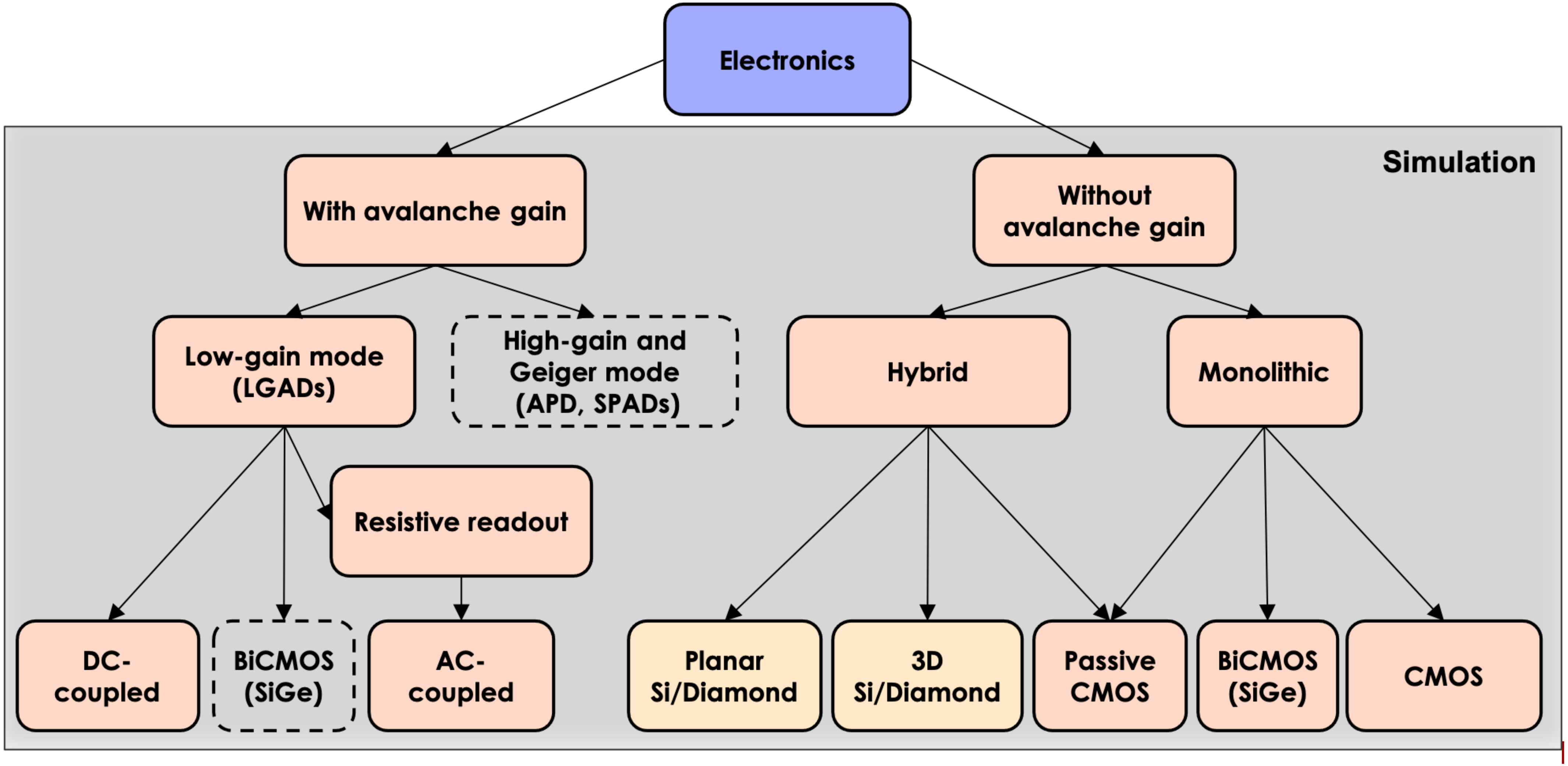
Summary of the input section



Status of the document

Almost all sections have text, some bulleted and some extended.

