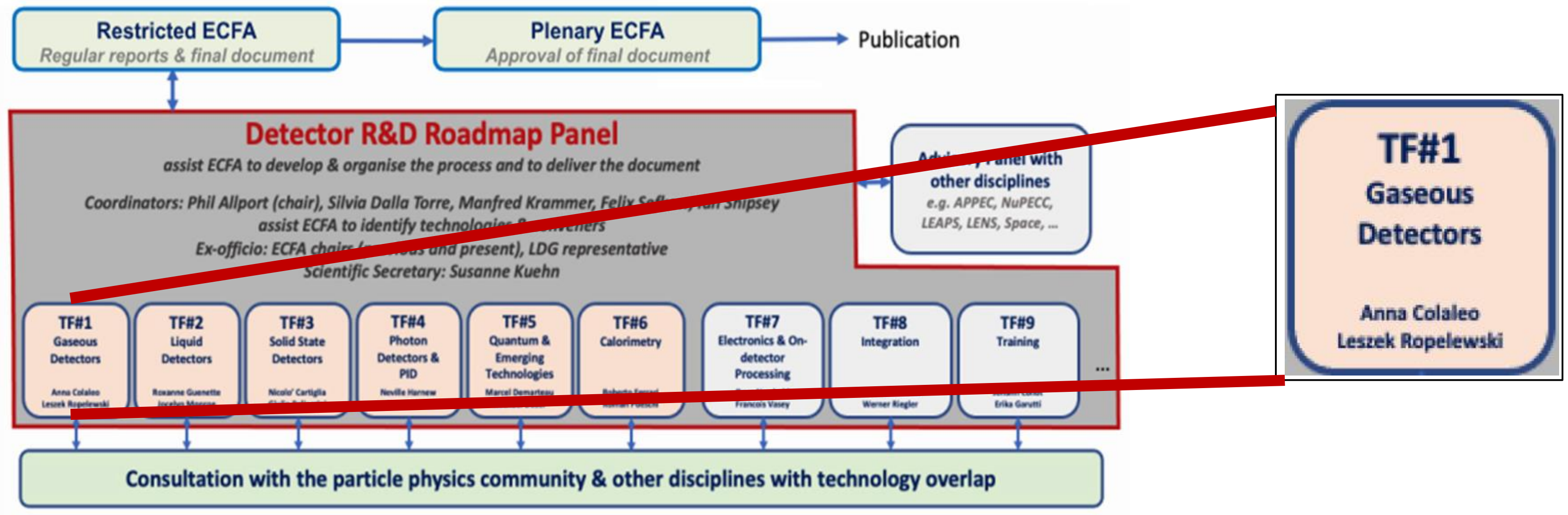
The ECFA Detector R&D Roadmap:

gaseous detector

Anna Colaleo
University and INFN -Bari

Detector Roadmap TF1 organization



TF1 Gaseous Detectors team

Conveners: Anna Colaleo (University and INFN Bari) , Leszek Ropelewski (CERN)

Experts: Klaus Dehmelt (SUNY), Barbara Liberti (INFN - Tor Vergata), Maxim Titov (CEA Paris-Saclay), Joao Veloso (University of Aveiro)

Link to the coordination team : Silvia Dalla Torre (INFN Trieste)

Process and Timeline

Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
Questionnaires of Task Forces to national contacts*

Task Forces liaise with experts in
- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia **

Organisation for Consultation of Relevant Communities

Input from future facilities

Session I (in general collider oriented), afternoon 19 February 2021: Input Session I
•Talk I: HL-LHC (incl. flavour physics)
•Talk II: strong interactions at future colliders
•Talk III: strong interactions at future fixed target facilities
•Talk IV: future linear high energy e+e- machines
•Talk V: future circular high energy e+e- machines
•Talk VI: FCC-hh
•Talk VII: muon collider
Session II (in general non-collider oriented) afternoon 22 February 2021: Input Session II
•Talk I : neutrino short and long baseline
•Talk II: astro-particle neutrinos
•Talk III: DM-like facilities
•Talk IV: decay facilities
•Talk V: low energy facilities

The full list of future facilities can be found in the Roadmap Mandate document.

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TF1 Symposium

Technologies: overview, limitations and perspectives.
- MPGD: GEM, Micromegas, THGEM, uRWELL, and other ongoing developments
- RPC, MRPC, and other ongoing developments,
- Drift chambers, straw tubes, TGC, CSC, and other wire chambers
- PID: TPC, TRD, RICH and other large area detectors

Future applications.
- Tracking and muon detection at future colliders
- TPCs at future lepton and lepton-hadron colliders (TPCs, drift chambers, large volume gaseous detectors)
- Nuclear physics applications (tracking, extremely low mass detectors, photon detection, TRD, neutron detection)
- Recoils imaging for DM, neutrino, and BSM physics applications (TPCs variations, optical readout)
- Calorimetry (RPC, MPGD) at future colliders

Challenges and new developments.
- Detector stability (ageing, discharge issues) and rate capability: resistive electrodes
- Novel readout electrodes, optical readout, hybrids with ASICS
- Precise timing detectors
- IBF, photocathode stability and alternatives (including solid converters and nanotech)
- Precision manufacturing techniques (electrical.mechanical properties), additive manufacturing and new materials (low mass, radio-purity)
- Eco gas mixtures and mitigations procedures for GHG gas (recirculation, recuperation etc.)

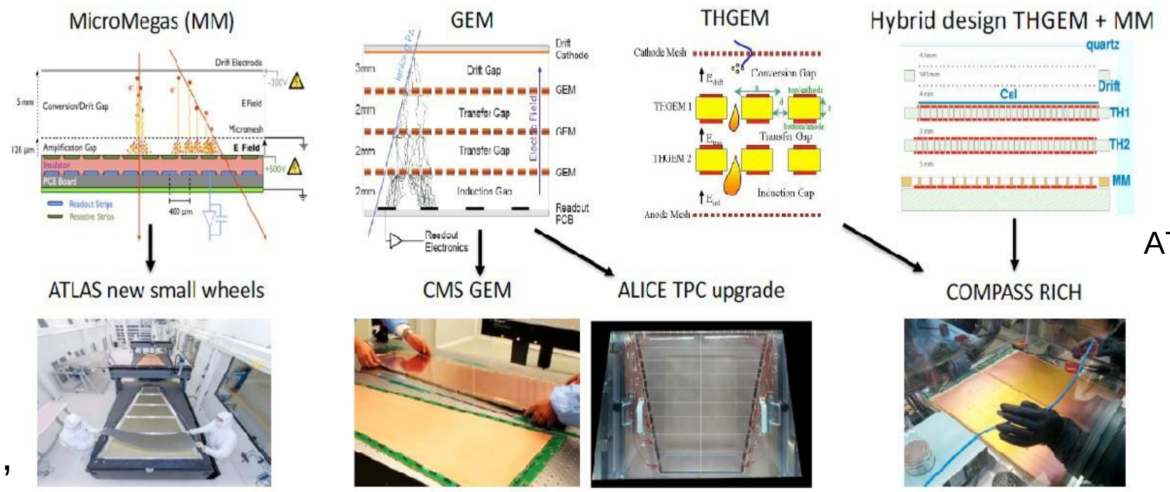
Applications beyond fundamental research.

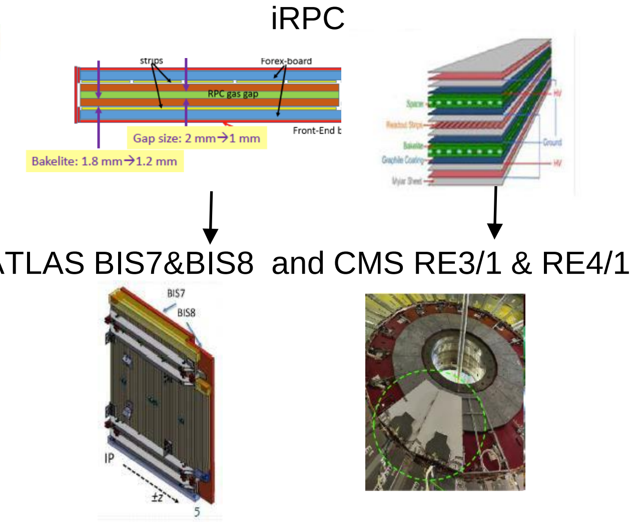
Development tools and R&D environment.
- Electronics (front-end and DAQ) for gaseous detectors R&D
- Software tools for detector physics simulations
- Infrastructures – development, testing and production facilities
- Relations with industry
- Networking – collaborations, technology dissemination and training

