LHC Luminosity Upgrade: Gas Detector Challenges

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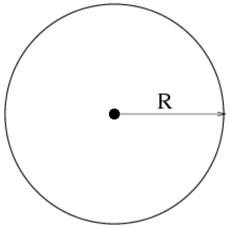
March 17, 2006

- **The basic gas detector geometries**
- **LHC gas detector inventory**
- **Limitations of LHC gas detectors**
- **Upgrade possibilities**
  - **without changing the detectors**
  - **by scaling the existing geometries**
  - **by introducing novel gas detectors**
- **Current gas detector upgrade plans for SLHC**

The basic geometries

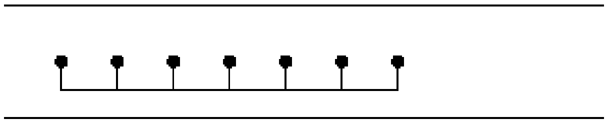
1

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

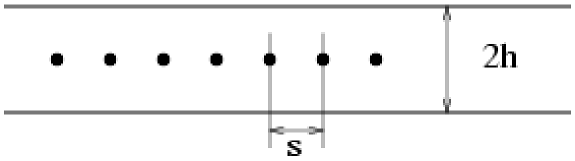


2

Multi Wire Geometry,
in H. Friedmann, 1949



G. Charpak, 1968
Multi Wire Proportional Chamber



3

W. Keuffel, 1949
Spark Counter

R. Santonico, 1980
Resistive Plate Chamber

- **These geometries are widely used at LHC**
- **Basic elements are unchanged since many years**
- **Electronics and operating parameters have changed considerably**

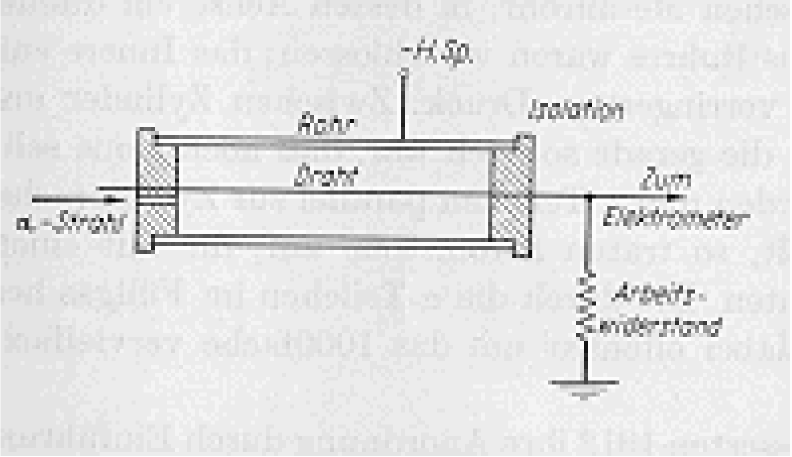
Geiger Tube 1908: The Father (Mother) of all Gas Detectors

In 1908, Rutherford and Geiger developed an electric device to measure alpha particles.

The alpha particles ionize the gas, the electrons drift to the wire in the electric field and they multiply there, causing a large discharge which can be measured by an electroscope.

The 'random discharges' in absence of alphas were interpreted as 'instability', so the device wasn't used much.

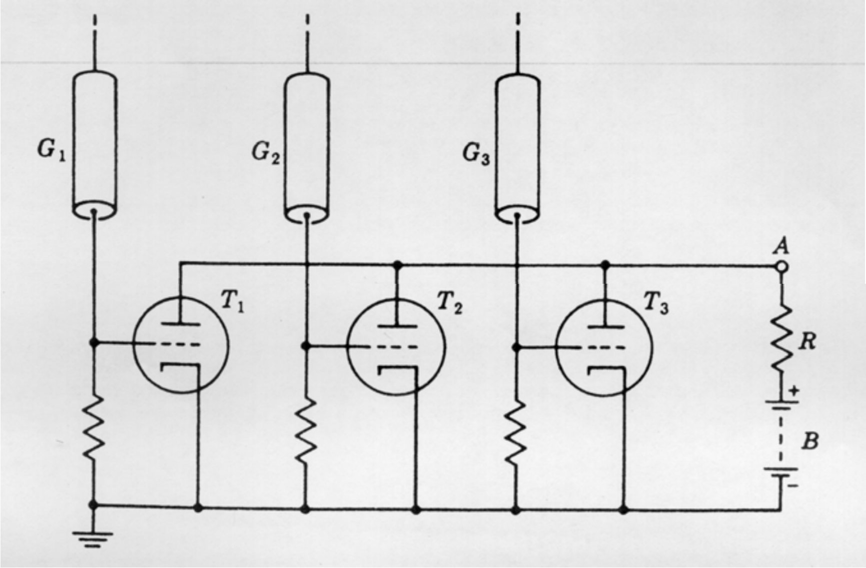
In 1928 Walther Müller started to study the spontaneous discharges systematically and found that they were actually caused by cosmic rays discovered by Victor Hess in 1911.



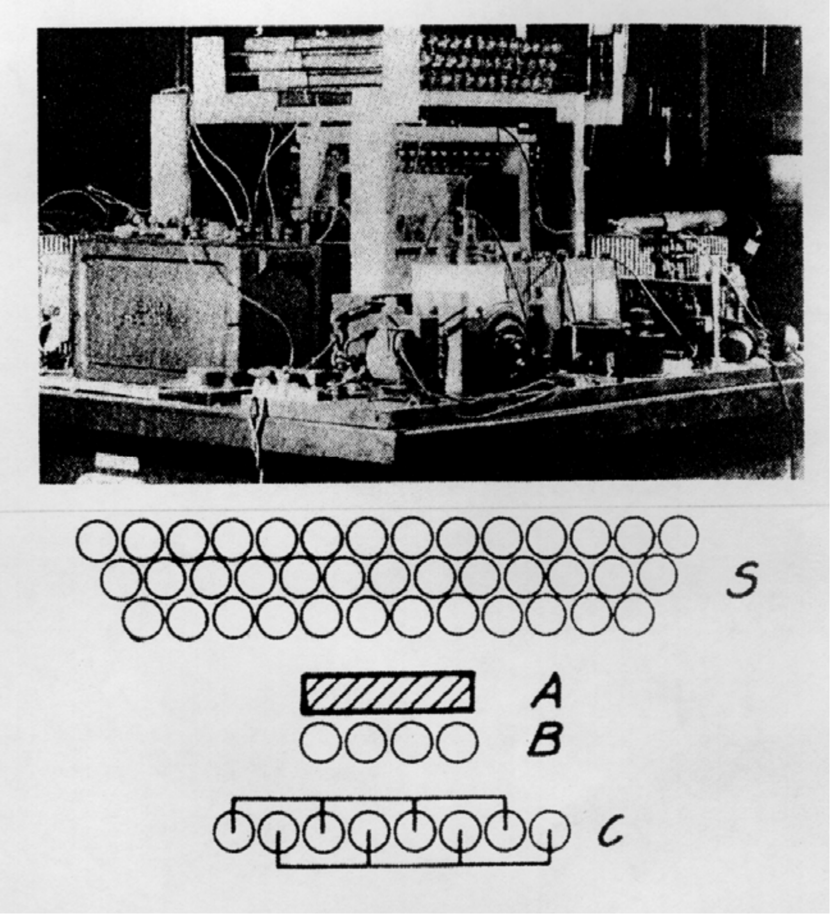
By realizing that the wild discharges were not a problem of the counter, but were caused by cosmic rays, the Geiger-Müller counter went, without altering a single screw from a device with 'fundametal limits' to the most sensitive Instrument for cosmic rays physics.

1930 - 1934

Rossi 1930: Coincidence circuit for n tubes

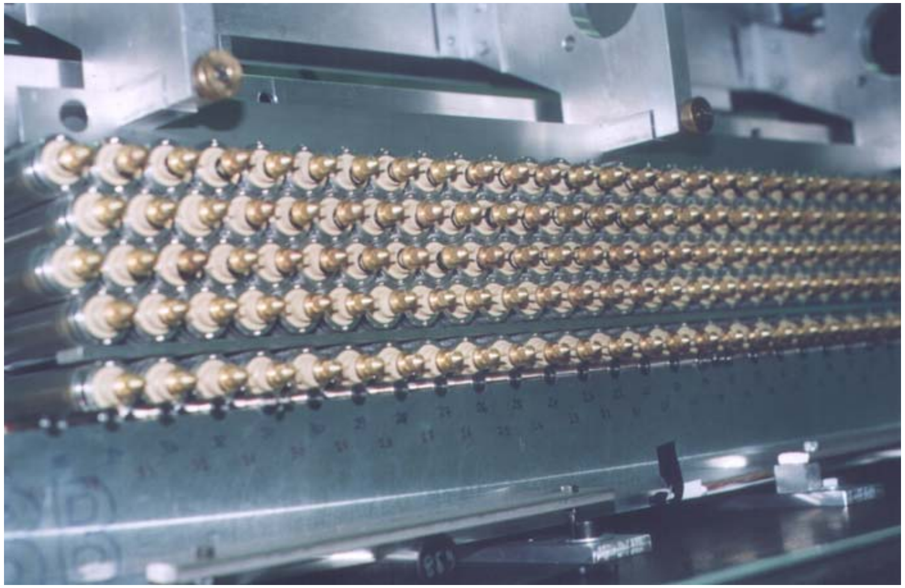


Cosmic ray telescope 1934

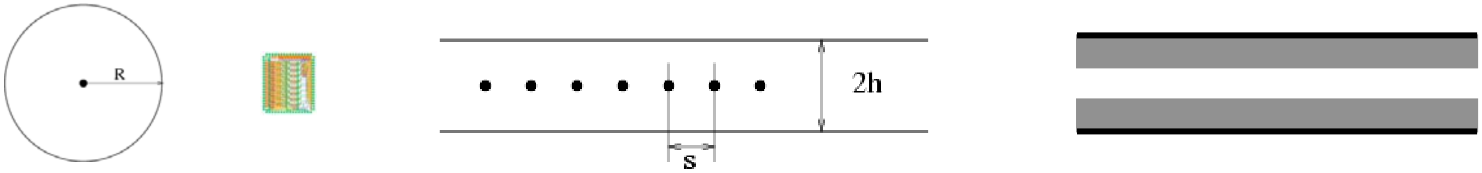


ATLAS Muon Chamber 2006

Looks fairly similar to 1934



Gas Detectors at LHC



- The LHC experiments use very ‘conservative’ gas detector principles.

- While the principle detecting elements are unchanged since many years, several aspects have improved dramatically:
    - Readout electronics (integration, radiation resistance)
    - Excellent understanding and optimization of detector physics effects (HEED, MAGBOLTZ, GARFIELD)
    - Improvement in ageing characteristics due to special gases

- Situation can be compared to astronomy. Telescope mirrors haven’t changed much but detecting elements (CCDs etc.) improved dramatically.

- The principles are traditional but all other aspects are 100% state of the art. The ATLAS MDTs are NOT Geiger counters.

Gas Detectors at LHC

- Original plans to use ‘novel’ gas detectors for tracking close to the IP for ATLAS and CMS (Microstrip Gas Chamber - MSGCs) were dropped due to the steady decrease in price for SI detectors and the difficulties to convince the community of the stable operation of these detectors for the entire LHC lifetime.
- Novel gas Detectors like GEMs and MICROMEGAS came too late and were also not really trusted in the beginning.
- Although spectacular progress in the performance and understanding of these novel gas detectors has been made since that time, there is currently very little GEM/MICROMEGA activity for the LHC upgrade.
- ‘Micro-pattern Gas Detectors: status and perspectives’, Workshop, 20.1. 2006.
- An LHC upgrade talk about gas detectors seems not to be a presentation about ‘How novel gas detectors will live’ but ‘How state of the art gas detectors will die’.
- However the reality is more positive: ‘How traditional gas detectors will survive even an LHC upgrade i.e. $L=10^{34} \rightarrow 10^{35}$ ‘

Gas Detectors HEP Experiments

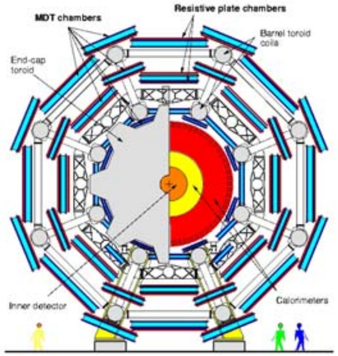
- **The elimination of gas detectors by solid state detectors is predicted since decades. Reality shows quite the opposite.**

- **E.g. ALICE experiment: ALICE can be viewed as a ‘gas container’. Removing everything but the detecting elements from ALICE, ‘nothing’ but a cloud of gas remains (+silicon tracker).**

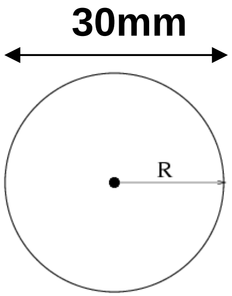
- **Gas detectors are even regaining territory that was occupied by other technologies. Example: Resistive plate chambers replacing scintillators for triggering and time of flight measurements.**

- **Very ambitious ideas to even regain Si detector territory by monolythic MICROMEGA detectors (see talk by H. Van der Graaf at previously cited workshop).**

Gas Detectors HEP Experiments



- While solid state detectors have replaced gas detector for vertex detection, gas detectors are dominating in the muon systems at large radii, and to date it totally unrealistic to replace such a system by Si detectors.
- The TPC for Heavy Ion Physics is unbeatable in terms of radiation length and channel number economy.
- TPC is also a proposed for the Future Linear Collider.
- Neutrino Experiments, cosmic ray experiments use very large areas of RPCs.



