L’upgrade dell’esperimento

& relativa attività in Sezione

Alexis Pompili

(in rappresentanza del Gruppo CMS-Bari)

25 giugno 2018 / INFN-Sezione di Bari / Aula multimediale

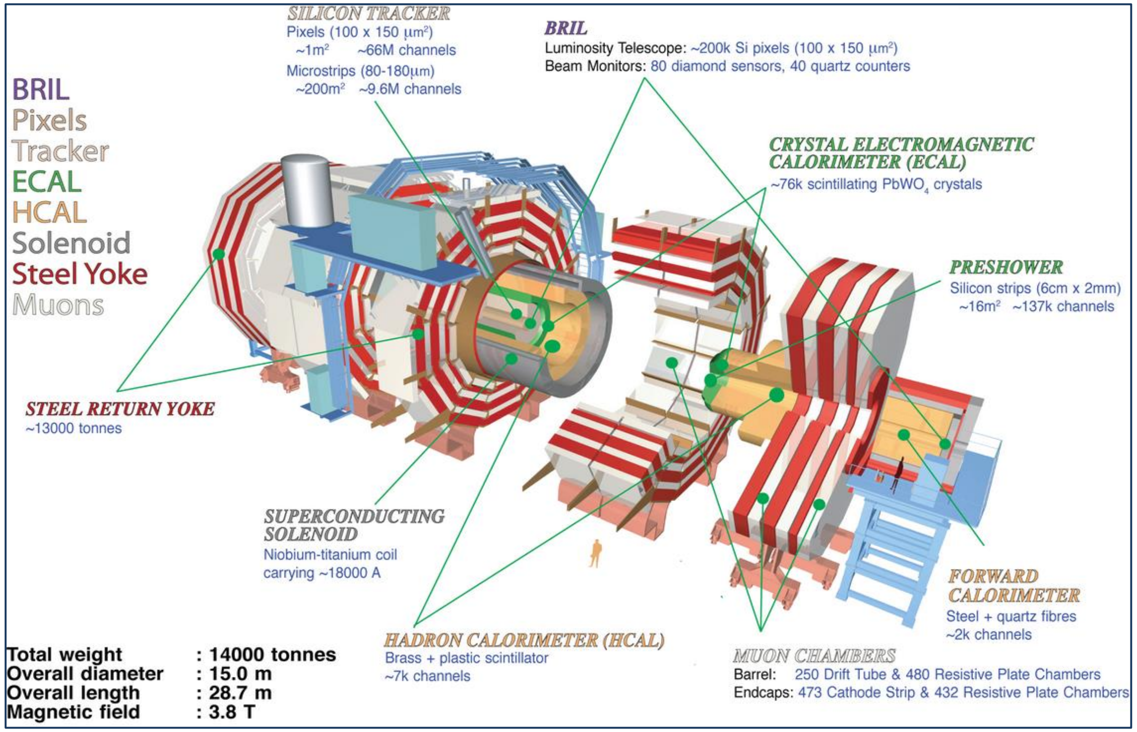
Outline

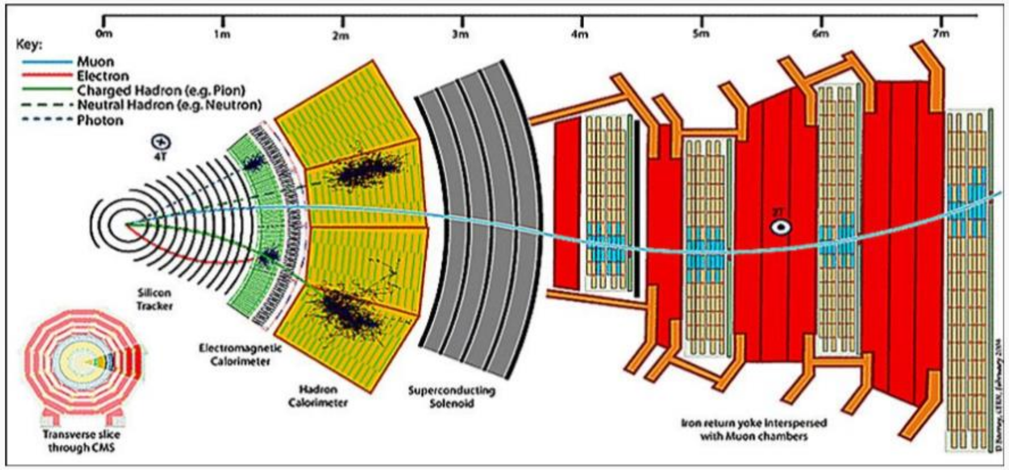
- **HL-LHC & Phase-2 upgrade of CMS experiment**
  [issues, opportunities, solutions]

- **Activities & responsibilities of the CMS-Bari group for the CMS Phase-2 upgrade**
  [needs: manpower, technicians' work, newly dedicated temporary expertise (contracts); labs; schedules]

  - **New Tracker construction & commissioning**

  - **Muon system upgrade : - new GEM detectors (construction, installation & commissioning)**
    - improved RPC (installation & commissioning)





High-luminosity LHC

- **The CERN Council approved (06/2016) the High Luminosity upgrade of the LHC (HL-LHC)** [by year 2026]

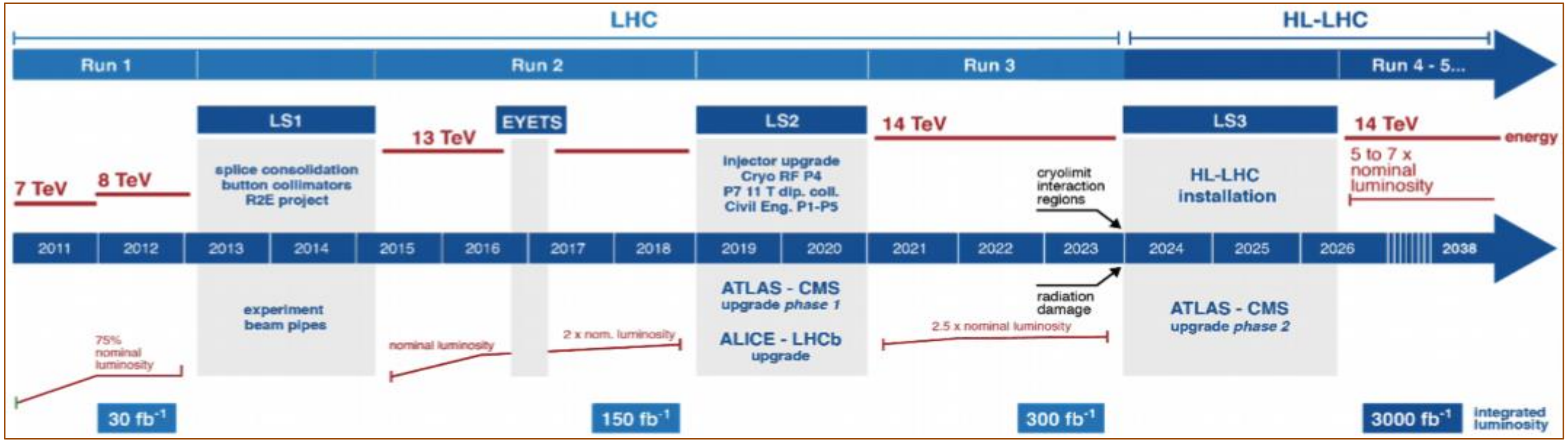
  - **During the 3rd Long Shutdown (LS3) [2024-26] the accelerator will be upgraded to enable:**

    Instantaneous Peak Luminosity $\mathcal{L}_{inst} \sim 5 \times 10^{34} cm^{-2} s^{-1}$ [stable] (or even $\mathcal{L}_{inst} \sim 7.5 \times 10^{34} cm^{-2} s^{-1}$) [ultimate]

  - **HL-LHC is expected to run @ $\sqrt{s} = 14 TeV$ with a $25 ns$ bunch spacing** (close to current values) **but with :**

    - an event pile-up rate 5 times higher than the current PU [stable: 140; ultimate: 200]

    - an integrated radiation dose (after 10 years of operation) **1 order of magnitude higher than originally foreseen for the current LHC detectors)**



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- **Scientific program :**

  - precision measurements of Higgs boson properties (couplings to fermions & vector bosons**)**

  - studies of vector boson scattering

  - searches of new heavy or exotic particles (BSM phenomena)

  - measurements of rare decays & rare production modes of standard particles (precise SM)

CMS Phase-2 Upgrade - I

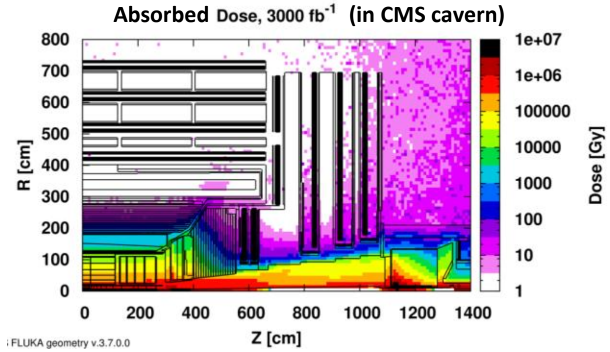
- **An upgrade programme of the CMS experiment (*Phase-2*) is accompanying the HL-LHC upgrade**

... in order to :

- maintain the excellent detector performance while fully profiting from the HL-LHC capabilities

... in spite of ...

- the challenging radiation levels & operating conditions



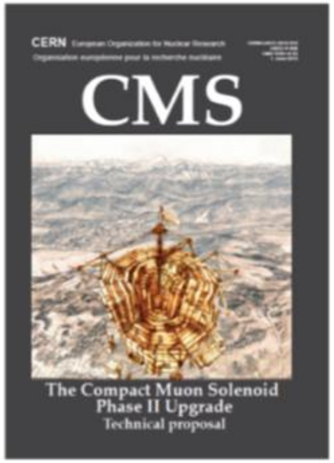
- **Radiation level increase** → **improved detector radiation hardness**

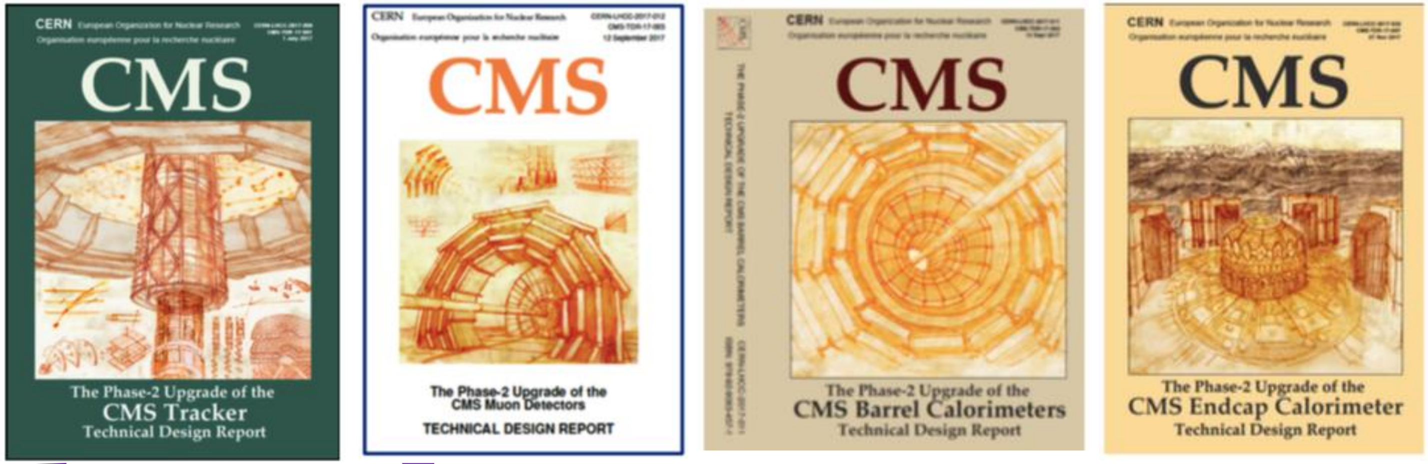
Higher PU rate →
- **higher detector granularity (**to reduce occupancy**)**
- **increased bandwidth (**to accomodate higher data rates**)**
- **improved trigger capability (**to keep acceptable the trigger rate while not compromising the physics potential**)**

200 collisions per bunch crossing considered while designing the upgraded detector

Most of first step is done :

- **Tracker, Barrel Calorimeter, Endcap Calorimeter, Muons Technical Design Reports (TDRs) have been approved by CERN Research Board (RB)**





(*) (*)

- **MIP precision Timing Detector (MTD) approved to go from Technical Proposal (TP) to TDR**
  (to be submitted by 2019/Q1)

(*)

- L1 trigger, HLT trigger & DAQ TDRs will follow (expected in 2020).
  LHCC reviews just ended and recommendations are being actively pursued.

CMS is entering a new phase of engineering, prototyping & construction

(*) with Bari contribution

INFN commitments in the CMS Phase-2 Upgrade

- **INFN is going to participate to the following (upgraded) detectors**
  - **Tracker**
  - **Muon system**
  - **ECAL Barrel**

  INFN - participated to build the current detectors
  & to run them along all these years
  - had prominent role in proposing and designing the inclusion of GEM detectors in the Phase-2 Muon system

  - **MIP Timing Detector** — INFN had also prominent role in proposing and designing it

- **We will briefly review the expected performances and features and the physics impact** but you can refer to the TDRs and TPs for details.

