

Gaseous Detectors at the LHC

22 Oct 2014

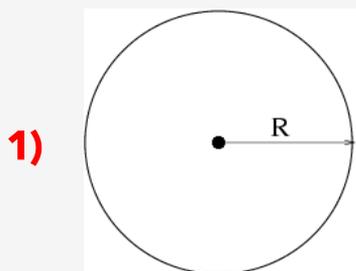
Christian Lippmann

2nd ECFA High Luminosity LHC Experiments Workshop
Aix-les-bains, France, 21 – 23 October 2014

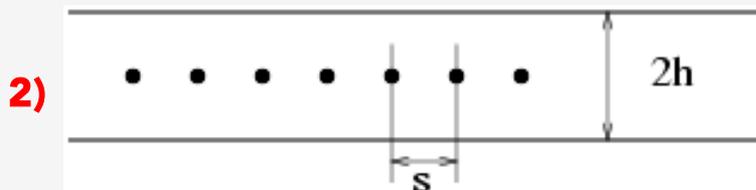
Gas detector geometries

- These **3 basic gas detector geometries** are widely used at the LHC:

**Geiger- Müller (1908), 1928
Drift Tube (1968)**



**G. Charpak, 1968
Multi Wire Proportional Chamber**



**R. Santonico, 1980
Resistive Plate Chamber**



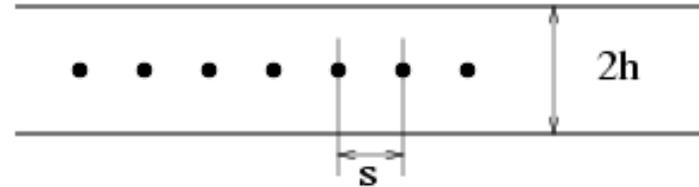
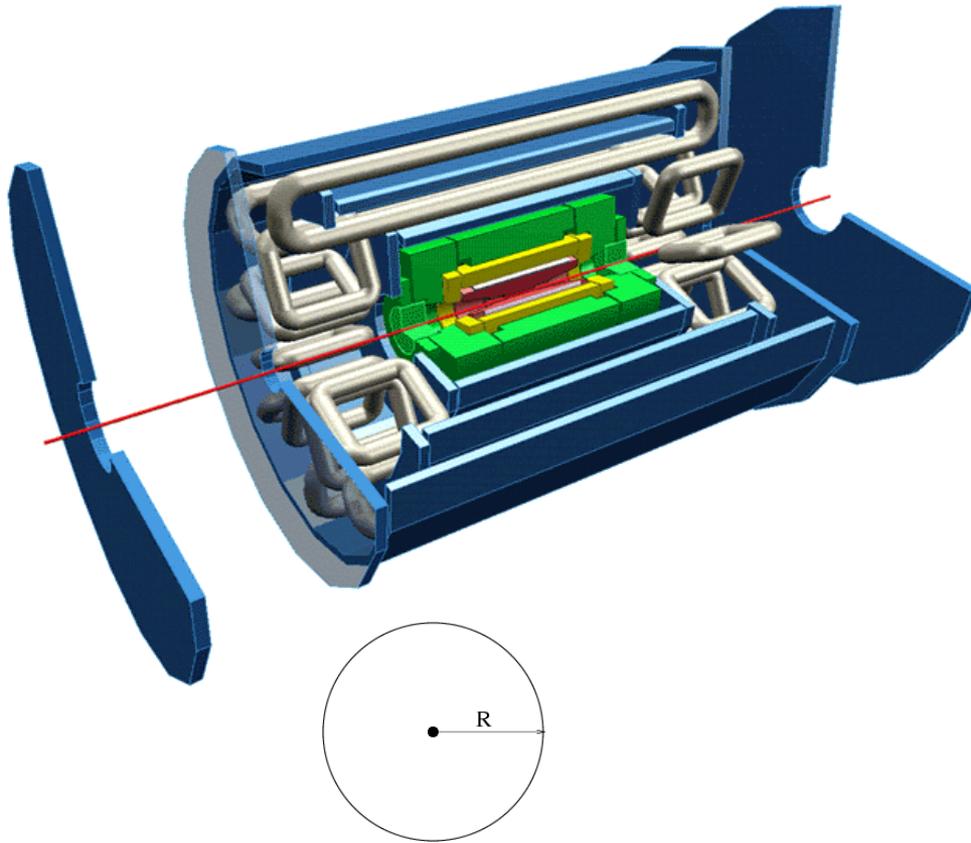
- They are well known devices for many years ...
- ... but several aspects have improved dramatically since their invention
 1. Readout electronics (integration, radiation resistance)
 2. Understanding and optimization of detector physics effects
 3. Improvement in ageing characteristics due to special gases



