LHCb trigger in Run 3

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IGFAE

Instituto Galego de Física de Altas Enerxías

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The LHCb upgrade

<table>
<tr><td>2019</td><td>2020</td><td>2021</td><td>2022</td><td>2023</td><td>2024</td><td>2025</td><td>2026</td><td>2027</td><td>2028</td><td>2029</td><td>2030</td><td>2031</td><td>2032</td><td>…</td></tr>
<tr><td colspan="2">LS2</td><td colspan="3">Run 3</td><td colspan="2">LS3</td><td colspan="4">Run 4</td><td colspan="2">LS4</td><td colspan="2">Run 5</td></tr>
<tr><td colspan="2">LHCb 40 Mhz
Upgrade
Phase 1a</td><td colspan="3">$L = 2 \times 10^{33}$</td><td colspan="2">LHCb 40 MHz
Upgrade Phase 1b</td><td colspan="4">$L = 2 \times 10^{33}$
$50\ fb^{-1}$</td><td colspan="2">LHCb
Upgrade Phase II</td><td colspan="2">$L = 2 \times 10^{34}$
$300\ fb^{-1}$</td></tr>
<tr><td colspan="2">ATLAS
Upgrade Phase I</td><td colspan="3" rowspan="2">$L = 2 \times 10^{34}$
$300\ fb^{-1}$</td><td colspan="2">ATLAS
Upgrade Phase II</td><td colspan="4" rowspan="2">HL-LHC
$L = 5 \times 10^{34}$</td><td colspan="2">ATLAS</td><td colspan="2" rowspan="2">HL-LHC
$L = 5 \times 10^{34}$
$3000\ fb^{-1}$</td></tr>
<tr><td colspan="2">CMS
Upgrade Phase I</td><td colspan="2">CMS
Upgrade Phase II</td><td colspan="2">CMS</td></tr>
<tr><td>Belle II</td><td colspan="2">$5\ ab^{-1}$</td><td colspan="2">$L = 8 \times 10^{35}$</td><td colspan="2">$50\ ab^{-1}$</td><td colspan="7"></td></tr>
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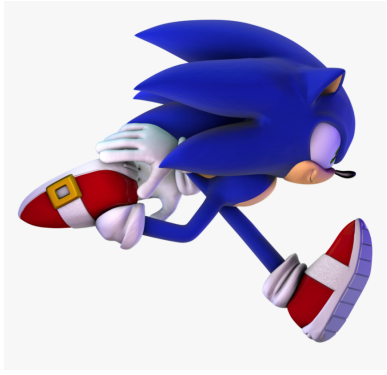
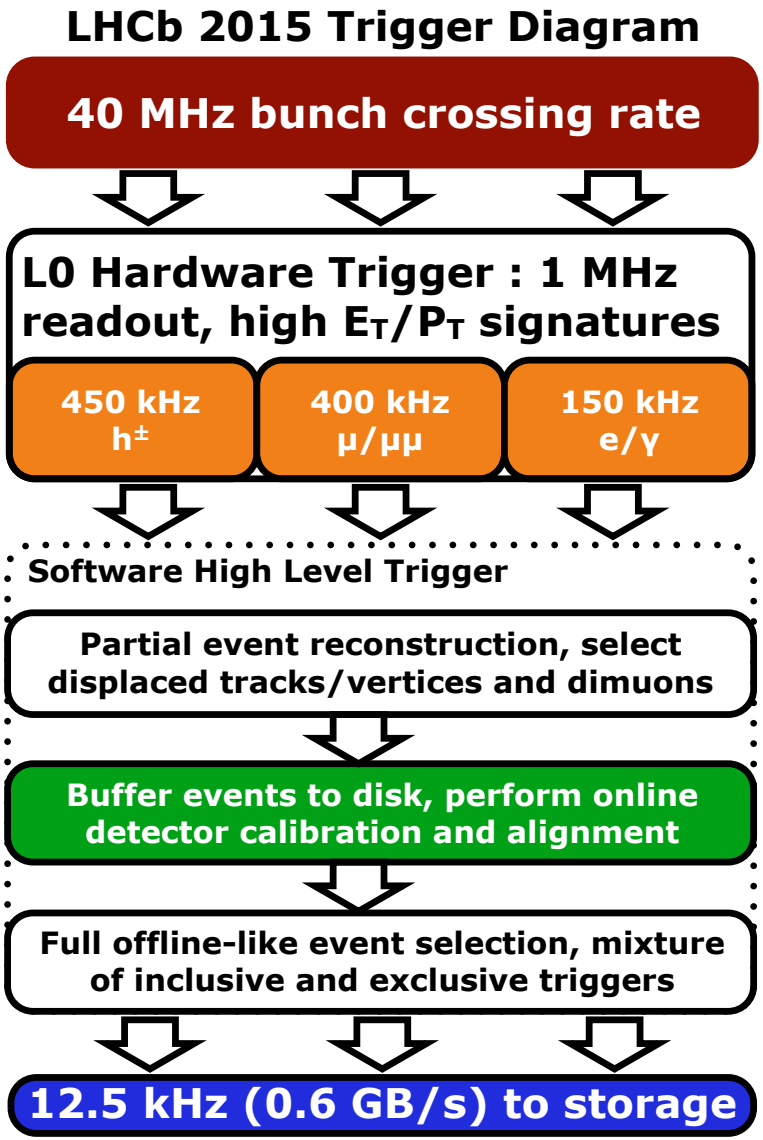
- Facing a luminosity 5 times higher 4×10^{32} cm^{-2}s^{-1} $\rightarrow 2 \times 10^{33}$ cm^{-2}s^{-1}.
- A more extreme environment is ahead of us:
  - $\times 5$ increased instantaneous luminosity.
  - $\times 5$ more radiation damage.
  - $\times 5$ more vertices.
- Need to drastically improve the granularity of our tracking detectors and boost our DAQ.
- Big improvements in the software side are necessary; profit from C++ developments, new algorithms, smarter techniques...

Very challenging from the experimental point of view!



Run 1 - - - - Run 2 - - - - Run 3

The Run 2 trigger



Features:

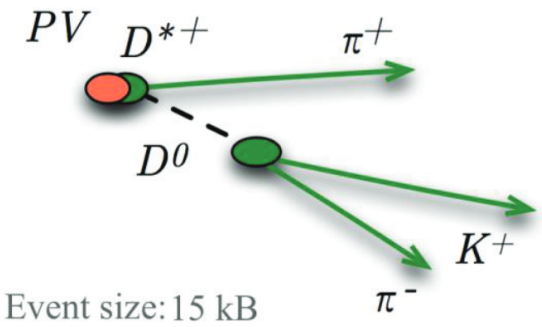
- L0 trigger implemented in hardware with high E_T/p_T signatures.
- Very versatile high level trigger composed by two stages.
- Inclusive lines at HLT1.
- Mixture of inclusive and exclusive lines at HLT2.

