DRD1 WG1: goals and challenges

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Who we are

Paul Colas: works on TPCs (ILC, T2K), especially charge spreading with DLC for high space resolution and good stability with Micromegas. Co-convener of RD51 WG1.

Ingo Deppner: specialist of MRPCs. Develops high rate and position sensitive MRPCs for CBM at FAIR. Project leader of the CBM Time-of-Flight subsystem.

Luca Moleri: expert on R&D of ThGEMs concepts, with focus on resistive configurations also in cryogenic conditions. Develops next generation TGCs.

Filippo Resnati: involved on general MPGD developments to extend high flux capability and precise timing. Use of ThGEM in dual phase LAr argon TPCs. Co-convener of RD51 WG1.

Michael Tytgat: specialist of RPCs/GEMs. Works on RPCs/GEMs for the CMS Muon system, RPC-based calorimetry, and gaseous detector-based muon radiography.

Peter Wintz: Straw Tracker in vacuum for COSY-T'OF experiment, Straw Tracker for HADES@GSI experiment and central Straw Tracker with PID for PANDA@FAIR experiment.

Detector technologies

- MicroPattern Gaseous Detectors
- Resistive Plate Chambers and Multigap RPCs
- Wire chambers (Straw Tubes, TGC, CSC, ..)
- Large Volume Detectors (drift chambers, TPCs)
- Hybrid and new amplifying structures

RD51 WG1 topics

The DRD1 proposed structure has a lot in common with RD51 structure.

Interests of the RD51 community as seen from contributions to the WG1 sessions in the last **~three years**:

- Commissioning of detector in operation or in construction
- Lessons learned from long standing detector operation
- Discharge limitation/mitigation (materials and geometry)
- Charging up and gain stability
- Resistive electrodes for stability and charge spread
- Optical readout
- Ultra-clean and sealed detectors
- Precise timing
- MPGDs in cryogenic environment
- High pressure operation
- Additive fabrication with conductors, insulator and resistive materials

MPGD technology

MPGDs born with the Micro-Strip Gas Chambers (**MSGS**) (1988) to cope with **high particle fluxes**. Micro-electrodes created on substrates borrowing technologies from semiconductor industry (Photolithography, Etching, …).

From the MSGC concept, a number of **new structures** were developed:
- micro electrodes: micro-gap, micro-dot, microgroove, microWELL, …
- and with *uniform* amplification field: MicroMegas, GEM, ThGEM, …

A problem that never abandoned MPGDs: **discharges**
- stability degradation, various aging effects, permanent damage, …

Reduce the discharge probability, or discharge effects?
- Gain shared over **multi-amplification** stages (reduce the probability)
- Discharge quenched with **resistive** electrodes (mild the effects)

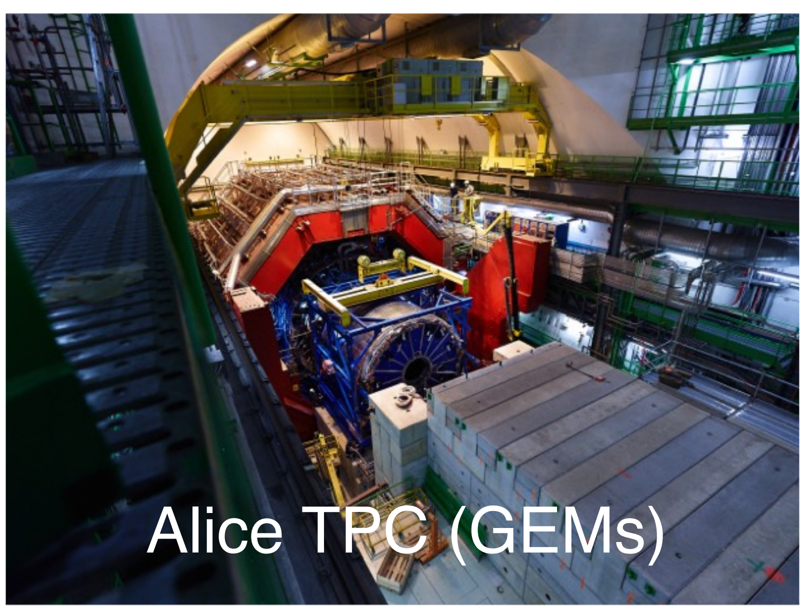
Several new structures were developed for HEP applications and beyond. **RD51 WG1 goals:**
- Developments towards structures and techniques for instrumenting **large area**
- **New amplification** structures, **hybrid structures** coupled with CMOS chips
- **Radiation hard**, **reduce aging** effects (geometry and gas)
- Low dead region and low **material budgets** (HEP), **low radioactive** materials (rare events)
- **Sealed and portable** detectors (low outgassing, low power consumption, multiplexing)

MPGDs applications

Without the intention of being complete or exhaustive

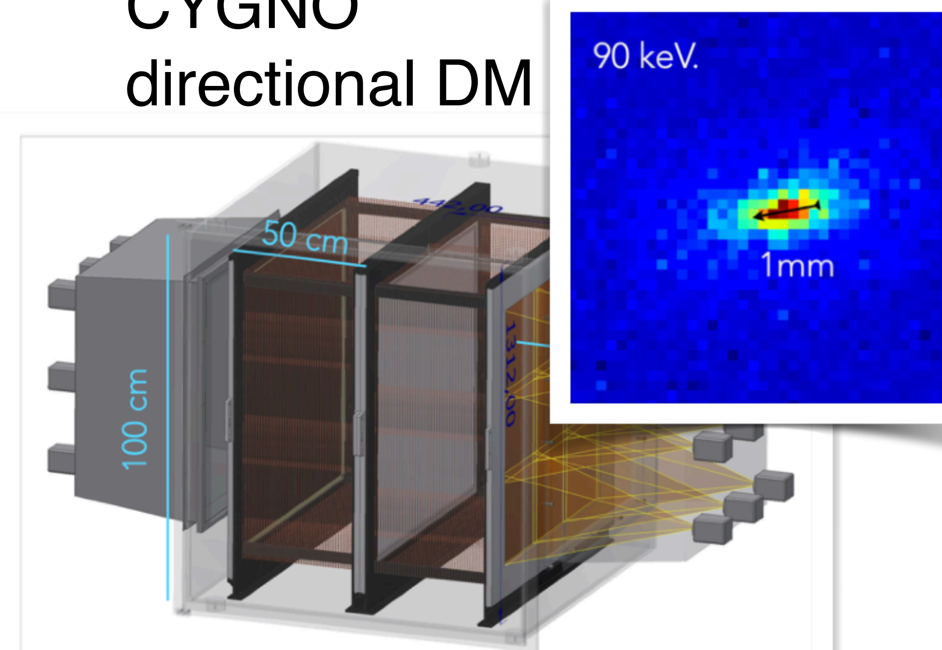
HEP

CMS forward muon
(GEM & CSC)



