LHCb at High Luminosity: implications

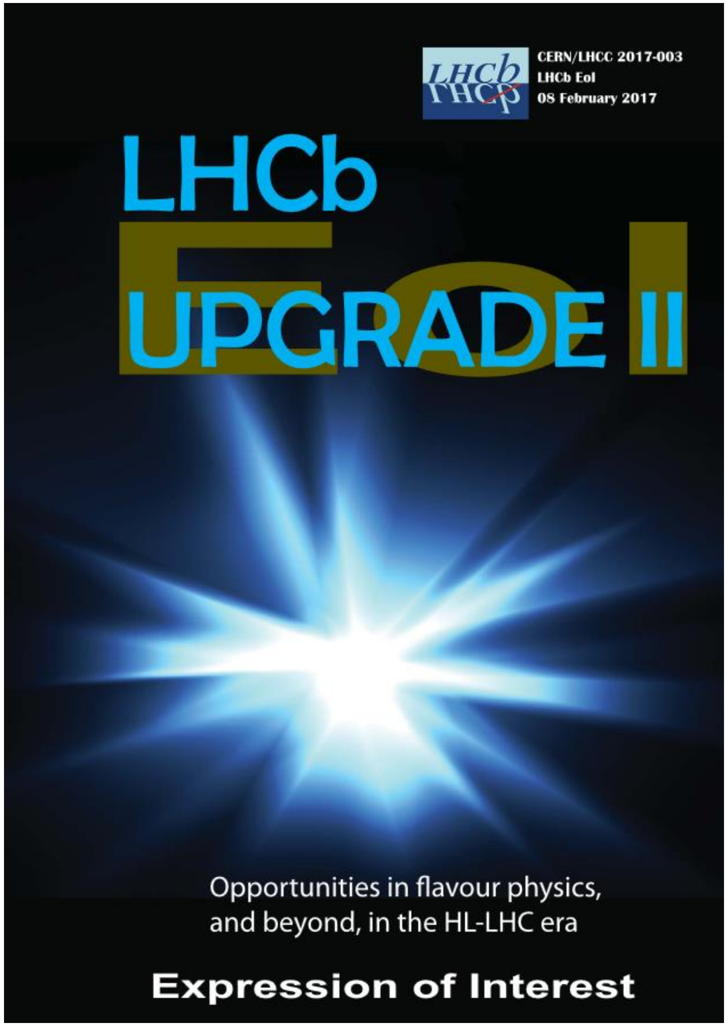
HL-LHC Collaboration meeting 16-10-2018, CERN

- The LHCb Upgrade II
- Implication for detectors
- Implication for Beam

LHCb Upgrade II (Physics)

CERN/LHCC-2017-004
LHCC-129
February 2017

- The **LHCC notes** the submission of the EoI for LHCb upgrades beyond Phase-I, and **encourages** LHCb to pursue the physics studies and collaboration with the LHC experts to motivate these upgrades with a solid physics case, taking into account the expected results from LHCb Phase-I and Belle II, and establish feasible running conditions that do not interfere with other LHC experiments. The **LHCC urges** the LHCb management to ensure that these activities have no impact on the on-going Phase-I upgrades, which must take priority.



Physics case: **LHCb-PUB-2018-009**

HL-LHC machine study: **CERN-ACC-NOTE-2018-0038** (see next talk)

LHCb Upgrade II (Physics)

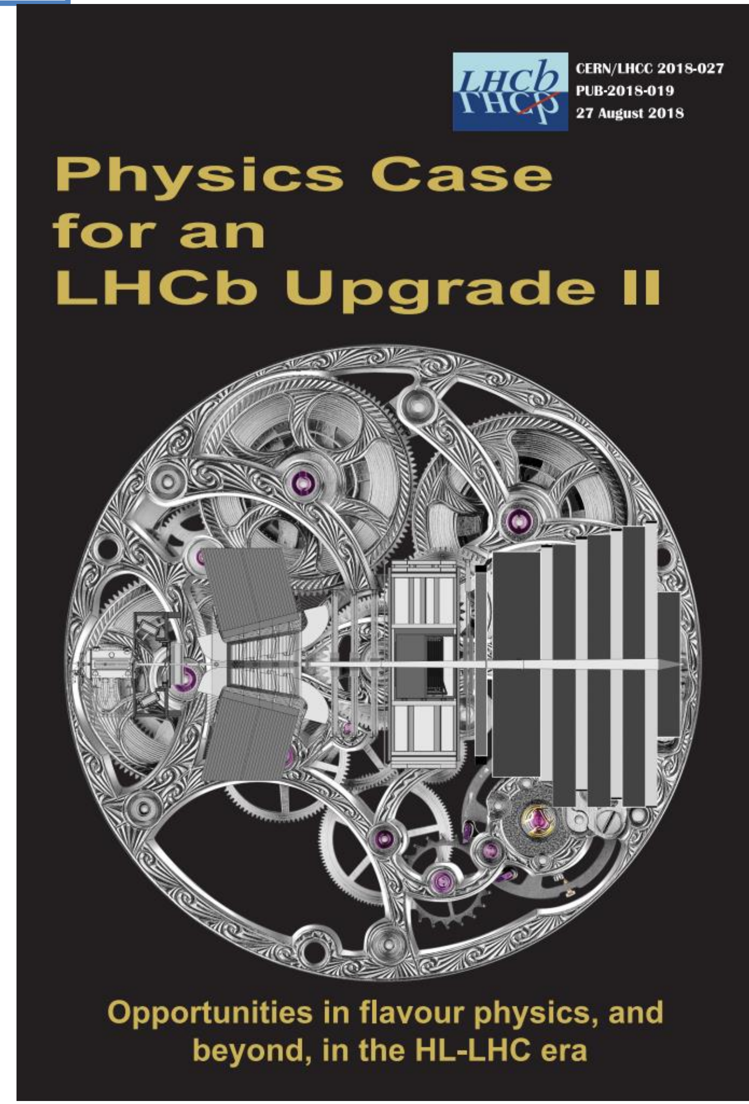
Strong Physics case:

CP – CKM matrix
Many key flavour observables will still not have been measured with the 'ultimate' precision.

