L1 Muon Trigger at the HL-LHC
few thoughts about the Atlas and CMS perspectives

Nicola Pozzobon - Università degli Studi di Padova e INFN sezione di Padova

with significant contribution by:
Fabio Montecassiano, Riccardo Vari, Sandro Ventura, and Pierluigi Zotto

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a little introduction

- the current perspectives are open after the 7 and 8 TeV results and H(126) → “what next?” can be answered running the LHC at 14 TeV
    - our best target, as of today: maintain the acceptance of the key leptonic, photonic, and hadronic trigger objects such that the overall physics acceptance, in particular for low-mass scale processes, i.e. H production, can be analogous to the one we had in 2012
        - understanding this H we observed is mandatory
- the design of Atlas and CMS dates back to the Nineties
    - goals, operational environment and available technologies do really change in 20+10 years

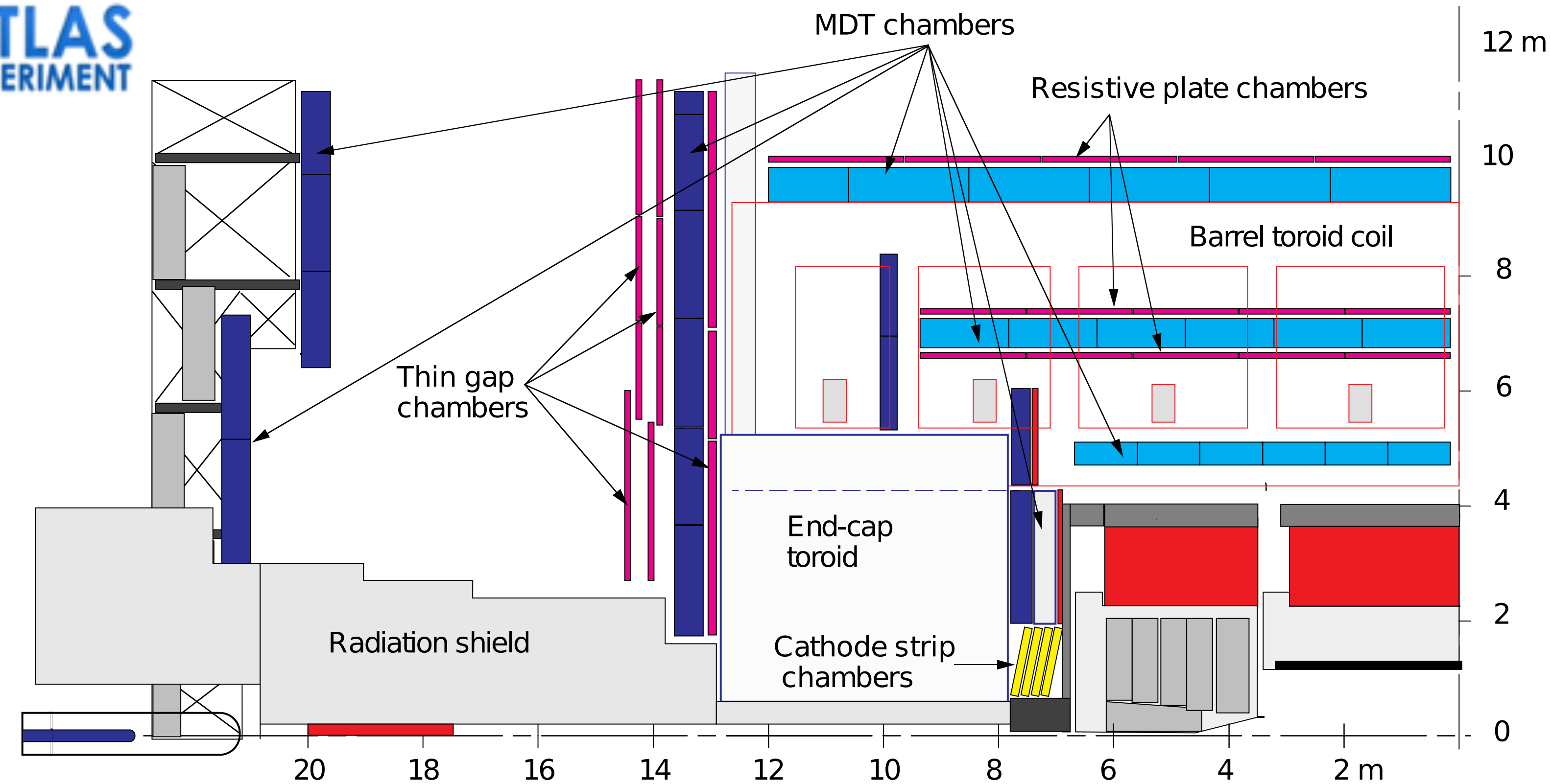
- we ask the detectors and the trigger to be functional and efficient in a more and more dangerous environment (lots of radiation), with higher and higher luminosity (lots of superimposed events to disentangle), being older and older
  - something must be refurbished
  - something must be redesigned and or/replaced
  - something must be able to do something new
- in the Nineties: to put some intelligence in your detector, you designed and built your trigger and readout around custom and really expensive ASIC’s
  - meanwhile, industry and telecommunications have taken over science when it comes to microelectronics and data transmission

