TRIGGERING DISCOVERIES
IN HIGH ENERGY PHYSICS III
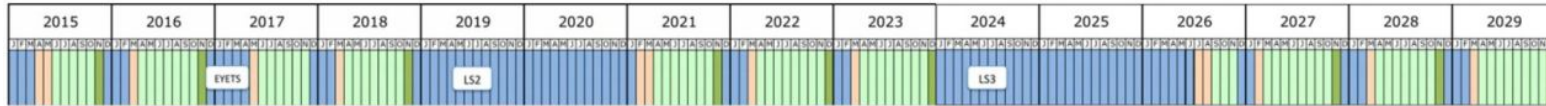
High Tatras, Slovakia   9.-13. December 2024

ALICE software trigger Run 3/Run 4

Anton Riedel
for the ALICE collaboration
Technical University of Munich
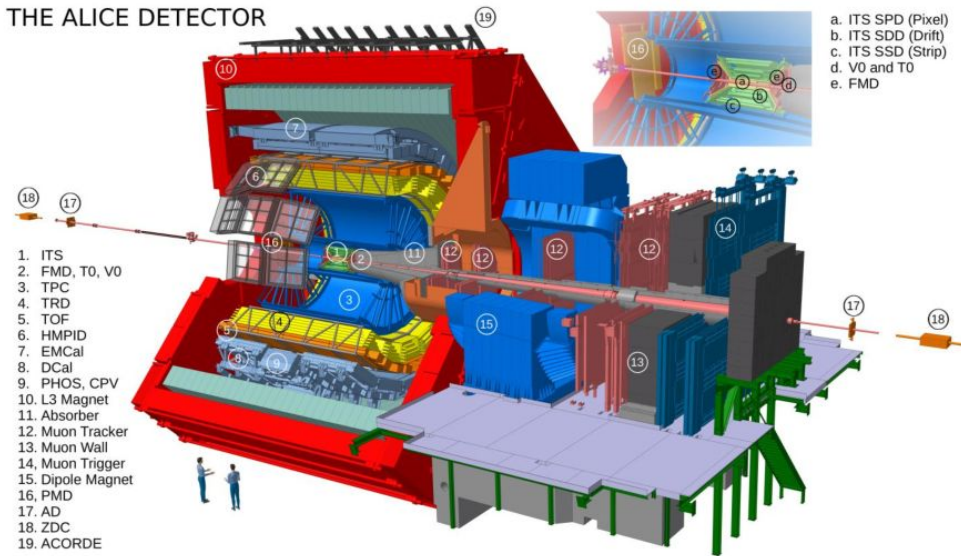12.12.2024

ALICE detector in Run 2

Run2: $\mathcal{L}_{int}^{Pb-Pb} = 1.0\ nb^{-1}$

Run3: $\mathcal{L}_{int}^{Pb-Pb} = 6.0\ nb^{-1}$

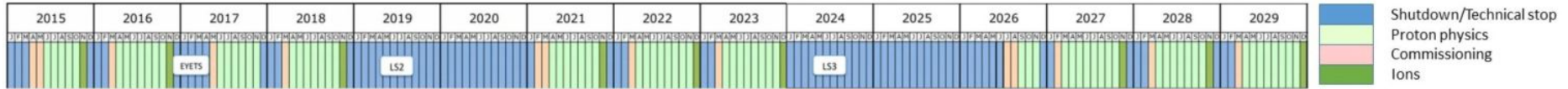Run4: $\mathcal{L}_{int}^{Pb-Pb} = 7.0\ nb^{-1}$

THE ALICE DETECTOR

a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14. Muon Trigger
15. Dipole Magnet
16. PMD
17. AD
18. ZDC
19. ACORDE

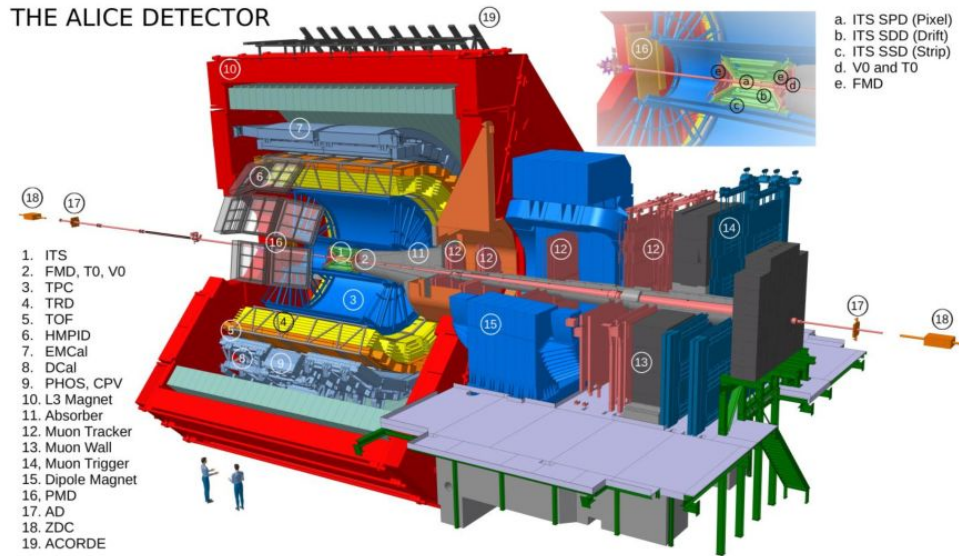- In Run 2: ~7-10 kHz Pb–Pb interaction rates with trigger rate < 1 kHz

ALICE detector in Run 2

Run2: $\mathcal{L}_{int}^{Pb-Pb} = 1.0$ nb^{-1}

Run3: $\mathcal{L}_{int}^{Pb-Pb} = 6.0$ nb^{-1}

Run4: $\mathcal{L}_{int}^{Pb-Pb} = 7.0$ nb^{-1}

Shutdown/Technical stop
Proton physics
Commissioning
Ions

THE ALICE DETECTOR

a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14. Muon Trigger
15. Dipole Magnet
16. PMD
17. AD
18. ZDC
19. ACORDE

- In Run 2: ~7-10 kHz Pb–Pb interaction rates with trigger rate < 1 kHz
- Trigger rate limited by TPC
  - TPC has ~90 μs drift time + at least ~200 μs gating grid to collect the ion backflow
  - trigger rate limited to ~3 kHz
  - For planned 50kHz Pb–Pb a HLT trigger is not realistic
- **Upgrade to continuous readout!**

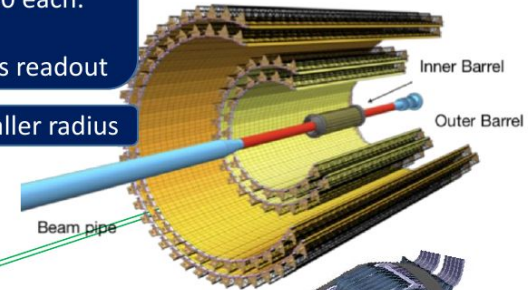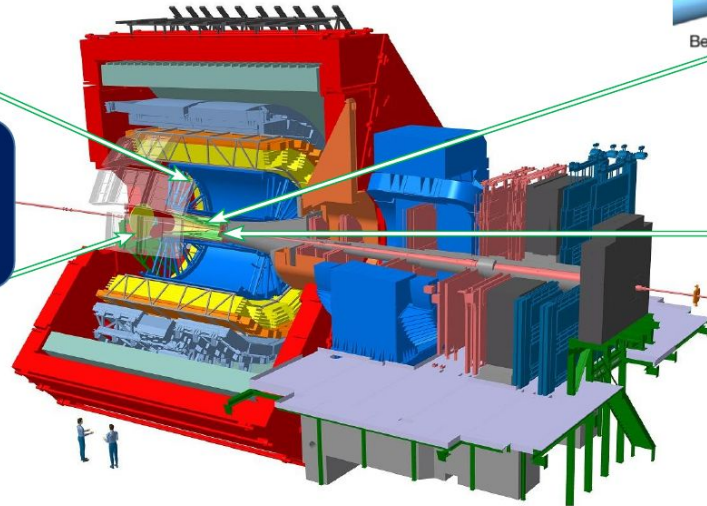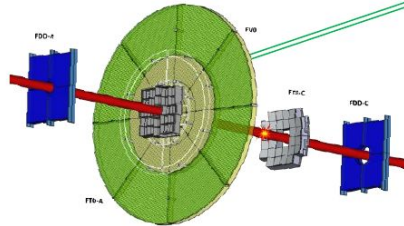# ALICE HW upgrades for Run 3
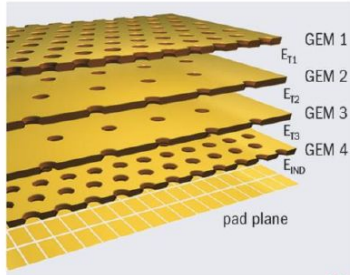
TPC MWPC readout → 4 layer GEM
(Intrinsic ion backflow ~99% blocking)
5MHz continuous sampling

New Si Inner Tracker: 10 m² of
MAPS with 29x27μm² pixel size
3 inner layers ~0.3% X0 each.
Closer to the beam
50-500 kHz continuous readout

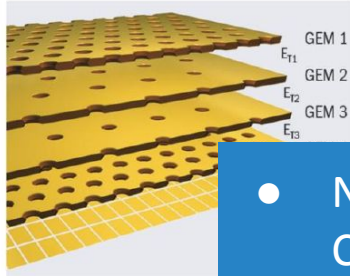New beam pipe of smaller radius

Fast Interaction Trigger (FIT) detector
Scintillator (FV0, FDD) + Cerenkov (FT0)
detectors to provide Min.Bias trigger
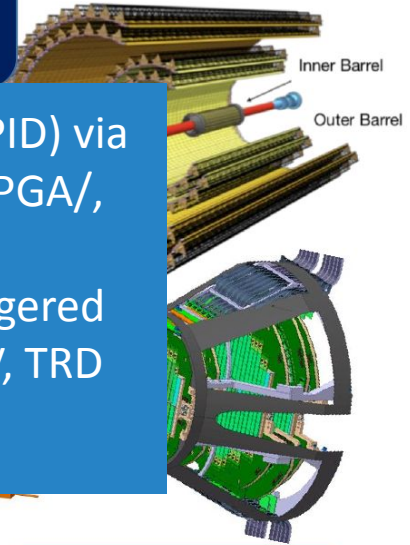for detectors with triggered R/O

Muon Forward Tracker
to match muons before
and after the absorber.
Same Si chips as new ITS

