LAPP
Laboratoire d'Annecy de Physique des Particules

New FCPPL Project: LHCbECAL2

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24 April 2019

12th FCPPL – Shanghai Jiao Tong University

LHCb

cnrs

UNIVERSITÉ SAVOIE MONT BLANC

LHCb timeline

	Running [yr]	Int. Lumi. [fb^{-1}]	Inst. Lumi. [$cm^{-2}s^{-1}$]	μ (*)	Status
LHCb	7	9	$4x10^{32}$	1.1	Done
LHCb Upgrade I	7	50	$2x10^{33}$	5.5	Construction underway

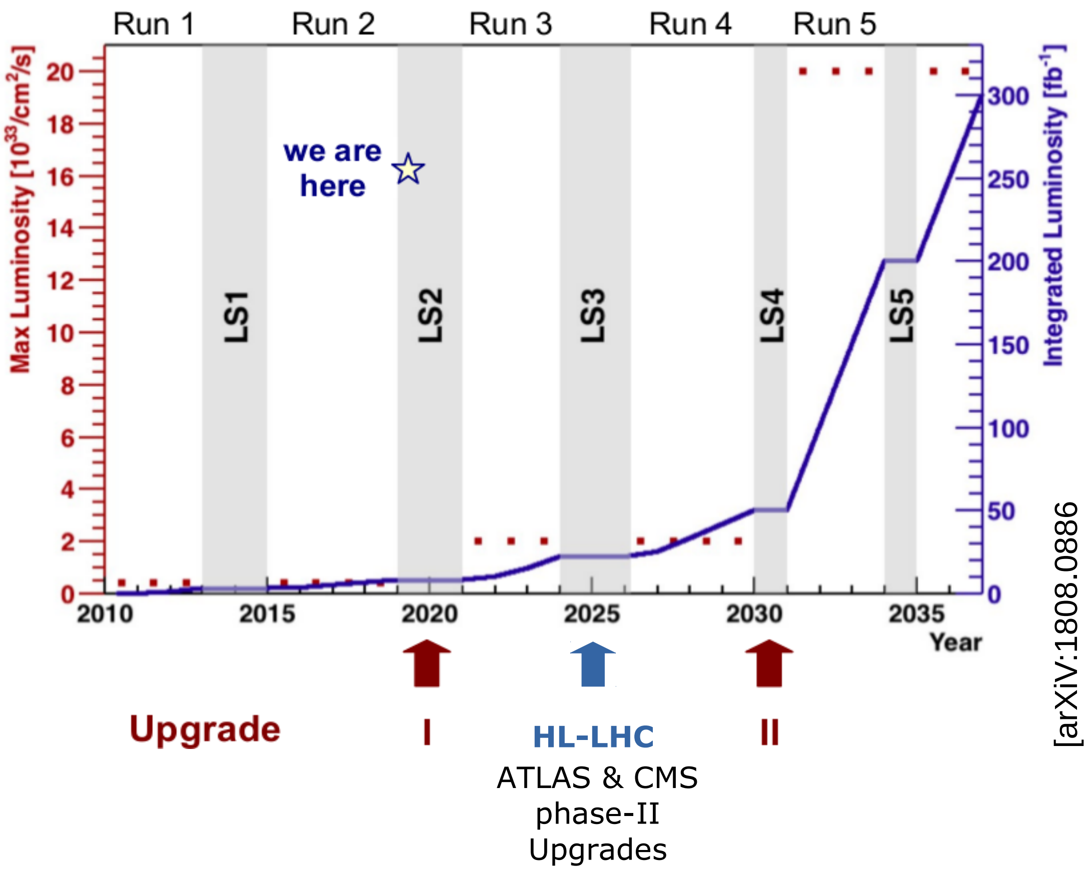
(*) average number of visible pp interactions per bunch crossing

Upgrade I (2021-2029):

- Raise operational **luminosity x5**
- ***Full* software trigger**:
  - Allows effective operation at higher luminosity
  - Improved efficiency in hadronic modes

Upgrade II (2031-~2038):

proposal to upgrade the LHCb experiment in order to ***take full advantage of the flavor-physics opportunities at the HL-LHC***



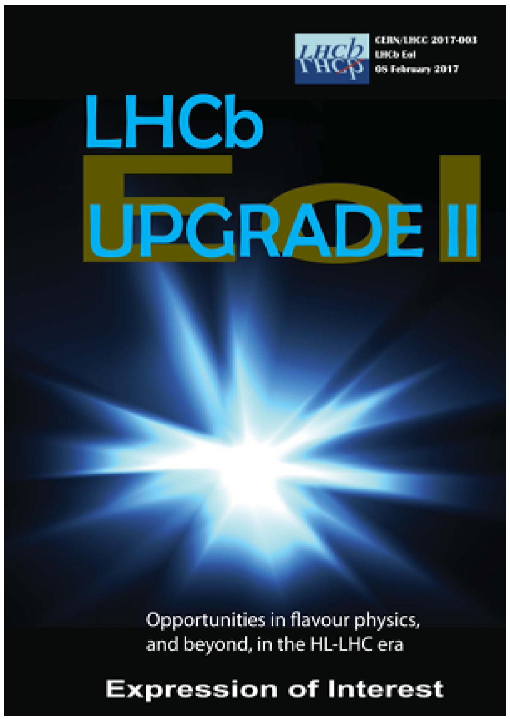
[arXiV:1808.0886

Flavor physics has the potential to continue **exploring new physics territory** provided **large enough samples** are available
➔ Precision Frontier

LHCb Upgrade II

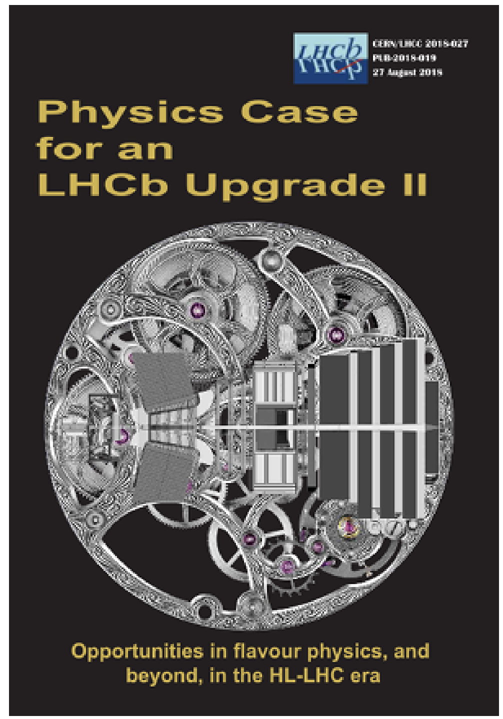
Begin after LS4 (2030). Operate at up to $2x10^{34}$ $cm^{-2}s^{-1}$ & collect (at least) 300 fb^{-1}.
➔ Significant experimental challenges to perform flavor physics at such a luminosity

EoI submitted to LHCC in early 2017



[CERN-LHCC-2017-003]

Full physics case submitted to Sept. LHCC



[CERN-LHCC-2018-027, also arXiv:1808.08865]

In parallel, many studies from the machine side, summarized in a report which identifies

“a range of potential solutions for operating LHCb Upgrade II at a luminosity of up to 2×10^{34} cm^{-2} s^{-1} and permitting the collection of 300 fb^{-1} or more at IP8 during the envisaged lifetime of the LHC”

