LHCb Velo and UT

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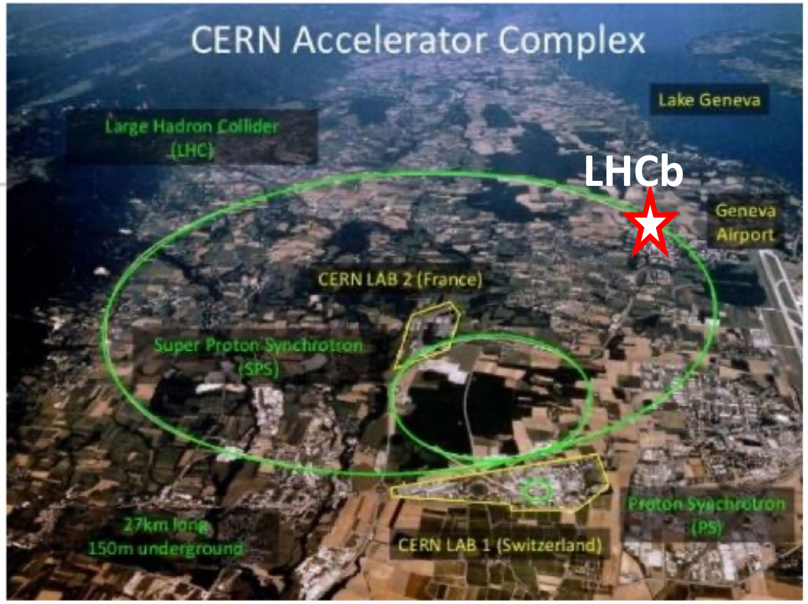
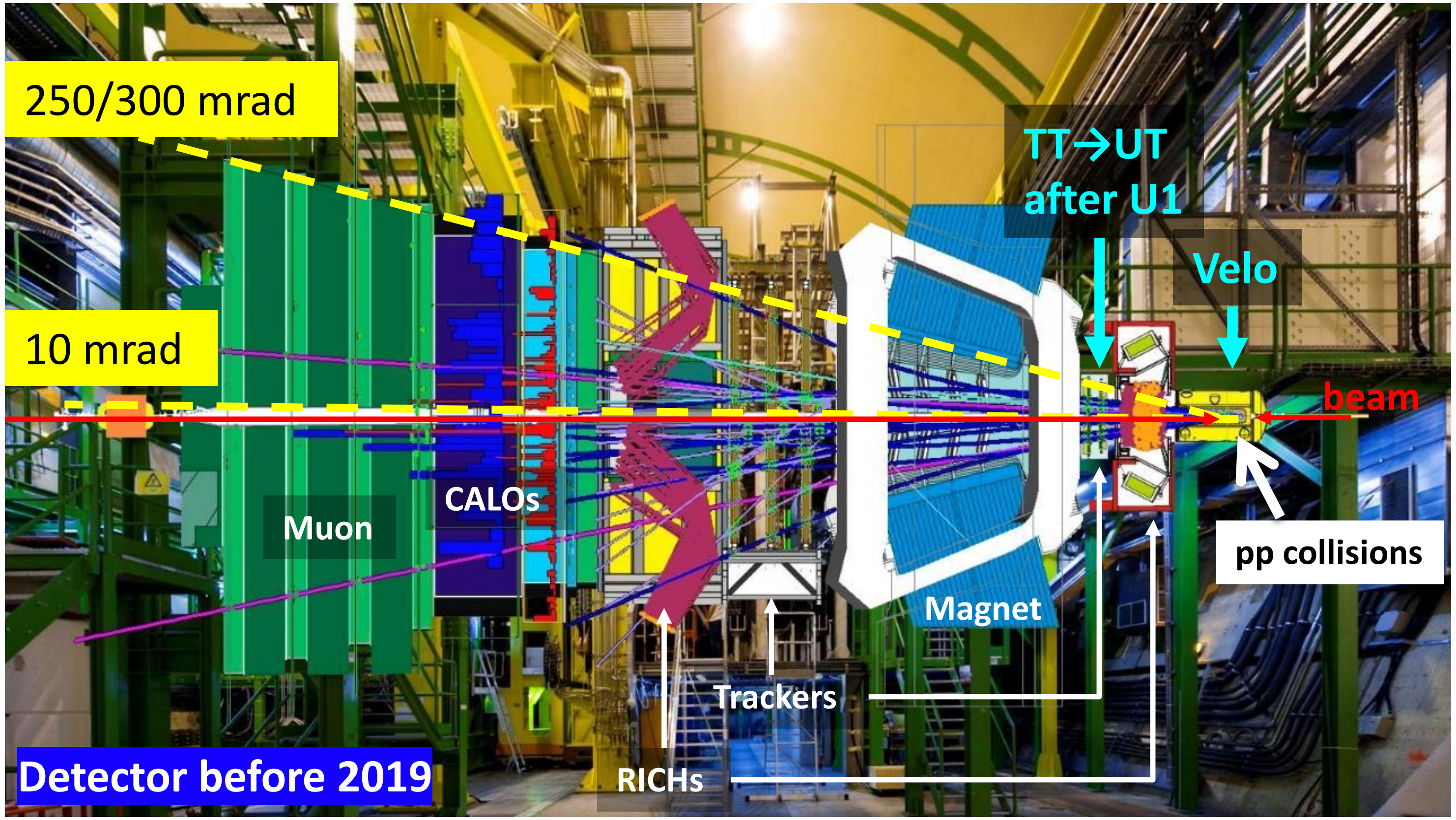
On behalf of LHCb collaboration

2023-10-23

International Workshop on The High Energy Circular Electron Positron Collider

LHCb: a forward spectrometer @ LHC





Main physics goal

- To study b & c sectors on CPV, rare decays, new physics...