For the first two subsystems we will go into the details of the INFN-Bari commitments and responsibilities in the hardware activities related to the CMS Phase-2 upgrade (numbers are taken from official document approved by referees and provided for CTS scrutiny)

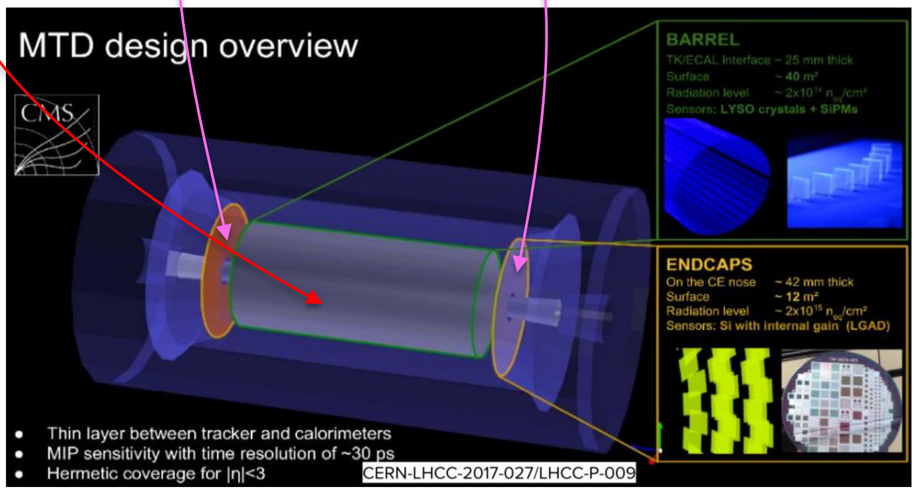
- **Computing resources needed for the big data foreseen for CMS Phase-2 will not be discussed in this presentation!**

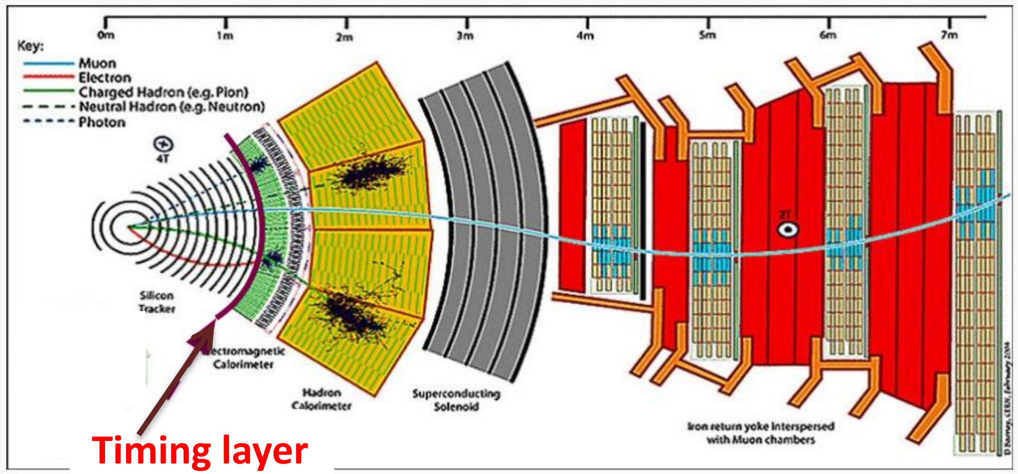
Main CMS upgrade features – new MIP Timing Detector - I

- **The CMS Phase-2 upgraded detector will include a dedicated minimum ionizing particle (MIP) Timing Detector (MTD), expected to provide timing info with ~30ps resolution for <u>each</u> charged track.**

The detector will consist in:

- **a single layer providing timing in the barrel region surrounding the Tracker & inside its thermal screen (shared cooling)** [LYSO crystals read out by silicon photomultipliers (SiPMs)**]**
- **another single layer providing timing for each endcap region located in front of the neutron moderator of the endcap calorimeter**
  [silicon low gain avalanche detectors (LGADs)**]**

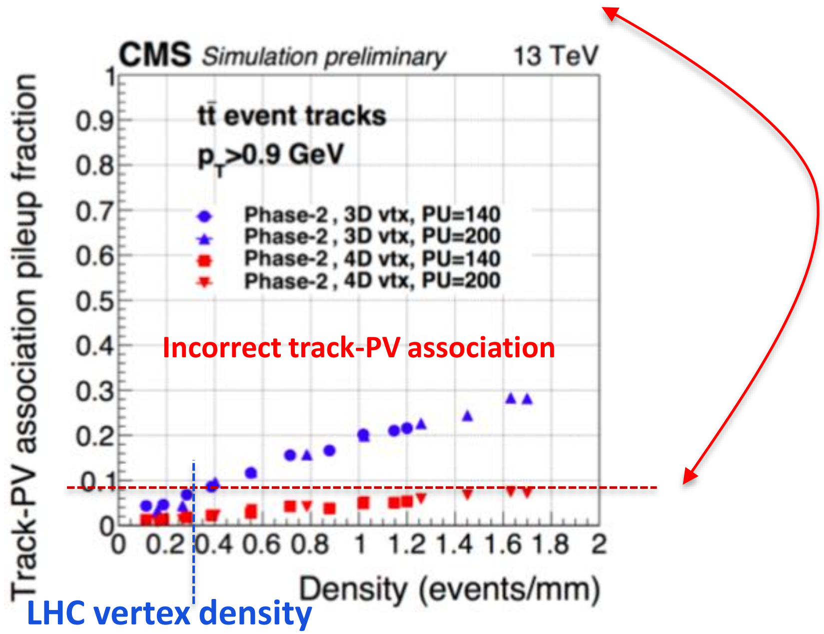




Main CMS upgrade features – new MIP Timing Detector - II

Particle reconstruction & correct assignment to primary interaction vertex (of the hard interaction) in the presence of as many as 200 concurrent collisions per beam crossing (pileup events) represent an incredible challenge to the detectors

- **Pileup mitigation** tipically relies upon the removal from relevant quantities of charged tracks inconsistent with the vertex of interest (and of neutral deposits in the calorimeters with statistical inference techniques like PUPPI).
- **Time tagging of MIPs** produced in LHC collisions provides further discrimination of interaction vertices in the same 25*ns* bunch crossing beyond spatial tracking algorithms: time of arrival measurement can separate collisions very close in space but separated in time.
- Simulation studies indicate that a time resolution of ~30*ps* (allowing to "slice" bunch crossing in "exposures" of 30*ps*) will offset the performance degradation due to PU recovering the track purity of vertices of current LHC conditions.



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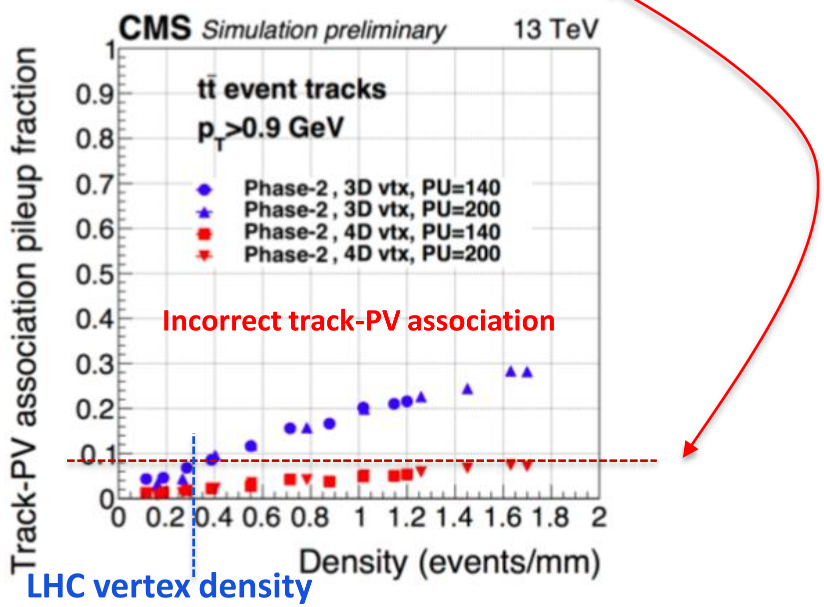
Improvements: vertex identification, acceptance extension for isolated objects, improved missing transverse momentum resolution & pileup jet rate reduction.
This will have significant impact on the physics program [precision H measurements (couplings to SM particles) & searches for SM rare & BSM decays].
Precise track-time reconstruction can have incredible impact in searches for neutral long-lived particles (in SM extensions).

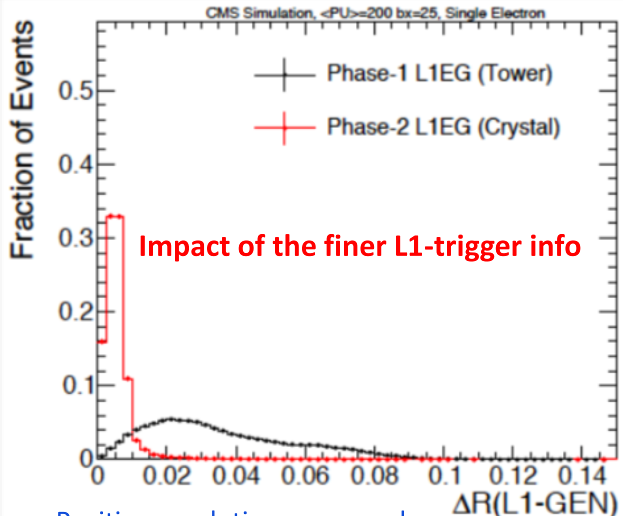


Main CMS upgrade features – ECAL barrel

- **The principal requirement of the ECAL barrel is to maintain Run-1 physics performance for photons & electrons at higher luminosity & pile-up of HL-LHC.**
  To accomplish this, the electronics must accommodate the new L1 trigger requirements on : latency ($3.2 \rightarrow 12\mu s$) & rates ($100 \rightarrow 750kHz$). It also must provide more precise timing resolution and help mitigate the increasing noise from photodetectors.
  Loss of transparency in lead-tungstate crystals (not to be replaced) will be kept @ acceptable level.

All electronics FE cards & all off-detector electronics must be replaced to meet these requirements !

- The current system provides trigger primitives of 5-by-5 crystals and there is no tracking information. **The upgrade will provide single crystal information to the L1 calorimeter trigger**, thus better matching e.-m. showers to tracks and providing better isolation. The significantly reduced level of background will allow a precision study of the Higgs boson ($H \rightarrow \gamma\gamma$).



Position resolution expressed as difference w.r.t. generated electrons

- Precision time measurement will be an additional feature of the upgraded electronics, allowing an improved determination of the location of the production vertex for di-photon events: a precision of 30*ps* on the time arrival of photons produced by H boson is the target, thus allowing a constraint of 1*cm* on the vertex longitudinal position.

New Tracker for Phase-2 CMS

Main CMS upgrade features / new Tracker – I

- **The entire Silicon Tracking System will be replaced !**

  The new Tracker (Inner Tracker (IT) based on silicon pixel modules
  + Outer Tracker (OT) made from silicon modules with strips and macro-pixel sensors)
  will feature :

  - **increased radiation hardness**
    - radiation tolerance must ensure fully efficiency up to $\mathcal{L}_{int} \sim 4500 fb^{-1}$
    - without any intervention for OT; it will still be possible to replace IT modules (during shutdowns)
  - **higher granularity & extended tracking acceptance**
    - channel occupancy kept below the per cent(mille) level in the IT(OT)
    - improved 2-track separation [currently hit-merging in pixel detector for closeby tracks (energetic jets)]
    - efficient tracking up to $\sim |\eta| = 4$

rz layout

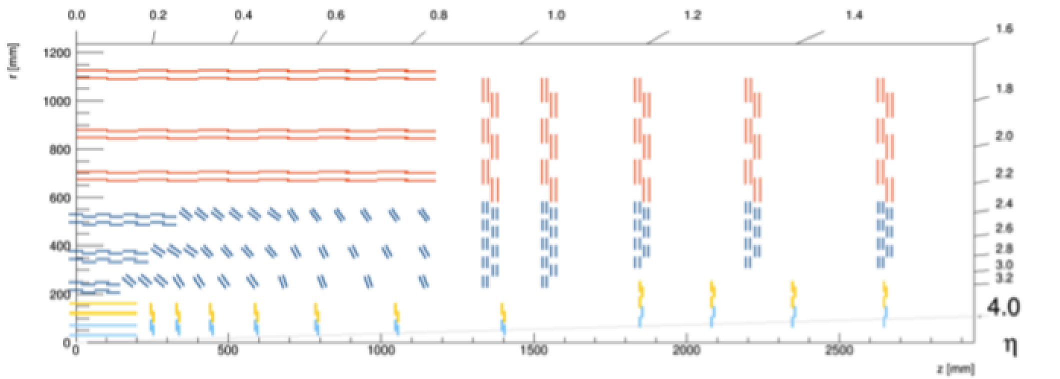


Figure 1: Sketch of one quarter of the tracker layout in *rz* view. In the Inner Tracker the green lines correspond to pixel modules made of two readout chips and the yellow lines to pixel modules with four readout chips.

Main CMS upgrade features / new Tracker – II

- **robust pattern recognition**
  - optimized design for track finding under high PU conditions
  - also aided by parallel computing solutions & application of ML/DL concepts (**already ongoing also in Bari**)

- **reduced material in the tracking volume**
  - lighter than the current Tracker having performance affected by the amount of material (that influences the performance of the calorimeters & of the overall event reconstruction)

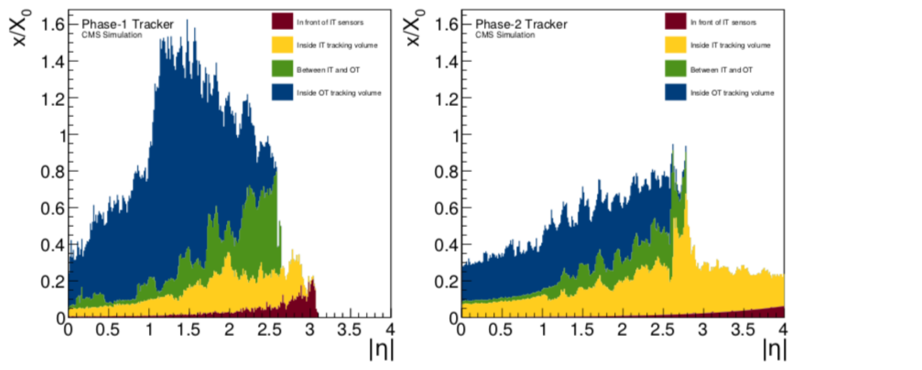
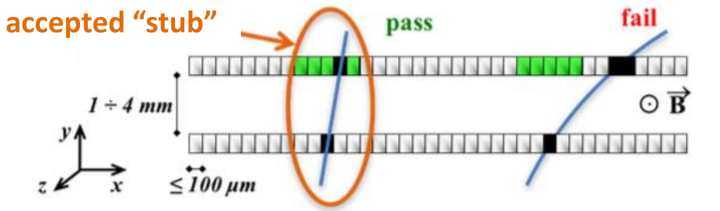


Figure 3: Material budget inside the tracking volume estimated in units of radiation lengths, comparing the Phase-1 (left) and the Phase-2 (right) detectors. The material in front of the IT sensors is shown in brown, that inside the IT tracking volume in yellow, that between IT and OT sensors in green, and that inside the OT tracking volume in blue. The histograms are stacked.

