# PHYS 3446 – Lecture #17


*Monday, Oct. 31, 2016*

*Dr. Jae Yu*


- Particle Detection
    - Semi-Conductor Detectors
    - Calorimeters
- Particle Accelerators
    - Electro-static Accelerators
    - Cyclotron Accelerators
    - Synchrotron Accelerators

# Announcements

- Quiz #2 result
  - Class average: 28.6/66
    - Equivalent to: 43.3/100
    - Previous result: 47.1/100
  - Top score: 65/66
- Mark on your calendar two special colloquia – double extra credit:
  - Nov. 30: Dr. Steven Sand
  - Dec. 7: Dr. K.C.Kong

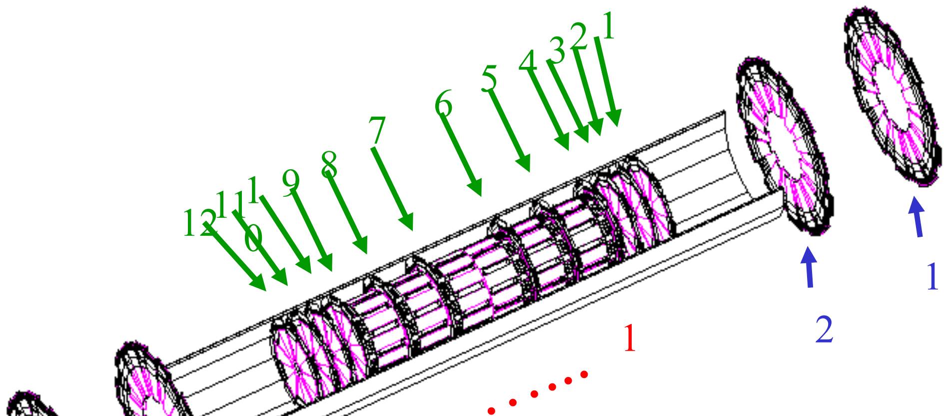
# Homework #8

- Carry out Fourier transformation and derive equations 9.3 and 9.5
- Due for these assignments is Monday, Nov. 7

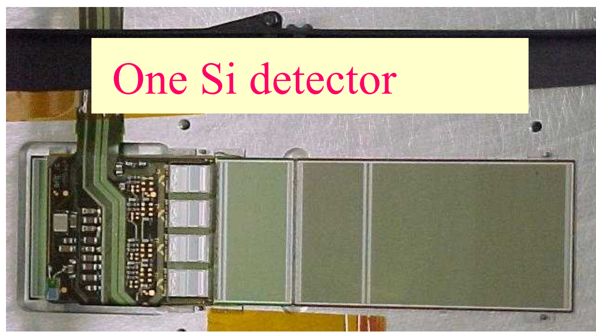
# Semiconductor Detectors

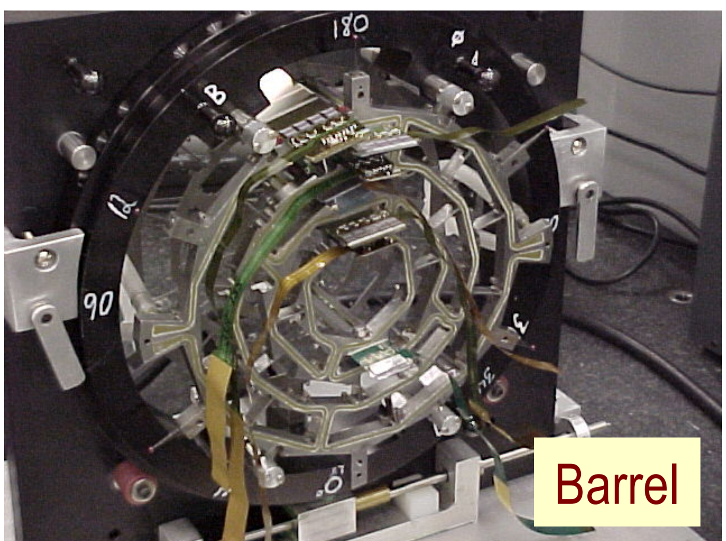
- Semiconductors can produce large signal (electron-hole pairs) for a relatively small energy deposit (~3eV)
  - Advantageous in measuring low energy at high resolution
- Silicon strip and pixel detectors are widely used for high precision position measurements
  - Due to large electron-hole pair production, thin layers (200 – 300 $\mu$m) of wafers are sufficient for measurements
  - Output signal proportional to the ionization loss in the semiconductor
  - Low bias voltages sufficient to operate
  - Can be deposit in thin stripes (20 – 50 $\mu$m) on a thin electrode
  - High position resolution achievable
  - Can be used to distinguish particles in multiple detector configurations
- So what is the catch?
  - Very expensive ➔ On the order of \$30k/m$^2$

