The LHCb Upgrade

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on behalf of LHCb

Outline

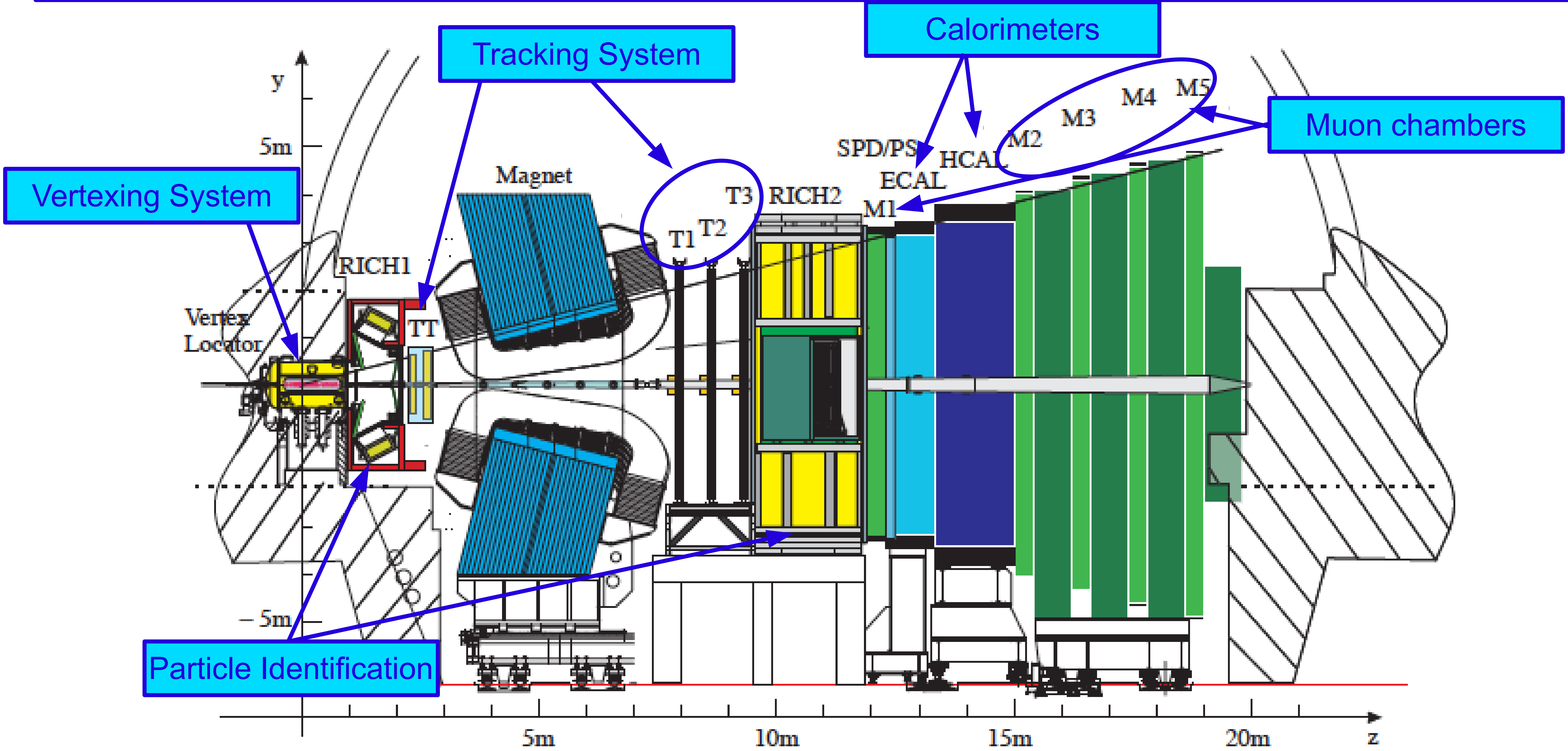
- Introduction to the current LHCb
- Motivations for the upgrade
  - Why?
  - How?
  - Operations and plans
- Trigger and Data acquisition system upgrade
- Sub-systems upgrade
  - Vertex system & Tracking stations
  - Particle Identification systems
  - Calorimeters & Muon chambers
- Summary

Current LHCb

- Forward detector designed for New Physics and rare decay searches in beauty and charm sectors at LHC $\bar{b}$
- Unique coverage in pseudo-rapidity: $2 < \eta < 5 \rightarrow$ ~4% of solid angle, detects ~ 40% heavy quark production cross section
- Excellent vertex & momentum resolution, particle ID and flexible triggering system
- Design luminosity of $2\times10^{32}cm^{-2}s^{-1}$ and 2012 running luminosity of $4\times10^{32}cm^{-2}s^{-1}$
- LHCb is generating excellent physics results (see Konstantinos Petridis's talk)

Introduction to the current LHCb

The LHCb detector



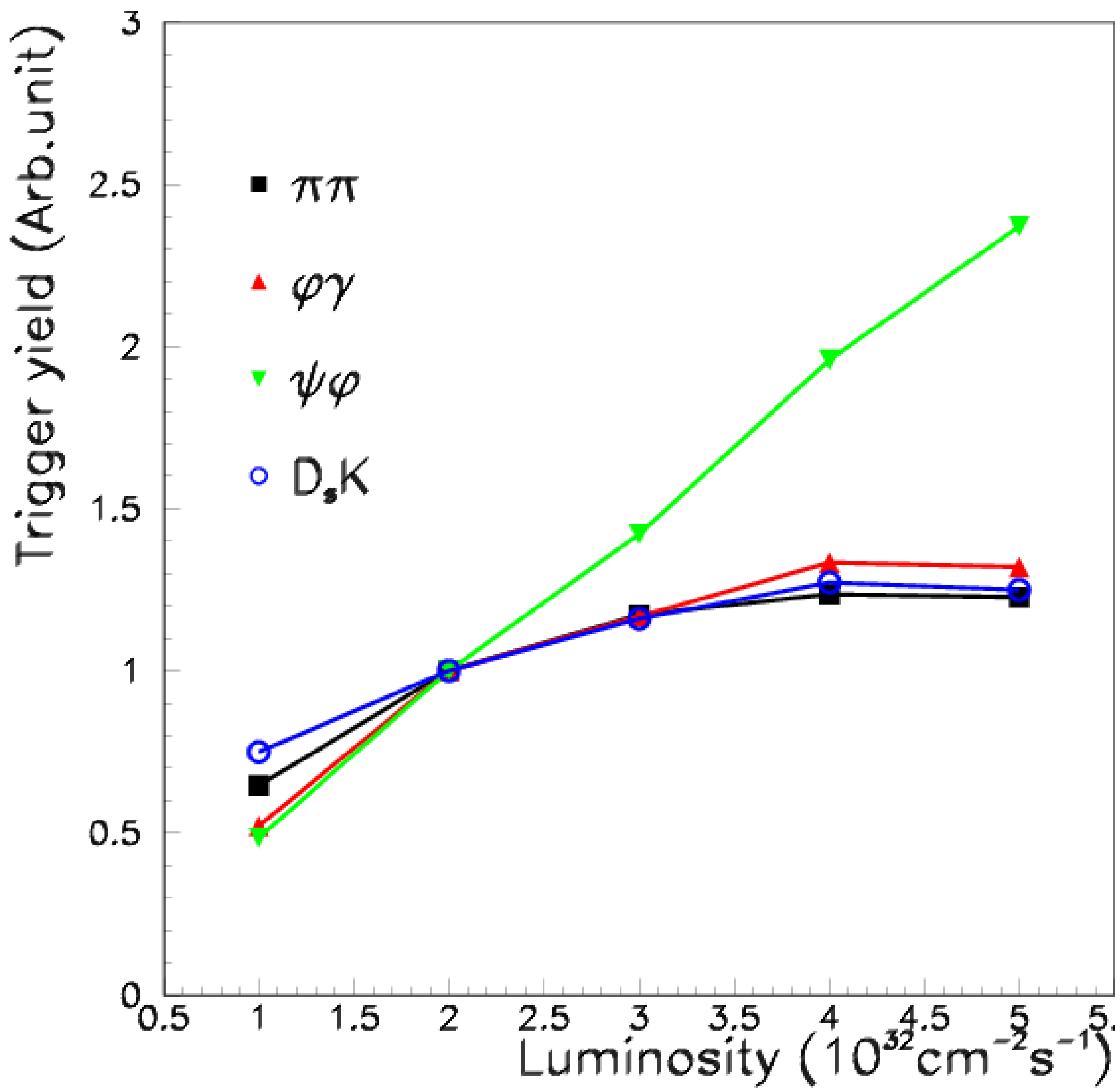
Motivations for the upgrade

Why?

