# DRD1 – Gaseous detectors for Muon systems

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# Overview of present and future muon systems

Present → mostly gaseous detectors

- A muon system is usually all what is placed after calorimeters…
- Very large volumes (i.e. large detector surface) and relatively low rate
- Is a typical primary trigger detector → must work in real time at very low latency and needs a good time resolution to identify the BC

Future

- Could be partly fused with calorimeter
- Larger volumes and higher rates
- Higher speed and time resolution for increased BC rate and pileup
- Suitable for DM searches in large decay volumes
- Competition from novel low-cost solid state detectors

Essential to study the electronics integration in the detector Faraday cage to exploit high sensitivity electronics and work at minimum threshold

| Muon System | Inner and Central tracking | Calorimetry | Photon detection | TOF | Rare decays |
|---|---|---|---|---|---|
| • Radiation hardness and stability of large area up to integrated charges of hundreds of C/cm2:<br>- aging issues and discharges;<br>• Operation in a stable and efficient manner with incident particle flows up to ~10 MHz/cm2:<br>- miniaturisation of readout elements needed to keep occupancy low<br>• Manufacturing, on an industrial scale, large detectors at low cost, by means of a process of technological transfer to the industry and identifies processes transferable to industries<br>• Identification of eco-friendly gas mixture and mitigation of the issue related to the operation with high WGP gas mixture:<br>- gas tightness;gas recuperation system;accessibility for repairing<br>• Study of resistive materials (RPC and MPGD):<br>- higher gain in a single multiplication layer, with a remarkable advantage for assembly, mass production and cost<br>- new material and production techniques for resistive layers for increasing the rate capability<br>• Thinner layers and mechanical precision over large area | **Drift chambers**<br>• High rate, unique volume, high granulari<br>m<br>• Hydrocarbon-free mixture for long-t m high-rate operation<br>• Prove the cluster counting principle with electronics<br>• Mechanics: new wiring procedure, new wire materials<br>• Integration: accessibility for repairing<br><br>**TPC**<br>• R&D on detector sensors to suppress the IBF ratio<br>• Optimize IBF together with energy resolution<br>• Gain optimization: IBF, discharge stability<br>• Uniformity of the response of the sensors<br>• Gas mixture: stability, drift velocity, ion mobility, aging<br>• Influence of Magnetic field on IBF<br>• High spatial resolution<br>• Very low material budget (few %)<br>• Mechanics: thickness minimization but robust for precise electrical properties for stable drift velocity<br>• Integration: cooling of electronics<br><br>**Straw chambers**<br>• Ultra-long and thin film tubes<br>• "Smart" designs: self-stabilized straw module, compensating relaxation<br>• Small diameter for faster timing, less occupancy, high rate capability<br>• Reduced drift time, hit leading times and trailing time resolutions, with dedicated R&D on the electronics<br>• PID by dE/dx with "standard" time readout and time-over-threshold<br>• 4D-measurement: 3D-space and (offline) track time<br>• Over-pressurized tubes in vacuum: control the leakage rate to maintain the shape | • Rate capability in detectors based on resistive materials: resistivity uniformity, discharge issue at high rate and in large area detector<br>• R&D on sub-ns in active elements: resolution stables over wide range of fluxes<br>• Gas homogeneity and stable over time<br>• Eco-friendly gas mixture for RPC<br>• Stability of the gas gain: fast monitoring of gas mixture and environmental conditions<br>• Mechanics:<br>- large area needed to avoid dead zone: limitation on size and planarity of PCB is an issue<br>- multi-gap with ultra-thin modules: very thin layer of glass and HPL electrodes, gas gap thickness uniformity few micron | • Very low noise when coupling large capacitance<br>• Large dynamic range of the FEE<br>• Separate the TR radiation and the ionization process<br>• In TRD use of cluster counting technique and improve it by means of a InGrid | apability and<br>ver large<br>or high rate<br>adiation<br>- uniform gas distribution<br>- thinner structures: mechanical stability and uniformity<br>• Eco-gas mixture<br>• Electronics: Low noise, fast rise time, sensitive to small charge<br>• Possibly optical readout<br>• Precise clock distribution and synchronization over large area | • Radio-purity of the materials<br>• Low background<br>• High granularity<br>• For large volume detectors: transparency over large distance<br>• Pressure stability and control<br>• Electronics with large dynamic range and flexible configuration.<br>• Self-trigger capability<br>• Low noise electronics<br>• Fast electronics<br>• Optical readout |

