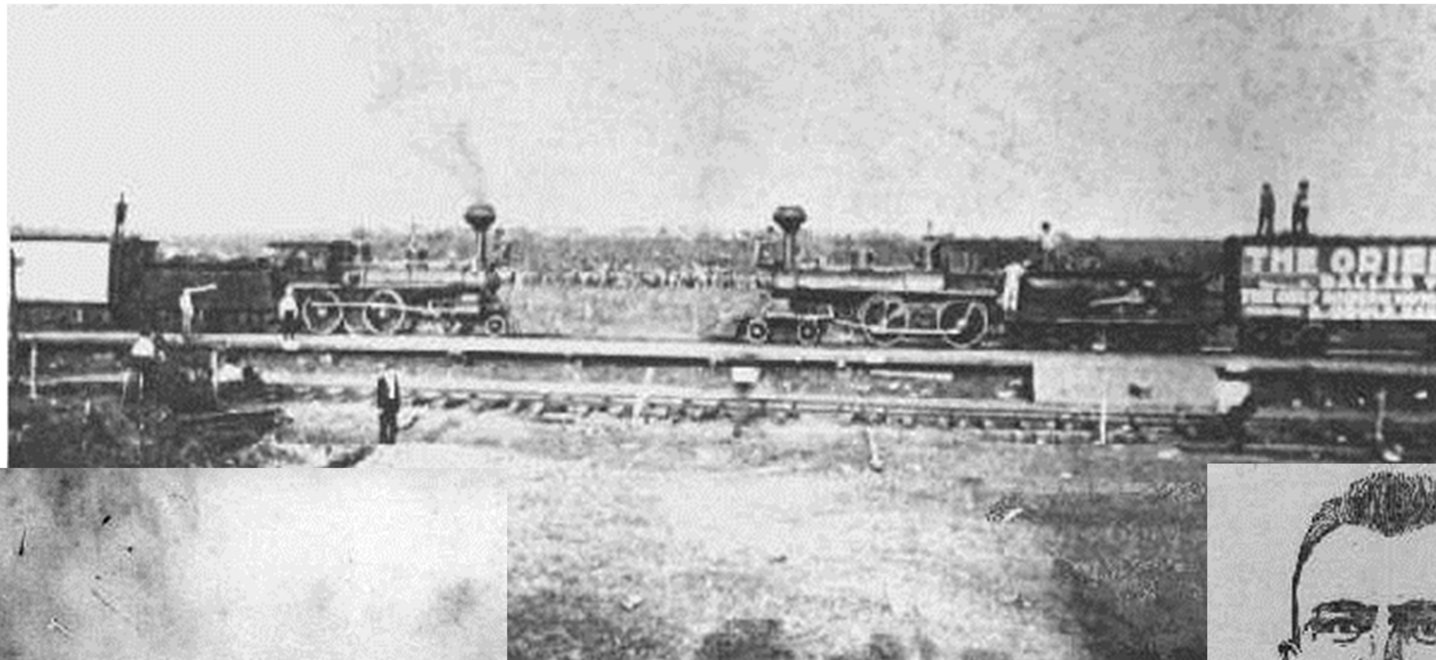
LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

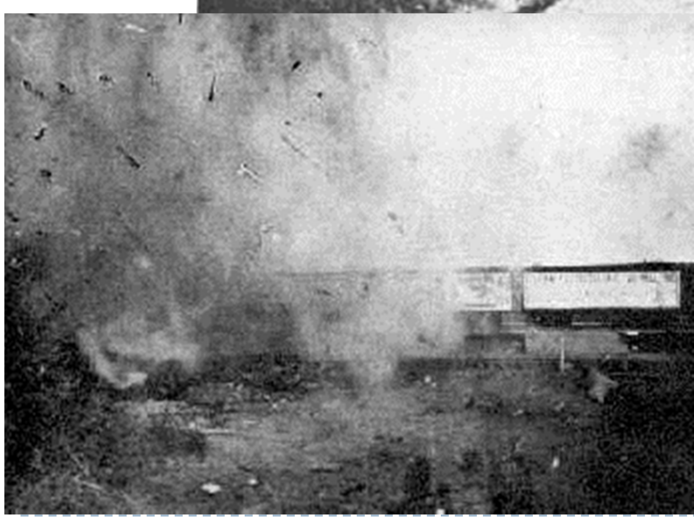
Detector Physics

M. Weber

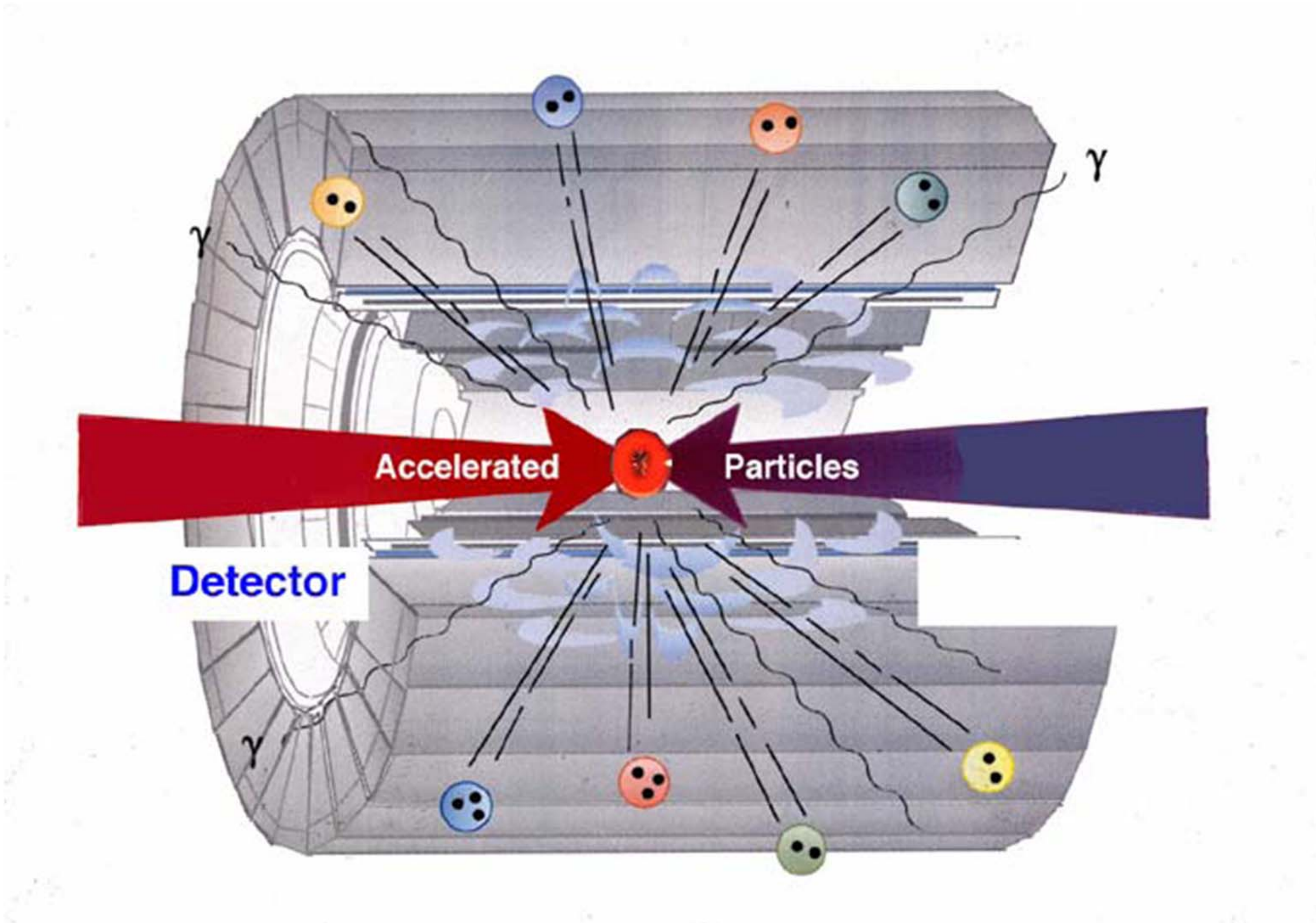
Crash at Crush, TX (1896)

First attempt to produce Higgs ?





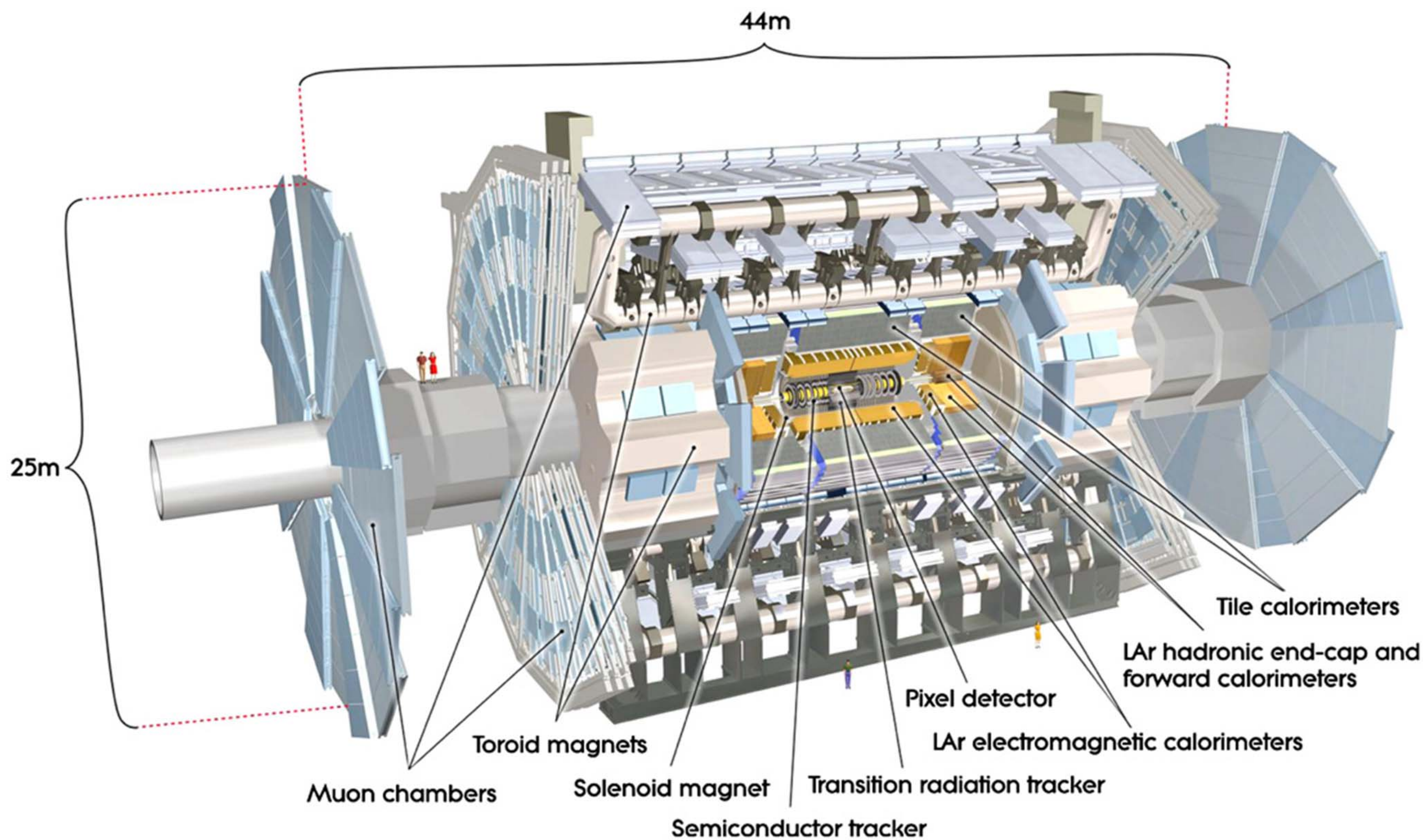
Mr. Crush

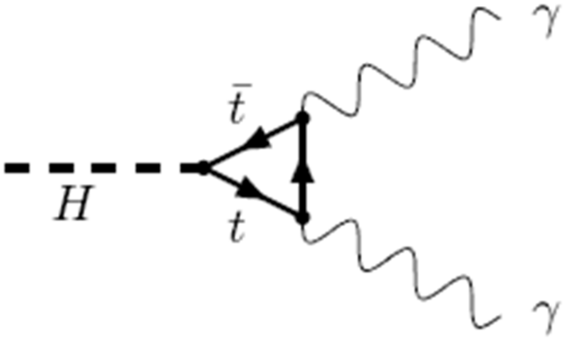

γ
γ
γ
Accelerated
Particles
Detector

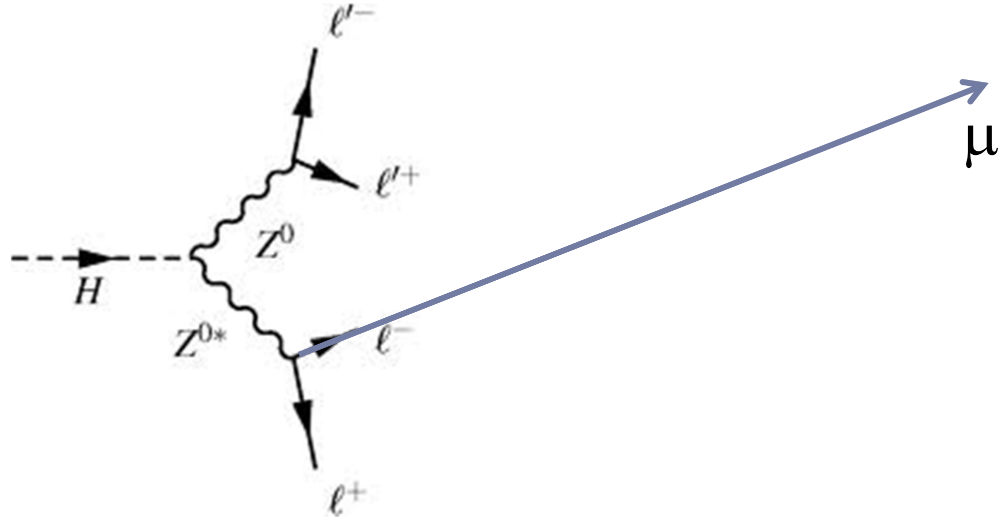
Overview

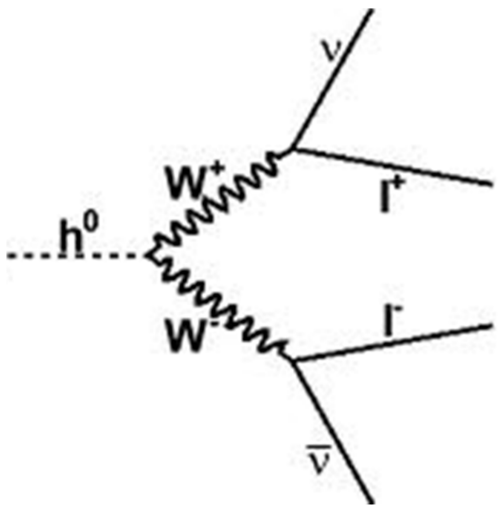
- How do we "measure" particles ?
- What we measure (tracks, momentum, energy)
- How well we do it

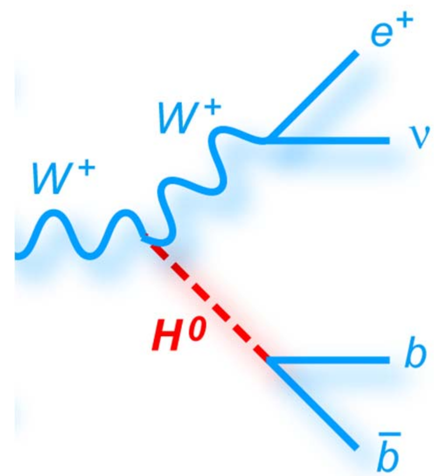
One hour…
I chose to stay general and give an overview…The basics…

