LHCb
on-line/off-line computing

Domenico Galli, Bologna

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Outline

- **Off-line computing:**
  - LHCb DC04 Aims.
  - Transition to LCG.
  - Production statistics.
  - Production performance.
  - LHCb DC04 Phase 2 (stripping phase, scheduled analysis)

- **On-line computing:**
  - LHCb L1 and HLT architecture.
  - Sub-Farm Prototype built in Bologna.
  - Studies on Throughput and Datagram Loss in Gigabit Ethernet Links.
  - On-line Farm Monitoring, Configuration and Control.
LHCb DC04 Aims

Physics Goals:
- HLT studies, consolidating efficiencies.
- B/S studies, consolidate background estimates + background properties.
- Validation of Gauss/Geant 4 and Generators: (Vincenzo Vagnoni from Bologna, as a member of the Physics Panel, coordinates the MC generator group).

Requires quantitative increase in number of signal and background events:
- $3 \times 10^7$ signal events (~80 physics channels).
- $1.5 \times 10^7$ specific backgrounds.
- $1.25 \times 10^8$ background (B inclusive + min. bias, 1:1.8).

Split DC’04 in 3 Phases:
- Production: MC simulation (done, May–August 2004).
- Stripping: Event pre-selection (to start soon).
- Analysis (in preparation).
LHCb DC04 Aims

- **Computing goals**: gather information to be used for writing LHCb computing TDR:
  - **Robustness test** of the LHCb software and production system;
  - **Test of the LHCb distributed computing model**:
    - Including distributed analyses;
  - **Incorporation** of the LCG software into the LHCb production environment;
  - **Use of LCG resources** as a substantial fraction of the production capacity.

- **Scale of computing resources involved**
  - Numerous
    - Up to **10k** different CPU’s involved, **90 TB** data produced.
  - Heterogeneous
    - DIRAC, LCG.
Transition to LCG or moving DIRAC into LCG

- Production has been started using mainly **DIRAC**, the LHCb distributed computing system:
  - Light implementation.
  - Easy to deploy on various platforms.
  - Non-intrusive (no root privileges, no dedicated machines on sites).
  - Easy to configure, maintain and operate.

- During DC04 production has been moved to **LCG**.
  - Using LCG services to deploy DIRAC infrastructure.
  - Sending **DIRAC** agent as a regular LCG job.
  - Turning a WN into a virtual LHCb production site.
DIRAC Services and Resources

User interfaces

- Job monitor
- Production manager
- GANGA UI
- User CLI
- BK query webpage
- FileCatalog browser

DIRAC services

- JobMonitorSvc
- JobAccountingSvc
- DIRAC Job Management Service
- Agent
- Agent
- Agent
- AccountingDB
- BookkeepingSvc
- InformationSvc
- MonitoringSvc

DIRAC resources

- DIRAC Sites
- DIRAC CE
- Resource Broker
- LCG
- CE 1
- CE 2
- CE 3
- DIRAC Storage
- gridftp
- bbftp
- rfio

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Classic DIRAC Job

DIRAC deployment (CE)
- DIRAC JobAgent
  - Check CE status
  - Request a DIRAC task (jdl)
  - Install LHCB sw if needed
  - Submit to Local Batch System

DIRAC Job
- Execute tasks
  - Event Generation
  - Detector Simulation
  - Digitization
  - Reconstruction
- Check Steps
- Upload Results
  - Log Files
  - Data Files
  - Bookkeeping reports
  - Mail developers on ERROR

DIRAC TransferAgent

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Dynamically Deployed Agents

The Workload Management System:

- Put all jobs in its task queue;
- **Submit** immediately in push mode an agent in all CEs which satisfy initial matchmaking job requirements:
  - This agent do all sort of configuration checks;
  - Only once these are satisfied pull the real jobs on the WN.

