

Rudi Frühwirth Institute of High Energy Physics Austrian Academy of Sciences, Vienna

CSC 2009, Göttingen



## **Outline of the lectures**

- Introduction
- Event Filtering
- Calibration and alignment
- Event Reconstruction
- Event Simulation
- Physics Analysis
- Data Flow and Computing Resources



## What is Physics Computing?

- Input: A few petabytes of data
- Output: A few hundred physics papers
- > Data reduction factor of 10<sup>7</sup> to 10<sup>8</sup> !!
- > How is it done?



## <Digression>

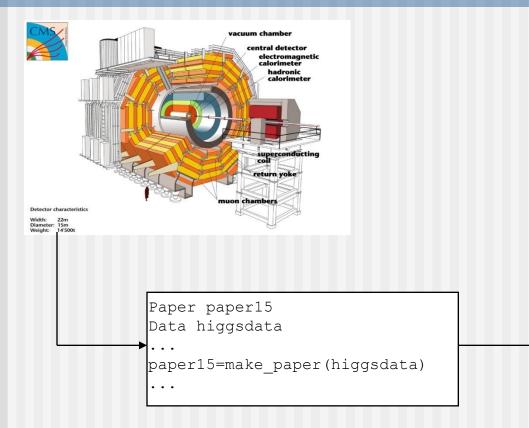


#### </Digression>

CSC 2009



#### It's simple ... is it?



INSTITUTE OF PHYSICS POBLISHING J. Phys. G: Nucl. Part. Phys. 31 (2005) 857-871 JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS doi:10.1088/0954-3899/31/8/017

#### Electroweak phase transition in an extension of the standard model with a real Higgs singlet

S W Ham1, Y S Jeong2 and S K Oh12

Center for High Energy Physics, Kyungpook National University Daegu 702-701, Korea
 Department of Physics, Konkuk University, Seoul 143-701, Korea

Received 1 December 2004 Published 24 June 2005 Online at stacks.iop.org/JPhysG/31/857

#### Abstract

The Higgs potential of the standard model with an additional real Higgs single is studied in order to examine if it may allow the strongly first-order electroweak phase transition. It is found that there are parameter values for which this model at the cone-loop level with a finite-temperature effect may allow the desired phase transition. Those parameter values also predict that the masses of the neutral scalar Higgs bosons of the model are consistent with the present experimental bound, and that their production in e<sup>+</sup>e<sup>+</sup> collisions may be searched at the proposed ILC with  $\sqrt{z} = 500$  GeV in the neutral true.

#### 1. Introduction

The possibility of baryogenesis by means of electroweak phase transition has recently been widely examined, since the electroweak haryogenesis can, in principle, be tested in the future accelerator experiments (1). If the electroweak phase transition is strongly first créder, if can tull the departure from themal equalibrium within is one of the three conditions required by Sakharov that are necessary for the dynamic generation of the baryon asymmetry during the evolution of the universe [2]. It has already been observed that in the standard model (SM) the electroweak phase transition cannot be strongly first order unless the mass of the scalar Higgs boson is smaller than its lower bound set experimentally by LEP [3]. The sufficient strength asymmetry at the electroweak scale. In the literature, a number of articles have been dowcide to study the possibility of accommoduling the strongly first-order electroweak phase transition in various models beyond the SM [4].

Among them, an interesting possibility has been investigated several years ago, where an eventsion of the SN with a real Higgs singlet field has been adopted within the context of the electrowak phase transition [5]. We consider that the model is impiring, because adding a real Higgs singlet field is the simplexe textension of the Higgs sector of the SM. In that nodel, the strength of the first-order electrowak phase transition has been strenger than that in the case of the SM. Due to the presence of cubic terms in the tre-level Higgs performance the partial, a strongly the strength of the transmitter of the strength of the tre-level Higgs net of the strength and the strength of the transmitter of the strength of the strength of the transmitter strength of the st

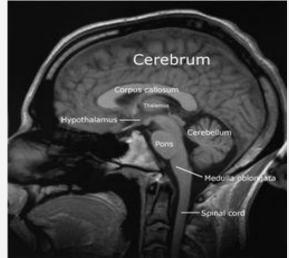
0954-3899/05/080857+15\$30.00 € 2005 IOP Publishing Ltd Printed in the UK

#### CSC 2009



## At LHC we need...

- > Millions of lines of code (C++,Python, ...)
- > Hundreds of neural networks (BNNs, not ANNs)
- Large infrastructure
  - Customized hardware
  - PC farms
  - Database and storage systems
  - Distributed analysis facilities
  - The grid





## What happens to the data?

- > Event filtering, tagging and storage
- Calibration, alignment
- > Event reconstruction
- Persistency
- > Event simulation
- > Physics analyses



## Step by step

- > Each step involves some data reduction
  - data are ignored or thrown away (online)
  - data are compressed (offline)





- In each step the data get closer to be interpretable in physical terms
- Some steps are repeated many times until the output is satisfactory



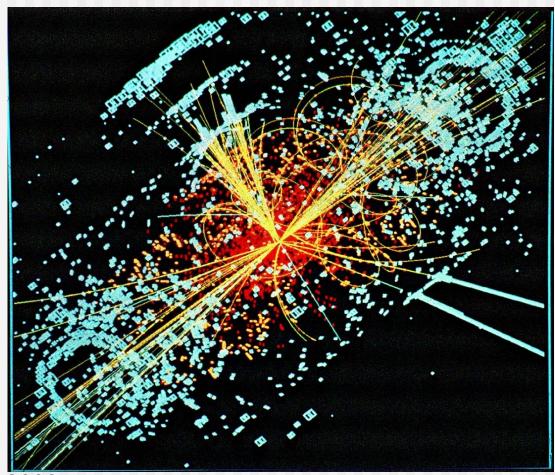


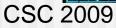
## The technical challenge

- > Very high event rate (40 Mhz)
- Large event size (>1MB)
- Large background of uninteresting events
- Large background in each event
  - many interactions in each beam crossing
  - many low-momentum particles



## The technical challenge (ctd)





Rudi Frühwirth, HEPHY Vienna



## The social challenge

#### Large number of physicists doing analysis

- CMS: 183 institutes in 39 countries
- > High pressure, competitive spirit
  - Important discoveries to be made
  - Fast turnaround required



CMS and ATLAS chasing the Higgs

CSC 2009



# Online vs Offline computing

#### > Online

- In real time, fast!
- Decisions are irreversible
- Data cannot be recovered

#### > Offline

- From almost real time to long delays
- Decisions can be reconsidered
- Data can be (and frequently are) reprocessed





Physicist reconsidering



## **Online processing**

#### > Trigger: event selection

- Needs only a small subset of the detector data
- Fast, very little dead-time
- Gives "green" or "red" light to the data acquisition



CSC 2009



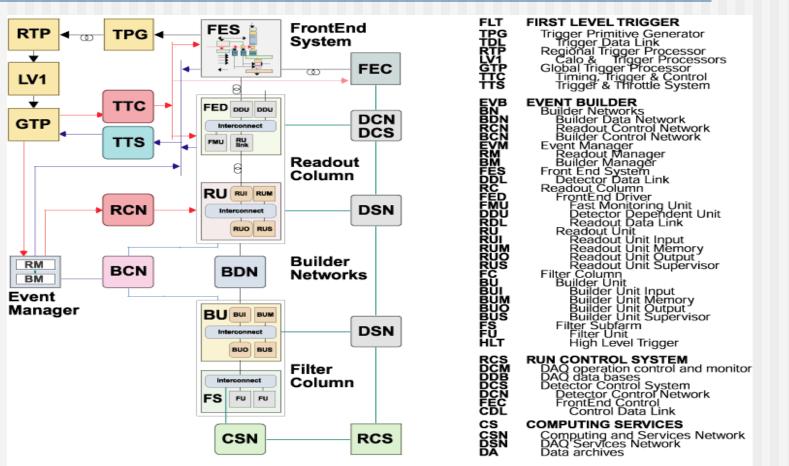
## Online processing (ctd)

#### Data acquisition

- Interfaces to detector hardware
- Builds complete events from fragments
- Sends them to the higher level event filter(s)
- Writes accepted events to mass storage
- Very complex system



#### **Complexity of Data acquisition**



#### Computing and Communication main subsystems



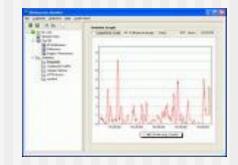
## Online processing (ctd)

#### Monitoring

- Detector status
- Data acquisition performance
- Trigger performance
- Data quality check

#### Control

- Configure systems
- Start/stop data taking
- Initiate special runs (calibration, alignment)
- Upload trigger tables, calibration constants, ...







