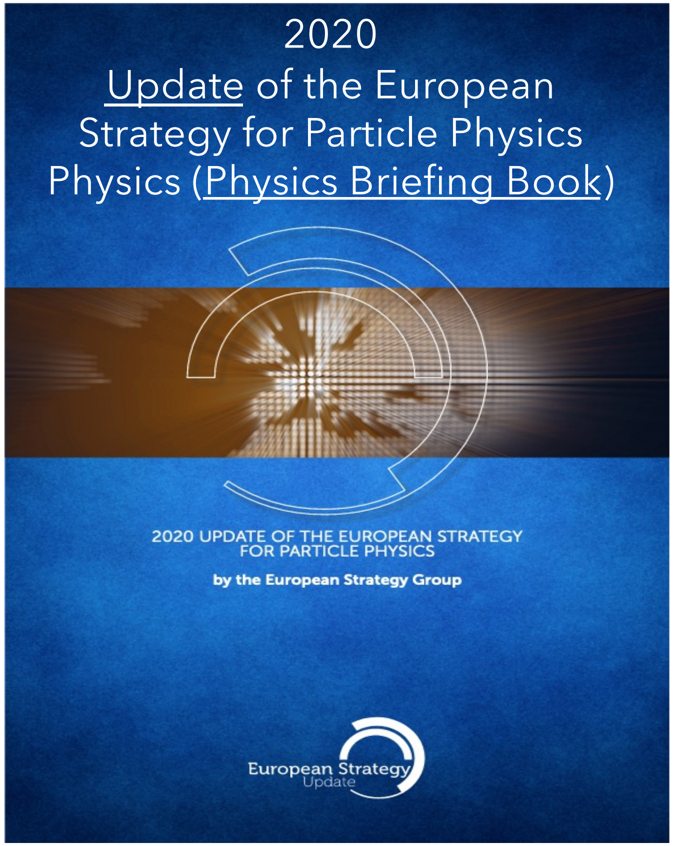
Introduction aux prospectives IP2I

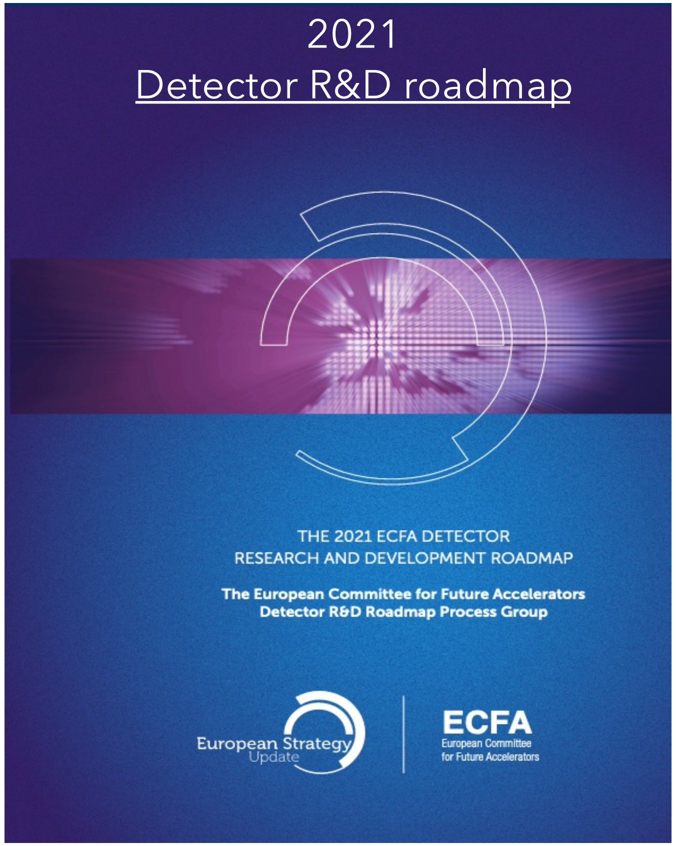
AG IP2I, 7 Avril 2023

Programmes futurs en Physique des Hautes Energies et feuille de route ECFA R&D détecteurs

D. Contardo

Stratégie Européenne élaborée avec la communauté internationale sous l'égide du CERN – feuilles de routes techniques préparées par l'ECFA



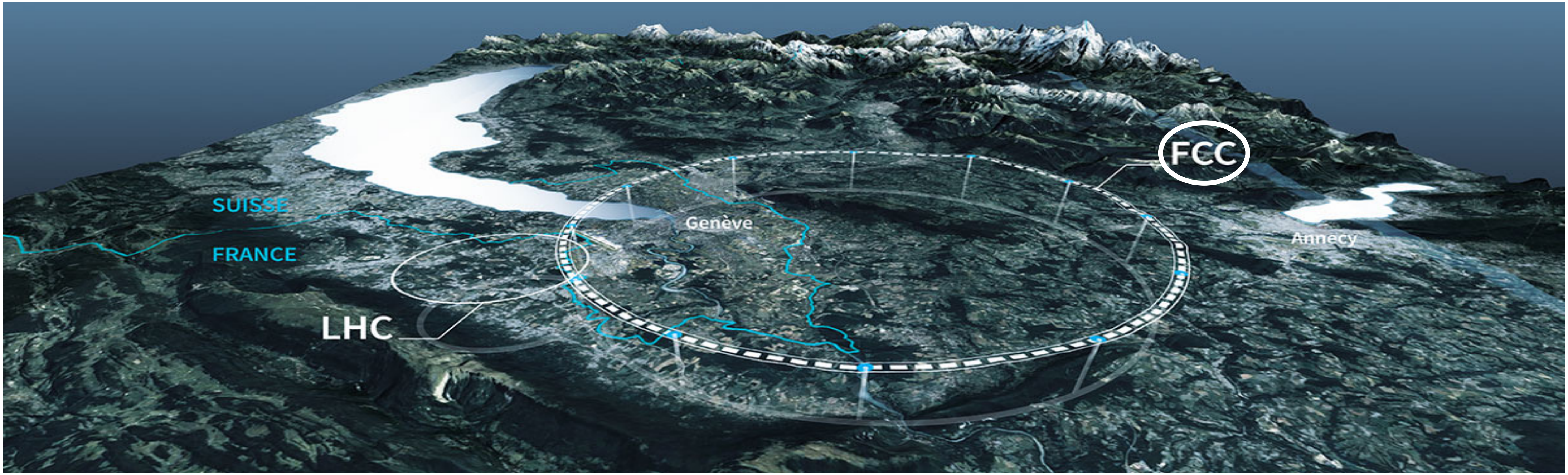


Procédure similaire en cours aux USA : 2022 Snowmass symposium physics briefing book, P5 strategy update automne 2023

Aperçu des projets de collisionneurs

Conclusion principale de l'ESPP

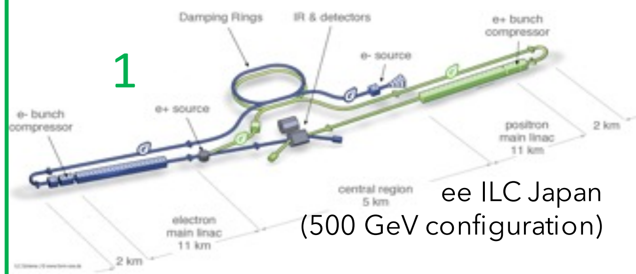
" An electron-positron Higgs factory is the highest-priority next collider…"



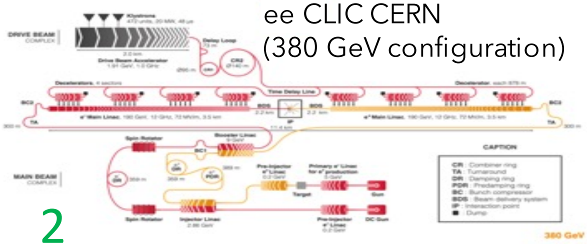
"Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage"

FCC un des 3(4-5) concepts de collisionneurs proposés en continuité du HL-LHC

1



ee ILC Japan
(500 GeV configuration)

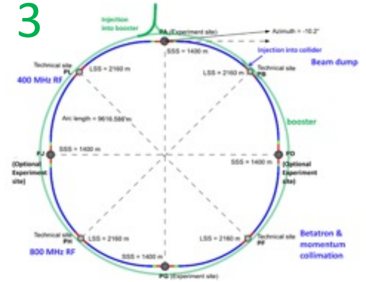


ee CLIC CERN
(380 GeV configuration)

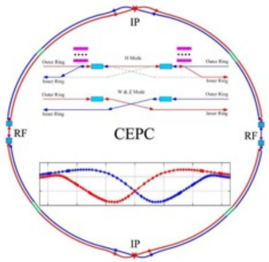
2

3

FCCee/hh CERN



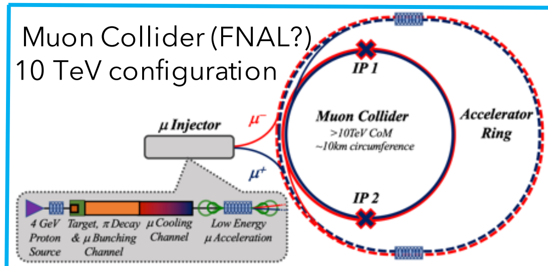
CepC/SppC China



ee CCC FNAL 250 GeV

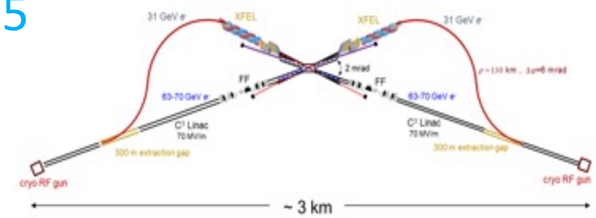
4

Muon Collider (FNAL?)
10 TeV configuration

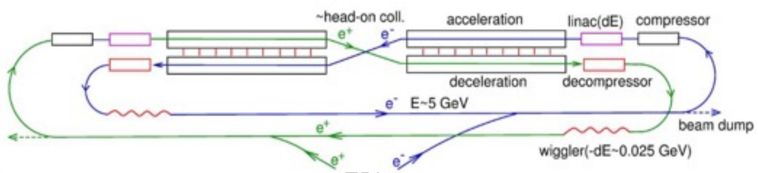


5

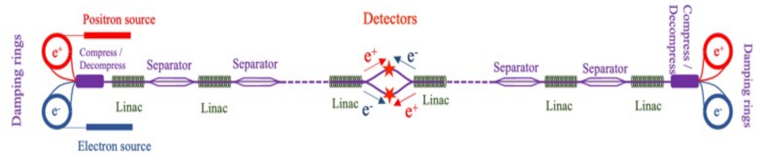
XCC $\gamma\gamma$ collider 125 GeV



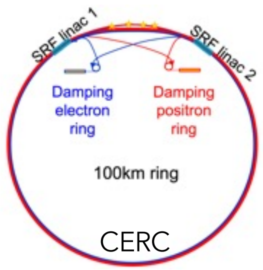
ee energy recovery collider concepts, possibly w/ wakefield acceleration RF for high energies



ERL



ReLIC

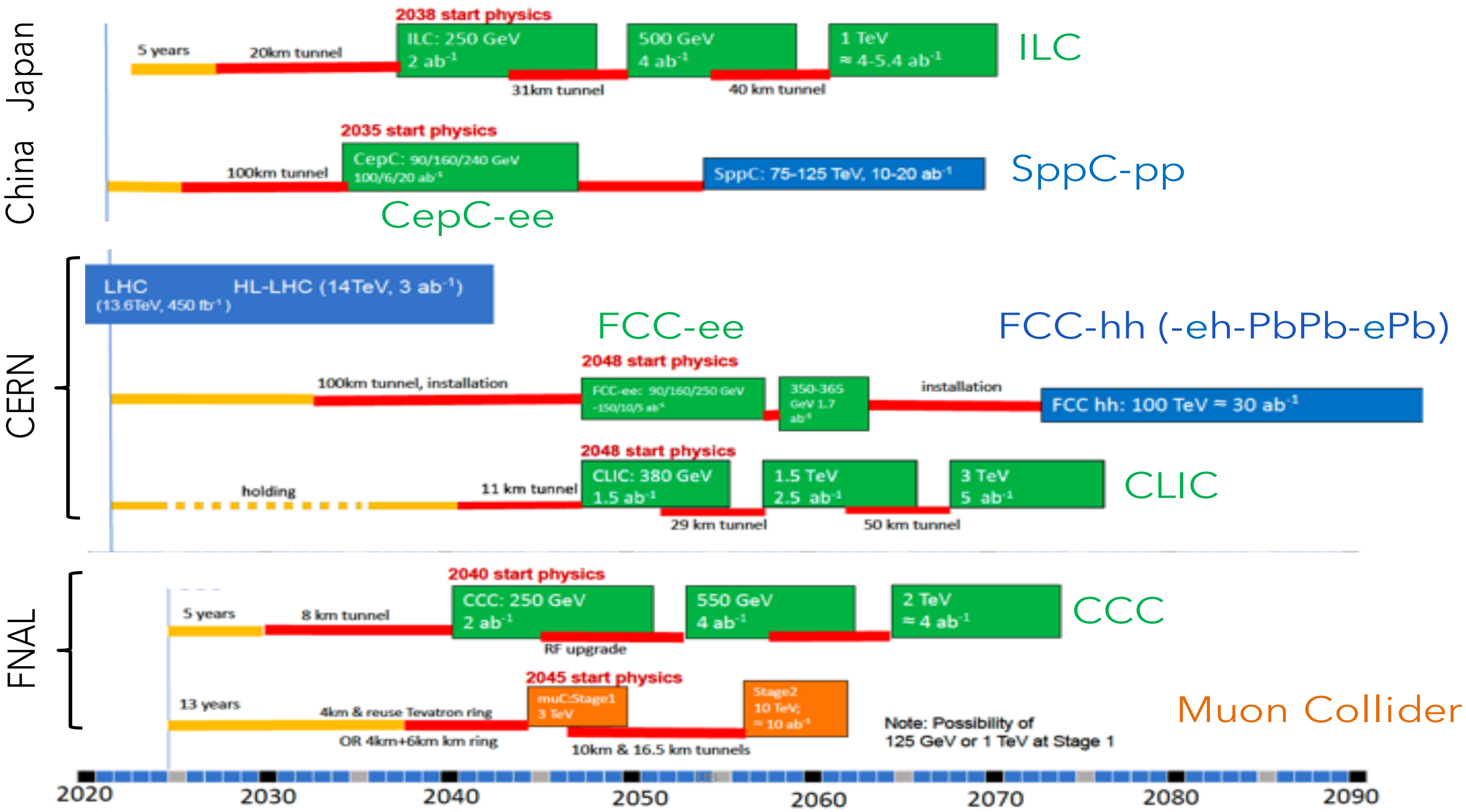


CERC

Etat de R&D très avancé/intermédiaire/initial

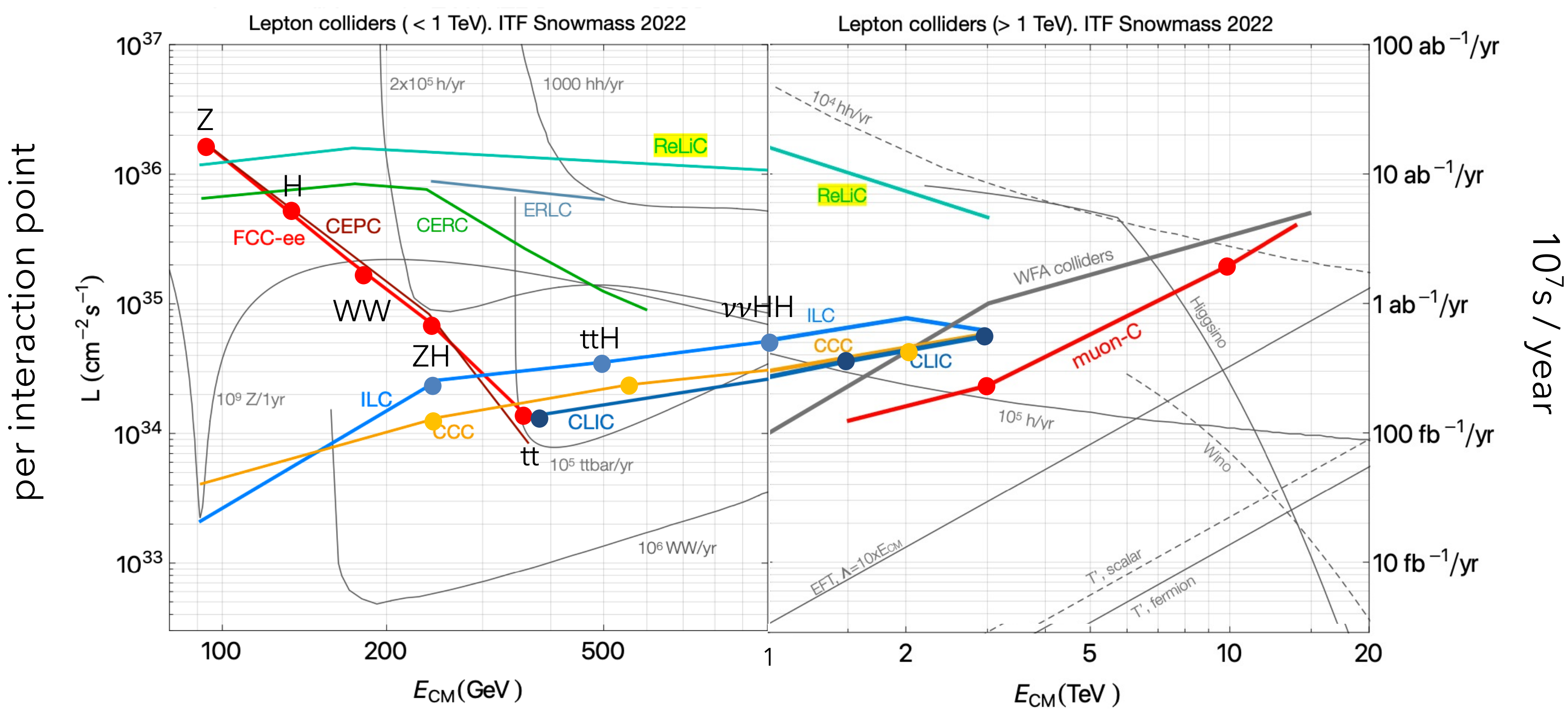
Calendriers prévisionnels des projets

préparation - construction - ee, hh, μμ



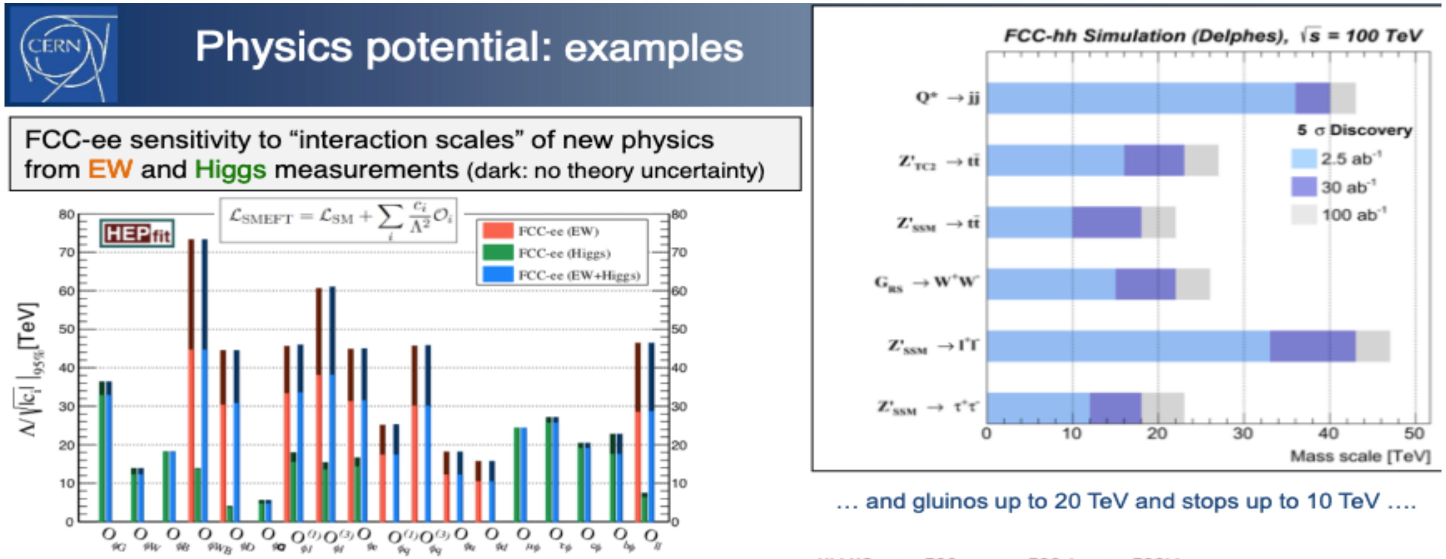
Projections de luminosité pour les collisionneurs leptons

