Big Data solutions for the online processing of trigger-less detectors data

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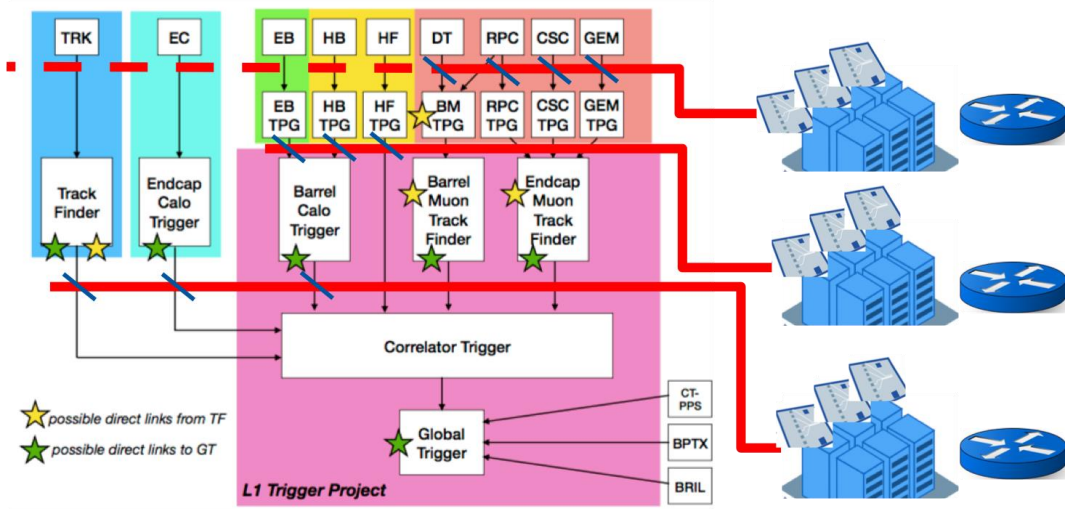
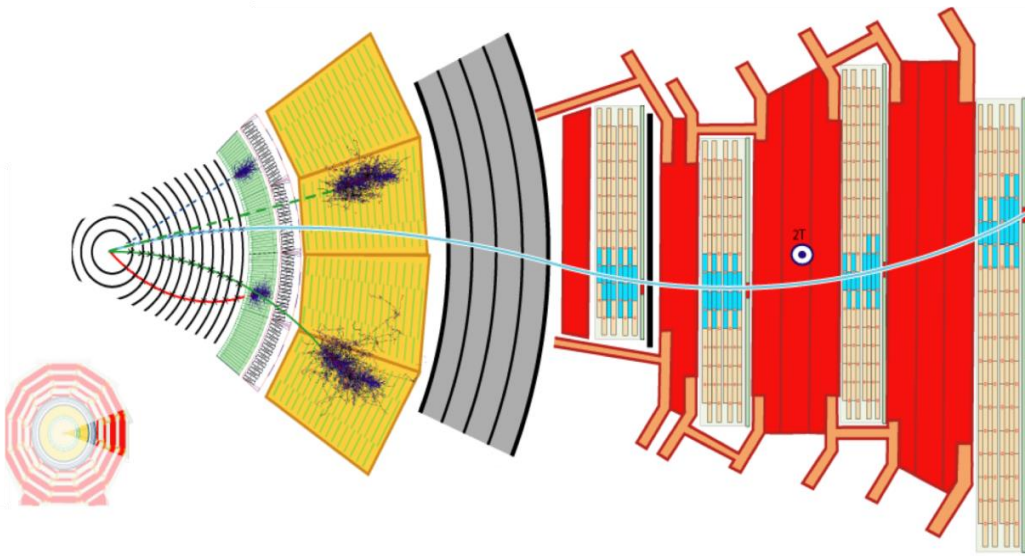
University of Padova

Introduction and Scope



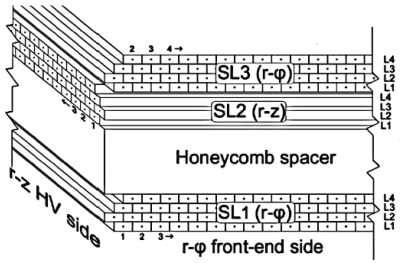
Trigger-less (a.k.a) 40 MHz readout key to unbiased analysis for New Physics searches

- Typically trigger-less RO is applied to trigger information
- Here an example of RO of detector raw data
- Not just stored, but processed/analyzed online

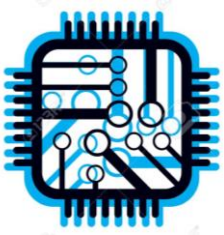


Online processing setup

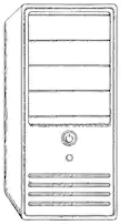
Detector



Detector's electronics



Accelerated server

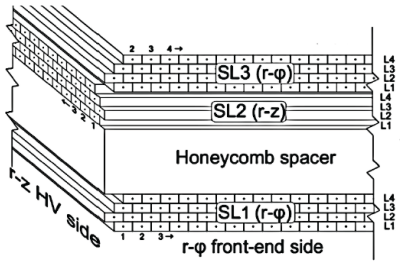


Broker

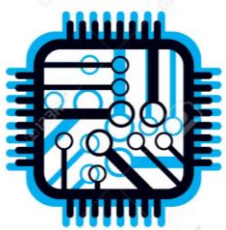
Distributed processing

Online processing setup

Detector



Detector's electronics



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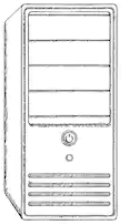


Broker

Distributed processing

CMS Drift Tubes muon chambers

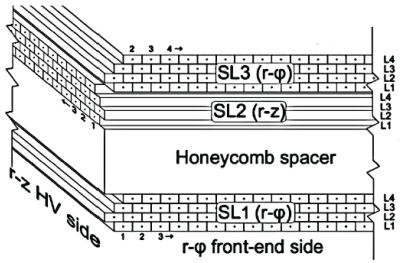
HL-LHC prototype electronics

Xilinix KCU PCIe FPGA

INFN CloudVeneto data-center

Online processing setup

Detector



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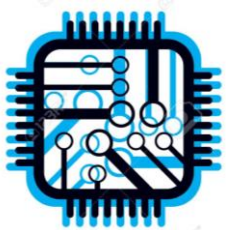

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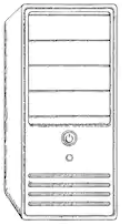

