Physics Analysis at LHC-I

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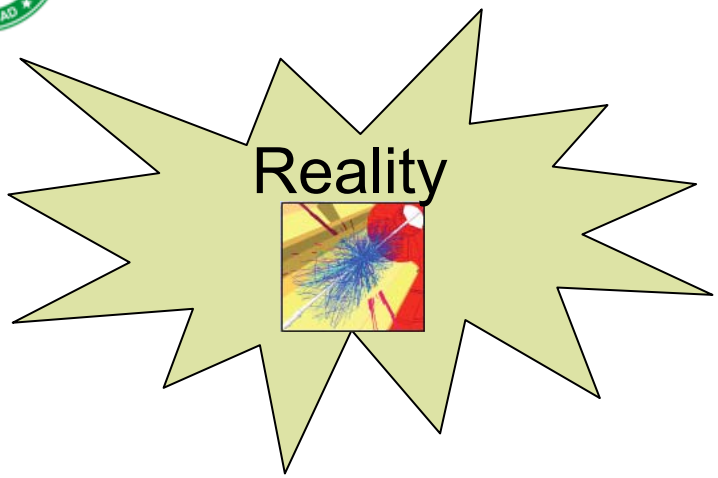
National Centre for Physics

Outline

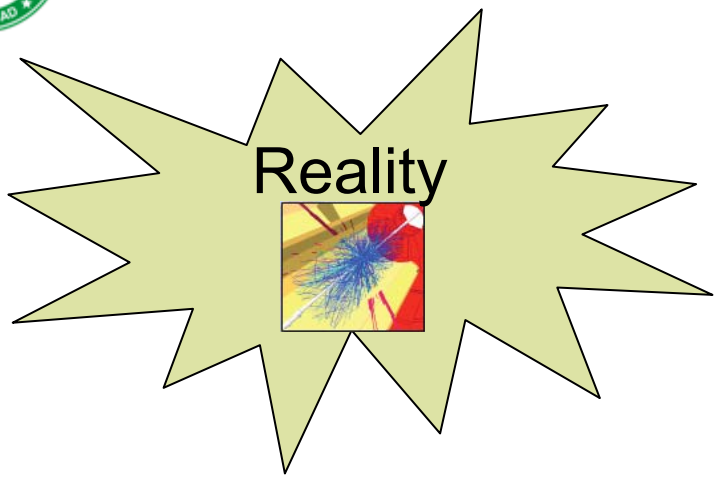
- Raw data Format
- Event Generators
- Physics data objects
- The software : CMSSW, ROOT
- A real analysis

Our Task



We use experiments to inquire about what reality (nature) does.

Our Task



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Theory

The goal is to understand in the most general; that's usually also the simplest.

-A.Eddington

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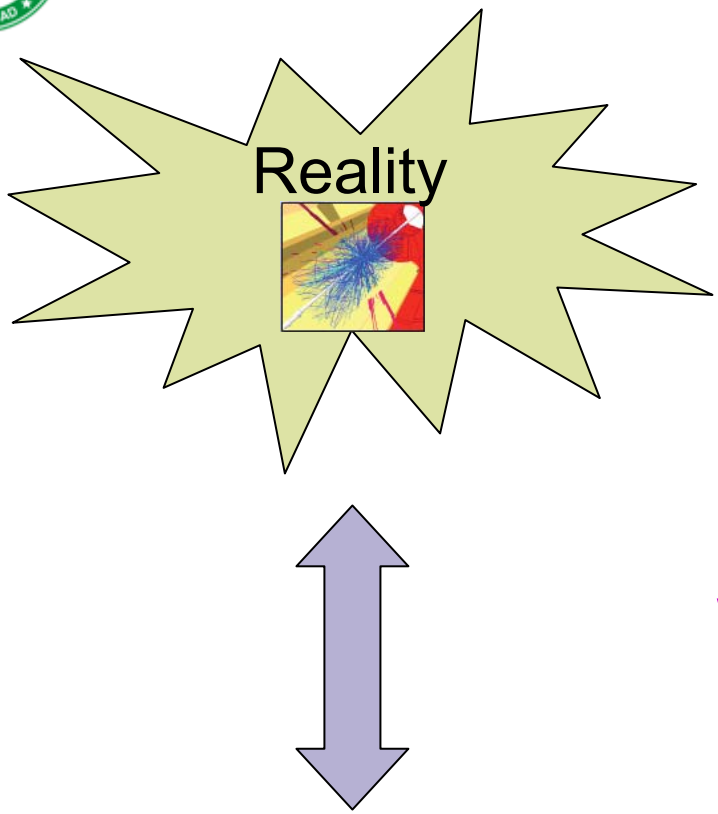

We use experiments to inquire about what reality (nature) does.

We intend to fill this gap

The goal is to understand in the most general; that's usually also the simplest.

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Theory……

$$\mathcal{L} = -\tfrac{1}{4}\mathbf{W}_{\mu\nu}\cdot\mathbf{W}^{\mu\nu} - \tfrac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

$\mathrm{W}^{\pm}, \mathrm{Z}, \gamma$ kinetic energies and self-interactions

$$+\overline{L}\gamma^{\mu}\left(i\partial_{\mu} - g\tfrac{1}{2}\tau\cdot\mathbf{W}_{\mu} - g'\tfrac{Y}{2}B_{\mu}\right)L$$
$$+\overline{R}\gamma^{\mu}\left(i\partial_{\mu} - g'\tfrac{Y}{2}B_{\mu}\right)R$$

lepton and quark kinetic energies and their interactions with $\mathrm{W}^{\pm}, \mathrm{Z}, \gamma$

$$+\left|\left(i\partial_{\mu} - g\tfrac{1}{2}\tau\cdot\mathbf{W}_{\mu} - g'\tfrac{Y}{2}B_{\mu}\right)\phi\right|^{2} - V(\phi)$$

$\mathrm{W}^{\pm}, \mathrm{Z}, \gamma$ and Higgs masses and couplings

$$-(G_1\overline{L}\phi R + G_2\overline{L}\phi_c R + h.c.)$$

lepton and quark masses and coupling to Higgs

L ... left–handed fermion (l or q) doublet
R ... right–handed fermion singlet

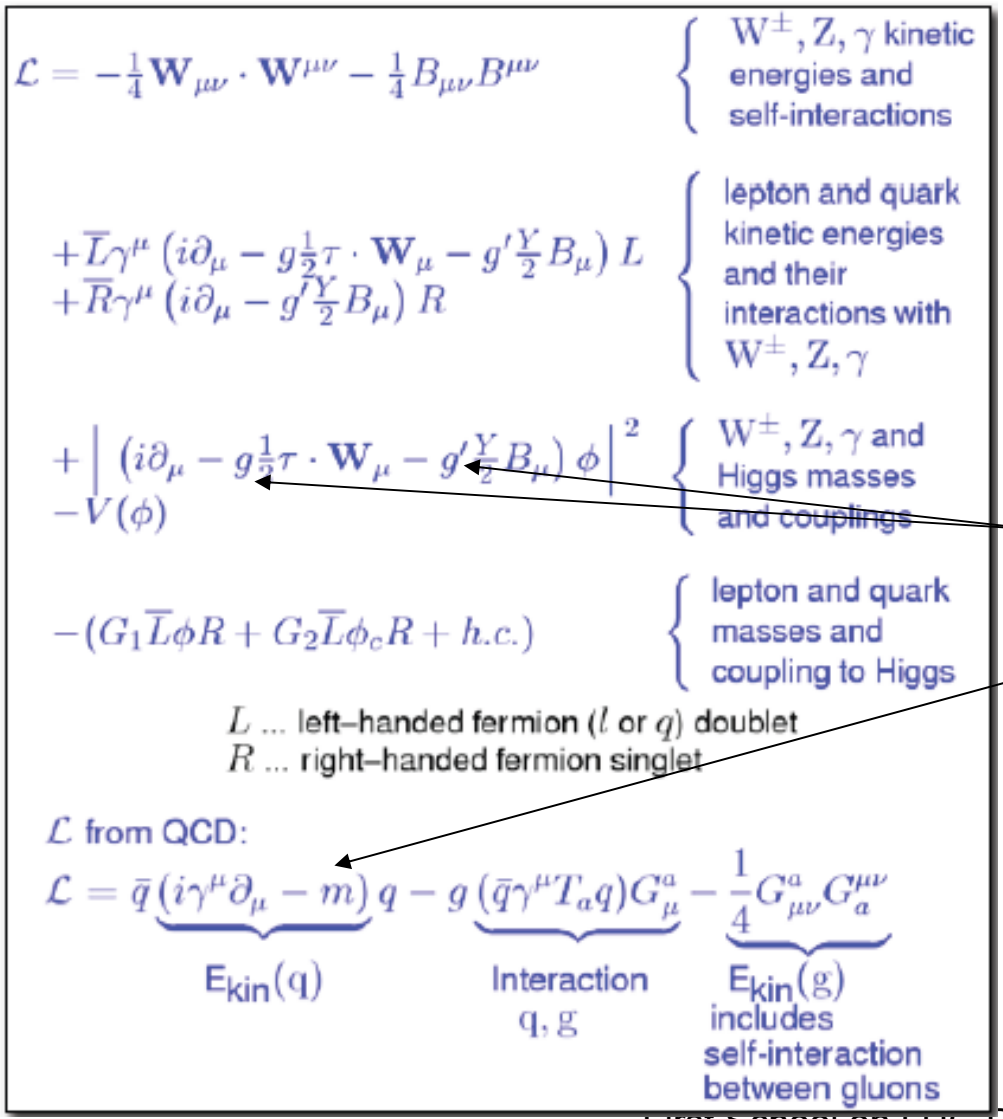
$\mathcal{L}$ from QCD:

$$\mathcal{L} = \bar{q}\underbrace{(i\gamma^{\mu}\partial_{\mu} - m)}_{\mathrm{E_{kin}(q)}}q - g\underbrace{(\bar{q}\gamma^{\mu}T_a q)G^a_{\mu}}_{\text{Interaction } q,g} - \underbrace{\frac{1}{4}G^a_{\mu\nu}G^{\mu\nu}_a}_{\mathrm{E_{kin}(g)}}$$

$\mathrm{E_{kin}(g)}$ includes self-interaction between gluons

e.g
The Standard Model

Theory……



e.g
The Standard Model

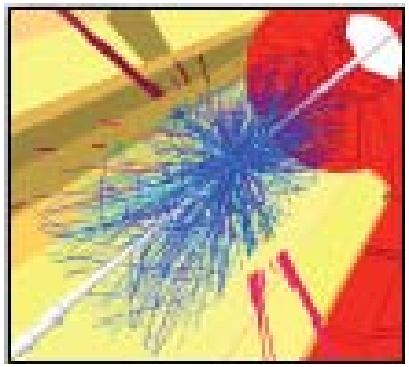
has paramaters

coupling constants

masses

predicts:
cross-sections,
branching ratios,
lifetimes,…

Experiment…..



Output is a set of signals from all the detector channels

Signal has two parts

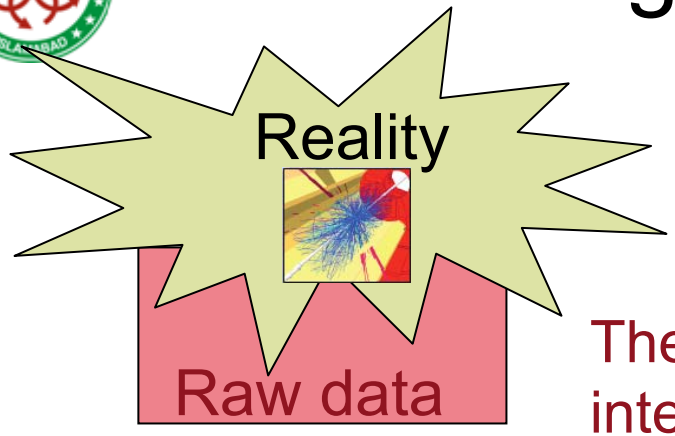
- Address

– which detector element took the reading

- Value(s)

– what the electronics wrote out

Making the connection



The imperfect measurement of a set of interactions in a detector

Theory

A small number of general equations, with some parameters (poorly or not known at all)

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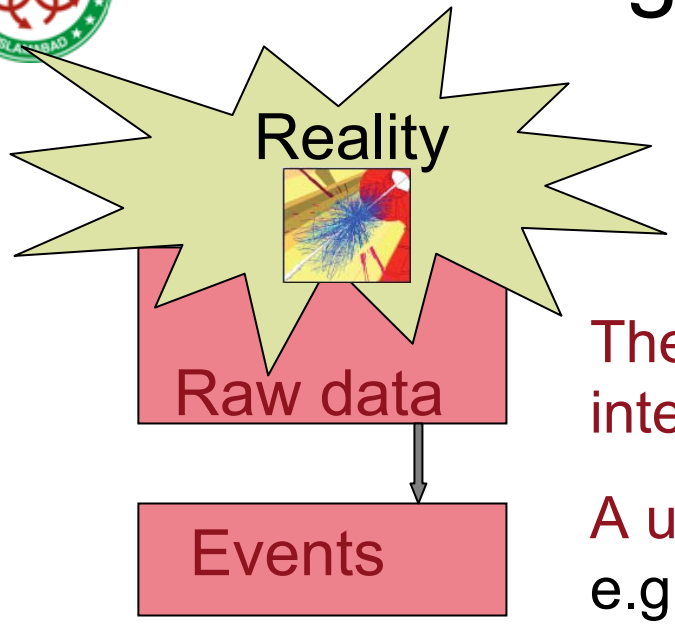

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A unique happening:
e.g Run 2345, event 123

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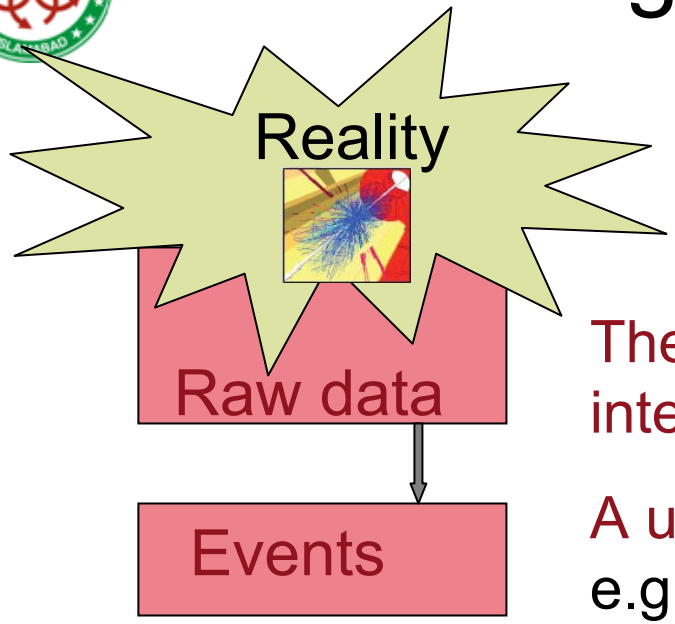

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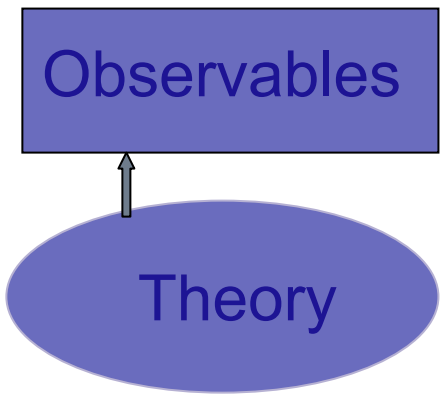

cross-sections (probabilities for interactions), branching ratios (BR), lifetimes,…..

