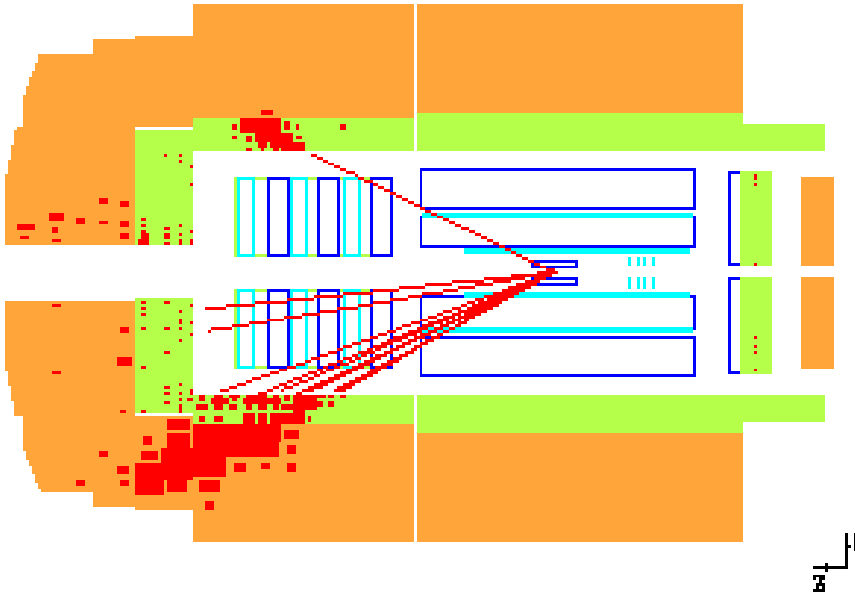
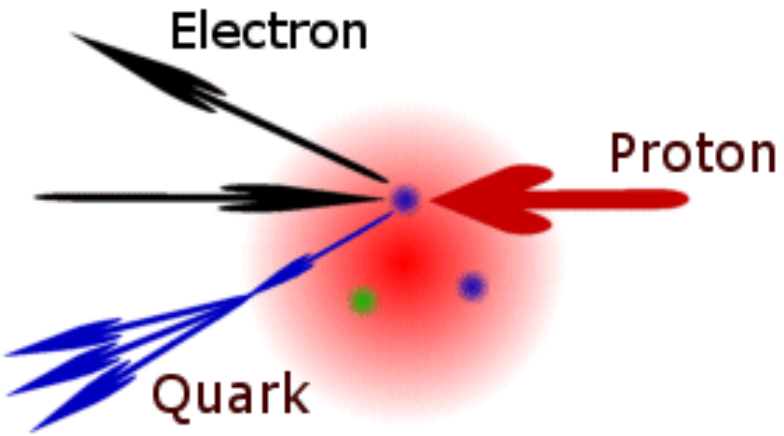
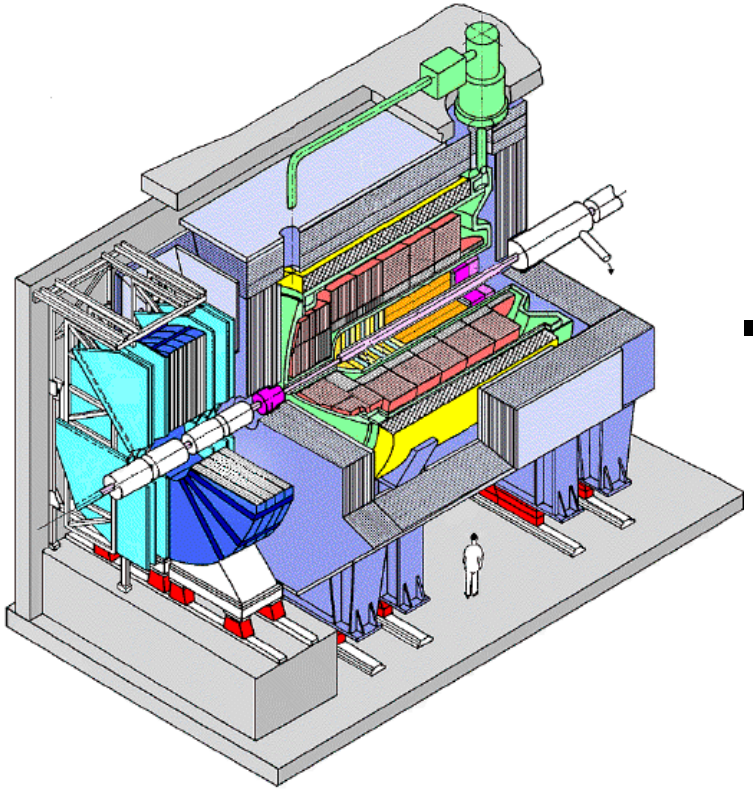
# HERA e-p scattering events observed in the H1Detector

