Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

Particle Detection

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Outlook

- Particle interaction --- Particle detection
- Determination of particle properties
  - Direct measurement -- indirect measurement
- HEP Detectors
  - Tracking detectors
  - Energy measurement -- Calorimetry
  - **P**article **Id**entification PID
  - „Multipurpose“ detectors
  - Infrastructure

Interactions

Properties

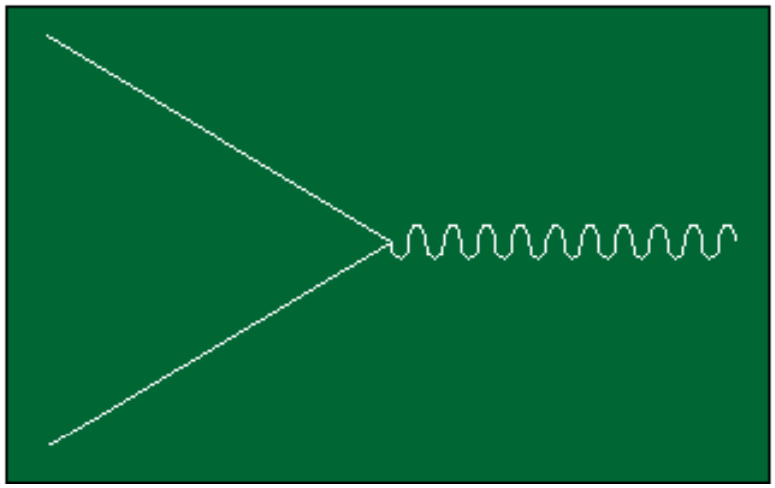
PARTICLE DETECTION

- Particle can‘t be seen nor measured „directly“
- Only the result of an interaction with matter (detector) is observable
- In the end, everything is converted to

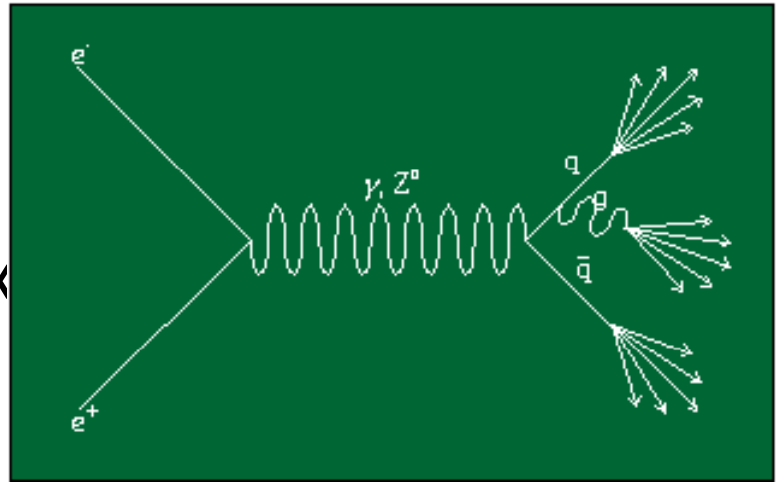
1. Optical pictures
2. Voltage or current signals

Particle – Particle Interactions

- Scattering

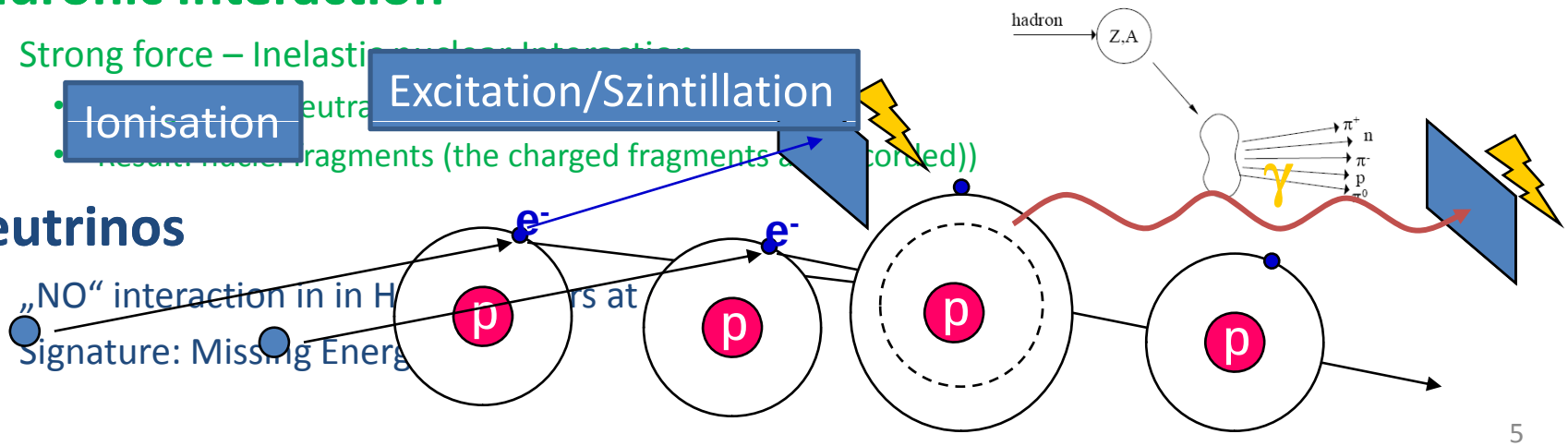


- Annihilation
- And the production of new particles
- All interactions at
  - Colliding Beam Ex
  - Fixed Target Expe



Interactions

- **Photons**
  - Compton Scattering
  - Photo Effect
  - Pair production
- **Charged Particles**
  - Scattering (at atoms, electrons, etc.) -- highly undesired
  - Ionization (Kick-off an electron from an atom)
    - Bethe-Bloch-formula
  - Excitation (excite electron to higher orbit ➔ fall back ➔ light emission)
    - (e.g. scintillation)
  - Photon radiation
    - Bremsstrahlung (accelerated charge emits photons)
    - Transition radiation
    - Cherenkov light (faster than light in a medium)
- **Hadronic Interaction**
  - Strong force – Inelasti
    - eutra
    - ragments (the charged fragments a corded))
- **Neutrinos**
  - „NO“ interaction in in H rs at
  - Signature: Missing Energ



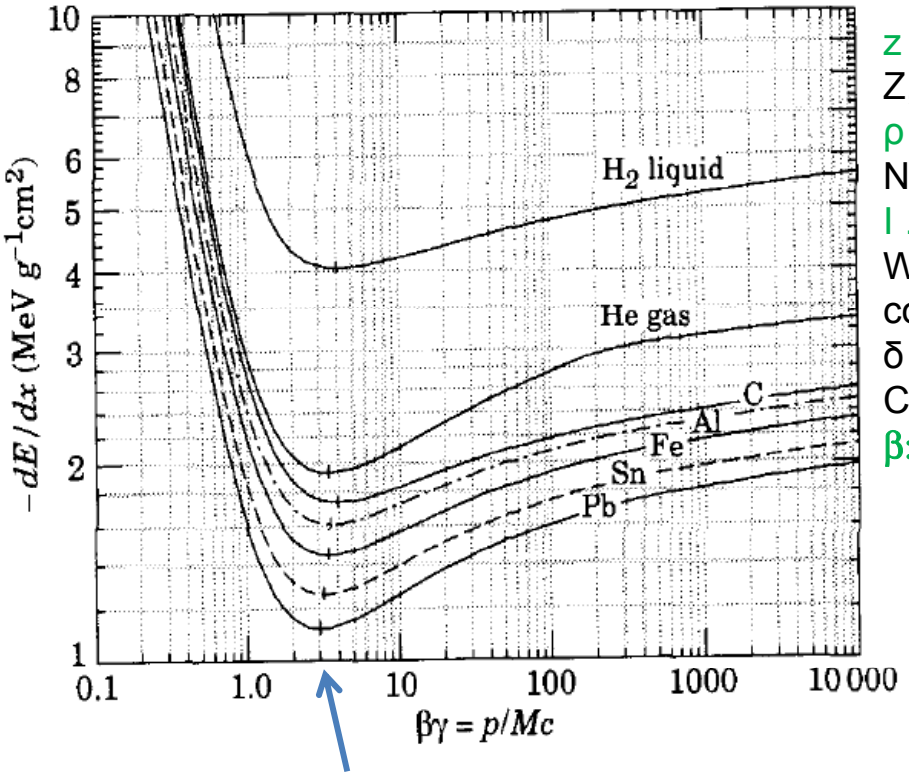
Ionisation: Bethe-Bloch-Formula

Coulomb interaction

Energy deposit of traversing charged particle per unit length

➔ Ionisation (Ions, electron-hole pairs are recorded)

$$-\left(\frac{dE}{dx}\right)_{coll} = 2\pi N_A r_e^2 m_e c^2 \rho \frac{Z}{A}\frac{z^2}{\beta^2} \cdot \left[\ln\left(\frac{2m_e c^2 \gamma^2 \beta^2 W_{max}}{I^2}\right) - 2\beta^2 - \delta - 2\frac{C}{Z}\right]$$



Minimal **i**onising **p**article MIP

z … charge of traversing particle

Z, A … Atomic number and nuclear number of the target

ρ … density of target,

N_A … Avogadro's number

I … mean ionisation potential (material constant of target)

W_{max} ... max. energy imparted to a free electron in a single collision

δ … correction for density (polarisation effect, $\delta \approx 2.\ln\gamma + K$)

C … correction

β: v/c velocity/speed of light

$$\beta = \frac{v}{c}, \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}},$$

$$r_e = \frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{m_e c^2} \quad \text{… klassischer } e^- \text{– Radius}$$

Particle Properties

- Which properties does a particle have?
  - energy
  - momentum
  - ~~charge~~
  - mass
  - ~~life time~~
  - spin
  - decay modes

- And which of those are measurable *directly*?

Particle Properties

$$\left.\begin{matrix} E \\ \vec{p} = \begin{pmatrix} p_1 \\ p_2 \\ p_3 \end{pmatrix} \end{matrix}\right\} \quad \begin{pmatrix} E \\ \vec{p} \end{pmatrix}$$

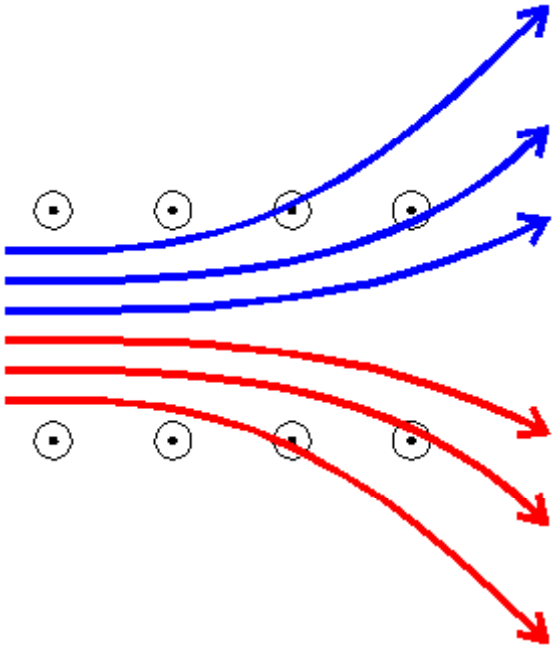
- Which can be derived?

Mass: $$E^2 = m^2 \cdot c^4 + \vec{p}^2 c^2 \Rightarrow m = \frac{\sqrt{E^2 - \vec{p}^2 c^2}}{c^2}$$

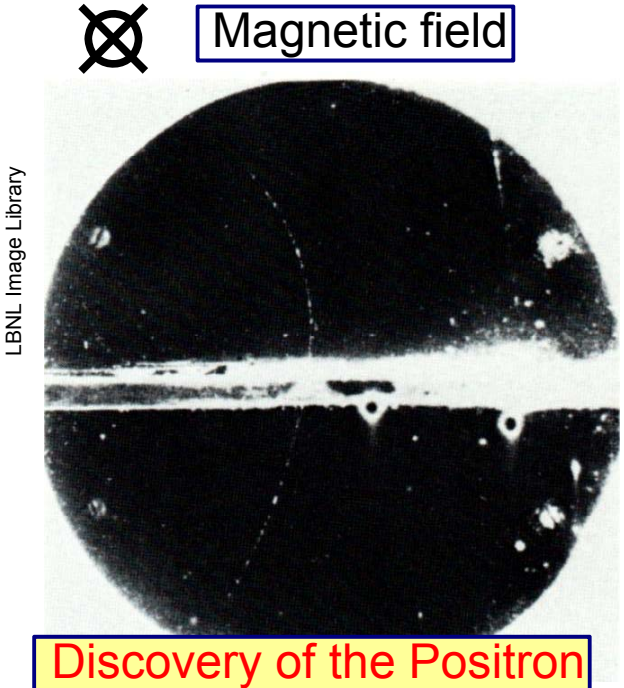
Spin: a bit more abstract ← angular distribution

Measurement of Particle Properties

- Charge
  - Direction



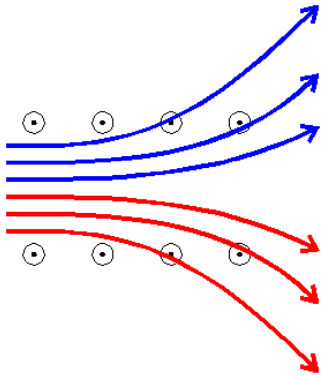
- Lifetime
  - Measurement of path length



Discovery of the Positron
1932 Carl Anderson,
Noble Prize 1936

Measurement of Particle Properties

- Momentum



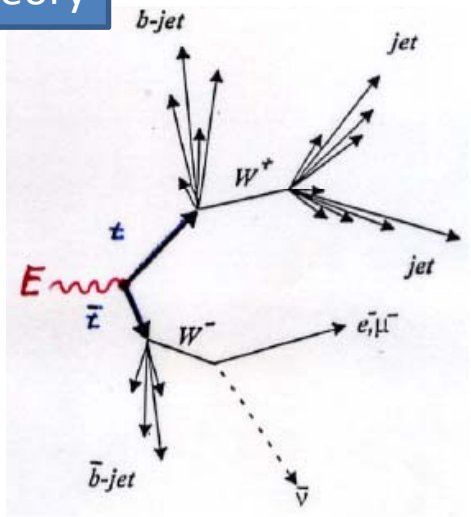
$$F = q \cdot v \cdot B = m \cdot \frac{v^2}{R}$$

$$\Rightarrow q \cdot B \cdot R = m \cdot v = \left| \vec{p} \right|$$

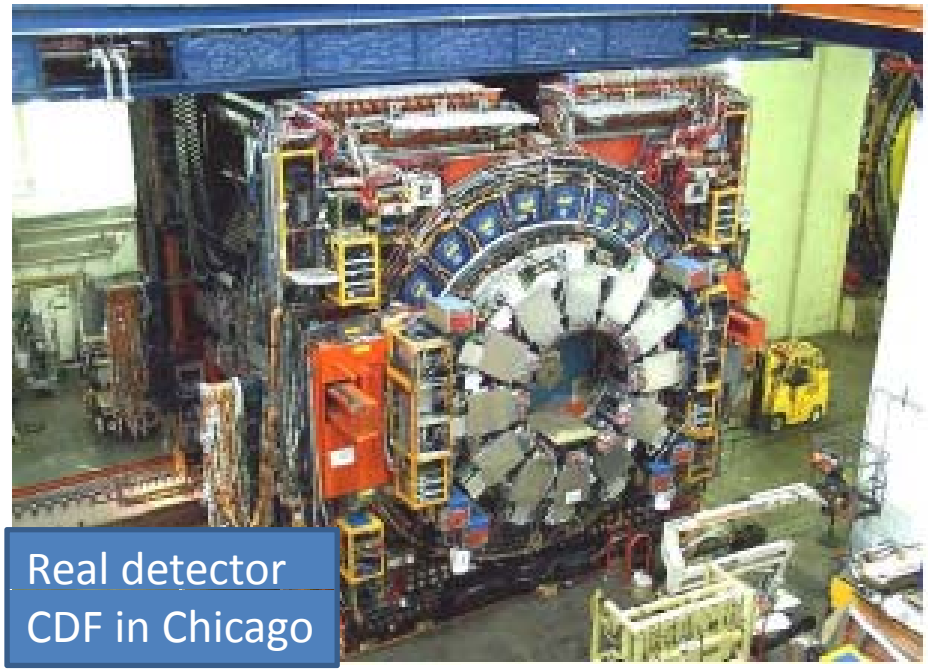
- Velocity
  - time of flight TOF
  - RICH (see later/tomorrow)
- Energy
  - Calorimter

The Principle – an Example TOP Quarks

Theory

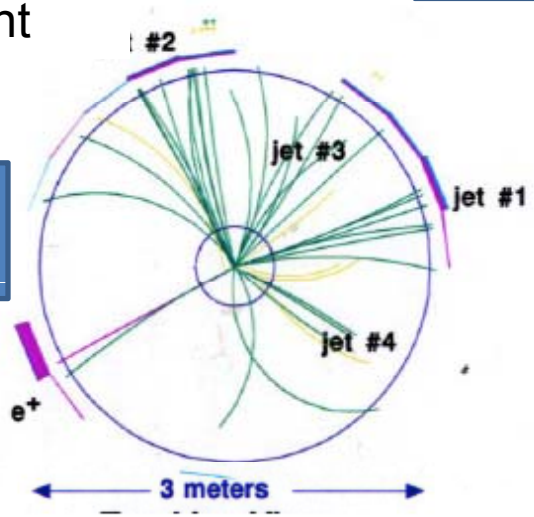


Discovery by decay product measurement



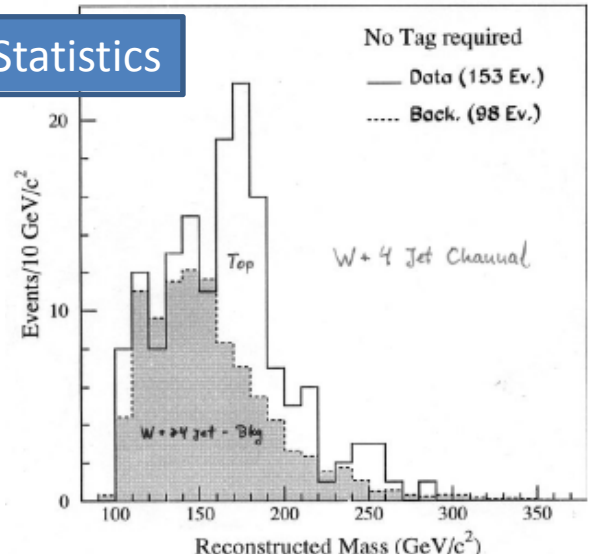
Real detector
CDF in Chicago

Event (reconstructed)



Top-AntiTop event

Statistics

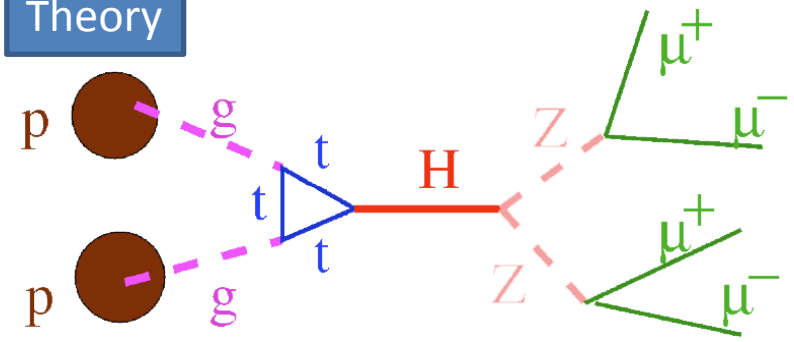


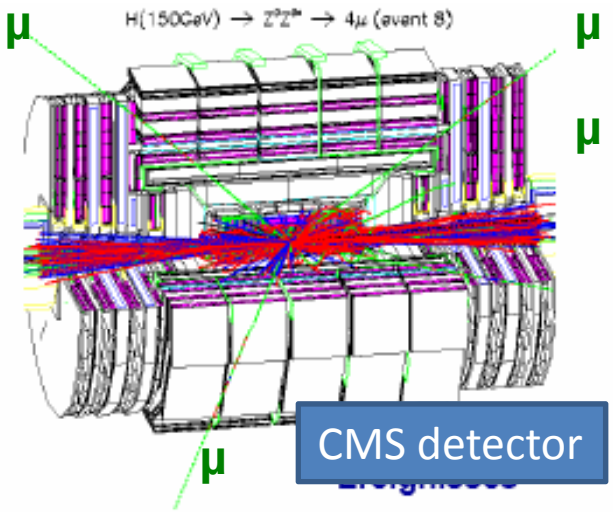
TOP Quark Signal - Statistics

A bit more complex

pp → H → ZZ → 4μ

Theory

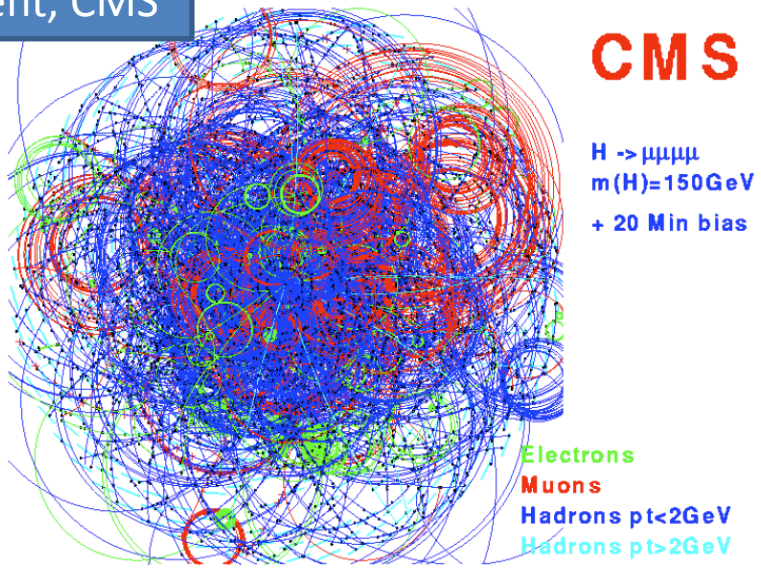


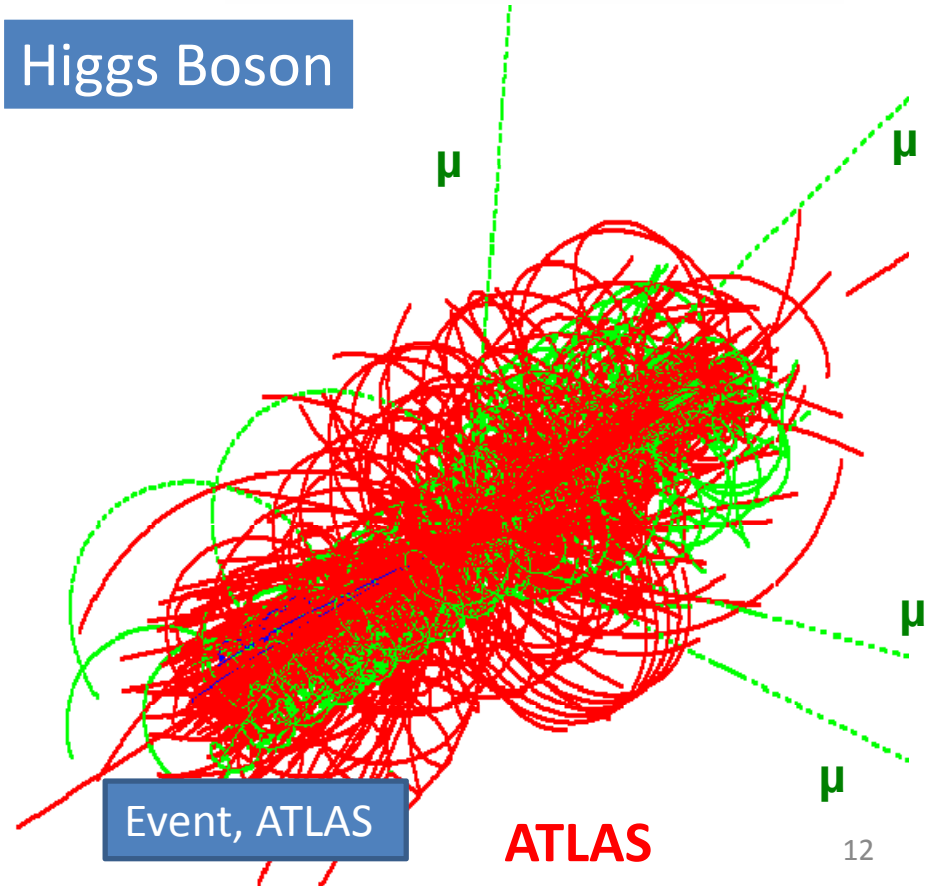


CMS detector

Higgs Boson

Event, CMS





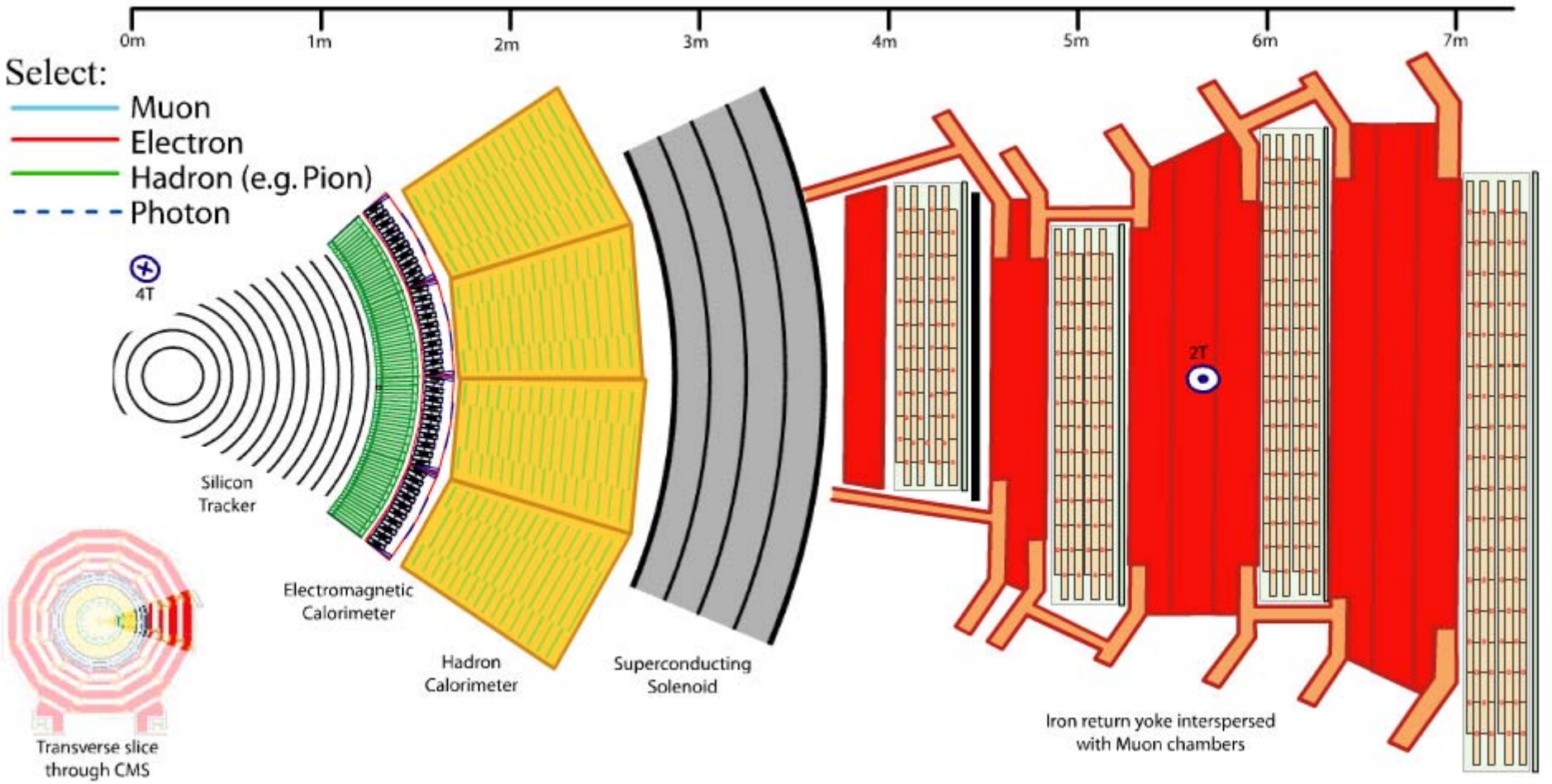
Event, ATLAS

ATLAS

Slice through the CMS detector

Particle interaction and reconstruction

Different detectors for different particles



Tracking detectors (Tracks: Momentum, Charge, Decay)

Calorimeter (Energy)

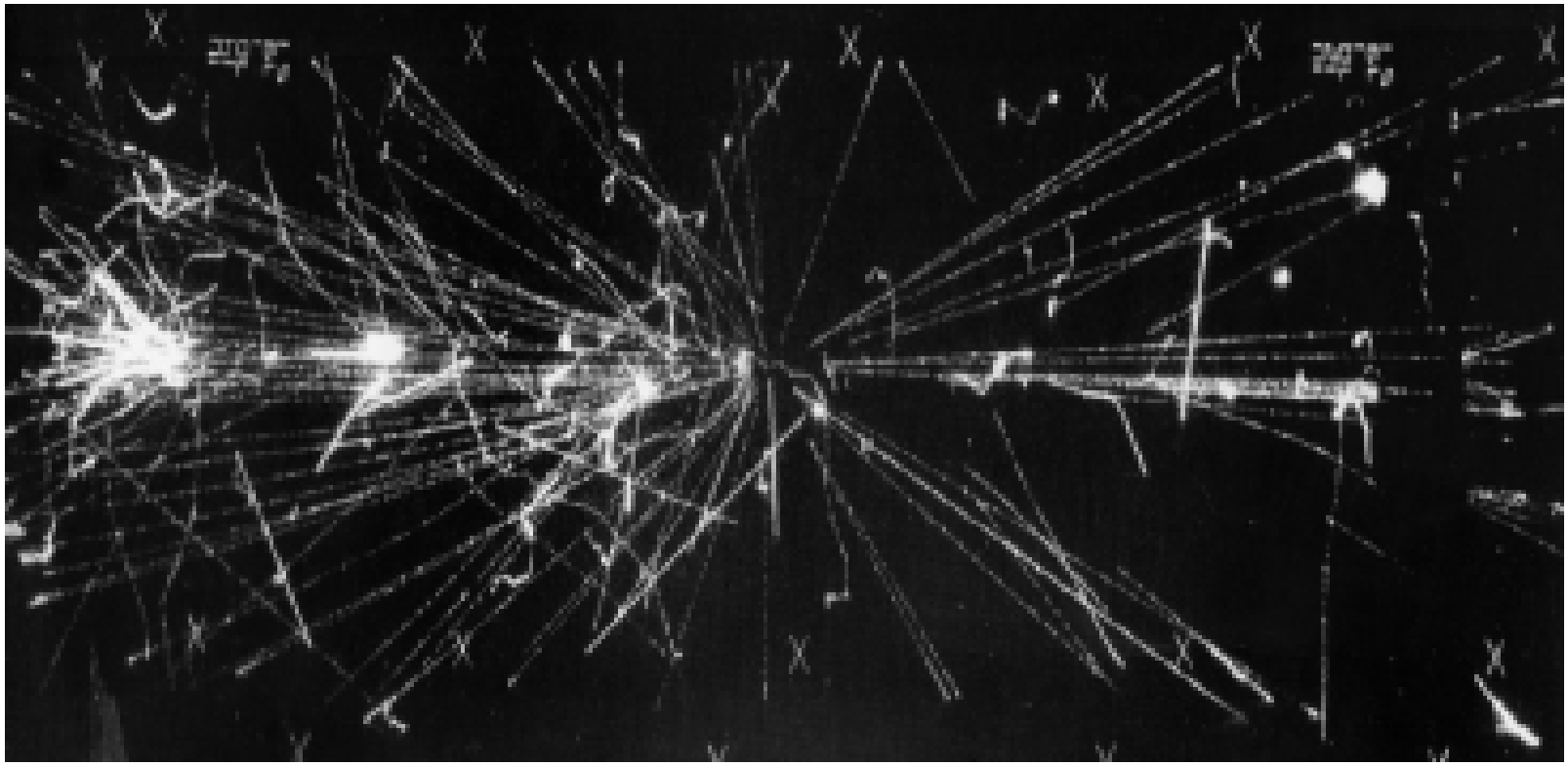
- ECAL: Electromagnetic calorimeter
- HCAL: Hadronic calorimeter

Particle Identification

Muon chamber (Tracks, muon identification)

Multipurpose detector: A BIT FROM EVERYTHING

DETECTOR TYPES



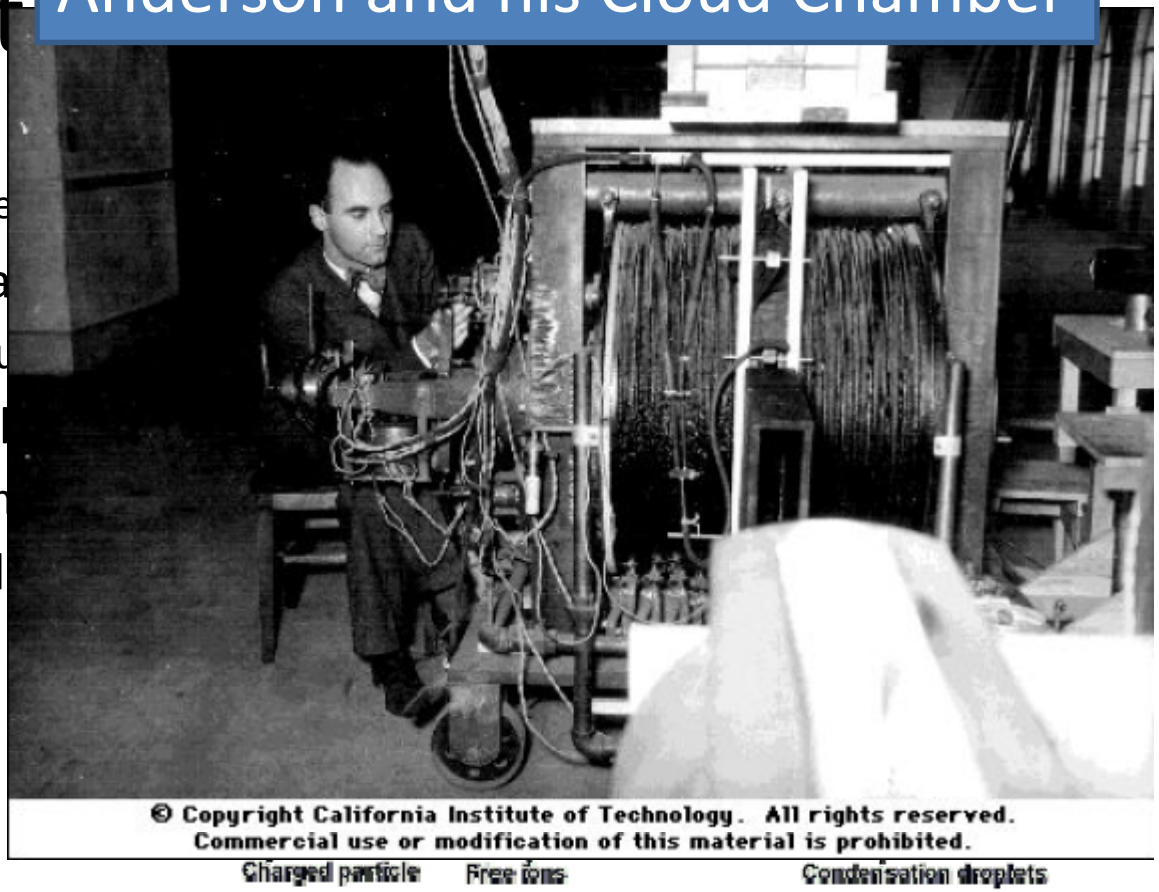
- Cloud, (Spark-), Bubble chamber

HISTORIC TRACKING DETECTORS

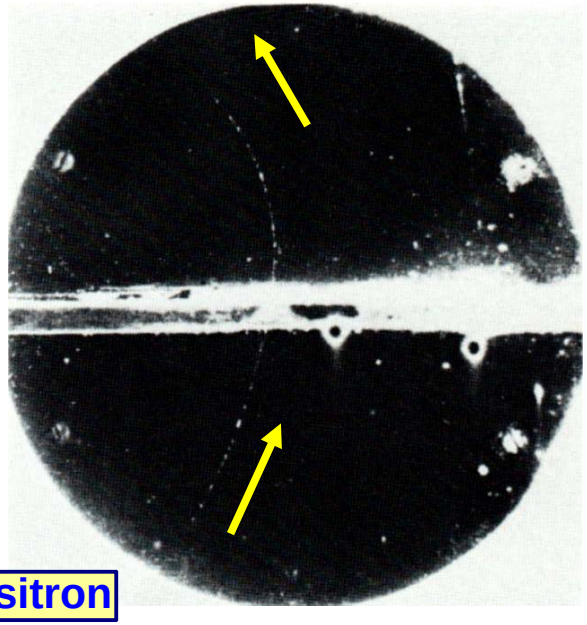
"Historic" Det

- Cloud chamber (1911 by Charle
  - chamber with saturated wa
    - originally developed to stu
  - charged particles leave trai
    - water is condensing aroun
  - visible track as line of small
  - Photography

