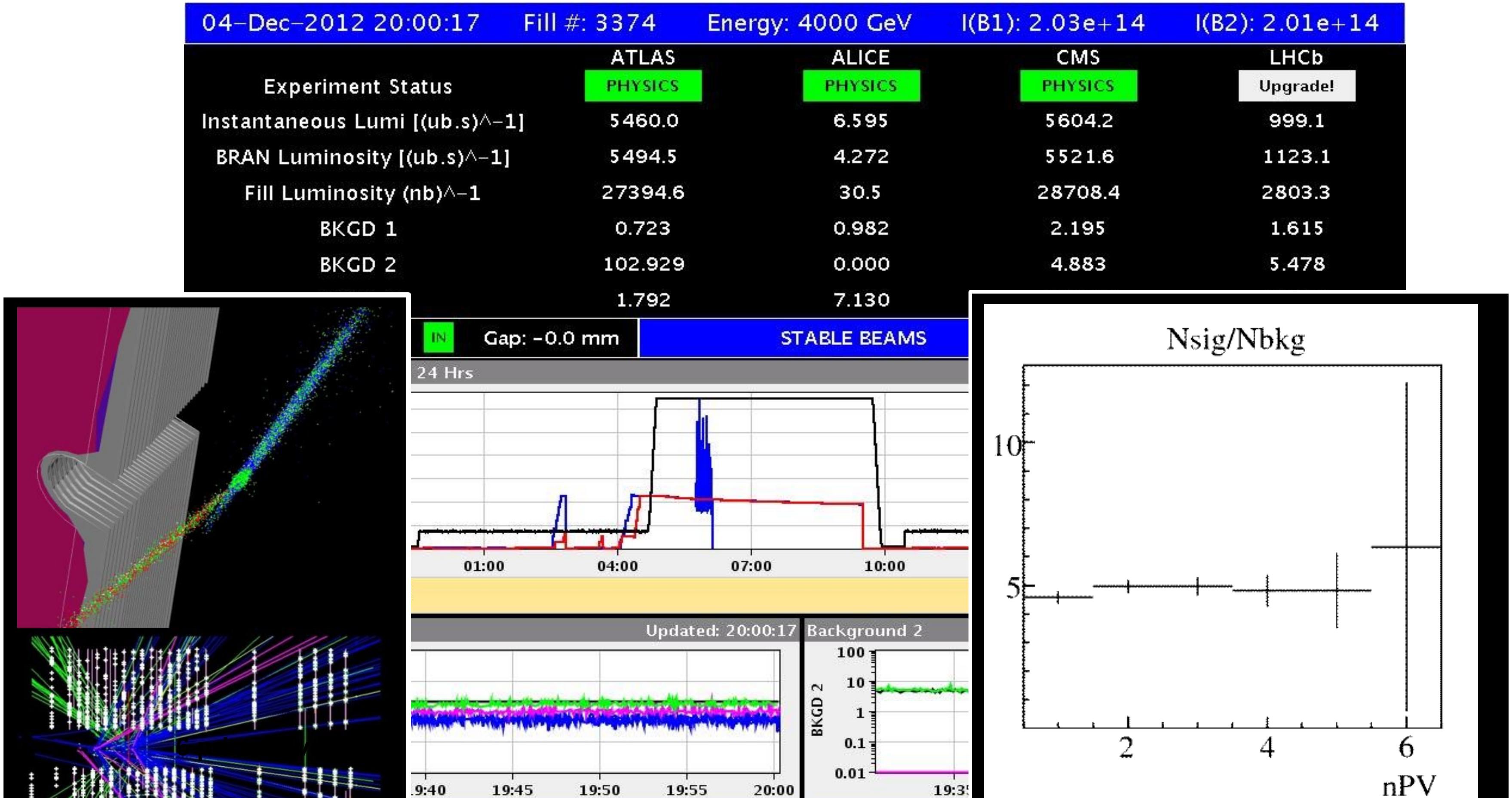
Outline

- Brief Introduction to LHCb
- Motivations for upgrading the LHCb detector
  - Timeline plans
- Phase-I Upgrade:
  - Physics prospects
  - Strategy and detector changes
  - Detector changes
- Phase-II Upgrade:
  - Physics prospects
  - Strategy and detector changes
- Conclusions



Is it feasible?