Born as a hack, it has shown several **benefit**:

- It **copes with misconfiguration problems** minimizing theirs effect.
- **When the grid is full and there are no free CE, pull jobs to queues which are progressing better.**
- Jobs are consumed and executed in the order of submission.
Integrated Event Yield

186 M Produced Events

LCG paused

LCG restarted

1.8 10^6/day

3-5 10^6/day

Phase 1 Completed

Events integrated: All jobs with ANY known replica

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Daily Job Production

**DIRAC**

**LCG**

(*) Job = Brunel Step = DST File

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Production Share

- **LCG**: 4 RB in use:
  - 2 CERN
  - 1 RAL
  - 1 CNAF

**43 LCG Sites**

**20 DIRAC Sites**

**DIRAC Sites to 0.72%**

- CNAF 5.56%
- Legnaro 2.08%
- MI 0.53%
- NA 0.06%
- PD 0.10%
- CT 0.03% + CA 0.05%
- CNAF 4.10%
- BA 0.01%

**Legend**: LHCb on-line/off-line computing.
### Production Share (II)

<table>
<thead>
<tr>
<th>Site</th>
<th>CPU Time (h)</th>
<th>Events</th>
<th>Events %</th>
<th>% Committed</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>1408.04</td>
<td>32500</td>
<td>0.02%</td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>2493.44</td>
<td>64600</td>
<td>0.03%</td>
<td></td>
</tr>
<tr>
<td>Brasil</td>
<td>4488.70</td>
<td>231355</td>
<td>0.12%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>19826.23</td>
<td>726750</td>
<td>0.39%</td>
<td>0.50%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>8332.05</td>
<td>757200</td>
<td>0.41%</td>
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<tr>
<td>Canada</td>
<td>21285.65</td>
<td>1204200</td>
<td>0.65%</td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>24058.25</td>
<td>1224500</td>
<td>0.66%</td>
<td>1.90%</td>
</tr>
<tr>
<td>Hungary</td>
<td>31102.91</td>
<td>1999200</td>
<td>1.08%</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>135632.02</td>
<td>4997156</td>
<td>2.69%</td>
<td>9.10%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>131273.26</td>
<td>7811900</td>
<td>4.21%</td>
<td>4.00%</td>
</tr>
<tr>
<td>Russia</td>
<td>255324.08</td>
<td>8999750</td>
<td>4.85%</td>
<td>3.20%</td>
</tr>
<tr>
<td>Spain</td>
<td>304432.67</td>
<td>13687450</td>
<td>7.38%</td>
<td>3.00%</td>
</tr>
<tr>
<td>Germany</td>
<td>275036.64</td>
<td>17732655</td>
<td>9.56%</td>
<td>16.20%</td>
</tr>
<tr>
<td>Italy</td>
<td>618359.24</td>
<td>24836950</td>
<td>13.39%</td>
<td>10.70%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>917874.03</td>
<td>47535055</td>
<td>25.62%</td>
<td>30.20%</td>
</tr>
<tr>
<td>CERN</td>
<td>960469.79</td>
<td>53708405</td>
<td>28.95%</td>
<td>21.20%</td>
</tr>
<tr>
<td><strong>All Sites</strong></td>
<td><strong>3711397.01</strong></td>
<td><strong>185549626</strong></td>
<td><strong>100.00%</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>
Migration to LCG

**424 CPU · Years**

- **May:** 89%:11%
  - 11% of DC’04
- **Jun:** 80%:20%
  - 25% of DC’04
- **Jul:** 77%:23%
  - 22% of DC’04
- **Aug:** 27%:73%
  - 42% of DC’04

LHCb on-line/off-line computing. 14
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## DC04 Production Performance