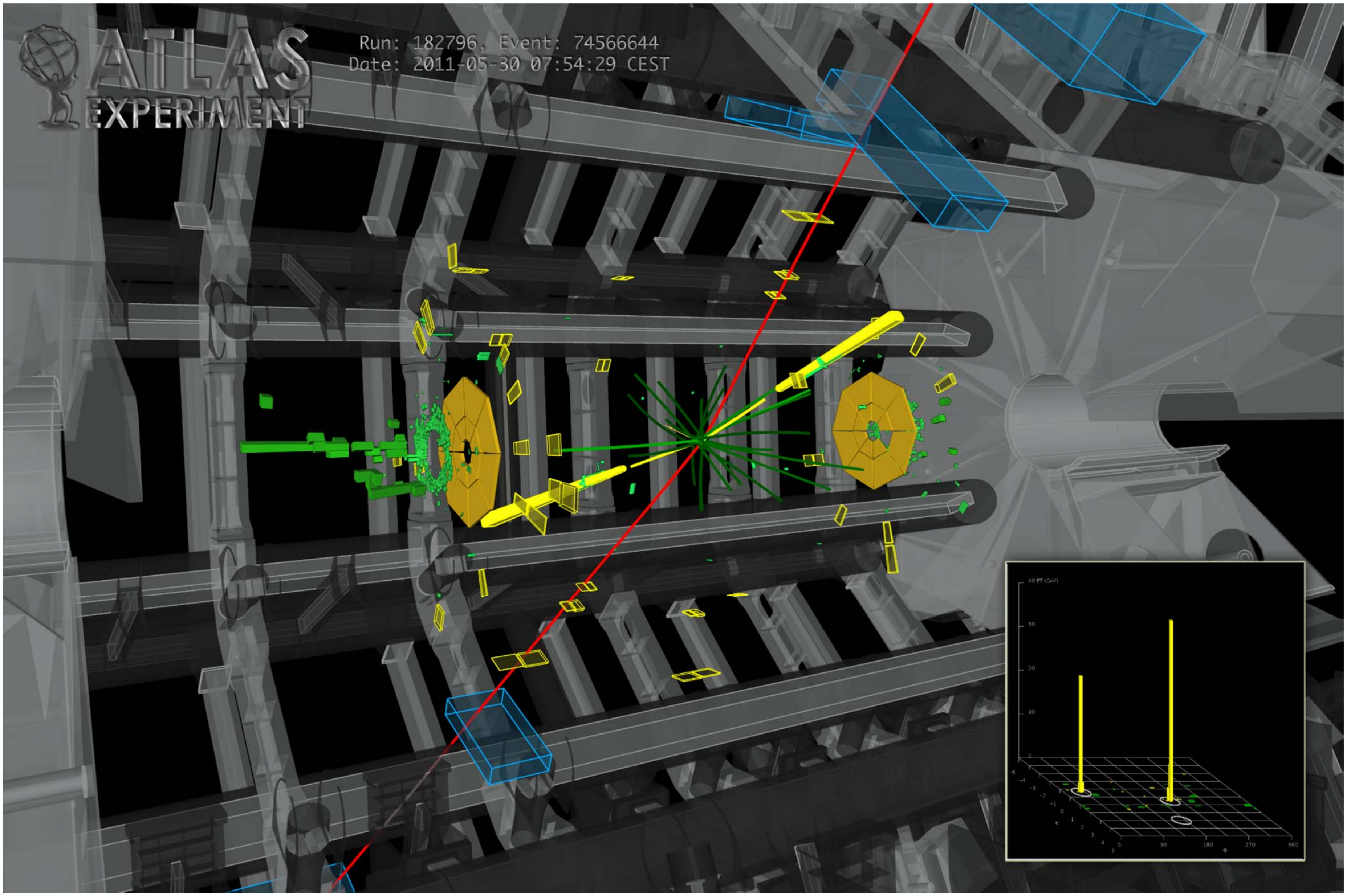

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker


γ
t̄
H
t
γ

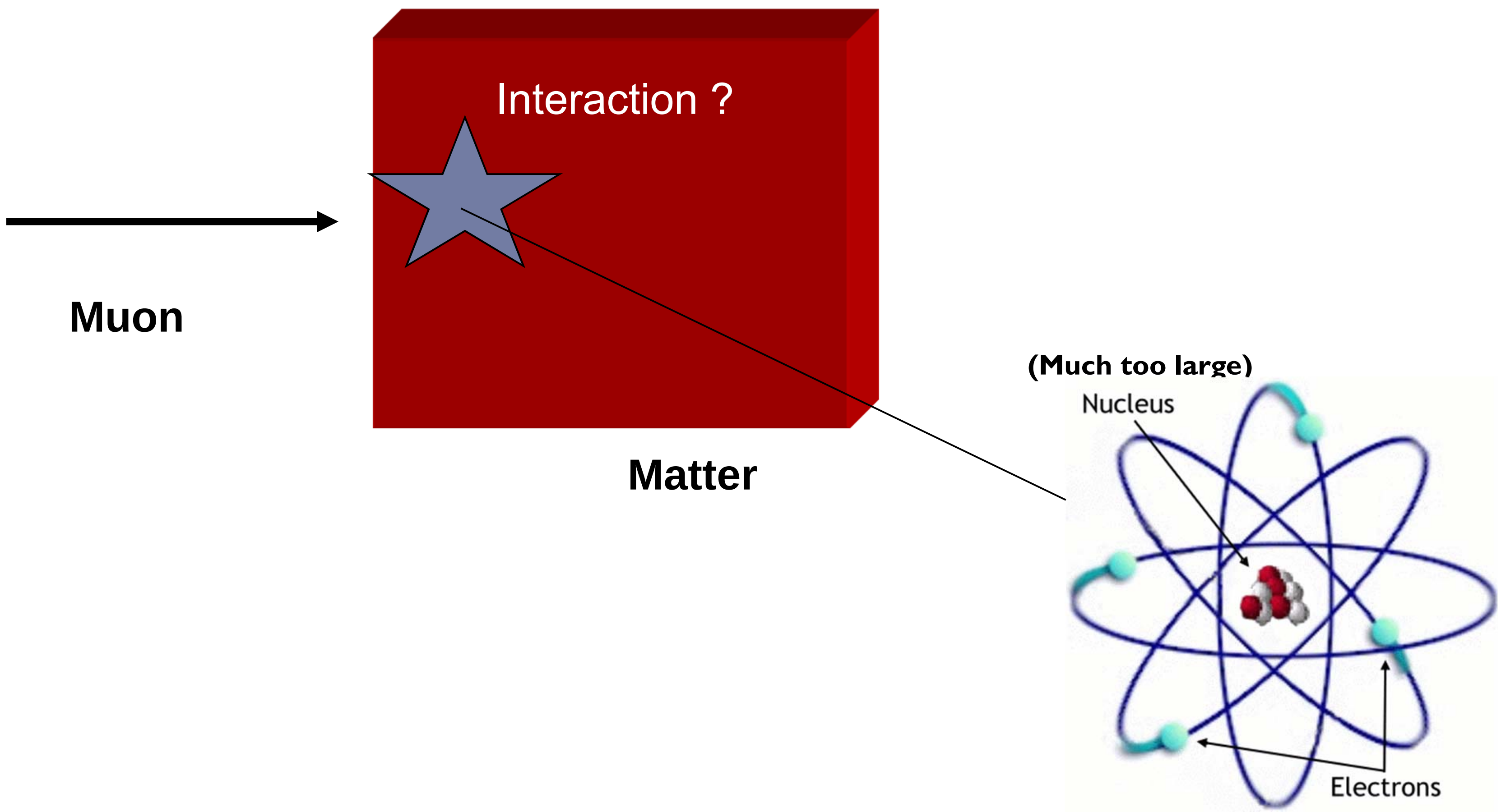

ℓ'−
ℓ'+
Z0
H
Z0*
ℓ−
ℓ+
μ


ν
W+
l+
h0
W-
l-
ν̄


e+
W+
ν
W+
H0
b
b̄


ATLAS
EXPERIMENT
Run: 182796, Event: 74566644
Date: 2011-05-30 07:54:29 CEST

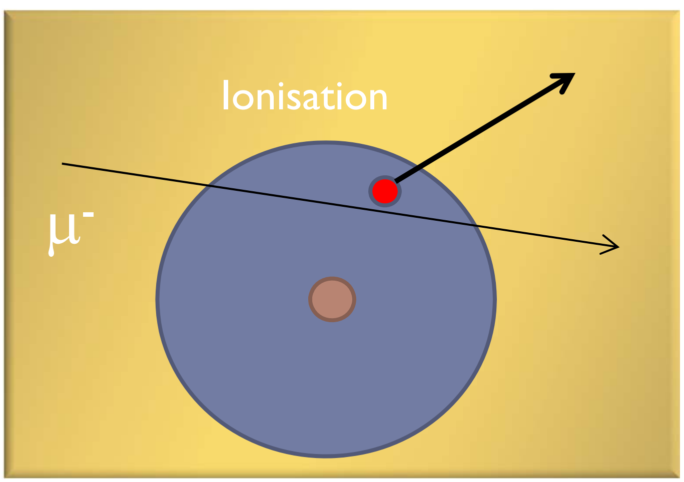
Charged Particles

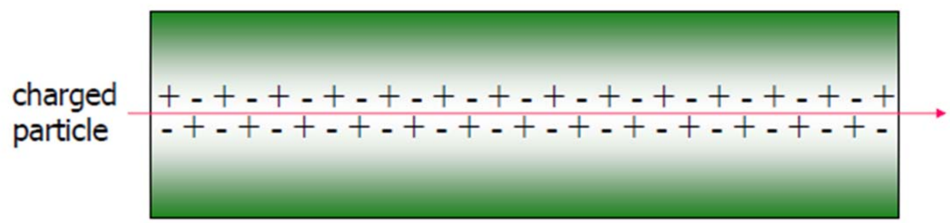


Energy loss by interaction with atomic electrons

- Soft collision: atom is excited (electron to higher shell)
- Hard collision: atom is **ionised** (electron kicked out)
- Negligible deflection since m(particle) >> m(electron)
- Small energy loss per collision (eV)
- But many electrons in the way: in total a large effect:

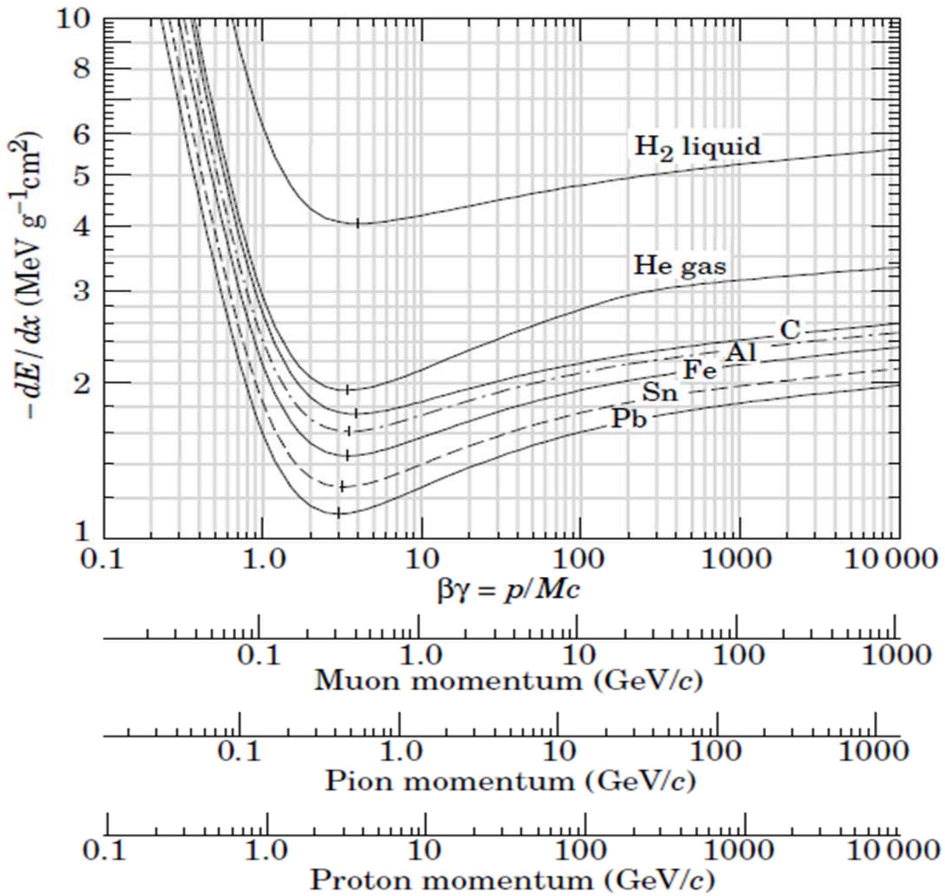
Charged particles





Ionization energy loss (Bethe Bloch)

$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



$K = 4\,\pi N_A r_e^2 m_e c^2$

Z: Atomic number of absorber

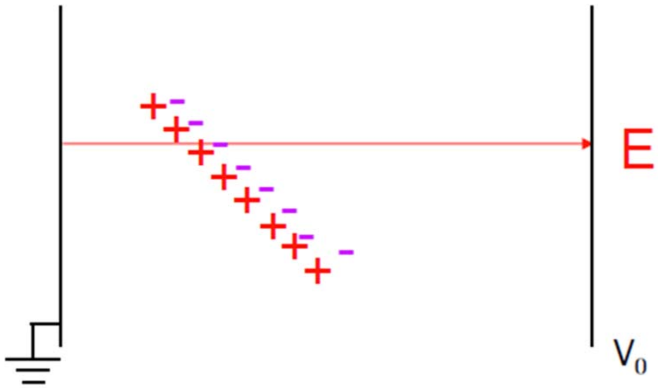
A: Atomic mass of absorber

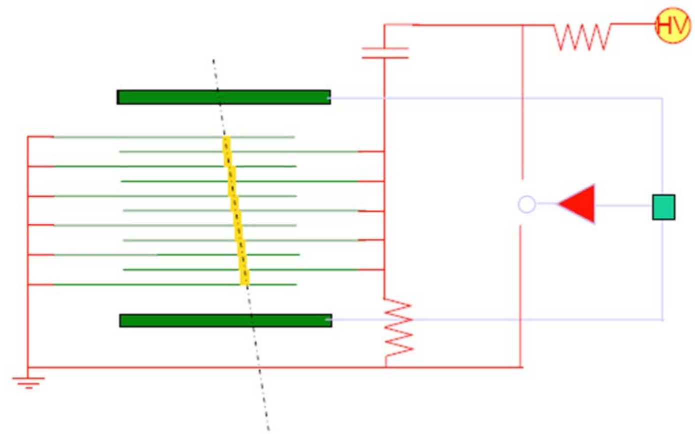
I: Mean excitation energy

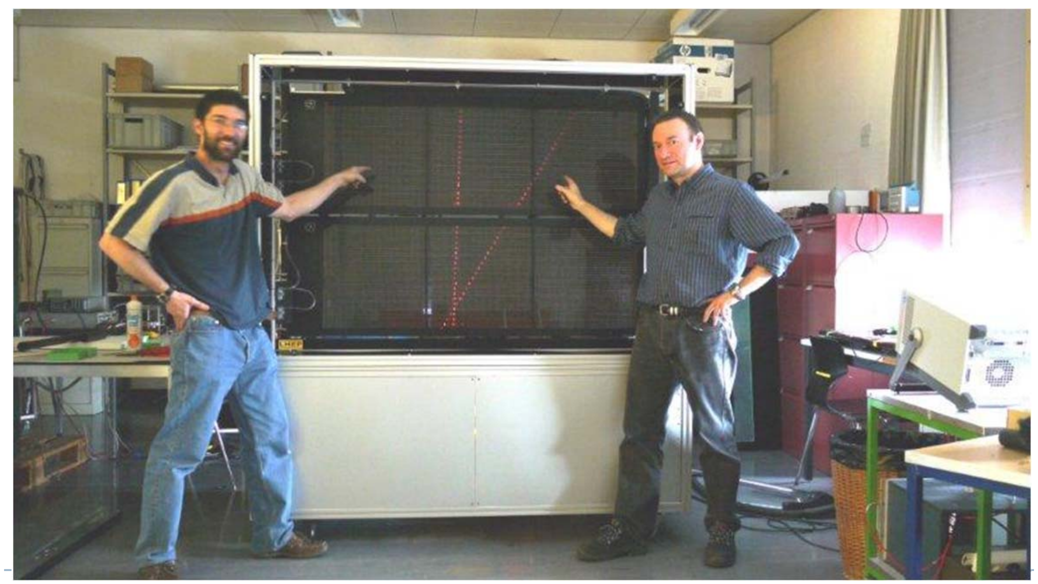
δ: density effect correction

- *dE/dx* in MeVg^{-1}cm^2
- *dE/dx* depends on β
- MINIMUM: M.I.P.
- *Z/A* similar for most elements
- $I \approx I_0 Z$, with $I_0 \approx 10$ eV

