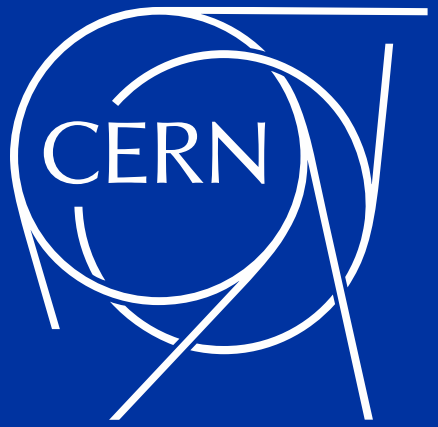


Preparing the evolution from Copper to Fibre Optics at CERN (ATS and beyond)

Joint Electronics Forum and RadWG

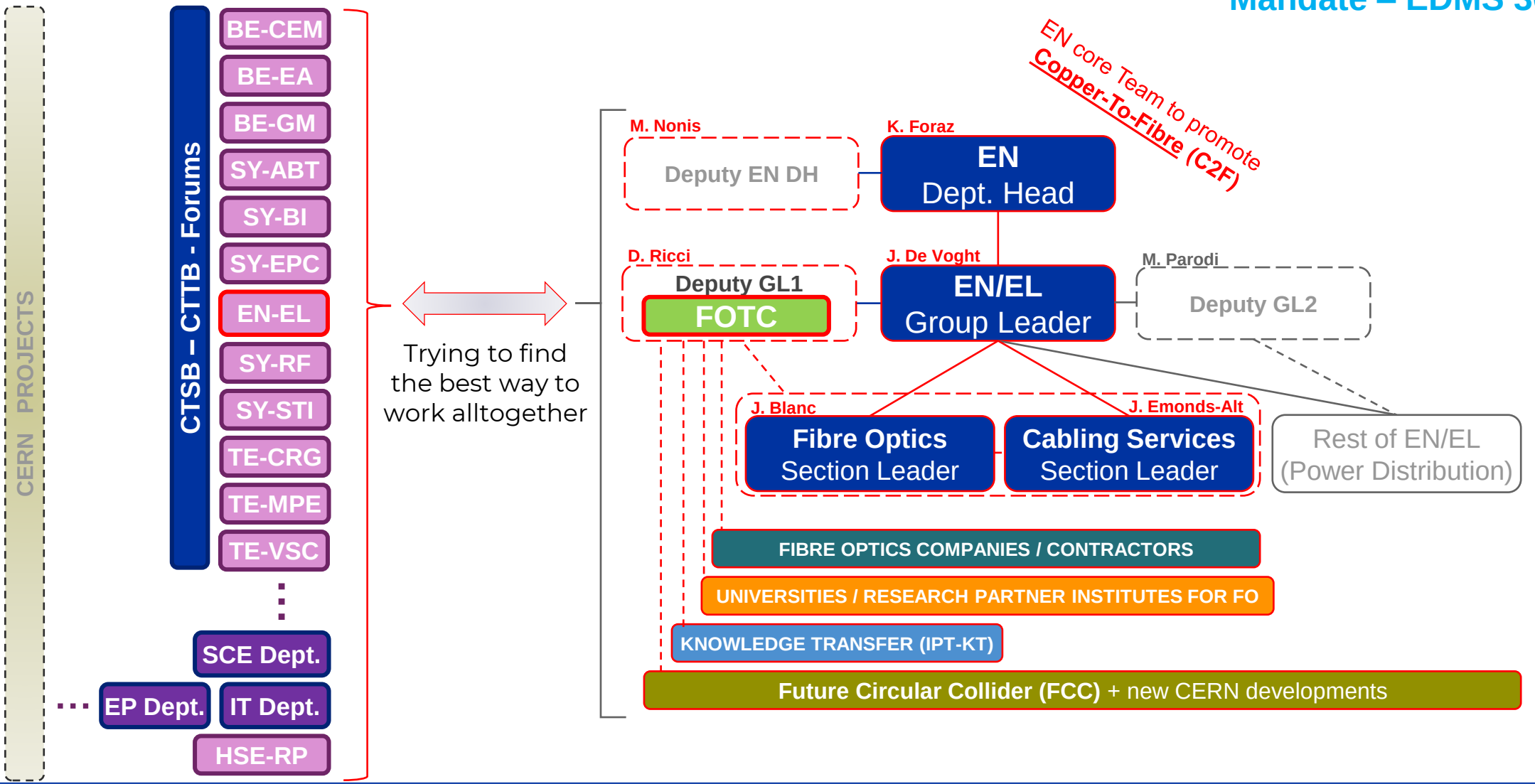
Daniel RICCI – EN/EL Fibre Optics Technology Coordinator

2024-06-20

Indico: 1423974

Fibre Optics Technology Coordinator (FOTC)

Mandate – EDMS 3082996



Conclusions (?!!)

We (ATS) need to **buy a full set of certified rad-tol opto-components**

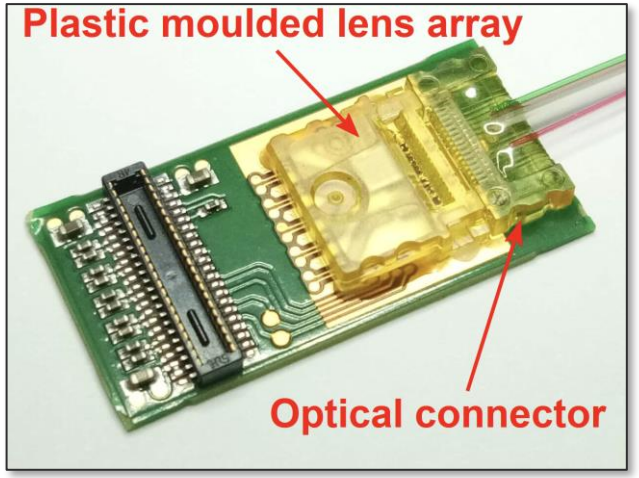
- Lasers, laser drivers, optical transceivers (see J. Troska's talk)

We need to buy them **NOW** from EP-ESE

- Profiting of a **new contract in preparation**;

Money should not be a worry/driver at this stage → we talk technical, … and we come out with a list of possible needs!

- To be finalized at the **next EF + RadWG joint meeting** (August? early September?)



Outline

- Copper cabling situation in the accelerators
- Existing (or quasi-existing) opto-electronics system solutions
- Feedback from past experience
- Proposal and open discussion

Copper cabling situation in the accelerators

…at a glance

- **~450,000 copper cables (mostly signal) registered in the EN-EL database**
- **Most of the injector areas (and related galleries) are clogged. LHC areas soon to come**
- **Cabling services provoked project arbitration for both LS1 (2013-14) and LS2 (2019-21)**
  - Will be hardly accepted for LS3 (2026-28)
  - Not tolerated for LS4 (2033-34)
- **De-cabling project was launched in 2016 (to continue up to LS3)**
  - Massive investment of resources (~10MCHF in 10 years + proj. coordination)
  - Still removed volumes are insufficient to free space durably
- **Replacement of irradiated (and aging) cables in the injectors**
  - ~1 MCHF per SPS half-point (>1000 cables) + ALARA 3 + removal beam-line
  - ~30m^3 of radioactive waste
  - Not anymore able to keep the periodicity within current LS schedule
  - LHC never done so far: estimated at double the complexity for P3 and P7

Future project cabling remains challenging

HL-LHC, NA-CONS, PSS, Acc. systems Cons/Upgrade, …

Signal copper cables vs optical fibres for HL-LHC

Daniel RICCI (Fibre Optics & Cabling, EN-EL-FC)
HL-LHC TCC meeting 15 April 2021

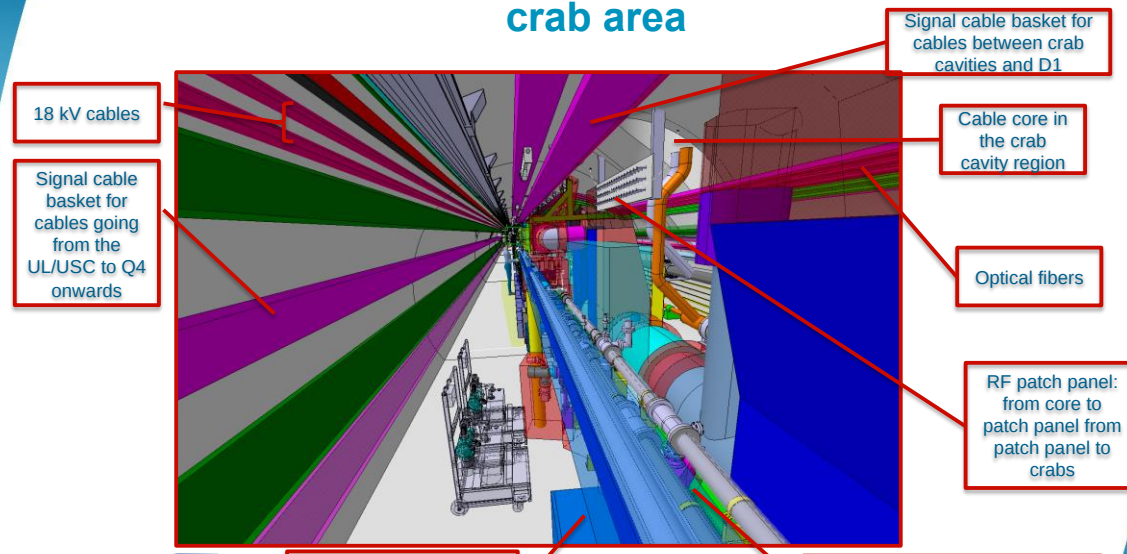
Acknowledgments: J. BLANC, D. DE LUCA, S. MACHADO