Rare or Forbidden decays, lepton universality
Statistics needed to confirm existing/find new anomalies/disentangle NP scenario

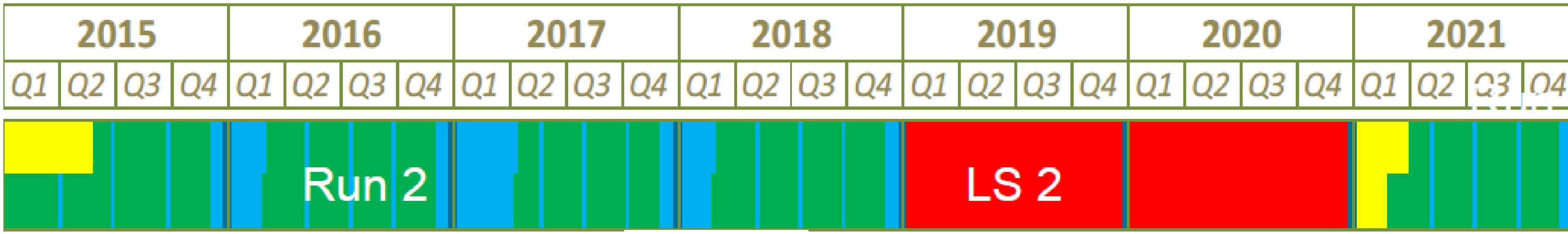
Beyond Flavour Physics
- Exotic Hadrons and spectroscopy
- Electroweak physics, e.g. $A_{FB}(qqbar \rightarrow \mu\mu)$ & $\sin^2\theta_W$
- Forward top and Higgs physics

Heavy ions, Fixed Target, Long Lived
....



LHCC encourages us to proceed towards TDRs

LHCb Upgrade 1



Current LHCb

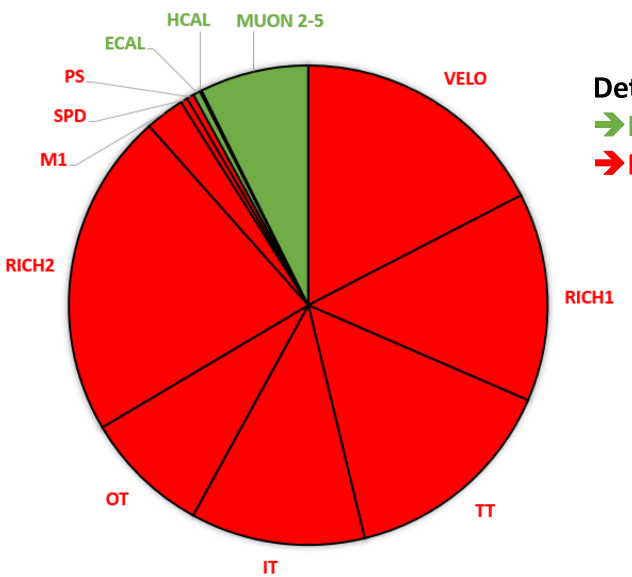
Lumi 4×10^{32} cm^{-2} s^{-1}

LHCb Upgrade Ia

- **Lumi x 5**
- **40 MHz readout**

Upgrade 1a

Lumi 2×10^{33} cm^{-2} s^{-1}



Detector Channels
→ Re-used
→ New for Upgrade 1

Less than 10% of LHCb detector channels will be kept

+ 100% NEW R/O electronics
+ NEW DAQ system

UPGRADE 1a and 1b

Upgrade 1a

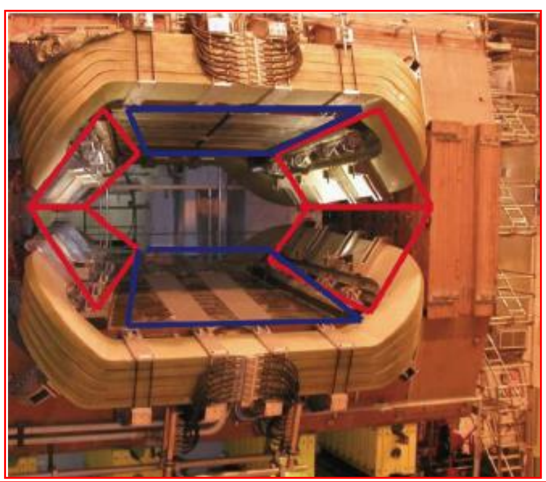
Lumi 2 x 10^{33} cm^{-2} s^{-1}

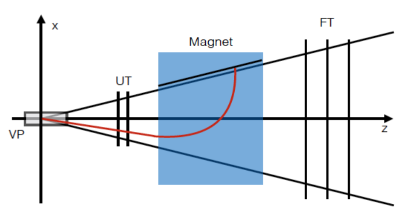
- **Consolidation**
- **Detector improvements**

