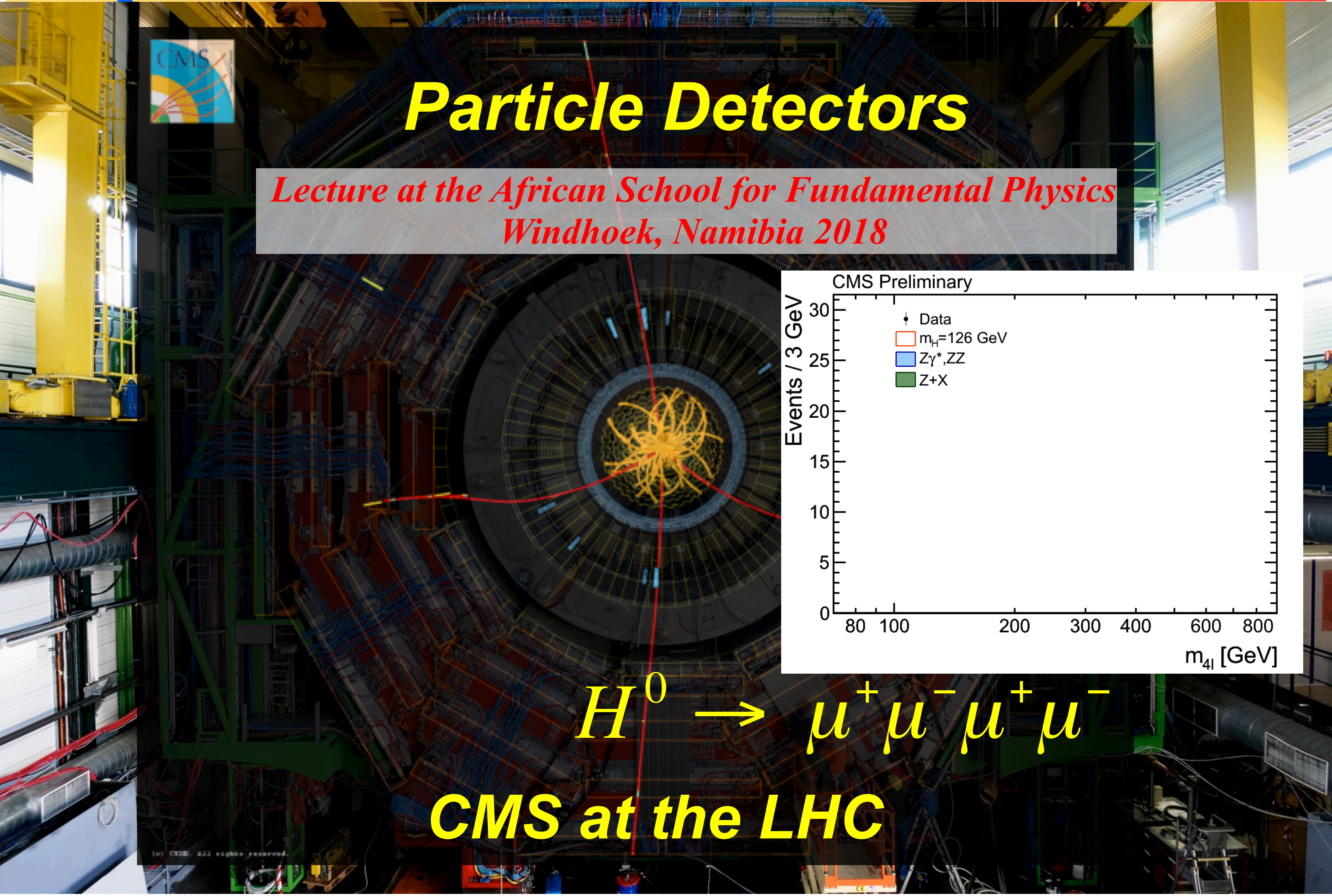


# Particle Detectors

## *Lecture at the African School for Fundamental Physics*
## *Windhoek, Namibia 2018*

$$H^0 \rightarrow \mu^+\mu^-\mu^+\mu^-$$

## CMS at the LHC

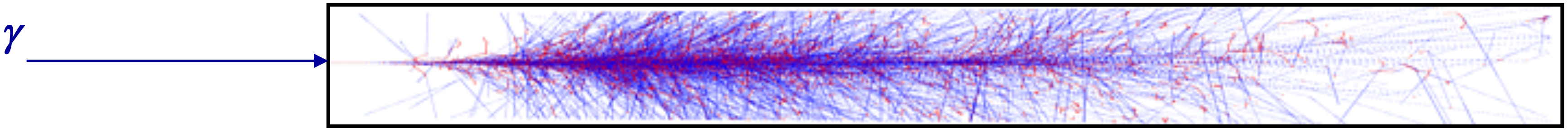
# Summary
# Particle interaction with matter

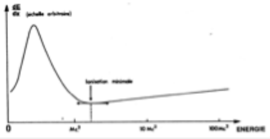
**Photons :**

- At low energy (< 10 MeV) photons are absorbed by a single interaction (photoelectric, Compton effect or pair creation). The number of photons is attenuated exponentially, the energy of the remaining photons is not changed, however by the Compton effect lower energy photons are created.

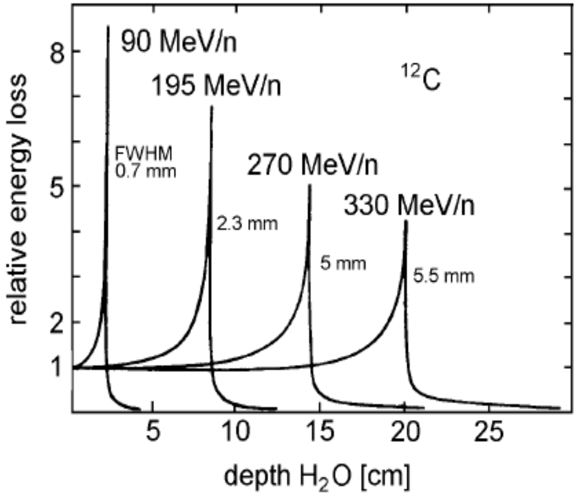
$$N(x) = N_0 \exp(-x/\lambda) \;; \quad \frac{1}{\mu} = \lambda_{\text{specific process}} = \text{attenuation length;} \quad x = \text{thickness}$$

- At high energy (E>> 10 MeV) successive pair creation followed by electron Bremsstrahlung will lead to extended elm showers characterized by the “radiation length $X_0$”





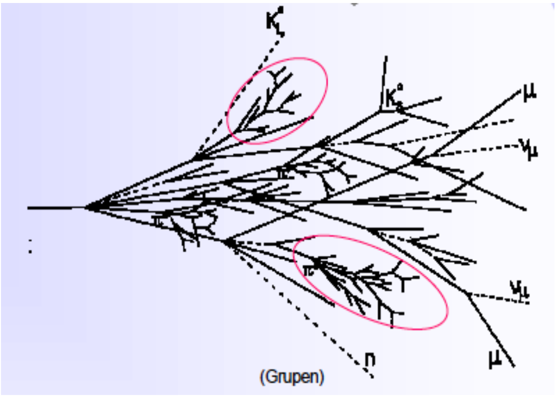
# Summary
# Particle interaction with matter



## Heavy charged particles

- loose continuously kinetic energy along their path (ionization) with small fluctuations until they are stopped after a well defined distance; until that point their number remains constant and they travel on a straight line.
- At high energies also hadronic interactions may occur, leading to an hadronic shower :

$$N(x) = N_0 \exp\left(-x/\Lambda\right) \;; \qquad \frac{1}{\Lambda} = \sigma_{\text{int}} \cdot n_b$$

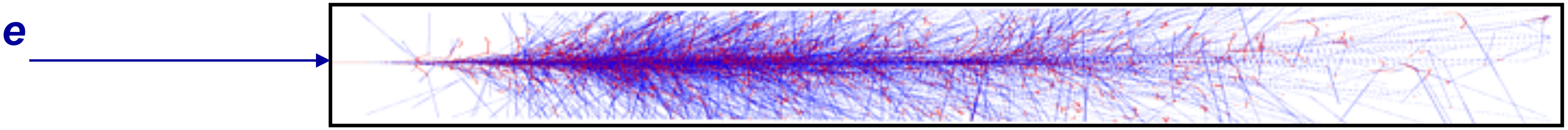


# Summary
# Particle interaction with matter

**Electrons**

- **also loose their energy by ionization but with much larger fluctuations in the energy loss and deflections leading to a badly defined range in matter.**
- **At energies higher than a critical energy Bremsstrahlung is emitted. This process becomes rapidly dominant.**
- **Multiple pair creation and Bremsstrahlung will lead to extended showers characterized by the "radiation length $X_0$"**
- **The energy of the incoming electron (not the number !) decreases exponentially with the path length.**

$$E^e(x) = E_0^e \exp(-x / X_0)$$



# Particle Detectors

*Lecture at the African School for Fundamental Physics*
*Windhoek, Namibia 2018*

## Second Lecture

- Detector systems, some examples, strategies
  - Experimental conditions, fixed target or collider, neutrinos, dark matter…
  - Experiments at the LHC (Atlas and CMS, ALICE, LHCb ?

- The basic "building blocks", characteristics (efficiency, resolution)
  - Gas detectors
  - Semiconductors
  - Scintillators
  - Calorimeters
- Detectors at lower energies, nuclear physicsDetectors at lower energies, nuclear physics

- Conclusions or recommendations

- *Exercises !!!*

# Some general characteristics of electronic detectors

## Single detector (the building blocks)

- Energy-response function and linearity
- Time-response and dead time
- Energy, spatial or angular and time resolution
- Efficiency of a detector
- Availability and price !!!
- …

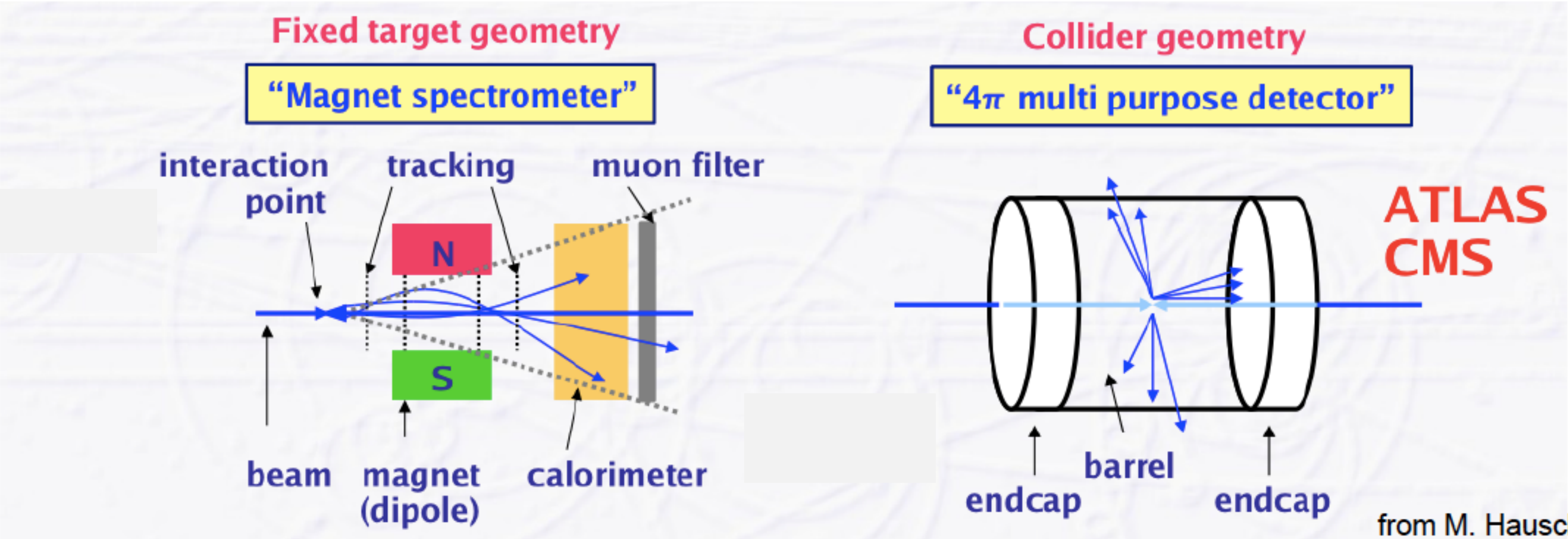
## Combination of many detectors → experiment

- Propagation of charged particles in a magnetic field, reconstructing their trajectories

$$p_T\,(\mathrm{GeV}/c) \;=\; 0.3\, B(\mathrm{Tesla})\, R(\mathrm{m})$$

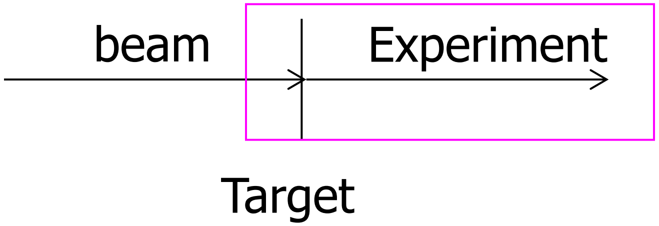
- Measure the energy of electrons, photons and jets
- Detect muons as penetrating particles
- Particle identification!
- Trigger (event selection) and Data acquisition (DAQ)

# Experiments at colliders and fixed target geometry



from M. Hauschild

$$E_{CM}^{\text{collider}} = 2E_{beam} = \sqrt{s}$$

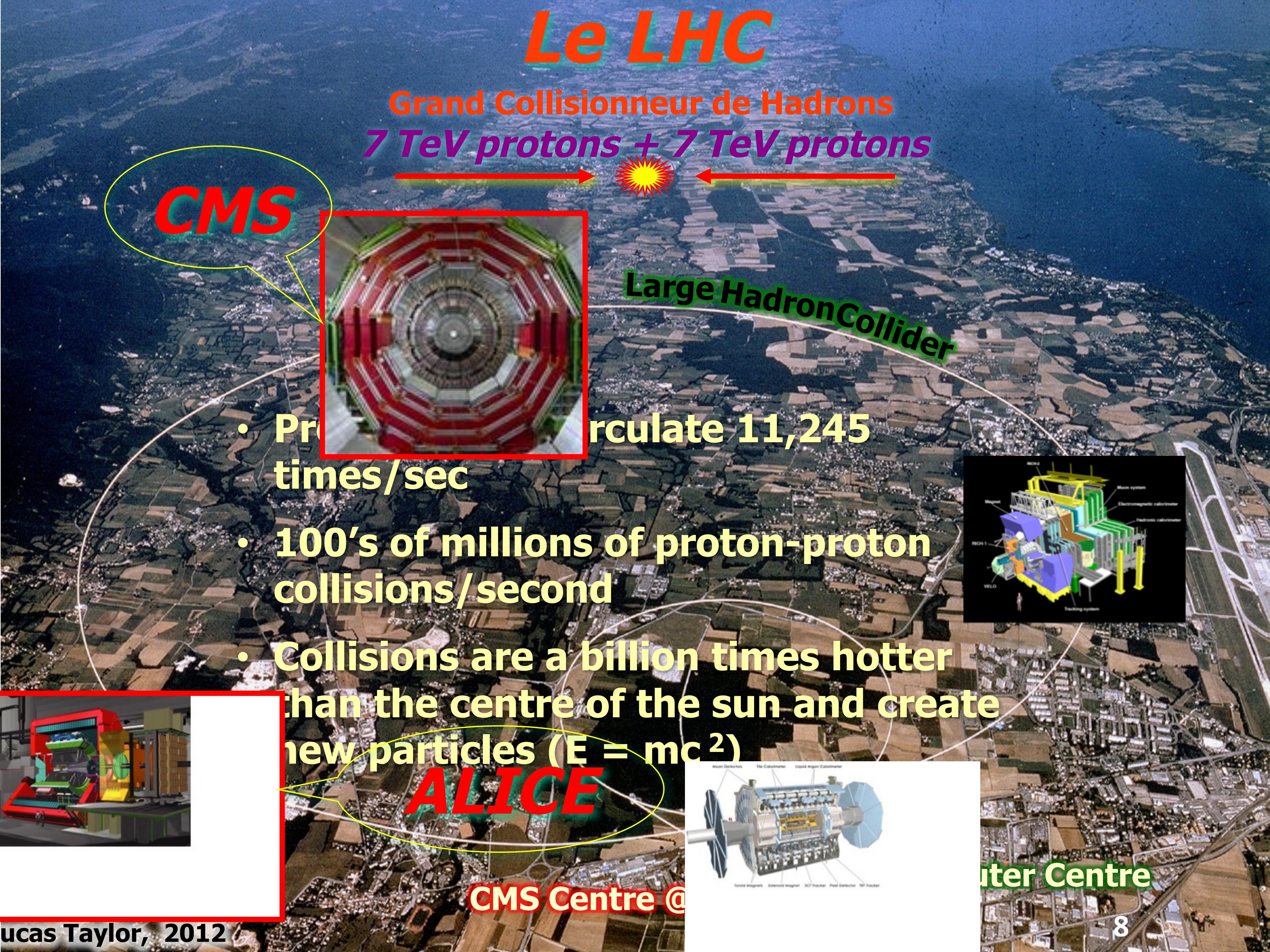


$$E_{CM}^{\text{fixed target}} = \sqrt{2Mc^2E + M^2c^4 + m^2c^4} \cong \sqrt{2Mc^2E}$$

# Le LHC

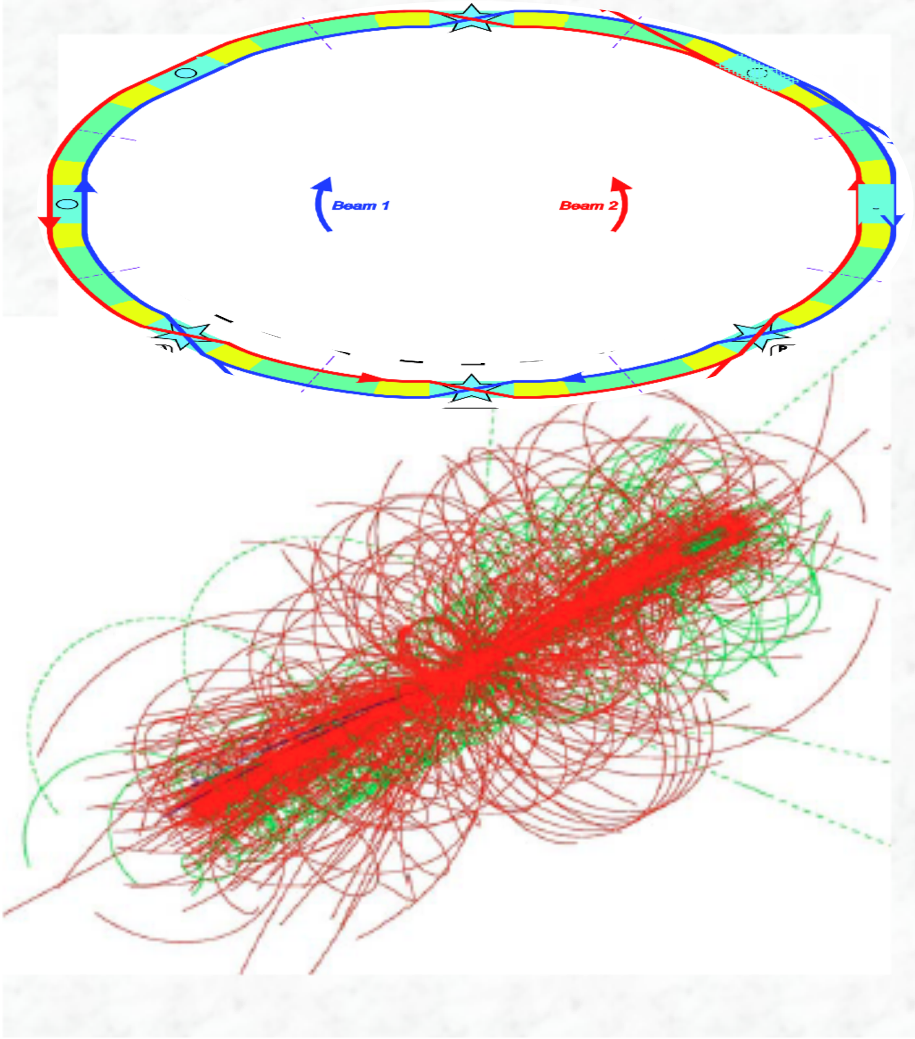
**Grand Collisionneur de Hadrons**

*7 TeV protons + 7 TeV protons*



- Pr rculate 11,245 times/sec
- 100's of millions of proton-proton collisions/second
- Collisions are a billion times hotter than the centre of the sun and create new particles ($E = mc^2$)

# Proton proton collisions at the LHC



Proton – proton:

2835 x 2835 bunches
Separation: 7.5 m ( 25 ns)

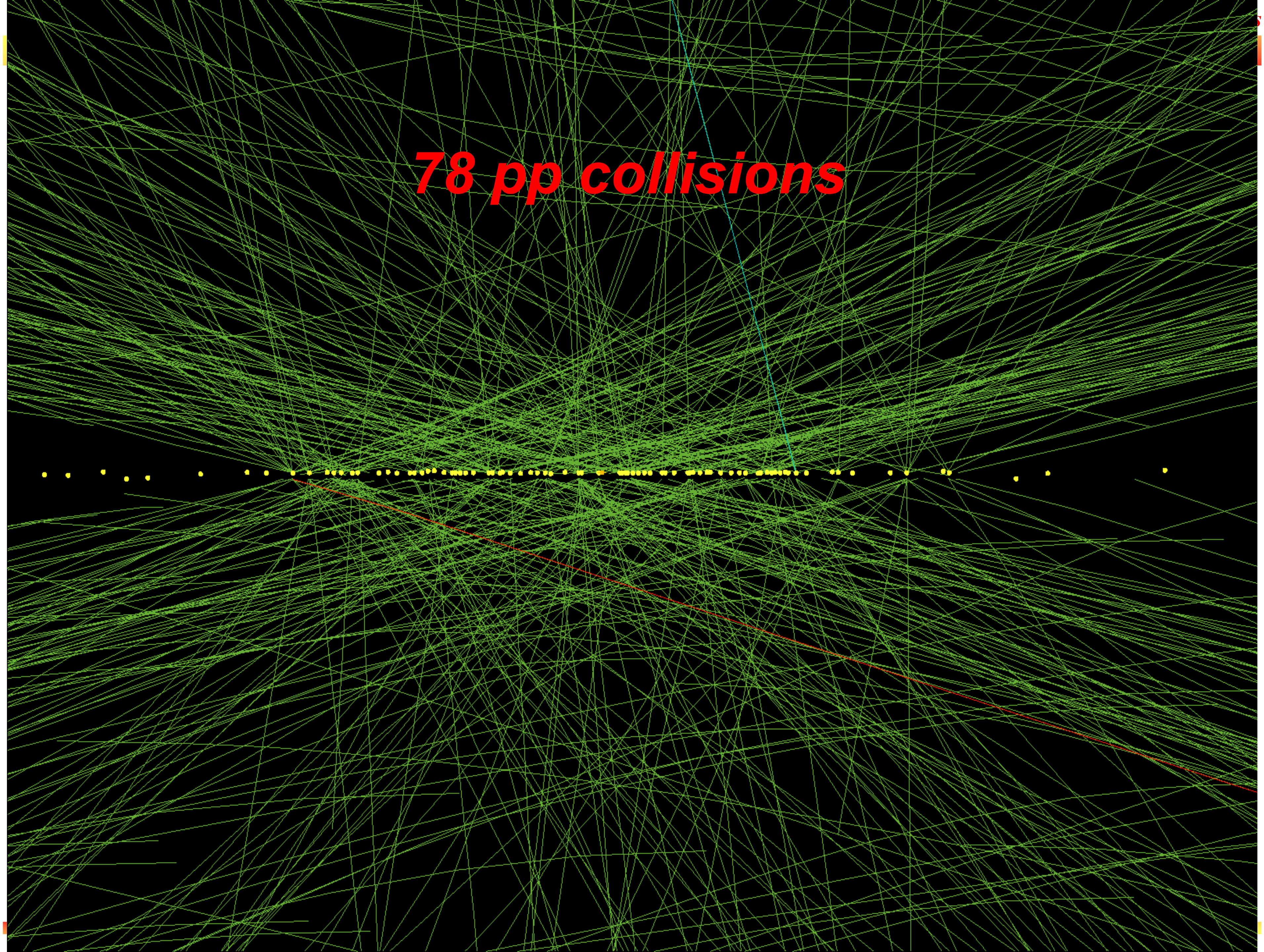
$10^{11}$ protons / bunch
Crossing rate of p-bunches: 40 Mio. / s
Luminosity: $L = 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

~$10^{9}$ pp collisions / s
(superposition of 23 pp-interactions
per bunch crossing: **pile-up**)

