The LHCb Upgrade

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on behalf of the LHCb Collaboration
Nikhef, Amsterdam
April 12, 2013

Beauty 2013, Bologna, April 7-12 2013

Outline

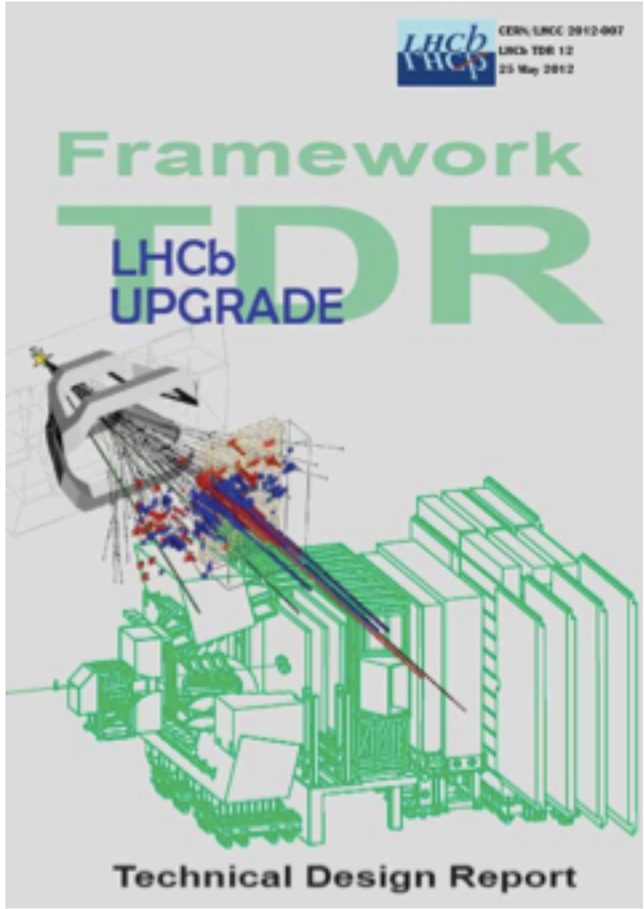
More information:

- LHCb Status
- Physics Motivation
- LHCb Upgrade
- Conclusions

Letter of Intent

CERN/LHCC-2011-001

Framework TDR



CERN/LHCC-2012-007

LHCb Upgrade fully endorsed by LHCC and approved by CERN Research Board

LHCb Status

- LHCb is performing extremely well. Operations are running smoothly and as expected (even better...)

design parameters

	2011	2012
Beam Energy	3.5 TeV	4.0 TeV
Instantaneous Luminosity	2-4x10^{32} [$cm^{-2}s^{-1}$]	4x10^{32} [$cm^{-2}s^{-1}$]
Interactions/crossing	0.4-2.5	1.6
Data Taking Efficiency	>91%	>95%
HLT output	3kHz	5kHz
Integrated Luminosity	>1.0fb^{-1}	>2.0fb^{-1}

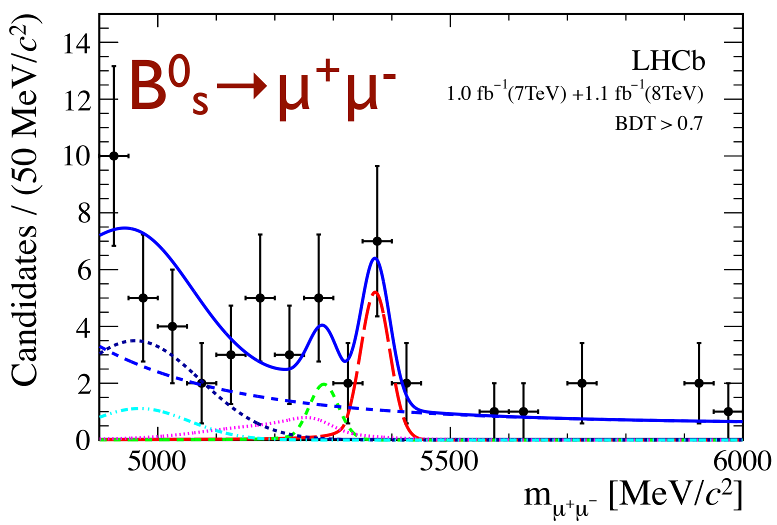
+ a successful pA/Ap run in 2013

Recent LHCb Results

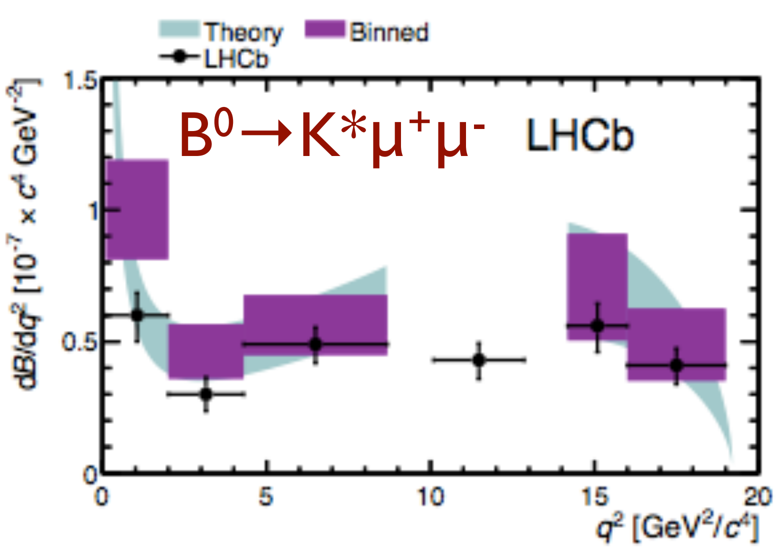
- The efficient data-taking allowed to reach the targets posed while designing the detector and added on the way