Upgrade 1b

Lumi: NO CHANGE

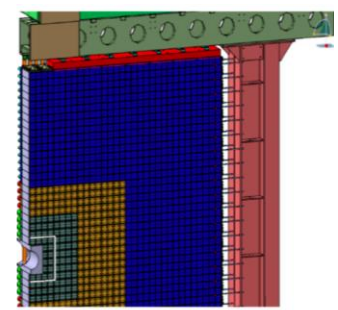
For Example:
Improve LHCb performance and physics acceptance by adding tracking station inside magnet

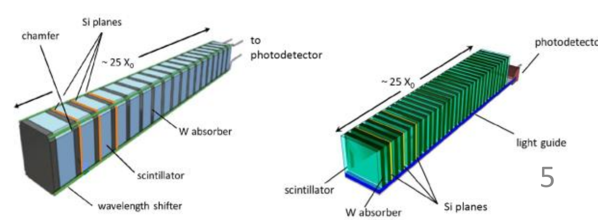




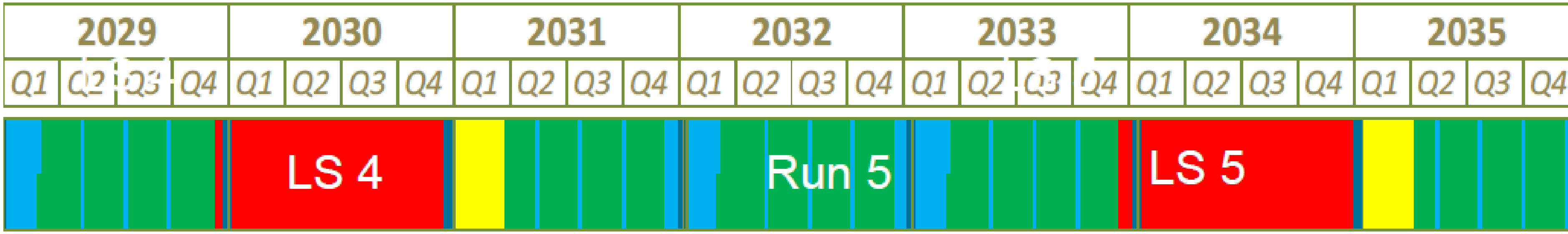
channel	gain
$D^* \to D\,(\pi K)$	21%
$\Lambda_b \to \Lambda_c^* \tau\nu$	60%
$B \to D^* \tau\nu$	26%
$\sum_b \to \Lambda_b \pi$	29%

Innermost part of ECAL shall be replaced in LS3 due to radiation damage. Replace by more performant technology, incl. timing





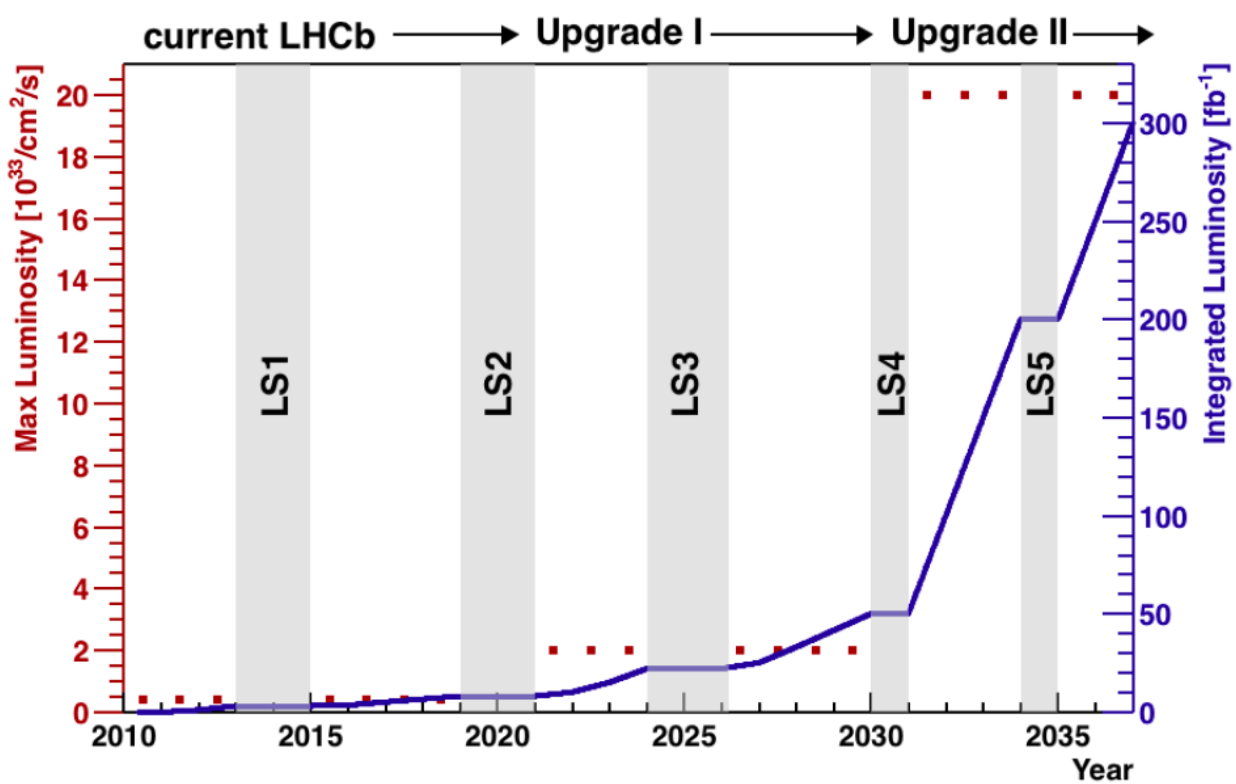
Upgrade II



LHCb Upgrade II
Enable full exploitation of flavor potential of LHC
→Modify key detector elements