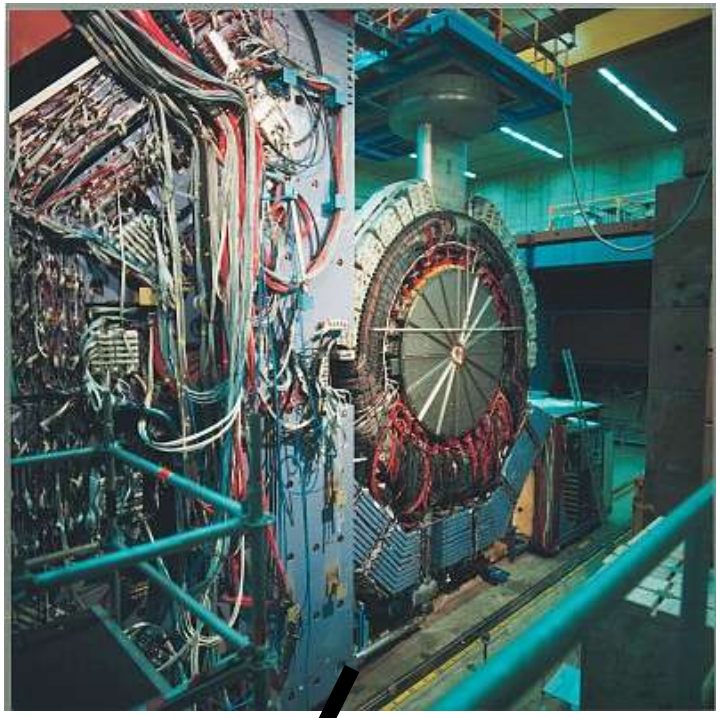


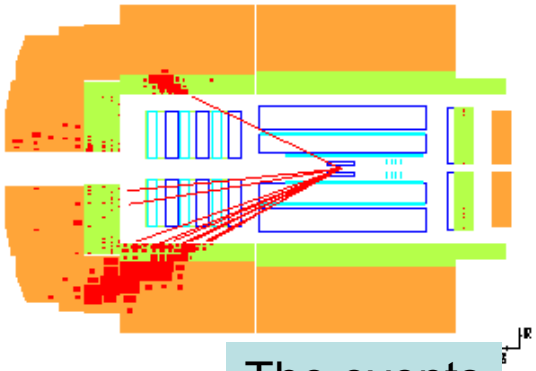


The idea

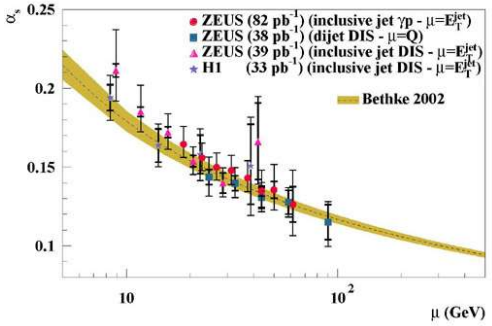


The realisation



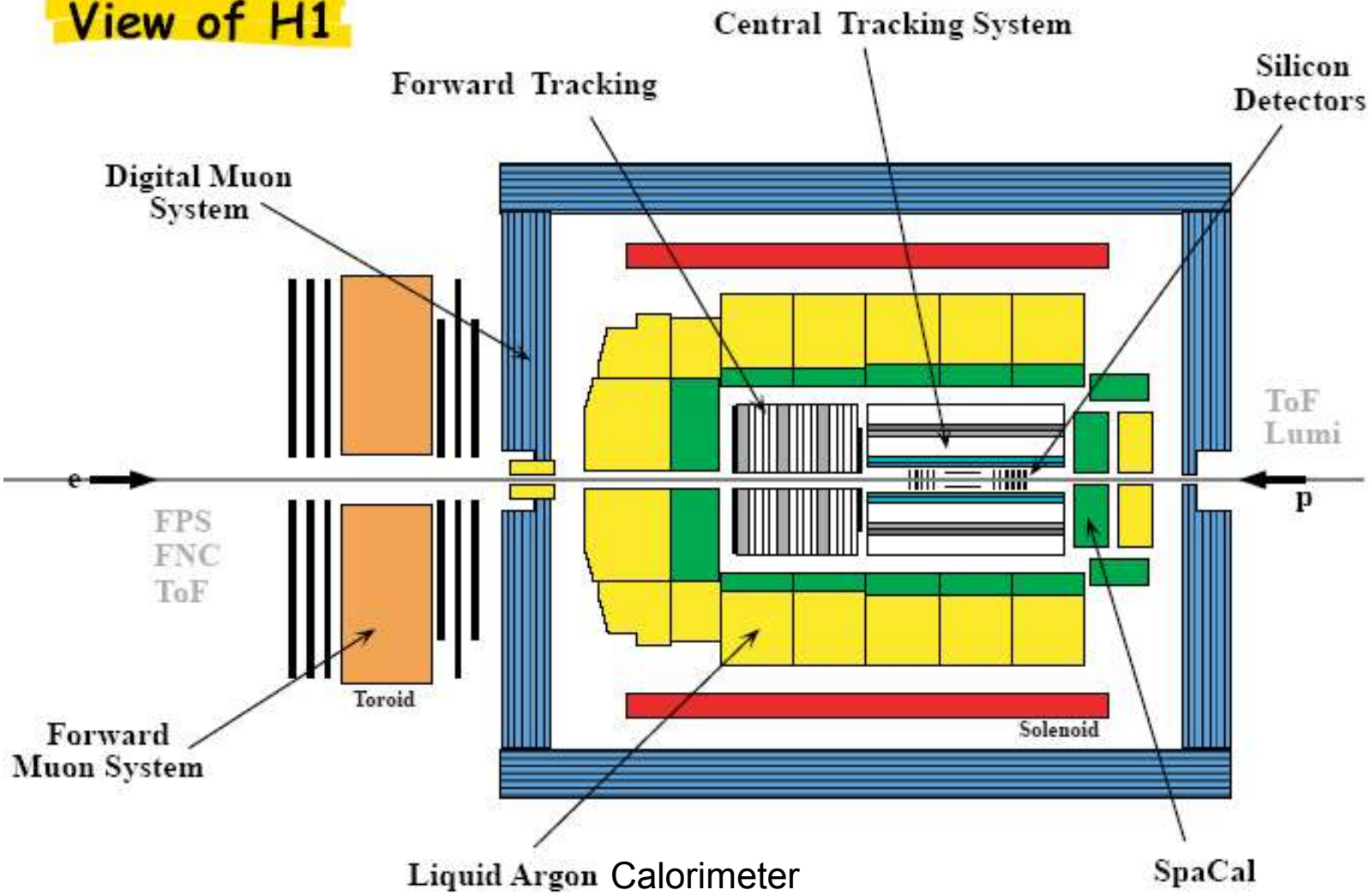


The events

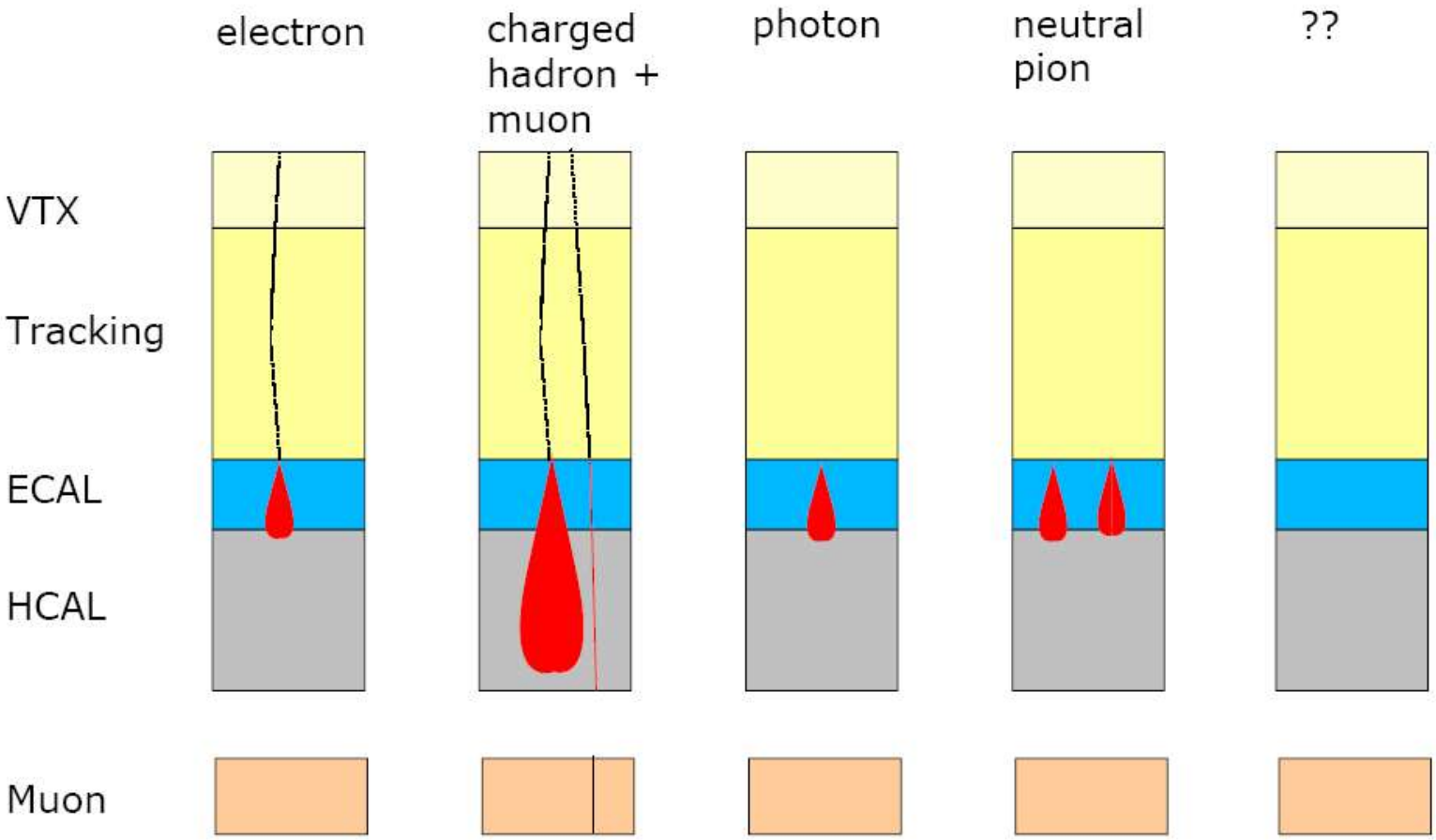



The Physics

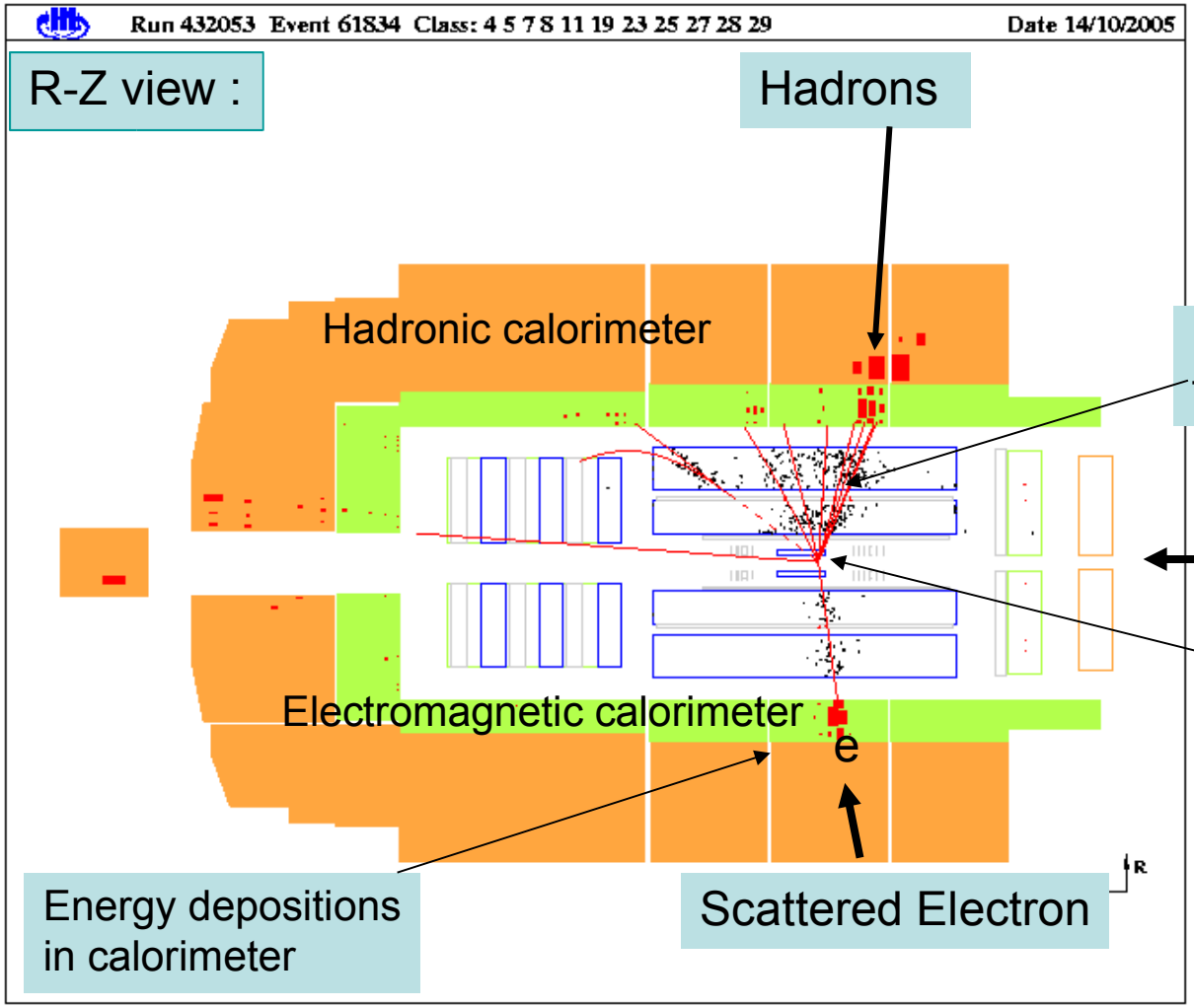
# Schematic View of H1



# Principle of particle identification

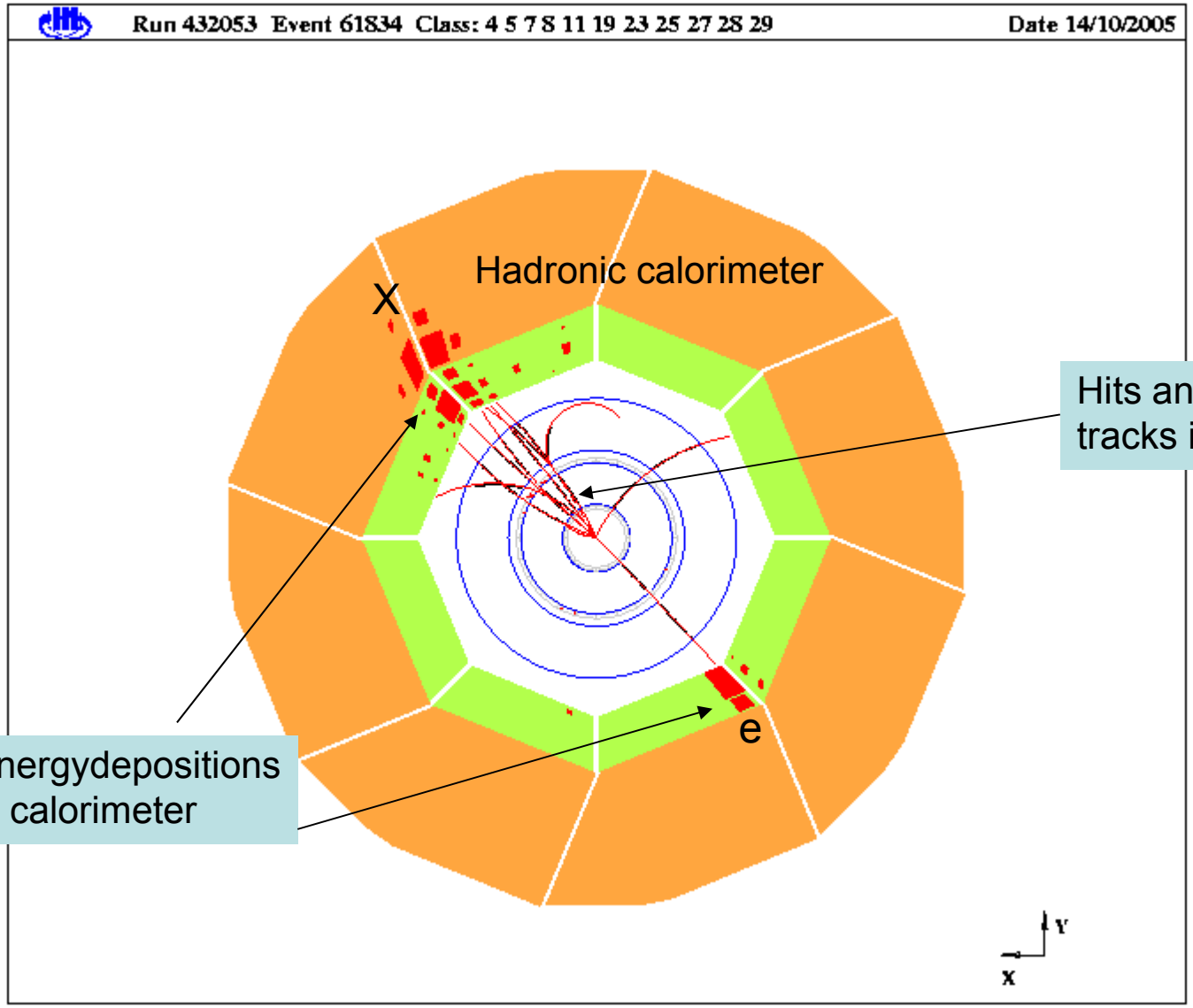


# An event display : What do we see ?



Same event in radial view :

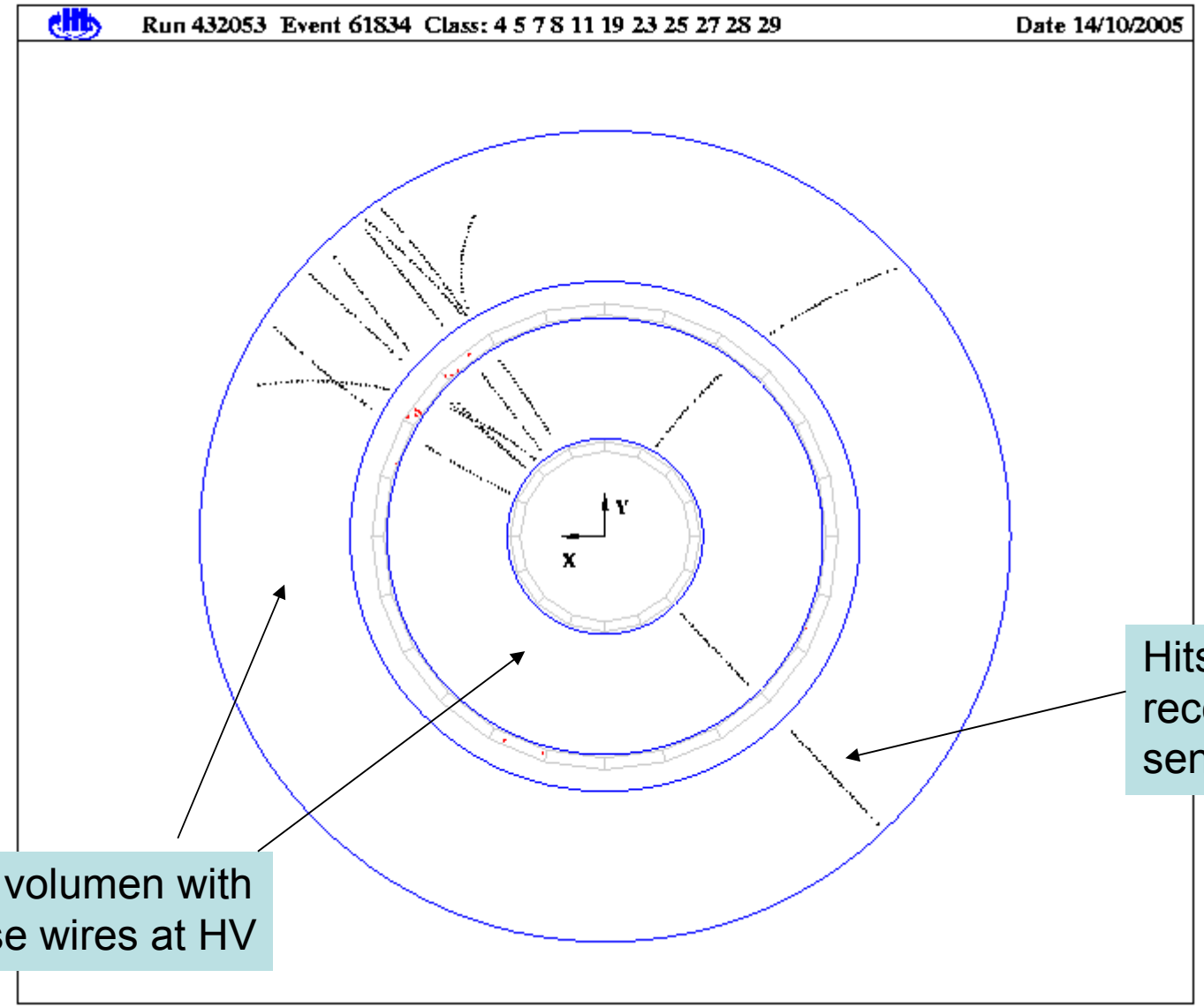
$$ep \rightarrow e'X$$




Hits and reconstructed tracks in tracker

Energydepositions in calorimeter

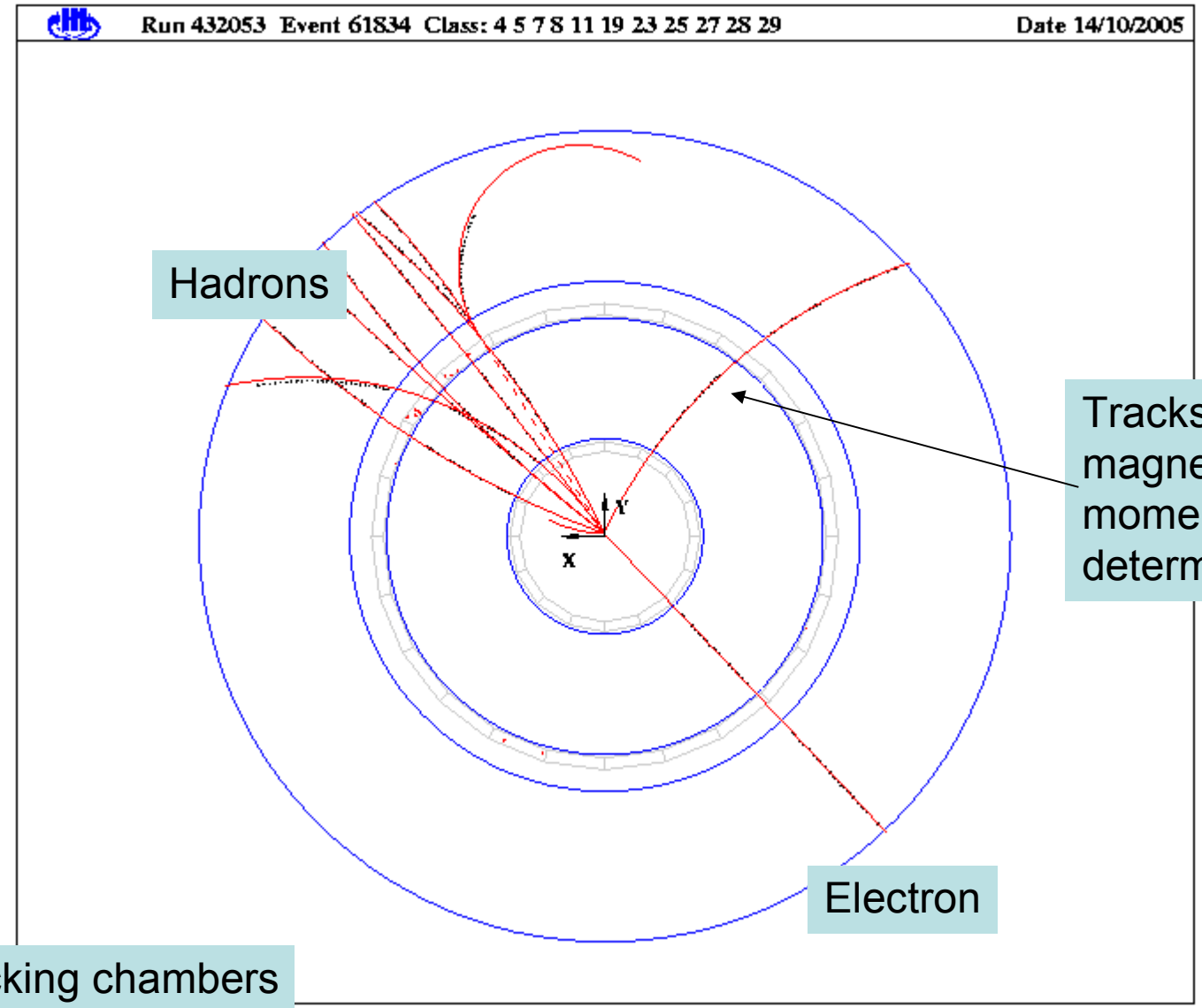
# The hits (fired wires) in the tracking chambers




Hits = Signals recorded on sense wires

Gas volumen with sense wires at HV

..and the result of the pattern recognition program trying to combine the hits to tracks (red lines) :




Hadrons

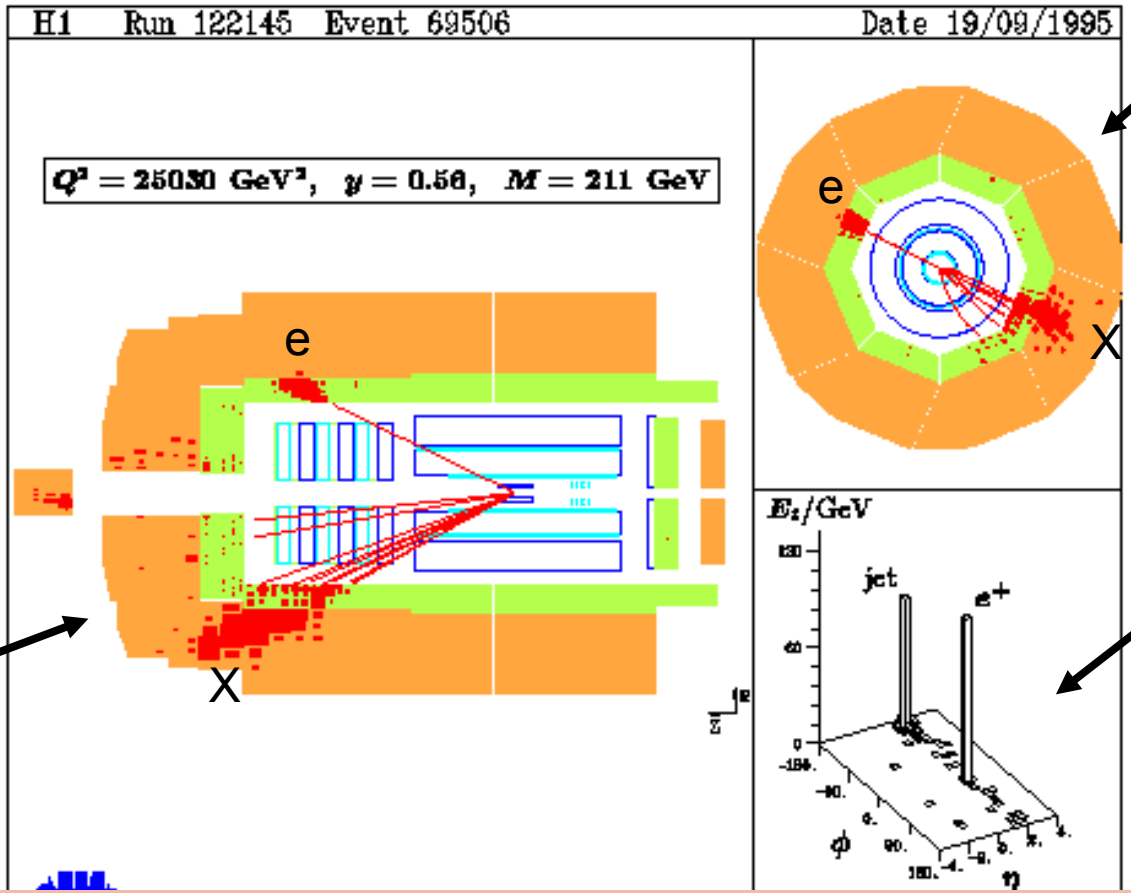
Tracks bend in magnetic field : momentum determination

Electron

Central tracking chambers

# Event : Combined view (R-z, R-Phi , calorimeter energies)

$ep \rightarrow e'X$




Transverse view (R-Phi)