ATLAS MDTs: 80μm resolution in a 30mm element with a single channel at 0.5kHz/cm^2 → what more do you want.

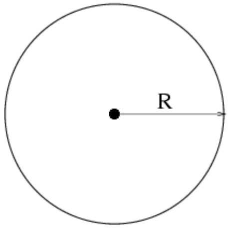
Operation principle of the basic objects

1

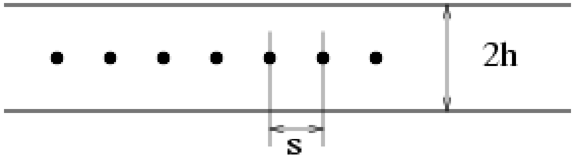
2

3

Drift Tube

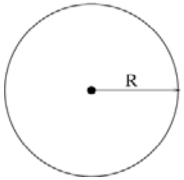


Multi Wire Proportional Chamber

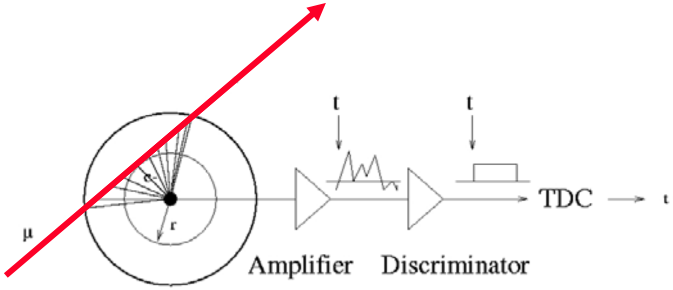


Resistive Plate Chamber

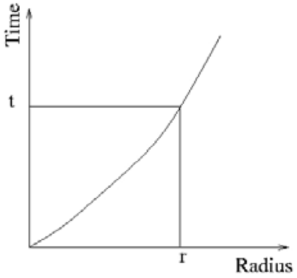
1) Drift Tube for Tracking



ATLAS MDT R=15mm, TRT R=2mm



Calibrated Radius-Time correlation



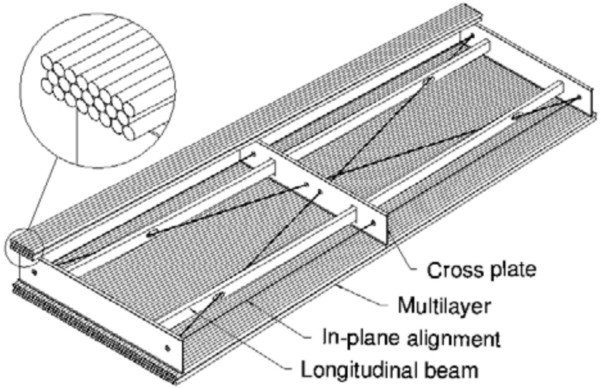
Primary electrons are drifting to the wire.

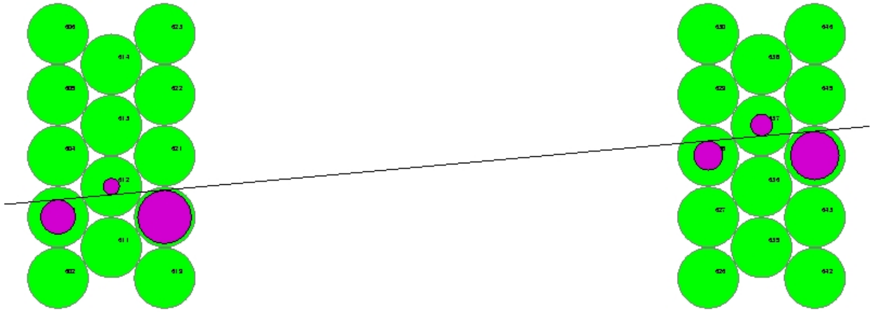
Electron avalanche on the wire (typical gas gain 2x10^4) induces a detectable signal on the wire.

The measured drift time is converted to a distance, giving the tangent circle.

Several circles define the track.

ATLAS Muon Chambers



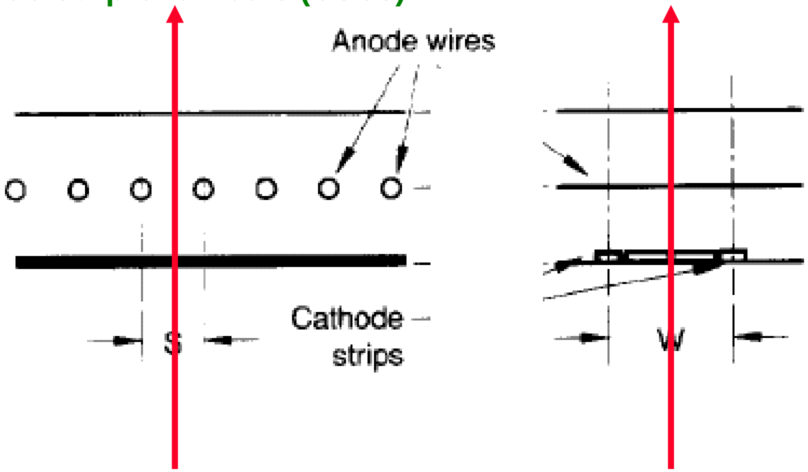


ATLAS MDTs, 80μm per tube

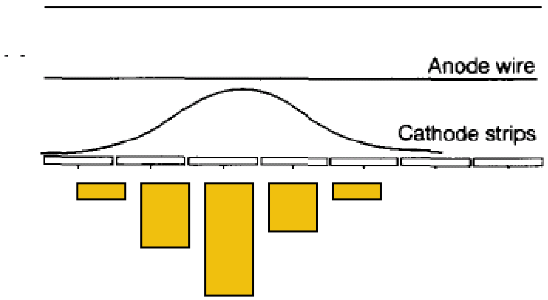
2) Multi Wire Proportional Chamber for Triggering (Timing) and Tracking

‘Multi Wire Proportinal Chambers (MWPCs)’

‘Cathode Strip Chambers (CSCs)’



At LHC: wire distance 2-3mm, cathode distance 5-10mm



Primary electrons are drifting to the wire.

Electron avalanche on the wire (typical gas gain 2×10^4) induces a detectable signal on the wire AND the cathode.

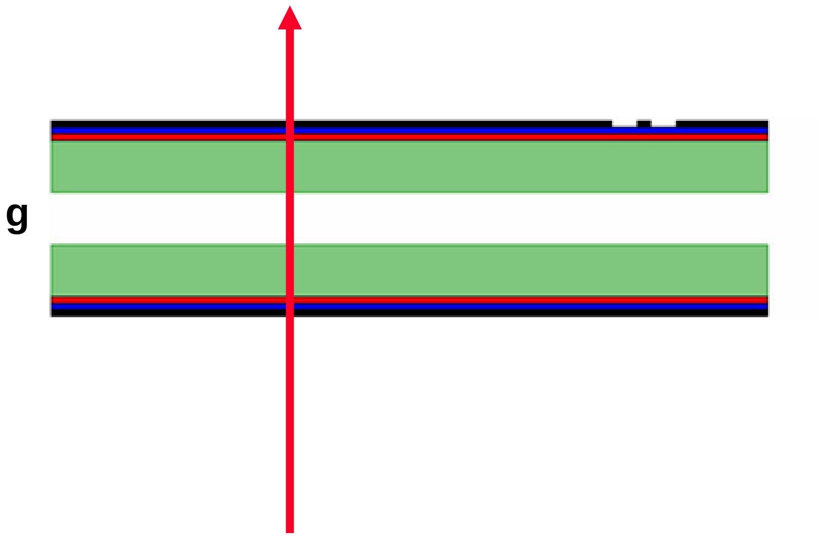
Position resolution by segmenting the cathode into strips or pads and applying center of gravity.

For small wire distance the chamber can be used for timing.

Time resolution of 3ns and position resolution of 50μm have been achieved with LHC chambers.

3) Resistive Plate Chamber for Triggering and Time of Flight

ATLAS, CMS g=2mm, ALICE g=0.25mm



Primary electrons start the avalanche 'instantly' in the high electric field (50-100kV/cm).

Electron avalanche induces signals on the electrodes.

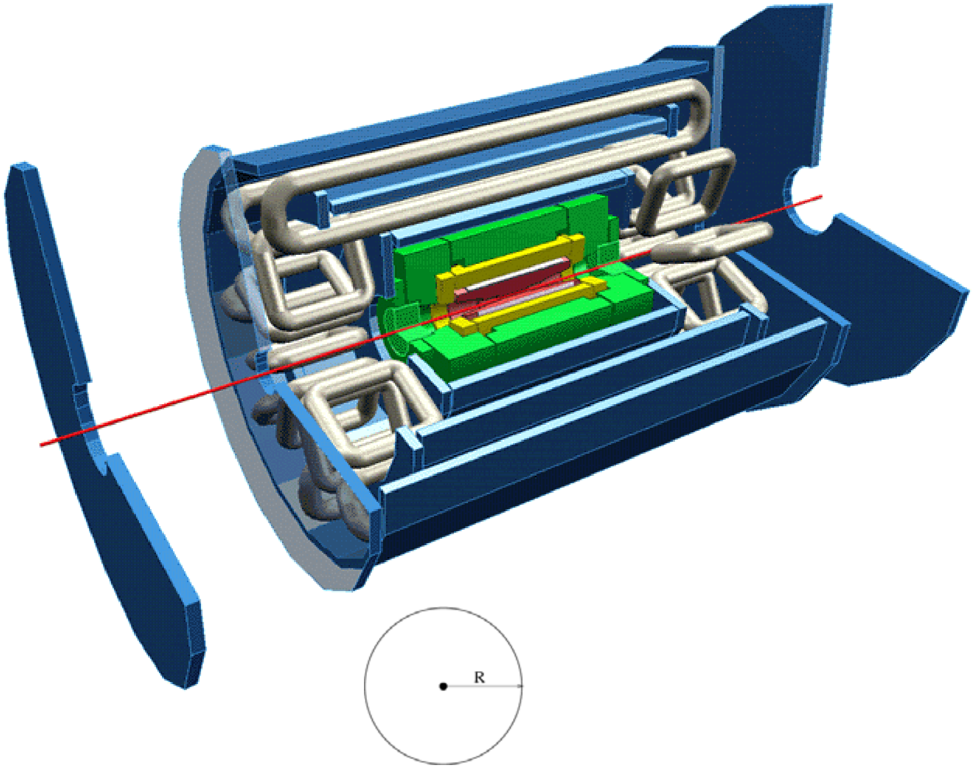
Works in principle with two metal electrodes only. Resistive plates avoid discharges of the entire surface in case of a spark.

Time resolutions of 1ns for 2mm gap and 50ps for 0.3mm gap have been achieved.

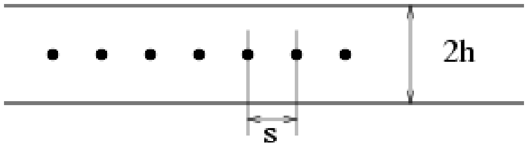
Can in principle also be used for precision tracking.

