Gaseous Detectors at the LHC

22 Oct 2014

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

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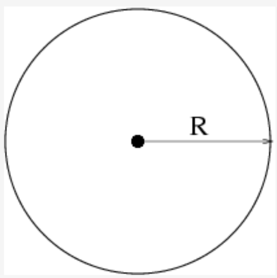
Physics and technology developments
21st - 23rd October 2014
Aix-les-Bains | France

Gas detector geometries

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

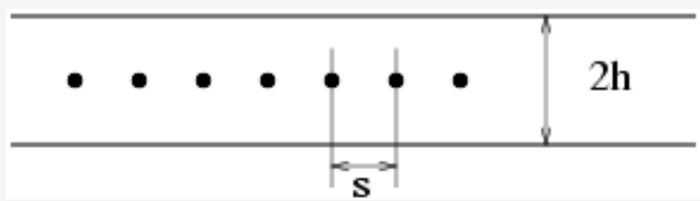
Geiger- Müller (1908), 1928
Drift Tube (1968)

1)



G. Charpak, 1968
Multi Wire Proportional Chamber

2)



R. Santonico, 1980
Resistive Plate Chamber

3)

- 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

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History and future

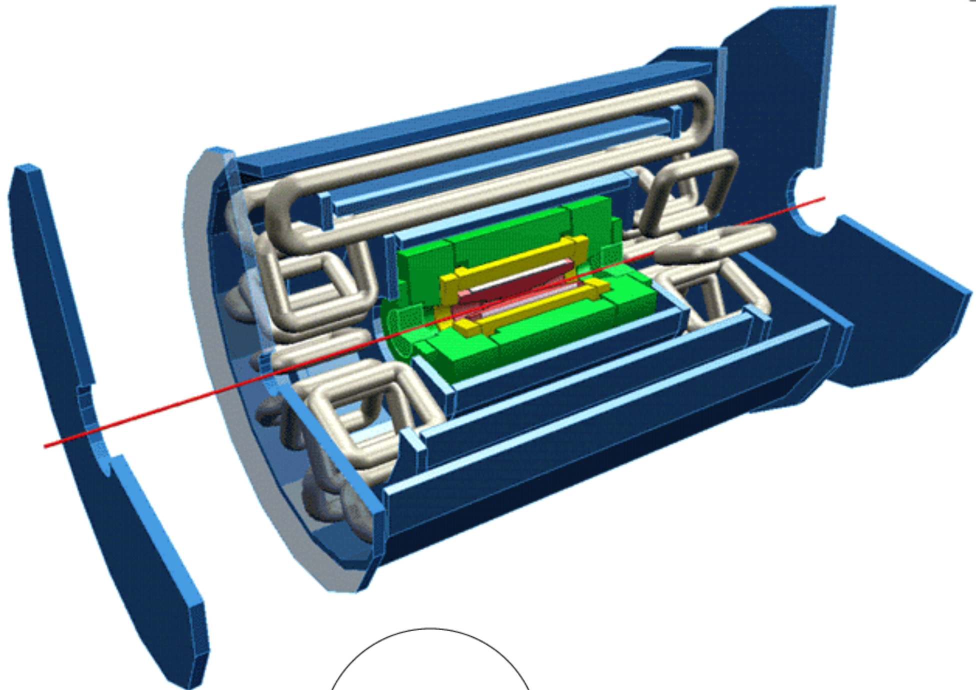
- **The elimination of gas detectors by solid state detectors is predicted since decades. But reality shows quite the opposite**

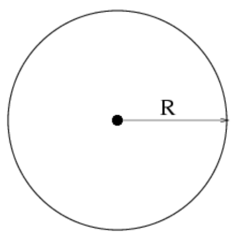
- **Silicon detectors have replaced gas detectors for vertex detection**

