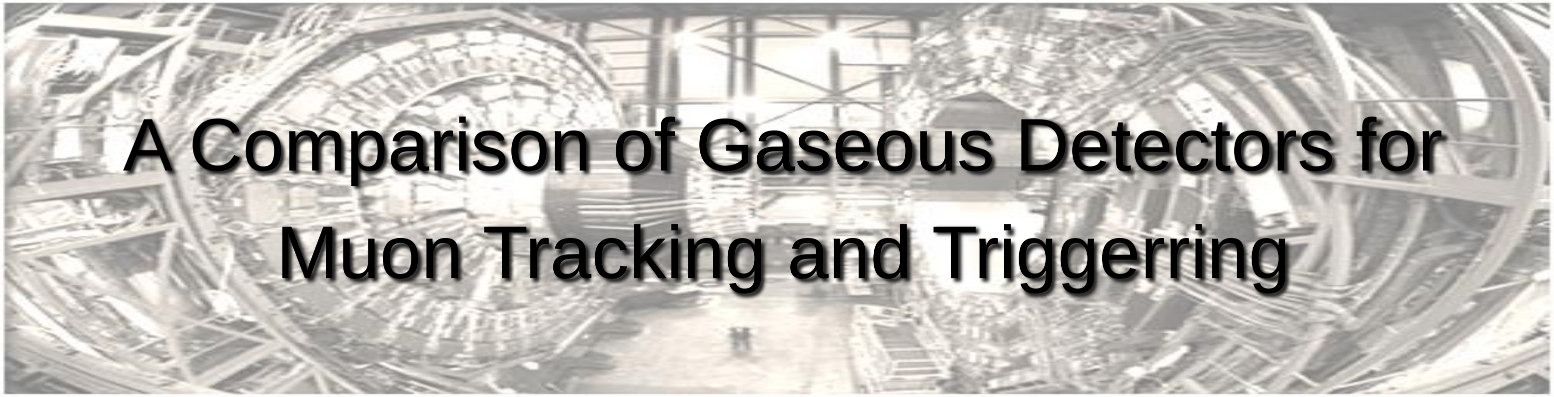


A Comparison of Gaseous Detectors for Muon Tracking and Triggerring

A bit LHC centric

Archana SHARMA
CERN

RPC 2012

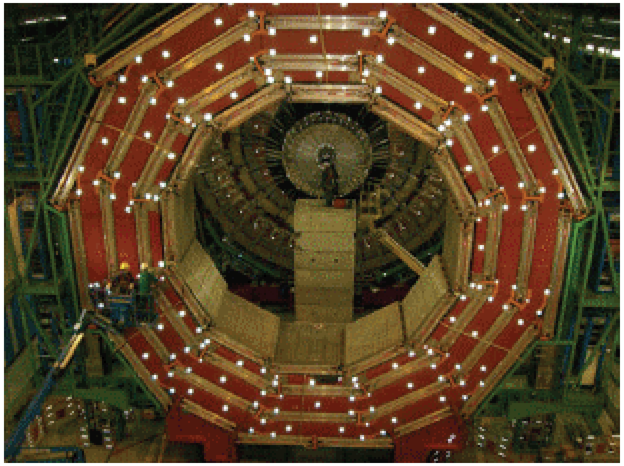
XI Workshop on Resistive Plate Chambers

and Related Detectors

INFN - Laboratori Nazionali di Frascati

5-10 February, 2012

Muon Chambers



Purpose: measure momentum / charge of muons

Recall that the muon signature is extraordinarily penetrating

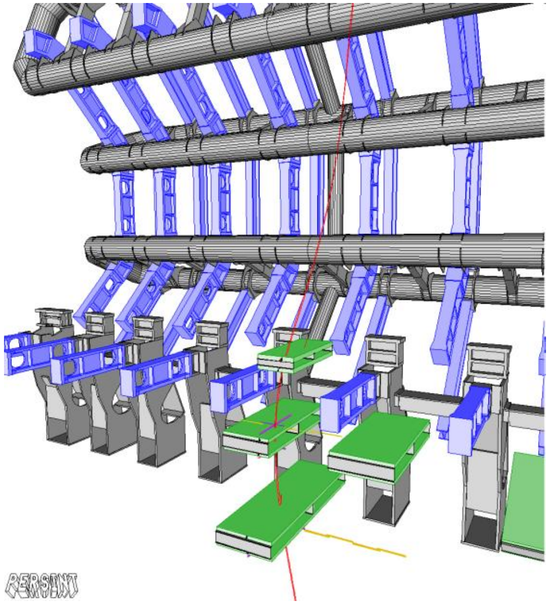
Muon chambers are the outermost layer

Measurements are made combined with inner tracker

Muon chambers in LHC experiments:

Series of tracking chambers for precise measurements

- RPC's: Resistive Plate Chambers
- DT's: Drift Tubes; MDTs;
- CSC's: Cathode Strip Chambers
- TGC's: Thin Gap Chambers



Challenges for future

Classic RPCs established successfully

How to survive the harsh environment at the LHC and upgrades; similar

High particle rates and cavern background

New chamber technologies for precision tracking and trigger

How to contain trigger rate

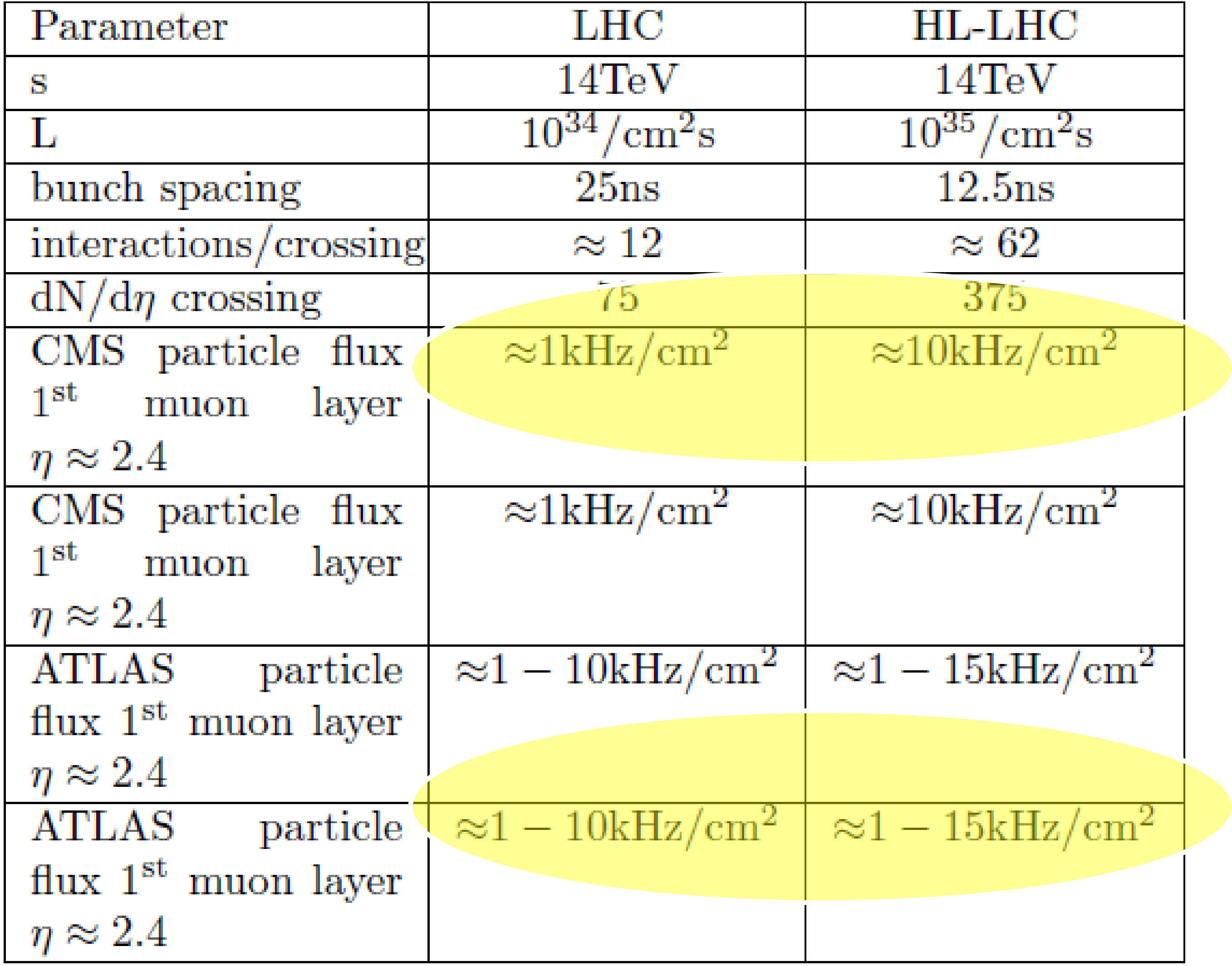
Cluster size compatible with trigger rate

What do we need?

Good resolution
Good efficiency
Good acceptance
Completely understood detector, dead zones, supports,..
Stability – Plateau vs HV, Gas content,temperature, humidity
Optimized granularity for physics
Minimum multiple scattering
Minimum loss due to noise / background, fake tracks
Minimum dead time
Minimum aging (radiation, rate, materials, environment..)

CMS and ATLAS

Rates at Muon Trigger Upgrade



Parameter	LHC	HL-LHC
s	14TeV	14TeV
L	$10^{34}/\text{cm}^2\text{s}$	$10^{35}/\text{cm}^2\text{s}$
bunch spacing	25ns	12.5ns
interactions/crossing	≈ 12	≈ 62
$dN/d\eta$ crossing	75	375
CMS particle flux 1^{st} muon layer $\eta \approx 2.4$	$\approx 1\text{kHz}/\text{cm}^2$	$\approx 10\text{kHz}/\text{cm}^2$
CMS particle flux 1^{st} muon layer $\eta \approx 2.4$	$\approx 1\text{kHz}/\text{cm}^2$	$\approx 10\text{kHz}/\text{cm}^2$
ATLAS particle flux 1^{st} muon layer $\eta \approx 2.4$	$\approx 1 - 10\text{kHz}/\text{cm}^2$	$\approx 1 - 15\text{kHz}/\text{cm}^2$
ATLAS particle flux 1^{st} muon layer $\eta \approx 2.4$	$\approx 1 - 10\text{kHz}/\text{cm}^2$	$\approx 1 - 15\text{kHz}/\text{cm}^2$

CMS

Forward Region	**Rates Hz/cm^2 LHC (10^{34} cm^2/s)**	**High Luminosity LHC 2.3 x LHC**	**($10^{35}cm^2$/s) Phase II**
RB	30	Few 100	kHz (tbc)
RE 1, 2, 3,4 $\eta < 1.6$	30	Few 100	**kHz (tbc)**
Expected Charge in 10 years	0.05 C/cm^2	0.15 C/cm^2	~ C/cm^2
RE 1,2,3,4 $\eta > 1.6$	**500Hz ~ kHz**	**Few kHz**	**Few 10s kHz**
Total Expected Charge in 10 years	(0.05-1) C/cm^2	few C/cm^2	Several C/cm^2

Improve Muon momentum meas

Muon systems only (standalone)

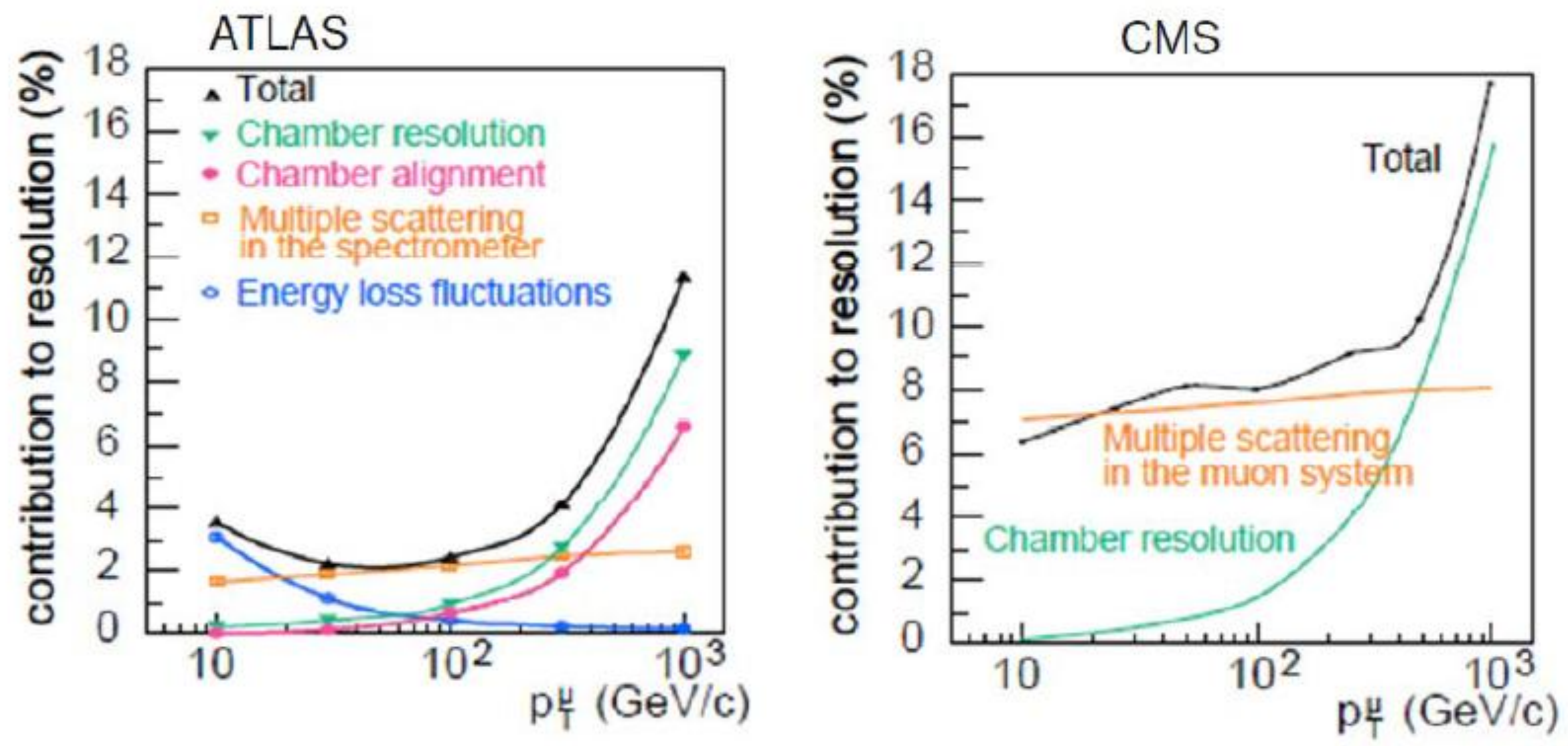
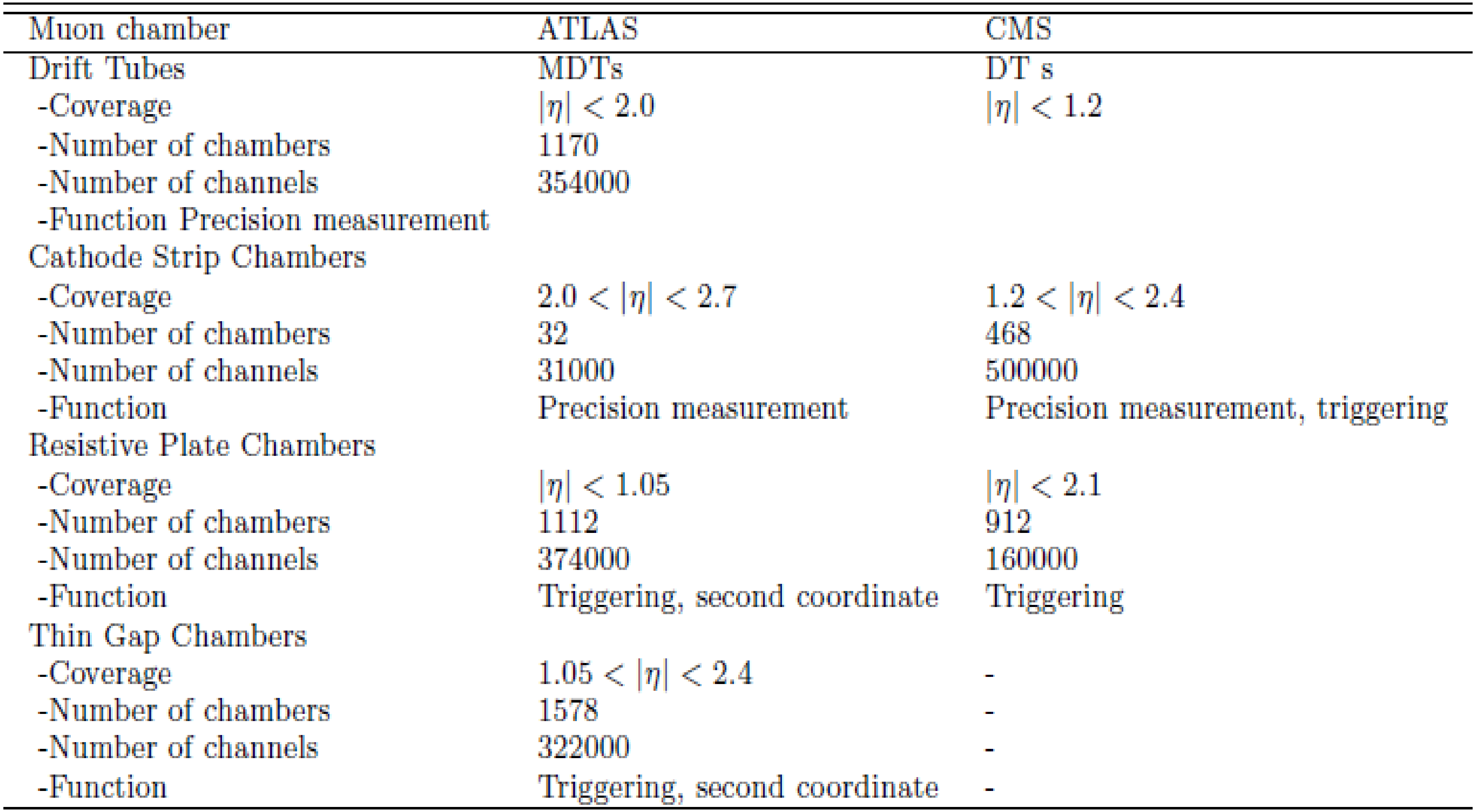