LHC Gas Detector Inventory

ATLAS



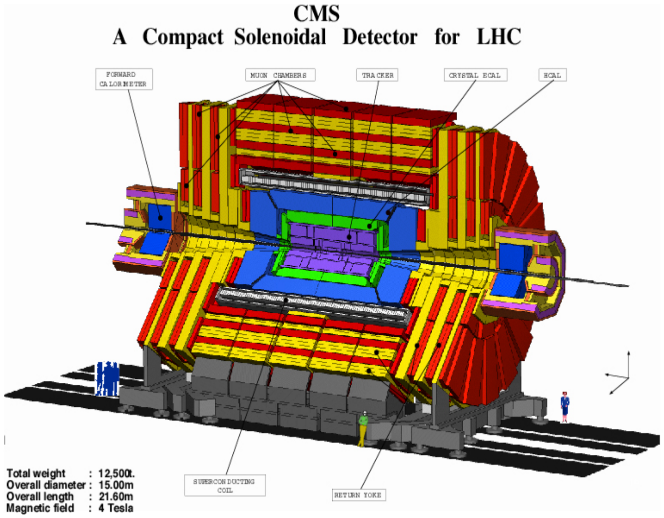
- **Monitored Drift Tubes (Tracking)**
  - R=15mm
  - 370k anode channels
  - Ar/CO_2 93/7 (3 bars)
  - < 80μm
- **Transition Radiation Tracker (Tracking)**
  - R=2mm
  - 372k anode channels
  - $Xe/CO_2/CF_4$ 70/10/20
  - $Xe/CO_2/O_2$ 70/27/3
  - < 150 μm

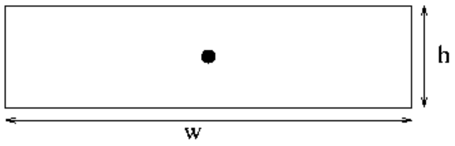


- **Cathode Strip Chambers (Tracking):**
  - h=2.54mm, s=2.54mm
  - 67k cathode channels
  - $Ar/CO_2/CF_4$
  - < 60 μm
- **Thin Gap Chambers (Trigger)**
  - h=1.4mm, s=1.8mm
  - 440k cathode and anode channels
  - n-Pentane /CO_2 45/55
  - < 99% in 25ns with single plane

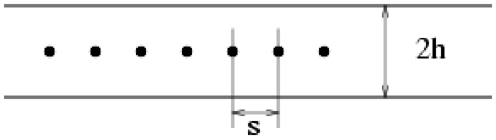
- **RPCs (Trigger):**
  - g=2mm, 2mm Bakelite
  - 355k channels
  - $C_2F_4H_2$/Isobutane/SF_6 96.7/3/0.3
  - < 98% with a single plane in 25ns

CMS





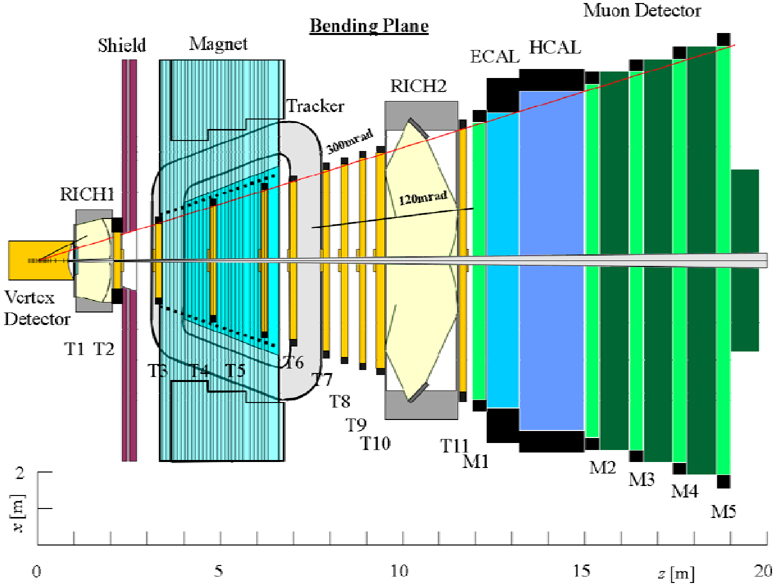
- **Rectangular ‘Drift Tubes’ (Trigger, Tracking)**
  - w=42mm, h=10.5mm
  - 195k anode channels
  - Ar/CO_2 85/15
  - $<$ 250 μm

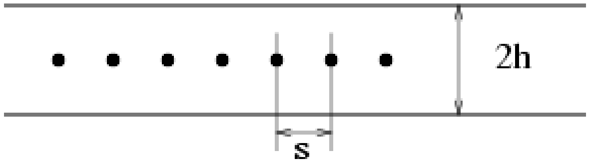


- **Cathode Strip Chambers (Trigger, Tracking):**
  - h=4.25mm, s=3.12mm
  - 211k anode channels for timing
  - 273k cathode channels for position
  - $Ar/CO_2/CF_4$ 30/50/20
  - $<$ 75-150 μm

- **RPCs (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

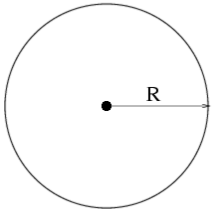
LHCb





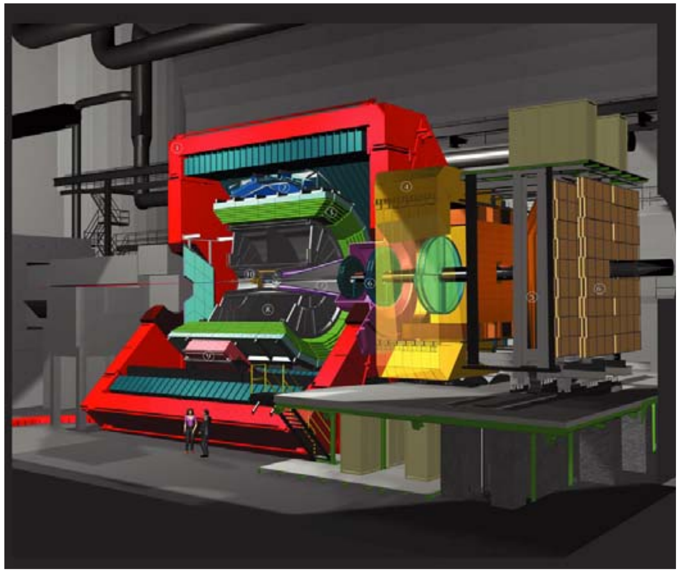
- **Muon Chambers (Trigger):**
  - h=2.5mm, s=2mm
  - 125k cathode and anode pads
  - $\mathrm{Ar/CO_2/CF_4}$ 40/55/5
  - < 3ns for two layers

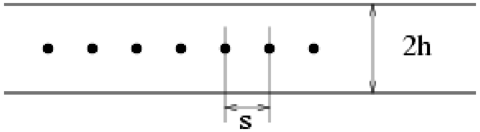
- **GEM (Trigger):**
  - 5k channels
  - $\mathrm{Ar/CO_2/CF_4}$ 75/10/15
  - <4.5 ns for one triple GEM



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

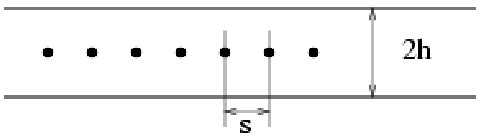
ALICE

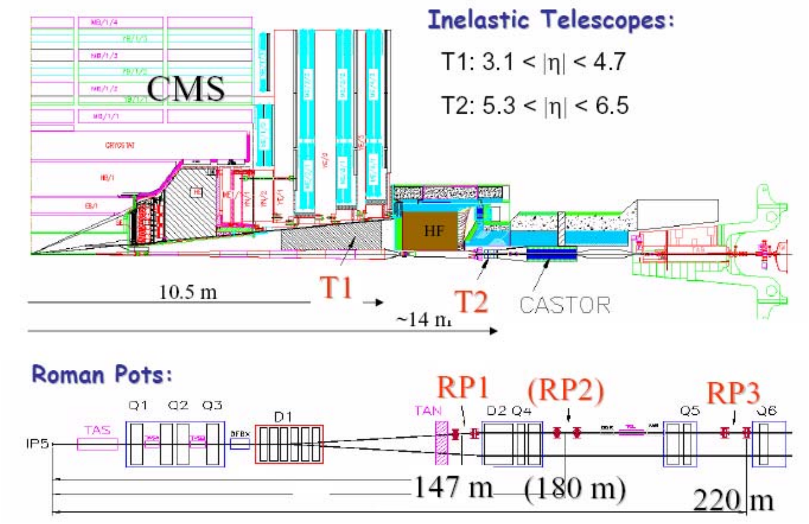




- **TPC with wire chamber cathode pad readout**
  - 1.25-2.5mm wire pitch
  - 2 - 3 mm plane separation
  - 570k Readout Pads
  - Ne/CO_2 90/10
- **TRD**
  - 1160 k channels
  - Xe/CO_2 85/15
  - s=5mm, h=3.5mm
- **HMPID**
  - s=2mm, h=2mm
  - Methane
  - 160k channels
- **Muon Chambers**
  - 1000k channels
  - <100um
  - S=2.5mm, h=2.5mm
  - Ar/CO_2 80/20
- **TOF RPCs**
  - G=0.25mm, 0.4mm glass, 10gaps
  - 160k channels
  - <50ps/10gaps
  - $C_2F_4H_2$/Isobutane/SF_6 96.5/3.5/0.5
- **Trigger RPCs**
  - G=2mm, 2mm bakelite
  - Ar/Isobutane/$C_2F_4H_2$/SF_6 49/7/40/4
  - 21k channels

TOTEM

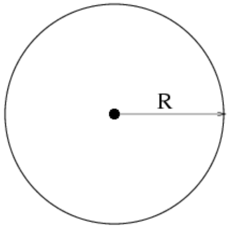


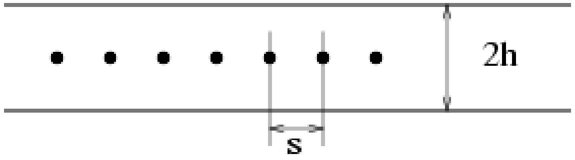


- **T1: CSCs**
  - **13k anode channels**
  - **21k cathode channels**
  - **s=3mm, h=5mm**
  - **Ar/CO_2 50/50**

- **T2: GEMs**
  - **Ar/CO_2 50/50**
  - **24.5k channels**

LHC Gas Detector Inventory





‘All’ LHC gas detectors use these basic geometries.

Wire Chambers use Ar(Ne,Xe)/CO_2/(CF_4) gas mixtures.

RPCs use $C_2F_4H_2$/Isobutane/SF_6 gas mixtures.

Luminosity Upgrade

- **Increase in Luminosity by a factor 10 (10^{34} → 10^{35} 1/cm^{2}s) → Rate capabilities of the detectors.**

- **Decrease of bunch crossing interval from 25 to 12.5ns → time resolution of the trigger detectors.**

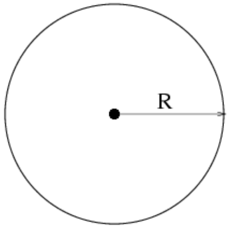
Possible Solution to Upgrade Challenge

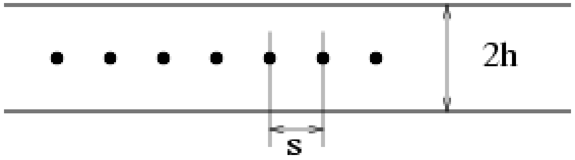
- If your detector was designed for a safety factor 10 on the rate capability, the upgrade challenge consists in praying that the real LHC particle rates are as expected and the detector will therefore also run for SLHC.

- ATLAS Muon system: Detector is designed to work at 5 times the expected rate in the ‘worst’ region of the muon system.

- The rates in the muon systems can possibly be reduced by improved shielding (ATLAS, CMS).

Limits of LHC Gas Detectors





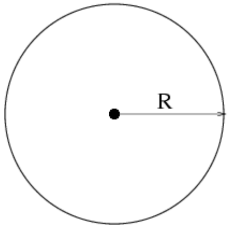
1) Occupancy

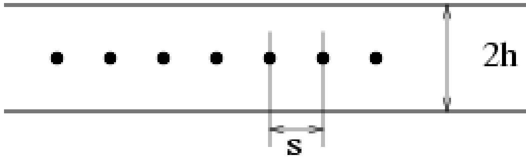
2) Time Resolution

3) Space Charge Effects (Wire Chambers), Voltage Drop (RPCs)

4) Aging

Limits of LHC Gas Detectors





1) Occupancy

2) Time Resolution

3) Space Charge Effects (Wire Chambers), Voltage Drop (RPCs)

4) Aging

1) Occupancy

The occupancy is the fraction of time a readout channel is occupied by a signal. With a pulse-width of T and a rate of ν the occupancy is equal to T x ν. Occupancy scales with the particle rate.

ATLAS TRT: ν=10MHz, T=20ns, occupancy = 0.2 → 20%.

Large occupancy results in inefficiency and fake tracks.