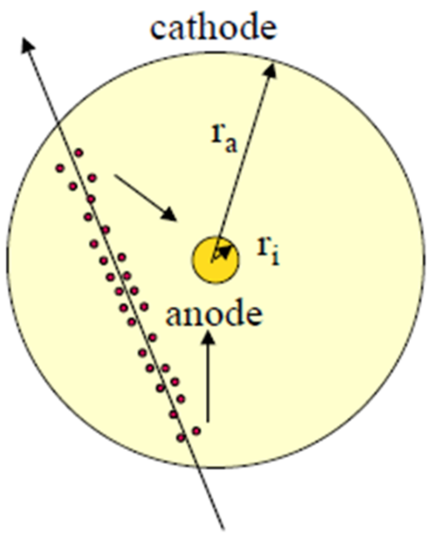
A first detector







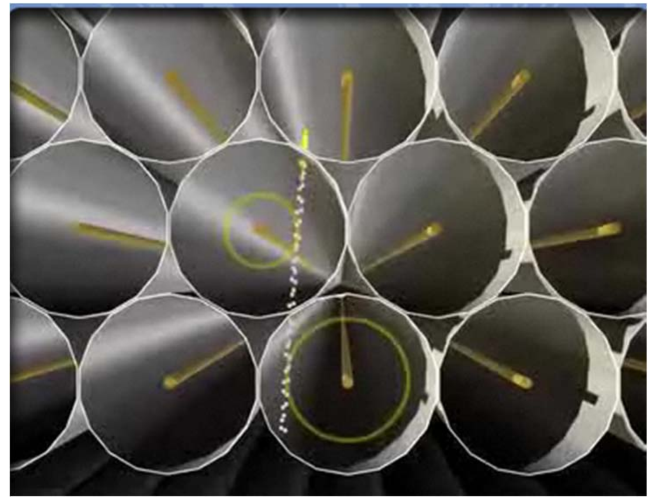
Drift tubes

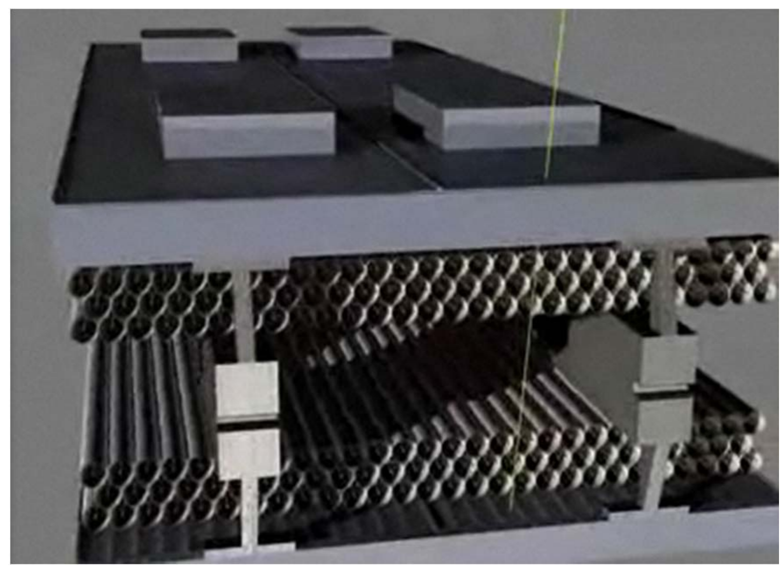


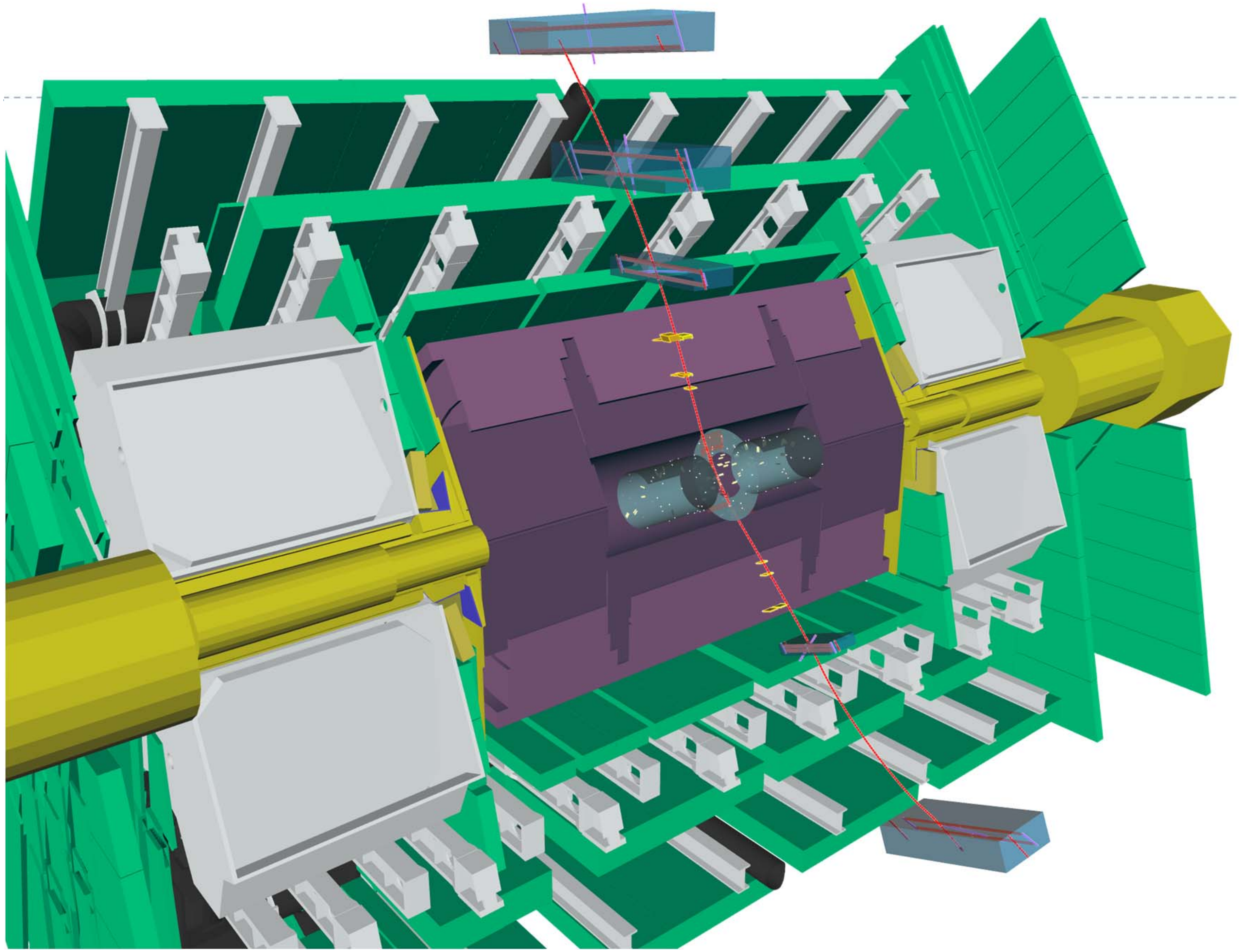
$$V(r)=V_0\frac{\ln r/r_a}{\ln r_i/r_a}$$

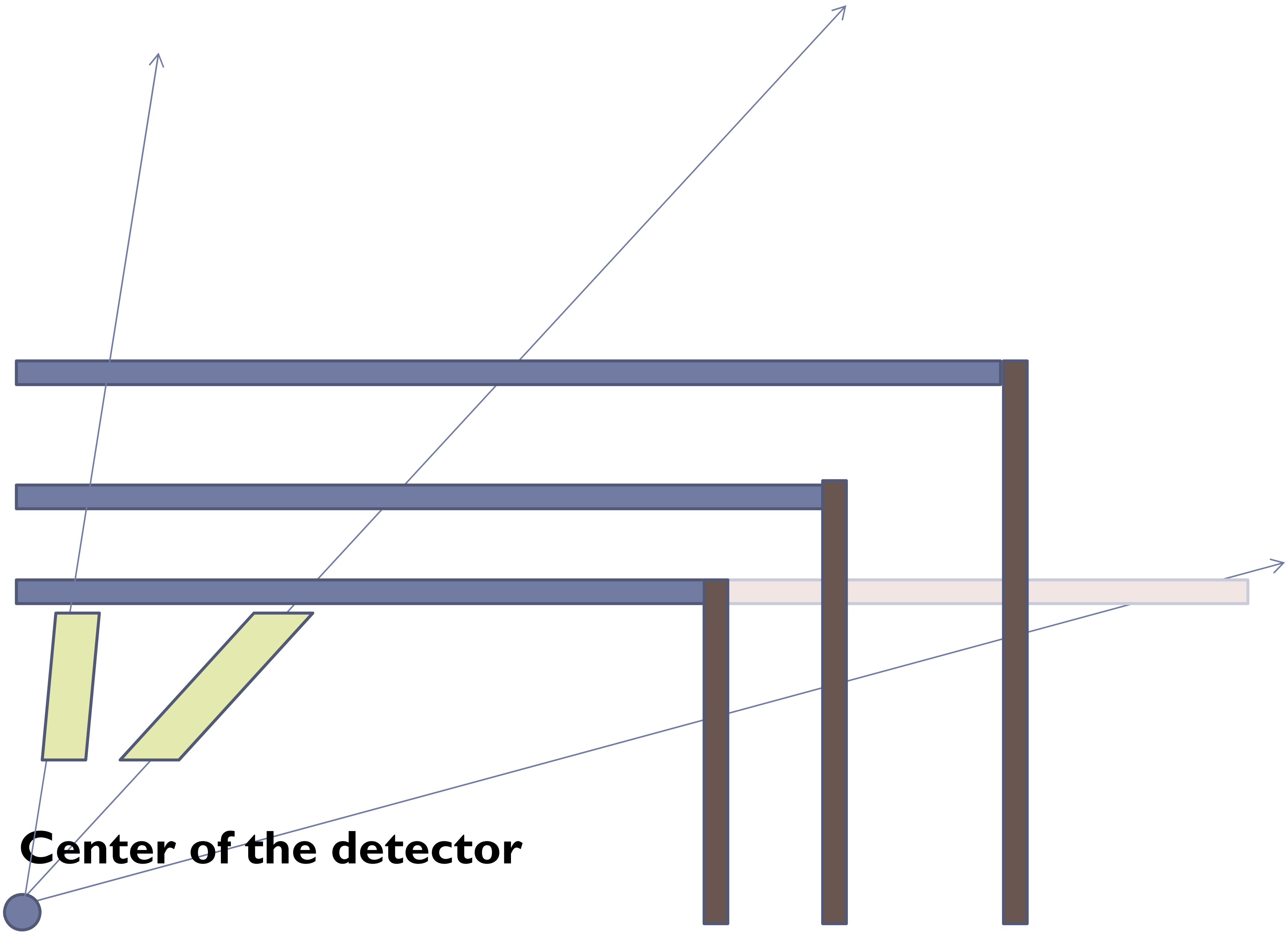
$$\vec{E}(r)=-\frac{V_0}{\ln r_a/r_i}\frac{1}{r}$$

NOTE: Drift speed (mobility) of electrons is much larger than the one of ions

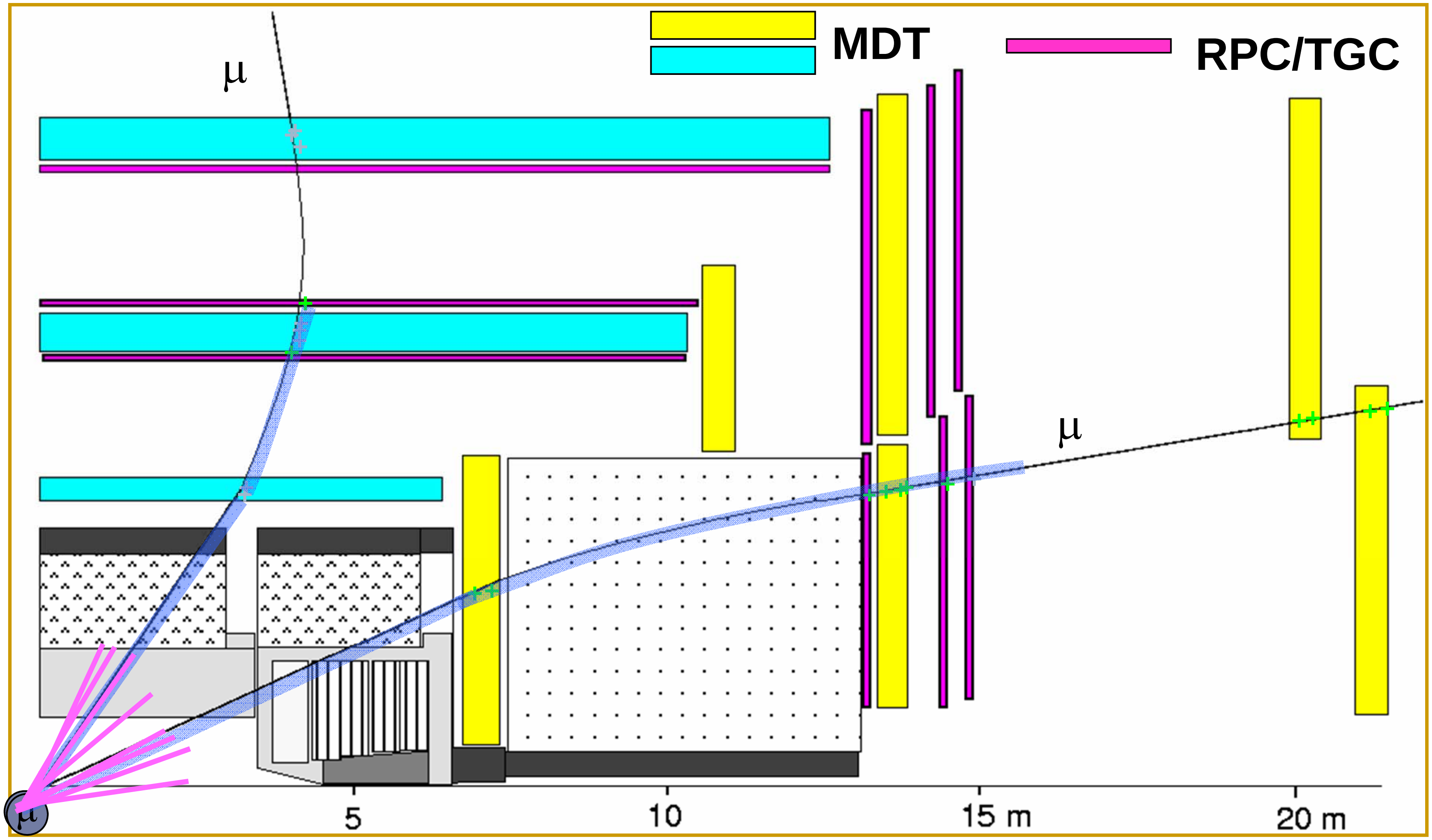




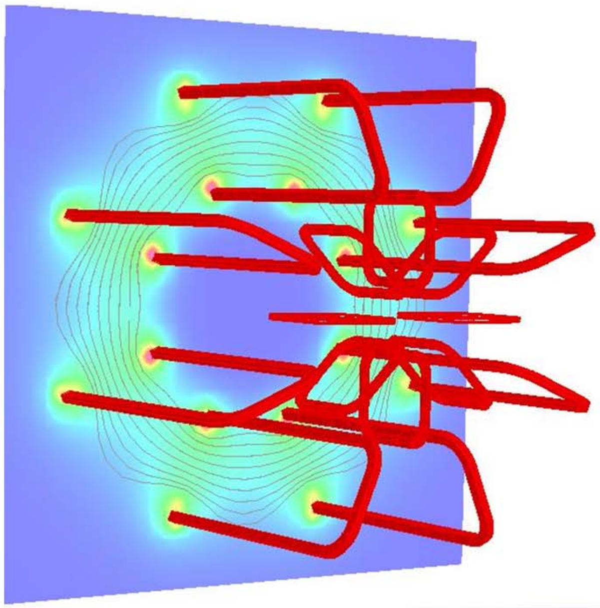


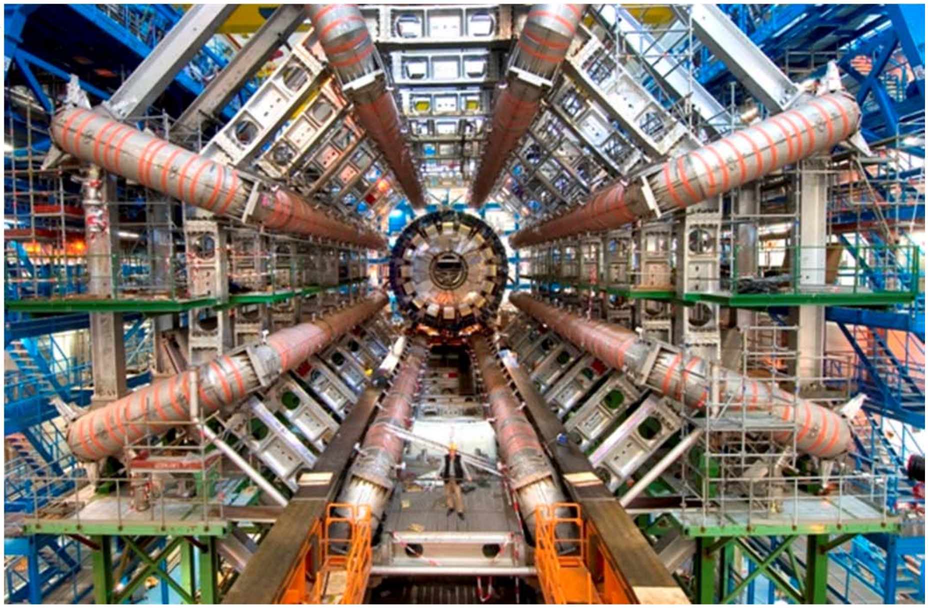

Center of the detector

Magnets / bending



Toroid

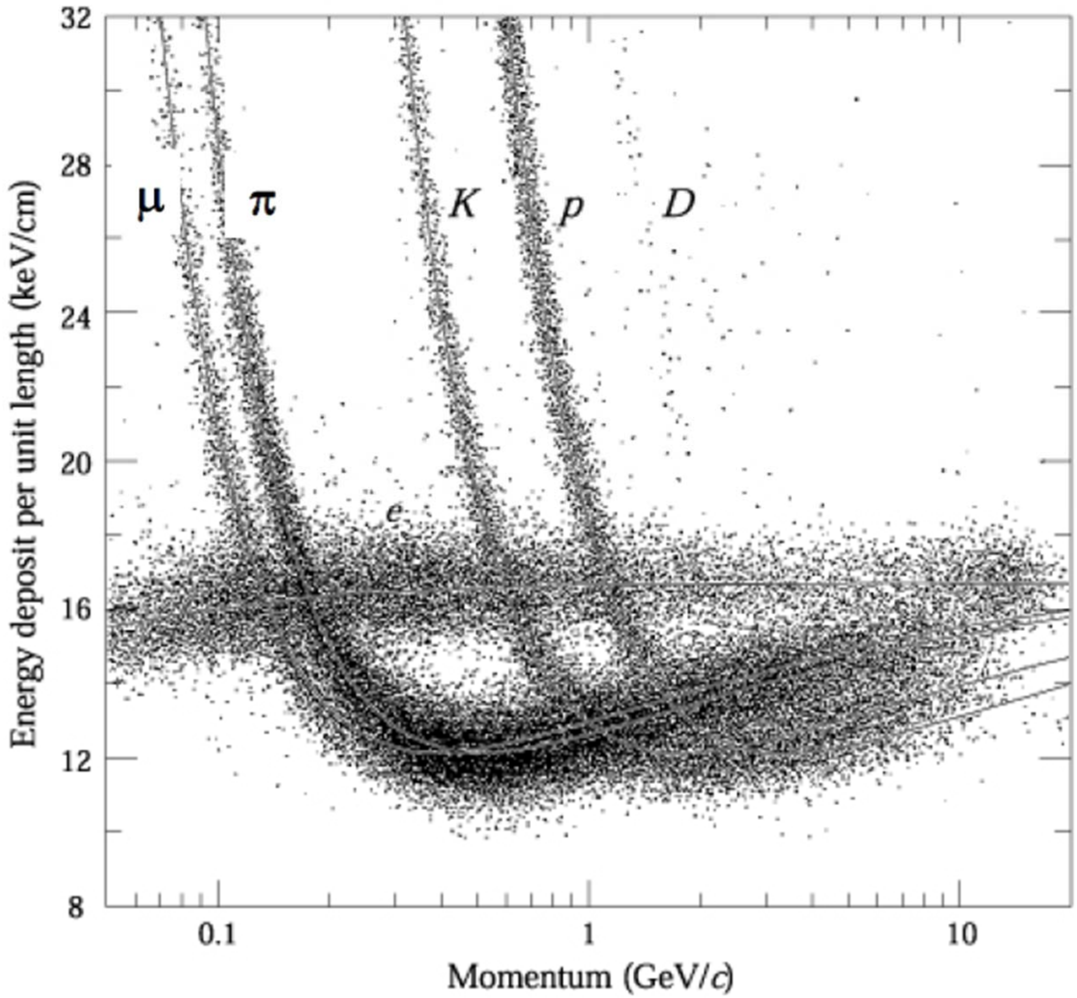




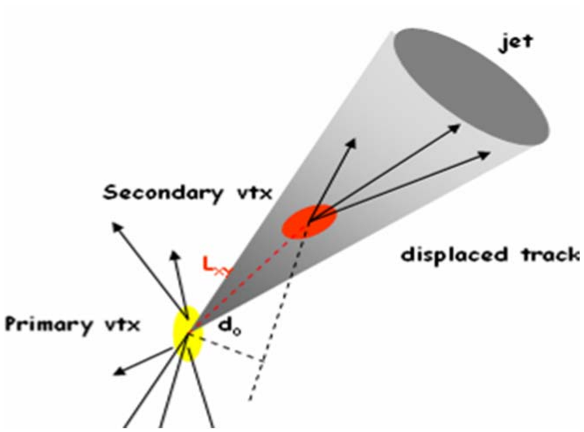
$$qvB = \frac{p}{R} v$$

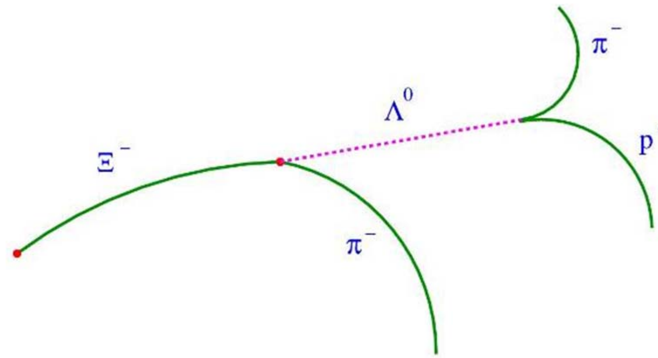
$$B[\mathrm{T}] \cdot R[\mathrm{m}] = 3.3356 \cdot p\left[\mathrm{GeV}/\mathrm{c}\right]$$