A small number of general equations, with some parameters (poorly or not known at all)

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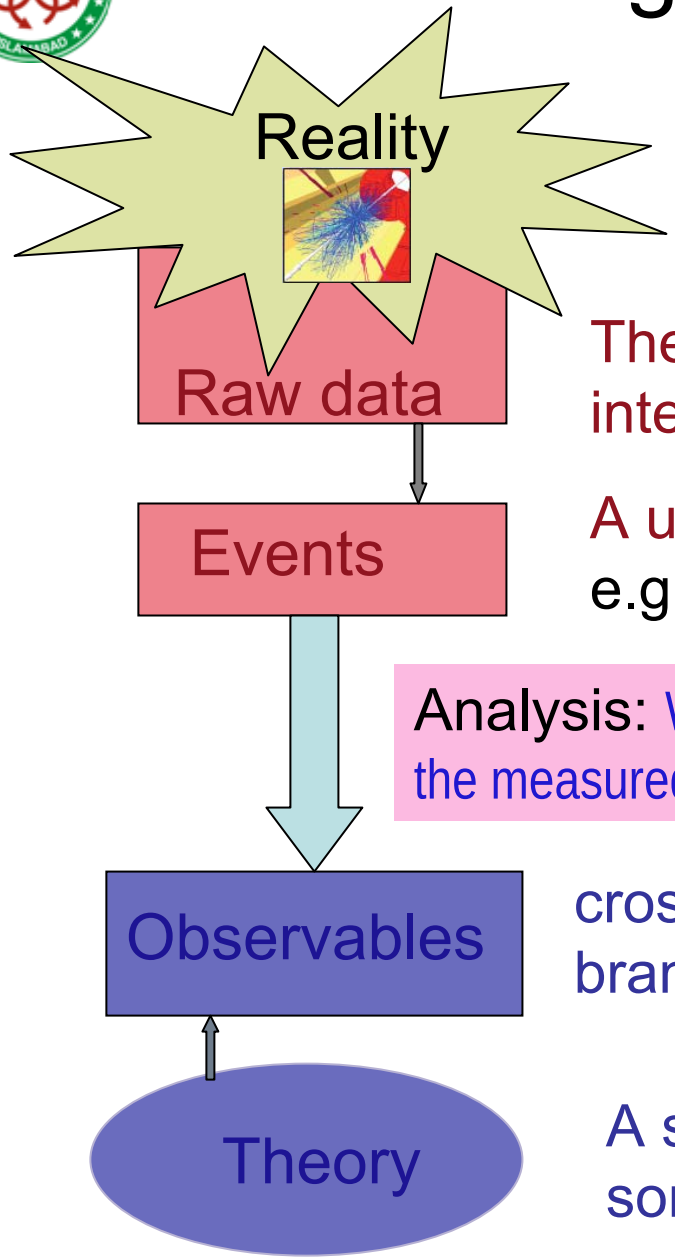


The imperfect measurement of a set of interactions in a detector

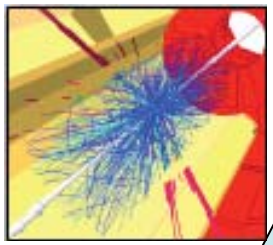
A unique happening:
e.g Run 2345, event 123

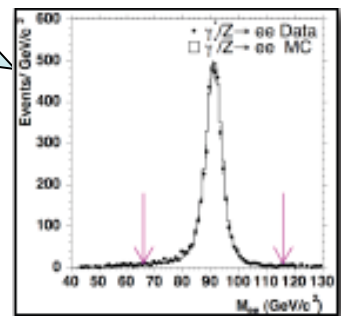
Analysis: We "confront theory with experiment" by comparing the measured quantity (observable) with the prediction.

cross-sections (probabilities for interactions), branching ratios (BR), lifetimes,…..

A small number of general equations, with some parameters (poorly or not known at all)

Data Analysis Chain





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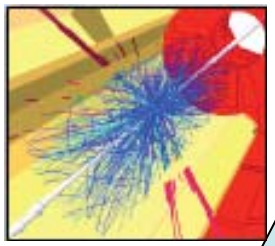
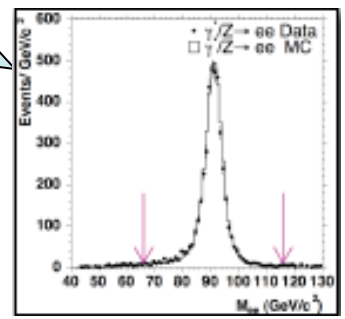


- Have to collect data from many channels on many sub-detectors



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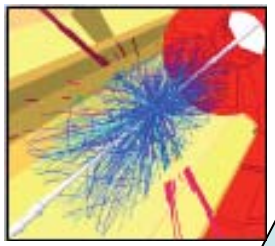

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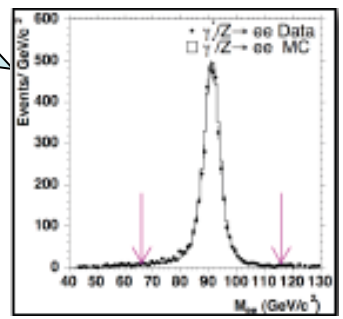

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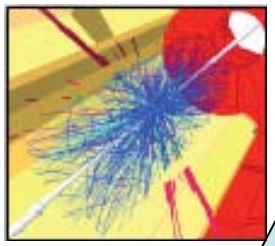

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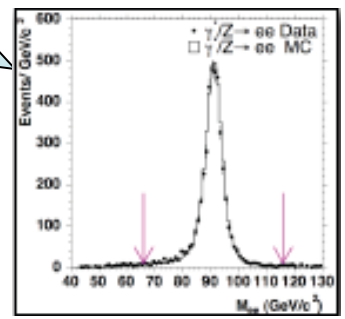

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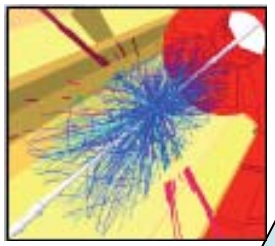

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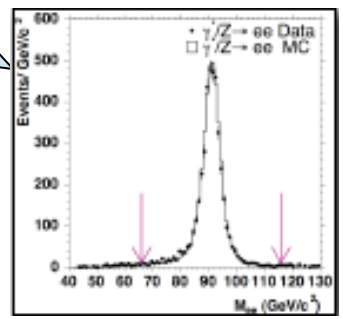
- Store the data



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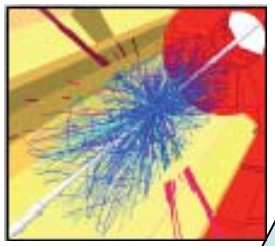

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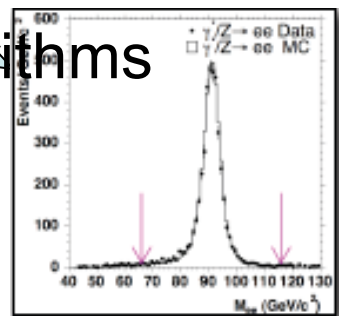
- Analyze the data
  - Reconstruction, user analysis algorithms



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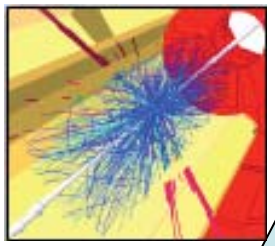

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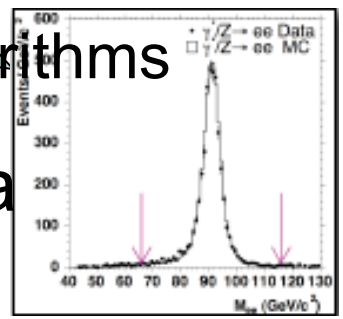

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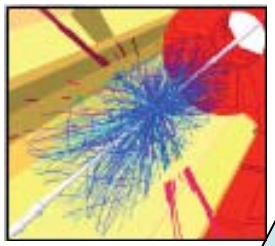

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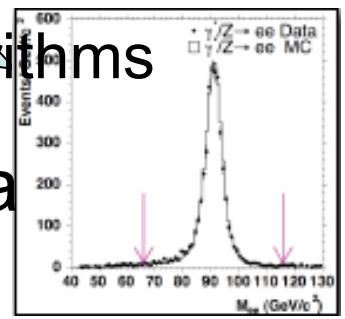
- Compare theory with data



Data Acquisition Chain

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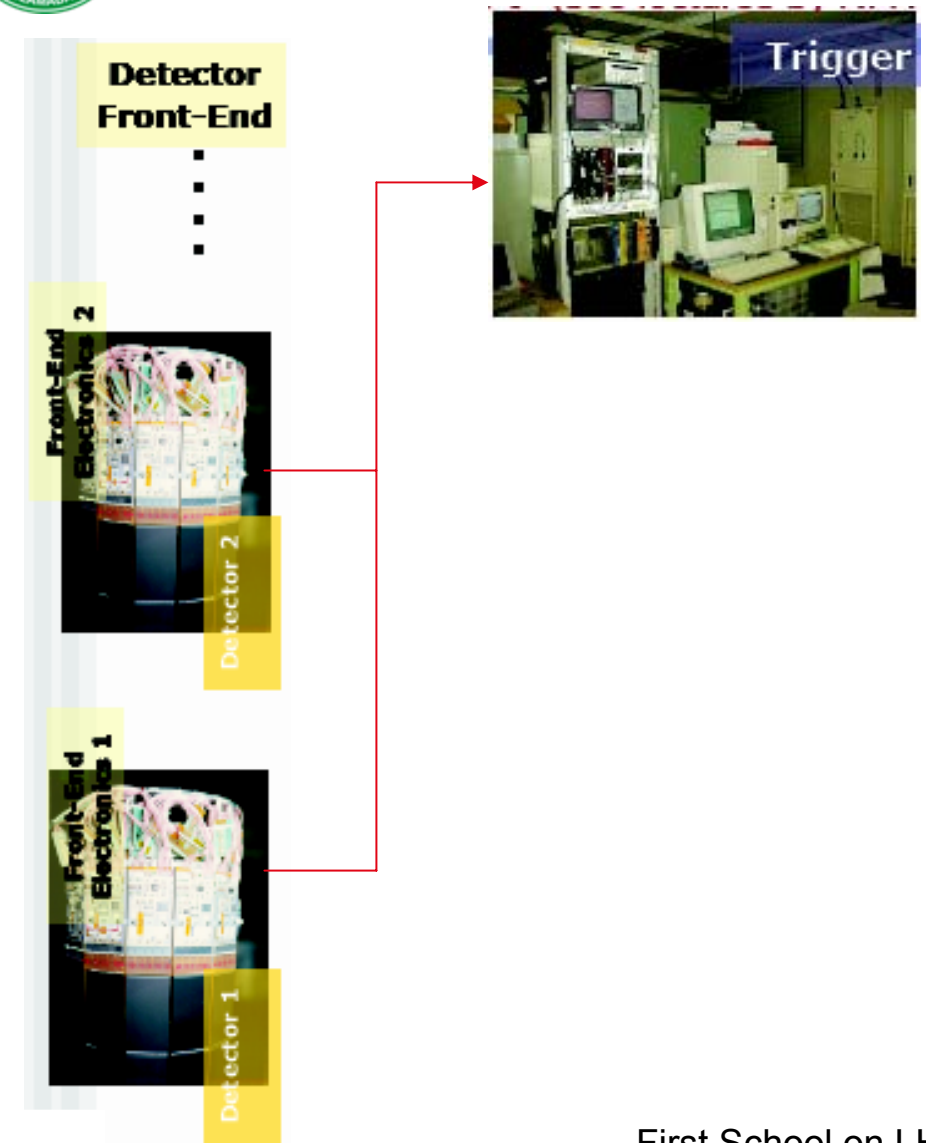

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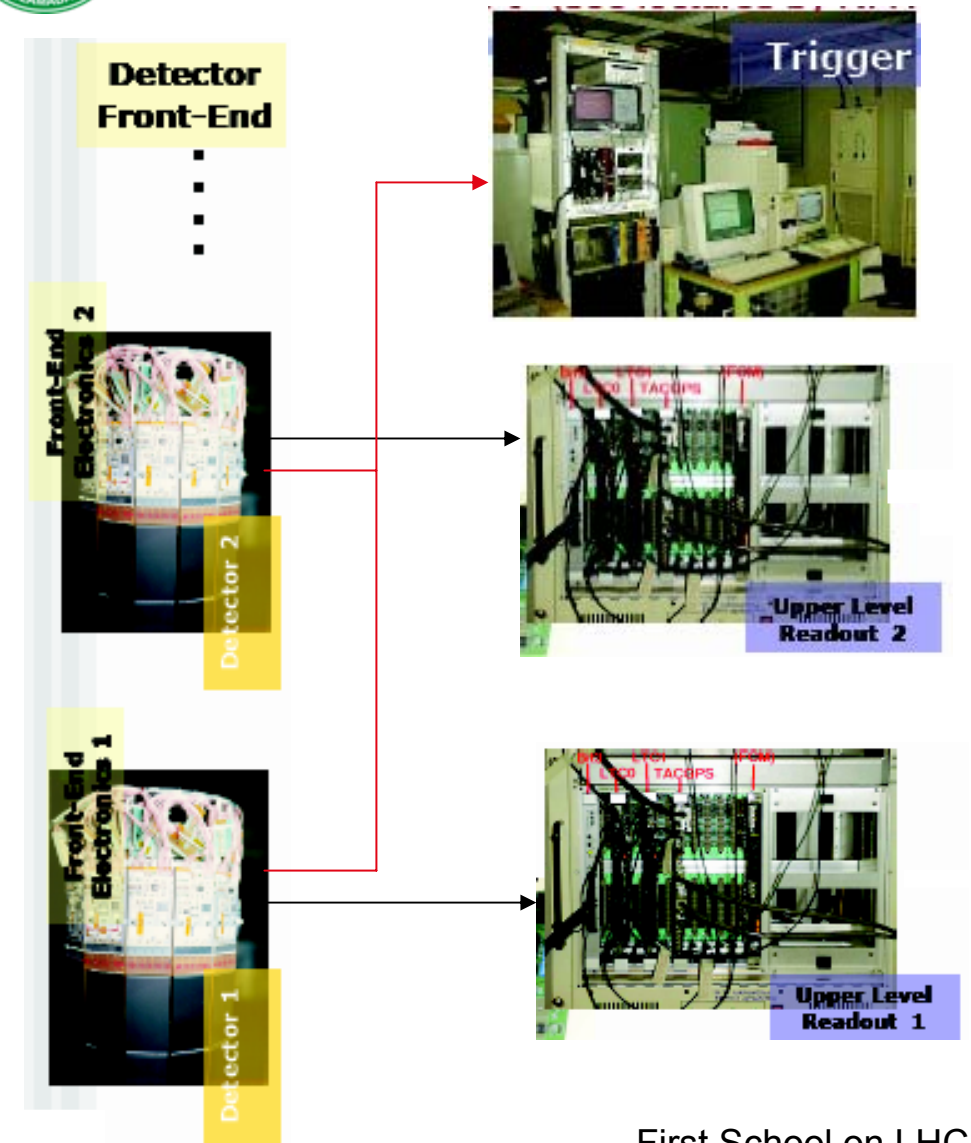

