The RD51 Collaboration: « Development of Micro-Pattern Gaseous Detector Technologies »

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OUTLINE of the TALK:

- RD51 Motivation and Main Objectives (2008-2013)
- Future RD51 Activities (beyond 2013)
- Summary of the RD51 Highlights (2013-2014)
  (Large area MPGDs - Support of HL- HLC Upgrades, R&D (quality control, long-term tests), Academia-Industry Matching Event, Software & Simulation, SRS Electronics, CERN MPGD Production Facility & Industrialization, RD51 Test Beam Facility, Training)

118th LHCC Meeting, CERN, June 4-5, 2014
Micromegas

GEM

Thick-GEM, Hole-Type and RETGEM

MPDG with CMOS pixel ASICs (“InGrid”)

Micro-Pixel Chamber (μPIC)

Rate Capability: MWPC vs MSGC
Why Micro-Pattern Gaseous Detectors are so attractive ...

- High Rate Capability
- High Gain
- High Space Resolution
- Good Time Resolution
- Good Energy Resolution
- Excellent Radiation Hardness
- Ion Backflow Reduction
- Photon Feedback Reduction

One of the recent reviews describing the progress of the RD51 collaboration:

Modern Physics Letters A
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MICRO-PATTERN GASEOUS DETECTOR TECHNOLOGIES AND RD51 COLLABORATION

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Many of the Micro-Pattern Gaseous Detector Technologies were introduced before the RD51 Collaboration was founded.

With more techniques becoming available (or affordable), new detection concepts are being introduced and the existing ones are substantially improved.
World-wide Collaboration for the MPGD Developments ➔ RD51 (91 institute, > 500 people):

- Large Scale R&D program to advance MPGD Technologies
- Access to the MPGD “know-how”
- Foster Industrial Production

A fundamental boost is offered by RD51: from isolate MPGD developers to a world-wide net

Advances in photolithography ➔ Large Area MPGDs (~ m² unit size)

http://rd51-public.web.cern.ch/rd51-public

The main objective is to advance MPGD technological development and associated electronic-readout systems, for applications in basic and applied research”
Consolidation of the Collaboration and MPGD Community Integration (> 80 institutes, 450 members);

Major progress in MPGD Technologies: Large area GEM (single mask), Micromegas (resistive) and THGEM; picked up by experiments, including LHC upgrades;

Secured future of the MPGD Technologies development through the TE MPE workshop upgrade and FP7 AIDA contribution

Contacts with industry for large volume production; MPGD industrialization and first industrial runs

Major improvement to the MPGD simulation software framework for small-scale structures for applications;

Development of common, scalable readout electronics (SRS); many developers and > 50 user groups; Production (PRISMA company and availability through CERN store); Industrialization (re-design of SRS in ATCA in EISYS)

Infrastructure for common RD51 test beam and facilities (> 20 user groups);
Future RD51 Collaboration Activities (beyond 2013)

Large Area Detectors Assembly Optimization

RD51 Common Projects Generic R&D, QA Long Term Stability

MPGD Electronics

RD51 Common Projects

WG1:

WG5:

WG2:

WG4:

WG3/NEW WG:

• Conferences / Schools
• Academia-Industry Matching Events

WG6:

WG7:

CERN MPGD Workshop, Quality Control and Industrialization

RD51 Test Beam and Lab Facilities
RD51 Highlights (2013-2014)  … as a part of the RD51 Collaboration Working Plan beyond 2013 …

