ESR6: Optimization of HLT2 selections at the LHCb experiment

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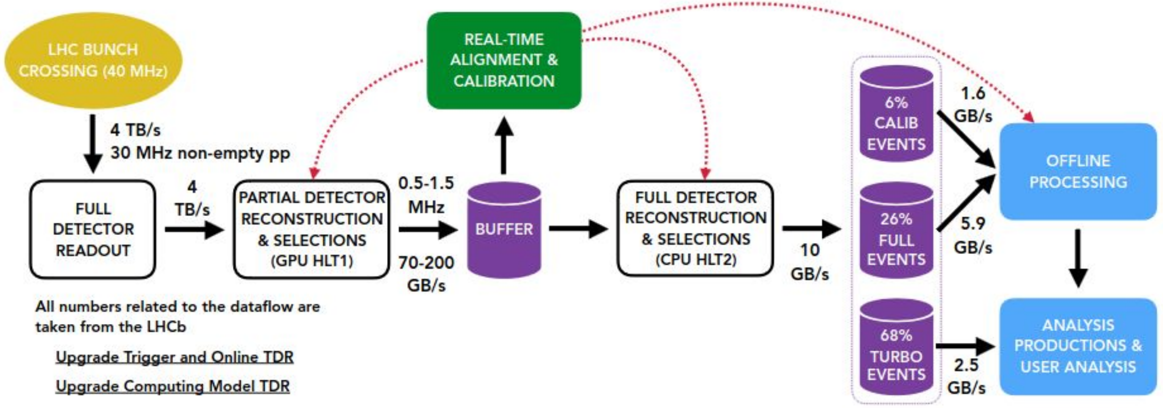
LHCb Run 3 trigger

- HLT1: 30 MHz -> 1 MHz
  - GPU-based algorithms focused on tracks, displaced decay vertices and muons
- Alignment & Calibration: 30 PB
  - Event buffer between HLT1 and HLT2 enabling real-time alignment and calibration



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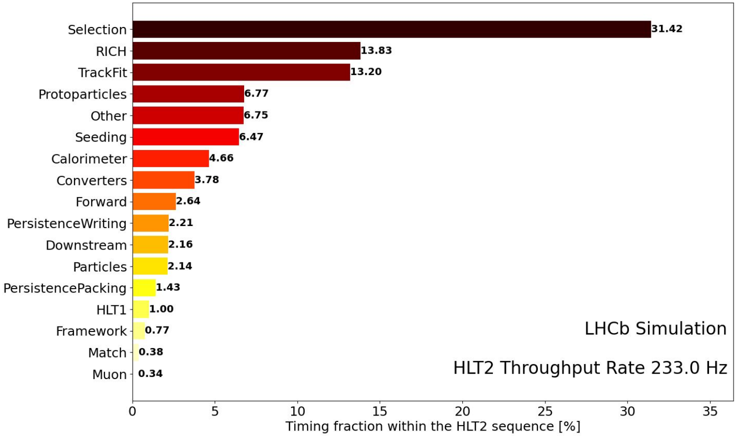
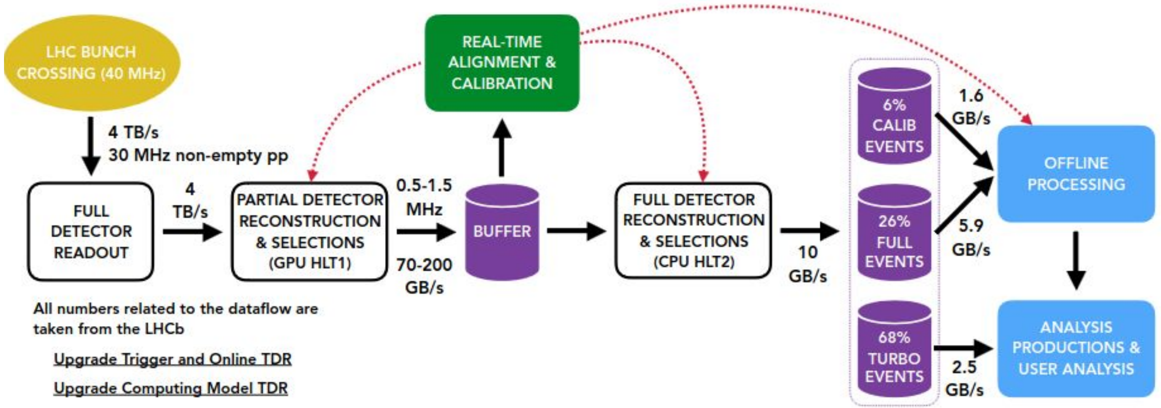
- HLT2: ~ 0.5-1 MHz
  - Offline-level reconstruction and selection of physics objects for analysis





