The Jet/Energy Processor of the ATLAS Level-1 Calorimeter Trigger

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On behalf of

ATLAS Level-1 Calorimeter Trigger Collaboration

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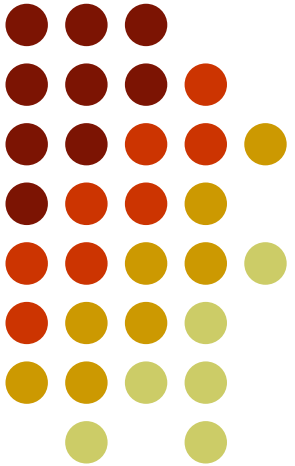

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bmb+f - Förderschwerpunkt ATLAS Großgeräte der physikalischen Grundlagenforschung

(*) Now at Albert-Ludwigs Universität Freiburg

Motivation

Jets and E_T^{miss}

Jets in LHC physics

- **Jet multiplicity and E_T distribution: QCD, SUSY …**
- **Reconstruction of resonances:** W -> jj, t -> bW, Z -> bb^-, Z* -> jj…
- **Forward jet tagging** To select vector boson fusion Higgs production processes
- **Low p_T jet veto** To reject background from multijet events (mostly tt^-)

E_T^{miss} in LHC physics

- **Missing transverse momentum is important signal for new physics (Higgs, SUSY,…)**
- **Used in invariant mass reconstruction in decays involving neutrinos: A/H -> tau tau …**

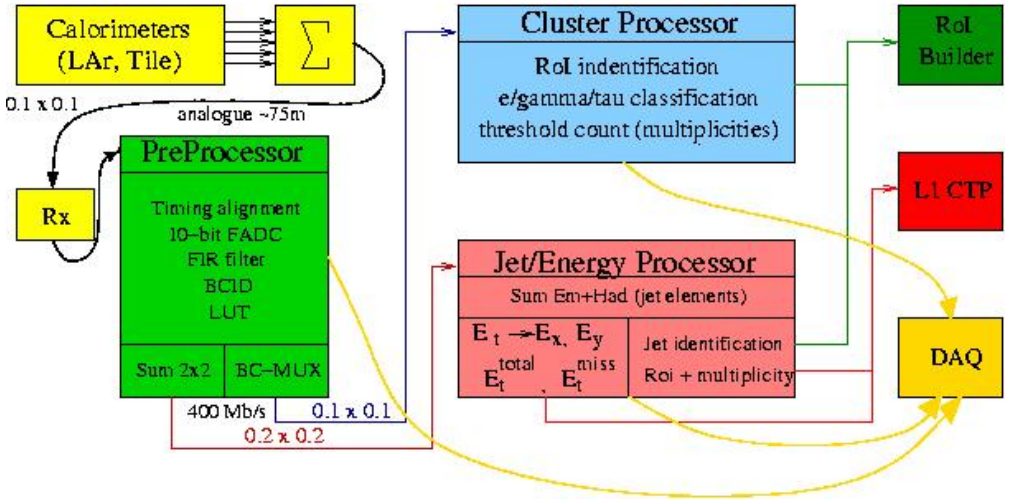
Combined Jet+E_T^{miss} and Tau+E_T^{miss} triggers :

- **allow selection of hadronic decay mode**
  - **of Higgs, e.g. A/H -> tau tau (had/had) from large had. backgrounds**
  - **of invisible Higgs (ttH-> invisible)**