ALICE HW upgrades for Run 3

TPC MWPC readout → 4 layer GEM
(Intrinsic ion backflow ~99% blocking)
5MHz continuous sampling

New Si Inner Tracker: 10 m² of
MAPS with 29x27μm² pixel size
3 inner layers ~0.3% X0 each.
Closer to the beam
50-500 kHz continuous readout

Inner Barrel

Outer Barrel

- New readout (all except EMCal, PHOS and HMPID) via CRU(Common Readout Unit, PCIe40 /Arria10 FPGA/, developed by LHCb)
- Detectors can be read out in continuous or triggered modes,except triggered-only EMCal, PHOS/CPV, TRD (~40kHz)and HMPID (2.5 kHz)

Fast Interaction Tr...
Scintillator (FV0, F...
detectors to provi...
for detectors with...
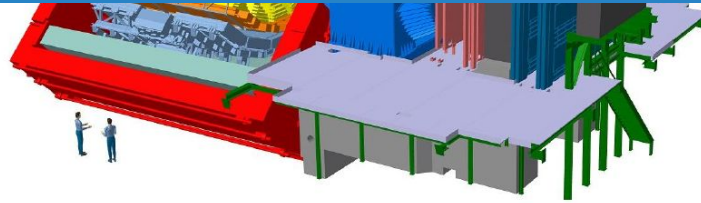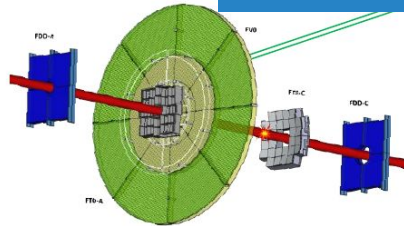
Muon Forward Tracker
to match muons before
and after the absorber.
Same Si chips as new ITS

ALICE raw dataflow in Run 3
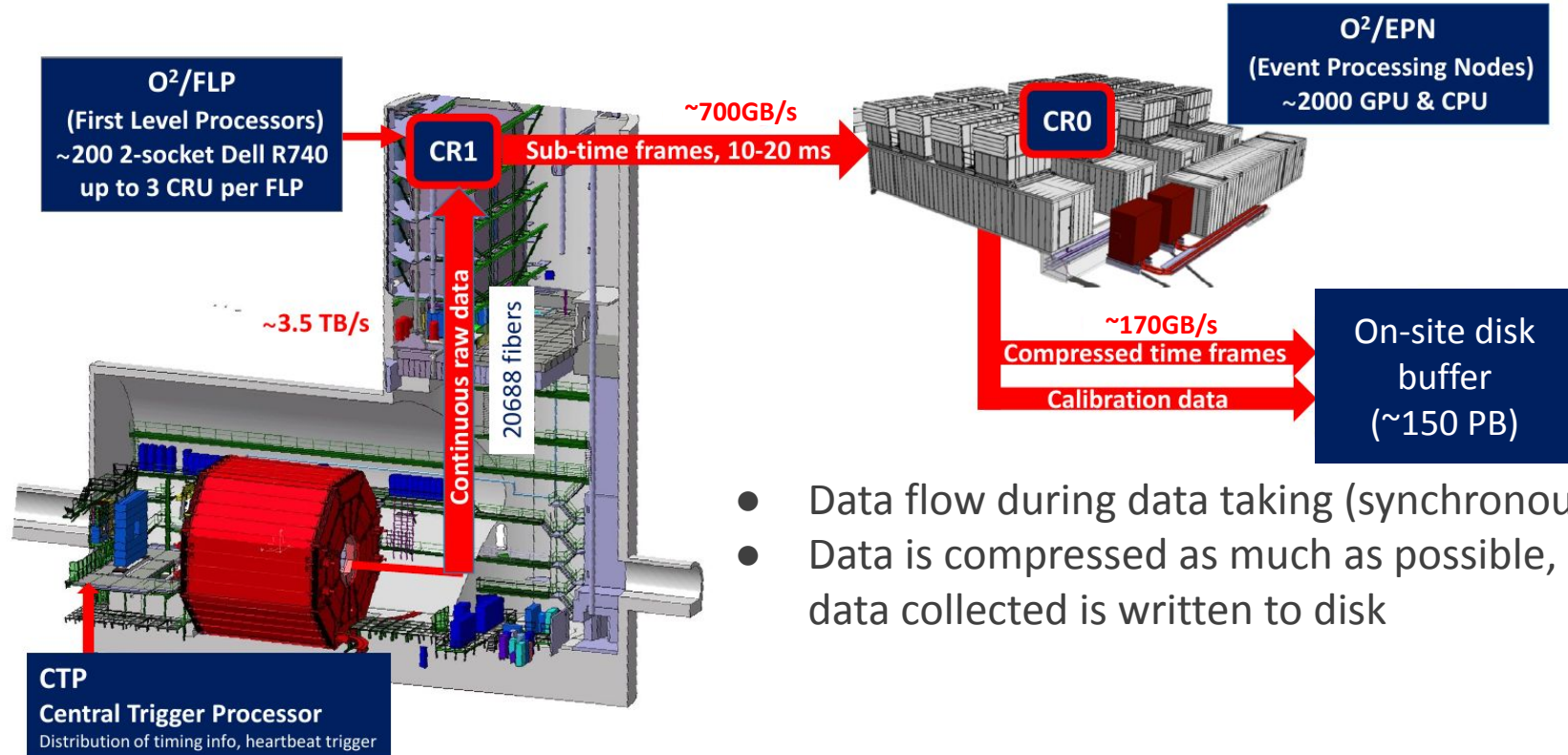
- Data flow during data taking (synchronous phase)
- Data is compressed as much as possible, but all data collected is written to disk

ALICE raw dataflow in Run 3

O²/FLP
(First Level Processors)
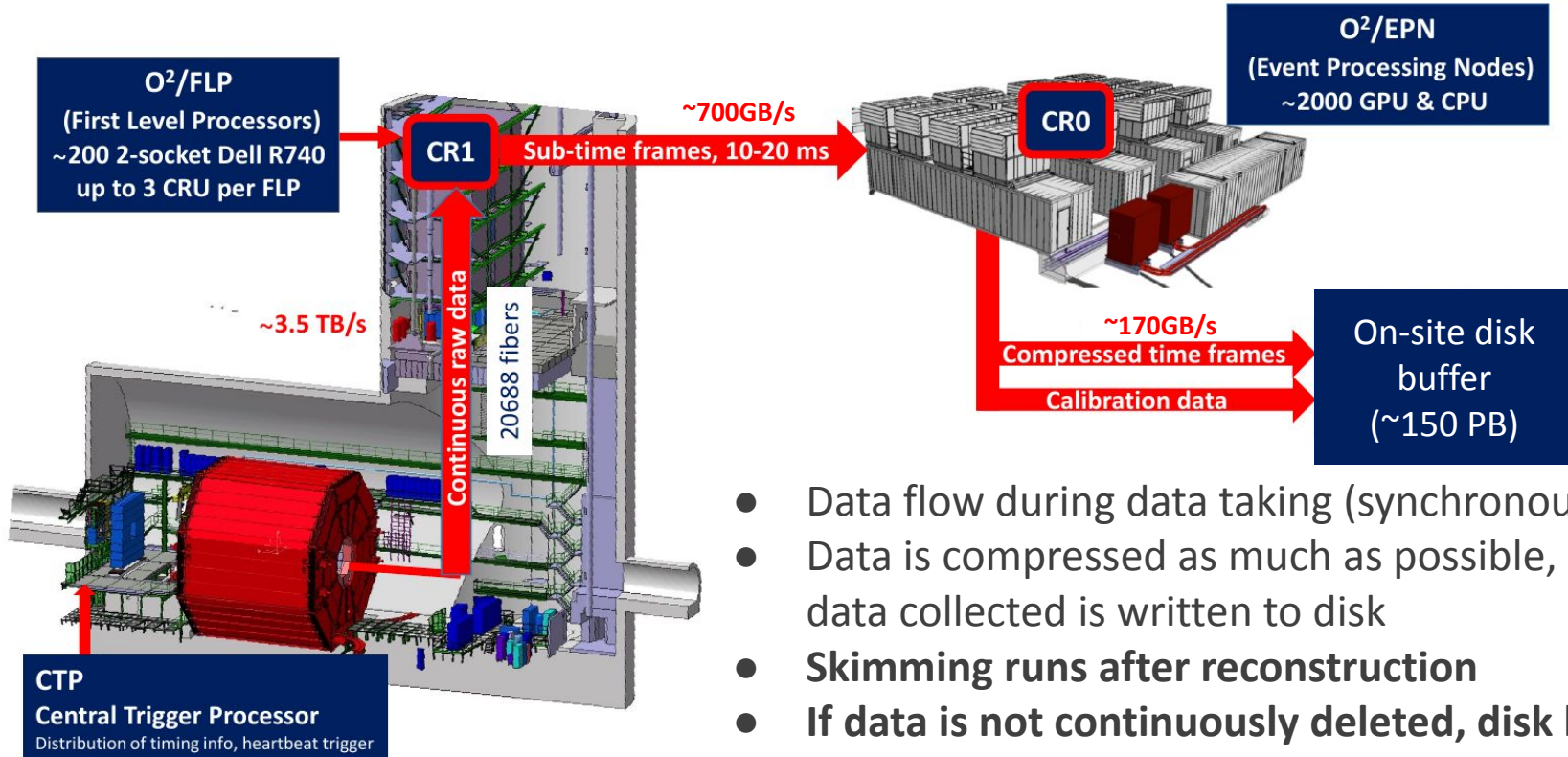~200 2-socket Dell R740
up to 3 CRU per FLP

CR1

~700GB/s
Sub-time frames, 10-20 ms

O²/EPN
(Event Processing Nodes)
~2000 GPU & CPU

CR0

~3.5 TB/s

Continuous raw data

20688 fibers

~170GB/s
Compressed time frames
Calibration data

On-site disk buffer
(~150 PB)

CTP
Central Trigger Processor
Distribution of timing info, heartbeat trigger

- Data flow during data taking (synchronous phase)
- Data is compressed as much as possible, but all data collected is written to disk
- **Skimming runs after reconstruction**
- **If data is not continuously deleted, disk buffer would fill up and no new data can be taken!**