(Snowmass [collider implementation task force](#))

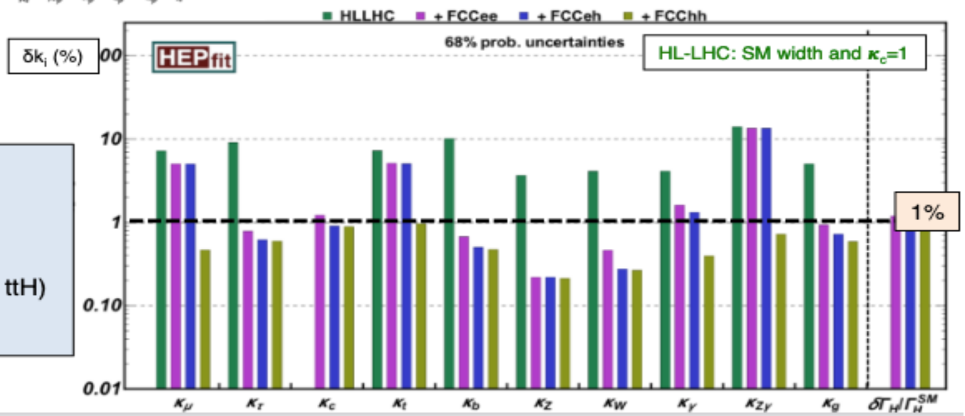


2-3 collisionneurs complémentaires en énergie/luminosité pour une couverture complète des domaines de physique
Collisionneur linéaire e-e usine à Higgs – complété par μ-μ recherche de particules massives
FCC-ee usine à Z/W (électrofaible, saveurs) et Higgs, complété par hh recherche de particules massives (+ e-h/Pb, Pb-Pb)

Potentiel de physique du FCC (ee, eh, hh)
Une vision intégrée de la recherche de nouvelles physique



F. Gianotti

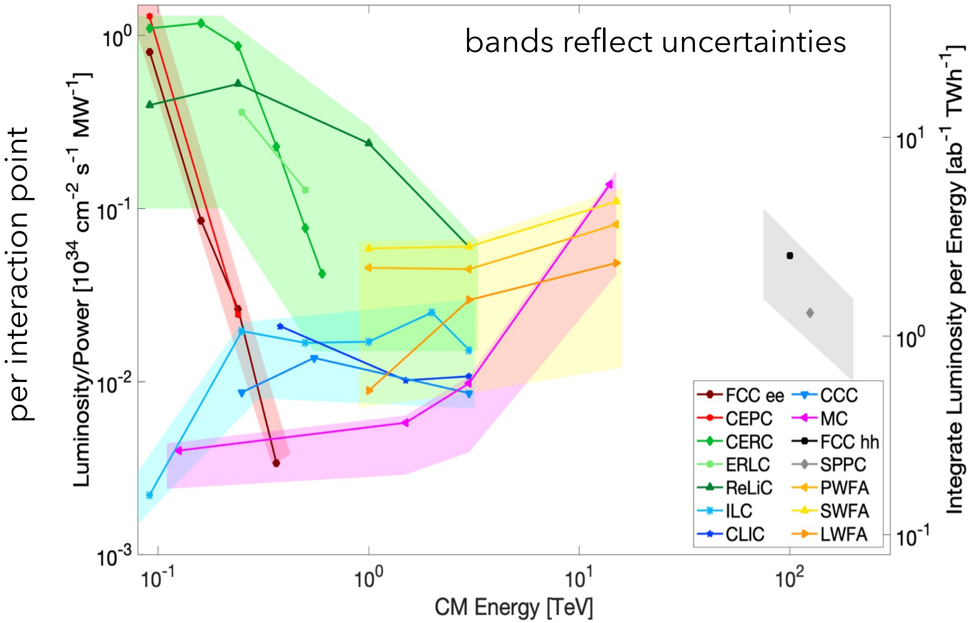


Input from FCC-ee (e.g. HZZ coupling and ttZ cross-section) removes model-dependence of several couplings that are best measured at FCC-hh (e.g. H→ $\mu\mu$, H → $\gamma\gamma$, H → Zγ, ttH)
In addition: k_λ to ~ 5%
https://inspirehep.net/literature/1790243

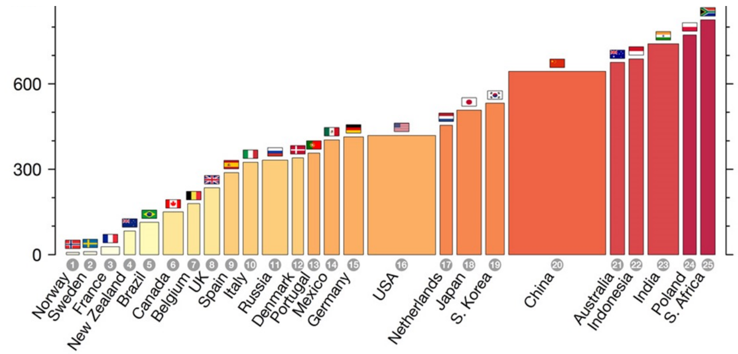
Bénéfices sociétaux et impact environnemental sont des considérations importantes de viabilité des projets

en particulier la consommation d'électricité

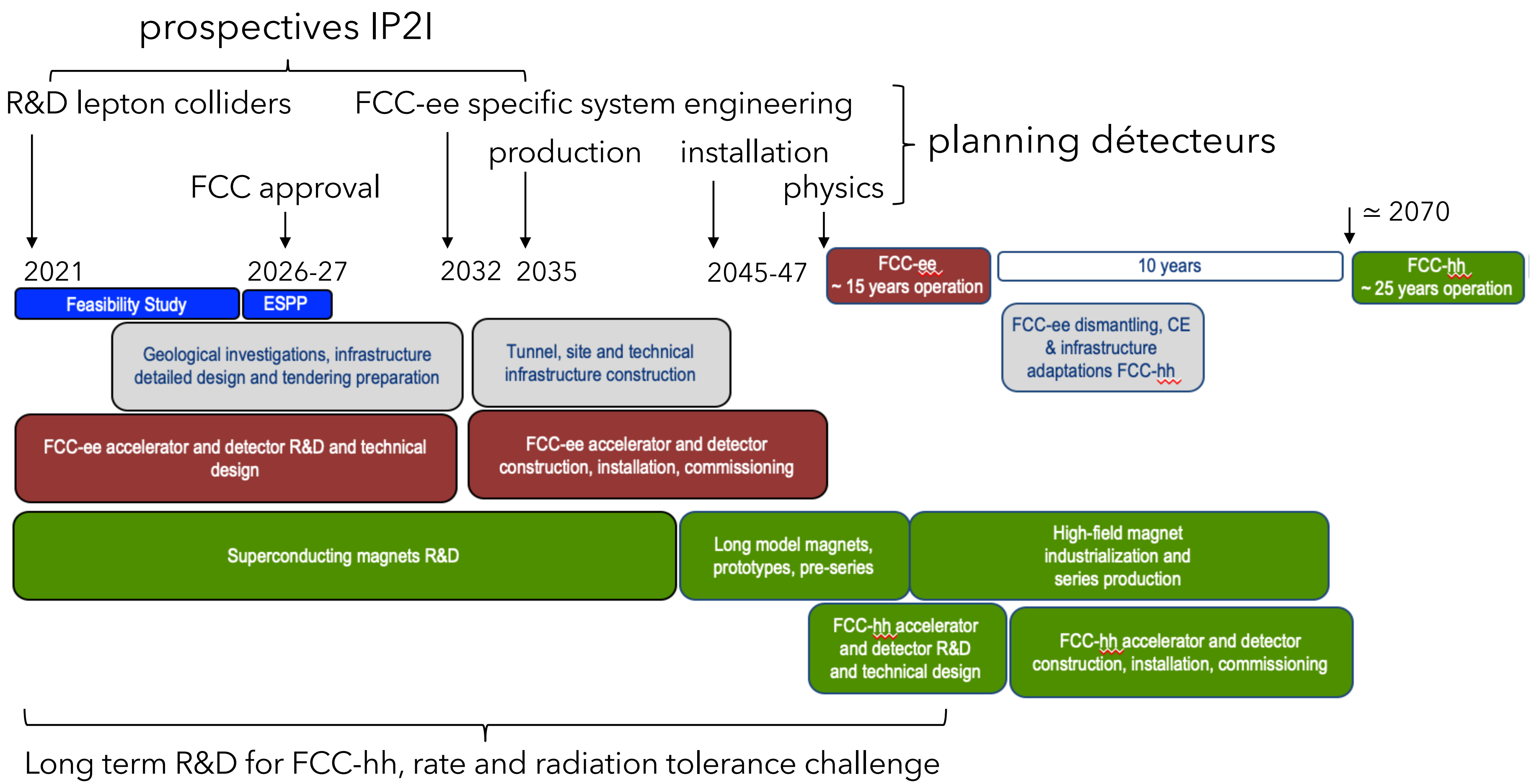
luminosity per electrical power is one figure of merit



France & Switzerland ≃ lowest electricity C content



Planning technique du programme FCC



Aperçu des concepts de détecteurs

Concept de détecteur pour un collisionneur e^+e^-, secteur du Higgs

défi de précision pour la trajectographie et la calorimétrie

ex. FCC-ee CLD*

Trajectoire des muons

Solenoid superconducting magnet 2 to 4 T

Energie des hadrons

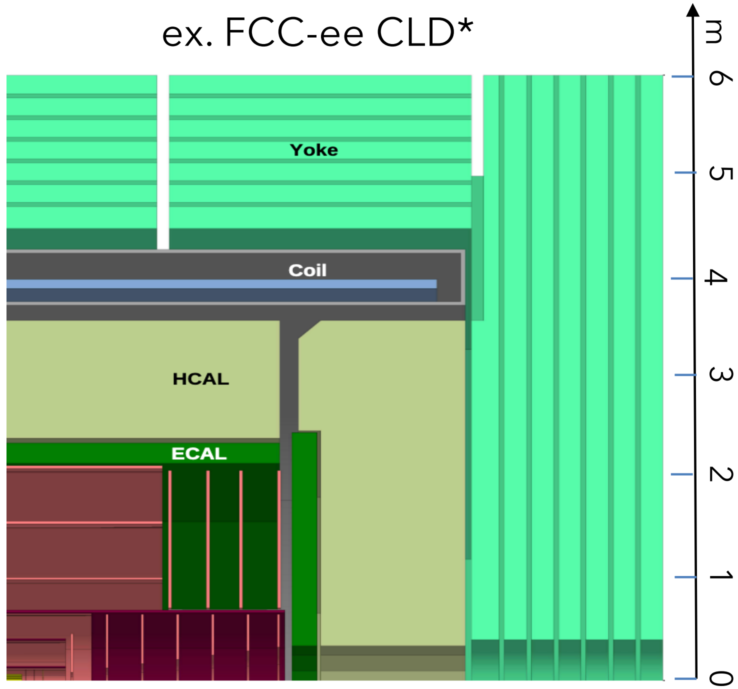
High Granularity PFlow calorimeter to resolve Z/W jet decays

Energie des électrons et photons

Trajectoire des particules chargées

Central Tracker Full Silicon (here) or TPC

Vertex Detector Silicon



* *Facteur d'échelle aux conditions de faisceaux de FCC-ee des détecteurs proposés pour les collisionneurs ILC et CLIC*

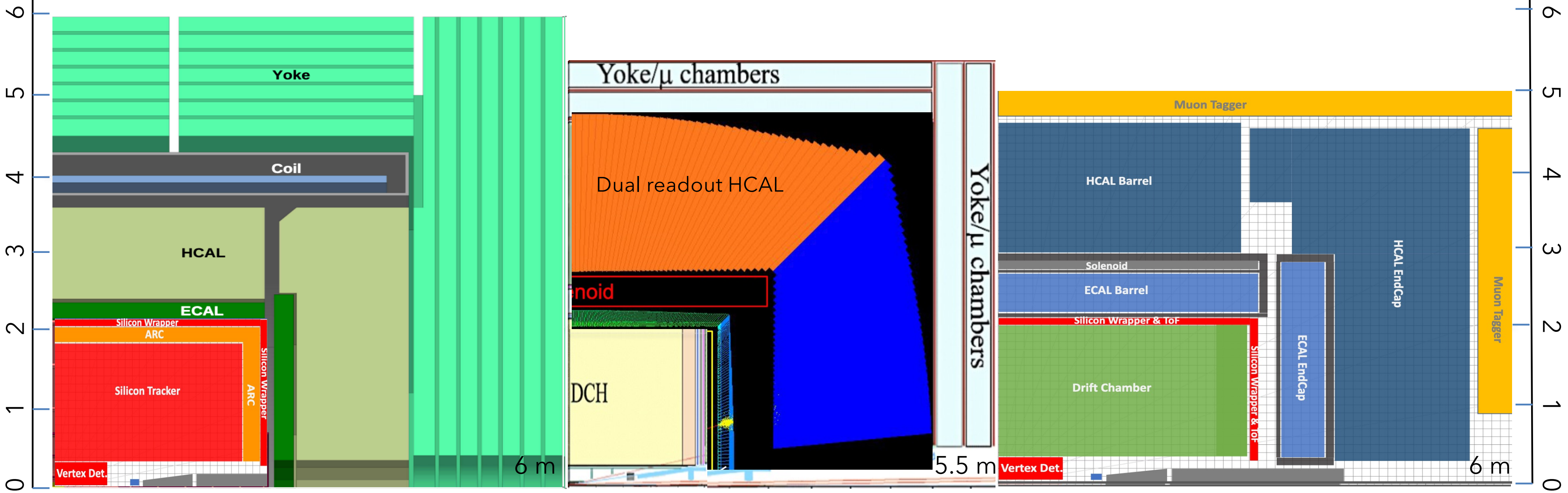
FCC-ee à la masse du Z, secteur électrofaible et saveurs

nouveaux concepts pour l'identification de particules, et la précision en énergie des photons

défis des erreurs systématiques de mesures: précision $\sqrt{s}$ O(10^{-6}), lumi. O(10^{-4}), accep. O(10^{-5}), B-field O(10^{-6})

FCC-ee can feature 4 detectors, 3 examples of concepts below

driven by calorimeters inside and/or outside solenoid, with tracking options exchangeable



ex. CLD with FST plus PID RICH and ToF

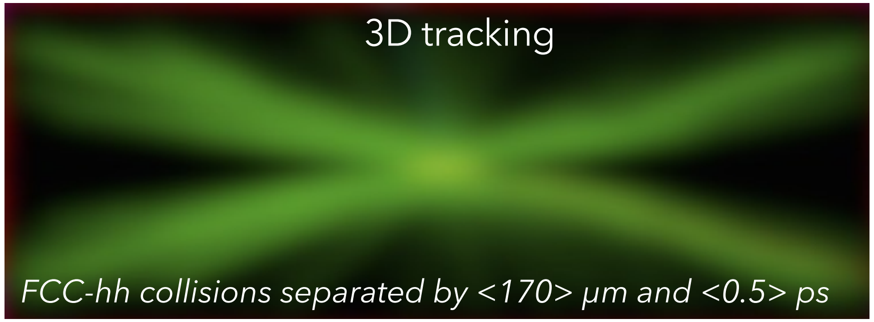
ex. IDEA with DCH PID crystal ECAL inside solenoid

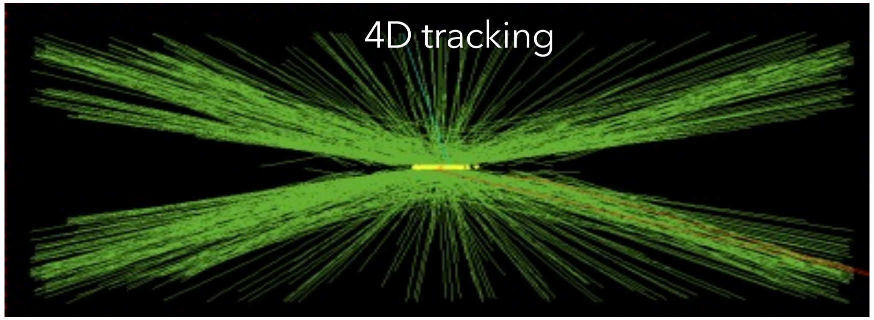
ex. Noble Liquid ECAL inside solenoid with DCH