- No deviation from Standard Model observed yet
  - Need more statistics
- LHCb runs beyond its designed luminosity (up to $4 \times 10^{32} cm^{-2} s^{-1}$)
  - Increasing statistics by factor 2 will take another 5 years
- Range of measurements can be extended with higher amount of data
  - Better accuracy for precision measurements in many channels with respect to theoretical predictions
  - Determination of CKM angle $\gamma < 1°$
  - PDF measurements in forward rapidity range
- Need an upgrade of the detector to withstand higher luminosity

Motivations for the upgrade
How?

- Current Level0 trigger based on calorimeter and muon system limits the interaction rate down to ~ 1MHz
  - Remove the Level0 trigger
- Saturation of trigger yield in hadronic channels at $4x10^{32}cm^{-2}s^{-1}$
  - Readout the full detector at 40MHz (~30MHz of colliding bunches)
- Current detector not designed for higher luminosity
  - Need more radiation hard materials



Motivations for the upgrade

Operations and plans

	2010 – 2012	2013 – 2014	2015 – 2018	2018 – 2020	2020 – 2024 … 20xx
Bunch spacing	50ns	Long Shutdown 1	25ns	Long Shutdown 2 LHCb Upgrade	25ns
$\sqrt{s}$	0.9 – 7TeV		13 – 14TeV		13-14TeV
$\mathscr{L}$	$1 - 4.10^{32} cm^{-2}s^{-1}$		$4.10^{32} cm^{-2}s^{-1}$		$>10^{33} cm^{-2}s^{-1}$
$\int\mathscr{L}$	$3fb^{-1}$		$5 - 7fb^{-1}$		$> 50fb^{-1}$

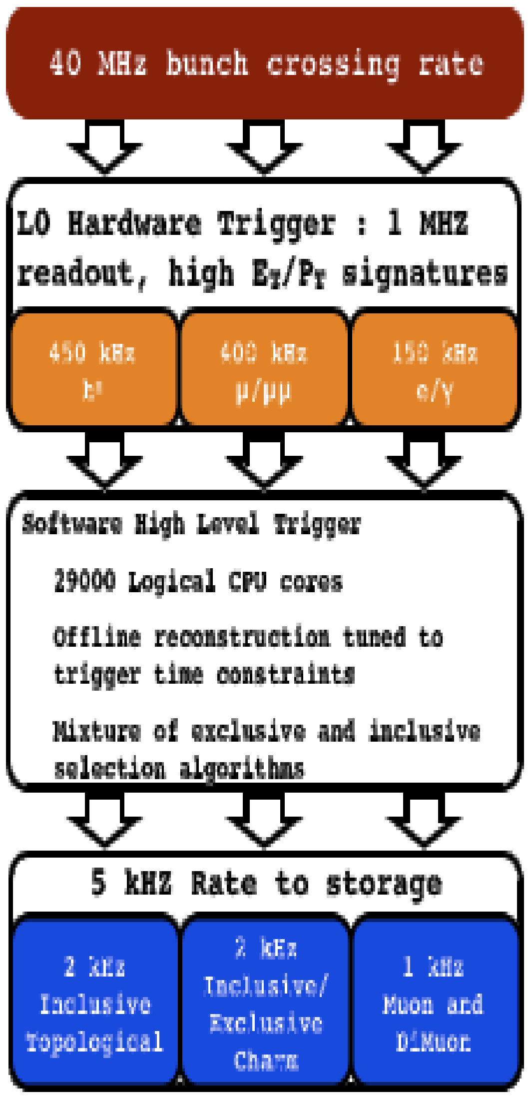
http://cds.cern.ch/record/1333091/files/LHCC-I-018.pdf

http://cds.cern.ch/record/1443882/files/LHCB-TDR-012.pdf

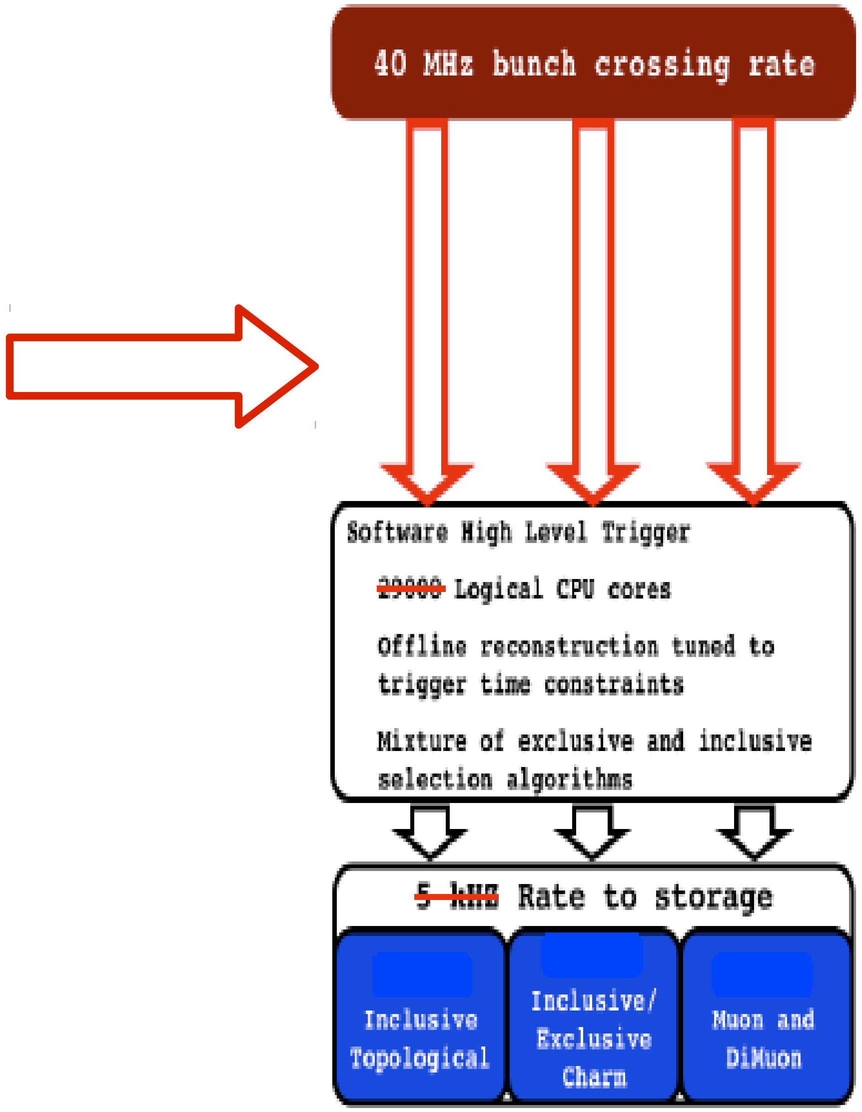
Trigger and data acquisition Schemes

- Remove Level0 hardware trigger → gain a factor 5 in luminosity
- Data from every bunch crossing sent to the CPU farm