Rare Decays

see talk by F. Dettori

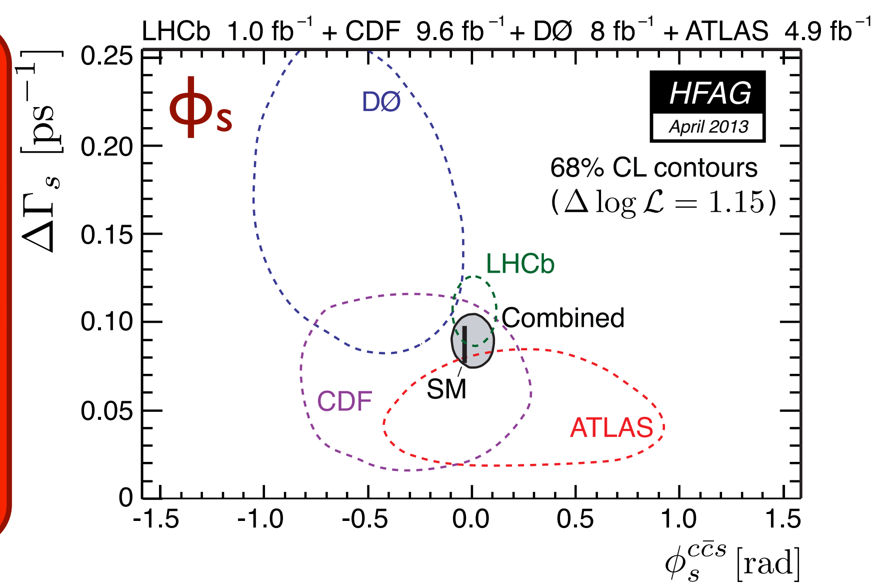


see talk by M. Kreps

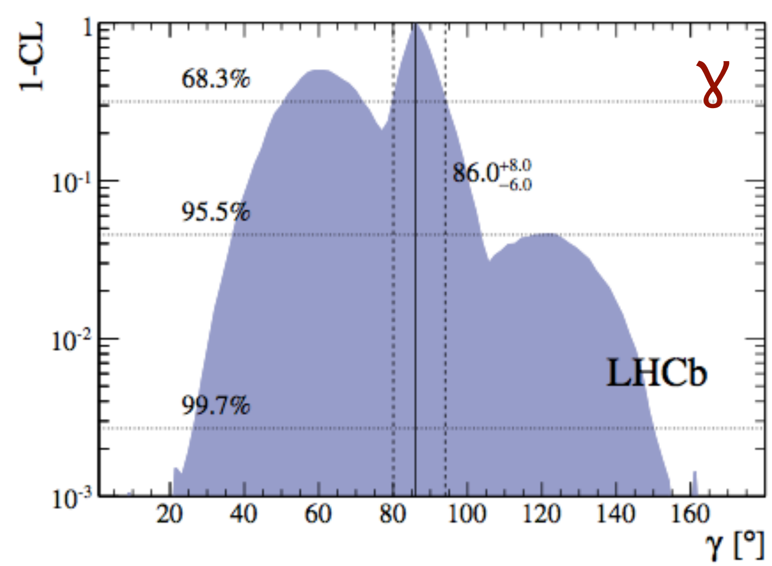


CPV in B decays

see talk by F. Dupertuis

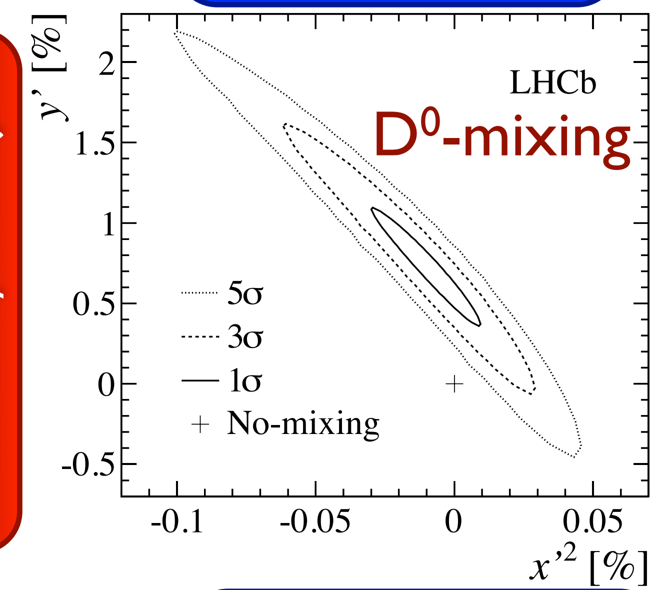


see talk by M. Schiller



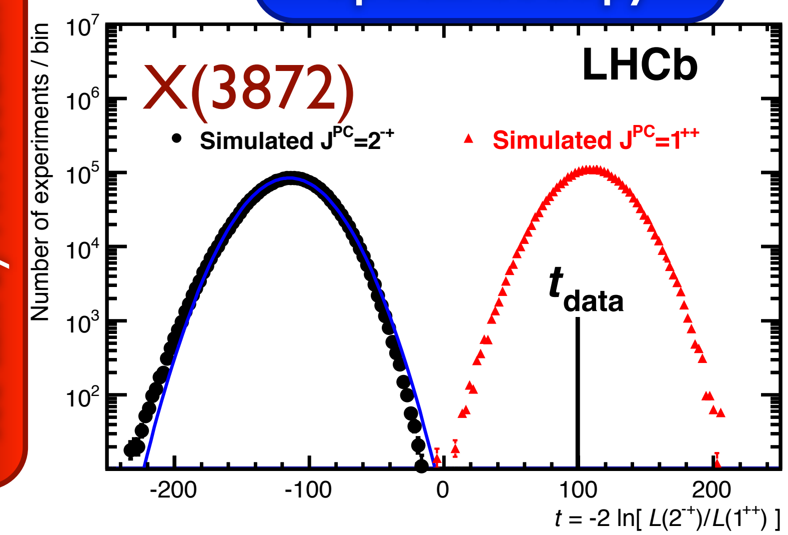
Charm

see talk by A. Ukleja

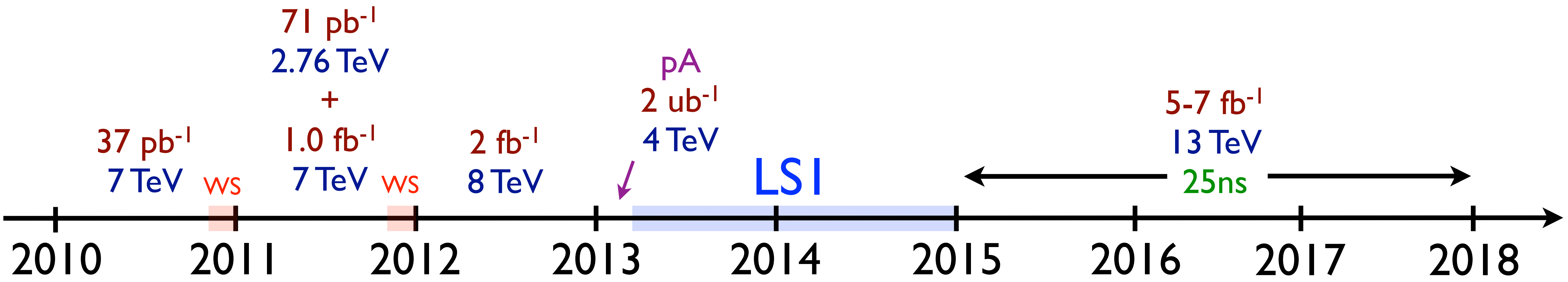


Spectroscopy

see talk by M. Needham

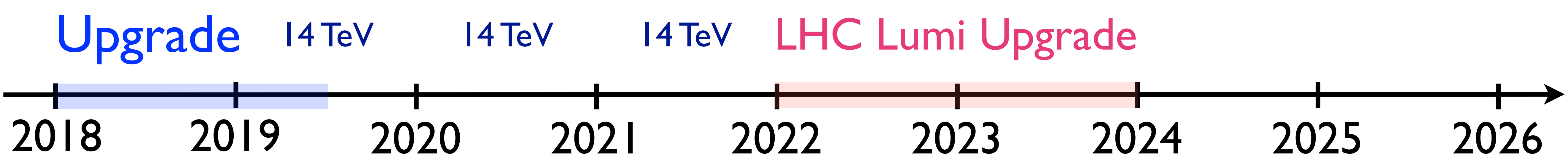


LHCb Plans



- We are now in LS1: time to think on how to improve our trigger and reconstruction chain to face new conditions
- Get ready for 25ns, E_{CM}=13TeV
- LHCb plan is to record 10fb^{-1} before 2018

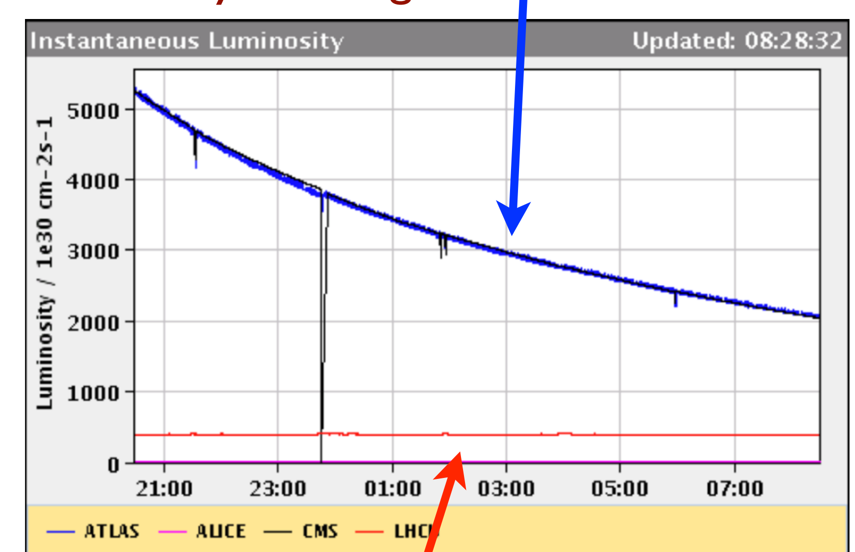
LHCb Upgrade Plans



- E_{CM}=14 TeV
- Instantaneous luminosity up to 3×10^{33} $cm^{-2}s^{-1}$
- plan to record $50fb^{-1}$ in total
- Improve muon triggers to increase linearly with luminosity (5x)
- Improve hadronic triggers to increase linearly with luminosity and add a factor 2 (2x5→10x)

ATLAS, CMS

luminosity levelling



LHCb

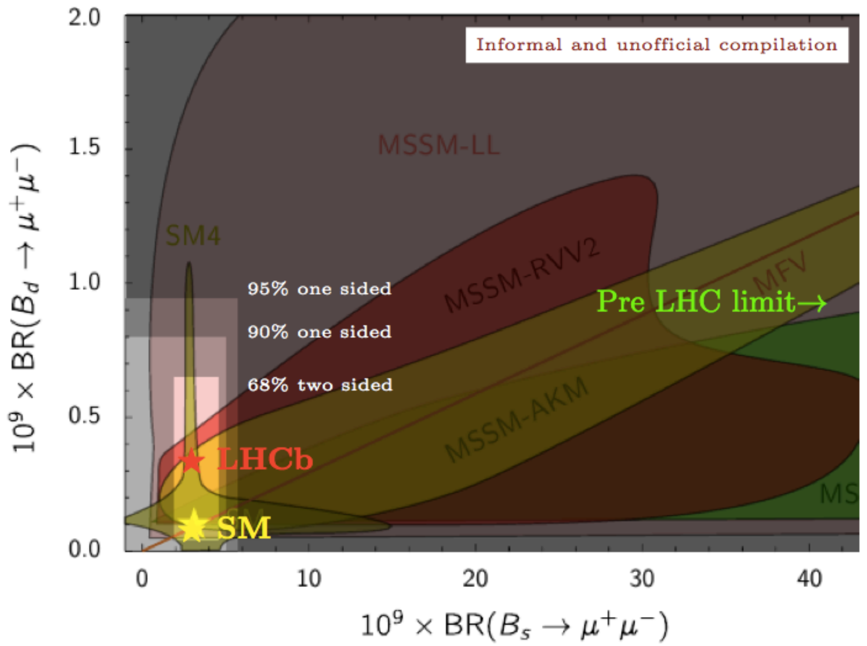
Physics Reach LHCb Upgrade

- LHCb Upgrade will significantly increase the LHCb Physics reach:
  - Unique for NP searches in B_s system, very competitive for B_d
  - Unprecedented Charm yields
  - General purpose experiment with forward geometry
- Can pursue both discovery and precision Physics

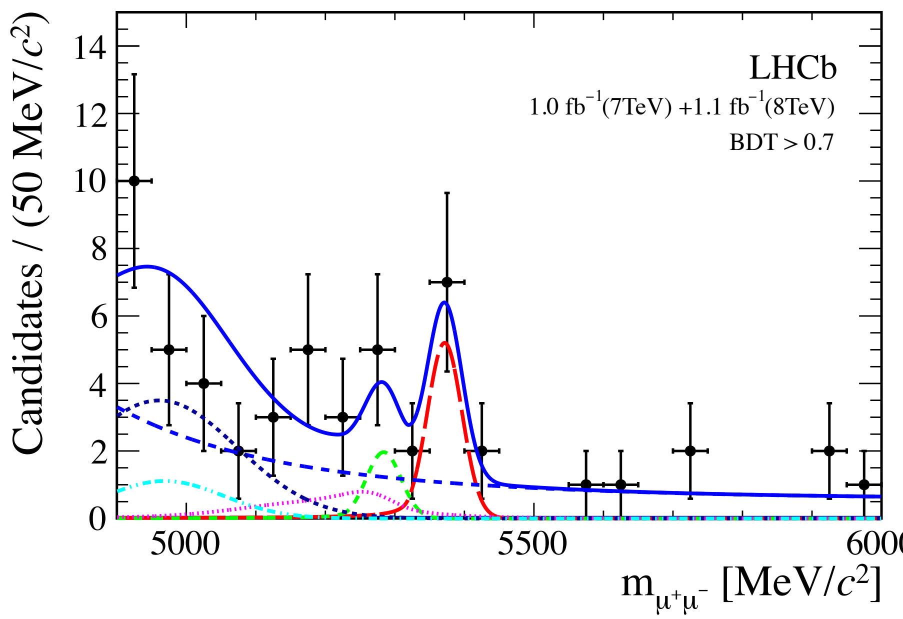
$B \rightarrow \mu^+\mu^-$

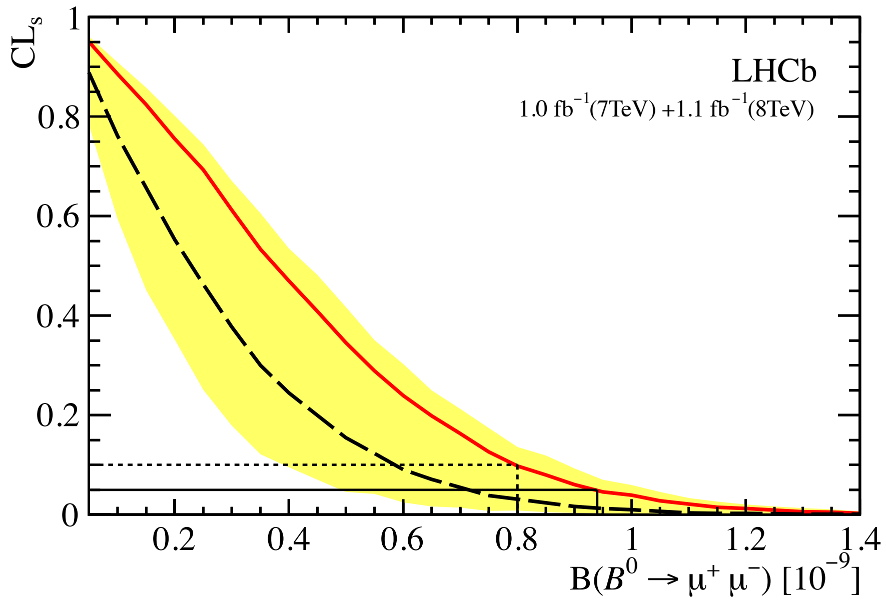
Phys. Rev. Lett. 110, 021801 (2013)