All numbers related to the dataflow are taken from the LHCb

Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

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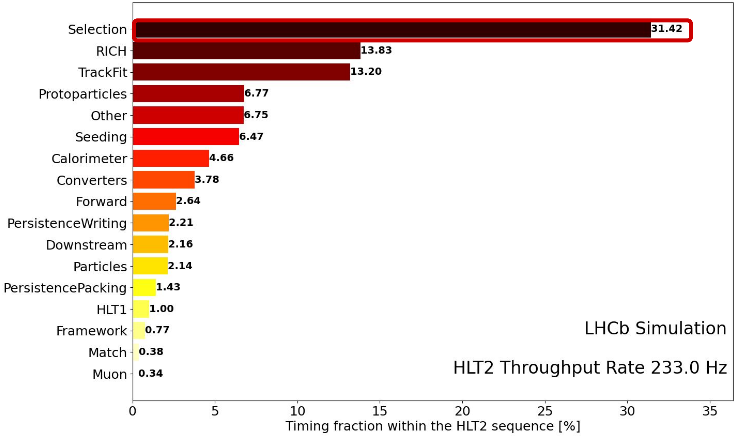

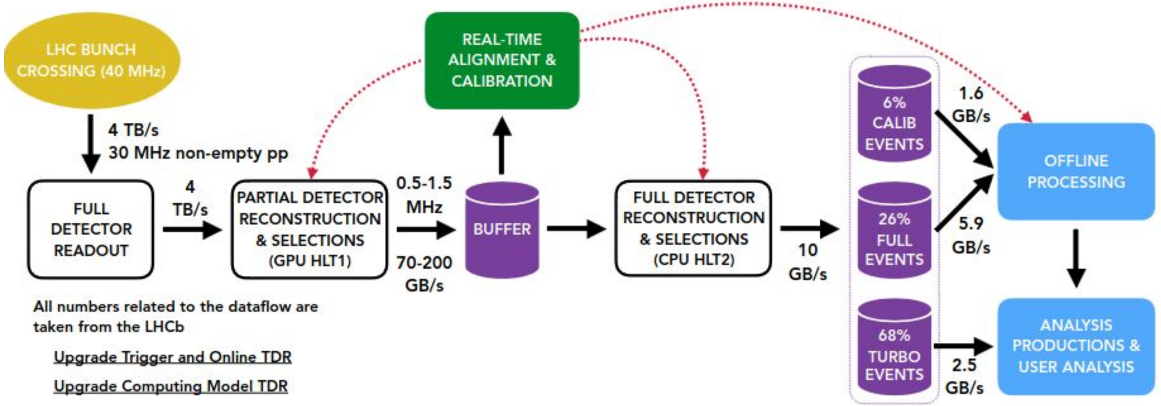

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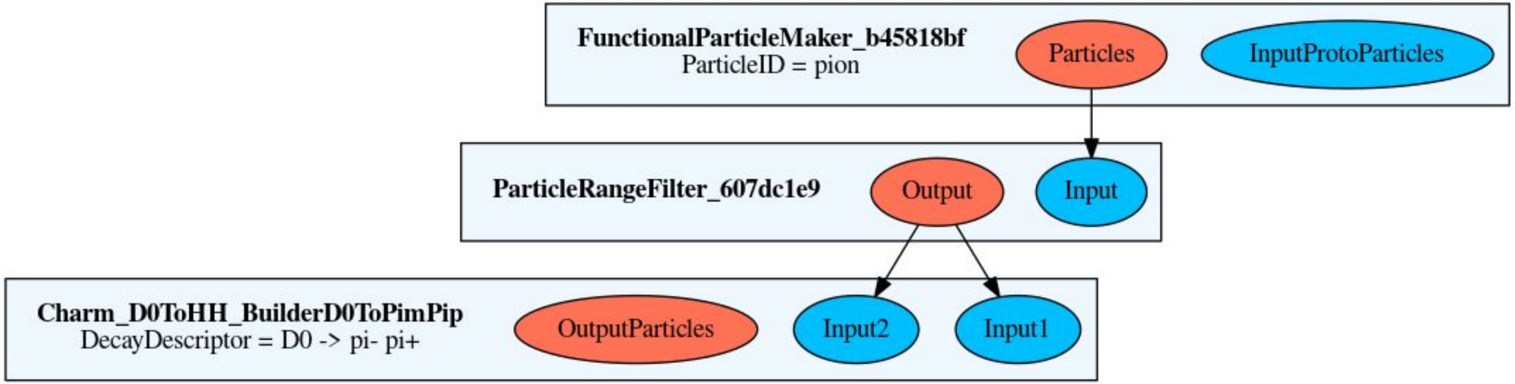
Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

