The gaseous detectors within the ECFA Detector Roadmap

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INFN - Trieste

66th INFN ELOISATRON WORKSHOP:
New gas mixtures for RPC and MRPC detectors.
20–23 Nov 2022.

OUTLOOK

- The **ECFA Detector Roadmap** process in short words

- **Gaseous Detectors**, status and perspectives from the ECFA Detector Roadmap

The RoadMap process

Update of the European Strategy for Particle Physics

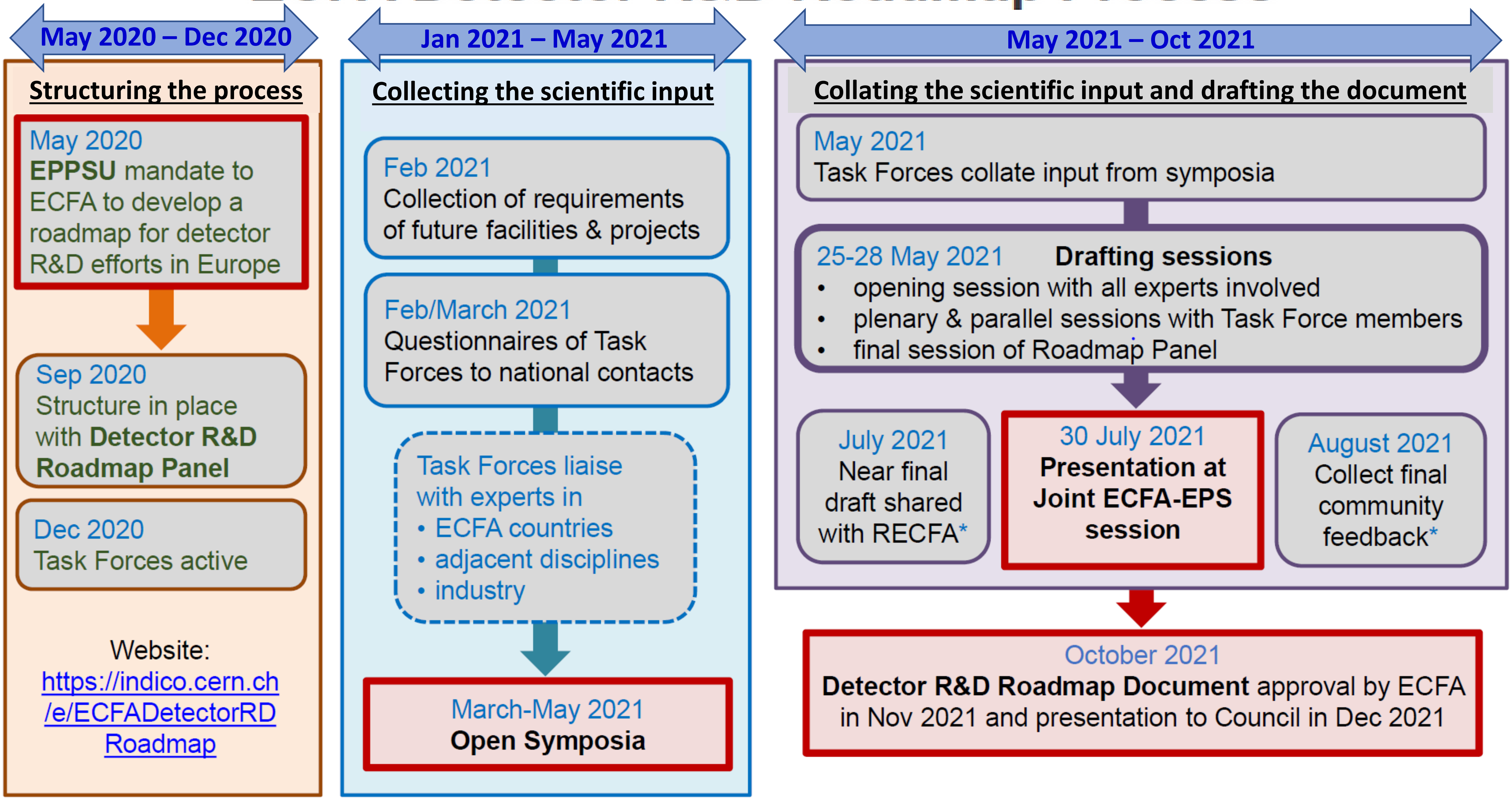
4. Other essential scientific activities for particle physics

…

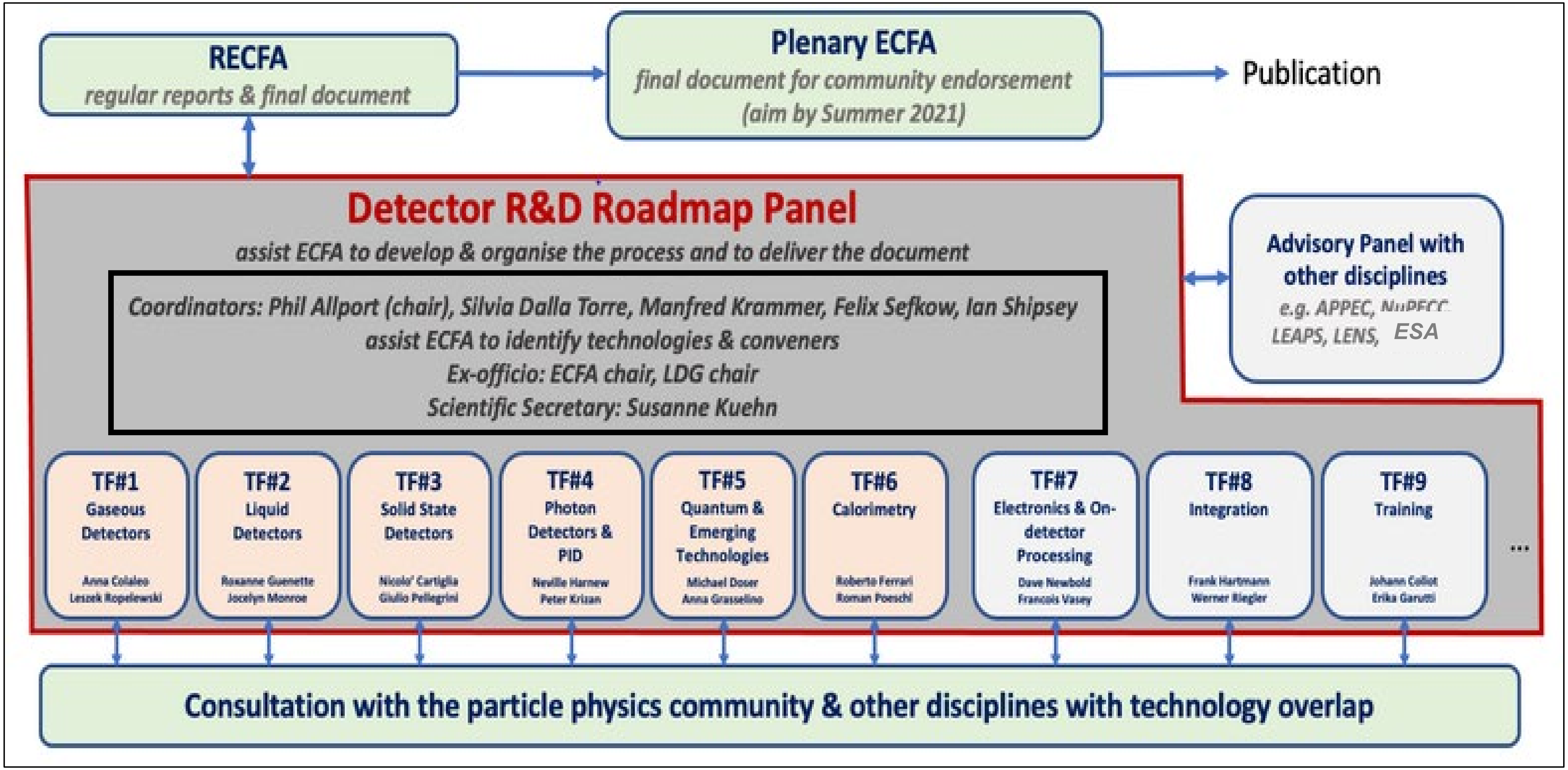
c) *The **success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures.** To prepare and realise future experimental research programmes, the community must **maintain a strong focus on instrumentation**. **Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities**. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a **global detector R&D roadmap** that **should be used to support proposals at the European and national levels.***

Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields. The roadmap should identify and describe a diversified detector R&D portfolio that has the largest potential to enhance the performance of the particle physics programme in the near and long term. …

ECFA Detector R&D Roadmap Process



Structuring the process



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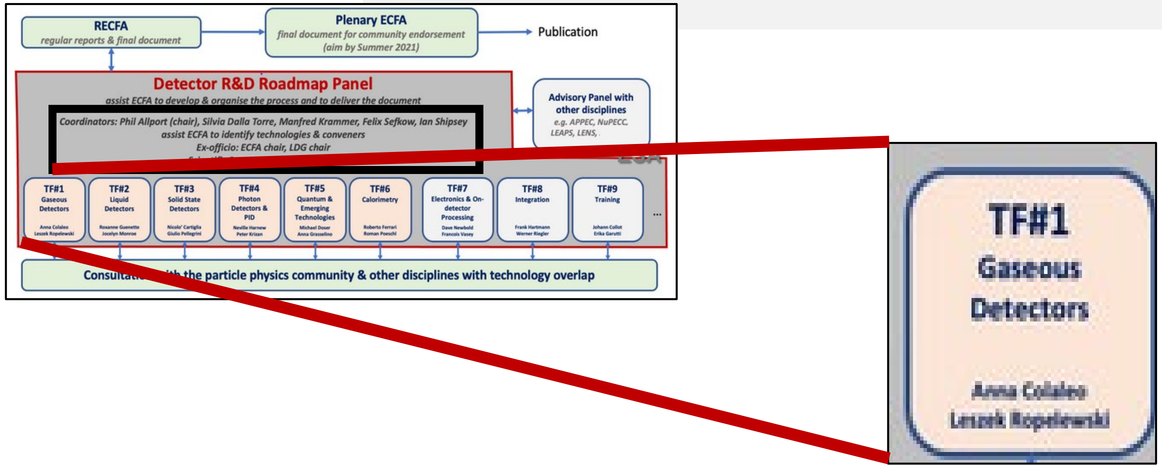

TF#1 Gaseous Detectors

Overview of the Panel members and Task Forces

- TF1 Gaseous Detectors
  - Convenors: Anna Colaleo (INFN Bari), Leszek Ropelewski (CERN)
  - Expert members: Klaus Dehmelt (Stonybrook), Laura Fabbietti (TUM Munich), Barbara Liberti (INFN Roma), Joao Veloso (Aveiro)

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

Collecting the scientific input 1/2

- **Input from future facilities**
  - **2 sessions in Feb 2021**

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

to reach the whole scientific material:
https://indico.cern.ch/e/ECFADetectorRDRoadmap

Collecting the scientific input 2/2

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- **Detector symposia**
  - **9 symposia in Feb-May 2021:**
    Major source of information!

