Update of LHCb at High Luminosity

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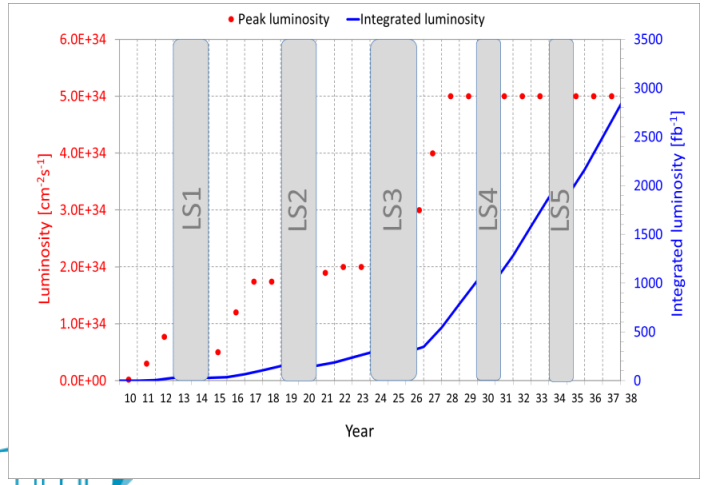
LHCb

	Run II	Run III	Run IV	Run V-VI
Duration [years]	3.5	3	3.5	5
L [10^{32} $cm^{-2}s^{-1}$]	4	<20	20	100-200
Int. L [fb^{-1}]	~8[1)]	?[3)]	50[2)]	300[2)]
Ppb [10^{11}]	1.1	1.1→2.2	2.2	2.2
Bunches in IP8	2036→ 2378	2572 or 2378	2572 or 2378	2572 or 2378
Emit [µm/γ]	2.8	2.8→2.1 2.5→1.7	2.1 or 1.7	2.1 or 1.7