- **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**

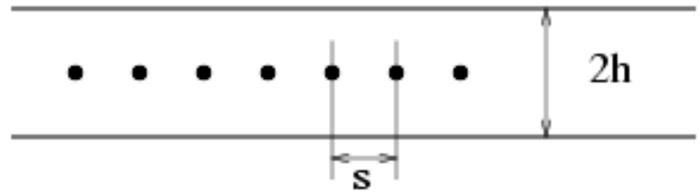
ATLAS





- **Monitored Drift Tubes MDT (Tracking)**
  - R=15mm
  - 370k anode channels
  - Ar/CO_2 93/7 (3 bars)
  - <80μm

- **Transition Radiation Tracker TRT (Tracking)**
  - R=2mm
  - 372k anode channels
  - $Xe/CO_2/CF_4$ 70/10/20
  - $Xe/CO_2/O_2$ 70/27/3
  - <150 μm



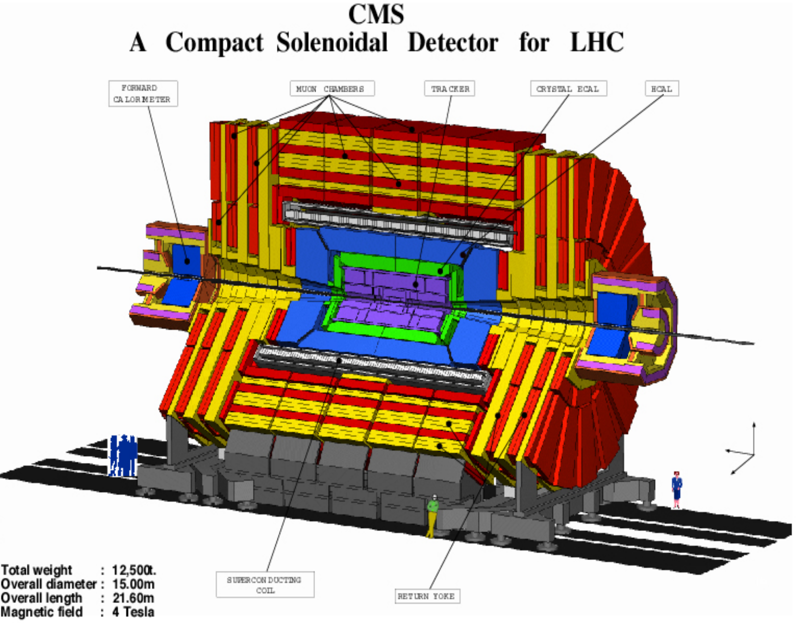
- **Cathode Strip Chambers CSC (Tracking)**
  - h=2.54mm, s=2.54mm
  - 67k cathode channels
  - $Ar/CO_2/CF_4$
  - <60 μm

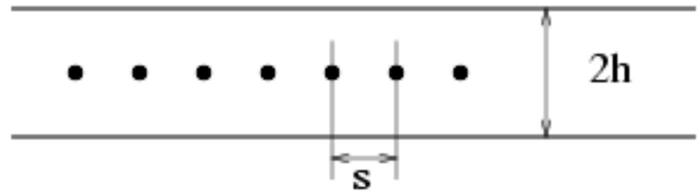
- **Thin Gap Chambers TGC (Trigger)**
  - h=1.4mm, s=1.8mm
  - 440k cathode and anode channels
  - n-Pentane $/CO_2$ 45/55
  - <99% in 25ns with single plane

- **Resistive Plate Chambers RPC (Trigger):**
  - g=2mm, 2mm Bakelite
  - 355k channels
  - $C_2F_4H_2$/Isobutane/SF_6 96.7/3/0.3
  - <98% with a single plane in 25ns

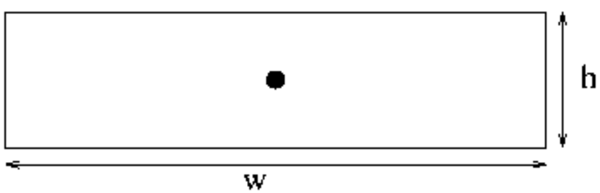
Data compiled by Werner Riegler. Thanks!