- LHCb recently observed evidence for $B^0_s \rightarrow \mu^+\mu^-$ using (1.0[7TeV]+1.1[8TeV])fb^{-1}
- Put limits on NP
- Next challenge is measuring $B^0 \rightarrow \mu^+\mu^-$



Original figure from D. Straub - Nuovo Cim. C035N1 (2012) 249-256



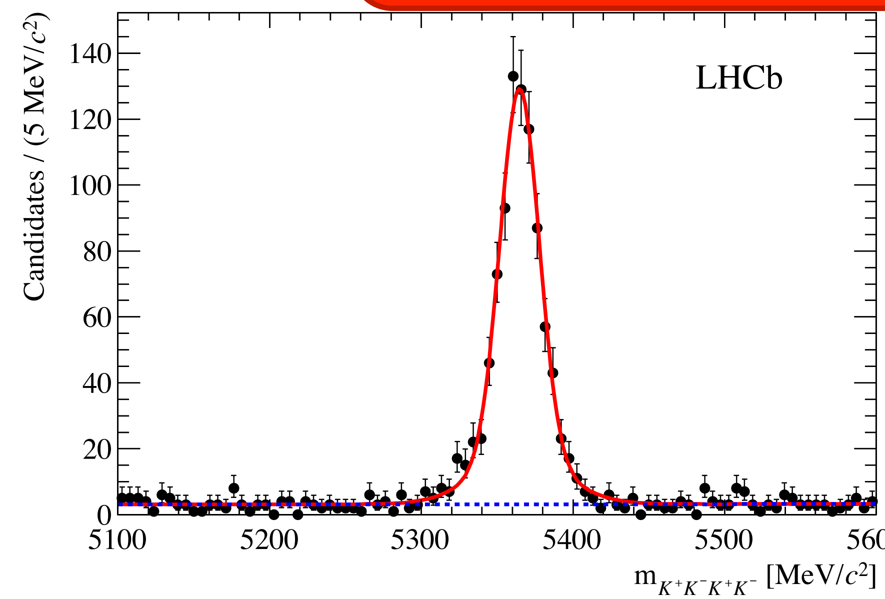


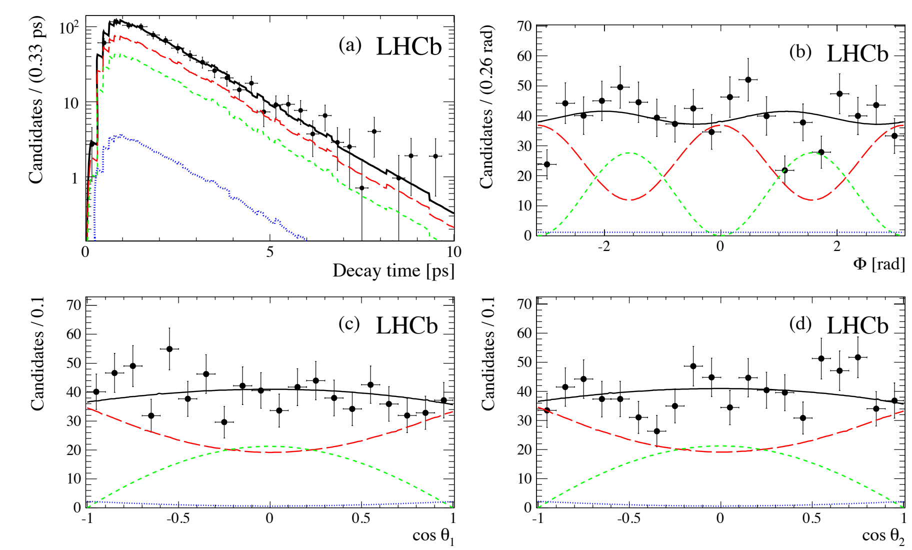
Measurement	LHCb (1fb^{-1})	LHCb (10fb^{-1})	LHCb Upgrade	Theory
$\sigma(\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s \to \mu^+\mu^-))$	-	100%	35%	5%

CPV in $B^0_s \to \phi\phi$

LHCB-PAPER-2013-007

- Penguin dominated, particularly sensitive to NP
- SM: cancellation between decay and mixing phases → ϕ_s~0
- We recently made first time-dependent measurement of ϕ_s: [-2.76,-0.76]rad @68%CL
- In the upgrade we expect to approach theoretical error

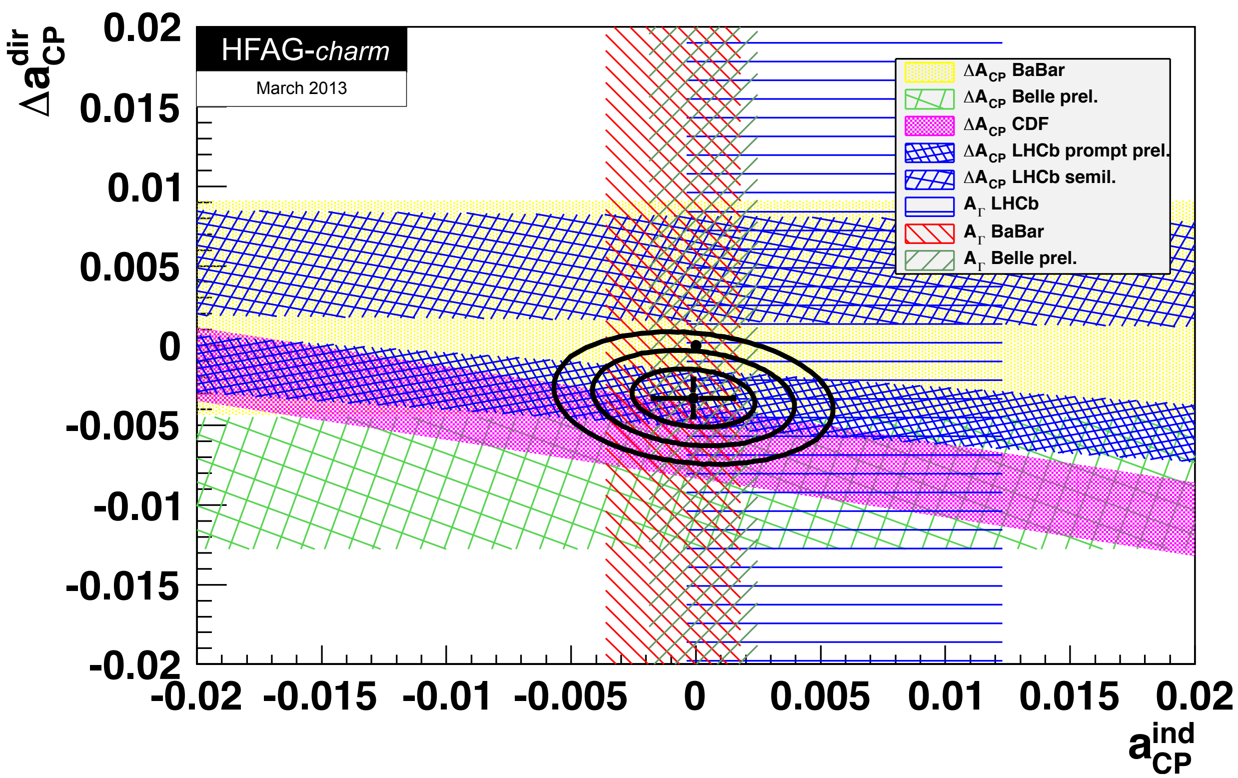




Measurement	LHCb (1fb^{-1})	LHCb (10fb^{-1})	LHCb Upgrade	Theory
$\sigma(\phi_s)[B_s \to \phi\phi]$	100%	17%	3%	2%

CPV in Charm Decays

- Expected <0.1%
  NP may enhance it
- Recent results on ΔA_{CP} show that high precision needs to be achieved
- LHCb upgrade can probe many channels with precision 2 to 3 order of magnitudes better than B factories



Measurement	LHCb ($1 fb^{-1}$)	LHCb ($10 fb^{-1}$)	LHCb Upgrade	Theory
ΔA_{CP}	2×10^{-3}	0.40×10^{-3}	0.07×10^{-3}	-

Flavour Physics Capabilities

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	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}	–

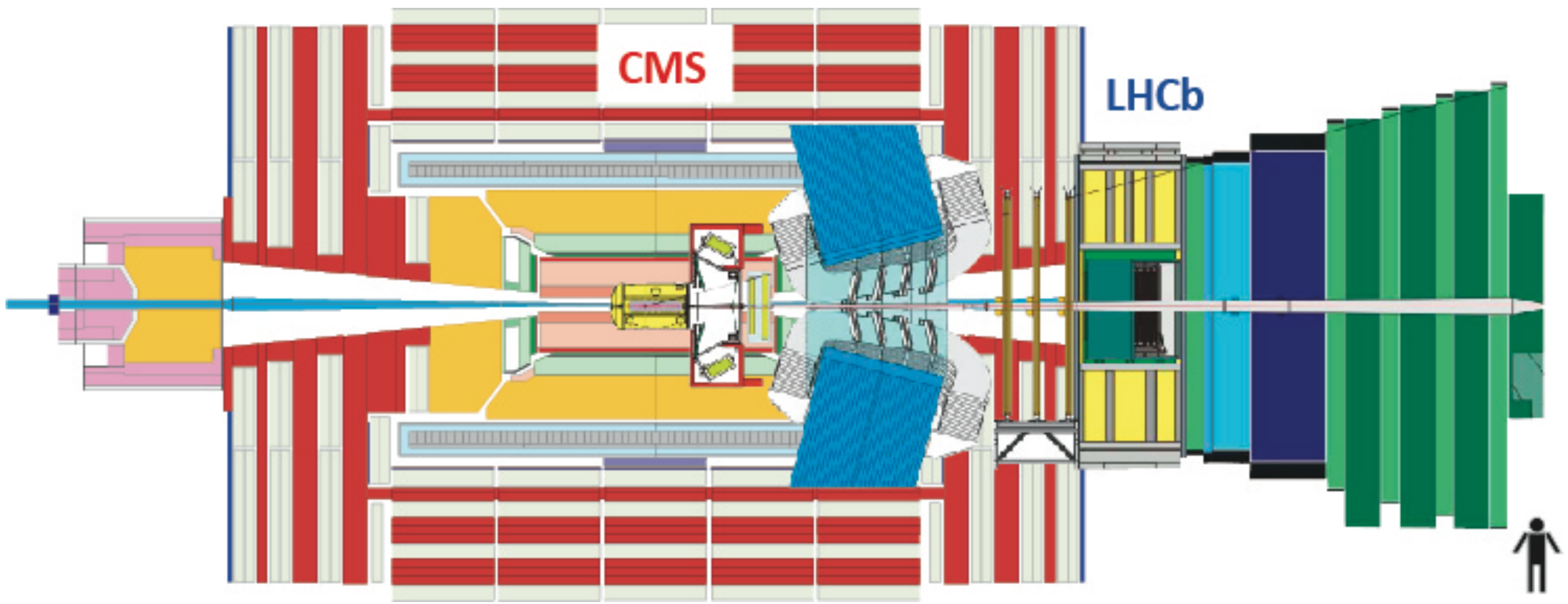
Table 1: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with $50\,\mathrm{fb}^{-1}$ by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities.