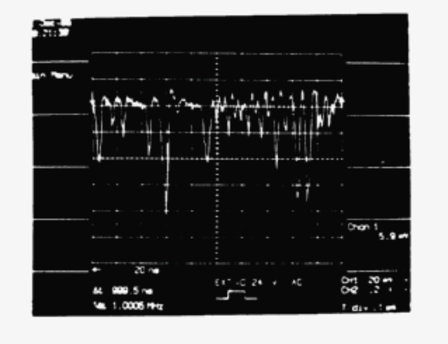
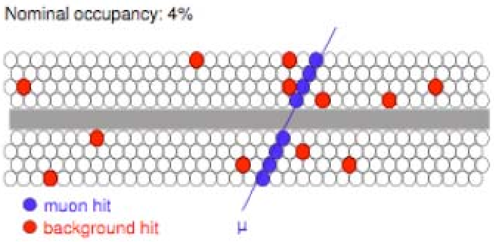
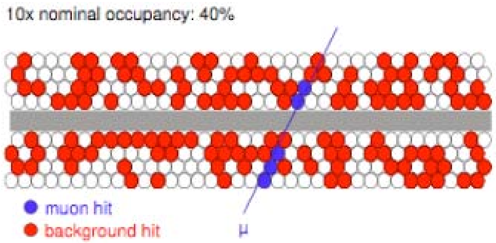


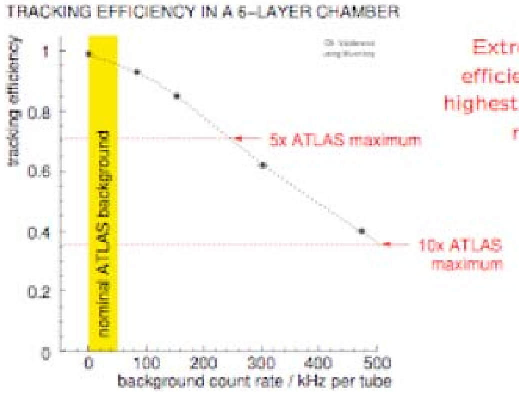
Fig.19 Sample of signals after base line restoration at 30 MHz counting rate



Nominal occupancy: 4%



10x nominal occupancy: 40%

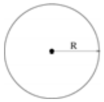


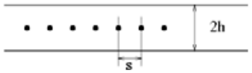
TRACKING EFFICIENCY IN A 6-LAYER CHAMBER

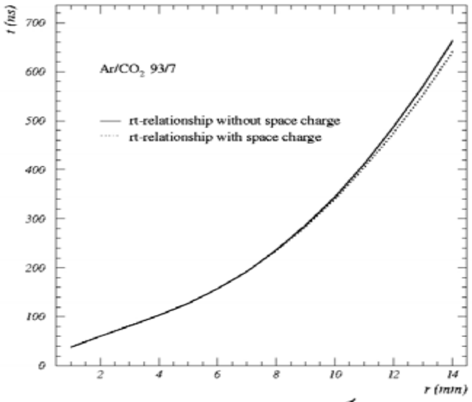
Extremely low efficiency at the highest background rates.

1) Occupancy: Pulsewidth T

Wire Chambers:







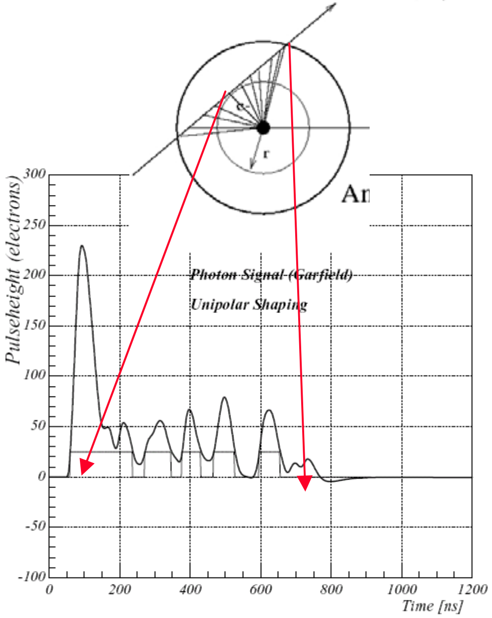
Irreducible pulse-width: Avalanche signal stops when all electrons have reached the wire.

Electronics: Shape of the individual avalanche signals is determined by the electronics. Wire chamber signals have a short electron component and a long ion tail $i(t)=Q_e\delta(t)+I_0/(t+t_0)$.

t_0=1.5ns for ATLAS TRT, t_0=10ns for ATLAS MDT. In order to accumulate a certain amount of ion signal charge the electronics peaking time tp should be >= t_0.

ATLAS MDT tp=15ns. ATLAS TRT, tp=5ns. Design such that 'irreducible' pulse-width dominates.

For charge measurement on cathode strips (position resolution) one has to integrate significantly longer (100-200ns) to arrive at a goon S/N ratio.



RPCs:

Detectable signal is from electrons only. Intrinsically very fast.

T of visible signal ≈ 10% of electron transit time.

ATLAS: T< 0.1* 2mm/(130um/ns) = 1.5ns

ALICE: T<0.1*0.25mm/(210um/ns)=0.1ns

ATLAS MDT $T_{av}\approx$520ns

ATLAS TRT $T_{av}\approx$20ns

1) Occupancy

Occupancy is a limiting factor for LHC wire chambers. This is obvious by design – for economical reasons the channel granularity was designed such that the occupancy is 'just' O.K. – typically few %.

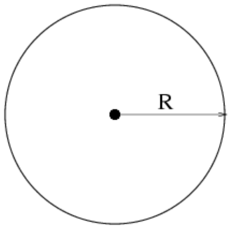
ATLAS TRT has already 20% occupancy at nominal LHC rates. Will be fully occupied at SHLC.

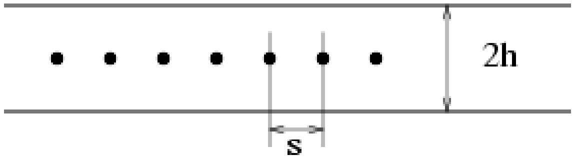
ATLAS muon system wire chambers (MDTs, TGCs, CSCs) were designed to work at 5x the nominal background rate with a few % occupancy. Large safety factor (complex background processes) and large variation of occupancy in η. Possibly additional shielding foreseen. From point of view of frontend channel occupancy the idea is that the current system will (just) work at SHLC. Some higher level electronics and trigger algorithms will have to be modified.

CMS wire chambers (Barrel Drift Tubes, Forward CSCs) follow the same line of thought. Possibly additional 'standard' RPCs in the forward region.

Intrinsic frontend channel occupancy is not a limiting factor for LHC RPCs.

Limits of LHC Gas Detectors





1) Occupancy

2) Time Resolution

3) Space Charge Effects (Wire Chambers), Voltage Drop (RPCs)

4) Aging

2) Time Resolution: BX 25ns→12.5ns

The luminosity upgrade includes a reduction of the bunch-crossing interval from 25-12.5ns.

Trigger Detectors are designed to provide the bunch ID, i.e. the time resolution must be such that identification efficiency within 25ns is close to 100%. Time resolution must therefore be better than 5ns.

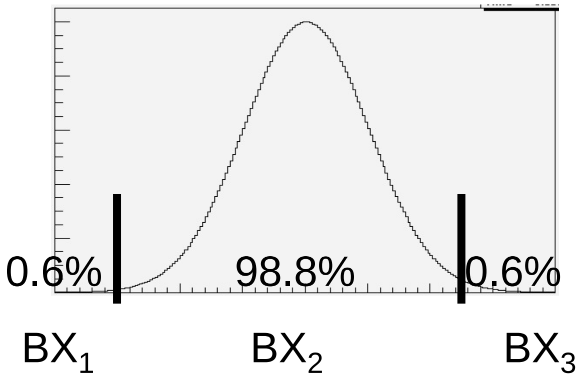
Wire Chambers: CMS CSCs 5ns, LHCb MWPCs 3.5ns, ATLAS TGCs 3.5ns

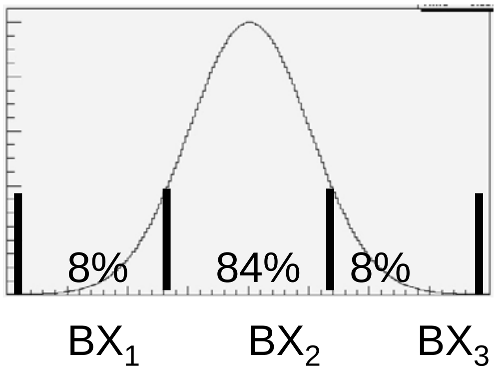
CMS+ATLAS RPCs: 1.5ns

At 12.5ns bunchcrossing time the wire chambers will lose efficiency. RPCs are O.K.

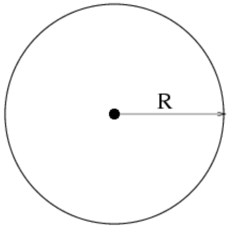
CMS CSCs: σ_t=5ns 99→84%

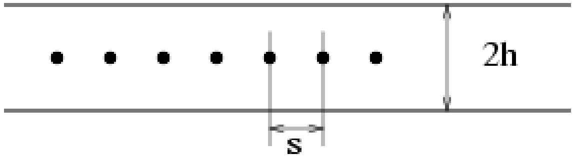
→ More bunchcrossings have to be included in the trigger and more sophisticated algorithms must be used.





Limits of LHC Gas Detectors





1) Occupancy

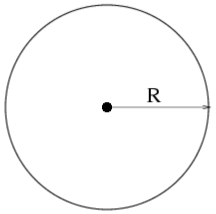
2) Time Resolution

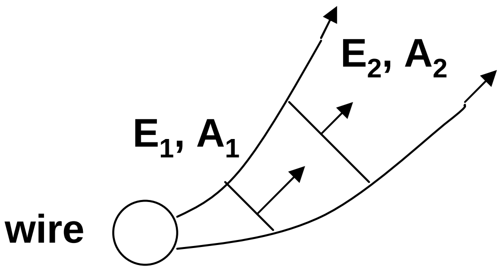
3) Space Charge Effects (Wire Chambers), Voltage Drop (RPCs)

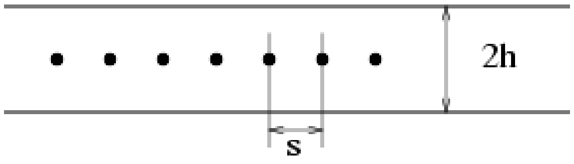
4) Aging

3) Space Charge Effects in Wire Chambers

The Ions, drifting from the wires to the cathode are representing a space charge in the chamber volume.







$v_{Ion}=\mu E$

$E_1A_1 = E_2A_2$ (Gauss' Law)

Volume= $A*v*dt = \mu EAdt$

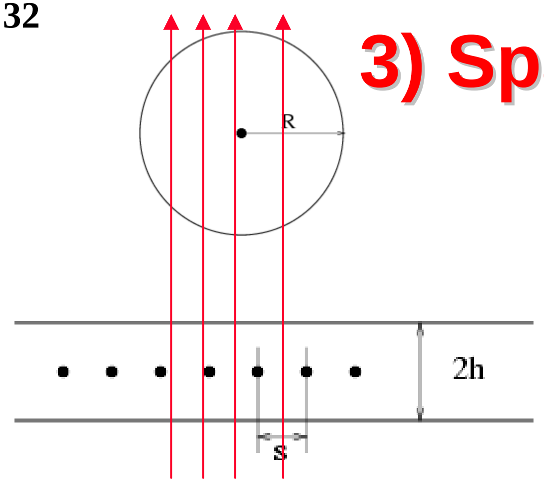
Since EA = constant along the 'flux tube', the ion charge density is constant along the entire flux tube.

In case the electric field is uniform around the wire and the wire is uniformly irradiated (which is the case for the standard LHC geometries), the volume entered by the fields lines from the wire is filled with a constant space charge density.

For both geometries this means that the entire chamber volume is filled with a constant space charge density.

This charge density causes a drop of the electric field near the wire and therefore a reduced gas gain.

3) Space Charge Effects in Wire Chambers



$$\Delta V = \frac{R^3 q \ln \frac{R}{R_a}}{4\pi\varepsilon_0 \mu V_0} \times Flux$$

$$\Delta V = \frac{s h^2 q \ln \frac{R_c}{R_a}}{4\pi\varepsilon_0 \mu V_0} \times Flux \qquad R_c = \frac{s}{2\pi} e^{\frac{\pi h}{s}}$$

Flux = tracks/cm^{2}s

R_a = wire radius

μ= ion mobility

V_0=applied wire voltage

q=average total avalanche charge per track

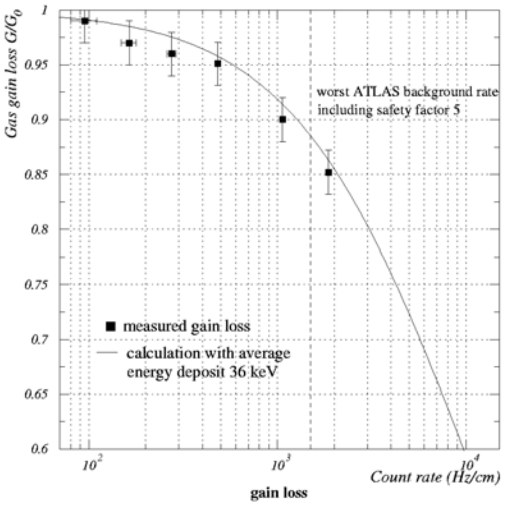
dV = effective voltage drop, i.e. gas gain reduction due to the spacecharge is equal to the a voltage reduction of dV without spacecharge.

Strongest dependence on chamber geometry.

MDT, TRT: (15mm/2mm)^3=422

In addition: MDT 3 bars, TRT 1 bar → ion mobility of TRT is factor 3 higher → factor 422*3=1265 higher rate capability !

0.5 kHz/cm^2 → 10% gain loss.



