Oracle at CERN
Database technologies

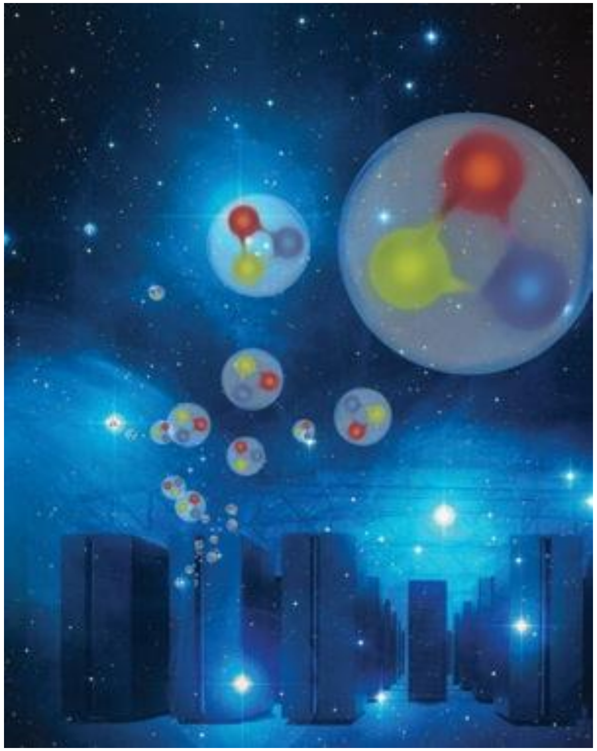

Image courtesy of Forschungszentrum Jülich / Seitenplan, with material from NASA, ESA and AURA/Caltech

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CERN IT department

Outline

CERN IT Department

- Experience at CERN
  - Current usage and deployment
  - Replication
  - Lessons from last 15 years
- Oracle and MySQL
- Trends
  - Flash
  - Compression
  - Open source “relational” databases
  - NoSQL databases

