LHC Upgrades and Future Accelerators

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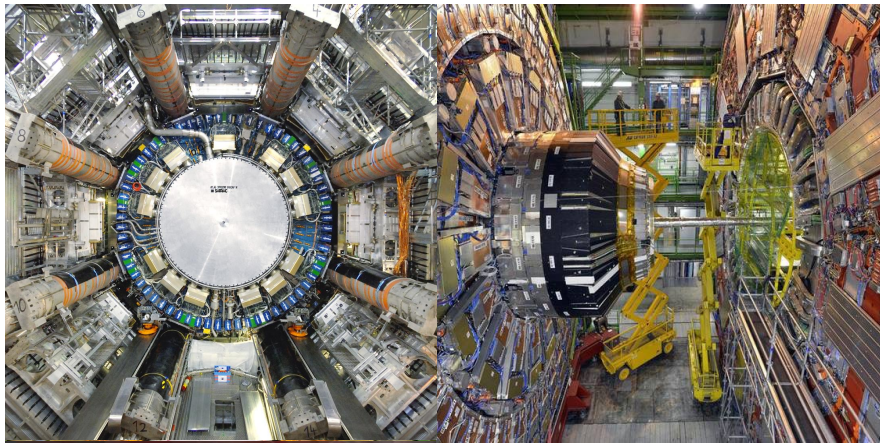
RECFA Visit to Portugal

Biblioteca Nacional de Portugal, Lisbon – 15 Sep. 2023

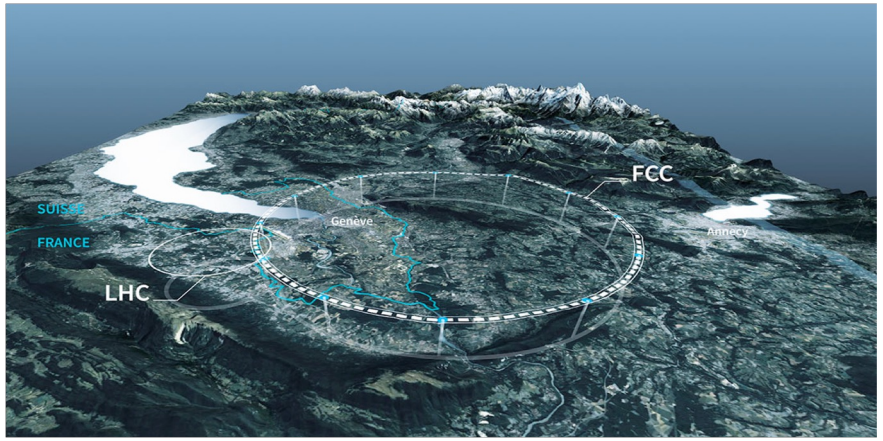
LIP FCT Fundação para a Ciência e a Tecnologia CERN

LHC Upgrades and Future Accelerators

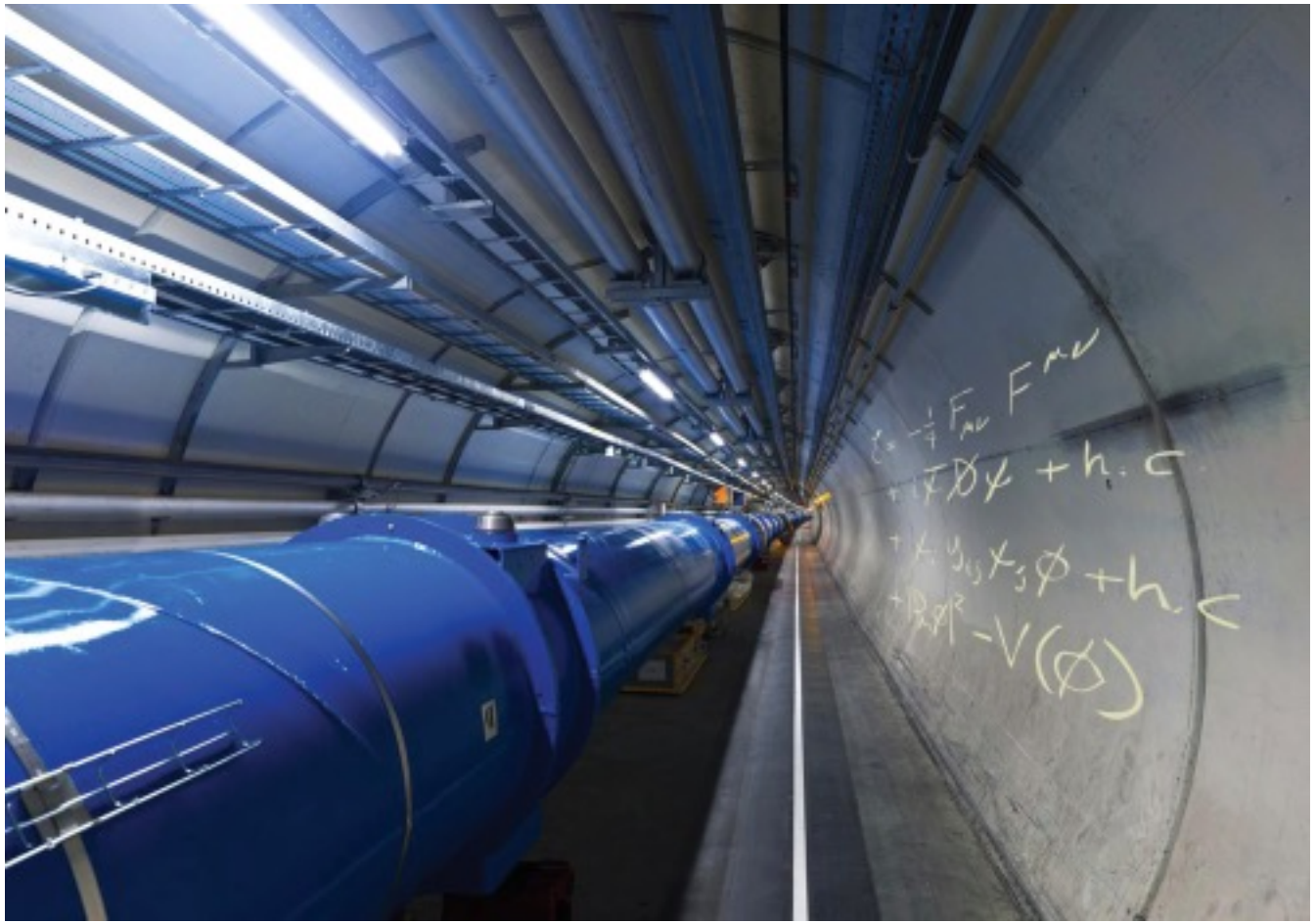
- LHC Phase II Upgrade
  - ATLAS Upgrades: TileCal, HGTD , HTT…
  - CMS Upgrades: MTD, PPS, ECAL, HGCAL



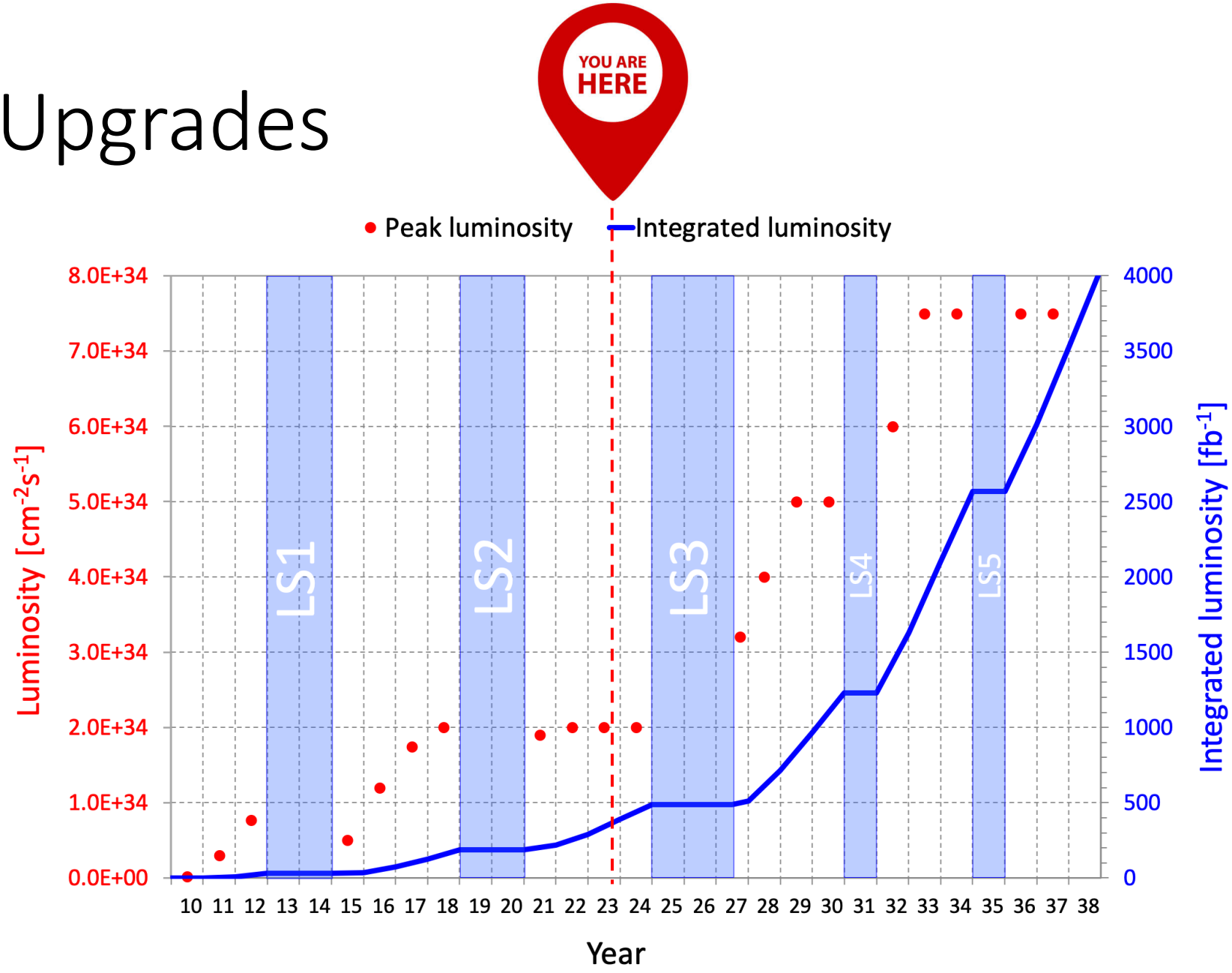
- Future Colliders:
  - FCC activities in Portugal
  - Detector R&D Collaborations