History and future

- **The elimination of gas detectors by solid state detectors is predicted since decades. But reality shows quite the opposite**
- **Silicon detectors have replaced gas detectors for vertex detection**
- **Gas detectors are still dominating in the **muon systems** at large radii**
 - to date it totally unrealistic to replace such a system by Si detectors
- **The **Time Projection Chamber** (TPC) for Heavy Ion Physics is unbeatable in terms of radiation length and channel number economy**
- **Gas detectors have even regained territory that was occupied by other technologies**
 - **Example: Resistive plate chambers replacing scintillators for triggering and time of flight measurements**

ATLAS



◆ Monitored Drift Tubes MDT (Tracking)

- $R=15\text{mm}$
- 370k anode channels
- Ar/CO₂ 93/7 (3 bars)
- $<80\mu\text{m}$

◆ Transition Radiation Tracker TRT (Tracking)

- $R=2\text{mm}$
- 372k anode channels
- Xe/CO₂/CF₄ 70/10/20
- Xe/CO₂/O₂ 70/27/3
- $<150\mu\text{m}$

◆ Cathode Strip Chambers CSC (Tracking)

- $h=2.54\text{mm}$, $s=2.54\text{mm}$
- 67k cathode channels
- Ar/CO₂/CF₄
- $<60\mu\text{m}$

◆ Thin Gap Chambers TGC (Trigger)

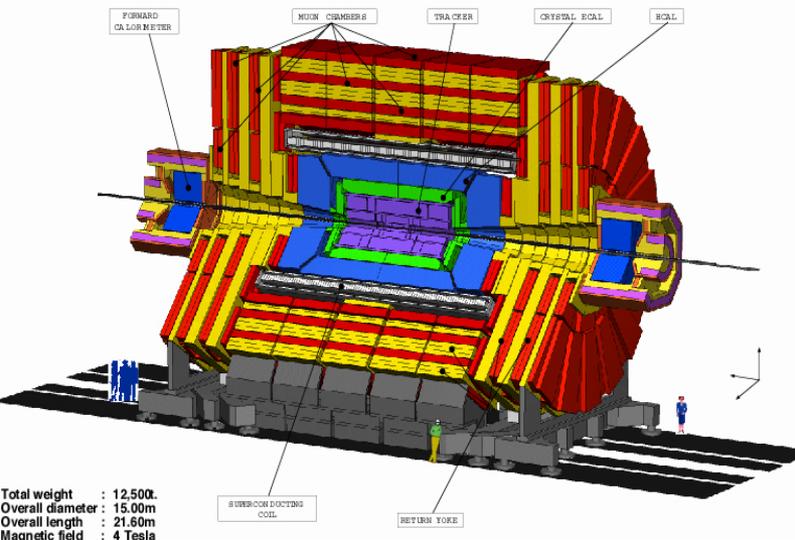
- $h=1.4\text{mm}$, $s=1.8\text{mm}$
- 440k cathode and anode channels
- n-Pentane /CO₂ 45/55
- $<99\%$ in 25ns with single plane

RPC

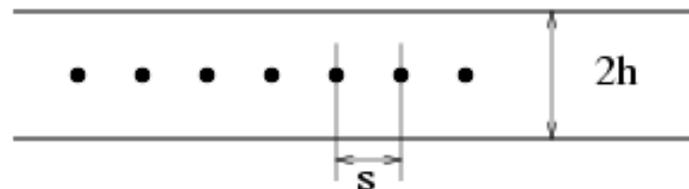
◆ Resistive Plate Chambers RPC (Trigger):