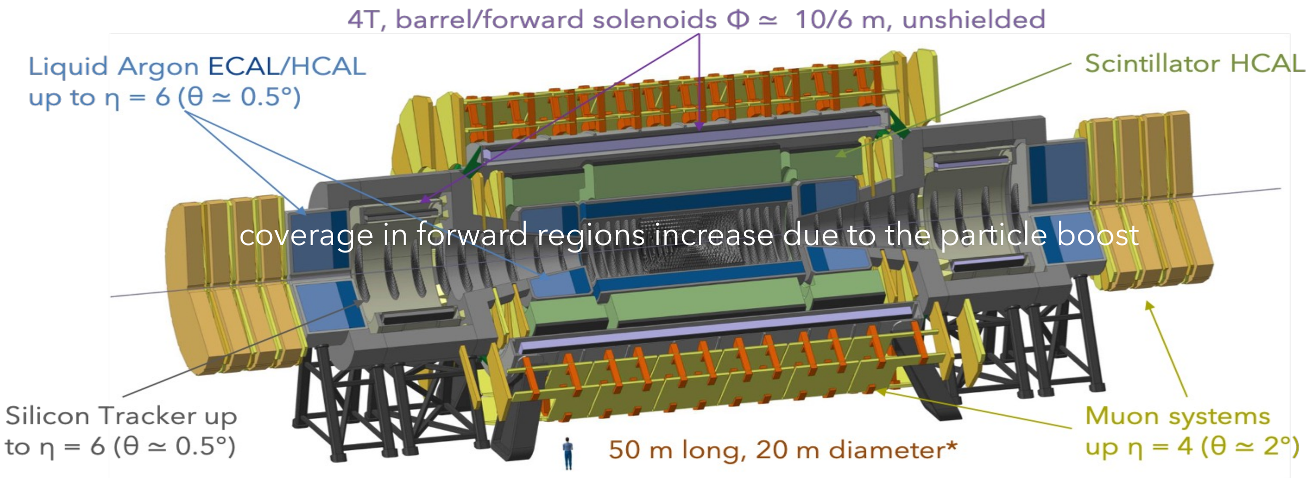
Complémentarité à étudier

Concept de détecteur FCC-hh

défi de taux de collisions 30 GHz - <1000>/croisement (25 ns) et irradiation $O(10^2)$ x LHC
précision en 4D, espace et temps O(5) ps, nouvelles technologies pour la tolérance aux radiations et l'électronique de lecture, de traitement et de transmission des données





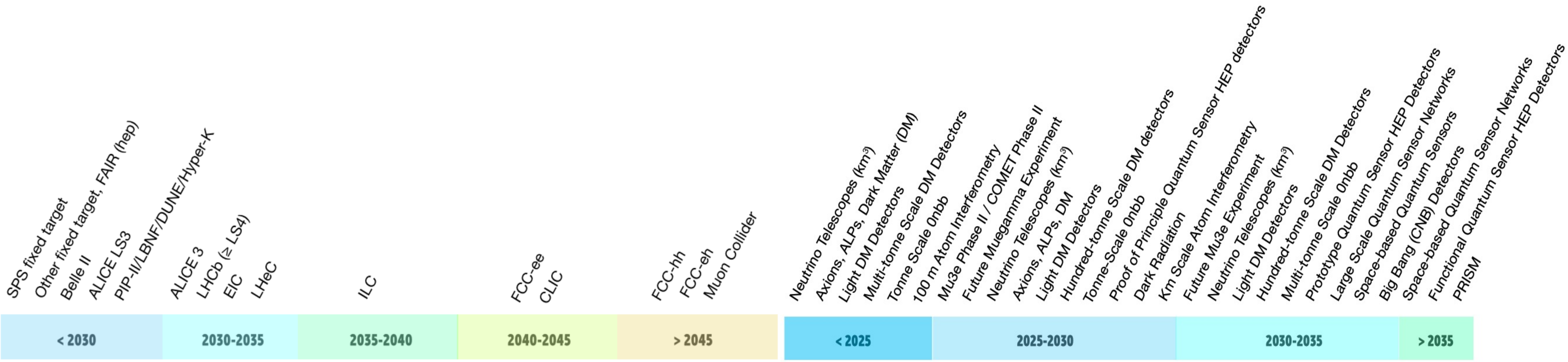


https://cds.cern.ch/record/2842569/files/CERN-2022-002.pdf

Feuille de route ECFA
aperçu des enjeux et tendances de R&D

Feuille de route ECFA détecteurs R&D

établie pour satisfaire les besoins et le calendrier des programmes “stratégiques” de l’ESPP



Future experiments at large accelerator facilities

Future experiments at small accelerators, nuclear reactors, with cosmic rays

6 domaines technologiques considérés

Gas Detector, Liquid Detectors, Solid State Detectors, Particle ID & Photons, Calorimeters, Quantum

3 domaines transverses

Electronics and on-detector processing, Integration, Training

Test facilities and infrastructures, industrial partnership, networking considered for all

Nuclear Physics, AstroParticle (including Gravitational Wave) not considered, but NuPPEC and ApPEC invited to the process
And also joint ECFA - NuPECC - ApPEC seminars in 2019 - 2022 to develop common instrumental projects

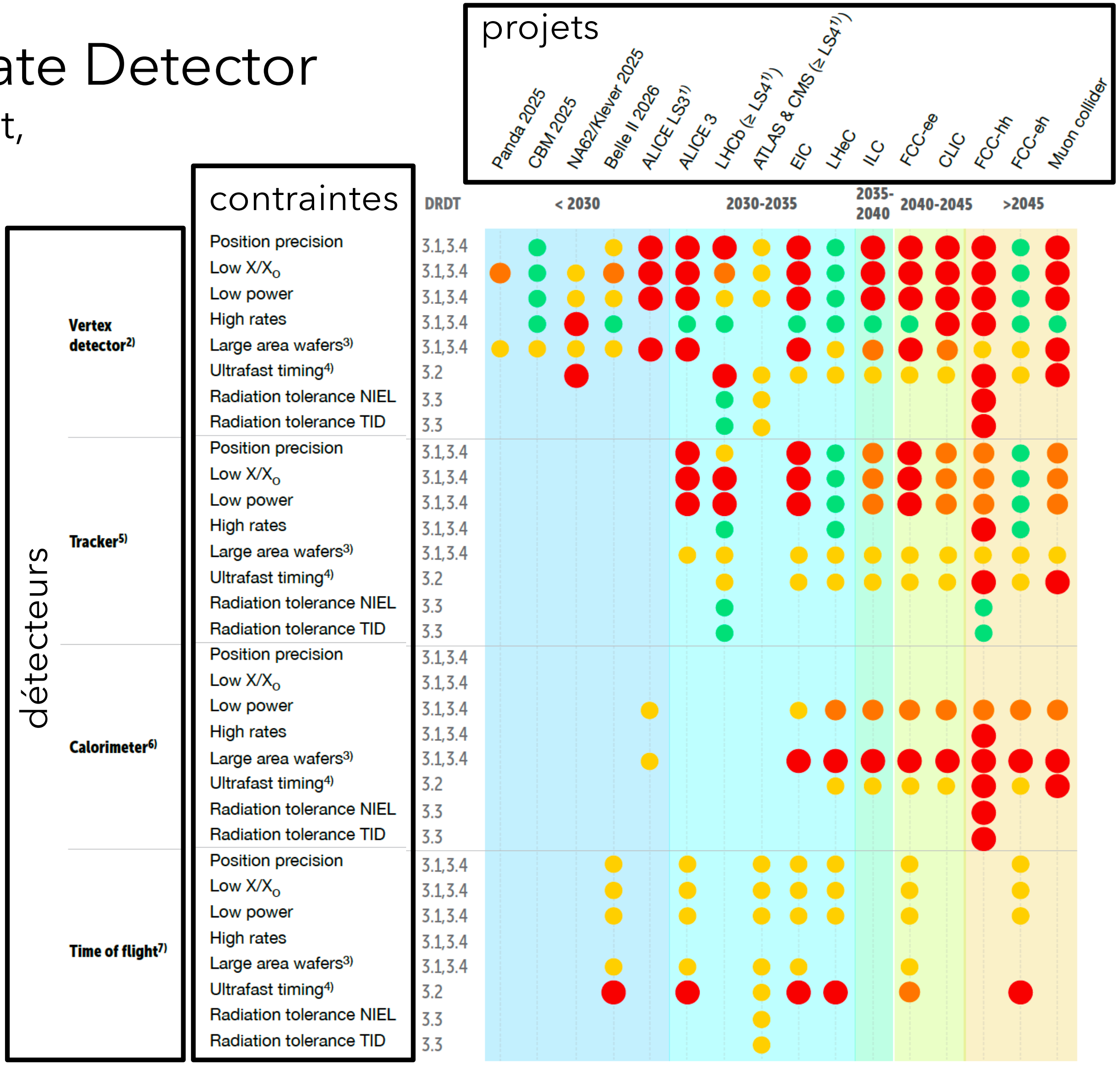
ECFA roadmap DRD3: Solid State Detector

Semi-conductor sensors highly granular, fast, transparent and radiation tolerant

Thèmes de R&D

Solid state

- **DRDT 3.1** Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
- **DRDT 3.2** Develop solid state sensors with 4D-capabilities for tracking and calorimetry
- **DRDT 3.3** Extend capabilities of solid state sensors to operate at extreme fluences
- **DRDT 3.4** Develop full 3D-interconnection technologies for solid state devices in particle physics



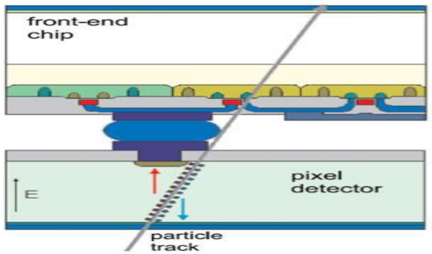
Criticité par projet: ● Must happen or main physics goals cannot be met ● Important to meet several physics goals ● Desirable to enhance physics reach ● R&D needs being met

2 configurations de SSD

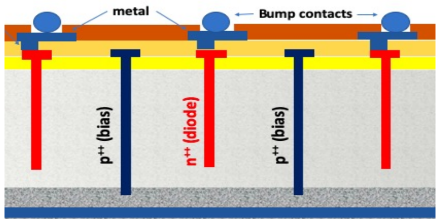
Hybrid design

electronics bumped or wire bonded to Si-sensor
highest rates & radiation tolerance

planar sensors



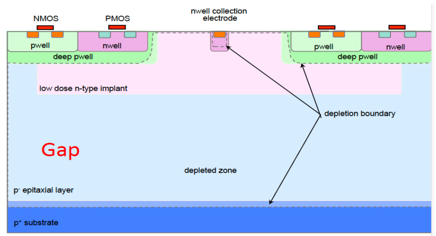
3D sensors



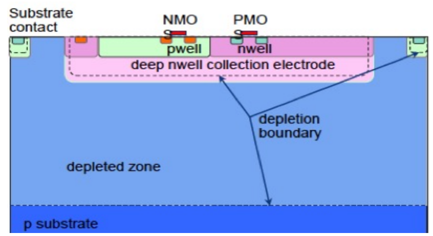
Monolithic CMOS

single CMOS imaging process
thinnest, highest granularity

small electrode



large electrode



Sujets de R&D (souvent corrélés et parfois en tension pour la performance)

- Finesse de gravure → densité de pixels, basse puissance
- Configurations et procédé de fabrication → formation/collection du signal
- Electronique rapide et basse puissance → précision en temps et hauts taux de données
- Senseurs de grande taille, très amincis → quantité de matière
- Technologies de connexion, intégration 3D des fonctions électroniques → optimisation densité/puissance
- Nouveaux matériaux semiconducteurs (WBG) → tolérance aux radiations

ECFA roadmap DRD1: Gaseous Detectors

Versatile (cost-efficient) systems in large areas
wide range of application as sensitive and/or readout elements

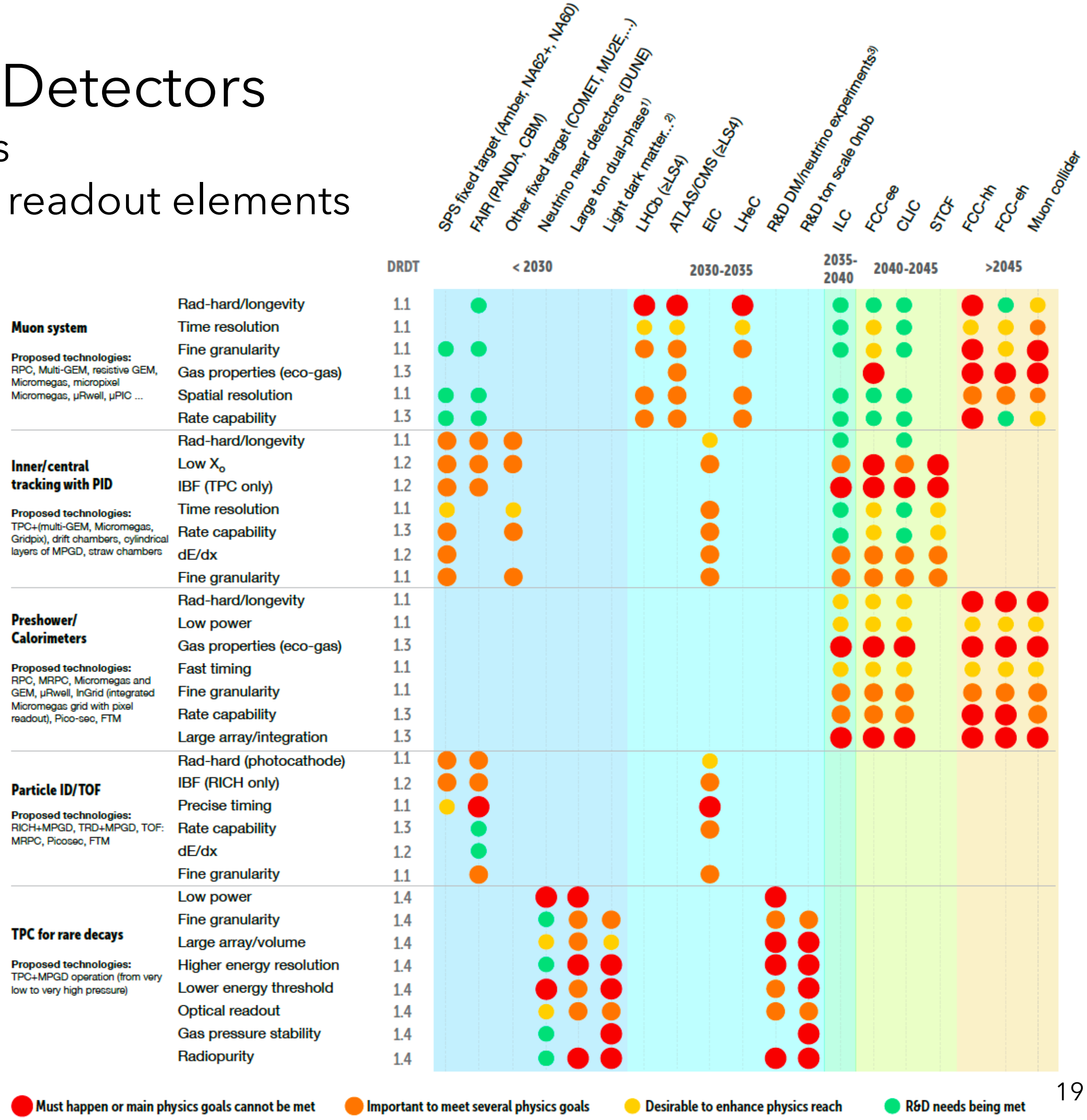
Gaseous

DRDT 1.1 Improve time and spatial resolution for gaseous detectors with long-term stability

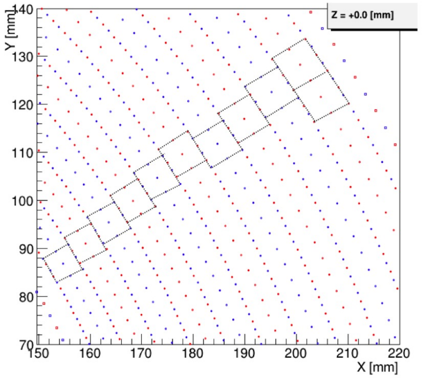
DRDT 1.2 Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes

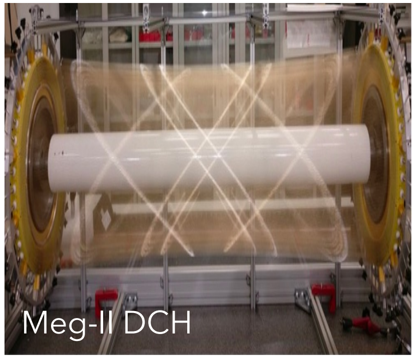
DRDT 1.3 Develop environmentally friendly gaseous detectors for very large areas with high-rate capability

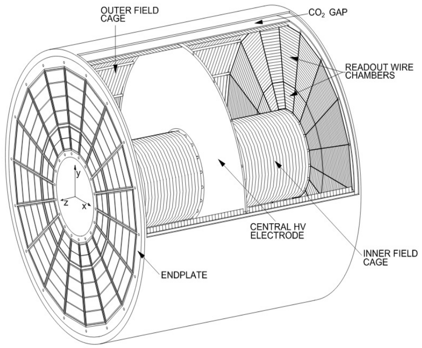
DRDT 1.4 Achieve high sensitivity in both low and high-pressure TPCs



Chambre à Drift et Time Projection Chamber
pour la trajectographie centrale et l'identification de particules







DCH engineering challenge

- large size design structure and production
- light and thin wires

TPC main challenge to reduce ion backflow

- operating conditions (gas, voltages, pressure)
- highly sensitive and granular readout MPGD