Lumi 1-2 x 10^{34} cm^{-2} s^{-1}
→Aim for **>300 fb^{-1}** integrated lumi

The way to 300fb^{-1}



LHCb Upgrade II: Implications for Detector

DETECTORS CHALLENGES

x10 particle multiplicity

Higher granularity – smaller pixels

x10 vertex multiplicity

timing

x10 radiation damage

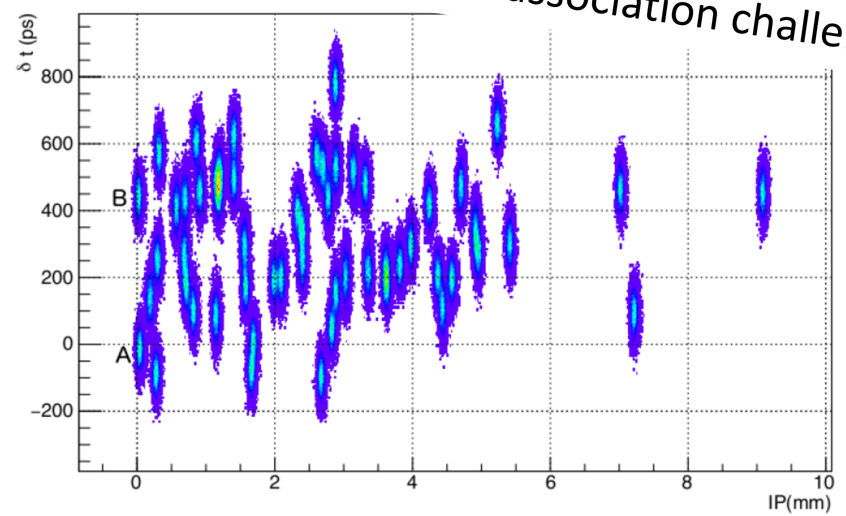
Novel rad-hard sensors replacement

R&D started

LHCb Upgrade II: Implications for Detector

Vertex

PV association challenge



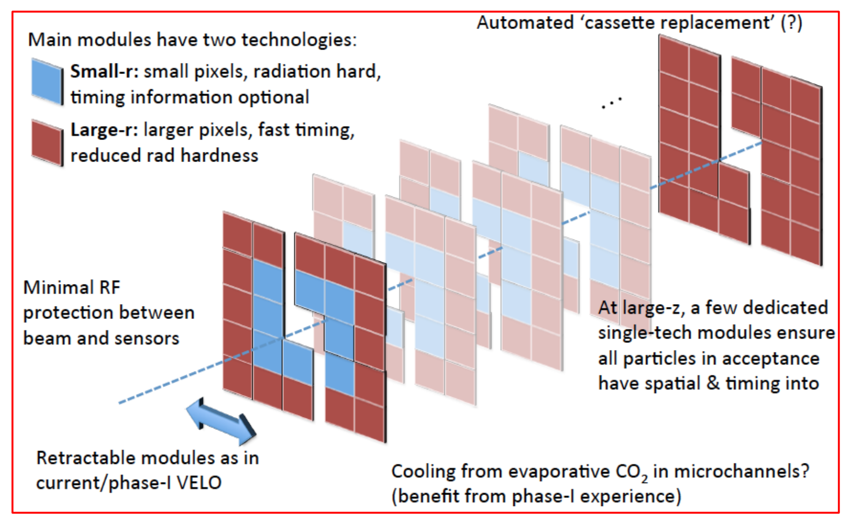
Challenges:

- Increase of Pile-up
- Radiation Hardness

Solution

- Timing
- Rad hard sensors
- Detector replacement

A possible solution being considered is to have a 'mixed' solution where the inner region has a smaller pitch (emphasising space resolution) and the outer region has a larger pitch emphasising more precise timing