$\Delta p/p = 0.5\%$ @ < 20 GeV/c, 1% @ < 200 GeV/c

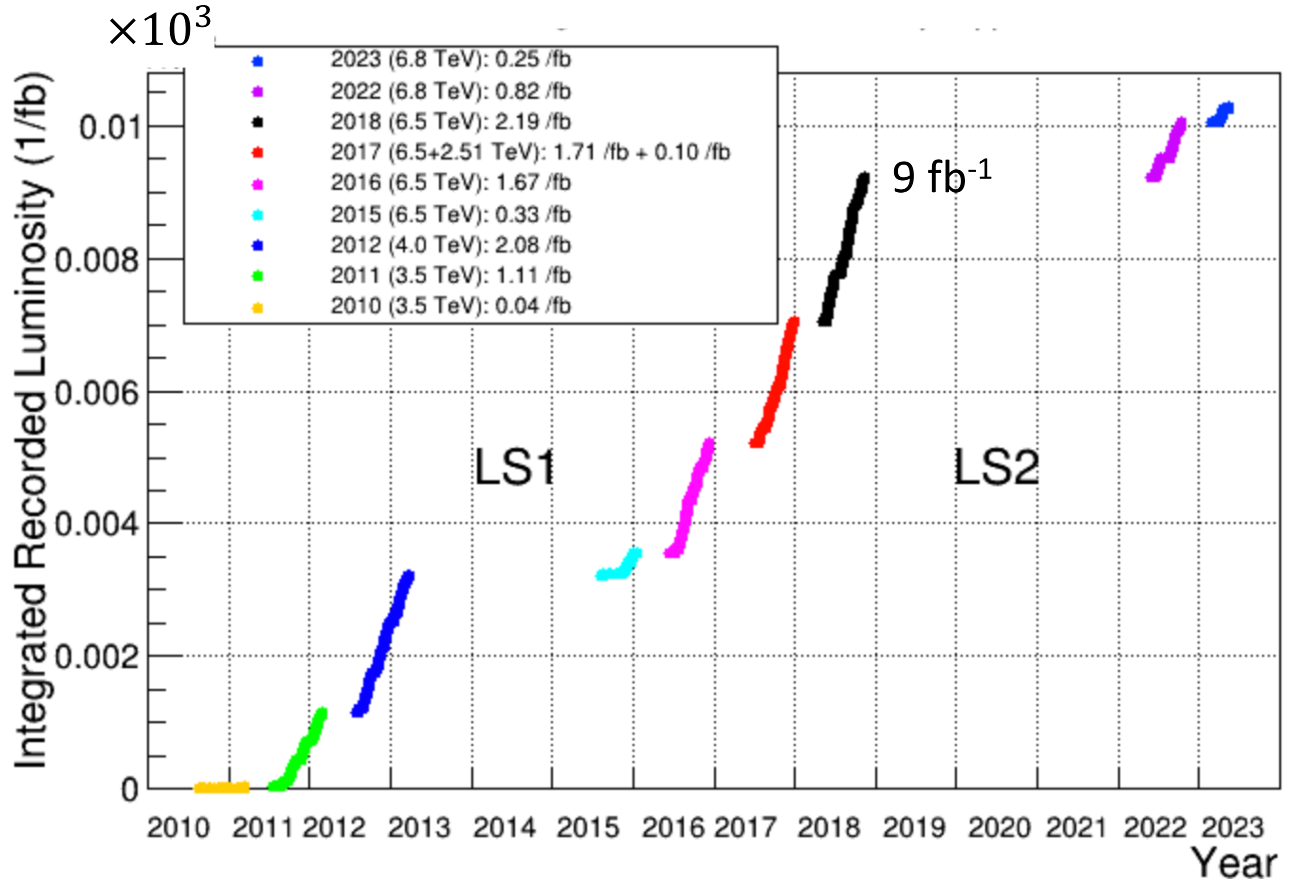
IP resolution ~ $15 + 29/p_T$ [GeV/c] μm

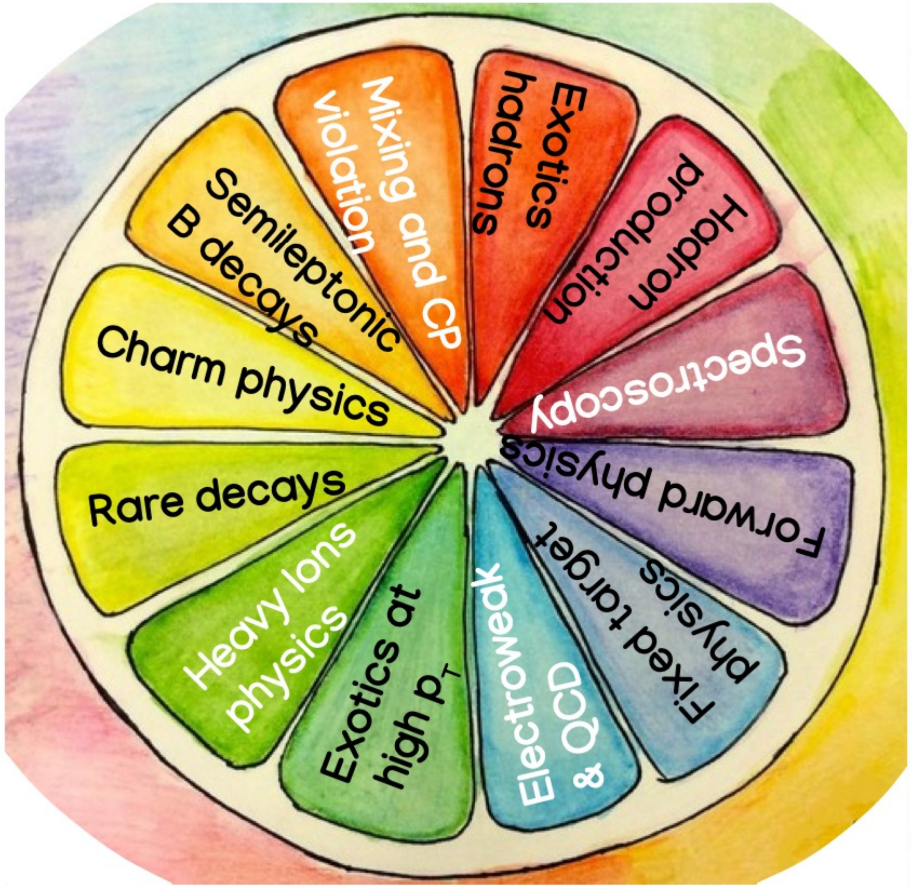
Decay time resolution 45 fs ($B_s \to J/\psi\phi$)

Kaon ID ~ 95% for 5% $\pi \to K$ mis-ID probability

LHCb physics performance in Run 1 & 2

A decade of important discoveries and precision measurements (9 fb^{-1} pp data by end of 2018)





More details in Yin's talk by Thu.