<table>
<thead>
<tr>
<th>Jobs((k))</th>
<th>%Sub</th>
<th>%Remain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submitted</td>
<td>211</td>
<td>100.0%</td>
</tr>
<tr>
<td>Cancelled</td>
<td>26</td>
<td>12.2%</td>
</tr>
<tr>
<td>Remaining</td>
<td>185</td>
<td>87.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100.0%</td>
</tr>
<tr>
<td>Aborted (not Run)</td>
<td>37</td>
<td>20.1%</td>
</tr>
<tr>
<td>Running</td>
<td>148</td>
<td>79.7%</td>
</tr>
<tr>
<td>Aborted (Run)</td>
<td>34</td>
<td>18.5%</td>
</tr>
<tr>
<td>Done</td>
<td>113</td>
<td>61.2%</td>
</tr>
<tr>
<td>Retrieved</td>
<td>113</td>
<td>61.2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Jobs((k))</th>
<th>%Retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrieved</td>
<td>113</td>
</tr>
<tr>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>Initialization Error</td>
<td>17</td>
</tr>
<tr>
<td>No Job in DIRAC</td>
<td>15</td>
</tr>
<tr>
<td>Application Error</td>
<td>2</td>
</tr>
<tr>
<td>Other Error</td>
<td>10</td>
</tr>
<tr>
<td>Success</td>
<td>69</td>
</tr>
<tr>
<td>Transfer Error</td>
<td>2</td>
</tr>
<tr>
<td>Registration Error</td>
<td>1</td>
</tr>
</tbody>
</table>

- **Missing python, Fail DIRAC installation, Fail Connection DIRAC Servers, Fail Software installation…**
- **Error while running Applications (Hardware, System, LHCb Soft….)**
- **Error while transferring or registering output data (can be recovered retry).**

**LHCb Accounting:**

81k LCG Successful jobs
LHCb DC04 phase 2

- Stripping phase/scheduled analysis.
- DaVinci job that either:
  - executes a **physics selection** on signal + bkgrd events;
  - selects an event **passing LO+L1 trigger** on min bias events.
- Plan to run at following proto-Tier 1 centres:
  - CERN, **CNAF**, PIC, Karlsruhe.
- Processing **65 TB** of data.
- Produced datasets (~1 TB) will be **distributed to all Tier-1's**.
<table>
<thead>
<tr>
<th>Physics selection</th>
<th>Physics stripping jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of events per job</td>
<td>40,000</td>
</tr>
<tr>
<td>Number of files per job</td>
<td>80</td>
</tr>
<tr>
<td>Input data size per job</td>
<td>80x0.3 = 24 GBytes</td>
</tr>
<tr>
<td>Job duration</td>
<td>48 h</td>
</tr>
<tr>
<td>Input bandwidth (for 2.4 GHz machines)</td>
<td>4.4 Mbits/s</td>
</tr>
<tr>
<td>Number of output files</td>
<td>3 (1 DST + 2 event collections)</td>
</tr>
<tr>
<td>Output DST size</td>
<td>600 MBytes</td>
</tr>
<tr>
<td>Event collection size</td>
<td>1.2 MByte</td>
</tr>
<tr>
<td>Number of events</td>
<td>6x10⁷</td>
</tr>
<tr>
<td>Number of jobs</td>
<td>1,500</td>
</tr>
<tr>
<td>Total input data size</td>
<td>36 TB</td>
</tr>
<tr>
<td>Total output data size</td>
<td>0.9 TB</td>
</tr>
</tbody>
</table>
### LHCb DC04 phase 2 (III)

<table>
<thead>
<tr>
<th>Trigger selection</th>
<th>Trigger stripping jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of events per job</strong></td>
<td>360,000</td>
</tr>
<tr>
<td><strong>Number of files</strong></td>
<td>400 (files of 900 evts) or 200 (files of 1800 evts)</td>
</tr>
<tr>
<td><strong>Input data size per job</strong></td>
<td>$400 \times 0.18 = 72 \text{ GBytes}$</td>
</tr>
<tr>
<td><strong>Job duration</strong></td>
<td>48 h</td>
</tr>
<tr>
<td><strong>Input bandwidth (for 2.4 GHz machines)</strong></td>
<td>13.3 Mbits/s</td>
</tr>
<tr>
<td><strong>Number of output files</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Output DST size</strong></td>
<td>500 Mbytes</td>
</tr>
<tr>
<td><strong>Number of events</strong></td>
<td>$9 \times 10^7$</td>
</tr>
<tr>
<td><strong>Number of jobs</strong></td>
<td>250</td>
</tr>
<tr>
<td><strong>Total input data size</strong></td>
<td>18 TB</td>
</tr>
<tr>
<td><strong>Total output data size</strong></td>
<td>125 GBytes</td>
</tr>
</tbody>
</table>