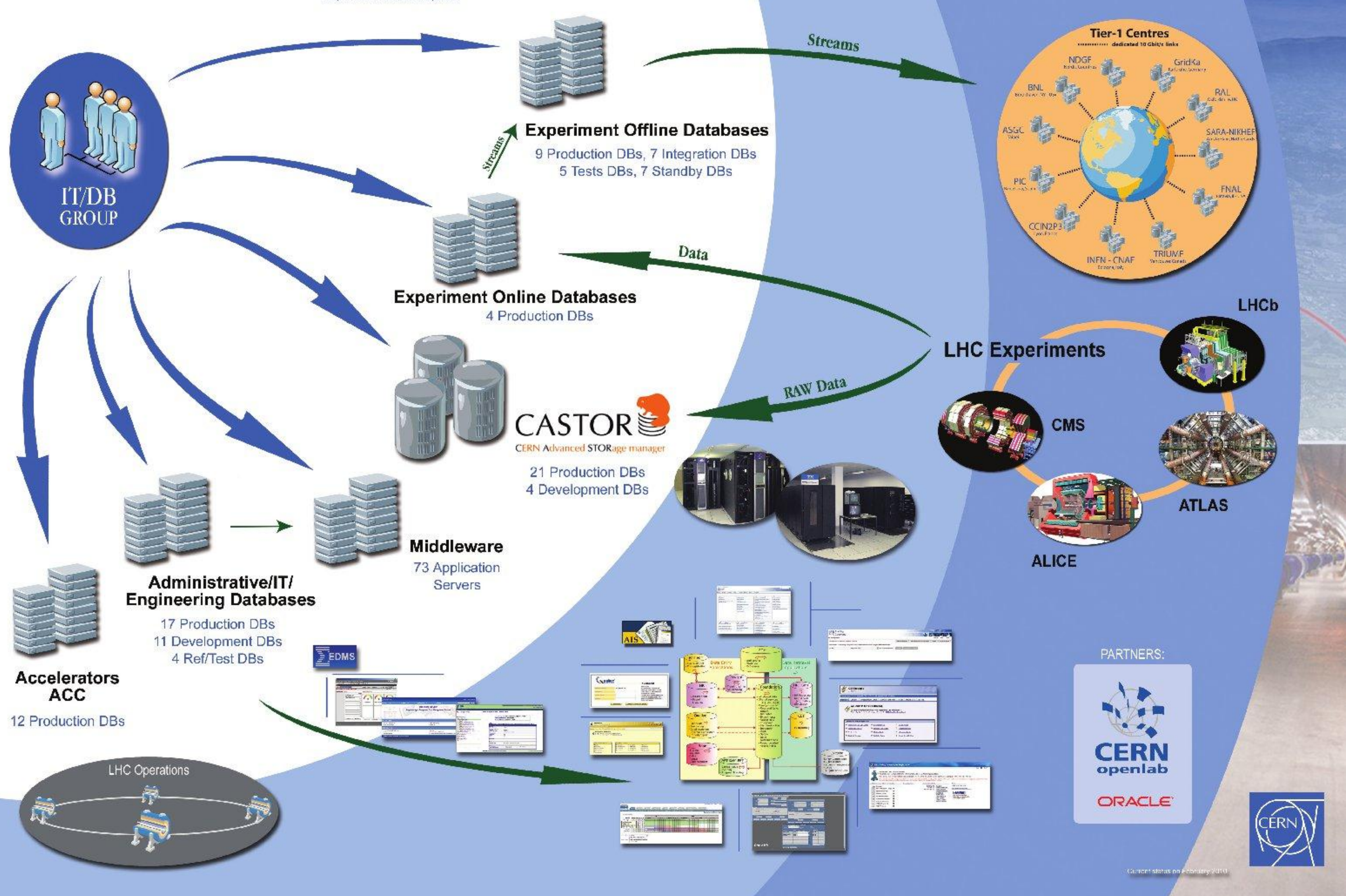
http://www.wordle.net/

Database SERVICES

At the heart of CERN, LHC and Experiment Operations

CERN IT Department

http://cern.ch/it-dep/db/

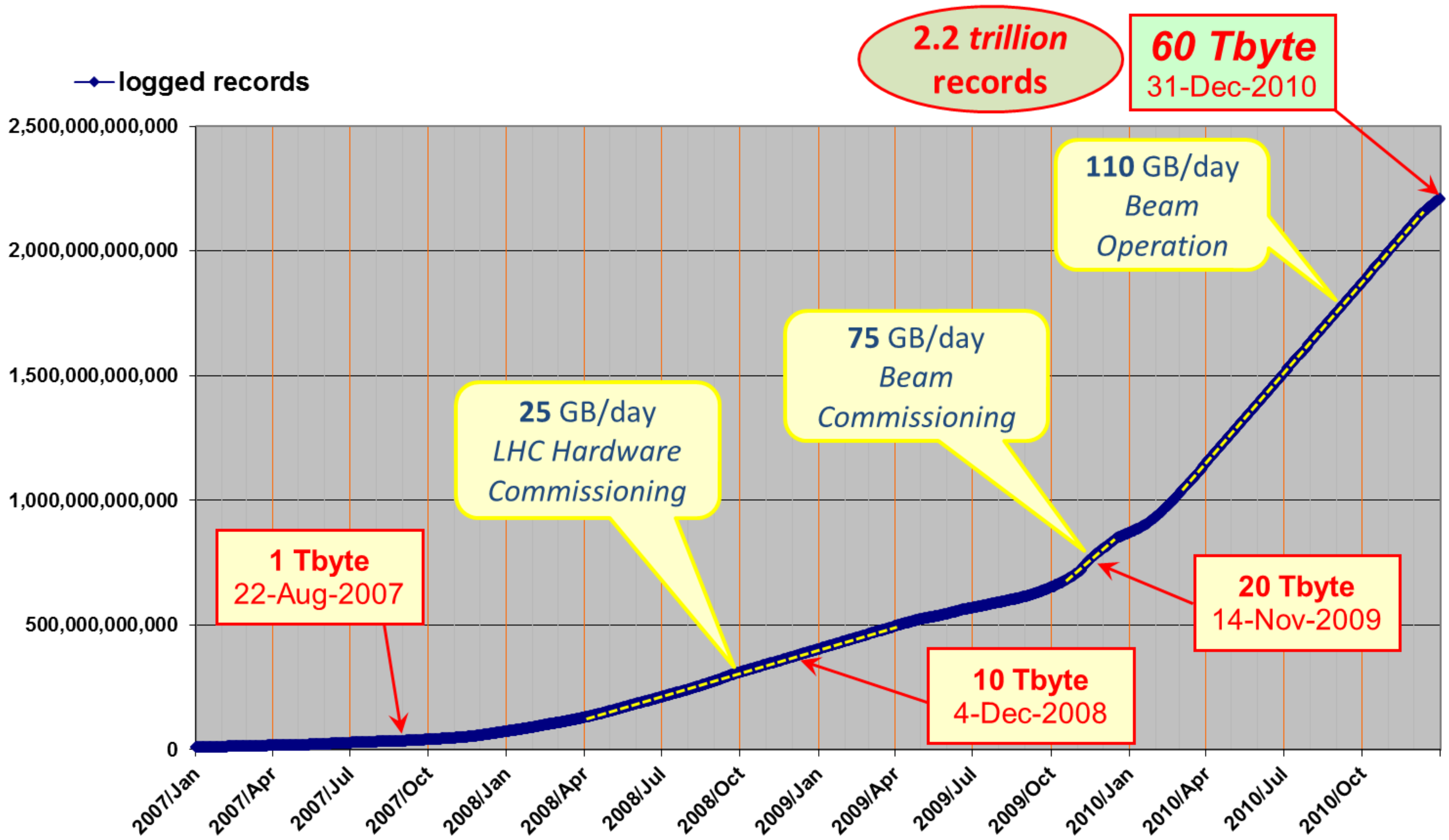


CERN databases in numbers

- CERN databases services
  - ~130 databases, most of them database clusters (Oracle RAC technology RAC, 2 – 6 nodes)
  - Currently over 3000 disk spindles providing more than ~3PB raw disk space (NAS and SAN)
  - MySQL service
- Some notable databases at CERN
  - Experiments' databases – 14 production databases
    - Currently between 1 and 12 TB in size
    - Expected growth between 1 and 10 TB / year
  - LHC accelerator logging database (ACCLOG) – ~120TB, >$3.8.10^{12}$ rows, expected growth up to 70TB / year
  - ... Several more DBs in the 1-2 TB range

original slide by Luca Canali

LHC logging service, >2.10^{12}



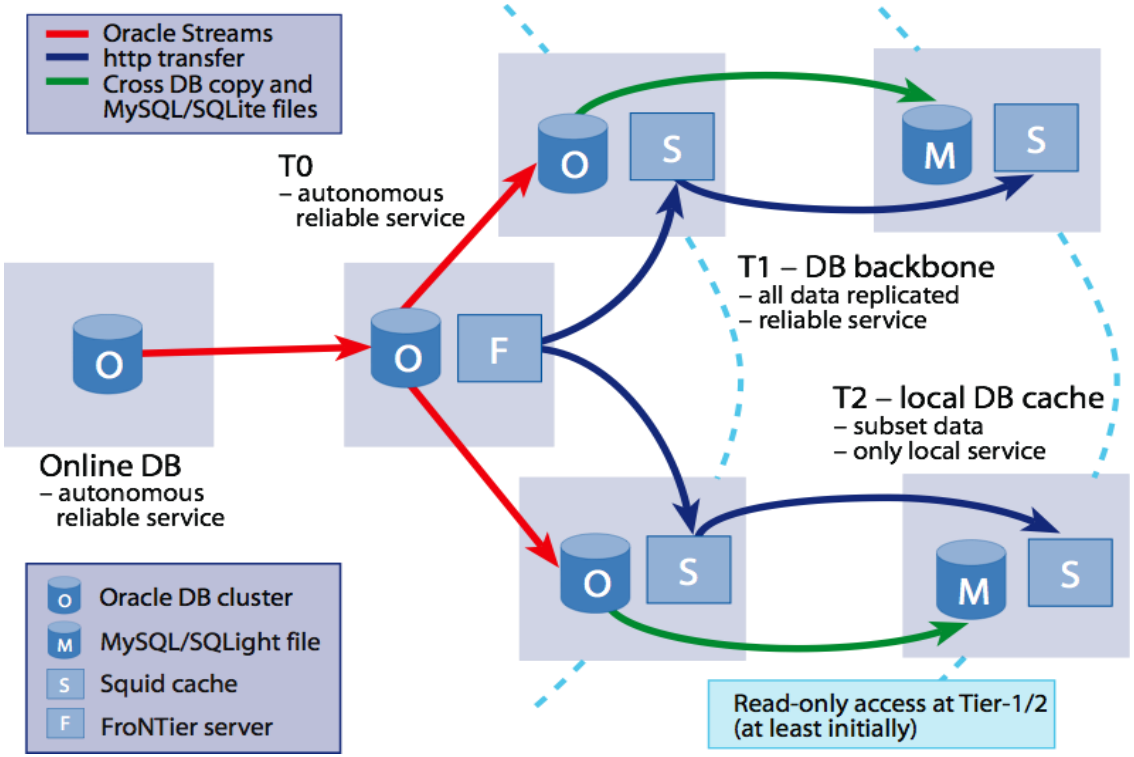
graph by Ronny Billen

Key role for LHC physics data processing

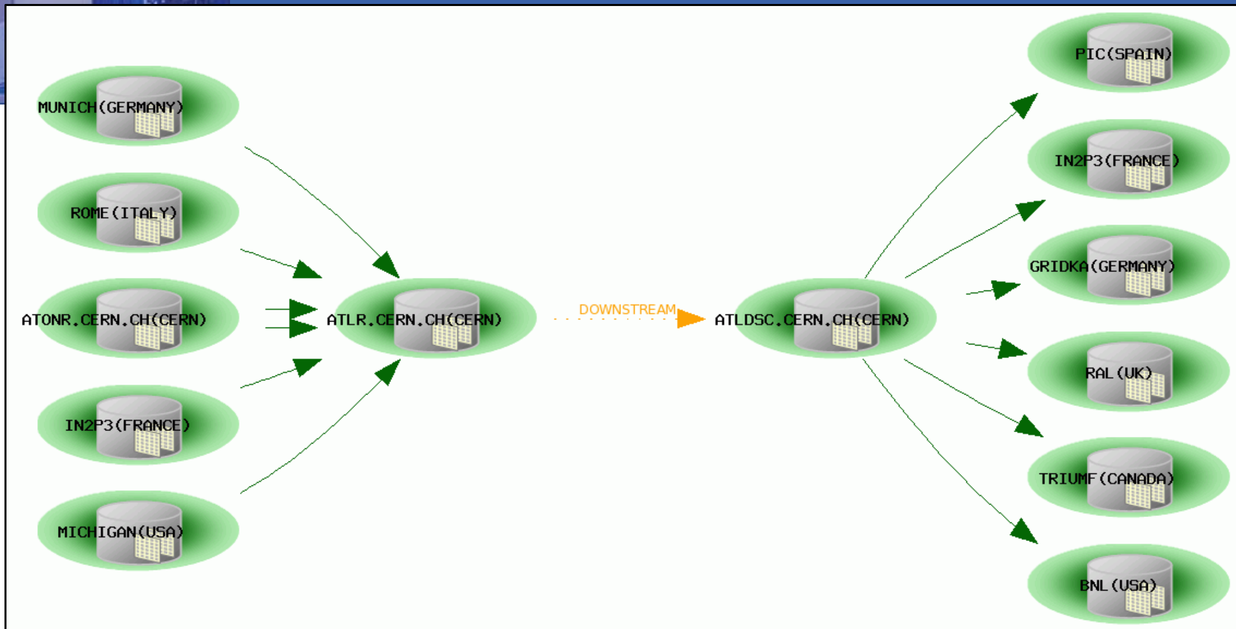
- Online acquisition, offline production, data (re)processing, data distribution, analysis
  - SCADA, conditions, geometry, alignment, calibration, file bookkeeping, file transfers, etc..
- Grid Infrastructure and Operation services
  - Monitoring, Dashboards, User-role management, ..
- Data Management Services
  - File catalogues, file transfers and storage management, …
- Metadata and transaction processing for custom tape-based storage system of physics data
- Accelerator control and logging systems
- AMS as well: data/mc production bookkeeping and slow control data