CERN | EN ENGINEERING DEPARTMENT

EDMS 2536098

From the HL-LHC C&S cabling review (Nov 2022)

Integration, a quick view from RR towards the IP crab area



Conclusions II

The cable tray integration in the LHC tunnel is a major challenge that has been requiring a lot of resources. The limited real estate available has led to reduce the quantity of available space for spare cables (see S. Bertolasi presentation). The choice of basket is not the preferred one, but no other solutions have been identified. (If in P1 the larger tunnel size will allow to use a less aggressive approach, this will be implemented). In the last days EN-EL has pointed out that, following the latest PRE-DIC, some cable tray section would not be enough to host all the required cables. We will start tackling this new issue from next week. The cable tray philosophy cannot change; local adjustments could be needed, requiring (i.e.) the use locally of special cable tray profiles.

Enabling copper-to-fibre conversion

Motivation:

- Keep organising **copper cabling** in the accelerators like today is **not realistic in the long-term**
- There is a clear requirement from the hierarchy to come out with **innovative solutions**, in order **to drastically limit the impact of arbitrations** in preparation of long-shutdowns
  - …while possibly optimising the space in the machines, to limit civil engineering and operation costs
  - …while possibly reducing the radioactive waste and power consumption (green transition)
- **Optical fibre passive components and installation techniques** are nowadays **mature enough to support the transition**
  - Rad-resistant fibres available for multiple applications
  - Specialty hollow core fibre R&D launched
  - Air-blowing technique is consolidated

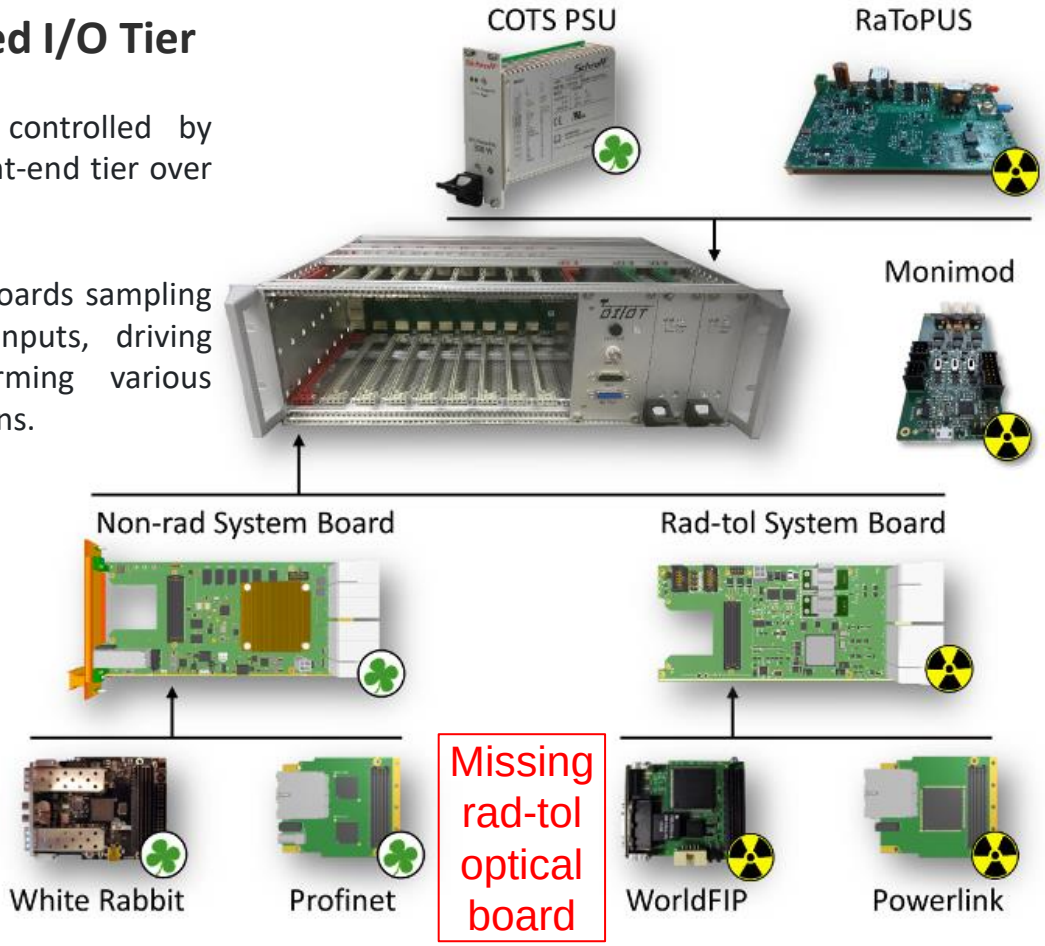
How to achieve maturity on the active equipment (rad-tol) side?

Existing opto-electronics solutions

*Developed in **BE-CEM***

DI/OT - Distributed I/O Tier

- electronics modules controlled by the master in the Front-end tier over the fieldbus.
- Usually FPGA-based boards sampling digital and analog inputs, driving outputs and performing various safety critical operations.



One available **optical** board (non-rad)

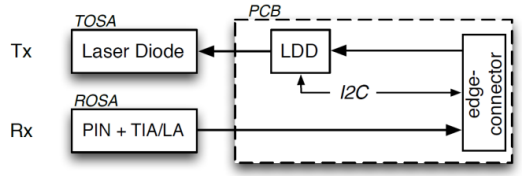
Missing rad-tol optical board

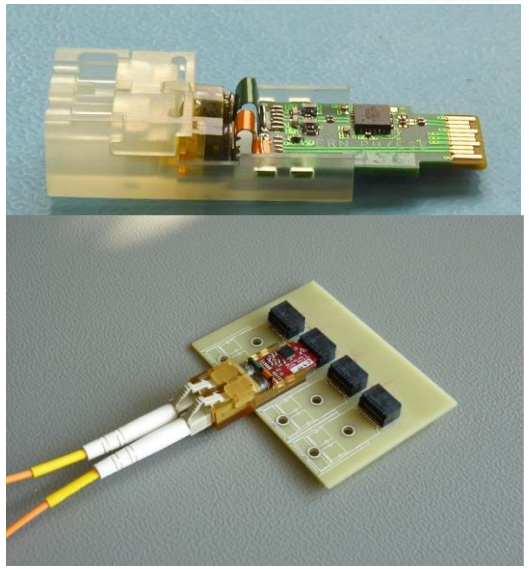
Courtesy Grzegorz Daniluk (BE-CEM) – Wiki: https://ohwr.org/project/diot/wikis/home

*Past development in **EP-ESE***
(precursor of the current CTRx and CTTx)

Versatile Transceiver (VTRx)

- bi-directional rad-tol custom-developed module loosely following the SFP+ form-factor