YES! We already tried in 2012: took some data at 10^{33} (5x designed values)

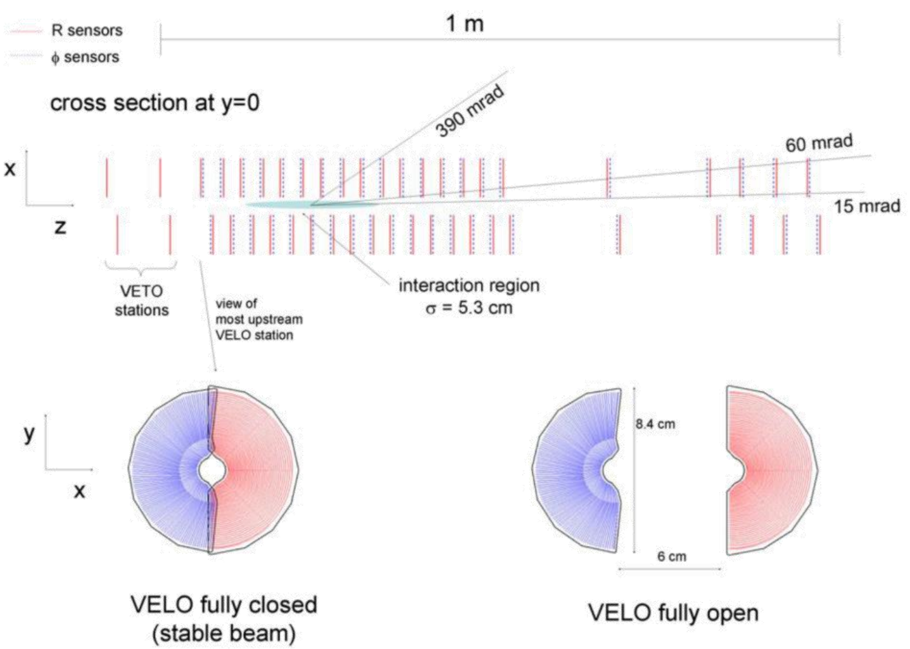


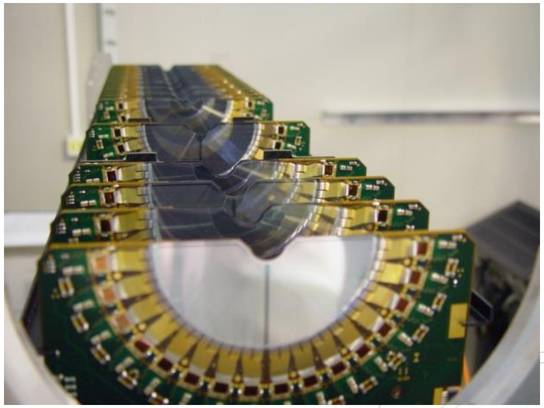
B S/N almost independent of pileup
D S/N shows some degradation vs pileup.

Current LHCb Vertex Detector

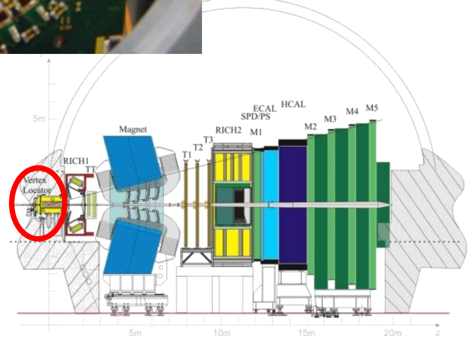
Current Vertex Detector (VELO) is at the heart of LHCb tracking, triggering and vertexing

- Excellent performance, reliable, cluster efficiency >99.5%, best hit resolution down to <4μm
- Movable device! ~50mm to ~5mm close to LHC beams when in collisions (autonomously…)





Si-strips measuring r and ϕ



New LHCb Vertex Detector

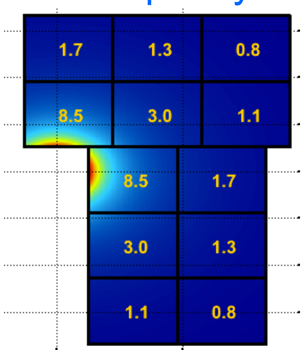
Future VELO must maintain same performance, but in harsher conditions

