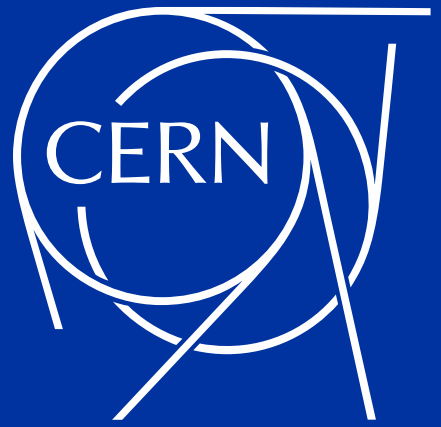

FCC ee – BI Workpackages

S. Mazzoni, R. Keiffer, D. Butti, M. Gasior, E.R. Howling, A. Schlogelhofer, K. Lasocha and T. Lefevre

SY-BI group

Overview of BI for FCCee

	Dump line	Main ring	Booster ring	Injection line	20GeV linac	Common linac	e- linac	e+ DR	e+ TL	e+ linac	Total
Quadrupole BPM	20	5800	2944	420	82	35	11	258	30	17	**9617**
Special BPM (tune, chromaticity,..)		20	5					4			**29**
Collimator BPM		66		5							**71**
BLM fast	20	100		200							**320**
BLM arc cell monitoring		1468									**1468**
Fast BCT, WCM	3	4	2	1	2	2	2	1	4	2	**23**
DC BCT		4	2					1			**7**
Tranverse profile											**0**
Screen (OTR/ODR)	6	6	2	20	2	2	2	2	4	2	**48**
Synchrotron rad.		4	1					1			**6**
Laser Wire Scanner		2									**2**
Longitudinal profile											**0**
b/b profile (EOS, Streak)		2	1		1	1	1	1	1	2	**10**
LDM, Coherent rad.		2	1		1	1	1	1	1	2	**10**
Beamstrahlung / luminosity		8									**8**
Polarimeter		2									**2**

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BI Workpackage Proposal

- **8 Tasks**
  1. Coordination, collaboration and cost/industrialisation
  2. Beam intensity and tune monitoring
  3. Beam loss monitoring
  4. Beam position monitoring
  5. Transverse profile monitoring
  6. Longitudinal profile monitoring
  7. Instrumentation required to Energy calibration and polarisation, i.e. measurement of Energy spread and Compton polarimeter – in close collaboration with EPOL WG
  8. Instrumentation for Luminosity monitoring and optimisation, e.g. Beamstrahlung and Bhabha scattering monitors – in close collaboration with MDI WG

BI Workpackage Proposal

- **8 Tasks**

Different categories

Standard solutions VS challenging specifications requiring extensive R&D

Small number of devices VS very large serie (standardisation and industrialisation)

A good news - there is no complex design that needs to be produced in large quantity

Beam instrumentation workpackage

Task 1 – Coordination, Collaboration and Cost/industrialisation (Stefano, Ray and Thibaut)

- Coordinate the beam instrumentation work for FCCee
  - Weekly meeting internal to SY-BI
  - Monthly meeting with external collaborators (https://indico.cern.ch/category/8560/)

- Develop cost model for Beam instrumentation and for industrialization
  - Identifying components that can be standardized throughout the complex
  - Looking for industrial partners
  - Investigating best ways for industrialisation and cost/design optimisation

Task 1 : Coordination		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**0.4**	**0.4**	**0.4**	**0.4**
	Engineer/Physicist	*0.4*	*0.4*	*0.4*	*0.4*
	Technician/ Tech. Engineer				
Missing Manpower [FTE]		**0**	**0**	**0**	**0**
	TOTAL [FTE]	***0.4***	***0.4***	***0.4***	***0.4***
Material Budget [kCHF]					
	AOB (travel., collaboration)	*20*	*20*	*20*	*20*
	Total [kCHF]	***20***	***20***	***20***	***20***

- Will require more resources when project is approved (>2028)

Beam instrumentation workpackage

Task 2 - Beam Intensity and Tune Monitoring (Marek Gasior)