- $g=2\text{mm}$, 2mm Bakelite
- 355k channels
- C₂F₄H₂/Isobutane/SF₆ 96.7/3/0.3
- $<98\%$ with a single plane in 25ns

A Compact Solenoidal Detector for LHC

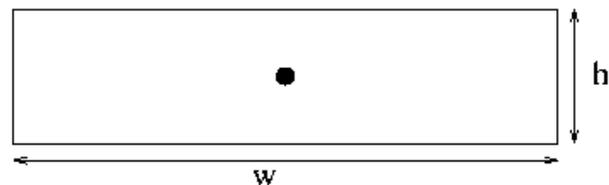


CMS



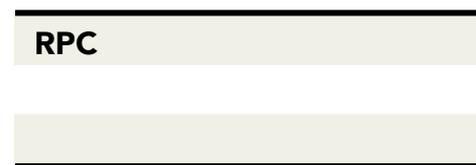
◆ Cathode Strip Chambers CSC (Trigger & Tracking):

- $h=4.25\text{mm}$, $s=3.12\text{mm}$
- 211k anode channels for timing
- 273k cathode channels for position
- Ar/CO₂/CF₄ 30/50/20
- <75-150 μm



◆ Rectangular 'Drift Tubes' DT (Trigger & Tracking):

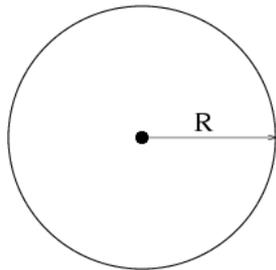
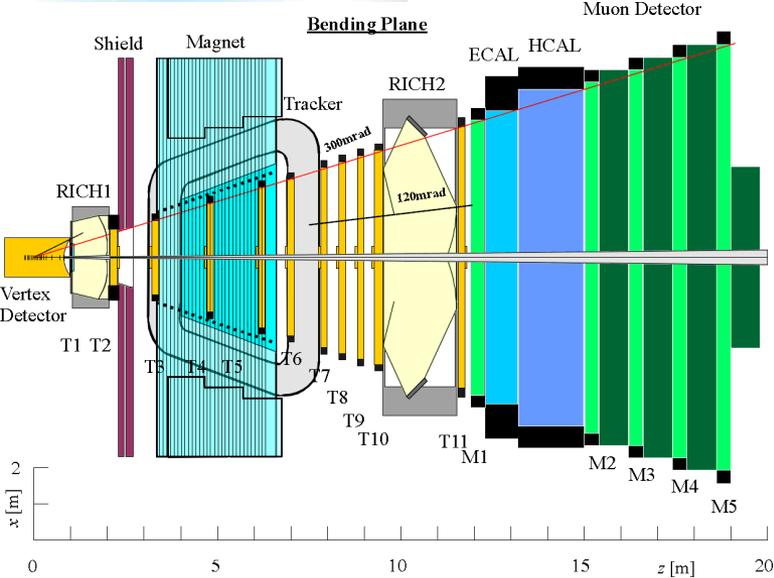
- $w=42\text{mm}$, $h=10.5\text{mm}$
- 195k anode channels
- Ar/CO₂ 85/15
- <250 μm



◆ Resistive Plate Chambers RPC (Trigger):

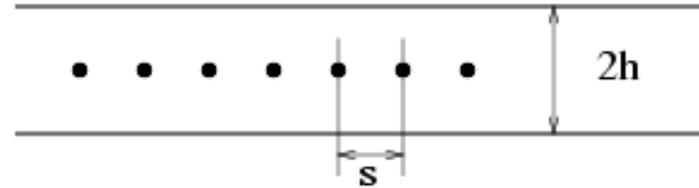
- $g=2\text{mm}$, 2mm Bakelite
- Many k channels
- C₂F₄H₂/Isobutane/SF₆ 96.5/3.5/0.5
- <98% with a single plane in 25ns

LHCb



◆ Outer Tracker (Tracking):