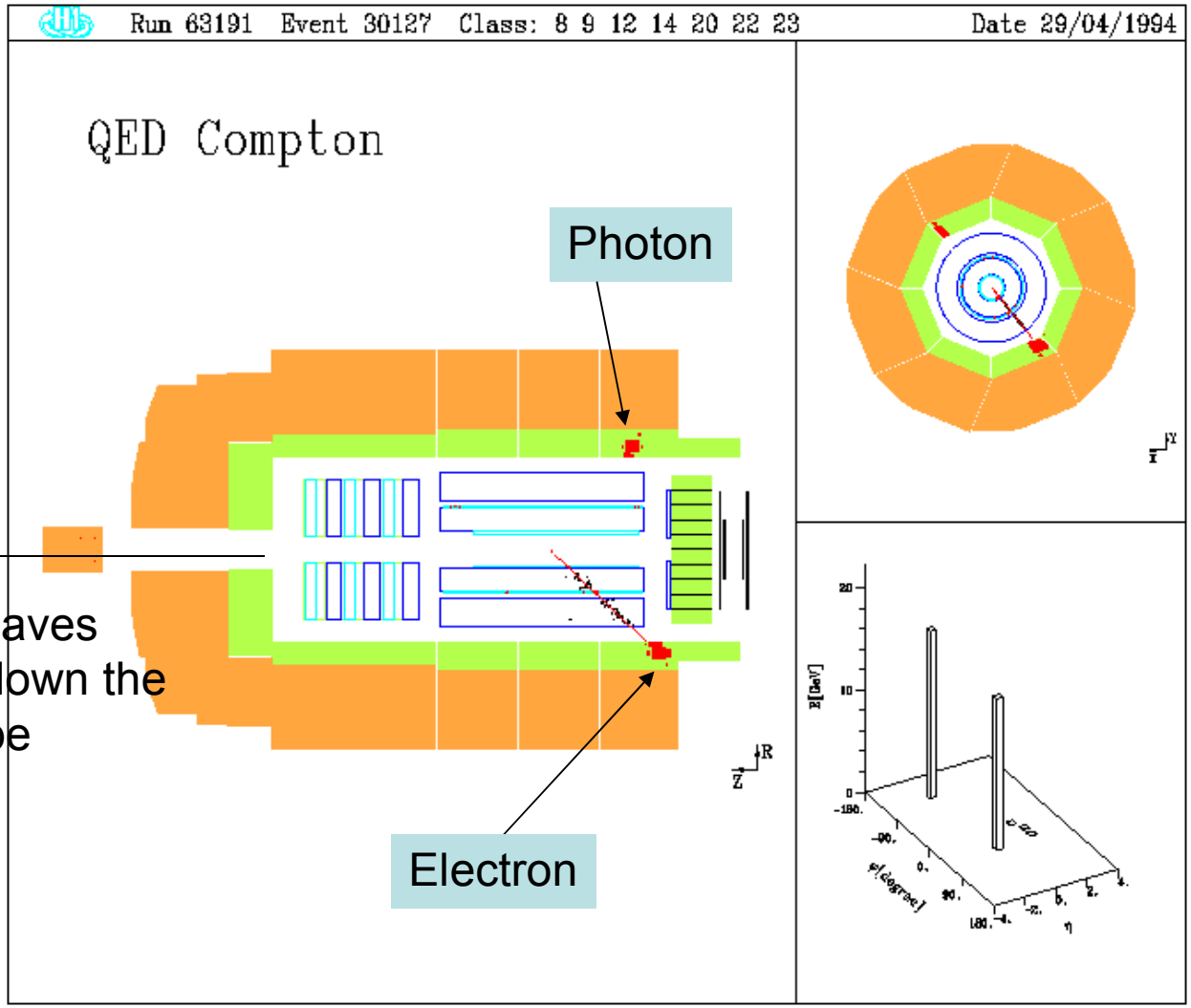
Calorimeter energies

Side view (R-z)

Electron and hadronic system X balanced in transverse momentum

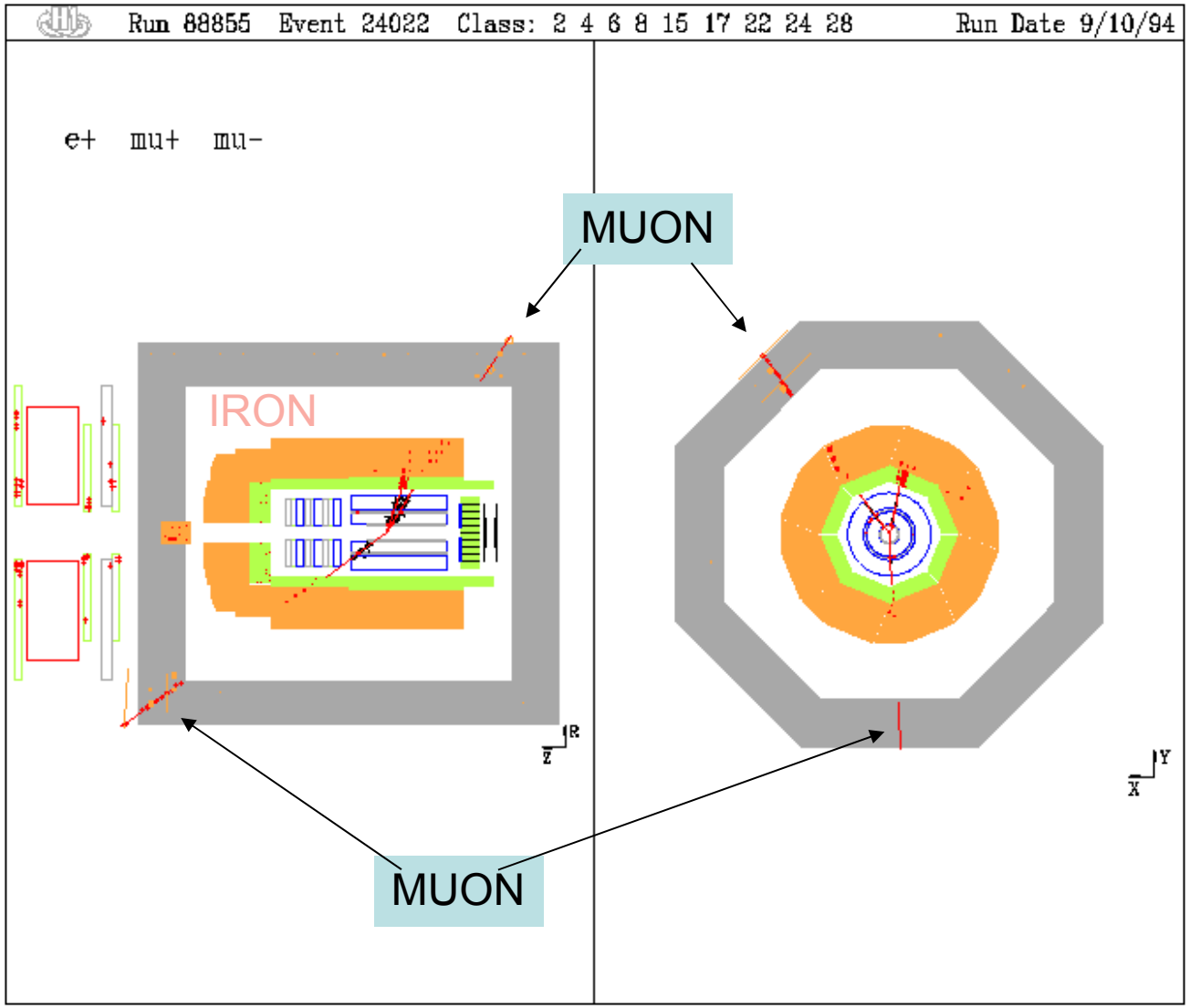
A very simple event :

$$ep \to e\gamma\,(p)$$



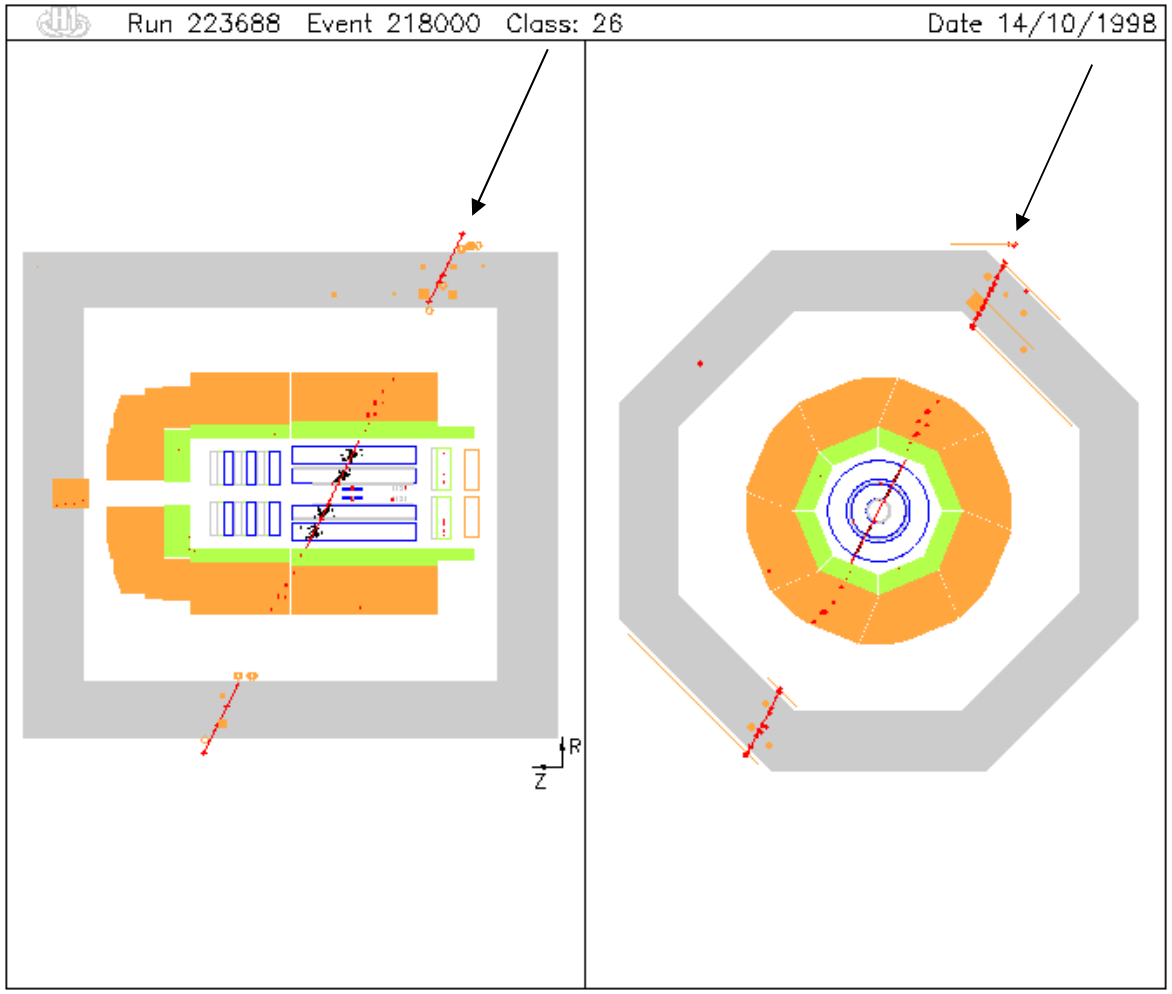
# Another ‘simple’ event : A elastic dimuon production

$$ep \to e\mu^+\mu^-(p)$$



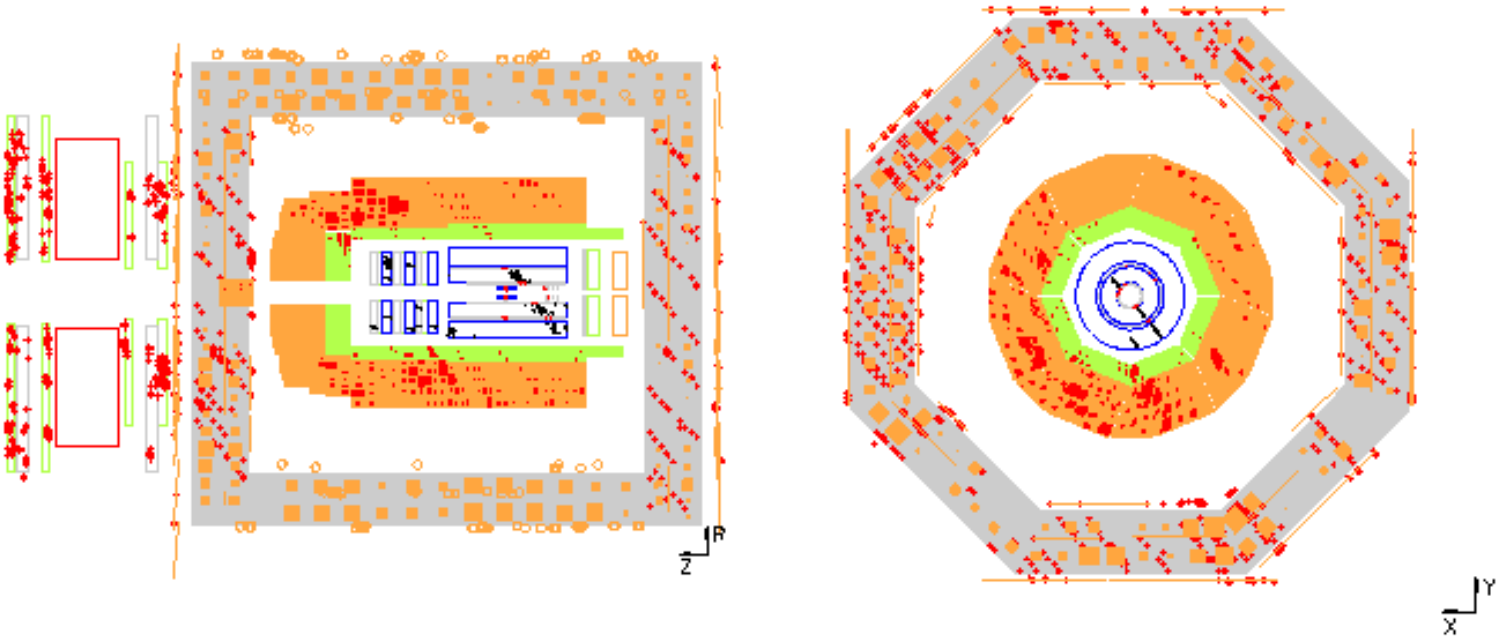

Muons penetrate thick materials !

# Muons also come from the sky ……



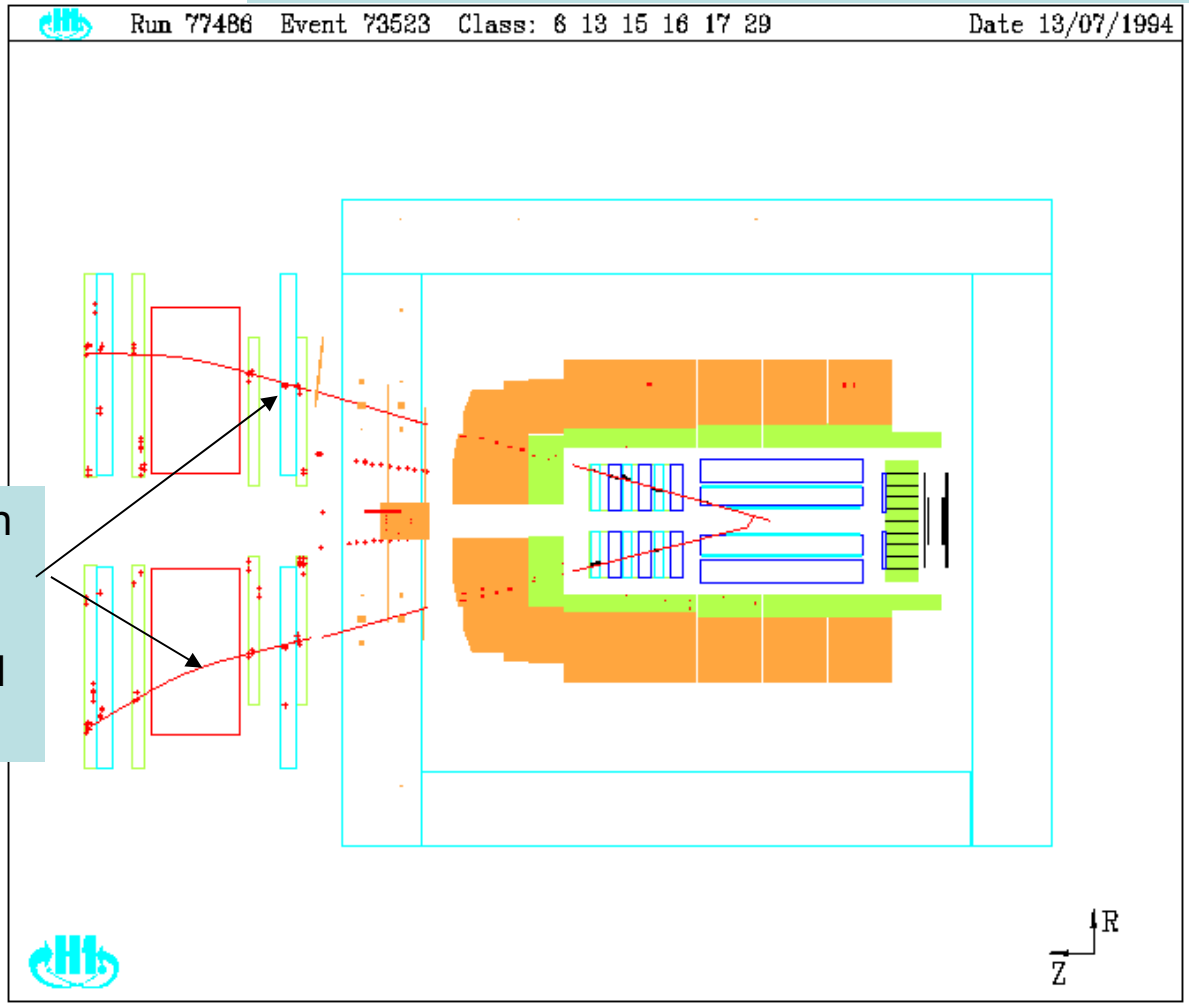

This is BACKGROUND, which we do not like !

…and it can be even more fierce ….