- **compatibility with higher data rates (output trigger rate) & longer trigger latency**

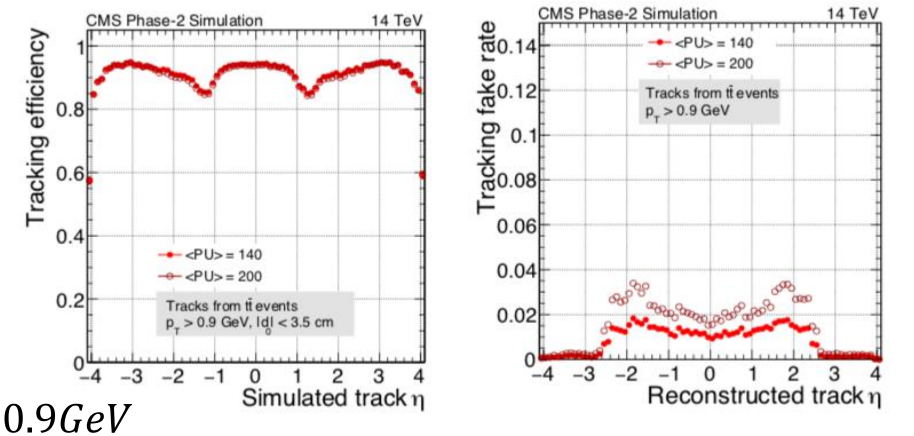
... and will provide ... **tracking information to the L1 trigger** (now available only at HLT)
thus allowing to keep trigger rates at sustainable level:
a part of the track reconstruction presently performed in the HLT will be anticipated to be used in L1 event selection

concept used to provide L1 trigger primitives, based on correlation of signals in closely-spaced sensors in order to enable rejection of low-p_T tracks :



Upgraded Tracker performances

- **Few examples of foreseen performances** (with full MC simulation):

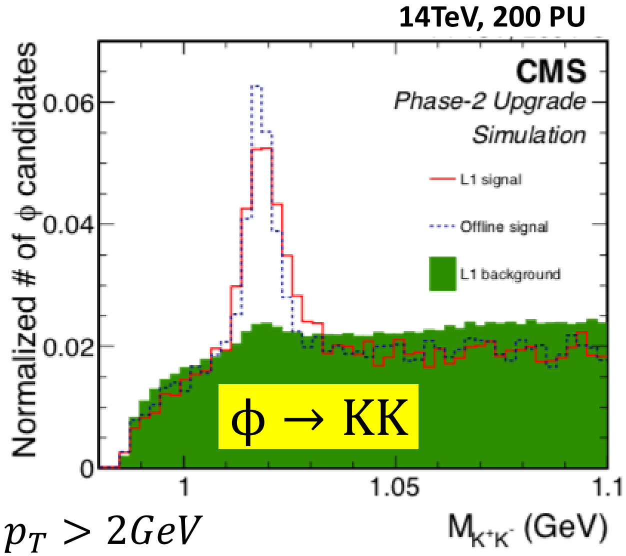


$t\bar{t}$ events

$p_T > 0.9GeV$

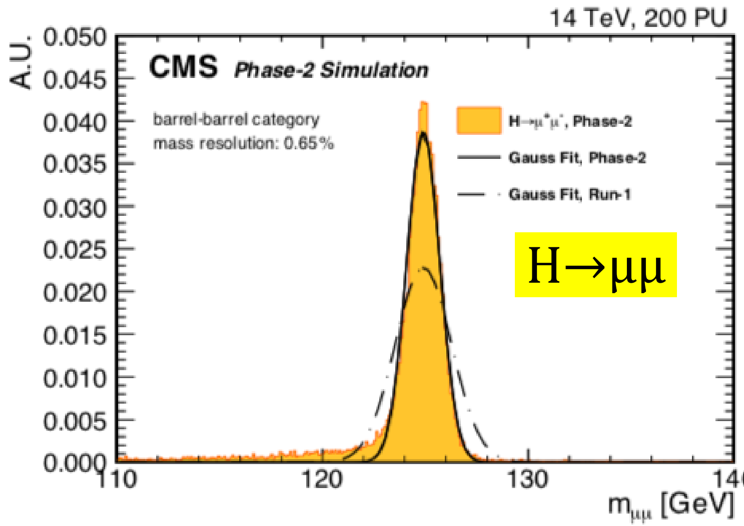
Figure 4: Tracking efficiency (left) and fake rate (right) as a function of the pseudorapidity for $t\bar{t}$ events with 140 pile-up events (full circles) and 200 pile-up events (open circles). The tracks are required to have $p_t > 0.9$ GeV. The efficiency is shown for tracks produced within a radius of 3.5 cm from the centre of the luminous region.

New L1 trigger capabilities



$p_T > 2GeV$

Expected resolution for H→μμ compared to current detector



Detection with higher S/N over the dominant D-Y background

INFN commitments in Tracker construction – overview - I

Legend:
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	Sensor Quality Control	ASICs Quality Control	FE Hybrid Quality Control	Bump bonding Quality Control	On-detector Service Electronics	Module production	Module burn-in	Integration of sub-assemblies	Mechanics	Beam pipe	Optical Data links	DAQ hardware	DAQ software	L1 track finder	Dry gas system	Safety system	Cooling system	Power system	Power cables	Commissioning	Installation	Construction database
INFN Sezione di Bari and Università di Bari, Bari, ITALY			TBPX TEPX			TBPS														OT		
INFN Sezione di Catania and Università di Catania, Catania, ITALY			TBPS										OT	X						OT		
INFN Sezione di Firenze and Università di Firenze, Firenze, ITALY					TBPX TEPX	TBPX TEPX							IT					X		IT		
INFN Sezione di Genova and Università di Genova, Genova, ITALY					TBPS															OT		
INFN Sezione di Milano-Bicocca and Università di Milano-Bicocca, Milano, ITALY													IT							IT		
INFN Sezione di Padova and Università di Padova, Padova, ITALY		IT								X										IT		
INFN Sezione di Pavia, Università di Pavia and Università di Bergamo, Pavia, ITALY		X	TBPX TEPX																	IT		
INFN Sezione di Perugia and Università di Perugia, Perugia, ITALY	OT					TBPS								X				OT		OT		
INFN Sezione di Pisa, Università di Pisa and Scuola Normale Superiore di Pisa, Pisa, ITALY	IT			TBPX TEPX			TBPS	TBPS	TBPX				OT	X		X				OT	IT	
INFN Sezione di Torino, Università di Torino and Politecnico di Torino, Torino, ITALY		IT					TBPX TEPX	TBPX TEPX	TBPX				IT							IT	IT	

INFN commitments in Tracker construction – overview - II

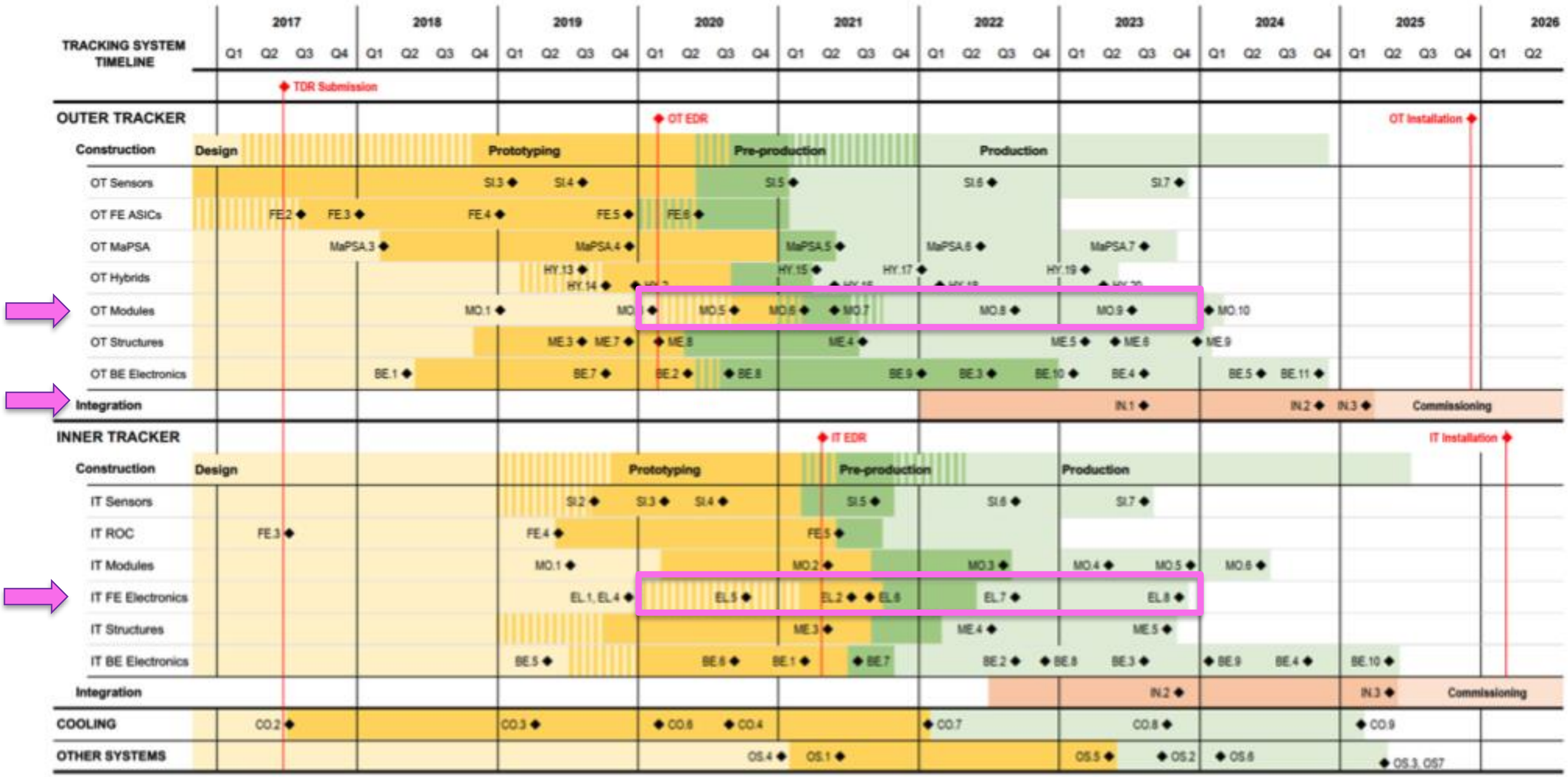
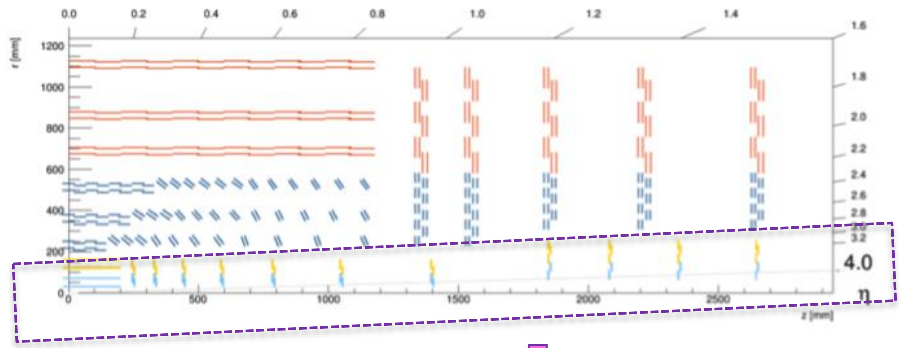


Figure 19: Construction schedule for the Phase-2 Tracker Upgrade (from TDR). The columns correspond to different phases of the project: design (light yellow), prototyping (dark yellow), preproduction (dark green) production (light green), integration (dark salmon), and commissioning (light salmon). The codes indicate milestones described in the TDR.