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LHCb DC05

- The plan is to generate similar number of events as in 2004.
- These events will be used in the high level trigger challenge and for use with the alignment challenge. Both these are anticipated for ~June 2005.
- We would start production January/February time and continue through to the summer.
On-line computing and trigger

- The most **challenging** aspect of LHCb on-line computing is the use of a **software trigger for L1** too (not only in HLT) with 1 MHz input rate.
  - **Cheaper** than other solutions (hardware, Digital Signal Processors).
  - **More configurable**.

- **Data flow**:
  - L1: 45-88 Gb/s.
  - HLT: 13 Gb/s.

- **Latency**:
  - L1: < 2 ms.
  - HLT: ~ 1 s.
LHCb on-line/off-line computing. 21
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**L1&HLT Data Flow**

- **Front-end Electronics**
- **CPU Farm**
- **Storage System**
- **Sorter**

**Network Flow Diagram**:
- **SFCs**: 21 nodes
- **CPU**: ~1800 nodes
- **Gb Ethernet**: 94 links, 7.1 GB/s
- **Level-1 Traffic**: 94 SFCs
- **Mixed Traffic**: 7.1 GB/s

**Key Events**:
- **Level-1 (L1)**
- **Trigger (L1 Trigger)**
- **High-Level Trigger (HLT)**

**Symbols**:
- **Switch**
- **L1 Decision**
- **B→ΦK**

**Institutional Logos**:
- INFN
- INFN di Pisa
- INFN di Frascati
First Sub-Farm Prototype Built in Bologna

- 2 Gigabit Ethernet switch
  - 3com 2824, 24 ports
- 16 1U rack-mounted PC
  - Dual processor Intel Xeon 2.4 GHz
  - Motherboard SuperMicro X5DPL-iGM
  - 533 MHz FSB (front side bus)
  - 2 GB ECC RAM
  - Chipset Intel E7501 (8 Gb/s Hub interface)
  - Bus Controller Hub Intel P64H2 (2 x PCI-X, 64 bit, 66/100/133 MHz)
  - 3 1000Base-T interfaces (1 x Intel 82545EM + 2 x Intel 82546EB)
Farm Configuration

- **16 Nodes** running Red Hat 9b, with **2.6.7 kernel**.
  - 1 **Gateway**, acting as bastion host and NAT to the external network;
  - 1 **Service PC**, providing network boot services, central syslog, time synchronization, NFS exports, etc.;
  - 1 diskless **Sub-Farm Controller** (SFC), with 3 Gigabit Ethernet links (2 for data and 1 for control traffic);
  - 13 diskless **Sub-Farm Nodes** (SFNs) (26 physical, 52 logical processors with HT) with 2 Gigabit Ethernet links (1 for data and 1 for control traffic).
Bootstrap Procedure

**Little disks, little problems:**
- Hard disk is the PC part more subject to failure.
- **Disk-less** (and swap-less) system already successfully tested in Bologna off-line cluster.
- Network bootstrap using **DHCP + PXE + MTFTP**.
- **NFS**-mounted disks.
- Root filesystem on **NFS**.

**New scheme** *(proposed by Bologna group)* already tested:
- Root filesystem on a **150 MB RAMdisk** (instead of NFS). Compressed image downloaded together with kernel from network at boot time *(Linux initrd)*.
- **More robust** in temporary congestion conditions.
“Reliable” protocols (TCP or level 4) can’t be used, because retransmission introduces an unpredictable latency.

A dropped IP datagram means 25 event lost.