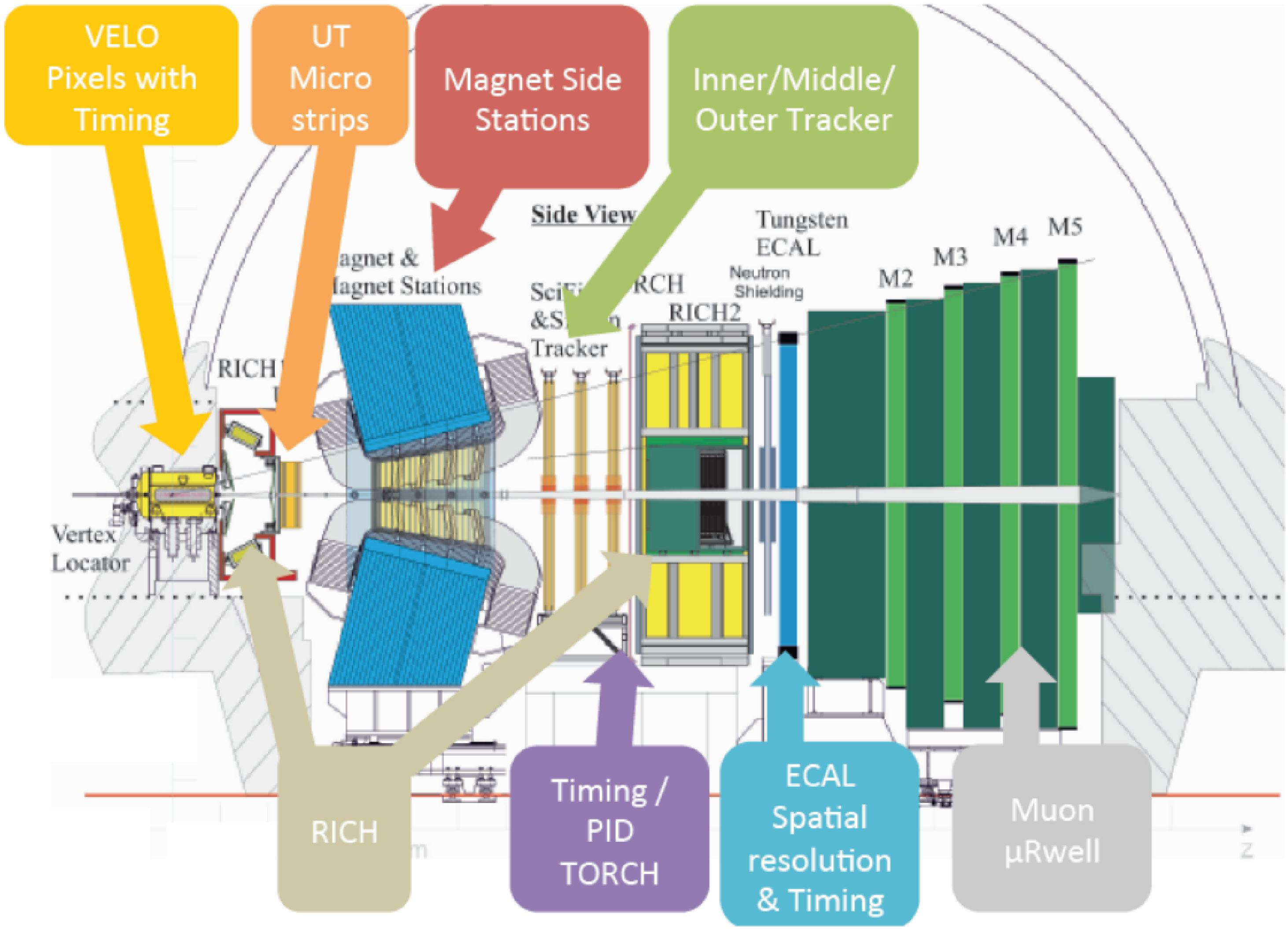
[CERN-ACC-NOTE-2018-038]

Approved by LHCC (Feb. 2019)
→proceed to Framework TDR (including computing) by end of 2020/early 2021

LHCb phase-II upgrade (design phase)

Main features to cope with high luminosity:

- **Radiation hardness**
- Increase **granularity** to cope with increased multiplicity
- **Fast-timing** information essential for suppressing combinatorial background



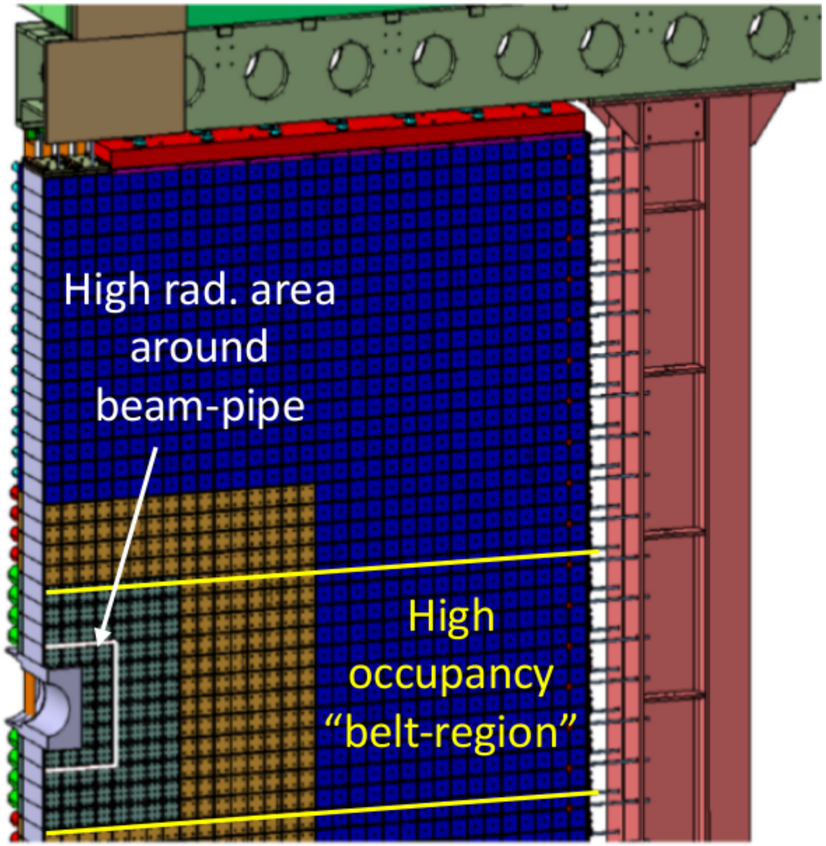
LHCb ECAL Upgrade II

LS3 in 2024/25: Consolidation

- **Replace modules around beam-pipe** (≥ 32 modules, ~50-60 kGy) compatible with $L=2x10^{33}\ cm^{-2}s^{-1}$

LS4 in 2030/31: LHCb Upgrade II

- **Rebuilt ECAL in high occupancy "belt-region"** compatible with luminosity up to $L=2x10^{34}\ cm^{-2}s^{-1}$
- Include **timing information** to mitigate multiple interactions/crossing



- 32 modules for extreme conditions (up to 1 MGy!)
- 150 new modules with "moderate" radiation requirements (up to 200 kGy)
- Can reshuffle inner type modules (176 modules). Can reshuffle middle type modules (448 modules). 2688 out of 3312 modules are of outer type.