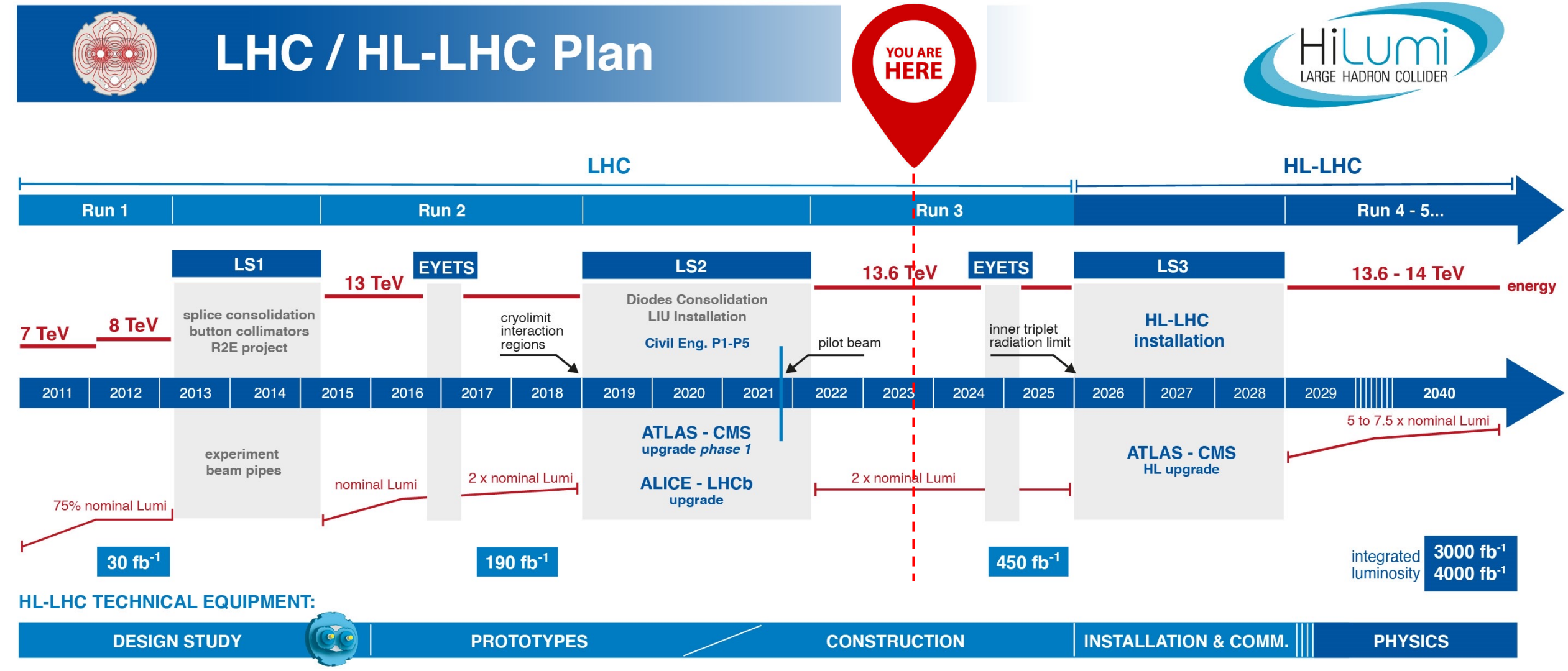
LHC Upgrades



LHC Upgrades



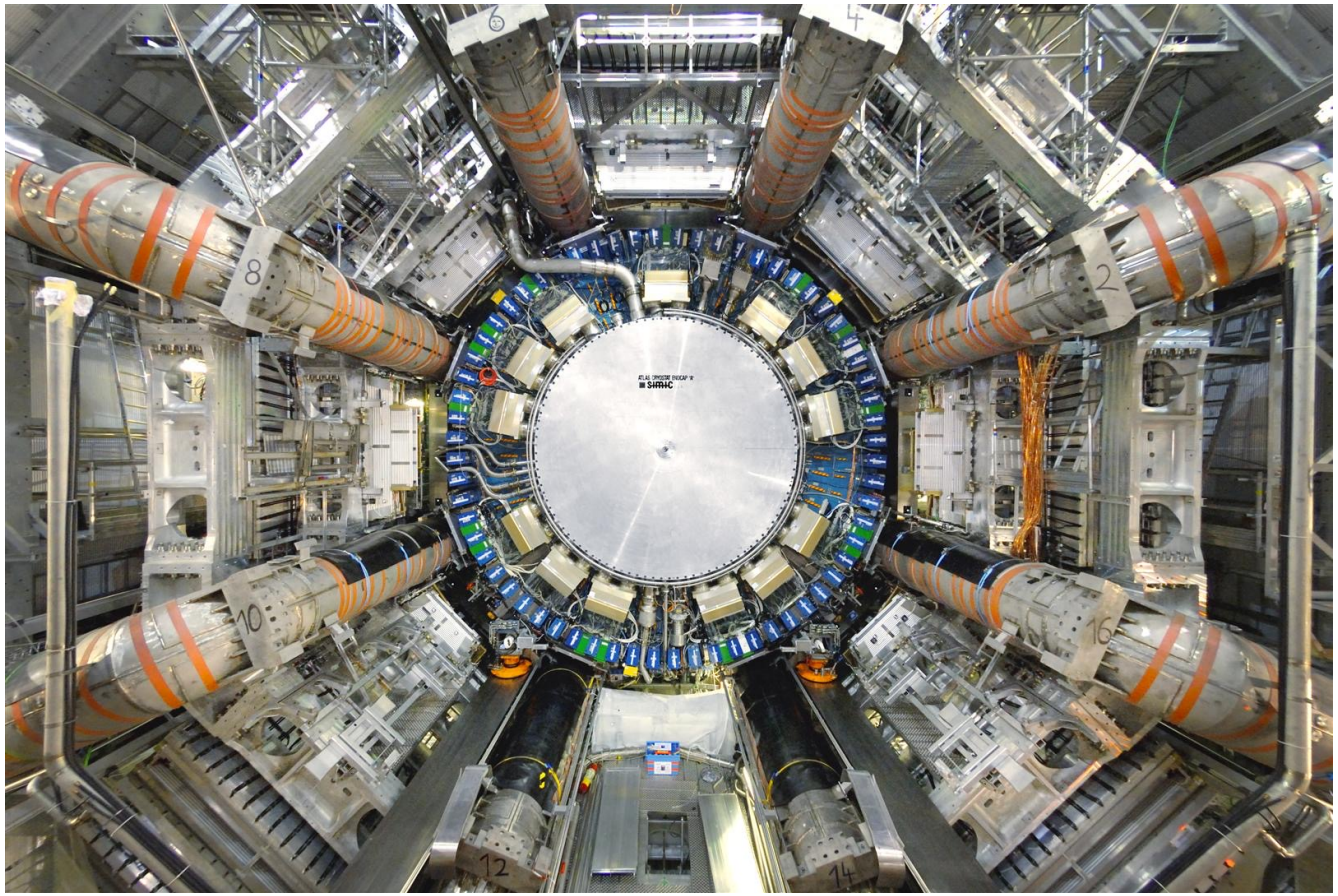
LHC / HL-LHC Plan

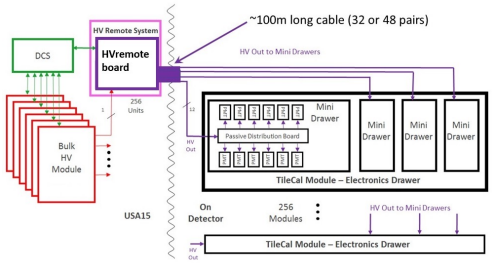


HL-LHC TECHNICAL EQUIPMENT:

HL-LHC CIVIL ENGINEERING:

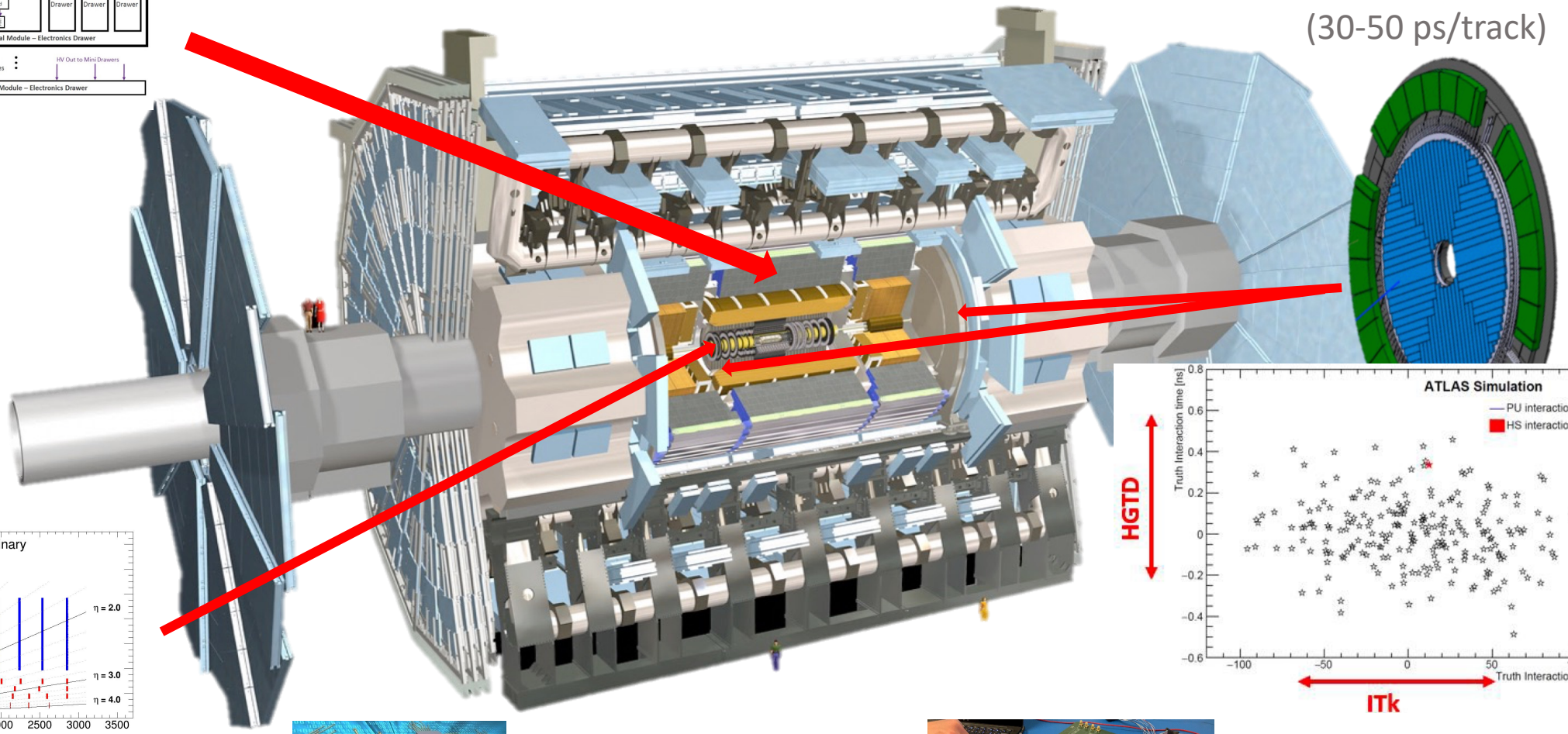
LHC Upgrades for Phase II: ATLAS

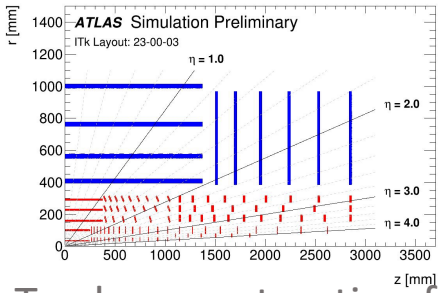




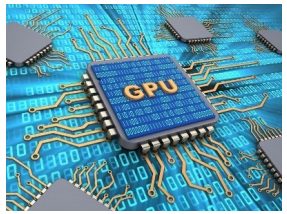
New Tile Calorimeter High-Voltage system

High Granularity Timing Detector (30-50 ps/track)

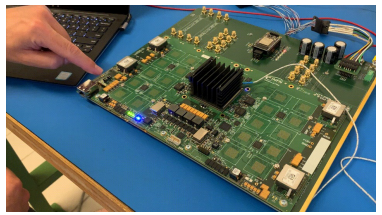




Track reconstruction for New Inner Tracker (ITk)



R&D on hardware acceleration for trigger



Previously: Hardware Tracking for the Trigger (HTT) – abandoned

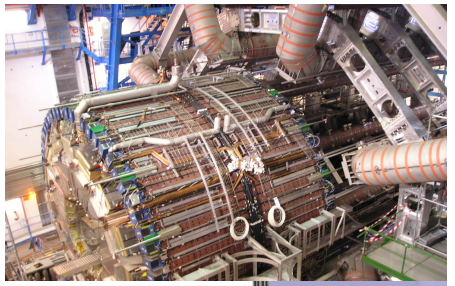
LHC Upgrades for Phase II: ATLAS

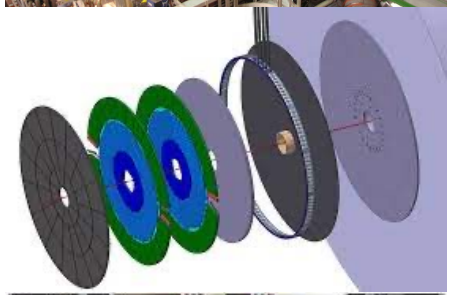
- **Tile calorimeter** (TileCal) **High Voltage** system – PT contribution: 1 M€
  - Large team effort and entirely under LIP's responsibility
  - Team: 4 senior researchers/academics; 3 engineers; 2 PhD students; 4 MSc students
  - Close collaboration with LIP Electronics Lab

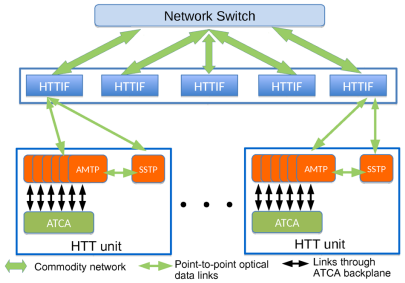
- **High Granularity Timing Detector** (HGTD) – PT contribution: 400 k€
  - Contributions to readout ASIC development, DCS and Interlock systems, High Voltage
  - Team: 3 researchers/academics; 2 engineers; 2 MSc students
  - Close collaboration with LIP Detector and Electronics Labs