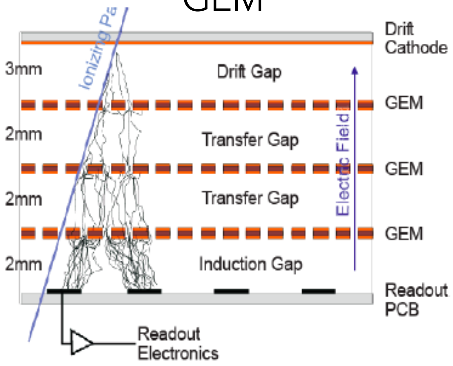
Nouveau concept de PID par dN/dx (+ dE/dx)

- with waveform sampling
- through cluster counting

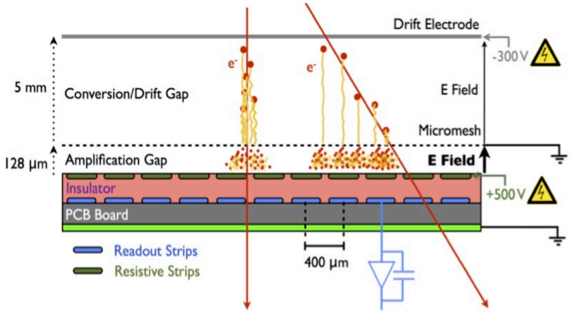
2 concepts de Micro Pattern Gas Detectors

pour la détection des muons ou comme systèmes de lecture de TPC ou de RICH

GEM



MicroMegas

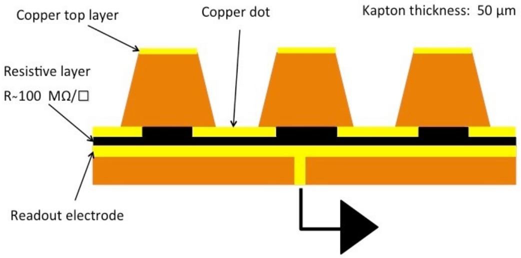


Sujets de R&D

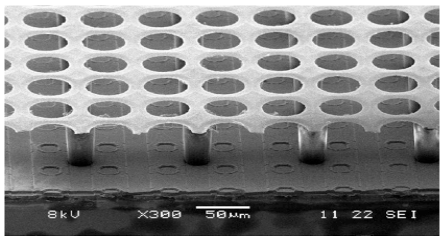
- granularité plus fine
- meilleure tenue flux instantané et irradiation
- impression 3D, dry plasma ink jet
- intégration monolithique avec l'électronique
- mélange gazeux à bas coefficient de GPW
- nouveaux matériaux ex. Graphene grid

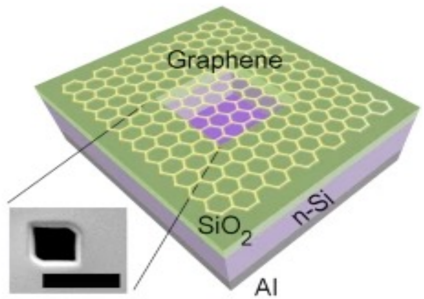
μ -Resistive-Well

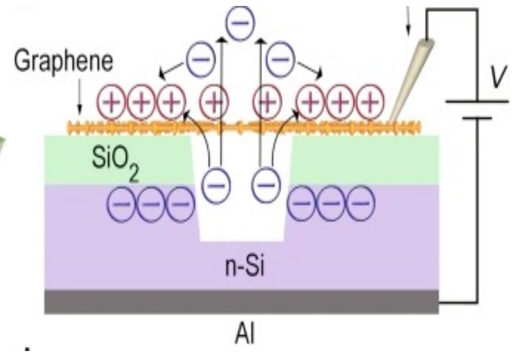
Well pitch: 140 μm
Well diameter: 70-50 μm
Kapton thickness: 50 μm



CMOS MicroMegas grown on pixel ASIC







ECFA roadmap DRD4: Particle ID and photon

Ring Imaging Cherenkov and Time of Flight detectors
Sensitive materials producing light and photosensors

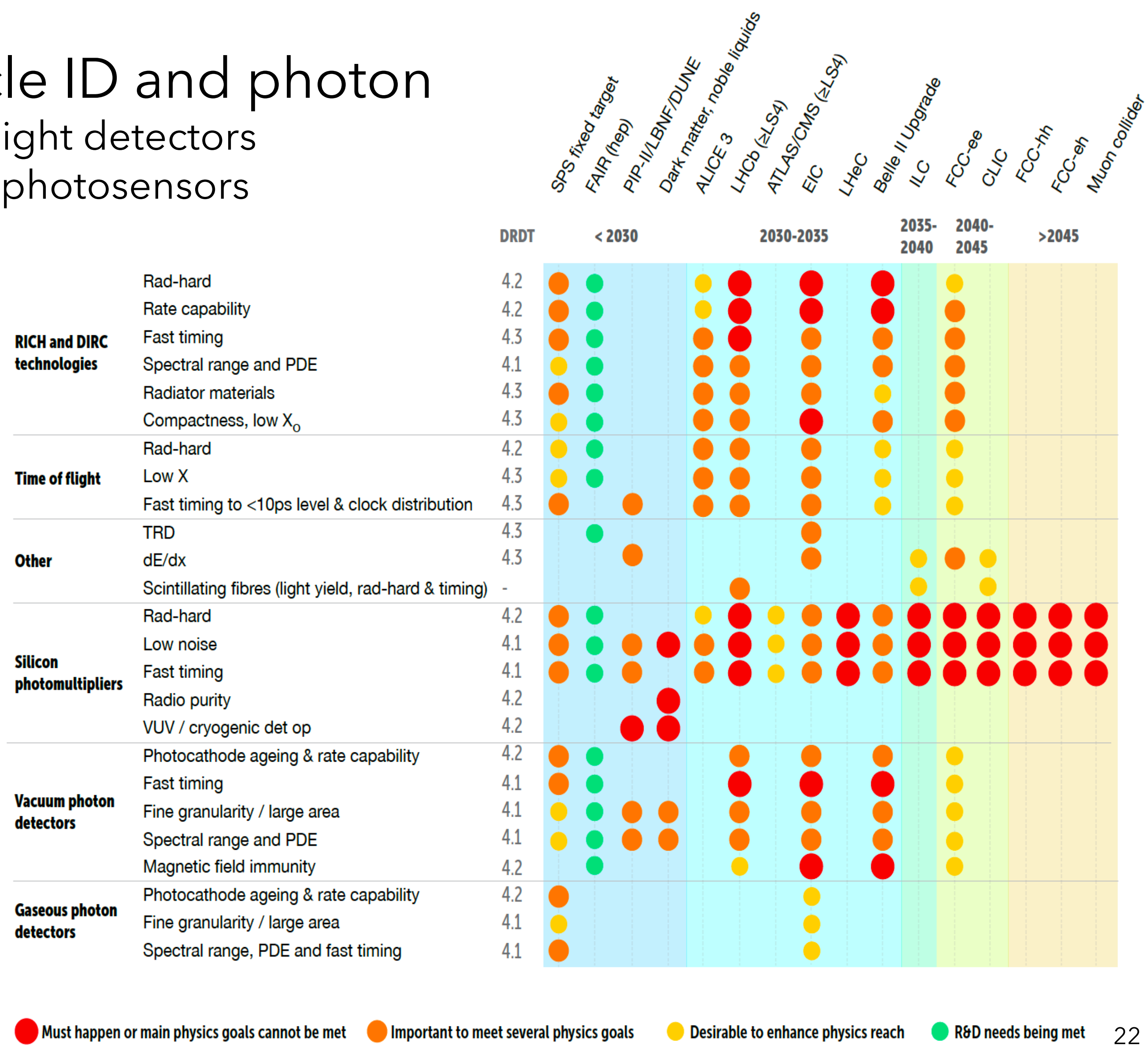
PID and Photon

DRDT 4.1 Enhance the timing resolution and spectral range of photon detectors

DRDT 4.2 Develop photosensors for extreme environments

DRDT 4.3 Develop RICH and imaging detectors with low mass and high resolution timing

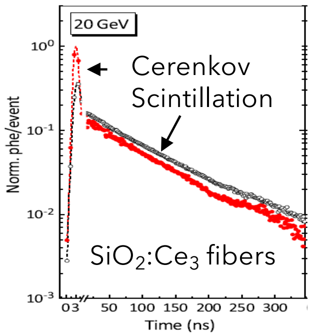
DRDT 4.4 Develop compact high performance time-of-flight detectors

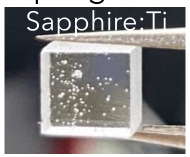


R&D matériaux scintillants et Cherenkov, photo-senseurs

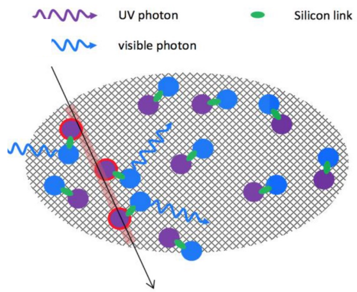
- Crystals for both scintillation & Cherenkov, luminophore, nano-materials ex. quantum dots
- Fabrication process and 3D printing

Separate sources
with waveform sampling

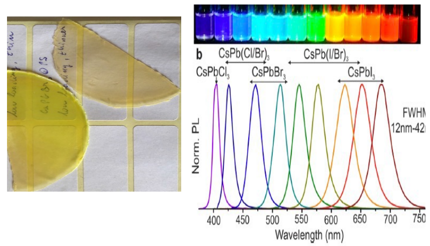




luminophore

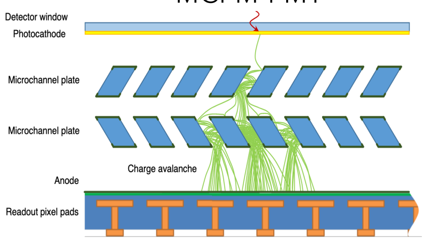


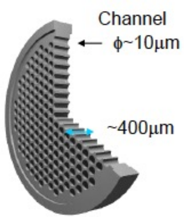
Quantum Dot ex. perovskite
embedded in polymer

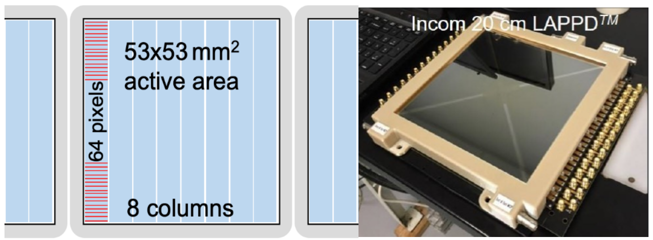


- MCP-PMT, SiPM, SPAD
  - Photocathode efficiency (MC-PMT), sensitivity in UV and Near Infrared Red (SiPM/ SPAD)
  - Higher granularity and fill factors, monolithic integration with electronics
  - Radiation tolerance (MCP-PMT), Dark Current Rates (SiPM/SPADs)

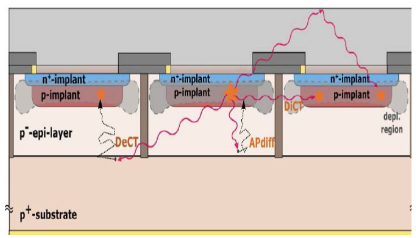
MCPM-PMT

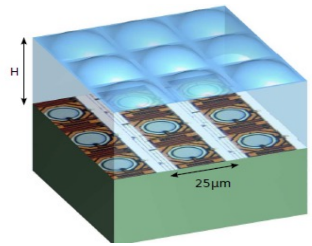






SPAD

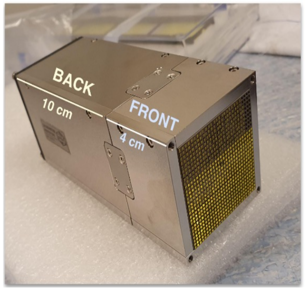




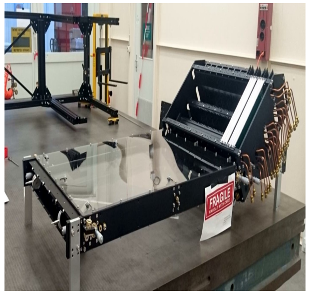
Systèmes de PID par cône Cherenkov et/ou temps de vol

objectif de précision moins de 10 ps

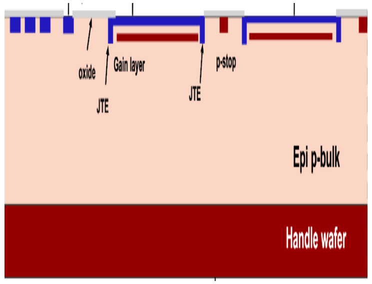
quartz/crystal/scint + MCP-PMT/SiPM + WS/ ToA-ToT ≃ 20 ps   Low Gain Avalanche Diodes and 3D SSD ≃ 25 ps   MicroMegas ≃ 25 ps



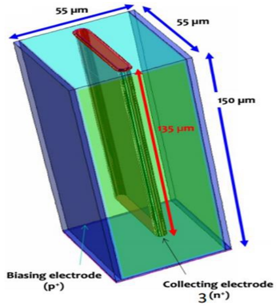
LHCb Spaghetti Calo.

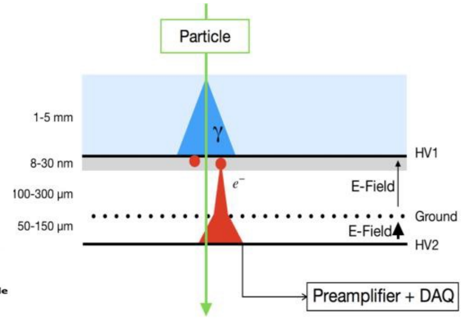


LHCb TORCH RICH



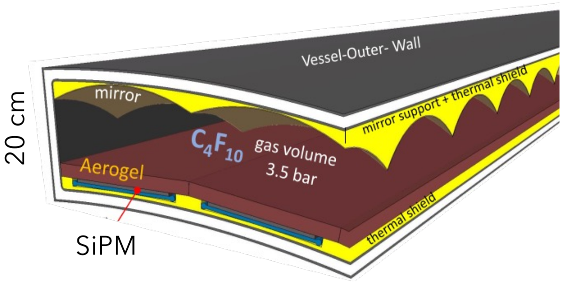
CMS Timing Layers



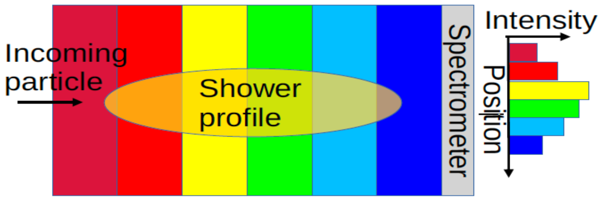


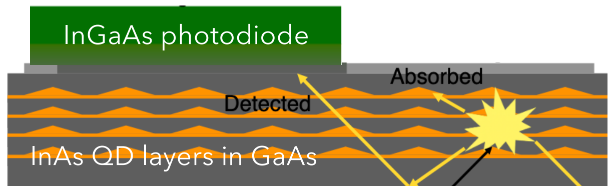
New detector concepts RICH but also calorimetry and tracking

Thin Array of RICH Cells for FCC-ee
aerogel and gas radiator with single SiPMs readout



Quantum Dots concepts for segmentation in crystal calorimetry (left)
and 4D scintillating tracking monolithic photodiode sensors (right)





ECFA roadmap DRD6: Calorimeters

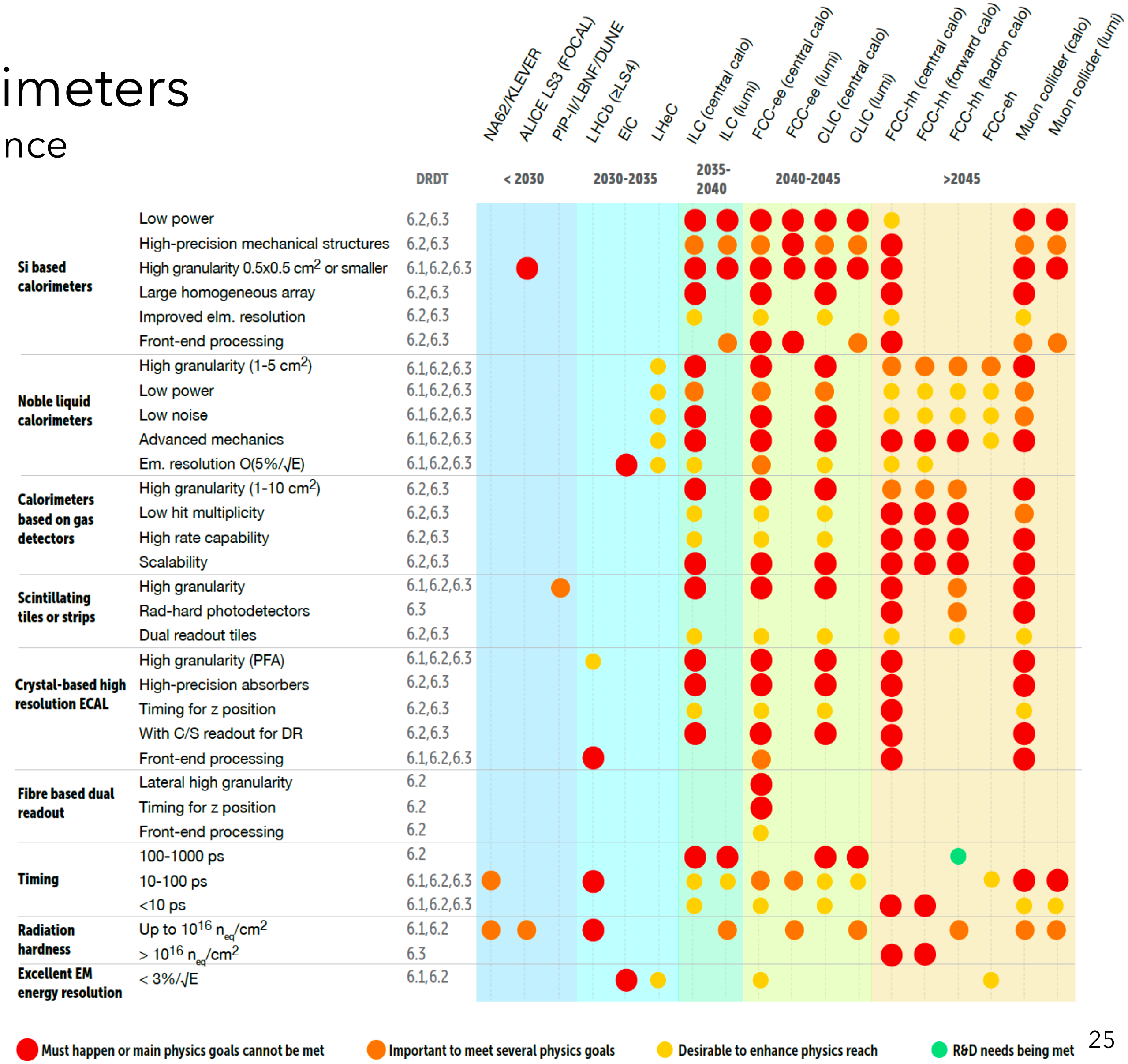
Several concepts with specific performance several sensor technology options

