Performance of the LHCb trigger and full real-time reconstruction in Run 2 of the LHC

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on behalf of the LHCb collaboration

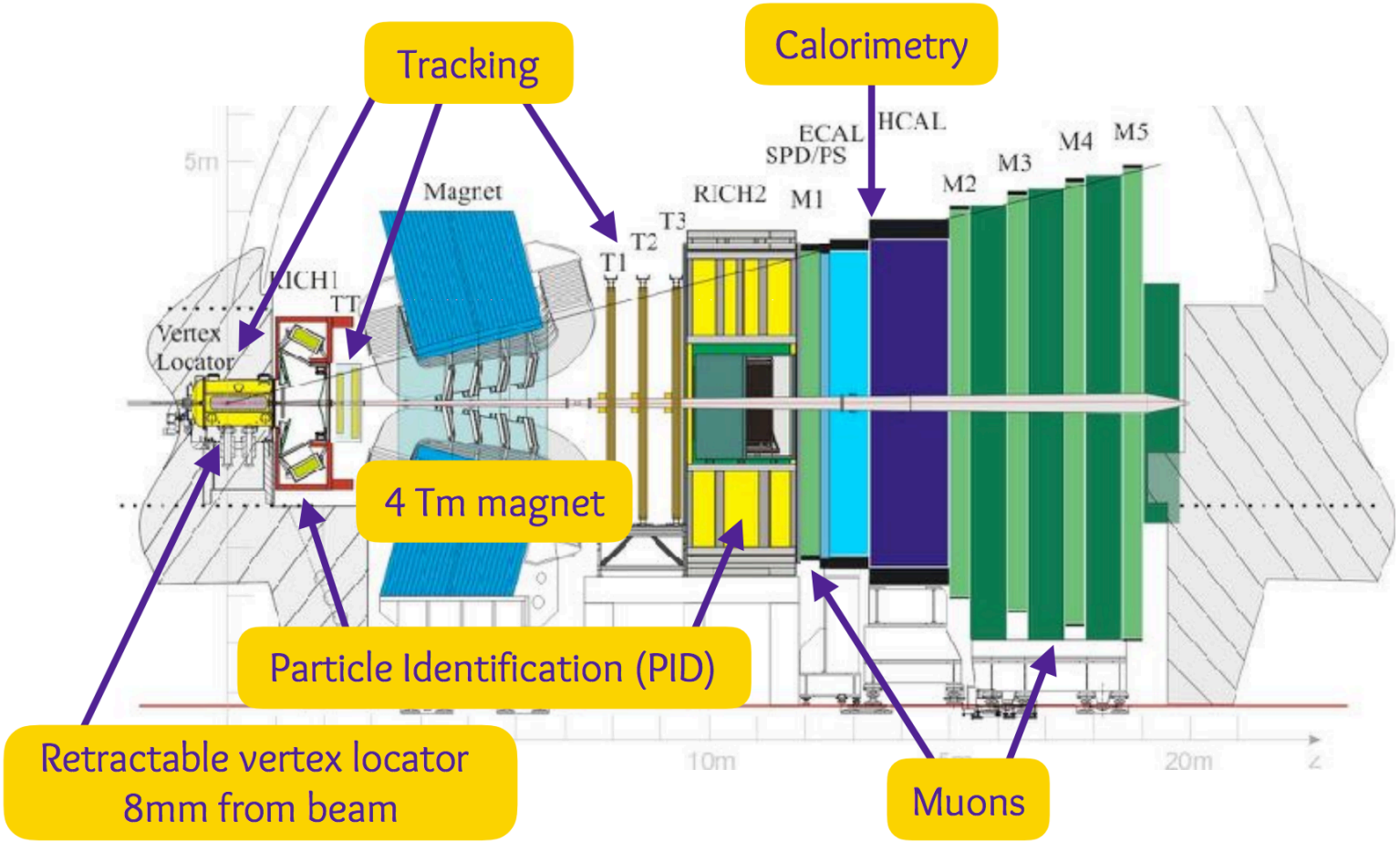
LHCP 2019, Puebla (Mexico)

THE LHCb DETECTOR

Single arm forward spectrometer (2<eta<5 mrad)

Dipole magnet changing polarity every few weeks

Trigger in three stages, one hardware and two software



$\Delta p/p \approx 0.5\%$

$\Delta t \approx 45fs$

$\varepsilon^{track} \approx 96\%$

$\varepsilon^{PID}(K) \approx 95\%$

$\varepsilon^{PID}(mu) \approx 97\%$

$\varepsilon^{PID}(e) \approx 90\%$

A BROAD PHYSICS PROGRAM

LHCb has a broad physics program, ranging from beauty and charm to electroweak physics.

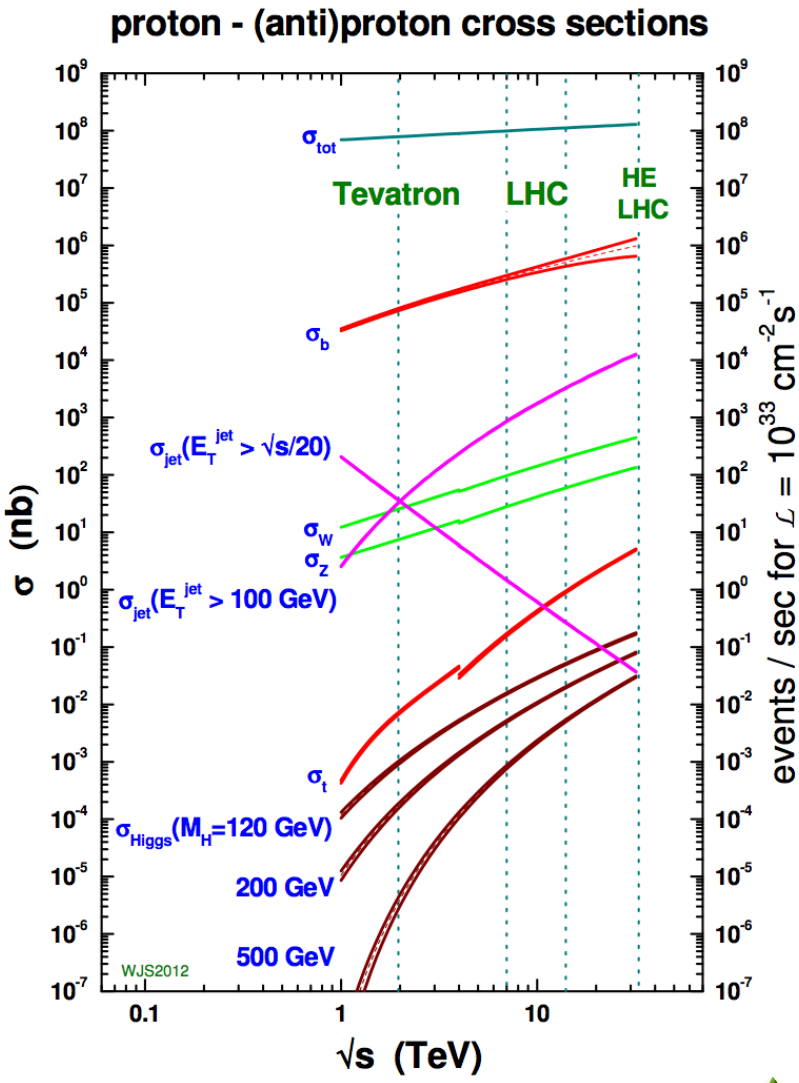
In order to pursue the physics objectives, new strategy for the trigger have been put in place, providing a high efficient use of the available resources.

The challenge:

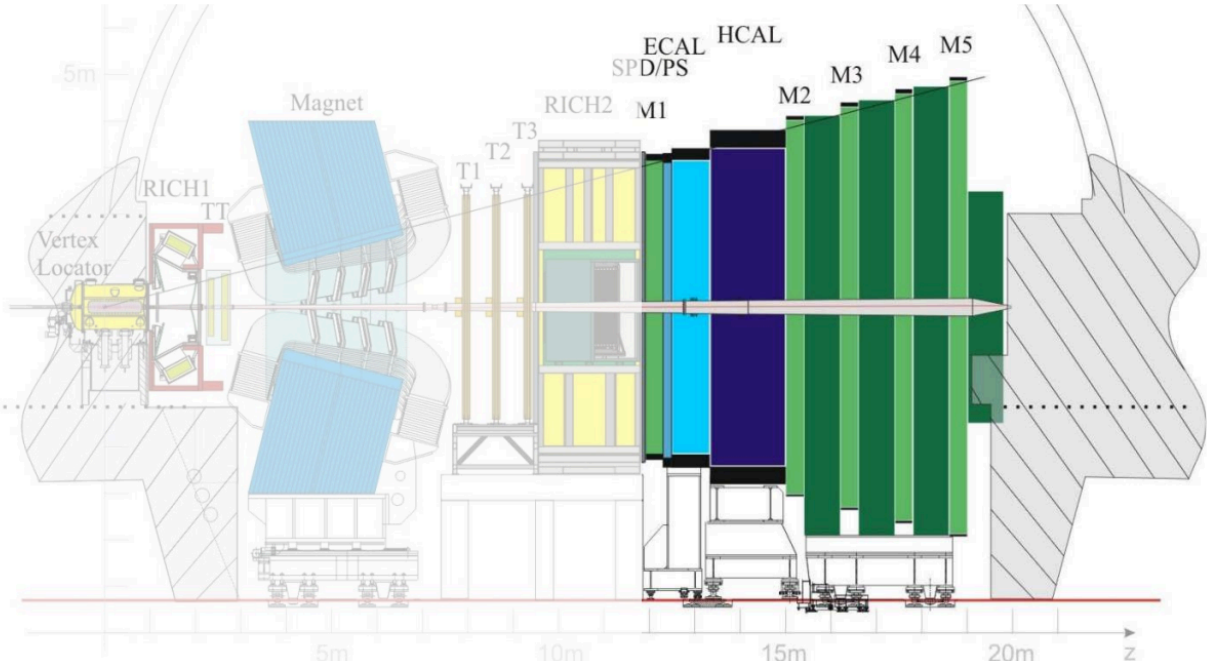
- up to 40 MHz p-p collisions at sqrt(s) = 13 TeV
- charm ~1MHz, beauty ~45kHz
- raw event size is ~60 kB
- Trigger bandwidth [MB/s] ∝
  Trigger rate [kHz] x Average event size [kB]

  => charm+beauty ~60GBs-1

- computing resources (disk space) are limited
  => need to keep only interesting informations!