- **WG1:** Continuation of the R&D support for the experiments and LHC upgrades
  - **WG2:** Generic R&D (long-term stability, quality control); RD51 Common Projects
    - Development of new structures and consolidation of the existing structures
  - **WG3 (NEW):** Applications - organization of series of specialized workshops disseminating MPGD applications beyond fundamental physics – RD51, potential users and industry (e.g. dosimetry, neutron detection, medical physics, …)
  - **WG4:** Development and Maintenance of Software & Simulation Tools; basic studies & software support for the RD51 community
  - **WG5:** Development and Maintenance of the SRS Electronics; An extended support for the SRS including new developments and implementations of additional features
  - **WG6:** MPGD Production and QA Control - GEM, MicroMegas, Thick GEM; completion of the industrialization of main technologies
  - **WG7:** Maintenance and extension of the RD51 Lab and Test-Beam Infrastructure
  - **WG (NEW):** MPGD Education and Training: organization of schools for students and newcomers & academic training
  - Participation in the funding requests / funding contributions: Marie-Curie/GASNET, AIDA2
GEMs for the CMS Muon System Upgrade:
R&D Started in 2009 within the RD51 collaboration:

Single-mask GEM technology (instead of double-mask) → Reduces cost / allows production of large-area GEM

Self-stretching technique: assembly time reduction from 3 days → 2 hours

Future work will focus on stability and uniformity of GEMs, and development of electronics, ...

During the LHC End-Year stop of 2016/2017, two GEM super-chamber demonstrators will be installed

MM for the ATLAS Muon System Upgrade:
R&D Started in 2007 within the RD51 collaboration:

Standard Bulk MM suffers from limited efficiency at high rates due to discharges induced dead time
Solution: Resistive Micromegas concept

2.4 x 1m² MM resistive chamber constructed and characterized at CERN RD51 lab

➢ Resolution for inclined tracks (μTPC method) better than 80 µm
➢ MM can operate in magnetic field

NSW Technical Design Report (TDR) approved by LHCC (October 2013) →

~ 1280 m² of resistive MM will be installed (LS2) in ATLAS → the largest MM system, ever built
⇒ FOSTER INDUSTRIAL PRODUCTION NEEDS
ALICE TPC Upgrade → replace MWPC with GEM

- Continuous TPC readout at 50 kHz
- Physics requirement: IBF < 1%, energy: σ(E)/E < 12% achieved

Energy resolution vs IBF (4-GEM detector):

Special ALICE TPC / RD51 workshop will be organized on June 18th, 2014 (during the RD51 Collaboration Week)
- Electrical rigidity
- Hole diameter uniformity in GEM
- Gap uniformity in MicroMegas
- THGEM thickness uniformity
- Final detector calibration and characterization protocols and infrastructure
- Classical gas detectors ageing detector
- Radiation hardness and activation of detector components
- Sustainability to neutrons and heavily ionizing particles induced discharges
- Exposure to X-Ray, Gamma, Neutron and Alpha Sources
- Monitoring infrastructure

**Portable gas monitoring system** for detector stability studies

→ to be used by LHCb and CMS upgrade for the muon system

**Resistive MicroMegas stability** performance under X-Ray irradiation

**Discharge studies of the triple GEM detector** exposed to the low energy neutron flux
Research + industry + potential users focused on dedicated applications
91 participants: https://indico.cern.ch/conferenceDisplay.py?confId=265187
Summaries based on workshop contributions and follow-up “Neutron Session” (end of 2014):

- Richard Hall-Wilton: “The importance of defining proper methods to characterize the detectors; detector needs for ESS”
- Bruno Guerard: “Status of MPGDs already used in NSS; fabrication and physical constraints of neutron gas detectors”
- Fabrizio Murtas: “Performance of MPGDs, and development status in HEP”
- Robert McKeag: “Lesson learned from a technology transfer from NSS to the industry”

2nd RD51 Academia-Industry Matching Event (topic to be defined) is planned for December 2014
Focus on providing techniques for calculating electron transport in small-scale structures.
The main difference with traditional gas-based detectors is that the electrode scale (~ 10 μm) is comparable to the collision mean free path.

Development and Maintenance of Garfield++:
Garfield++ is a collection of classes for the detailed simulation of small-scale detectors.