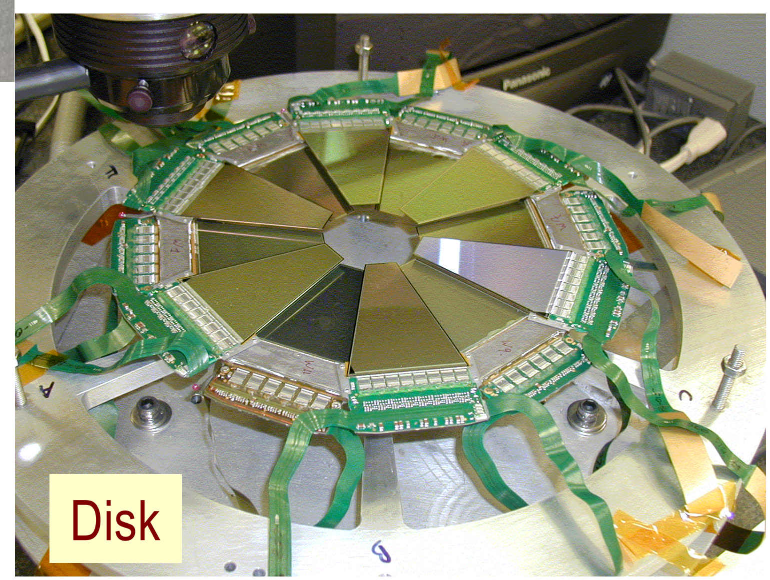
# DØ Silicon Vertex Detector




| | Barrels | F-Disks | H-Disks |
|---|---|---|---|
| Channels | 387120 | 258048 | 147456 |
| Modules | 432 | 144 | 96 |
| Inner R | 2.7 cm | 2.6 cm | 9.5 cm |
| Outer R | 9.4 cm | 10.5 cm | 26 cm |



