The ATLAS B-physics Trigger

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On behalf of the ATLAS T/DAQ group

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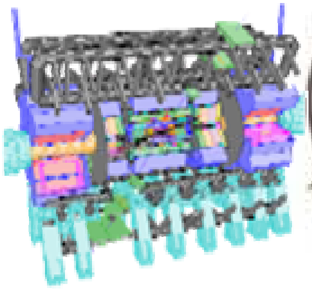
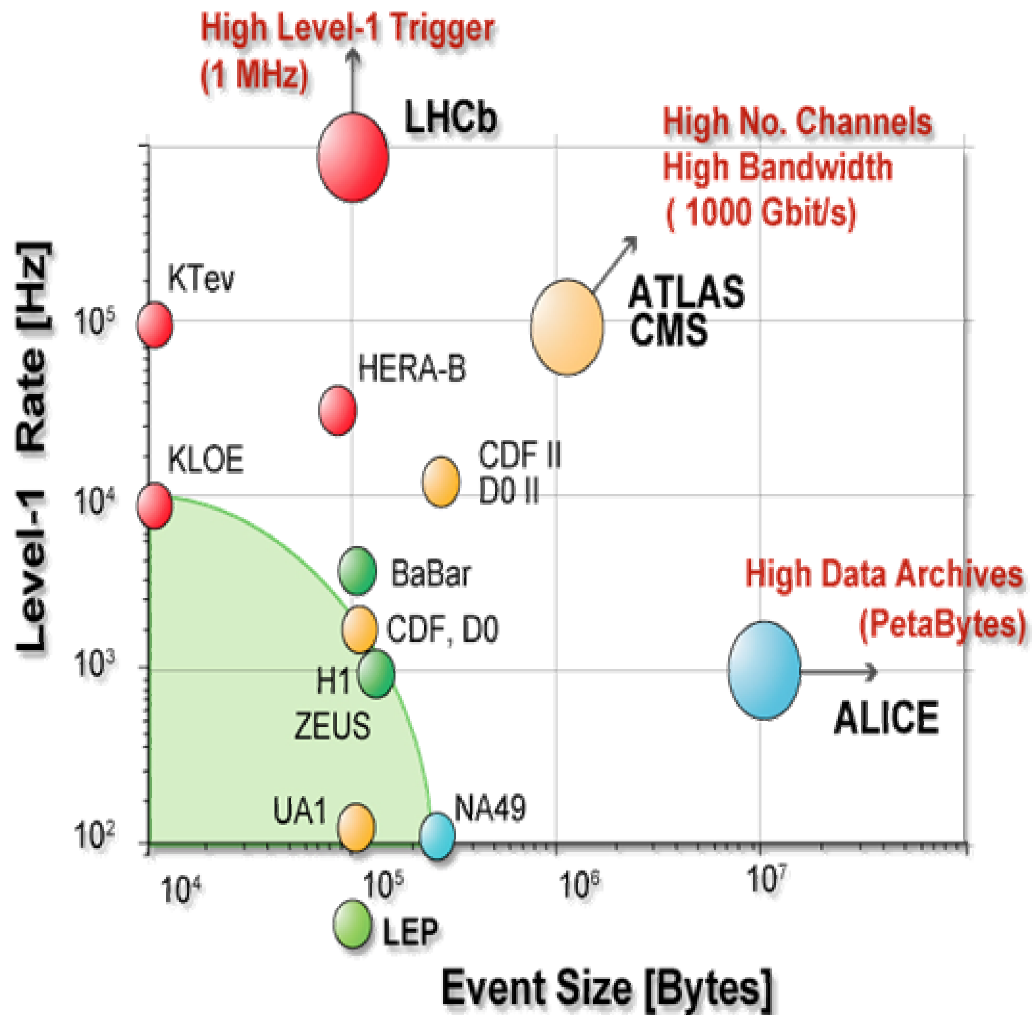
Carnegie Mellon University

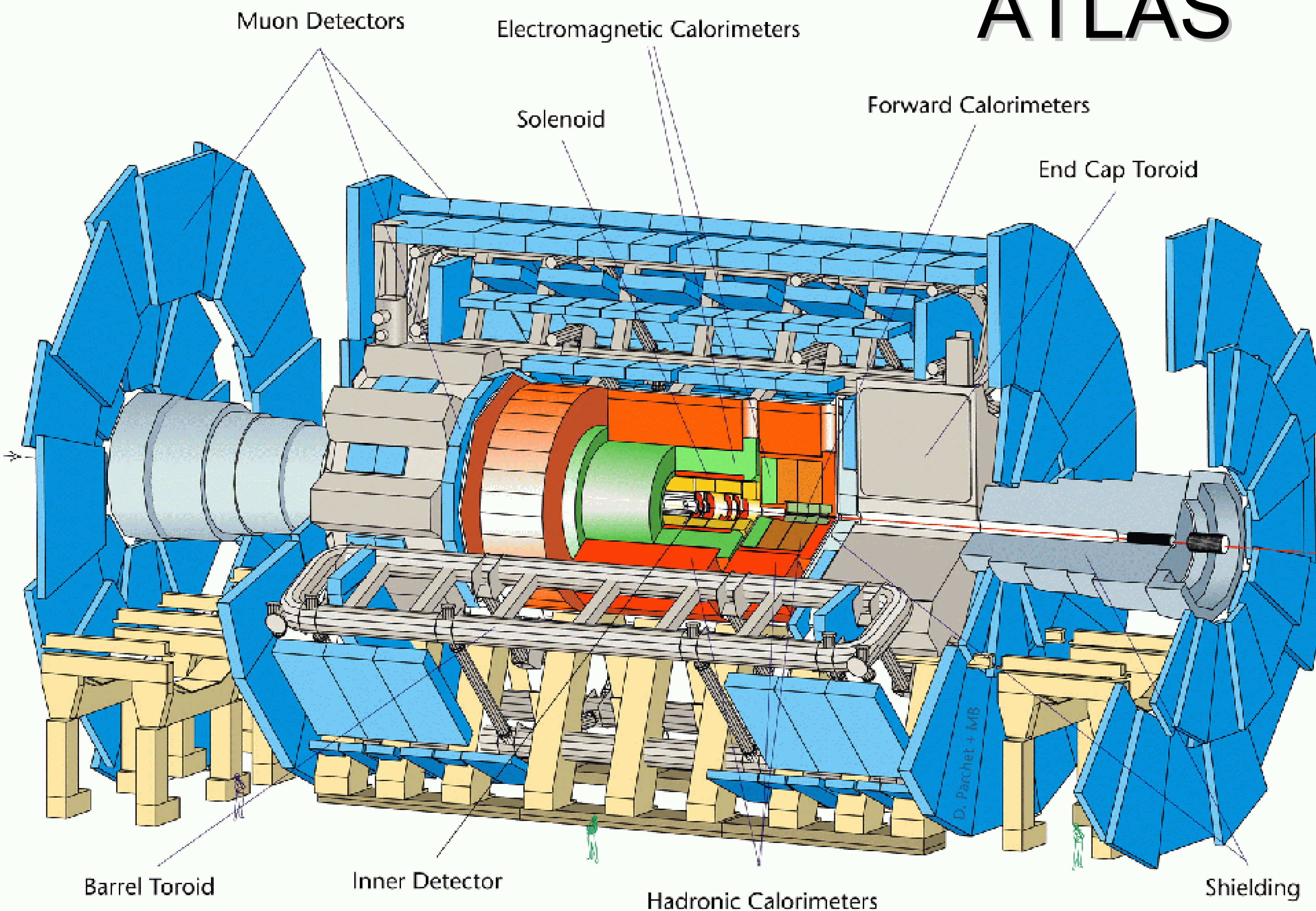


LHC and ATLAS

- LHC
  - 14 TeV centre-of-mass p-p, bunch crossing @ 40 MHz
  - target peak luminosity 2×10^{33} cm^{-2}s^{-1} initially, rising to 1×10^{34} cm^{-2}s^{-1}
  - 4.6 – 23 interactions per bunch crossing
  - discovery physics "needle in a haystack"
- ATLAS
  - decision every 25 ns
  - about 10^8 channels
  - mass storage limits accept rate to *O*(100MB/s)



ATLAS



Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding
D. Parchet + MB

Contents

- News headlines
- ATLAS challenge and physics programme
- T/DAQ system overview
- RoI strategy extended to B-physics
- Start up scenario
- Rates
- Trigger strategies
- Timing and resources
- Conclusion