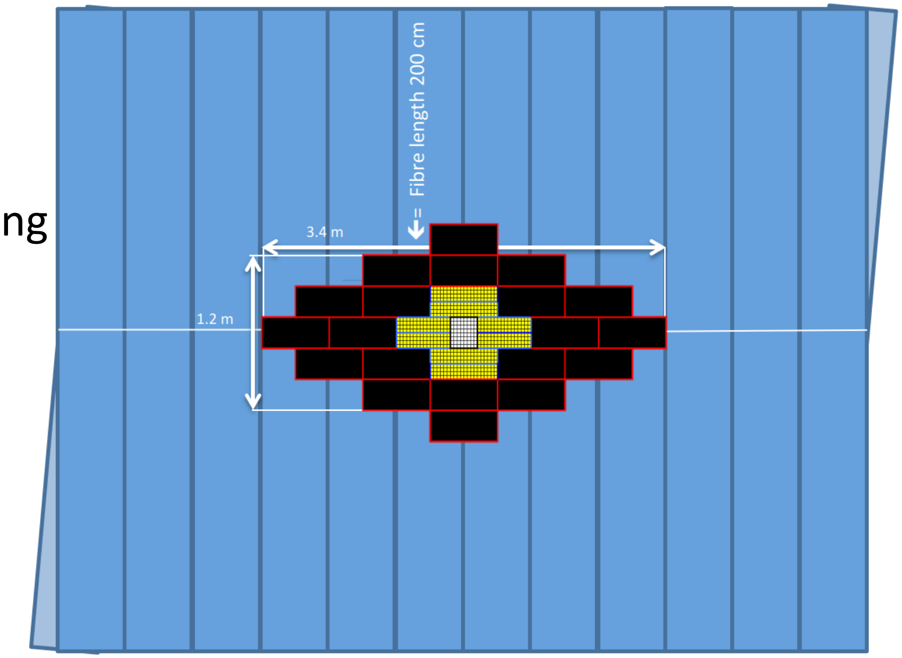


LHCb Upgrade II: Implications for Detector

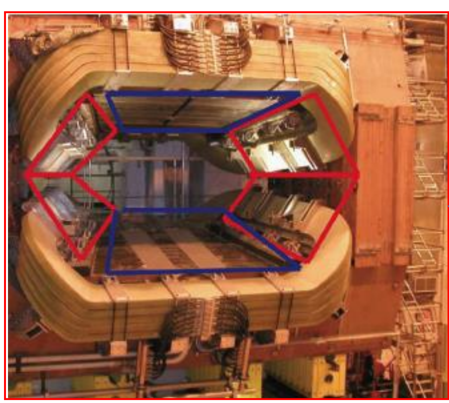
Tracking

Challenges
- High occupancy
- Upstream-downstream track matching

Solutions
- High granularity
- Optimization of Upstream Tracker
- Minimize material
- Add timing information



Hybrid solution being envisaged:
Scintillating fibres tracker – external part
Silicon Inner/Middle Tracker (using CMOS)– inner part



The magnet chambers to be installed in LS3 (Scintillating fibres) will be Upgrade II compatible

LHCb Upgrade II: Implications for Detector

PID

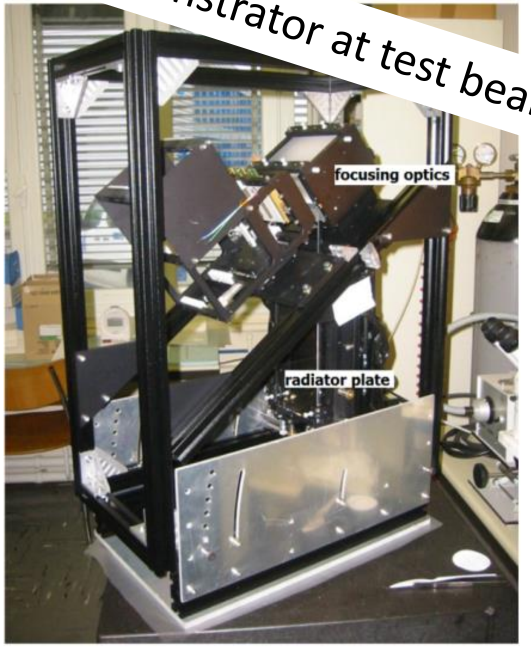
2 RICHs , same footprint as now
Challenges:
- Higher occupancy

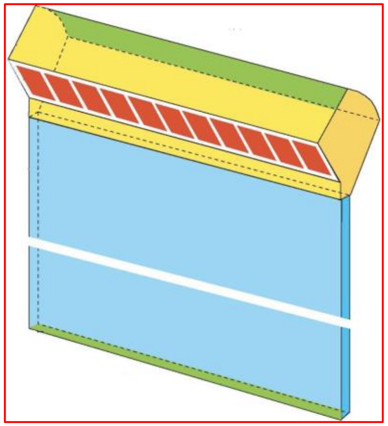
Solution:
- Replace MaPMT by e.g SiPM
- Modify optics (improve Cerenkov angle resolution)
- Add timing

TORCH (between RICH2 and ECAL)
Time-**O**f-flight through detecting internally **R**eflected **CH**erenkov light.

Low momentum PID by TOF measurement
Radiator: quartz
Photon detectors: MCP

Torch demonstrator at test beam



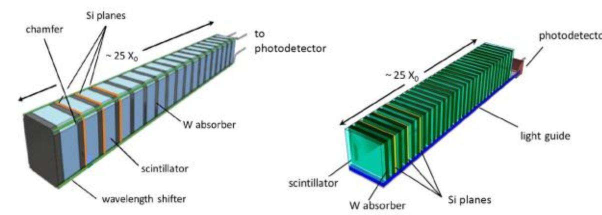


CALO

LHCb Upgrade II: Implications for Detector

Challenges:

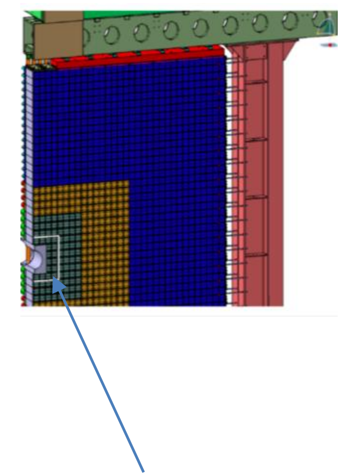
- High radiation (200 Mrad for innermost modules)
- Overlapping showers, degradation of resolution and shower finding efficiency



Solutions:

- Reduce the Moliere Radius, smaller cell size in the inner ECAL
- Timing shall be introduce to reduce combinatorial background   (eg. π^0 reconstruction)
- Access longitudinal shower information

- Vigorous R&D program ongoing including sampling calorimeter (*Shashilk, SPACAL*) with Tungsten alloy as converter, including crystal for timing … Timing could also be provided by preshower layer involving silicon pad.
- Granularity, technology can be combined as long as they group into module of uniform dimension (12 x 12 cm^2)