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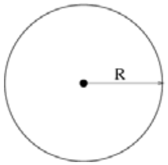
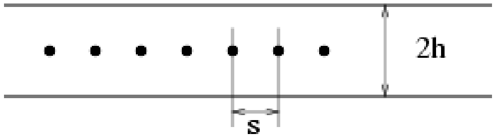
3) Space Charge Effects in Wire Chambers



R^3/μ



sh^2/μ

μ(ARGON,1bar) ≈ 1.5cm²/Vs

10% gain loss

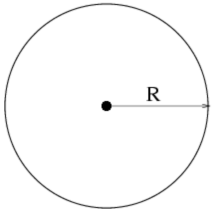
			10%loss @	real rate
ATLAS MDT:	R^3/μ =6.75 (Vcm s)	→	0.5 kHz/cm²	0.5 kHz/cm²
Assuming naïve scaling only due to geometry (same gain, HV, Ionization …)				
ATLAS TRT:	sh^2/μ= 0.0053	fact 1274	637 kHz/cm²	1200kHz/cm²
LHCb OT:	R^3/μ =0.0104	fact 650	324 kHz/cm²	500kHz/cm²
CMS CSCs:	sh^2/μ=0.03757	fact 180	90 kHz/cm²	0.5kHz/cm²
ATLAS CSCs:	sh^2/μ=0.011	fact 614	307 kHz/cm²	0.5kHz/cm²
LHCb MWPC:	sh^2/μ=0.00833	fact 810	405 kHz/cm²	50kHz/cm²
TOTEM CSCs:	sh2/μ=0.05	fact 135	67kHz/cm²	
(ATLAS TGCs:	sh^2/μ=0.0023	fact 2934	1450 kHz/cm²	0.2kHz/cm²

Resistivity Limit 0.5kHz/cm², gain 10^6)

→LHC drift chambers are operated at particle rates where gain drop due to spacecharge effects becomes significant.

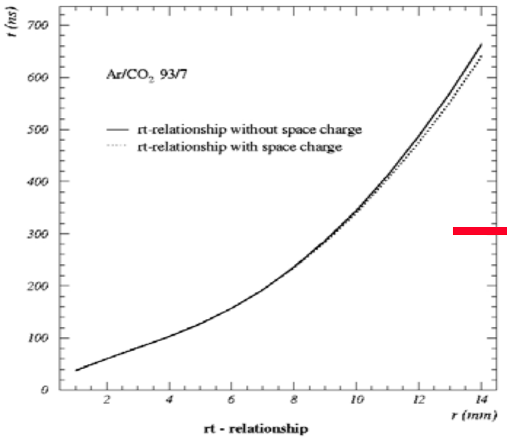
→LHC MWPCs (CSCs) have a large margin.

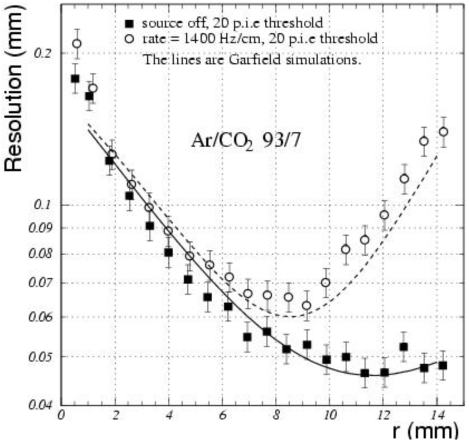
3) Space Charge Effects in Wire Chambers



In addition to the gain loss, the space charge changes the relation between radius and drift time. This would in principle not change the resolution (if the space charge is constant).

At a given stationary particle rate there is still a fluctuation due to Poisson statistics, so the space charge is fluctuating. This fluctuation of the space charge results in a fluctuating field and therefore a deterioration of the resolution.





Note that the solid lines represent a first principle GARFIELD simulation with inclusion of fluctuating space charge !!

ATLAS MDTs and CMS DT will have reduced resolution due to this effect.

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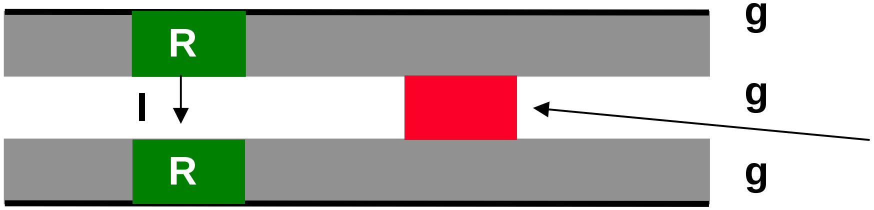
3) Rate effects in RPCs



Fields due to space charge from drifting ions become relevant only at rates of MHz/cm^2.

Even at this high rate there is, to first order, no Gain reduction since the uniform space charge density leaves $\int\alpha(z)dz$, which determines the total gain, unaffected.

The rate limitation of an RPC is due to the resistive plates. The current due to the incident particles flows through the plates and causes a voltage drop in the as gap reducing the gas gain.

A typical operating voltage is 10kV. The voltage drop is given by $dV=R*I = 2\rho\nu gQ$

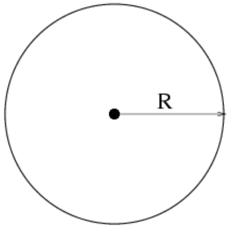
Example ATLAS, CMS RPCs: Q=total charge/track=25pC, ν=rate Hz/cm^2, g=2mm, ρ=volume resistivity =$10^{10}\Omega$cm.

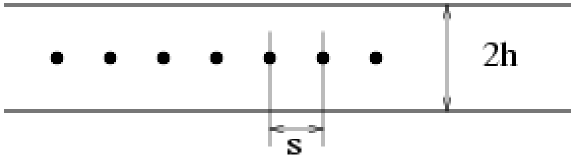
100Hz/cm^2 → 10V. Operation up to 1kHz/cm^2 has been proven in testbeams.

The typcal nominal rates for the RPCs in ATLAS and CMS (eta<1.6) are <10Hz/cm^2, so from this point of view the chambers might operate at SLHC in most regions (if ageing effects can be brought under control and the resistivity stays constant over time).

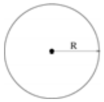
CMS forward region has already >100Hz/cm^2 at nominal LHC rates, so there one will push the limit at SLHC rates.

Limits of LHC Gas Detectors

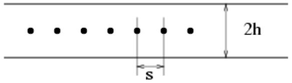




1) Occupancy
2) Time Resolution
3) Space Charge Effects (Wire Chambers), Voltage Drop (RPCs)
4) Aging



4) Aging



The typical gas gain of LHC wire chambers is 2×10^4 (except TGC 10^6)

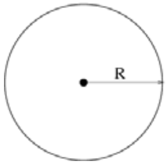
Magic number for charge deposit in 10 years of LHC operation is 1C/cm of wire (LHCb OT 2.5C/cm, ATLAS TRT 8C/cm) and 1C/cm^2 of cathode.

Fortunately gas mixtures have been found which seem to withstand this accumulated charge.

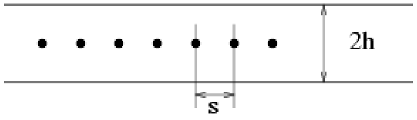
Aging effects are in general the main decisive factor for the gas choice.

‘Traditional Gases’ containing hydrocarbons as quenchers showed severe aging effects, mainly polimerization resulting in deposits on wires and cathodes (painful learning process).

Wire chambers prototypes have been proven to work for the entire LHC period without performance degradation. Since the testing conditions shouldn’t be far from reality these tests took several years.



4) Aging



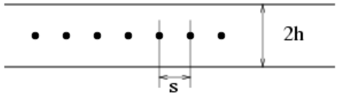
All LHC wire chambers are based on noble gases (Ar, Xe, Ne) together with $C0_2$ for quenching.

Some of them add CF_4 for 'cleaning'. CF_4 --- Medicine or Poison ?

Attractive because of fast electron drift velocity, it can prevent polymer formation and even remove them from electrodes if already present.

CF_4 is however also etching detector materials, especially in connection with water. ATLAS TRT had to abandon CF_4 because glass wire joints inside the modules were etched to the point of breakage. CF_4 mixture will only be used for dedicated cleaning runs. LHCb wire chambers had to reduce CF_4 because of etching of the FR_4 boards.

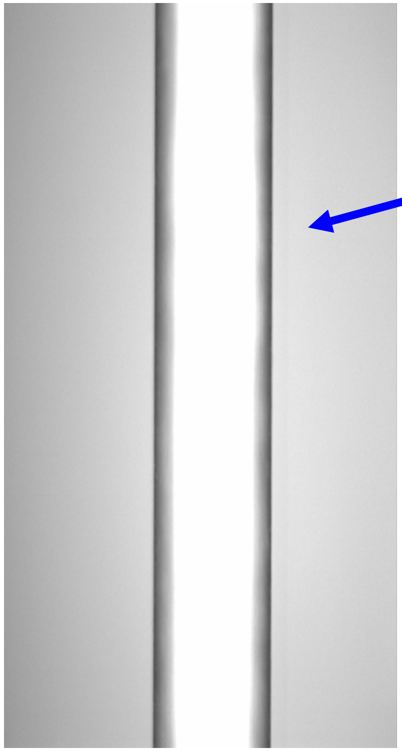
4) Aging



LHCb MWPCs:

Wire after 0.5C/cm

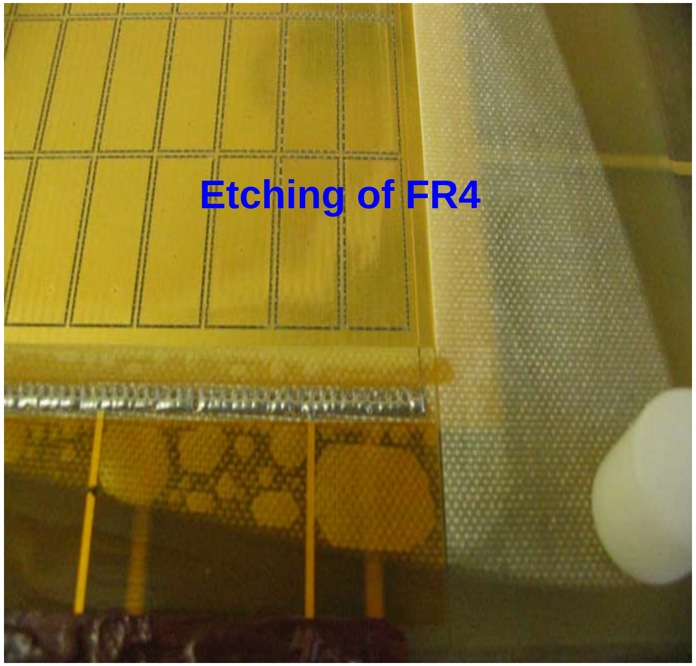
Ar/CO_2/CF_4 40/40/20

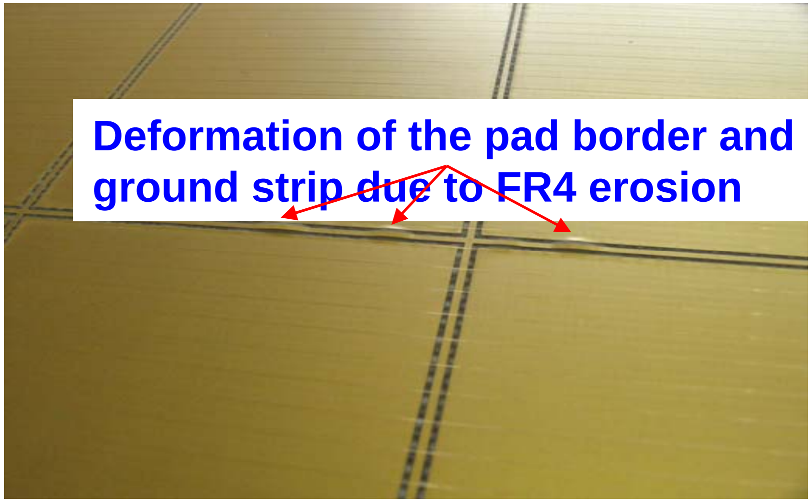


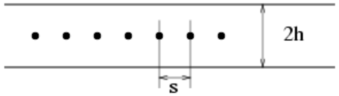
CF_4 is a fantastic gas !

Cathode after 1.7C/cm2

CF_4 is a terrible gas !