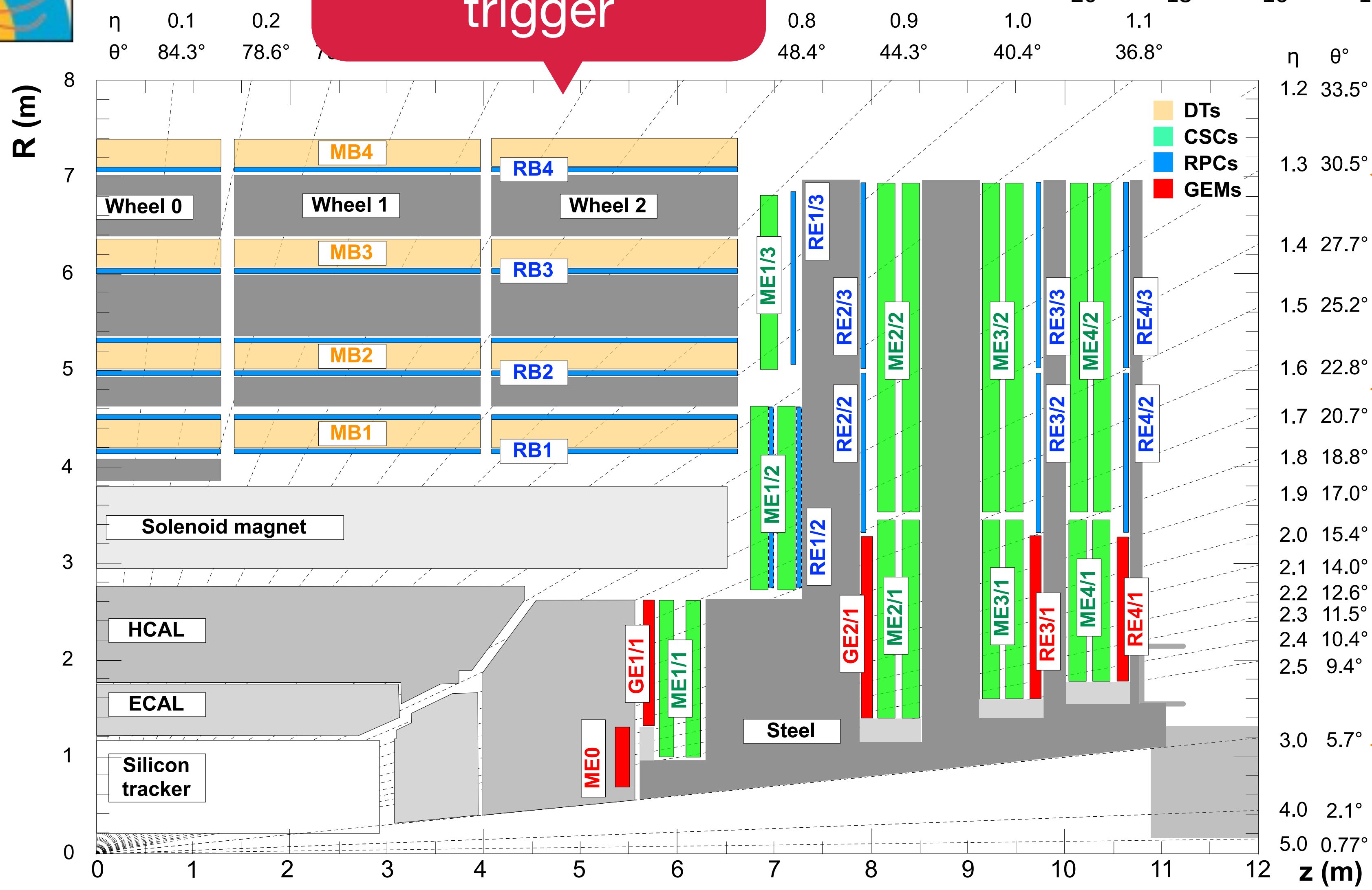
- today: as you want much more intelligence and flexibility from your readout, you survey the market to get such capabilities and limit the cost, and then you build your trigger around big FPGA’s
    - if you move your intelligence off-detector, when possible and recommendable, you can enhance flexibility and maintenance of the system, have multiple/refined algorithms, and handle, at the same time, more candidates than ever done so far
    - track trigger at early level: confirmation of triggers from other subsystems, improved momentum resolution, and primary vertex finding at trigger level
    - improved resolution and isolation from finer granularity
    - increased L1 rates and latencies: make lower thresholds and complex triggers (such as hadronic) affordable

new RPC trigger boards and logic

MDT in L1 trigger?