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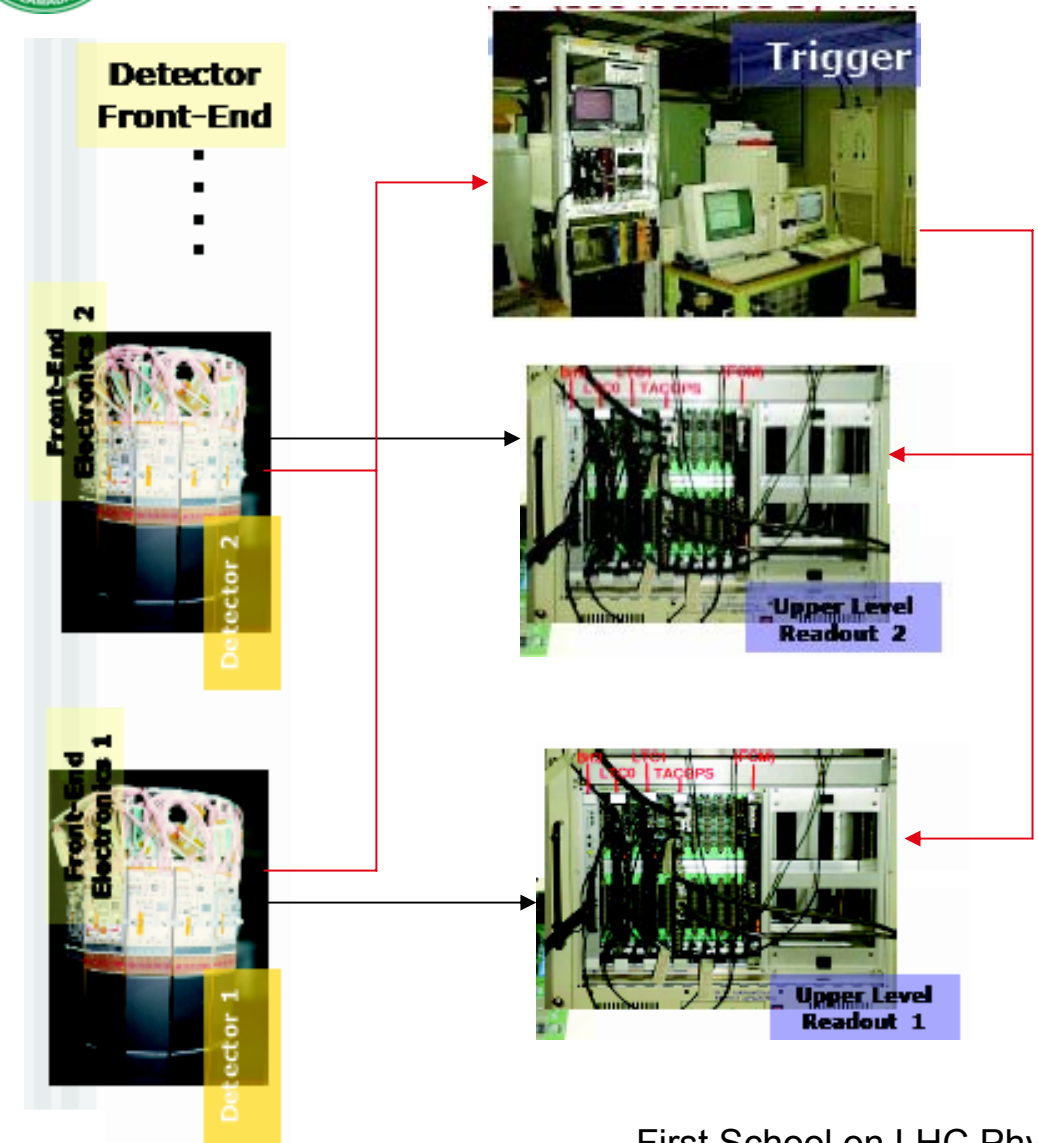

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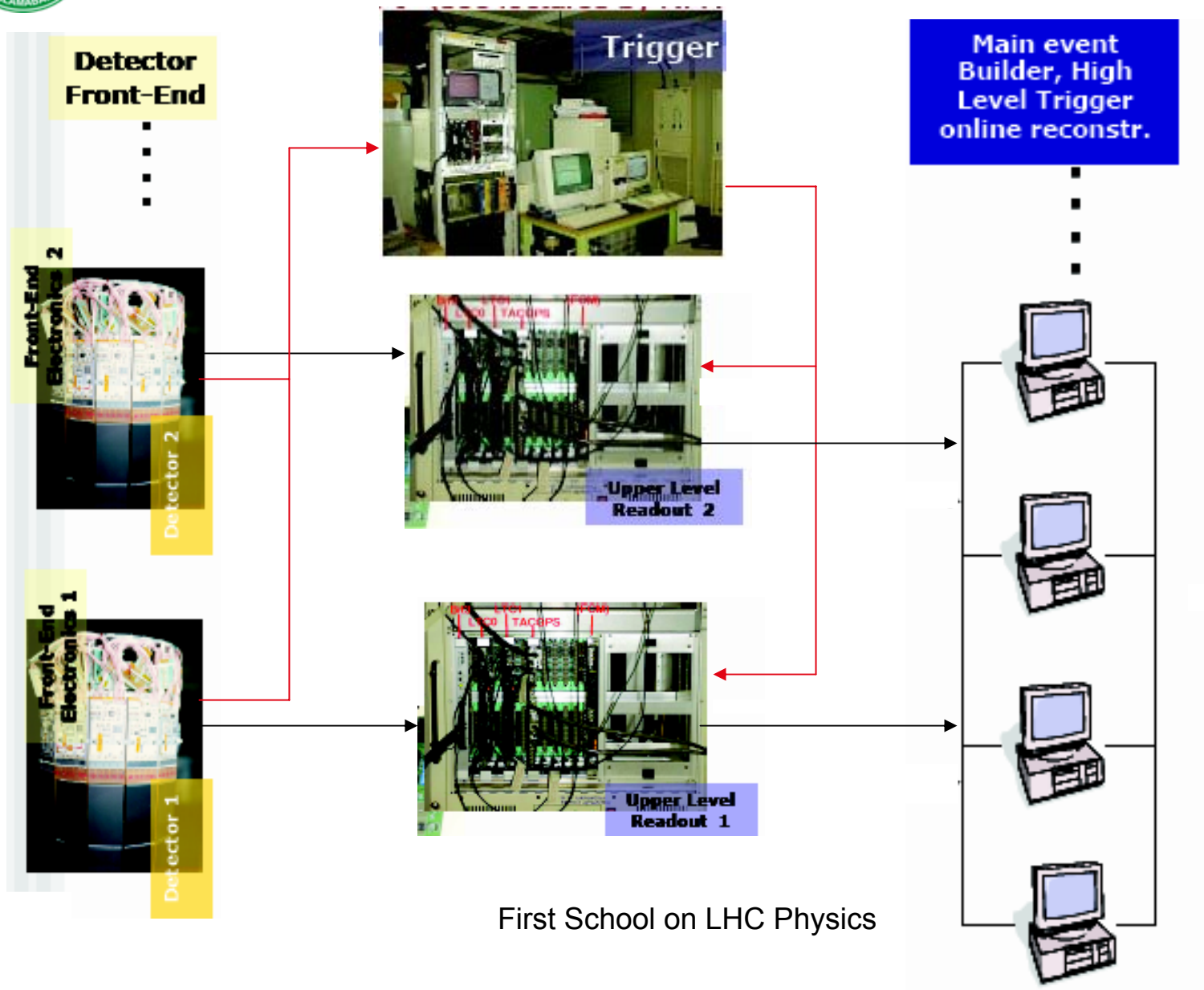

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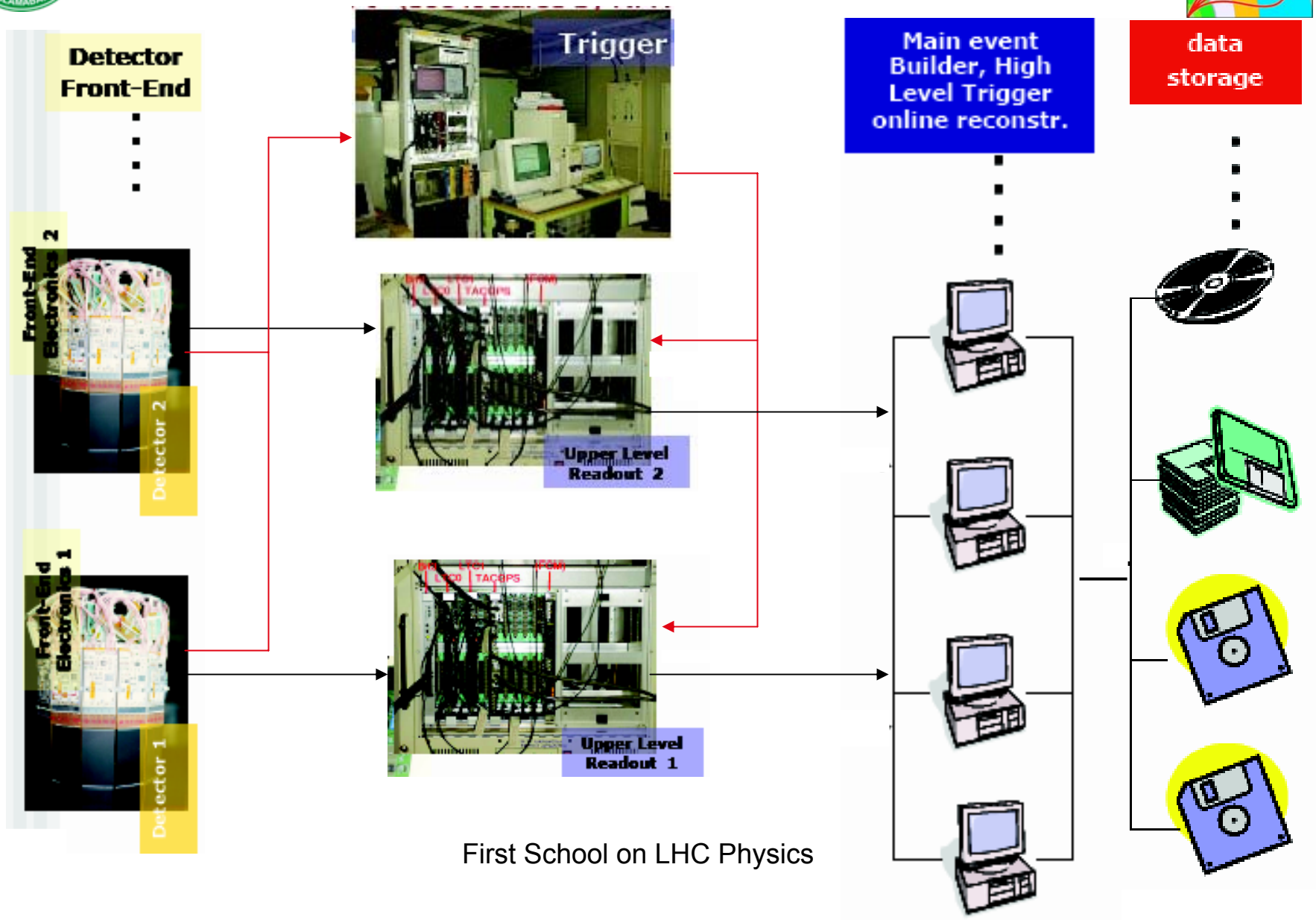