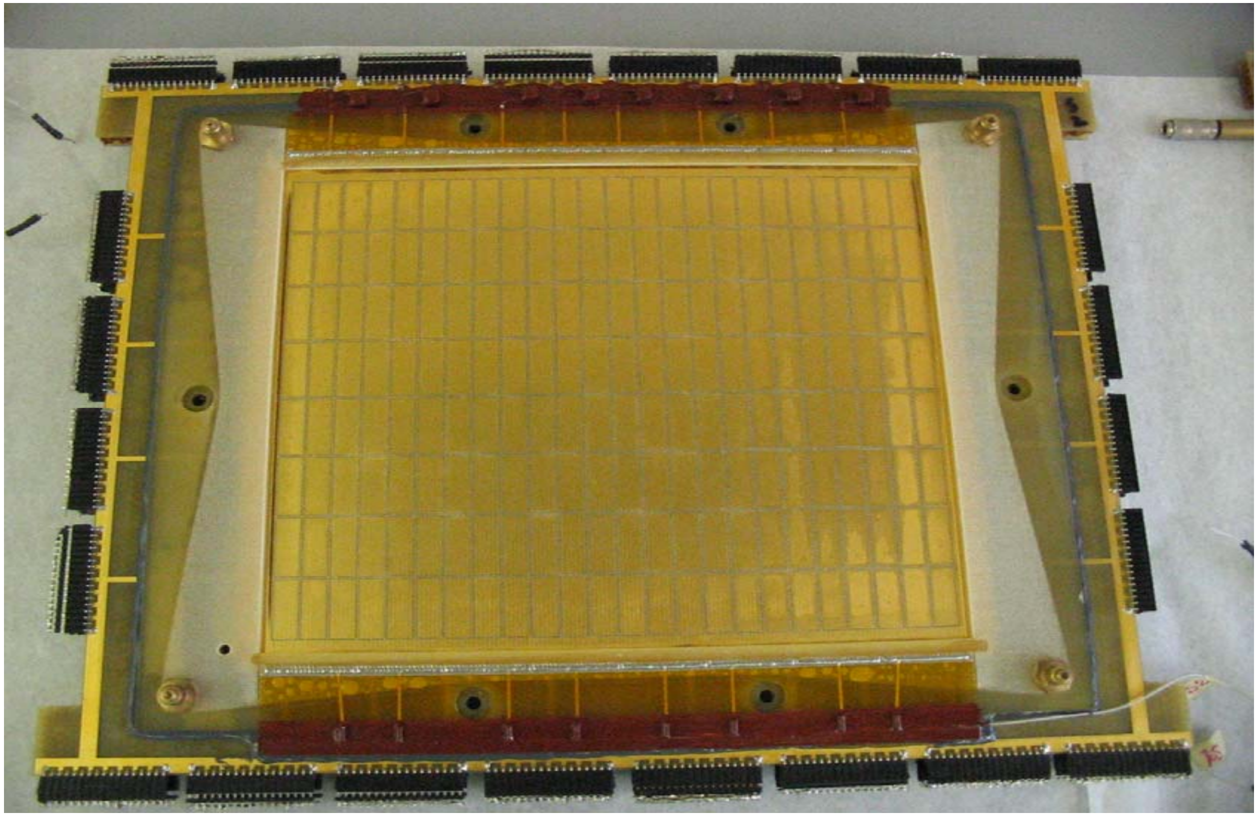


4) Aging

LHCb MWPCs:

Cathode after 1.7C/cm^2 Ar/CO2/CF4 40/40/20 → Decision to go back to 5% CF$_4$

→ Delicate Balance



4) Aging

All LHC RPCs use Freon/Isobutane/SF$_6$ gas mixtures. Non flammable heavy gas (large primary ionization, efficiency) with strong electronegativity (streamer suppression).

Long term operation of resistive plate chambers is known to produce two main ageing effects:

1) Gradual increase of the electrode resistivity (i.e. reduced rate capability) under very high working currents. The reason is the drying out of the bakelite plates. Humidification of the gas and also the external environment is necessary to limit the problem.

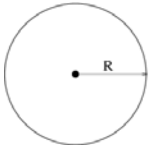
2) Degradation of the inner surface of the plates due to operation with fluorine-rich gas mixtures, leading to an increase of the noise in the detector. Gas flow must be properly adjusted.

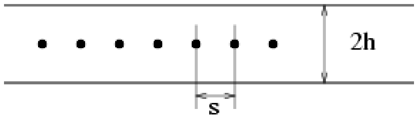
Up to 0.25C/cm^2 have been accumulated at GIF tests over the last years.

10(Hz/cm^2)*10^7(s/year)*10(years)*50pC(per hit)=0.05C/cm^2

Certified for ATLAS and CMS barrel regions. Not yet for forward CMS regions.

4) Aging





Aging tests have (hopefully) shown that LHC gas detectors can survive 10 years of LHC operation. Clearly, several C/cm wire or cm^2 of cathode are not ‘a piece of cake’.

The success will strongly depend on the proper operation of gas systems and gas quality controls.

In principle one has reason to hope that LHC gas detectors will survive even SLHC rates, although this clearly has to be proven.

Aging test are clearly a central point for SHLC Gas detector R&D.

Upgrade Possibilities

Higher level electronics that deals with the extremely complex readout and trigger issues must clearly be adapted to SLHC rates.

What about the Detector and frontend electronics ?

1) Upgrade without changing detectors
2) Upgrade by scaling standard geometries
3) Upgrade by introducing novel gas detectors

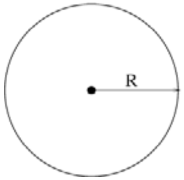
Upgrade without changing detectors

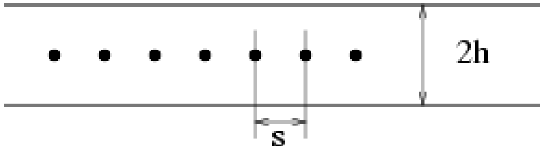
Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors

Occupancy,

Time resolution





Wire chambers:

Frontend electronics for drift chambers is typically designed with a bandwidth such that the additional deadtime is negligible with respect to the intrinsic detector deadtime. ATLAS TRT cannot be saved by a new frontend. Improvements for all other drift tube systems by new frontend electronics would be marginal.

Cathode readout electronics can be speeded up, the prices is reduced S/N i.e. resolution.

Reduction of intrinsic deadtime could be achieved by faster gases (different pressure for ATLAS MDT). More than factor 2 would be a miracle, reality probably much less. Aging risks and R&D for verification are severe constraints.

Time resolution if trigger chambers can be improved by faster gases. 20-30% would already be helpful. However also difficult to achieve (aging questions for new gases).

For SHLC one will of course trade gas gain vs. resolution in order to limit space charge and aging effects.

Upgrade without changing detectors

Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors

Rate capability

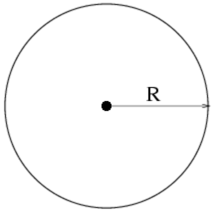
RPCs:

Frontend electronics and detector gas are not the limiting factors. Rate capability fixed by the resistivity. Possibly lower gas gain to reduce voltage drop → price is reduced efficiency.

Upgrade without Changing Detectors

Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors



Drift Chambers:

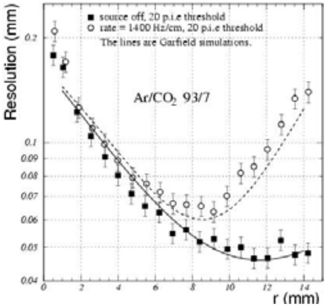
The ATLAS or CMS muon drift chambers could clearly be scaled down (smaller R) in order to increase the rate capabilities. The increase of channel number of the already enormous muon systems will make the cost of such an option quite high.

The ATLAS TRT and LHCb OT (R=2mm, 2.5mm) could in principle also be scaled down.

However, efficiency of these tubes is already <90%. Reducing R will reduce the efficiency to very low levels.

In addition the spatial resolution close to the wire is worse than at large distance due to primary ionization statistics. Reducing the wire radius, the spatial resolution of 150μm will quickly approach R=2mm/√12 = 600μm.

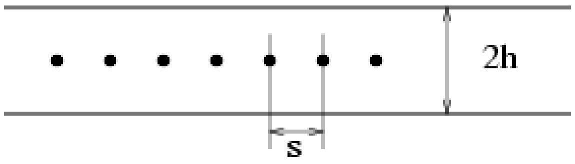
Scaling down the LHCb and ATLAS straw trackers to increase the rate capability by a factor 10 seem unreasonable.

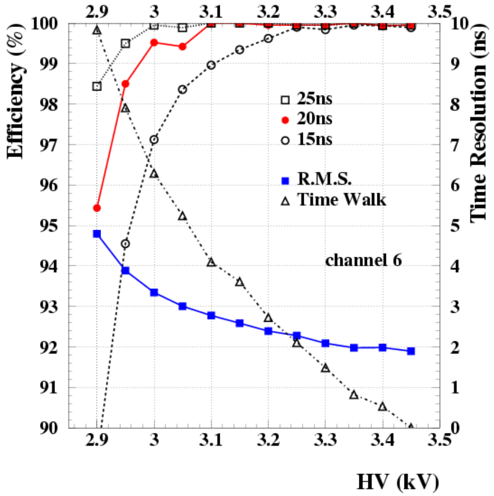


Upgrade without Changing Detectors

Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors





MWPCs:

In case time resolution is an issue for the 12.5ns bunch spacing, the time resolution can be improved by reducing s → Reduction of the drift time.

CMS: 6 planes of s=3.12mm → 5ns

LHCb MWPC prototype with s=1.5mm at very high gain: 2ns

Further reduction of s doesn’t improve the time resolution significantly since the primary ionization statistics becomes the limiting factor ! Average distance of 0.25 mm between clusters.

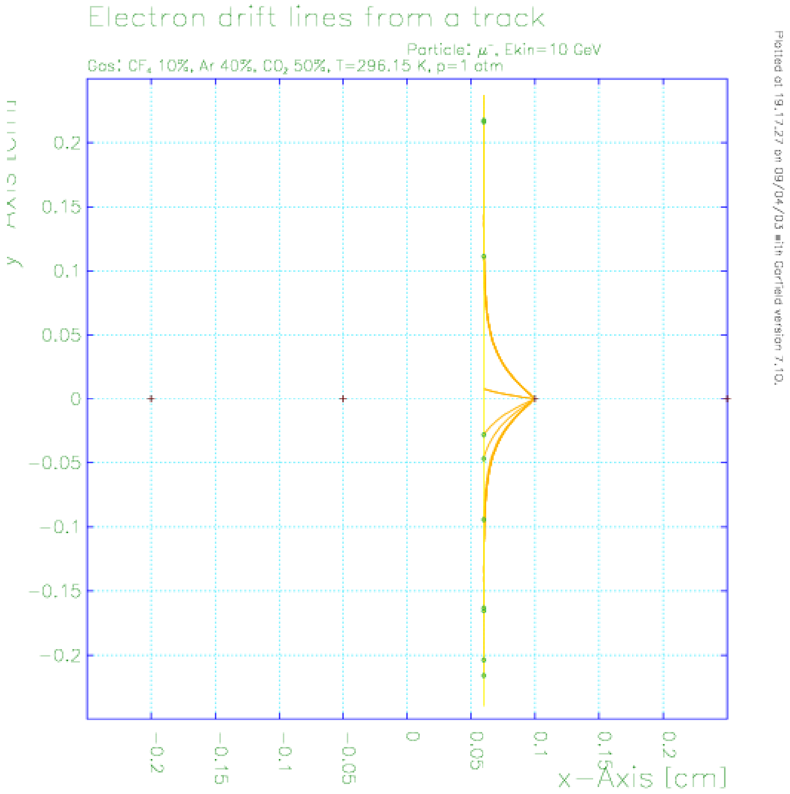
!! This means that the time resolution of MWPCs with ‘common’ gases at atmospheric pressure is limited to approx 2ns (maybe 1ns …) !!

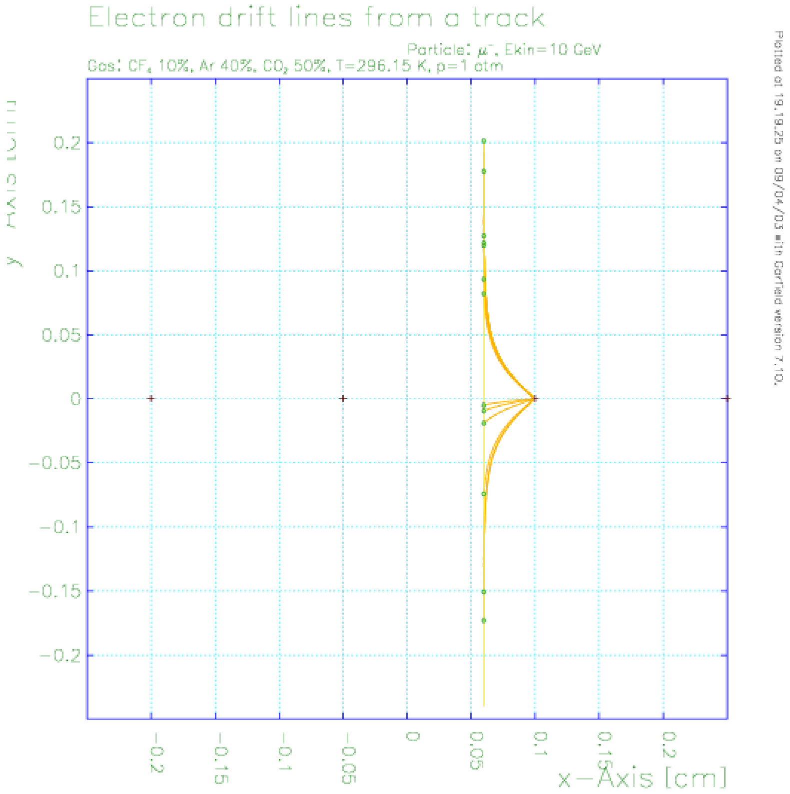
→ 99% BX ID for 12.5ns beam might just be possible with a few layers of wire chambers with narrow wire spacing, but that’s where it stops.

Upgrade without Changing Detectors

Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors





Because the primary ionization statistics I.e. Poisson distributed cluster number =exponentially distributed distance between clusters around average of 0.23mm.

Time resolution doesn’t improve much for pitch <1.5mm.