Interlude: Heart beat and time frame

Heart Beat (HB)
issued in continuous &
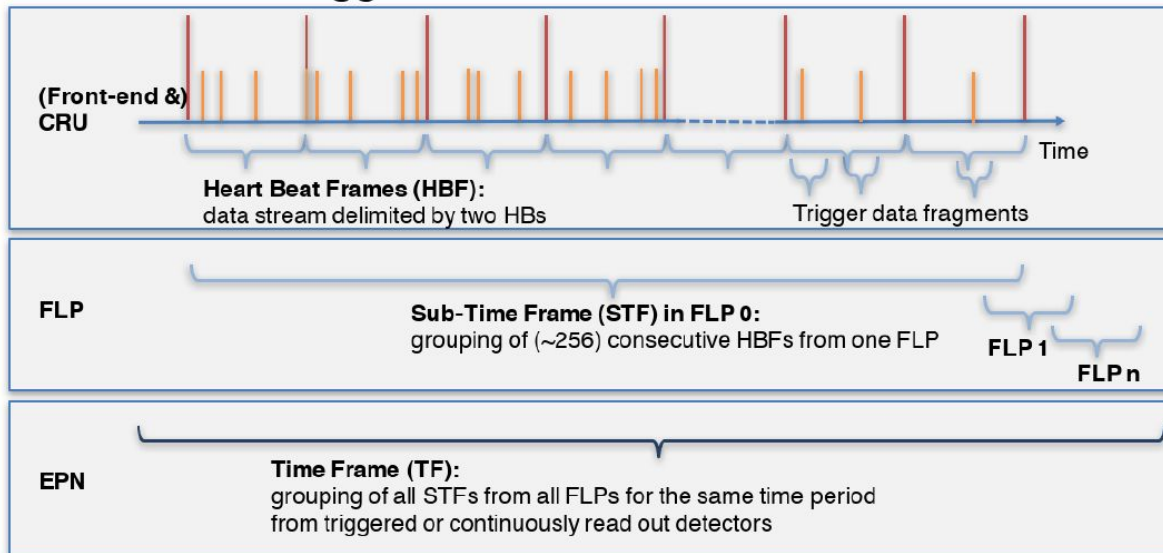triggered modes
to all detectors

Physics trigger
can be sent to upgraded detectors
will be sent to
non-upgraded detectors

HBF and TF rates programmable
Typical values:
- HB: 1 per orbit, 89.4 μs: ~10 kHz
- TF: 1 every ~20 ms: ~50 Hz
- → 1 TF = ~256 HBF

Continuous & Triggered read-out

(Front-end &) CRU

Heart Beat Frames (HBF):
data stream delimited by two HBs

Time

Trigger data fragments

FLP

Sub-Time Frame (STF) in FLP 0:
grouping of (~256) consecutive HBFs from one FLP

FLP 1

FLP n

EPN

Time Frame (TF):
grouping of all STFs from all FLPs for the same time period
from triggered or continuously read out detectors

- HB allows synchronization and TF sampling from detectors with continuous and triggered readouts
- Synchronized with LHC clock
- HB Frame is the smallest chunk of data which is inspected by CTP and can be dropped if the quality is bad
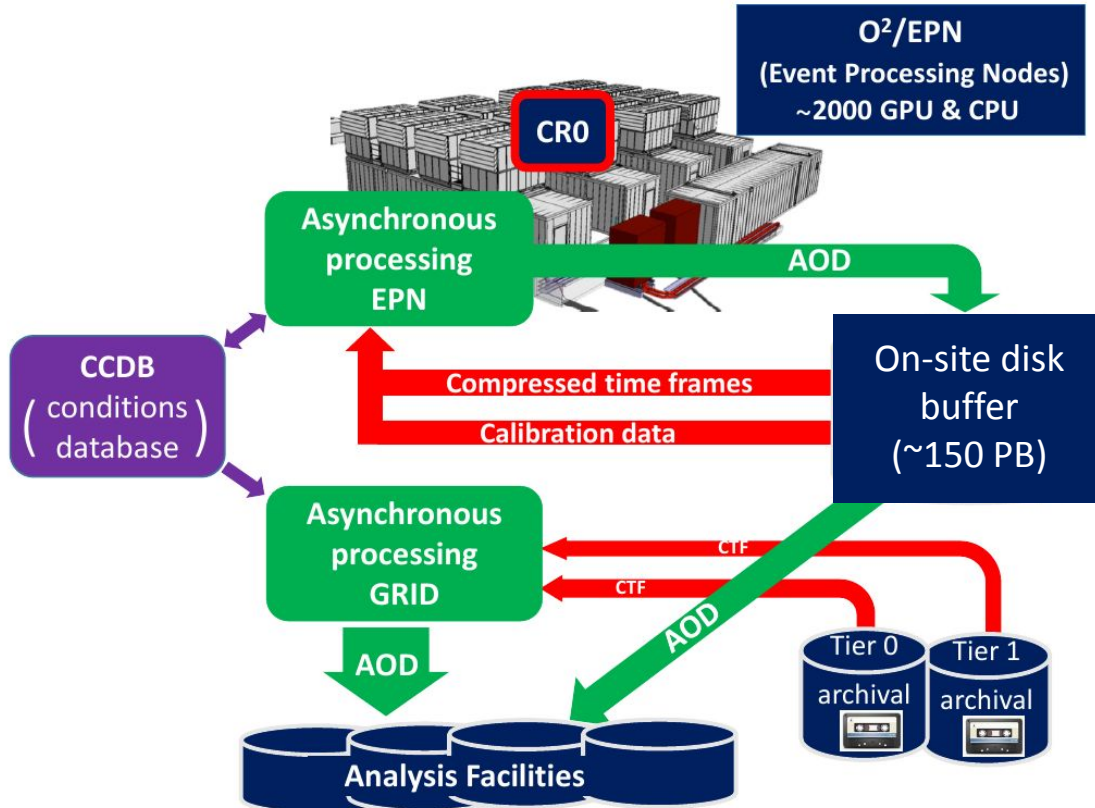- Single EPN sees non-consecutive TFs

NB: In current ALICE configuration TF is set to 2ms.

ALICE reconstruction dataflow in Run 3
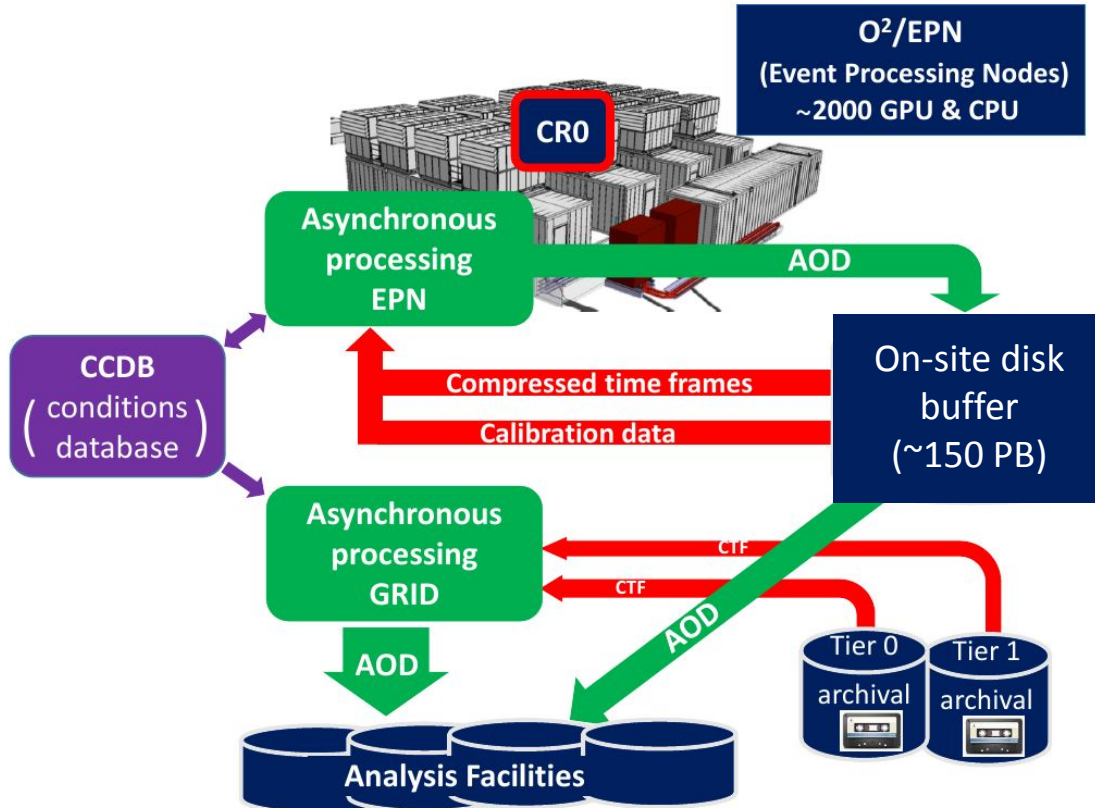
- Data flow during data reconstruction (asynchronous phase)
- EPNs and Grid resources are used for reconstruction and Analysis object files (AODs) become available on analysis facilities
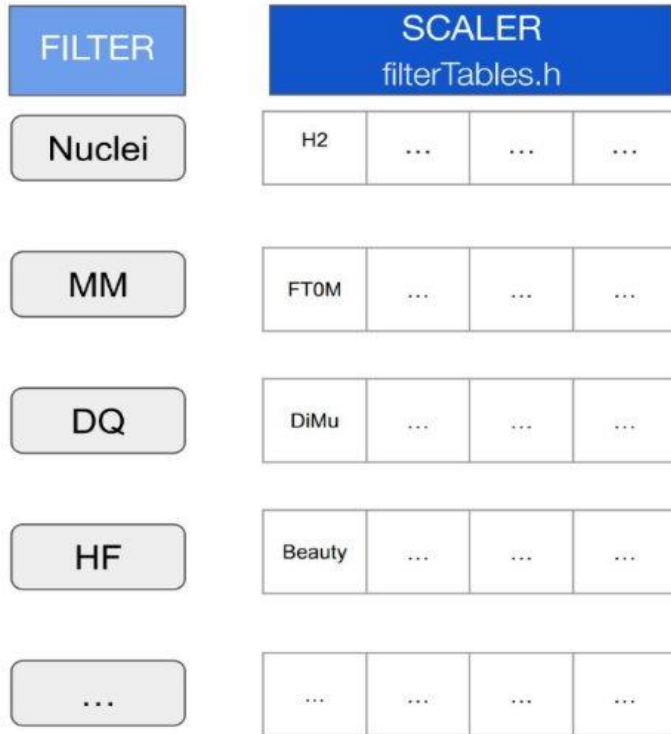
ALICE reconstruction dataflow in Run 3