LHCb Upgrade Framework TDR, CERN/LHCC-2012-007

Implications of LHCb measurements and future prospects, LHCB-PAPER-2012-031

Beyond Flavour Physics

- Effective EW mixing angle
- High sensitivity for exotics Long Lived Particles
- QCD studies in forward region ($2<\eta<5$)



Upgrade Challenges

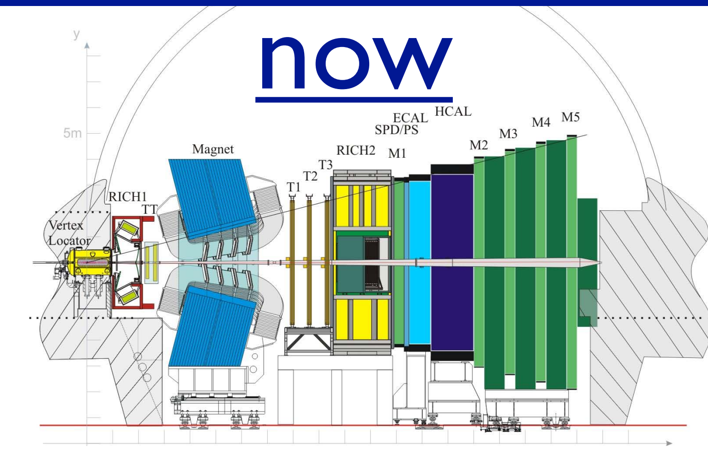
- Increase 2x hadronic triggers:
  - need L0 40MHz, output 20kHz

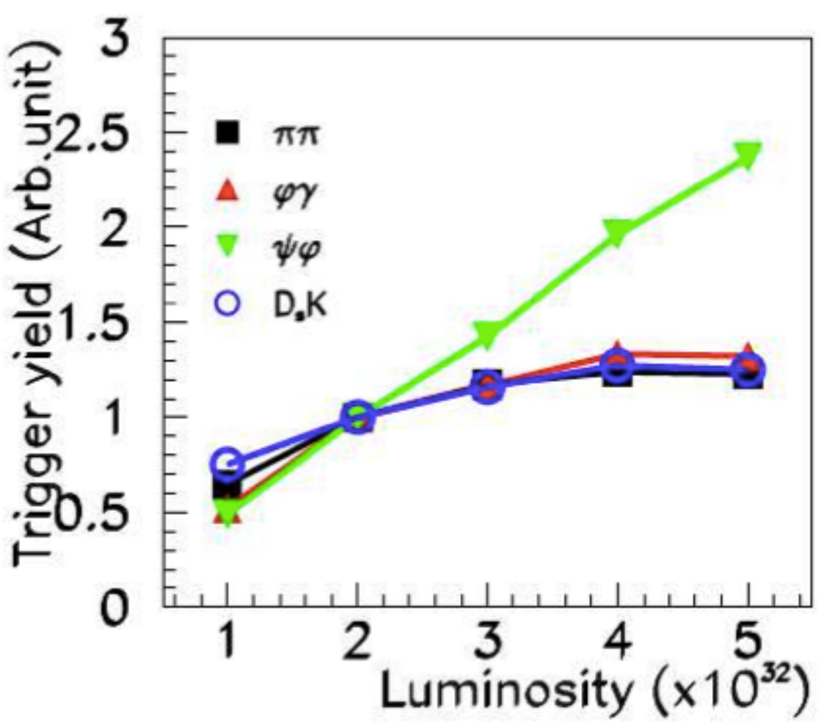
now: 1MHz, 5kHz

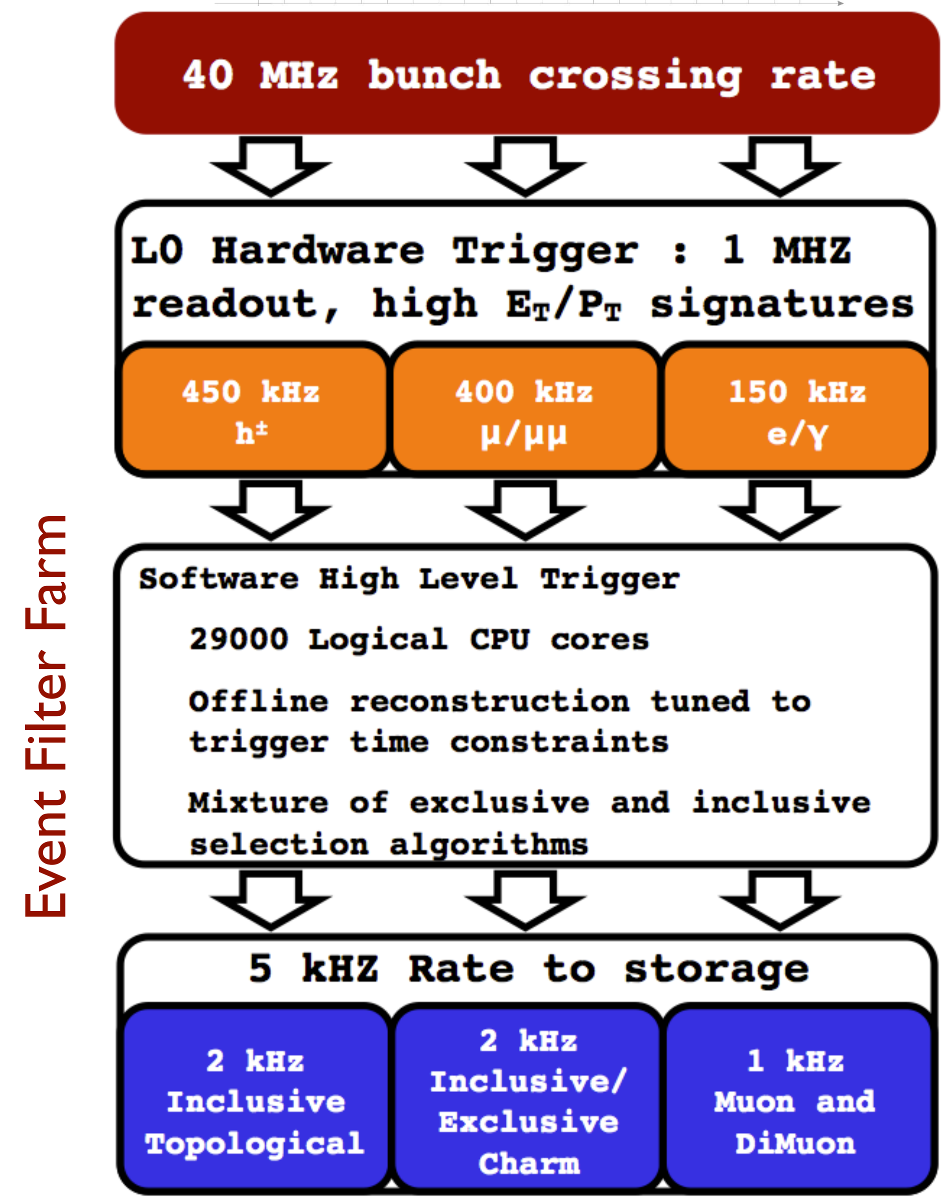
- Increased radiation dose:
  - replace VELO
  - replace Silicon Tracking stations
- Higher occupancy:
  - modify RICH, tracking stations

Actual LHCb Trigger

- L0 (hardware) + HLT (software)
- LHC clock rate: 40MHz
  Current hardware 1MHz
- With current layout, we need selections to keep rate under limit.
  Those selections flatten the yields with luminosity

