Les detecteurs du futur

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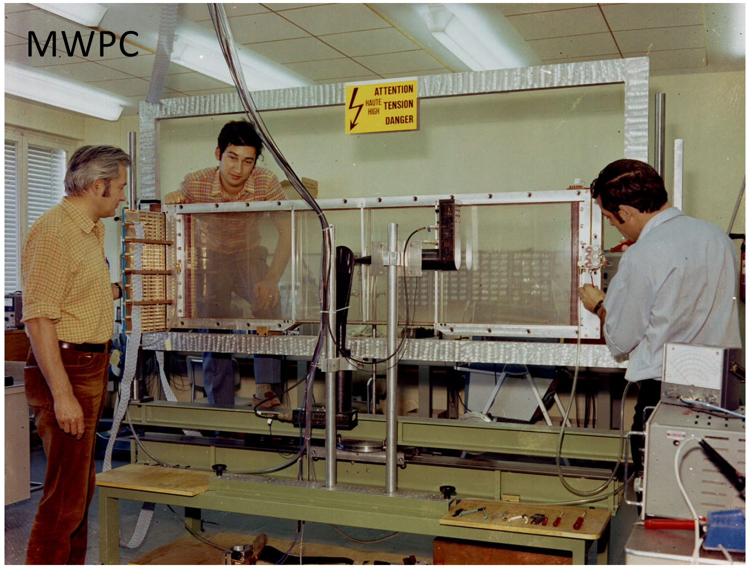
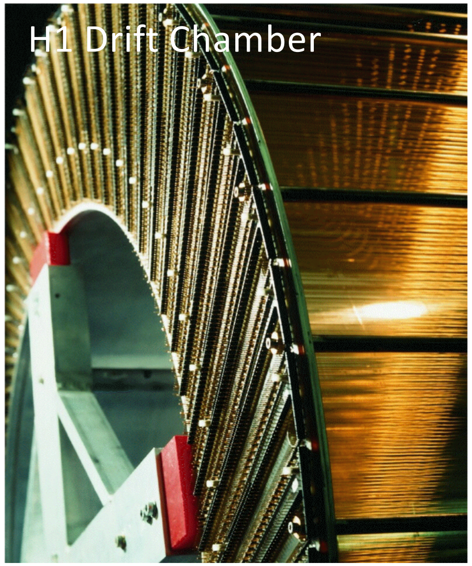
Gas detectors

Measure charged particle trajectories and/or dE/dx for mass identification
well adapted to large area muon systems or large tracking volumes
wide range of granularity and designs, provide hardware trigger





Gas detectors: primary signal parameters

- Ionization
  - I_0 = ionization potential, minimum energy required to create an e^--ion pair
  - W_i average energy of a pair
  - $n_{prim} = L/\lambda$, L thickness, λ mean free path[1)]
    - Fluctuations, dE/dx resolution, efficiency
  - $n_{tot} = L.(dE/dx)/W_i$
    - Estimate of signal

Gas	ρ (g/cm³)	I_0 (eV)	W_i (eV)	min dE/dx (keV/cm)	n_{prim} (cm⁻¹)	n_{tot} (cm⁻¹)
He	1.79×10^{-4}	24.6	41	0.32	3.5	8
Ar	1.66×10^{-3}	15.7	26	2.53	25	97
CH_4	6.67×10^{-4}	12.1	30	1.61	28	54
iC_4H_{10}	2.49×10^{-3}	10.6	26	5.67	90	220
CO_2	1.84×10^{-3}	13.8	54	3.35	35	100

- Transport of charge in E-field
  - μ mobility ∝ time between collisions[2)]
  - v_d drift velocity = μE, E-field
    - O(cm/μs) for e^- and O(10 μm/μs) for ions
      - The low ion drift velocity is a rate limiting factor
  - Diffusion (electron cloud expansion) can affect detector resolution
    - $\sigma_\perp(t) = \sqrt{2/3.D.t}$, t drift time, $D = \lambda^2/\tau$, λ mean free path, τ average time between collisions[3)]
      - $\sigma_\perp$ is O(100 μm/cm)

1) λ depends on temperature and pressure

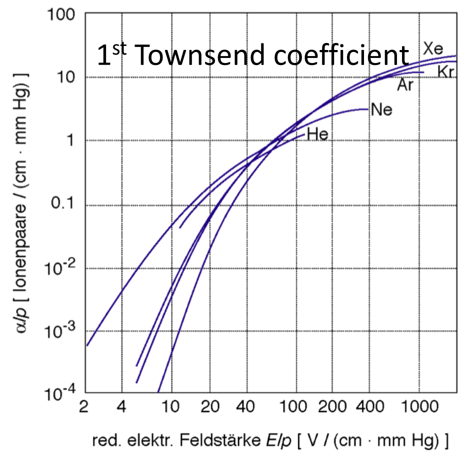
2) *For e^- μ ∝ to E.τ, τ mean time between collisions (Ramsauer-Townsend effect), it is ≃ cst (saturation with E for proper choice of gas mixture)*

3) *E and B fields, reduce diffusion effect*

Gas detectors: amplification process

If E-field is high close to anodes, e^- are accelerated and generates an ionization avalanche process with an exponential gain:

- $G = N/N_0 \exp \int \alpha(x)dx$, $\alpha(x)$ first Townsend coefficient $\propto$ to interaction cross section
  - Typically G is $O(10^4\text{-}10^5)$, this is the proportional regime



- Excitation of atoms in addition to ionization produce mostly UV photons (8 - 14 eV) creating photo-electrons and then secondary avalanches, overall gain becomes:
  - $N/N_0 = G/(1-\gamma G)$, γ second Townsend coefficient (probability to create a photo-electron per e^-)
    - $\gamma G \simeq 1$ is Geiger- Muller mode (signal no longer local)
- Avalanche quenching allows to remain in the proportional domain through
  - Switching of high voltage or with resistive electrodes
  - Adding gas components that absorb UV before photo-electron production, or transfer excitation to molecules (too heavy to generate ionization)
  - At high gain O (10^{10}) and high gas quenching fraction (50%) secondary avalanches can be controlled, this is the streamer mode (signal still local)

Gas detectors: operation modes and generic designs

Proportional mode:

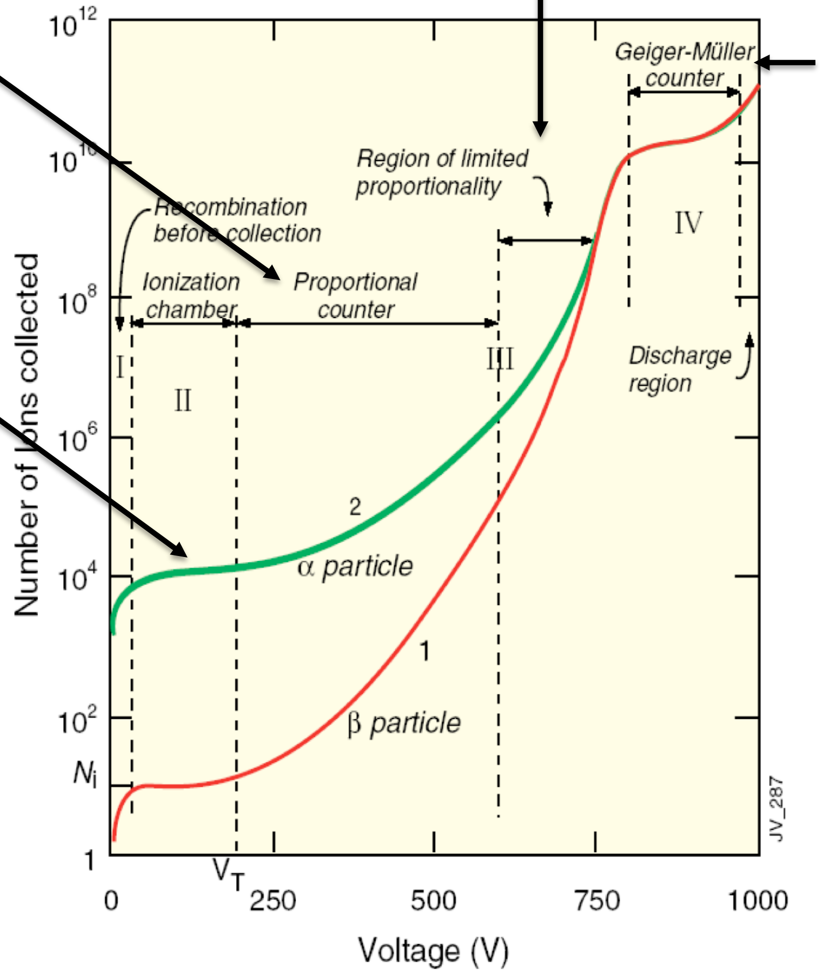
- Single wire: Straw/Drift tubes…
- MultiWire Proportional Chambers (MWPC), CSC, Drift Cahmber, TPC...
- MicroPattern Gas Detectors (MPGD): MSGCs, GEMs, MicroMegas …

Ionization chambers:

- Parallel plate capacitors

Streamer mode: Resistive Plate Chambers…

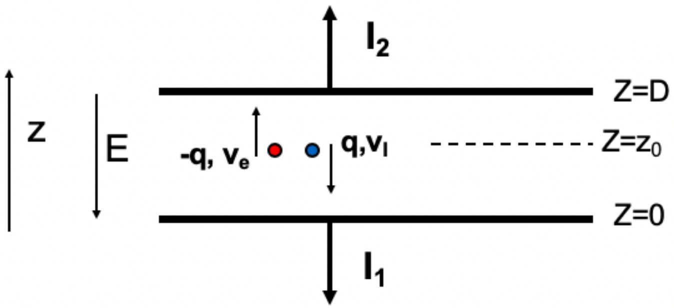
Counting

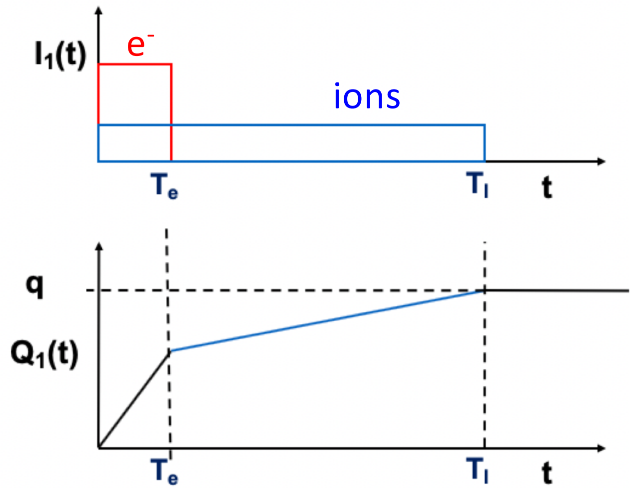


Gas detectors: signal time development

Collected signal is from induction of e^--ion pairs drift

- Q induced on a given electrode respectively by e^- and ions depends on detector geometry (field configuration), it follows Shokley-Ramo law
- It drives the signal time development as drift velocity is very different for e^- and ions