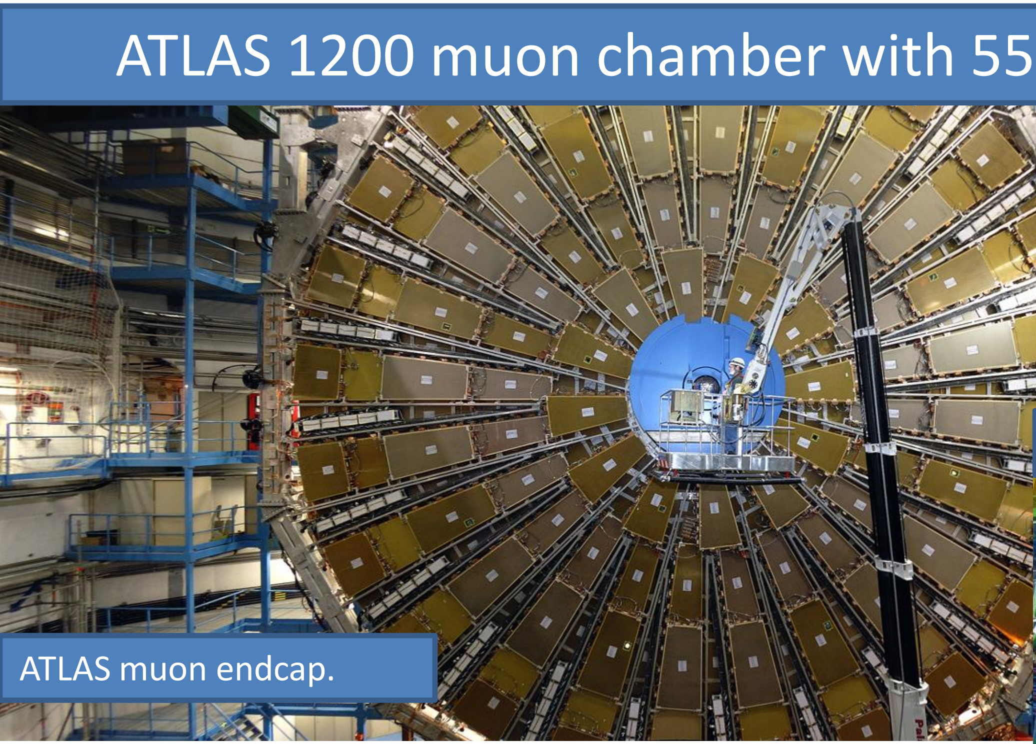
Table 3: A comparison of typical coverage and performance parameters for muon detectors in ATLAS and CMS



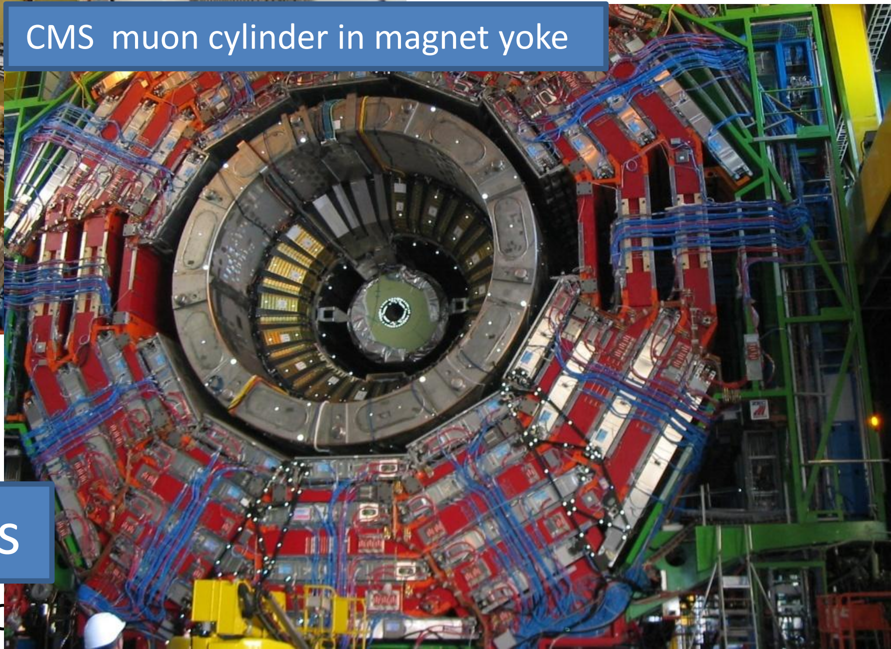
Muon chamber	ATLAS	CMS
Drift Tubes	MDTs	DT s
-Coverage	$\lvert\eta\rvert < 2.0$	$\lvert\eta\rvert < 1.2$
-Number of chambers	1170	
-Number of channels	354000	
-Function Precision measurement		
Cathode Strip Chambers		
-Coverage	$2.0 < \lvert\eta\rvert < 2.7$	$1.2 < \lvert\eta\rvert < 2.4$
-Number of chambers	32	468
-Number of channels	31000	500000
-Function	Precision measurement	Precision measurement, triggering
Resistive Plate Chambers		
-Coverage	$\lvert\eta\rvert < 1.05$	$\lvert\eta\rvert < 2.1$
-Number of chambers	1112	912
-Number of channels	374000	160000
-Function	Triggering, second coordinate	Triggering
Thin Gap Chambers		
-Coverage	$1.05 < \lvert\eta\rvert < 2.4$	-
-Number of chambers	1578	-
-Number of channels	322000	-
-Function	Triggering, second coordinate	-

Muon-detectors SWPCs, MWPCs, DTs, CSCs, TGCs …..

ATLAS 1200 muon chamber with 5500 m^2



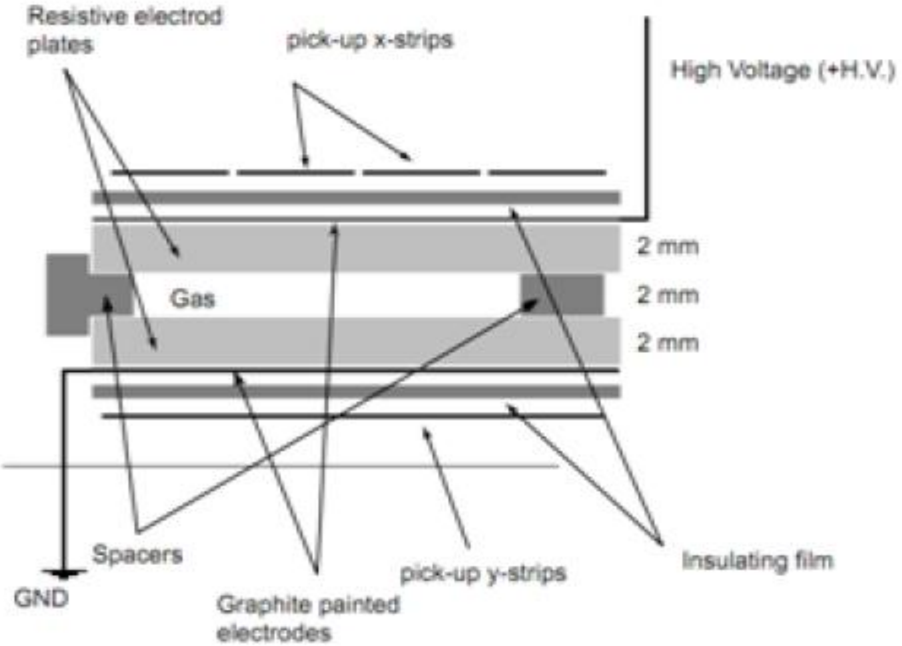
ATLAS muon endcap.

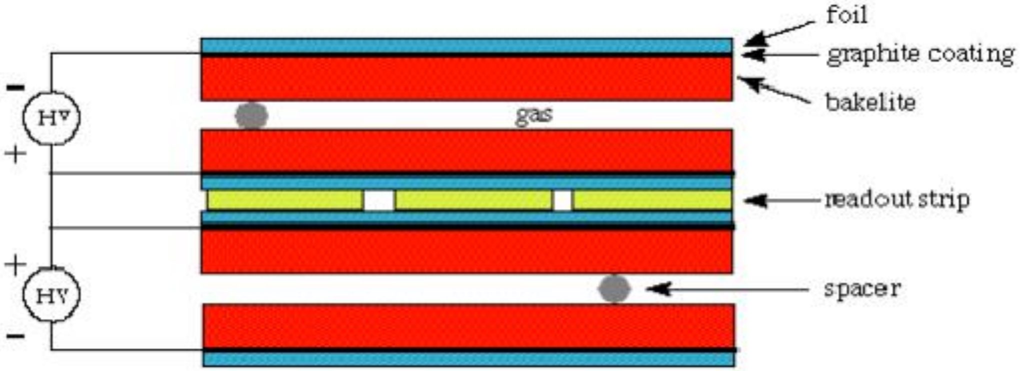


CMS muon cylinder in magnet yoke

Muon detectors

Classic - Resistive Plate Chamber





Fully Efficient; very low noise

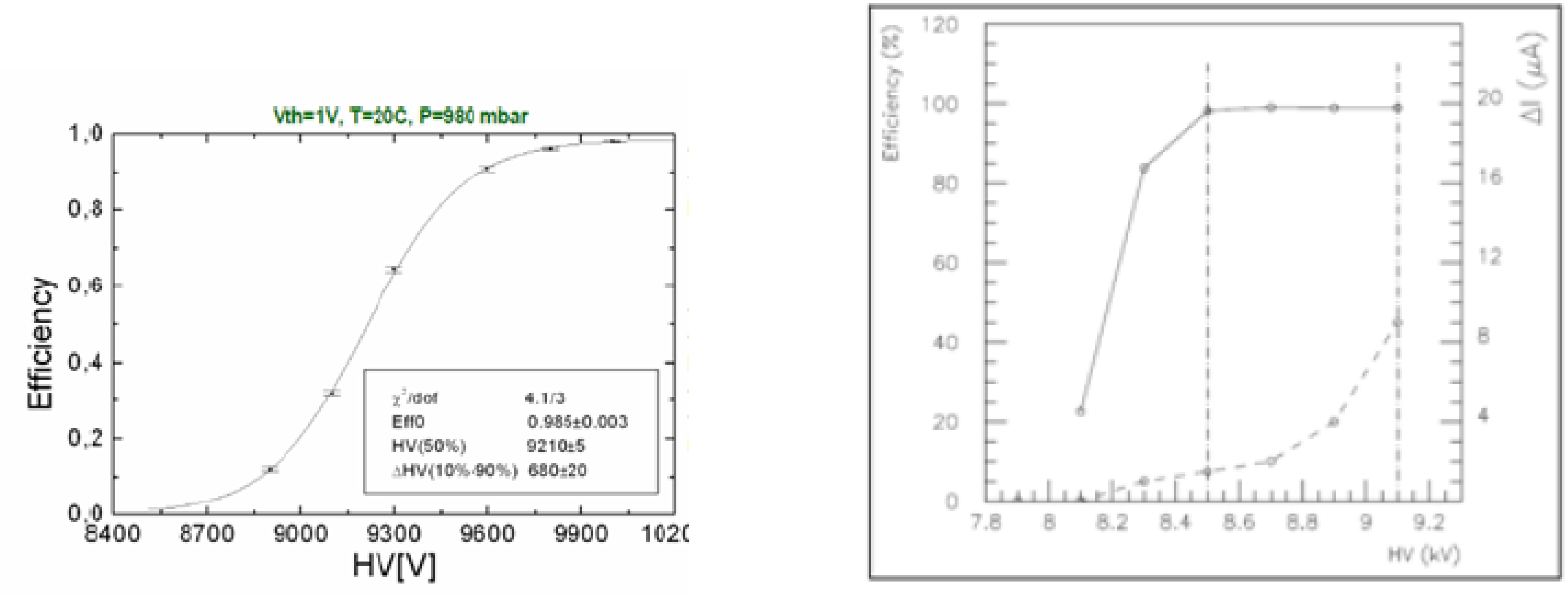


Figure 16: Efficiency measurements from RPCs for ATLAS (left) and CMS (right)

Full systems functional

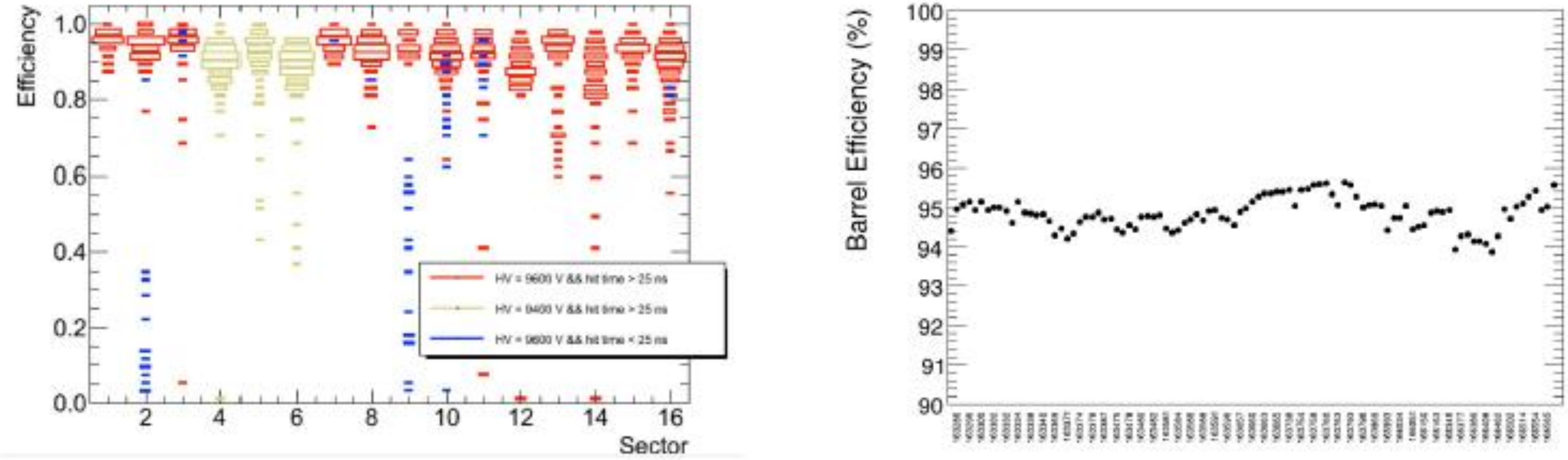


Figure 17: On top left we see the performance of ATLAS RPCs and in top right the efficiency for CMS RPCs.

Gas Monitoring

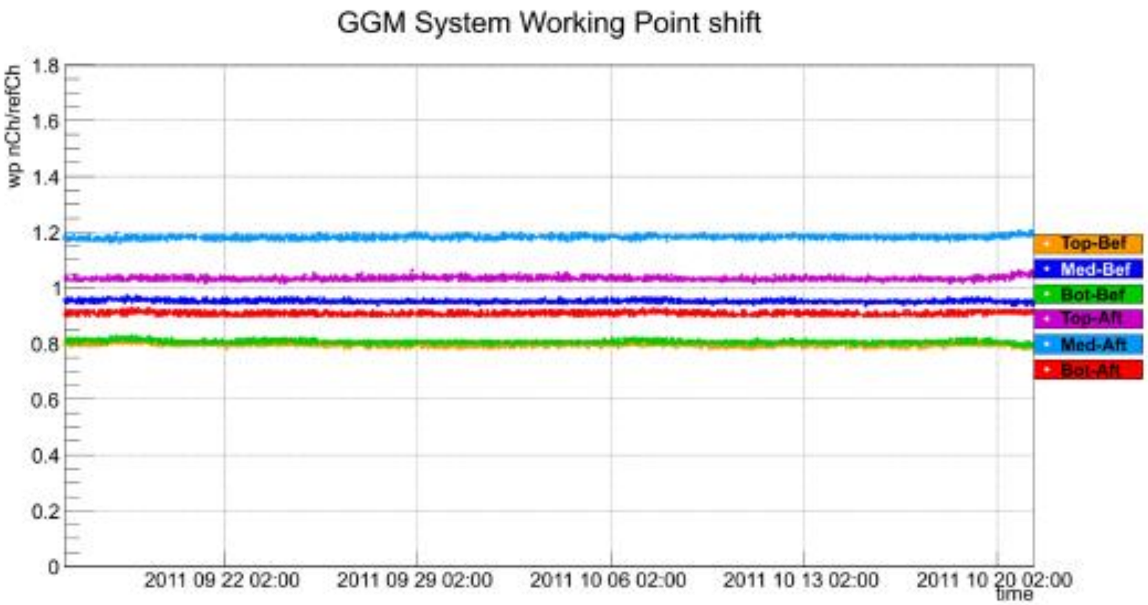


Figure 19: RPC Working point monitoring performed by the Gas Gain Monitoring system at CMS-SGX5 gas building. The dependance of environmental variable is actually removed online in order to spot the presence of any gas contaminant.