Innermost part of the ECAL, to be replaced in LS3 because of radiation damage

LHCb Upgrade II: Implications for Detector

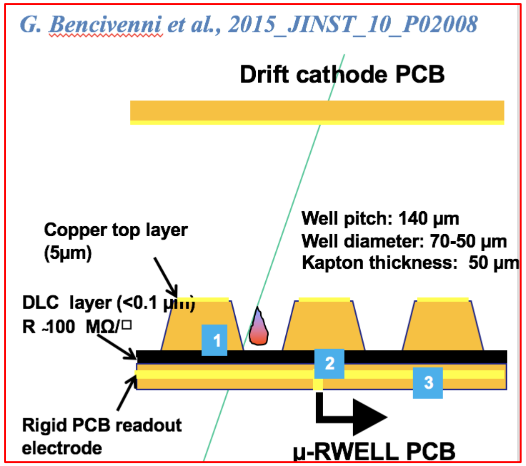
MUON

Challenges:

- high occupancy would lead to degraded performance of the Upgrade I detector (dead time inefficiency)
- Ghost hits from background

Solutions:

- Replace HCAL (used only for trigger) by 1.7m of iron shield.
- μ-RWELL detector, MPGD: GEM foil embedded with the PCB coated with resistive layer. Expect to give good time and space resolution and to be rad hard



LHCb Upgrade II: Implications for beams

Parameter	Unit	Lumi Scenario						
Target Leveled Lumi	$10^{34} cm^{-2} s^{-1}$	**0.2**	**1.0**			**2.0**		
β*	m	3.0	1.5					
Crossing Plane		H	H		V	H		V
Magnet Polarity		$-$	$-$	$+$	$\pm$	$-$	$+$	$\pm$
External x-ing angle	μrad	500	400	300	320	400	300	320
Full x-ing angle at IP	μrad	230	130	570	419	130	570	419
Virtual (Peak) Luminosity	$10^{34} cm^{-2} s^{-1}$	1.07	2.16	1.57	1.79	2.16	1.57	1.79
Leveled pile-up	1	5.6	28	28	28	56	44.2	50.3
RMS luminous region (start)	mm	52.2	52.7	39.5	44.7	52.7	39.5	44.7
Peak line Pile-up density (start)	mm^{-1}	0.04	0.20	0.28	0.25	0.41	0.44	0.44
eff. line Pile-up density (start)	mm^{-1}	0.03	0.13	0.17	0.15	0.20	0.20	0.20
Fill duration	h	8.5	8.0	8.0	8.0	7.7	8.0	7.9
leveling time	h	>8.5	4.7	3.1	3.6	0.6	0	0
Yearly integ. lumi. at IP8	fb^{-1}/y	10.7	**46.3**	**40.9**	**42.5**	**61.7**	**46.2**	**51.0**
Yearly integ. lumi. at IP1/5	fb^{-1}/y	261.5	257.1	257.7	257.5	255.1	257.0	256.4

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- A range of potential solution exist to run IP8 up to 2 x 10^{34} and collect 300 fb^{-1} over HL-LHC expected life time
- Limited impact (<3%) on IP1/5, considering p burn-off only.
- More studies are needed to converge to a final design

Luminosity Scenarios and B polarity flip

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Magnet Polarity		−	−	+	±	−	+	±
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CERN-ACC-NOTE-2018-0038

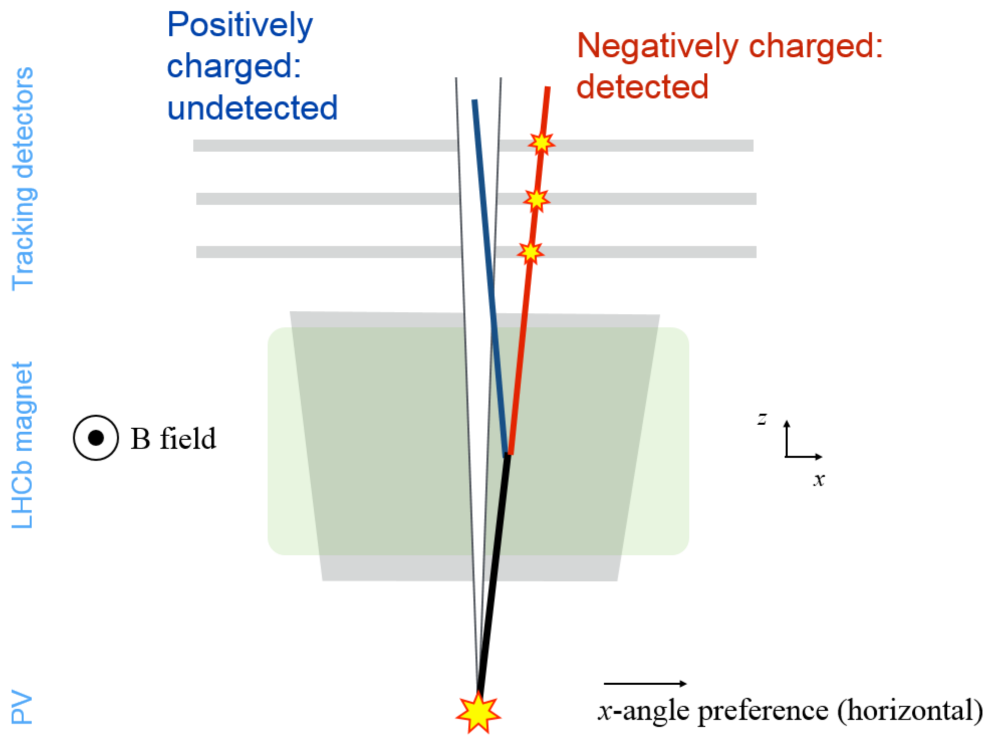
Experimental conditions changes with B polarity:

- Net crossing angle
- Pile-Up density
- IP RMS
- …

Given the increased statistical precision expected for Upgrade II, systematic errors shall be kept to minimum.