# Muon system impact from ECFA

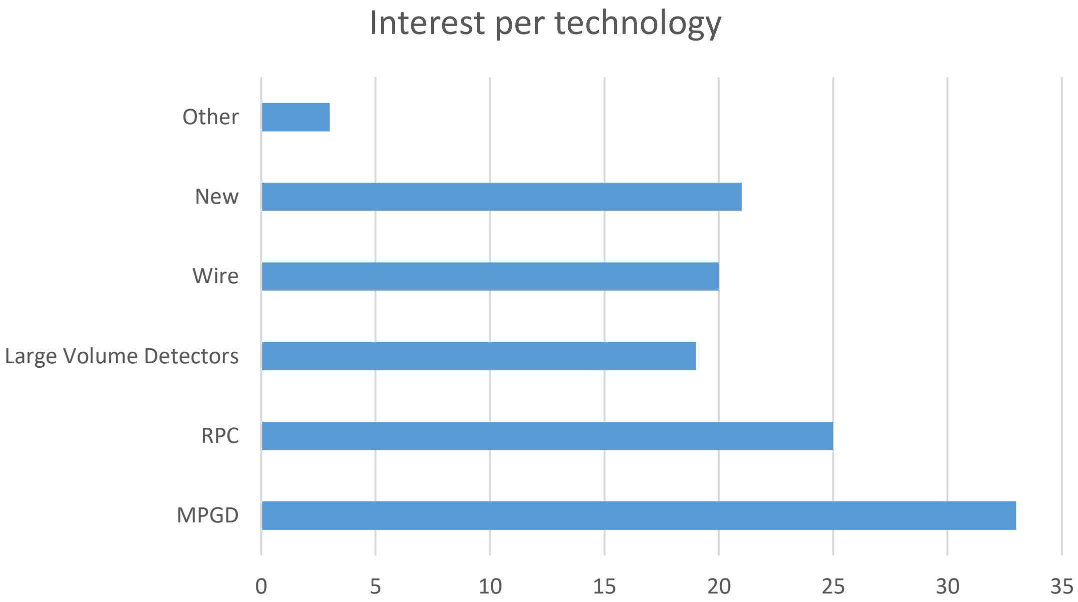
| Facility | Technologies | Challenges | Most challenging requirements at the experiment |
|---|---|---|---|
| HL-LHC | RPC, Multi-GEM, resistive-GEM, Micromegas, micro-pixel Micromegas, μ-RWELL, μ-PIC | Ageing and radiation hard, large area, rate capability, space and time resolution, miniaturisation of readout, eco-gases, spark-free, low cost | **(LHCb)**: Max. rate: 900 kHz/cm²<br>Spatial resolution: ~ cm<br>Time resolution: O(ns)<br>Radiation hardness: ~ 2 C/cm² (10 years) |
| Higgs-EW-Top Factories (ee) (ILC/FCC-ee/CepC/SCTF) | GEM, μ-RWELL, Micromegas, RPC | Stability, low cost, space resolution, large area, eco-gases | **(IDEA):** Max. rate: 10 kHz/cm²<br>Spatial resolution: ~60-80 μm<br>Time resolution: O(ns)<br>Radiation hardness: <100 mC/cm² |
| Muon collider | Triple-GEM, μ-RWELL, Micromegas, RPC, MRPC | High spatial resolution, fast/precise timing, large area, eco-gases, spark-free | Fluxes: > 2 MHz/cm² ($\theta<8^0$)<br>< 2 kHz/cm² (for $\theta>12^0$)<br>Spatial resolution: ~100μm<br>Time resolution: sub-ns<br>Radiation hardness: < C/cm² |
| Hadron physics (EIC, AMBER, PANDA/CMB@FAIR, NA60+) | Micromegas, GEM, RPC | High rate capability, good spatial resolution, radiation hard, eco-gases, self-triggered front-end electronics | **(CBM@FAIR):** Max rate: <500 kHz/cm²<br>Spatial resolution: < 1 mm<br>Time resolution: ~ 15 ns<br>Radiation hardness: $10^{13}$ neq/cm²/year |
| FCC-hh (100 TeV hadron collider) | GEM, THGEM, μ-RWELL, Micromegas, RPC, FTM | Stability, ageing, large area, low cost, space resolution, eco-gases, spark-free, fast/precise timing | Max. rate 500 Hz/cm²<br>Spatial resolution = 50 μm<br>Angular resolution = 70 μrad ($\eta$=0) to get $\Delta p/p \leq 10\%$ up to 20 TeV/c |