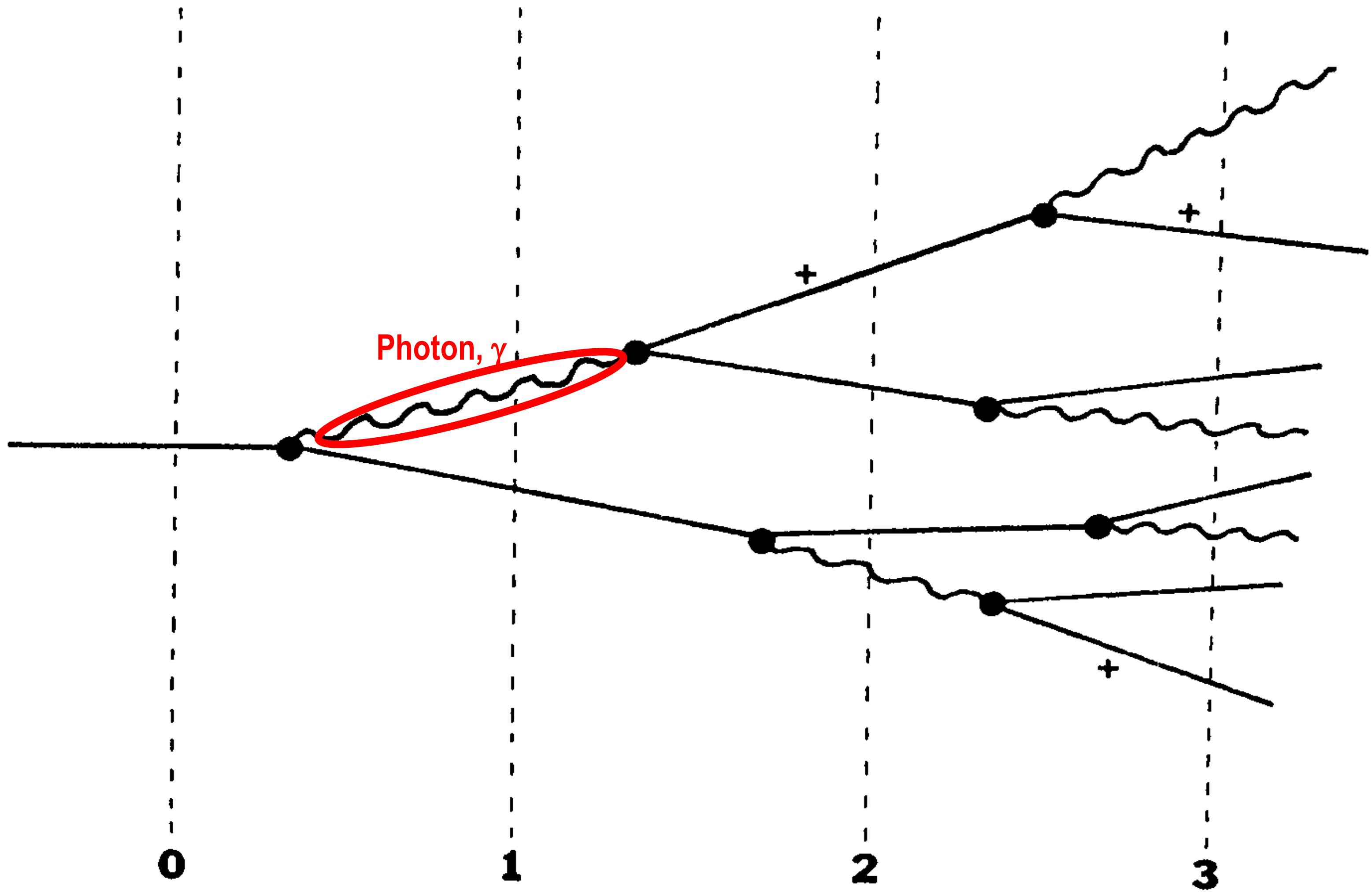
# Calorimeters

- Magnetic measurement of momentum is not sufficient for physics, why?
  - The precision for angular measurements gets worse as particles' momenta increases
  - Increasing the magnetic field or increasing the precision of the tracking device will help but will be expensive
  - Cannot measure neutral particle momenta
- How do we solve this problem?
  - Use a device that measures kinetic energies of the particle
- Calorimeter
  - A device that absorbs the full kinetic energy of the particle
  - Provides signal proportional to deposited energy

# Calorimeters

- Large scale calorimeter were developed during 1960s
  - For energetic cosmic rays
  - For particles produced in accelerator experiments
- How do high energy EM (photons and electrons) and Hadronic particles deposit their energies?
  - Electrons: via bremsstrahlung
  - Photons: via electron-positron conversion, followed by bremsstrahlung of electrons and positrons
  - These processes continue occurring in the secondary particles causing an electromagnetic shower losing all of its energy

# Electron Shower Process

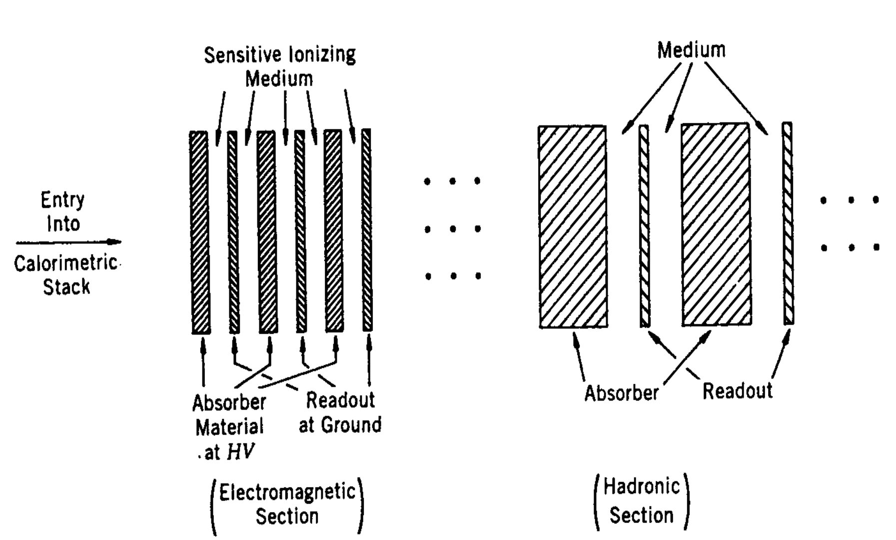


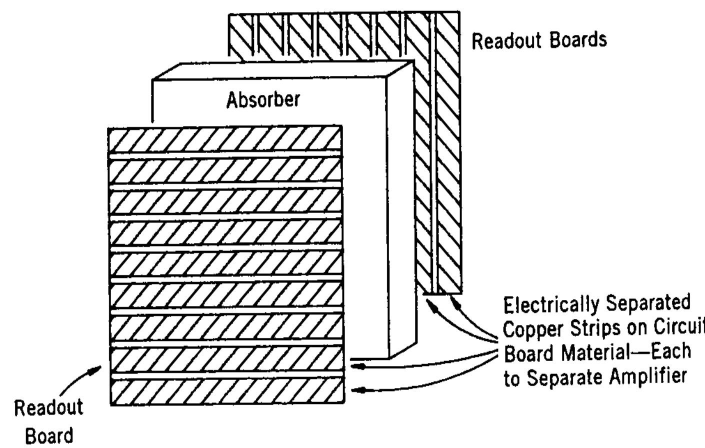
# Calorimeters

- Hadrons are massive thus their energy deposit via brem is small
- They lose their energies through multiple nuclear collisions
- An incident hadron produces multiple pions and other secondary hadrons in the first collision with a nucleus
- The secondary hadrons then successively undergo nuclear collisions
- Mean free path for nuclear collisions is called nuclear interaction lengths or nuclear absorption length ($\lambda_0^{abs}$) and is substantially longer than that of EM particles, radiation length ($X_0$)
- Hadronic shower processes are therefore more erratic than EM shower processes