original slide by Luca Canali

- Worldwide distribution of experimental physics data using Oracle Streams

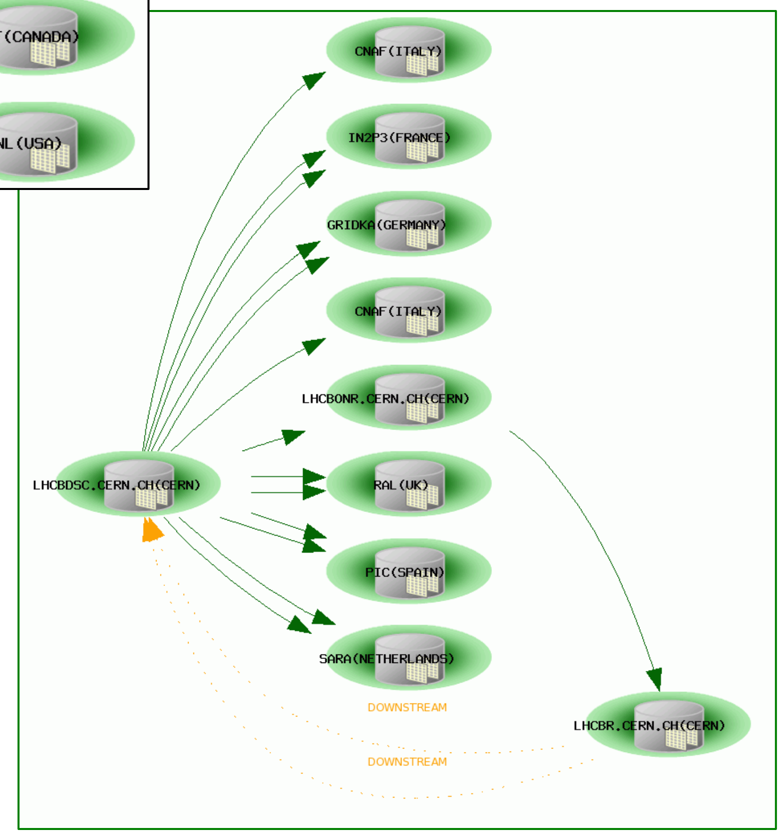


- Huge effort, successful outcome

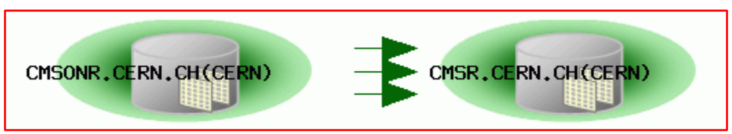


ATLAS

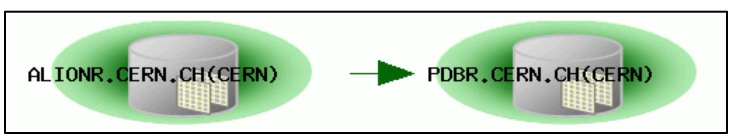
LHCb



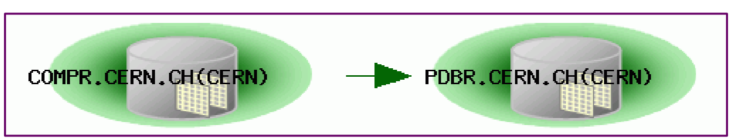
CMS



ALICE

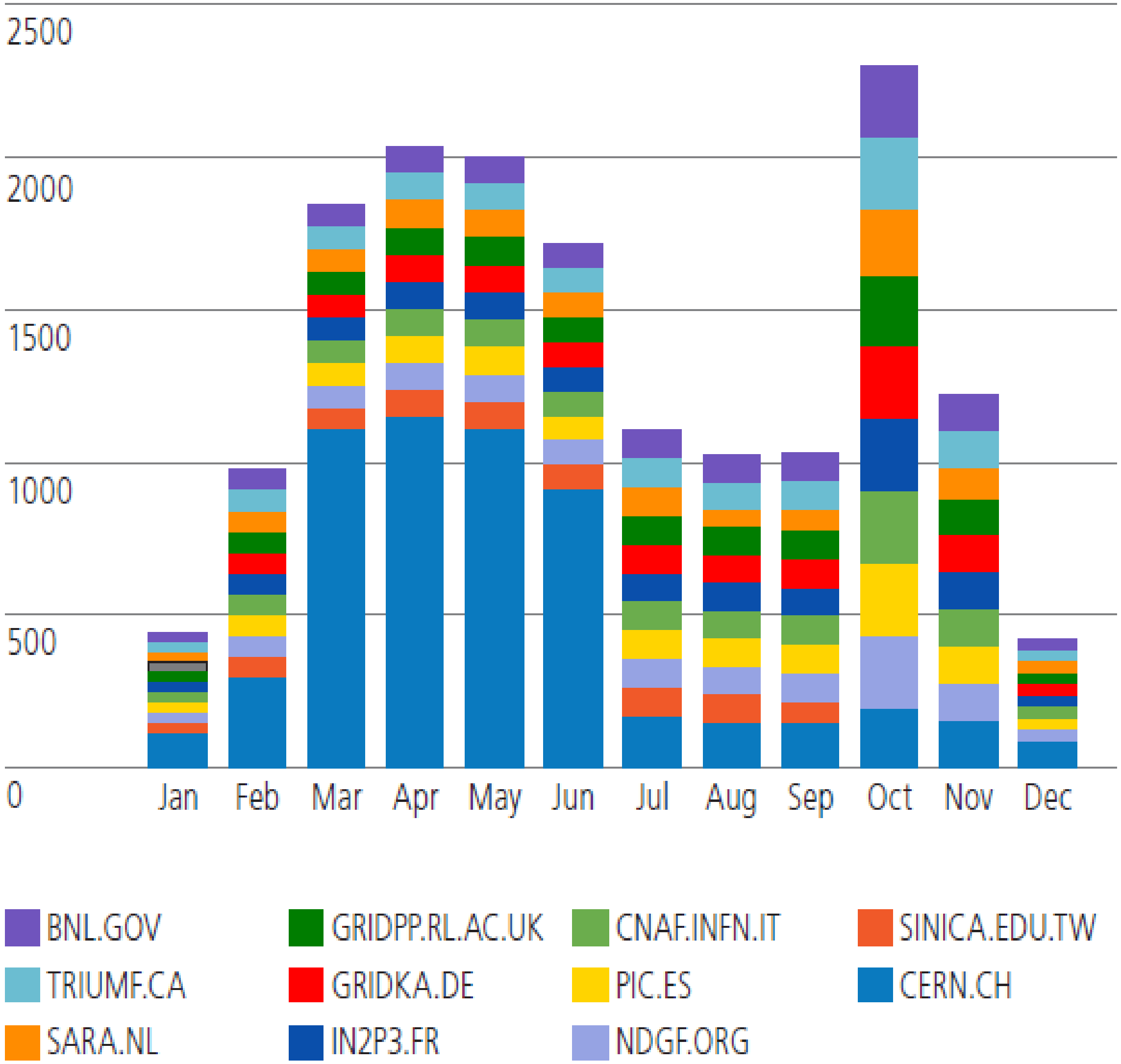


COMPASS



slide by Eva Dafonte Pérez

Number of Logical Change Records (LCRs) in Millions, per Month, by Tier-1 Site



Replication rate for conditions data from the ATLAS experiment to the different WLCG Tier-1 sites in 2010

Oracle is fully instrumented

- All actions
  - Network related
  - IO related
  - Internals (cluster communication, space management, etc.)
  - Application related (transaction locks, etc.)
  - etc.
- Key for “scientific” performance understanding.

The Tuning Process

1. run the workload, gather ASH/AWR information, 10046…

2. find the top event that slows down the processing

3. understand why time is spent on this event

4. modify client code, database schema, database code, hardware configuration

Demo 1

- Single.java
  - Tanel Poder’s snapper.sql
  - Disable autocommit
  - Tanel Poder’s snapper.sql
- Batch.java

DEMO

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	Program	Time per row	Top wait event	Notable statistics
	Single	0.76 ms / row	log file sync 57.1%	User commits=user calls=1.4k/s
* 2.45	Single autocommit=false	0.31 ms/row	SQL*Net message from client 69.9%	Requests to/from client = execute count= 3.69k/s
* 267	Batch	0.00116 ms	log file sync 18.4%, SQL*Net message from client 19.0%	

Oracle Linux “perf top”