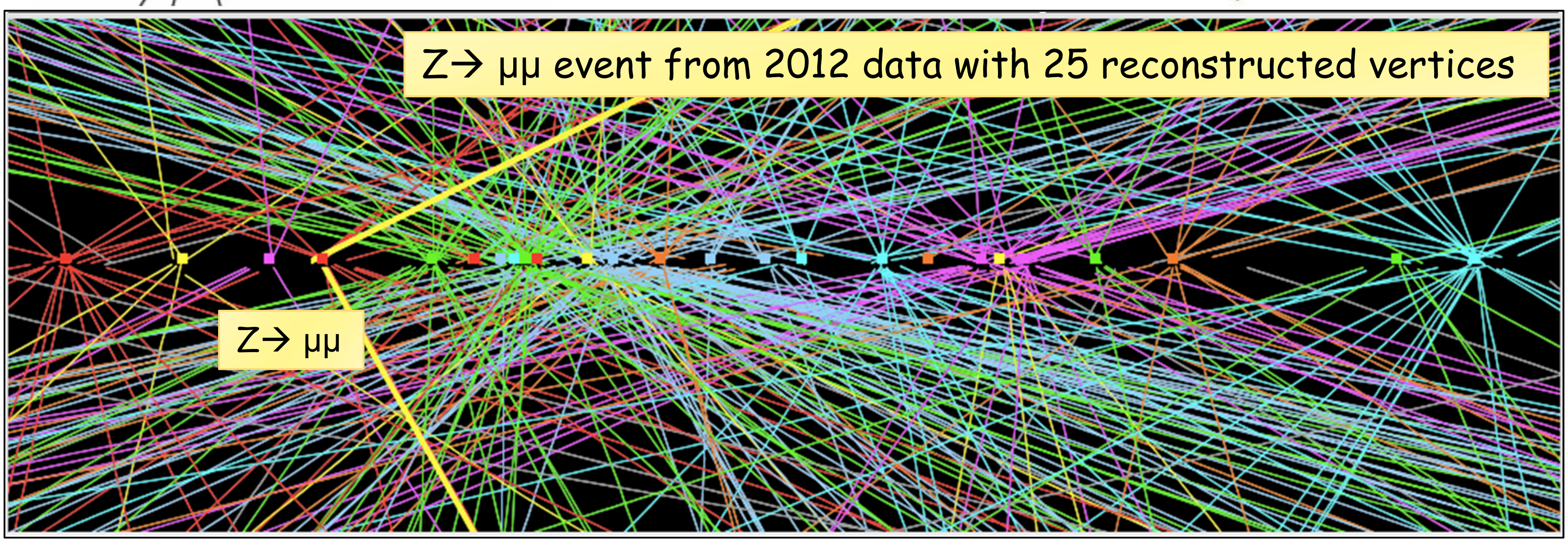
Particle ID and tracking



Impact parameter resolution

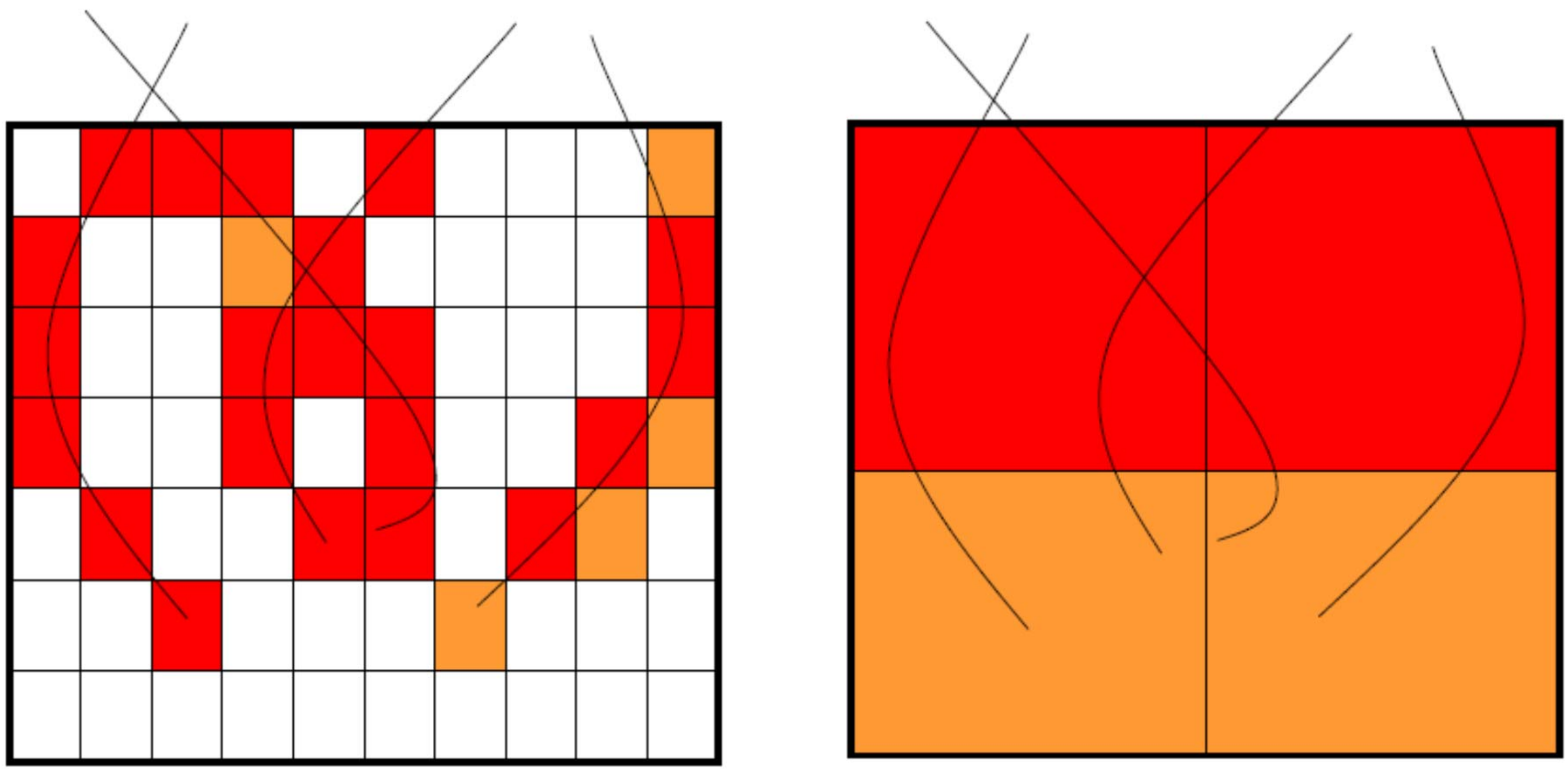




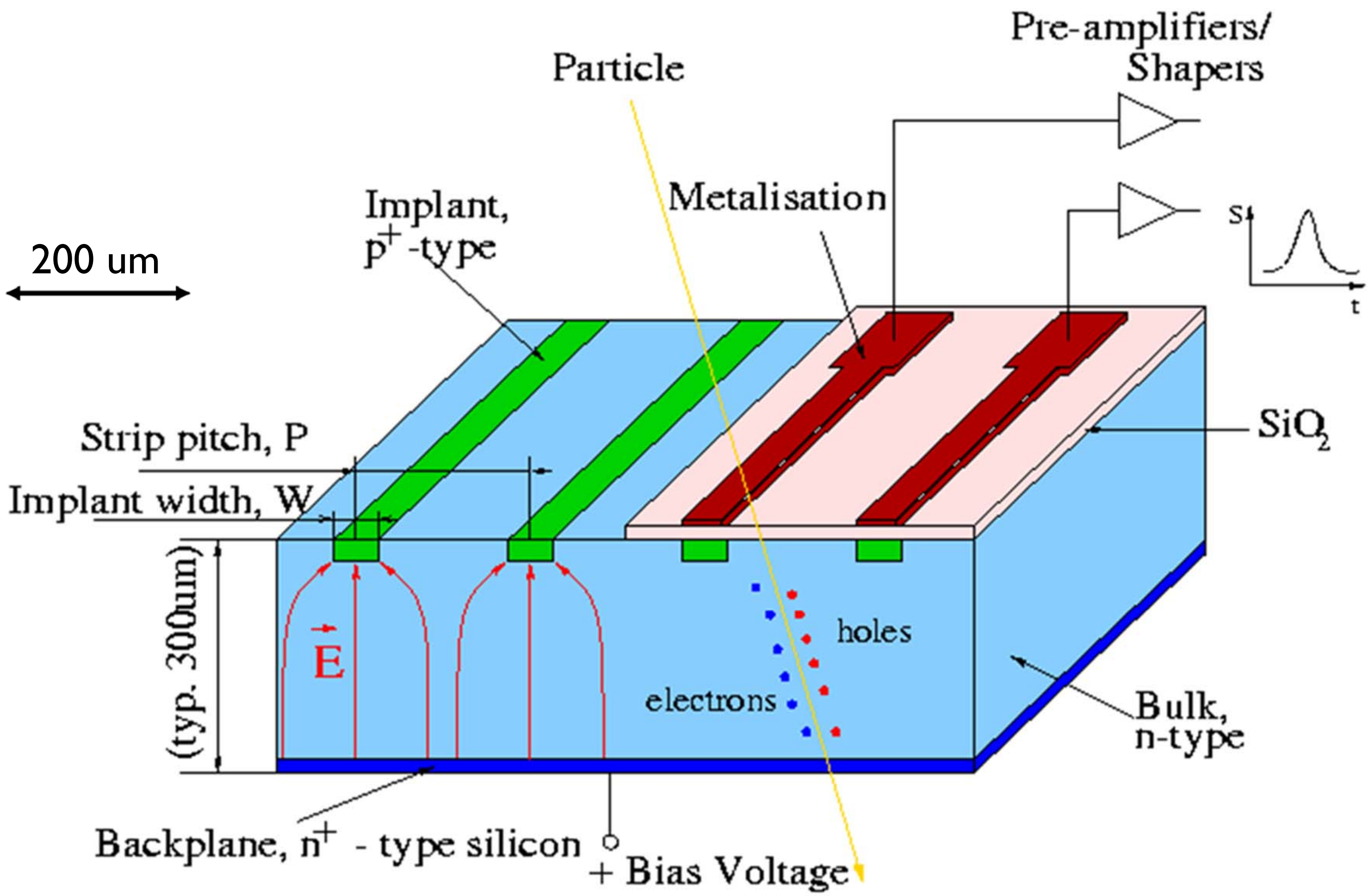


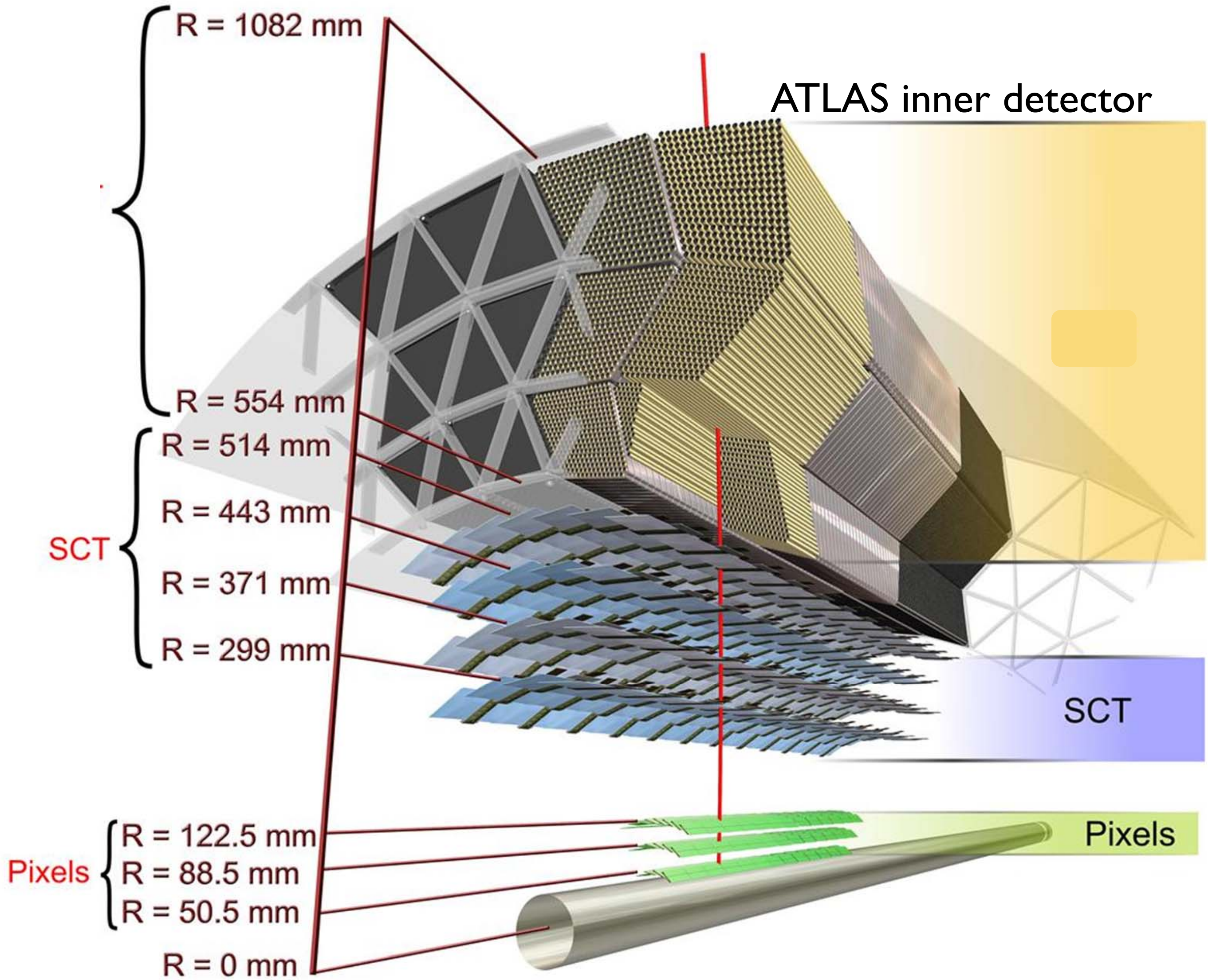
Resolution

- Tracking close to the interaction point: need resolution !