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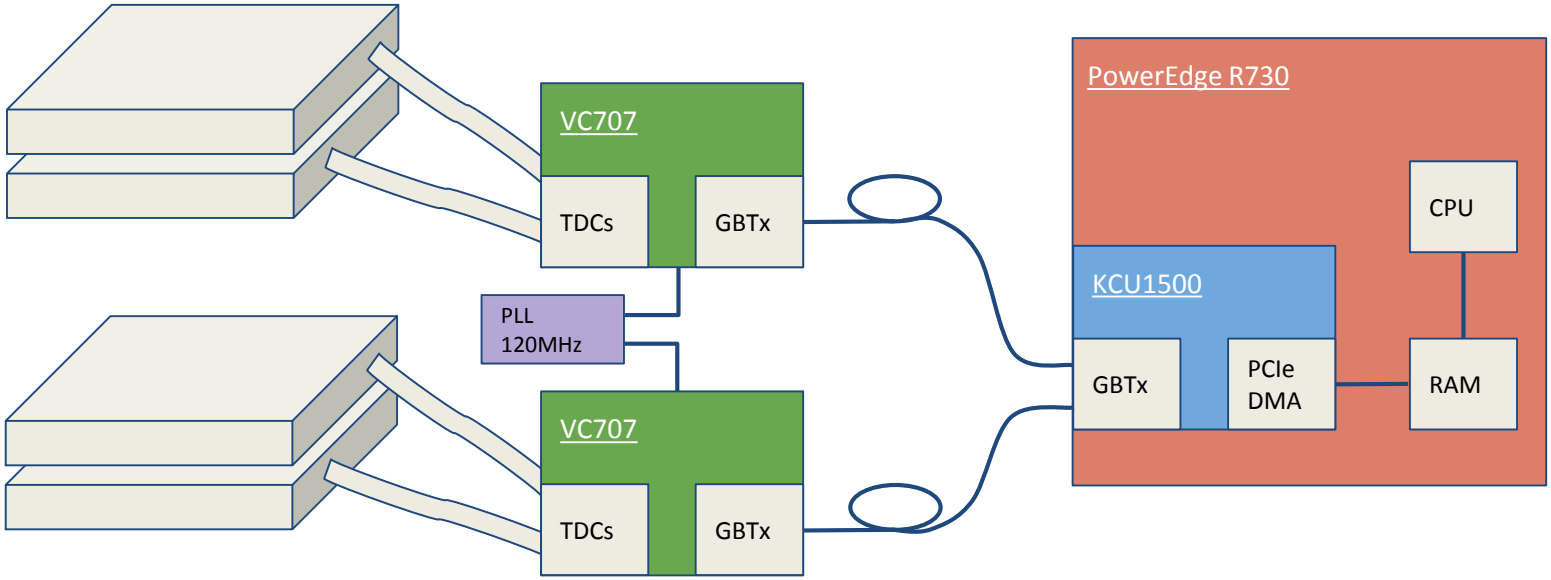
~20 km

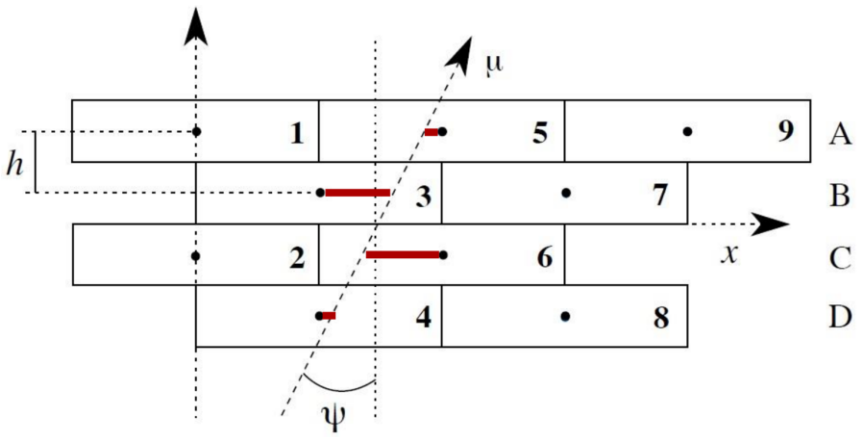
Hardware setup

- Chamber FrontEnd ASICs connected to Virtex 7 evaluation boards (VC707).
  - 138 TDC channels implemented in each VC707 (128 connected to detector's channel)
  - Trigger logic ("mean timer") computed and added to the TDC data stream
- Funnelling of TDC hits from VC707 to Kintex Ultrascale evaluation board (KCU1500)
  - Transmission based on GBTx protocol
  - VC707 use the 120MHz reference clock for serializing data at 4.8Gbps
  - KCU1500 recover the clock from received data
  - Gearbox in KCU1500 firmware for aggregating the two optical GBTx lanes
  - Data transferred to RAM by DMA transfers via Gen3 PCIe



Data stream

- The data stream of TDC hits is read out continuously and as soon as the data is available
- With each 1kB data transfer via xDMA driver ➔ 128 TDC hits (8Bytes each)
- Stream of a-priori unordered hits ➔ Not "Event-like" structure



H	V7	CHAN	ORBIT	BX	TDC
1	0	119	2946985412	2649	11
1	0	121	2946985412	2652	13
1	1	109	2946985414	2651	21
1	1	107	2946985414	2651	5
1	1	139	2946985414	2656	0
1	1	108	2946985414	2655	27
1	1	110	2946985414	2661	17
1	0	12	2946985414	2654	15
1	0	11	2946985499	1951	20
1	0	16	2946985499	1955	28

Hits from Orbit **2946985412**

Coherent Hits from **2946985414**

+ Internal-trigger bit (CHAN = 139)

+ Spurious hit from other VC707

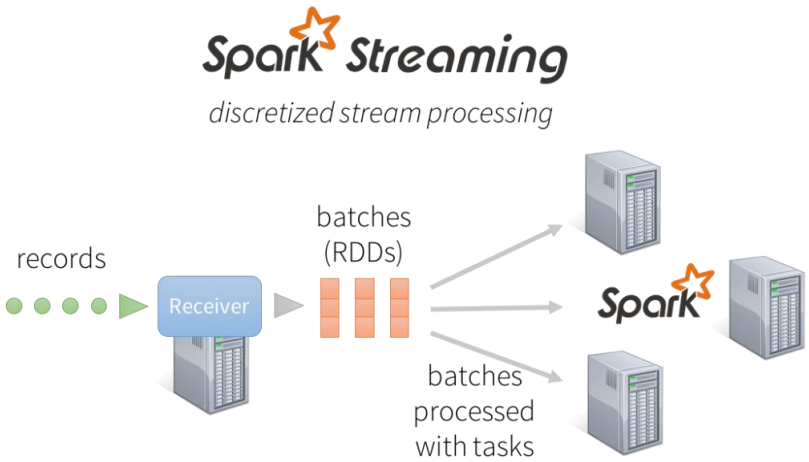
Hits from Orbit **2946985499**

Analytic framework

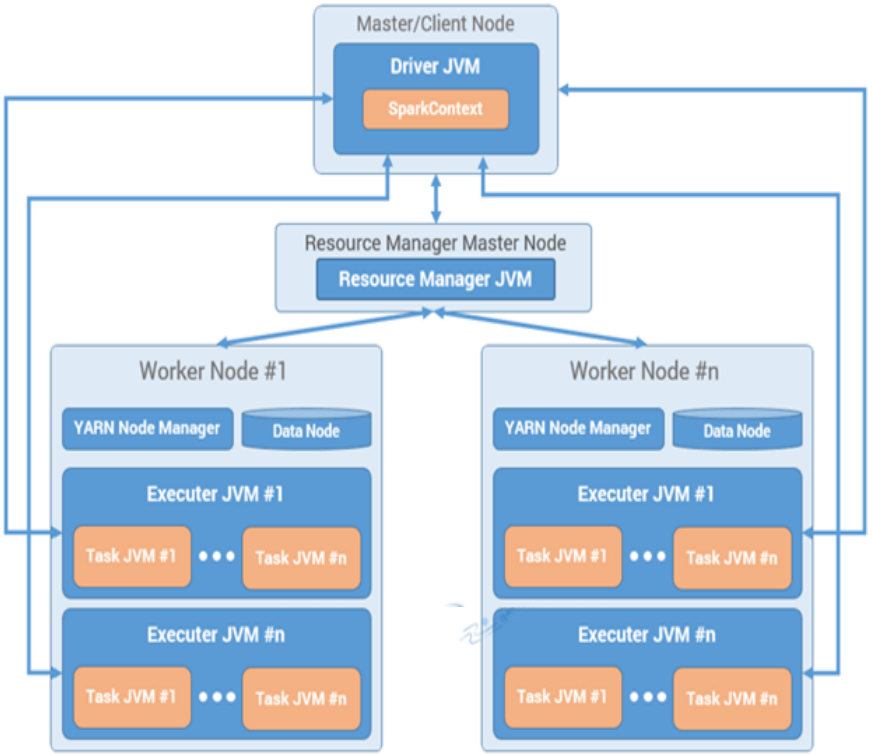
- Non-sequential analysis of the hit stream needed in order to match coherent signals and extract higher-level features ➔ DataFrame-based analytics