Anderson and his Cloud Chamber



LBNL Image Library



Steal plate

magnetic field

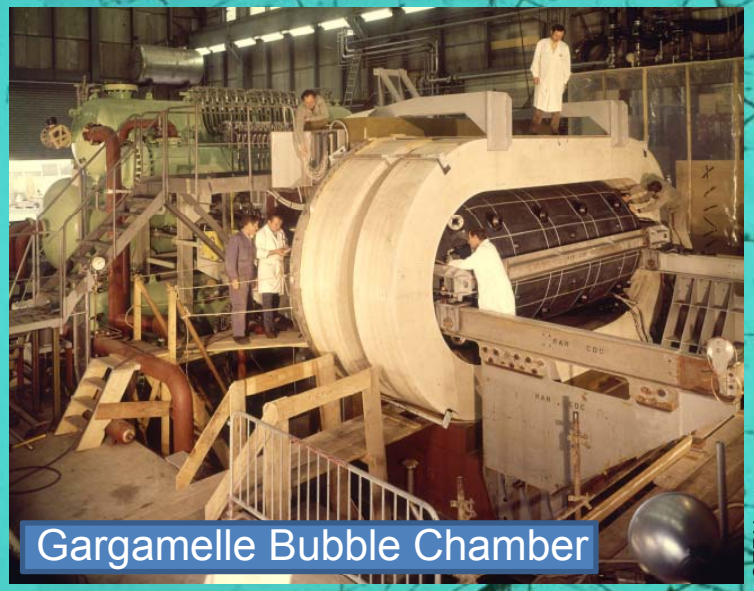
Positron

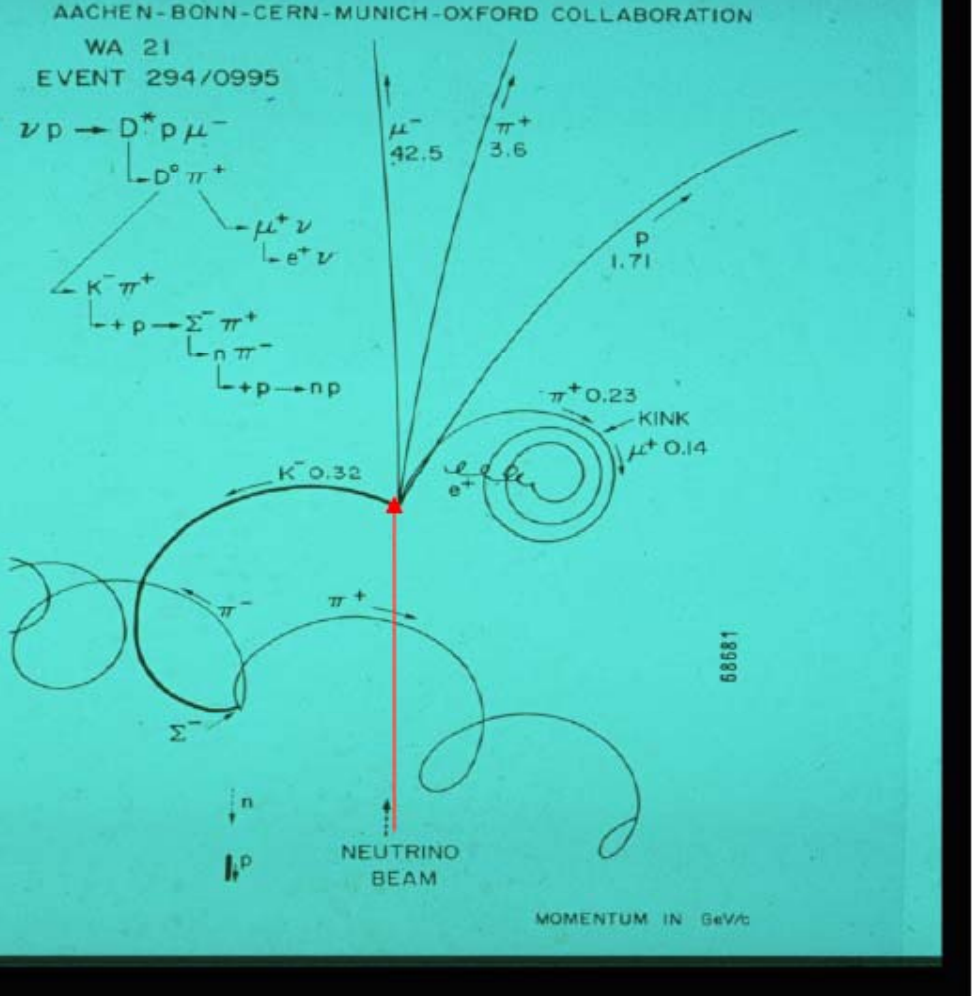
Discovery of the Positrons
(1932 Carl Anderson, Noble Prize 1936)

“Historic” Detector: Bubble Chamber

Similar principle as Cloud Chamber:
Chamber with Liquid, e.g. H2 at boiling point („superheated“)
Charged particle➔ creates ions ➔ condensation of small gas bubbles ➔track ➔ photography

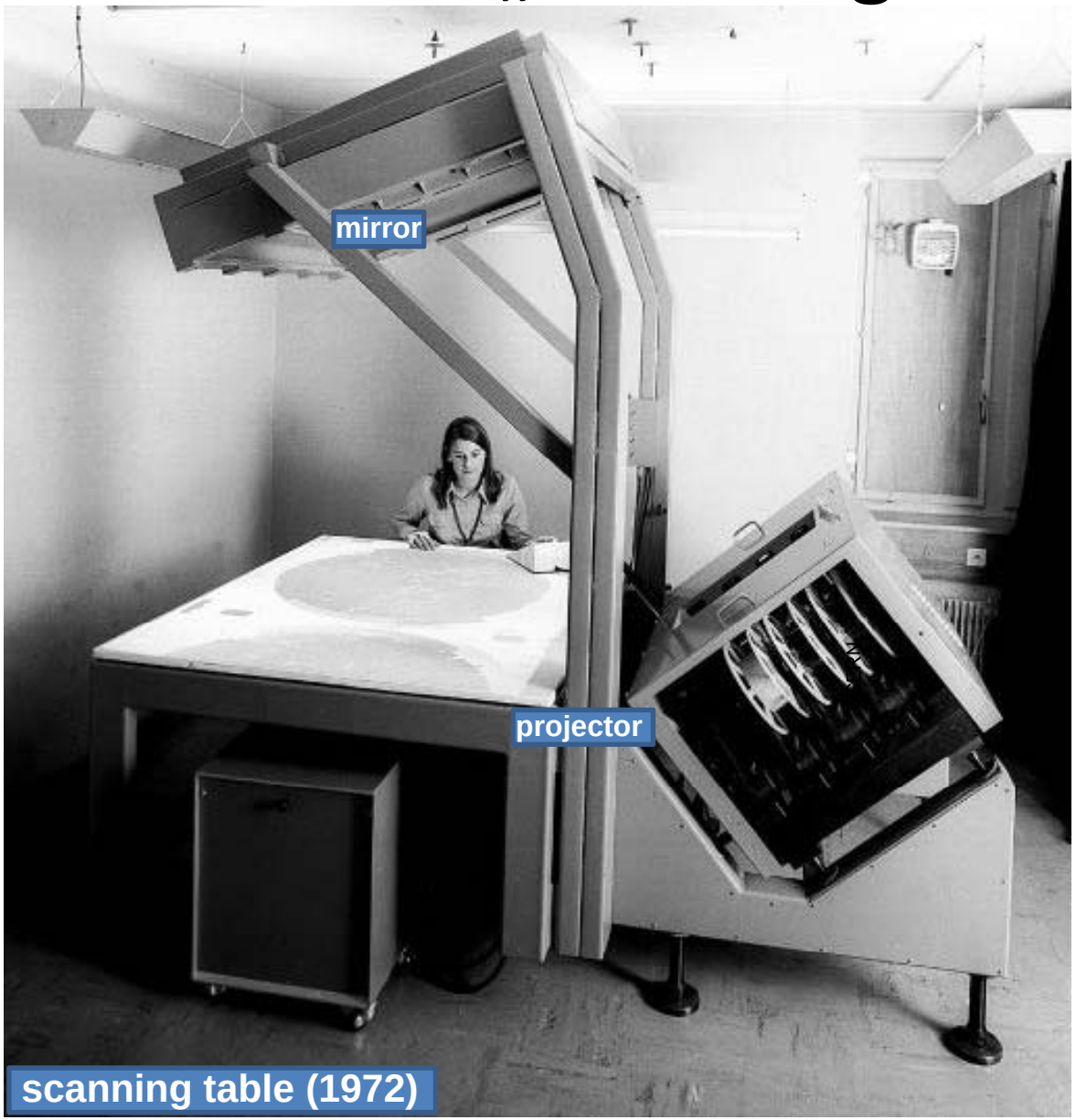
Discovery of the “Neutral Current”
(1973 Gargamelle Kollaboration)





A neutrino event in the Big European Bubble Chamber (BEBC), CERN Photo

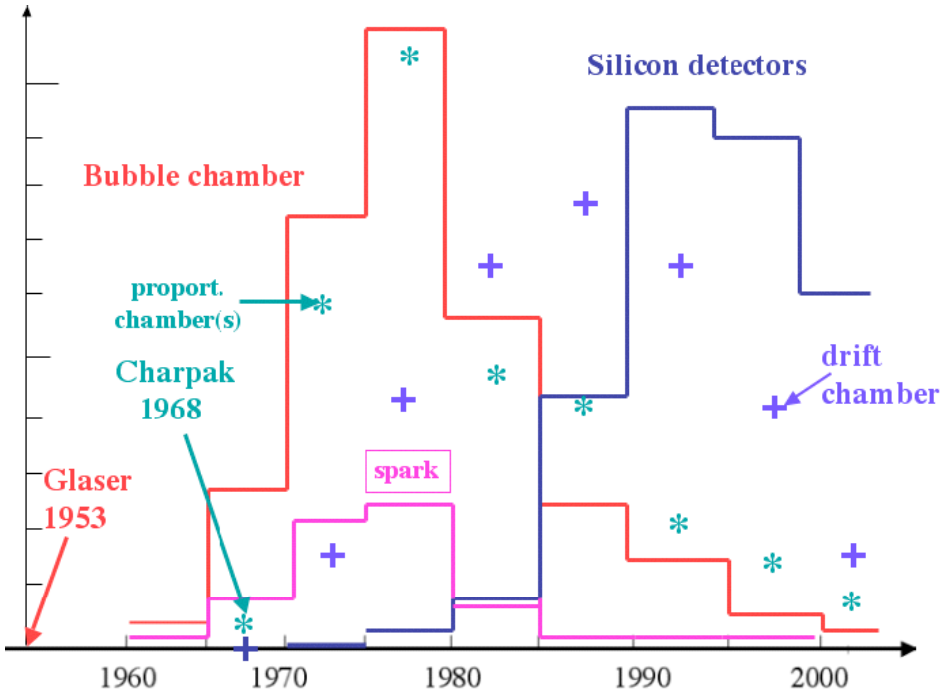
The social component of CERN
The era of the „Scanning Girls“



scanning table (1972)

Detector History

- Cloud Chambers dominating until the 1950s
  - now very popular in public exhibitions related to particle physics
- Bubble Chambers had their peak time between 1960 and 1985
  - last big bubble chamber was BEBC at CERN (Big European Bubble Chamber), now in front on the CERN Microcosm exhibition
- Wire Chambers (MWPCs and drift chambers) started dominate since 1980s
- Since early 1990s solid state detectors are in use
  - started as small sized vertex detectors
  - now ~200 m^2 silicon surface CMS tracker



Historic Detectors

- Cloud Chambers
- Bubble Chambers
- Spark Chambers

Gaseous detectors

Solid state- (semiconductor-) Detectors

(Szintillator-Trackingdetectors)

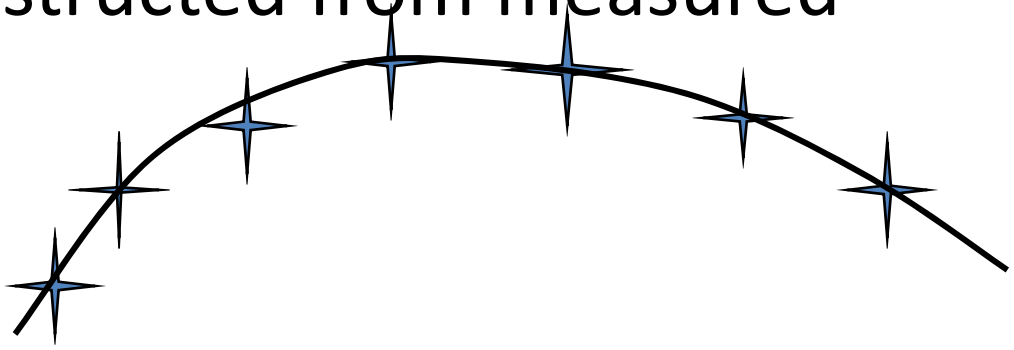
TRACKING DETECTORS TODAY
ELECTRONIC READOUT

Detects only charged particles

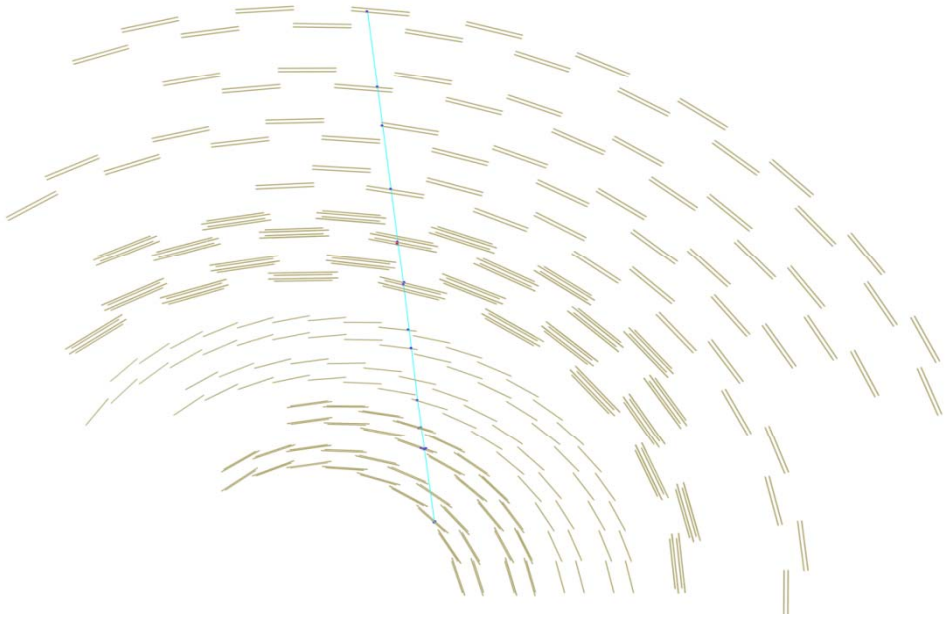
Functioning Principal of Tracking Detectors

- measure the tracks of emerging particles
- determine
  - charge and
  - momentum

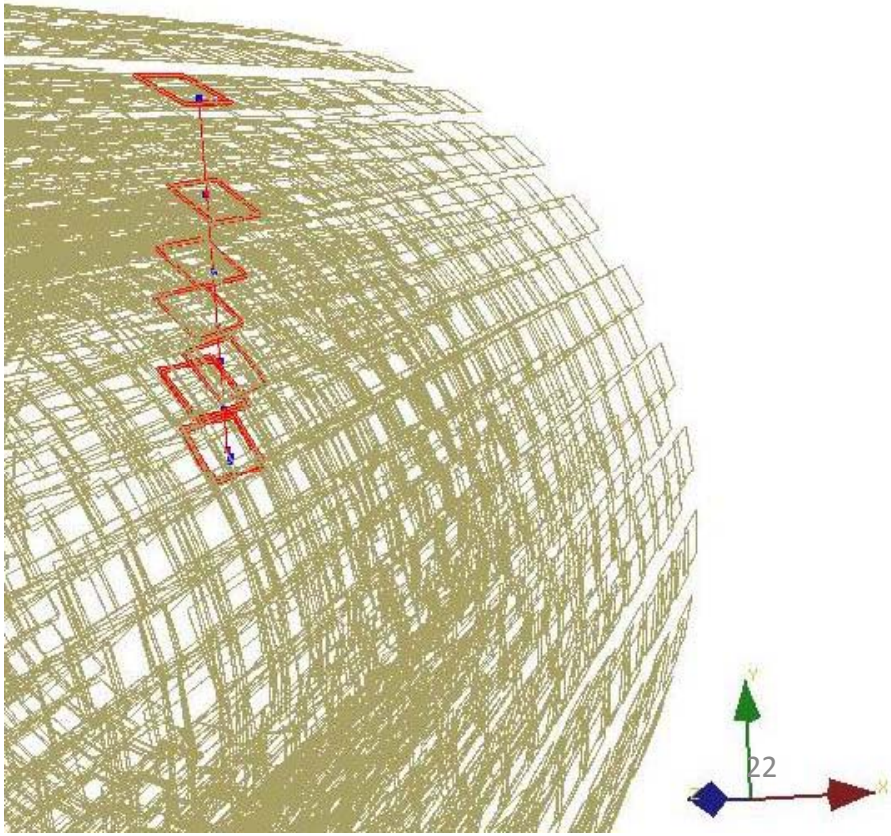
  in connection with a magnetic field
- tracks are reconstructed from measured space-points



Track Reconstruction



CMS Silicon Tracking Detector under test



Ionization counter(Geiger-Müller-Counter)

Proportional Chamber

Multiwire-Proportional-Chamber (MWPC)

Drift Chamber

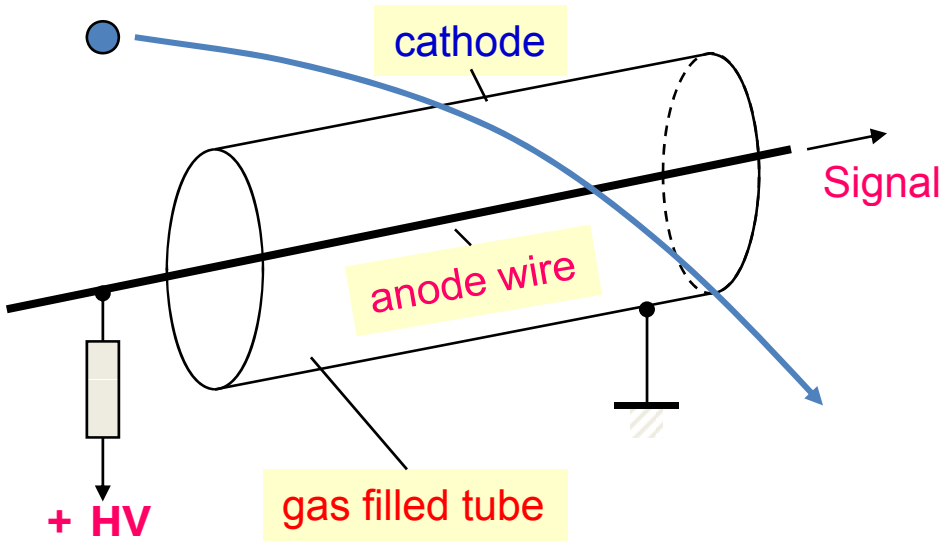
Time Projection Chamber TPC

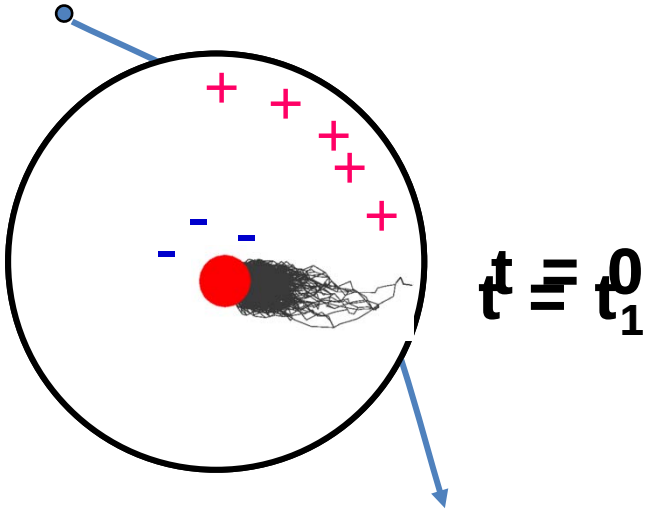
Micro-Strip-Gas-Chamber

Resistive Plate Chambers

GASEOUS TRACKING DETECTORS

Ionization Counter

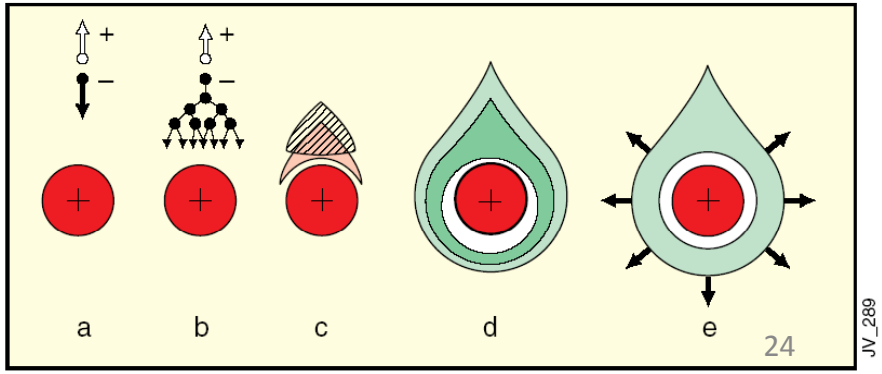




- Avalanche near anode
- Signal proportional to deposited energy

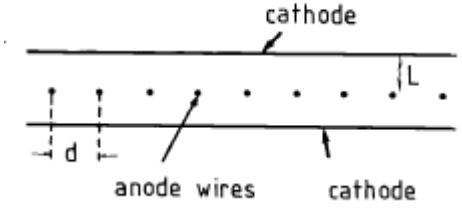
Signal

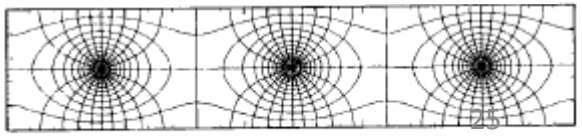
F.Sauli, CERN 77-09



Evolution of gaseous detectors

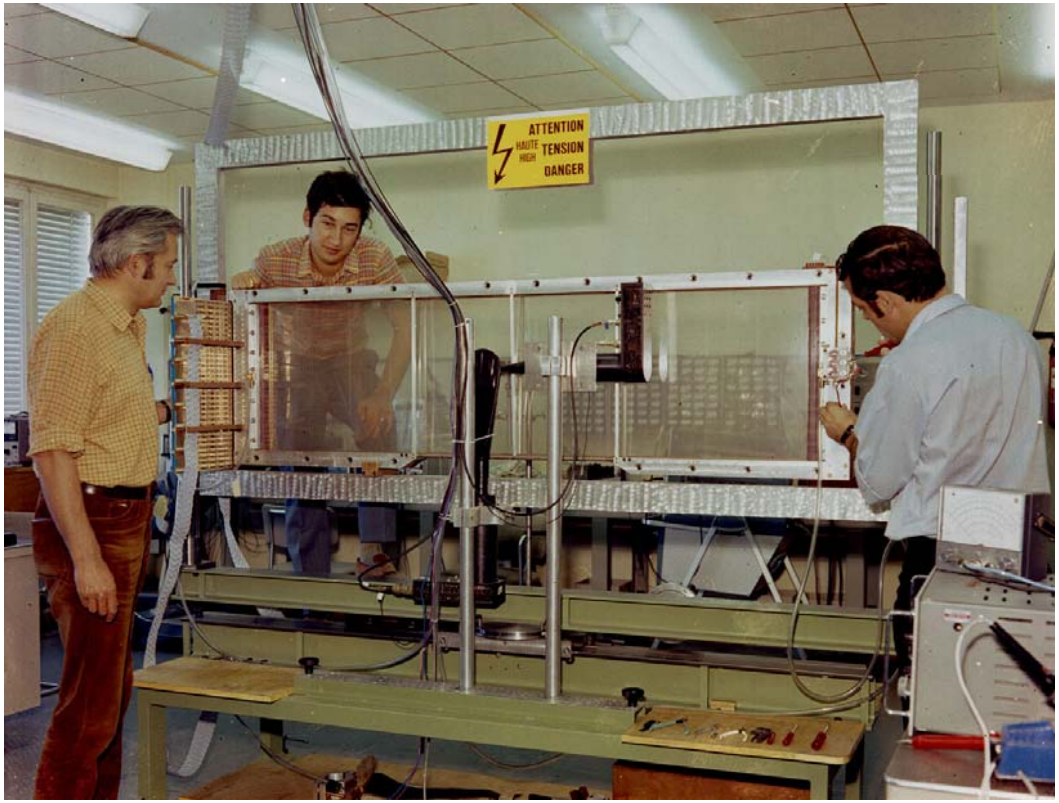
- **Geiger-Counter**: Binary response
  - Number of particles
  - same charge for every particle
- **Proportional Counter**:
  - Primary ionisation ➔ secondary ionisation (avalanche)
- **Multiwire-Proportional Chamber**
  - Many proportional wires in a single chamber
    - Anode wires alternate with cathode wires
  - Space resolution (Track reconstruction)
  - Nobel prize: G. Charpak, 1992





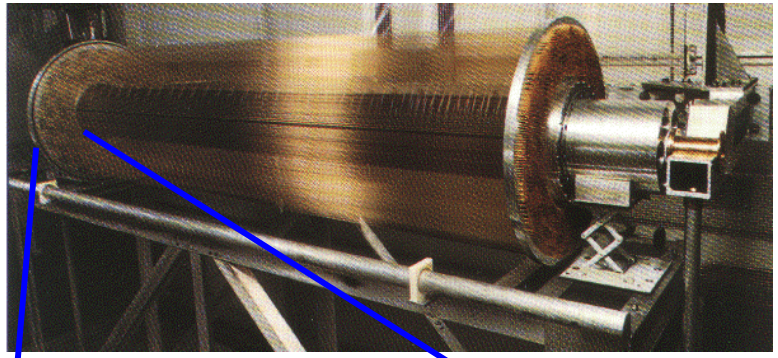
field lines and equipotentials around anode wires

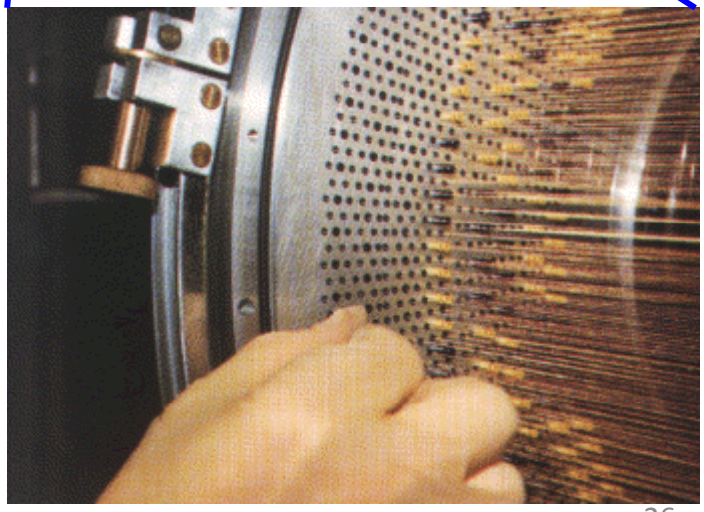
MWPC



ITC (ALEPH)

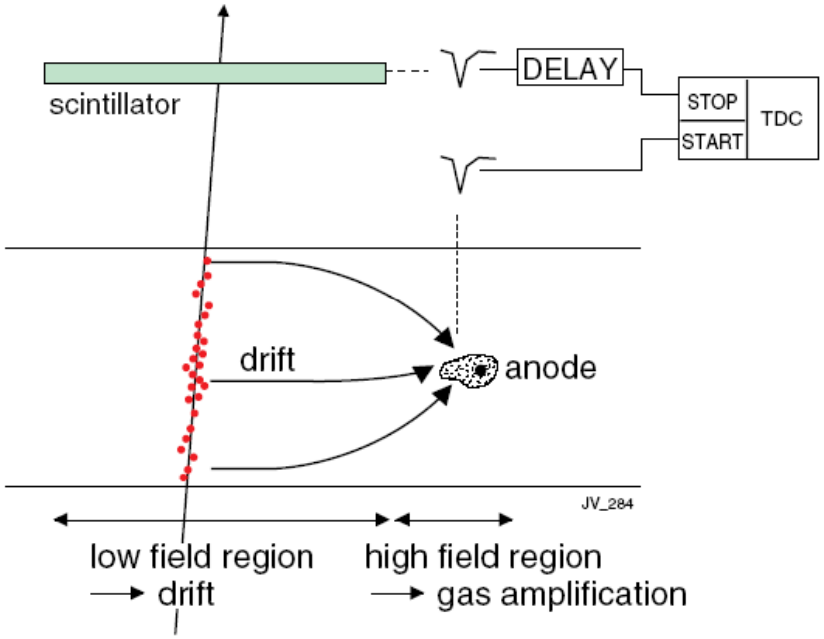
Inner Tracking Chamber





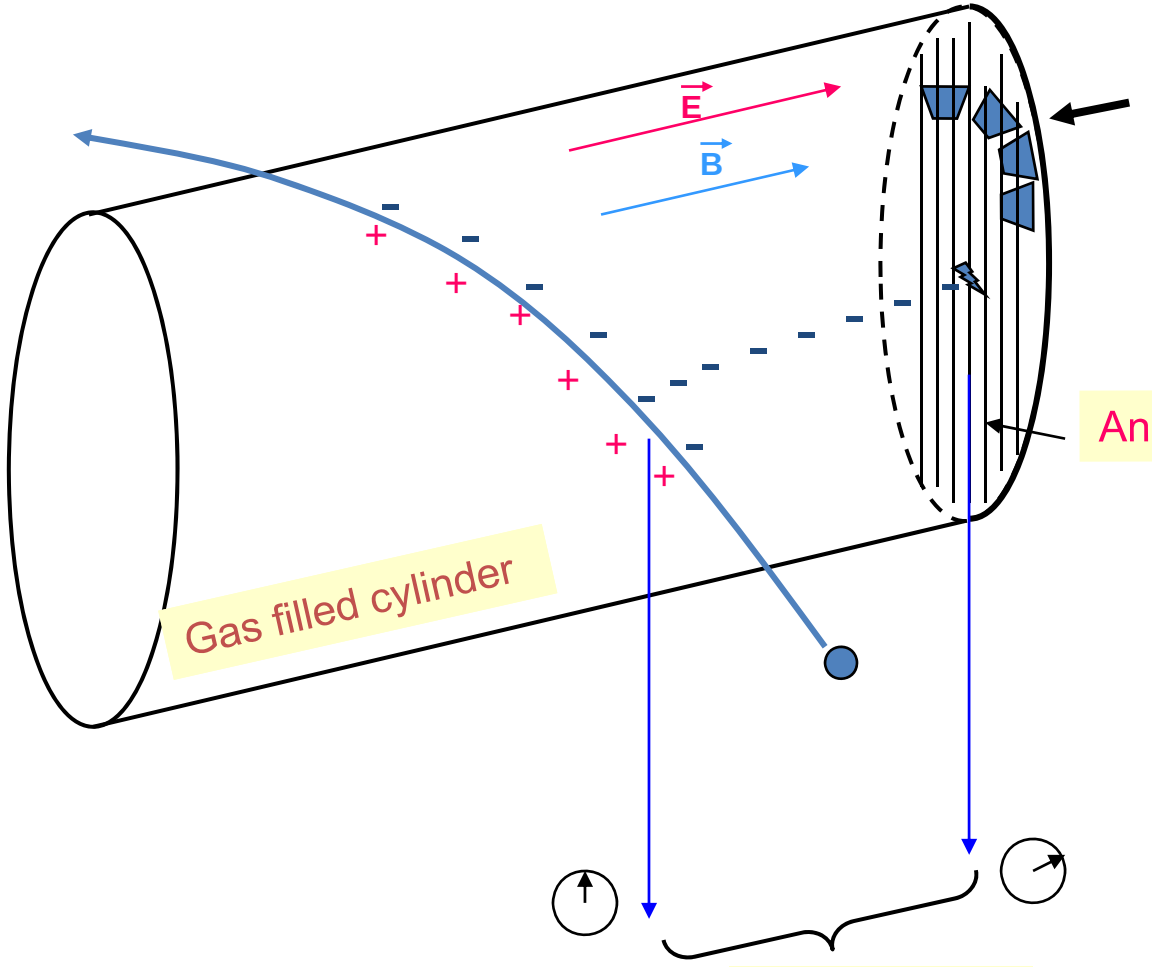
Drift Chamber

- Standard wire chambers are limited in space resolution by the minimal possible wire spacing
- Drift chambers increase spacing but take the drift time into account
  - Of course, the time of passage must be known

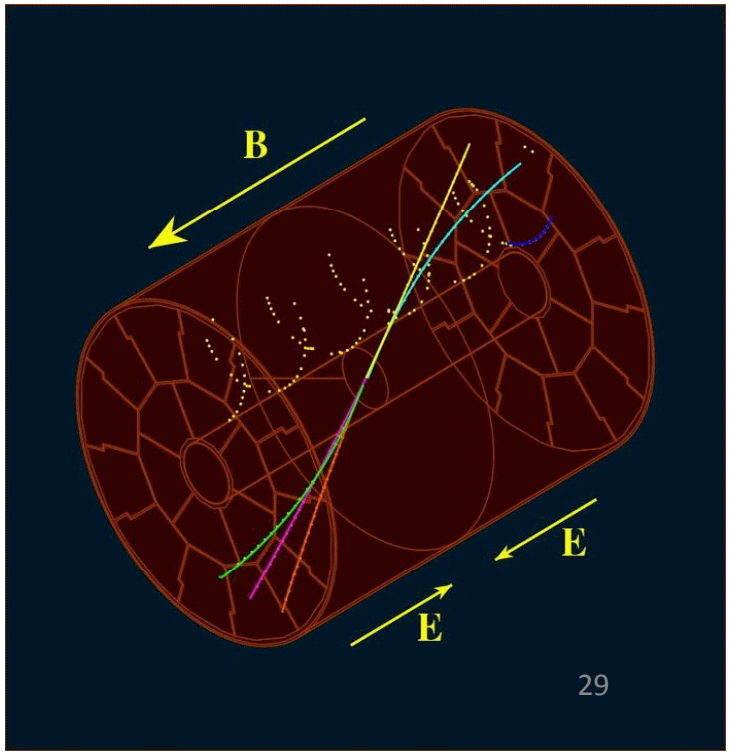


Kloe Drift Chamber in Frascati

Time Projection Chamber (TPC)