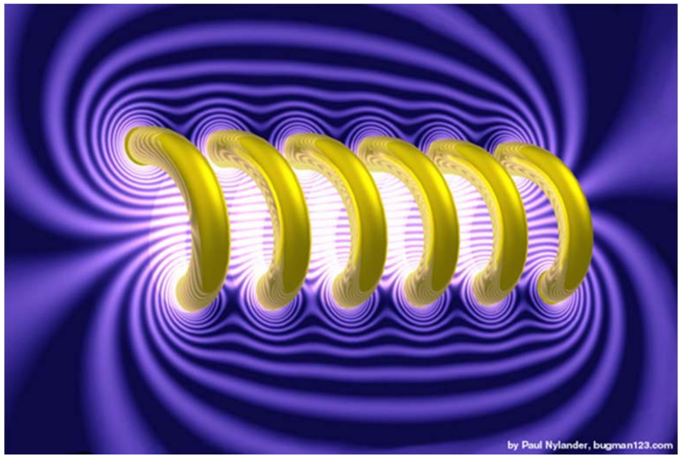


Silicon detectors

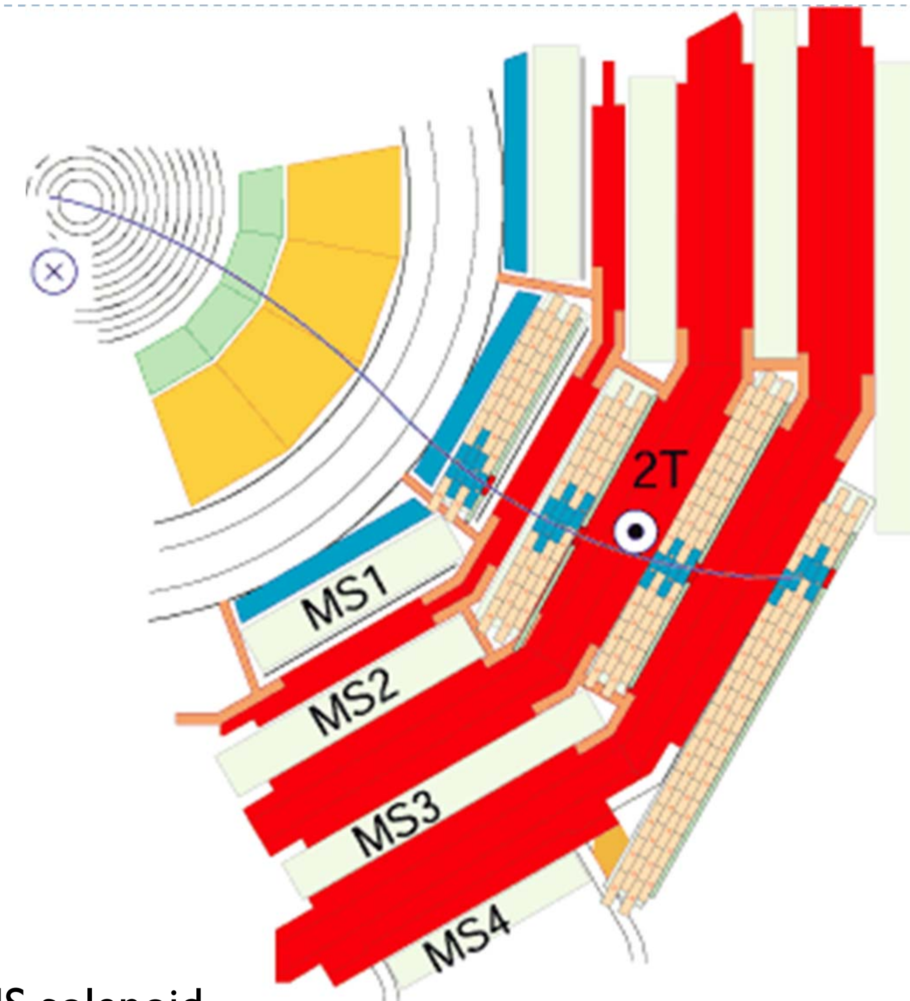



R = 1082 mm
ATLAS inner detector
R = 554 mm
R = 514 mm
R = 443 mm
SCT
R = 371 mm
R = 299 mm
SCT
Pixels
R = 122.5 mm
R = 88.5 mm
R = 50.5 mm
Pixels
R = 0 mm

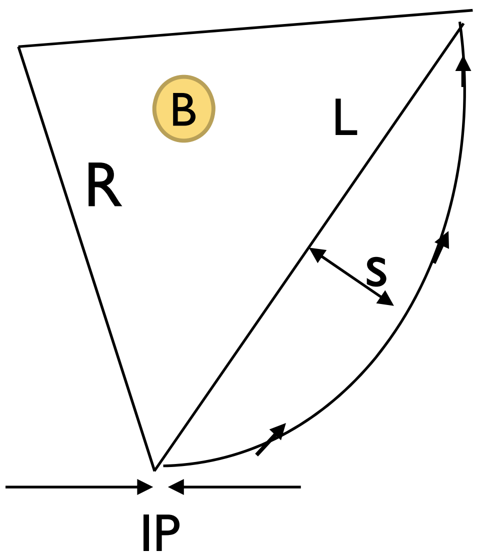
Solenoid magnets



CMS solenoid



Momentum Resolution



$s = L^2/8R$

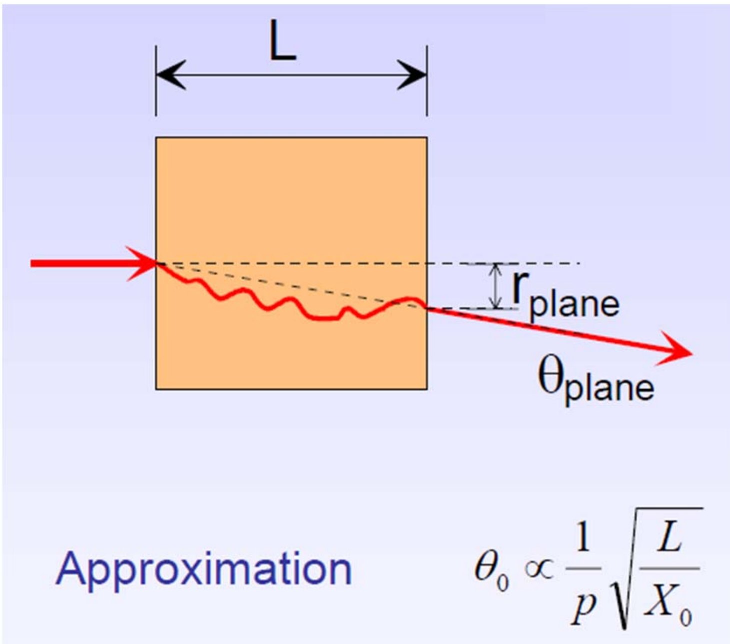
$B\,R = p\,/\,q \qquad q=1$

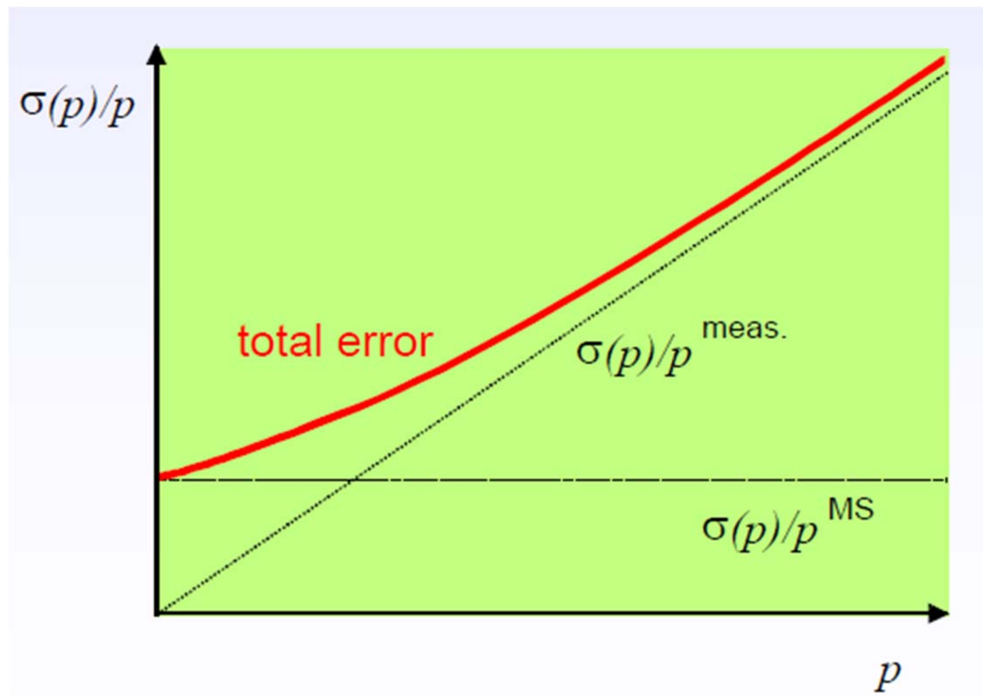
$$\frac{\Delta p}{p} \approx 0.25 \frac{\Delta s[\mu m]}{(L[\mathrm{cm}])^2\, B[\mathrm{T}]}\, p[\mathrm{GeV}]$$

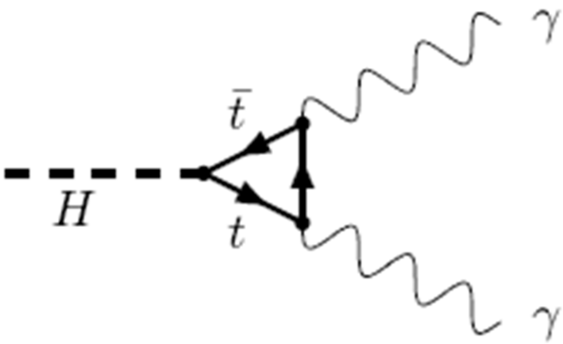
$$\frac{\Delta p}{p} \cong 0.25 \frac{50\mu\mathrm{m}}{(40\mathrm{cm})^2\, 2\mathrm{T}} 10\mathrm{GeV} \cong 4\%$$

- **Momentum resolution goes linear with the momentum**
- Momentum resolution gets better with the square of the lever arm L and linearly with B
- 100% error means that charge cannot be measured
- **Ideal undisturbed particle path**

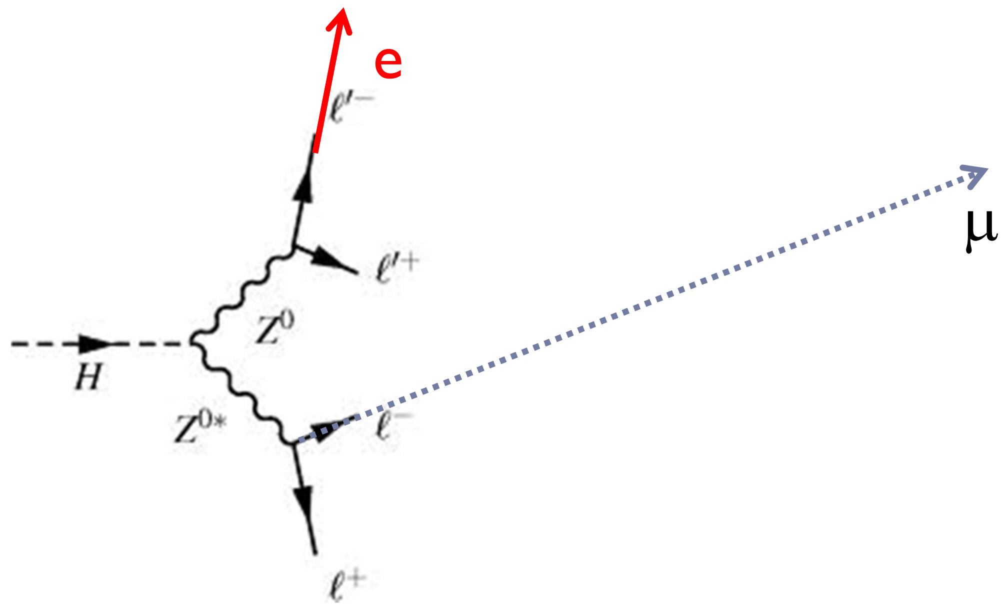
Multiple scattering



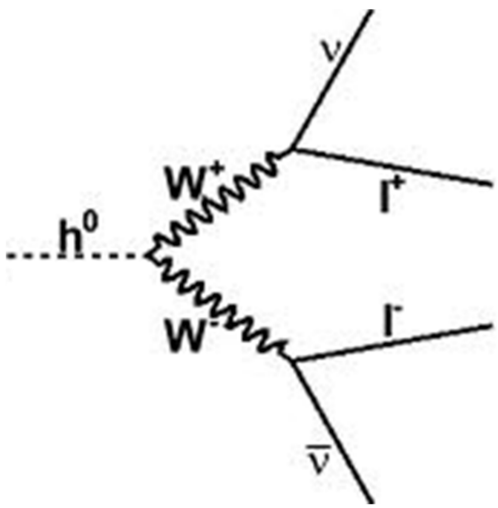




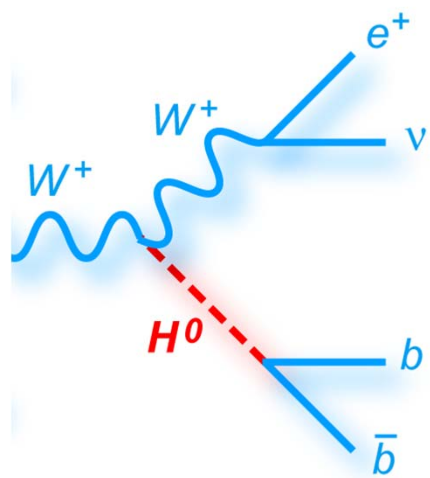
H
t̄
t
γ
γ



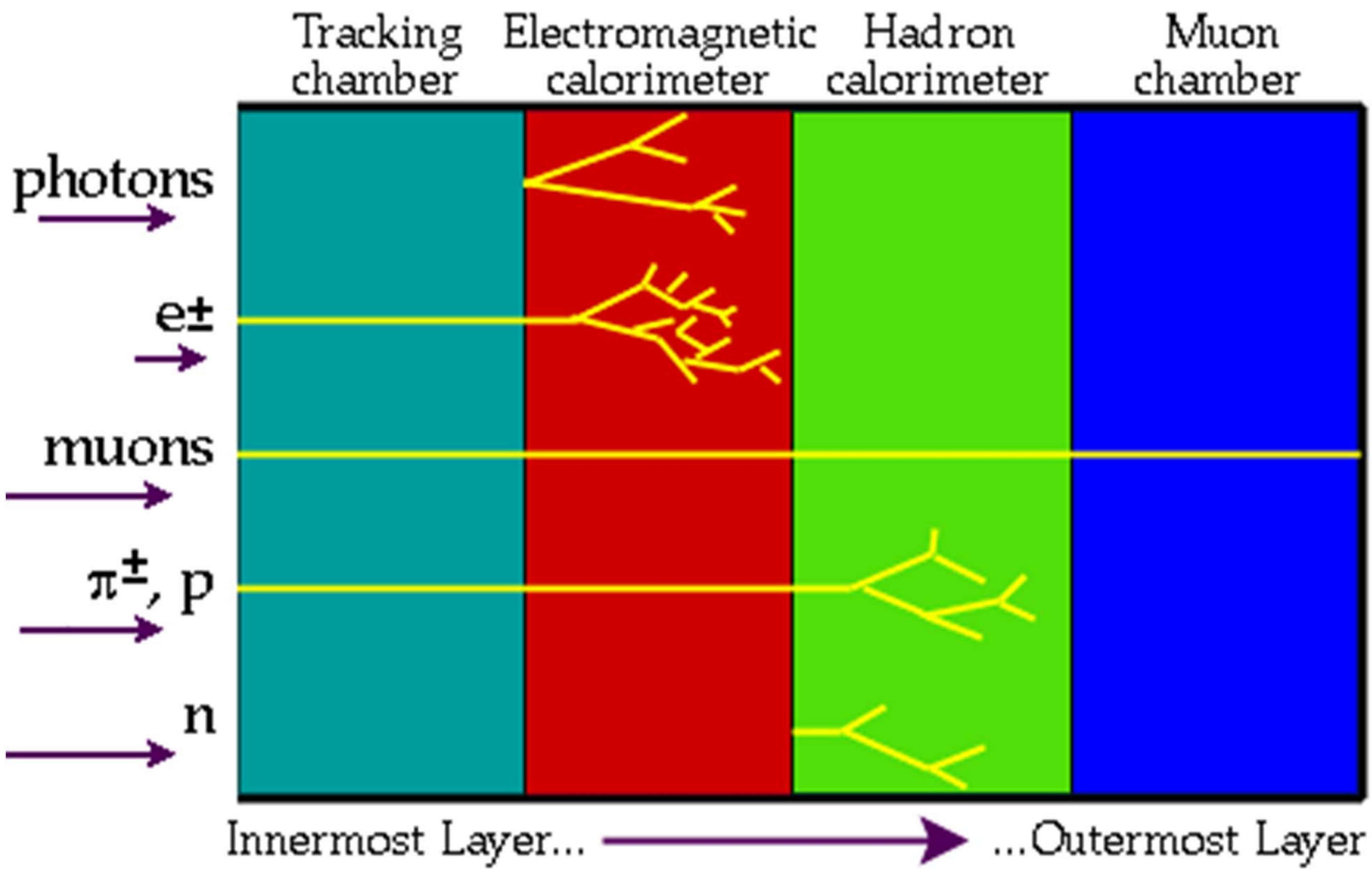
e
ℓ′⁻
μ
ℓ′⁺
Z⁰
H
Z⁰*
ℓ⁻
ℓ⁺



ν
W⁺
l⁺
h⁰
W⁻
l⁻
ν̄



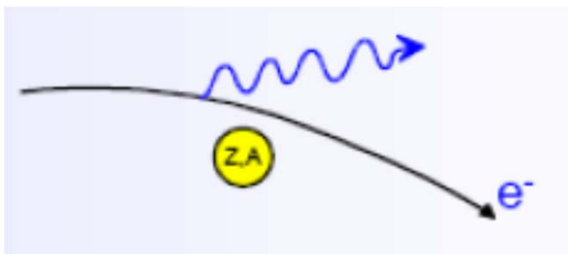
e⁺
W⁺
ν
W⁺
H⁰
b
b̄



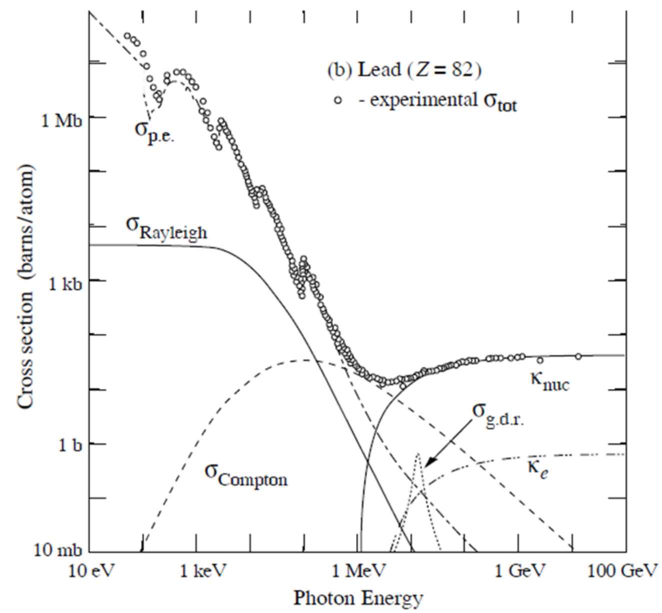
Tracking chamber
Electromagnetic calorimeter
Hadron calorimeter
Muon chamber
photons
e±
muons
π±, p
n
Innermost Layer...
...Outermost Layer

Bremsstrahlung / Pair production

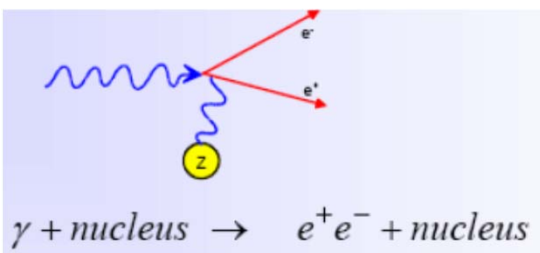
- Energy loss due to emission of photons in the electromagnetic field of the nucleus (and of the atomic electrons).