# Back to HERA -e-p scattering events :
## A very forward Dimuon event

These muons are decay products of the famous J/Psi particle

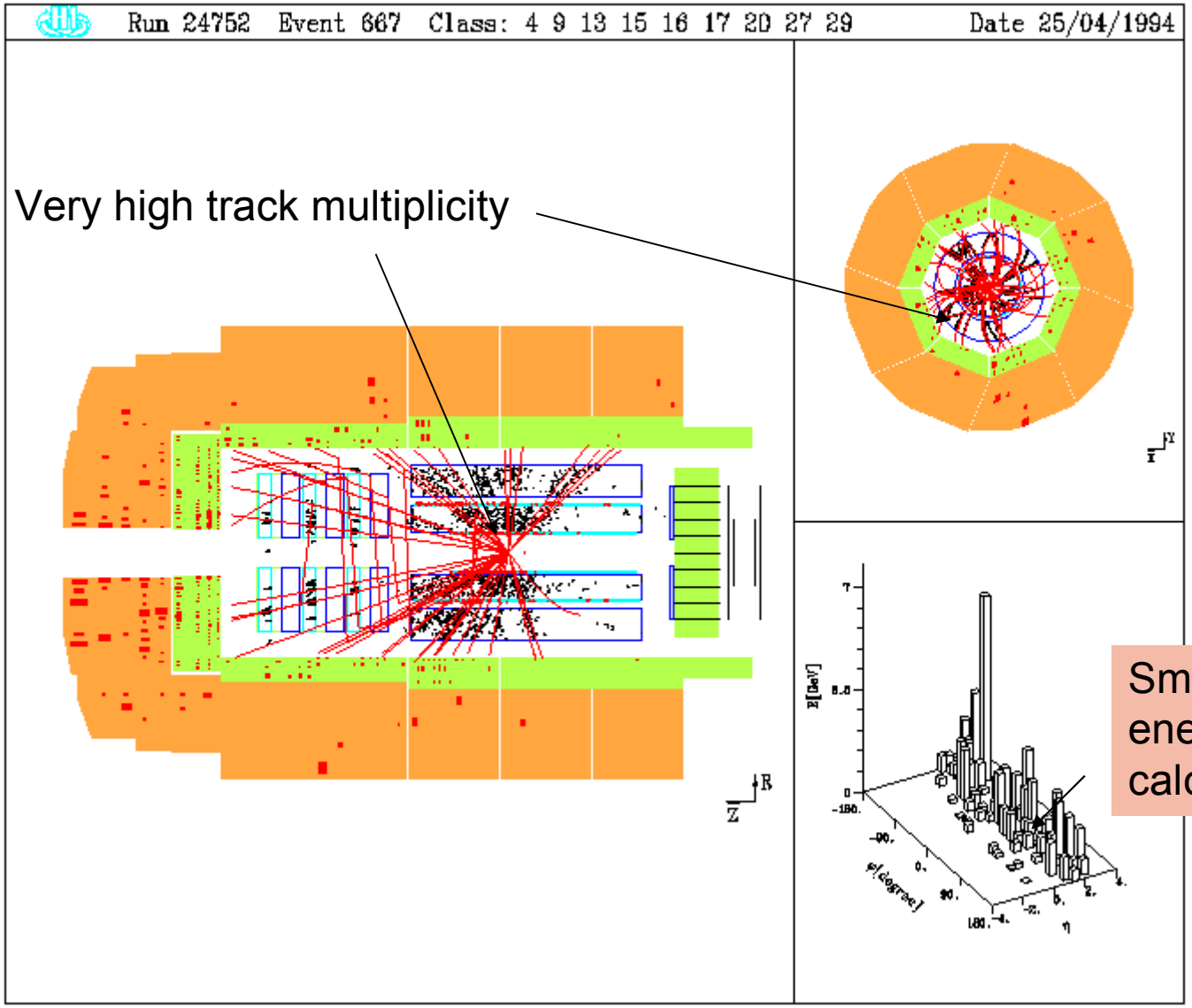



Muons bent in the magnetic field of the forward toroid magnet

$$ep \rightarrow (e)(p)J/\Psi$$

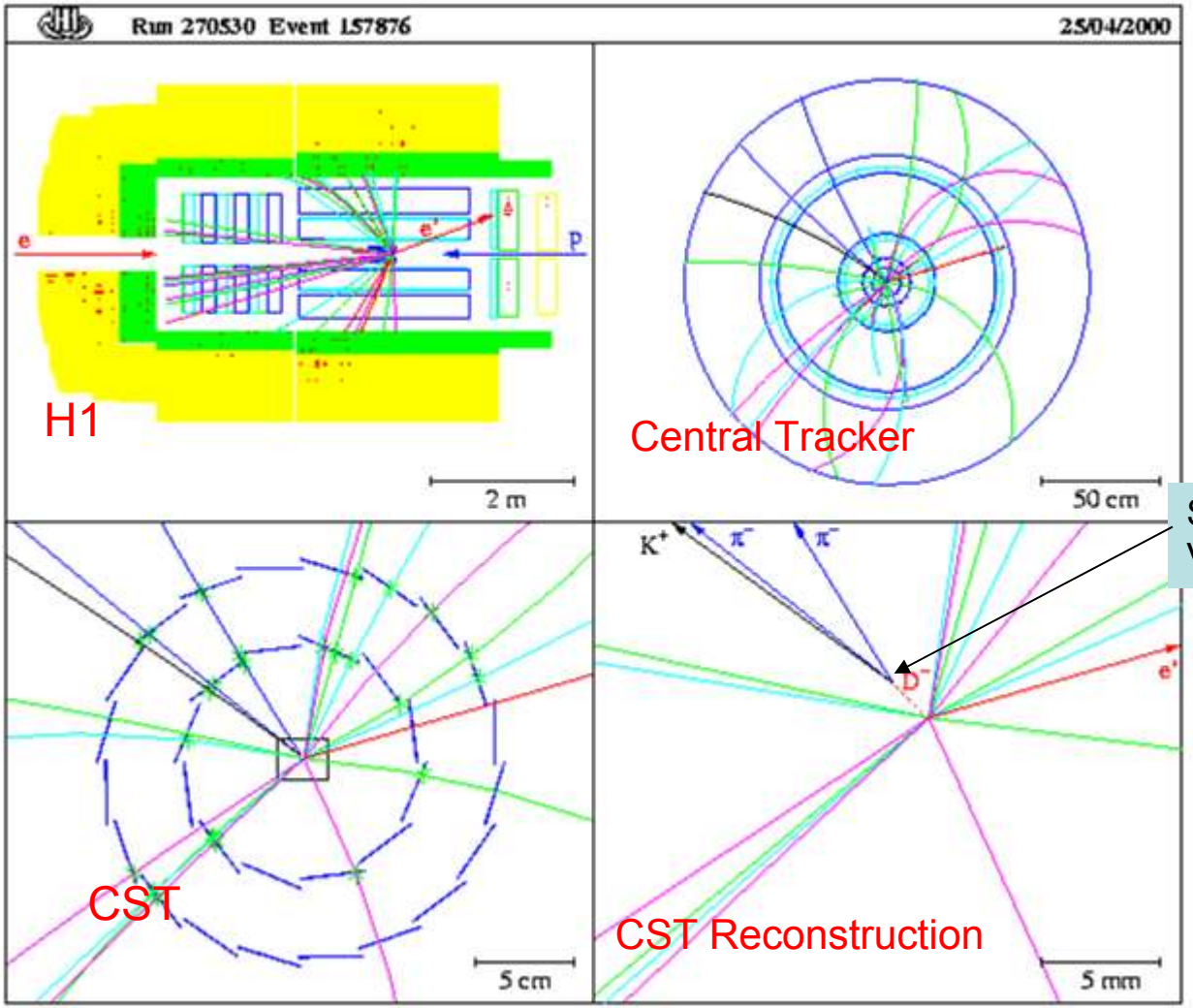
$$J/\Psi \rightarrow \mu^+\mu^-$$

Most events are much more complicated :

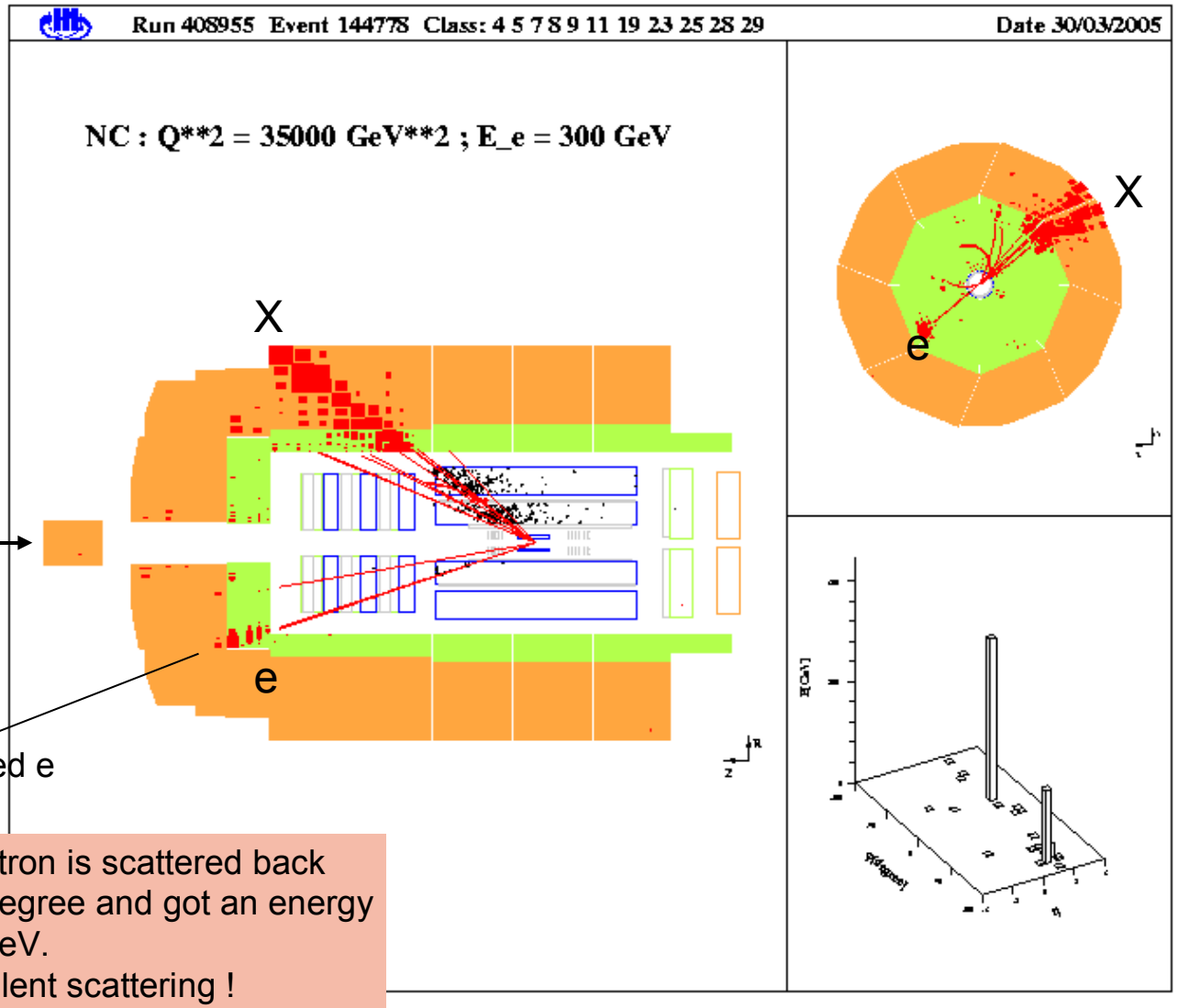


The Central Silicon Detector (CST) measures hits very precisely (10 micrometer). search for secondary vertices of heavy quark (charm,bottom) decays :

Zoom in ….



# Back to the Deep-Inelastic-Electron-Proton-Scattering (DIS) $ep \rightarrow e' X$



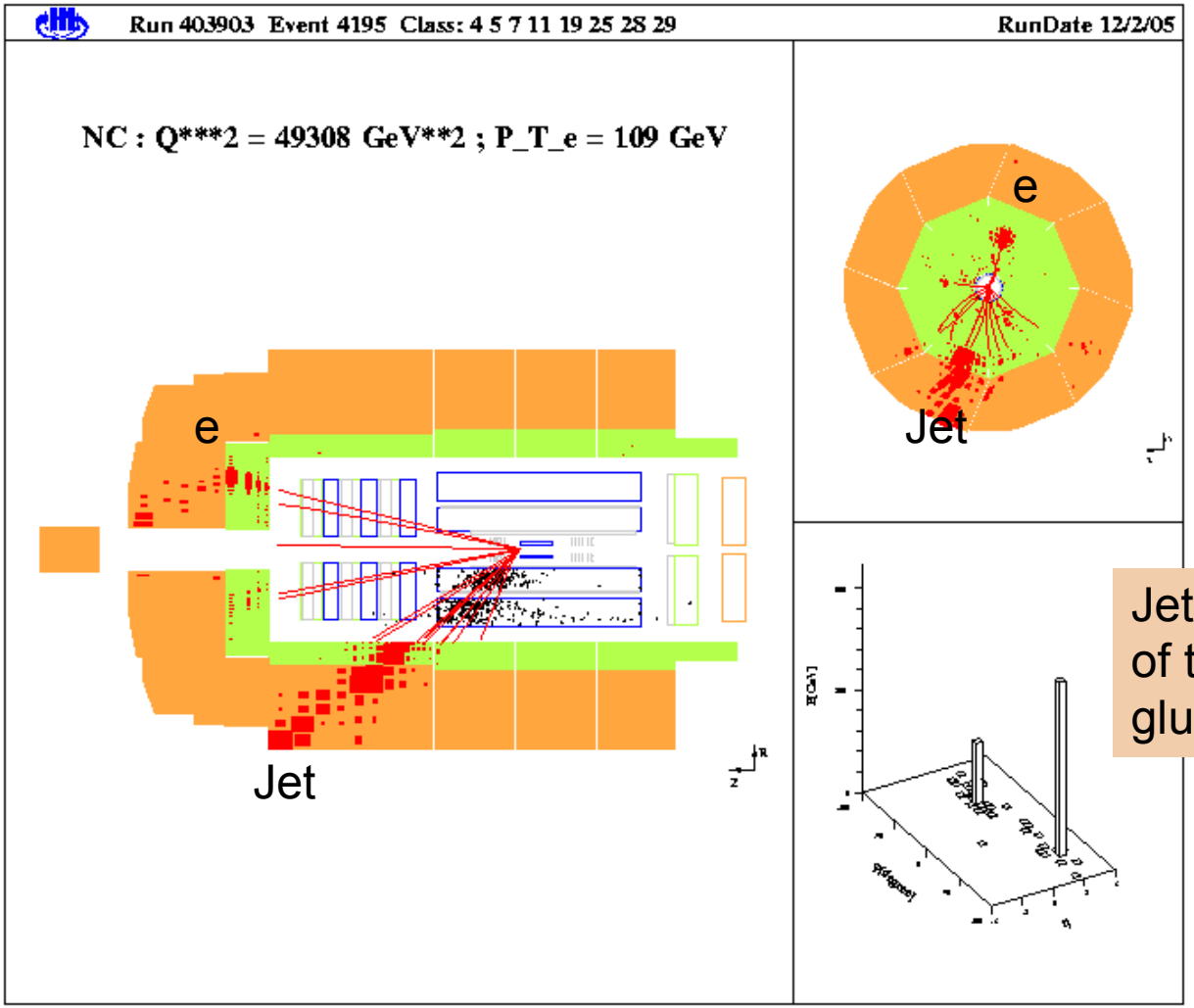

The electron is scattered back by 160 degree and got an energy of 300 GeV.
Very virulent scattering !