LHCb Upgrades

Upgrade I (U1), started in LS2 and installation completed in this March

$\mathcal{L}_{max}$~2x10^{33} cm^{-2}s^{-1}

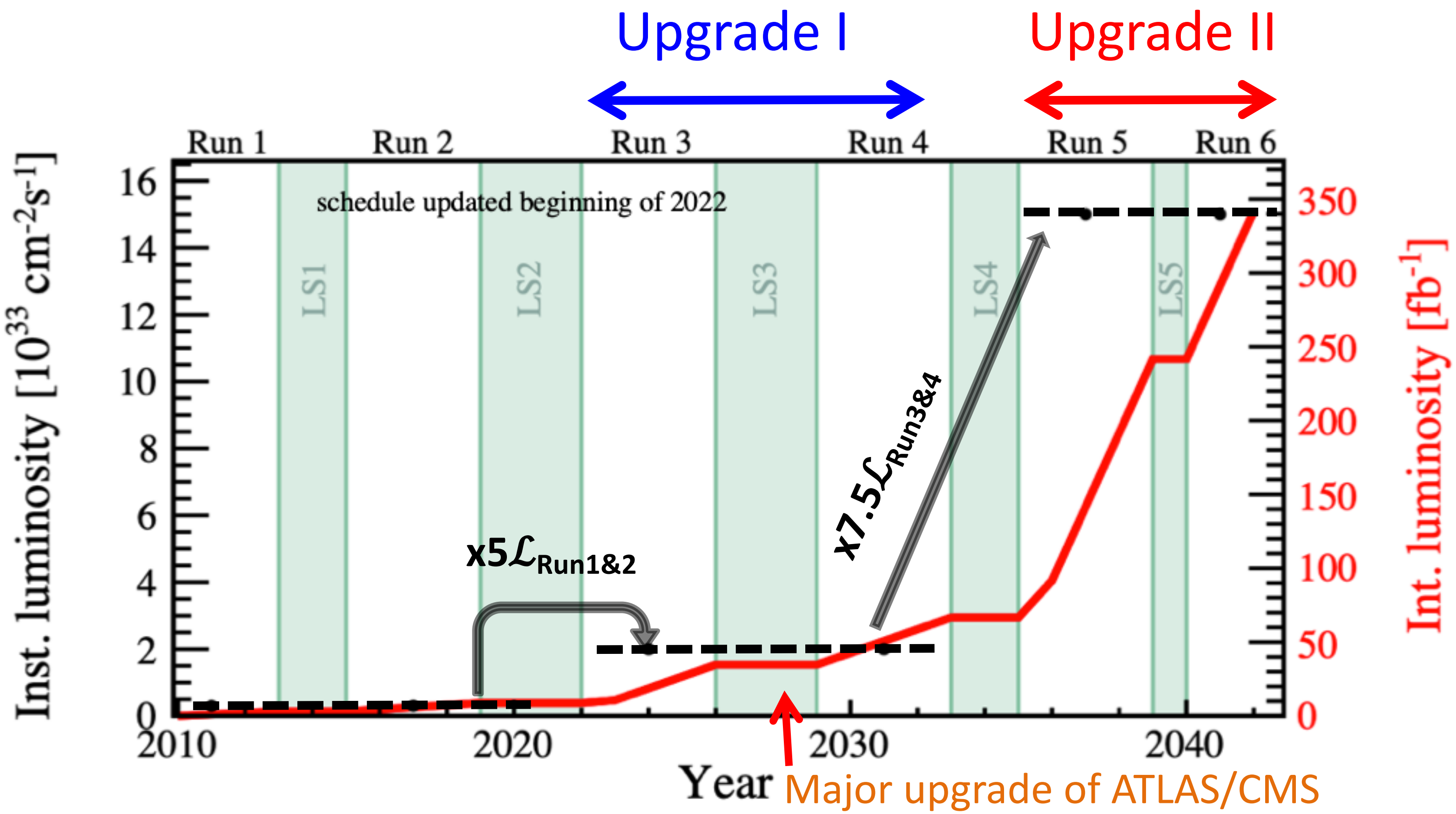
$\mathcal{L}_{int}$~50 fb^{-1}

Upgrade II (U2), starts after LS4

$\mathcal{L}_{max}$~1.5x10^{34} cm^{-2}s^{-1}

$\mathcal{L}_{int}$~300 fb^{-1}

Some smaller detector consolidation and enhancements in LS3 (2026) ⇦ U1b



Major upgrade of ATLAS/CMS

LHCb also plan enhancements (U1b)

LHCb upgrades

- ❑ **Velo & UT @ Upgrade I (U I) (2019 - 2023)**
- ❑ Velo & UT @ Upgrade II (U II) (2032 -)

Upgrade I: a brand new detector

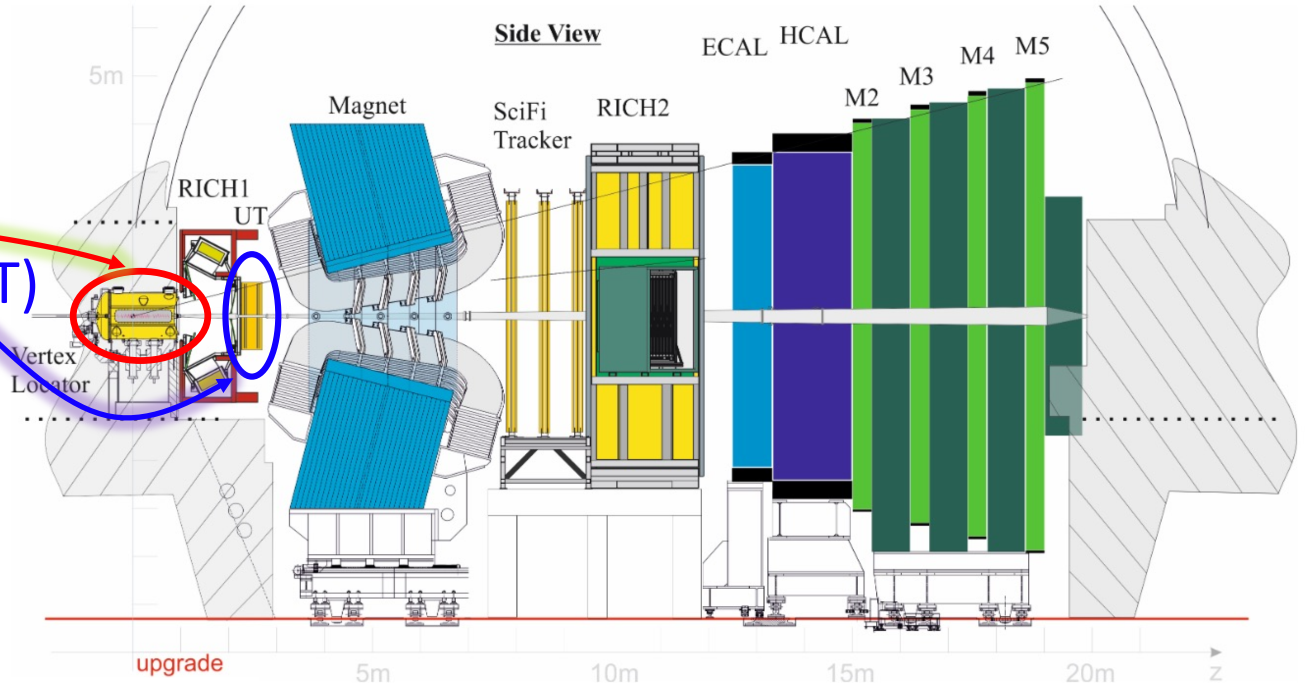
Higher luminosity ($5\mathrm{x}\mathcal{L}_{\mathrm{Run1\&2}}$) results in

- Higher rate, pile up, occupancy, fluence

New tracking system

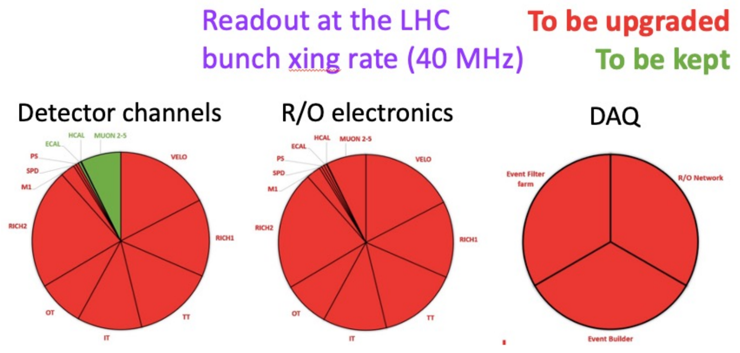
- **VErtexLOcator (VELO)**, **U**pstream **T**racker (UT) and **Sci**ntillating **Fi**ber Tracker (SciFi)