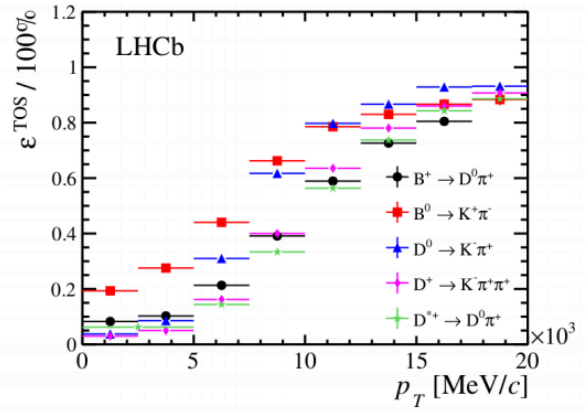


L0 TRIGGER



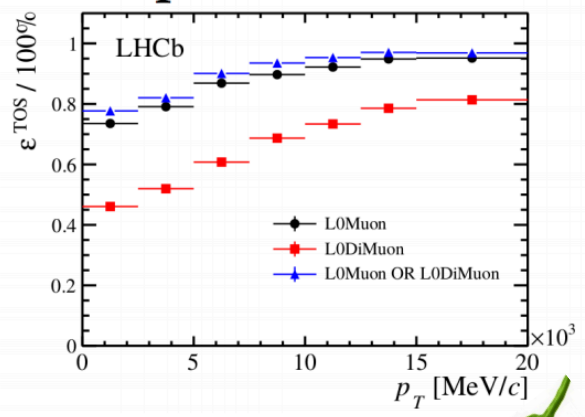
L0 efficiencies:

Hadronic modes



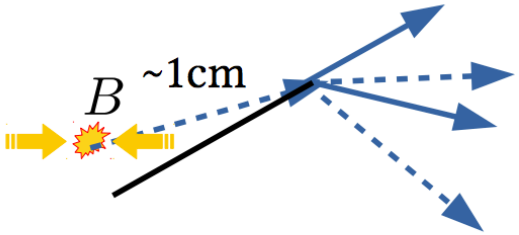
Int.J.Mod.Phys. A30 (2015) 1530022

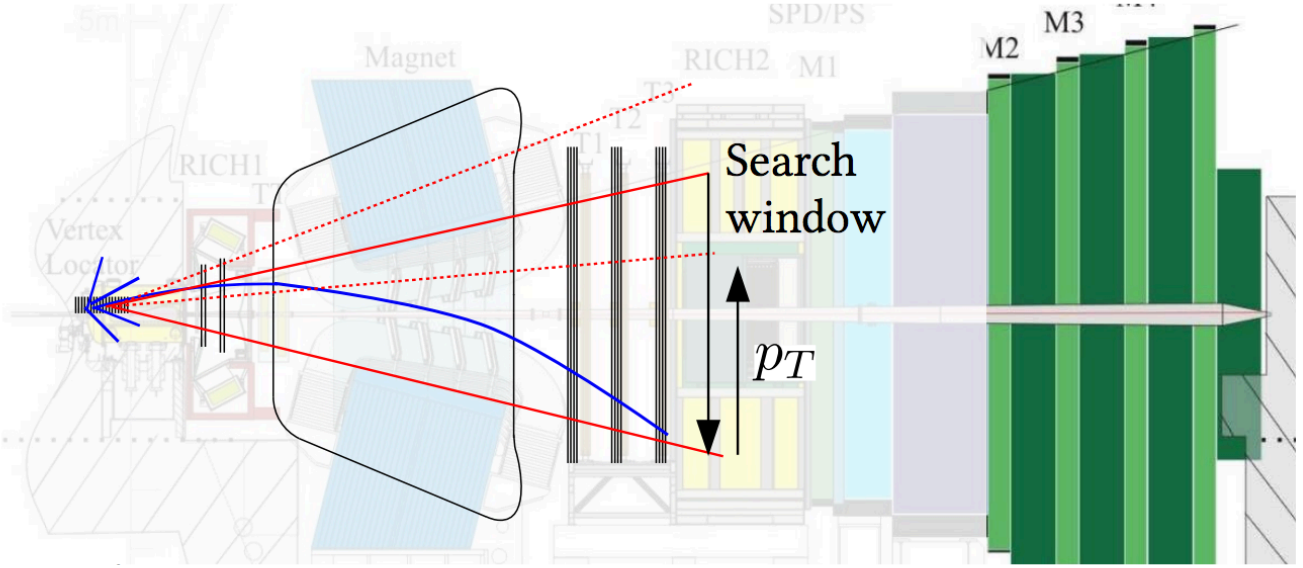
Leptonic modes



- Hardware stage, FPGA based
  => Readout limited to 1 MHz
- Selection based on high momentum on muon station or high transverse energy in calorimeters
- Inefficient for hadronic signatures:
  high occupancy of calorimeters => high thresholds

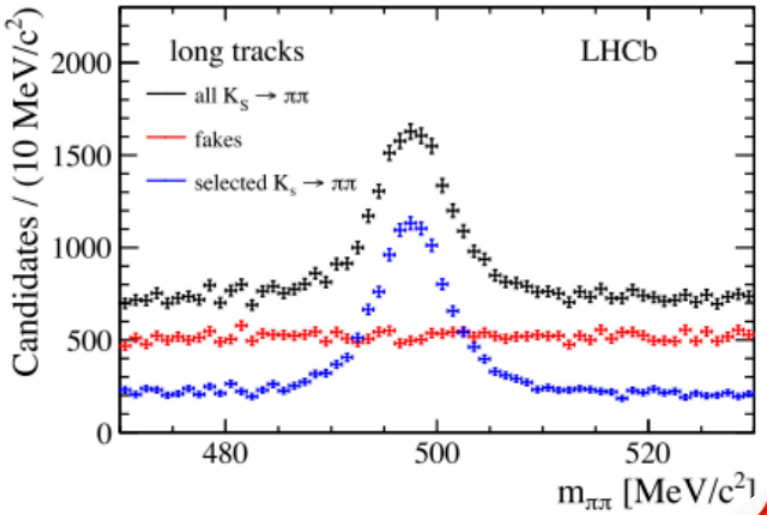
FIRST STAGE OF HIGH LEVEL TRIGGER (HTL1)





LHCb-PUB-2017-011

- First software stage
- Fast reconstruction of high pT tracks (>500 MeV)
- Trigger on pT, muons, vertex displacement
- Fast neural networks to reject fake tracks



FIRST STAGE OF HIGH LEVEL TRIGGER (HTL1)

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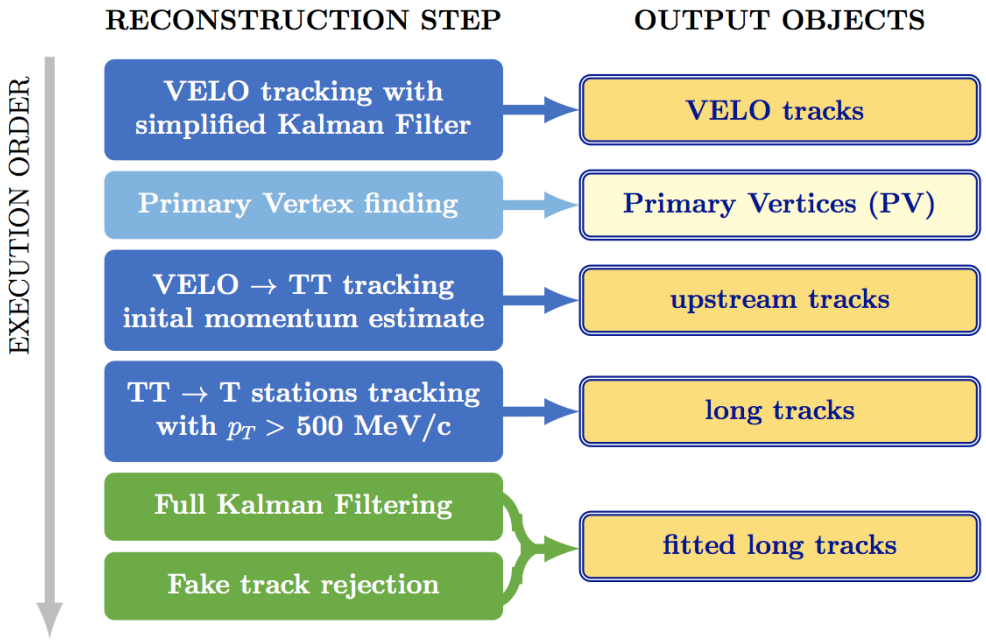