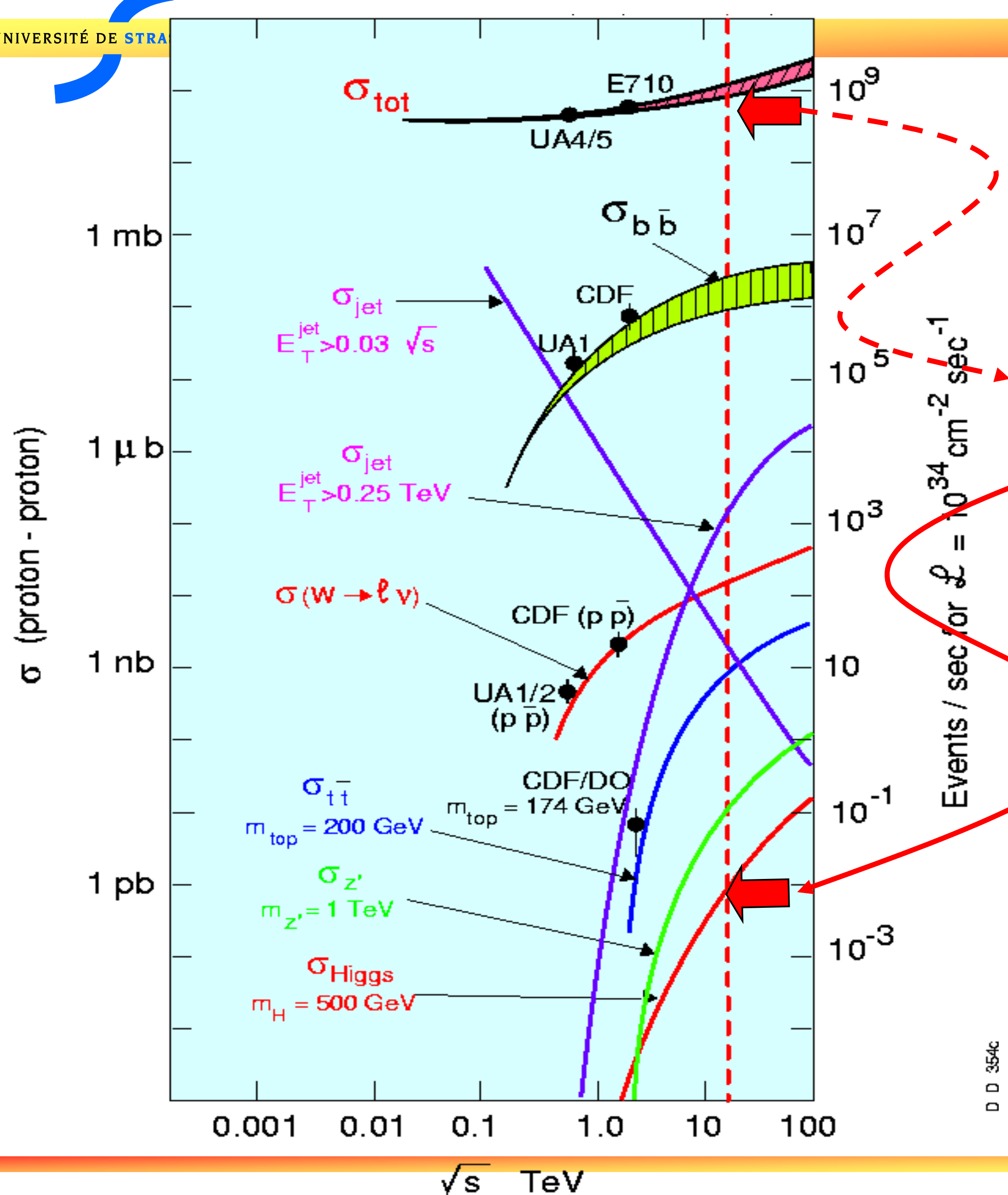
~1600 charges particles in the detector

⇒ high particle densities
high requirements for the detectors

# 78 pp collisions



# pp Collisions at LHC



$\sigma_{\text{tot pp}} = 40 - 100\,mb$

$\sigma_{\text{H(500GeV)}} \approx 1\,pb$

$\mathcal{L} = 10^{34}\,cm^{-2}s^{-1}$

Beam crossing rate:

40 MHz

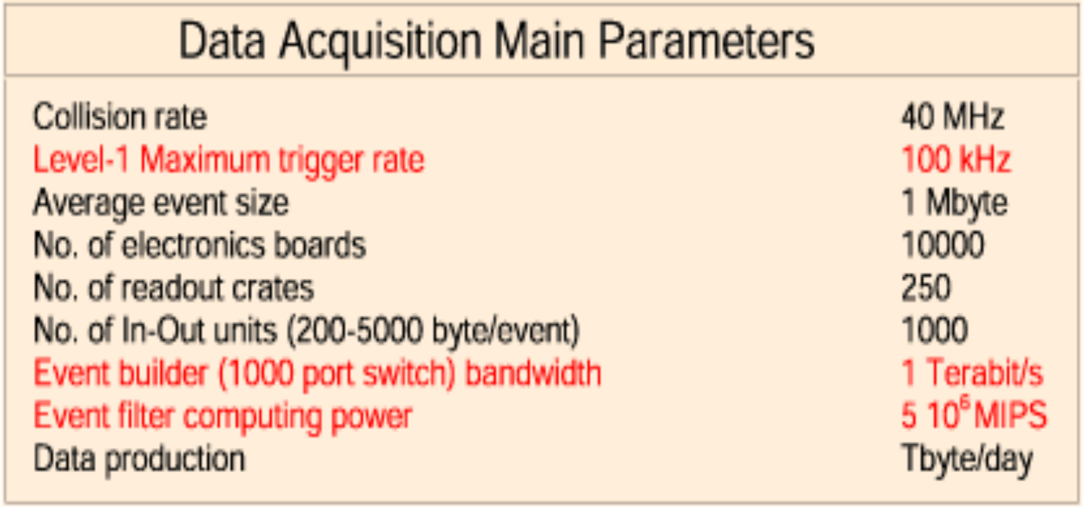
25 interactions

per crossing

$\dot{N}_{tot} = 10^{9}\,s^{-1}$

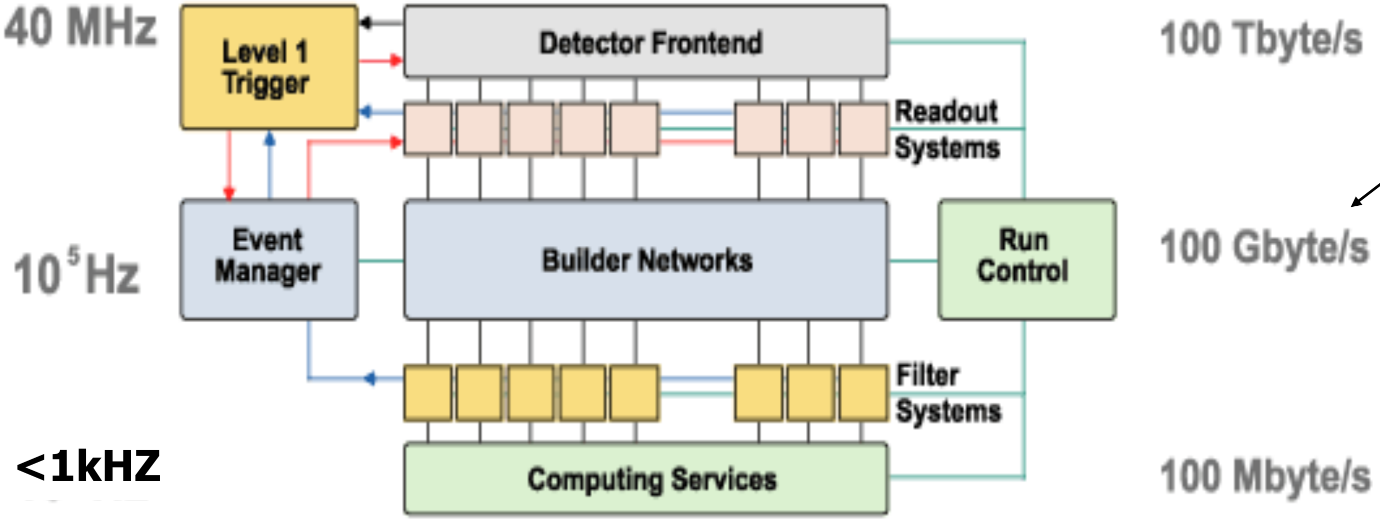
$\dot{N} = 10^{-2}\,s^{-1}$

# The Trigger and Data Acquisition System



Data Acquisition Main Parameters

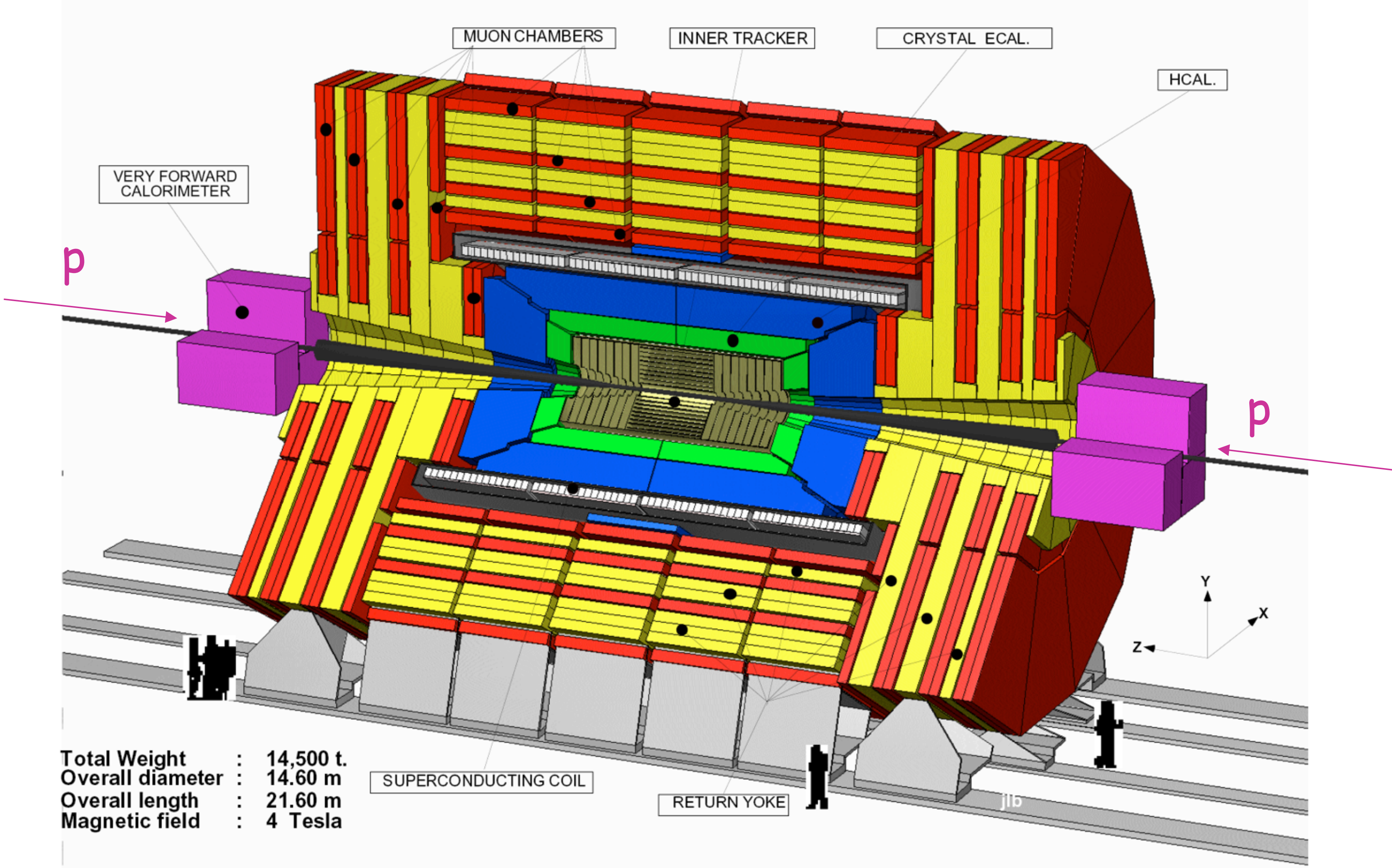
| | |
|---|---|
| Collision rate | 40 MHz |
| Level-1 Maximum trigger rate | 100 kHz |
| Average event size | 1 Mbyte |
| No. of electronics boards | 10000 |
| No. of readout crates | 250 |
| No. of In-Out units (200-5000 byte/event) | 1000 |
| Event builder (1000 port switch) bandwidth | 1 Terabit/s |
| Event filter computing power | $5\ 10^6$ MIPS |
| Data production | Tbyte/day |



Trigger and Data Acquisition baseline structure

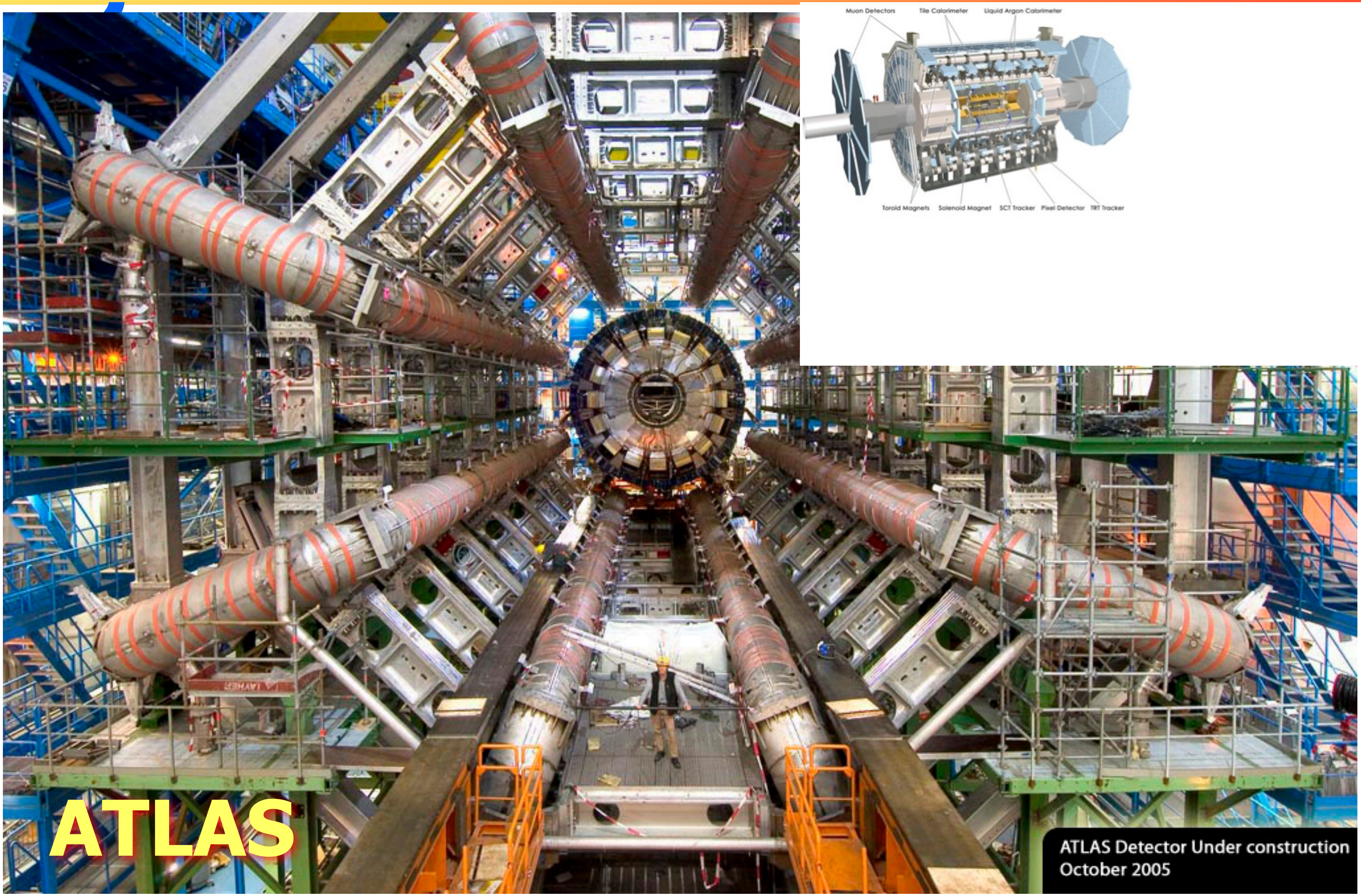
~same as whole world's telecom network!

# Compact Muon Solenoid



| | | |
|---|---|---|
| Total Weight | : | 14,500 t. |
| Overall diameter | : | 14.60 m |
| Overall length | : | 21.60 m |
| Magnetic field | : | 4 Tesla |

# ATLAS

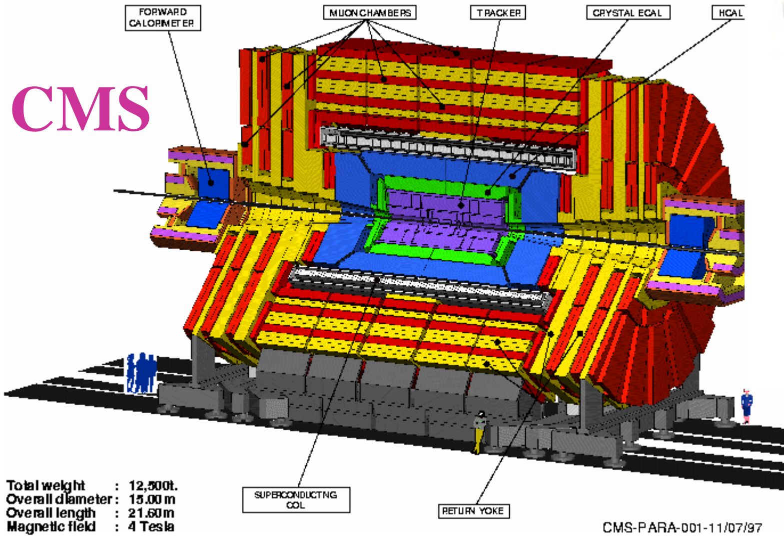


ATLAS Detector Under construction
October 2005

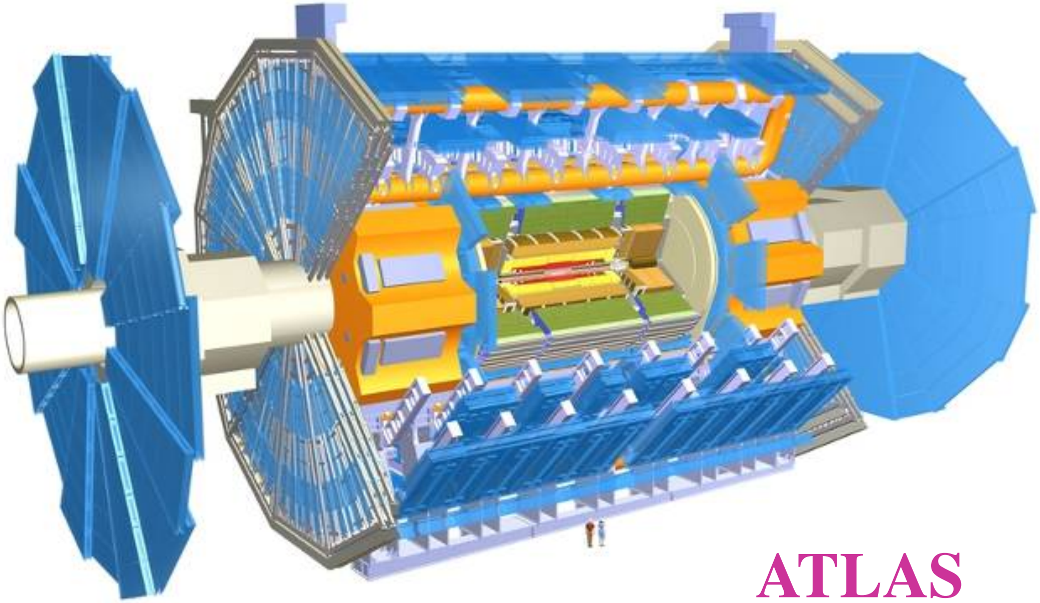
# How huge are ATLAS and CMS?

ATLAS superimposed to

the 5 floors of building 40



CMS



ATLAS

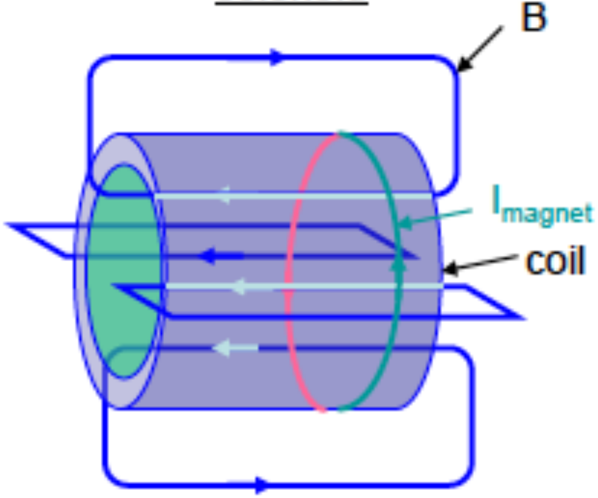
| | | |
|---|---|---|
| *Overall weight (tons)* | *7000* | *12500* |
| *Diameter* | *22 m* | *15 m* |
| *Length* | *46 m* | *22 m* |
| *Solenoid field* | *2 T* | *4 T* |

# Design Goals

- **A good and redundant *muon system*** (= many layers – if one layer fails we can fall back on the others)
- **The best possible *electromagnetic calorimeter***
- **A high quality *central tracking***
- **A *hadronic calorimeter* that has good energy resolution and that is as hermetic as possible**
- **Affordable! (= ~500 MCHF)**

Magnetic field configurations:

solenoid

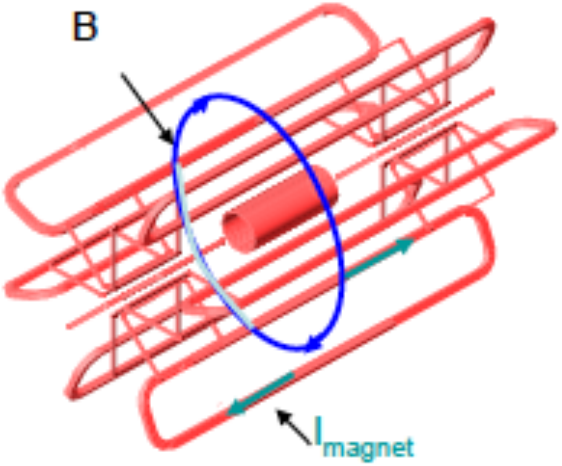


- \+ Large homogenous field inside coil
- \- weak opposite field in return yoke
- \- Size limited (cost)
- \- rel. high material budget

Examples:

- DELPHI (SC, 1.2T)
- L3 (NC, 0.5T)
- CMS (SC, 4T)

toroid

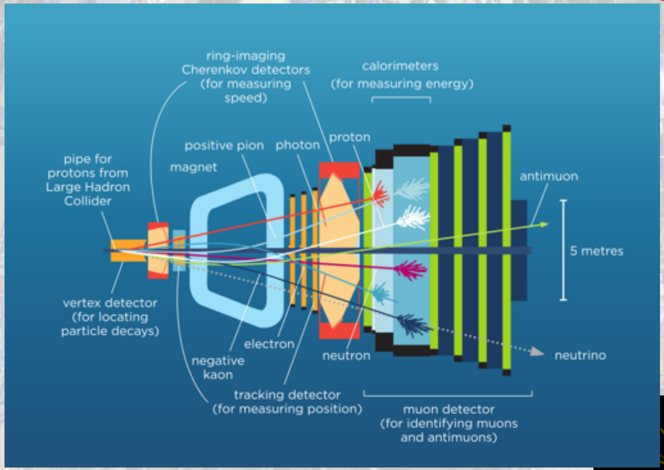


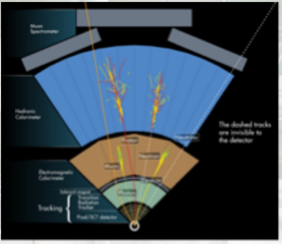
- \+ Rel. large fields over large volume
- \+ Rel. low material budget
- \- non-uniform field
- \- complex structure

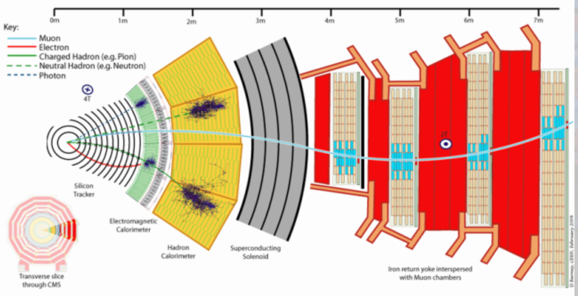
Example:

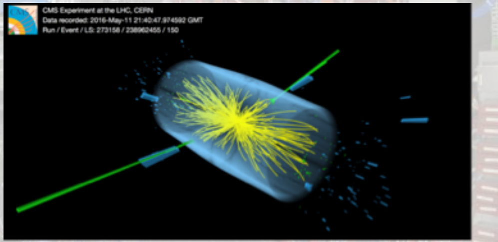
- ATLAS (Barrel air toroid, SC, 0.6T)