Calorimetry

DRDT 6.1 Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution

DRDT 6.2 Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods

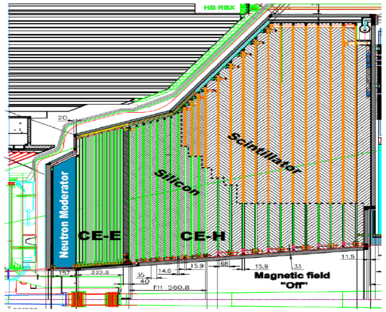
DRDT 6.3 Develop calorimeters for extreme radiation, rate and pile-up environments



2 configurations de calorimètres, 4 classes d'éléments sensibles

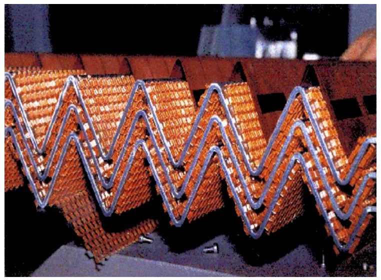
Sampling
absorber (W/Pb/Cu/Fe/Brass)
Solid State, Scint. tiles/fibers, Gas, Noble Liquid

High Granularity
Si-pads, scint. tiles/MPGDs

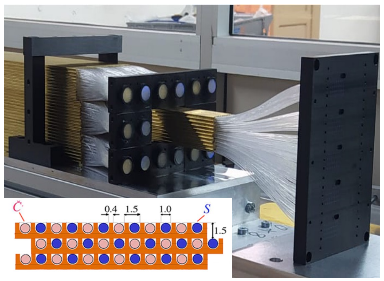


Shashlik EM concept
Scintillator + WLS

Noble Liquid (LAr)

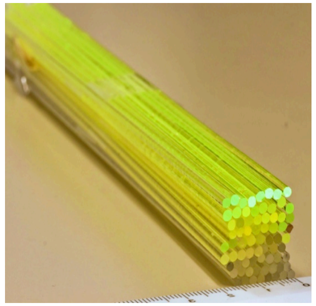


Spaghetti Dual Readout
Scint. & Cherenkov fibers

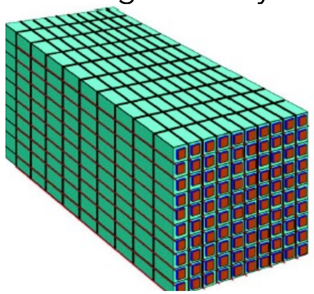


Homogenous
new concepts

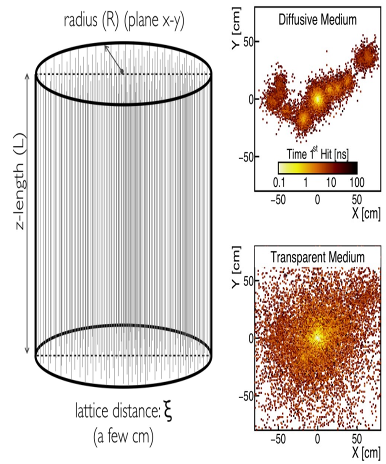
ECAL
crystal fibers



HCAL with
⊥ & // granularity



Opaque scintillator
crystal grains



Enjeux de R&D essentiellement au niveau systèmes avec des éléments sensibles développés dans les autres DRD

- High Granularity Calorimeter
  - Improve sampling fraction for e-γ energy
    - monolithic Si-sensors, 3D electronics integration (DRD3)
      - Consider pixel digital counting with < 10 ps time resolution for 5D shower profiling
    - minimize power consumption to avoid/minimize cooling effects (DRD7)
- Dual Readout calorimeter
  - Single fibers providing dual readout of scintillating and Cherenkov light (DRD4)
  - Waveform sampling for shower ToF (depth in calorimeter) (DRD7)
- Noble Liquid Calorimeter
  - Improve transverse and depth segmentation with large size multiple layer PCBs
  - Cold electronics (DRD7)
  - Light cryostat vessel, high density feedthrough* (DRD8)
- Homogenous calorimeters
  - Implement dual readout, ex. wavelength filtering w/ two photosensors, waveform sampling of signal or physical depth segmentation (DRD4/DRD7)

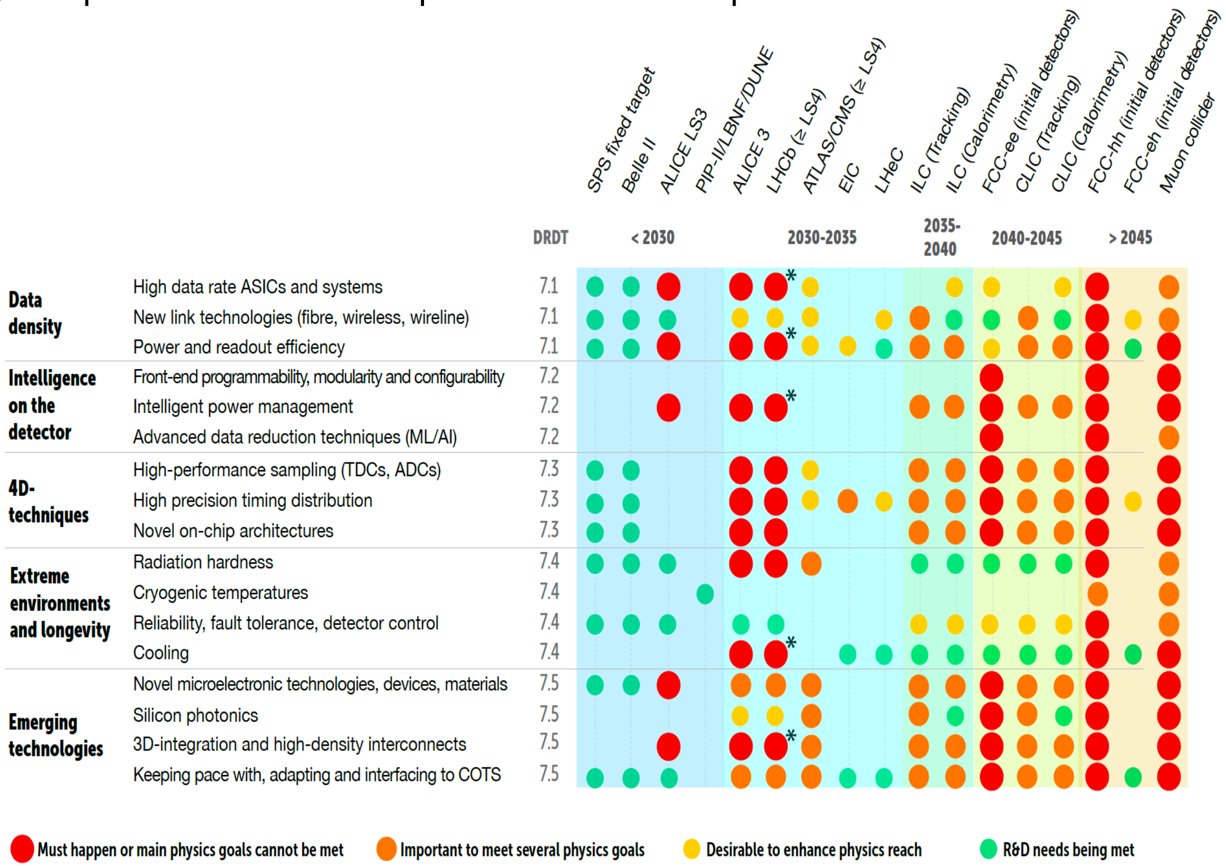
** common problematics with magnet R&D and for NL TPC readout*

ECFA roadmap DRD7: Electronics

Provide high data density readout and processing in extreme environments,
Organise access to technologies, training, help shared developments of complex ASICs
Ensure new technology watch

Electronics

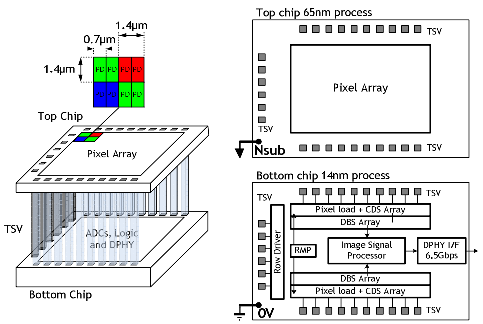
- **DRDT 7.1** Advance technologies to deal with greatly increased data density
- **DRDT 7.2** Develop technologies for increased intelligence on the detector
- **DRDT 7.3** Develop technologies in support of 4D- and 5D-techniques
- **DRDT 7.4** Develop novel technologies to cope with extreme environments and required longevity
- **DRDT 7.5** Evaluate and adapt to emerging electronics and data processing technologies



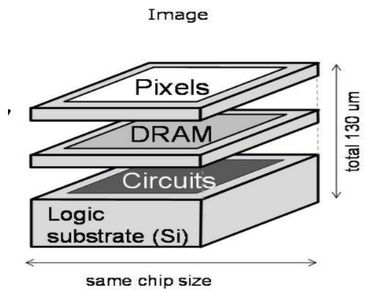
R&D générique électronique sur et hors détecteurs

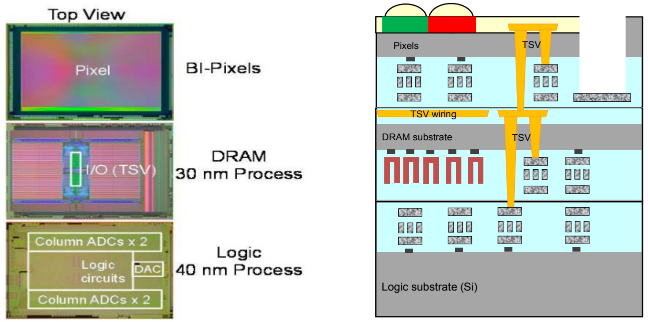
- IP blocks in new finer ASIC technology nodes
  - including high precision timing
  - capable to operate at cryogenic temperature
- Low power architectures with high channel density and rate capabilities
- Data transfer with photonics and wireless devices
- 3D integration of analogic, digital and data transfer components with sensitive elements
- New semiconductor materials (WBG) (considered in microelectronics industry)
- AI(ML) implementation in frontend and backend electronics

ex. of commercial imagers



Samsung: 1.4 μm pixels in 65 nm & 14 nm Fin-FET (3D transistors) readout , wafer level stacking





Sony (left) 3D layer thinned to 3 μm design for 960 fps
Samsung (right) 1.2 μm pixels, 2.5 μm TSV 6.3 μm pitch, 20 nm DRAM, 28 nm logic

ECFA roadmap DRD8: Integration

Magnets, cooling, mechanical structures, management of radiation environment

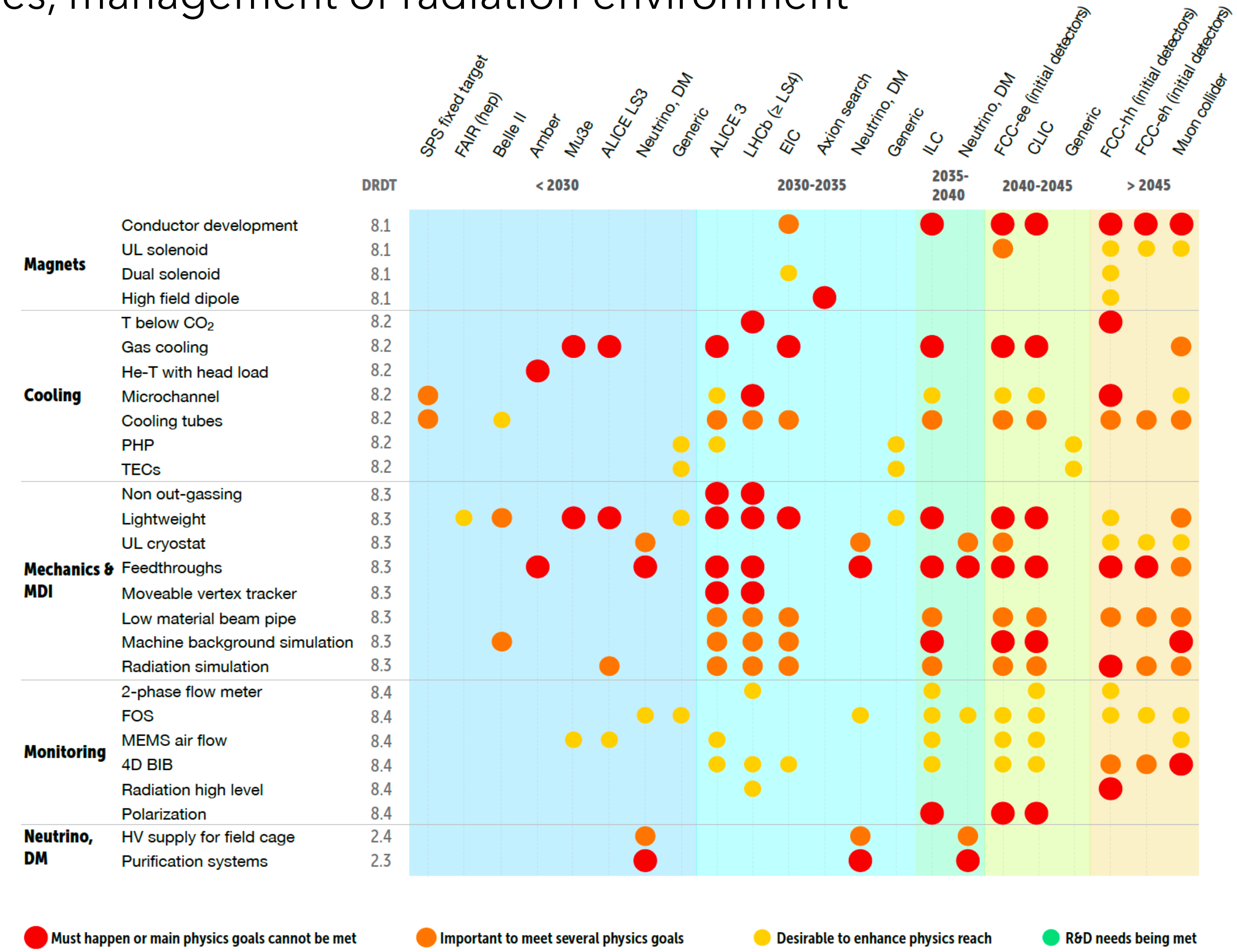
Integration

DRDT 8.1 Develop novel magnet systems

DRDT 8.2 Develop improved technologies and systems for cooling

DRDT 8.3 Adapt novel materials to achieve ultralight, stable and high precision mechanical structures. Develop Machine Detector Interfaces.

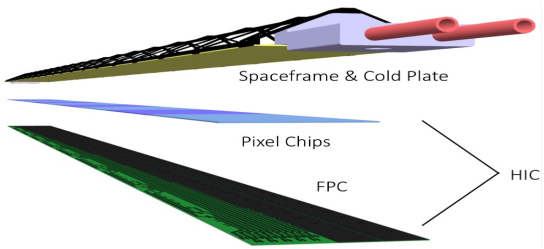
DRDT 8.4 Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects



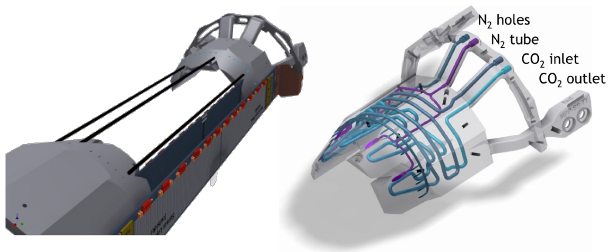
R&D intégration et systèmes mécaniques

- Thin superconducting solenoid magnet, and cryostat
- Management of irradiated environment, measure and manipulation robots
- Cooling systems
- Light stable mechanical structures
  - new materials, additive technologies (3D printing)