## **Event selection**

- Primary collision rate: 40 Megahertz
- Recording rate: 100 Hertz
- > How is this achieved?
  - Multilevel trigger chain of yes/no decisions
  - Very fast first level: (Programmable) hardware
  - Slower higher level(s): Software on specialized or commodity processors



## Event selection (ctd)

#### Reliable

- Rejected data are lost forever
- Continuous monitoring
- Cautious
  - Do not lose new physics
- > Versatile
  - Many different trigger channels run parallel
  - Trigger conditions can be changed quickly



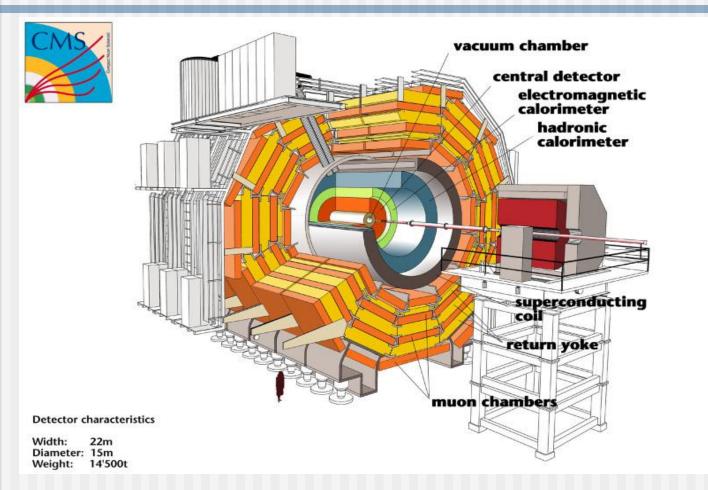


## Multilevel selection

- Dead-time has to be minimized
- Many events can be discarded very quickly
   Fast Level 1 Trigger
- > Only the surviving ones are scrutinized more carefully – High Level Filter(s)
- Triggers are tailored to specific physics channels (Higgs, top, WW, ZZ, ...)



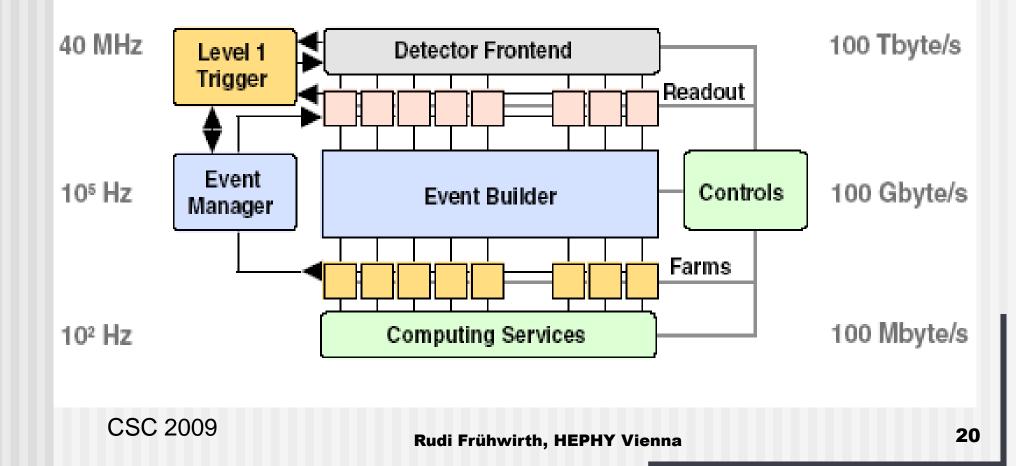
## Example: CMS



**CSC 2009** 



## Trigger/DAQ layout



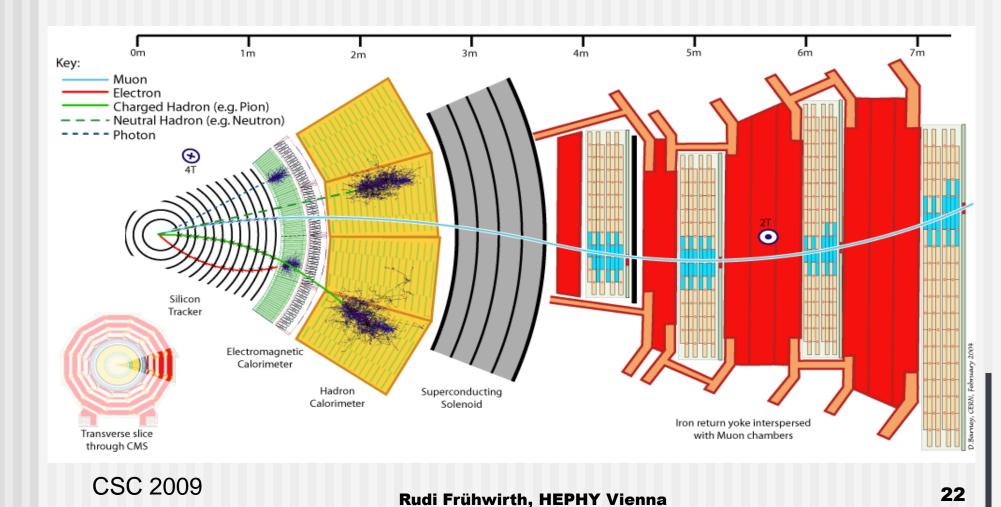


## What CMS subdetectors measure

- Inner tracker (pixels+strips)
  - Momentum and position of charged tracks
- > Electromagnetic calorimeter
  - Energy of photons, electrons and positrons
- > Hadron calorimeter
  - Energy of charged and neutral hadrons
- > Muon system
  - Momentum and position of muons



#### What CMS subdetectors measure





## CMS L1 trigger

- Input rate: 40 MHz
- > Output rate: 30 100 kHz
- > Latency: 3.2 μs (128 BX)
- > Pipelined, dead-time < 1%</p>
- > Available time for calculations: 1.25  $\mu$ s
- > 2 detector systems: muons/calorimeters
- > 3 main steps: local/regional/global



## CMS L1 calorimeter trigger

## Calorimeter trigger:

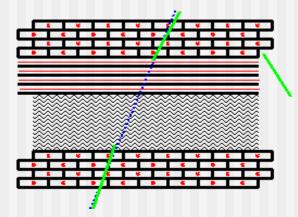
- Two types of calorimeters: hadronic, electromagnetic
- Local: Computes energy deposits
- Regional: Finds candidates for electrons, photons, jets, isolated hadrons; computes transverse energy sums
- Global: Sorts candidates in all categories, does total and missing transverse energy sums, computes jet multiplicities for different thresholds



# CMS L1 muon trigger

#### > Muon trigger:

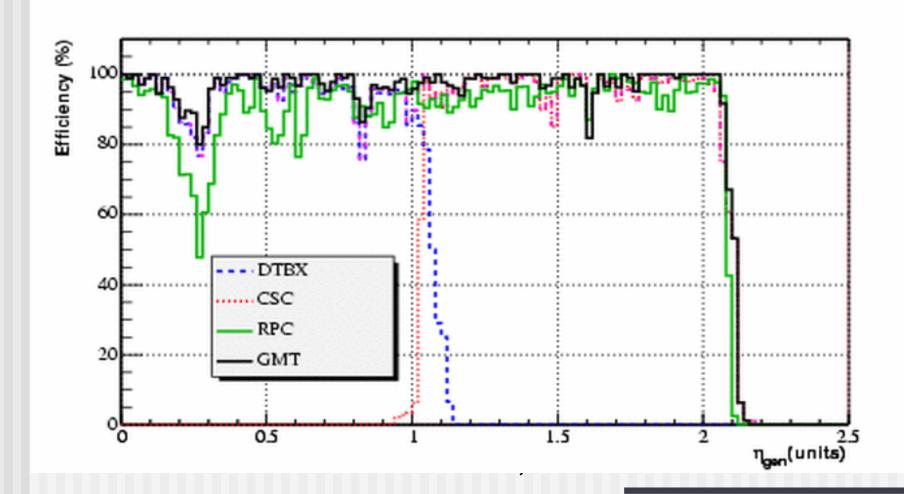
- Three types of muon detectors
- Local: Finds track segments
- Regional: Finds tracks



 Global: Combines information from all regional triggers, selects best four muons, provides energy and direction



### Efficiency of global muon trigger



26



# CMS L1 global trigger

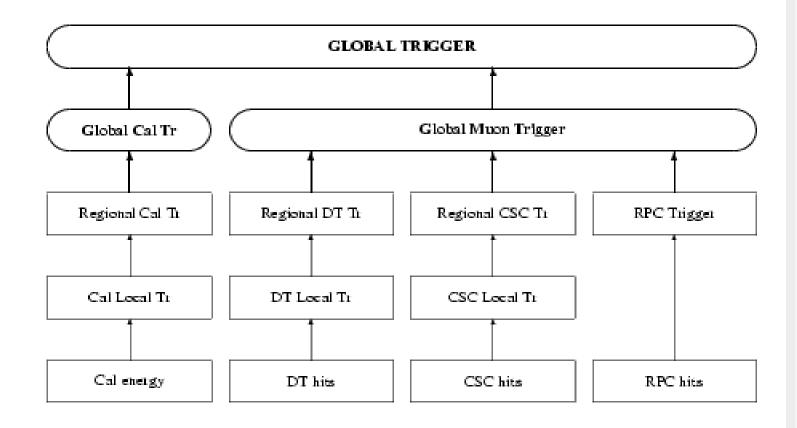
#### Global trigger:

- Final decision logic
- 28 input channels (muons, jets, electrons, photons, total/missing E<sub>T</sub>)
- 128 trigger algorithms running in parallel
- 128 decision bits
- Apply conditions (thresholds, windows, deltas)
- Check isolation bits
- Apply topology criteria (close/opposite)

CSC 2009



## CMS L1 trigger

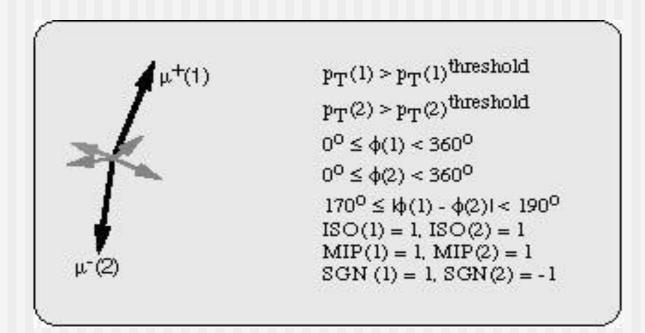


CSC 2009



## CMS L1 trigger example

#### back-to-back opposite sign isolated muons





## CMS L1 trigger software

- > Algorithms are developed in C++
- ➤ They are tested by extensive simulation studies (→ Event Simulation)
- Manual translation into VHDL (Very high speed integrated circuit Hardware Description Language)
- Comparison with C++ implementation



## High level filter

#### Further data selection:

- 30 100 kilohertz input rate
- 100-150 Hertz output rate
- Event tagging:
  - Reconstruct physics objects
  - Mark events having interesting features
  - Facilitates quick access later







## High level filter (ctd)

- More detailed analysis of event and underlying physics
- > Runs on standard processors (commodity PCs)
- > CMS: 1 stage
- > ATLAS: 2 stages (LVL2, Event filter)



This L1 is

Really fast!

