Contributi alla discussione sulla Roadmap ECFA per Detector R&D

R&D on Resistive MPGD technologies

Bari, Bologna, Ferrara, Frascati,
Napoli, Pavia, Roma3, Torino

Technology - resistive materials

Resistive Micro-Pattern Gaseous Detectors (MPGD) are among the most promising technologies for gaseous particle detectors at future accelerators.

- To strengthen the efforts in new developments in particle detectors, **several Italian groups** involved for years in the R&D of MPGDs, are currently conducting a **joint effort** aiming at **developing a novel generation of resistive MPGDs**, focusing the R&D on **µRWELL**, **Micromegas, sRPC** and **Fast Timing MPGD** technologies, together with high performance **integrated front-end electronics**.

All these technologies use resistive DLC layers

with **CERN**, the Italian community is investing in this technology to **improve production** and carry out dedicated research and development activities
The baseline is to finally **ensure** the production of **well-controlled, high-quality** sheets and implement different coatings (Cu clad DLC, B4C, ITO)

R&D on new resistive materials (e.g. graphene) and functional cathodes

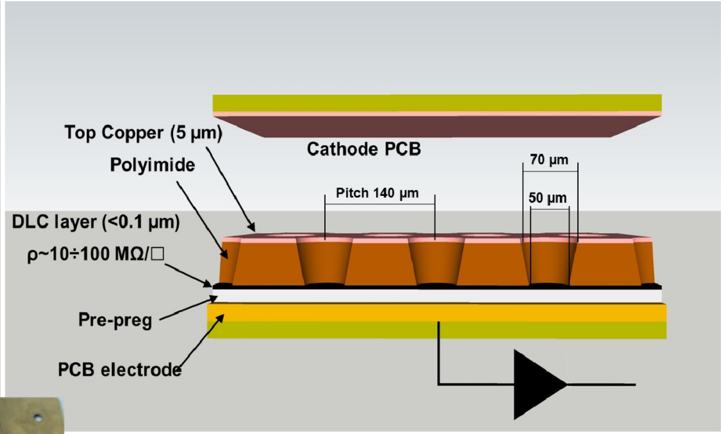
Multiple Challenges - general Considerations

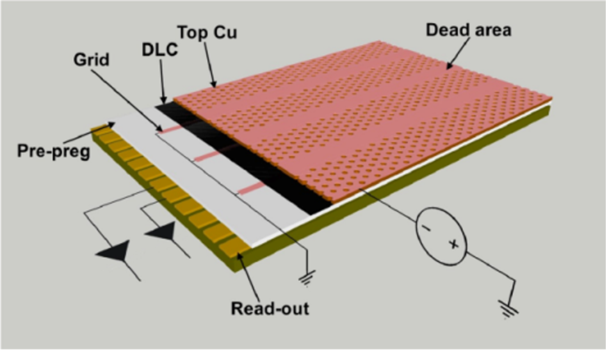
- **Stable** and efficient **operation** up to particle fluxes of 10 MHz/cm^2 (and beyond)
- **Radiation hard** and effective **spark quenching** up to integrated charges of tens of C/cm^2
- **Low occupancy**: high granularity readout to operate efficiently at high rate
    - pixels of order of few mm^2
    - fully integrated electronics and cooling systems
- **High gain** for improved performance, single-electron detection & Fast Timing
- Maintain **good spatial resolution** (~50um and below)
- **Gas** optimisation: **eco-friendly** vs **resolution** vs **high gain** & **fast timing** … *still a long way...*
- **Fast timing** requires high gain structures and gas mixture & dedicated sensitive electronics
- **Improved Electronics:** faster, low-noise and low signal threshold (< fC) amplifiers
- **Low material budget**, compact structures in single or multilayers
- **Reliable and cost-effective** production process
    - suitable for (industrial) mass production, in order to be able to build large apparatuses

Current developments – the μ-RWELL

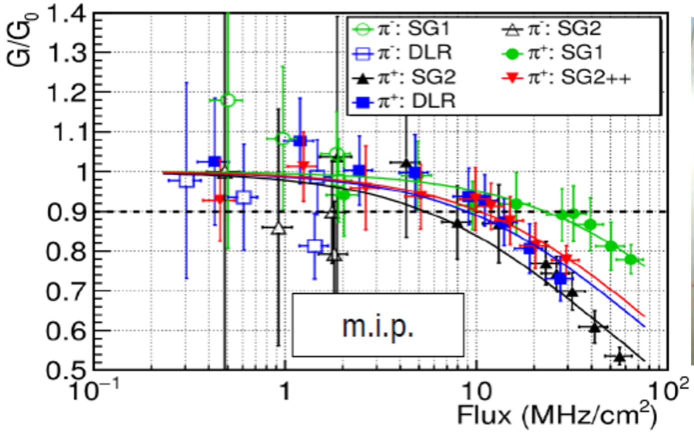
G. Bencivenni et al., 2015_JINST_10_10_P02008