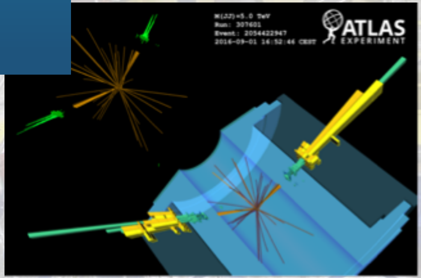
# Detecting particles at the LHC

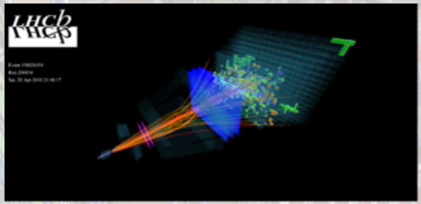








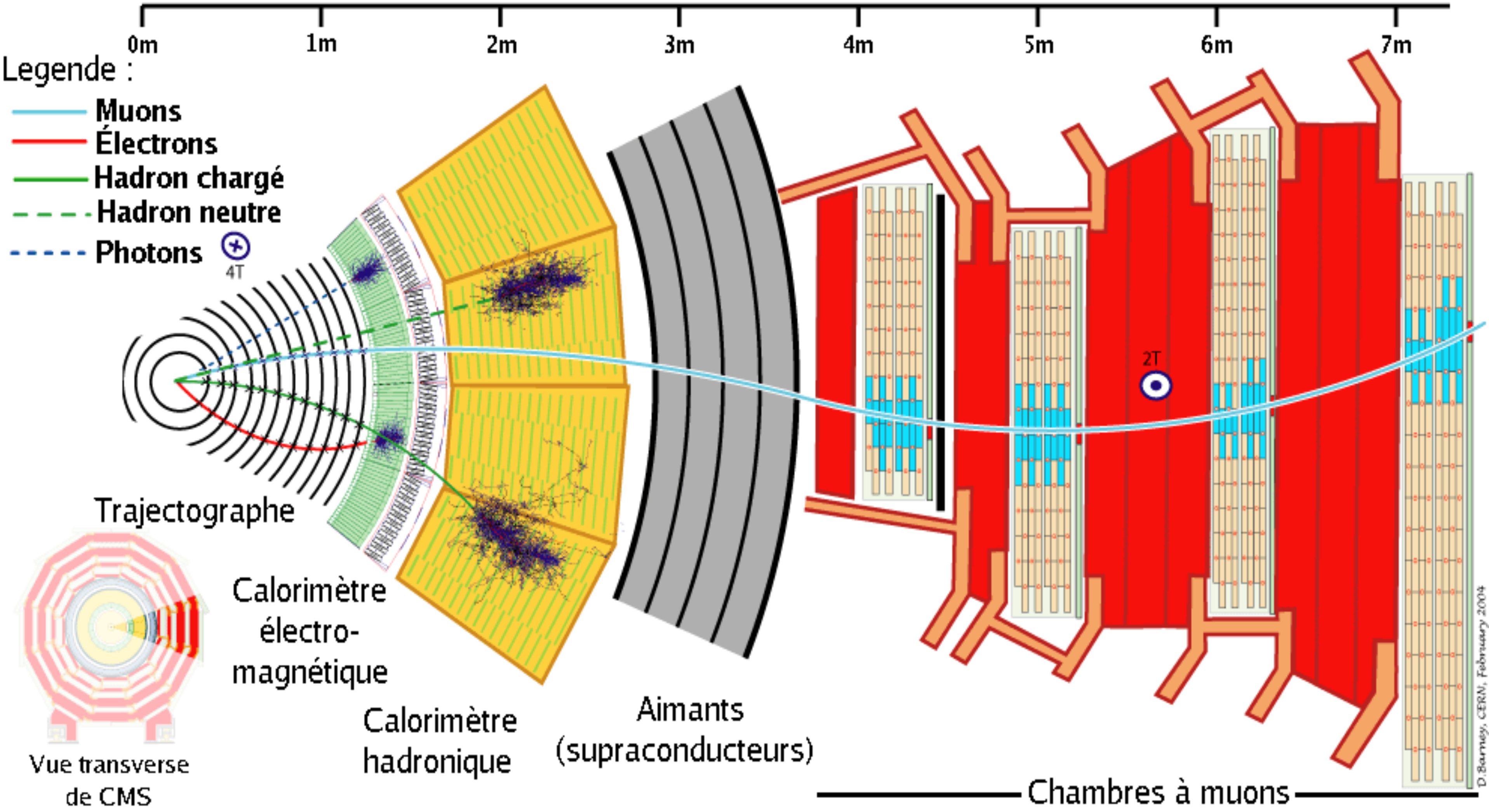




**LHCb b-jet event**

**ATLAS dijet event**

**CMS dijet event**



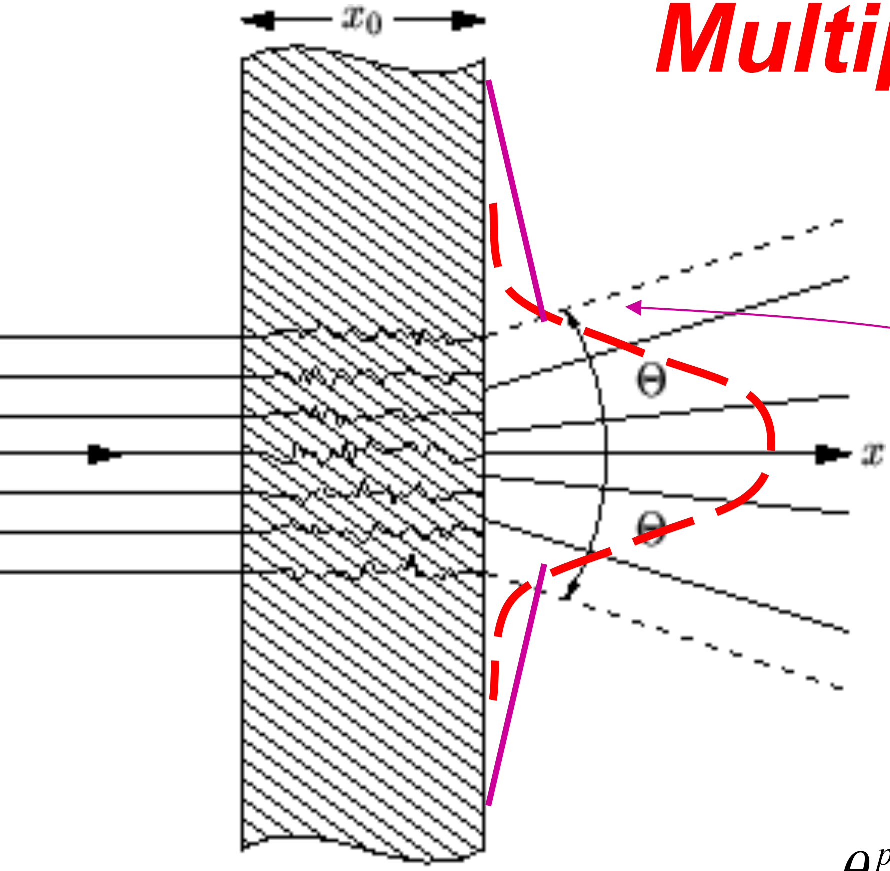
# Transverse slice through CMS detector

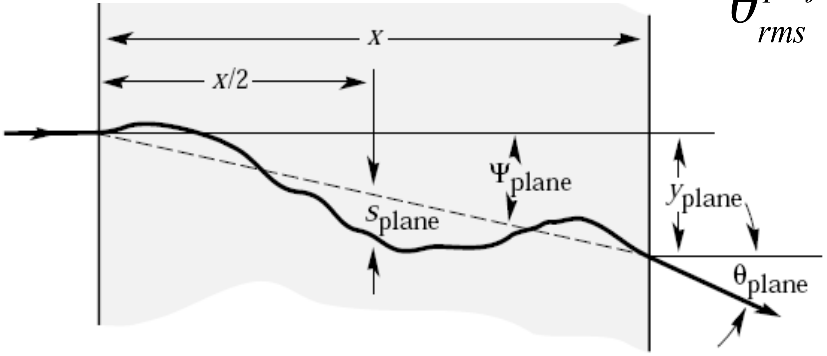
# Particle Identification, (PID)

- Photon vs neutral hadron
- Electron vs hadron
- Hadrons vs muons

- Neutral particle:
  - No ionization track
  - Electromagnetic or hadronic shower
- Charged particle
  - Ionization track visible
  - Electromagnetic or hadronic shower
- Charged particle,
  - Ionization track visible
  - No absorption by a shower

# Multiple scattering





**Scattering in the coulomb field of the nucleus (Rutherford)**

**Gaussian (θ) distribution for small angles θ,**

**Violant scatters can lead to large values of θ**

$$\theta^{proj}_{rms} = \frac{13.6MeV/c}{p\cdot\beta} Z_0 \sqrt{\frac{x}{X_0}}\left(1+0.038\ln(x/X_0)\right)$$

**$X_0$=radiation length**

# Tracking in a magnetic Field: Resolution and multiple scattering

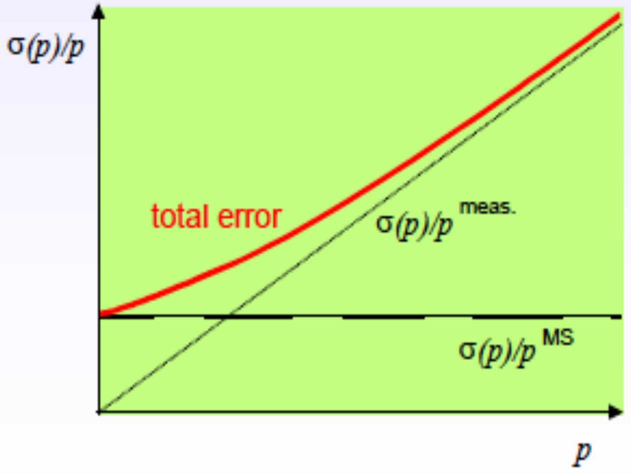
$$\left.\frac{\sigma(p_T)}{p_T}\right|^{meas.} = \frac{\sigma(x)\cdot p_T}{0.3\cdot BL^2}\sqrt{720/(N+4)}$$

(for N ≥ ~10)

$$\left.\begin{aligned} \frac{\sigma(p)}{p_T} &\propto \sigma(x)\cdot p_T \\ \sigma(x)\Big|^{MS} &\propto \theta_0 \propto \frac{1}{p} \end{aligned}\right\} \quad \left.\frac{\sigma(p)}{p_T}\right|^{MS} = \text{constant}$$

, i.e. independent of p !

More precisely: $$\left.\frac{\sigma(p)}{p_T}\right|^{MS} = 0.045\frac{1}{B\sqrt{LX_0}}$$



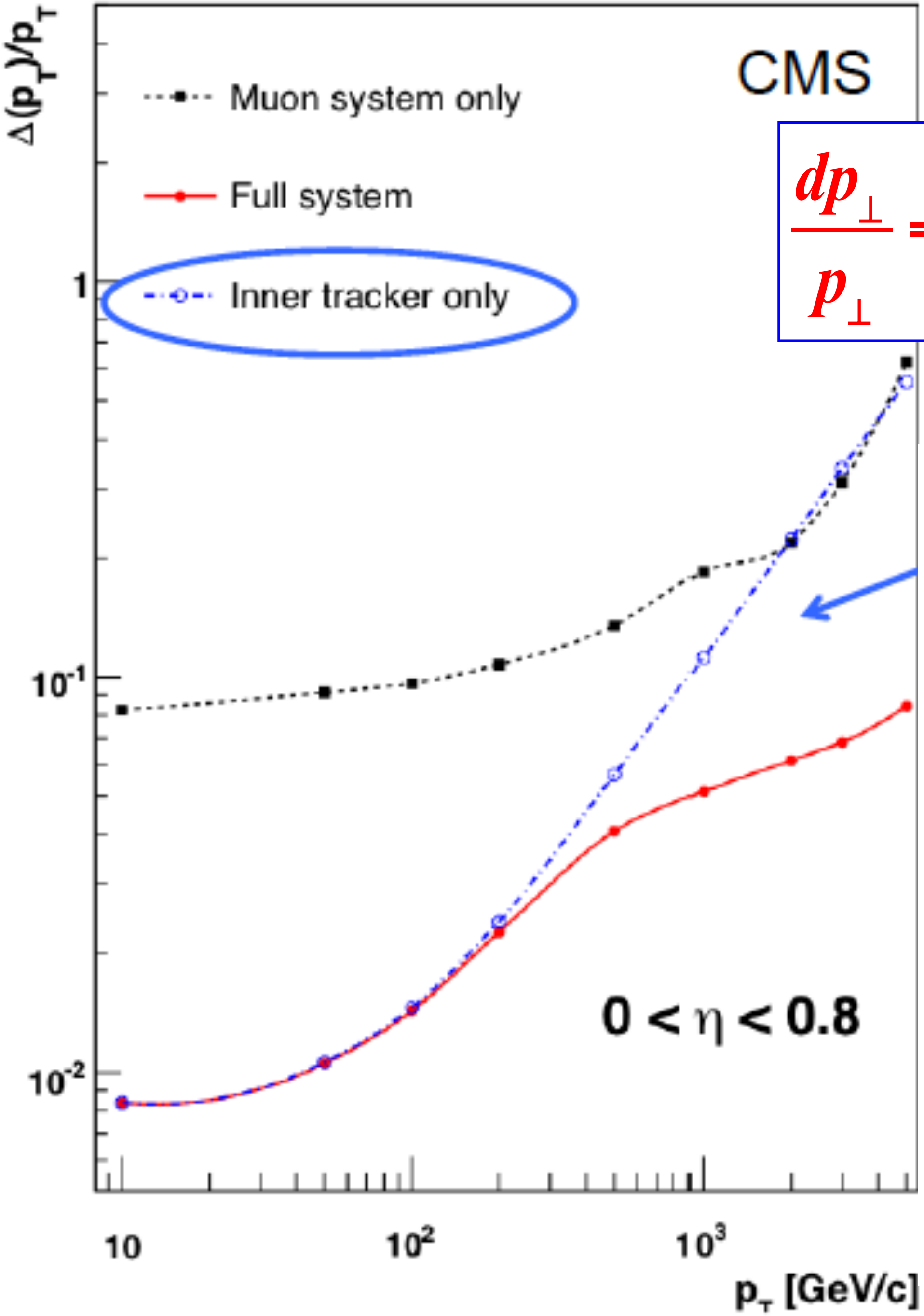
Example:

$p_t = 1$ GeV/c, $L = 1$m, $B = 1$ T, $N = 10$

$\sigma(x) = 200$ µm: $$\left.\frac{\sigma(p_T)}{p_T}\right|^{meas.} \approx 0.5\%$$

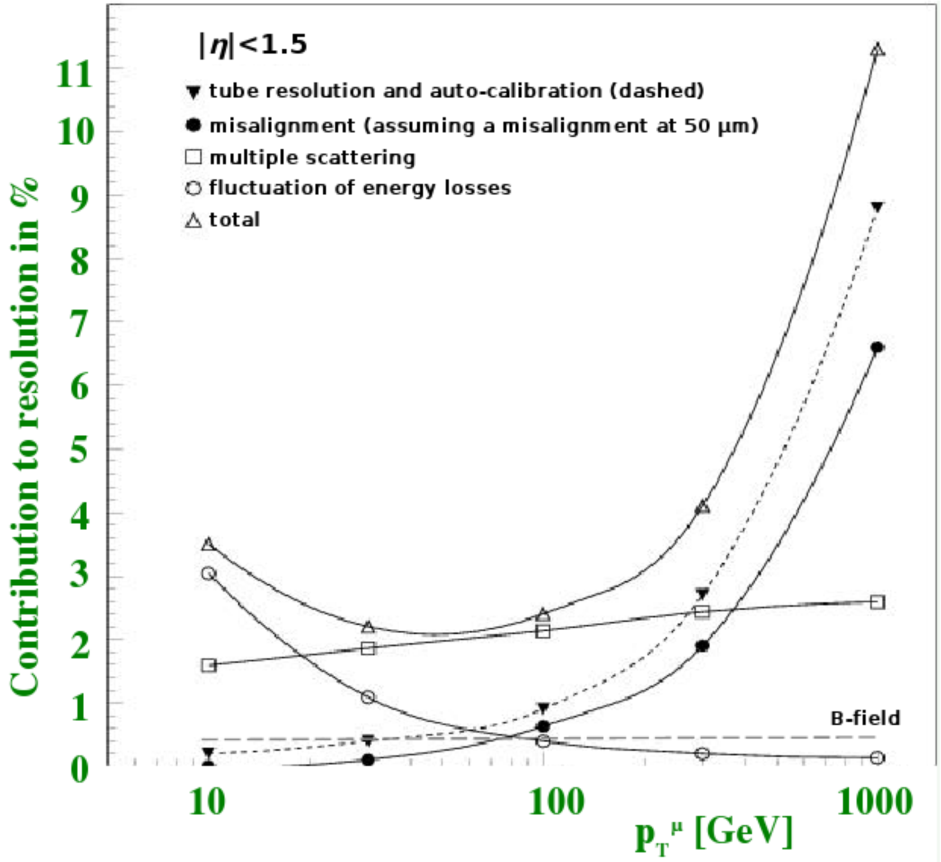
Assume detector (L = 1m) to be filled with 1 atm. Argon gas ($X_0$ = 110m),

$$\left.\frac{\sigma(p)}{p_T}\right|^{MS} \approx 0.5\%$$



$$\frac{dp_\perp}{p_\perp} = \alpha \times p_\perp dS \oplus \left(\text{multiple scattering}\right)$$

**Atlas**



# Detectors for Particle and Nuclear Physics

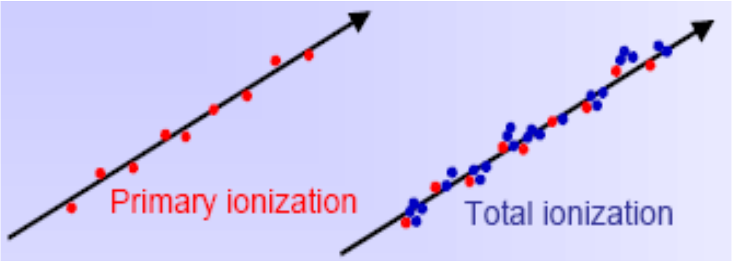
- **The building blocks and assemblies**

# Gas detectors

- Ionisation chambers
- Proportional counters
- Multi Wire Proportional chambers
- Drift chambers and Time Projection Chambers
- Many many more …..

# *Ionisation and excitation in a gas*

- **Excitation : X+p → $X^*$+p**
  - **$\sigma \approx 10^{-17}$ cm$^2$**
- **Ionisation : X+p → $X^+$+p + $e^-$**
  - **$\sigma \approx 10^{-16}$ cm$^2$**



**$n_{primary} \approx n_{total}$ x1/3**

| Gaz | Excitation (eV) | Ionisation (eV) | Energie moyenne pour ($e^-$, ion) (eV) | ($e^-$,ion$^+$) /cm au minimum d'ionisation $n_{total}$ |
|---|---|---|---|---|
| $H_2$ | 10.8 | 15.4 | 37 | 14 |
| He | 19.8 | 24.6 | 41 | 16 |
| Ne | 16.6 | 21.6 | 35 | 42 |
| Ar | 11.6 | 15.8 | 26 | 103 |
| $CO_2$ | 10.0 | 13.7 | 33 | 62 |
| $CH_4$ |  | 13.1 | 33 | 107 |
| $C_4H_{10}$ |  | 10.8 | 23 | 113 |