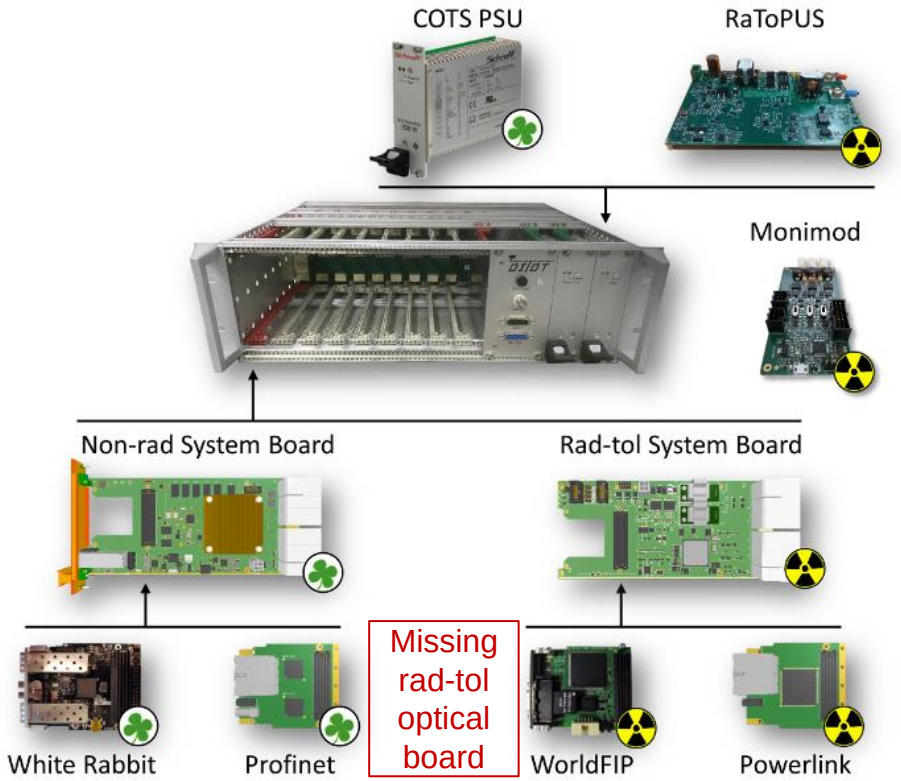




Courtesy F. Vasey et al. (EP-ESE) – Versatile Link Application Note v2.7

Quasi-existing opto-electronics solutions…?

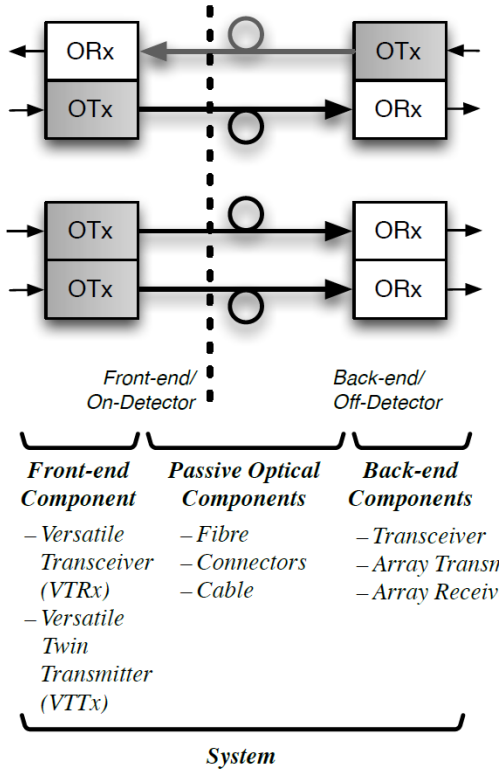
DI/OT - Distributed I/O Tier



Past development in EP-ESE
(precursor of the current CTRx and CTTx)

Versatile Link architecture

- Customized (rad-tol) VTRx at front-end
- COTS TRx at back-end
- Conventional SM or MM optical fibres (rad-tol available)



Front-end VTRx	Fiber	Back-end TRx
EE Laser, 1310 nm InGaAs PIN, 1310 nm	SM G.652a G.652b	LR-SFP+ TRx Board-edge Tx, Rx, TRx Mid-board Rx
VCSEL, 850 nm GaAs PIN, 850 nm	MM OM3 OM4	SR-SFP+ TRx Board-edge Tx, Rx, TRx Mid-board Tx, Rx, TRx

Could these two be effectively combined?

Activities in EP-ESE group (1/2)

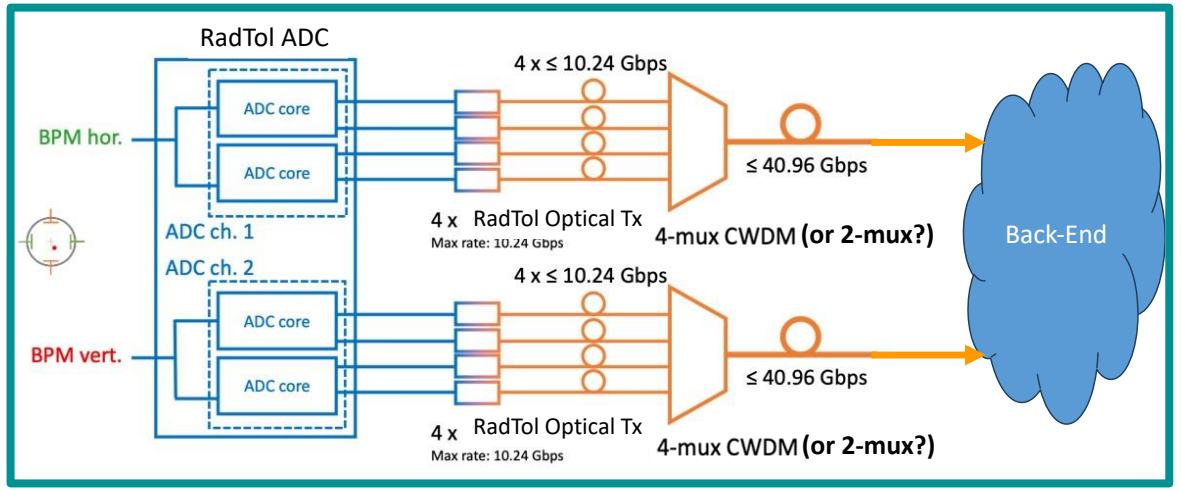
Electronics Systems for Experiments

Its expertise covers (among others): radiation-hard ASIC design, optical links, access to deep submicron technologies. ***It has unique expertise in radiation hard electronics and systems.***

Coarse Wavelength Division Multiplexing (CWDM)

- They are developing **with SY-BI a customization of the VTRx/VTTx single-mode module (CTRx/CTTx)** for the **BLM and BPM** consolidation projects.
  - This customization includes running the **Tx at 10Gbps**, and selecting its operation wavelength on a CWDM grid to allow wavelength multiplexing of **up to 4 channels into one fiber** (so, up to **40Gbps per fiber**).
  - This is a rolling project with a **production forecast of about 7000 modules (in one shot) by end-2025.**
  - **If more users** are interested in this concept, it would be relatively easy to **integrate them at this stage**, and to **build a stock of components** in view of a **standardized solution** available **from 2026 onwards**.

SY-BI: LHC BPM consolidation project



Radiation tested **COTS as an alternative to VTRx/VTTx** (Nov. 2022):

- Small and Quad Form-factor Pluggable transceivers (**SFP**, **QSFP**)
- **6 out of 8 DUT did not pass the test**

PAUL SCHERRER INSTITUT

COmpact MEdical Therapy cyclotron (COMET)

Courtesy Manoel Barros Marin (SY-BI) ***@RadWG****:*
https://indico.cern.ch/event/1383997/timetable/#20240222

Activities in EP-ESE group (2/2)

Electronics Systems for Experiments

- Longer term: they are doing **R&D on a 4x25G SM WDM system based on Si photonics**. This path is not fully developed yet, but it **would be an elegant standard solution for 100Gbps links from 2030 onwards**.