muon + track trigger

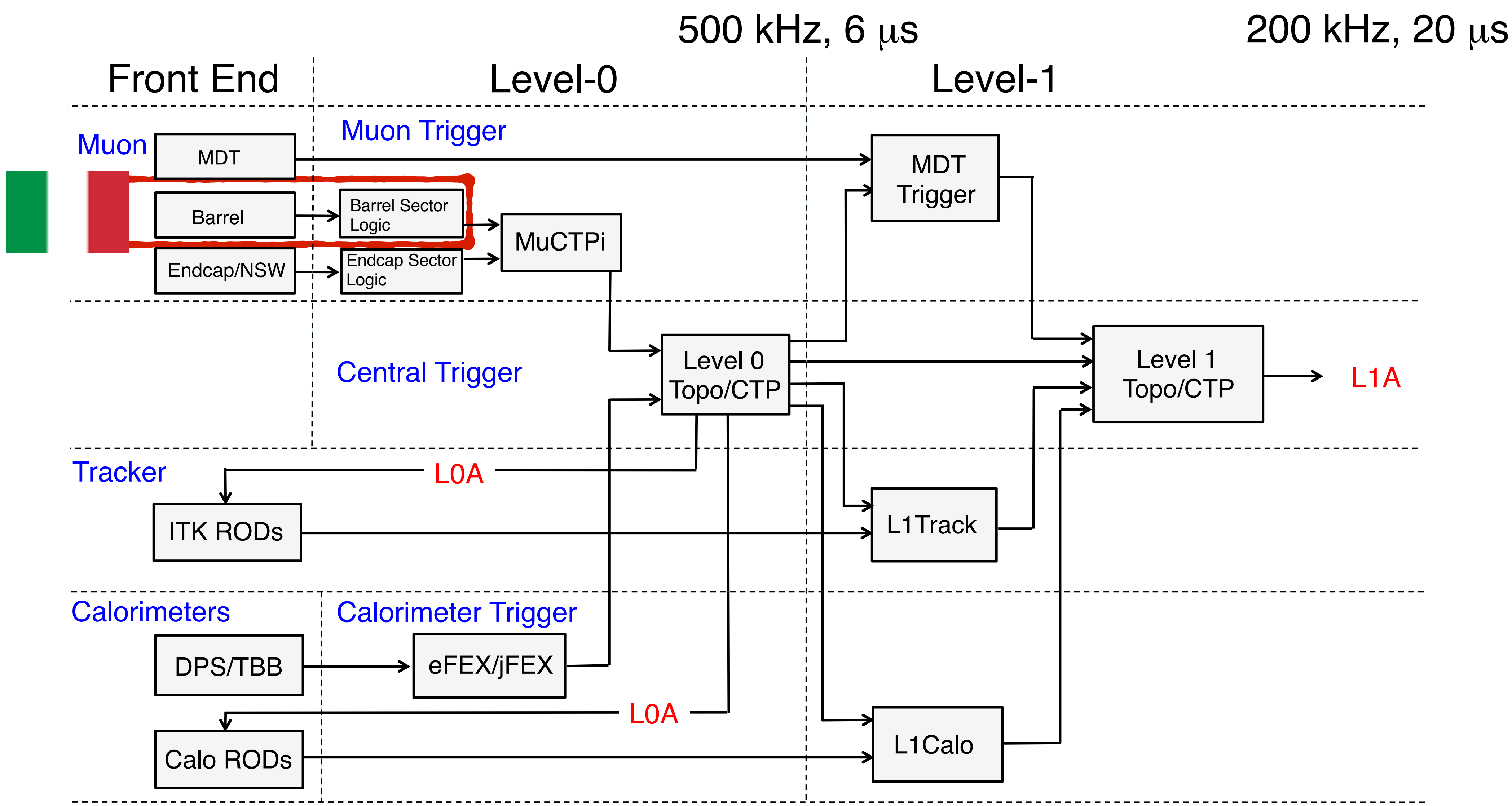




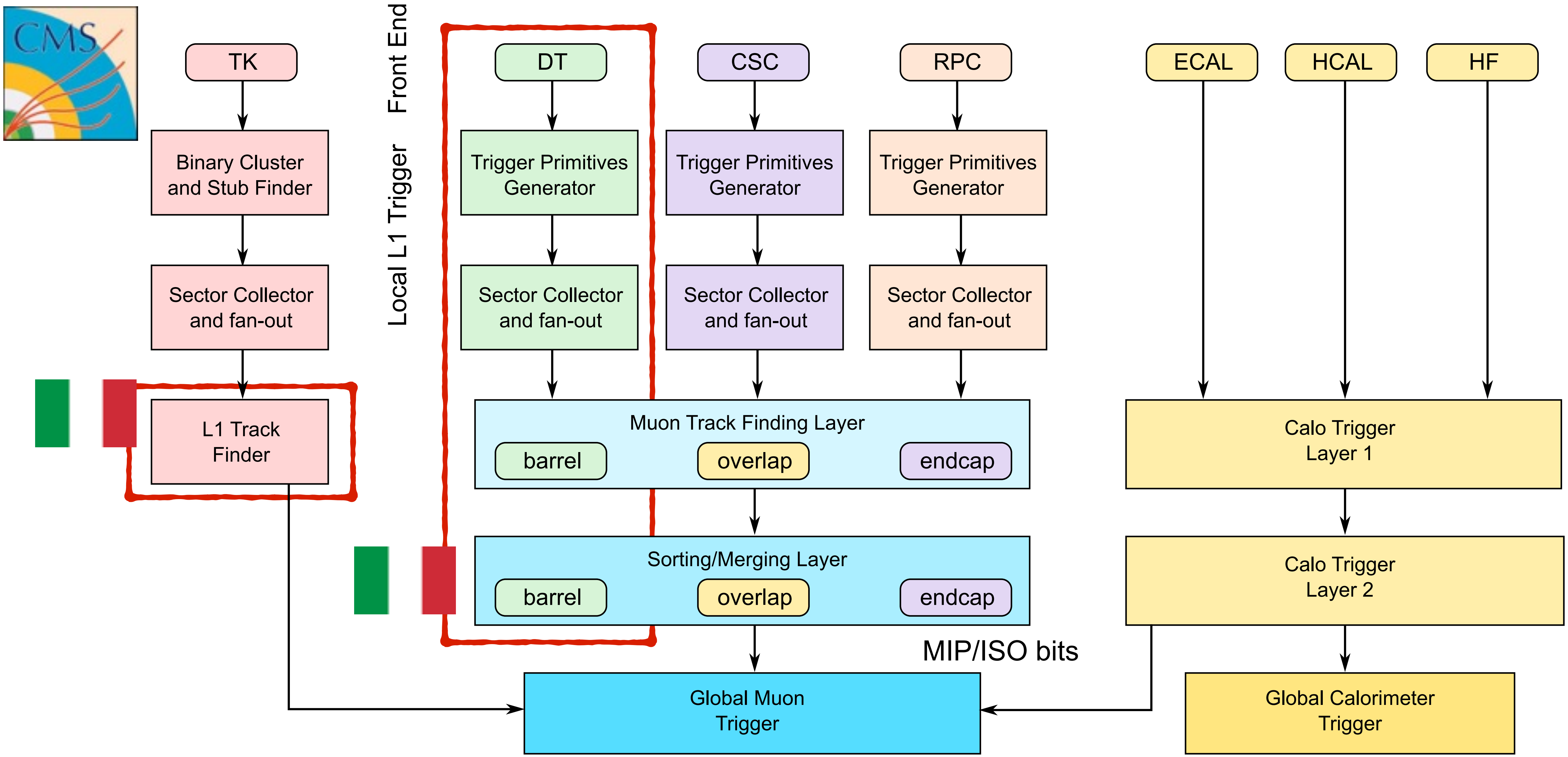
new DT readout and trigger electronics

new DT sector collector and common track finding layer available since Phase 1

enhanced coverage/ redundancy with GEM's and improved-RPC's



- improvement hosted by an additional layer built over the current L1 trigger
  - possible use of MDT for muon trigger under evaluation
  - use of RoI-based track trigger to confirm the L1 muon candidates
