# Future of solid state detectors within DRD3 collaboration

*Dimitris Varouchas (IJCLab-Orsay, CNRS/IN2P3),*

*With special thanks to (random order): Claudia Gemme, Giovanni Calderini, Sally Seidel, Nicolo Cortiglia, Michael Moll*

*Material mostly stolen from the various DRD3 kick-off meetings*

université PARIS-SACLAY
IJCLab Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

DRD3

# European Strategy for Particle Physics

https://europeanstrategy.cern

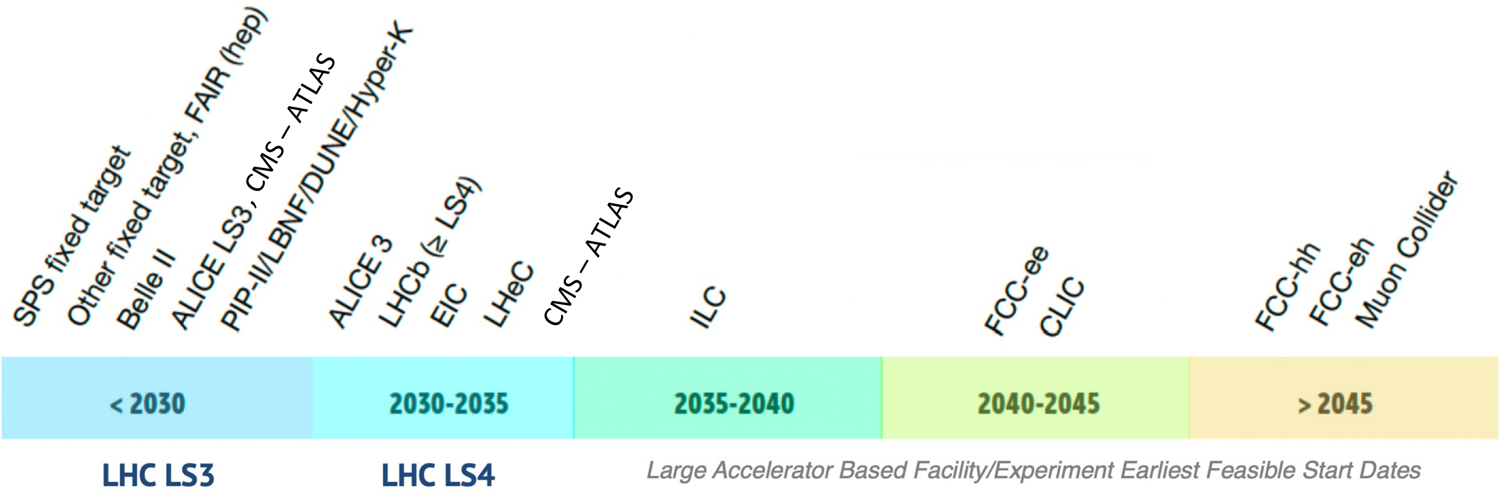
- Strategy established in 2006
- 1st update in 2013 to evaluate HL-LHC upgrades
- 2nd update in 2020-2021 to propose post HL-LHC strategy
  - A ~200 page **report/roadmap** was then published
  - *" **Europe, together with its international partners**, should investigate the technical and financial feasibility of a **future hadron collider at CERN** with a centre-of-mass energy of at least **100 TeV** and with an **e+ e- Higgs and electroweak factory as a possible first stage**.*
  - *The **success** of particle physics **experiments relies on innovative instrumentation and state-of-the-art infrastructures**.*
  - ***Detector R&D programmes and associated infrastructures** should be **supported** at CERN, national institutes, laboratories and universities.*
  - ***Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe and its partners. "***


https://cds.cern.ch/record/2784893

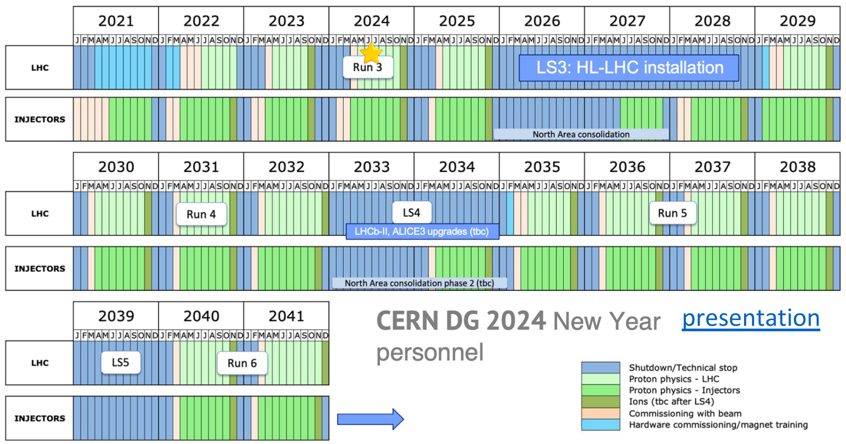
Synopsis

# ECFA detector R&D roadmap

- Five time-periods are defined from now until > 2045

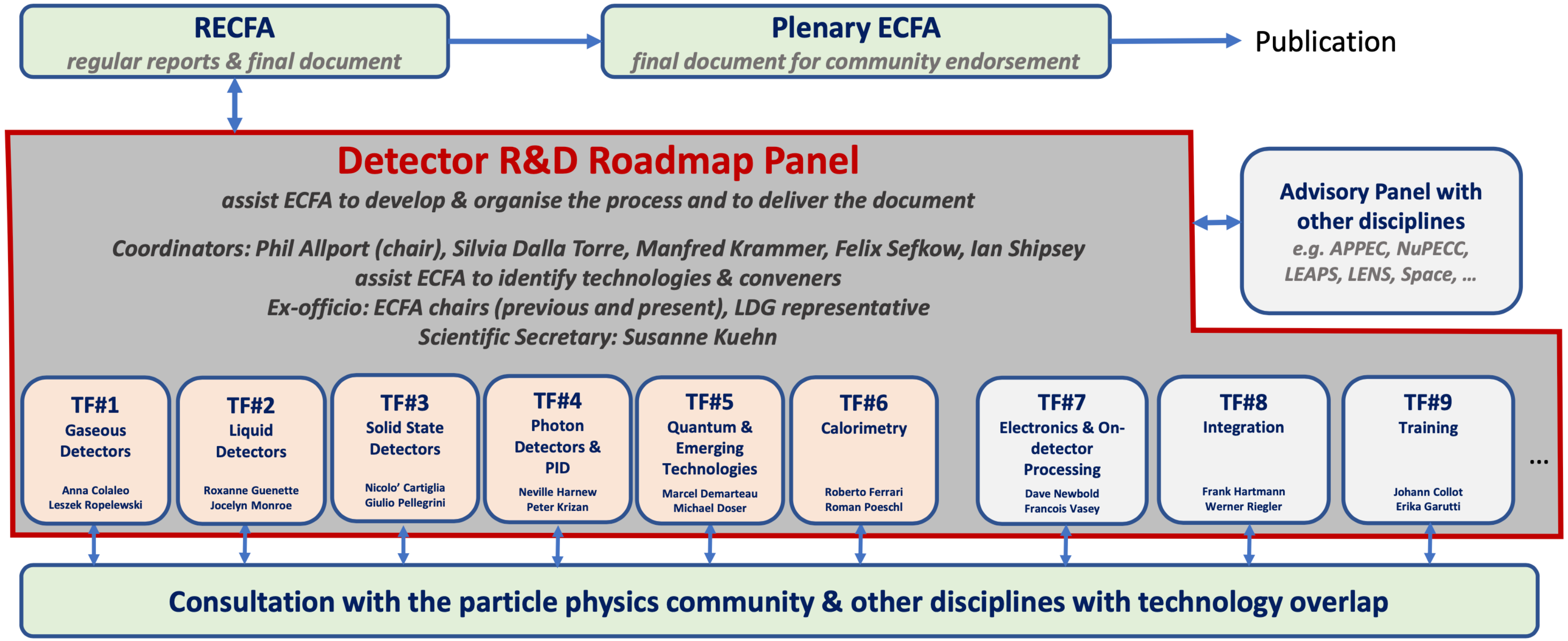



**Indicative timeline out to 2041** **for (HL)-LHC Schedule**



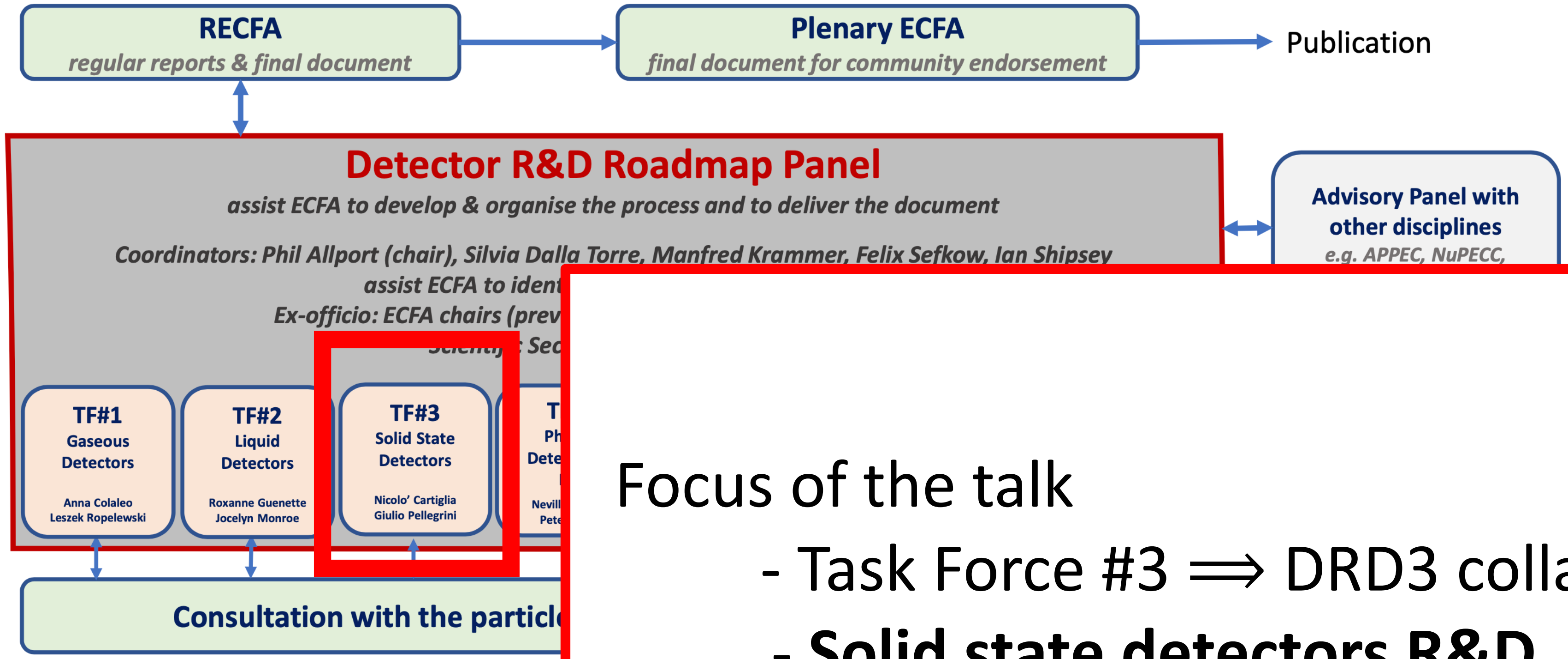

- Requirements for the future detectors
  - Excellent **time** and **space resolution** in **high occupancy** environment
  - **Radiation hard** components
  - High event rate: detectors with **super fast response** are needed

