The High-Rate Data Challenge: Computing for the CBM Experiment

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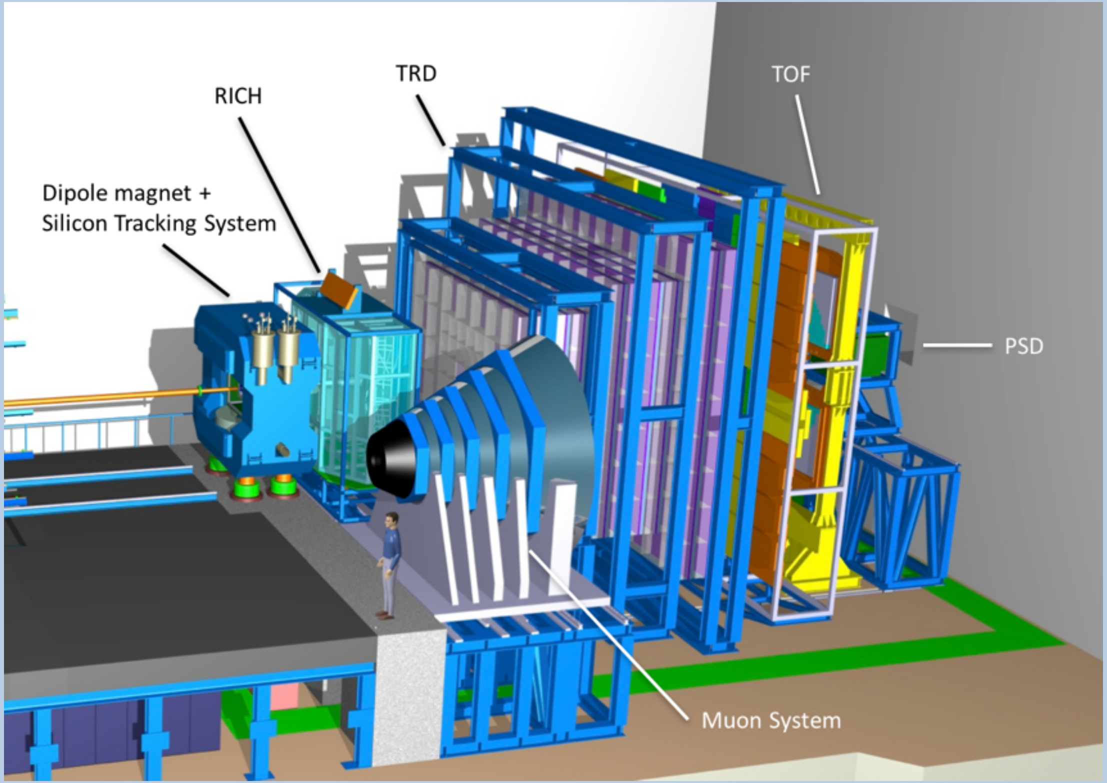
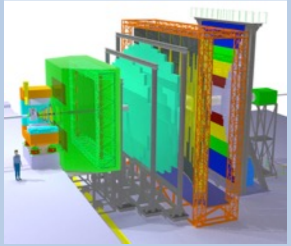
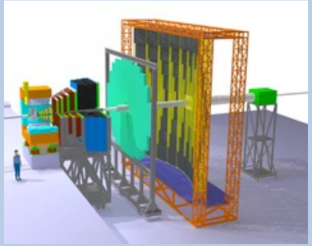
The Experiment