https://indico.cern.ch/event/999799/

The wide family of gaseous detectors

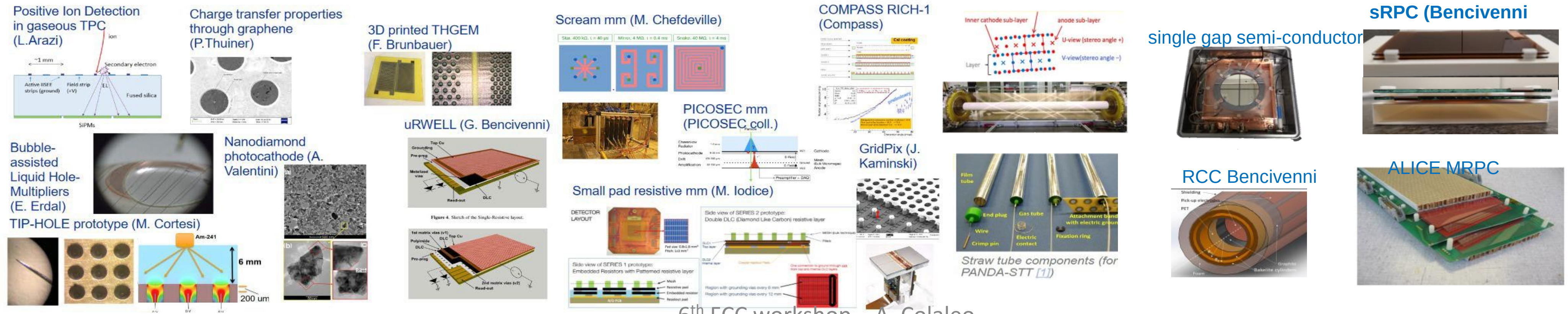
- **Upgrades at the LHC** for tracking, muon spectroscopy and triggering have **taken advantage of the renaissance in gaseous detectors** (*ex.* MPGDs, RPC.)
- **New generation of TPCs use MPGD-based readout**: e.g. ALICE Upgrade, T2K, ILC CepC





- **Gaseous detectors offer very competitive timing** through e.g.
  - **Multi-gap Resistive Plate Chambers** (down to 60 ps time resolution) (Alice TOF)
  - An enabling emerging R&D: **Micromegas with timing** (PICOSEC concept)

New Technologies, new architectures and hybridization of technologies



The wide family of gaseous detectors

Summary of R&D Challenges for the different applications

Figure 1.8:

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: - aging issues and discharges; • Operation in a stable and efficient manner with incident particle flows up to ~10 MHz/cm2: - miniaturization of readout elements needed to keep occupancy low; • 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 • Identification of eco-friendly gas mixture and mitigation of the issue related to the operation with high WGP gas mixture: - gas tightness;gas recuperation system;accessibility for repairing. • Study of resistive materials (RPC and MPGD): - higher gain in a single multiplication layer, with a remarkable advantage for assembly, mass production and cost. - new material and production techniques for resistive layers for increasing the rate capability • Thinner layers and mechanical precision over large area	**Drift chambers** • High rate, unique volume, high granularity, low mass • Hydrocarbon-free mixture for long-term and high-rate operation • Prove the cluster counting principle with the related electronics • Mechanics: new wiring procedure, new wire materials • Integration: accessibility for repairing. **TPC** • R&D on detector sensors to suppress the IBF ratio • Optimize IBF together with energy resolution • Gain optimization: IBF, discharge stability • Uniformity of the response of the sensors • Gas mixture: stability, drift velocity, ion mobility, aging • Influence of Magnetic field on IBF) • High spatial resolution • Very low material budget (few %) • Mechanics: thickness minimization but robust for precise electrical properties for stable drift velocity. • Integration: cooling of electronics. **Straw chambers** • Ultra-long and thin film tubes; • “Smart“ designs: self-stabilized straw module, compensating relaxation; • Small diameter for faster timing, less occupancy, high rate capability; • Reduced drift time, hit leading times and trailing time resolutions, with dedicated R&D on the electronics; • PID by dE/dx with “standard“ time readout and time-over-threshold; • 4D-measurement: 3D-space and (offline) track time; • Over-pressurized tubes in vacuum: control the leakage rate to maintain the shape.	• Uniformity of the response of the large area and dynamic energy range; • Optimization of weights for different thresholds in digital calorimeters • Rate capability in detectors based on resistive materials: resistivity uniformity, discharge issue at high rate and in large area detector; • R&D on sub-ns in active elements: resolution stables over wide range of fluxes; • Gas homogeneity and stable over time. • Eco-friendly gas mixture for RPC; • Stability of the gas gain: fast monitoring of gas mixture and environmental conditions; • Mechanics: - large area needed to avoid dead zone: limitation on size and planarity of PCB is an issue. - multi-gap with ultra-thin modules: very thin layer of glass and HPL electrodes, gas gap thickness uniformity few micron	• Preserve the photocathode efficiency by IBF and more robust photoconverters; • Gas radiator: alternative to CF4 • Gas tightness • Very low noise when coupling large capacitance; • Large dynamic range of the FEE; • Separate the TR radiation and the ionization process • InTDD use of cluster counting technique and improve it by means of a Ingrid.	• Uniform rate capability and time resolution over large detector area; • New material for high rate (low resistivity, radiation hardness); - uniform gas distribution; - thinner structures: mechanical stability and uniformity; • Eco-gas mixture; • Electronics: Low noise, fast rise time, sensitive to small charge; • Possibly optical readout; • Precise clock distribution and synchronization over large area.	• Radio-purity of the materials • Low background • High granularity • For large volume detectors: transparency over large distance • Pressure stability and control • Electronics with large dynamic range and flexible configuration. • Self-trigger capability • Low noise electronics • Fast electronics • Optical readout

Report and timeline

- Timescale of projects as approved by European Lab Director Group (LDG)

The Roadmap has identified

- Set of detector R&D areas which are required if the physics programmes of experiments at these facilities are not to be compromised.

Guiding principle: Project realisation must not be delayed by detectors R&D

- Detector R&D Themes (DRDT) for each of the taskforce topics

- General Strategic Recommendations (GSR)

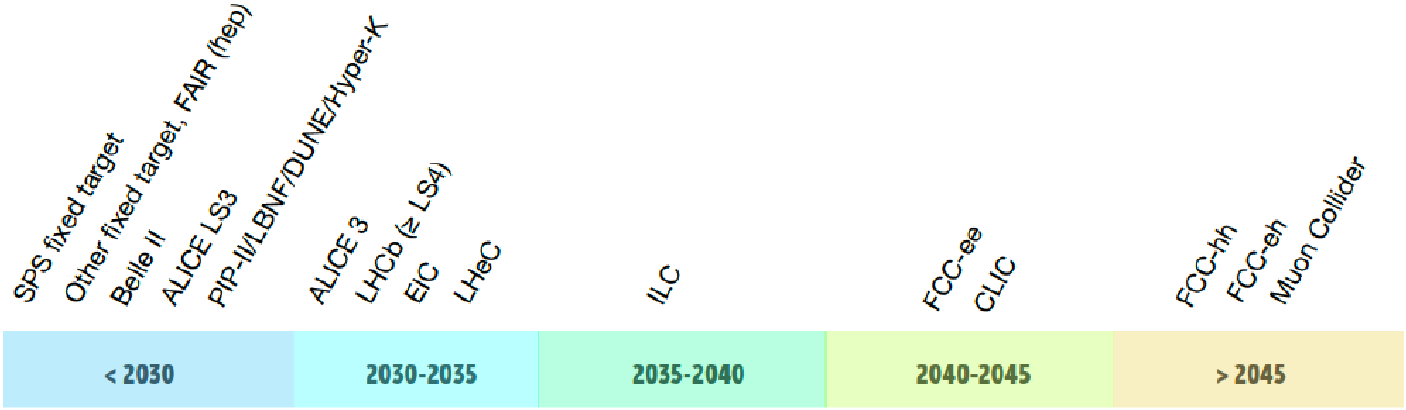


Figure 3: Large Accelerator Based Facility/Experiment Earliest Feasible Start Dates.