Garfield++ contains:
- electron and photon transport using cross sections provided by Magboltz
- ionisation processes in gases, provided by Heed and MIP
- ionisation and electron transport in semi-conductors
- field calculations from finite elements, boundary elements, analytic methods

Simulation Improvements:

→ Transport:
- ion mobility and diffusion, measurement and modelling
- Magboltz cross sections (Ar, Xe, He, Ne; GeH₄, SiH₄, C₂H₂F₄) are frequently updated in collaboration with LxCAT (http://www.lxcat.laplace.univ-tlse.fr)
- e-ion recombination process in Xe
- thermal motion

→ Photons:
- update in UV emission
- inclusion of IR production
- photon trapping and resulting excitation transport
- photon absorption in the gas (gas feedback)
- photon absorption in and electron emission from walls (feedback)
- photo cathodes
Applications:
- GEM: multiplication process and polyimide properties; charging up effects
- MicroMegas: timing and effects of resistive layers
- TPC GEM: ion backflow
- ALICE TPC end-cap upgrade studies: rate dependence of the Ion Back Flow in GEM

Summary of simulation improvements in 2013:
- Systematic calculations of GEM charging-up as function of hole shape; these reproduce the trends observed in experimental data
- Measurements in Krakow for numerous gas mixtures of energy transfer rates which permit much more accurate avalanche gain calculations
- Start of a collaboration with Coimbra on ion transport measurements in mixtures and start of an effort to model ion transport microscopically, which will help to predict charging-up and ion feedback
- Measurement in Orsay at particularly low gain and low noise of the avalanche fluctuations in He/iso, Ne/iso and Ar/isobutane (these fluctuations are reproduced by MC run)
**Physical Overview of SRS:**

- **Scalability** from small to large system
- **Common interface** for replacing the chip frontend
- **Integration** of proven and commercial solutions for a minimum of development
- **Default availability** of a very robust and supported **DAQ software package**

**RD51 Development / Industrialization:** portable multi-channel readout system (2009-2012)

- **Scalable readout architecture:** from ~100 channels up to very large LHC systems (>100 k ch.)
- **Project specific part (ASIC) + common acquisition hardware and software**

**Frontend hybrids:** based on APV25, VFAT, Beetle, VMMx and Timepix chips

**ADC frontend adapter for APV and Beetle chips**

ADC plugs into FEC to make a 6U readout unit for up to 2048 channels

**FEC cards (common):**

- Virtex-5 FPGA, Gb-Ethernet, DDR buffer, NIM and LVDS pulse I/O, High speed Interface connectors to frontend adapter cards
“SRS Classic” (developed by RD51):
→ Produced by PRISMA (Greece),
sold via CERN store

EicSys Germany reworked “SRS classic” into ATCA → functionally equivalent “SRS Classic” with triple channel density

SRS IP and licence has been finalized
(KN2288/KT/PH/203A, SRS ; CERN + IFIN HH Bucharest + UPV Valencia)

→ 1st license taker (EicSys GmbH, Hamburg)

→ royalties to CERN/RD51 if sold outside RD51 and/or research domain

SRS Progress (May 2013- May 2014):

User purchases from ~ 30 teams:

~ 40 SRS classic (CERN store) - 250 kFs
~ 10 SRS classic parts (RD51) - 50 kFs
4 SRS – ATCA (EicSys GmbH) - 70 kFs

Total SRS turnaround 12 month ~ 370 kFs

Major SRS experiments and plans for 2014/15

<table>
<thead>
<tr>
<th>Planned 2014-2015 Experiments with SRS readout</th>
<th>130 k APV channels, 15k VMM channels, 10k Beetle channels, 10 k Timepix arrays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr. Channels</td>
<td>EDH Nr</td>
</tr>
<tr>
<td>15 k APV</td>
<td>SRS Classic</td>
</tr>
<tr>
<td>30 k APV</td>
<td>SRS Classic</td>
</tr>
<tr>
<td>72 k APV</td>
<td>SRS ATCA</td>
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<tr>
<td>15 k VMM</td>
<td>SRS ATCA</td>
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<tr>
<td>10 k Beetle</td>
<td>SRS ATCA</td>
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<tr>
<td>10 k SiPM</td>
<td>SRS ATCA + SRS Classic</td>
</tr>
<tr>
<td>8k APV</td>
<td>SRS Classic</td>
</tr>
<tr>
<td>10 PMT</td>
<td>SRS ATCA</td>
</tr>
</tbody>
</table>