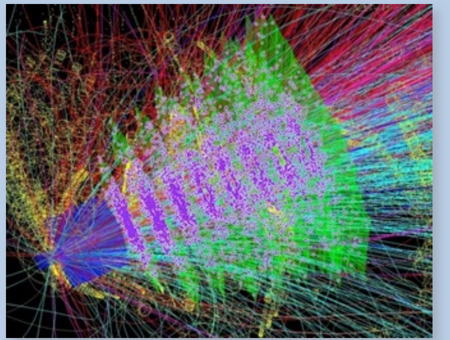
- Compressed Baryonic Matter: a heavy-ion experiment at the future facility FAIR in Darmstadt
- Fixed-target operation on extracted beams, 2 – 45 GeV/nucleon
- Spectrometer: silicon tracking system in a dipole magnetic field
- Hadron, lepton and photon ID: RICH, Muon System, TRD, TOF, ECAL
- Observables: yields, spectra, flow, correlations, fluctuations of bulk hadrons, multi-strange hyperons, open charm and charmonium; low-mass di-leptons
- First beam in 2022

Characteristics

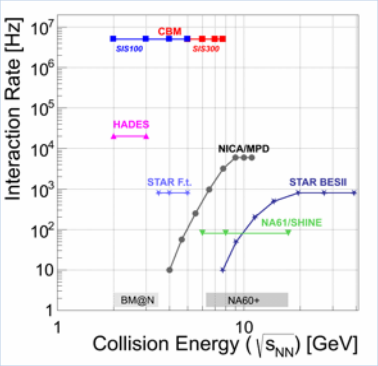

electron + hadron setup


muon setup

- Versatility: exchange or replace detector systems according to physics aim (e.g. electrons / muons) or conditions (beam energy)



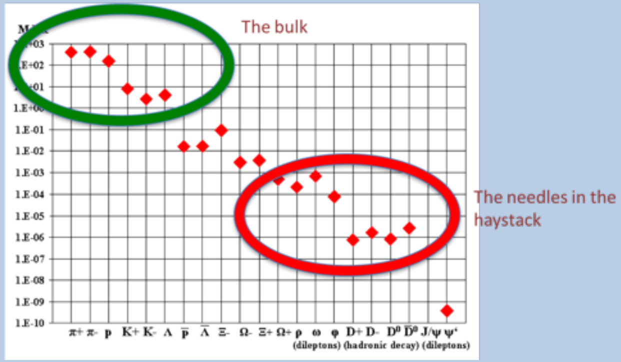
- Complexity: up to 600 charged tracks per collision in the acceptance