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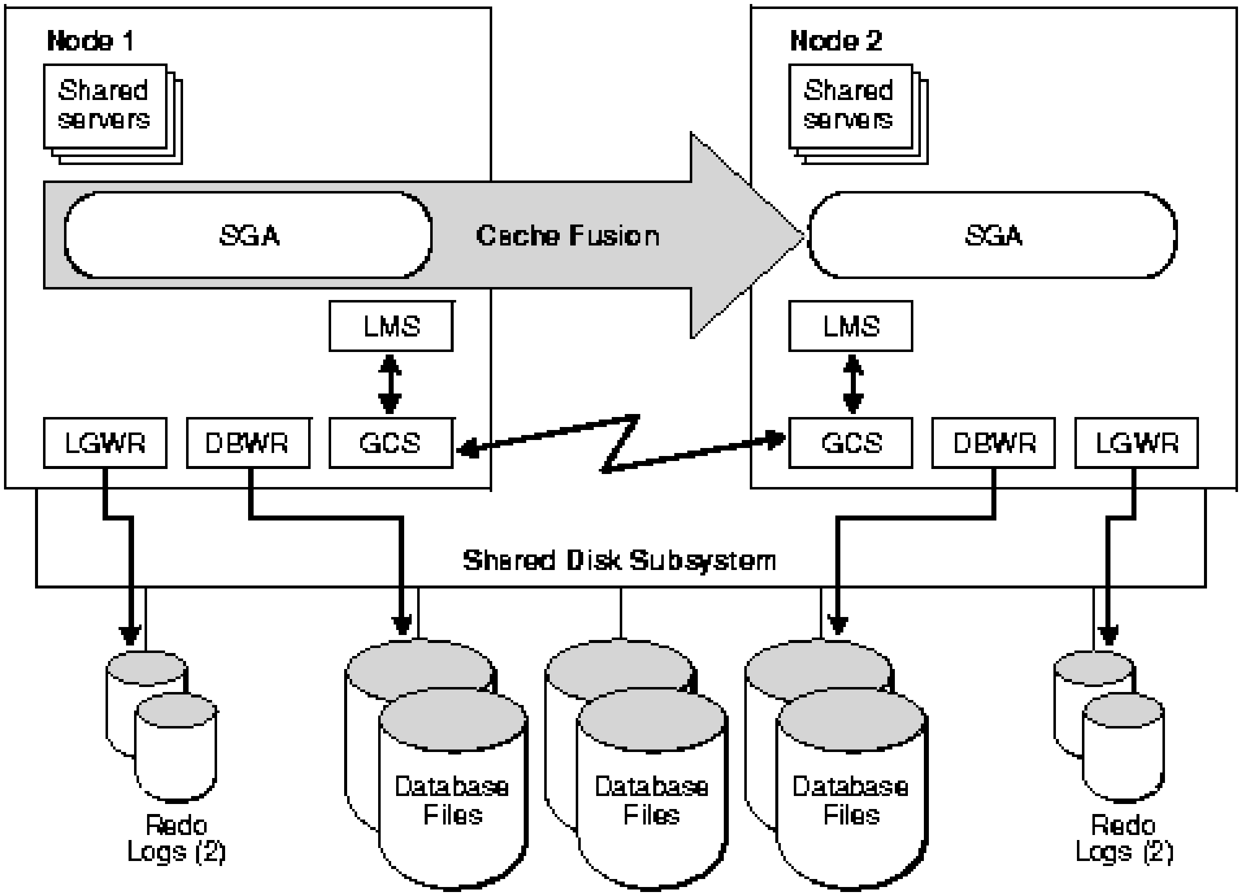
```
 PerfTop:    1002 irqs/sec  kernel: 0.6%  exact:  0.0% [1000Hz cpu-clock],  (target_pid: 4344)
------------------------------------------------------------------------------------------------------

           samples  pcnt function           DSO
           _______ _____ _________________  __________________________________________

           2999.00 29.8% kcbgtcr            /ORA/dbs01/oracle/product/rdbms/bin/oracle
           1199.00 11.9% qetlbr             /ORA/dbs01/oracle/product/rdbms/bin/oracle
           1120.00 11.1% kdsgrp             /ORA/dbs01/oracle/product/rdbms/bin/oracle
           1105.00 11.0% kafger             /ORA/dbs01/oracle/product/rdbms/bin/oracle
            724.00  7.2% kcbz_fp_buf        /ORA/dbs01/oracle/product/rdbms/bin/oracle
            407.00  4.0% kcbrls             /ORA/dbs01/oracle/product/rdbms/bin/oracle
            322.00  3.2% ktrgcm             /ORA/dbs01/oracle/product/rdbms/bin/oracle
```

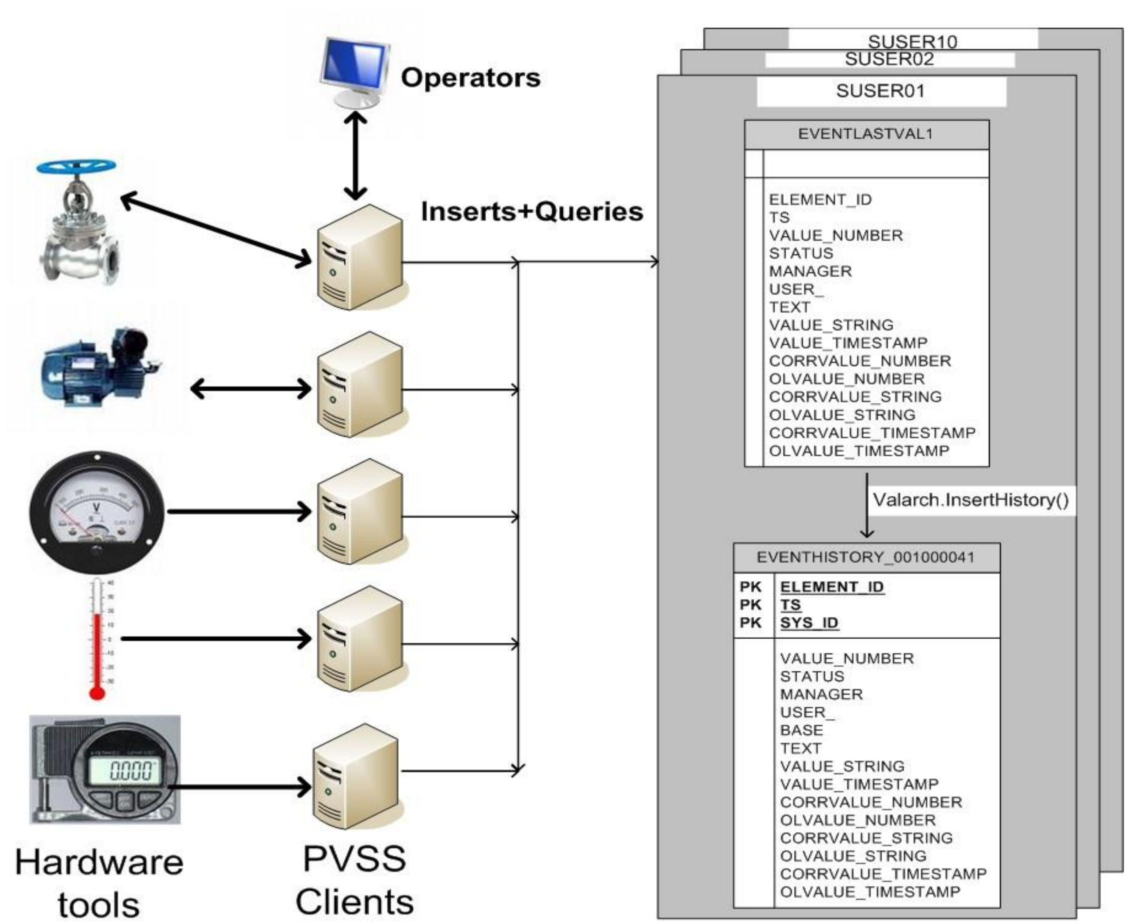
Oracle Real Application Cluster



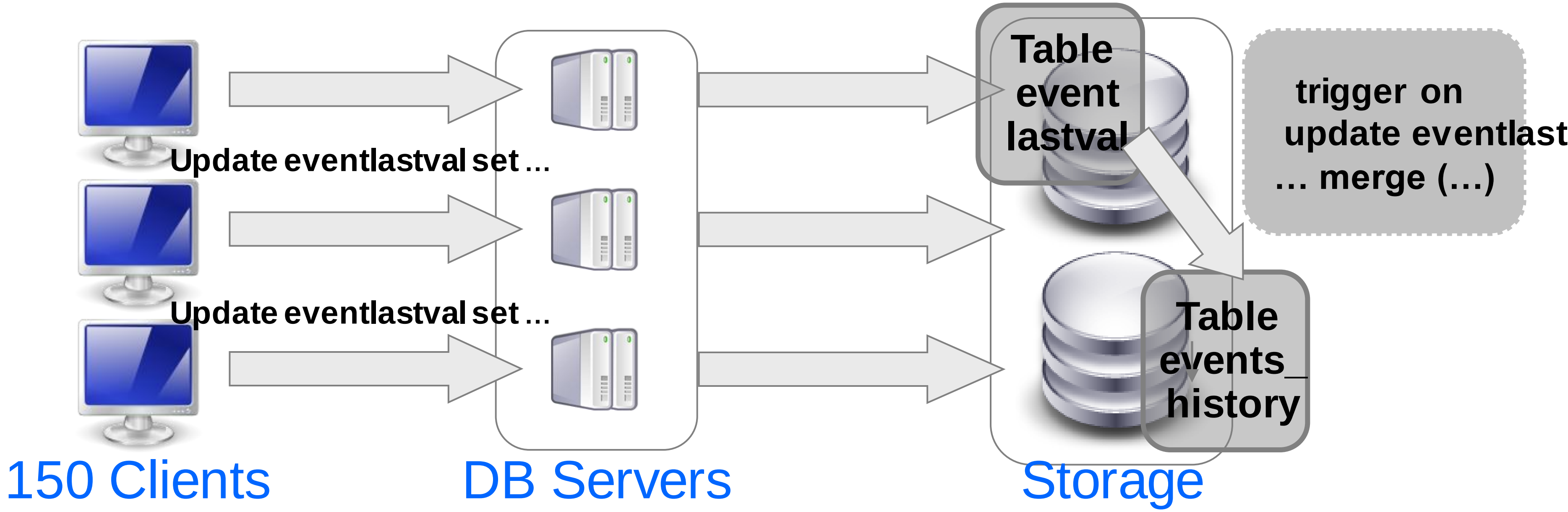
from Oracle9i Real Application Clusters Deployment and Performance