    - both need higher latencies than now



- track trigger runs "in parallel"
  - may improve muon candidates
  - may also be used for a combined muon + tracker track finder at L1

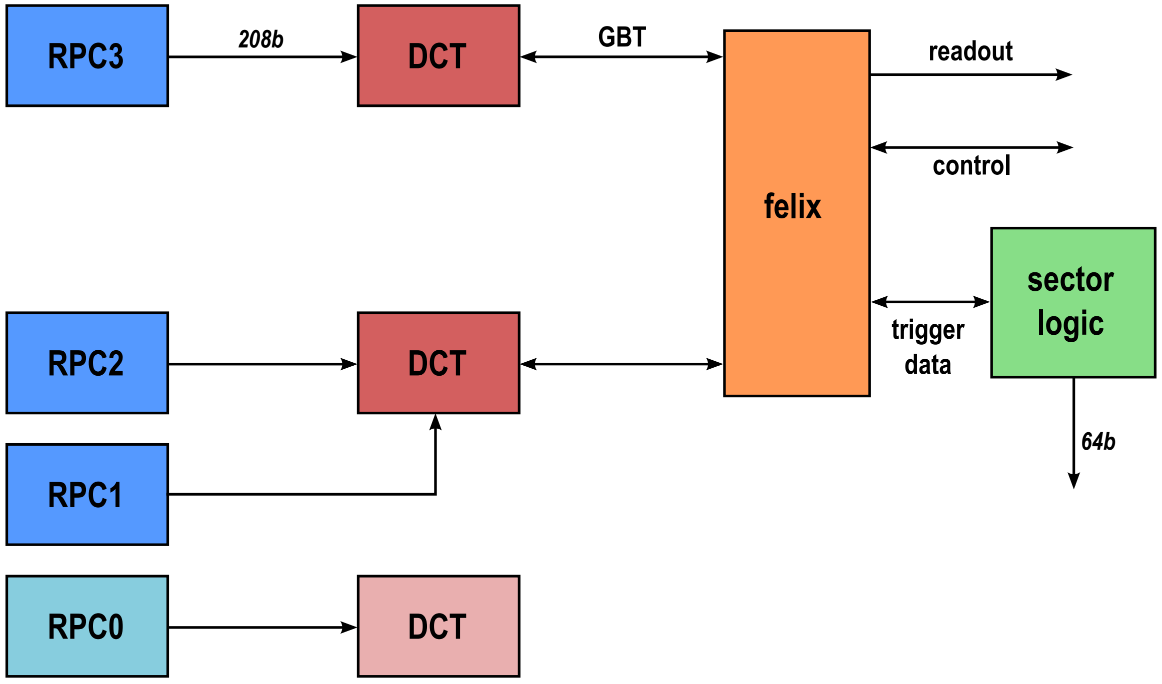
interests: barrel DT
goal: architecture to be uniform/shared with endcap

system	current	HL-LHC (ATLAS)	HL-LHC (CMS)
level	L1	L0 + L1	L1 w/ TT
rate	100 kHz	500 kHz @ L0 200 kHz @ L1	500 kHz (1 MHz ?)
latency	3.2 μs	6 μs + 14 μs	10 μs (20 μs)