Apache Spark

- Cluster computing system for distributed analytics
- Widely used for fast large-scale data processing
- Including API for streaming and ML applications



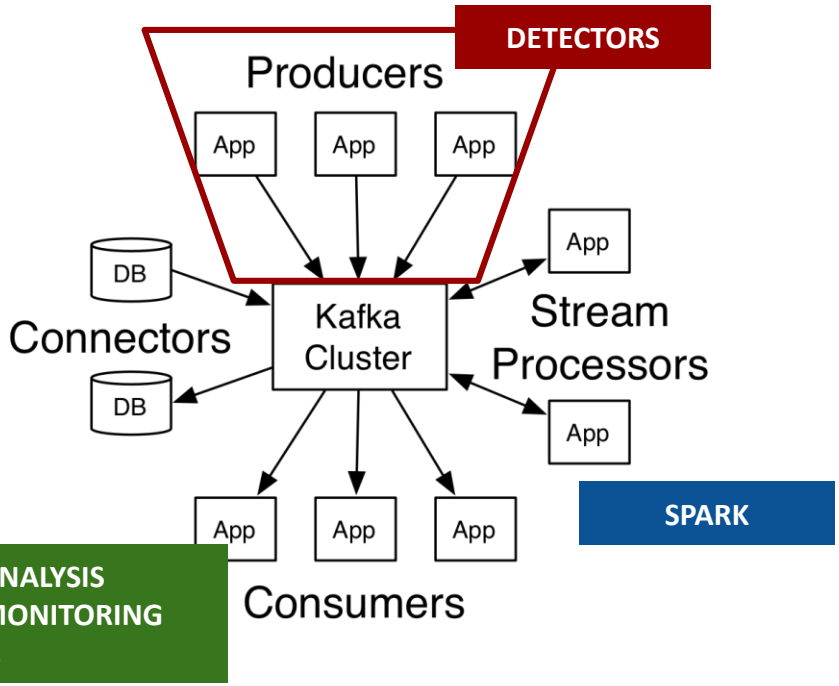
records processed in batches with short tasks
each batch is a RDD (partitioned dataset)

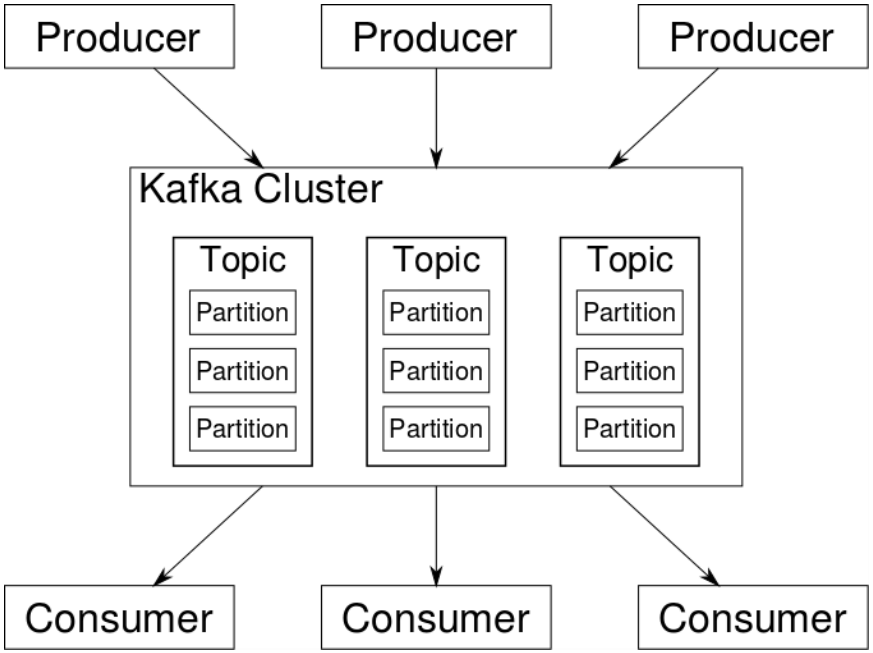


Stream brokerage

- Data stream brokerage solution to serve the Apache Spark cluster ➔ Efficiently feed Spark cluster by streaming directly to the executors' cores

Apache Kafka
- Distributed real-time stream processor platform
- allow log-retention and replication