Task Force 1: Gaseous Detectors

Symposium date: Thursday 29.4.2021
Indico link to agenda

Task Force 2: Liquid Detectors

Symposium date: Friday 9.4.2021
Indico link to agenda

Task Force 3: Solid State Detectors

Symposium date: Friday 23.4.2021
Indico link to agenda

Task Force 4: Photon Detectors and Particle Identification Detectors

Symposium date: Thursday 6.5.2021
Indico link to agenda

Task Force 5: Quantum and Emerging Techologies

Symposium date: Monday 12.4.2021
Indico link to agenda

Task Force 6: Calorimetry

Symposium date: Friday 7.5.2021
Indico link to agenda

Task Force 7: Electronics and On-detector Processing

Symposium date: Thursday 25.3.2021
Indico link to agenda

Task Force 8: Integration

Symposium date: Wednesday 31.3.2021
Indico link to agenda

Task Force 9: Training

Symposium date: Friday 30.4.2021
Indico link to agenda

Conclusive Document

Basic information

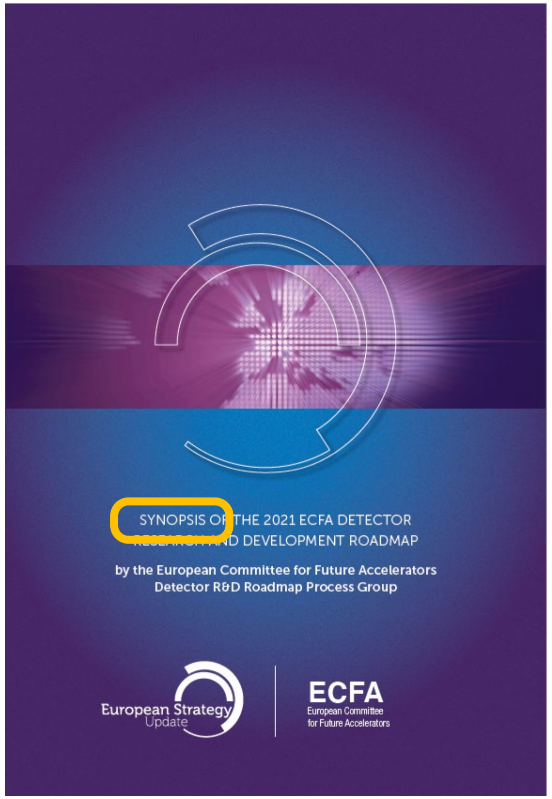
- ~ 250 pages
- Document structure
  - ➢ Introduction
  - ➢ A chapter per TF (9 FTs)
    - Introduction
    - Main drivers from the facilities
    - Key technologies
    - Observations
    - Recommendations
    - References
  - ➢ General Observations and Considerations
  - ➢ Conclusions

Authors

Task Force convenors, Task Force expert members and Panel members of the ECFA Detector R&D Roadmap Process Group

https://indico.cern.ch/event/957057/page/23281-the-roadmap-document

- Available also a synopsis for external readers
  - 8 pages, colourfull
  - Available in printed form



Goals

- Match EPPSU mandate:
  - “Identify and describe a **diversified detector R&D portfolio** that has the largest potential **to enhance** the performance of **the particle physics programme in the near and long term**”
  - Considering projects listed in the Deliberation Document of the EPPSU ”**High-priority** future initiatives" or “**Other essential scientific activities** for particle physics"
- Create a **time-ordered technology requirements** driven R&D roadmap
- Other aspects to be considered:
  - Bring out **synergies** and stress **interconnections** between developments of similar technologies needed at different times by **different programmes**
  - **Facilities needed for detector evaluation**, including test beams and different types of irradiation sources, along with the advanced instrumentation required for these;
  - **Infrastructures facilitating detector developments**, including technological workshops and laboratories, as well as tools for the development of software and electronics;
  - **Networking structures** in order to ensure *collaborative environments*, to help in the *education and training, for cross-fertilisation* between different technological communities, and in view of *relations with industry*;
  - **Overlaps with neighbouring fields** and key specifications required for exploitation in other application areas;
  - **Opportunities for industrial partnership** and technical developments needed for potential commercialisation.

Report & timelines

- Reference timelines used in the report, as dictated from CERN, ECFA and other external bodies
- The timelines indicate when a certain technology/technological achievement is needed and the relevance it has for the project
- **These tables are not detector development timelines**, as dictated by technical/technological considerations

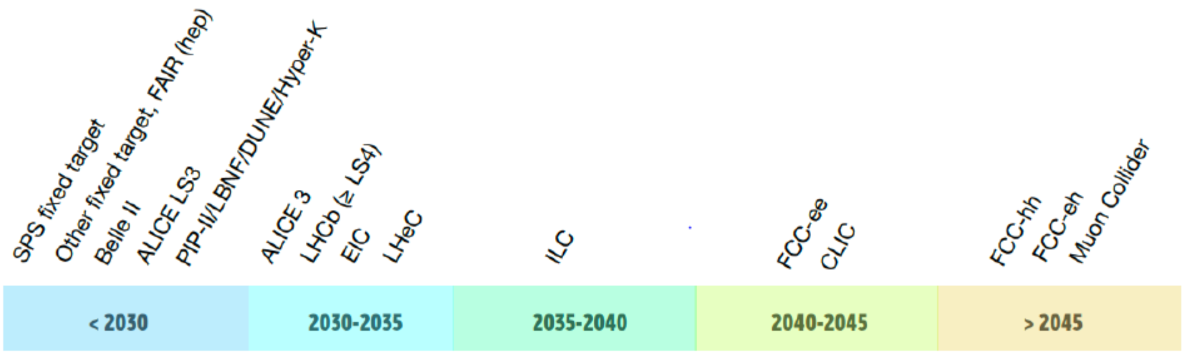


Figure 3: Large Accelerator Based Facility/Experiment Earliest Feasible Start Dates.

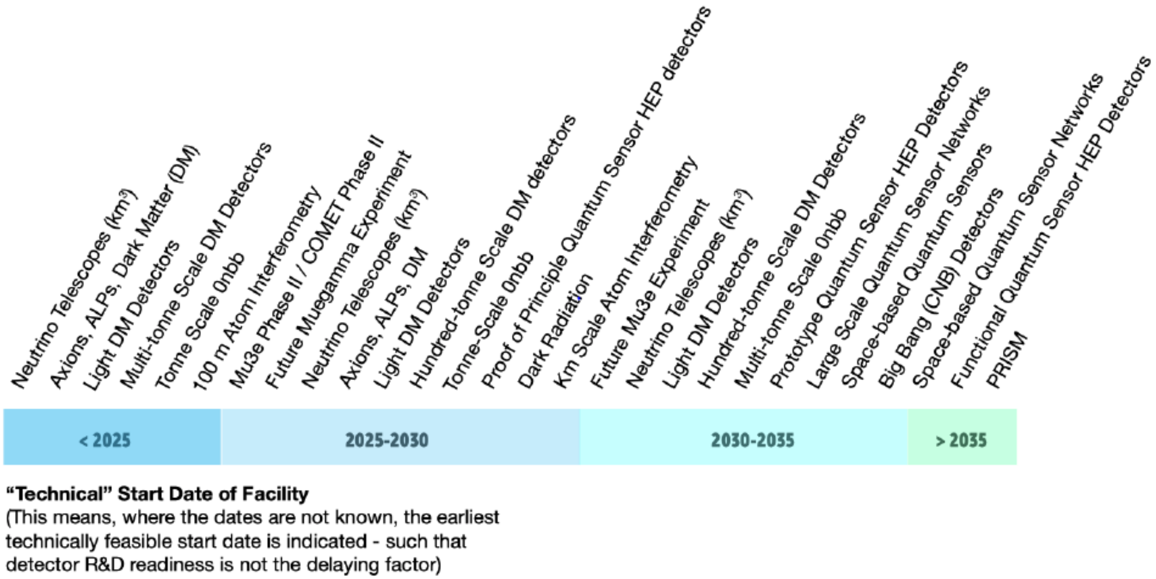


Figure 4: (Representative) Smaller Accelerator and Non-Accelerator Based Experiments Start Dates (*not intended to be at all an exhaustive list*).

A special and strategic TF: «training» (TF9)

TF9 – Training

Needs of the community

- **Stimulate** and **recognise the field of instrumentation** in particle physics and specifically the importance of innovation, detector development and operation
  - **Need of training at all levels**, from initial university studies up to continuous update of professionals: **presently, perception of insufficient training opportunities (from ECFA - Early Career Researchers Panel survey)**
  - Role of Universities (bachelor and dedicated masters), Schools, Lab training, Virtual labs, Academia meats Industry
- **Attract and train** outstanding talented individuals in physics and engineering
  - **Recognition** at all stages (dedicated scholarships, stipends, awards)
  - Opportunity for publications **in high-ranked journals** of technology and experimental methods
  - Attractive **career prospects: presently, negative perception (from ECFA - Early Career Researchers Panel survey)**
- Recognise the **diversity of skills needed** in the field
- Find an appropriate **balance between specialisation and breadth**

Observations

- **VITAL for HEP**: w/o implementing a strategic promotion of instrumentation→ missing the continuity of highly qualified detector experts from R&D to construction and to operation of HEP detectors
- Need of a coordinated European training programme

Recommendations

- **Each point above can be directly translated into corresponding recommendations**

The general strategic recommendations

GENERAL STRATEGIC RECOMMENDATIONS

GSR 1: Supporting R&D Facilities

GRS 2: Engineering support for detector R&D

GRS 3: Specific software for instrumentation

GRS 4: International coordination and organisation of R&D activities

GRS 5: Distributed R&D activities with centralised facilities

GRS 6: Establish long-term strategic funding programmes

GRS 7: “Blue-sky” R&D”

GRS 8: Attract, nurture, recognise and sustain the careers of R&D experts

GRS 9: Industrial partnerships

GRS 10: Open Science

RoadMap implementation

Characteristics of the implementation process

- The Roadmap process was built up in consultation and with the support of the European (and beyond) R&D community
- The implementation process has largely been driven from top, with the R&D community informed and called to contribute after taking the major initial decisions
- It has been identified as first urgencies the need of **organisational structures** and **adequate resources, therefore privileging GRS4 to leverage also on GRS6**
- So far, the implementation is related to these two GRSs only
- In concrete: “establish the **DRD collaborations**, which should **start work in January 2024**, with a ramp-up of resources through 2024/2025, reaching a steady state by 2026” (CERN/SPC/1190/RA CERN/3679/RA)

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More recently,
***ECFA Training Panel** under study*

Implementing GRS 4:
“international coordination and organization of R&D activities”

- Newly established **Detector R&D (DRD) Collaborations**, one for each TF of the Roadmap process
- DRD Collaborations should be **anchored at CERN** → CERN recognition, DRD label
- The formation of new DRD collaborations should adopt a **community-driven**
- Taking **full account of existing, well-managed and successful ongoing R&D collaborations** and other existing activities
  - RD50, RD51, …, CERN EP R&D programme, EU-funded initiatives, collaborations exploring particular technology areas for future colliders
- **Non-European collaborators** are welcome
- Suggested **timelines**: DRDs implemented by 2024-Q1