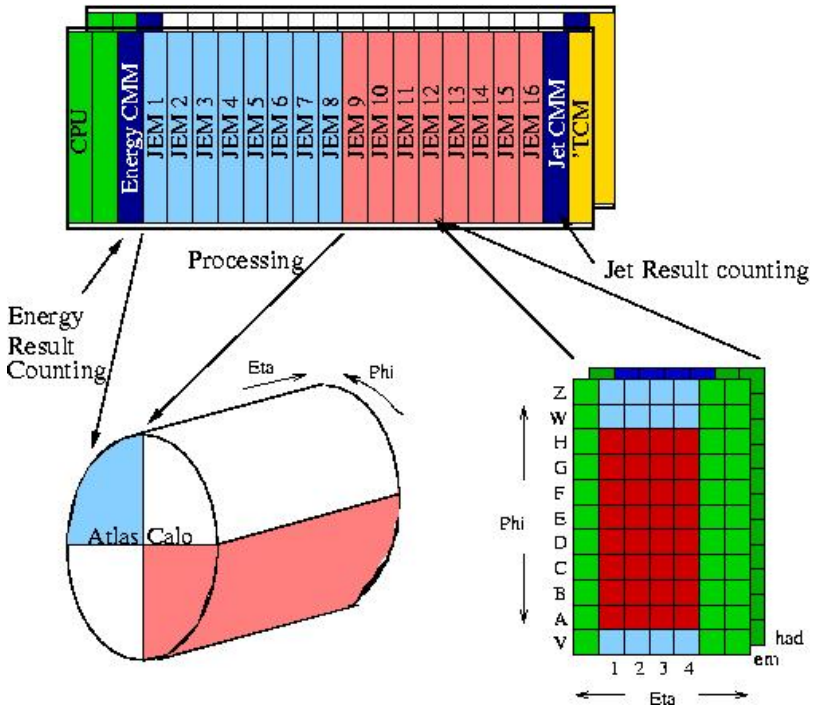
L1Calorimeter Trigger
(Overview and Requirements)

Requirements

- Reduce 1 GHz interaction rate to a 75 kHz trigger rate
  => 2 μs decision latency
- Provide trigger multiplicity information:
  - e/γ and tau/hadron
  - Jets and E_T^{total},E_T^{miss}
  - Muons (separate trigger)
- Decision by LVL1 Central Trigger Processor (CTP) on basis of multiplicity of objects at multiple thresholds
- Provide Region of Interest (RoI) sent to Level-2 Trigger System
- Provide data for monitoring and diagnostics



Architecture and Mapping (JEP)



Architecture:

- Jet/Energy Processor (JEP) in two 9U Crates
- Each crate consists of 16 Jet/Energy Modules (JEMs),a common CPU, 2 Common Merger Modules (CMM) and a Timing Control Module (TCM)
- One quadrant of the ATLAS calorimeters is mapped to a set of 8 JEMs

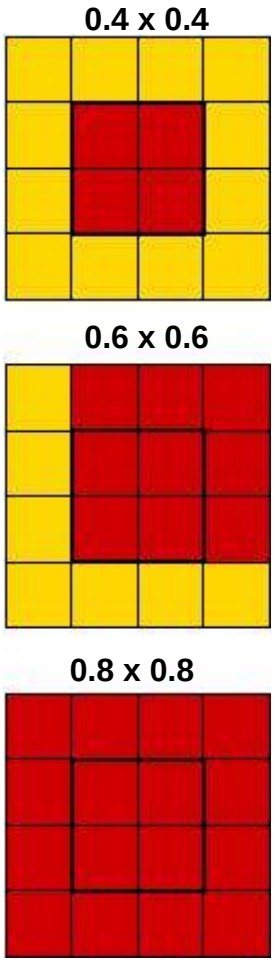
Mapping:

- Processed data per JEM: $\Delta\Phi \times \Delta\eta = 11 \times 7$ of em. and had. channel which include the core region 8 x 4
- Uses jet elements (em+had) of reduced granularity of mainly $\Delta\Phi \times \Delta\eta = 0.2 \times 0.2$
- PreProcessor and neighbouring JEMs provide duplicated channels in η and Φ