News since last Beauty conference

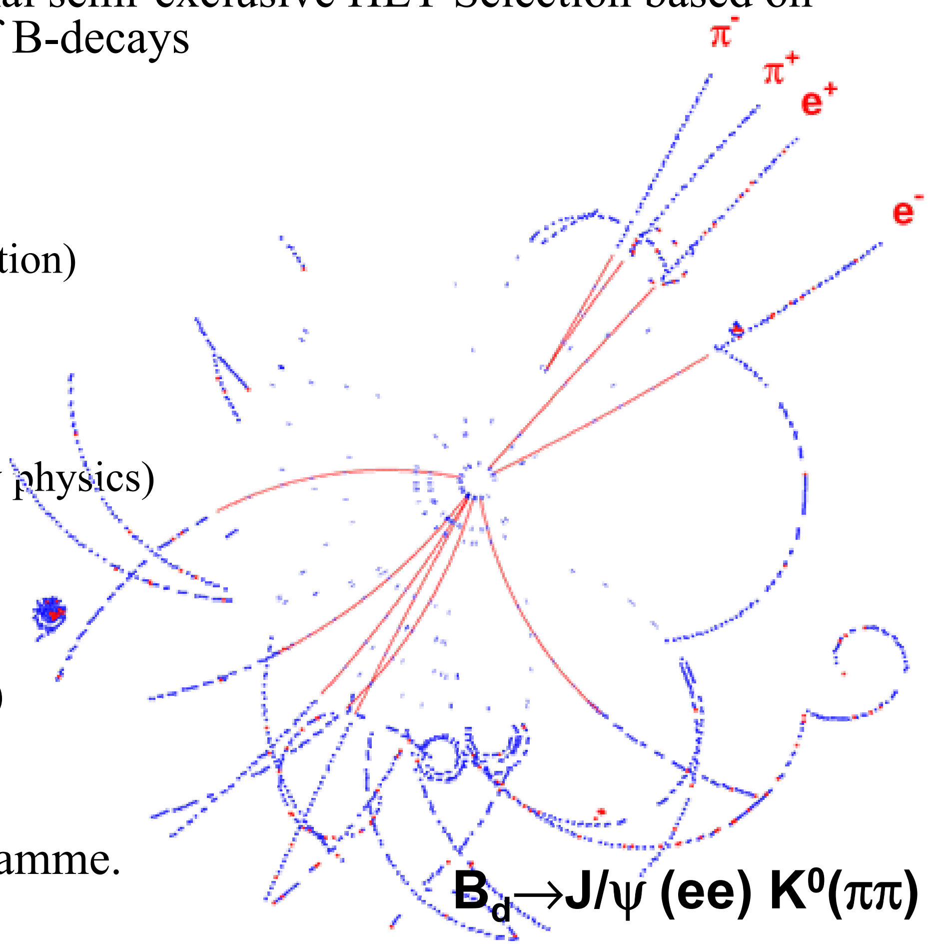
- Technical Design Report
  - High Level Trigger, Data Acquisition and Control
- Further work on how to maintain B-physics programme within constraints
  - Higher target start-up luminosity
  - Incomplete detector at start up
  - Cost constraints for T/DAQ
- Software further advanced
  - new performance measurements

B-physics triggering – the challenge

- About 1% of collisions produce a $b\bar{b}$ pair
- Trigger must therefore be more selective
- At luminosity $\geq 2\times10^{33}$ cm^{-2}s^{-1} : di-muon trigger
- At lower luminosities: introduce additional semi-exclusive HLT Selection based on single muon and partial reconstruction of B-decays

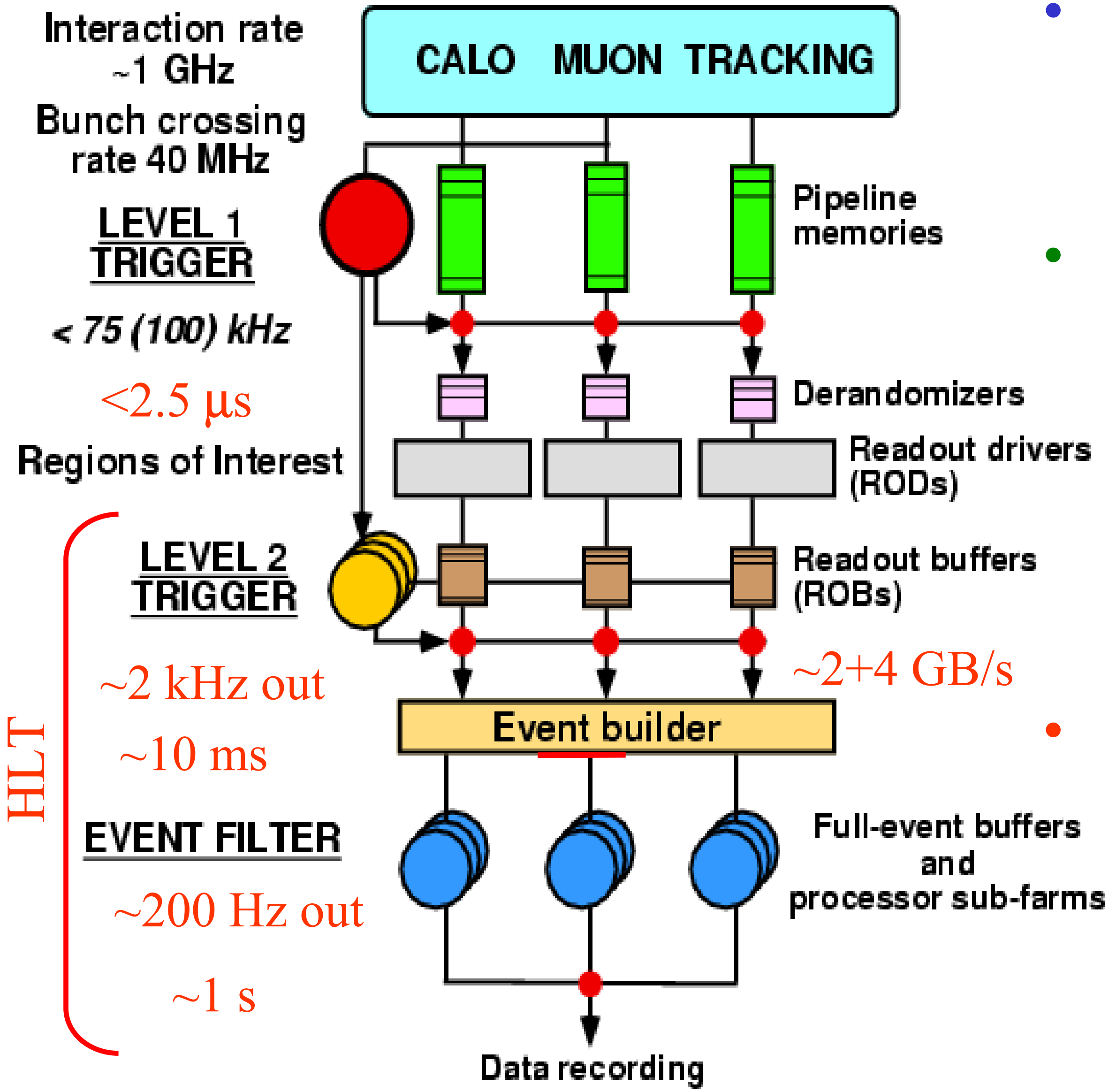
- Channels of interest, e.g. CP violation
  - $B_d \rightarrow J/\psi\ K_S$ ($J/\psi \rightarrow ee$ and $\mu\mu$)
  - $B_d \rightarrow \pi^+\pi^-$ (or generally any π/K combination)
- B_s oscillations
  - $B_s \rightarrow D_s\pi/a_1$, $D_s \rightarrow \phi\pi$
- Final state analysis
  - $B_s \rightarrow J/\psi\phi$, $B_s \rightarrow J/\psi\eta$ (enhanced by new physics)
- Rare decays
  - $B_{d,s} \rightarrow \mu\mu(X)$
- B-hadron production
  - B_c properties, Λ_b polarisation ($J/\psi \rightarrow \mu\mu$)
  - precision measurements

- See Paula Eerola's talk for physics programme.



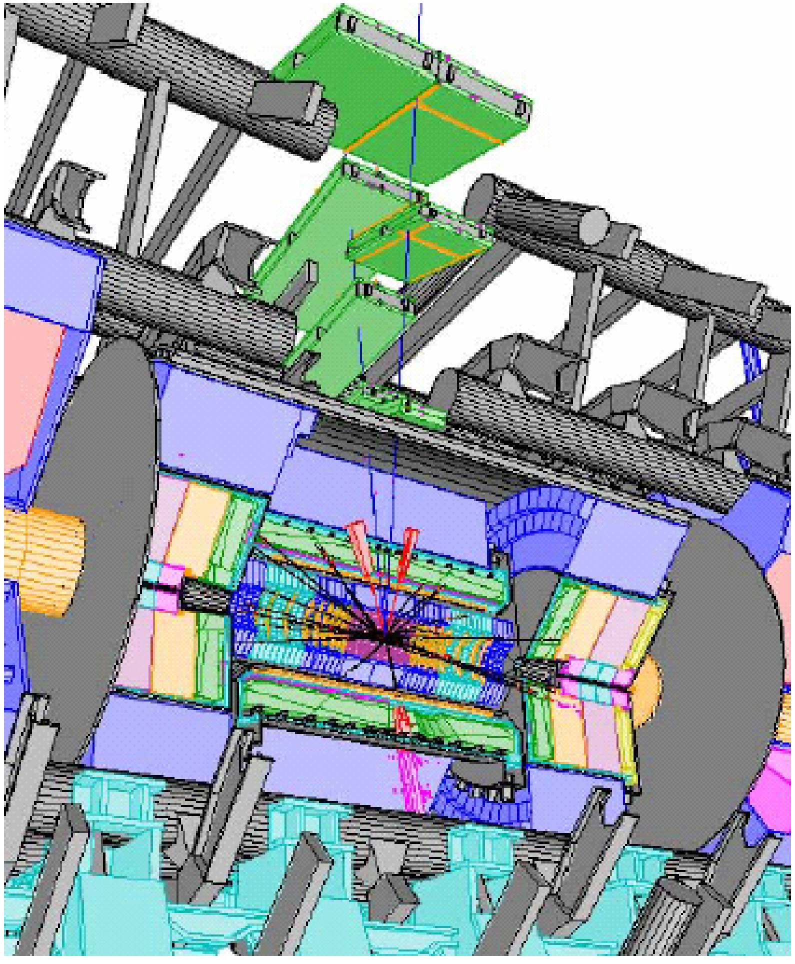
$B_d \rightarrow J/\psi\ (ee)\ K^0(\pi\pi)$

ATLAS T/DAQ system overview



- LVL1 decision based on coarse granularity calo towers and muon trigger stations
- LVL2 can get data at full granularity and combine info from all detectors. Emphasis on fast rejection. Region of interest from LVL1 used to reduce data requested to few % of full event.
- EF refines selection according to LVL2 classification, performing fuller reconstruction. More detailed alignment and calibration data available.