Beam parameters induced systematics

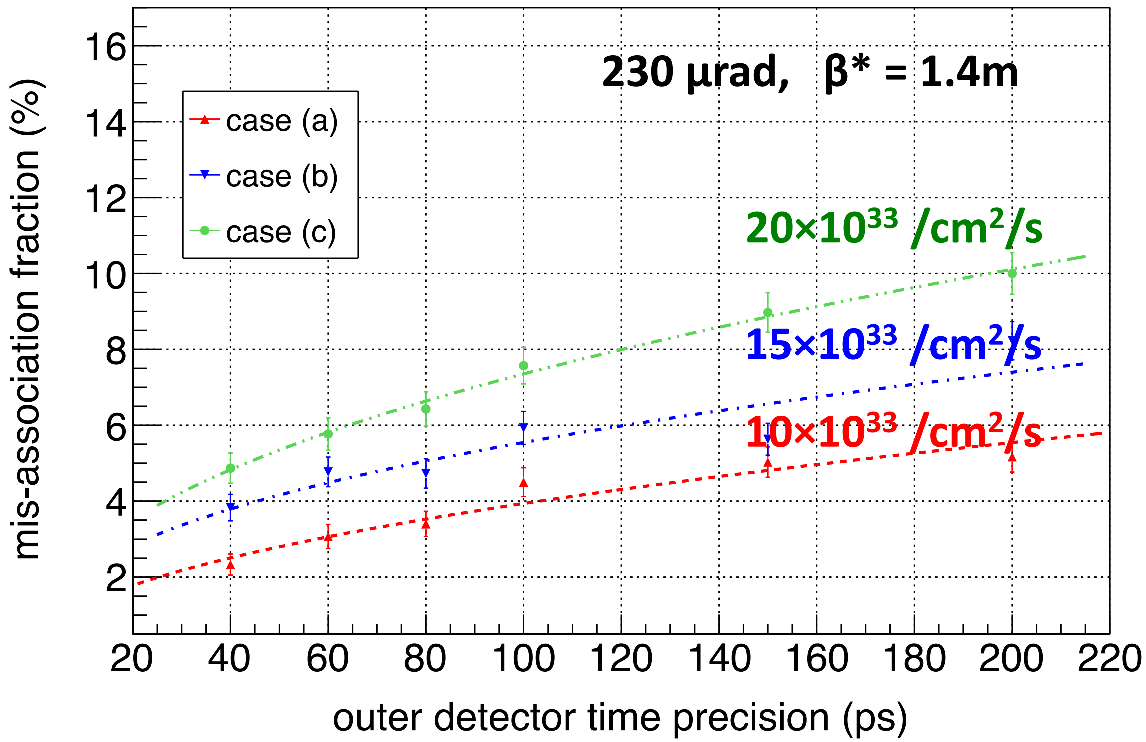
Acceptance - Crossing Angle



CROSING ANGLE should not change with B reversal
Otherwise experimental bias does not cancel!