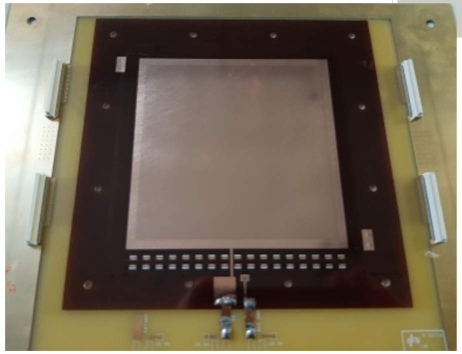
- **Single-amplification stage**, **spark-protected** resistive MPGD based on a breakthrough technology suitable for **large area** planar, fine tracking, high rate devices
- **Gas gain ~10^4, rate capability ~10 MHz/cm^2, efficiency 98%**

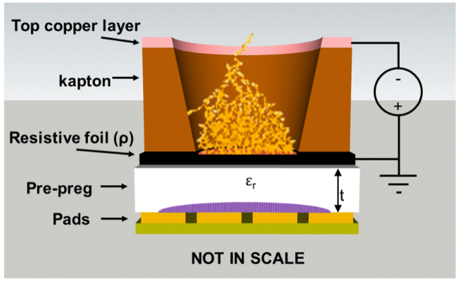


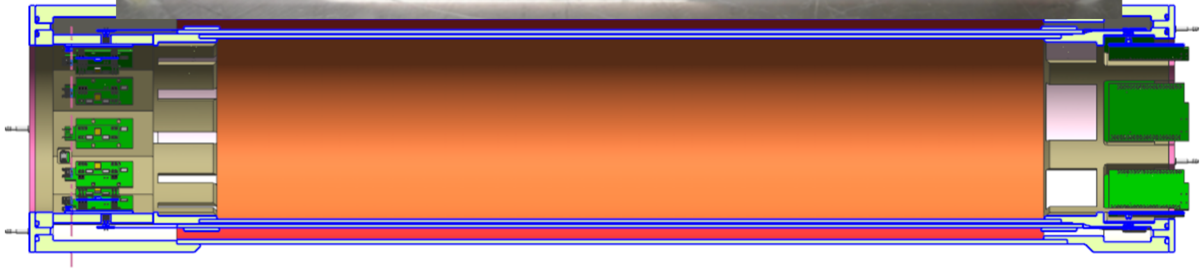


G. Bencivenni et al., 2019_JINST_14_P05014









- Realized on **flexible substrate** the technology can be exploited for **cylindrically shaped low-material budget radial TPC** as Inner Tracker

Current developments – the Pixelated Micromegas

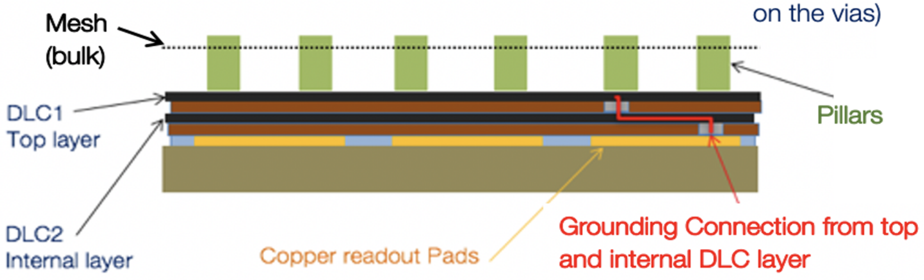
R&D on Pixelated Micromegas

- R&D basic steps:
  - Optimization of the spark protection resistive scheme
  - Implementation of Small pad readout (for low occupancy under high irradiation)