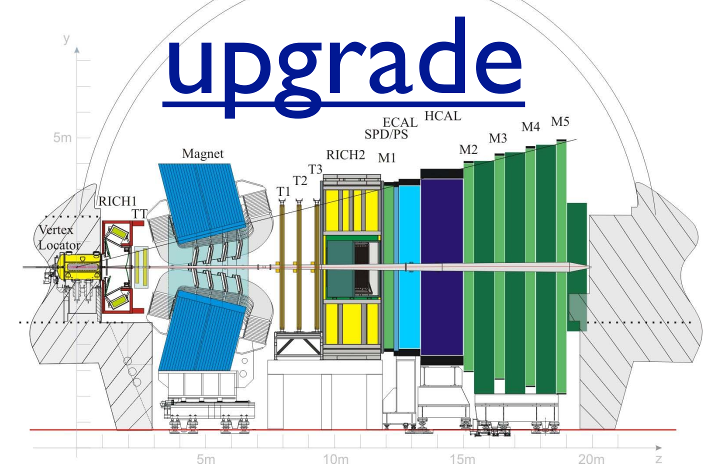


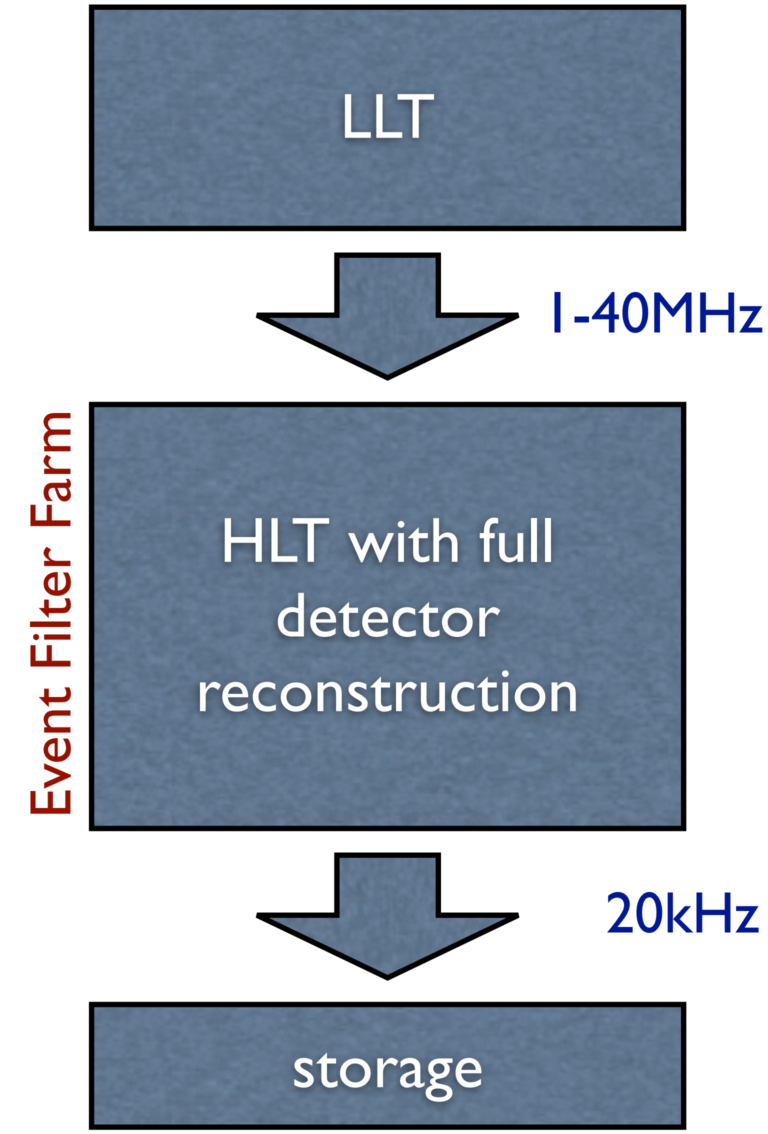


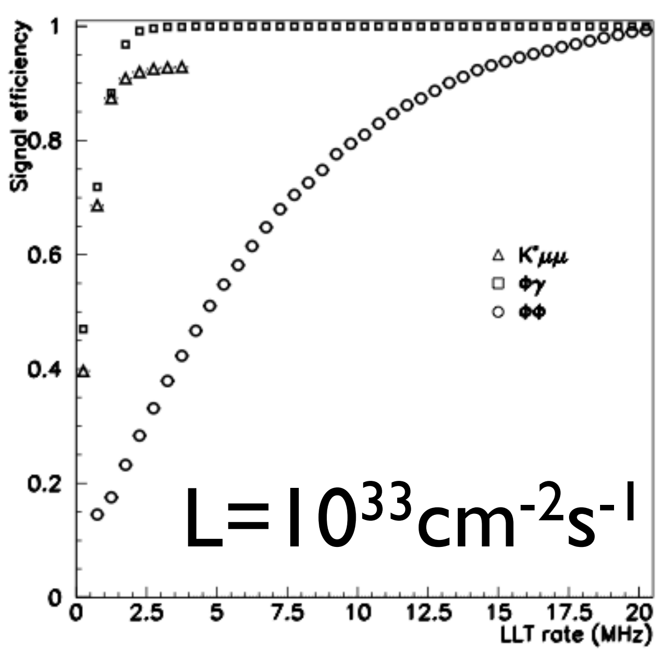


LHCb Upgrade Trigger

- change electronics readout to get up to 40MHz and match LHC bunch crossing
- Event Filter Farm reconstructs the event and makes trigger decisions
- Improvements of the CPU computing power are needed

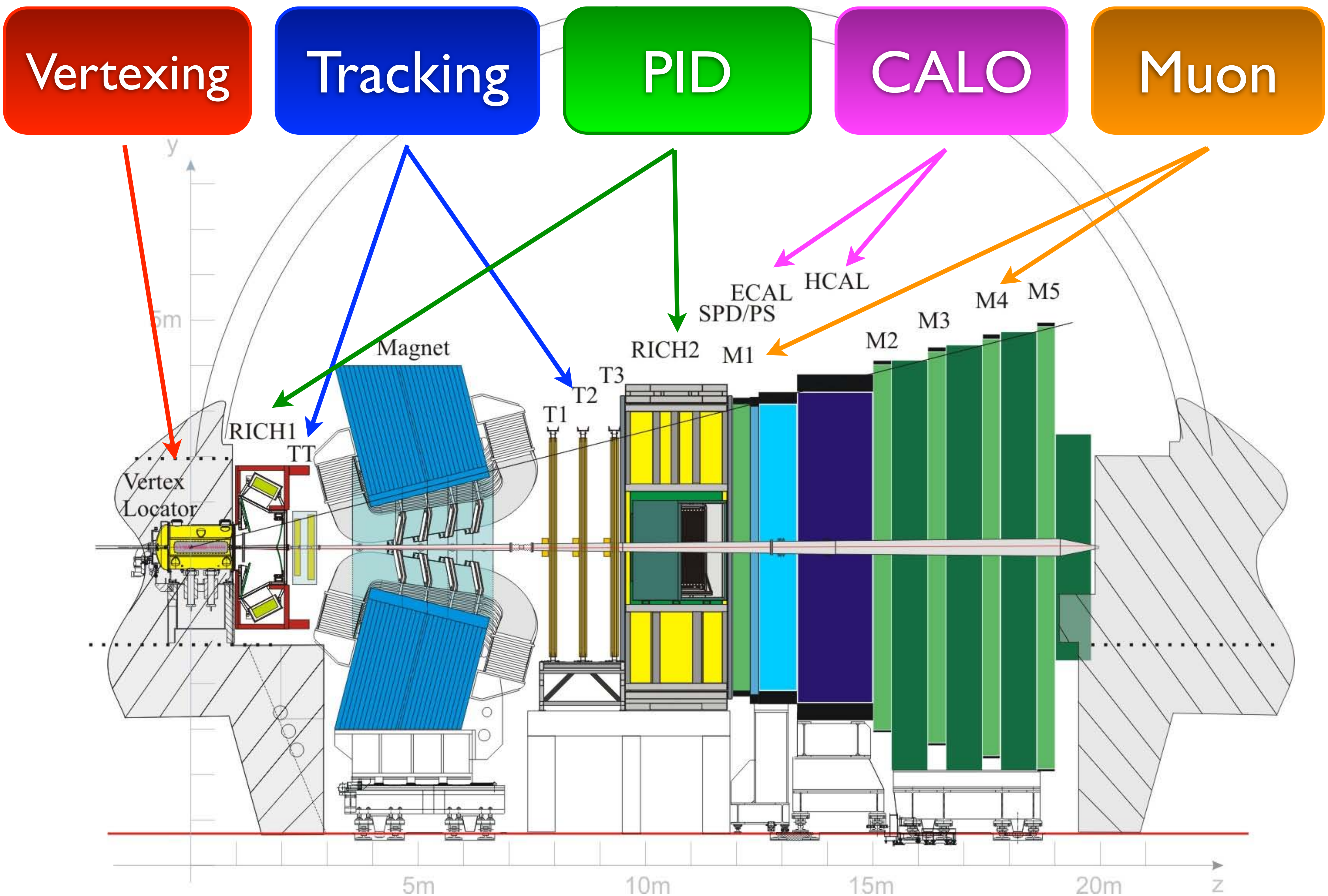






EFF size	5×2011	10×2011
LLT-rate (MHz)	5.1	10.5
HLT1-rate (kHz)	270	570
HLT2-rate (kHz)	16	26
Total signal efficiency		
$B_s \to \phi\phi$	0.29	0.50
$B^0 \to K^*\mu\mu$	0.75	0.85
$B_s \to \phi\gamma$	0.43	0.53

The LHCb Detector

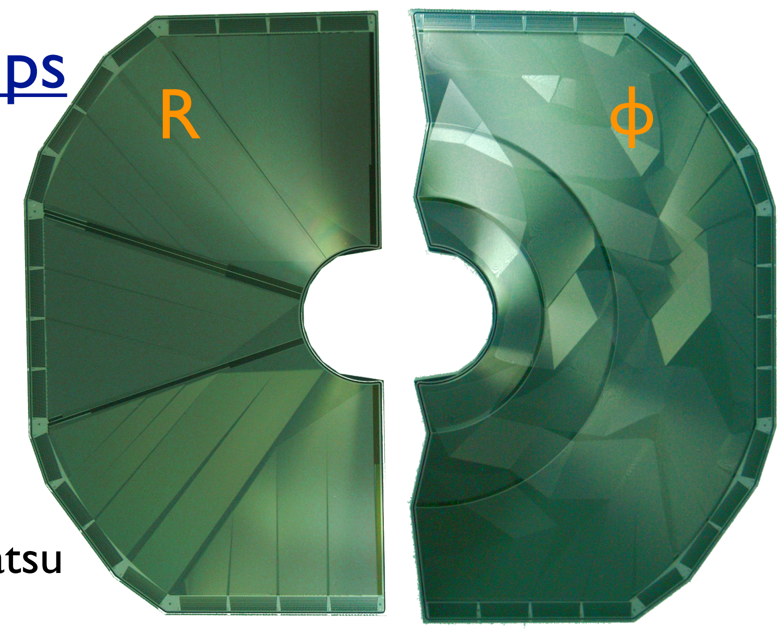


VELO Upgrade

- Modules need to be redesigned to cope with 40MHz readout and high irradiation
- Requirements:
  - stand increased irradiation (up to $0.3\times10^{16} n_{eq} cm^{-2}$)
  - enhanced cooling
  - improve IP resolution: first measured point as close as possible to IR, reduce material budget
- Options:
  A. Pixel, VELOPIX readout chip
  B. Strips