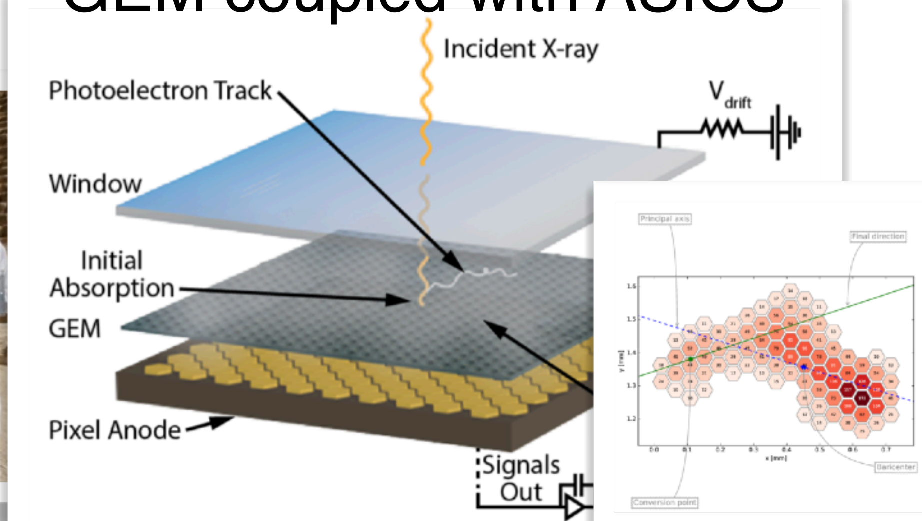
non-HEP

CYGNO
directional DM



ScanPyramids
Muography with MM

IXPE X-ray polarimeter
GEM coupled with ASICS



Prospects

MPGD strengths:

high spatial resolution, high-flux capability, high and uniform gain, large area, radiation resilient

Developments captured at RD51 WG1:

- Precise timing (aiming at < 20 ps) (radiators, photocathodes, gas mixtures)

- Optical readout (relative low rate, highly parallelised readout)

- Harsh conditions (high radiation, cryogenics, high and low pressures)

- Low outgassing material (seal detectors, reduce gas consumption)

- Gain stability and discharge mitigations (resistive materials, coating, charging up, electrode geometry and gas studies)

Wires

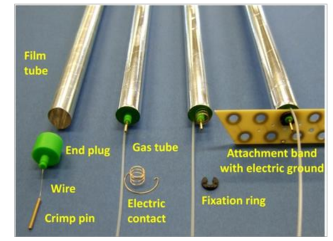
Straw Tubes
Overview

Straws = metallized tube as cathode, anode wire in center, gas filled

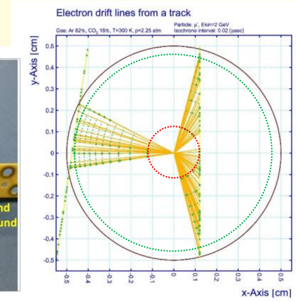
- Ionization (MIP): *⟨dE/dx⟩ ~ 2.5 keV/cm ~ 94 I.P./cm* in Argon (ntp)
- Ioniz. avalanche at thin wire, gas gain: ~ 10^4-10^5 ($\varnothing$ ~ 20-30µm, HV ~ 2kV, $E \propto 1/r$)
- Electron drift time (LE-time) → isochrone radius r(t)
- Charge signal for dE/dx (sampling or time-over-thresh.)
- **Robust electrostatic configuration: shielded cell around wire**
- **Robust mechanical shape if thin-wall tube is pressurized**

Specifications:	*standard*	*perspective*
Diameter, wall	~ 10 mm / 30 µm	~ 5 mm / 15 µm
Typical X/X0	~ 0.04 %	~ 0.02 %
Spatial resolution	**100-150 µm**	same
Drifttime range	**~ 100-200 ns**	**< 80 ns**
Gas gain	**~ 5 × 10^4**	**~ 1 × 10^4**
Rate limit	**~ few 10 kHz/cm**	**~ few 100 kHz/cm**
Aging resistance:	> 1 C/cm	same

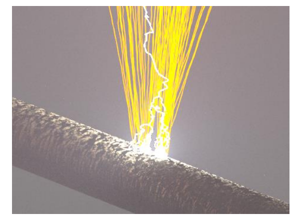
- **Staggered multi-layers** to resolve ambiguities in 2D-tracking
- **Stereo-layers** for 3D-tracking, alternative: propagation time difference, but ~ cm resol.



Straw tube components (for PANDA-STT [1])

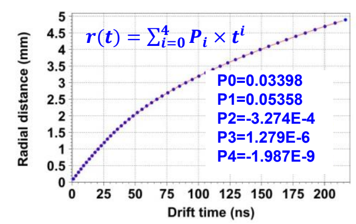


Ionisation and electron drift lines (simulation, Garfield)

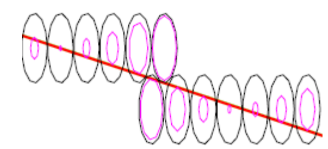

Avalanche simulation: drift electron (white), pos. ions (orange). Photo from [2].