- Collect the specifications for beam intensity and tune measurements in the FCCee collider rings from others WP in terms of resolution, accuracy and dynamic range.
- Design both DC beam and bunch-by-bunch intensity measurement systems
- Design of tune monitoring systems (on-going work at Solaris – 10.18429/JACoW-IBIC2024-THP59)

Functional specifications

Years:	T_0-15				T_0-10				T_0-5				T_0-1
R&D													
Design + prototyping													
Industrialization + pre-series													
Series prod. + testing													

- At least 10 different designs (Main rings, booster and injector) for each monitors (Tune, Fast and DC BCTs)
- Assuming no shortage of workforce (not the case today !)
- Small numbers of units <50 and relatively standard solutions
- Assuming beam tests can be performed on existing facilities (i.e. CLEAR, SOLARIS, ..)

Beam instrumentation workpackage

Task 2 - Beam Intensity and Tune Monitoring (Marek Gasior)

- Collect the specifications for beam intensity and tune measurements in the FCCee collider rings from others WP in terms of resolution, accuracy and dynamic range.
- Design both DC beam and bunch-by-bunch intensity measurement systems
- Design of tune monitoring systems (on-going work at Solaris – 10.18429/JACoW-IBIC2024-THP59)

Task 2 : Beam Intensity and Tune monitoring		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**0.1**	**0.1**	**0.1**	**0.1**
	Engineer/Physicist	*0.1*	*0.1*	*0.1*	*0.1*
Missing Manpower [FTE]		**0**	**0**	**0.1**	**0.1**
	Engineer/Physicist				
	Technician/ Tech. Engineer			*0.1*	*0.1*
	TOTAL [FTE]	***0.1***	***0.1***	***0.2***	***0.2***
Material Budget [kCHF]					
	Design and prototyping		*20*	*20*	*20*
	FSUs				
	AOB (travel., collab.)	*10*	*10*	*10*	*10*
	Total [kCHF]	***10***	***30***	***30***	***30***

- Types of monitors (tune, fast and DC BCTs)
- Adapting design from similar existing monitors for TDR phase
- Small development budget for validation on existing machines
- With current resources – most of the work starting after project approval

Beam instrumentation workpackage

Task 3 - Beam Loss Monitoring (Belen, Christos, new staff in 2026, new TS in 2025)

- Collect the specifications for the FCCee BLM system linked to Machine protection and operation needs
  - fast bunch by bunch monitors and slower (turn by turn) monitors
- Design a BLM monitoring system capable of identifying losses from main rings vs booster
- Design a Beam loss monitor insensitive to SR x/γ-rays.
- Rad-hard, rad-tol Arc cell electronic acquisition system

Years:	T_0-15				T_0-10				T_0-5				T_0-1
R&D													
Design + prototyping													
Industrialization + pre-series													
Series prod. + testing													

- At least 2 different designs – slow and fast BLMs
- Large numbers of units ~ 10000
- Need to study industrialisation for cost reduction
- Installation time not discussed here
- This is just starting now !

Beam instrumentation workpackage

Task 3 - Beam Loss Monitoring (Belen, Christos, new staff in 2026, new TS in 2025)

- Collect the specifications for the FCCee BLM system linked to Machine protection and operation needs
  - fast bunch by bunch monitors and slower (turn by turn) monitors
- Design a BLM monitoring system capable of identifying losses from main rings vs booster
- Design a Beam loss monitor insensitive to SR x/γ-
- Arc cell electronic acquisition system

- New staff for BLM and Ph.D student for simulations and monitor design
- Graduate for the design of electonic DAQ (rad-hard solution) at 50% with BPM DAQ
- Material budget for developing detectors and testing prototypes

Task 3 : Beam Loss Monitoring		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**0.2**	**1.2**	**1.3**	**1.3**
	Engineer/Physicist	*0.2*	*1.2*	*1.3*	*1.3*
	Technician/ Tech. Engineer				
Missing Manpower [FTE]		**1**	**1.5**	**1.7**	**1.7**
	Technician/ Tech. Engineer			*0.2*	*0.2*
	Graduate		*0.5*	*0.5*	*0.5*
	TS/PhD	*1*	*1*	*1*	*1*
	Associate				
	TOTAL [FTE]	***1.2***	***2.7***	***3***	***3***
Material Budget [kCHF]					
	Design and prototyping	*100*	*100*	*100*	*100*
	FSUs		*10*	*10*	*10*
	M4P	*40*	*95*	*95*	*95*
	AOB (travel., collab.)				
	Total [kCHF]	***140***	***205***	***205***	***205***