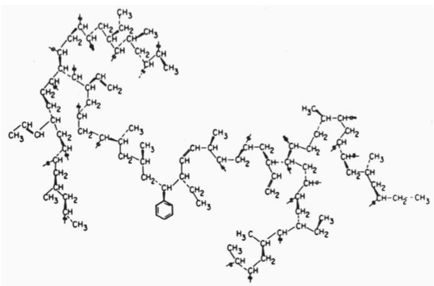
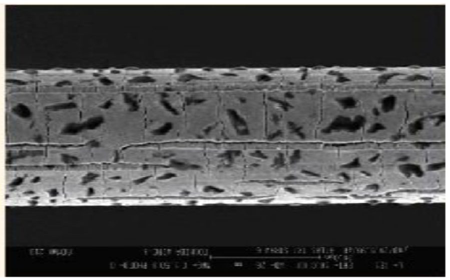
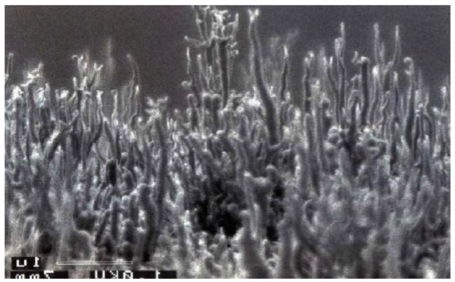


Garfield simulation software include all process of signal collection to guide detector design

Gas detectors: radiation tolerance

Radiation tolerance is referred to as aging and is characterized by the gain degradation with the charge integrated over time per unit length (area) of electrode (C/cm(cm^2))

- Aging process is typically due to formation of deposit on the electrodes
  - Deposits on anodes can be conductive, creating thicker electrode, or insulating, creating charge accumulation, they decrease gain and/or introduce non uniformities
  - Deposits on cathode plans can create insulating layers and a dipole effect generating electron field emission resulting in dark current or discharges
- Source of aging are:
  - Gas components: ex hydrocarbons, e^- break CH_4 to $CH_2 + H_2$, CH_2 radicals create polymer deposits
  - Accidental pollution of gas mixture (ex. silicon present in several materials)
  - Outgassing of construction material and possible effect of irradiation on these materials (ex. glues)


Gas detectors: radiation tolerance

Integrated charge: Q ∝ Gain x Rate x Time x Primaries

- Depend on gas, pressure, temperature, flow, operation voltage(s), detector geometry…
- Dose rate, particle type, ionization density

Aging is not an intrinsic property, gas detectors can be radiation tolerant with careful control of aging causes and thorough pre-qualification with accelerated tests, eg:

- Choice of gas mixture
- Choice of operation parameters, renewal of flow, minimized gain (low noise electronics helps)
- Strict control of gas system, pipes, leaks
- Choice of chamber materials (databases exist)
- Addition of small amount of O_2, H_2O to etch/prevent deposits
- Some geometry are less prone to aging, ex. multiple amplification stages in GEM, far from collecting electrode, substantially increase longevity

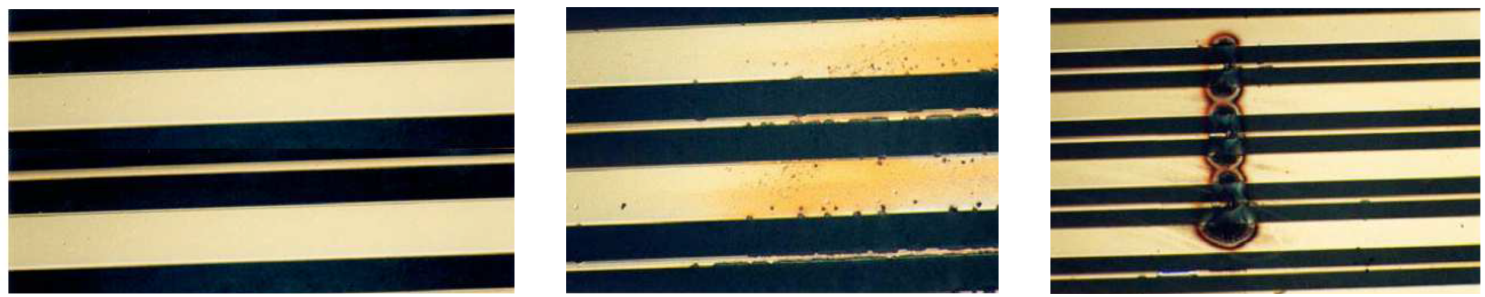
Example of integrated charges in CMS muon systems at HL-LHC (3000 fb^{-1})

$\|\eta\|$ range	DT 0-1.2	CSC 0.9-2.4	RPC 0-1.9	iRPC 1.8-2.4	GE1/1 1.6-2.15	GE2/1 1.6-2.4	ME0 2.0-2.8
neutron fluence (10^{12} n/cm^2)	0.4	40	1	7	20	12	200
total ionization dose (kRad)	0.12	10	2	3	3	7	490
hit rate (Hz/cm^2)	50	4500	200	700	1500	700	48000
charge per wire (mC/cm)	20	**110**	-	-	-	-	-
charge per area (mC/cm^2)	-	-	280	**500**	6	3	280

Gas detectors: discharges

Under high voltage local sharp edges on electrodes and/or charge accumulations can generate discharges, that destroy electrodes and/or readout and/or introduce recovery dead time

- This is a typical effect of MicroPattern devices where metal electrodes are etched and/or distance between anodes and cathodes are small O(10-100) µm
- Quality of electrode etching process is crucial to reach required high voltage (gain)
- Control of material resistivity for charge evacuation is important
- Strict QA/QC tests need to be implemented to evaluate discharge rates
  - Test can be long, acceleration can influence result (charge accumulation is rate dependent)
- Thorough electronics protections needs to be implemented considering energy released in discharges (it depends on electrode capacitance)
- Some geometries are less prone to discharges, operation at lower gain is beneficial



Gas detectors: gas mixture choice

- Gas parameters
  - Large primary ionization (fluctuations): noble gas (Ar, Kr, Ne, Xe), CO_2, hydrocarbons (similar)
  - Total ionization (signal amplitude): similar behavior as primary ionization[1)], He and CO_2 better for sensitivity to single primary ionization
  - Drift velocity (signal rise time, charge collection time (rates)): Hydrocarbons better than CO_2 better than noble gases[2)], He x 5 better than noble gas for ions, in Ar:iC_4H_{10} e^- mobility saturates at low E-field[3)]

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- Other criteria
  - Avalanche quenching: iC_4H_{10}, CH_4, Ethanol in proportional mode, special hydrocarbons in streamer mode
  - Aging properties: CF_4, O_2, H_2O
  - Multiple scattering of incident particle or primary electrons: high X_0, favor low Z eg. Ne, He

Experiment	Sub- Detector	Gas Mixture
ALICE	TPC, TRD, PMD	Noble Gas (Ar, Ne, Xe) + CO_2 Additive: O_2
ATLAS	CSC, MDT, TRT	
CMS	DT	
LHCb	OT straws	
TOTEM	GEM, CSC	
LHCb	MWPC, GEM	Ar - CF_4 - CO_2
CMS	CSC	
	RPC	$C_2H_2F_4$ - iC_4H_{10} - SF_6
	TGC	CO_2 – n-pentane
	RICH	CF_4 or C_4F_{10}

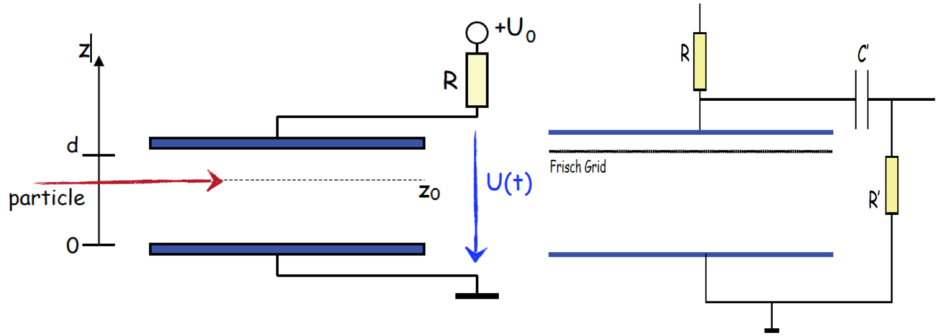
Main components are noble gases (mostly Ar), gas mixture proportions allow optimization according to different detector types and choice of compromise in performance criteria

1) Some times due to compensation in different parameters, eg density, dE/dx, mean pair energy

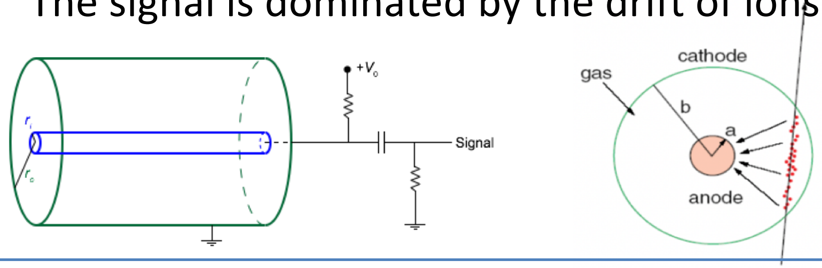
2) Difference somewhat higher for electrons than for ions, 3) constant mobility is important for drift time measurement

Gas detector designs: Ionization Chambers and Straw Tubes

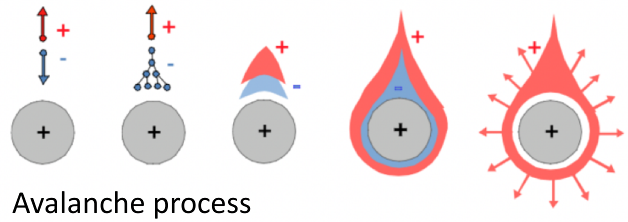
- Ionization chambers
  - Large cells suitable to monitor particle flow from current or pulse measurement (not really for position)
    - Typical size: O (cm x cm x cm)
    - Frisch grid filter ion signal, sensitivity only to electron drift (signal doesn't depend on crossing position)



- Straw tubes, used for Transition Radiation Tracker[1)]
  - Single anode wire (usually gold plated W) in cylindrical cathode tube (ex Kapton doped carbon)
    - Typically anode wire radius O(10's) µm, and radius order O(mm-cm)
    - Voltage application allows amplification in 10's of µm around anode (order of mean free path)
    - The signal is dominated by the drift of ions toward the cathode