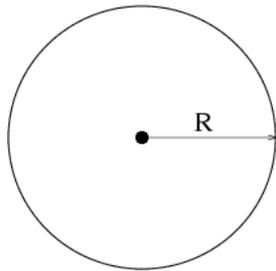
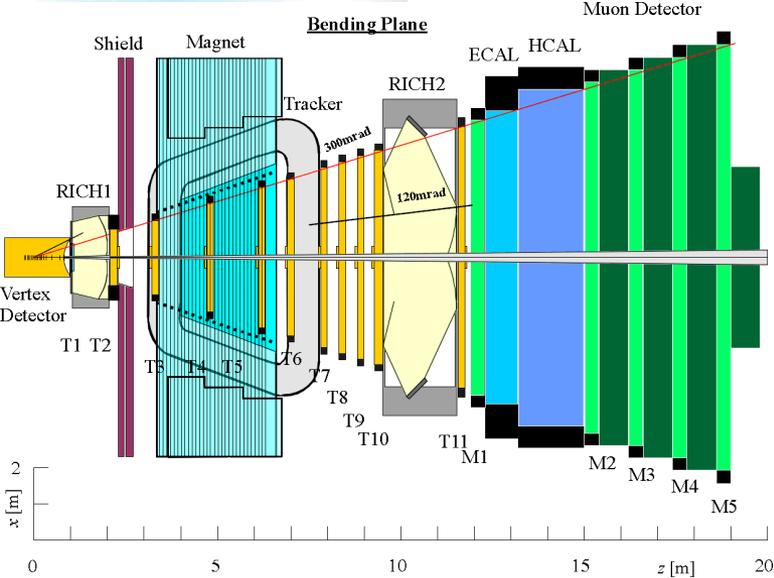
- $R=2.5\text{mm}$
- 51k anode channels
- Ar/CO₂/CF₄ 75/10/15
- $<200\ \mu\text{m}$



◆ Muon Chambers (Trigger):

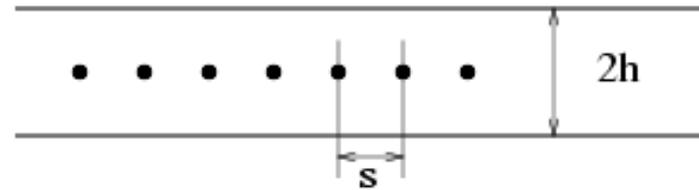
- $h=2.5\text{mm}$, $s=2\text{mm}$
- 125k cathode and anode pads
- Ar/CO₂/CF₄ 40/55/5
- $<3\text{ns}$ for two layers

LHCb



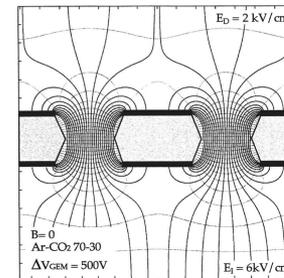
◆ Outer Tracker (Tracking):

- $R=2.5\text{mm}$
- 51k anode channels
- Ar/CO₂/CF₄ 75/10/15
- $<200\ \mu\text{m}$



◆ Muon Chambers (Trigger):