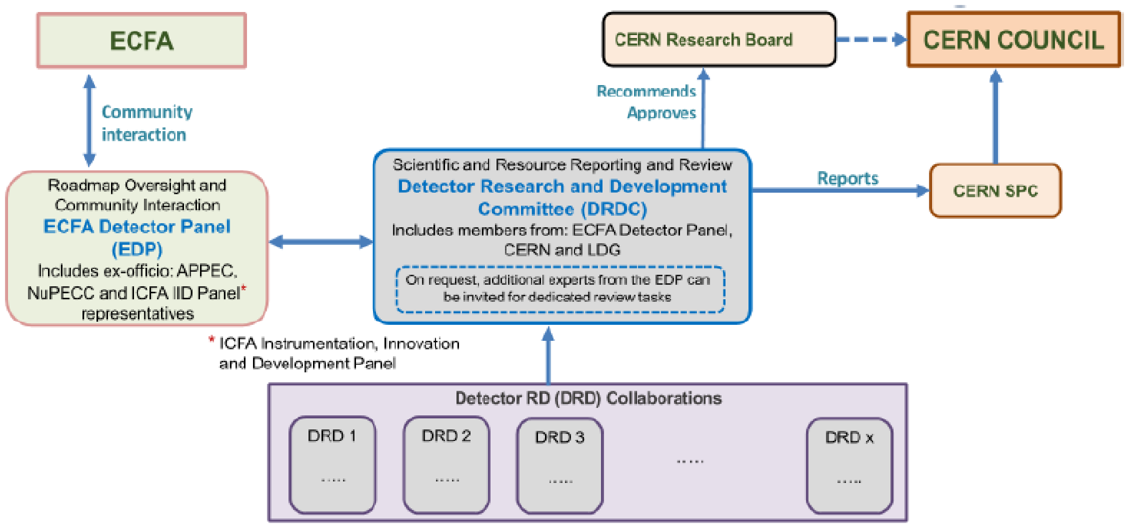
join the groups of interest, subscribe at :

https://indico.cern.ch/event/957057/page/27294-implementation-of-the-ecfa-detector-rd-roadmap

The underlaying model assumed proposing DRDs

Three areas of Detector R&D:	
Strategic R&D via DRD Collaborations (long-term strategic R&D lines)	• address the high-priority items defined in the Roadmap via the DRDTs
Experiment-specific R&D (with very well defined detector specifications)	• funded outside of DRD programme, via experiments, usually not yet covered within the projected budgets for the final deliverables
”**Blue-sky**” R&D	• competitive, short-term responsive grants, nationally organised

Approving and reviewing DRDs



1. Scientific and Resource Reporting and Review by a Detector Research and Development Committee (DRDC)

   Assisted by the ECFA Detector Panel (EDP): the scope, R&D goals, and milestones should be vetted against the vision encapsulated in the Roadmap. (EDP: http://cds.cern.ch/record/2211641/files/, exists, hosted at DESY)

2. Funding Agency involvement via a dedicated Resources Review Board (~once every two years)

3. Yearly follow-up by DRDC → report to SPC → Council

The implementation process,
a single slides of personal considerations

- Driving community **attention to Detector R&D is great!**
- Starting from **organisational structures**, **can help in ensuring resources**, even if the resource model is an open and it can come at different time and via different mechanism in the different agencies/countries
- Nevertheless, even if "money makes the world go round (*)", I still believe that **cultural revolutions can have even a larger impact**: I look forward having attention and dedication to GRS 8, and, more in general, to the global set of GRSs
    - ***ECFA Training Panel*** under study
- The delimitation in **3 distinct areas**:
    - The Strategic R&D via DRD Collaborations (DRDs)
    - Experiment-specific R&D
    - "Blue-sky" R&D

  Can represent an obstacle for the transversal spirit of creativity, which is driving the R&D domain

  → Up to all of us to overcome the potential difficulties of internal barriers in the world of Detector R&D

(*) from the film CABARET, 1972

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TOWARDS DRD1 – Gaseous Detectors

- **DRD1 formation** promoted by the TF1 conveners : Anna Colaleo and Leszek Ropelevski
- Taking advantage of RD51 experience
- A dedicated WG has been formed:
  - ECFA TF1 Conveners : Anna Colaleo, Leszek Ropelewski; TF1 Members: Klaus Dehmelt, João Veloso
  - ECFA Coordinators Group Member: Silvia Dalla Torre
  - MPGDs: Eraldo Oliveri, Fulvio Tessarotto, Maxim Titov
  - RPCs: Ingo Deppner, Giuseppe Iaselli, Barbara Liberti
  - TPCs: Esther Ferrer Ribas, Jochen Kaminski
  - Large volume detectors: Marco Panareo, Francesco Renga
  - Straw tubes, TGC, CSC, drift chambers, and other wire detectors: Peter Wintz
  - Infrastructure, detector R&D programmes (CERN EP R&D, AIDAinnova): Roberto Guida, Beatrice Mandelli

- In the following slides the **current <u>proposal</u>**
- **a major effort**: reaching out to as many major groups in the field as possible (short timelines!)

DRD1 current proposal (slides from L. Ropelewsky)

WG1: Technologies, limitations and challenges
Includes detector physics aspects

- MPGDs
- RPCs, MRPCs
- Large Volume Detectors (drift chambers, TPCs)
- Straw tubes
- 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
- Fundamental research applications beyond HEP
- Medical and industrial applications

WG3: Gas and material studies
Interdisciplinary working group

- Ageing
- Radiation hardness
- Eco-gases searches
- Light emission in gases
- Light (low material budget) materials
- Resistive electrodes
- Precise mechanics
- Photocathodes (novel, ageing, protection)
- 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

DRD1 current proposal (slides from L. Ropelewsky)

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

Gaseous Detectors

ECFA Detector R&D Roadmap Symposium of Task Force 1 Gaseous Detectors

Thursday 29 Apr 2021, 09:00 → 19:40 Europe/Zurich

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 and mechanical properties of detector components), 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

Largely built on the experience gained within RD51

GASEOUS DETECTORS

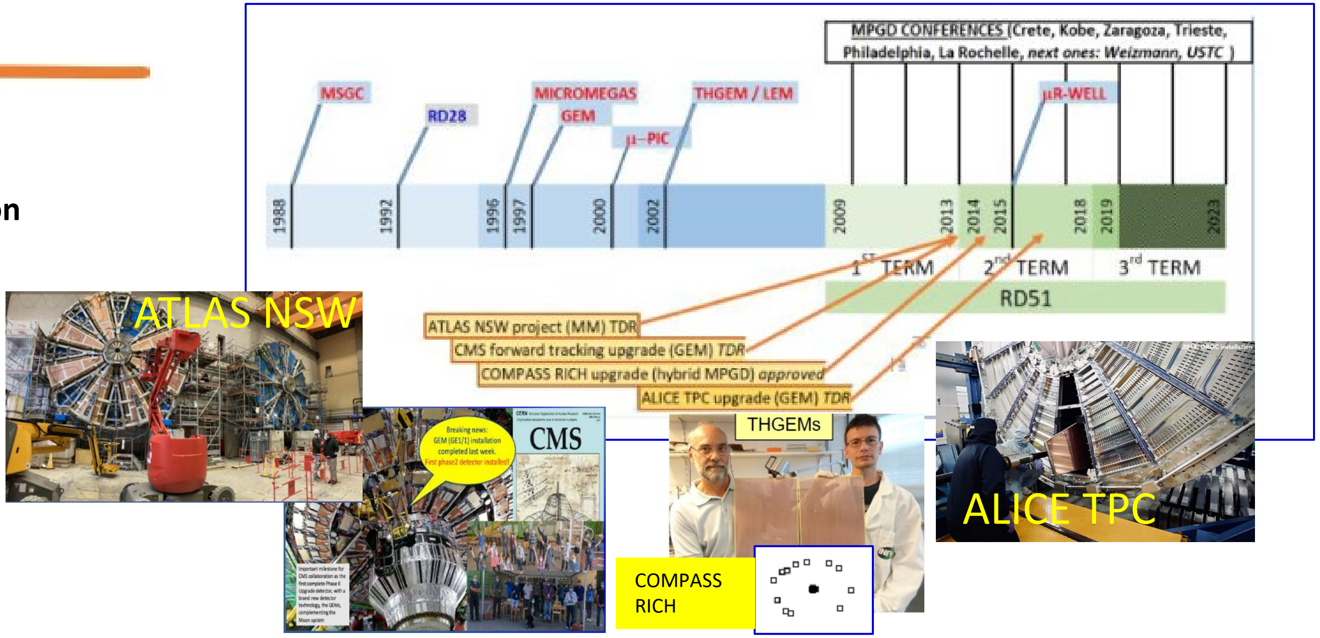
- 4 major families
  - **MPGDs**
  - **RPC & mRPC** for fine time resolution
  - Large volume: **TPCs & Drift Chambers**
  - and more: **Straw Tubes, Cathode Strip & Thin Gap Chambers**

A quick tour among technologies

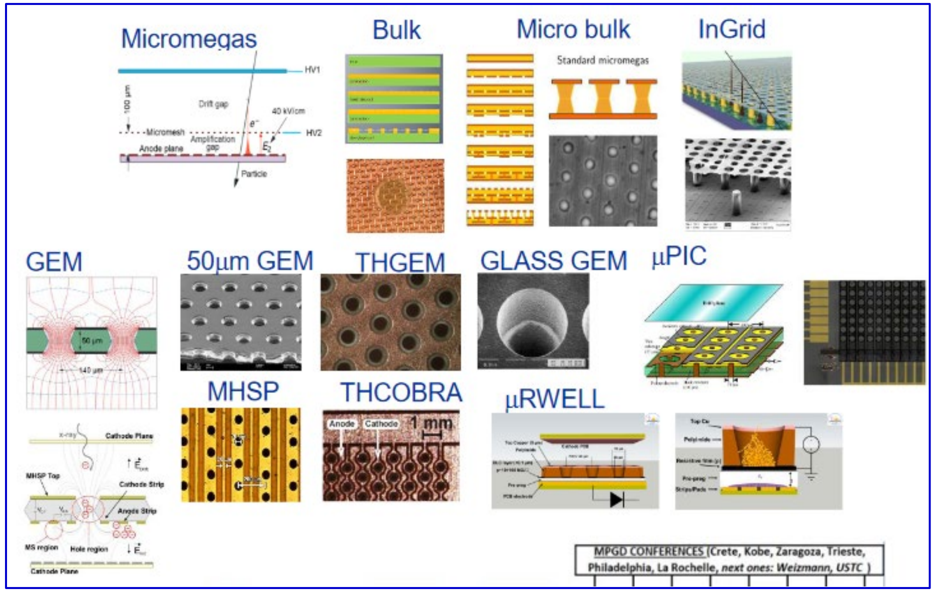
MPGD

- A **wide family** of detectors : **MPGDs**
  - **Key role of the RD51 technological Collaboration**, **CERN-based, world-wide, dedicated to MPGD developments and dissemination**