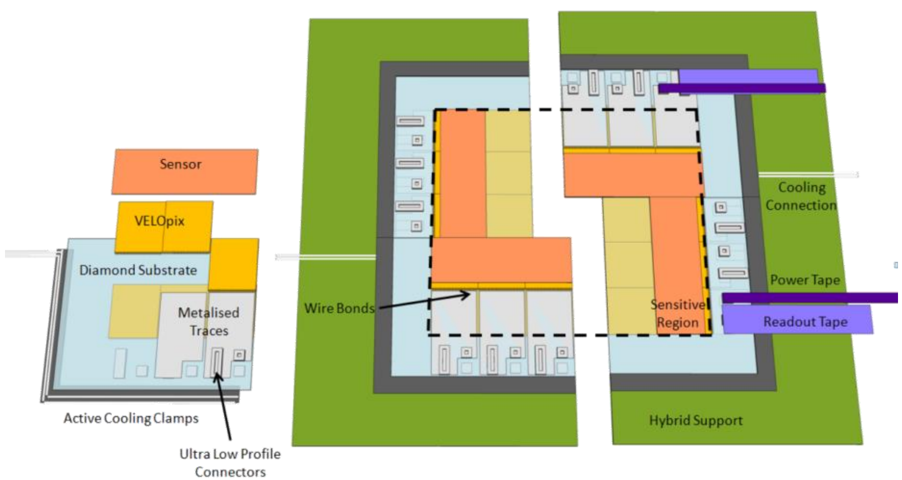
- Low material budget, cope with > radiation damage, deal with > multiplicities
- Trigger-less readout ASICs and provide fast and efficient reconstruction at HW level

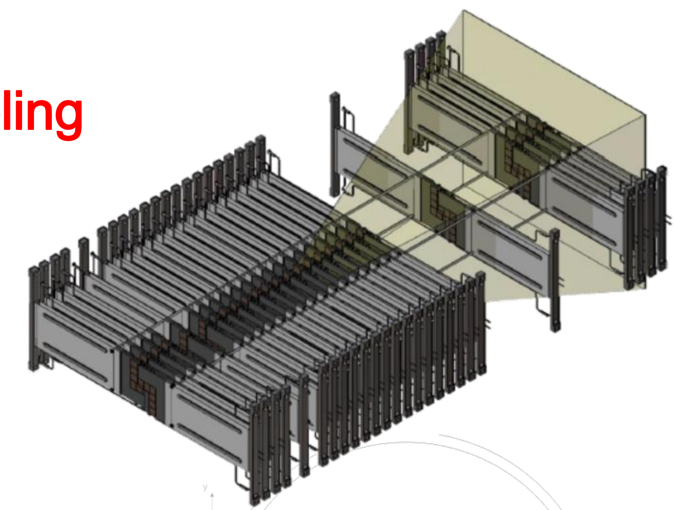
→ Recent technology reviews favored the choice of a

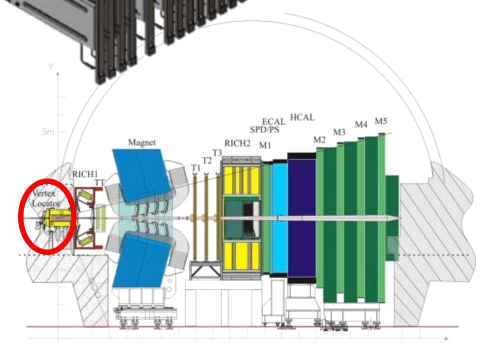
Si-pixel detector with microchannel cooling