more channels to reduce occupancy

B. Strips

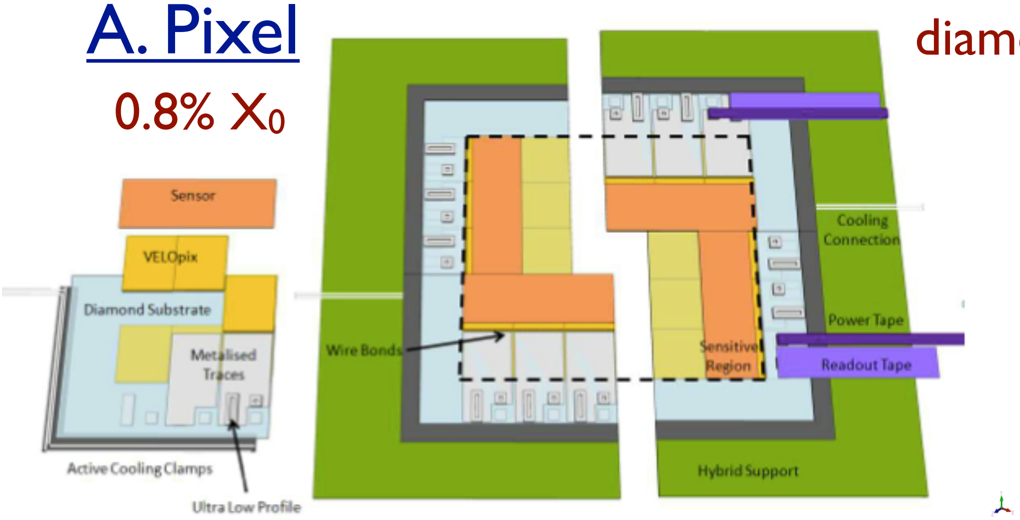


Hamamatsu

reduced radius of first measured point
SALT readout chip, common to ST

A. Pixel

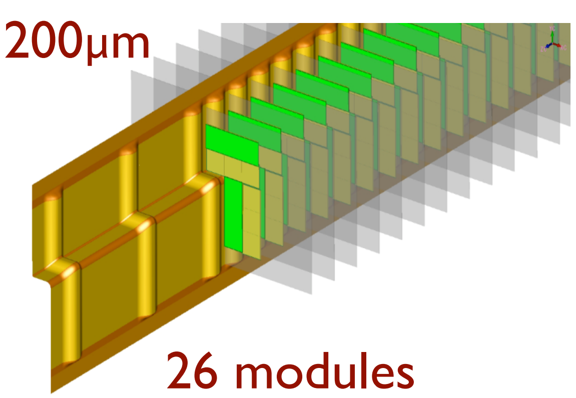
0.8% X_0



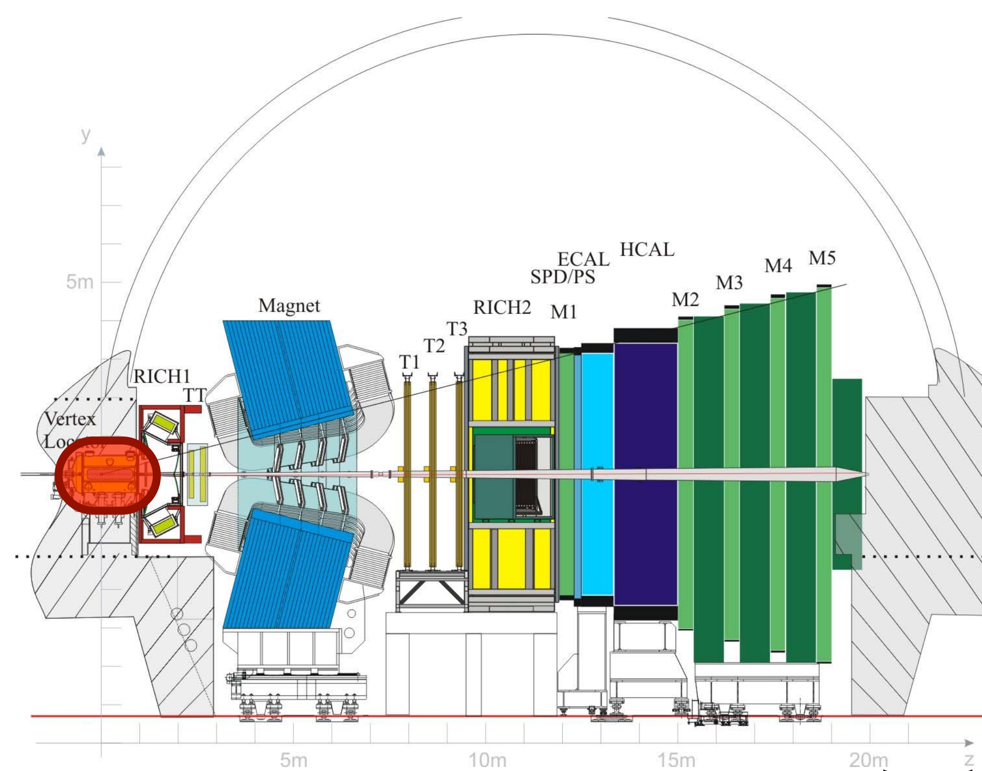
sensor: (55µm x 55µm) x (256 x 256)

diamond substrate cooling

200µm

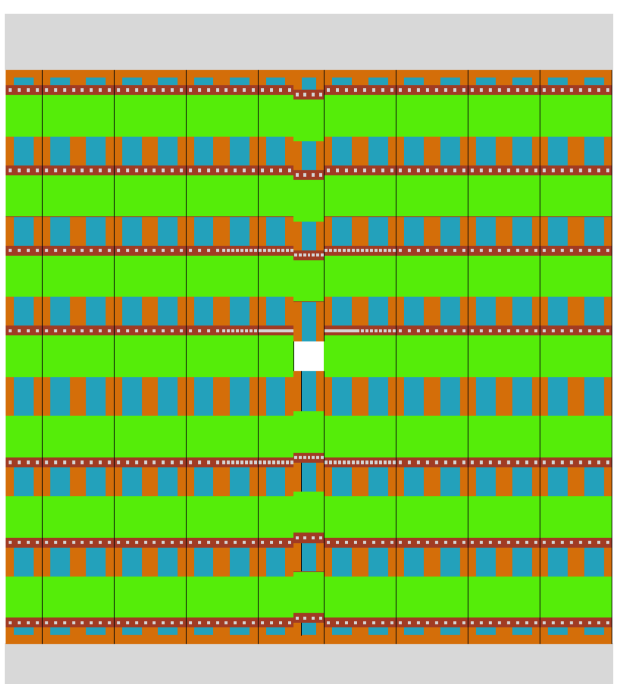


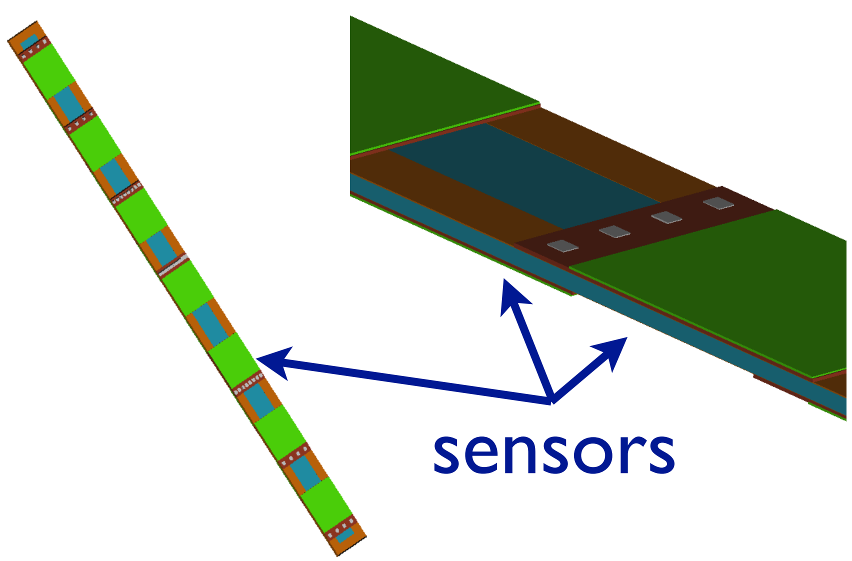
26 modules

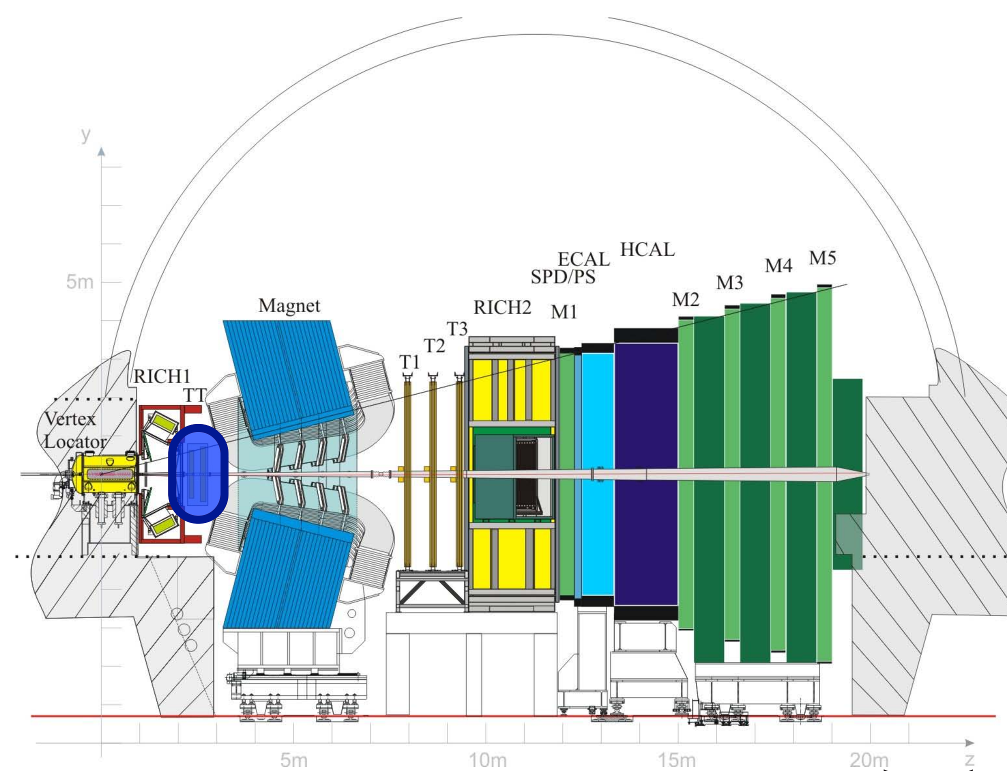


Tracking Stations Upgrade

- In LHCb one tracking detector (TT) before the magnet and three stations after (IT/OT)
- Larger occupancy → more ghosts
- Tracking algorithms are still able to remove a large quantity of ghosts, but a larger inner coverage for TT is needed
- Less material budget → decrease momentum error







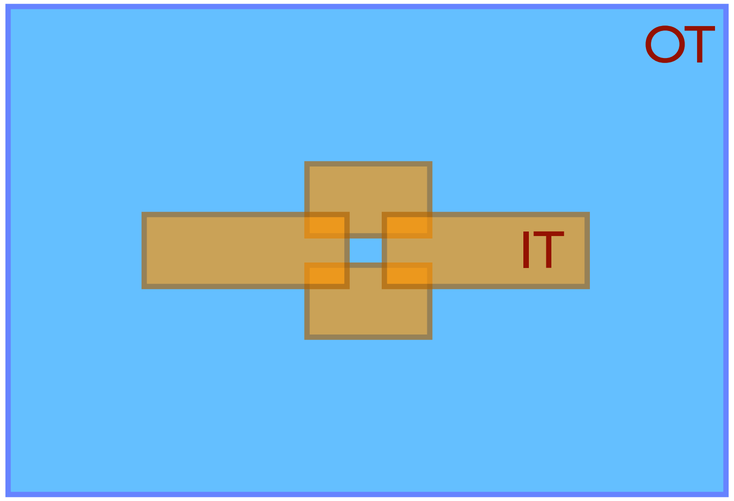
Tracking Stations Upgrade

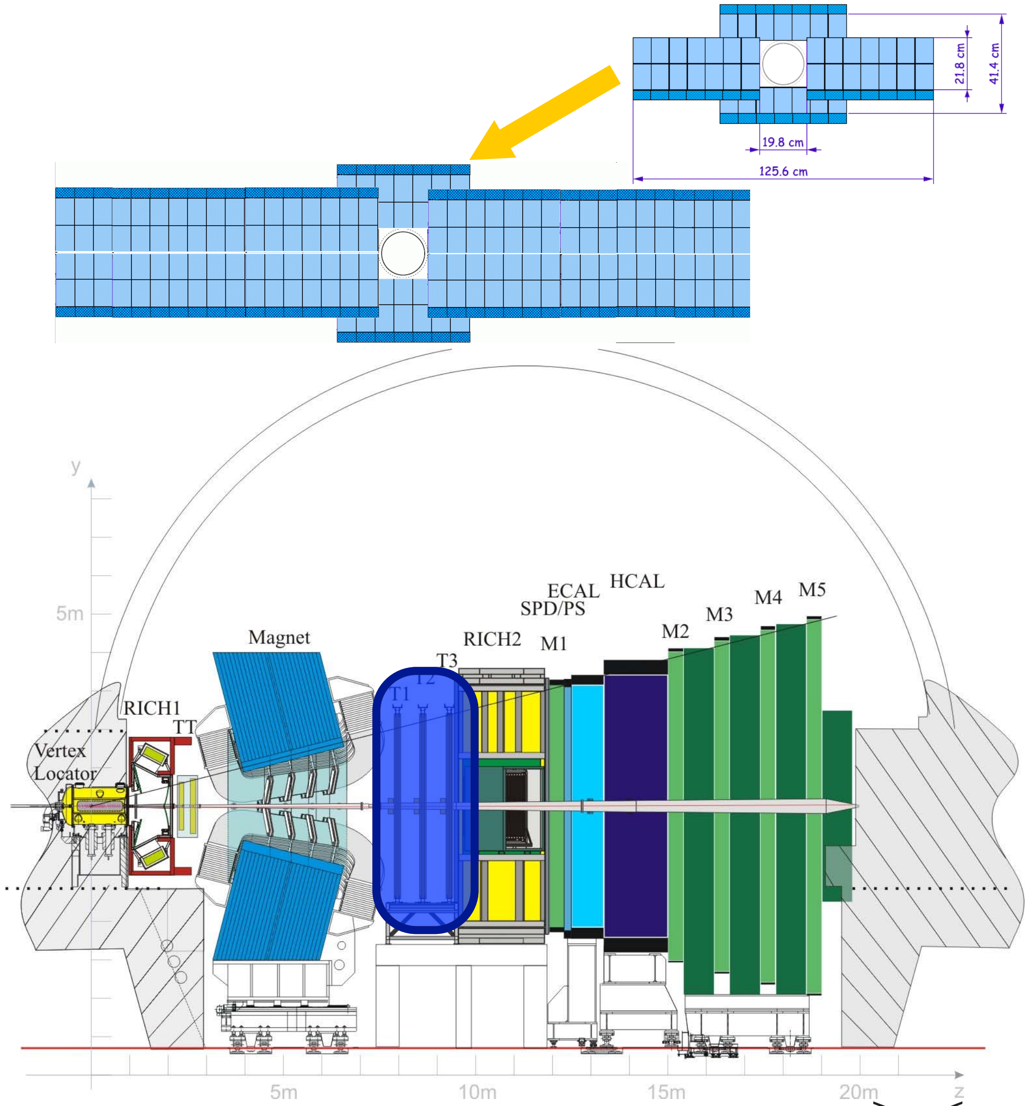
- Two solutions for downstream trackers:

  1. Enlarged, thinner and lighter IT
     - reduce occupancy in OT by 20%
     - reduce spill-over in OT

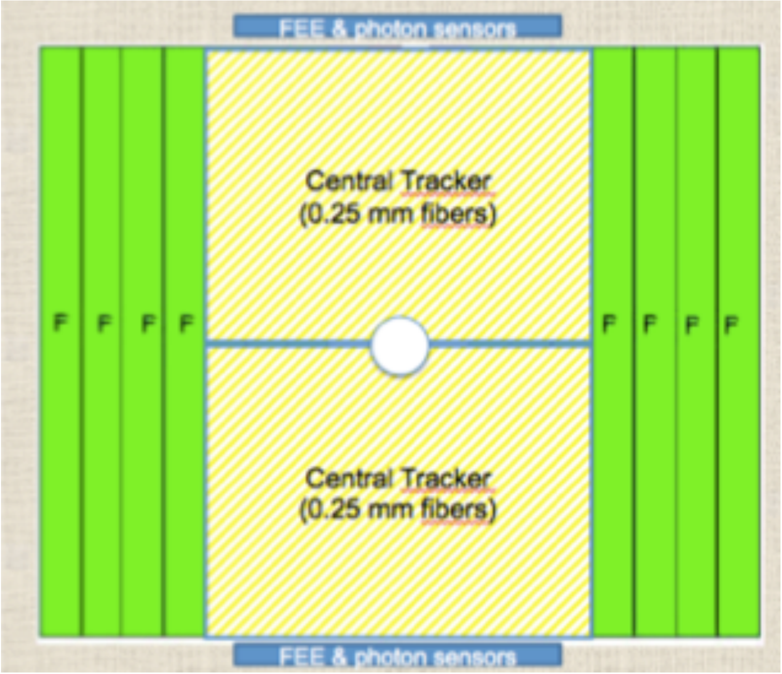
  2. Fiber Tracker+straw tubes
     - less material in central region
     - readout with silicon Photo Multipliers

1.



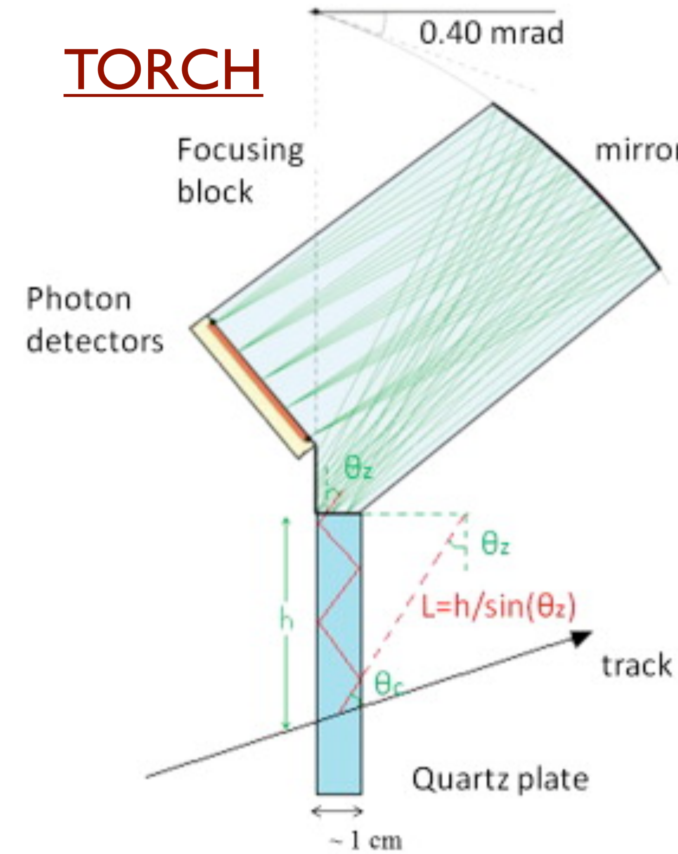


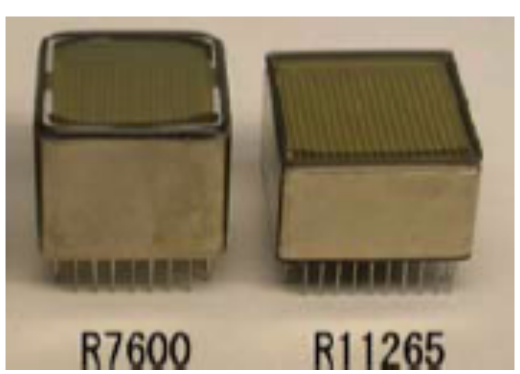
2.

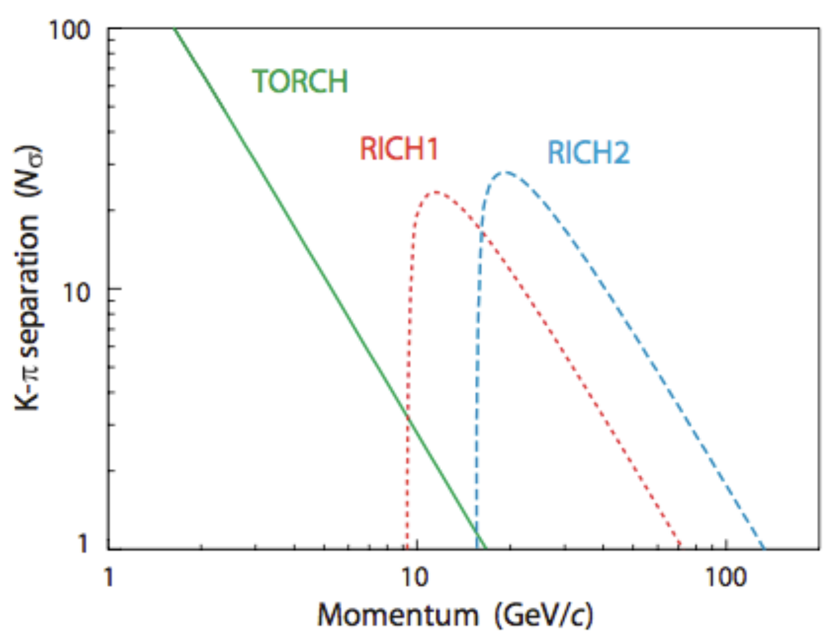


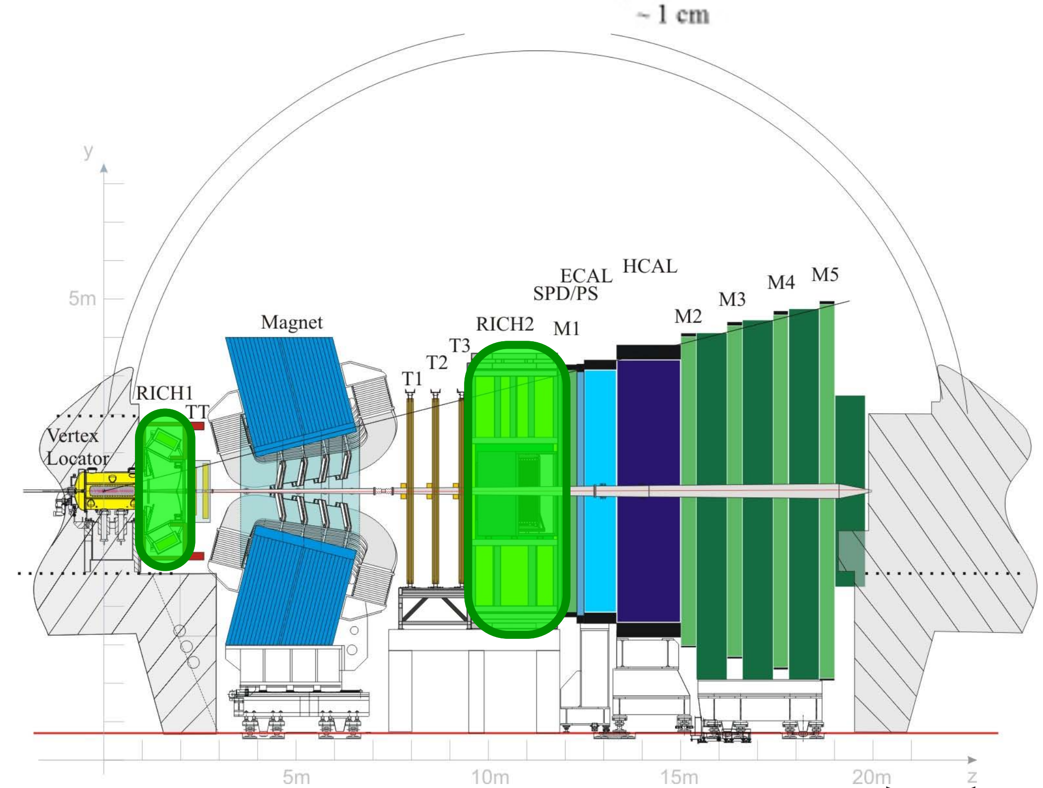
Particle ID

- Current RICH:
  - RICH1 aerogel + C_4F_{10}
  - RICH2 CF_4
- Upgrade:
  - increased occupancy→remove aerogel
  - Hybrid Photo Detectors readout not sufficient →replace with MultianodePMT (R11265)
- Under Study (R&D):
  - add TORCH (1-10GeV/c)
  - optimize RICH geometry