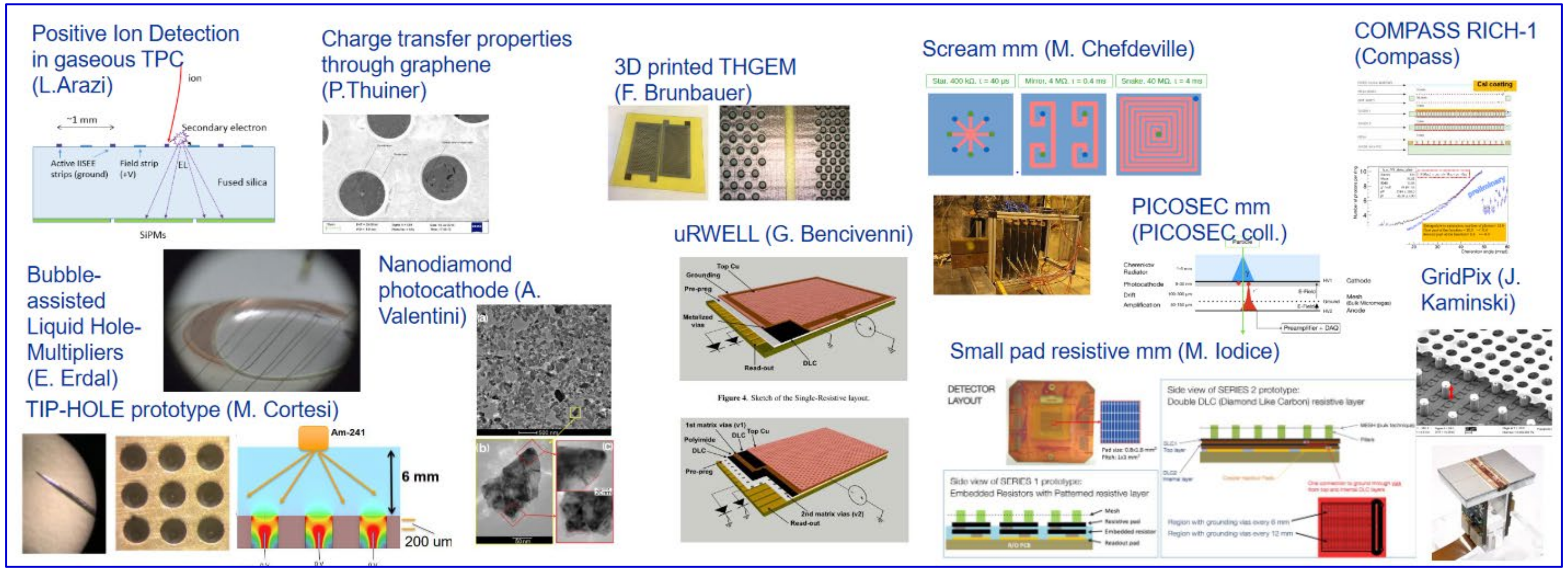
MPGD, the history



MPGD: the present

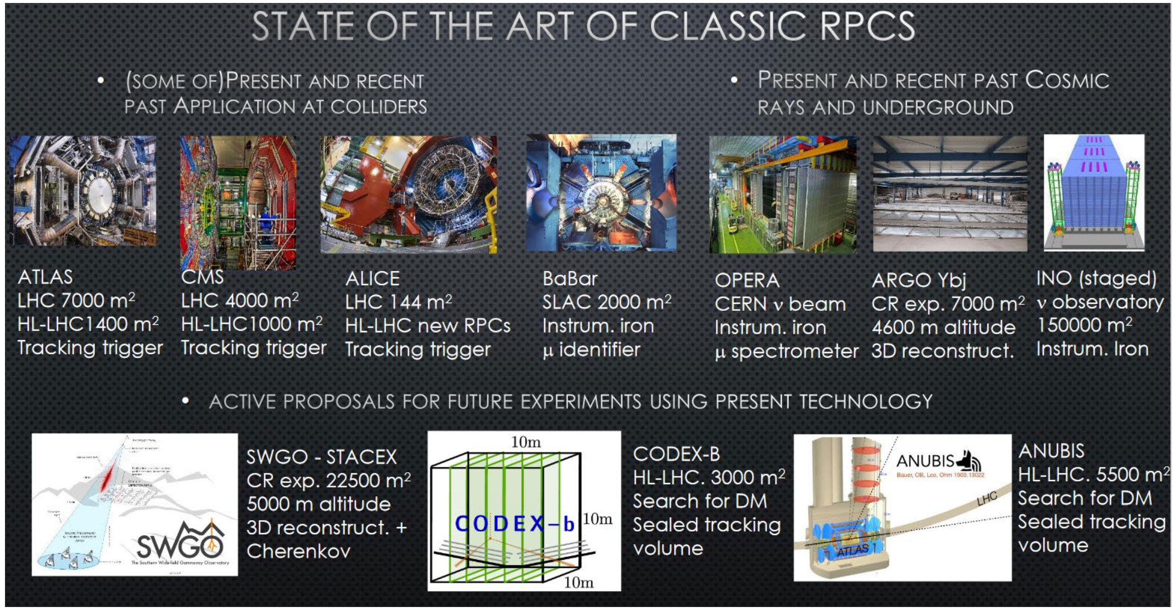


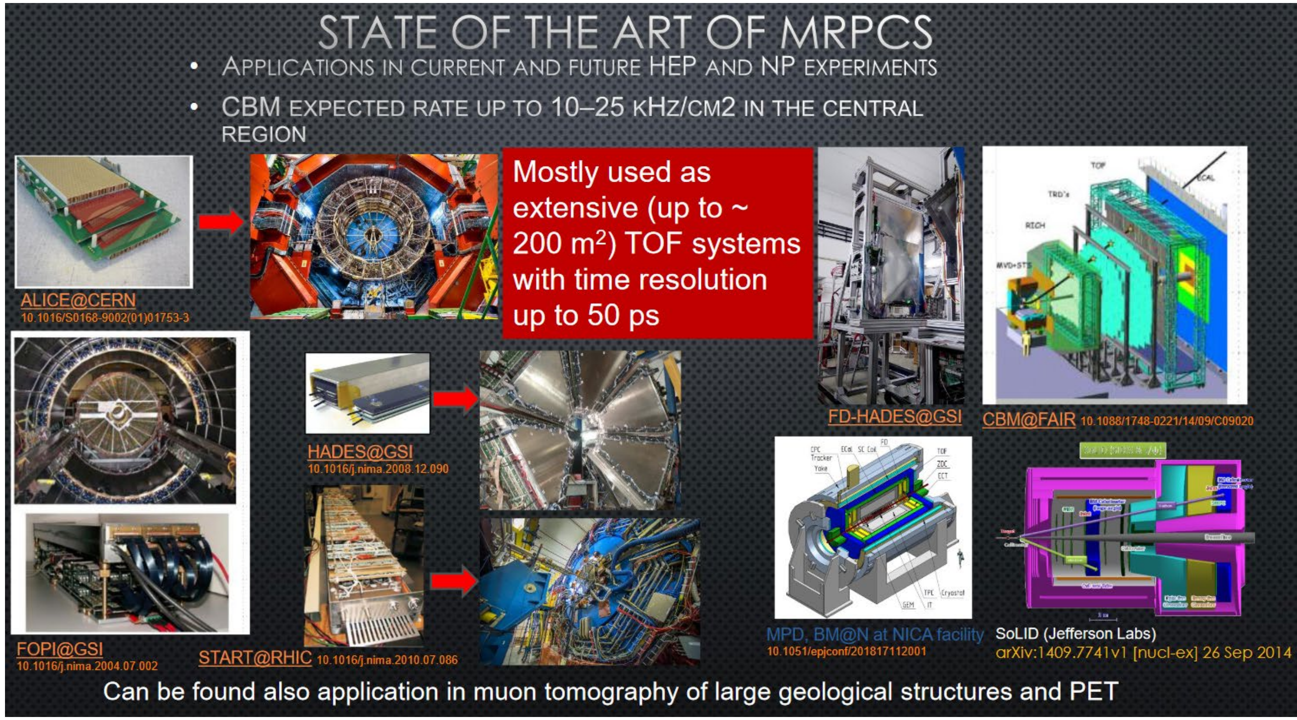
MPGD: New technologies on the way

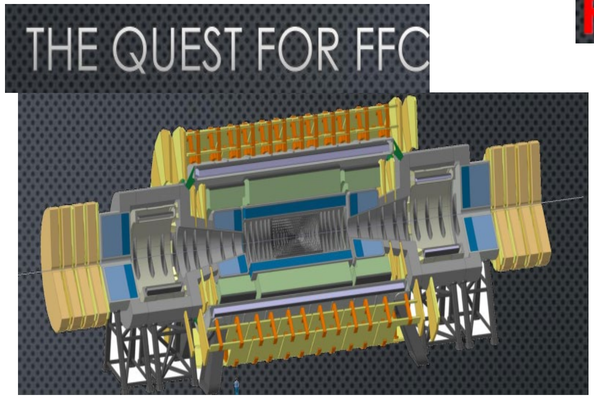


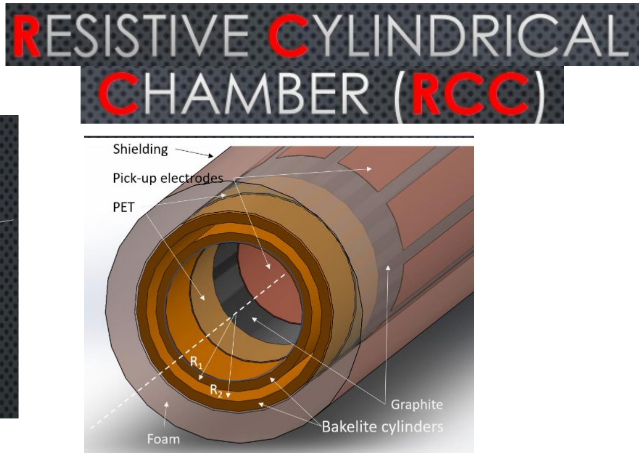
RPCs

- A **wide family** of detectors: (m)RPCs







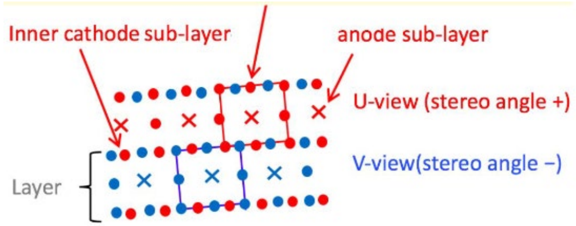


- R&D themes
  - High rates → lower resistance
  - Longevity → lower charge (electronics)
  - Time resolution (~ 50 ps) → thinner mRPCs with increased number of layers
  - 2-D tracking → a new idea: diffusion wave time-walk on graphite electrodes
  - Eco-friendly gasses → smaller gaps, lower gains (electronics)

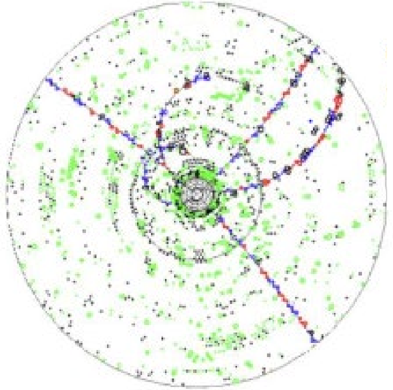
LARGE VOLUME GASEOUS DETECTORS

- A **wide family** of detectors: **large volume drift chambers and TPCs**

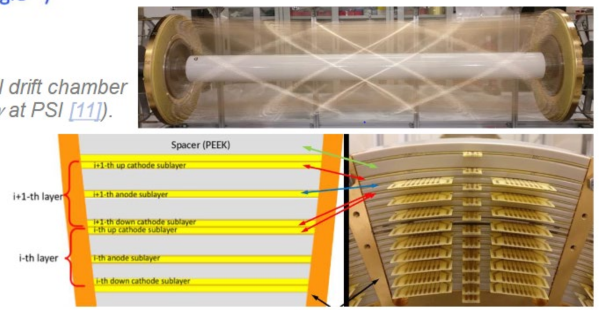
Drift Chambers



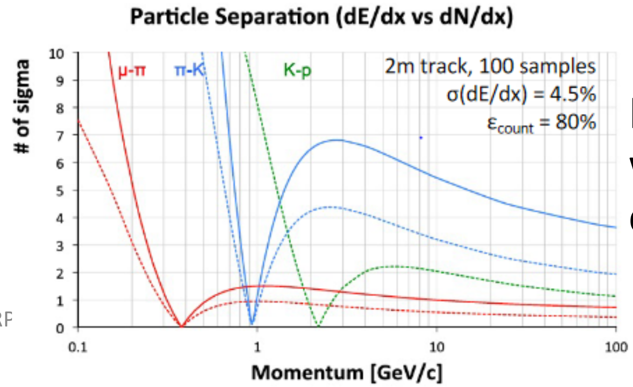
Belle II



MEG-II drift chamber ($\mu \rightarrow e\gamma$ at PSI [11]).