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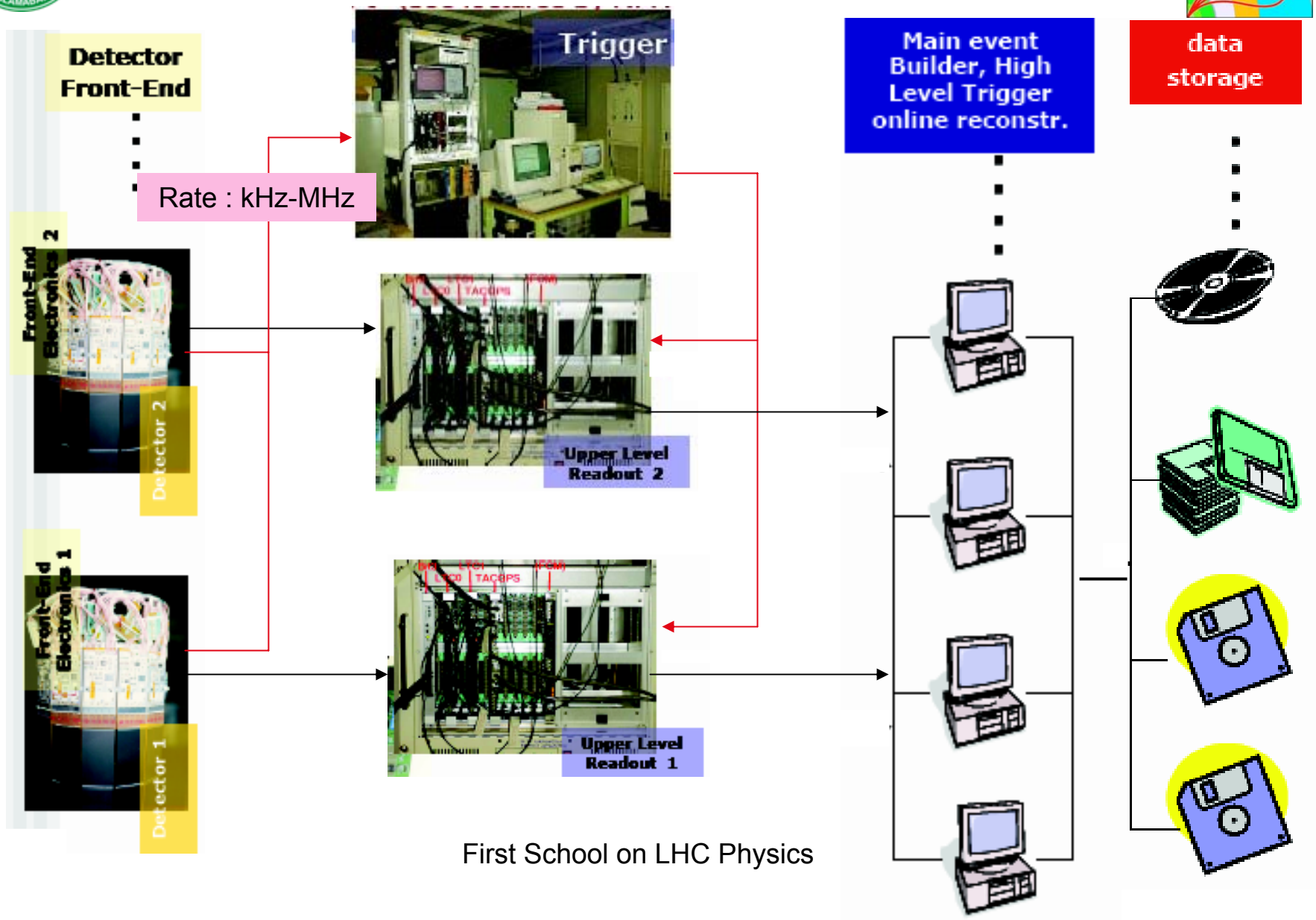

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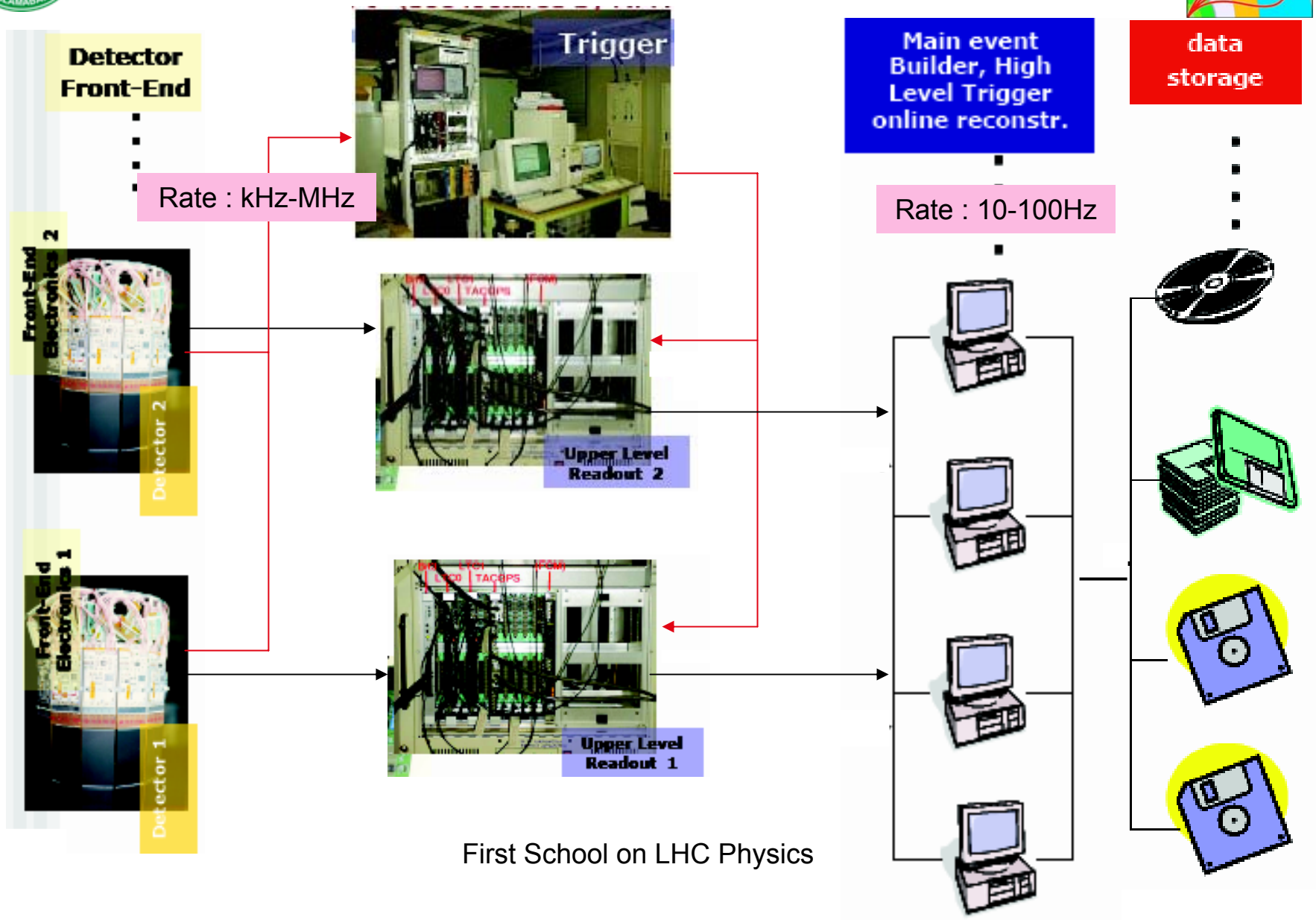

Offline Analysis Chain

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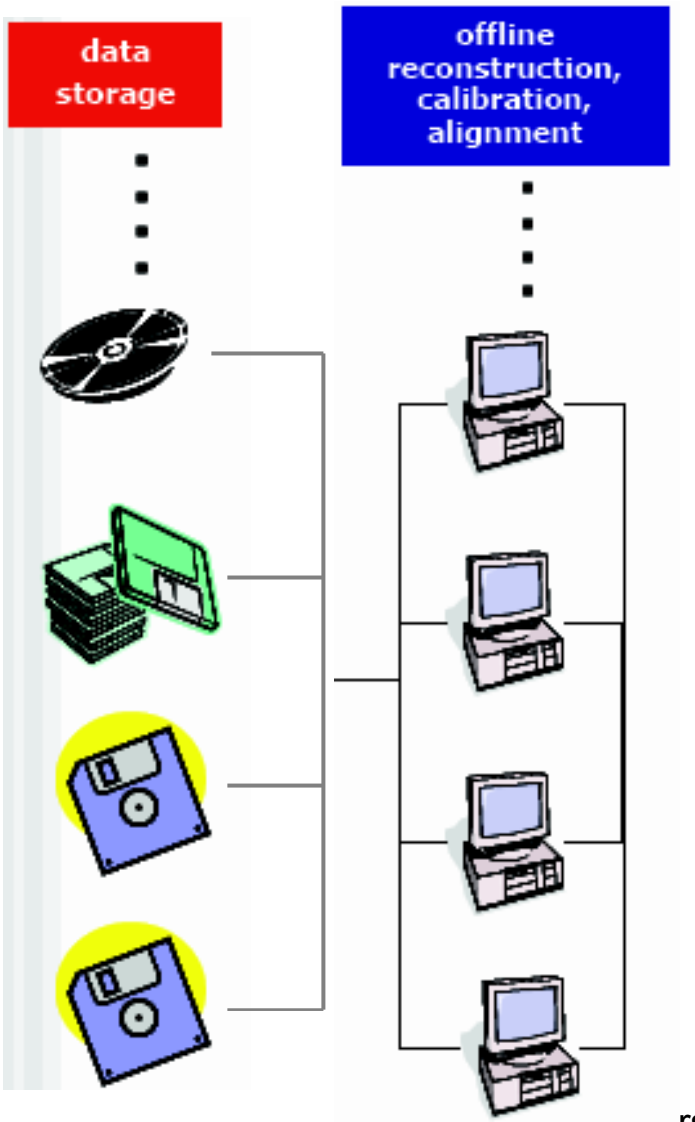

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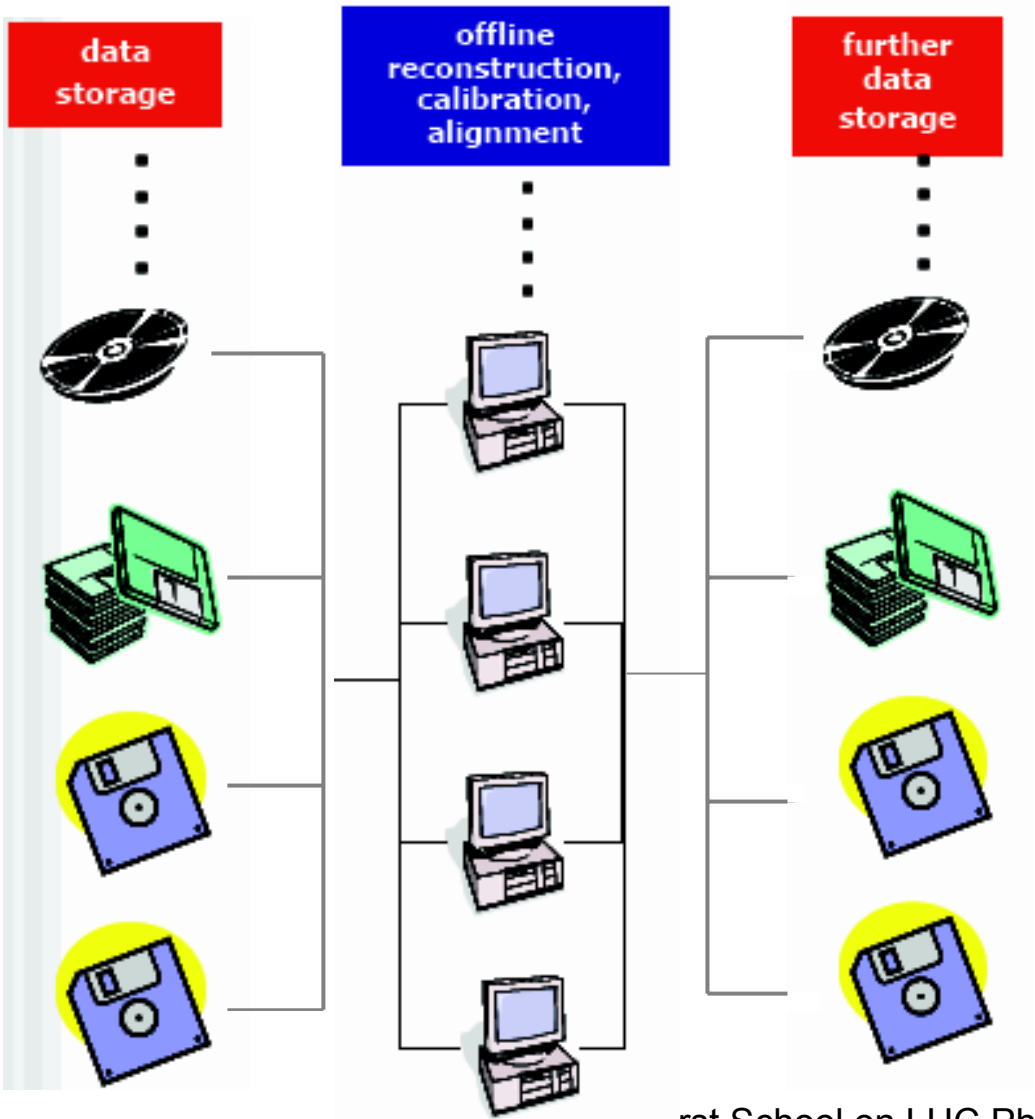

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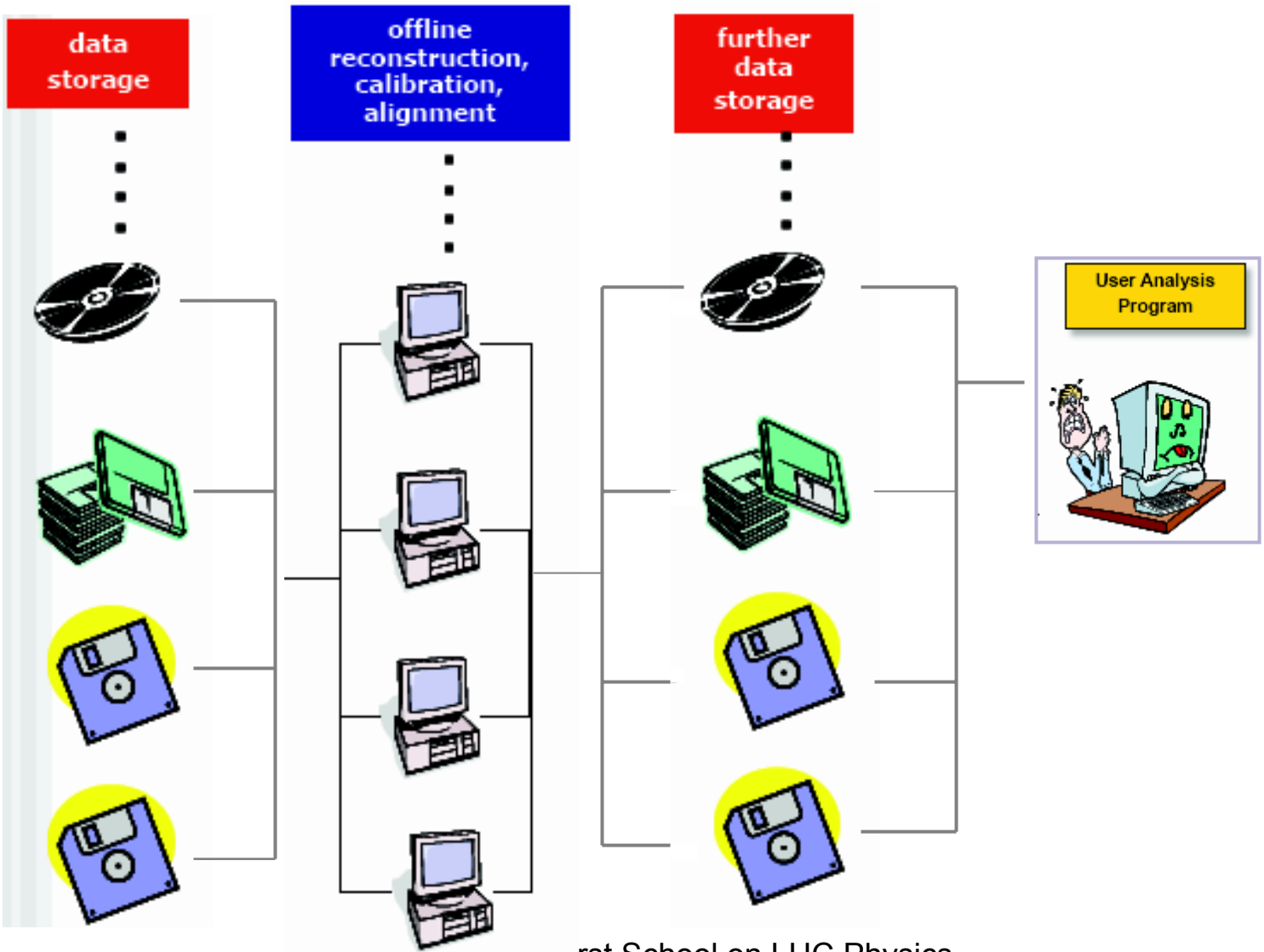