CMS





- **Cathode Strip Chambers CSC (Trigger & Tracking):**
  - h=4.25mm, s=3.12mm
  - 211k anode channels for timing
  - 273k cathode channels for position
  - $Ar/CO_2/CF_4$ 30/50/20
  - <75-150 μm

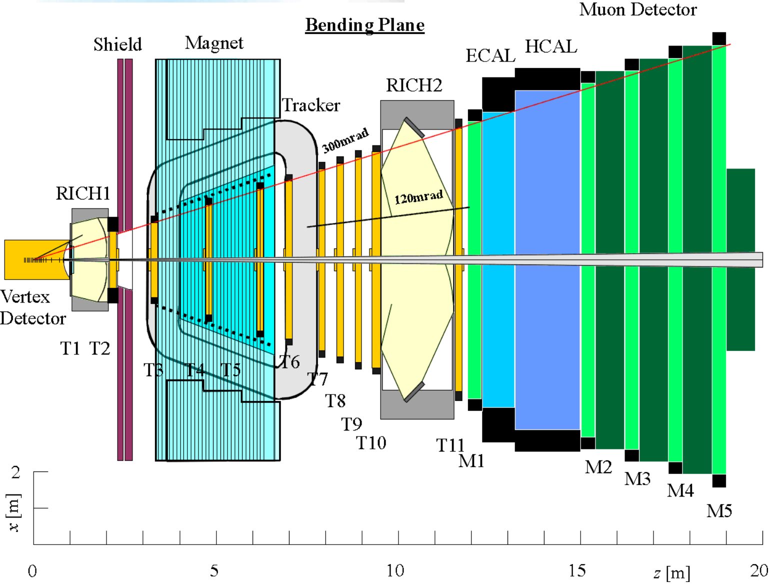


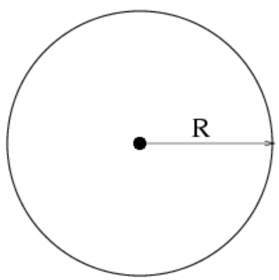
- **Rectangular 'Drift Tubes' DT (Trigger & Tracking):**
  - w=42mm, h=10.5mm
  - 195k anode channels
  - Ar/CO_2 85/15
  - <250 μm

- **Resistive Plate Chambers RPC (Trigger):**
  - g=2mm, 2mm Bakelite
  - Many k channels
  - $C_2F_4H_2$/Isobutane/SF_6 96.5/3.5/0.5
  - <98% with a single plane in 25ns

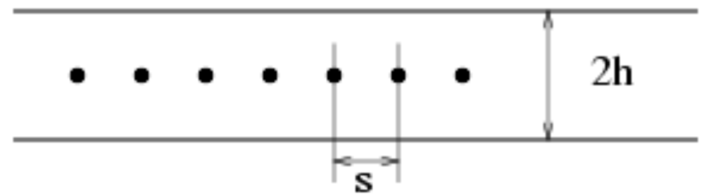
Data compiled by Werner Riegler. Thanks!