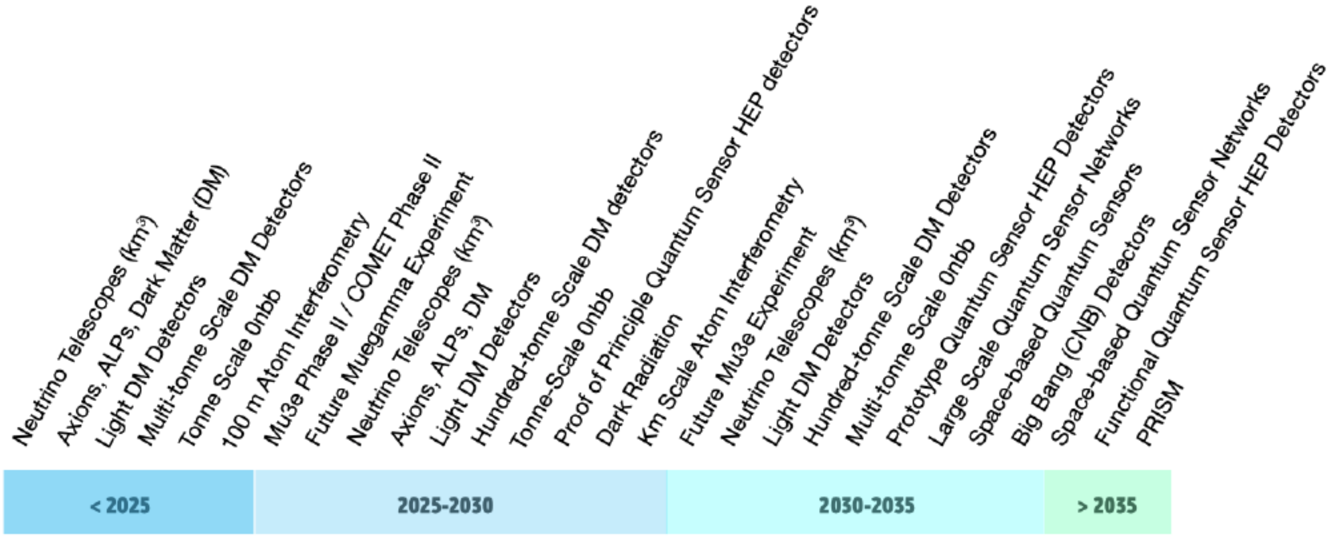
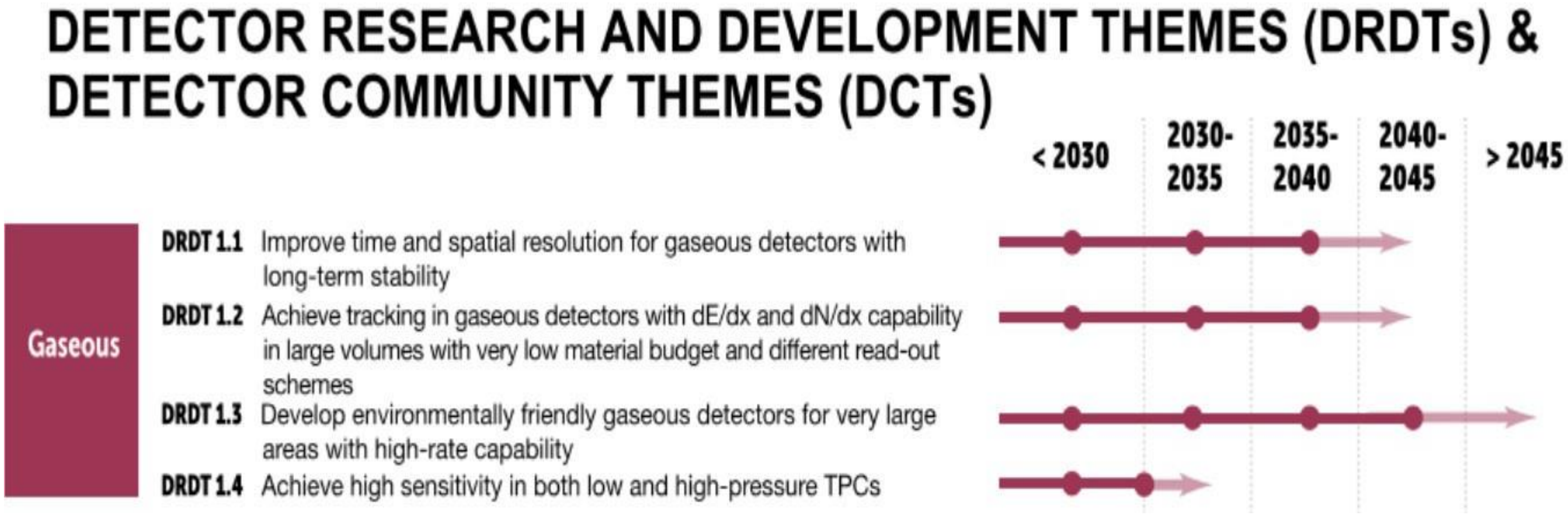


Figure 4: (Representative) Smaller Accelerator and Non-Accelerator Based Experiments Start Dates (*not intended to be at all an exhaustive list*).

DRD1 Themes and timeline

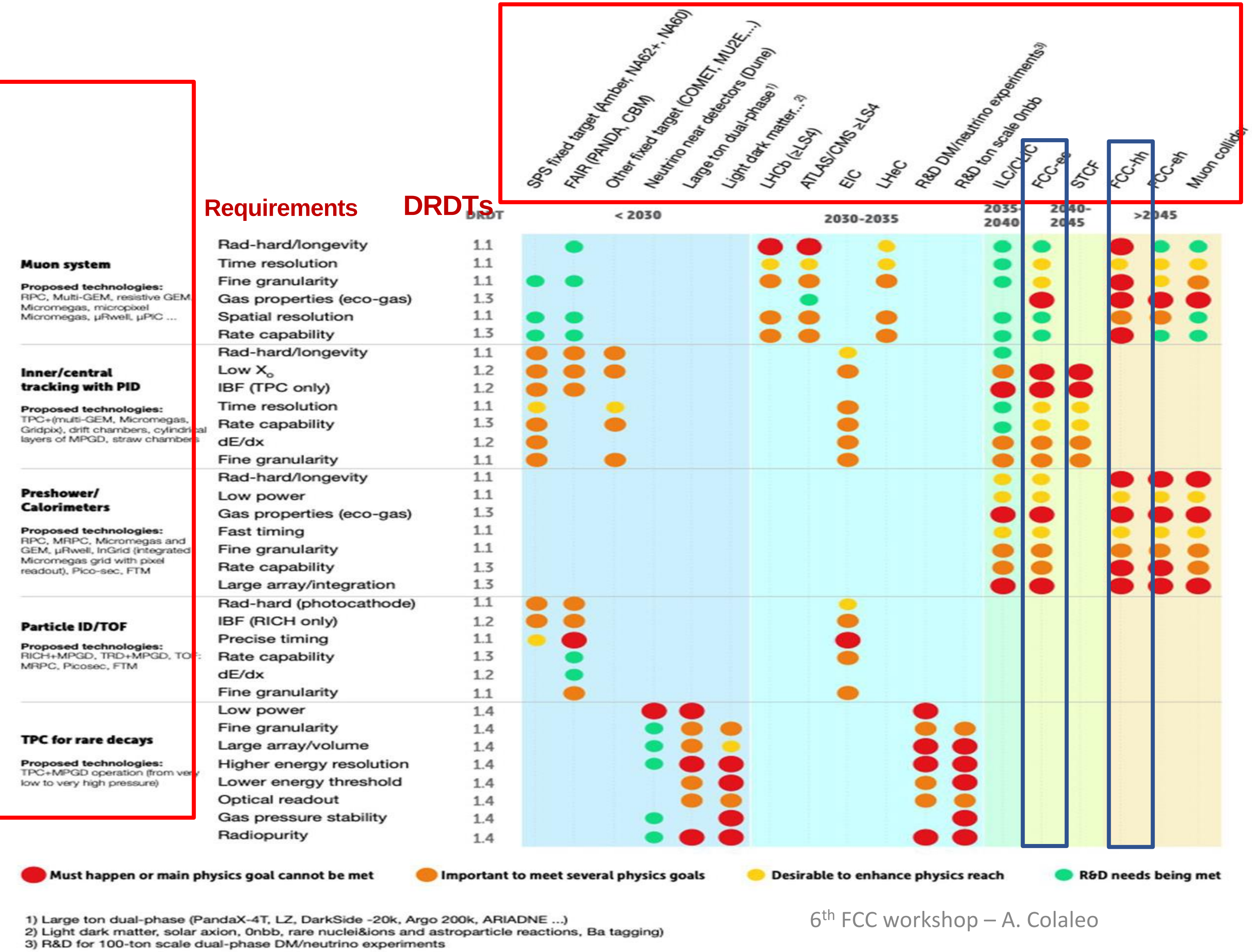
The DRDTs of Task Force 1 Gaseous detectors



To highlight the most important drivers for research in each technology area

- The faded region acknowledges the typical time needed between the completion of the R&D phase and the readiness of an experiment at a given facility.
- Stepping stones are shown to represent the R&D needs of facilities intermediate in time.
- It should be emphasised that the future beyond the end of the arrows is simply not yet defined, <u>not that there is an expectation that R&D for the further future beyond that point will not be needed</u>.

