Particle Detectors.

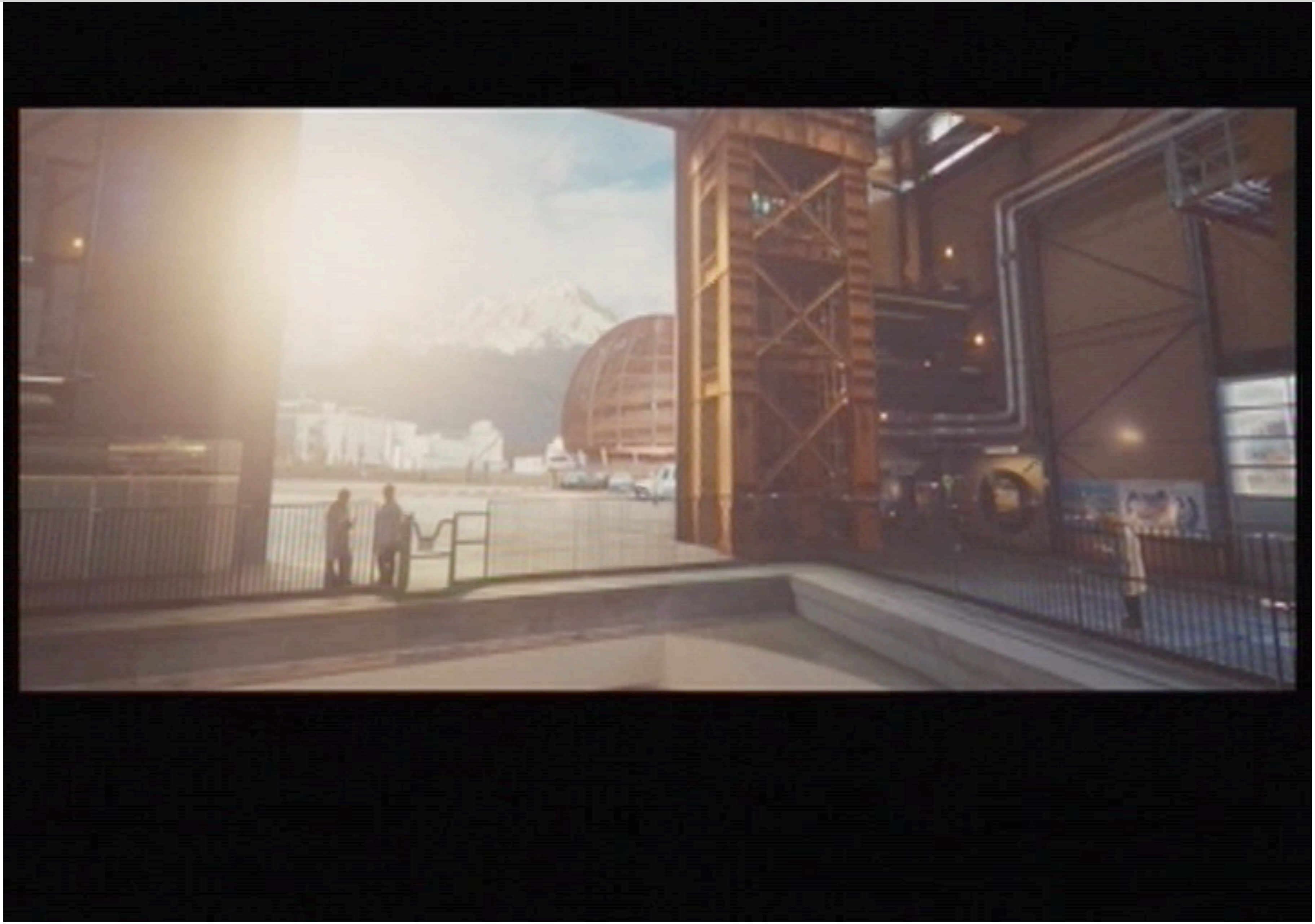
Lectures at the CHIPP PhD Winter School 2012
Christoph Rembser (CERN)

Disclaimer

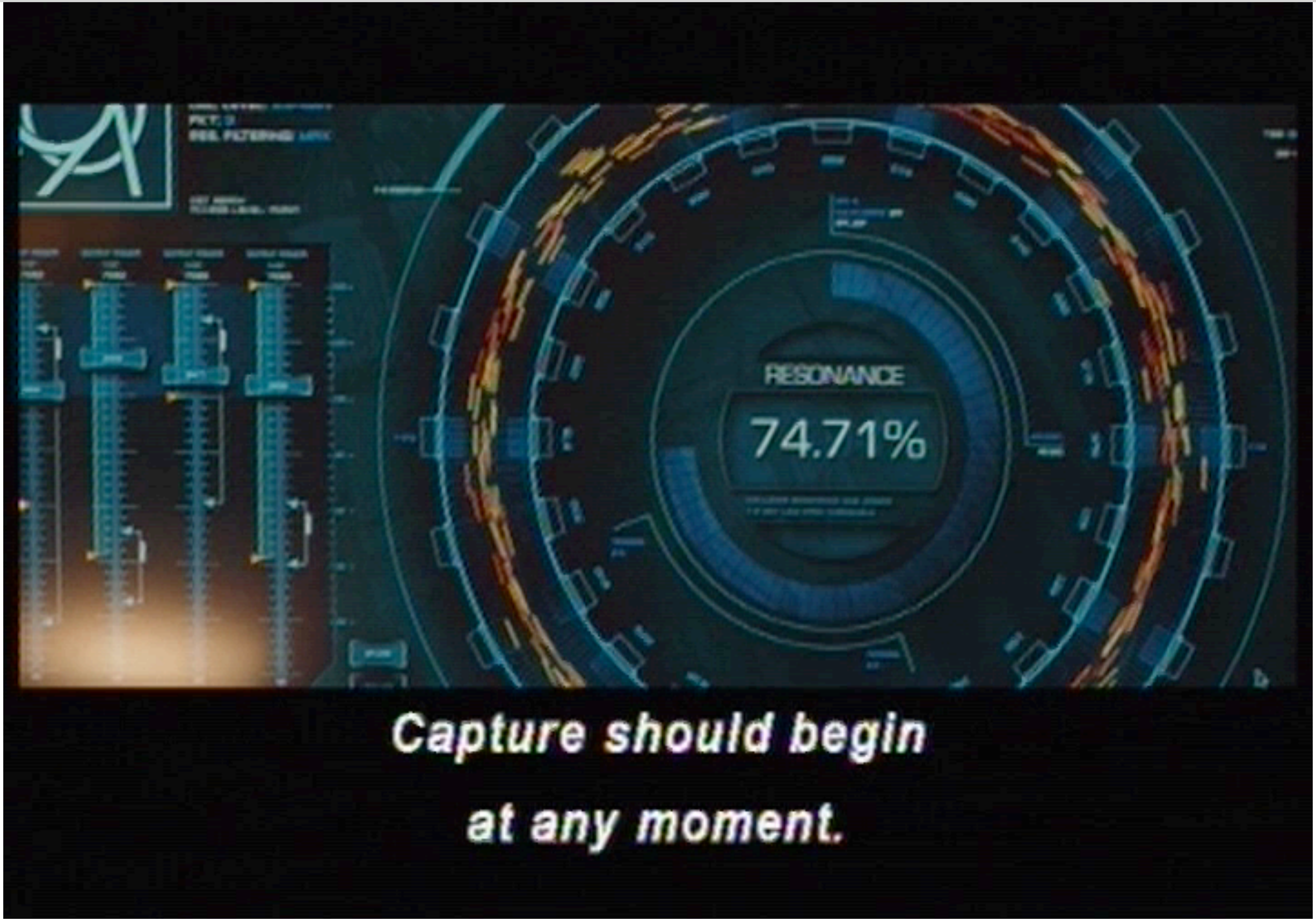
- Particle detectors are very complex and many different fields of physics are involved in the detection of particles e.g. particle physics, material science, electronics and mechanics.
- To get a good understanding of detectors, one needs to work on a detector project ...
- This lectures can only give a glimpse at particle detector physics and cannot cover everything.
- Also: biased towards my favourite detectors!

Detectors for particle physics - an overview

In Hollywood they have never built detectors...



...but they think they know how they work

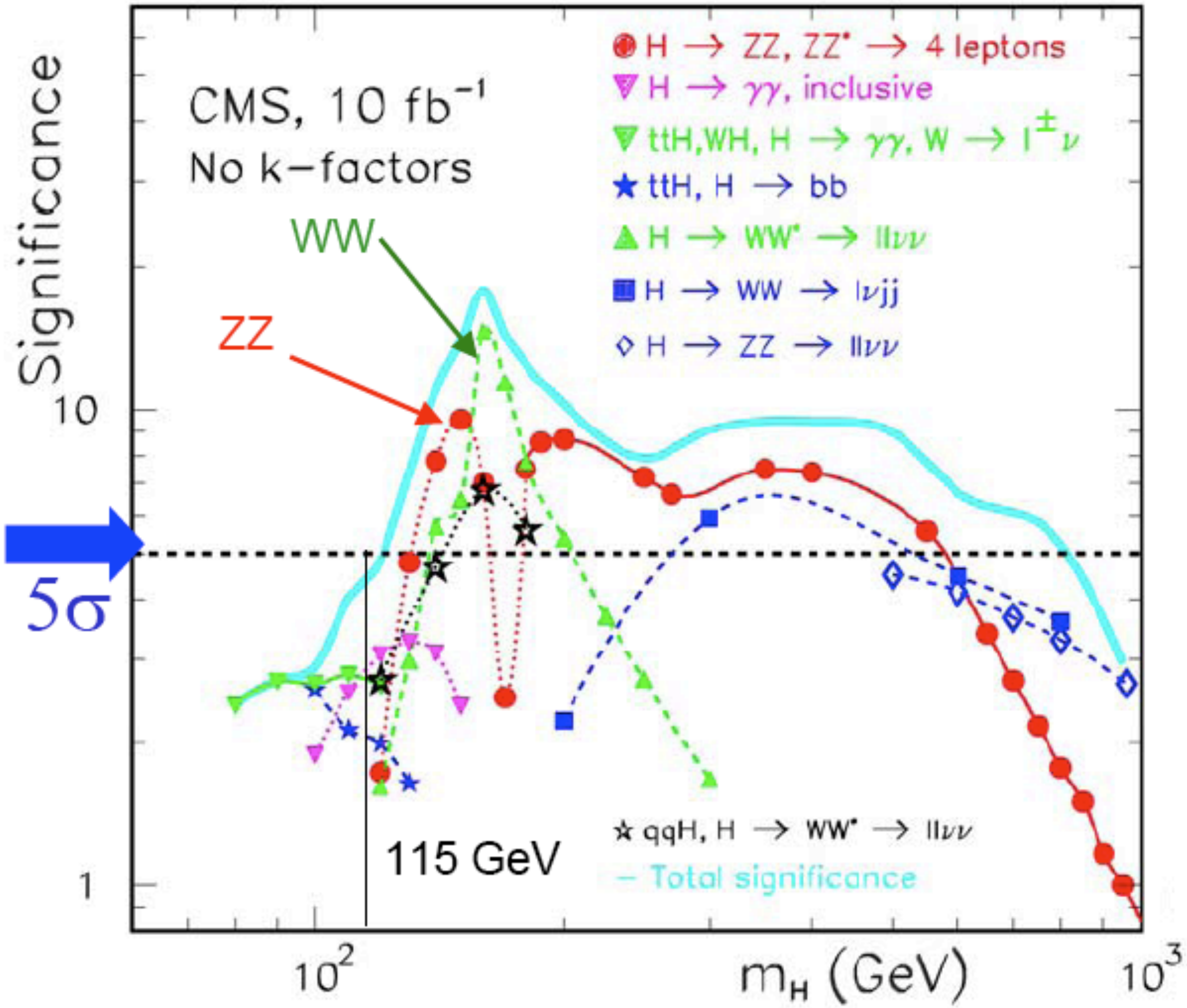


Capture should begin
at any moment.

Outline of this lectures

- Detectors for particle physics - an overview
- Particle interactions with matter
- Tracking detectors
- Calorimeters
- Detectors for particle identification and triggering
- Interleaved with examples of building detectors and lessons from real life

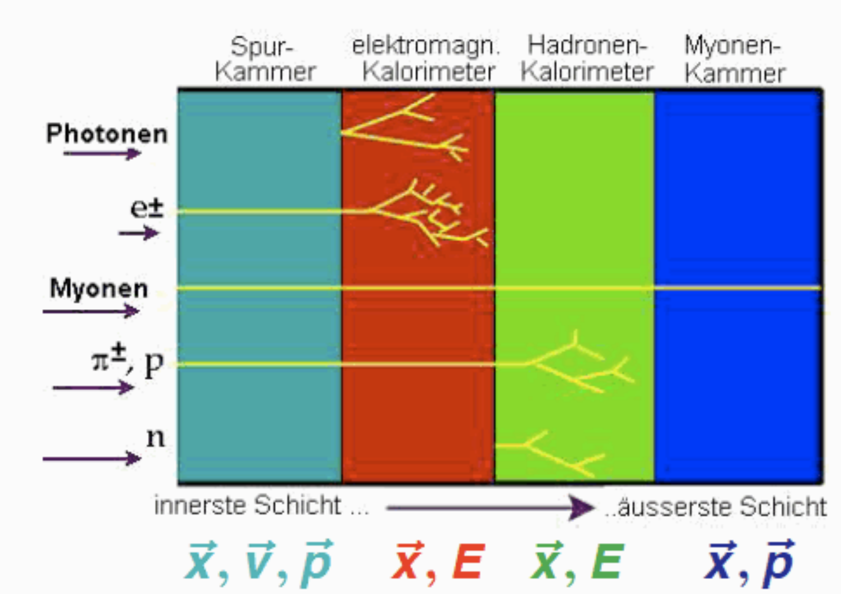
Detectors - our cameras for (new) particles

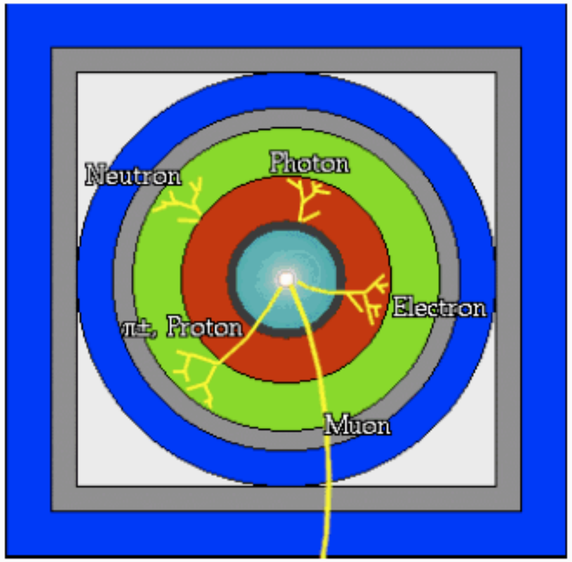


- Search for new particles (e.g. the Higgs boson):
  - ➡ prediction of the decay mode, the expected signature in the detector and the event kinematics defines the design of a detector

Particle detectors

- There is not one type of detector which provides all information (measurements) we need
  - ➡ concept of different layers providing different measurements



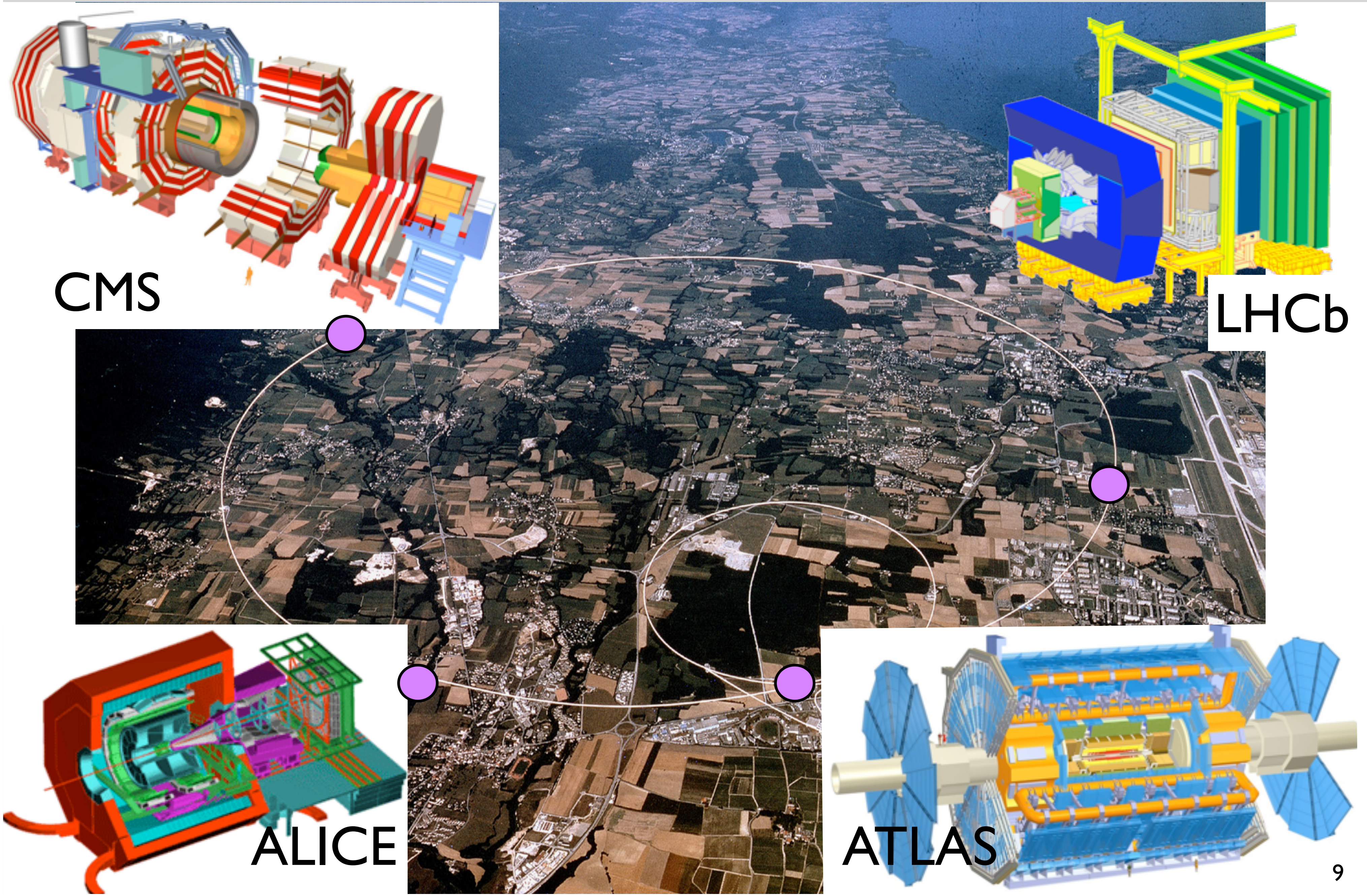


Tracker: Momentum of charged particles due to magnetic field and precise measurement of track

Calorimeter: Energy measurement of photons, electronics and hadrons through total absorption

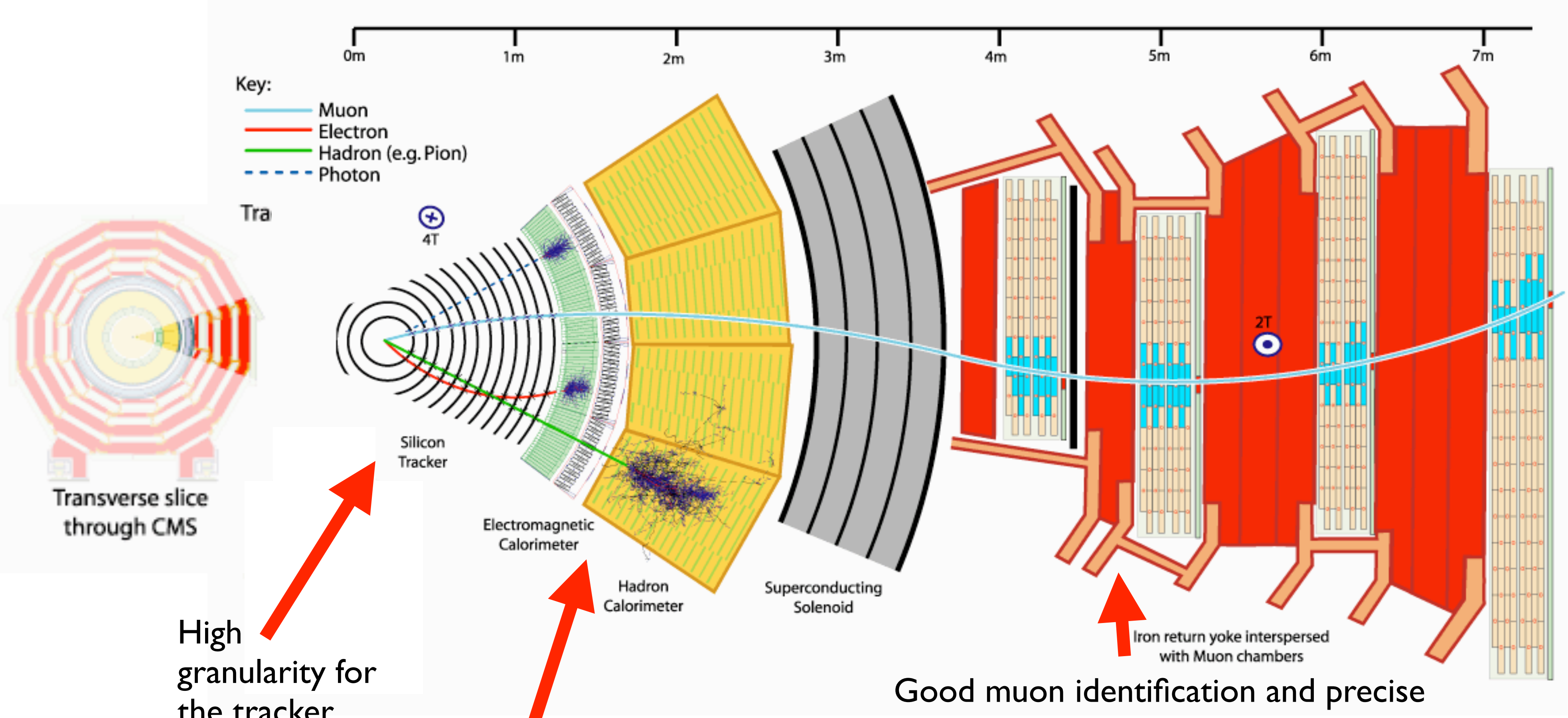
Muon-Detector: Identification and precise momentum measurement of muons outside of the magnet

The big particle detectors at the LHC



A collider detector: cross-section

Example: the CMS experiment



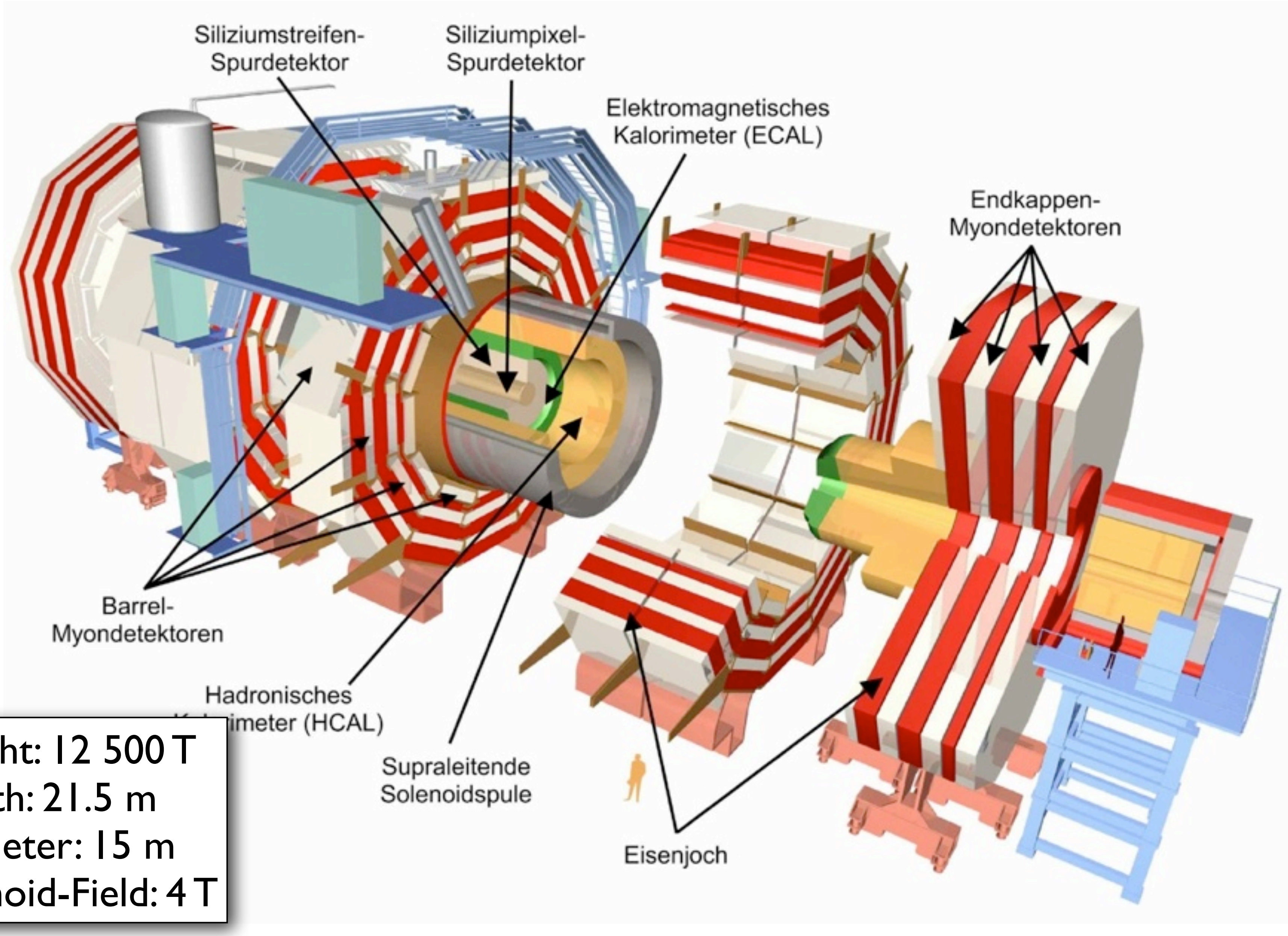
High granularity for the tracker (high occupancy)

Good energy resolution of the calorimeters up to highest particle energies

Good muon identification and precise muon momentum measurement

Important for all components: should be radiation hard (operation at hadron collider)