Jet and Energy-sum Algorithm

Jet algorithm

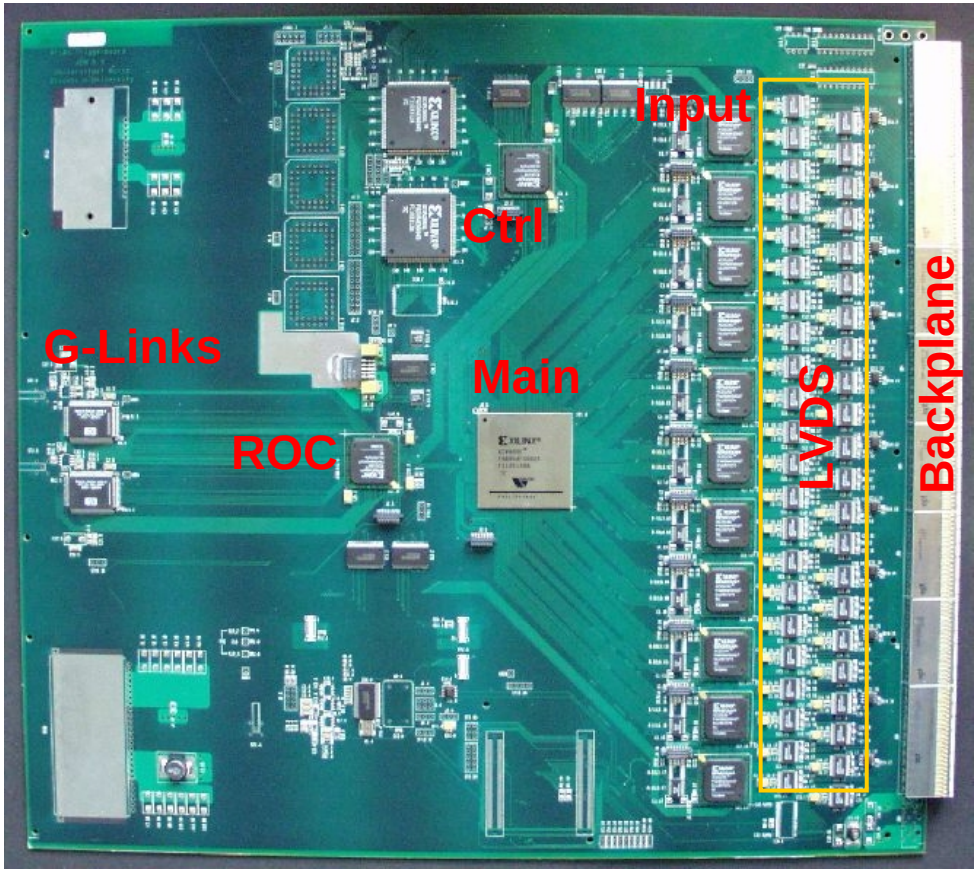
- Sliding window algorithm of 2 x 2 cluster (0.2 x 0.2) moved by 0.2 defines the jet location and provides the RoI
- E_T threshold is applied to the entire window of 2 x 2, 3 x 3 or 4 x 4
- 8 independent, programmable jet thresholds
- Each threshold represents an energy value and a cluster size



Energy-sum algorithm

- Sum up all jet elements in the core region => E_T^{total}
- Calculate E_T^{miss} components E_x and E_y from the E_T values using azimuth angle Φ => E_T^{miss}

Prototype: Jet/Energy Module (JEM0.2)



- **2 full-function modules exist**
  - Provide all required interfaces
  - Main technology: FPGAs