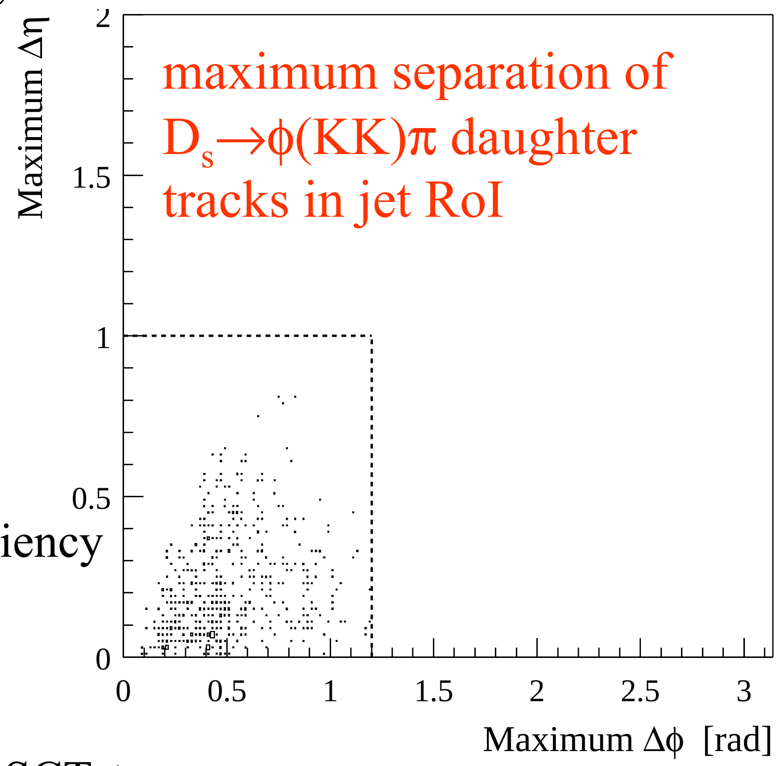
Region of interest mechanism



- LVL1 selection is mainly based on local signatures identified at coarse granularity in muon detectors and calorimeter .
- Further rejection can be achieved by examining full granularity muon, calo and and inner detector data in the same localities
- The **Region of Interest** is the geometrical location of a LVL1 signature.
- It is passed to LVL2 where it is quickly translated into a list of corresponding readout buffers
- LVL2 requests RoI data sequentially, one detector at a time, only transfers as much data as needed to reject the event.
- The RoI mechanism is a powerful and important way to gain additional rejection before event building
- Order of magnitude reduction in dataflow bandwidth, at small cost of more control traffic

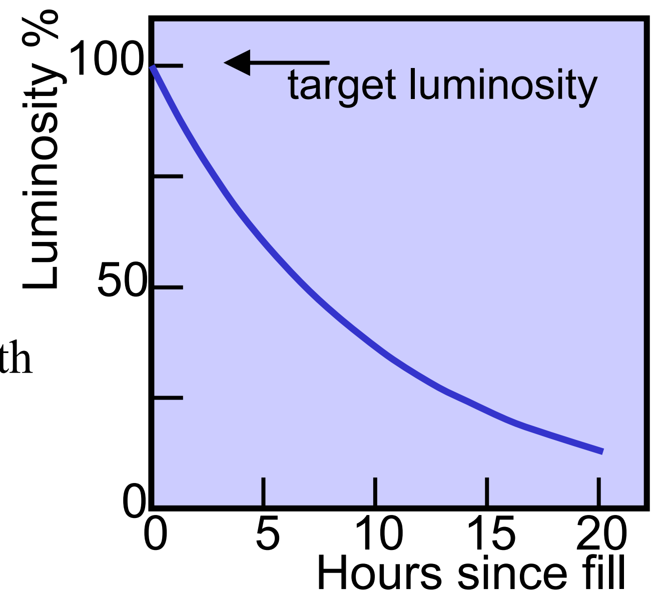
Two strategies for B-physics triggering

- At luminosity $\geq 2\times10^{33}$ cm^{-2}s^{-1}: di-muon trigger
- For low luminosity semi-inclusive B-physics selection ($\sim1\times10^{33}$):
- **1) RoI-guided**
  - LVL1 single muon (e.g. p_T>8GeV) + jet or EM
  - LVL2 validate muon
  - LVL2 & EF reconstruct tracks in jet/EM RoI, select $J/\psi(ee)$ $B_d(hh)$ $D_s(\phi\pi)$
  - **Pro**: significantly reduces resources (~10%)
  - **Con**: could be too many RoIs or too low efficiency
- **2) Full scan**
  - LVL1 single muon (e.g. p_T>8 GeV)
  - LVL2 validate muon
  - LVL2 reconstruct tracks in full acceptance of SCT + Pixels, select $B_d(hh)$ $D_s(\phi\pi)$
  - $J/\psi(ee)$ requires further resources for TRT scan
  - EF full scan or use LVL2 tracks to form RoI
  - **Pro**: higher efficiency than option 1
  - **Con**: needs more resources (CPU and network)



B-Trigger for start up conditions

- At start up, expect
  - luminosity varying from fill to fill
  - variable beam-related background
  - incomplete detector
  - understanding and tuning of detector
  - limited T/DAQ processing capacity and bandwidth



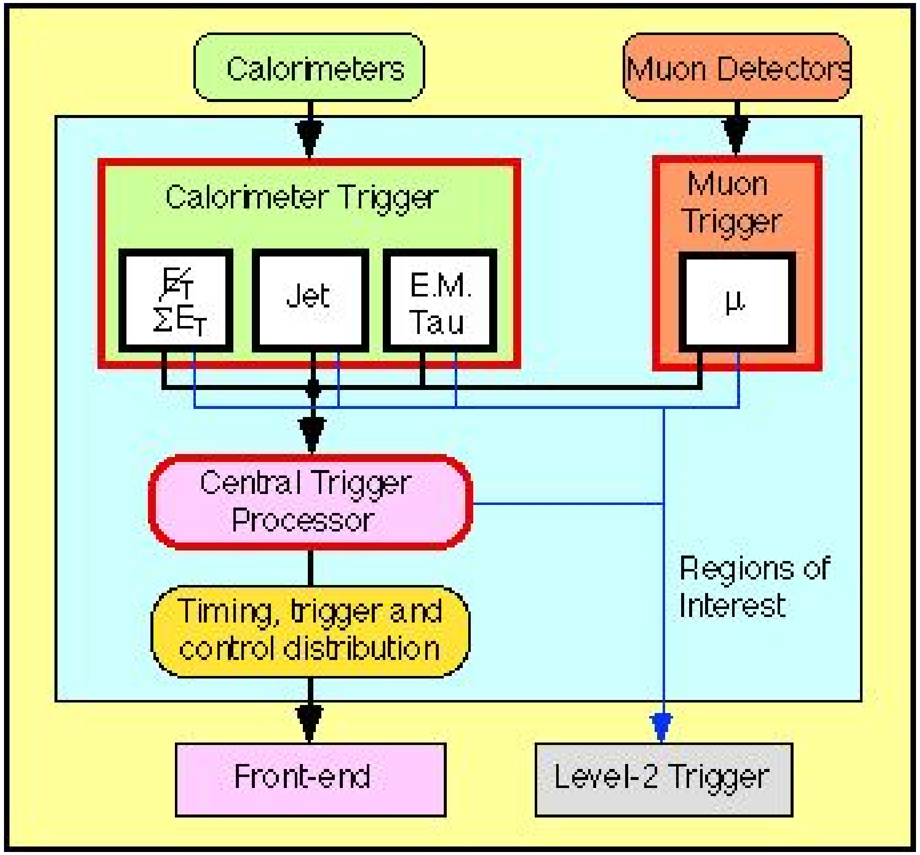
- Take advantage of LHC luminosity drop
  - Fall by factor of ~2 from start of fill to end of coast
  - Initial T/DAQ system built to requirements of target peak luminosity (2×10^{33})
  - As luminosity drops, use spare capacity for B-physics triggers
  - "Checkpoint" feature of run control system planned to enable rapid update of configuration mid-run
- Robust algorithms
  - w.r.t. noise, alignment
- Flexible configuration
  - adapt thresholds, pre-scales and other parameters to cope with varying noise, luminosity, etc.