Advantages and Disadvantages

Robust Proven technology

Large systems Operational

Excellent time resolution

Over a decade of experience in construction, understanding of operation

Stability of operation demonstrated for moderate rates

Gas contains Freon, Isobutane

Large complex (Expensive) and sophisticated gas system necessary

Humidification and gas purification

Spacers mandatory

Multi Gap RPCs -Glass

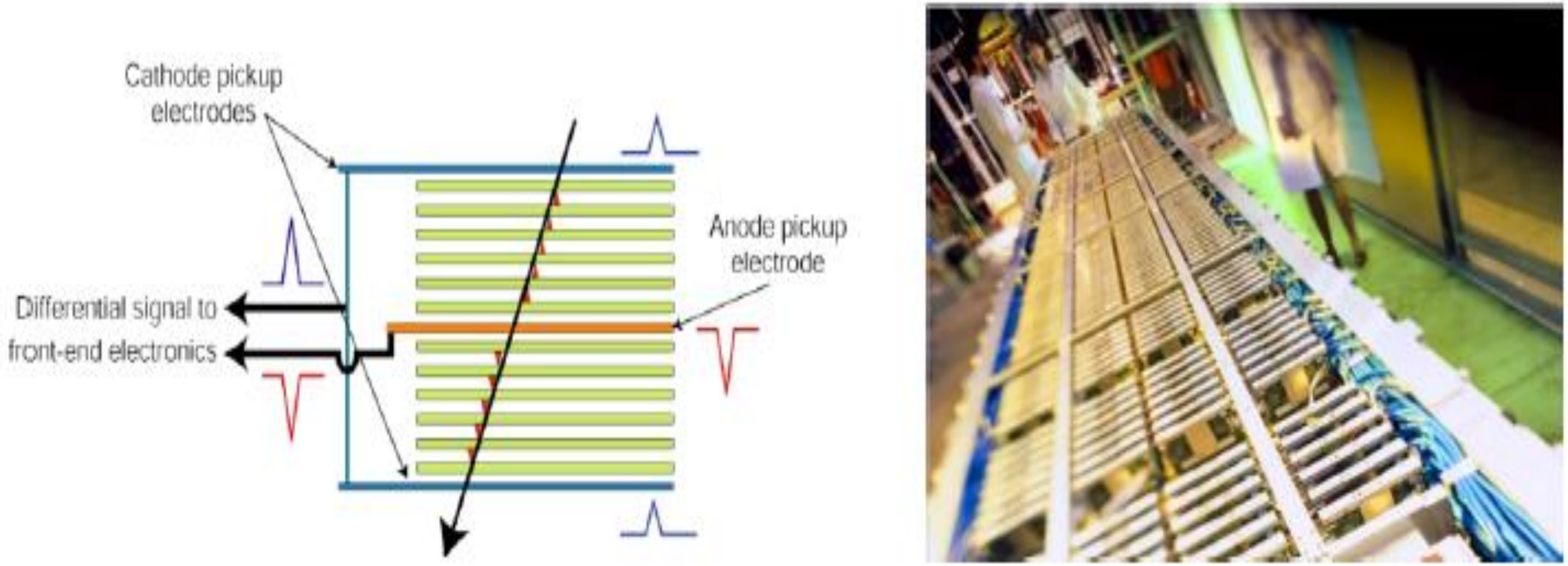


Figure 20: (left) Schematic of a multigap resistive plate chamber (right) Large MRPC module under construction for the ALCE Time Of Flight detector

Performance - MRPC

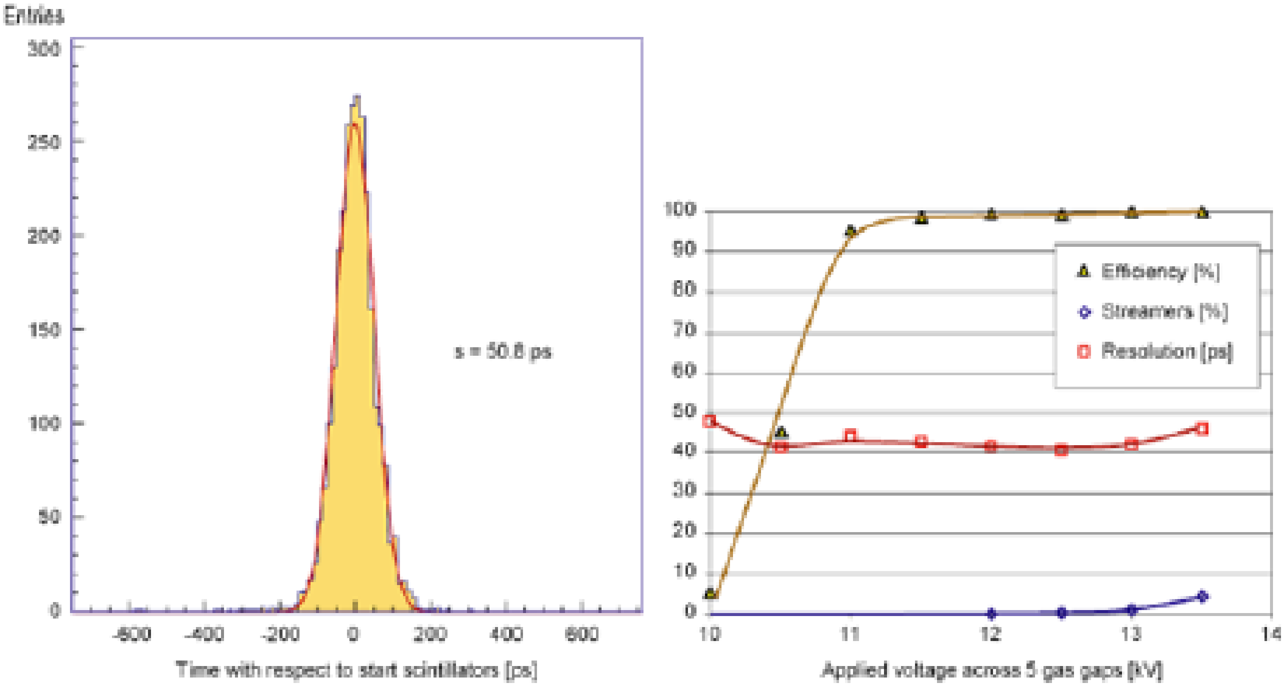
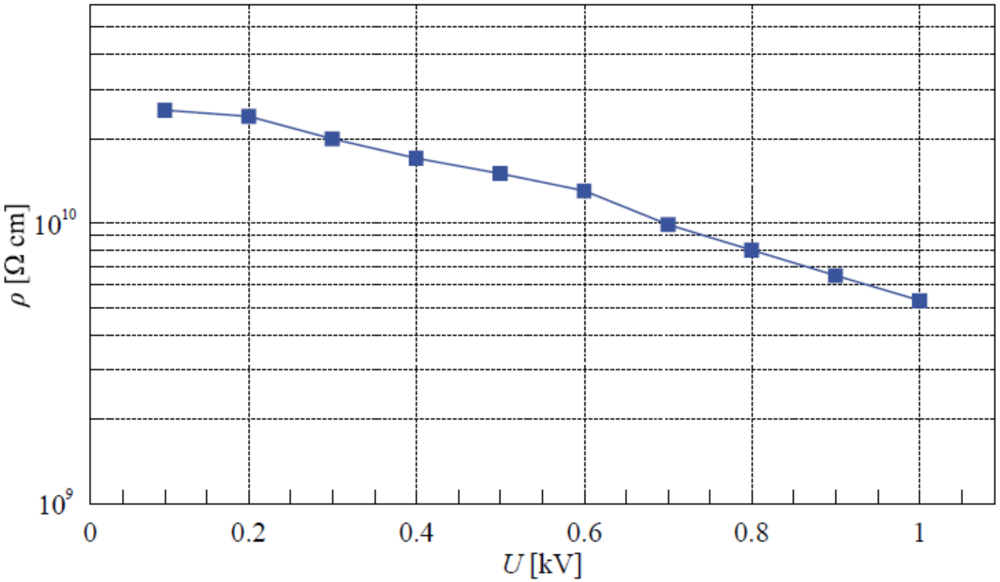
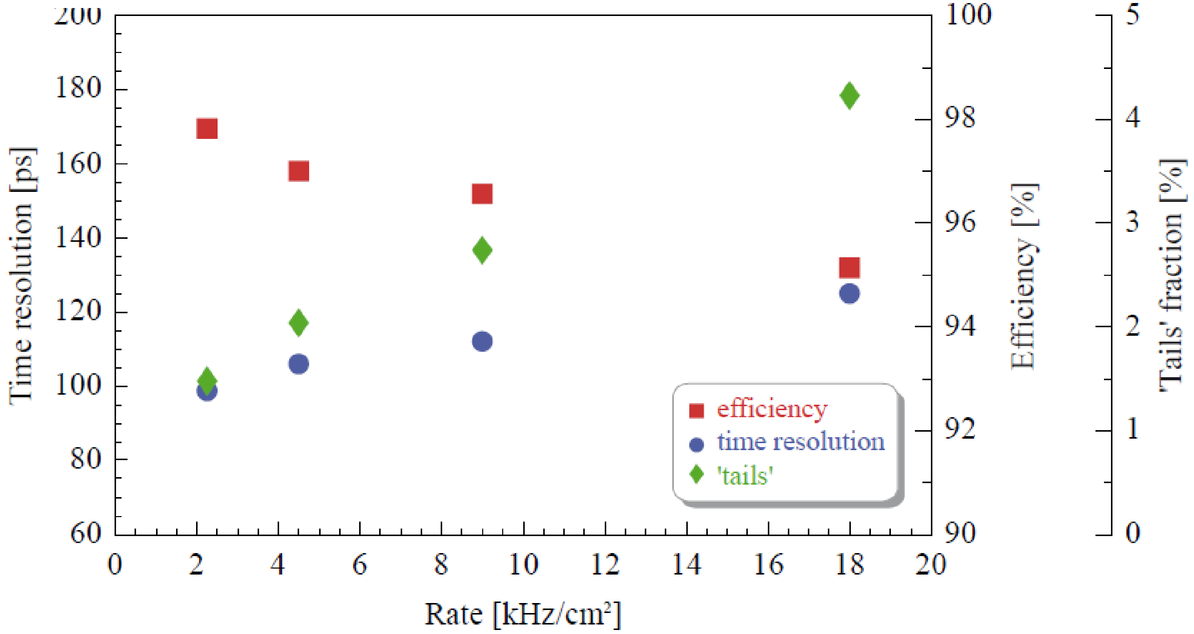


Figure 21: Performance of a multigap resistive plate chamber: time resolution and effici
with fraction of streamers

CBM HIGH RATE - TOF



MRPC: low-resistive glass electrodes



Akindiov et al

Multi Gap RPCs - Phenolic

Detector structures

Oiled Phenolic Multigap Panel-type RPCs for CMS high-η triggers

Panel-shape multigap RPCs

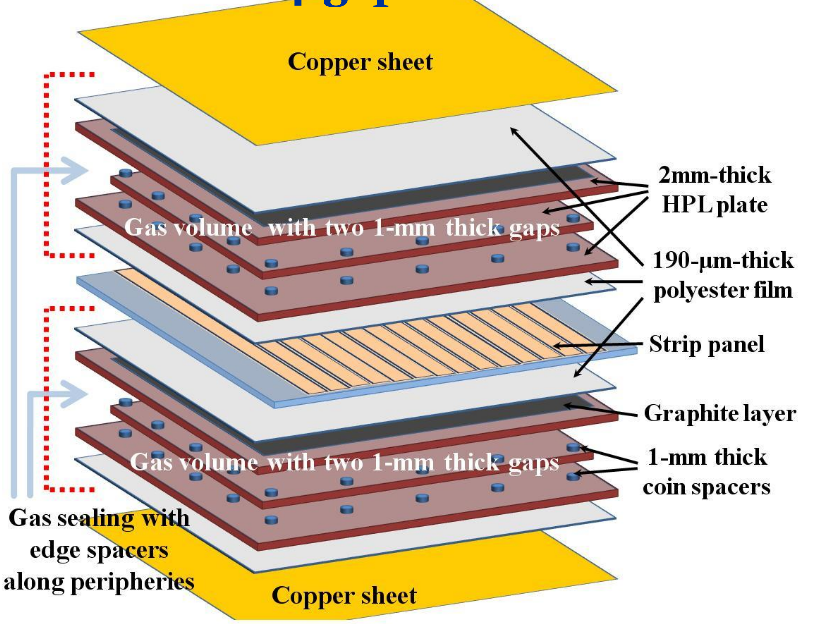
~ Two separated gas envelopes + a strip panel
Each gas envelope ~ 2 gaps in 4-gap RPCs
3 gaps in 6-gap RPCs

Prototype detectors

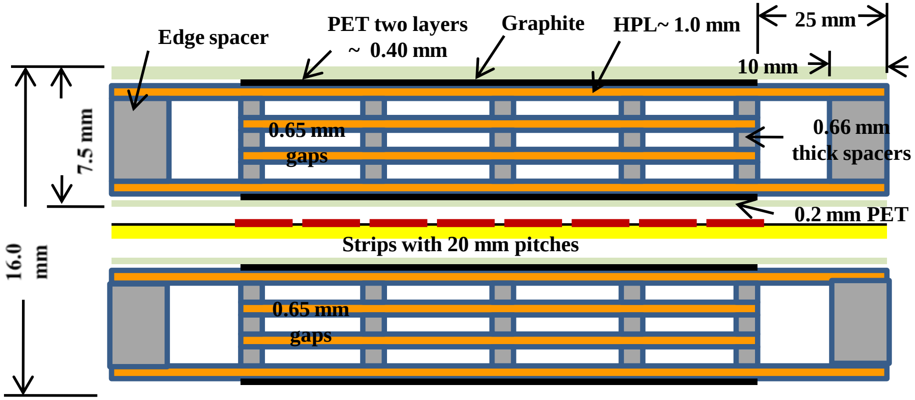
4-gap RPC: 45 x 45 cm² (active area)
- **HPL : 2 mm**
- **Coin spacers : 1000 ± 10 μm (Polycarbonate)**
- **Strip pitch = 27 mm**

6-gap RPC: 15 x 29 cm² (active area)
- **HPL : 1 mm**
- **Coin spacers : 660 ± 10 μm (Polycarbonate)**
- **Strip pitch = 20 mm**

4-gap RPC



6-gap RPC



4. Conclusions and Milestones

Conclusions

R&D on Oiled Phenolic 4- and 6-gap Panel-type RPCs

(1) Prototype detectors: manufactured with the same technology as the one applied for the double-gap RPCs for the CMS experiments.

(2) For 2-gap RPCs (Thr. ~ 200 fC), mean q_e ~ 4.0 pC at the mid of the plateau
For 4-gap RPCs (Thr. ~ 150 fC), q_e ~ 1.5 pC
For 6-gap RPCs (Thr. ~ 100 fC), q_e ~ 0.9 pC

(3) Size of efficiency plateaus ≥ 600 V for both 4- & 6-gap RPCs

(4) Technical issue: 6-gap structure seems to be marginal to manufacture real size panel–type detectors.

- **Low stiffness of HPL → Technical difficulty in manufacturing gaps**
- **Adding water vapor deforms the thin HPLs (1.0 mm) → lost the gap uniformity**

(6) Aging issue: Small pulses will be really conductive to reduce radiation-induced aging at high rate environments

For 2-gap RPCs, aging study with an intensive gamma rate > 3 kHz cm^{-2}
→ The high gamma rate caused Fast Degradation of gaps
(H. C. Kim *et al.*, NIM A602 (2009) 771)

MARGINS of OPERATION !

Future R&D scopes

(1) QC based R&D for the manufacture procedure and parts

(2) Real-size prototype detector for high-η RE (RE1/1, RE2/1, RE3/1) RPCs with the 4-gap structure & the FEBs for the CMS RPCs

MRPCs Advantages and Disadvantages

Dividing the gas volume into several gaps results in higher rate capability.

Advances in electronics

Addition of small amounts of SF6 increased the range of voltages in which the chambers can operate without streamer formation

Improvements have been achieved by using lower resistivity bakelite / glass ($10^{9-10}\Omega cm$).

Several small gas gaps limit time walk and resolution

using gas mixtures with a high content of freon gases, isobutane

Flatness quality; Stringent tech tolerances requirement

Humidity and environment conditions

Mechanical stiffness for large area

Sustained Operation

Aging Open Issue

MWPCs - THIN GAP CHAMBERs

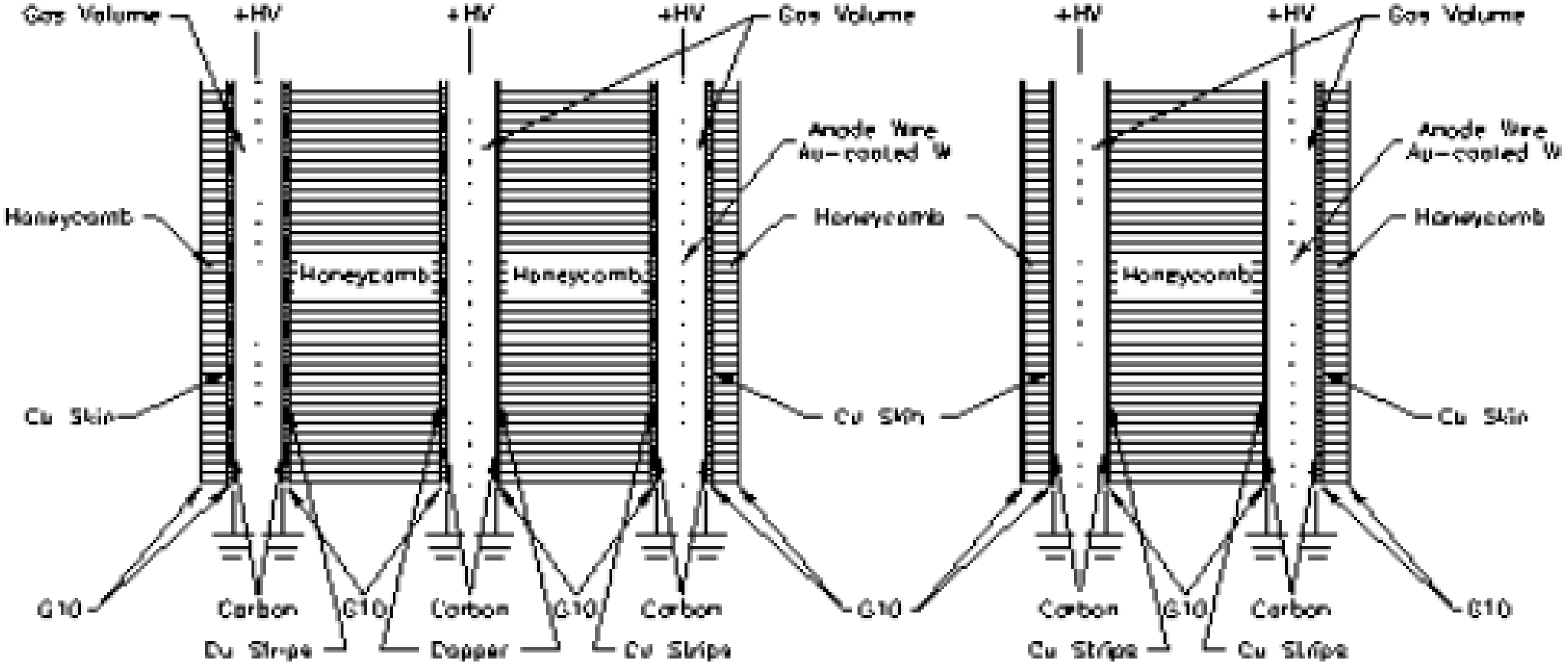


Figure 22: Schematic of Thin Gap Chambers

Time Resolution and efficiency TGCs

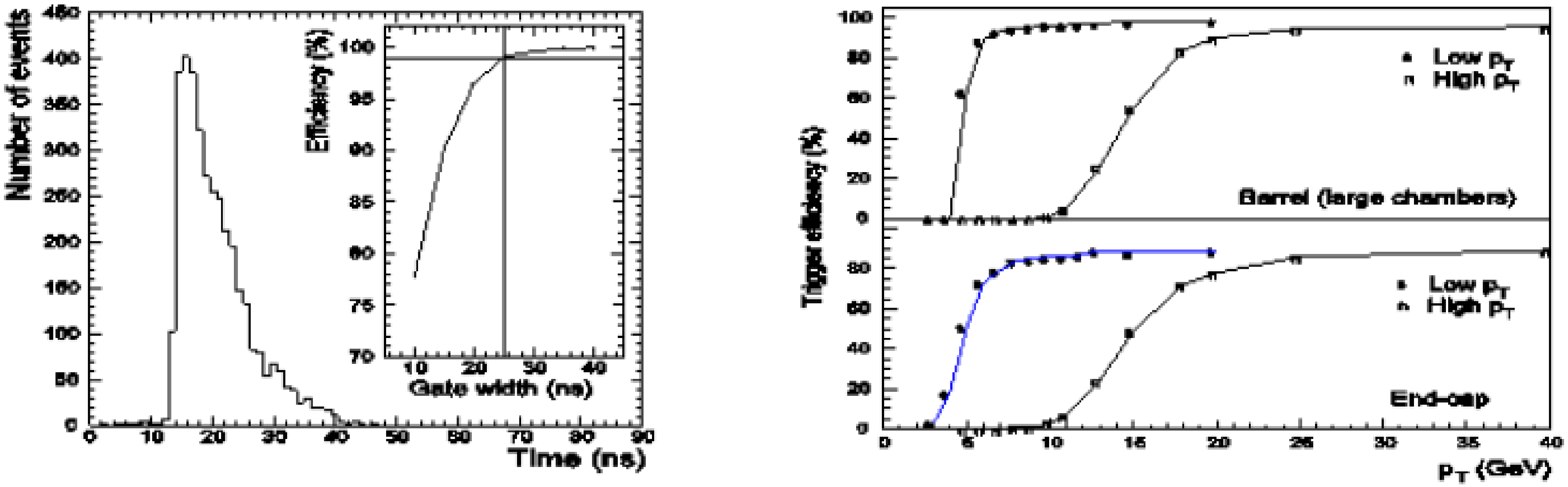


Figure 23: Time resolution and efficiency for low and high p_T muons for ATLAS TGCs

Upto 200 kHz/cm2 ! Space res 150 μm Time res 3.5-4 ns
BUT use n-pentane !!