ALICE ITS2 0.36% X_0 /layer

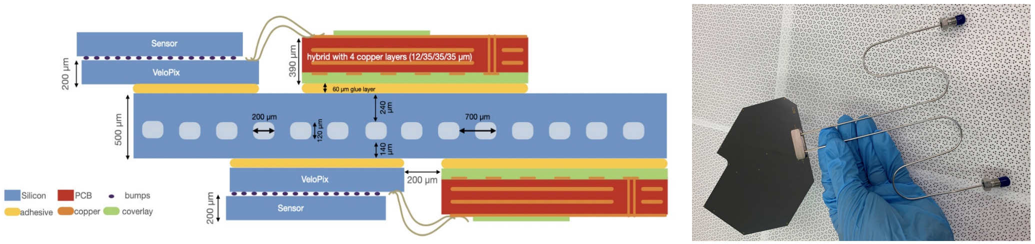


BELLE-II 0.2% X_0 /layer mixed cooling N_2 with carbon tubes flow and CO_2

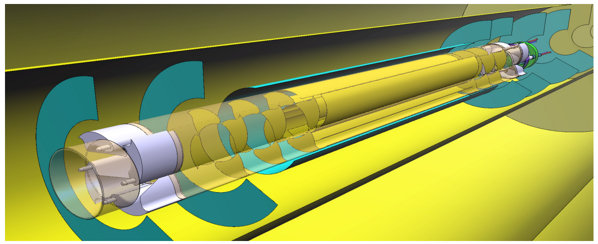


Mu3e 0.12 % X_0 /layer, He cooling

LHCb microchannel cooling embedded in Si-sensors

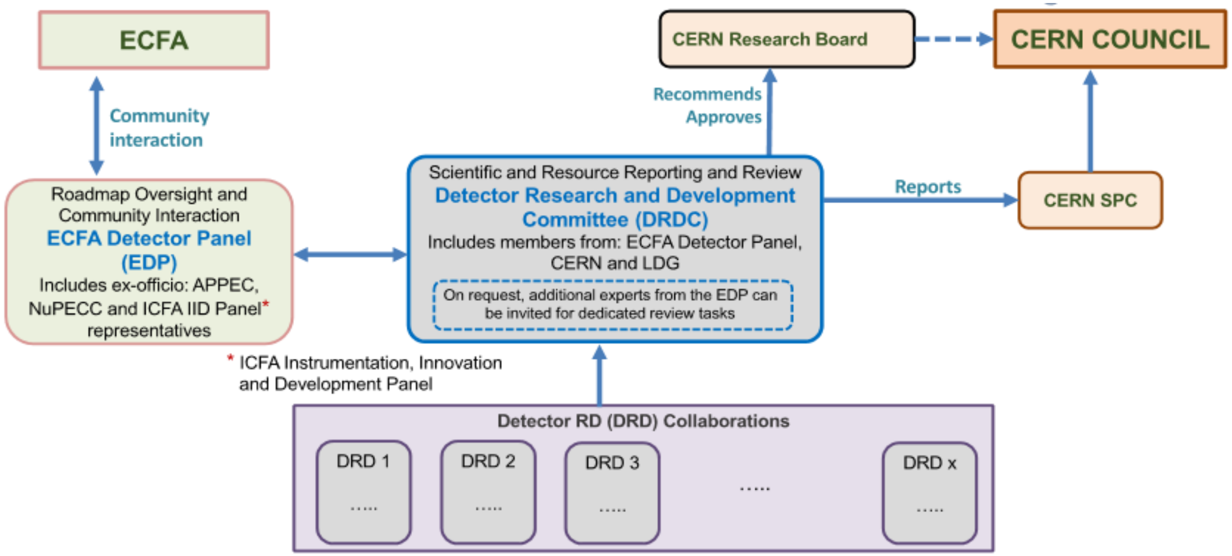


ALICE-3 retractable layer at 5 mm inside Beam Pipe



Implémentation de la feuille de route ECFA

formation de collaborations internationales DRD hébergées par le CERN



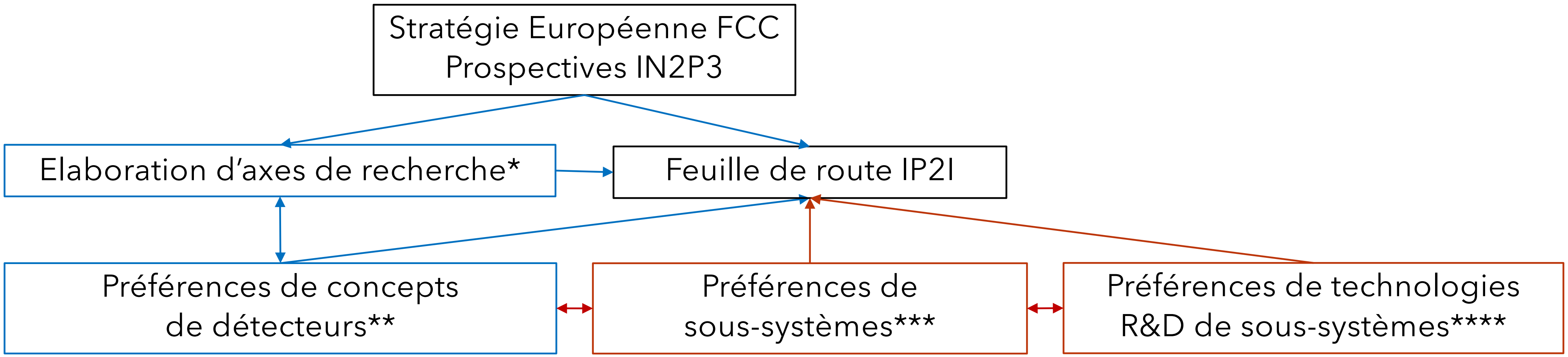
Calendrier

- Soumission de propositions* au DRDC Fin-Juillet 2023
  - consultation de la communauté en cours: https://indico.cern.ch/event/957057/page/27294-implementation-of-the-ecfa-detector-rd-roadmap
  - planning de delivrables/milestones, organisation des collaborations, ressources necessaires/attendues
- Collaborations actives début 2024
- Préparation de MoUs** et signatures par les agences de financement en 2024

** Seulement LoI pour DRD7, proposition fin 2023 (aussi pour DRD5 et DRD8)*

*** Memorendum of Uderstanding: signed engagement between CERN and the Funding Agencies to support achievement of the DRD programs*

Prospectives IP2I HEP



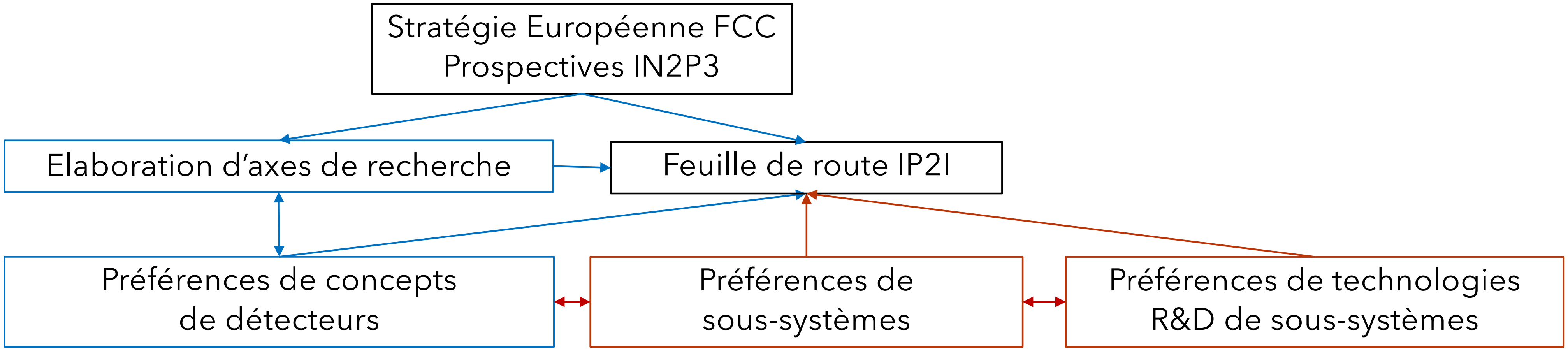
* à court terme participation aux études de performance pour le document de faisabilité fin 2025

** capacite à atteindre les objectifs de physique avec les différents concepts de détecteurs

*** à moyen terme optimisation des configurations et spécification des sous-systèmes

**** en relation avec les options et performance des R&D technologiques

Préparation de la feuille de route, thèmes HEP



- Thème 1: axes de recherche et concepts de détecteurs en relation avec les moyens informatiques
  - opportunités et intérêts pour la physique
  - moyens de simulation à développer/mettre en œuvre (software et computing, techniques d'analyses)
  - estimation des ressources associées
- Thème 2: sous systèmes – options de R&D techniques en relation avec instru./elec./meca.
  - 2 axes privilégiés la trajectographie et la calorimétrie
    - opportunités, dans le contexte national et international
    - axes de R&D possibles en relation avec les compétences et les intérêts à l'institut
    - environnement technique à déployer et partenaires académiques et industriels
    - synergies avec d'autres projets et tendances technologiques à long terme
    - Estimation des ressources associées

Préparation de la feuille de route proposition de méthode et calendrier (HEP + OG)

- Mi-Avril
  - Identifier des leaders par thème (sous-thèmes): 1 physicien, 1 représentant par service technique (suggestions à R.B, DC, PV + chefs de service + direction)
- Mi-Avril à mi-Mai
  - Appel à idées, structuration des thèmes en forums: eg mix approprié entre aspects spécifiques projets et moyens techniques transverses, éventuellement communs HEP/OG (minimiser les recouvrements)
- Mi-Mai à fin-Septembre
  - Séminaires (ouverts) ciblés par forum avec intervenant(s) expert(s) externe(s)
- Oct. à Mi-Novembre
  - Préparation de synthèse des thèmes et présentation en AG
- Mi-Novembre à mi-Décembre
  - Rédaction de la feuille de route et soumission à la direction de l'IP2I
- Début 2024
  - Présentation au conseil scientifique de l'IP2I

Feuille de route ECFA détecteurs R&D hors collisionneurs

ECFA roadmap Liquid detectors (DRD2)

Water Cerenkov, Noble Liquid, Liquid Scintillator

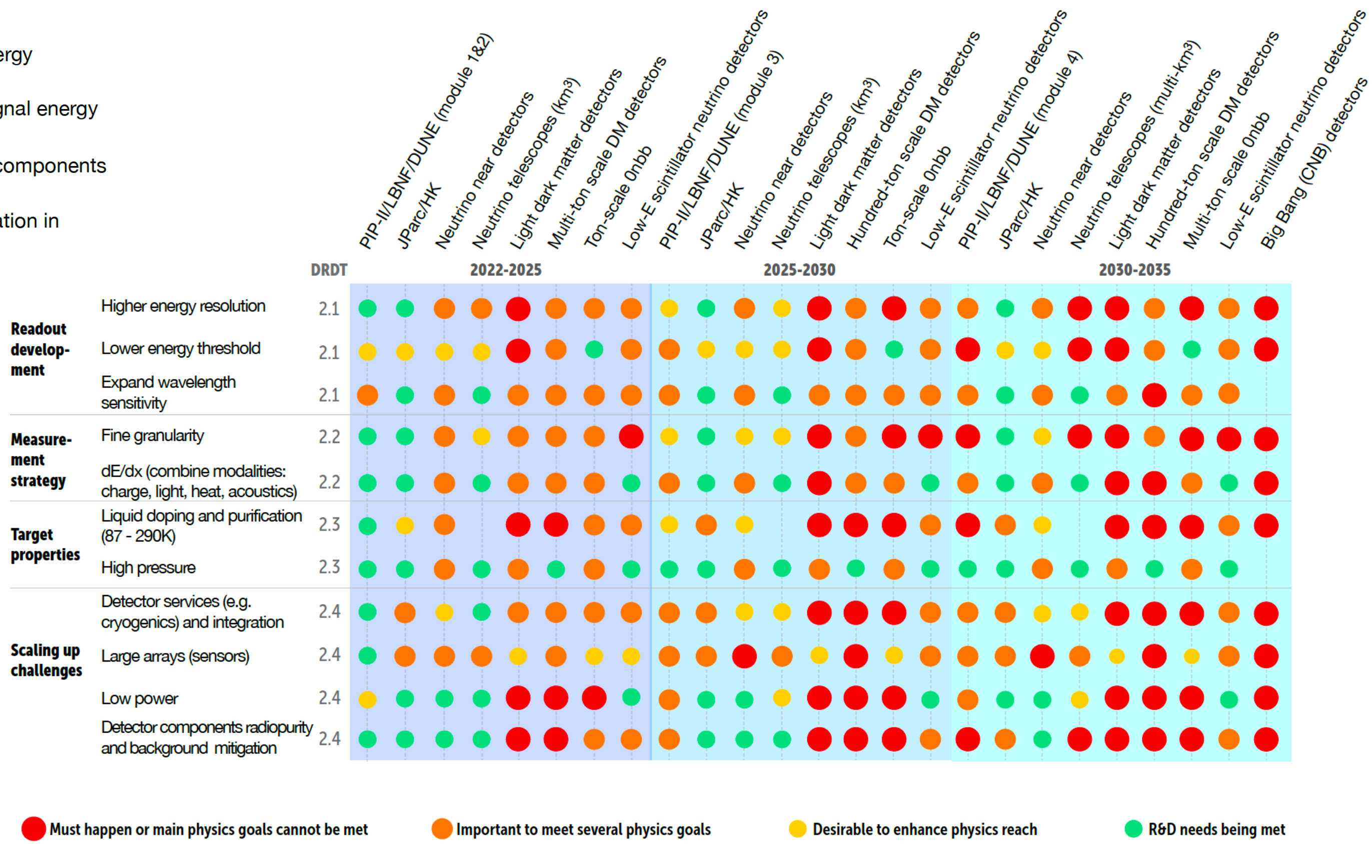
Liquid

DRDT 2.1 Develop readout technology to increase spatial and energy resolution for liquid detectors

DRDT 2.2 Advance noise reduction in liquid detectors to lower signal energy thresholds

DRDT 2.3 Improve the material properties of target and detector components in liquid detectors

DRDT 2.4 Realise liquid detector technologies scalable for integration in large systems



Neutrino, Dark Matter, $0\nu\beta\beta$ decay detectors

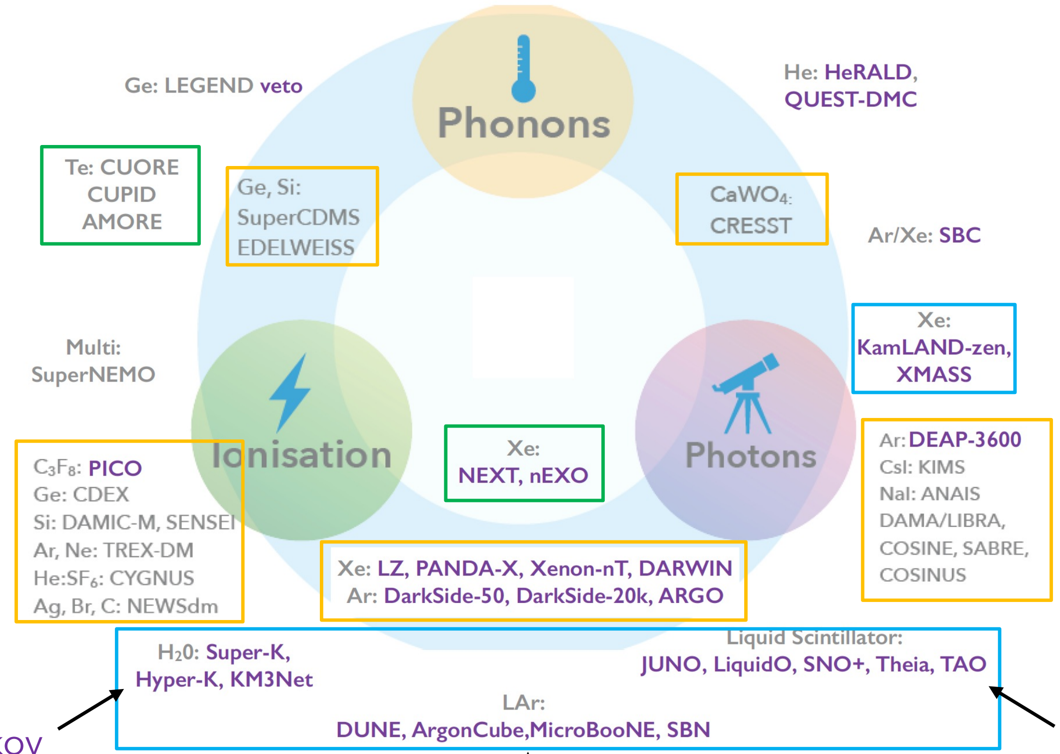
Strategy driven by energy sensitivity

goal to measure the different signals in same multi-purpose detectors with increasing volumes

Low energy thresholds
small detectors crystals
with quantum sensors

Neutrino
$0\nu\beta\beta$
Dark Matter

Bolometers



Large detector volumes,
different readout schemes

Water Cherenkov
O(10^2) γ/MeV
visible range

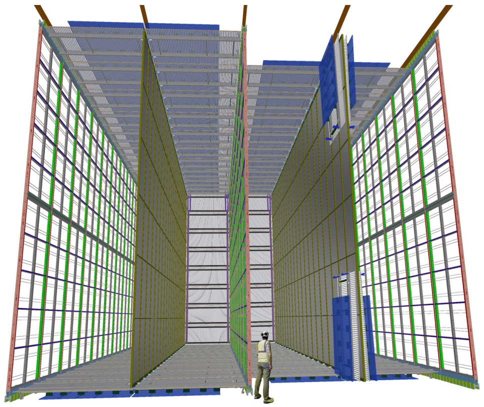
Liquid Scintillators
O(10^4) γ/MeV
visible range

Noble Liquid TPC
Ionization and O(4×10^4) γ/MeV VUV 128(178) nm for LAr(Xe)

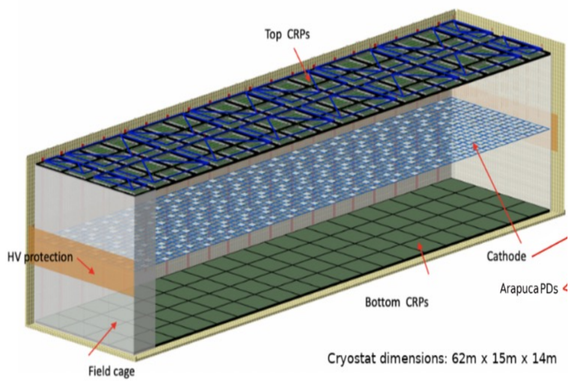
Noble liquid TPC Neutrino

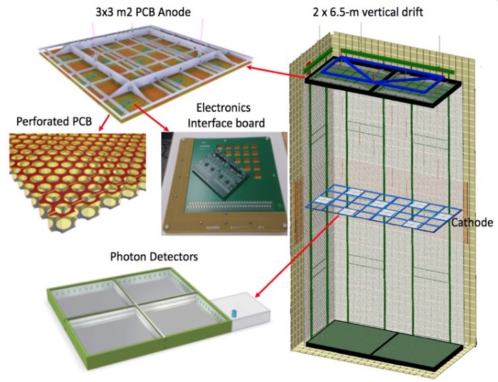
DUNE at Stanford Underground Research Facility 1.5km deep and 1300 km from Fermilab 2026-28
Far Detector 1 and 2 Single Phase LAr TPCs 17 kt 68(l) x 14(w) x 12(h) m^3 1.5 km undeground

- Next step FD3 and FD4 technologies to be decided ex. Theia Liquid Scintillator module 60(r) m x 60(h) m