occupancy





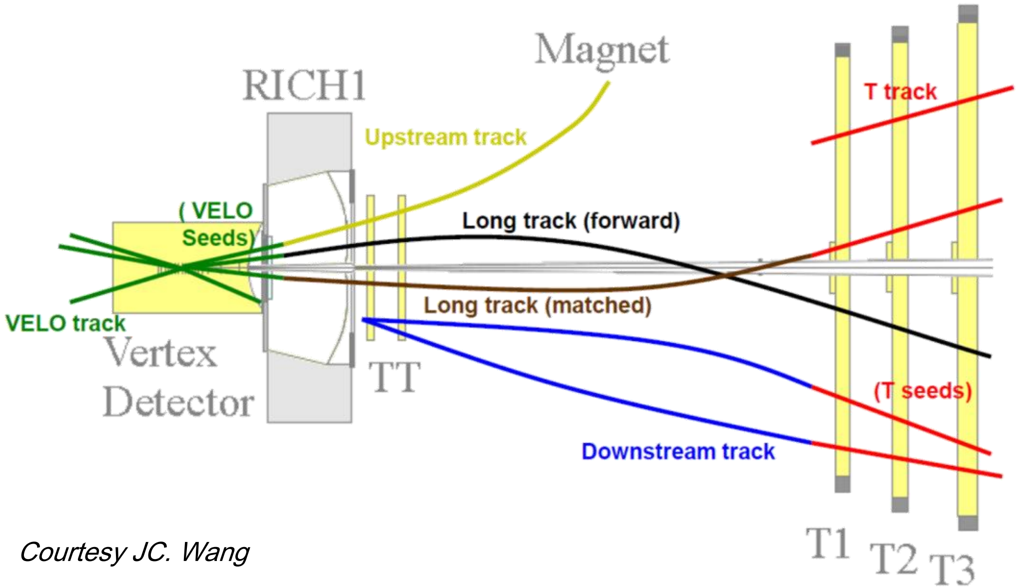




Current LHCb Tracking system

Present Tracking System will be upgraded:

- VELO + TT (Si-strip) + DIPOLE (no change) + IT (2% inner area, Si) / OT (Straw Tubes)

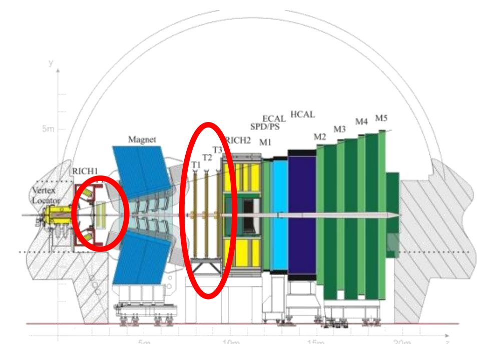


Courtesy JC. Wang

Current pattern-recognition based on current tracking system would not be efficient in upgraded scenario

- Too high occupancy in central region
- R&D for different solutions
  - → for downstream and upstream tracking

Sidenote: R&D in increasing Dipole field (x1.8 Bdl)

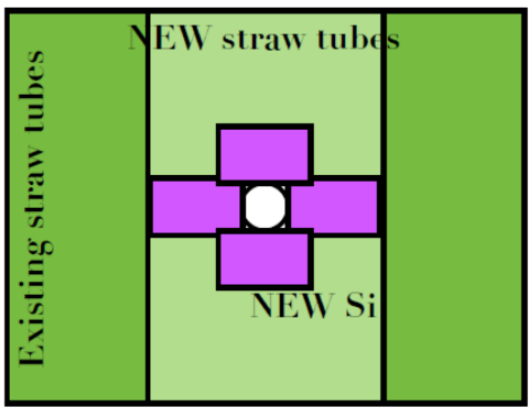


New Downstream Tracking Stations

R&D donwstream:

- Various options still on the table
  - all aimed at reducing the occupancy in the inner region

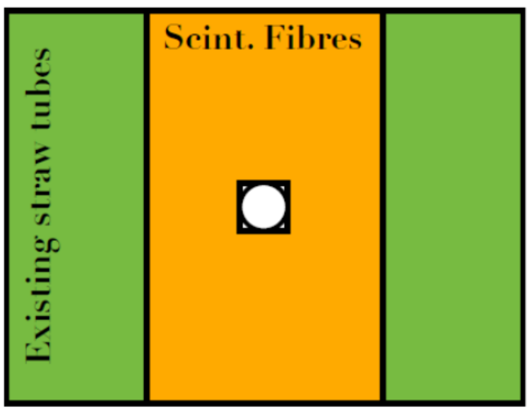
Baseline option!



Enlarged, thinner and lighter IT

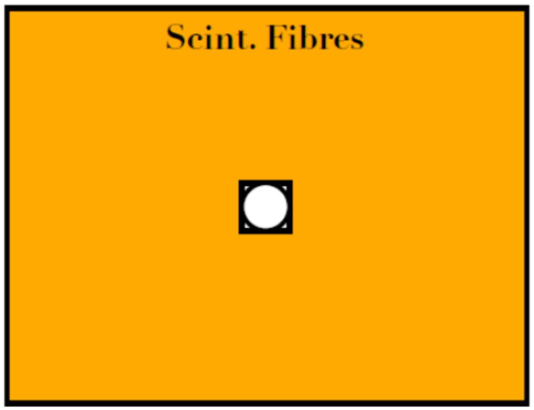
→ Based on Si-strip

→ New OT straw tubes in central region

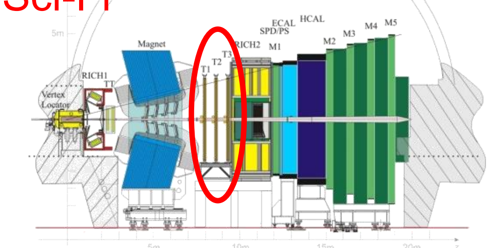


Replace central region with Central Tracker (Sci-Fi detector)