PVSS Oracle scalability

- Target = 150 000 changes per second (tested with 160k)
- 3 000 changes per client
- 5 nodes RAC 10.2.0.4
- 2 NAS 3040, each with one aggregate of 13 disks (10k rpm FC)



PVSS Tuning (1/6)



- **Shared resource**:
  EVENTS_HISTORY (ELEMENT_ID, VALUE…)
- Each client "measures" input and registers history with a "merge" operation in the EVENTS_HISTORY table

Performance:

- **100** "changes" per second

PVSS Tuning (2/6)

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Initial state observation:

- database is waiting on the clients

  "**SQL*Net message from client**"

- Use of a generic library C++/DB
- Individual insert (one statement per entry)
- Update of a table which keeps "latest state" through a trigger

PVSS Tuning (3/6)

Changes:

- bulk insert to a temporary table with OCCI, then call PL/SQL to load data into history table

Performance:

- **2000** changes per second

Now top event: "**db file sequential read**"

awrrpt_1_5489_5490.html

Event	Waits	Time(s)	Percent Total DB Time	Wait Class
db file sequential read	29,242	137	42.56	User I/O
enq: TX - contention	41	120	37.22	Other
CPU time		61	18.88	
log file parallel write	1,133	19	5.81	System I/O
db file parallel write	3,951	12	3.73	System I/O

PVSS Tuning (4/6)

Changes:
- Index usage analysis and reduction
- Table structure changes. IOT.
- Replacement of merge by insert.
- Use of “direct path load” with ETL

Performance:
- **16 000** “changes” per second
- Now top event: **cluster related wait event**

test5_rac_node1_8709_8710.html

Event	Waits	Time(s)	Avg Wait(ms)	% Total Call Time	Wait Class
gc buffer busy	27,883	728	26	31.6	Cluster
CPU time		369		16.0	
gc current block busy	6,818	255	37	11.1	Cluster
gc current grant busy	24,370	228	9	9.9	Cluster
gc current block 2-way	118,454	198	2	8.6	Cluster

PVSS Tuning (5/6)

Changes:

- Each “client” receives a unique number.
- Partitioned table.
- Use of “direct path load” to the partition with ETL

Performance:

- **150 000** changes per second
- Now top event : “**freezes**” once upon a while

rate75000_awrrpt_2_872_873.html

Event	Waits	Time(s)	Avg Wait(ms)	% Total Call Time	Wait Class
row cache lock	813	665	818	27.6	Concurrency
gc current multi block request	7,218	155	22	6.4	Cluster
CPU time		123		5.1	
log file parallel write	1,542	109	71	4.5	System I/O
undo segment extension	785,439	88	0	3.6	Configuration

PVSS Tuning (6/6)

Problem investigation:

- Link between foreground process and ASM processes
- Difficult to interpret ASH report, 10046 trace

Problem identification:

- ASM space allocation is blocking some operations

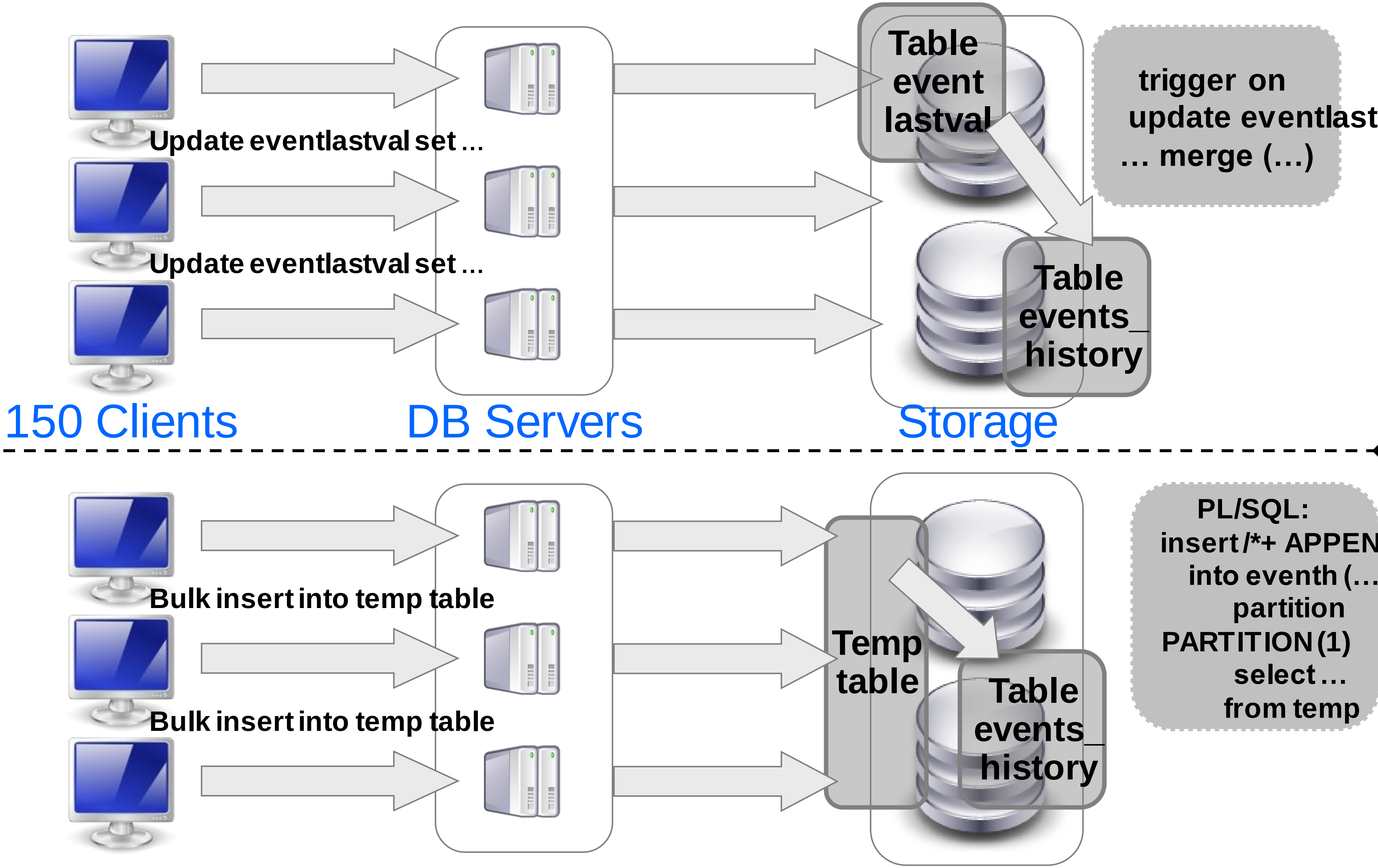
Changes:

- Space pre-allocation, background task.

Result:

- Stable 150 000 “changes” per second.

PVSS Tuning Schema



PVSS Tuning Summary

Conclusion:

- from **100** changes per second to **150 000** “changes” per second
- **6 nodes RAC** (dual CPU, 4GB RAM), 32 disks SATA with FCP link to host
- **4 months effort:**
  - Re-writing of part of the application with changes interface (C++ code)
  - Changes of the database code (PL/SQL)
  - Schema change
  - Numerous work sessions, joint work with other CERN IT groups

Overload at CPU level (1/)