CMS: the “heavy” detector



Weight: 12 500 T
Length: 21.5 m
Diameter: 15 m
Solenoid-Field: 4 T

The CMS detector in the experimental cavern

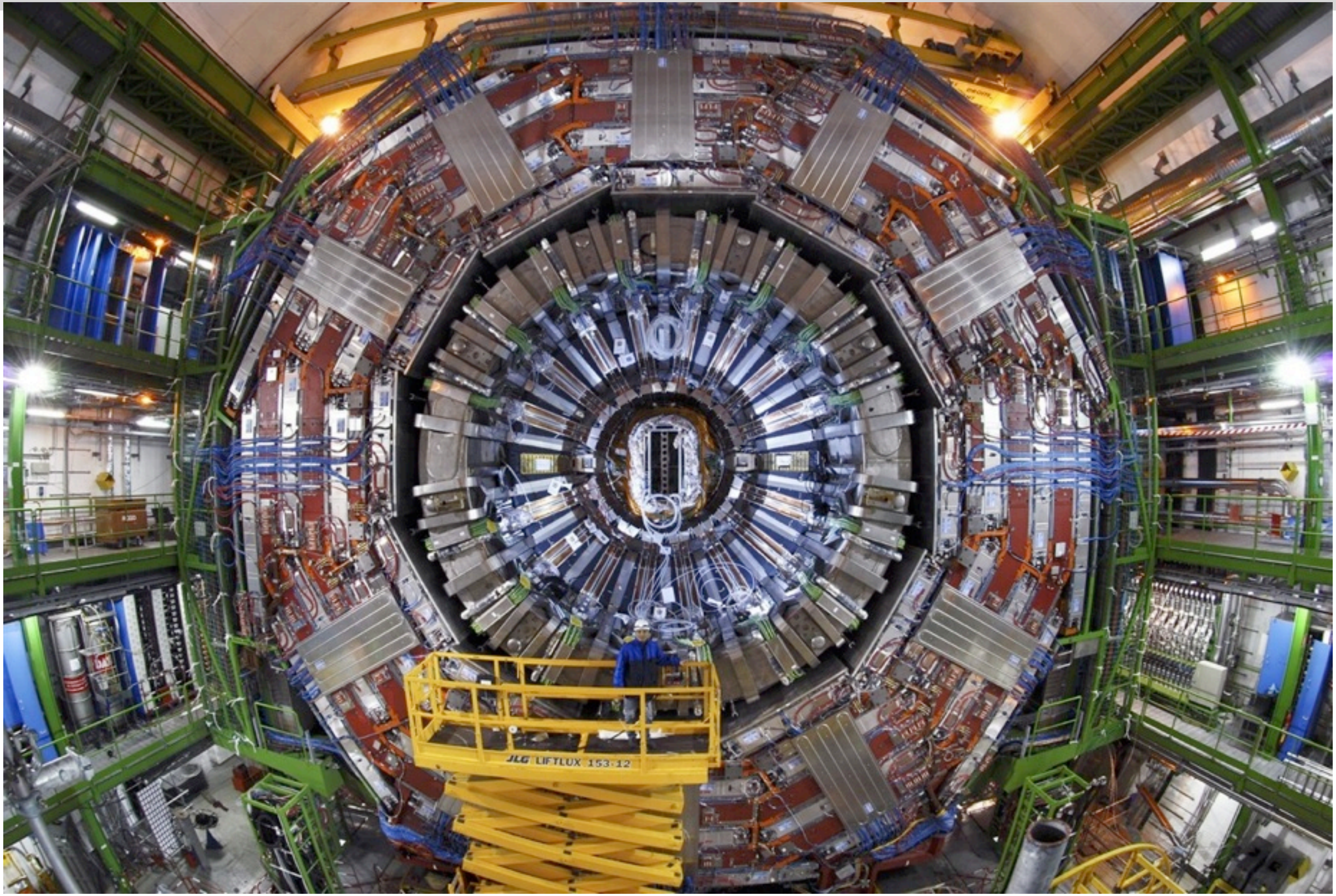
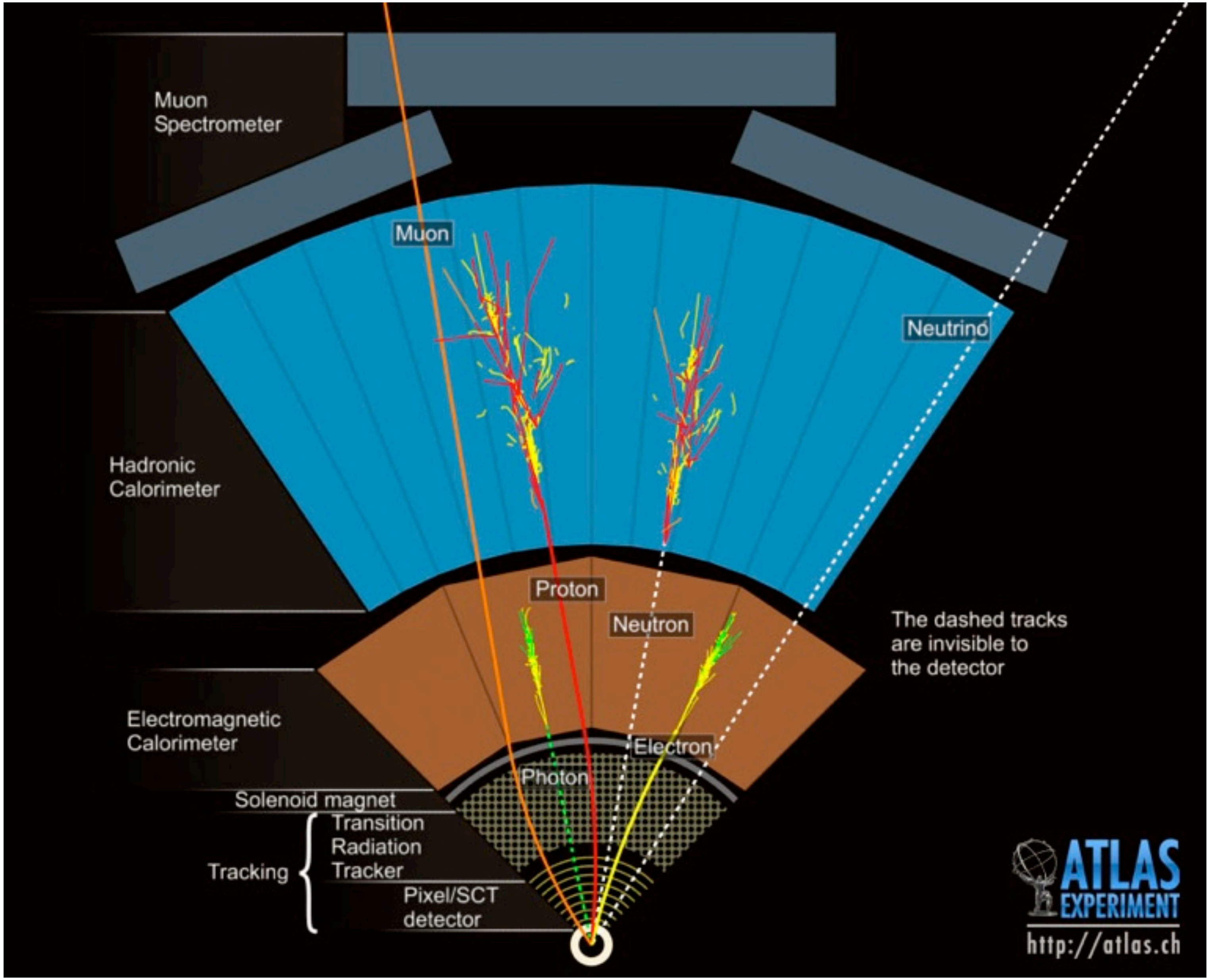
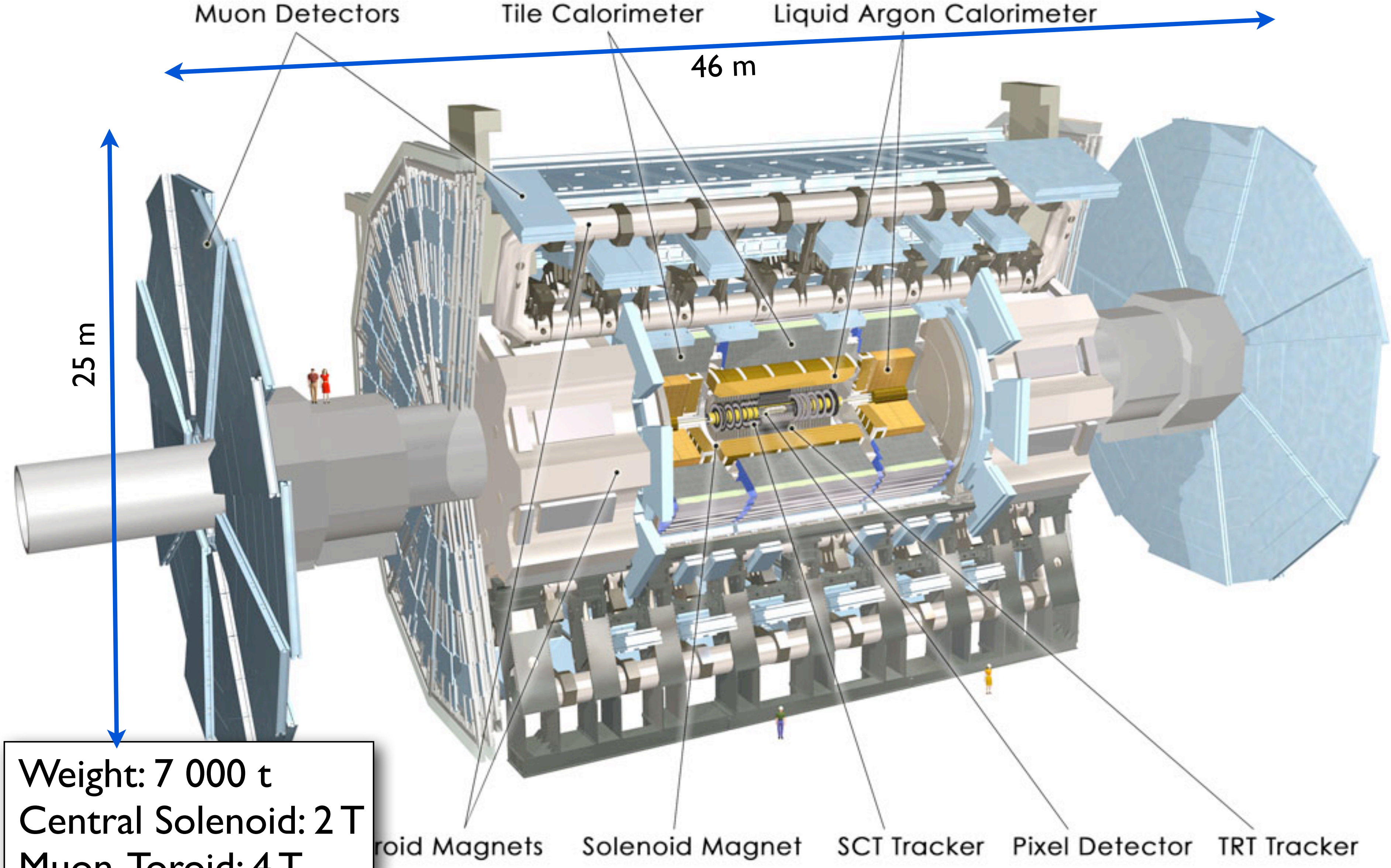


Foto: CERN

Particles in ATLAS

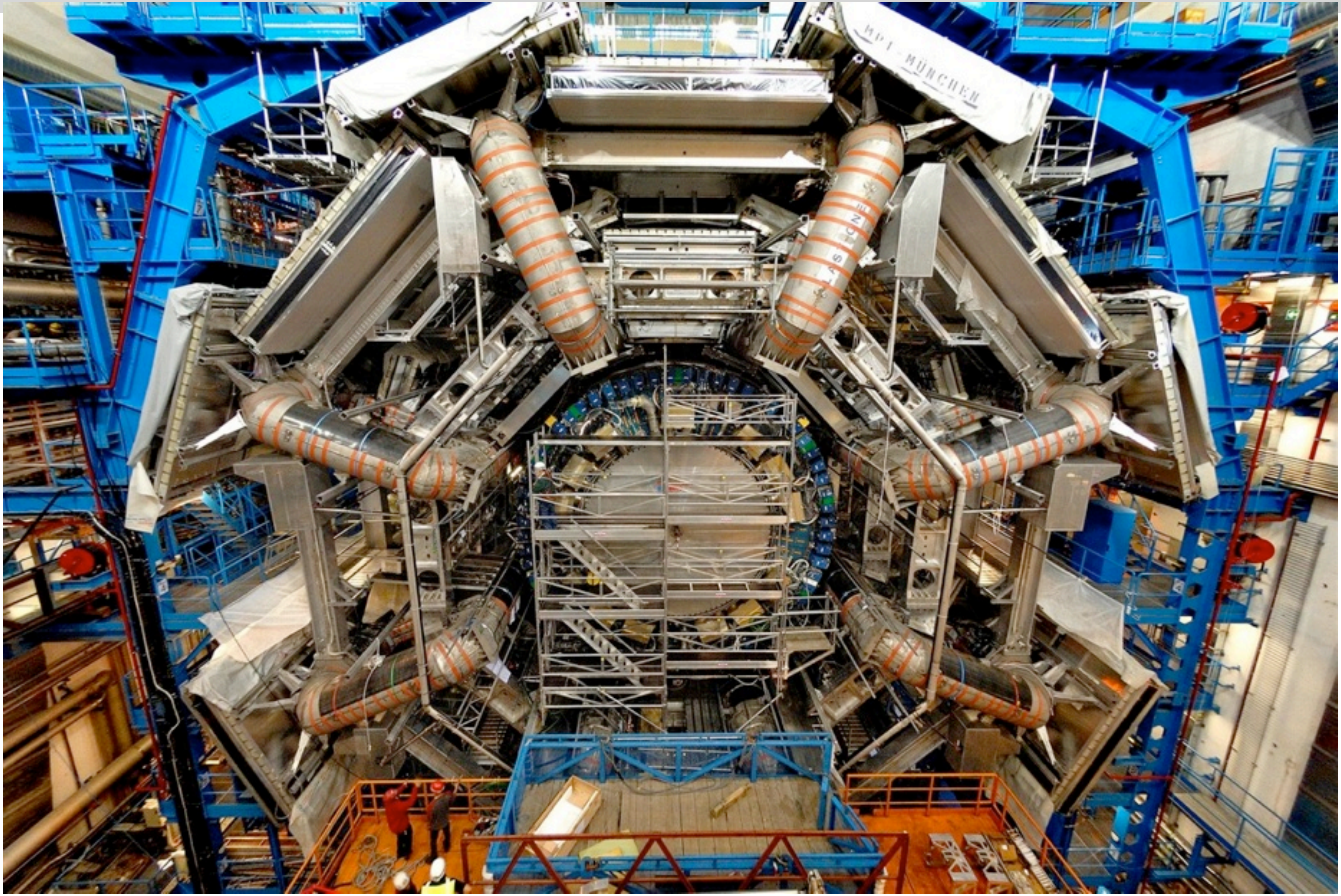


ATLAS: the largest detector in particle physics

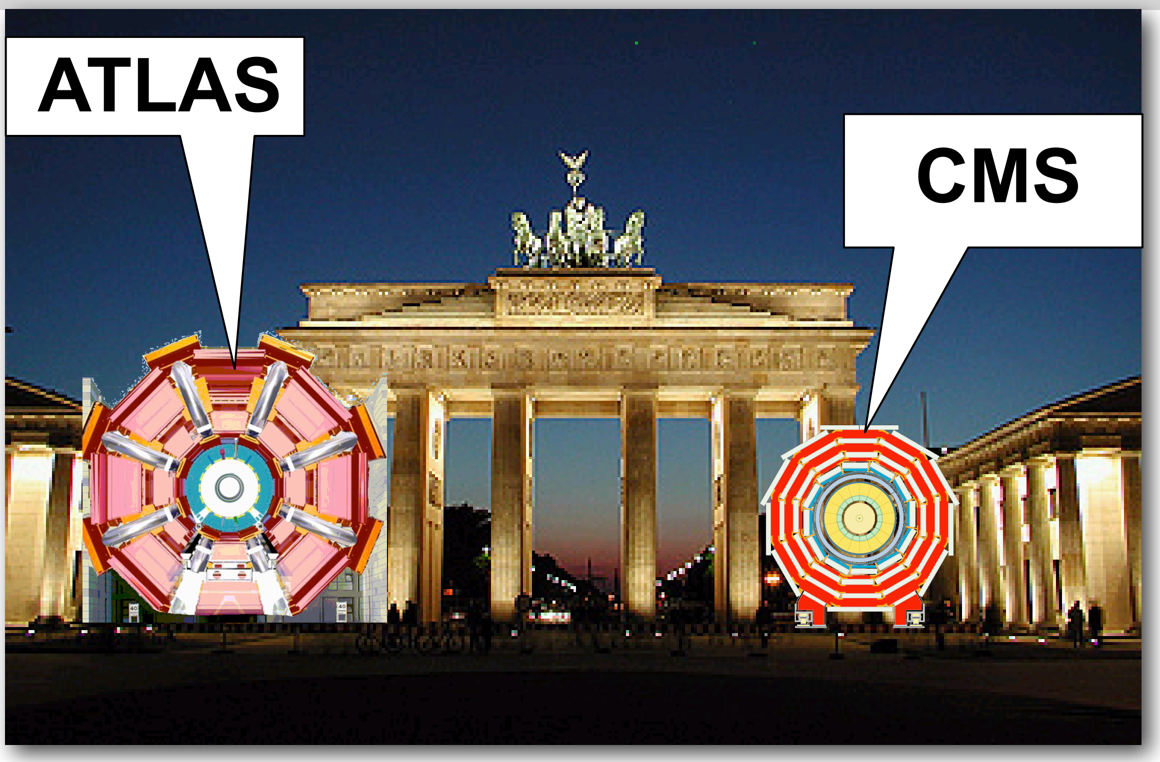


Weight: 7 000 t
Central Solenoid: 2 T
Muon-Toroid: 4 T

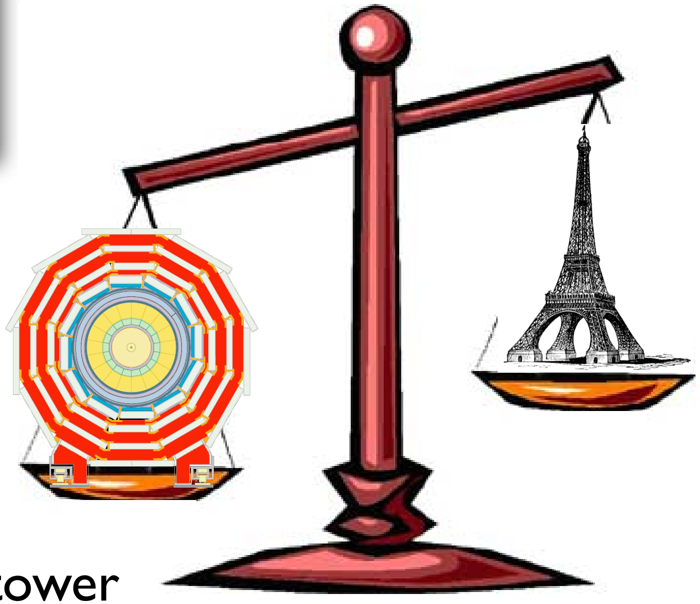
ATLAS cross-section



Size and weight



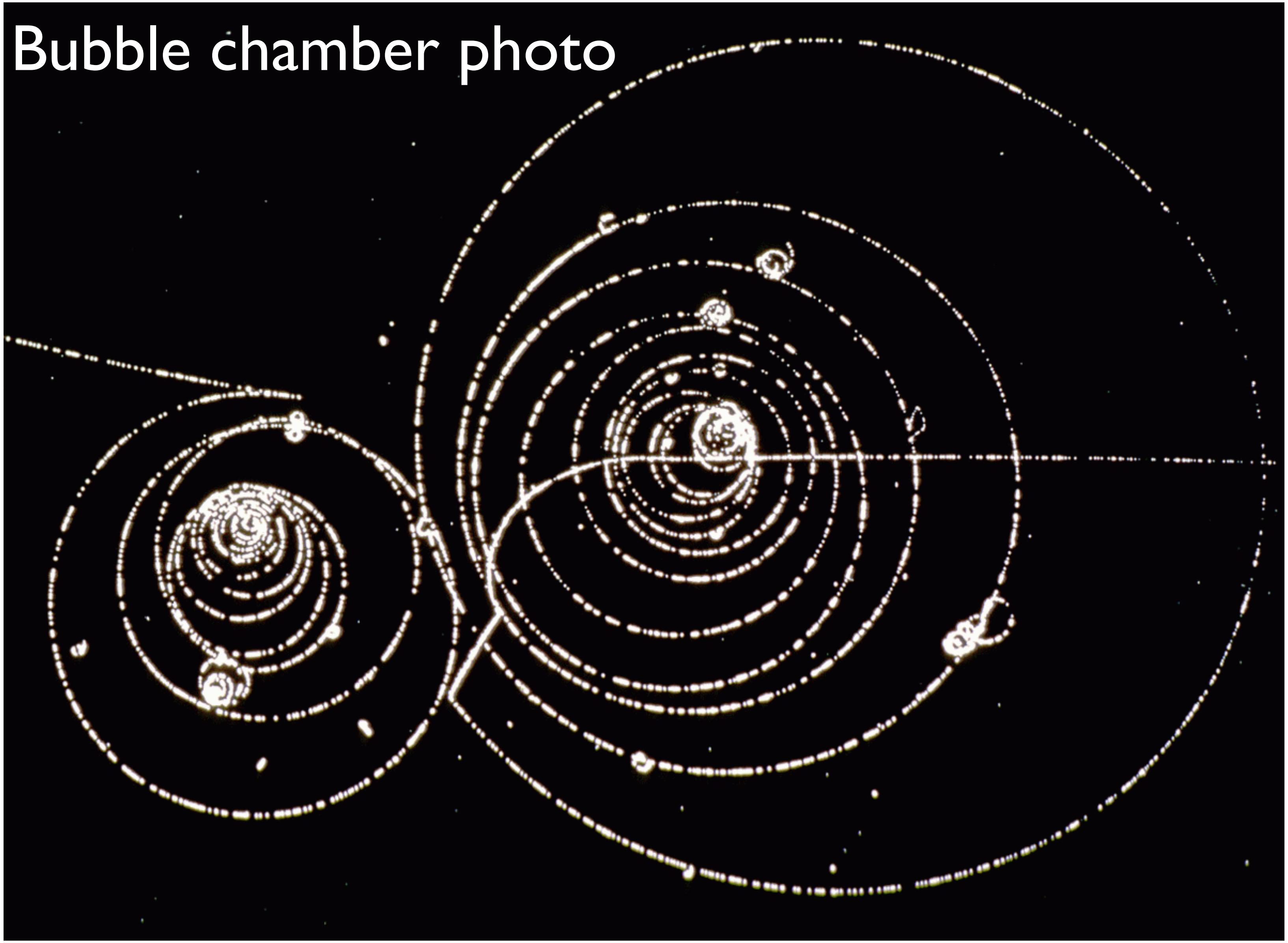
Brandenburg Gate in Berlin



CMS is 30% heavier than the Eiffel tower

Particle interactions with matter

...or: we try to understand all on this picture

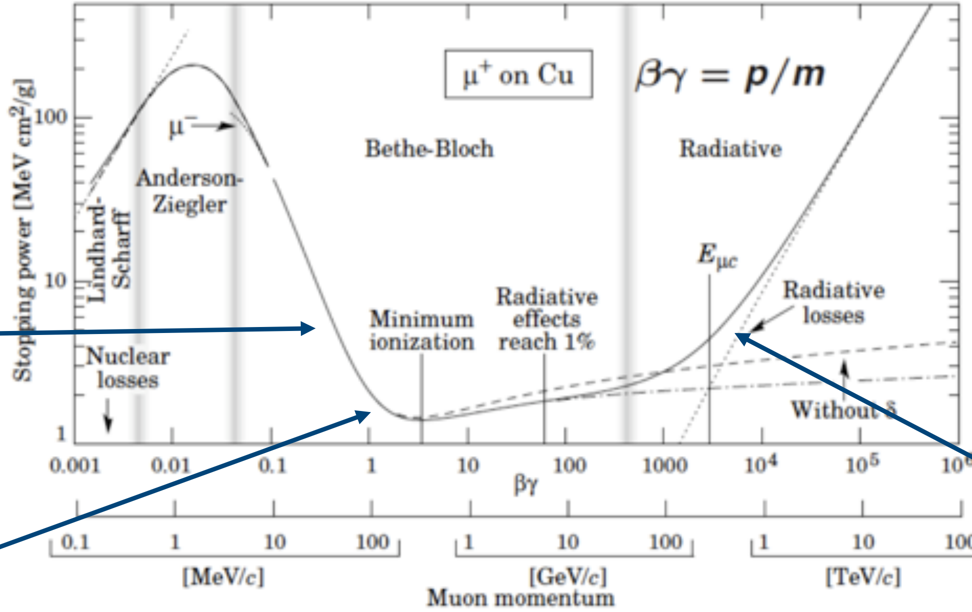


Interactions of “heavy” particles with matter

- Mean energy loss is described by the Bethe-Bloch formula

$$-\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 z^2 \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot [\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2} - \frac{C}{Z}]$$

$T_{\max}$	Maximum kinetic energy which can be transferred to the electron in a single collision
I^2	Excitation energy
$\frac{\delta}{2}$	Density term due to polarisation: leads to saturation at higher energies
$\frac{C}{Z}$	Shell correction term, only relevant at lower energies



$$\left\langle \frac{dE}{dx} \right\rangle \propto \frac{1}{\beta^2}$$

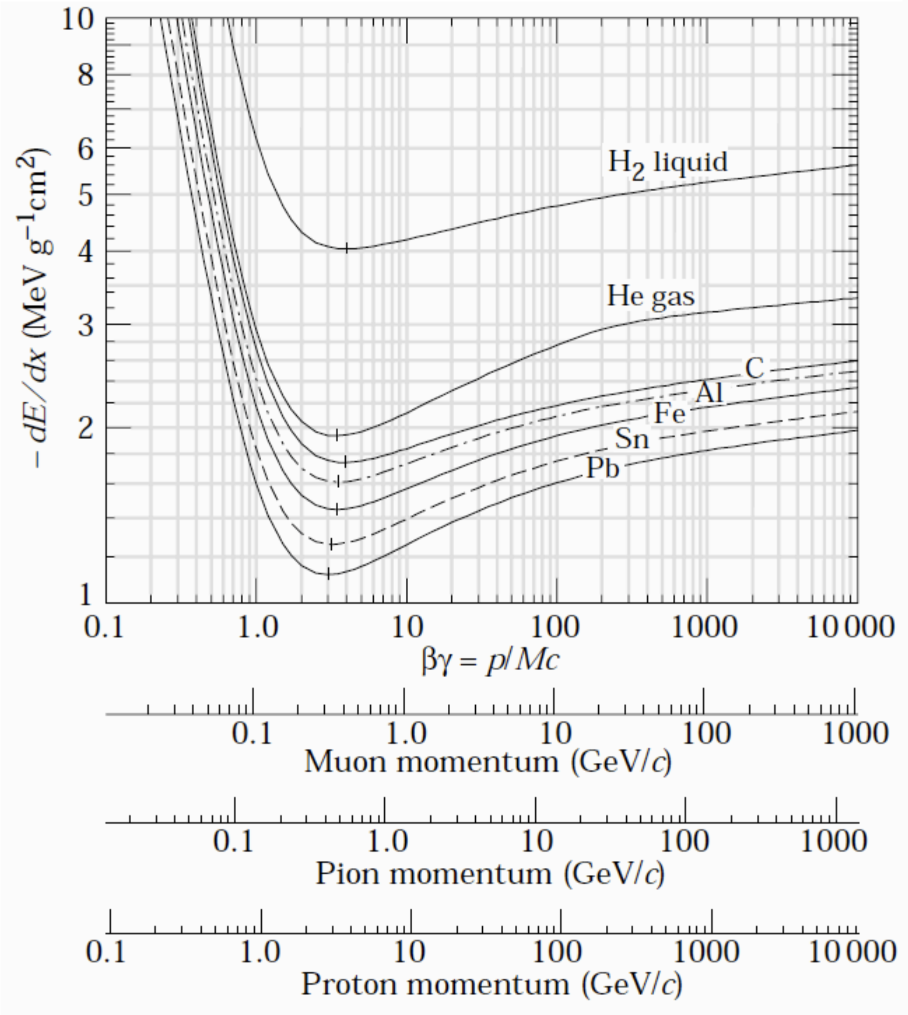
“kinematic term”