HLT2 trigger selections

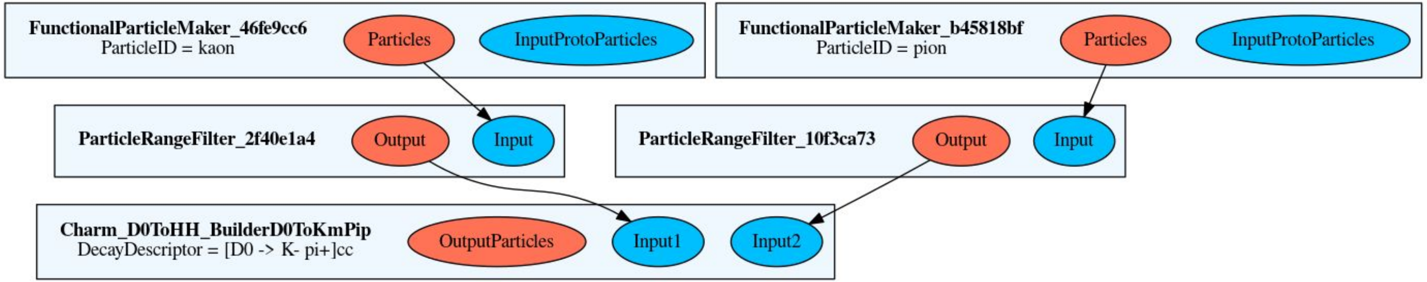
- ~3000 trigger lines currently written
- Line is a collection of selection algorithms
- Lines usually consists of at least
  - Maker: Container of particles coming from reconstruction
  - Filter: Performs cuts on input particles
  - NBodyCombiners: Iterates over combinations of N input particles and performs cuts on the combination



HLT2 control flow optimization

HLT2 trigger control flow

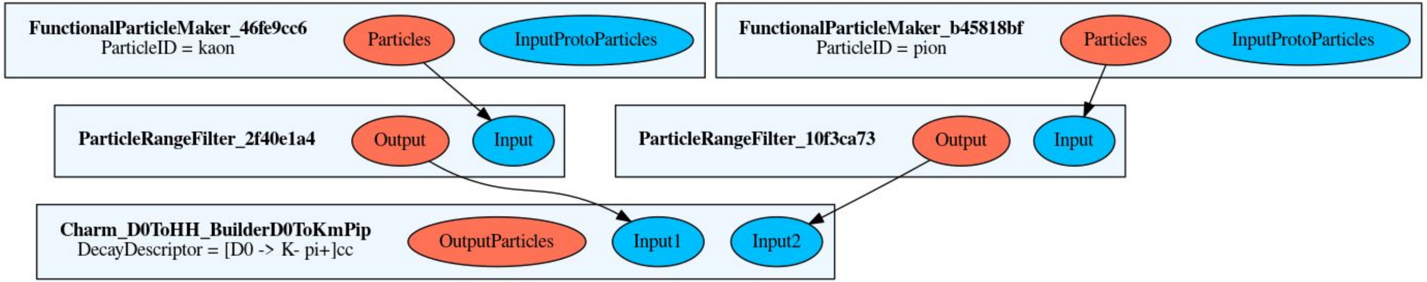
- Control Flow optimization
  - Data flow: The data dependence of trigger line algorithms



HLT2 trigger control flow

- Control Flow optimization
  - Data flow: The data dependence of trigger line algorithms
  - Control flow: Which algorithm(s) that decide if the line triggers
    - Can be a list of algorithms to perform early stopping

```python
@register_line_builder(all_lines)
def dzero2kpi_line(name='Hlt2Charm_D0ToKmPip', prescale=1):
    kaons = make_charm_kaons()
    pions = make_charm_pions()
    dzeros = make_dzeros(kaons, pions, '[D0 -> K- pi+]cc')
    return Hlt2Line(
        name=name, algs=charm_prefilters() + [dzeros], prescale=prescale)
```



HLT2 trigger control flow

- Control Flow optimization
  - Data flow: The data dependence of trigger line algorithms
  - Control flow: Which algorithm(s) that decide if the line triggers
    - Can be a list of algorithms to perform early stopping
- Automatic generation
  - Iterate through data flow
    - Add next algorithm to control flow
    - if > 1 option: add the first algorithm
  - Simple but works well because combiner inputs are sorted