# ECFA detector R&D roadmap




- Roadmap was approved by ECFA in November 2021
  - Overview of **future accelerators/colliders** (EIC, ILC, CLIC, FCC, Muon collider) with their timelines
  - **9 Task forces were formed** with respect to the **most urgent Detector R&D**, that are now **evolving to collaborations** in each domain
  - Within the community, they are identified as **Detector R&D Themes (DRDTs)**

# ECFA detector R&D roadmap




- Roadmap was approved by ECFA in Nov
  - Overview of **future accelerators/co**
  - **9 Task forces were formed** with re
    **collaborations** in each domain
  - Within the community, they are ide

Focus of the talk

- Task Force #3 $\Longrightarrow$ DRD3 collaboration
- **Solid state detectors R&D**

# Solid state detectors in a nutshell

- **Initial development** of solid state detectors **began** in the **1950s**

- **First use** of solid-state detectors in HEP in the **1960s** at **SLAC**
  - To **measure** the **energy** of **protons** and **other charged particles** in 1961 (W. Panofsky)
  - **Silicon detector** to measure **electron – proton elastic scattering** in 1966
    - First solid proof of the advantages of this type of detectors: high resolution, compact size

- **1970s** technology of solid state detectors **continue to improve** and integrated into various experiments for **vertexing, tracking and measuring energy of particles**

- Notable establishment thanks to **Fermilab** and **CERN** experiments the following decades until nowadays

- Revolution in particle detection
  - **Improved spatial and energy resolution:** more precise measurements and particles identification
  - **Compactness:** smaller and more manageable detectors
  - **Fast response:** strengthen ability of to handle high event rates (eg hadron colliders)

# Solid state detectors in a nutshell

- Applications in HEP
  - **Tracking detectors:** reconstructions of the trajectories of charged particles. This information is crucial for identifying particles
  - **Vertex detectors:** placed close to the interaction point to precisely determine the positions of particle collisions, which helps in identifying short-lived particles and mitigating pile-up
  - **Calorimeters:** (more recent) applications to measure the energy of particles by absorbing them and measuring the total charge created

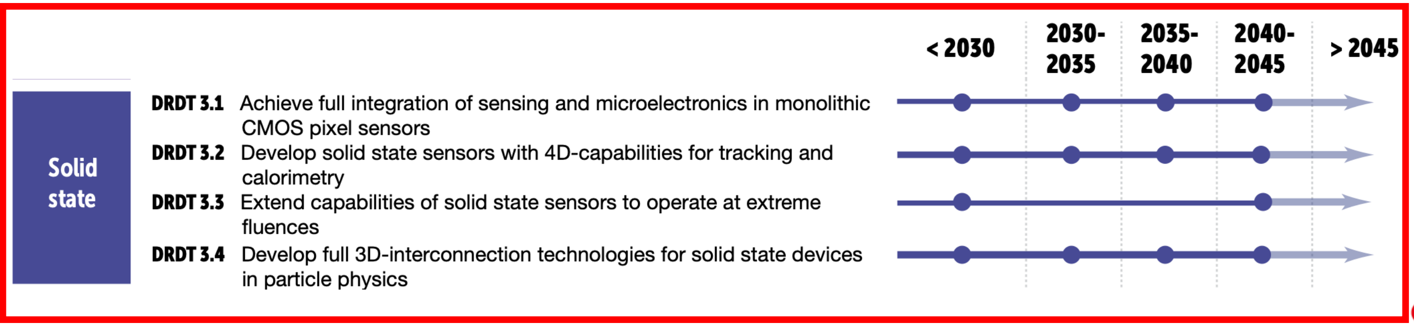
- Types of solid-state detectors

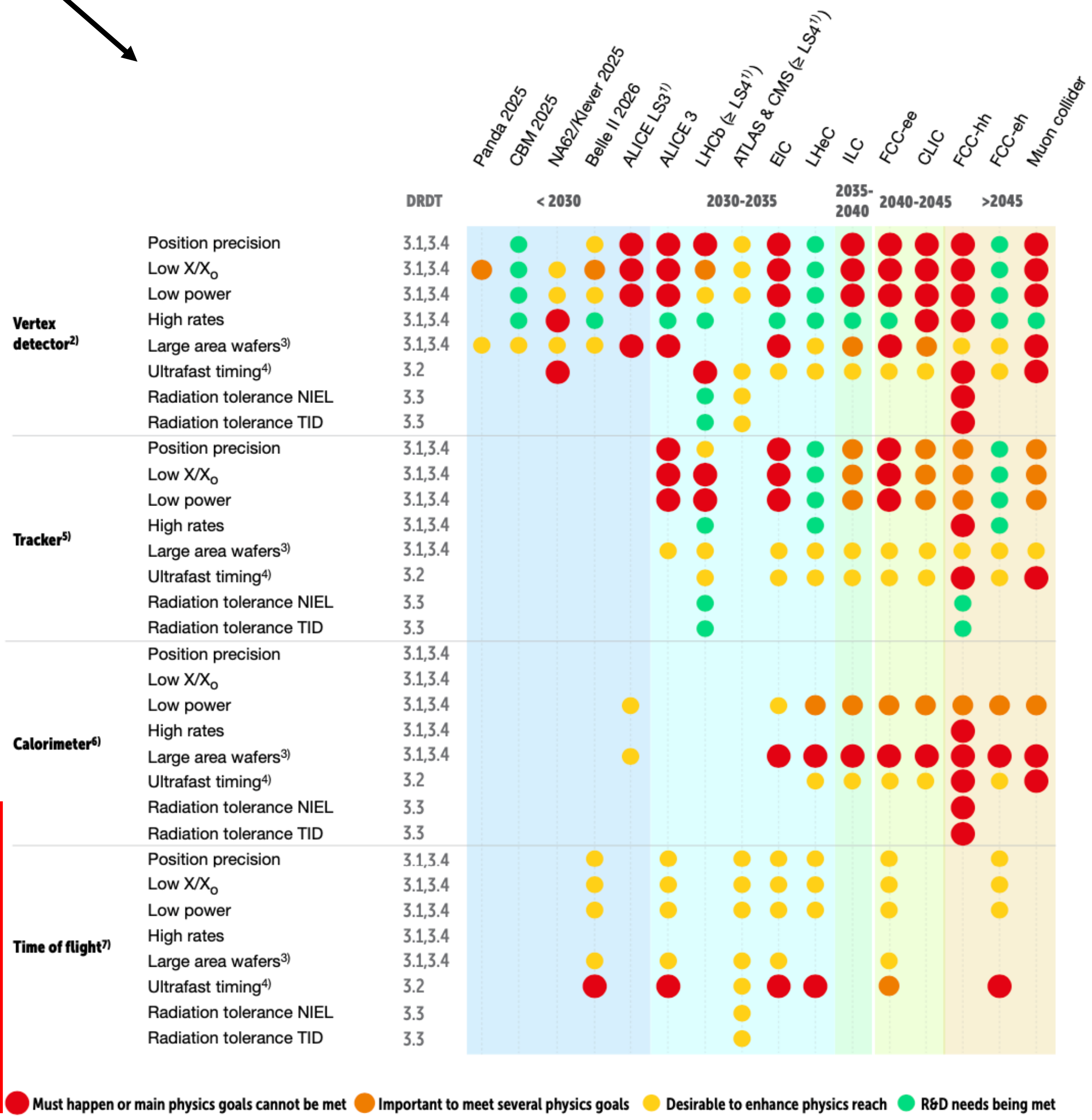
*Two main applications in collider detectors*

  - **Silicon strip detectors:** thin strips of silicon, each acting as individual detector element, widely used for tracking
  - **Silicon pixel detectors:** grid of microscopic pixelated regions, each acting as detector. Higher resolution compared to strips, used for vertexing close to interaction point and tracking
  - Charged-Coupled Devices (CCDs): used in imaging applications (commercial digital cameras), can be used for low energy particle detection
  - Silicon Drift Detectors (SDDs): high resolution energy measurements, usually in X-ray spectroscopy

# ECFA Roadmap TF#3: what do experiments need?

- Detector Readiness Matrix: a graphical representation highlighting **where significant R&D is required** with its respective **timeline**
- **Colour coding** represents the **potential impact on the intended physics programme** at the experiment
  - E.g.: Red dot "•" means that absence of the proposed R&D would compromise the main motivation for the experiment as a whole
- **TF#3 ECFA Recommendations: 4 main areas of research** have been identified



- This nice (but difficult-to-read) table complements table from previous slide showing the **required values of the future detectors specifications,** as a function of **time** and **facility**