Estimated Trigger Rates

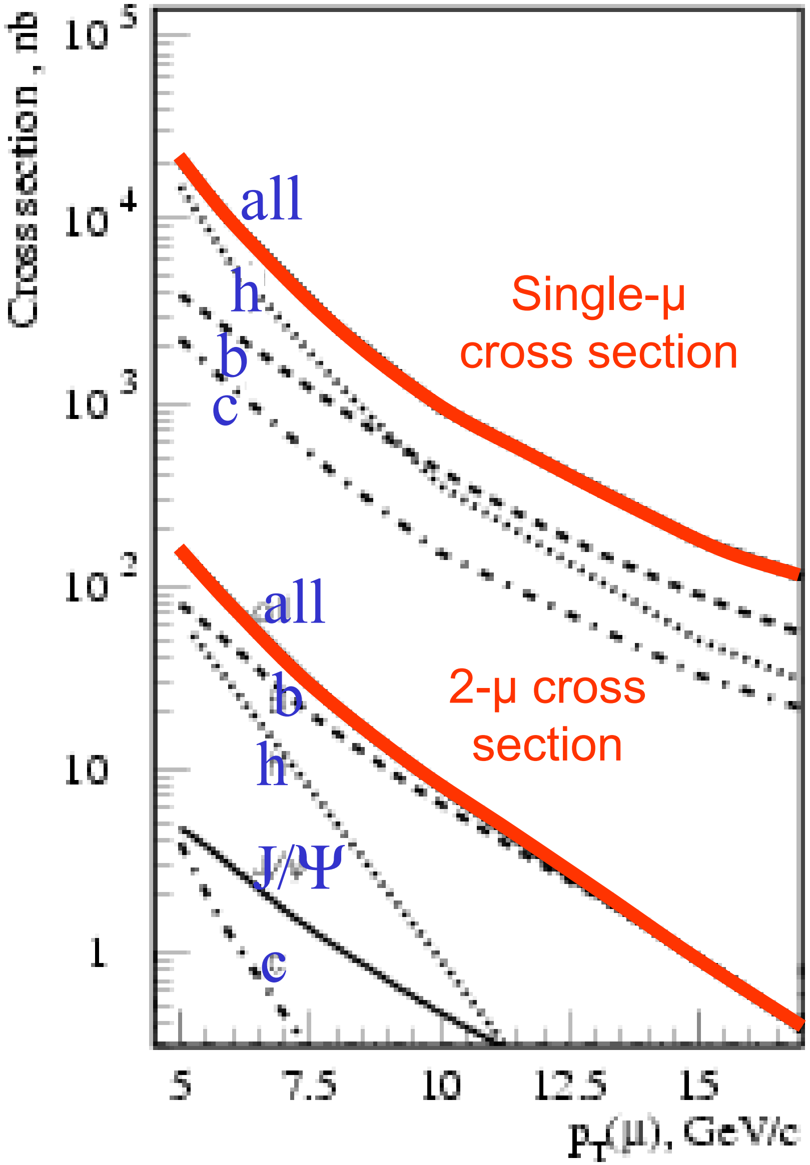
	2×10^{33} cm^{-2} s^{-1}		1×10^{33} cm^{-2} s^{-1}	
Trigger	LVL2	EF	LVL2	EF
$B_{d,s} \to \mu^+\mu^-(X)$	200 Hz	small	100 Hz	small
$J/\psi(\mu^+\mu^-)$		10 Hz		5 Hz
$D_s(\phi\pi)$	–	–	60 Hz	9 Hz
$B(\pi\pi)$	–	–	20 Hz	3 Hz
$J/\psi(ee)$	–	–	10 Hz	2 Hz
Total	200 Hz	10 Hz	190 Hz	20 Hz

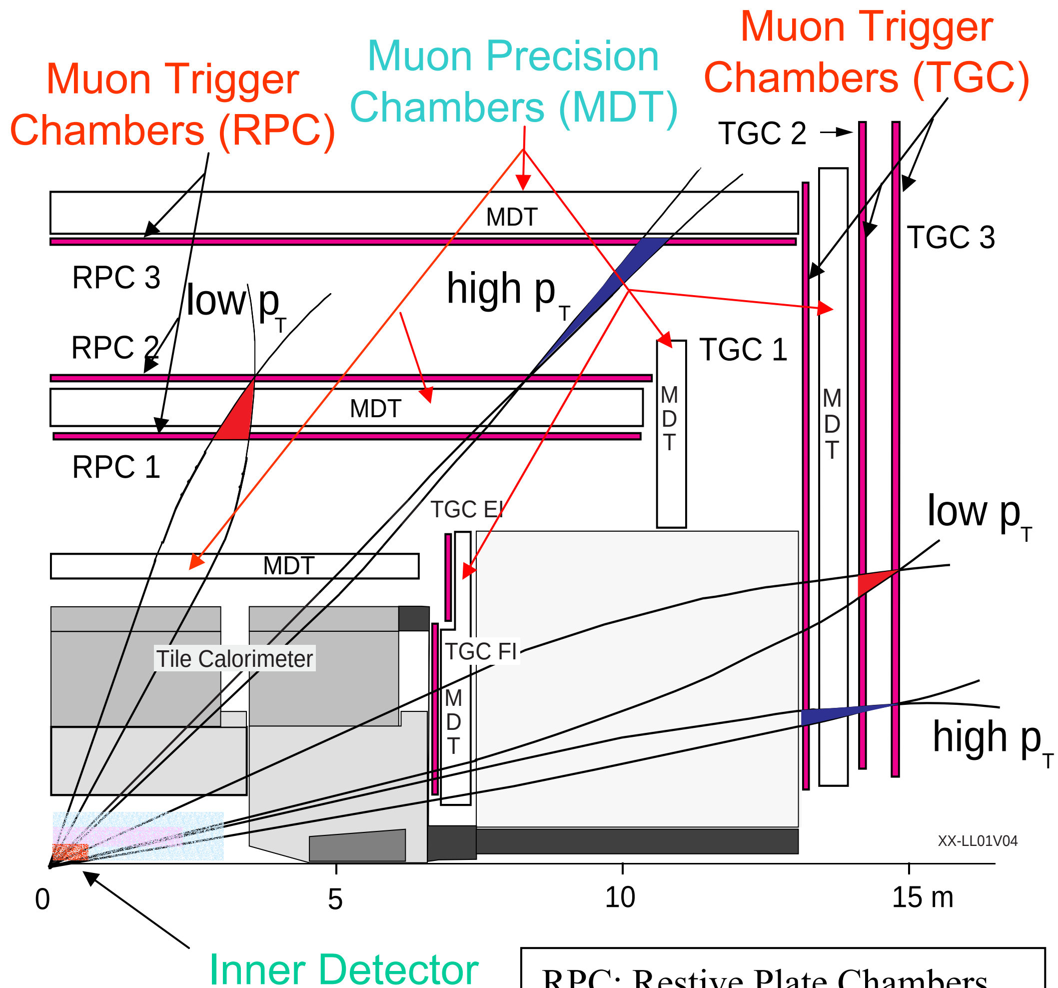
LVL1 Overview

- Identify basic signatures of interesting physics
  - muons
  - em/tau/jet calo clusters
  - missing/sum E_T
- Hardware trigger
  - programmable and custom electronics (FPGA + ASIC)
  - programmable thresholds
- Decision based on multiplicities and thresholds