$E(r) = V/[r\ln(r_b/r_a)]$

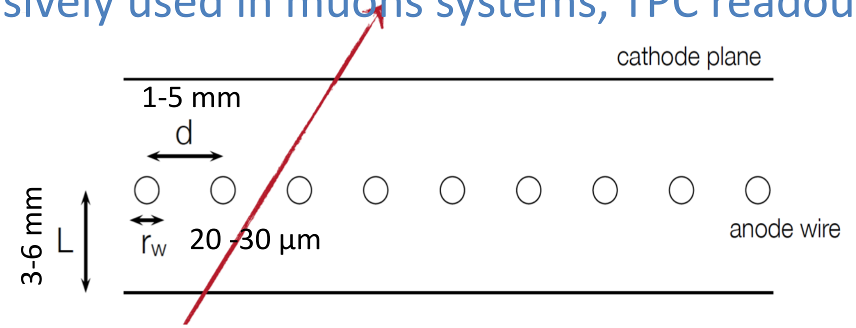


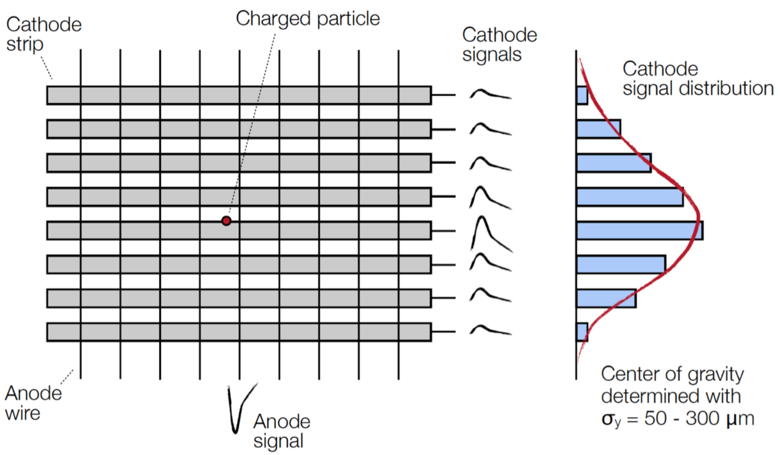
Avalanche process

1) See Cerenkov section

Gas detectors designs: MultiWire Proportional Chambers (MWPC)

- Planar geometry to extend sensitive area to O(m^2), extensively used in muons systems, TPC readout
  - Operation at few kV
  - Rates O(10's) kHz/cm^2
  - Resolution O(50-100) µm with center of gravity of signal
  - Cathode segmentation allows readout for 2D-coordinates measurement

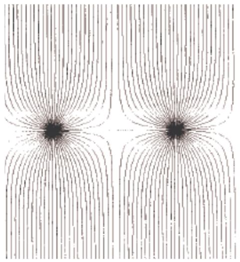


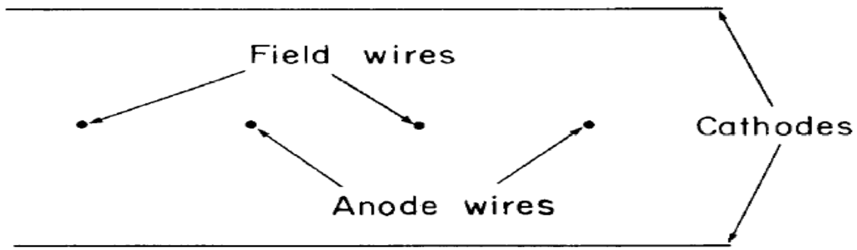


CMS resolutions: ≃ 50-250 µm and ≃ 5 ns

ATLAS Thin Gap Chambers resolution ≃ 50 µm

Field lines



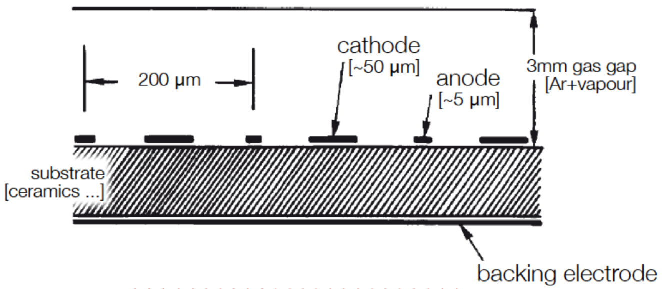


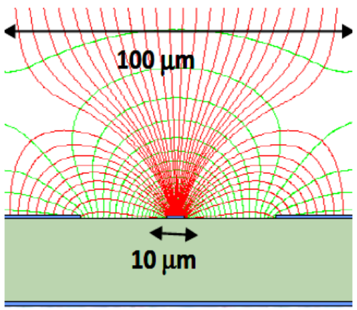
Field wires reduce weak field area between anodes

Gas detector designs: MicroPattern Gaz Detectors (MPGD)

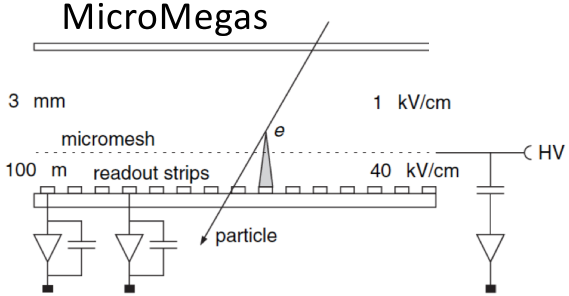
- Micro-structures on insulator using etching technologies replace wires to increase granularity for rate/occupancy capability and resolution, used for muon systems and TPC readout
  - Rates O(MHz)/cm^2, $\sigma_{hit} \simeq 50$ µm, $\sigma(t) \simeq$ few ns
  - Original design with MicroStrip Gas Chambers (on glass/silicon wafers)
    - Lythography technics not good enough at that time to avoid discharges
  - MicroMegas: mesh design with amplification between mesh and anodes
  - GEM: Intermediate amplification in metalized foil holes

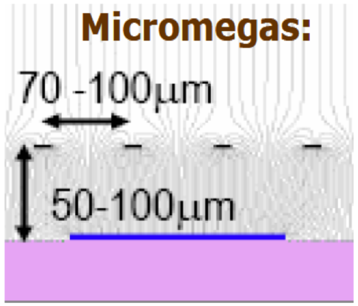
MSGC



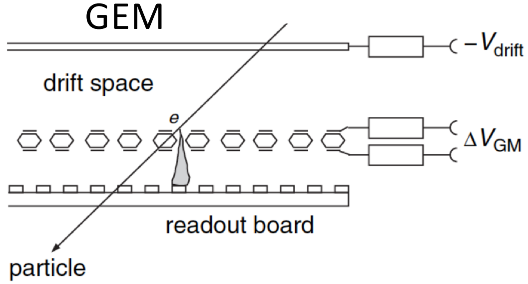


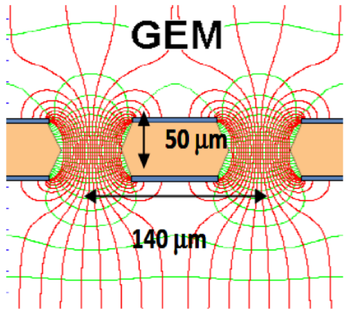
MicroMegas





GEM

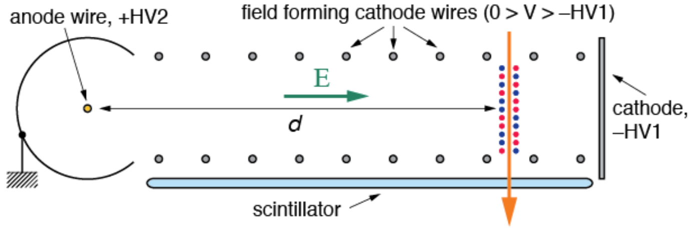




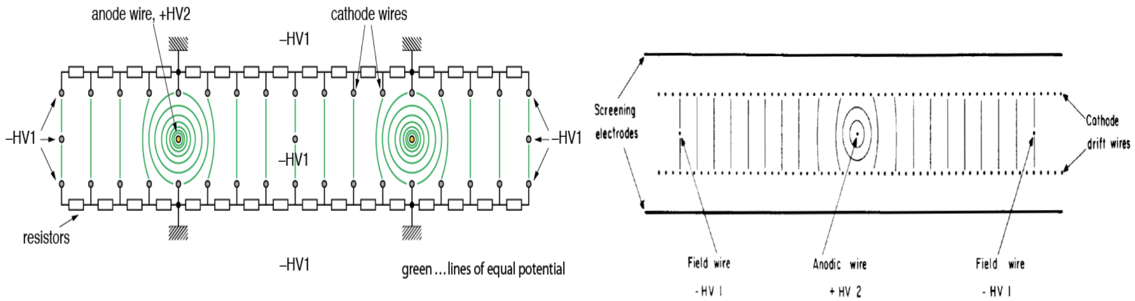
Gas detector designs: Drift detectors planar design

- Provide good resolution at relatively low granularity by measuring particle impact position[1)]
  $x = v(t-t_0)$, v velocity, t_0 crossing time, t signal detection time, used for muon systems
  - Drift length is a detector design parameter O(cm) for muon applications (< kHz/cm2 rate)
  - Resolution[2)] O(50-200) μm depending on drift length

$$\sigma_x = \frac{1}{8N}\cdot\frac{1}{\mathbf{x}}(\text{ionization}) \oplus \sqrt{\frac{2D}{v_D}}\cdot\sqrt{x}\,(\text{diffusion}) \oplus \sigma_\delta \oplus \sigma_{\text{electronics}}$$

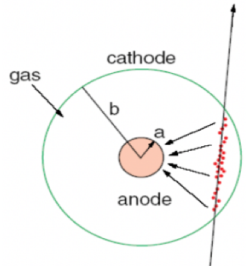


MultiWires design, field adjusted to maintain constant field (velocity) with HV divider on cathodes wires



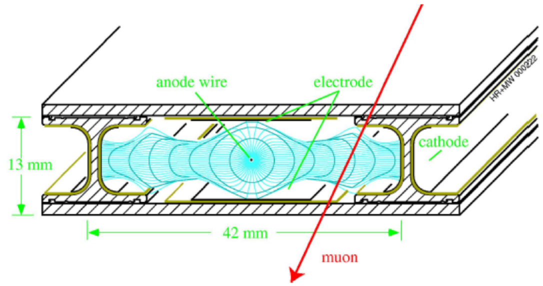
Drift Tube designs

ATLAS/LHCB



resolution:
ATLAS ≃ 100 μm
LHCb to 200 μm

CMS

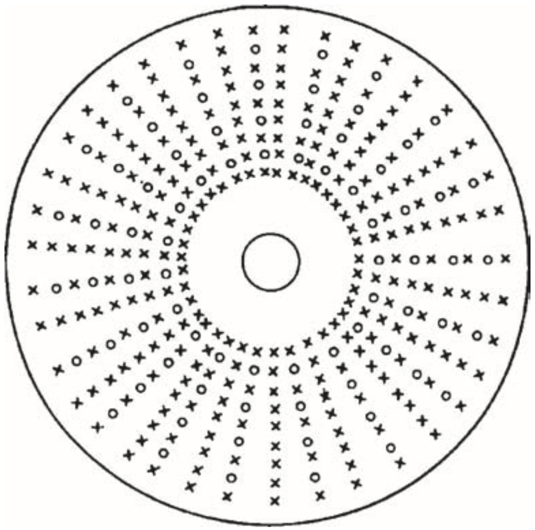


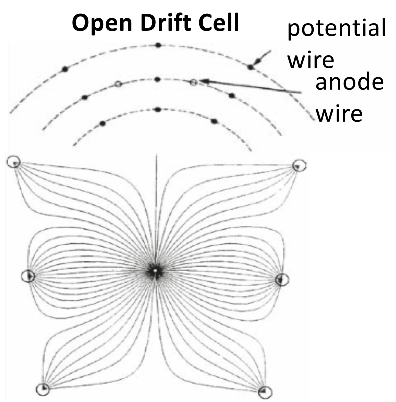
resolutions:
≃ 100 μm and ≃ 2 ns

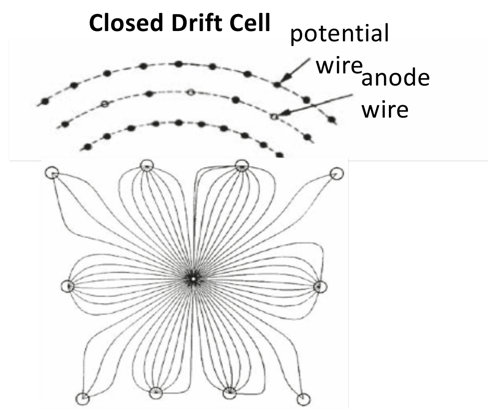
1) *z-coordinate can be measured from charge division with readout at both ends of anodes*
2) *Pressure can improve primary ionization N and reduce diffusion*