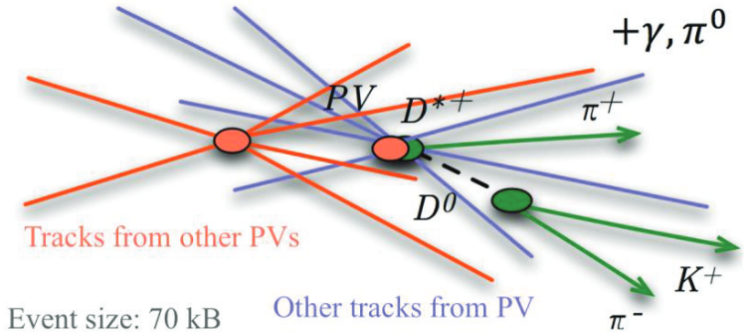
During Run 2, it was shown that applying online alignment and calibration was possible.

Same performance as offline in HLT2, profiting from the same tools and efficiencies.

The Turbo stream

All events must satisfy at least one L0 and one HLT1 trigger lines. After this, candidates can go to a Full stream (all the event is kept) or the Turbo stream [J.CPC.2016.07.022].

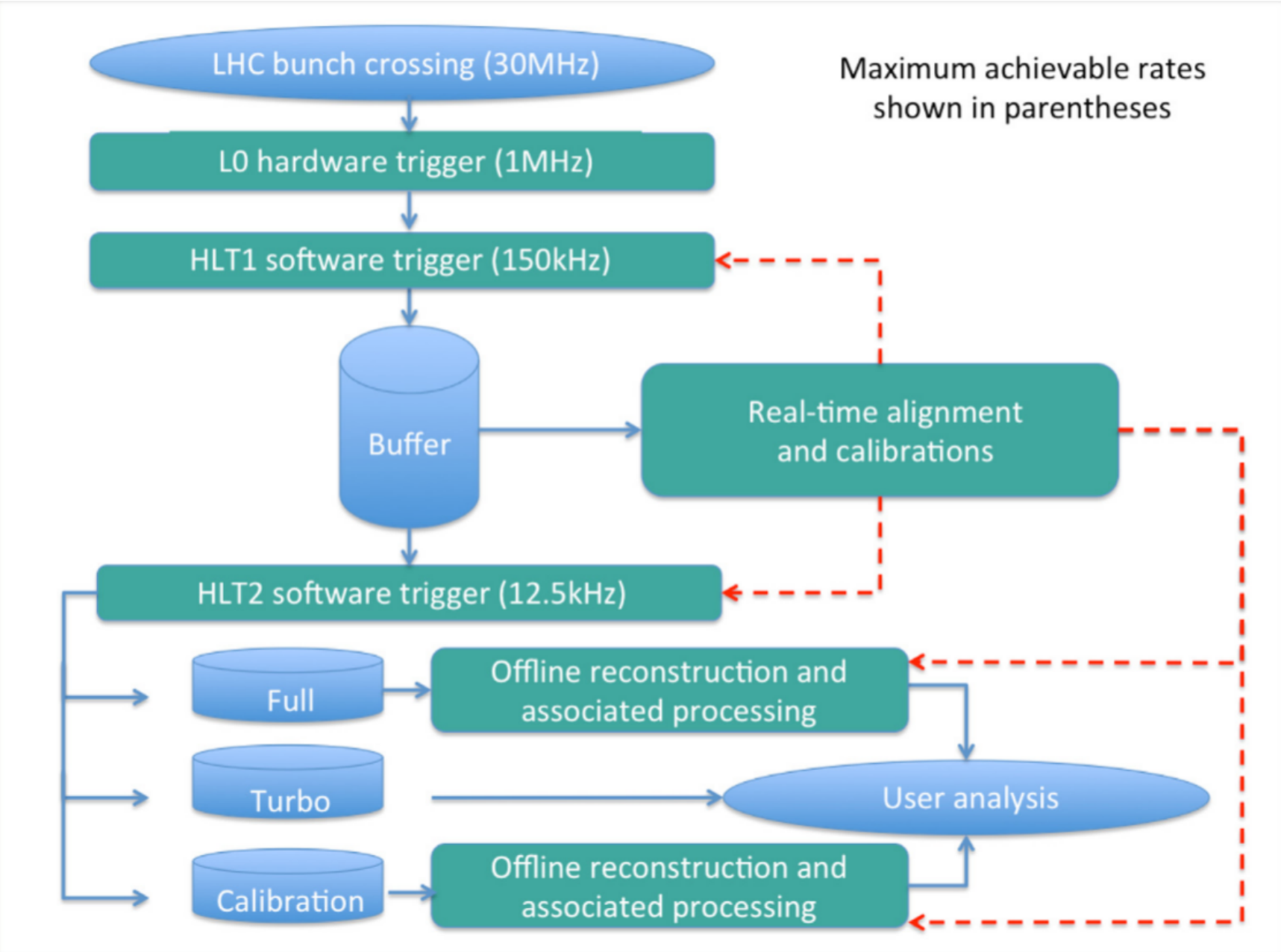




The inclusion of Turbo stream in Run 2 increased even more the flexibility after HLT1:

- New data stream composed by L0 + HLT1 + Turbo events.
- Keep only the information of interest from the event.
- Events can not be reprocessed.
- Trigger configuration based on many different lines devoted to specific decays (exclusive).
- Drastically reduce the bandwidth and increase the signal discrimination.

Data flow in Run 2



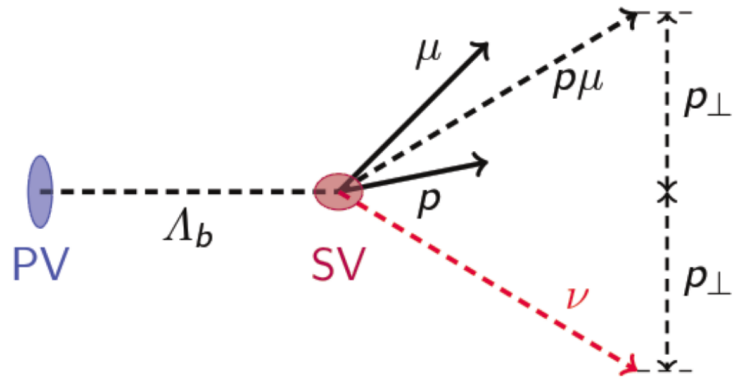
Topological triggers [LHCb-PUB-2011-002]

Most important lines at LHCb, selecting n-body b-hadron decays:

- Lines based on rectangular cuts and MVA selections.
- Single-track and two-track lines at HLT1 ($p_T > 0.5$ GeV/c).
- Combination of 2, 3 and 4 tracks at HLT2 (iterative method).
- Mainly designed to select decays with hadrons in the final state.
- Use the corrected mass in order to make mass-cuts (remain inclusive).
- Possibility to exclude c-hadrons by requiring a minimum corrected mass of 4 GeV/c^2 on any n-body combination:

$$m_{\text{corr}} = \sqrt{m^2 + p_\perp^2} + p_\perp$$

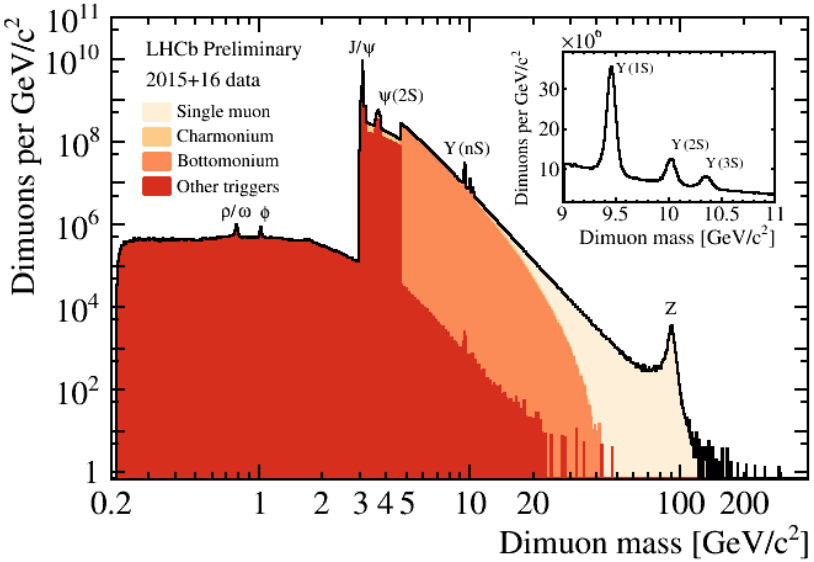
Useful for normalization and jet tagging.



(Semi)leptonic triggers

Profit from inclusive single-muon and dimuon/dielectron trigger lines for exotic searches at HLT1.

- Widely use the Turbo stream for exotic studies.
- Many different lines included for exotic searches: ALPs, dark photons, light Higgs bosons, ...
- Take advantage of the offline processing of the Full stream in order to do some analyses not planned beforehand.



Profit also from inclusive leptonic lines.

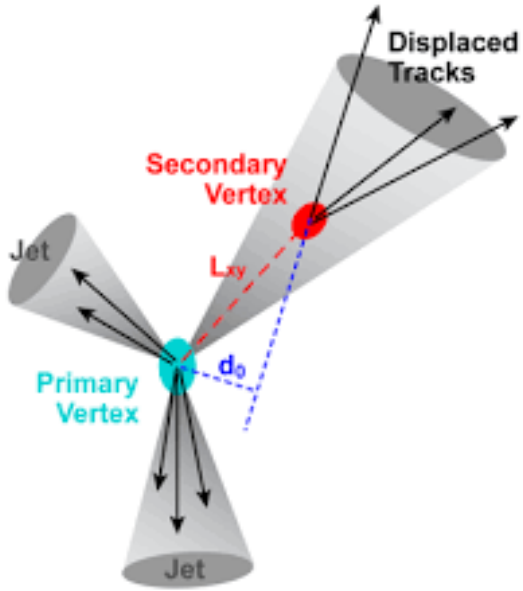
A lot of interesting results already obtained, and many more to come!

Displaced jet triggers (HLT2/Turbo only)

- Included jet reconstruction at LHCb in 2014 [JHEP (2014) 01 033].
- Use of particle-flow algorithm (including neutral recovery) for jet input.
- Anti-k_T algorithm for clustering (R=0.5, $\varepsilon > 95\%$, $p_T > 20$ GeV).
- Jet energy calibrated on data, with $Z^0 \to \mu^+\mu^-$ + jets.
- Complement jet-tagging with search for secondary vertices (SV) [JINST 10 (2015) P06013].