- Therefore, this table **provides quantitative targets for the R&D**

| **"Technical" Start Date of Facility** (This means, where the dates are not known, the earliest technically feasible start date is indicated - such that detector R&D readiness is not the delaying factor) | | | | < 2030 | | | | | 2030-2035 | | | | | 2035 - 2040 | 2040-2045 | | > 2045 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Panda 2025 | CBM 2025 | NA62/Klever 2025 | Belle II 2026 | ALICE LS3 [1] | ALICE 3 | LHCb (≳LS4) [1] | ATLAS/CMS (≳LS4) [1] | EIC | LHeC | ILC [2] | FCC-ee | CLIC [2] | FCC-hh | FCC-eh | Muon Collider |
| Vertex Detector [3] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.1 DRDT 3.4 | Position precision $\sigma_{hit}$ (μm) | | ≃ 5 | | ≲ 5 | ≃ 3 | ≲ 3 | ≲ 10 | ≲ 15 | ≲ 3 | ≃ 5 | ≲ 3 | ≲ 3 | ≲ 3 | ≃ 7 | ≃ 5 | ≲ 5 |
| | | | $X/X_0$ (%/layer) | ≲ 0.1 | ≃ 0.5 | ≃ 0.5 | ≲ 0.1 | ≃ 0.05 | ≃ 0.05 | ≃ 1 | | ≃ 0.05 | ≲ 0.1 | ≃ 0.05 | ≃ 0.05 | ≲ 0.2 | ≃ 1 | ≲ 0.1 | ≲ 0.2 |
| | | | Power ($mW/cm^2$) | | ≃ 60 | | | ≃ 20 | ≃ 20 | | | ≃ 20 | | ≃ 20 | ≃ 20 | ≃ 50 | | | |
| | | | Rates ($GHz/cm^2$) | | ≃ 0.1 | ≃ 1 | ≲ 0.1 | | ≲ 0.1 | ≃ 6 | | ≲ 0.1 | ≃ 0.1 | ≃ 0.05 | ≃ 0.05 | ≃ 5 | ≃ 30 | ≃ 0.1 | |
| | | | Wafers area (") [4] | | | | | 12 | 12 | | | 12 | | | 12 | | 12 | | 12 |
| | | DRDT 3.2 | Timing precision $\sigma_t$ (ns) [5] | 10 | | ≲ 0.05 | 100 | | 25 | ≲ 0.05 | ≲ 0.05 | 25 | 25 | 500 | 25 | ≃ 5 | ≲ 0.02 | 25 | ≲ 0.02 |
| | | DRDT3.3 | Radiation tolerance NIEL ($x 10^{16}$ $neq/cm^2$) | | | | | | | ≃ 6 | ≃ 2 | | | | | | ≃ $10^2$ | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | ≃ 1 | ≃ 0.5 | | | | | | ≃ 30 | | |
| Tracker [6] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.1 DRDT 3.4 | Position precision $\sigma_{hit}$ (μm) | | | | | | ≃ 6 | ≃ 5 | | ≃ 6 | ≃ 6 | ≃ 6 | ≃ 6 | ≃ 7 | ≃ 10 | ≃ 6 | |
| | | | $X/X_0$ (%/layer) | | | | | | ≃ 1 | ≃ 1 | | ≃ 1 | ≃ 1 | ≃ 1 | ≃ 1 | ≃ 1 | ≲ 2 | ≃ 1 | |
| | | | Power ($mW/cm^2$) | | | | | | ≲ 100 | ≃ 100 | | ≲ 100 | | ≲ 100 | ≲ 100 | ≲ 150 | | | |
| | | | Rates ($GHz/cm^2$) | | | | | | | ≃ 0.16 | | | | | | | | | |
| | | | Wafers area (") [4] | | | | | | 12 | | | 12 | | 12 | 12 | 12 | 12 | | 12 |
| | | DRDT 3.2 | Timing precision $\sigma_t$ (ns) [5] | | | | | | 25 | ≲ 25 | | 25 | 25 | ≲ 0.1 | ≲ 0.1 | ≲ 0.1 | ≲ 0.02 | 25 | ≲ 0.02 |
| | | DRDT3.3 | Radiation tolerance NIEL ($x 10^{16}$ $neq/cm^2$) | | | | | | | ≃ 0.3 | | | | | | | ≲ 1 | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | ≃ 0.25 | | | | | | | ≲ 1 | | |
| Calorimeter [7] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.2 | Timing precision $\sigma_t$ (ns) [5] | | | | | | | | | | | ≲ 0.05 | ≲ 0.05 | ≲ 0.05 | ≲ 0.02 | | ≲ 0.02 |
| | | DRDT 3.3 | Radiation tolerance NIEL ($x 10^{16}$ $neq/cm^2$) | | | | | | | | | | | | | | ≳ $10^2$ | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | | | | | | | | ≃ 50 | | |
| Time of Flight [8] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.2 | Timing precision $\sigma_t$ (ns) [5] | | | | ≃ 0.02 | | ≃ 0.02 | | ≲ 0.03 | ≃ 0.02 | ≃ 0.02 | | ≲ 0.01 | | ≲ 0.01 | ≃ 0.02 | |
| | | DRDT 3.3 | Radiation tolerance NIEL ($x 10^{16}$ $neq/cm^2$) | | | | | | | | | | | | | | ≃ $10^2$ | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | | | | | | | | ≃ 30 | | |

- This nice (but difficult-to-read) table complements table from previous slide showing the **required values of the future detectors specifications,** as a function of **time** and **facility**

- Therefore, this table **provides quantitative targets for the R&D**

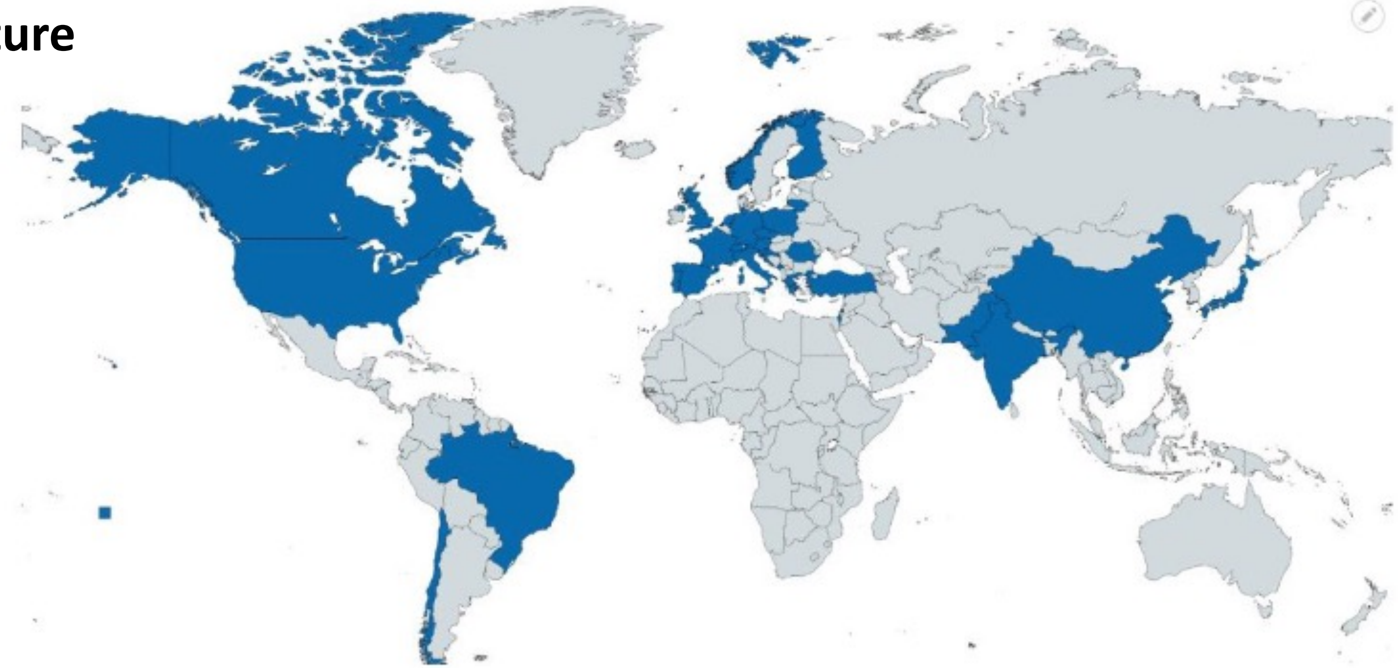
**Position resolution 5-10 µm**

| **"Technical" Start Date of Facility** (This means, where the dates are not known, the earliest technically feasible start date is indicated - such that detector R&D readiness is not the delaying factor) | | | | < 2030 | | | | | 2030-2035 | | | | | 2035 - 2040 | 2040-2045 | | > 2045 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Panda 2025 | CBM 2025 | NA62/Klever 2025 | Belle II 2026 | ALICE LS3 [1] | ALICE 3 | LHCb (≳LS4) [1] | ATLAS/CMS (≳ LS4) [1] | EIC | LHeC | ILC [2] | FCC-ee | CLIC [2] | FCC-hh | FCC-eh | Muon Collider |
| Vertex Detector[3] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.1 DRDT 3.4 | Position precision $\sigma_{hit}$ (µm) | | ≃ 5 | | ≲ 5 | ≃ 3 | ≲ 3 | ≲ 10 | ≲ 15 | ≲ 3 | ≃ 5 | ≲ 3 | ≲ 3 | ≲ 3 | ≃ 7 | ≃ 5 | ≲ 5 |
| | | | $X/X_0$ (%/layer) | ≲ 0.1 | ≃ 0.5 | ≃ 0.5 | ≲ 0.1 | ≃ 0.05 | ≃ 0.05 | ≃ 1 | | ≃ 0.05 | ≲ 0.1 | ≃ 0.05 | ≃ 0.05 | ≲ 0.2 | ≃ 1 | ≲ 0.1 | ≲ 0.2 |
| | | | Power ($mW/cm^2$) | | ≃ 60 | | | ≃ 20 | ≃ 20 | | | ≃ 20 | | ≃ 20 | ≃ 20 | ≃ 50 | | | |
| | | | Rates ($GHz/cm^2$) | | ≃ 0.1 | ≃ 1 | ≲ 0.1 | | ≲ 0.1 | ≃ 6 | | ≲ 0.1 | ≃ 0.1 | ≃ 0.05 | ≃ 0.05 | ≃ 5 | ≃ 30 | ≃ 0.1 | |
| | | | Wafers area (")[4] | | | | | 12 | 12 | | | 12 | | | 12 | | 12 | | 12 |
| | | DRDT 3.2 | Timing precision $\sigma_t$ (ns)[5] | 10 | | ≲ 0.05 | 100 | | 25 | ≲ 0.05 | ≲ 0.05 | 25 | 25 | 500 | 25 | ≃ 5 | ≲ 0.02 | 25 | ≲ 0.02 |
| | | DRDT3.3 | Radiation tolerance NIEL ($\times 10^{16}$ $neq/cm^2$) | | | | | | | ≃ 6 | ≃ 2 | | | | | | ≃ $10^2$ | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | ≃ 1 | ≃ 0.5 | | | | | | ≃ 30 | | |
| Tracker[6] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.1 DRDT 3.4 | Position precision $\sigma_{hit}$ (µm) | | | | | | ≃ 6 | ≃ 5 | | ≃ 6 | ≃ 6 | ≃ 6 | ≃ 6 | ≃ 7 | ≃ 10 | ≃ 6 | |
| | | | $X/X_0$ (%/layer) | | | | | | ≃ 1 | ≃ 1 | | ≃ 1 | ≃ 1 | ≃ 1 | ≃ 1 | ≃ 1 | ≲ 2 | ≃ 1 | |
| | | | Power ($mW/cm^2$) | | | | | | ≲ 100 | ≃ 100 | | ≲ 100 | | ≲ 100 | ≲ 100 | ≲ 150 | | | |
| | | | Rates ($GHz/cm^2$) | | | | | | | ≃ 0.16 | | | | | | | | | |
| | | | Wafers area (")[4] | | | | | | 12 | | | 12 | | 12 | 12 | 12 | 12 | | 12 |
| | | DRDT 3.2 | Timing precision $\sigma_t$ (ns)[5] | | | | | | 25 | ≲ 25 | | 25 | 25 | ≲ 0.1 | ≲ 0.1 | ≲ 0.1 | ≲ 0.02 | 25 | ≲ 0.02 |
| | | DRDT3.3 | Radiation tolerance NIEL ($\times 10^{16}$ $neq/cm^2$) | | | | | | | ≃ 0.3 | | | | | | | ≲ 1 | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | ≃ 0.25 | | | | | | | ≲ 1 | | |
| Calorimeter[7] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.2 | Timing precision $\sigma_t$ (ns)[5] | | | | | | | | | | | ≲ 0.05 | ≲ 0.05 | ≲ 0.05 | ≲ 0.02 | | ≲ 0.02 |
| | | DRDT 3.3 | Radiation tolerance NIEL ($\times 10^{16}$ $neq/cm^2$) | | | | | | | | | | | | | | ≳ $10^2$ | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | | | | | | | | ≃ 50 | | |
| Time of Flight[8] | MAPS Planar/3D/Passive CMOS LGADs | DRDT 3.2 | Timing precision $\sigma_t$ (ns)[5] | | | | ≃ 0.02 | | ≃ 0.02 | | ≲ 0.03 | ≃ 0.02 | ≃ 0.02 | | ≲ 0.01 | | ≲ 0.01 | ≃ 0.02 | |
| | | DRDT 3.3 | Radiation tolerance NIEL ($\times 10^{16}$ $neq/cm^2$) | | | | | | | | | | | | | | ≃ $10^2$ | | |
| | | | Radiation tolerance TID (Grad) | | | | | | | | | | | | | | ≃ 30 | | |