LHCb, ALICE: triggerless: investing on readout and HLT

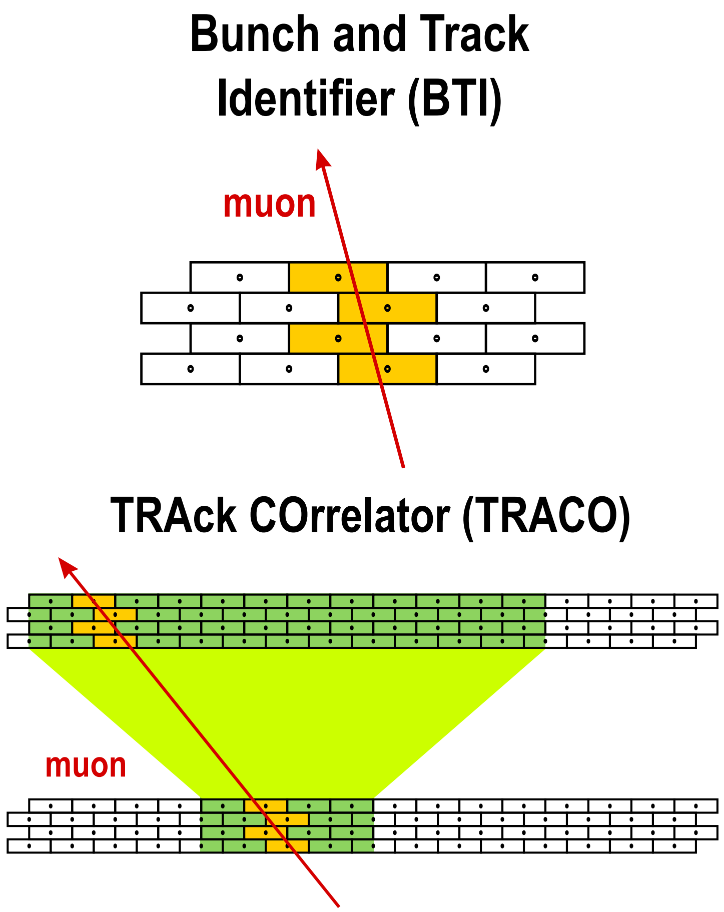
- current systems will be severely limiting the trigger performances at such rates and latencies: upgrade is ~~recommended~~ necessary
- main topic for today: *Atlas barrel RPC and CMS DT triggers*
    - will be mostly moved off-detector into service caverns for safer environment and easier maintenance
    - will be mostly moved from ASIC-based to FPGA-based

- RPC front-end cabling will not be replaced
- new DCT box: collect RPC front-end data and add some simple logic
  - timing information w/ σ ~3 ns
  - time-over-threshold: improve spatial resolution and sharpen turn-on
  - one GBT link per DCT for both trigger and readout (main limit: bandwidth of the fibre)
  - noisy channel masking and SEU recovery



- RoI-based trigger algorithm mostly implemented in off-detector Sector Logic
  - increase coverage through different algorithm and/or new RPC layer
  - muon charge information could be added
  - several flexible and fully-programmable thresholds (min. 6)

- DT L1 trigger and readout in dedicated on-detector mini-crates: is it possible to relocate the L1 MC ASIC functionalities (trigger primitives) into a single FPGA-based board placed off-detector?
    - baseline for this evaluation: same algorithms, with current state-of-the-art FPGA's, which will be "already available" technology in 10 years
    - 1 MC = 7 boards × (32 BTI + 4 TRACO + 1 TSS) ~ 20 M gates (including 20% safety margin)
    - better estimates of the scale need an implementation of the MC L1 with a real target FPGA



- this estimate does not take into account that the new DT MC readout will provide the L1 with all the DT MC data: higher resolution means larger number of bits
- also not taken into account: higher combinatorics due to pile-up, implementation of the track finding layer

- putting this aside for a moment, is this scale affordable?
  - Xilinx claims 20 M gates for Virtex 7 (7V2000T), 28 nm
  - Virtex UltraScale VU440 3D IC, 20 nm, available in 2014 ~ 50 M gates
- reasonable assumption: number of gates in one state-of-the-art FPGA in 2020 will scale at least by 4×
  - 1 FPGA = 4 MC (2012-equivalent) = 1 sector
  - 12 sectors can be hosted in one µTCA crate = 1 wheel
  - 5 wheels = 60 FPGA boards, which can all be hosted in one single rack
    - the complete generation of muon barrel trigger primitives is likely to be hosted in one single rack
- similar numbers from Atlas (64 boards)

something both experiments must face

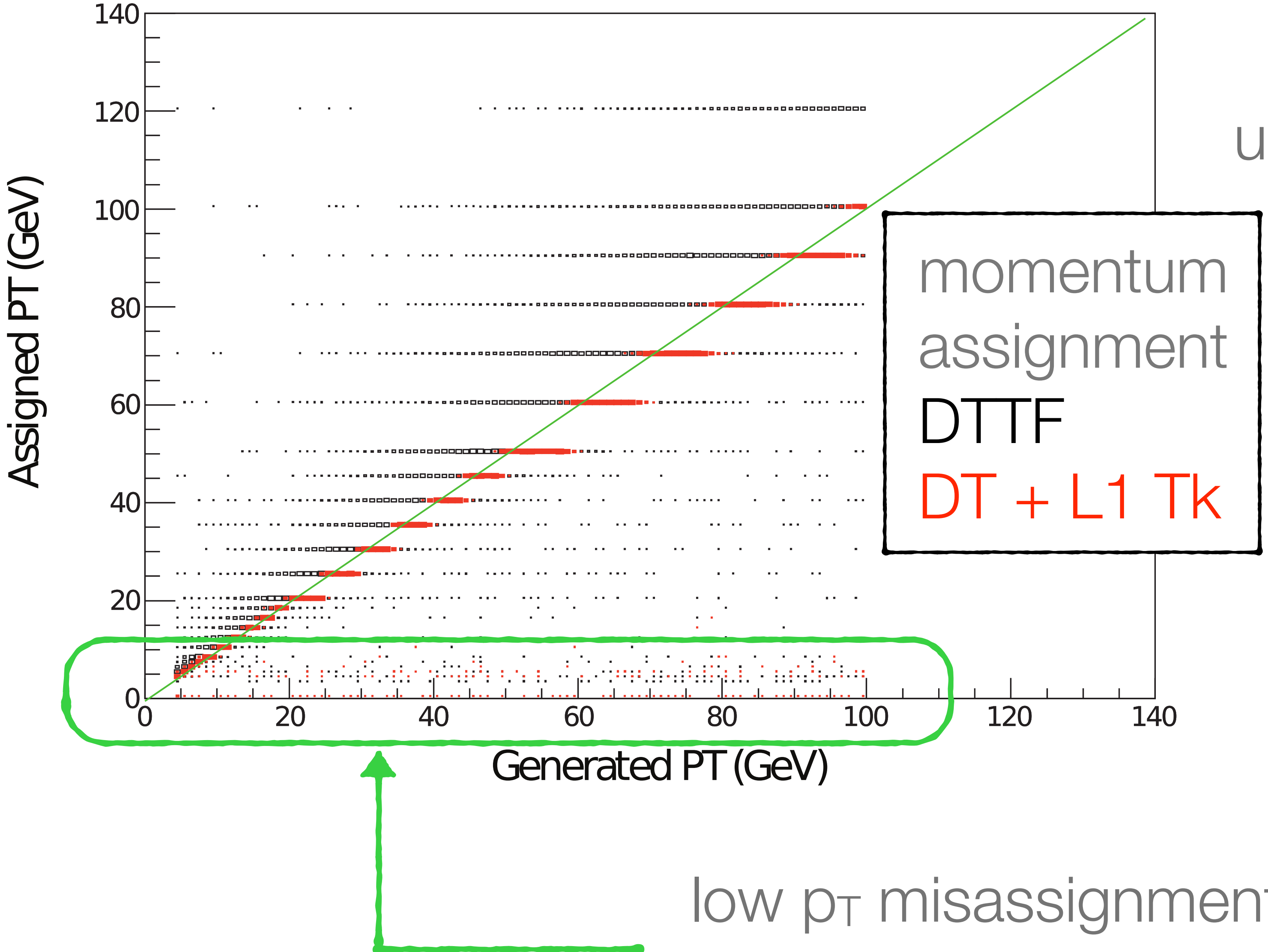
- qualification of trigger boards (both on- and off-detector)
- data transmission off-detector
  - will be based on the GBT being developed at CERN and high speed serial links
    - being an end-user of such devices and tools will be a common experience for both Atlas and CMS and for all subsystems (e.g. CMS tracker)
    - different experiments will require different specifications for the use of such general devices
      - different trade-offs must be understood