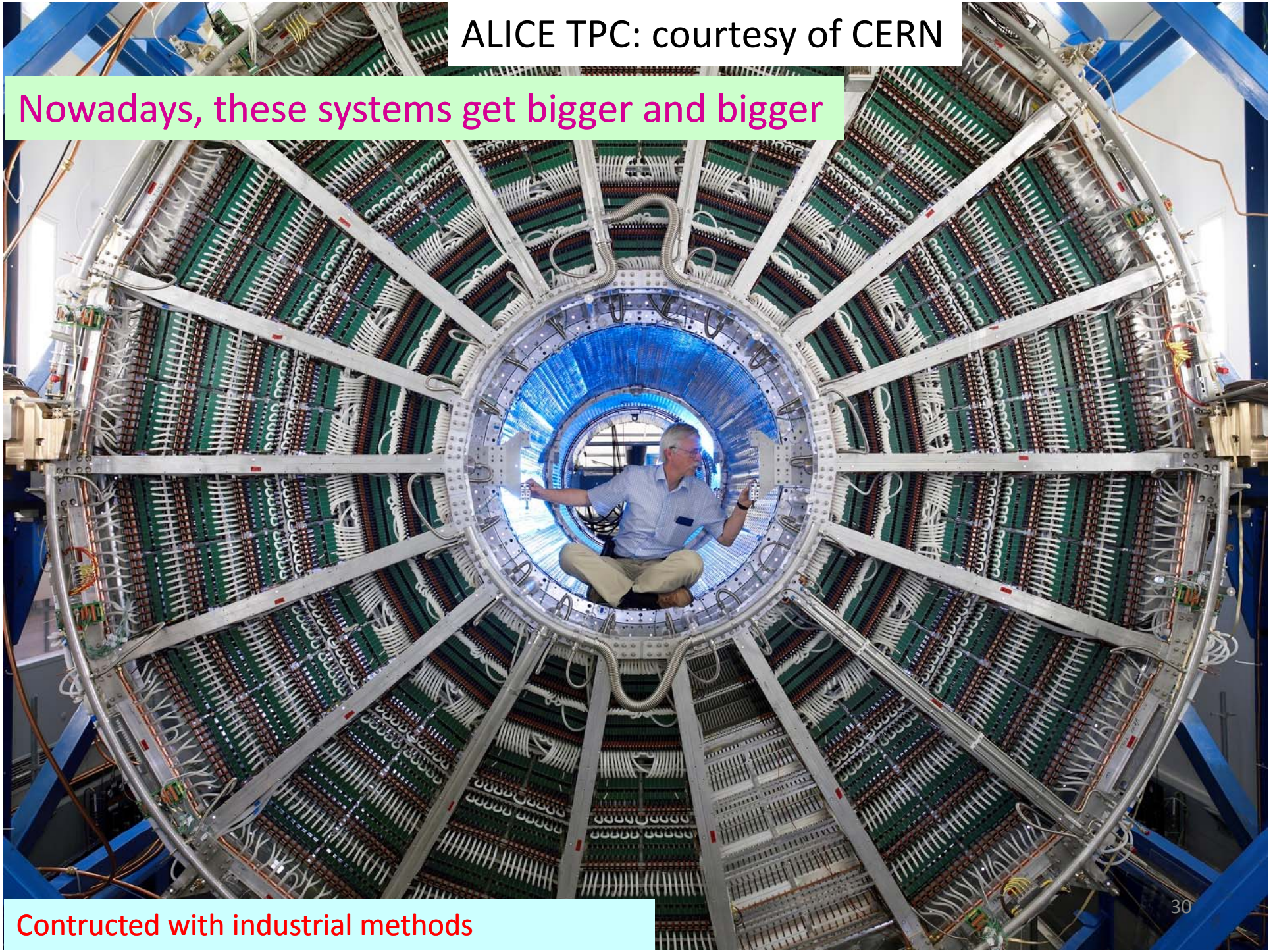
Drift chamber measures r,ϕ



Maximizing drift time
Not suited for high rate experiments
Perfect for (1) electron-positron collider
and (2) Heavy ion collider

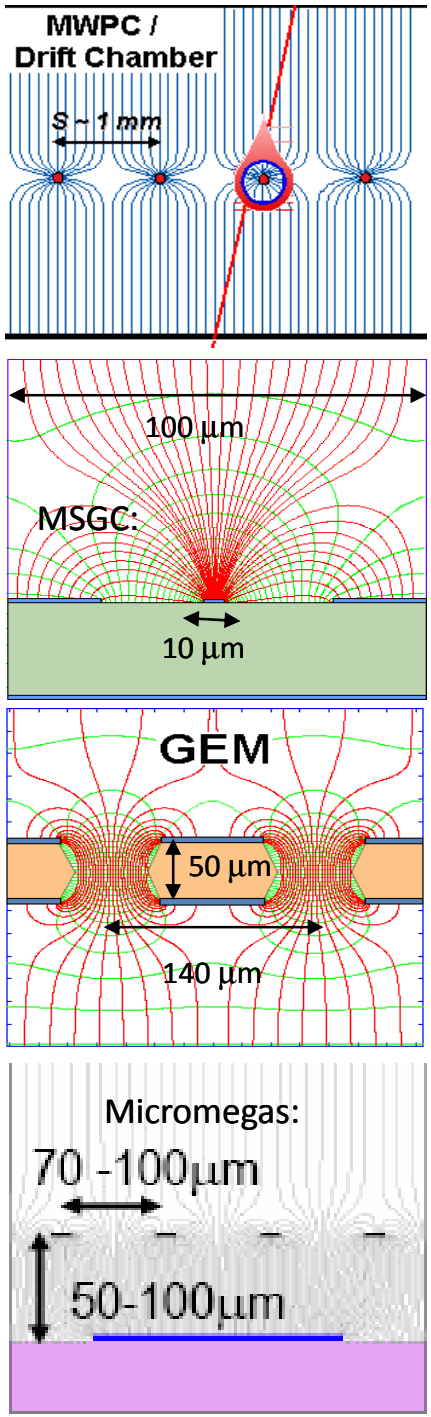
ALICE TPC: courtesy of CERN

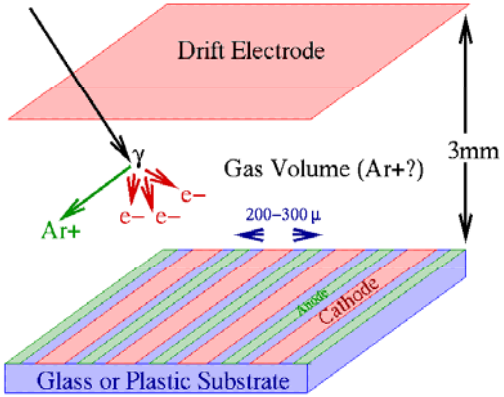
Nowadays, these systems get bigger and bigger



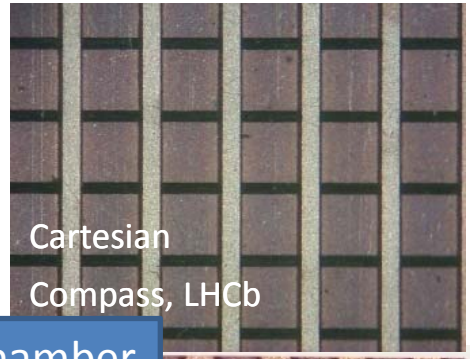
Contructed with industrial methods

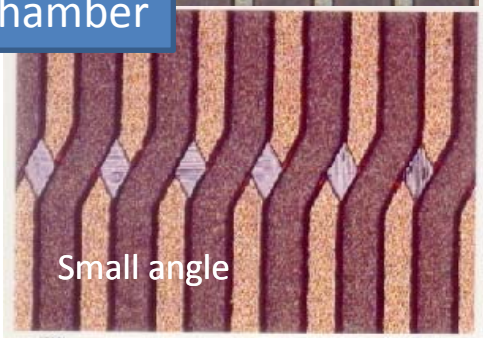
Gaseous detectors without wires





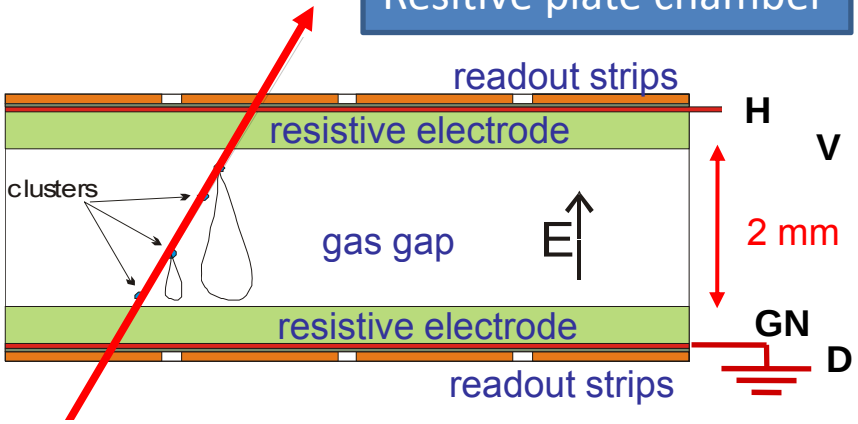
Micro-strip-gas-Chamber

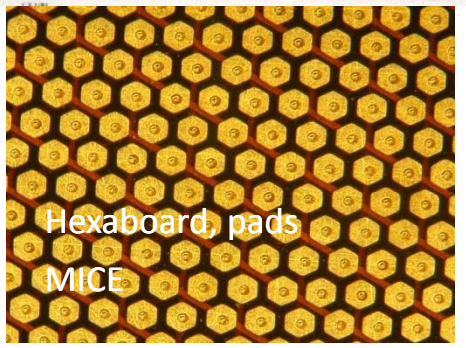


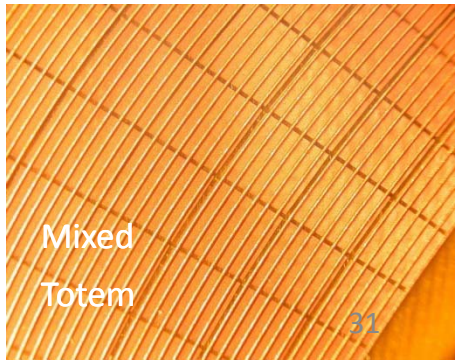


- Structured planes (glas,PCB, etc) instead of wires
- Thin chambers; HIGH voltage (field)
- Dedicated field configuration for gas amplification

Resitive plate chamber







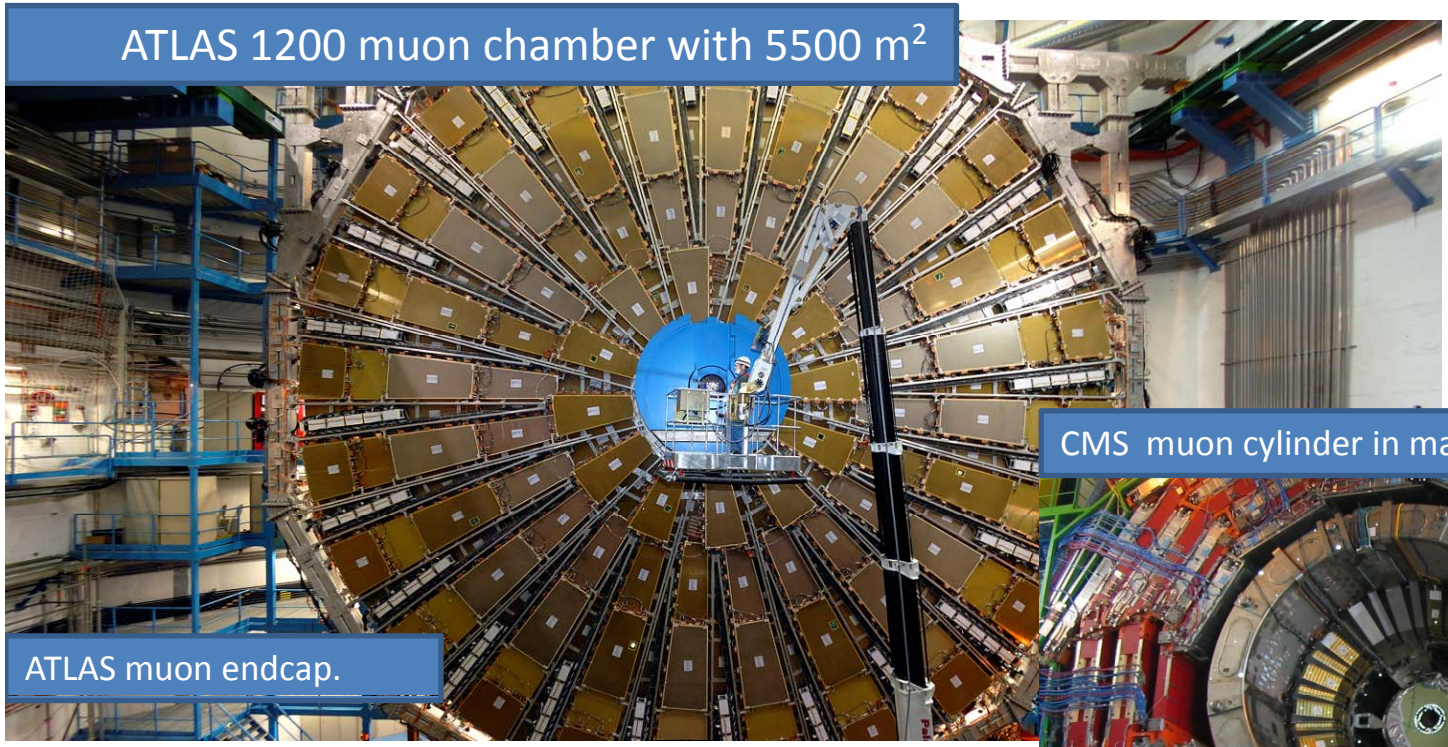
Muon-”detectors”

Muons do pass through the calorimeter and the magnet yoke

➔ All particle there are muons (neglecting neutral neutrinos, which are undetectable here)

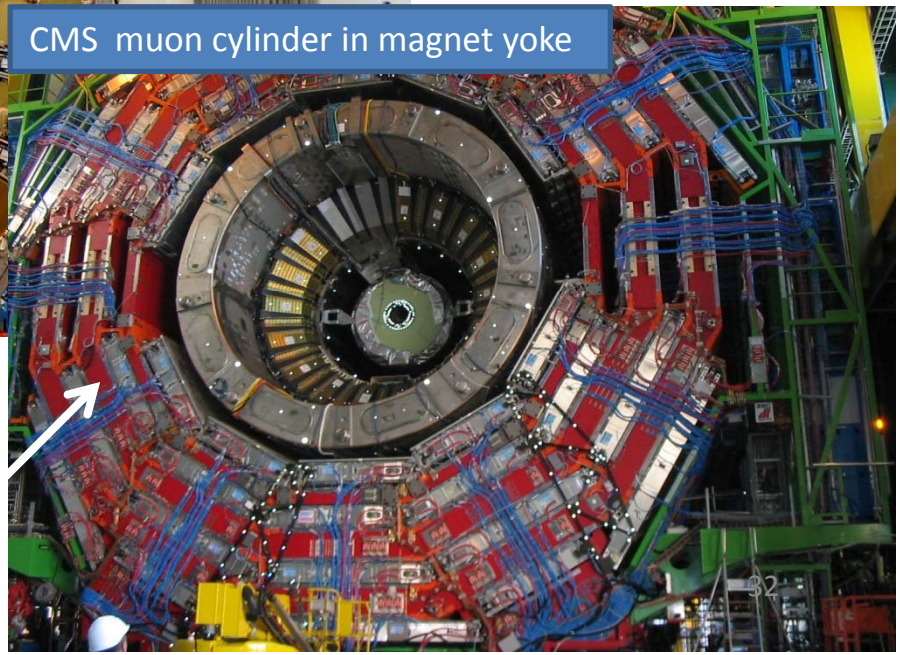
➔ the gaseuous detectors measure the muon tracks in the magnet field

ATLAS 1200 muon chamber with 5500 m^2



ATLAS muon endcap.

CMS muon cylinder in magnet yoke



Muon detectors

New chip with time resolution TIMEPIX @ Freiburg

TIMEPIX Chip: Add 3rd coordinate (TIME) and TOT

TIME Mode → determine time arrival of electron
(clock ~ 48 MHz, 580-600 counts range → ~ 400 ns)

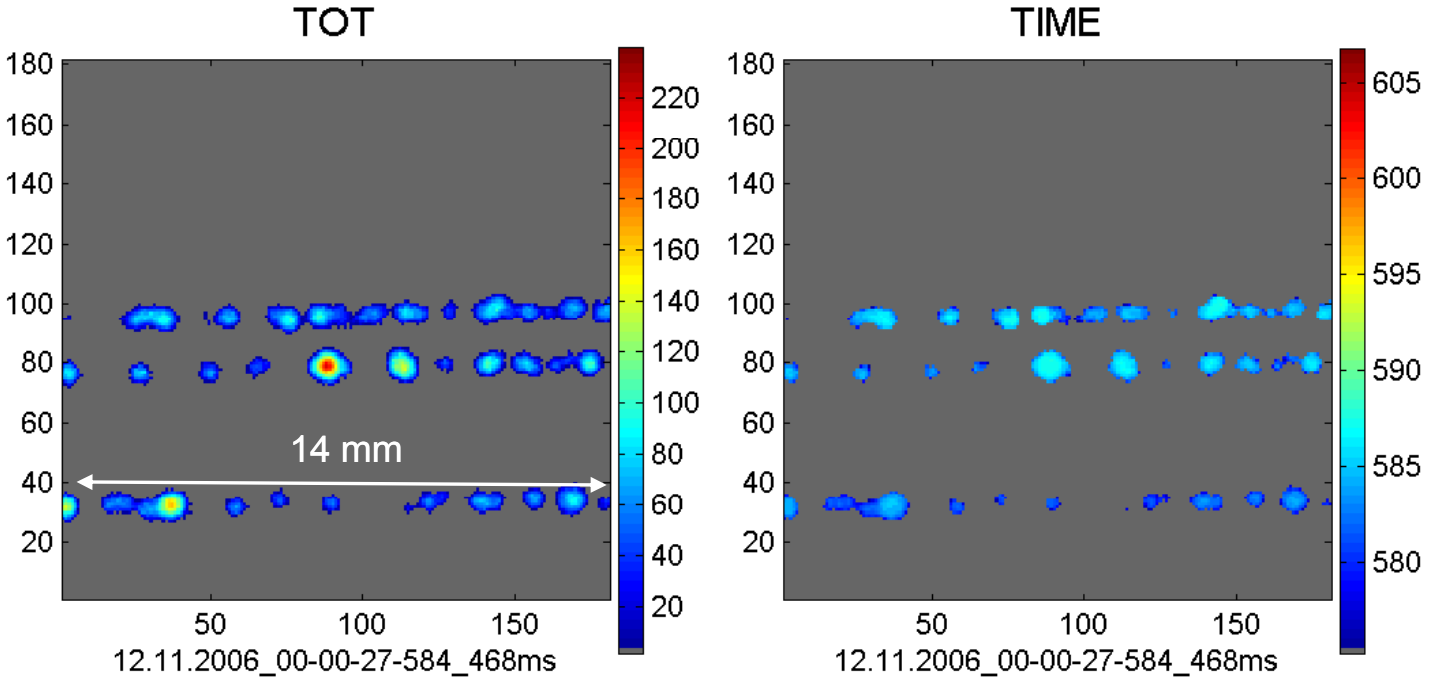
Time Over Threshold (TOT) Mode →
possibility to evaluate cluster charge and to correct
for time-walk (25 - 600 count range → 800 - 35000 e $^{-}$)

Mixed Mode (both measurements at the same time) →
consecutive pixels are in TOT / TIME mode

FINE GRANULARITY
3D TRACKING
+ TOT Information :

- Superior double track resolution

- Benefit from
TOT & TIME information
simultaneously
(correct timewalk using TOT)



Here connected to a gaseous detector but works also with others

Strip detectors

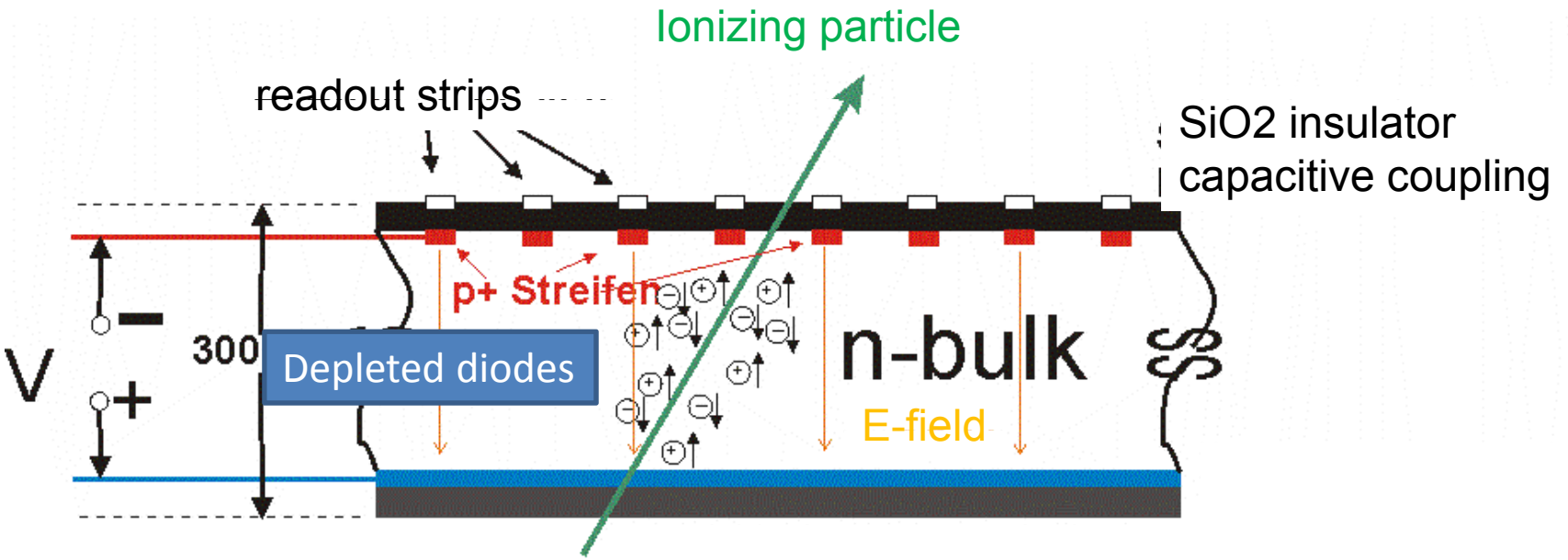
Pixel

(Silicon drift detector; DepFET, CCD, CMOS)

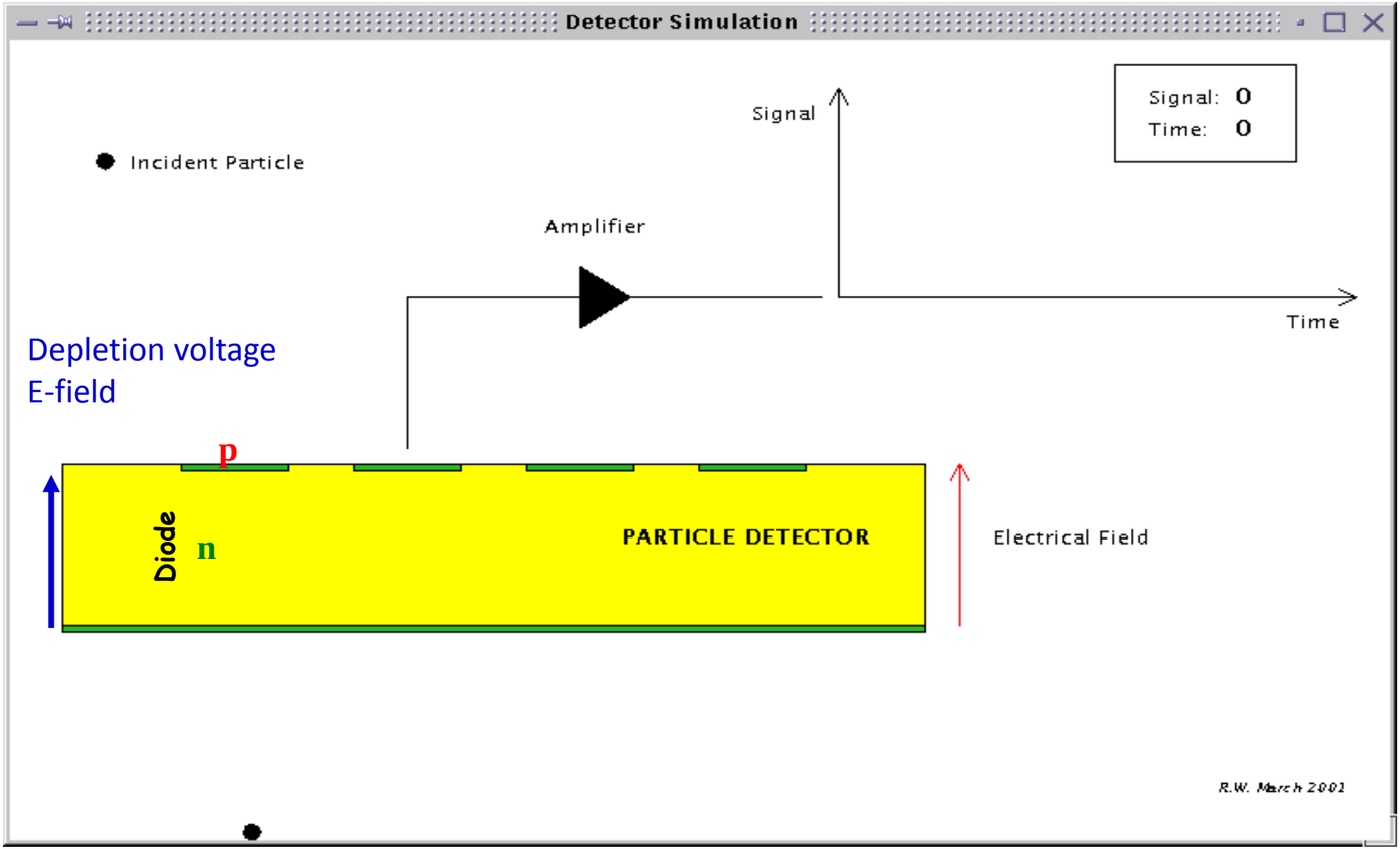
SEMICONDUCTOR DETECTORS - SILICON

Semiconductor Detectors(Silicon)

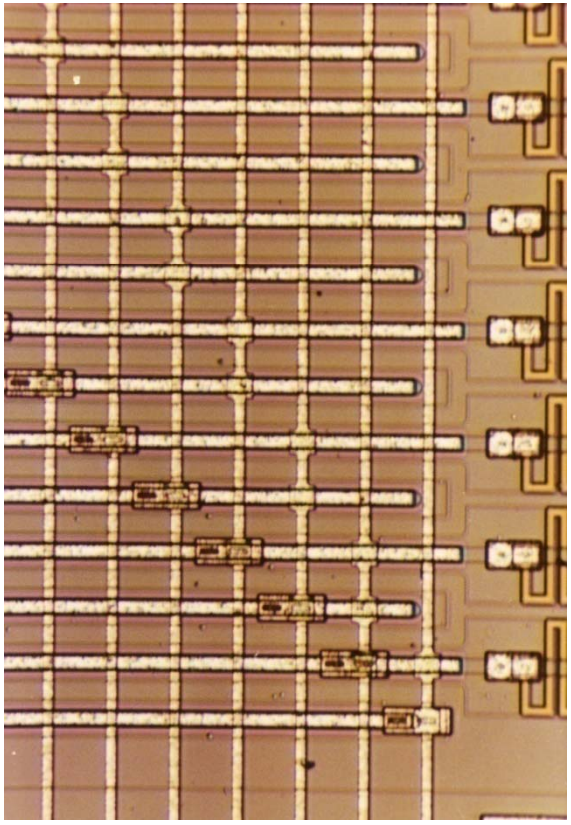
- Functioning principle: similar to gaseous detectors ;-)
  - Ionisation in a solid instead of gas
  - **NO charge amplification**!
    - Ca. 10^{12} free charge carriers versus10^{8} created charge carriers (at room temperature) ☹
      ➔ **Depletion of free charge carriers necessary**
    - Segmentation of diodes under reverse bias voltage

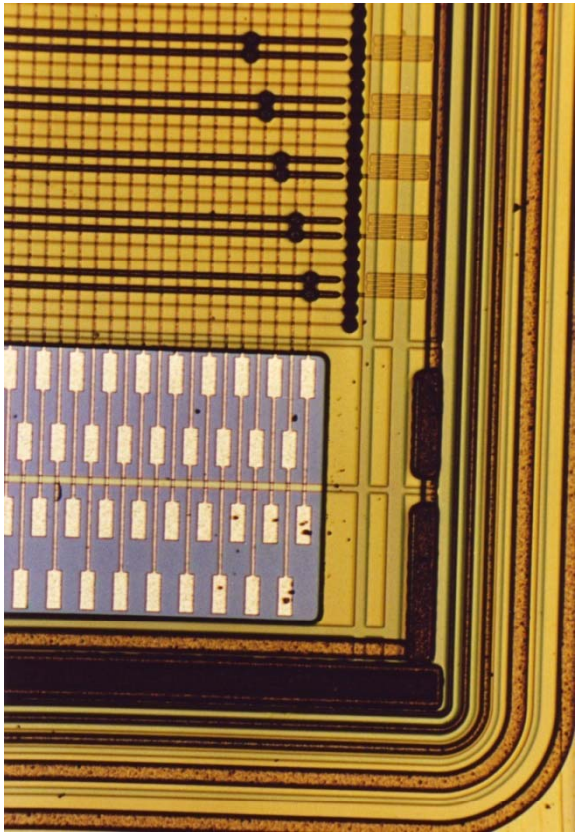


Functioning principle



A silicon strip detector – view from above





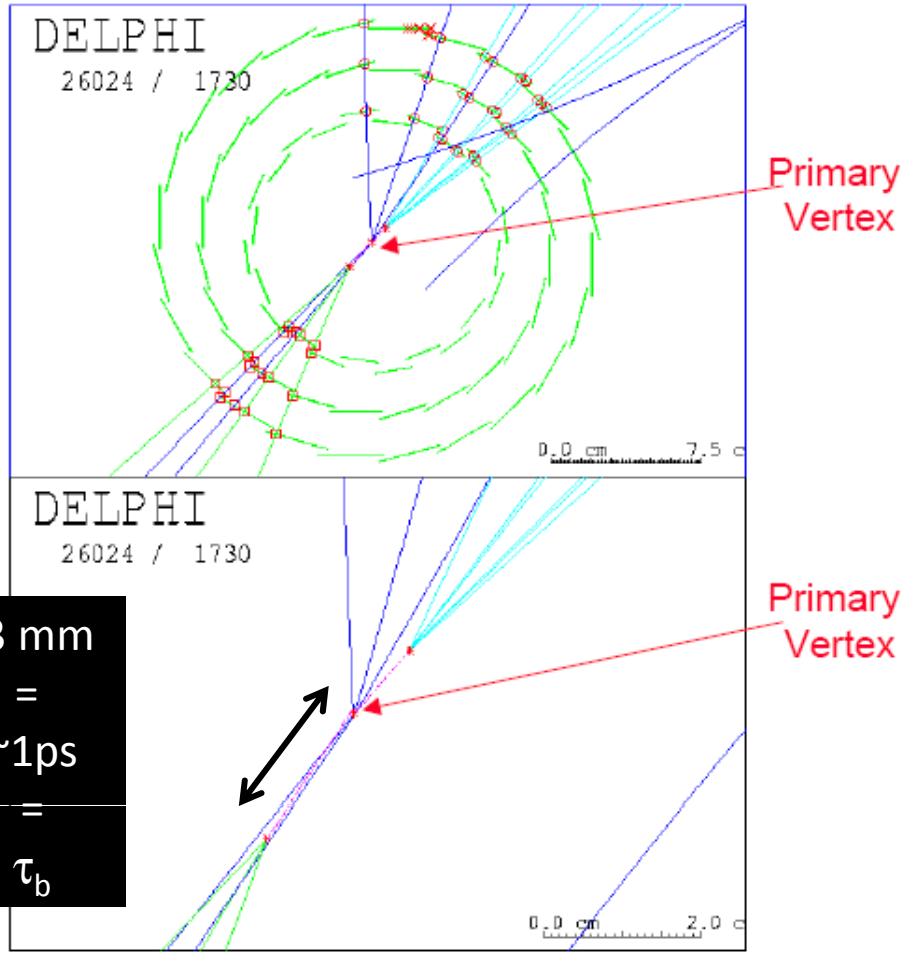
- Small strip spacing possible: 20-200µm
- Very good resolution~3-5µm
- Very fast ~10ns

Do we need such a high resolution?