Beam instrumentation workpackage

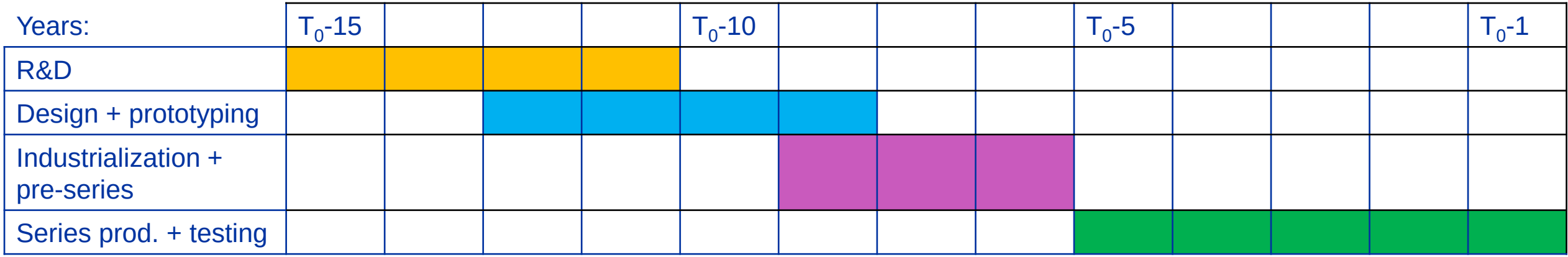
Task 4 - Beam Position Monitoring (Emily, Marek, Diogo, new staff in 2025,…)

Design and prototype of a low impedance pick-up

- Electro-magnetic simulations, Heat load simulations and design of water cooling system
- Mechanical design integrated in the machine layout including alignment tolerances
- Prototyping and validation by laboratory and beam tests

Design a cost-efficient bunch-by-bunch and turn-by-turn data acquisition system

- System architecture and cost including radiation hardness, ORAMS aspects
- Prototyping – laboratory and beam tests



- Different designs – Arc BPMs, IR BPMs, Booster and injector BPMs
- Large numbers of Arc BPMs ~ 9000 (Main rings and booster)
- Study in collaboration with TE-VSC, TE-MSC, EN-MME, BE-GM
- Orbit feedback not mentioned here but should be discussed how to launch the study

Beam instrumentation workpackage

Task 4 - Beam Position Monitoring (Emily, Marek, Diogo, new staff in 2025,…)

Design and prototype of a low impedance pick-up

- Electro-magnetic simulations, Heat load simulations and design of water cooling system
- Mechanical design integrated in the machine layout including alignment tolerances
- Prototyping and validation by laboratory and beam tests

Design a cost-efficient bunch-by-bunch and turn-by-turn da

- System architecture and cost including radiation hardness, ORAM
- Prototyping – laboratory and beam tests

- New staff for BPM and Ph.D student for simulations and monitor design (Arc and IR BPMs)
- Graduate for the design of electonic DAQ (rad-hard solution) at 50% with BLM DAQ
- Material budget for developing detectors and testing prototypes
- Challenging BPM-QUAD alignment – Test benches / Mock-up – Budget for that is not requested here !

Task 4 : Beam Position Monitoring		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**1.2**	**1.3**	**1.3**	**1.3**
	Engineer/Physicist	*1.2*	*1.3*	*1.3*	*1.3*
	Technician/ Tech. Engineer	*0*	*0*	*0*	*0*
Missing Manpower [FTE]		**1**	**2.7**	**1.7**	**1.7**
	Engineer/Physicist				
	Technician/ Tech. Engineer		*0.2*	*0.2*	*0.2*
	Graduate		*0.5*	*0.5*	*0.5*
	TS/PhD	*1*	*2*	*1*	*1*
	Associate				
	TOTAL [FTE]	***2.2***	***4***	***3***	***3***
Material Budget [kCHF]					
	Design and prototyping	*80*	*80*	*80*	*80*
	FSUs	*10*	*10*	*10*	*10*
	M4P	*0*	*135*	*95*	*95*
	AOB (travel., collab.)				
	Total [kCHF]	***90***	***225***	***185***	***185***