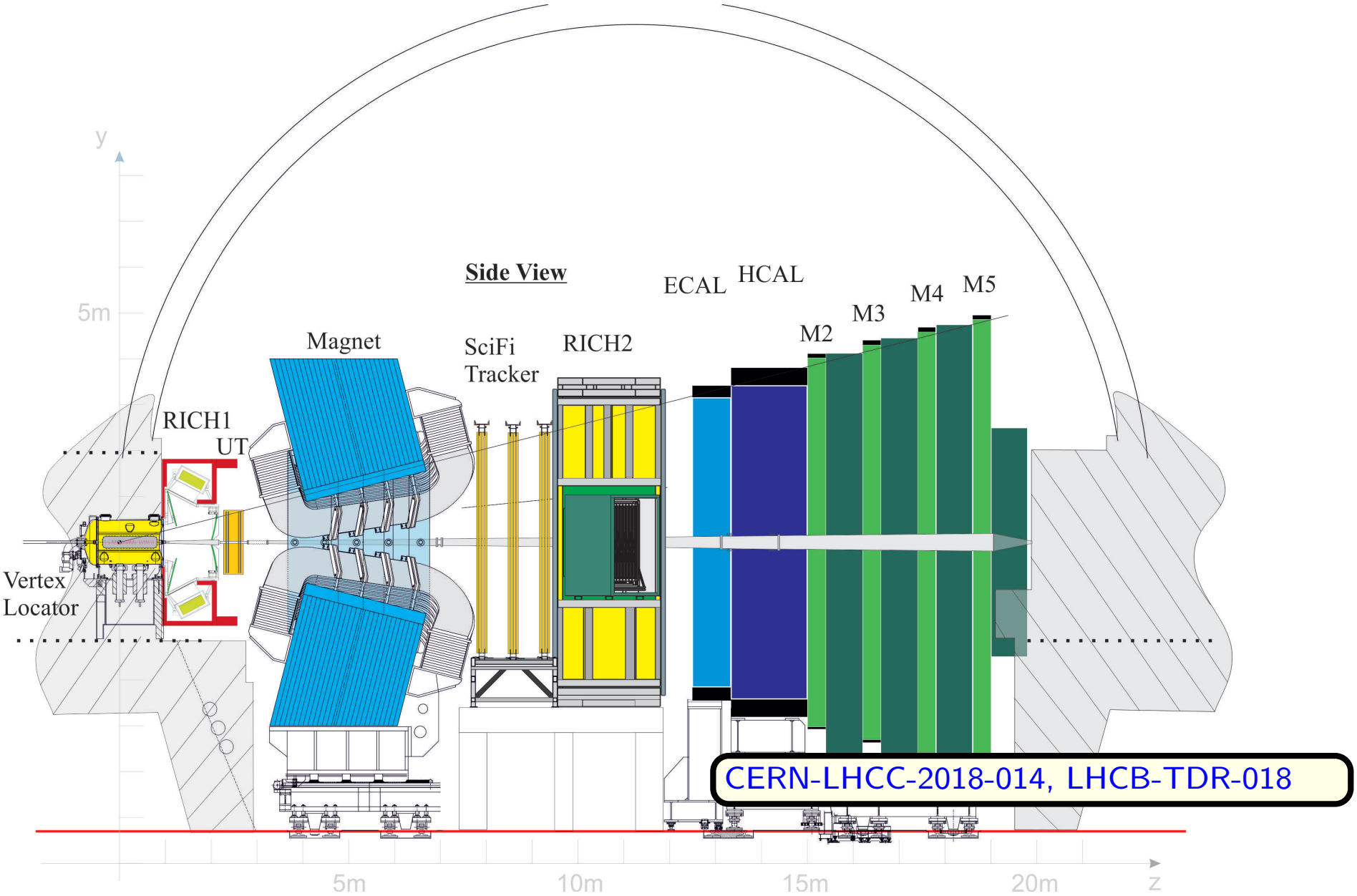
Trigger lines

- Reconstruct a jet, and look for a SV using two displaced tracks.
- If the SV lies in $\Delta R < 0.5$ w.r.t. jet axis the jet is SV-tagged.
- Definition of different lines depending on the number of SV-tagged jets.
- Downscale depending on the number of SV-tagged jets.




Into Run 3

The LHCb detector

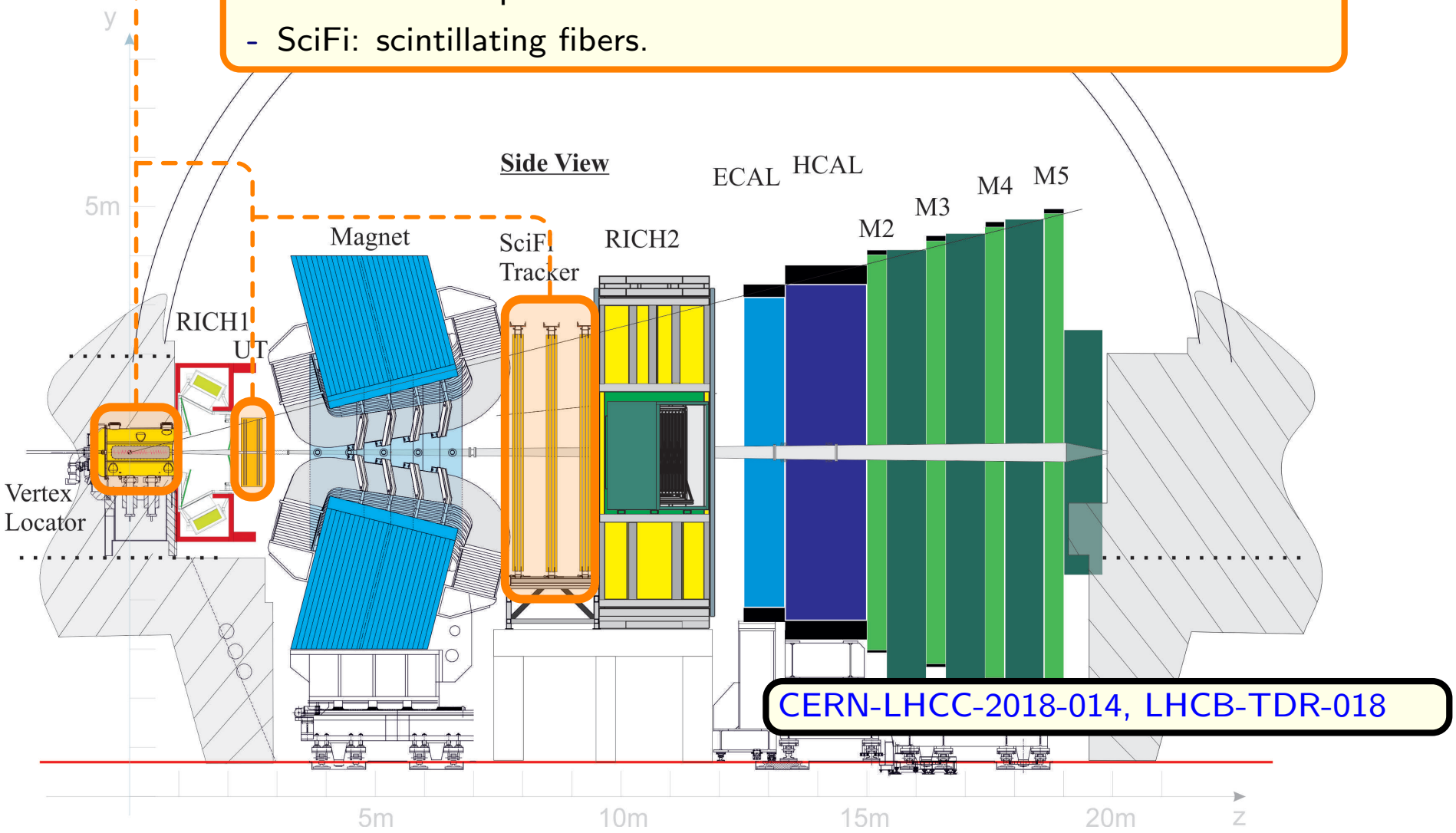


CERN-LHCC-2018-014, LHCB-TDR-018

The LHCb detector

Increase granularity of tracking stations and reduce material budget:

- VELO: silicon-pixel technology.
- UT: silicon-strip.
- SciFi: scintillating fibers.