Identification of b-quark event

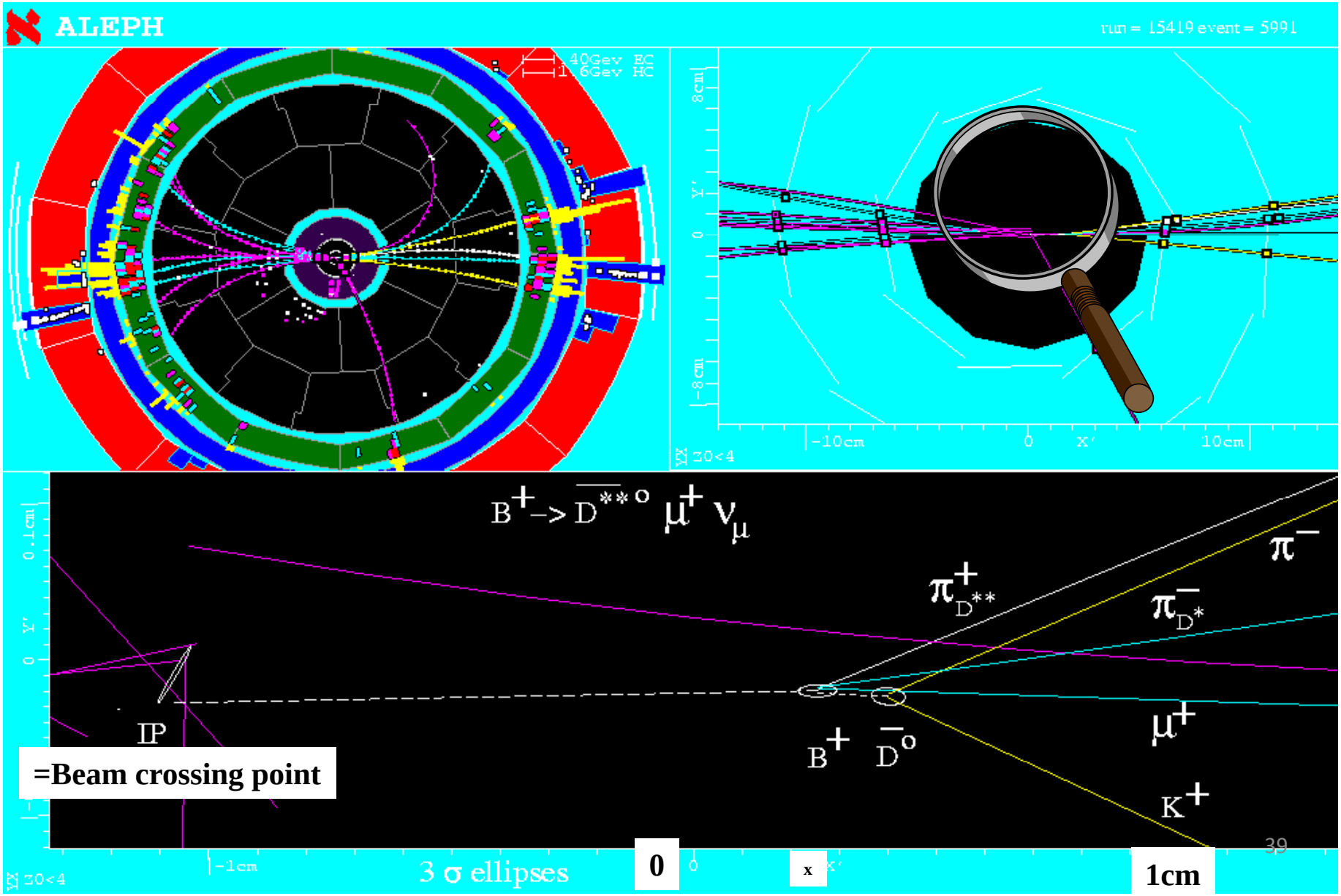
Reconstructed B-mesons in the DELPHI micro vertex detector

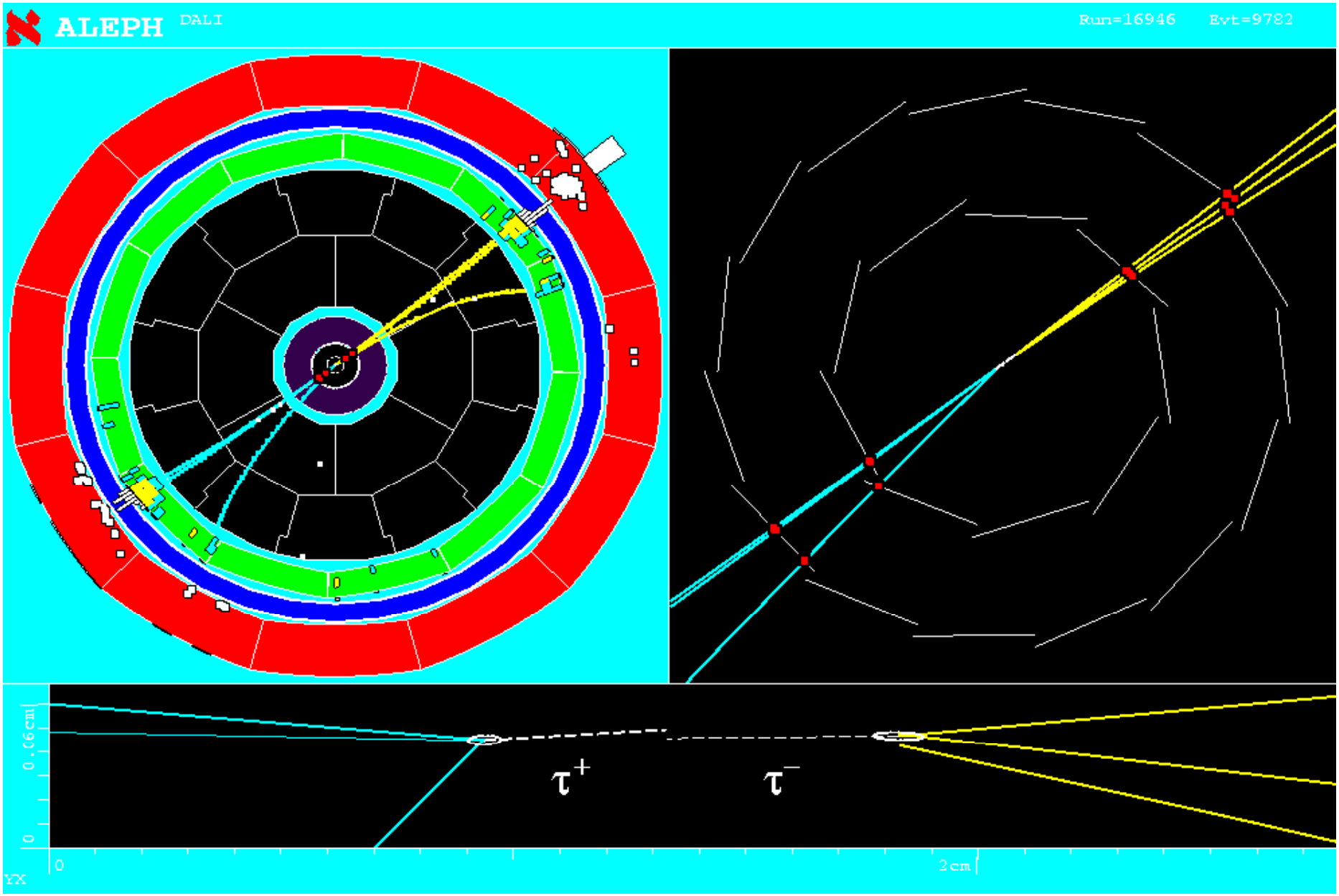
$\tau_B \approx 1.6$ ps $l = c\tau\gamma \approx 500\ \mu m \cdot \gamma$



~3 mm
=
~1ps
=
τ_b

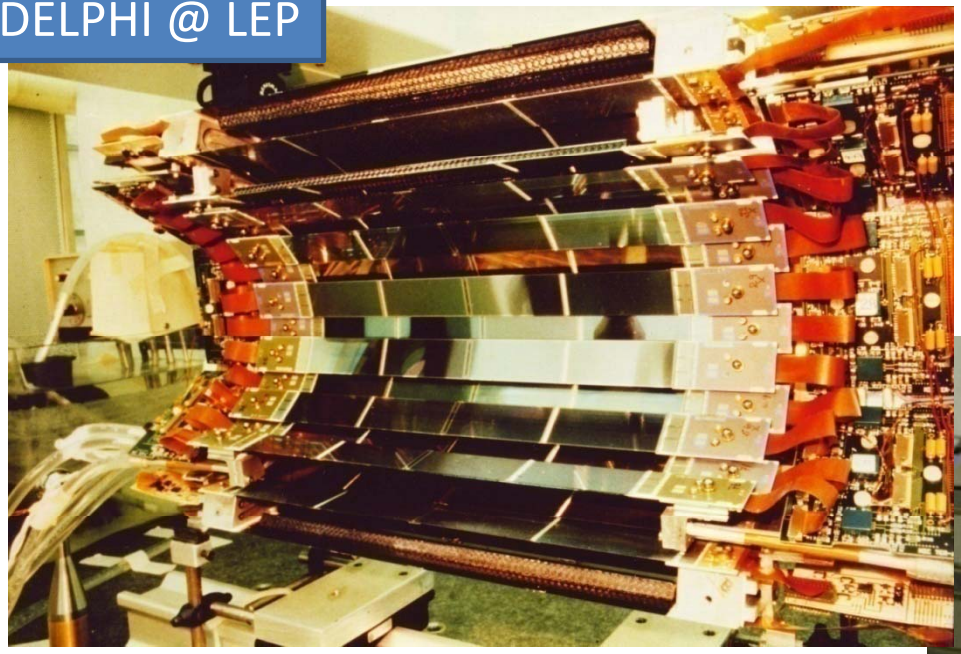
Increase in precision



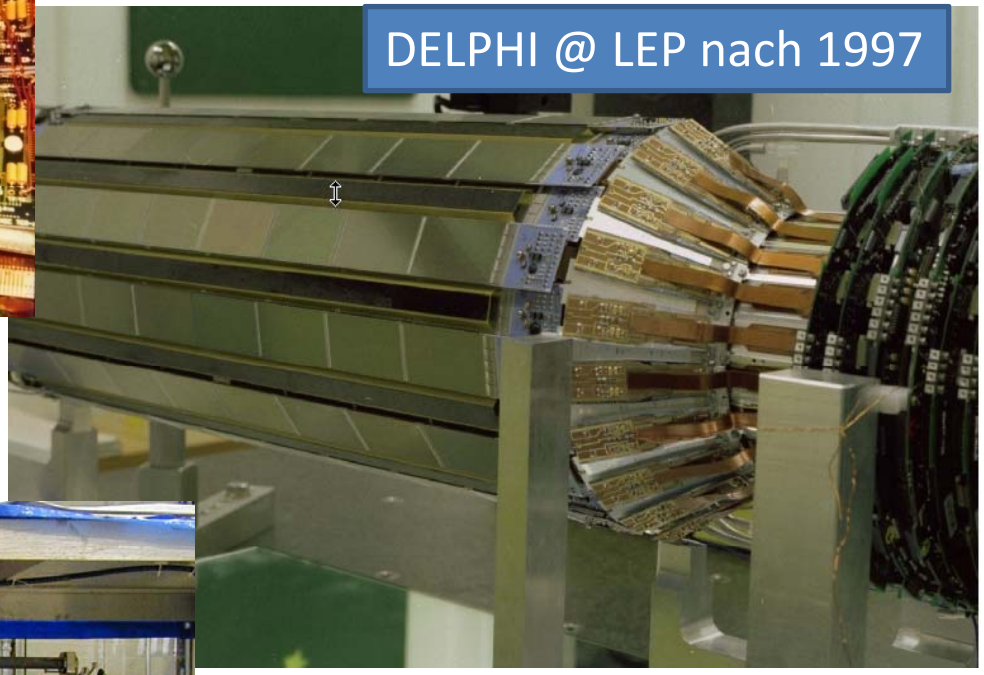


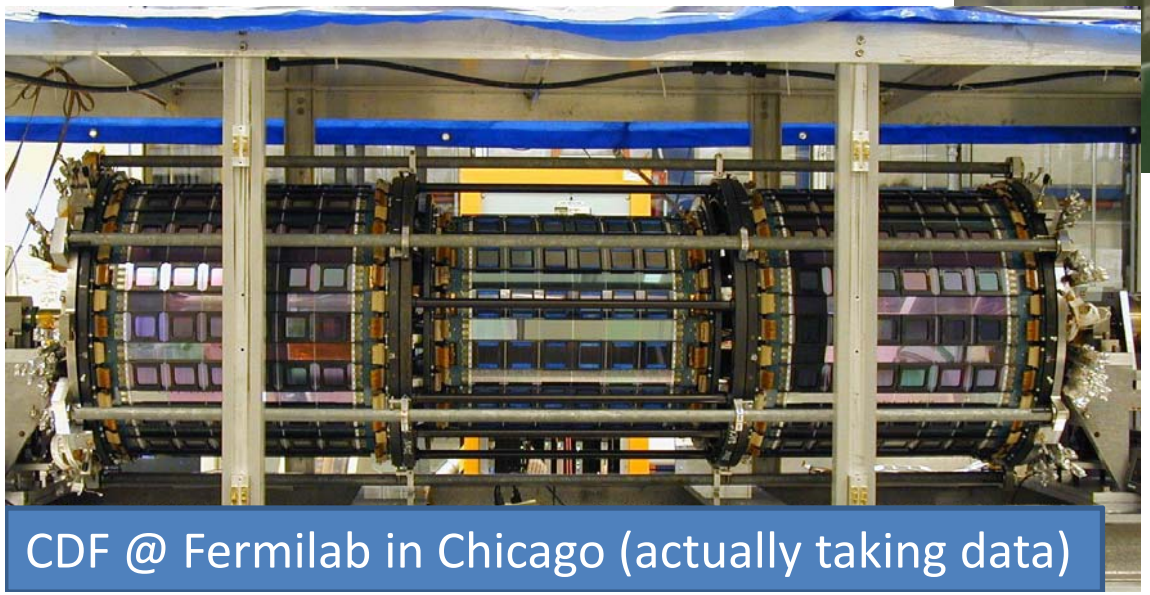
Mean Lifetime of tau $\tau = 290 \times 10^{-15}$ sec !! --> $c\tau = 87\ \mu m$!?

DELPHI @ LEP



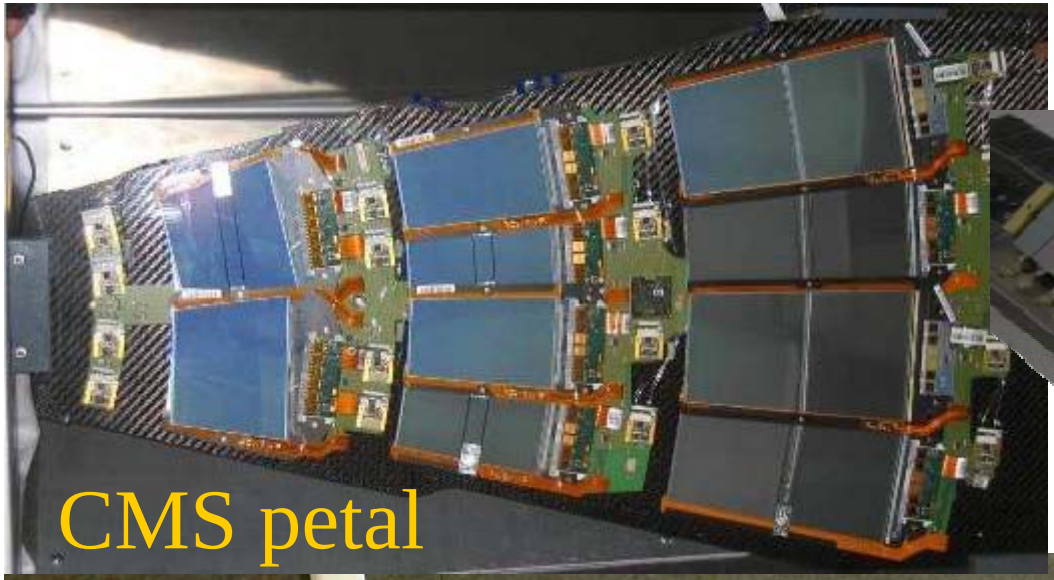
DELPHI @ LEP nach 1997

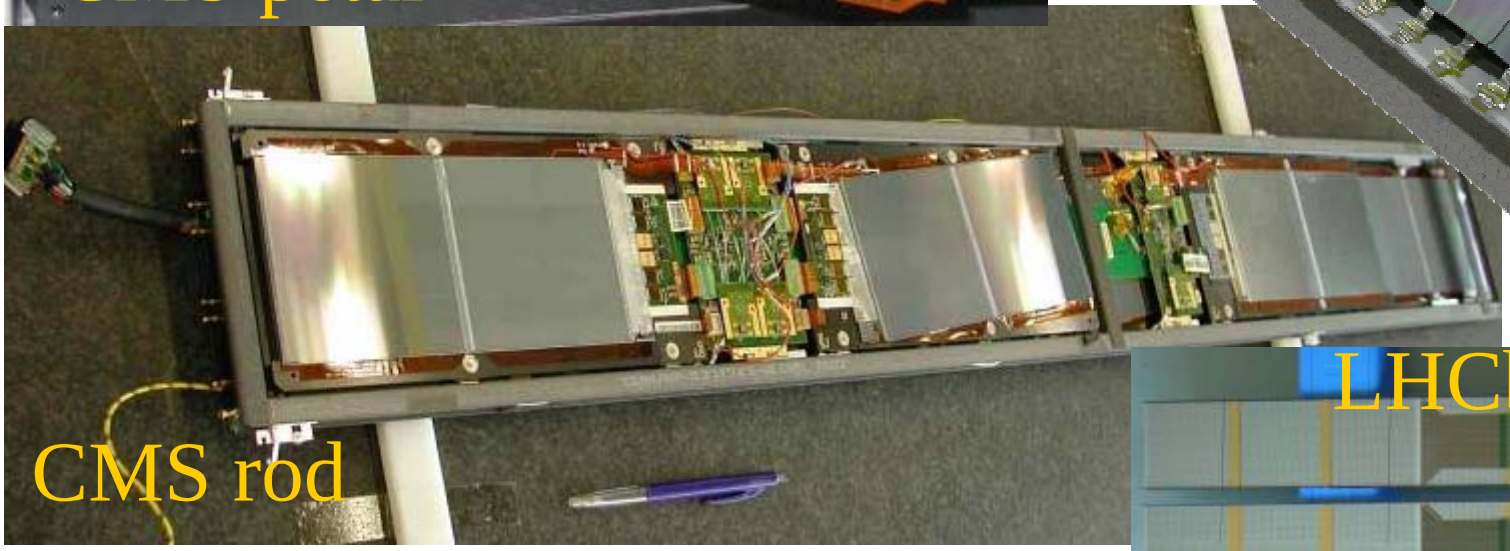


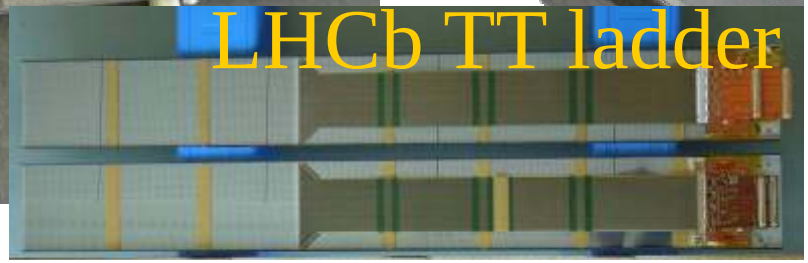


CDF @ Fermilab in Chicago (actually taking data)

Petals & rods & ladders & halfhells:

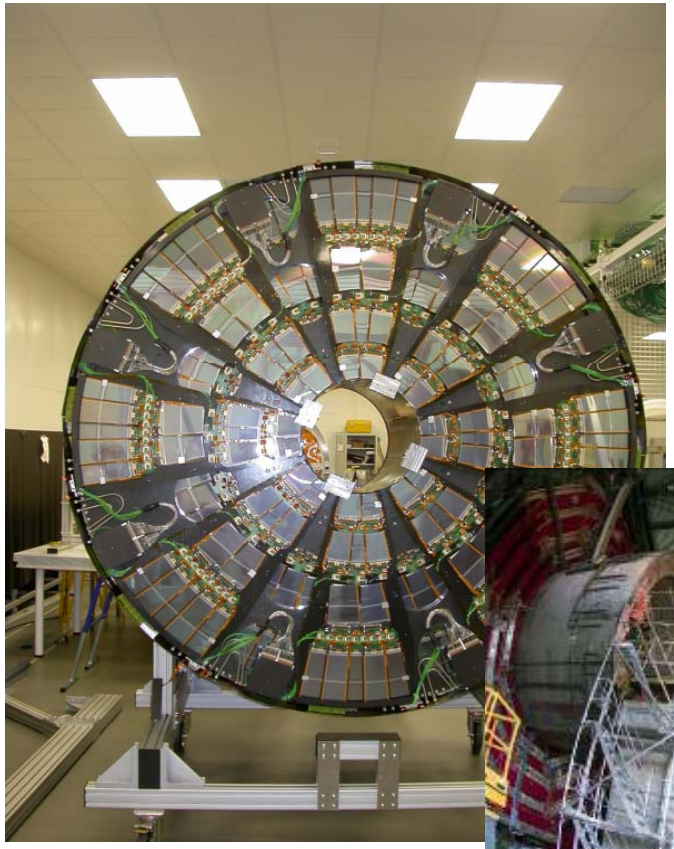


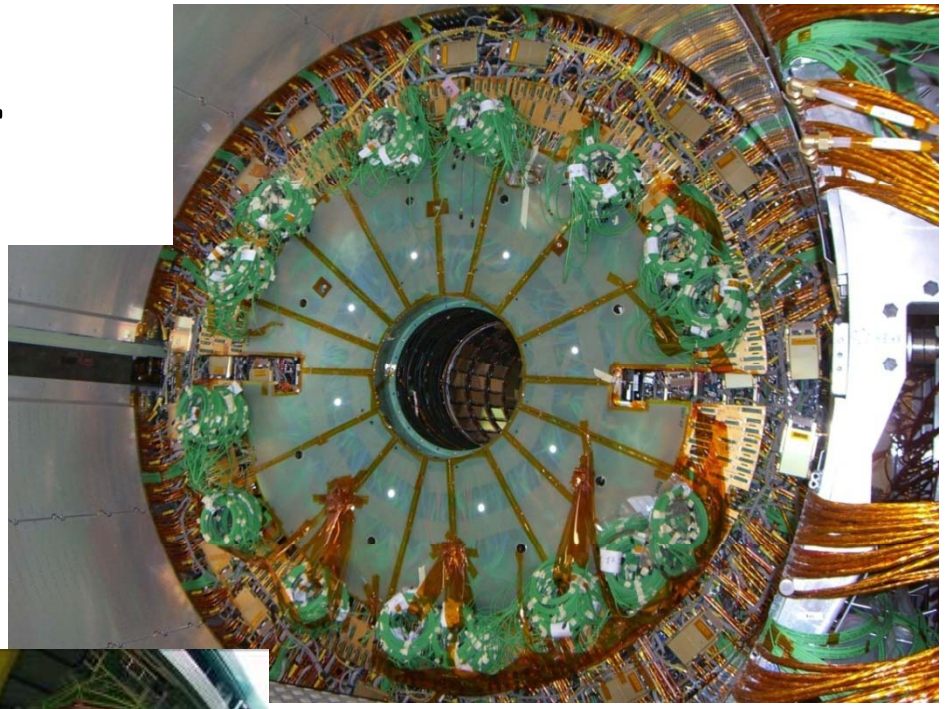


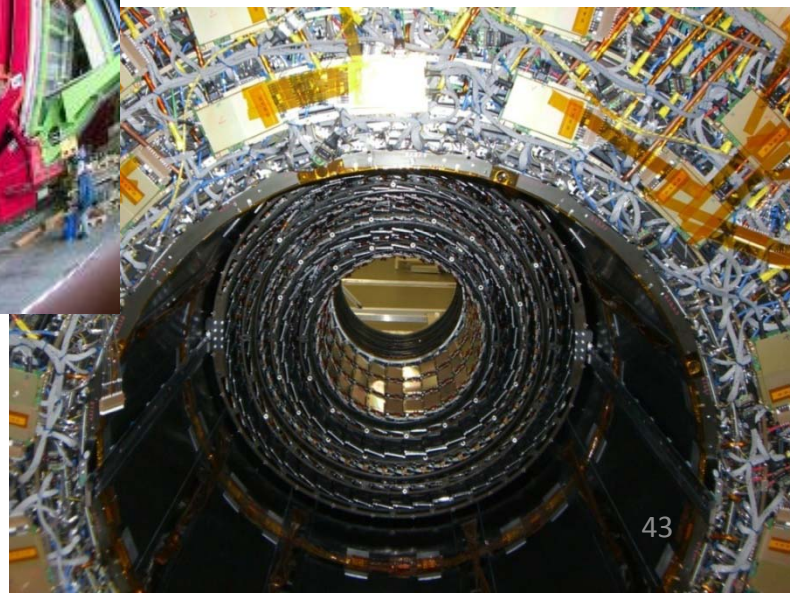


Up to 14 sensors per ladder(4 sensoren per hybrid)

The CMS Tracker

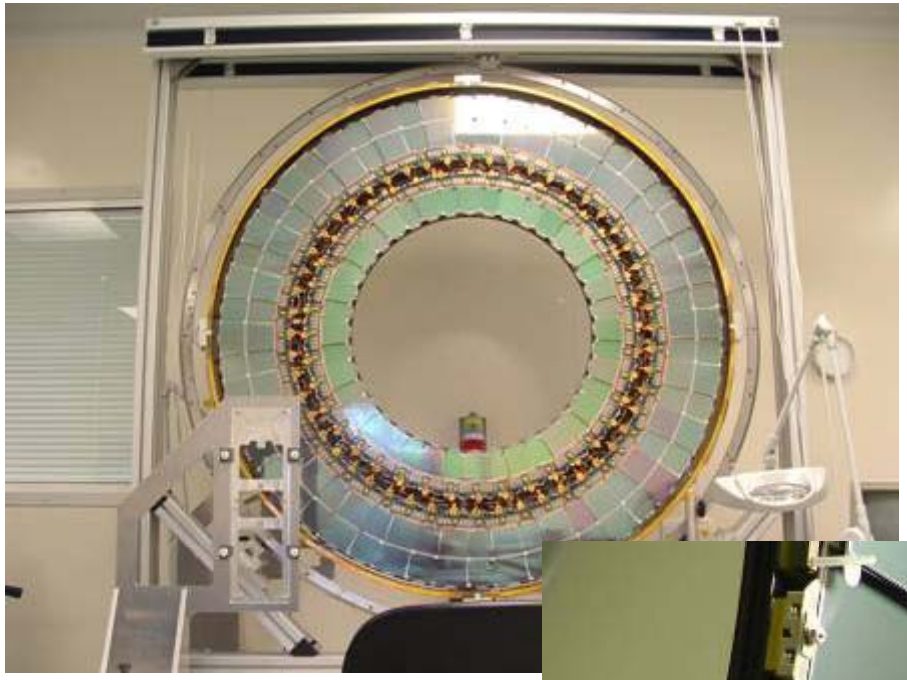


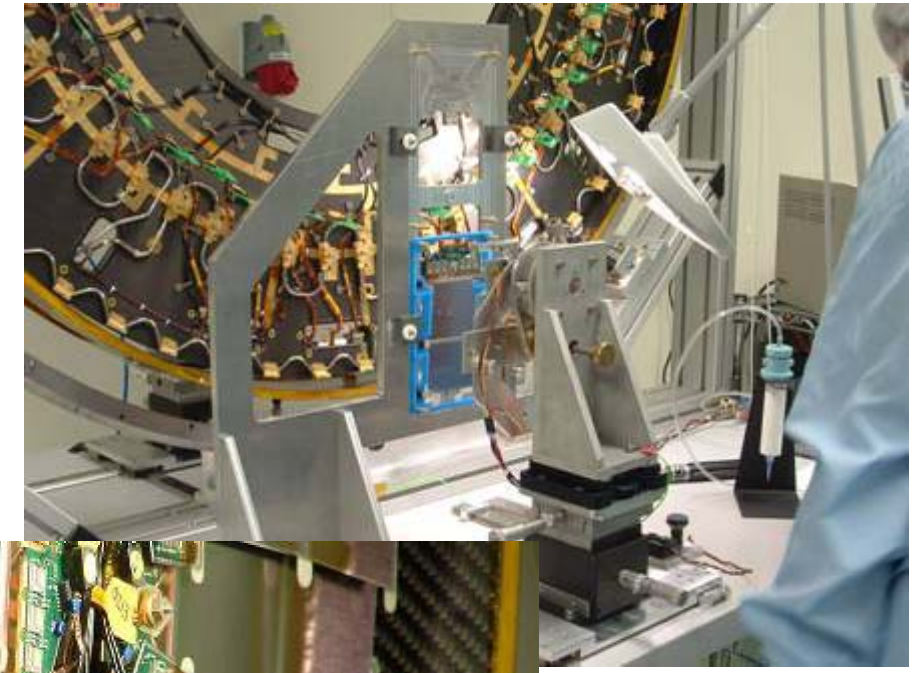


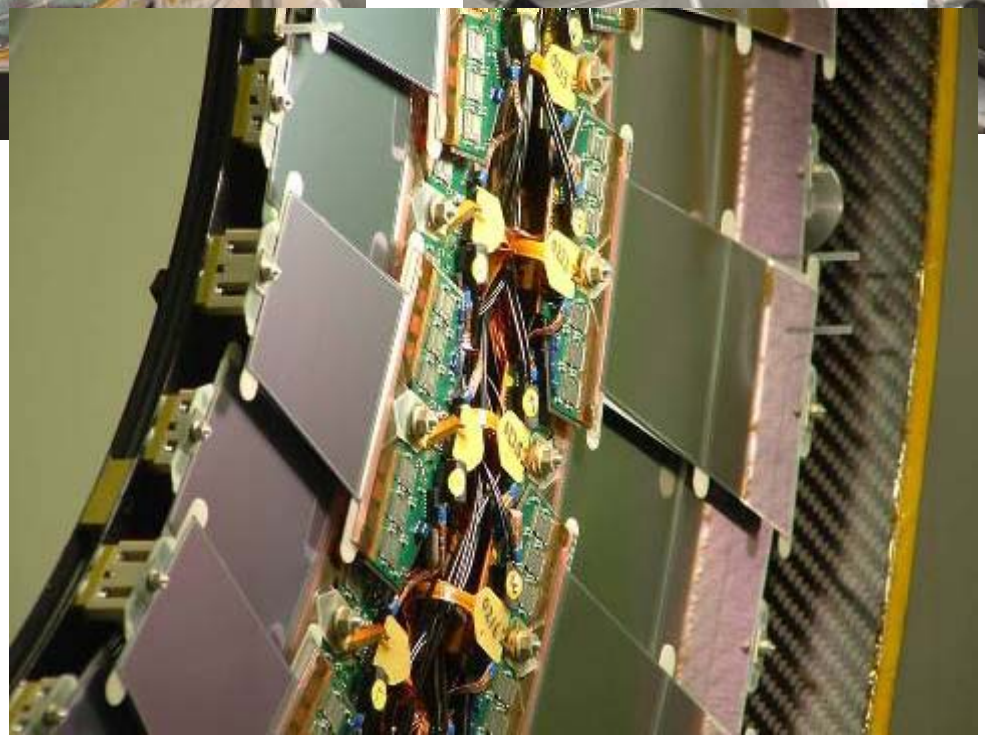


206 m² area
25.000 silicon sensors
10Mio strips ≡ electronic channels
75.376 readoud chips
26.000.000 bonds
37.000 analog optical links
3.000 km optical fibers

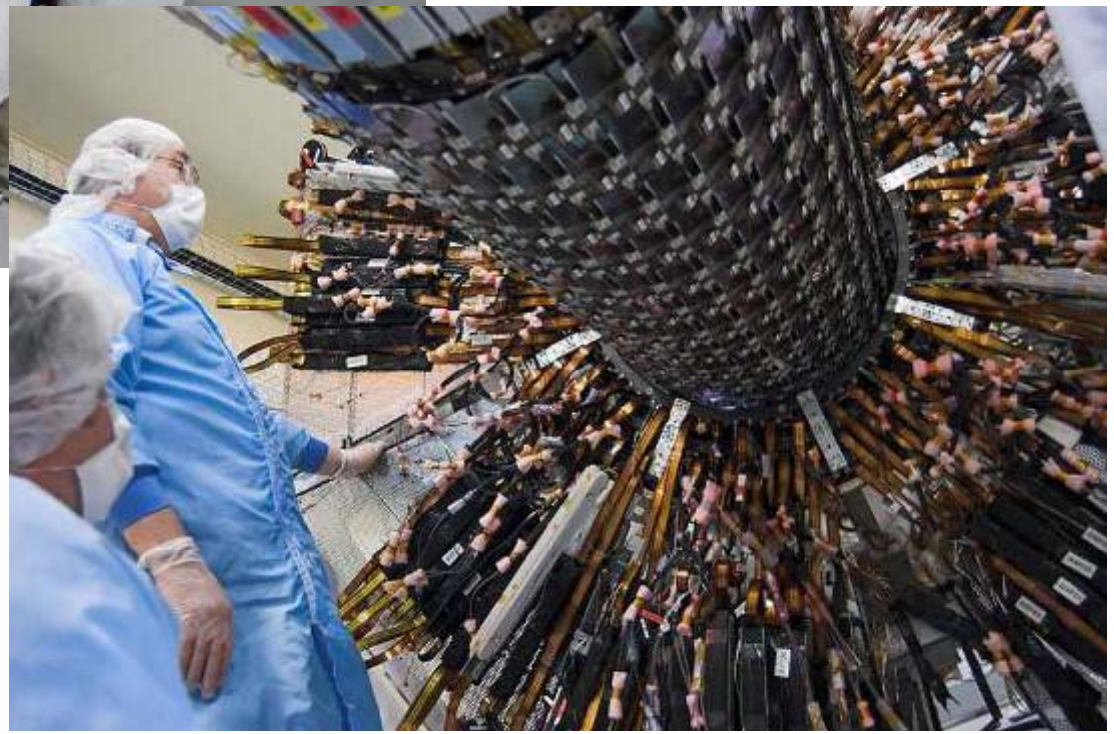
ATLAS endcap





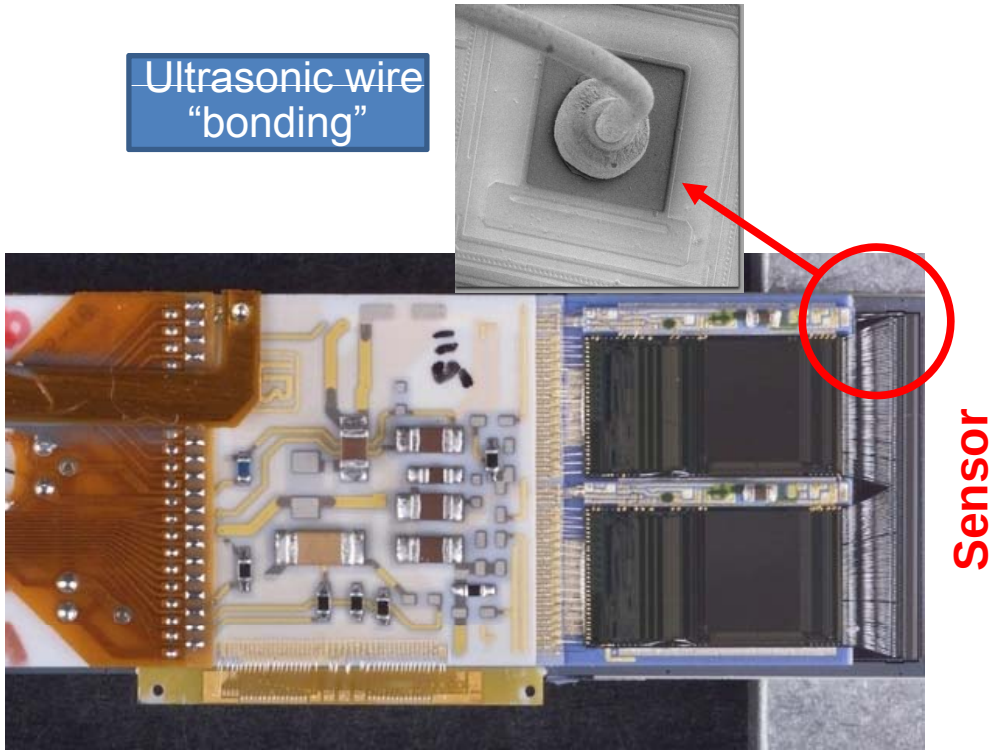


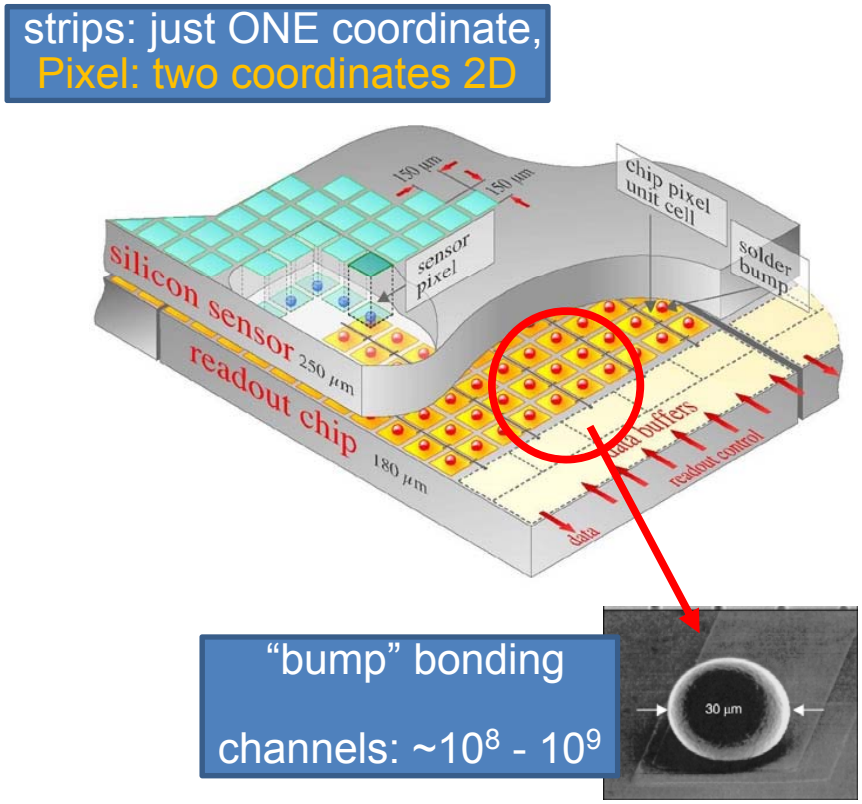
ATLAS Barrel 3



Silicon Pixel detectors

- Principle similar to silicon strip sensors
- Segmentation: Pixel(-diodes) instead of Strip(-diodes)
  - Electronic on top of sensor to reach all pixels





ECAL

Electromagnetic Calorimeter

electrons and photons

HCAL

Hadronic Calorimeter

Hadrons

Mesons (e.g. pions)