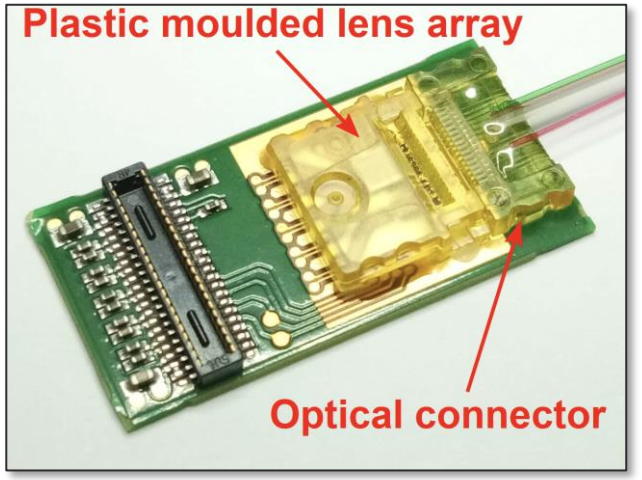
→ **FCC !**

To summarize, there are **two paths the ATS could follow**:

I. Keep on testing COTS, and establish a catalogue (and stock) of acceptable parts for selected environments;

II. Standardize **certified rad-tol components** produced by EP-ESE

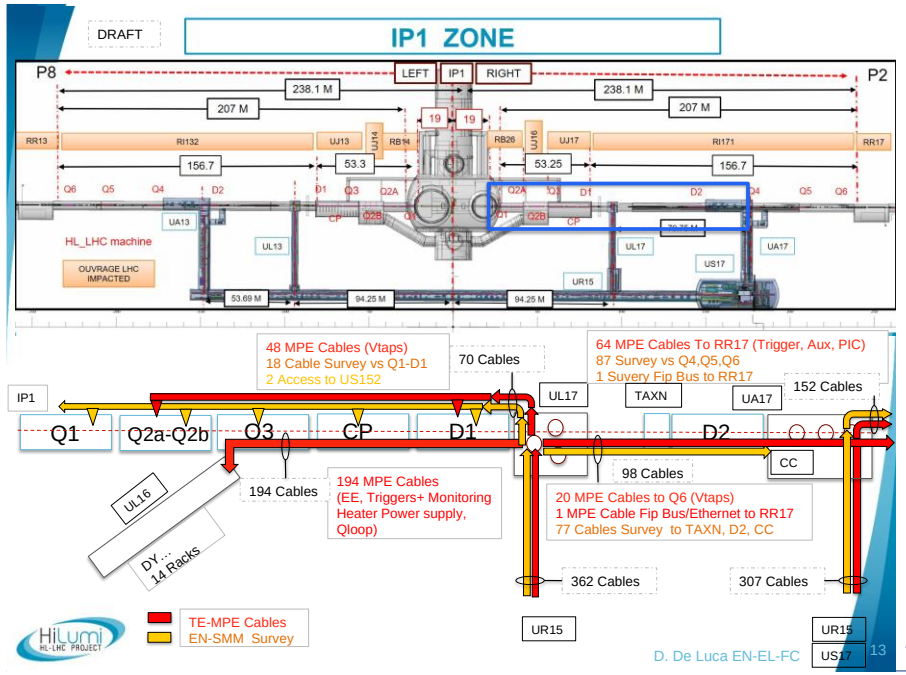
- **For the short term (2025):**
  - Short distance MM links: VTRx+
  - Long distance SM: CTRx/CTTx (as for BLM/BPM)
  - Note that **the time to decide on either short-term solution is NOW** as production (in the VTRx+ case) or procurement and qualification are **ongoing**.
- **For the long term (2030):**
  - **Contribute to R&D on Silicon photonics**



SOME FEEDBACK FROM PAST (AND PRESENT) EXPERIENCE

HL-LHC (speculation)

HL-LHC cabling plant (copper)



Typical configuration for two major systems transiting from UR to LHC (via UL and UA)

NB: numbers outdated

From the HL-HLC TCC meeting: 15 Apr 2021

Too late!

Replacement assumption

- 3 options considered
  1) 1 optical fibre = 1 copper wire

  2) 2 optical fibres = 1 signal cable

  3) 2 optical fibres = all signal cables between two positions

Summary of very preliminary estimates

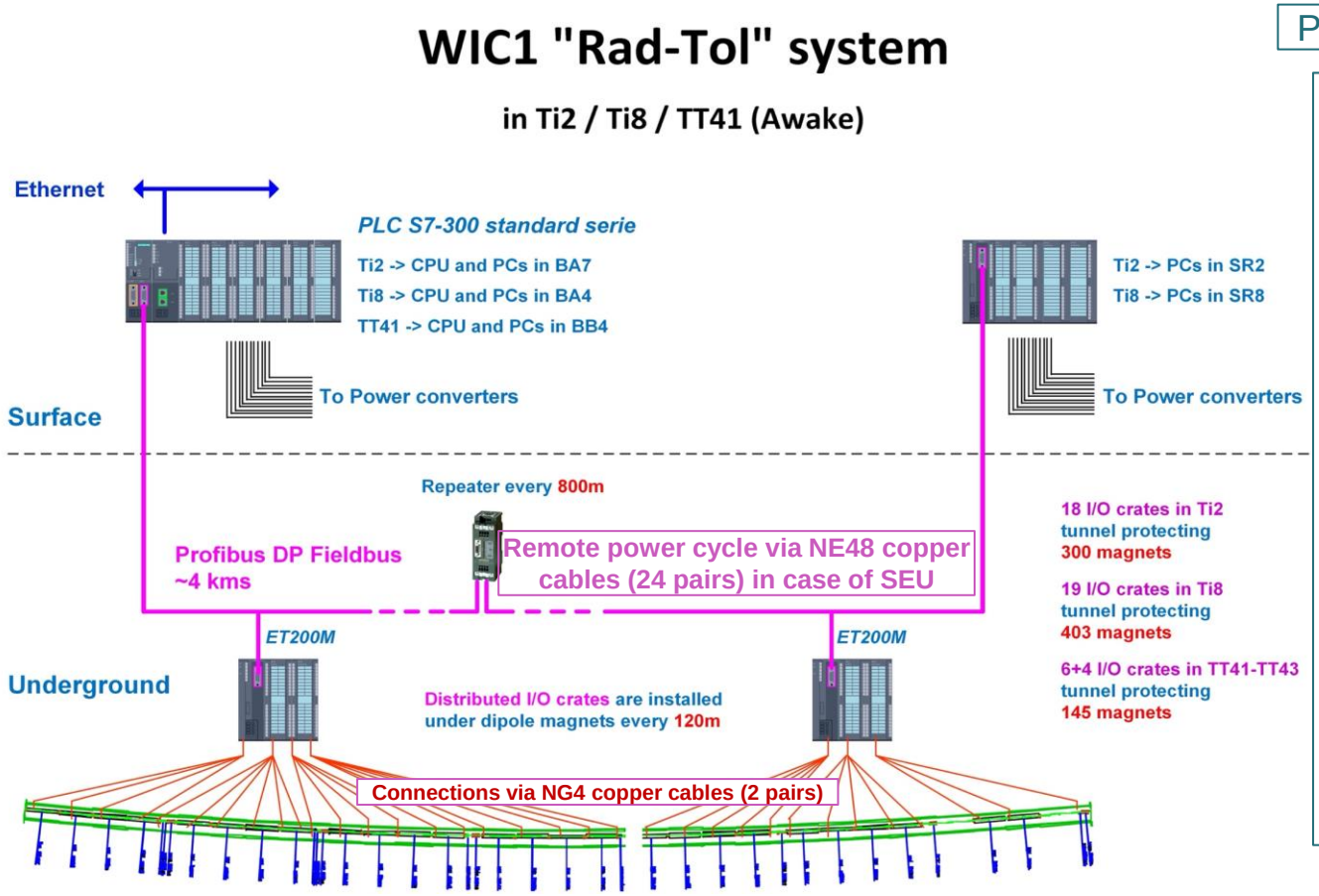
	Copper cables	Optical fibre (option 1)	Optical fibre (option 2)	Optical fibre (option 3)
Cable/duct quantity	87	11	3	2
Cable/duct length	13659 m	11500 m	2512 m	1727 m
Space occupancy in UL17	**154.10 cm²**	**68.75 cm²**	**18.75 cm²**	**12.5 cm²**
Space occupancy in racks	-	62U (LHC) + 48U (UR15)	14U (LHC) + 8U (UR15)	11U (LHC) + 4U (UR15)
Total cost	**112.6 kCHF**	**473 kCHF**	**84.5 kCHF**	**48 kCHF**

Most realistic option

Replacement of the WIC system (in YETS 2024-25)