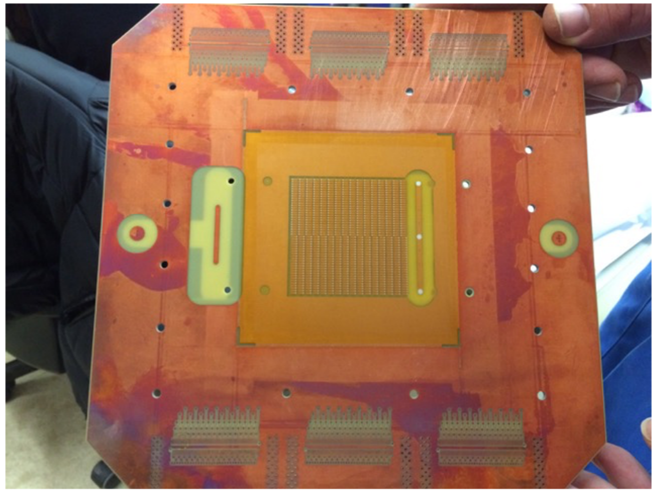
Aiming at:

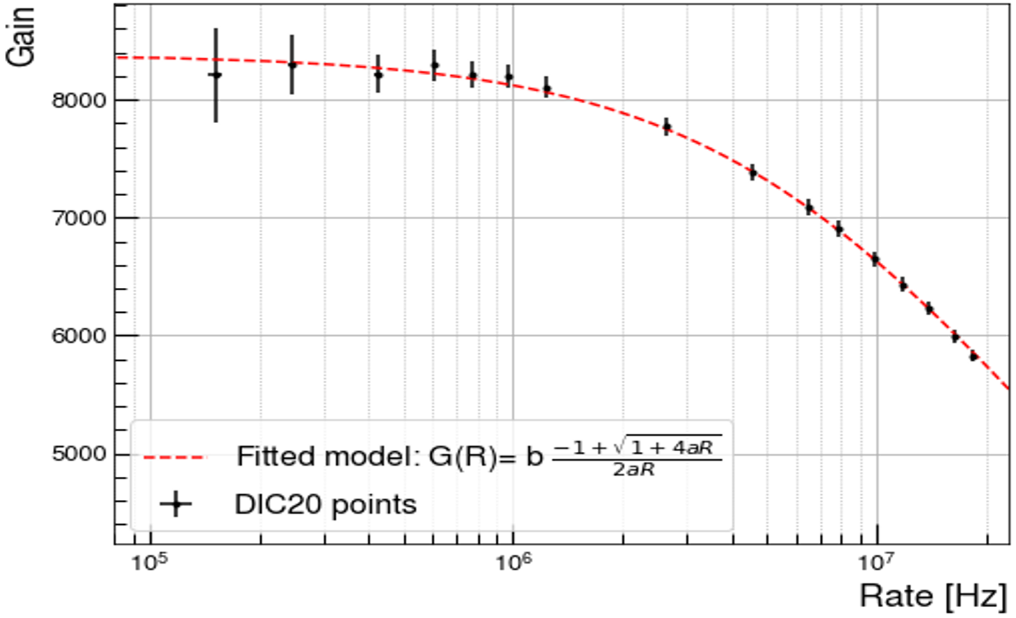
- HIGH GAIN
- HIGH Rate Capability
- HIGH Granularity
- HIGH STABILITY – robustness