→ Based on Scintillating fibers and SiliconPM

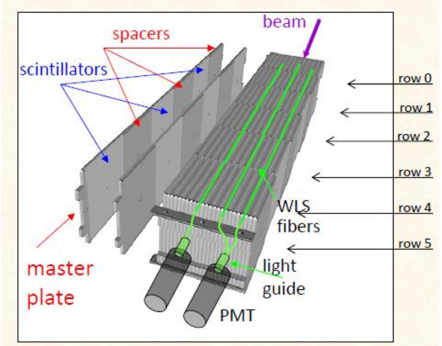


Replace entire IT+OT with Sci-Fi



Upgraded Calorimeters

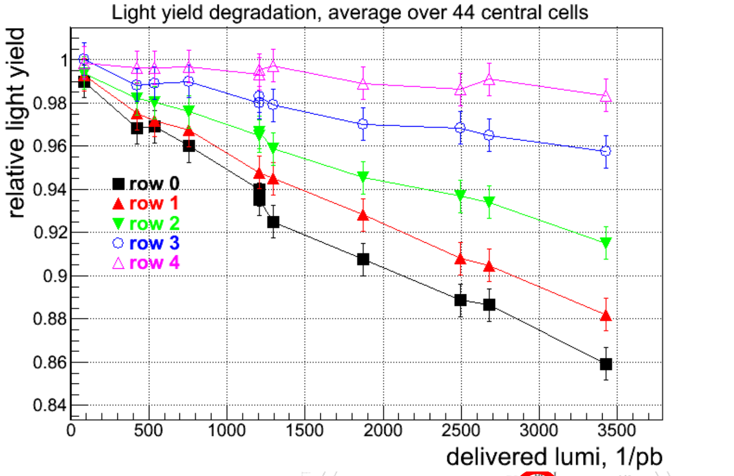
HCAL



Present Calorimeters detectors will be kept:

- ECAL (Shashlik 25 X_0 Pb + scintillator)
- HCAL (TileCal Fe + scintillator)

→ PreShower / ScintillatingPadDetector (PS/SPD) will be removed



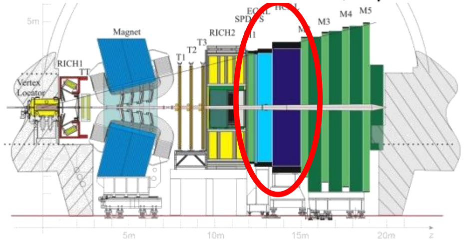
Main changes:

PMT gain will be reduced by a factor 5

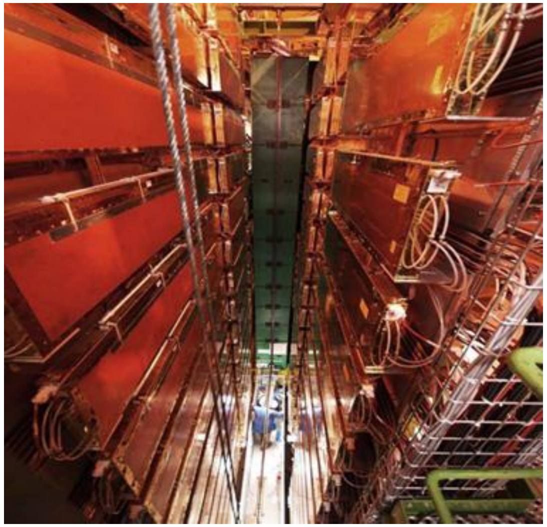
- to reduce ageing due to higher luminosities

Front-End electronics will be redeveloped

- to be compatible with the reduced gain (R&D)
- to be compatible with trigger-less readout



Upgraded Muon Detectors



Present Muon detector will be kept:

- 4 layers (M2-M5) of Multi-Wire Proportional Chambers (MWPC)

→ first layer of Muon Detector (M1 – used in first-level trigger, with GEMs) will be removed

Main changes:

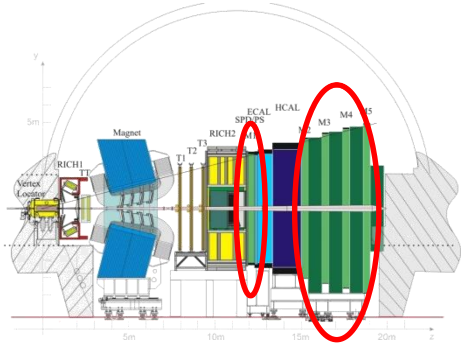
Front-End electronics will be redeveloped

- to be compatible with trigger-less readout

R&D:

Replace inner part of M2 (closest to IP) with GEMs detectors

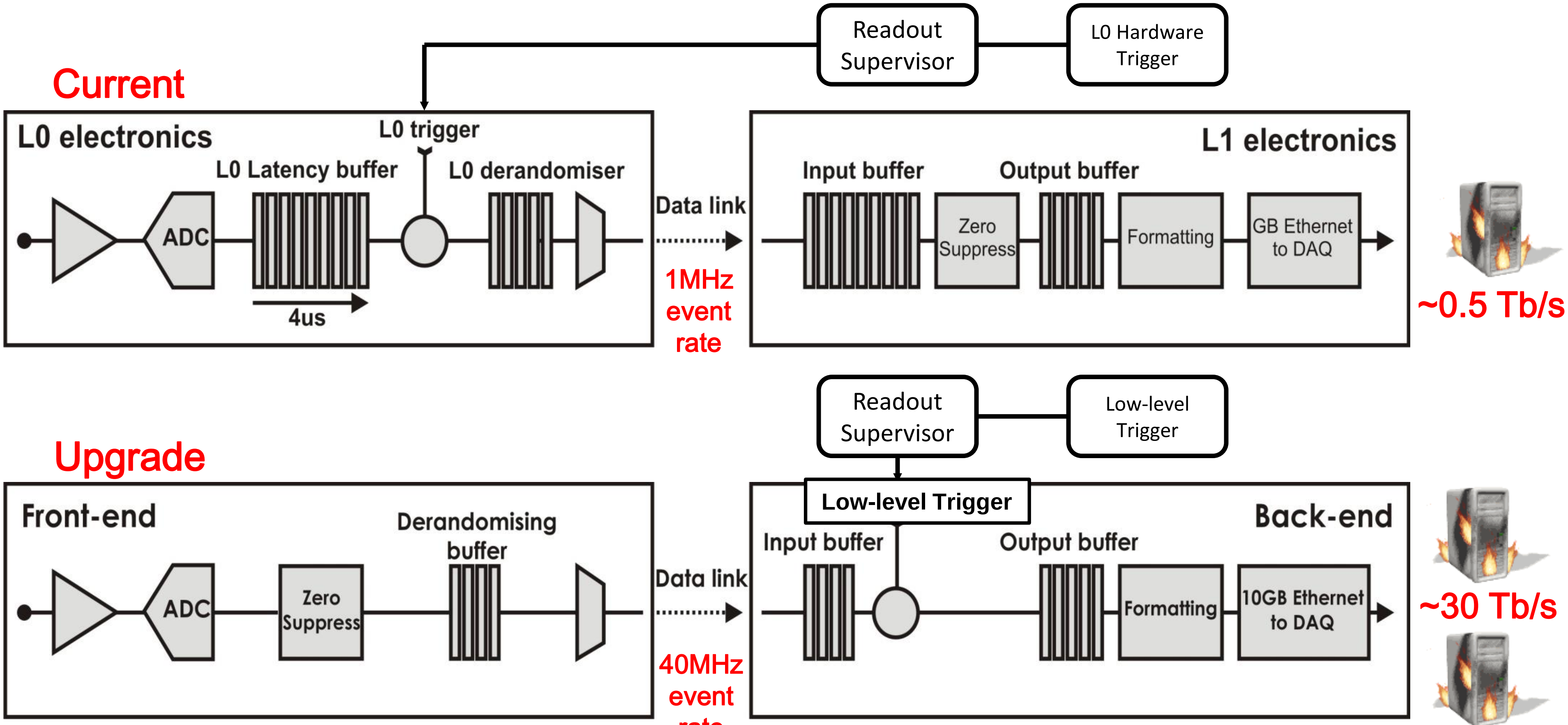
- to have higher-granularity



Upgraded Readout Architecture

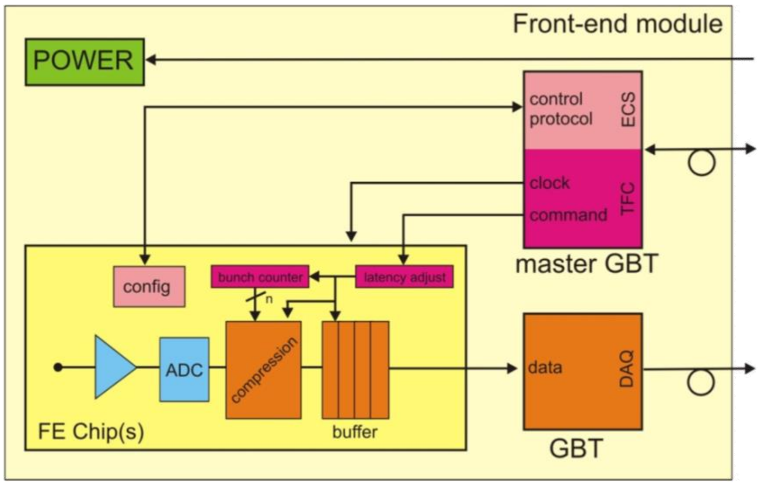
Reminder: remove the first-level hardware trigger

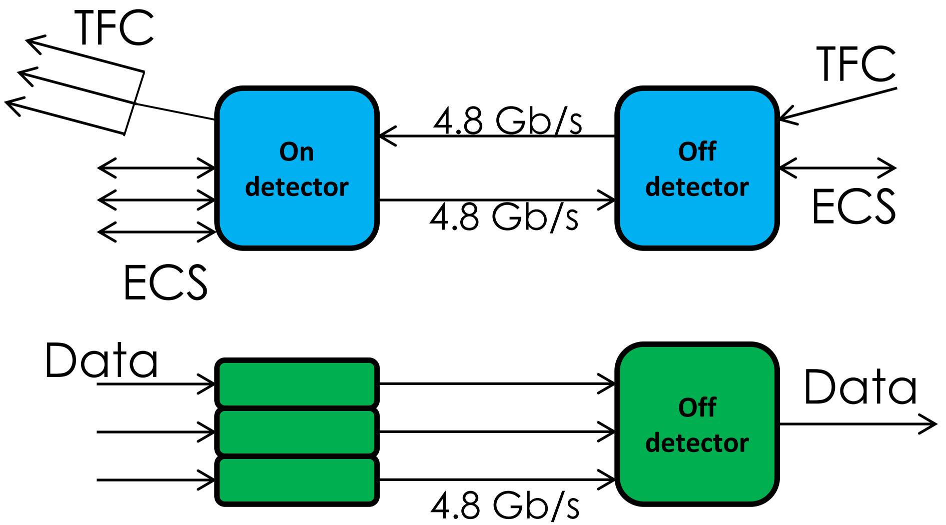
→ accept all LHC bunch crossing: trigger-less Front-End electronics!



Courtesy K. Wyllie

Trigger-less Front-Ends





1. Need to compress (zero-suppress) data already at the FE to reduce data throughput
   - reduce # of links from ~80000 to ~12500 (20 MCHF to 3.1 MCHF)
2. Use separate link bandwidth efficiently for data
   - Pack data across data link continuously with elastic buffer before link
3. Compact links merging Timing, Fast (TFC) and Slow Control (ECS).
   - Extensive usage of the CERN GBT development

→ Support data driven readout (asynchronous) + big latencies!

Readout & DAQ

Future LHC DAQs in numbers

	Event-size [kB]	Rate [kHz]	Bandwidth [Gb/s]	Year [CE]
ALICE	20000	50	8000	2019
ATLAS	4000	200	6400	2022
CMS	2000	200	3200	2022
LHCb	100	40000	32000	2019