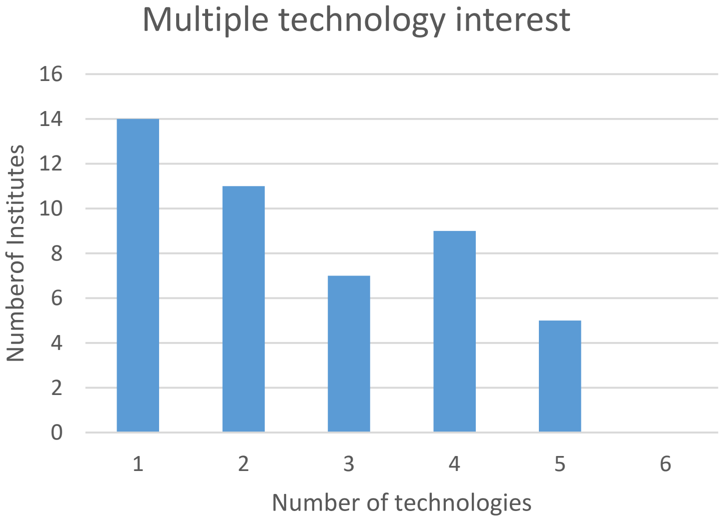
Figure 1.2: Main drivers for the Muon Systems at future facilities. The most stringent requirements for the future R&D activities are quoted in the last column.

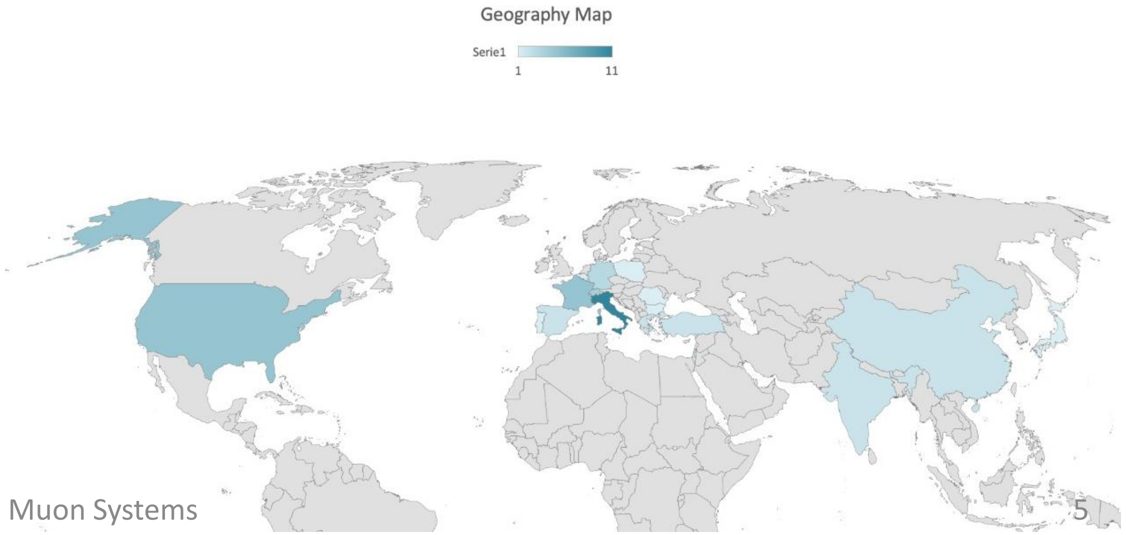
- Additional observations:
  - Time resolution is requested to increase in any sub-system
  - Muon system state of the art time resolution is up to 250ps/single gap
  - Needed for Muon-ToF capability, identify the BC in high rate colliders, help with the pileup
- Muon system are often proposed to be used and extended as DM search experiments
- Pre-shower function for particle identification has been proposed in the case above
- Wire detectors are not mentioned in this table but there are notable examples of high performance wire chambers (e.g. sMDTs and sTGCs) which are suitable for application in future experiments