Beam instrumentation workpackage

Task 5 - Transverse Beam Size/Profile Monitoring (Stefano, Daniele, KEK, Alba, Uni. Milano)

Design and prototype of a Beam Size monitoring system based on Synchrotron Radiation interferometer

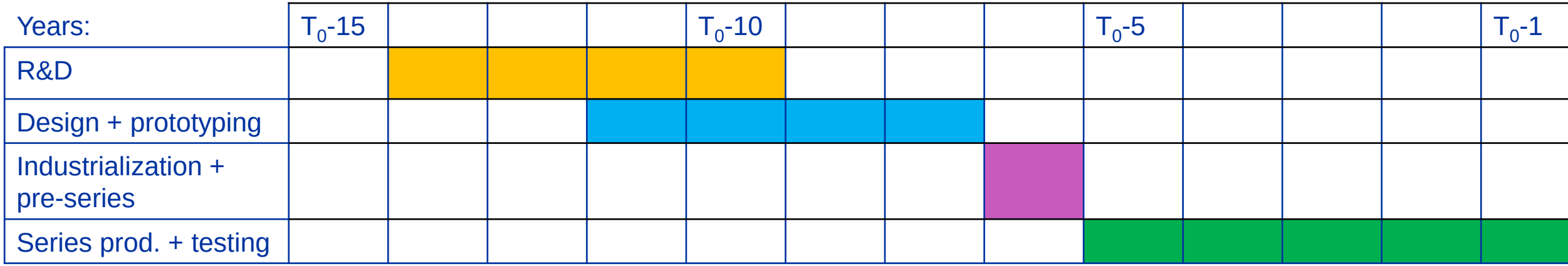
- Simulations of the Synchrotron radiation source properties and of the SR extraction system.
- X-ray monitor systems using Pinhole imaging systems and interferometric systems (KEK, Alba, Univ. Milano)

Design of a Beam Profile monitoring system based Laser wire scanner

- System design and integration including beam tracking simulations of Compton photons and electrons (similar to polarimeter)

Design of a Beam imaging system – larger system and different designs

- System designed reusing standard solution adapted to FCCee needs



- Complex design of SR based monitors requiring longer R&D, several iteration for design
- Medium numbers of Beam imaging sytems across the complex
- Some diversity in equipment types, X-ray detectors, laser and optics

Beam instrumentation workpackage

Task 5 - Transverse Beam Size/Profile Monitoring (Stefano, Daniele, KEK, Alba, Uni. Milano)

Design and prototype of a Beam Size monitoring system based on Synchrotron Radiation interferometer

- Simulations of the Synchrotron radiation source properties and of the SR extraction system
- X-ray monitor systems using Pinhole imaging systems and interferc

Design of a Beam Profile monitoring system based Laser w

- System design and integration including beam tracking simulations

Design of a Beam imaging system – larger system and diffe

- System designed reusing standard solution adapted to FCCee nee

- Covered with existing staffs and graduates
  - Would need add. Staff in 2027
- New Ph.D student requested for SR monitor design, prototype and validation
- Graduate for the TDR phase
- Material budget for developing detectors and testing prototypes (collab with Uni. Milano and Alba)

Task 5 : Transverse Profile Monitoring		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**0.6**	**0.7**	**0.2**	**0.2**
	Engineer/Physicist	*0.6*	*0.7*	*0.2*	*0.2*
	Technician/ Tech. Engineer	*0*	*0*	*0*	*0*
Missing Manpower [FTE]		**0**	**1.2**	**2.7**	**2.7**
	Engineer/Physicist			*1*	*1*
	Technician/ Tech. Engineer		*0.2*	*0.2*	*0.2*
	Graduate			*0.5*	*0.5*
	TS/PhD		*1*	*1*	*1*
	Associate				
	TOTAL [FTE]	***0.6***	***1.9***	***2.9***	***2.9***
Material Budget [kCHF]					
	Design and prototyping	*100*	*150*	*150*	*150*
	FSUs				
	M4P	*0*	*40*	*95*	*95*
	AOB (travel., collab.)	*110*	*60*	*10*	*10*
	Total [kCHF]	***210***	***250***	***255***	***255***