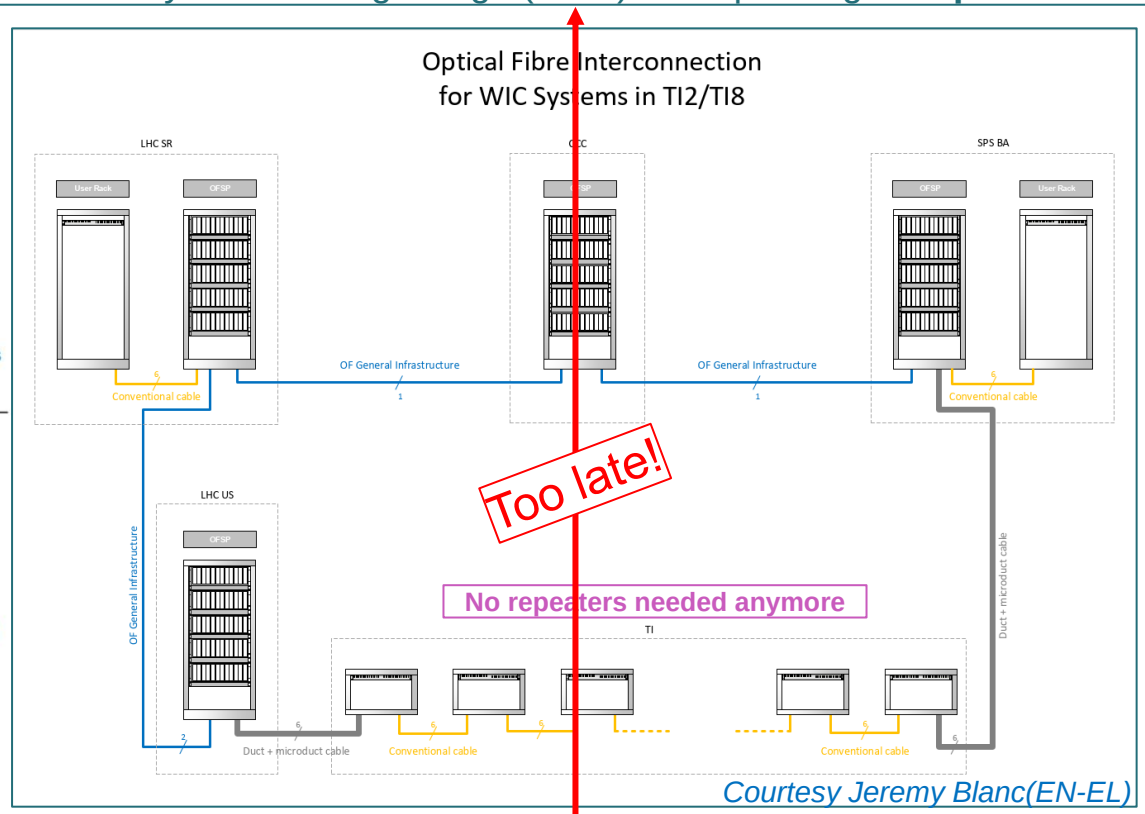
Warm Magnet Interlock Controller

Aging system to be replaced: **new design (copper based)** already **finalised and rolled out** for deployment (see backup slides)



Courtesy Richard Mompo (TE-MPE) - wic.web.cern.ch

Preliminary new-cabling design (**2022**) → all passing via **optical fibres**



Courtesy Jeremy Blanc(EN-EL)

Unavailability of opto rad-tol cards for the crates, lead to abandon this design

FCC – Future Circular Collider

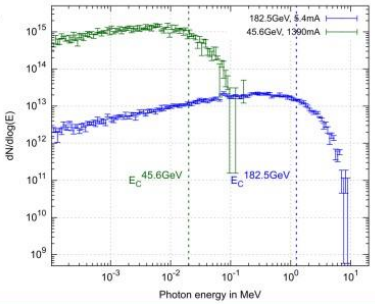
FCC-ee Radiation and Shielding Meeting: raises questions on radiation resistance of systems active equipment and cabling.

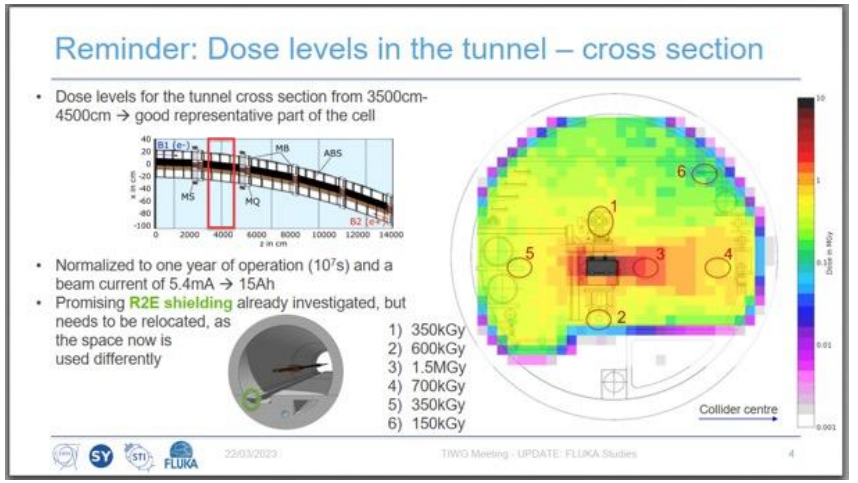
- Simulated radiation levels in FCC-ee arcs are very high for optical fibres.
- Given the size of FCC optical links are expected to be very long

FCC-ee will require further developments of radiation resistant OF technologies

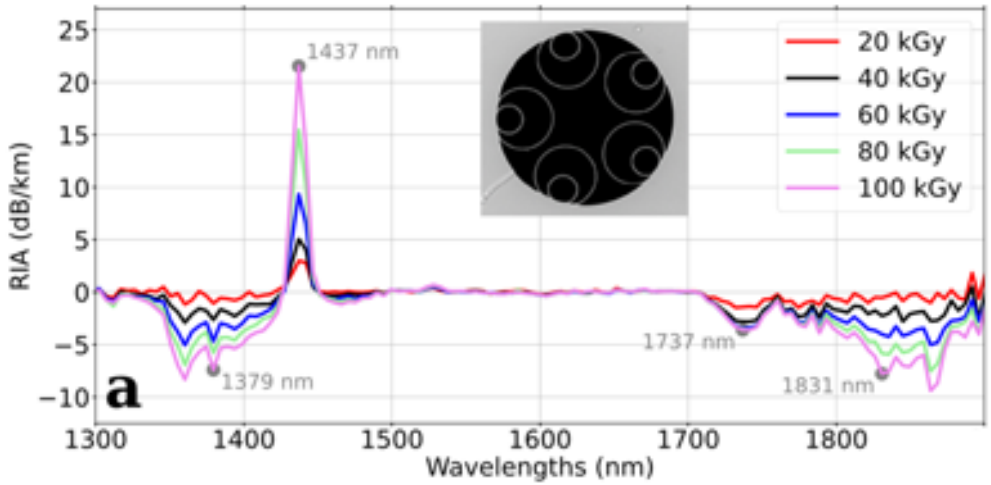
Courtesy of B. Humann

	LEP (100GeV, 15A*h)	HL-LHC (per year)	FCC-ee (182.5GeV, 15A*h)
2)	2-3kGy	1.4Gy	600kGy
5)	50kGy		350kGy
6)	4-5kGy		150kGy





RECORD RADIATION RESISTANCE [7]



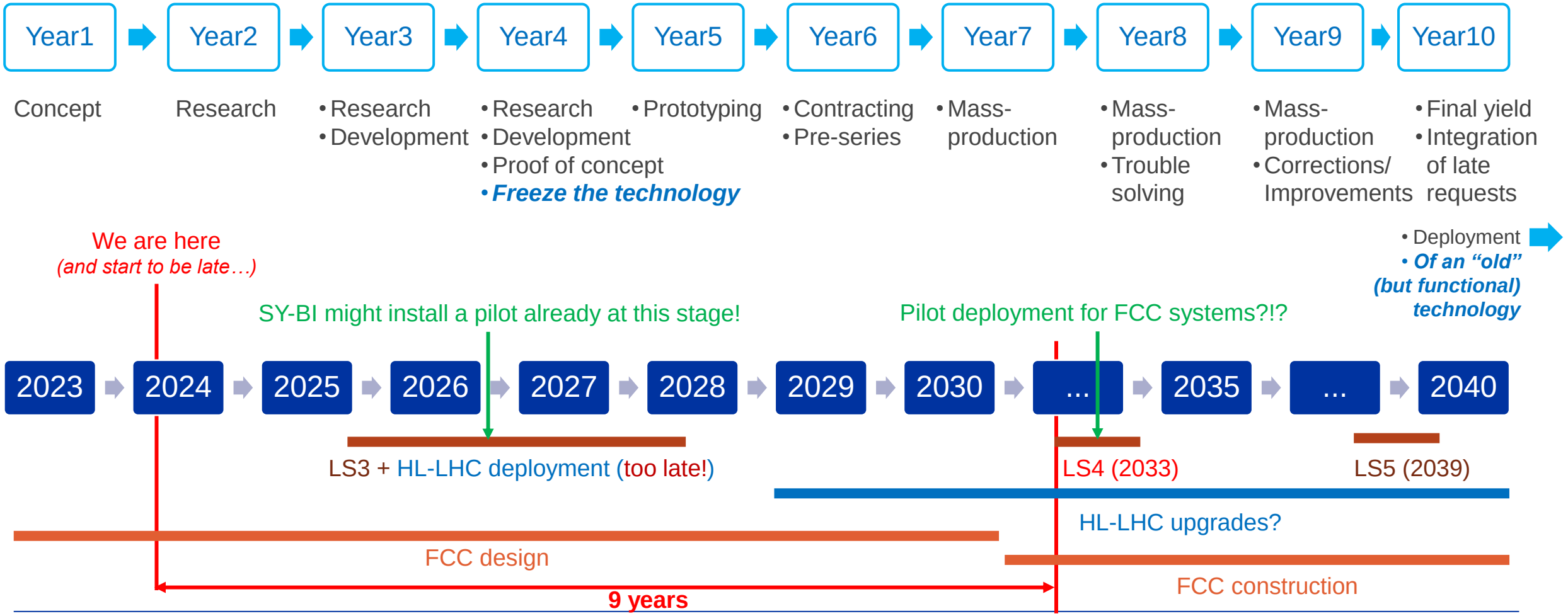
First spectral study of a nested anti-resonant hollow core fibre demonstrating 200 nm of near-zero radiation induced attenuation (C+L bands)

EN-EL is **anticipating** this trend by sustaining an R&D program on next generation **radiation-immune (hollow core) fibres**.