- Data flow during data reconstruction (asynchronous phase)
- EPNs and Grid resources are used for reconstruction and Analysis object files (AODs) become available on analysis facilities
- **AOD are now available for skimming (i.e. to be analyzed by software triggers)**
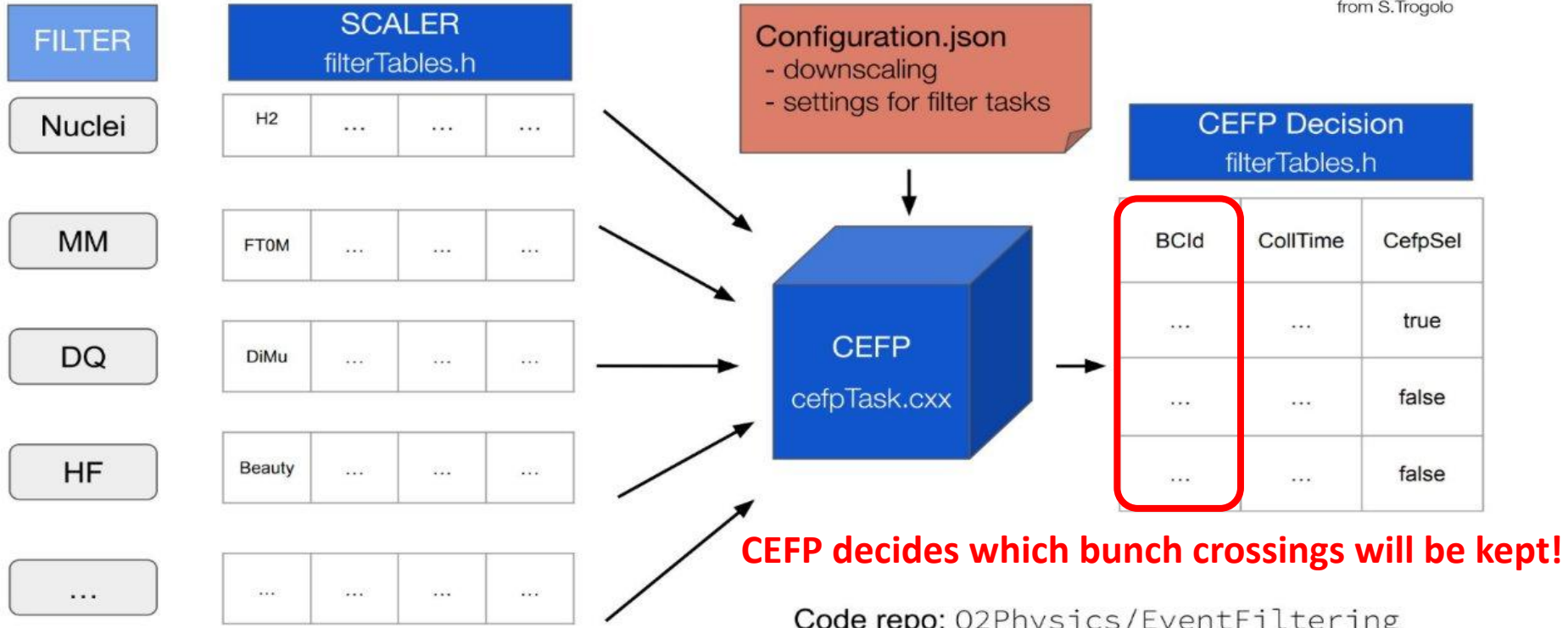
ALICE software trigger

- Analyzers from different working groups write analysis tasks which tag events to select events of interest
- Data is fully calibrated at this stage so information from every detector can be used, especially PID information from TPC
- **All decisions will be collected and the bunch crossings of the selected collisions will be tagged**

CEFP = Central Event Filtering Processor

ALICE software trigger

CEFP decides which bunch crossings will be kept!

Code repo: O2Physics/EventFiltering

CEFP = Central Event Filtering Processor

ALICE software trigger

TOF data stream: stream of hits sorted in time

TRD data stream: triggered readout frames of ~3us

TPC data stream: time bins of 200ns

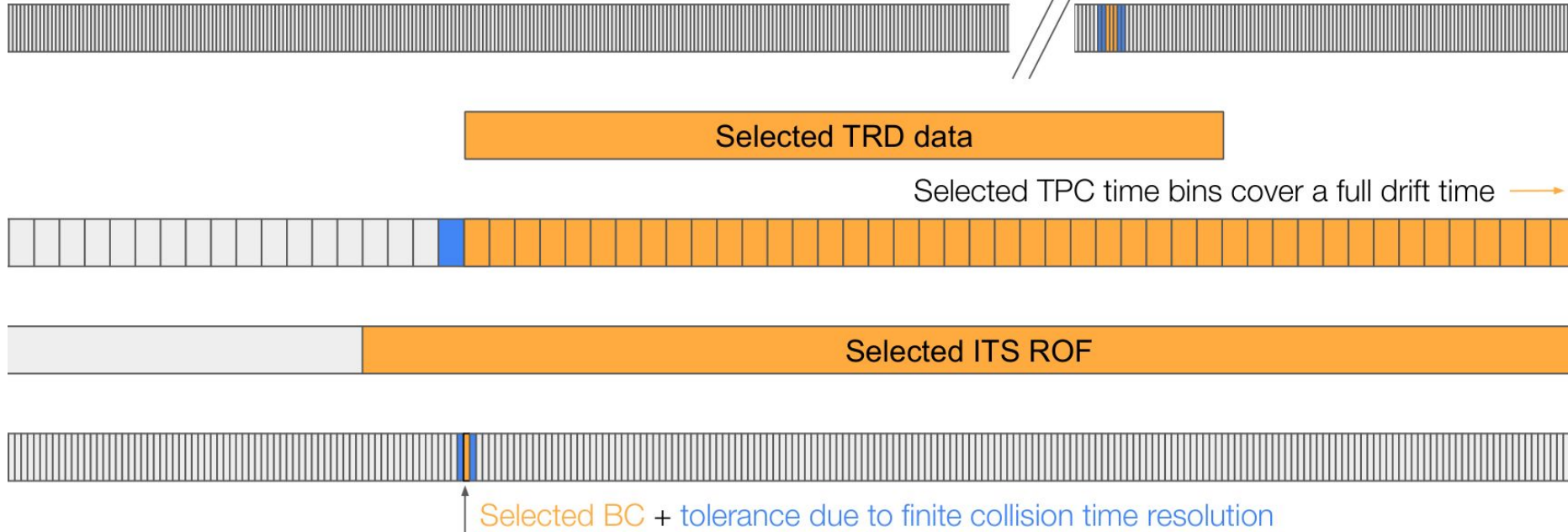ITS data stream: readout frames of 198BC

Bunch Crossings

NB: pictorial view of data streams for illustration purposes (Courtesy from M.Puccio)

ALICE software trigger

TOF raw time has a constant shift of ⅓ orbit

Selected TRD data

Selected TPC time bins cover a full drift time

Selected ITS ROF

Selected BC + tolerance due to finite collision time resolution

NB: pictorial view of data streams for illustration purposes (Courtesy from M.Puccio)

ALICE software trigger

TOF raw time has a constant shift of ⅓ orbit
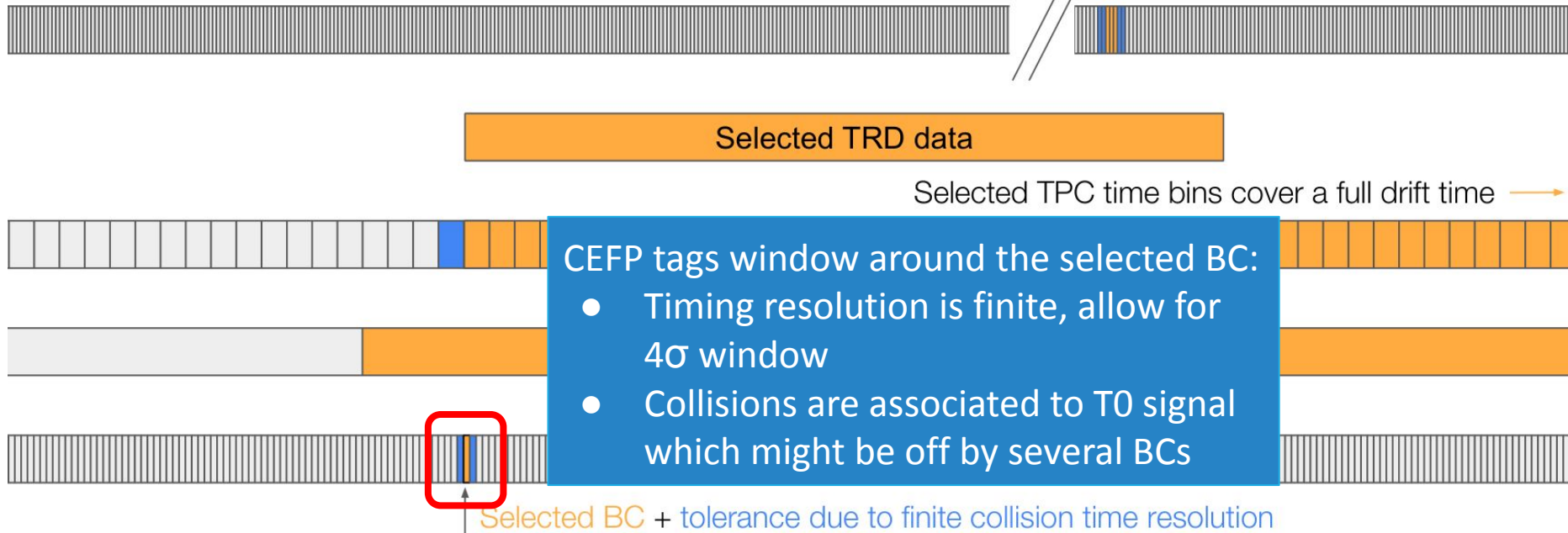
Selected TRD data

Selected TPC time bins cover a full drift time

CEFP tags window around the selected BC:
- Timing resolution is finite, allow for 4σ window
- Collisions are associated to T0 signal which might be off by several BCs

Selected BC + tolerance due to finite collision time resolution

NB: pictorial view of data streams for illustration purposes (Courtesy from M.Puccio)