Current Trigger



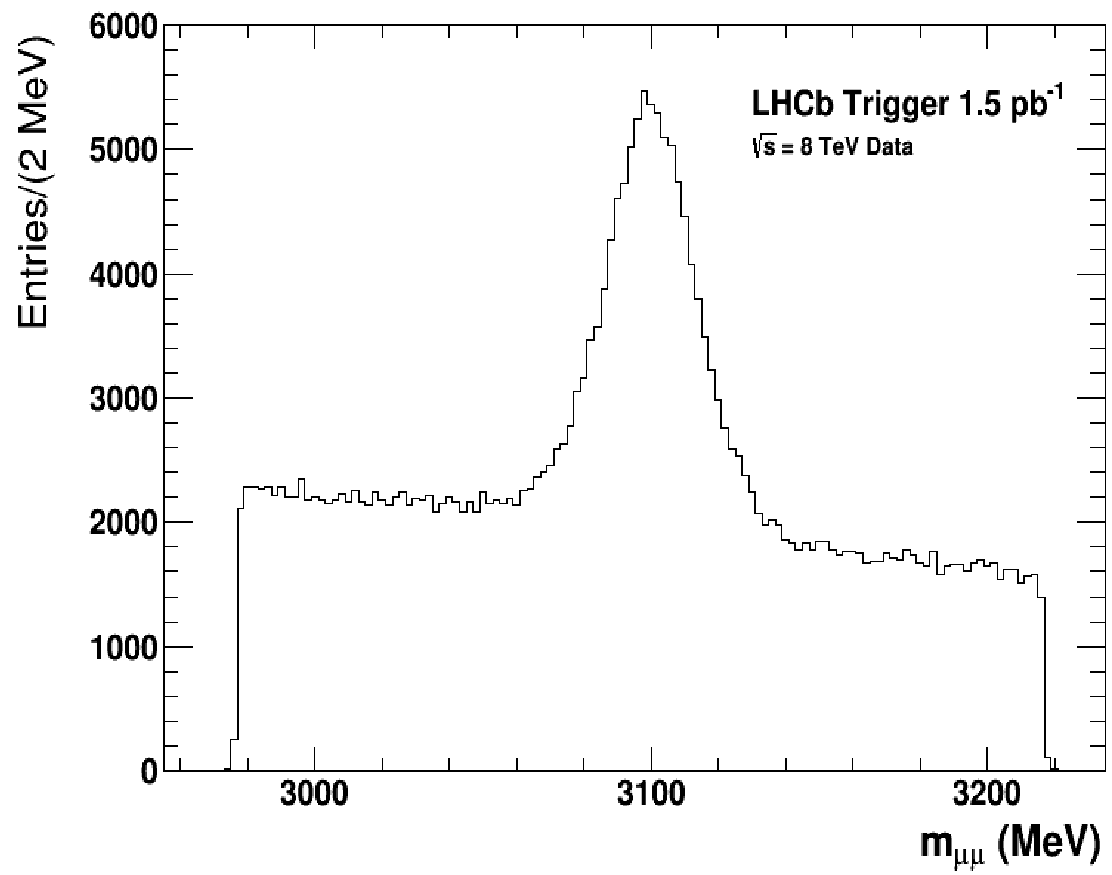
Upgraded Trigger



50000

20kHz

Online plot from data



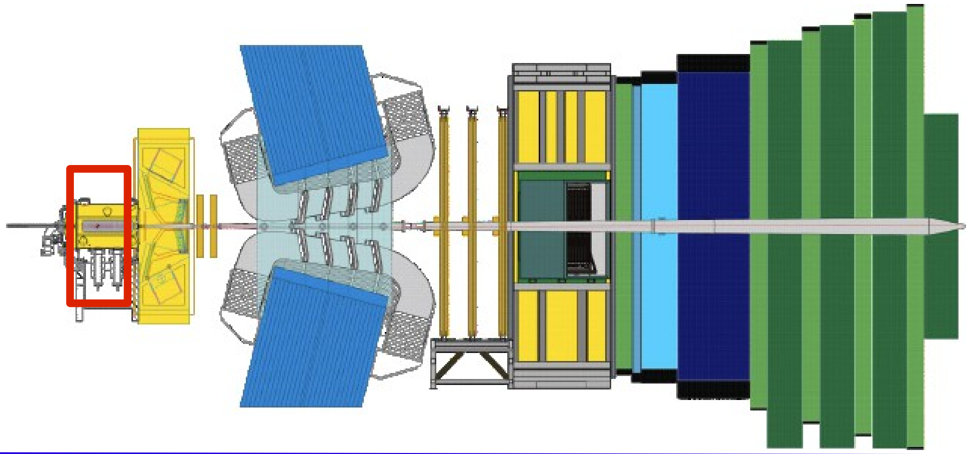
Sub-systems upgrade

Current Vertex locator | Vertex system

- Single sided Si strip sensors
  - n-on-n sensors of 300μm thicknesses
  - R and Φ measuring sensors mounted back-to-back

- Movable from ~50mm to ~5mm close to LHC beams during collisions

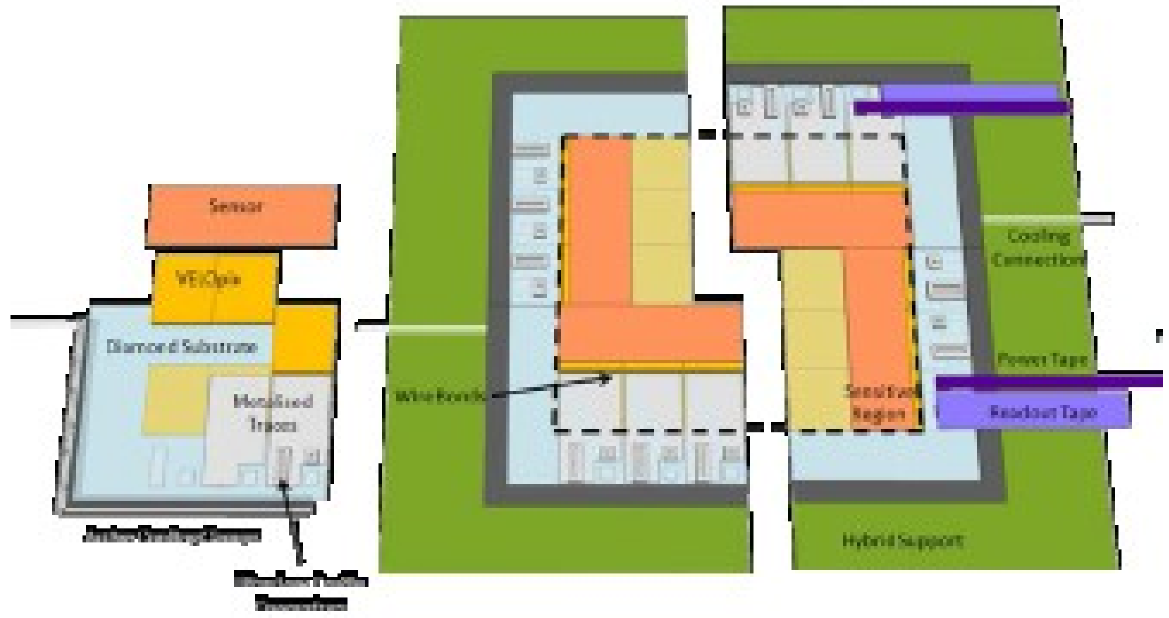
- Excellent performance with cluster efficiency >99.5%, hit resolution <4μm