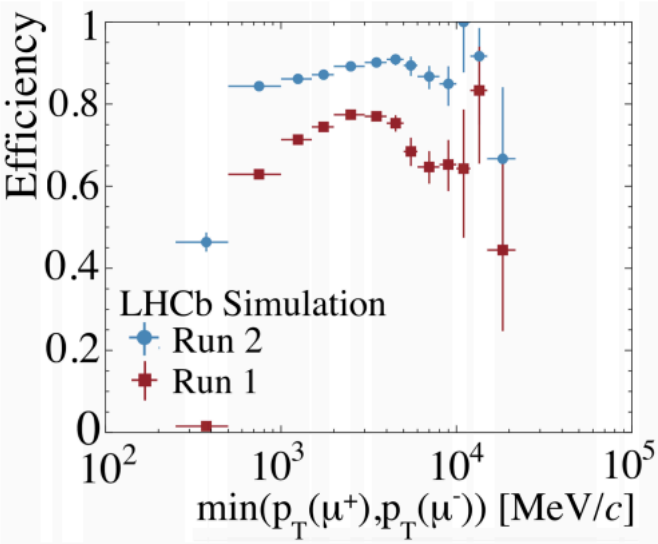
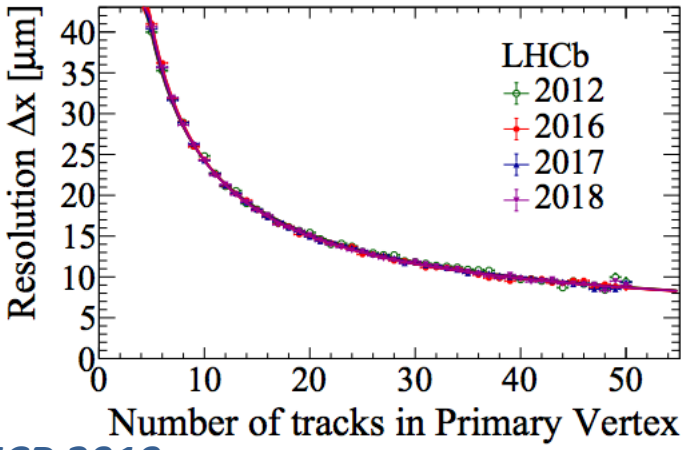
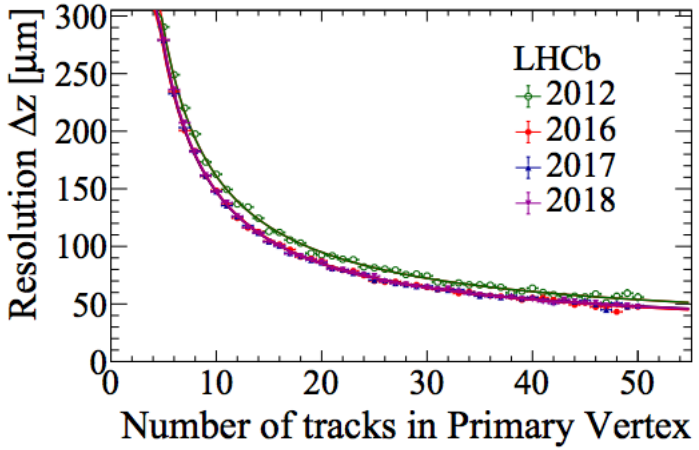
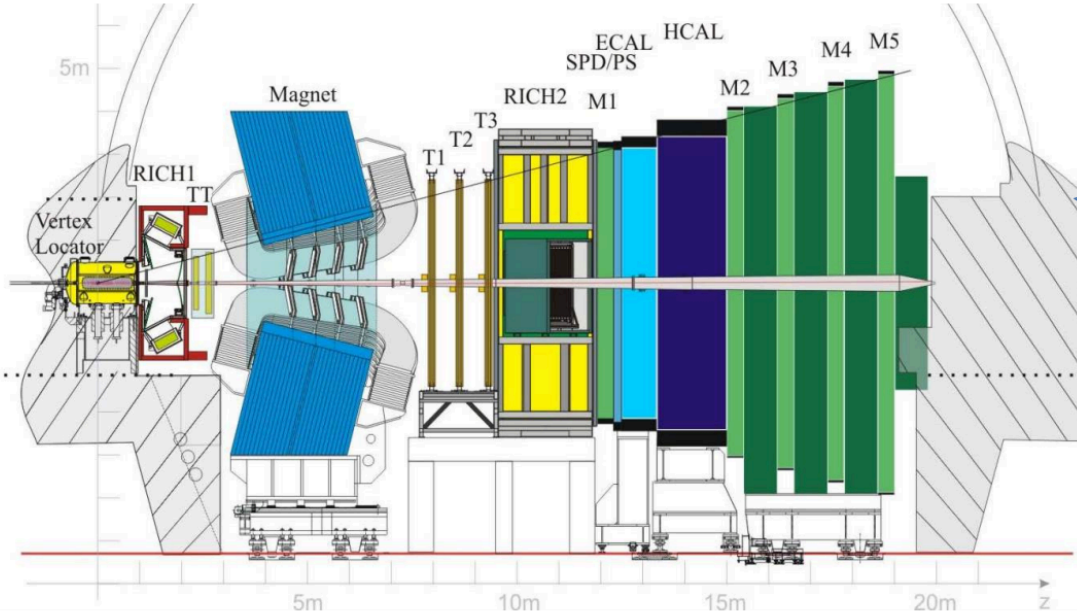


Figure 4: Sketch of the HLT1 track and vertex reconstruction.





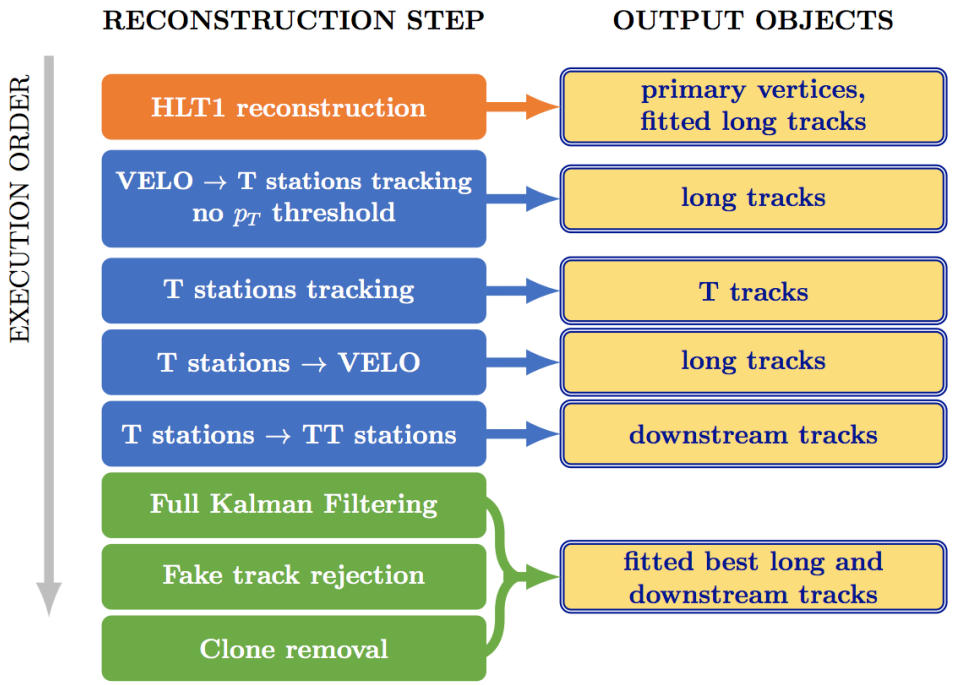
SECOND STAGE OF HIGH LEVEL TRIGGER (HTL2)



- Second software stage
- Full reconstruction of the event (all detector used!)
- Speed optimised

Algorithm	Time
Total HLT1	~ 35 ms
Track finding	~ 200 ms
Full track fit	~ 120 ms
RICH reconstruction	~ 100 ms
Calo reconstruction	~ 50 ms
Muon ID	~ 2 ms
Total Hlt2	~ 650 ms

SECOND STAGE OF HIGH LEVEL TRIGGER (HTL2)