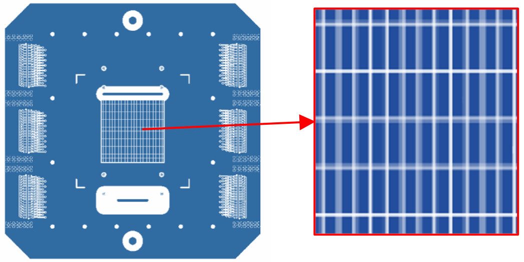
Double DLC uniform resistive layer



- Double DLC layer with connection vias to ground every "few" mm





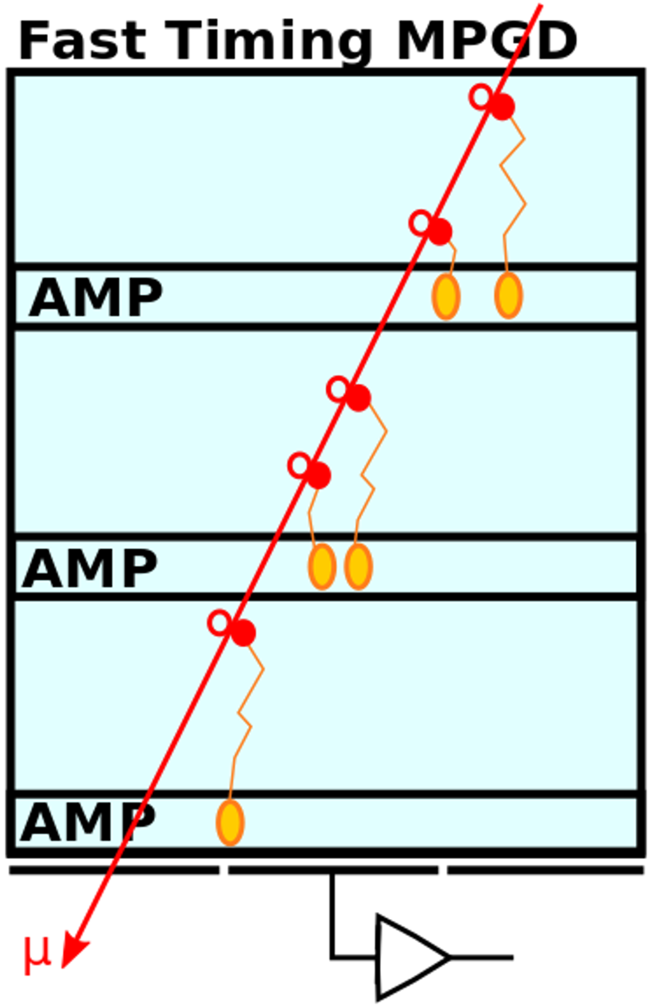


Pixelated readout pitch of 1 x 3 mm^2

Current developments – Fast Timing MPGD (FTM)

- Time resolution of <u>all</u> proportional gas detectors (GEM,MM,uRWELL,…) is limited to 5-10ns [1]
- Typical <u>fluctuation of closest primary electron</u> to amplification structure:

λ~ 2.8mm^{-1} → $\langle d \rangle$ = 350μm @ v_{drift} = 50-70μm/ns → σ_t = 5-7 ns time resolution [2]



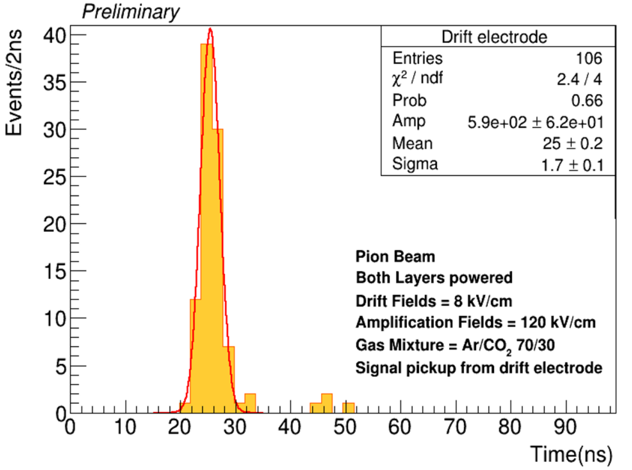
Fast Timing MPGD: Working Principle

- Divide drift in multiple layers, each with Amplification
- Resistive electrodes => Electrode Transparency
- Closest primary electron => Fastest Signal
- Time Resolution σ_t = 1/($\lambda \cdot v_{drift} \cdot N$), where N = layers
- Observed: 2ns with 2 layer-detector [4] (→ OK)

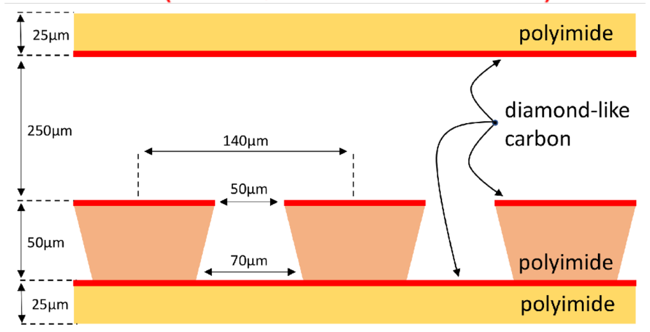
Fast Timing MPGD: Challenges

- Fully Resistive MPGD (no Copper, only DLC, resist. kapton)
- Detect single-electron (or single cluster) instead of many primary+secondary electrons created in drift gap
- **Requires High Gain Structures: G = 10^4 - 10^5**
- **Requires sensitive front-end** (< 1fC, few ns rise-time)

Test Beam Results (2 layers)