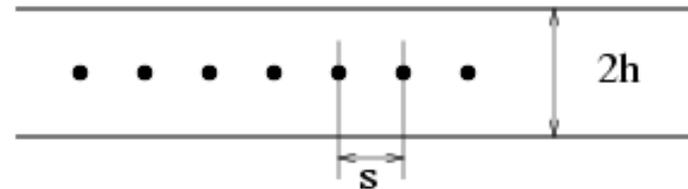
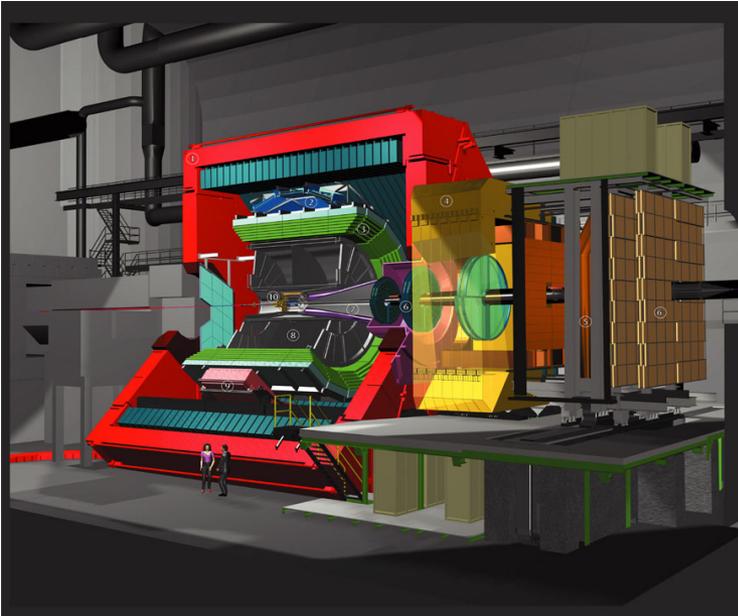
- $h=2.5\text{mm}$, $s=2\text{mm}$
- 125k cathode and anode pads
- Ar/CO₂/CF₄ 40/55/5
- $<3\text{ns}$ for two layers



◆ GEM (Trigger):

- 5k channels
- Ar/CO₂/CF₄ 45/15/40
- $<4.5\ \text{ns}$ for one triple GEM

ALICE



RPC

- ◆ **Time Of Flight TOF (Trigger & PID)**
 - $G=0.25\text{mm}$, 0.4mm glass, 10gaps
 - 160k channels
 - $<50\text{ps}/10\text{gaps}$
 - $\text{C}_2\text{F}_4\text{H}_2/\text{Isobutane}/\text{SF}_6$ 96.5/3.5/0.5
- ◆ **Muon System (Trigger)**
 - $G=2\text{mm}$, 2mm bakelite
 - Avalanche mode, Isobutane / $\text{C}_2\text{H}_2\text{F}_4$ / SF_6 10/89,7/0,3, rel. humidity 37%
 - Ar/Isobutane/ $\text{C}_2\text{F}_4\text{H}_2/\text{SF}_6$ 49/7/40/4
 - 21k channels

- ◆ **TPC with wire chambers, cathode pad readout (Tracking & PID)**
 - 1.25-2.5mm wire pitch
 - 2 - 3 mm plane separation
 - 570k Readout Pads
 - Ne/ CO_2 90/10
- ◆ **Transition Radiation Detector (Tracking & PID)**
 - 1160 k channels
 - Xe/ CO_2 85/15
 - $s=5\text{mm}$, $h=3.5\text{mm}$
- ◆ **RICH detector (PID)**
 - $s=2\text{mm}$, $h=2\text{mm}$
 - Methane
 - 160k channels
- ◆ **Muon Chambers (Tracking)**
 - 1000k channels
 - $<100\mu\text{m}$
 - $S=2.5\text{mm}$, $h=2.5\text{mm}$
 - Ar/ CO_2 80/20

Luminosity Upgrade

High Luminosity LHC:

1. **After LS2: High luminosity heavy ion collisions:**
Pb—Pb luminosity increases by factor ~ 10 up to $6 \times 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$
2. **After LS3: High luminosity pp collisions:**
pp luminosity increases by factor ~ 10 up to $5 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ (lumi levelled)



Currently installed gaseous detectors may run into limitations:

- **Occupancy**
- **Space Charge Effects (Wire Chambers), Voltage Drop (RPCs)**
- **Ageing**
- **Ion backflow**
- **Time resolution**

Upgrade options

1. Upgrade without changing detectors

- ATLAS, CMS and LHCb: Largest part of the Muon systems
- ALICE: Replace only electronics for TRD and Muon system
- CMS: New electronics with better trigger capabilities for DT chambers
- R&D: Run RPCs at lower gas gain with new low noise electronics

2. Upgrade by scaling standard geometries

- ATLAS: sMDT (small Muon Drift Tubes) for BME (in LS1) and BIS (in LS2) regions
- ATLAS: sTGCs (small-strip Thin Gap Chambers) for New Small Wheel
- R&D: RPCs with thinner or lower resistivity electrodes