# CMS High level trigger

- Has to keep pace with the L1 Output
- Solution: massive parallelism
- Filter farm
  - 720 PCs with dual quad-core Intel Harpertown @2.6 GHz, 16 GB RAM
  - Up to 200 events/s per PC
  - Decision time: ~ 40 ms





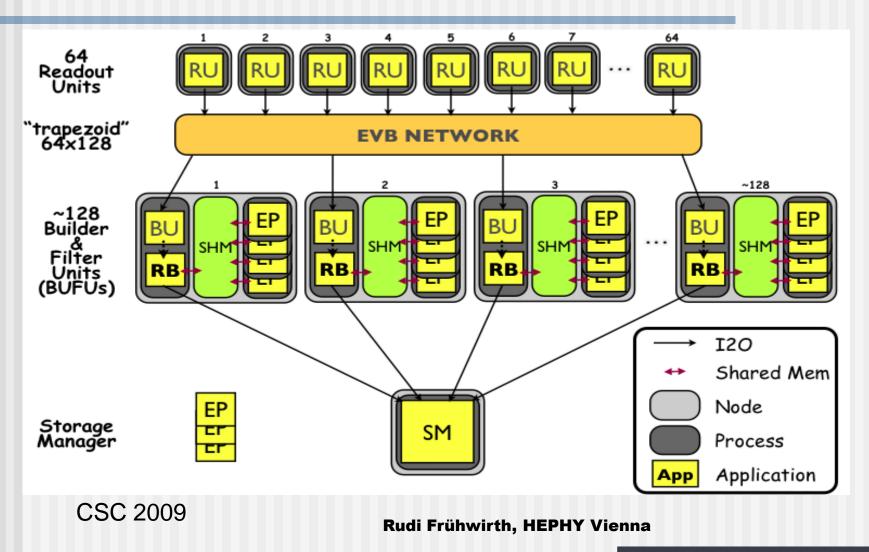
# CMS High level trigger (ctd)

- Same software framework as in "offline" reconstruction
- Transparent exchange of algorithms with off-line code
- > Regional reconstruction
  - Concentrates on region(s) found by Level 1
- > Partial reconstruction
  - Stop as soon specific questions are answered

CSC 2009

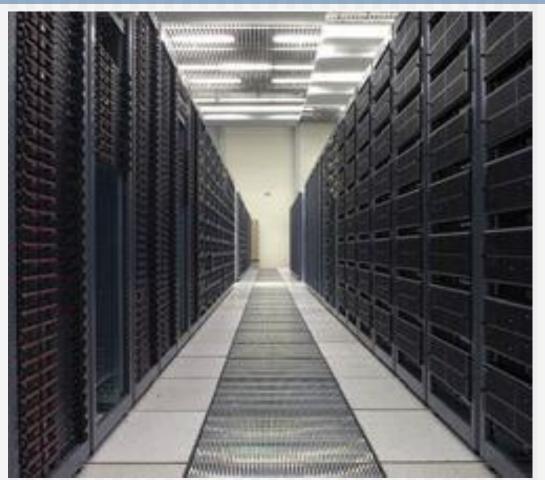


#### CMS HLT farm – schema ...





## ... and reality



CSC 2009



# Output of the high level trigger

- Raw data are sent to Tier-0 farm
  - Detector data (zero compressed)
  - Trigger information + some physics objects
  - O(50) primary datasets, depending on trigger history, O(10) online streams
- Physics: 1.5 MB @ 150 Hertz = 225 MB/sec
- > Alignment/Calibration: 100 MB/sec



# Output of the high level trigger (ctd)

- > Total: 325 MB/s ( ~ 1/6<sup>th</sup> of maximum bandwidth)
- > LHC runs for ~  $10^7$  sec/year
- >>3 PB per year!



## **Tier-0 Processing**

- > Archive raw data on mass storage
- First event reconstruction without or with a small delay

> Archive reconstructed data on mass storage

- 200 to 800 MByte/event, depending on physics
- Reconstructed objects (hits/clusters, tracks, vertices, jets, electrons, muons)
- Send raw and processed data to Tier-1



# **Offline Processing**

#### Calibration

Convert raw data to physical quantities

### > Alignment

Find out precise detector positions

#### > Event reconstruction

- Reconstruct particle tracks and vertices (interaction points)
- Identify particle types and decays
- Impose physics constraints (energy and momentum conservation)

Introduction to Physics Computing



# Offline Processing (ctd)

#### Simulation

- Generate artificial events resembling real data as closely as possible
- Needed for background studies, corrections, error estimation, ...



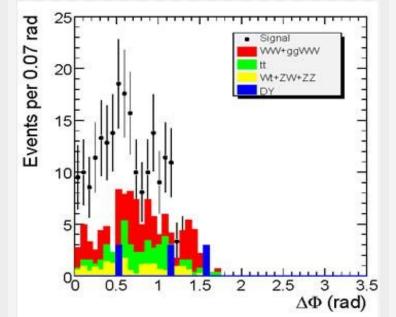
**Monte Carlo Method** 



# Offline Processing (ctd)

#### > Physics analysis

- Extract physics signals from background
- Compute masses, cross-sections, branching ratios, discovery limits, ...



- Requires sophisticated multivariate techniques
- Series of lectures and exercises on data analysis methods later in this track



# Calibration: From bits to GeV and cm

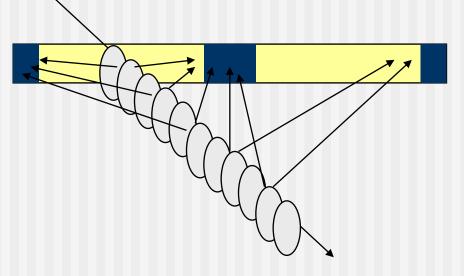
- Raw data are mostly ADC or TDC counts
- They have to be converted to physical quantities like energy or position
- > Very detector dependent
- > Every detector needs calibration
- Calibration constants need to be updated and stored

Introduction to Physics Computing



## Silicon Tracker calibration

#### Incoming particle creates electric charge in strips or pixels



Incoming particle

Rudi Frühwirth, HEPHY Vienna





# Silicon Tracker calibration (ctd)

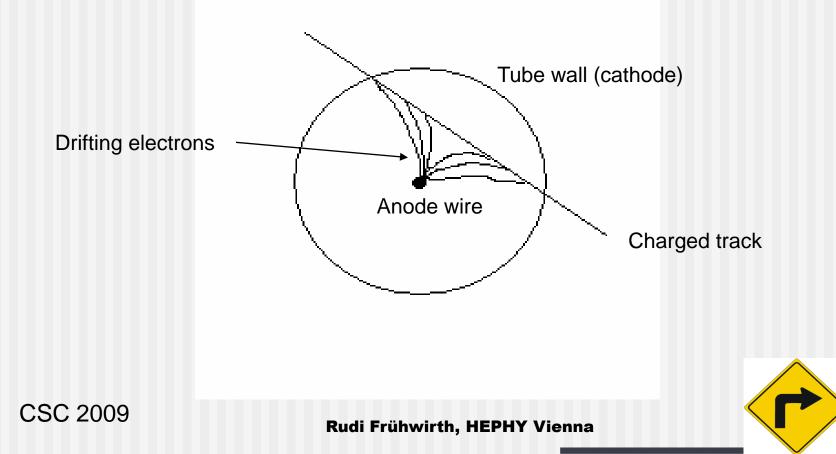
- Charge distribution depends on location of crossing point and crossing angle
- Solve inverse problem: reconstruct crossing point from charge distribution and crossing angle
- > Test beam, real data



Introduction to Physics Computing



#### Drift tube calibration



46



# Drift tube calibration (ctd)

- Incoming particle ionizes gas in tube
- > Electrons/ions drift to anode/cathode
- > Drift time is measured
- > Must be converted to drift distance
- Time/distance relation must be determined (not always linear)
- > Test beam, real data





# Alignment: Where are the detectors?

- Tracking detectors are very precise instruments
- > Silicon strip detector: ~ 50  $\mu$ m
- > Pixel detector: ~ 10 μm
- > Drift tube: ~ 100  $\mu$ m



Position needs to be known to a similar or better precision





### Example: CMS tracker





# Alignment

- > Mechanical alignment
- Measurements taken before assembly
- Switching on the magnetic field
- Laser alignment
- > Alignment with charged tracks from collisions, beam halo and cosmic rays



# Alignment (ctd)

- > Difficult because of huge number of parameters to be estimated (≈ 100000)
- Continuous process
- > Alignment constants need to be updated and stored

Introduction to Physics Computing



## **Environmental data**

- Calibration data
- > Alignment data
- > Temperatures, gas pressures, ...
- > Machine parameters
- > Need to be made persistent