- **TDAQ** Phase-II upgrade – PT contribution: 200 k€
  - Contribution to High-Level Trigger computing farm
  - Event Filter software: GPU acceleration for Trigger calorimeter reconstruction
  - Team: 1 academic, 1 PhD student; collaboration with INESC-ID Computing group

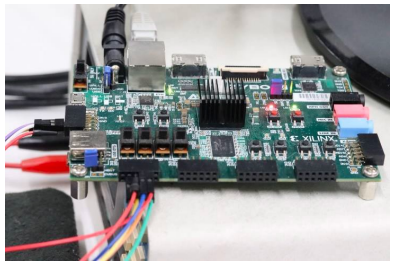
- Formerly: **Hardware Tracking for the Trigger** – planned PT contribution 600 k€
  - Team: 2 researchers/academics; 2 engineers; 1 PhD student; 1 MSc student
  - Solution abandoned by ATLAS in favor of a software-based solution



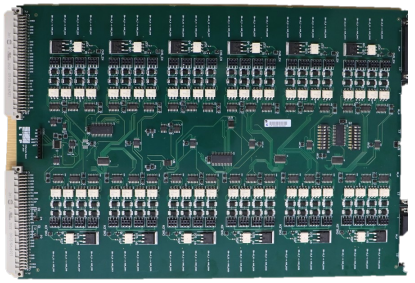




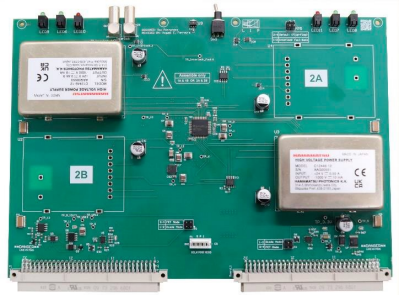
ATLAS: TileCal High-Voltage System (LIP)



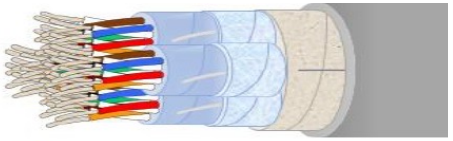
DCS system: SoC board for High Voltage monitoring & control



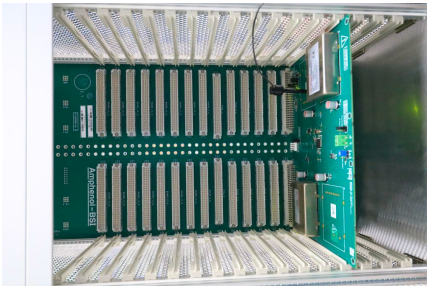
HVRemote boards - Regulation and control system off detector at USA15 (256 boards)



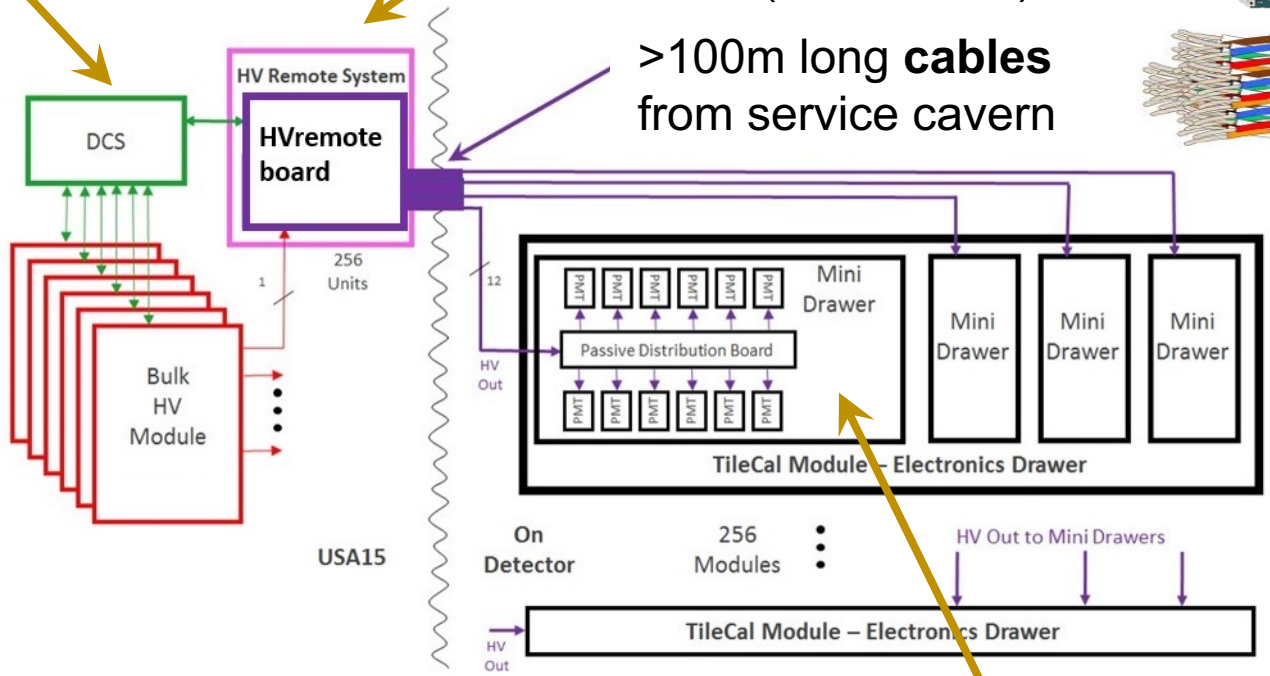
HVSupplies provide primary High Voltage (256 boards)



>100m long **cables** from service cavern



16 crates in service cavern

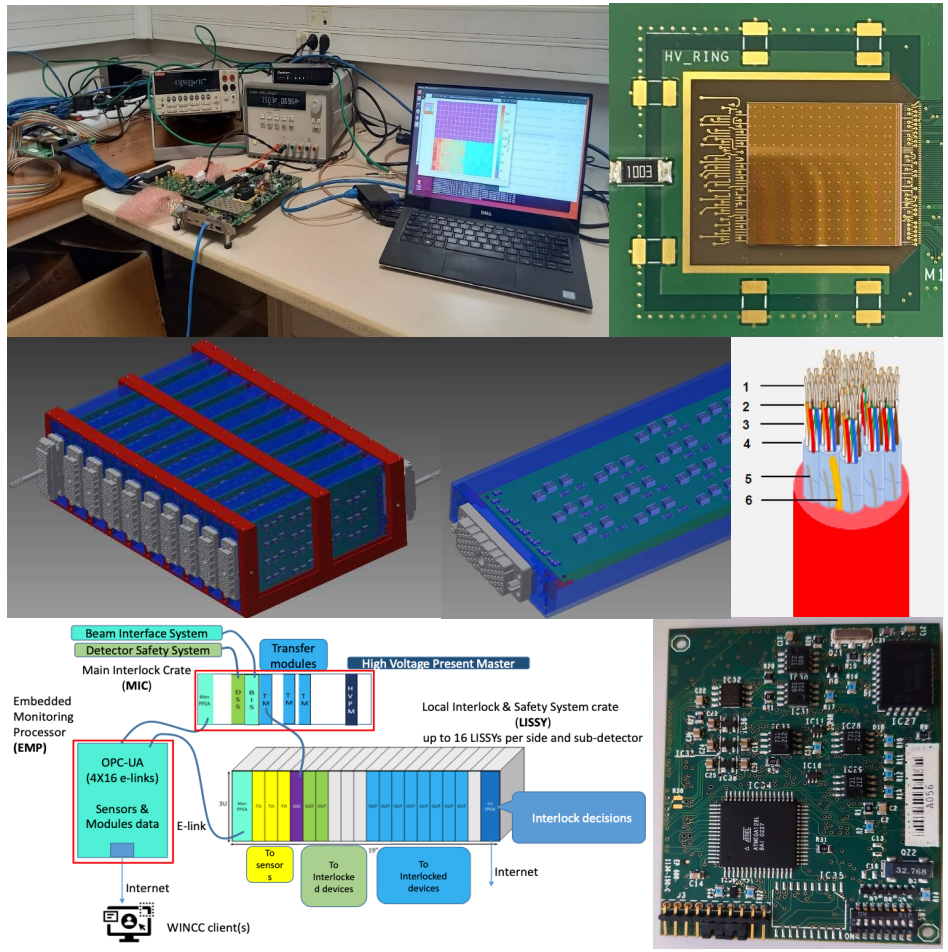


HVBus – passive distribution board distributes HV to PMTs (1024 boards)

System parameters:
10000 Photomultipliers
High Voltage < 950 V – so far used ≈750 V
Individual currents < 400 μA
High Voltage stability < 0.5 V rms

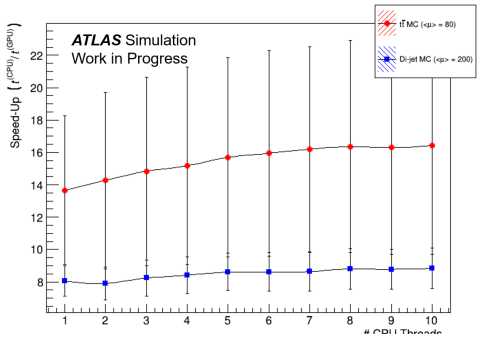
ATLAS: High Granularity Timing Detector

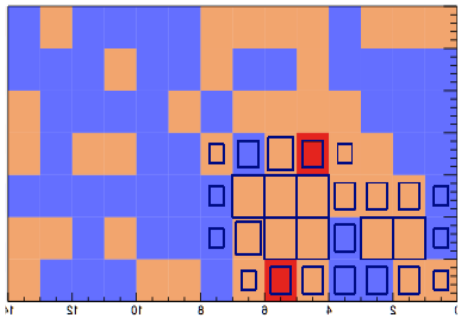
- Based on novel **Low Gain Avalanche Detectors**
- Good timing resolution: 30 – 50 ps/track
- LIP's contributions:
  - Development of **front-end ASIC** (ALTIROC)
    - Functionality and radiation hardness tests
  - High voltage infrastructure:
    - **Coordinating** High Voltage filters and patch panels
    - Also cables, pigtail connectors, etc
  - Detector Control System (DCS) and Interlock:
    - **Coordinating** Interlock system
    - In charge of interlock Transfer Module board
    - DCS: monitoring of high voltage and CO_2 cooling
    - Strong expertise in DCS and Interlock systems

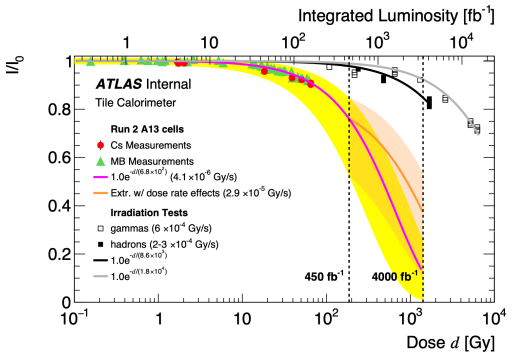


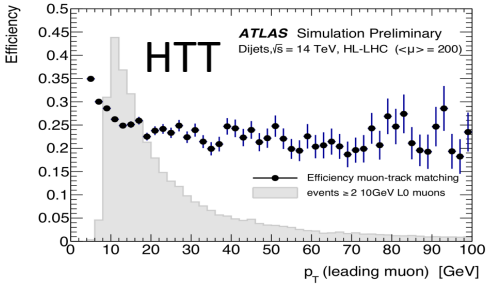
ATLAS: Trigger/DAQ, Performance, and Tracking

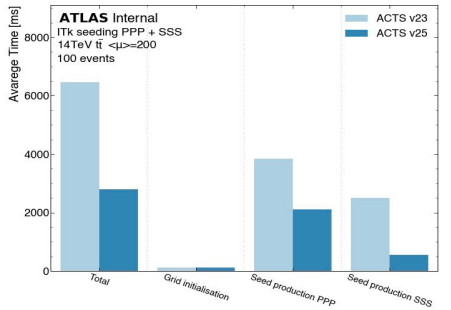
- **Trigger** and data acquisition
  - Development of **GPU-based algorithms** for acceleration of high level filter calorimeter reconstruction
  - Demonstrated important improvement factor over CPU algorithm: J. Phys.: Conf. Ser. 2438 012044
- **TileCal radiation hardness** for HL-LHC
  - Monitoring of optics light response versus radiation dose using calibration systems
  - Modelling and extrapolation to future conditions essential to **predict detector behaviour**
- Contributed to former project on Hardware Tracking for the Trigger
  - Simulation and performance studies
  - [ATL-DAQ-PUB-2023-001]
- Tracking software development for HL-LHC
  - PhD student at CERN working on optimization of common tracking package for HL-LHC