Gaseous detectors R&Ds timeline



It illustrate the way requirements could evolve over time to help define the planning for the corresponding detector R&D to ensure the main physics goals of the updated strategy for particle physics do not risk being compromised by detector readiness

Note the dots relate to the importance to the listed facilities of the R&D activity not the intensity of effort needed to meet these requirements

- Must happen or main physics goals cannot be met
- Important to meet several physics goals
- Desirable to enhance physics reach
- R&D needs being met

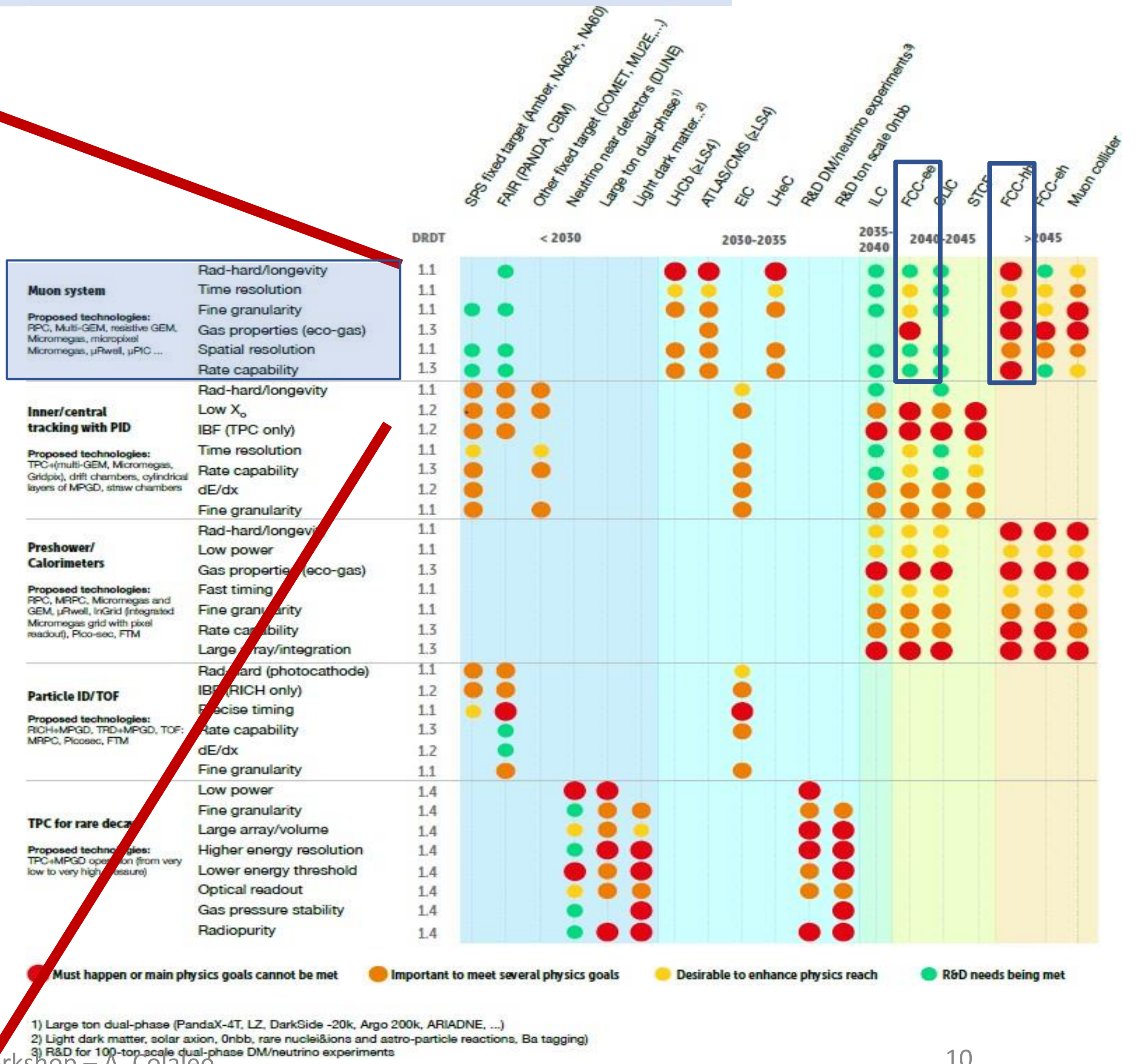
Muon System

Main drivers from facilities:

Muon systems:

- radiation hardness, longevity and stability
  - O(100 C/cm^2)
  - relevance of discharge studies
- large area (low cost),
- time resolution (< 1 ns)
  - mitigate uncorrelated background and pile-up
- fine granularity
  - Pile-up and space resolution
  - space resolution ➔momentum resolution
- rate capability
  - O (10MHz/ cm^2)
  - Resistive materials

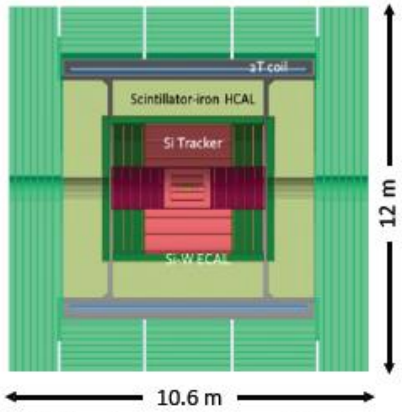
- **FACILITIES:** HL-LHC, EW-Higgs-Top facilities, Mu-collider, hadron physics (EIC and fix target), FCC-hh
- **TECHNOLOGIES:** MPGDs and new (M)RPC



Muon system: FCC-ee

M. Dam, M. Titov

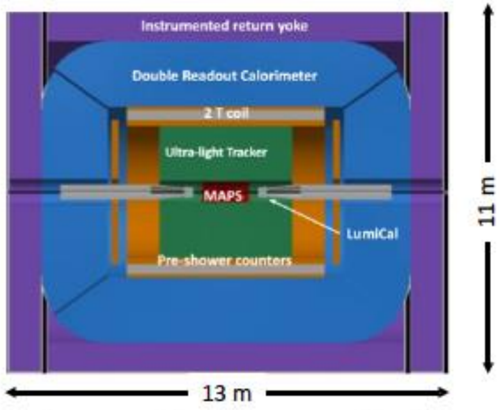
CLD



Based on CLIC detector design; profits from technology developments carried out for LCs

- All silicon vertex detector and tracker
- 3D-imaging highly-granular calorimeter system
- Coil outside calorimeter system

IDEA

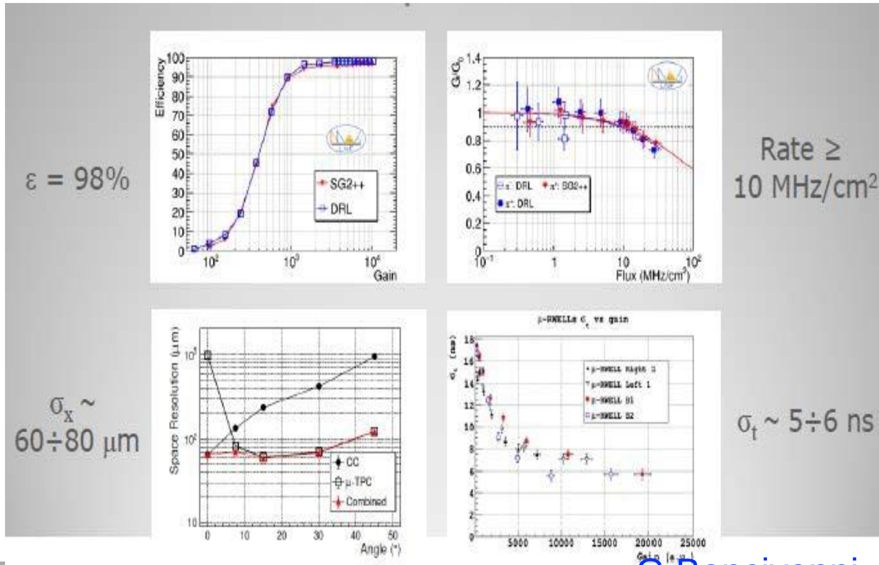


New, innovative, possibly more cost-effective concept

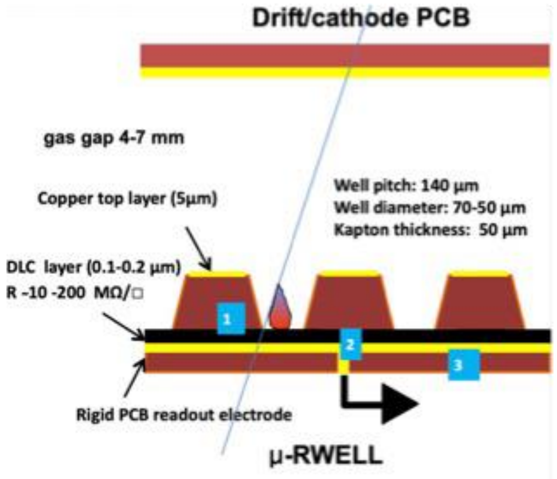
- Silicon vertex detector
- Short-drift, ultra-light wire chamber
- Dual-readout calorimeter
- Thin and light solenoid coil inside calorimeter system