FD1 horizontal anode drift wire readout and SiPMs





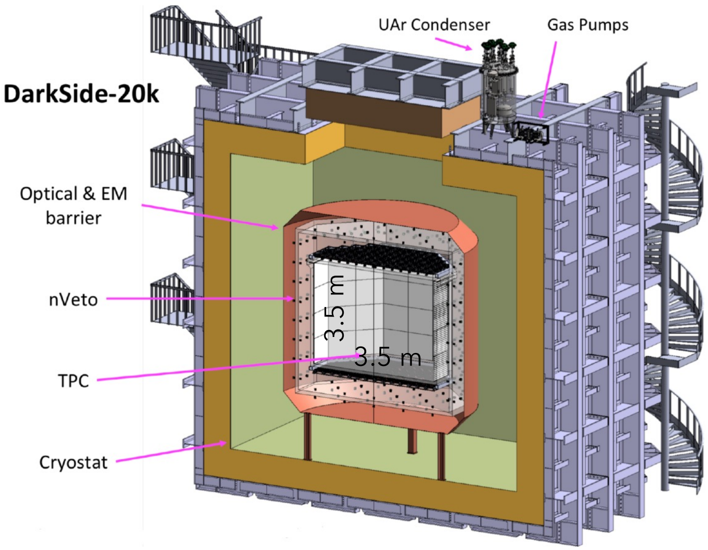
FD2 vertical drift PCB anode readout and SiPMs in cathod plane

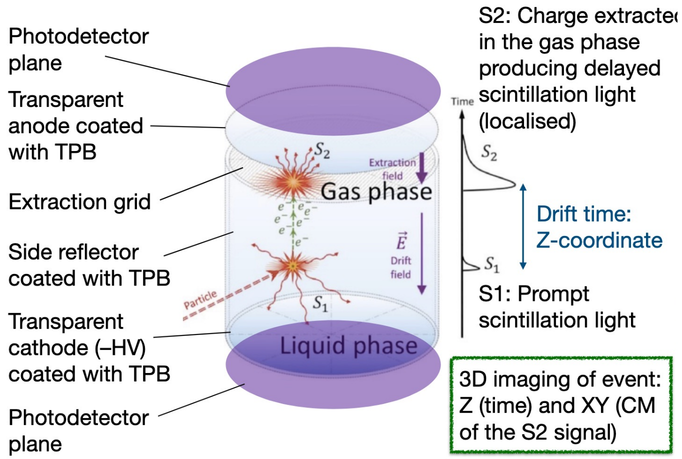
Noble liquid TPC Dark Matter

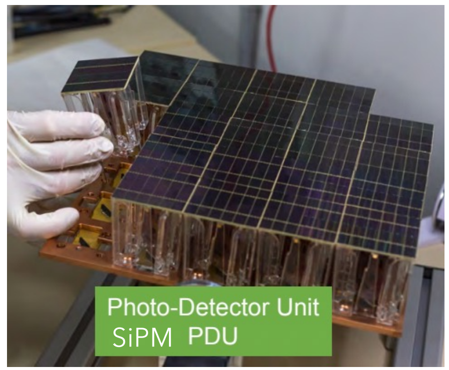
DarkSide-20k 20t (30 m³) double phase LUAr* TPC at Lab. Nat. Grand Sasso, 2025

- readout both scintillation and ionisation proportionale electroluminescence

➢ Next step ARGO at SNOLAB (Canada) 300t







DARWIN 50t 2.6 x 2.6 m double phase LXe TPC ≲ 2030?

- Also using water Cherenkov and Liquid Scintillator to shield TPC

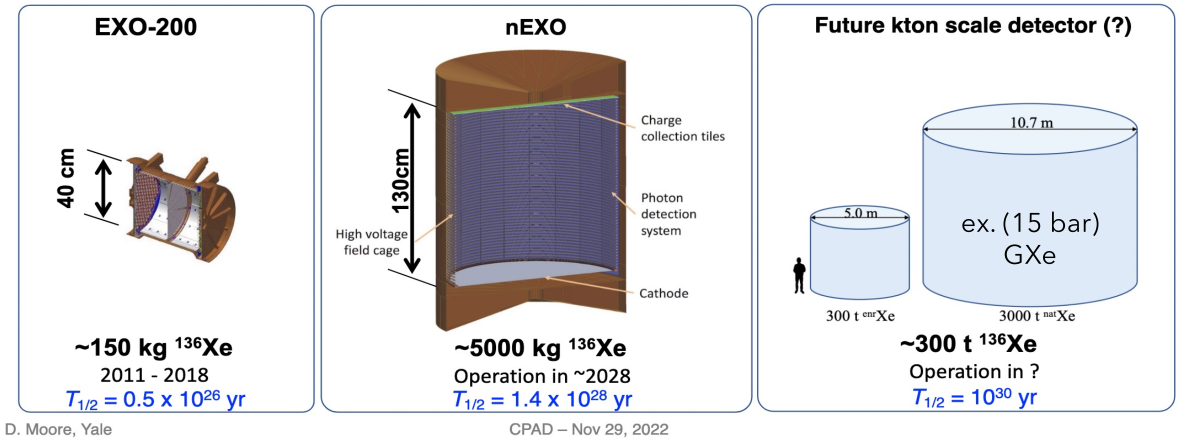
** Underground extracted, free of ^{39}Ar radoactive isotope*

Noble liquid TPC 0$\nu\beta\beta$

nEXO 5t single phase LXe single phase TPC (2028)

^{136}Xe decay source and the sensitive medium – readout anode tiles and SiPMs

- Next generation 300t
  - Supply of Xe is a major challenge
  - High Pressure (15 bar) GXe versus LXe is a compromise between energy resolution and backgroung

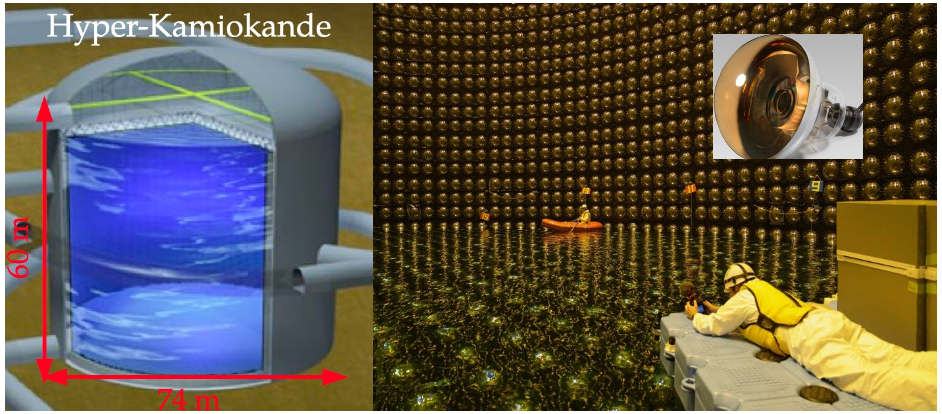


NEXT High Pressure Xenon TPC (2028) with double phase like readout

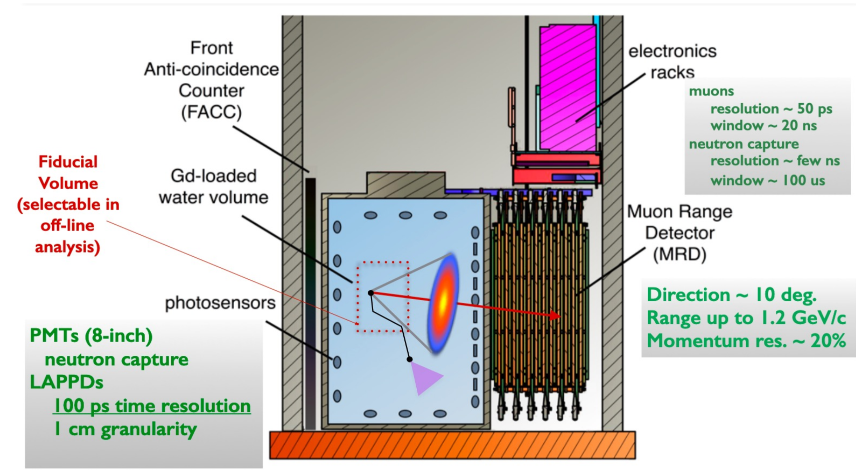
- Study daughter Ba^{++} combination with fluorescence molecules to tag signal for background rejection

Water Cherenkov Neutrino

Hyper-Kamiokande 2027
300 km from JPARC (Tokai, Japan)
650 m underground 260 kt ultra pure water Cherenkov, readout 40 000 PMT Φ = 50 cm, PDE ≃ 30%, 2.6 ns time resolution inner tank and 67000 PMT Φ = 20 cm outer tank



Accelerator Neutrino Neutron Interaction Experiment at FNAL Booster Neutrino Beam
26 t Gadolinium loaded water Cherenkov*
(measure neutrons), Large Area Picosecond PhotoDetectors
20x20 cm^2, 60 ps, 1 cm resolutions



Gd loaded Liquid Scintillator also used in TAO at (JUNO) and LZ for veto

Liquide scintillator Neutrino

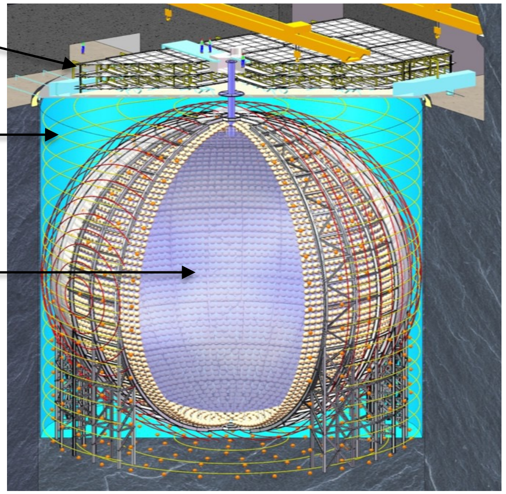
Jiangmen Underground Neutrino Observatory China (2023)

53 km from 2 nuclear power plants, 700 m underground
20 kt of liquid scintillator, 35 m (d) sphere

Tracking veto, 3 layers of plastic scintillators

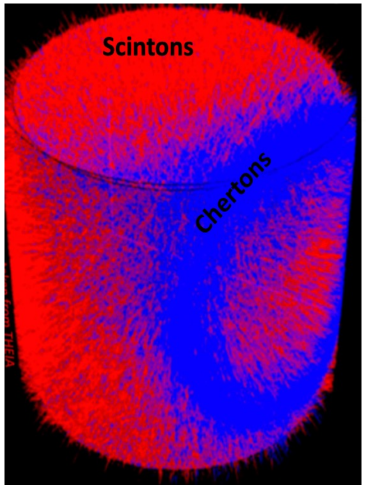
35 kt Water Cherenkov veto
5000 PMT Φ 50 cm

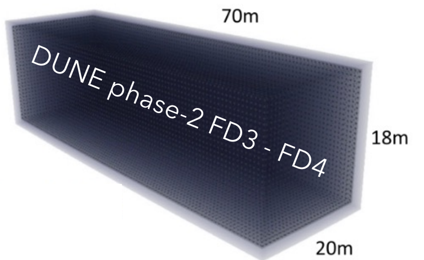
Liquid scintillator
75% coverage
- 15000 PMT Φ 50 cm
- MCP and Dynode
- 26000 PMT Φ 7.5 cm



DUNE Phase2 new concept Theia

25kt Water Based Liquid Scintillator
Scintillation high light yield & Cherenkov ring directionality, dychroic filters to separate WL on 2 photosensors or waveform sampling with LAPPD

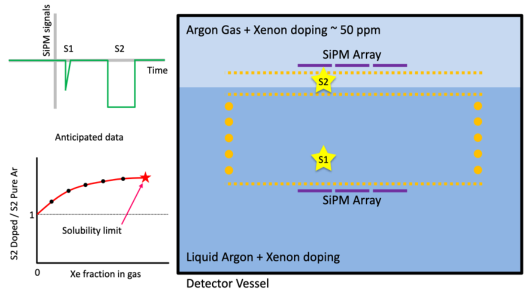


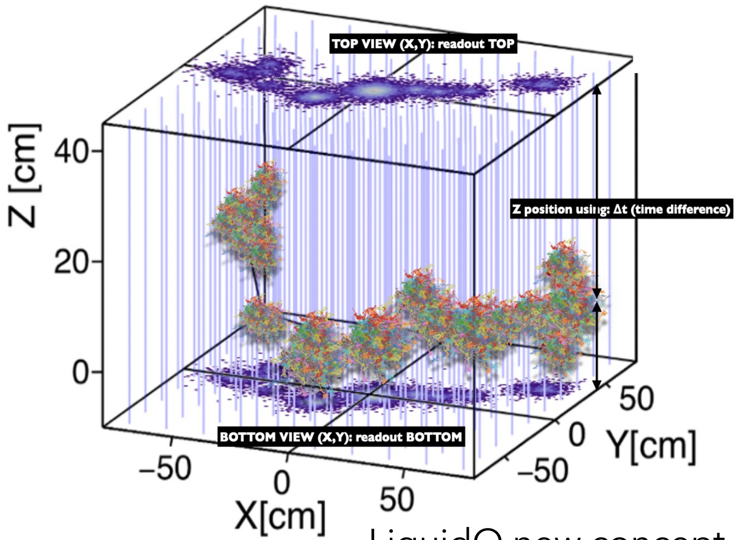


R&D Liquid

Increased signal and reduced background

- Noble Liquid (TPC)
  - ➢ Xe doping in LAr to increase electro-luminescence in DP
- Liquid Scintillator
  - ➢ Develop liquid scintillators with luminophore/quantum dots
  - ➢ Develop water-based LS for both scintillation and Cherenkov
    - ex. (Theia DUNE Phase-2 module)
  - ➢ Develop opaque liquid scintillator (LiquidO)
- Improve purity of liquid by O(10) to reduce signal absorption
- Improve radiopurity by O(10-1000) all materials
  - ➢ ex. new concept of crystal/vapor Xe dual phase to eliminate Radon



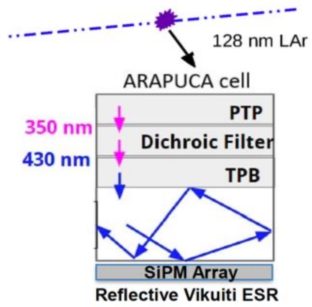


LiquidO new concept

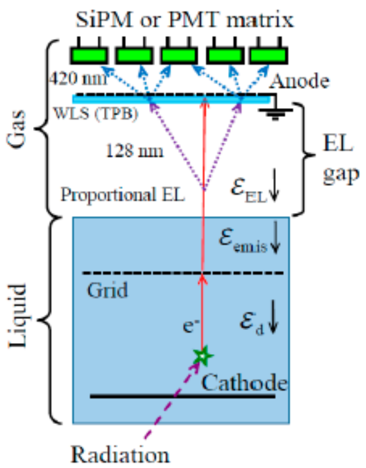
R&D readout

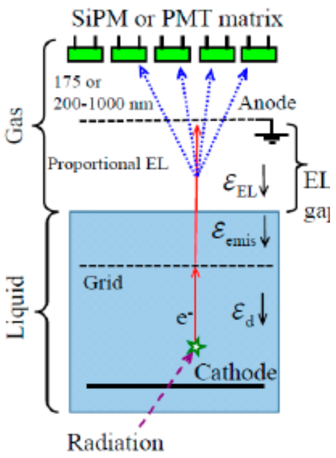
Improved photon/ionisation sensitivity and higher granularity

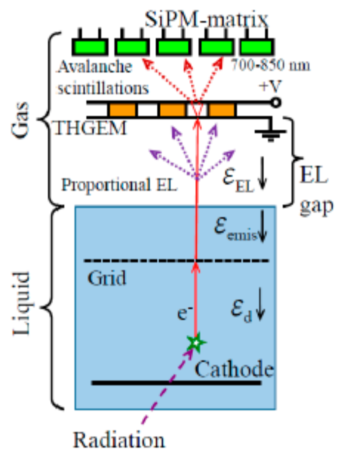
- Photosensors (PMT, LAPPD, SiPM/SPADs, CCD)
  - ➢ Improve Wave Length Shifting and/or VUV – NIR Quantum Efficiency
  - ➢ Design devices with both ionisation and light sensitivity
- Readout schemes
  - ➢ Improved amplification scheme in DP TPC
  - ➢ Increase granularity ex CCD with TimePix ASIC for spatial NEXT)

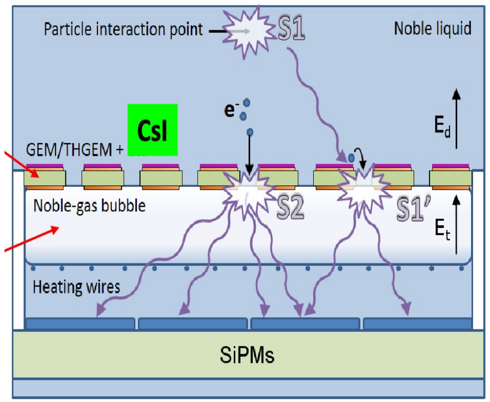


Dune Arapuca SiPM

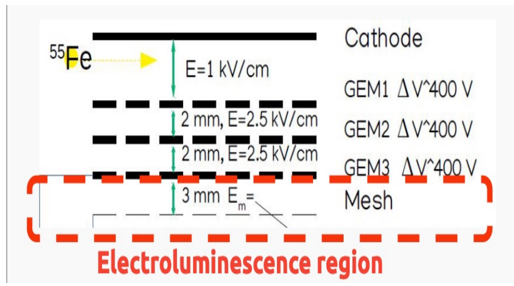






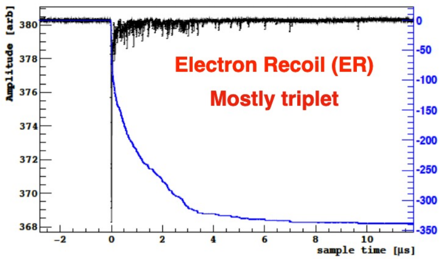


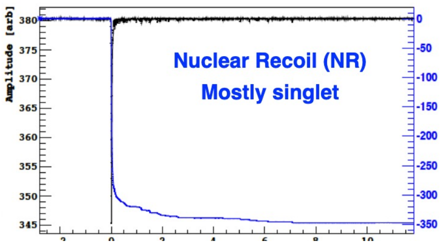
CYGNO directional DM 30 m^3
TPC low density $HeCF_4$