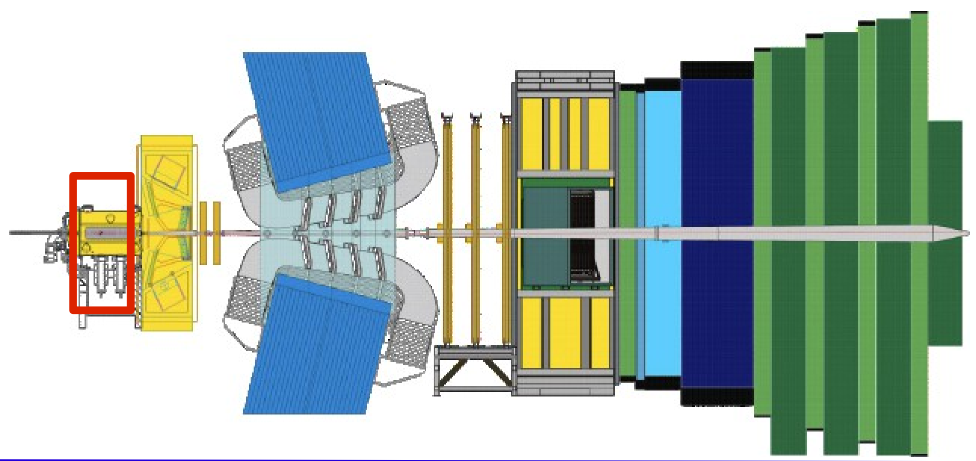


Sub-systems upgrade

New Vertex locator | New Vertex system

- Maintain the same performance in harsher environments
  - Low material budget → more radiation hard
- Si-pixel detector with micro-channel cooling
  - Excellent heat transfer between fluid and sensors
- Sensors thicknesses of 200μm
- Square pixel sensor of 55μmx55μm

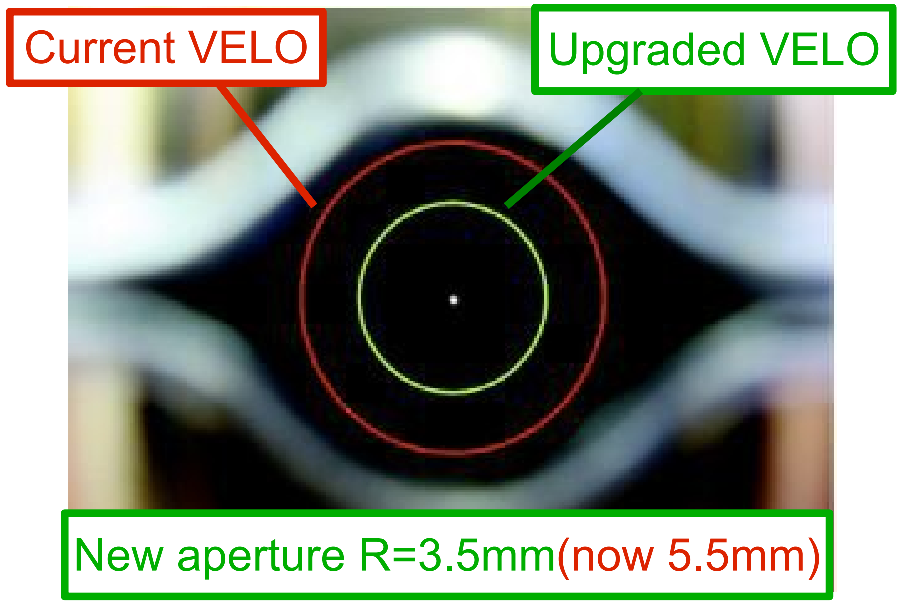


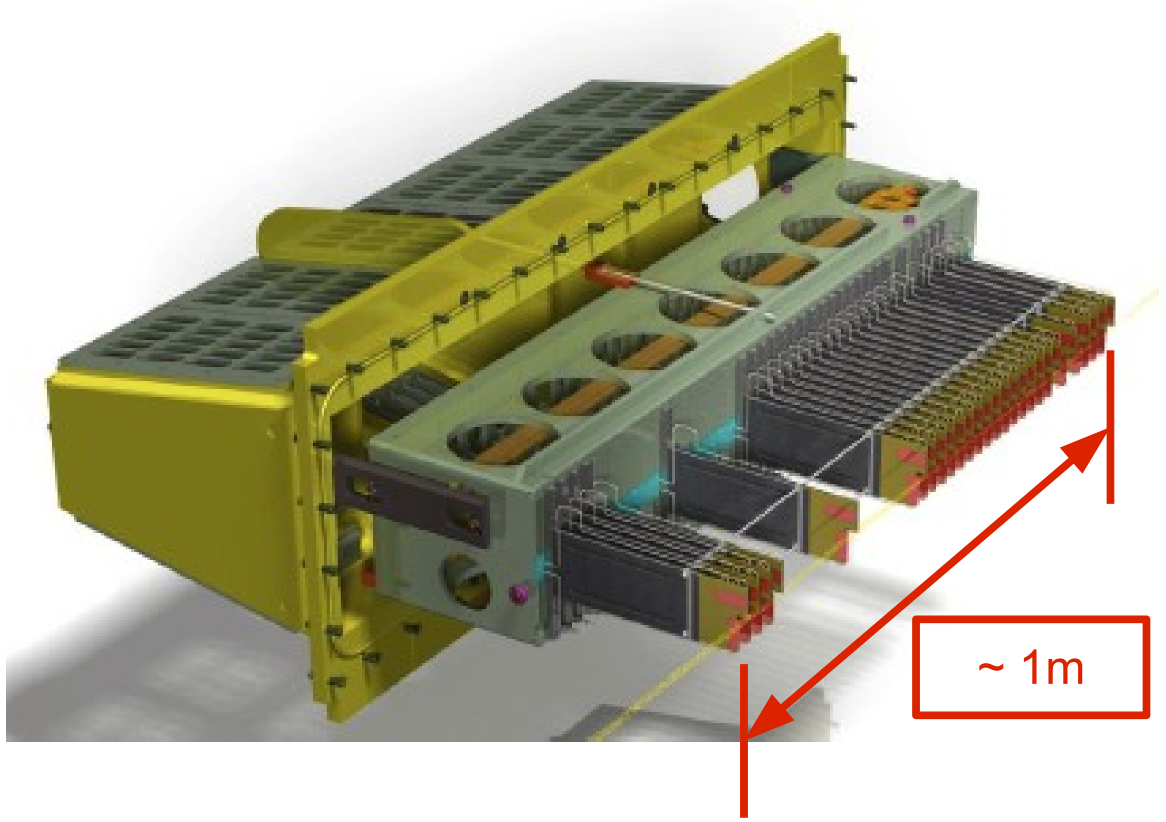


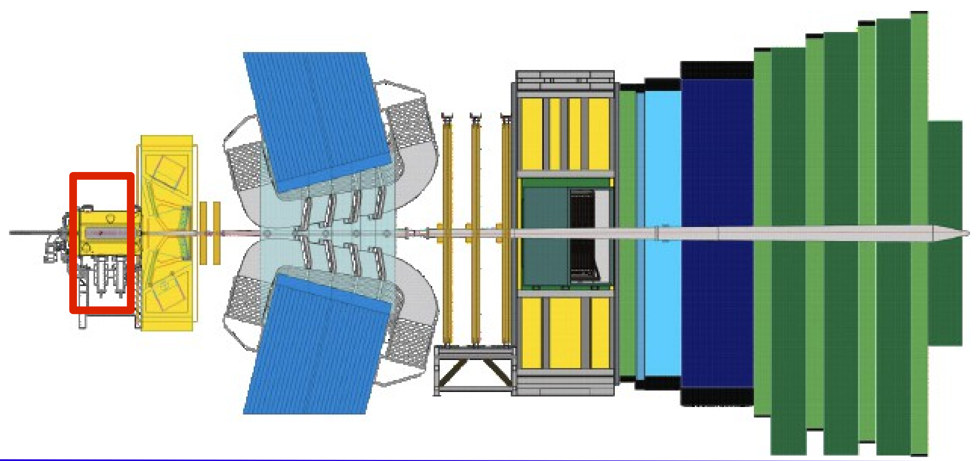
Sub-systems upgrade

New Vertex locator | New Vertex system

- Full detector of 26 stations, 2 modules per station, 1 on each side of the beam
- New thinner RF foil of 150µm (currently 300µm) separation between detector and beam volume from beam
- Geometrical efficiency > 99 % for R < 10mm