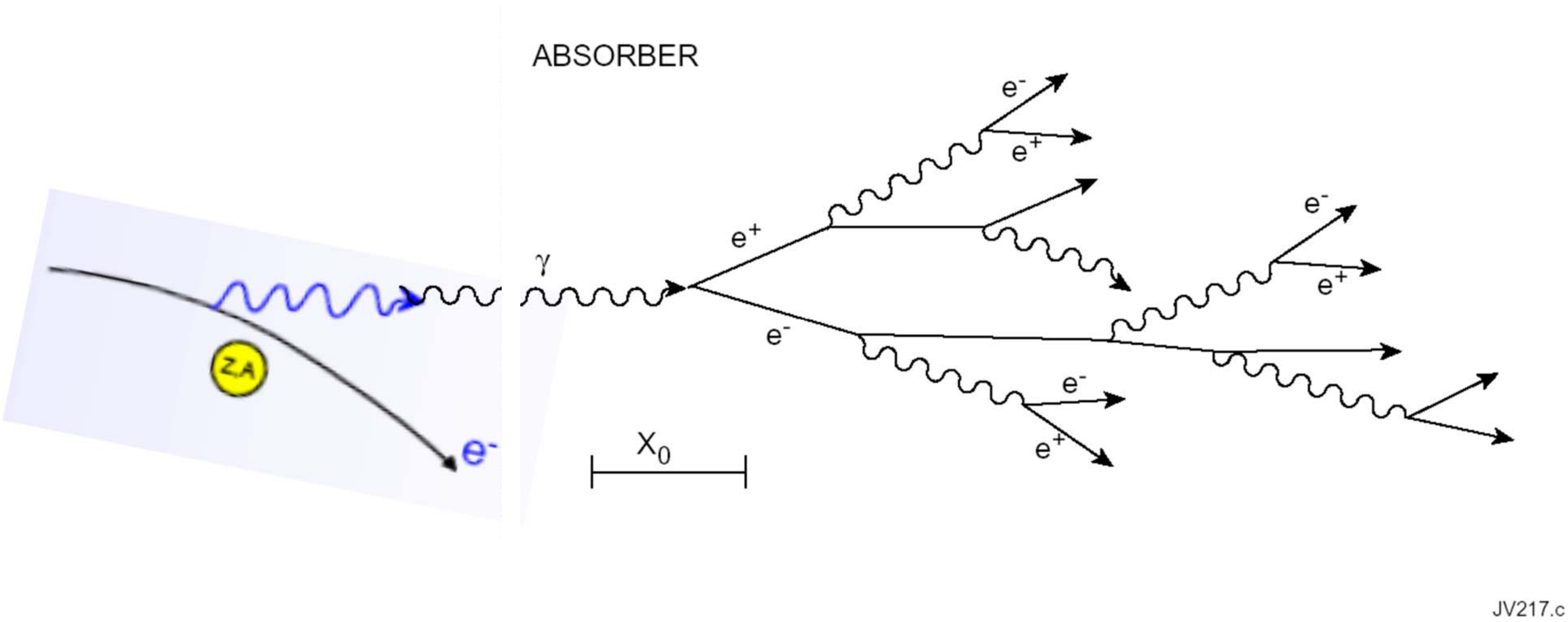
$$\sigma \propto E / m^2_{\text{particle}}$$



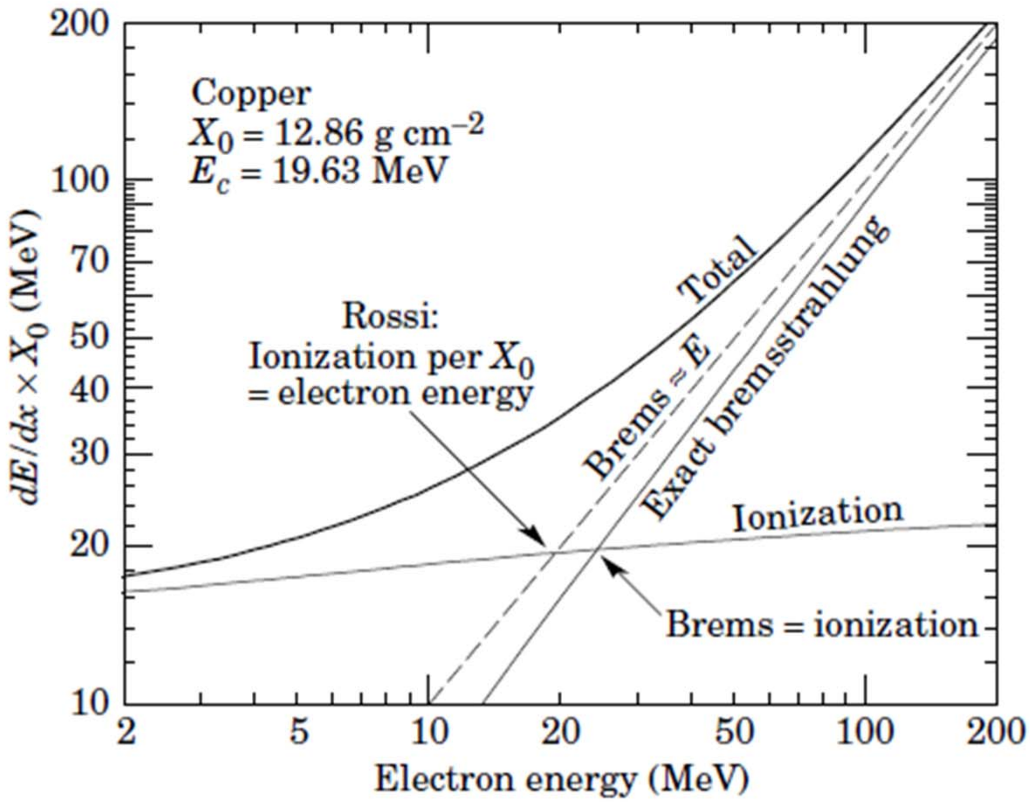
- Pair Production

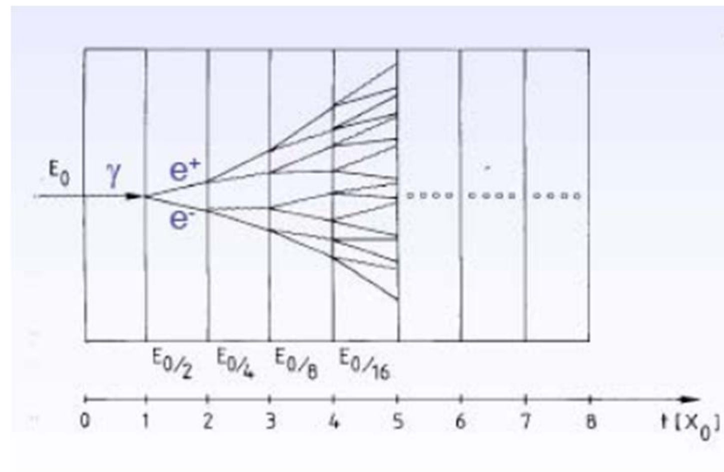


Bremsstrahlung and Pair production



Radiation Length

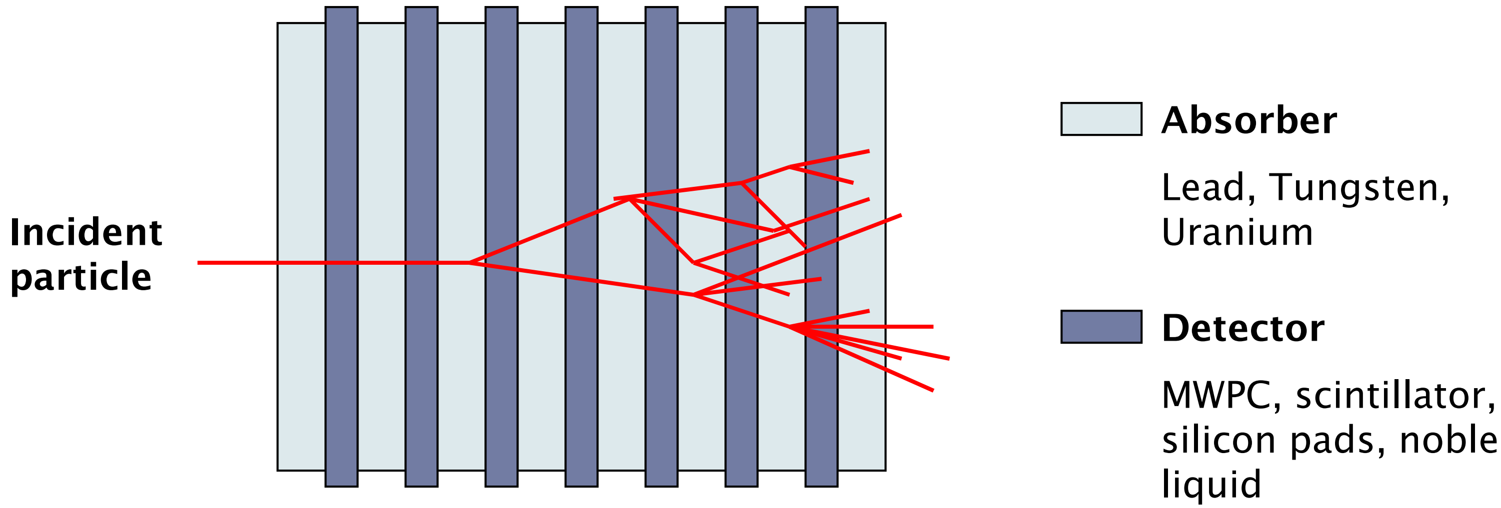




E.g. Lead: X_0=6.3 mm

$20X_0$ =12.6 cm

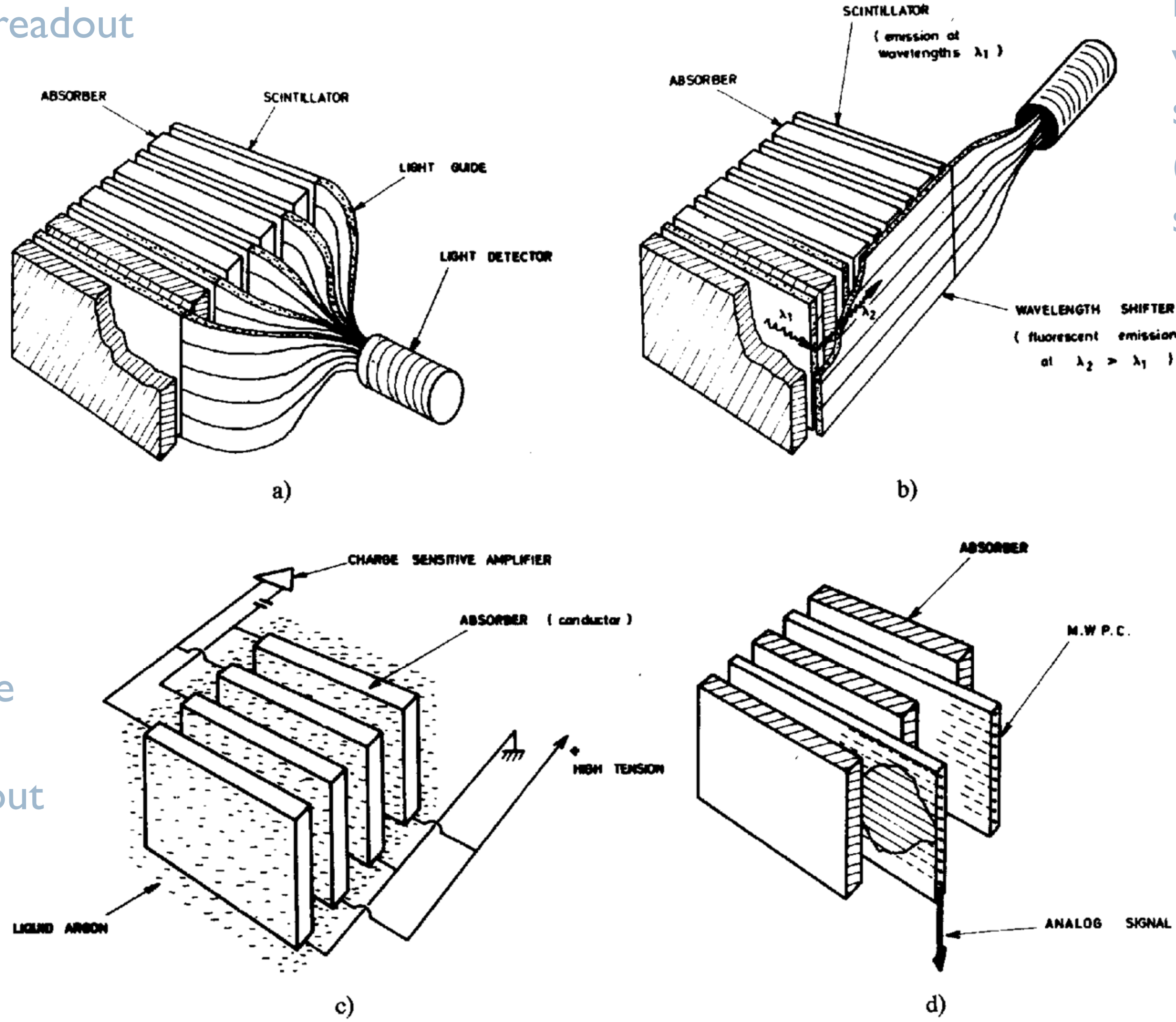
Sampling Calorimeters



- Absorber (passive) and detector (active) layers
- Fluctuations in visible energy: "sampling fluctuations" due to variation of the nnumber of charged particles in the detector

Scintillator readout

Scintillator readout with wavelength shifter bars (or wavelength shifting fibers)



Noble liquid readout

Readout with gaseous detectors (MWPCs or streamer tubes)

C.Joram. CERN Academic Training 1997-1998

Energy resolution

- Statistical fluctations
  - In the number of particles in the shower
  - In the number of escaping or undetected particles
- Noise
  - Electronic noise
  - Pile up
- Constant
  - Dead material
  - Calibration errors
  - Mechanical imperfections

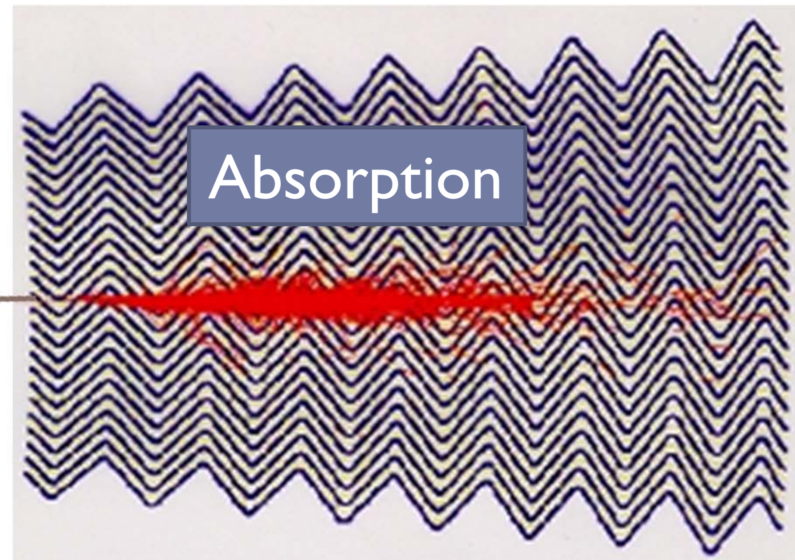
$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{\sigma_n}{E} \oplus \text{constant}$$

- **Higher energy -> better resolution**

Position, momentum, energy

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{\sigma_n}{E} \oplus \text{constant}$$