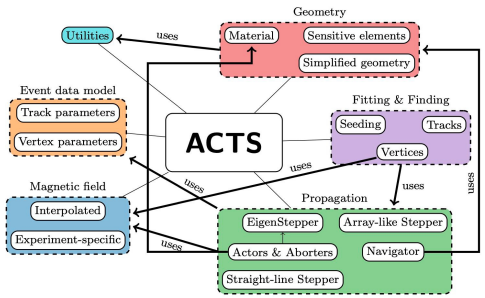






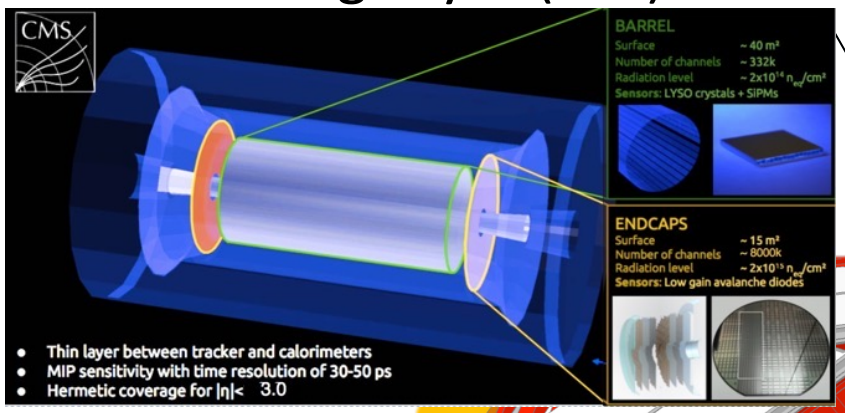


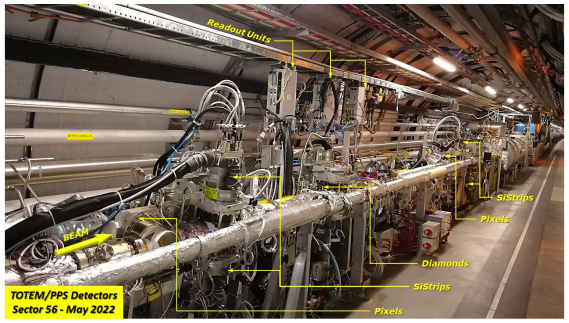




LHC Upgrades for Phase II: CMS

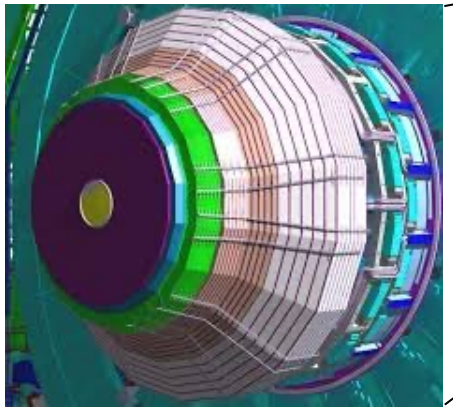
Barrel Timing Layer (BTL)

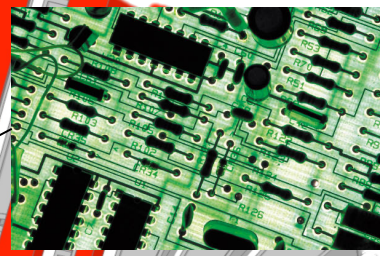




Upgrade of Precision Proton Spectrometer (PPS)

High Granularity Calorimeter (HGCAL)



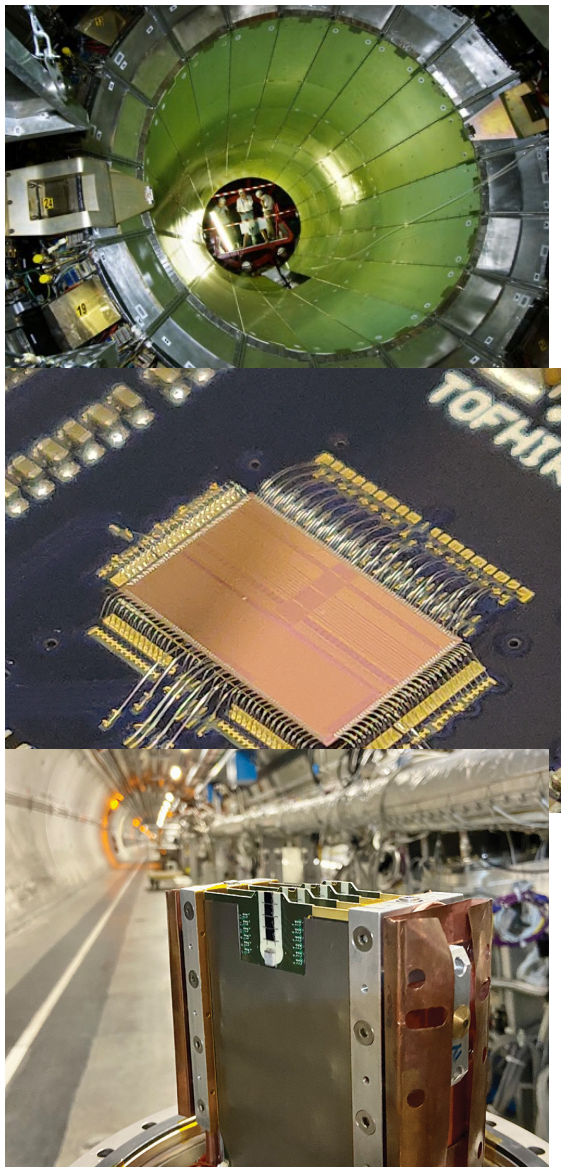


Electronics for Electromagnetic calorimeter

LHC Upgrades for Phase II: CMS

- MIP Timing Detector – PT contribution: 1070 k€
  - **Barrel: Full responsibility for TOFHIR ASIC and front-end cards**
  - Budget 790 k€, Executed 1070 k€
  - Team: 3 senior researchers/academics; 2 engineers; 2 PhD students
  - MTD/BTL electronics coordination (J. Varela)
- Precision Proton Spectrometer (Phase II program under approval)
  - **Project manager** (J.Hollar) – Level 1 position
  - Team: 4 senior researchers/academics; 1 engineer; 3 PhD students;
- HGCAL calorimeter – PT contribution: 290 k€
  - **Rad tolerant regulator ASIC in collaboration with CERN**
  - Budget: 360 k€, Executed 240 k€
  - Team: 1 senior researchers/academics; 1 engineer
- ECAL calorimeter – PT contribution: 400 k€
  - **Frontend ADC ASIC in collaboration with Torino/Italy**
  - Budget: 400 k€, Executed 325 k€
  - Team: 1 senior researchers/academics; 1 engineer

Missing Funds: 200 k€

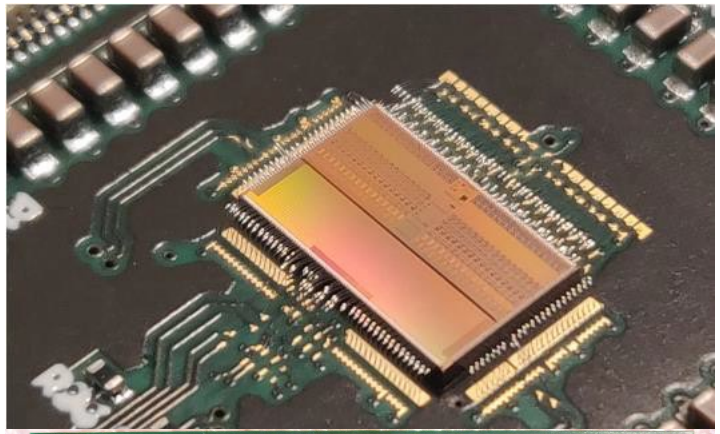


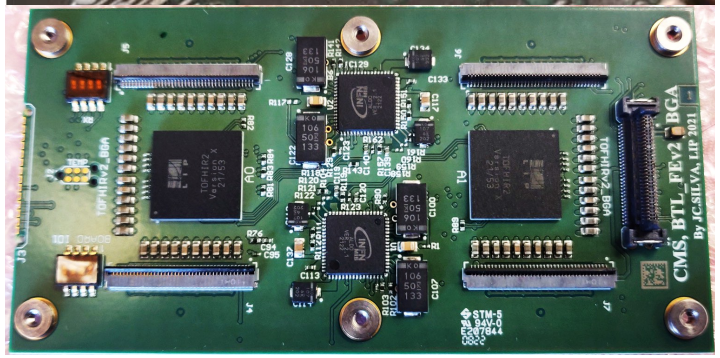
CMS: MIP Timing Layer

- Very good **time resolution**!
  - 30 ps at Beginning of Operation
  - Degrades to 60 ps at End of Operation due to radiation damage of SiPMs

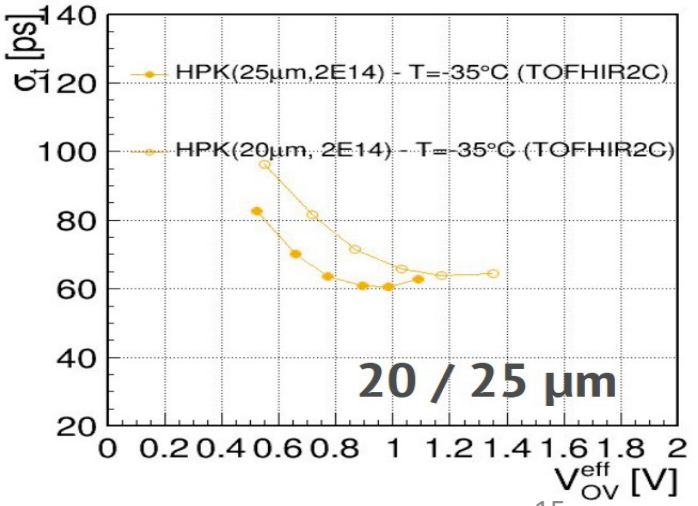
- **Suppress pileup** and **increase physics reach** in vertex reconstruction precision
  - Impact on: long-lived/stable particle searches, di-Higgs, b-tagging, PID for heavy ions/flavor physics, etc…

- Barrel Timing Layer (BTL, $|\eta| < 1.5$):
  - **TOFHIR2 readout ASIC** (15k chips)
  - Front-end cards (5500 cards)
  - Developing TOFHIR ASIC together with the PETSYS Portuguese company – a **major endeavour**!





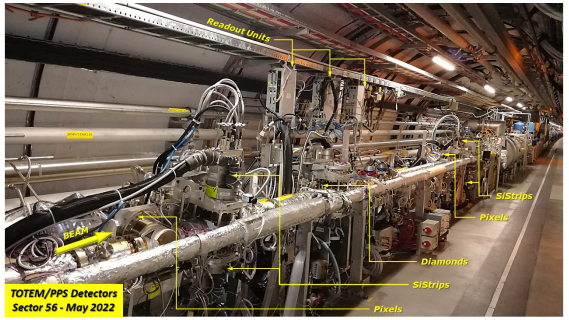
Test beam results with TOFHIR2 and modules irradiated to 2×10^{14} neq/cm^2 (End of Operation)