ALICE software trigger processing chain

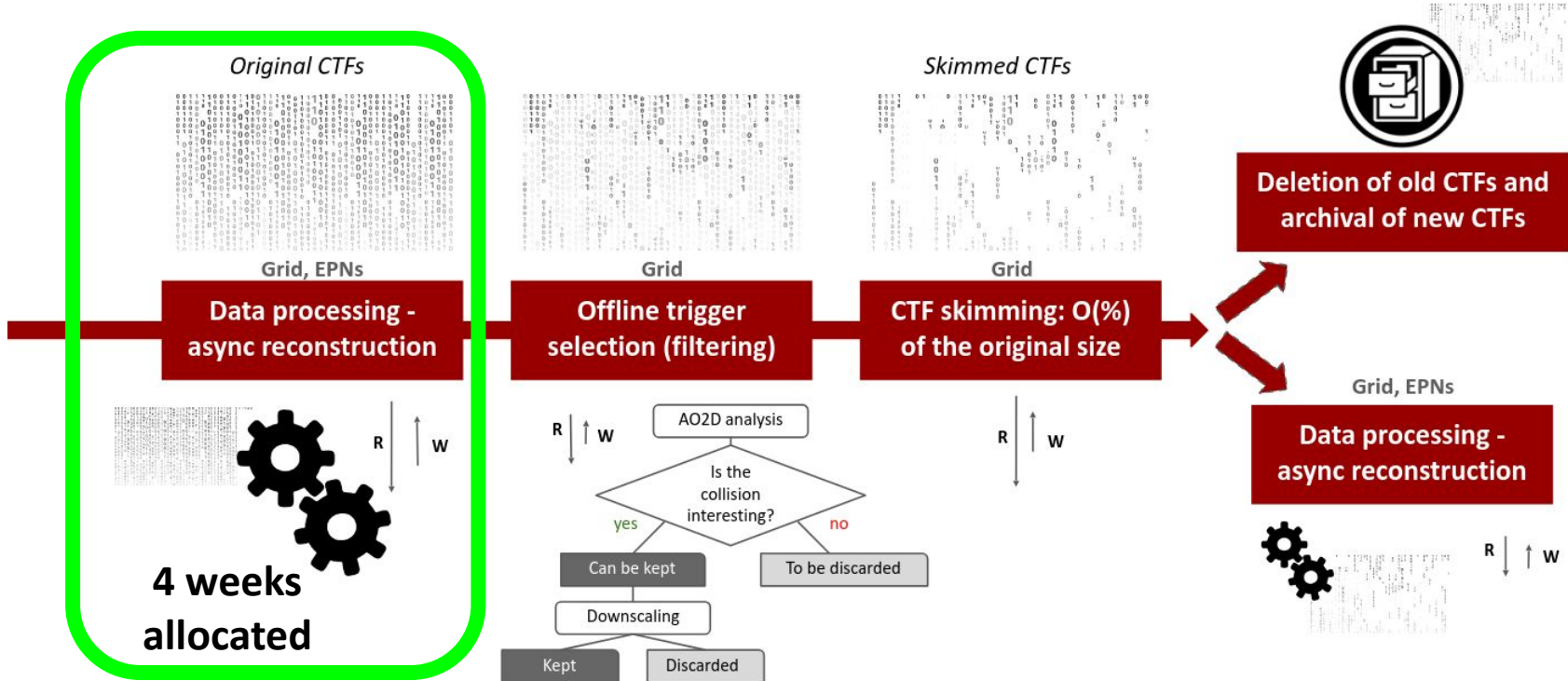

NB: sizes of symbols/images only for illustration purposes (Courtesy from C. Zampolli)

ALICE software trigger processing chain

Original CTFs

Grid, EPNs

Data processing - async reconstruction

R | W

4 weeks allocated

Offline trigger selection (filtering)

R | W

AO2D analysis

Is the collision interesting?

yes — Can be kept

no — To be discarded

Downscaling

Kept — Discarded

Skimmed CTFs

Grid

CTF skimming: O(%) of the original size

R | W

Deletion of old CTFs and archival of new CTFs

Grid, EPNs

Data processing - async reconstruction

R | W
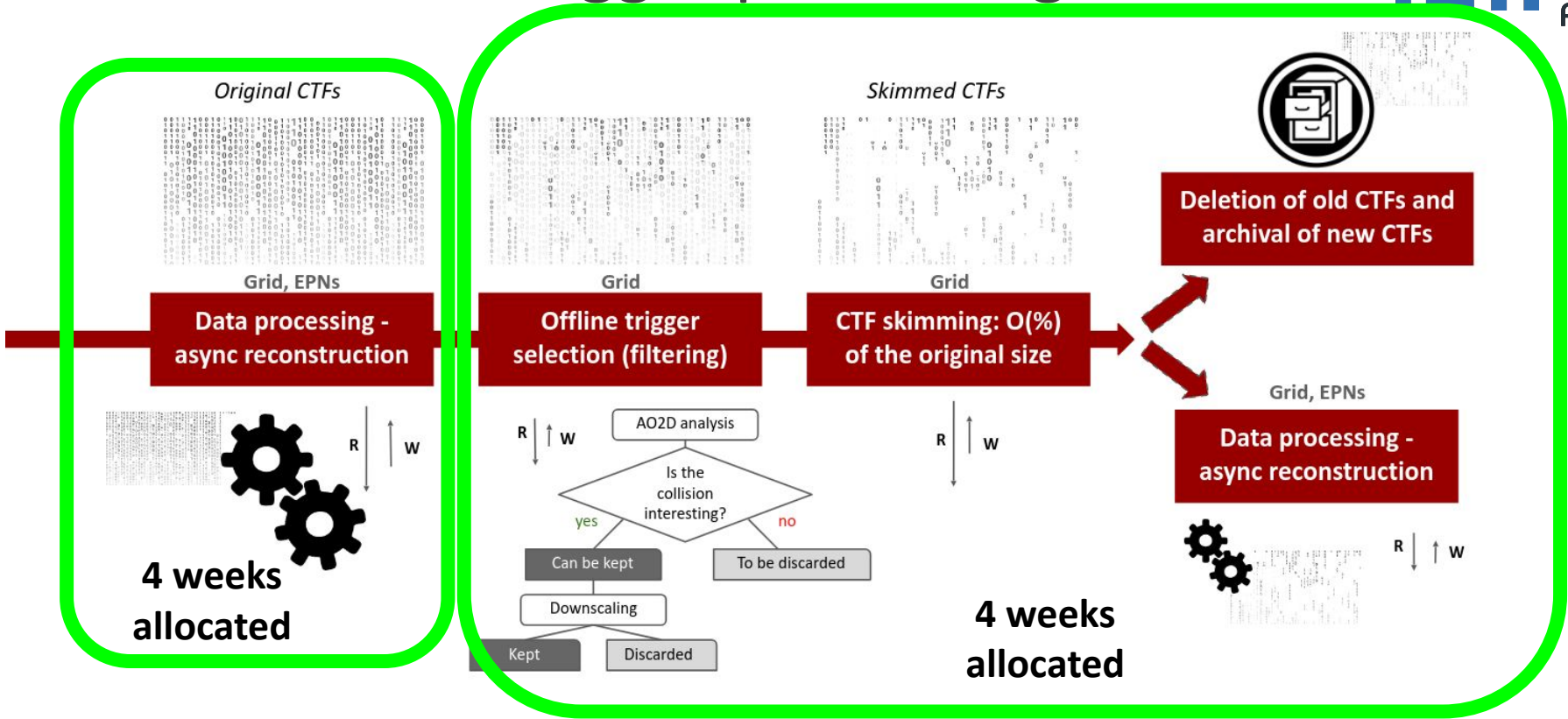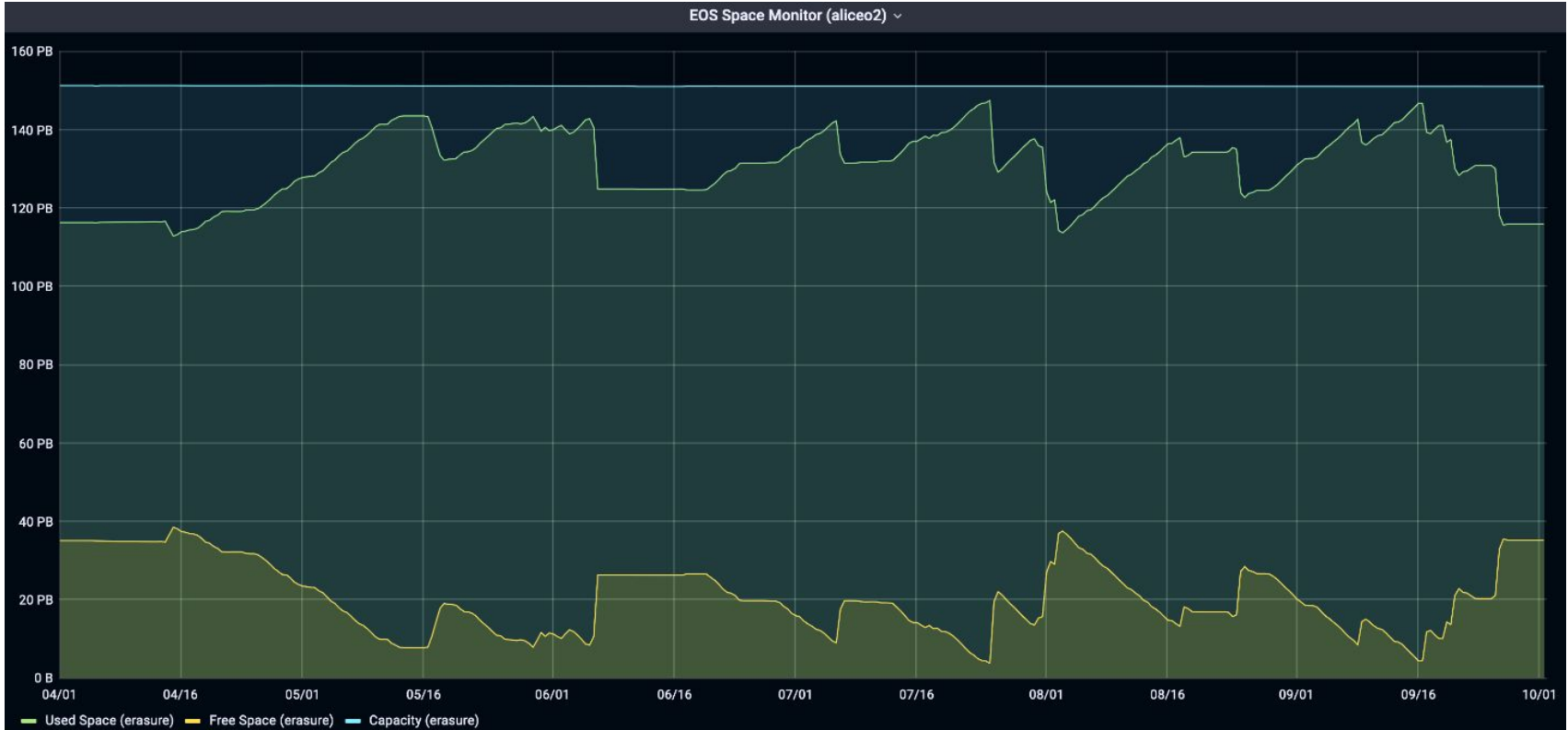
NB: sizes of symbols/images only for illustration purposes (Courtesy from C. Zampolli)