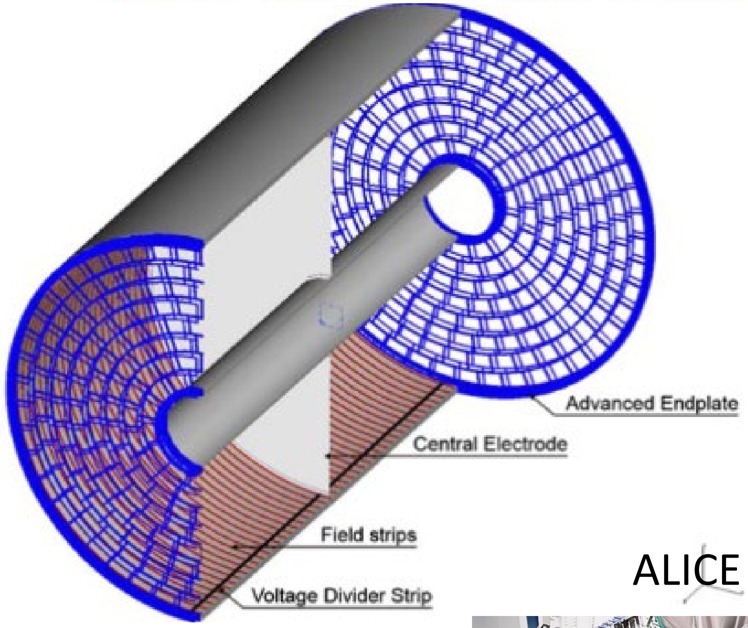


IDEA (Planned) at FCC-ee



Improved dE/dx with cluster counting

MPGD-based TPC with continuous readout



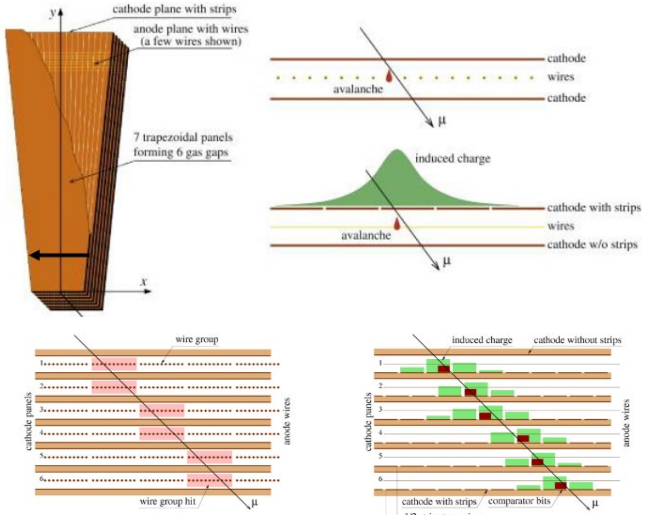
ALICE TPC

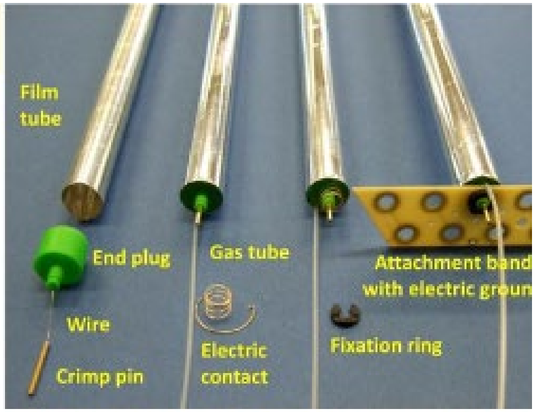
GASEOUS DETECTORS, more

- A **wide family** of detectors: Straw Tubes, Cathode Strip & Thin Gap Chambers

Cathode Strip Chambers

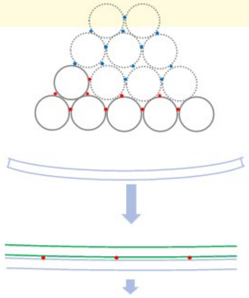
At CMS / ATLAS



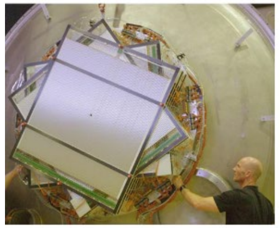


Straw tube components (for PANDA-STT [1])

NA62 Straw station [3].

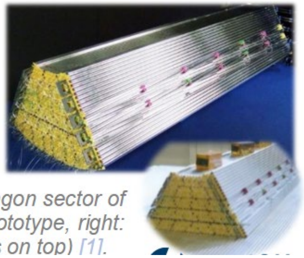


Close-packed glued straw layers sustain wire tension and reduce bending.



COSY-TOF Straw tracker [4]

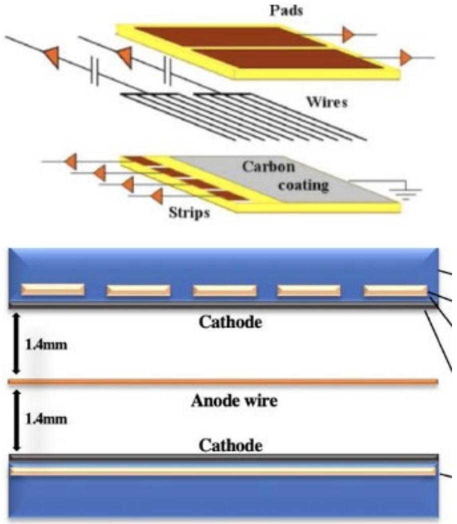
[3], COSY-TOF [5])



Self-supporting hexagon sector of the PANDA-STT (prototype, right: with 3×3kg Pb bricks on top) [1].

Thin Gap Chamber

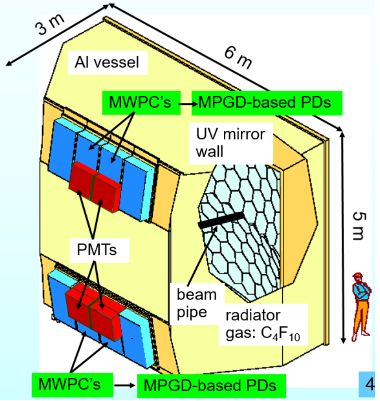
ATLAS NSW Upgrade for HL-LHC



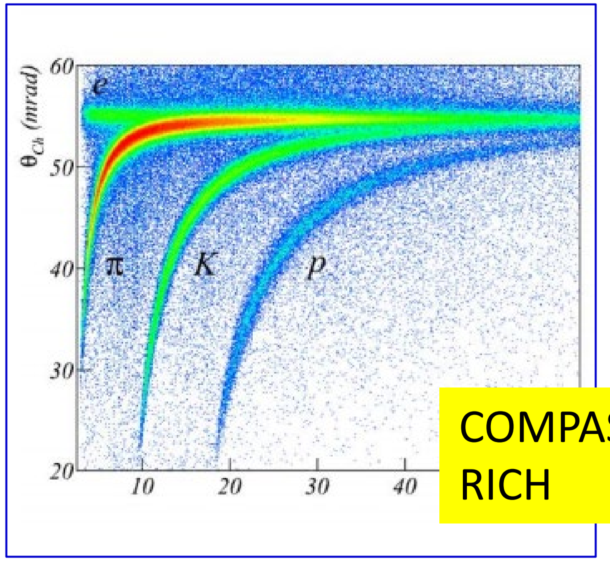
GASEOUS DETECTORS, beyond standard applications

- A **wide family** of detectors:

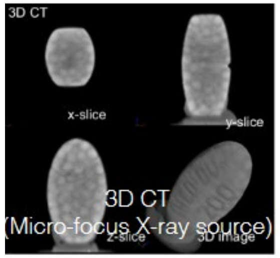
gas also where you would not expect it

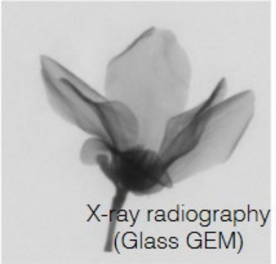


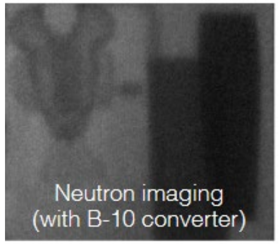
- Initially, MWPC with CsI PC *(also in ALICE, TIC, HADES, …)*
- 2016 upgrade: hybrid MPGDs : 2 THGEMs and a MM layer → increased robustness, larger signals



COMPASS RICH







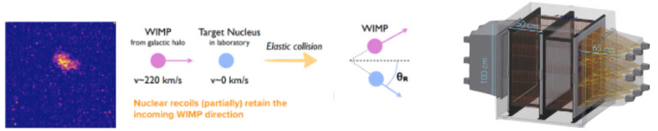
OPTICAL R-O TPCs

CYGNO Experiment

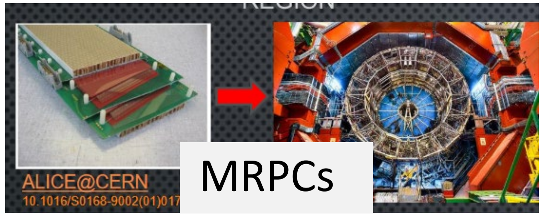
Atmospheric pressure Optical TPC

Rare event searches, directional dark matter

Triple GEM with **CMOS + PMT/SiPM** readout requiring low radioactivity background