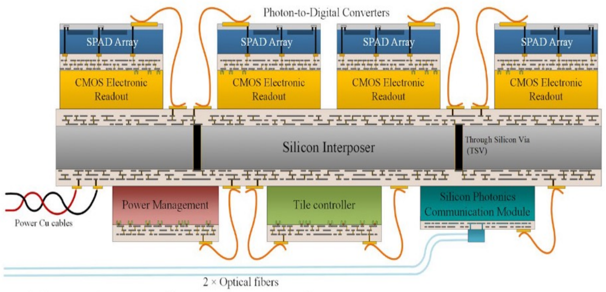
R&D Electronics

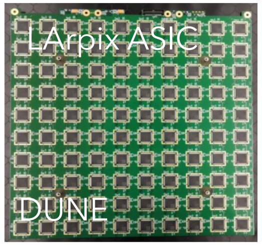
- Electronics
  - ➢ Waveform sampling to reject background (potentially to separate Cherenkov/Scintillation)
  - ➢ 3D integrated readout operated at cryogenic temperature (including optical transmission)
- Other engineering challenges for volume scaling
  - ➢ Cryostat vessels, cryogeny systems, feedthrough, power supplies, monitoring and calibration

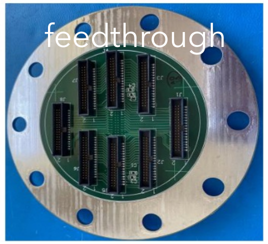


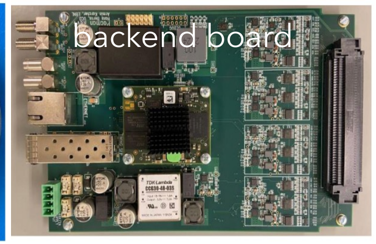


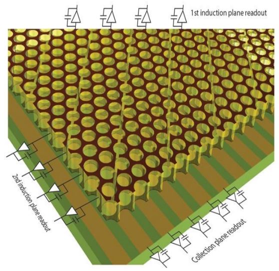
ARGO integrated readout with SPADs





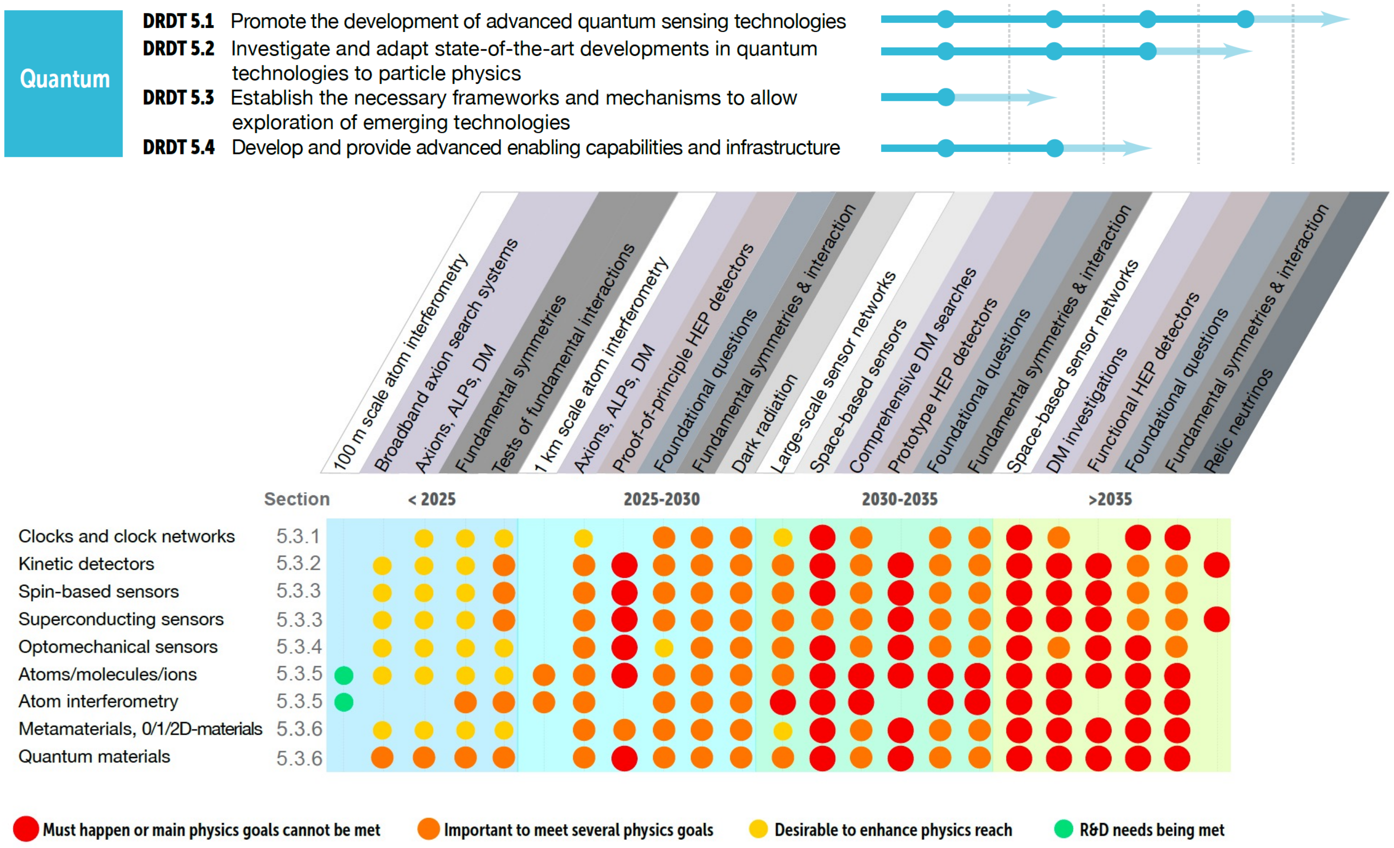






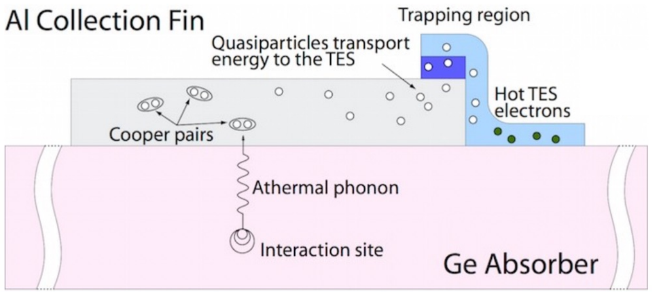
ECFA roadmap Quantum Sensors and emerging technologies (DRD5)

Sensors to measure very small signals with high resolution



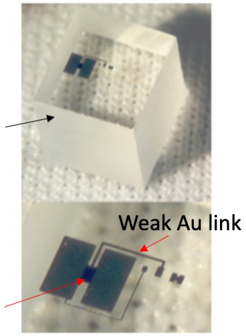
Phonon detection

- Transition Edge Sensors loss of superconductivity
  - Kinetic Inductance Detector transmission in a LC resonator
    - Quantum Capacitance Detector shift of resonator frequency with change of capacity in a tunnel junction



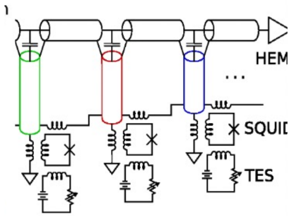
$CaWO_4$ or Al_2O_3 or Ge or Si…

TES W thin film T_C 20 mk



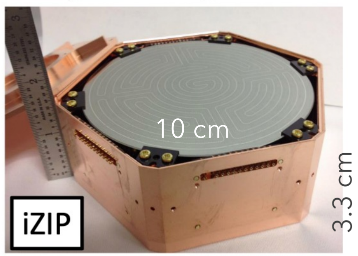
J. Rothe, PhD thesis, TUM 2020

Squid multiplexed readout

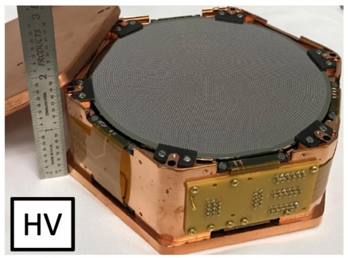


Super CDMS DMS 1.39(0.61) kg

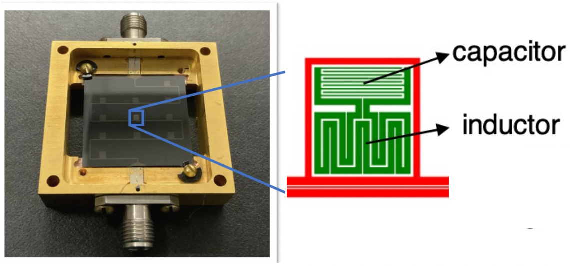
12 phonon, 4 charge channels
sensitive to ≥5GeV/c² DM
Ge(Si) σ_{ph}=50(25) eV σ_{ch}= 160(180) eV



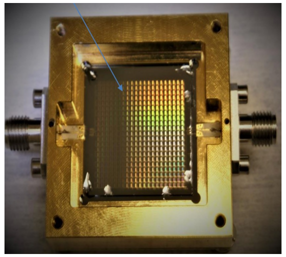
12 phonon channels
sensitive to sub-GeV DM
Ge(Si) σ_{ph}=10(5) eV

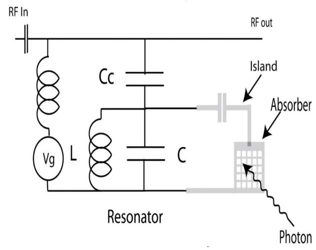


Single KID 2 cm CRESST 1-10gr



Quantum Capacitance Detector





R&D to reach sub-ev sensitivity, with larger scale systems

- ➢ Superconducting film material (Al, W, TiNx, Nb)
- ➢ Configuration of signal measurement structures
- ➢ Production process and readout

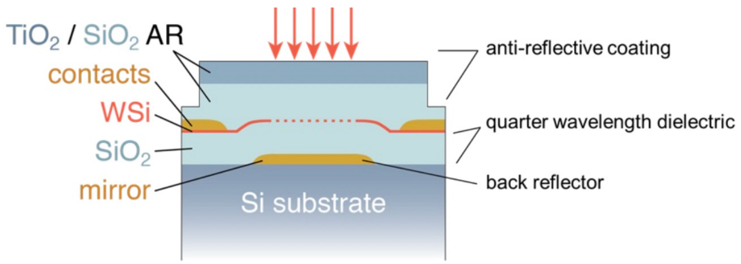
Superconducting Nanowire Single Photon Detector

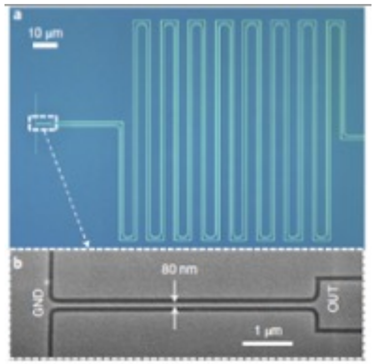
Measure resistance variation of nanowires (< 1 μm) at 1–4 K

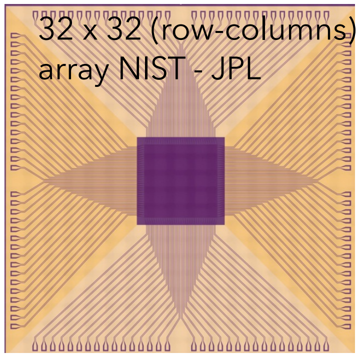
- Very high QE 10 nm to 10 μm WL, ultralow DCR < 10^{-5} cps, timing ≃ 3 ps, rate capability O(1) GHz/mm^2

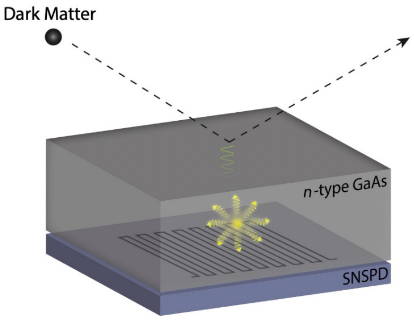
➢ Configuration for further improved sensitivity for threshold below 70 meV

➢ Larger size sensors accompanied by electronics for channel multiplexing









Informations complémentaires FCC-ee
programme de physiques et contraintes détecteurs
signaux de références pour études de faisabilités

Résumé du programme de physique au FCC

”Higgs Factory” Programme

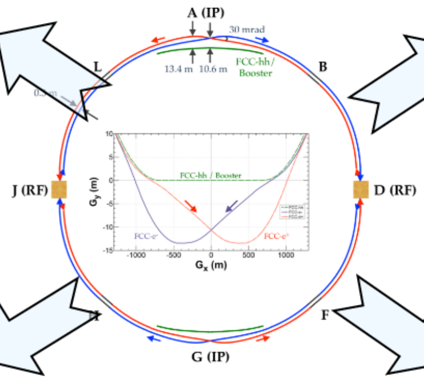
- At two energies, 240 and 365 GeV, collect in total
  - 1.2M HZ events and 75k WW → H events
- Higgs couplings to fermions and bosons
- Higgs self-coupling (2-4 σ) via loop diagrams
- Unique possibility: measure electron coupling in s-channel production $e^+e^- \to H$ @ $\sqrt{s}$ = 125 GeV

Ultra Precise EW Programme & QCD

Measurement of EW parameters with factor ~300 improvement in *statistical* precision wrt current WA

- $5x10^{12}$ Z and 10^8 WW
  - m_Z, Γ_Z, Γ_{inv}, $\sin^2\theta_W^{eff}$, R^Z_ℓ, R_b, α_s, m_W, Γ_W,...
- 10^6 tt
  - m_{top}, Γ_{top}, EW couplings

Indirect sensitivity to new phys. up to Λ=70 TeV scale



Heavy Flavour Programme

- Enormous statistics: 10^{12} bb, cc; $1.7x10^{11}$ ττ
- Extremely clean environment, favourable kinematic conditions (boost) from Z decays
- CKM matrix, CP measurements, ”flavour anomaly” studies, e.g. b → sττ, rare decays, CLFV searches, lepton universality, PNMS matrix unitarity

Feebly Coupled Particles - LLPs

Intensity frontier: Opportunity to directly observe new feebly interacting particles with masses below m_Z:

- Axion-like particles, dark photons, Heavy Neutral Leptons
- Signatures: long lifetimes – LLPs

https://indico.cern.ch/event/1064327/contributions/4893208/attachments/2454038/4214309/20220601-Paris-DetectorConcepts.pdf

Résumé des prérequis de performance des détecteurs au FCC

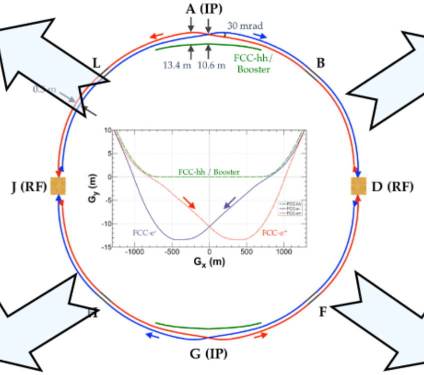
"Higgs Factory" Programme

- Momentum resolution of $\sigma_{p_T}/p_T^2 \simeq 2 \times 10^{-5}\,\text{GeV}^{-1}$ commensurate with $\mathcal{O}(10^{-3})$ beam energy spread
- Jet energy resolution of 30%/√E in multi-jet environment for Z/W separation
- Superior impact parameter resolution for c, b tagging

➢ new detector features
  - Enhanced tracking precision
  - Particle ID
  - γ-energy resolution

Ultra Precise EW Programme & QCD

- Absolute normalisation (luminosity) to 10^{-4}
- Relative normalisation (e.g. $\Gamma_{had}/\Gamma_{\ell}$) to 10^{-5}
- Momentum resolution "as good as we can get it"
  - Multiple scattering limited
- Track angular resolution < 0.1 mrad (BES from μμ)
- Stability of B-field to 10^{-6} : stability of √s meast.



Heavy Flavour Programme

- Superior impact parameter resolution: secondary vertices, tagging, identification, life-time measts.
- ECAL resolution at the few %/ √E level for inv. mass of final states with π^0s or γs
- Excellent π^0/γ separation and measurement for tau physics
- PID: K/π separation over wide momentum range for b and τ physics

Feebly Coupled Particles - LLPs

Benchmark signature: Z → νN, with N decaying late

- Sensitivity to far detached vertices (mm → m)
  - Tracking: more layers, continous tracking
  - Calorimetry: granularity, tracking capability
- Large decay lengths ⇒ extended detector volume
- Precise timing for velocity (mass) estimate
- Hermeticity

https://indico.cern.ch/event/1064327/contributions/4893208/attachments/2454038/4214309/20220601-Paris-DetectorConcepts.pdf

Signaux de références pour études de faisabilité

test de la capacité des concepts de détecteur à satisfaire les objectifs de physique

	Track mom. reso	Impact Par reso	PID	ECAL reso	ECAL granularity	HadronicMassRes. PFlow	lep/pi separ.	Comments
mH from recoil mass, Z(mumu)H	+							
tau -> 3 mu	+ (collimated tracks)							
B-field monitoring from JPsi, D0's	+ (low momenta)							
B0, Bs to mumu	+						+	
Z(ll)H(qq) for Hbb, Hcc, Hgg		+				+		
Vcb from W decays		+ (high purity WP)						
EW HF observables (Rb, Rc, AFB)		+						
B to K* tau tau		++ (soft tracks)	+		+ (pi0 in jets)			also efficiency for low p tracks
Tau Lifetime		+						systematics to be understood
gamma from Bs->Ds K	+	+	+	++				
Z(ll)H(ss) (BSM)		+	+			+		
Vcs from W decays		+	+ (high purity WP)					
B->pi0pi0				+	+			
B->pi0pi0 w/ Dalitz		+			+			
Tau polarization (Z to tautau)			+	+	+	+(tau reco)		
ve coupling Z->vvgamma				+				
tau->mugamma				+	+(spatial)			
ALPS, ee->agamma				+	+(spatial)			
sigma(ZH) from recoil avec Z->qq						+		also testing Pflow algo
Higgs width: ee->vvH, H->bb		+				+		also testing Pflow algo
bb,cc,gg coupling ZH-> qqqq		+				++(association)		testing association/jet clustering
m(top) direct in ee->tt->qqbqqb,lvbqqb	+	+		+		++(association)		testing association/kinematic fit
Higgs Width ZH->qqqqqq		+				++(association)		testing association/kinematic fit
m(W) direct reconstruction	+			+		++		kinematic fit
AFB(bb,cc)		+				+(jet charge)		
H->inv						+		
Total x-section at the Z								inclusive. calo selection, ECAL & HCAL resolutions
LLP, very displaced objects								granularity of ECAL,HCAL,timing, Muons
electron Yukawa, H->gg (at the pole)						++		qq/gg separation

Organisation de la collaboration FCC
≃ 120 instituts de ≃ 30 pays