LHCb

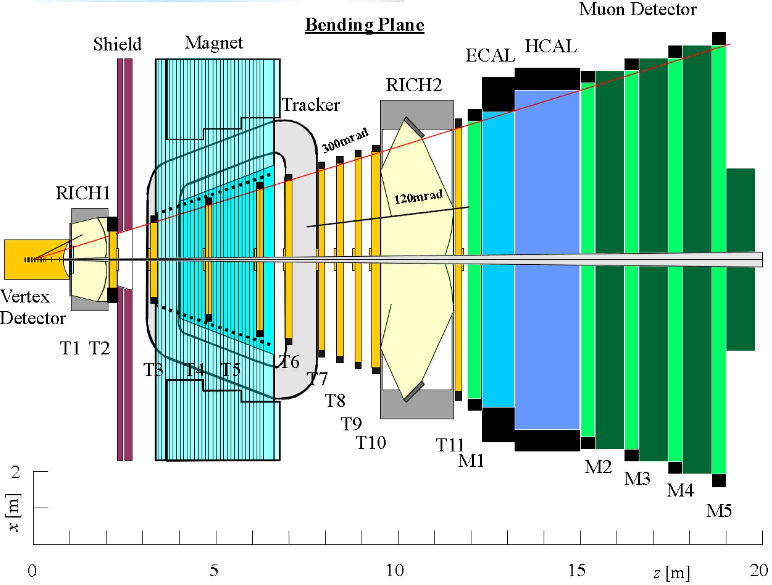




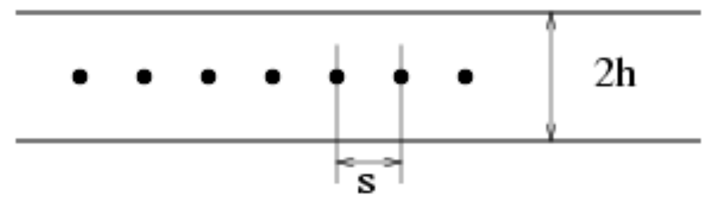
- **Outer Tracker (Tracking):**
  - R=2.5mm
  - 51k anode channels
  - $Ar/CO_2/CF_4$ 75/10/15
  - <200 μm



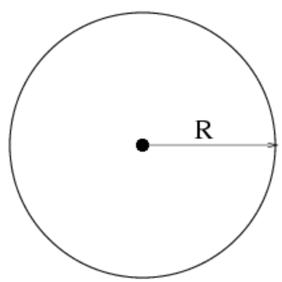
- **Muon Chambers (Trigger):**
  - h=2.5mm, s=2mm
  - 125k cathode and anode pads
  - $Ar/CO_2/CF_4$ 40/55/5
  - <3ns for two layers

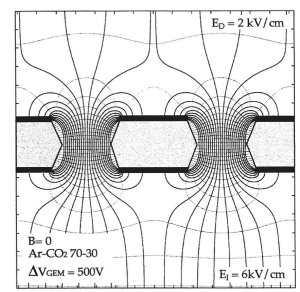


LHCb



- **Muon Chambers (Trigger):**
  - h=2.5mm, s=2mm
  - 125k cathode and anode pads
  - $Ar/CO_2/CF_4$ 40/55/5
  - <3ns for two layers



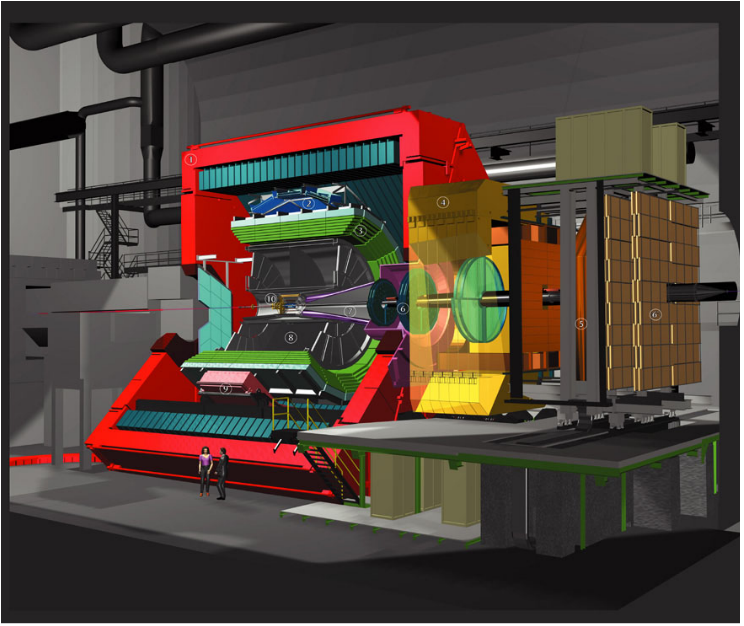


- **Outer Tracker (Tracking):**
  - R=2.5mm
  - 51k anode channels
  - $Ar/CO_2/CF_4$ 75/10/15
  - <200 µm