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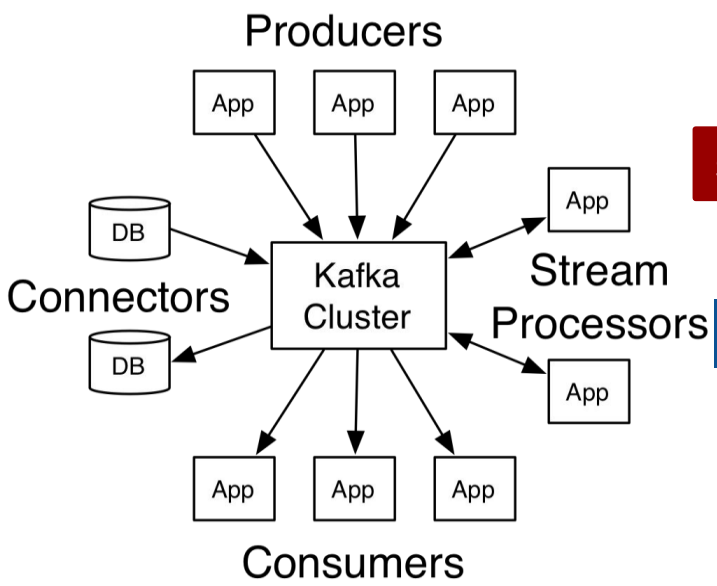
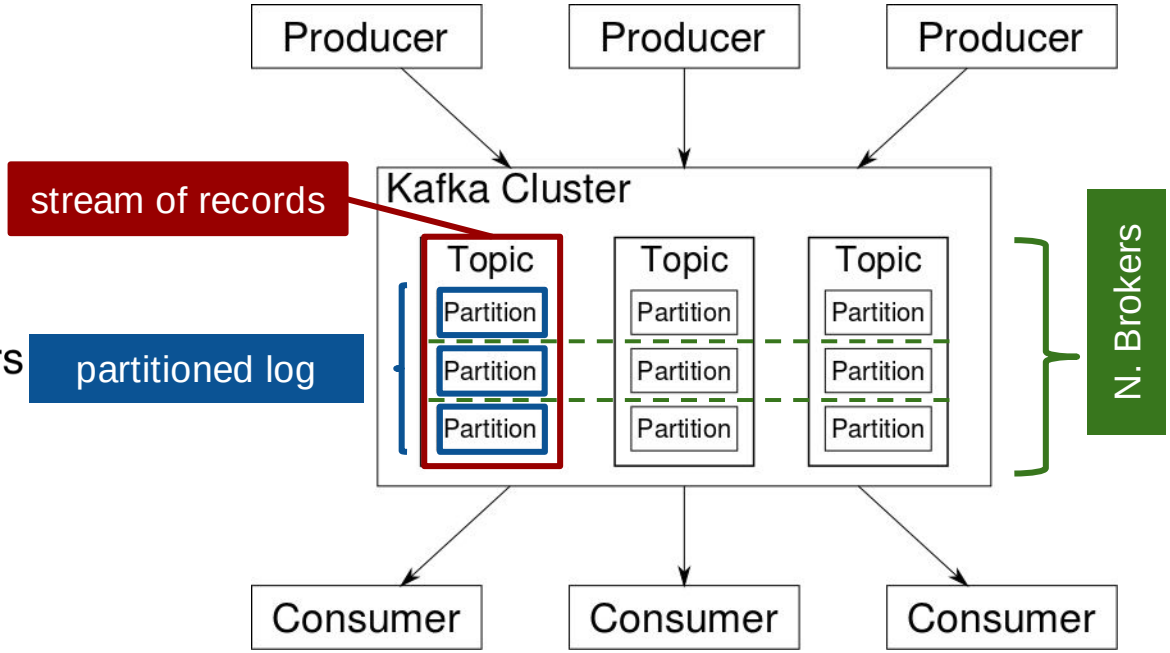
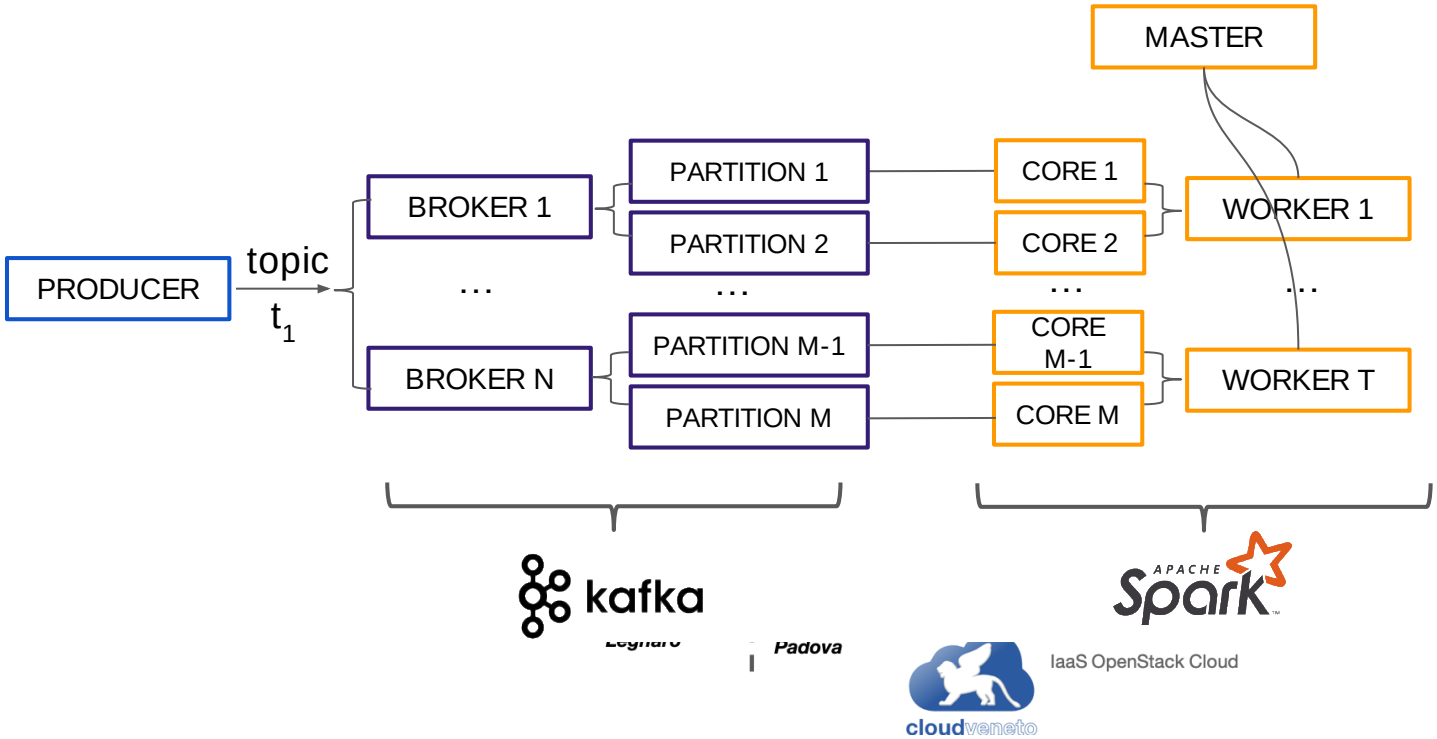




Data stream processing

- Hits are broadcasted to the Kafka cluster via a Kafka producer. Each DMA transfer (1kB ⇔128 hits) maps into a “message” sent by the producer to the brokers
  - At this point data from Legnaro to Padova
- Kafka brokers provides the data to the Spark cluster
  - Num of brokers matches number of spark executors



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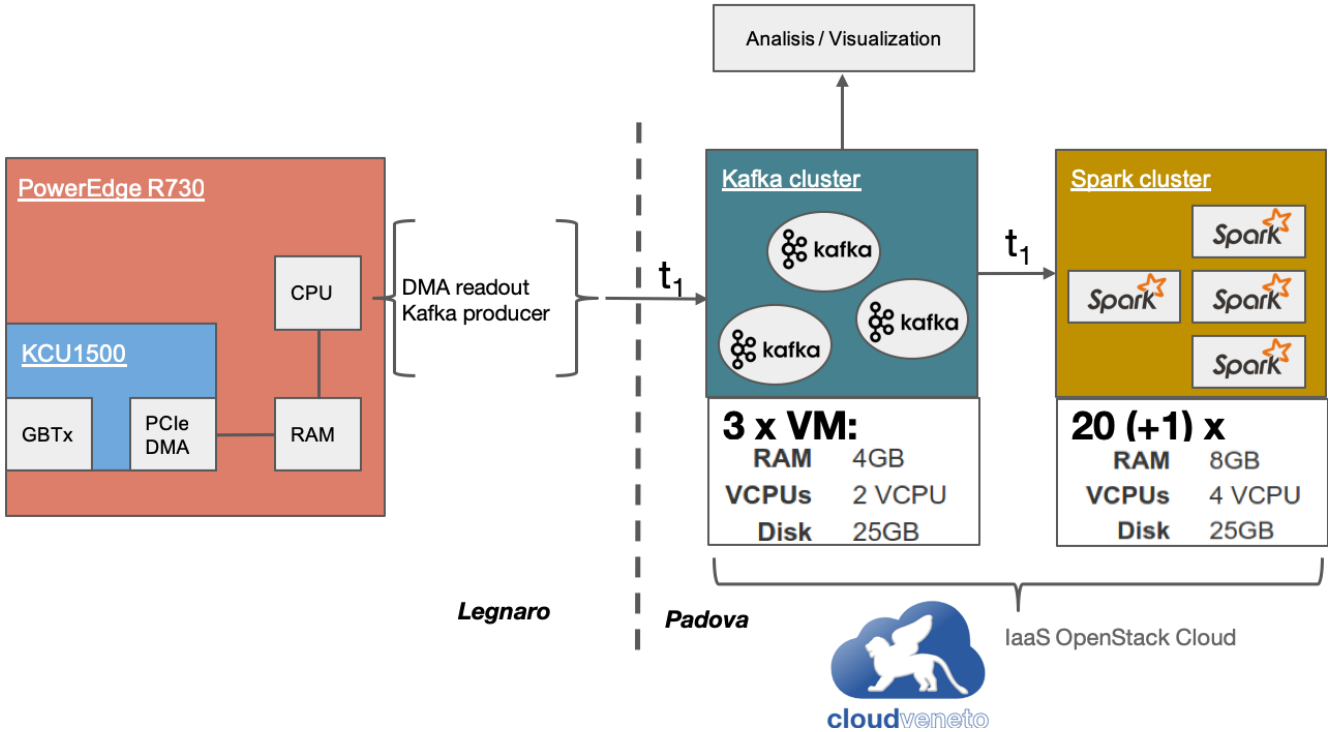
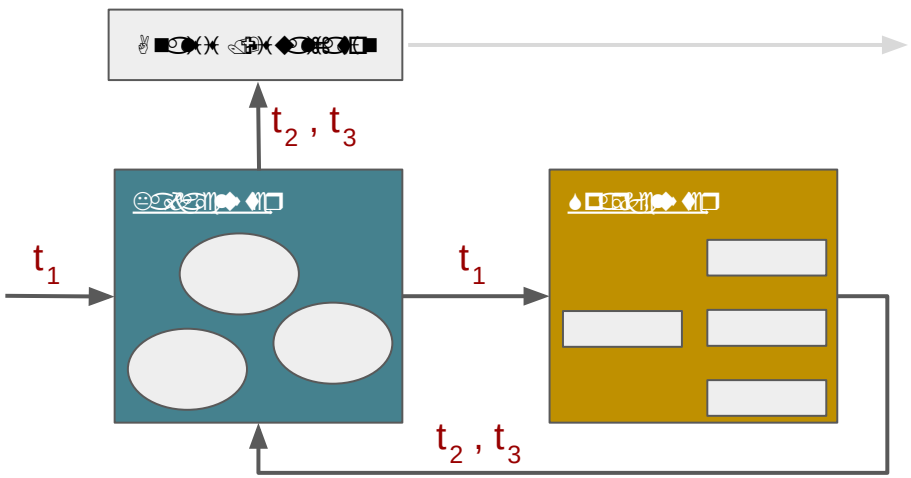
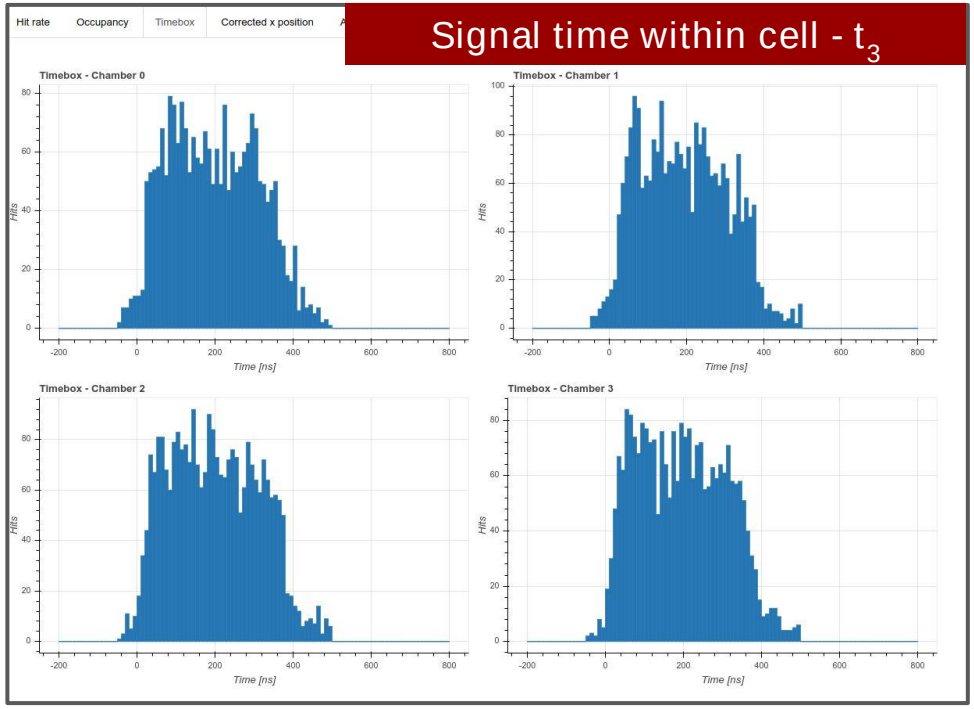