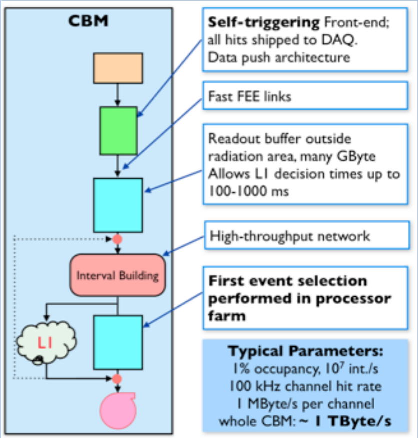


- Capability: up to 10^7 collisions per second

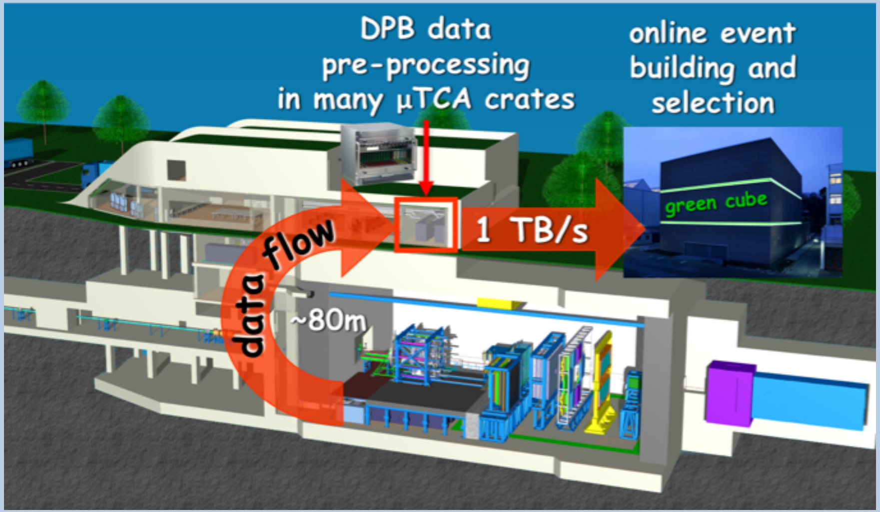
The Rate Problem

- CBM targets at extremely rare probes, which necessitates very high interaction rates (design rate 10 MHz).
- That entails a raw data rate of up to 1 TB/s.
- To be reduced online to a storage rate of several GB/s.
- Trigger signatures are mostly complex (e.g. weak cascade decays) and cannot be realized in hardware.
- Readout concept:
  - No hardware trigger