It’s mandatory to verify that IP datagram loss is acceptable for the task.

Limit value for BER specified in IEEE 802.3 (10^{-10} for 100 m cables) is not enough.

Measures performed at CERN show a BER < 10^{-14} for 100 m cables (small enough).

However we had to verify that are acceptable:

- Datagram loss in IP stack of Operating System.
- Ethernet frame loss in level 2 Ethernet switch.
Concerning PCs, best performances reached are:

- **Total throughput** (4096 B datagrams): \(999.90\) Mb/s.
- **Loss datagram fraction** (4096 B): \(7.1 \times 10^{-10}\).

Obtained in the following configuration:

- **OS**: Linux, kernel 2.6.0-test11, compiled with **preemptive** flag,
- **NAPI**-compliant network driver.
- **FIFO** Scheduling;
- **Tx/Rx ring descriptors**: 4096;
- **qdisc queue (pfifo discipline) size**: 1500.
- **IP socket send buffer size**: 512 kiB.
- **IP socket receive buffer size**: 1 MiB.
Studies on Throughput and Datagram Loss in Gigabit Ethernet Links (III)

- **rate [Mb/s]**
  - 1000 Mb/s

- **payload**
  - + UDP header (8 B)
  - + IP header (20 B)
  - + Ethernet header (14 B)
  - + Ethernet preamble (7 B)
  - + Ethernet Start Frame Delimiter (1 B)
  - + Ethernet Frame Check Sequence (4 B)
  - + Ethernet Inter Frame Gap (12 B)

- **Kernel**: 2.6.0-test11
- **Flow Control**: on

- **Datagram Size [B]**:
  - 498 B
  - 1472 B
  - 2952 B
  - 4432 B
  - 5912 B
  - 7392 B
  - 8872 B

- **Graph**
  - Total rate
  - UDP payload rate

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Studies on Throughput and Datagram Loss in Gigabit Ethernet Links (IV)

 Datagram size [B]  
 1000 Mb/s 660 Mb/s 560 Mb/s 1472 B 2952 B 4432 B 5912 B 7392 B 8872 B  
 tuned kernel configuration  
 standard kernel configuration  
 kernel 2.6.7  
 total rate  
 UDP payload rate  
 rate [Mb/s]  
 1000 1000 900 800 700 600 500 400 300 200 100 0  
 10 2 10 3 10 4 
 datagram size [B]  
 LHCb on-line/off-line computing. 29  
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Studies on Throughput and Datagram Loss in Gigabit Ethernet Links (V)

Kernel 2.6.0-test11
Point-to-point flow control on

Packet rate [p/s]

Datagram size [B]

LHCb on-line/off-line computing. 30
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Studies on Throughput and Datagram Loss in Gigabit Ethernet Links (VI)

Frame Loss in the Gigabit Ethernet Switch HP ProCurve 6108

LHCb on-line/off-line computing. 31
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Studies on Throughput and Datagram Loss in Gigabit Ethernet Links (VII)

An LHCb public note has been published:

Studies on Port Trunking

- In several tests performed at CERN, AMD Opteron CPUs show better performances than Intel Xeon in serving IRQ.

- The use of Opteron PC, together with port trunking (i.e. splitting data across more than 1 Ethernet cable) could help in simplifying the on-line farm design by reducing the number of sub-farm controllers.
  
  - Every SFC could support more computing nodes.

- We plan to investigate Linux kernel performances in port trunking in the different configurations (balance-rr, balance-xor, 802.3ad, balance-tlb, balance-alb).

LHCb on-line/off-line computing. 33
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On-line Farm Monitoring, Configuration and Control

- **Monitoring**
  - Display of relevant parameters concerning the status of the farm (~2000 nodes).
  - Induce a state machine transition to an alarm state when the monitored parameters indicate error/warning conditions.

- **Control**
  - Action execution (system reboot, process start/stop, etc.) triggered by manual command or by a state machine transition.