## **Detector related software**

### Configuration

 Load trigger files, set thresholds, set HV, set amplifier gains, …

#### Slow control

 Measure and adjust temperature, gas pressure, dark currents, …

#### Monitoring

 Check trigger rates, detector efficiency, cluster sizes, wire maps, …

CSC 2009



### **Event reconstruction**

- Find out which particles have been created where and with which momentum
- Some of them are short-lived and have to be reconstructed from their decay products
- Some of them (neutrinos) escape without leaving any trace

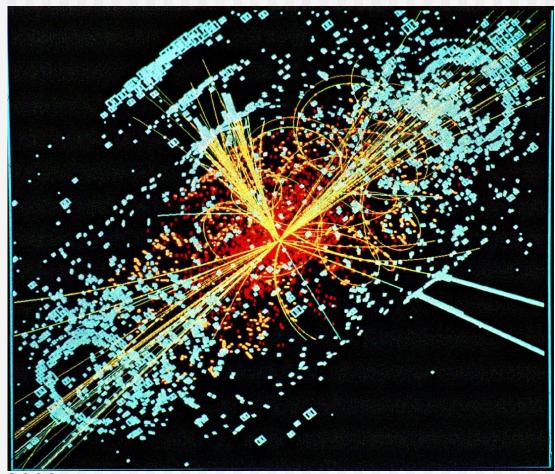


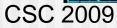
# Event reconstruction (ctd)

- > Reconstruct charged particles
- Reconstruct neutral particles
- Identify type of particles
- > Reconstruct vertices (interaction points)
- > Reconstruct kinematics of the interaction
- > Not trivial, very time-consuming ...



## CMS: Higgs decay into two jets





Rudi Frühwirth, HEPHY Vienna

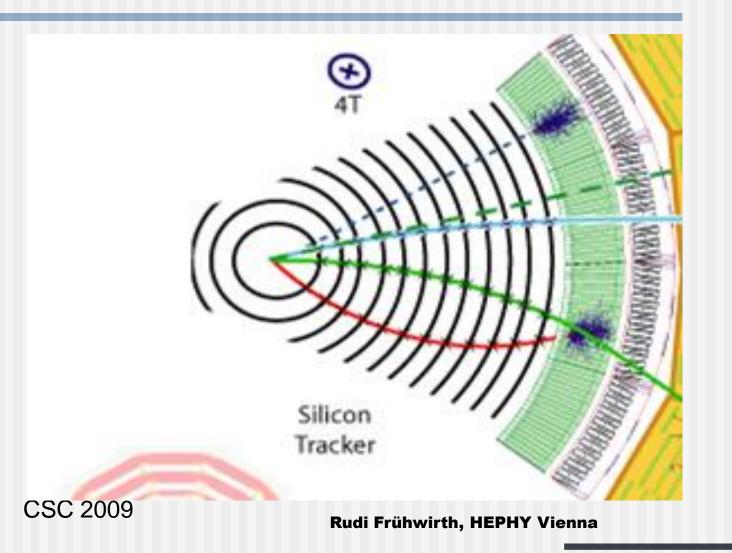


# **Charged** particles

- Charged particles are detected by tracker and calorimeters
- > Muons also reach the muon system
- Very high number of low-momentum charged particles
- Select by threshold on transverse momentum



## Charged particles (ctd)





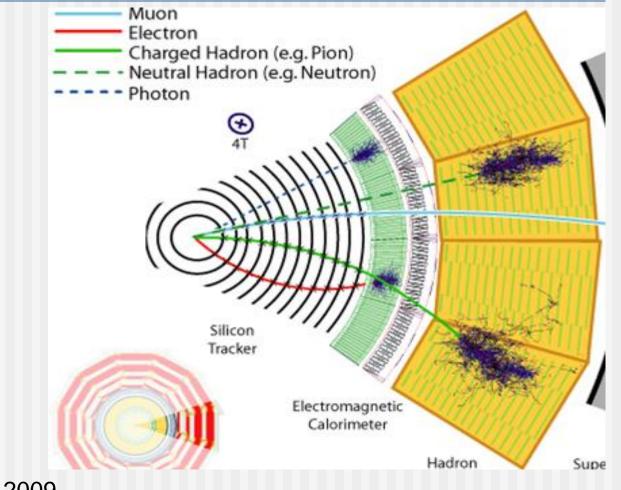
## **Neutral particles**

- Neutral particles are detected mainly by calorimeters (e.g. photons, neutrons)
- > They should deposit their entire energy
- Some of them decay into two (or more) charged tracks which are detected by the tracker (e.g. K<sup>o</sup>)
- Some of them escape without leaving a trace (neutrinos)

CSC 2009



### Neutral particles (ctd)



CSC 2009

Rudi Frühwirth, HEPHY Vienna



# Reconstruction of charged particles

- Trajectory is curved because of the magnetic field
- Position is measured in a number of places –"hits"
- Determine track parameters (location, direction, momentum) plus errors from the position measurements
- Data compression

CSC 2009



# The difficulties

- > Assignment of hits to particles is unknown
- > Huge background from low-momentum tracks
- > Additional background from other interactions in the same beam crossing and from adjacent beam crossings

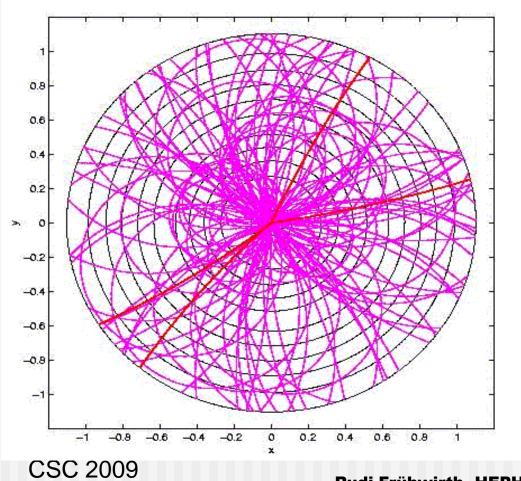


## More difficulties

- Charged particles interact with all the material, not only the sensitive parts
- > Multiple Coulomb scattering
  - Changes direction, but not momentum
- Energy loss by ionization
  - All charged particles
- Energy loss by bremsstrahlung
  - Mainly electrons and positrons



### Tracks only

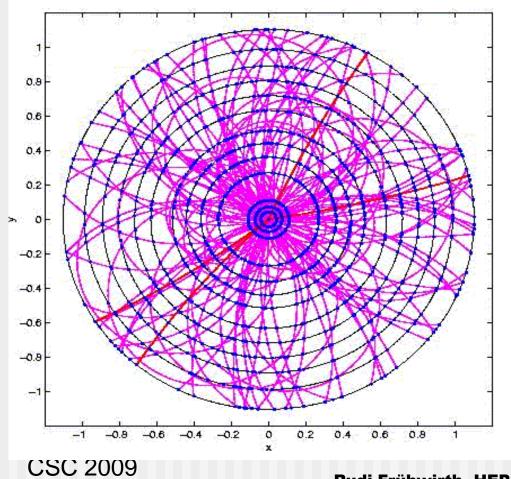


Rudi Frühwirth, HEPHY Vienna

Introduction to Physics Computing



#### Tracks with hits

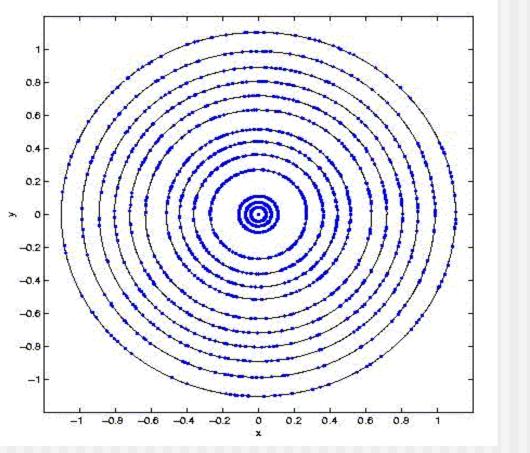


Rudi Frühwirth, HEPHY Vienna

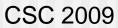
Introduction to Physics Computing



### Hits only









# Decomposition of the problem

- Pattern Recognition or Track Finding
  - Assign hits to track candidates
- > Parameter estimation or Track Fit
  - Determine track parameters + covariance matrix
- > Test of the track hypothesis
  - Check chi-square, residuals, remove outliers



# Track finding

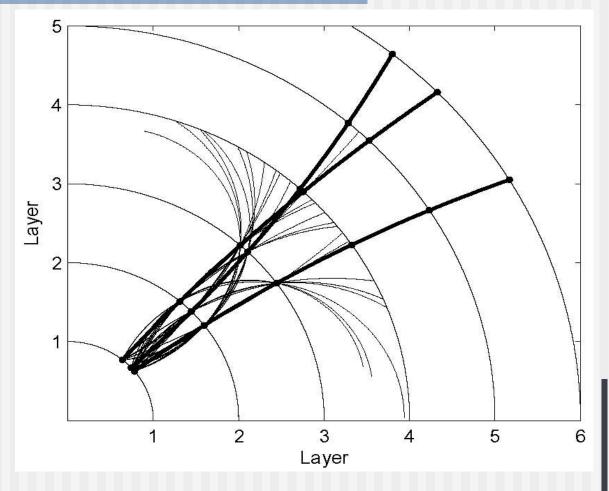
- Depends a lot on the properties of the detector:
  - Geometry, configuration
  - Magnetic field
  - Precision
  - Occupancy
- Many solutions available
- > No general recipe





# A few track finding algorithms

- Track following
- Kalman filter
- Combinatorial Kalman filter
- Hough transform
- Artificial neural network





# Track fit

- > Determine track parameters
- > Determine errors (covariance matrix)
- > Test track hypothesis
- > Reject outliers
  - Distorted hits
  - Extraneous hits
  - Electronic noise