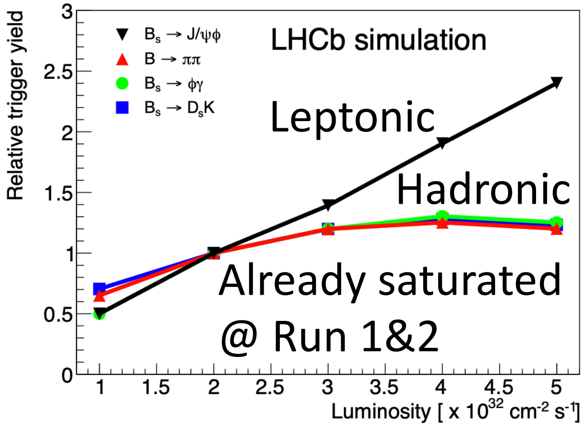
More details on Sigrid Scherl's talk



Particle ID: New optics + photon detectors

Calos: Reduce PMT gain + new electronics



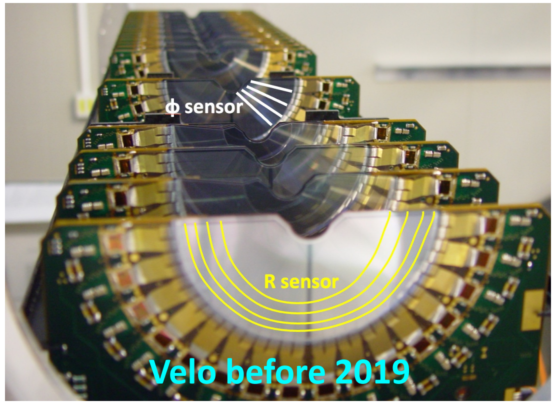


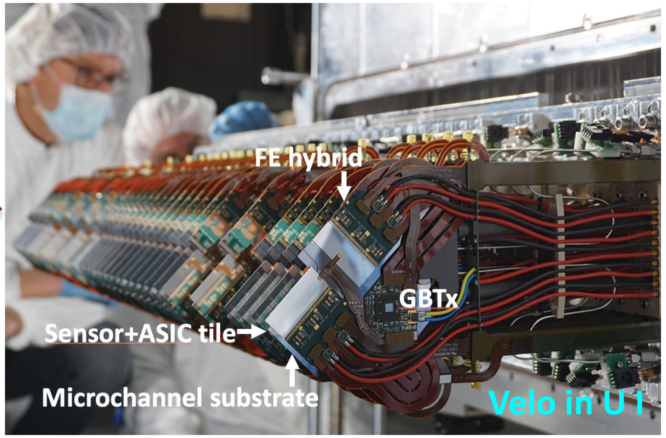
No hardware trigger

- 1st GPU trigger in a HEP experiment

Velo @ LHCb U I

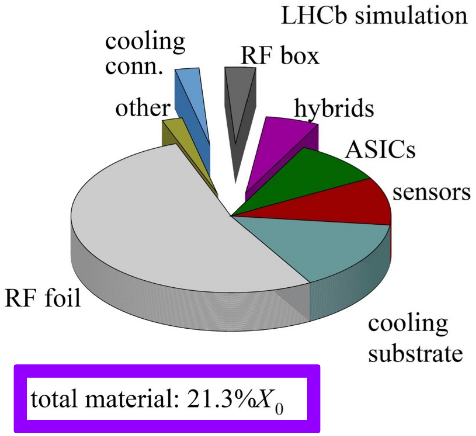
LHCB-TDR-013



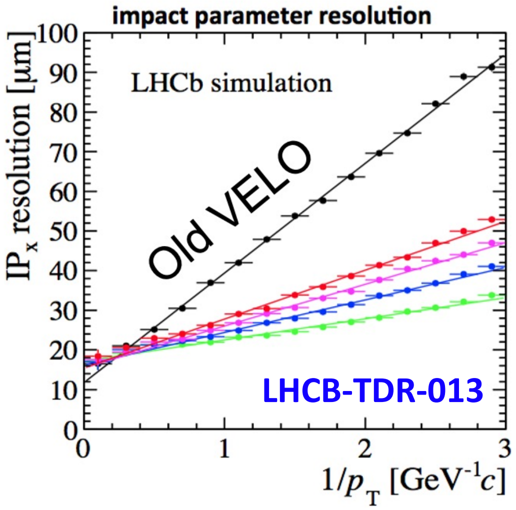


New hybrid pixel detector

- c/b hadrons: flight ~mm before decay
  distinctive feature to select them
- Silicon pixels (55x55 μm)
  single hit resolution 12-15 μm
- Closer to beam (5 mm → 3 mm) ⇒ better σ_{IP} (2x better @ $p_T \sim 0.5$ GeV)



Reduced material interaction (x3 better)



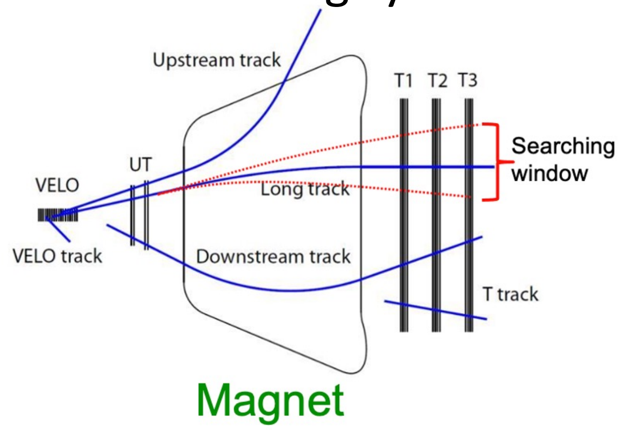
RF foil (185 μm thickness)

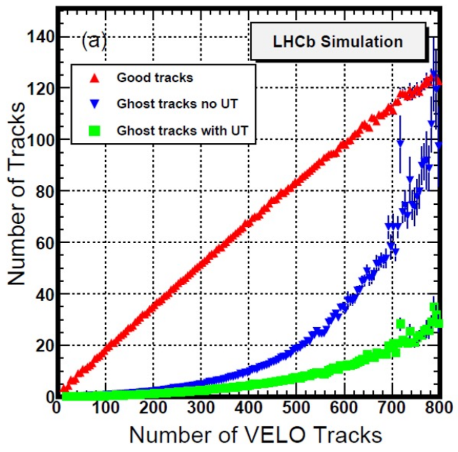
- Separate VELO from primary vacuum
- An vacuum incident on 2023 Jan 10
  - ❑ RF foils deformed
  - ❑ No damage on sensors
  - ❑ Cant fully close (3 mm → 24.5 mm x2)
  - ❑ Replace during YETS 2023

Upstream Tracker (UT)