# Results of the survey – General

- 69 Institute participating
- 46 interested about  muon systems
- In 17 countries
- Interest on various technologies
- Multiple technologies per institute

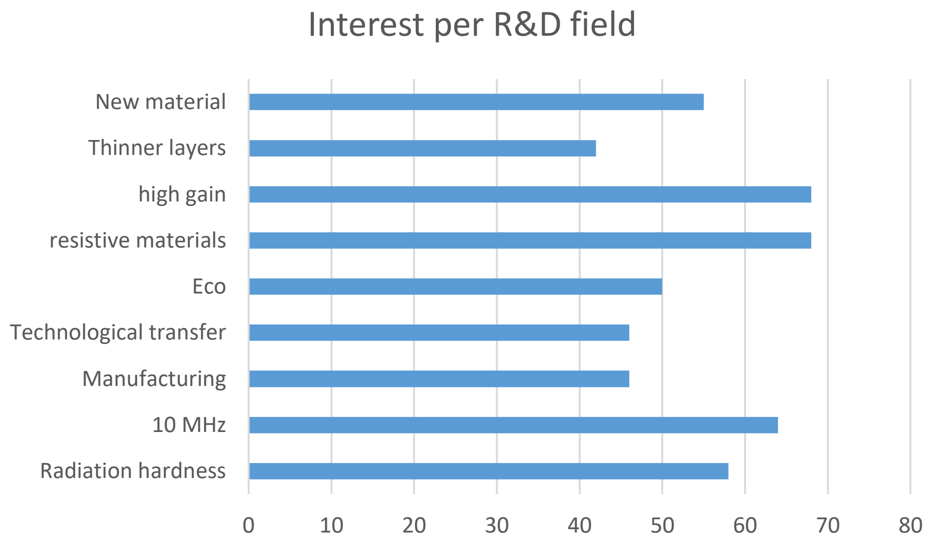


# Results of the survey – Tech vs. R&D field

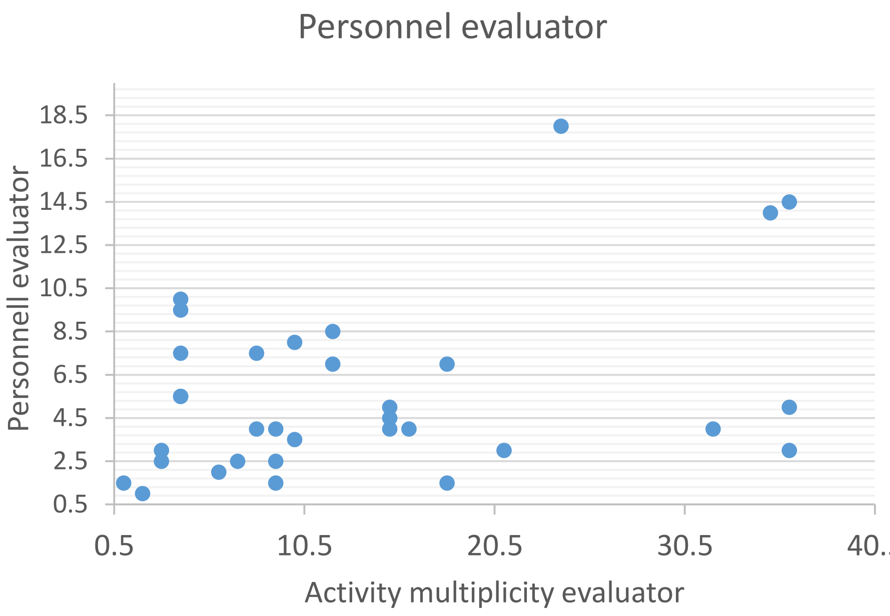
| | Radiation hardness | 10 MHz | Manufacturing | Technological transfer | Eco | resistive materials | high gain | Thinner layers | New material |
|---|---|---|---|---|---|---|---|---|---|
| DRDT | 1.1-1.3 | 1.1-1.3 | 1.3 | 1.3 | 1.3 | 1.1 | 1.1 | 1.1 | 1.3 |
| TOTAL entries (one entry per institute) | 26 | 29 | 23 | 23 | 21 | 30 | 30 | 19 | 22 |
| MPGD | 19 | 22 | 16 | 16 | 15 | 25 | 25 | 14 | 18 |
| RPC | 16 | 15 | 12 | 12 | 16 | 18 | 18 | 10 | 16 |
| Large Volume Detectors | 11 | 12 | 10 | 10 | 10 | 13 | 13 | 9 | 10 |
| New | 12 | 15 | 8 | 8 | 9 | 12 | 12 | 9 | 11 |
| TOTAL entries (one entry per technology) | 58 | 64 | 46 | 46 | 50 | 68 | 68 | 42 | 55 |
| number of declared tech. Per R&D themes | 2.2 | 2.2 | 2.0 | 2.0 | 2.4 | 2.3 | 2.3 | 2.2 | 2.5 |