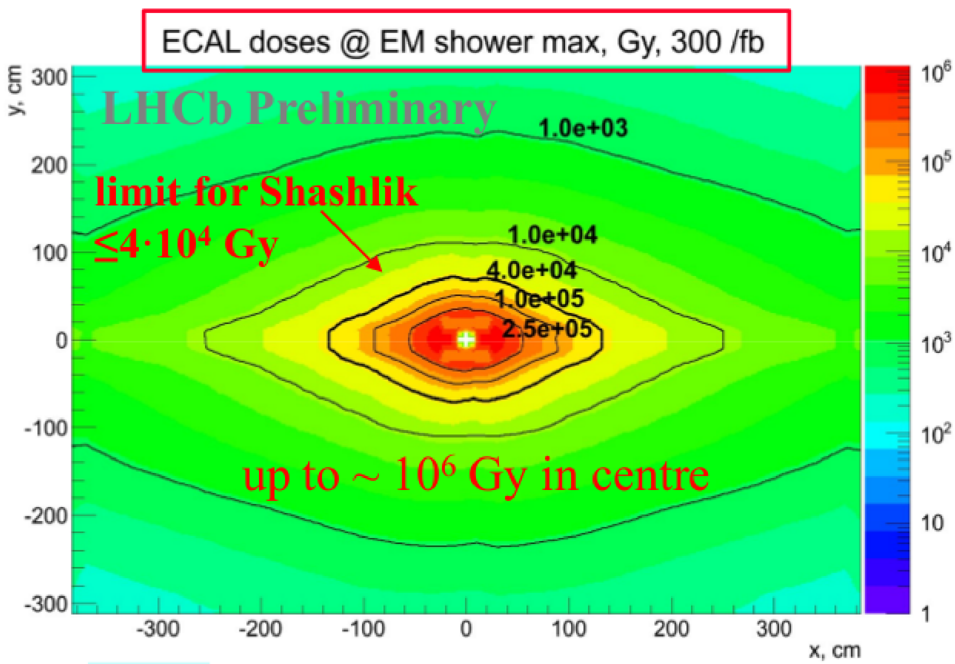
ECAL requirements for Upgrade II

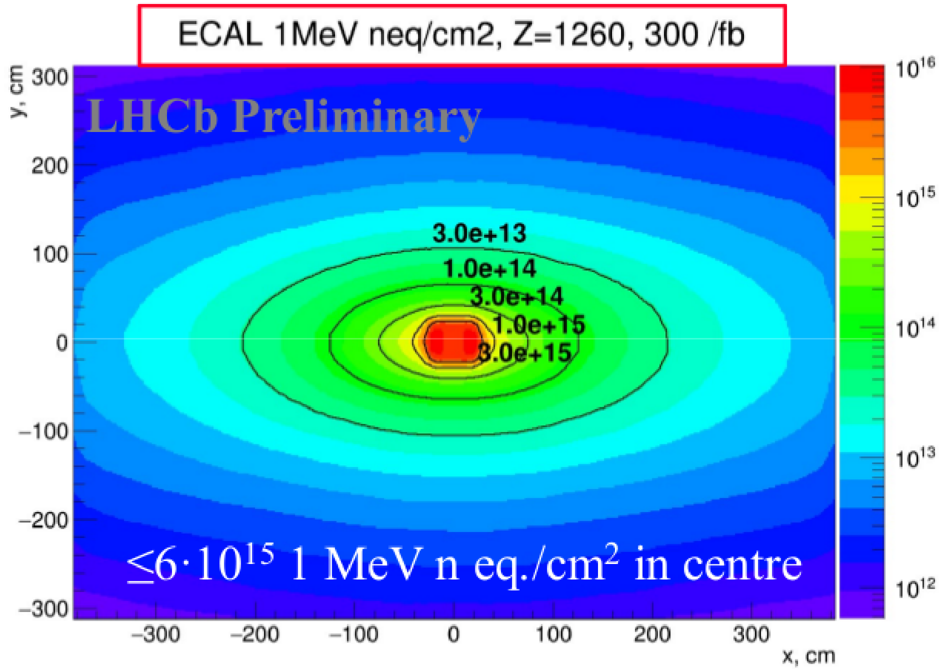
Overall requirements:

- sustain **radiation doses** of up to ~1MGy and ≤$6 \cdot 10^{15}$ cm^{-2} for 1MeV neq/cm^2 at 300 fb^{-1}
- **good timing properties** for both, the decay time component (spill-over, 25ns) and the rise time (pile-up mitigation, ~several 10^{th} of ps)

(1MGy = 100Mrad)

- keep good **energy resolution** of order $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1\%$
- handle **increased occupancy** by improving spatial resolution in inner & middle region
- respect dimensional **constraints of a module**: 12 x 12 cm^2 outer dimension





On-going R&D at CERN and test-beam evaluations

https://ep-dep.web.cern.ch/rd-experimental-technologies

Fast-timing to mitigate pile-up

<u>Possible options:</u>

1) dedicated timing layer in front of the ECAL modules (“timing pre-shower”)

   a) with silicon layers?

   b) with fast crystal layers?

2) ~tenth of ps timing incorporated to the ECAL module

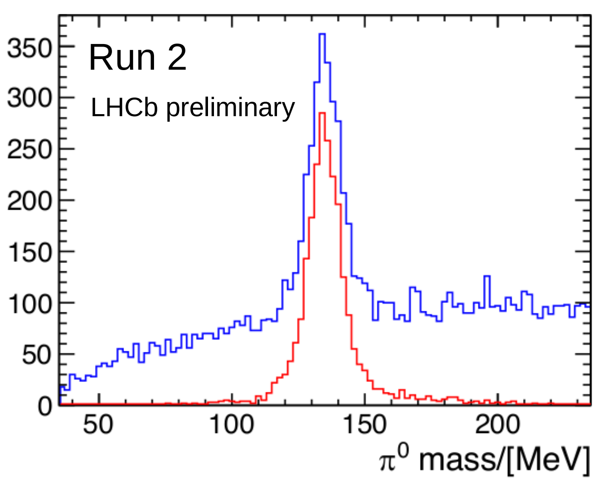
➔ Possibly a mixture of the two depending on the region (inner, middle, outer)?

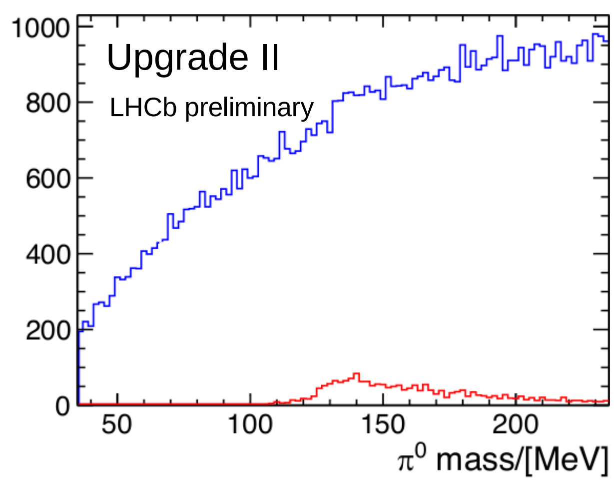
<u>Preliminary</u> studies done with fast parametric simulation (DELPHES) ArXiv:1307.6346 JHEP 02 (2014) 057

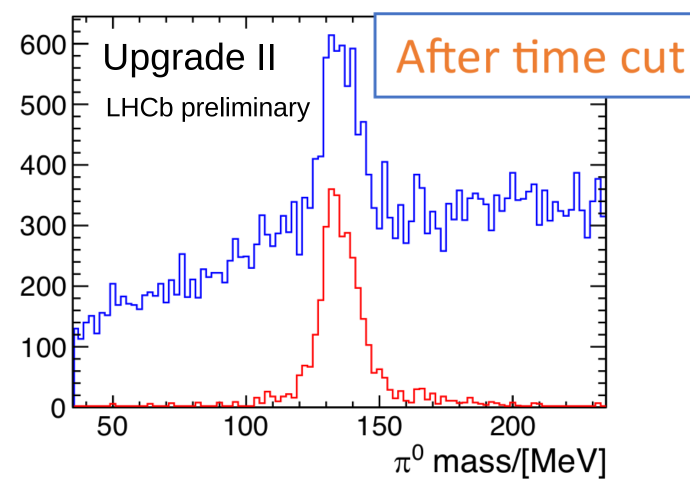
Reconstruct π^0 in minimum bias sample:

- $p_T(\gamma) > 0.2$ GeV/c
- $p_T(\pi^0) > 2$ GeV/c
- Time resolution 40 ps

Z. Xu *et al.*, 4th workshop on LHCb Upgrade II
https://indico.cern.ch/event/790856/



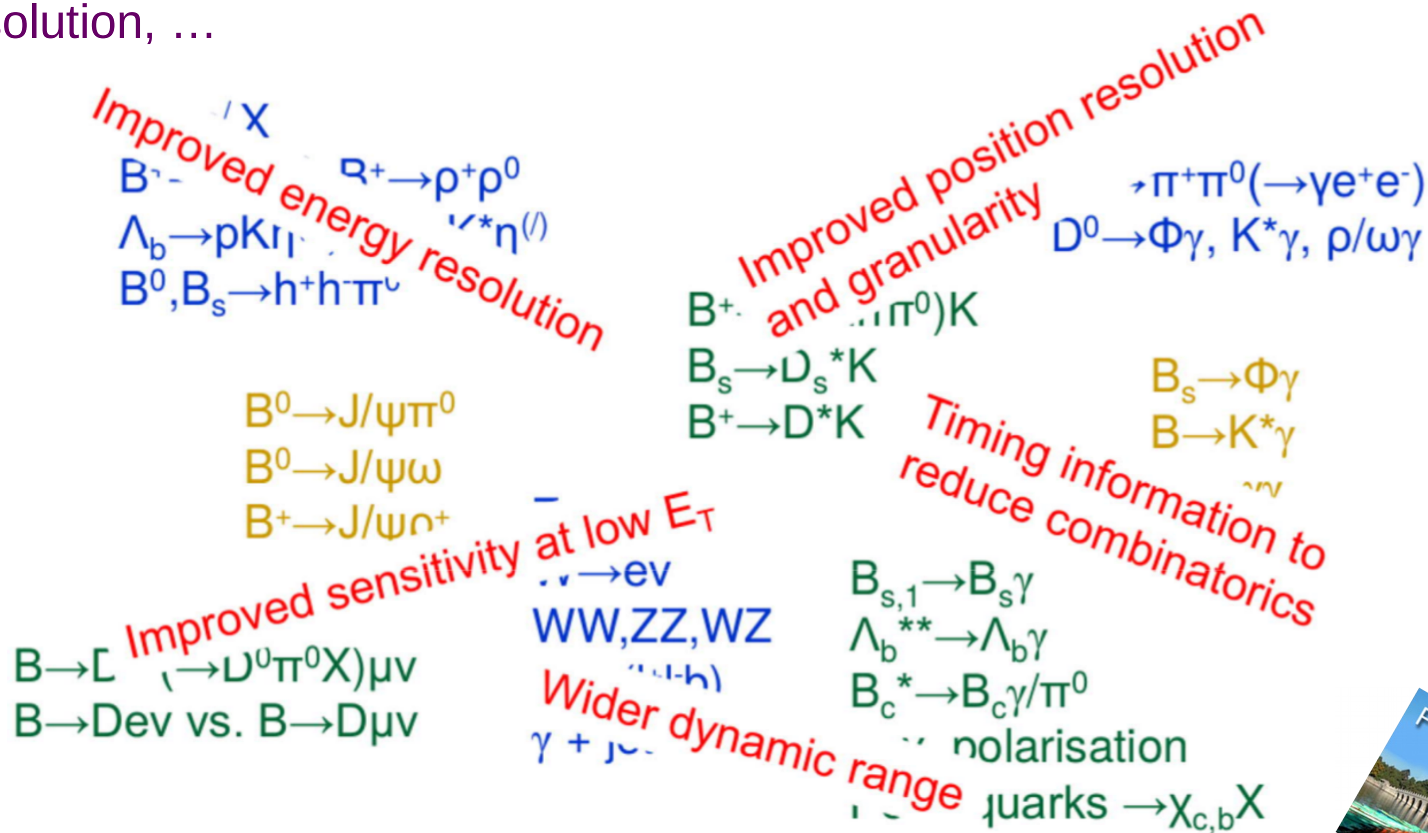




ECAL design parameters and performance studies

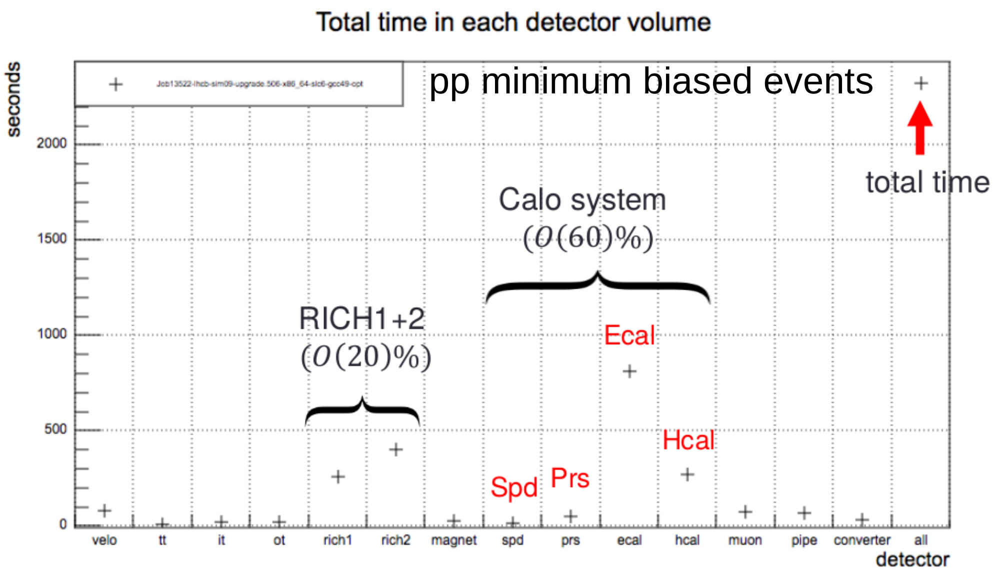
5D ECAL requirements (E, x, y, z, t) to be determined from **physics performance studies** for:

- “hottest” and “intermediate” inner region to define E-resolution, cell size, Moliere radius, …
- middle and outer region to optimize “re-shuffling strategy”
- optimization of the reconstruction procedure in the high pile-up environment: clustering, timing resolution, …



➪ Simulation studies for an overall detector optimization to define the design parameters from physics and environment

ECAL fast simulation

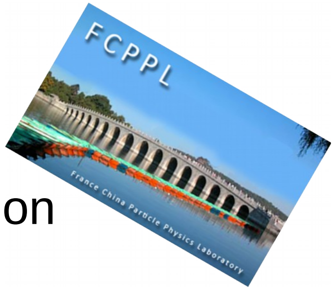


Most of the CPU time in Geant4-simulated events is spent in the calorimeter system

On-going developments:

- Frozen-shower Libraries [SLAC-PUB-14790]
- Hits generation based on Generative Adversarial Network (GAN)

➔ Aim to speed up ~O(3-10)



- Fully parametric fast simulation (DELPHES)

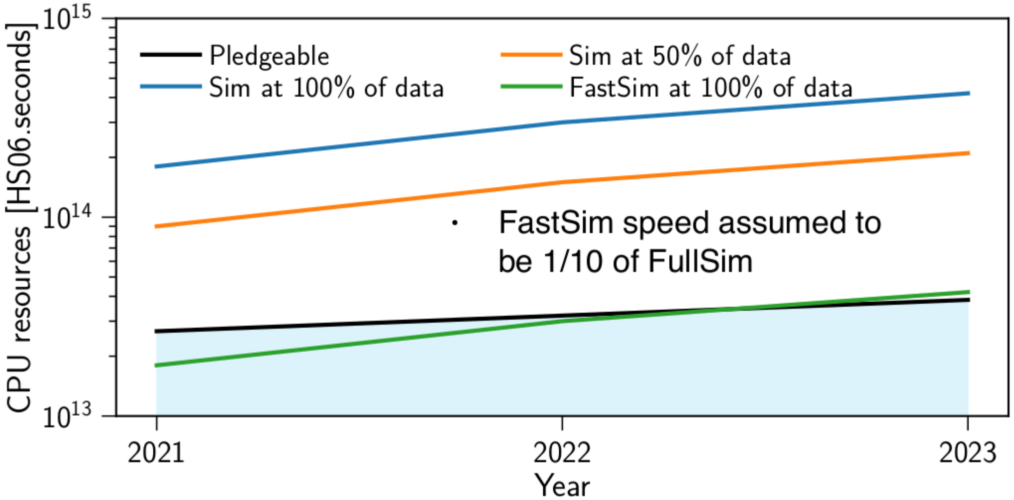
➔ Aim to speed up ~O(100-1000)

Simulation takes most of the distributed resources

- Run 2: 75%
- Run 3: >90%

➔ Simulation for Upgrade I:

Full/Fast/Parametric (40%/40%/20%)



Crucial to have reliable fast/parametric simulations for upgrade I and design studies for upgrade II

LHCb phase-I upgrade: software-only trigger!