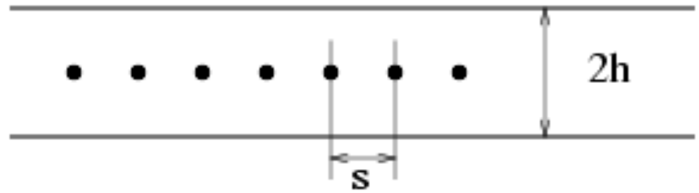
- **GEM (Trigger):**
  - 5k channels
  - $Ar/CO_2/CF_4$ 45/15/40
  - <4.5 ns for one triple GEM

Data compiled by Werner Riegler. Thanks!

ALICE



- **Time Of Flight TOF (Trigger & PID)**
  - G=0.25mm, 0.4mm glass, 10gaps
  - 160k channels
  - <50ps/10gaps
  - $C_2F_4H_2$/Isobutane/SF_6 96.5/3.5/0.5
- **Muon System (Trigger)**
  - G=2mm, 2mm bakelite
  - Avalanche mode, Isobutane / $C_2H_2F_4$ / SF_6 10/89,7/0,3, rel. humidity 37%
  - Ar/Isobutane/$C_2F_4H_2$/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=5mm, h=3.5mm
- **RICH detector (PID)**
  - s=2mm, h=2mm
  - Methane
  - 160k channels
- **Muon Chambers (Tracking)**
  - 1000k channels
  - <100um
  - S=2.5mm, h=2.5mm
  - Ar/CO_2 80/20

Data compiled by Werner Riegler. Thanks!

Luminosity Upgrade

High Luminosity LHC:

1. **After LS2: High luminosity heavy ion collisions:**
   Pb—Pb luminosity increases by factor ~10 up to 6×10^{27} cm^{-2} s^{-1}
2. **After LS3: High luminosity pp collisions:**
   pp luminosity increases by factor ~10 up to 5×10^{35} cm^{-2} 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

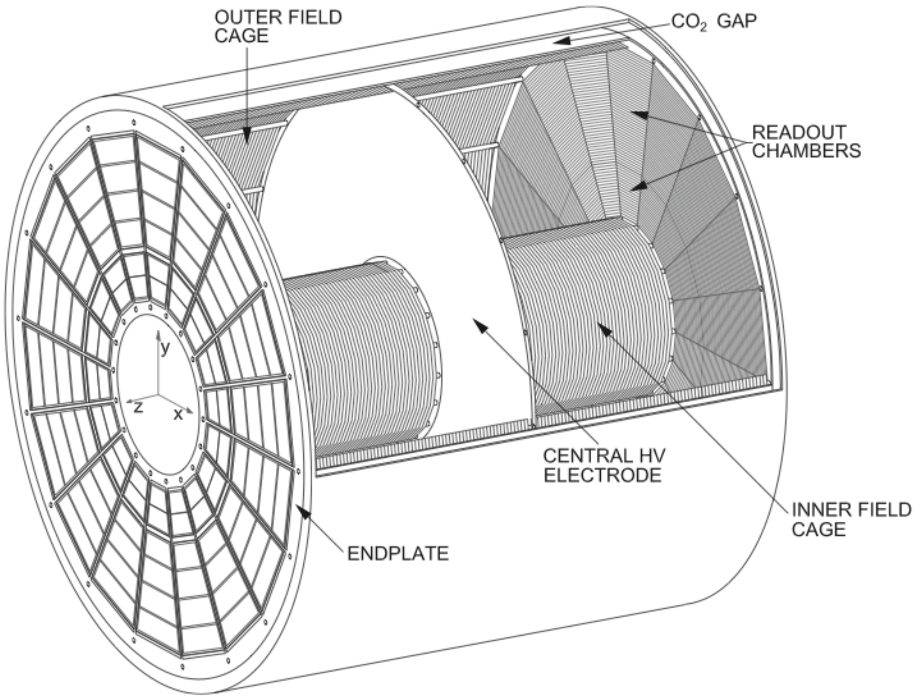
Upgrade options

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)