This outline does not overlap directly with the talks

- **Overview**
- **Summary of the future facilities requirements**
- **Silicon at extreme fluences**
- **Status and evolution of the simulation tools**
- **Sensors for 4D tracking**
  - Sensors without internal gain (pros/cons)
  - Sensors with internal gain (pros/cons)
- **MAPS for particle tracking and high time resolution (still empty)**
  - Passive CMOS
- **Wide band-gap semiconductors (Diamond and more)**
  - Diamond
- **The future of interconnections**
- **Summary of panel about industrialization**
- **Summary of panel about facilities**

Overview - I

Solid state sensors R&D is broadly dominated by silicon

- **Requests for future facilities are both reasonable and absolutley challenging**
  - Important point: there is a lot more that extreme fluence. Obviously FCC-hh fill a lot of phase space in R&D, but there is a lot more to do
- **Simulation needs to follow this path, with a specific focus on highly irradiated sensors**
- **R&D is moving away from standard planar silicon**
  - MAPS is filling its place
  - Hybrid systems maintain relevance in specialized features such as timing
  - Specialized sensors (such as 3D or diamond) are maintaining a phase space in specific applications
- **R&D: it is becoming very costly. Presently is organized in:**
  - Blue sky (RD50 from project/experiments, European money, not a sure stream)
  - Experiment driven, often is too late to do blue sky

    ==> needs to look at a different way

Overview - II

- **Very important R&D in interconnections**
  - 3D stacking essential for both MAPS and hybrids
  - future facilities requires more compact and more reliable packging.

- **Large area/sensors producers: dependance on a single producer should be addressed**
  - MAPS is a way to get away from it, important to push passive CMOS R&D
  - A focused industrial policy is another

    ==> aka magnet R&D led by CERN

- **Facilities:**
  - Very difficult to handle irradiated sensors, we are not ready to handle, ship, and test them
  - Charge hadron facilities cannot irradiate at 1E17 n/cm2. Need to plan for it
  - Beamtest are a luxury, we need to actively support them

Cross issues to be worked out in the next days

TF6 - Calorimetry: Large area sensors for calorimetry not in TF3. Silicon timing not directly addressed

TF7- Electronics: not in TF3. High timing is a common problem, not a sensors' or front-ends'

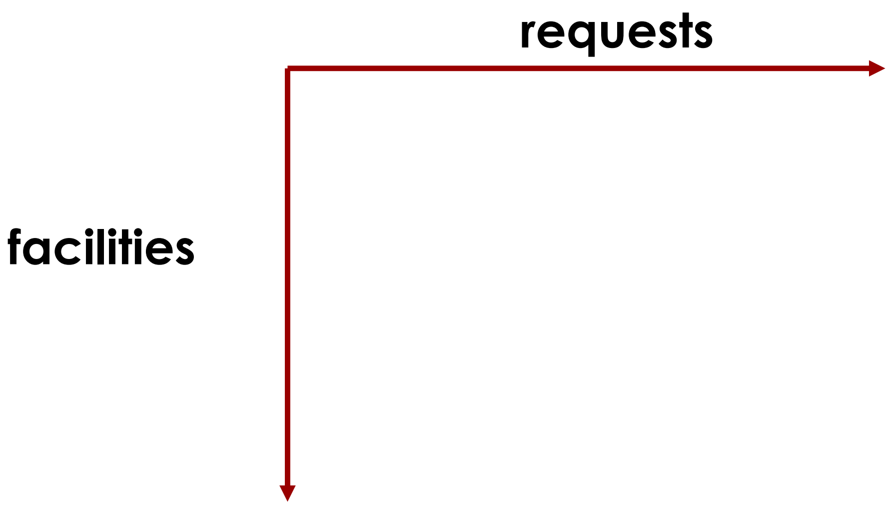
TF8 – Integration: hybridization, 3D integration is present

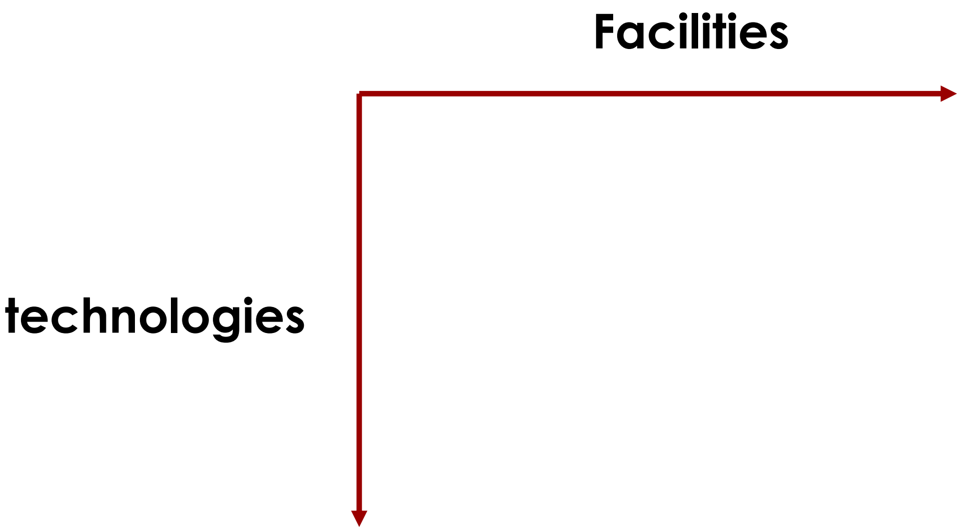
TF0 – Training: formal recognition is key. We need a patent of "detector guru"