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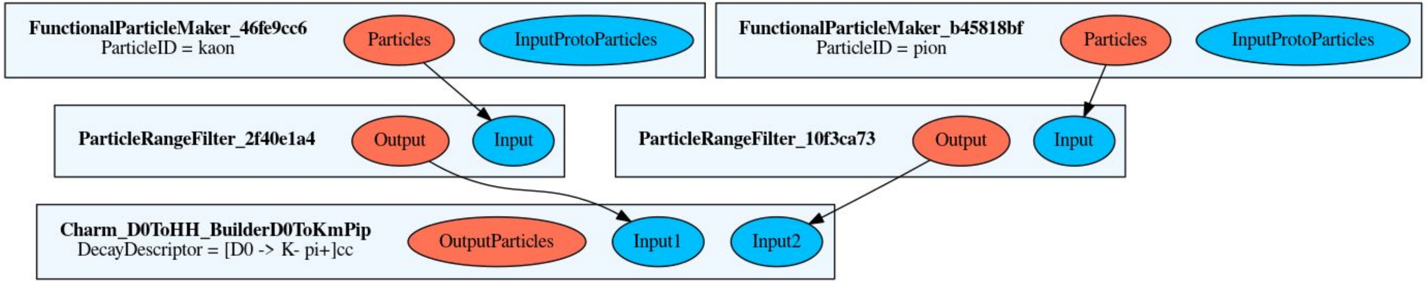
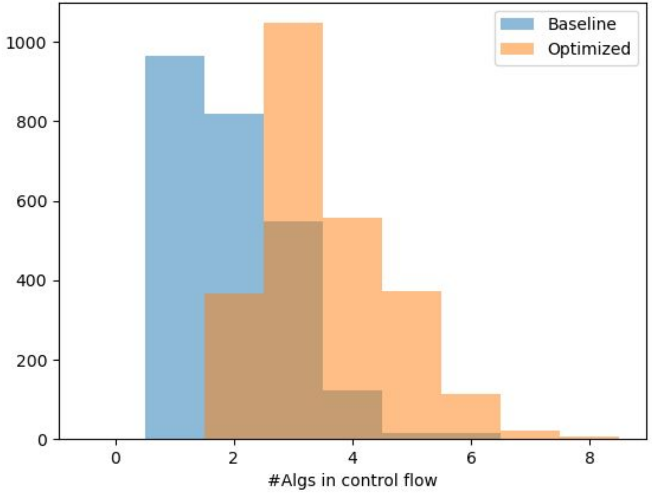


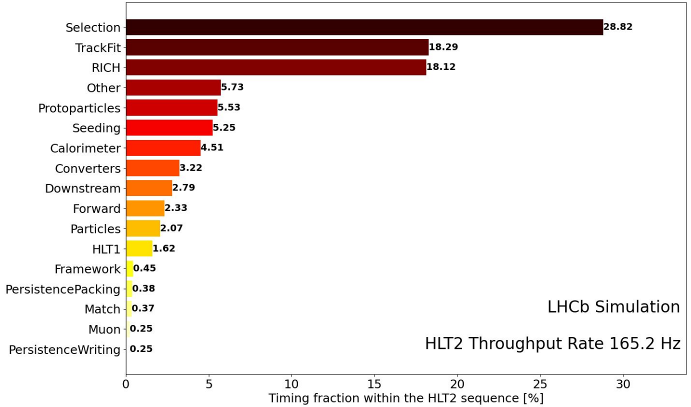
Results

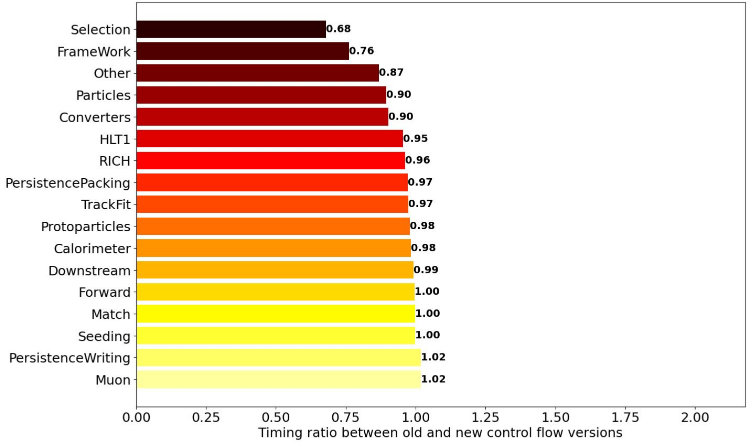
- 92% of control flows altered
  - 2 -> 3.5 average algs per control flow