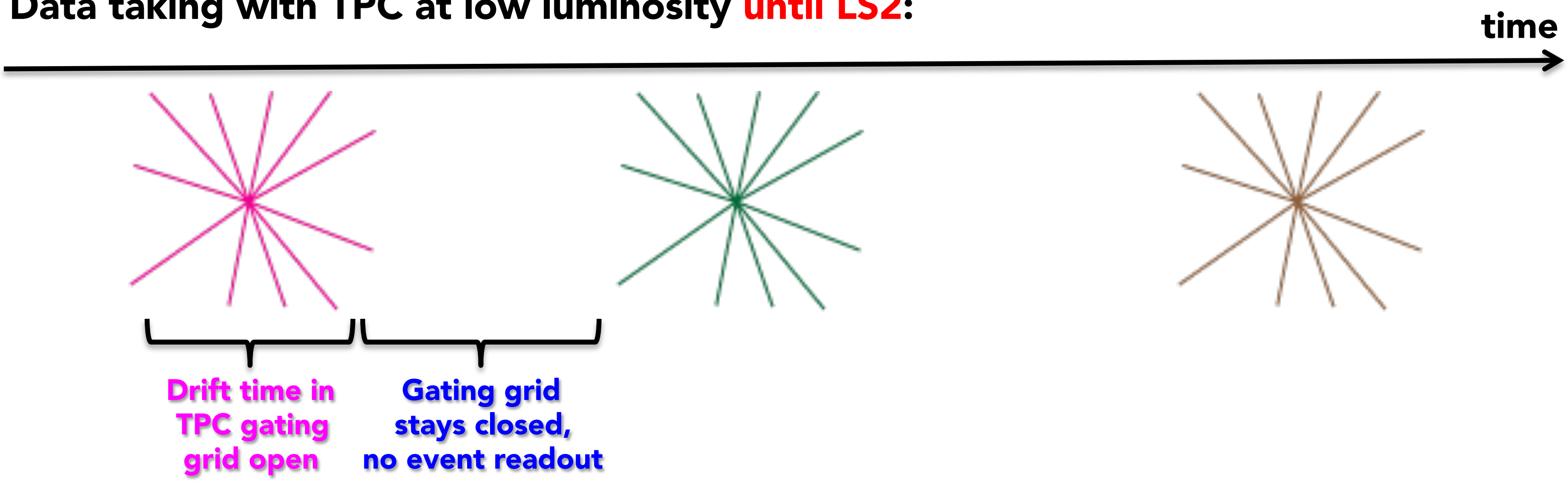
- A Time Projection Chamber (TPC) is the perfect detector for HI collisions:
  - almost the whole **volume** is **active**
  - minimal **radiation length** (only field cage and gas)
  - easy **pattern recognition** (continuous tracks)
  - **P**article **ID**entification from ionization measurements



- … but there are also limitations:
  - Gating needed to limit **Ion BackFlow (IBF)**, otherwise **drift field distortions** due to **space charge** ⇒ 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:

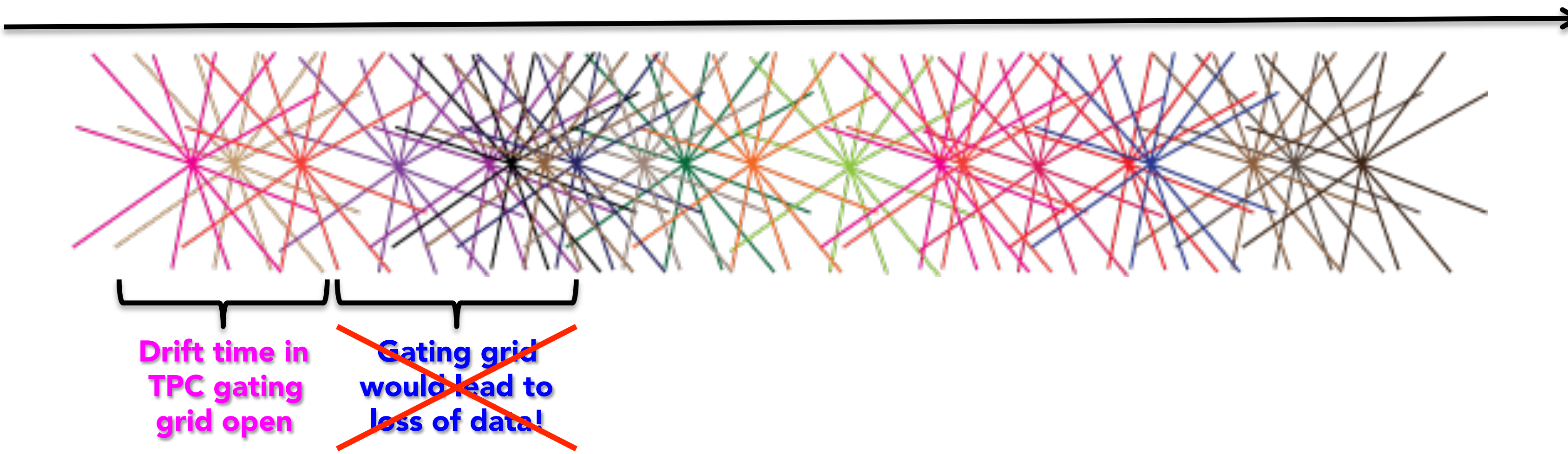


- **Maximum drift time of electrons in TPC: ~ 100us**
- **After each trigger: Additional gating grid closure time: 180us**
  - Minimize backflow of positive ions into TPC drift volume
  - Minimize space charge to get best possible data quality

Maximum theoretical readout time: 1/280us ≈ 3.5kHz
Far to slow for HL-LHC (50 kHz collision rate)

Example: ALICE TPC (3)

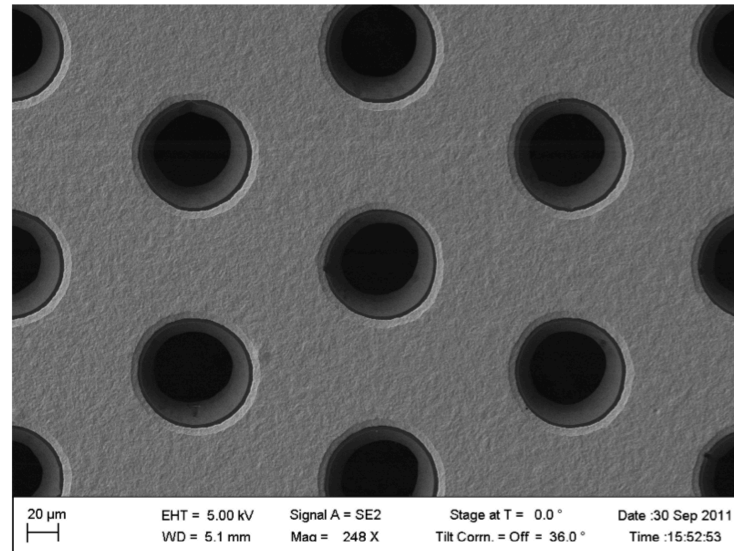
Data taking with TPC at 50kHz in after LS2:



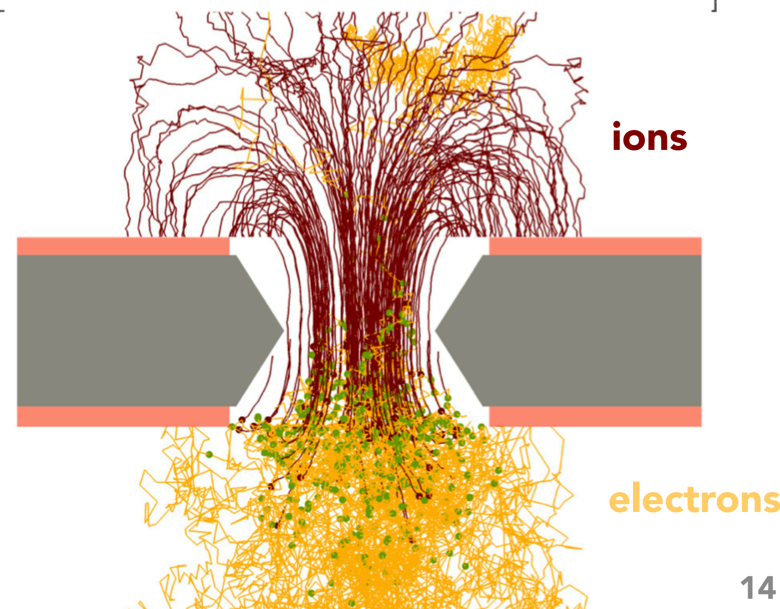
- **Maximum drift time of electrons in TPC: ~ 100us**
- **Interaction rate at HL-LHC: 50 kHz ⇒ Event spacing: ~20us**

➡ **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 → GEMs

Example: ALICE TPC (4)

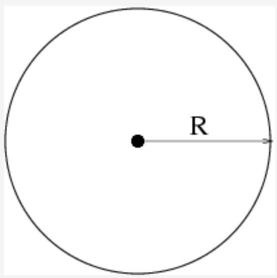


- Strategy: Make use of the intrinsic Ion BackFlow (IBF) suppression in GEM detectors
  - Positive ions are trapped on upper foil
- Optimization of IBF suppression performance:
  - 4-GEM configuration
  - optimisation of operational voltages
- Continuous read-out becomes possible
- Remaining drift-field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

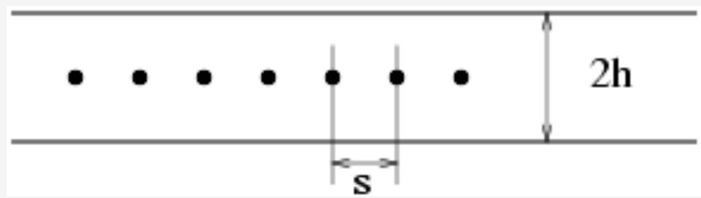


Summary & conclusion

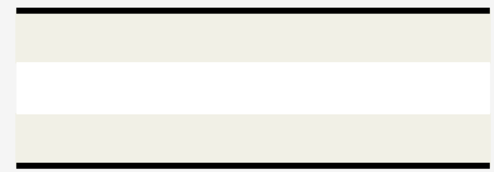
Geiger- Müller (1908), 1928
Drift Tube (1968)

1) 

G. Charpak, 1968
Multi Wire Proportional Chamber

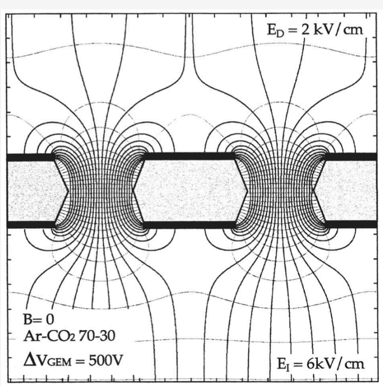
2) 

R. Santonico, 1980
Resistive Plate Chamber

3) 

… will at HL-LHC be joined by:

F. Sauli (1997)
Gas Electron Multiplier

4) 

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

5)