# ECFA Roadmap TF#3 ⇒ DRD3 Collaboration

- DRD3 collaboration goal two-fold
  - Realization of the **strategic R&D** defined by the TF#3 in the ECFA road map: **develop technologies** that **solve well-defined problems** of (near-) **future experiments**
  - Promoting **blue-sky R&D**: explore **new ideas** and **techniques** that **might be of use** in the **future**

- DRD3 working group structure
  - WG1 Monolithic CMOS sensors
  - WG2 Sensors for tracking and calorimetry
  - WG3 Radiation damage and extreme fluences
  - WG4 Simulation
  - WG5 Characterization techniques, facilities
  - WG6 Wide bandgap and innovative sensor materials
  - WG7 Interconnect and device fabrication
  - WG8 Dissemination and outreach

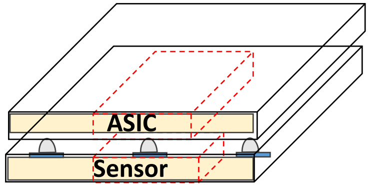


134 institutes
537 people on the mailing list

https://drd3.web.cern.ch/institutes

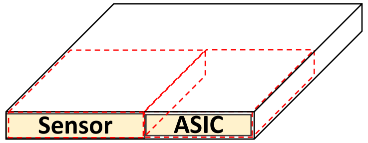
# What detection technologies will be used?

**WG 2**




- **Hybrid**
  - **Low-gain (LGADs)**
    - Standard read-out
    - Resistive read-out
  - **No gain**
    - Planar
    - 3D Si/Diamond

**WG 1**




- **Monolithic** — *pixel sensors & readout electronics contained on a single silicon substrate*
  - **Low-gain (LGADs)**
    - BiCMOS (SiGe)
    - CMOS
  - **No gain**
    - BiCMOS (SiGe)
    - CMOS

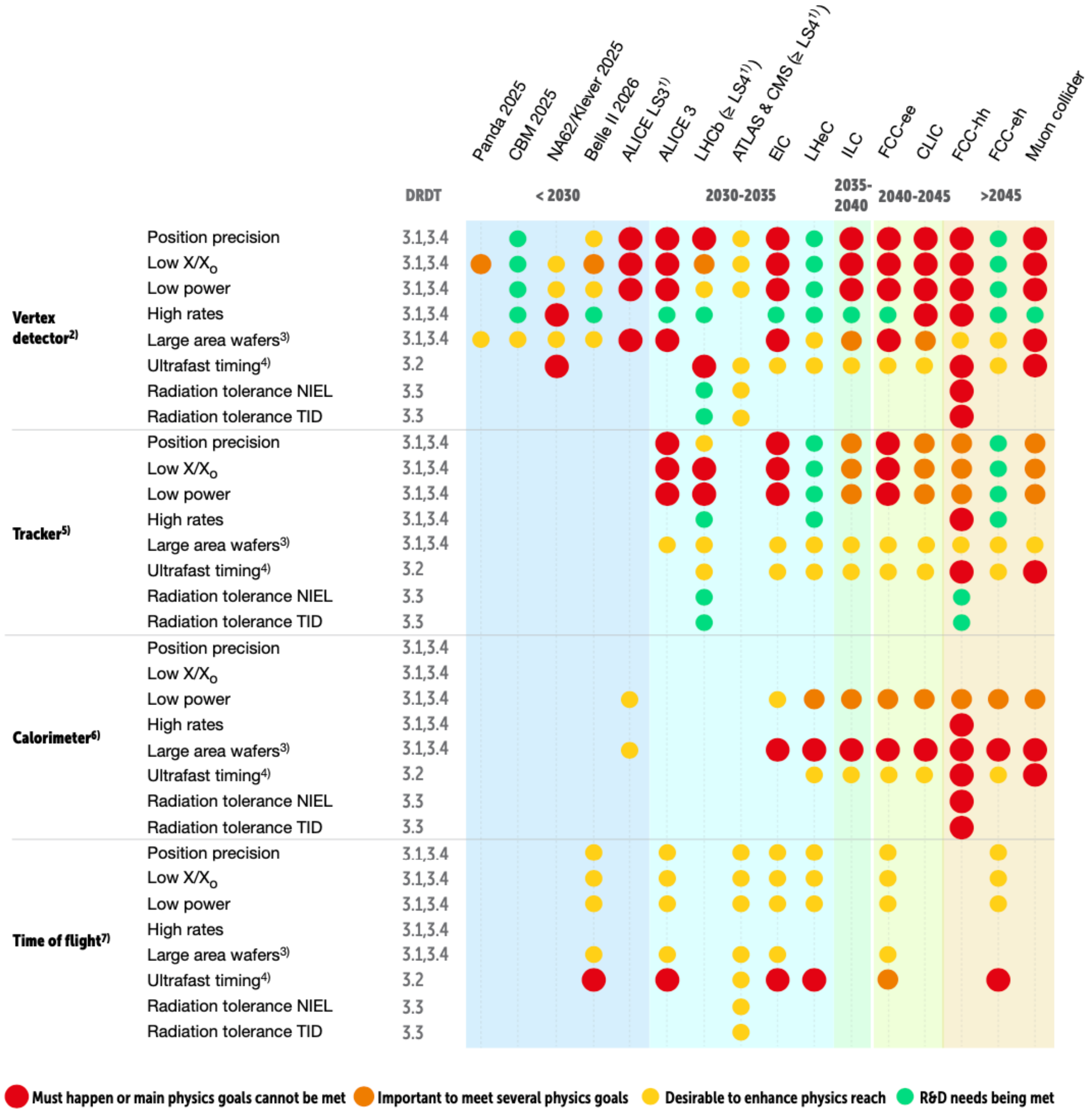
## WG 2: Hybrid sensor technologies

## WG 3: Radiation Damage & Extreme Fluences

# Requirements of strategic R&D

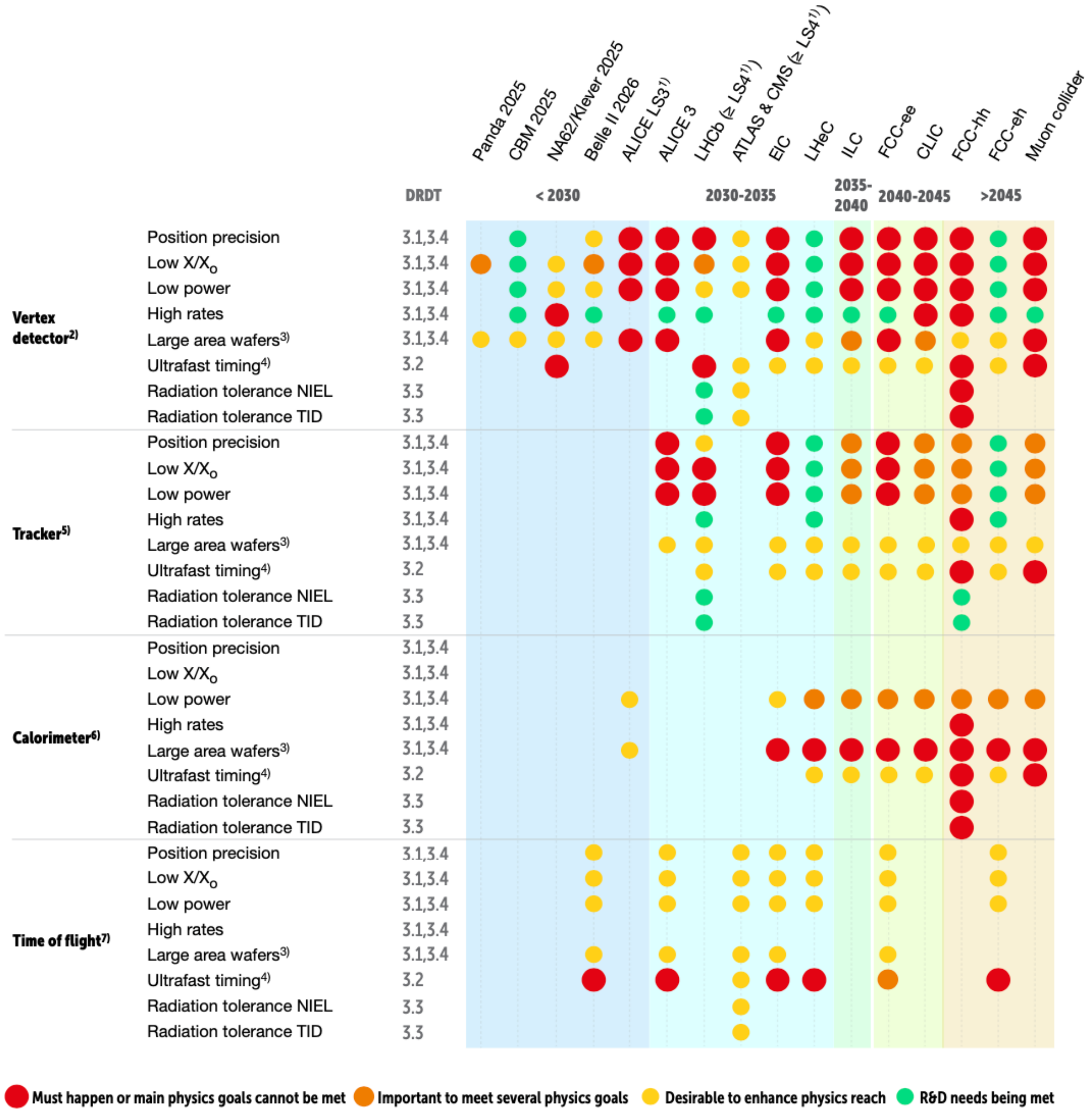
- The **obvious metric** for R&D is **space** and **time resolution**; the highest precision, the better