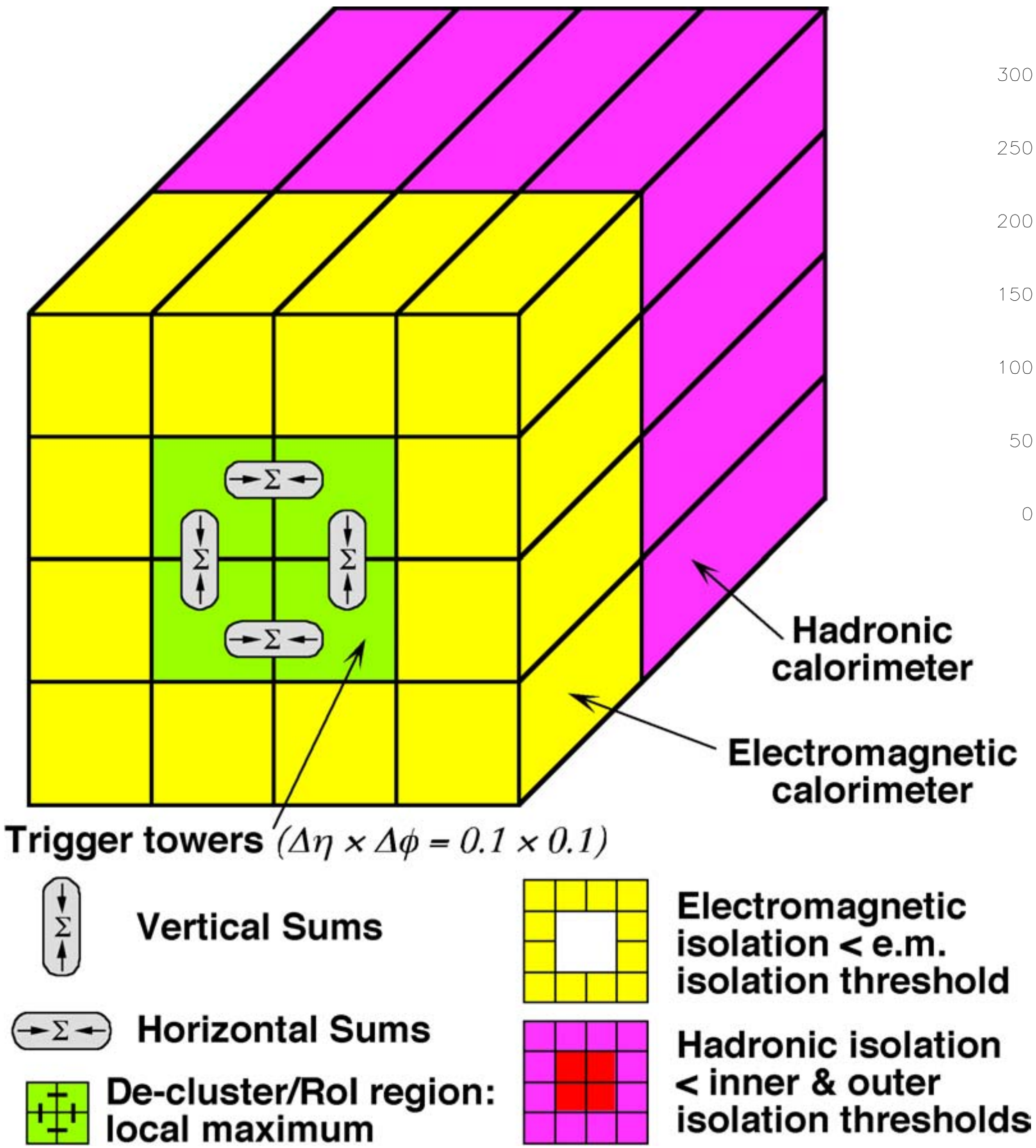
LVL1 Muon trigger

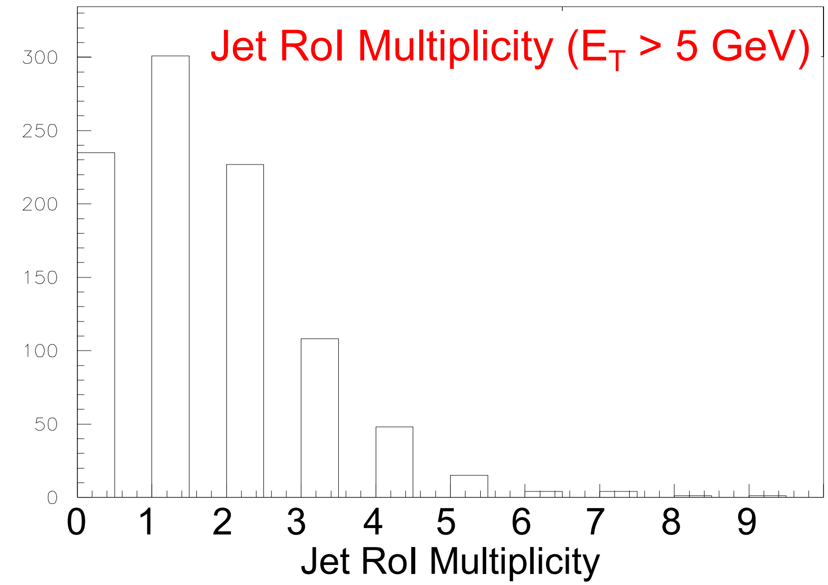


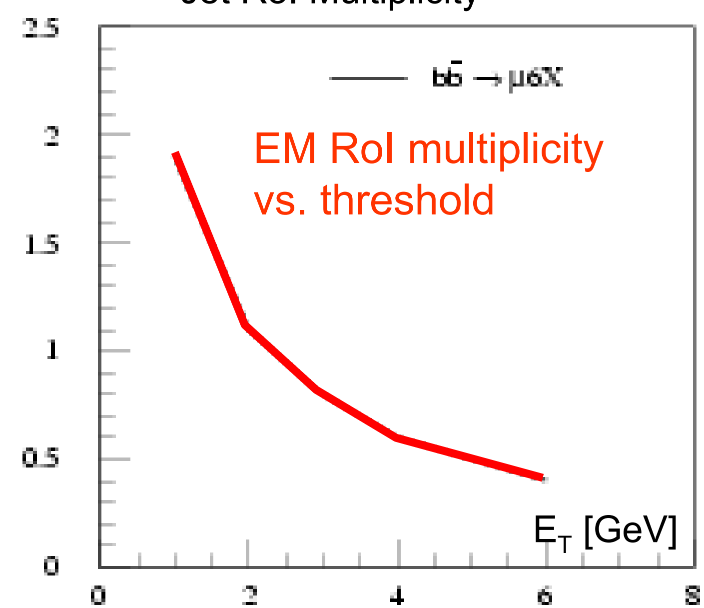


RPC: Restive Plate Chambers
TGC: Thin Gap Chambers
MDT: Monitored Drift Tubes

LVL1 Jet & EM triggers

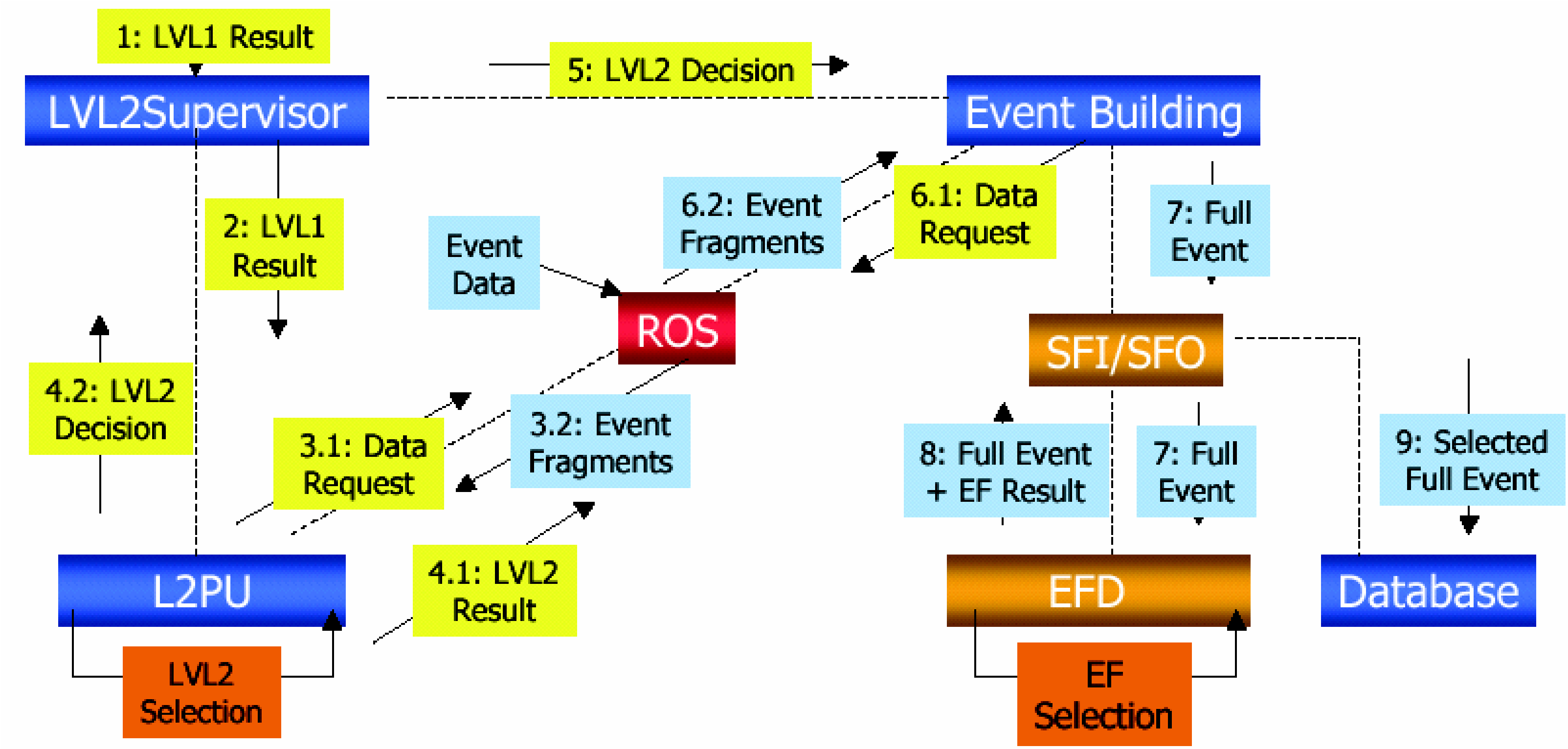




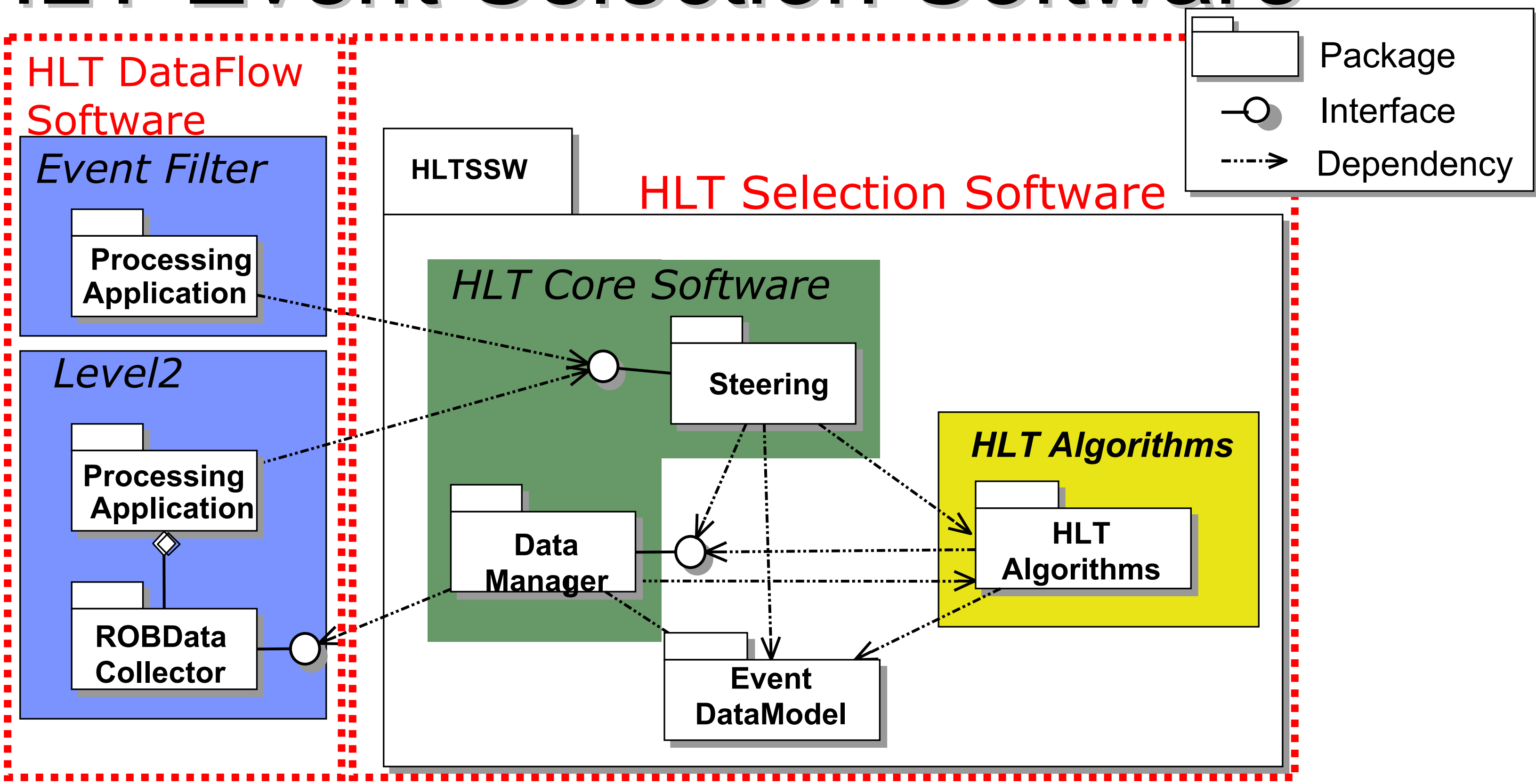


High Level Trigger

- Commodity electronics (PCs, switches)
  - few custom components e.g. readout buffers
- Software based
  - large and complex software engineering project

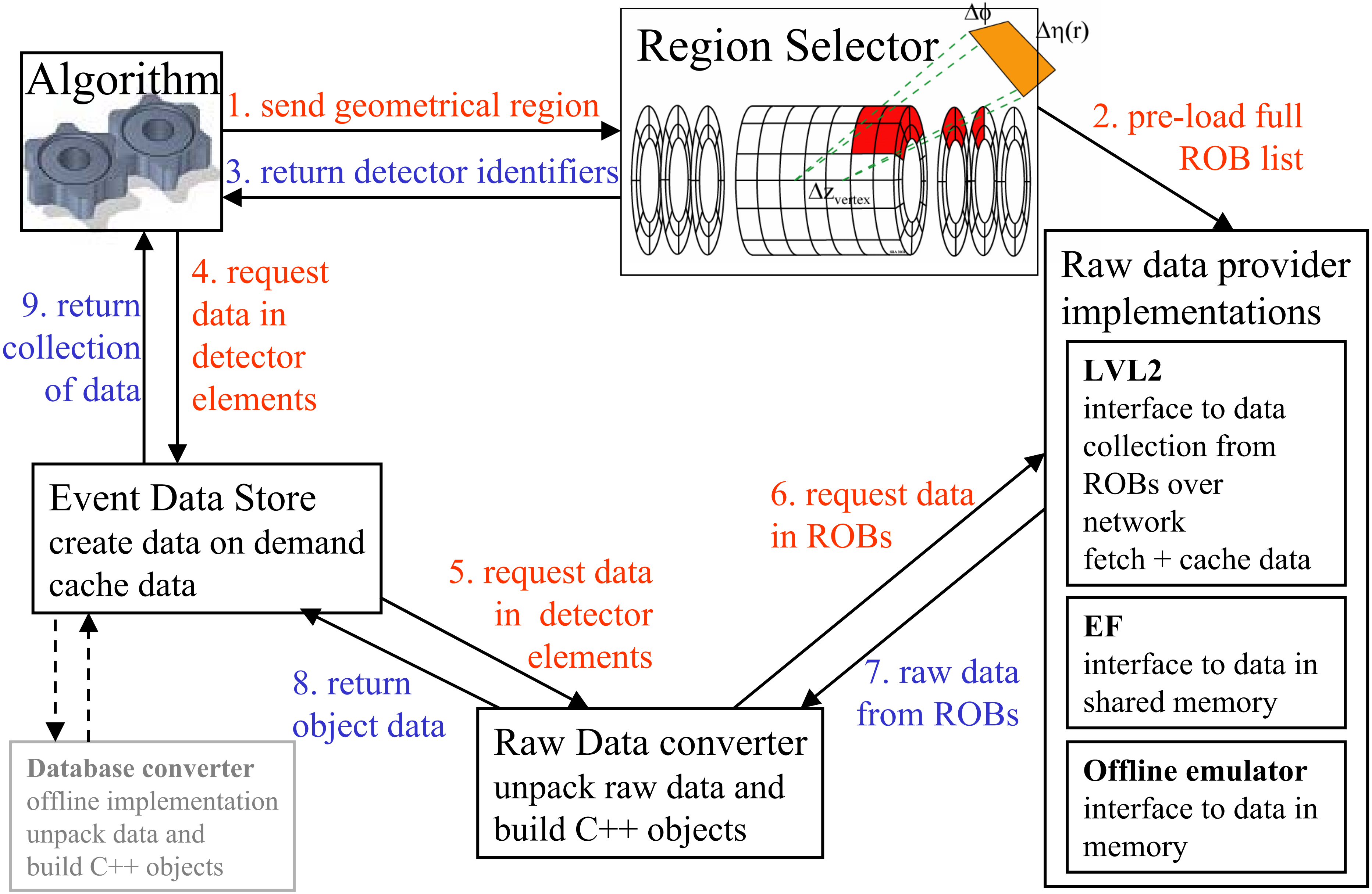


HLT Event Selection Software



- Common selection software for LVL2, EF, offline - differences hidden behind interfaces