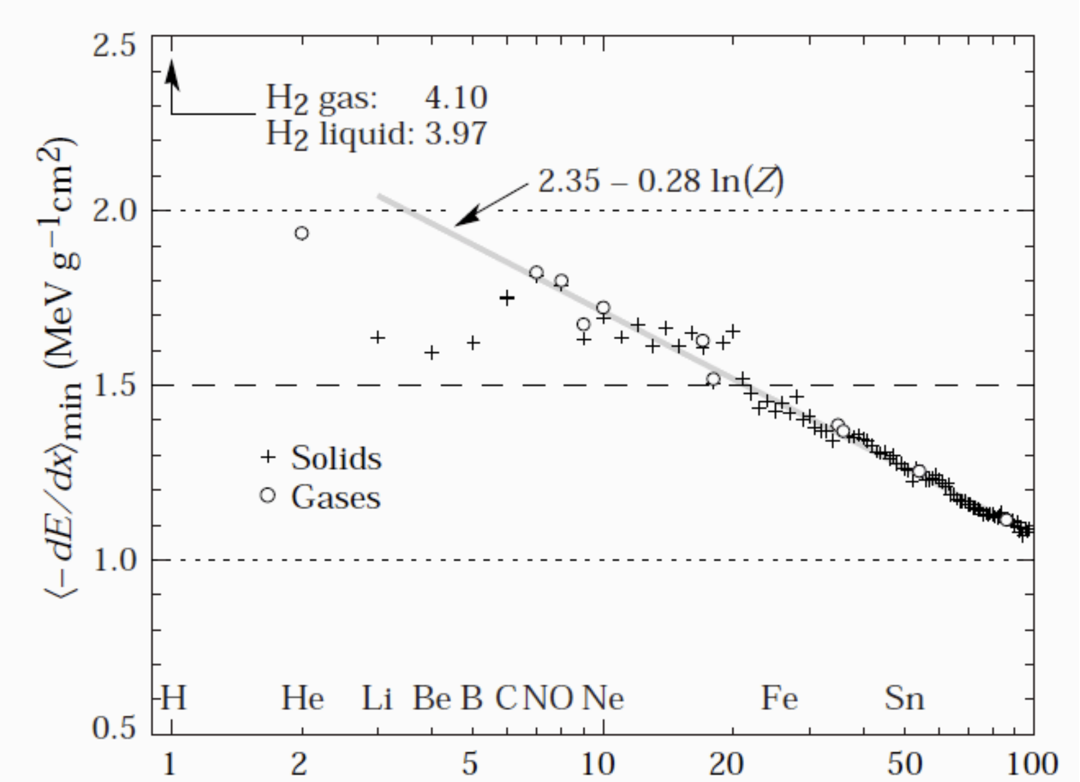
$$\left\langle \frac{dE}{dx} \right\rangle \propto \ln \beta^2 \gamma^2$$

“relativistic rise”

“minimum ionising particles” βγ ≈ 3-4

Material dependence of the energy loss



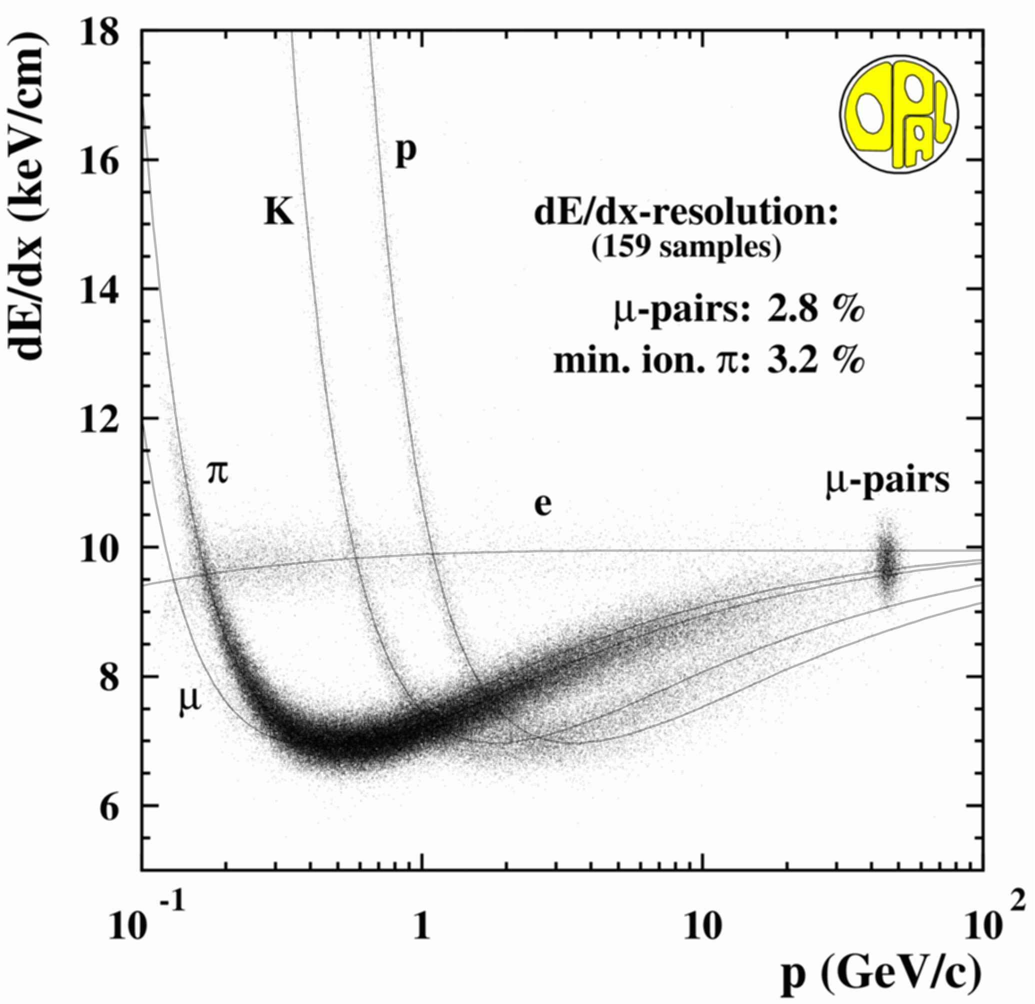


- **Rule of thumb:** energy loss of MIPs ($\beta\gamma \sim 3$): 1-2 MeV g^{-1} cm^2 (except H)

Particle Identification using dE/dx

- Energy loss depends on the particle velocity and is ~ independent of the particle's mass m.
- The energy loss as a function of particle momentum **is** however depending on the particle's mass
- By measuring the particle momentum and the measurement of the energy loss one can determine the particle mass

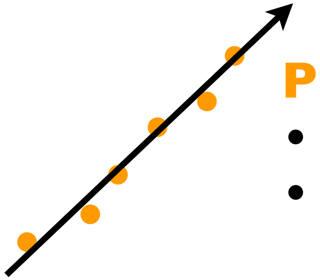
➡ **Particle Identification !**



$$-\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 z^2 \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot [\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2} - \frac{C}{Z}]$$

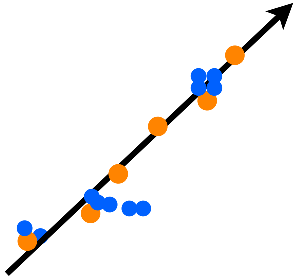
A closer look at the energy loss

- Bethe-Bloch displays only the average
- energy loss is a statistical process
- discrete scattering with different results depending on “intensity’ of scattering
- primary and secondary ionisation



Primary ionisation

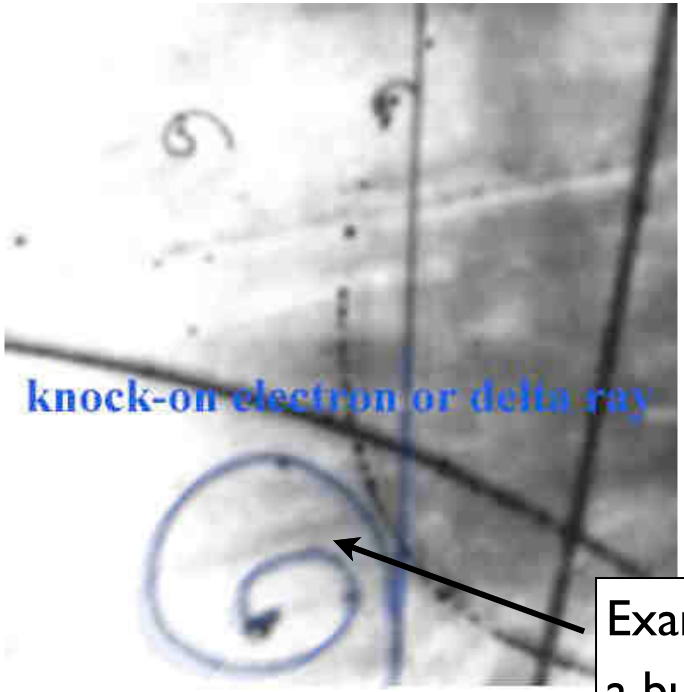
- Poisson distributed
- Large fluctuations per reaction



Secondary ionisation

- Created by high energetic primary electrons
- sometime the energy is sufficient for a clear secondary track: δ-Electron

Total ionisation = **primary ionisation**
+ **secondary ionisation**

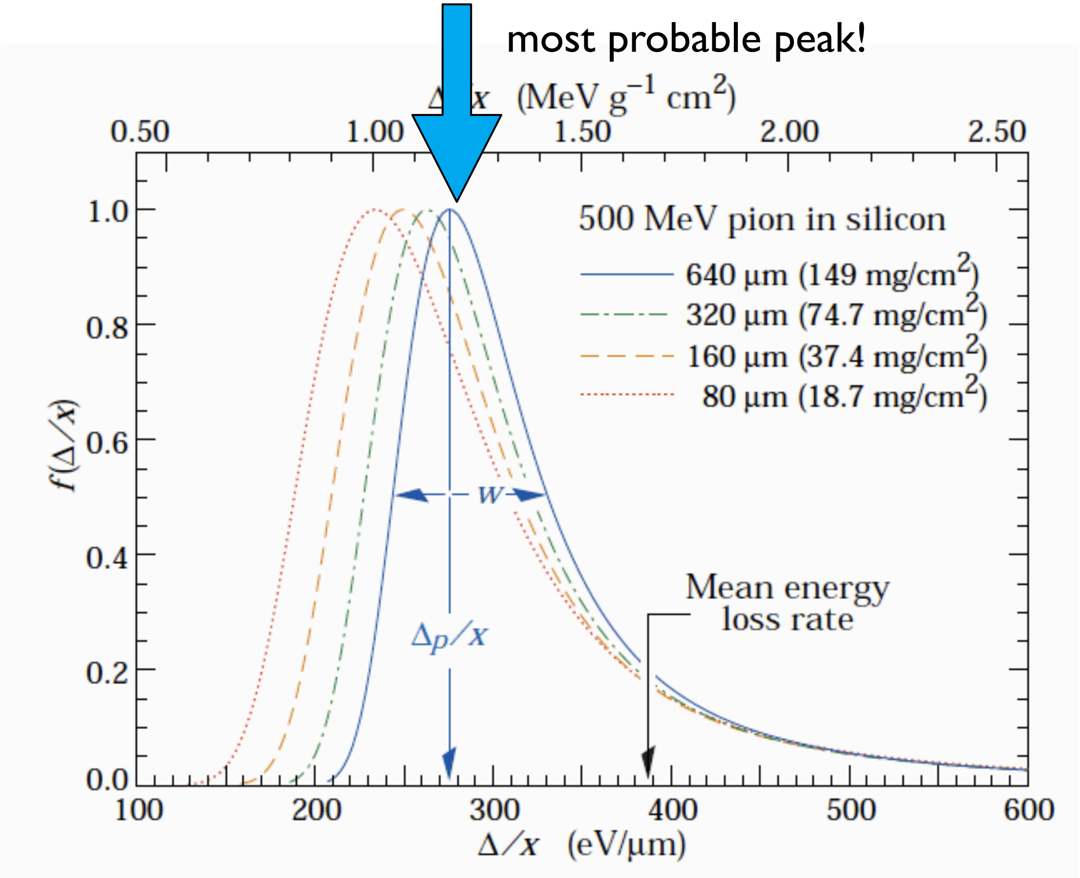


Example of a delta electron in a bubble chamber: visible path

Energy loss in thin layers

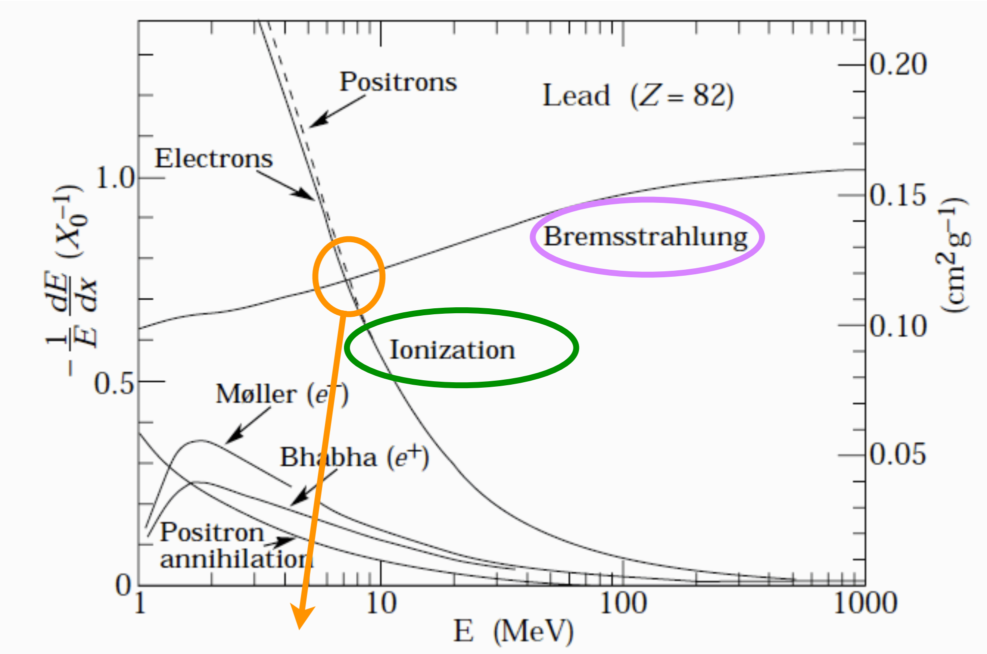
- In case of thin detectors the variation width within the energy transfer of the reactions leads to a **large variation** of the energy loss:
  - broad maximum: collisions with little energy loss
  - long tail towards higher energy loss: few collisions with large energy loss, δ-electrons

The **Landau distribution** is used in physics to describe the fluctuations in the energy loss of a charged particle passing through a thin layer of matter


most probable peak!

Energy loss of electrons

- Energy loss by electrons (positrons) differs w.r.t other particles because of the kinematics, spin and the identity of the incident electron and ionised electron.



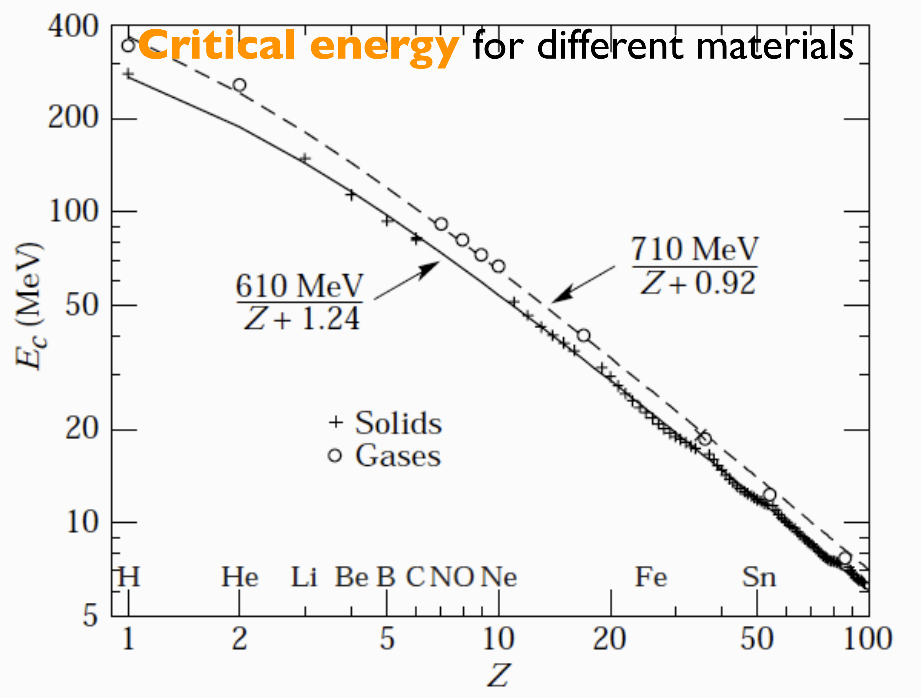
- Bremsstrahlung is dominating at high energies
- At low energies: ionisation, additional scattering

- **Critical energy**: the energy at which the losses due to ionisation and Bremsstrahlung are equal

$$\frac{dE}{dx}(E_c) = \frac{dE}{dx}(E_c)$$

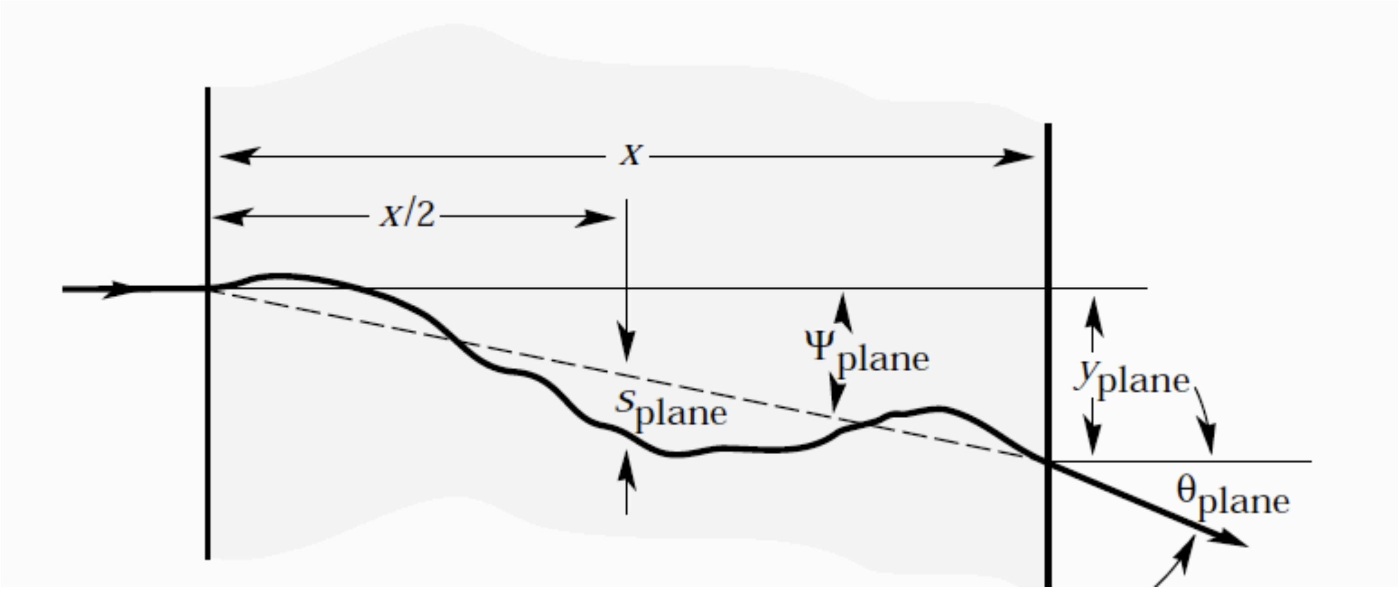
For electrons approximately:

$$E_c^{\text{solid+liq}} = \frac{610MeV}{Z+1.24} \qquad E_c^{\text{gas}} = \frac{710MeV}{Z+1.24}$$


Critical energy for different materials

Multiple scattering

- Charged particles are forced to deviate from a straight track when moving through a medium: multiple scattering due to Coulomb field



$$\theta_0 = \theta^{\text{rms}}_{\text{plane}} = \frac{1}{\sqrt{2}}\theta^{\text{rms}}_{\text{space}} \qquad \theta_0 = \frac{13.6\,\text{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\,\left[1 + 0.038\ln(x/X_0)\right]$$

- relevant for relativistic particles, for material thickness from 10^{-3} X_0 up to 100 X_0

Photons and electrons: radiation length

- An important parameter for particle detectors: **radiation length**

- Defines the amount of material a particle has to travel through:
  - until the energy of an electron is reduced by Bremsstrahlung to 1/e of its original energy

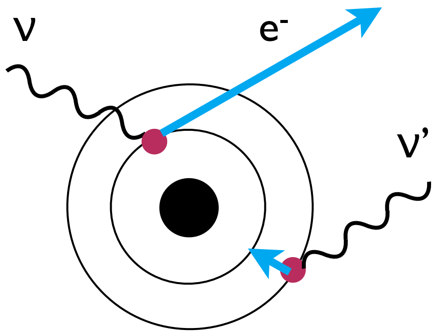
empirical: $$X_0 = \frac{716.4\,A}{Z(1+Z)\,ln(287/\sqrt{Z})}\,\frac{g}{cm^2} \propto \frac{A}{Z^2}$$

- The radiation length is also an important quantity in multiple scattering
- It is a very important number when building detectors, one always has to keep in mind how much material is within the detector volume
  - Usually quoted in [g/cm^2], typical values are:
    - Air: 36.66 g/cm^2, ➙ ~ 300 m
    - Water: 36.08 g/cm^2, ➙ ~ 36 cm
    - Aluminium: 24.01 g/cm^2, ➙ 8.9 cm
    - Tungsten: 6.76 g/cm^2, ➙ 0.35 cm

Interactions of photons

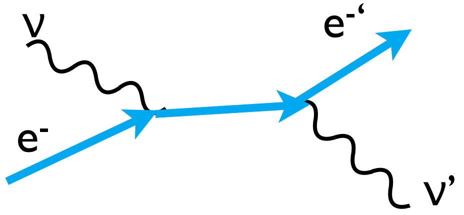
Photons appear in detector systems as primary photons, they are created in bremsstrahlung and de-excitations, and they are used for medical applications, both imaging and radiation treatment.

Photo effect



Only possible in the close neighbourhood of a third collision partner → photo effect releases mainly electrons from the K-shell.

Compton scattering

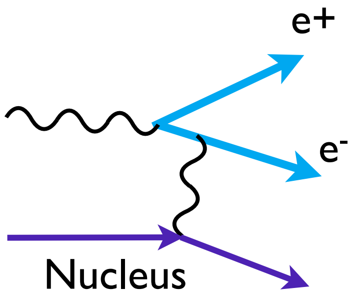


$$\gamma + e \rightarrow \gamma' + e'$$

Elastic scattering of a photon with a free electron

$$E'_\gamma = \frac{1}{1 + \epsilon(1 - \cos\theta_\gamma)}$$

Pair creation



Only possible in the Coulomb field of a nucleus (or an electron) if

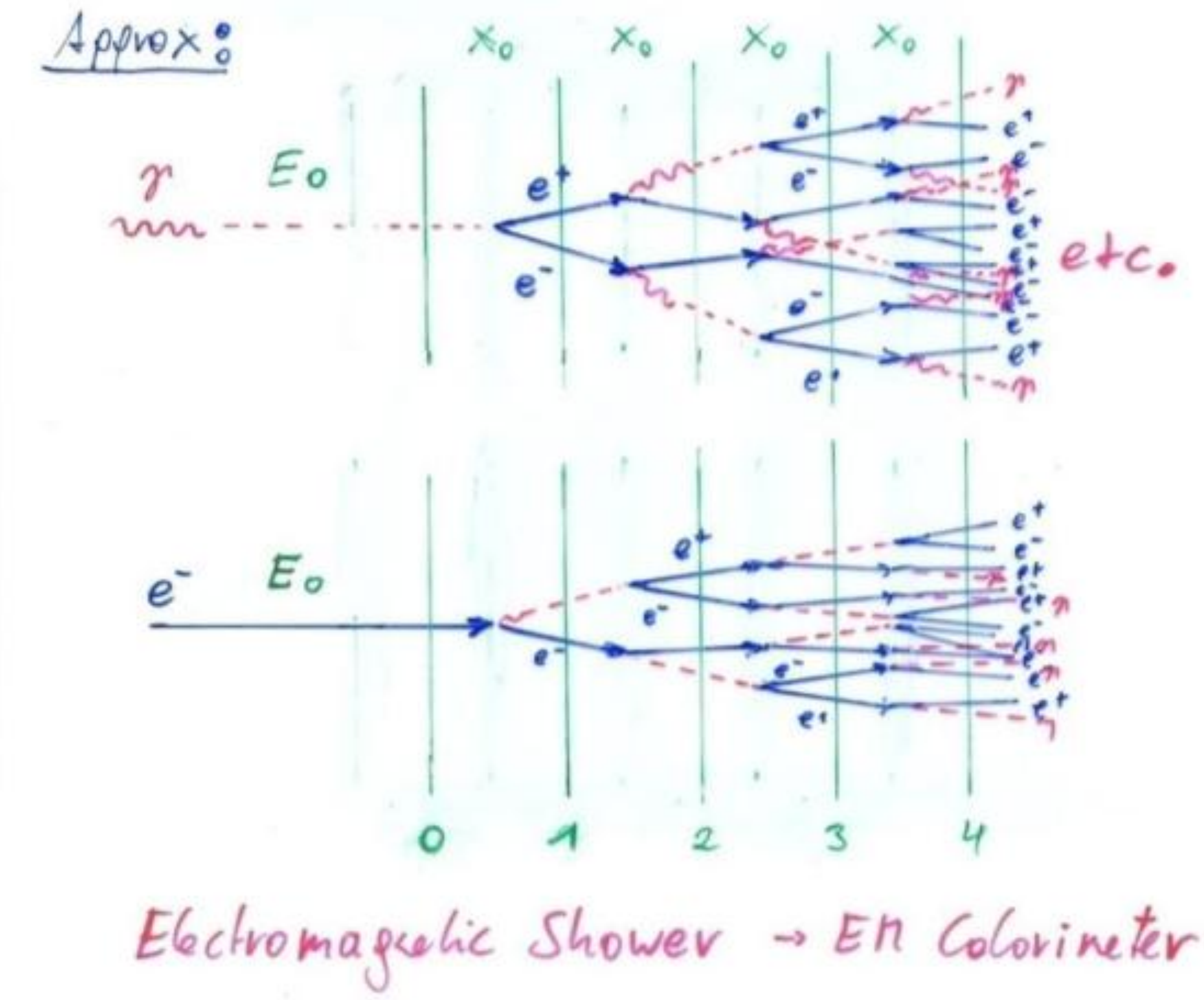
$$E_\gamma \geq 2m_e c^2$$

~1.022 MeV

➩ Reduction of photon intensity with passage through matter:

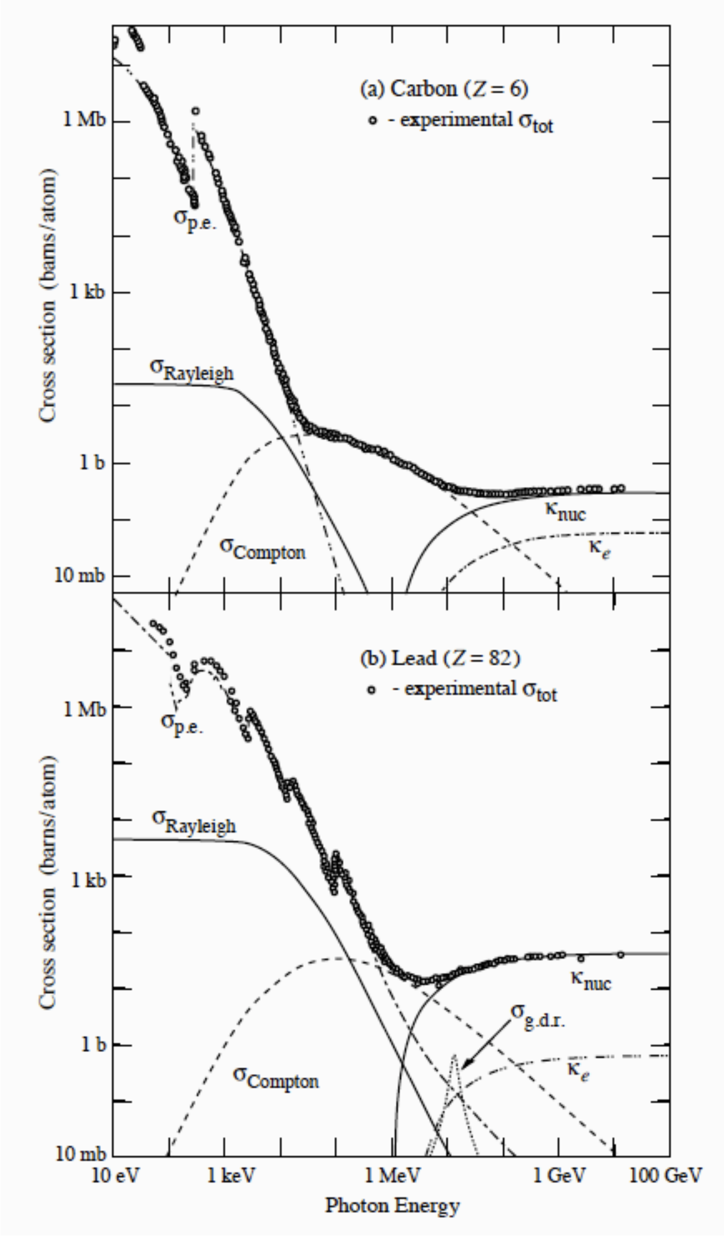
$$I(x) = I_0 e^{-\mu x}$$

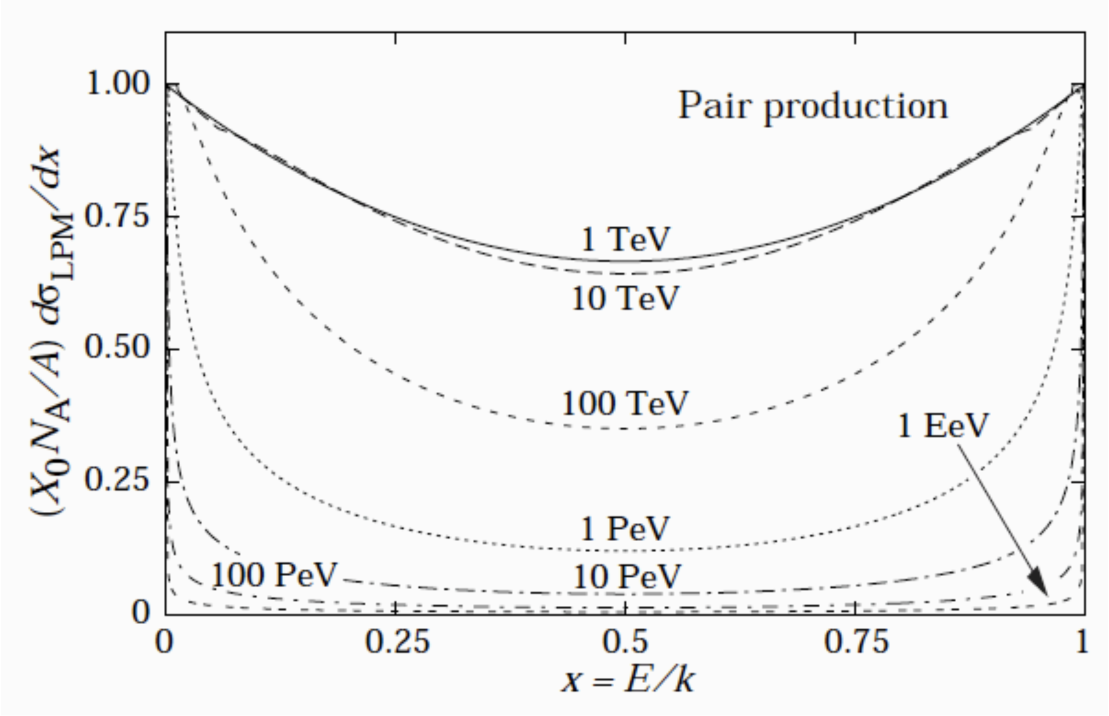
Bremsstrahlung + pair creation = electromagnetic shower!



Electromagnetic Shower → EM Colorimeter

Photons in matter





- At high energies, pair creation is dominating
- At low energies:
  - Photo electric effect
  - Coherent scattering: Rayleigh scattering
  - Compton scattering
  - Nucleus excitation

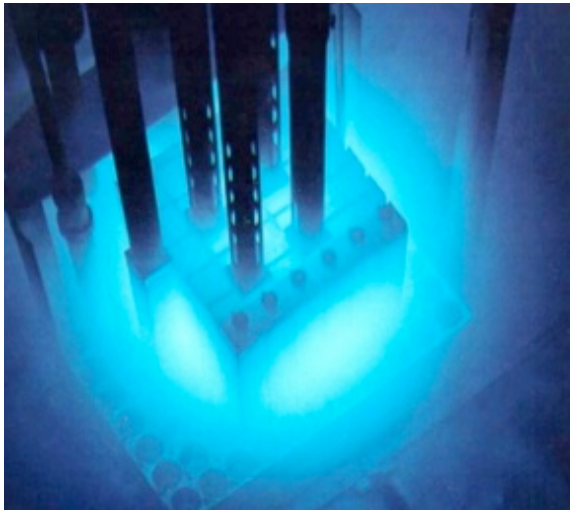
Other effects of photon emission

Two important effects:

- **Cherenkov radiation**

  "Sonic boom for charged particles"

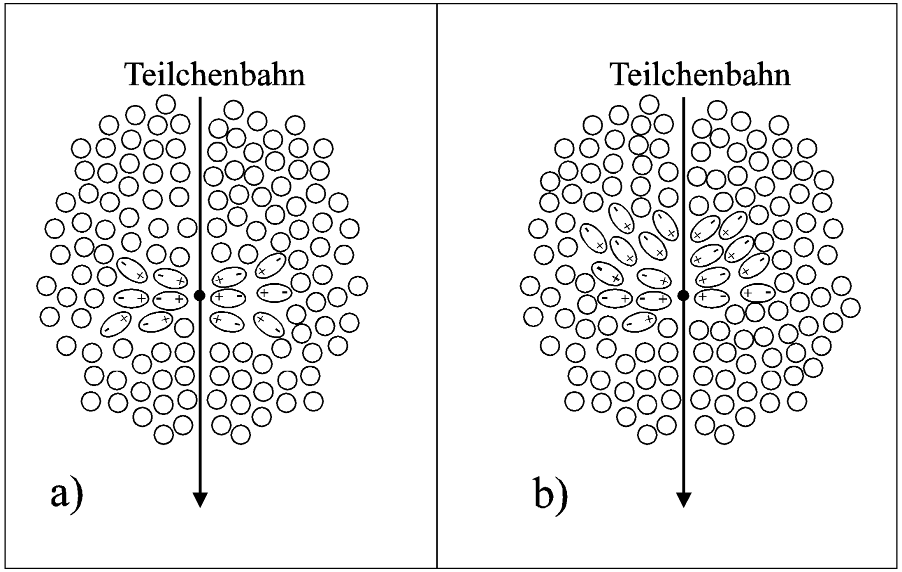
  - Very useful for particle identification



- **Transition Radiation**
  - is produced by relativistic charged particles when they cross the interface of two media of different dielectric constants
  - significant radiation only at large γ (O ~ 1000) in the keV range.
    Very useful for electron/pion separation

Both effects do not significantly contribute to the energy loss of the particles!

Cherenkov radiation



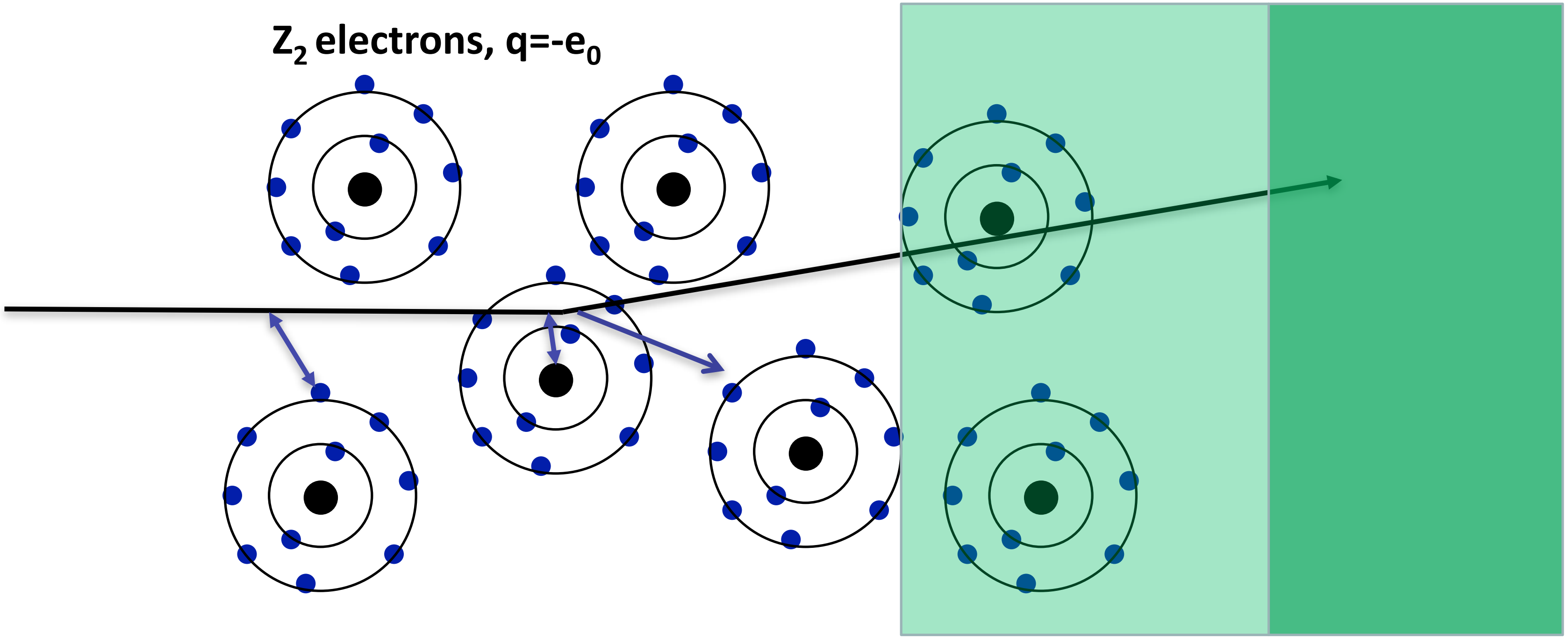
- Emission of photons when a charged particle is faster than speed of light within a medium: constructive interference

  Emission at a characteristic angle:

$$cos\theta_c = \frac{c\,t\,/\,n}{v\,t} = \frac{1}{n\beta}$$

wave length maximum
within UV

Electromagnetic interaction of particles with matter



Interaction with the atomic electrons. The incoming particle loses energy and the atoms are excited or ionised.

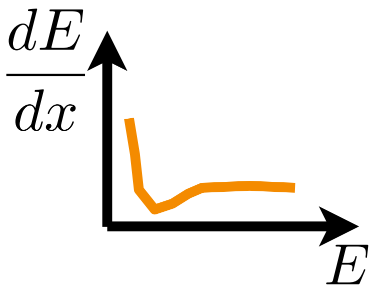
Interaction with the atomic nucleus. The particle is deflected (scattered) causing multiple scattering of the particle in the material. During this scattering a Bremsstrahlung photon can be emitted.

In case the particle's velocity is larger than the velocity of light in the medium, the resulting EM shockwave manifests itself as Cherenkov Radiation. When the particle crosses the boundary between two media, there is a probability of the order of 1% to produced and X ray photon, called Transition radiation.

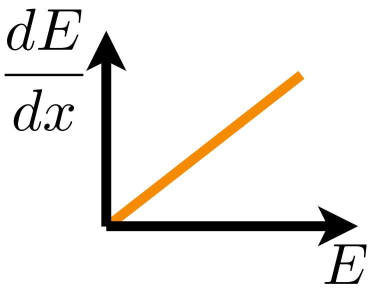
Another summary...

e^+/e^-

Ionisation

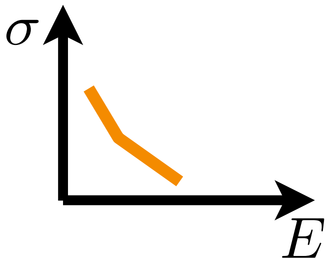


Bremsstrahlung

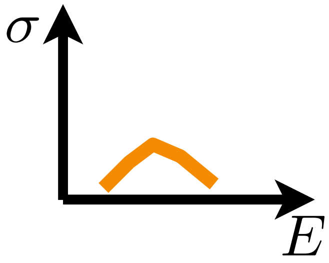


γ

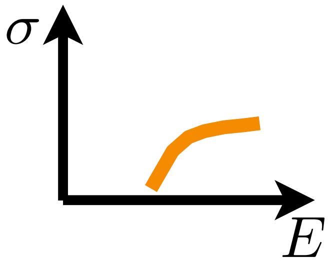
Photoelectric Effect



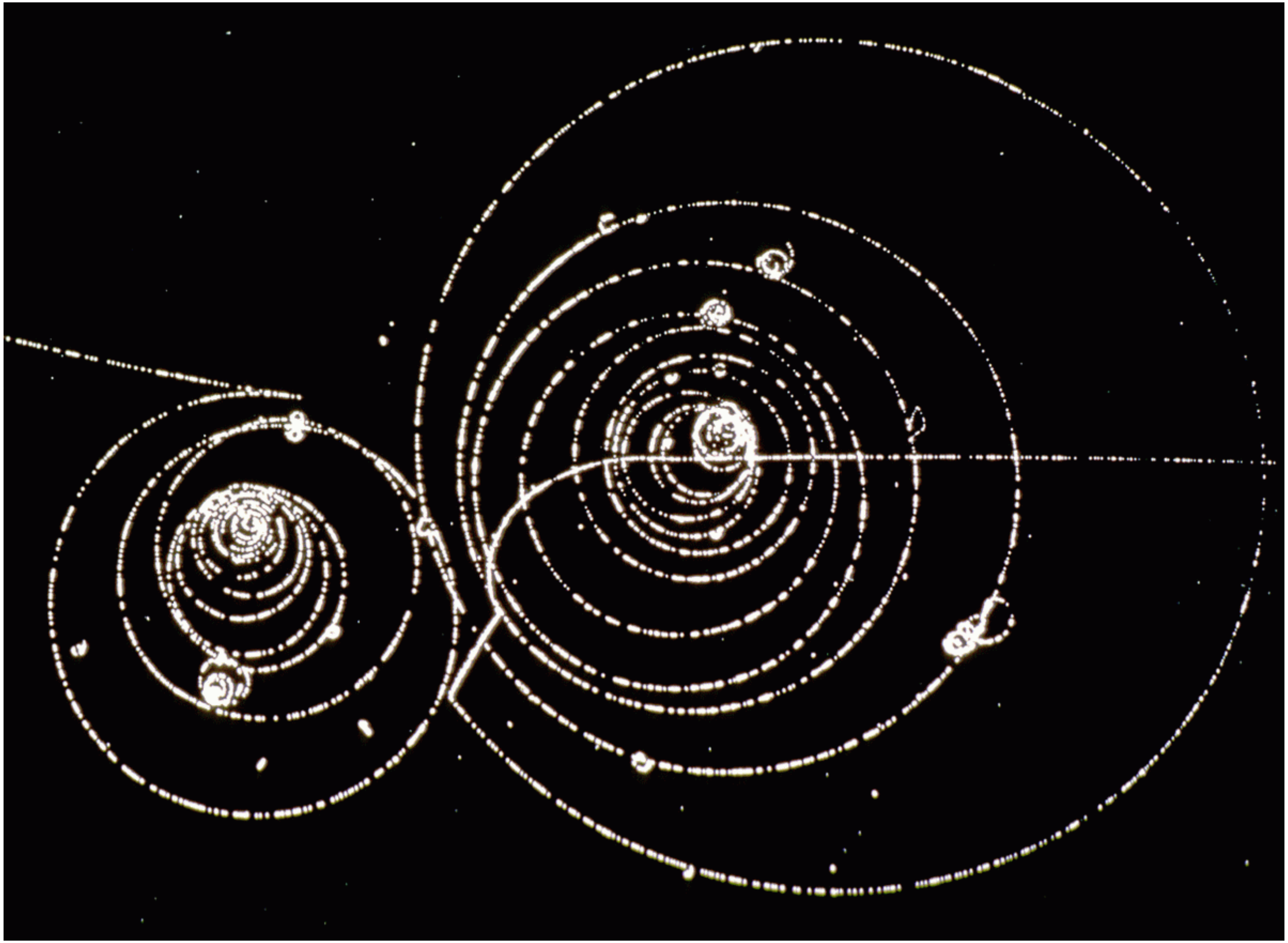
Compton Effect



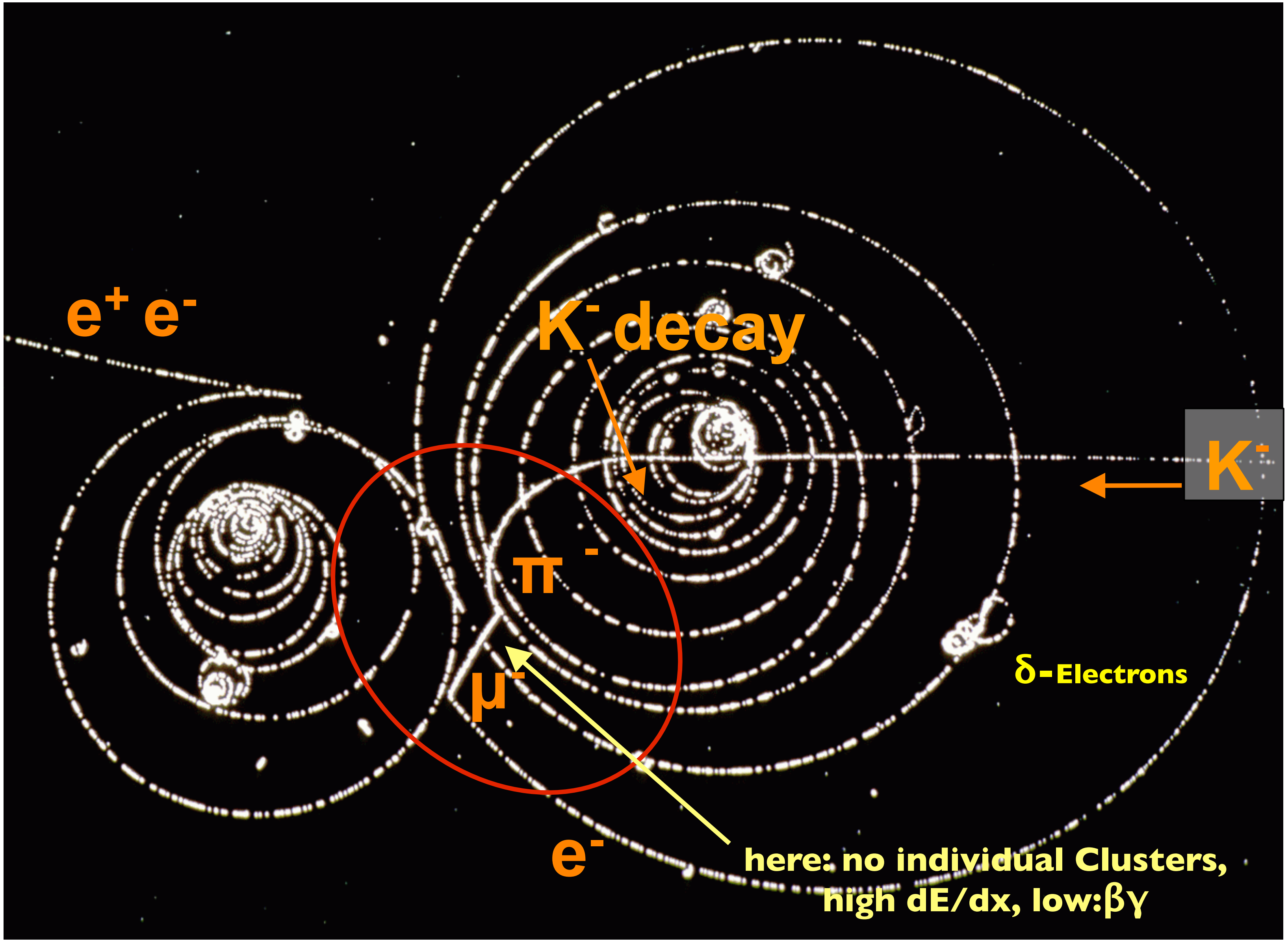
Pair Production



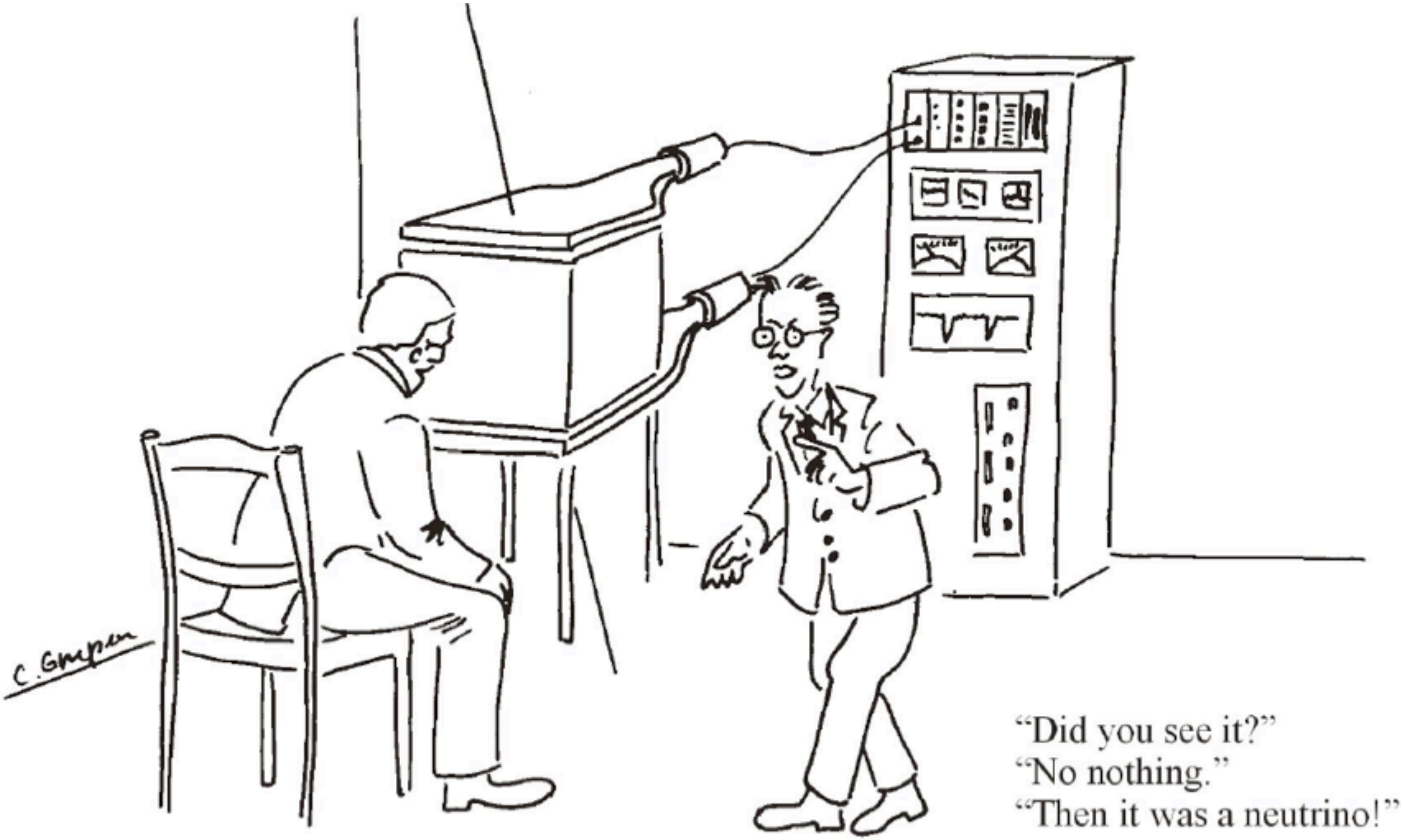
...and another one



A short summary



About neutrinos



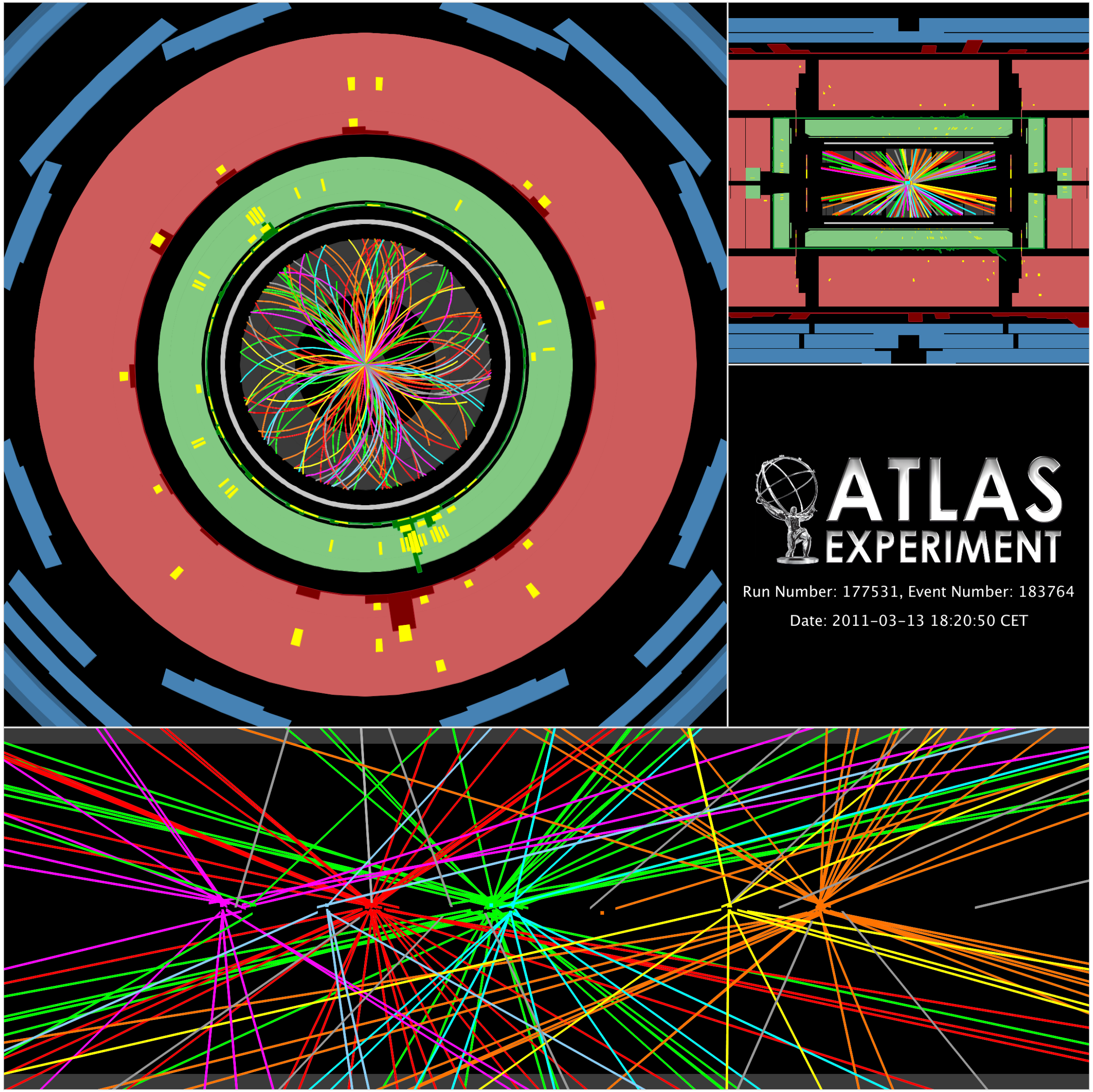
"Did you see it?"
"No nothing."
"Then it was a neutrino!"