Online Analysis

- Spark process the stream in batches via Spark Streaming API, producing 2 outputs
  - chambers occupancy (all hits)
  - Slimmed-down DataFrame (an “event”) consisting of hits compatible with the trigger tag ← “Event Building”
- Both outputs are injected back to Kafka and processed by a python consumer for analysis and bokeh for visualization





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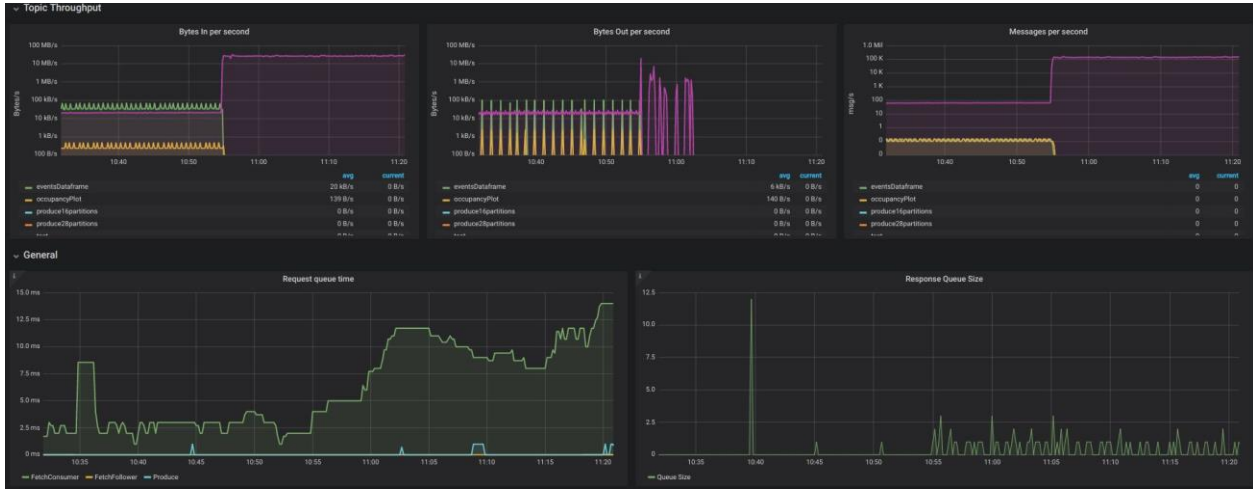
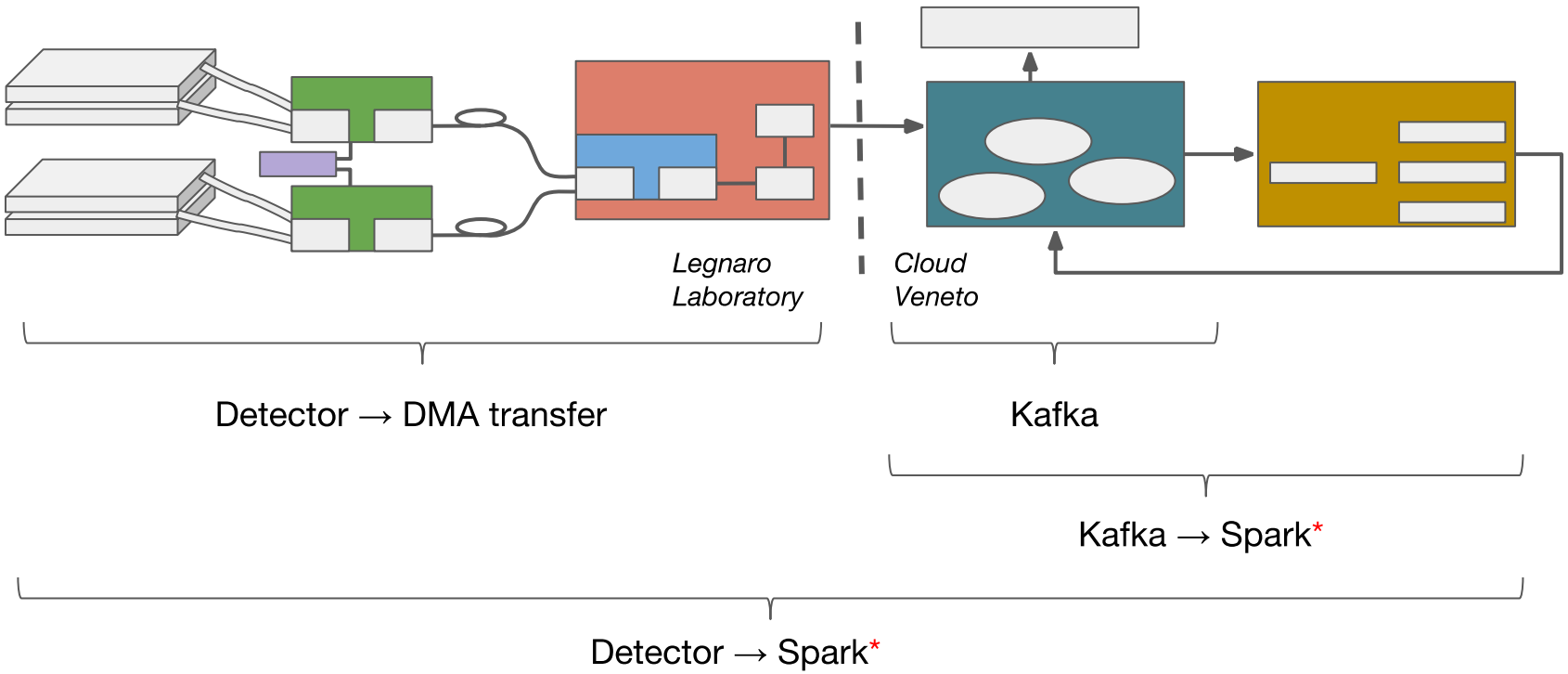
Cluster monitoring