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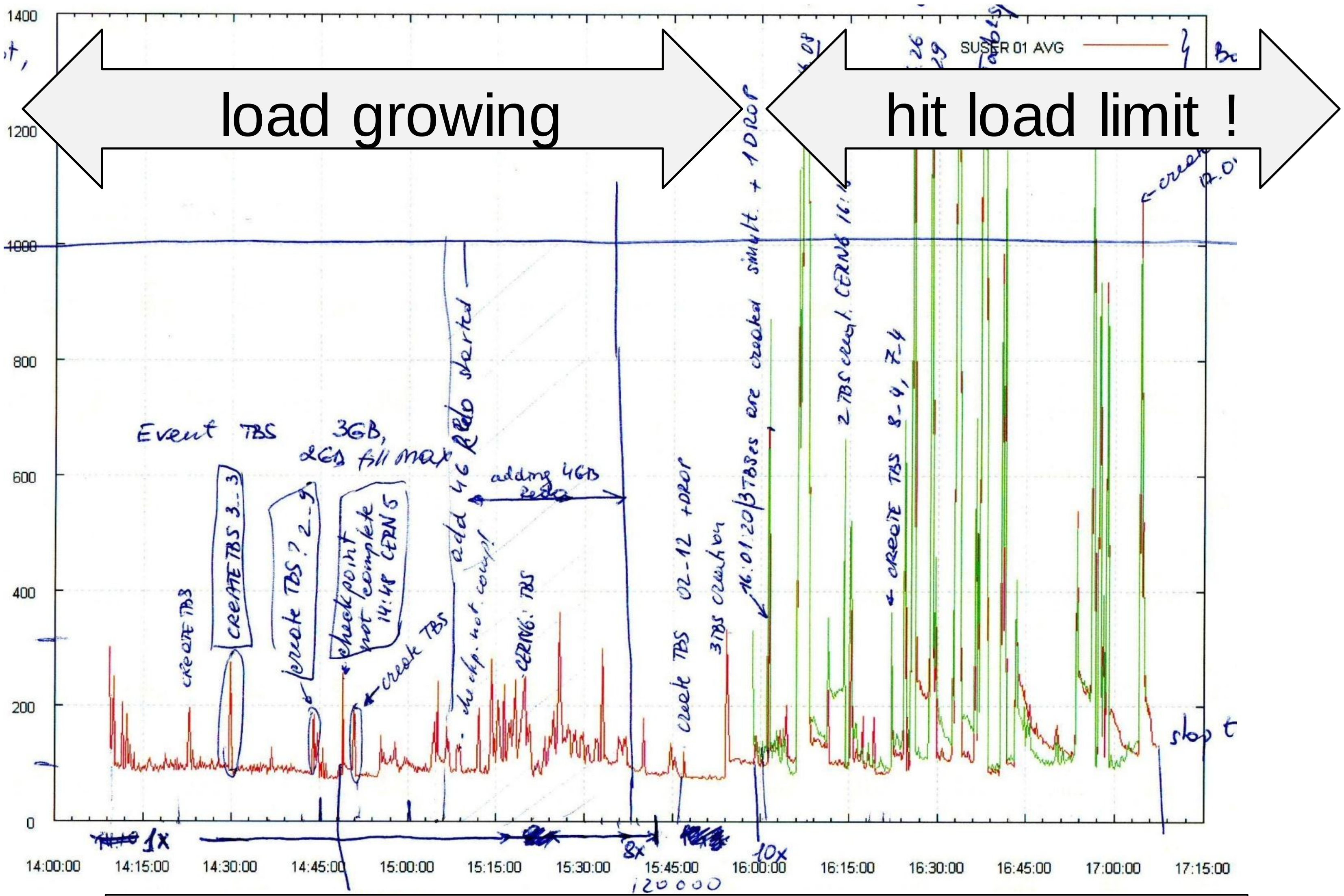
- Observed many times: "the storage is slow" (and storage administrators/specialists say "storage is fine / not loaded")
- Typically happens that observed (from Oracle rdbms point of view) IO wait times are long if CPU load is high
- Instrumentation / on-off cpu

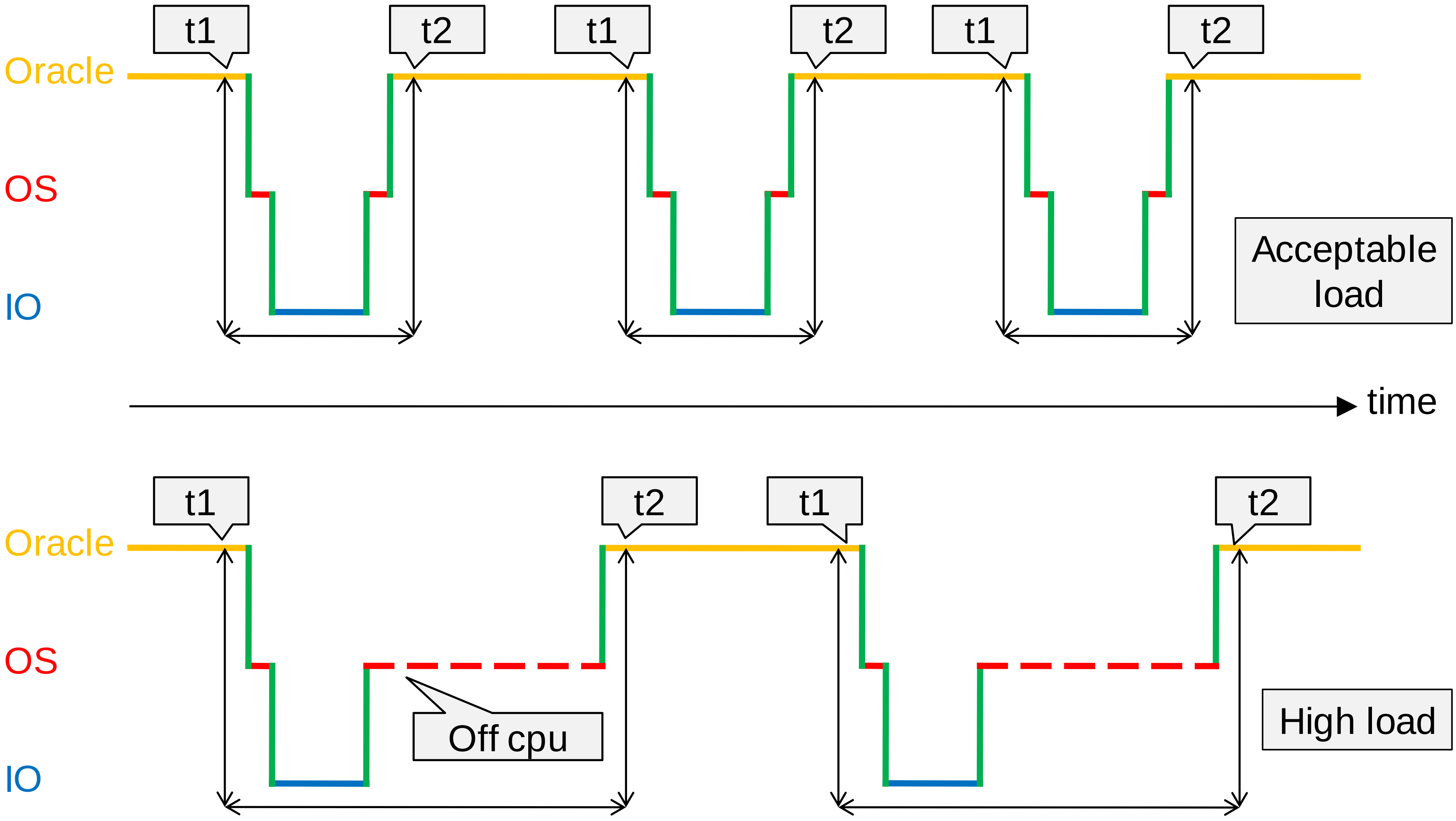
Overload at CPU level (2/) example

Insertion time (ms), has to be less than 1000ms



15k... 30k ... 60k... 90k... 120k ...135k... || 150k (insertions per second)

OS level / high-load



Overload at CPU level (3/), Dtrace

- Dtrace (Solaris) can be used at OS level to get (detailed) information at OS level

```
syscall::pread:entry
/pid == $target && self->traceme == 0 /
{
  self->traceme = 1;
  self->on = timestamp;
  self->off= timestamp;
  self->io_start=timestamp;
}

syscall::pread:entry
/self->traceme == 1 /
{
  self->io_start=timestamp;
}

syscall::pread:return
/self->traceme == 1 /
{
  @avgs["avg_io"] = avg(timestamp-self->io_start);
  @[tid,"time_io"] = quantize(timestamp-self->io_start);
  @counts["count_io"] = count();
}
```

Dtrace

CERN IT Department

```
sched:::on-cpu
/pid == $target && self->traceme == 1 /
{
  self->on = timestamp;
  @[tid,"off-cpu"] = quantize(self->on - self->off);
  @totals["total_cpu_off"] = sum(self->on - self->off);
  @avgs["avg_cpu_off"] = avg (self->on - self->off);
  @counts["count_cpu_on"] = count();
}
sched:::off-cpu
/self->traceme == 1/
{
  self->off= timestamp;
  @totals["total_cpu_on"] = sum(self->off - self->on);
  @avgs["avg_cpu_on"] = avg(self->off - self->on);
  @[tid,"on-cpu"] = quantize(self->off - self->on);
  @counts["count_cpu_off"] = count();
}

tick-1sec
/i++ >= 5/
{
  exit(0);
}
```

Dtrace, “normal load”

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```
-bash-3.00$ sudo ./cpu.d4 -p 15854
dtrace: script './cpu.d4' matched 7 probes
CPU     ID                    FUNCTION:NAME
  3  52078                       :tick-1sec

  avg_cpu_on                                              169114
  avg_cpu_off                                            6768876
  avg_io                                                 6850397

[...]