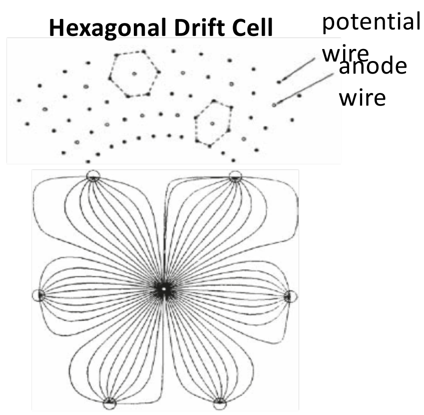
Gas detector designs: Drift Chambers cylindrical design (DC)

- Extend the planar drift measurement concept to large volume and number of measurement points on track path, with low material mass, can provide particle ID with multiple dE/dx measurements, used for tracking in relatively low rate environment
  - Longitudinal anode and cathode wires in cylindrical gas volumes
  - Cell size can be adjusted to performance needs
  - Staggered anodes can allow solving ambiguities
  - Stereo can measure z coordinate



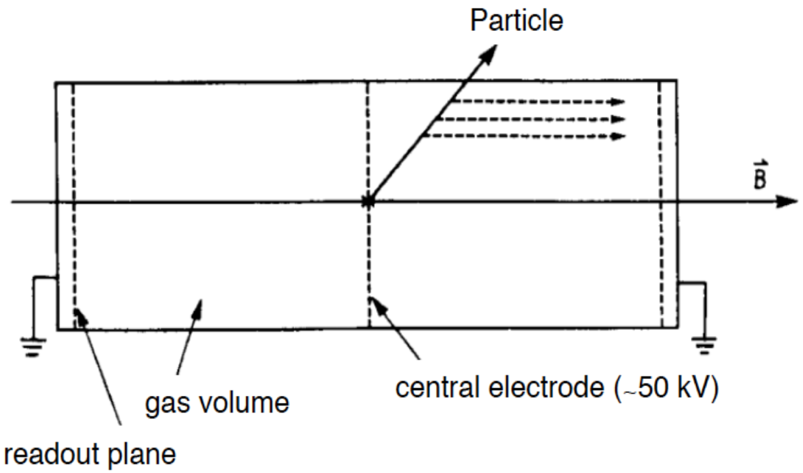






Gas detector designs: Time Projection Chamber principle

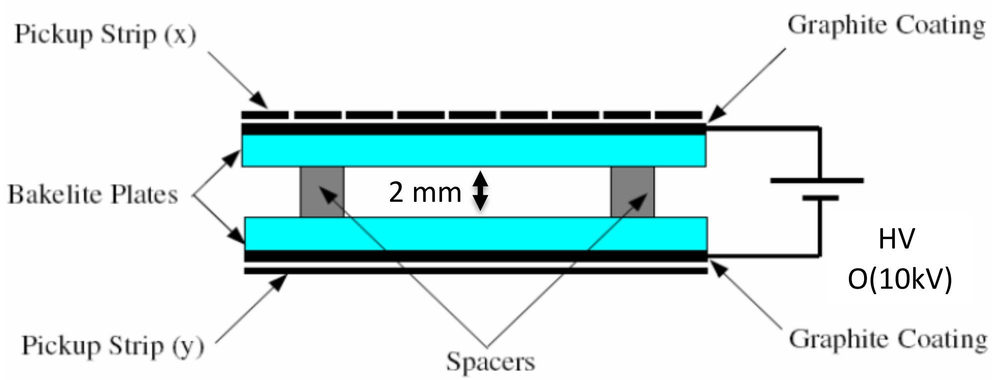
- Large ionization volume and long drift from middle of cylindrical detector to endcap region equipped with MWPC/MPGD for amplification, used for tracking in relatively low rate environment
  - Wires/pad provide xy coordinate as a function of drift time for full x/y/z measurement
    - Typical resolutions: z O(cm), x O(100 µm), y O(mm)
  - Charge measurement provide dE/dx for particle ID
    - Typical resolution 5-10%
  - Rate capability limited by long drift
    - A gating grid in front of the MWPC/MPGD can be biased to prevent electrons to enter the amplification region in absence of trigger, it also collects ions to minimize feedback in the drift volume between events



1) Pressure can improve primary ionization N and reduce diffusion, B-field // to drift minimize diffusion

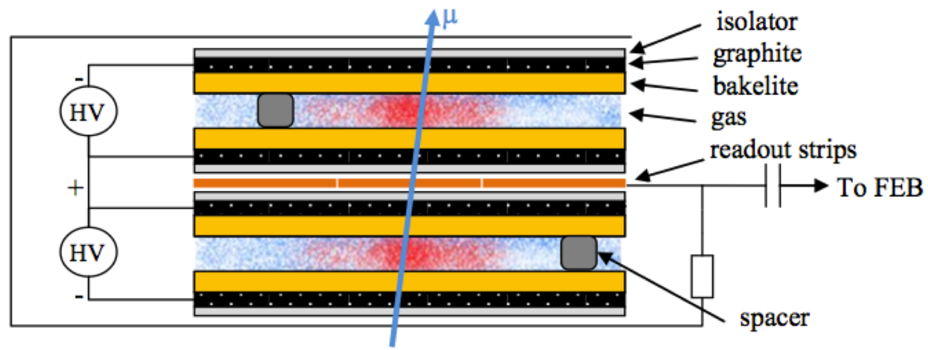
Gas detector designs: Resistive Plate Chamber

- An ionization chamber operated in steamer mode (no wires), used in muon systems for trigger
  - Fast signal (from first primary ionization streamer), O(ns) time resolution
  - High voltage O(10kV)
  - Special gas mixture with quenching ability: ex $C_2H_2F_4$:isoC_4H_{10}:SF_6 (95.2:4.5:0.3%)
  - Strip or pad electrodes for readout with relatively large pitch O(cm)
  - Relatively low rate O(0.1-1) kHz (depending on geometry and electrode resistivity)
  - Relatively low resolution O(cm) (large electron cloud)



ATLAS design resolutions: O(cm) and $\simeq$ 2 ns

Double gap design



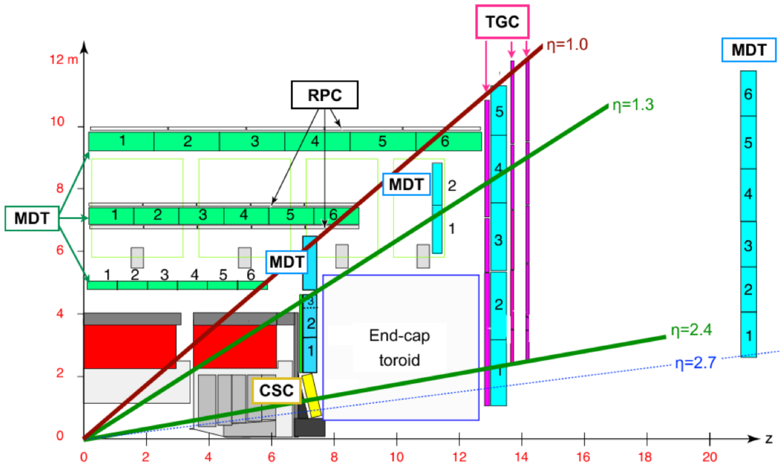
CMS design resolutions: O(cm) and $\simeq$ 1.5 ns

Gas detectors: ATLAS and CMS today's muon systems

ATLAS

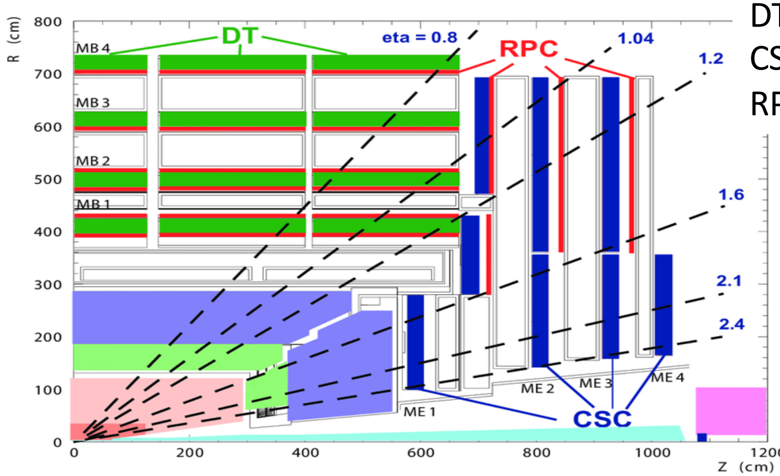
$\sigma(p_t)/p_t \simeq 5(10)\%$ ATLAS (CMS) in trigger (w/o tracker)

CMS



- 1171 Muon Drift Tubes 354 kch
- 544 Resistive Plate Chambers 380 kch for trigger$^{1)}$
- 3588 Thin Gap Chambers 440 kch for trigger$^{1)}$
- 32 Cathode Strip Chambers 70 kch

1) Also provide coordinate in the non bending plan



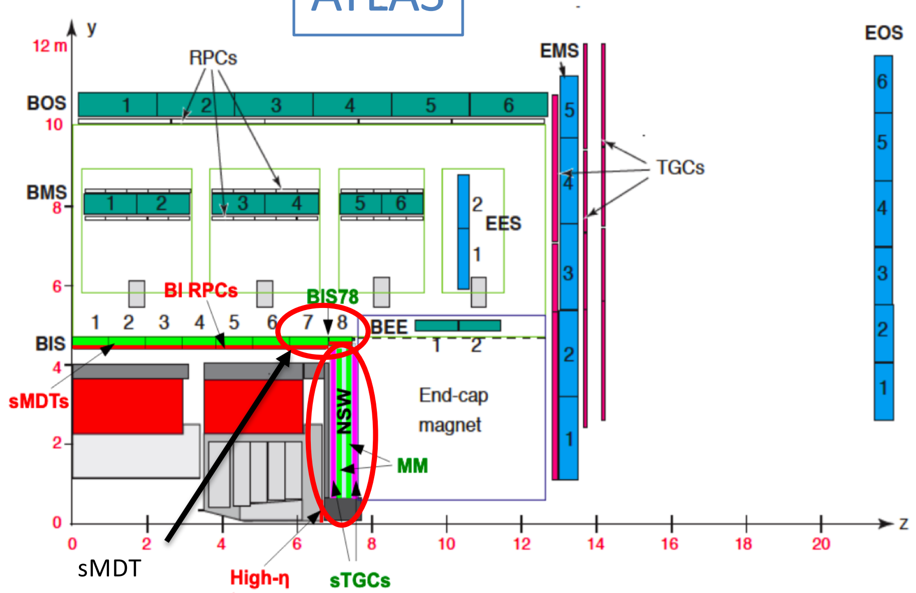
DT: 18000 m^2
CSC: 7000 m^2
RPC: 3200 m^2