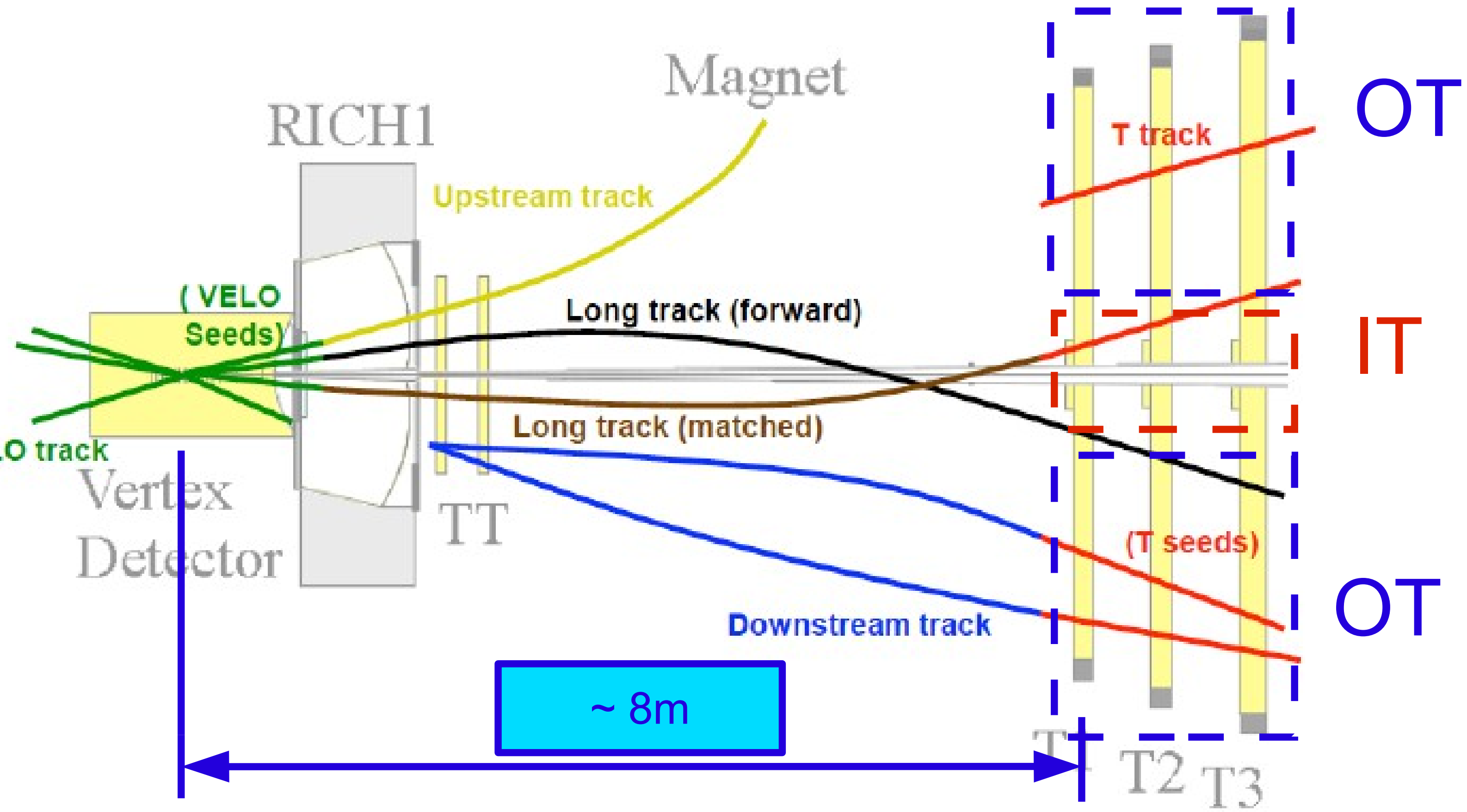
Sub-systems upgrade

Current Tracking system

- Tracking stations before (Tracker Turicensis) and after the magnet (T-stations = Inner Tracker + Outer Tracker)
  - Inner regions Si strip detectors (TT & IT)
  - Outer region (downstream) straw tubes (OT)

- TT connects Velo tracks to the downstream stations for accurate tracking

- High momentum resolution(<0.5%)