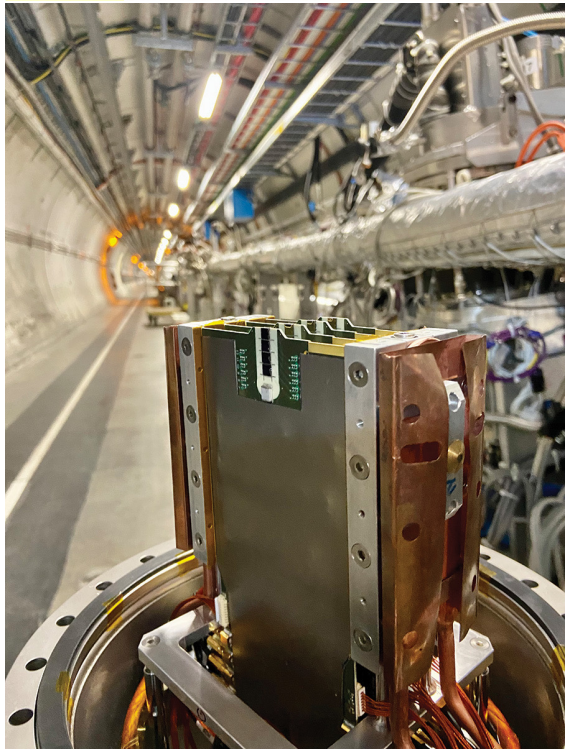


CMS: Precision Proton Spectrometer

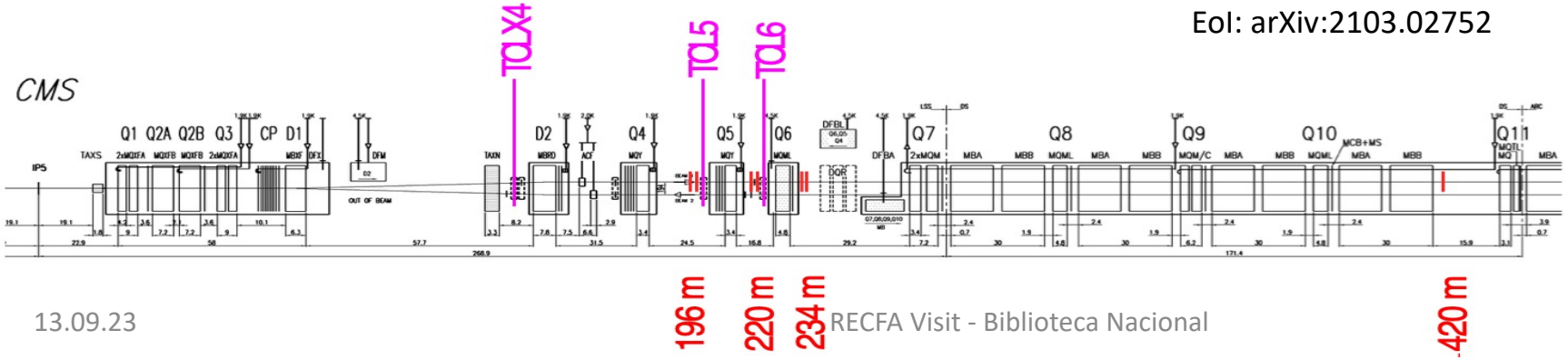
- **Forward proton spectrometer**
  - Tracking and timing detectors very close to beam
  - ≈200 m from the CMS interaction point
  - In Roman Pots with vertical movement: mitigate radiation damage
  - Good spatial and time resolution (goal is 50 ps)

- For HL-LHC: upgrade to run at high luminosity
  - **Challenge**: huge flux and highly non-uniform irradiation profile
  - Use **LGADs** and adapt solutions developed for Endcap Timing Layer
  - LIP **contributing strongly** to detector preparation, test beam activity, detector R&D and characterization, silicon sensor studies, simulation, DAQ, etc.





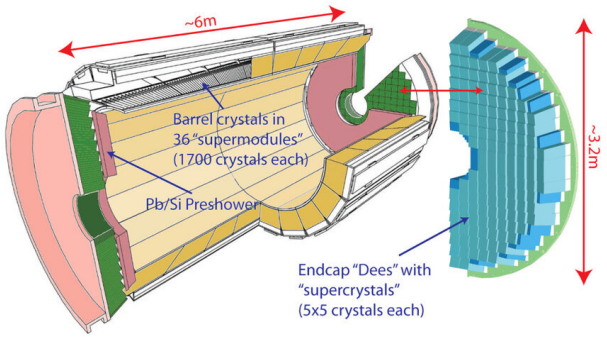
EoI: arXiv:2103.02752

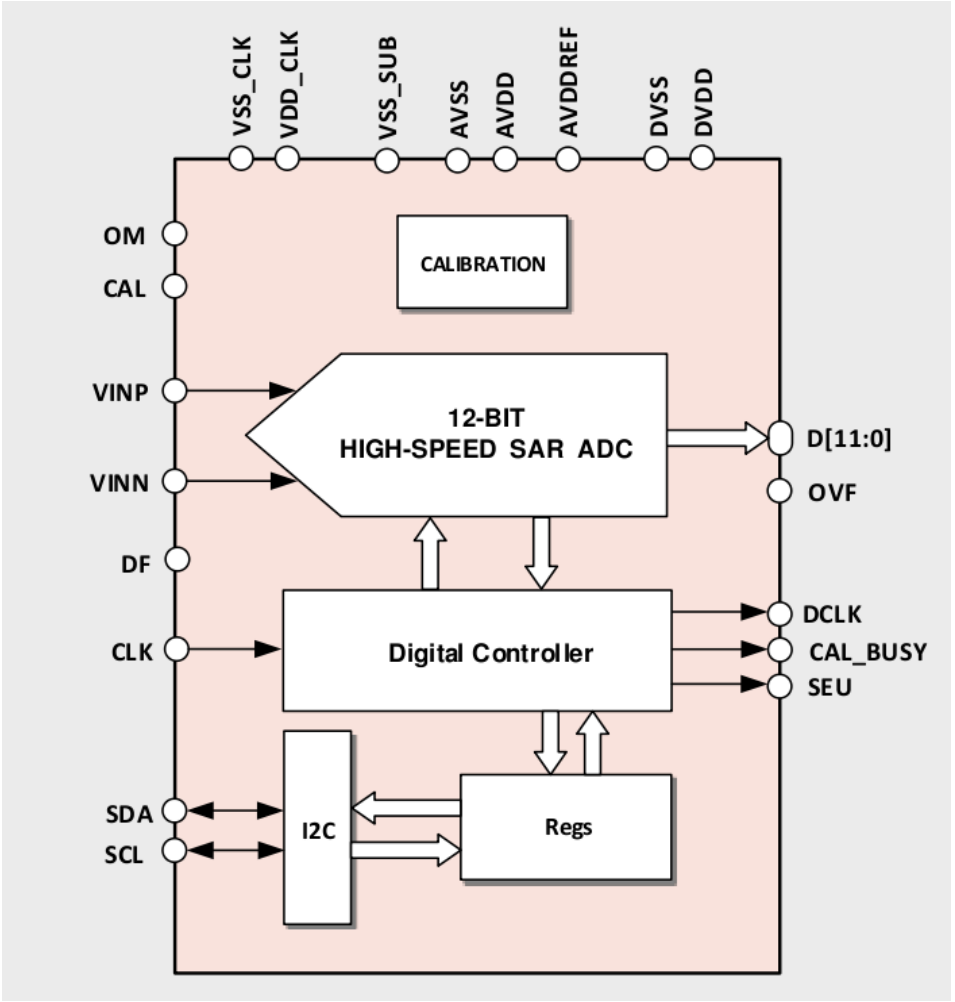


CMS: Electromagnetic Calorimeter (ECAL)

- LIP responsible for ECAL back-end electronics for many years

- For HL-LHC:
  - **Full replacement** of electronics, to meet pileup/rate requirements
  - LIP contribution: collaboration with Portuguese industry to develop **new low-power ADC ASIC**
    - 12-bit resolution, with 160 MS/s sampling rate

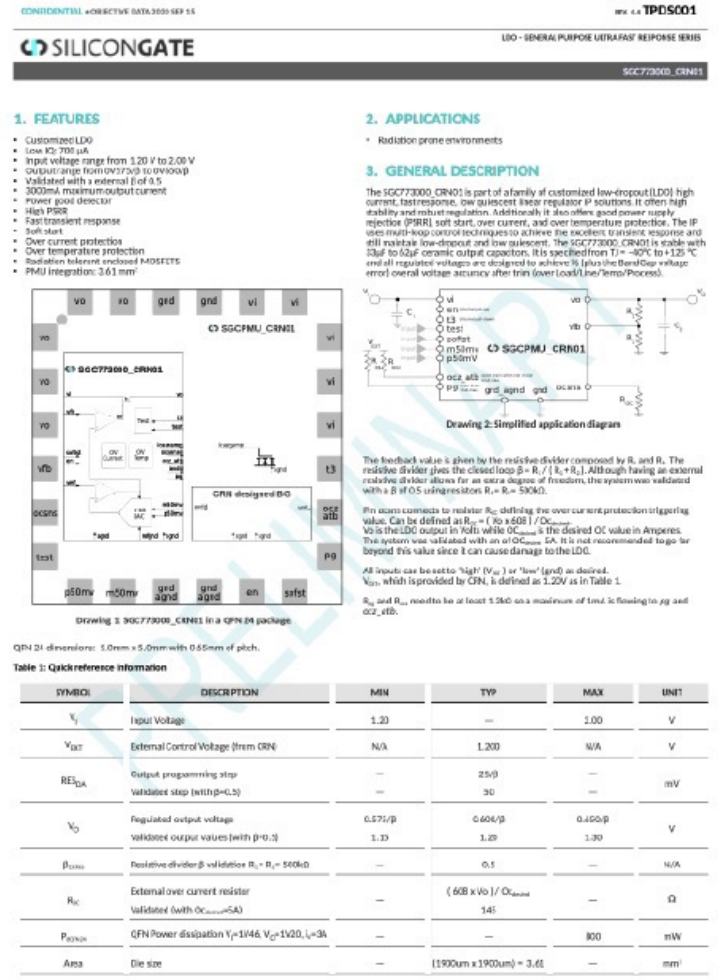




CMS: HGCAL

- New **High Granularity Endcap Calorimeter** (HGCAL)
  - **State of the art** in electromagnetic and hadronic Calorimetry for proton colliders
  - Very challenging project

- LIP contribution
  - A new high current (3A); <200 mV dropout, radiation-tolerant; adjustable linear voltage regulator
  - Developed by Portuguese company Silicon Gate
  - Used extensively in the HGCAL front-end electronics
  - Chip production and testing organized by CERN



CONFIDENTIAL «OBJECTIVE DATA 2020 SEP 15

rev. 1.1 TPDSC01

SILICONGATE

LDO - GENERAL PURPOSE ULTRAFAST RESPONSE SERIES

SGC77300D_CRN01

1. FEATURES

- Customized LDO
- Low IQ: 700 µA
- Input voltage range from 1.20 V to 2.00 V
- Output range from 0V575/β to 0V900/β
- Validated with a external β of 0.5
- 3000mA maximum output current
- Power good detector
- High PSRR
- Fast transient response
- Soft start
- Over current protection
- Over temperature protection
- Radiation tolerant enclosed MOSFETS
- PMU integration: 3.61 mm²

2. APPLICATIONS

- Radiation prone environments

3. GENERAL DESCRIPTION

The SGC77300D_CRN01 is part of a family of customized low-dropout (LDO) high current, fast response, low quiescent linear regulator IP solutions. It offers high stability and robust regulation. Additionally it also offers good power supply rejection (PSRR), soft start, over current, and over temperature protection. The IP uses multi-loop control techniques to achieve the excellent transient response and still maintain low-dropout and low quiescent. The SGC77300D_CRN01 is stable with 33µF to 62µF ceramic output capacitors. It is specified from TJ = -40°C to +125 °C and all regulated voltages are designed to achieve ½ (plus the BandGap voltage error) overall voltage accuracy after trim (over Load/Line/Temp/Process).

Drawing 1: SGC77300D_CRN01 in a QFN 24 package

Drawing 2: Simplified application diagram

The feedback value is given by the resistive divider composed by R_1 and R_2. The resistive divider gives the closed loop $\beta = R_2 / (R_1 + R_2)$. Although having an external resistive divider allows for an extra degree of freedom, the system was validated with a β of 0.5 using resistors $R_1 = R_2 = 590k\Omega$.

Pin ocsns connects to resistor R_{OC} defining the over current protection triggering value. Can be defined as $R_{OC} = (Vo \times 60B) / OC_{desired}$

Vo is the LDO output in Volts while $OC_{desired}$ is the desired OC value in Amperes. The system was validated with an of $OC_{desired}$ 5A. It is not recommended to go far beyond this value since it can cause damage to the LDO.

All inputs can be set to 'high' (V_{DD}) or 'low' (gnd) as desired.

V_{DD}, which is provided by CRN, is defined as 1.20V as in Table 1.

R_{t1} and R_{t2} need to be at least 1.2kΩ on a maximum of 1mA is flowing to pg and ocz_atb.

QFN 24 dimensions: 1.0mm x 5.0mm with 0.65mm of pitch.