INFN commitments in Tracker construction - IT

INFN will deliver for the IT :

- **1128 Pixel modules** installed in :
  - inner layers (**TBPX** L1 & L2)
  - inner rings (**TEPX** R1 & R2 in Disks 1-4)



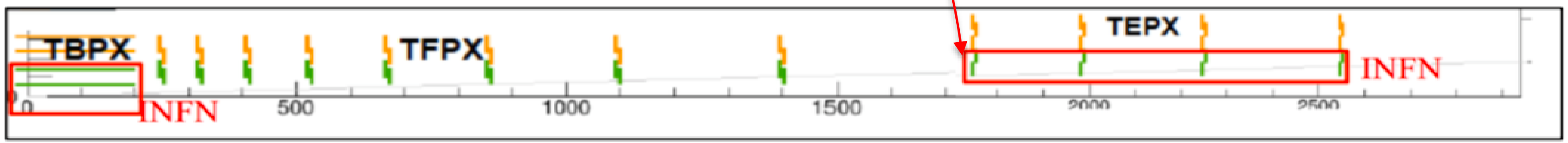


Figure 20: schematics structure of one side of the Inner Tracker with enlightened the modules in the inner rings (TEPX rings 1 and 2) and inner layers (TBPX layers 1 and 2) delivered by INFN

- **integration, test & delivery of 4-Layers Barrel Pixel (full TBPX)**
- **integration, contribution to development & commissioning of IT common system** (power backend, DAQ & safety systems)

the DAQ system of IT is under development (having as starting point the test-setup of RD53A chip)

INFN-BARI commitments in IT construction - I

INFN-Bari will take care of the HDI Hybrids testing task :

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INFN Sezione di Bari and Università di Bari, Bari, ITALY			TBPX TEPX			TBPS														OT		
INFN Sezione di Catania and Università di Catania, Catania, ITALY			TBPS										OT	X						OT		
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INFN Sezione di Padova and Università di Padova, Padova, ITALY		IT								X										IT		
INFN Sezione di Pavia, Università di Pavia and Università di Bergamo, Pavia, ITALY		X	TBPX TEPX																	IT		
INFN Sezione di Perugia and Università di Perugia, Perugia, ITALY	OT					TBPS								X				OT		OT		
INFN Sezione di Pisa, Università di Pisa and Scuola Normale Superiore di Pisa, Pisa, ITALY	IT			TBPX TEPX			TBPS	TBPS	TBPX				OT	X		X				OT	IT	
INFN Sezione di Torino, Università di Torino and Politecnico di Torino, Torino, ITALY		IT					TBPX TEPX	TBPX TEPX	TBPX				IT							IT	IT	

INFN-BARI commitments in IT construction - II

- **INFN-Bari will take care of the HDI Hybrids testing task :**

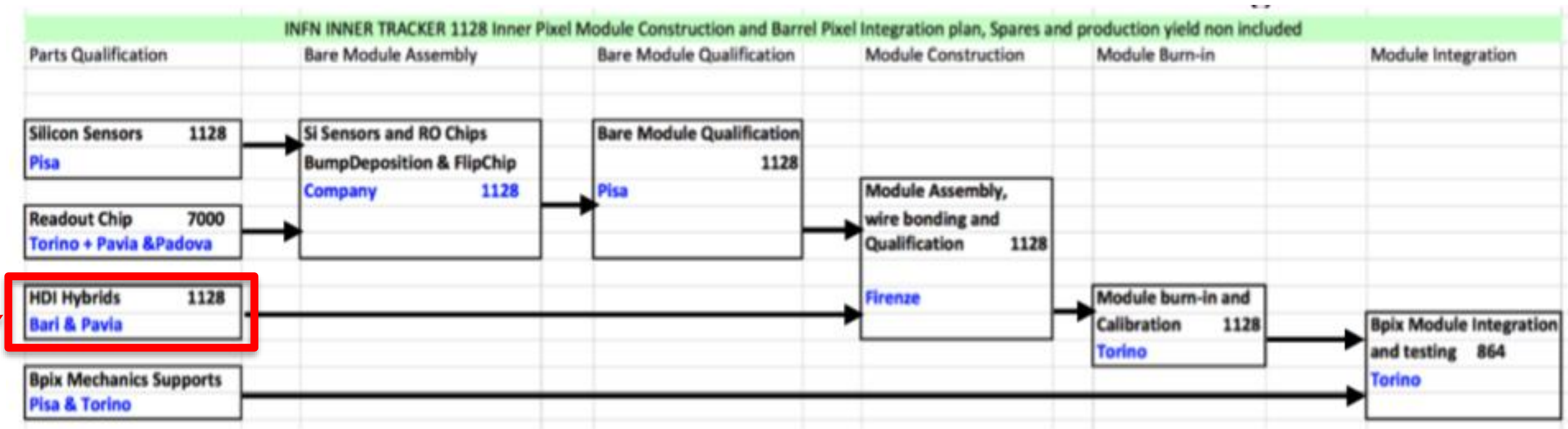


Figure 23: INFN construction flow for Inner Tracker

High Density Interconnect (HDI) Hybrids – produced by a supplier company – will be qualified in Bari & Pavia using a dedicated setup.
Qualified good HDIs will be delivered to Firenze for module assembly.

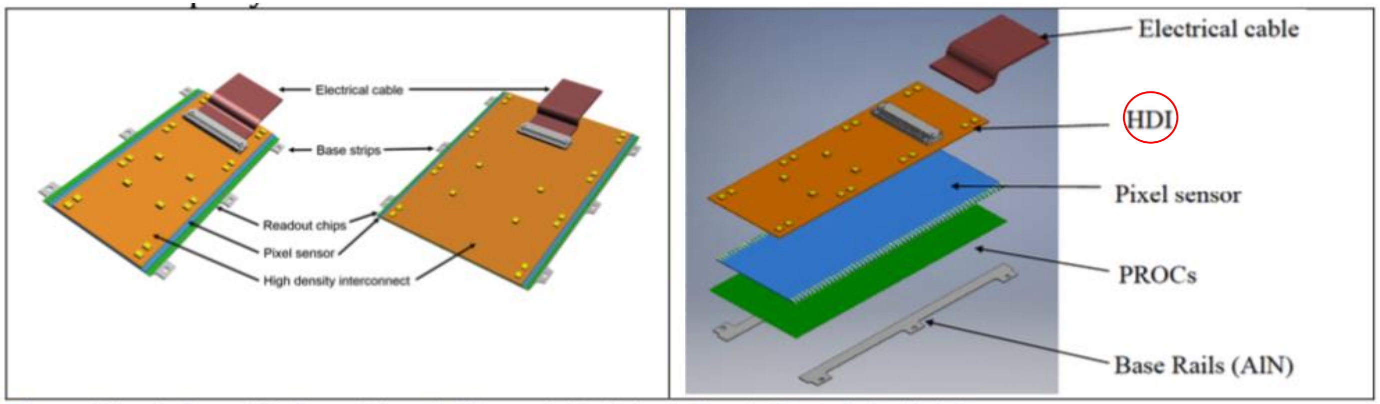
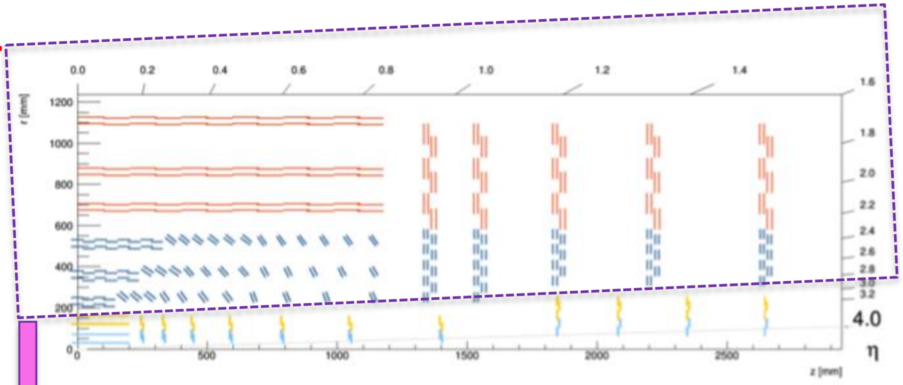


Figure 21: 1x2 and 2x2 modules (left); exploited view of a 1x2 module (right).

- **INFN will deliver for the OT :**
  - **1920 PS modules** mounted, integrated & tested in :
    - – 72 rings of the Tilted Barrel (**TBPS**)

OT



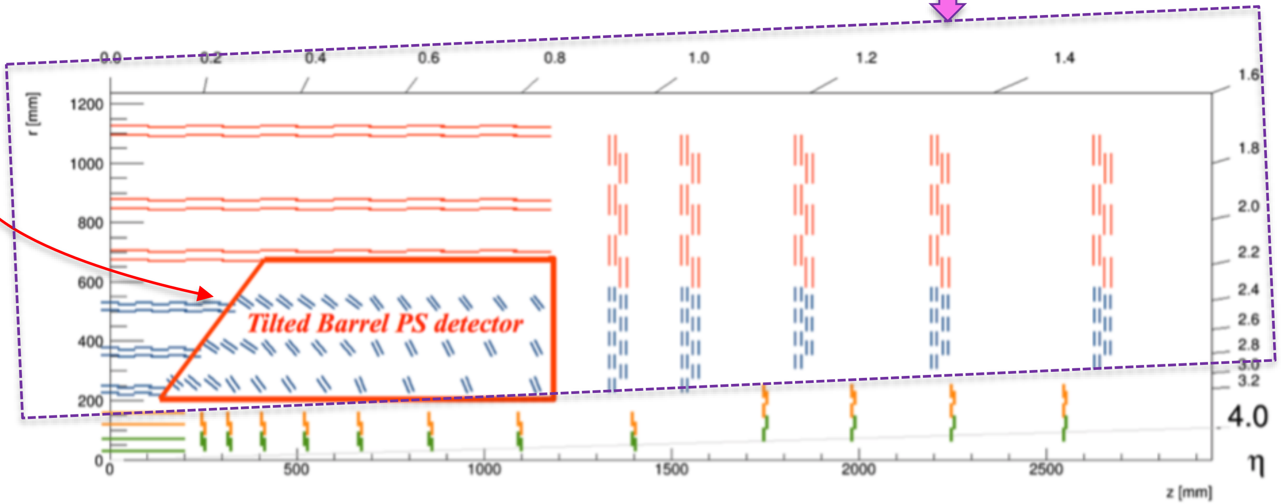


Figure 24: schematics structure of one side of the Outer Tracker with enlighten the modules in the inner rings and layers delivered by INFN

- contribution to **OT common system** (in particular power supply backend system & DAQ)
- contribution to **OT commissioning**
- contribution to **Track Trigger** [Track Finder L1 system (implemented by dedicated boards)]

INFN-BARI commitments in OT construction - I

- **INFN-Bari will take care of the production of the TBPS modules (and later will participate to the OT commissioning) :**

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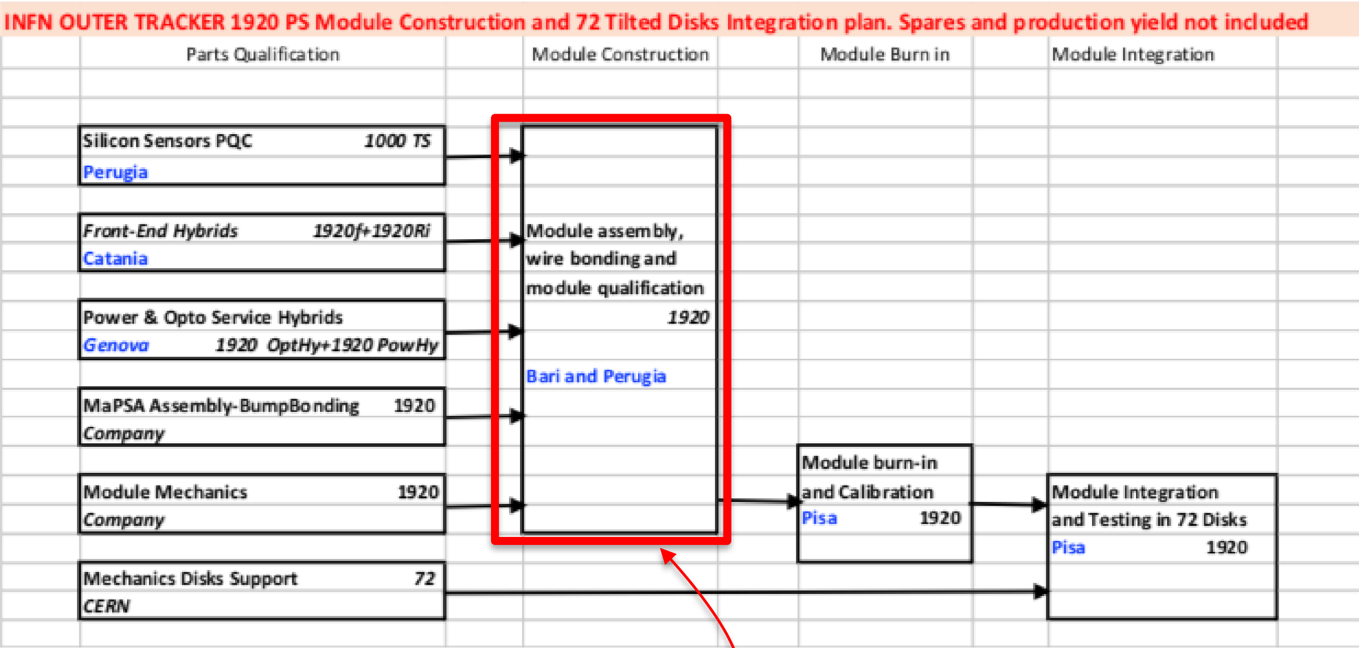
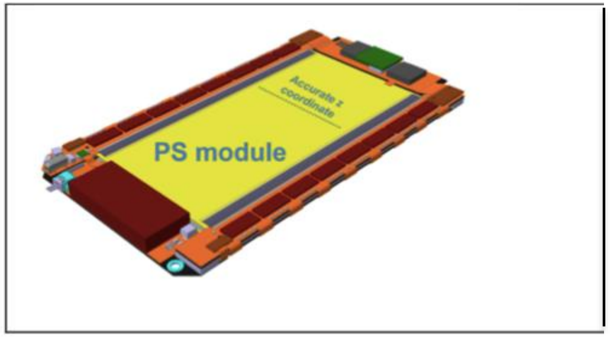
INFN Sezione di Bari and Università di Bari, Bari, ITALY			TBPX TEPX			TBPS														OT		
INFN Sezione di Catania and Università di Catania, Catania, ITALY			TBPS										OT	X						OT		
INFN Sezione di Firenze and Università di Firenze, Firenze, ITALY					TBPX TEPX	TBPX TEPX							IT					X		IT		
INFN Sezione di Genova and Università di Genova, Genova, ITALY					TBPS															OT		
INFN Sezione di Milano-Bicocca and Università di Milano-Bicocca, Milano, ITALY													IT							IT		
INFN Sezione di Padova and Università di Padova, Padova, ITALY		IT								X										IT		
INFN Sezione di Pavia, Università di Pavia and Università di Bergamo, Pavia, ITALY		X	TBPX TEPX																	IT		
INFN Sezione di Perugia and Università di Perugia, Perugia, ITALY	OT					TBPS								X				OT		OT		
INFN Sezione di Pisa, Università di Pisa and Scuola Normale Superiore di Pisa, Pisa, ITALY	IT			TBPX TEPX			TBPS	TBPS	TBPX				OT	X		X				OT	IT	
INFN Sezione di Torino, Università di Torino and Politecnico di Torino, Torino, ITALY		IT					TBPX TEPX	TBPX TEPX	TBPX				IT							IT	IT	