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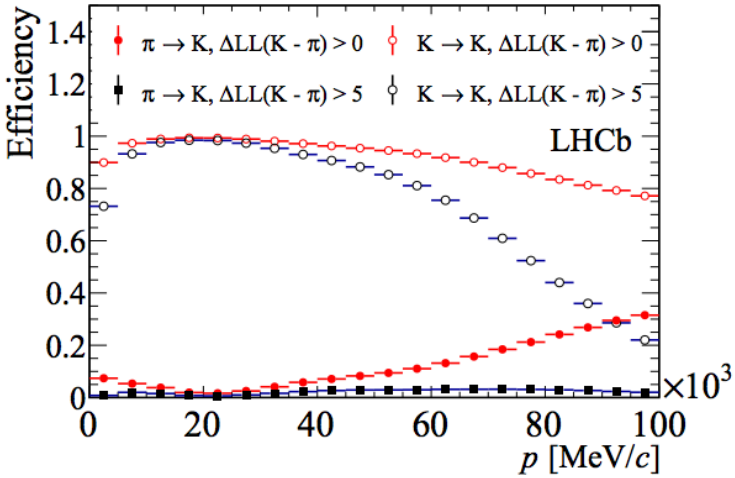
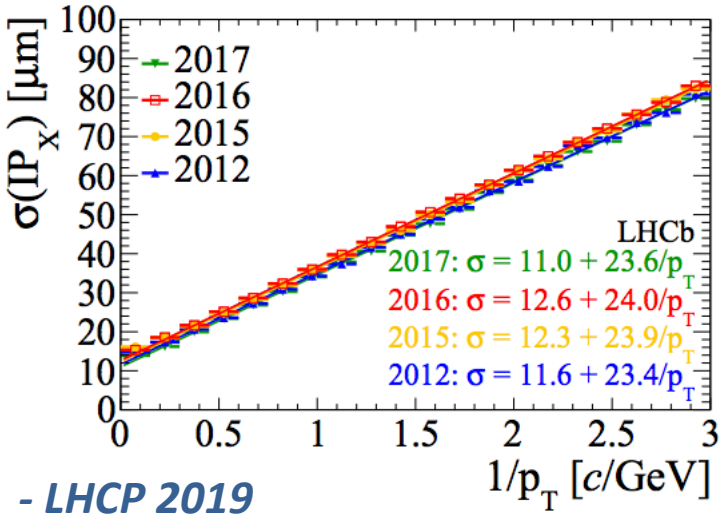
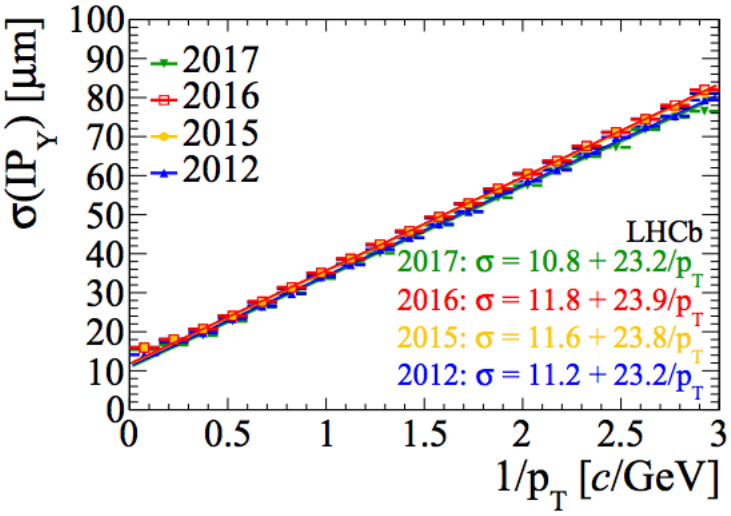
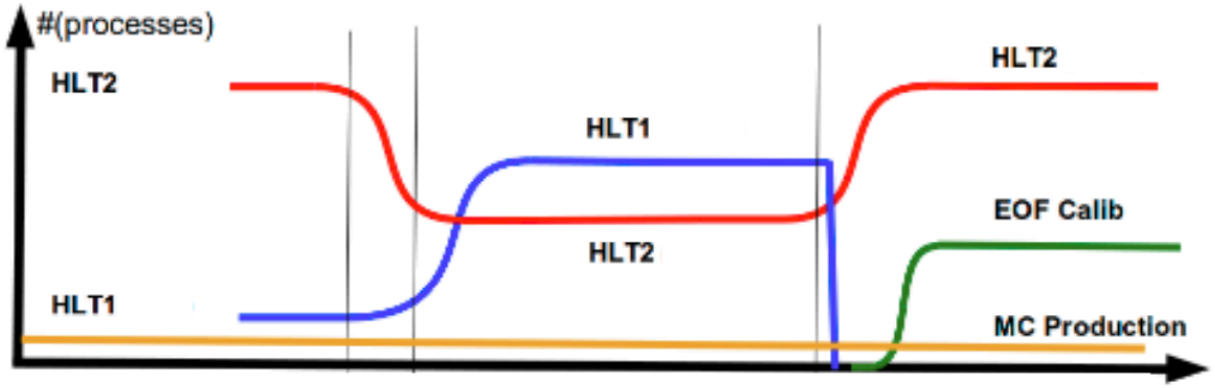






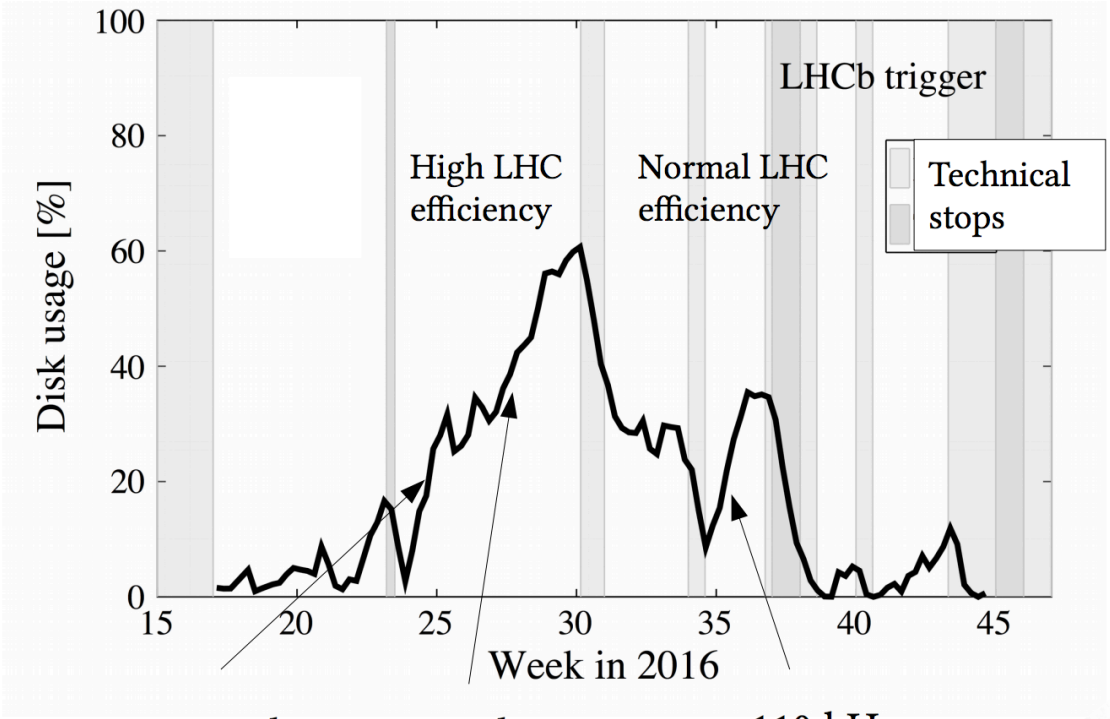
OPTIMIZED USE OF EVENT FILTER FARM

Activate the software stages as function of LHC phases.



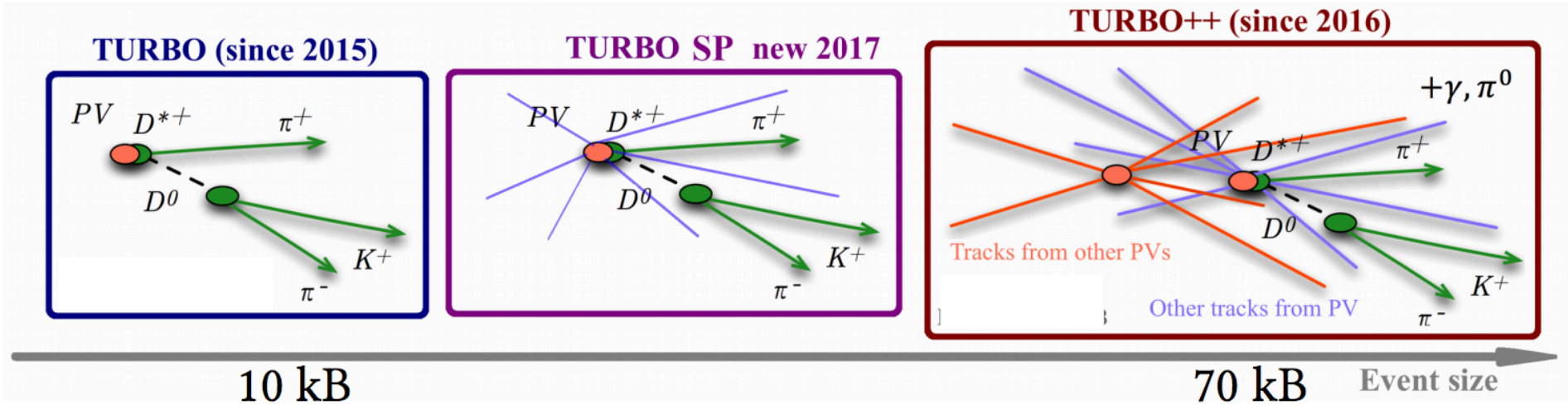
LHC phases: Ramp Stable Beams Beams dumped

Adjust thresholds as function of LHC efficiency



HLT1 output rate ~130 kHz ~80 kHz ~110 kHz

THE TURBO STREAM



Idea: keep what you need!
=> Raw objects discarded, reconstructed object persisted
⟹ Event size reduced up to a factor 10

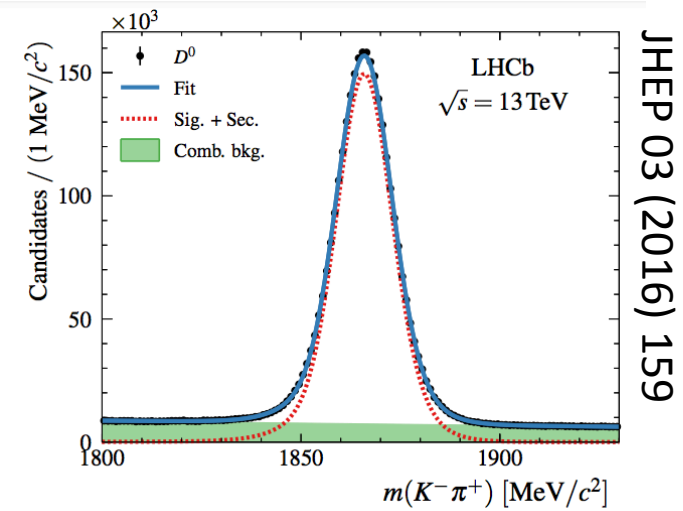
Different format for different analyses needs:
- TURBO: only objects involved in trigger decision, plus all PVs
- TURBO SP: flexible specification of additional object to save
- TURBO++: entire HLT2 reconstructed objects

More events for same bandwidth!