Beam instrumentation workpackage

Task 6 – Longitudinal profile Monitoring (Andreas, Kacper. KIT)

Design and prototype of a Bunch Length monitoring system based on Electro-Optical (EO) Spectral Decoding (KIT)

- Design and prototyping of an in-vacuum, low impedance EO pick-up with appropriated resolution
- Design of a bunch-by-bunch, turn-by-turn acquisition system with sub-picosecond time resolution

Design and prototype of a Bunch Length monitoring system based beam induced radiation (CERN)

- Design of radiation source : Synchrotron radiation or Cherenkov Diffraction radiation
- Testing of incoherent Cherenkov Diffraction radiation (KEK and IOTA)
- Testing of coherent radiation monitoring at CLEAR

Years:	T_0-15				T_0-10				T_0-5				T_0-1
R&D													
Design + prototyping													
Industrialization + pre-series													
Series prod. + testing													

- New technologies requiring longer R&D, several iterations for design and prototyping
- Collaboration with KIT, RHUL, KEK and FNAL

Beam instrumentation workpackage

Task 6 – Longitudinal profile Monitoring (Andreas, Kacper, KIT)

Design and prototype of a Bunch Length monitoring system based on Electro-Optical (EO) Spectral Decoding (KIT)

- Design and prototyping of an in-vacuum, low impedance EO pick-up with ap
- Design of a bunch-by-bunch, turn-by-turn acquisition system with sub-picose

Design and prototype of a Bunch Length monitoring system ba

- Design of radiation source : Synchrotron radiation or Cherenkov Diffraction r
- Testing of incoherent Cherenkov Diffraction radiation (KEK and IOTA)
- Testing of coherent radiation monitoring at CLEAR

- Covered with existing graduates (not funded by FCC)
  - Would need add. Staff in 2027
- New Ph.D students requested for monitor design, prototype and validation
- Material budget for developing detectors and testing prototypes at CLEAR, ATF2@KEK and IOTA@FNAL

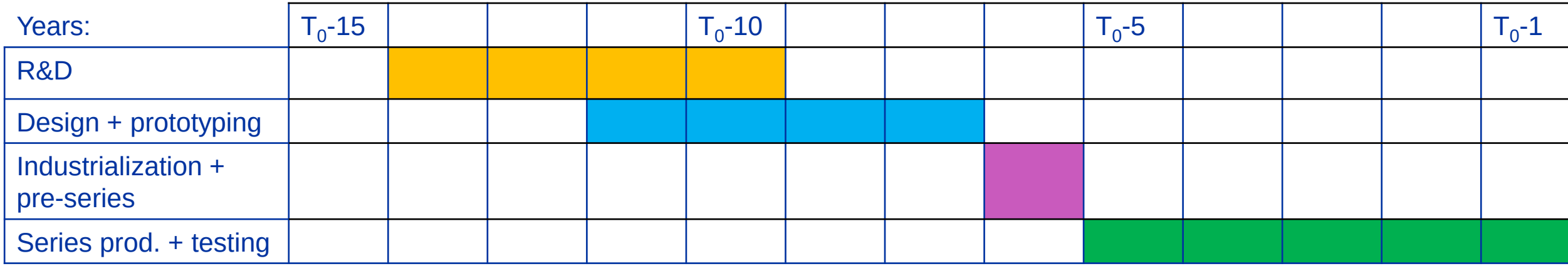
Task 6 : Longiudinal Profile Monitoring		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**0.5**	**0.5**	**0**	**0**
	Engineer/Physicist	*0.5*	*0.5*		
	Technician/ Tech. Engineer	*0*	*0*	*0*	*0*
Missing Manpower [FTE]		**0.5**	**2.2**	**3.2**	**2.7**
	Engineer/Physicist			*1*	*1*
	Technician/ Tech. Engineer		*0.2*	*0.2*	*0.2*
	Graduate				
	TS/PhD	*0.5*	*2*	*2*	*1.5*
	Associate				
	TOTAL [FTE]	***1***	***2.7***	***3.2***	***2.7***
Material Budget [kCHF]					
	Design and prototyping	*100*	*100*	*100*	*100*
	FSUs	*10*	*10*	*10*	*10*
	M4P	*20*	*80*	*80*	*60*
	AOB (travel., collab.)	*20*	*20*	*20*	*20*
	Total [kCHF]	***150***	***210***	***210***	***190***