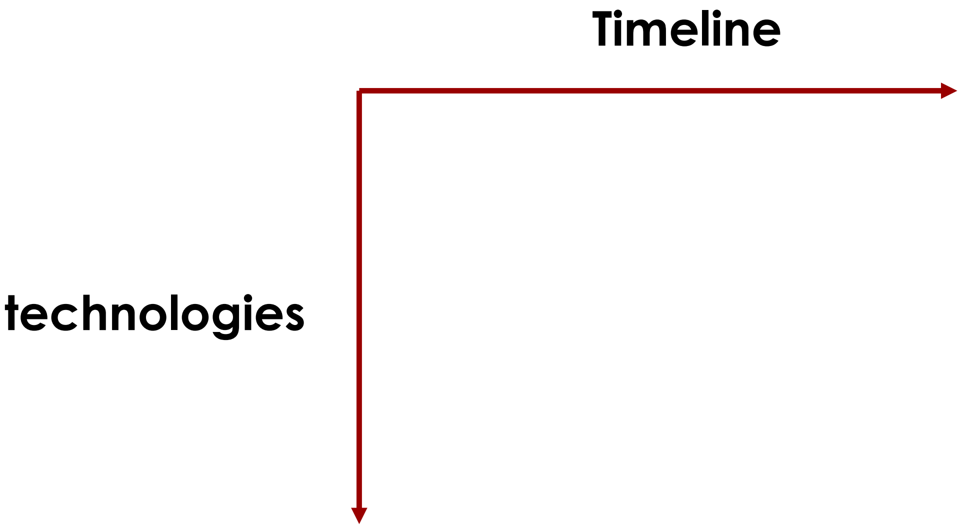
The brand "CERN" is excellent, a "CERN expert detector patent" would be great to have. I wish I had it..