3. Upgrade by introducing novel gas detectors (Micro-Pattern Gas Detectors)

- ATLAS: MicroMegas for New Small Wheel
- ALICE (TPC), CMS (Forward Muon system) and LHCb (Muon system): GEMs



See presentations by R. Santonico, A. Sharma, G. Graziani and M. Abbrescia

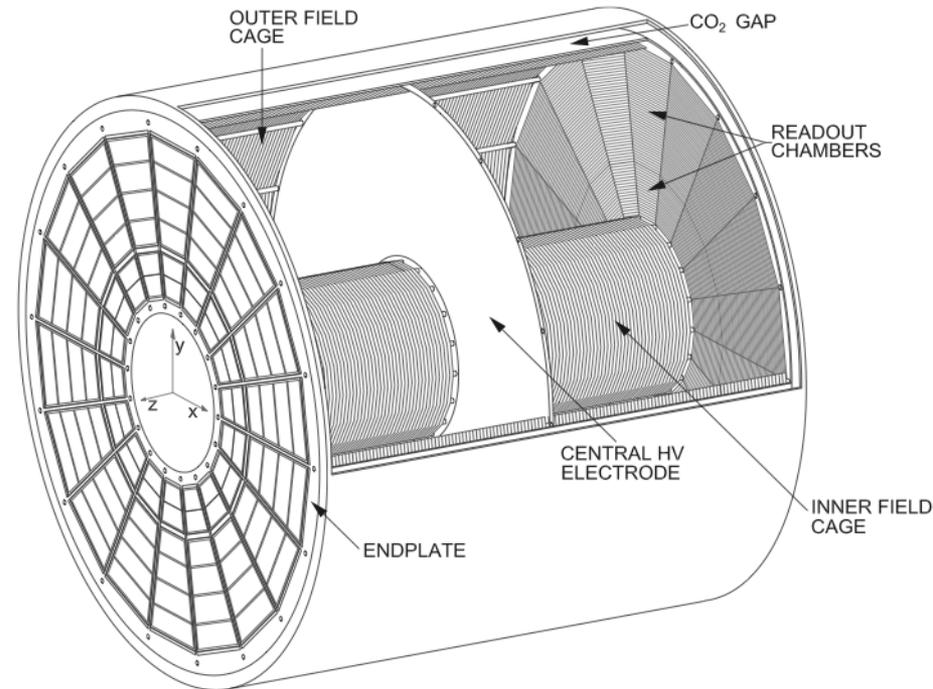


Example: ALICE TPC (1)

- A Time Projection Chamber (TPC) is the perfect detector for HI collisions:

- almost the whole **volume** is **active**
- minimal **radiation length** (only field cage and gas)
- easy **pattern recognition** (continuous tracks)
- **P**article **I**Dentification from ionization measurements