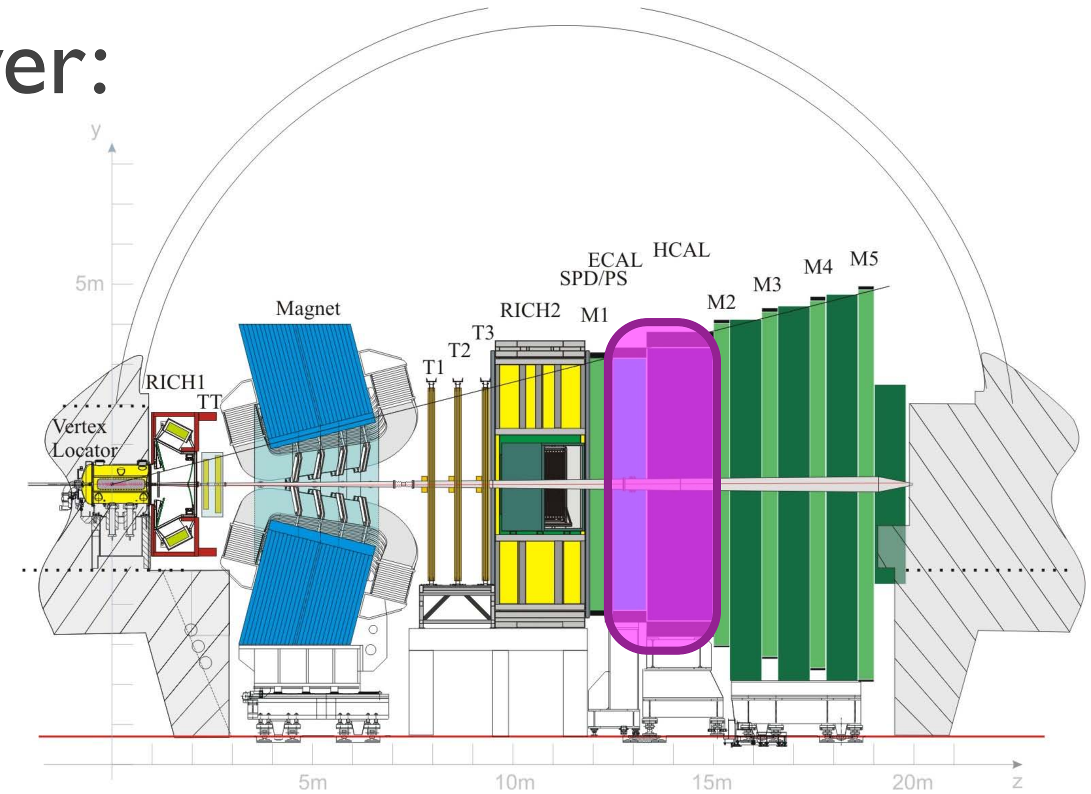




Calorimeter

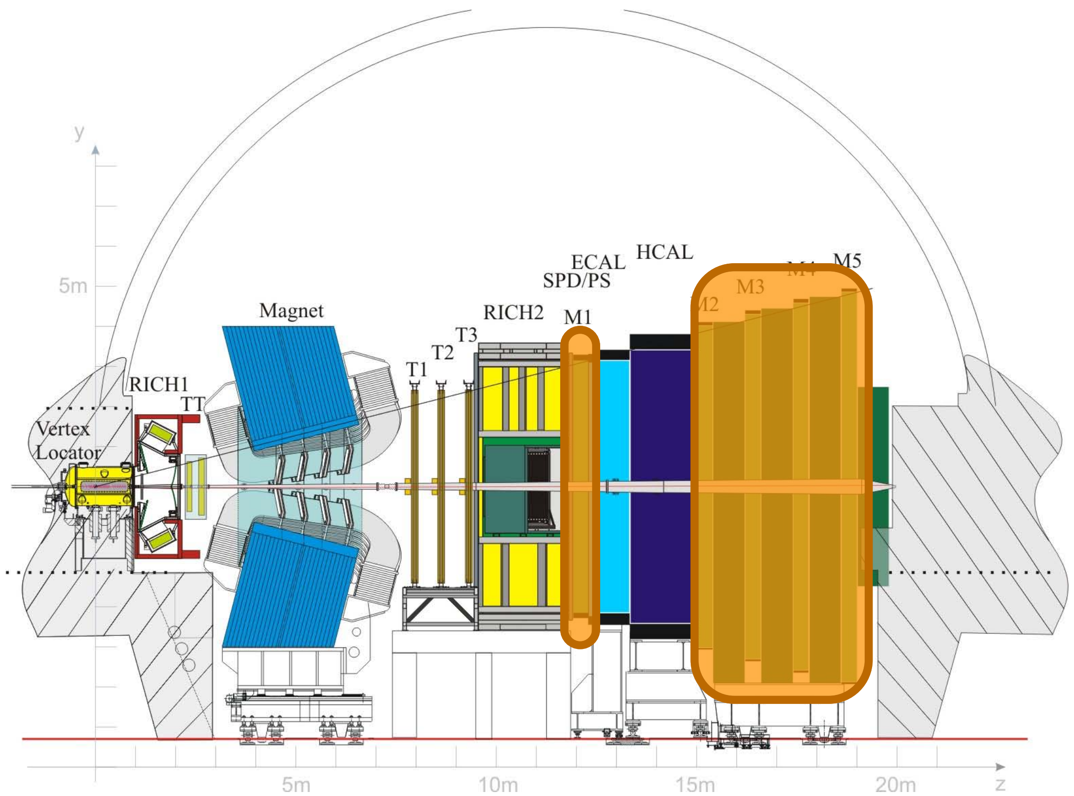
- ECAL and HCAL:
  - keep detector modules and PMTs → can withstand radiation
  - reduce PMT gain → keep anode current constant at higher occupancy, compensated with increased FE amplification
  - modify electronics to 40MHz FE readout

- Scintillating Pad Detector & PreShower:
  - remove them
  → Trigger does not need them
  - under study how much e/γ id affected



Muon

- Muon chambers (MWPC) and Front End almost meet upgrade requirements
  - keep the chambers
  - modify readout electronics
  - remove first station
- Studies ongoing
  - high occupancy performance
  - aging of chambers
- R&D
  - replace with GEMs



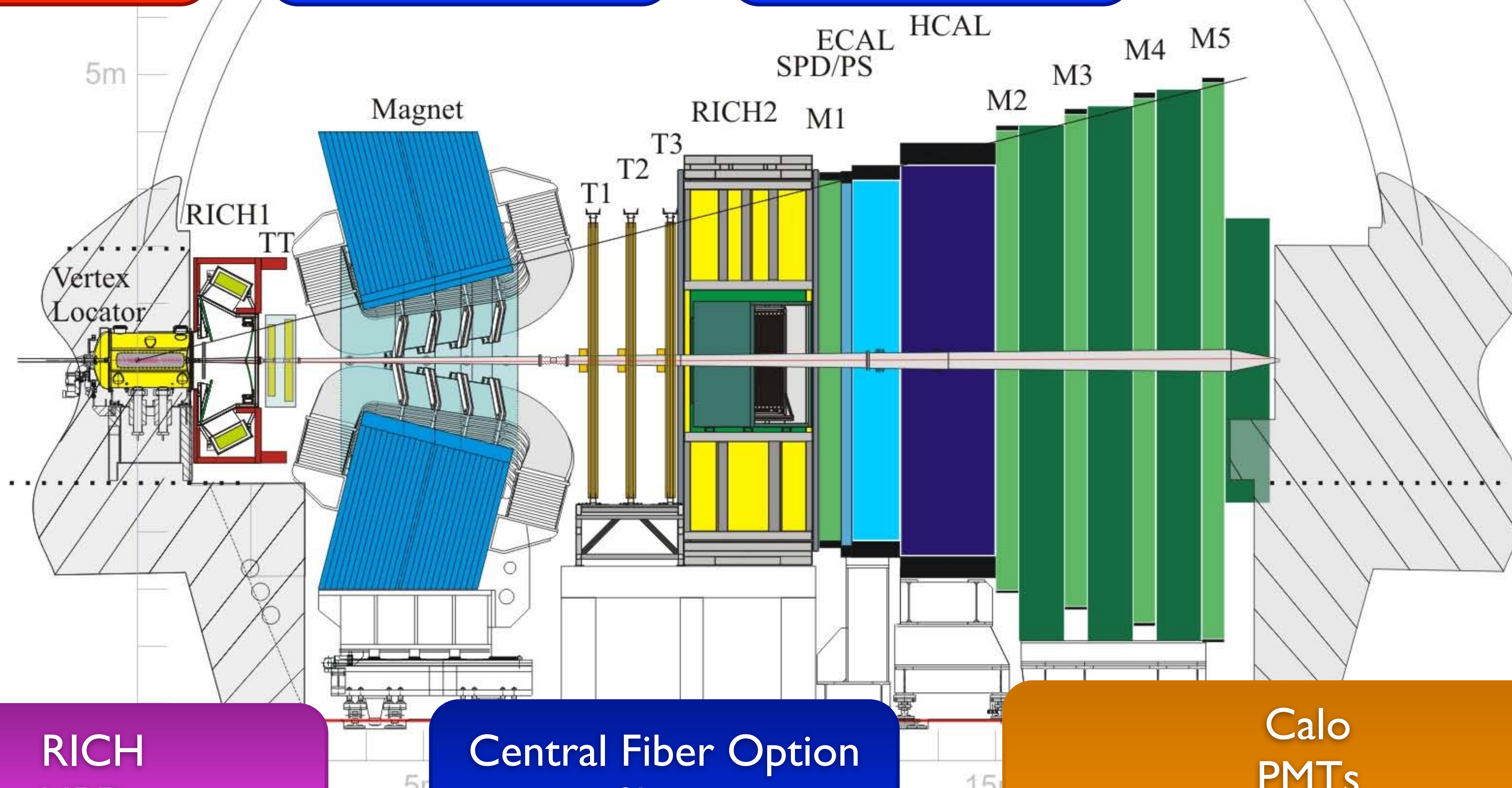
Detector Changes

VELO
Si strips
Replace all

Silicon Tracker
Si strips
Replace all

Outer Tracker
straw tubes
Replace R/O

MUON
almost compatible



RICH
HPDs
Replace HPD, R/O

Central Fiber Option
fibers
New design and R/O

Calo
PMTs
Reduce PMT gain,
Replace R/O

Conclusions

- LHCb is performing very well in difficult conditions:
  - luminosity per crossing = 4x design
  - detectors over 99% operational
  - vertex and momentum resolution as expected
- Already produced outstanding Physics results
  - $B^0_s \to \mu^+\mu^-$
  - ϕ_s from $B^0_s \to J/\psi\phi$
  - $B^0 \to K^*\mu^+\mu^-$
  - mixing and CP measurements in Charm
- Upgrade studies and simulations show feasibility of the proposed solutions to meet the requirements
  - 40MHz read out from all detectors
  - Full software trigger with 2x efficiency for hadronic modes
  - Retain key LHCb performance parameters: vertex/momentum resolution, particle id, tracking reconstruction efficiency
- Installation will start in 2018
- Starting 2019, LHCb upgrade will allow to search for NP at 1% level and test SM with best precision ever