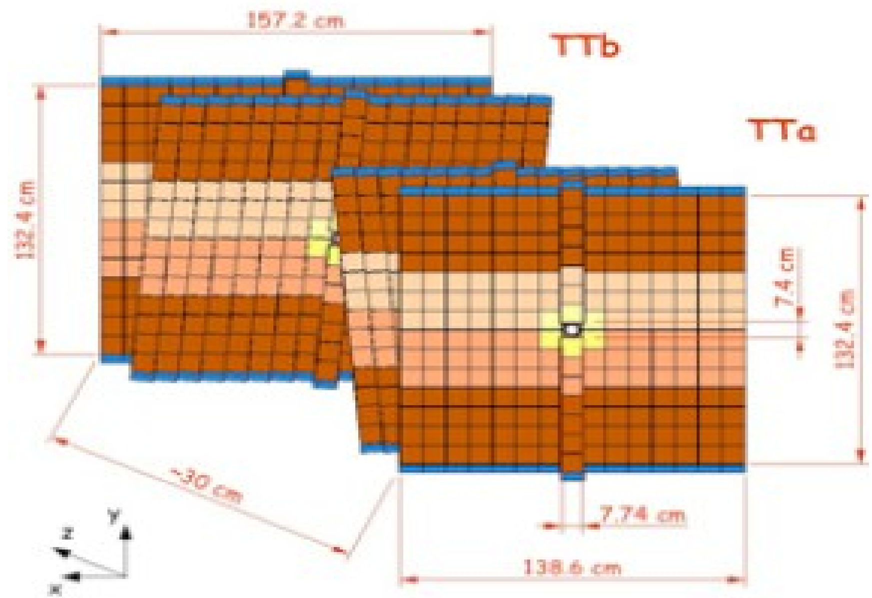


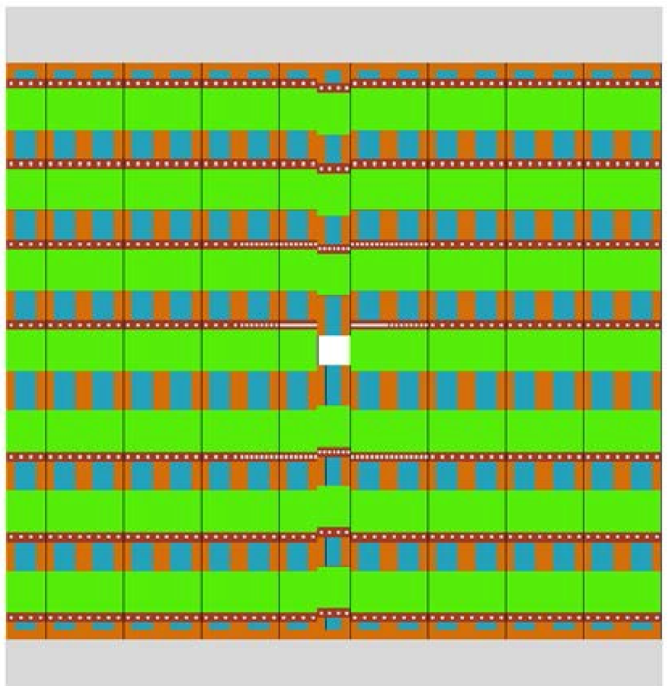
Sub-systems upgrade

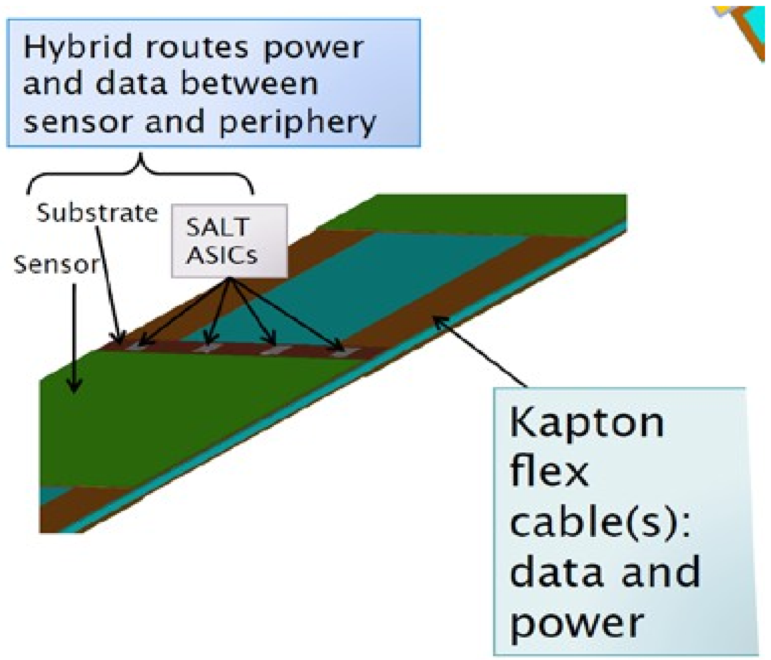
Upstream Tracker | New Tracking system

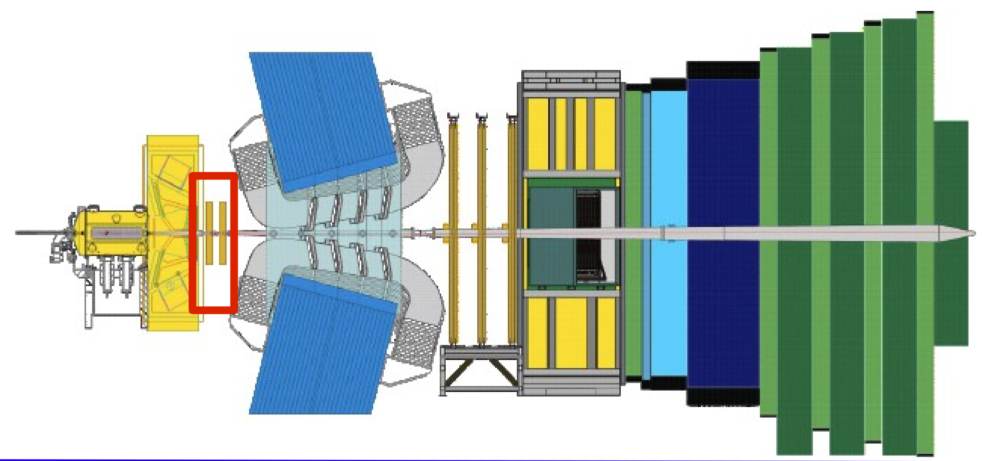
- Replacement of the current TT also based on Si-strips
- Reduced thickness (500μm → 300μm)
  - Finer granularity:~180 μm strip pitch. 90 μm pitch at inner region where the particle flux is higher
  - Larger coverage (innermost cut-out at 34 mm)
  - Less material ($< 5\%\ X_0$)

Current TT





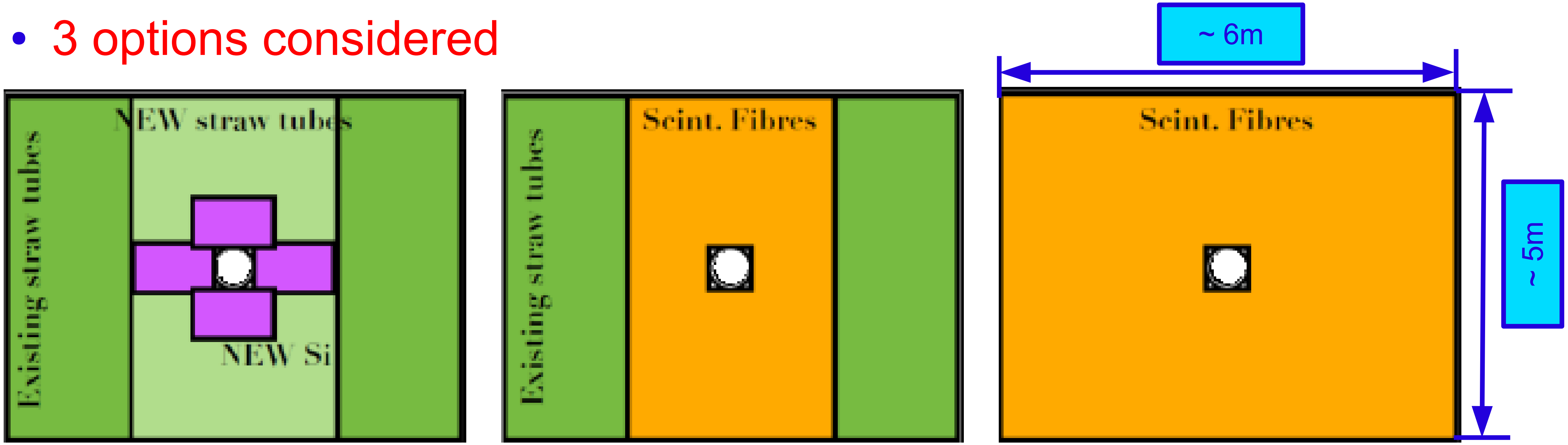




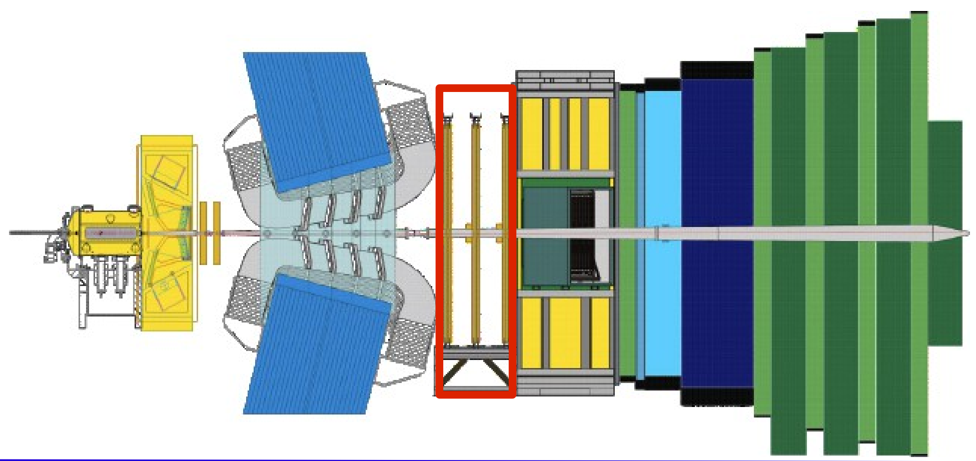
Sub-systems upgrade

New T- Stations | New Tracking system

- 3 options considered



- Enlarged, thinner and lighter IT
  - Based on Si-trip
  - New OT straw tubes in central region
- Central region replaced with Central Tracker (SciFi)
  - Based on Scintillating and SiliconPM
- Replace entire IT+OT with SciFi (Baseline option)