Design of single Layer:
Perforated GEM foil with DLC electrode

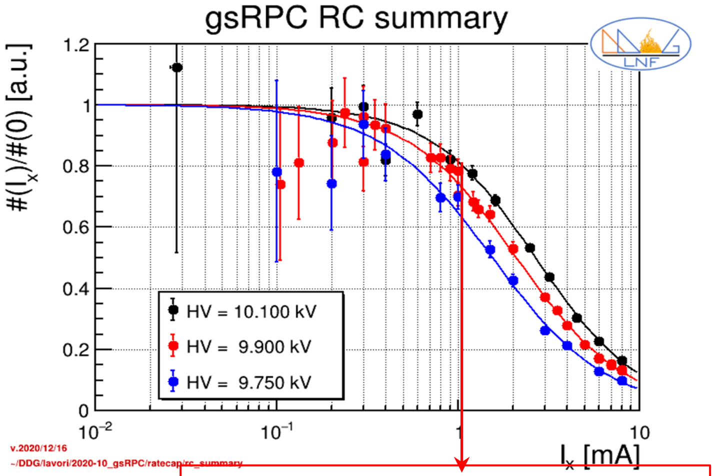


References:
[1] F.Sauli, Yellow Report, CERN-77-09 (1977)
[2] P.Verwilligen *et al.* J.Phys.Conf.Ser. 1498 (2020)
[3] M.Maggi *et al.* arXiv:1503.05330 (2015)
[4] I.Vai *et al.* NIM A 845 (2017) 313

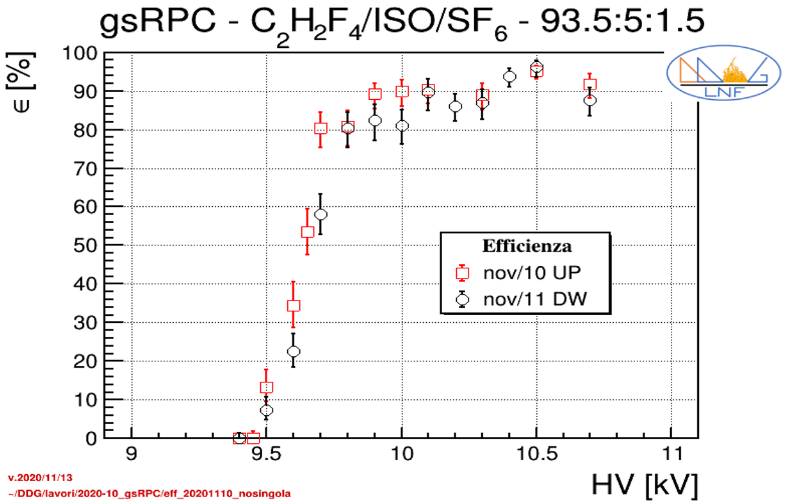
Future R&D on Higher Gain structures (thick Polyimide), innovative resistive electrodes & for fast timing