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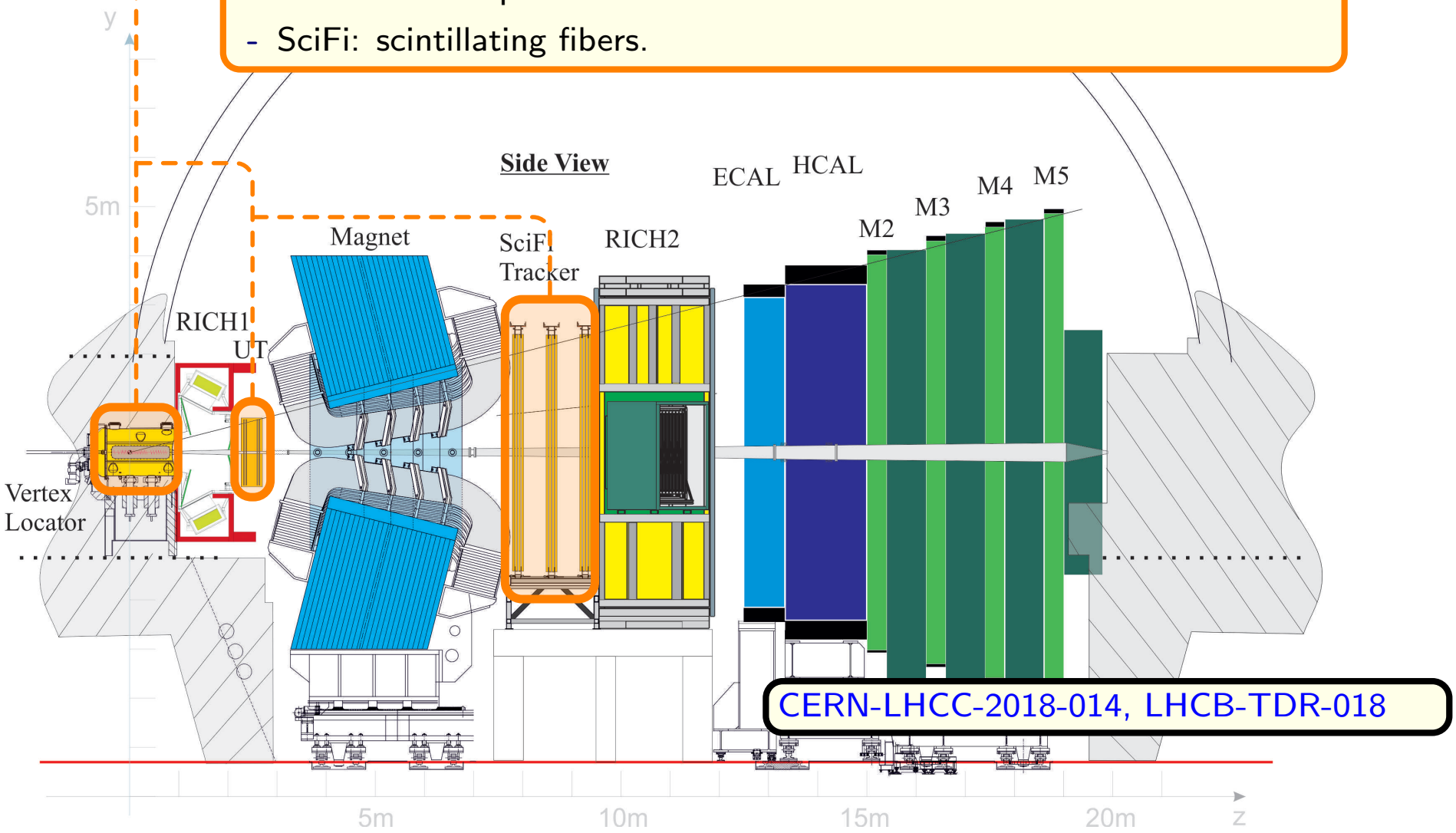

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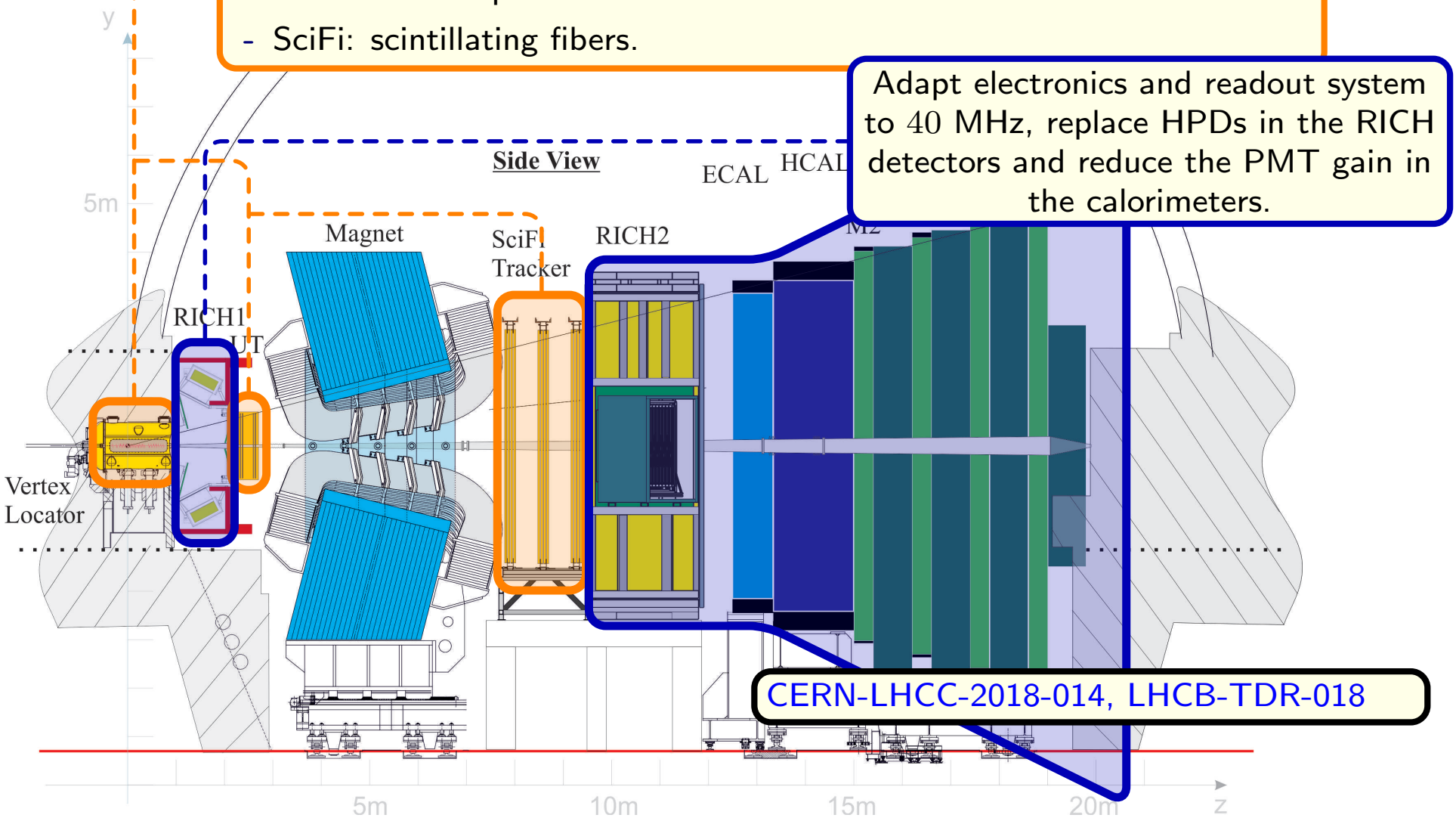
Adapt electronics and readout system to 40 MHz, replace HPDs in the RICH detectors and reduce the PMT gain in the calorimeters.