Good basis for a more structured coordination with active equipment designers...
see Versatile Link+ in backup slides, as an example

Locate ourselves…

A typical R&D process may take ~ 5-7 years. Plus 2-4 years more to achieve stability and high yield in the mass-production → we span over ~10 years (at best…)



Proposal for an open discussion

Seeking for the collaboration of the groups represented at the *Electronics Forum & Radiation Working Group* **to promote a change of mindset** across the organisation:

- To progressively switch **from copper to fibre optics technology** (~10 years)
- With the endorsement of the Common Hardware & Software Technologies Technical Board (CTTB)

We have now a good momentum at CERN to capitalize the efforts done on:

- ✓ **Pre-assessing rad-tol COTS** transceivers (by **BE-CEM** and **SY-BI,** via **RadWG**)
  - E.g.1: Radiation test campaign in Nov 2022 on COTS transceivers for BPM devices
  - E.g.2: bPOL project (DCDC converters)
- ✓ **Co-developing new ad-hoc transceiver concepts** (by **EP-ESE and ATS**)
- ✓ **Mass-producing certified rad-tol transceivers** → contract is running now! (by **EP-ESE**)
- ✓ Preparing the **new generation optical fibres** for existing **accelerator complex and FCC** (by **EN-EL**)

PILOT:

➢ **Target the development of a rad-tol opto-electronics board to add to the existing DI/OT catalogue**

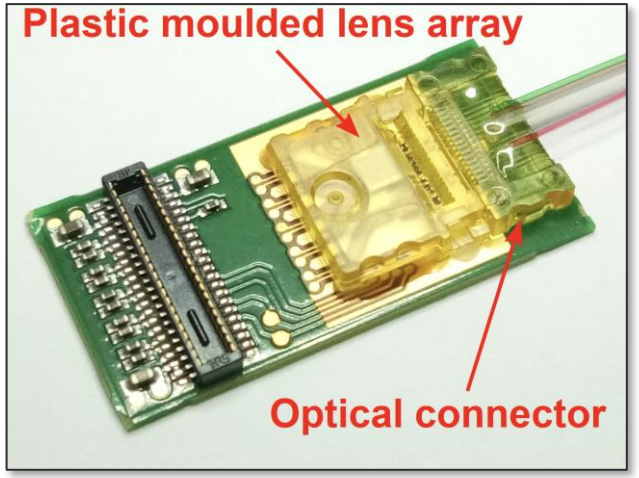
❑ To fill up the DI/OT catalogue void in rad-tol opto-components

MORE PILOTS ARE WELCOME!

Conclusions (~~?!~~)

We (ATS) need to **buy a full set of certified rad-tol opto-components**

- Lasers, laser drivers, optical transceivers (see J. Troska's talk)
- **To practice**, during the next 2-3 years, the design and development of optical links
  - replacing progressively the existing copper links?
  - as a new technological concept for CERN future projects/machines.

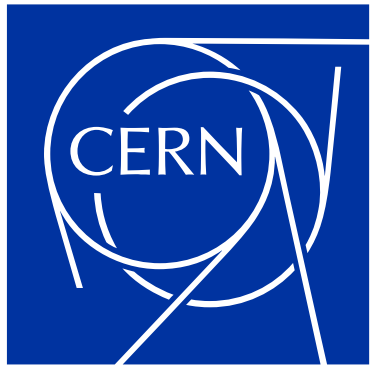


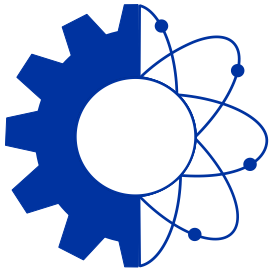
We need to buy them **NOW** from EP-ESE

- Profiting of a **new contract in preparation**;
- The purchase list to be compiled by the **end of the summer** (…2024)

Money should not be a worry/driver at this stage → we talk technical,
… and we come out with a list of possible needs!

- To be finalized in the **next EF + RadWG joint meeting** (August? early September?)
- Actual **cost estimate** for the purchase to be updated **in parallel**;
- **Logistics for the storage** of the components at the ATS premises to be defined **in parallel**;
- **FOTC to sponsor this at CTTB and with Dept. Head(s), as required**.





ENGINEERING
DEPARTMENT

Daniel.Ricci@cern.ch

home.cern

Reference sites and publications

- **DI/OT page**: https://ohwr.org/project/diot/wikis/home

- **"WARM MAGNET INTERLOCK SYSTEM (WIC) FOR THE SPS" by Richard MOMPO**
  Link: https://edms.cern.ch/document/SPS-CIW-ES-0001/2.0/approvalAndComments

- **Versatile Link PLUS project page:** https://cern.sharepoint.com/sites/project-Versatile-Link-Plus

2023 EN-EL Fibre Optics publications:

1. D. Di Francesca *et al.*, "Low radiation dose calibration and theoretical model of an optical fiber dosimeter for the International Space Station," *Appl. Opt.*, vol. 62, no. 16, p. E43, Jun. 2023.
2. N. Kerboub *et al.*, "Radiation Induced Attenuation and Luminescence study in Radioluminescent Optical Fibres," *IEEE Trans. Nucl. Sci.*, pp. 1–1, 2023.
3. K. Biłko et al., "CERN Super Proton Synchrotron radiation environment and related Radiation Hardness Assurance implications," *IEEE Trans. Nucl. Sci*., pp. 1–1, 2023.
4. M. Roche et al. "Solar Particle Event Detection with the LUMINA Optical Fiber Dosimeter aboard the International Space Station" submitted to *IEEE Trans. Nucl. Scie*.
5. K.Bilko et al. "Overview of total ionizing dose levels in the large hadron collider during 2022 restart" accepted in *IEEE Trans. Nucl. Scie*.
6. D. Prelipcean et al. "Measured and FLUKA simulated radiation levels from proton collision losses during Run II of the CERN Large Hadron Collider at the high luminosity interaction points and the radiation to electronics impact on its operation" to be submitted to *Phys. Rev. Acceler. and Beams*.
7. S. Medaer et al., "Near-infrared Radiation Induced Attenuation in Nested Anti-resonant Hollow-core Fibres," *Opt. Lett.*, vol. 48, no. 23, p. 6224, Dec. 2023.
8. Kandemir K., Tagkoudi E. et al. "Investigation of Ge/P-doped Silica-Based Optical Fibers for Radiation Sensing", submitted to *IEEE Trans. Nucl. Scie*. 2023.

Reference presentations on C2F

- D. Ricci, "**Preparing the evolution from Copper to Optical Fibres – a brainstorming on opto-electronics system options**", RadWG Workshop 24 Feb 2023 - Link: https://indico.cern.ch/event/1257469/timetable/

- D. Ricci, "**Preparing the evolution from Copper to Optical Fibres at CERN (ATS and beyond)**", CTTB 15 Mar 2024 - Link: https://indico.cern.ch/event/1241509/

➢ **To the members of the joint EF + RadWG: let me know if you want to add your relevant presentation(s)…**

BACKUP SLIDES

Some detailed feedback from EP-ESE

- Available to work together to identify the right partner group in the AT sector to develop something that meets the requirements.
  - To come up with an engineered solution to the problems identified in this talk.