Proportional -Drift Tubes

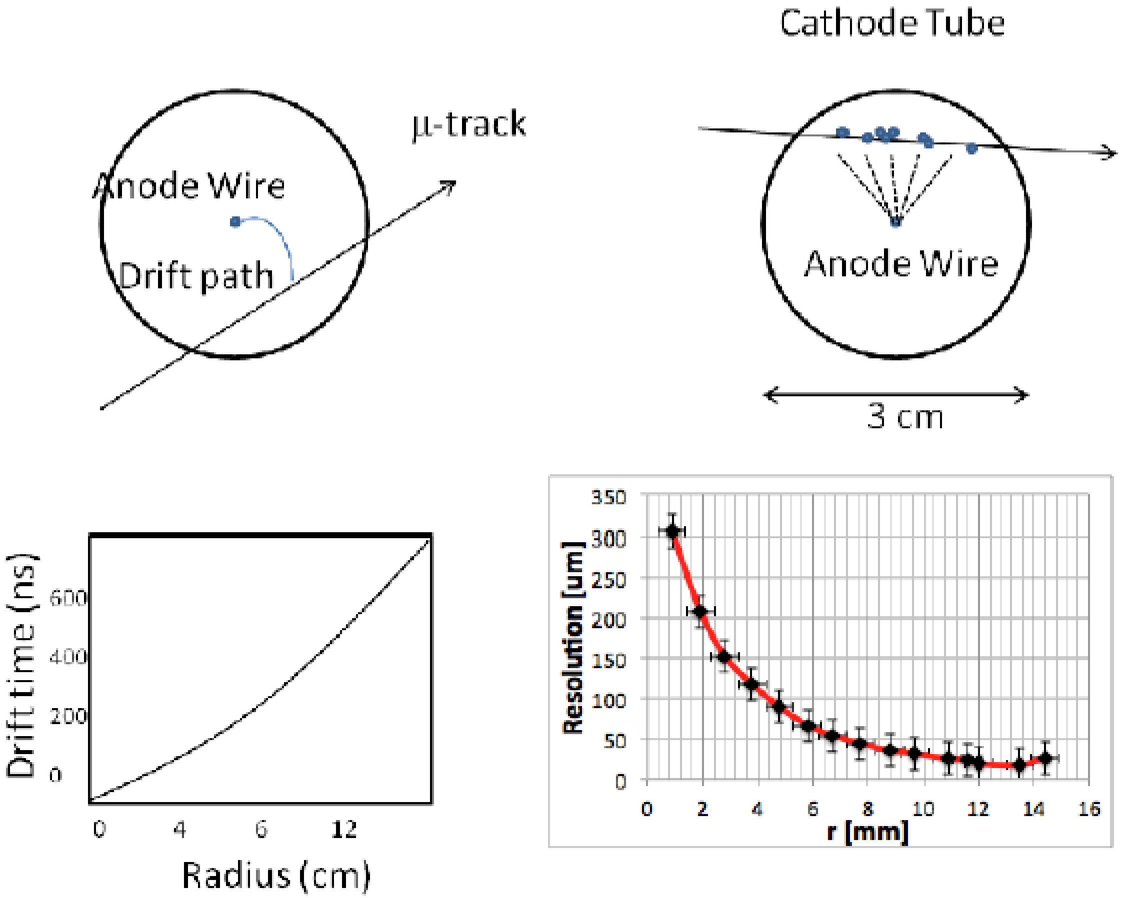


Figure 26: With a radius of 1.5cm, a gas mixture of Ar/CO_2 at 3bar pressure, the space time relationship and results of resolution measurement for the ATLAS MDTs.

Drift Tubes in CMS

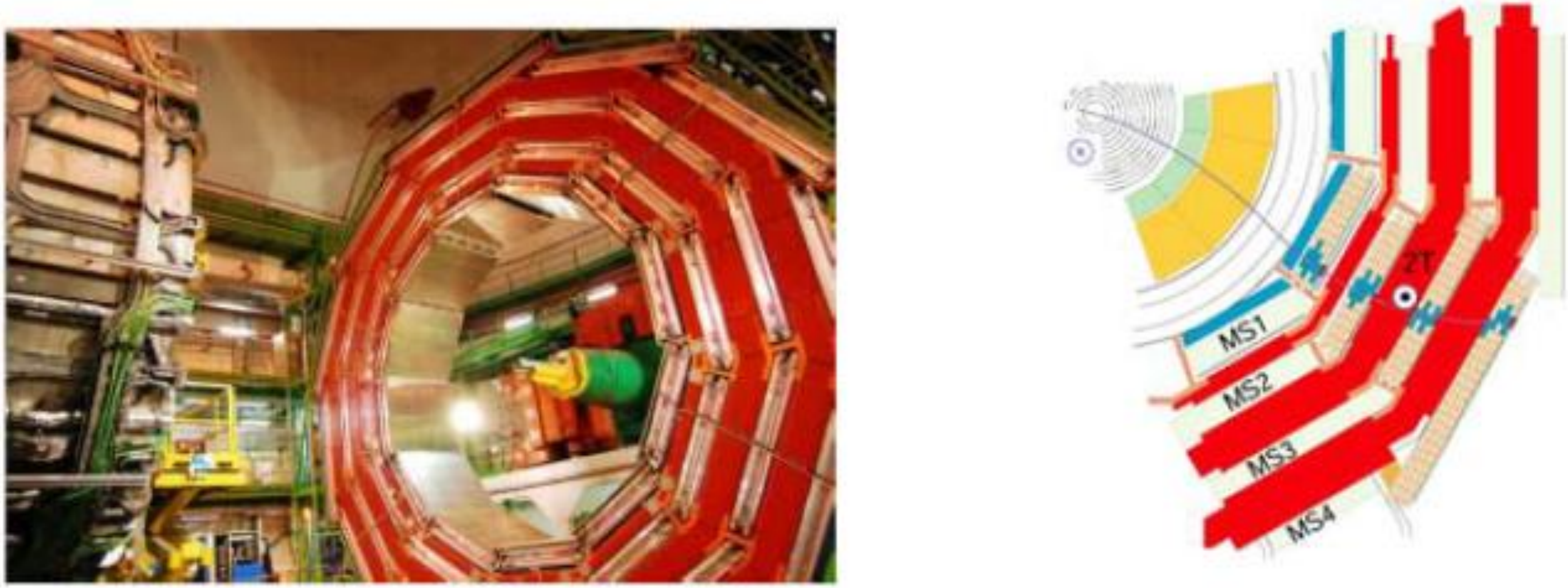


Figure 30: Drift tubes inserted in one of the wheels of CMS. The red part is the iron yoke of the CMS solenoid which houses the muon detectors; in (b) one can see the detector providing a muon measurement extending up to the interaction point with several points (blue) given from the four layers of drift tubes.

ATLAS

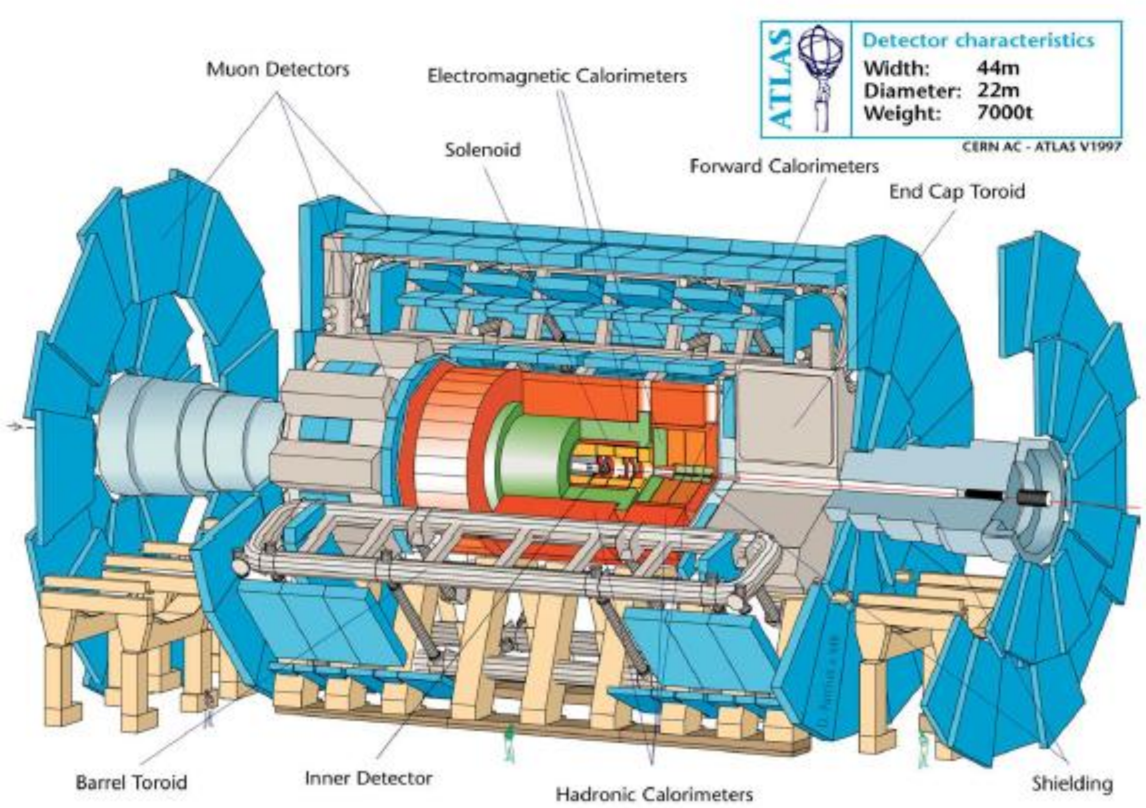
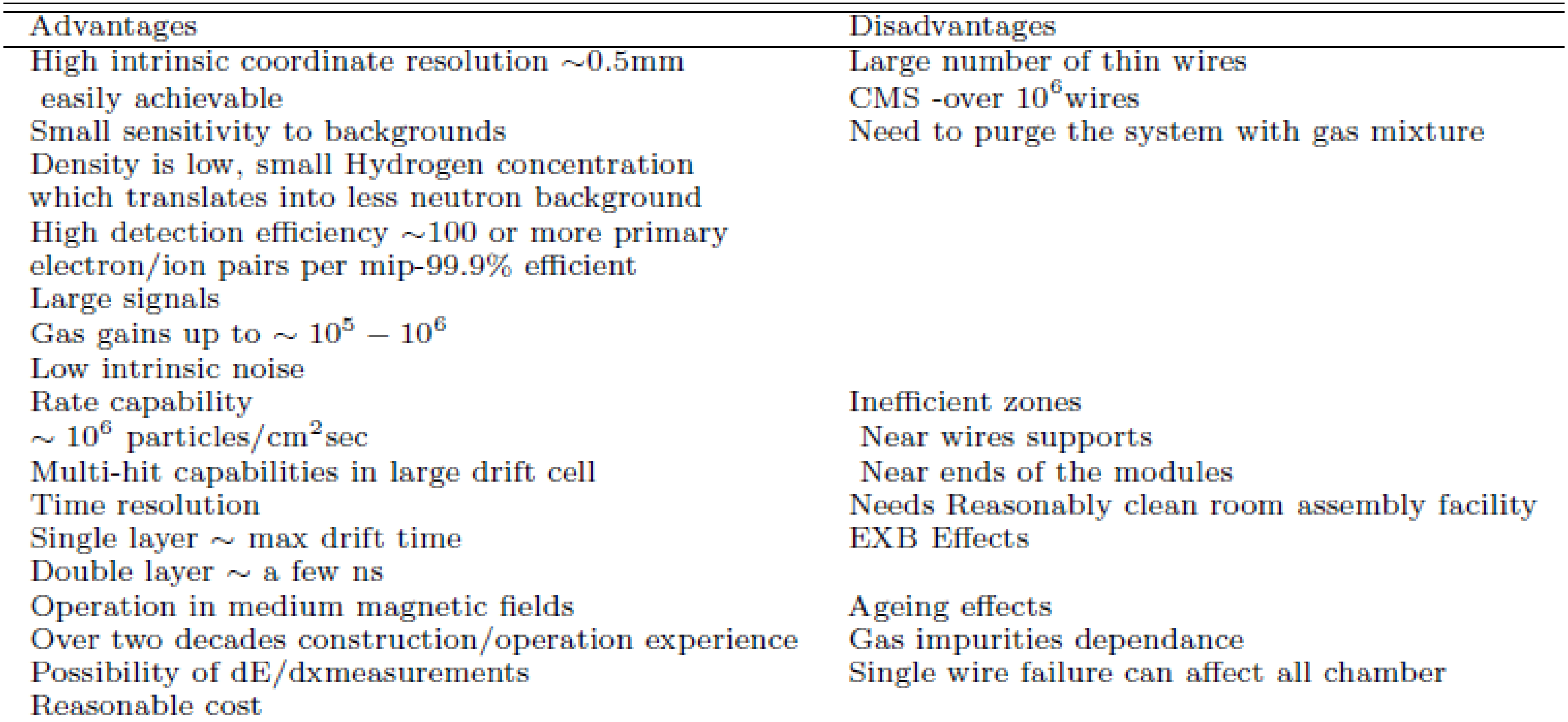


Figure 11: The ATLAS MUON Spectrometer Muon spectrometer is the outer layer (in blue) of ATLAS detector (~22m high and 44m long); 5500m^2 covered by muon detectors or 400000 single drift tube detector, grouped in 1200 chambers

Cathode Strip Chamber

Figure 33: Cathode Strip Chambers mounted on a CMS Endcap

MWPCs - Advantages and Disadvantages



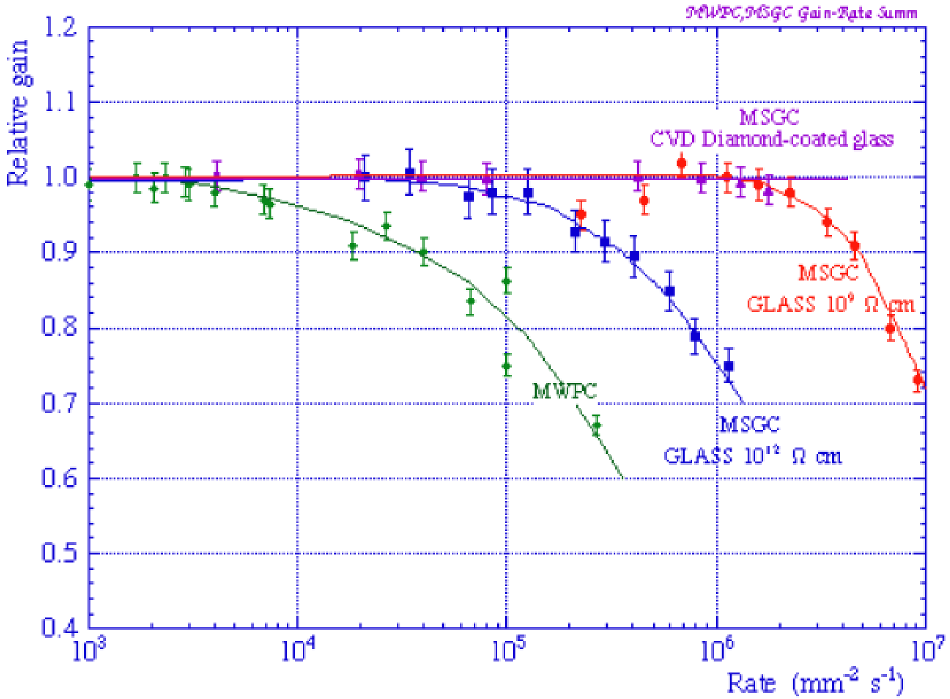
Advantages	Disadvantages
High intrinsic coordinate resolution ~0.5mm	Large number of thin wires
easily achievable	CMS -over 10^6wires
Small sensitivity to backgrounds	Need to purge the system with gas mixture
Density is low, small Hydrogen concentration	
which translates into less neutron background	
High detection efficiency ~100 or more primary	
electron/ion pairs per mip-99.9% efficient	
Large signals	
Gas gains up to $\sim 10^5 - 10^6$	
Low intrinsic noise	
Rate capability	Inefficient zones
$\sim 10^6$ particles/cm^{2}sec	Near wires supports
Multi-hit capabilities in large drift cell	Near ends of the modules
Time resolution	Needs Reasonably clean room assembly facility
Single layer ~ max drift time	EXB Effects
Double layer ~ a few ns	
Operation in medium magnetic fields	Ageing effects
Over two decades construction/operation experience	Gas impurities dependance
Possibility of dE/dxmeasurements	Single wire failure can affect all chamber
Reasonable cost	

What next ?