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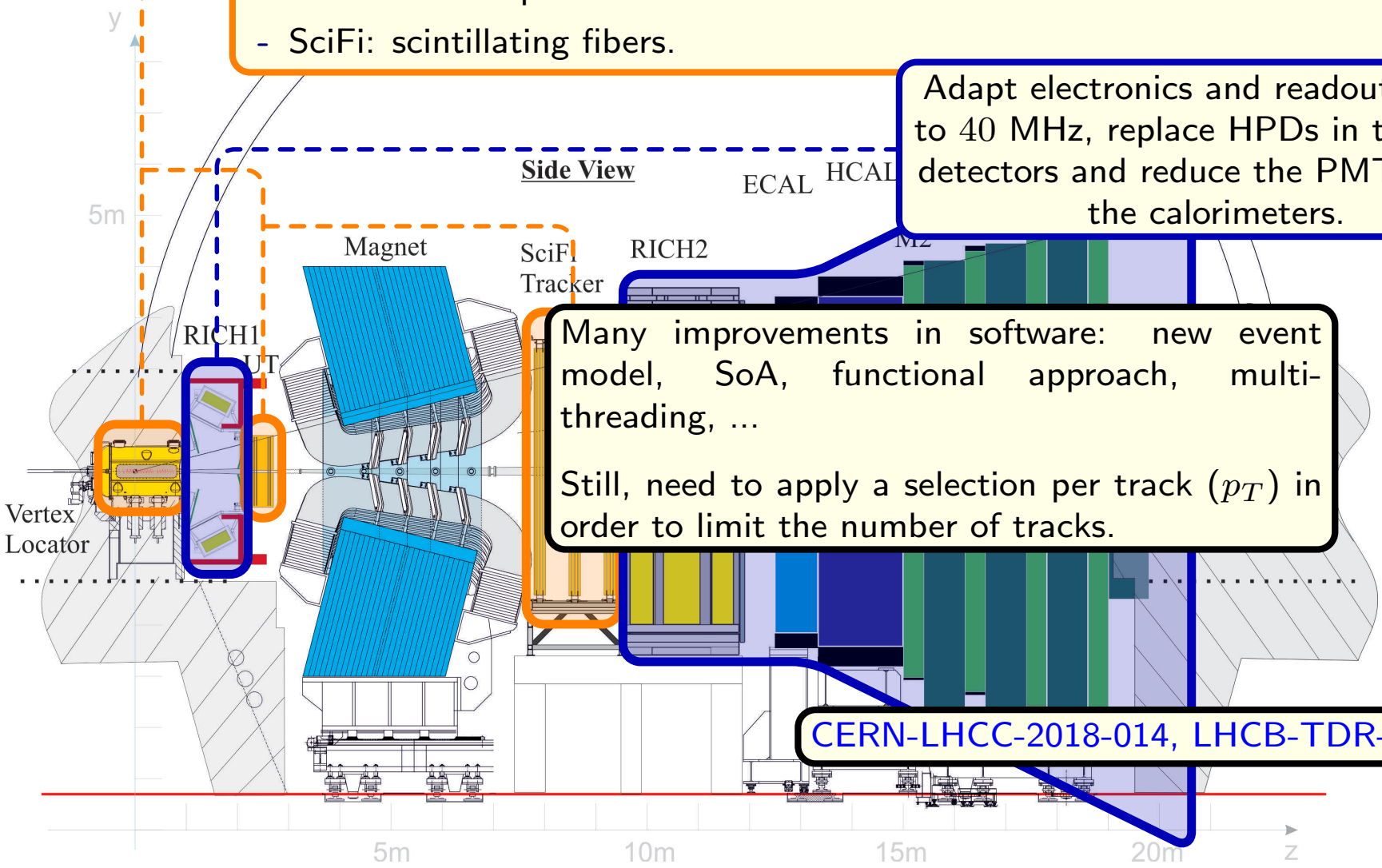
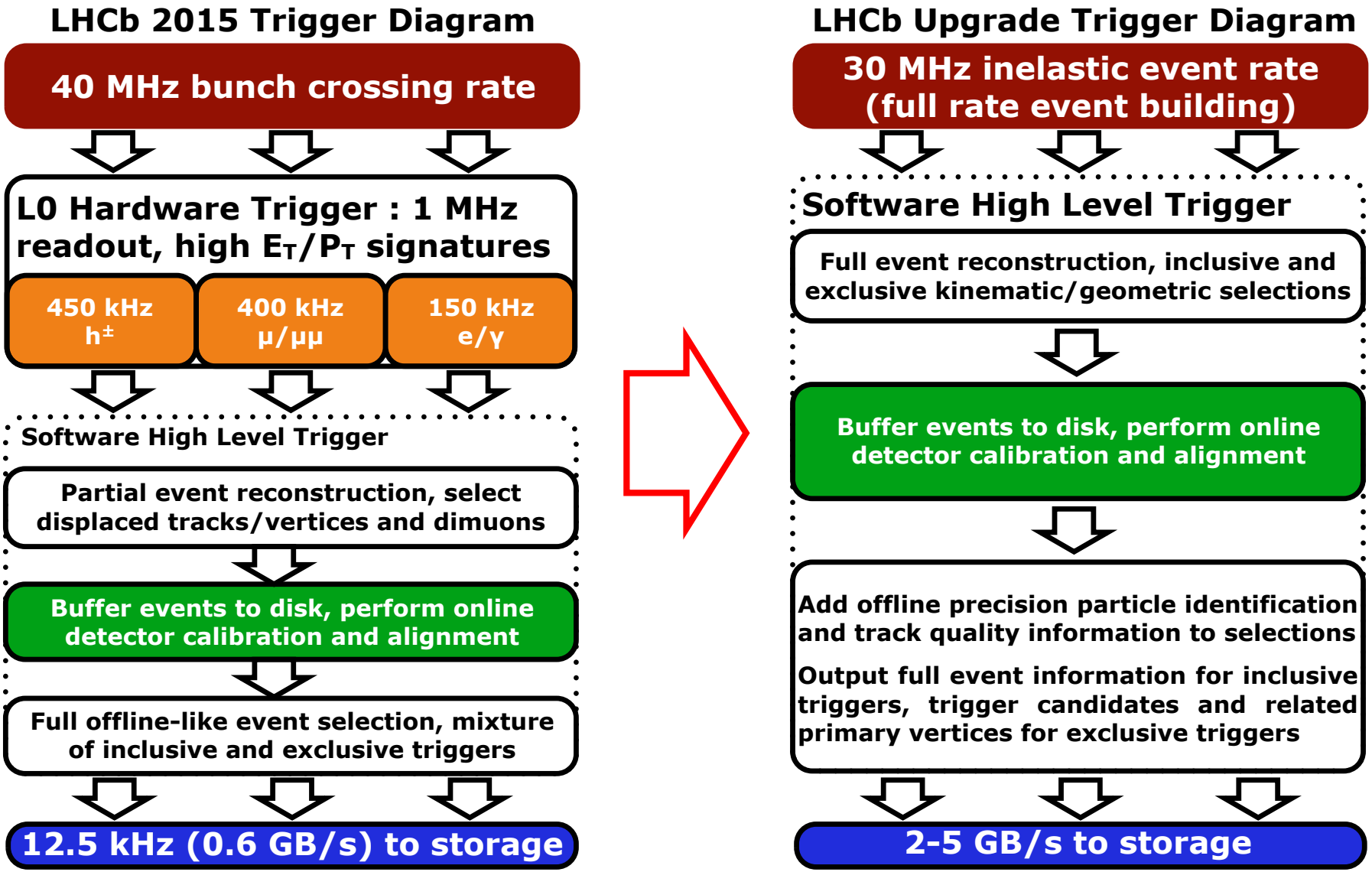