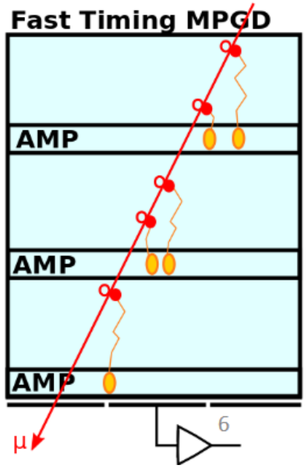


Fast Timing

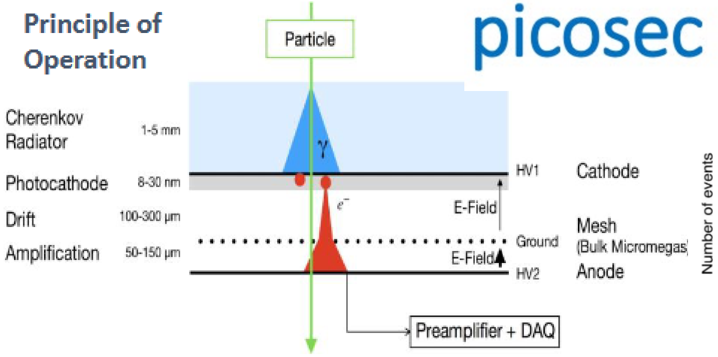


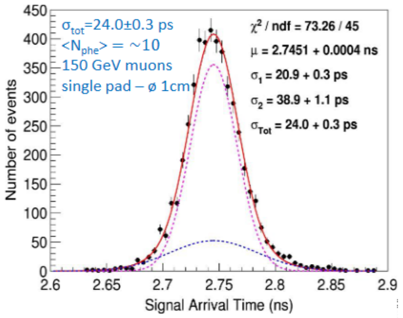
MRPCs

FTM

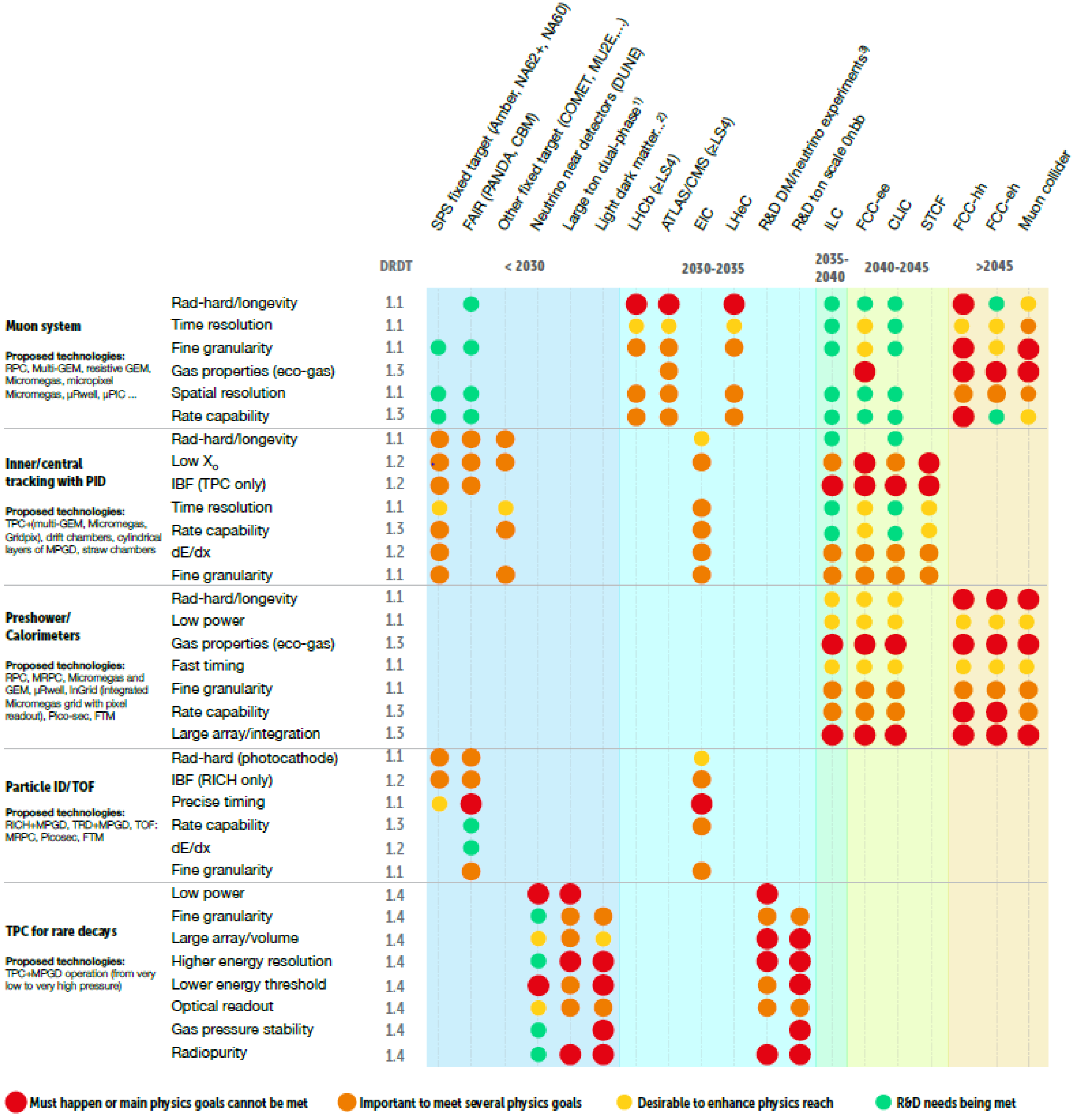


picosec



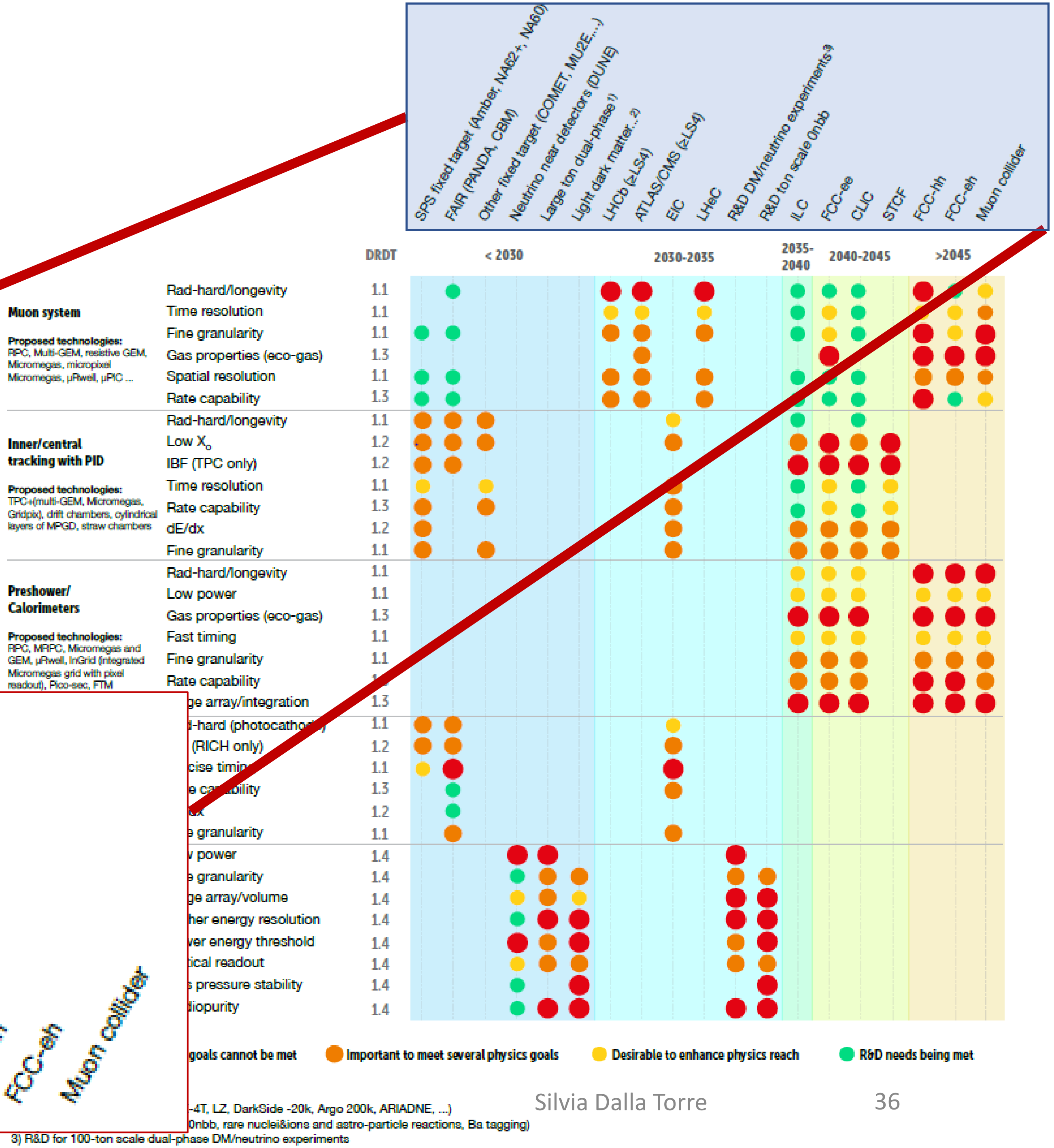


GASEOUS DETECTORS



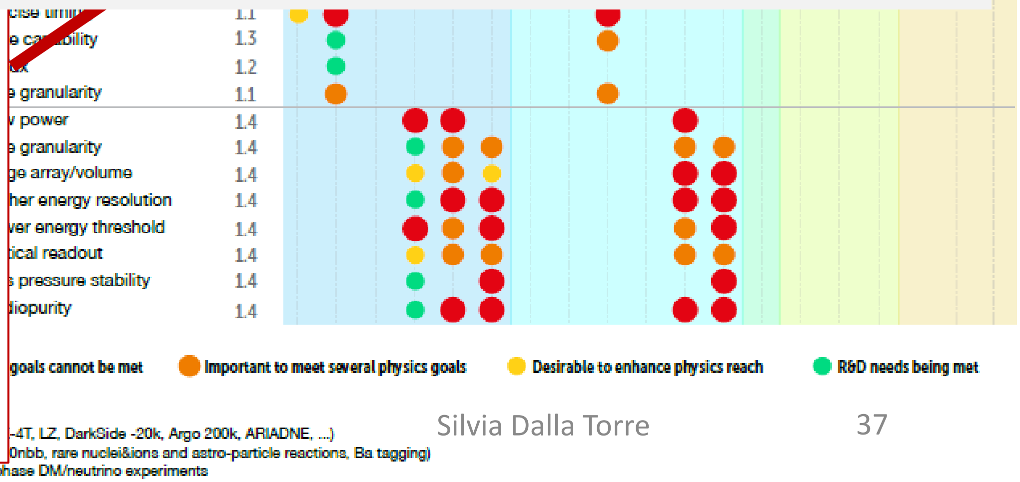
1) Large ton dual-phase (PandaX-4T, LZ, DarkSide -20k, Argo 200k, ARIADNE, ...)
2) Light dark matter, solar axion, 0nbb, rare nuclei&ions and astro-particle reactions, Ba tagging)
3) R&D for 100-ton scale dual-phase DM/neutrino experiments

GASEOUS DETECTORS



GASEOUS DETECTORS

- Extremely **wide range** of applications **including highest energies and luminosities**, long term projects
  - ubiquitous in **collider**
  - Largely needed in **fix target**
  - key also for **ν-physics** and **dark matter**
  - Even if not included in the Roadmap timelines, also **low energy NP, applications beyond fundamental research**