- 250 Drift Tubes (DT), 170 kch
- 480 Resistive Plate Chambers (RPC) 120 kch
- 540 Cathode Strip Chambers (CSC) 266k cat. 210k ano.
- 576 Resistive Plate Chambers (RPC) 55kch

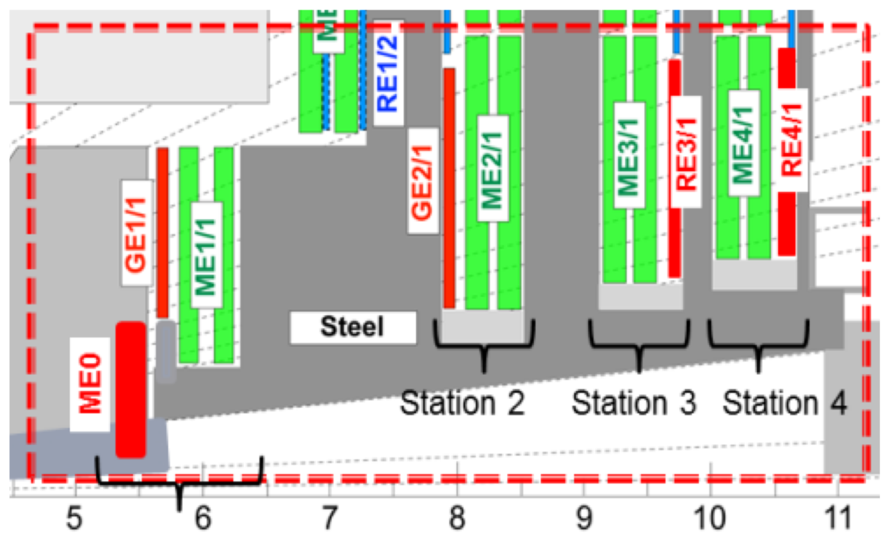
Gas detectors: ATLAS and CMS muon system upgrades

- No substantial aging issues anticipated, confirmed by several test at GIF++
  - Mitigations reducing gain with adjustments of operating conditions and new more sensitive electronics
- Improved forward region with new stations for higher rate capability and precision to maintain low trigger thresholds and allow triggering on long-lived particles - higher granularity
- Extended coverage for μ-tagging up to $\eta \lesssim 4$ (in conjunction with tracker extensions)
- New electronics for trigger

ATLAS



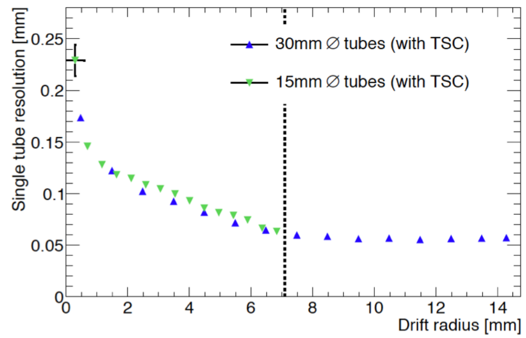
CMS



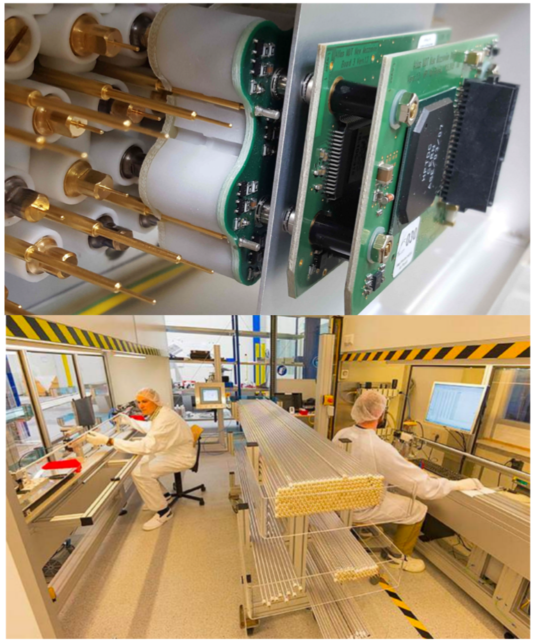
Gas detectors: ATLAS new muon system upgrades

- Small Wheels
  - Small Thin Gap (2.8 mm) Chambers, shorter strips 2 cm to 3.2 mm, 3 mm pitch, $\sigma \simeq 50$ µm, up to 2 x 1.2 m^2, CO_2:n-pentane (55:45)
  - Resistive strip Micro-Megas (0.5 mm pitch), $\sigma \simeq 80$ µm per layer, largest module 2 x 2.3 m^2 made of 5 PCBs, Ar:CO2 (93:7)
- Small Monitoring Drift Tubes
  - Reduced Φ 30 mm (200 Hz/cm^2) to 15 mm (2 kHz/cm^2), wires 50 µm, $\sigma \simeq 100$ µm, L = 1.6 m, Ar:CO2(93:7)

MDT/sMDT resolution



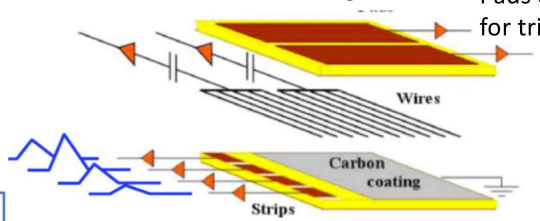
sMDT



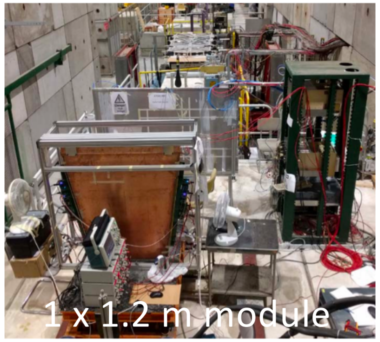
sTGC

Wires 1.8 mm coarse azimuthal angle

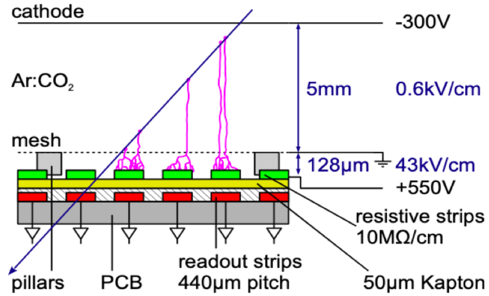
Pads 8 cm pitch for trigger regions

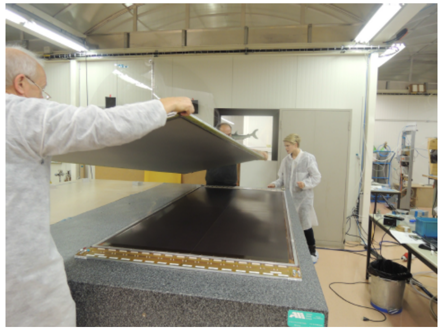


Strips 3 mm pitch for precise polar angle



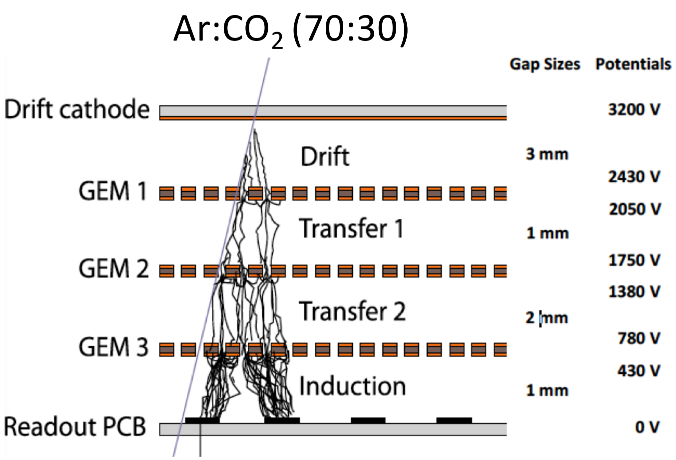
MicroMegas

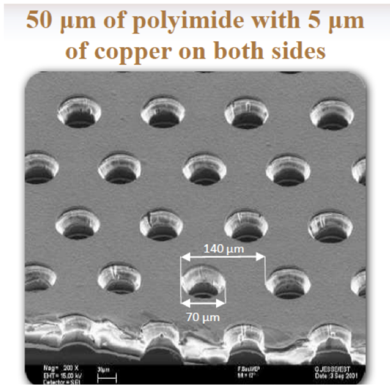




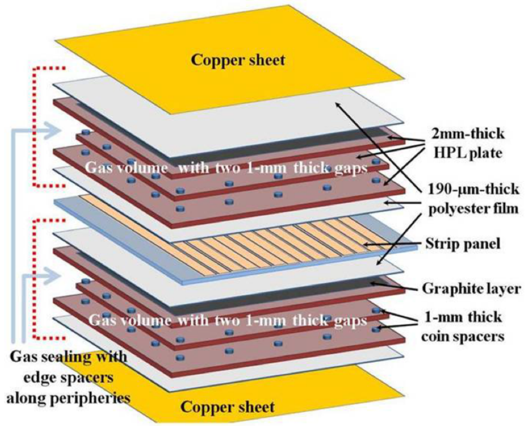
Gas detectors: CMS new muon systems upgrades

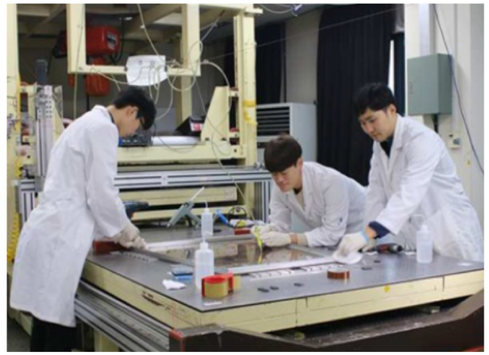
- New GEM stations
  - Triple GEM design, H = 1.8 m x W = 1.2 m wedges in 4 modules largest foil size so far (0.5 x 1.2 m^2)
  - Improved fabrication single mask foil photolithography, foil stretching mechanism
  - PCB with radial strips, pitch from 0.7 mm to 1.6 mm, $\sigma \simeq$ 200 to 450 µm
  - Rate capability up to > 1 MHz/cm^2, time resolution O(10ns),
- New multigap RPC stations
  - Low resistivity Bakelite 1 to 3 10^6 Ω.cm, thinner gap and electrodes 2 mm to 1.4 mm,
  - Φ pitch 1.3° to 1.2°, rate capability few kHz/cm^2, $\sigma \simeq$ 0.3(2) cm ⊥ (//) to strips
  - Front-end electronics with 2 ns time resolution, 2 strip-ends readout for r(η)-coordinate