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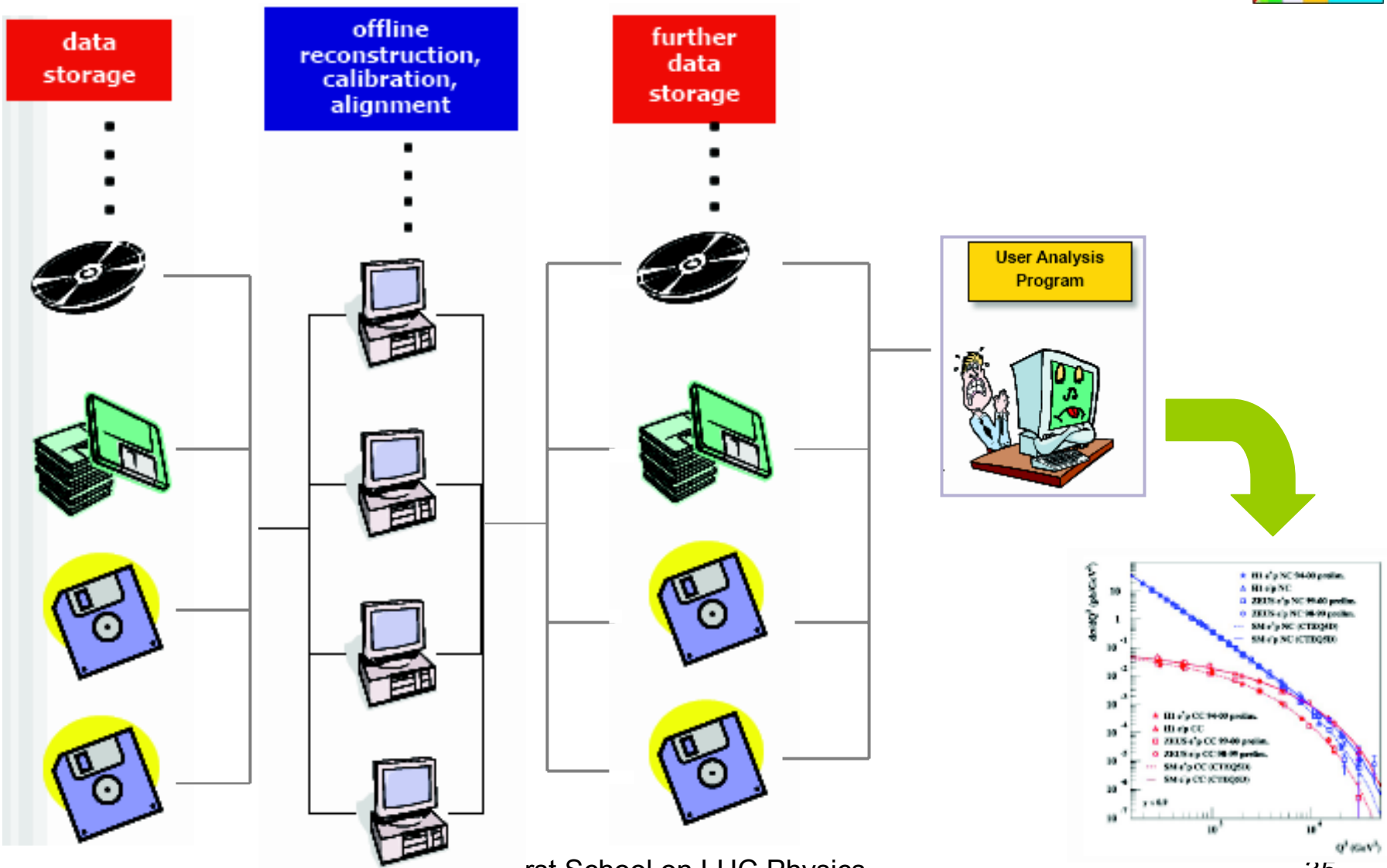

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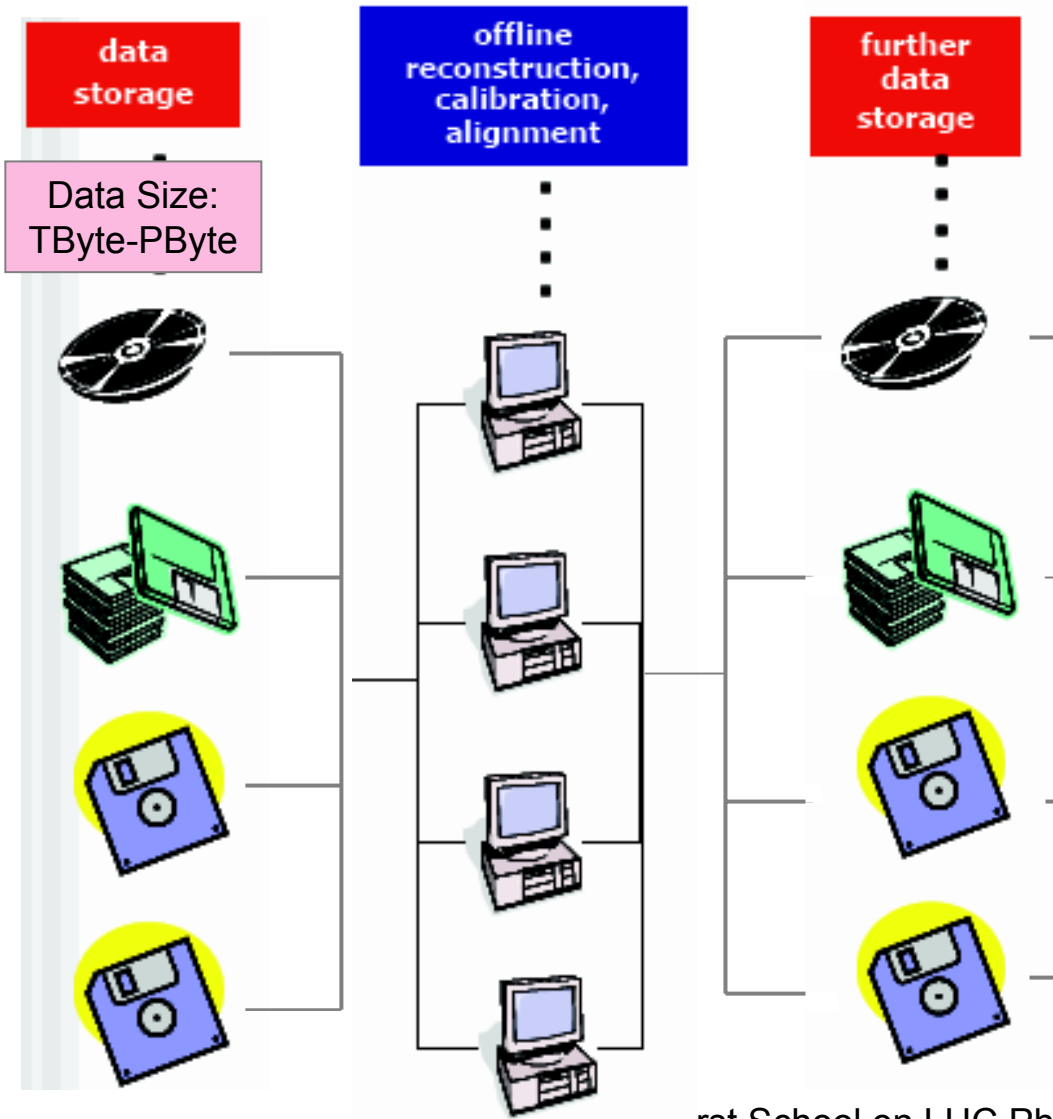

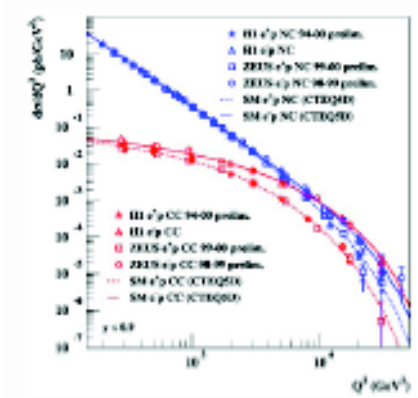

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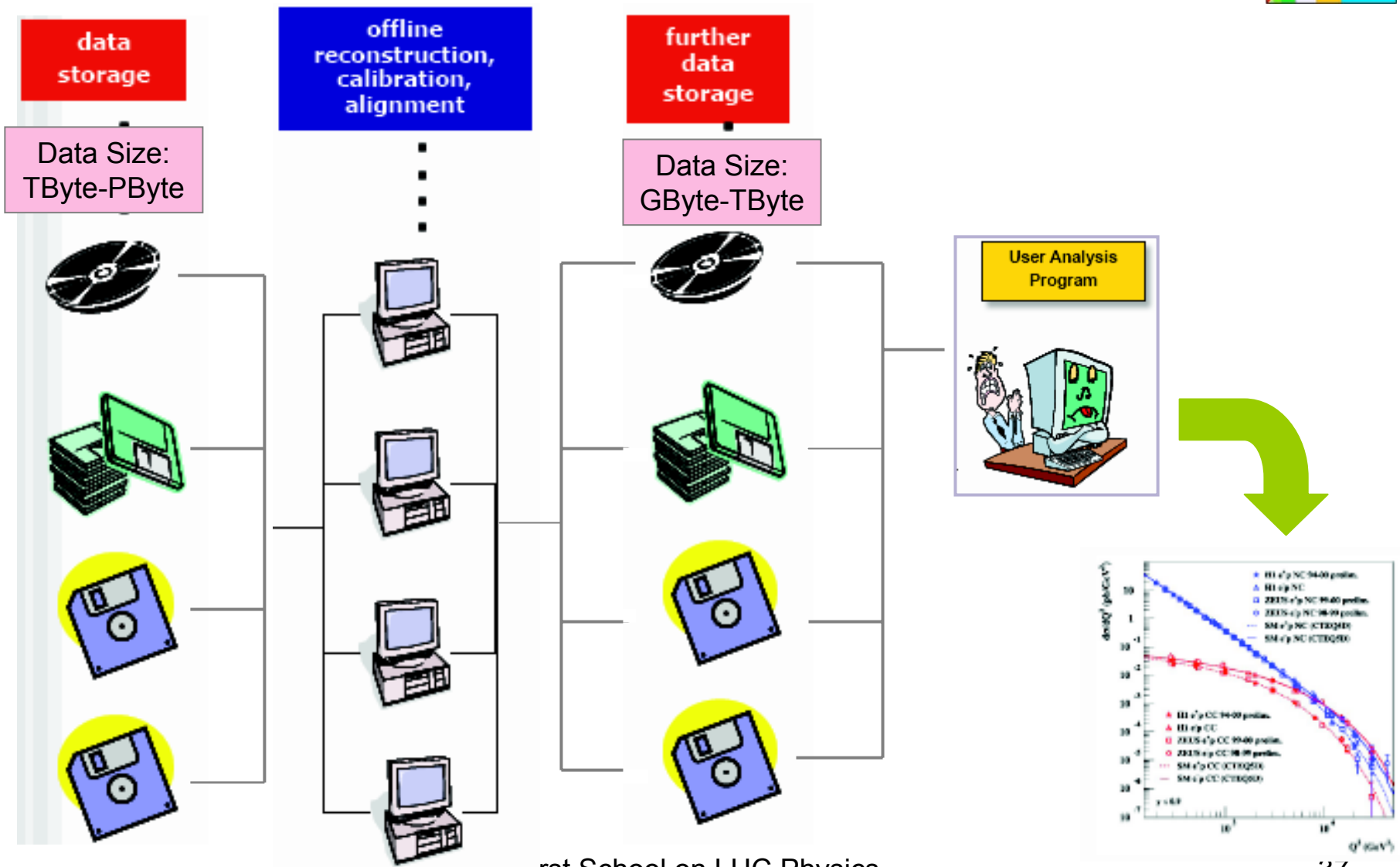