.and here its even more virulent.

$$ep \rightarrow e' X$$

The squared momentum transfer is $Q^2 \approx 50000 GeV^2$ , this corresponds to a space resolution of

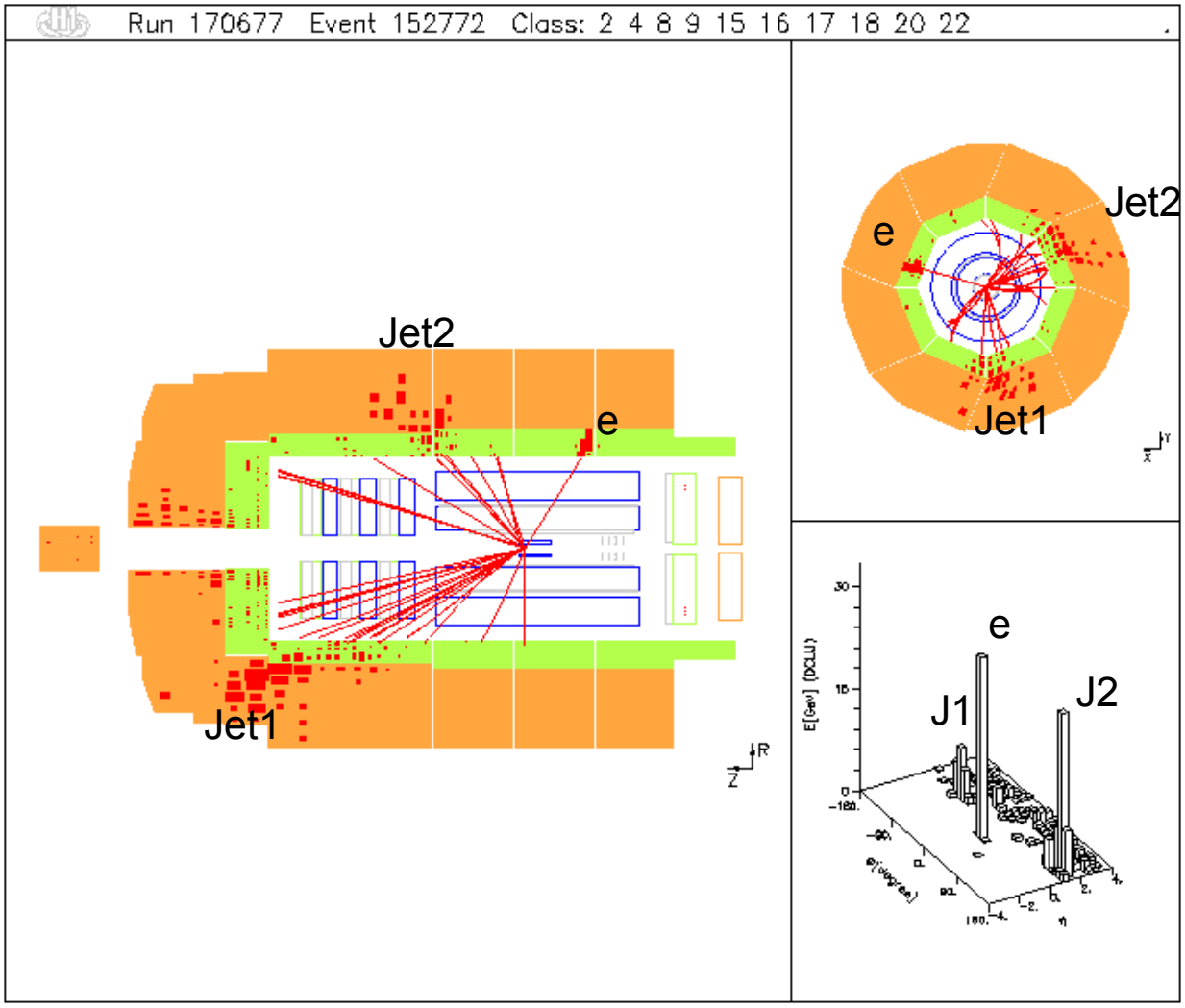
$$\Delta x \approx 10^{-18} m$$




Notice :
The hadronic system X is a well collimated bundle of particles. This is called JET

Jets are the 'footprints' of the quarks and gluons

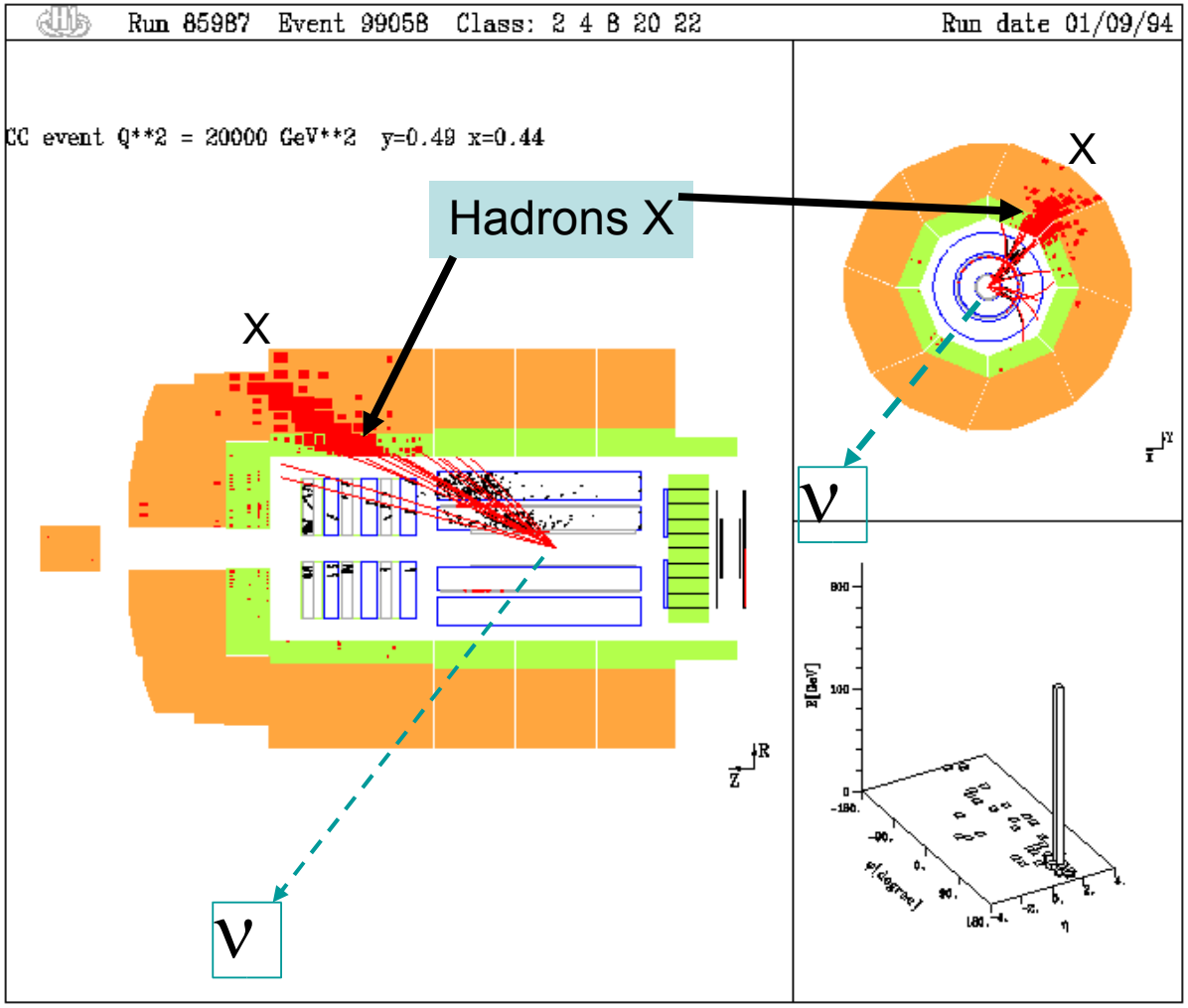
A NC-DIS event with two jets $ep \rightarrow e' Jet_1 Jet_2$



# A new event class : In this event the hadrons X are NOT balanced by an electron !

$ep \rightarrow \nu X$

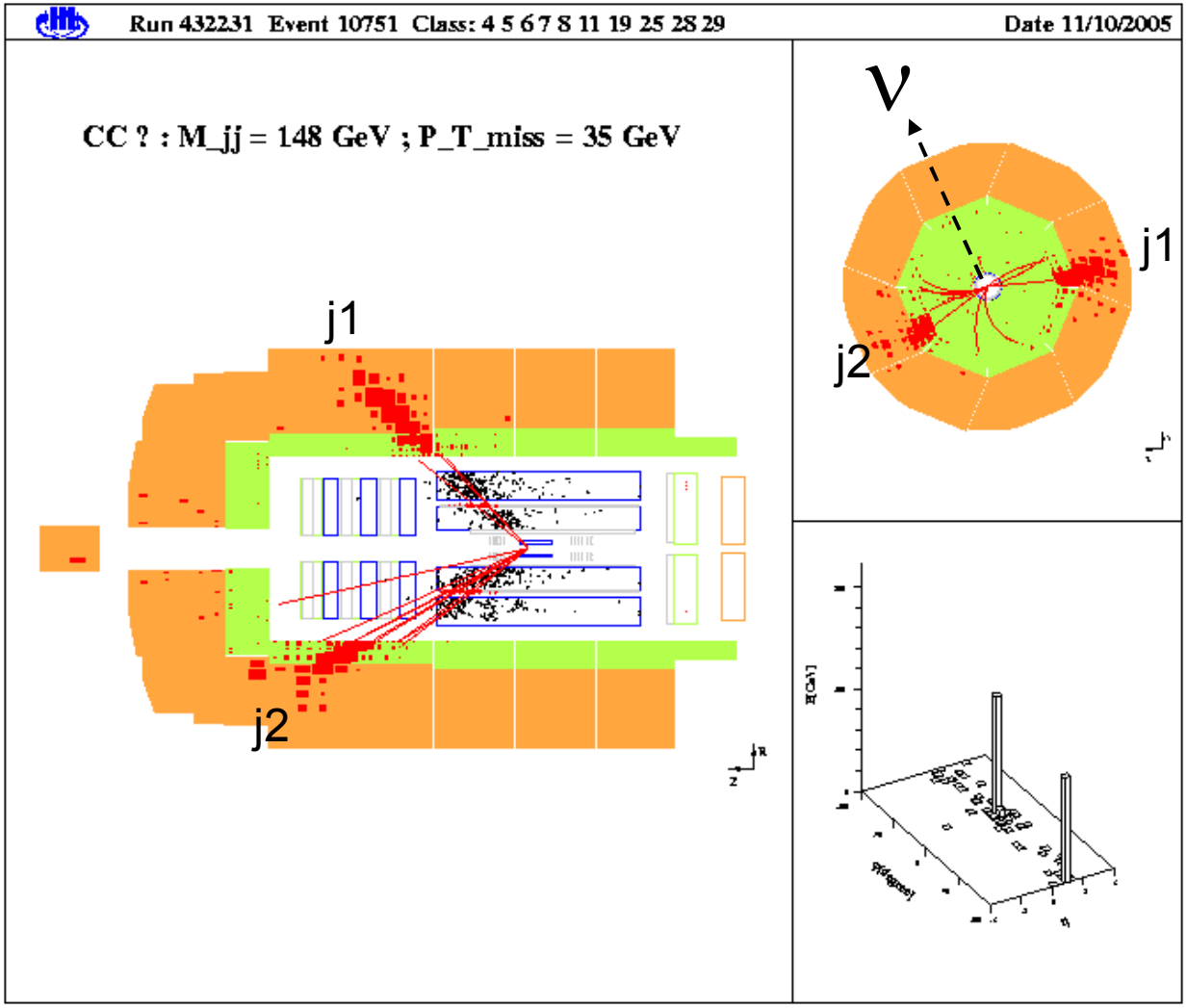
The Neutrino does not leave a trace in the detector



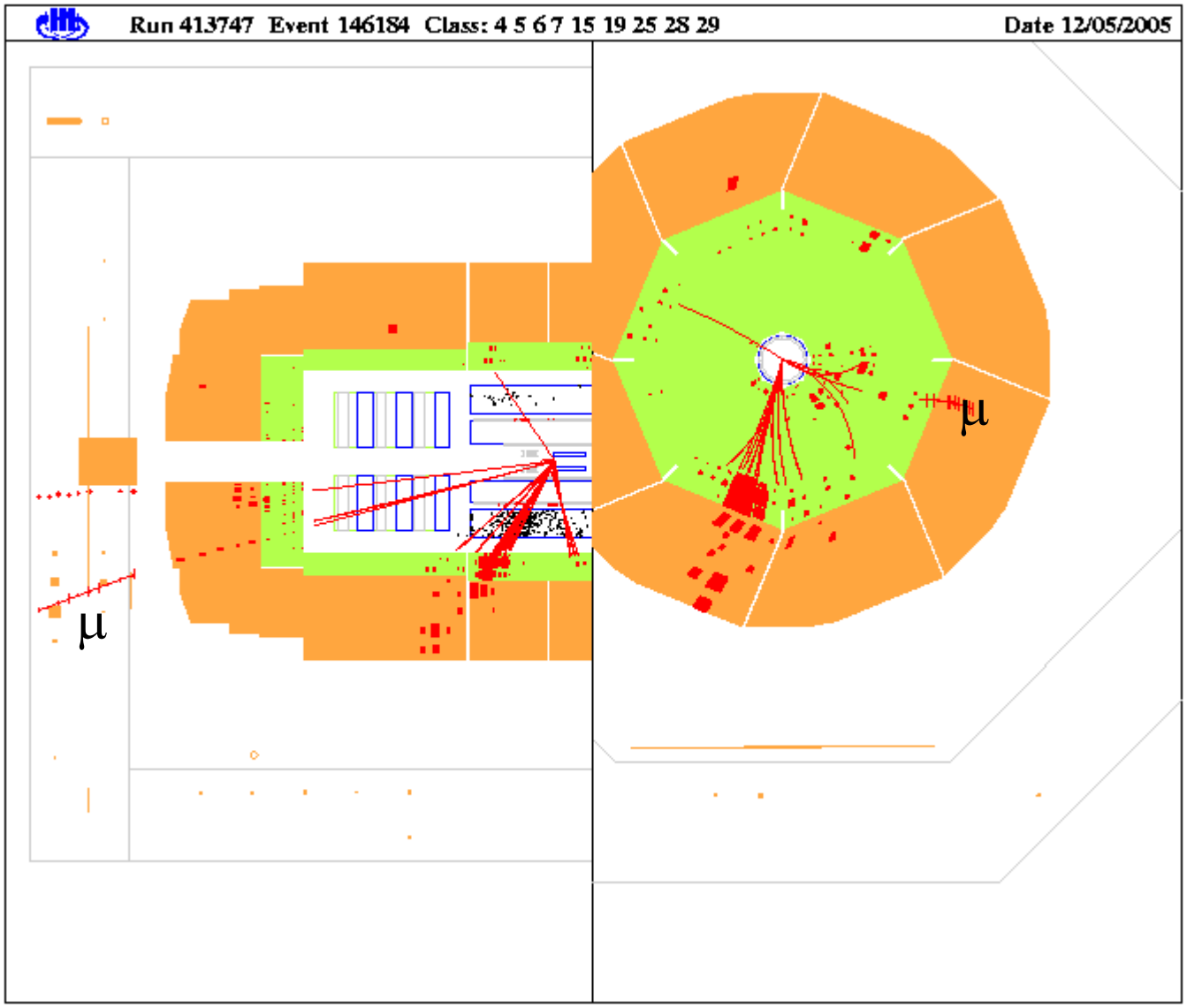

This is a different type of DIS event
It is pure weak interaction.