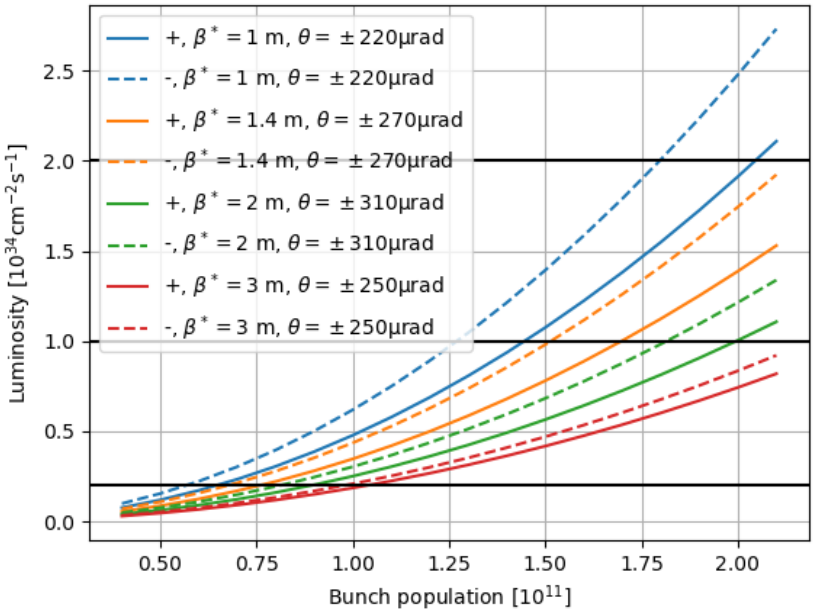


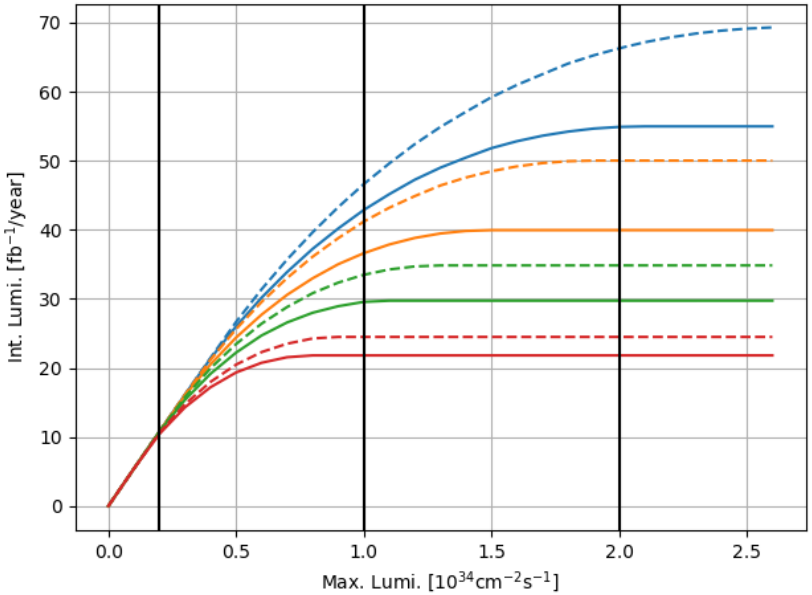
[1)]Assuming 5.8 fb^{-1} , 2 fb^{-1} in 2016 with 4 10^{32} $cm^{-2}s^{-1}$ and 2036 bunches, extrapolating to 2378 bunches and same efficiency.

[2)] target.

[3)] Scaling in Run IV gives 35 fb^{-1}, then target in Run III does not need strictly need higher levelled luminosity.

Peak and Integrated luminosity





Estimates for 2.5 µm/γ and 2378 colliding bunches based on scalings from a 250 fb $^{-1}$ fill for ATLAS and CMS.

Large impact of spectrometer polarity on luminosity.
Difficult to reach the final target of 300 fb $^{-1}$,
unless extending the target of Run IV beyond 50 fb $^{-1}$.

Aperture and crossing angle

- Horizontal crossing aperture limited by TCDDM (Beam 2) then triplet
- Vertical crossing aperture limited by triplet
- Crossing angle limited by orbit corrector strength to 310 µrad (with 20 µrad margin and repaired MCBY)
- Protected aperture 14.6 σ (best aperture for worst phase advance from MKD)

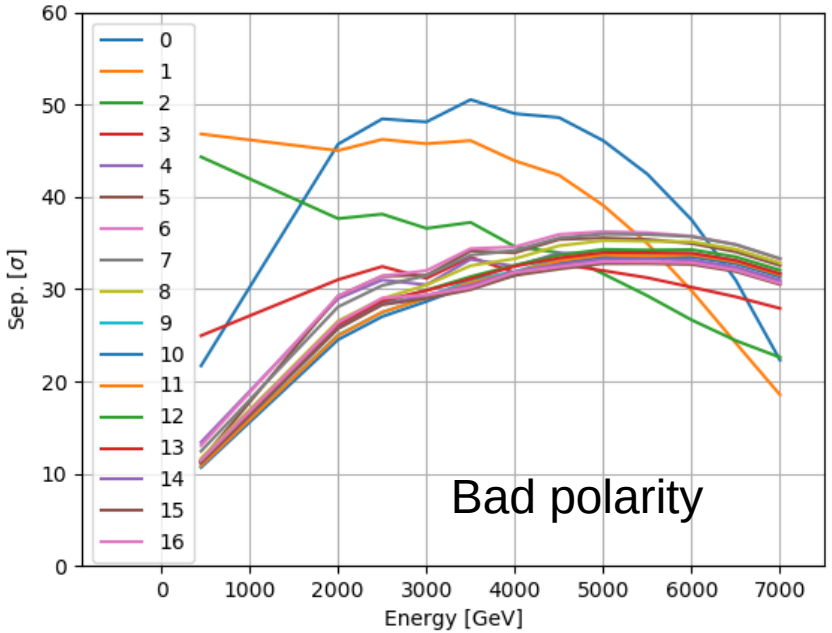
Maximum crossing angle without or (*) with new TCDDM