PHYSICS WITH TURBO STREAM

Measurements of prompt charm production cross-sections in pp collisions at $\sqrt{s} = 13\,\text{TeV}$

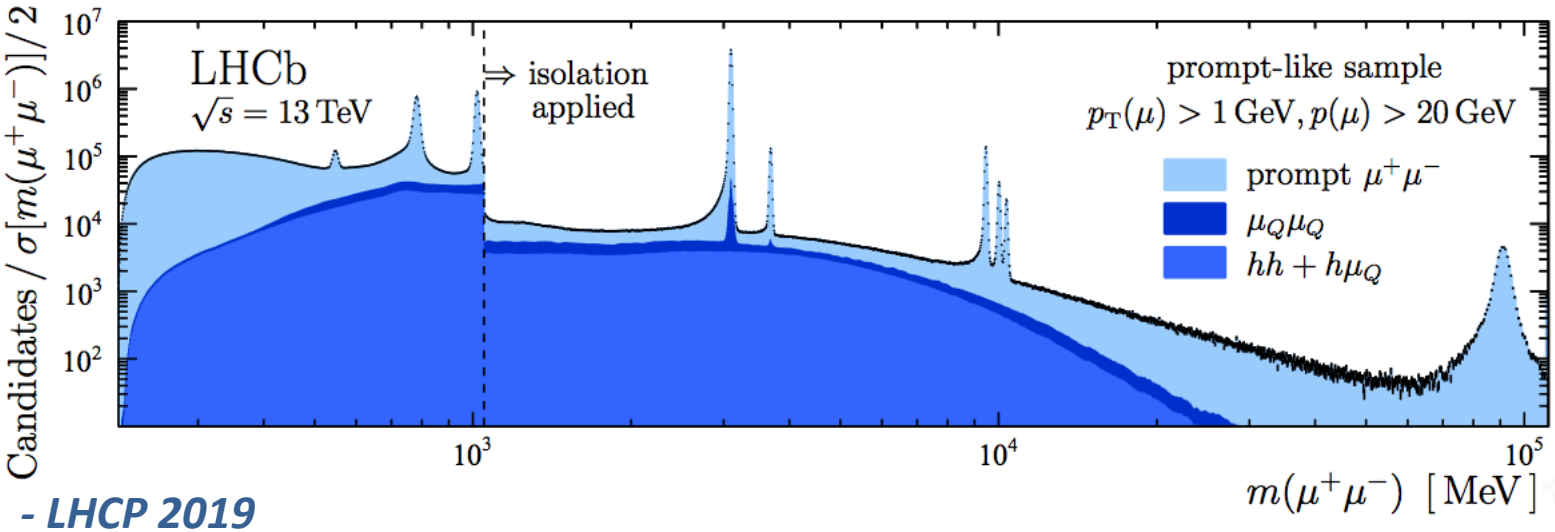
Almost all charm was sent to Turbo stream



JHEP 03 (2016) 159

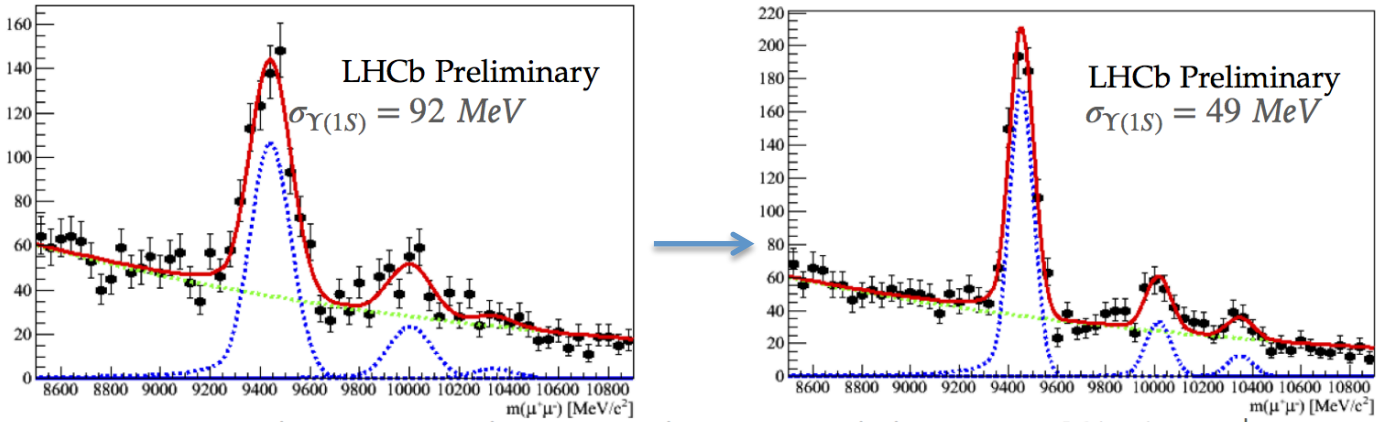
Also prompt di-muons:

"Search for dark photons produced in 13 TeV pp collisions" (Phys. Rev. Lett. 120 (2018))061801

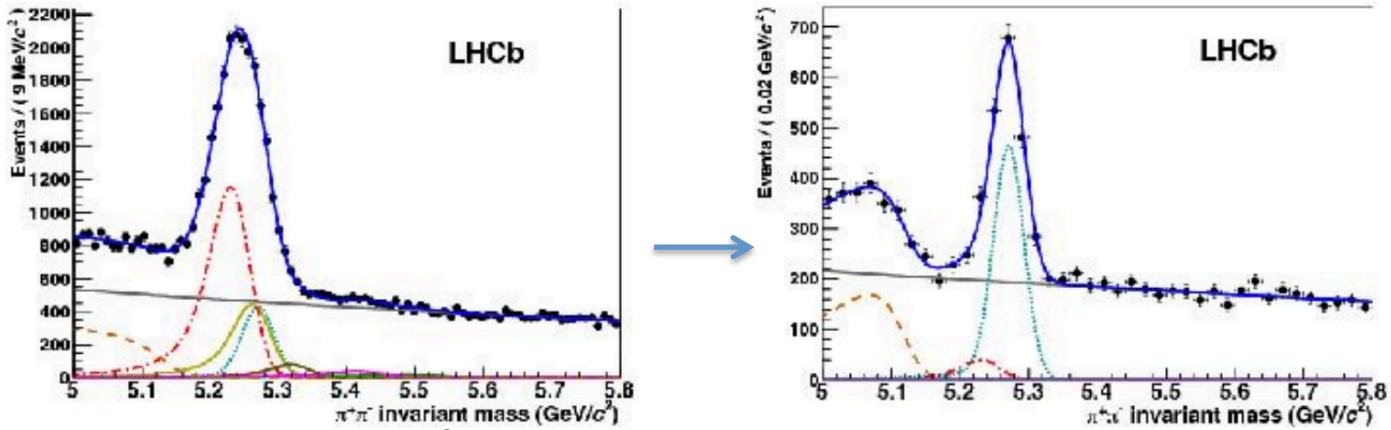


REAL-TIME ALIGNMENT AND CALIBRATION

- Not only quantity but quality!
- Alignment and calibrations provide:
  - better mass resolution
  - better particle identification
  - better background rejection => more bandwidth for signal



Difference between a preliminary and an improved alignment in $\Upsilon(1S) \rightarrow \mu^+\mu^-$