Why MPGD?

Limitations of wire-based chambers:

- Resolution: reduction of wire spacing <1 mm very difficult
  - – mechanical tolerances
  - – electrostatic repulsion ⇨ wire tension!
- Rate capability: limited by build-up of positive space-charge around anode

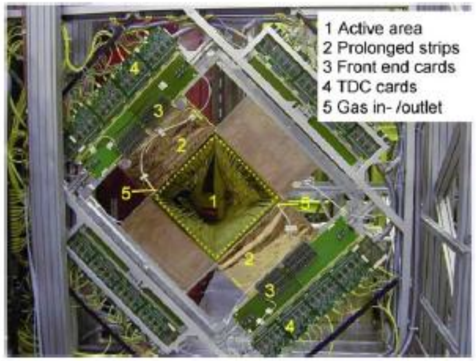


⇨Reduction of cell size by a factor of 10

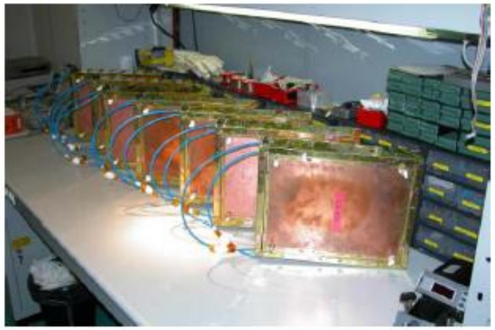
- Photolithography
- Etching
- Coating
- Wafer post-processing

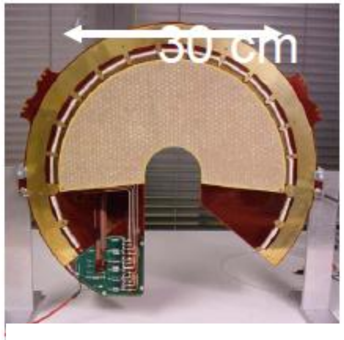
MPGD in Running Experiments

Exp.	#	Type	Readout	# of ch.	Size (cm^2)	Gas	σ_{space} (μm)	σ_{time} (ns)	ε (%)
COMPASS	22	GEM	2-D strips	1536	31×31	Ar/CO_2 (70/30)	70	12	>97
	12	MM	1-D strips	1024	40×40	$Ne/C_2H_6/CF_4$ (80/10/10)	90	9	>97
LHCb	24	GEM	pads	192	10×24	$Ar/CO_2/CF_4$ (45/15/40)		4.5	>97
TOTEM	40	GEM	pads + strips	1536 + 256	30 × 20	Ar/CO_2 (70/30)	~70 (θ)		>92



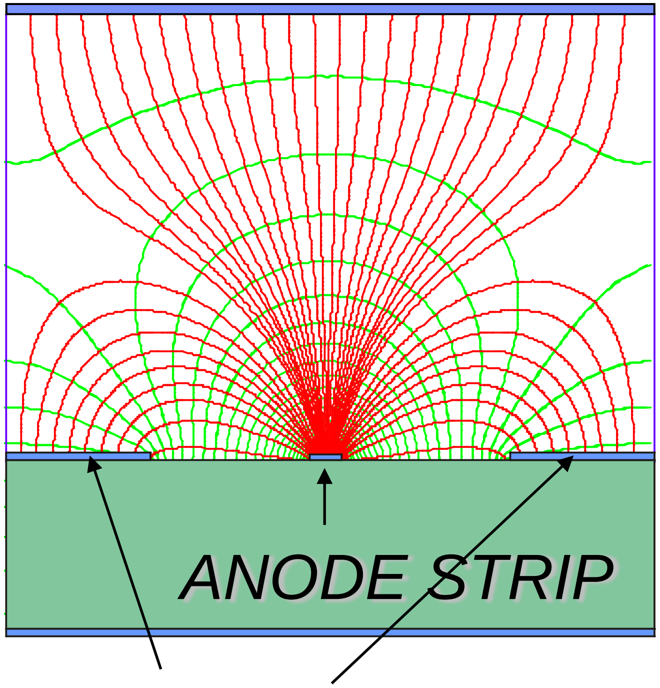
also CAST, NA48, PHENIX …





MICRO-STRIP GAS CHAMBERS: ANTON OED (1988)

THIN METAL STRIPS ON INSULATING SUPPORT (GLASS):

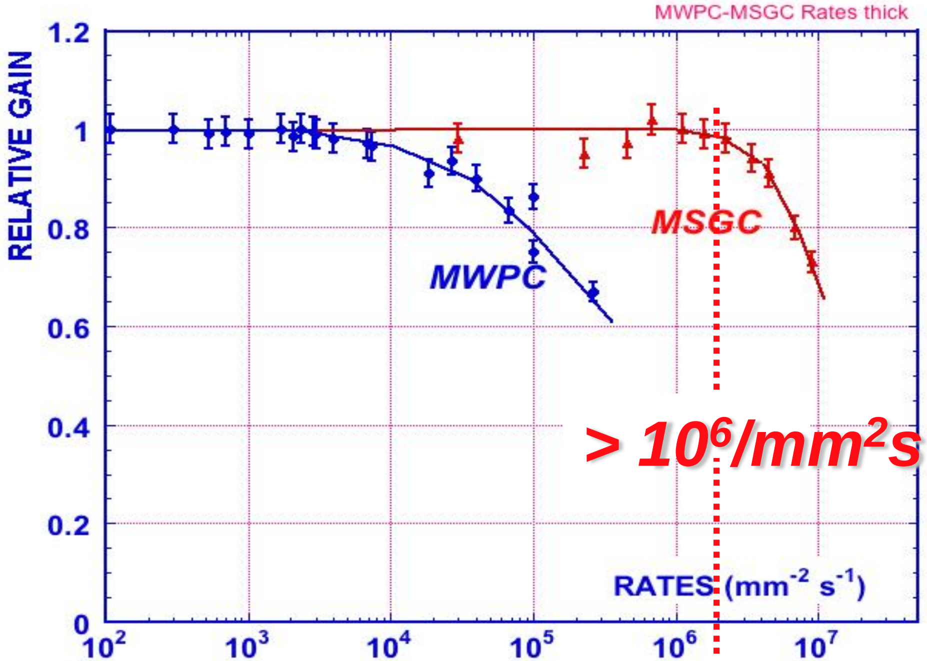


DRIFT ELECTRODE

ANODE STRIP

CATHODE STRIPS

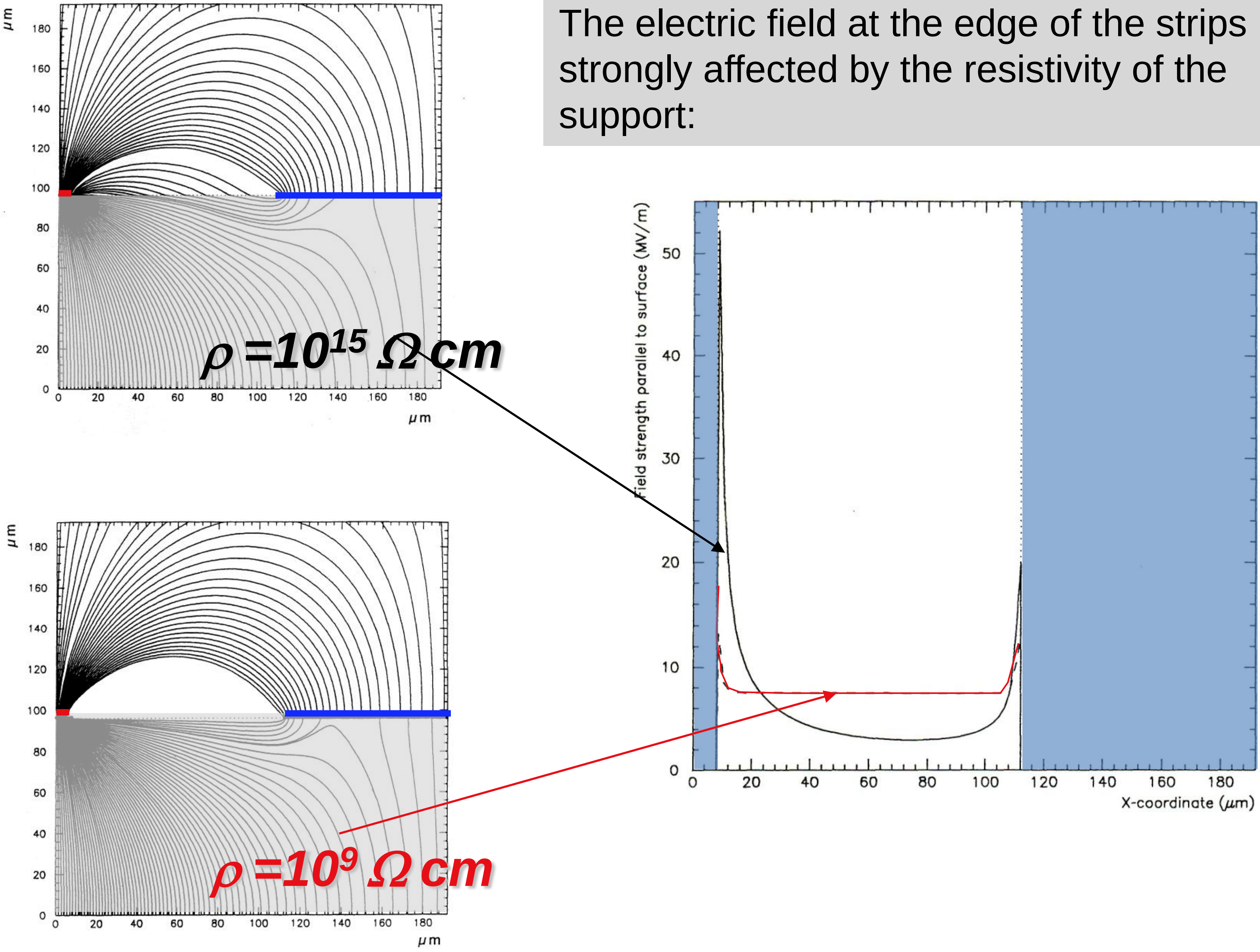
DUE TO SMALL PITCH AND FAST IONS COLLECTION, MSGC HAVE VERY HIGH RATE CAPABILITY:



> 10^6/mm^{2}s

MSGC: STRIP EDGE FIELDS

The electric field at the edge of the strips is strongly affected by the resistivity of the support:

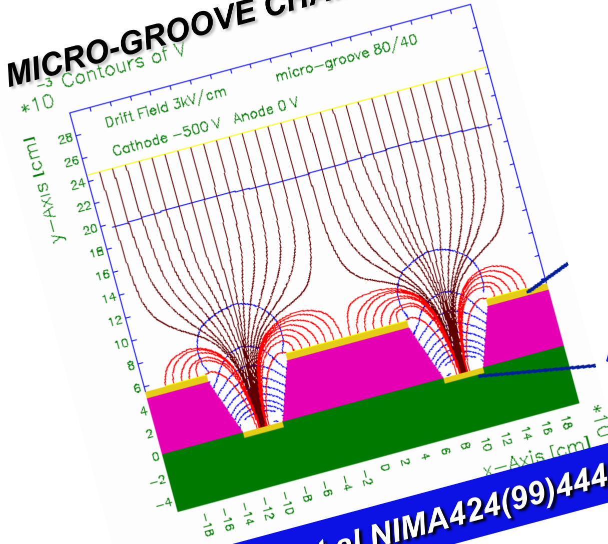


$\rho = 10^{15}\ \Omega\,\mathrm{cm}$

$\rho = 10^{9}\ \Omega\,\mathrm{cm}$

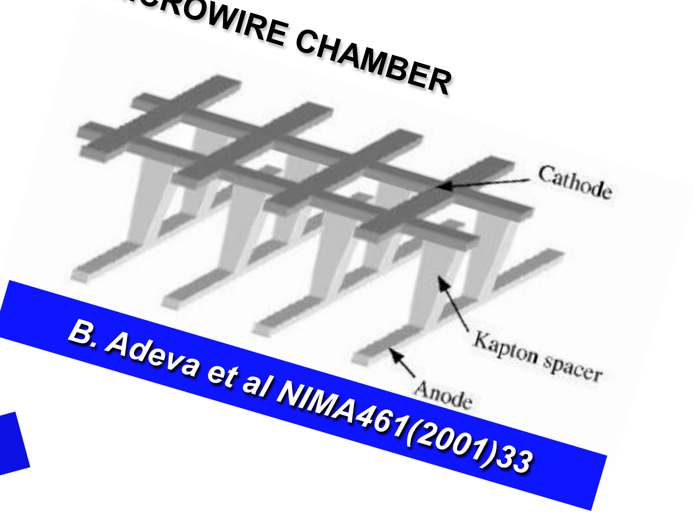
NEW DEVELOPMENTS: MICRO-PATTERN GAS DETECTORS

MICRO-GROOVE CHAMBER



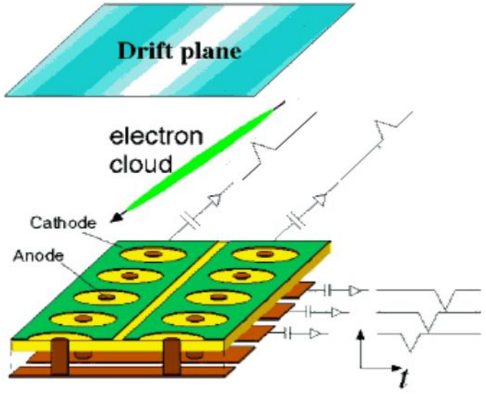
Bellazzini et al NIMA424(99)444

MICROWIRE CHAMBER



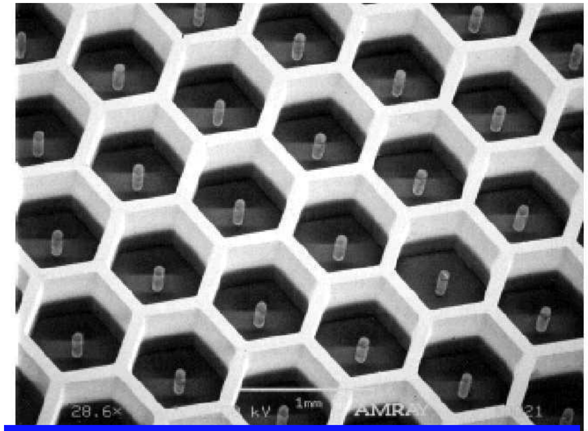
B. Adeva et al NIMA461(2001)33

MICRO-PIXEL CHAMBER



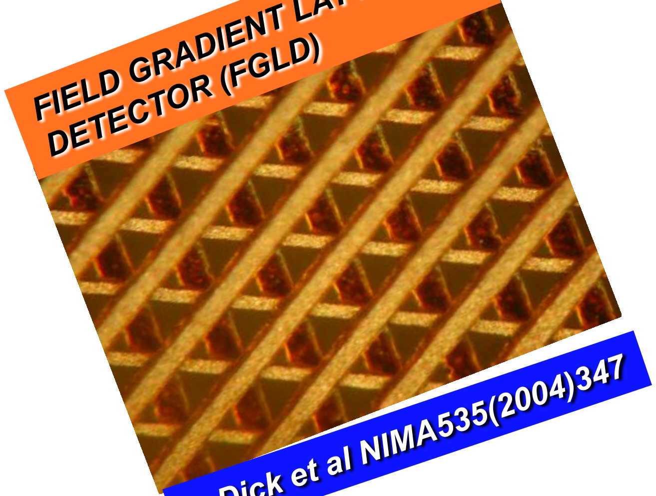
Ochi et al NIMA471(2001)264

MICRO-PIN ARRAY (MIPA)



P. Rehak et al TNS NS47(2000)1426

FIELD GRADIENT LATTICE DETECTOR (FGLD)

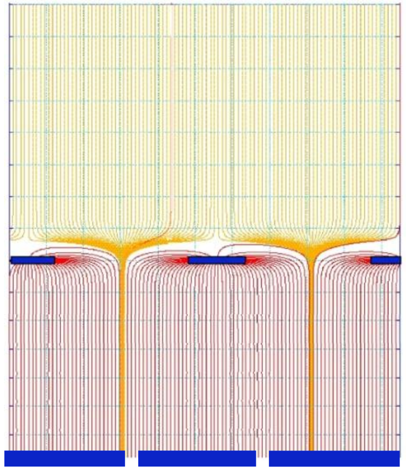


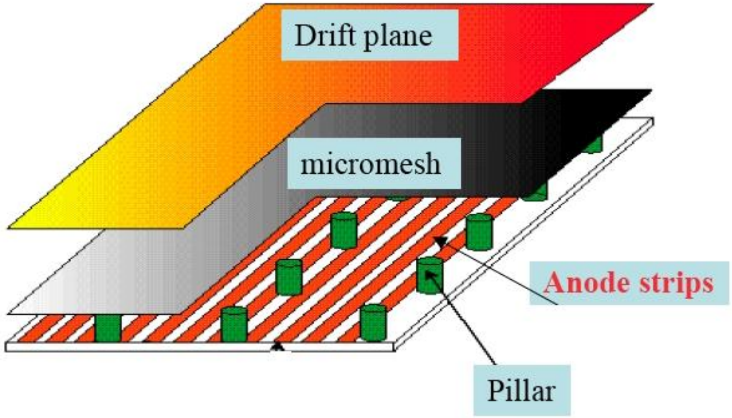
L.Dick et al NIMA535(2004)347

XI RPC Workshop FRASCATI, Italy 2012

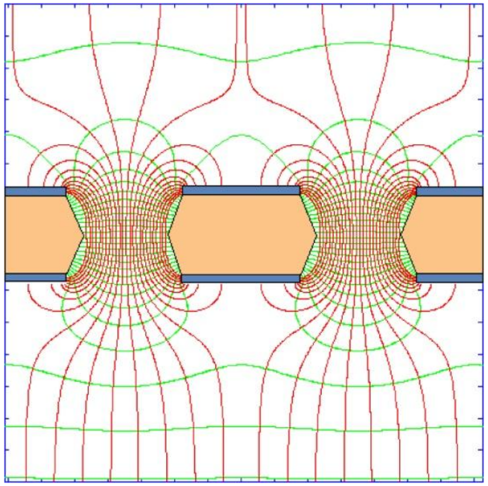
MICROMEGAS AND GEM

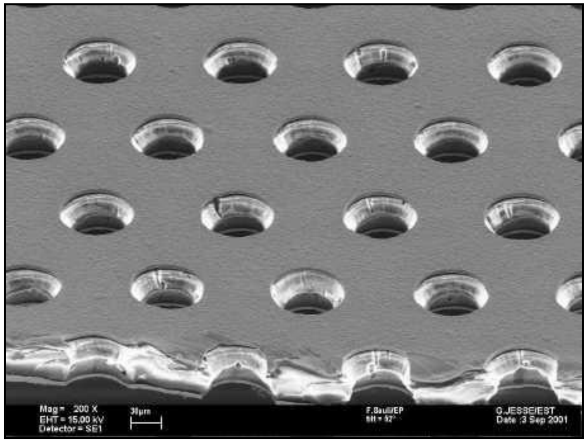
MICROMEGAS
Narow gap (50-100 µm) PPC with thin cathode mesh
Insulating gap-restoring wires or pillars