Many improvements in software: new event model, SoA, functional approach, multi-threading, ...

Still, need to apply a selection per track (p_T) in order to limit the number of tracks.

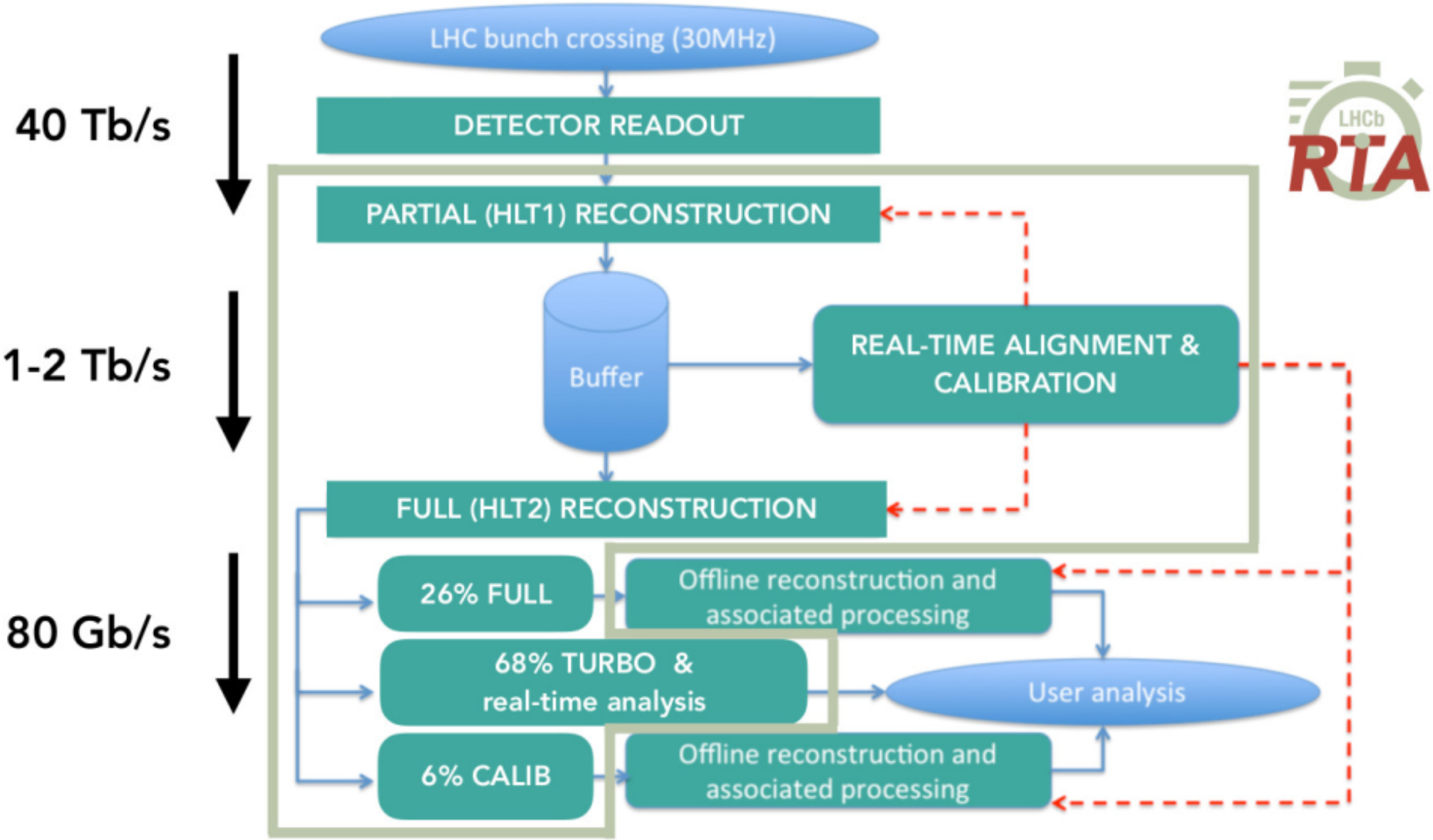
CERN-LHCC-2018-014, LHCB-TDR-018

The Run 3 trigger



Data flow in Run 3

[CERN-LHCC-2018-014, LHCB-TDR-018]

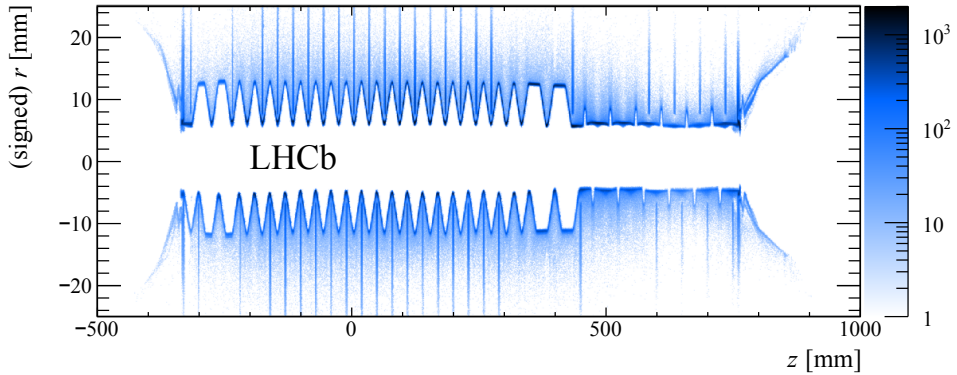


Ongoing work

- The definition of the trigger selections for the start of data-taking is being done right now.
- Trigger lines can be modified after the start of Run 3.
- Porting Run 2 lines to the Upgrade, including new ones.
- Some very useful tools must still be ported to Upgrade conditions.
- Jet reconstruction is challenging (even at HLT2) due to timing constraints.