- Re-use of offline software in framework, basic services, data unpacking
- LVL2 has specialised algorithms and constraints of multi-threading
- EF re-uses offline reconstruction algorithms (toolkit approach)
- Integration tool “AthenaMT” provides single-PC test environment for offline software
- Test data has fully simulated detector, format expected from readout electronics

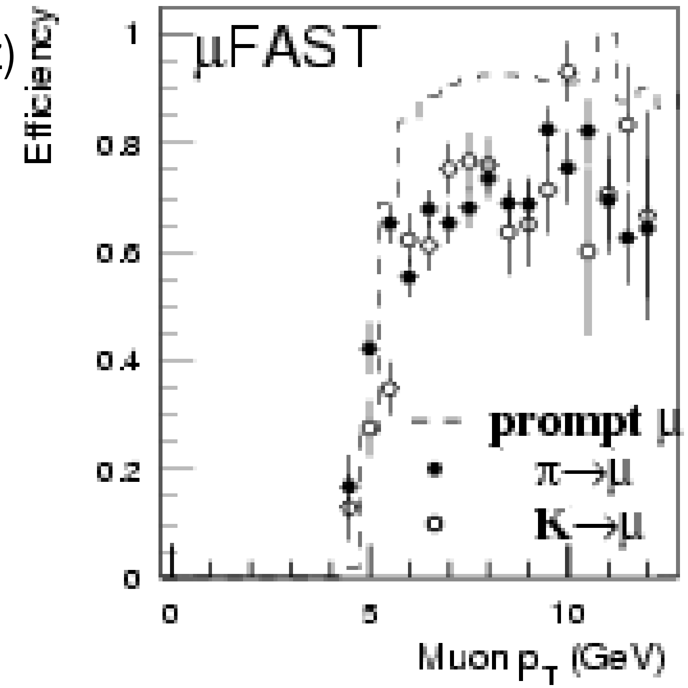
RoI mechanism and data access

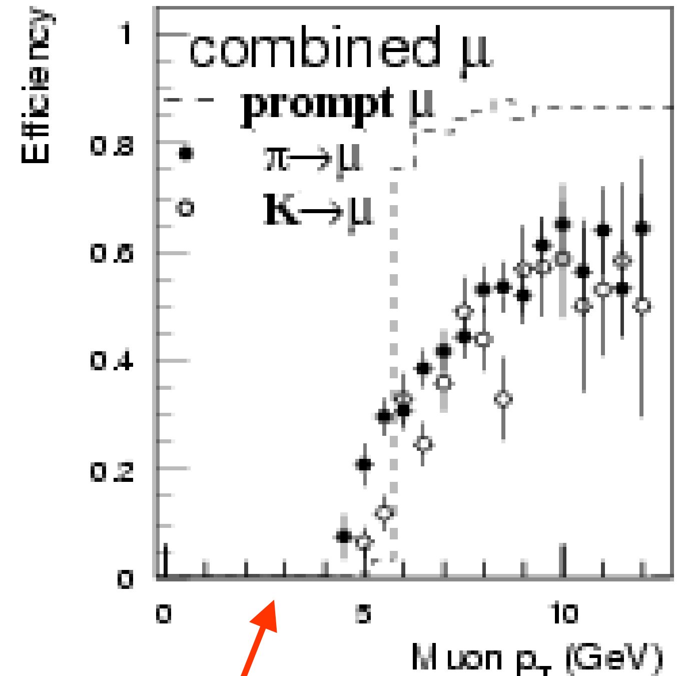


LVL2 Muon algorithm

1×10^{33}, $|\eta|<1$

Physics process	Rate (kHz)
π/K decays	3.00
b decays	0.90
c decays	0.50
W→μν	0.003
cavern background	negligible
Total	4.40