ALICE software trigger processing chain

Original CTFs

Skimmed CTFs

Grid, EPNs

Data processing - async reconstruction

R | W

4 weeks allocated

Grid

Offline trigger selection (filtering)

R | W

AO2D analysis

Is the collision interesting?

yes — Can be kept

no — To be discarded

Downscaling

Kept | Discarded

Grid

CTF skimming: O(%) of the original size

R | W

4 weeks allocated

Deletion of old CTFs and archival of new CTFs

Grid, EPNs

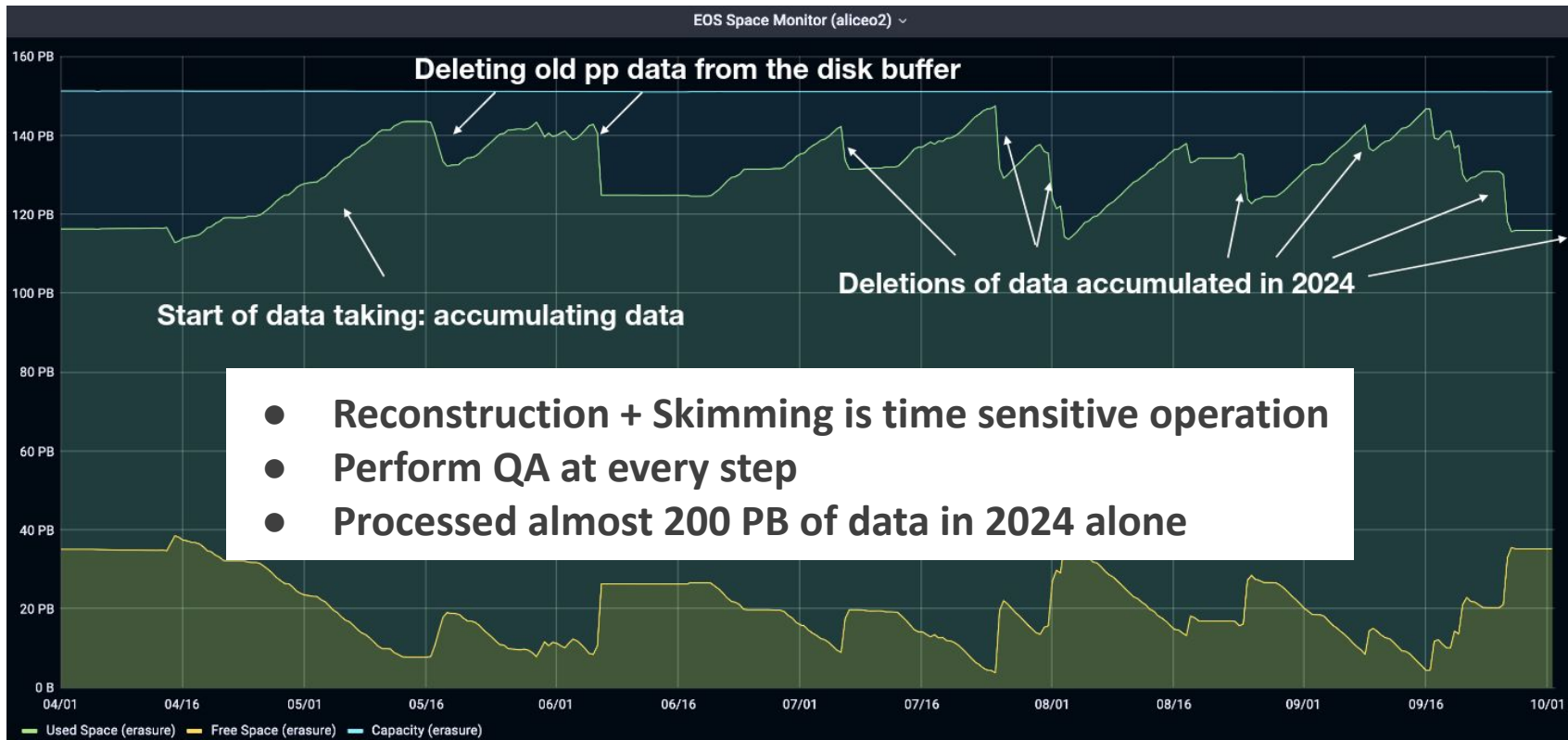**Data processing - async reconstruction**

R | W

NB: sizes of symbols/images only for illustration purposes (Courtesy from C. Zampolli)

Data accumulation in 2024 (pp data)

Data accumulation in 2024 (pp data)
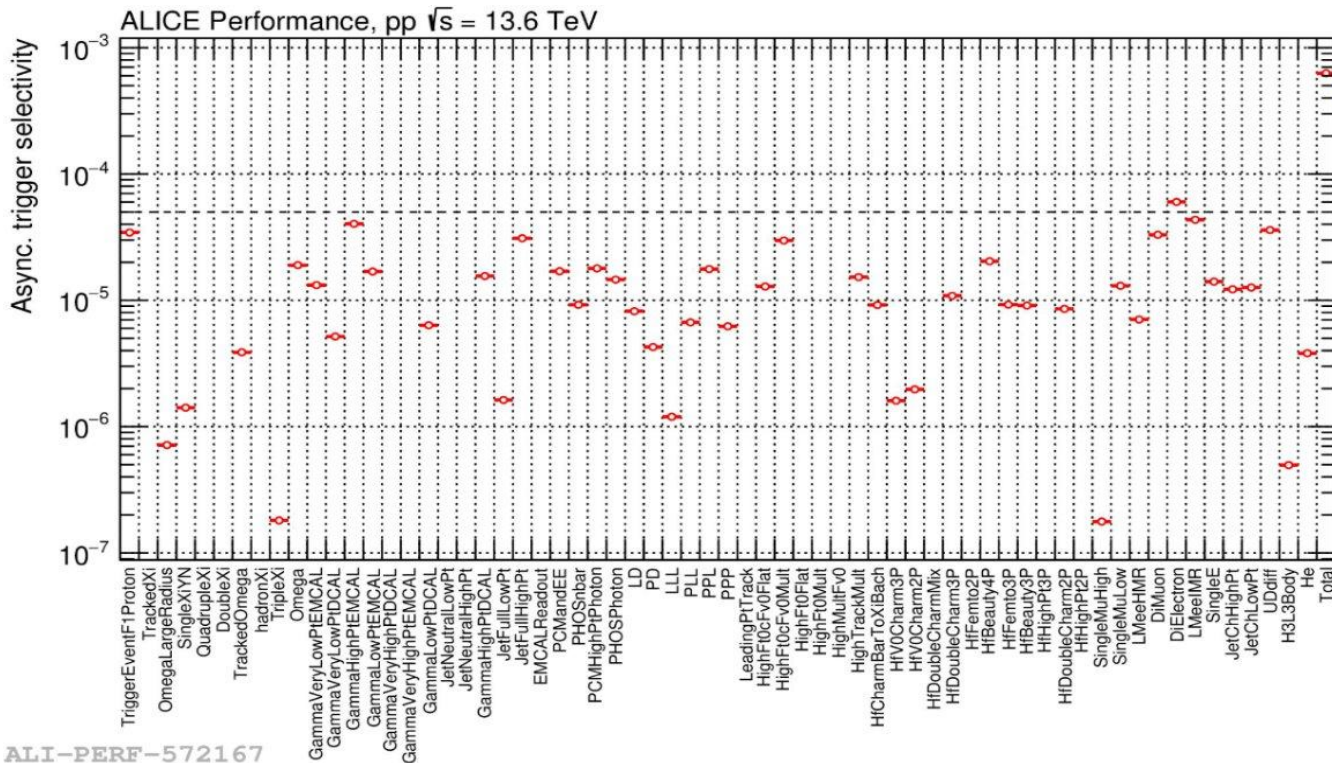
EOS Space Monitor (aliceo2)

Deleting old pp data from the disk buffer

Start of data taking: accumulating data

Deletions of data accumulated in 2024

- **Reconstruction + Skimming is time sensitive operation**
- **Perform QA at every step**
- **Processed almost 200 PB of data in 2024 alone**

Used Space (erasure) — Free Space (erasure) — Capacity (erasure)

ALICE trigger menu

ALICE Performance, pp $\sqrt{s}$ = 13.6 TeV

ALI-PERF-572167

- Selectivity =
  (Triggered Events)/
  (Analyzed Events)
- Total selectivity $<10^{-3}$
- Individual channels
  can be downsampled
- Total compression of
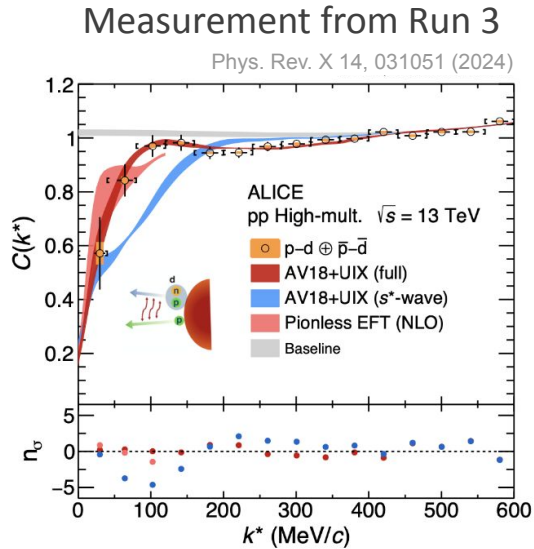 raw data ~4.5%