Background of long-lived particles is dominated by material interactions with the detector material.

In Run 2, a material map was created from beam-gas events, aim for something similar in the Upgrade.



Ideas for the Run 3

Displaced light hadron triggers

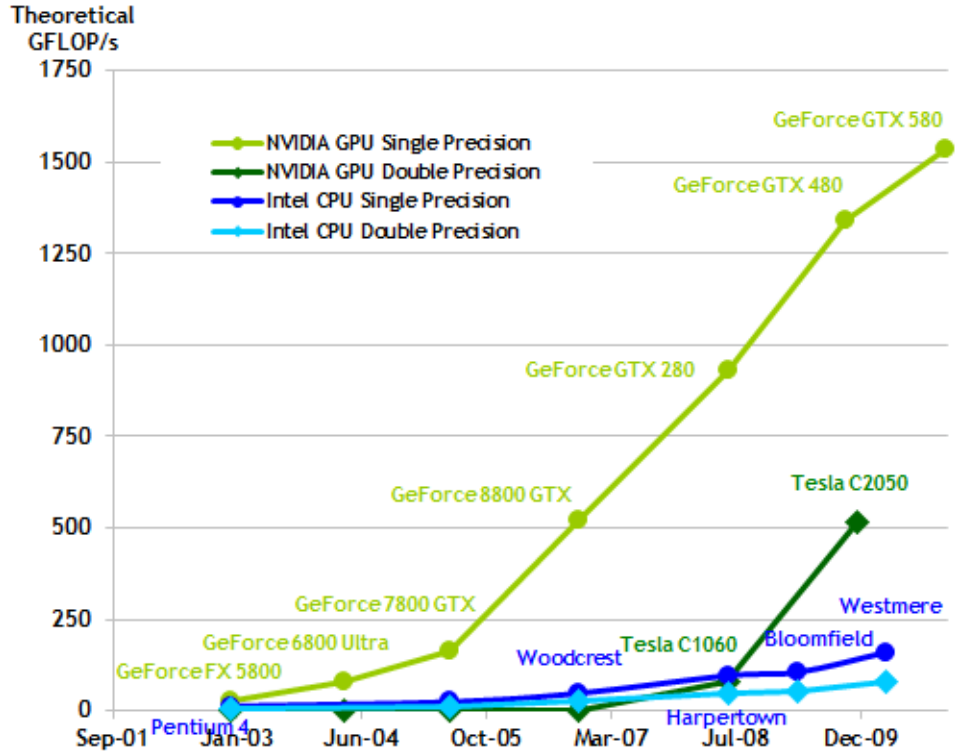
- Select a long-lived object decaying into pairs of light hadrons $X \to hh'$.
- Production mode is relevant; selection is different if X comes from the PV or not.
- In Run 3 the relaxed cuts in p_T will increase the sensitivity to lower masses.
- Some ongoing works in Run 2 data, but nothing published so far.

Tau triggers

- Tau leptons are more challenging than μ/e: missing particles, more tracks to reconstruct (hadronic modes) or no vertex (muonic mode).
- At LHCb this kind of signals are triggered by inclusive lines.
- Implement ditau triggers based on both muonic and hadronic modes? Will benefit other analyses too.

What if...

- LHCb is exploring ways to boost even more trigger processing.
- Wide use of GPUs in physics due to the large gain in throughput.
- Possibility to implement an HLT1 trigger fully on GPUs, with no p_T thresholds.
- Could gain a lot in terms of efficiency.
- Cost w.r.t. CPU implementation reduced.
- The Allen project aims to do this task [arXiv:1912.09161].



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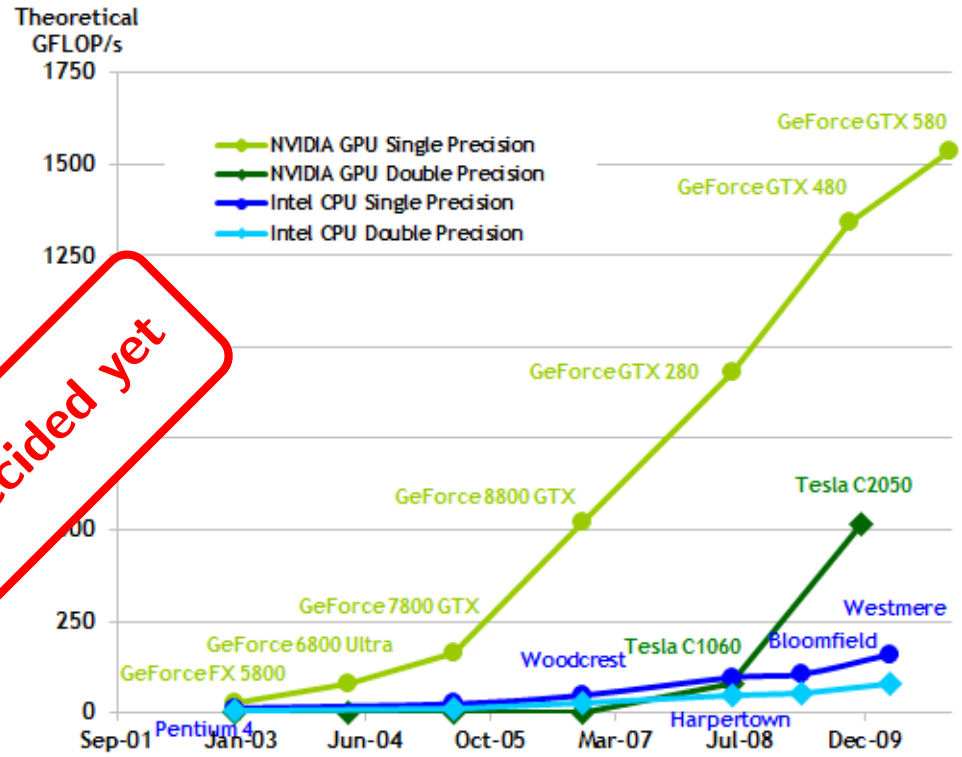

Not decided yet

Conclusions

- LHCb has proven to be able to easily adapt itself to new fields.
- The removal of the L0 trigger makes our trigger be extremely flexible.
- LHCb is currently the most sensitive experiment to high-energy processes in the forward region; complementary to ATLAS and CMS.
- We have learned a lot from Run 1 and Run 2, we are optimizing the selections for the Upgrade.
- The time to define new trigger selections for the start of Run 3 is now, and we have some ideas in mind.

Any new proposals are very welcome!


Thank you!