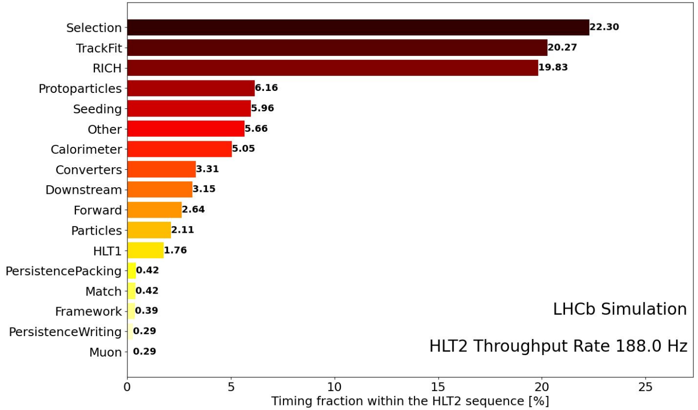


Results

- 92% of control flows altered
  - 2 -> 3.5 average algs per control flow
- LHCb throughput testing of HLT2
- Throughput rate: 165.2 Hz → 188.0 Hz
  - 14% improvement
  - 32% improvement in Selections







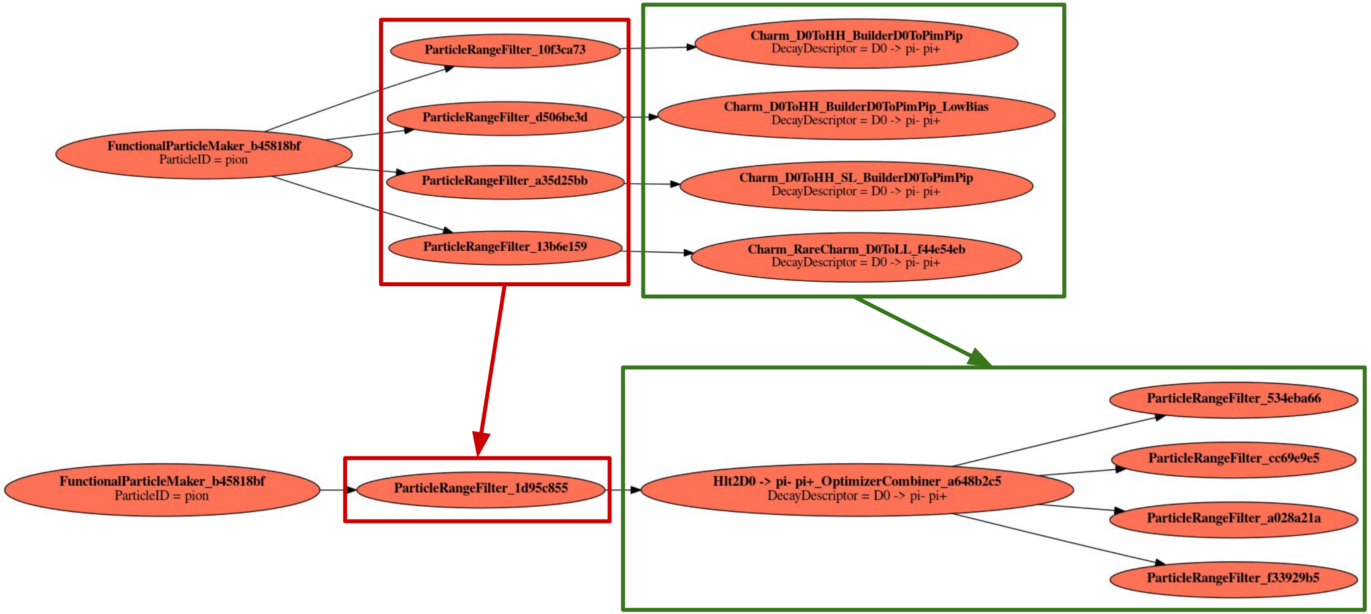
Finally implemented

- Method was merged end of April and activated in data taking shortly after
- Merge request open since December 2023

- This was quite useful as throughput was lower than expected
  - Occupancy in the detector was higher in data than MC
- This optimization together with others helped to increase the throughput to stable data taking levels