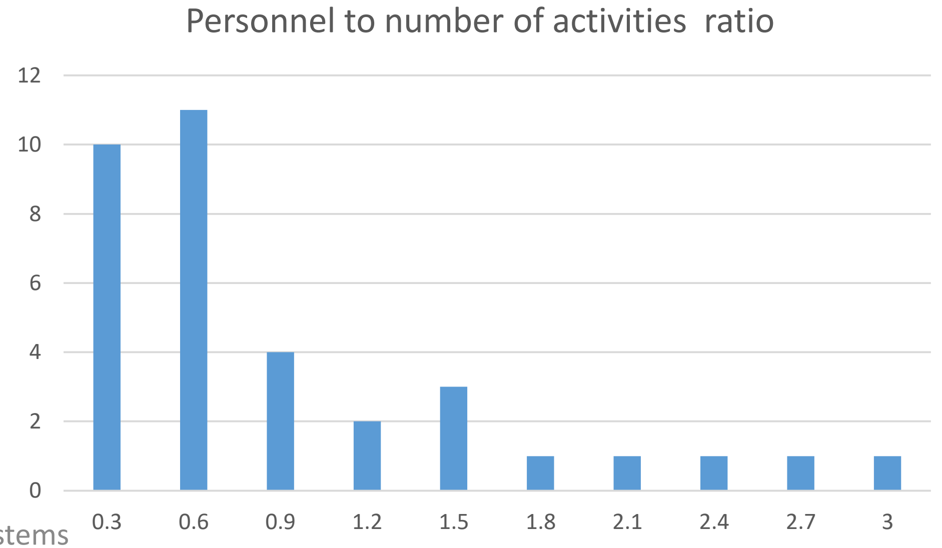



- Most of the technologies have a good number of institutes in each R&D field
- For each R&D theme, there are at least 2 Technologies declared in average by the institutes
- Synergies are expected

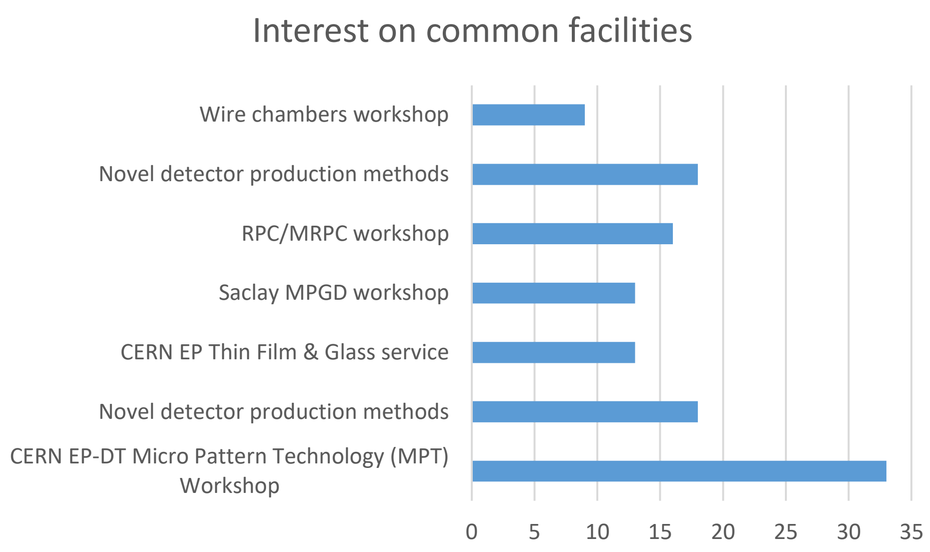
# Consistency of the resources – man power