- Monitoring of Spark cluster is provided out-of-the-box via the Spark WebUI
- Kafka brokers are configured to expose their metrics on a given port
  - Collected in a Prometheus database
  - Metrics visualized in a Grafana Dashboard



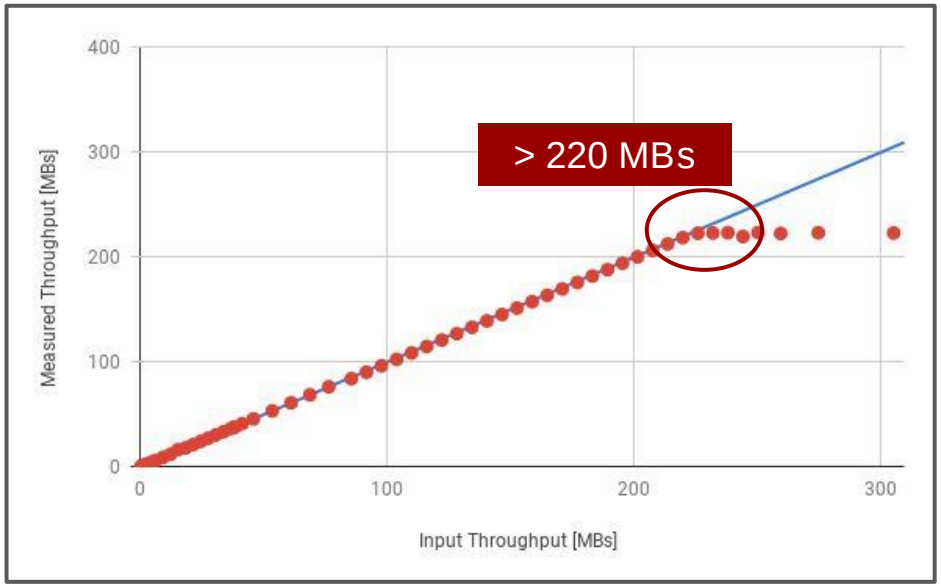
Scaling tests

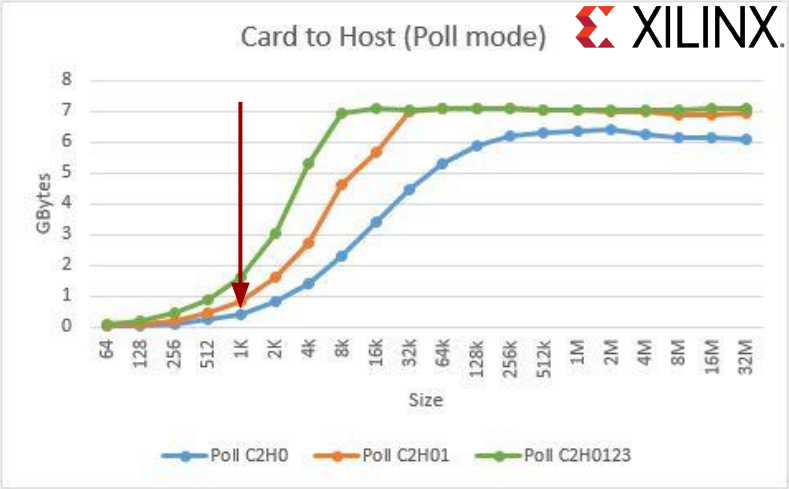
- Aim at verifying scaling properties in view of dimensioning the system for HL-LHC operations
- Test scaling of block-by-block and overall



Scaling tests (1)

- Generate test pulse signals at high rate to test throughput to DMA
  - Currently implementing 1-lane 1kB DMA transfers
- Large improvements expected
  - Doubling the DMA channels (one DMA-lane per V7)
  - Increasing the DMA transfer size



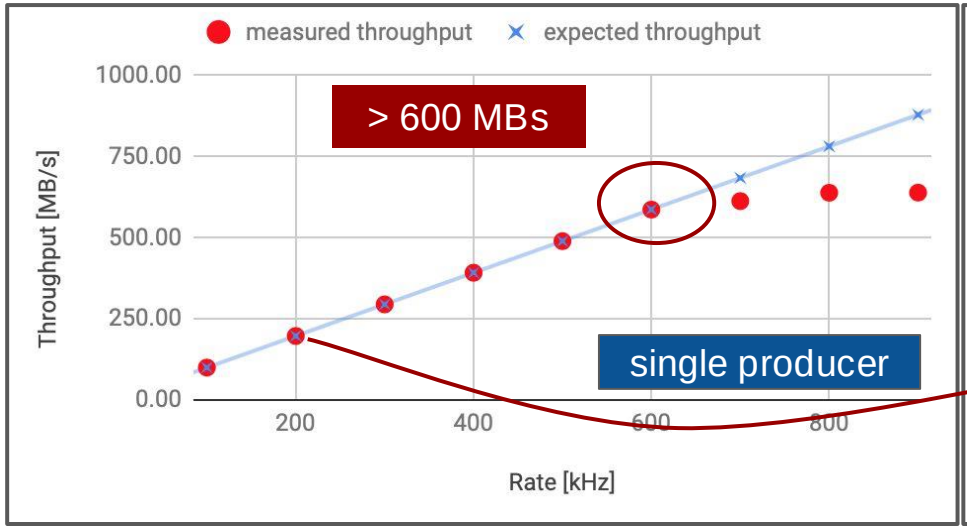


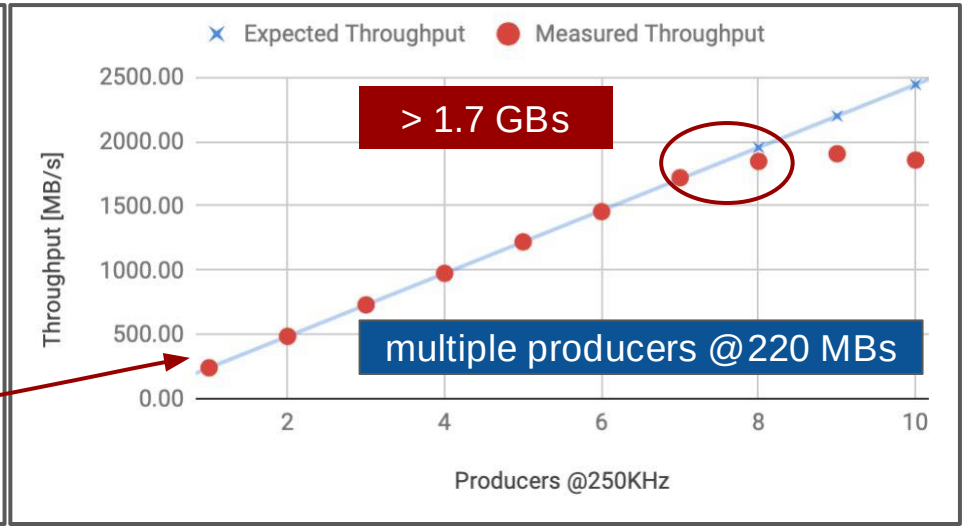
Card to Host transfer (poll mode) for 1, 2, and 4 channels