β* [m]	H* [µrad]	H [µrad]	V [µrad]
1	±220	±165	±115
1.4	±270	±220	±160
2	±310	±265	±205
3	±310	±310	±250

Ramp and squeeze

Present ramp and squeeze:

- H Crossing -170 µrad → -250 µrad [0.45 → 7TeV]
- V Separation -3.5 mm → -1 mm [2 → 7TeV]
- V Angle offset -40 µrad → 0 [2 → 7TeV]
- β* 10 m → 3 m [2 → 7TeV]

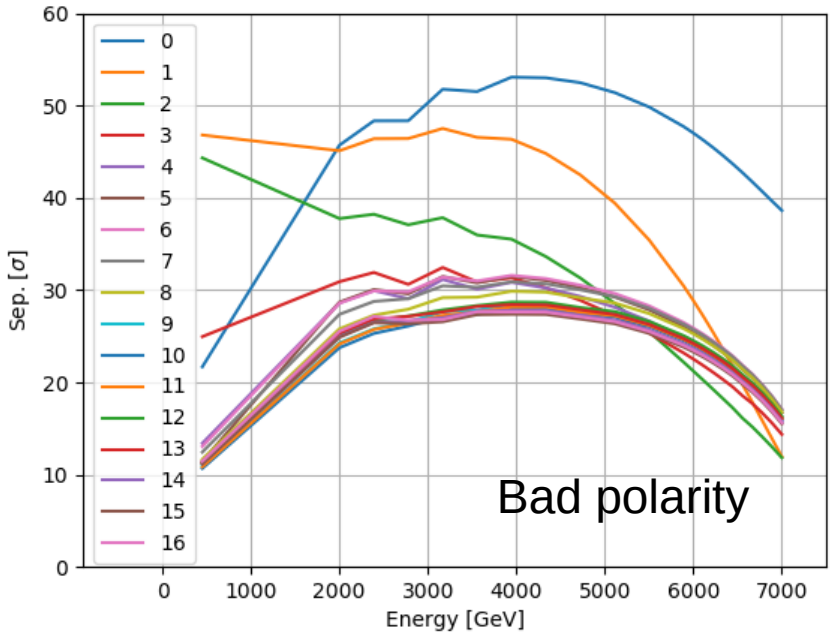


Most of the LR above 30σ,
Minimum is still about 20σ

Ramp and squeeze

Pushed case β*=1, ramp and squeeze:

- H Crossing -170 μrad → -220 μrad [0.45 → 7TeV]
- V Separation -3.5 mm → -1 mm [2 → 7TeV]
- V Angle offset -40 μrad → 0 [2 → 7TeV]
- β* 10 m → 1 m [2 → 7TeV]

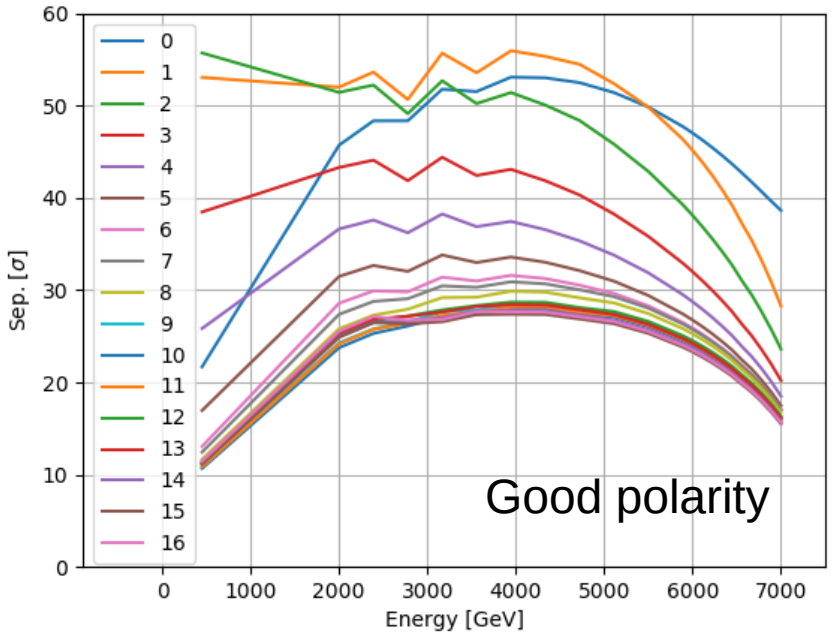


All LR in between 12 and 18 σ

Ramp and squeeze

Pushed case β*=1, ramp and squeeze:

- H Crossing -170 μrad → -220 μrad [0.45 → 7TeV]
- V Separation -3.5 mm → -1 mm [2 → 7TeV]
- V Angle offset -40 μrad → 0 [2 → 7TeV]
- β* 10 m → 1 m [2 → 7TeV]

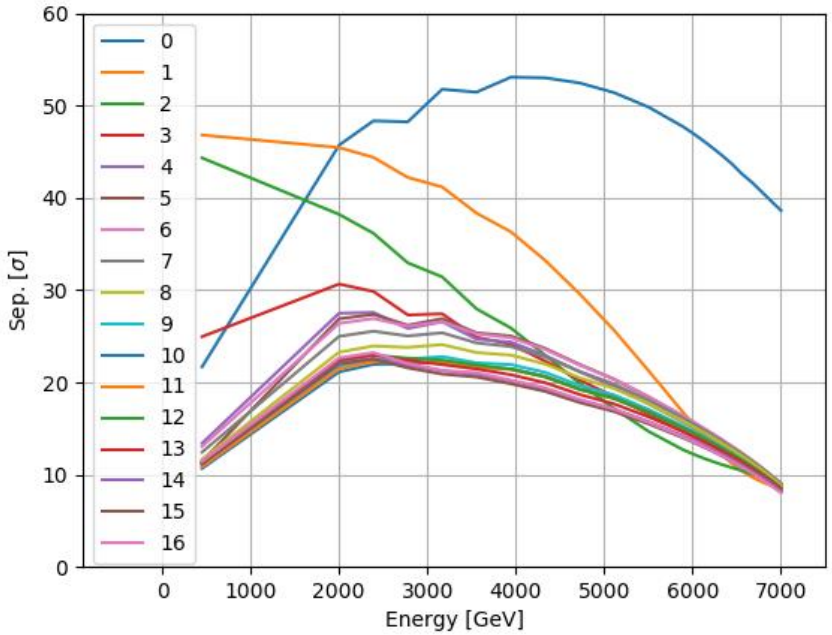


All LR in above 16 σ

Ramp and squeeze

Vertical crossing β*=1, ramp and squeeze:

- Crossing -170 µrad → -115 µrad
- Separation -3.5 mm → -0.5 mm [2→7 TeV]
- Crossing plane 0 → 90° [from 2→7 TeV]
- V Angle offset -40 µrad → 0 [from 2→7 TeV]
- β* 10 m → 1 m [from 2→7 TeV]