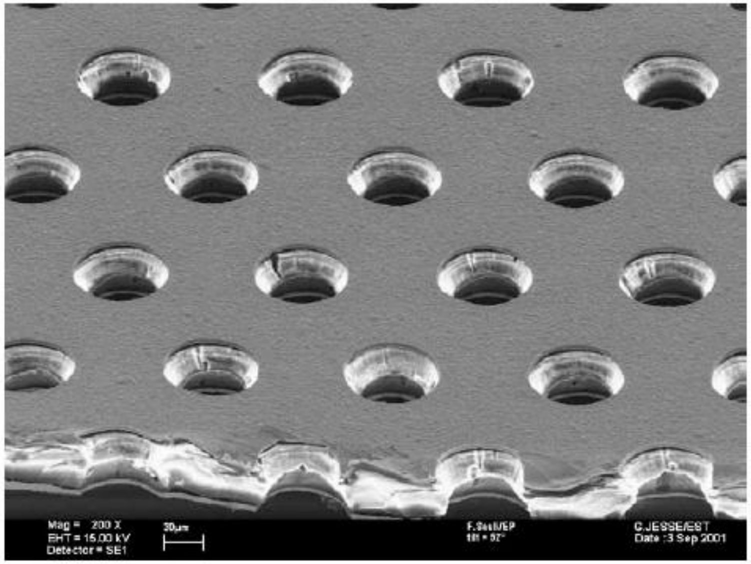
GAS ELECTRON MULTIPLIER (GEM)
Thin metal-coated polymer foils
70 µm holes at 140 mm pitch

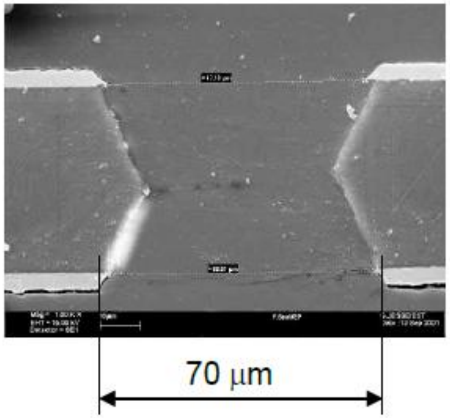




GEM

Gas Electron Multiplier



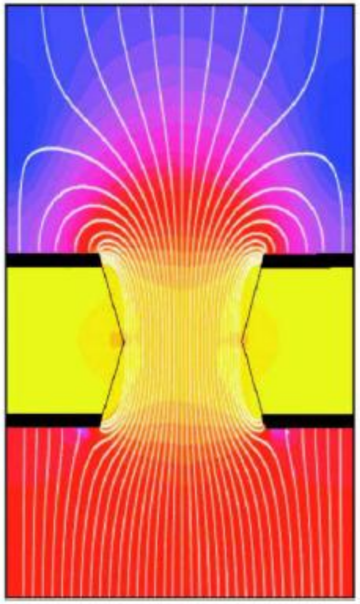


- Thin polyimide foil, typ. 50 µm
- Cu-clad on both sides, typ. 5 µm
- Photolithography: ~ 10^4 holes/cm^2
- Manufactured by CERN-TS-DEM

- ΔU=300-500 V

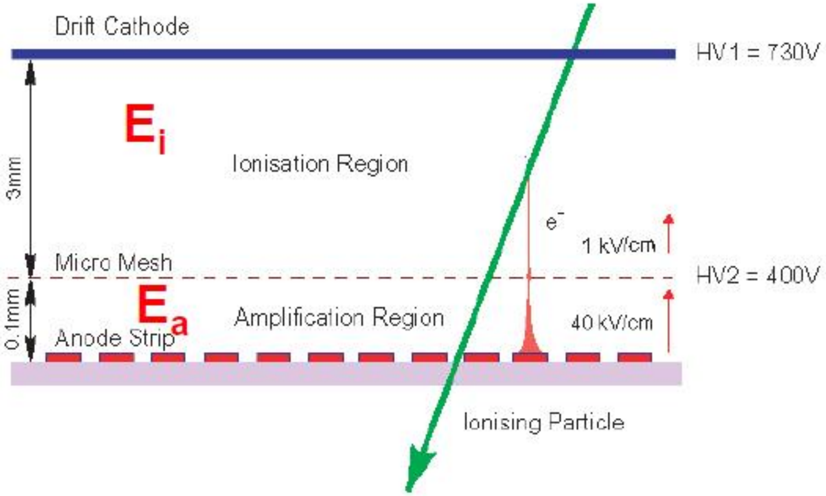
➡ high E-field inside holes: ~ 50 kV/cm

➡ avalanche multiplication



[F. Sauli, NIM A386, 531 (1997)]

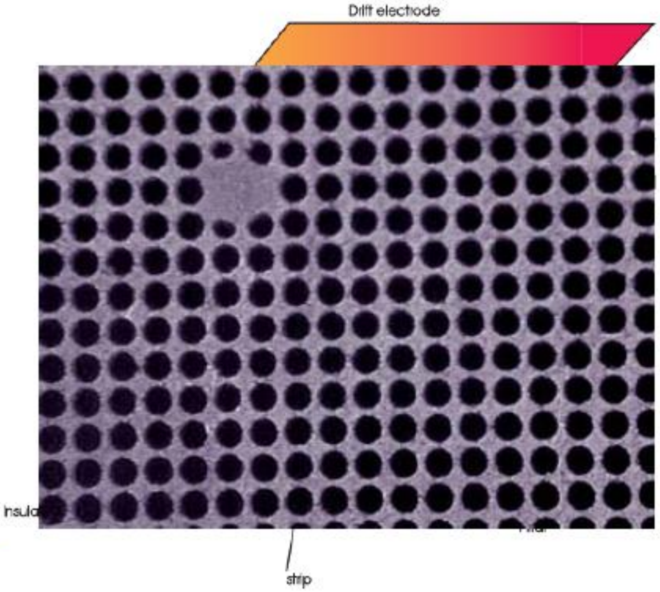
Micromegas

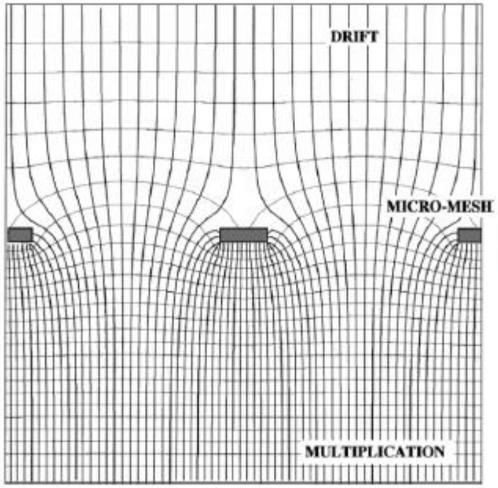


Micromesh Gaseous Structure

[I. Giomataris et al., NIM A376, 29 (1996)]

- Thin gap parallel plate structure
- Fine metal grid (Ni, Cu) separates conversion (~ 3 mm) and amplification gap (50-100 μm)
- Very asymmetric field configuration: 1 kV/cm vs. 50 kV/cm





➡ Fast collection of ions (~ 100 ns)

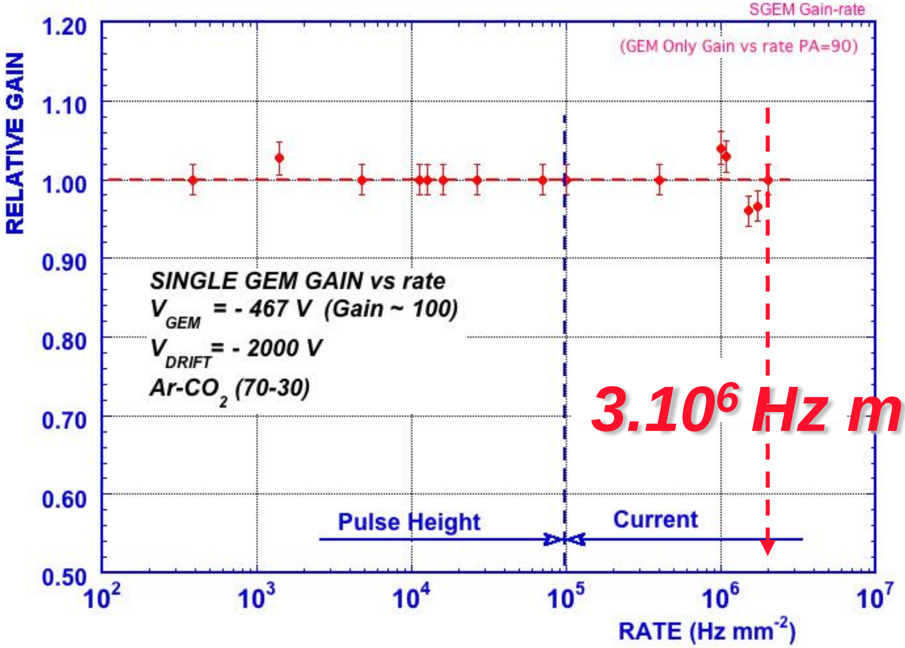
➡ Saturation of Townsend coefficient (mechanical tolerances)

➡ good energy resolution

HIGH RATES - GEM

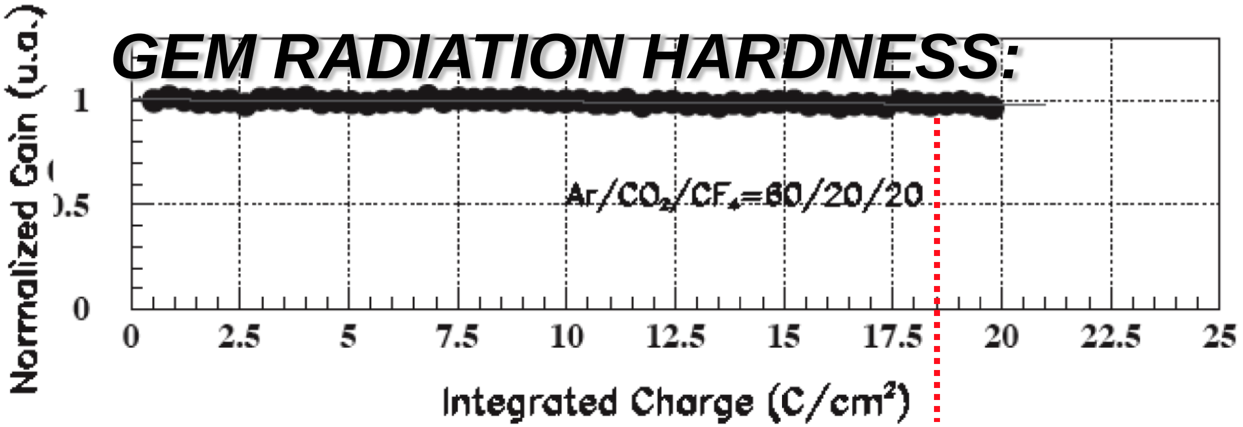
GEM RATE CAPABILITY:

Due to the small gaps and fast ion collection, MPGDs have very high rate capability.
The radiation hardness has been verified up to a collected charge of 20 C cm^{-2}, corresponding to an integrated flux of 4.10^{14} minimum ionizing particles.



3.10^6 Hz mm

GEM RADIATION HARDNESS:



20 C/cm^2

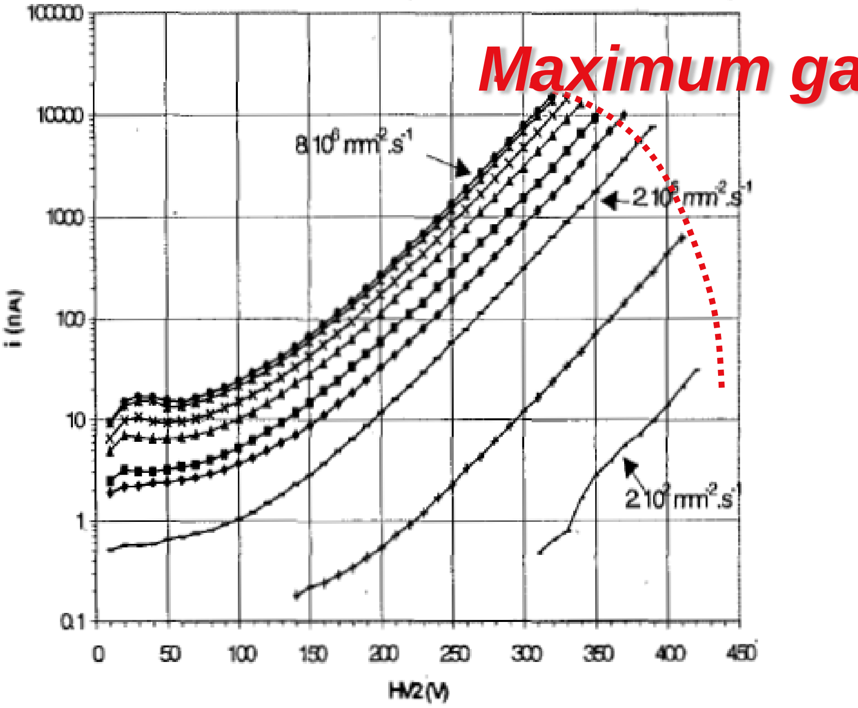
~ 4 10^{14} MIPS cm^{-2}

LHCb MUON TRIGGER:
Triple GEM with fast gas mixture (Ar-CO2-CF_4 45-15-40)

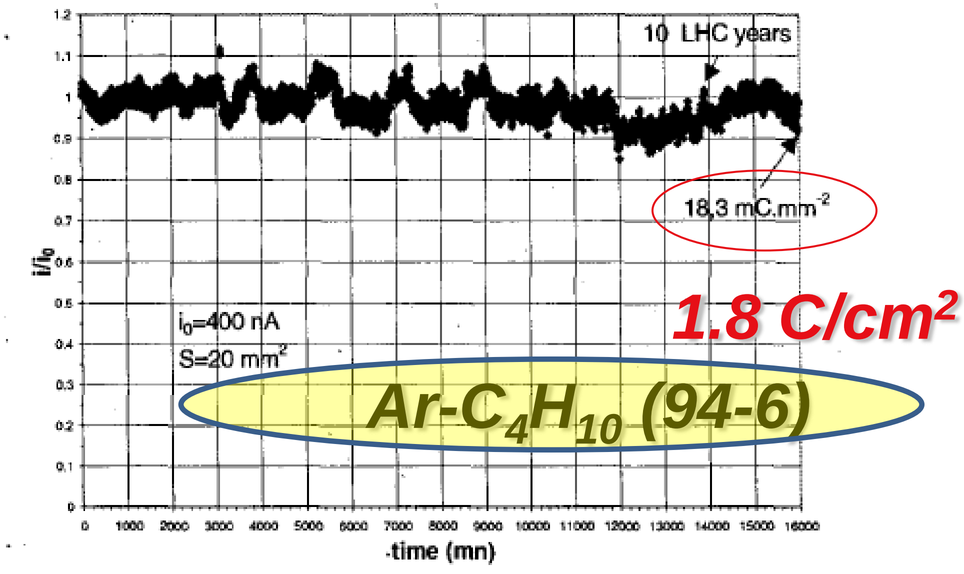
HIGH RATES - MICROMEGAS

High-flux experiments (COMPASS) deploy GEM and Micromegas detectors since several years without change in performances.