- Evaluation of the correlation between the effective Institute resources and the multiplicity of the declared fields of interest
  - Personnel evaluator → permanent staff + 50% of non-permanent staff
  - Institute interest multiplicity → # technologies * # R&D fields
- It looks like that most Institutes interest in different technologies and R&D fields could be insufficiently covered by resources
- This indicates the need for common D&D, construction and test facilities

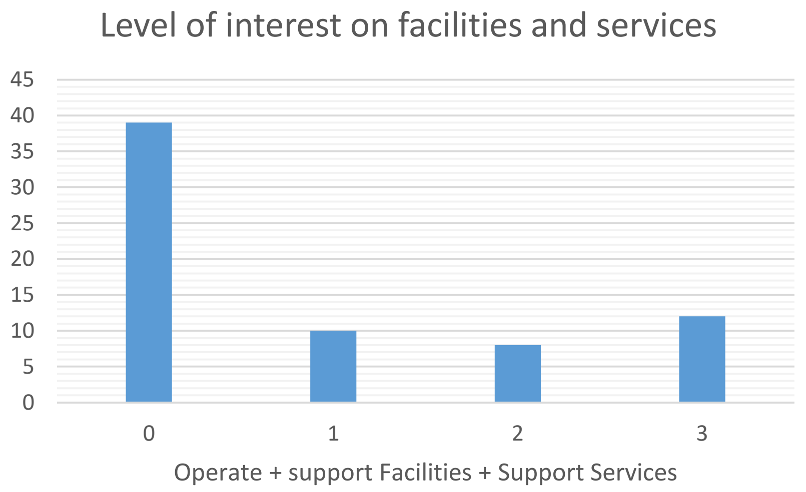


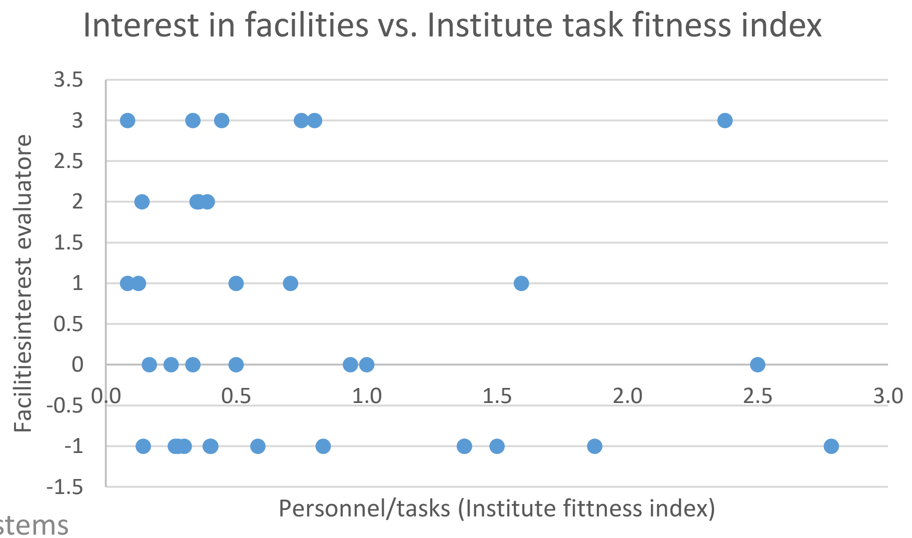



# Present and future facilities for muon oriented institutes




- Interest spread about several different facilities, technology oriented
- 1/3 of institute are not interested
- Of the rest the majority is interested in extended support
- Lower the Institute proficiency higher the interest for common facilities



# Conclusions

- The survey indicates a wide interest for the muon systems
- Future systems will require an important R&D and industrialization
- Well distributed in between various detector technologies
- The number of FTE per R&D task seems systematically smaller than needed
- From the data emerges the need to pool know how in design, construction and test
- Similar facilities exist at CERN for MPGD rising a lot of interest
- Similar facilities would be needed for RPCs and other detectors with the scope of helping new experiments developers to find all what is needed for efficiently carrying out design, prototyping, and production.