## Ingredients

### Magnetic field

Constant or variable

### > Track model

- Solution of the equation of motion
- Analytic (explicit) or numerical

### > Error model

- Observations errors
- Process noise





# Estimation of track parameters

- Most estimators minimize a least-squares objective function
- Least-squares estimation
  - Linear regression
  - Kalman filter
- > Robust estimation
  - Adaptive filter





# **Reconstruction of neutral particles**

- Neutral particles are only seen by the calorimeters
- Photons are absorbed in the electromagnetic calorimeter
- Neutral hadrons are absorbed in the hadronic calorimeter
- > Neutrinos are not detected directly

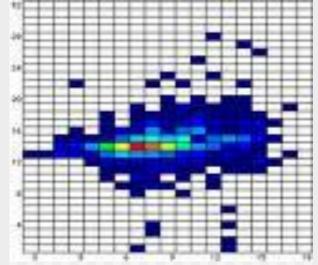




# Shower finding

An incident particle produces a shower in the calorimeter

> A shower is a cluster of cells with energy deposit above threshold



Rudi Frühwirth, HEPHY Vienna



# Shower finding (ctd)

> Overlapping clusters must be separated

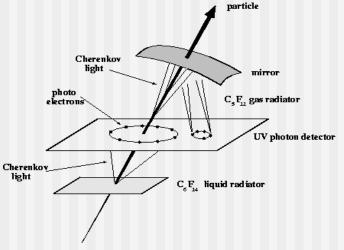
- Various clustering techniques are used to find showers
- The algorithms depend on various characteristics of the calorimeter
  - Type (electromagnetic or hadronic)
  - Technology (homogeneous or sampling)
  - Cell geometry, Granularity



# Particle identification

# Determining the type of a particle Dedicated detectors

- Type (electromagnetic or hadronic)
- Threshold Cherenkov
- Ring imaging Cherenkov (RICH)
- Transition radiation detector
- Ionization measurements





# Particle identification (ctd)

#### Combining information from several detectors

- Shower in electro-magnetic calorimeter
   + no matching track in tracker → photon
- Shower in electro-magnetic calorimeter
   + matching track in tracker → electron/positron
- Shower in hadronic calorimeter
   + matching track in tracker → charged hadron
- Track in muon system
  - + matching track in tracker  $\rightarrow$  muon

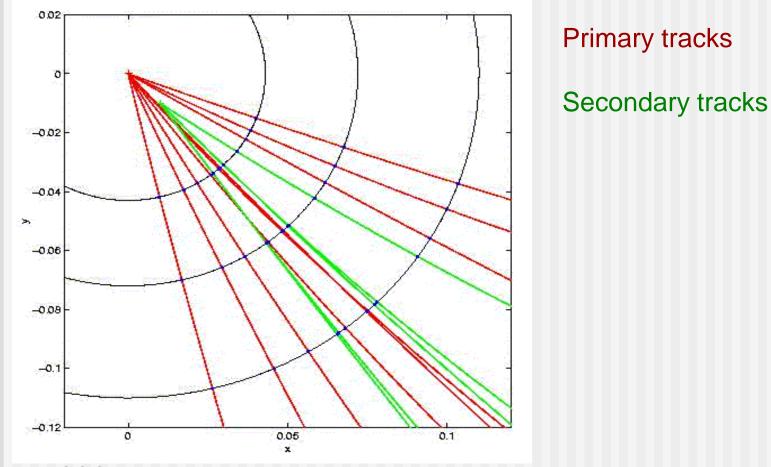


#### Vertex reconstruction

- Primary vertex: interaction of the two beam particles – easy
- Secondary vertices: decay vertices of unstable particles – *difficult*
- Emphasis on short-lived unstable particles which decay before reaching the tracker
- Data compression



#### Primary and secondary tracks



CSC 2009

#### Rudi Frühwirth, HEPHY Vienna



# The difficulties

- > Association of tracks to vertices is unknown
- Secondary tracks may pass very close to the primary vertex
  - Especially if decay length is small
- Track reconstruction may be less than perfect
  - Outliers, distortions, incorrect errors



# Decomposition of the problem

- Pattern Recognition or Vertex Finding
  - Assign tracks to vertex candidates
- > Parameter estimation or Vertex Fit
  - Determine vertex location + covariance matrix, update track parameters
- > Test of the vertex hypothesis
  - Check chi-square, residuals, remove outliers



# Vertex finding

- > Almost independent of the detector geometry
- Secondary vertex finding may depend on the physic channel under investigation
- > Essentially a clustering problem
- Many solutions available





# A few vertex finding algorithms

#### > Hierarchical clustering

• Single linkage, complete linkage,...

#### > Non-hierarchical clustering

k-means, robust location (mode) estimation, iterated vertex fit

#### > Neural network/physics inspired

 Competitive learning, deterministic annealing, superparamagnetic clustering, quantum clusterio



# Vertex fitting

- Most estimators minimize a least-squares objective function
- Least-squares estimation
  - Linear regression
  - Kalman filter
- > Robust estimation
  - Adaptive filter





# Persistency

#### > Event reconstruction produces physics objects

- Tracks
- Vertices
- Identified particles
- Jets
- Tags

#### Need to be made persistent





# Persistency (ctd)

#### Physics objects depend on

- Alignment
- Calibration
- Version of the reconstruction program
- Algorithm parameters
- > Must be made persistent as well
- > Tools: ROOT, POOL
  - Series of lectures and exercises later in this track



# Simulation

#### > Why do we need simulation?

- Optimization of detector in design phase
- Testing, validation and optimization of trigger and reconstruction algorithms
- Computation of trigger and reconstruction efficiency
- Computation of acceptance corrections
- Background studies
- Systematic error studies



# Simulation steps

#### Physics generation

 Generate particles according to specific physics processes

#### Event simulation

- Track particles through the detector, using detector geometry and magnetic field
- Simulate interaction of particles with matter
- Generate signals in sensitive volumes
- Simulate digitization process (ADC or TDC)
- Simulate trigger response



# Simulation steps (ctd)

#### Reconstruction

- Treat simulated events exactly as real events
- Keep (some) truth information: association of hits to tracks, association of tracks to vertices, true track parameters, true vertex parameters, ...
- Make everything persistent



# Physics generation packages

#### > General purpose event generators

- Hadron-hadron, hadron-lepton, lepton-lepton collisions
- PYTHIA/JETSET, also known as "Lund Monte Carlo"
- Herwig++, Hadron Emission Reactions With Interfering Gluons
- PANDORA, event generator for linear collider studies, collisions of electrons, positrons and photons
- Specialized generators



# **Event simulation**

- > Was frequently (and still sometimes is) experiment-specific
- > Now there is a widely used standard: GEANT
  - GEANT3: procedural, FORTRAN
  - GEANT4 : object oriented, C++



# **Detector description**

#### Geometry

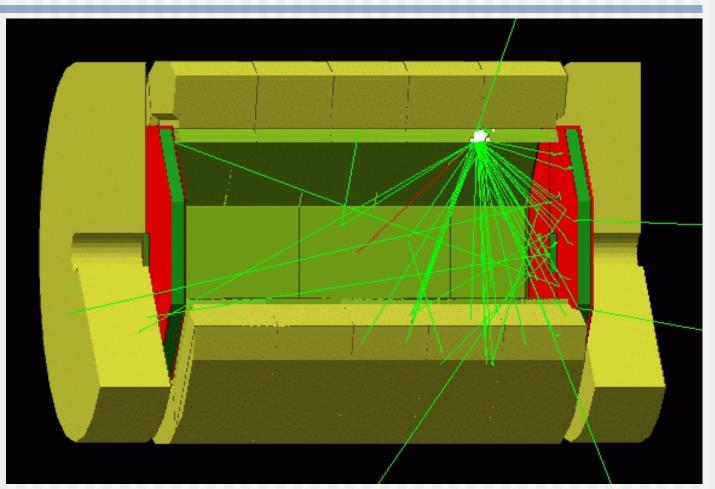
- Shape
- Placement relative to mother volume
- Symmetries

#### Material

- Composition
- Density
- Radiation length, interaction length, ...



#### An example detector model



CSC 2009

Rudi Frühwirth, HEPHY Vienna



# **Physics analysis**

#### > Event selection

- Multidimensional criteria
- Statistics, neural networks, genetic algorithms, ...

#### Signal extraction

- Study background
- Determine significance of signal
- Corrections



- Detector acceptance, reconstruction efficiency, …
- From simulated data

CSC 2009



# Physics analysis (ctd)

#### Computation of physical quantities

- Cross sections, branching rations, masses, lifetimes, …
- > ... and of their errors
  - Statistical errors: uncertainty because of limited number of observations
  - Systematic errors: uncertainty because of limited knowledge of key assumptions (beam energy, calibration, alignment, magnetic field, theoretical values, background channels, ...)