This is a fundamental limit of time resolution for an MWPC at 1bar.

Upgrade without Changing Detectors

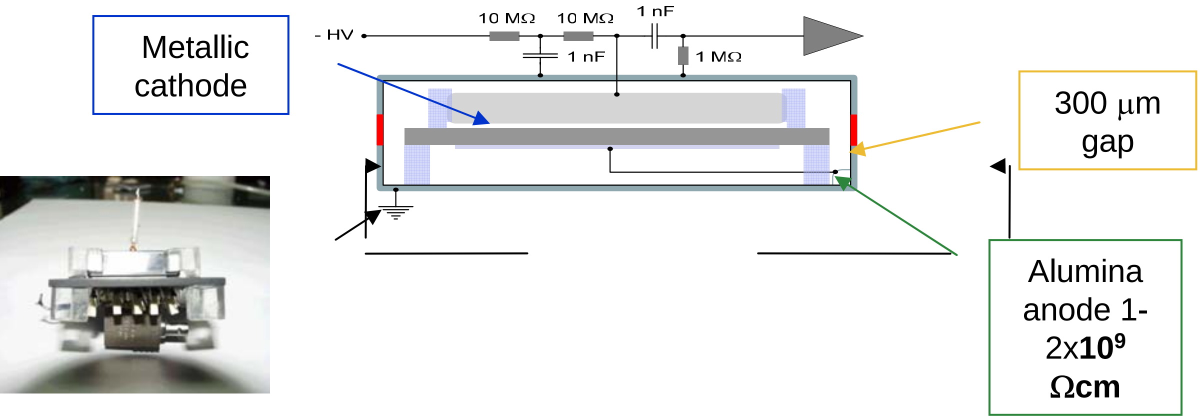
Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors

Rate capability of RPCs is proportional to volume resistivity and thickness of the resistive plates. Just use material with lower resistivity.

Sounds simple, but many attempts to find cheap and stable large area materials with defined tunable resistivity have failed.

Also: Going from $10^{10}\Omega$cm to $10^{9}\Omega$cm, the requirements on surface quality, in order to achieve low noise count rate, are already much more stringent. First attempts on high rate RPC have been made.



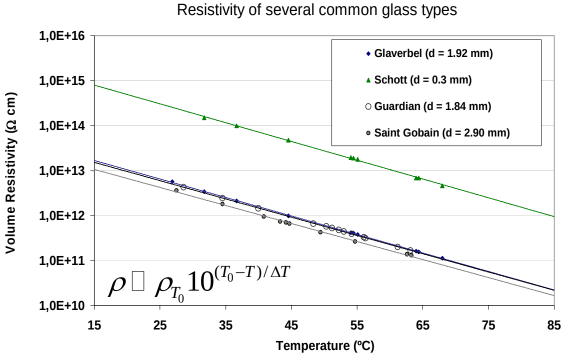
Metallic cathode

300 μm gap

Alumina anode 1-2x10^{9} Ωcm

P. Fonte: Not straight forward, not yet a practical device.

Small, but produces 500 kHz count rate at 90 ps resolution.



$$\rho \approx \rho_{T_0} 10^{(T_0-T)/\Delta T}$$

Resistivity of glass decreases about one order of magnitude every 25 degrees → heat your detector ?

Upgrade without Changing Detectors

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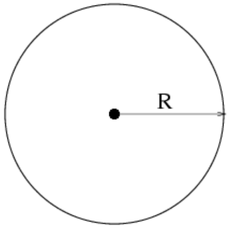
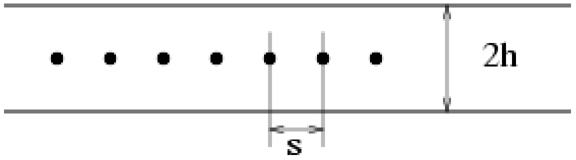
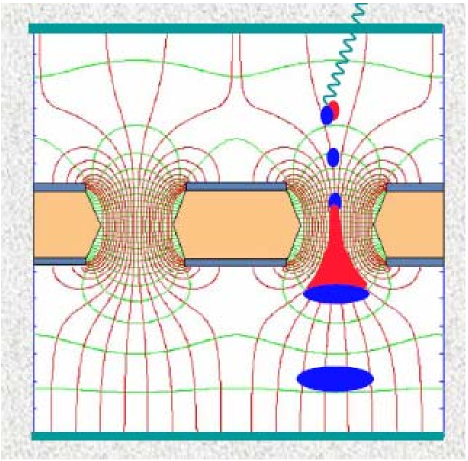


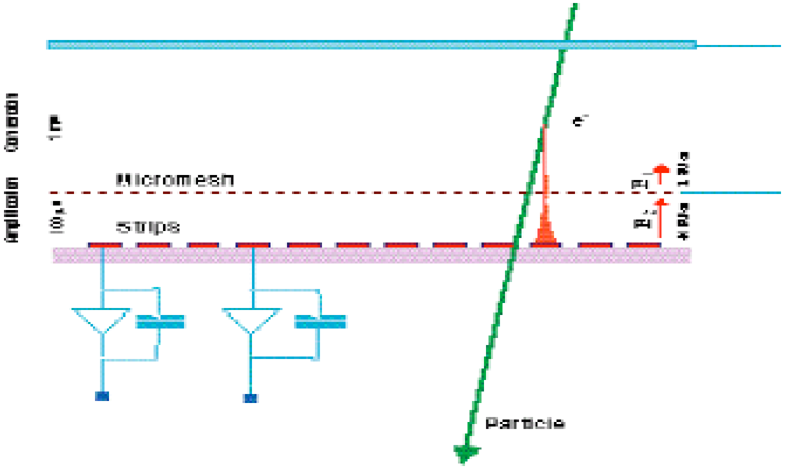


in comparison with

GEM

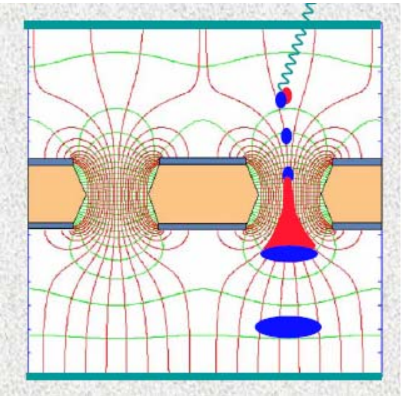


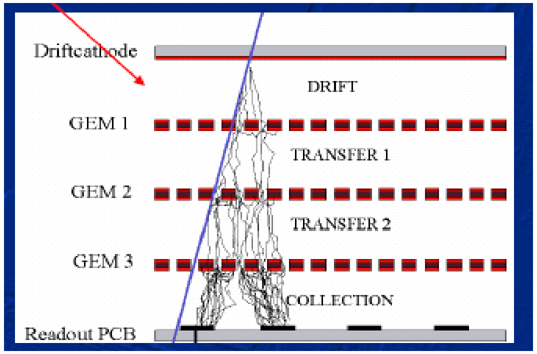
MICROMEGA



Upgrade without Changing Detectors
Upgrade by scaling standard geometries
Upgrade by introducing novel gas detectors

GEM

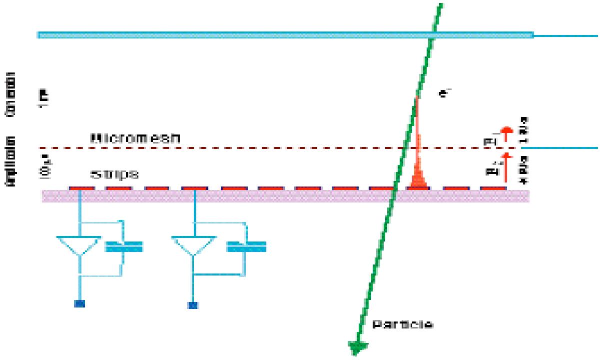




Metallized foil with ≈50μm holes.

Potential difference on the foil produces large electric field in the holes. Electrons avalanche induces a signal on the strips.

MICROMEGA



A mesh at distance of ≈50-100μm from the readout strips. Potential difference between mesh and anode produces large electric field. Electron avalanche induces signal on the readout strips.

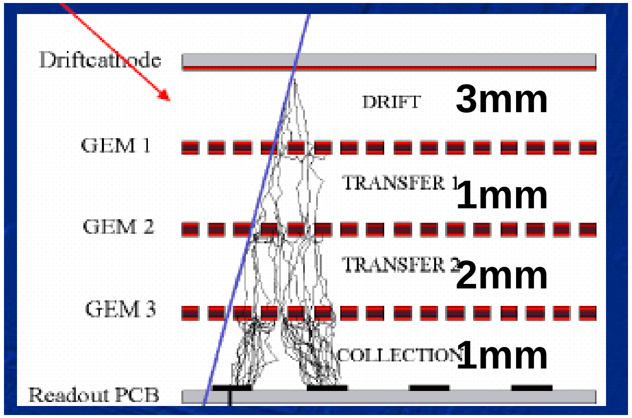
Upgrade without Changing Detectors

Upgrade by scaling standard geometries

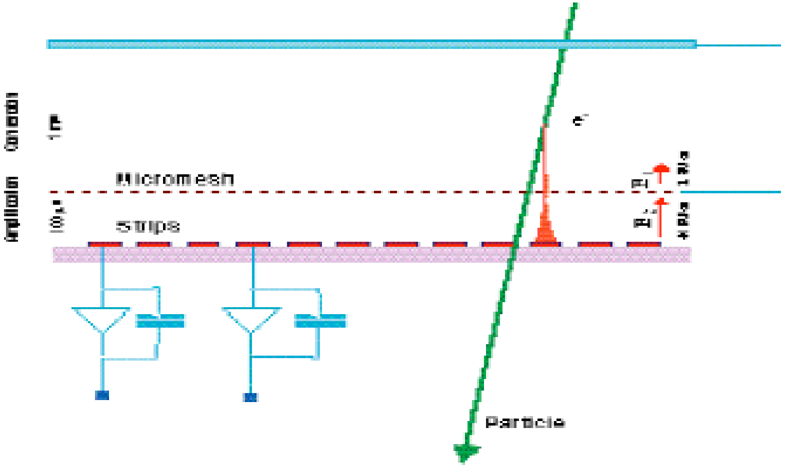
Upgrade by introducing novel gas detectors

Time resolution

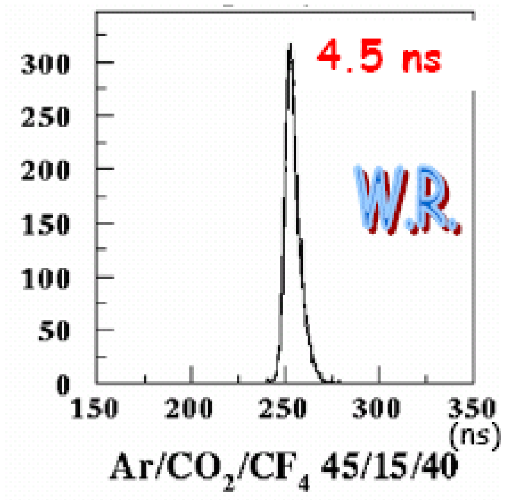
GEM



MICROMEGA



World record time resolution of triple GEM for perpendicular tracks is 4.5ns.



$Ar/CO_2/CF_4$ 45/15/40

MICROMEGAS are typically a bit better due to higher field in drift gap.

Primary ionization statistics in the first gas gap limits the time resolution ($\sigma \propto 1/nv$)

Remember 2ns time resolution for LHCb muon wire chambers.

Wire chambers (2ns) beat GEM and are comparable to MICROMEGA !

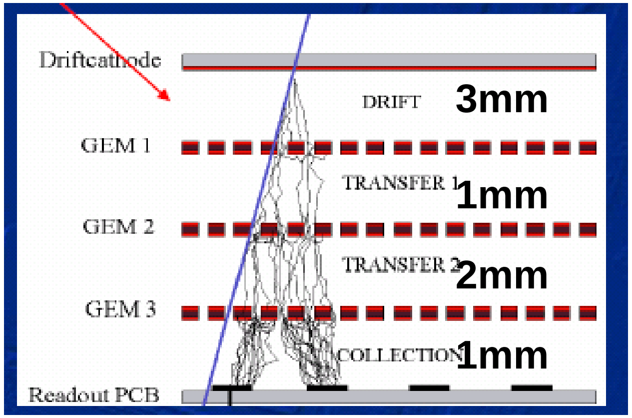
Upgrade without Changing Detectors

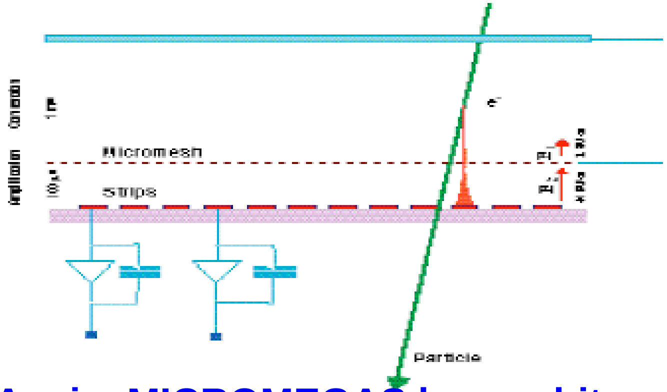
Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors

Occupancy

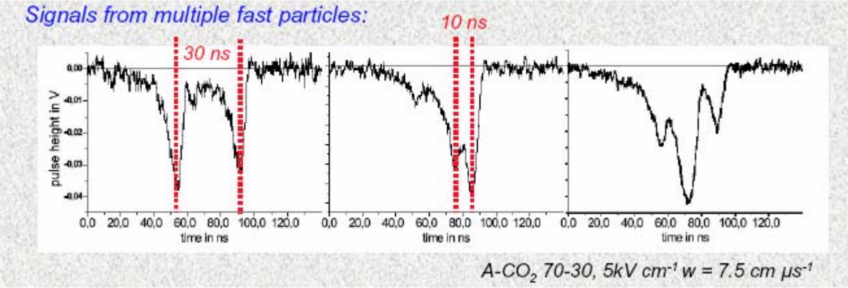
For reasonable efficiency an ionization gap of a few mm is needed e.g. 3mm





E.g.: 0.3cm/10cm/μs → 30ns

Again, MICROMEGAS have a bit shorter pulses due to smaller ionization gap, but comparable.