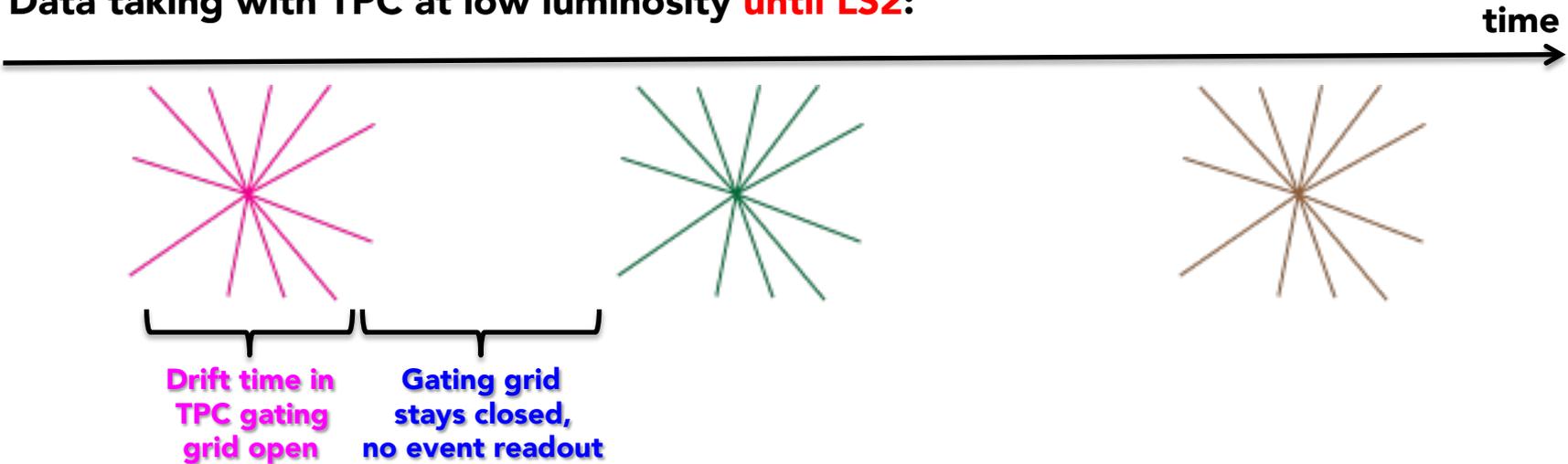
- ... but there are also limitations:
 - Gating needed to limit **Ion BackFlow (IBF)**, otherwise **drift field distortions** due to **space charge** \Rightarrow rather low trigger rates ($<$ few kHz)
- Can a TPC be operated at HL-LHC with 50 kHz Pb–Pb collision rate?





Example: ALICE TPC (2)

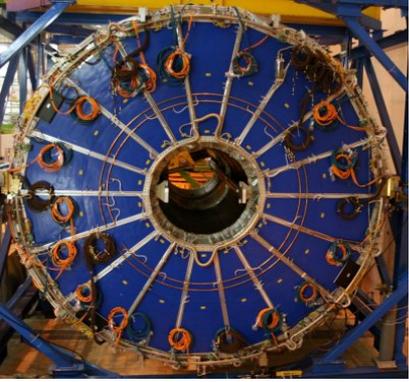
Data taking with TPC at low luminosity **until LS2:**



- Maximum drift time of electrons in TPC: $\sim 100\mu\text{s}$
- After each trigger: Additional gating grid closure time: $180\mu\text{s}$
 - Minimize backflow of positive ions into TPC drift volume
 - Minimize space charge to get best possible data quality



Maximum theoretical readout time: $1/280\mu\text{s} \approx 3.5\text{kHz}$
Far to slow for HL-LHC (50 kHz collision rate)



Example: ALICE TPC (3)

Data taking with TPC at 50kHz in **after LS2**:



- Maximum drift time of electrons in TPC: ~ 100us
- Interaction rate at HL-LHC: 50 kHz \Rightarrow Event spacing: ~20us