Element	Material	X [mm]	X_0 [cm]	X/X_0
Film Tube	Mylar, 27µm	0.085	28.7	3.0× 10^{-4}
Coating	Al, 2×100nm	6×10^{-4}	8.9	7.0× 10^{-6}
Gas (2bar)	Ar/CO_2 (10%)	7.85	6131	1.3× 10^{-4}
Wire	W/Re, 20µm	3×10^{-5}	0.35	8.6× 10^{-6}
			Σ_{Straw}	4.5× 10^{-4}

Material budget for PANDA straw tube [1]



r(t) relation for Ar/CO2(20%), p=2 bar (simulation)


Track fit tangent to isochrones (red circles) in staggered straw layers determines track point

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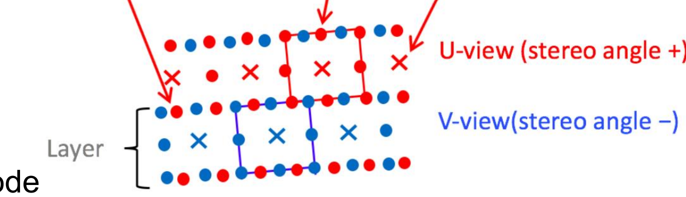
Drift Chambers
Overview

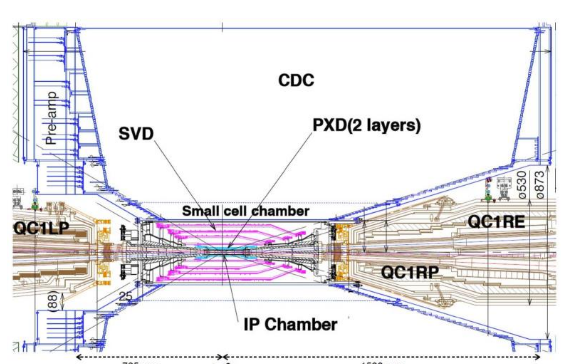
Feature: highest transv. momentum resolution tracking in solenoid B-field

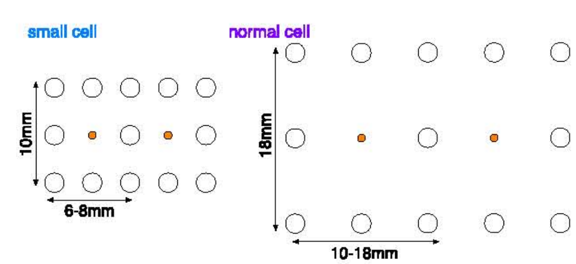
- Large gas volume and long lever arm (L ~ 1m)
- High transparency (X/X0 ~ 10^{-3}) for low MS, favours He-based gas
- **Helium requires high gas gain ~5×10^5** (*8 I.P./cm, ntp*)

- Small drift cells for short drift times (few 100ns), cathode wires surround anode
- Stereo drift cells for 3D-tracking, full stereo layout possible (MEG-II DCH)
- dE/dx or ion cluster counting (dN/dx) for PID

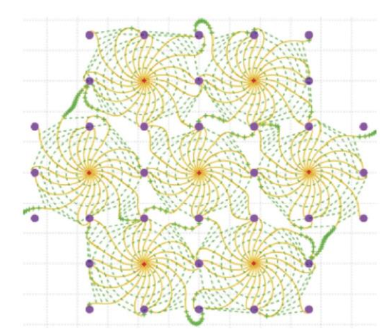


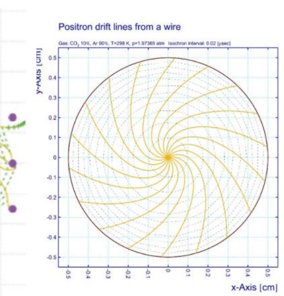
Full stereo drift cell layout with high field homogeneity in MEG-II drift chamber [11].





Belle drift chamber CDC (left). Smaller cells in inner region [10].





Electron drift lines for drift cells (left) and straw tube (right) in solenoid B-field (Garfield simulation).

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Wires

Cathode Strip Chambers
At CMS / ATLAS

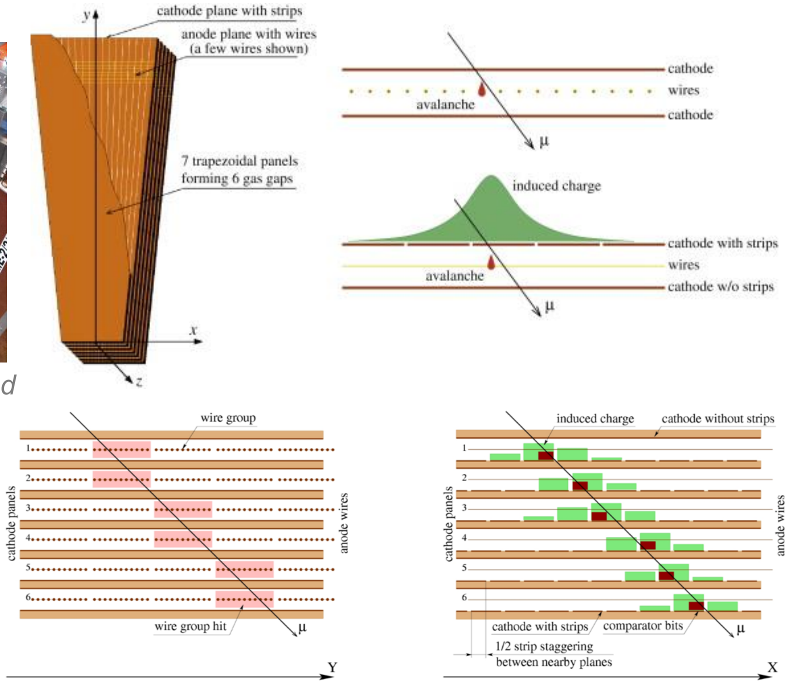
CSC: grid of anode wires and cathode strips [14]

- Upgrade muon system in end caps for HL-LHC: L=5x10^{34} cm^{-2}s^{-1}
- CSC for **precise muon tracking and triggering**
- CMS: all endcap muon precision chambers are CSC
- ATLAS: CSC in low-angle region, Monitored DT (MDT) else
- HL-upgrades: readout with high speed optical links, trigger

Specifications:

CSC size:	3.3 x 1.5 / 0.8 m^2 (trapezoidal)
Number of layers	6 layers per chamber
Anode wire:	50µm W/Au-plated
Anode-cathode gap:	**4.75 mm**
Wire spacing:	**3.12 mm**
Number wire groups:	210´816, 5 to 16 wires per group
Cathode strip width:	**8-16 mm (trapez.)**
Number cathode strips:	266´112
Gas:	Ar(40%)+CO2(50%)+CF4(10%)
Maximum drift time:	**60ns**