ALICE trigger menu

Examples
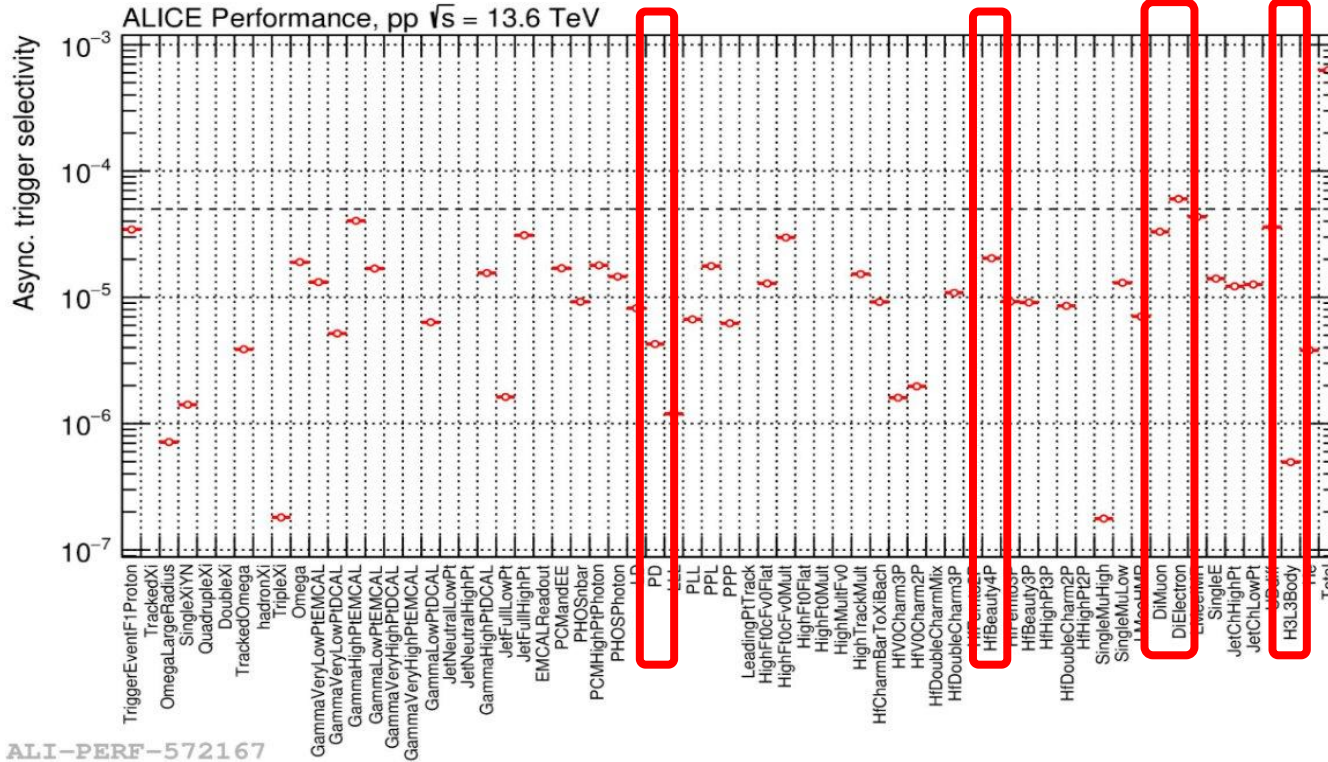
- Selectivity = (Triggered Events)/ (Analyzed Events)
- Total selectivity $<10^{-3}$
- Individual channels can be downsampled
- Total compression of raw data ~4.5%

Example: proton-deuteron trigger

Measurement from Run 3

Phys. Rev. X 14, 031051 (2024)

Increase statistical significance of the measurement to pin down genuine 3-body interactions

Preliminary Measurement in Run 3

ALI-PREL-574442
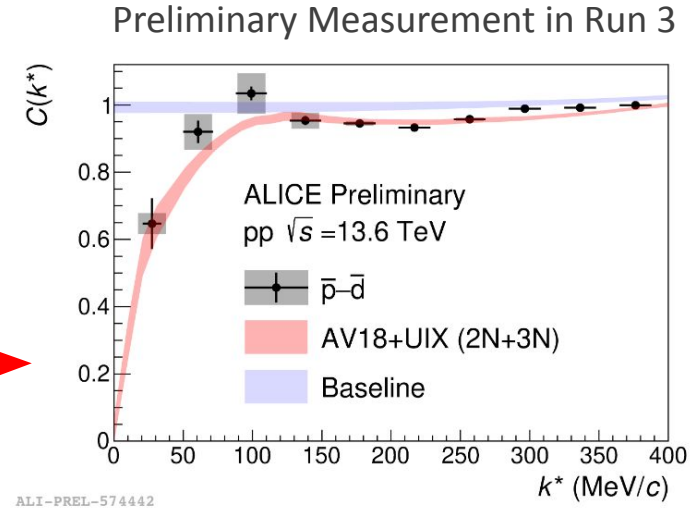
- Trigger on proton-deuteron pairs with small relative momenta
- Rare channel (correlation signal between baryon and light nuclei)
- Physics quality reconstruction required (especially calibrated PID from TPC and TOF)
- Selection not possible with HLT trigger

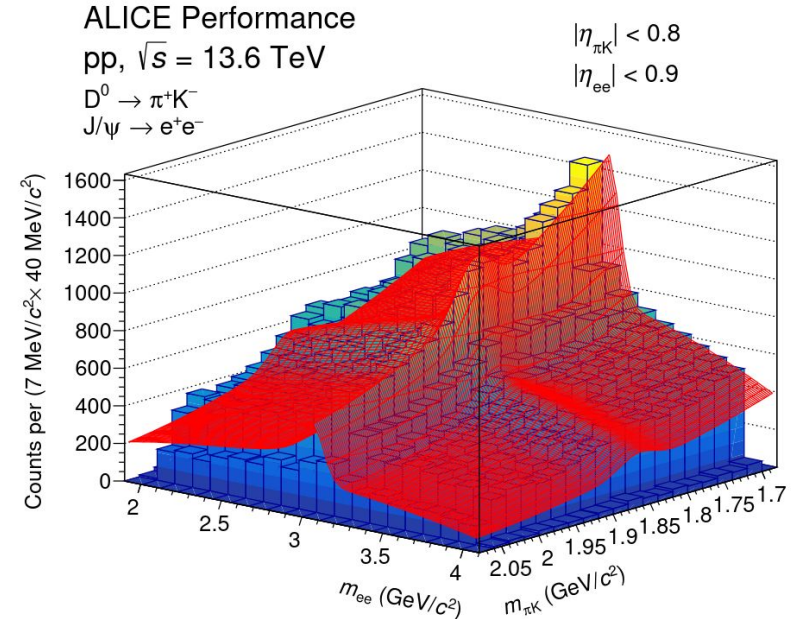# Example: 4-prong beauty trigger
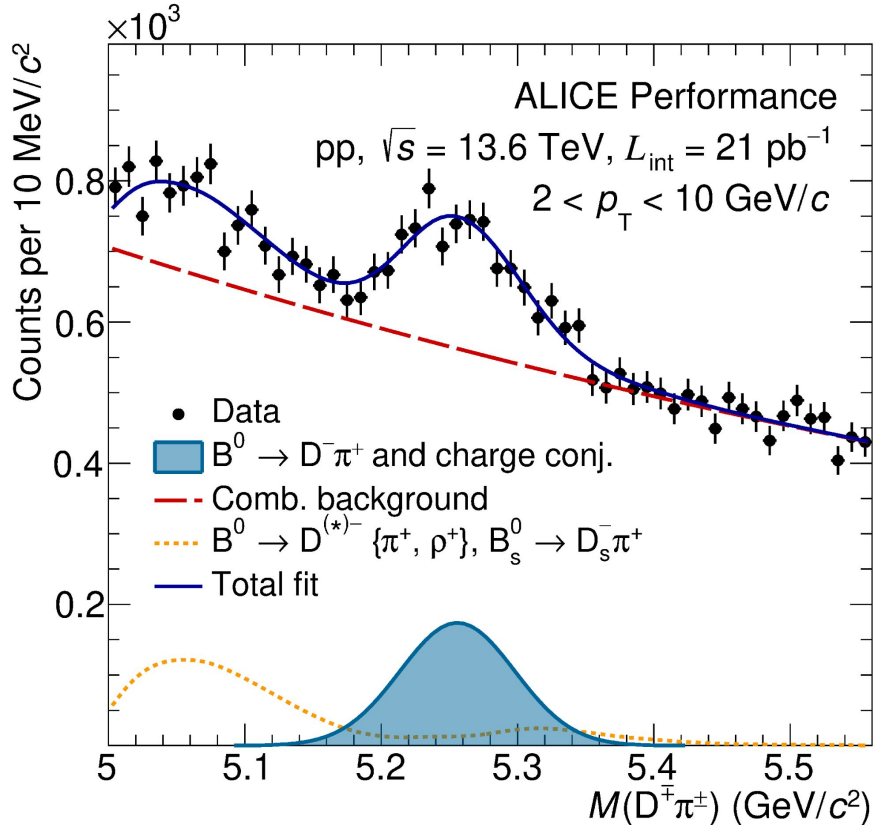
- Trigger on 4-prong beauty decay
- First time to observe the B meson directly in ALICE with the trigger data
- Measurement of B mesons at low p_T at mid-rapidity
- Physics quality reconstruction required (especially calibrated PID from TPC and TOF)