It is a Charged Current (CC) event

This is a CC event with a pronounced two-jet structure $ep \to \nu j_1 j_2$

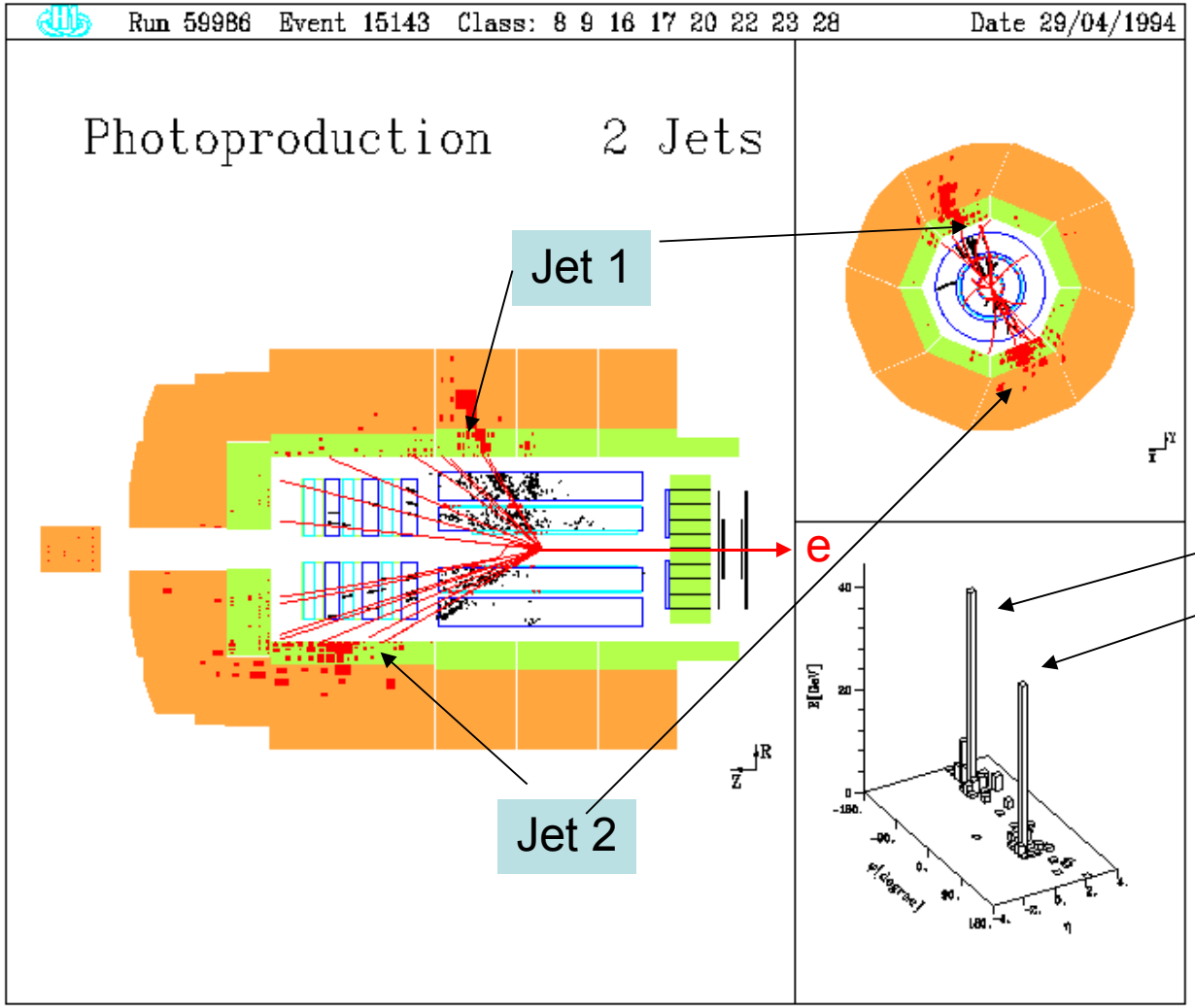


This CC event shows a muon separated from the jet

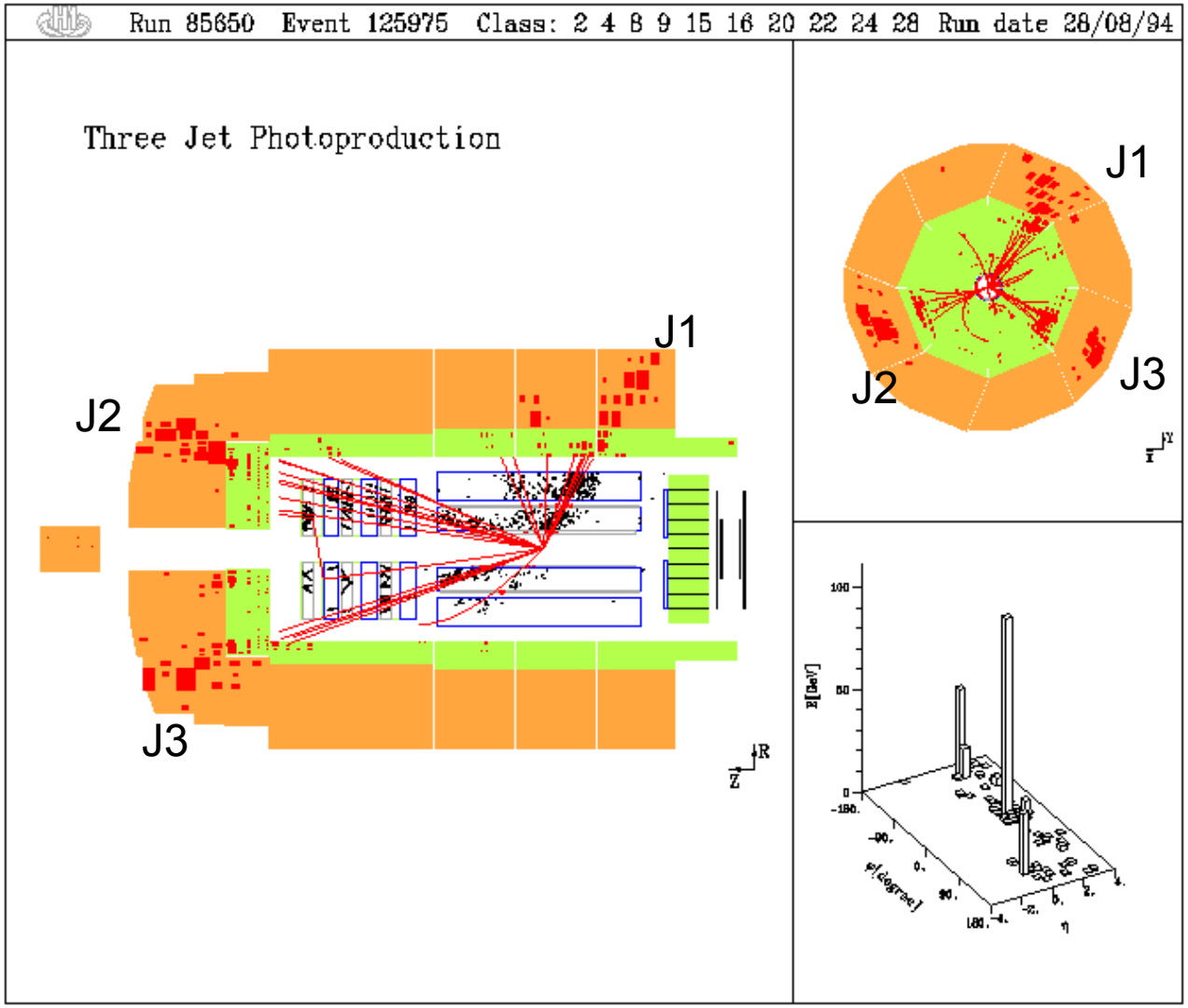



This could be a muon produced in the semileptonic decay of a charm quark

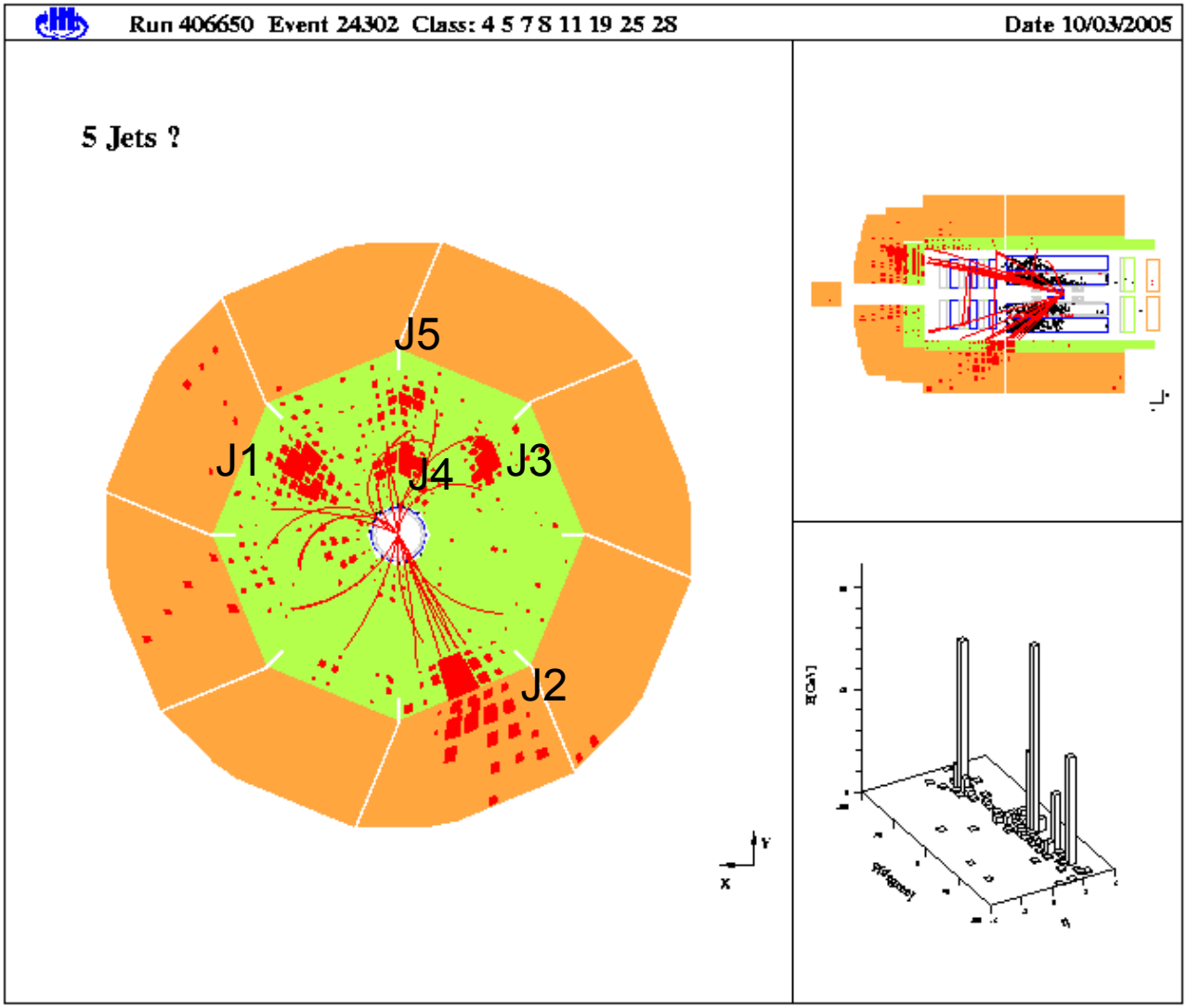
Another event class : ‘Photoproduction’
Here two jets are visible, but the scattered electron is not recorded, it leaves the detector under very small scattering angle



# Here a THREE-JET-EVENT



Here 5 jets are visible, there is no limit in the number.

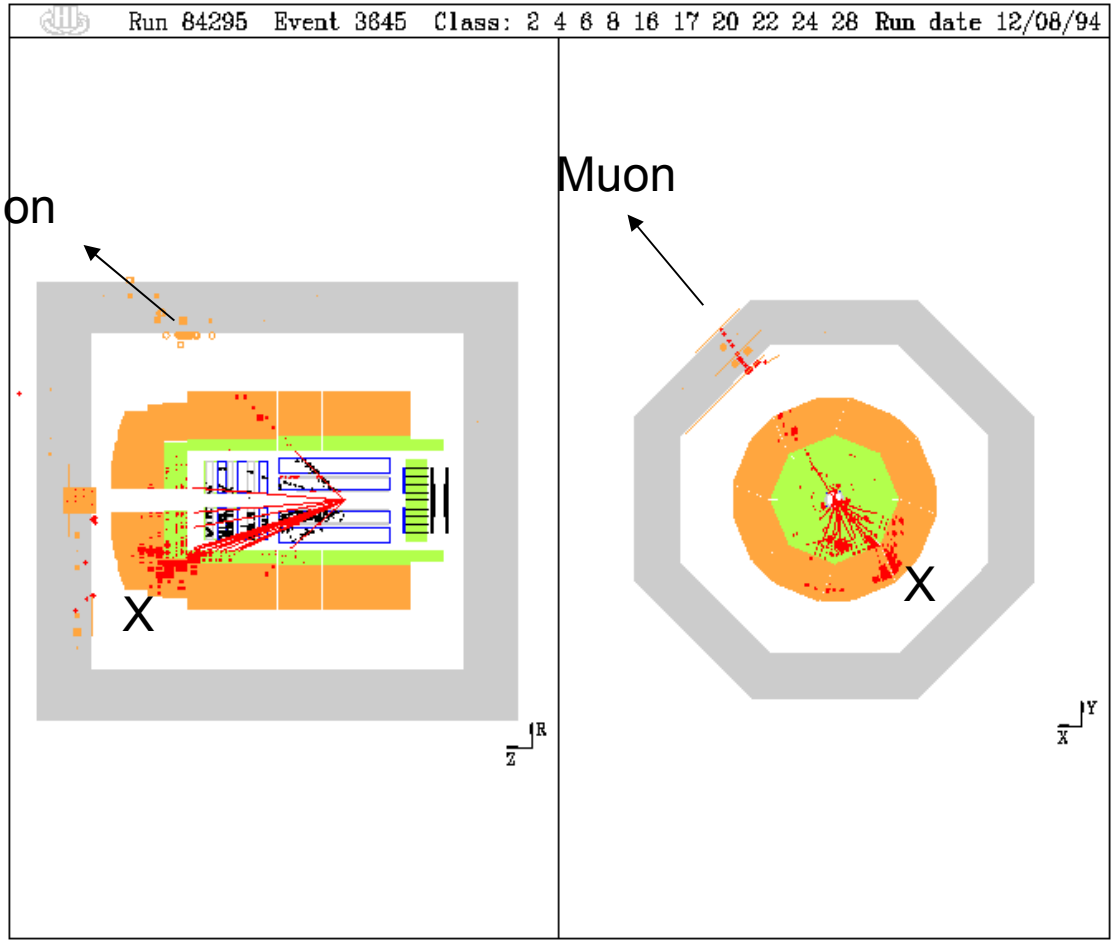



Quarks radiate gluons, which in turn may radiate gluons or produce quark-antiquark pairs.
All turn (if energetic enough) to visible jet structures

## The most exciting issue : Are there new phenomema, we don't expect ?

We have seen $ep \rightarrow e' X$ DIS - events

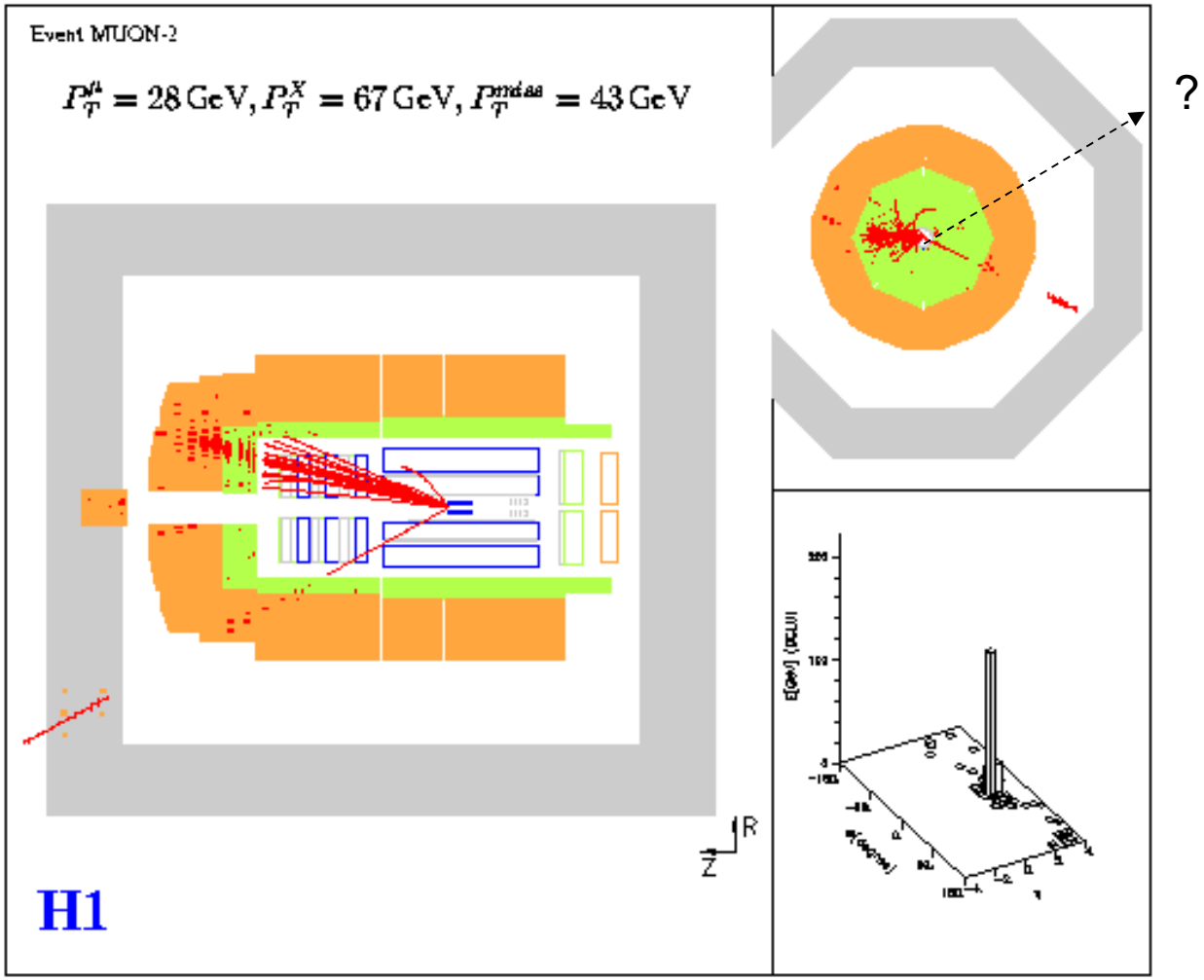
But this looks like $ep \rightarrow \mu X$ (As such forbidden in HEP Standard Model)




Fluctuating background
or
sign of new physics ?