CSC with upgraded readout

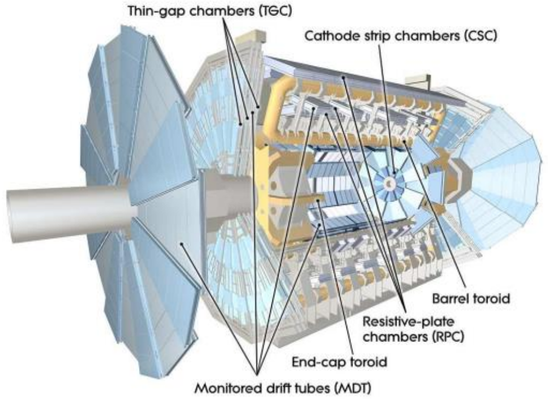


Thin Gap Chamber
ATLAS NSW Upgrade for HL-LHC

Thin Gap Chamber (TGC): smallest wire to cathode gap [15,16]

- Small-strip Thin Gap Chambers (sTGC) upgrade the ATLAS muon endcap
- New Small Wheel upgrade: fast trigger (<25 ns) and high precision tracking
  - 1mrad angular online resolution reduces fake muon trigger, 100µm spatial resolution (offline)
- Small gap issue: **gain uniformity**, **high chamber flatness required**

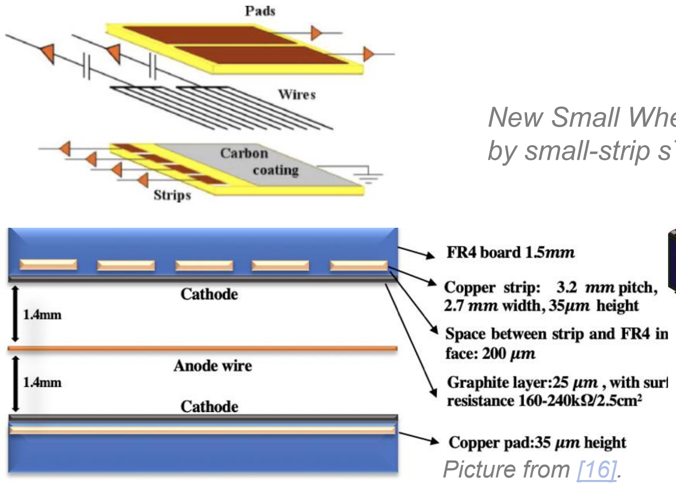
sTGC with smaller cathode strip width, readout upgrade, ..



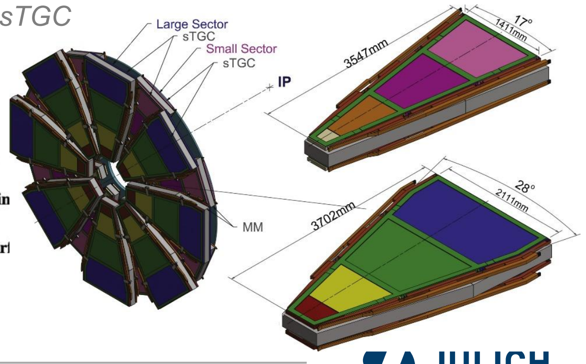
New Small Wheel upgrade by small-strip sTGC

Specifications:

sTGC trapez. size:	**3.7 x 2.1 / 0.5 m^2**
HV:	2.8 kV
Gas mixture:	CO2(55%)+n-Pentane
Wire pitch:	**1.8 mm**
Wire to cathode gap:	**1.4 mm**
Wire, diameter:	50 µm W(-Au)



Picture from [16].



R&D on Wires

Fast timing (< 80ns) and **less occupancy**
- Smaller straw diameter: from “standard“ 10 mm down to 5 mm
- Items: wire centring, ~ 100ps resolution time readout, trailing edge timing
- Smaller diameter sMDT, sTGC with smaller cathode strip widths

Low material budget: X/X0 ~ 0.02% per straw
- Thinner straw film walls: from “standard“ 30 μm down to 15 μm
- Items: film tube winding, gluing or ultrasonic welding, cathode coating
- Operation in vacuum and leakage control

Large area, long straw film tubes: up to 5 m length
- Items: Wire centerings, sag control, long-term material relaxation
- Large straw area detector designs (50 m^2) and in vacuum

New wire **materials**, new **alloys**, metallised carbon wire, …
- Items: wire corrosion, coating quality, … thinner field wires for low X/X0

PID by dE/dx: with time readout and time-over-threshold

4D-measurement: 3D-space and track time (t0), trailing edge timing

Transversal issues on Wires

Gas system design to achieve high purity

Replace **gas admixtures** with high Global Warming potential

Ageing prevention
- “Aging-free“ gas mixtures, materials and components
- Ageing curing recipes for wires and cathodes

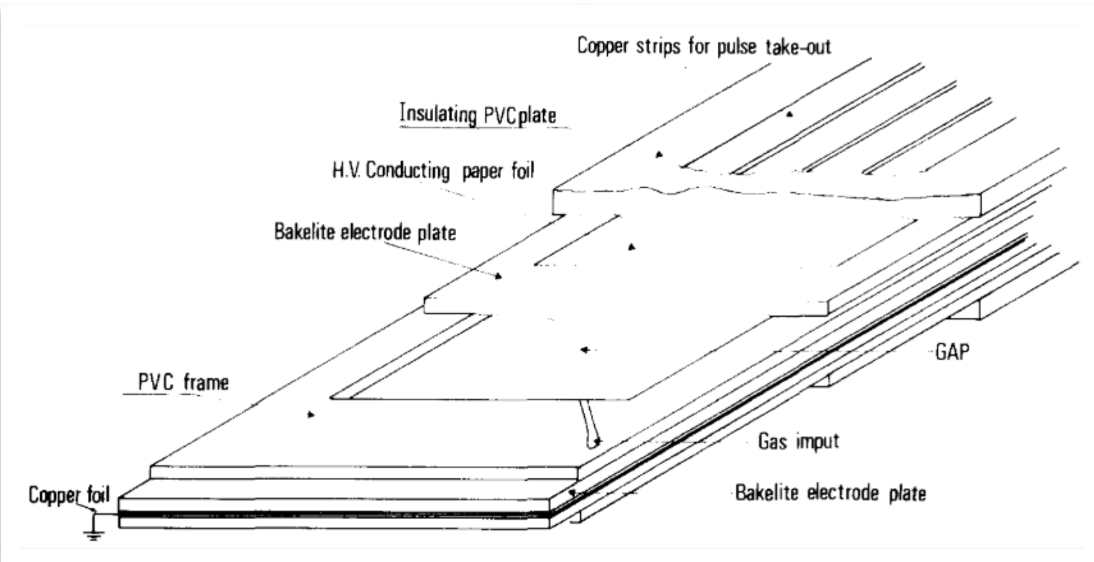
Detector **designs** incl. front-end
- Low X/X0 materials and frame structures, foils and coating
- Detector alignment techniques and measures
- Cooling scheme and system, detector control system