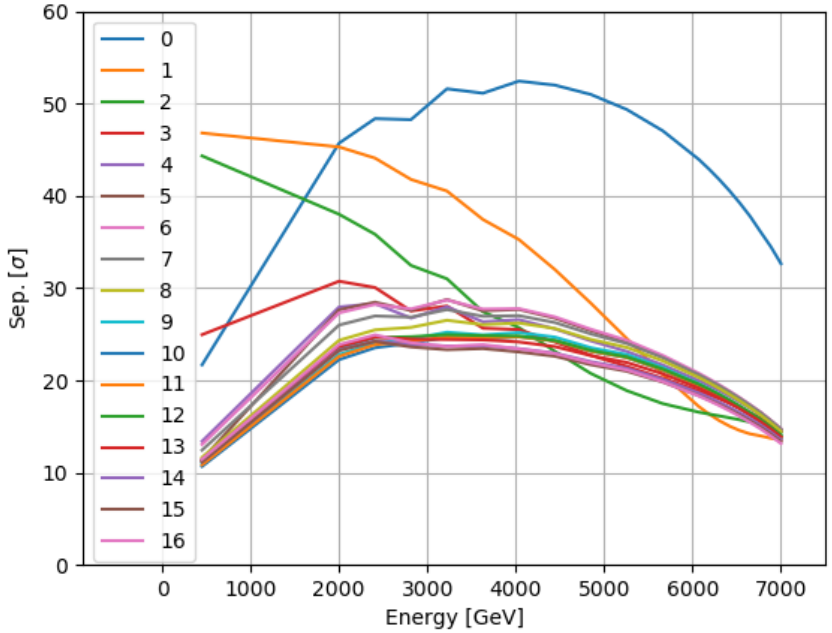


Previous case required exchange of TCDDM, however now all LR around 10 σ.

Ramp and squeeze

Vertical crossing β*=1.4, ramp and squeeze:

- Crossing -170 µrad → -160 µrad
- Separation -3.5 mm → -0.5 mm [2→7 TeV]
- Crossing plane 0 → 90° [from 2→7 TeV]
- V Angle offset -40 µrad → 0 [from 2→7 TeV]
- β* 10 m → 1.4 m [from 2→7 TeV]



Increasing to β*=1.4, put LR to about 14 σ.

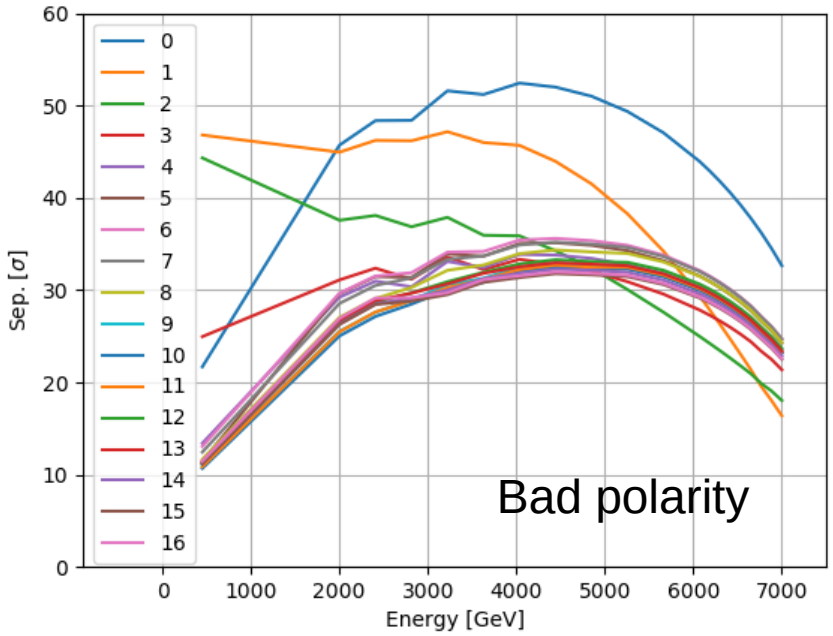
Overall vertical crossing does not seem too advantageous.

However one needs to solve the TCDDM problem.

Ramp and squeeze

Pushed case β*=1.4, ramp and squeeze:

- H Crossing -170 μrad → -270 μrad [0.45 → 7TeV]
- V Separation -3.5 mm → -1 mm [2 → 7TeV]
- V Angle offset -40 μrad → 0 [2 → 7TeV]
- β* 10 m → 1.4 m [2 → 7TeV]