  - Self-triggered front-end electronics deliver time-stamped data
  - Data-push architecture to online compute farm
  - Event reconstruction and –selection to be performed on CPU





Online Data Flow



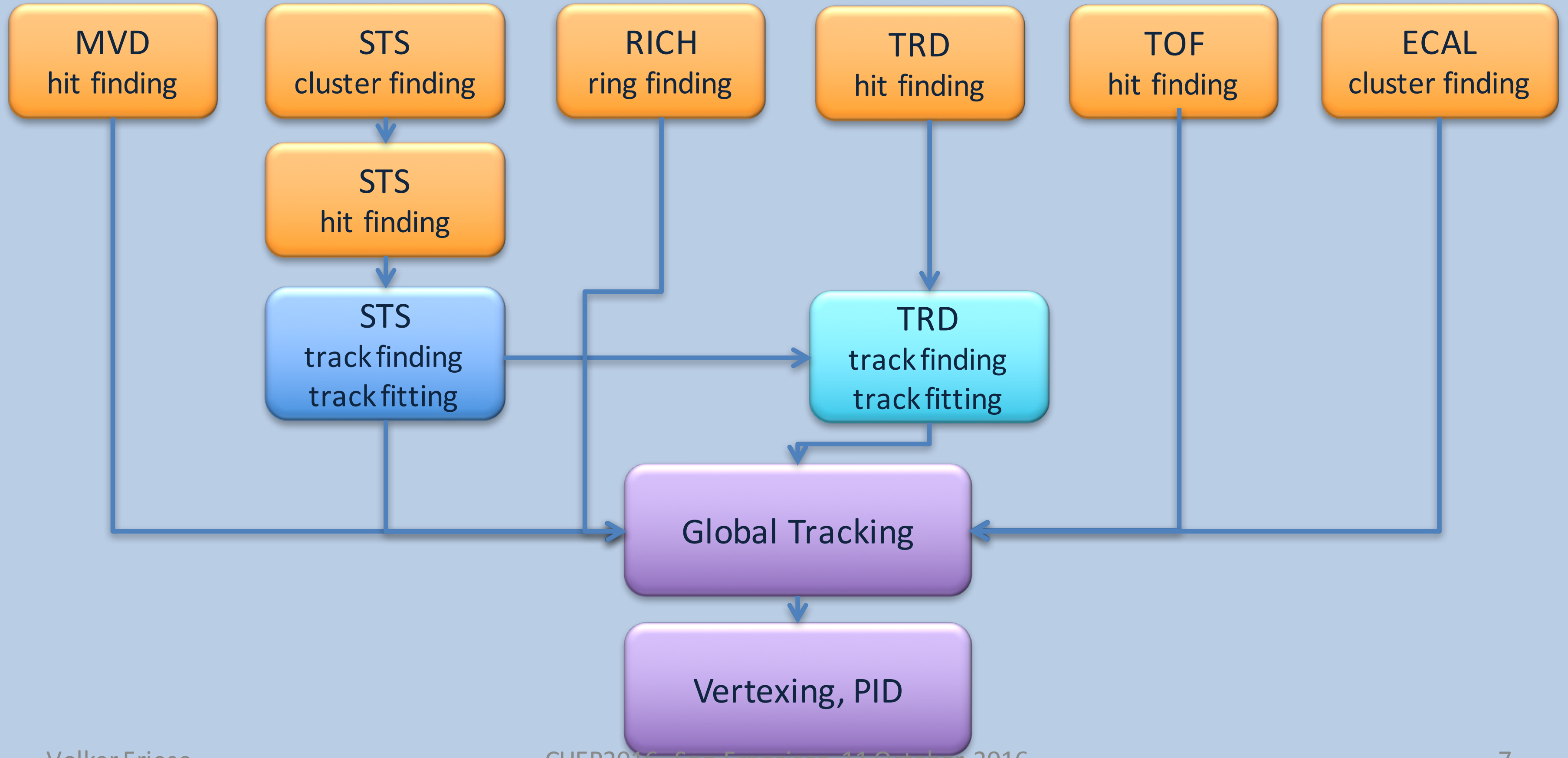
- Data are aggregated and pre-processed in an FPGA layer near the experiment.
- Time-slice building is performed on CPU (input nodes).
- Event reconstruction and –selection is performed in real-time on CPU (compute nodes) in the GSI "Green Cube".