- **Improving resolution** is getting very **complex** in advanced R&D, therefore **more parameters** should be taken into **consideration**
  - Material budget, power, event rates, occupancy, radiation hardness, cost
  - Interplay with electronics: capacitance, resistivity, characteristics of signal and noise, etc



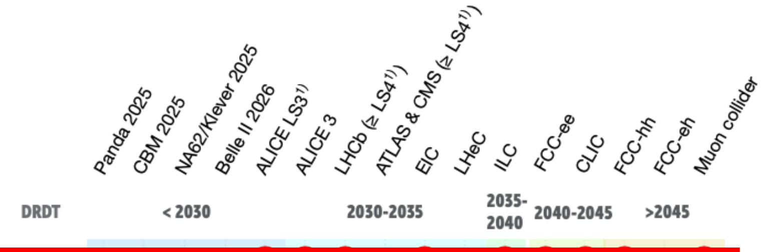
# Requirements of strategic R&D

- Requirements vary from application to application
- A good example of this is timing resolution
  - **Time of Flight (TOF)** systems, require **the best possible accuracy** (5-10 ps)
  - **Large 4D-tracking systems** might need relatively lower time accuracy (50-100 ps)
  - **4D-tracking systems** that **use timing** in their **tracking pattern recognition** require high single hit timing accuracy (5-10 ps)
- Detectors for **hadron colliders** require **ultra-fast timing** to deal with **pileup** and **high event rate**; they should **achieve unprecedented radiation hardness**

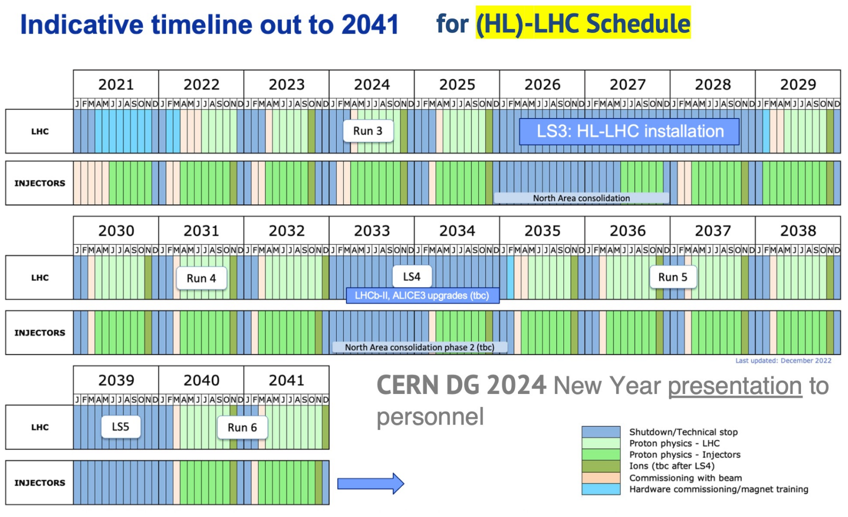


# Requirements of strategic R&D

- Requirements vary from application to application
- A good example of this is timing resolution
  - **Time of Flight (TOF)** systems, require **the best possible**

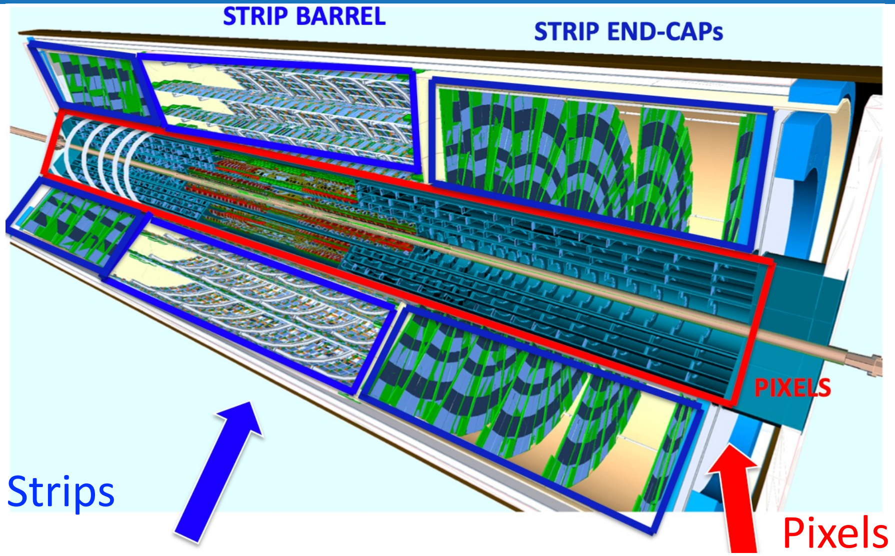


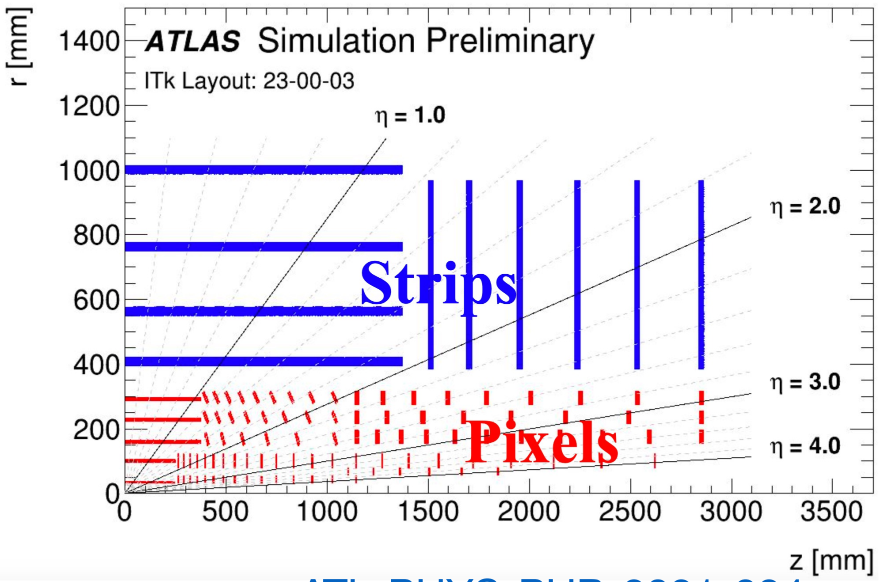

- Experiments requirements guide our R&D goals
- I will present in the following an example from ATLAS (LS4? LS5?)
- There are many many more:
  - CMS tracker (LS4? LS5?)
  - LHCb VELO (LS4)
  - ALICE (LS4)
  - EPIC detector at Electron-Ion Collider (to operate in 2030s)
  - ILC/CLIC
  - Belle-2 vertex detector (medium term ~2027, long term beyond 2032)
  - Etc…




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

# ATLAS ITk for HL-LHC




ATL-PHYS-PUB-2021-024

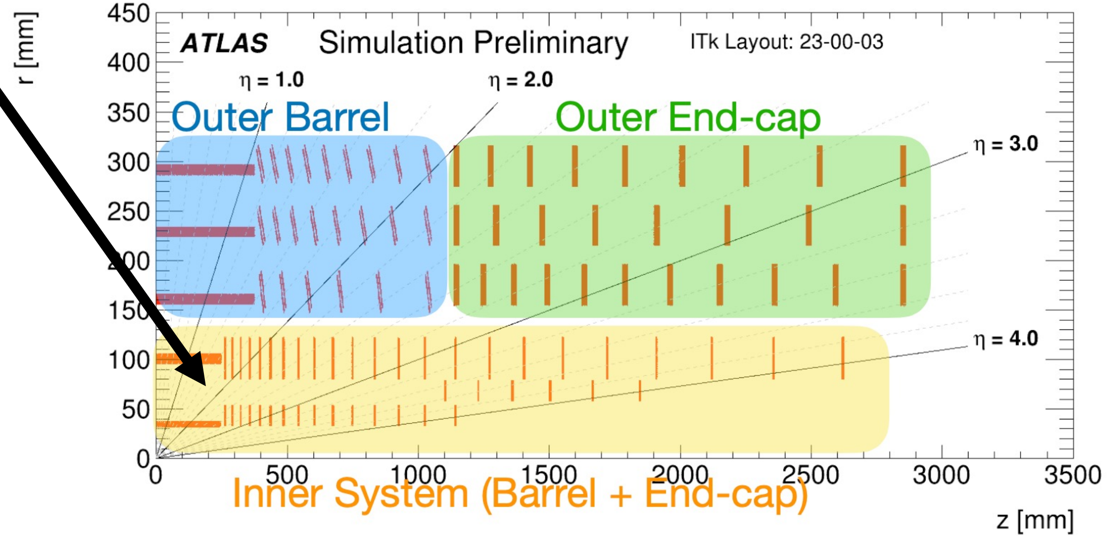
- **ATLAS** is planning to install a completely new **All-silicon inner tracker** for the HL-LHC phase (4000 $fb^{-1}$) during LS3 (2026-2028)
  - Composed by Pixels and Strips
  - Improved pile-up suppression in the forward region
  - Similar tracking efficiency and $p_T$ resolution wrt current ATLAS tracker, but at pile-up of 200
- As described in the TDR, partial replacement is foreseen at ~half lifetime (2000 $fb^{-1}$)
  - The **replacement** involves the areas **more exposed** to **large fluences** and **doses**
  - Thus, **innermost Pixel layers**
- ( Similar replacement is planned for CMS tracker as well )