INFN-BARI commitments in OT construction - II

INFN-Bari will take care of the production of the TBPS modules :

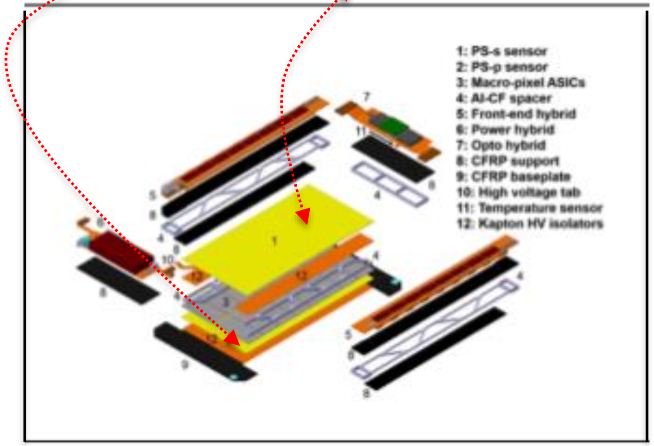


INFN construction flow for Outer Tracker



macro-pixel sensor (**PS-p**)

short-strip sensor (**PS-s**)



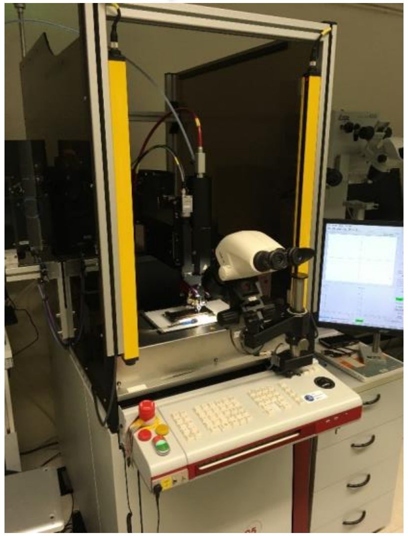
PS module assembly **: PS-s sensor, Macro-Pixel Sub Assembly (MaPSA) [**1 PS-p sensor bump bonded with 16 Macro Pixel Asics**], Front-End Hybrid** to readout short strips **(HL & HR** are the 2 types of FEH**), Power Hybrid (PH) [**equipped with Power DCDC regulator**], Optohybrid (OH) [**equipped with optical link drivers & opto-fiber connector**] will be assembled and glued to mechanical parts in 5 steps, using different jigs, in order to finally form a PS module. Modules will be built in Bari & Perugia (**50%-50%**).**

A full qualification test will be performed to assess quality and identify issues. Encapsulation of wire bonding will be made after testing. Qualified modules will be delivered to Pisa.

Infrastructures for Outer Tracker commitments

Infrastructures @ INFN-Bari for the CMS (Outer) Tracker upgrade :

Description	Location	Comments and Motivations	Task associated	Cost [ke]	INFN Contrib . [kE]	Year
Wire bonding machine	BARI	Replacement of old machine. Already bought	OT 5	150	100	2017
Wire bonding pull tester	BARI	New for wire bonding testing	OT 5	8,5	8,5	2018
Upgrade for Module assembly	BARI	Glue dispenser robot with volumetric control	OT 5	26	26	2019
Climatic chamber	CATANIA	For OT hybrid burn-in	OT 3	40	40	2019
Wire bonding machine	FIRENZE	Replacement of old machine	IT 5	192	112	2017
Probe station	FIRENZE	Silicon sensor receptiom test	IT 5	100	50	2019
Wire bonding machine	PERUGIA	Replacement of old machine	OT 5	150	150	2018
3D Measuring machine	PERUGIA	Update of machine for module survey	OT 5	20	20	2018
8" Probe station	PERUGIA	Replacement of old machine for sensor QA	OT 1	250	250	2018
Upgrade for Module assembly	PERUGIA	Glue dispenser robot with volumetric control	OT 5	26	26	2019
Probe station maintenance	PISA	Pixel Silicon sensor Qualification center	IT 1	35	35	2018
X-ray test station	PISA	For diagnostic of bump-bonding connection and calibration	OT 7	50	50	2018
Termo-camera	PISA	Verification during OT module assemb ly	OT 7	27	27	2018
Cold Box	PISA	Burn-in of OT modules	OT 7	25	20	2019
3D Measuring machine	PISA	Module integration on OT rings	OT 7	60	35	2018
Stocking of mechanical structure	PISA	To store and manipulate OT rings	OT 7	30	30	2019
Climatic chamber	PISA	For testing of sub-assembly of OT rings	OT 7	112	112	2018
12" probe station	TORINO	New for wafer level testing of IT ASIC	IT 2	480	200	2018
Cold box	TORINO	Burn-in of IT modules	IT 7	25	20	2019
X-ray test station	TORINO	For diagnostic and final calibration of IT modules	IT 7	50	50	2018
			Total	1857	1361,5	

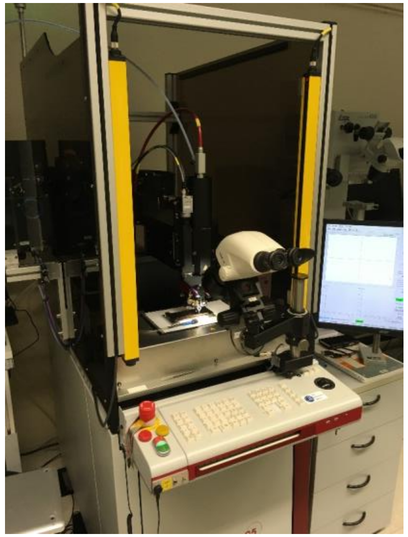


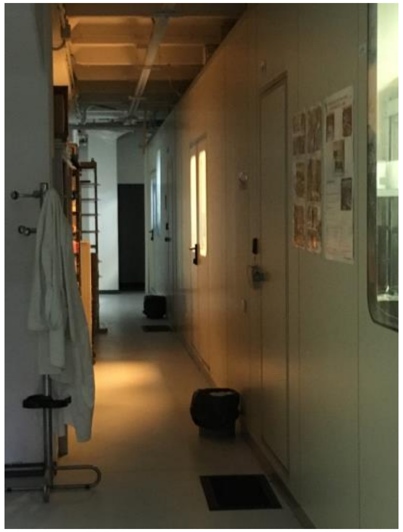
List of infrastructures requested to INFN for the CMS Tracker upgrade

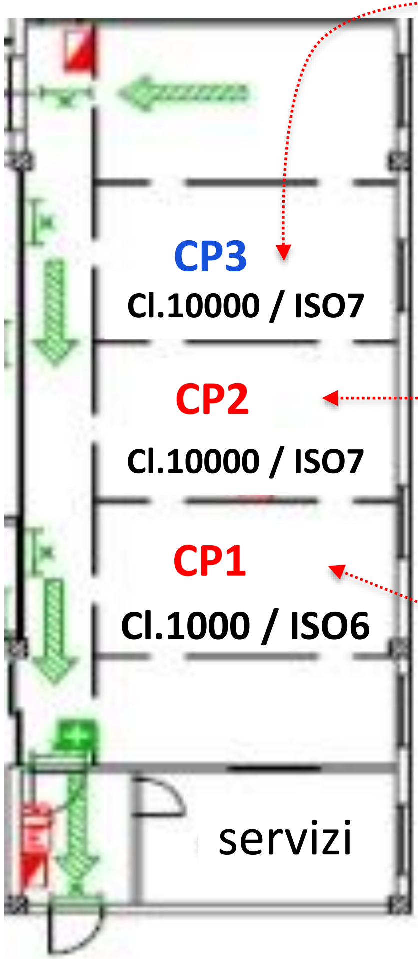
Lab space of INFN-Bari for Outer Tracker commitments

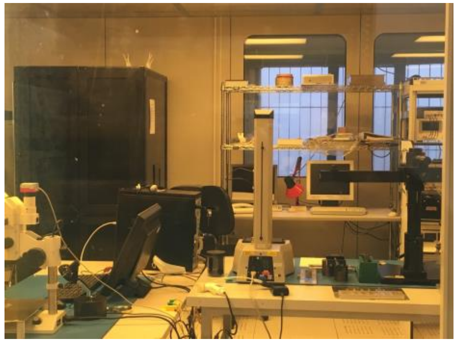
- **Currently used Clean Rooms (CP1, CP2) will be confirmed till 2023 and will be saturated in the construction period 2020-2023**

GEM clean room









Manpower of INFN-BARI for Tracker commitments

INFN/CMS-Bari manpower involved in the activities for the construction of new Tracker :

Institute	2018 FTE	TASK	Average Man Power (without request)			REQUEST of MANPOWER [FTE]							
			Physicists & Engineers	Technicians	PhD /Temporary	2018	2019	2020	2021	2022	2023	2024	2025
Bari	3,9	IT FE Hybrid QC/QA	3	0,9	0,2			1	1	1	1		
		OTPS Module construction						1	1	1	1		
Catania	1,6	OTPS FE Hybrid QC	1,3	0,2	0			1	1	1			
Firenze	7,4	IT Module construction	5,1	1	1,5				1	1	1		
		IT system test											
		IT Serial Power electronics						1	1	1	1		
		TK Power System						1	1	1	1	1	1
Genova	0,5	OTPS Service Hybrids (OH&PH) QC	0,8	0,5				1	1	1	1		
Milano Bic	2,1	IT DAQ Software/system test	1,5	0	0,7					1	1	1	1
Padova	0,6	TK ASICs QC	0,5	0,2	0			1	1	1			
		TK Beam Pipe development											
Pavia	1,7	IT ASICs QC	1	0	0,4			1	1	1			
		IT FE Hybrids QC							1	1	1		
Perugia	6	OT Sensor Process QC	4,3	1,9	1,3		1	1	1	1			
		OTPS Module construction						1	2	2	1		
		OT Power System						1	1	1	1		
Pisa	5,4	IT Sensor QC	7,2	1	1,7				1	1			
		IT Bump Bonding QC							1	1	1		
		IT Mechanics construction						1	1	1			
		OTPS Module Burn in							1	1	1		
		OTPS Module Integration								1	1	1	
		OT DAQ software										1	1
		OT Track Trigger						0,5	1	1	0,5		
		TK Safety System											
Torino	6,6	IT ASIC QC	4,2	2,1	1,2			1	1	1			
		IT Module Burn in											
		IT Mechanics construction						1	1				
		IT Module Integration									1	1	
Total FTE	35,8		28,9	7,8	7	0	1	14,5	21	22	14,5	5	3

IT task (IT3)

OT task (OT5)

Manpower of INFN/CMS-BARI for Tracker commitments

INFN/CMS-Bari manpower involved in the activities for the construction of new Tracker :

Institute	2018FTE	TASK	Average Man Power (without request)			REQUEST of MANPOWER [FTE]							
			Physicists & Engineers	Technicians	PhD /Temporary	2018	2019	2020	2021	2022	2023	2024	2025
Bari	3,9	IT FE Hybrid QC/QA	3	0,9	0,2			1	1	1	1		
		OTPS Module construction						1	1	1	1		

IT task (IT3)

OT task (OT5)

	Profile	2018	2019	2020	2021	2022	2023	2024	2025	ToT	Task
BARI										41,20	
Donato Creanza	PA	0,5	0,7	0,7	0,7	0,7	0,7	0,1	0,0	4,1	OT 5
Mauro de Palma	PO	0,1	0,1	0,1	0,3	0,3	0,2	0,0	0,0	1,1	OT 5
Luigi Fiore	PR	1,0	1,0	1,0	1,0	1,0	1,0	0,5	0,0	6,5	OT 5
Salvatore My	PA	0,6	0,7	0,7	0,8	0,8	0,8	0,4	0,0	4,8	OT 5
Alexis Pompili	RU	0,0	0,0	0,1	0,1	0,1	0,0	0,0	0,0	0,3	OT 5
Lucia Silvestris	PR	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,0	0,4	OT 5
Giuseppe De Robertis	PT El	0,3	0,3	0,3	0,2	0,2	0,2	0,2	0,0	1,7	IT 3
Flavio Loddo	PT El	0,7	0,7	0,7	0,5	0,5	0,5	0,3	0,0	3,9	IT 3
Tecnologo	TE	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,0	1,4	IT 3
Tecnico INFN 1	Tec	0,2	0,6	1,0	1,0	1,0	1,0	0,3	0,0	5,1	OT 5
Tecnico INFN 2	Tec	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,0	1,4	OT 5
Tecnico INFN 3	Tec	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,7	OT 5
Dottorando	PhD	0,0	0,3	0,3	0,3	0,3	0,3	0,3	0,0	1,8	OT 5
request to INFN	Tec	0,0	0,0	1,0	1,0	1,0	1,0	0,0	0,0	4,0	OT 5
request to INFN	AdR	0,0	0,0	1,0	1,0	1,0	1,0	0,0	0,0	4,0	IT 3
TOTAL FTE/year		3,90	4,90	7,40	7,50	7,50	7,30	2,70	0,00		

Activity OT in clean room

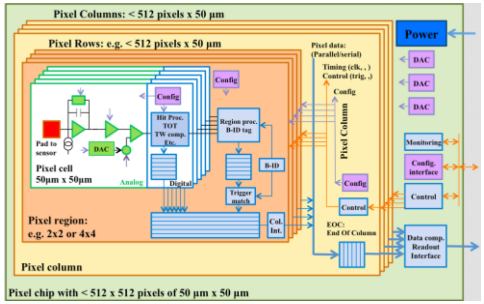
Current development of CMS Pixel readout chip for Phase-2 upgrade (see next slide)

CMS Pixel readout chip design for Phase-2

Design/development activity started in 2013 within RD53 Collaboration & *CHIPIX65* experiment of INFN-GruppoV frameworks

Purposes:

- Study of the radiation tolerance of the TSMC CMOS 65nm tecnology to evaluate the suitability of the innermost Tracker layers to the expected radiation levels (> 500 Mrad)
- Development of a library of Front-Ends & IP blocks according to CMS&Atlas requirements
- Design, production & test of a pixel chip 64x64 demonstrator in the framework of the Chipix65 exp. (2016)
- Design, production & test of a large scale demonstrator "**RD53A**" (2017)
- Design of the production pixel chip for CMS&Atlas on the basis of the "**RD53A**" measurements and the final specifications of the two experiments (2018-2019)



RD53 digital pixel chip architecture

F.Loddo is RD53A Project Engineer since 6/2016; recently appointed in this role for the development of the final chip with additional coordination responsibility within RD53 Collaboration. Since 5/2018 also responsible for the development of the pixel ASIC within IT coordination for CMS Phase-2 upgrade.