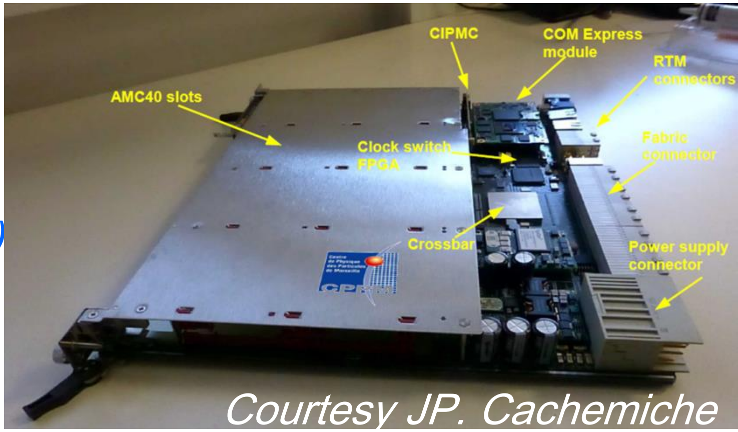
Courtesy N. Neufeld

- Exploit the economies of scale → try to do what everybody does but smarter!
- Some overlapping trends across experiments, at least conceptually
  - custom-made Readout Boards with fast optical links and big&powerful FPGAs
    - ✓ ideally with fast interface to PCs (PCIe Gen3 or future…)
    - ✓ ideally with some co-processing (GPUs…)
  - commercial network technologies following market trends in terms of BW & costs
    - ✓ distributed vs data-center-like network. Ethernet vs InfiniBand.

New LHCb DAQ

Currently two options under R&D:

- Very compact, high density, FPGAs-based ATCA card with >0.5 Tb/s throughput onboard *(distributed approach)*
  - Profit from interconnectivity on backplane
  - High link density on board
  - Technologically-dependent (Ethernet)
  - Custom-made
- PCIe Gen3 NIC cards, with FPGAs and ~150 Mb/s throughput to host PC *(data-center approach)*
  - Technologically-independent
    - host PC acts as FARM PC already: open choice for interface technology as late as possible
  - Commercially available
  - Put everything in a box, keep distances short, reduce costs for interconnects and network switches



Courtesy JP. Cachemiche

OR

LHCb physics prospects for a Phase-I upgrade

Rare decays can give hints against Minimal Flavour Violation (MFV) hypothesis in case of significantly inconsistent measurements with the SM

→ Important to make sure that ratio of B ($B^0 \to \mu^+\mu^-$) / B ($B_s \to \mu^+\mu^-$) since MFV predicts that this is given by its SM value, $|V_{td}/V_{ts}|^2$

Observation of $B^0 \to \mu^+\mu^-$ requires huge statistics and excellent control of background and can only be made by the upgraded LHCb background to the desired precision

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B^0_s mixing	$2\beta_s\ (B^0_s \to J/\psi\,\phi)$	0.10 [9]	0.025	0.008	~0.003
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	$\sim 10\,\%$
Higgs	$\mathcal{B}(B^0_s \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
penguin	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B^0_s \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$
Unitarity	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–12° [19, 20]	4°	0.9°	negligible
triangle	$\gamma\ (B^0_s \to D_s K)$	–	11°	2.0°	negligible
angles	$\beta\ (B^0 \to J/\psi\, K^0_S)$	0.8° [18]	0.6°	0.2°	negligible
Charm	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
CP violation	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

LHCb physics prospects for a Phase-I upgrade

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	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
	$A_{\rm fs}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
Unitarity	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–12° [19, 20]	4°	0.9°	negligible
triangle	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
angles	$\beta\ (B^0 \to J/\psi\ K_S^0)$	0.8° [18]	0.6°	0.2°	negligible
Charm	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
CP violation	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Primary goal of LHCb is to probe NP in B_s mixing

→ $B_s \to J/\psi\phi$ dominated by b -> c cbar s tree diagram and sensitive to the weak phase $\beta_s = \arg(-V_{ts}V_{tb}^* / V_{cs}V_{cb}^*)$

If no anomalous effect is seen in this channel, then it is necessary to control experimental systematics from an experiment point of view

→ LHCb upgrade will address such systematics

LHCb physics prospects for a Phase-I upgrade

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B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [9]	0.025	0.008	~ 0.003
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	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
Higgs	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	[illegible] [2]	[illegible]	[illegible]	[illegible]
penguin	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$
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}	–

Charmless hadronic B decays highly sensitive to NP
→ Rare decay topologies such as penguin diagrams
→ Big experimental challenge to control SM uncertainties to the necessary precision

LHCb physics prospects for a Phase-I upgrade

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
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CP violation	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Only the LHCb upgrade will provide the huge statistics needed to reach the precision that is necessary to remove the SM uncertainty in NP searches.

→ γ measurement is ideally suited for LHCb as it's largely based on analyses

1. that do not require flavour-tagging
2. that exploit LHCb's unique capability to trigger on fully hadronic decay modes.

→ With 50 fb^{-1}, γ will be determined to better than 1° precision