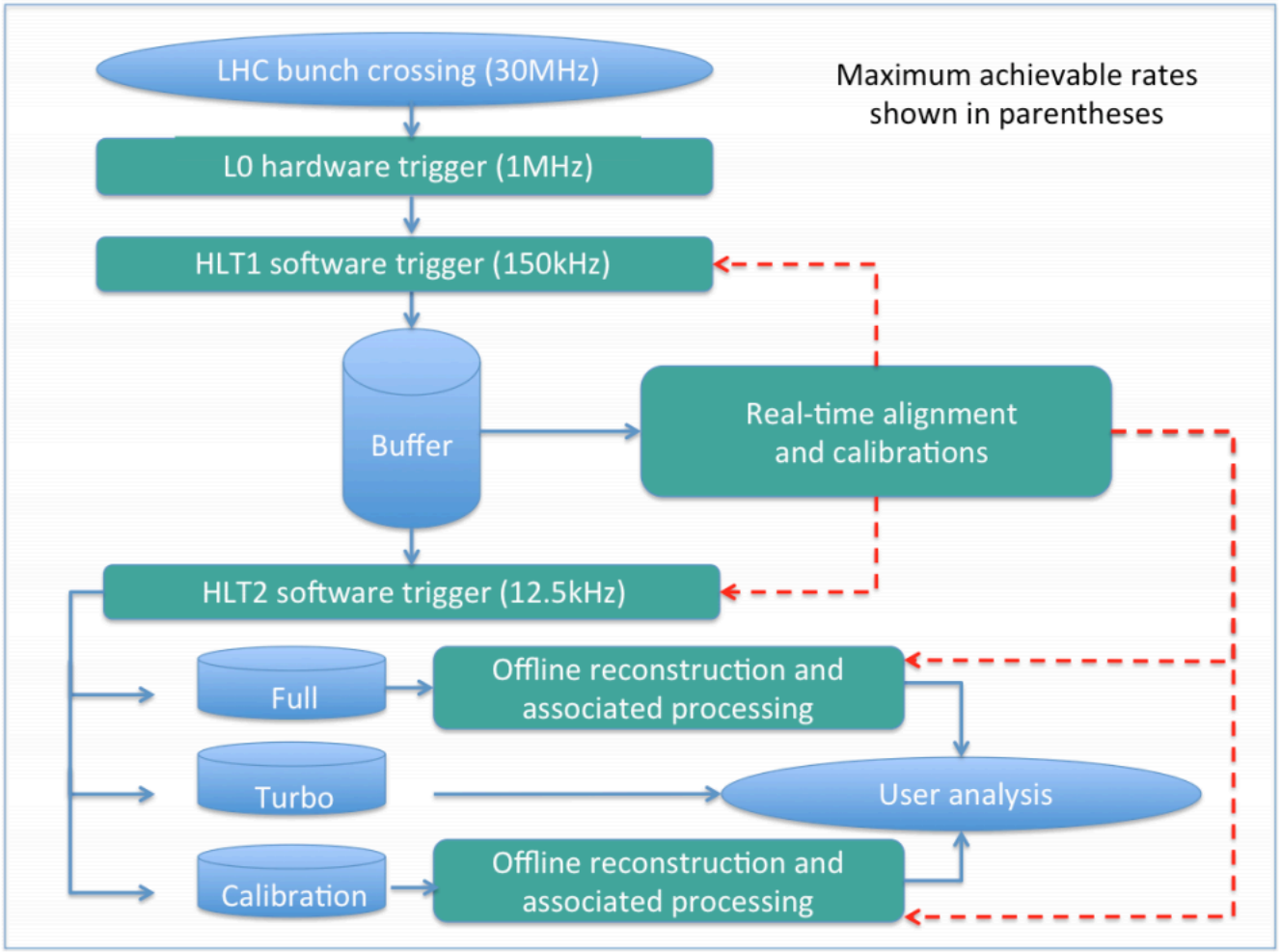


Invariant mass for $B^0 \rightarrow \pi^+\pi^-$ without (left) and with (right) PID applied

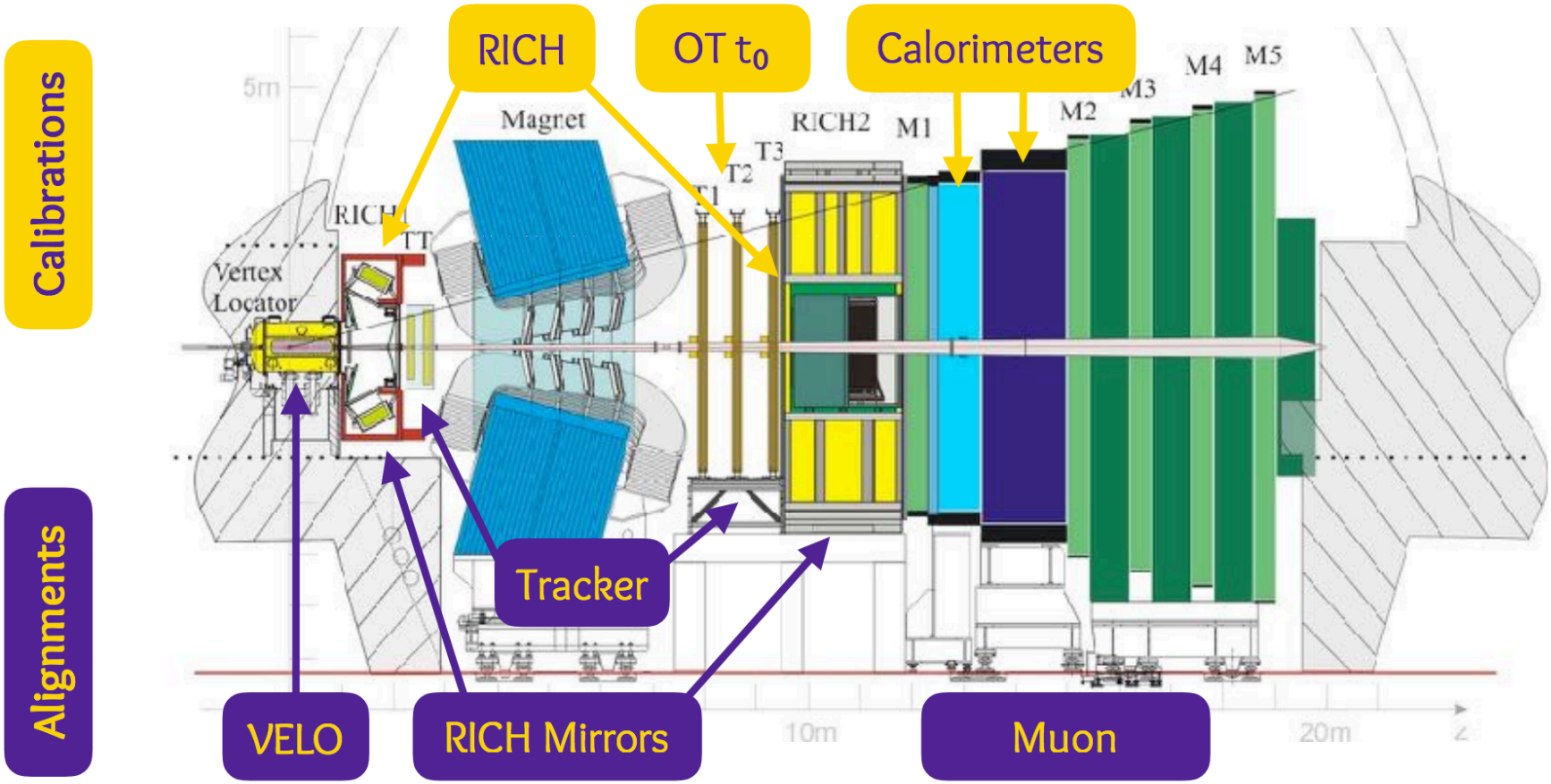
REAL-TIME ALIGNMENT AND CALIBRATION

Since raw data are not persisted, alignment and calibrations need to be performed online.

https://doi.org/10.1016/j.cpc.2016.07.022

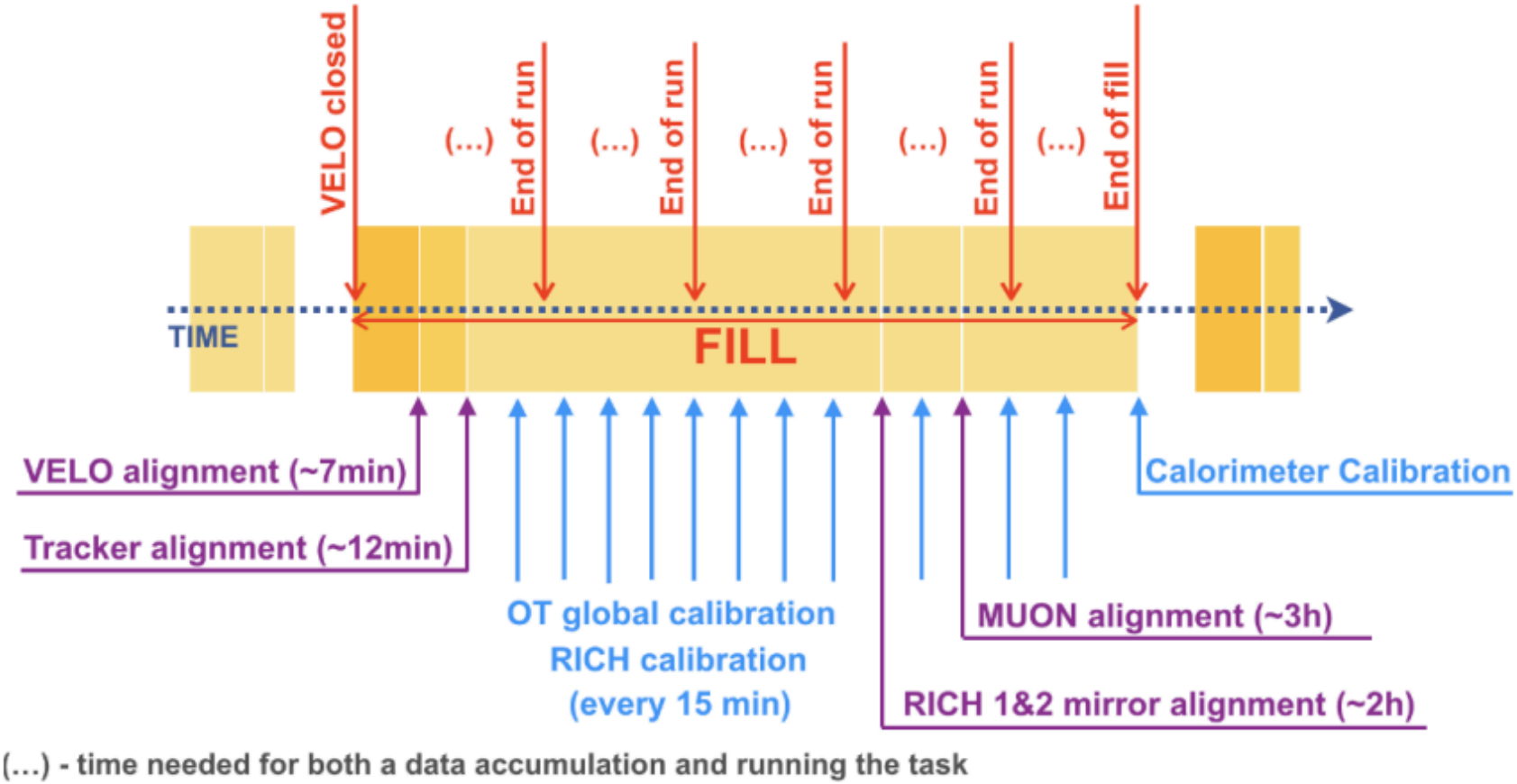


WHAT IS ALIGNED AND CALIBRATED?