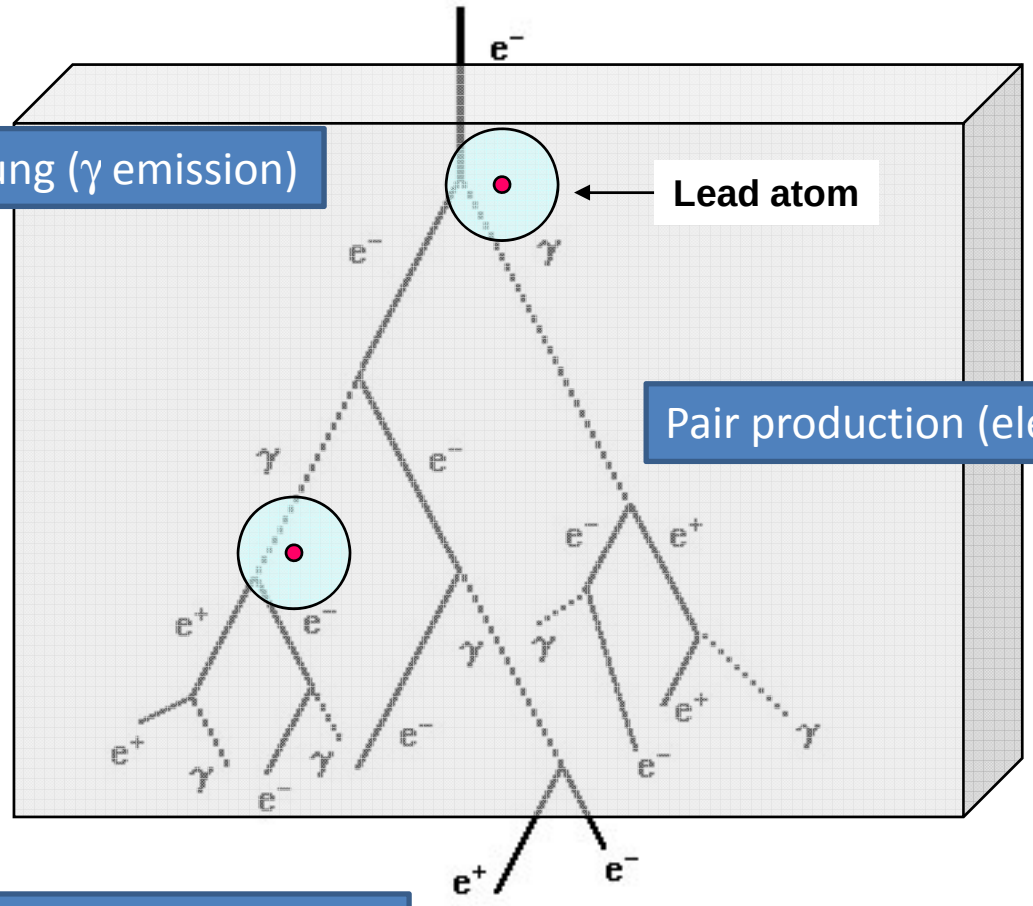
Baryons (e.g. protons)

CALORIMETER (MEASURES ENERGY)

Purpose and principle of a Calorimeter

- Measurement of energy via *total* absorption
- (destructive measurement)
- Detector response ~ E for
  - Charged particles
    - Electrons/positrons and hadrons
  - Neutral particles
    - neutrons, γ
- Prinziple of measurement:
  - Electromagnetic **shower**
  - Hadronis **shower**
- Conervsion due to ionisation or excitation of the detector material ➔ current, voltage

Electromagnetic Shower



Bremsstrahlung (γ emission)

Pair production (electron-positron)

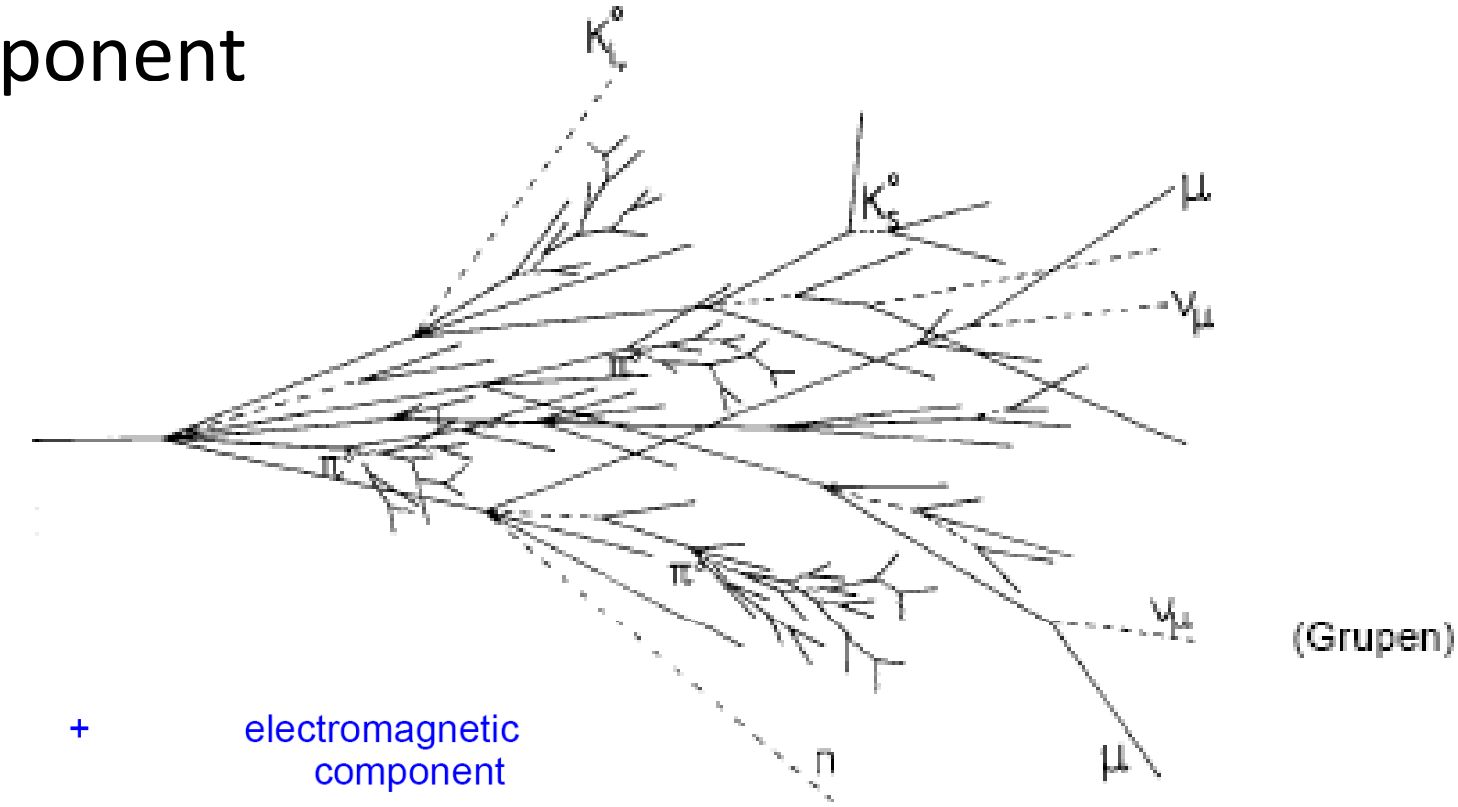
etc.

Until all particle energy is spent ;-)

Radiation length: X_0 = Lentgh, where 1/e particle enegry is emitted via Bremsstrahlung

Hadronic Calorimeter

- Cascade with electromagnetic and hadronic component



(Grupen)

Hadronic + electromagnetic component

↓ charged pions, protons, kaons ….
Breaking up of nuclei
(binding energy),
neutrons, neutrinos, soft γ's
muons …. → invisible energy

↓ neutral pions → 2γ →
electromagnetic cascade

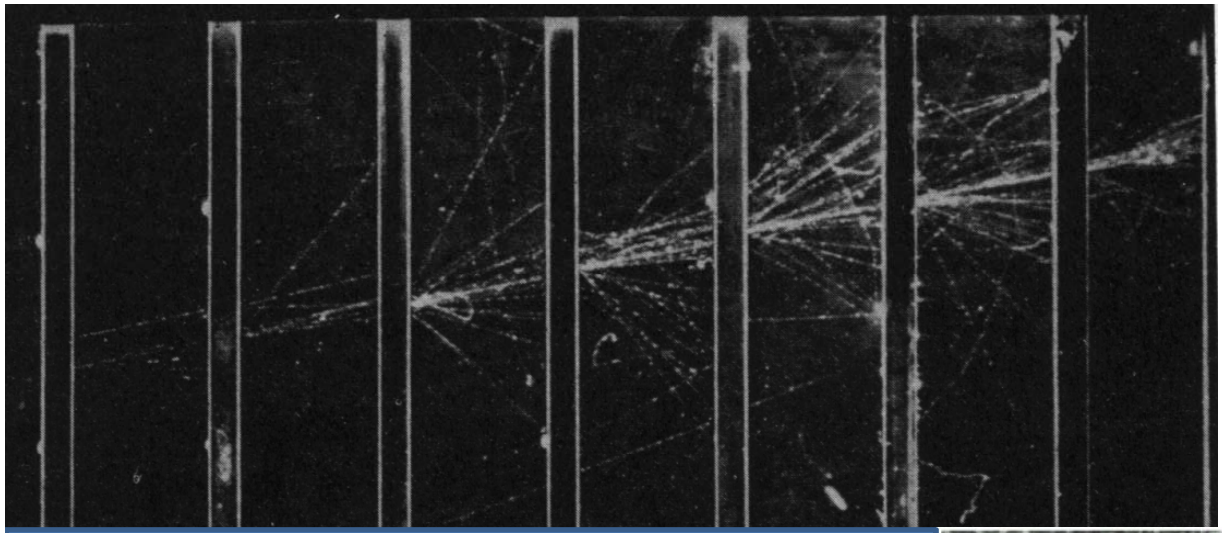
$$n(\pi^0) \approx \ln E(GeV) - 4.6$$

example 100 GeV: $n(\pi^0) \approx 18$

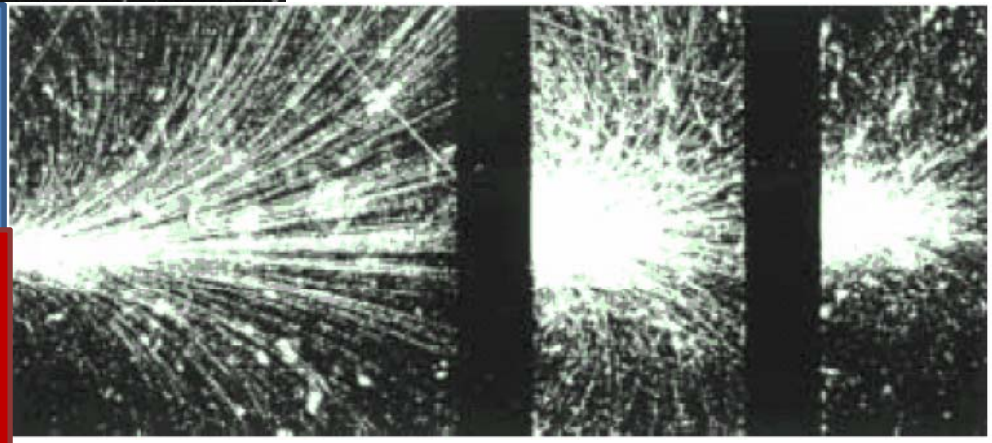
Energy resolution much worse than for em calorimeters

larger fluctuations in hadronic shower

Calorimeter and Shower
How to measure finally the energy?



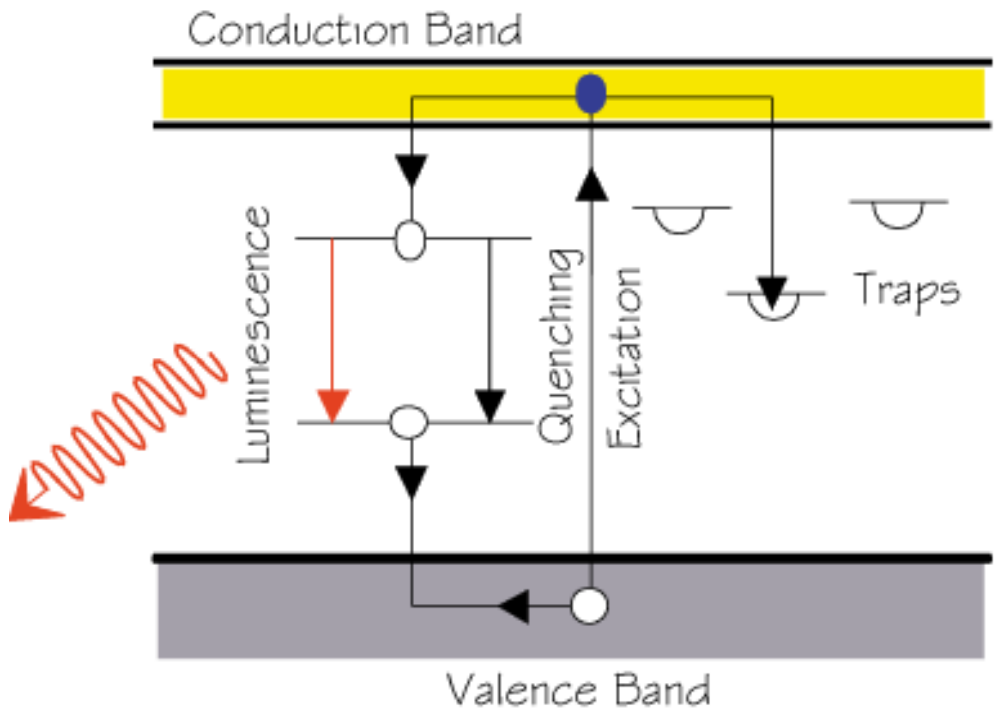
Photon-induced shower in a cloud chamber;
The intermediate black parts are lead blocks;
in addition, there is a magnetic field perpendicular to the figure plane



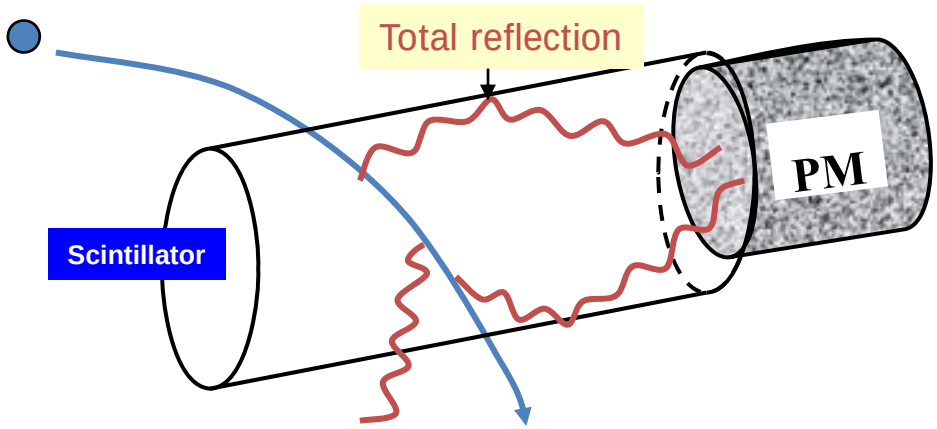
The energy is then proportional to
Light & penetration depth
of the shower

The mere eye is not able to quantify this ;-(
We have to measure the amount of light and penetration path electronically!

Szintillator: Principle



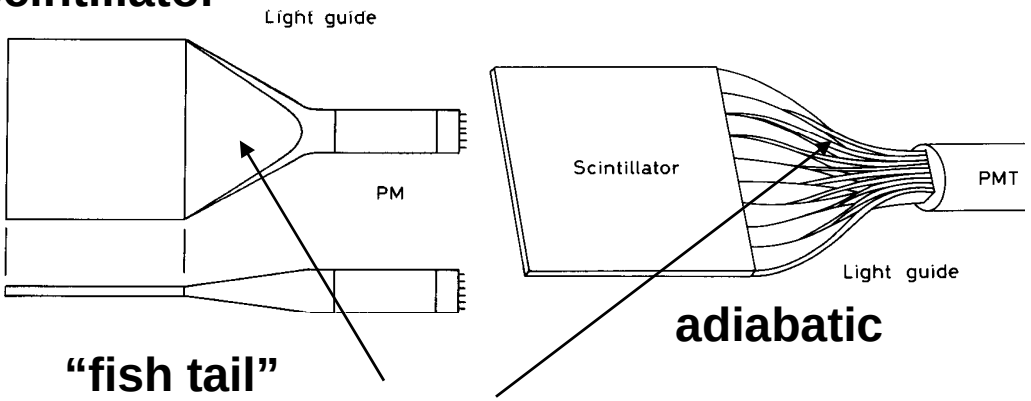
Material with special colour centers



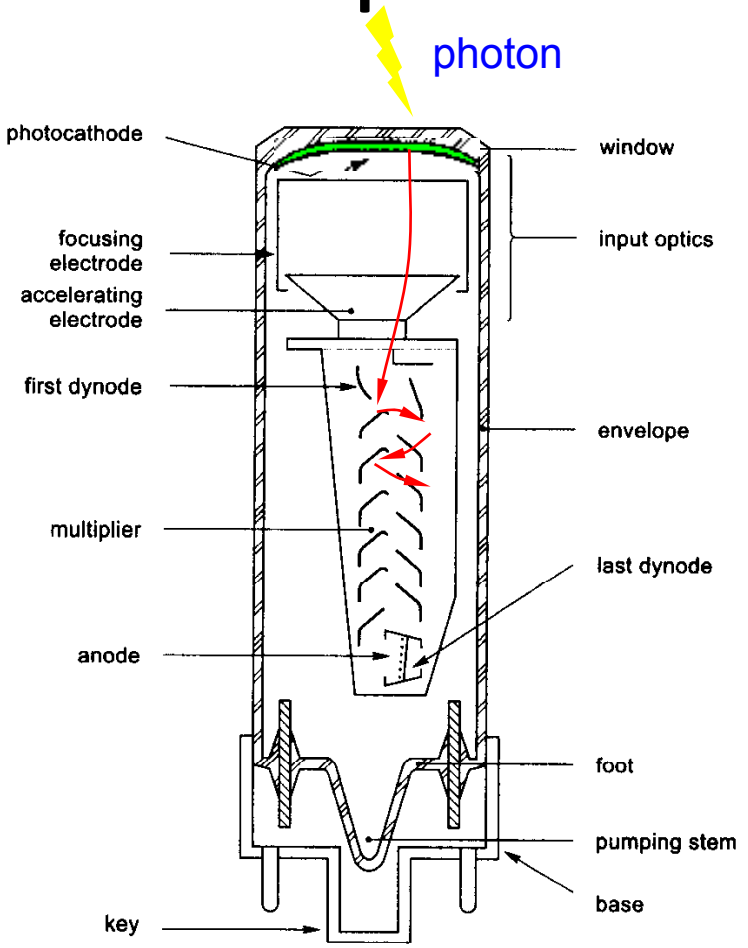
Photomultiplier:
converts light into electronic signal

Scintillator plus Photomultiplier

Scintillator



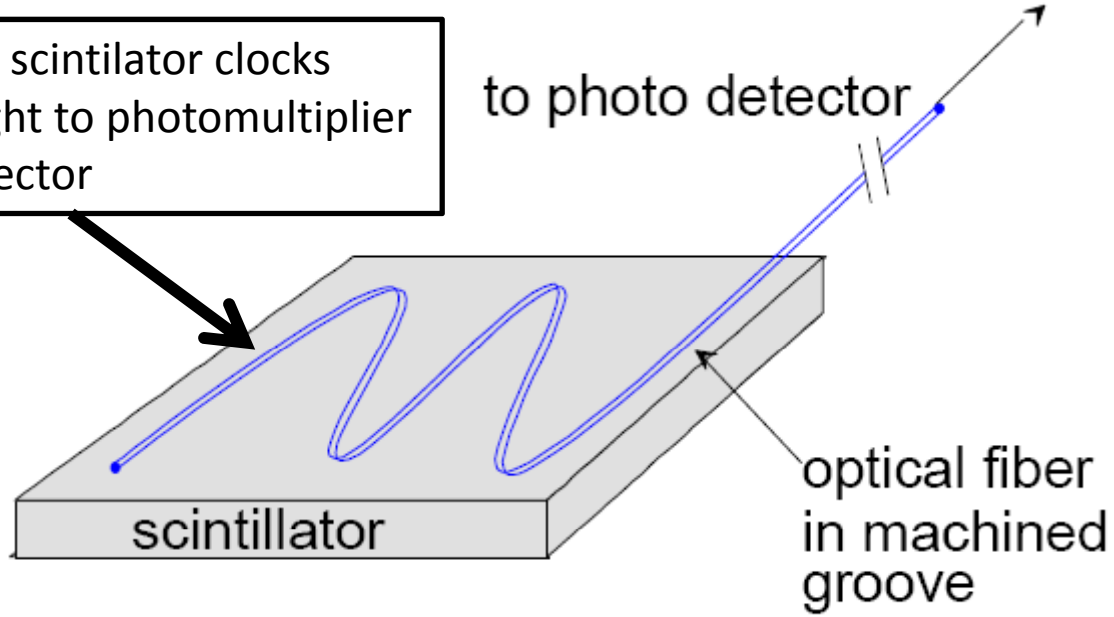
Light guides: transfer via total internal reflection

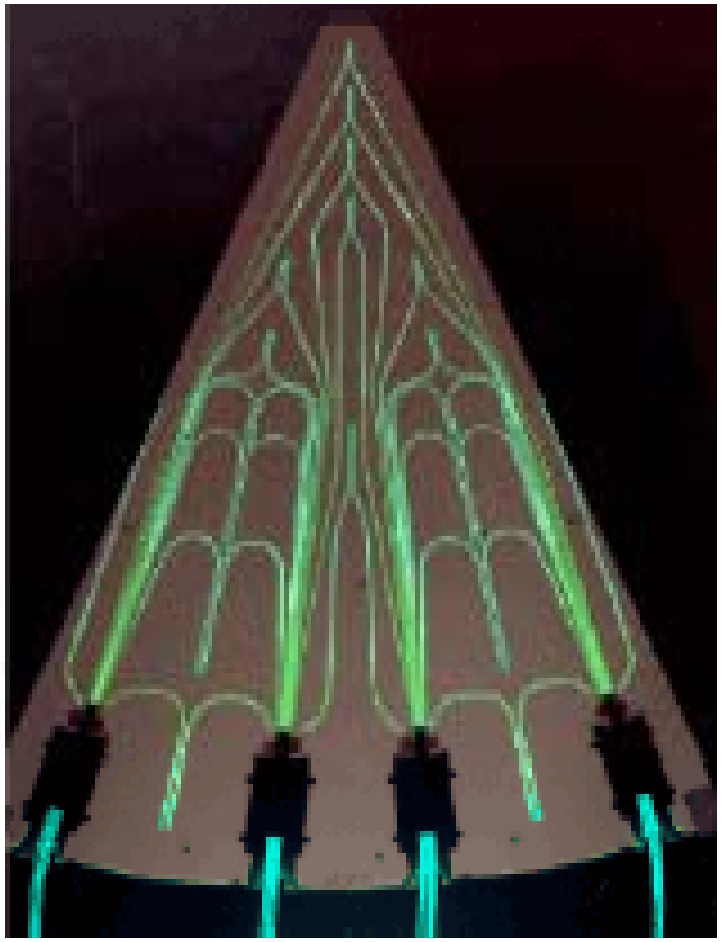


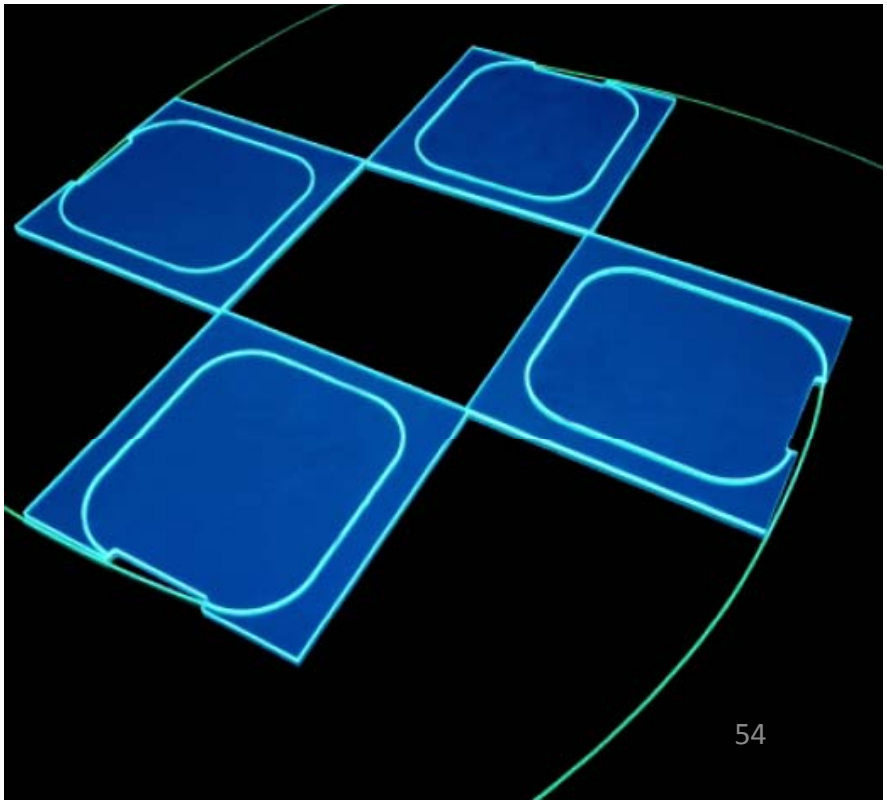
Particle crossing through scintillator ➔ atomic excitation ➔ γ radiation ➔ guide to photo cathode ➔ Photoeffekt ➔ primary electron ➔ multiplictaion on dynodes with high voltage G~4, M~10^6

CMS Hadronic Calorimeter

Light guides in scintilator clocks
Guiding the light to photomultiplier
outside of detector

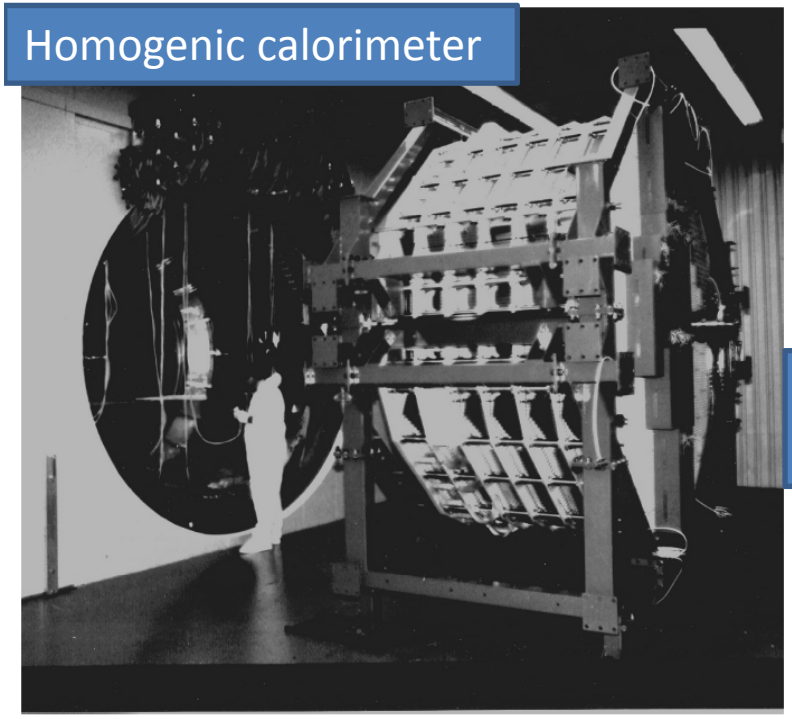






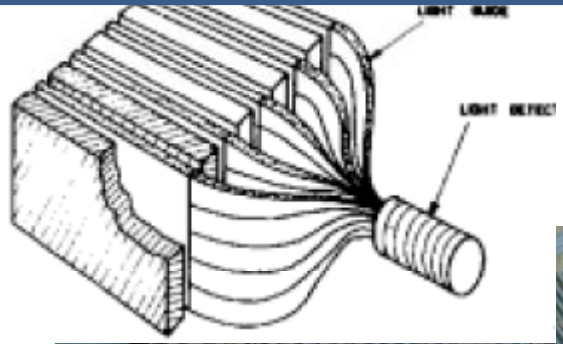
Calorimeter

Homogenic calorimeter



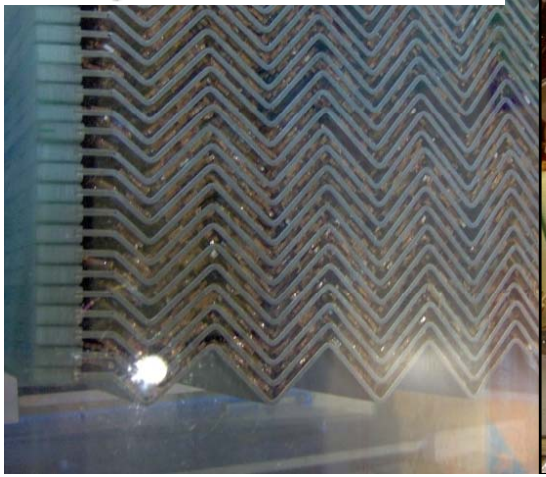
The NA48 LKr calorimeter prior to installation in the cryostat.

Sampling calorimeter:
Scintillator alternates with detector material

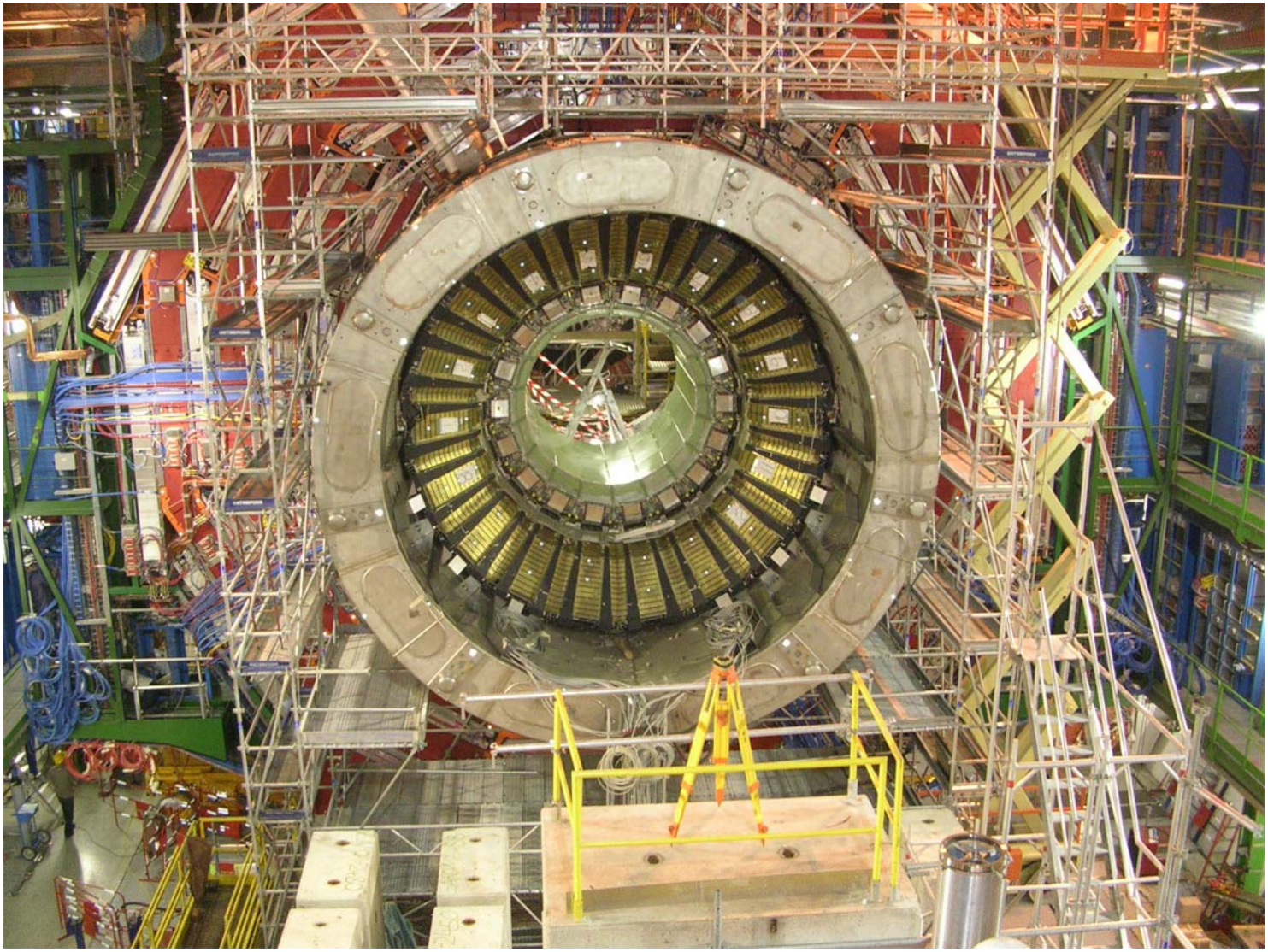


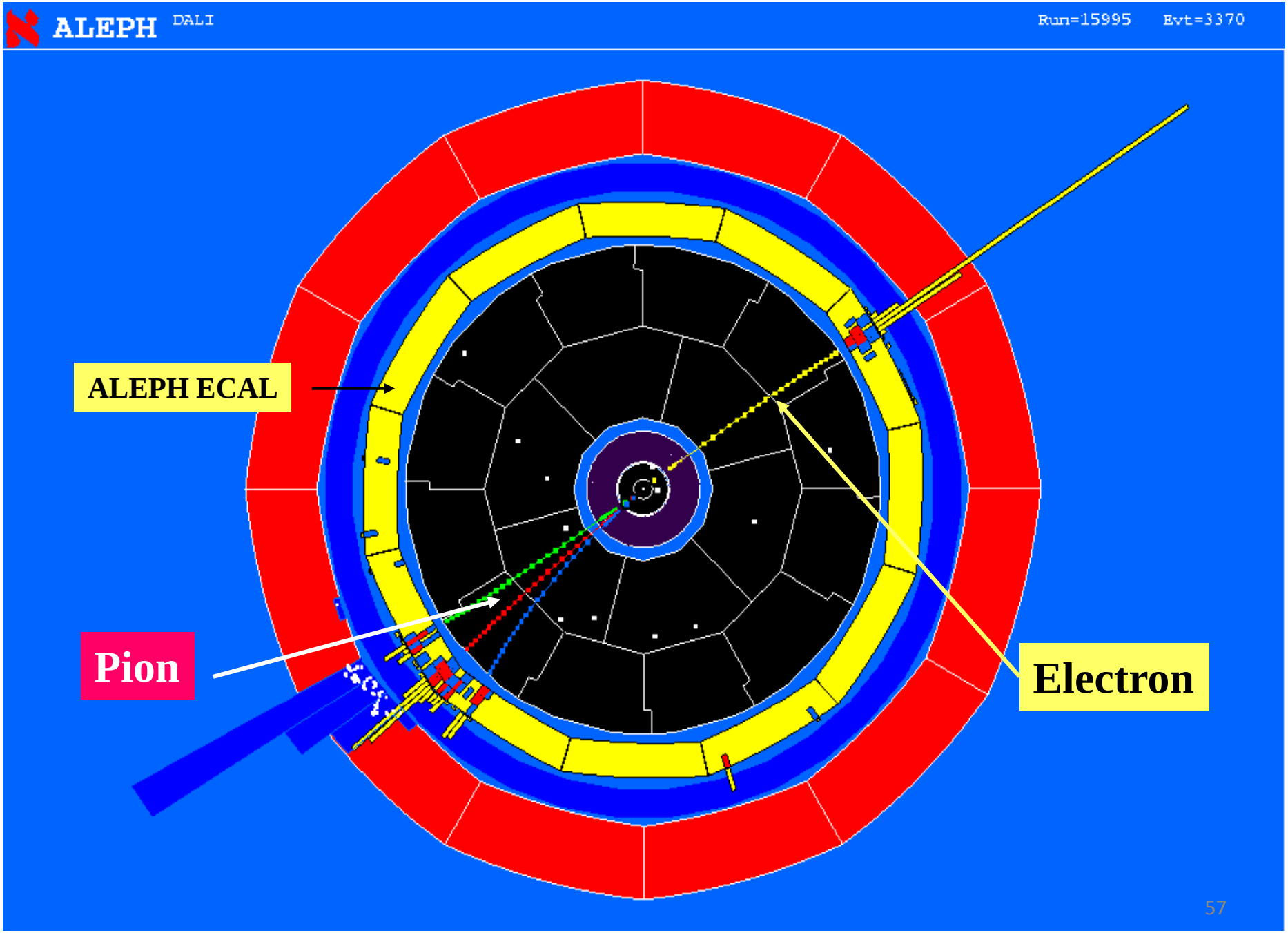
Light guides & PM

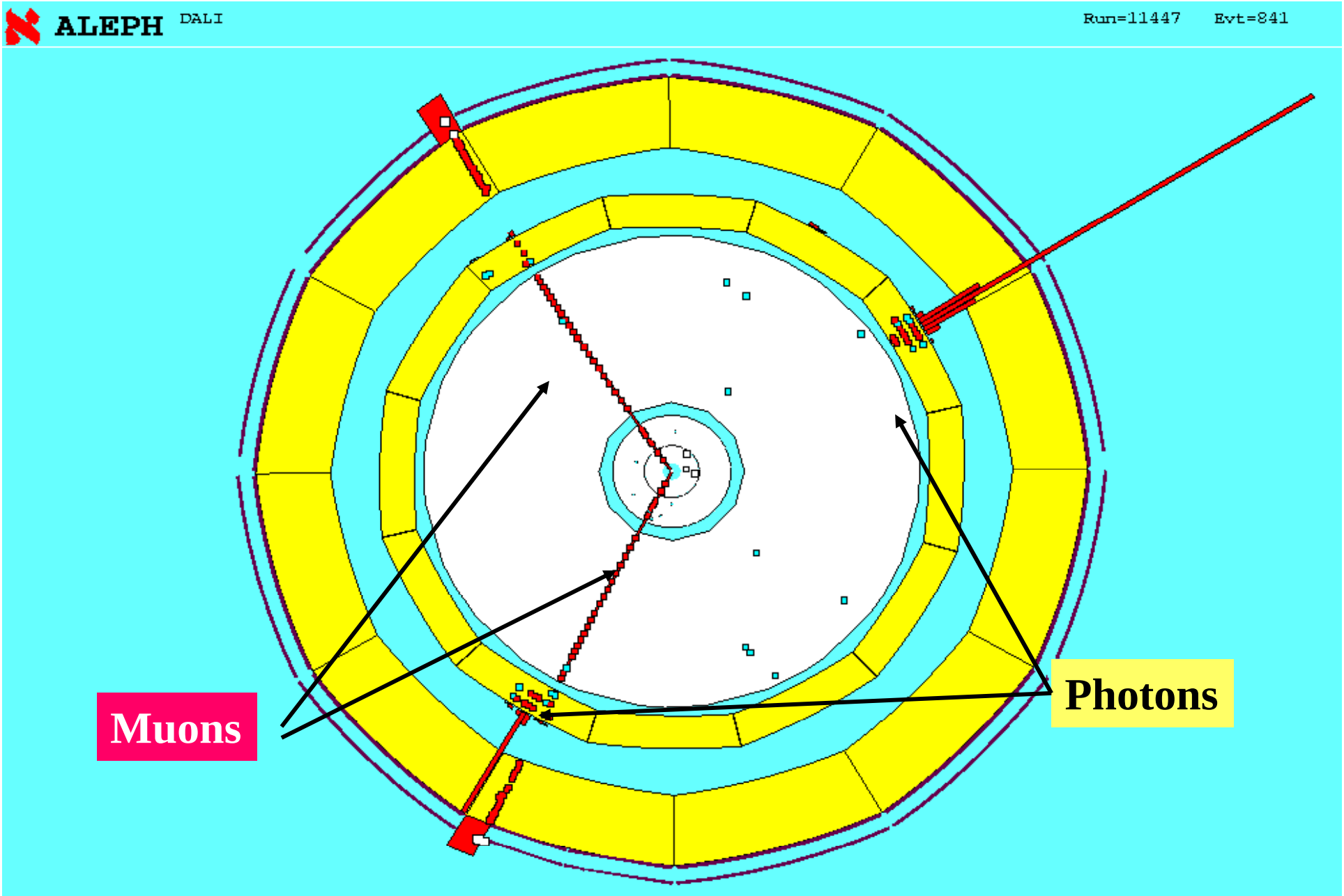
Sampling calorimeter



CMS ECAL in the cavern 2007




ALEPH
DALI
Run=15995
Evt=3370
ALEPH ECAL
Pion
Electron


ALEPH
DALI
Run=11447
Evt=841
Muons
Photons

TOF (Time Of Flight)

RICH (Ring Image Cherenkov Counter)

Faster than light! Is that possible?