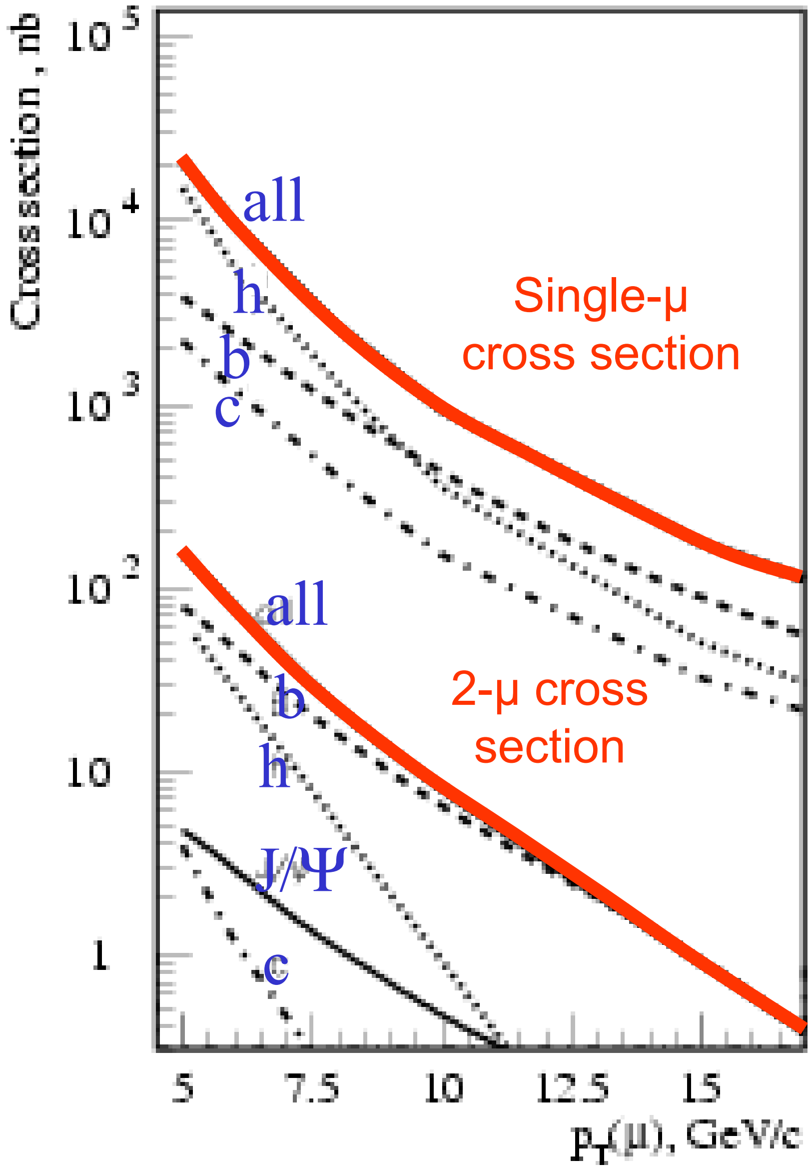


- LVL2 MuFast algorithm uses data from precision chambers
  - better p_T measurements allows tighter threshold, rejects low- p_T background
- output rates after LVL2 muon-spectrometer trigger still dominated by π/K decays
- reject π/K → μ by combining muon and inner detector tracks
  - z, φ and p_T matching
  - p_T resolution further improved
  - π/K → μ rate reduction by factor 3
- Total rate (extrapolate from barrel to full detector)
  - ~5 kHz for a 6 GeV threshold and 1×10^{33}

Full simulation results for barrel only

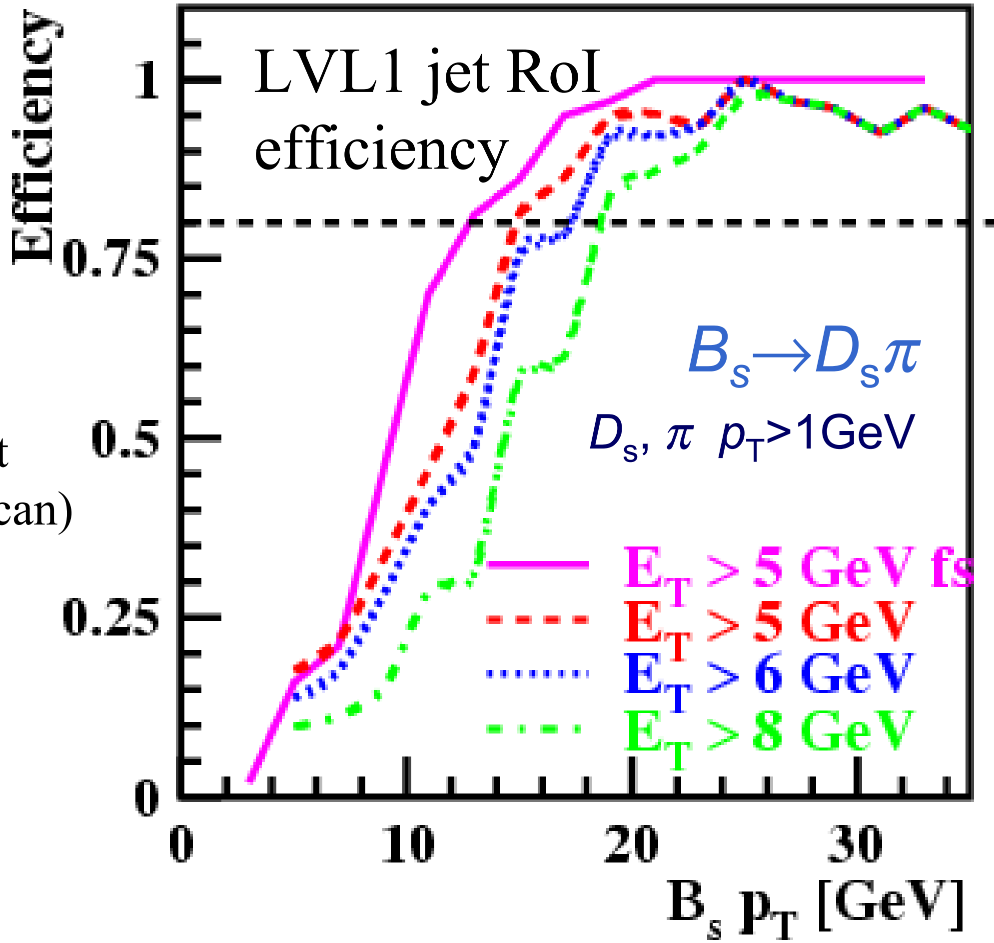
Di-muon trigger

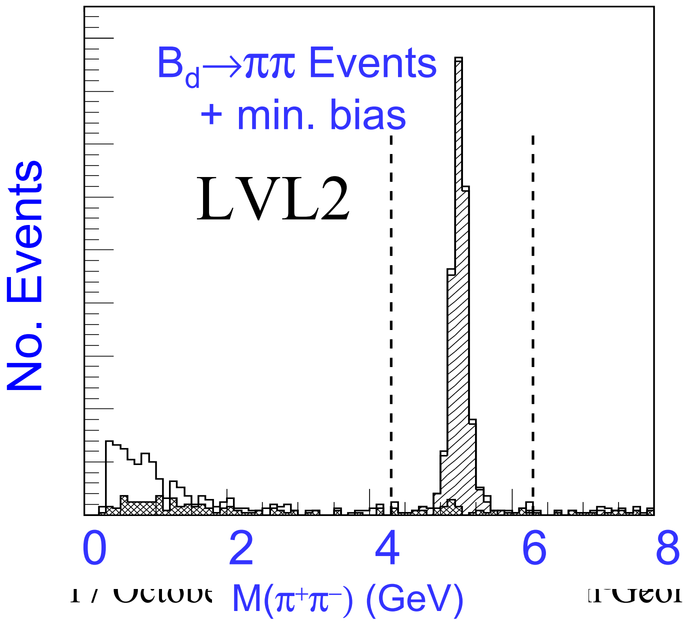
- LVL1 trigger efficient to low p_T
  - down to $p_T > 5$ GeV in barrel, 3 GeV in endcaps.
  - Actual thresholds determined by rate limitations
- LVL1 rate at 2×10^{33} will be a small fraction of the total LVL1 rate, < 1 kHz for a reasonable threshold around 6 GeV
  - dominated by heavy flavour decays
  - Subject to uncertainties in low p_T rate
- LVL2 can give e.g. ~200 Hz
  - sharpen p_T threshold
  - Resolve double counting
- EF does near offline-quality track reconstruction, vertex fit and mass cuts
  - to select for example J/ψ decays
  - ~10 Hz
- At all levels, cuts can be tuned to optimise rate vs. efficiency
  - Further studies