Alignment constant updated if significant change observed.

REAL-TIME ALIGNMENT AND CALIBRATION



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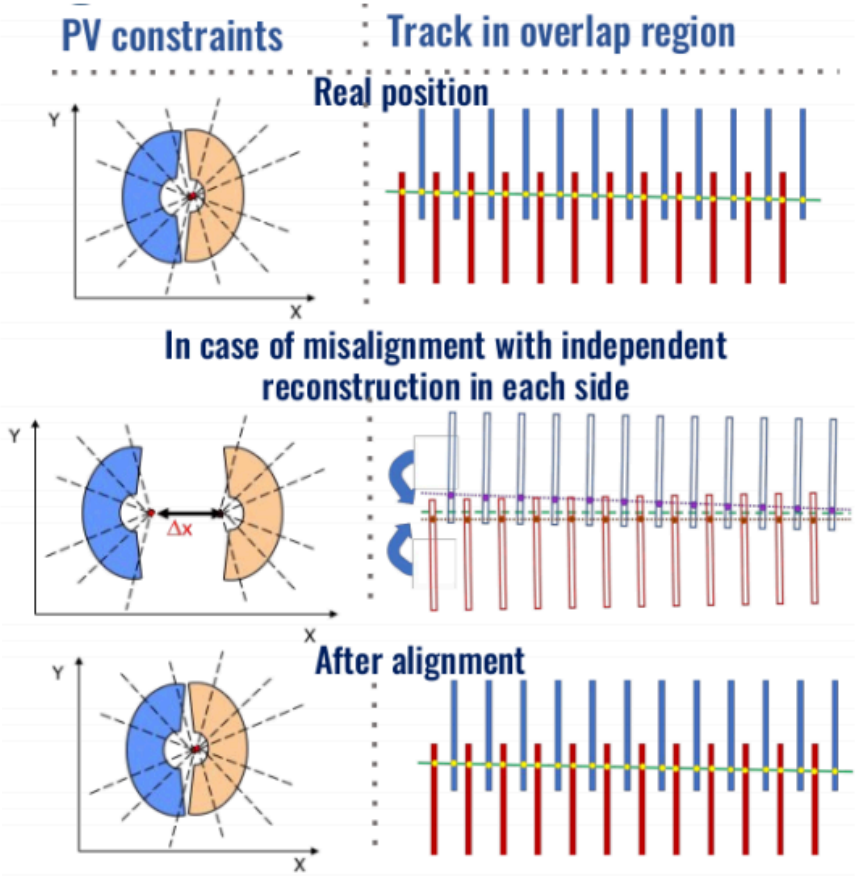
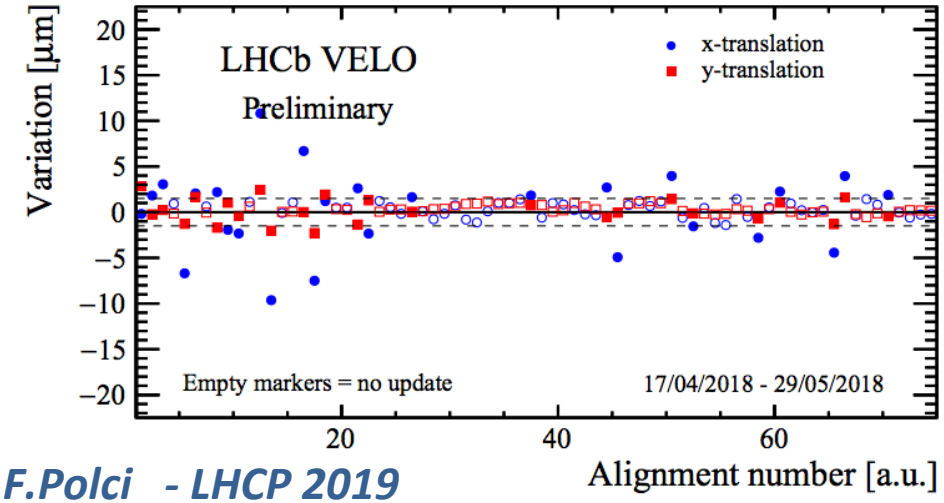
VELO ALIGNMENT

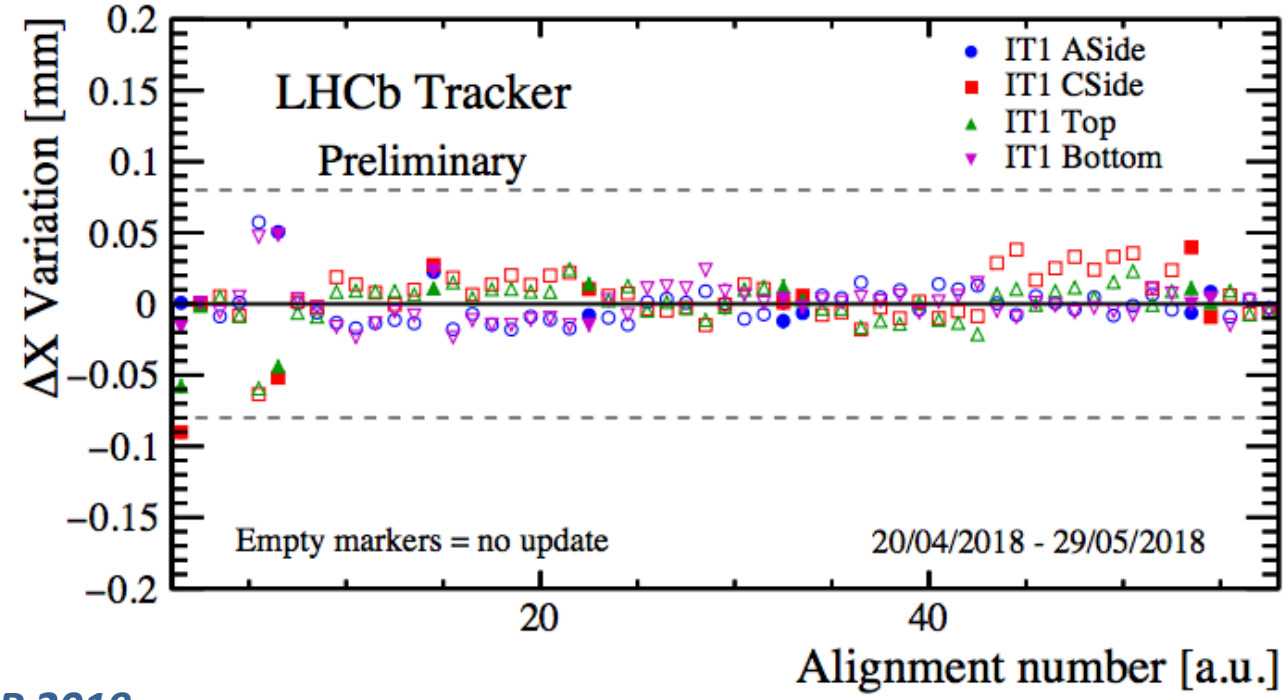
- VELO moves into close position at stable beams
- Kalman filter approach used for alignment, based on track residuals with PV constraints
- Typical duration: 3 minutes
- Very stable conditions
- Automated procedure.