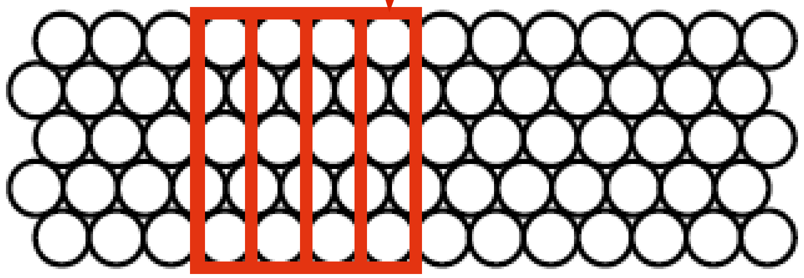


Sub-systems upgrade

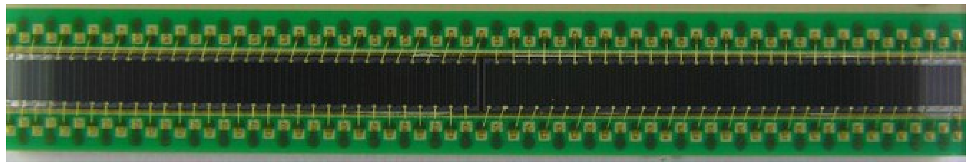
Fibre Tracker option | New Tracking system

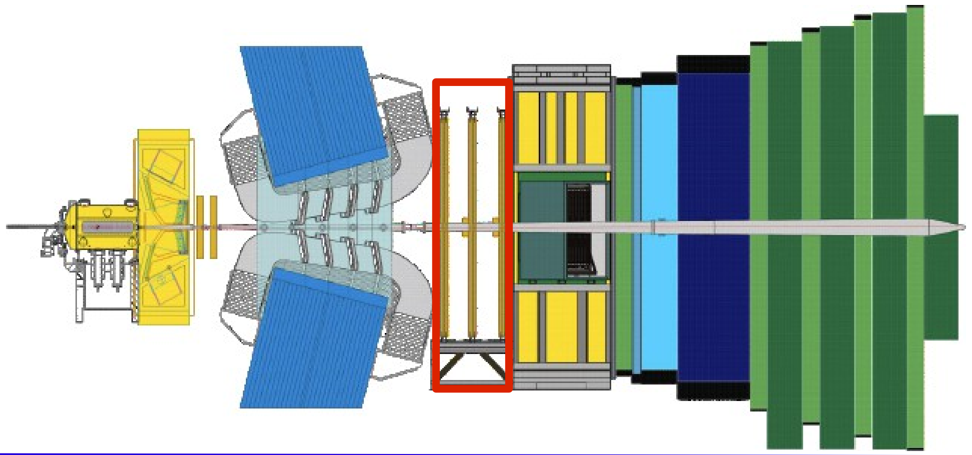
- SciFi modules of 2.5m long with fibers of 250µm diameter
- 5 fiber layers per module
- Readout by SiliconPM (250µm pitch) outside the acceptance
  - Due to radiation damage → SIPM will be cooled and shielded
- Use of a custom designed ASIC to readout the SiliconPM at 40MHz
- Shown feasible (Viability assessment review in March 2013)
- The technology choice SciFi vs others option in November 2013

Single SiPM channel (250µm x 1100µm)



128 channels SiliconPM



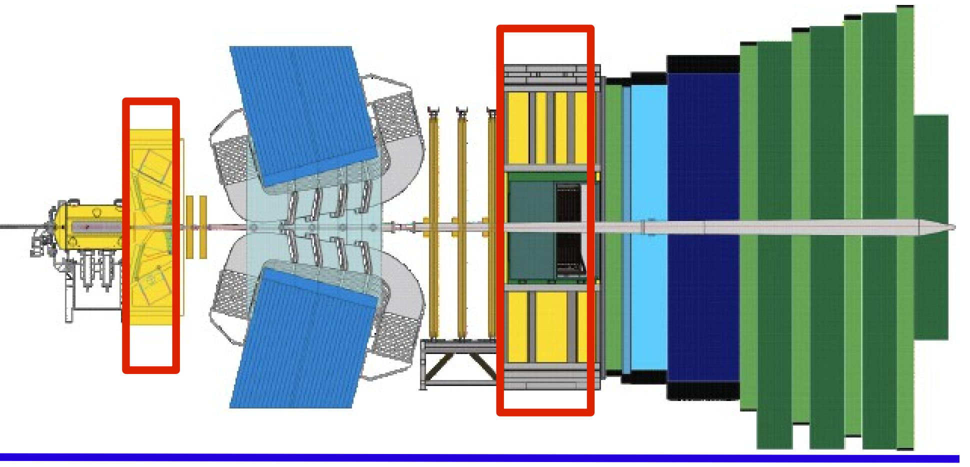


Sub-systems upgrade

Current RICH detectors | Particle identification

- Separation between muons and kaons from decay products

- Both RICH1 & RICH2 are Ring Cherenkov detectors with different radiators
  - RICH1 contains a silica aerogel (low momentum range) and C_4F_{10} radiator (medium-high momentum range)
  - RICH2 contains a CF_4 radiator (high momentum range)



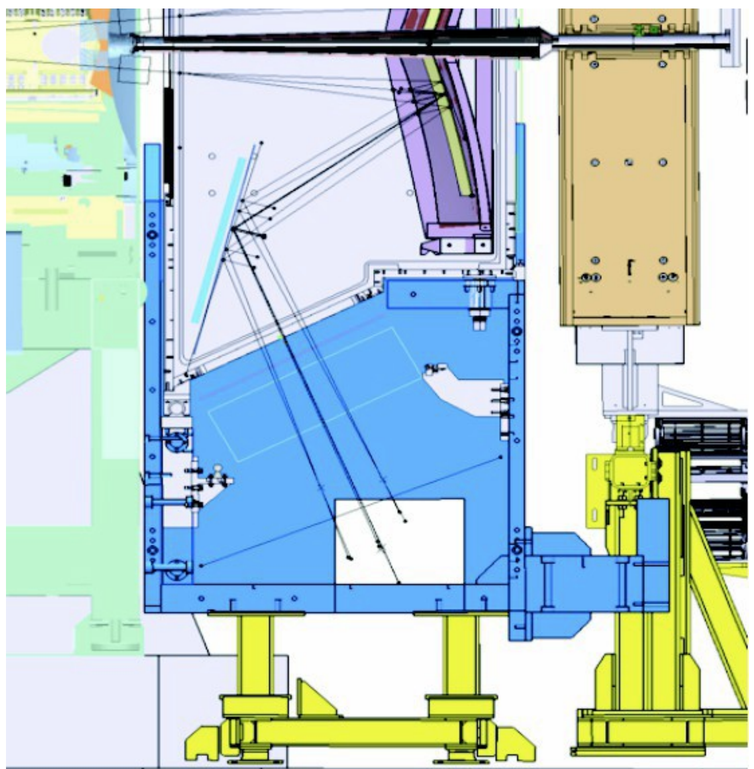
Sub-systems upgrade

New RICH detectors

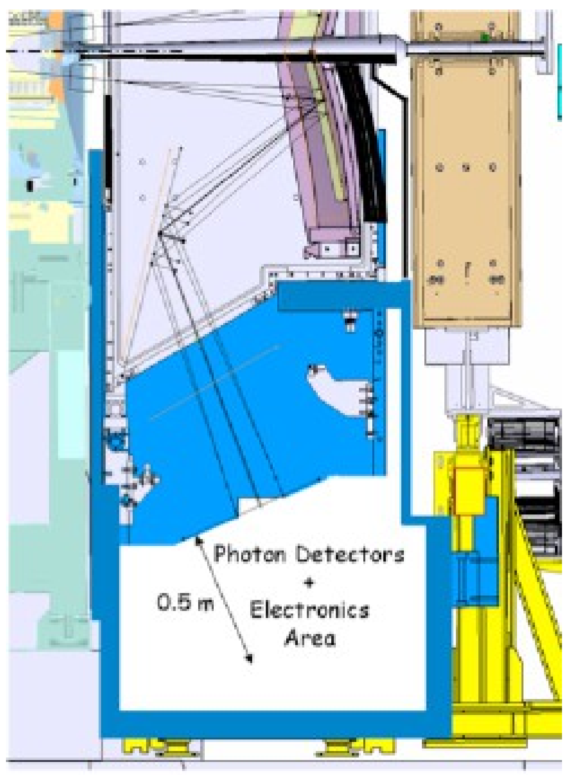
- RICH1 with high occupancy
  - Remove aerogel radiator