Track



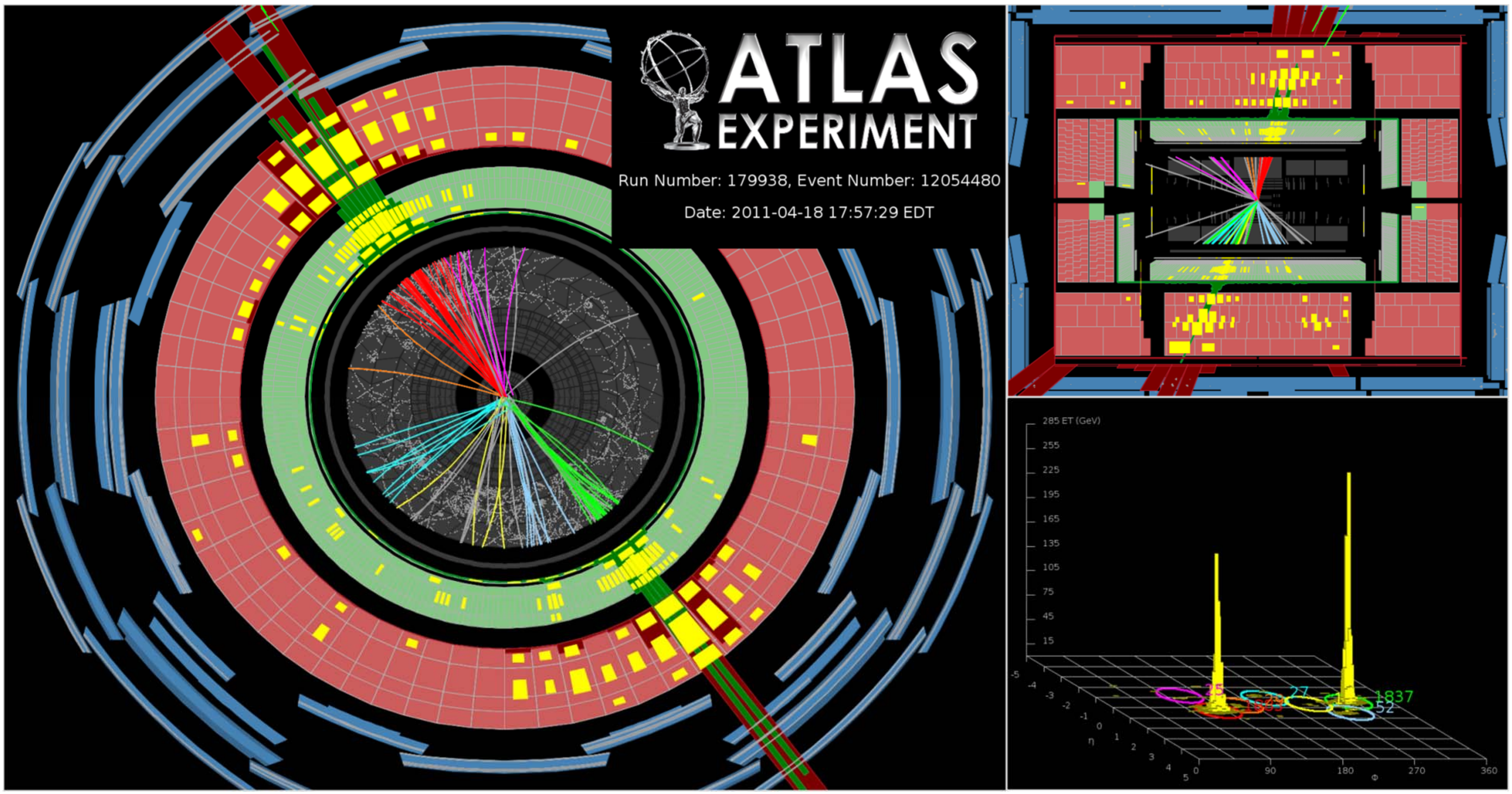
Position, Momentum

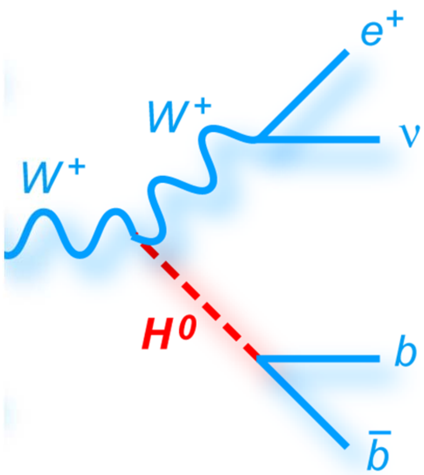
$$\frac{\Delta p}{p} \approx 0.25 \frac{\Delta s[\mu m]}{(L[\mathrm{cm}])^2 B[\mathrm{T}]} p[\mathrm{GeV}]$$

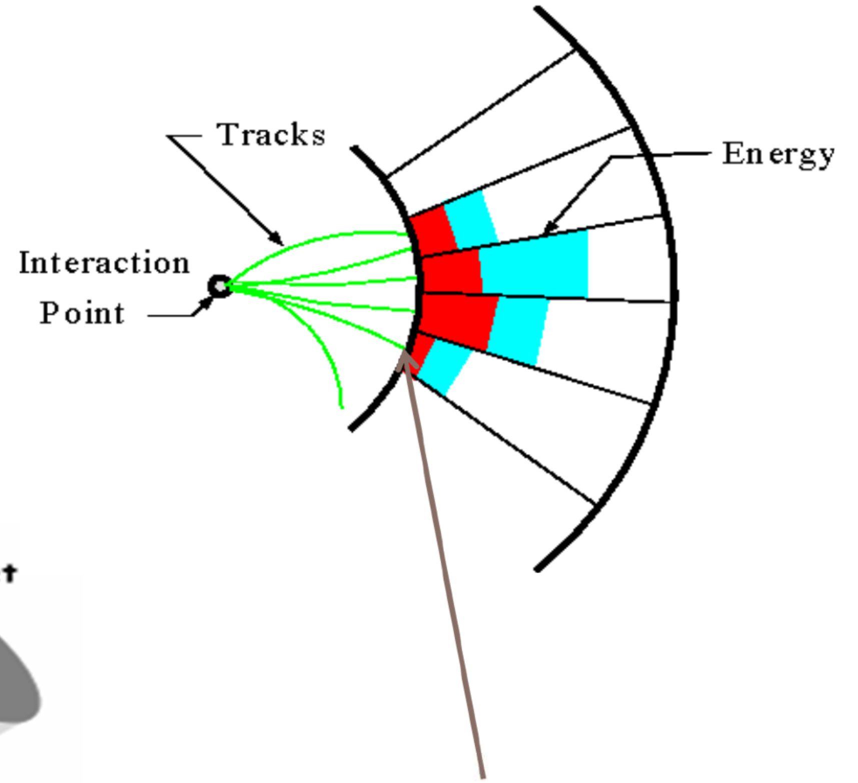
Energy

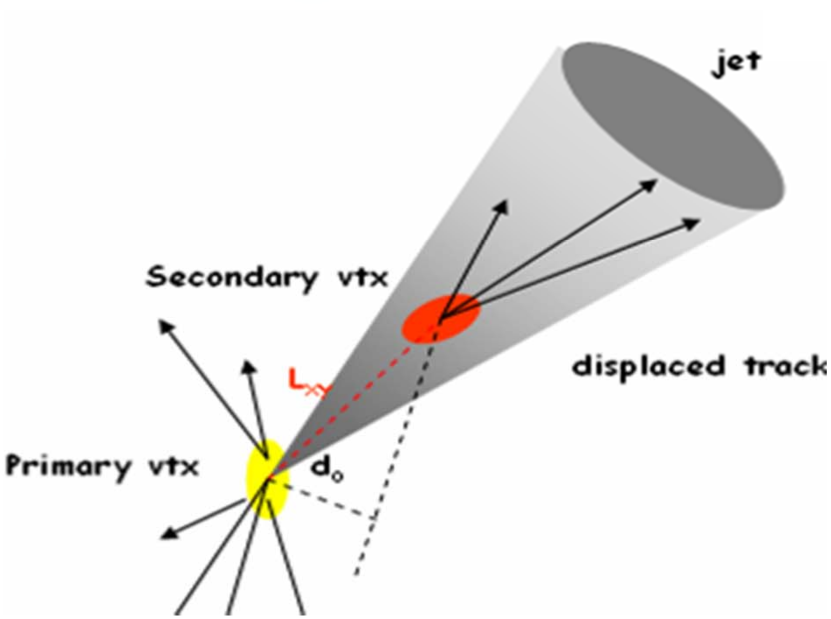
And… the most common objects ?

- Jets



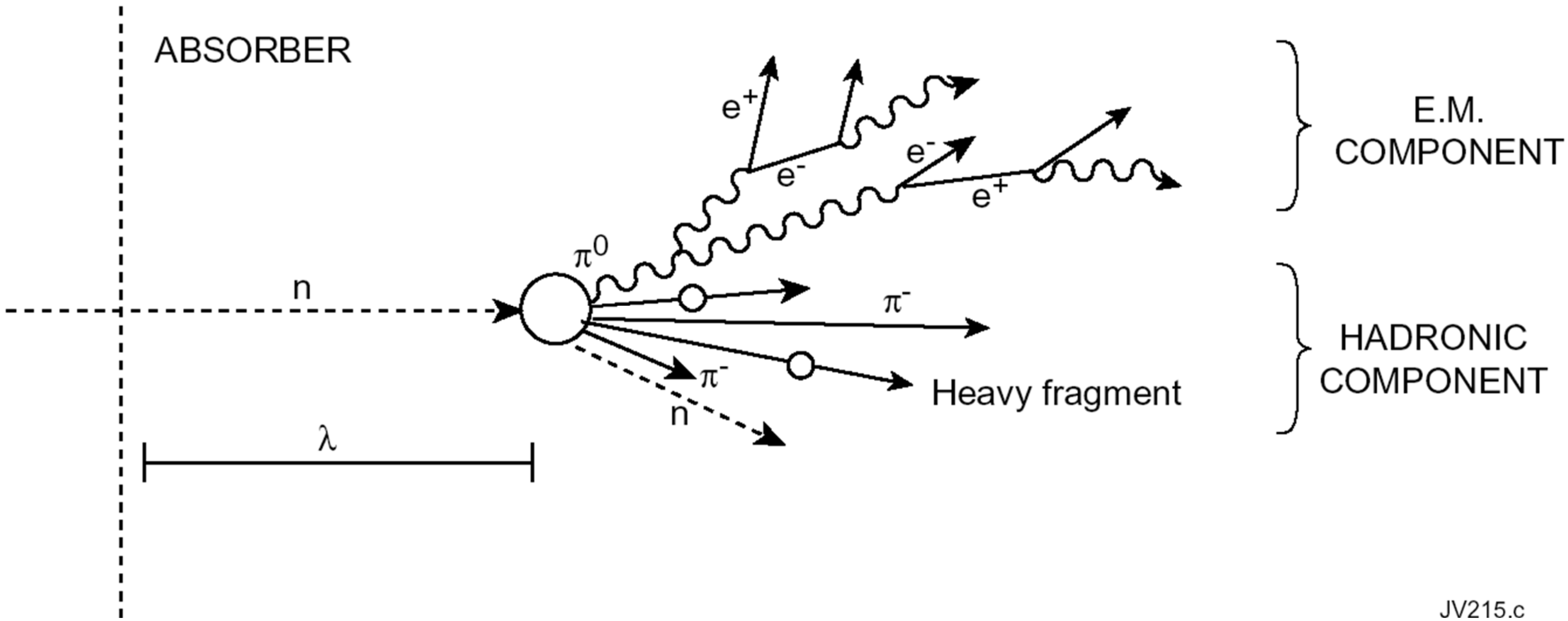




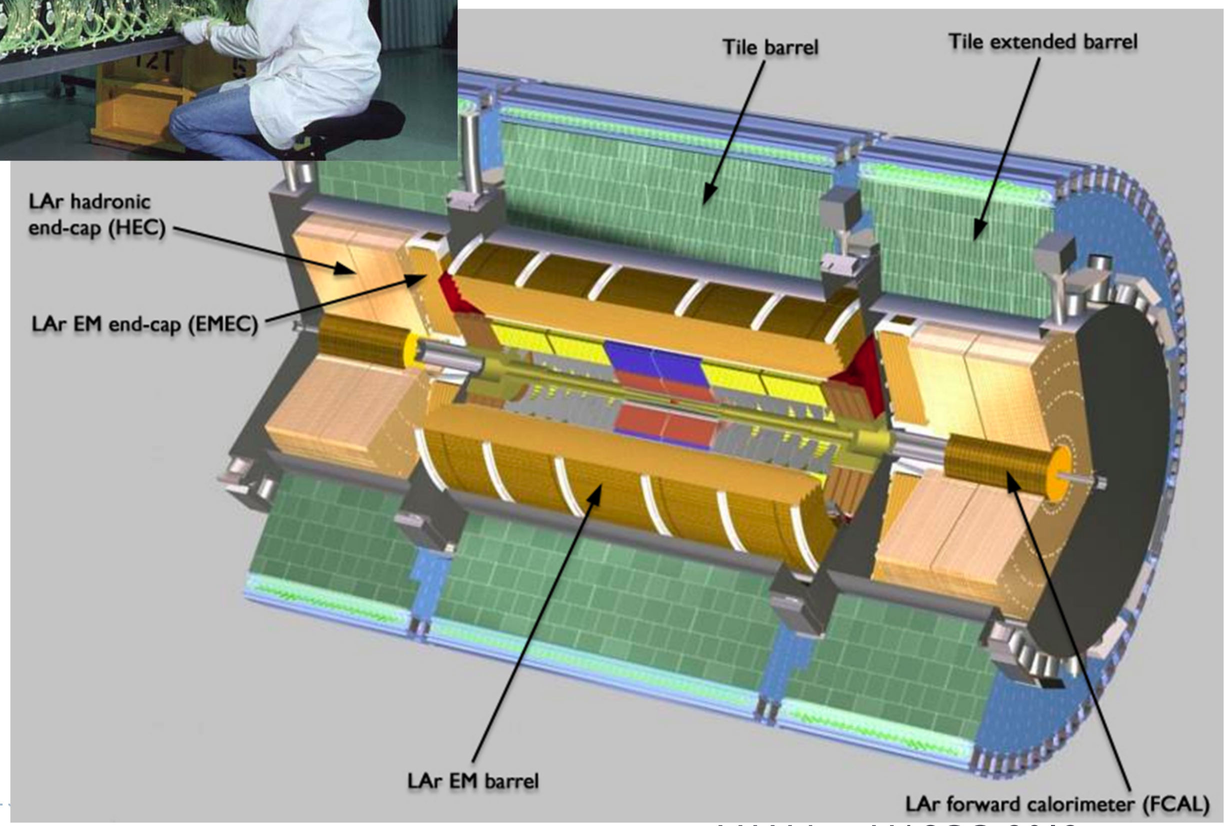


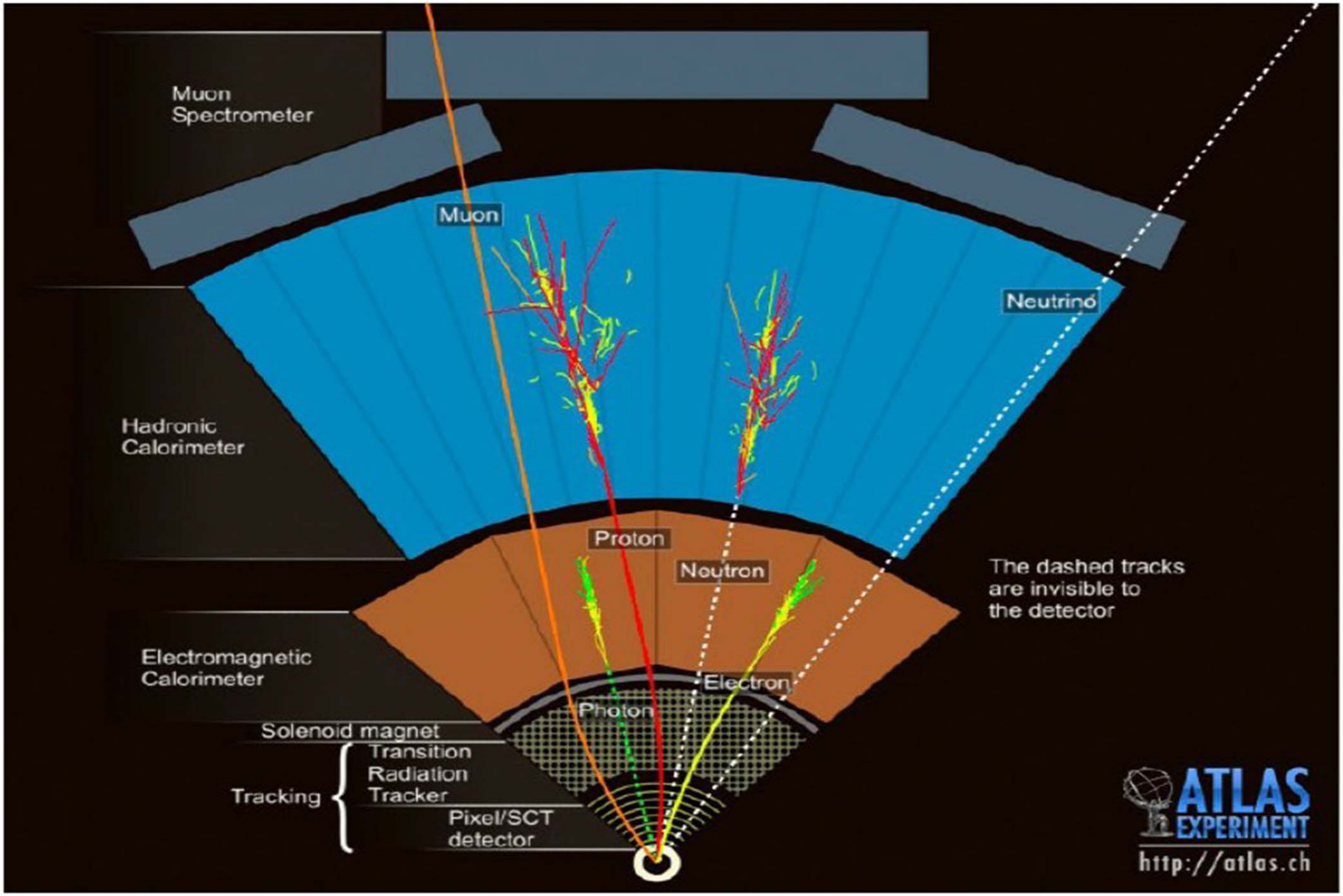
What happens here ?

