RADIAMM:
Radiation hard DIAmond-based secondary emitter
for development of an ultra-fast timing
MicroMegas detector

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The "Picosec" Project

Started as an RD51 common fund project:

Fast Timing for High-Rate Environments: A Micromegas Solution

Awarded 3/2015

Collaborating Institutes:

- CEA (Saclay)

- CERN

- NCSR Demokritos
  G. Fanourakis

- NTU Athens
  Y. Tsipolitis

- University of Thessaloniki
  I. Manthos, V. Niaouris, K. Paraschou, D. Sampsonidis, S.E. Tzamarias

- University of Science and Technology of China (USTC), Hefei
  Zhiyong Zhang, Jianbei Liu, Zhou Yi

1 Present Institute: University of Santiago de Compostela
2 Also University of Virginia.
Motivation: why ~10 ps are interesting?

High Luminosity Upgrade of LHC:
- To mitigate pile-up background.
- ATLAS/CMS simulations: ~150 vertexes/crossing (RMS 170 ps).
- 10 ps timing + tracking info.

Extra detector requirements:
- Large surface coverage.
- Multi-pads for tracking.
- Resistance to aging effects.

PID techniques: Alternatives to RICH methods, J. Va’vra, accepted in NIMA, 
https://dx.doi.org/10.1016/j.nima.2017.02.075
State-of-art precision timing

Solid state detectors
- Avalanche PhotoDiodes: $\sigma_t \sim 20$ ps
- Low Gain Avalanche Diodes: $\sigma_t \sim 30$ ps
- HV/HR CMOS: $\sigma_t \sim 80$ ps
  ➔ Radiation hardness?

Gaseous detectors
- RPCs: $\sigma_t \sim 30$ ps
  ➔ High rate limitation
- MPGDs: $\sigma_t \sim 1$ ns

Question:
Can a MicroPattern Gaseous Detector reach a timing resolution of the order of few tens of picoseconds?
➔ performance improvement by ~2 orders of magnitude

➔ First step: proof of concept

➔ Next steps: Large-area, position-sensitive, radiation hardness
The Micromegas detector

Conversion region
Radiation create electrons, which drift to the readout plane.

Amplification region
Electrons are amplified & the charge movement induces signals.

Interesting features for many applications:
Simplicity, Granularity, Homogeneity, Scalability, High rate capabilities, Radiation hardness

Timing limitation factors:
• **Large conversion region**: charges created in different positions.
• **Diffusion effects**: \( \sim 0.3 \text{ mm/cm}^{0.5} \rightarrow \sim 6 \text{ ns for 3 mm drift distance} \!)
Improving the Micromegas timing

Standard MPGD detector:
- Large ionization volume.
- Big diffusion (~ns).

Drift gap is reduced:
- Diffusion limited.
- Preamplification.

Cerenkov radiator:
- Primary electrons localized in time & space.

Picosec: 24 ps with Micromegas

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The Picosec detector

- A particle produces Cerenkov radiation.
- Photons produce electrons in the photocathode.
- Electrons are amplified by a two-stage Micromegas detector.
- Two signal components:
  - Slow: ion tail (~100 ns).
**Beam tests with 150 GeV muons @ CERN SPS H4**

- **Trigger:** coincidence of two 5x5 mm² scintillators and a veto downstream (avoid showers)
- **Tracker:** three GEMs to measure where the triggered particle passed (reject showers too)
- **Time reference:** two Hamamatsu MCP-PMTs (160 ps rise time)
- **Tracking acquisition:** APV25 + SRS
- **Timing acquisition:** CIVIDEC C2 preamp + 2x 2.5 GHz LeCroy scopes (synchronised with the tracker) and SAMPIC
Results of beam tests: 24 ps

- Best result: 24 ps (bulk MM + Cr/CsI photocathode).
- Optimum operation point: Anode +275V / Drift - 475V.
- Nphe = 10.1 ± 0.7
- Result repeated in two different beam campaigns.