GEM





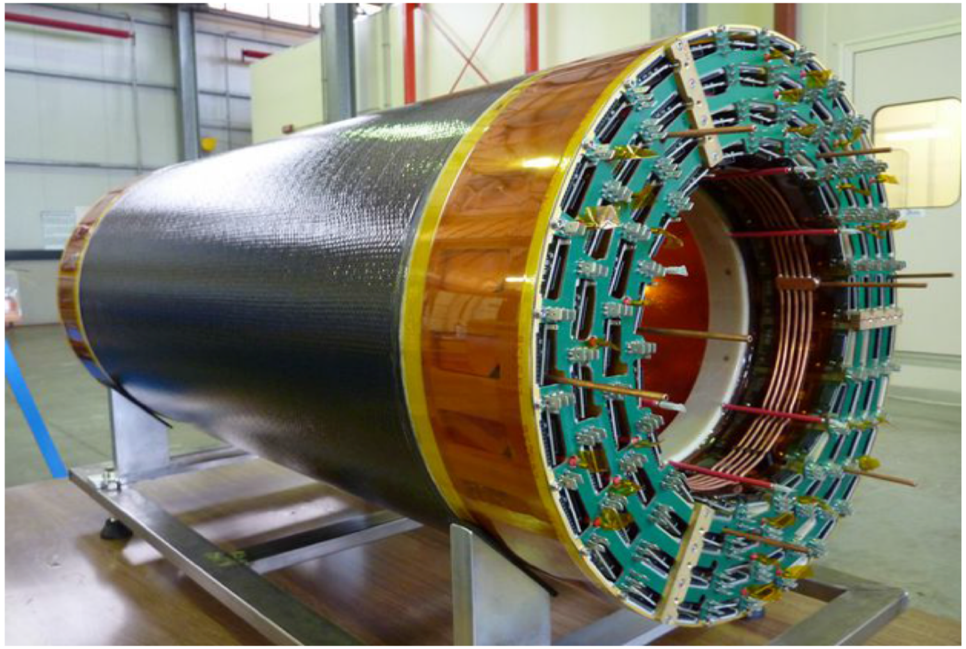
RPC

Gas detectors: KLOE-2 and BES III tracking systems

Cylindrical designs with Kapton GEMs allows low material budget

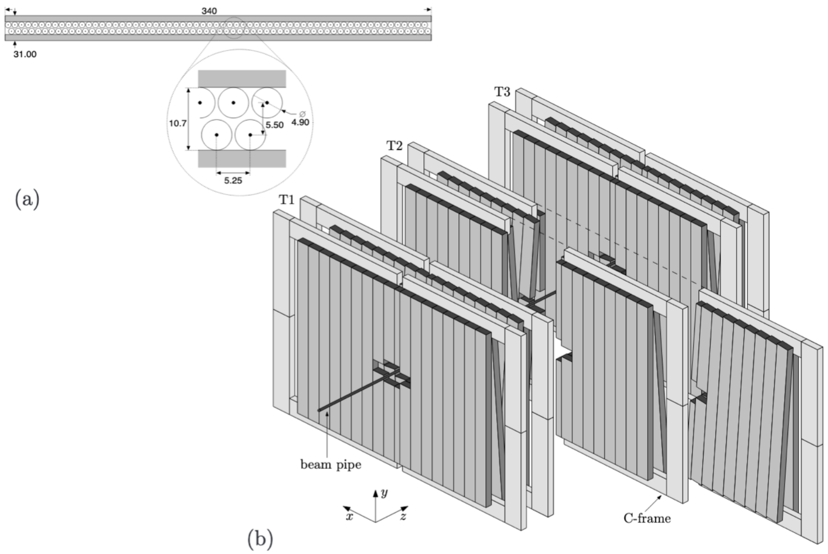
KLOE-2 at Daphne Φ-factory in Frascati
- 4 layers, R from 13 to 20 cm, 70 cm long
- Total $X/X_0 < 2\%$

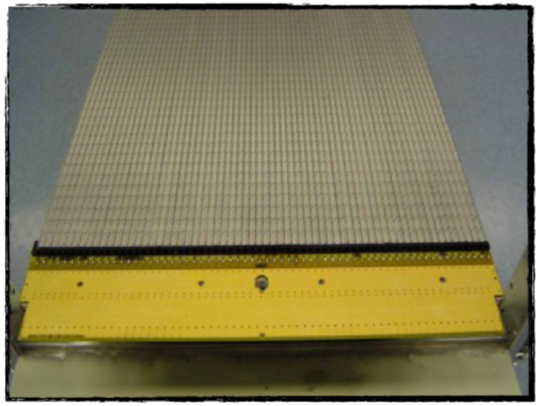
BES III at BECP-2 in Beijing
- 3 layers, R from 8 to 18 cm,
- Total $X/X_0 <1.5\%$

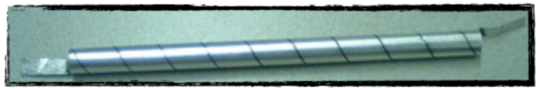


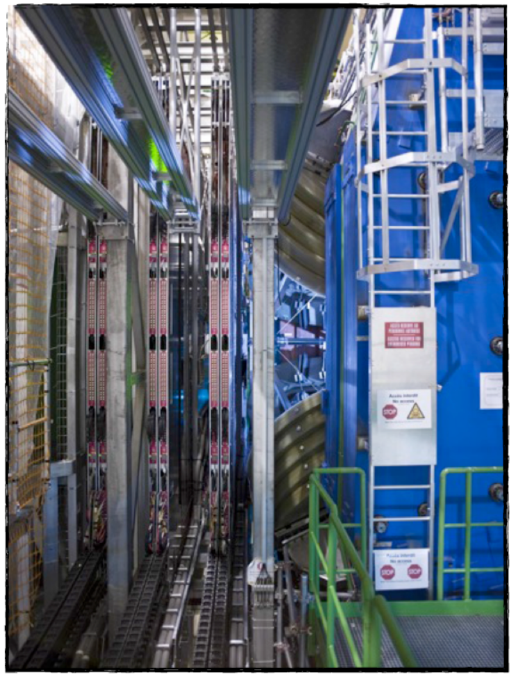
Gas detectors: LHCb straw (drift) tubes Outer Tracker

- 3 stations 5 x 6 m^2 made of 4 modules of double layers (x/u/v/x orientation, u/v titled by ± 5°)
  - Double layers staggered straw tubes L = 2.4 m, Φ_{in} = 4.9 mm and pitch 5.25 mm, 3% X_0 /station
  - Ar:CO2:O2 (70:28.5:1.5), $V_{anode} \simeq 1.5$ kV
    - Fast drift time ≤ 50 ns, $t_{drift}(r) = 20.5\ \text{ns}\cdot|r|/R + 14.85\ \text{ns}\ r^2/R^2$ (measured), $\sigma_t \simeq 3$ ns[1)]
    - $\sigma_{hit} \simeq 200$ μm (σ(p)/p = 0.4 % 9≃ 25 MeV mass resolution in B_0 decay)







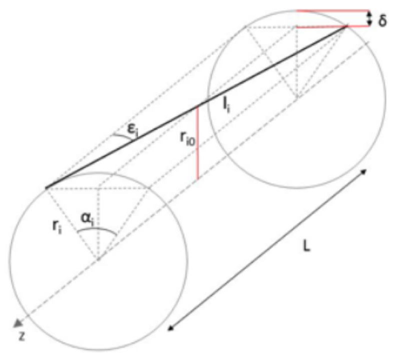


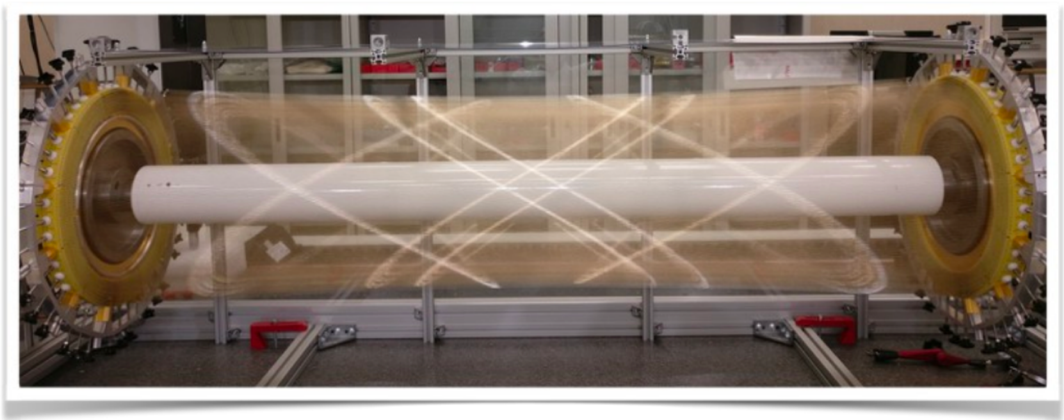
1) The CMS DT upgrade is targeting $\sigma_t \simeq 2$ ns for a $\sigma_{hit} \simeq 200$ μm

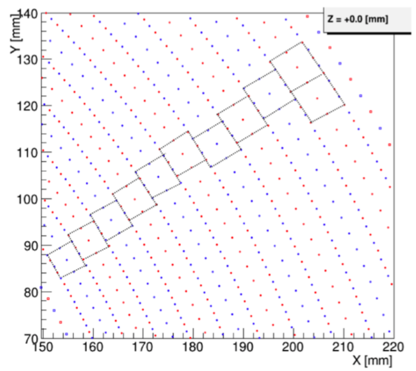
Gas detectors: MEG-II Drift Chamber[1]

The ultimate lightness tracking system designed to measure low momentum e^+ (50 MeV)

- Wires along z with alternating stereo layers for z-coordinate[2] (6° (8.5°) inner(outer))
  - Hyperbolic shape in z, very thin wires 20 to 50 µm, HV $\simeq$ 1.5 kV
- 10 concentric radial layers 2 m long, r from 17 cm to 29 cm and very small cell size 6 x 6 mm^2 and 9 x 9 mm^2
- 12 sectors in phi (stereo introduces a 2 sector shift of wires start and end)
- HE:C_4H_{10} (85:15) large radiation length ensures very low MS and high drift velocity[3]
  - $X/X_0 < 0.2\%$, $\sigma(r/\Phi) \simeq 110$ µm, momentum resolution $\simeq$ 450 keV for 50 MeV, 30 kHz/cm^2 rate
- Further improvements investigated with primary cluster counting technique, eg signal sampling at O(GHz)[3]