# ATLAS ITk for HL-LHC

- **Pixel-ITk** is composed by 3 parts
  - Outer barrel, Outer End-cap and **Inner System**
- **Inner system**
  - 2 barrel layers and 2x44 disks in the end-cap
  - Layer-0: 3D sensors (25x100 $\mu m^2$ in the barrel and 50x50 $\mu m^2$ in the end-cap); most innermost layer: 33-34 mm from the beam pipe
  - Layer-1: 100µm thick planar sensors (50x50 $\mu m^2$ )
  - Pretty large detector, ~2.4 $m^2$ of active area, larger than the current Run3 ATLAS pixel detector (~1.9 $m^2$ )

- It is the full inner system that is planned to be replaced after about half lifetime (**LS4**? **LS5?**)
  - Similar requirements as the current systems, but **improvements in terms of pixel size, material budget and timing will be attempted**
  - **Monolithic sensors** might be an **alternative**, need to make sure radiation is not an issue (ongoing R&D)
  - **This upgrade** will be a **preliminary step** for **future hadrons colliders**

**Pixel ITk**



WG 2: Hybrid sensor technologies

# WG 3: Radiation Damage & Extreme Fluences

# Need for radiation hardness studies

- Technology need and timeline evaluated during ECFA roadmap process

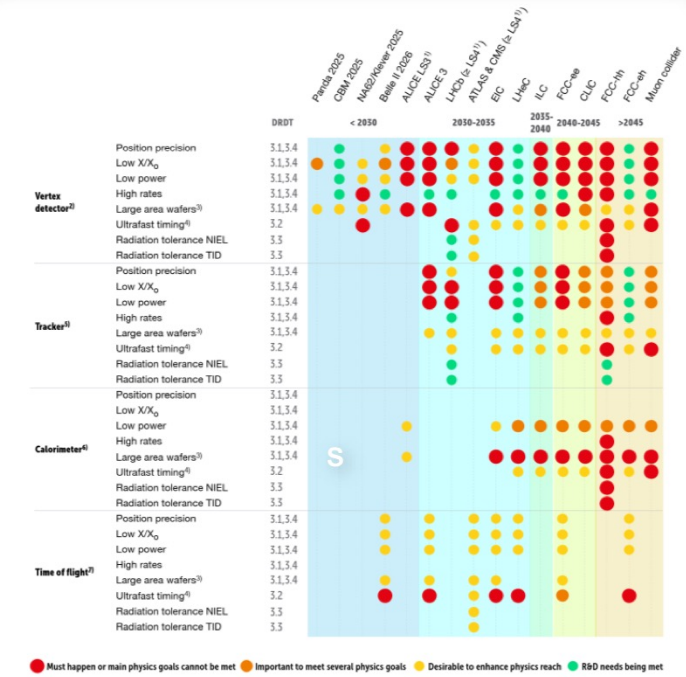
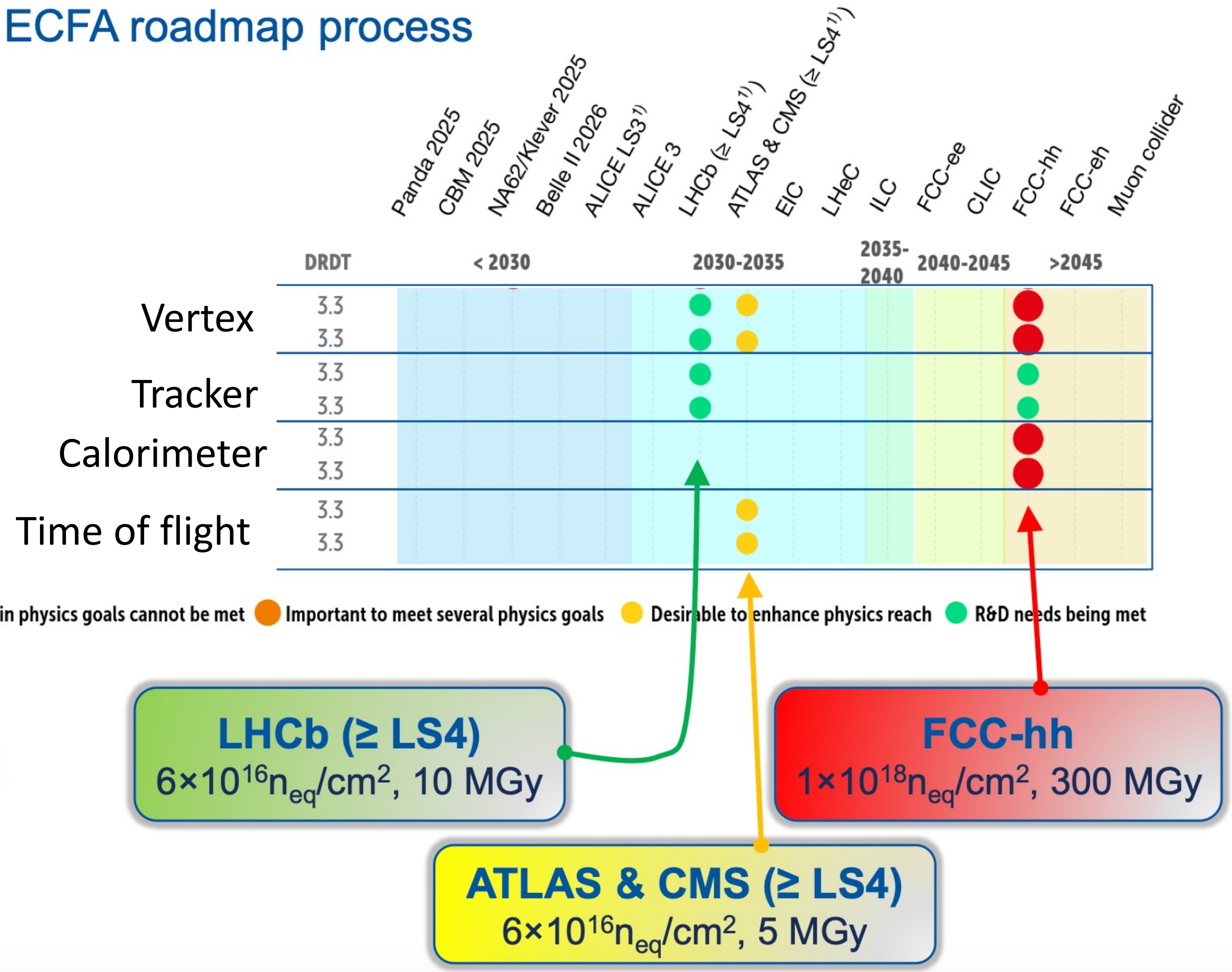



Figure 3.1: Schematic timeline of categories of experiments employing solid state sensors together with DRDTs and R&D tasks. The colour coding is linked not to the intensity of the required effort but to the potential impact on the physics programme of the experiment: Must happen or main physics goals cannot be met (red, largest dot); Important to meet several physics goals (orange, large dot); Desirable to enhance physics reach (yellow, medium dot); R&D needs being met (green, small dot); No further R&D required or not applicable (blank).

ECFA Detector R&D roadmap [CERN CDS]



# Radiation damage studies

- **HL-LHC upgrades**: LGADs, 3D, planar sensors will continue to **need regular irradiations** up to **6 x $10^{16}$ $n_{eq}/cm^2$** (**$10^{15}$ $n_{eq}/cm^2$** is the fluence by the end of Run 3).

- New efforts in **high-granularity calorimetry**, applications for **LHCb upstream tracker**, **Electron-Ion Collider** will need **radiation testing** and **radiation damage modelling**

- **Later upgrades** (FCC, CLIC, Muon Collider) need **radiation damage studies already now**, for hybrid sensors, monolithic CMOS, ASICs. Calls are made already for facilities (PS protons, reactor neutrons) able to provide up to **$10^{18}$ $n_{eq}/cm^2$**

- TCAD/MC/GEANT4/… **simulations** are an **active field of research atm** for the new structures and need benchmark data

# Radiation damage studies

- Motivations for **technology transfer beyond HEP**, eg medical imaging, dosimetry, nuclear safety and security – **require rigorous radiation validation**

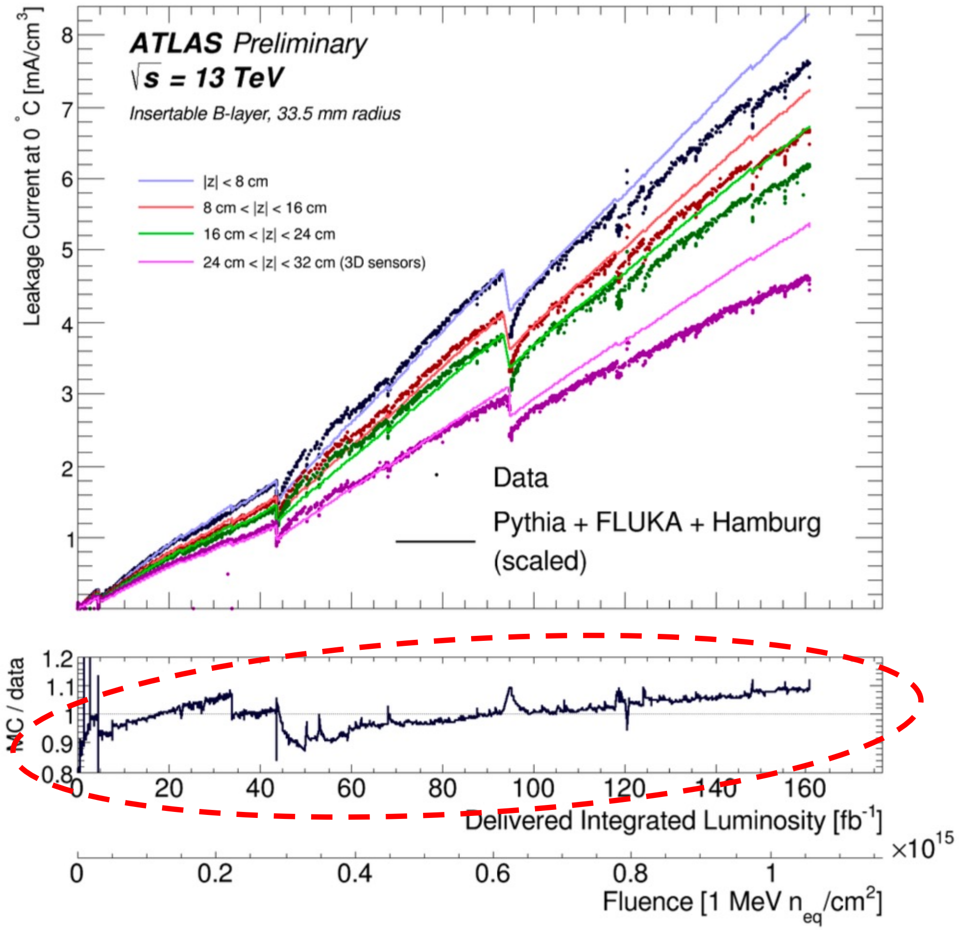
- Data are urgently needed; **test beam combined** with **dedicated data collected by the LHC** experiments for **leakage current** and **depletion**.