Events are overlapping due to finite drift time in TPC

Gating grid would lead to loss of data

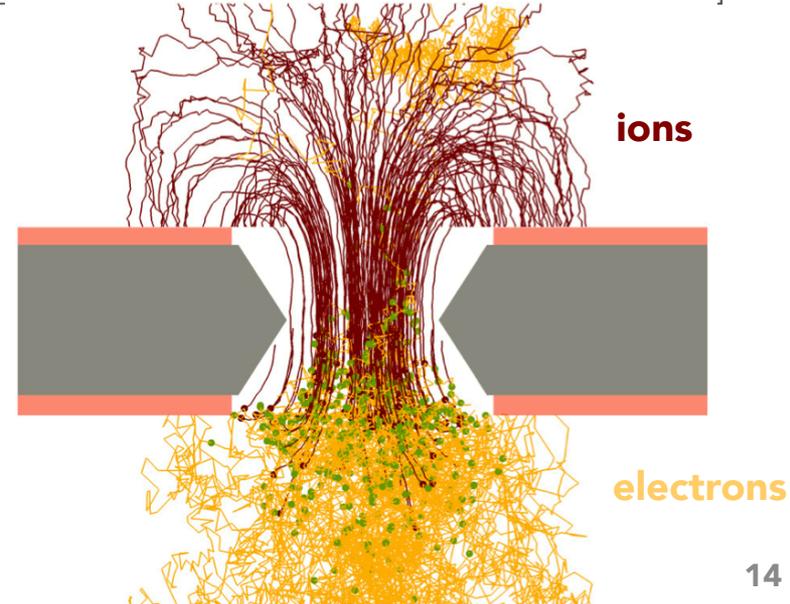
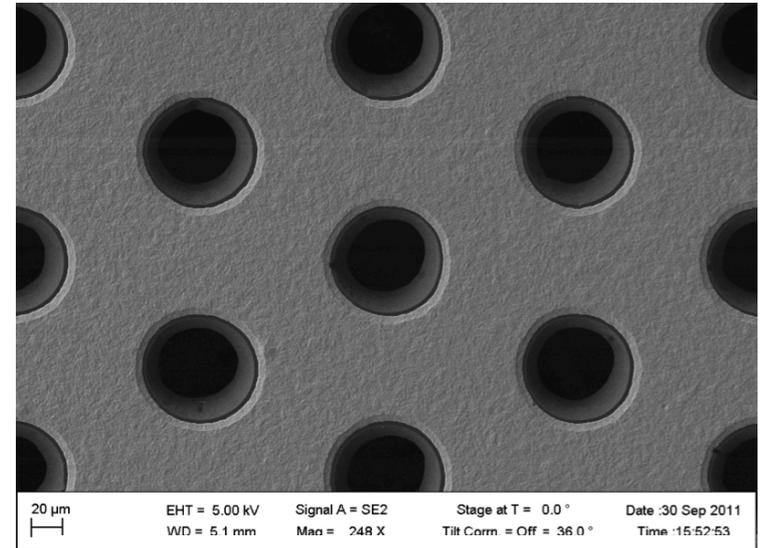
No more triggering, **continuous read-out**

Need to minimize ion backflow in different way \rightarrow **GEMs**



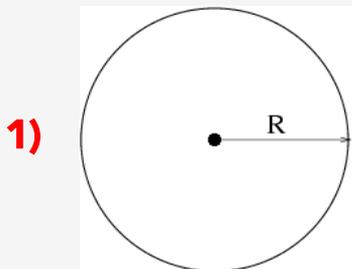
Example: ALICE TPC (4)

- **Strategy: Make use of the intrinsic Ion BackFlow (IBF) suppression in GEM detectors**
 - Positive ions are trapped on upper foil
- **Optimization of IBF suppression performance:**
 - 4-GEM configuration
 - optimisation of operational voltages
- **Continuous read-out becomes possible**
- **Remaining drift-field distortions must be calibrated**

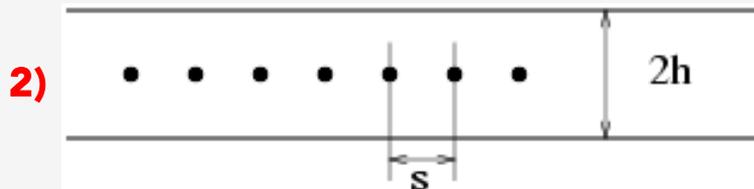


Summary & conclusion

**Geiger- Müller (1908), 1928
 Drift Tube (1968)**



**G. Charpak, 1968
 Multi Wire Proportional Chamber**

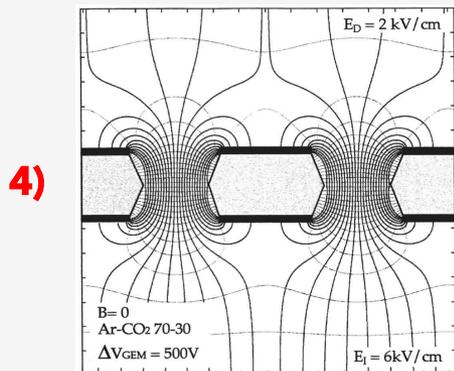


**R. Santonico, 1980
 Resistive Plate Chamber**



... will at HL-LHC be joined by:

**F. Sauli (1997)
 Gas Electron Multiplier**



**I. Giomataris et al. (1996)
 Micro-mesh gaseous chamber (Micromegas)**