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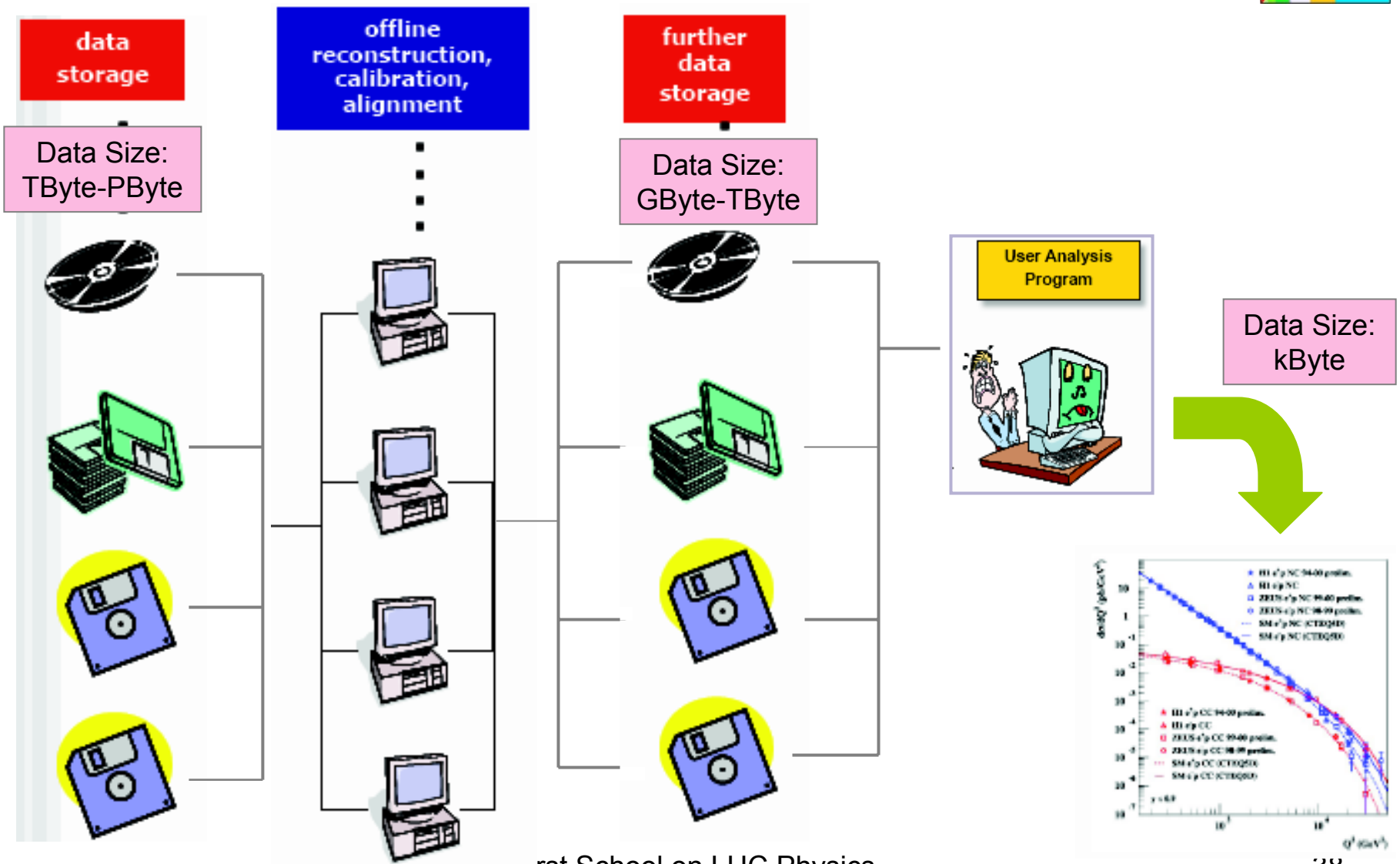

From Electronics to Physics

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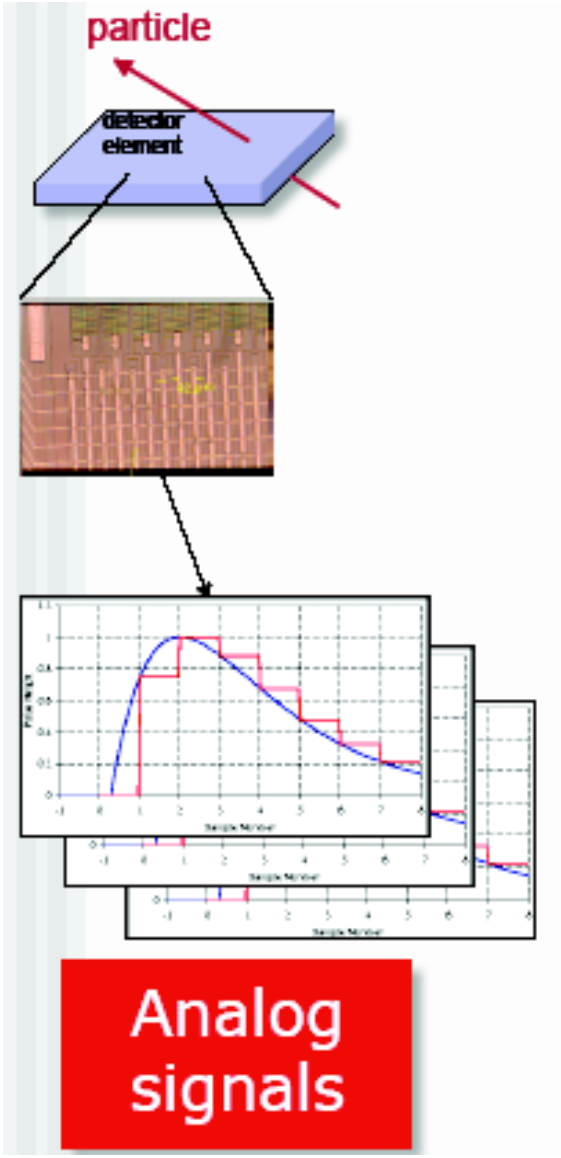

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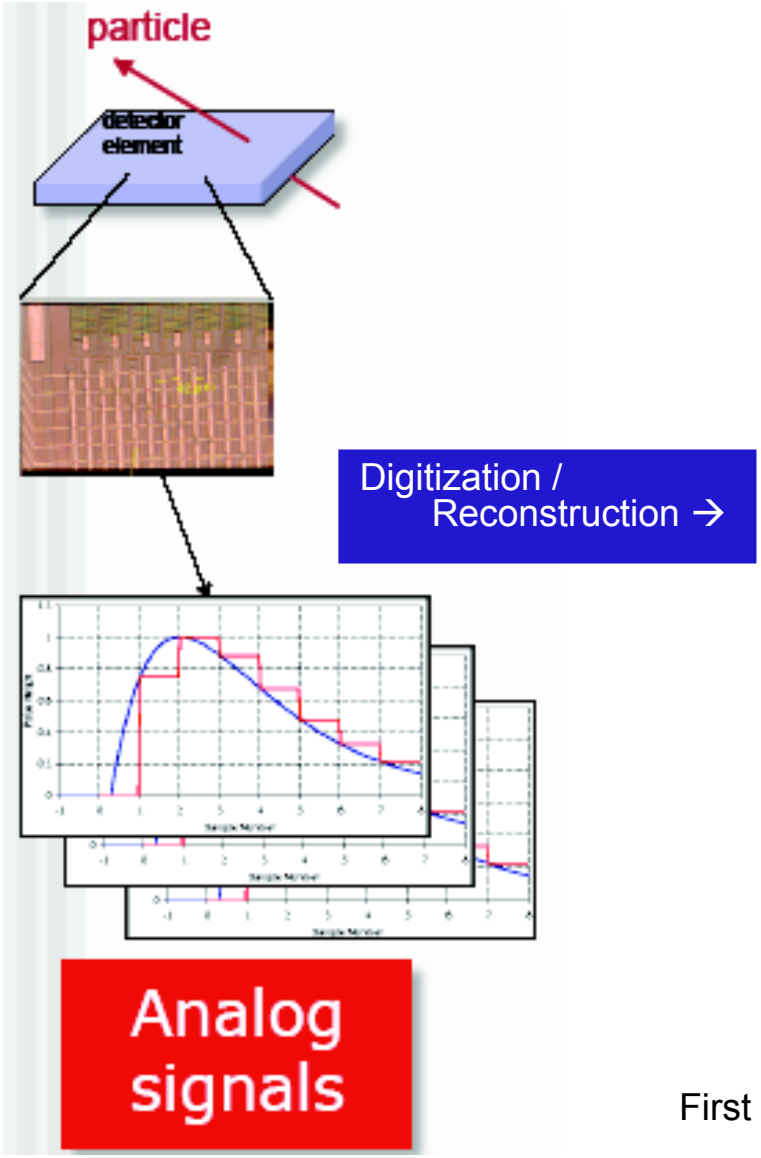

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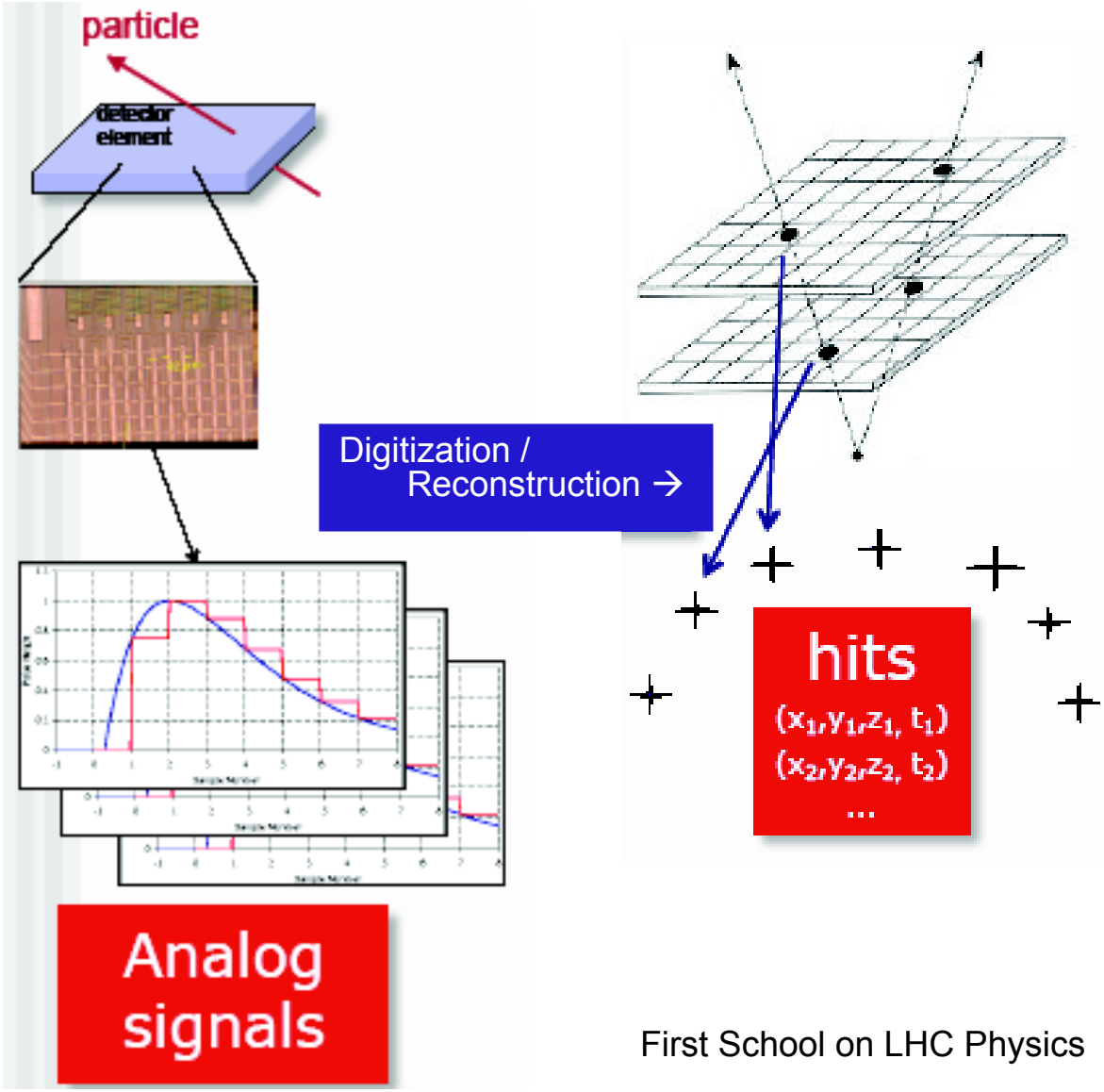

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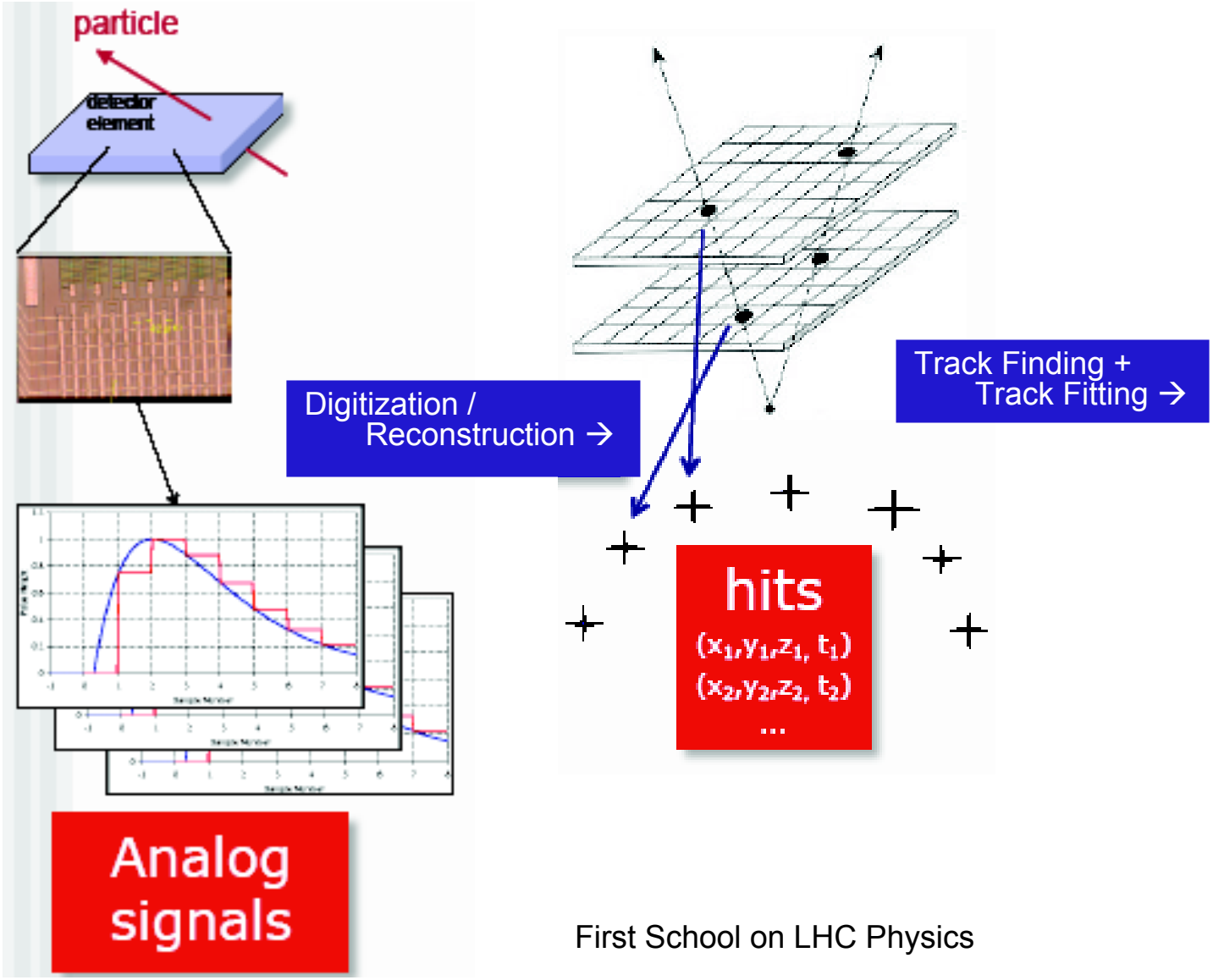