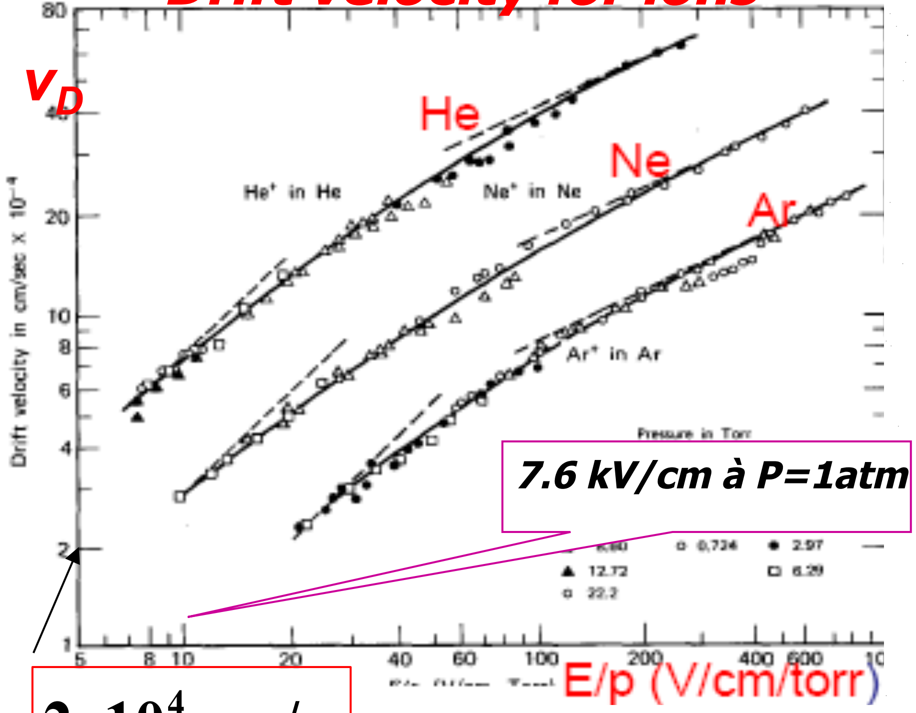
# Mobility and collection of charge

$$v_D = \mu \cdot E;\ \ E = \text{electric field};\ \ p = \text{pressure}$$

$$\text{in general it's more complicated } \mu = \mu\left(E, p\right)$$

$$v_D\left(\text{electrons}\right) \gg v_D\left(\text{ions}\right) \sim E / p$$

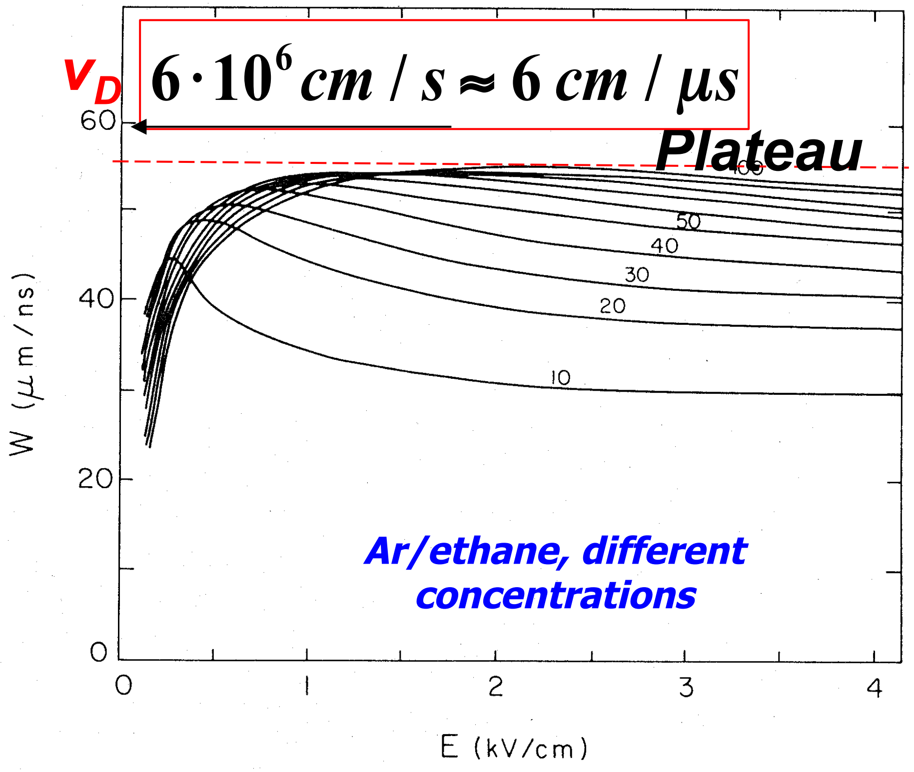
## Drift velocity for ions



**7.6 kV/cm à P=1atm**

$$2 \cdot 10^4\, cm / s$$

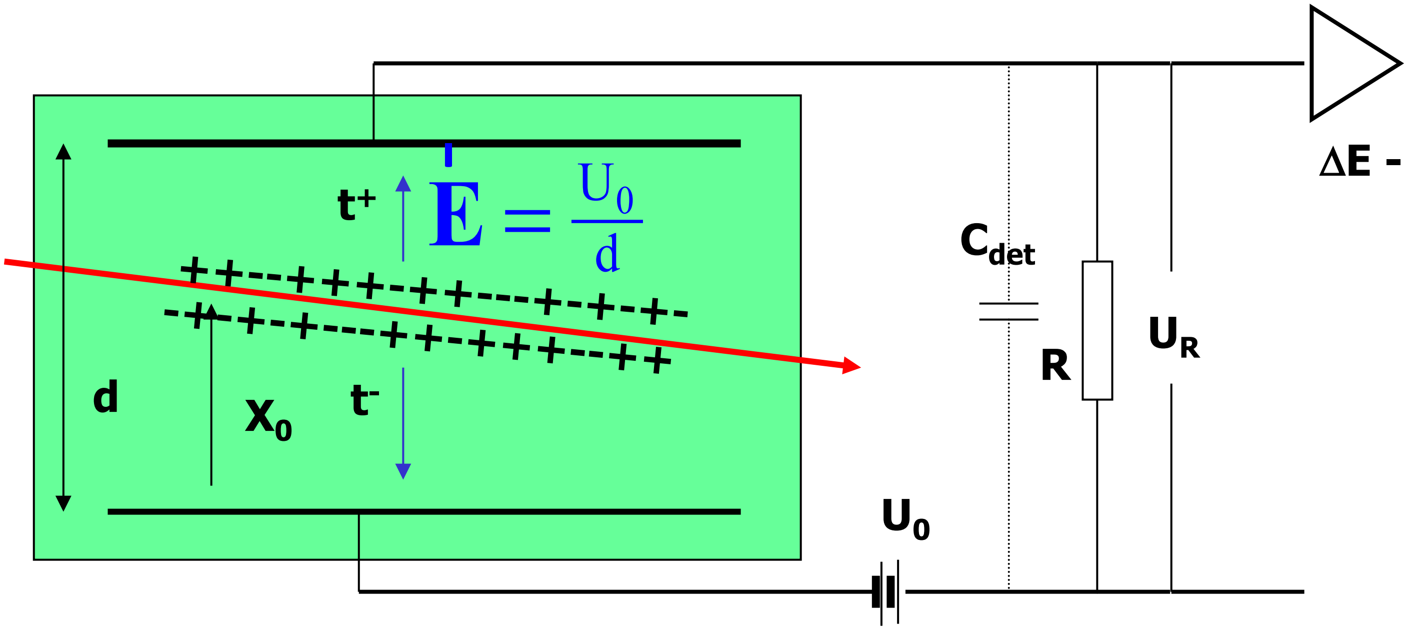
## Drift velocity for electrons



$$6 \cdot 10^6\, cm / s \approx 6\, cm / \mu s$$

**Ar/ethane, different concentrations**

# Ionisation chamber



**$\Delta E$ -> charges $\Delta Q^+ = Ne$**
**and $\Delta Q^- = -Ne$**

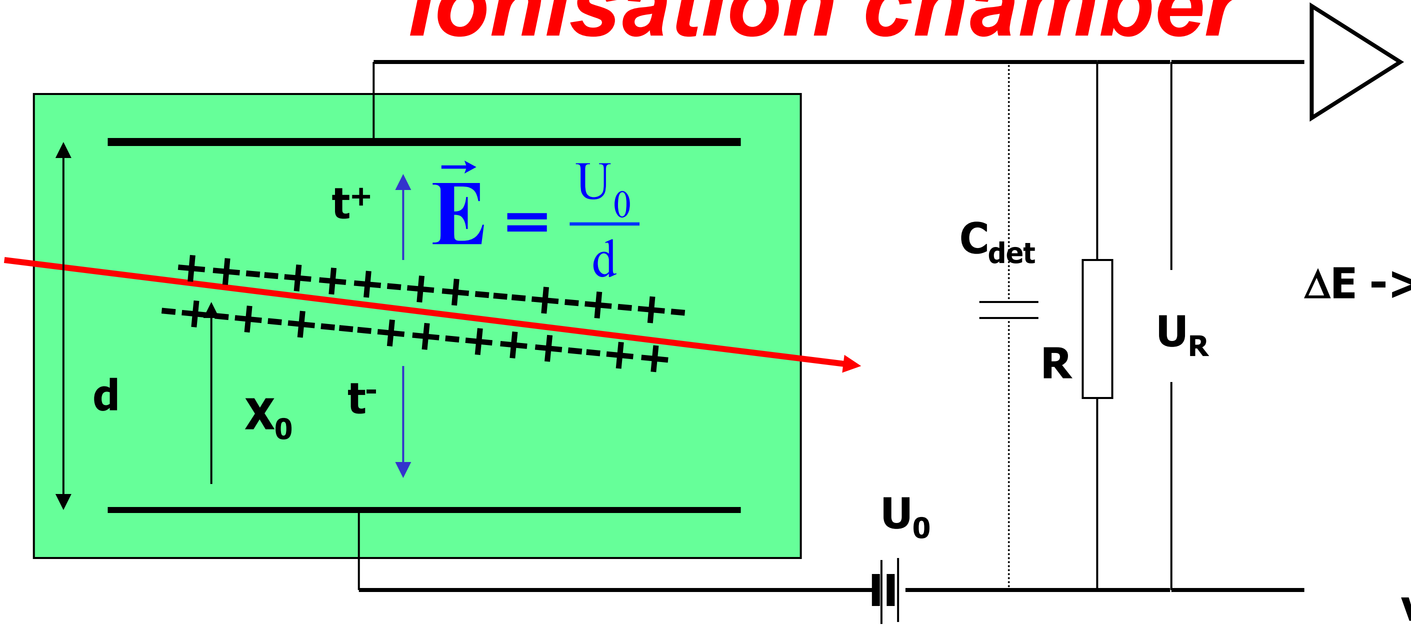
**Drift velocity $v_D$**

**$v_D(e^-) >> v_D(\text{ions})$**

**$v_D \sim E/p$**

**$\Delta U_{max} = \Delta Q/C$**

# Ionisation chamber



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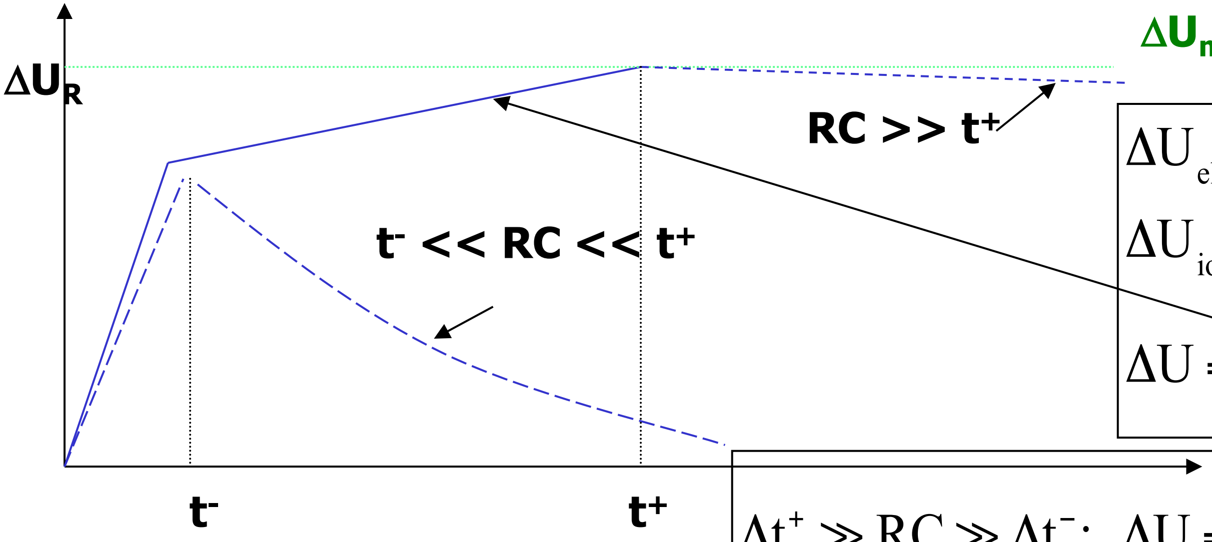
$v_D \sim E/p$



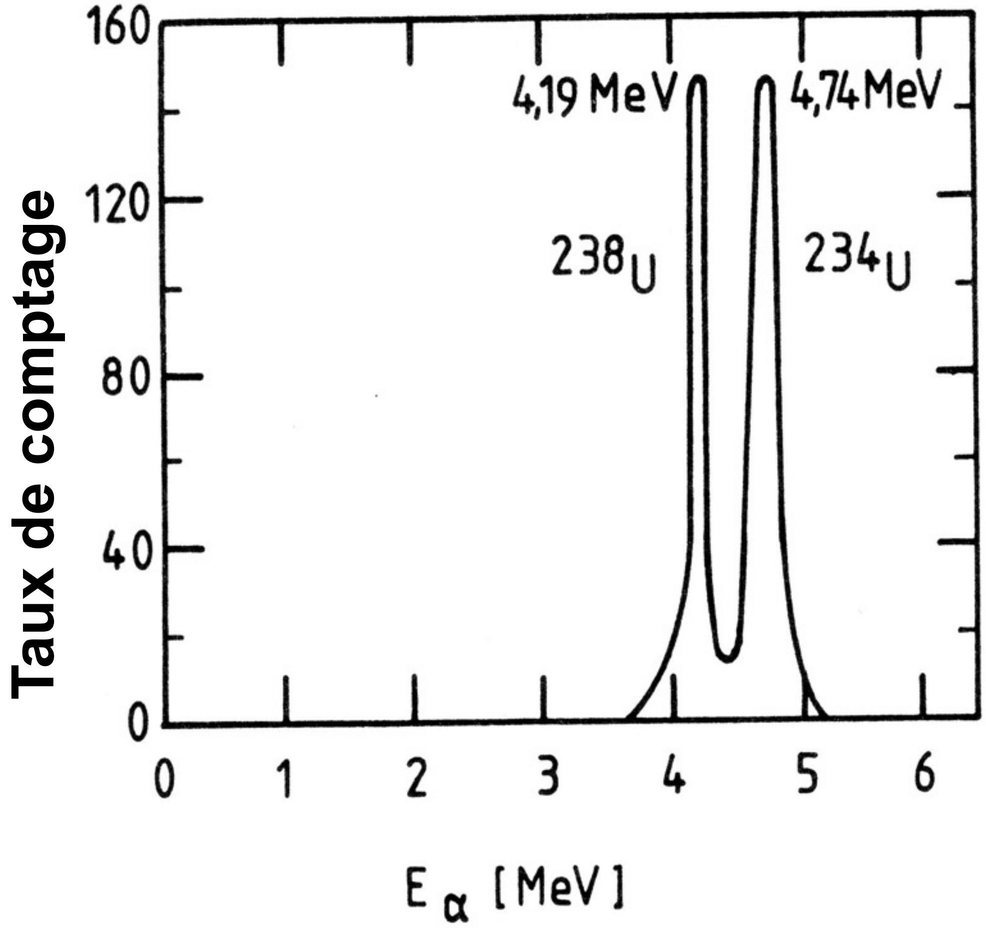
$$\Delta U_{el} = \frac{Ne}{Cd}(-x_0)$$

$$\Delta U_{ion} = \frac{-Ne}{Cd}(d - x_0)$$

$$\Delta U = \Delta U_{el} + \Delta U_{ion} = -\frac{Ne}{C} = \Delta Q / C$$

$$\Delta t^+ \gg RC \gg \Delta t^-;\ \ \Delta U = -\frac{Ne}{d}\left(\frac{x_0}{C} - v^+ R\left(1 - e^{-\Delta t^+/RC}\right)\right)$$

# *Alpha particles in a ionization chamber*



- Mix of $^{234}$U and$^{238}$U :
- $^{234}$U : 4.77 MeV (72%) and 4.72 MeV (28%)
-
- $^{238}$U : 4.19 MeV

$$\left|\vec{E}\right| = U_0 / d$$

# Signal formation in a planar drift chamber

**Discharging the capacitance decreases its energy:**

$$\tfrac{1}{2}CU_0^2 \to \tfrac{1}{2}CU^2 = \tfrac{1}{2}CU_0^2 - N\int_{x_0}^{x} qE\,dx$$

$$\tfrac{1}{2}CU^2 - \tfrac{1}{2}CU_0^2 = \tfrac{1}{2}C\left(U+U_0\right)\left(U-U_0\right) = -NqE\left(x-x_0\right)$$

$$U \approx U_0;\ U+U_0 \approx 2U_0;\ U-U_0 = \Delta U;$$

$$\tfrac{1}{2}C\cdot 2U_0\cdot\Delta U = -Nq\frac{U_0}{d}\left(x-x_0\right)$$

$$\Delta U = -\frac{N}{C}\frac{q}{d}\left(x-x_0\right);\quad q = +e\ (ions)\quad q = -e\ (electr.)$$

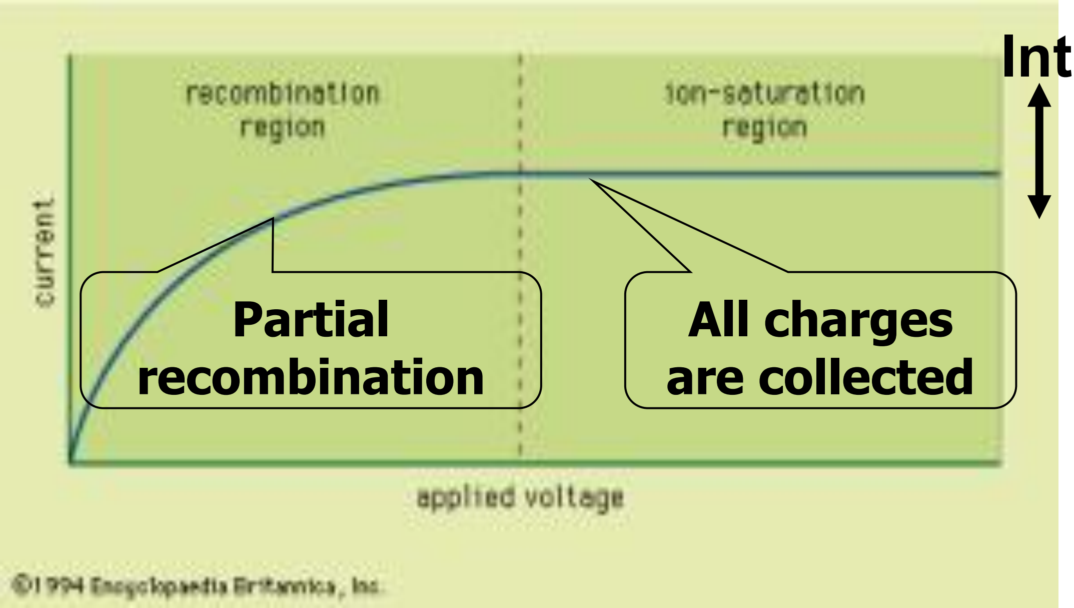
$$\left(x-x_0\right) = v^{\pm}\Delta t^{\pm};\quad v^{+} \ll v^{-}$$

$$\Delta U^{-} \xrightarrow{x\to 0} = -\frac{N}{C}\frac{e}{d}x_0$$

$$\Delta U^{+} \xrightarrow{x\to d} = -\frac{N}{C}\frac{e}{d}\left(d-x_0\right)$$

$$\boxed{\Delta U = \Delta U^{-} + \Delta U^{+} = -\frac{Ne}{C} = \Delta Q / C}$$

$$\boxed{\Delta t^{+} \gg RC \gg \Delta t^{-};\ \ \Delta U = -\frac{Ne}{d}\left(\frac{x_0}{C} - v^{+}R\left(1-e^{-\Delta t^{+}/RC}\right)\right)}$$



©1994 Encyclopaedia Britannica, Inc.

**Partial recombination**

**All charges are collected**

**Intensity/current**

# *Activation measurement*

**Irradiation by a constant flux (gamma or beta)**

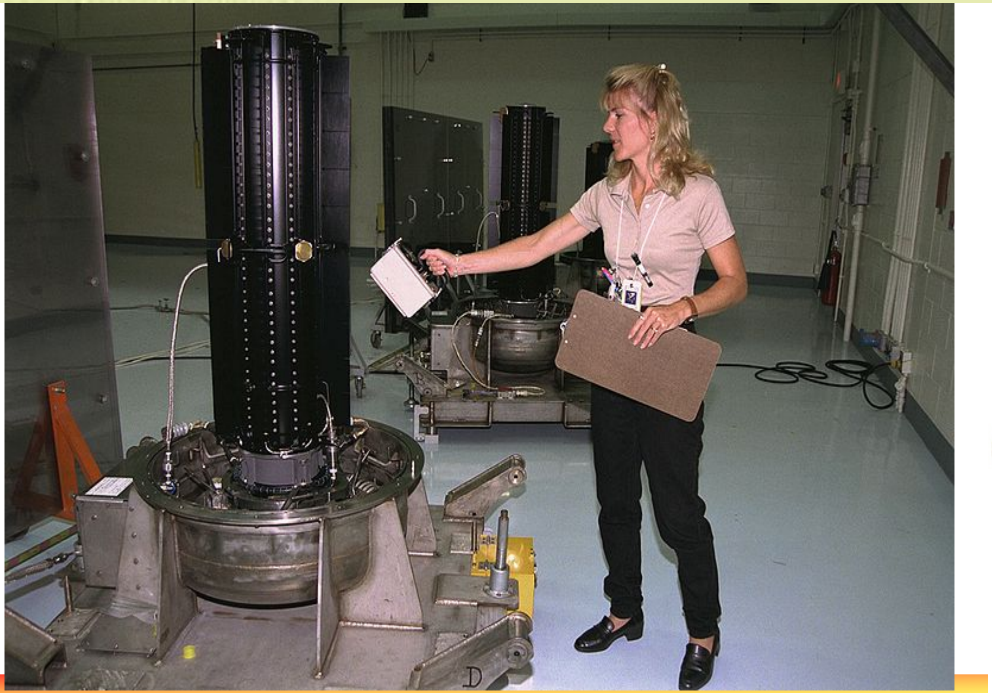
**Ionisation, electric field ⇒ current is proportional to the incoming dose**

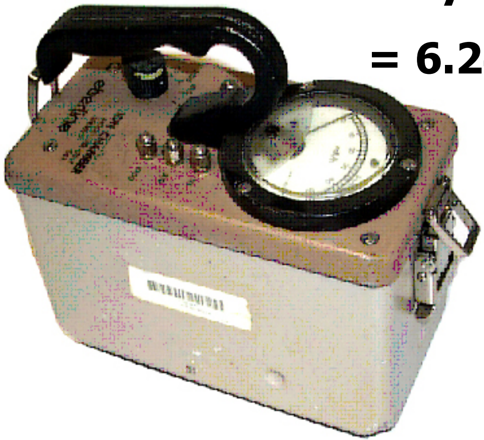
**Dose=energy/mass**

**Units: gray:**

**1 Gy = 1J/Kg**

**= 6.24x$10^{12}$ MeV/Kg**





# Efficiency of a detector

(valid in general!!)

- Absolute or total efficiency

$$\varepsilon_{tot} = \frac{(\text{particles or gammas})\ \text{registered}}{(\text{particles or gammas})\ \text{emmitted}}$$

  - This depends on the geometry between the source and the detector (its distance and opening, its solid angle)

$$\varepsilon_{tot} = \underbrace{\left[1 - \exp\left(\frac{-D}{\lambda}\right)\right]}_{\text{probability of an interaction}} \times \underbrace{\frac{\Delta\Omega}{4\pi}}_{\substack{\text{probability of an emmission}\\ \text{in the solid angle of the detector}}}$$

$$\boxed{\varepsilon_{tot} \cong \varepsilon_{\text{int}} \times \varepsilon_{geom}}$$

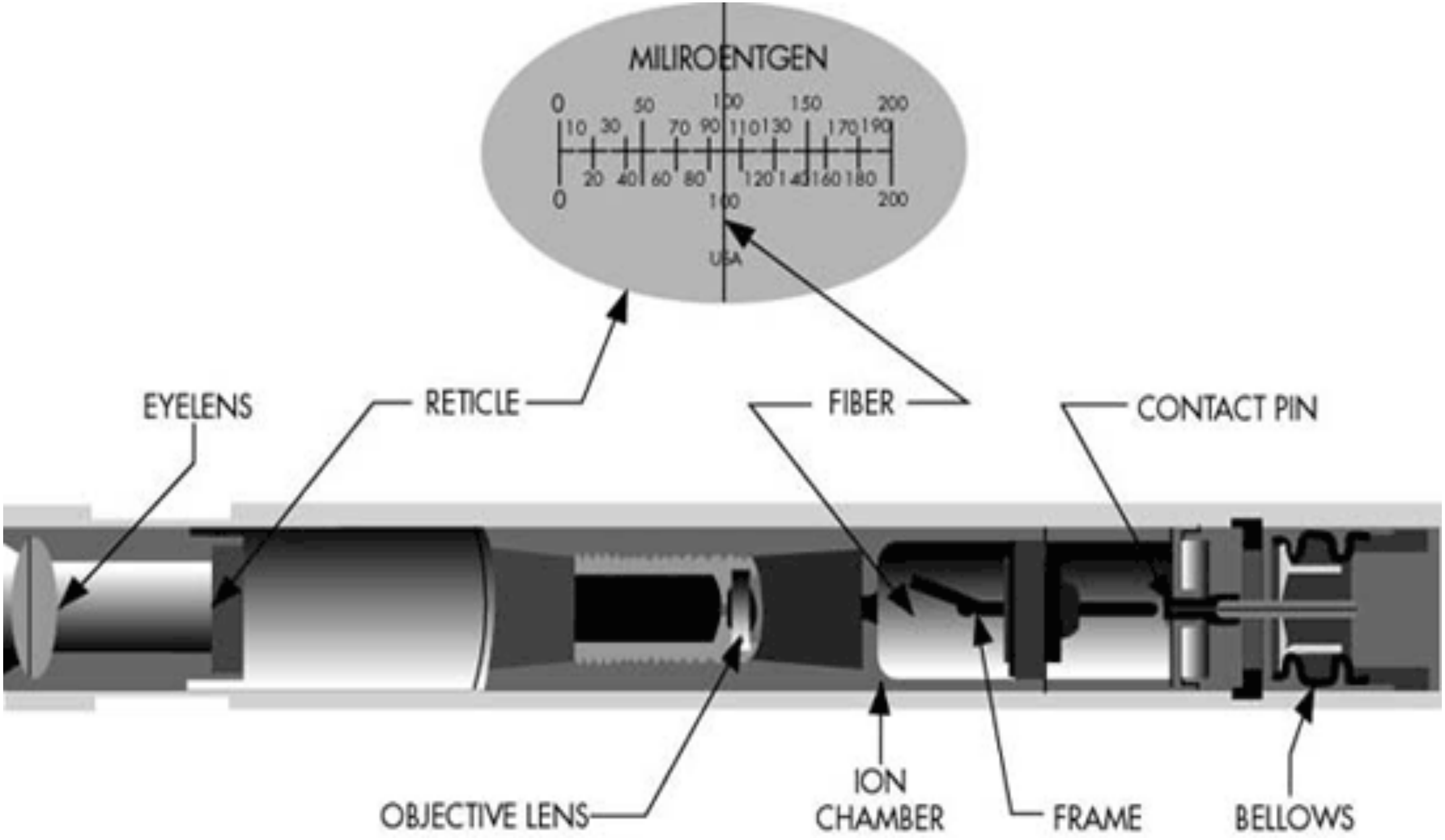
$$\lambda = \text{attenuation length;} \left\{\frac{1}{\lambda} = \sigma \cdot n_b\right\};\ D = \text{Depth of the detector}$$

- Intrinsic efficiency

$$\varepsilon_{\text{int}} = \frac{(\text{particles or gammas})\ \text{"registered"}}{(\text{particles or gammas})\ \text{in the acceptance of the detector}}$$