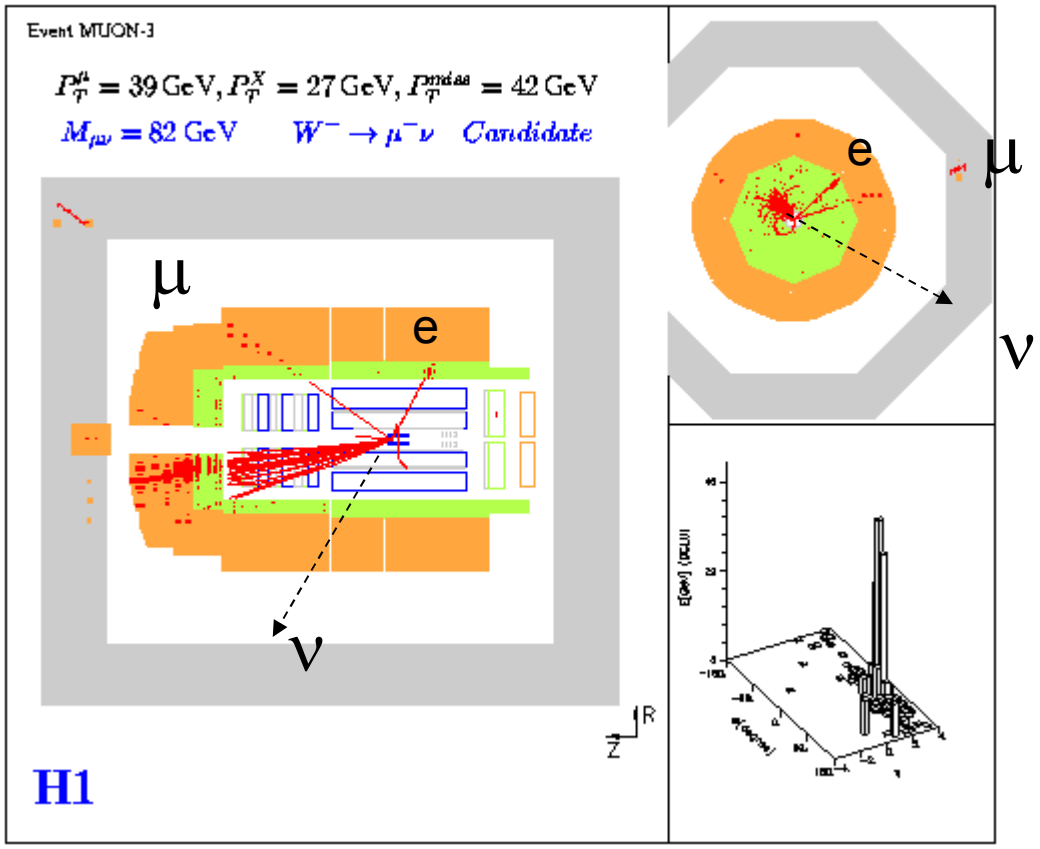
A similar event, but here muon and hadronic jet are not back-to-back : clear evidence for unobserved particle (neutrino ?)

$$e^+p \rightarrow \mu^+X$$



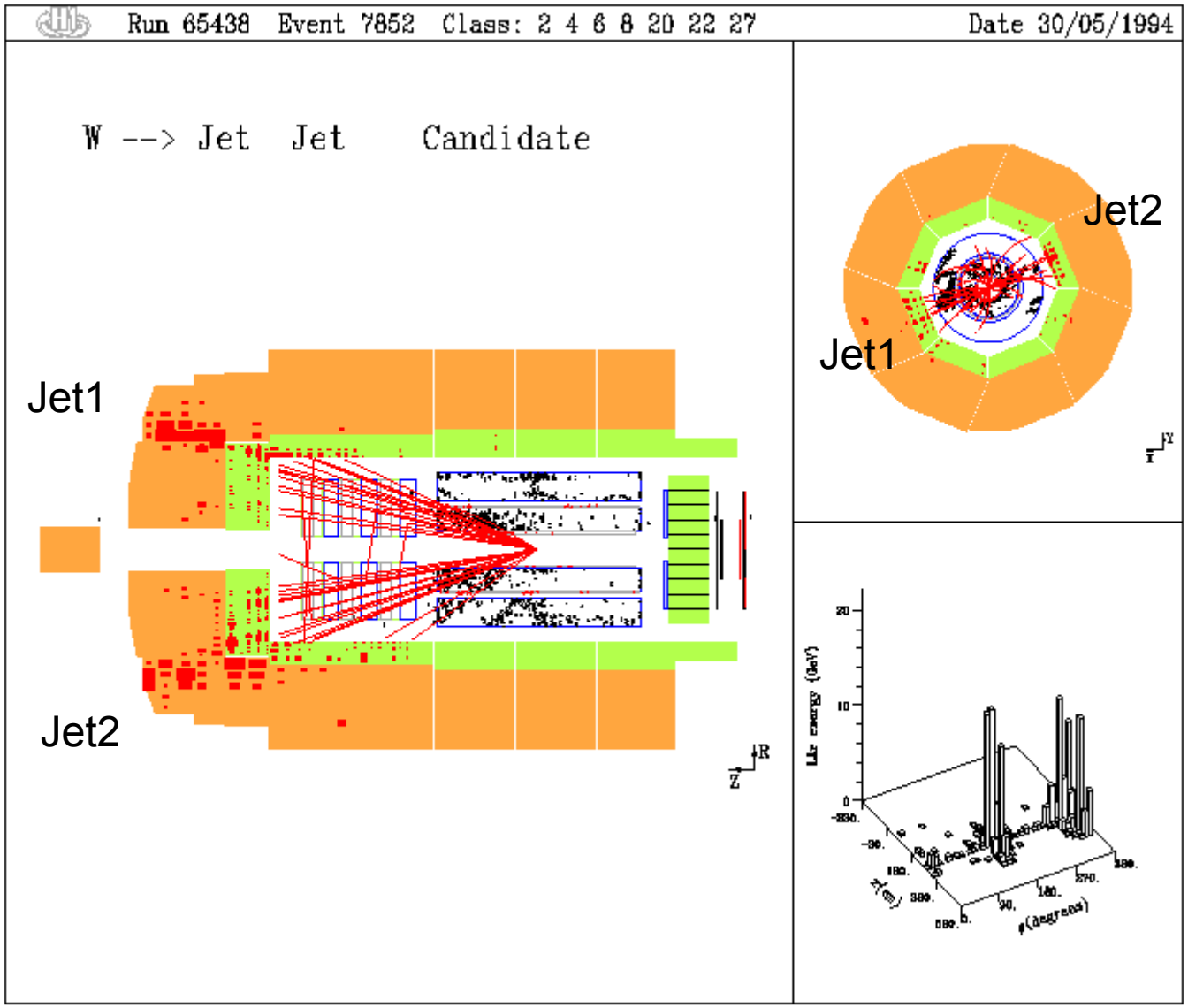
Similar event, but here also the scattered electron is visible.
This allows to reconstruct the invariant mass of the muon-neutrino-system.
It turns out to be 82 GeV. That's close to the W mass.

$$e^+ p \rightarrow e^+ \mu^- X$$



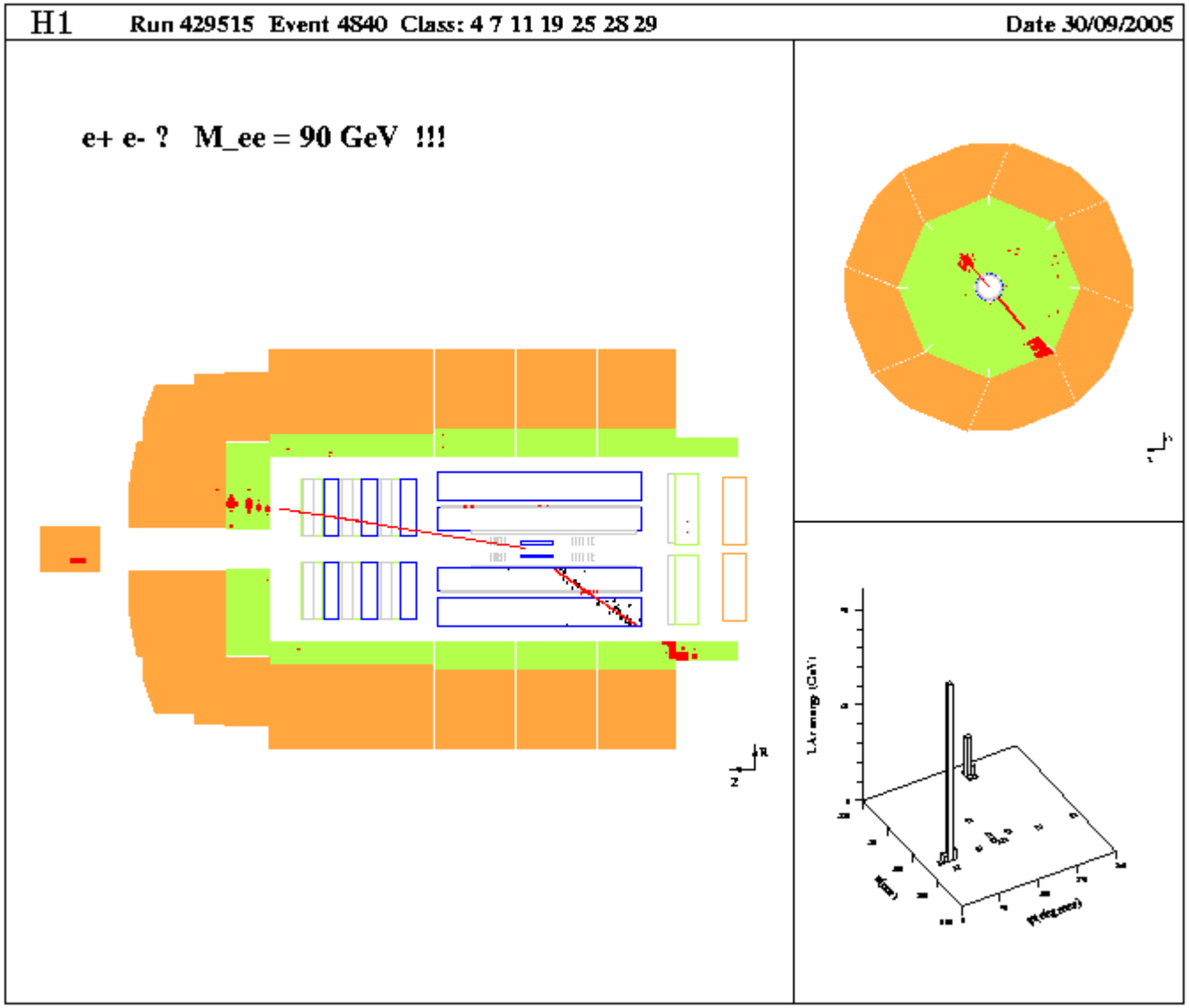

$$ep \rightarrow eXW \ldots\ldots W \rightarrow \mu\nu$$

H1 sees more events than expected from this reaction. New physics ?



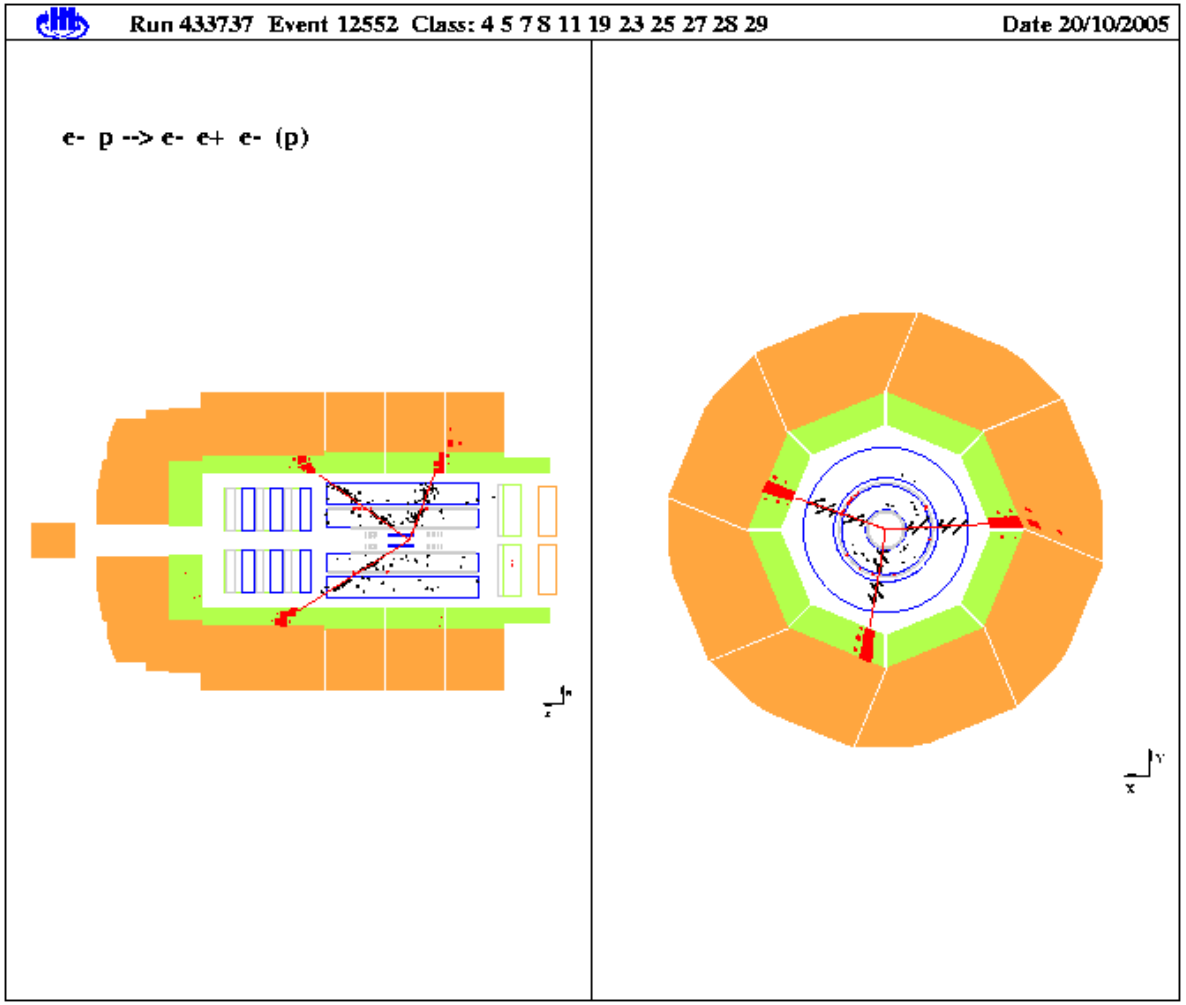

The W decays also into quark-antiquark producing two jets.
The jet-jet-mass is 80 GeV, just the known W-mass.

The W particle has a sister, the Z , of 90 GeV mass, decaying into lepton pairs



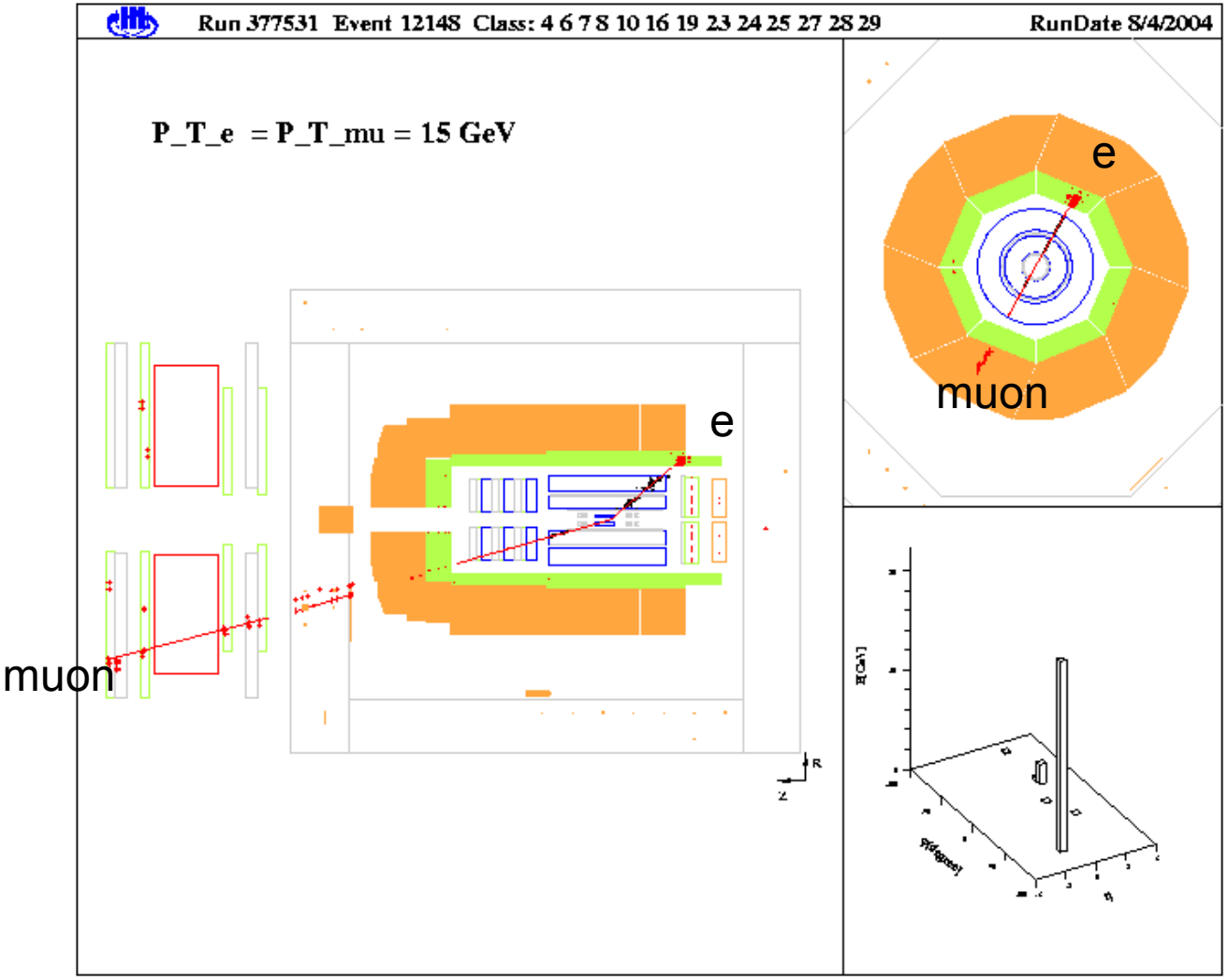

$$Z_0 \rightarrow e^+e^-$$

Here a positron and 2 electrons are recorded. Presumably the scattered electron and a pair created in the interaction