Consequences for Online Computing

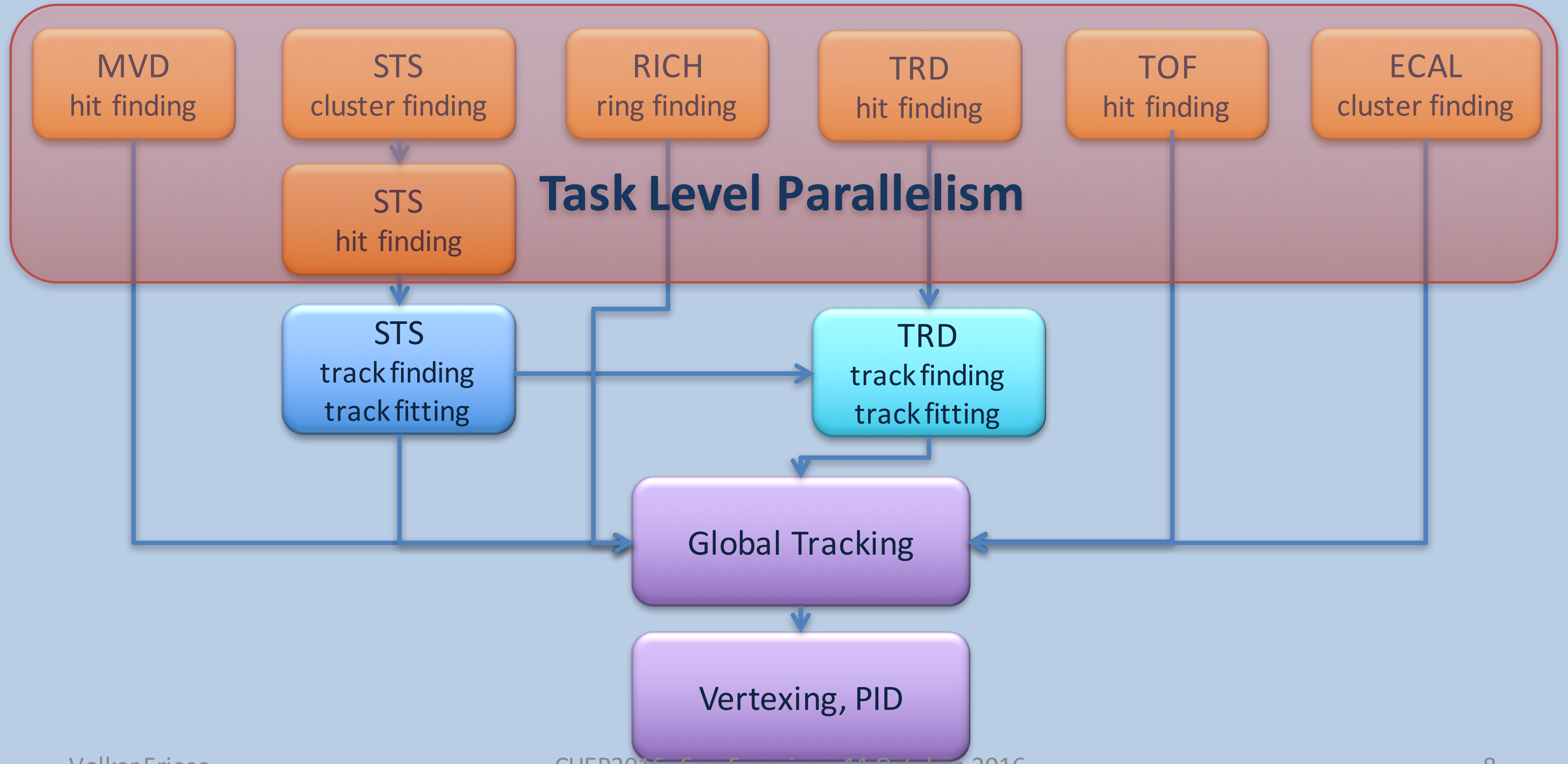
- Reconstruction does not start from events (defined by hardware trigger) but from „time slices“ containing many events.
  - size of time slice adjusted to architecture of compute farm
  - typical value: 100 MB (1000 events)
  - one time slice delivered to one compute node; avoid intercommunication between compute nodes
  - events can overlap in time; no trivial event definition: ”4-D reconstruction”