combining muon and track trigger

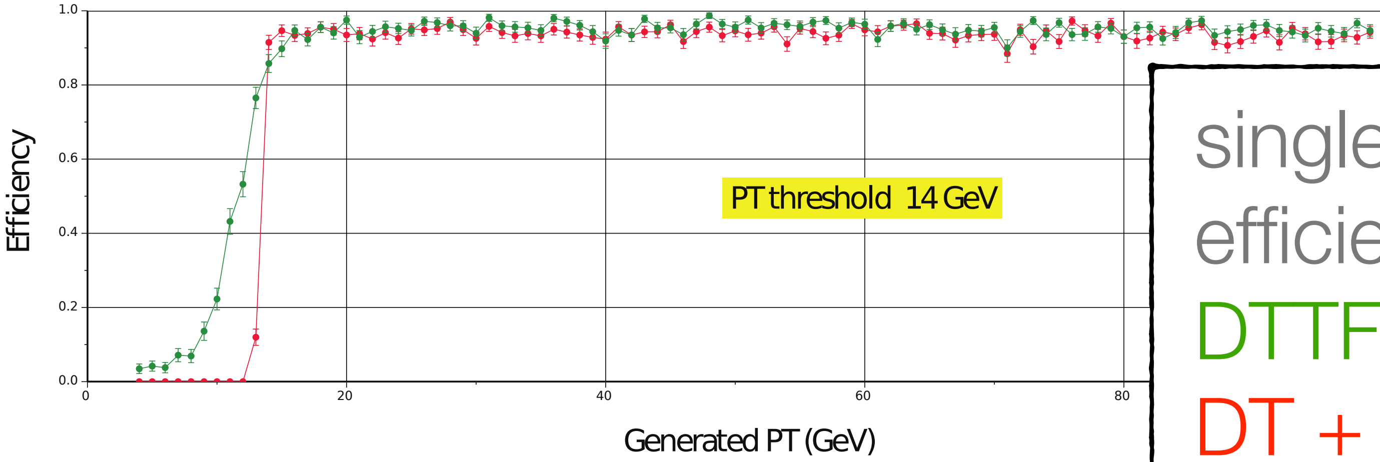
- given what is currently implemented (i.e. L1 DT trigger as in 2012) how can a track trigger improve muon candidates? a test algorithm has been studied at CMS
  - muon track segments from TS (Trigger Server) are combined together and projected to the tracker
    - searching for matches with L1 tracker tracks (vertex and momentum)
    - full parameterisation (symmetric by muon charge) of track extrapolation, including low quality muon p_T, and of matching windows in ϕ and θ - still early to move to LUT's
    - further work in progress: searching for matches with L1 tracker stubs, inside-out track-to-muon matching …