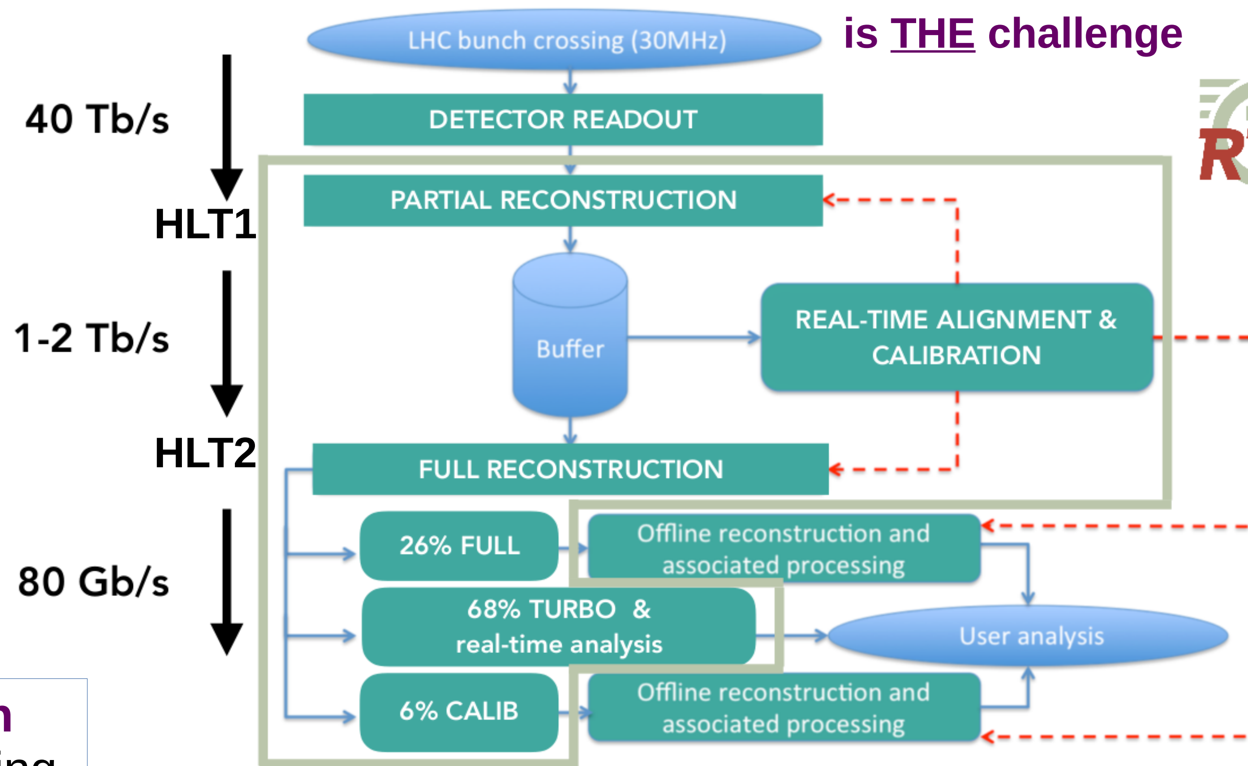
In the LHCb upgrade I, every event will contain at least 2 light, long-lived hadrons with displaced vertices → **saturate any trigger**.

⇒ New paradigm is required: **readout and reconstruct 30 MHz of collisions in software** with

- offline-quality reconstruction
- offline-quality selections

Re-design of algorithms from sequential to concurrent framework.

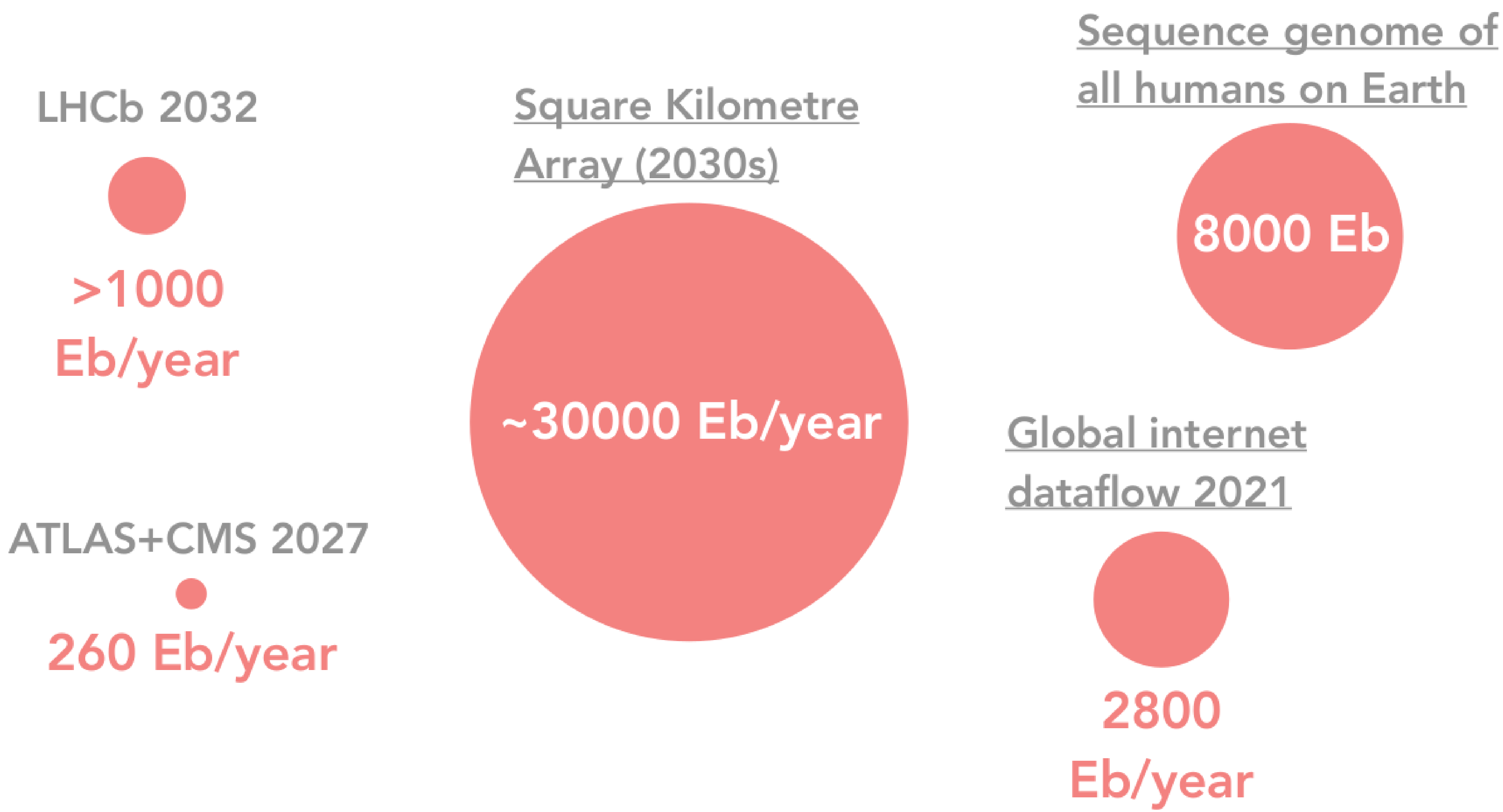
x30 input rate, but x100 input bandwidth wrt Run 2: Data processing is THE challenge



LHCb Run 3 data flow

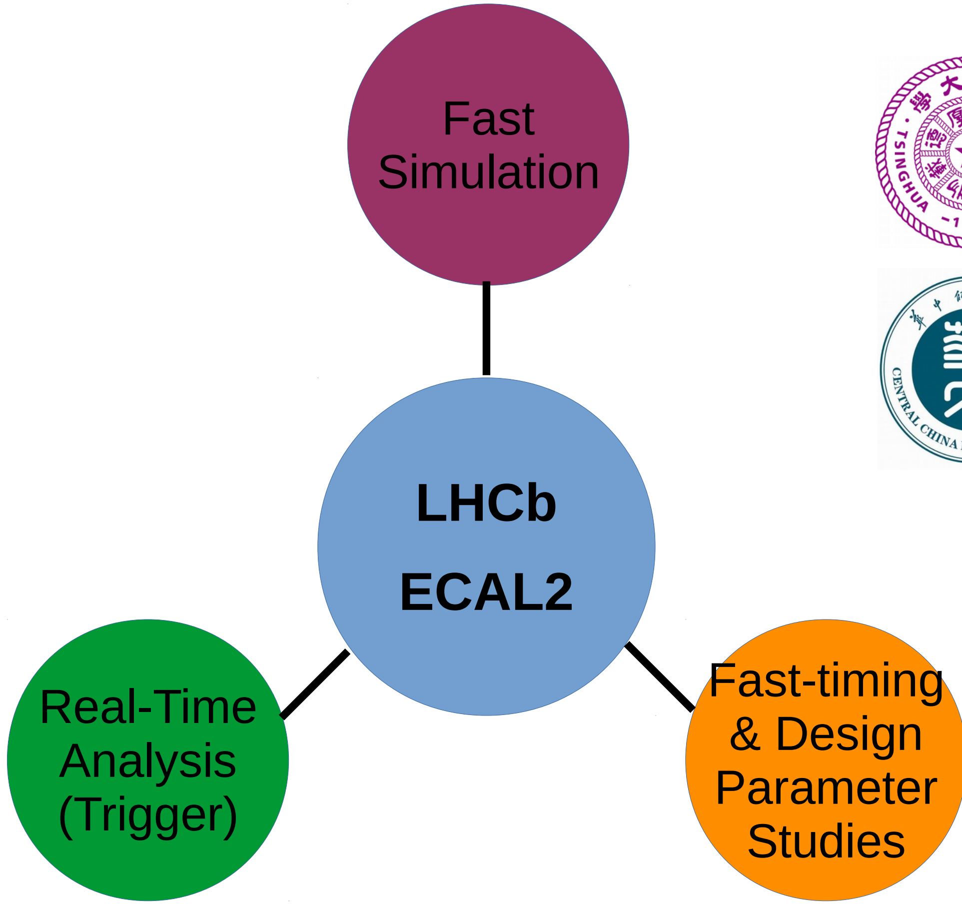
Your analysis selection done in HLT2 (~1 MHz)! (there is no turning back...), **enabled** by analysis-quality calibration and alignment

The main challenge of Upgrade II: exabyte era!