LHCB-TDR-015

LHCb tracking system



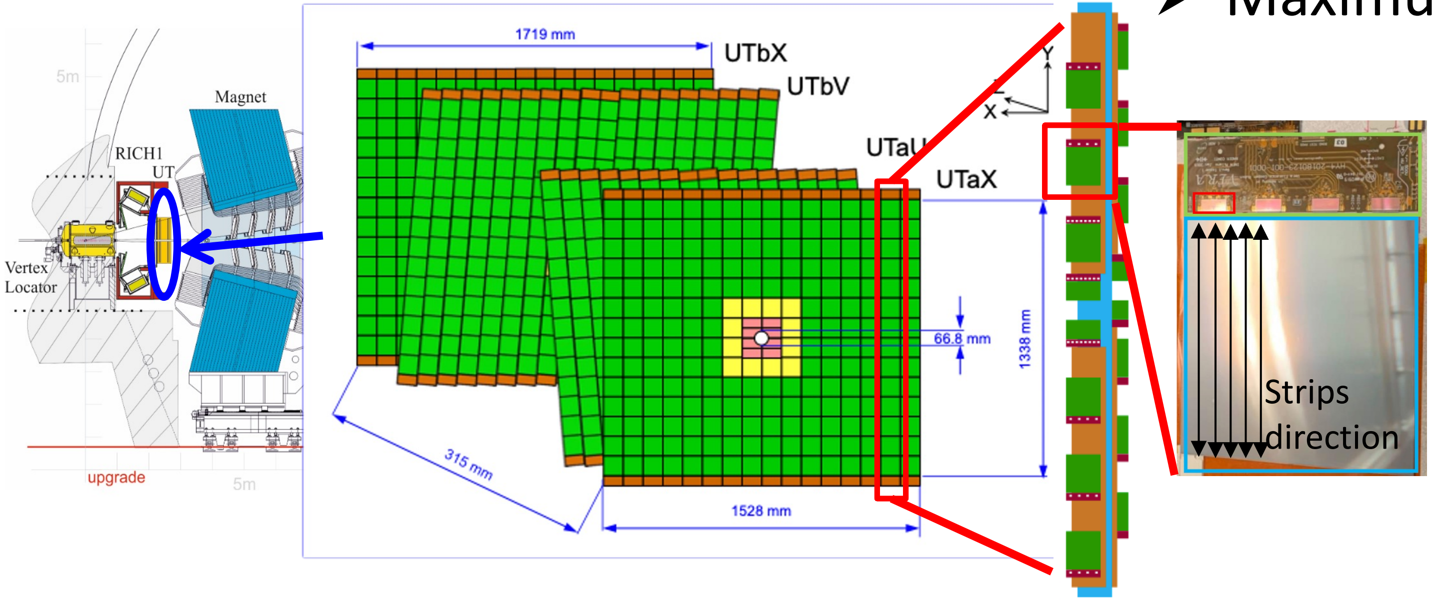


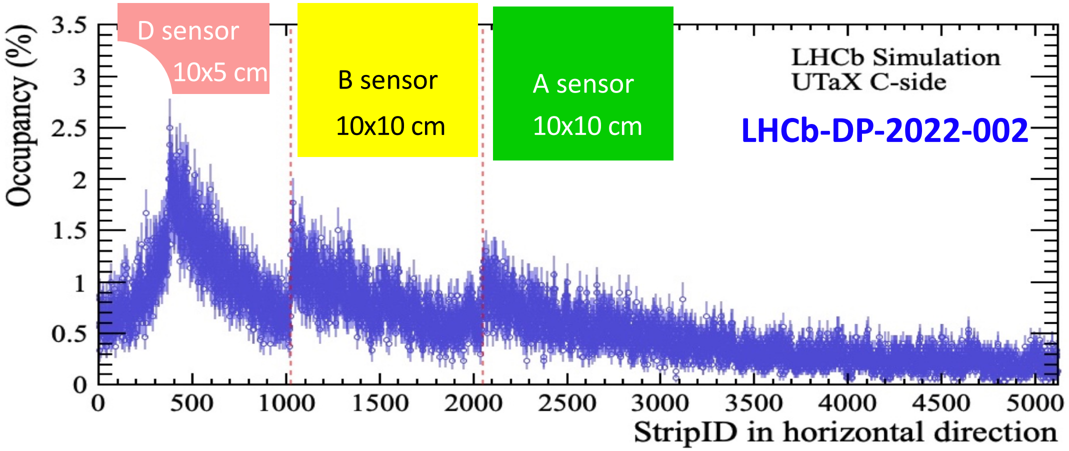
UT: Si Strip detector

- High coverage, segmentation, resolution
- Speed up tracks reconstruction & reduce $P_{GhostTrk}$

Different sensors for different regions

- A type: p-in-n; 98x98 mm; strip pitch 190 μm
- B type: n-in-p; 98x98 mm; strip pitch 95 μm
- C/D type: n-in-p; 98x49 mm; strip pitch 95 μm
- Maximum occupancy ~ 1%



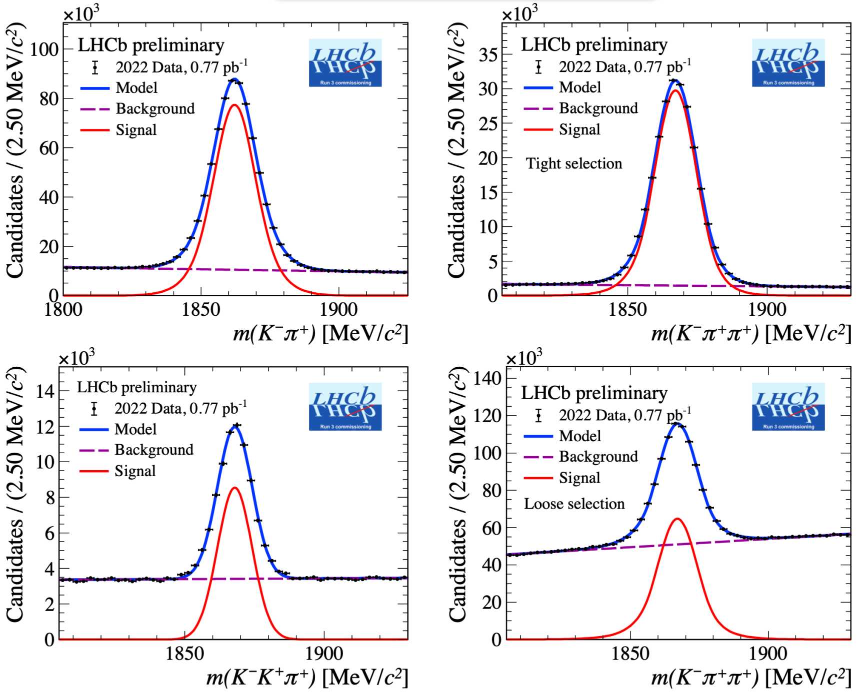


Installation ends by 2023 March

Commissioning ongoing

Physics performance @ LHCb U I

Charmed mesons

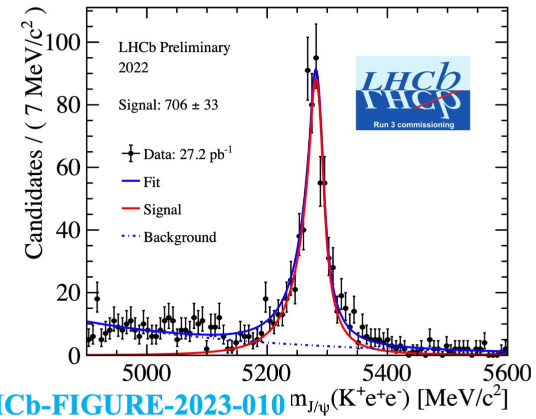


- D^0 and K_S^0 candidates reconstructed directly @ 1st level trigger
- Trigger efficiency can be improved w.r.t. Run2

LHCb upgrade I detectors functions well

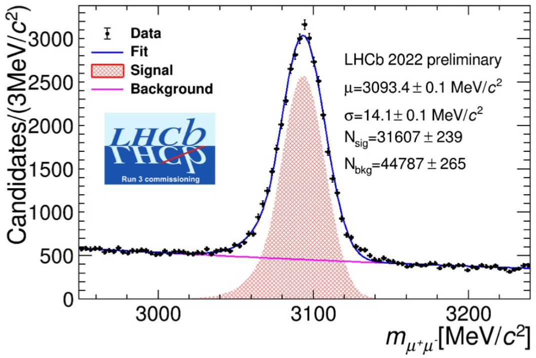
- W/ full triggers/"sub-detectors" signals return in 2022

Beauty mesons



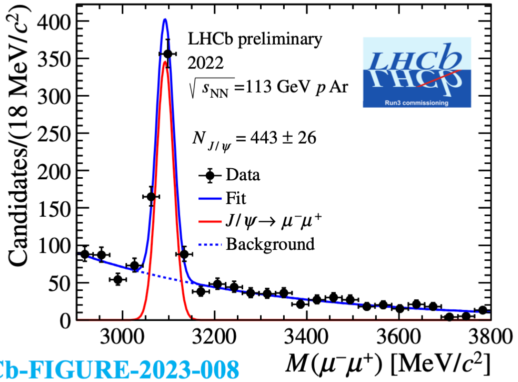
LHCb-FIGURE-2023-010

$J/\psi \to \mu^+\mu^-$



LHCb-FIGURE-2023-015

J/ψ in pAr collisions



LHCb-FIGURE-2023-008

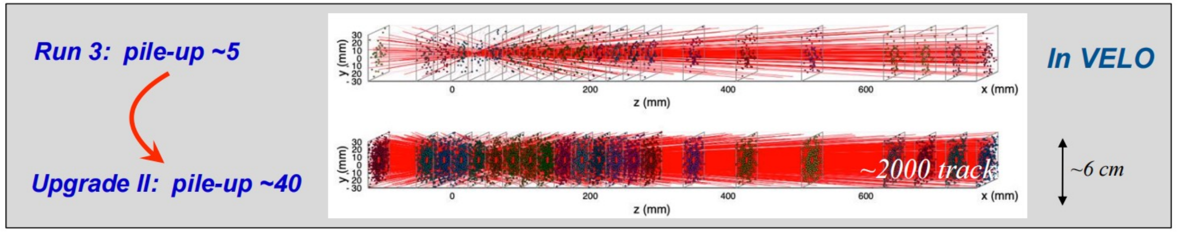
Mass resolution compatible with MC expectations within 1 MeV