SRS is Very successful → to be used outside MPGD fields (e.g SiPM, …)

Synergy between RD51 & ATLAS NSW:

- Design of 128-channel hybrid plug-compatible with 128 channel APV hybrid → VMM is the new, 64 channel, digital readout chip with Z-suppression (RD51 baseline RD51)

AVD active Voltage Divider for GEMs

Several prototypes built: tested OK with triple GEM incl. readout of GEM foil voltages via SRS
New version: continued operation with short circuit on one GEM foil sector

QUAD MPGD signal amplifier 2 GHz, 25dB

One prototype built: tested on MicroMega 1 channel works OK
3 channels have ringing problem. New version: Improvement of shielding, new 50 OHM PCB

RD51: Towards complete SRS-Lab equipment for MPGDs

Trigger pickup box for MPGD meshes

5 TP boxes built and are used. Integrate HV filter and charge sensitive preamplifiers

Femto-ampere measuring box

Several FEMTO built: sensitivity from 10 fA – to 1 uA. Tested Ok with MPGD detector pickup. New version: larger analogue display, triax input connect Oscilloscope 50 Ohm output
Currently CERN-MPGD workshop is the UNIQUE MPGD production facility (generic R&D, detector components production, quality control)

Upgrade of the workshop equipment approved by CERN management (Nov. 2009) → installation of the new infrastructure (to fabricate 2x1m² Bulk MM & 2x0.5m² GEM) COMPLETED

Construction of the new workshop’s building:

Start: beginning 2012
Completion: mid of 2015

MPGD Projects using new equipment (detector size):

- SBS tracker: GEM - 600 x 500 mm²
- ALICE TPC upgrade: GEM - 600 x 400 mm²
- CMS muon: GEM - 1.2m x 450mm
- ATLAS NSW muon: MM - 2m x 1m
- COMPASS Micromegas: GEM/MM - 500x 500mm²
- BESIII: GEM - 600 x 400 mm²
- KLOE: GEM - 700 x 400 mm²
- SOLID: GEM - 1.1m x 400mm
- CLAS 12: MM - 500 x 500 mm²
- LSBB (geoscience): MM - 1m x 500 mm

Most of them are still at R&D phase, but a few are close to full production:

- SBS Tracker: 100 GEMs
- ALICE TPC upgrade: 250 GEMs
- COMPASS pixel MM: 20 GEM + MM
- BESIII: 15 GEM
- CLAS 12: 30 MM
- CMS: 450 GEM
- ATLAS NSW: ~2000 MM-PCB; 1280 m² area
**GEM Technology (contacts):**
- Mecharonix (Korea, Seoul)
- New Flex (Korea, Seoul)
- Tech-ETCH (USA, Boston)
- Scienergy (Japan, Tokyo)
- TECHTRA (Poland, Wroclaw)

**GEM Licenses signed by:**
- Mecharonics, 21/05/2013
- TECH-Etch, 06/03/2013
- China IAE, 10/01/2012
- SciEnergy, 06/04/2009
- Techtra, 09/02/2009
- CDT, 25/08/2008
- PGE, 09/07/2007

**MicroMegas Technology (contacts):**
- ELTOS S.p.A. (Italy)
- TRIANGLE LABS (USA, Nevada)
- SOMACIS (Italy, Castelfidarco)
- ELVIA (France, CHOLET)

**THGEM Technology (contacts):**
- ELTOS S.p.A. (Italy),
- PRINT ELECTRONICS

**GEM Industrialization Status (May 2014):**

**TECH-ETCH:**
- The GEM single mask process is fully understood, many 10cm x 10cm have been produced and characterization is being performed.
- A first batch of 30cm x 30cm GEM is being produced.
- The next step will be to raise to the CMS GE1/1 size of 1m x 0.5m.