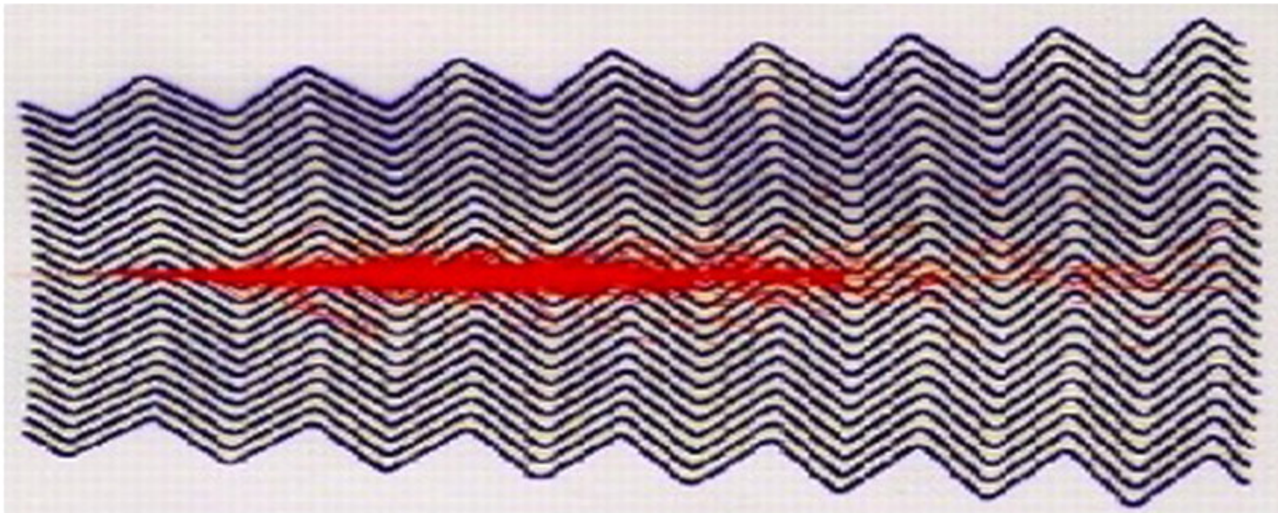
# Sampling Calorimeters

- High energy particles require large calorimeters to absorb all of their energies and measure them fully in the device (called total absorption calorimeters)
- The number of shower particles is directly proportional to the energy of the incident particles
- One can deduce the total energy of the particle by measuring only the fraction of their energy, as long as the fraction is known ➔ Called sampling calorimeters
  - Most the high energy experiments use sampling calorimeters