MICROMEGAS RATE CAPABILITY CURRENT VS X-RAY FLUX:



MICROMEGAS RADIATION HA

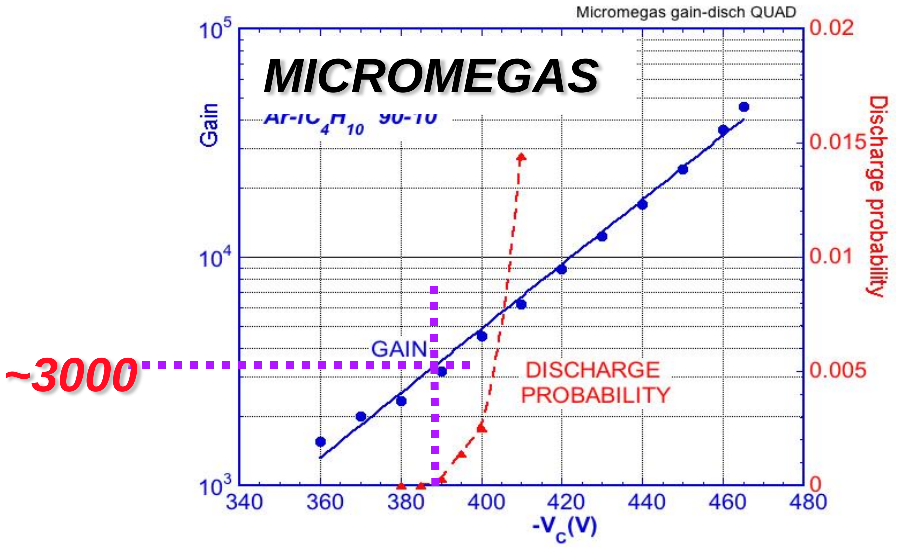


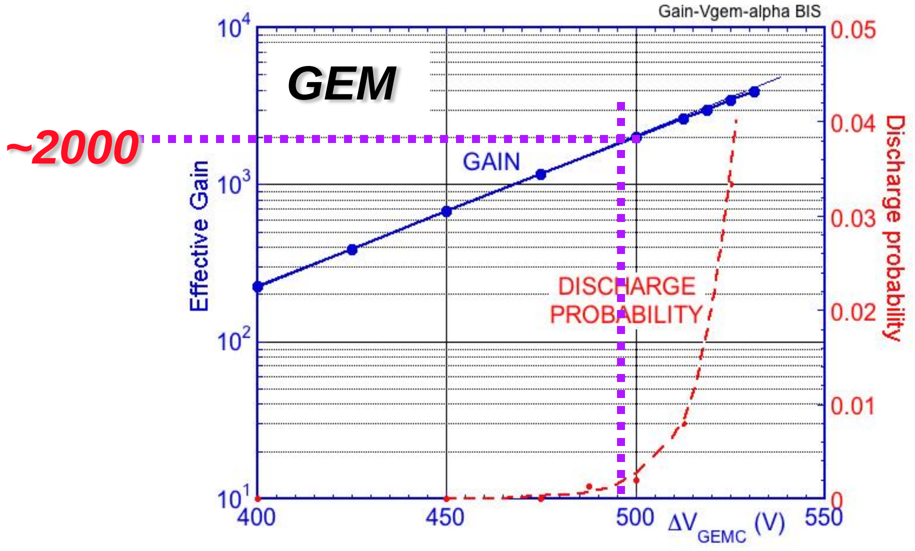
Proportionality: the current is proportional to the flux and the curves are parallel up to 8.10^6 mm^{-2}s^{-1}
The maximum gain depends on flux: at 10^6 mm^{-2}s^{-1} it is about 10^3.

MPGD CERTIFICATION

The maximum gain before discharge is almost the same for all MPGDs tested:

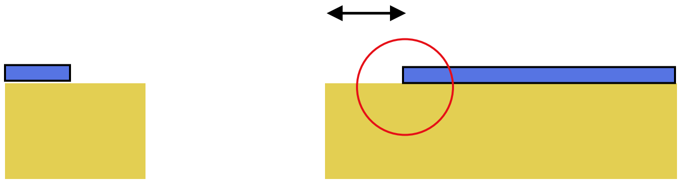
MEASURE GAIN WITH ^{55}Fe X-RAYS AND DISCHARGE PROBABILITY WITH INTERNAL ALPHA SOURCE FROM ^{220}Rn

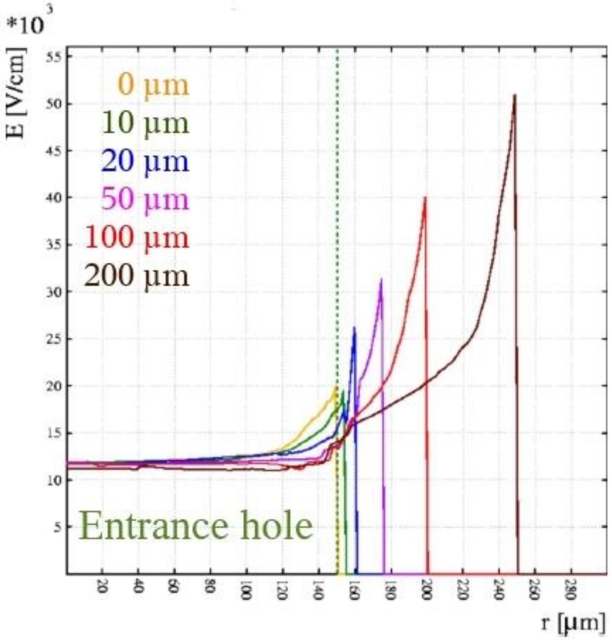


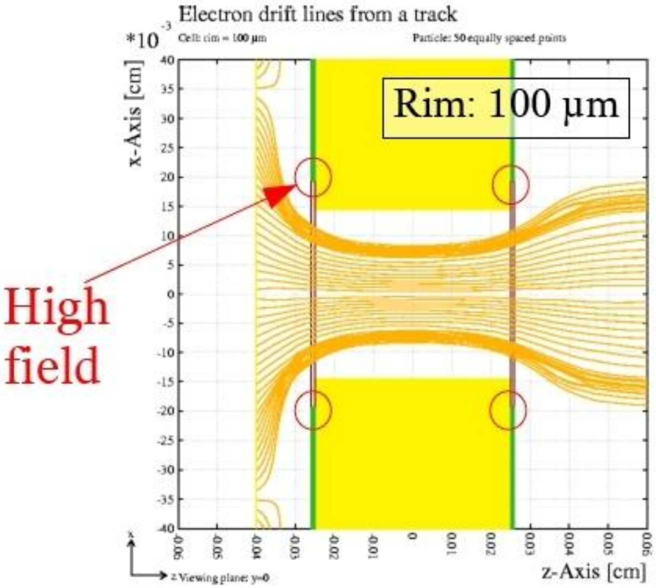


MPGD: ELECTRODE EDGES

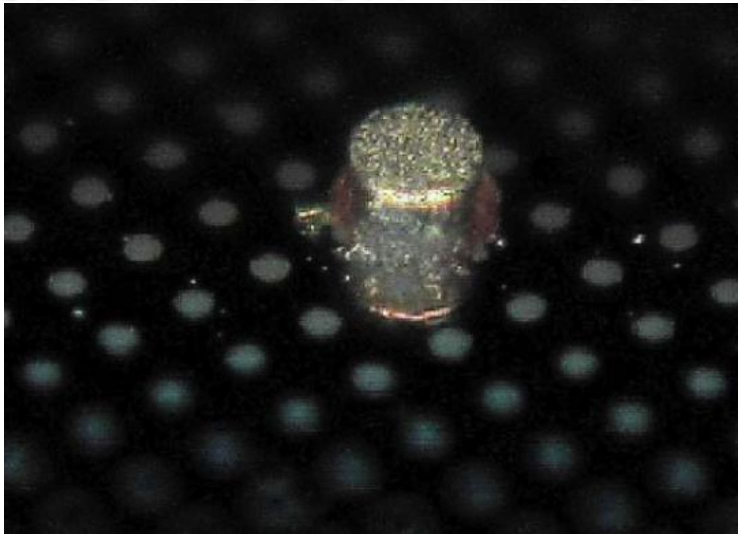
In GEM, there is a region of high field at the metal edge of the holes; the field strength depends from the width of the “rim” (retreat of the metal). The field increases for large rims.







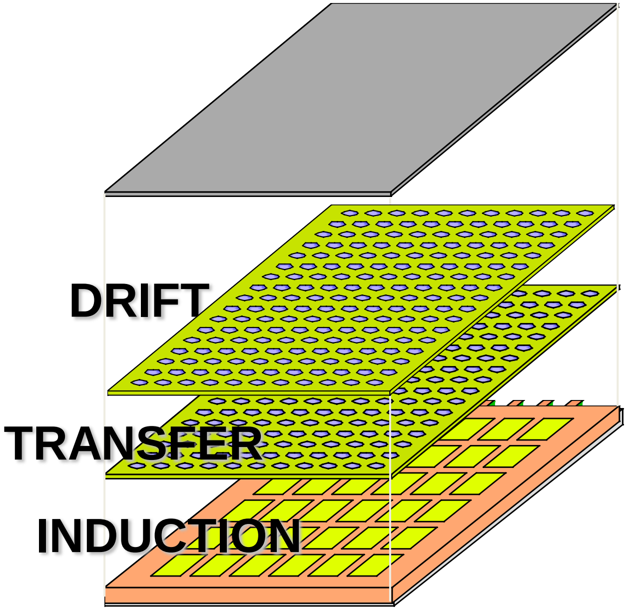
MICROMEGAS: PILLARS!

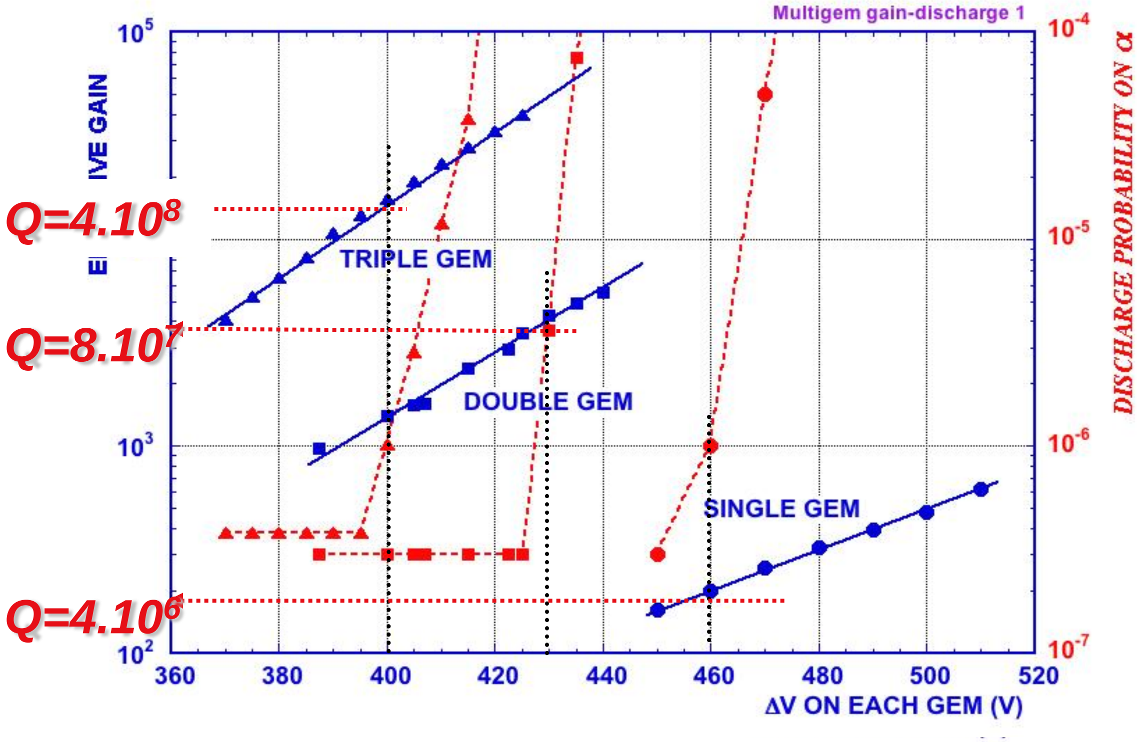


HOW to DEFEAT RAETHER?

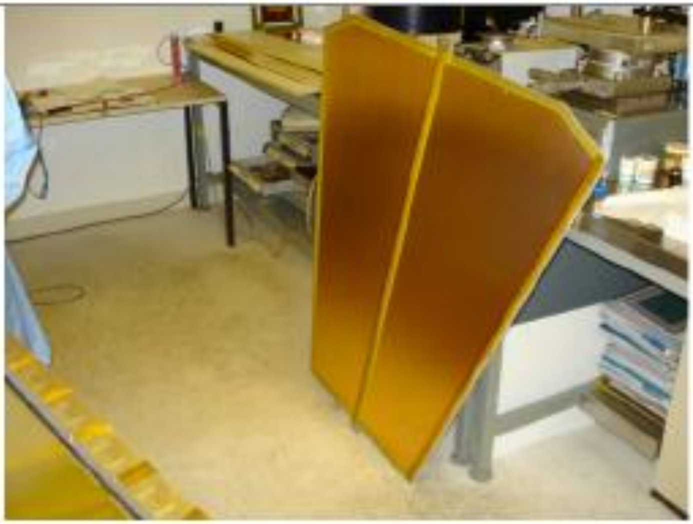
Cascading several GEMs reduces the voltage needed on each foil for the same gain, and largely increases the maximum gain

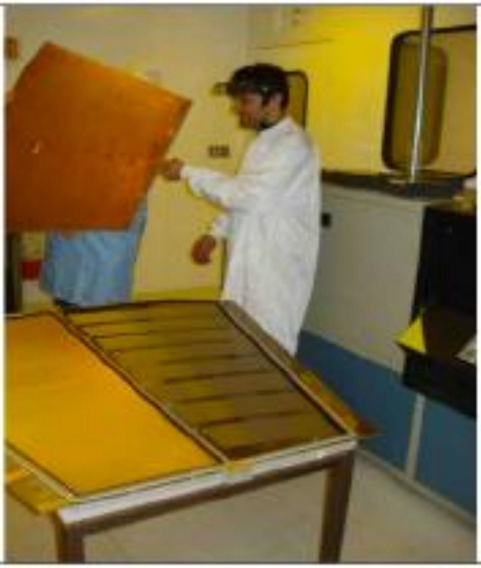
^{241}Am a particles ~ 2.10^4 e-I$^+$ pairs

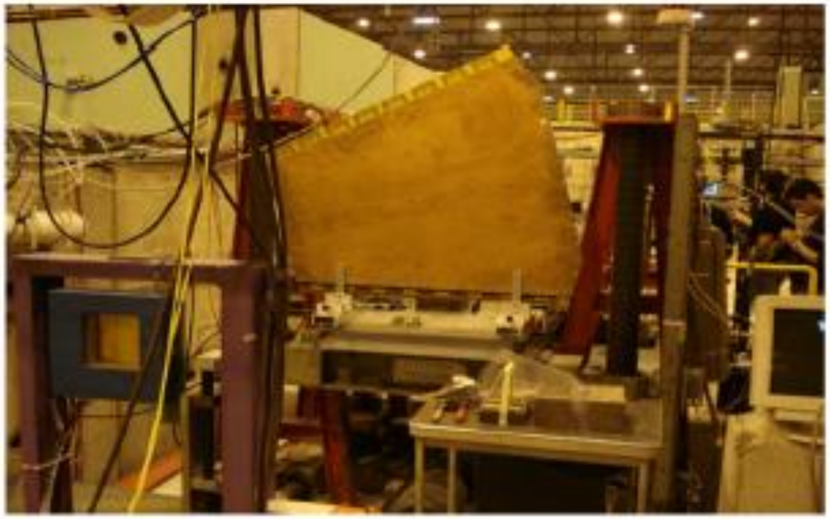


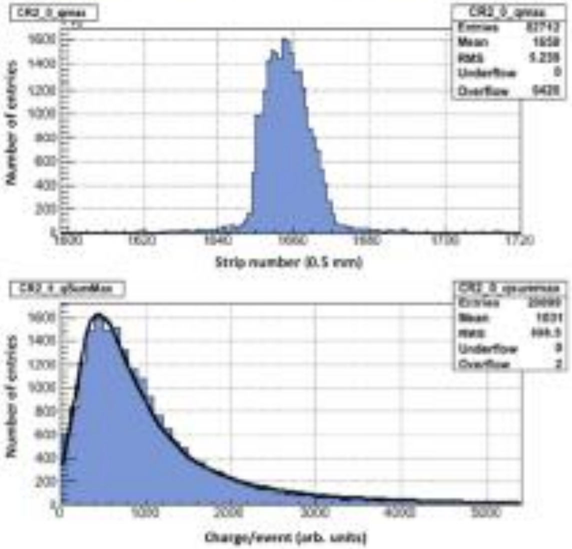


Studies: 2011
Large (Resistive) Micromegas Modules for ATLAS

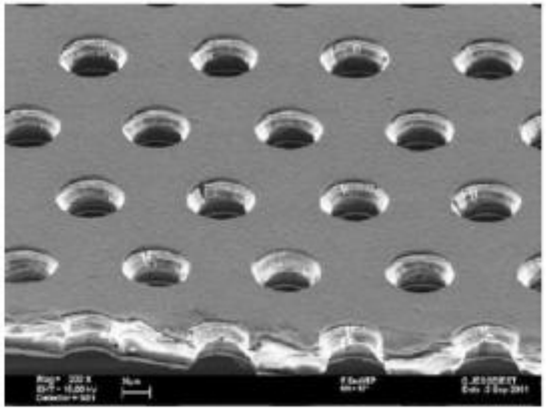


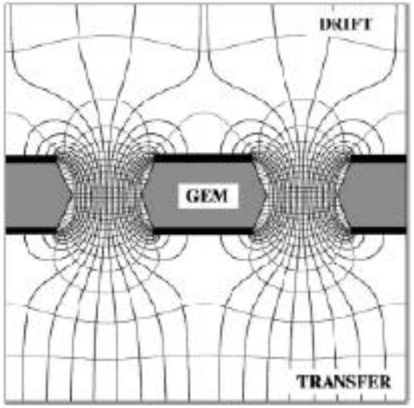


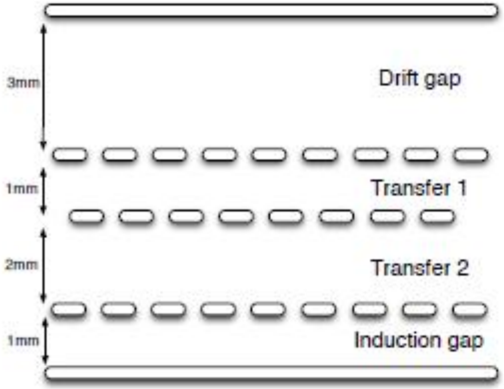




Triple GEM







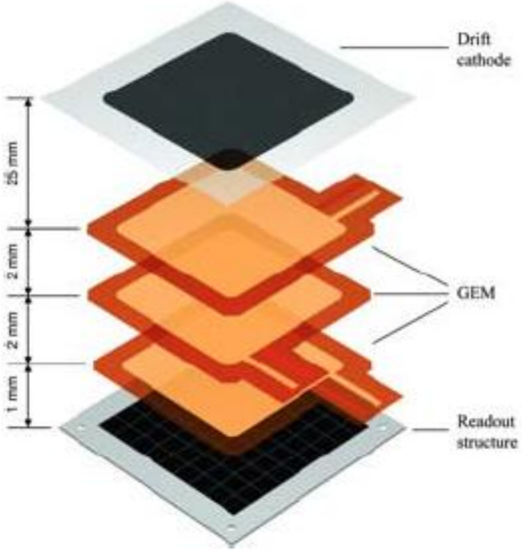


Figure 40: GEMs come in multiple configurations, double or triple GEM detectors depending on the number of amplifying stages used.