Claus Grupen, Particle Detectors, Cambridge University Press, Cambridge 1996 (455 pp. ISBN 0-521-55216-8)

***… only true for experiments at accelerators.**
How to detect neutrinos: later this lecture

Tracking detectors

Tracking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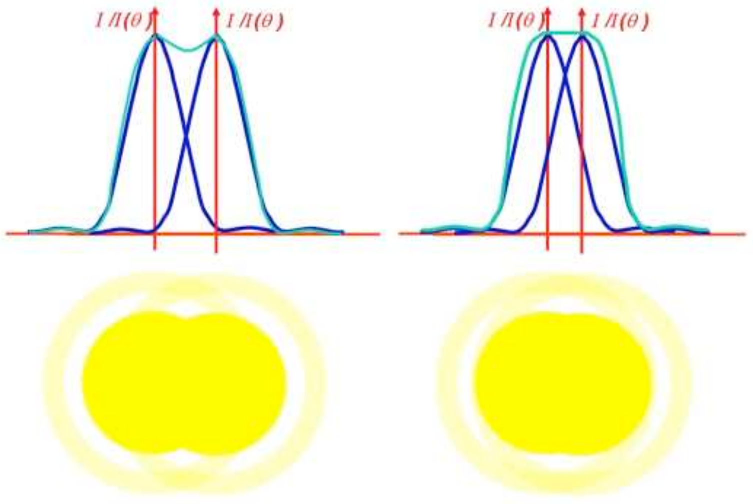
Date: 2011-03-13 18:20:50 CET

Tracking detectors: resolution



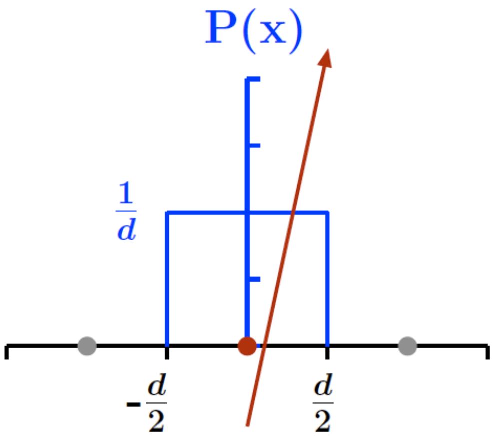
An important figure of merit is the resolution

- Depending on detector geometry and charge collection
  - Pitch (distance between channels)
  - Charge sharing between channels

Simple case: all charge is collected by one strip

- Traversing particle creates signal in hit strip
- Flat distribution along strip pitch; no area is pronounced

Probability distribution for particle passage:



$$P(x) = \frac{1}{d} \qquad \Rightarrow \int_{-d/2}^{d/2} P(x)\,dx = 1$$

The reconstructed point is always the middle of the strip:

$$\langle x \rangle = \int_{-d/2}^{d/2} x\,P(x)\,dx = 0$$

Tracking detectors: resolution

- Calculating the resolution orthogonal to the strip:

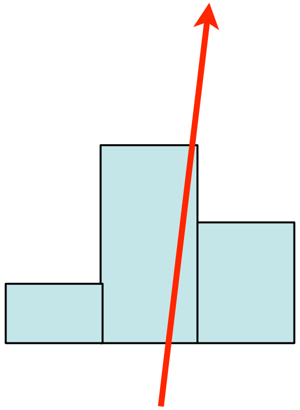
$$\sigma_x^2 = \langle (x - \langle x \rangle)^2 \rangle = \int_{-d/2}^{d/2} x^2 \, P(x) \, dx = \frac{d^2}{12}$$

- Resulting in a general term (also valid for wire chambers):

$$\sigma = \frac{d}{\sqrt{12}}$$

very important !

- For a silicon strip detector with a strip pitch of 80 µm this results in a minimal resolution of ~23µm
- In case of charge sharing between the strip (signal size decreasing with distance to hit position)
  - Resolution improved by center of gravity calculation



Determination of the particle momentum

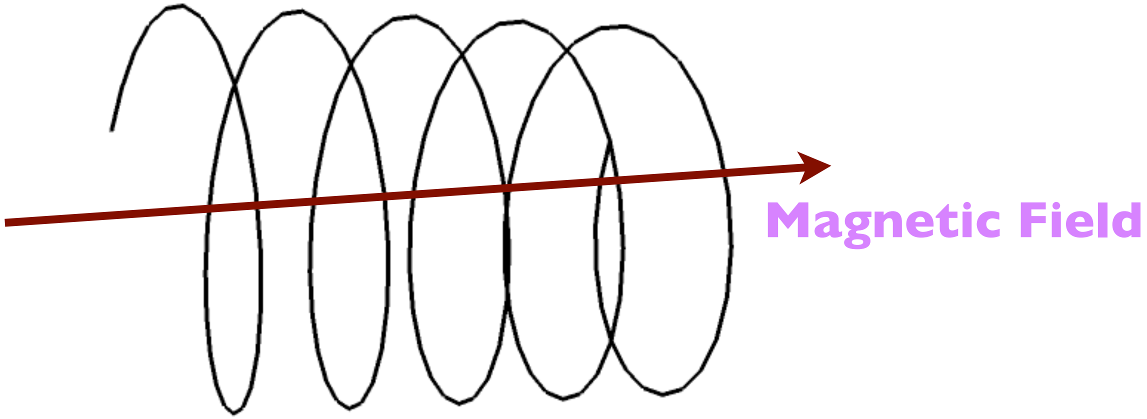
- A tracking detector is typically placed within a B-field to enable momentum measurements
- Charged particles are deflected in a magnetic field:
  - takes only effect on the component perpendicular to the field

Radius of the circular path is proportional to the transversal momentum:

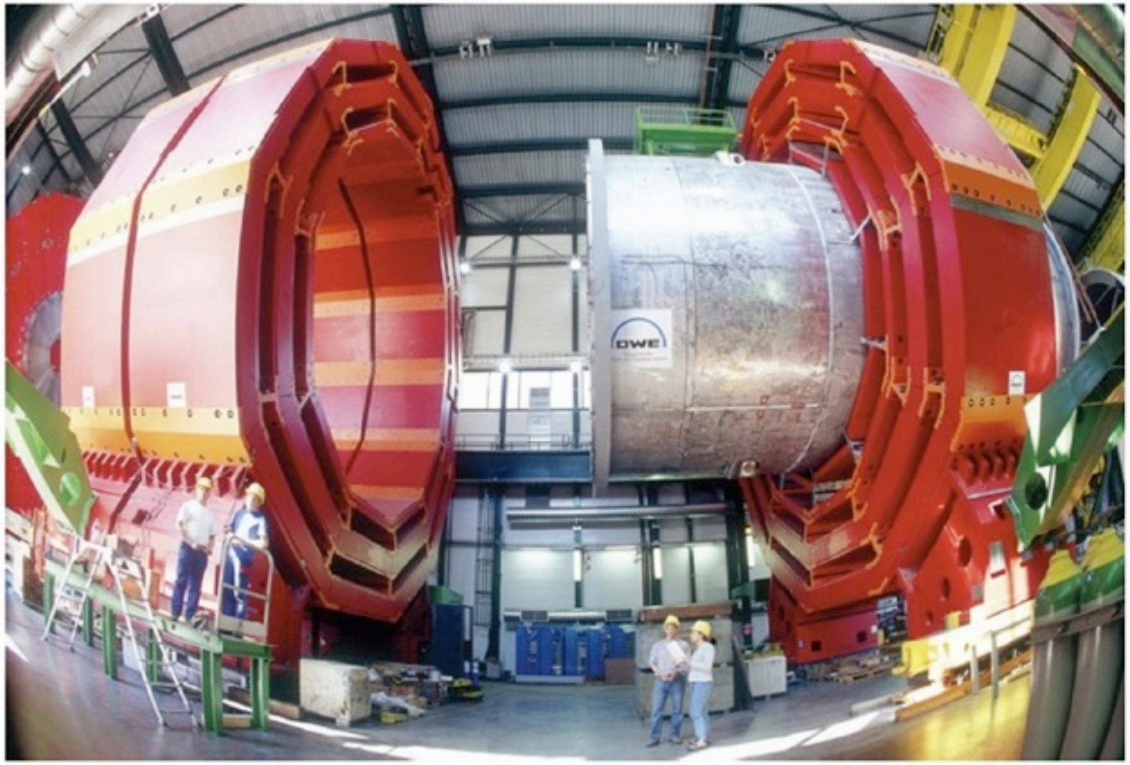
$$\boxed{\frac{p_T}{\mathrm{GeV}/c} = 0.3\,\frac{B}{\mathrm{T}}\,\frac{r}{\mathrm{m}}}$$

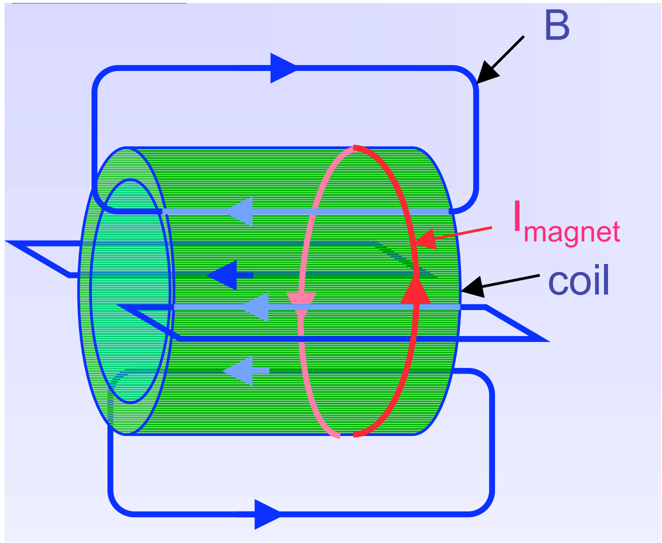
- parallel to the field is no deflection:

➯ particle is moving on a helix, the radius is determined by the field and p_T



Magnet concept: CMS → one solenoid



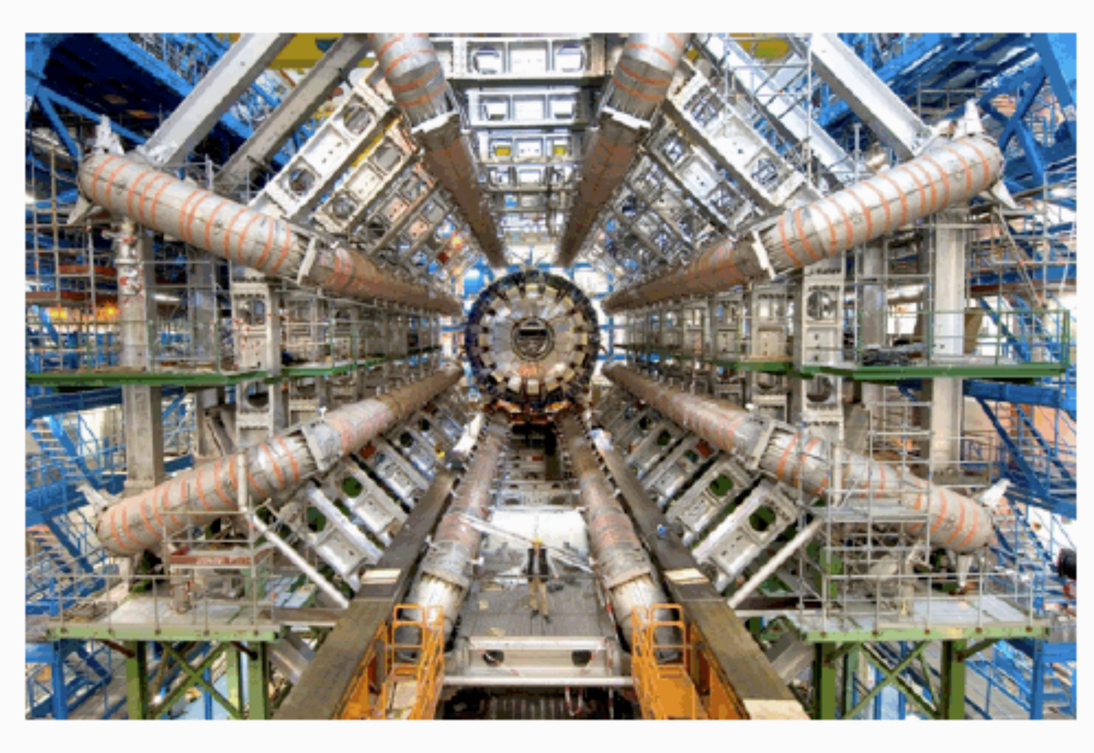


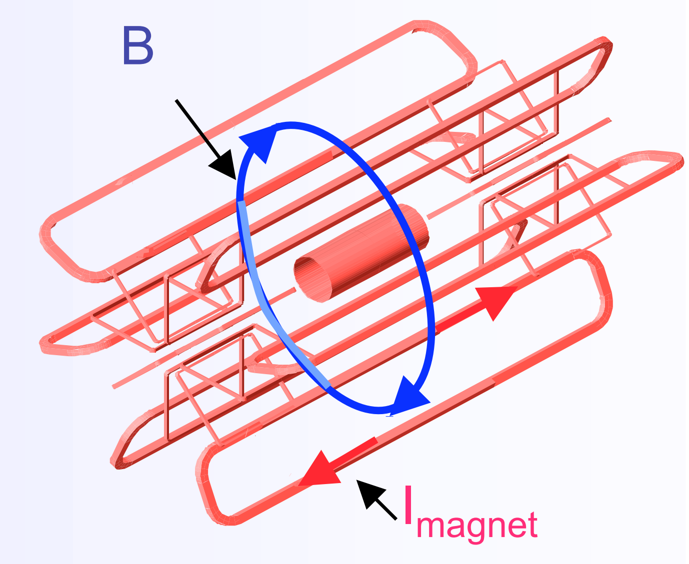
- Largest Solenoid in the world:
  - superconducting, 4 T field
  - encloses trackers and calorimeter
  - 13 m long, inner radius 5.9 m, I = 20 kA, weight of coil: 220 t

+ large homogeneous field inside coil
+ weak opposite field in return yoke
- size limited (cost)
- relative high material budget

Magnet concept: ATLAS ➔ toroid

the largest magnet in the world

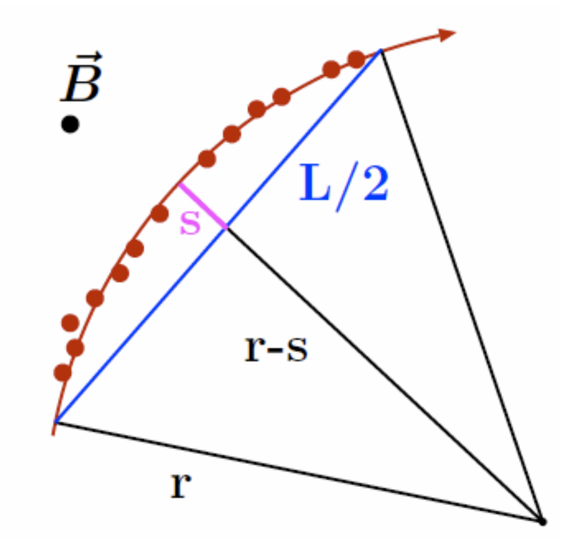




- Central Toroid field within Muon-System: 4 T
  - Closed field, no yoke
  - Complex field
- 2 T Solenoid-field for trackers

\+ field always perpendicular to p_T
\+ relative large field over large volume
\- non uniform field
\- complex structure

Determination of the particle momentum



- In real applications usually only slightly bent track segments are measured
  - Figure of merit: Sagitta s

Segment of a circle: $$s = r - \sqrt{r^2 - \frac{L^2}{4}}$$

$$\Rightarrow \ r = \frac{s}{2} + \frac{L^2}{8s} \approx \frac{L^2}{8s} \ (s \ll L)$$

With the radius-momentum-B-field relation: $$r = \frac{p_T}{0.3\,B} \Rightarrow s = \frac{0.3\,B\,L^2}{8\,p_T}$$

In general, for many measurement points:

$$\frac{\sigma(p_T)}{p_T} = \frac{\sigma(x)}{0.3\,B\,L^2}\sqrt{720/(N+4)}\,p_T$$

➠ The larger the magnetic field B, the track length L and the number of measurement points, and the better the spacial resolution, the better is the momentum resolution
ex.: N =7, L = 0.5m, B = 2T, σ(x) = 20 μm, p_t = 5 GeV/c:
$\Delta p_t / p_t$ = 0.5 %, r = 8.3 m, s = 3.75 mm

Momentum resolution

Spatial resolution and multiple scattering (MS)

- Two components are influencing the resolution $\sigma(p_T)/p_T$ of a tracking system

- Inaccuracy of the tracking detector: $\sigma(p_T) \propto p_T$
- Influence of the particle due to MS:

$\theta \propto \frac{1}{p}$ and therefore also the spacial imprecision: $\sigma(x)_{MS} \propto \frac{1}{p}$

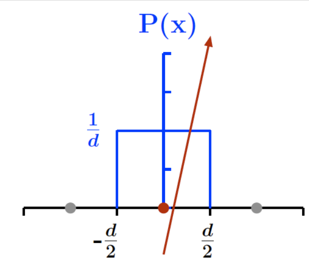
Known: $$\frac{\sigma(p_T)}{p_T} \propto \sigma(x)_{MS} \times p_T$$

and therefore $$\left.\frac{\sigma(p_T)}{p_T}\right|_{MS} = const$$

The measurement of low momentum particles is limited by multiple scattering!
At higher momenta the spacial resolution of the detector is dominating!

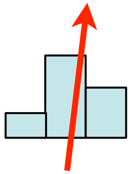
Tracking detectors: important parameters

- Spatial resolution:



$$\sigma = \frac{d}{\sqrt{12}}$$ in case of a binary read out (only information of hit or not hit)

Better in case of analog readout (signal size added to the information)



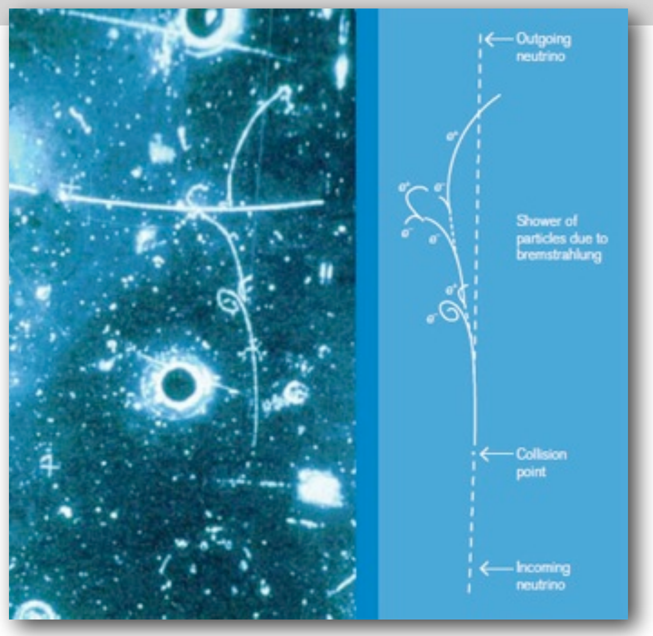
- Detection efficiency: probability to detect a particle; typically 99.x% for one layer -> e.g. 7 layer system:

$$\epsilon = 0.99 \qquad \epsilon = 0.98$$
$$\epsilon^7 = 0.93 \qquad \epsilon^7 = 0.87$$

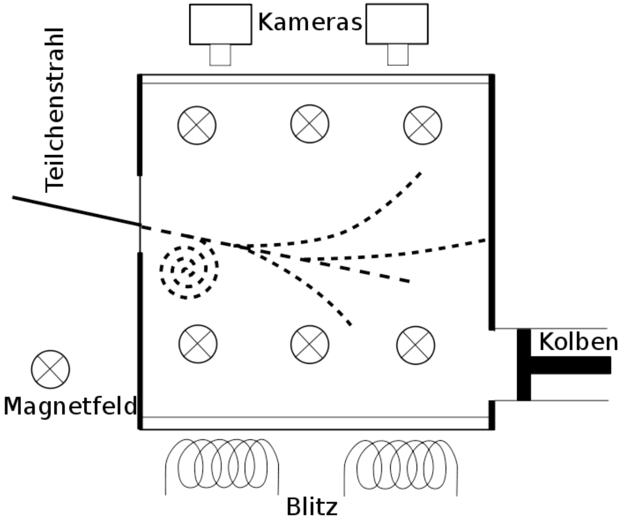
- Momentum resolution
- $$\frac{\sigma(p_T)}{p_T} = \frac{\sigma(x)}{0.3\,B\,L^2}\sqrt{720/(N+4)}\,p_T$$

- Signal/noise ratio: signal size for a certain input signal (i.e. a Mip) over the intrinsic noise of the detector (better than 15 ….)

“Classic” tracking detectors: Bubble Chambers



Discovery of neutral currents
Gargamelle, 1972



Invented by Donald Glasser 1952 (NP 1960)

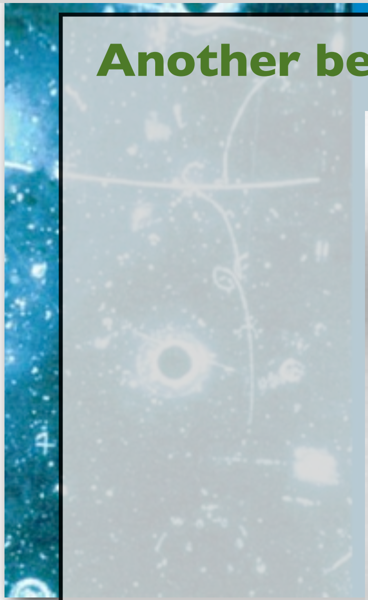
- A vessel filled with a superheated transparent liquid (most often liquid hydrogen) used to detect electrically charged particles moving through it
- Superheat is reached by suddenly decreasing the pressure

Pros:
High resolution and a complete picture
of the reaction is gained.

Cons:
Very slow, complex analysis of the data (manually using a photo)

“Classic” tracking detectors: Bubble Chambers

Another beautiful pro: bubble chamber photos were scanned by “scanning girls”



ansparent liquid (most

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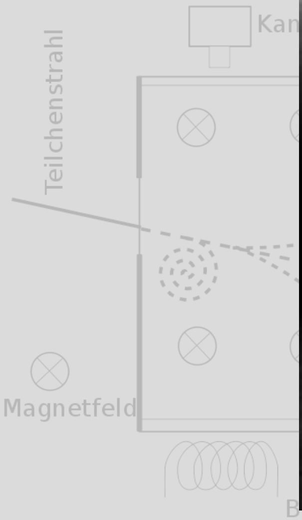
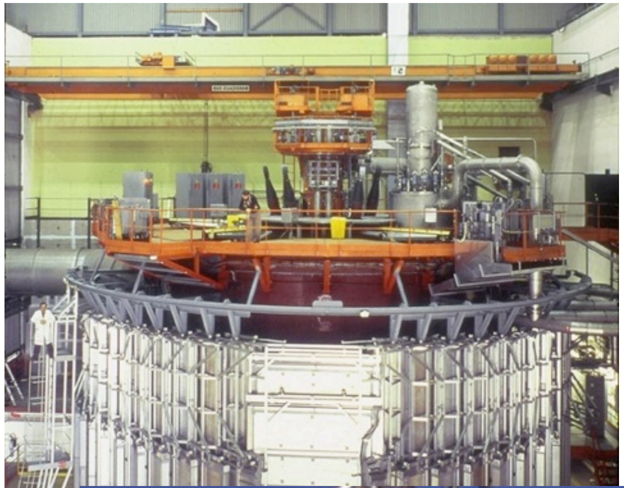
photo)

Discovery of neutral

Gargamelle, 1972

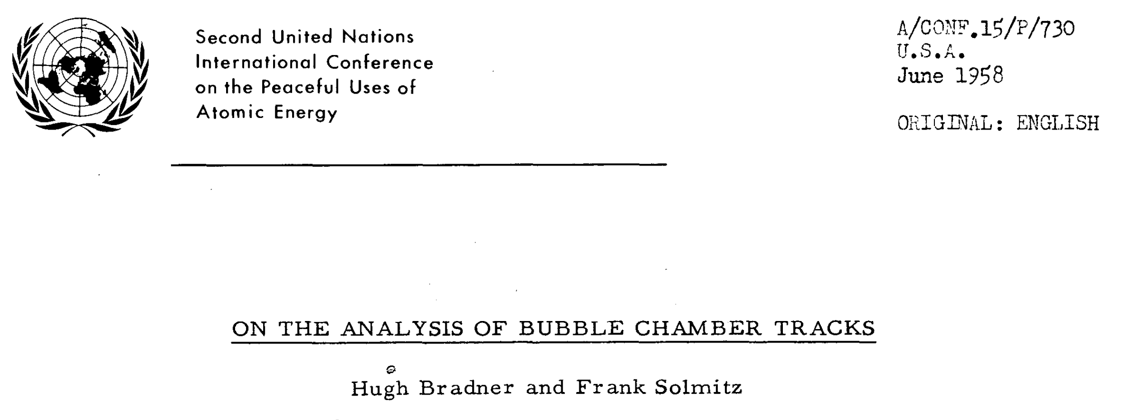


Bubble chambers



- The biggest: Big European Bubble Chamber
  - 3.7 m diameter
  - Until 1984 used at CERN for the investigation of neutron hadron interactions

Early report on bubble chamber analysis:



Second United Nations
International Conference
on the Peaceful Uses of
Atomic Energy

A/CONF.15/P/730
U.S.A.
June 1958

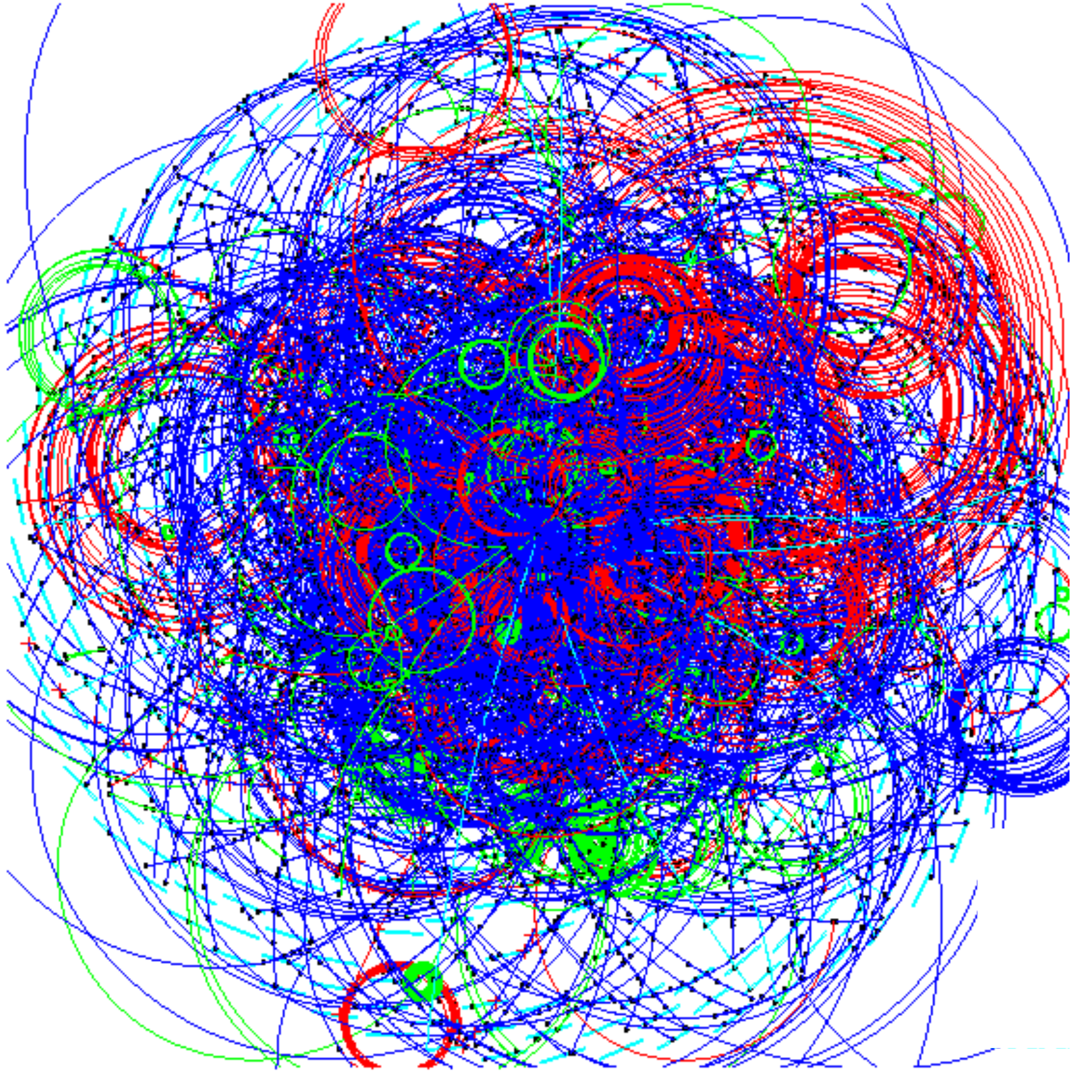
ORIGINAL: ENGLISH

ON THE ANALYSIS OF BUBBLE CHAMBER TRACKS

Hugh Bradner and Frank Solmitz

… the large number of possible reactions, the variability of appearance of interaction, and the importance of being alert to possible new phenomena make it very important for a trained physicist to look at the bubble chamber pictures….