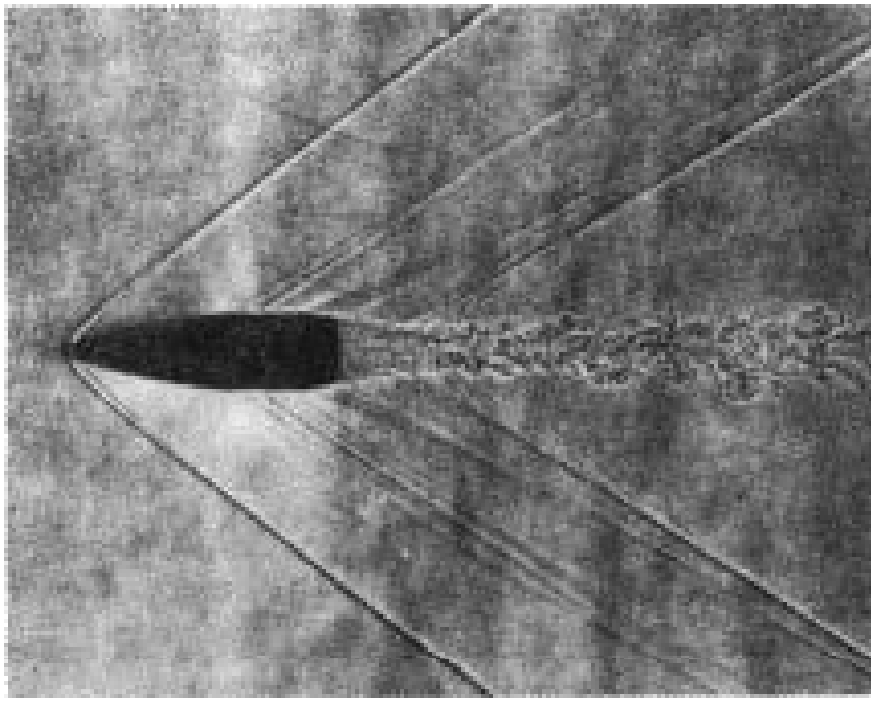
dE/dx (Energy deposition per length)

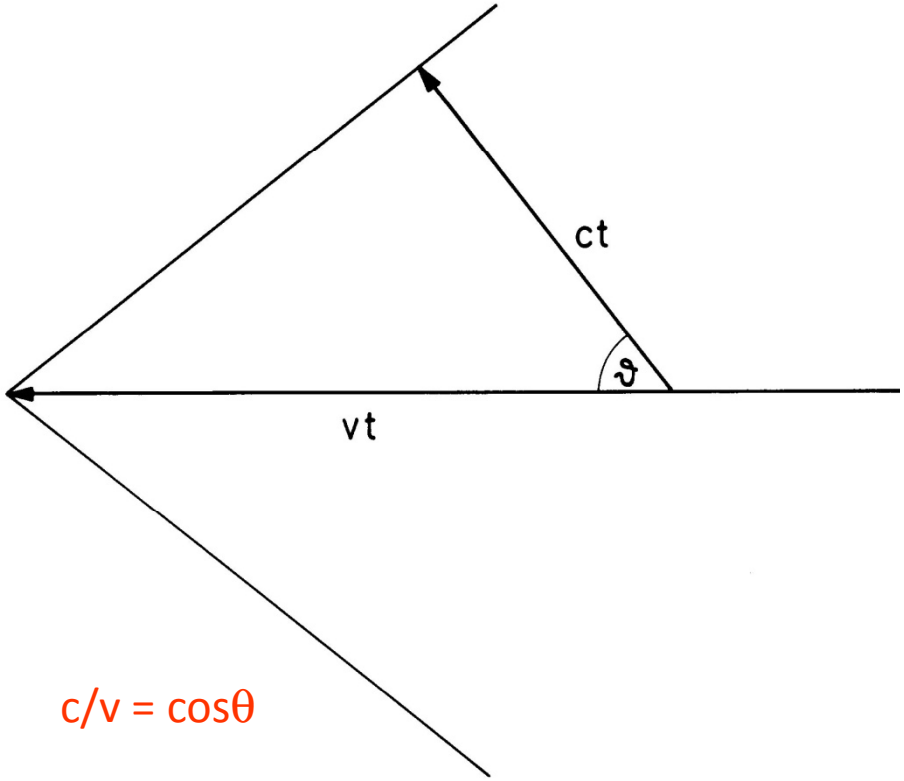
PARTICLE ID

Momentum & velocity
➔ Mass (Identity)

Exkurs: Velocity measurement by determining the shock wave geometry! MACH

Velocity of the projectile?





$c/v = \cos\theta$

See picture:

angle 52°, $v = c/\cos\theta$ = 340m/s / cos52° = 552m/s

Refer also Mach' cone with a supersonic plane

Cherenkov Radiation

Determination of the particle velocity

1. Principle: Passing of a charged particle ➔ atomic excitation ➔ photon radiation
2. Velocity of particle superceeds „speed of light“ in the medium

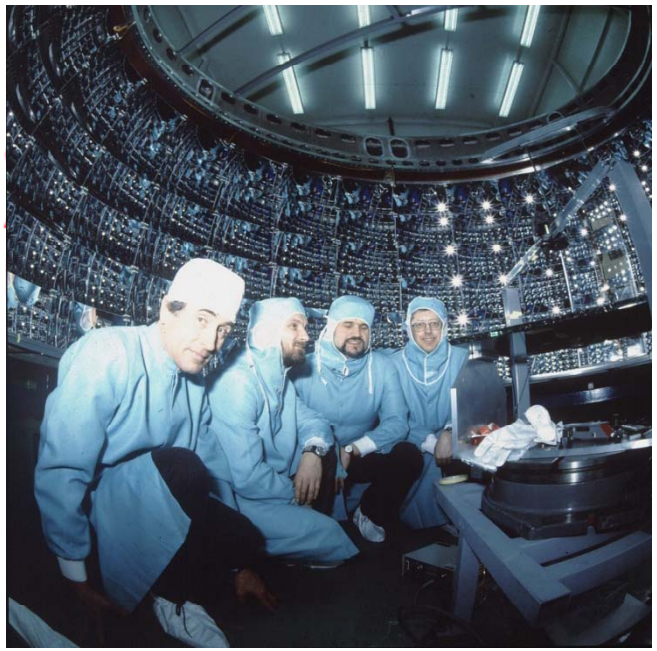
$$c_{medium} = \frac{1}{\mathrm{n}} c_{vacuum}$$

3. Shock wave ➔ v

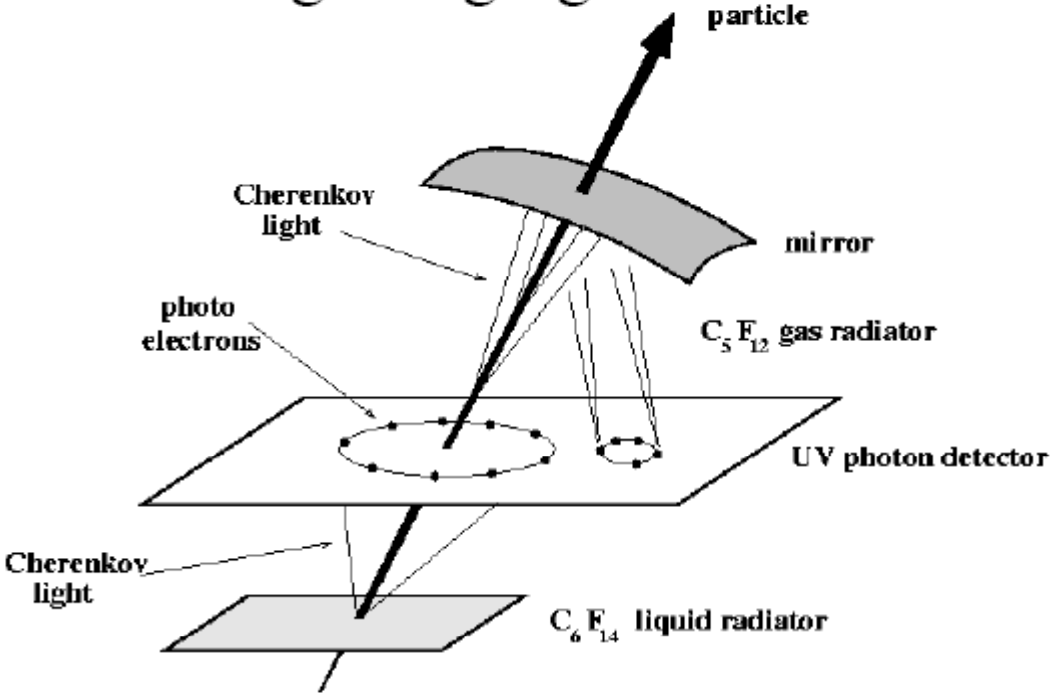
$$v = \frac{c_{medium}}{\cos\alpha} = \frac{c_{vacuum}}{\mathrm{n}} \frac{1}{\cos\alpha}$$

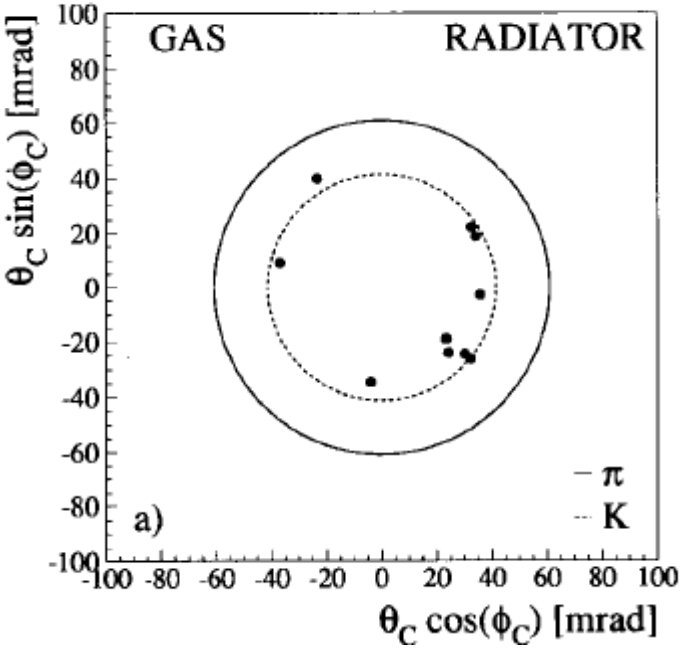
4. Projection of the cone onto a circle with defined distance ➔r➔ α ➔ v

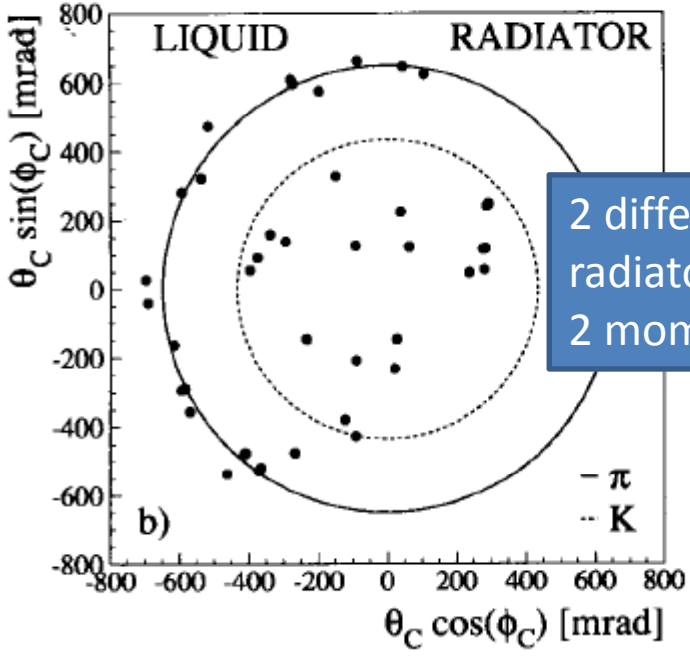
DELPHI (LEP/CERN):



Ring Imaging Cherenkov



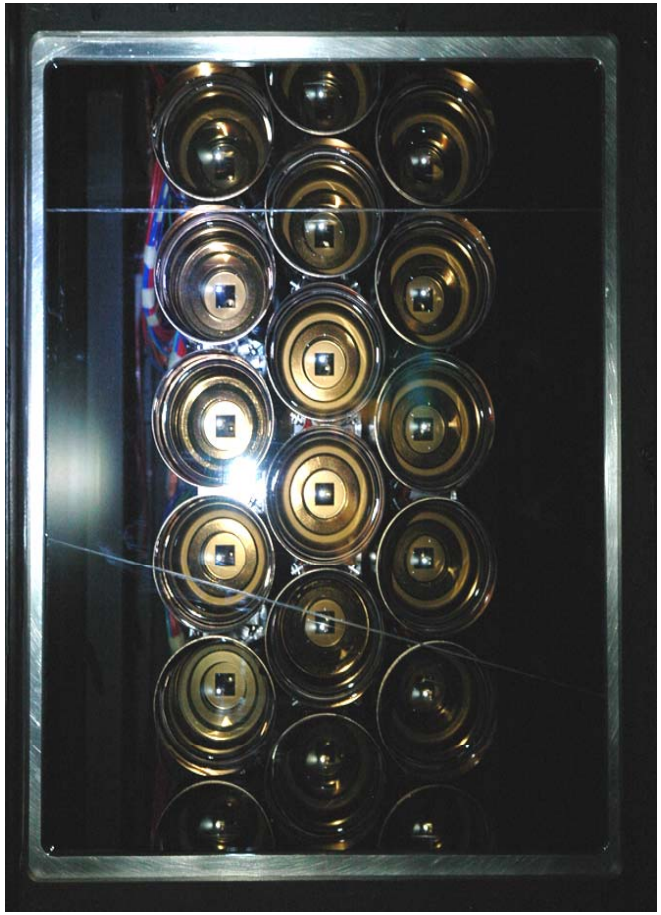


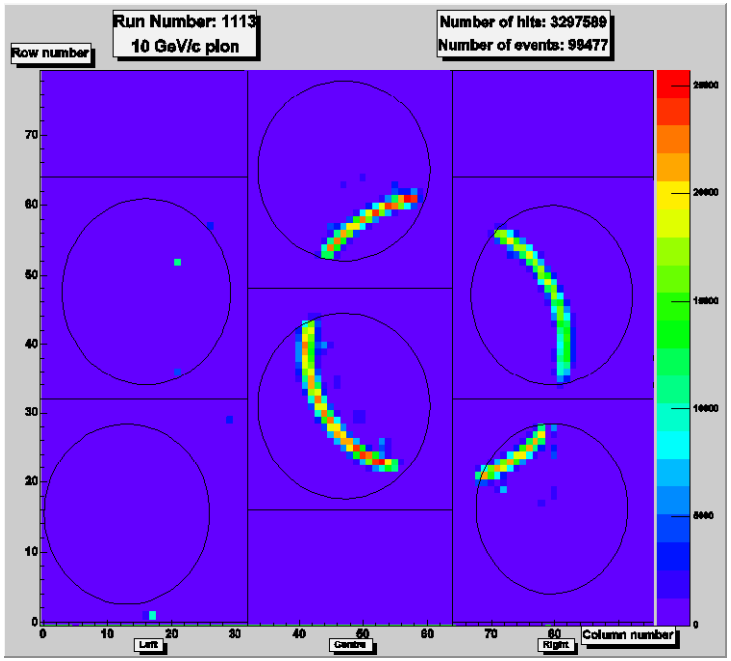


2 different dedicated radiators =
2 momentum levels

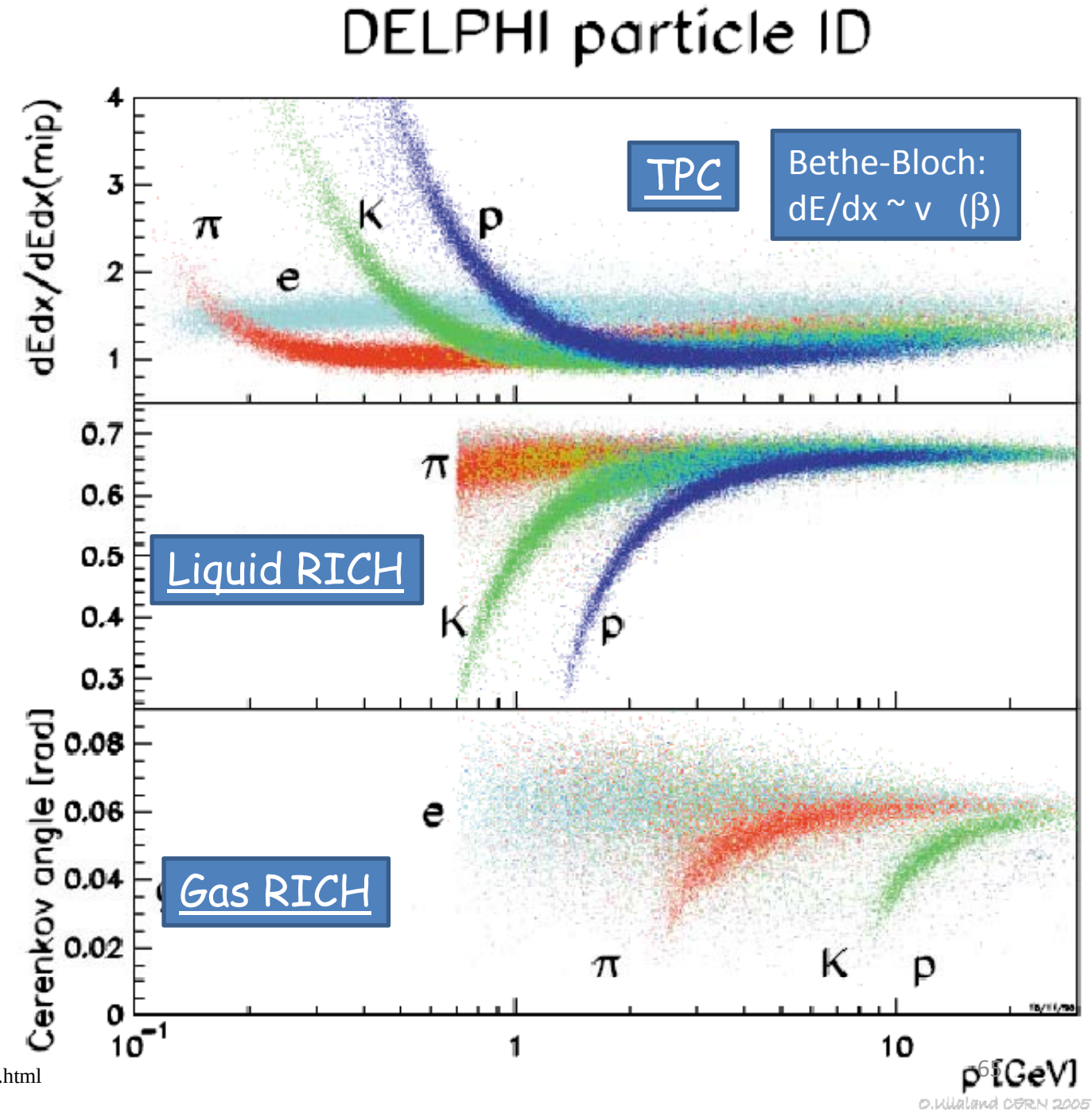
LHC ALICE RICH Installation

LHCb RICH System test

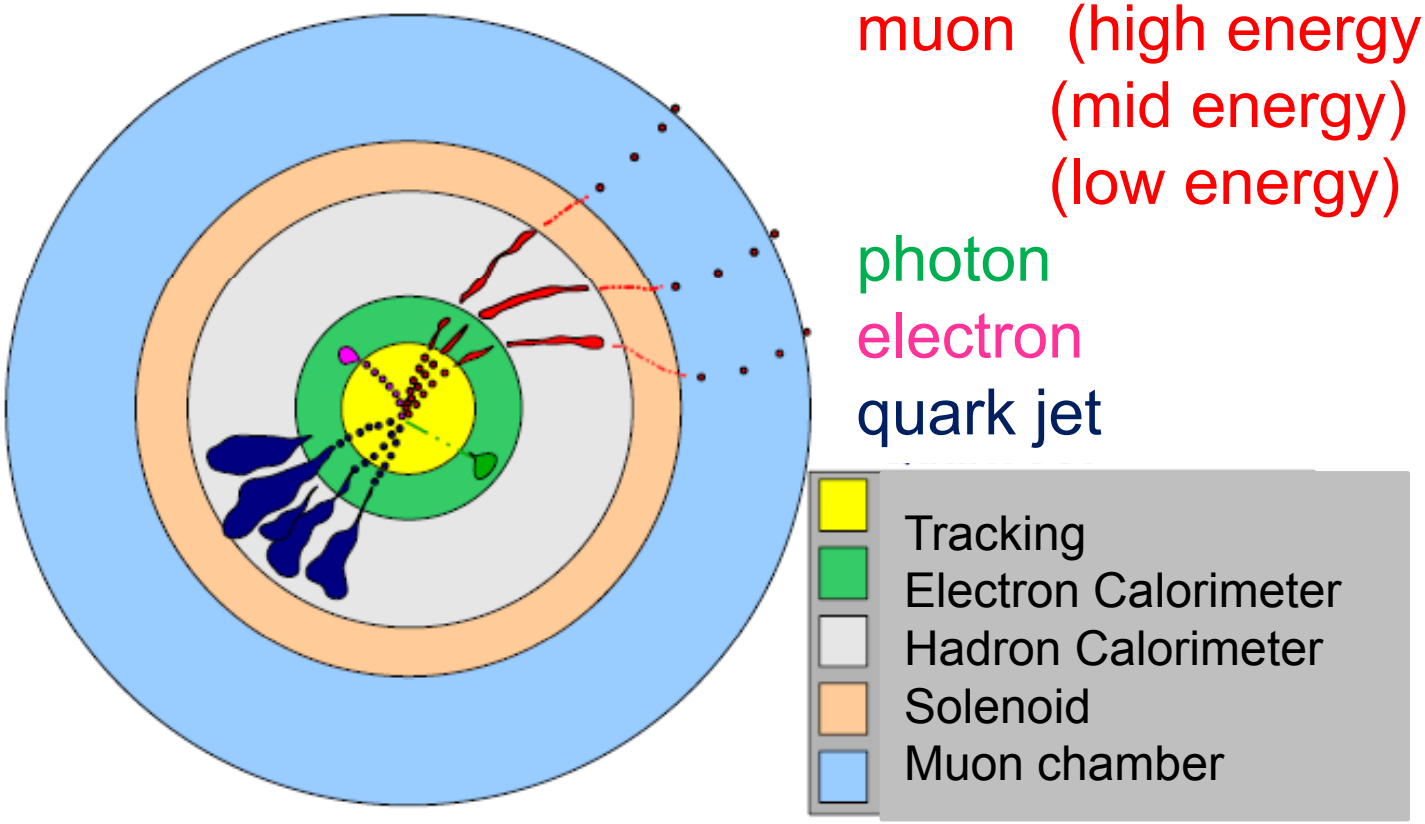




DELPHI Particle Identification



http://delphiwww.cern.ch/delfigs/export/pubdet4.html
DELPHI, NIM A: 378(1996)57

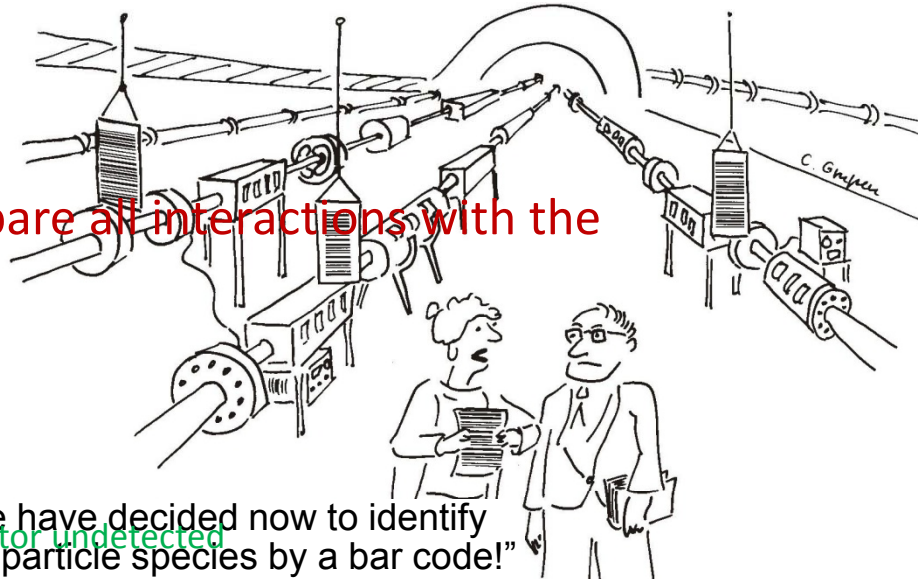


Repetition: Location and purpose of the individual detectors

Multipurpose

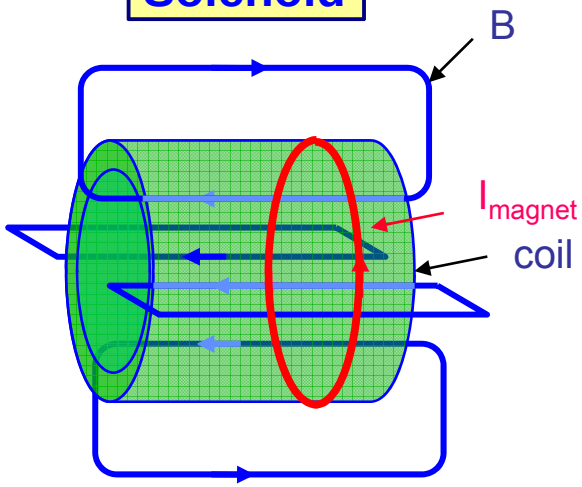
Excursion: The Perfect Detector

- Should reconstruct **ALL** interactions with 100% efficiency **WITHOUT** changing any particle property
  - No limit on resolution for all ranges of energy and momentum and for all particle types
  - The full phase space of 4p should be covered without any defective area
  - The detector should identify ALL particle
  - Easy access for maintenance
  - Radiation hard
- Then, we would be able do **directly** compare all interactions with the theoretical prediction
- **Why is this not possible?**
  - Efficiency:
    - Not all particle are detected
    - Holes, cracks allow particles to escape the detector undetected
    - Noise: Channels statistically show unreal signals
  - Interaction
    - Each interaction changes particle properties (refer calorimeter)
    - At best, all cables, cooling pipes and support structures should be massless to prehibit any multiple scattering
  - Access for maintenance
    - Large LHC detectors are like satellite experiments
      - Heavily radiated, very compact and complex



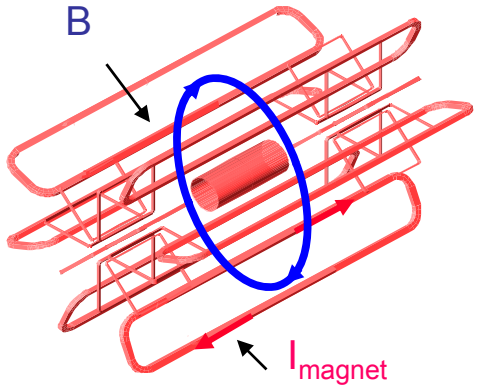
Magnet Configuration of the LHC Experiments

Solenoid



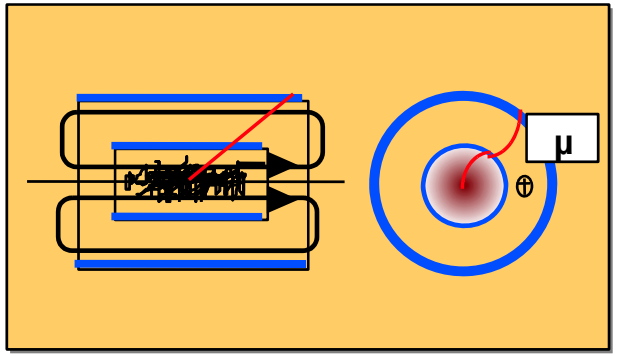
+ strong and homogeneous field in solenoid
- massive iron return yoke necessary
- limited in size (cost)
- solenoid thickness (radiation length)

(air-core) Toroid

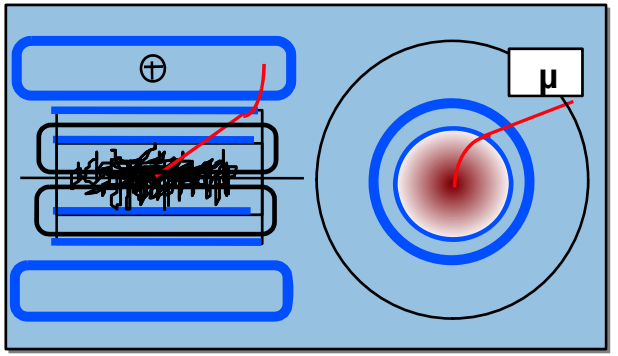


+ large air core, no iron, low material budget
- additonal solenoid in the imner parts necessary
-- inhomogeneous field
- complexe strukture

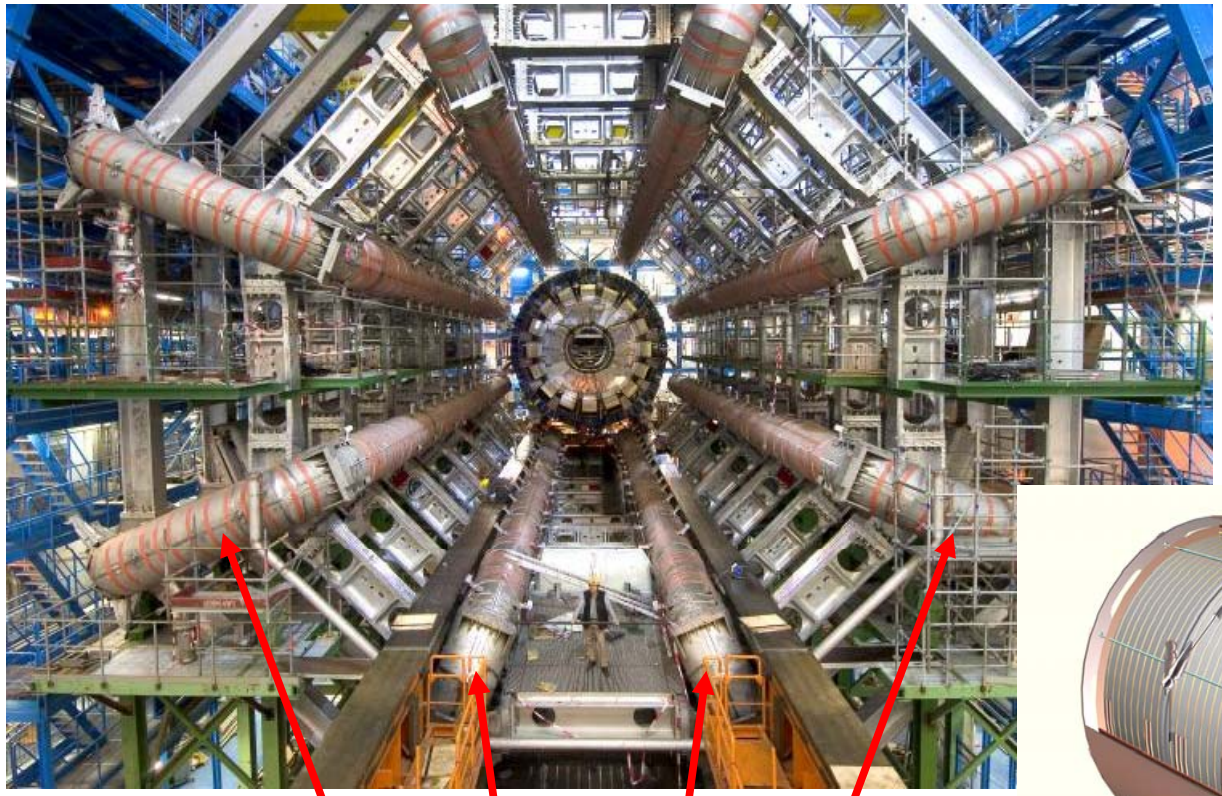
CMS, ALICE, LEP Detectors



ATLAS



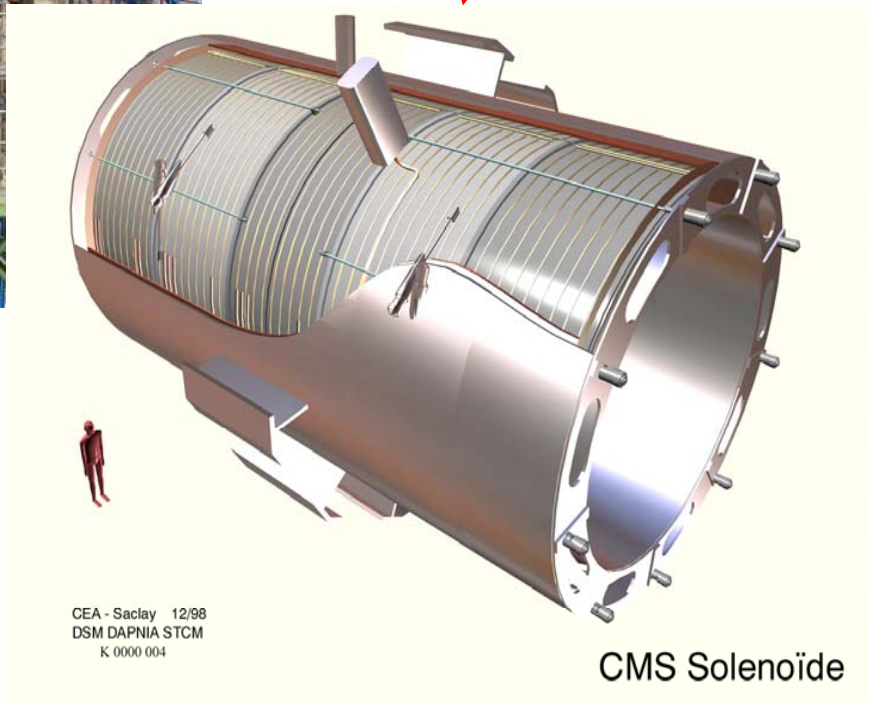
ATLAS and CMS magnet coils



ATLAS toroid coils

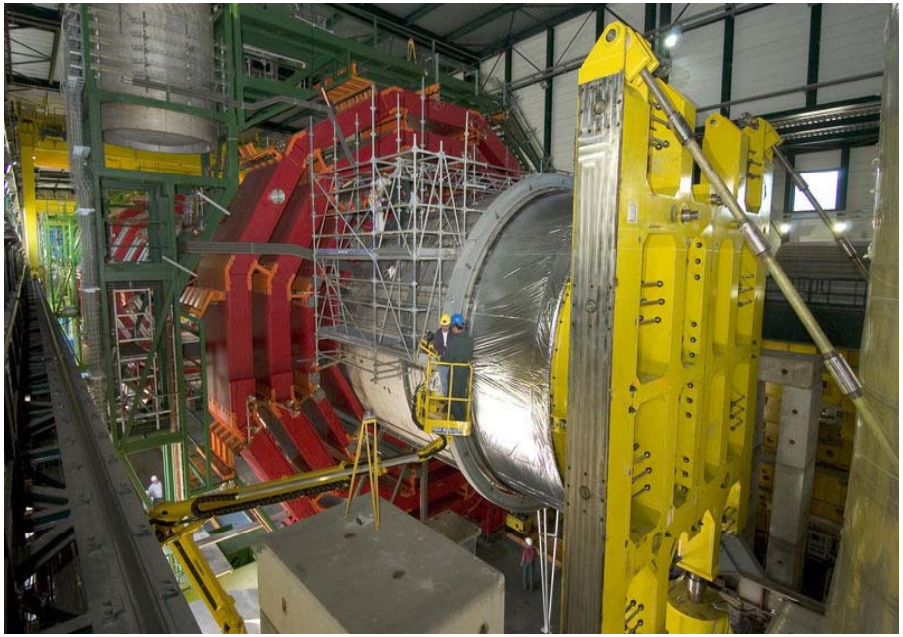
Autumn 2005

CMS solenoid (5 segments)