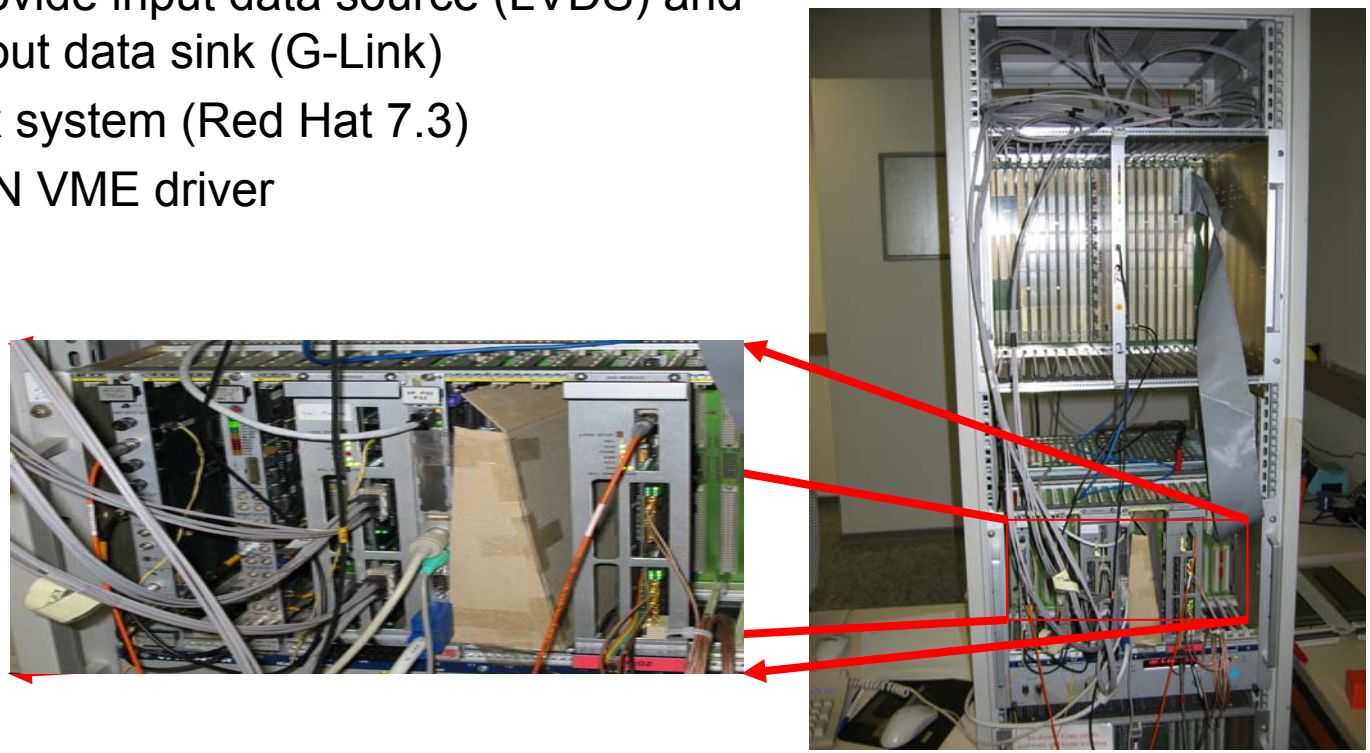
Firmware:

- For development, simulation and implementation use the hardware description language VHDL
- Both algorithms are implemented into a common Xilinx device (MainProcessor)
  - Energy algorithm firmware successfully implemented and tested
  - Jet algorithm firmware currently being tested