Muon system in instrumented return yoke

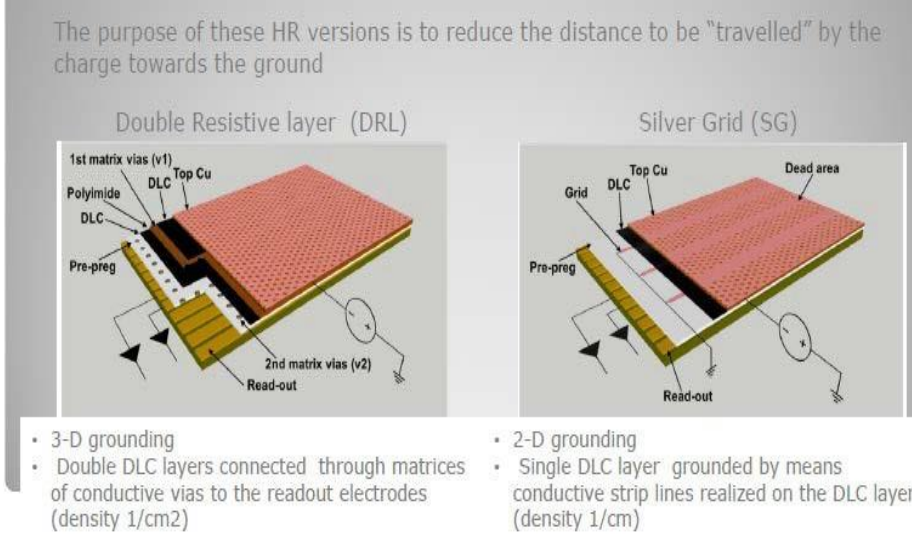
- 3-7 layers considered: 3000-6000 m²
- Proposed technologies
  - RPC (30 × 30 mm² cells)
  - µRWell chambers (1.5 × 500 mm² cells)
    - Also for IDEA pre-shower detector
    - Ongoing R&D work



G.Bencivenni

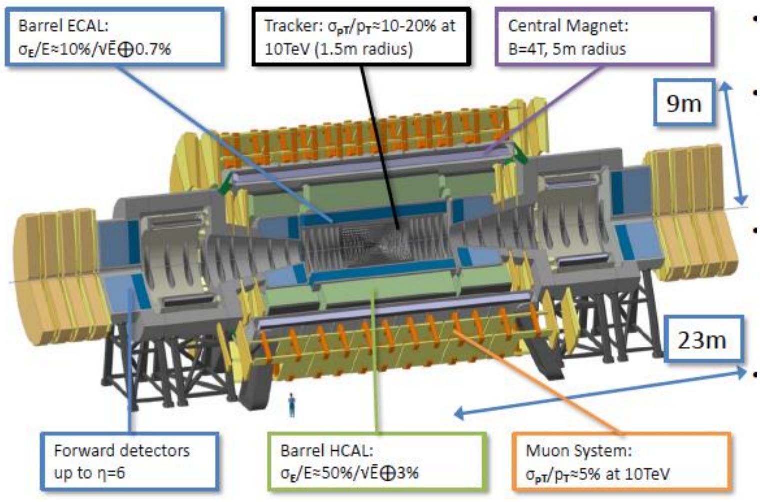


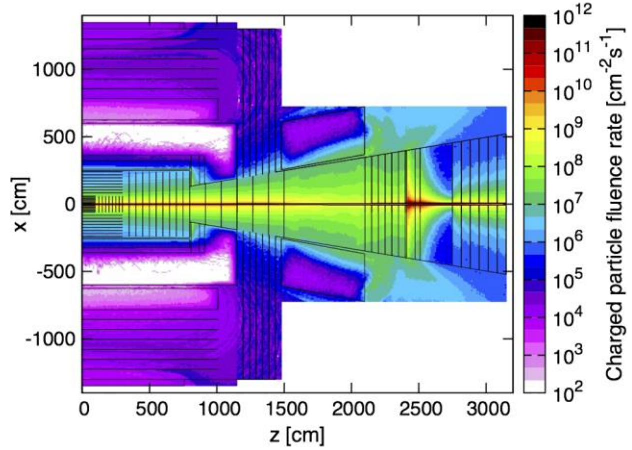
G. Bencivenni et al., 2015_JINST_10_P02008

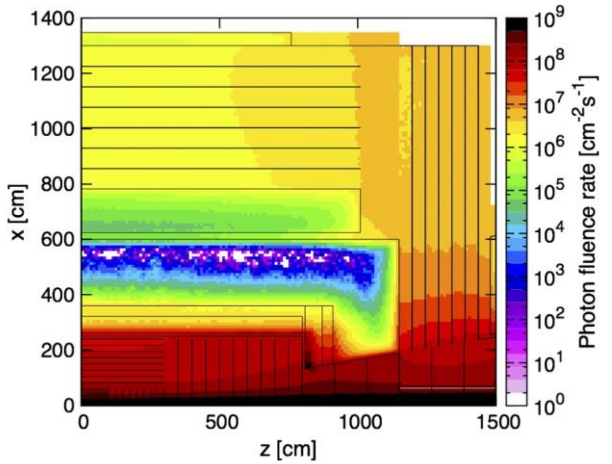


Muon system for FCC-hh

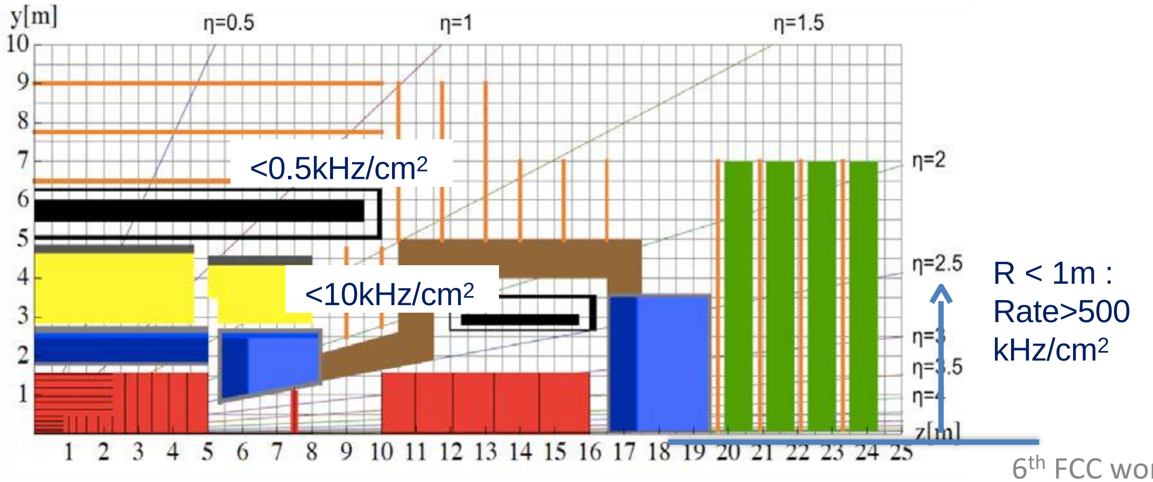
M. Dam, M. Aleksa, M. Titov







Barrel Muon system (2 layers) : 2000 m^2 total
Endcap Muon System (2 layers): 500 m^2 total
Forward Muon System: (4 layers): 320 m^2 total



Hardest challenge

- pp collisions at 100TeV (FCC-hh)
- Pileup: 1000 events/bunch crossing → spatial resolution, timing