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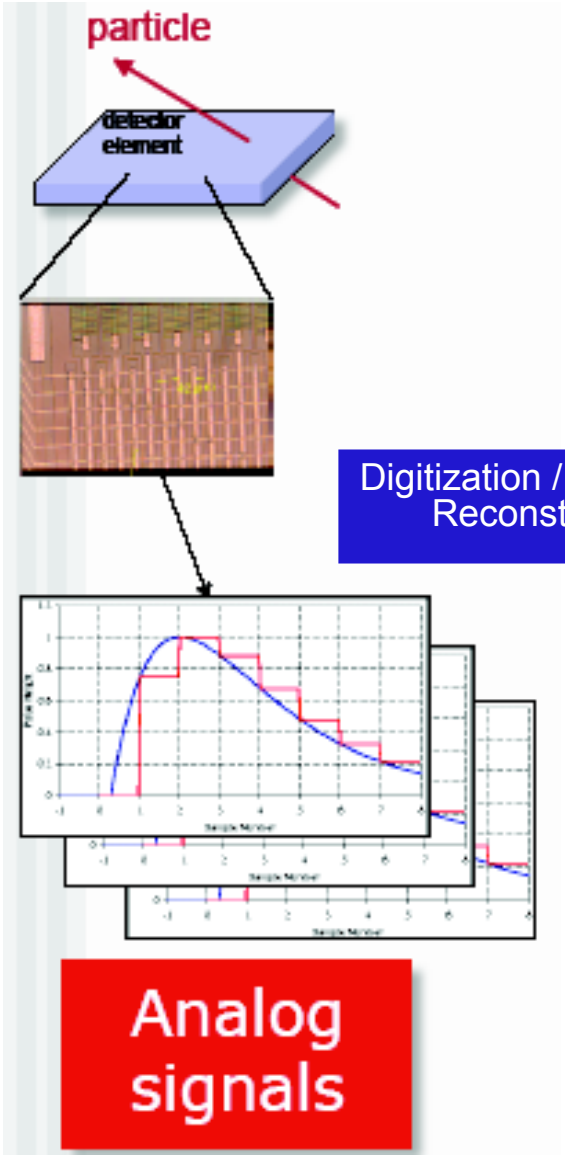
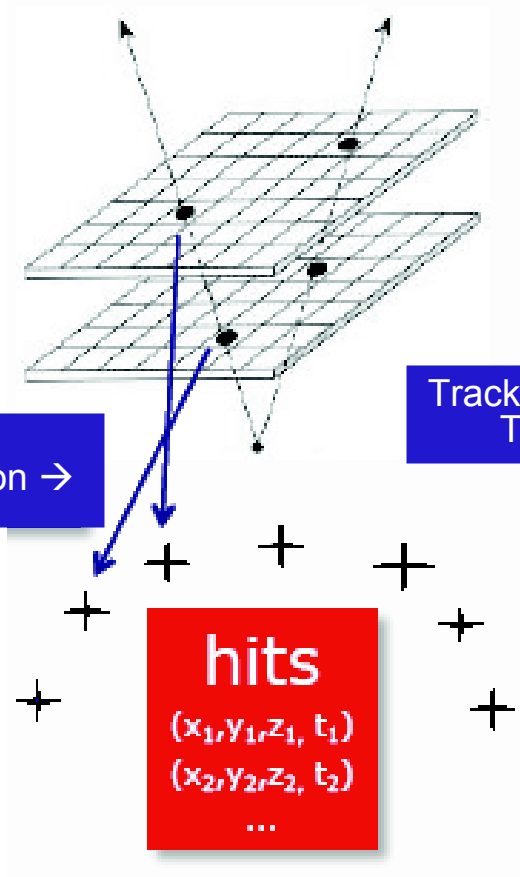
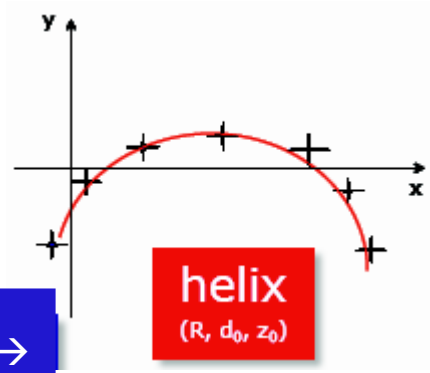


Digitization / Reconstruction →



Track Finding + Track Fitting →



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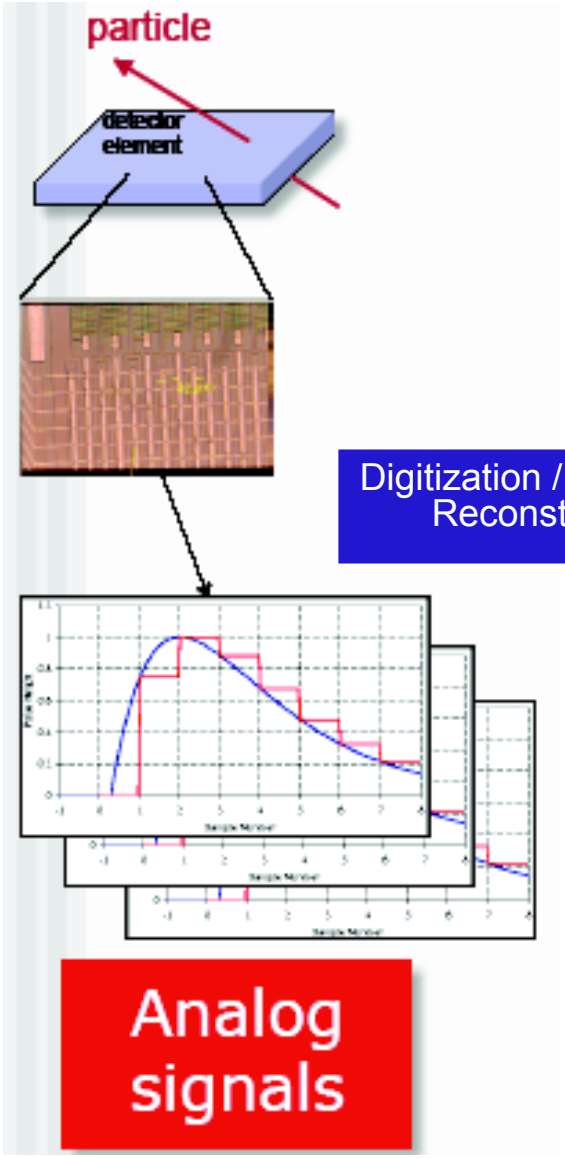
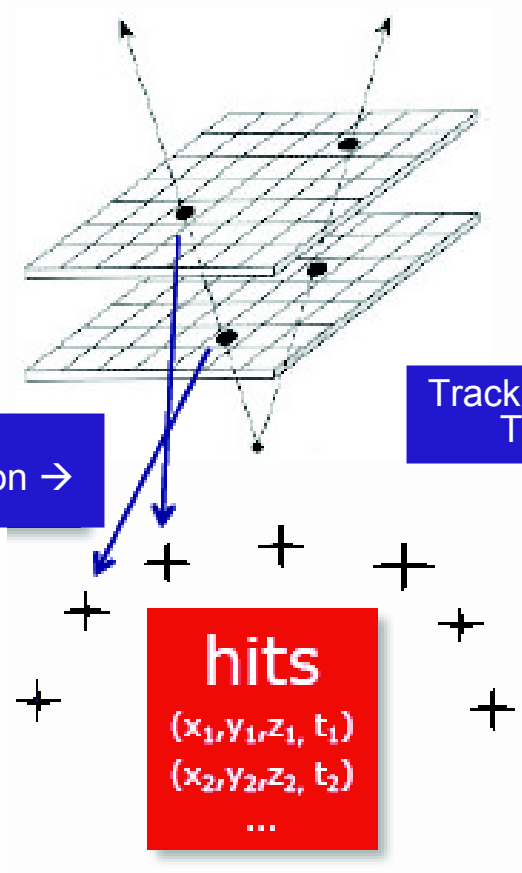
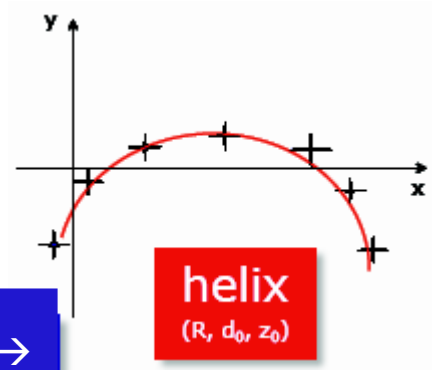
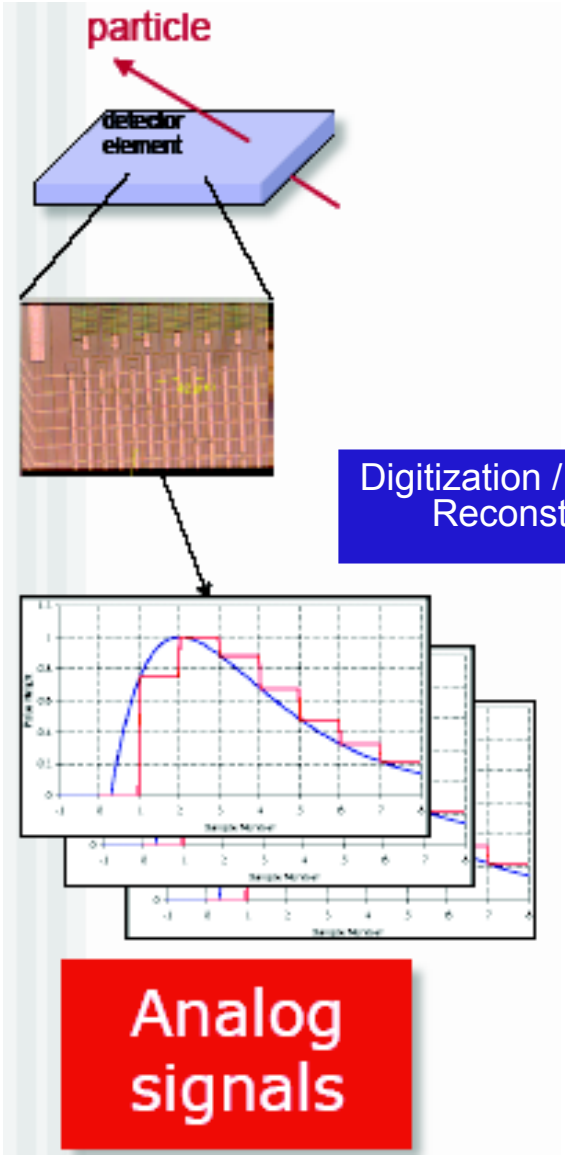