Table 1: Quick reference information

SYMBOL	DESCRIPTION	MIN	TYP	MAX	UNIT
V_I	Input Voltage	1.20	–	2.00	V
V_{EXT}	External Control Voltage (from CRN)	N/A	1.200	N/A	V
REF_{DA}	Output programming step	–	25/β	–	mV
	Validated step (with β=0.5)	–	50	–	
V_O	Regulated output voltage	0.571/β	0.606/β	0.650/β	V
	Validated output values (with β=0.5)	1.13	1.20	1.30	
β_{CRN}	Resistive divider β validation $R_1 = R_2 = 590k\Omega$	–	0.5	–	N/A
R_{OC}	External over current resistor	–	(60B x Vo) / $OC_{desired}$	–	Ω
	Validated (with $OC_{desired}$=5A)		14R		
P_{QFN24}	QFN Power dissipation V_I=1V46, V_{OT}=1V20, I_O=3A	–	–	800	mW
Area	Die size	–	(1900um x 1900um) = 3.6t	–	mm²

Coordination roles in HL-LHC upgrade projects

ATLAS:

- Agostinho Gomes (Tile Calorimeter, since 2018):
  - Phase-II Upgrade Power Supplies Coordinator
  - High-Voltage Power Supply Regulation Board Production Coord.
  - Calorimeter High-Voltage Power Supply System Responsible
  - High-Voltage Bulk Power Supply Installation Coordinator
  - High-Voltage Power Supply Cables Production Coordinator
  - High-Voltage Power Supply Bus Board Production Coordinator
- Rute Pedro:
  - TileCal Phase II Software and Performance group (>2023)
- Helena Santos:
  - HGTD Interlock Coordinator (> 2022)
- Ricardo Gonçalo:
  - HGTD Patch Panels Coordinator (> 2022)
  - Member of HGTD Speakers Committee (> 2023)

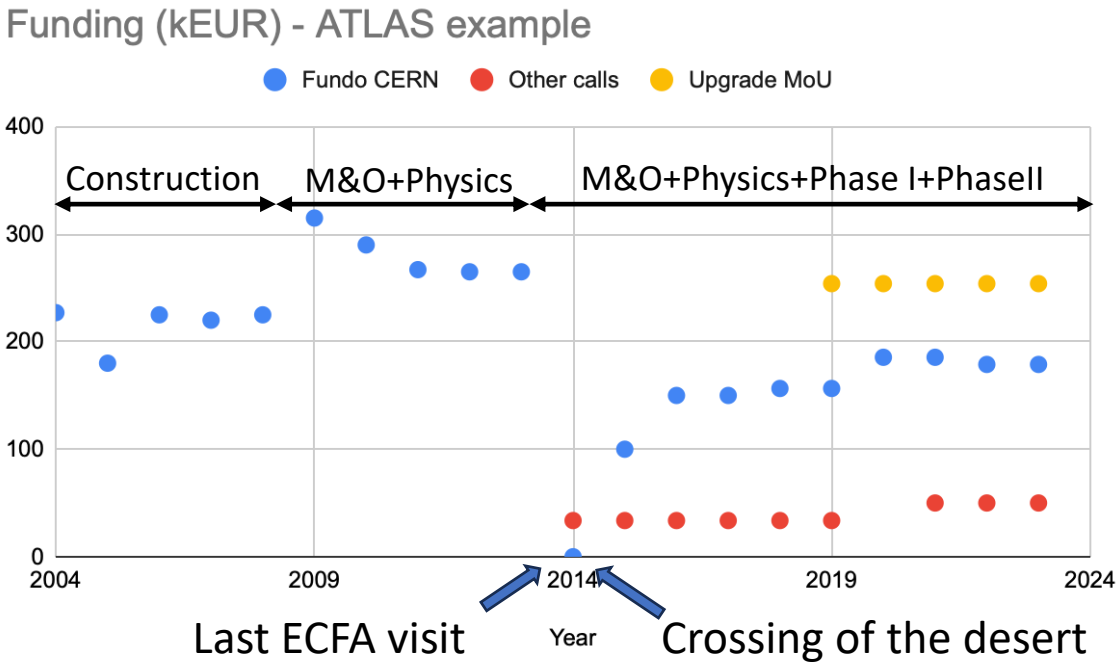
CMS:

- J.Varela:
  - MTD/BTL electronics systems coordinator (> 2018)
  - ECAL, MTD, HGCAL Institution Boards
  - MTD Steering Committee
- M.Gallinaro:
  - PPS Institution Board
- J.C.Silva:
  - MTD/BTL front-end electronics coordinator (2018-2023)
- J.Hollar:
  - Level-1 role: PPS Deputy Coordinator (2018-22)
  - Level-1 role: PPS Project Manager (> 2022)

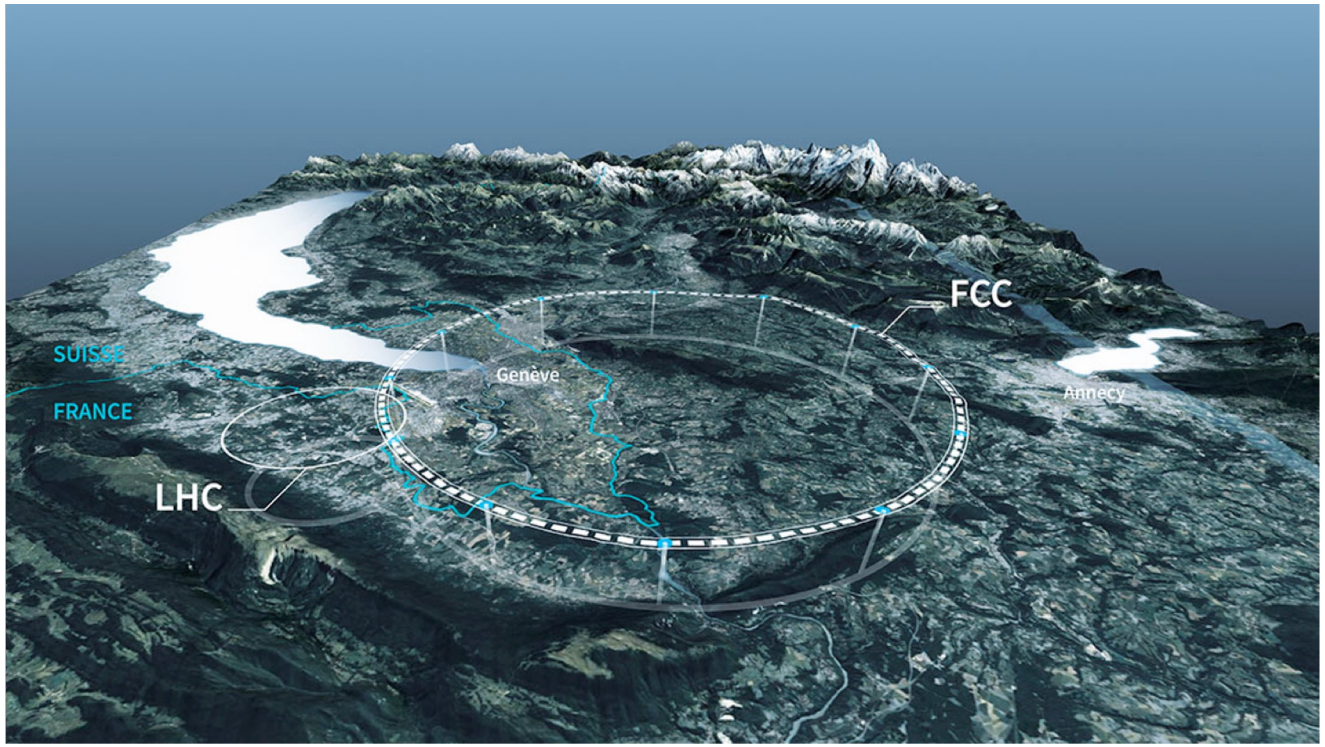
LHC Upgrades for Phase II: Funding

- **Portuguese investment in HL-LHC**:
  - **MoU**s signed by FCT funding agency and experiments
  - ATLAS: 1.6 M€ / 6 years
  - CMS: 1.6 M€ / 6 years
  - Fund experiments directly
  - Normally accompanied by similar funds for R&D, prototypes and human resources in the country, but not in our case

- R&D funds through “Fundo CERN” competitive calls
  - **Essential** funds to **capitalize on MoU investment**
  - Both **scientifically** and in **industrial return**

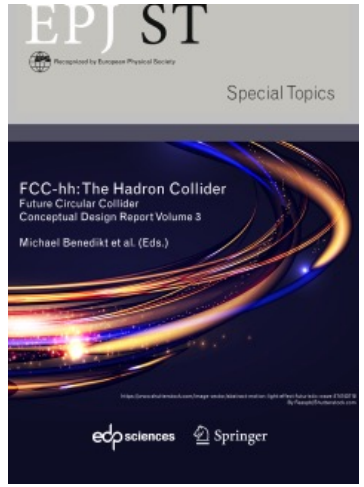


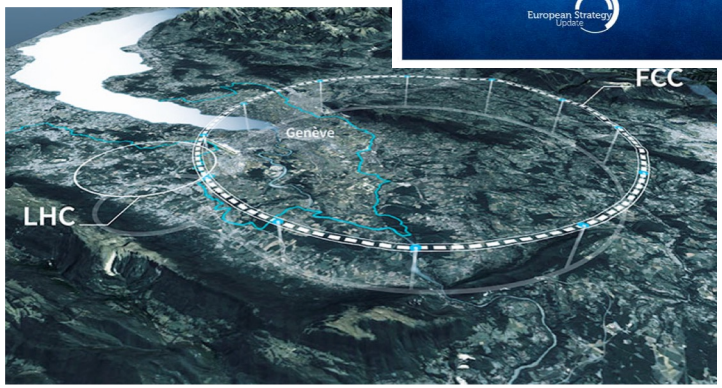
Future Acceleratos



Future Circular Collider and ECFA Roadmap

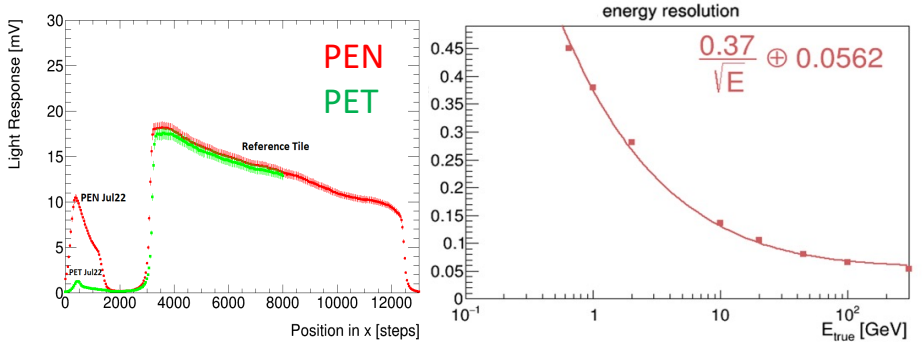
- FCC proposal for a 100 km collider at CERN
  - **FCC-ee** (e^+e^-, 90 – 365 GeV) followed by **FCC-hh** 100 TeV pp collider
- **New group at LIP**
  - Joined FCC Collaboration in 2022
  - 9 academics/researchers; 1 PhD student; 2 MSc students
  - Small research projects funding this activity:
    - 15 k€ to fund initial activity of FCC group
    - 50 k€ exploratory project to develop radiation-hard scintillators
- **ECFA Detector Roadmap:**
  - Detector R&D (DRD) Collaborations ramping up now
  - Long history of **excellent detector research** in Portugal - talk by A.Blanco
  - Can make a difference in Detector R&D: DRD1 (gaseous detectors); DRD 2 (liquid); DRD 3 (Solid state); DRD 6 (calorimetry)
  - Great **opportunity** to make leading contributions to these collaborations
  - **Long-term planned funding is crucial**
  - Fundo CERN is **essential** first step towards this!