muon track p_T assignment is better when using L1 tracks

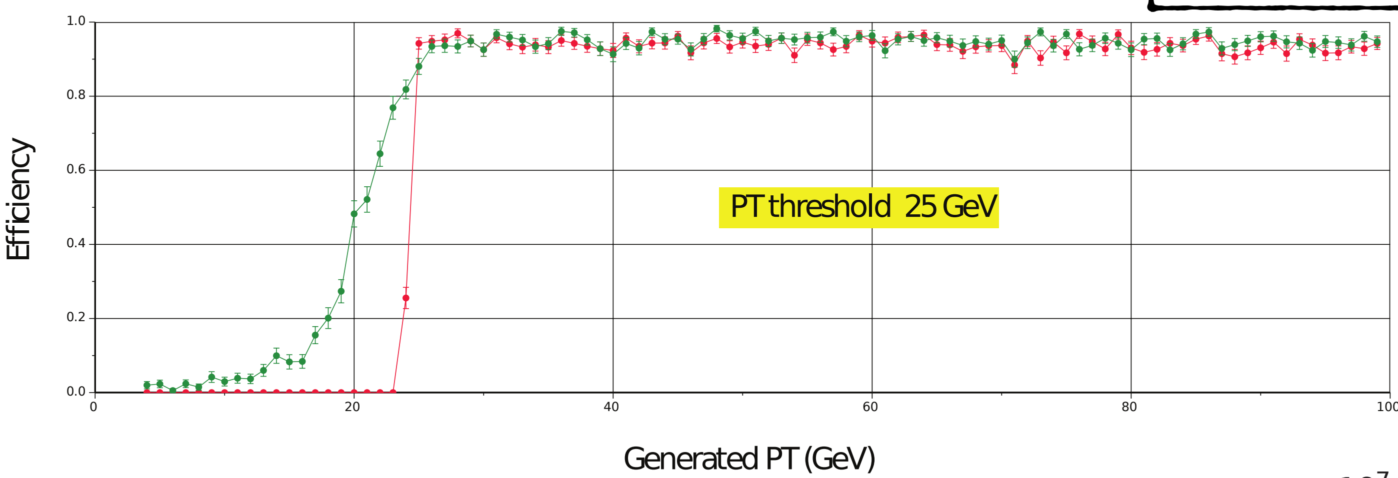
using only muon detectors: p_T is overestimated



low p_T misassignment is due to badly built seeds in the DT

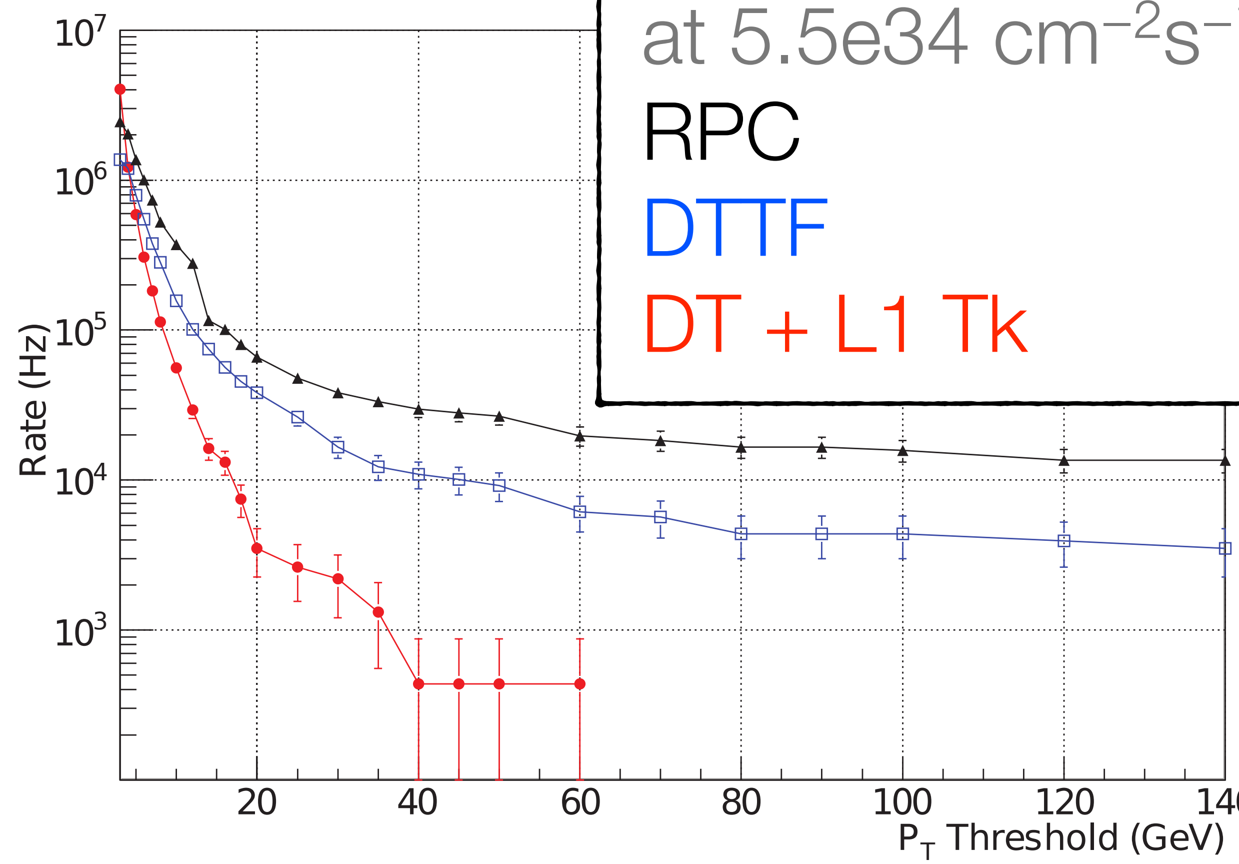


single μ efficiency
DTTF
DT + L1 Tk



DT + L1 Tk features less contamination from muons below threshold and a sharper threshold

background rate at 5.5e34 $cm^{-2}s^{-1}$
RPC
DTTF
DT + L1 Tk



a rate reduction of a factor 5 at 20 GeV should be achievable w.r.t. DTTF

there is still room for improvement (i.e. inside-out matching)