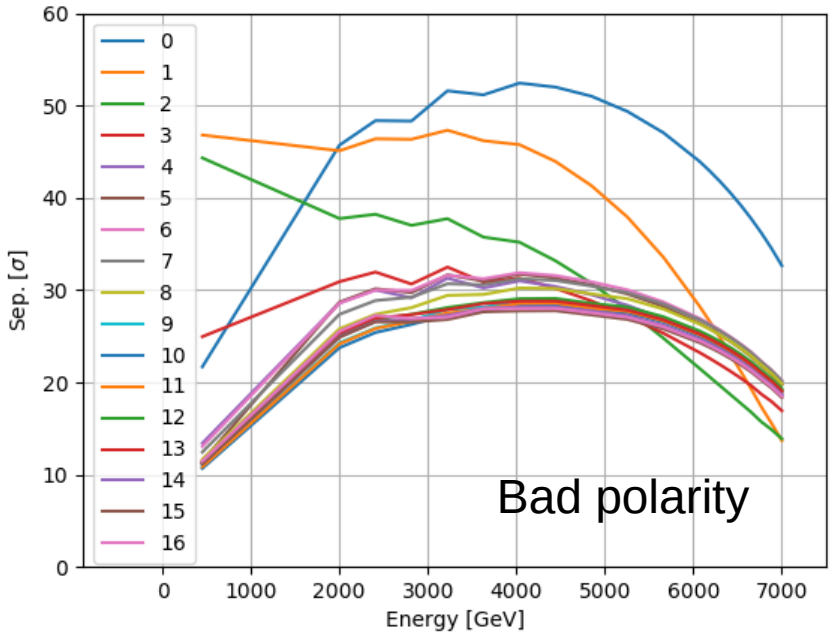


Most LR above 22 σ.
Assuming new TCDDM.

Ramp and squeeze

Pushed case β*=1.4, ramp and squeeze:

- H Crossing -170 μrad → -220 μrad [0.45 → 7TeV]
- V Separation -3.5 mm → -1 mm [2 → 7TeV]
- V Angle offset -40 μrad → 0 [2 → 7TeV]
- β* 10 m → 1.4 m [2 → 7TeV]