No problem in finding jobs outside academia

Summaries: how many and what format







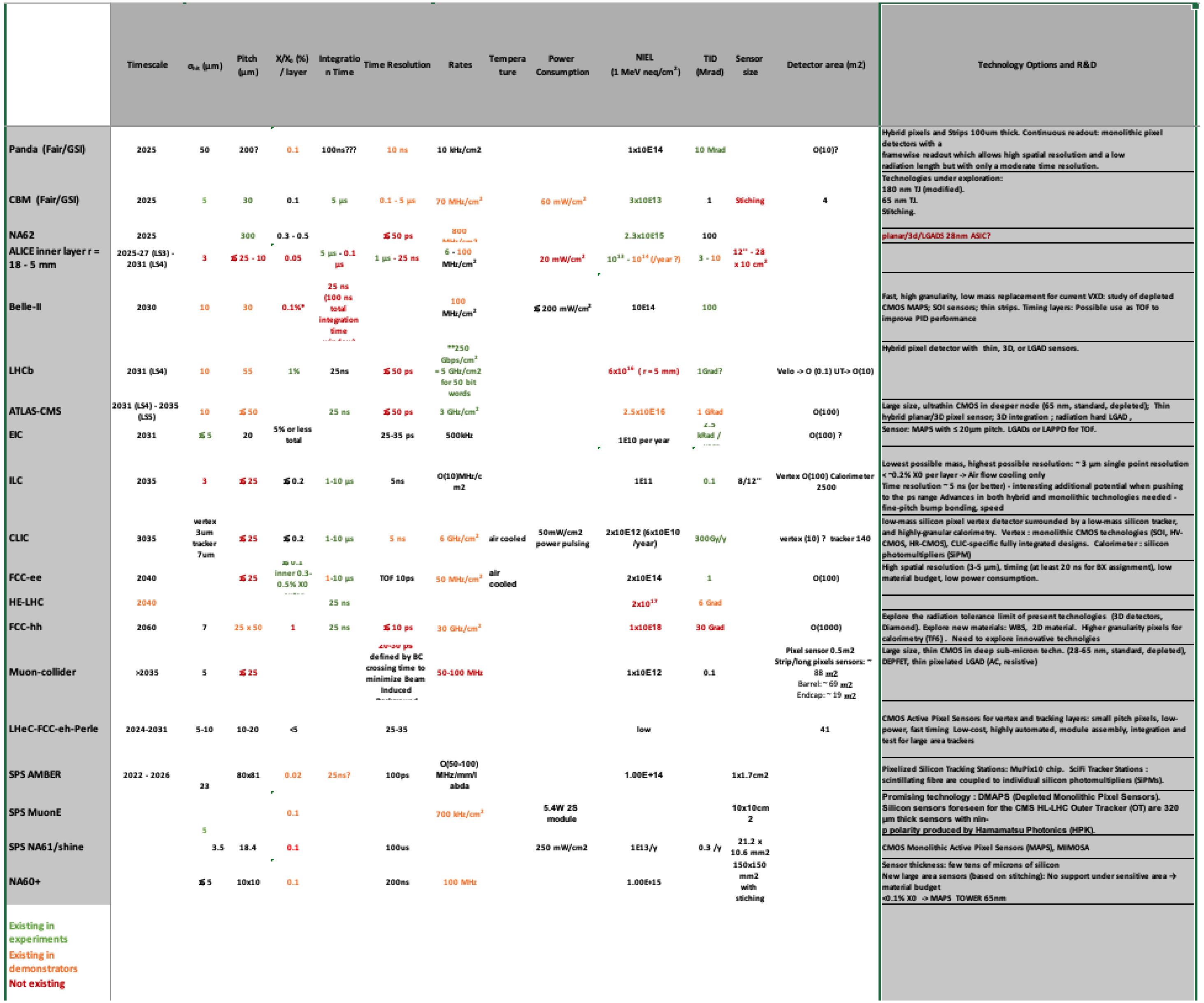
Problem in showing summary

The document begins with a summary. It is difficult to combine clarity and precision

This table has facilities vs technology

- Contains a lot of info
- took a long time to fill
- Impossible to see
- The numbers are important

This is a practical problem: how do we display it?