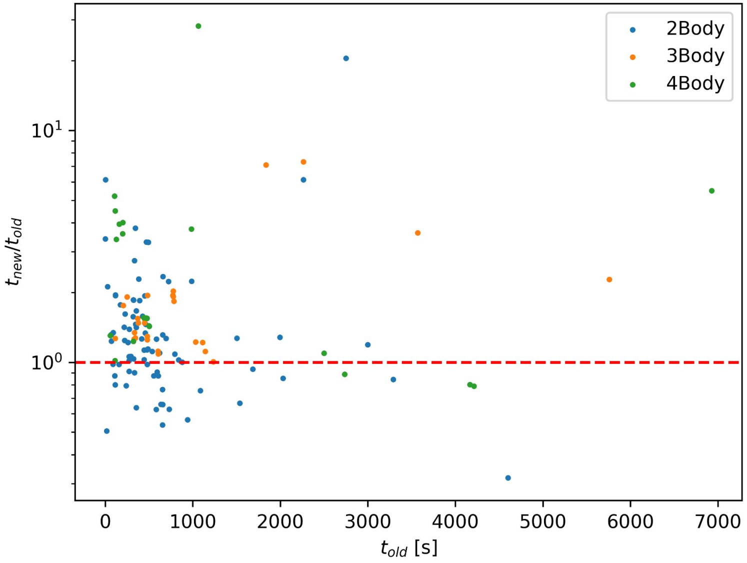
Algorithm overlap

- Last year I presented work on combiner optimization



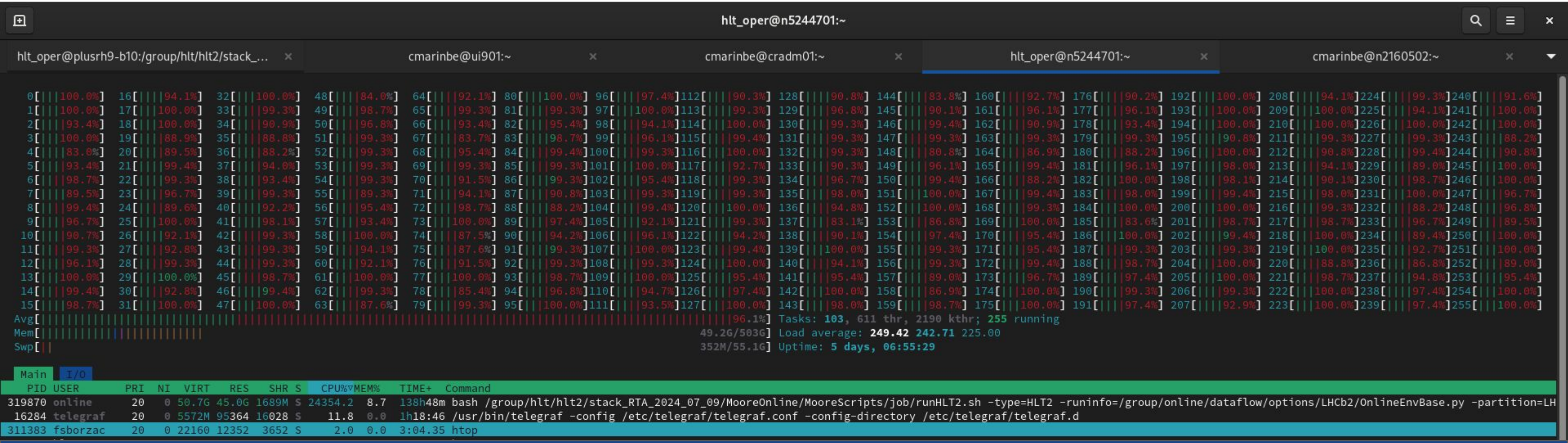
Algorithm overlap

- Last year I presented work on combiner optimization
- Results were not amazing
- Implementation was tricky
  - Creating new line configurations in-situ
  - Framework not made to support it
- Still some interest in approaching this “manually” in LHCb
- I’ve developed overlap testing of algorithms to aid with this
  - Saves input Ids of particles passing an algorithm
  - Enables comparison of algorithms even when the line doesn’t trigger



HLT piquet

- HLT piquet shifts in August(available 24/7) for two weeks
- Online installed new 256 thread CPUs for HLT2, I was helping to commission them
- CPUs were spending 75% of their time in kernel space…