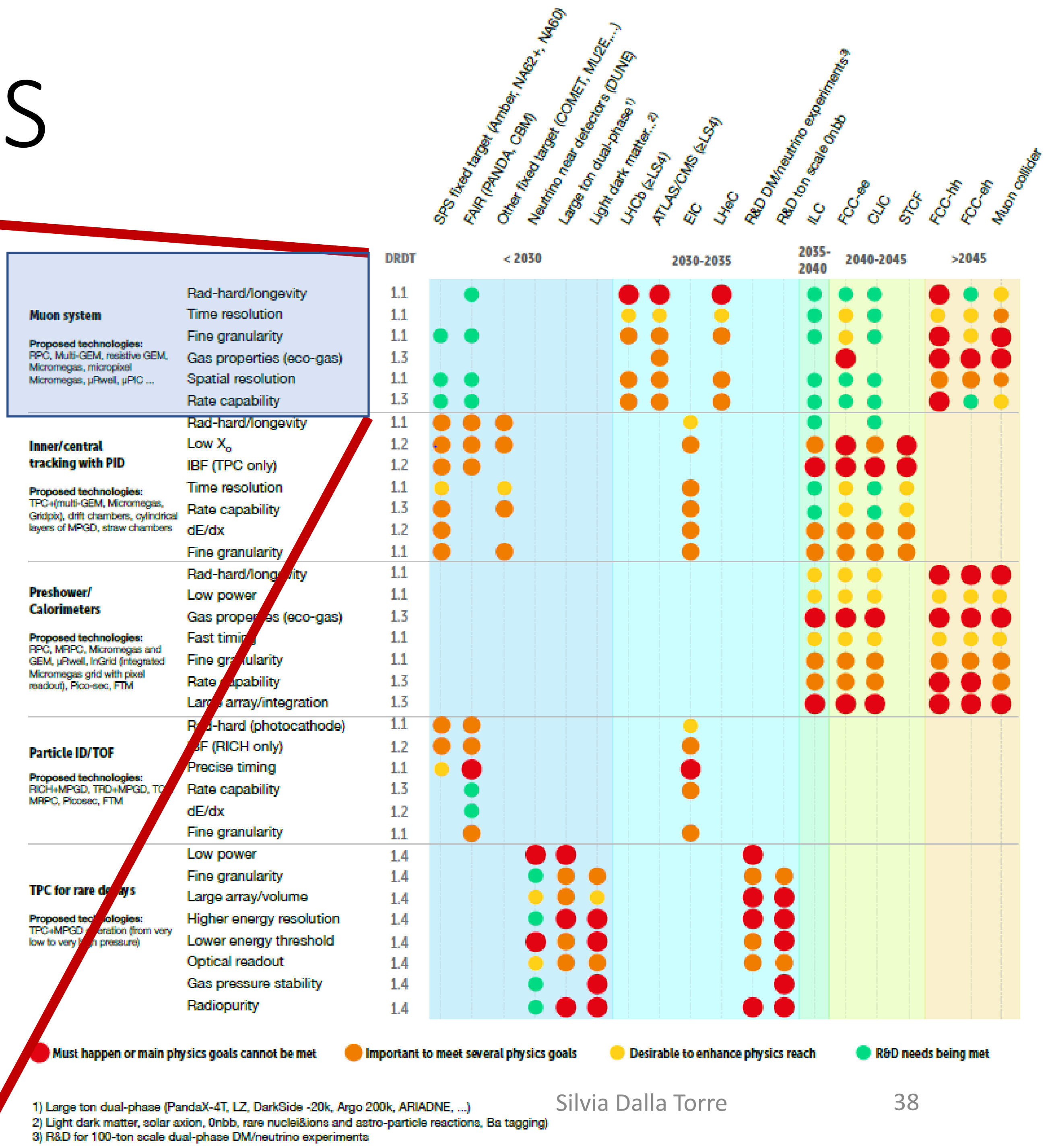
GASEOUS DETECTORS

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



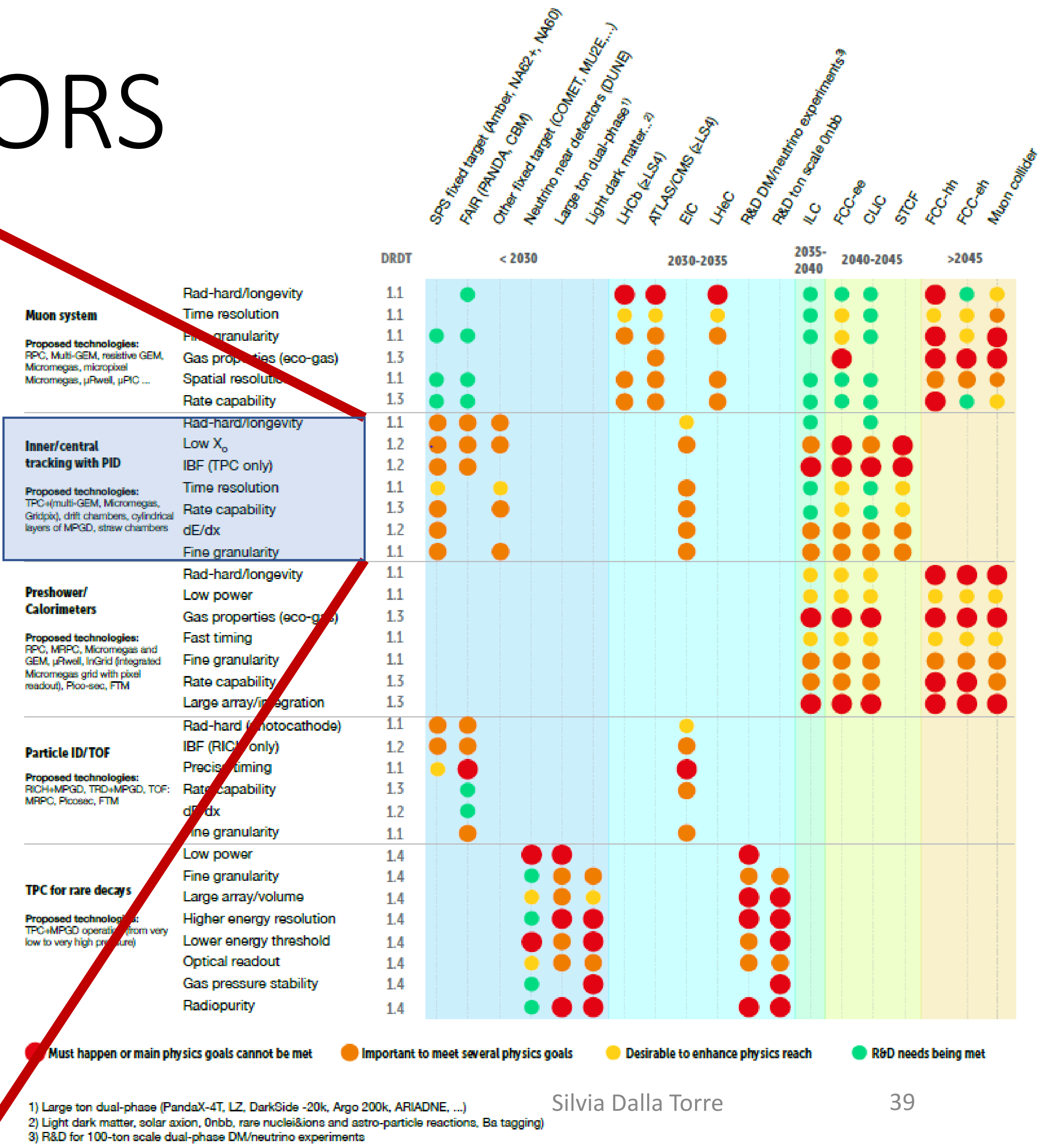
GASEOUS DETECTORS

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
  - Cluster counting: *Grid-Pix, electronics*
- fine granularity
- rate capability

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

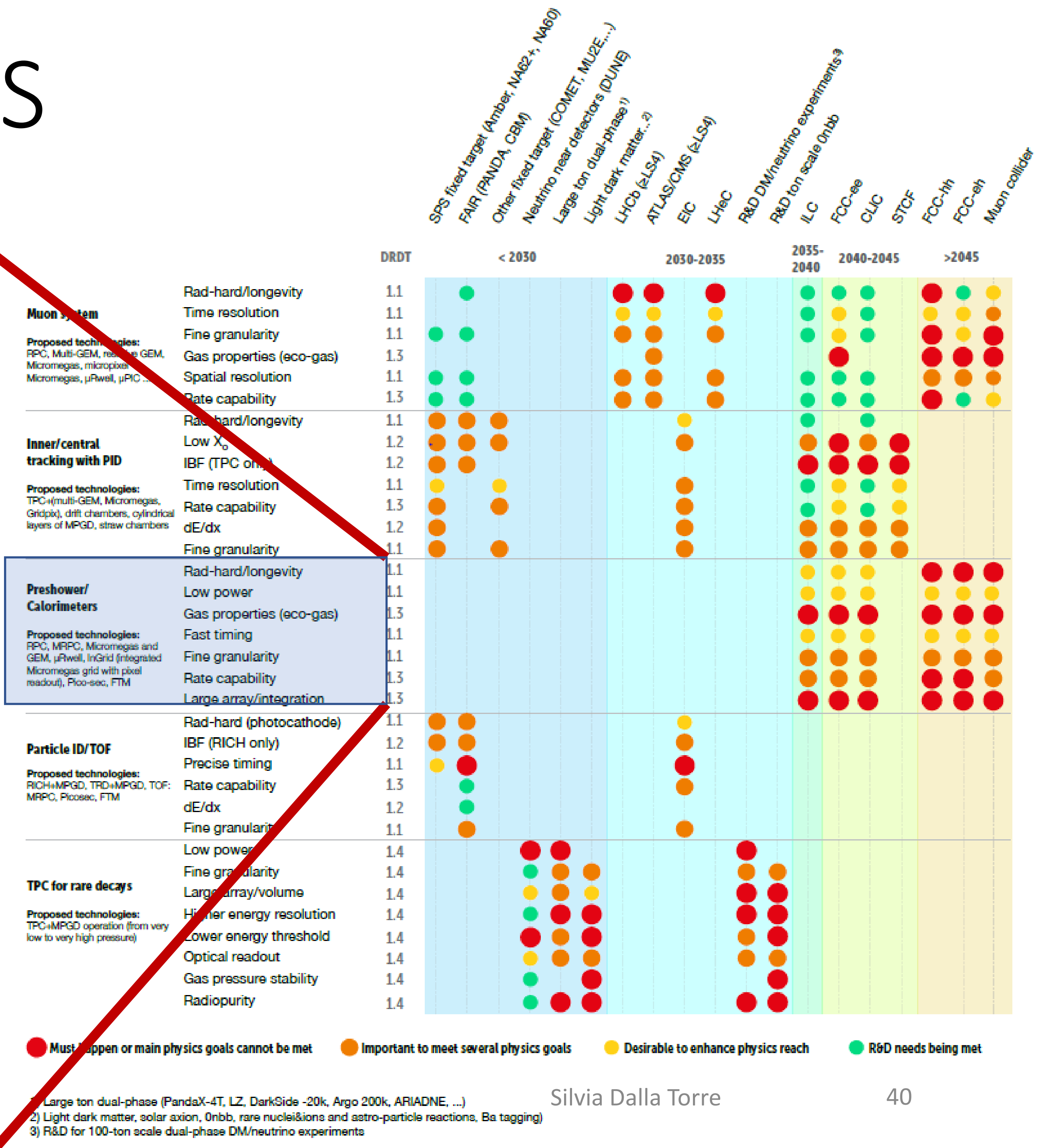


GASEOUS DETECTORS

Main drivers from facilities:

Pre-shower and calorimetry:
- CONTEXT: particle flow 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: e+e-, mu, e-h
- **TECHNOLOGIES:** MPGDs (PicoSec, FTM), RPCs



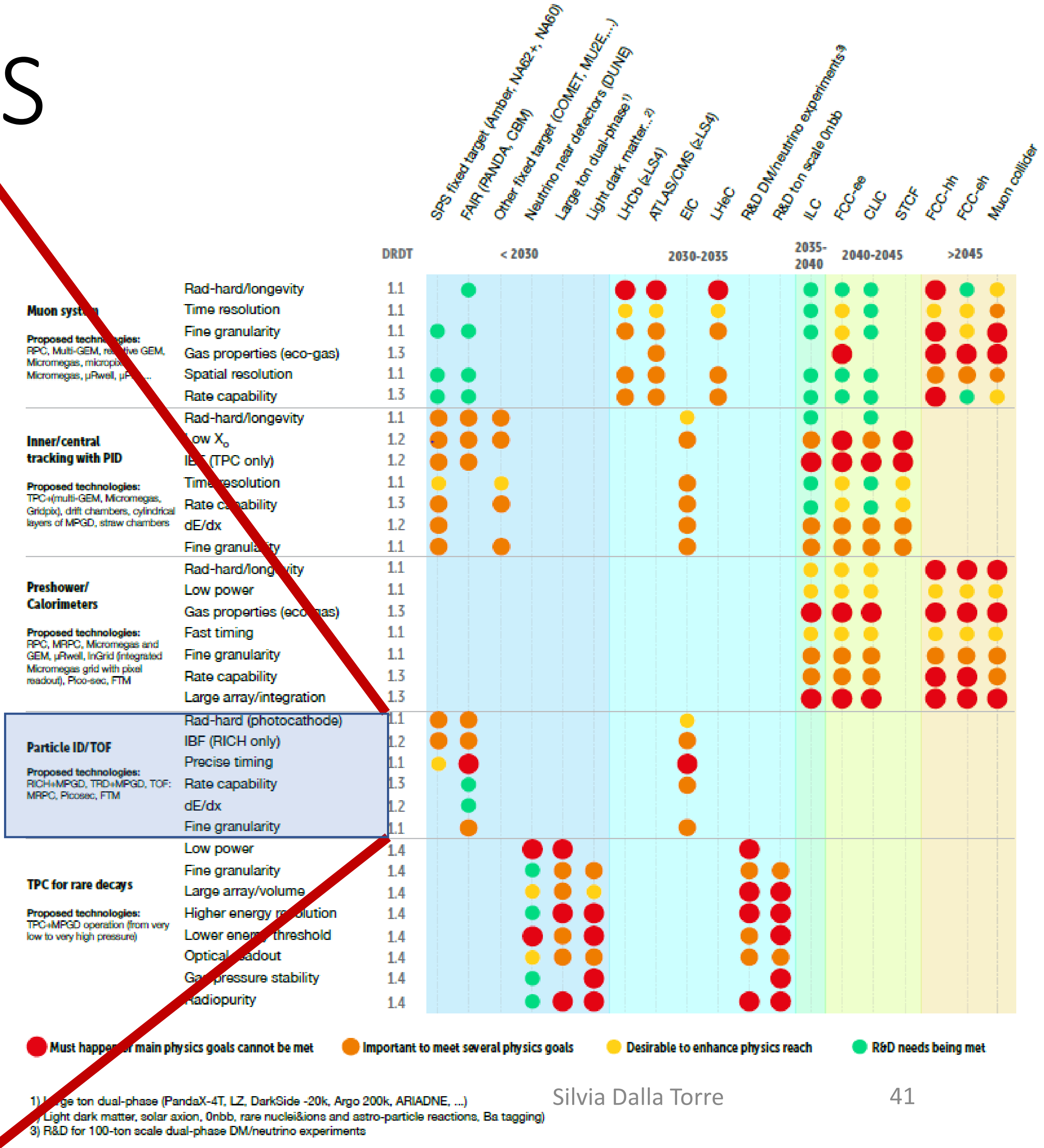
GASEOUS DETECTORS

Main drivers from facilities:

ToF:
- precise timing, goal: ~ 20 ps
- rate capability: 100 kHz/cm^2
  - Low resistivity glass for MRPCs
- Optical R-O approaches
- **FACILITIES:** h physics
- **TECHNOLOGIES:** MRPCs, MPGDs (PicoSec, FTM)

Gaseous sensors for RICHes:
- Photocathode radiation hardness
  - Low IBF rates
  - New photoconverters: nano-diamond powder
- Fine granularity
- **FACILITIES:** h and flavour physics
- **TECHNOLOGIES:** MPGDs

dE/dx and TRDs
- The frontier is cluster counting



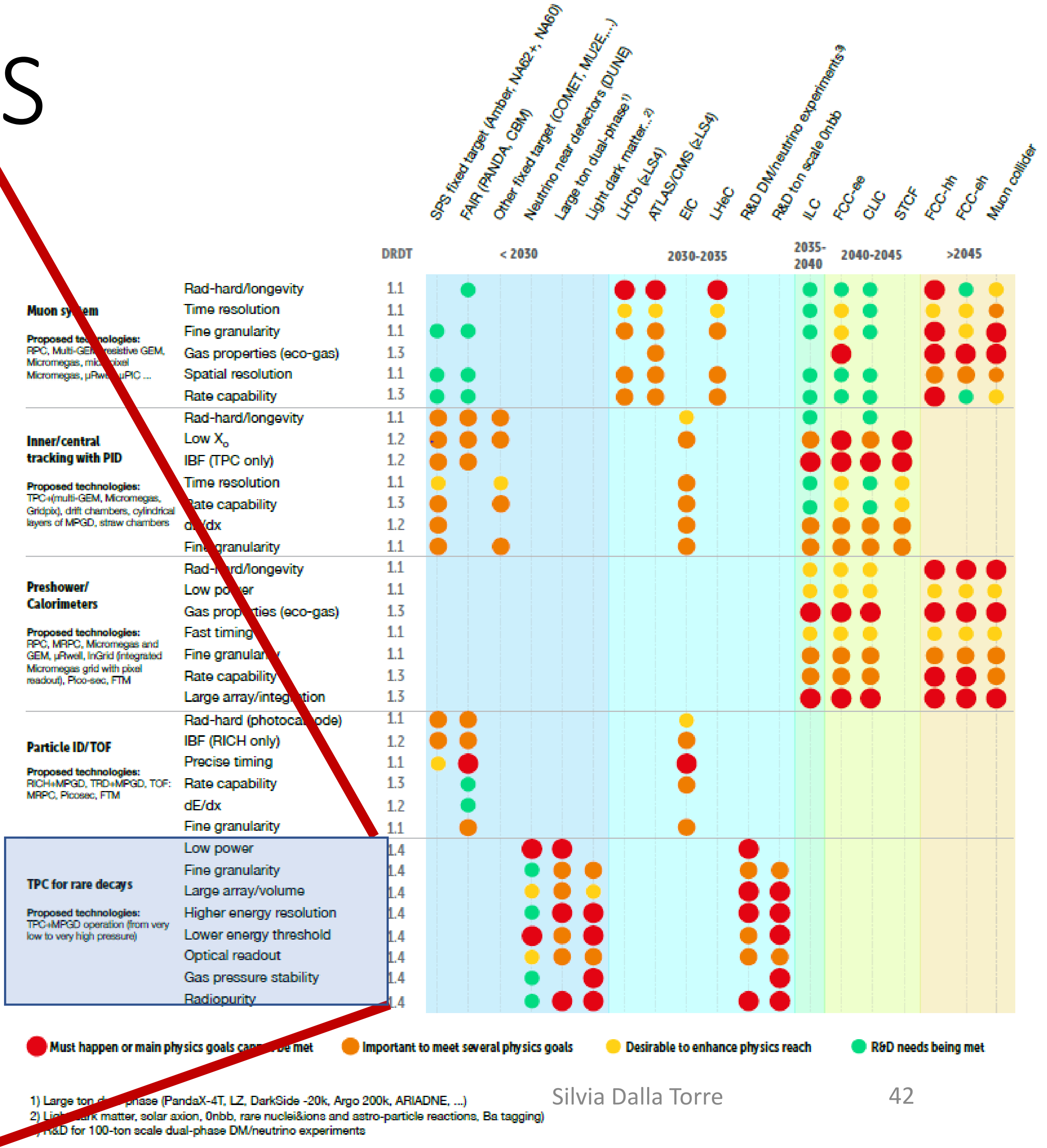
GASEOUS DETECTORS

Main drivers from facilities:

TPC for rare decays

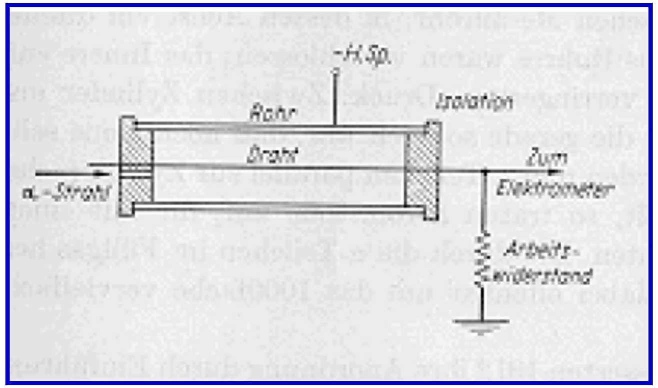
- CONCEPT:
  - The TPC gas is the target material
    - Purified gas
    - Pressure 1-10 bar → *pressure control*
  - Detection of both ionization and scintillation in noble gasses
    - Purified gasses and radiopurity
    - Scintillation; CF_4 (gas tightness, recuperation)
- High space resolution
- Large arrays and large volumes
- High energy resolution, low energy threshold *(dynamic range → electronics)*

- **FACILITIES:** WIMPS, Solar Axion, ν-exp.s:
- **TECHNOLOGIES:** high-pressure TPC with MPGD sensors (also optical read-out)



Gaseous Detectors
Main Messages as guidance for the R&D path

- Stability & longevity (ageing, discharge issues)
- Rate capabilities (segmentation, resistive electrodes)
- Electronics for Gaseous Detectors (specific for gas, dynamic range, cluster counting capabilities)
- Eco gas mixtures and mitigations procedures for GHG gas (recirculation, recuperation, leak free)
- Detector stability (ageing, discharge issues) and rate capability: resistive electrodes.
- Novel technologies, materials, architectures
- Novel readout electrodes, optical readout with imaging sensors, hybrids with pixelated ASICs
- Precise timing detectors
- IBF, photocathode stability and alternatives (including solid converters and nanotech)



Thank you

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