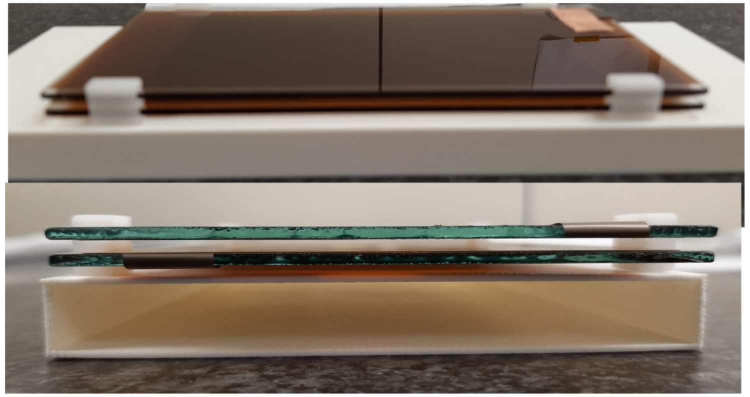
Current/future developments – the sRPC

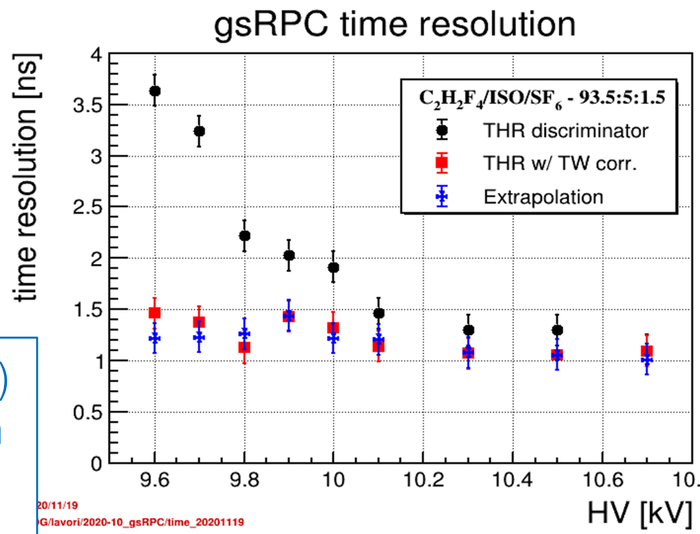
- The **Surface Resistive Plate Counter** is based on **surface resistivity thin electrodes** (1-10 GOhm/square) manufactured with **industrial DLC coating techniques** on flexible or semi-rigid supports, a completely different concept w.r.t. traditional RPCs characterized by volume resistivity



~ 1 kHz/cm² - m.i.p. equivalent







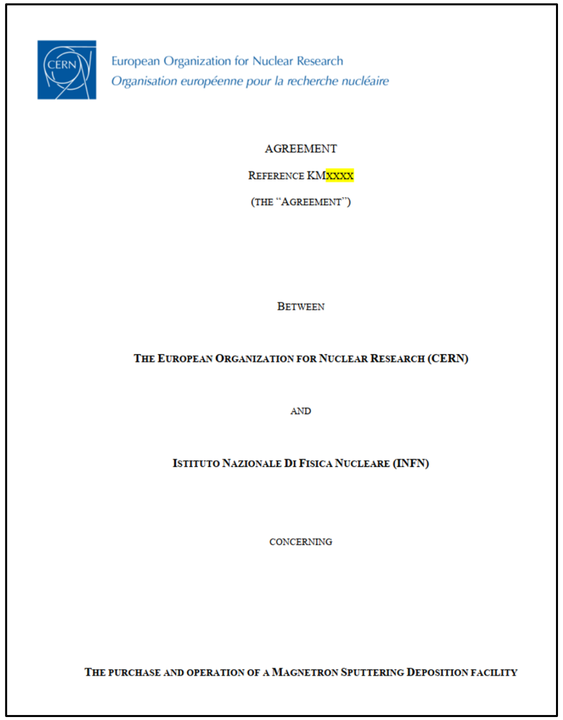
- The detector can be operated in a stable and efficient way over a wide voltage range (>1 kV)
- Typical **time resolution of 1 ns** and a rate capability of **1 kHz/cm²** has been obtained with a 2 mm gas gap
- **Exploiting the technology developed for resistive MPGDs should allow the development of sRPC achieving very high particle rates (>10 kHz/cm²)**

- **Multi-micro-gap structures should allow to achieve tens of picosecond time resolution**

NEW FACILITY FOR RESITIVE-MPGD R&D

C.I.D: the joint CERN-INFN DLC facility

- Several INFN members of RD51 together with CERN groups (*EP-DT-MPT Workshop, EP-DT, RD51*) are collaborating to the **acquisition of a Magnetron Sputtering Deposition facility** to be installed in the new MPT Workshop at CERN



European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

AGREEMENT

REFERENCE KMxxxx

(THE "AGREEMENT")

BETWEEN

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

AND

ISTITUTO NAZIONALE DI FISICA NUCLEARE (INFN)

CONCERNING

THE PURCHASE AND OPERATION OF A MAGNETRON SPUTTERING DEPOSITION FACILITY

The main characteristics of the machine are:

- Hybrid Physical Chemical Vapour Deposition (HPCVD) using DC magnetron technique: DLC, Cu, Cr, Al, B4C
- Reactive sputtering: add H_2, N_2, CH_4, C_4H_{10}, Ne to Ar
- Large coating area (2000x600 mm^2) with a good thickness homogeneity to improve resistance uniformity

- The project mainly **focuses on the R&D on resistive MPGDs**
- The machine will offer **new opportunities for depositing different coatings** in other research domains in addition to the MPGD (DLC, B4C, new photo-sensitive coatings, Aluminum, ITO layers for transparent MPGD)

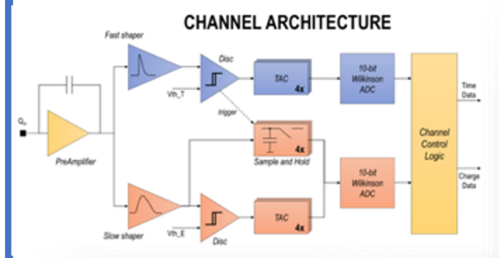
Future developments – Front-End Electronics