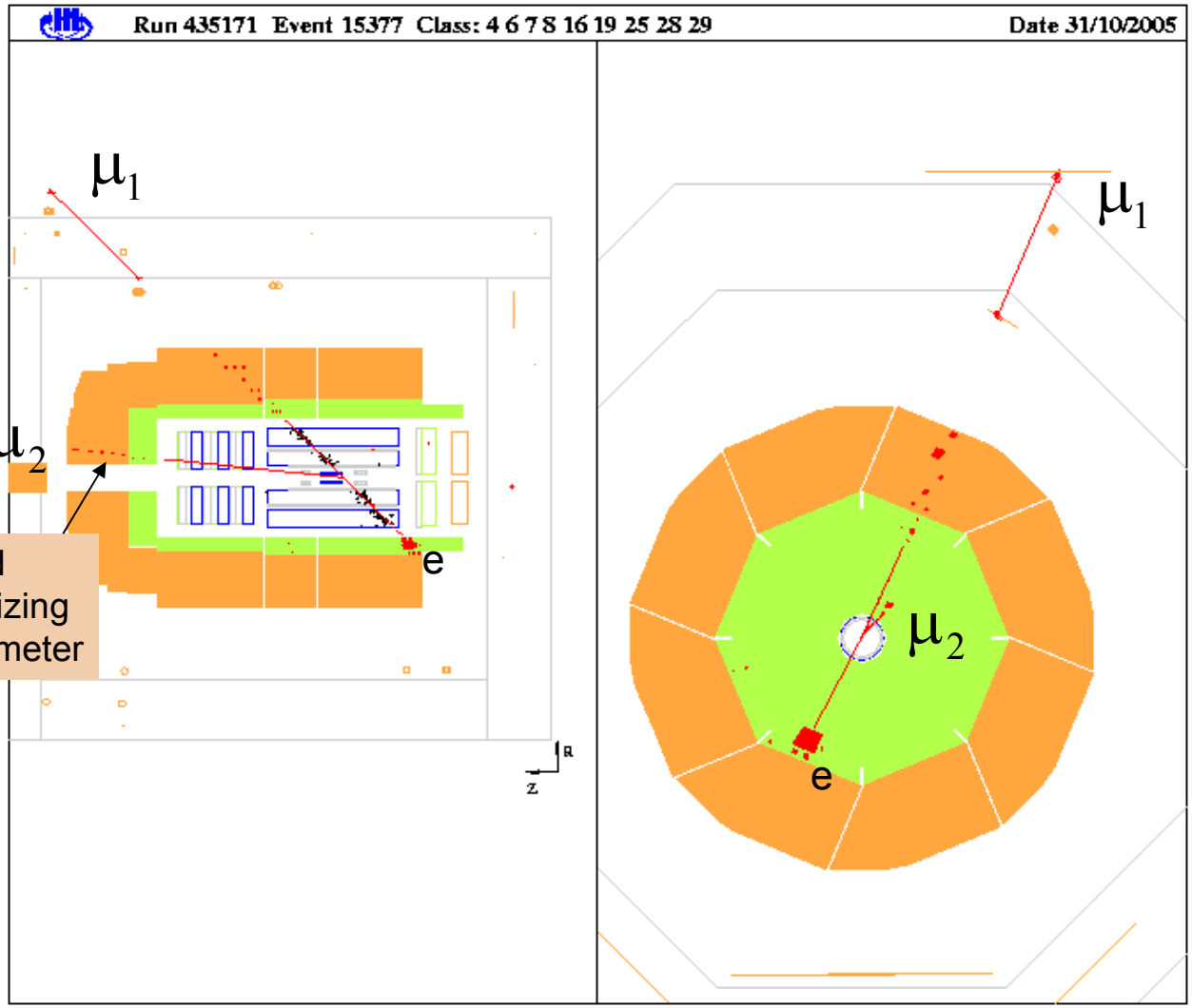



Note :
All ‘electrons’ are well confined in the electromagnetic part (green) of the calorimeter

# There are also dilepton events with different lepton types : Electron and muon



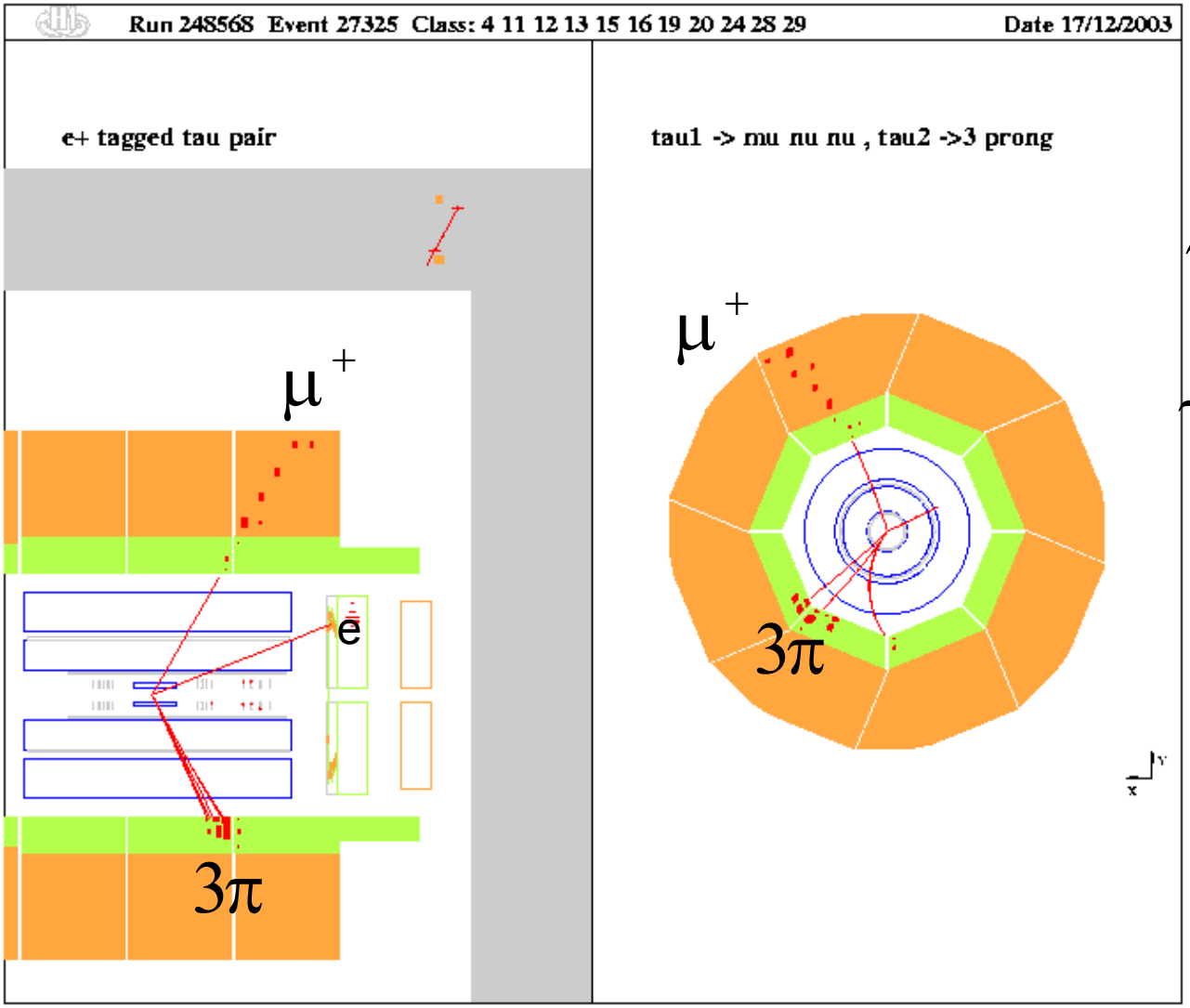
Here it is evident that a pair of muons is produced




Muon2 identified as minimum ionizing particle in calorimeter

A pair of tau-mesons with the scattered electron

$$ep \to e(p)\tau^+\tau^-$$



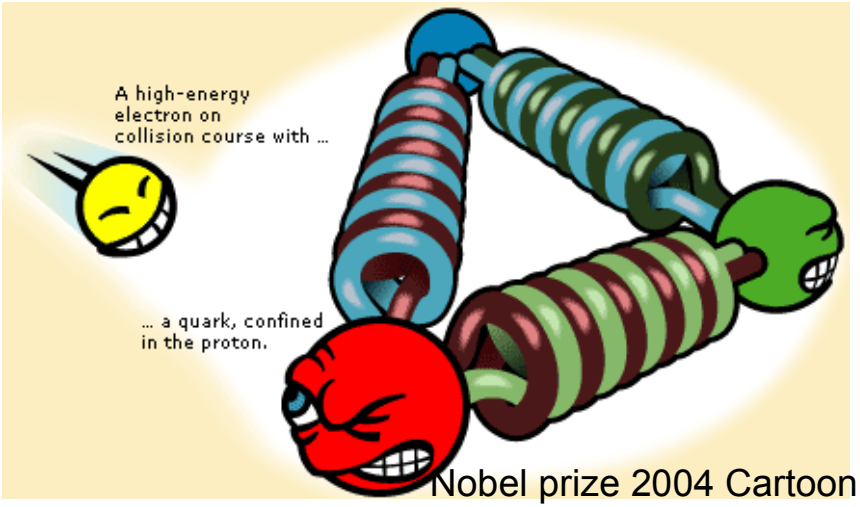

$$\tau^+ \to \mu^+\nu$$

$$\tau^- \to \pi^-\pi^+\pi^-\nu$$

# Summary

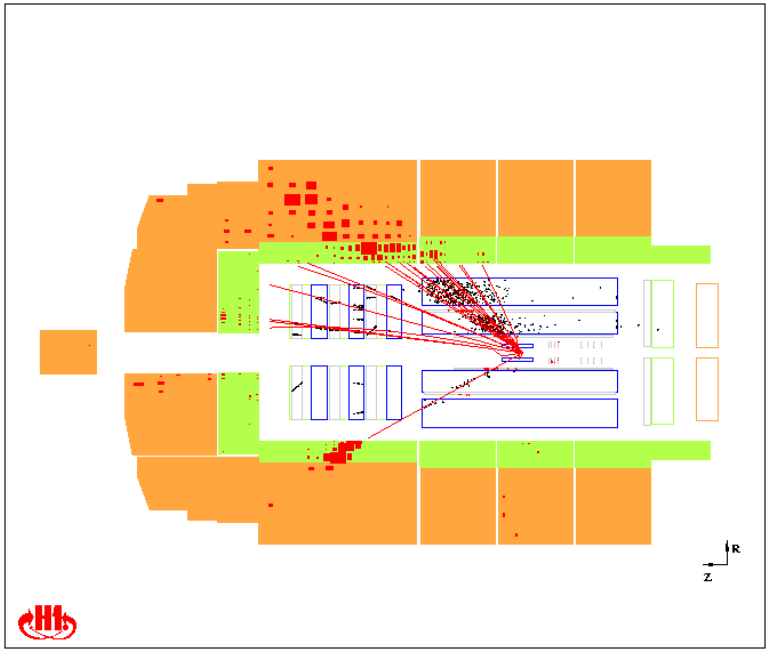
The Method:

e p scattering



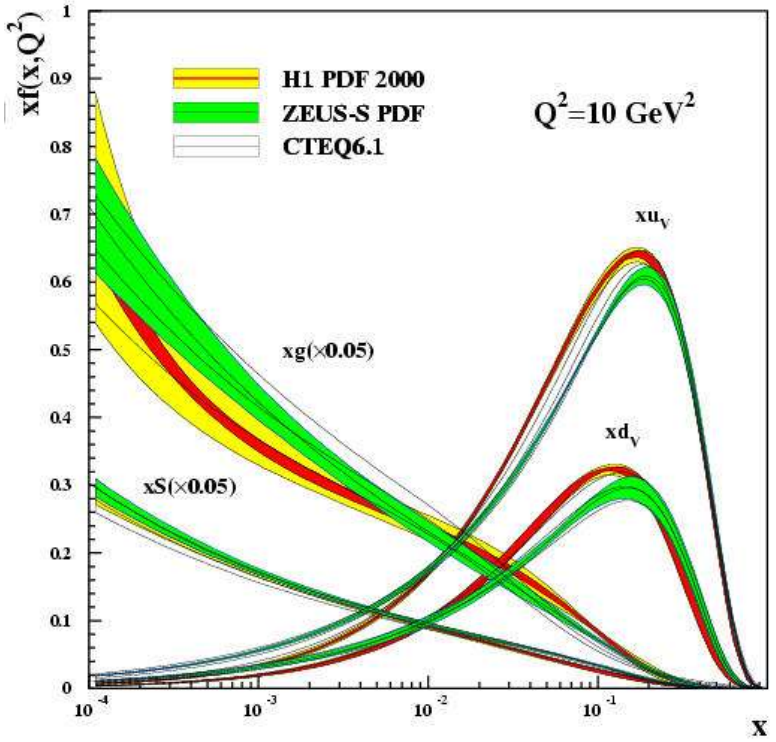

Nobel prize 2004 Cartoon

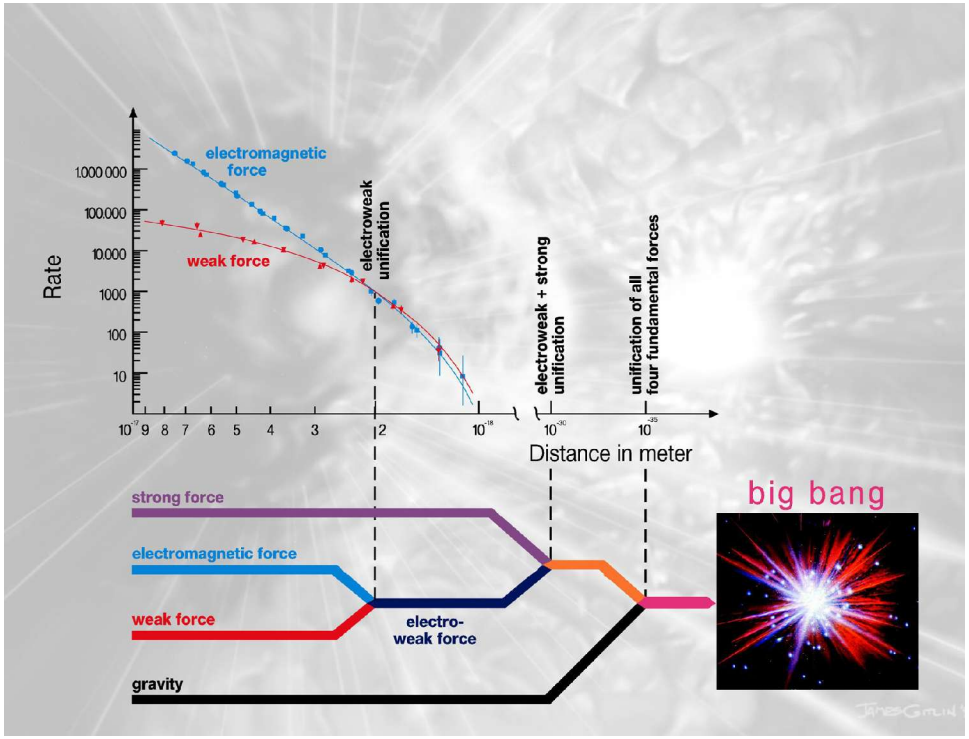
The Data



# Physics Results

examples :



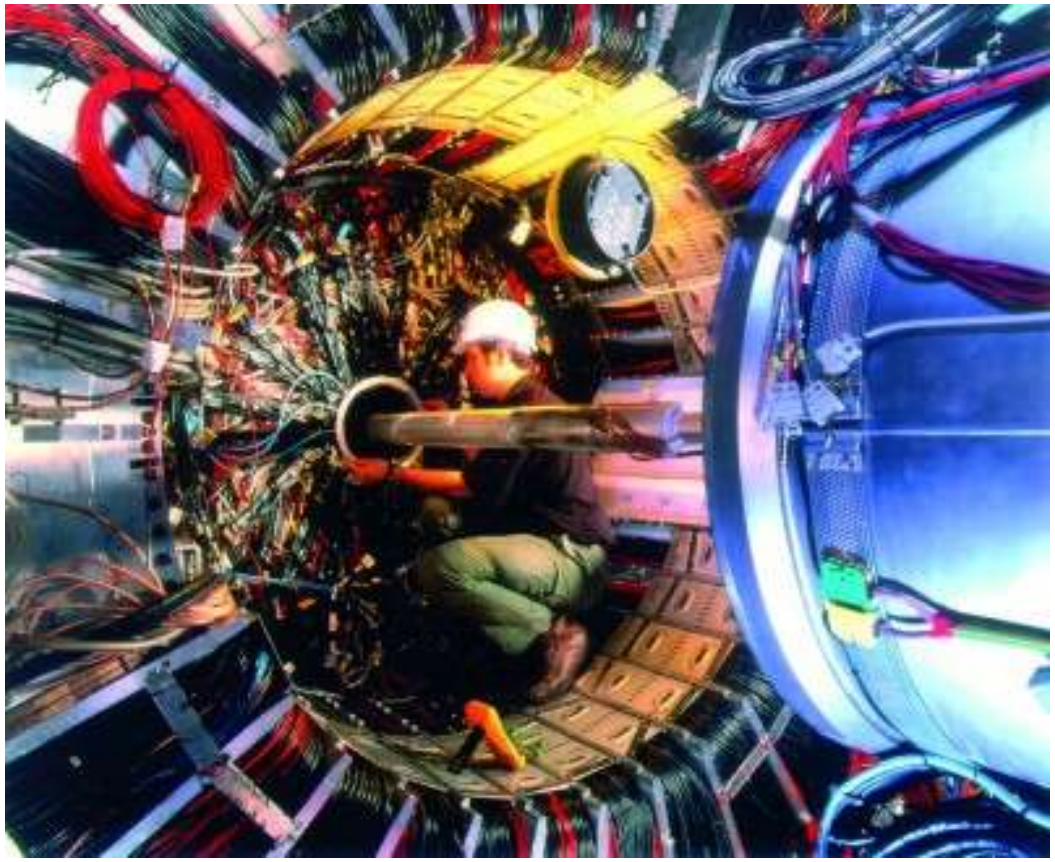




Protonstructure : Quarks and Gluons

Electroweak Unification

..and many more …..

All this became possible thanks to the work of the H1 members……



Work at the innermost parts of the H1 detector

Some members of the H1 Collaboration

…and thanks to HERA….


.. the worlds most powerful microscope $\Delta x \approx 10^{-18}\, m$