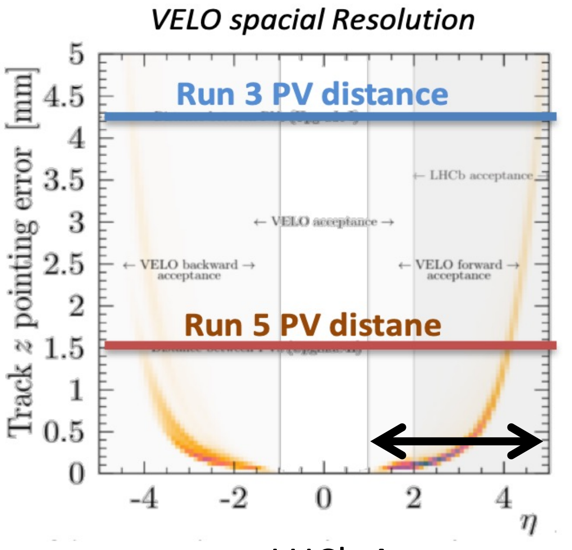
LHCb upgrades

- Velo & UT @ Upgrade I (U I) (2019 - 2023)
- **Velo & UT @ Upgrade II (U II) (2032 -)**

High pile-up in Upgrade II

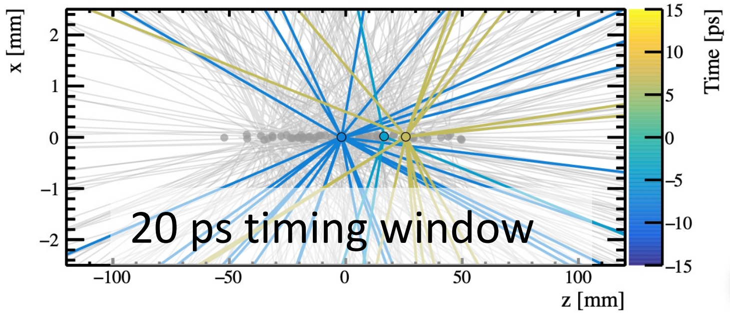
In Upgrade II
$\mathcal{L}_{max}$~1.5x10^{34} cm^{-2}s^{-1}
$\mathcal{L}_{int}$~300 fb^{-1}
~ 40 visible interactions/Xing

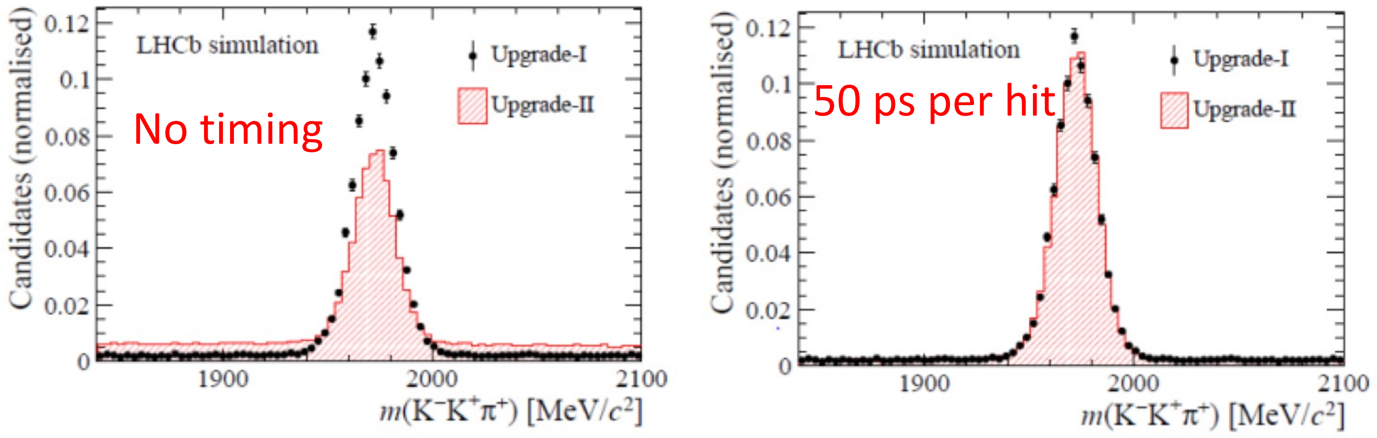




- High pile-up induces PV spatial separation of the same order as VELO resolution → PV unresolvable
- Ensure $\varepsilon_{trigger}$ at high pileup condition

VELO: 4D detector with timing



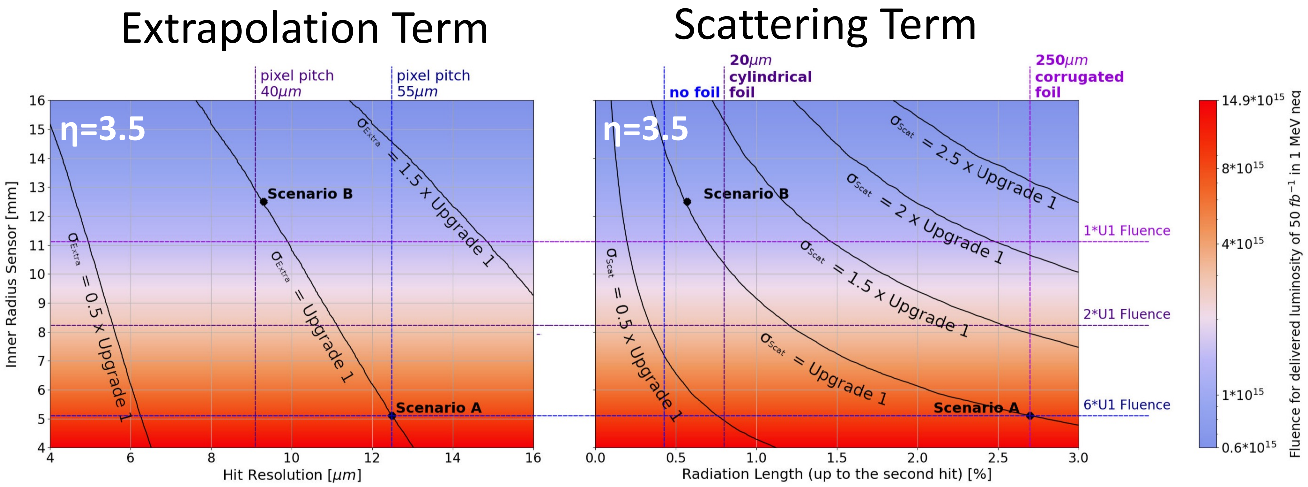


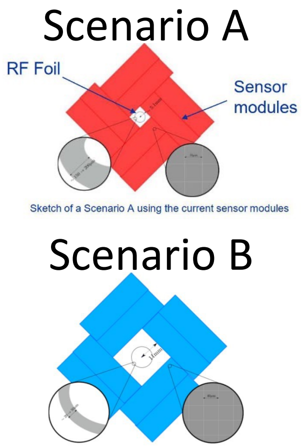
σ_t(Track)=20 ps restores the performance to U1 level