- EP-ESE has expertise and pedigree to design optical link systems for deployment in future systems for the accelerators. But this will have to be a new development, to match whatever the requirements are.
  - The model for working with the Experiments is that common developments take place that will be useful to a wide range of users. These users commit to paying for the parts once they are delivered. The EP department provides a line of funding to pay for components during production, but there is no stock kept after the production is complete. If the AT sector would like to put in place a similar model then this could be done.

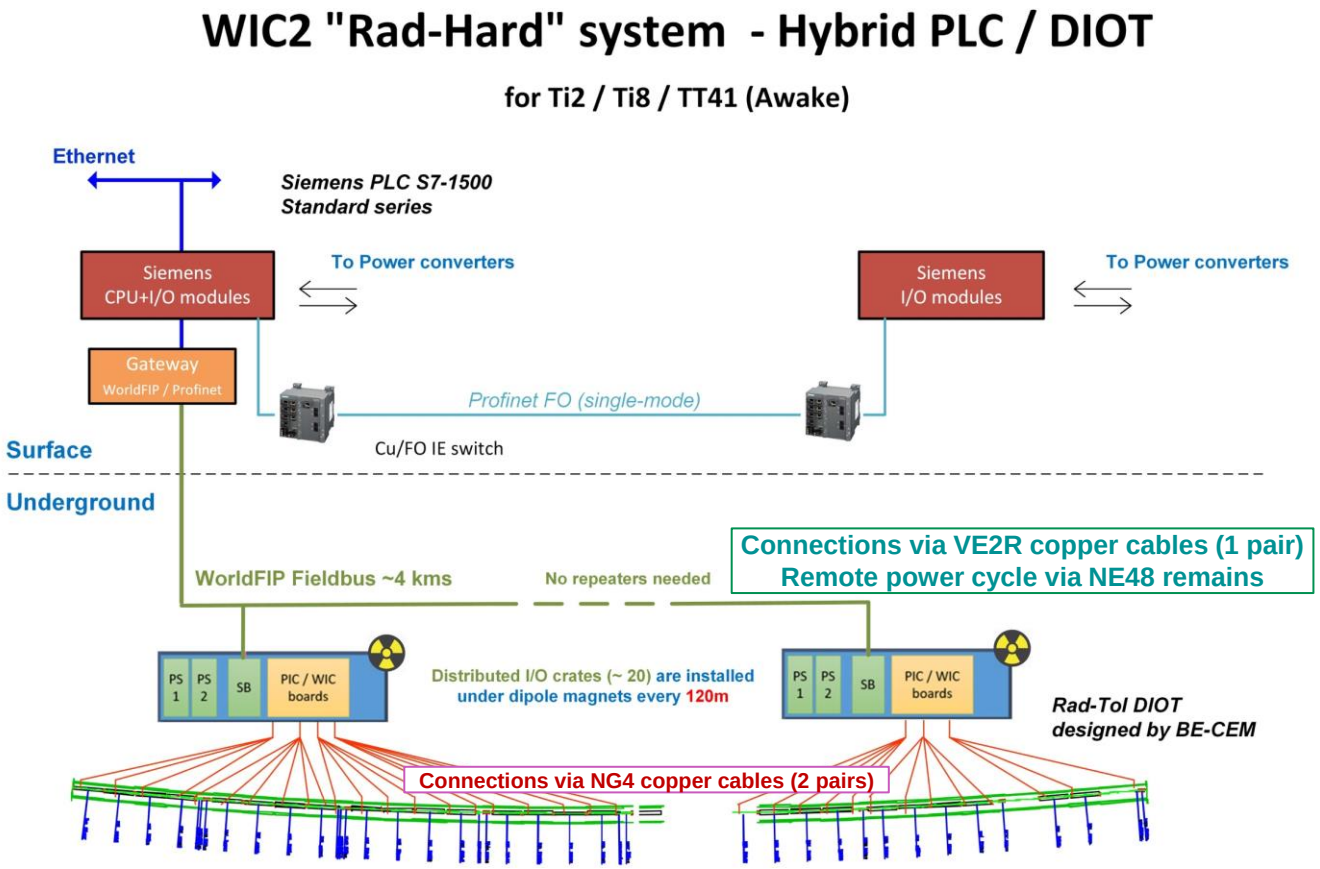
- Concerning the ongoing development/production:
  - Adding more users would require modification of the orders they have already placed. The related expenditure would be incurred at the time of ordering, i.e. in 2024.
  - The difficulty with the standardising and adding to catalogue concept is that this does not match EP-ESE current model. It has proven quite difficult to restart productions that have been completed. This is maybe different from the DIOT catalogue and Open Hardware concepts, where you can relaunch a production batch when you run-out of stock. For us this is not the model at present.
  - The ATS sector has recently reserved 20'000 - 25'000 bPOLs to serve as "standardized" rad tol converters for various projects in the future. The model is: ESE sells the parts in one shot, and ATS stores them centrally to redistribute them when/as needed. It is this model that I am proposing to follow for the CTRx and CTTx. **It is thus appropriate to ask the question now: should we produce more CTRx and CTTx and sell them to ATS for their future needs? There is no additional development effort needed in this case.**

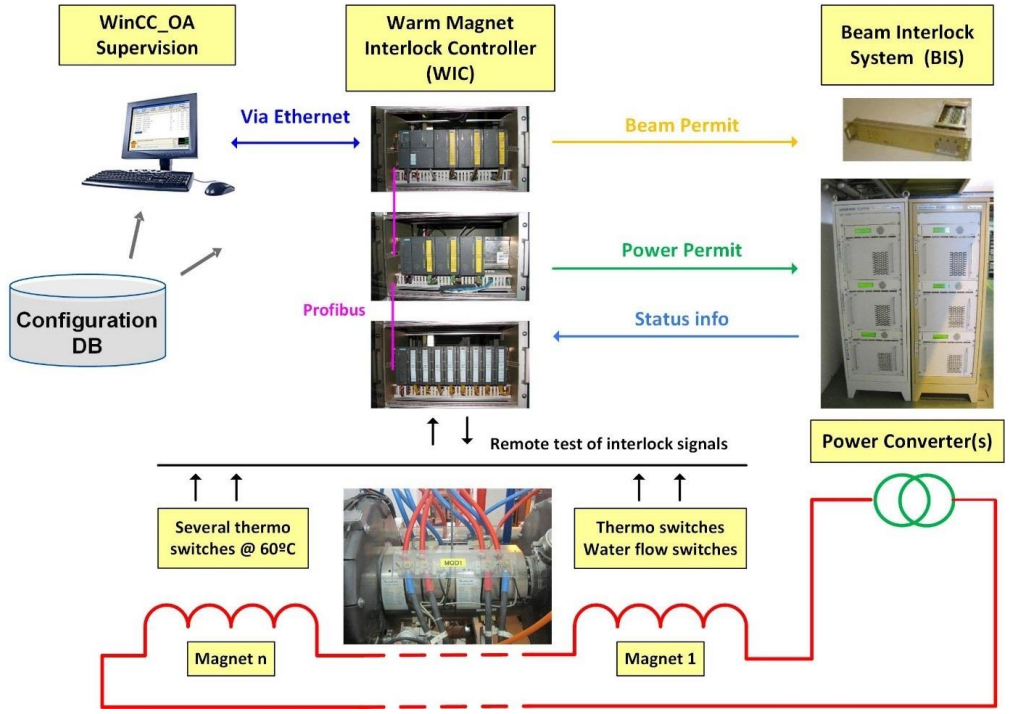
- **Finally, EP-ESE would be keen to associate with ATS to develop a SiPh module. This is R&D work, and EP-ESE has flexibility.**

Replacement of WIC system (new-design)

Warm Magnet Interlock Controller

New-design using WorldFIP (copper) – first installation in Ti2 **foreseen YETS24-25**





NB: the WIC is interconnected with BIS and SCADA which could have shared in principle the same fibre cabling infrastructure