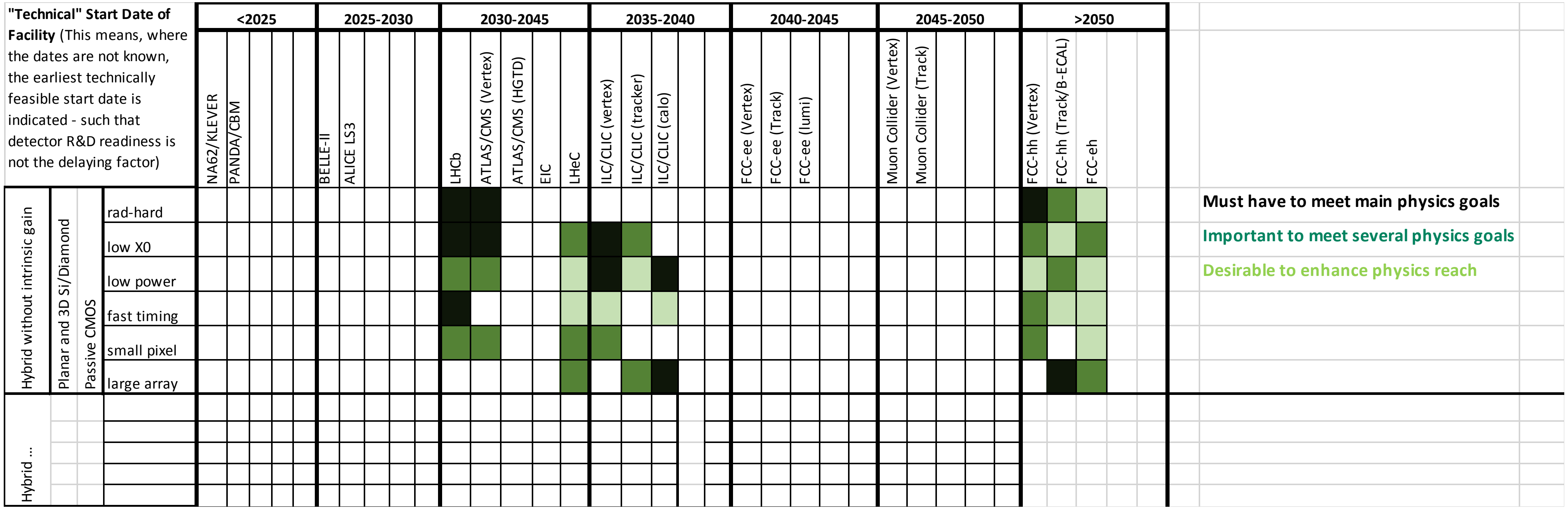


	Timescale	σ_{hit} (µm)	Pitch (µm)	X/X_0 (%) / layer	Integration Time	Time Resolution	Rates	Temperature	Power Consumption	NIEL (1 MeV neq/cm^2)	TID (Mrad)	Sensor size	Detector area (m2)	Technology Options and R&D
Panda (Fair/GSI)	2025	50	200?	0.1	100ns???	10 ns	10 kHz/cm2			1x10E14	10 Mrad		O(10)?	Hybrid pixels and Strips 100um thick. Continuous readout: monolithic pixel detectors with a framewise readout which allows high spatial resolution and a low radiation length but with only a moderate time resolution.
CBM (Fair/GSI)	2025	5	30	0.1	5 µs	0.1 - 5 µs	70 MHz/cm^2		60 mW/cm^2	3x10E13	1	Stiching	4	Technologies under exploration: 180 nm TJ (modified). 65 nm TJ. Stitching.
NA62	2025		300	0.3 - 0.5		≲ 50 ps	800			2.3x10E15	100			planar/3d/LGADS 28nm ASIC?
ALICE inner layer r = 18 - 5 mm	2025-27 (LS3) - 2031 (LS4)	3	≲ 25 - 10	0.05	5 µs - 0.1 µs	1 µs - 25 ns	6 - 100 MHz/cm^2		20 mW/cm^2	10^{13} - 10^{14} (/year ?)	3 - 10	12'' - 28 x 10 cm^2		
Belle-II	2030	10	30	0.1%*	25 ns (100 ns total integration time		100 MHz/cm^2		≲ 200 mW/cm^2	10E14	100			Fast, high granularity, low mass replacement for current VXD: study of depleted CMOS MAPS; SOI sensors; thin strips. Timing layers: Possible use as TOF to improve PID performance
LHCb	2031 (LS4)	10	55	1%	25ns	≲ 50 ps	**250 Gbps/cm^2 = 5 GHz/cm2 for 50 bit words			$6x10^{16}$ (r = 5 mm)	1Grad?		Velo -> O (0.1) UT-> O(10)	Hybrid pixel detector with thin, 3D, or LGAD sensors.
ATLAS-CMS	2031 (LS4) - 2035 (LS5)	10	≲ 50		25 ns	≲ 50 ps	3 GHz/cm^2			2.5x10E16	1 GRad		O(100)	Large size, ultrathin CMOS in deeper node (65 nm, standard, depleted); Thin hybrid planar/3D pixel sensor; 3D integration ; radiation hard LGAD ,
EIC	2031	≲ 5	20	5% or less total		25-35 ps	500kHz			1E10 per year	2.5 kRad /		O(100) ?	Sensor: MAPS with ≤ 20µm pitch. LGADs or LAPPD for TOF.
ILC	2035	3	≲ 25	≲ 0.2	1-10 µs	5ns	O(10)MHz/cm2			1E11	0.1	8/12''	Vertex O(100) Calorimeter 2500	Lowest possible mass, highest possible resolution: ~3 µm single point resolution < ~0.2% X0 per layer -> Air flow cooling only Time resolution ~5 ns (or better) - interesting additional potential when pushing to the ps range Advances in both hybrid and monolithic technologies needed - fine-pitch bump bonding, speed
CLIC	3035	vertex 3um tracker 7um	≲ 25	≲ 0.2	1-10 µs	5 ns	6 GHz/cm^2	air cooled	50mW/cm2 power pulsing	2x10E12 (6x10E10 /year)	300Gy/y		vertex (10) ? tracker 140	low-mass silicon pixel vertex detector surrounded by a low-mass silicon tracker, and highly-granular calorimetry. Vertex : monolithic CMOS technologies (SOI, HV-CMOS, HR-CMOS), CLIC-specific fully integrated designs. Calorimeter : silicon photomultipliers (SIPM)
FCC-ee	2040		≲ 25	inner 0.3-0.5% X0	1-10 µs	TOF 10ps	50 MHz/cm^2	air cooled		2x10E14	1		O(100)	High spatial resolution (3-5 µm), timing (at least 20 ns for BX assignment), low material budget, low power consumption.
HE-LHC	2040				25 ns					$2x10^{17}$	6 Grad			
FCC-hh	2060	7	25 x 50	1	25 ns	≲ 10 ps	30 GHz/cm^2			1x10E18	30 Grad		O(1000)	Explore the radiation tolerance limit of present technologies (3D detectors, Diamond). Explore new materials: WBS, 2D material. Higher granularity pixels for calorimetry (TF6) . Need to explore innovative technolgies
Muon-collider	>2035	5	≲ 25			defined by BC crossing time to minimize Beam induced	50-100 MHz			1x10E12	0.1		Pixel sensor 0.5m2 Strip/long pixels sensors: ~ 88 m2 Barrel: ~ 69 m2 Endcap: ~ 19 m2	Large size, thin CMOS in deep sub-micron techn. (28-65 nm, standard, depleted), DEPFET, thin pixelated LGAD (AC, resistive)
LHeC-FCC-eh-Perle	2024-2031	5-10	10-20	<5		25-35				low			41	CMOS Active Pixel Sensors for vertex and tracking layers: small pitch pixels, low-power, fast timing Low-cost, highly automated, module assembly, integration and test for large area trackers
SPS AMBER	2022 - 2026	23	80x81	0.02	25ns?	100ps	O(50-100) MHz/mm/l abda			1.00E+14		1x1.7cm2		Pixelized Silicon Tracking Stations: MuPix10 chip. SciFi Tracker Stations : scintillating fibre are coupled to individual silicon photomultipliers (SiPMs).
SPS MuonE				0.1			700 kHz/cm^2		5.4W 2S module			10x10cm2		Promising technology : DMAPS (Depleted Monolithic Pixel Sensors). Sillicon sensors foreseen for the CMS HL-LHC Outer Tracker (OT) are 320 µm thick sensors with n-in-p polarity produced by Hamamatsu Photonics (HPK).
SPS NA61/shine		5 3.5	18.4	0.1		100us			250 mW/cm2	1E13/y	0.3 /y	21.2 x 10.6 mm2		CMOS Monolithic Active Pixel Sensors (MAPS), MIMOSA
NA60+		≲ 5	10x10	0.1		200ns	100 MHz			1.00E+15		150x150 mm2 with stiching		Sensor thickness: few tens of microns of silicon New large area sensors (based on stitching): No support under sensitive area → material budget <0.1% X0 -> MAPS TOWER 65nm