ALI−PERF−578341

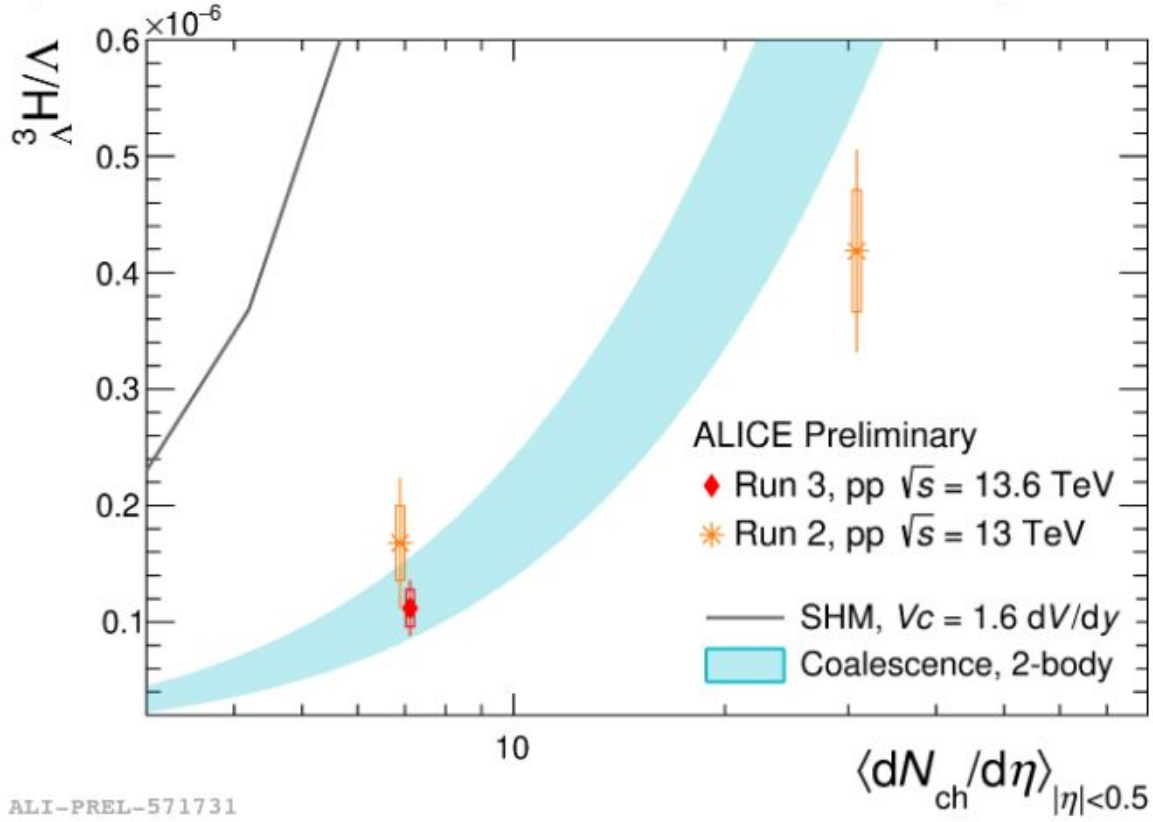# Example: Charm/Dimuon/Dielectron
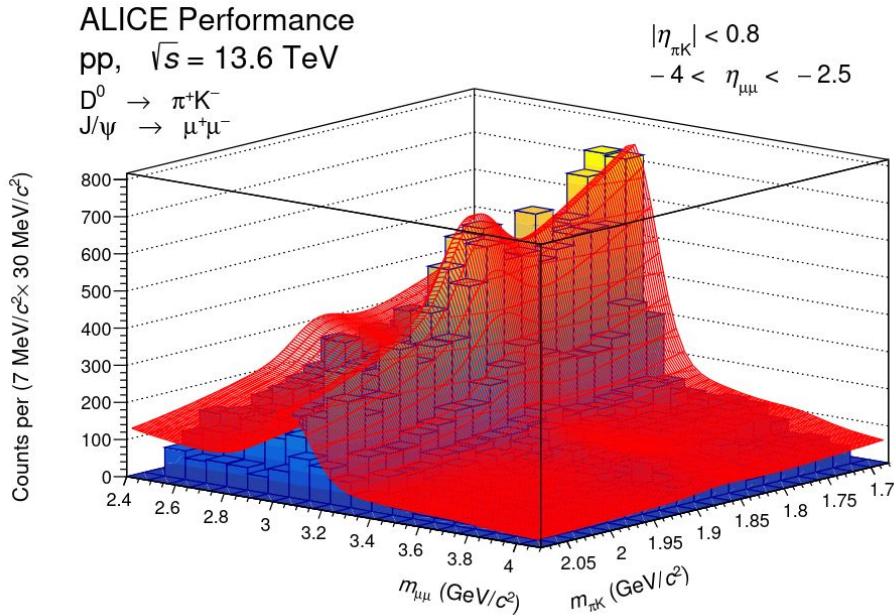
- D_0-J/Psi associated production with large rapidity gap (Double parton scattering):
- Physics quality reconstruction required (especially calibrated PID from TPC and TOF)
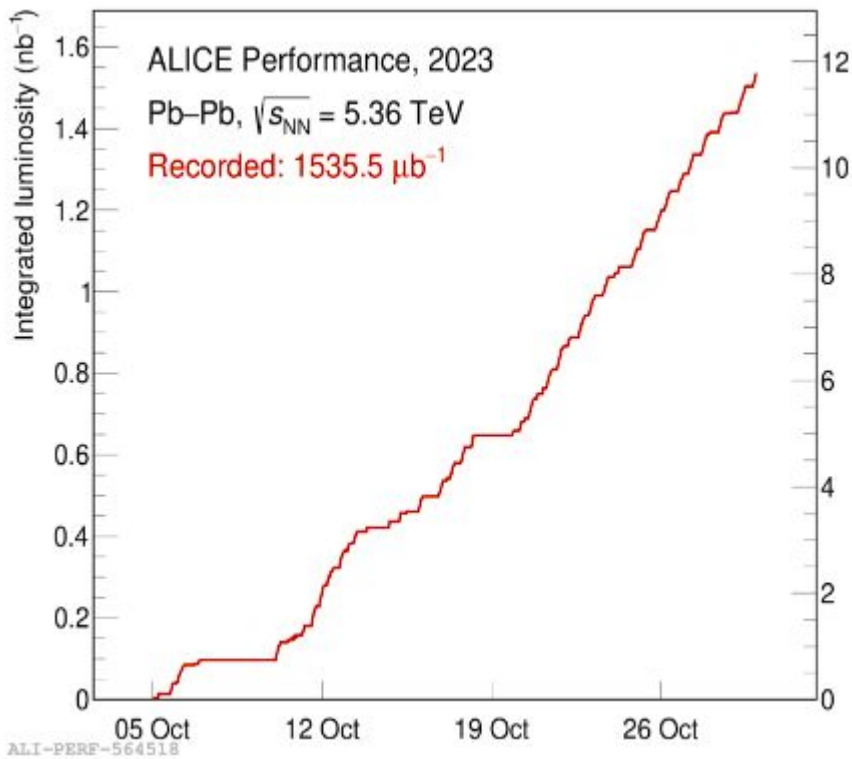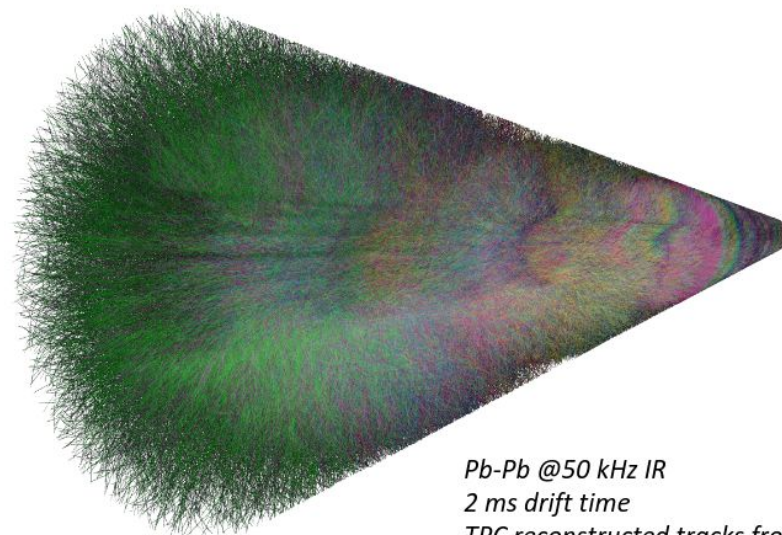
Example: Hypertriton

ALI-PREL-571731

- Twice better precision than Run 2, well-described by 2-body coalescence prediction
- Physics quality reconstruction required (especially calibrated PID from TPC and TOF)

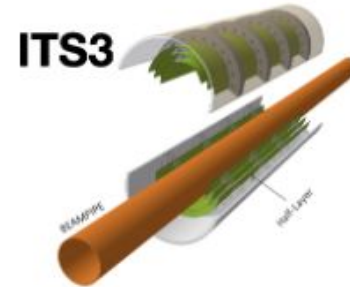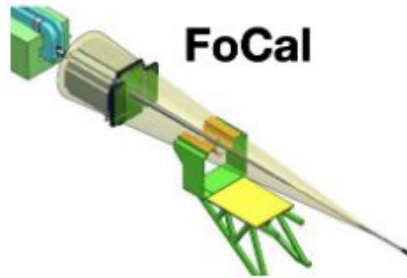# ALICE Software trigger in Pb–Pb?

ALICE Performance, 2023
Pb–Pb, $\sqrt{s_{NN}}$ = 5.36 TeV
Recorded: 1535.5 μb^{-1}

ALI-PERF-564518

All data taken during Pb–Pb runs is stored to disk!

Pb-Pb @50 kHz IR
2 ms drift time
TPC reconstructed tracks from
different colour-coded events

ALICE Software trigger in Run 4?

High luminosity for ions

High luminosity LHC

Run 3   LS3   Run 4

2022   2023   2024   2025   2026   2027   2028   2029   2030   2031   2032

ALICE 2   **FoCal**   **ITS3**
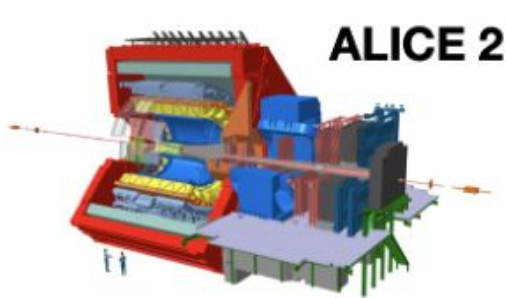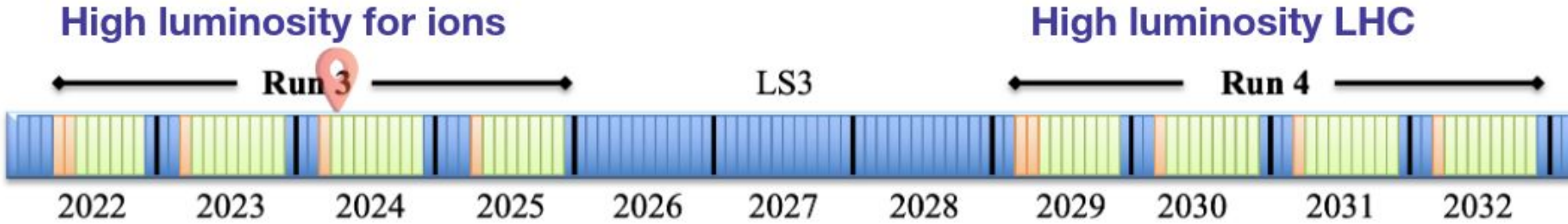
- With Focal opportunity to trigger on new signals
- With ITS3 improve triggering on heavy flavor signals

Summary and outlook

- Continuous detector readout and offline trigger selection work very well for ALICE
- Great success of the 2024 trigger processing campaign: more than 50pb^{-1} ready to be analyzed (pp data)
- Integrated luminosity collect in 2024 is more than ALICE ever inspected (Run1+Run2+Run3 until 2023)
- Discussions about increasing instantaneous luminosity delivered to ALICE

ALICE Performance, Run 3, pp, $\sqrt{s}$ = 13.6 TeV

Recorded
2022: 19.3 pb^{-1}
2023: 9.7 pb^{-1}
2024: 45.9 pb^{-1}

ALI-PERF-581127