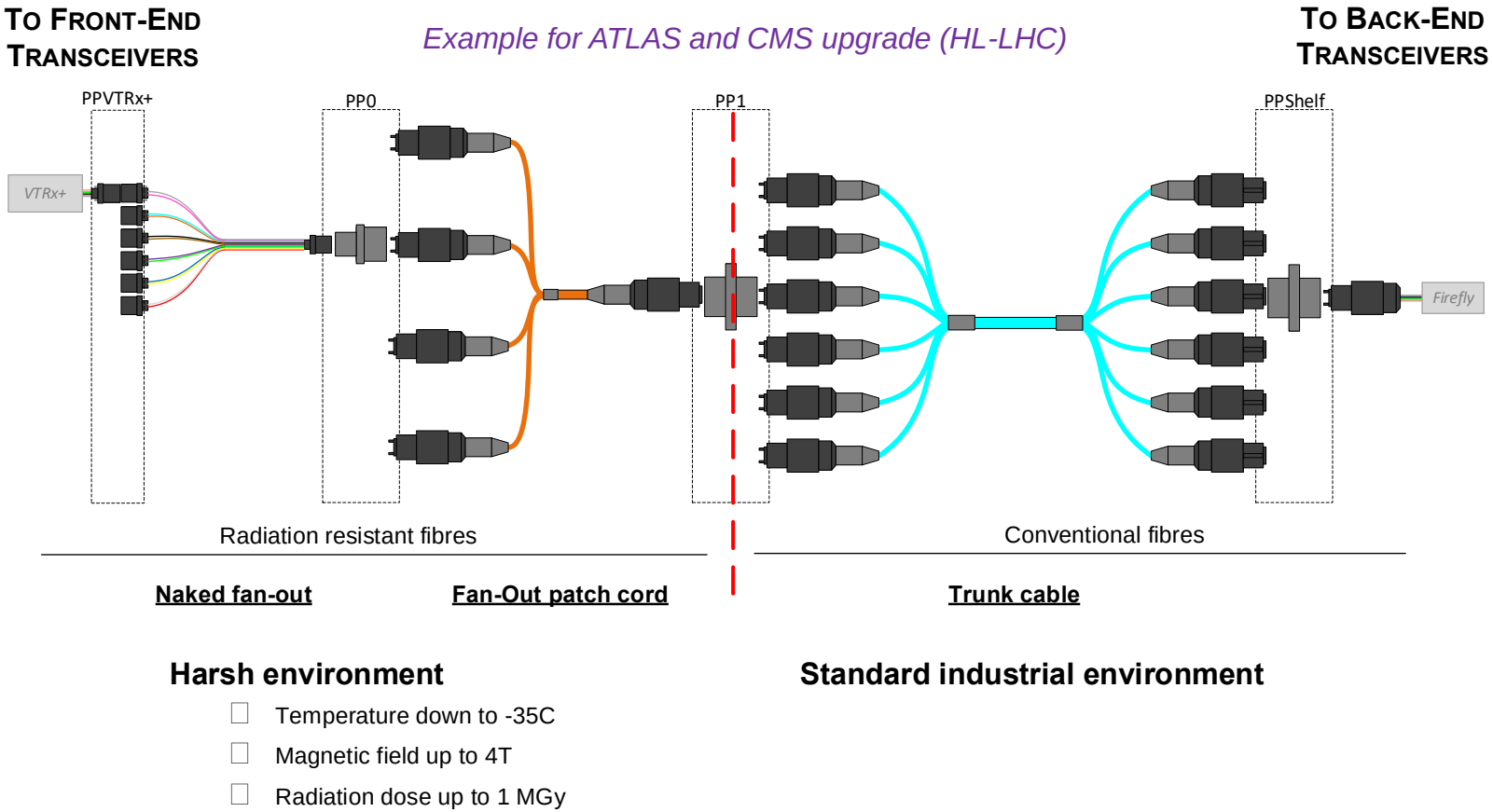
Courtesy Richard Mompo (TE-MPE) - wic.web.cern.ch

Accessory question: would WorldFIP bus bandwidth saturate if many users start using it?

Versatile Link+ project

Example collaboration between EN-EL (passives) and EP-ESE (actives)

Versatile Link Plus Passive Optical Components Specifications EDMS 1762900



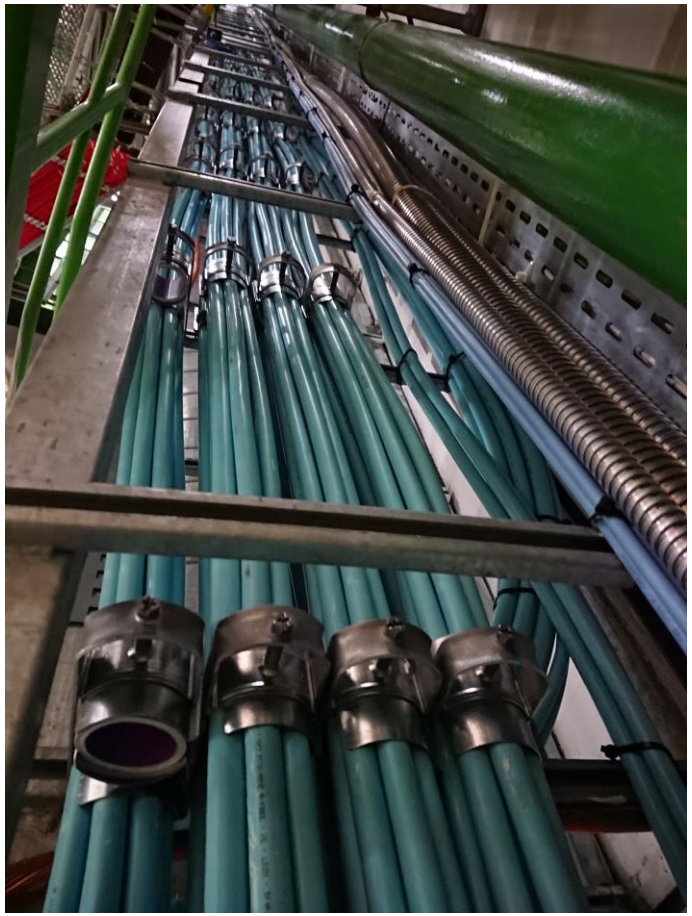
Harsh environment

- Temperature down to -35C
- Magnetic field up to 4T
- Radiation dose up to 1 MGy

Standard industrial environment

Custom (dedicated contract)

Standard (frame contracts)



Example of similar cabling for ALICE new DAQ system. 221 cables, ~ 21000 fibres installed during LHC Long Shutdown 2

bPOL : DCDC converter project

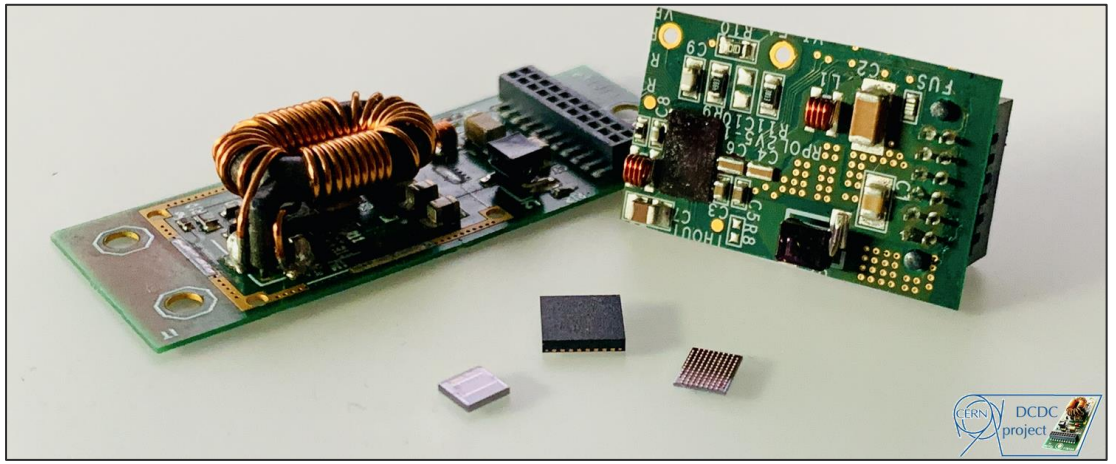
Example of integration of EP-ESE ASICs into ATS boards

New DCDC converter for HL-LHC High Energy Physics (HEP) applications

Required the development of a **radiation-tolerant ASIC** embedding both the power switches and the control circuitry. Plus, its integration on a DCDC module satisfying the EMC requirements of the low-noise HEP detectors at LHC.

~ 10 years

- **2007**: first concept
- **2007-2012**: development
- **2013**: preparation for series production
- **2014**: first delivery from series production
- **2015**: introduction of an improved ASIC version
- **2018**: introduction of a second improved ASIC version
  - More robust against Total Ionising Dose effects



Two production-grade modules developed:

- **FEASTMP** switches at a frequency of 1.8MHz and use a custom toroidal air-core inductor. The layout and SMD components were chosen to minimize the emitted noise (conducted and radiated). A modified version of the module,
- **FEASTMP_CLP:** uses different connector and a slightly modified layout to reduce the stack height below 1cm, still providing identical performances.

More than 30,000 modules have been delivered so far to LHC experimental teams.

https://espace.cern.ch/project-DCDC-new/_layouts/15/start.aspx#/index/Home.aspx