Beam instrumentation workpackage

Task 7- Energy Calibration and Polarisation with EPOL WG (Robert)

Compton Polarimeter

- System design and integration including beam tracking simulations of Compton scattered photons and electrons
- Design of laser technology, laser interaction chamber, detection of Compton scattered photons and electrons. It includes impedance studies for laser interaction chamber.
- Prototype of the laser system, the interaction chamber and the detectors



- Complex system and integration requiring R&D, several iterations for design and prototyping
- EPOL WG with external collaborators (IJClab) and SY-STI for laser systems

Beam instrumentation workpackage

Task 7- Energy Calibration and Polarisation with EPOL WG (Robert)

Compton Polarimeter

- System design and integration including beam tracking simulations of C
- Design of laser technology, laser interaction chamber, detection of Com studies for laser interaction chamber.
- Prototype of the laser system, the interaction chamber and the detectors

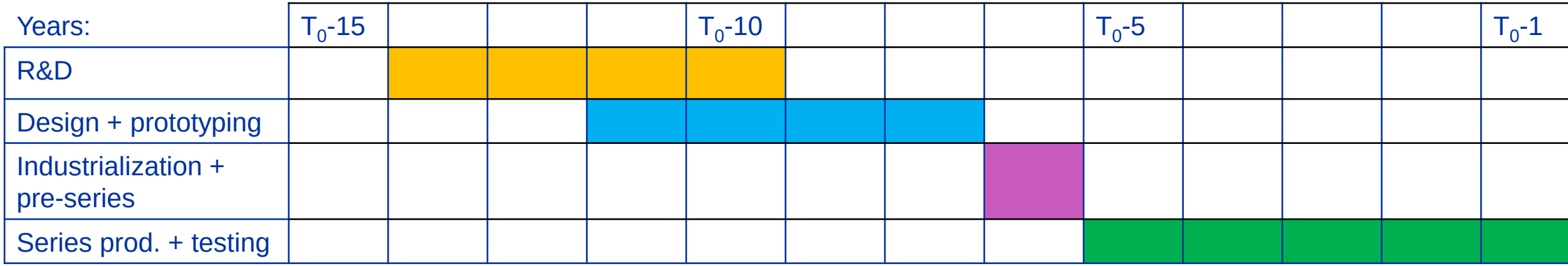
- Covered with existing staff
- New Ph.D student requested for monitor design, prototype and validation
- Material budget for developing detectors and testing prototypes

Task 7 : Energy Calibration & Polarisation		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**0.5**	**0.5**	**0.5**	**0.5**
	Engineer/Physicist	*0.5*	*0.5*	*0.5*	*0.5*
	Technician/ Tech. Engineer				
Missing Manpower [FTE]		**1**	**1.2**	**1.2**	**1.2**
	Engineer/Physicist				
	Technician/ Tech. Engineer		*0.2*	*0.2*	*0.2*
	Graduate				
	TS/PhD	*1*	*1*	*1*	*1*
	Associate				
	TOTAL [FTE]	***1.5***	***1.7***	***1.7***	***1.7***
Material Budget [kCHF]					
	Design and prototyping		*50*	*200*	*200*
	FSUs			*10*	*10*
	M4P	*40*	*40*	*40*	*40*
	AOB (travel., collab	*10*	*10*	*10*	*10*
	Total [kCHF]	***50***	***100***	***260***	***260***

Beam instrumentation workpackage

Task 8 - Luminosity monitoring (Robert)
Design, integration and prototyping of a Beamstrahlung monitor

Design, integration and prototyping of a Bhabha scattering monitor



- Complex system and integration requiring R&D, several iterations for design and prototyping
- MDI WG and collaboration with SY-STI for BS dump line