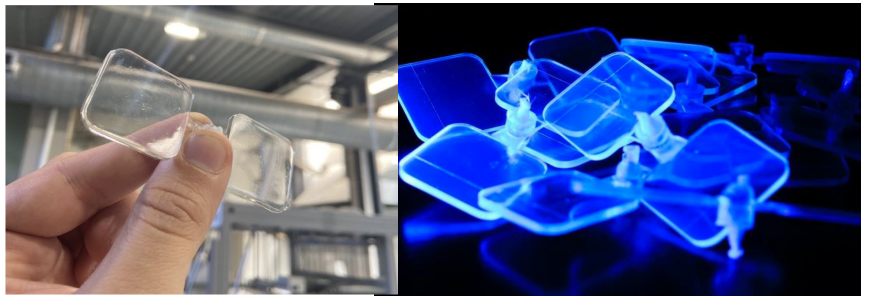


Future Circular Collider ongoing activity

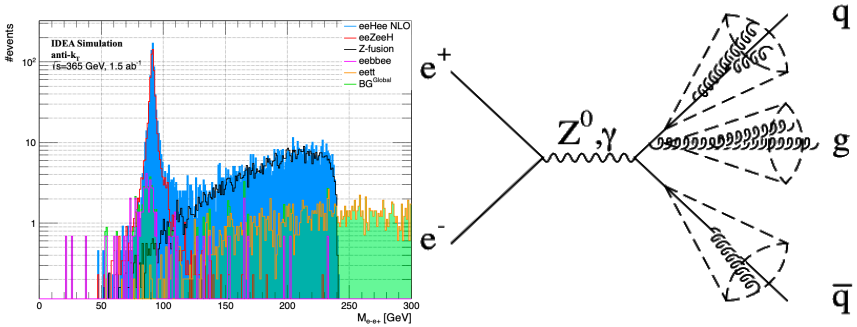
- Hadronic calorimeter simulation for FCC-ee detector concept
  - **Co-proponent** of scintillator+Fe/Pb HCAL concept (DRD6)
  - Optimizing geometry, material, granularity, depth, compensation etc, including with Machine Learning



- R&D for **novel radiation-hard scintillator** development
  - Variety of PET/PEN samples being produced and tested
  - Exploratory R&D project (50 k€) in collaboration with IPC/UM polymer group

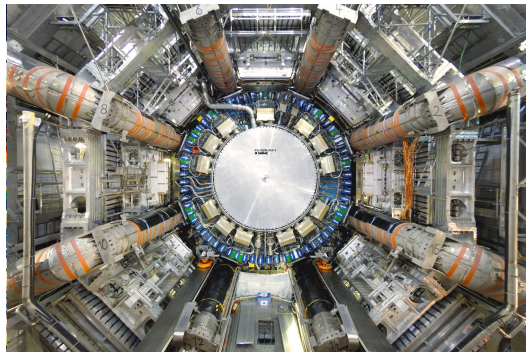


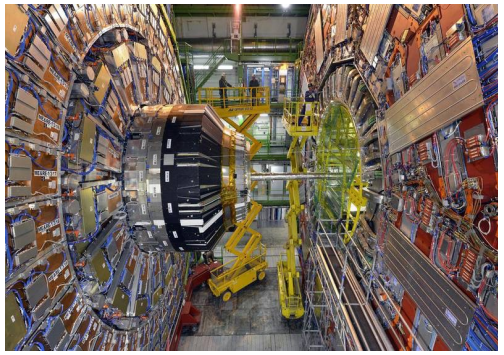
- Theory & Phenomenology:
  - Prepare measurement of α_s **at ‰ accuracy** at FCC-ee
  - Phenomenological study of Higgs production: **triple-Higgs coupling** in FCC-ee

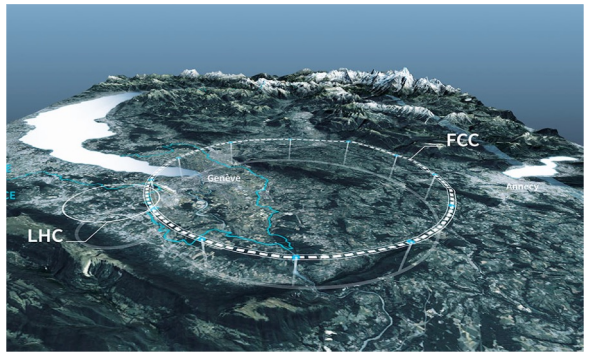


Conclusions

- Both ATLAS and CMS groups strongly involved in **HL-LHC** effort
  - Important Portuguese **investment** in this programme and occupying **key positions**
  - Essential that R&D funds allow us to **capitalize on investment** and effort
- Preparing the **future beyond the LHC**
  - Main activity so far on FCC activity – soon also ECFA DRD collaborations
  - Still subsidiary to HL-LHC activity, but producing first results
- **Concerns**:
  - PhD **grant programmes** and scientific employment essential to all this! No people means no future!
  - MoU budgets are fixed: no means to account for **increased prices** since COVID and war in Ukraine
  - **Stability** of funding is essential for very long-term international scientific endeavours







Thank you!

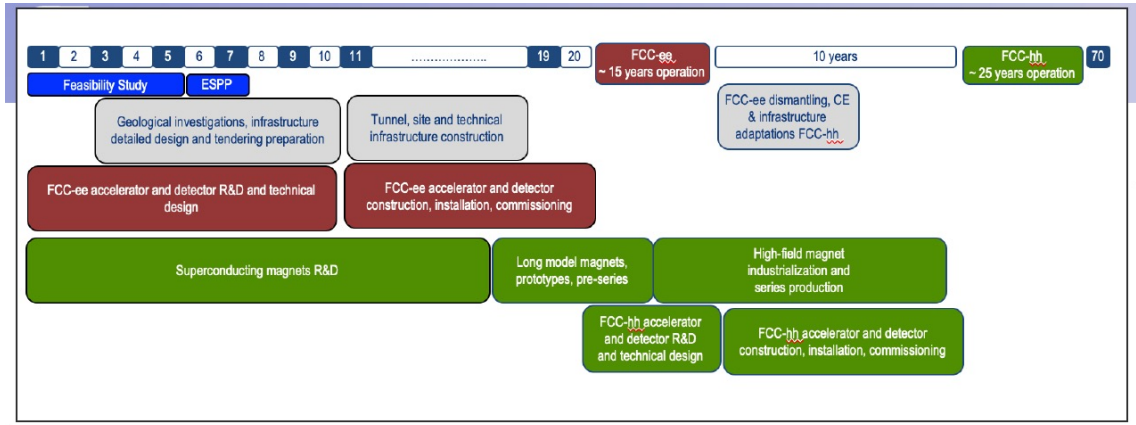
LIP

LET'S INSPIRE PEOPLE

jgoncalo@lip.pt

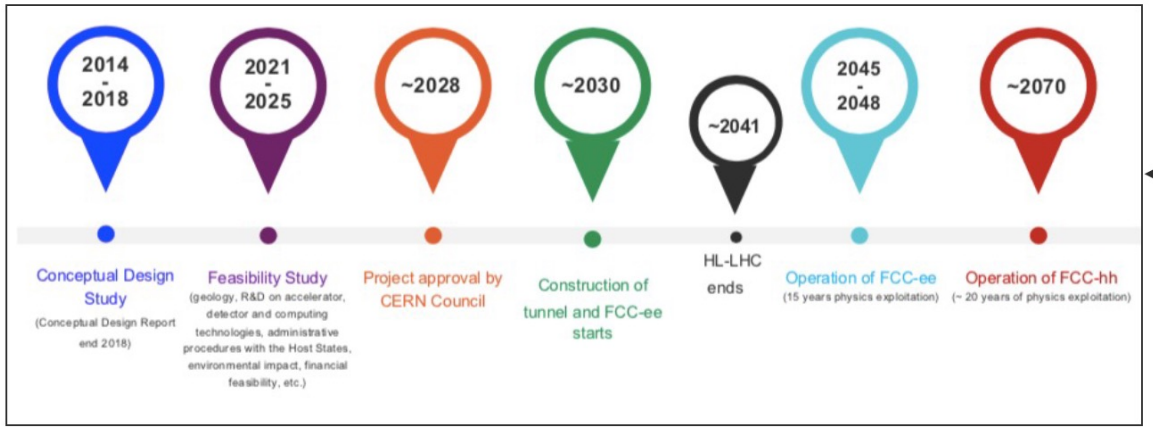
Future Circular Collider: Timeline

F.Gianotti, FCC Week 2023



FCC estimated timeline

Technical schedule:
FCC-ee could start
physics operation **in 2040 or earlier**



"Realistic" schedule takes into account:
- ❑ past experience in building colliders at CERN
- ❑ approval timeline: ESPP, Council decision
- ❑ that HL-LHC will run until ~ 2041
- → **ANY future collider at CERN cannot start physics operation before ~ 2045**
  (but construction will proceed in parallel to HL-LHC operation)

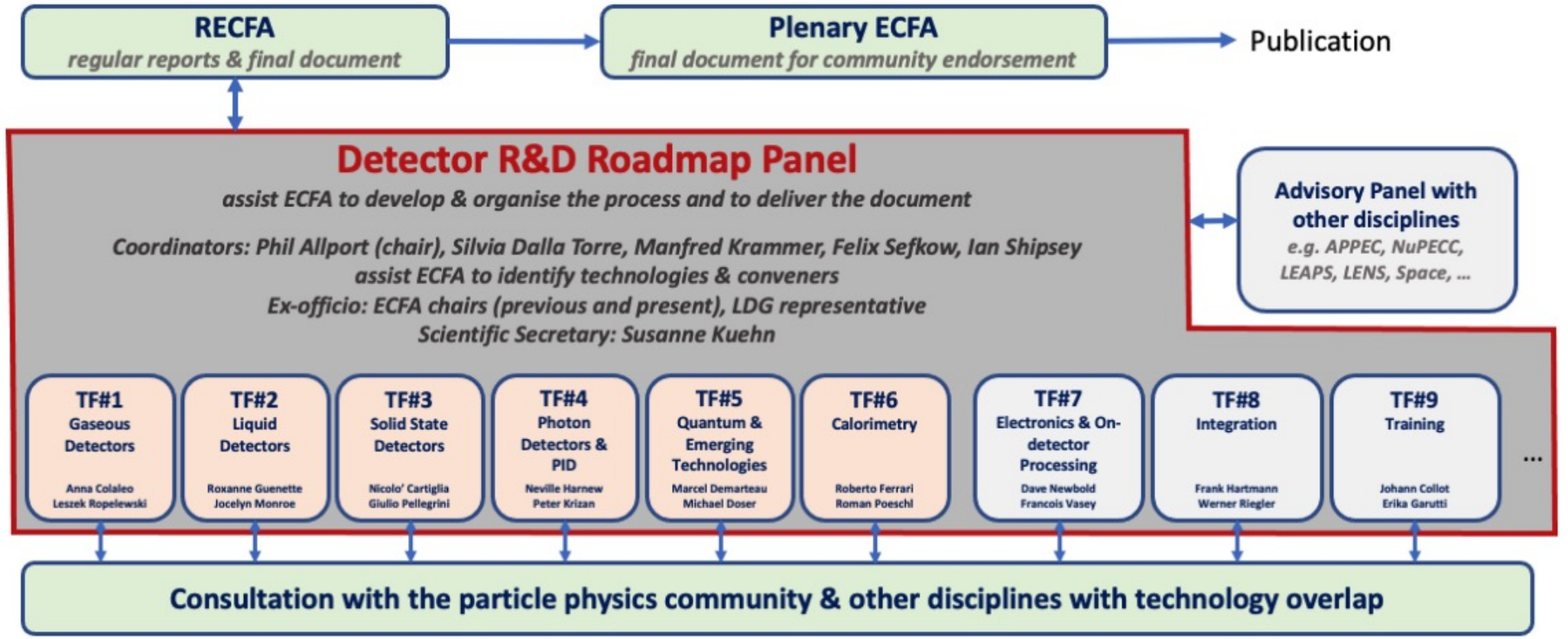
1st stage collider, FCC-ee: electron-positron collisions 90-360 GeV
Construction: 2033-2045 → Physics operation: 2048-2063

2nd stage collider, FCC-hh: proton-proton collisions at ≥ 100 TeV
Construction: 2058-2070 → Physics operation: ~ 2070-2095

Care should be taken when comparing to other proposed facilities, for which in some cases only the (optimistic) technical schedule is shown

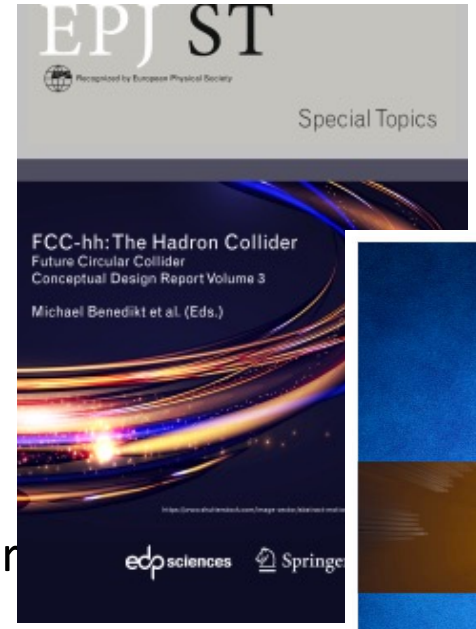
3

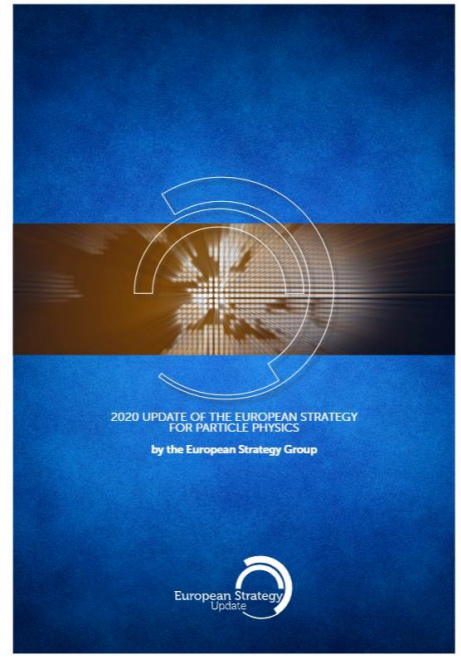
ECFA Detector R&D Roadmap

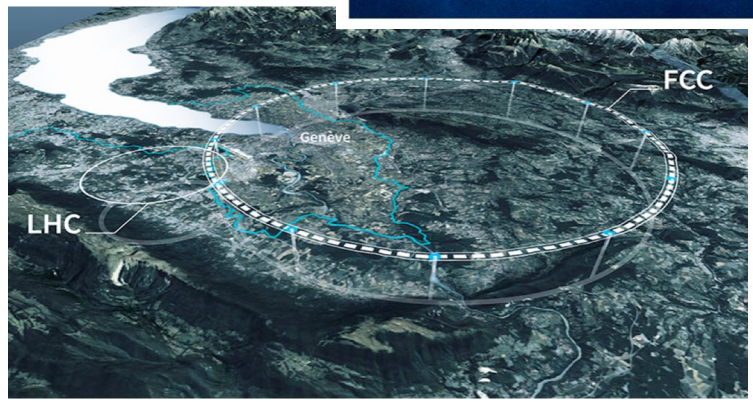


Future Circular Collider (FCC)