# Dosimeter

# Dosimètre


MILIROENTGEN
0
50
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10
30
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90
110
130
170
190
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40
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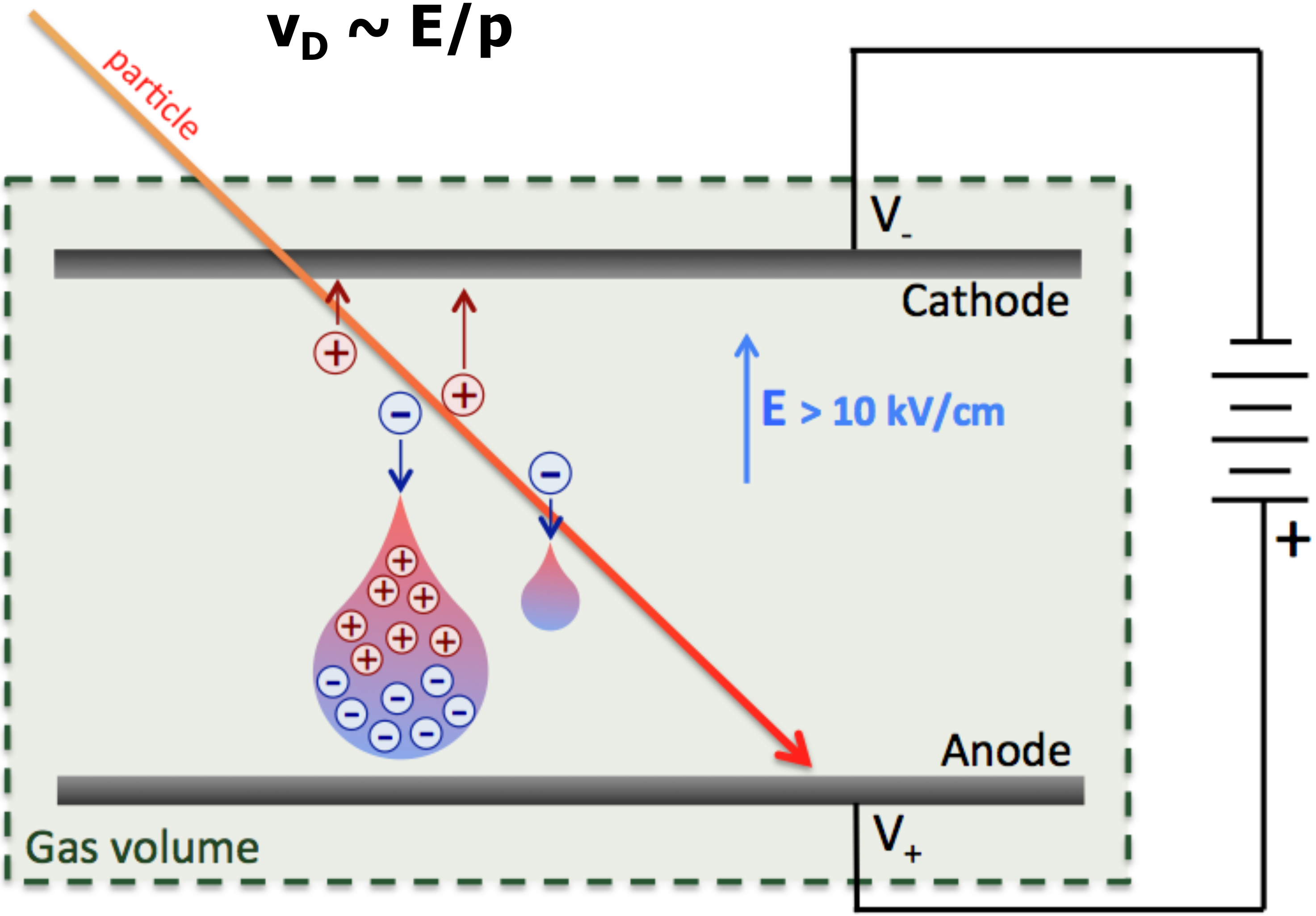
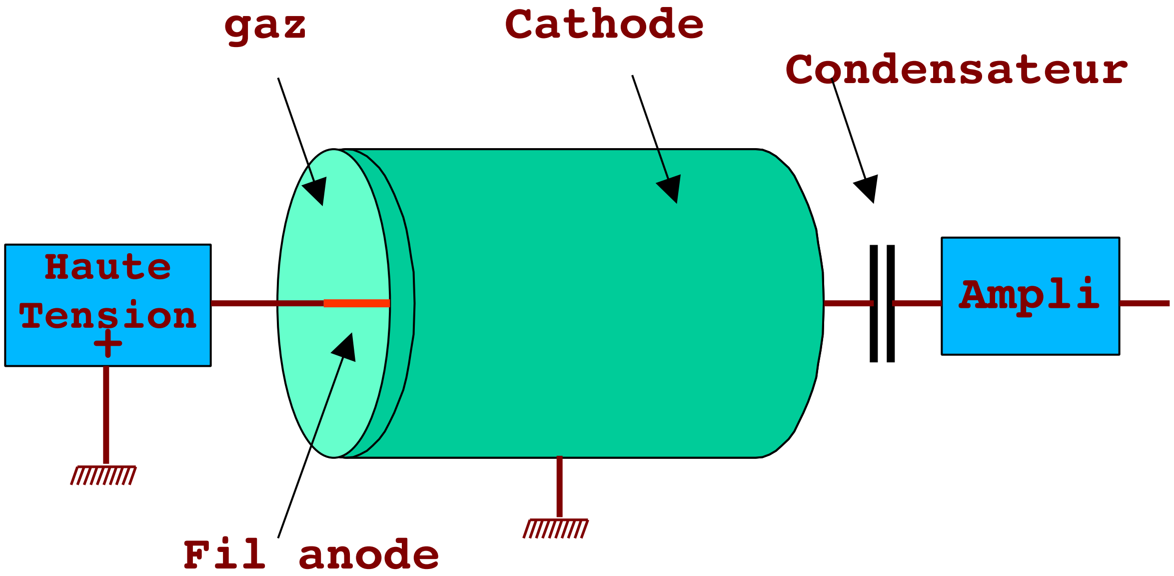
80
120
140
160
180
0
100
200
USA
EYELENS
RETICLE
FIBER
CONTACT PIN
OBJECTIVE LENS
ION CHAMBER
FRAME
BELLOWS

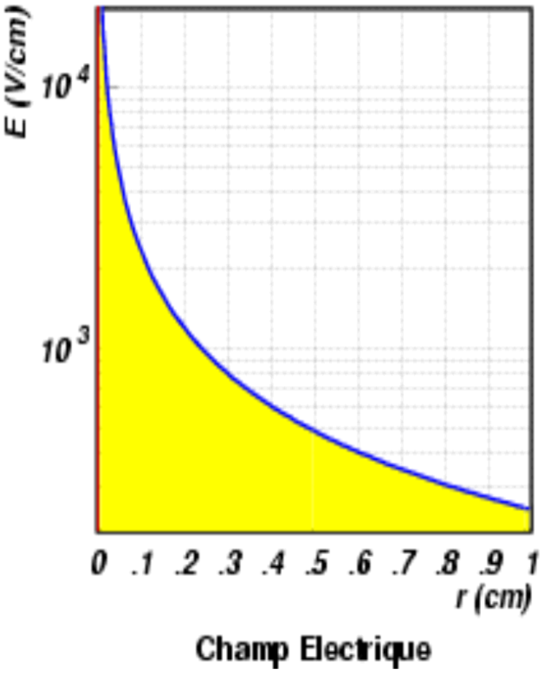
# Proportional Counters

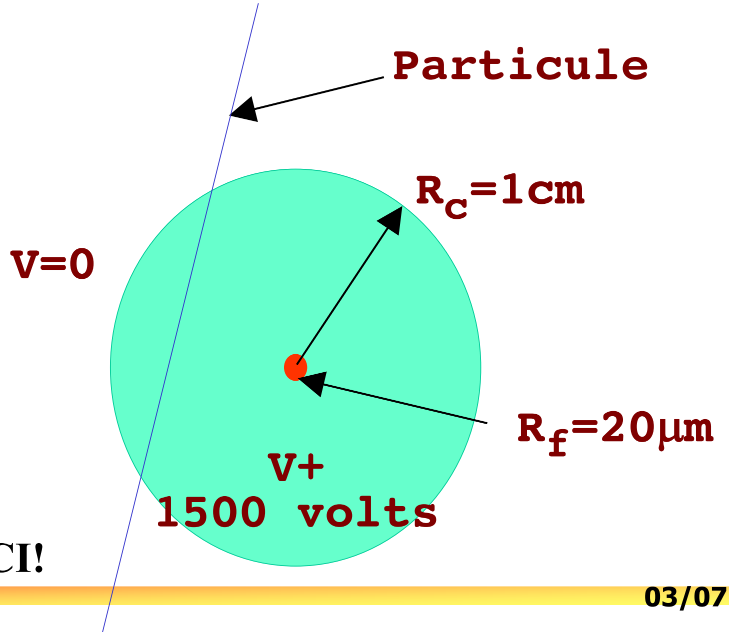
$v_D \sim E/p$



# Proportional Counters





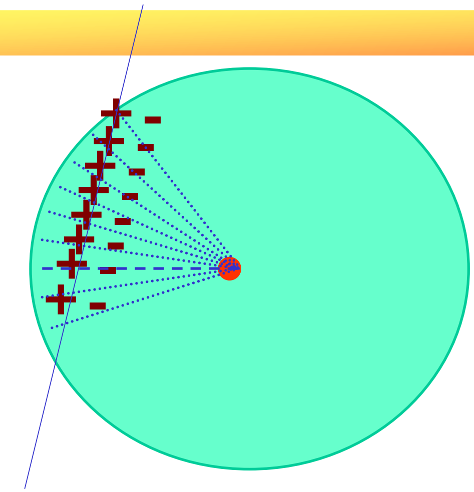


Après B.Jean-Marie, Roscoff 2000, école IN2P3, MERCI!

## *T=0*

**Passage of a charged particle**

**Creation of paires ion-electron.**

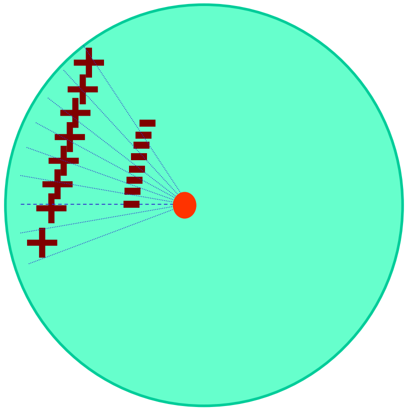


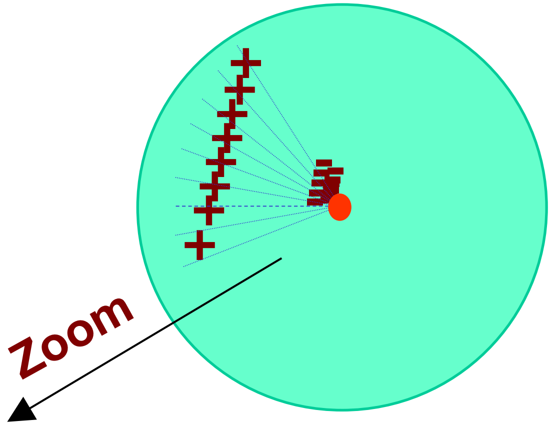
## *T~100ns*

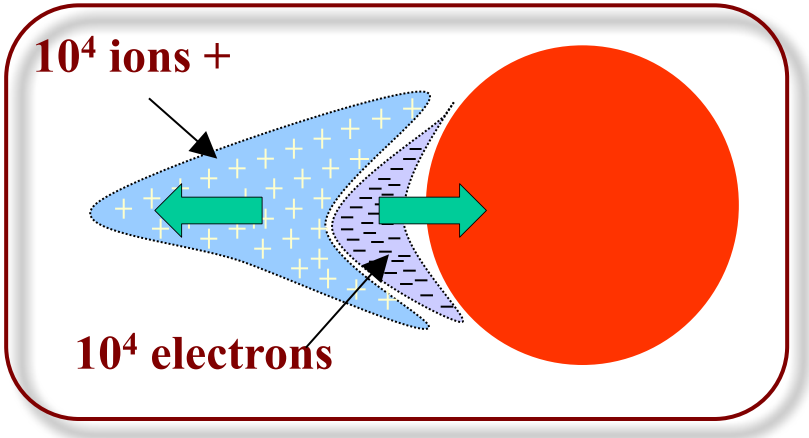
**The primary electrons have sufficient energy to ionize the gas. This multiplication happens close to the wire, where the field is very high and stops when all electrons have reached the wire**

## *T de 0 à 100ns*

**Ions and electrons are separated by the electric field.**

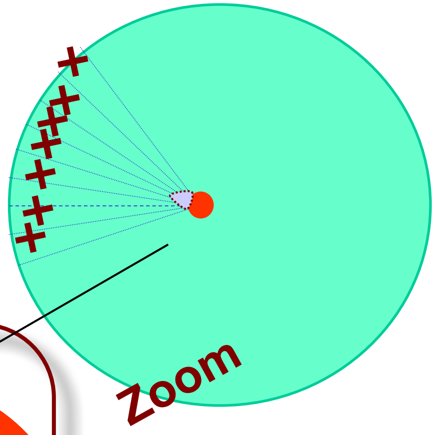


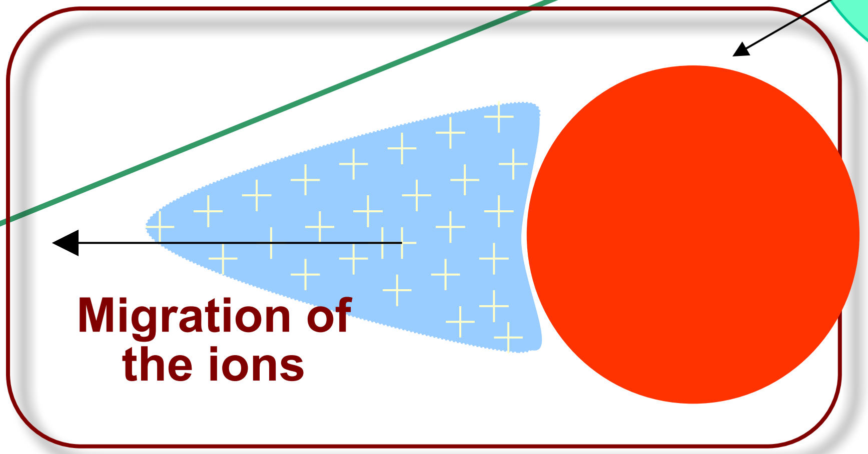


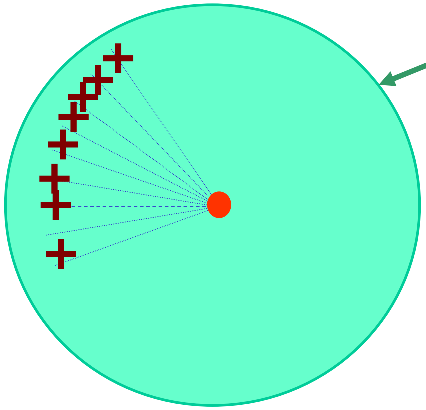


# *T~150ns*

**The electrons have been collected by the wire, all ions (primary and secondary) migrate slowly to the cathode. An electric signal is produced by this mouvement of the charges**







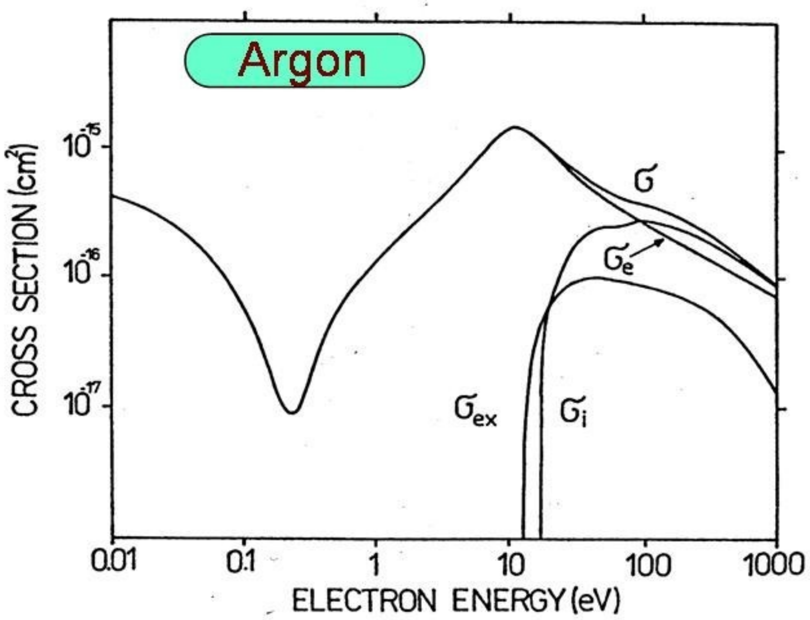
# *T some ms*

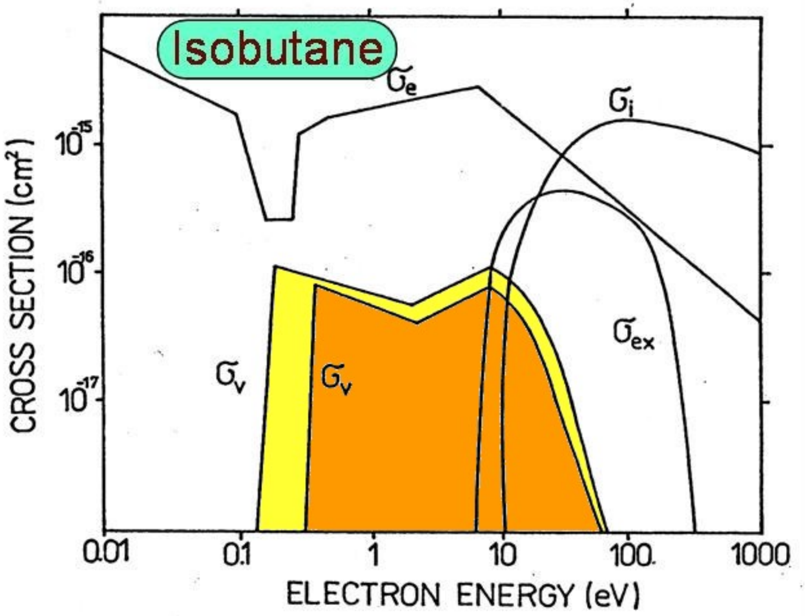
**The secondary ions from the avalanche have reached the cathode, the counter is ready for the next particle .**

## The essential points:

- ⇒ **Very high field close to the anode wire**
- ⇒ **Creation of an avalanche around the anode**
- ⇒ **Slow motion of the ions**
- ⇒ **The gas is at the same time the detecting and amplifying material**

# *The role of the gas*





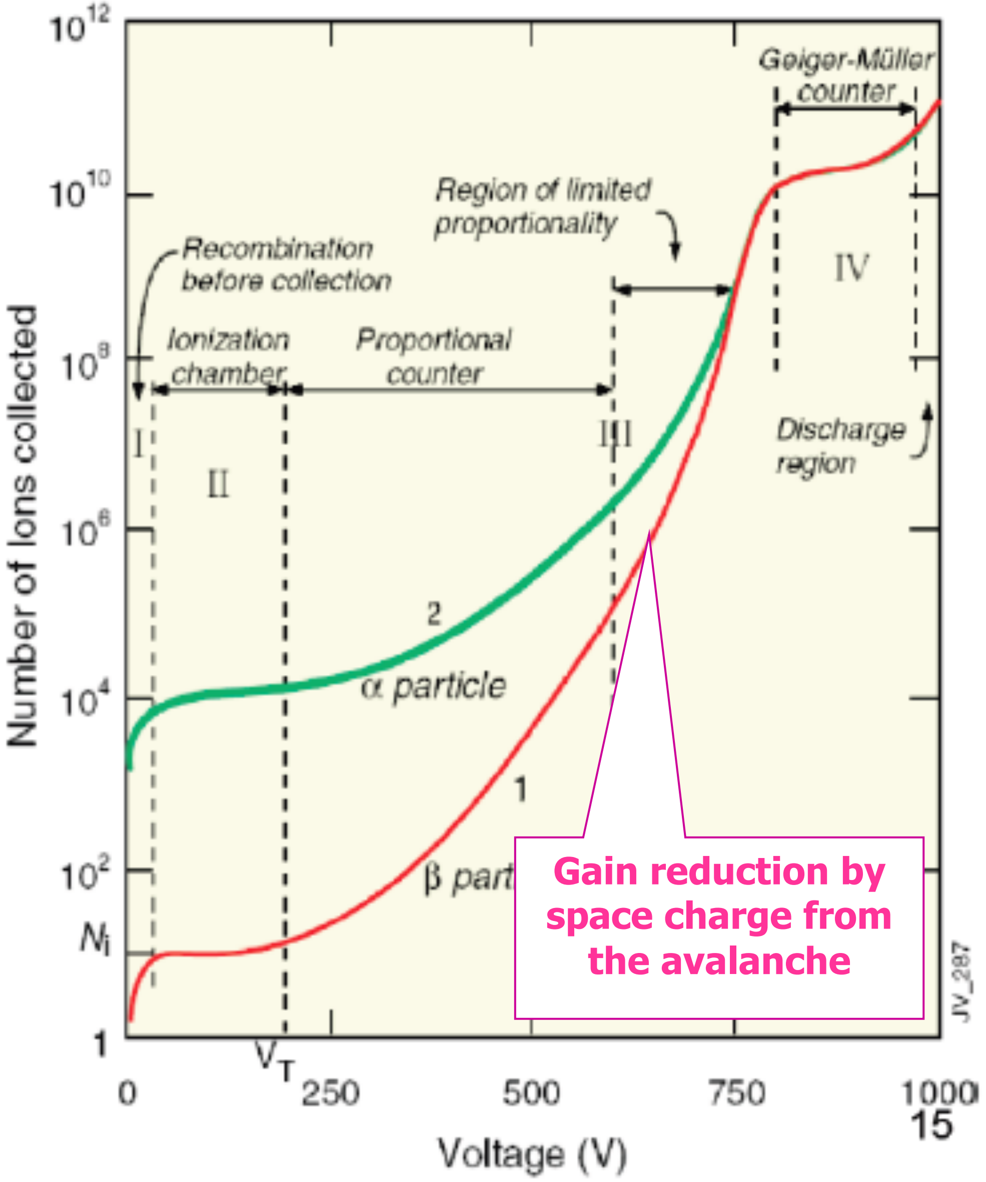
**In practice one uses a mixture of gases, a noble gas and a molecular gas:**

**Noble gas: Ar, He, neon, xenon, krypton to favour ionisation.**

**High excitation energies, the photons from the de-excitation can generate new electrons by photoelectric effect on the cathode, which will provoke a second avalanche and so on. The detector is not stable**

**A molecular gas: $CO_2$, $CH_4$, $C_2H_6$, $C_4H_{10}$, have a lot of vibrational and rotational degrees of freedom. These exitations can absorbe some of these photons.**

# Simplified scheme of different regimes of gas counters



Gain reduction by space charge from the avalanche

I. ionization mode: full charge collection, but no multiplication;

II. proportional mode: multiplication of ionization; detected signal proportional to original ionization → possible energy measurement (dE/dx); secondary avalanches are quenched; gain ~ $10^4 – 10^5$

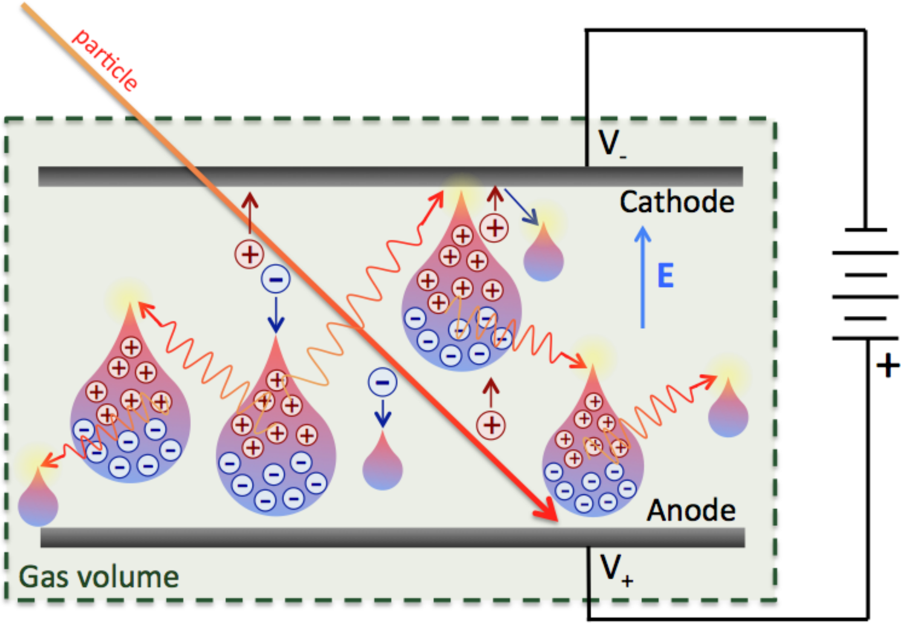
III. limited proportional mode (saturated, streamer) strong photoemission; secondary avalanches merging with original avalanche; requires strong quenchers or pulsed HV; large signals → simple electronics; gain ~ $10^{10}$

IV. Geiger mode – massive photoemission; full length of the anode wire affected; discharge stopped by HV cut; strong quenchers needed as well

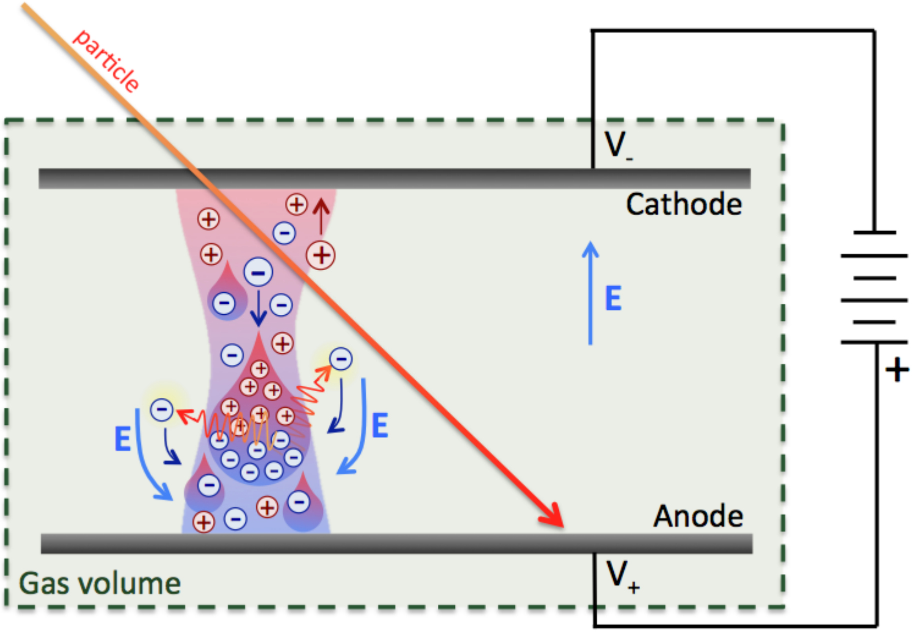
CERN Academic Training Programme 2004/2005

# *Geiger-Müller and Streamer modes*

Schematic representation of Geiger-Muller counters.