HLT piquet

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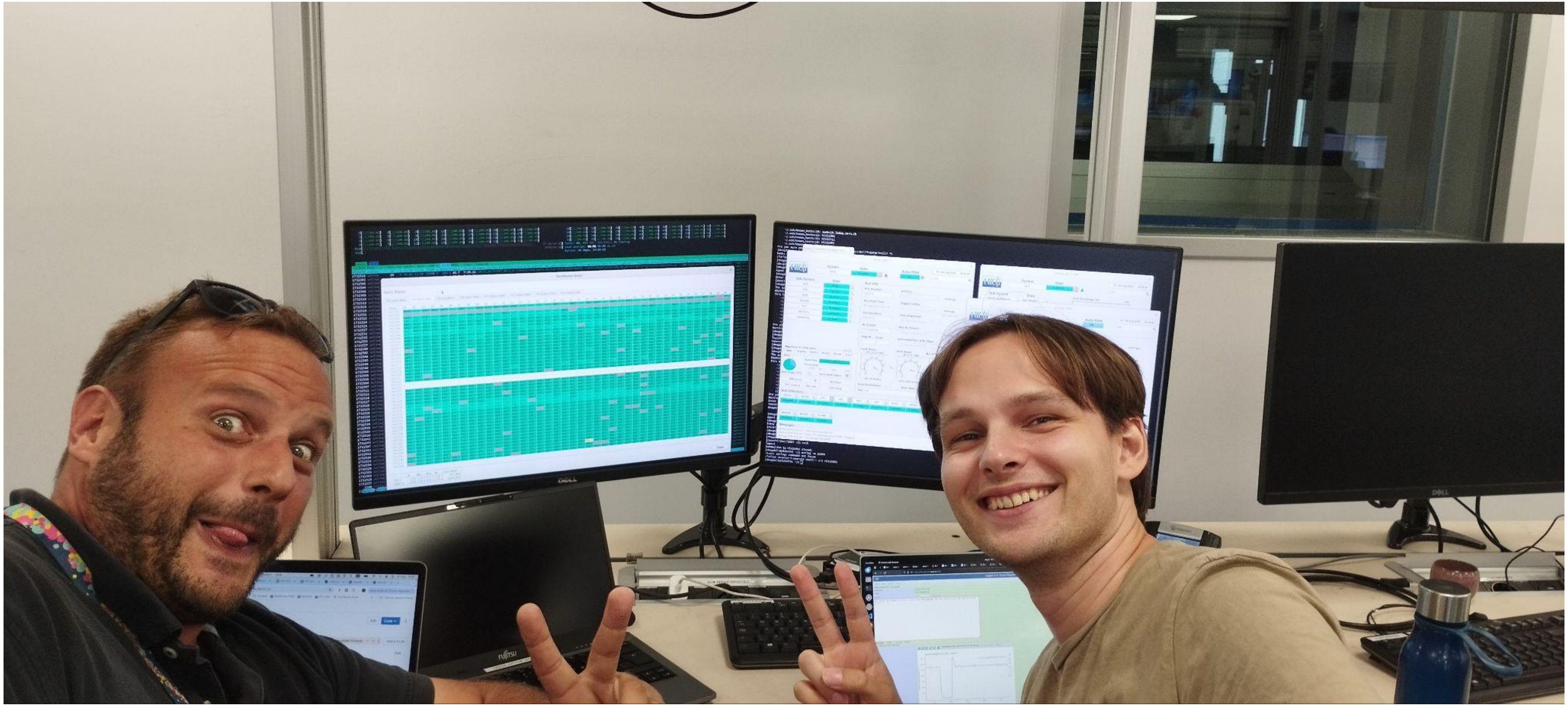
- Online installed new 256 thread CPUs for HLT2, I was helping to commission them
- CPUs were spending 75% of their time in kernel space…
- Together with Online we did some profiling
  - An algorithm had a mutex counter which all threads were queuing to access
  - Mutex counter was moved to only be used in Debug
- With this change the throughput went from 400 Hz -> 1400 Hz
- After some further optimizing HLT2 reached 1 MHz of input rate!

HLT2 reaching 1 MHz!!



Analysis: DeltaGammaD

- Difference in decay width between B0 mass states
  - A “Null test” of the Standard Model
- Experiment: $\frac{\triangle\Gamma_d}{\Gamma_d} = 0.001 \pm 0.01$, Theory: $\frac{\triangle\Gamma_d}{\Gamma_d} = 0.00397 \pm 0.00090$
- Experimental method: Compare decay time distributions of
  - Bd -> J/ψ + K*(flavour-specific)
  - Bd -> J/ψ + KS(CP specific)
- Re-activating Run 2 measurement with Master student
- Preparations for Run 3 measurement

Conclusions & Outlook

- Control flow optimization finally finished and in production
  - ~15% gain for HLT2
- Continued work on trigger optimization
  - Overlap work continues manually
- Analysis work ramping up on DeltaGammaD measurement
- Future:
  - Point 8 secondment: October - December
  - Focus shifting to DeltaGammaD analysis