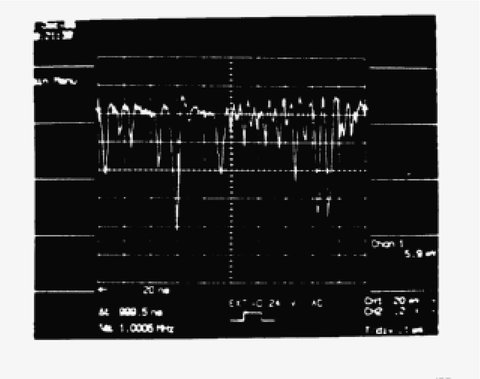


Fig.19 Sample of signals after base line restoration at 30 MHz counting rate

Wire chambers with ASDBLR: 20ns pulsewidth at threshold.

Pulsewidth is comparable for Wire Chambers, GEMs and Micromega.

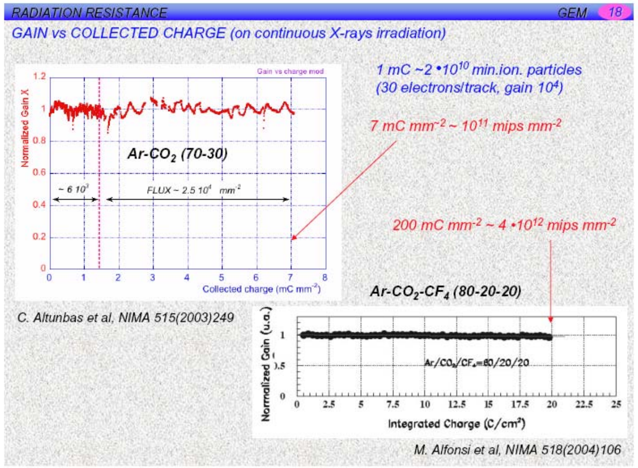
Ageing

Wire chambers have been certified up to 10C/cm wire and 2C/cm^2 of cathode (typical gain 20 000)

GEMs have been certified up to 20C/cm^2 (typical gain 8000)

MICROMEGAS: certified up to 2.4C/cm^2 (typical gain 3000)

GEM 20C/cm^2



RADIATION RESISTANCE GEM 18

GAIN vs COLLECTED CHARGE (on continuous X-rays irradiation)

1 mC ~2 •10^{10} min.ion. particles
(30 electrons/track, gain 10^4)

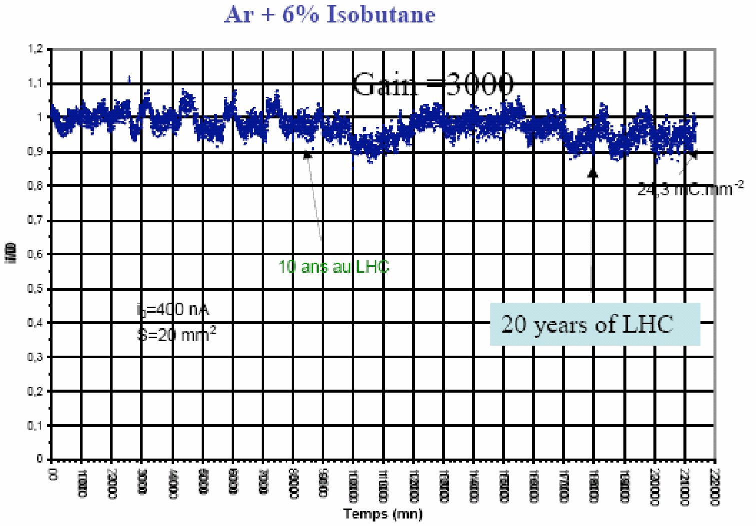
7 mC mm^{-2} ~ 10^{11} mips mm^{-2}

200 mC mm^{-2} ~ 4 •10^{12} mips mm^{-2}

C. Altunbas et al, NIMA 515(2003)249

M. Alfonsi et al, NIMA 518(2004)106

MICROMEGA 2.4C/cm^2

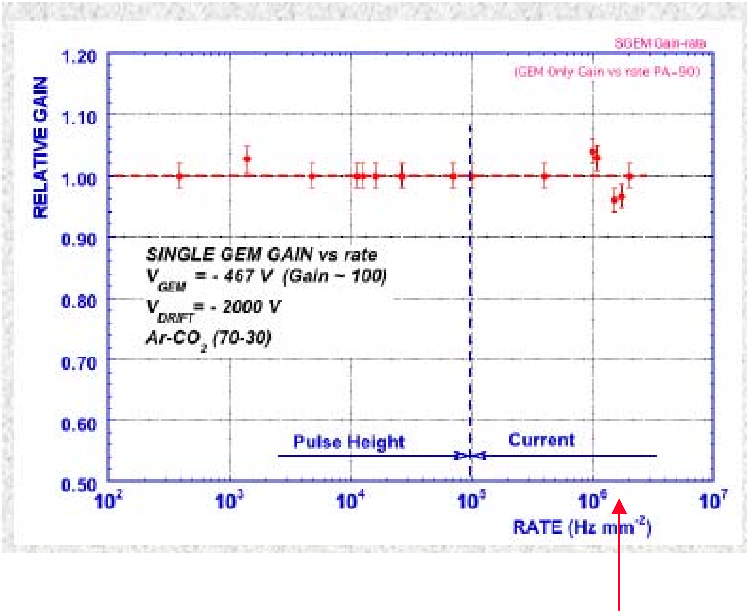


GEMs and MICROMEGAs have survived more particles/cm^2 compared to wire chambers (not enormous factors, but still …)

Upgrade without Changing Detectors
Upgrade by scaling standard geometries
Upgrade by introducing novel gas detectors

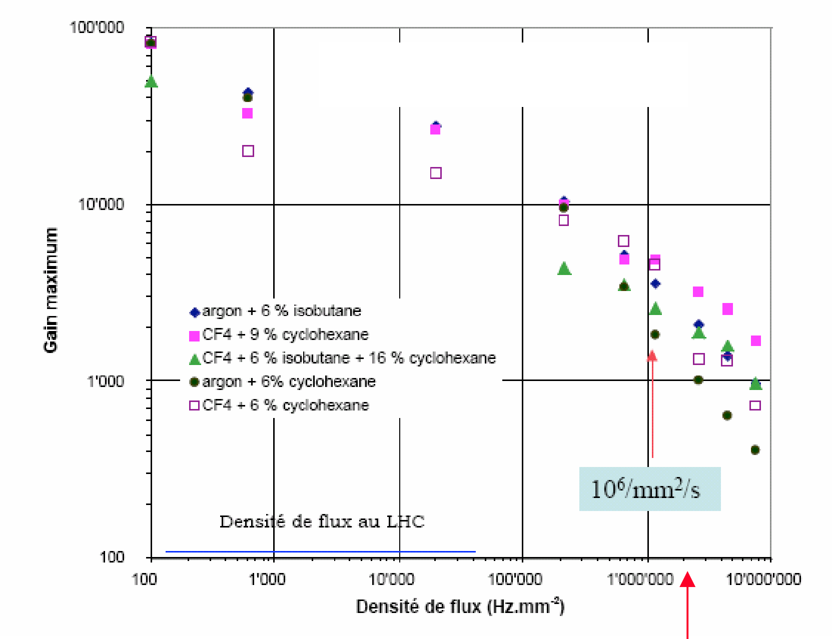
Spacecharge
Rate Capability

GEM

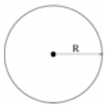


200MHz/cm^2

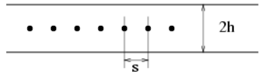
MICROMEGA



200MHz/cm^2



TRT straw tubes (R=2mm) and LHCb MWPCs (s=1.5mm, h=2.5mm) are limited at about 1MHz/cm^2 due to spacecharge.



In terms of rate capability due to spacecharge effects, MICROPATTERN detectors win over wire chambers by several orders of magnitude → BUT

Upgrade without Changing Detectors

Upgrade by scaling standard geometries

Upgrade by introducing novel gas detectors

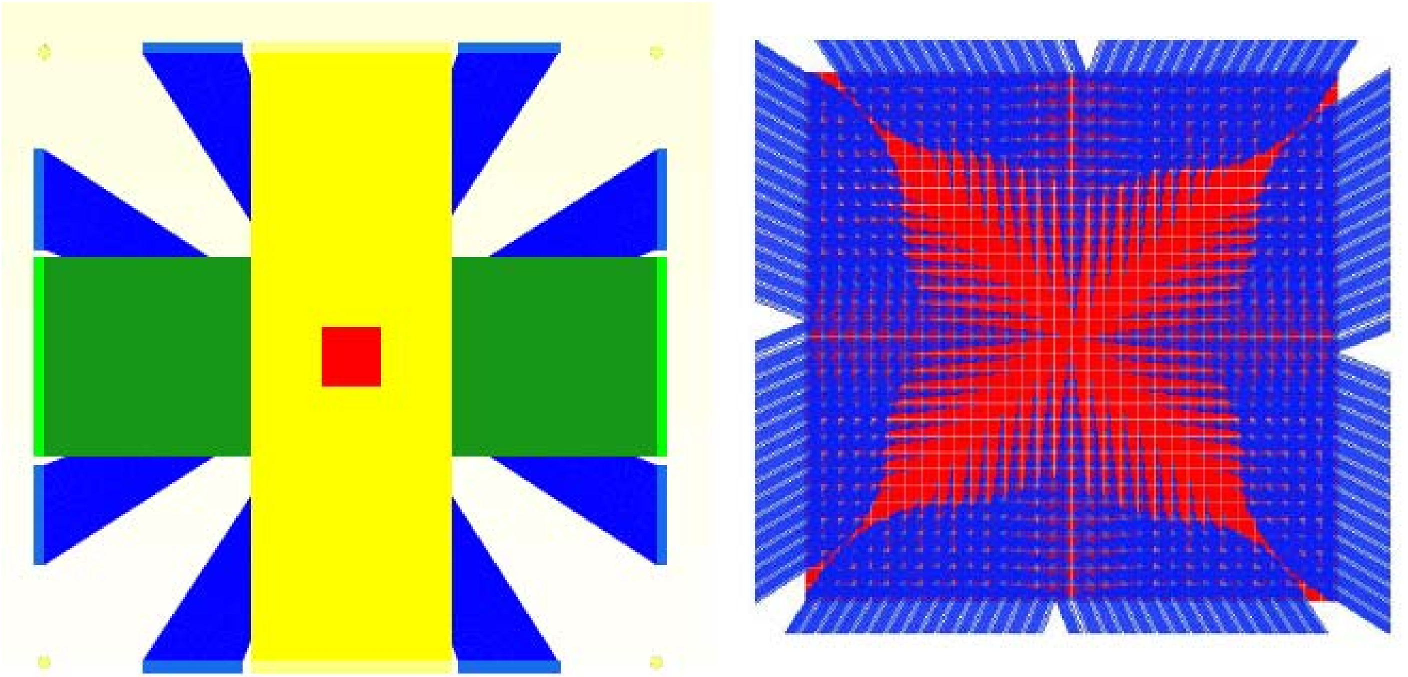
Spacecharge

Rate Capability

GEMs in Compass:

Rates of 2.5MHz/cm^2 result in occupancy up to 25% (readout strips).

Clearly in order to profit from 200MHz rate capability one has to pixelize the readout electrodes.



Current Upgrade Plans

- **ATLAS:**
  - Muon system detectors unchanged, possibly improved shielding
  - TRT replaced by Silicon Tracker
- **CMS:**
  - Muon system detectors unchanged. Possibly additional ‘standard’ RPC stations, improved shielding
- **LHCb, ALICE:**
  - To be defined
- **TOTEM:**
  - Possibly replace CSCs with GEMs

Thinking about LHC upgrade is important, but don’t forget that the LHC experiments are NOT yet up and running.

There is an enormous amount of installation and commissioning work to be done.

See you in the Pit