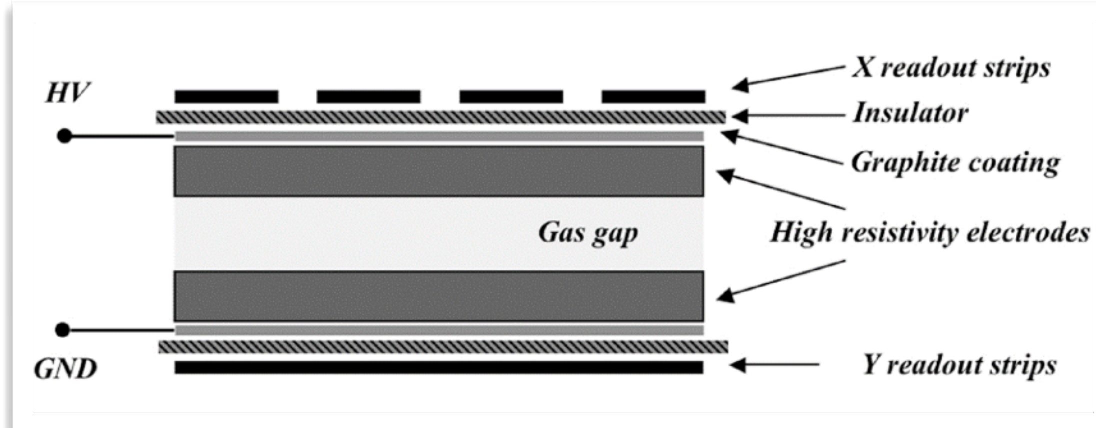
Assembly techniques
- Wiring robot, precise positioning; series production and QA

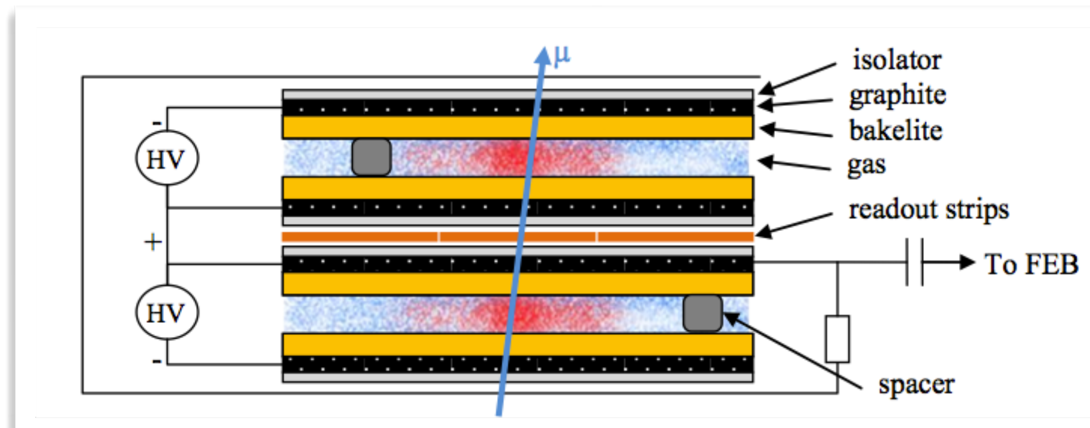
Electronic readout
- Time resolution, EMI shielding & grounding, low noise, low threshold