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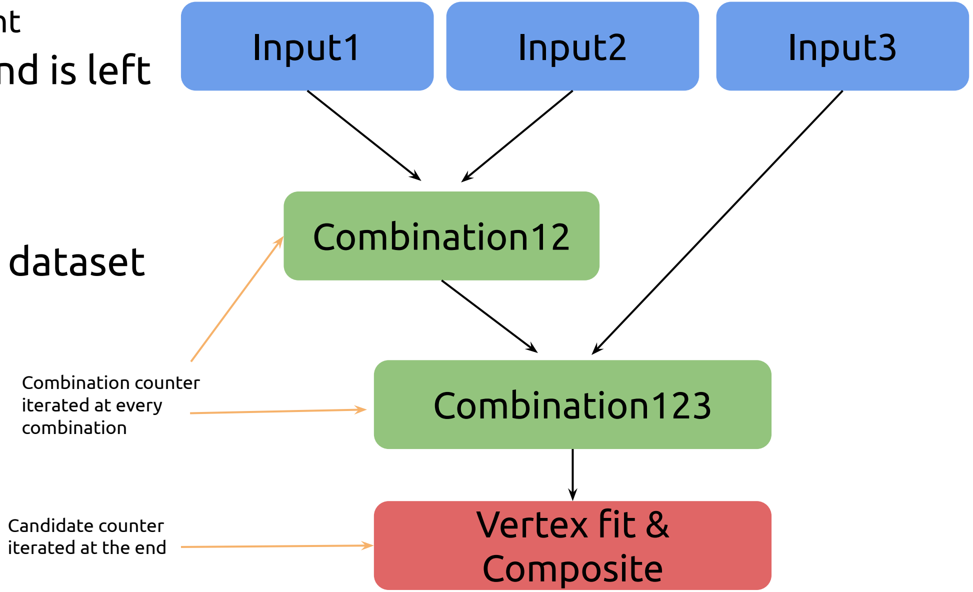
Thank you for your attention!

Backup

Combiner limits

- Combinations scale by N^M, MBodyCombiner, N size of Input
- Combination is capped by limits:
  - **2K** candidates and **50M** combinations per event
- If limit is hit the Combiner stops running and is left with whatever it generated so far
  - Creates a difficult inefficiency to handle
  - A sign of a inefficient combiner
- I created a test that runs over a extra busy dataset
  - Track worst offenders
  - Benchmark combiners on this issue

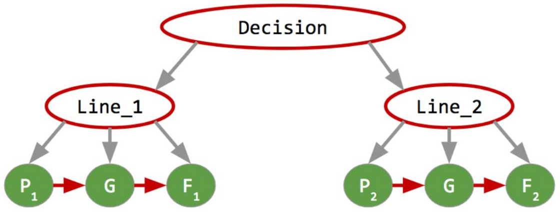


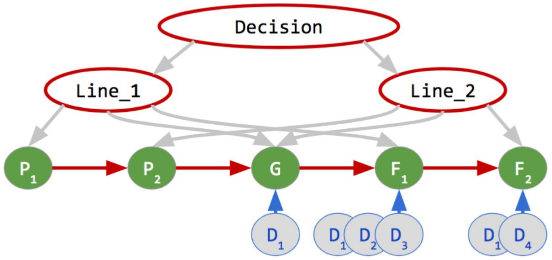
Miscellaneous

- Teachers assistant:
  - CP violation course
- LHCb hackathon
- Poster at NWO Veldhoven: “Real-time analysis at the LHCb experiment”
- EuCAIF
  - Part of conference organizing team
- Future collider lectures and workshop
- SMARTHEP outreach hackathon
- SMARTHEP Edge ML school

Circular control flow

- Control flow is scheduled globally
  - Meaning that algorithms have to be ordered globally
  - Trigger lines have to agree on order of algorithms
- This is difficult to take into account
  - Therefore we just want to avoid it
  - If one would only pick one algorithm per data flow iteration we would ensure no circular control flow





Nolte N. A Selection Framework for LHCb's Upgrade Trigger. TU Dortmund U., 2020.

```
@register_line_builder(all_lines)
def dzero2kpi_line(name='Hlt2Charm_D0ToKmPip', prescale=0.2):
    kaons = make_charm_kaons()
    pions = make_charm_pions()
    dzeros = make_dzeros(kaons, pions, '[D0 -> K- pi+]cc')
    return Hlt2Line(
        name=name,
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```

```
def dstarp2dzeropip_dzero2kppim_line(name='Hlt2Charm_DstpToD0Pip_D0ToKpPim',
                                     prescale=1):
    kaons = make_charm_kaons()
    pions = make_charm_pions()
    dzeros = make_dzeros(kaons, pions, '[D0 -> K+ pi-]cc')
    dstars = make_dstars(
        dzeros, self_conjugate_d0_decay=False, d0_name="D0ToHH_D0ToKpPim")
    return Hlt2Line(
        name=name,
        algs=charm_prefilters() + [kaons,pions,dzeros,dstars],
        prescale=prescale,
        #extra_outputs=isolation.make_iso_particles(dstars, coneangle=0.5)
    )
```