Local Test Setup

-Mainz-

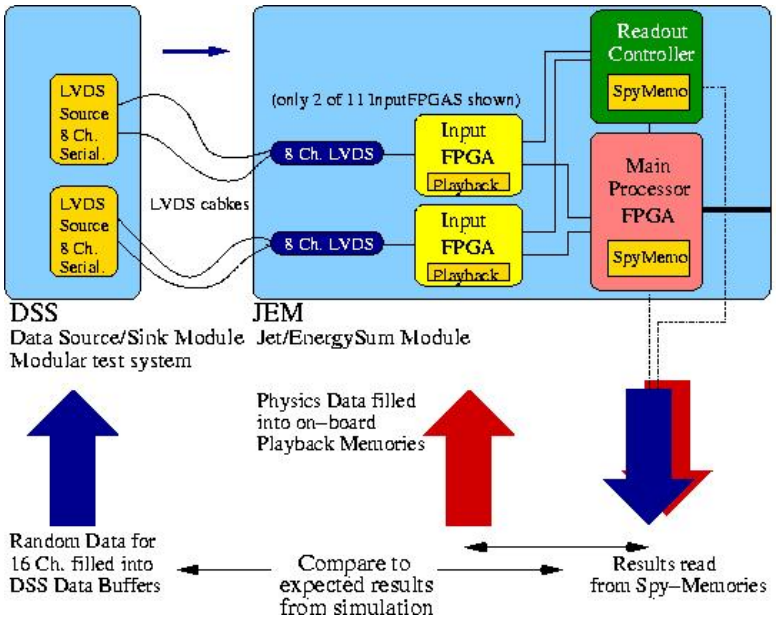
- Custom built 9U backplane with fan in/out of data and a reduced VME bus
- Two multipurpose modular data sink/source modules (DSS) to provide input data source (LVDS) and readout data sink (G-Link)
- Linux system (Red Hat 7.3)
- CERN VME driver



Energy Summation Tests

(approach)

Validate correct functioning of Real-Time Data Path in firmware (algorithm, control path in implementation) and in hardware (connectivity, mapping)



- generate input stream and check results from Module by comparing simulation to readback from JEM
  - Simulation based on Fast Trigger Simulation *ATL1CT*
  - Two types of test vectors available for energy summation tests (physics data tt->WW->4jets, random patterns)
  - Two different options to execute the test
    - On-board memories (Playback and Spy)
    - 16 channels serial LVDS input data from DSS and Spy memories

Energy Summation Tests
(results)

- **Stand-alone test using on-board memories (playback and spy)**
  - Test vector library of 2.5 million events for one JEM (core region of 8x4 jet elements) processed

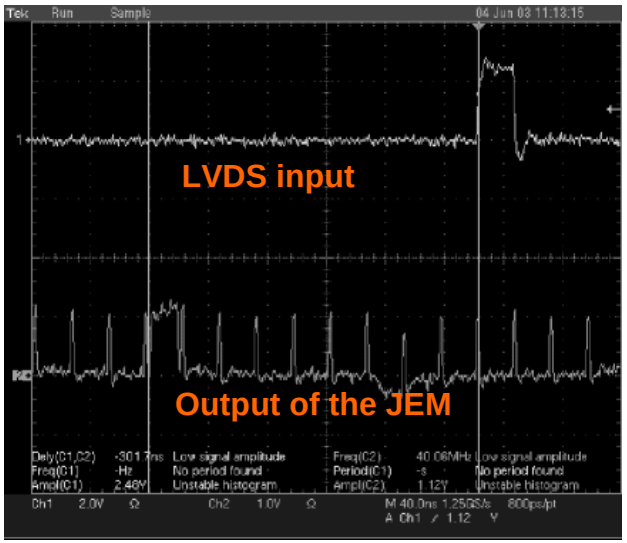
  ⇒ All results from energy summation as expected
- **Using data input from DSS and on-board memory (spy)**
  - Random test vectors for adjacent InputFPGAs on one JEM (2x4 jet elements) generated
  - Library of 1.8 million events are available
  - Test performed for all four pairs of InputFPGAs in core region