Beam instrumentation workpackage

Task 8 - Luminosity monitoring

Design, integration and prototyping of a Beamstrahlung

Design, integration and prototyping of a Bhabha scatter

- Covered with existing staff
- New Ph.D student requested for monitor design, prototype and validation
- Material budget for developing detectors and testing prototypes

Task 8 : Luminosity Monitoring / Beamstrahlung		**2025**	**2026**	**2027**	**2028**
Available Manpower [FTE]		**0.5**	**0.5**	**0.5**	**0.5**
	Engineer/Physicist	*0.5*	*0.5*	*0.5*	*0.5*
	Technician/ Tech. Engineer				
Missing Manpower [FTE]		**1**	**1.2**	**1.2**	**1.2**
	Engineer/Physicist				
	Technician/ Tech. Engineer		*0.2*	*0.2*	*0.2*
	Graduate				
	TS/PhD	*1*	*1*	*1*	*1*
	Associate				
	TOTAL [FTE]	***1.5***	***1.7***	***1.7***	***1.7***
Material Budget [kCHF]					
	Design and prototyping		*50*	*200*	*200*
	FSUs			*10*	*10*
	M4P	*40*	*40*	*40*	*40*
	AOB (travel., collab	*10*	*10*	*10*	*10*
	Total [KCHF]	***50***	***100***	***260***	***260***

Beam instrumentation workpackage

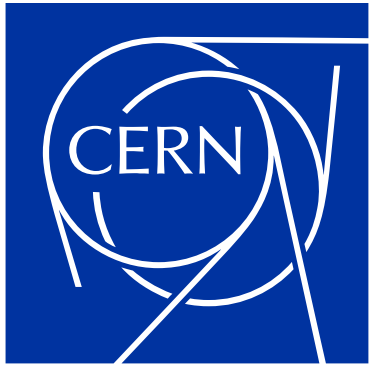
Total BI		2025	2026	2027	2028
Available Manpower [FTE]		**4**	**5.2**	**4.3**	**4.3**
	Engineer/Physicist	*4*	*5.2*	*4.3*	*4.3*
	Technician/ Tech. Engineer	*0*	*0*	*0*	*0*
Missing Manpower [FTE]		**4.5**	**10**	**11.8**	**11.3**
	Engineer/Physicist	*0*	*0*	*2*	*2*
	Technician/ Tech. Engineer	*0*	*1*	*1.3*	*1.3*
	Graduate	*0*	*1*	*1.5*	*1.5*
	TS/PhD	*4.5*	*8*	*7*	*6.5*
	Associate	*0*	*0*	*0*	*0*
	TOTAL [FTE]	***8.5***	***15.2***	***16.1***	***15.6***
Material Budget [kCHF]					
	Design and prototyping	*380*	*550*	*850*	*850*
	FSUs	*20*	*30*	*50*	*50*
	M4P	*140*	*430*	*445*	*425*
	AOB (travel., collab	*180*	*130*	*80*	*80*
	Total [kCHF]	***720***	***1140***	***1425***	***1405***

- Most of BI workpackages would need support from impedance working group and design office (MME)
- Extra staffs in 2027 for transverse and longitudinal profile monitoring
- Question on extra staff for Orbit feedback ?
- After 2026, we would also need add. Support for design and integration (MME). This would also require a new staff in BI (Tech. engineer) to follow this up
- Mainly asking for TS/Ph. D students and very few graduates.

Conclusion

- We have put in place a plan to meet the FCC FS and TDR goals
  - We would like to have the plan reviewed, possibly approved and funded
  - Some extra staffs needed in 2027 (middle of LS3)
- The most challenging tasks have been started already.
- Interaction with many working groups (integration, impedance, alignment, machine protection, EPOL and MDI)
- A structure like the one of Hilumi with workpackages and a clear interface with the project structure will be beneficial.

Thanks for your attention



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Beam instrumentation workpackage

The different tasks would actually require the support of several CERN groups, especially

- **Integration team**
- **Design office**
- **Central Workshop, metrology etc…**
- Controls hardware, software and communication
- Vacuum and surface technologies
- Cabling
- Energy requirements
- Alignment and Geodesy
- Support from Operation (CLEAR, SPS North Area)