Activity foreseen in 2018/19 : participation to the pixel chip design & submission to production company (fonderia) foreseen in Q4 2019.

CMS Muon system upgrade

Main CMS upgrade features – Muon system overview - I

- **Upgrade goal : maintain excellent triggering, μ measurement & ID** under harsher HL-LHC conditions up to $|\eta| = 2.8$

  - **All currently installed Muon detectors will be kept operational @ HL-LHC**

  - **High radiation, PU, longer trigger latency require : - the upgrade of several components (**electronics**)**
    - the addition of new ones (in forward region)

  - **The CMS Muon system consists of 4 distinct detector systems : Drift Tubes (DT), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC) and Gas Electron Multiplier Detectors (GEM). The first 3 are existing systems which will be upgraded, while the GEMs are new detectors.**

    - A longevity validation campaign took place (with Bari contribution) in the past years. As a result : the components requiring upgrade & the actions to be undertaken were identified

      - DT, CSC & RPC detectors currently installed will survive the radiation doses

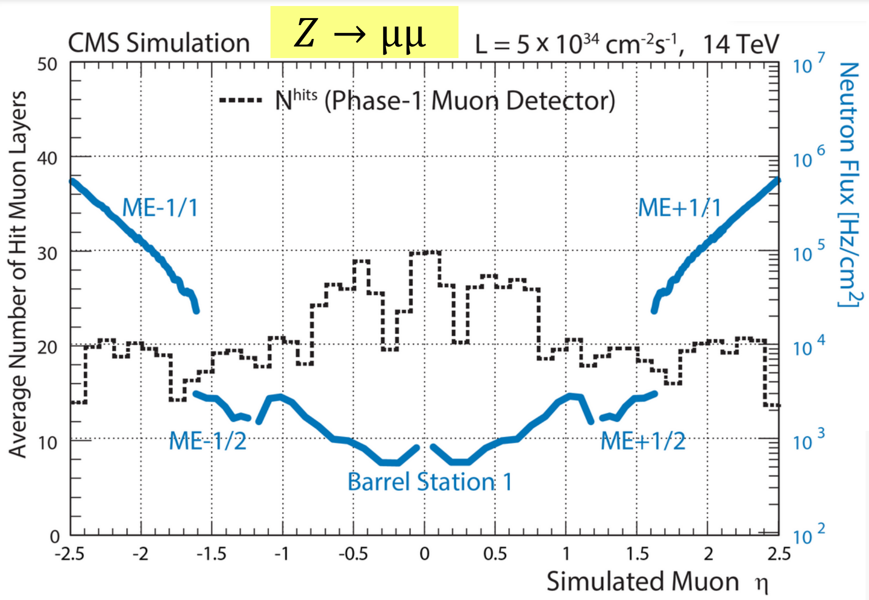
      - new GEM & iRPC detectors will be able to deal with the expected radiation doses

  - Key issues :

Main CMS upgrade features – Muon system overview - II

Key issues :

- **detector electronics must be upgraded** to handle high particles rates (high bandwidth optical transfer, ...) & to deal with longer latency (DT)
- **longevity** : aging electronic parts need to be replaced while detector life expectancy (related to radiation damage) is more than acceptable
- **event reconstruction capabilities (@trigger & offline)** particularly in forward region that will be completed with the missing RPC chambers & complemented by new GEM chambers to enhance redundancy, to increase # of measurements, spatial & time resolution, to solve @ trigger level of track reconstruction ambiguities
- **extended acceptance (|η| coverage)** to partially complement the wider tracking coverage



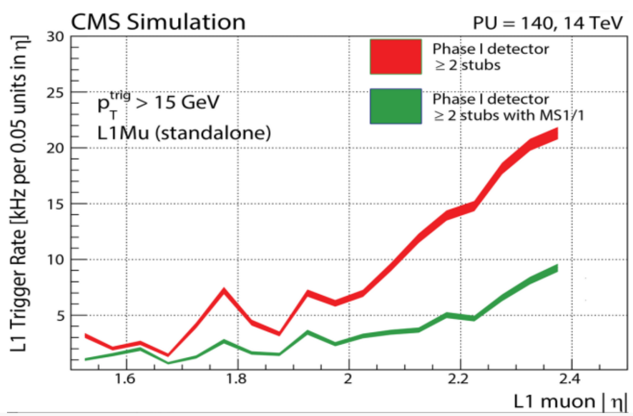


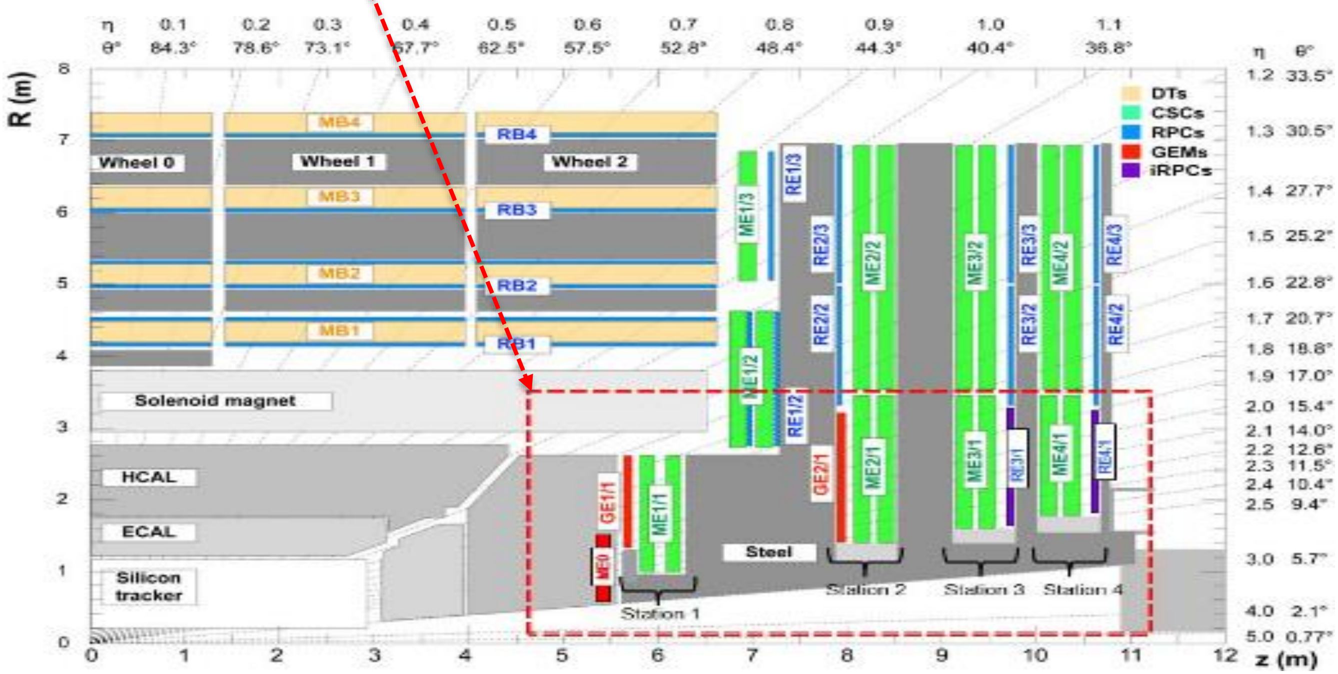
Figure 4.16-a:
(Left) the histogram shows the average number of Hi-measuring muon layers with reconstructed hits that are attached to a standalone muon track, for simulated muons from $Z \rightarrow \mu\mu$ as a function of η. It is compared to the flux of neutrons in Hz/cm^2 shown as colored curves (note the log scale on the right), which are the dominant cause of background hits, for the muon station first crossed by a muon with a given η. (Right) Standalone muon trigger rate as a function of pseudeorapidity for the current Phase-I muon detector under loose (red) and tight (green) trigger conditions.

Main CMS upgrade features – Muon system overview - III

Upgrade goal : maintain excellent triggering,

μ measurement & ID under harsher HL-LHC conditions up to $|\eta| = 2.8$

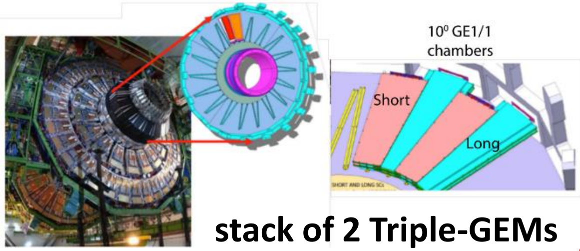
1. New forward μ detectors:



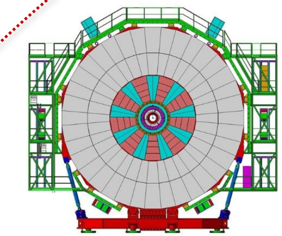
Main CMS upgrade features – Muon system overview - III

- **Upgrade goal : maintain excellent triggering,**
  μ measurement & ID under harsher HL-LHC conditions up to $|\eta| = 2.8$

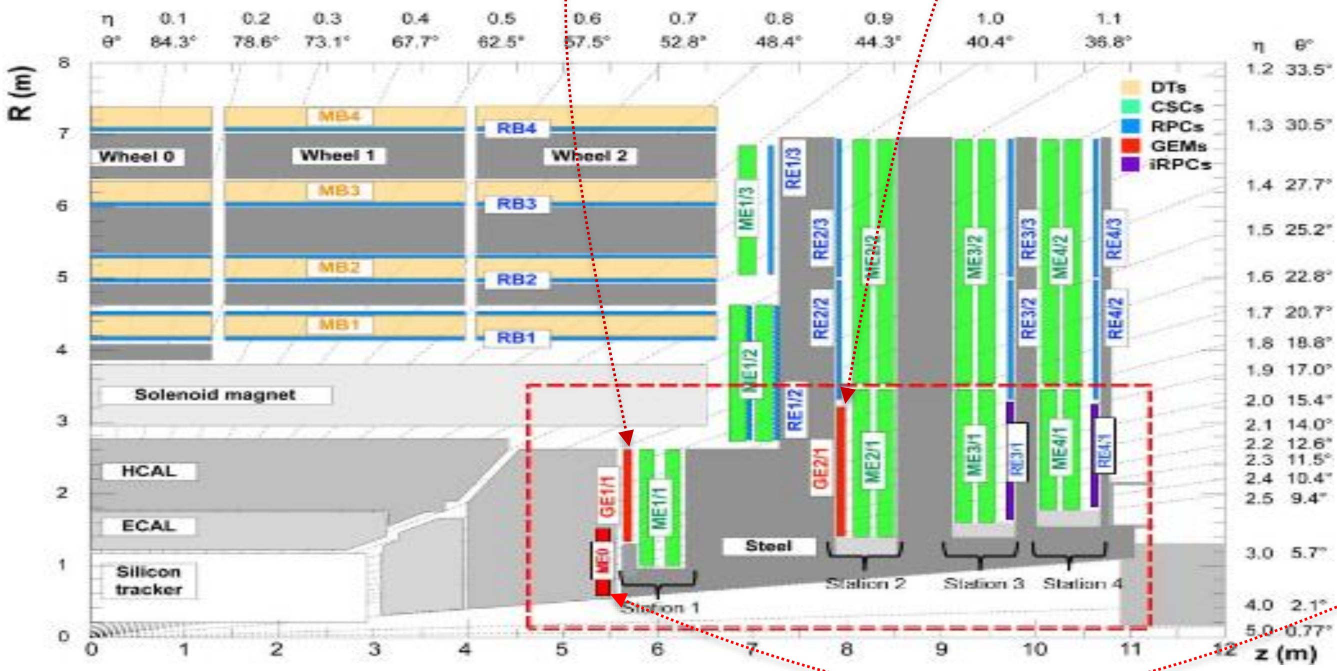
- **1. New forward μ detectors:** - **Triple GEM technology** [in **GE1/1**, **GE2/1** & **ME0**] to enhance trigger & μ-reco