        1  off-cpu
           value  ------------- Distribution ------------- count
          524288 |                                         0
         1048576 |                                         2
         2097152 |@@@@                                     86
         4194304 |@@@@@@@@@@@@@@@@@@@@@@@@@@@              577
         8388608 |@@@@@@@@@                                189
        16777216 |                                         2
        33554432 |                                         0

[...]

  count_cpu_on                                               856
  count_io                                                   856
  count_cpu_off                                              857
  total_cpu_on                                         144931300
  total_cpu_off                                       5794158700
```

Dtrace, “high load”

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```
-bash-3.00$ sudo ./cpu.d4 -p 15854
dtrace: script './cpu.d4' matched 7 probes
CPU     ID                    FUNCTION:NAME
  2  52078                         :tick-1sec

  avg_cpu_on                                                     210391
  avg_cpu_off                                                  10409057
  avg_io                                                       10889597
[...]
        1  off-cpu
           value  ------------- Distribution ------------- count
            8192 |                                         0
           16384 |                                         4
           32768 |@                                        11
           65536 |                                         2
          131072 |                                         0
          262144 |                                         0
          524288 |                                         0
         1048576 |                                         0
         2097152 |@                                        15
         4194304 |@@@@@@@@@@@@@@                           177
         8388608 |@@@@@@@@@@@@@@@@@@@@                     249
        16777216 |@@@                                      41
        33554432 |                                         4
        67108864 |                                         0
[...]
  count_io                                                          486
  count_cpu_on                                                      503
  count_cpu_off                                                     504
  total_cpu_on                                                106037500
  total_cpu_off                                              5235756100
```

Lessons learnt

CERN IT Department

- Aiming for high-availability is (often) adding complexity… and complexity is the enemy of availability
- Scalability can be achieved with Oracle Real Application Cluster (150k entries/s for PVSS)
- Database / application instrumentation is key for understanding/improving performance
- NFS/D-NFS/pNFS are solutions to be considered for stability and scalability (very positive experience with NetApp, snapshots, scrubbing, etc.)
- Database independence is very complex if performance is required
- Hiding IO errors from the database leaves the database handle what it is best at (transactions, query optimisation, coherency, etc.)

Storage operations

- Demo2

Evolution

CERN IT Department

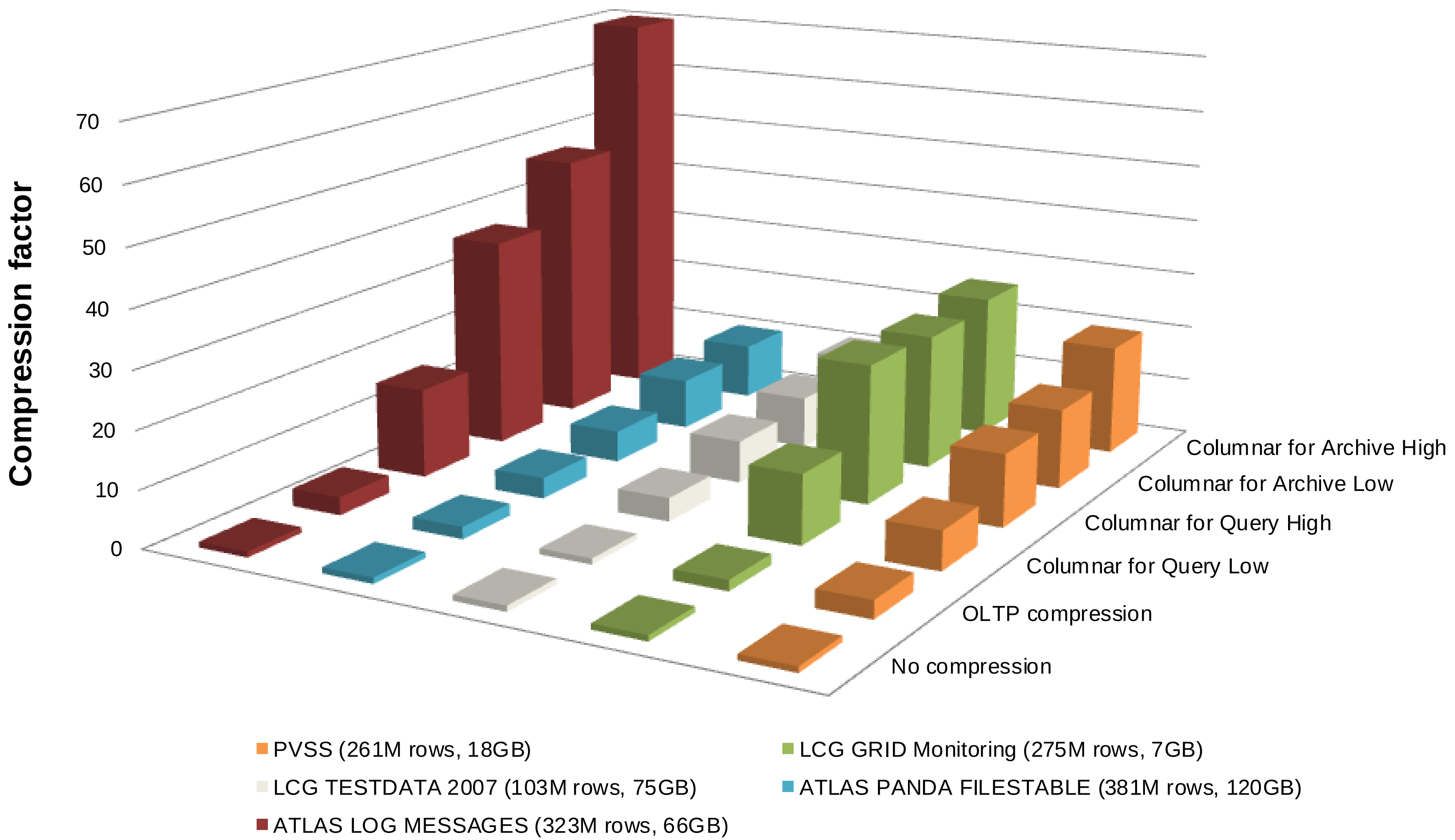
- Flash
- Large memory systems
- Compression
- Open source “relational” databases
- NoSQL databases

Flash, memory and compression

- Flash changes the picture in the database area IO
  - Sizing for IO Operations Per Second
  - Usage of fast disks for high number of IOPS and latency
- Large amount of memory
  - Enables consolidation and virtualisation (less nodes)
  - Some databases fully in memory
- Compression is gaining momentum for databases
  - For example Oracle's hybrid columnar compression
  - Tiering of storage

Exadata Hybrid Columnar Compression on Oracle 11gR2

Measured Compression factor for selected Physics Apps.



slide by Svetozar Kapusta

Local analysis of data

CERN IT Department

- "Big Data", analysis of large amount of data in reasonable of time
- Goole MapReduce, Apache Hadoop implementation
- Oracle Exadata
  - Storage cells perform some of the operations locally (Smart Scans, storage index, column filtering, etc.)
- Greenplum
  - shared-nothing massively parallel processing architecture for Business Intelligence and analytical processing
- Important direction for *at least* the first level of selection

Physics Analysis in SQL

Done using SQL-query making temporary tables for different selections and joining data from different tables via "EventNumber"

```
with selectedmuon as (select "muon_i","EventNumber","RunNumber","E","px","py","pz" from "muon" where
MLIMPER.PHYSANALYSIS.IS_MUON("muon_i", "pt", "eta", "phi", "E", "me_qoverp_exPV",
"id_qoverp_exPV","me_theta_exPV", "id_theta_exPV", "id_theta","isCombinedMuon",
"isLowPtReconstructedMuon","tight","expectBLayerHit", "nBLHits", "nPixHits","nPixelDeadSensors", "nPixHoles",
"nSCTHits","nSCTDeadSensors", "nSCTHoles","nTRTHits", "nTRTOutliers",0,20000.,2.4) = 1 ),

selectedeventsmuon as (select "EventNumber", COUNT(*) as "mu_sel_n" from selectedmuon group by
"EventNumber" HAVING COUNT(*)=2),

selectedbjet as (select "jet_i","EventNumber","RunNumber","E","pt","phi","eta" from "jet" INNER JOIN
selectedeventsmuon USING("EventNumber") where "pt"/1000>25 and abs("eta")<2.5 and "fl_w_Comb">1.55 ),

selectedevents as (select "EventNumber", COUNT(*) as "jet_sel_n" from selectedbjet group by "EventNumber"
HAVING COUNT(*)=2)

select MLIMPER.PHYSANALYSIS.INV_MASS_LEPTONS(mu1."E",mu2."E",mu1."px",mu2."px",mu1."py",
mu2."py",mu1."pz",mu2."pz")/1000. as "DiMuonMass",
MLIMPER.PHYSANALYSIS.INV_MASS_JETS(jet1."E",jet2."E",jet1."pt",jet2."pt",jet1."phi",jet2."phi",jet1."eta",jet2.
"eta")/1000. as "DiJetMass" from selectedmuon mu1, selectedmuon mu2, selectedbjet jet1, selectedbjet jet2,
selectedevents evSel

where mu1."muon_i"<mu2."muon_i" and mu1."EventNumber"=evSel."EventNumber" and
mu2."EventNumber"=evSel."EventNumber" and jet1."jet_i"<jet2."jet_i" and
jet1."EventNumber"=evSel."EventNumber" and jet2."EventNumber"=evSel."EventNumber" and
jet1."pt"/1000.>45.
```