More info: http://irfu.cea.fr/Phocea/Vie_des_labos/Seminaires/index.php?type=6&id=4015 (seminar by F. Iguaz)
Next steps

- Spark quenching in the mm gap (ongoing)
  - Resistive Micromegas

- Spark quenching in the drift/preamp gap (under consideration)
  - Resistive mesh
  - Protection or robust photocathode
  - Graphite - DLC

- Multichannel readout
  - Pads / pixels
  - Strips
  - Multi-channel electronics

Most critical: an efficient & robust photocathode against sparks & ion feedback

⇒ RADIAMM project

A picture of sparks in a CsI photocathode
The RADIAMM project

A 3-year project, starting on 1st November 2017 with objective: 
RADiation hard DIAMond-based secondary emitter for the development of an ultra-fast timing MicroMegas detector

Main Partners:

- **CEA/DRF/Irfu/DEDIP**  
  (Thomas Papaevangelou)

- **CEA/DRT/List/DM2I/LCD**  
  (Michal Pomorski)

- **CEA/DRF/Iramis/Lidyl/DICO**  
  (Thomas Gustavsson)

Partner tasks:

- Coordination
- Multi-channel detector
- Establish a test bench for QE measurements and aging tests

- Diamond photocathode
- **Secondary Emitters**

- Time resolution measurements for the multi-channel prototype
BNCD growth on quartz
BNCD growth on MgF2
Conclusions - Outlook

We have coupled a Micromegas detector with a radiator / photocathode in order to surpass the physical constrains on precise timing with MPGDs, aiming to an important improvement of their performance (~two orders or magnitude are needed in order to be considered for the HL-LHC upgrade)

- The detector has been tested with a femtosecond UV laser in order to investigate the time spread of single photoelectrons. \( \sigma_t \sim 70 \text{ ps for single p.e.} \) has been measured for strong drift field with a standard bulk Micromegas in semi-transparent mode, without gas circulation.

- The Micromegas photodetector has been tested with 150 GeV muon beam. Data taking is on-going. \( \sigma_t \sim 25 \text{ ps} \) has been measured for 3 mm MgF2 + 5.5 nm Cr substrate + 18 nm CsI photocathode. The estimated number of photoelectrons for this photocathode was: \( \langle N_{\text{p.e.}} \rangle = 10 \)

- Results from various radiator/photocathode setups are pending.

  ➔ Still some margin for improvement: gas / drift gap / photocathode studies & optimization

  ➔ Single p.e. result very interesting for less efficient but more robust photocathodes (metallic, graphite/DLC, polycrystalline diamond... )

The RADIAMM project aims to address:

- **Multiple-pad readout performance**
  - Design a pixelated prototype (~5x5 cm\(^2\))
  - Readout Electronics (Sampic/FAMMAS amplifiers)

- **Radiator & photocathode aging / radiation hardness**
  - IBF, photon feedback, discharges
  - Particle flux (high rate tests @ IRAMIS / SEDI)
  - Deterioration with time
  - Metallic photocathodes
  - DLC / polycrystalline diamond photocathodes
  - Operation in reflective mode

- **Polycrystalline diamond as secondary emitter**
  - Replace the crystal + photocathode with secondary electron emitter
    - Robustness / radiation hardness
    - No radiator - flexible choice of substrate material
    - Possibility to increase thickness towards 1 \( \mu \text{m} \)
  - Investigate materials with high secondary electron yield. (Doped-) diamond deposition, DLC, graphene...

  ➔ multi layer detector
  ➔ graphene layer for photocathode protection ?
**Detector optimization**

**Photocathode:**
- CsI and different:
  - producer (CERN, Saclay)
  - thicknesses (11, 18, 25, 36nm)
  - metallic interface (Al, Cr) & thicknesses (Cr 3, 5.5nm)
- Pure metallic
  - Al(8nm), Cr (10,15,20nm)
  - Diamond, B-doped Diamond

**Crystal:**
- Different Thicknesses of MgF2 (2,3,5mm)
- Different Material

**Gas Mixture**
- Compass gas
- CF4 + 10% C2H6
- Ne + 20% C2H6

**Micromegas:**
- standard bulk
- bulk with 6 pillars
- thin mesh bulk
- Resistive (different values)