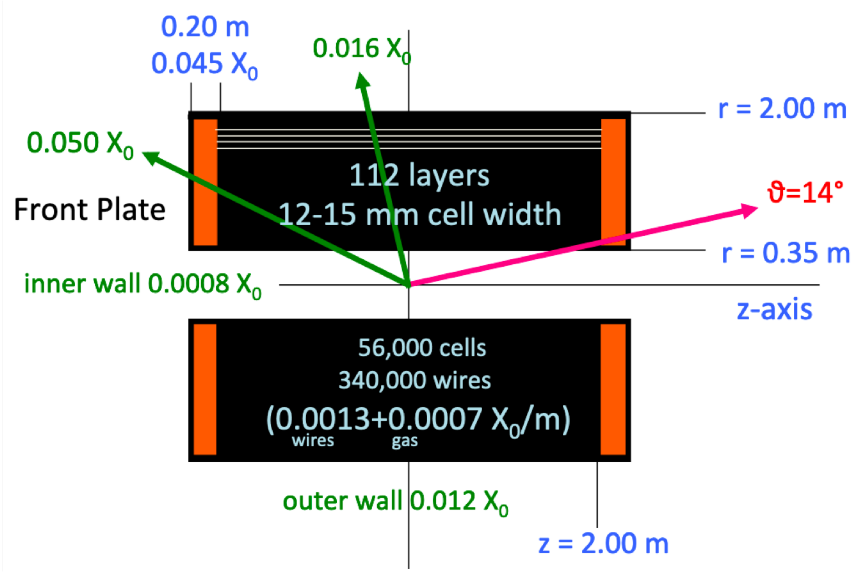


20(40) µm sense (field) wires

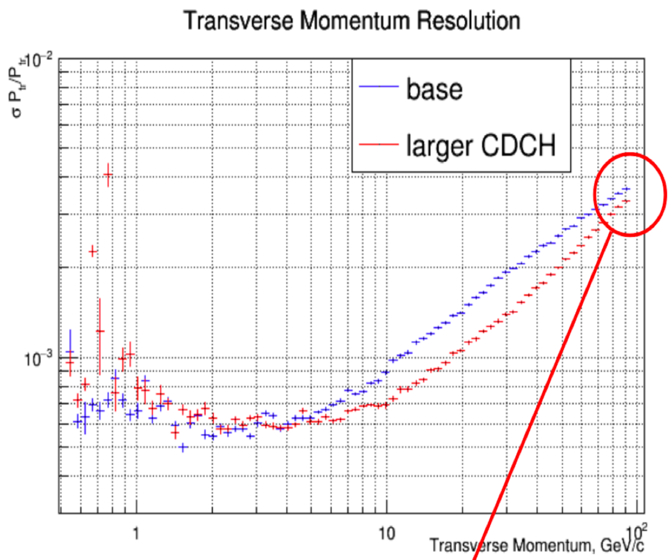
1) *Design is inspired from the KLOE-2 experiment DC in operation, MEG-II DC is being commissioned*
2) *Completed by charge division measurement*
3) *He is well adapted for cluster counting with a high primary pair average energy*

Gas detectors: IDEA DC proposal[1)] for FCC-ee and CEPC

Extension of MEG II concept to much bigger volume
will use cluster counting technique for dE/dx particle identification



	Base Line	Option 1	
	value	value	dim.
R_{in}	345	200*	mm
R_{out}	2000	2150	mm
active area length	4000	4000	mm
total length	4500	4500	mm
total cells	56448	34560	n.
layers	112	96	n.
Superlayers	14	12	n.
Layers per Superlay.	8	8	n.
phi sector	12	12	n.
smaller cell	11.85	14.2	mm
larger cell	14.7	2.25	mm
min. stereo angle	48	25	mrad
max. stereo angle	250	240	mrad



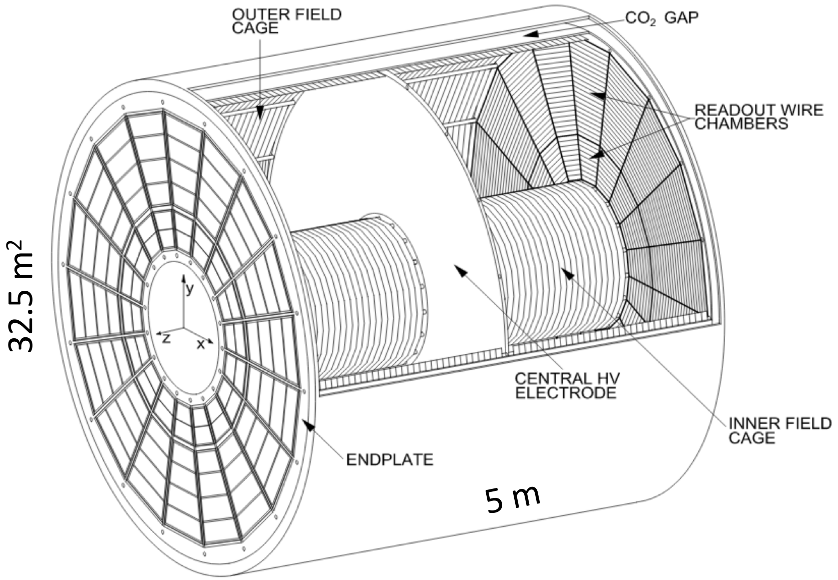
$$\frac{\sigma_{p_t}}{p_t^2} = 3-4 \bullet 10^{-5}$$

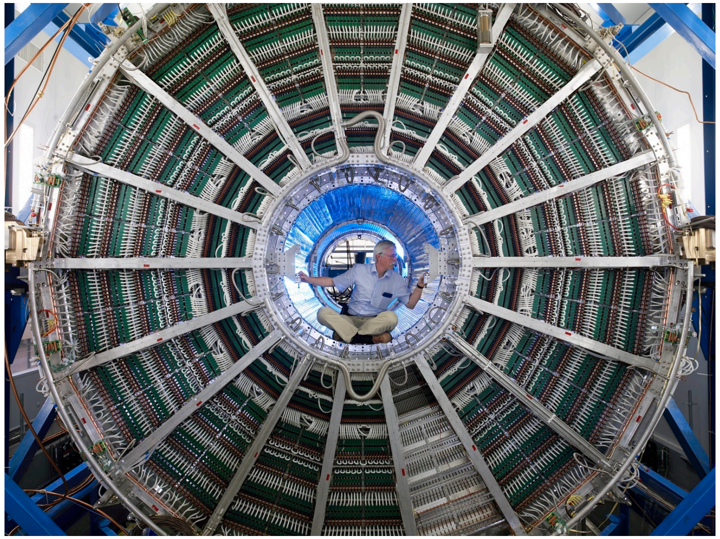
Gas detectors: ALICE TPC

Tracking with $\sigma(p)/p \simeq 2\%$ at 10 GeV

Particle identification with $\sigma\,(dE/dx)/(dE/dx) \simeq 5(6.8)\%$ single $(dN/d\eta = 8000)$

- Gas volume 5 m long 0.85-2.5 m radius for $88 m^3$, $\eta < 0.9$
  - $Ne:CO_2{:}N_2$ (87.5:10) low Z
    - Minimize diffusion 220 µm/√cm and high e^- velocity 2.65 cm/µs
    - Temperature controlled at 0.1° to avoid velocity fluctuations
  - HV at 100 kV (E = 400 V/cm)
  - Total drift time ≃ 94 µs
  - $X/X_0 \simeq 1\ \%$ seen by a track at η=0





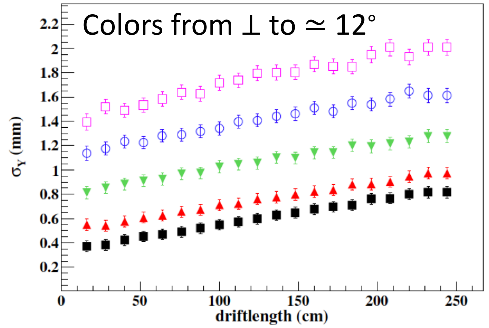
1) B-field = 0.5T

Gas detectors: ALICE TPC

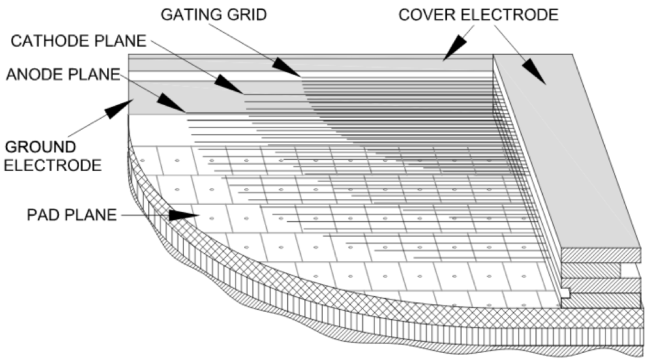
Tracking with σ(p)/p ≃ 2%[1)] at 10 GeV

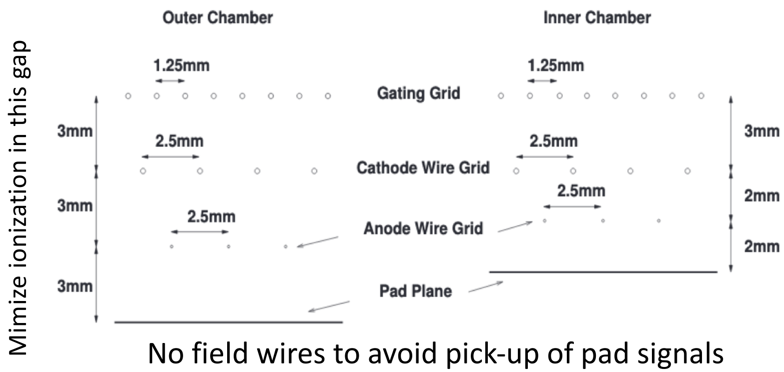
Particle identification with σ (dE/dx)/(dE/dx) ≃ 5(6.8)5 single (dN/dη = 8000)

- 18 endcaps MWPCs sectors with cathode pad readout (560000)
  - 3 pad sizes 4 x 7.5, 6 x 10 and 6 x 15 mm^2 front in to out 159 rows (eg number of track points)
    - Occupancy 40 % to 15 % (up to 20000 tracks in acceptance)
    - σ(r/Φ) and $\sigma_z \simeq$ 0.4 to 1 mm depending on drift length and angle

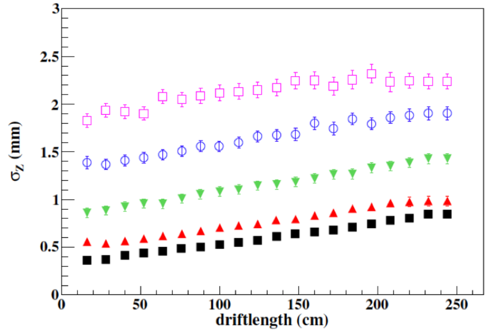


With gating grid[2)] ion back-flow is ≤ 10^{-4} to avoid drift field distortion
the opening time is set to ≃ 100 µs (drift time) + 200 µs, limiting rate capability to < 3.5 kHz)