Scaling tests (2)

- Using Kafka Java producers from a Cloud node (i.e. decoupled form detector)
- Topic with 80 partitions on 3 brokers , testing sending data from:
  - 1 single Producer (equivalent to 1 KCU in current setup)
  - Multiple Producers

- All tests involving Spark are very **processing-dependent**
  - Efficient implementation of the Spark processing to contain processing time
  - Appropriate batch size to minimize scheduling overheads
- and **depend on the output**
  - Storing to DB/disk or sending output back to Kafka





Summary and plans

Status

- Unfiltered raw data from a mock-up CMS muon spectrometer sector are processed online at 40 MHz
- Scaling tests performed to cope with expected throughput at HL-LHC
  - 1 good μ / BX in CMS ➔ 1 μ / 60 BXs / sector ➔ 50 hits / 1.5μs ➔ ~250MB/s / sector

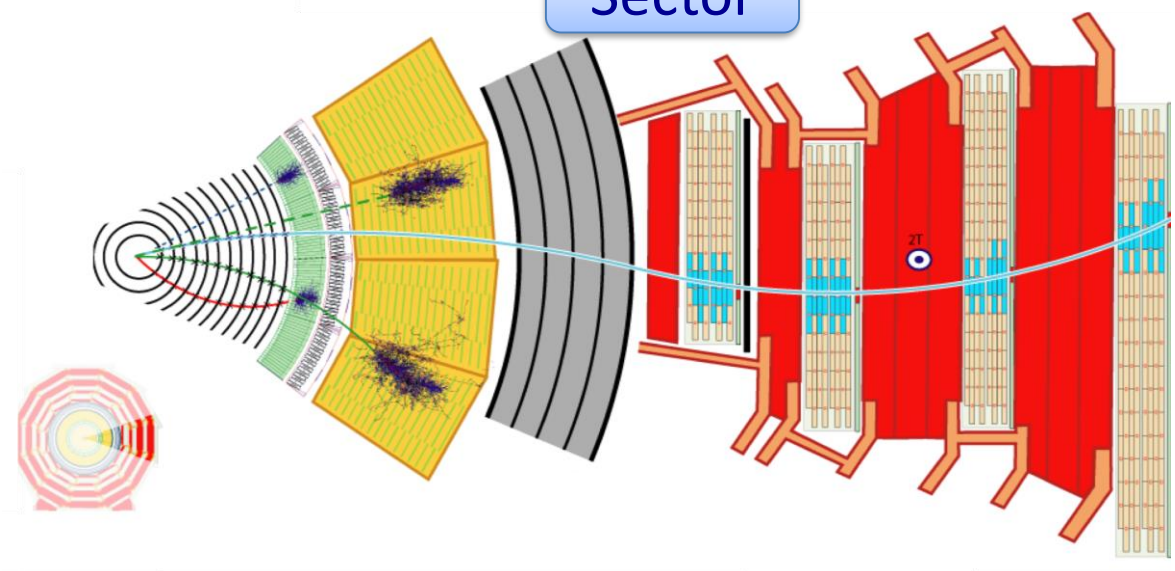
Plans

- Upgrade system to exceed 10Gbs
- Deploy it on a CMS sector for LHC run 3
- Add a processing step into PCIe card
  - Synergy with L1 local trigger reconstruction
  - Propagate downstream only high level information (muon tubs)
- Try out “new physics” cases, e.g. mimic slow muons (HSCP)

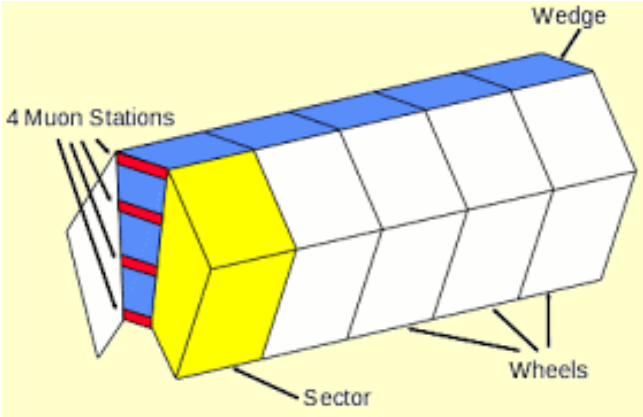
BACKUP

Geometry and nomenclature

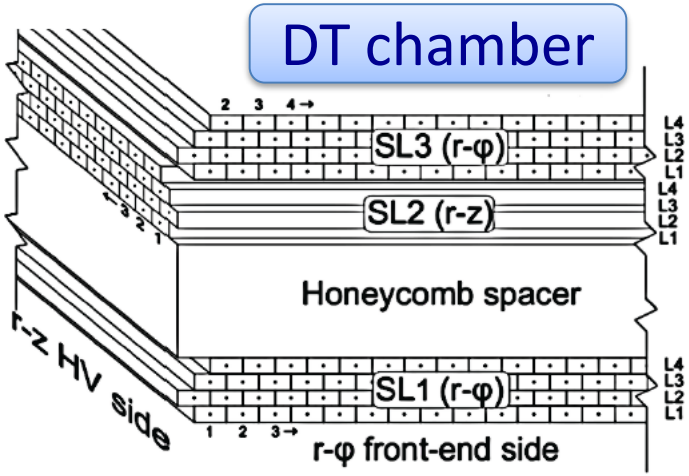
Sector



Wedge



DT chamber



- 4 layers of cells per super-layer (SL)
  - 50-80 cells per layer
- 3 SL per chamber
- 4 chambers per sector
- 5 sectors per wedge
- 12 wedges in CMS
  - 250k channels