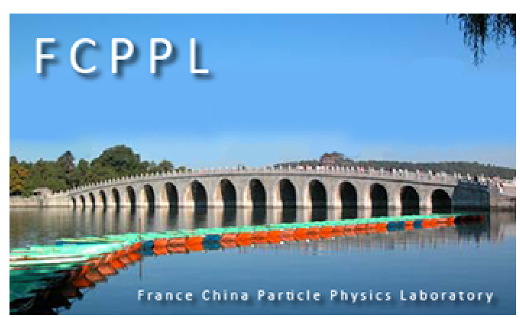
- Upgrade II **DAQ** must process 10x the HL-LHC GPD data rate
- Upgrade II **Offline** must process same data volume as HL-LHC GPDs

FCPPL LHCbECAL2



"Long expertise in the LHCb calorimeter (DAQ, operation, trigger, performances, PID, reconstruction software)"

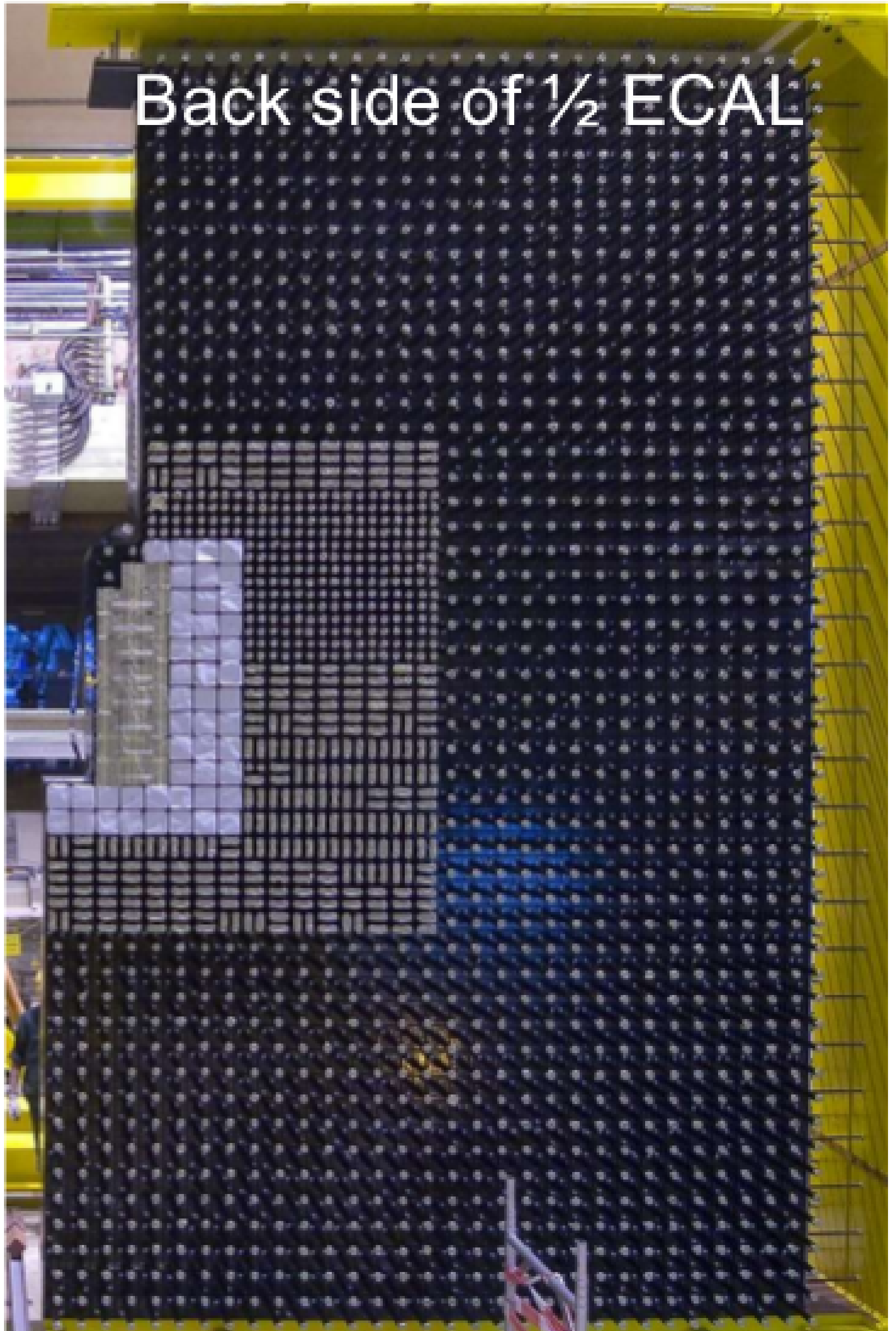
"ECAL as combined contribution for upgrade II. Leading role in fast simulation and timing studies."



► LHCbECAL2 workshop on April 27-28

BACKUP SLIDES

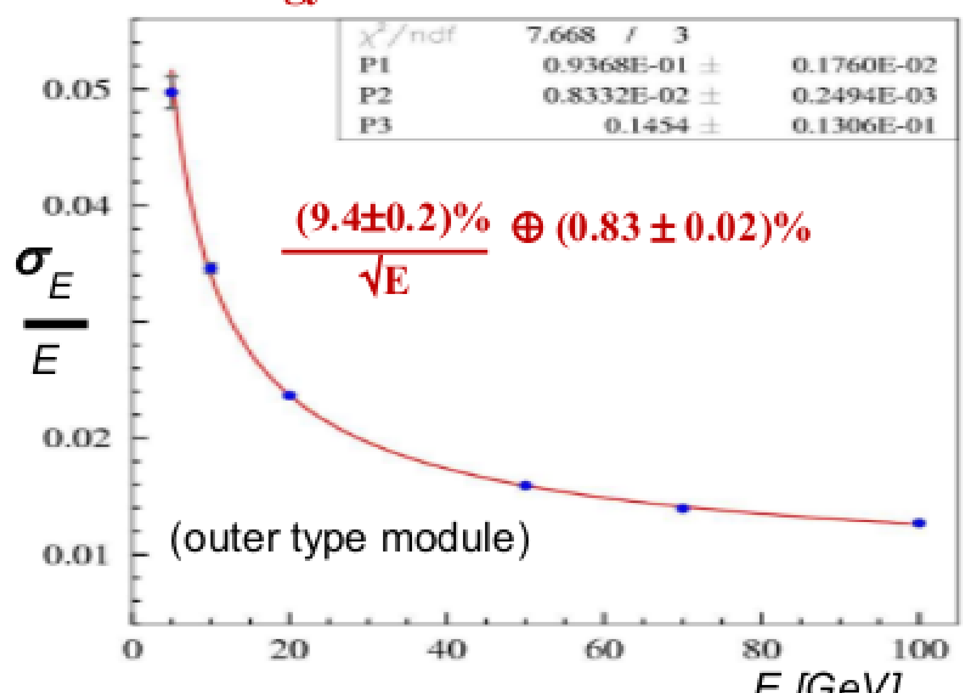
The current LHCb Electromagnetic Calorimeter



Current LHCb ECAL:

- Large Shashlik array ~50 m^2 with 3312 modules and 6016 channels
- Modular wall-like structure of ~8 x 7 m^2, two halves open laterally within few minutes
- Three sections (Inner, Middle, Outer) of cell size 4x4, 6x6, 12x12 cm^2
- **$\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1\%$**

Energy resolution with electrons

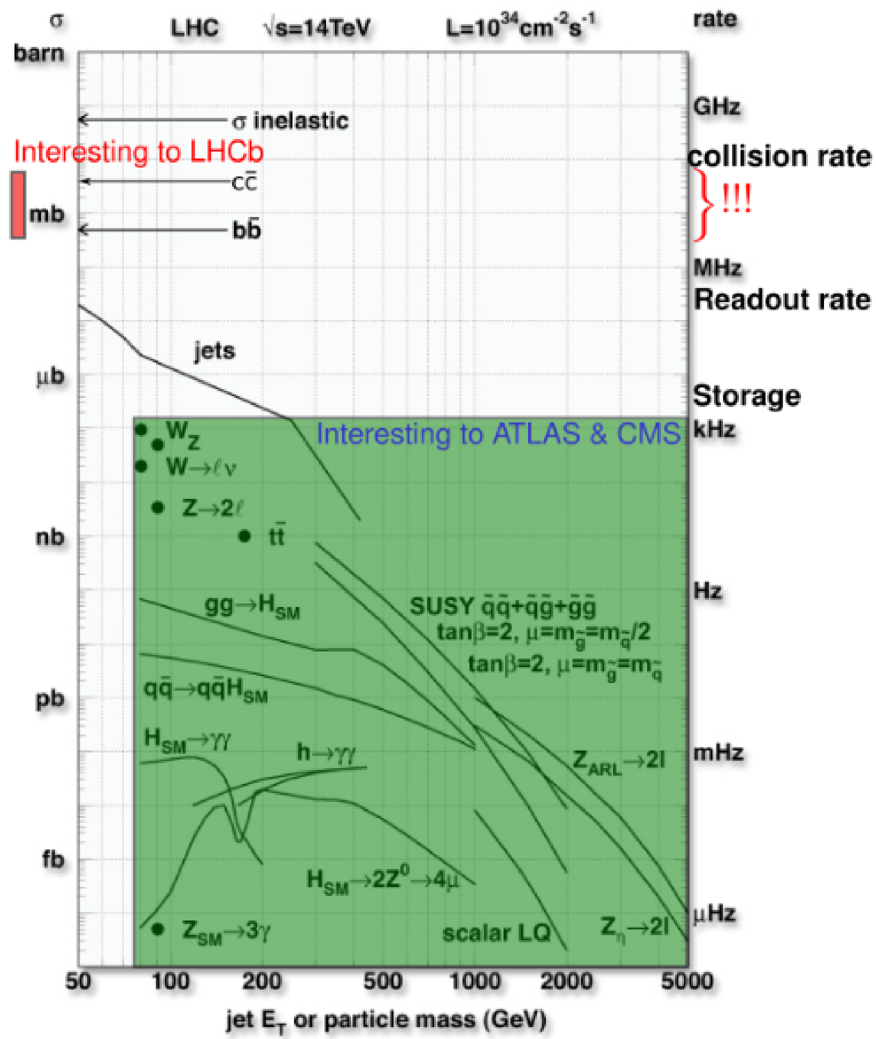


CERN-LHCC-2018-014

Model assumptions			
L ($cm^{-2}s^{-1}$)	2×10^{33}		
Pileup	6		
Running time (s)	5×10^6 (2.5×10^6 in 2021)		
Output bandwidth (GB/s)	10		
Fraction of `Turbo` events	73%		
Ratio `Turbo`/`FULL` event size	16.7%		
Ratio full/fast/param. simulations	40:40:20		
Data replicas on tape	2		
Data replicas on disk	2 (`Turbo`); 3 (`FULL`, `TurCal`)		
Resource requirements			
WLCG Year	Disk (PB)	Tape (PB)	CPU (kHS06)
2021	66	142	863
2022	111	243	1.579
2023	159	345	2.753
2024	165	348	3.467
2025	171	351	3.267

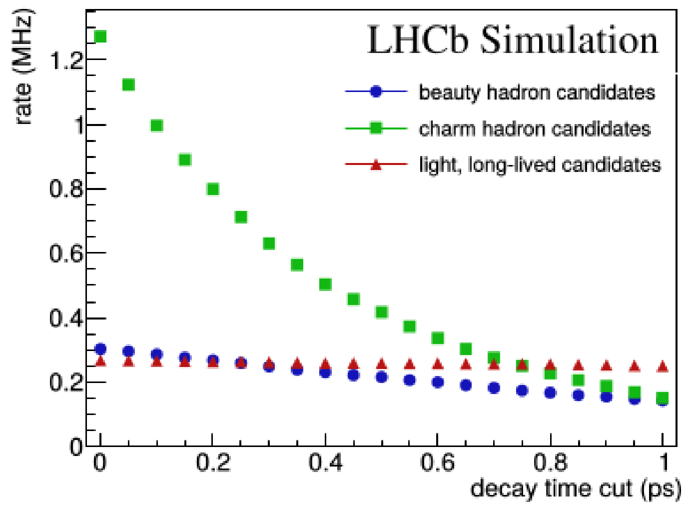
The LHCb trigger

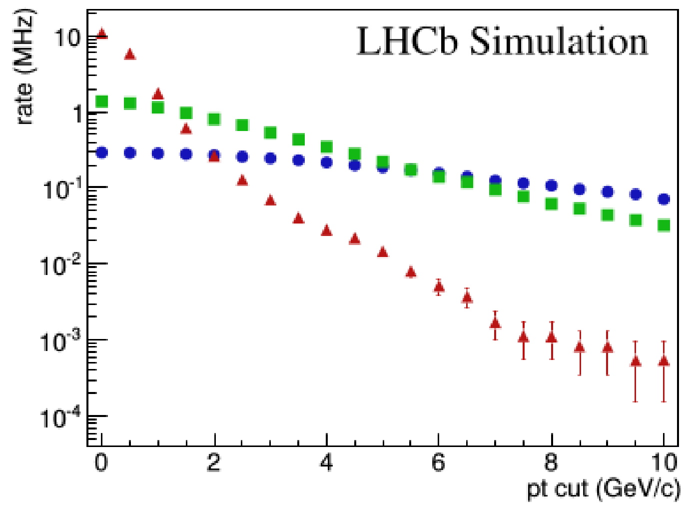
- A trigger is needed to reduce storage and readout costs
- A *good* trigger does so by keeping more signal than background
- General purpose LHC experiments are interested in signatures in the kHz region
  - Readout at 100kHz is efficient with reasonably straightforward E_T requirements
- LHCb ($\mathfrak{L} = 4 \times 10^{32} \text{cm}^{-2}\,\text{s}^{-1}$) faces a unique challenge:
  - 45kHz of $b\bar{b}$, $\sim$1MHz of $c\bar{c}$
  - 1MHz readout is needed to stay efficient for beauty signals



The MHz signal era

- Starting in 2021, LHCb will run at $\mathcal{L} = 2 \times 10^{33}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$: $5\times$ more collisions per second





- Readout becomes a bottleneck as signal rates $\rightarrow$ MHz even after simple trigger criteria [6]

[6] LHCb-PUB-2014-027

So what 'stuff' can we throw away?