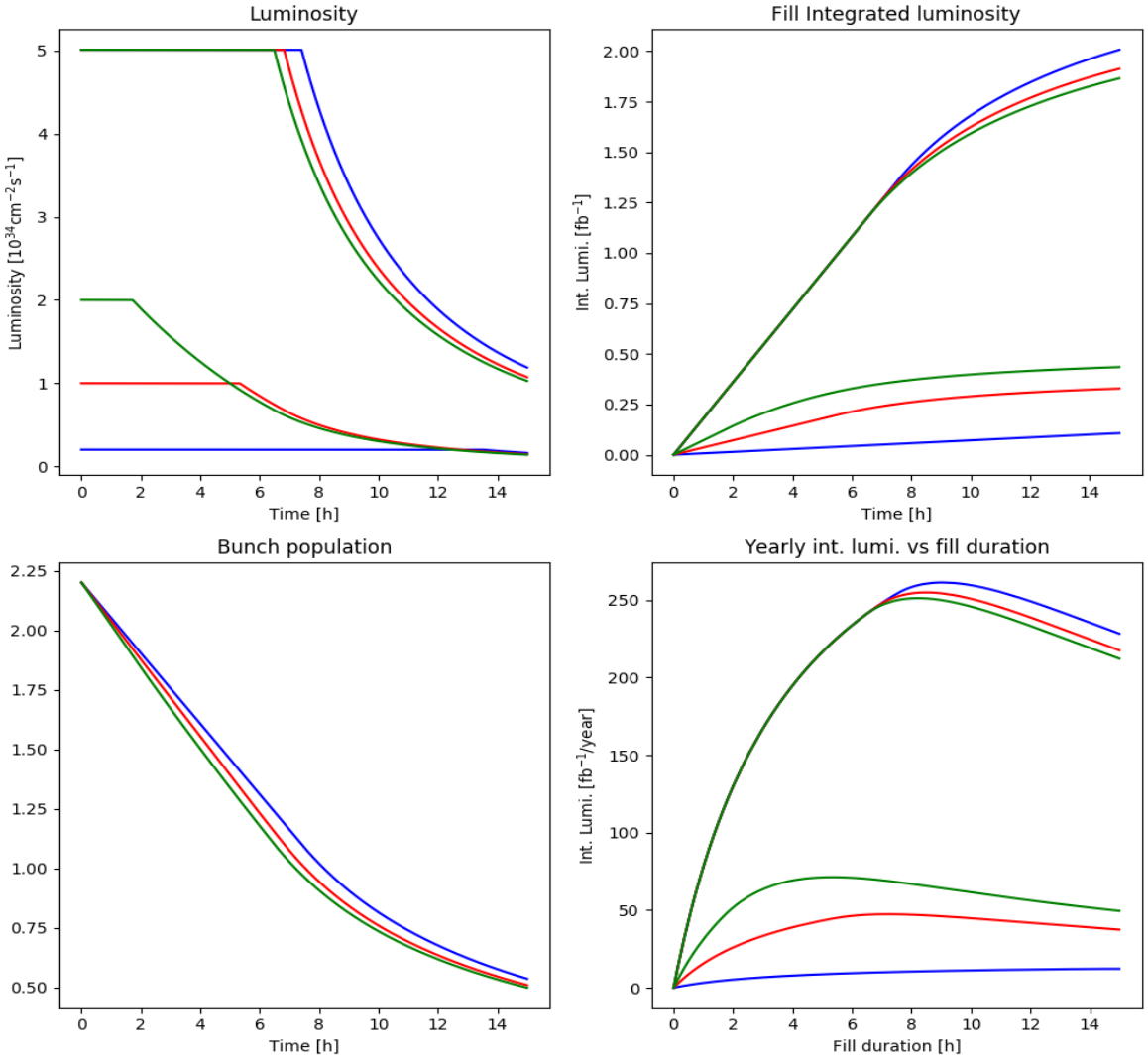


Most LR above 19 σ.
With present TCDDM.