Detector **calibration**, simulation and calibration **SW** and methods

RPC technology

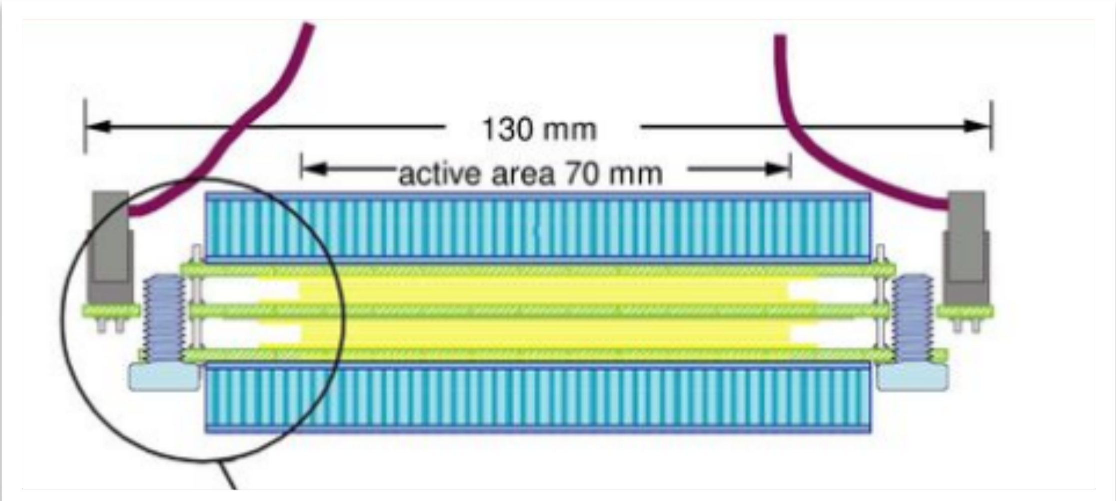




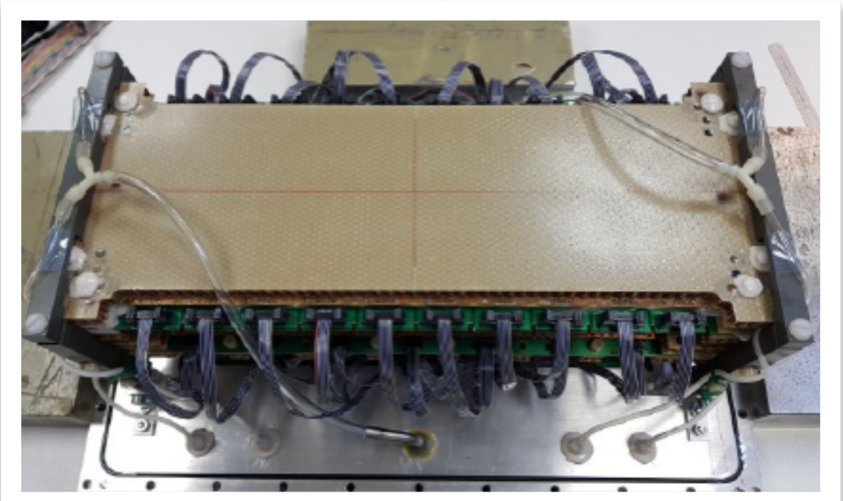


Resistive Plate Chambers (RPCs) (1981)
- Gap sizes ~1-2mm
- Single or double gap configurations
- HPL(bakelite) or glass as commonly used electrodes
- Electrode bulk resistivity ~10^9 to 10^{13} Ωcm
- Field values up to ~50 kV/cm
- Operation in streamer or avalanche mode depending on rate requirement
- Rate capability up to ~1 kHz/cm2
- Pickup strip or pixelated readout
- Spatial resolution few cm down to a few 100 μm
- Time resolution order of (ns)
- Gas mixtures: R134a - isobutane - SF_6 (most common today); CF_3Br; Ar; CO_2

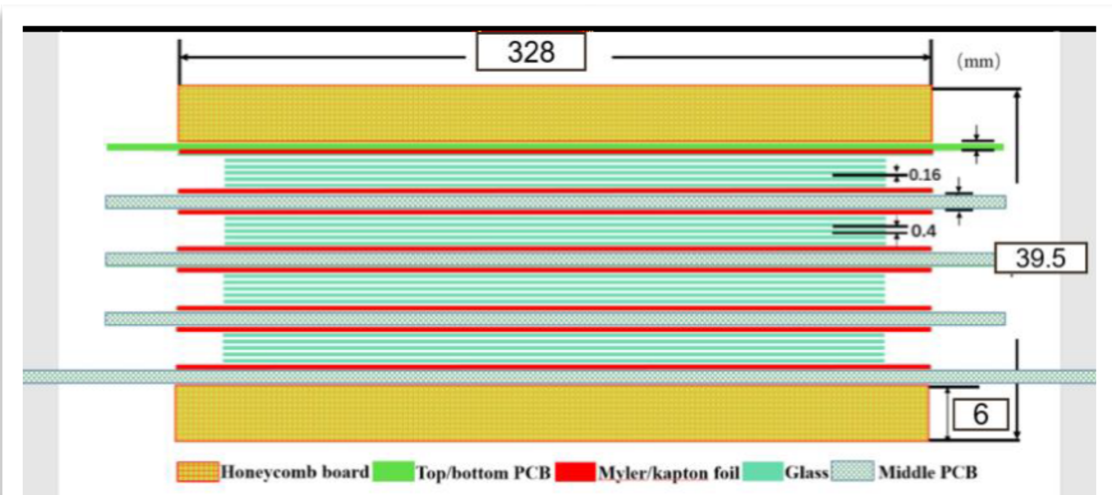
RPC technology (II)



Thin Multigap Resistive Plate Chambers (MRPCs) (2000)
- Gap size 200 µm – 300 µm,
- Number of gaps 6 – 12 gaps,
- Single gap/double stack
- Time resolution 40 ps – 150 ps
- Spatial resolution few cm down to a few 100 µm
- Rate capability of 100 Hz/cm² – 1kHz/cm²