- what can we learn from this? how can we improve the design of the muon trigger for the HL-LHC to profit from the availability of a track trigger at L1?
    - tracker tracks have much better p_T resolution
    - a L1 muon trigger could exploit the full muon detector data (i.e. TDC for the CMS DT) to enhance the correct projection and association of a muon segment to a tracker track at L1
        - algorithm is definitely a chance for new developments
    - there are no plans to change the current muon RPC trigger algorithm at Atlas (from L1 to L0), but there is a hypothesis for a RoI-based MDT trigger at L1
        - with a track trigger in place, what kind of improvement can be given by a MDT trigger?
        - high precision matching → need for high precision projection

interests of the Italian community

- Atlas muon barrel RPC and L1 trigger (Bologna, Napoli, Roma 1, Roma T. V.)
- CMS muon DT and L1 DT trigger (Bologna, Padova)
- muon trigger strategies cannot be decoupled from the detectors
  - common features may show up at the local track finding stage
  - both experiments are moving off-detector
    - readout, timing, control, GBT and high-speed links

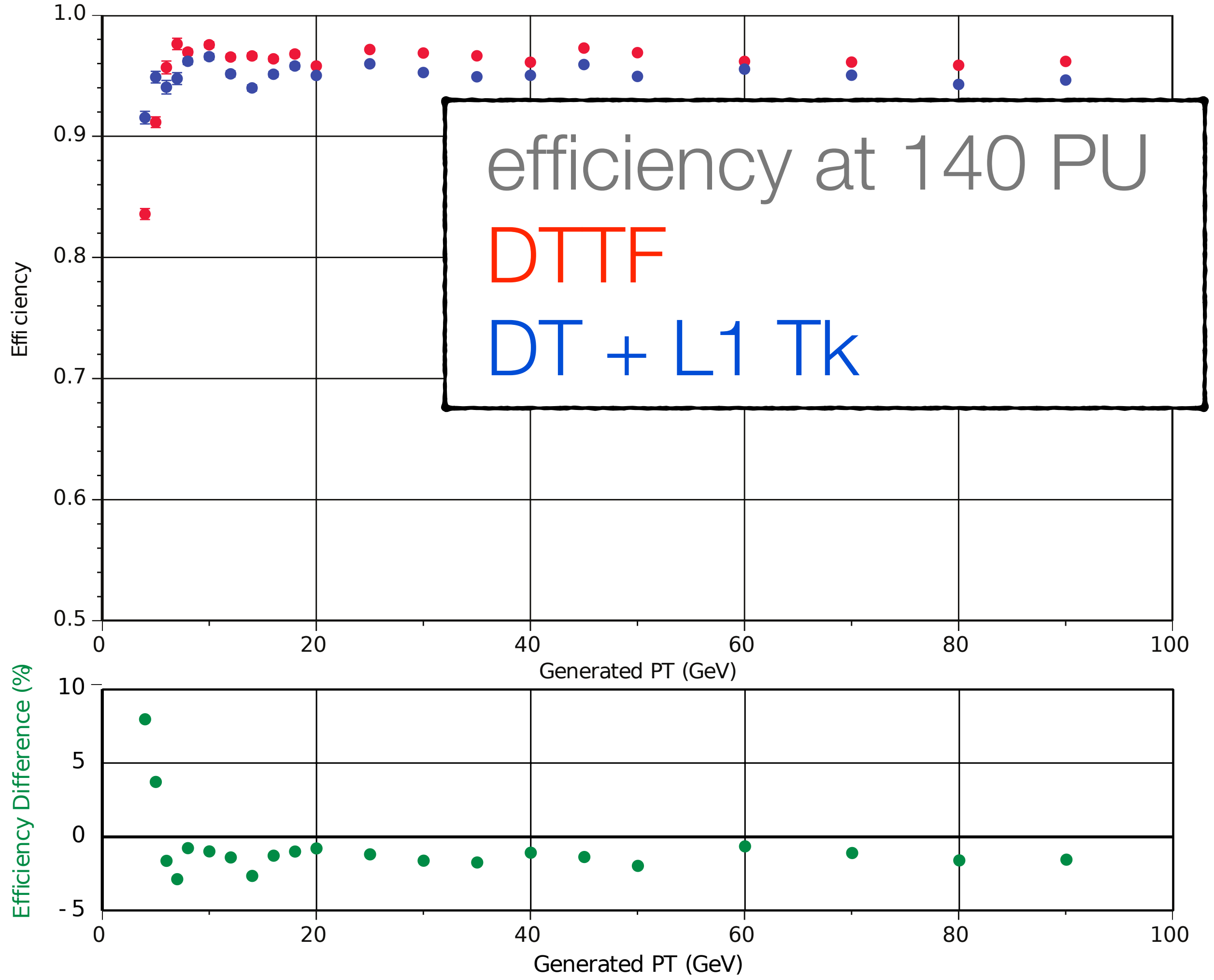
concluding remarks

- both Atlas and CMS are working on future muon triggers under common assumptions
  - higher rate and latencies must be sustained
  - triggers must be built off-detector: this is feasible
- similar solutions can be found for the data transmission: the task is analogous and shared by several subsystems
- the use of track trigger will require the muon triggers to be precise in matching with tracks, not in measuring muon p_T
  - room for new algorithms and clever ideas

backup

track trigger in CMS and Atlas

- CMS: push path
  - track trigger combined with muon and calorimeter triggers regionally, with finer granularity than nowadays
  - physics objects are built from all subsystems and transmitted to the GT
- Atlas: pull path
  - calorimeter and muon triggers produce a L0 (pre-trigger) with request for tracking info at ~500 kHz
  - tracking is requested only in RoI identified by the pre-trigger
  - tracker information is sent out only for RoI and combined with muon and calorimeter triggers in dedicated correlation logic



association efficiency for different values of assigned p_T

threshold due to minimum p_T assigned by the trigger (4 GeV)

low p_T misassignment is due to bad-built seeds in the DT