**TECHTRA:**
- The production line is operational
- The process for 10cm x 10cm GEM is now stable
- The GEM single mask process is fully understood and many 10cm x 10cm GEM have been produced.
- A batch of 30cm x 30cm Single mask process GEM is being produced.

**Mecharonics:**
- 10cm x 10cm double mask GEM have been produced and tested.
- We will receive soon at CERN soon a 30cm x 30cm double mask set for evaluation.

**Micromegas Industrialization Status (May 2014):**

**ELVIA:**
- Bulk Micromegas detectors are routinely produced with sizes up to 50cm x 50cm.
- The resistive screen printing process is still under evaluation and most probably a training will be organized at ELVIA premises to finalize it.
- We are waiting the offer for the production of 2304 Boards for NSW ATLAS.

**ELTOS:**
- Many small size bulk Micromegas detectors have been produced (100 pieces), the resistive screen printing is also still under evaluation.
- We are waiting the offer for the production of 2304 Boards for NSW ATLAS.

Waiting for an offer for production of ~ 2000 MM-PCB/1280 m² of MM-resistive for ATLAS NSW from ELVIA/ELTOS.
**WG7: Common Test Beam Facility at H4 SPS and DT GDD Lab Infrastructure**

- **Common RD51 Test-Beam Infrastructure:** 3 beam telescopes (1 Bulk MM, 1 resistive MM & 1 triple-GEM with SRS readout), HV, gas & power lines ...
- Fall 2014: Resume RD51 test-beam activities (e.g. interested groups are ALICE, CMS, ...)

- Extension and improvement of the RD51 DT-GDD Lab Infrastructure

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**RD51 Common Test Beam Facility @ H4 SPS:**

- GEM-TRT 1-period
- CMS-GEM 3-periods
- TOTEM-GEM 3-periods
- RD51-GEM-telescope

**RD51 Lab Facility @ CERN:**

- JLAB-GEM 1-period
- CALICE-MM 1 period
- RD51-gem-telescope

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2008-2013:

More than 20 RD51 groups participated
RD51 Event – 3rd MPGD Conference / Collaboration Meeting in Zaragoza (July 2013):

Article in CERN Courier:

Micropattern-detector experts meet in Zaragoza

2014: International Workshop on Advanced Detectors and 14th RD51 Collaboration meeting will take place in Kolkata, India, 27-31 October: http://indico.vecc.gov.in/indico/internalPage.py?pageId=1&confId=31
3 days school for students from 27 RD51 institutes; 10 teachers → Lectures/Training sessions
https://indico.cern.ch/conferenceDisplay.py?confId=283113

Earlier RD51 schools:
2009: MPGD Design and Assembly Training; 2011: MPGD Simulation School
RD51 Event - SRS Electronics School (February, 2014)

- Article published at the CERN website: under “Students and Educators”
  http://home.web.cern.ch/students-educators/updates/2014/02/students-get-charged-rd51-electronics-school

Students get charged up at RD51 electronics school

Cian O’Lumaigh ([authors/cian-olumaigh])

Eraldo Olveri of CERN (seated) talks through detector concepts with participants in the RD51 electronics school (Image: Anna Pantella/CERN)

This week at CERN, students in electronics design and implementation examined next-generation readouts, trackers and detectors as part of the RD51 collaboration’s electronics school.

RD51 SRS Electronics School Pictures: http://cds.cern.ch/record/1646429?ln=en
The Collaboration would like to ask LHCC for continuation:

- Access to the RD51 test beam facility (including the possibility to keep “semi-permanent” setup)
- Access to CERN DT DD Printed Circuit Workshop (similar to present availability level)
- Extra office and laboratory space (for students and users of the RD51)
- Access to central computing resources for MPGD simulations.