    → CF_4 in RICH1 and C_4F_{10} in RICH2
  - Optics redesign to spread out the rings

Current RICH1

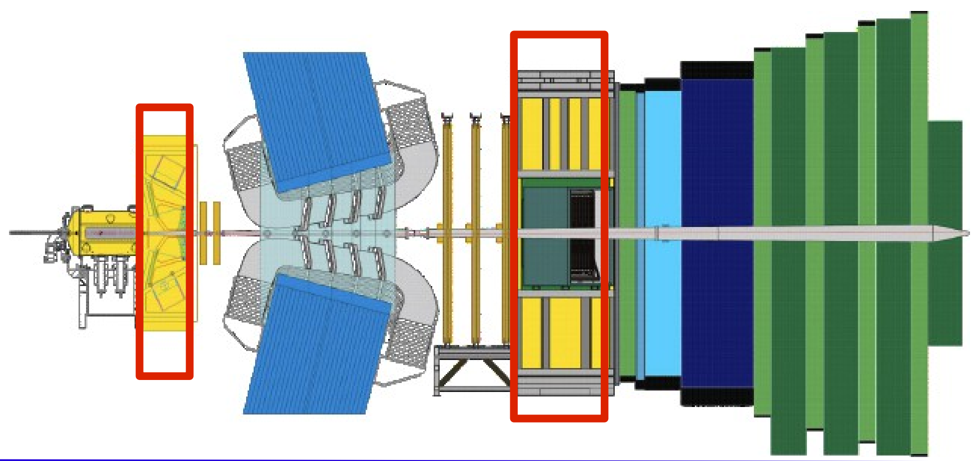


New optics RICH1



New Particle Identification

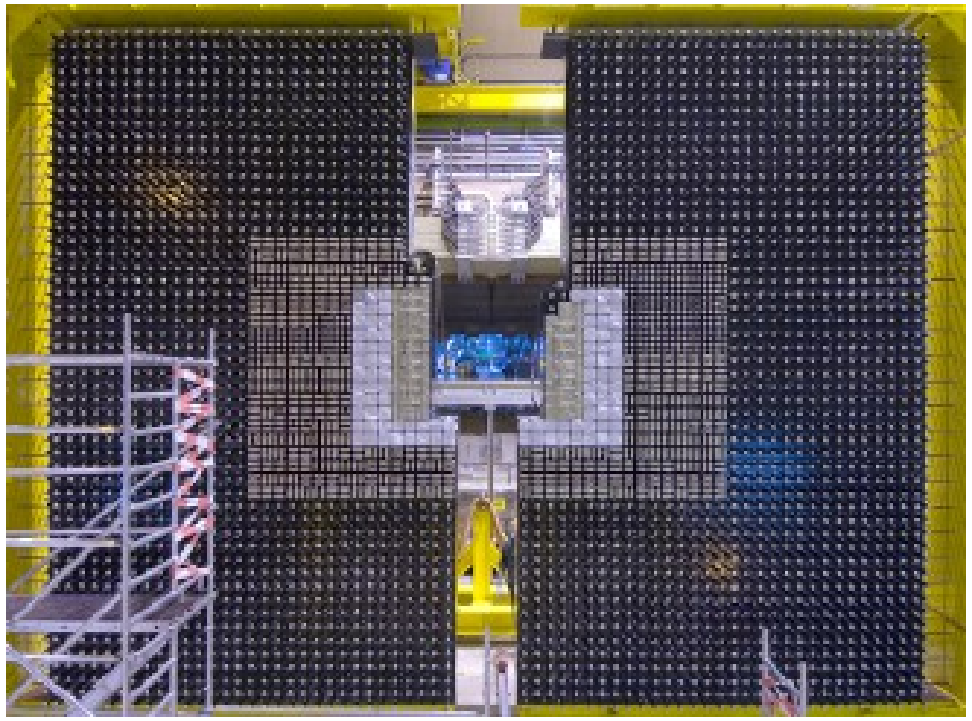
- RICH1 and RICH2
  - Replacement of their photo-detectors due to embedded FE
  - HPDs replaced with Multi-anode PMTs



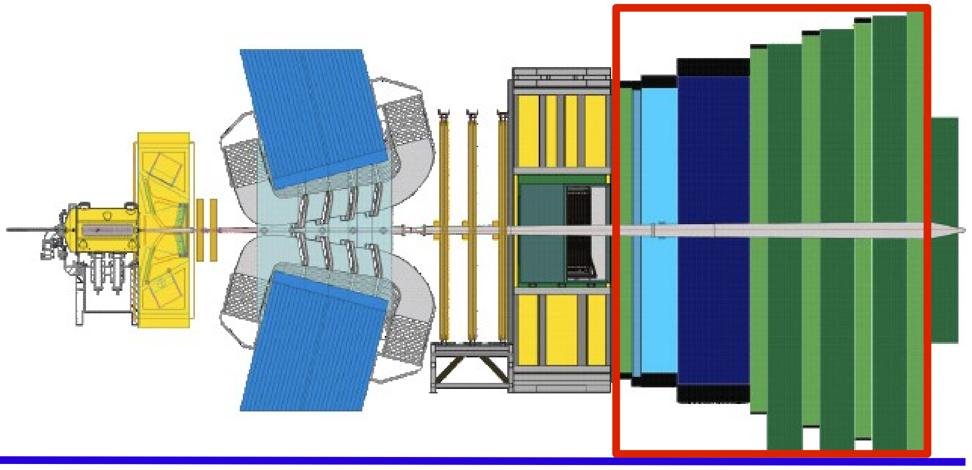
Sub-systems upgrade

Calorimeters & Muon chambers

- Calorimeters
  - Scintillating Pad Detector and Pre-Shower removed
  - Replace FE electronics for 40MHz readout
  - Current modules will be kept
  - Reduce HV and PMT gain to prevent premature aging



- Muon Chambers
  - Replace FE electronics
  - Possible installation of higher granularity detectors at a later stage



Summary

- LHCb is facing challenges in preparing for the upgrade in 2018
- Final design choices followed by TDRs for each sub-detector will happen in the coming months
  - VELO choice of pixel based readout with micro-channel cooling
  - RICH choice of redesigned of optics for RICH1 and removal of aerogel
  - T-stations technology choice in November 2013
- LHCb will move to an entirely software based trigger, reading out every single bunch crossing at 40MHz
- The upgraded detector will make possible the test Standard Model and search of New Physics at precisions of few percent

As Conclusion: Sensitivity of LHCb to key observables

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
	$A_{\mathrm{fs}}(B_s^0)$	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 currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\ A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	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	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 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}	–

Framework TDR for the LHCb upgrade, LHCB-TDR-012