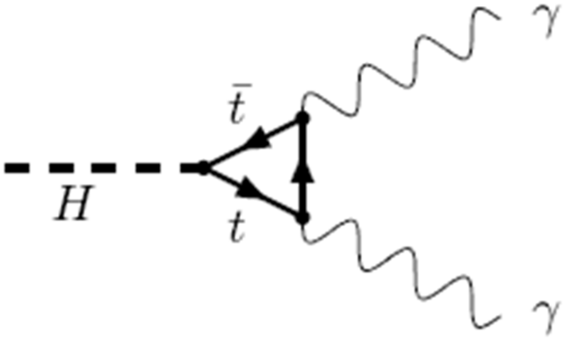
Hadron interactions

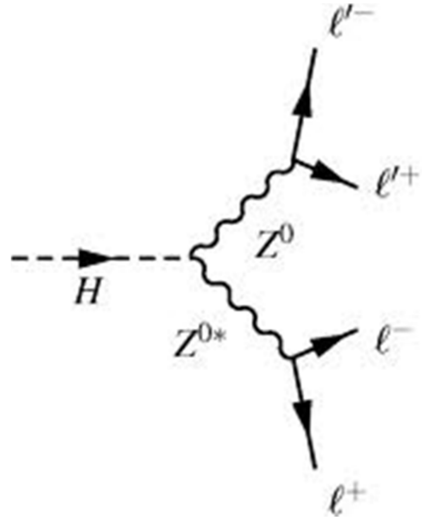


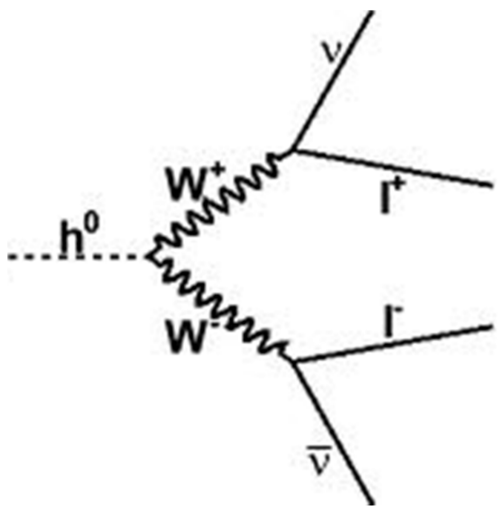
- Interaction length λ is much larger than the radiation length X_0
- Due to strong interaction, the shower is much wider

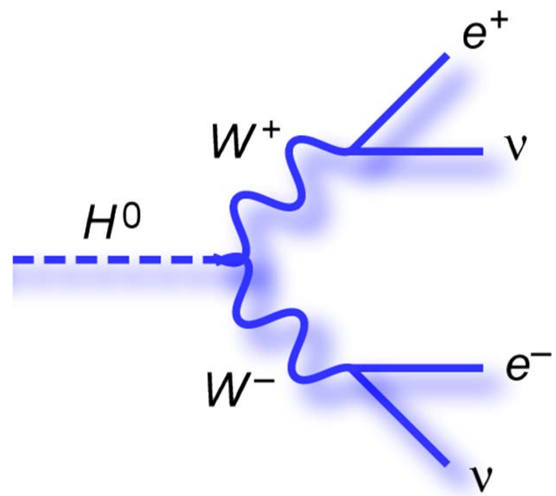

Tile barrel
Tile extended barrel
LAr hadronic end-cap (HEC)
LAr EM end-cap (EMEC)
LAr EM barrel
LAr forward calorimeter (FCAL)

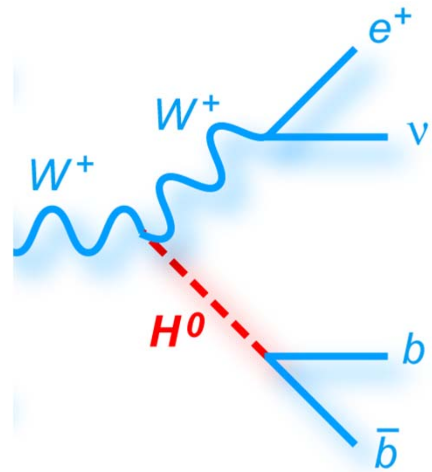

Muon
Spectrometer
Muon
Neutrino
Hadronic
Calorimeter
Proton
Neutron
The dashed tracks
are invisible to
the detector
Electromagnetic
Calorimeter
Electron
Photon
Solenoid magnet
Transition
Radiation
Tracker
Tracking
Pixel/SCT
detector
ATLAS
EXPERIMENT
http://atlas.ch

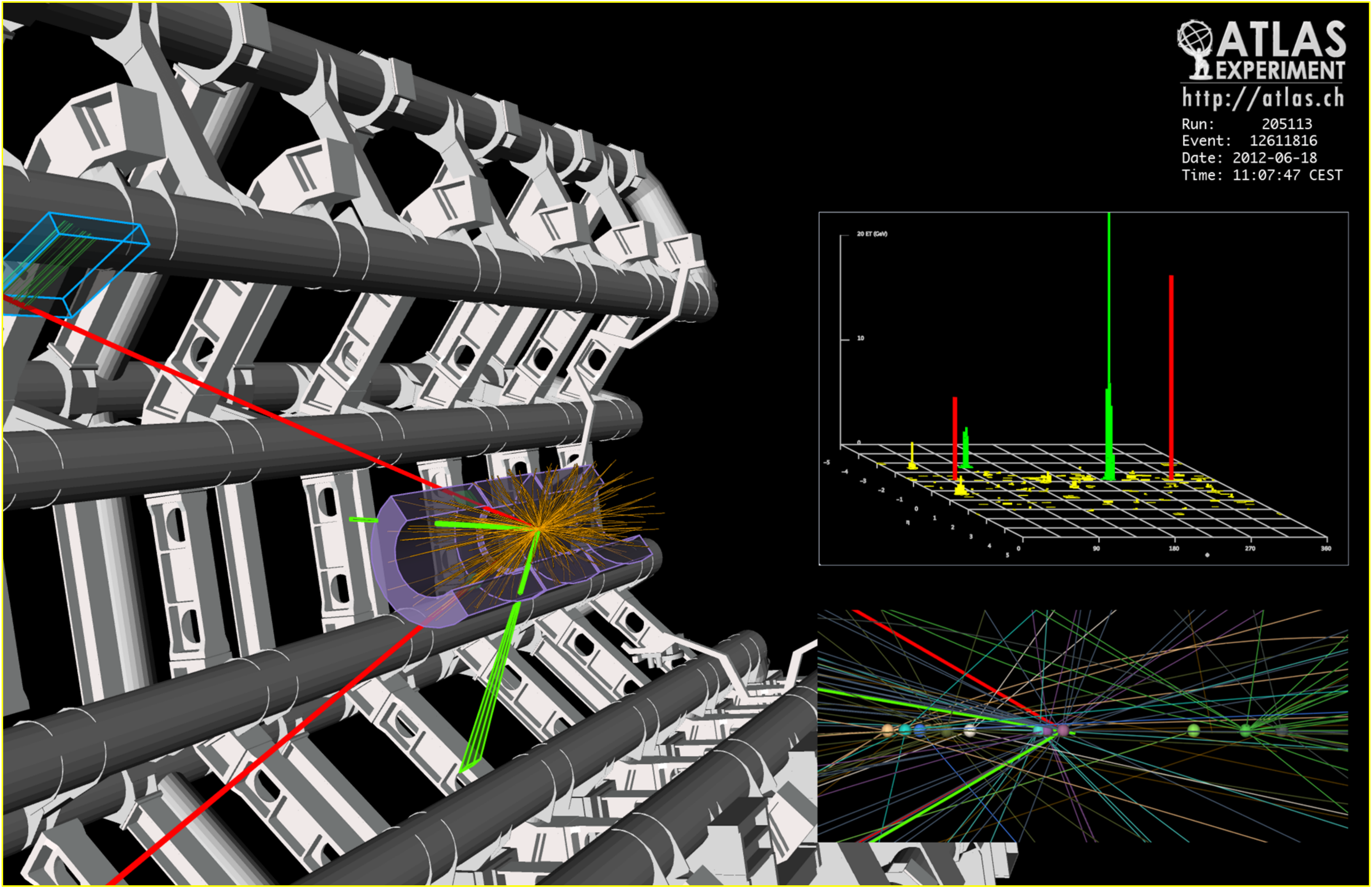

H
t̄
t
γ
γ

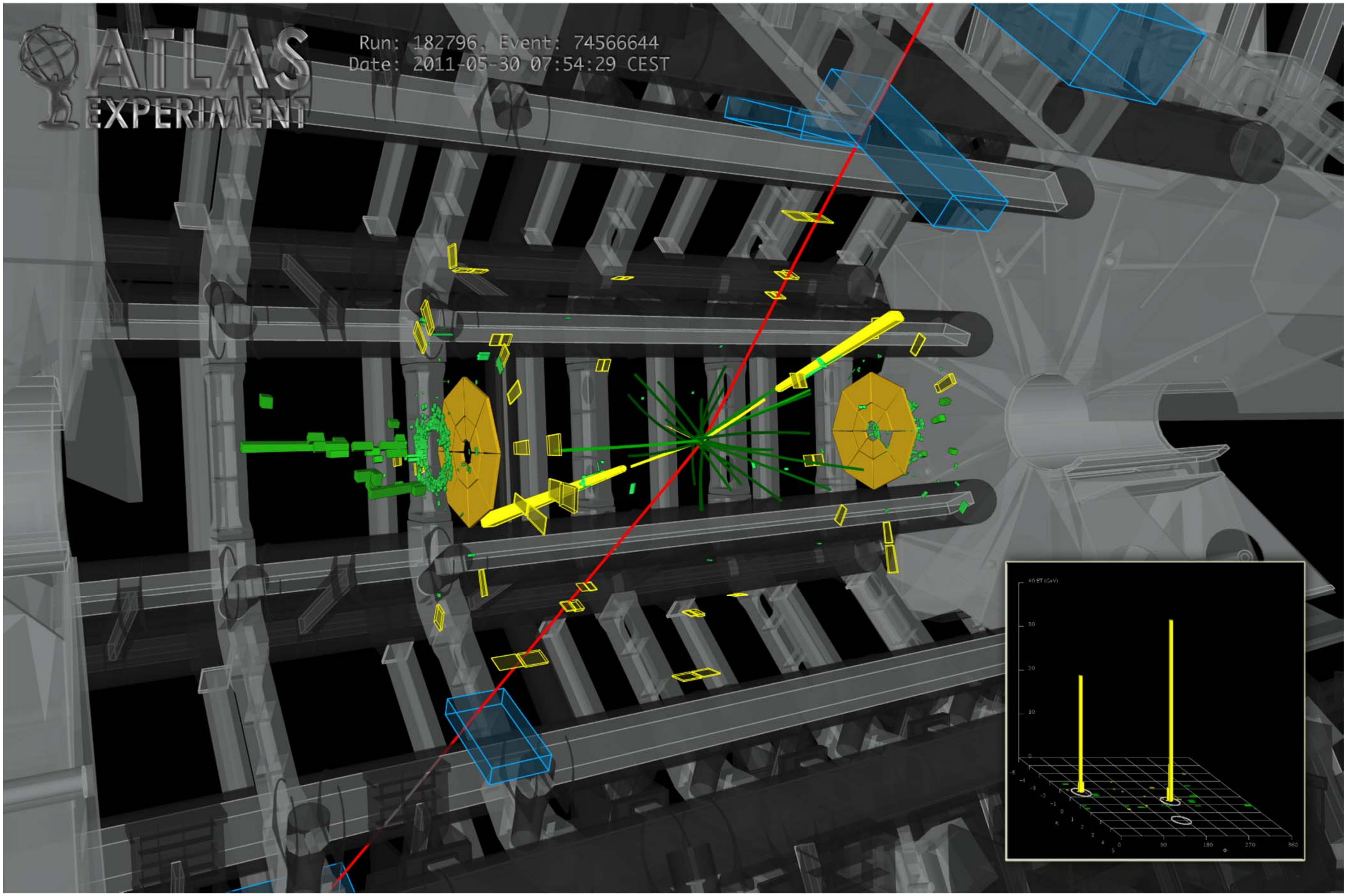

H
Z0
Z0*
ℓ′−
ℓ′+
ℓ−
ℓ+


h0
W+
W-
ν
l+
l-
ν̄


H0
W+
W−
e+
ν
e−
ν

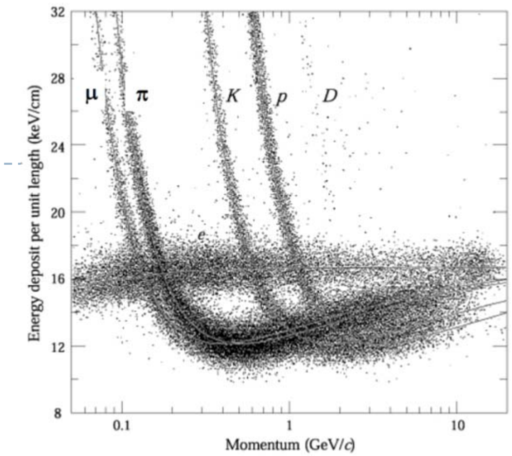

W+
W+
H0
e+
ν
b
b̄


ATLAS
EXPERIMENT
http://atlas.ch
Run: 205113
Event: 12611816
Date: 2012-06-18
Time: 11:07:47 CEST


ATLAS
EXPERIMENT
Run: 182796, Event: 74566644
Date: 2011-05-30 07:54:29 CEST

Summary

- Ionisation



- Magnets $B[\mathrm{T}]\cdot R[\mathrm{m}] = 3.3356 \cdot p\left[\mathrm{GeV}/\mathrm{c}\right]$

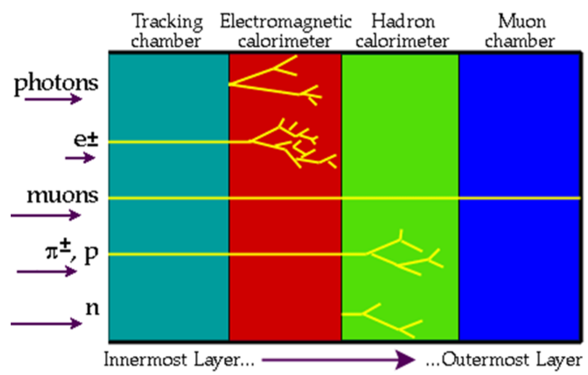
- Tracking detectors
  - Momentum resolution
  - Impact parameter resolution

$$\frac{\Delta p}{p} \approx 0.25 \frac{\Delta s[\mu m]}{(L[\mathrm{cm}])^2\, B[\mathrm{T}]}\, p[\mathrm{GeV}]$$

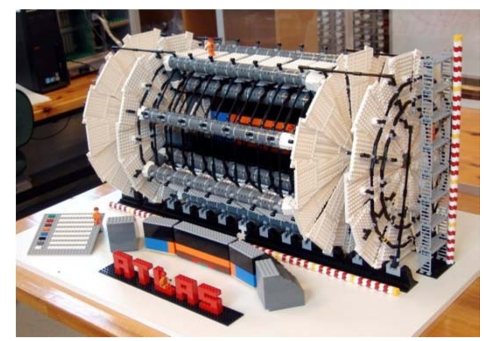
$$\frac{\sigma(\mathrm{E})}{\mathrm{E}} = \frac{\mathrm{a}}{\sqrt{\mathrm{E}}} \oplus \frac{\sigma_n}{\mathrm{E}} \oplus \text{constant}$$

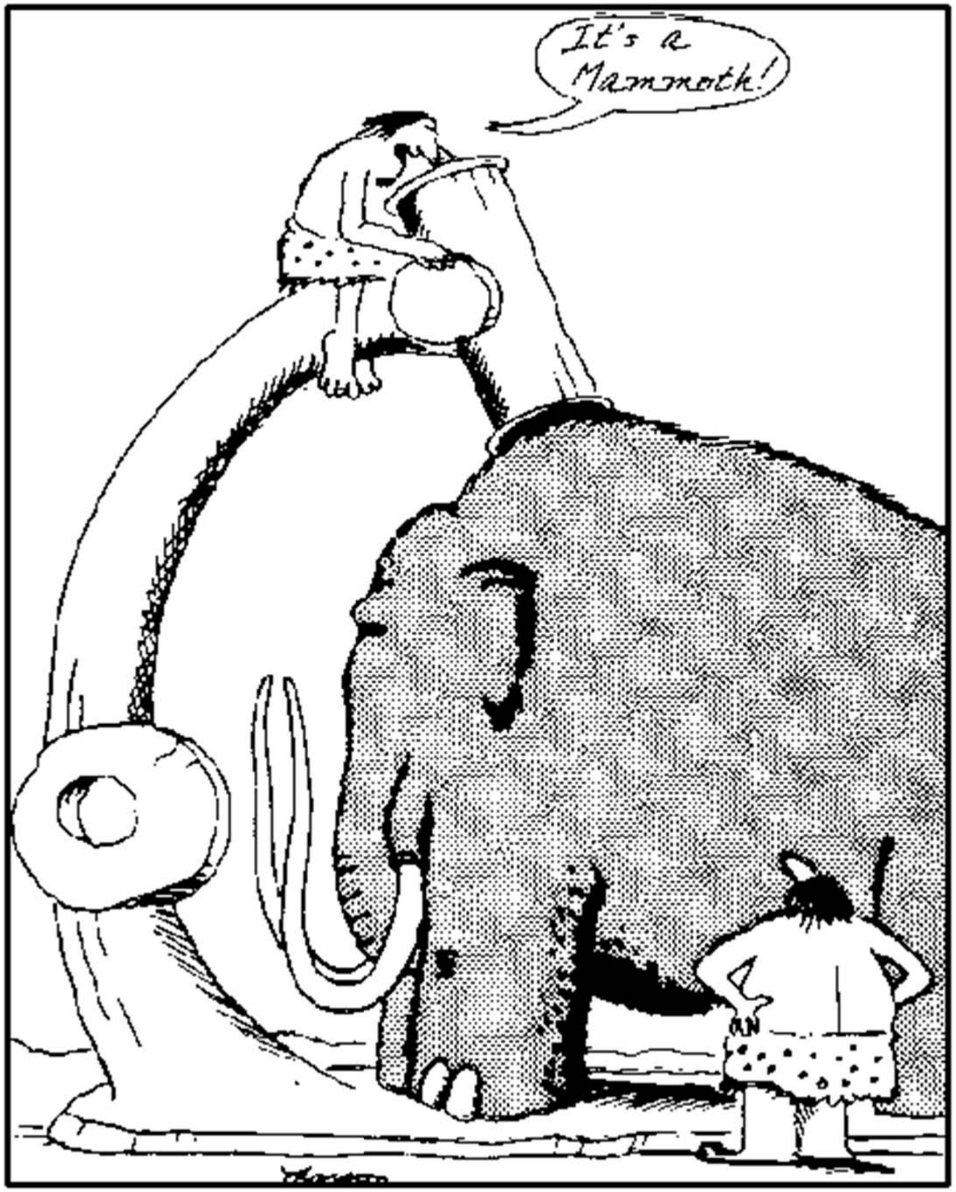
- Showers / Calorimeters

- Particle ID



- Collider detectors





Early Microscope