Hadronic final states

- Reconstruct tracks in jet RoI or full scan
- LVL1 muon p_T>6 GeV + jet RoI, E_T>5GeV ⇒ average ~2 RoIs per event
- Either way, use tracks to do semi-inclusive, partial decay reconstruction
  - $B_d \rightarrow hh$
  - $D_s \rightarrow \phi(KK)\pi$
- Kinematical and topological cuts
- EF makes tighter mass cuts and vertex fit
- Overall HLT efficiency ~60% (D_s, full scan) w.r.t. events selected by offline analysis

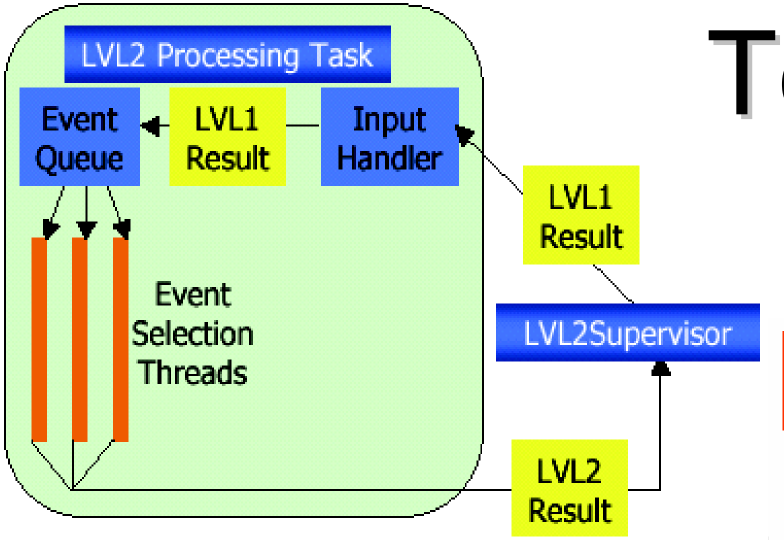




- Studies show this is very robust w.r.t.
  - missing middle pixel layer (initial layout)
  - anticipated levels of misalignment (LVL2)

Muon-electron final states

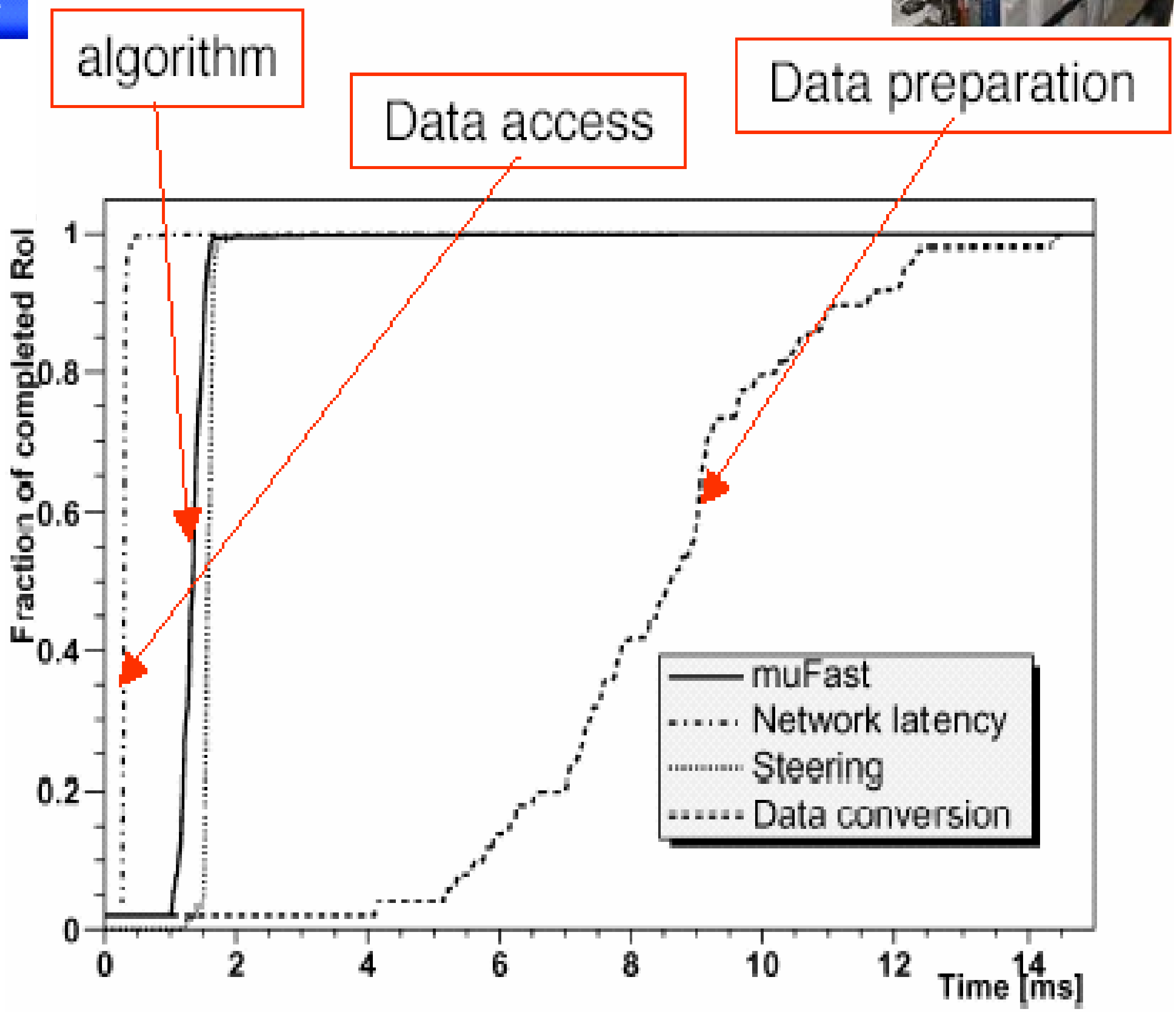
- To select channels such as
  - B_d->J/ψ(ee)K_S with opposite side muon tag, or
  - B_d->J/ψ(μμ)Ks with opposite side electron tag
- Two options:
  - Use LVL1 EM RoIs to find low-E_T electrons
  - Full reconstruction of tracks in TRT (for electron identification)
- LVL1 EM cluster E_T>2 GeV gives average of 1 RoI/event
  - about 80% efficiency to find RoI for both daughters of J/ψ->ee, when they both have p_T>3GeV.
- LVL2 confirm cluster at full granularity in calorimeter, including pre-sampler, then find matching track in SCT+pix (+TRT).
- Tracks reconstructed again in EF, plus vertex fit quality and decay length cuts.
- Conclusion
  - Using RoI guidance is much faster (typical size 0.2x0.2) than reconstructing the full volume of the inner detector
  - but the LVL1 lowest possible threshold is not efficient until a higher p_T than the full scan permits.



Test bed results:

LVL2 muon trigger

- Dual 2.2 GHz Xeon
- Confirmation of LVL1 muon trigger
- "Offline" framework and services re-used
- Prep time dominates
  - saves algo time
- Conservative result
  - high luminosity conditions, x2 cavern bg
- Already adequate
  - Continue to optimise



Resource estimates

- Estimates take into account
  - Reduced rates of later steps in sequential processing scheme
  - All aspects of processing time to the best knowledge we currently have
  - Extrapolated to 8 GHz CPUs
- Overall target
  - LVL2 target of 10 ms x 25 kHz LVL1 rate gives 250 CPUs
  - Scales to 750 CPUs for full system at 75 kHz LVL1 rate
  - From latest studies of high p_T physics it looks like this is achievable.
- For lower luminosity fills, or as lumi drops during a fill
  - Spare capacity due to lower LVL1 rate
  - Allows general lowering of thresholds and pre-scale factors
  - Some room for additional B-physics based on muon & calo RoI
- Conclusion
  - Following detailed studies, current understanding is that the resources needed for the RoI-guided B-physics trigger can be found within the planned resources.
    - Based on di-muon trigger at higher luminosity ($2x10^{33}$)
    - Introducing other triggers at lower luminosity ($\sim 1x10^{33}$)

Conclusions

- The latest picture of ATLAS & LHC at start up does not look so favourable for B-physics, but ATLAS has responded with a variety of flexible trigger schemes to make the most of it.
- RoI-based strategy allows a full programme at modest resource cost, with slightly reduced trigger efficiency
- Take advantage of beam-coast and lower-lumi fills to trigger on B-physics at lower luminosities
- Algorithms are robust enough for initial detector and conditions
- For muon spectrometer and calorimetry, now have simulation of realistic raw data and full chain of algorithms to retrieve, unpack and process it.
- Further studies of RoI strategy will be done and more of the software will be tested and optimised through test bed deployment
- Now looking towards commissioning and first collisions in 2007 when we hope to record B-physics data from ATLAS.