- All online algorithms have to be extremely fast
  - Trivial data-level parallelism for time slices (one time slice per node)
  - Use massive parallelisation also within one node (many-core CPU/GPU/...)

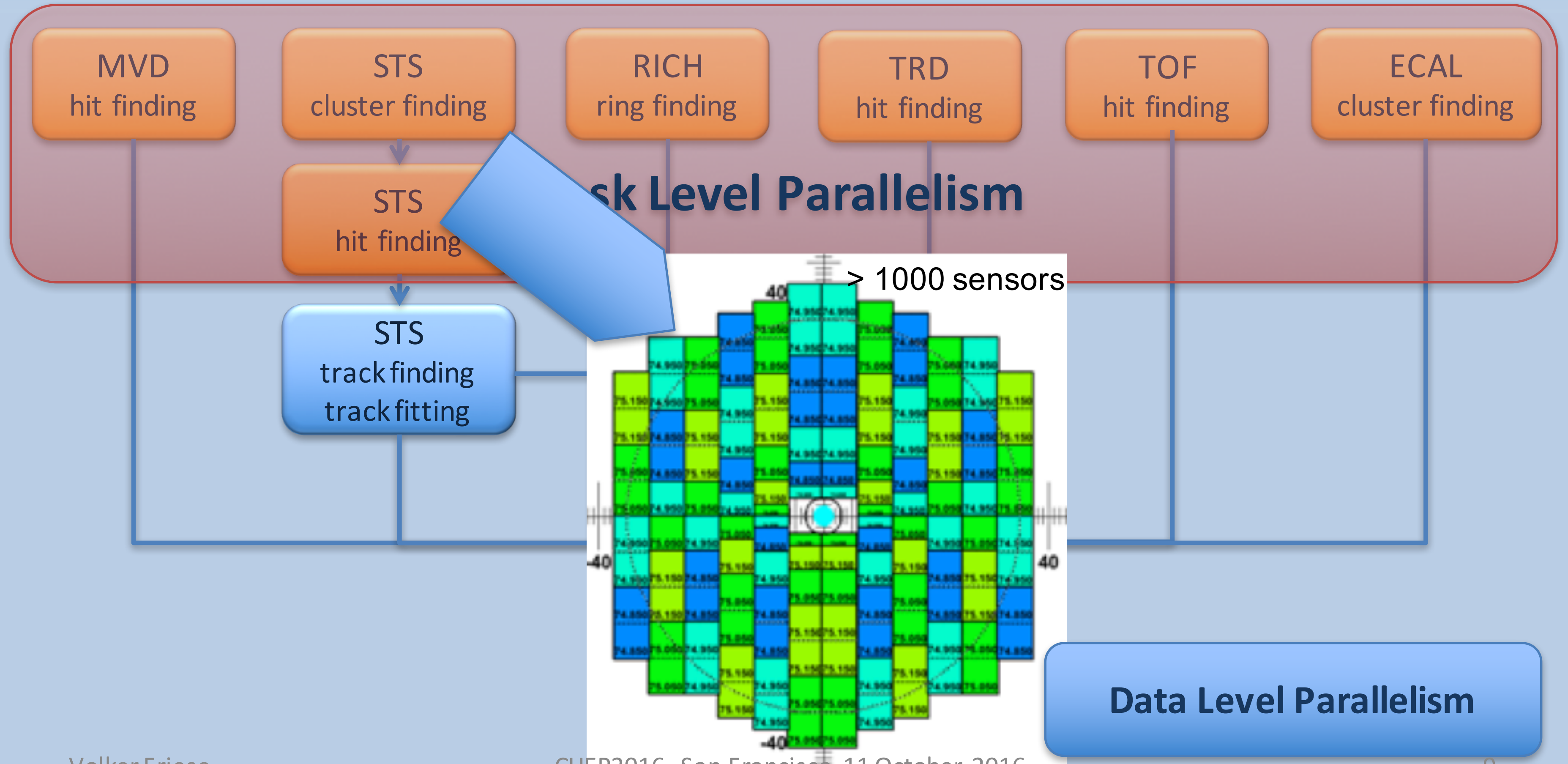
Parallelisation Within a Time Slice



Parallelisation Within a Time Slice

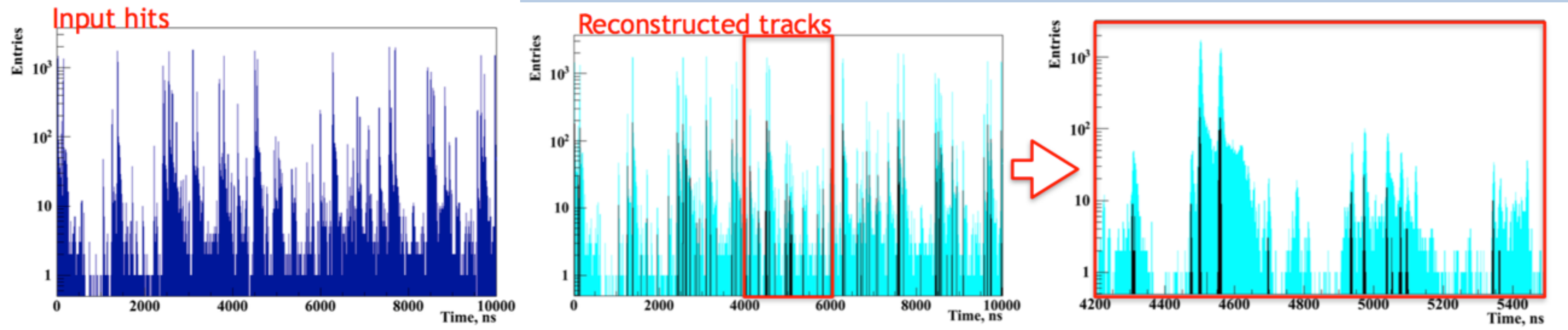


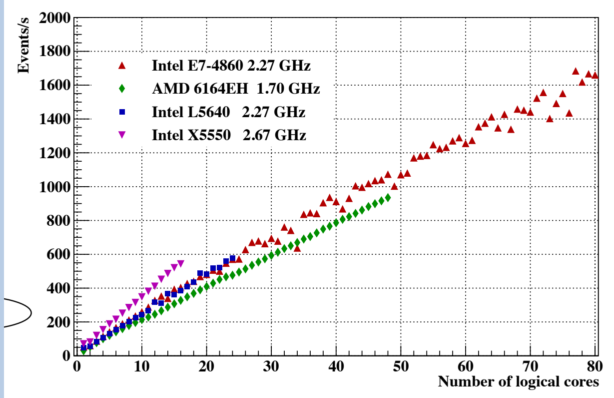
Parallelisation Within a Time Slice



Example: CA Track Finder

CBM Au+Au 25A GeV 10 MHz STS only

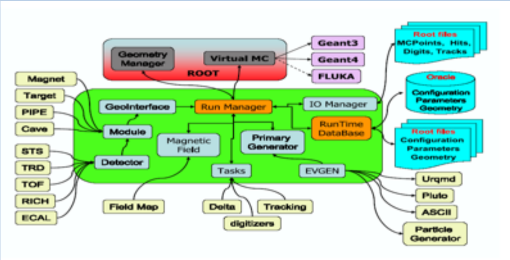




Track finding is performed on a stream of hits.
Events can be defined based on found tracks.

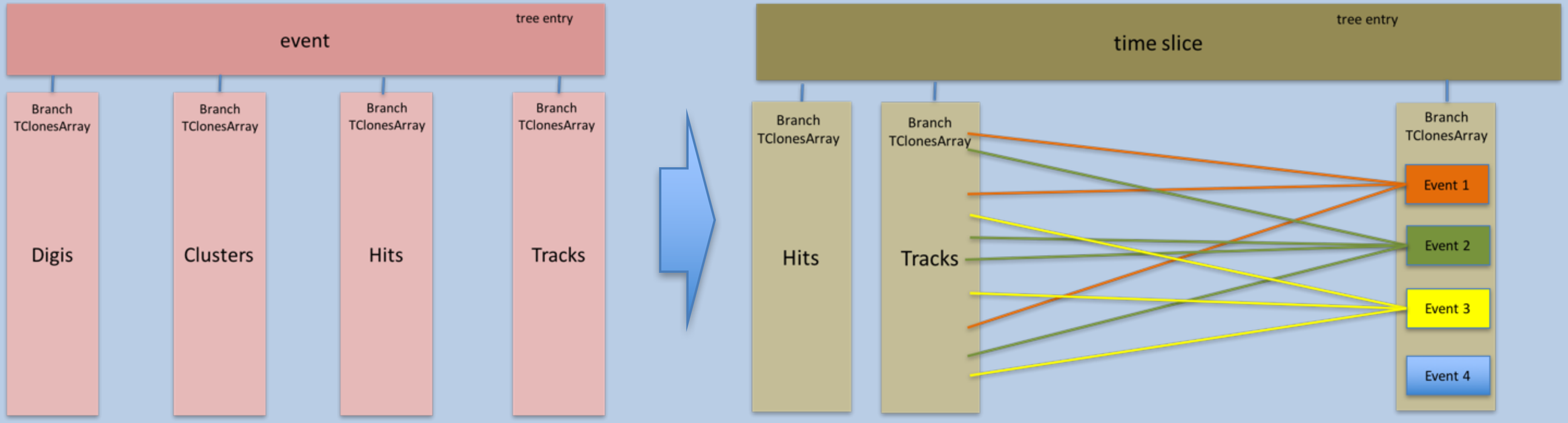
Good scalability of algorithm with multi-threading on many core CPUs

Framework and Data Model



- CBM uses the FairRoot framework (built on ROOT) for simulation, reconstruction and analysis.
- The data model is based on the ROOT TTree.
  - Different data branches: raw data (digis), clusters, hits, tracks, vertices, ...
  - A “run” produces an output tree from an input tree
- Conventionally, one tree entry corresponds to one event (collision)
- We have to deal with both time slices and events
  - In simulation: convert events (Monte-Carlo) into time slices (destroy association of data to events)
  - In reconstruction: reconstruct events from time slices
- Situation when output tree entry does not correspond to input tree entry not mapped in the framework