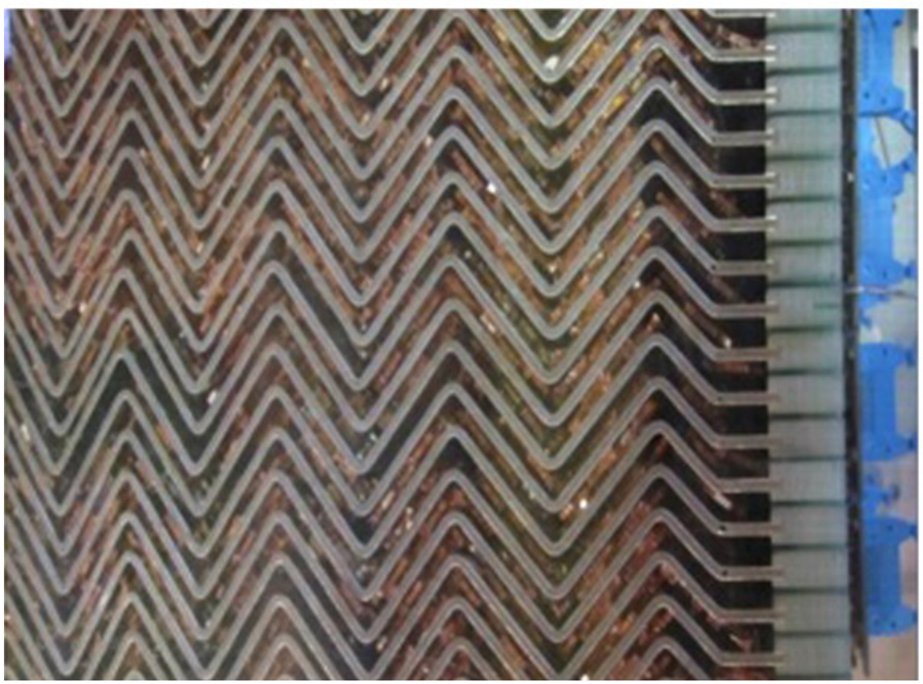



# ATLAS LAr EM Calorimeter

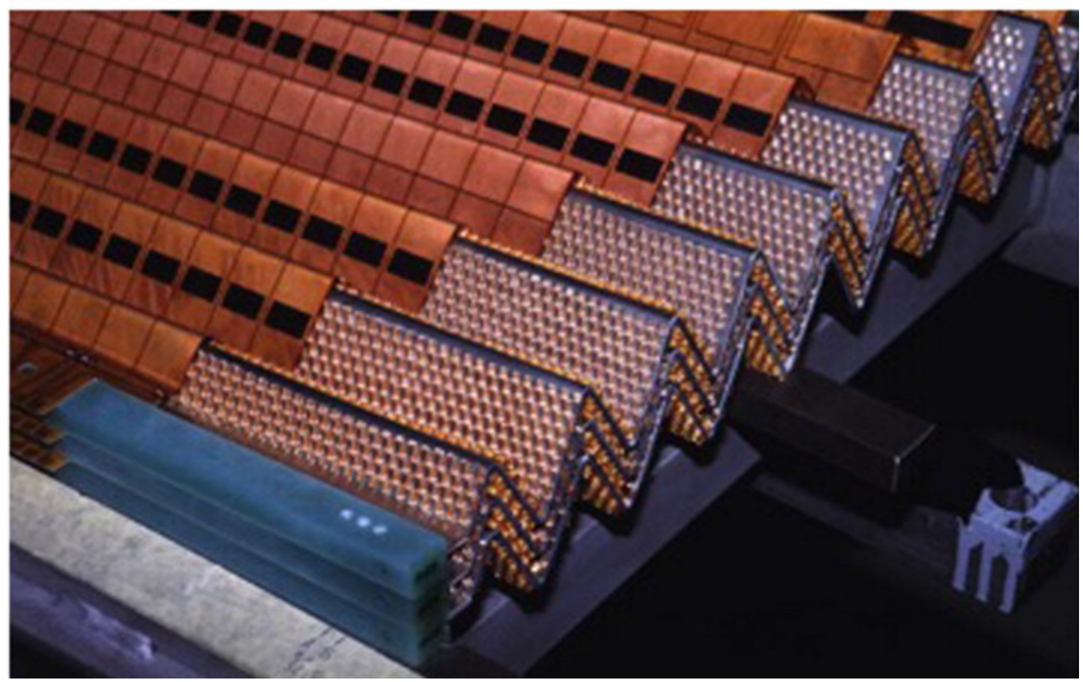


real device

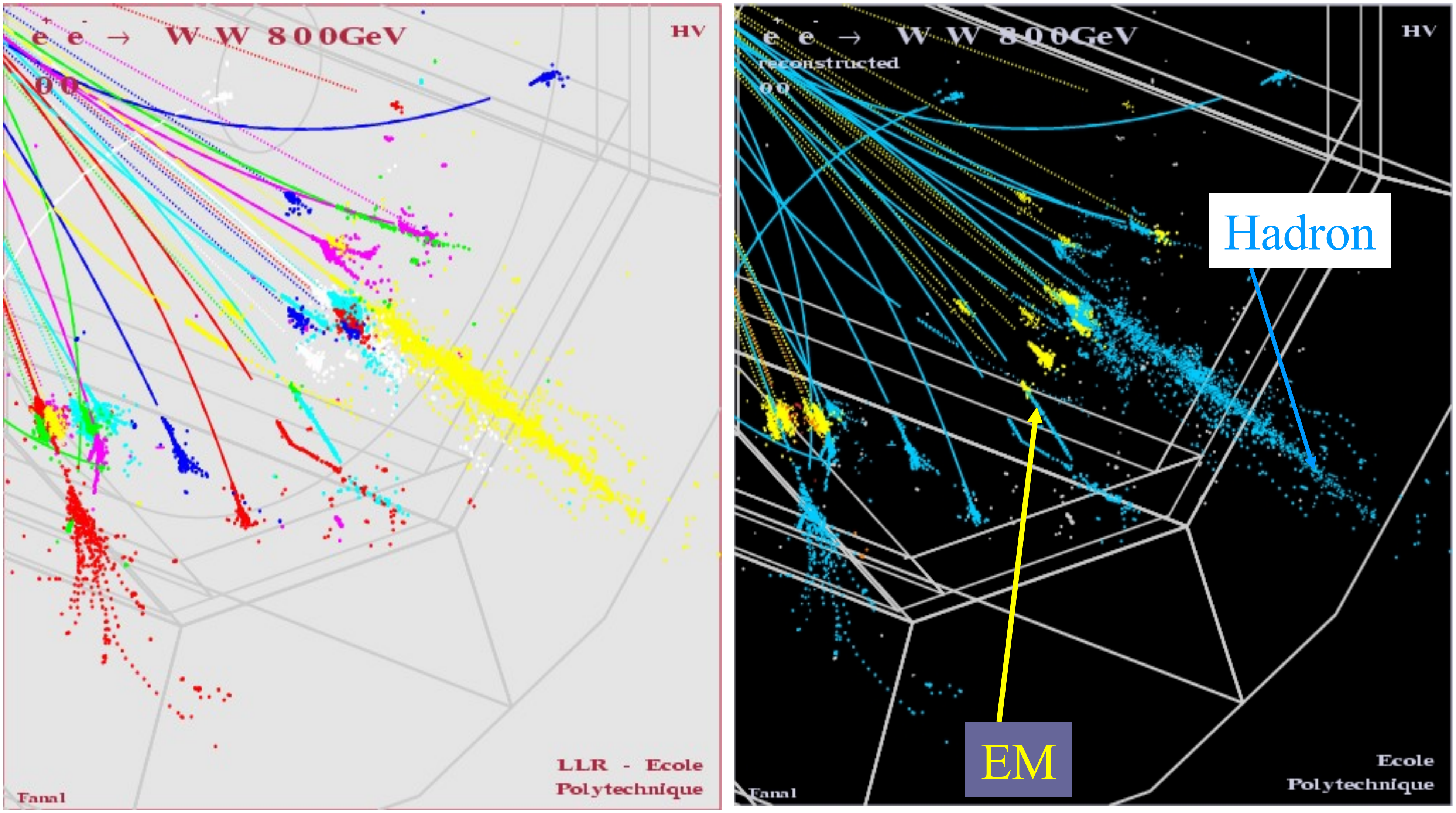