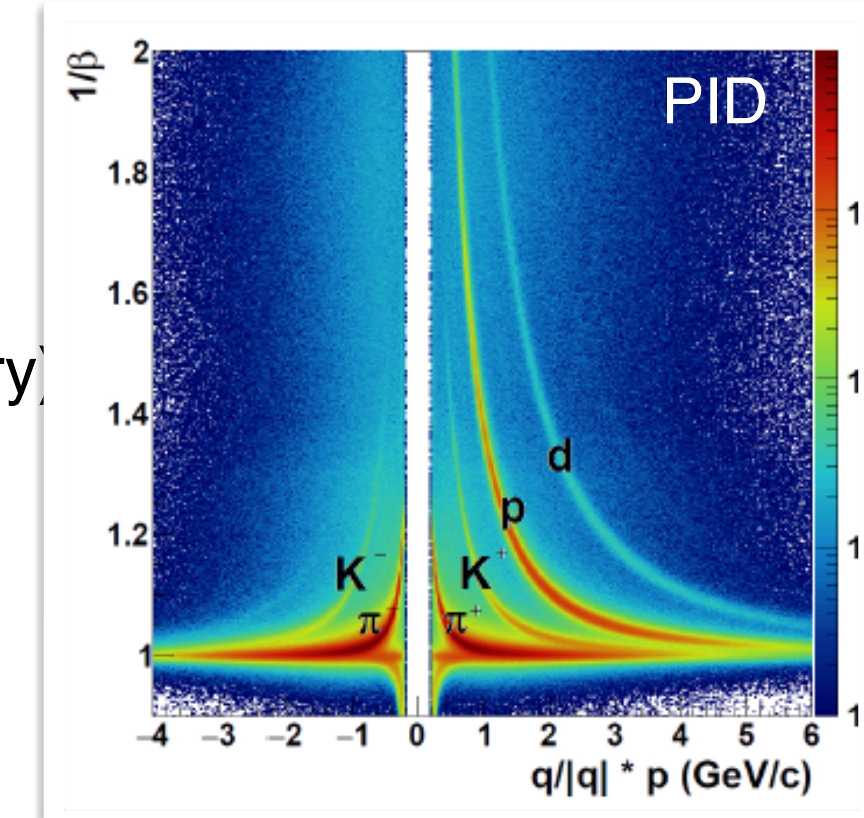


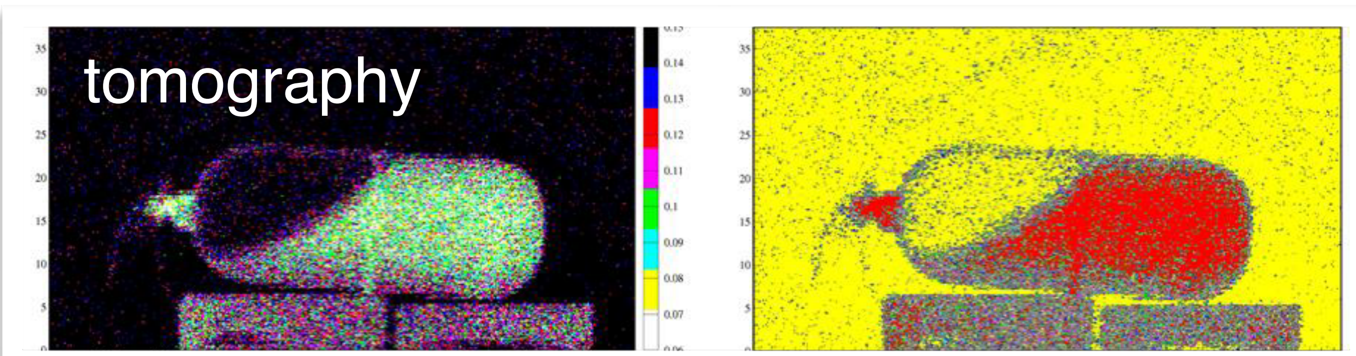
New development of MRPCs (second generation)
- Gap size down to 100 µm,
- Number of gaps up to 24 gaps,
- Time resolution down to 20 ps
- Spatial resolution down to few 100 µm
- Rate capability up to 50 kHz/cm²
- Sealed counter (gas reduction, aging mitigation)

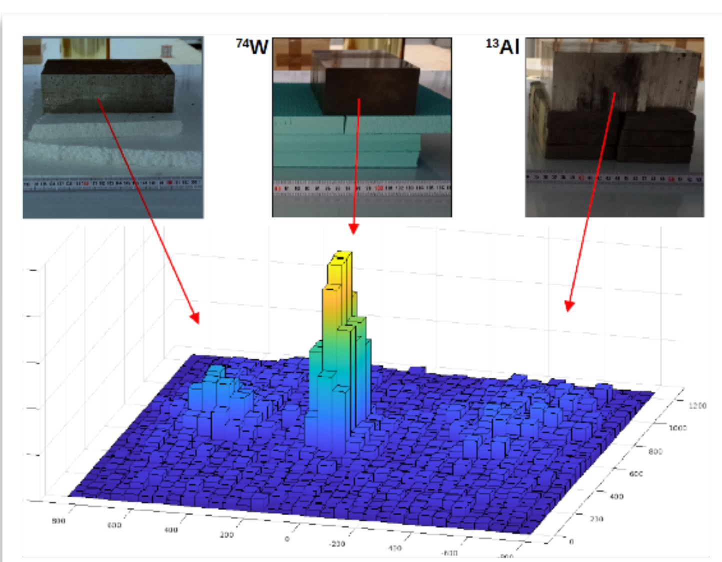


(m)RPC applications

- Muon tracking/triggering (e.g. CMS, ATLAS)
- Time of Flight (e.g. ALICE, STAR, HARP, FOPI, HADES, SHiP, BGO-EGG, CBM, CEE, Pi20, …)
- Calorimetry (e.g. CALICE SDHCAL)
- Cosmic ray experiments (e.g. EEE, Pierre Auger Observatory)
- Positron Emission Tomographie (PET)
- Gamma Tomography
- Muon radiography (mostly RPCs used so far, e.g. Tomuvol)