CSC 2009



# Analysis tools

#### Need versatile tools for

- Multidimensional selection
- Event display and interactive reprocessing
- Histogramming
- Plotting
- Fitting of curves and models
- Point estimation, confidence intervals, limits
- • • •



# Analysis tools (ctd)

# > ROOT

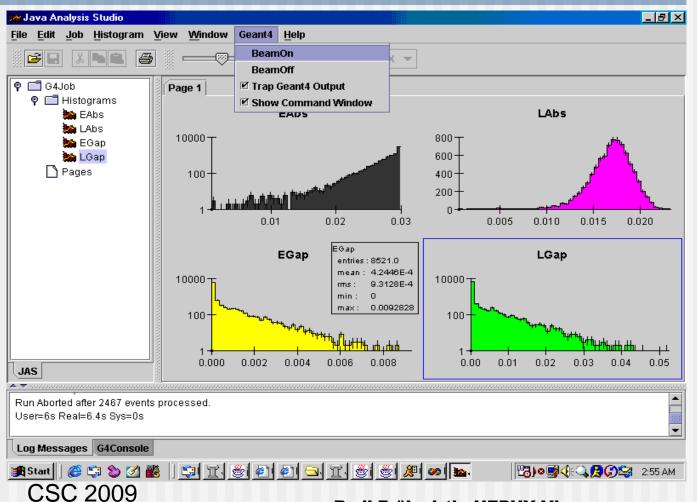
- Data analysis and persistency, but also detector description, simulation, data acquisition, ...
- Series of lectures and exercises later in this track
- ≻ JAS
  - Java Analysis Studio (SLAC)

# > WIRED

Platform independent event display (Java, SLAC)



#### JAS screenshot





# And finally ...

FERMILAB-PUB-07/094-E

Measurement of the  $\Lambda_b$  lifetime in the exclusive decay  $\Lambda_b \to J/\psi \Lambda$ 

We have measured the  $\Lambda_b$  lifetime using the exclusive decay  $\Lambda_b \to J/\psi \Lambda$ , based on 1.2 fb<sup>-1</sup> of data collected with the D0 detector during 2002–2006. From 171 reconstructed  $\Lambda_b$  decays, where the  $J/\psi$  and  $\Lambda$  are identified via the decays  $J/\psi \to \mu^+\mu^-$  and  $\Lambda \to p\pi$ , we measured the  $\Lambda_b$  lifetime to be  $\tau(\Lambda_b) = 1.218^{+0.130}_{-0.115}$  (stat)  $\pm 0.042$  (syst) ps. We also measured the  $B^0$  lifetime in the decay  $B^0 \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$  to be  $\tau(B^0) = 1.501^{+0.078}_{-0.074}$  (stat)  $\pm 0.050$  (syst) ps, yielding a lifetime

CSC 2009

**Rudi Frühwirth, HEPHY Vienna** 



ъ.

#### Well, actually ...

 E.F. Howe,<sup>14</sup> T. Hoursman,<sup>14</sup> Y. O'Di,<sup>14</sup> D.Z. O'Bi,<sup>1</sup> Z. O'Di,<sup>1</sup> Z. Okarak,<sup>15</sup> B. Orapitala,<sup>15</sup> H. Oraba,<sup>14</sup> J. Och,<sup>2</sup> K. Oraf, G.J. O'rar, y Carala,<sup>15</sup> M. Owa,<sup>14</sup> F. Palay,<sup>15</sup> M. Pongliana,<sup>15</sup> H. Palatatola,<sup>14</sup> H. Parakaa,<sup>2</sup> K.J. Proh,<sup>15</sup> K.Z. Palay,<sup>15</sup> K. Nathaga,<sup>15</sup> K. Nathaga,<sup>15</sup> K. Nathaga,<sup>15</sup> K. Nathaga,<sup>15</sup>

D. Particula, P. M. Para, <sup>10</sup> X. Parin,<sup>10</sup> Y. Dirin,<sup>11</sup> S. Parin,<sup>11</sup> S. Parin,<sup>11</sup> S. Papin,<sup>1</sup> J. Papin,<sup>11</sup>
 M. Parin,<sup>10</sup> S. M. Parinta Loose,<sup>11</sup> Y. M. Parinterlew,<sup>11</sup> T. Papine<sup>11</sup>, M. Papin,<sup>11</sup> J. Papin,<sup>11</sup>
 S. Papi,<sup>11</sup> A. V. Papin,<sup>11</sup> C. Patin,<sup>11</sup> W. M. Parinterlew,<sup>11</sup> Y. Papine<sup>11</sup>, M. Papin,<sup>11</sup> J. Quan,<sup>11</sup>
 S. Papin,<sup>11</sup> S. Quan,<sup>11</sup> A. Patinterlew,<sup>11</sup> W. M. Parinterlew,<sup>11</sup> Y. Papine<sup>11</sup>, M. Papin,<sup>11</sup> J. Quan,<sup>11</sup>
 A. Quan,<sup>11</sup> S. Quan,<sup>11</sup> A. Patinterlew,<sup>11</sup> M. Parinterlew,<sup>11</sup> X. Parinterlew,<sup>11</sup> S. Patinterlew,<sup>11</sup> J. Quan,<sup>11</sup> K. Parinterlew,<sup>11</sup> S. Patinterlew,<sup>11</sup> S.

Förflass,<sup>10</sup> P. Börberlein,<sup>10</sup> T. Billeybrin,<sup>11</sup> C. Bilszill,<sup>11</sup> C. Försteninger,<sup>10</sup> A. Bilszalman,<sup>10</sup> X. Bilszill,<sup>10</sup> Z. Frinde,<sup>10</sup> K. Bargerlei,<sup>11</sup> X. Berlein,<sup>11</sup> X. Bilszill,<sup>11</sup> V. Borgerlein,<sup>11</sup> X. Bilszill,<sup>11</sup> V. Borgerlein,<sup>11</sup> X. Bilszill,<sup>11</sup> Z. Bilszill,<sup>11</sup> D. Byrten,<sup>11</sup> V. Borgerlein,<sup>11</sup> X. Bilszill,<sup>11</sup> Z. Bilszill,<sup>11</sup> D. Byrten,<sup>11</sup> V. Borgerlein,<sup>11</sup> X. Bilszill,<sup>11</sup> Z. Bilszill,<sup>11</sup> D. Byrten,<sup>11</sup> V. Borgerlein,<sup>11</sup> K. Bilszill,<sup>11</sup> Z. Bilszill,<sup>11</sup> Z. Bilszill,<sup>11</sup> D. Bilszill,<sup>12</sup> D. Bilszill,<sup>12</sup> D. Bilszill,<sup>12</sup> D. Bilszill,<sup>12</sup> D. Bilszill,<sup>12</sup> D. Bilszill,<sup>12</sup> D. Bilszill,<sup>13</sup> D. Bilszill,<sup>14</sup> D. Bilszill,<sup>15</sup> D

A. Bayrado, "M. Bayrado," K. Bayrahamado, M. Bayrado, B. Byndrick, "A. Barky, "J. Barky, "M. Bayrado, "A. Bayrado, "S. Bayradow, "S. Bayradow, "M. Bayrado, "M. Bayrado, "S. Bayradow, "S

Borka,<sup>11</sup> D. Wann,<sup>11</sup> D. Wann,<sup>11</sup> D. Daving,<sup>11</sup> D. Waing,<sup>11</sup> P.J. Waing,<sup>11</sup> P.J. and due Hung,<sup>11</sup> D. and Kill,<sup>11</sup>
 Yao Kamina,<sup>11</sup> W.H. Kana Kamana,<sup>11</sup> D. Waing,<sup>11</sup> D. Waing,<sup>11</sup> D. Waing,<sup>11</sup> D. H. Waing,<sup>11</sup> D. Waing,

 <sup>1</sup> Internation de Reiner Alexe, Roment d'en, Argentine 1 <sup>1</sup> Martin, Control Roudow, et Parquise Articus, Neu de Nacha, Bend <sup>1</sup> Paramethia de Reine de Reiner, Neu de Nacha, Bend <sup>1</sup> Paramethia de Reiner and Bener Martin, Neu de Nacha, Bend <sup>1</sup> Paramethia, Maran Tarika, Benerathia Handa, Benda, Benda, Benda, <sup>1</sup> Paramethia de Reiner and Derenation and Paramethia London, Benda, Benda, <sup>1</sup> Paramethia de Reiner and Derenation and Paramethia London, Benda, Benda, <sup>1</sup> Paramethia de Reiner and Derenation and Argebia de Reiner <sup>1</sup> Paramethia de Reiner and Derenation and Argebia de Reiner <sup>1</sup> Paramethia de Reiner and Derenation, Paramethia de Reiner <sup>1</sup> Paramethia de Reiner and Derenation, Paramethia de Reiner <sup>1</sup> Paramethia de Reiner and Derenation, Paramethia de Reiner <sup>1</sup> Paramethia de Reiner Martin, Benga, Charlo Argebia de Reiner <sup>1</sup> Paramethia de Reiner and Derenation, Paramethia de Reiner <sup>1</sup> Paramethia de Reiner Martin, Benga, Charlo Argebia <sup>10</sup> Derenation de Reiner de Reiner de Reiner de Reiner de Reiner <sup>10</sup> Paramethia de Reiner, Albert de Reiner de Reiner de Reiner <sup>10</sup> Paramethia de Reiner de Reiner de Reiner de Reiner de Reiner <sup>10</sup> Paramethia de Reiner de Reiner de Reiner de Reiner de Reiner de Reiner <sup>10</sup> Paramethia de Reiner de Reiner de Reiner de Reiner de Reiner de Reiner <sup>10</sup> Paramethia de Reiner de Reiner de Reiner de Reiner de Reiner de Reiner <sup>10</sup> Paramethia de Reiner de Rei