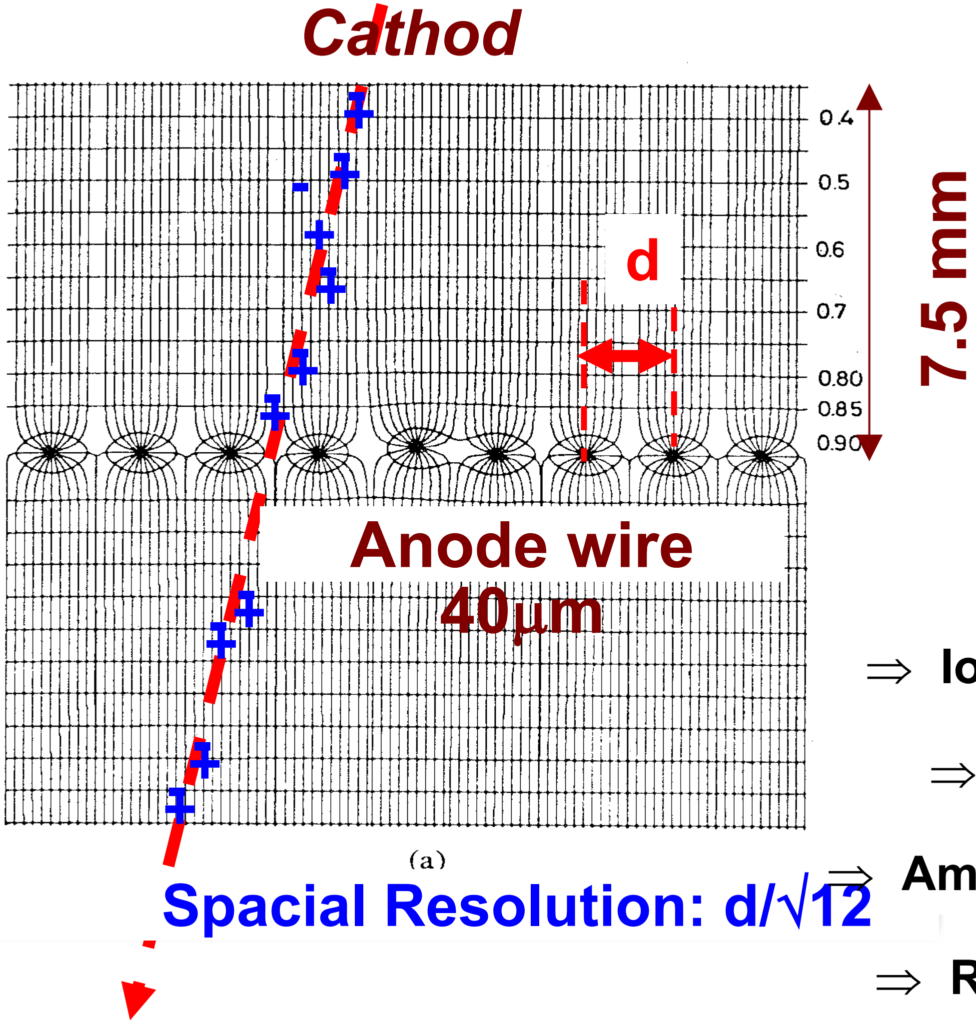


Schematic representation of a Streamer in parallel plate detectors



# *Multi Wire Proportional Chamber (MWPC)*

Proposed by G. Charpak in 1967



**Spacial Resolution: d/√12**

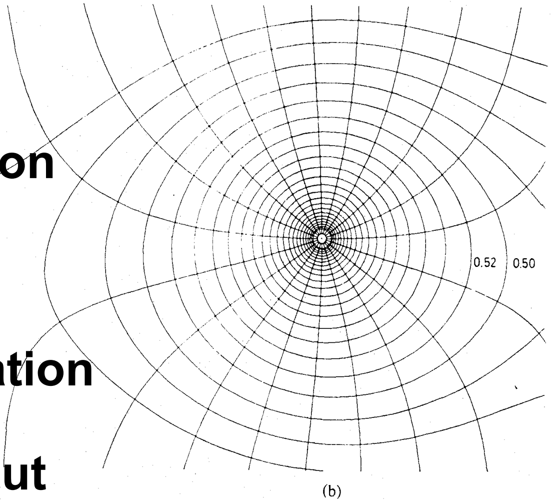
- ***Wire:*** *tungsten 30-50µm,*
- ***Surface :*** *10x10cm² → 4×4m²,*
- ***t=*** *100ns*
- ***Counting:*** *10⁵/fil,* ***signal:*** *qq mV,*
- ***gas:*** *argon+n-pentane.*
- ***Each wire is connected to an amplifier***

⇒ **Ionisation**

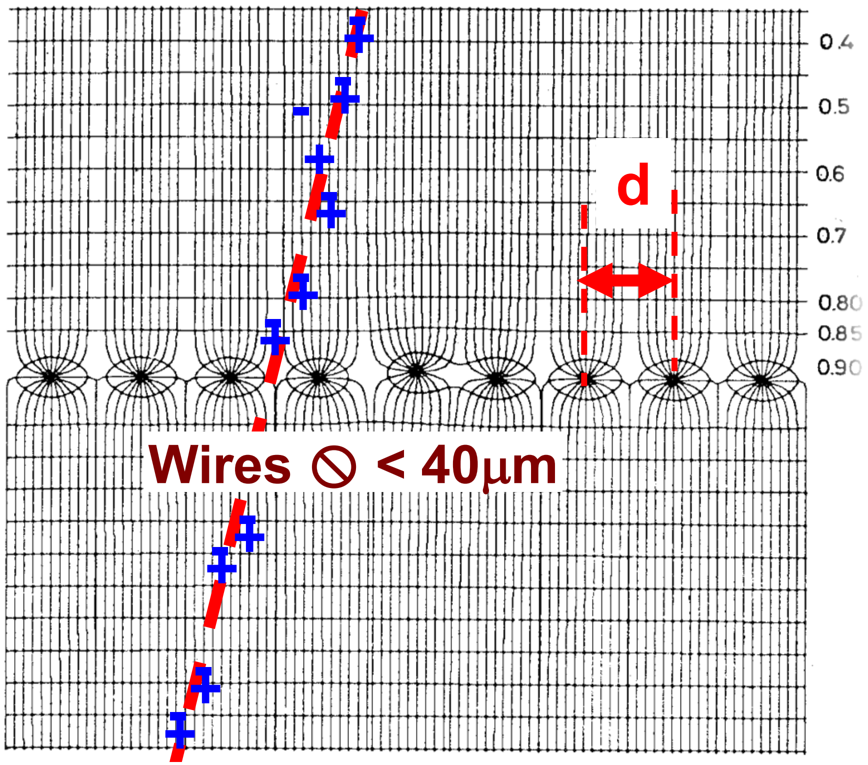
⇒ **Drift**

⇒ **Amplification**

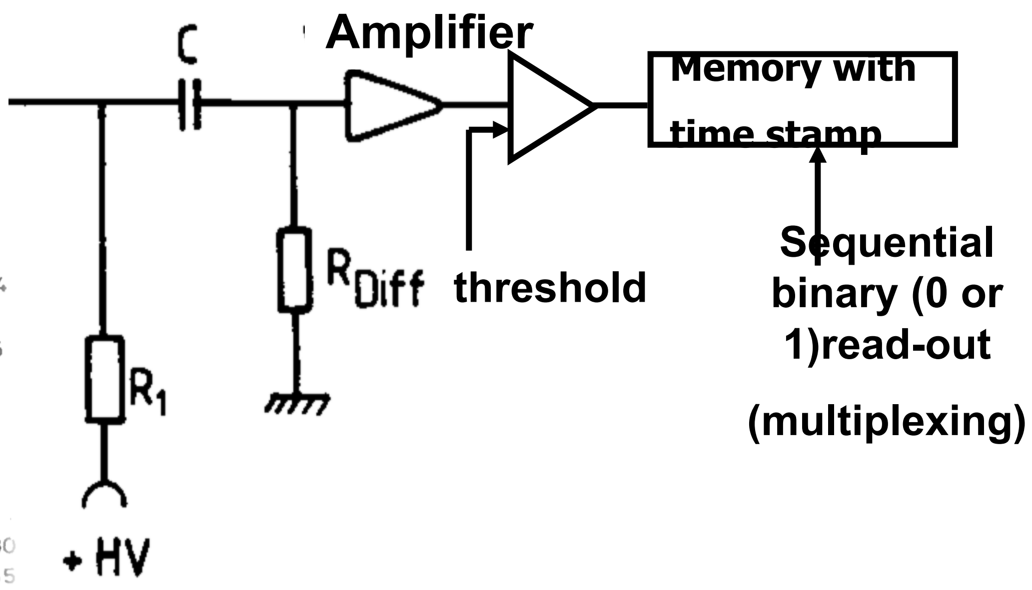
⇒ **Read-out**



# MWPC



**Wires ⌀ < 40μm**



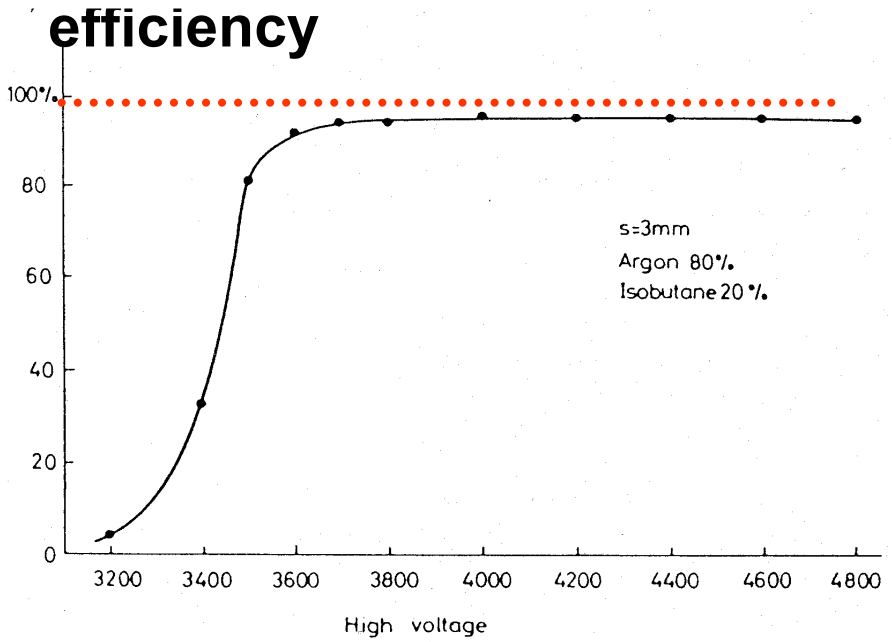
**Amplifier**

**Memory with time stamp**

**threshold**

**Sequential binary (0 or 1)read-out**

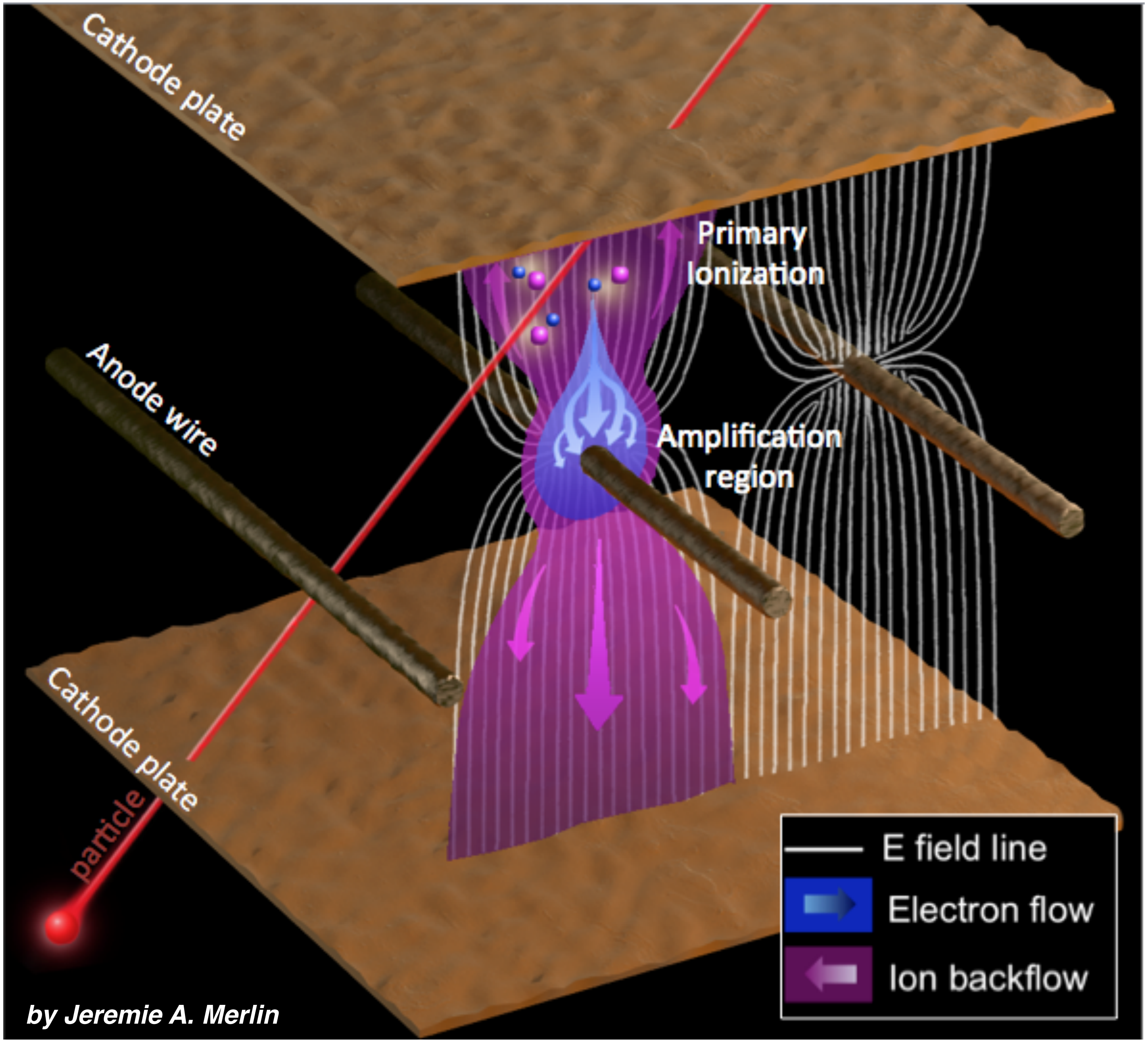
**(multiplexing)**



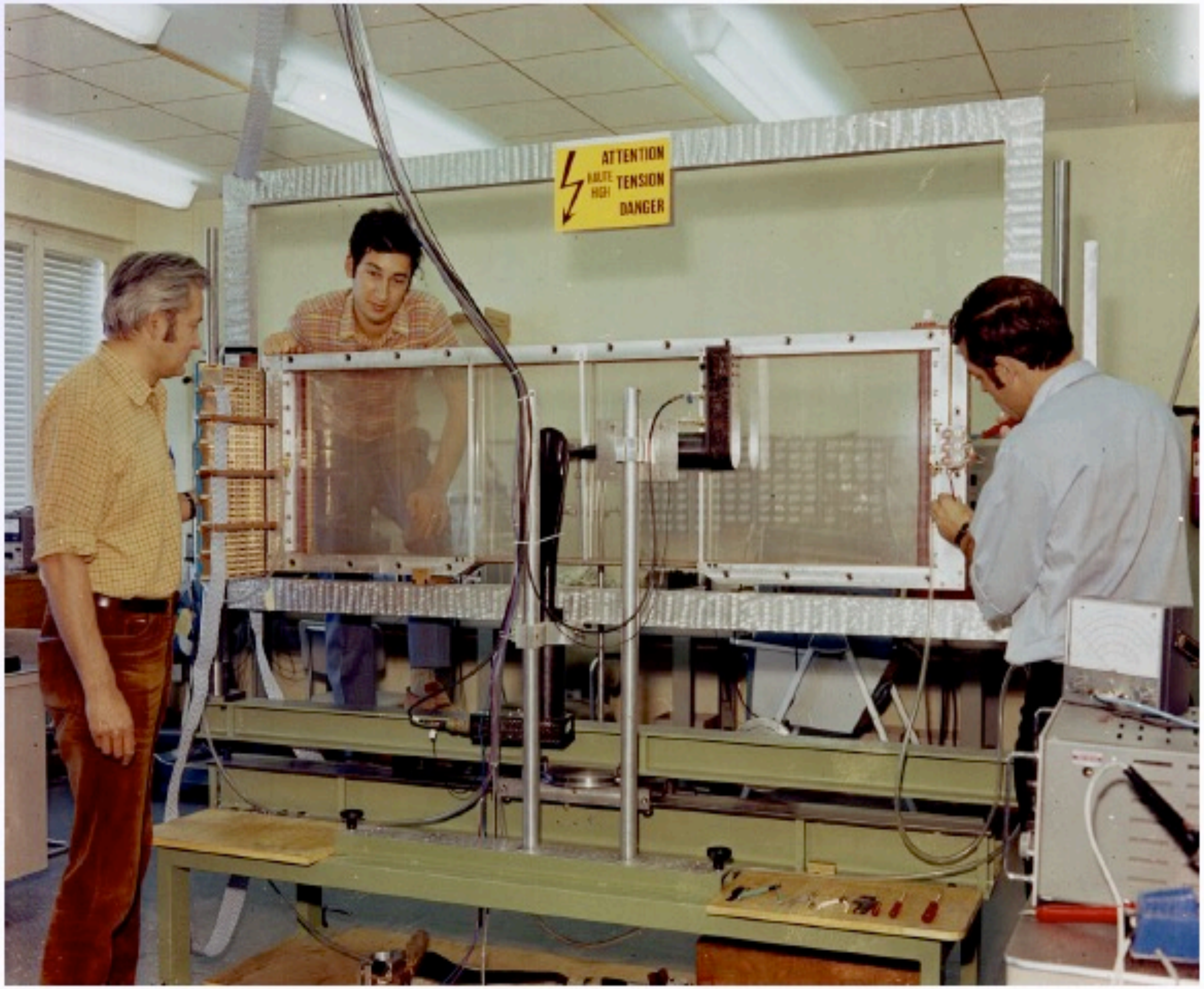
**Binary read-out :**

**Resolution:**

***$d/\sqrt{12}$; $d=2$mm → $\sigma \approx 0{,}6$ mm***



by Jeremie A. Merlin

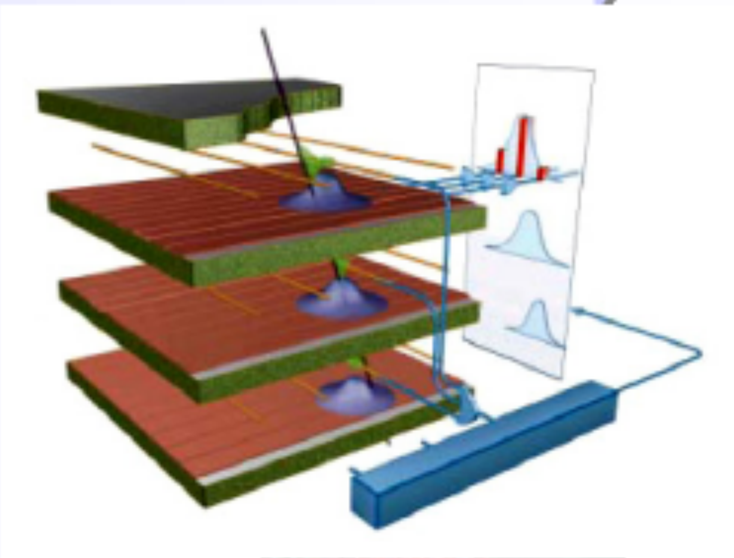


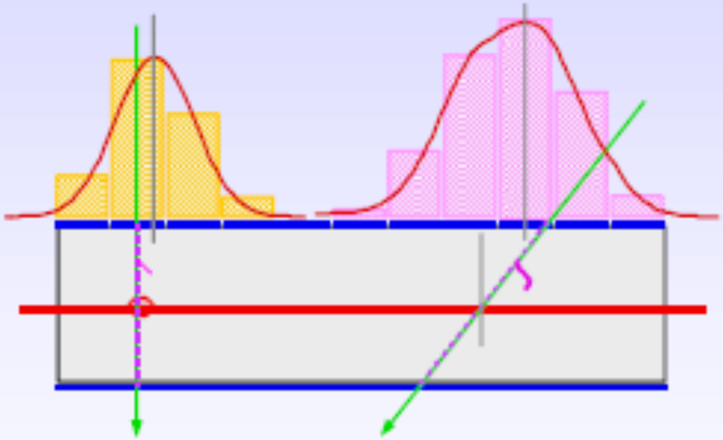
G. Charpak, F. Sauli and J.C. Santiard

1970

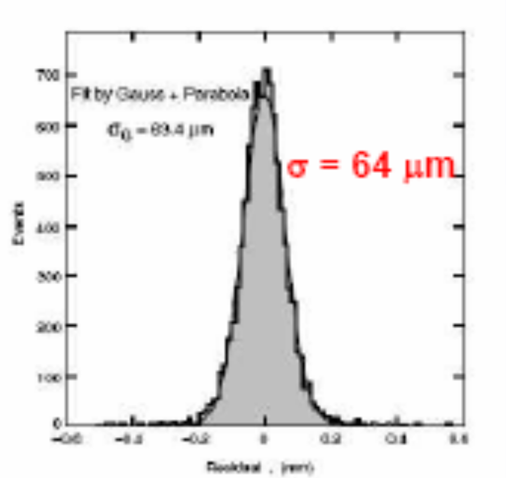
# CSC – Cathode Strip Chamber

Precise measurement of the second coordinate by interpolation of the signal induced on pads.
Closely spaced wires makes CSC fast detector.

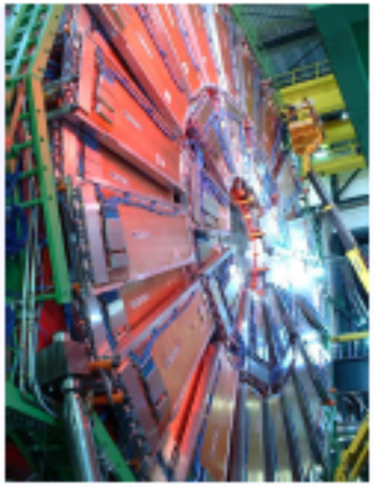




Center of gravity of induced signal method.