Muon barrel and endcap

- Charged rates ~ 5×10^{4} $cm^{-2}s^{-1}$
- photon rates ~ $5 \times 10^{6-8}$ $cm^{-2}s^{-1}$
- N fluence ~10^{14} cm^{-2} → shielding can mitigate effect

- **Current muon system gas detector technology will work for most of the FCC detector area**
- **Forward region (r < 1 m) → more R&D would be needed**

Muon system

Figure 1.2:

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 Spatial resolution: ~ cm Time resolution: O(ns) 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 Spatial resolution: ~60-80 μm Time resolution: O(ns) 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 ($\theta<8^0$) < 2 kHz/cm² (for $\theta>12^0$) Spatial resolution: ~100μm Time resolution: sub-ns 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 Spatial resolution: < 1 mm Time resolution: ~ 15 ns 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 Spatial resolution = 50 μm Angular resolution = 70 μrad (η=0) to get $\Delta p/p \leq 10\%$ up to 20 TeV/c

Inner/central tracking

Main drivers from facilities:

Inner/central tracking with PID capabilities:

- radiation hardness, longevity and stability
- Low X_0
  - New materials as carbon monofilament
- Low IBF (TPC only)
- Time resolution
- dE/dx and Cluster counting:
  - *Grid-Pix, electronics*
- fine granularity
- rate capability

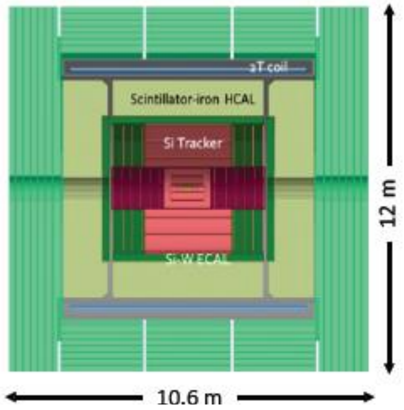
- **FACILITIES:** SCTF, CepC and FCC-ee, hadron physics, rare decays and rare events at accelerators, v-physics
- **TECHNOLOGIES:** TPC, large volume drift chambers, straw tubes, set of co-axial cylindrical MPGDs

Gaseous central tracking: FCC-ee

M.Dam, P.Gasik

Two Complementary Detector Concepts

CLD



Based on CLIC detector design; profits from technology developments carried out for LCs

- All silicon vertex detector and tracker
- 3D-imaging highly-granular calorimeter system
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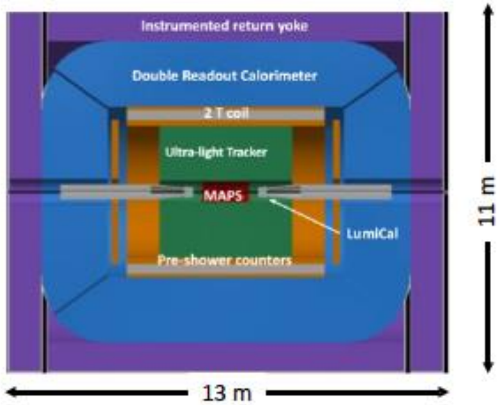
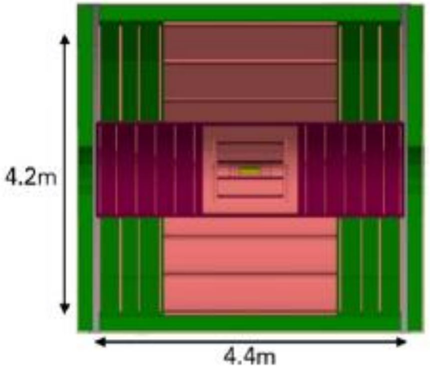


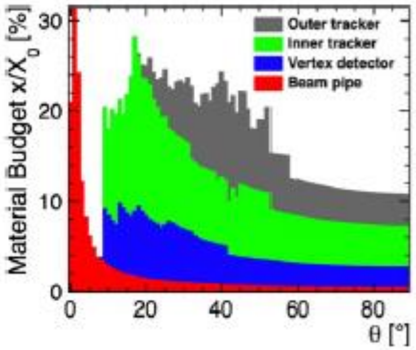
New, innovative, possibly more cost-effective concept

- Silicon vertex detector
- Short-drift, ultra-light wire chamber
- Dual-readout calorimeter
- Thin and light solenoid coil inside calorimeter system

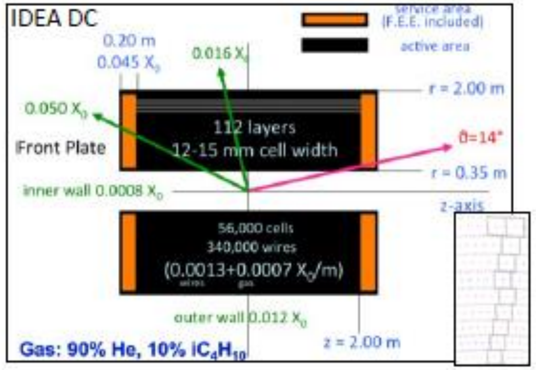
Two solutions under study

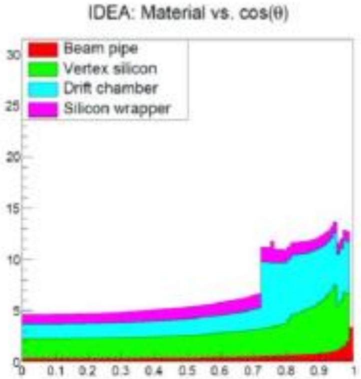
- CLD: All silicon pixel (innermost) + strips
  - Inner: 3 (7) barrel (fwd) layers (1% X_0 each)
  - Outer: 3 (4) barrel (fwd) layers (1% X_0 each)
  - Separated by support tube (2.5% X_0)





- IDEA: Extremely transparent Drift Chamber
  - GAS: 90% He – 10% iC_4H_{10}
  - Radius 0.35 – 2.00 m
  - Total thickness: 1.6% of X_0 at 90°
    - Tungsten wires dominant contribution
  - Full system includes Si VXTand Si "wrapper"





What about a TPC?

- Very high physics rate (70 kHz)
- B field limited to 2 Tesla
- Considered for CEPC, but having difficulties...

Gaseous tracking: FCC-ee

M.Dam, P.Gasik

Two Complementary Detector Concepts

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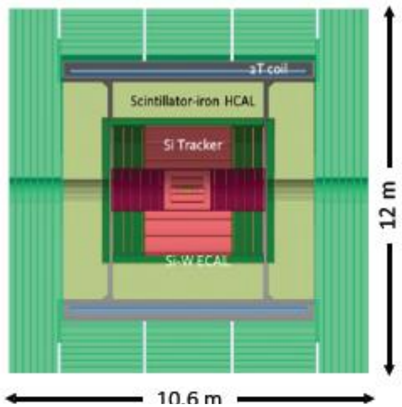

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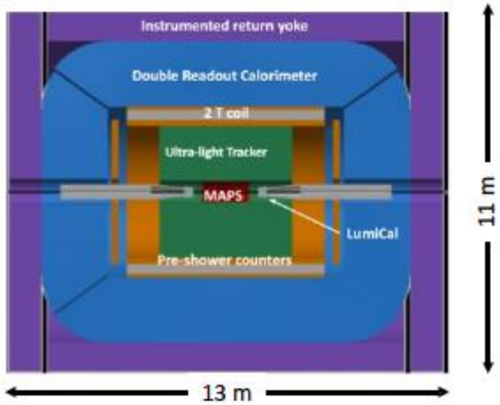

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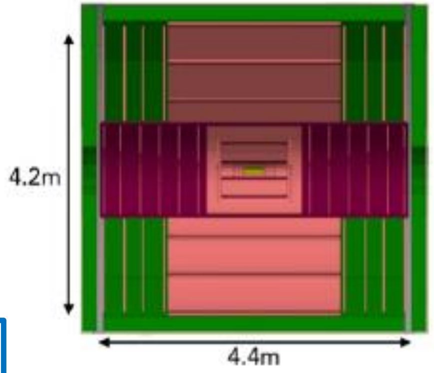