<sup>10</sup>Tala Indiana of Pandamenial Surrey, Mandai, India Distancely College Dation, Dation, Indian K ern Deinker Schurchen, Krein Beiserstig, Bern, Krein Beigkgenflum Beiserstig, Baser, Krein CHVERTAY, Marin Chy, Marin AST ANY and Determiny of Amatenian, RANNER, Amaterian, The Networks Solver By Nympo, NEX XIII, Nympo, The Networks in "Determiny Product Sources, Solver, Jonas Satisfie for Description and Approximated Marine, Marrie, Januar Pharme Data Defensity, Marrie, Zanie "Anthony for High Rowyy Physics, Problem, Name \* Number Nation Physics Asthony B. Princhers Frank Search, Republic Sciences, 1997 and Backbarn National Station, Berlin, and Sparsh Sciences, 1997 A. Search <sup>2</sup> Repúblické de Debendil Déck, Silvik, Balanind <sup>2</sup> Samula Debendig, Samula, Debal Replen <sup>2</sup> Saparisi Colap, Janim, Debal Replen "Deinersby of Mandanian, Manshatar, Shidol & Septem "Deinersby of Arbons, Theory, Arbons STM, 200 National Astronomy and Distances of Childrenia, Barbolay, Collineais 49187, 2024 Coldered Rate Defende, Franc, Coldered 2018, 5755 Defender of Coldered, Rosenite, Coldered 1999, 201 "Plants Sale Sciences, Tableson, Paris 2004, 024 Peril Robert Manufacture Antonio y Batania, Microb \$1031, 2020 Subservity of Microb at Oringe, Oninge, Microb \$1998, 2020 Warden Aller Steiners, Schult, Start 4011, 508 Warden Schurch, Strender, 20042 4000, 508 Andreas Determing Plannington, Andreas (1979, 2021 <sup>10</sup> Dahara Burg, Kabu Dama, Kabu Dama, Jackana JiWW, 508 <sup>10</sup> Paylor Distanting Colorad, Nanamard, Jackina J 400, 200 <sup>10</sup> June Data Datarrely, Ama, Ama 20111, 200 Deinenity of Konne, Jacorene, Konne Hillit, 2054 Konne Robe Deinenity, Machabia, Konner 1999, 2054 "Annisian Tele Sciencity Sector, Includes (1918, 200 <sup>10</sup> Seizer Sy of Maryland, Colleys Fack, Maryland \$1528, 505 (Spinsor Deferring, Spinsor, Margahards 1998), 518 "Norfeeders Debreity Josley, Manufrants 701 8, 004 <sup>40</sup>Octavelly, a/M Million, See, Seler, M Million J B 50, 0001 Million Pairs Presently, Stat Service, Michigan (1998), 0004 Shineray of Ministry, Shineray, Ministry, 1997, 2004 <sup>10</sup> Sciencelly of Relevants, J. Beach, Nutricular SPRE, 2008 Principal Delevanty, Netradar, Nur. Jonay 10454, 2004 Bats Defending of New York, Buffeld, New York 1988, Olds "Columbia Defending, New York, New York 1998", 506 "Designed by Archeology Restarting, New York 14 497, 1984 Rate Defensity of New York, Story Reach, New York 1973, 208 Reachance National Intensions, Optics, New York 1973, 208 "Largebra Uniterality, Jacquier, Childrens 1989), 508 Octavity of Oldsteine, Roman, Oblivers (1918), 0004
 Oblivers Park Deterring Statistics, Oblivers 5 (19, 00 Brown University, Presidence, Physic Aland 19818, 2081 "Determine of Tana, Articular, Tana 1999, 508 "Station Android: Determine Soliton, Tana 1997, 508 Aire Shihareng, Kreates, Direc 19845, 2024 Debreuty of Forgini, Conditionally, Popula Hill, 504 Unionally of Fundation, Statis, Workshop M 61, 504

PERSONAL ARCPORTATION AND Measurement of the  $\Lambda_0$  lifetime in the acclusive decay  $\Lambda_0 \rightarrow J/\psi \Lambda$ 7.36. Anna 🖉 2. Anna 2<sup>9</sup> 36. Anna 29 22. Anna 29 26. Anna 29 7. Anna 29 2. Agust, 28. Ann 29 34. Alters,<sup>14</sup> G.D. Altersen,<sup>14</sup> G. Alkhauer,<sup>14</sup> A. Alter,<sup>16,4</sup> G. Altersen,<sup>14</sup> G.A. Alters,<sup>1</sup> M. Anationaia, L.F. Anna,<sup>16</sup> T. Andrea,<sup>17</sup> E. Antonna,<sup>16</sup> E. Andrina,<sup>16</sup> M.E. Anaria,<sup>17</sup> T. Annasi,<sup>18</sup> M. Anna,<sup>19</sup> M. Aritmut,<sup>10</sup> A. Astrony<sup>10</sup> E. Kanany<sup>10</sup> A. C.E. Anda Suran<sup>1</sup> O. Astronomico,<sup>10</sup> C. Astronomy<sup>10</sup> C. Astron<sup>1</sup> C. Ag<sup>10</sup> Z. Estimati,<sup>10</sup> A. Roberth & Registry<sup>10</sup> R. Roberth<sup>10</sup> R.M. Rostonio<sup>10</sup> R. Romejer,<sup>10</sup> R. Rosenjer,<sup>10</sup> R. Roberth,<sup>11</sup> A. R. Roston,<sup>14</sup> S. Ragara,<sup>10</sup> S. Rainger,<sup>10</sup> J. Barris,<sup>1</sup> J.F. Baribil,<sup>10</sup> V. Basin,<sup>11</sup> D. Barn,<sup>11</sup> S. Bals,<sup>1</sup> A. Bon,<sup>10</sup> K. Fegell, M. Fegel,<sup>16</sup> C. Frikoper, Theoryper,<sup>16</sup> L. Fellenine,<sup>16</sup> A. Bellerane,<sup>16</sup> J.A. Ferler,<sup>16</sup> E.E. Feil,<sup>16</sup> Breach?" S. Bunkers," L. Burkers," I. Britsen," M. Banapen," S. Brankers," VA. Burkers," 2.0. Birth<sup>1</sup> V. Birtinger,<sup>1</sup> C. Birtsel,<sup>11</sup> G. Birtsel,<sup>11</sup> F. Birtsen,<sup>14</sup> E. Birtsley,<sup>14</sup> D. Birth,<sup>14</sup> E. Birtsel<sup>15</sup> A. Buchalds, S. Buller, T.A. Buller, G. Bullerr, H.X. Bur, T. Bur, H.A. Brendi, S. Brank, H. ant," A. Bran, " D. Barra," H.J. Barbara," D. Barkinia," M. Barkin," V. Barran," R. Bertin, "A. R. Bertin," T.S. Bernell, " C.S. Barrello," 254, Beller," F. Cellerer, " R. Cabell," J. Canada," E. Carry,<sup>10</sup> W. Carrylin,<sup>1</sup> E.C.E. Carry,<sup>10</sup> HM. Carry,<sup>11</sup> E. Carlita Velda,<sup>11</sup> E. Cheleninek,<sup>10</sup> D. Chalantonig<sup>10</sup> K. Chan,<sup>4</sup> K.M. Chen,<sup>41</sup> A. Chander,<sup>11</sup> S. Charles,<sup>12</sup> S. Chen,<sup>14</sup> S. Chendler,<sup>14</sup> D.K. Che,<sup>14</sup> E. Chri, \* E. Christian, \* L. Christian, \* T. Christian, \* E. Changia, \* D. Chen, \* E. Chanal, \* C. Charth,<sup>11</sup> T. Cradus,<sup>1</sup> M. Conis,<sup>11</sup> W.E. Carper,<sup>10</sup> M. Comme,<sup>10</sup> F. Caulon,<sup>10</sup> M.C. Centers, E. Origit Januarity<sup>11</sup> D. Ority<sup>12</sup> M. Oritz<sup>10</sup> H. Andritz<sup>1</sup> A. Day<sup>11</sup> G. Davity<sup>11</sup> E. Day<sup>11</sup> F. An Jang<sup>11</sup> R.J. An Jang<sup>11</sup> E. Da La Ora, Burdy<sup>11</sup> G. De Oliveira Marina<sup>1</sup>, J.D. Dependenti,<sup>11</sup> F. Diffel,<sup>11</sup> M. Davaritan,<sup>11</sup> Denins,<sup>10</sup> D. Denier,<sup>10</sup> S. Denier,<sup>11</sup> S. Deni,<sup>10</sup> M. Denier,<sup>10</sup> A. Denier,<sup>10</sup> S. Denier,<sup>10</sup> S. Denier,<sup>10</sup> S. Denier,<sup>10</sup> A. Denie R. Duning, V.E. Bedrikare,<sup>10</sup> A.V. Porpulae,<sup>10</sup> T. Polot,<sup>10</sup> F. Fields,<sup>11</sup> F. Filleri,<sup>11</sup> W. Zahn,<sup>10</sup> E.E. Fah,<sup>11</sup> M. Fort,<sup>11</sup> M. Farines,<sup>11</sup> M. Fas,<sup>11</sup> H. Fas,<sup>11</sup> H. Fass,<sup>11</sup> T. Galleri,<sup>11</sup> C.F. Galm,<sup>11</sup> E. Galler,<sup>11</sup> E. Gripser,<sup>11</sup> C. Garda,<sup>1</sup> A. Garda, B.Gida,<sup>11</sup> Y. Gardan,<sup>11</sup> F. Gag<sup>11</sup> W. Gaida,<sup>11</sup> D. Galda<sup>11</sup> C.E. Gardan,<sup>11</sup> Y. Gardada<sup>11</sup> D. Schnigh<sup>11</sup> G. Gardad<sup>11</sup> S. Gardada<sup>11</sup> S. Gardad<sup>11</sup> S. Gardad<sup>11</sup> S. G E.S. Gaurra, G. Gauta, "Ph. Ont," J. S. Oriva," A. Galagina, " E. Orivaniza," M.W. Orivania, S. Out," J. Gui, " G. Gulleren," J. Orivana, " A. Rao," S.J. Shilay, " F. Station," E. Steppin," 2 Mitry<sup>14</sup> I. Hal,<sup>16</sup> S.E. Hal,<sup>16</sup> L. Hu,<sup>1</sup> K. Huagdi,<sup>16</sup> F. Huann,<sup>16</sup> E. Kado,<sup>16</sup> A. Kaol,<sup>16</sup> R. Haringin,<sup>16</sup> J.M. Mauginan, P. S. Neuer, H J. Mays, P. T. Milleder, P. D. Mails, P. 203, Surman, P. 216, Microffler, A.S. Metana," U. Metala," C. Metala, " X. Berrer," C. Madera," M.D. Richera," S. Metala," 2D. Robert, R. Roserkee,<sup>15</sup> R. Reeth,<sup>14</sup> M. Zokriel,<sup>15</sup> R.J. Rong<sup>14</sup> Z. Henyes,<sup>16</sup> R. Mandes,<sup>16</sup> F. Markes,<sup>16</sup> Y. Hu,<sup>1</sup> Z. Schemb, V. Epste, <sup>1</sup> L Indell,<sup>11</sup> S. Ungenolb,<sup>11</sup> A.E. Dr.<sup>11</sup> E. Schus,<sup>11</sup> M. Sallel,<sup>14</sup> E. Schu<sup>14</sup> E. Schutz<sup>14</sup> C. Derik \* R. Datk/\* R. John \*\* C. Dilano,\*\* M. Dilano,\*\* A. Joshima,\* F. Douro,\*\* A. John D. Kite," S. Kale, " E. Kajhen," A.M. Kalada," 334, Kale, " 3.S. Kale," S. Kappin, " D. Kamman," J. Karpe,<sup>14</sup> S. Karpe,<sup>14</sup> I. Nelson,<sup>16</sup> D. Kar,<sup>14</sup> S. Kan,<sup>16</sup> V. Keuble,<sup>16</sup> S. Kelov,<sup>14</sup> S. Kemide,<sup>1</sup> P. Shalifert, A. Elman, A. Stamblert, Y.M. Stamber, D. Ebrilde, " R. Elm," T.J. Sim," M.R. Krieght M. Kumbert B. Klime, P. 216, Krister J.F. Konstite, M. Mapel, S. V.M. Konstite, S. Kallerd, S. A.V. English<sup>11</sup> D. English A. Separaditi,<sup>16</sup> T. Enklish A. Santa,<sup>11</sup> E. Ennel<sup>14</sup> A. Engen<sup>16</sup> T. Enrich<sup>14</sup> 3. Erite," D. Leen," E. Lenname, " G. Leenking," J. Leenkans," F. Leines," WM. Lee," A Lefter,"  $\begin{array}{l} 3.5\, (1+1)^{10} \, 3.5\, (1+1)^{10} \, 4.5\, (1+1)^{11} \, 3.5\, (1+1)^{11} \, 3.5\, (1+1)^{11} \, 3.5\, (1+1)^{11} \, 4.5\, (1+1)^{11} \, 3.5\,$ A. Lenninsky, "M. Lengers," A. Lennin, " P. Lenger, " R.Z. Lenger," A.L. Lynn," A.R.A. Morris," D. Marin, " R.J. Mahara,<sup>14</sup> R. Milling<sup>14</sup> G. Magara,<sup>16</sup> A. Magariariti,<sup>16</sup> H. Makern,<sup>14</sup> R.E. Mal,<sup>14</sup> R.E. Millimiana, R. Mola, \* V.L. Malpher, \* R.F. Mas, \* Y. Marwis, \* R. Morin, \* R. McCarlin, \* A. Michelson, \* A. Marriss,<sup>14</sup> L. Mendens,<sup>5</sup> F.C. Manasharin,<sup>5</sup> M. Martin,<sup>4</sup> K.W. Marris,<sup>15</sup> A. Mayne,<sup>14</sup> Z. Mayne,<sup>15</sup> M. Minister,<sup>15</sup>