Studies: Large Triple GEMs for CMS

Figure 41: GEM foil production and test setup at the RD51 beam area.

Some results - 2011

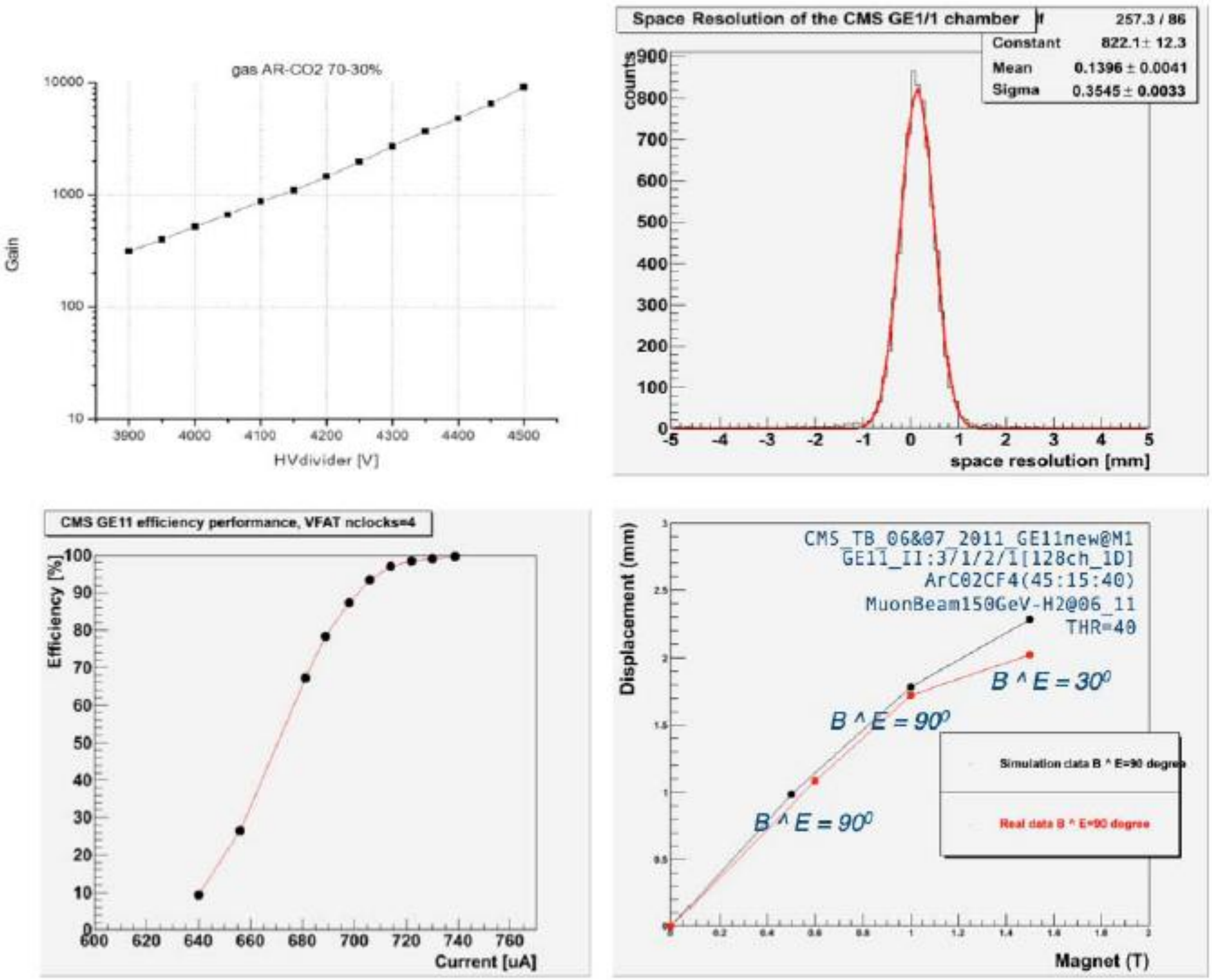
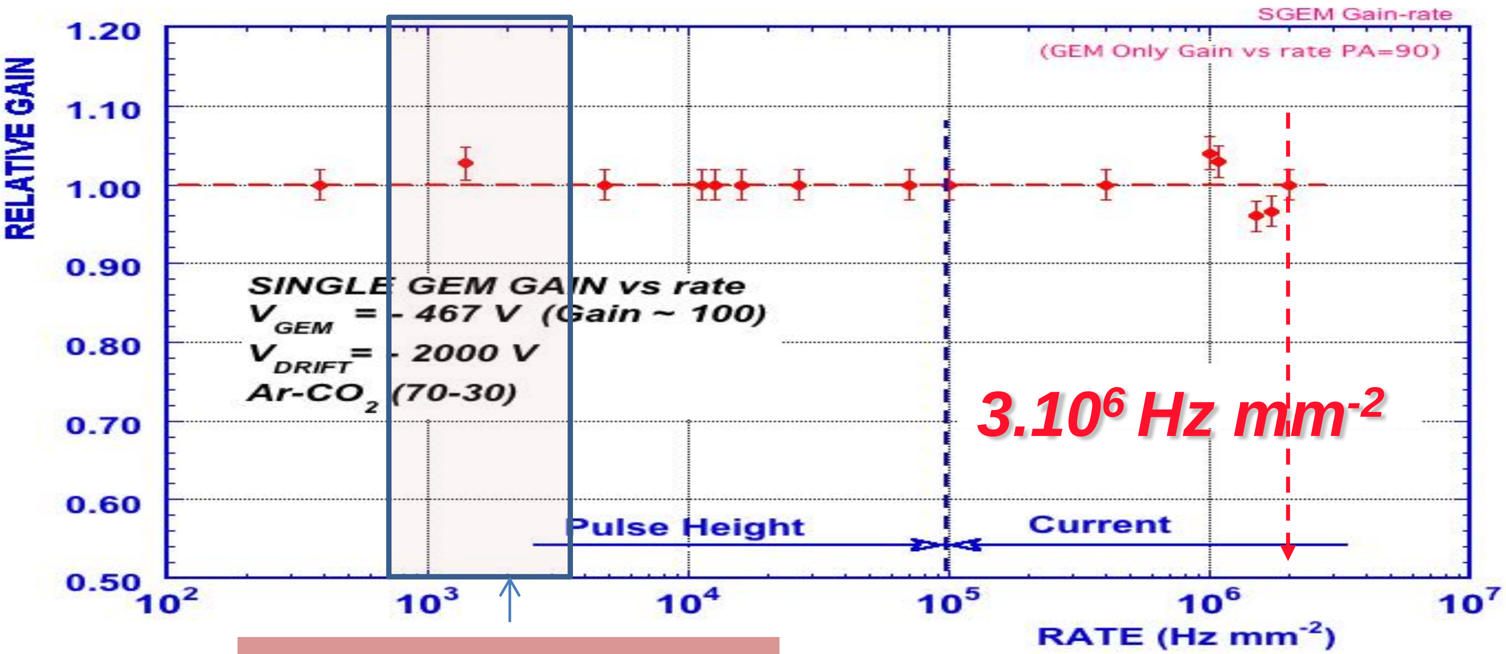


Figure 42: GEM performance in 2010-2011 CMS-RD51 test beams.

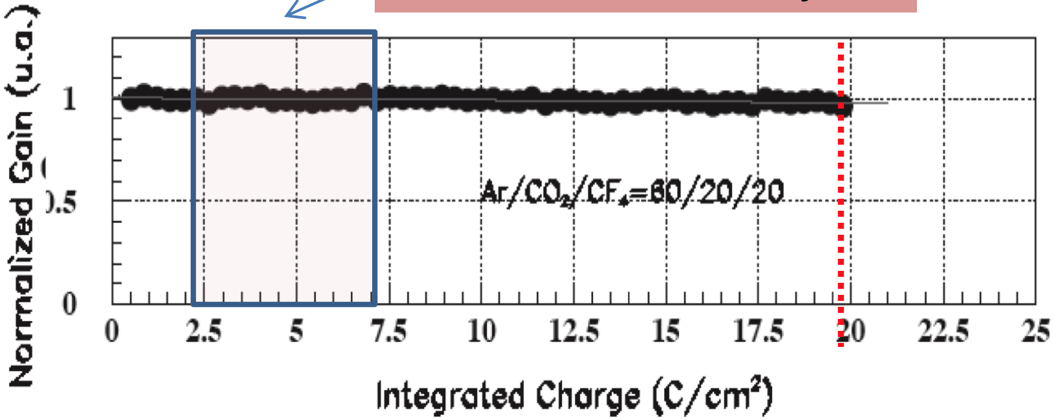
Rate Capability/Aging - GEM



3.10^6 Hz mm^{-2}

J. Benlloch et al, IEEE NS-45(1998)234

CMS Phase II and beyond



M. Alfonsi et al, NIMA518(2004)106

LHCb MUON TRIGGER:
Triple GEM with fast gas mixture
($Ar\text{-}CO2\text{-}CF_4$ 45-15-40)

20 C/cm^2

~ 4 10^{14} MIPS cm^{-2}

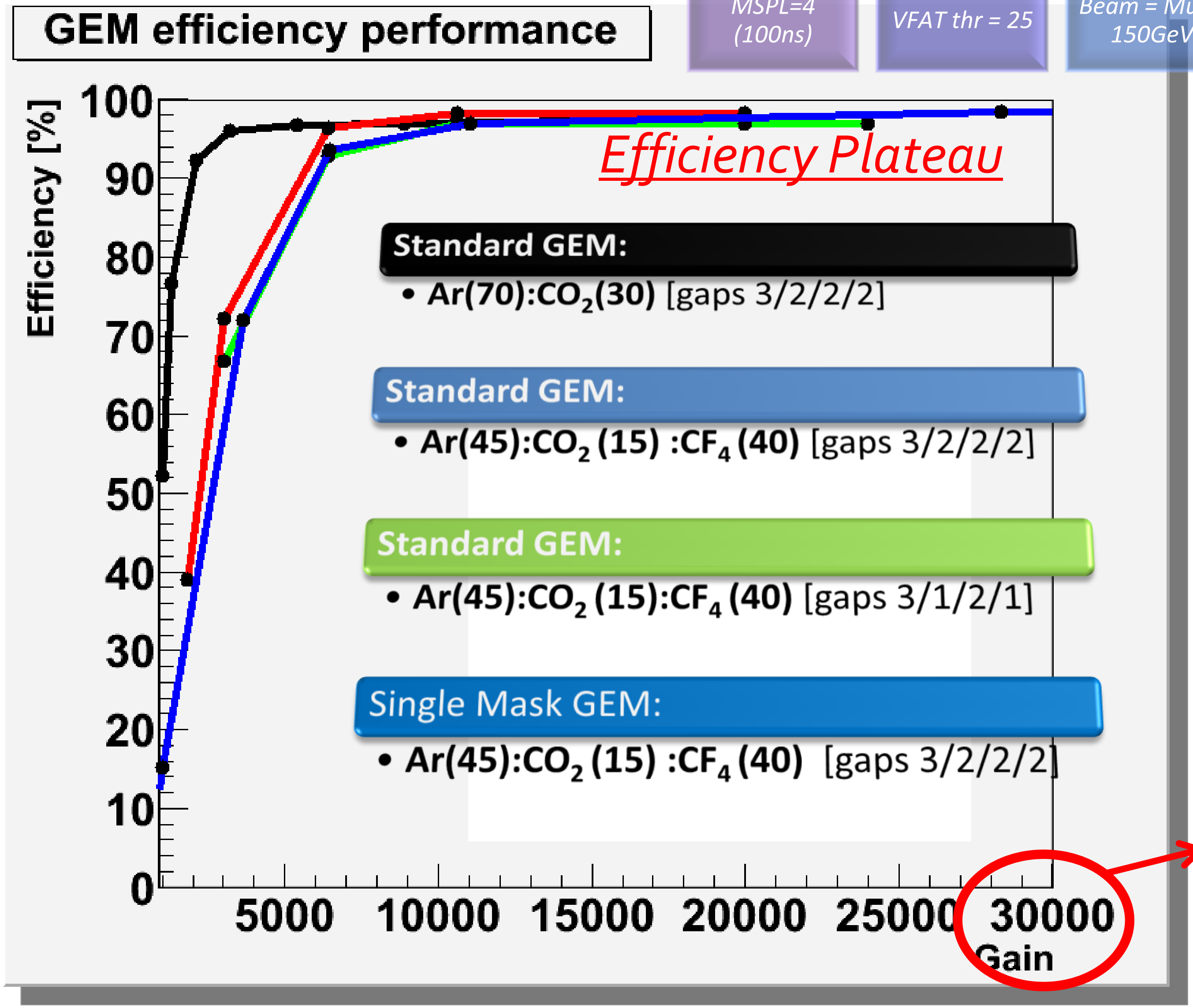
Performance Comparison Beam Tests 2010-2011

MSPL=4 (100ns)

VFAT thr = 25

Beam = Muon 150GeV

25kEvt ∀run



Efficiency Plateau

Standard GEM:
- **Ar(70):CO_2(30)** [gaps 3/2/2/2]

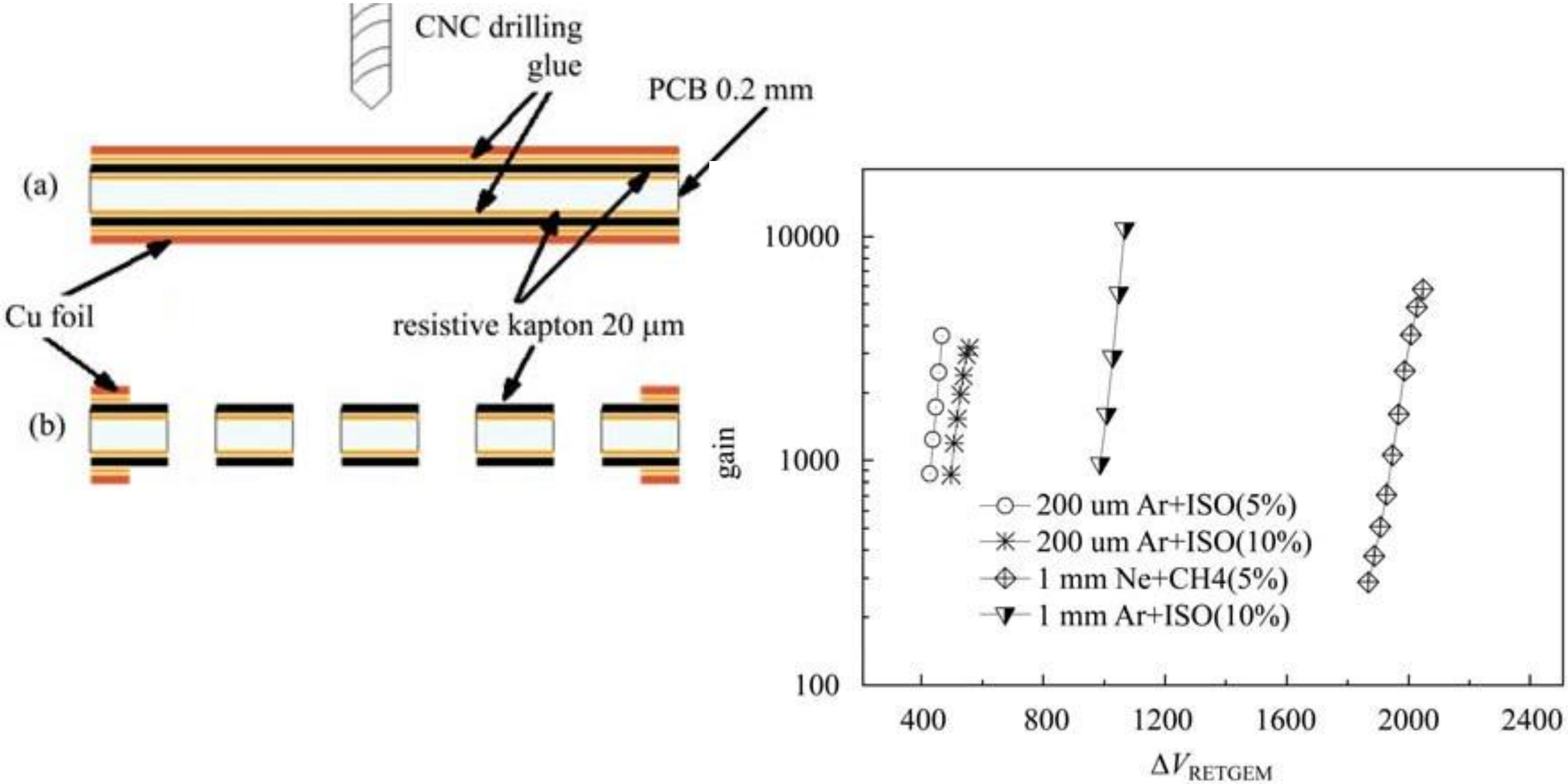
Standard GEM:
- **Ar(45):CO_2 (15) :CF_4 (40)** [gaps 3/2/2/2]

Standard GEM:
- **Ar(45):CO_2 (15):CF_4 (40)** [gaps 3/1/2/1]

Single Mask GEM:
- **Ar(45):CO_2 (15) :CF_4 (40)** [gaps 3/2/2/2]

High achievable gain!

RET GEM



Talk by Peskov !

Advantages and disadvantages MPGDs

Advantages	Disadvantages
High intrinsic coordinate resolution 0.1-0.2mm easily achievable, minimal inefficient zones	Smaller sectors for lowering discharge capacitance
Small sensitivity to backgrounds	Need to purge the system with gas mixture
Density is very low, small H concentration	Possible gas leaks
Small EXB Effect	Need to supply gas during operation
Better spatial resolution in a strong Magnetic field	Needs Reasonably clean room assembly facility
Better two Hit separation	
Capability To suppress Ion feed back	
High detection efficiency ~100 or more primary electron/ion pairs per mip-99.9% efficient	
Large signals Gas gains up to ~104	
Low intrinsic noise clean room assembly facility	High Rate Capability $10^6/\mathrm{mm}^2$ needs
Time resolution ~ a few ns	
Operation in magnetic field proven	
Over one decade construction/operation experience	
Possibility of dE/dxmeasurements	
Reasonable cost	

THANK YOU !