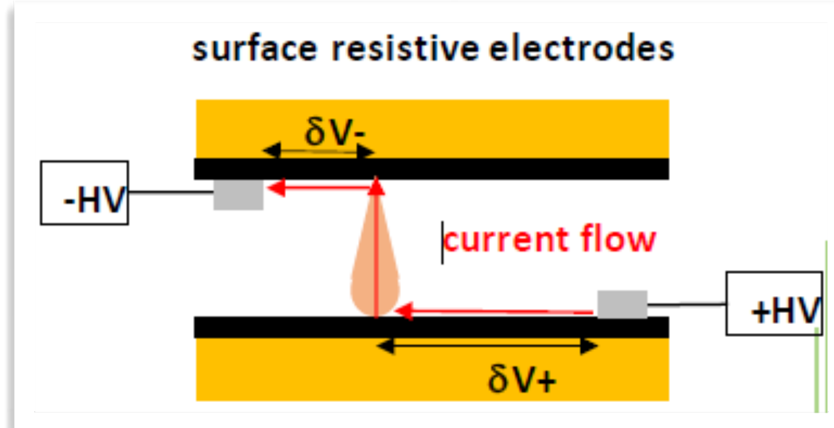


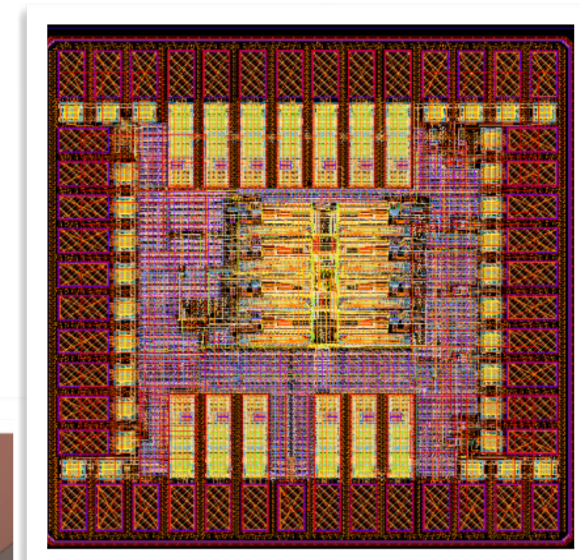


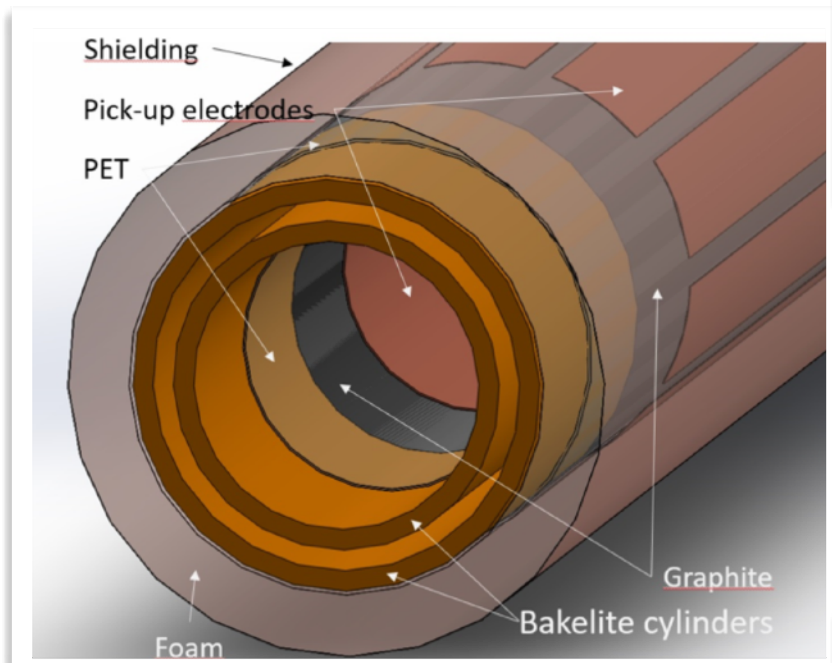


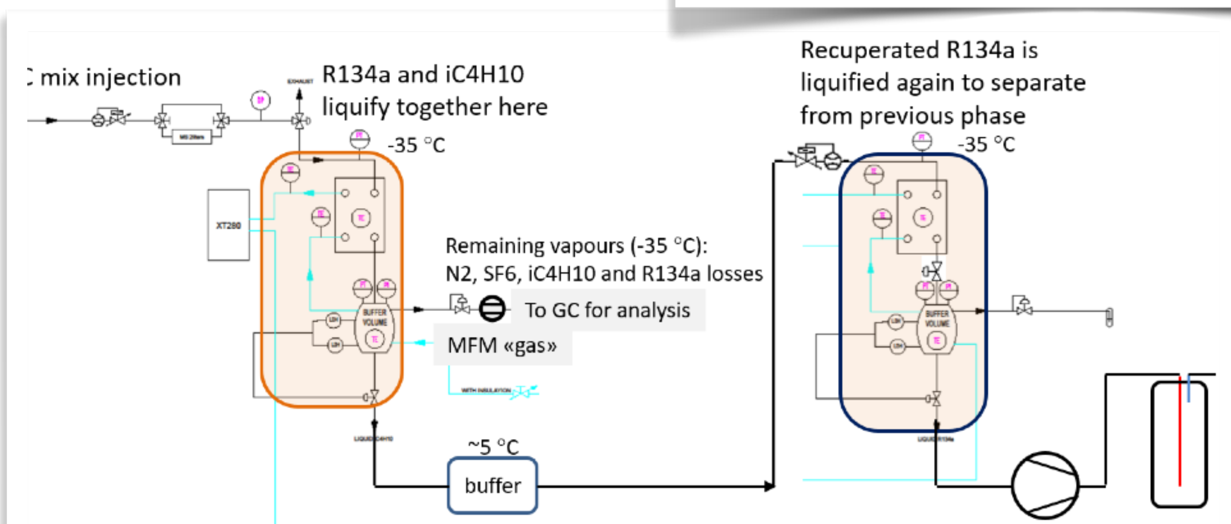
(m)RPC R&D

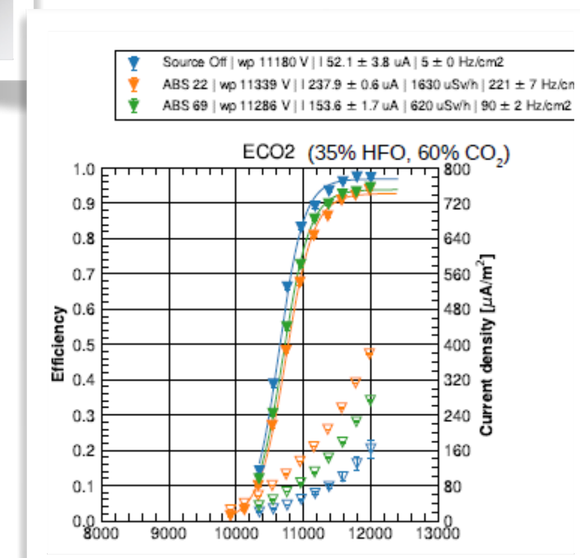
- High **rate capability**
- **New** resistive electrode **materials** (Chinese glass, vanadate-based glasses, ceramics, DLC, SI-GaAs wafers, …)
- **Radiation hard** materials
- Gas and material **ageing**
- Chamber **geometries** (cylindrical RPC, single electrode chambers …)
- Spacer geometry (fishing lines -> pads)
- New eco-friendly **gas mixtures**
- Gas recuperation systems
- Sealed detector operation
- **Faster** readout electronics (a few ps time resolution, high bandwidth)











Synergies

Common aspects in the developments/needs across the technology and involving several DRD1 WGs:

- Detector cleanliness, low outgassing, leakage limitation/control, gas system/recuperations, eco-friendly gases, reduce aging and corrosion (WG3, WG6).

- Resistive materials, resistive coatings, biasing schemes, limit effect of discharges and increase rate capability (WG2, WG3).

- Production/assembly *tricks* for precise assembly/winding/centring/aligning/spacing. Common issues solved in different ways (WG6).

- New structures arise also from new opportunities, i.e. new electronics, new pixellised chip… Interplay of developments of structure and electronics (WG5).

- Hot common R&D topic: extreme time resolution. Different approaches, but common fundamental developments of tools for testing (WG5, WG7).