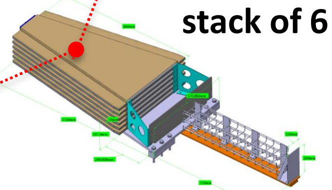


stack of 2 Triple-GEMs



stack of 2 Triple-GEMs

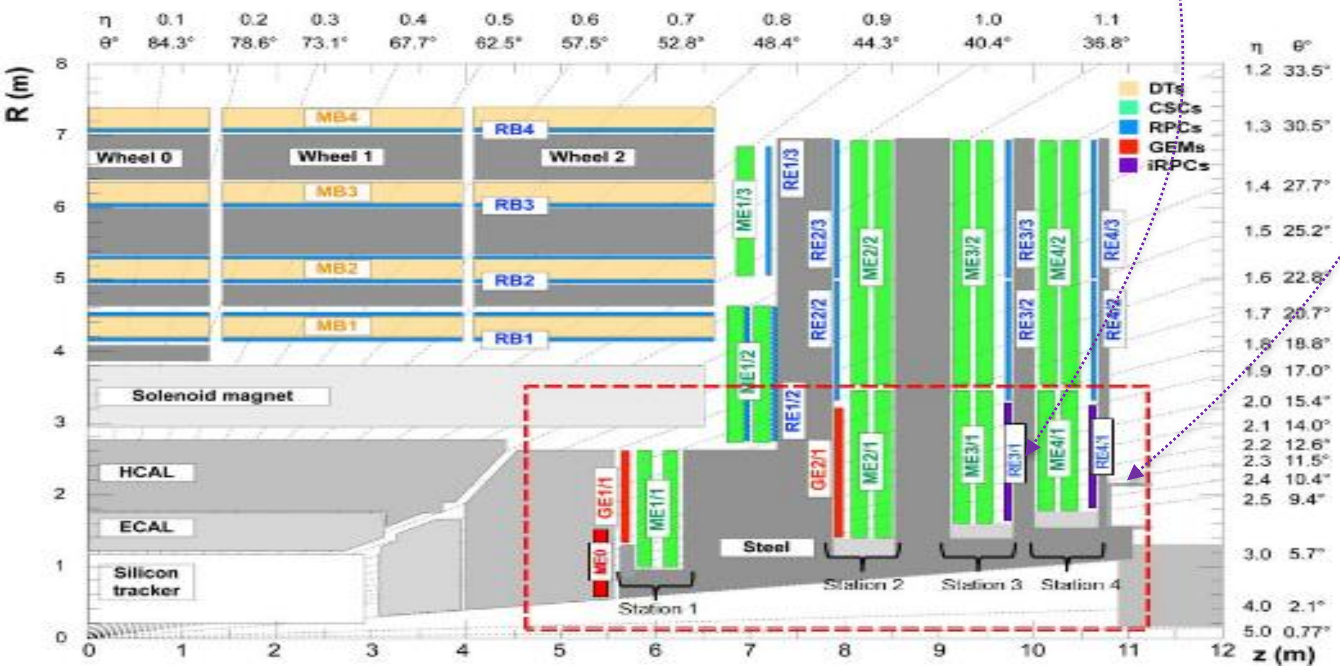


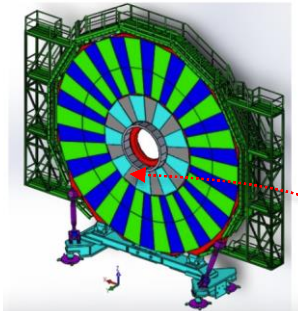


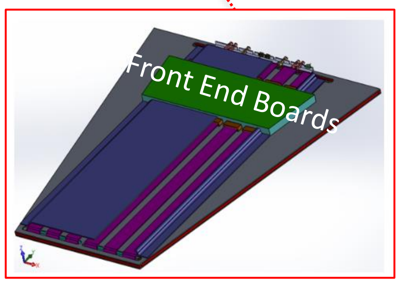
stack of 6 Triple-GEMs

- **Upgrade goal : maintain excellent triggering,**
  μ measurement & ID under harsher HL-LHC conditions up to $|\eta| = 2.8$

- **1. New forward μ detectors:** - **Triple GEM technology** [in **GE1/1**, **GE2/1** & **ME0**] to enhance trigger & μ-reco
  - Improved RPC (**iRPC**) **[** in **RE3/1** & **RE4/1** **] (** rates up to $2kHz/cm^2$, increased lever arm for μ-reco **)**







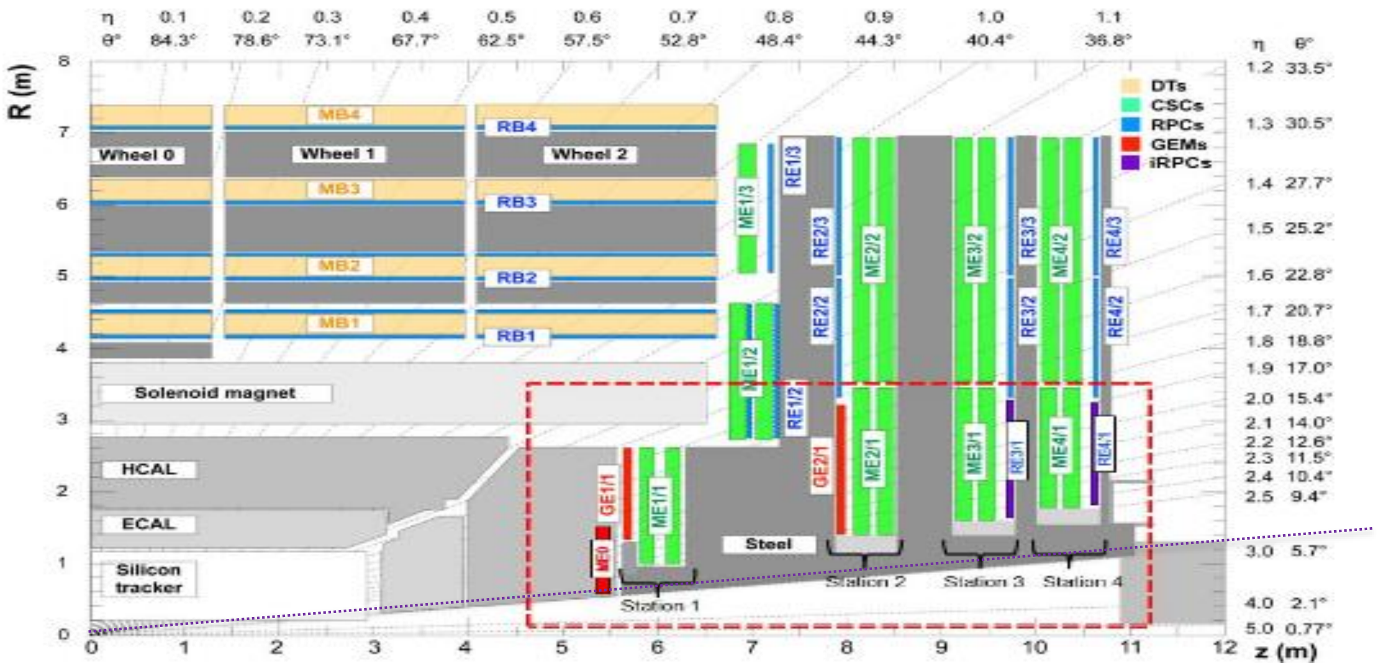
Main CMS upgrade features – Muon system overview - III

- **Upgrade goal : maintain excellent triggering,**
  μ measurement & ID under harsher HL-LHC conditions up to $|\eta| = 2.8$

- **1. New forward μ detectors:** - **Triple GEM technology** [in **GE1/1**, **GE2/1** & **ME0**] to enhance trigger & μ-reco
  - Improved RPC (**iRPC**) **[** in **RE3/1** & **RE4/1** **]** **(**rates up to $2kHz/cm^2$ **)**

- to handle (aiding CSCs) the most difficult region with high backgrounds, high readout & trigger rates and limited μ-bending (@ higher $|\eta|$)

- to extend the μ coverage by introduction of ME0 (a stack of 6 Triple-GEMs) up to $|\eta| = 2.8$ [complementary to tracker extension up to $|\eta| = 4$]; useful for μ-tagging & reduction of the lost-μ bkg



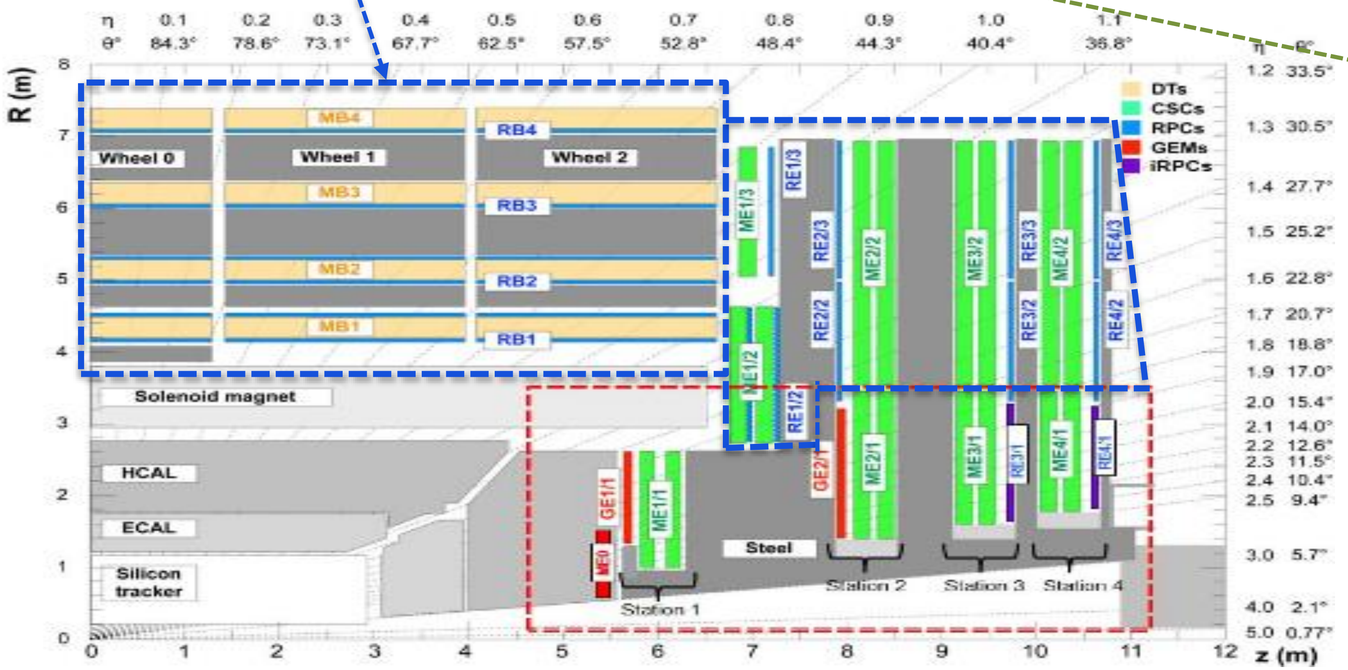
Main CMS upgrade features – Muon system overview - IV

Upgrade goal : maintain excellent triggering,
μ measurement & ID under harsher HL-LHC conditions up to $|\eta| = 2.8$

2. Existing detector: **- consolidation of detector operation** (based on detector longevity studies currently carried out at the GIF++)

- DT & CSC electronics upgrade: replacement to handle …
- longevity issues,
- higher L1 trigger rates ($100 \rightarrow 750kHz$ **),**
- higher latency ($3.2 \rightarrow 12\mu s$ **)**

- Trigger/DAQ upgrade of RPCs: to handle longevity issues & to be compliant to ...
... Phase-2 requirements



The upgrade of the existing RPC DAQ readout electronics (currently recording the hit time in steps of 25ns) will exploit the detector timing information (with resolution of ~1.5ns) thus improving the L1 trigger capabilities.

INFN commitments in Muon system upgrade – overview

- **The CSC is the only part of muon system without INFN involvement.**
  - **INFN CMS-Bari is involved in GEM & RPC upgrade project :**

	Longevity			Detector		On-detector Electronics and Power system			Trigger/DAQ	Services		Install. & Comm.		
INFN, University and Politecnico of Bari		RPC		RPC	GEM			GEM					RPC	GEM
INFN and University of Bologna	DT				GEM				DT	DT		DT		GEM
Laboratori Nazionali Frascati (LNF) INFN		RPC		RPC	GEM						GEM			GEM
INFN and Università "Federico II" di Napoli, Università della Basilicata and Università G. Marconi				RPC			RPC	GEM			GEM			GEM
INFN and Università di Padova	DT					DT			DT			DT		
INFN and Università di Pavia		RPC	GEM		GEM			GEM						GEM
INFN and Università di Torino and Università del Piemonte Orientale	DT					DT			DT	DT		DT		

Fig. 31: Extraction from TDR table of Muon construction responsibilities

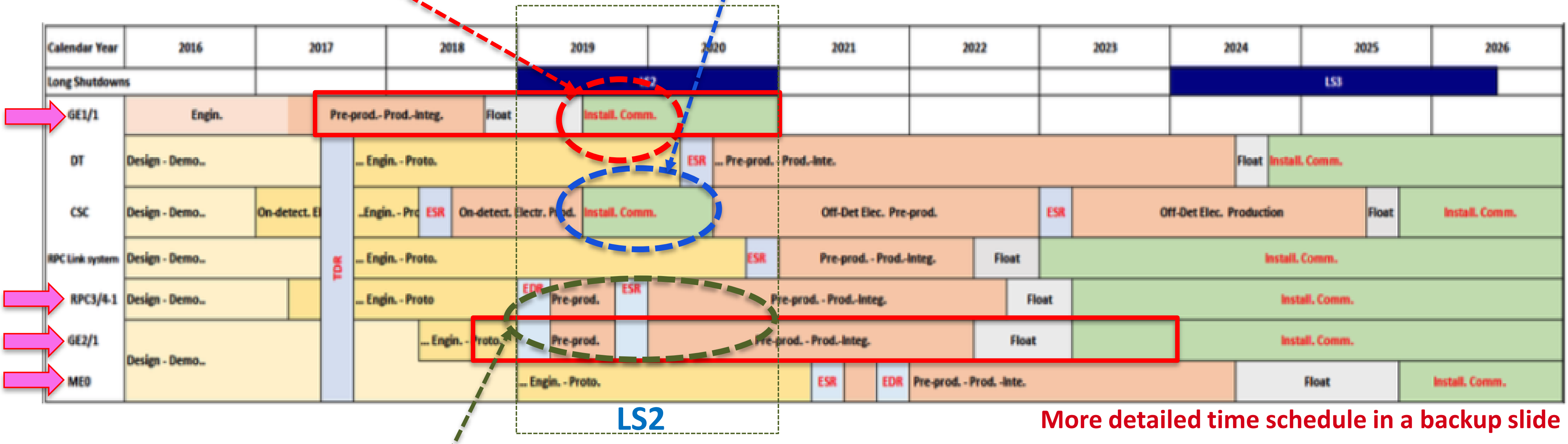
Muon system upgrade – schedule overview – I

The schedule for the Muon system upgrade foresees a time-staggered installation !