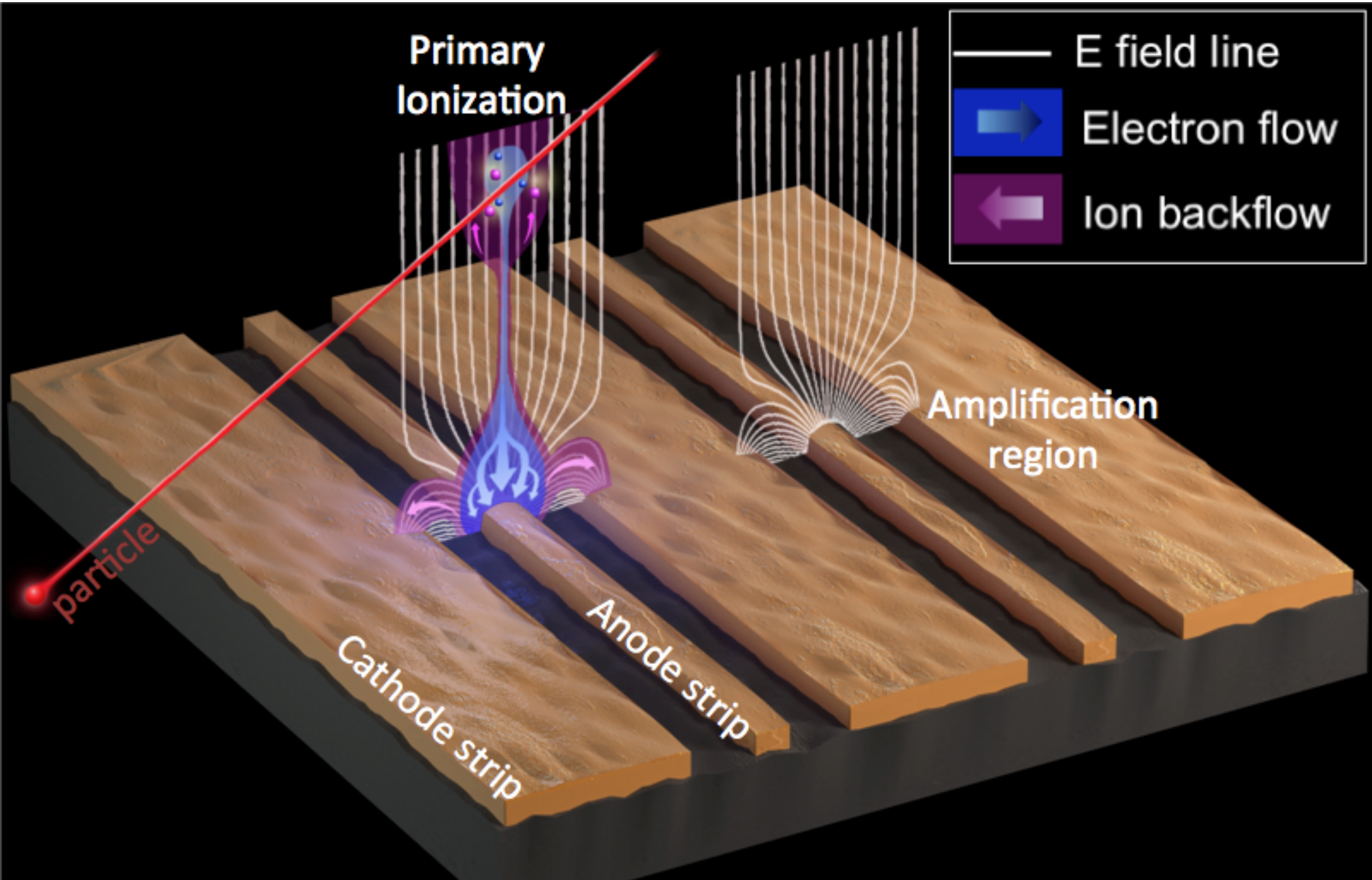


Space resolution



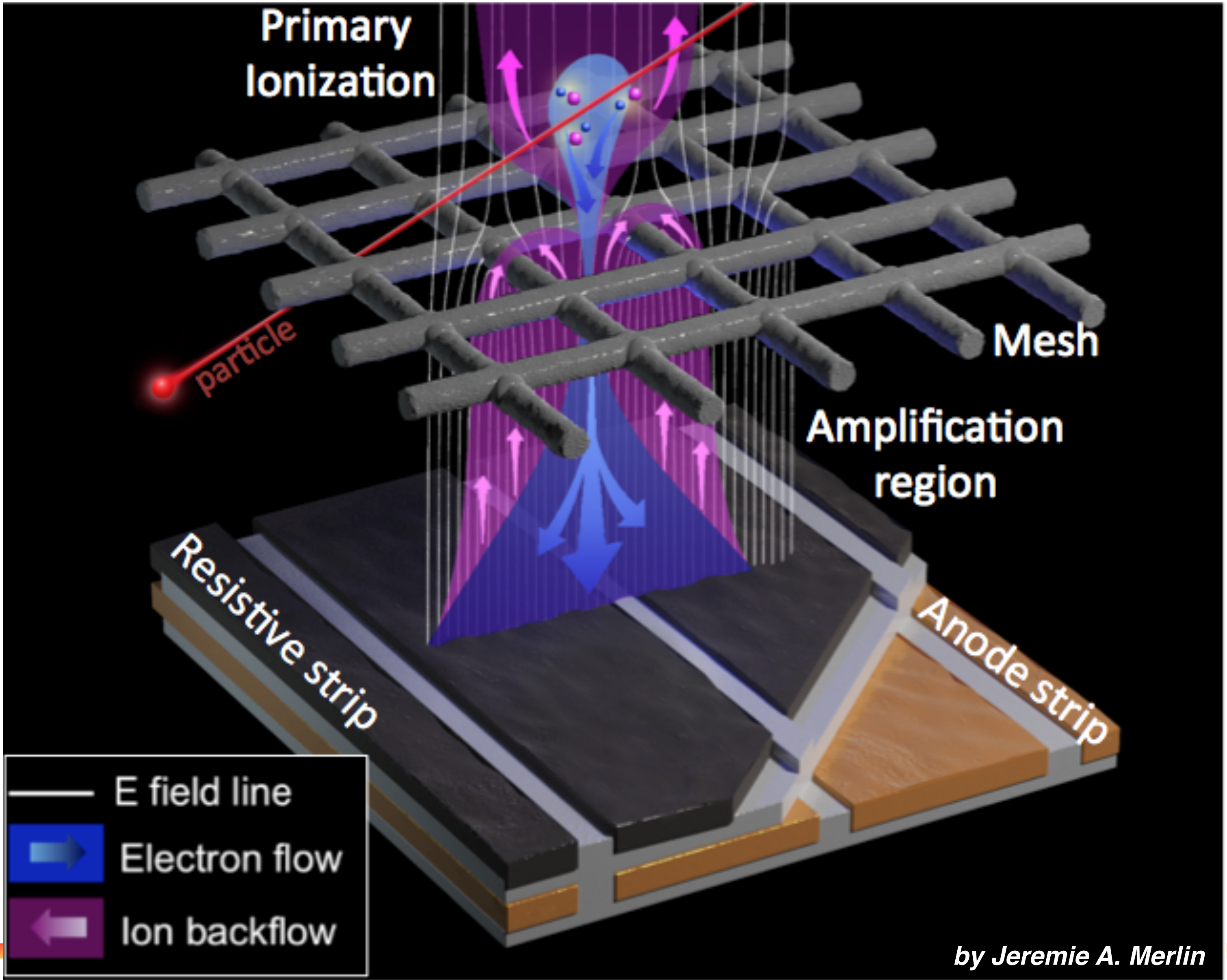
CMS

# Micro-Strip-Gas-Chambers

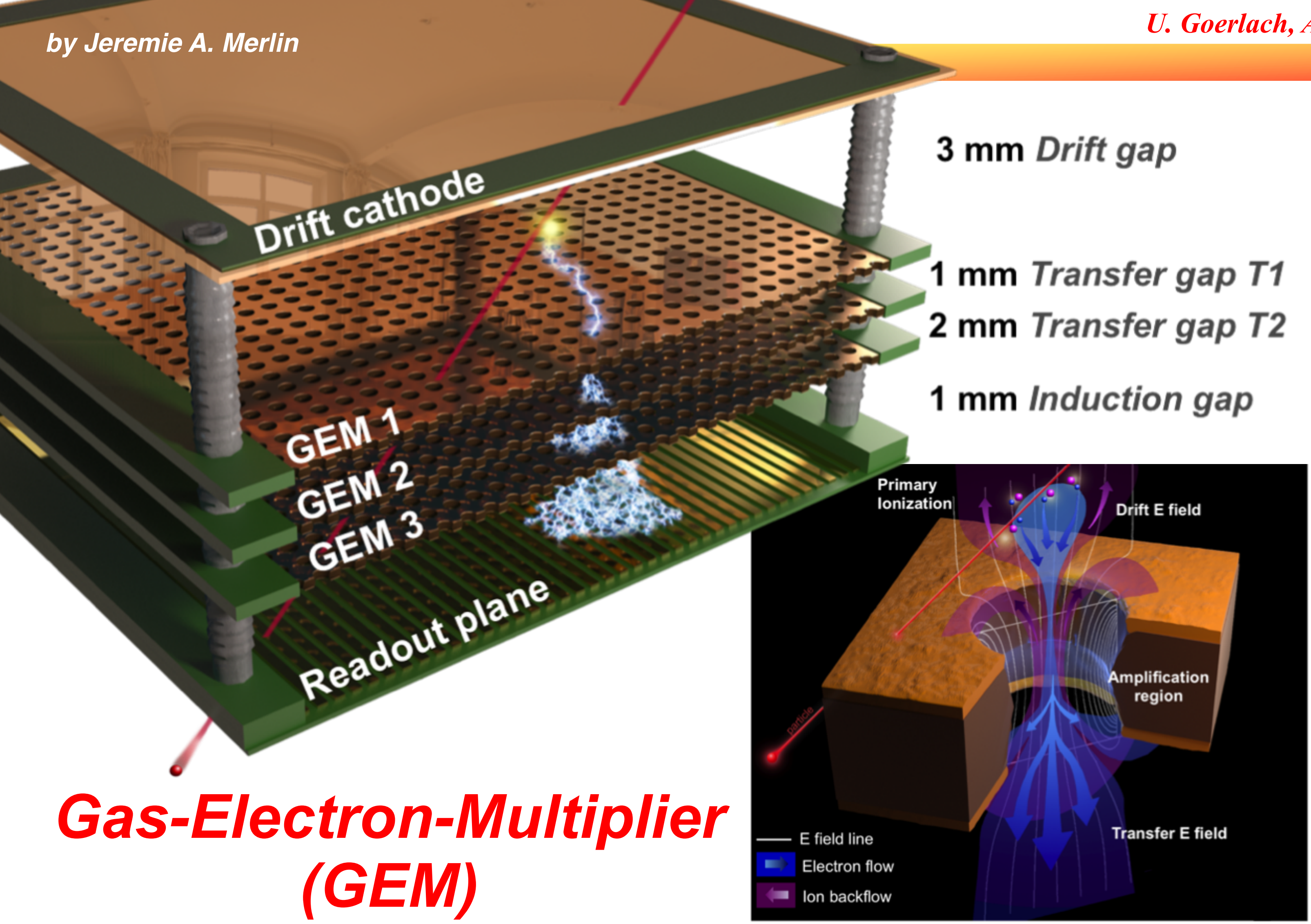


*by Jeremie A. Merlin*

# Micro MEshGAs Structure (Micromegas)



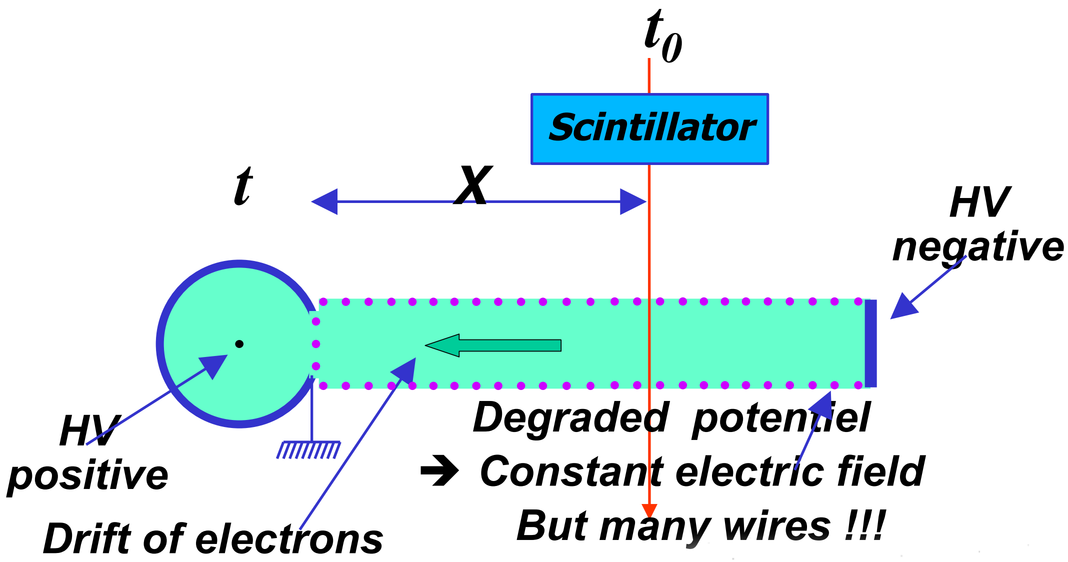
by Jeremie A. Merlin



# Gas-Electron-Multiplier (GEM)

# Proportional detectors

# *Classical Drift Chambers*



***Degraded potentiel***

***➔ Constant electric field***

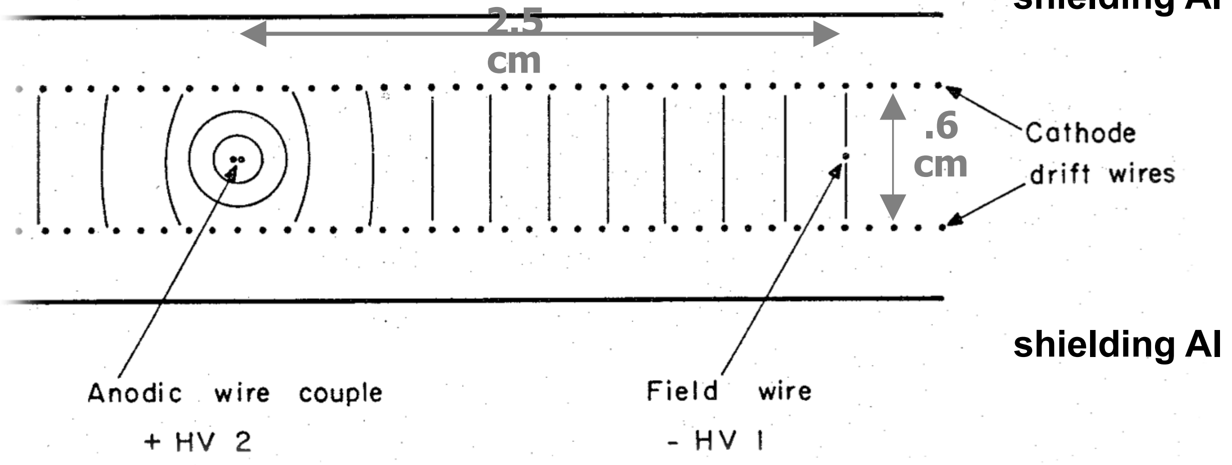
***But many wires !!!***

***Drift velocity of electrons:***

***50 µm/ns***

***If the drift time is measured one can calculate the drift distance***

***Spacial resolution 100-200 µm***

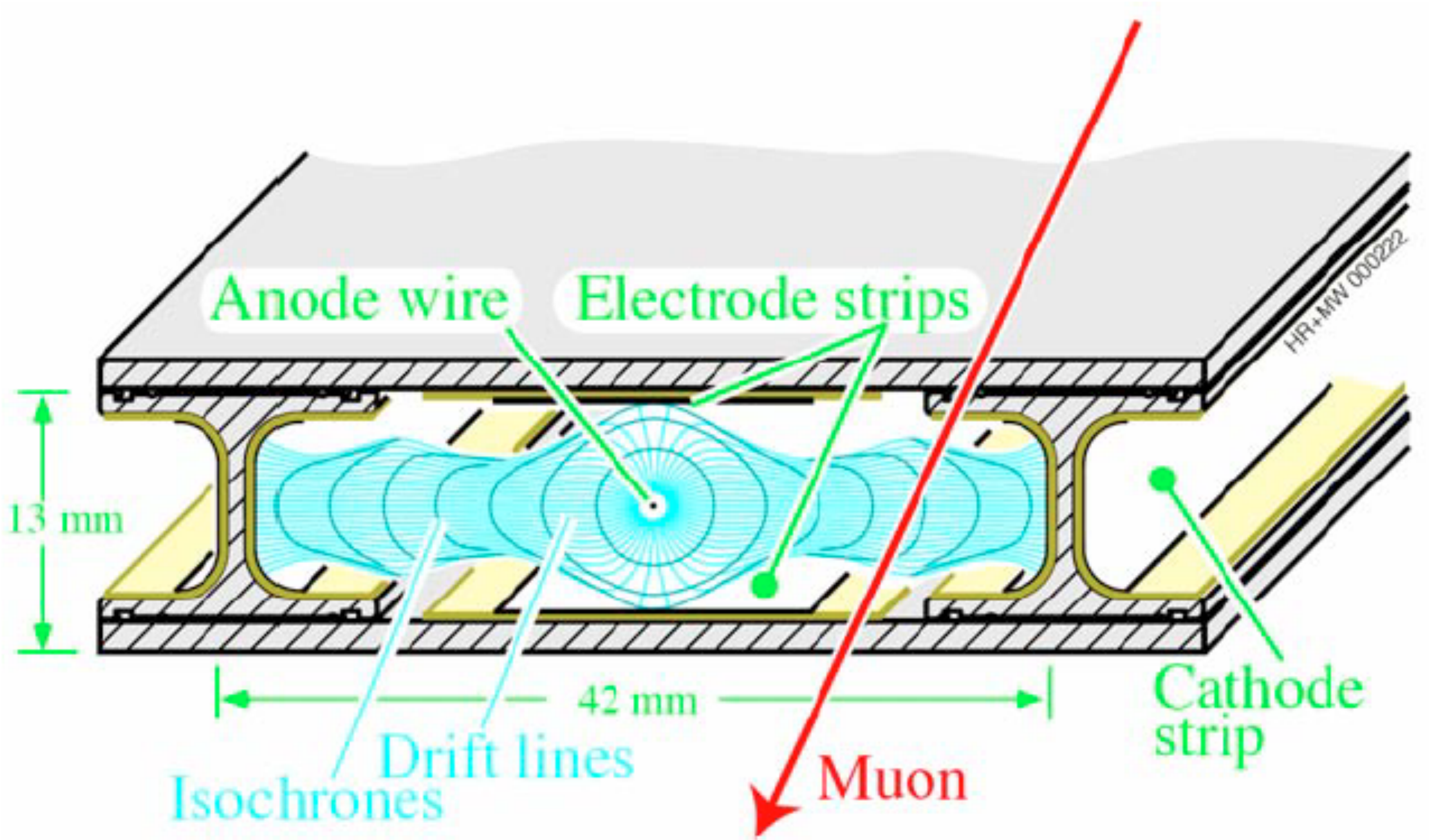


A. Breskin et al Nucl. Instr. Meth.A124 (1975) 189

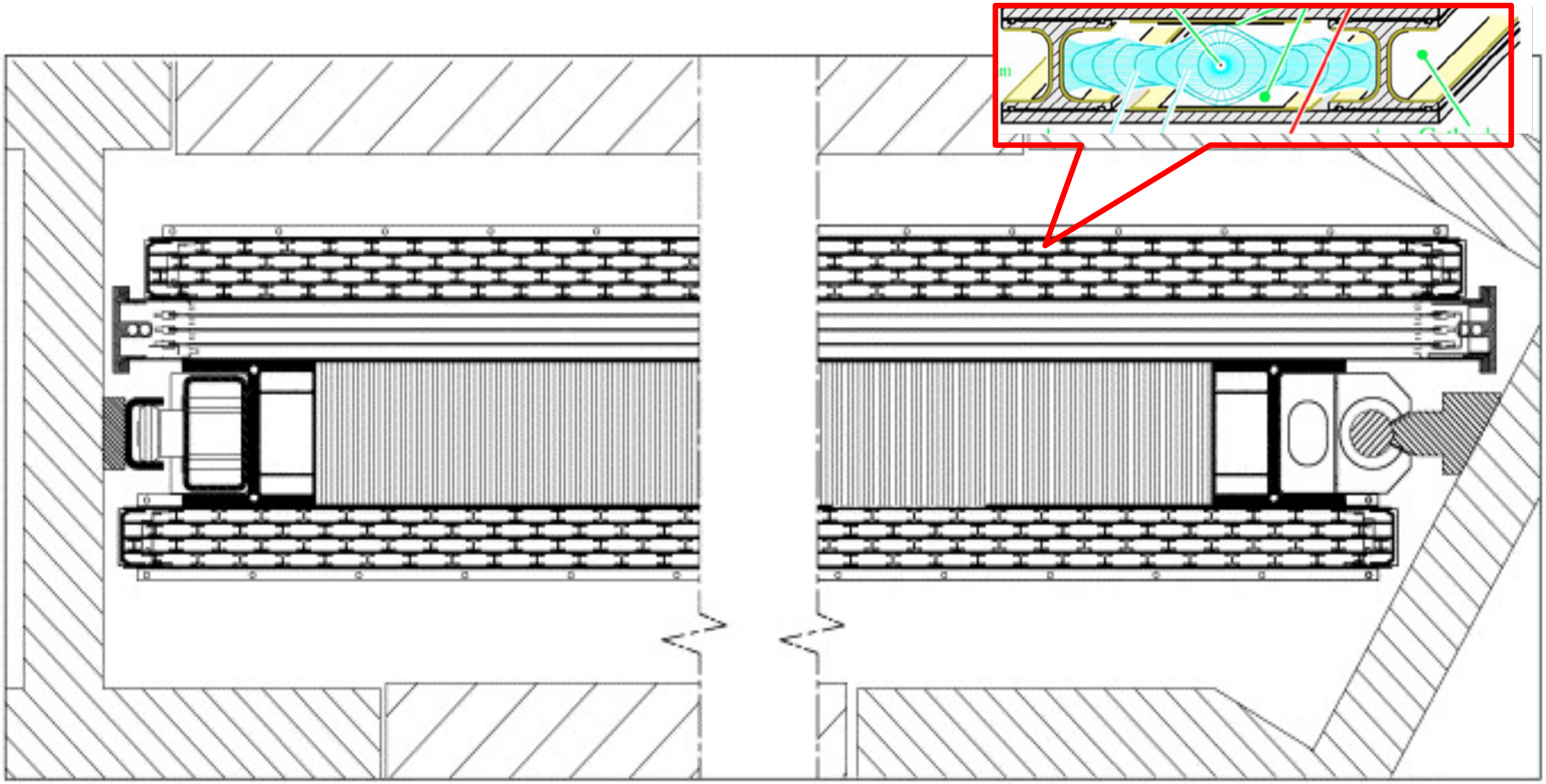
Chambre_a_derive_2.pct

B. Jean-Marie NIM A159 (1979) 213

Vitesse_argon_ethane.pct

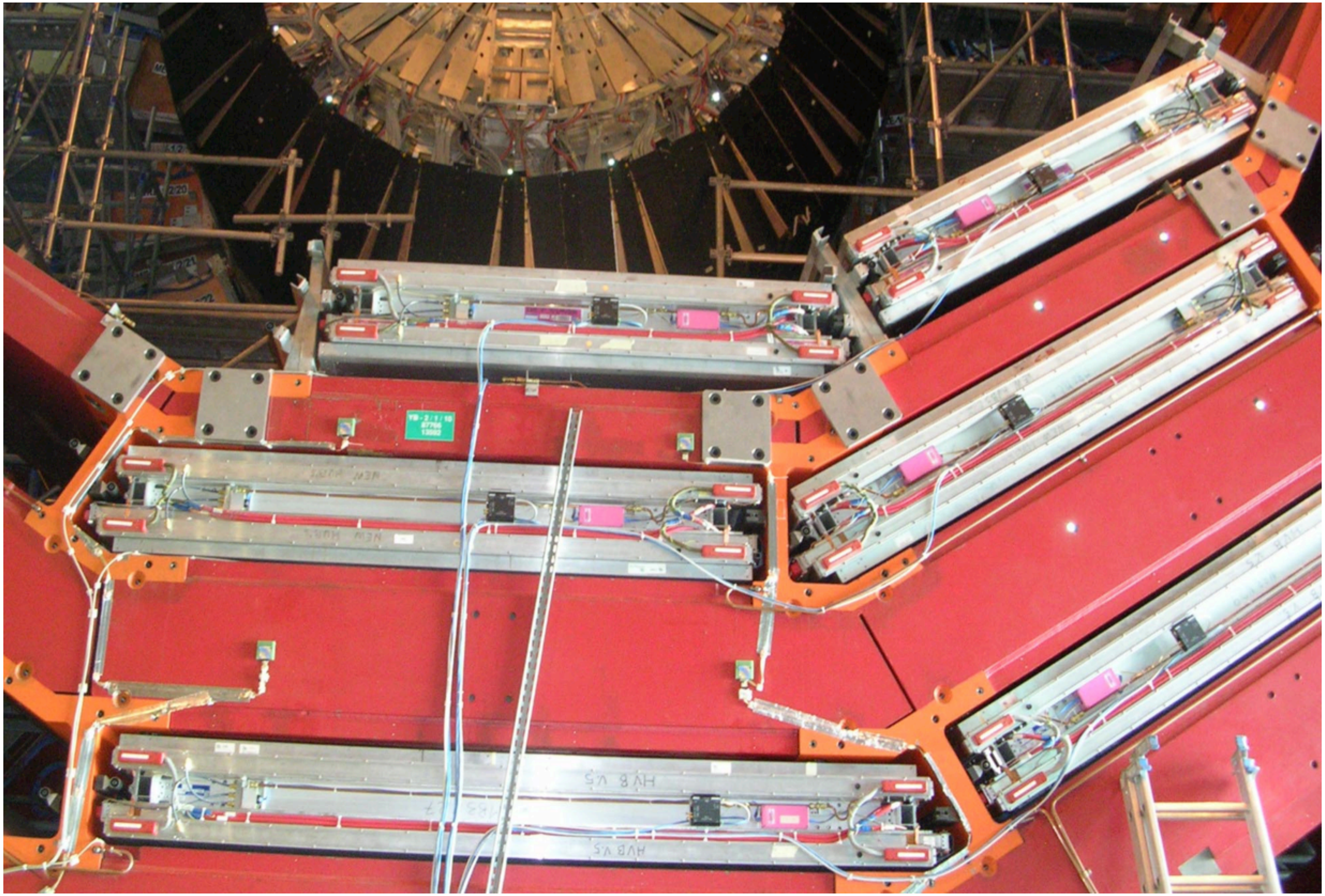

Anode wire
Electrode strips
13 mm
42 mm
Cathode strip
Drift lines
Isochrones
Muon
HR+MW 000222

# CMS Muon chambers



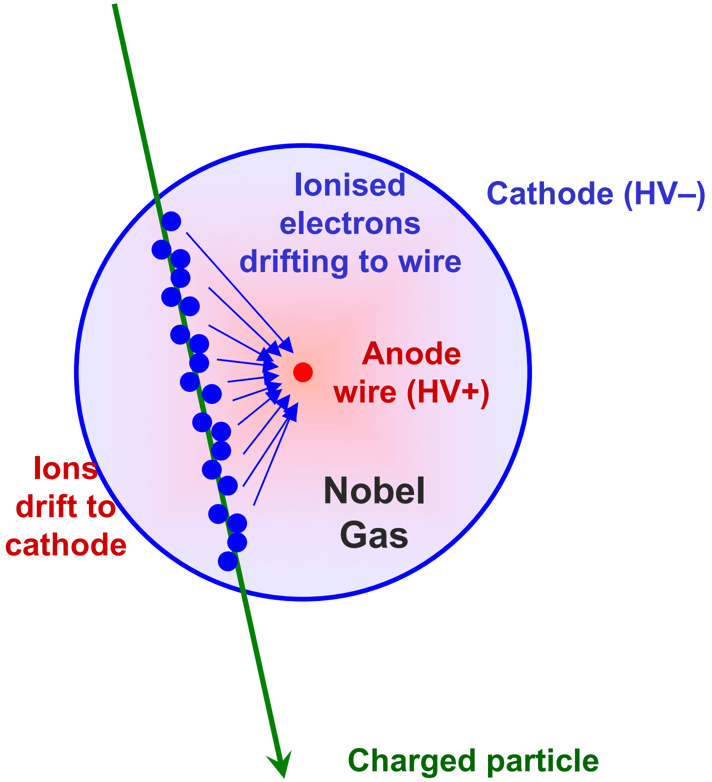
Cut view of a drift tube chamber in its final position inside the CMS iron yoke. Two superlayers with wires along the beam direction and a third crossed one can be seen as well as the honeycomb panel providing rigidity to the chamber.