Velo R&D

Balance btw Φ_{eq} and σ_{Hit}

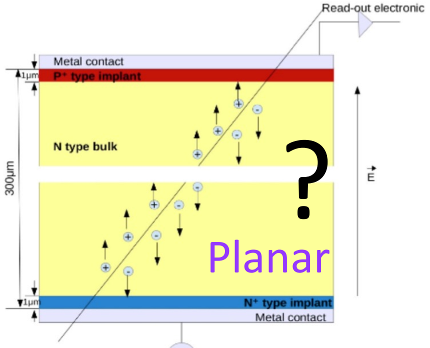
- $\sigma_{IP} = \sigma_{extrap} + \sigma_{scatter}$
- Two different layouts optimized





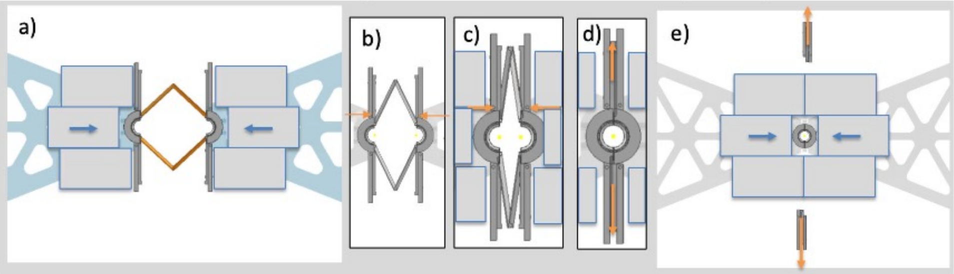
Sensor R&D, candidates: 3D pixel, Planar, LGAD, CMOS …

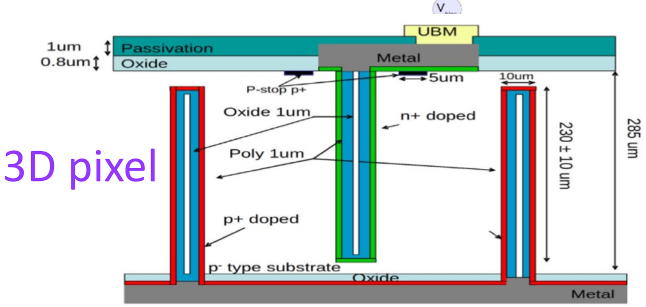
- timing ~50 ps
- Radiation hardness (max ~$6\times10^{16} n_{eq}/cm^2$)



- R&D on 28 nm technology: PicoPix, IGNITE
- Replaceable modules, thinner or no RF foil, robust 3D printed Ti cooling substrate...

Additional shielding when RF foil in open position





Upgrade II UT (U2UT)

Channel occupancy [%]

0.42	0.45	0.47	0.49	0.52	0.54	0.57	0.60	0.60
0.46	0.49	0.52	0.56	0.59	0.63	0.68	0.74	0.77
0.53	0.58	0.62	0.68	0.73	0.83	0.89	1.00	1.06
0.64	0.70	0.77	0.86	0.96	1.10	1.26	1.48	1.63
0.78	0.88	0.97	1.13	1.27	1.54	1.81	2.34	2.72
0.96	1.10	1.23	1.45	1.68	2.05	2.63	2.84	3.87
1.28	1.45	1.54	1.81	2.04	2.57	3.42	4.48	3.95 5.13

Beam pipe

Current UT optimized for $\mathcal{L}_{\text{Run 3\&4}}$

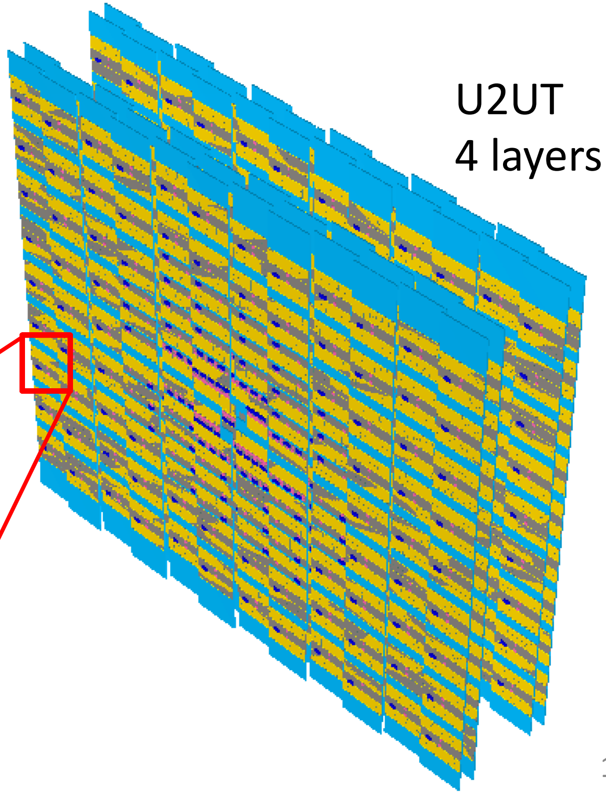
Upgrade II luminosity $1.5\times10^{34}\ cm^{-2}s^{-1}$ (**x7.5 $\mathcal{L}_{\text{Run 3\&4}}$**)

- ➢ The occupancy (max ~10%) will compromise the performance
- ➢ Radiation does ($3\times10^{15} n_{eq}/cm^2$) too high for current sensor

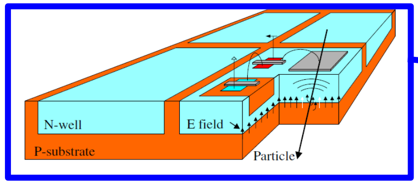
U2UT:

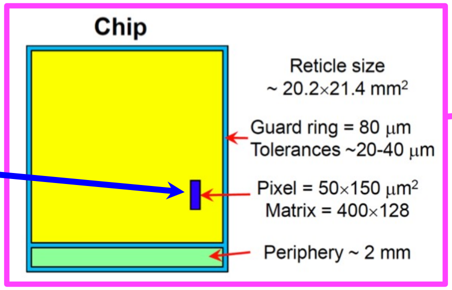
- ➢ CMOS MAPS technique applied
  Very promising and cost effective for large area pixel detectors.

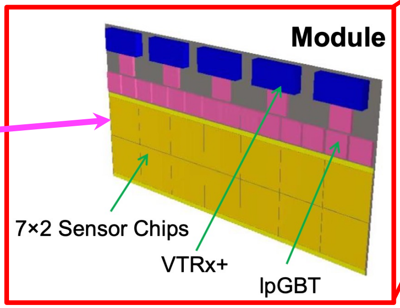
U2UT
4 layers



Monolithic Active Pixel Sensor (MAPS)