Requirements for (LHC) tracking detectors



E.g. search for
$H \rightarrow Z^0 Z^0 \rightarrow \mu^+\mu^-\mu^+\mu^-$

with $\Delta m_Z < 2\text{GeV}$
up to $p_z \sim 500\text{GeV}$

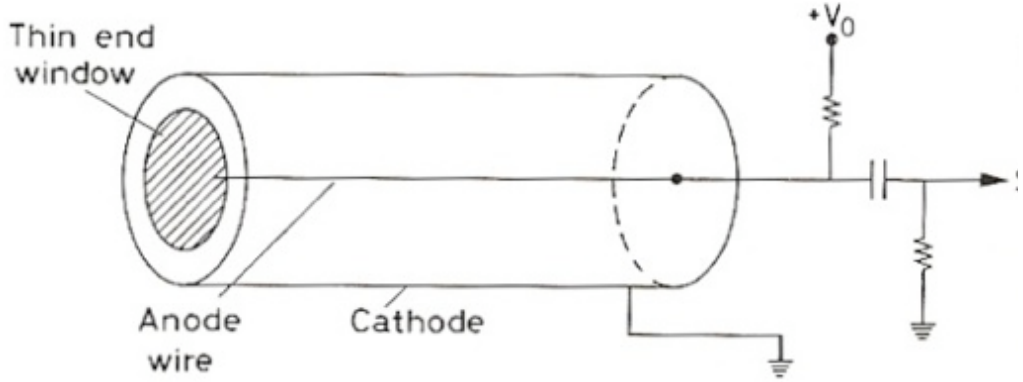
➙ reconstruction of high p_t tracks with

+ high efficiency
  - single track $\varepsilon > 95\%$
  - in jet $\varepsilon > 90\%$
+ momentum resolution
  - $\Delta p_t/p_t = 0.01$ pt [GeV]

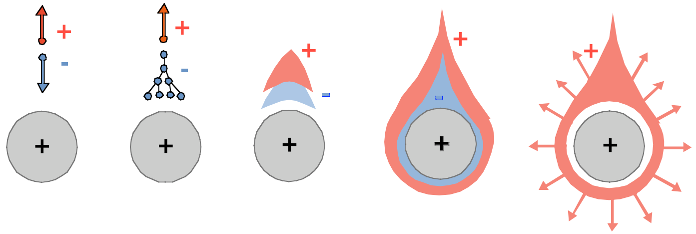
Tracking detectors

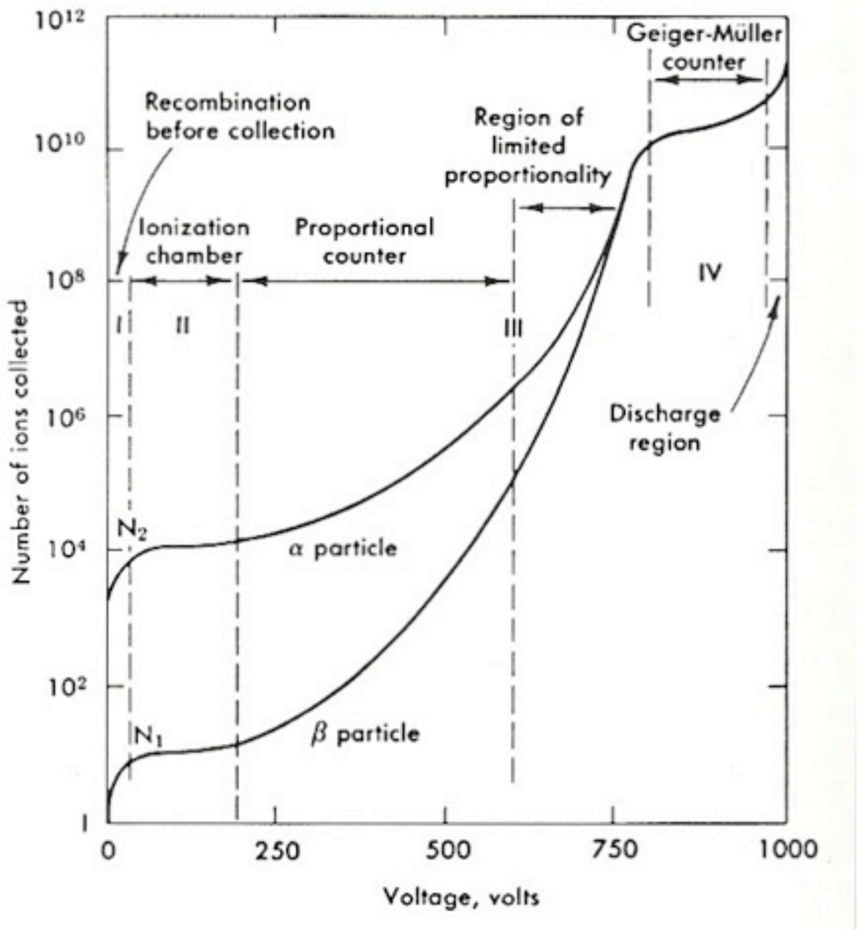
Gaseous detectors

A classical one: the ionisation chamber



Signal

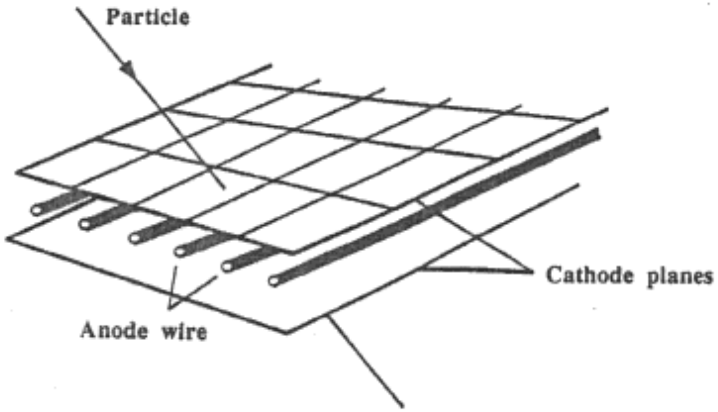


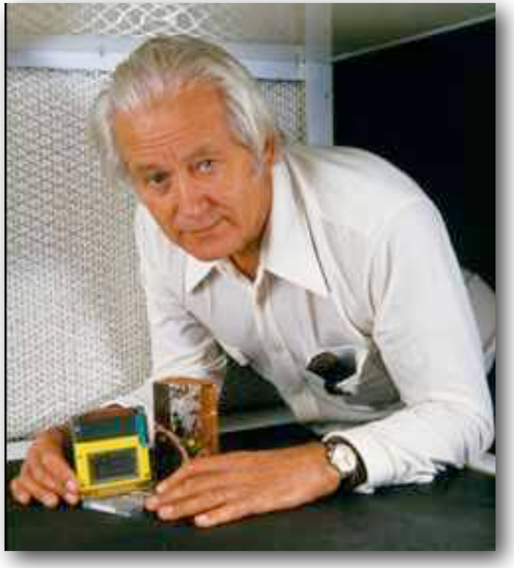


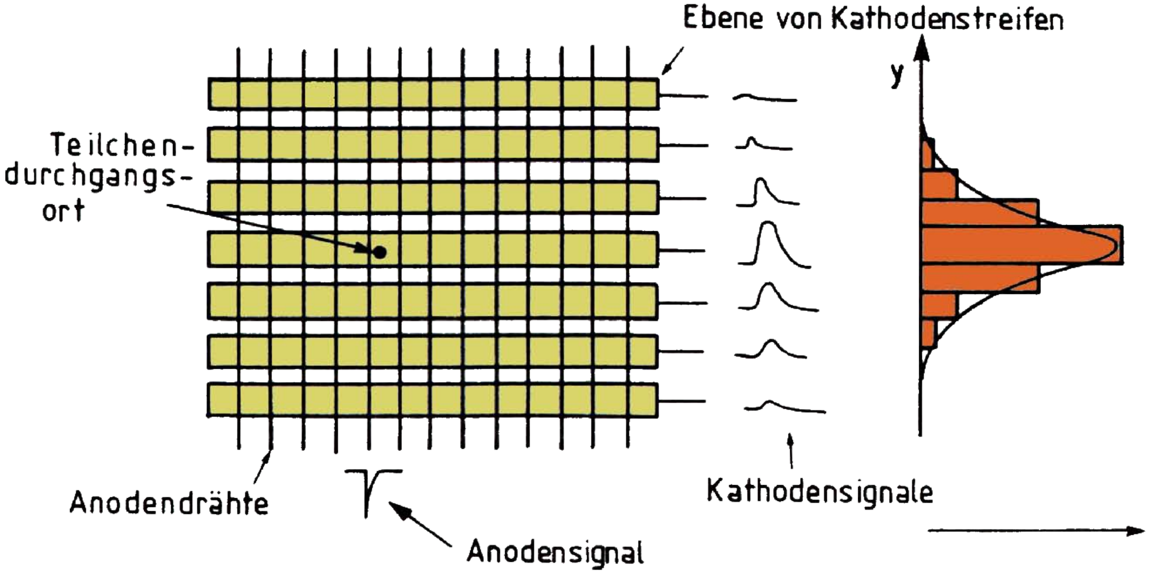
- Passage of particles creates within the gas volume electron-ion pair
- Electrons are accelerated in a strong electrics field → amplification
- The signal is proportional to the original deposited charge or is saturated (depending on the voltage)

Improving the ionisation chamber

- Adding spatial information by adding more wires
- **Multi wire proportional chamber** (MWPC)
- Gas-filled box with a large number of parallel detector wires, each connected to individual amplifiers
- First time applied and invented by G. Charpak 1968







Using more info: adding timing

- Drift chamber

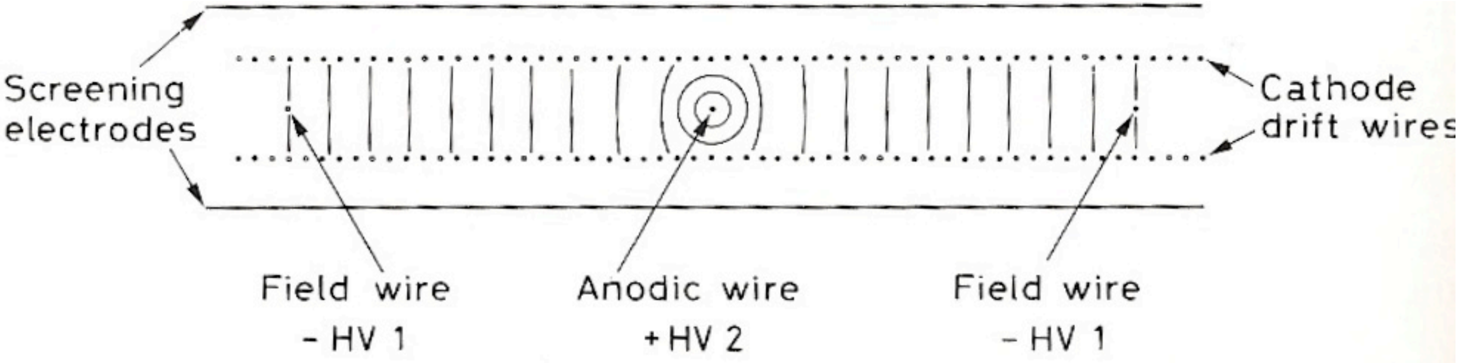
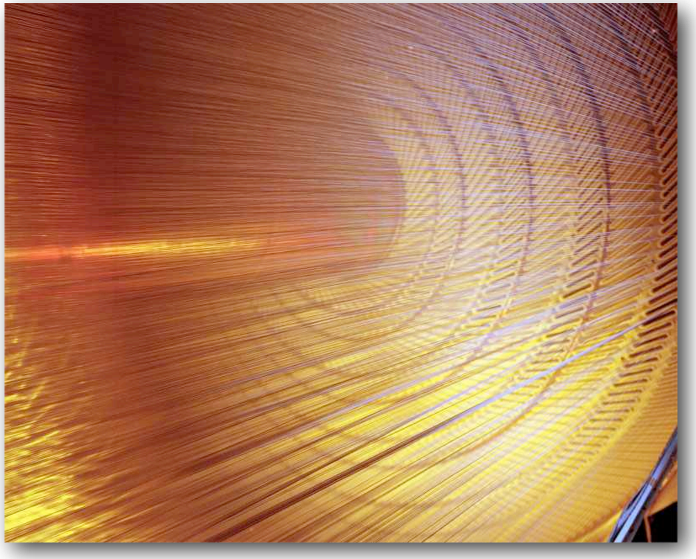


Fig. 6.16. Drift chamber design using interanode field wires (from *Breskin* et al. [6.22])

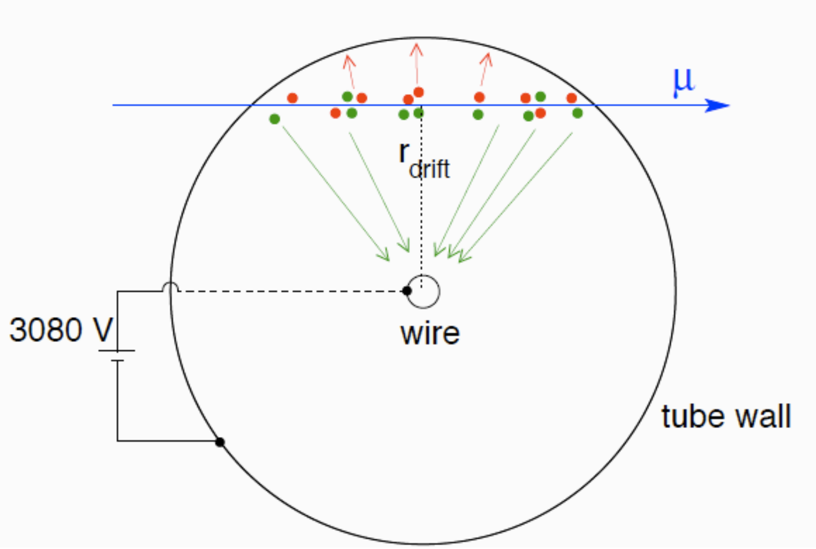
- The electric field is designed in a way that the electrons drift with a constant velocity and only amplify very close to the wire
- If the time of arrival of a particle is known (trigger), one can from the signal arrival time at the anode derive the position of the track
- Condition: the HV field distribution and therefore the drift velocity within the gas is well known

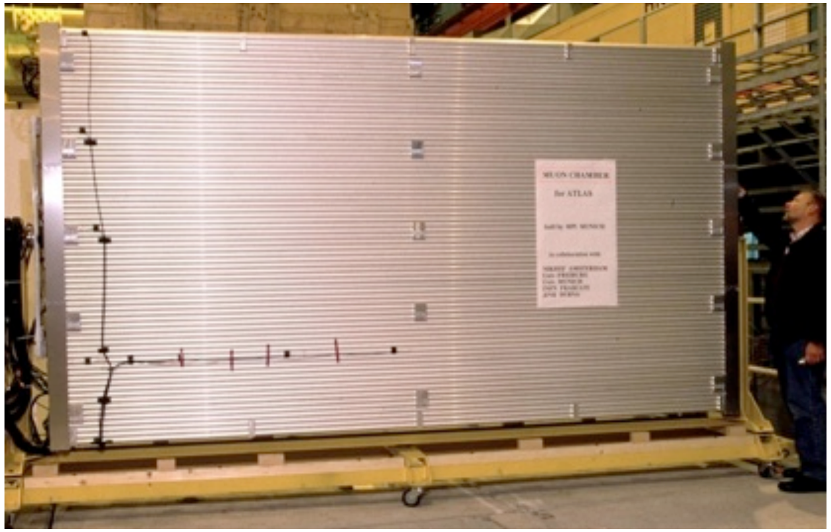


Wire chamber
CDF (@Tevatron)

Commonly used: drift tubes

Example: ATLAS Muon System

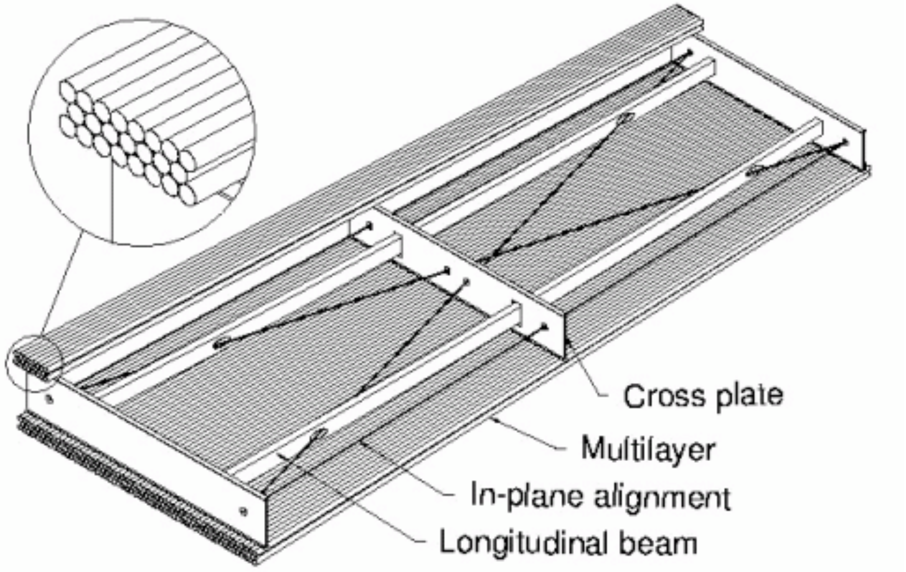




Measurement of the drift time: defines the smallest distance of the track to the wire

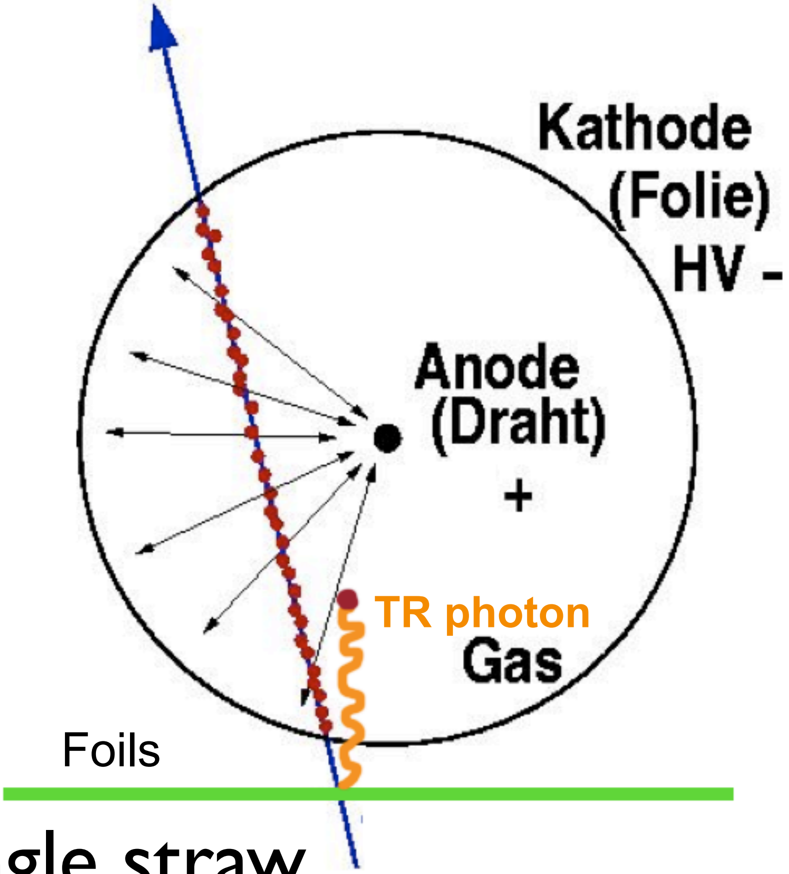
➪ right/left ambiguity: multiple layers shifted to each other necessary

➪ spatial resolution typically ~100 μm

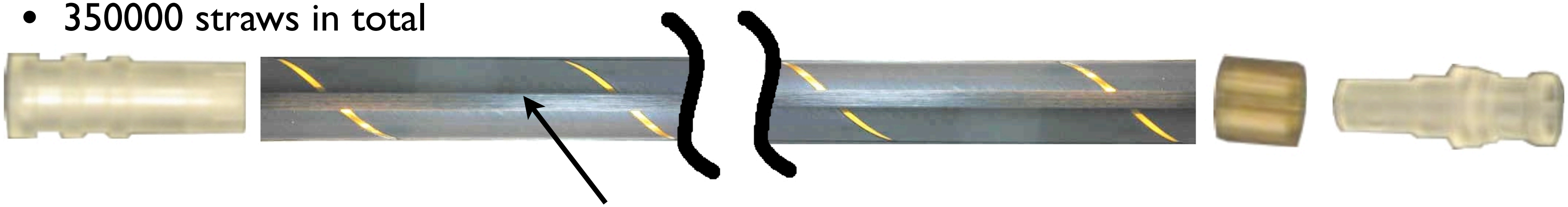


The ATLAS TRT

- Transition radiation -> X-ray photon is emitted when charged particle traverses boundary of materials with different di-electrical properties
- Depends strongly on the relativistic factor of the particle which makes it usable for particle identification
- used at LHCb, ATLAS
- advantages: additional info to tracking: ⇒ particle identification
  - not (too) expensive
  - robust (assembly & transport)
- ATLAS Transition Radiation Tracker
  - 35 track points
  - 350000 straws in total



A single straw



stiff straw, supported by **carbon fibre strips**, allows self supporting structures, thus reduced material inside the detector

An LHC detector’s story

Example: the ATLAS TRT

- 1989: R&D for the TRT begins (1990: RD6)
- 1994: LHC machine approved. First full-size TRT prototype completed (10’000 channels for end-cap wheel)
- 1996-1998: major Technical Design Reports for ATLAS construction approved, test beams
- 2000: assembly of barrel modules and end-cap wheels start.
  Front-end electronics specified and vendor chosen.
- 2002: wire-joint trouble
- 2003-2004: web trouble
- 2000-2007: many other troubles
- 2006: first cosmic tracks recorded
- 2006: installation of barrel ID in ATLAS
- 2007: installation of ID end-caps in ATLAS
- 2008: TRT routinely operated, first LHC beam seen (beam splashes)
- 2009: first proton collisions recorded
- 2010: first high energy proton collisions

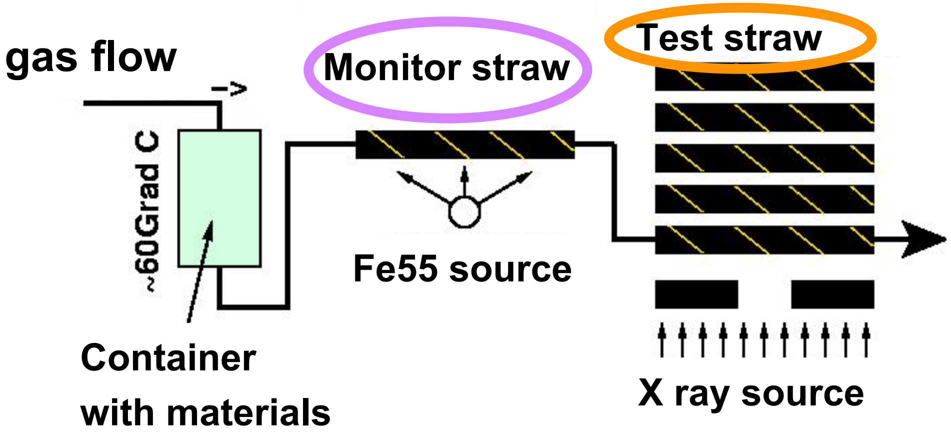
Challenges for an LHC detector

Example: ATLAS TRT challenges

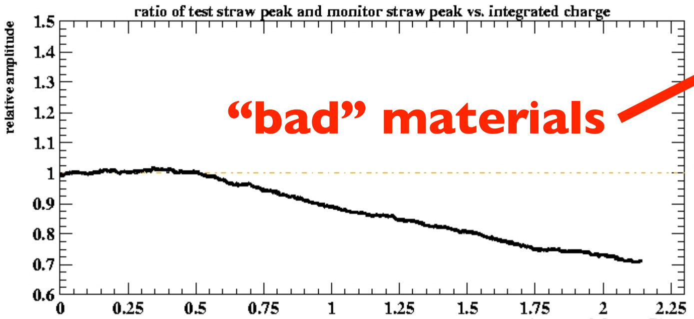
- Very high occupancy: up to 30%
- Very high counting rate: up to 20 MHz/straw
- Short bunch crossing interval: 25 ns
- High spatial resolution, good pattern recognition: need many points for measurement
- Radiation environment: ~10MRad, 10^{14} n/cm^2 year
- Fast and chemically passive straw gas: ageing!
- Chemically resistant straw materials: operating straw works as an electrochemical reactor
- Minimum amount of material (in radiation lengths)
- Extremely precise and robust mechanical structure, ~100mkm/few m =~10^{-5}
- Temperature stable: cooling