Event Data Model

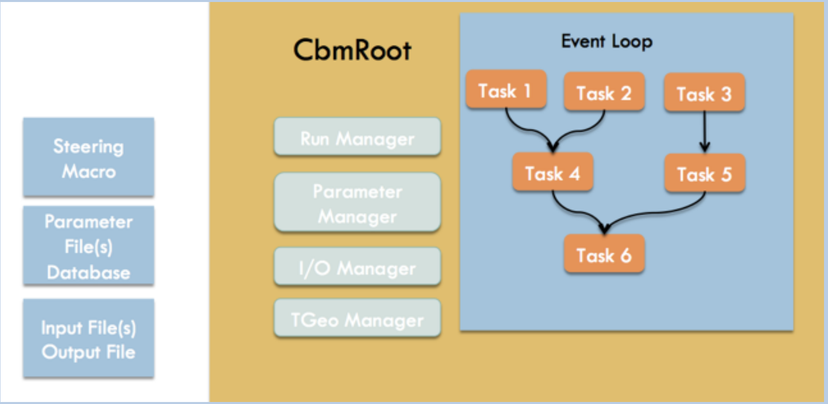


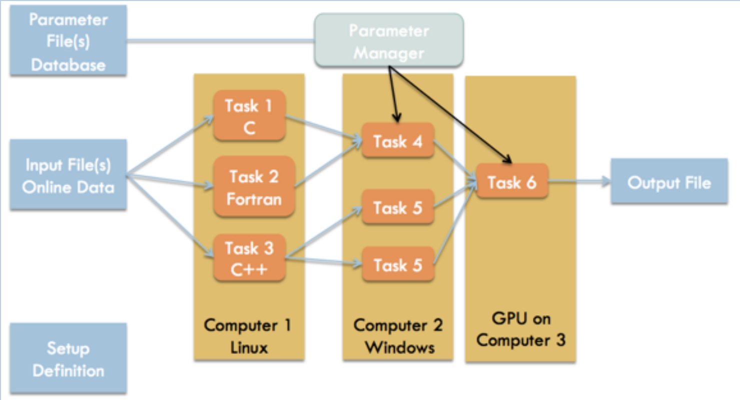
- No data copy when associating data to event
- Small overhead (one pointer/index per data object)
- Events can be defined based on any data level
- Algorithms are flexible to run on entire time slice (4-d reco) or on defined events (analysis)
- Ideal case (event-by-event) described in the same format (one event per time slice)

Outlook: Offline Computing

- Raw data volume per typical runtime (2 months): about 5 PB
- Limiting factor will not be computing capacity but storage costs
- Ansatz: store only raw data
  - For offline analysis: reconstruct on-the-fly
  - Assumes fast online algorithms deliver close-to-final precision
- Storage model is time slice with raw data, skimmed online from "uninteresting" data
- Consequence: no formal difference of online and offline algorithms
  - Use same framework
- But: no support of concurrency in the current ROOT-based framework

Outlook: A Concurrency Framework





- FairMQ: extension of FairRoot with a message queue-based data transport framework, providing asynchronous inter-process communication
  - See M. Al-Turany er al., J. Phys. Conf. Ser. 513 (2014) 022001 (Proc. of CHEP 2013)
- Promises flexibility w.r.t. architecture and data model
- Will be explored by CBM in the near future

Summary: Computing Challenges for CBM

- Huge interaction and data rates necessitate real-time event reconstruction and data selection
  - Reduce about 1 TB/s to several GB/s in real time in software
- Basis of the data model is a time slice containing many events
- Fast 4-D reconstruction algorithms under developments
  - Many achievements, but still some way to go
- Quest for a common online and offline software framework
  - Concurrency needed
  - Common data model allowing time-based and event-based analysis without change of code
  - Make use of the extension of the current FairRoot to FairMQ