radiator material



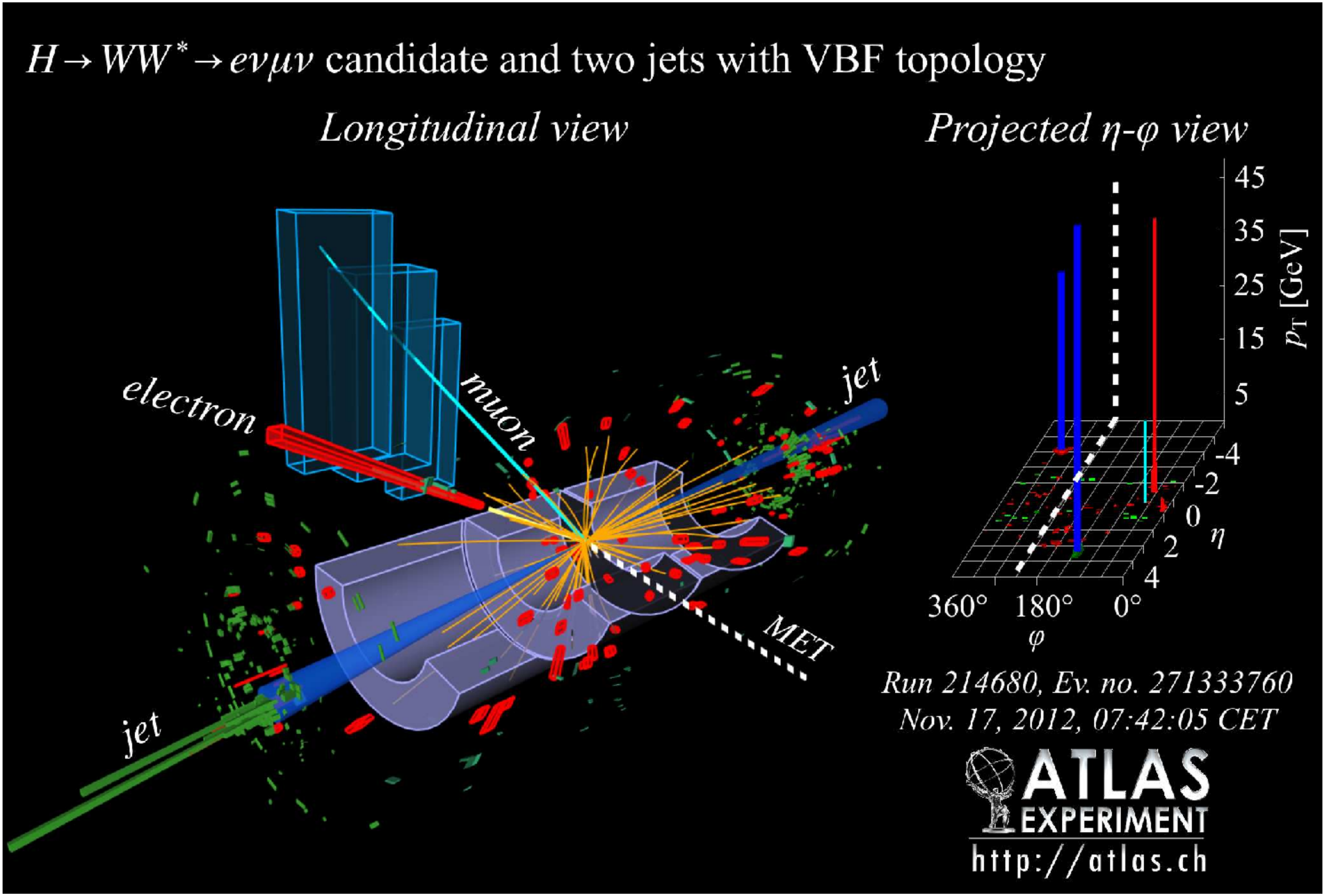
electrodes



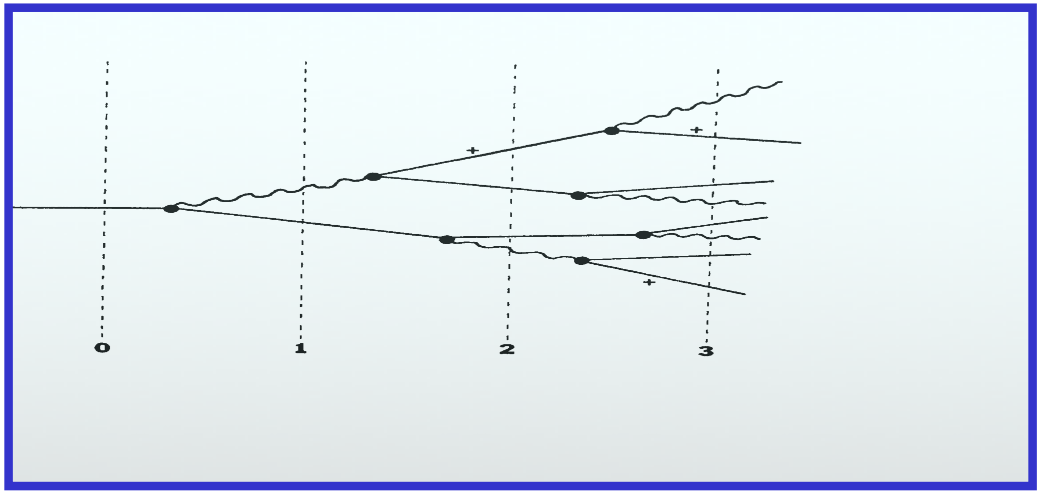
# How particle showers look in a detector



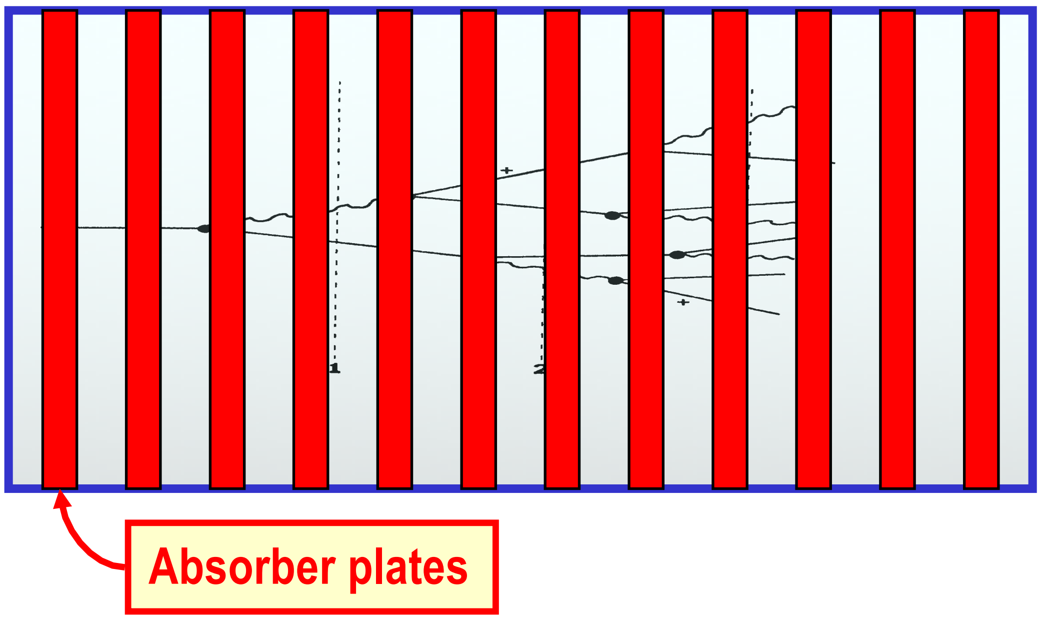
# A fresh new event at the ATLAS



# Principles of Calorimeters




Total absorption calorimeter: Sees the entire shower energy, all active volume!