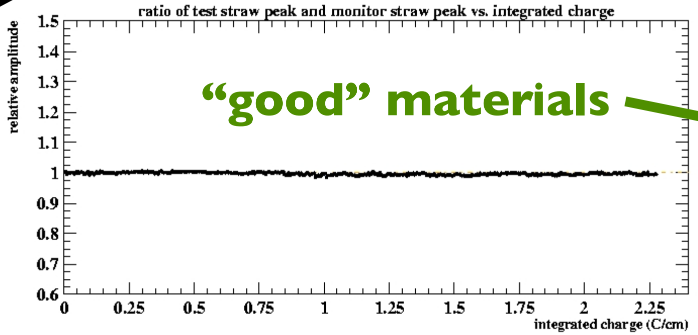
Detector@LHC: Systematic radiation tests of all materials used

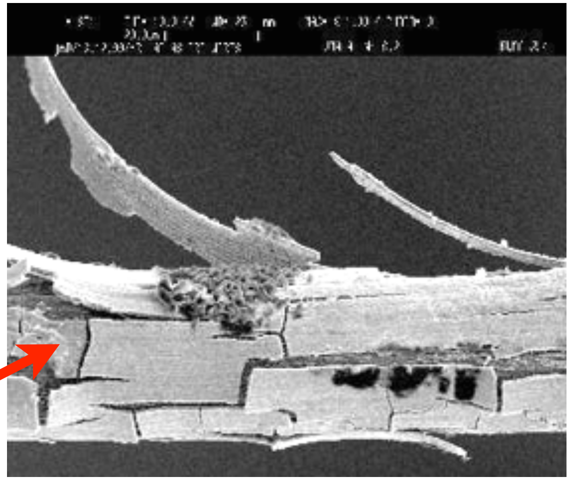
Example: ATLAS TRT wire tests

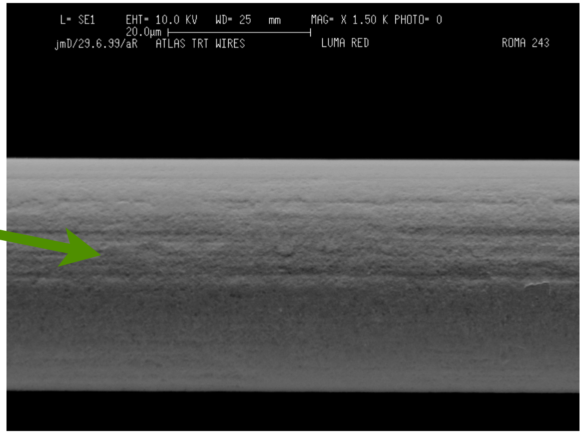


Comparison of time dependent signal amplitude for monitor straw and test straw





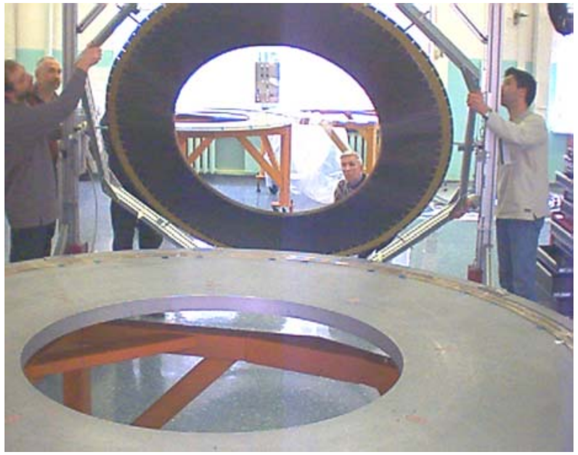




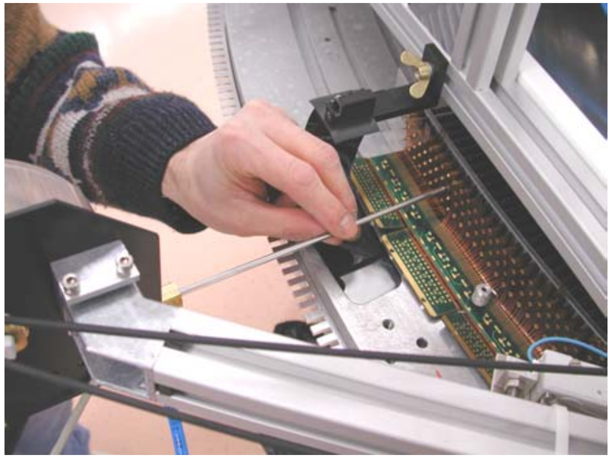
TRT end cap wheel production

- basic element: wheel with 4 straw planes

Installation of straws
(tests leak tightness)

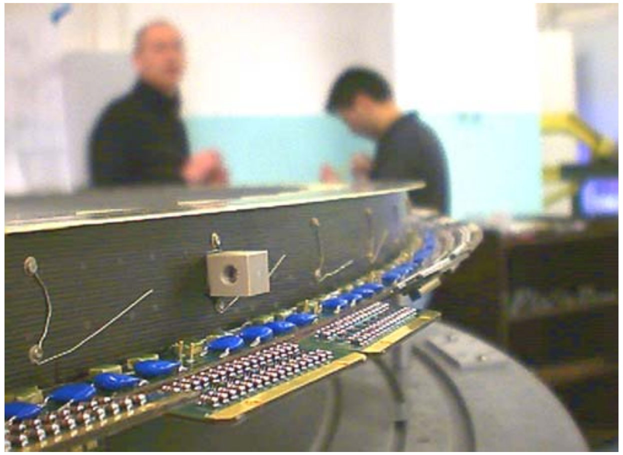


Transfer of wheel…

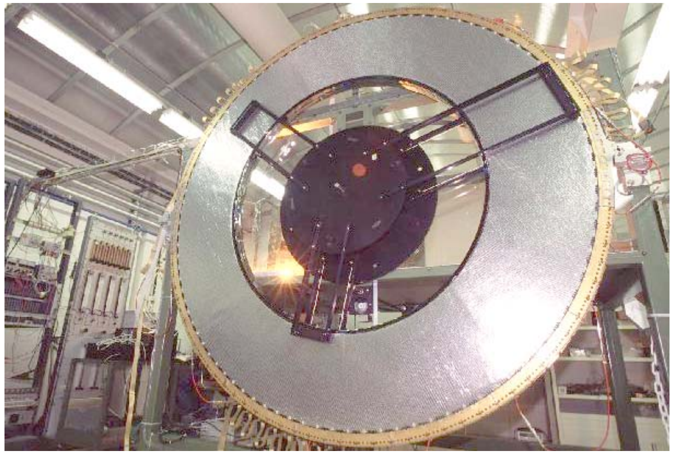


…to string wires

Fixating and connecting wires
(tests wire tension & HV)



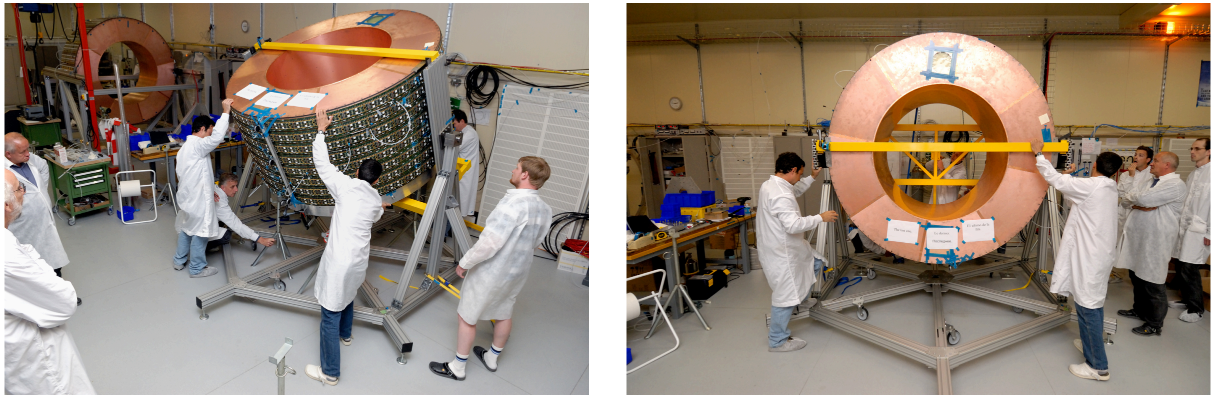
Sealing of wheel
(tests leak tightness & HV)



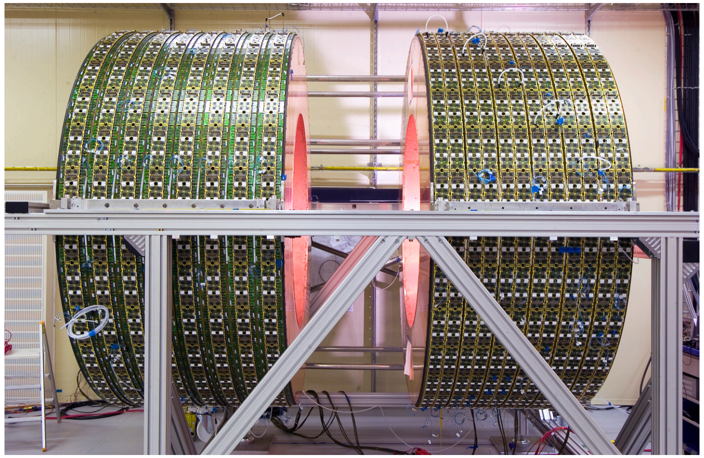
Final acceptance tests
(test wire centricity etc.)

Mounting TRT end cap

After the wheels have been stacked...

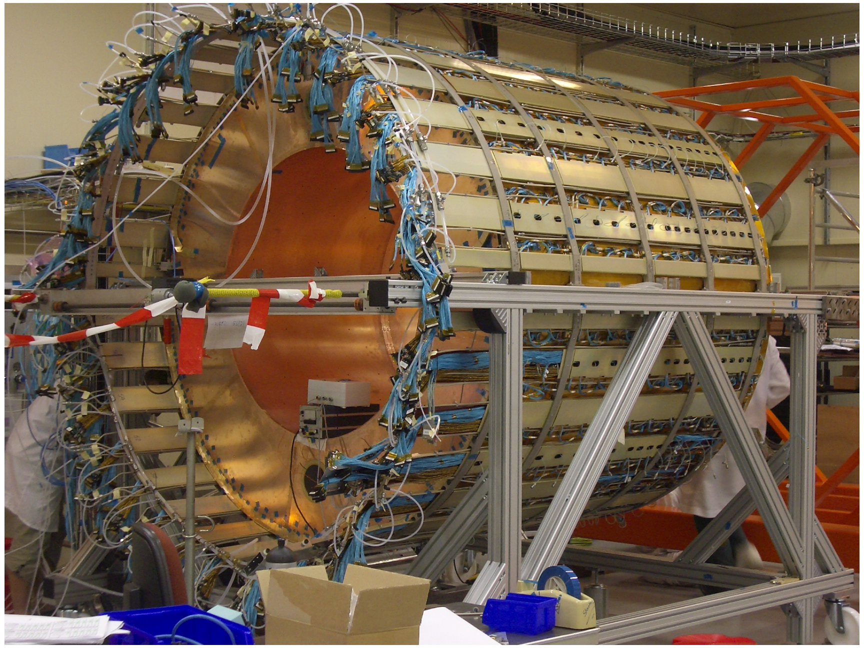


...the stack is rotated.



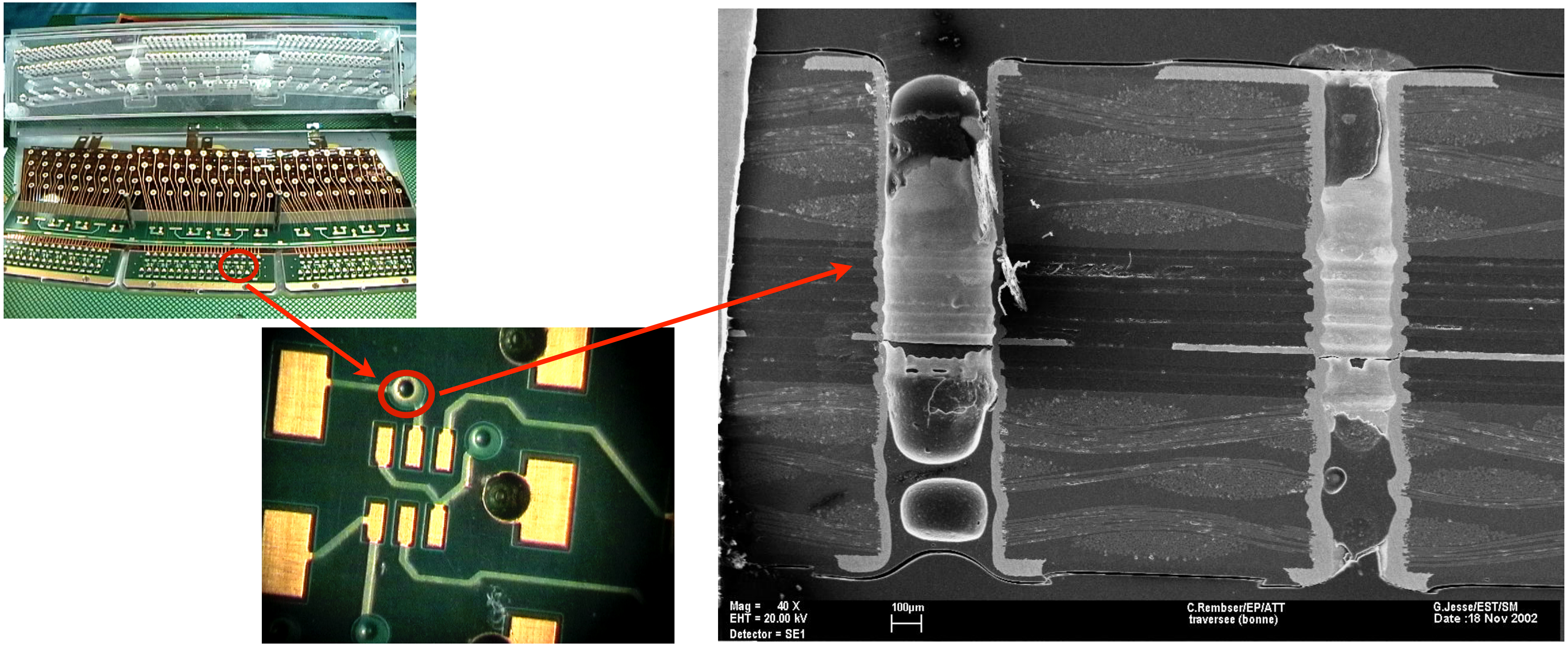
The two stacks of an end cap

The ready end cap, with all cables, pipes and supports (0.8% dead channels; ~50 man years of work)



Bad surprises (1)

- Wheel end cap electronics boards
  (connecting straws to HV, read-out and main mechanical structure of end-caps)
  - ➡ many problems during production and manufacturing

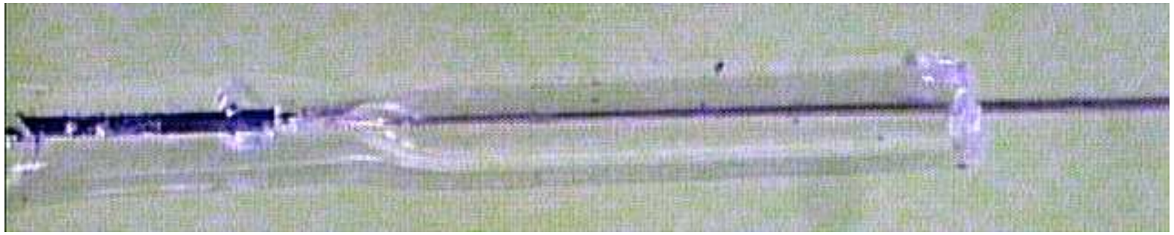


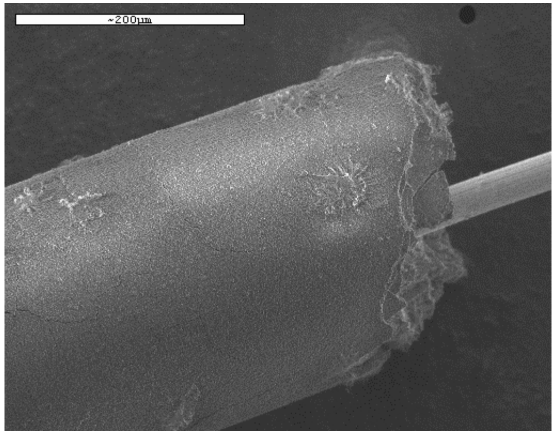
When building detectors

- ensure excellent quality control!!!
- ensure good contact to production companies!!!

Bad surprises (2)

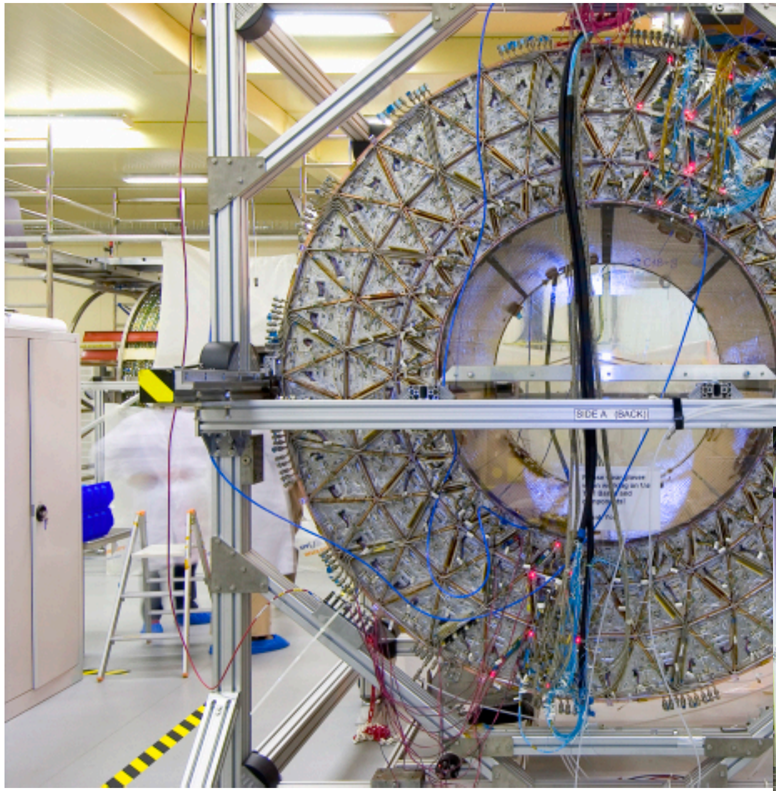
- Original TRT gas mixture (70% Xe, 20% **CF_4**, 10% CO_2) was destroying the detector (2002)
  - ➡ glass wire joints of barrel TRT “melting” with radiation 0.3-04 C/cm, less than 1 year nominal LHC operation
  - ➡ Reason: hydrofluoric acid HF



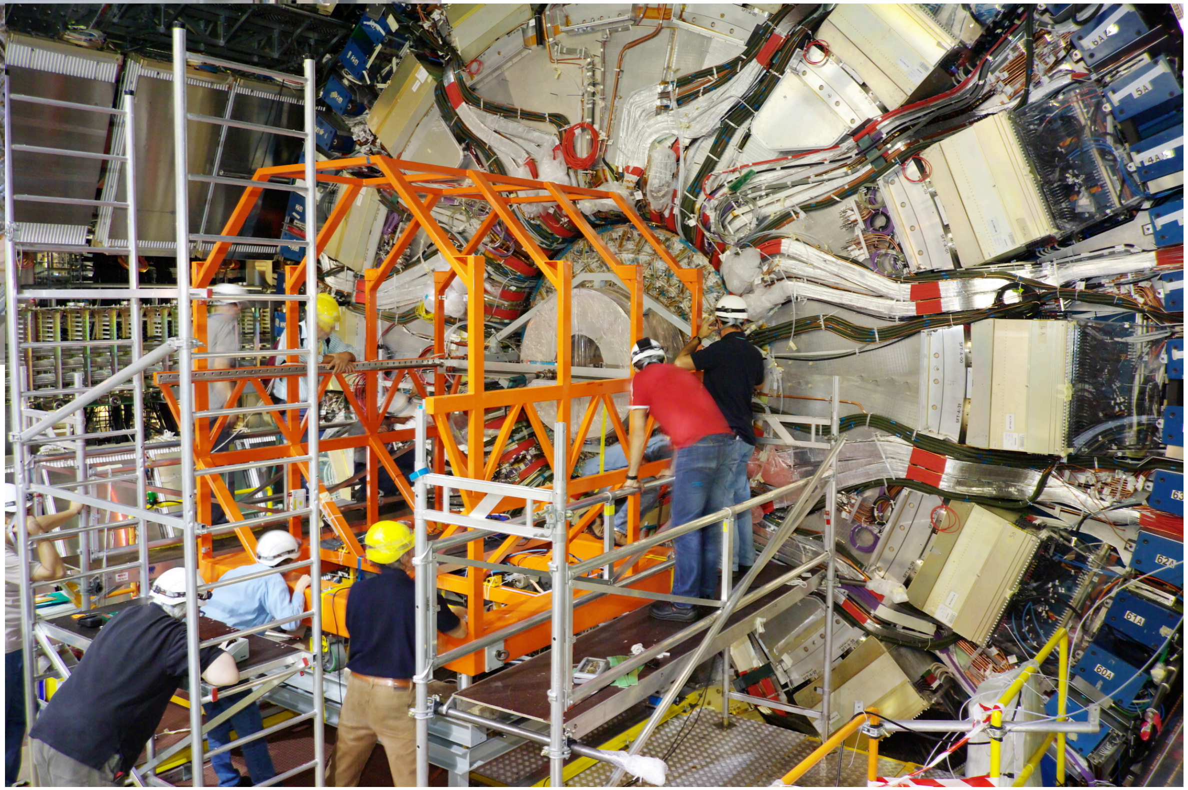


- Within one year, a new mixture was developed 70% Xe, 27% CO_2, 3% O_2
  - ➡ O_2 very unusual, strong quencher (“eats” electrons)
  - ➡ only works for TRT as straws have small diameter (lucky!)

But we managed...



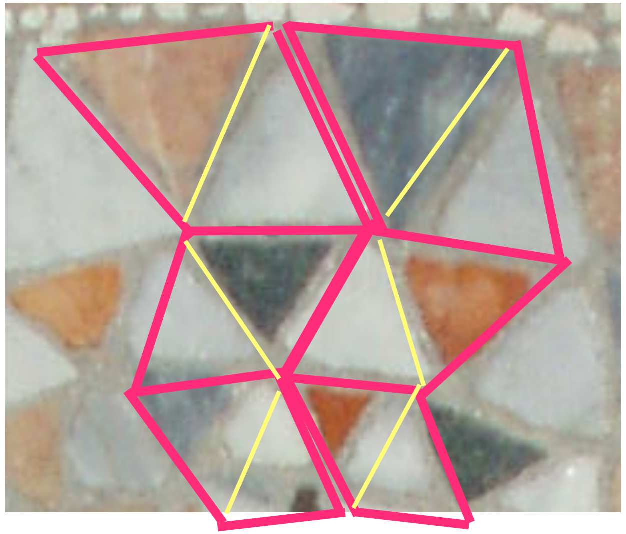
The TRT barrel in the assembly site



Installation into ATLAS

Inspired by a historical design (?)

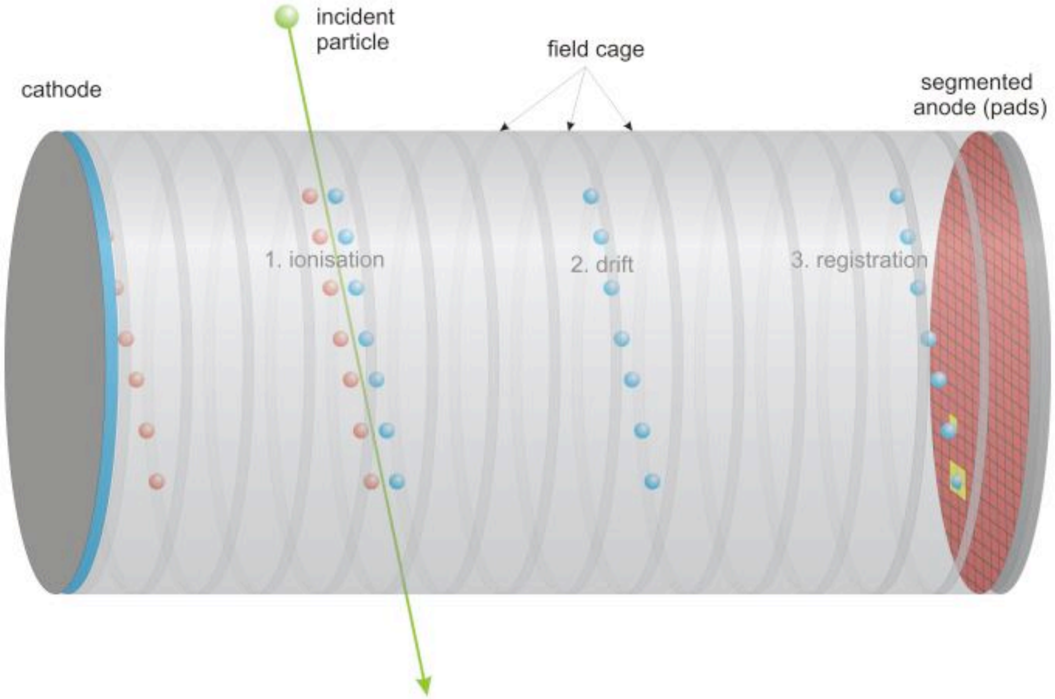
- ATLAS - a 12th century mosaic in the Otranto cathedral in Italy

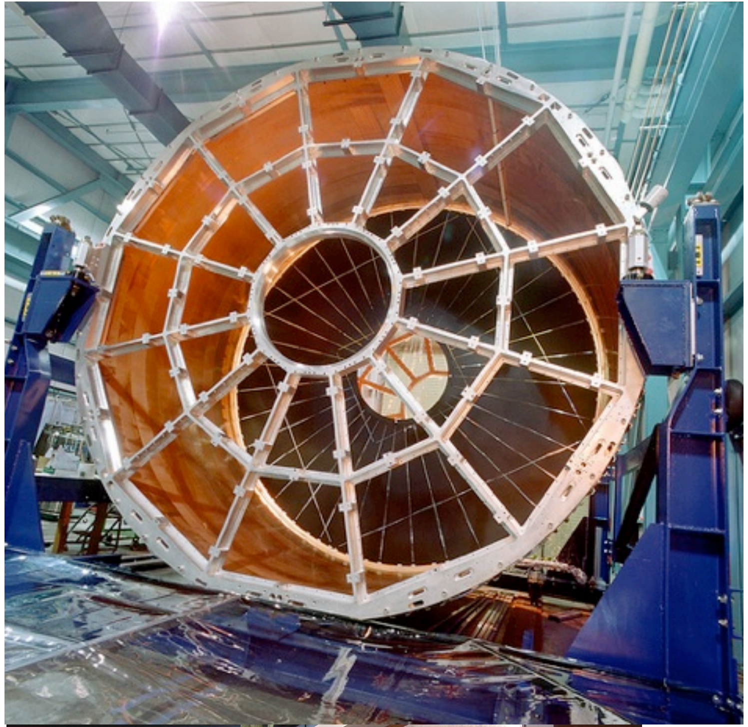


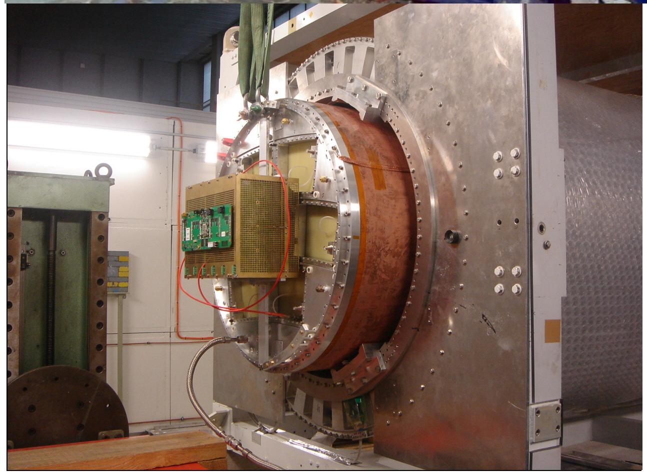
“Original” design has foreseen 4 layers.