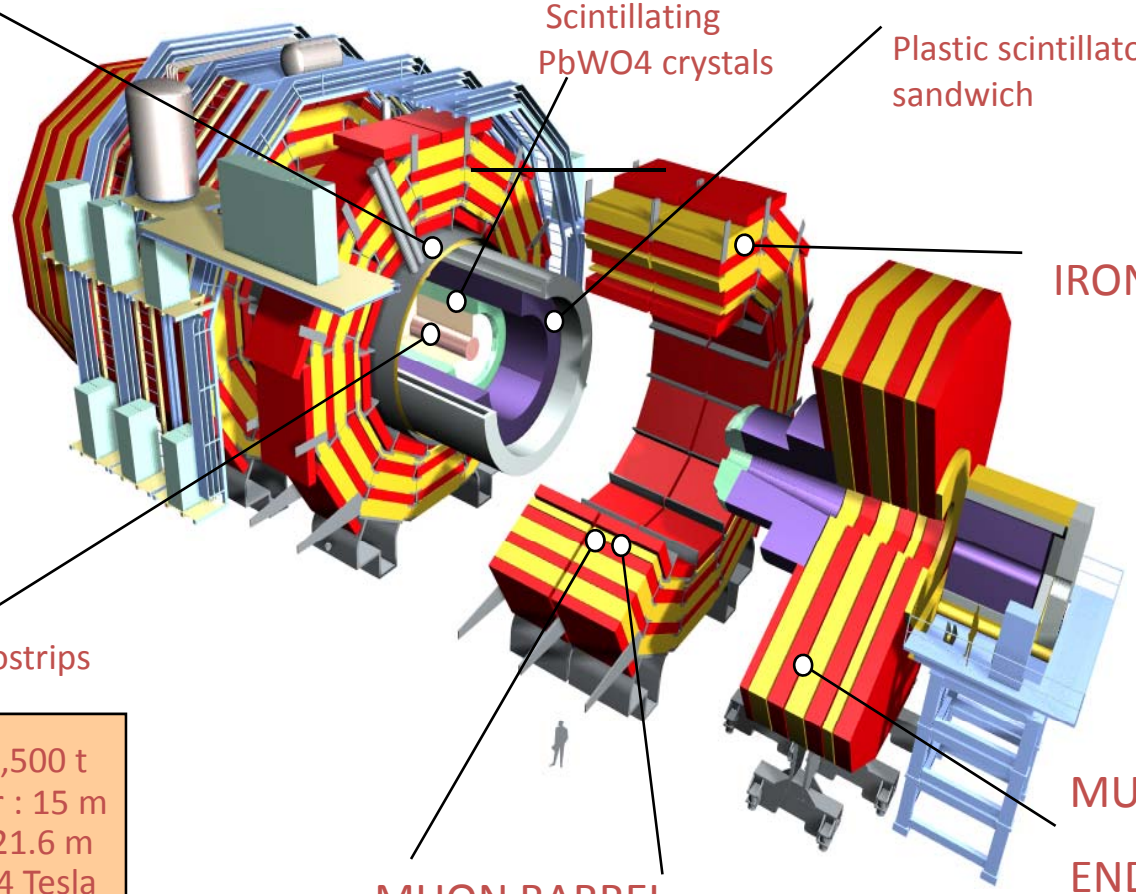


CMS Solenoïde

Coil Assembly in Surface Hall (August 05)

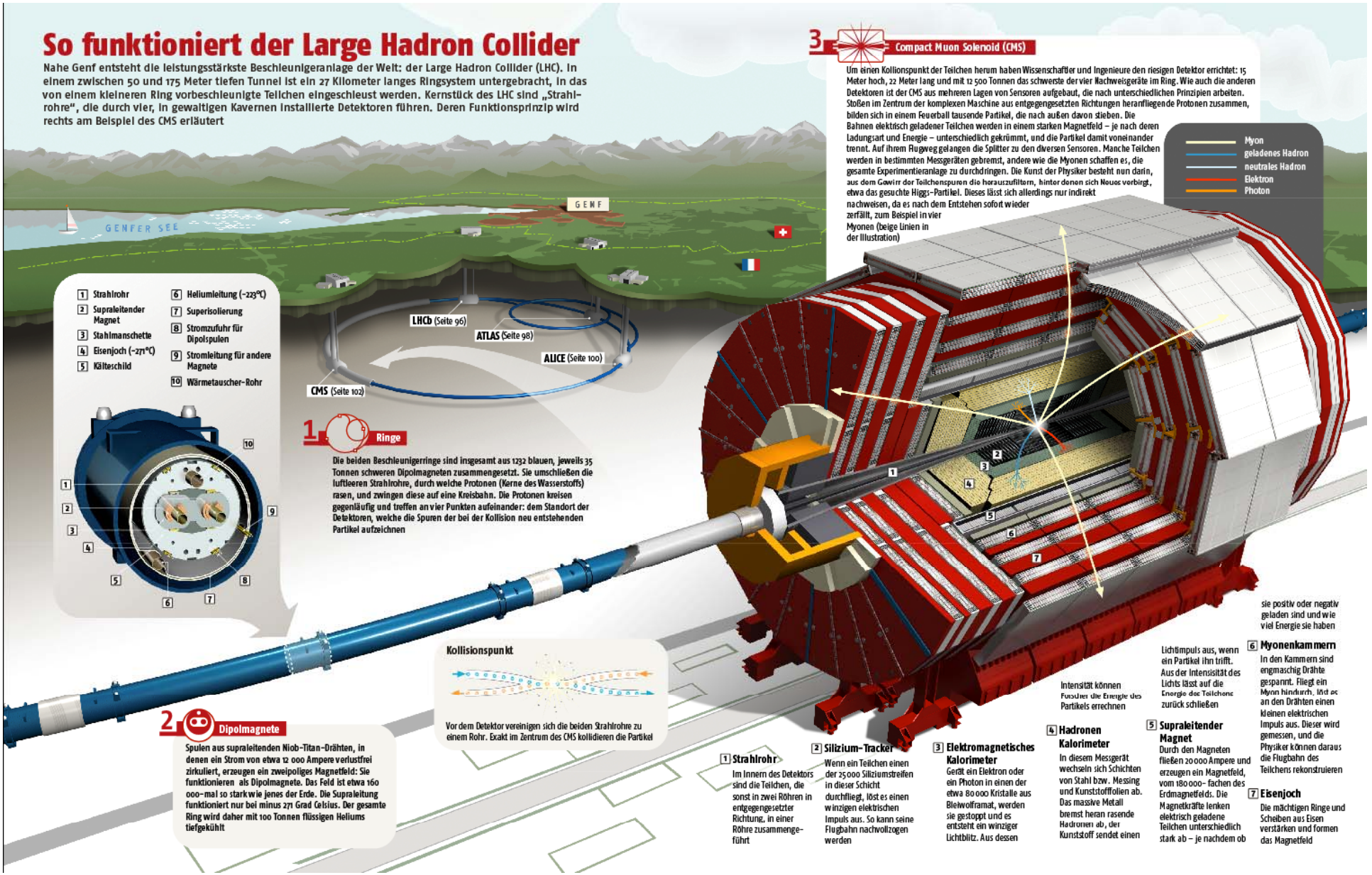


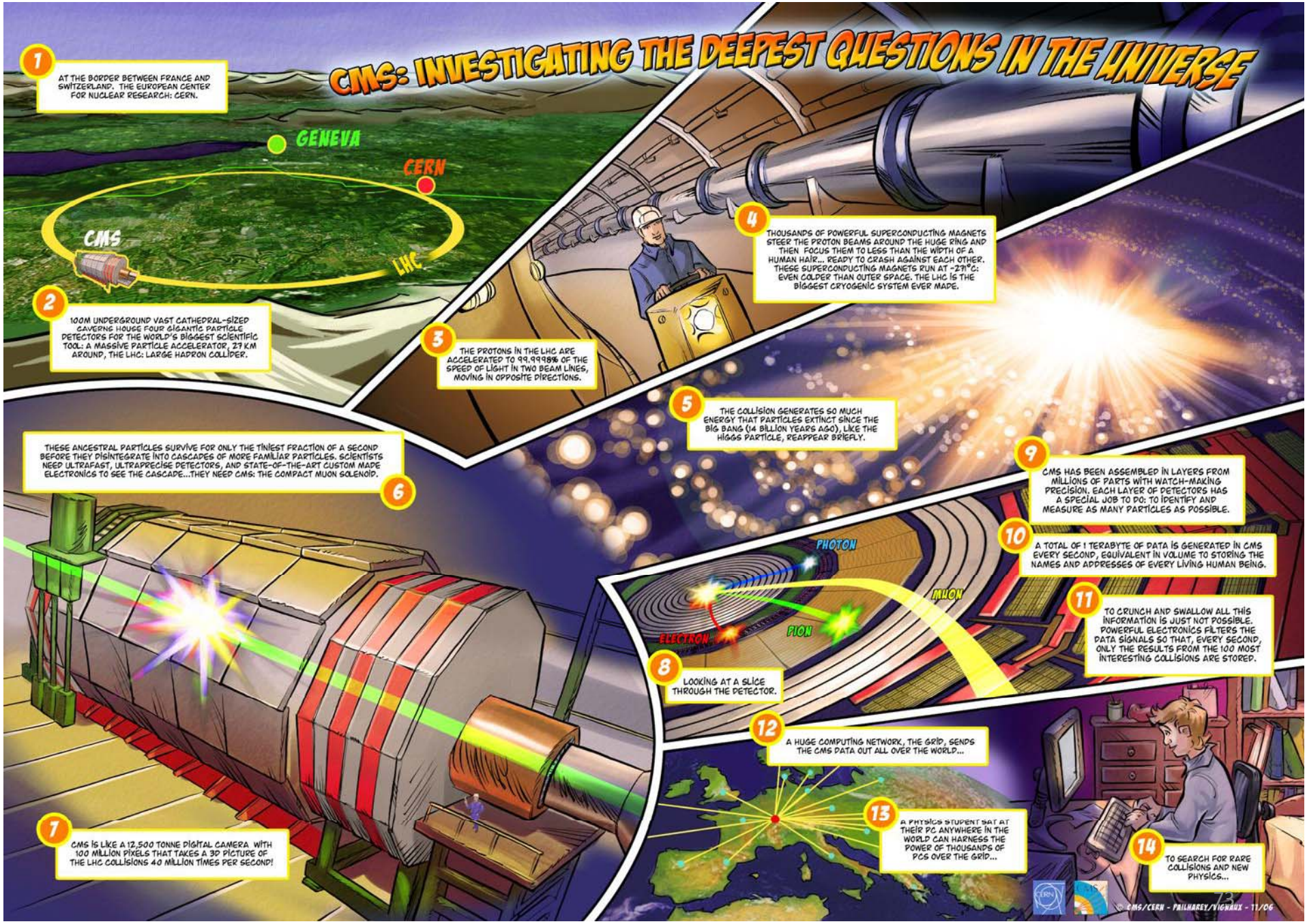
Exploded View of CMS



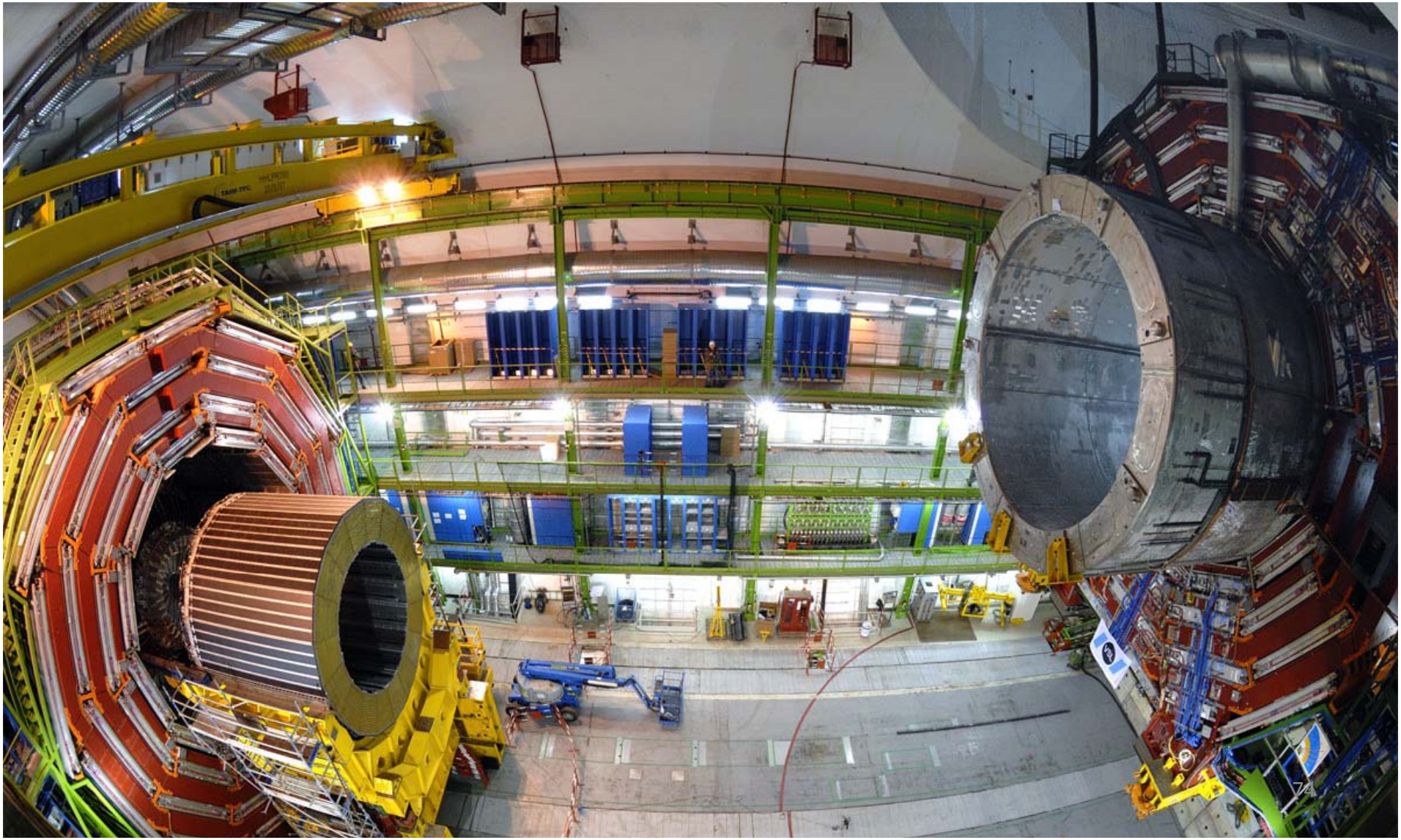
So funktioniert der Large Hadron Collider

Nahe Genf entsteht die leistungsstärkste Beschleunigeranlage der Welt: der Large Hadron Collider (LHC). In einem zwischen 50 und 175 Meter tiefen Tunnel ist ein 27 Kilometer langes Ringsystem untergebracht, in das von einem kleineren Ring vorbeschleunigte Teilchen eingeschleust werden. Kernstück des LHC sind „Strahlrohre", die durch vier, in gewaltigen Kavernen installierte Detektoren führen. Deren Funktionsprinzip wird rechts am Beispiel des CMS erläutert

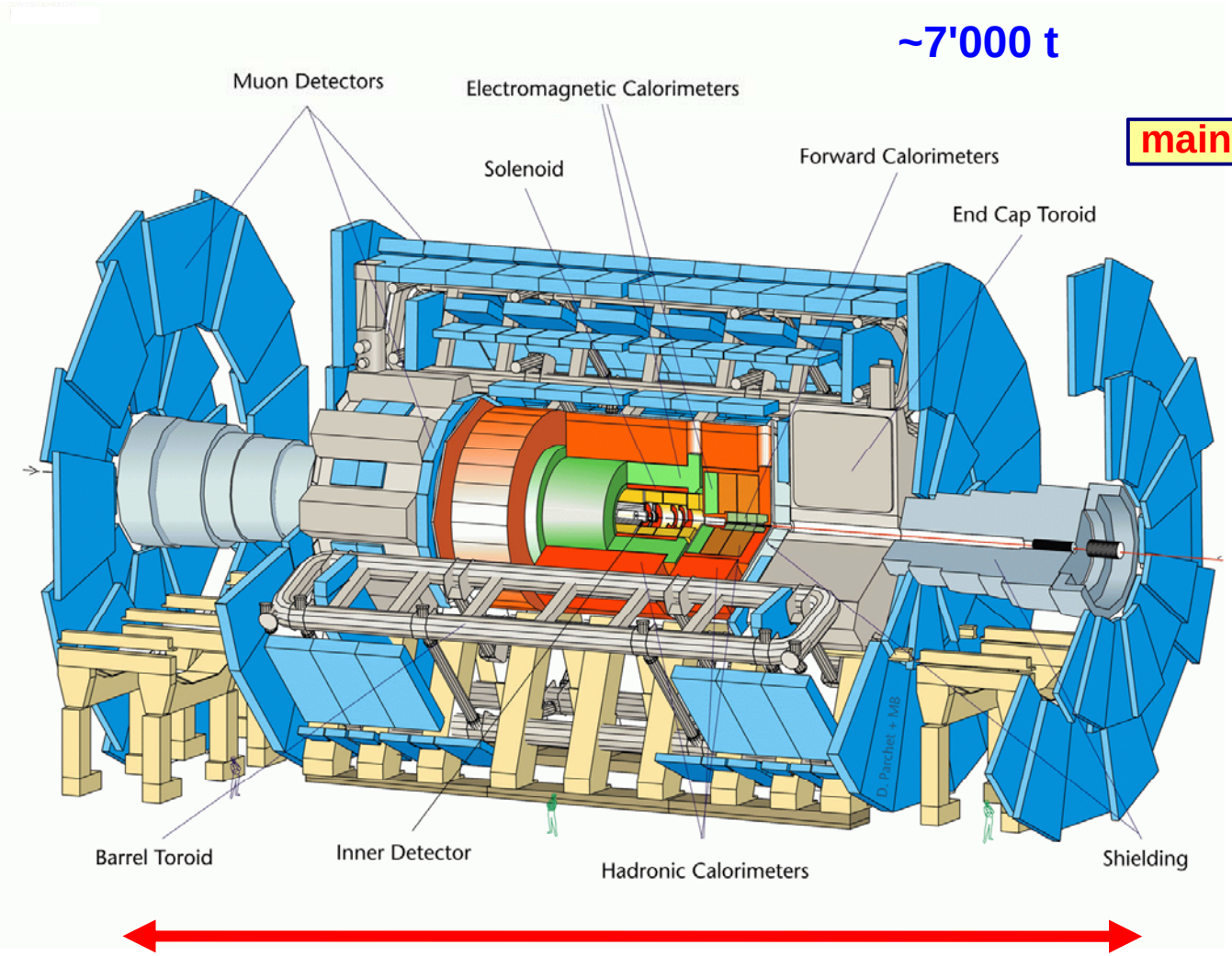



CMS: INVESTIGATING THE DEEPEST QUESTIONS IN THE UNIVERSE
1
AT THE BORDER BETWEEN FRANCE AND SWITZERLAND. THE EUROPEAN CENTER FOR NUCLEAR RESEARCH: CERN.
GENEVA
CERN
CMS
LHC
2
100M UNDERGROUND VAST CATHEDRAL-SIZED CAVERNS HOUSE FOUR GIGANTIC PARTICLE DETECTORS FOR THE WORLD'S BIGGEST SCIENTIFIC TOOL: A MASSIVE PARTICLE ACCELERATOR, 27 KM AROUND, THE LHC: LARGE HADRON COLLIDER.
3
THE PROTONS IN THE LHC ARE ACCELERATED TO 99.999896 OF THE SPEED OF LIGHT IN TWO BEAM LINES, MOVING IN OPPOSITE DIRECTIONS.
4
THOUSANDS OF POWERFUL SUPERCONDUCTING MAGNETS STEER THE PROTON BEAMS AROUND THE HUGE RING AND THEN FOCUS THEM TO LESS THAN THE WIDTH OF A HUMAN HAIR... READY TO CRASH AGAINST EACH OTHER. THESE SUPERCONDUCTING MAGNETS RUN AT -271°C: EVEN COLDER THAN OUTER SPACE. THE LHC IS THE BIGGEST CRYOGENIC SYSTEM EVER MADE.
5
THE COLLISION GENERATES SO MUCH ENERGY THAT PARTICLES EXTINCT SINCE THE BIG BANG (14 BILLION YEARS AGO), LIKE THE HIGGS PARTICLE, REAPPEAR BRIEFLY.
6
THESE ANCESTRAL PARTICLES SURVIVE FOR ONLY THE TINIEST FRACTION OF A SECOND BEFORE THEY DISINTEGRATE INTO CASCADES OF MORE FAMILIAR PARTICLES. SCIENTISTS NEED ULTRAFAST, ULTRAPRECISE DETECTORS, AND STATE-OF-THE-ART CUSTOM MADE ELECTRONICS TO SEE THE CASCADE...THEY NEED CMS: THE COMPACT MUON SOLENOID.
7
CMS IS LIKE A 12,500 TONNE DIGITAL CAMERA WITH 100 MILLION PIXELS THAT TAKES A 3D PICTURE OF THE LHC COLLISIONS 40 MILLION TIMES PER SECOND!
8
LOOKING AT A SLICE THROUGH THE DETECTOR.
PHOTON
MUON
ELECTRON
PION
9
CMS HAS BEEN ASSEMBLED IN LAYERS FROM MILLIONS OF PARTS WITH WATCH-MAKING PRECISION. EACH LAYER OF DETECTORS HAS A SPECIAL JOB TO DO: TO IDENTIFY AND MEASURE AS MANY PARTICLES AS POSSIBLE.
10
A TOTAL OF 1 TERABYTE OF DATA IS GENERATED IN CMS EVERY SECOND, EQUIVALENT IN VOLUME TO STORING THE NAMES AND ADDRESSES OF EVERY LIVING HUMAN BEING.
11
TO CRUNCH AND SWALLOW ALL THIS INFORMATION IS JUST NOT POSSIBLE. POWERFUL ELECTRONICS FILTERS THE DATA SIGNALS SO THAT, EVERY SECOND, ONLY THE RESULTS FROM THE 100 MOST INTERESTING COLLISIONS ARE STORED.
12
A HUGE COMPUTING NETWORK, THE GRID, SENDS THE CMS DATA OUT ALL OVER THE WORLD...
13
A PHYSICS STUDENT SAT AT THEIR PC ANYWHERE IN THE WORLD CAN HARNESS THE POWER OF THOUSANDS OF PCS OVER THE GRID...
14
TO SEARCH FOR RARE COLLISIONS AND NEW PHYSICS...
© CMS/CERN - PAILHAREY/VIGNAUX - 11/06

The center piece of CMS on ist voyage down to the cavern of CMS



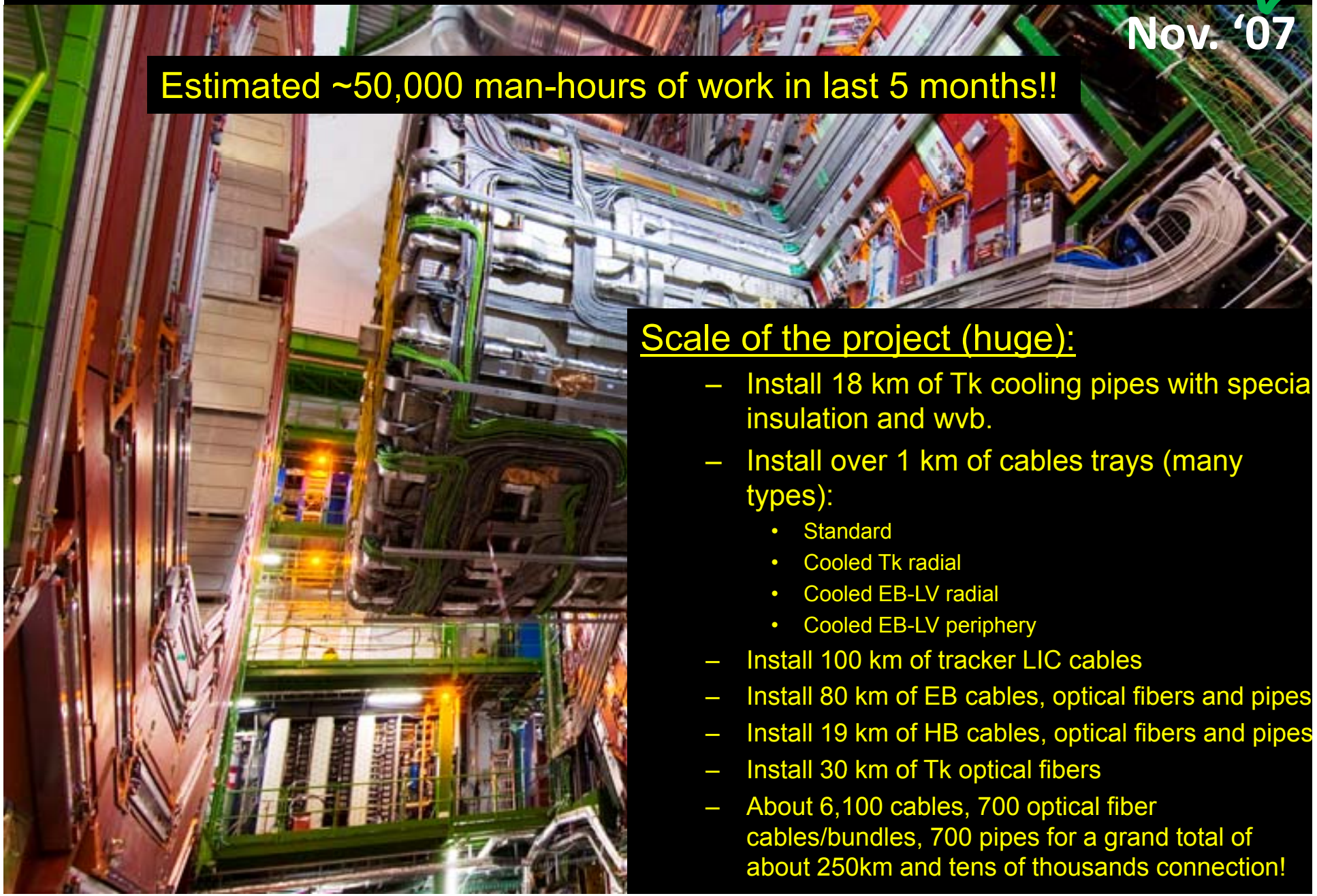
ATLAS (A Toroidal LHC ApparatuS)



Are Accelerators and Detectors all we need? What do we need in addition?

- Infrastructure
  - Elektronics, elektronics, elektronics
    - cable, cable, cable (logistic)
    - computers, cooling, gas, workshop, …
    - Fast ADCs, controller, power supplies, cable, …
- Support structures
- Slow control software
- Readout software and data storage
- Software to reconstruct and analyise the stored data
- Monte Carlo (simulation)
- A lot of enthuastic and hardworking people!!!!!!
- …

One example: Completion of Services on YB0



Nov. '07

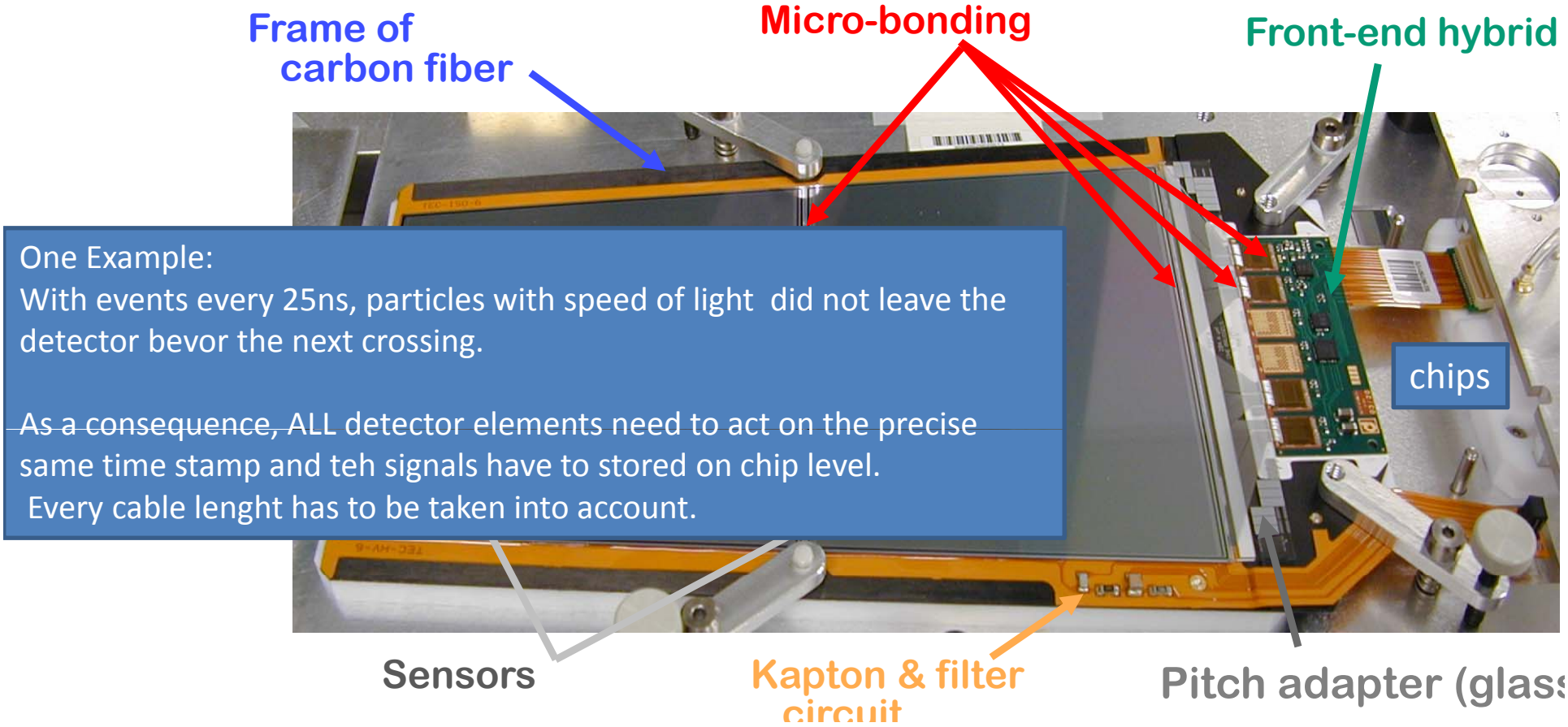
Estimated ~50,000 man-hours of work in last 5 months!!

Scale of the project (huge):

- Install 18 km of Tk cooling pipes with specia insulation and wvb.
- Install over 1 km of cables trays (many types):
  - Standard
  - Cooled Tk radial
  - Cooled EB-LV radial
  - Cooled EB-LV periphery
- Install 100 km of tracker LIC cables
- Install 80 km of EB cables, optical fibers and pipes
- Install 19 km of HB cables, optical fibers and pipes
- Install 30 km of Tk optical fibers
- About 6,100 cables, 700 optical fiber cables/bundles, 700 pipes for a grand total of about 250km and tens of thousands connection!

Chips & Modules (A lecture in itd own)

- Don‘t forget, most of the electronics are dedicated and home designed!
  - All experiments use dedicated chips and drivers
    - Time constants, radiation environment, magnetic field have to be taken into account at the time of design
    - Capacities, currents, voltages, …

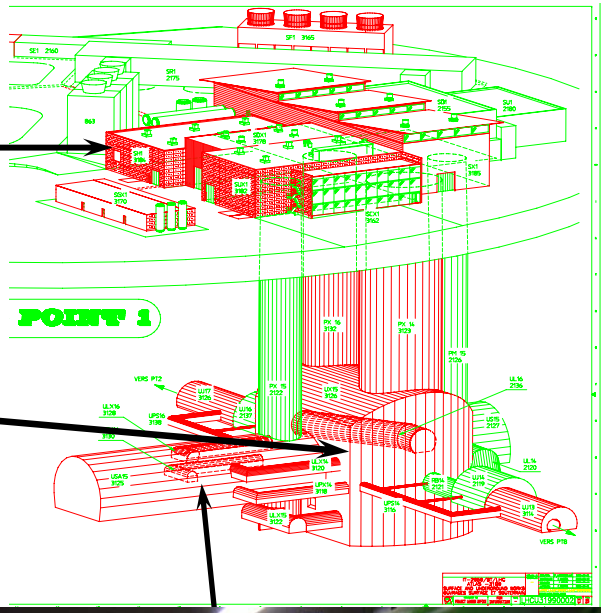


One Example:
With events every 25ns, particles with speed of light did not leave the detector bevor the next crossing.

As a consequence, ALL detector elements need to act on the precise same time stamp and teh signals have to stored on chip level.
Every cable lenght has to be taken into account.