# CMS Muon chambers



# Drift Tubes (DT) in ATLAS: inner detector and muon spectrometer

- **Classical detection technique for charged particles based on gas ionisation and drift time measurement**



- **DTs used in muon systems and ATLAS TRT**
- **Primary electrons drift towards thin anode wire**
- **Charge amplification during drift ($\gtrsim 10^4$) in high *E* field in vicinity of wire: $E(r) \propto U_0 / r$**
- **Signal rises with number of primary *e*'s (*dE*/*dx*) [signal dominated by ions → need differentiator]**
- **Macroscopic drift time: $v_D / c \sim 10^{-4}$ → ~30 ns / mm**
- **Determine $v_D$ from difference between DT signal peaking time and expected particle passage**

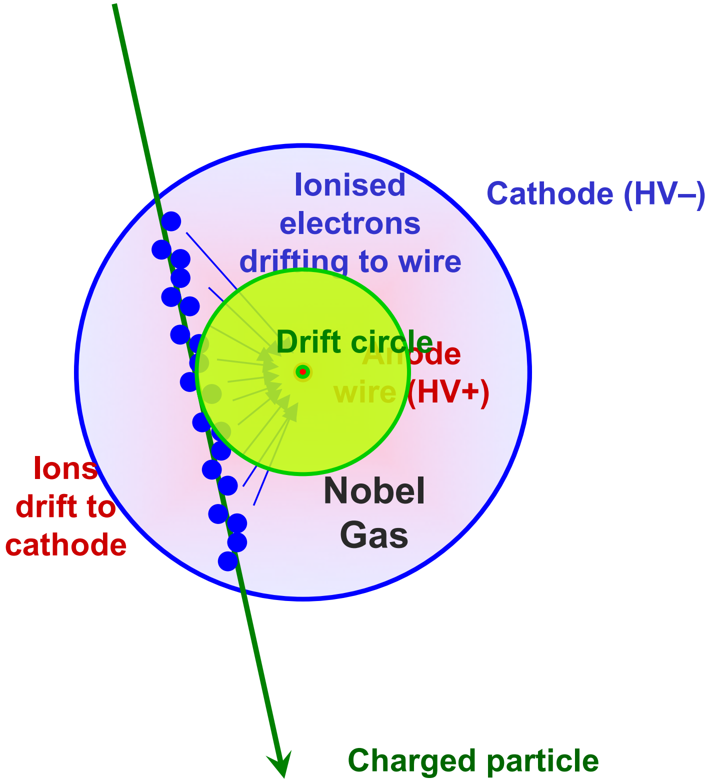
➡ **Spatial resolution of *O*(100 μm)**

**TRT: Kapton tubes, ∅ = 4 mm**
**MDT: Aluminium tubes, ∅ = 30 mm**

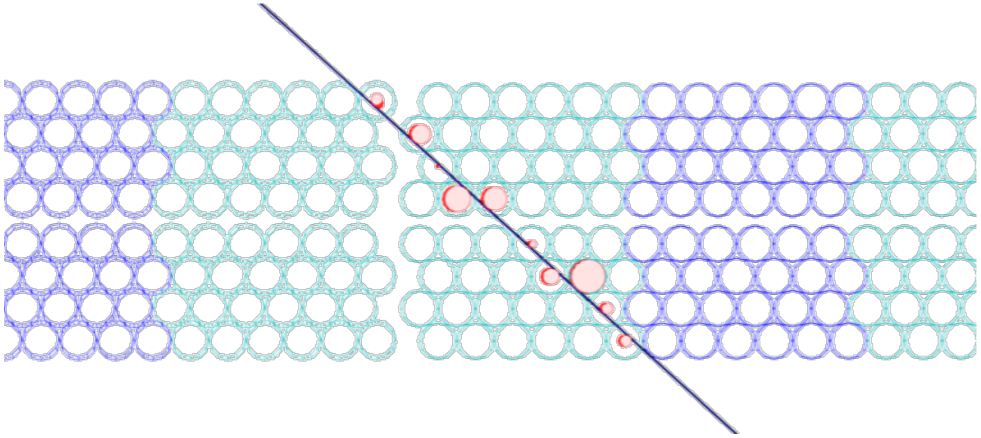
**From D. Froidevaux, ASP 2010**

# Drift Tubes (DT) in ATLAS: inner detector and muon spectrometer

- **Classical detection technique for charged particles based on gas ionisation and drift time measurement**



Example: muon in MDTs (aligned !)



TRT: Kapton tubes, ∅ = 4 mm

MDT: Aluminium tubes, ∅ = 30 mm

**From D. Froidevaux, ASP 2010**

# The ATLAS Muon Spectrometer

Big wheel, Feb 2007

**From D. Froidevaux, ASP 2010**

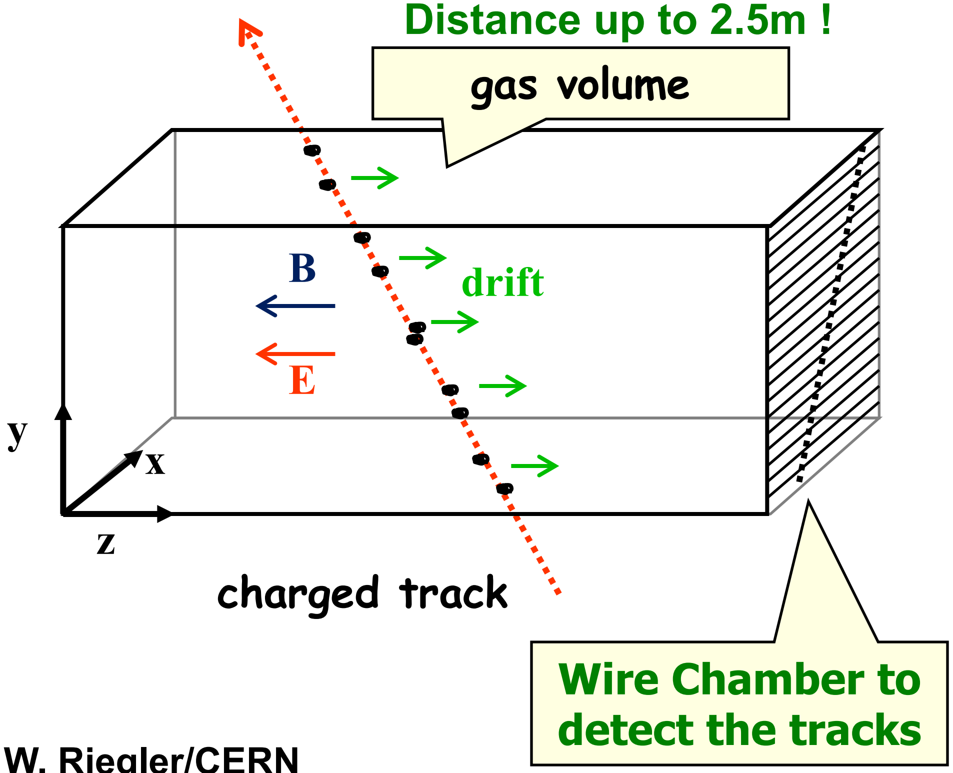
# Time Projection Chamber (TPC):

**Gas volume with parallel E and B Field.**

**B for momentum measurement. Positive effect:
Diffusion is strongly reduced by E//B (up to a factor 5).**

**Drift Fields 100-400V/cm. Drift times 10-100 μs.**

**Distance up to 2.5m !**



**Wire Chamber to detect the tracks**

W. Riegler/CERN

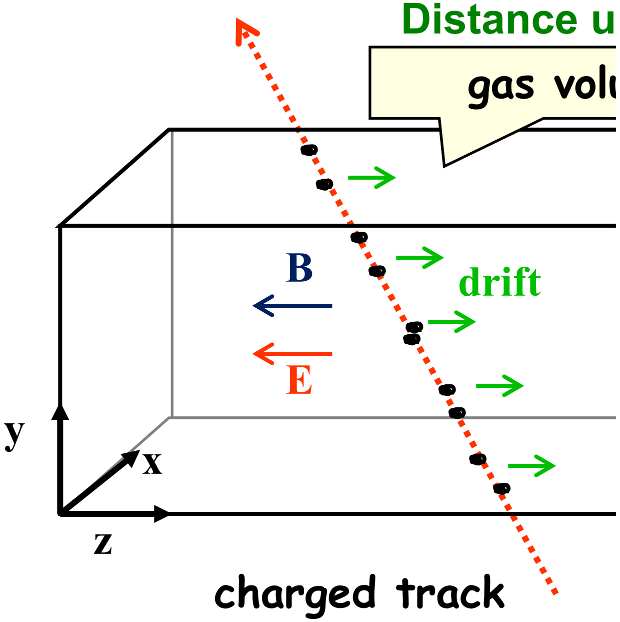
# Time Projection

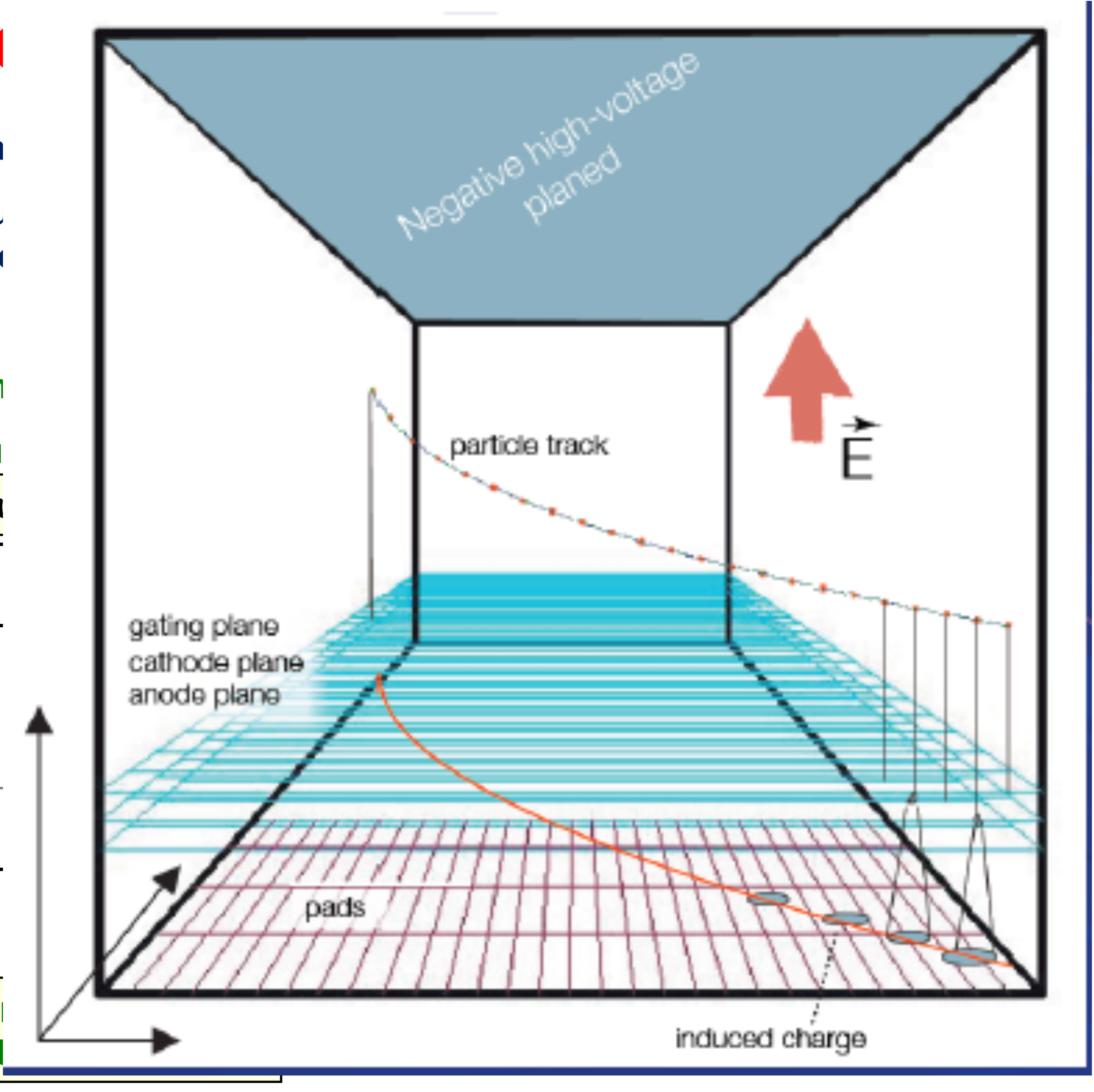
Gas volume with pa

B for momentum measu
Diffusion is strongly reduc

Drift Fields 100-400V/cm

Distance u





Wi
det

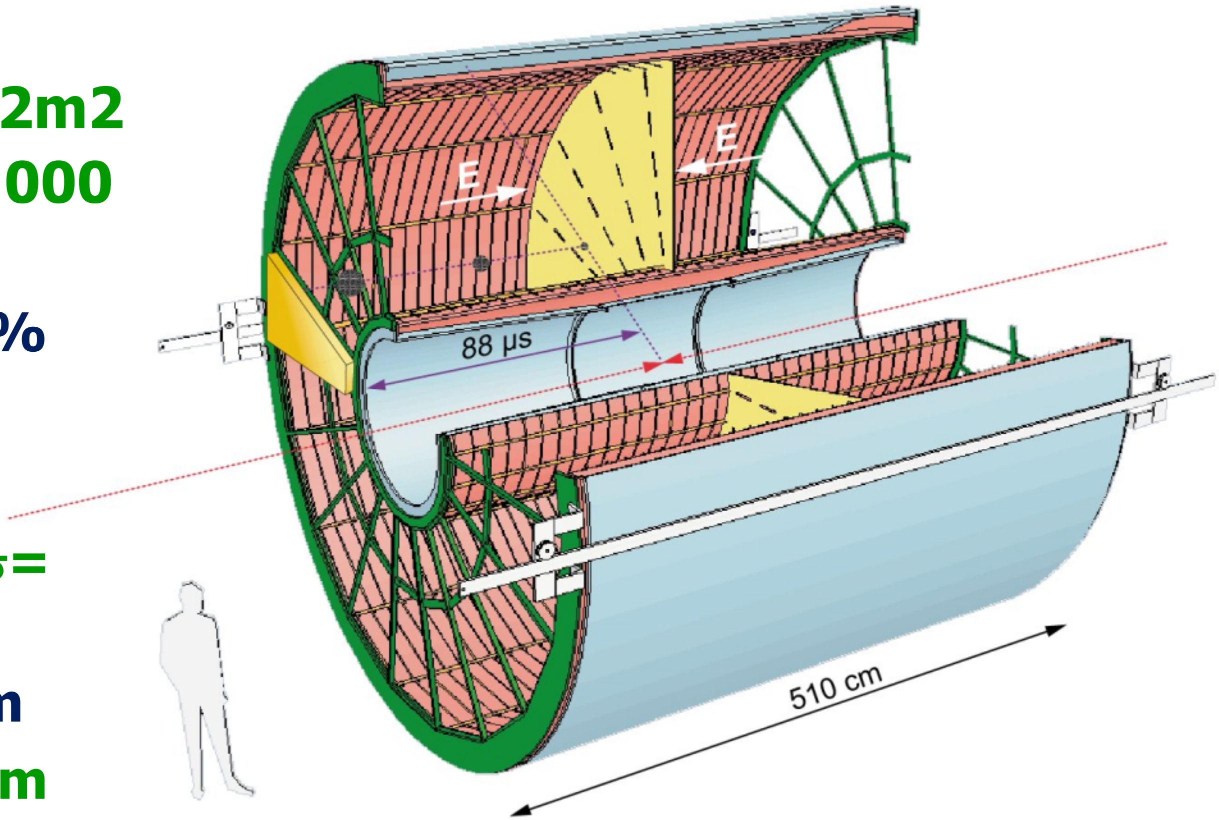
W. Riegler/CERN

# ALICE TPC: Detector Parameters

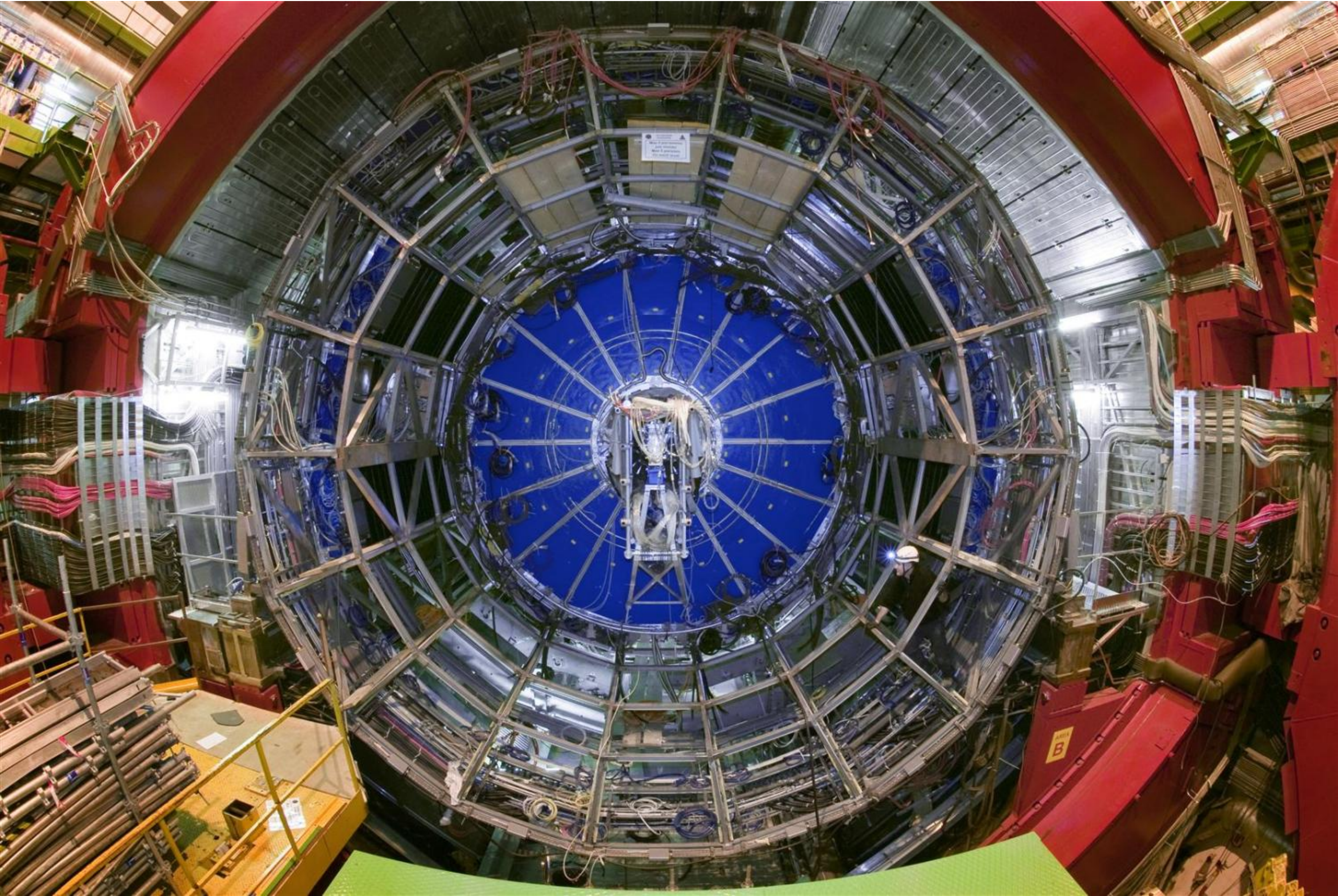
**Largest TPC:**

- Length 5m
- Diameter 5m
- Volume 88m3
- Detector area 32m2
- Channels ~570 000

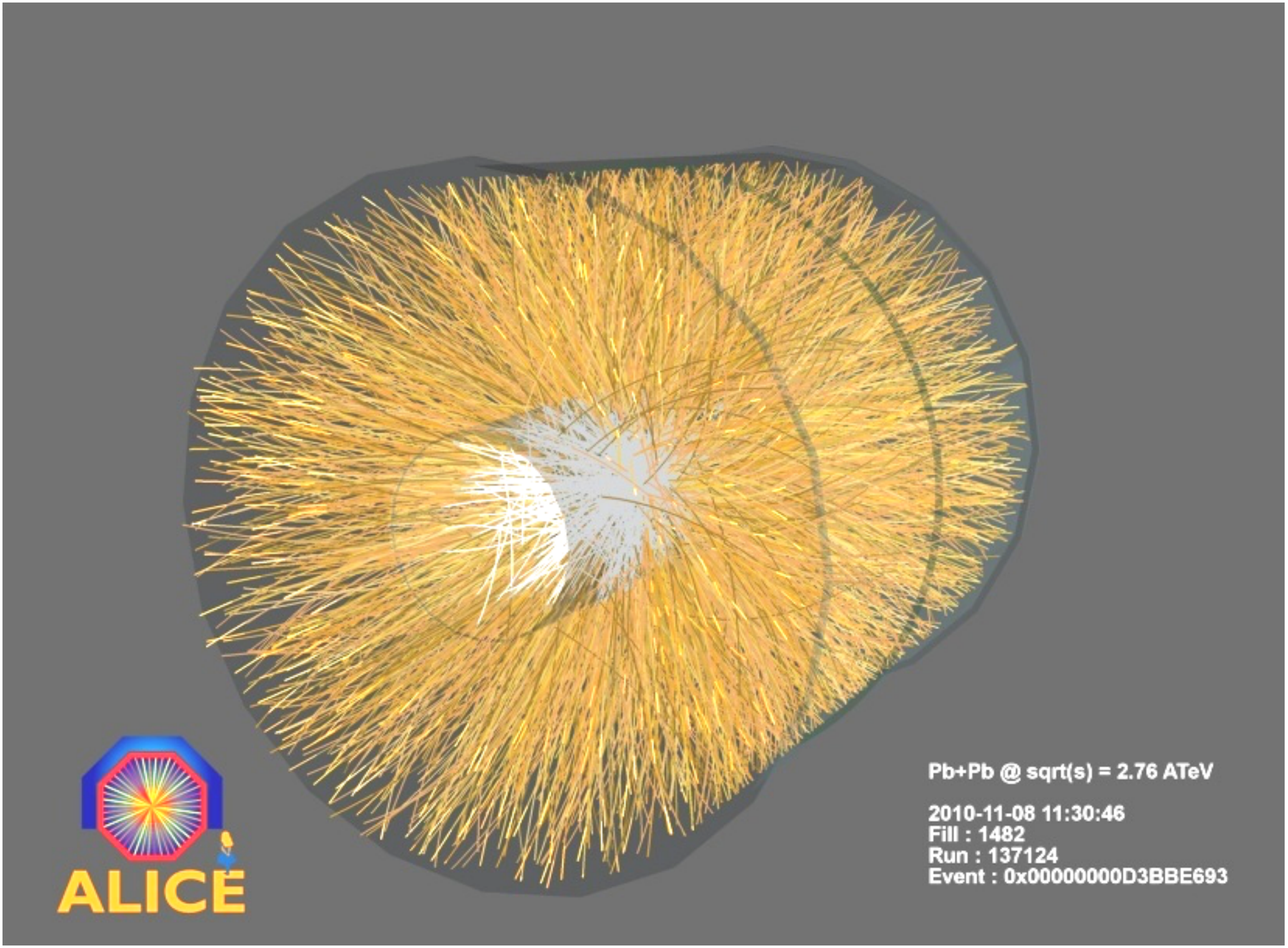
- Gas Ne/ $CO_2$ 90/10%
- Field 400V/cm
- Gas gain $>10^4$
- Position resolution $\sigma =$ 0.25mm
- Diffusion: $\sigma_t = 250\mu m$
- Pads inside: 4x7.5mm
- Pads outside: 6x15mm
- B-field: 0.5T



# TPC installed in the ALICE Experiment



# First Pb Pb Collisions in the ALICE TPC in Nov 2010 !



Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

**7/3/18**

# *Limitations of Gas Chambers*

- Operation stability
  - Gas control
  - HV / pressure and temperature control
- Rate capabilities
  - Limited by the drift time of the positive ions from the avalanche to the cathode
- Aging in high rate environment