- Need to understand the **limit of validity of the current Hamburg Model** and **best directions** in **radiation defects modelling**

# Radiation damage studies

- Moti[…] and s[…]
- Data […] expe[…]
- Need[…] **radia[…]**

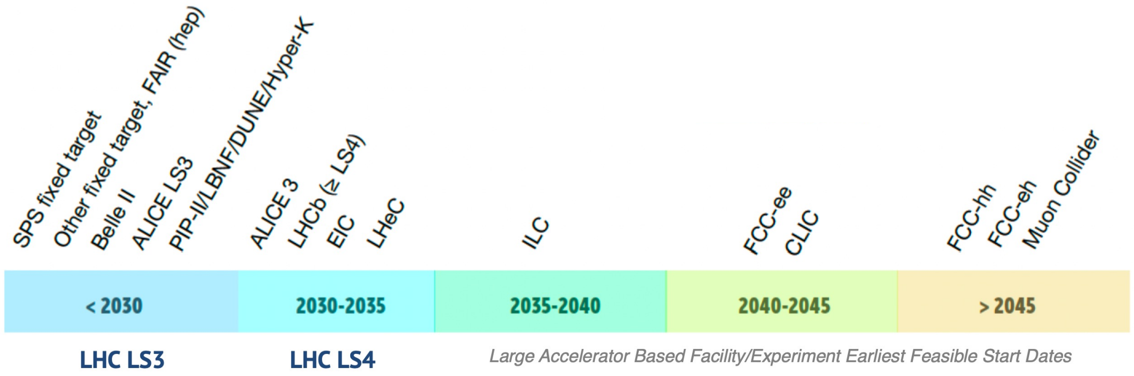
- The **Hamburg Model** has worked remarkably well but it is reaching its limit
- **Higher fluence data are needed**




[Yellow report: Radiation effects in the LHC experiments: Impact on detector performance and operation CERN-2021-001]

# Summary

- **DRD3 collaboration**: European strategy towards **solid state detectors R&D** for future experiments
  - Realization of the **strategic R&D** as outlined by the Task Force 3 (TF3) in the ECFA road map
  - Promoting **blue-sky R&D** in the field of solid-state detectors




- **R&D targets** to ensure the physic goals of future experiments
  - Improve (by a lot) **radiation hardness** to unprecedented levels
  - Improve **space and time resolution** to deal with very high occupancy and pile-up
  - Keep the **size** and the **cost** of detectors **as low as possible**
  - **Sustainability, environmental** impact to be taken (seriously) in consideration

- Come and join; effort is only starting now https://drd3.web.cern.ch

# Backup

# Sustainability

- Need to ensure that the advancements in technology and infrastructure development in HEP align with global efforts to mitigate climate change and reduce environmental impact
- Areas of consideration
  - **Energy efficiency**
    - Energy-Efficient Cooling Systems: R&D for development of new cooling technologies that are more energy-efficient for use in particle detectors and associated electronics
    - Sustainable computing: Develop new energy-efficient data centers and computing resources for processing the vast amounts of data generated by HEP experiments
  - **Materials and manufacturing:** Use recycling materials where possible and choose materials that have a lower environmental impact during their lifecycle, from extraction and processing to disposal
  - **Lifecycle management:** planning for the reuse, recycling, or safe disposal of materials and components used in detectors already put into initial design
    - Certain materials used in detectors, such as silicon, can be recycled and reused in new detectors.
  - **Reduced CO2 emissions:** optimize transportation logistics, reducing travel through virtual collaboration tools, and using renewable energy sources where feasible
- In general, adopt more stringent environmental standards and certifications for the design of future projects and facilities in every possible aspect

# Pixel sensors

Saverio D'Auria, ICHEP2022

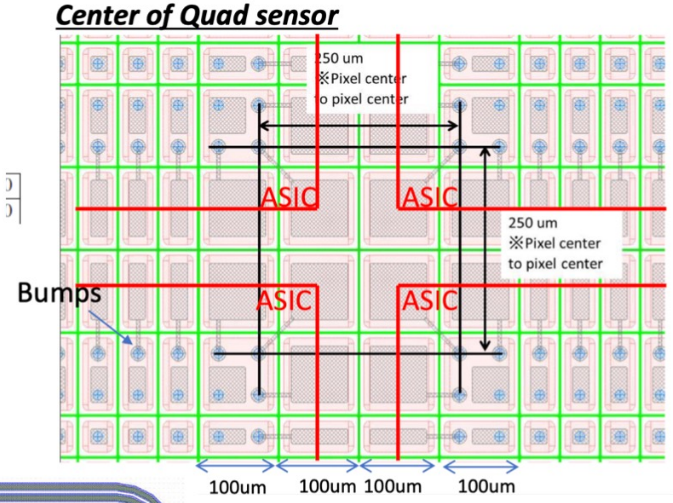
Two types of sensors:

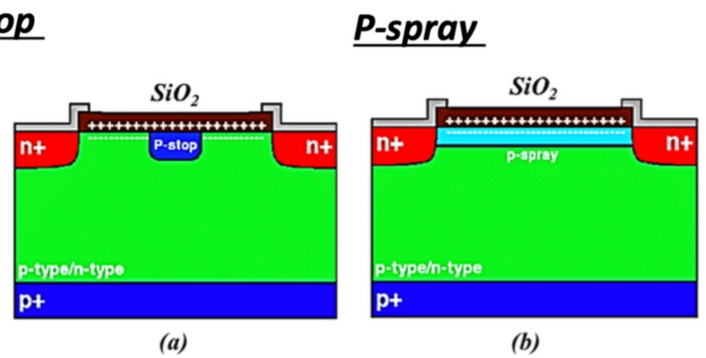
**Planar:**

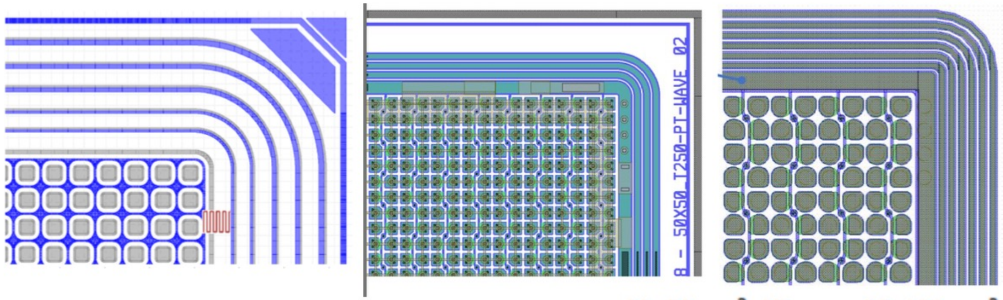
Various design detail left up to vendor :

- *p*-stop vs. *p*-spray insulation
- Polysilicon bias or punch-through
- Guard-ring geometry