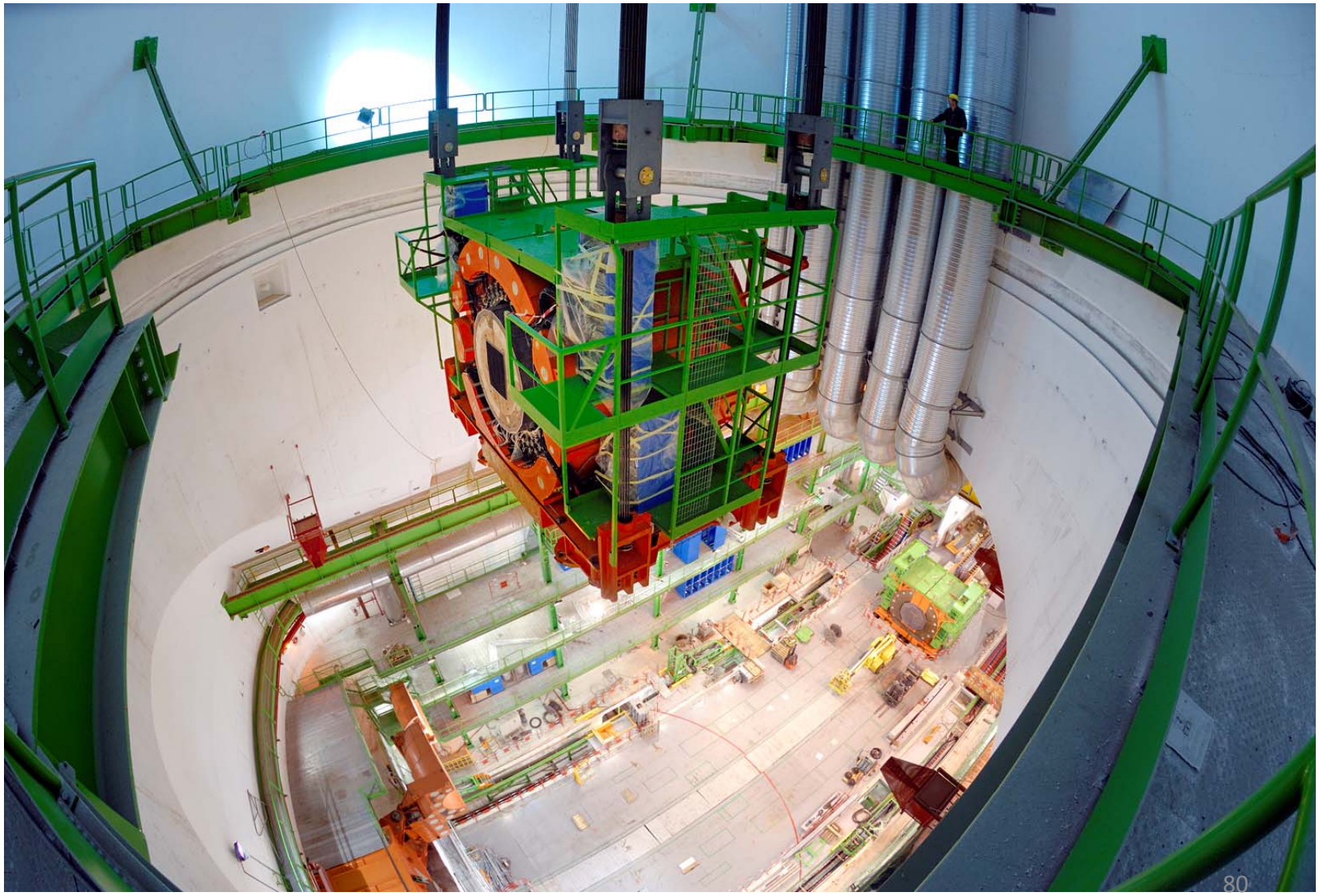
ATLAS: Infrastructure & Installation

Cryogenic plant ready and commissioned

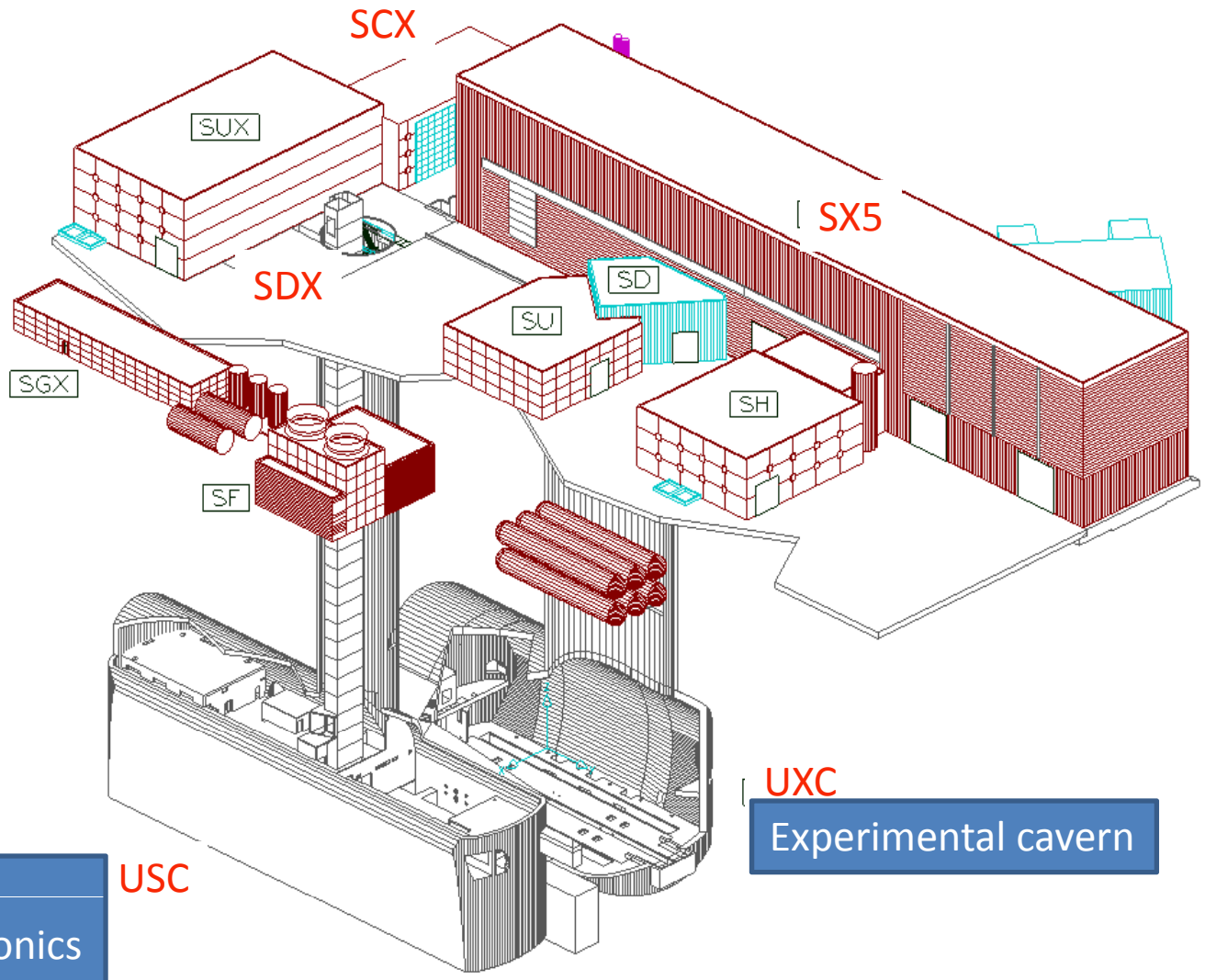


Cavern and basic infrastructure ready since 2003

The very forward CMS calorimeter

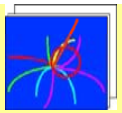


CMS: cavern and building structures



~~Infrastructure:~~
z.B. PCs, readout electronics
4 floors

CMS Trigger and DAQ



All 25 ns

40 MHz
COLLISION RATE

100 kHz
LEVEL-1 TRIGGER

DAQ accepts
Level-1 rate of 100kHz

1 Terabit/s
(50000 DATA CHANNELS)

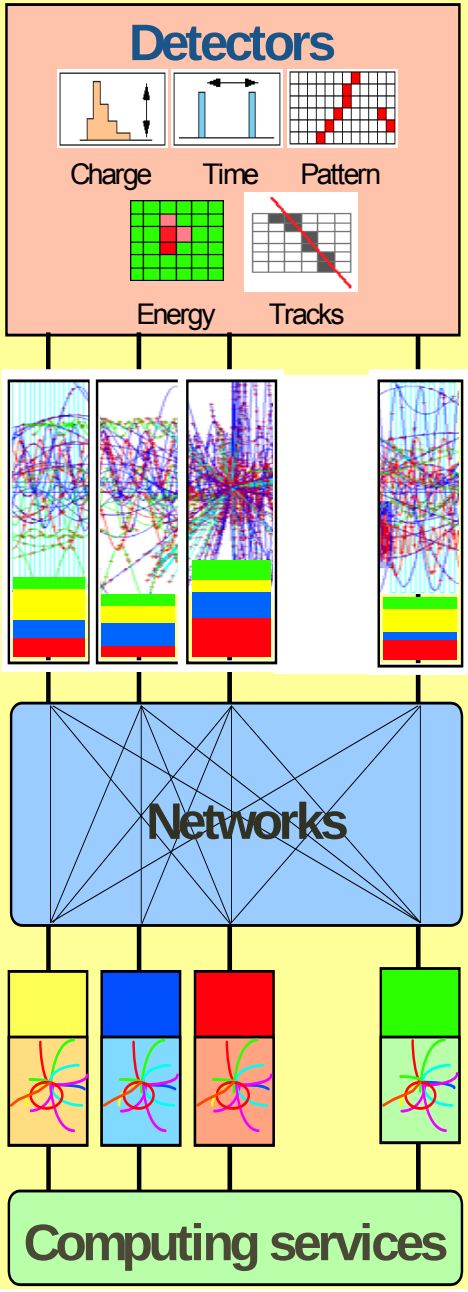
500 Gigabit/s

HLT (High Level Trigger)
designed for about 100Hz

- Reduction factor 1000

~2000 CPUs

Gigabit/s SERVICE LAN



16 Million channels
3 Gigacell buffers

1 Megabyte EVENT DATA

200 Gigabyte BUFFERS
500 Readout memories

EVENT BUILDER. A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and distributes event building commands (read/clear) to RDPMs

5 TeraIPS

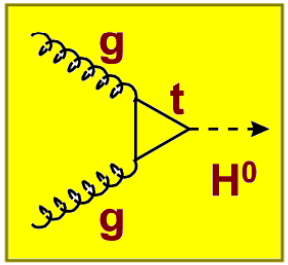
EVENT FILTER. It consists of a set of high performance commercial processors organized into many farms convenient for on-line and off-line applications. The farm architecture is such that a single CPU processes one event

Petabyte ARCHIVE

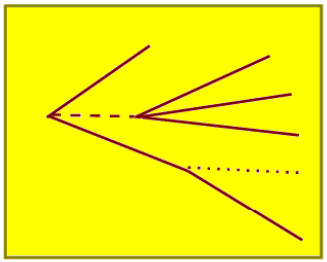
Trigger & DAQ

Many prototypes and simulations in the last years.

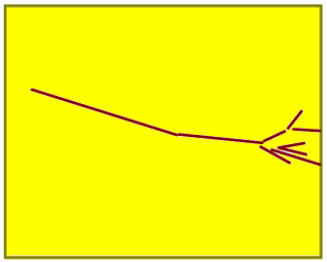
From Physics to Raw Data



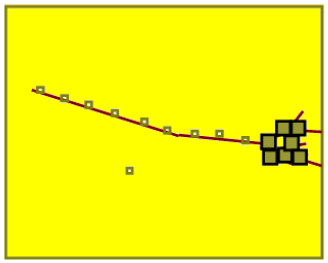
Basic physics



Fragmentation, Decay



Interaction with detector material
Multiple scattering, interactions



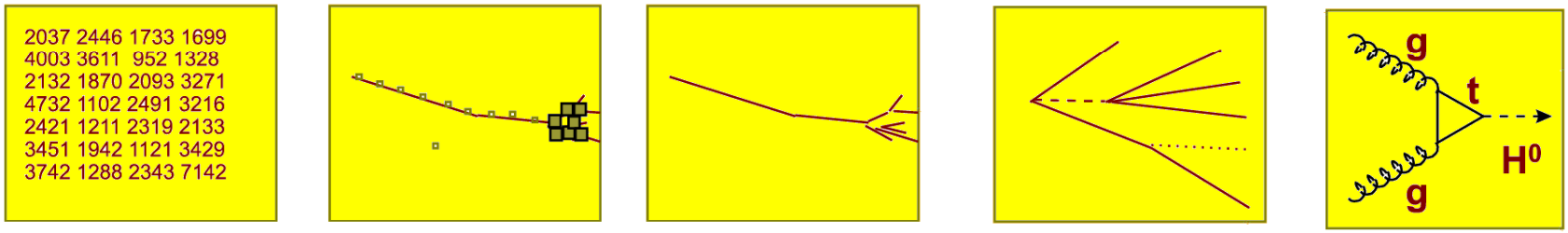
Detector response
Noise, pile-up, cross-talk, inefficiency, ambiguity, resolution, response function, alignment

Raw data

Read-out addresses, ADC, TDC values, Bit patterns

- Really recorded raw data for ATLAS/CMS ~400 MB/s
  - mainly electronics numbers
    - e.g. number of detector element where ADC (Analog-to-Digital converter) saw signal with x counts...

From Physics to Raw Data



Raw data

Convert to physics quantities

Detector response
apply calibration, alignment

Interaction with detector material
Pattern, recognition, Particle identification

Fragmentation
Decay
Physics analysis

Basic physics

Results

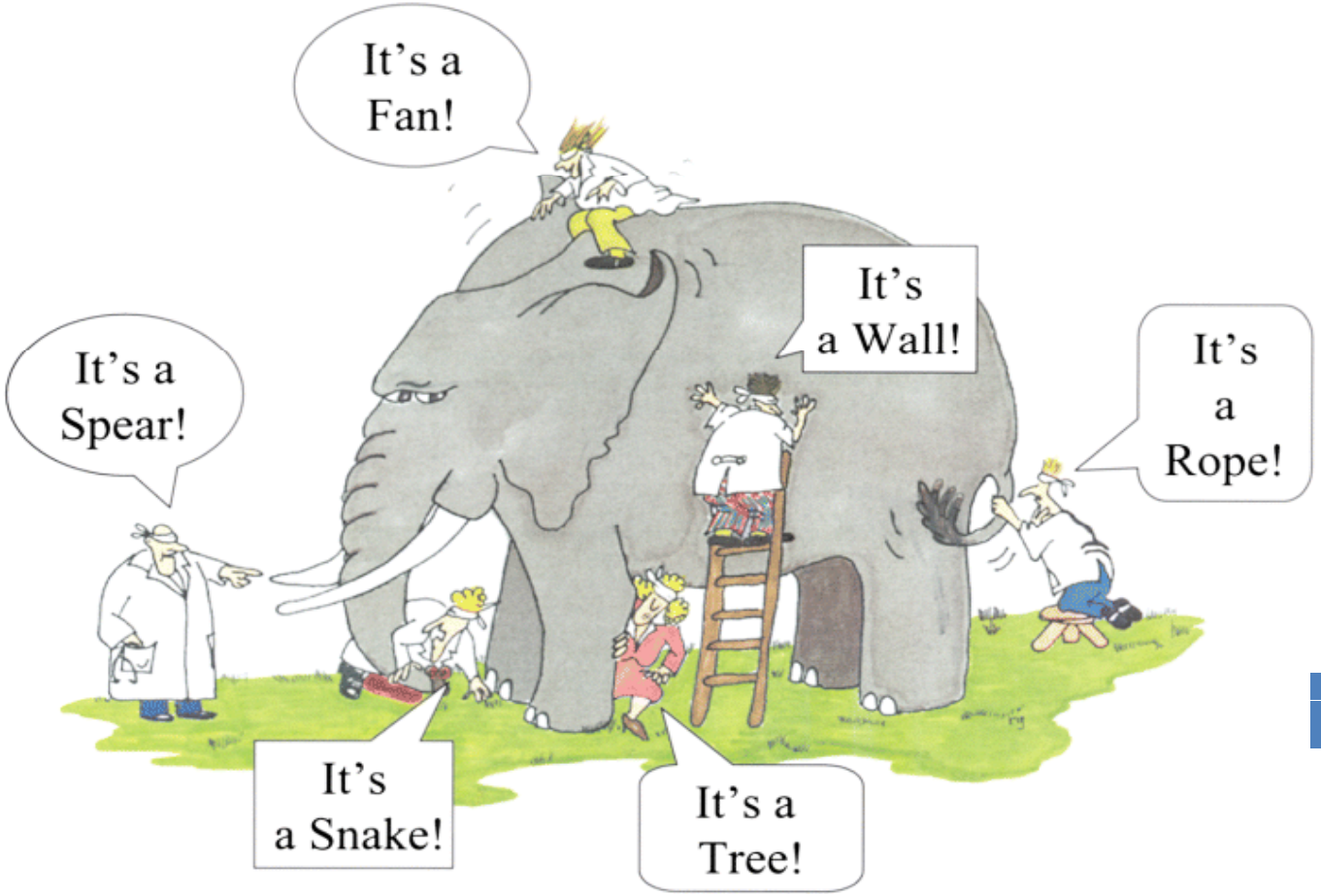
Reconstruction

Analysis

Simulation (Monte-Carlo)

- We need to go from raw data back to physics
  - reconstruction + analysis of the event(s)

Since we do not know what we will find…



Nature.com

…we will look at it from all angles….

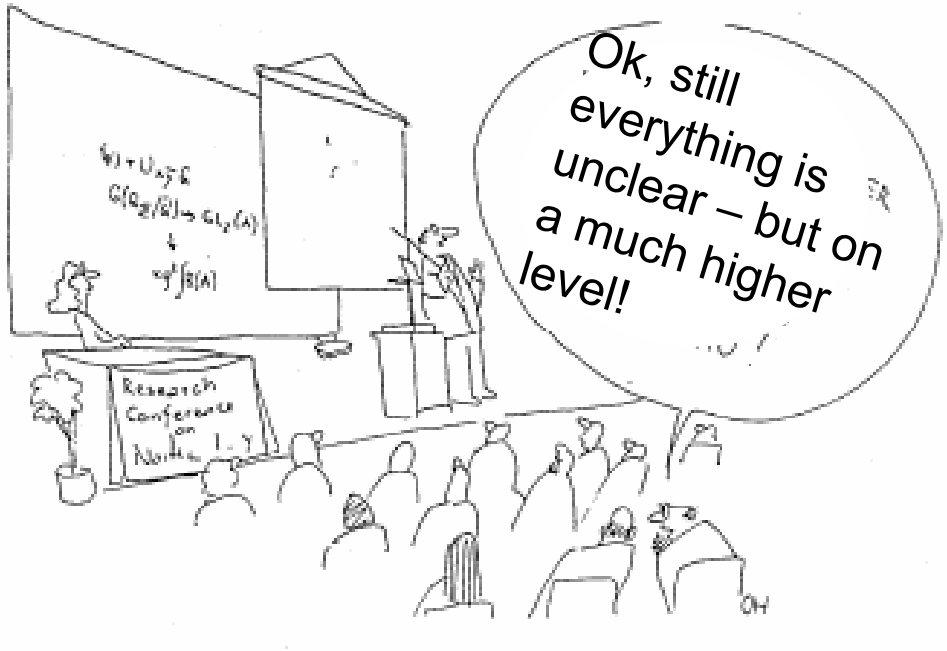
Close interaction between Experiment and Theory will be important.

Outlook

The search for the fundamental ingredients of nature is a philosophical adventure since early mankind!

In future, we will be judged, as we are judging long gone cultures. Discoveries are important.

The research is also neatly tight with high education and the search for inventions improving our all daily life.



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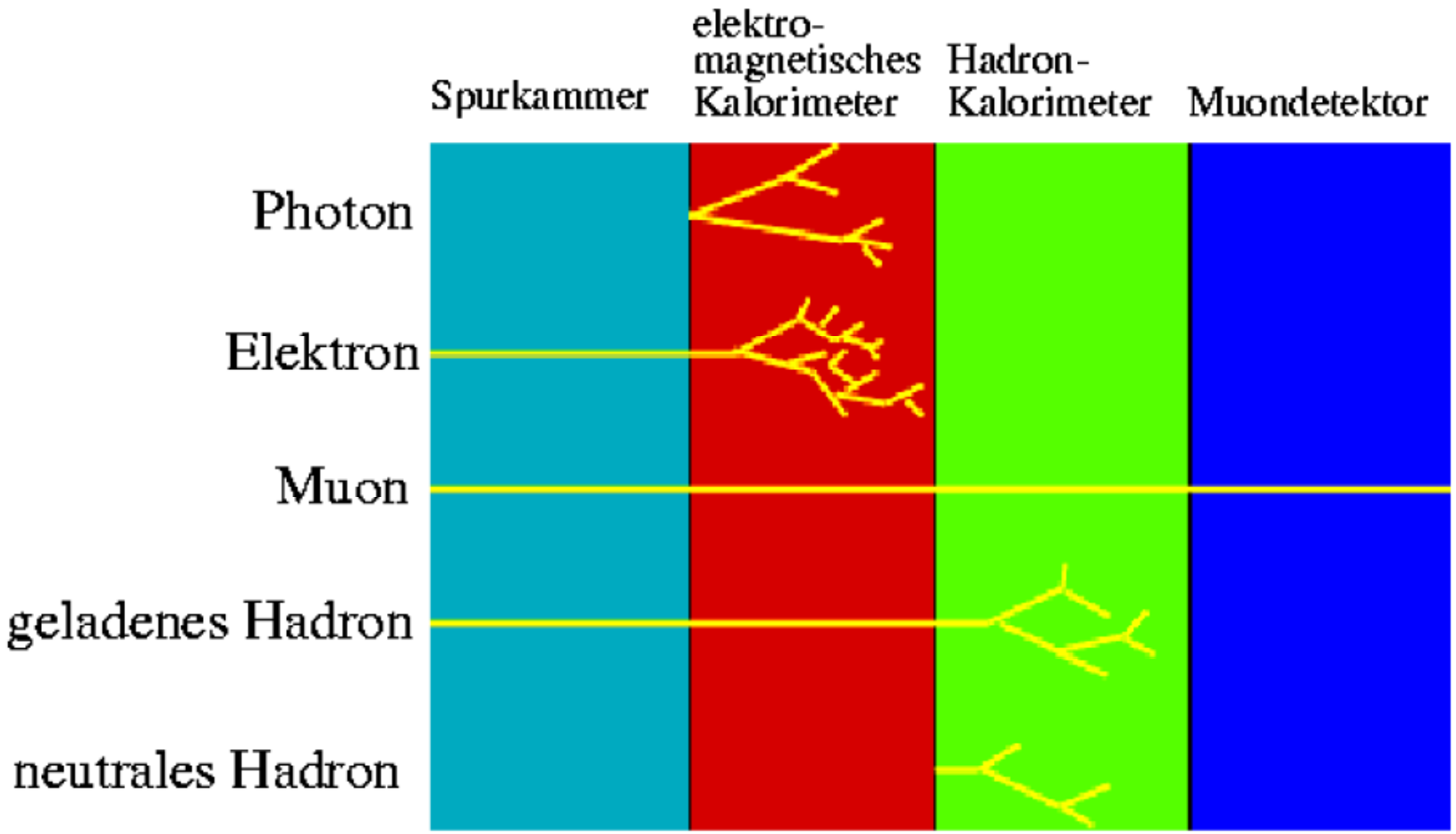
- Friends & colleagues
- M. Titov (VCI 2007) : New Developments and Future Perspectives of Gaseous Detectors
- Peter Križan *(VCI 2007)* Detectors for Particle Identification

- http://www-ekp.physik.uni-karlsruhe.de/~hartmann/CMS_Status_Seminar_Bonn1207.ppt

Backup

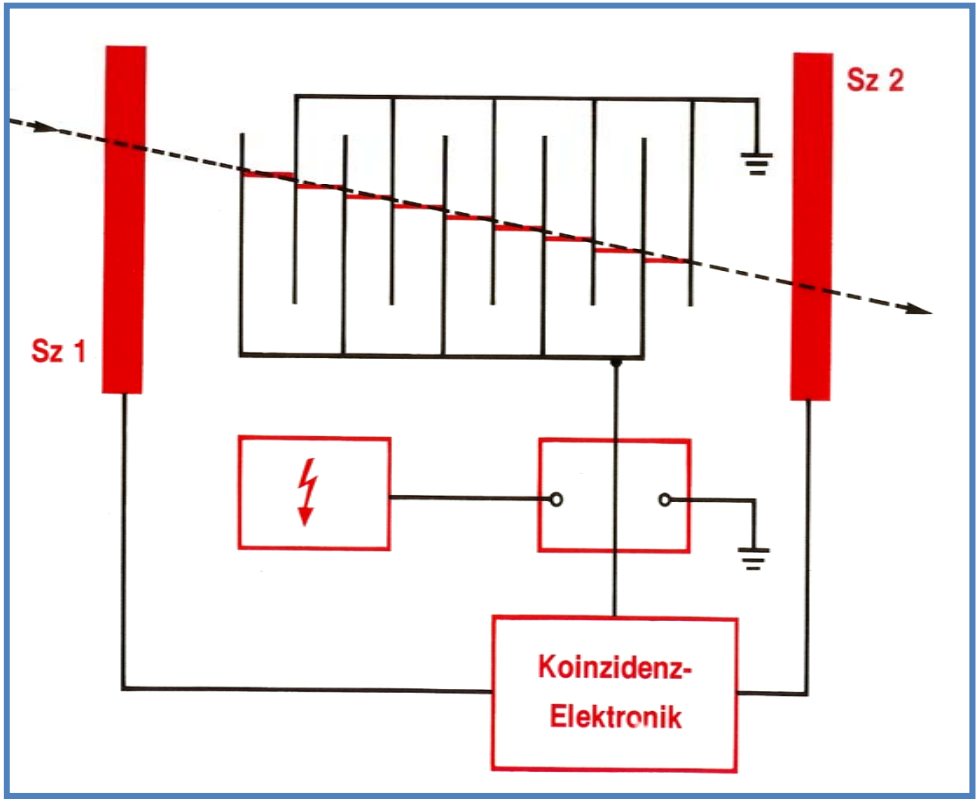
Zusammenfassung



prinzipieller Aufbau eines Detektorsystems

Funkenkammer:

- Elektronischer Detektor
- Teilchen erzeugen „Ionisationsbrücke“



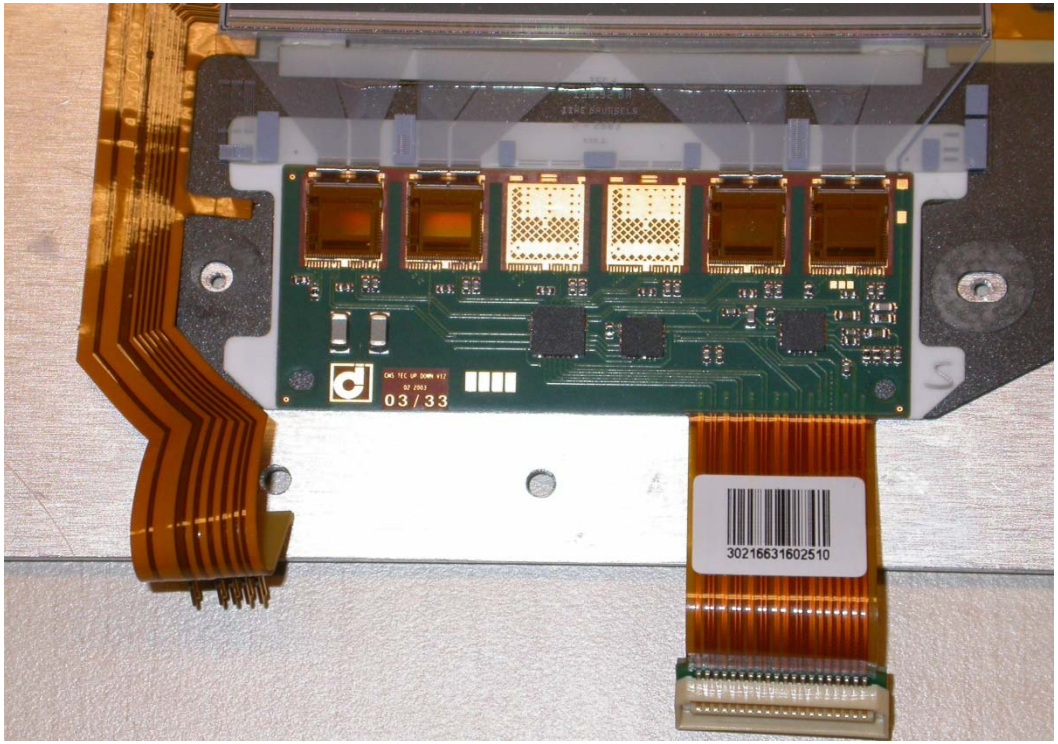
- Position dieser Durchschläge optisch oder durch elektronische Methoden ermittelt
- Versagen bei zu vielen gleichzeitig ankommenden Teilchen

Final front end hybrids

4-layer Kapton substrate (flex) laminated onto ceramic

4 or 6 APV25 readout chips

- radiation hard commercial 0.25❍m CMOS technology
- 128 strips per APV, multiplexed to one analog output
- per channel: pre-amplifier, CR-RC shaper, 4.8 ❍s pipeline



Detector Control Unit (DCU)

- 12-bit ADC
- 8 channels:
  - hybrid and sensor temperatures
  - leakage current
  - low voltages

2:1 multiplexer

- 2 APVs multiplexed to one readout channel

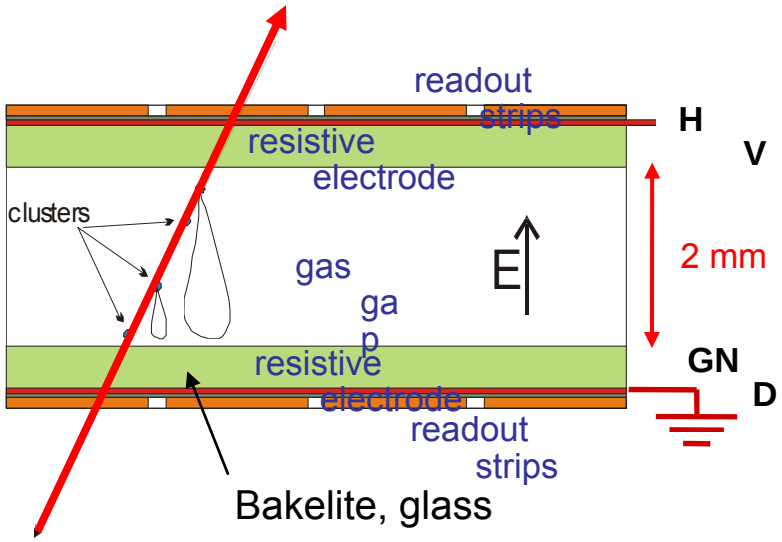
PLL chip

- decodes clock & trigger signals

Analog & optical readout!

Resistive Plate Chambers (RPC)

- There are also gaseous detectors without wires
  - two resistive plates (~10^9 Ωcm) with a small gas gap (2 mm) and large high voltage (12 kV) on outside electrodes
  - strong E-field: operation in "streamer mode"
    - gas avalance already starting in gas gap (no wires involved)
    - developing of "streamers" (blob with lots of charge, almost like a spark)
    - signal on external read-out strips via influence (segmented for position resolution)
    - streamer/discharge is "self-quenching": stops when near-by resistive electrodes are locally discharged (E-field breaks down)



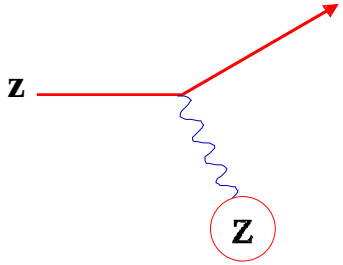
Advantages: simple device,
good to cover large areas,
VERY fast!!!

→ used as trigger devices
in LHC experiments,
time resolution ~ 50 – 100 ps

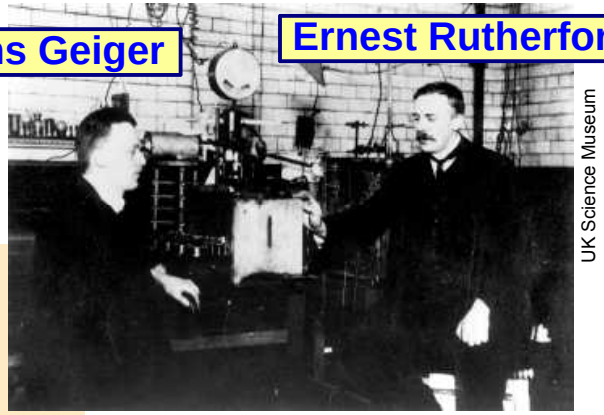
Disadvantages: Choice of resistive material
+ surface quality crucial,
affects "dark" trigger rate

Elastic Scattering

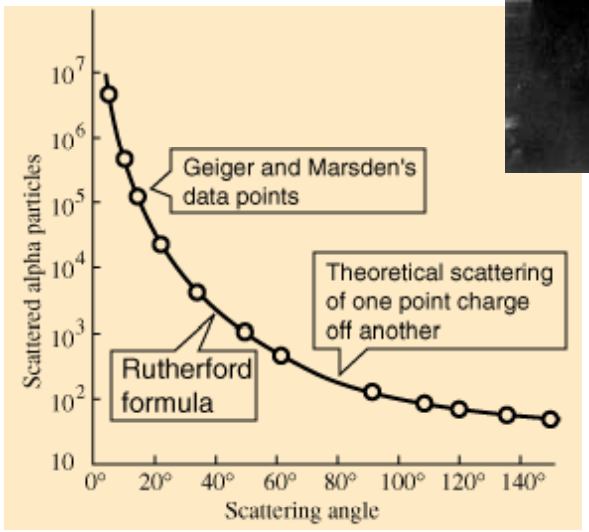
- Most basic interaction of a charged particle in matter
  - elastic scattering with a nucleus
    Rutherford (Coulomb) scattering



$$\frac{d\sigma}{d\Omega} = 4\,z\,Z\,r_e^2 \left[\frac{m_e c}{p}\right]^2 \frac{1}{\sin^4 \theta/2}$$



UK Science Museum

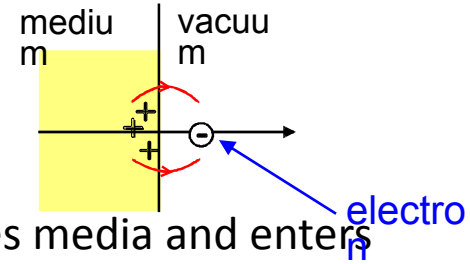


UK Science Museum

- Approximations
  - non-relativistic
  - no spins
- Scattering angle and energy transfer to nucleus usually small
  - No (significant) energy loss of the incoming particle
  - Just change of particle direction

Transition Radiation

- Predicted by Ginzburg and Franck in 1946
  - emission of photons when a charged particle traverses through the boundary of two media with different refractive index
  - (very) simple picture
    - charged particle is polarizing medium
    - polarized medium is left behind when particle
      unpolarized vacuum
    - formation of an electrical dipol with (transition) radiation



leaves media and enters

W □ □

- Radiated energy per boundary
  - only very high energetic particles can rad
    - need about γ > 1000
      - in our present energy range reachable

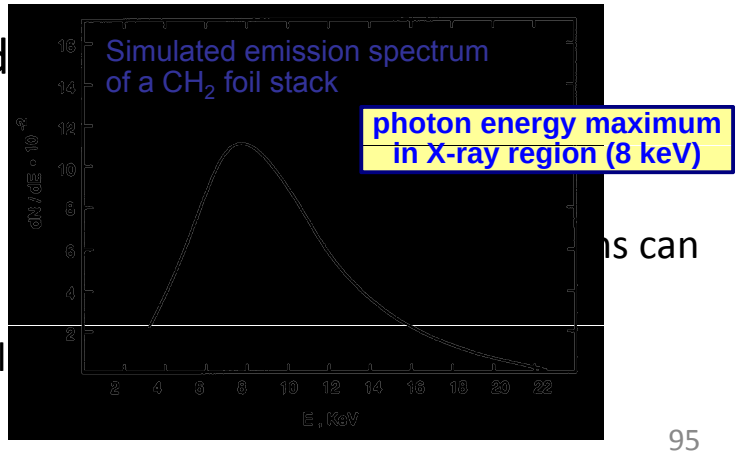
$N_{photons}$ □ □$_{EM}$ $\approx \frac{1}{137}$

with radiate

ns can

smal

need many boundaries (foils, foam) to get a few photons



Calorimeter types

Homogeneous calorimeters:

- ⇨ Detector = absorber
- ⇨ good energy resolution
- ⇨ limited spatial resolution (particularly in longitudinal direction)
- ⇨ only used for electromagnetic calorimetry

Sampling calorimeters:

- ⇨ Detectors and absorber separated → only part of the energy is sampled.
- ⇨ limited energy resolution
- ⇨ good spatial resolution
- ⇨ used both for electromagnetic and hadron calorimetry