Time Projection Chambers

- Combination of the the 2D track information and the time results in a real 3D point



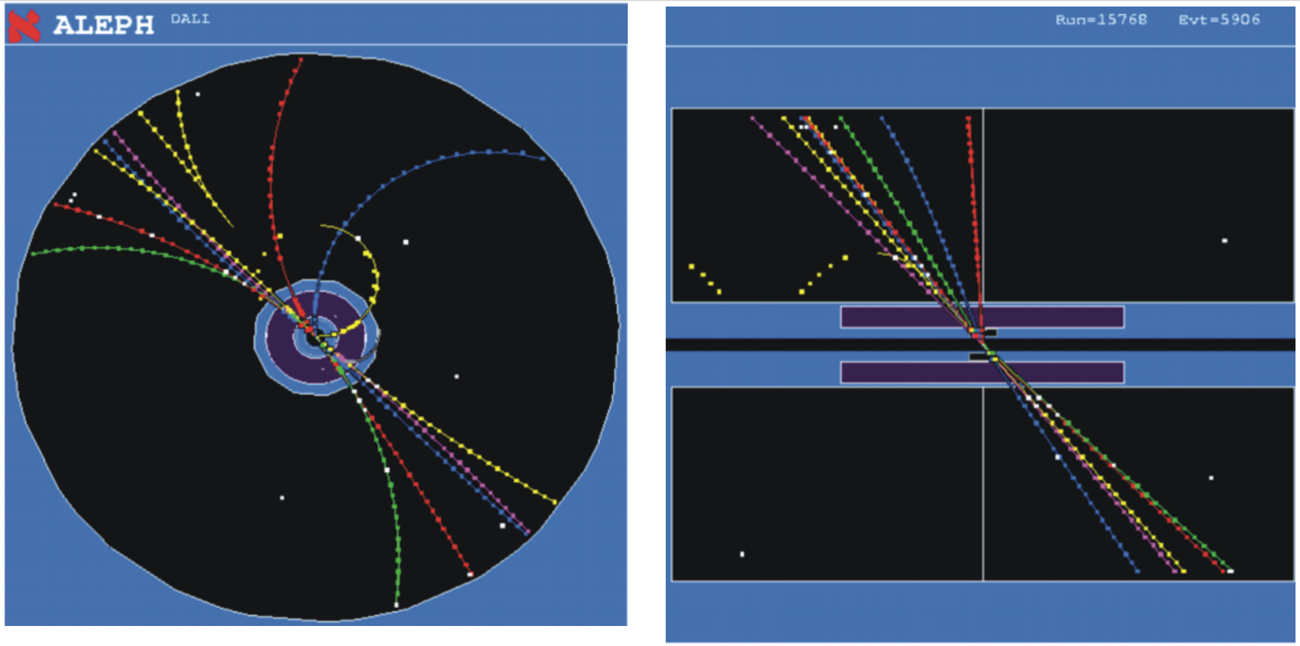




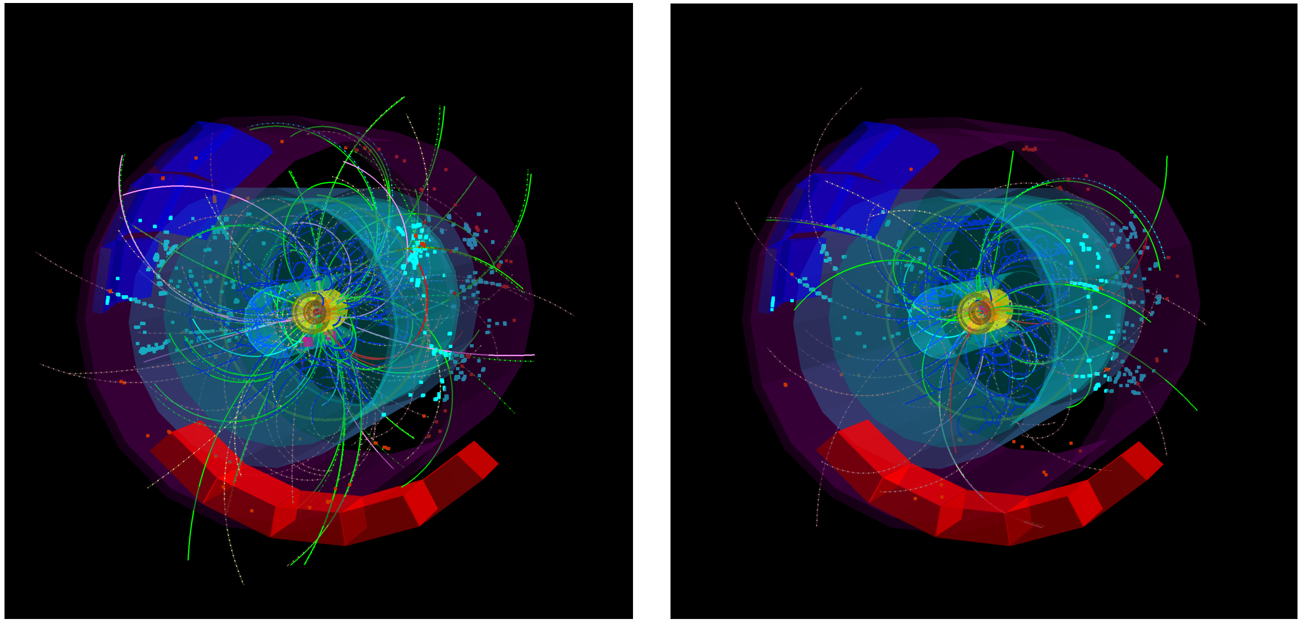
Readout of the anode usually with multi wire projection chambers; nowadays new developments under way.

TPCs at LEP and LHC

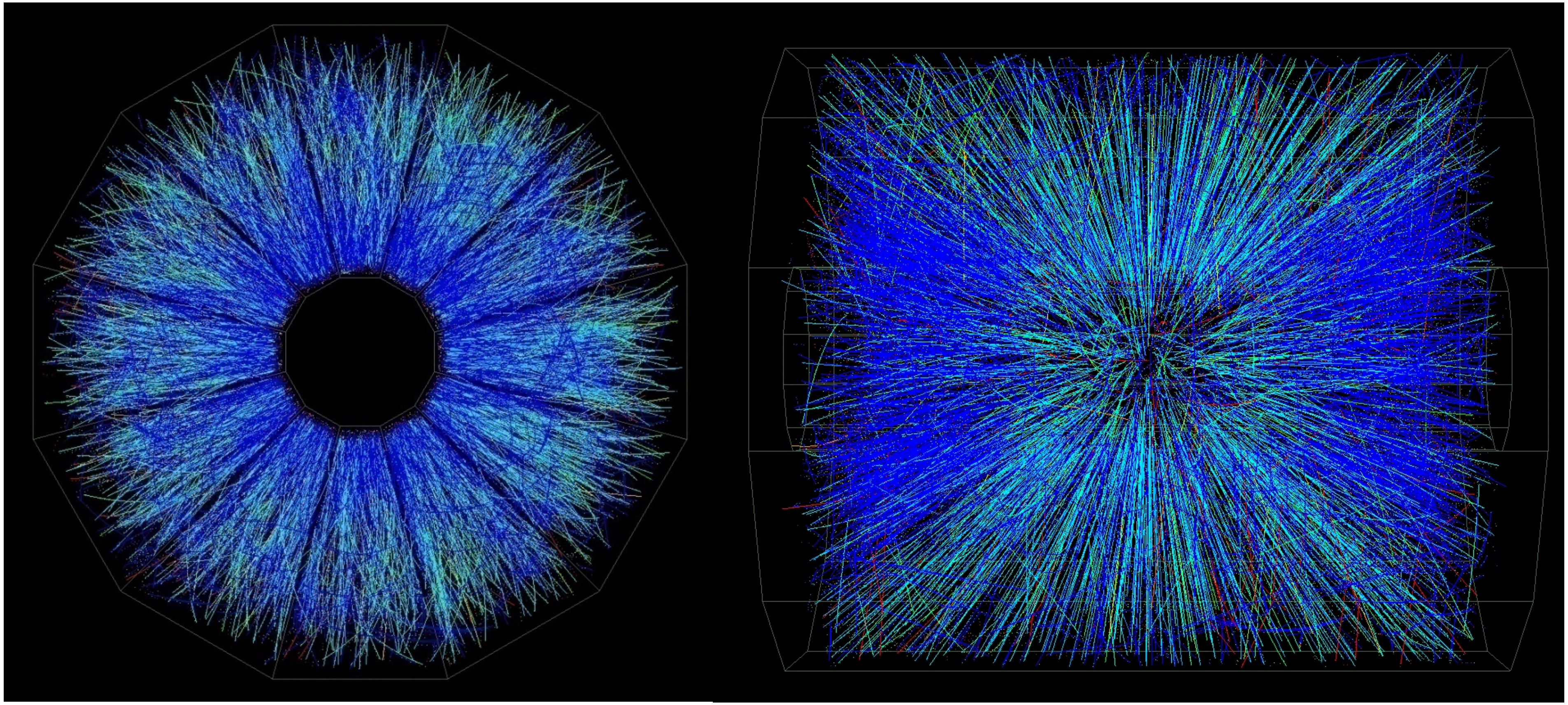
The TPC of the
ALEPH
experiment at
LEP
(e+ e-)



And the one of
ALICE at LHC
(p p)

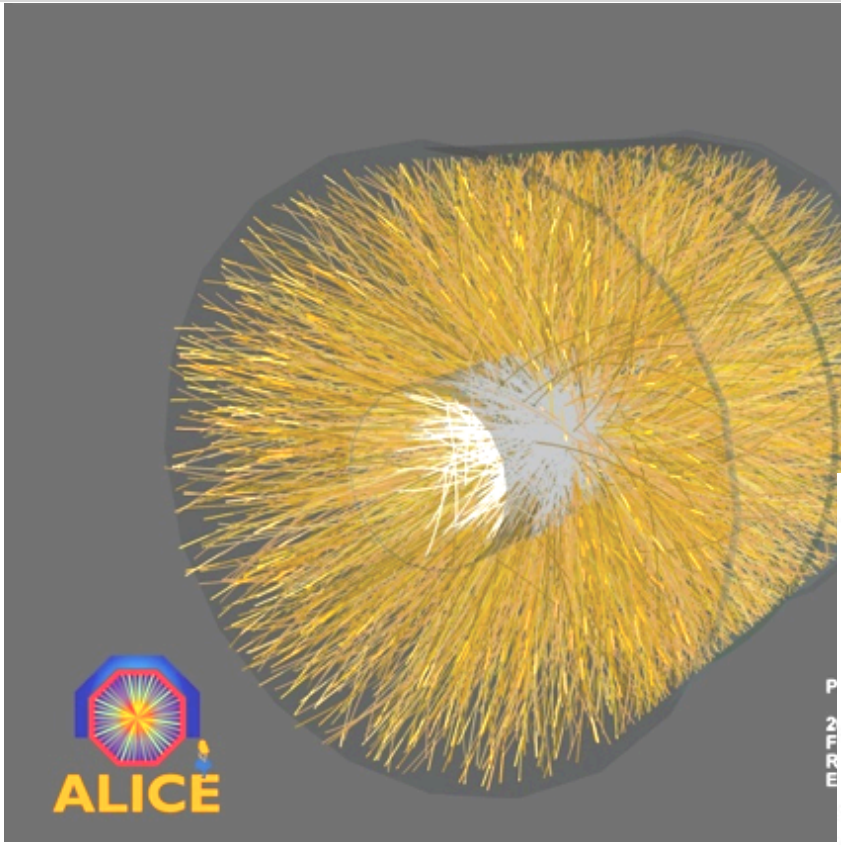


Higher track densities: heavy ion collisions at RHIC



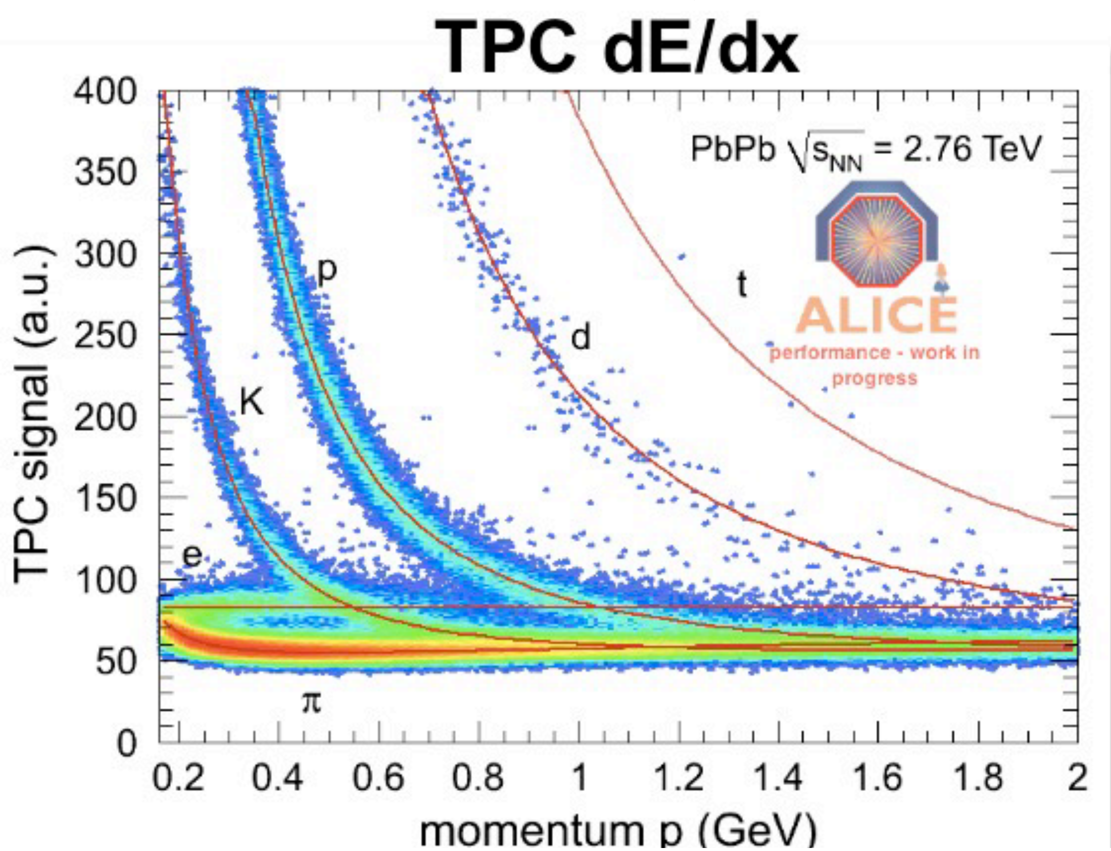
- Central Au-Au collission at 130GeV/nucleon at RHIC (Relativistic Heavy Ion Collider in Brookhaven), typically 200 tracks per event, recorded by STAR
- A TPC enables the reconstruction of very complex events with very high multiplicities
  - Limit: Due to the drifting time the readout is rather slow: ~ 40 µs

Even more tracks: heavy ions in the LHC



ALICE TPC:
Impressive tracking...

...and particle identification



ALICE TPC
Gas volume: 90 m3
Drift gas: Ne-CO2-N2 (85.7-9.5-4.8)

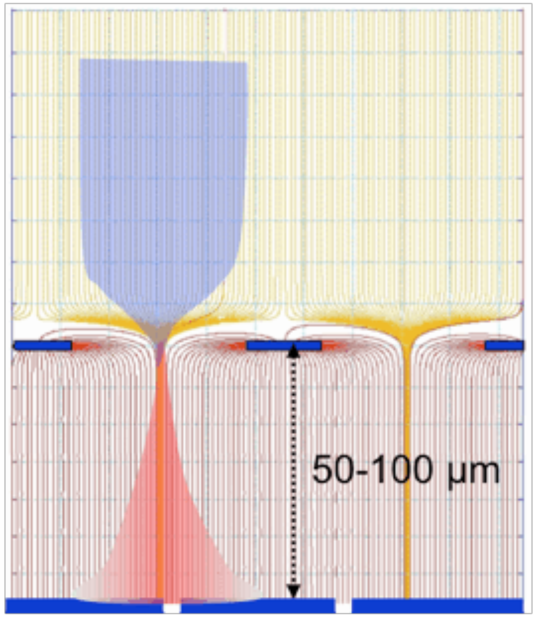
New developments

- Largely improved spacial resolution and higher particle rates:

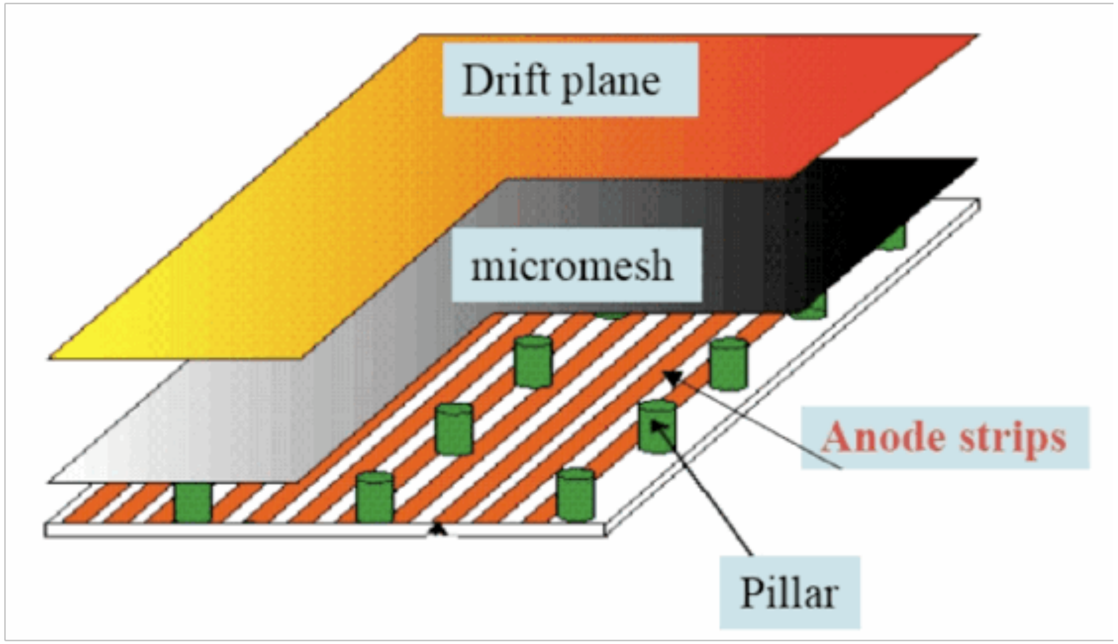
Micro-Pattern Gas Detectors

- a number of developments were started, some with a lot of problems
- two technologies are currently the most successful: GEMs and MicroMegas

MicroMegas: Avalanche amplification in a small gap



Y. Giomataris et al, NIM A376, 29(1996)



Micromega in action @ ATLAS?

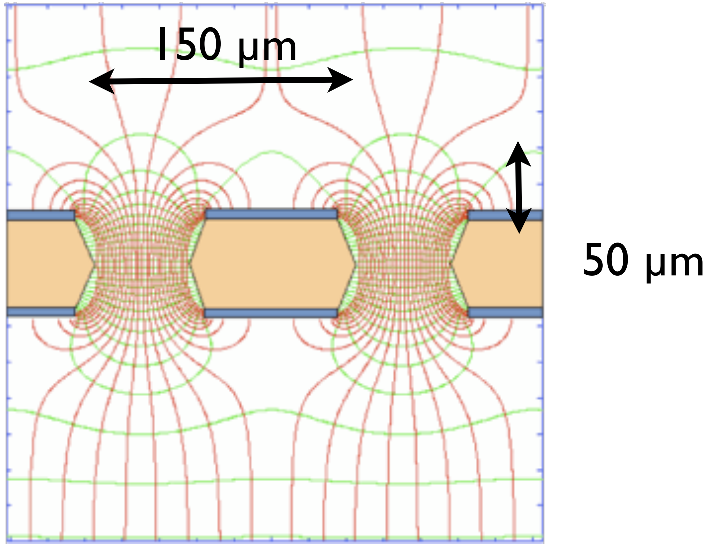
- Idea: replacing forward minimum bias scintillator
  - ➡ behind tracker, in front of calorimeter and muon chambers
  - ➡ improve triggering and tracking

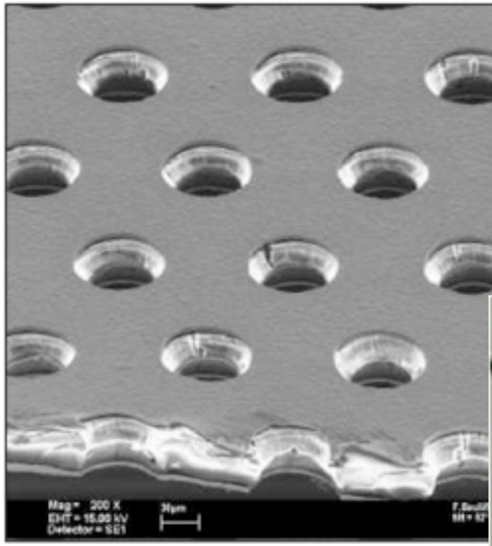
Before approval:
- need proof that detector can stand particle rate and radiation
  - test chamber (20x10cm2) just built in for operation in 2012
- interesting as micromegas are an option for upgrading ATLAS muon system


Current ATLAS minimum bias trigger scintillator, replaced by micromegas in 2013/2014?

New developments

- GEM: Gas Electron Multiplier: Gas amplification in small holes in a special foil





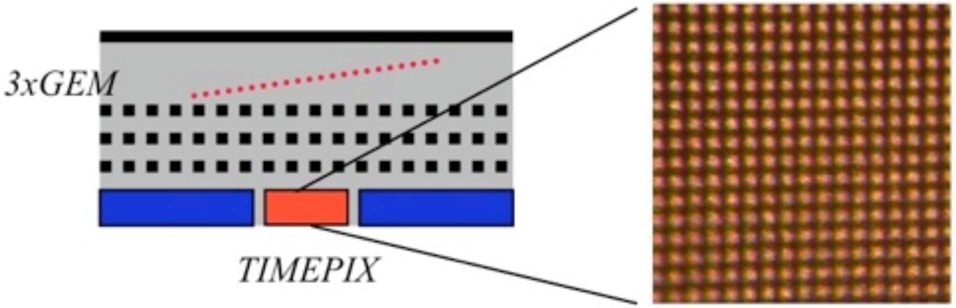
Charge collection on two separate levels: 2D structure possible: separation of amplification and read out

Both technologies, MicroMegas and GEMs are used in experiments. Typical spacial resolution: ~70 um

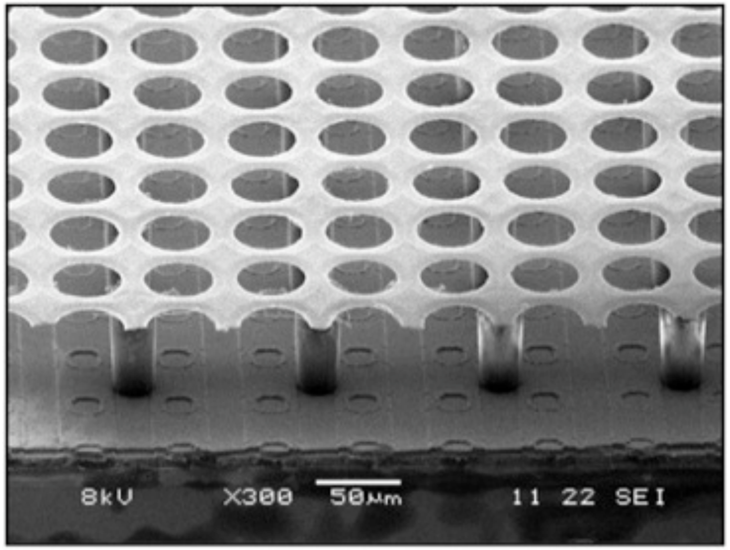
F. Sauli, NIM A386, 531(1997)

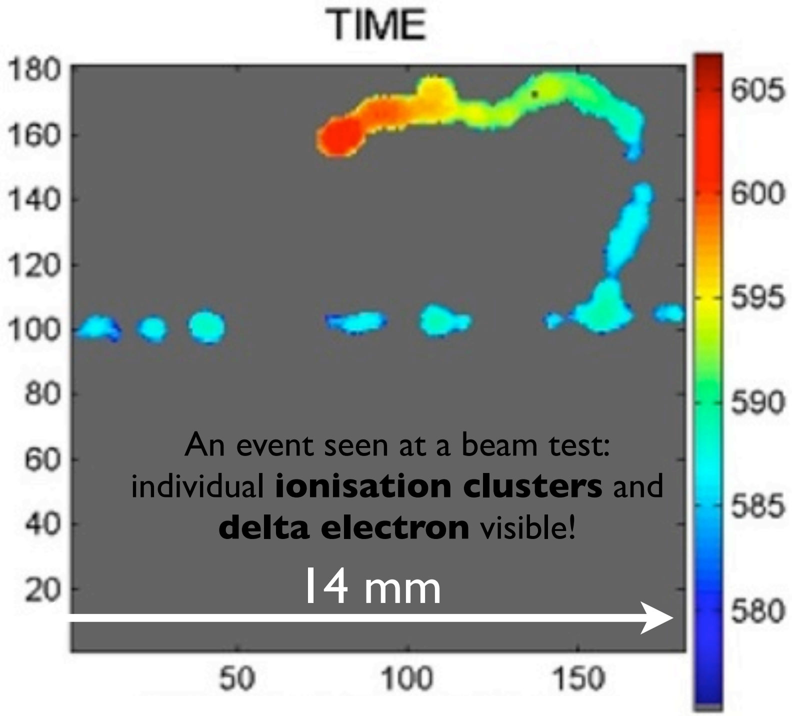
The next generation

- Combination of gas detectors and Silicon
  - Integration of MPGDs with pixel read out chips



- Amplification and read out made of silicon





An event seen at a beam test: individual **ionisation clusters** and **delta electron** visible!

Advantages of gas detectors:

- High amplification of the signal directly at the detector
- Low radiation length
- Gas can be replaced regularly: Reduction of radiation damages