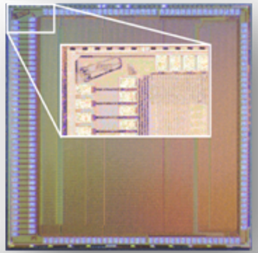
Front-End Electronics for Tracking

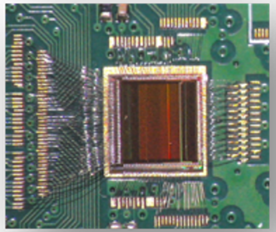
TIGER ASIC for the BESIII CGEM-IT

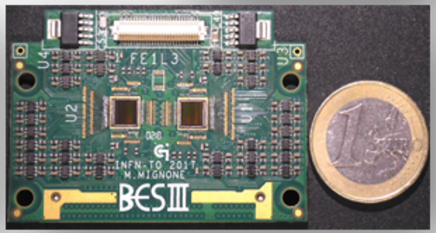
Status: commissioning phase with cosmic rays at IHEP (Beijing), on-detector electronics and DAQ with remote detector operation.

- Spatial resolution: σ_{xy} = 130 μm , σ_z = 1 mm
- Momentum resolution: σ_{pt}/p_t = 0.5% @ 1 GeV/c
- Efficiency = 98%
- Material budget ≤ 1.5% of X_0 for all layers
- Rate capability: ~10^4 Hz/cm^2
- Coverage: 93% 4π





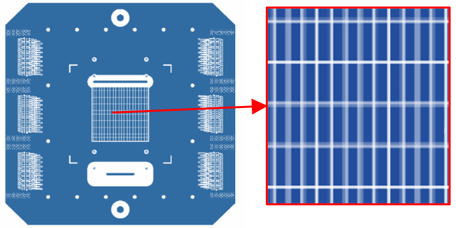




Integrated / Embedded Electronics

Easy guess: Near-term developments will target higher rate, better timing resolution, scalability to larger tiles (of pixelated MPGDs) or capable of reading longer strips.

However, pixel MPGDs pave the way for new opportunities...

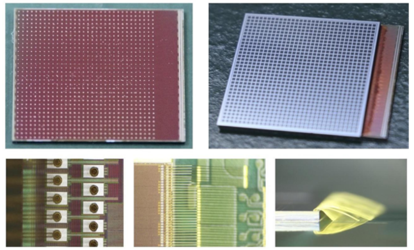


Pixelated readout: pitch O (1mm^2)

** from slide 5*

Is there an opportunity to bring MPGDs closer to the interaction point (inner tracker, vertex)?

Not an easy guess, but: a long-term strategy could lead us to develop high-performance cost-effective detector modules with MPGDs mounted on a CMOS active substrate for the readout and power routing.



INFN TechTransfer

Left: example of a 1024 sub-mm pixel readout ASIC for fast timing (3D hybrid sensor assembly)

From a cm2 size demonstrator chip (2022-2025)
To **wafer-scale pixelated MPGD readout modules** in 2030?

AIDA innova

Front-End Electronics for Timing & Tracking

Single-Stage MPGD detectors have typical gain of $3 \cdot 10^3$ – max 10^4. Assuming signal not dispersed over different strips, results in signals of 0.5-1fC

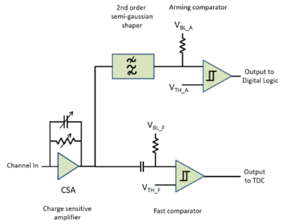
Fast Timing typically done for large signals:

$\sigma_t = \sigma_{noise}$ / dV/dt = t_{rise} / SNR

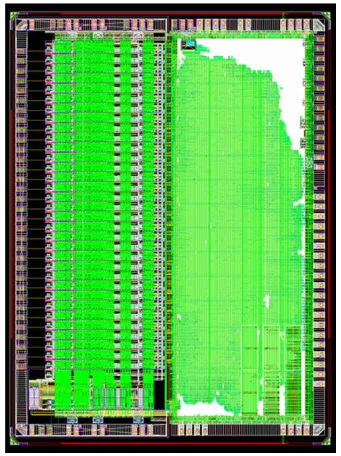
=> Now we want to bring fast timing to smaller signals. Need very low noise amplifiers

FATIC (130nm Si CMOS)