Physics Analysis in DB

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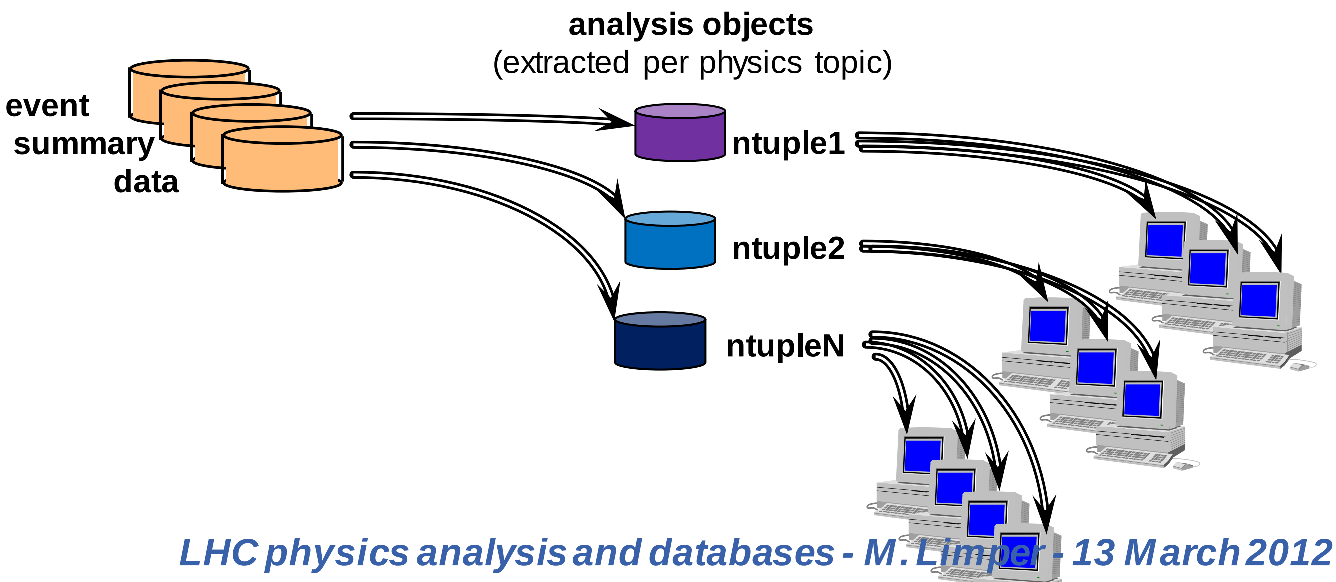
First implementation of Physics Analysis in Oracle DB

- **Data in multiple tables**
- **SQL-query can reproduce selection in loop over events**
- **Analysis from DB slower than original ntuple-analysis and many complexities still not implemented…**

Possible space-gain for DB version of analysis data:

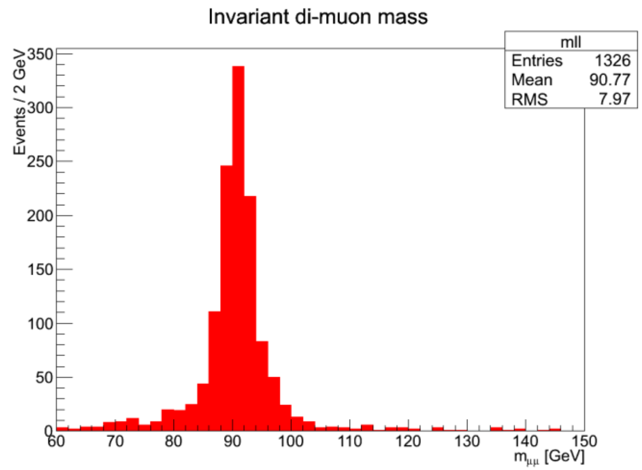
Each physics group optimized their own ntuple-size based on physics and level of detail required for their analysis, but sum of different ntuple contains duplicate info

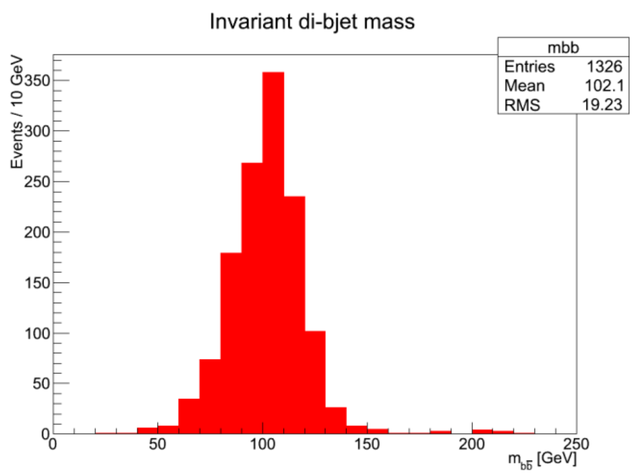
Physics Analysis DB would contains all physics objects, divided over multiple tables, each physics group can choose which tables to use



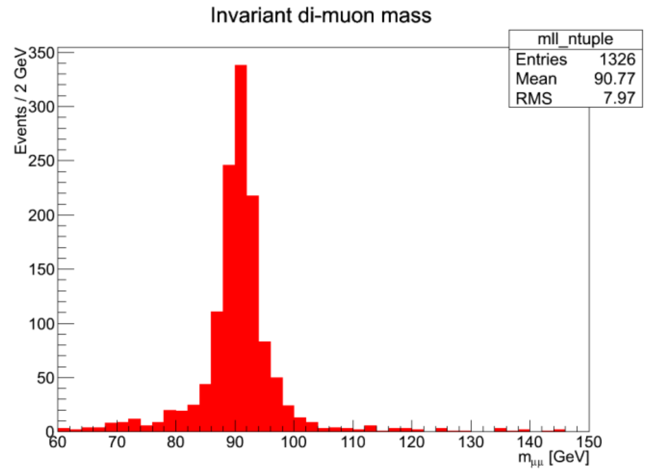
Physics Analysis benchmark

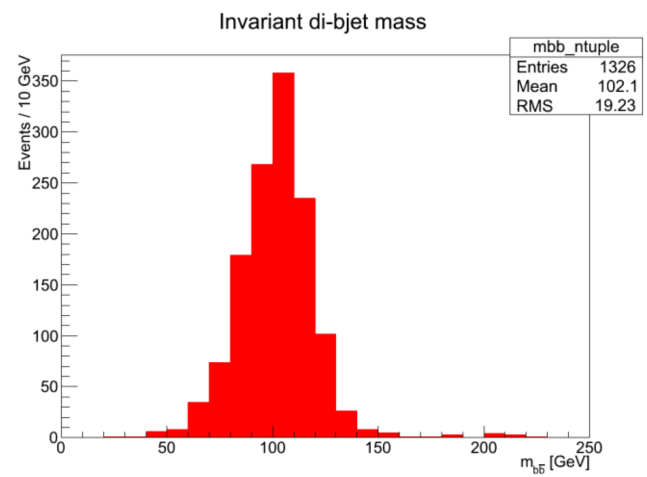
Output of SQL-query send to ROOT to produce standard root-histograms:





ROOT-macro using original ntuples as input produces identical histograms:





Summary

CERN IT Department

- Oracle
  - Critical component for LHC accelerator and physics data processing
  - Scalable and stable, including data replication
- CERN central services run on Oracle, for which we have components and experience to build high availability, guaranteed data, scalability
- MySQL as a “DataBase On Demand” service
  - Nice features and light, lacks some scalability and High-Availability features for some service requirements
- NoSQL is being considered
  - Ecosystem is evolving rapidly (architecture, designs and interfaces subject to change!)

References

- NoSQL ecosystem, http://www.aosabook.org/en/nosql.html
- Database workshop at CERN https://indico.cern.ch/conferenceDisplay.py?confId=130874 and ATLAS Computing Technical Interchange Meeting https://indico.cern.ch/event/132486
- Eva Dafonte Pérez, UKOUG 2009 “Worldwide distribution of experimental physics data using Oracle Streams”
- Luca Canali, CERN IT-DB Deployment, Status, Outlook http://canali.web.cern.ch/canali/docs/CERN_IT-DB_deployment_GAIA_Workshop_March2011.pptx
- CERN openlab, http://cern.ch/openlab/
- CAP theorem, http://portal.acm.org/citation.cfm?id=564601
- ACID, http://portal.acm.org/citation.cfm?id=291

Backup slides

Oracle

CERN IT Department

- EU director for research, Monica Marinucci
- Strong collaboration with CERN and universities
- Well known solution, easy to find database administrators and developers, training available
- Support and licensing