Requirements defined on performance

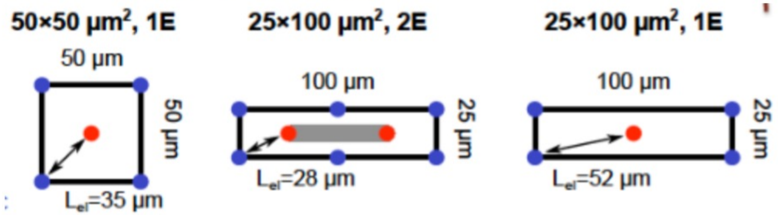


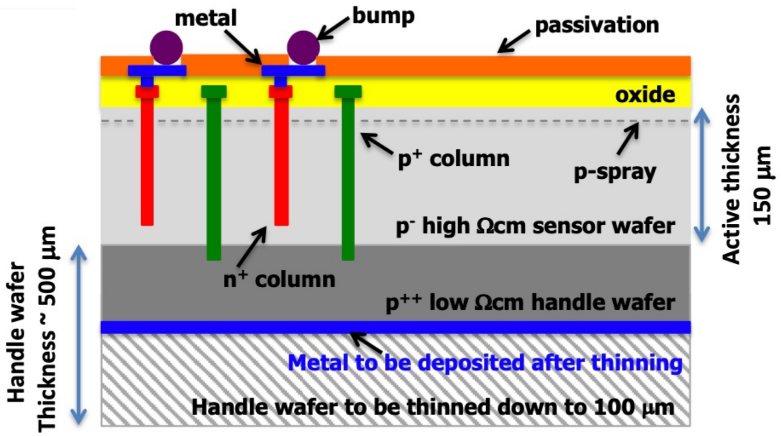



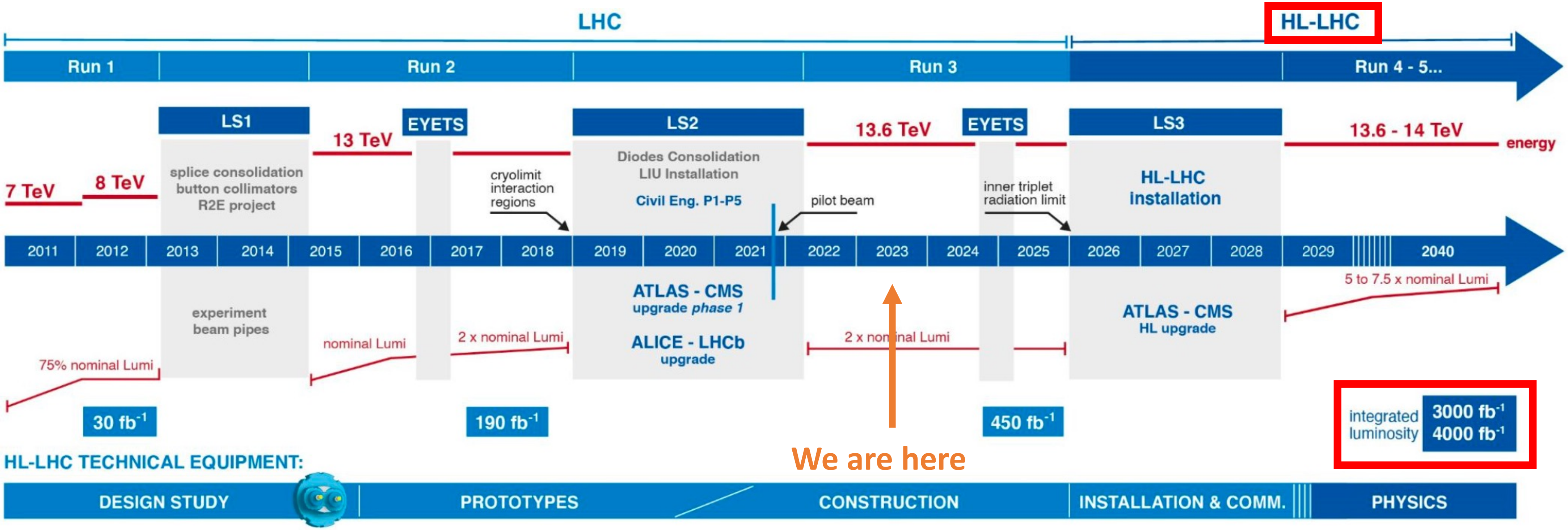
**Inner system** uses 3D sensors

- High radiation tolerance
- Lower bias voltage



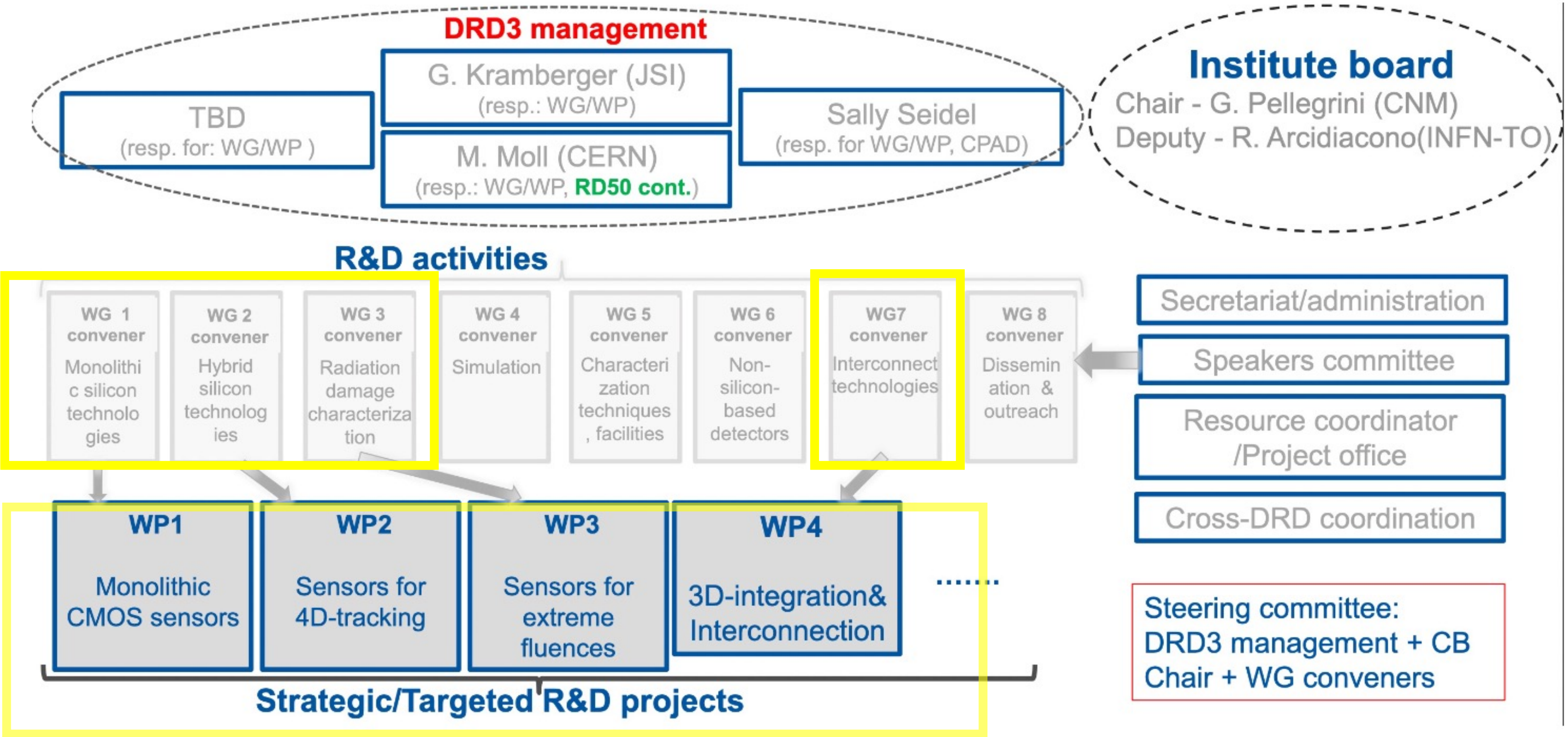
# LHC timeline including HL-LHC



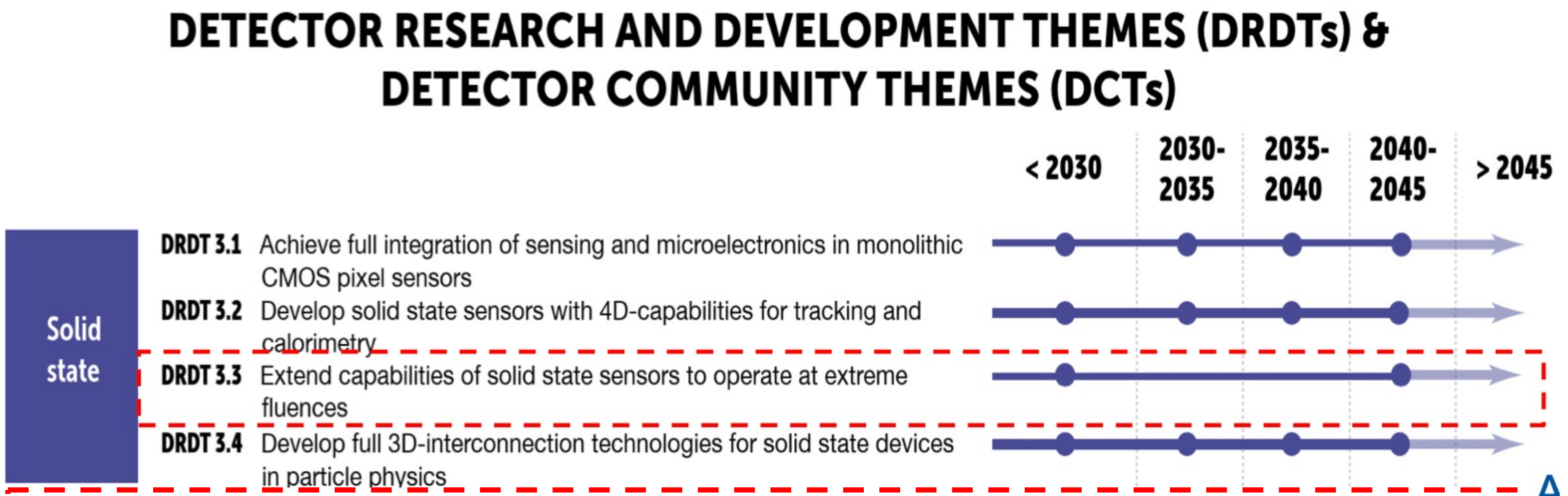

- **HL-LHC** phase currently scheduled to start in **2029**
- **Data taking foreseen up to ~2040**
  - Instantaneous luminosity to increase from 2 to ~7.5 × $10^{34}$ $cm^{-2}s^{-1}$ : very high detector occupancy
  - Pile-up increase to ~200, from ~60 currently
  - Estimated integrated luminosity at the end of HL-LHC: 3000-4000 $fb^{-1}$, **factor of 15-20 increase wrt present statistics**

# DRD3 Collaboration

- DRD3 collaboration goal two-fold
  - Realization of the strategic developments outlined by the Task Force 3 (TF3) in the ECFA road map
  - Promoting blue-sky R&D in the field of solid-state detectors



# ECFA recommendations for this Work Package




**DRDT 3.3 - Sensors for extreme fluences.**

- Measure the properties of silicon sensors in the fluence range $1\times10^{16}\,n_{eq}\,cm^{-2}$ to $1\times10^{18}\,n_{eq}\,cm^{-2}$. Map the limit of 3D sensors and evolve their design to cope with the highest possible fluences;
- Optimise the simulation models with the measurements at high fluence;
- Develop simulation models based on microscopically measured point and cluster defects (instead of a model based on "effective trap levels");
- Explore the use of WBG semiconductors as radiation detectors at high fluences;
- Develop innovative 2D-materials that can offer high radiation hardness and operate at room temperature.

- These recommendations define the R&D directions of the group

# Radiation damage studies

- New materials are under exploration – wide bandgap semiconductors, may reduce cooling requirements. New efforts in SiC, GaN, CdTe, CIGS, GaO, GaAs, diamond, silicon- and polymer-based conformal detectors. New or extended parametrized models for these materials are needed.

- Ongoing work to understand how fundamental material properties – effective dopant concentrations, carrier lifetimes, etc. - evolve with dose

- Motivations for tech transfer beyond HEP, eg medical imaging, dosimetry, nuclear safety and security – require rigorous radiation validation

- Data are urgently needed; test beam combined with dedicated data collected by the LHC experiments for leakage current and depletion.

- Need to understand the limit of validity of the current Hamburg Model and best directions in radiation defects modeling