- Contributions to the FCC Conceptual Design Report
  - Physics: Top, Higgs, Heavy Ion, etc – both theoretical explorations and feasibility studies
  - Detector design and studies
  - Input to update of European Strategy for Particle Physics
- FCC Design Study proposing a 100 km collider at CERN
  - FCC-ee (e^+e^-, 90 – 365 GeV) followed by FCC-hh 100 TeV pp collider
- Formed group at LIP and joined FCC Collaboration in 2022
  - 9 academics/researchers; 1 PhD student; 2 MSc students
  - Small research project (15 k€) to fund initial activity
- Activities in:
  - Development of radiation-hard scintillators
  - Detector simulation: contribution to detector concept
  - Phenomenology and feasibility studies: QCD and Higgs

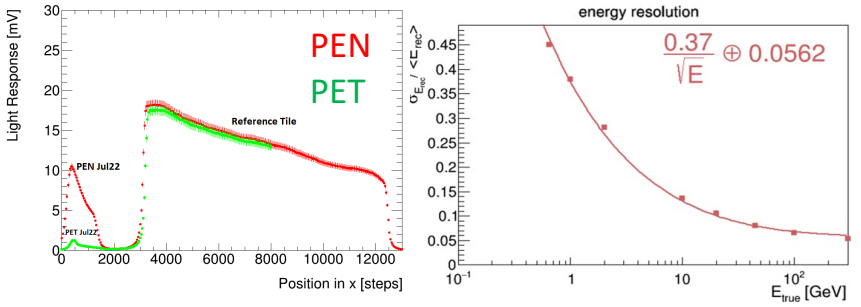






Future Accelerators: ECFA and FCC

- Synergies being pursued with ECFA Detector Roadmap:
  - Joining several Detector R&D collaborations preparing the road for future detectors: DRD1 (gaseous); DRD 2 (liquid); DRD 3 (Solid state); DRD 6 (calorimetry)
  - Long history of detector research at LIP
  - See talk by A.Blanco today



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  - Joined proposal for scintillator+Fe/Pb HCAL option (DRD6)
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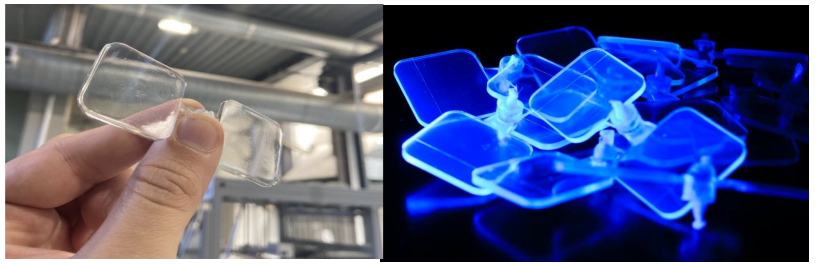
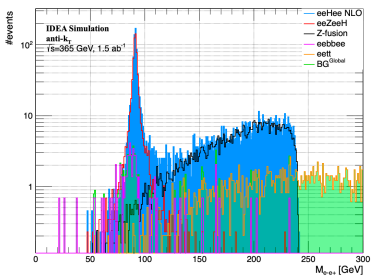
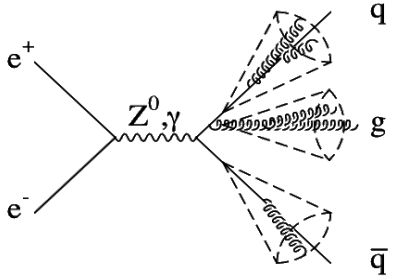


- R&D for novel radiation-hard scintillator development
  - Variety of PET/PEN samples being produced and tested
  - Exploratory R&D project (50 k€); collaboration with IPC polymer group

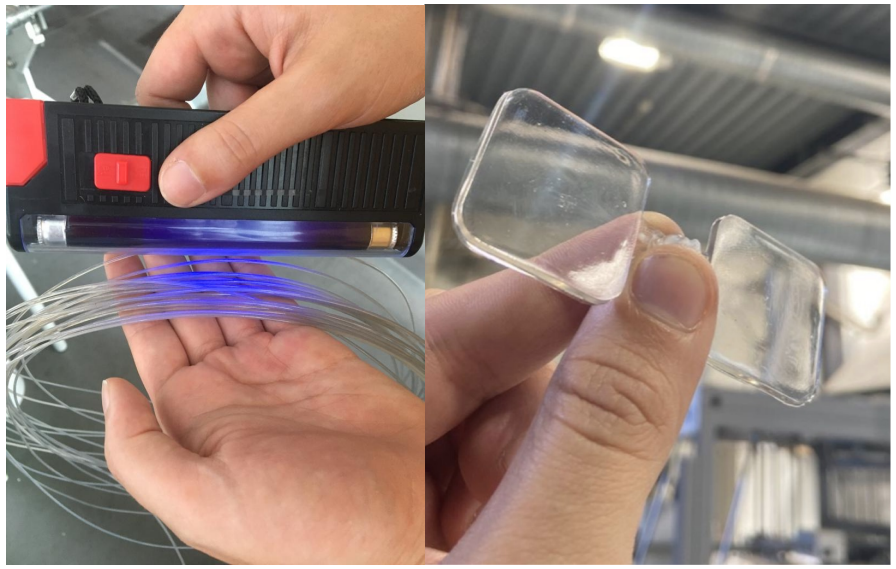


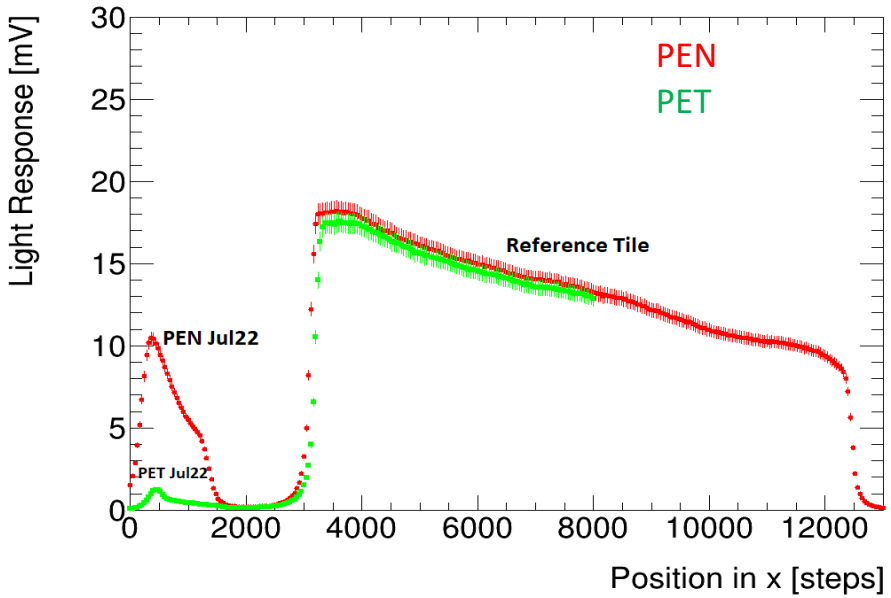


- Theory & Phenomenology:
  - Prepare measurement of α_s at ‰ accuracy at FCC-ee
  - Phenomenological study of Higgs production: triple-Higgs coupling in FCC-ee

Novel Rad-Hard Scintillators

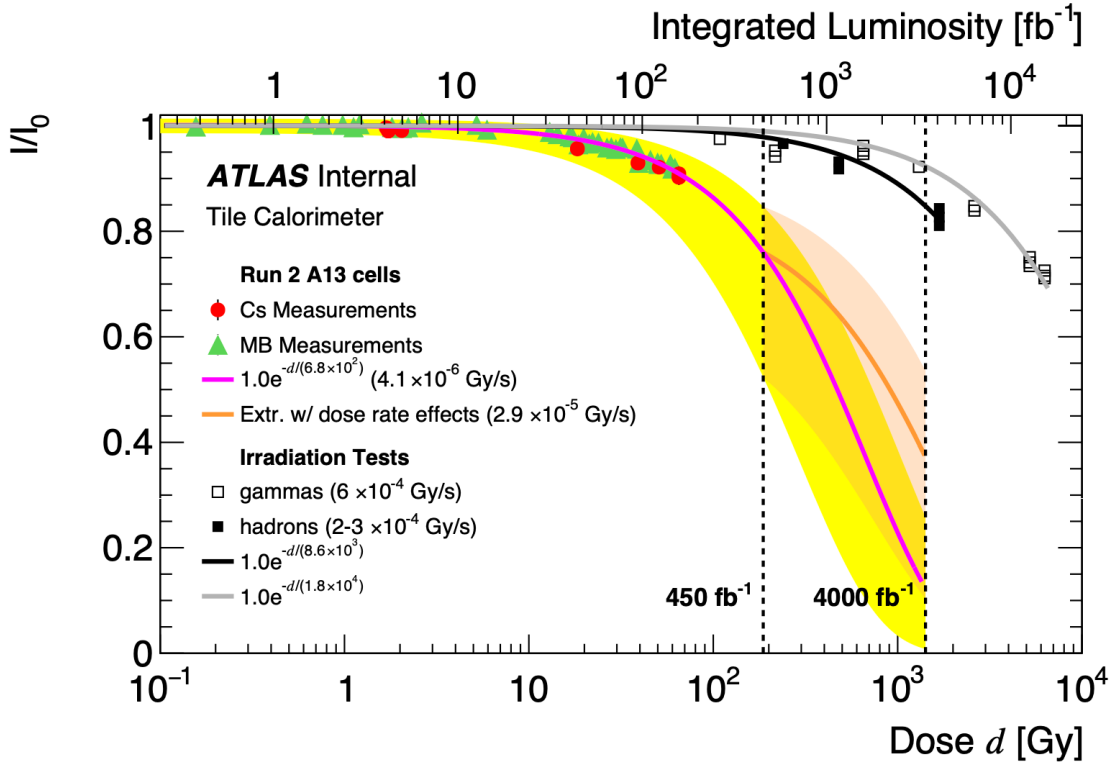
- Primary goal is to develop and characterize new rad-hard scintillating plastics: focus on PEN (Polyethylene Naphthalate) and PET (Polyethylene Terephthalate) polymers
- Collaboration with Institute for Polymers and Composites of the University of Minho (IPC/UMinho)
- Samples (3cm x 3cm x 2mm) produced with various compositions through:
  - Injection Moulding
  - Extrusion
- Crucial parameters:
  - Dosage; injection speed; pressure; cooling time; cooling temperature ; melting temperature; mold Polishing





ATLAS: TileCal radiation hardness for HL-LHC

- Monitoring of light response of TileCal optical components using calibration systems
- Modelling and extrapolation to future conditions essential to predict detector behaviour
- Dedicated publication being prepared



ATLAS: Trigger/DAQ and Tracking

- Trigger and data acquisition
  - Development of GPU-based algorithms for acceleration of high level filter calorimeter reconstruction
  - Demonstrated important improvement factor over CPU algorithm: J. Phys.: Conf. Ser. 2438 012044

- Contributed to former project on Hardware Tracking for the Trigger
  - Simulation and performance studies
  - [ATL-DAQ-PUB-2023-001]

- Tracking software development for HL-LHC
  - PhD student at CERN working on optimization of common tracking package for HL-LHC