  ⇒ As expected

⇒ **RTDP latency:**

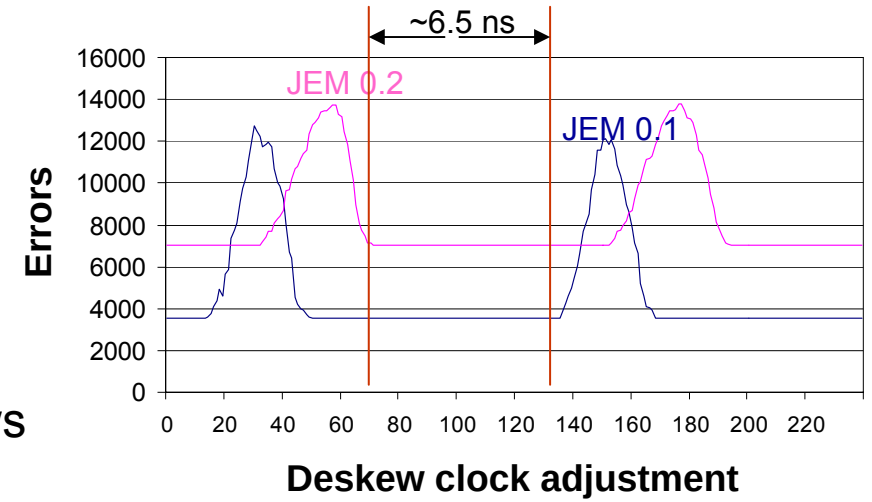
- Estimation for energy RTDP latency: 7 + 2.5 clock cycles of 40 MHz frequency

=> Hardware tests confirmed the latency of 8 clock cycles



Jet Algorithm Tests

- **Transmission test of neighbouring JEMs for overlapping regions for jet algorithm**
  - Delay scan for 2 JEMs (same deskew clock settings) to adjust the timing between adjacent JEMs
  - More than sufficient timing windows for error-free transmission



- **Jet algorithm**
  - All input data is received properly
  - Jet multiplicity: differences between simulation and output

=> Rework of Jet algorithm firmware was needed

JEM Integration Test Setup

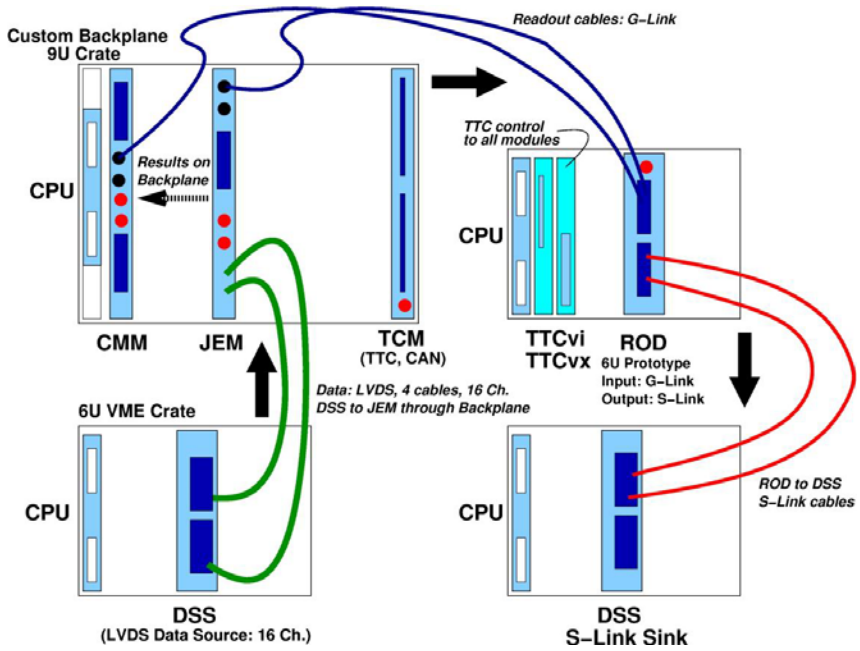
- RAL -

o Test Setup is operating within the ATLAS software framework

o all interface stages of the system have been tested

- o JEM to CMM
- o JEM to ROD to DSS

o TTC system guarantees consistent timing for all modules and provides control signals