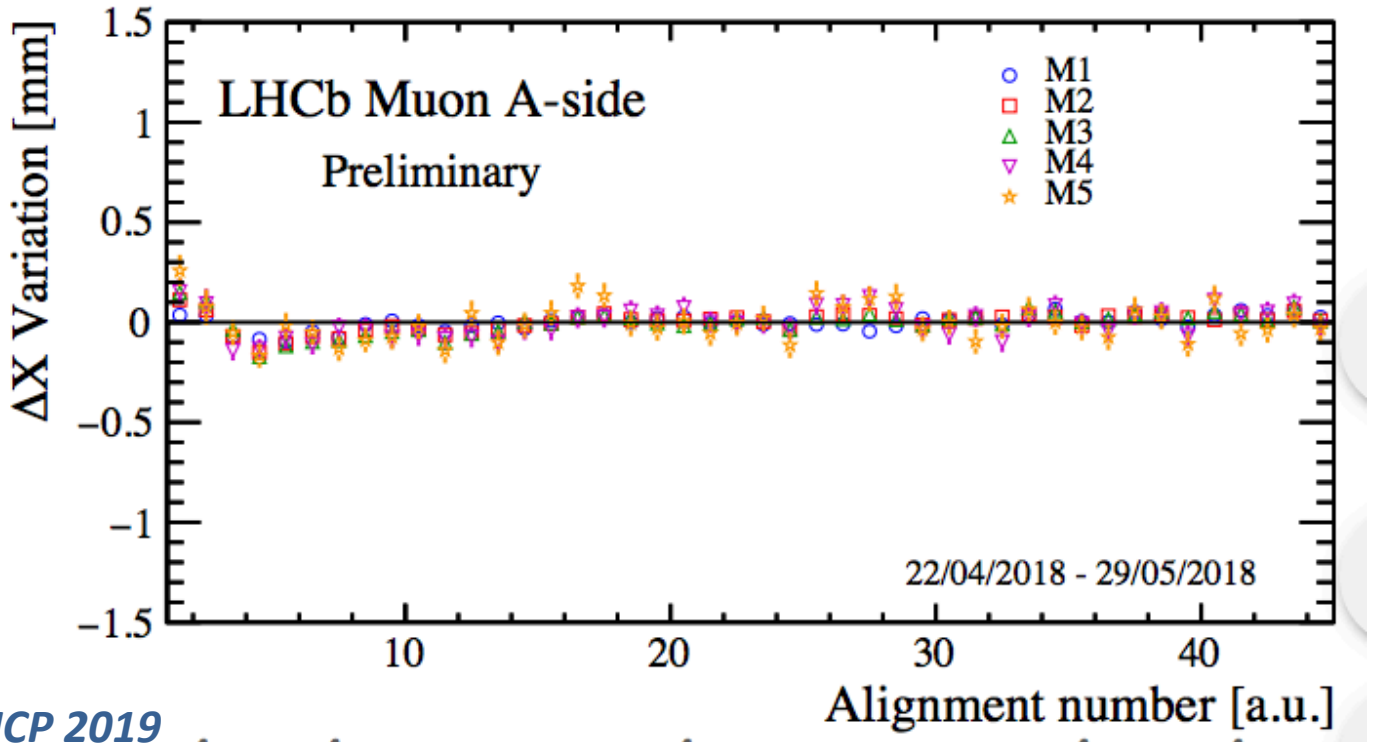
TRACKER ALIGNMENT

- Sensitive to magnet polarity changes
- Sample of tracks collected at beginning of the fill
- Kalman filter approach as for VELO
- Typical duration: 10 minutes
- Very stable conditions
- Automated procedure.



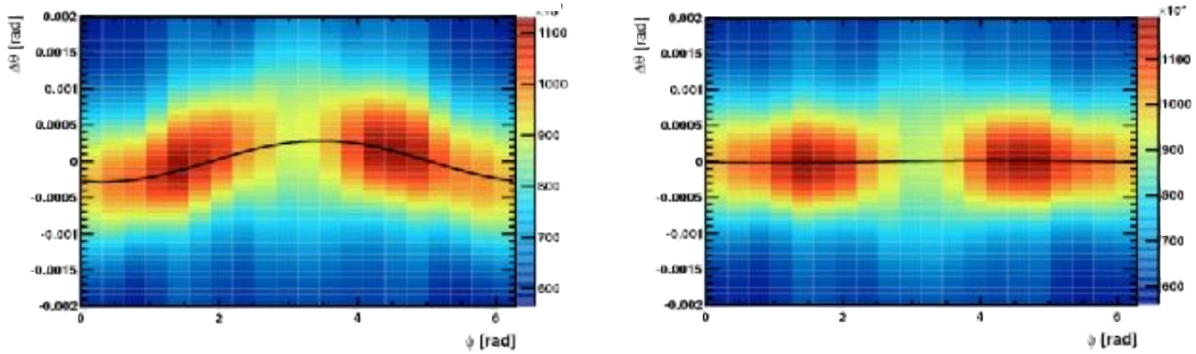
MUON DETECTOR ALIGNMENT

- Sensitive to physical interventions
- Kalman filter approach as for VELO
- Typical duration: sample collected in 3 hours, alignment run in 7 minutes
- Very stable conditions
- Automated procedure.

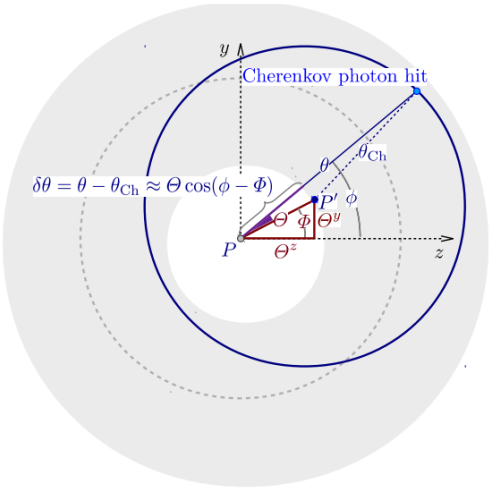


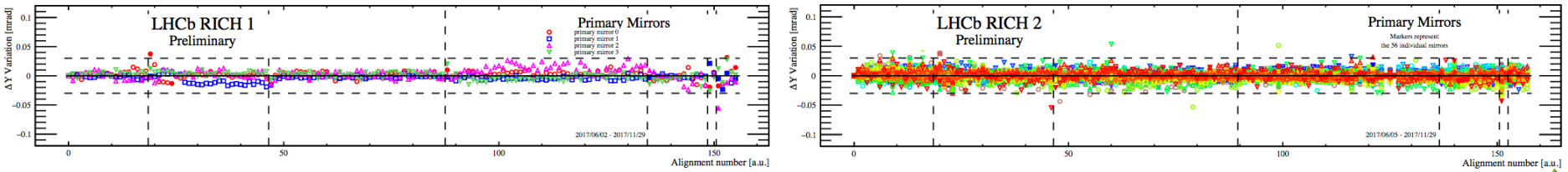
RICH ALIGNMENT

- Primary and secondary mirrors need alignment (110 mirror pairs)
- Fit the variation of the Cherenkov angle as function of polar angle
- Typically changes observed with magnet polarity flip
- Duration: 2 hours for collecting data, 20 minutes to run alignment
- Automated procedure since 2017



Cherenkov angle vs phi for misaligned (left) and correctly aligned (right) mirrors



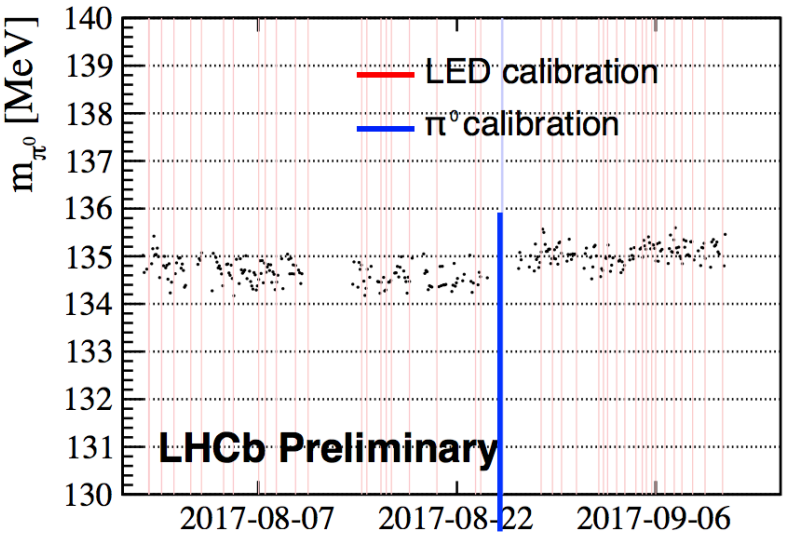


Difference in alignment constants of the primary mirrors of RICH 1 and RICH 2

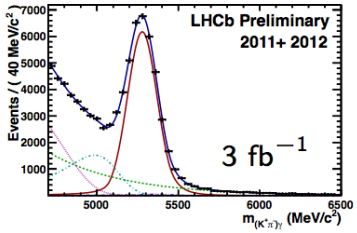
CALORIMETER CALIBRATION

- Ageing of calorimeters => need of calibration
- Relative calibration at end of every fill
  - compare LED monitoring system to the reference and update HV (and reference) accordingly
- Absolute calibration once per month
  - HCAL: Cesium scan
  - ECAL: 300M events randomly selected (~4 weeks), fit of π^0 mass in each cell

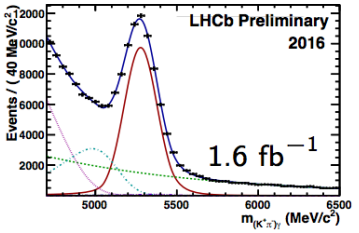
- Mostly automatics



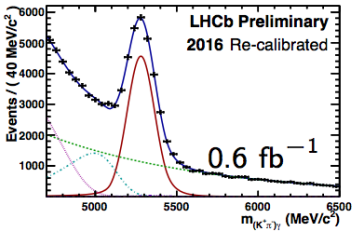
Effect of calibration in $B_d^0 \to (K^* \to K^+\pi^-)\gamma$ *decays*



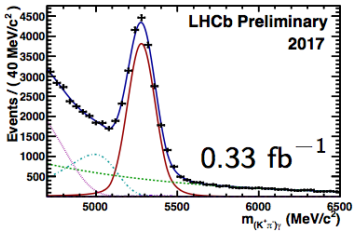
$\sigma = 90.7 \pm 0.6$ *MeV*



$\sigma = 101.3 \pm 0.1$ *MeV*



$\sigma = 84.4 \pm 0.7$ *MeV*



$\sigma = 85.1 \pm 0.7$ *MeV*

CONCLUSION

The Run2 LHCb strategy for trigger and real-time alignment has proven successful.

- Best use of resources (Turbo) with increased physics potential
- Largely automatized alignment and calibration procedures
- Smooth operations
- Efficient data taking

A great proof of principle for the upcoming upgrade!