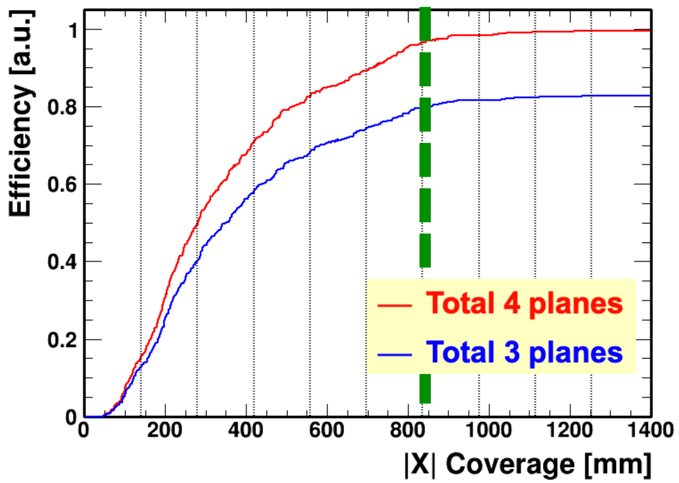




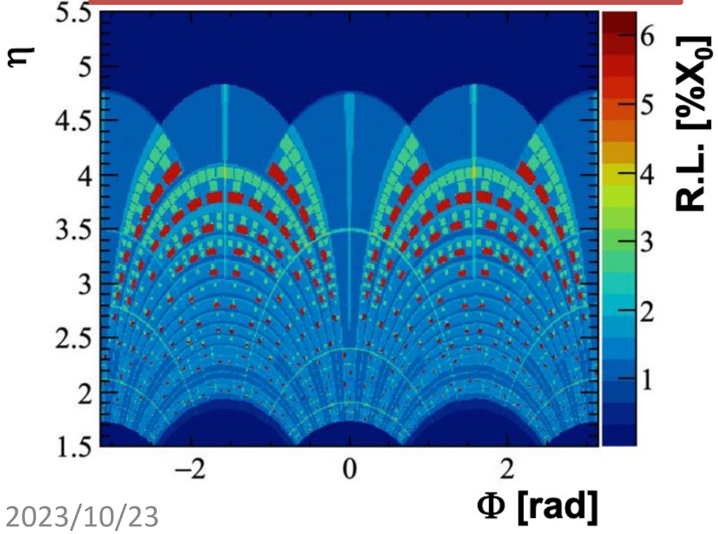


U2UT R&D status

Track efficiency vs X coverage



R.L. as functions of Φ and η



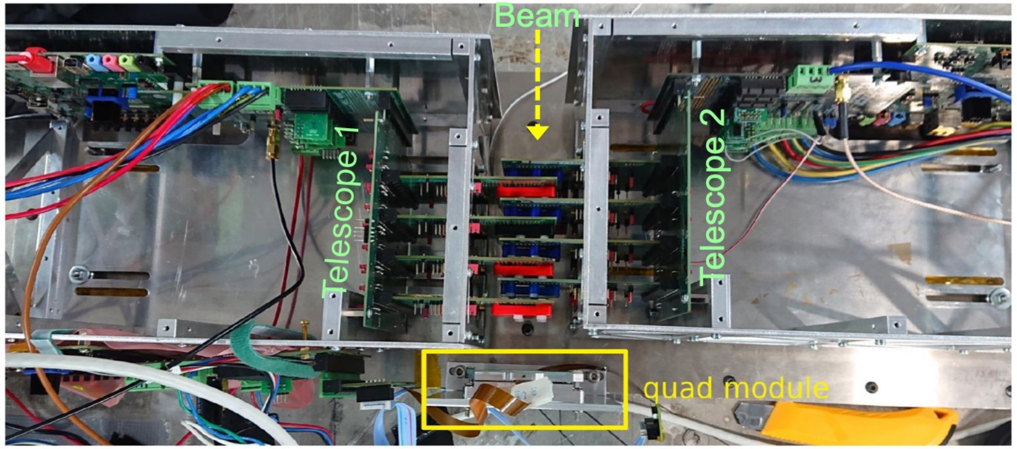
Also can see Shuqi + Zhiyu's posters

U2UT software

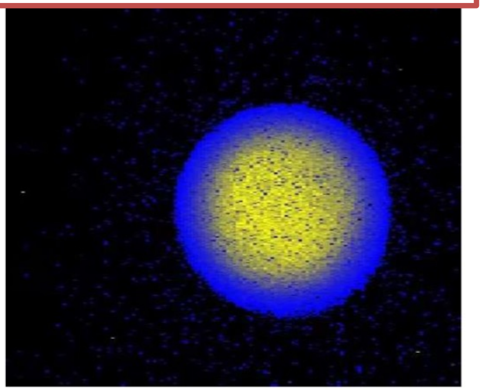
- Preliminary studies on
  - ❑ Track efficiency for $B^- \to D^0 K^-, D^0 \to K_S \pi^+ \pi^-, K_S \to \pi^+ \pi^-$ Optimizing U2UT coverage
  - ❑ Detector simulation mostly done and R.L. calculated

LHCb China group lead HVCMOS-based development

- Extensive tests using ATLASPix: lab test with cosmic ray and radioactive sources, testeam at DESY & CSNS @ 2022
- Search for domestic foundry ongoing



Hitmap with Fe55 source



Expected physics results @ LHCb Upgrade II

Key observables in flavor physics

Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I ($23\,\mathrm{fb}^{-1}$)	Upgrade I ($50\,\mathrm{fb}^{-1}$)	Upgrade II ($300\,\mathrm{fb}^{-1}$)
CKM tests					
γ ($B \to DK$, *etc.*)	4°	[9, 10]	1.5°	1°	0.35°
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29, 30]	3%	2%	1%
$a_{\rm sl}^d$ ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
$a_{\rm sl}^s$ ($B_s^0 \to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	[40, 41]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—		—	—	0.2
$A_{\rm T}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$A_{\rm T}^{\rm Im}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}(B_s^0 \to \phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	[51]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005	0.002

LHCC-2021-012

Upgrade II will fully realize the flavor physics potential of the HL-LHC

Further pursue a broad physics programme

- Spectroscopy
- High precision EW and Higgs
- Dark sector
- Exotic search
- Heavy ions and fixed target

Success of the physics programme relies on

- ➢ HL-LHC providing LHCb ~ 50 fb^{-1}/year during Run 5&6
- ➢ A detector with similar or better performance as the present one for Run 3

Summary

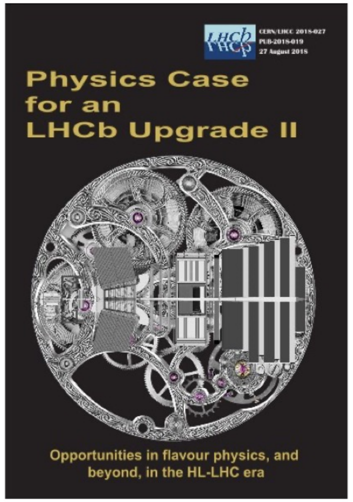
LHCb Velo & UT

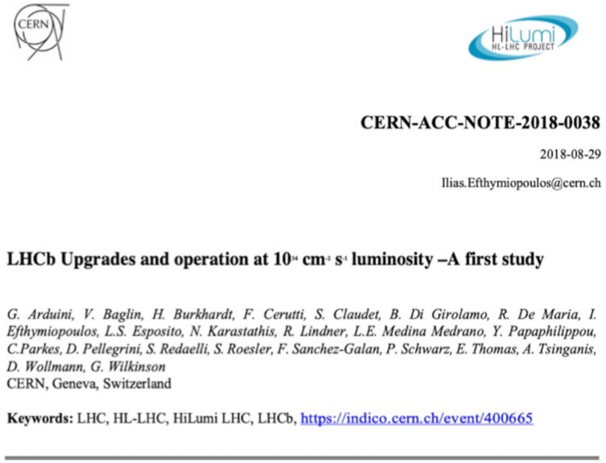
- Upgrade I: installation completed
- Upgrade II: starts in LS4, R&D now

LHCb Upgrade II to fully exploit HL-LHC for flavor physics and beyond

- FTDR approved and now in R&D phase
  Next: TDR @2026, construction, installation and eventually operation for physics
- LHCb China groups contribute more significantly in **UT** & CALO, and you are welcome to join

More physical results can be expected from LHCb





CERN-ACC-NOTE-2018-0038

2018-08-29

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LHCb Upgrades and operation at 10^{34} cm^{-2} s^{-1} luminosity – A first study

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Keywords: LHC, HL-LHC, HiLumi LHC, LHCb, https://indico.cern.ch/event/400665

- Expression of Interest, LHCC-2017-003
- Physics case, LHCC-2018-027
- Accelerator study, CERN-ACC-2018-038
- Framework TDR, CERN-LHCC-2021-012

Thank you for your attentions