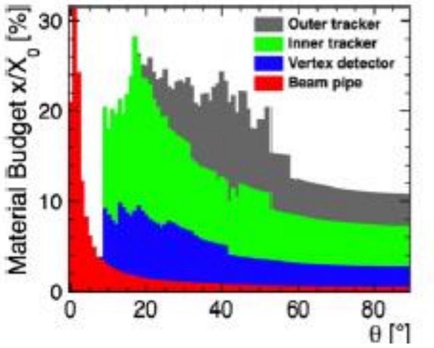

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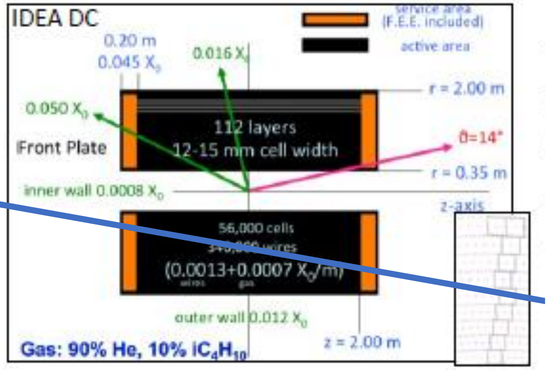
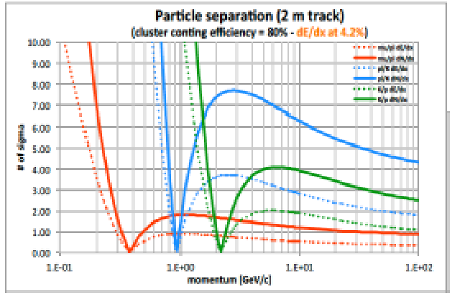


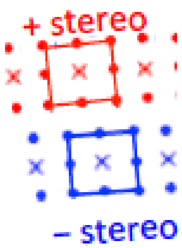
What about a TPC?

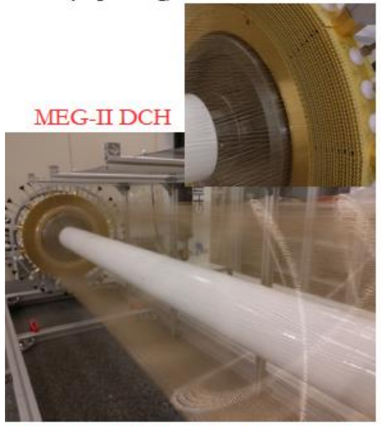
- Very high physics rate (70 kHz)
- B field limited to 2 Tesla
- Considered for CEPC, but having difficulties...

- **Point resolution:**
  - $\sigma_{xy} \leq 100$ µm
  - $\sigma_z = 750$ µm
- **Momentum resolution σ_{p_T}/p_T**
  - ~0.40% @ 100 GeV
  - ~0.25% @ 100 GeV
  - $\sim 0.6 \times 10^{-3} \oplus 4.0\times10^{-5} \times p_T$

- Drift chamber (gaseous tracker) advantages
  - Extremely transparent: minimal multiple scattering and secondary interactions
  - Continous tracking: reconstruction of far-detached vertices (K^0_S, Λ, BSM LLPs)
  - Particle separation via dE/dx or cluster counting (dN/dx)
    - dE/dx much exploited in LEP analyses







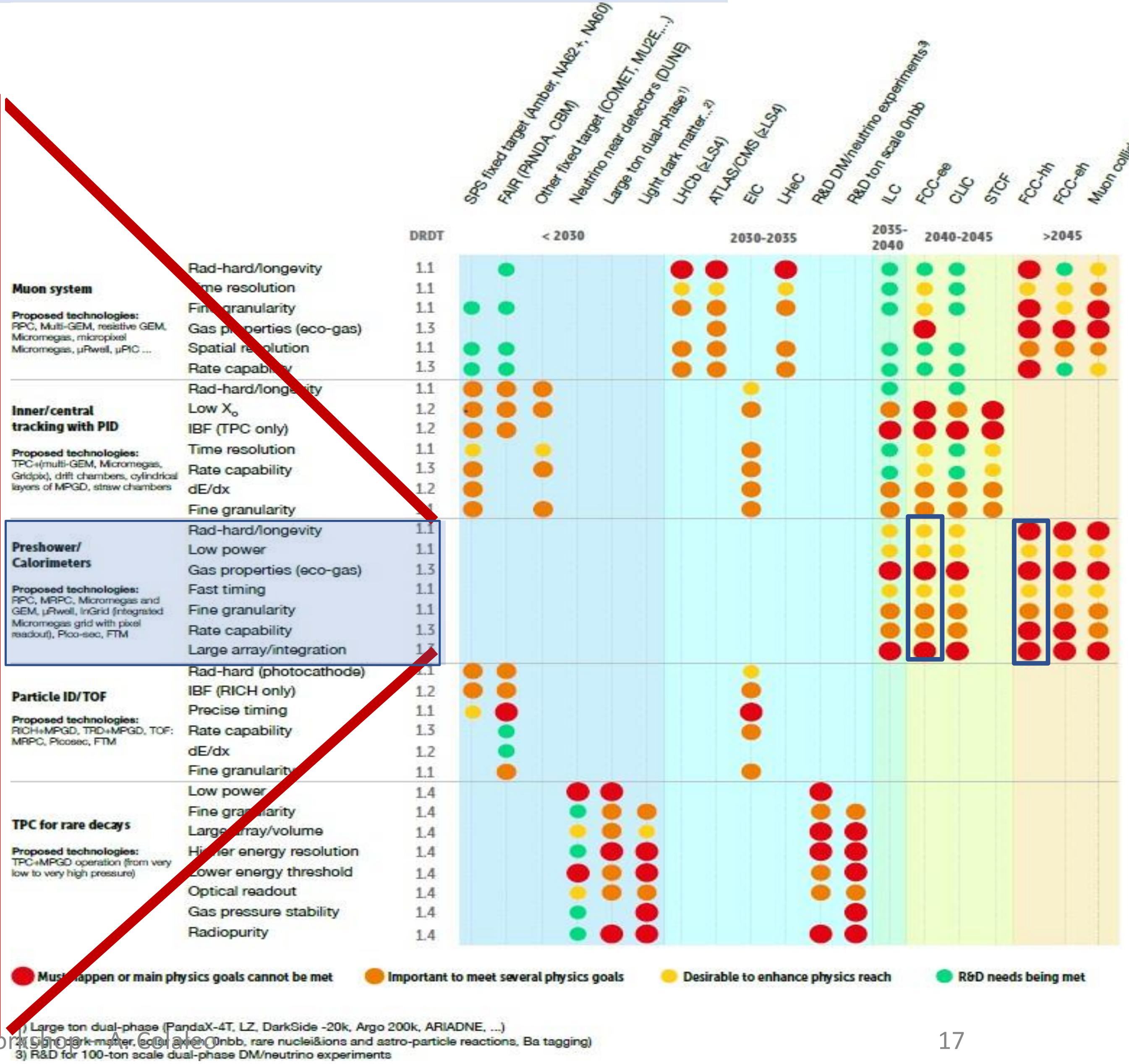
High wire densities prevent the use of feed-through, needing novel approaches to the wiring procedures

Calorimeter

- **Main drivers from facilities:**

- **Pre-shower and calorimetry:**
- CONTEXT: particle flow (PF) concept
- DHCAL/SDHCAL approaches
- radiation hardness, longevity and stability
  - Gas property (eco-gasses)
- Low power
- Fast timing, goal: 5D calorimeters (time development along the shower) ➔ *electronics*
- fine granularity
- rate capability
- Integration aspects:
  - Thin layers with integrated services
  - Large arrays: 10-100M ch.s, 10 k m^2 sensor surface

- **FACILITIES:** colliders: FCCee, mu, e-h, FCC-hh
- **TECHNOLOGIES:** MPGDs (PicoSec, FTM), RPCs