One could look at flat beams for higher luminosity

Back-up

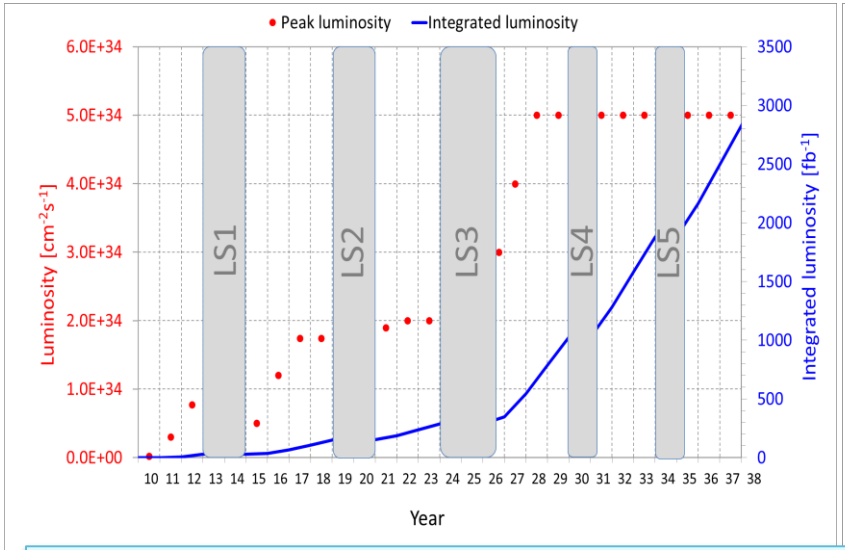
Luminosity scenarios

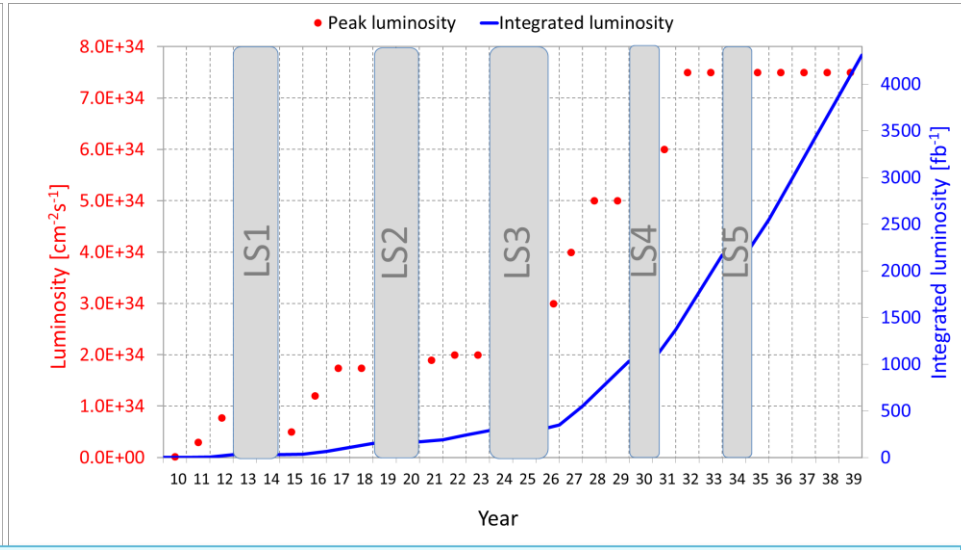


Scenario with large (2.7 10^{34} cm^{-2}s^{-1})IP8 virtual luminosity

Small impact on Atlas/CMS

HL-LHC Targets





After LS4, proton physics days increase from standard 160 days to 200 and after LS5 to 220

HL-LHC: mid 2026 to end 2039 after LS4

- Reach ≥ 3000 fb^{-1} by
  - Maximize availability, levelled luminosity per bunch, number of bunches, bunch population, brightness.
  - Crab-cavities to alleviate geometric reduction factor to small β* and long bunches and pile-up density.

Injector Brightness and LHC Filling Schemes

Production scheme	ppb [10^{11}]	ε [μm]	Inj.	BPI	Colliding 1,5/2/8
Standard	1.3→2.3	2.8→2.1	13	288	2748/2494/2572
BCMS	1.3→2.3	2.5→1.7	20	144	2544/2205/2308
			12	288	2736/2258/2378
8b+4e STD	1.6→2.5	2.4→2.1	13	144	*1960/1163/1806**
8b+4e BCMS	1.6→2.5	1.2→1.8	20	96	*1696/1470/1538**
80b	1.3→2.3	1.3→2.1	14	240	2732/2476/2549
			12	320	2800/2246/2606
50 ns	1.8	1.8	13	144	1374/1247/1286
Single	>3.0	>1.5	n/a	1	n/a

RunII → HL-LHC *scaling

New scheme thanks to 200 ns rise time, BCMS very close to standard for IP1/5.
288bpi BCMS and 320bpi 80b cannot be tested in Run II due to transfer line limitations.
Will always short non-colliding train be needed, can they at least collide?

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HiLumi HL-LHC PROJECT

Velo upgrade references

2013, Velo TDR
LHCb Tracker Upgrade TDR
20/7/2014, Velo Approval

Table 1: Overview of global upgrade settings for simulation.

Beam energy	7 TeV
Number of bunches colliding at IP8	2400
Bunch z RMS	90 mm
Half angle horizontal	135 μrad
Half angle vertical	120 μrad
Luminosity	$2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
Bunch charge	1.2×10^{11} protons
ν (# interactions per crossing)	7.6 (for $\sigma_{\mathrm{tot}} = 102.5$ mb)
μ (# visible interactions per crossing)	5.2 (for $\sigma_{\mathrm{vis}} = 70.6$ mb)
Bunch x,y RMS	37.70 μm
z RMS luminous region σ_{lumi}	63 mm

M. Giovannozzi, Velo aperture, 9th TREX 5/11/2015
R. Appleby et, al, VELO aperture considerations for the LHCb Upgrade, CERN-ATS-Note-2012-101

	Nominal		Post LS2		HL-LHC	
	25 ns	50 ns	25 ns	50 ns	25 ns	50 ns
N / $10^{11}p$	1.15	1.6	1.7	1.7	2.2	3.5
ϵ_n / μm	3.75	2.5	2	1	2.5	3.0

Neglects crossing angle effects, assume levelling but also 1.7 10^{11} for run III