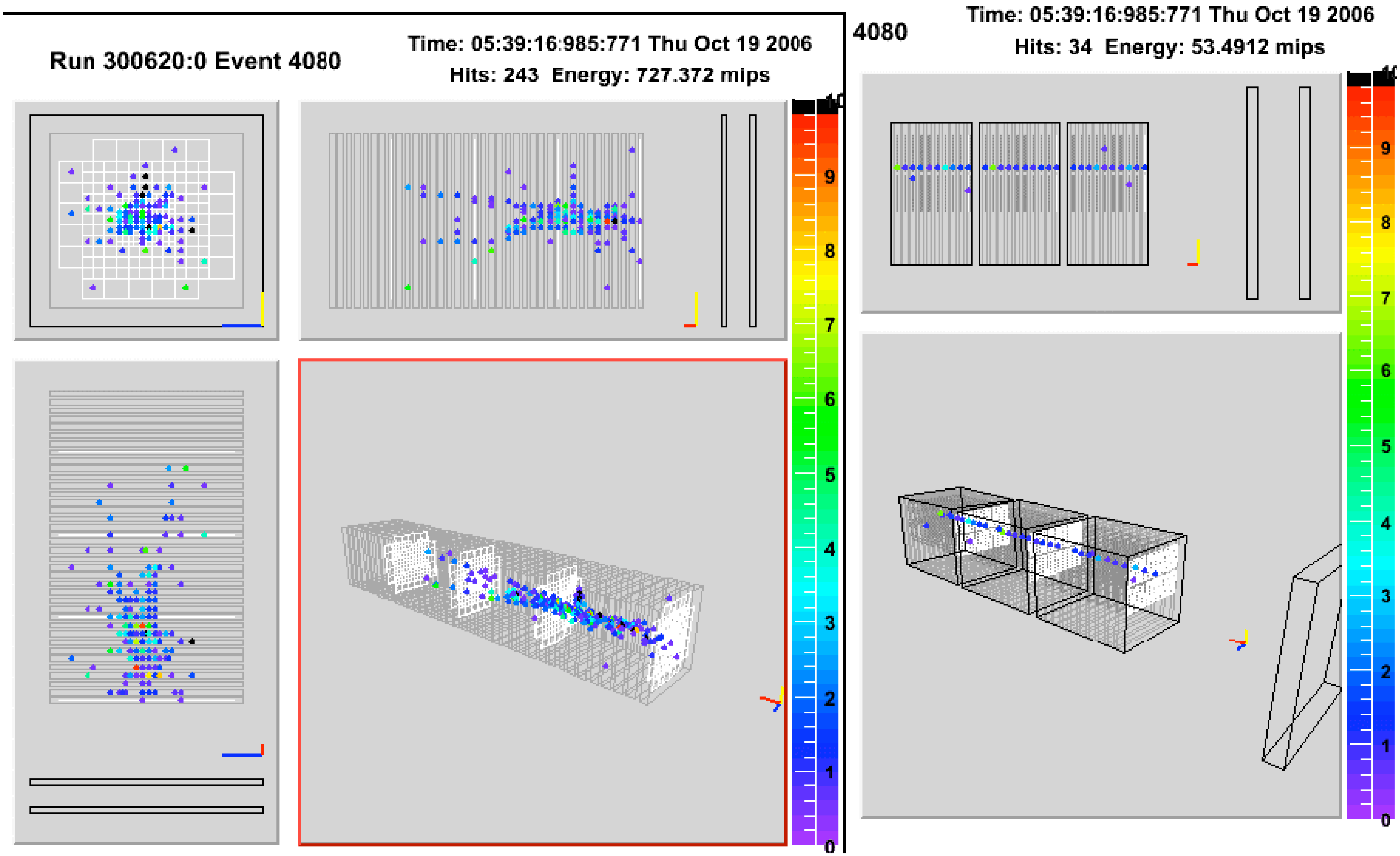



Sampling calorimeter: Sees only some fraction of the shower energy

For EM $$E_{vis} = fE_{in} = \frac{X_0^{vis}}{X_0^{vis} + X_0^{abs}} E_{in}$$

For HAD $$E_{vis} = fE_{in} = \frac{\lambda_0^{vis}}{\lambda_0^{vis} + \lambda_0^{abs}} E_{in}$$

# Example Hadronic Shower (20GeV)



# DØ Central Calorimeter 1990