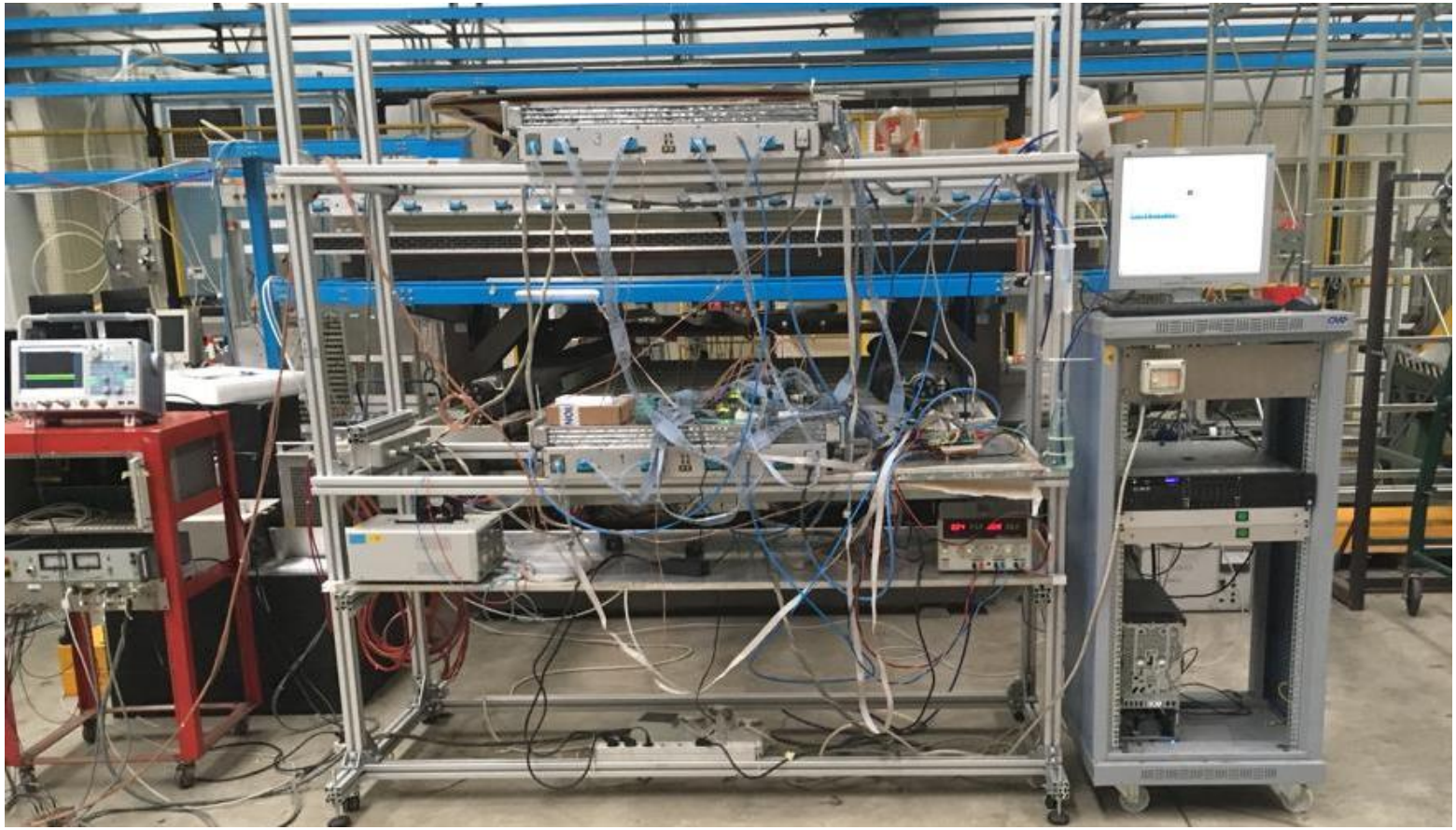
Setup at Legnaro INFN Lab (LNL)

- A mock-up of a sector with 4 reduced-size chambers (mini-DT)
  - 2 full scale MB3 chambers also available
  - 2 additional mini-DT ready in April
- Pre-amplified signals from detectors processed by phase2 front-end electronics
  - "OBDT" boards being commissioned (not for production yet), evaluation boards (Virtex7) used in the meanwhile
  - Substituting phase1 "minicrate"
- Operate with cosmics (O(100) Hz) or test pulses
  - Possibly firing all channels at 40 MHz
- Internal trigger generated and added as additional word to the data flow
  - Phase1 "mean-timer" algorithm

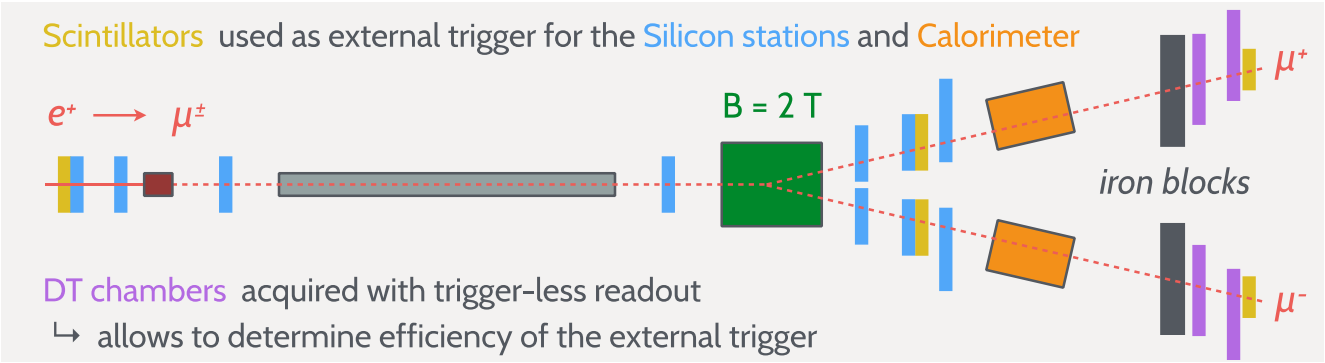
Mini-DT

- A rescaled and refurbished version of the CMS Drift Tubes chamber
  - Overall transverse dimensions: ~70x70 cm^2
  - Rather light, can be carried “by hand”
- Same cell geometry and electrodes configuration
- Same “superlayer” (quadruplet) configuration
  - Layers are staggered to allow mean-timer application
- At the test-beam:
  - 4 superlayers, 2 per line, all measuring the bending coordinate (x)
  - Structure to support them allows flexibility in x and y and place them ~50 cm apart in z

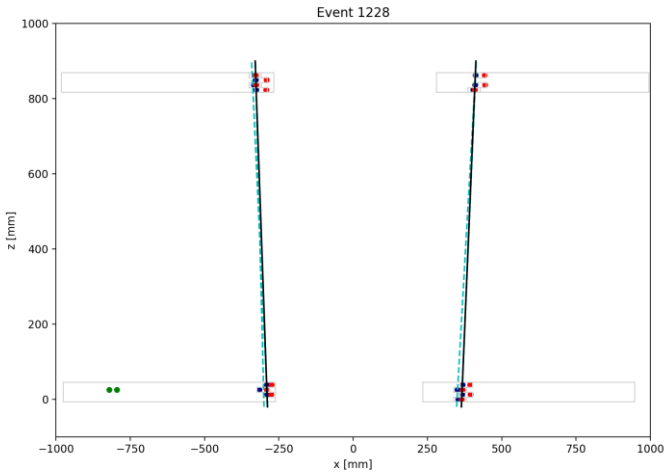
Setup at Legnaro INFN Lab

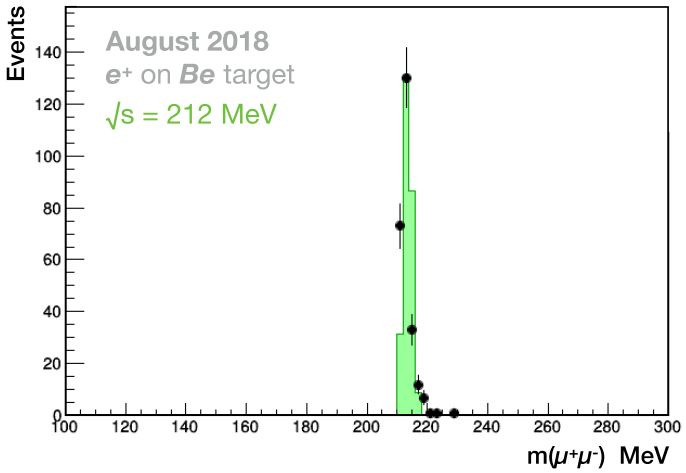


LEMMA test beam



- The 4 mini-DT installed on an experiment along H2 (North Area)
  - 5×10^6 positron on target per spill to study the $\mu^-\mu^+$ production at threshold
- Data recorded with the 40 MHz system
  - No online processing, data simply stored for offline analysis (TB in hours)





Sector test and Run 3

- Sector 11, wheel +2 is being equipped with phase2 front-end electronics (OBDT)
  - Take cosmic data from around summer
- Under discussion, but likely to leave OBDTs together with FE electronics for 3rd and 4th stations (spilt chambers' signals).