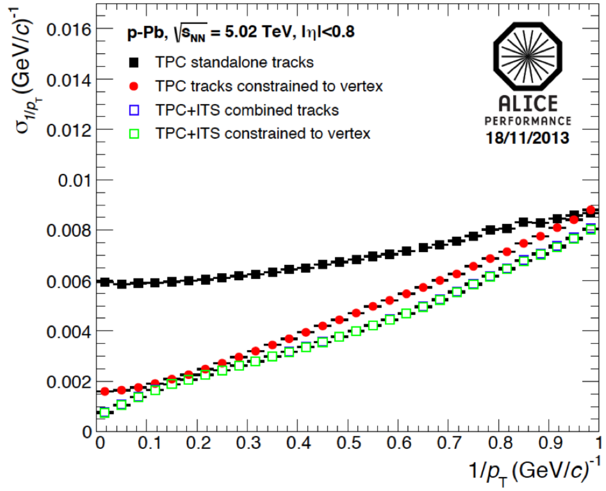


No field wires to avoid pick-up of pad signals



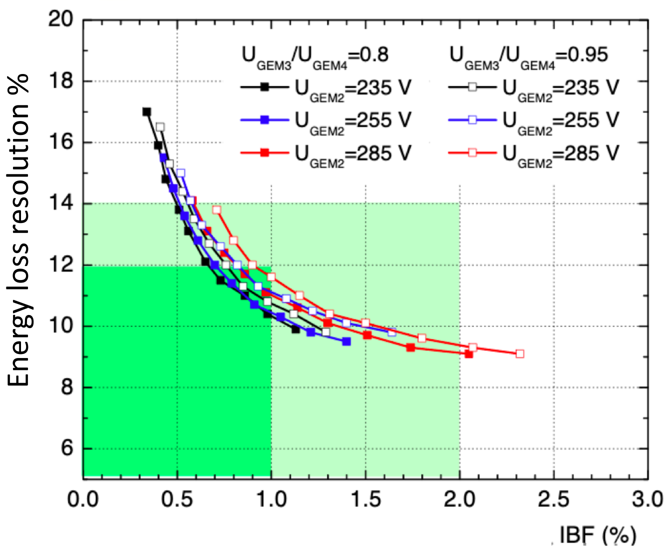
1) *B-field = 0.5T*
2) *In open mode all wires are at the same potential, in close mode potential is on alternate wires*

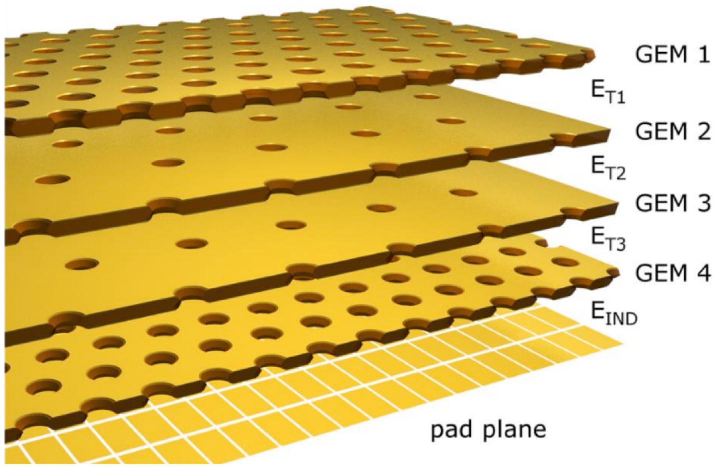
Gas detectors: ALICE TPC upgrade

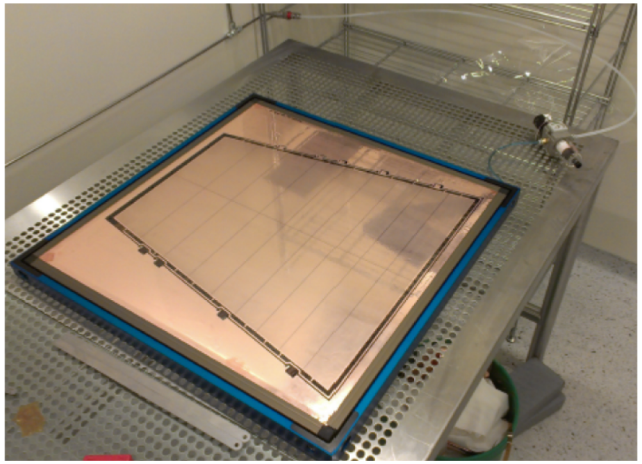


Operation at 50 kHz acquisition rate doesn't allow gating
MWPC are replaced with GEMs

- Ion feedback < 1% for dE/dx < 12%
  - Complex design optimization, stack of 4 GEMs with different hole size and orientation
- Hit and p_T resolutions similar to current TPC
- Continuous readout time resolution O(100) ns





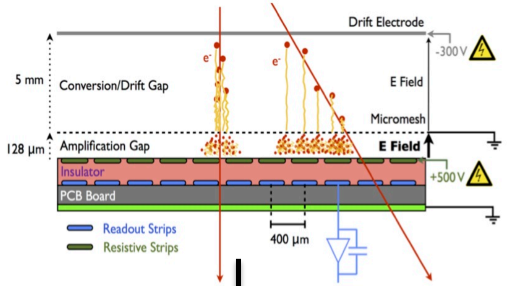


GEM foil

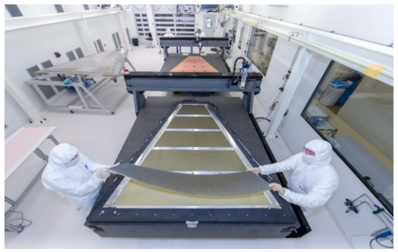
Gas detectors: R&D starting from state of the art MPGD

PCB photolithography progress allow high granularity and rate capability devices
several designs adjusted to requirements for muon detection and TPC/RICH readout

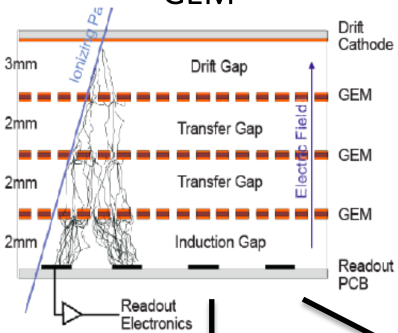
MicroMegas (MM)



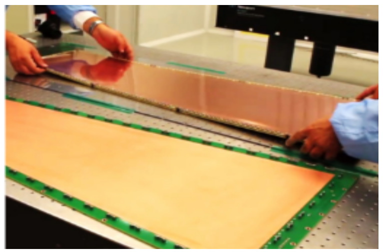
ATLAS new small wheels



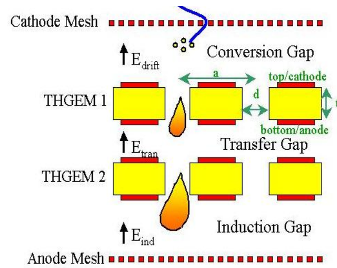
GEM



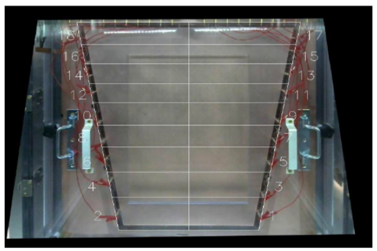
CMS GEM



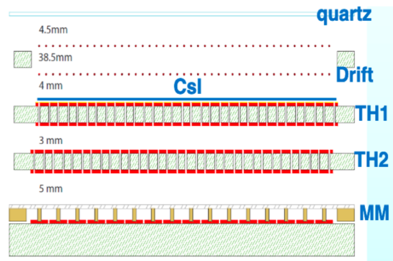
THGEM



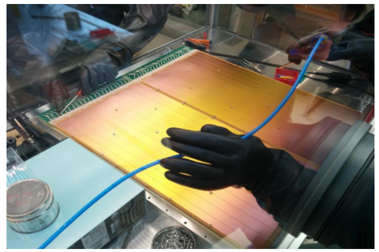
ALICE TPC upgrade



Hybrid design THGEM + MM



COMPASS RICH



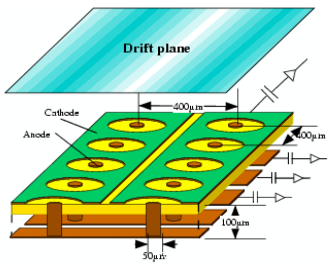
Gas detectors: MPGD R&D*

- Single amplification stage designs (µPIC, µ-Resistive-Well/Resistive-Plate-Well)
  - Ease fabrication, resistive layer with new material (ex. DLC) to improve rate capability ≥ MHz/cm^2
- Pixels devices (ex. InGrid CMOS integrated concept)
  - First prototype with Medipix pixel chip shows 20 µm resolution
- Picosecond devices with radiator and radiation tolerant photocathodes
- Fabrication process for large scale detectors and transfer to industry
  - 3D printing, dry plasma ink jet printing (developed for flexible devices)

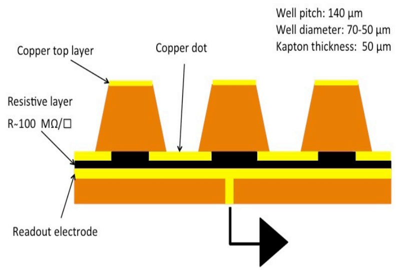
30-50 µm precision

25 ps achieved

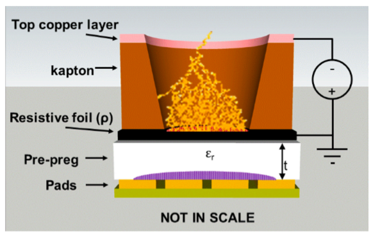
µPIC



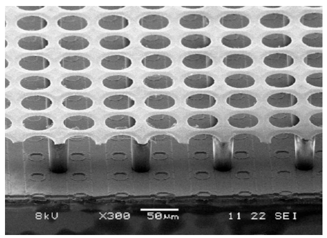
µ-Resistive-Well



Resistive-Plate-Well

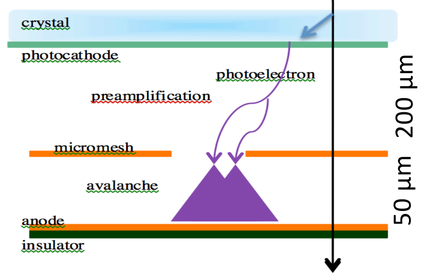


InGrid CMOS MM



Pixel chip

Radiator + photocathodes + MM



* CERN RD51: http://rd51-public.web.cern.ch/rd51-public/

Gas detectors: Gas mixture R&D

- New environment legislations requires reduction of Green House Gas emissions
  - eg HFC gas: $C_2H_2F_4$, CF_4, SF_6, C_4F_{10} ($C_2H_2F_4$ most critical for quantities in RPC)
    - Recirculation/recuperation/abatement should fulfil current regulation, however
      - Availability and cost of HFC will likely become an issue
    - Alternative mixtures HydroFluoroOlefin (C3H2F4 common refrigerant replacement) do not provide sufficient performance without some amount of HFC (CF4)
- Detector aging may need substantial effort to fulfill h-h collider requirements
  - Current level tested $\simeq$ 3 to 5 x HL-LHC

Gas detectors: example future/other domains of applications

- FCC-hh, SppC colliders could potentially use any of the MPGD techniques
  - For muons in high rate regions and possibly in calorimetry
- TPC for ILD experiment at ILC, target 150 μm & 15 ns resolutions, and dE/dx resolution of ≃ 5%
  - Gating needed for ion backflow (resolution energy, position)
  - MicroMegas or GEM option with pads (1 x 6 mm^2)
  - InGrid CMOS option with pixels (50 x 50 μm^2) for dE/dx from cluster counting
- DHCAL option for ILD/SiD experiments at ILC, target 150 μm & 15 ns resolutions
  - 4000 m^2 of MM, GEMS or Resistive-Plate-Well
- GEMs with photocathodes for RICH detector, ex. Electron Ion Collider project
- RPC multilayer development for precise timing (see Timing Detector section)
- Cryogenic MPGD for noble gas liquid TPCs and/or for Cherenkov detectors in Neutrino and Dark Matter experiments
  - Ex. of R&D MPGDs with photon readout by CCD cameras outside TPC volume