Beam parameters induced systematics

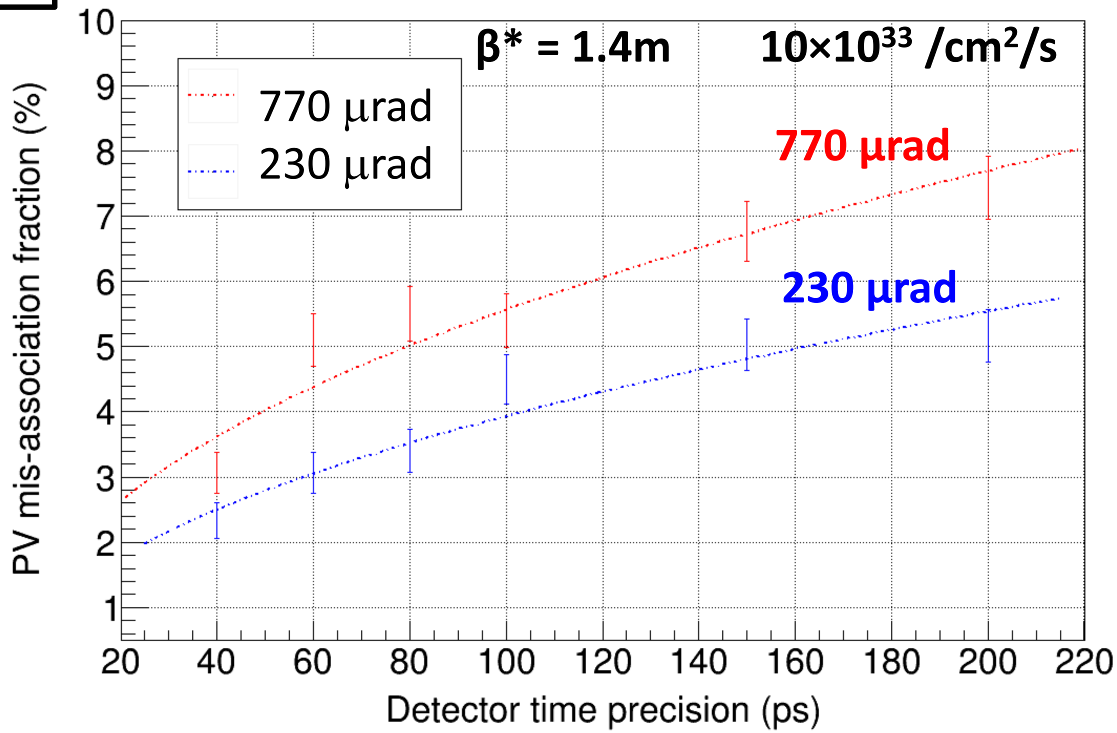
PV association - Luminosity



Change in **Pile-up density** leads to different performance (in terms of PV reconstruction, and PV-matching for long-lived particles)

Beam parameters induced systematics

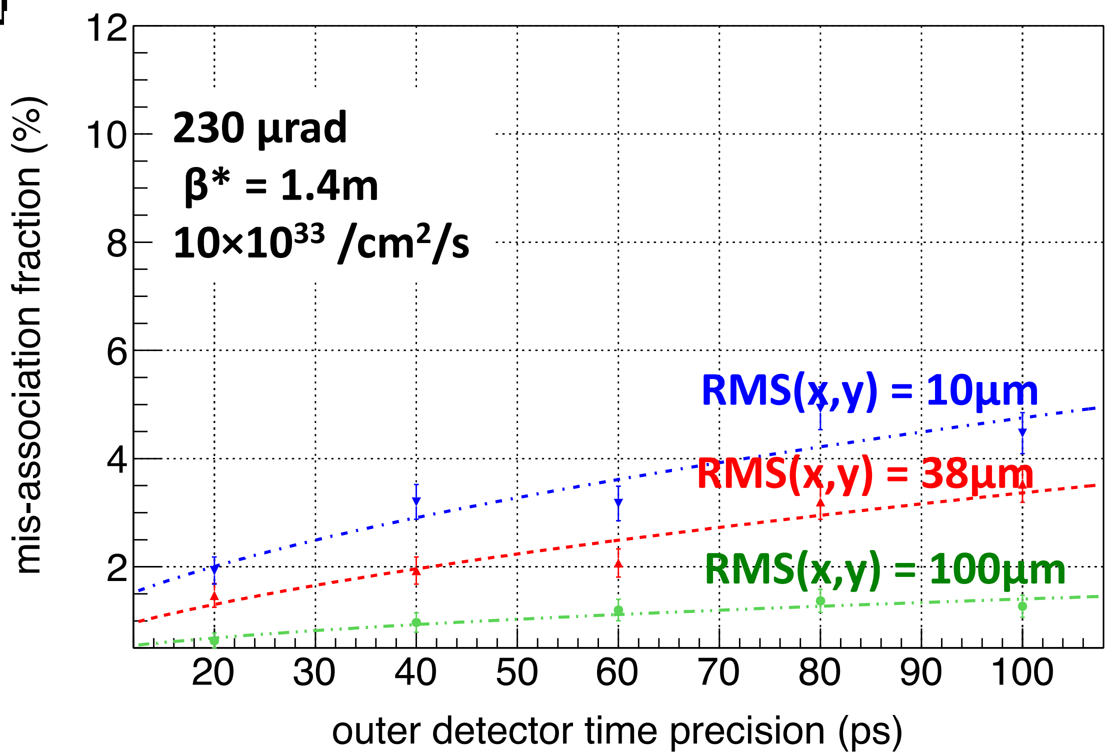
PV - Crossing Angle



Change in **crossing angles** leads to different performance (in terms of PV reconstruction, and PV-matching for long-lived particles)

Beam parameters induced systematics

PV - Transverse RMS



Change in **RMS of pile up region** leads to different performance (in terms of PV reconstruction, and PV-matching for long-lived particles)

SUMMARY

LHCb UPGRADE II is progressing well:

- Physics Case document issued
- Positive feedback from LHCC
- LHCb will proceed toward Framework TDR (tentatively Q4 2020)

Detector Requirements:

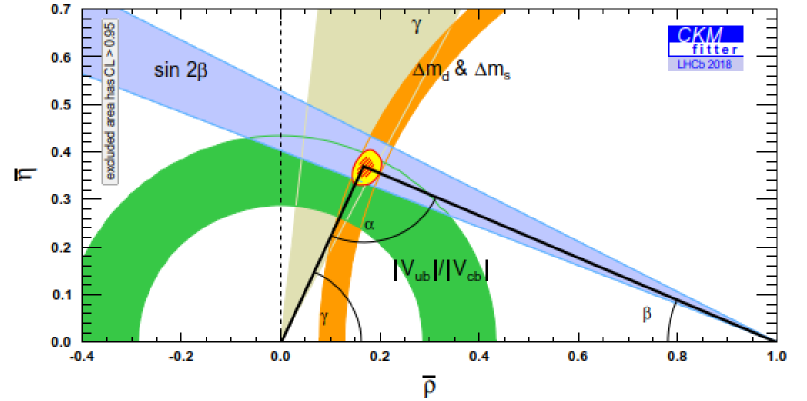
- Add timing
- Smaller granularity
- Radiation hardness

R&D in progress

Beam Requirements:

- Peak luminosity of 1-2 10^{34} Hz/cm^2
- Same crossing angle for both magnet polarities

Unitarity Triangle NOW



Unitarity Triangle post HL-LHC