Existing in experiments
Existing in demonstrators
Not existing

One of goal of the next few days

Find a way to give the correct message clearly



"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)				<2025					2025-2030					2030-2045					2035-2040					2040-2045					2045-2050					>2050					
				NA62/KLEVER	PANDA/CBM				BELLE-II	ALICE LS3				LHCb	ATLAS/CMS (Vertex)	ATLAS/CMS (HGTD)	EIC	LHeC	ILC/CLIC (vertex)	ILC/CLIC (tracker)	ILC/CLIC (calo)			FCC-ee (Vertex)	FCC-ee (Track)	FCC-ee (lumi)			Muon Collider (Vertex)	Muon Collider (Track)				FCC-hh (Vertex)	FCC-hh (Track/B-ECAL)	FCC-eh			
Hybrid without intrinsic gain	Planar and 3D Si/Diamond	Passive CMOS	rad-hard											⬛	⬛																			⬛	🟩	▨			**Must have to meet main physics goals**
			low X0											⬛	⬛			🟩	⬛	🟩														🟩	▨	🟩			**Important to meet several physics goals**
			low power											🟩	🟩			▨	⬛	▨	⬛													▨	🟩	▨			**Desirable to enhance physics reach**
			fast timing											⬛				▨	▨		▨													🟩	▨	▨			
			small pixel											🟩	🟩			🟩	🟩															🟩		▨			
			large array															🟩		🟩	⬛														⬛	🟩			
Hybrid ...																																							