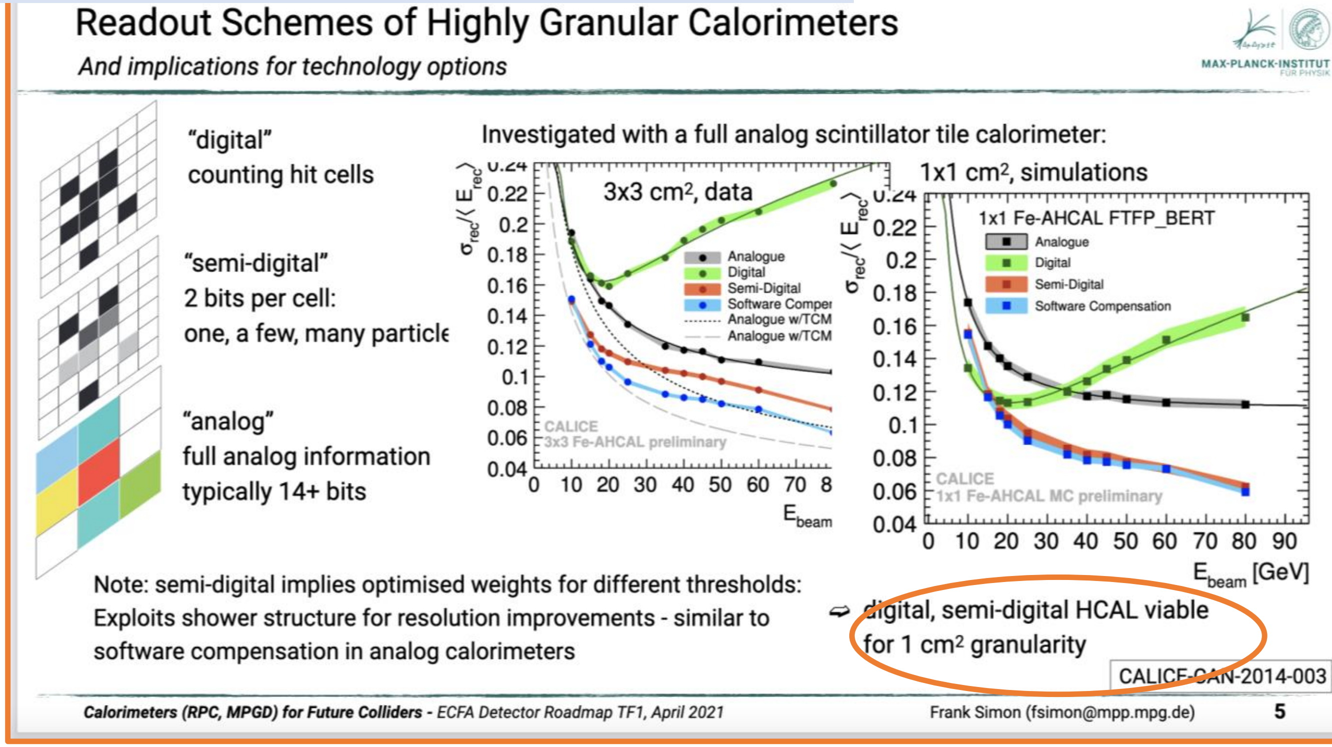


Calorimeter

F. Simon

Gaseous detectors provide:

- radiation hard detector
- high granularity (σ_{xy} = 50um, σ_t = 5ns) at low cost
- good energy resolution, imaging capability , background rejection:
  - *energy resolution with SDHCAL as good as AHCAL with software compensation*

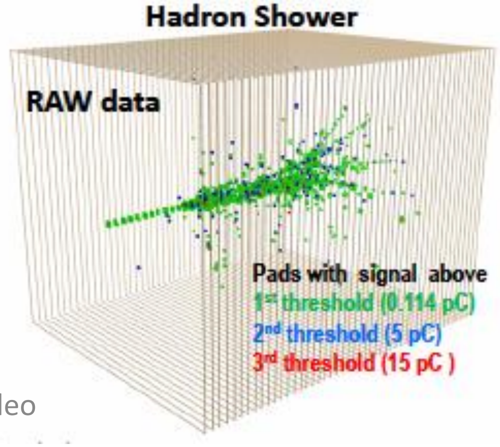


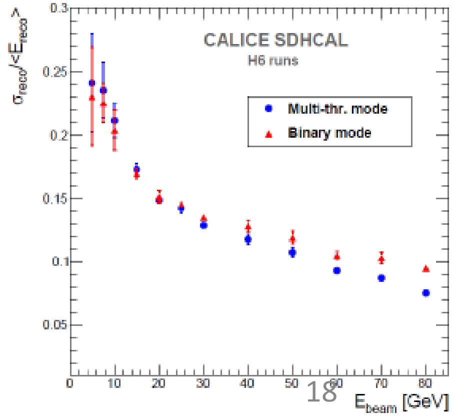
New handle: Fast- timing

- If pico-second-time and energy information are available at each point along the track ⇒ 5D imaging reconstruction

➔ Technologies: MRPC, PicoSec, FTM

SDHCAL with RPC





Lot of work done within CALICE collaboration:

- AHCAL Scint+SiPM 3 x 3 cm^2 granularity
- DHCAL glass RPC 1 x 1 cm^2 granularity
- SDHCAL RPC/MICROMEGAS/RPWELL1 x 1 cm^2 granularity

Roadmap implementation: towards a DRD1 Collaboration

- **DRD1 formation** promoted by the TF1 conveners : Anna Colaleo and Leszek Ropelevski
- Taking advantage of RD51 experience
- A dedicated working group has been formed:

  - **ECFA TF1** Conveners: Anna Colaleo (Univ. and INFN-Bari), Leszek Ropelewski (CERN);
  - Other TF1 Members: Klaus Dehmelt (Stony Brook Univ.-SUNY) , João Veloso (Univ. of Aveiro)
  - **ECFA Coordinators Group Member:** Silvia Dalla Torre (INFN - Trieste)
  - **MPGDs**: Eraldo Oliveri (CERN), Fulvio Tessarotto (INFN-Trieste), Maxim Titov (CEA Paris-Saclay)
  - **RPCs**: Ingo Deppner (Univ. Heidelberg), Giuseppe Iaselli (Politecnico & INFN-Bari), Barbara Liberti (INFN –Roma 2)
  - **TPCs:** Esther Ferrer Ribas (IRFU/CEA), Jochen Kaminski (University of Bonn)
  - **Large volume detectors:** Marco Panareo (Univ. and INFN-Lecce), Francesco Renga (INFN-Roma I)
  - **Straw tubes, TGC, CSC, drift chambers, and other wire detectors:** Peter Wintz (IKP, FZ Jülich)
  - **Infrastructure, R&D programs** (CERN EPR&D, AIDAinnova): Roberto Guida (CERN), Beatrice Mandelli (CERN)
  - **Administrative support:** Hans Taureg (University of Bonn), Florian Brunbauer (CERN)

- **a major effort**: reaching out to as many major groups in the field as possible.

Towards a DRD1 Structure: proposal

Keep RD51 structure in WGs including alignment with the scientific program of the ECFA roadmap, looking more generally to future facilities challenges and specifically to the ECFA roadmap selected Detector RD Themes (DRDT).

WG1: Technologies

Includes experimental detector physics aspects

- MPGDs
- RPCs, MRPCs
- Large Volume Detectors (drift chambers, TPCs)
- Straw tubes, TGC, CSC, drift chambers, and other wire detectors
- New amplifying structures

WG2: Applications

Full alignment with the ECFA detector R&D roadmap

- Muon systems
- Inner and central tracking with particle identification capability
- Calorimetry
- Photon detection
- Time of Flight systems
- TPCs for rare event searches
- Precision experiments
- Straw chambers in vacuum
- Fundamental research applications beyond HEP
- Medical and industrial applications

WG3: Gas and material studies

- Eco-gases searches
- Light emission in gases
- Ageing
- Radiation hardness
- Light (low material budget) materials
- Resistive electrodes
- Precise mechanics
- Photocathodes (novel, ageing, protection)
- New types of wires (coated carbon monofilaments)
- Solid converters
- Novel materials (nanomaterials)

WG4: Detector physics, simulations, and software tools

- Detector properties studies (simulations)
- Software tools development and maintenance
- Detector design tools
- Gas cross-section data bases maintenance

WG5: Electronics for gaseous detectors

- Readout electronics (SRS, ASICs, fast electronics, pixel, and optical readout)
- HV systems
- Dedicated lab instrumentation

WG6: Detector production

- CERN MPT workshop
- Saclay MPGD workshop
- Novel detector production methods
- Industrialization

WG7: Common test facilities

Incudes development of common detector characterization standards

- General purpose detector development labs
- Ageing facilities
- Irradiation facilities
- Gas studies facilities
- Test beam facility

WG8:Training and dissemination

- Schools and trainings
- Topical workshops
- Knowledge transfer
- (Young) Researcher Career

Towards a DRD1 Collaboration

- Help to pull the communities together over the coming months to converge on the DRD1 organisation and proposals
- Collecting the contact persons for each institution interested to join the collaboration
- A survey sent to the institute contact persons to get feedback from the community (deadline 15 February)
- **Community workshop planned at CERN on 1 - 3 March 2023.**

    - *establish the DRD1 community and begin preparing a short proposal outlining the path (including milestones, resources, and infrastructures available and needed) to fulfilling and developing the technological goals outlined in the ECFA R&D roadmap for the gaseous detector.*

    - We will invite all people registered at https://indico.cern.ch/event/1214405/manage/registration/

<u>Please feel free to contact me or any member of the DRD1 working group for any question</u>