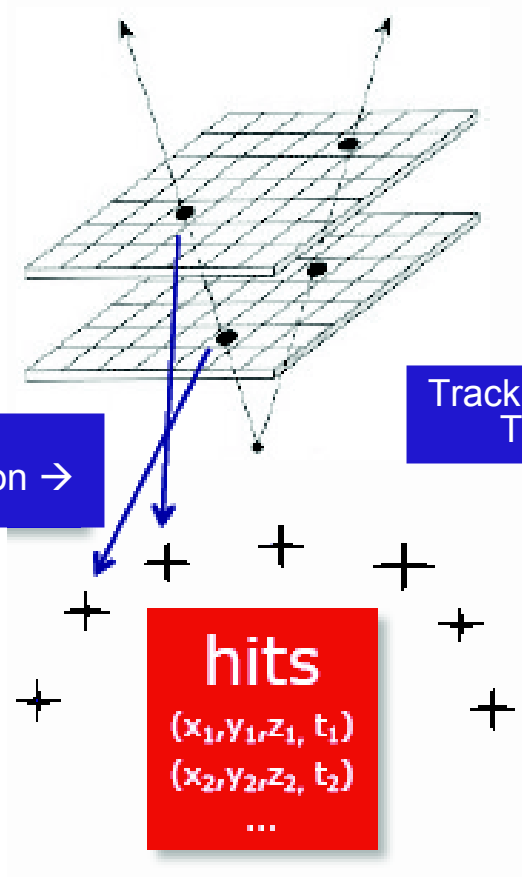


Magnetic Field B : Reconstruct

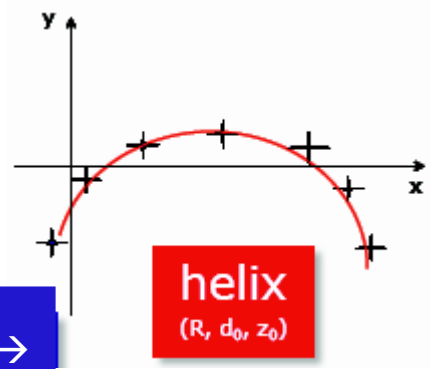
From Electronics to Physics



Digitization / Reconstruction →



Track Finding + Track Fitting →

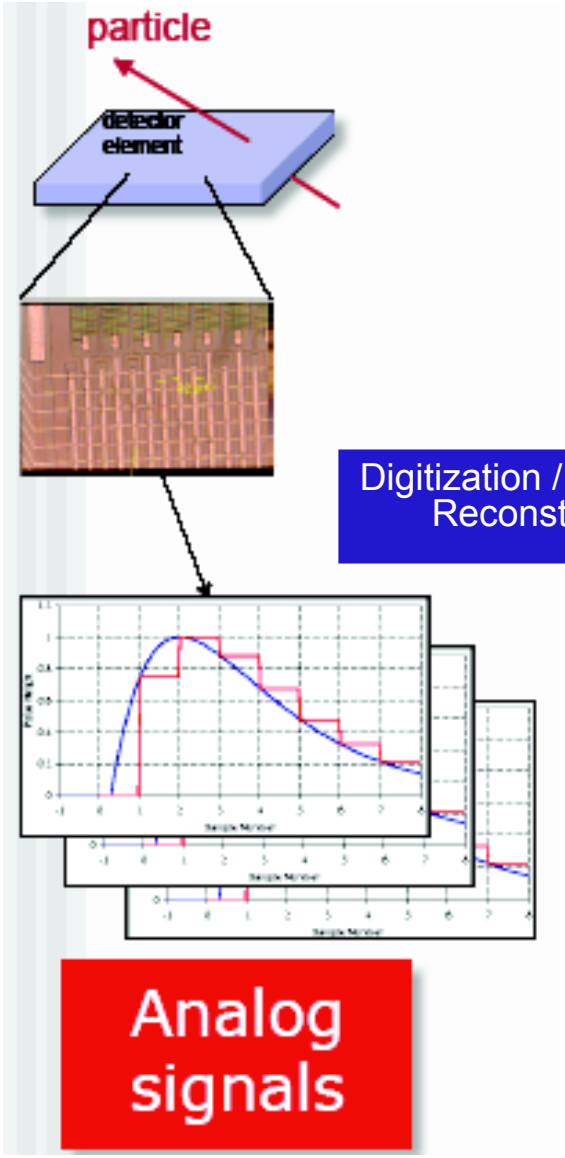


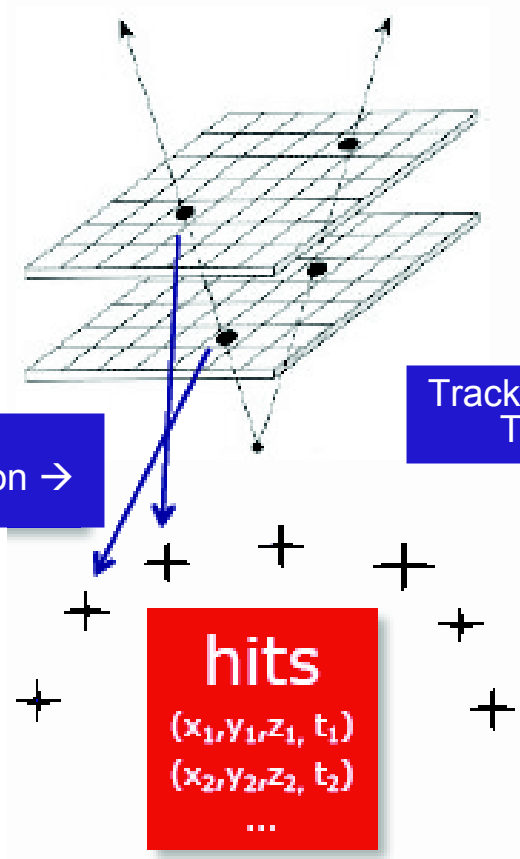
Magnetic Field B : Reconstruct

$$\vec{p} = \begin{pmatrix} p_x \\ p_y \\ p_z \end{pmatrix}$$

Track Momentum

From Electronics to Physics





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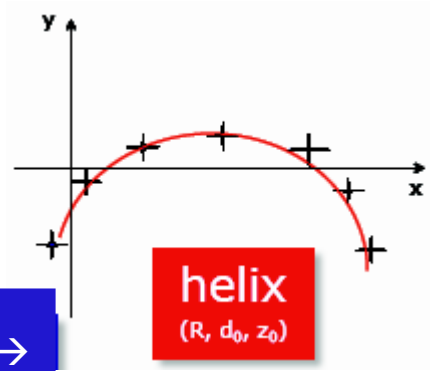
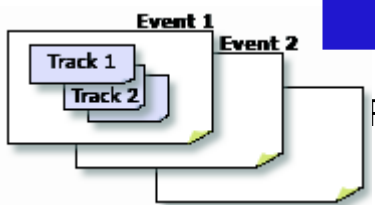


Magnetic Field B : Reconstruct

$\vec{p} = \begin{pmatrix} p_x \\ p_y \\ p_z \end{pmatrix}$

Track Momentum

Store info for every track for every event



Physics

Physics Objects

- Reconstruct Tracks
- Reconstruct Clusters
- Reconstruct Jets
- Apply Particle Identification
- Define Physics Data objects e, μ, γ and jets etc.

Track Reconstruction

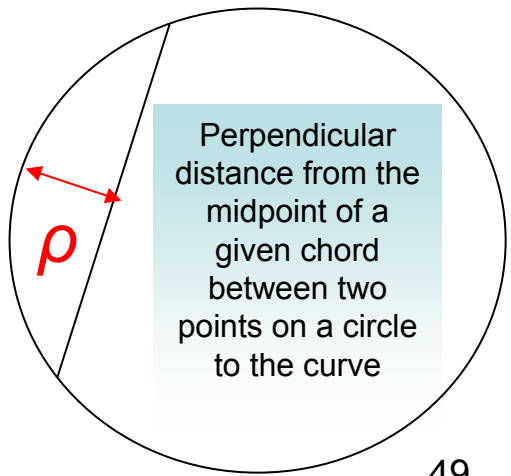
- Need at least two points to define a line
- Increase measuring points ➡ better measurements
- Find all the hits in all sub-detectors
- Curve Fitting using Method of least squares; Kalman-Filter algorithm for track fitting
- Transverse Momentum p_t: inverse of sagitta ρ
- Measurement of θ gives actual momentum p in lab frame
- Direction of bending in B field gives charge

position of i^{th} hit

Predicted track position at i^{th} hit

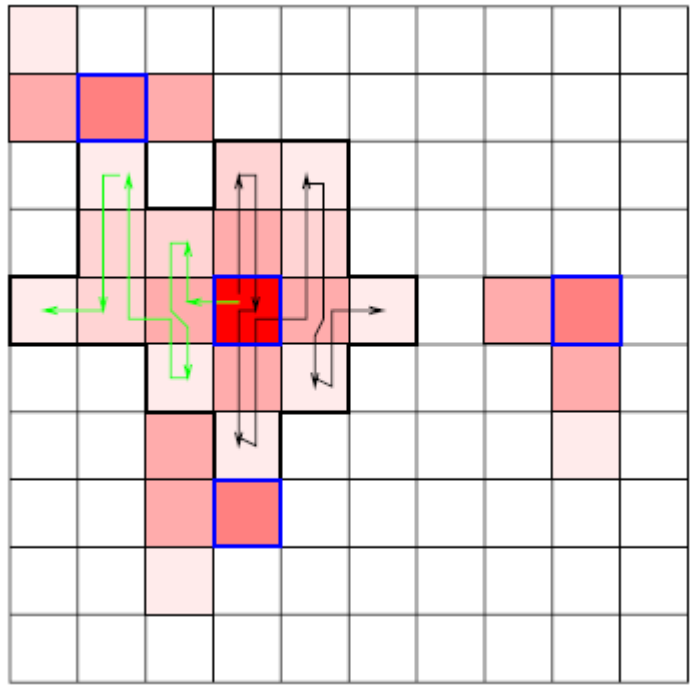
$$\chi^2 = \sum_{i=1}^{n_{hits}} \frac{(y_i - y_i(x_i))^2}{\sigma_i^2}$$

uncertainty in the i^{th} measurement



Cluster Reconstruction

- Lead Tungstate crystals of ECAL in barrel (61200) and endcap (14648)
- Start by searching for seeds; crystals with transverse energy above a certain threshold
- Seeds adjacent to the one with maximum energy forming an array of crystals in phi direction are called bumps
- Bumps are extended to include all eta directions to form clusters
- Clusters of clusters are called *super-clusters*

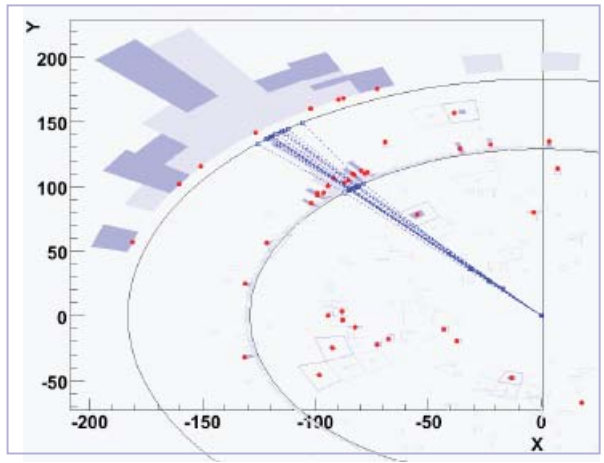


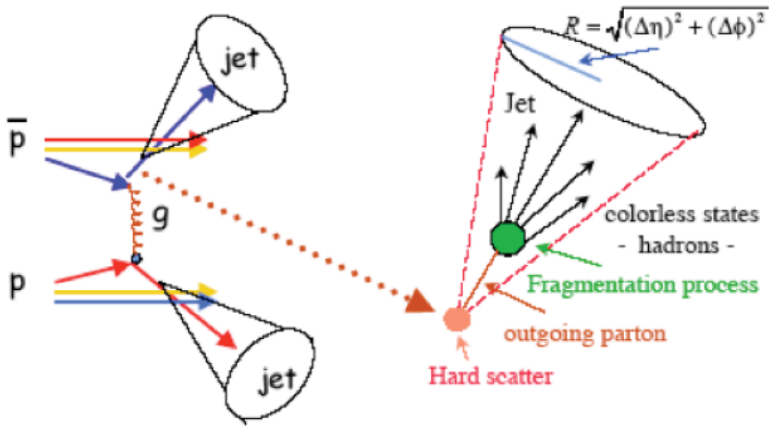
Jets Reconstruction

- What is a Jet? : Software artifact

  A cluster / spray of particle (tracks, calorimeter deposits) or flow of energy in a restricted angular region
- Represents perturbative part of QCD
- Cone : natural definition of a jet in hadron collider experiments
- Algorithms: Cone algorithm, Jade algorithm, Berkeley algorithm etc.
- Variables: sphericity, thrust, aplanarity, energy flow etc.

Simulation of a Jet in CMS





Particle Identification

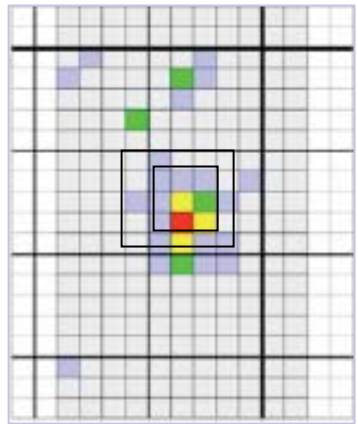
Four types of particles need to be identified

- Electrons
- Photons
- Muons
- Pions

Electrons and Photons

- Electrons radiate between the interaction point and the ECAL depositing all of their energy in ECAL
- Energy is deposited in φ direction due to 4T magnetic field
- Threshold Energy for electrons is lower than for photons
- Electron (narrow shower) $s9/s25 < 1$

  Photon (wide shower) $s9/s25 \approx 1$



s9 = 3 x 3

s25 = 5 X 5

- Standard collections of electrons and photons are intended to be efficient for electrons with pt > 5GeV and prompt photons with pt >10GeV

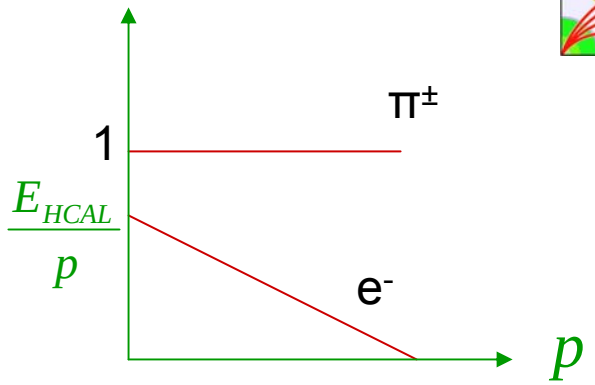
Muons

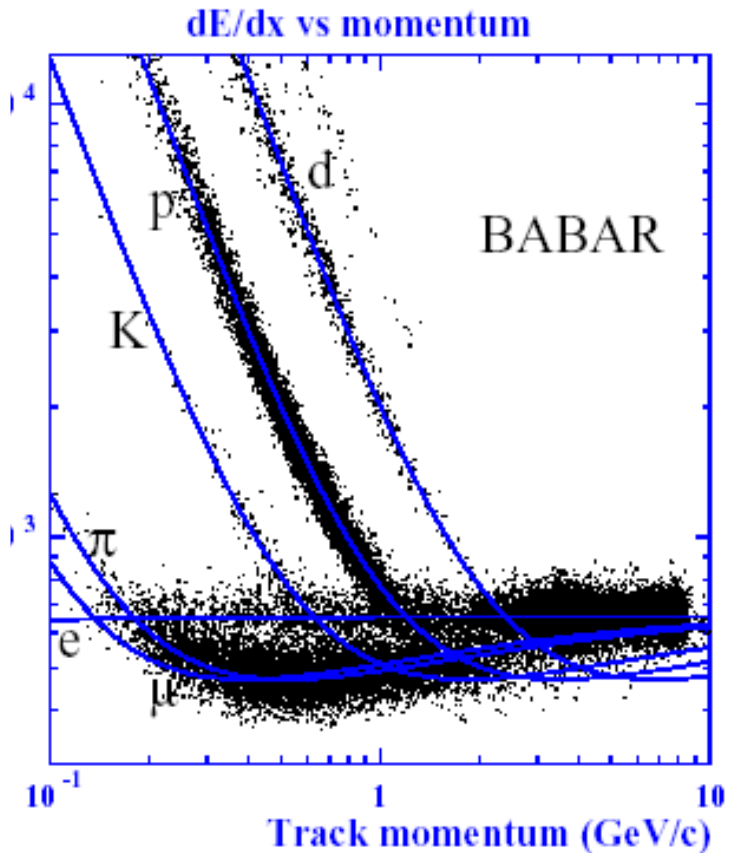
- Pass through to the outer most layers of muon chambers
- Generally do not shower in EMC, rather ionize
- Tracks are visible as very low energy clusters in EMC
- Cut-based identification for global muons, which consists of a set of track-quality requirements
- Likelihood-based identification for tracker muons, which uses compatibility of the calorimeter response with the muon hypothesis and the presence of matched segments in the muon system
- Cut-based identification for tracker muons, which selects muons on the basis of the track-penetration depth in the detector

Pions

- Do not shower in ECAL
- Get absorbed in HCAL
- Plot $\frac{E_{HCAL}}{p}$ for e- and π±

  – p is measured by the tracker
- Measurement of $\frac{dE}{dx}$





Include Detector Parameters

- Evaluation of acceptance corrections

  To account for the lost particles; e.g. some particles could be out of detector coverage or along the beam pipe etc.

- Evaluate the efficiency

  To account for cracks or malfunctioning parts in the detector

- Check purity of the sample

  To discard fake selections resulting due to the choice of cuts or wrong particle identification

- Need SIMULATED DATA

Why Simulated Data?

- Generators acts like accelerators (LHC,LEP,TEVATRON)
- Allow theoretical and experimental studies of complex multi-particle physics
- Vehicle of ideology to disseminate ideas from theorists to experimentalists
- Predict the event rates and topology (Kinematics of particles resulted from collisions)
- To trace back the history of end products need
- Simulate possible backgrounds
- Study detector requirements

Where do we stand now?

- After data flow from DAQ: data reduction and abstraction

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  - if distributions are measured : take care of calibrations and effects due to detector resolution → correct for these effects
  - determine statistical and systematic uncertainties
  - Compare with theory, found a deviation, something new?
    - book a ticket to Stockholm

THANK YOU!!!

Questions?

Comments..

BACKUP SLIDES

Outline

- Raw data Format
- Event Generators
- Physics data objets
- The software : CMSSW, ROOT
- A real analysis


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