- **Configuration**
  - Define the farm running conditions.
    - Farm elements and kernel version to be used.
    - Select the software version to be used.
To build a farm monitor system coherent with the monitor of the detector hardware, we plan to use PVSS software.

PVSS provides:

- **runtime DB**, automatic archiving of data to permanent storage;
- **alarm** generation;
- easy realization of **graphical panels**;
- **various protocols** to communicate via network.
On-line Farm Monitoring, Configuration and Control (III)

- **PVSS** need to be interfaced with *farm nodes*:
  - to receive monitor data;
  - to issue command to the nodes;
  - to set node configuration.

- On each node a few *very light processes* runs:
  - monitor *sensors*;
  - command *actuators*.

- **PVSS-to-nodes interface** is achieved using *DIM* light-weight network communication layer.
On-line Farm Monitoring, Configuration and Control (IV)

- **DIM** network communication layer is already integrated with PVSS:
  - It is **light-weight** and efficient.
  - It allows **bi-directional** communication.
  - It uses a **name server** for **services/commands publication and subscription**.
On-line Farm Monitoring, Configuration and Control (V)

- Bologna group has already developed 7 light-weight monitor sensors for nodes:
  - Temperatures and fans speeds;
  - CPU states (user, system, nice, idle, iowait, irq, softirq);
  - Hardware interrupt rates (separately per CPU and per irq source);
  - Memory usage;
  - Process status (including scheduling class and real time priority);
  - Network Interface Card counters' rates and error fractions;
  - TCP/IP stack rates and error fraction.
On-line Farm Monitoring, Configuration and Control (VI)

- **Guidelines** followed in sensors development:
  - Function written in **plain C** (C99, not C++) with optimizations (if possible use pointer copy, else if possible memcpy(), etc.)
  - **Low level access** to **procfs** and **sysfs** (open, not fopen) and **one-shot data read**.
  - If possible, **malloc()** called only during sensor initialization.
  - When possible for **complex tasks** use **maintained libraries** (like libprocps) to cope with changes in kernel version.
On-line Farm Monitoring, Configuration and Control (VII) – Display Architecture

Farm Display Panel

SubFarm Display Panel

Node Display Panel

Sensor Display Panel

Action: Event Click

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On-line Farm Monitoring, Configuration and Control (VII) – Display Architecture

Action: Event Click

SubFarm Display Panel

Node Display Panel

Sensor Display Panel

LHCb on-line

Missing service
DP doesn’t exist
On-line Farm Monitoring, Configuration and Control (VIII) – Display Screen Shot
On-line Farm Monitoring, Configuration and Control (IX) – Display Screen Shot
On-line Farm Monitoring, Configuration and Control (X) – Display Screen Shot

<table>
<thead>
<tr>
<th>numCpu</th>
<th>Cpu_rate</th>
<th>idle</th>
<th>iowait</th>
<th>irq</th>
<th>nice</th>
<th>soft_irq</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.90899985233672</td>
<td>86.327546801758</td>
<td>0</td>
<td>0</td>
<td>0.539302239771438</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.90899985233672</td>
<td>76.04754896262</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>1.197547754268</td>
<td>0</td>
</tr>
</tbody>
</table>
On-line Farm Monitoring, Configuration and Control (XI) – Process Control

- Basic mechanism to **start/stop a process** is ready (DIM Server publishing DIMCMD).

- When a process is started by DIMCMD an arbitrary **Unique Thread Group Identifier** (UTGID) is assigned to the process (no more then one process can be started with the same UTGID).

- Process then may be **traced and killed using UTGID**.

- The UTGID mechanism is achieved by setting an additional **environment variable**.
Requests for 2005

**Off-line:**
- 300 kSPECint2000 (CNAF + INFNGRID).
- 30 TB Hdd (CNAF).
- 50 TB Tapes (CNAF).

**On-line:**
- 5000 €: 1 managed Gigabit Ethernet switch with load balancing and IEEE 802.3ad trunking capabilities.