- The problem is no longer one of rejecting (trivial) background
- Fundamentally changes what it means to trigger

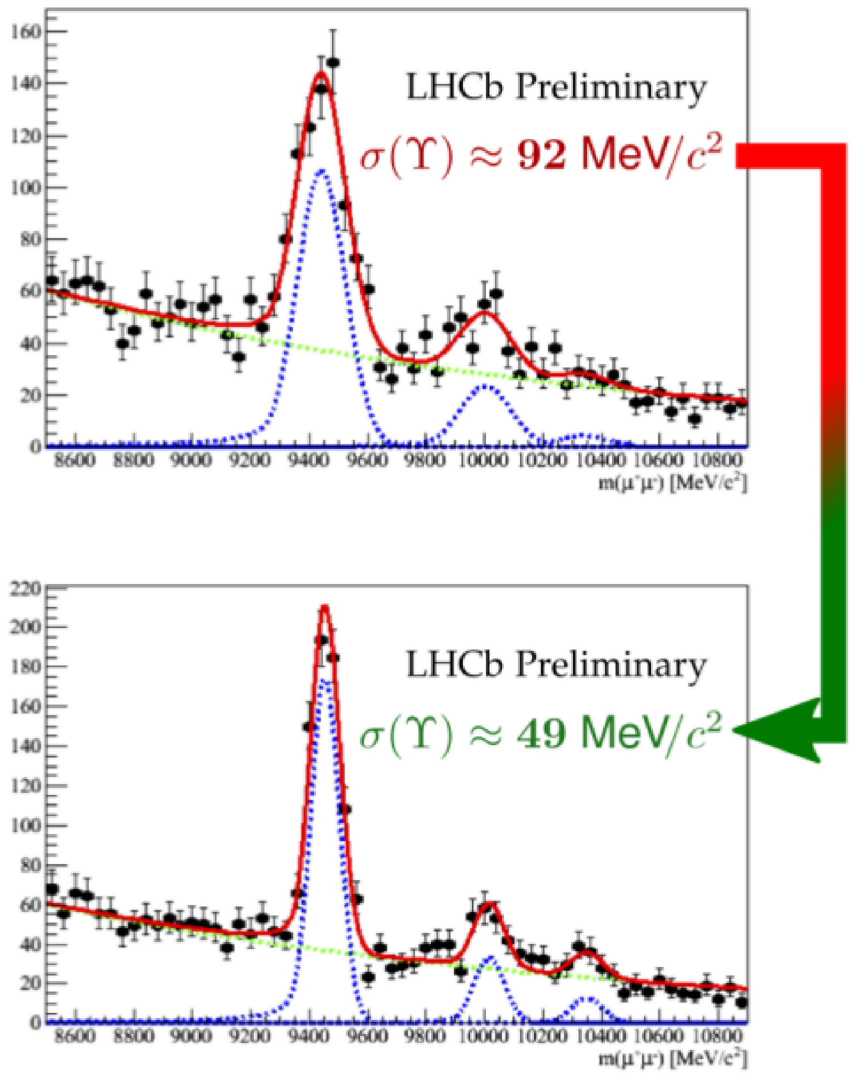
- Instead, we need to categorise different 'signals'
  - Requires access to as much of the event as possible, as early as possible

C. Fitzpatrick

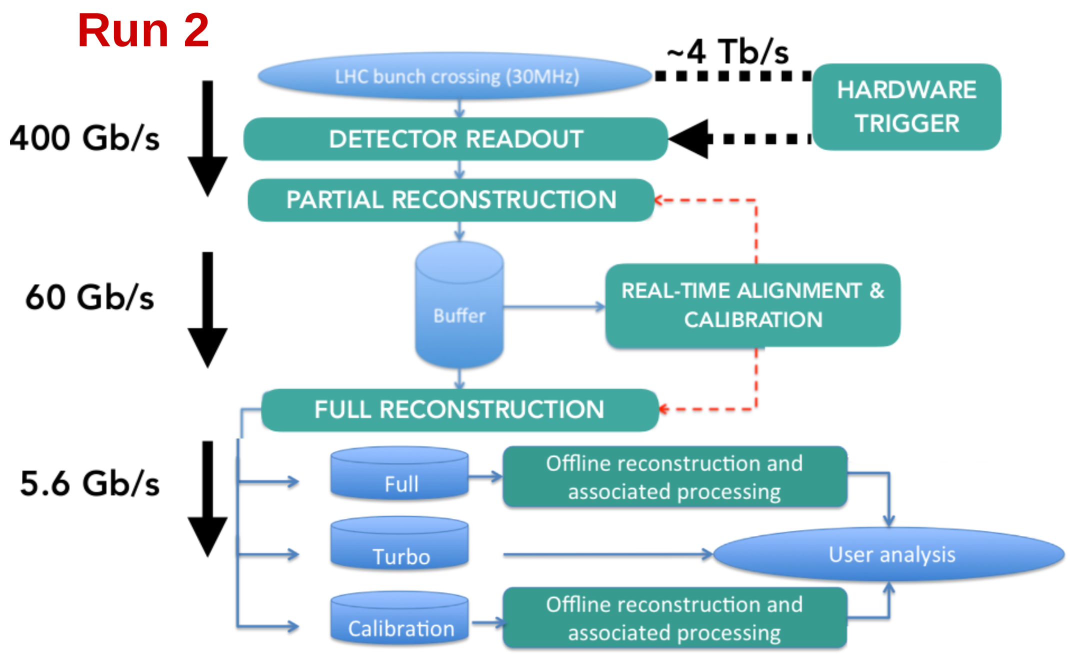
March 12, 2019

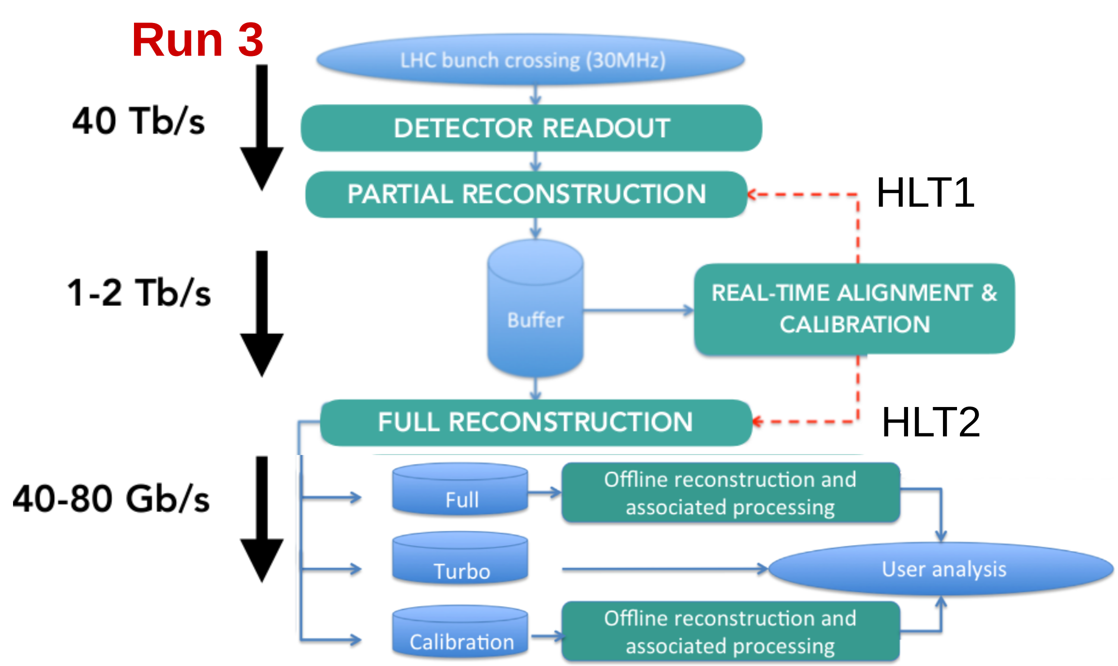
Real-time Alignment + Calibration

- With Run 2 signal rates, efficient & pure output requires full reconstruction at HLT2
  - Online selections → offline selections
  - Reduces systematic uncertainties and workload for analysts
- Alignment and calibration of full detector in the trigger needed
- While HLT1 is written to disk, alignment & calibration tasks run



Trigger: Run 2 versus Run 3





Run-1 ➔ Upgrade II: Order of magnitude in precision

Observable	Current LHCb	Upgrade II
EW Penguins		
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.007
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.008
R_ϕ, R_{pK}, R_π	–	0.02, 0.02, 0.05
CKM tests		
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	1°
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	0.35°
$\sin 2\beta$, with $B^0 \to J/\psi K^0_S$	0.04 [609]	0.003
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	4 mrad
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	9 mrad
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	11 mrad
a_{sl}^s	33×10^{-4} [211]	3×10^{-4}
$\lvert V_{ub}\rvert / \lvert V_{cb}\rvert$	6% [201]	1%
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$		
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	10%
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	2%
$S_{\mu\mu}$	–	0.2
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**		
$R(D^*)$	0.026 [215, 217]	0.002
$R(J/\psi)$	0.24 [220]	0.02
Charm		
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [613]	3.0×10^{-5}
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	1.0×10^{-5}
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	8.0×10^{-5}

Physics Case for an LHCb Upgrade II, CERN-LHCC-2018-027