T. Millel,<sup>11</sup> J. Milerril,<sup>11</sup> Z. Malar,<sup>1</sup> S. X. Manara,<sup>12</sup> X. Madal,<sup>12</sup> X. Madal,<sup>13</sup> X. Madal,<sup>13</sup> X. Madal,<sup>14</sup> X. Matal,<sup>14</sup> X. Maran,<sup>14</sup> M. Malara,<sup>14</sup> M. Matal,<sup>15</sup> X. Maran,<sup>14</sup> M. Matal,<sup>15</sup> X. Maran,<sup>15</sup> M. Matal,<sup>15</sup> X. Maran,<sup>15</sup> X. Maran,<sup>16</sup> X. Maran,<sup>16</sup> X. Maran,<sup>16</sup> X. Matal,<sup>16</sup> X. Maran,<sup>16</sup> X. Matal,<sup>16</sup> X. Matal,<sup>17</sup> X. Matal,<sup>17</sup> X. Matal,<sup>17</sup> X. Matal,<sup>17</sup> X. Matal,<sup>17</sup> X. Matal,<sup>17</sup> X. Matal,<sup>18</sup> X. Ma

#### **Rudi Frühwirth, HEPHY Vienna**



# **Distributed analysis**

- Physics analysis will take place in many labs all over the world
- Physicists need fast access to event data and corresponding calibration, alignment and bookkeeping data ... and to simulated data
- > We need the grid!



# The LHC Computing Grid

- Global collaboration of more than 140 computing centers in 34 countries
- Four-tiered model
- > Data storage and analysis infrastructure >  $O(10^5)$  CPUs
- > O(10<sup>5</sup>) CPUs
- >>25 PByte disk storage (tiers 0 and 1)



# Data management

- Dataset bookeeping
  - Which data exist?
- Dataset locations service
  - Where are the data?
- Data placement and transfer system
  - Tier-0  $\rightarrow$  Tier-1  $\rightarrow$  Tier-2
- Data access and storage
  - Long-term storage, direct access



# Datasets in CMS

#### > RAW: Raw data (1-1.5 MB)

 Detector data, L1 trigger results, HLT results, reconstructed HLT objects

#### > RECO: Reconstructed data (200-800 kB)

- Reconstructed objects (hits, clusters, tracks, vertices, muons, electrons, jets)
- > AOD: Analysis object data (50-100 kB)
  - High-level reconstructed objects (tracks, vertices, muons, electrons, jets)



# Datasets in CMS (ctd)

# > TAG: Tagging data (10 kB)

Run/event number, some high-level physics objects

#### Non-event data

- Construction data (information on sub-detectors)
- Equipment management data (detector geometry, electronics)
- Configuration data (front-end electronics)
- Conditions data (run conditions, calibration, alignment)



#### Data flow in CMS

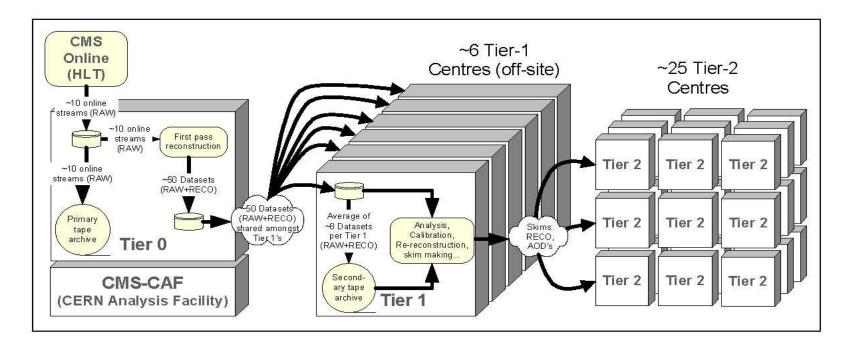


Figure 2.1: Schematic flow of bulk (real) event data in the CMS Computing Model. Not all connections are shown - for example flow of MC data from Tier-2's to Tier-1's or peer-to-peer connections between Tier-1's.

#### CSC 2009

#### Rudi Frühwirth, HEPHY Vienna



#### **Tiered resources**

#### > Tier-0 (CERN)

- First pass of reconstruction
- Primary archive on mass storage
- > Tier-1 (~10 centers)
  - Global and local services
  - (Only) copies of certain samples
  - Reconstruction
  - Monte Carlo production



# Tiered resources (ctd)

#### > Tier-2 (~25 centers)

- Associated to a particular Tier-1 centre
- Local use
- CMS controlled use
- Opportunistic use

#### > Tier-3 (~100 centers)

- Coordination with a specific Tier-2 centre
- Local use
- No guaranteed support, no guaranteed availability



# Additional resources

#### > CMS-CAF (CERN Analysis Facility)

- Ready access to RAW and RECO data
- Short turnaround
- Operation critical tasks: detector diagnostics, calibrations for HLT, trigger optimization, testing of new trigger algorithms
- Main repository for software and documentation



# Summary

# > Physics computing involves:

- Event filtering with multilevel trigger
- Persistency of raw data
- Calibration and alignment
- Persistency of calibration, alignment and environmental data
- Event reconstruction
- Persistency of reconstruction objects and metadata



# Summary (ctd)

#### > Physics computing involves:

- Simulation of many million events
- Persistency of simulated raw data and truth information
- Reconstruction of simulated events
- Persistency of reconstruction object and truth information
- Distributed physics analysis and event viewing
- Persistency of high-level physics objects



# Outlook on the track

# > ROOT

- 3 hours of lectures (A. Naumann, B. Bellenot)
- 3 hours of exercises (A. Naumann, B. Bellenot)

#### Data analysis

- 4 hours of lectures (A. Heikkinen, I. Puljak)
- 4 hours of exercises (A. Heikkinen, I. Puljak)