- 32 channels + 1 test
- Gain: 10mV/fC & 50mV/fC
- ENC: 500e$^-$ @ 15pF
- Rise time: 7.5ns
- Analog: time & Charge
- Digital: TDC (100ps)



2nd version submitted



Future developments:

AIDA innova

- Faster technology (28nm)
- Differential input (cfr MRPC approach)
- Constant Fraction Discriminator
- Improved timing TDC / waveform sampling

Future developments – Front-End Electronics

State-of-the-Art: INFN developed system-grade ASICs for MPGDs

Status: commissioning phase with cosmic rays at IHEP (Beijing)

larger tiles (of pixelated MPGDs) or capable of

from slide 5

New developments (2020-2023): ASICs for fast timing with MPGDs

New developments (2021-2026): IP cores with advanced CMOS technologies for future complex SOCs

New developments (2021-2026): Large pixel ASICs for advanced integration solutions with CMOS active substrates

New/Future developments

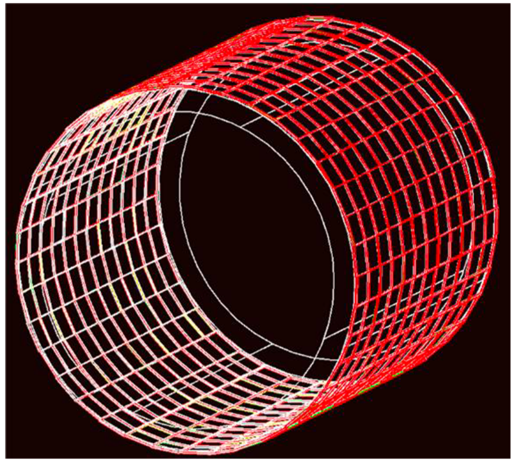
- **Transition** from small prototypes to large area detectors
- Keep and ensure **radiation hardness** and **ROBUSTNESS** against discharges
- **Careful choice of gas mixtures** and new ECO-gas for single **stage high gain amplification**, high **operation stability** and excellent performance, are the challenge of the next decade
- **Timing:**
  - FTM and sRPC exploiting the high rate resistive MPGD technology are the frontier of sub-nanosecond timing detectors
  - µRWell and MM need a paradigm shift to go below 1 ns time resolution (few ns is hard limit)
- The **acquisition** of **DLC machine** will support and **boost the R&D on future resistive MPGDs**
- Development and implementation of **innovative & integrated electronics**
- Development of **ultra-low-material budget** modules, using CMOS silicon as an active substrate; strategic with INFN's investment on the industrialisation of the sensor technology
- We need the **development of simulation tools** (integrated in Garfield++) to simulate the behaviour of resistive electrodes (charge spread, signal transparency, rate capability)

APPLICATIONS in HEP

Thanks to the good spatial resolution, timing capabilities and radiation hardness, the resistive MPGDs can be used for many applications in HEP:

- Muon tracking and trigger detectors
- Readout devices for Time Projection Chambers
- Readout for High-Granularity Hadronic Calorimeters
- Pre-shower tracking devices for calorimeters
- Low material budget Inner Trackers

μRWELL-based preshower of the IDEA detector concept for FCC-ee



μRWell and MM future development will open the way towards a new generation of high performance muon detectors.

FTM and sRPC promising detectors for high rate - high time resolution, with good spatial res.

MPGDs & sRPC could also be a promising technology for compact digital calorimetry.

Applications of low/moderate rates (e.g. for FCC-ee) will draw huge benefits from the R&D on resistive MPGD for high rate as well as the new challenges on timing detectors.

Other APPLICATIONS

Beyond HEP, innovative high-performance resistive MPGDs can find applications in:

- homeland security (muon tomography/neutron devices)
- cancer hadron-therapy as high rates/large dynamic range beam monitor
- fast large area detectors for Time-of-flight Positron Emission Tomography
- space weather research area, with the detection of neutral atoms in the terrestrial magnetosphere/ ionosphere

Such objectives require the development reconstruction algorithms taking advantage of a well established expertise, in the proponents and their units, of the simulation tools.

Outlook

- The creation of the CERN-based R&D collaboration RD51 in 2008 has given a boost to the development of MPGD
  - additional financing through common project
  - Involvement of MPT workshop experts (Rui)
- RD51 has been prolonged 2 times for 5-year terms (2013-2018 and 2019-2023)
  - We strongly support a new extension of RD51
- A **INFN-based MPGD technology Workshop** is strategic for future developments
- Need to strengthen the technology transfer path to industry