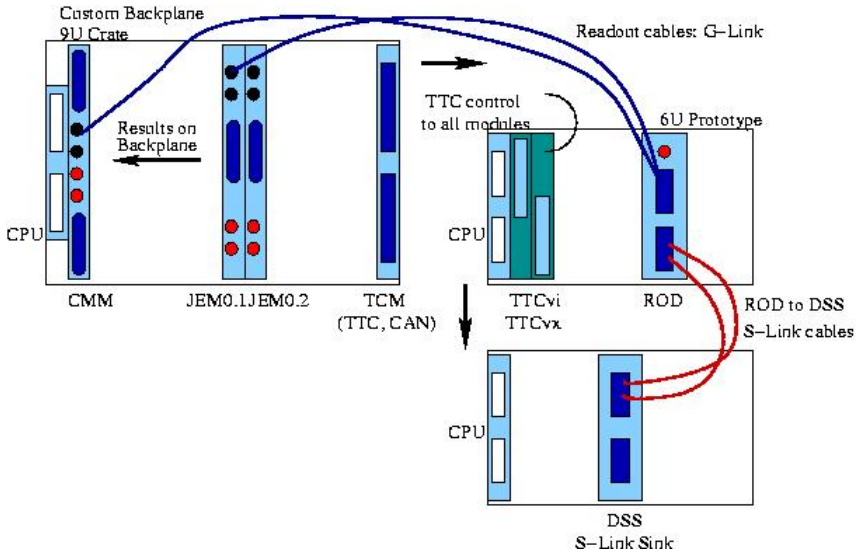


ATLAS Software Environment

- Test system is using Linux installation of Red Hat 7.3
  - DAQ-1 software package is included and Level-1 Calorimeter Trigger Software „l1calo“ is installed
    - Routines are integrated to initialise, configure and control the hardware as well as the simulation
    - „ModuleServices“ and „ModuleSim“ are being developed for each module
    - System setup (modules, location in crate, connections, settings and trigger menu, data source files) are described by database file in XML format
    - Test setup is controlled by the „RunControl“ tool

JEM Integration Test Setup
(JEM to ROD to DSS)

- Readout data of the JEM is connected to a prototype Readout Driver (RoD) via G-Link cables
- ROD transmits them to a DSS on S-Link

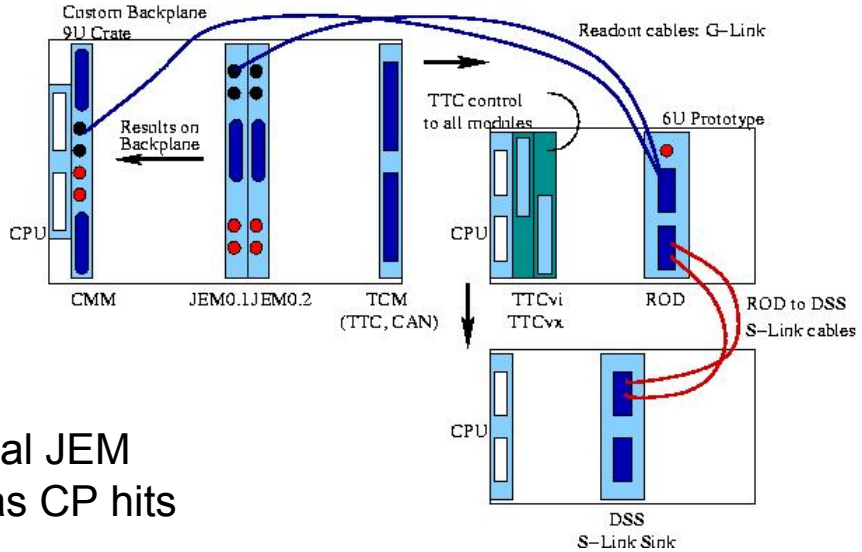


- Two data source options are used:
  - JEM playback memories (all 88 input channels)
  - DSS to feed LVDS data into the JEM (only for 16 channels)
- Readout signal (L1A) is provided by the TTC system
- Compare readout stream, which include all incoming data and results at all interface stages of the system (slice data), with the expected results by using the simulation
- System operates successfully for different slice sizes with several thousand events

JEM Integration Test Setup
(JEM to CMM)

- Communication between JEM and CMM has been tested by using internal memories of the CMM

- Tests of the data chain (JEM to ROD) are being done



Preliminary results:

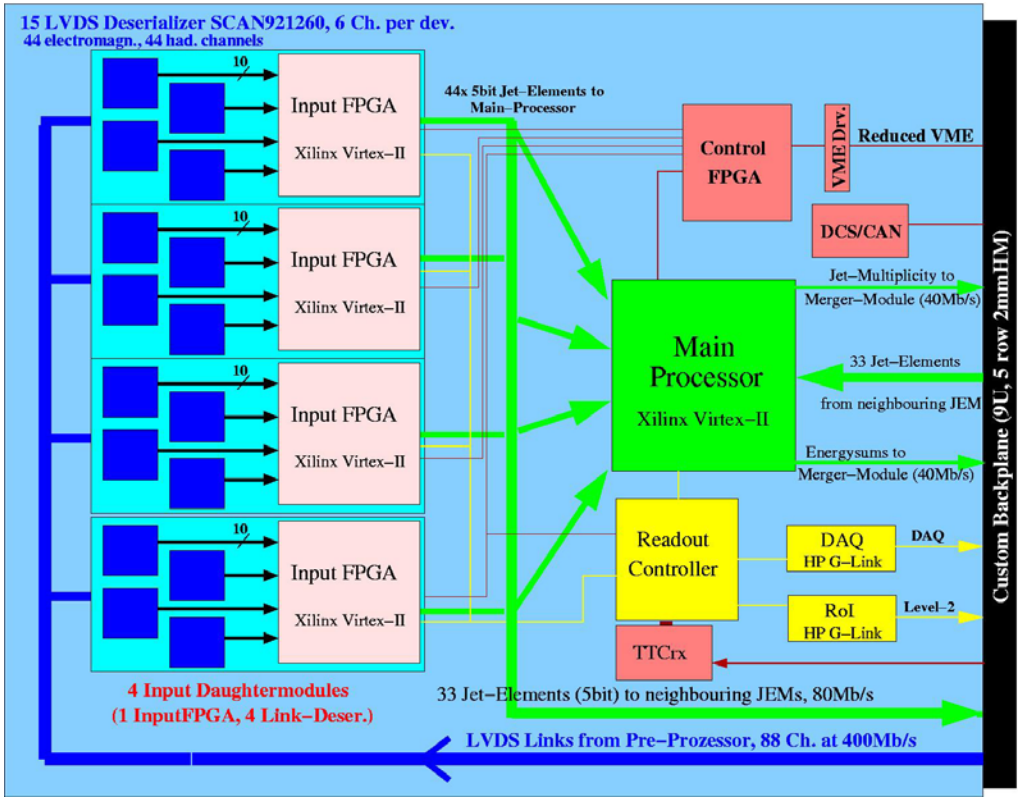
- Read out from CMM via ROD of identical JEM energy sums in each event interpreted as CP hits operates successfully
- But: with varying data invalid energy sum patterns were seen

To be done:

- to check JEM to CMM communication over the backplane in more detail
- to repeat the tests with the Energy Merging Implementation of CMM

Final Version Module (JEM1)

- Mother and daughter module architecture
- Four input daughter modules
- ROC daughter module
- New de-serialisers allow JTAG/Boundary Scan of onboard connections
- New generation of FPGAs: Virtex II
  - to improve the performance (more resources, hardware multipliers, …)
- firmware modifications are being done



Conclusion & Outlook

Conclusion

- 2 fully functional JEM prototypes have been produced and tested in a stand-alone test set-up
- The stand-alone test of JEM has used test vectors for the RTDP of the energy sum algorithm
- The data communication between the adjacent JEM modules via backplane has been tested
- Read-out facilities at board-level and the data communication to CMM and ROD have been tested
- The tests were controlled by a TTC system which includes the control software and trigger module simulation environment

Outlook

- Work continues on Jet algorithm firmware
- Additional tests of ROD interface
- Final spec version being designed
- …

⇒ **Goal for the near furture:**

„Full slice“ test of system this winter