Indeed - during LS3 - the Muon upgrade activities cannot be integrated due to the overloaded schedule [involving the installation of the new Tracker & High Granularity Calorimeter (HGCAL)]

Muon upgrade activities & installation can be widely anticipated to LS2, YETS 2022 & 2023 (during Run-3):

- the upgrade of the Endcap (CSC) chambers is @ LS2 [refurbish MEx/1 (x=1,…,4) with new FE boards]
- GEM stations (**GE1/1**) will be installed in LS2 (including pipes & cable services)[*] **[partly constructed in Bari]**



More detailed time schedule in a backup slide

- **other activities in LS2 :** - installation of services for GE2/1, RE3/1, RE4/1 [*]
  - RPC leak repairs [*]

[*] activities requiring INFN-Bari technicians @ CERN

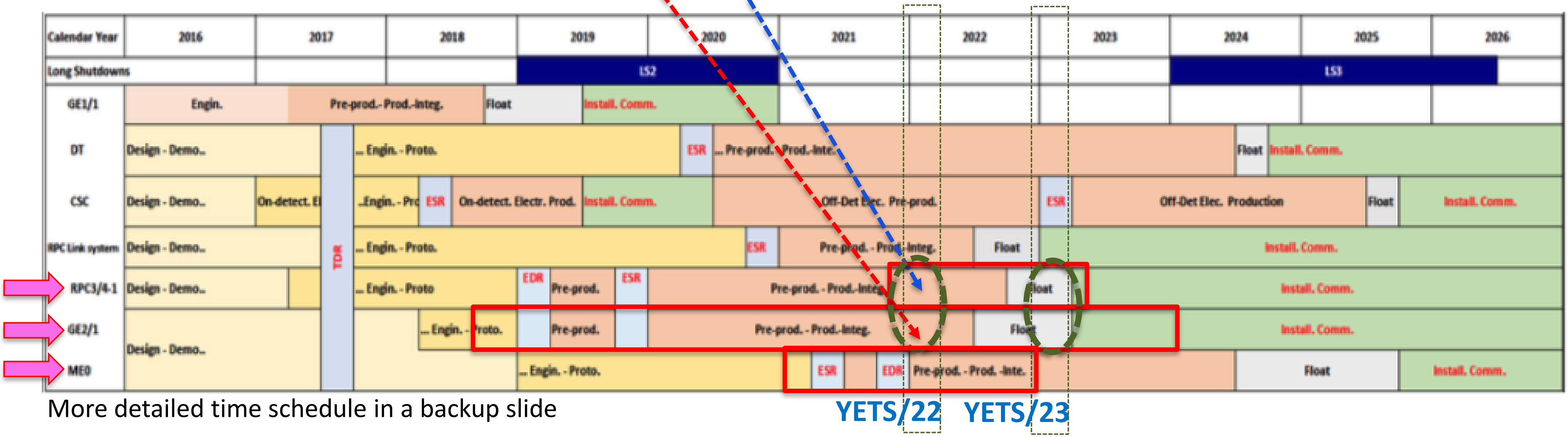
Muon system upgrade – schedule overview – II

The schedule for the Muon system upgrade foresees a time-staggered installation !

Indeed - during LS3 - the Muon upgrade activities cannot be integrated due to the overloaded schedule [involving the installation of the new Tracker & High Granularity Calorimeter (HGCAL)]

Muon upgrade activities & installation can be widely anticipated to LS2, YETS 2022 & 2023 (during Run-3):

- GEM stations (**GE2/1**) will be installed in YETS/22 & /23 [*]
- iRPC chambers (RE3/1, RE4/1) will be installed in YETS/22 & /23 [*]



More detailed time schedule in a backup slide

- **other activities in 2021-2022 : ME0 construction in Bari** (see slide later)

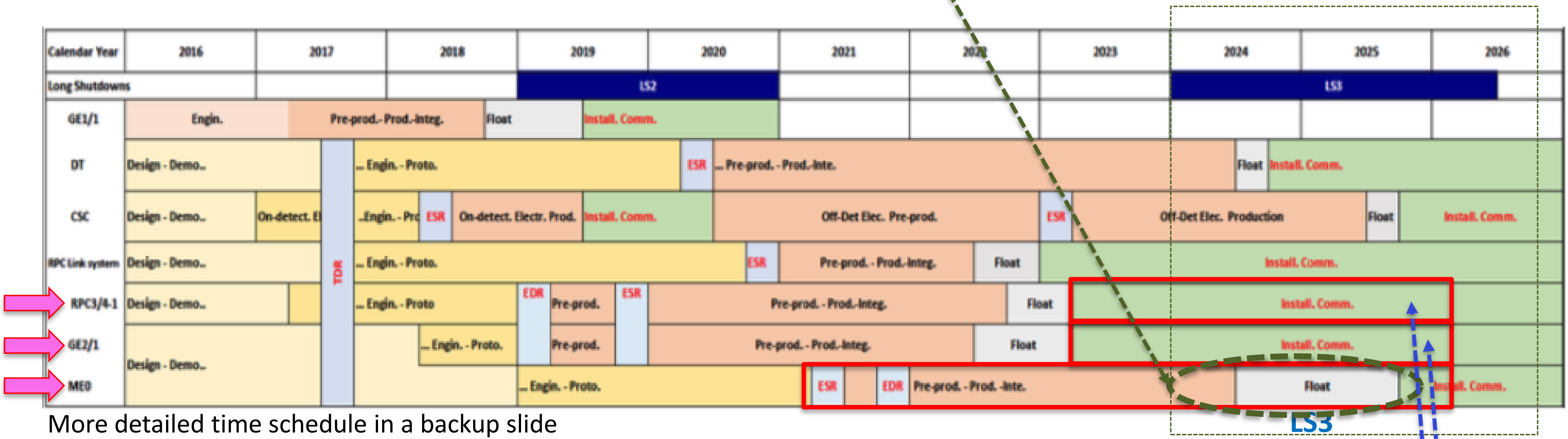
[*] activities requiring INFN-Bari technicians @ CERN

Muon system upgrade – schedule overview – III

The schedule for the Muon system upgrade foresees a time-staggered installation !

Indeed - during LS3 - the Muon upgrade activities cannot be integrated due to the overloaded schedule [involving the installation of the new Tracker & High Granularity Calorimeter (HGCAL)]

Last Muon upgrade activities concern LS3 : - ME0 GEM stations will be installed in 2024-2025 [LS3] [*]



More detailed time schedule in a backup slide

The ME0 installation will be done in surface while the assembly of the Calorimeter endcaps (HGCAL) will be carried out, during LS3, as CMS moves into a closed barrel configuration.
The installation of the HGCAL will require the extraction of the ME1 (CSC, RPC, GEM) chambers and subsequent re-installation & re-commissioning [*].

[*] activities requiring INFN-Bari technicians @ CERN

Upgraded Muon system performances - I

Few examples of foreseen performances (with full MC simulation)**:**

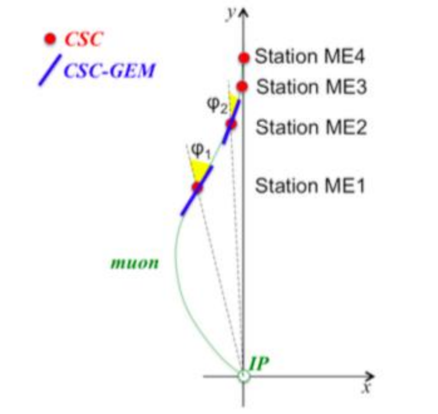
Enhanced μ triggering & identification in the forward region :

- The Phase-2 upgraded forward muon system has new detectors (GE1/1, GE2/1, RE3/1, RE4/1) that provide 1) further high-resolution measurement points & 2) an increased lever arm for μ reconstruction, in the current range $|\eta| < 2.4$

- The ME0 chambers extend the acceptance to $|\eta| = 2.8$, providing additional hits for triggering and offline μ reconstruction

- **GEM chambers, in tandem with CSC ones, provide accurate measurement of μ "local bending" angles, thus improving the muon momentum measurement**

Illustration of the additional info provided by the new GEM



Axial (transverse) point-of-view

Upgraded Muon system performances - I

Few examples of foreseen performances (with full MC simulation)**:**

Enhanced μ triggering & identification in the forward region :

- The Phase-2 upgraded forward muon system has new detectors (GE1/1, GE2/1, RE3/1, RE4/1) that provide 1) further high-resolution measurement points & 2) an increased lever arm for μ reconstruction, in the current range $|\eta| < 2.4$

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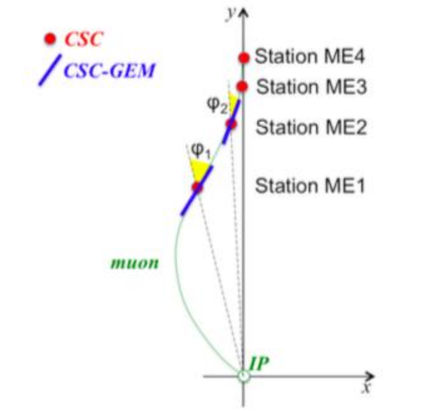


Axial (transverse) point-of-view

Standalone μ trigger capabilities are important, for instance for the reconstruction of long-lived particle decaying into muons outside the IT.

L1 Standalone Trigger :
- **sizable reduction of the rate (bkg ↓)**
- **relevant increase of the efficiency**

(in forward region)

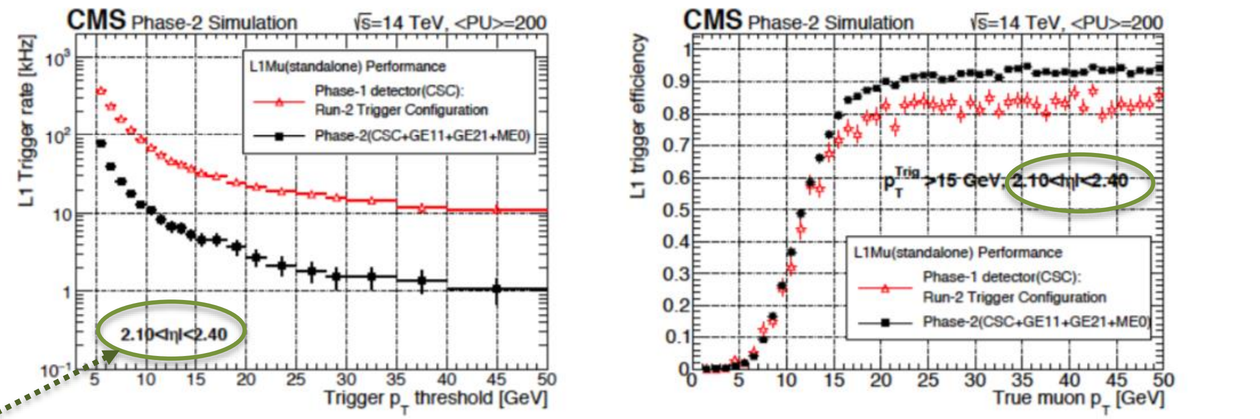
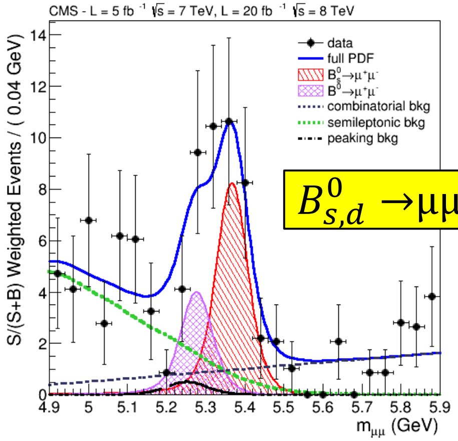


Figure 10: L1 standalone trigger rate (left panel) and efficiency (right panel) as a function of p_t, with (black dots) and without (red dots) the new GEM detectors.

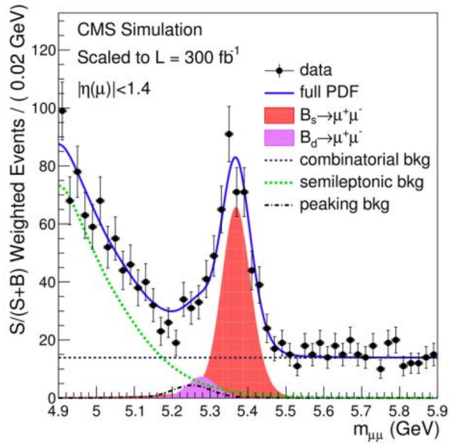
Upgraded Muon system performances - II

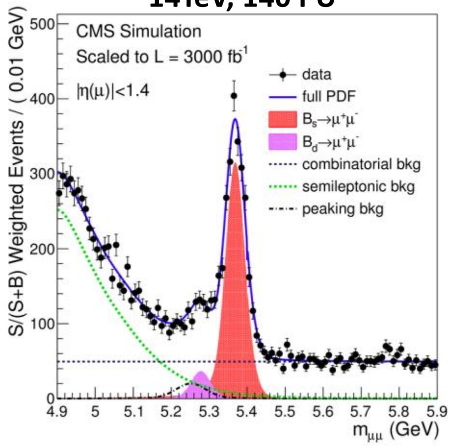


$B^0_{s,d} \to \mu\mu$

$B^0_{s,d} \to \mu\mu$

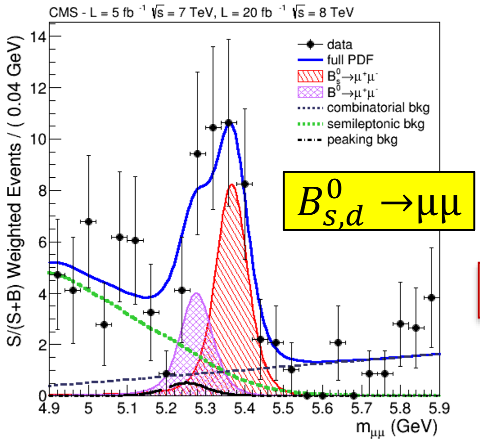
14TeV, 140 PU

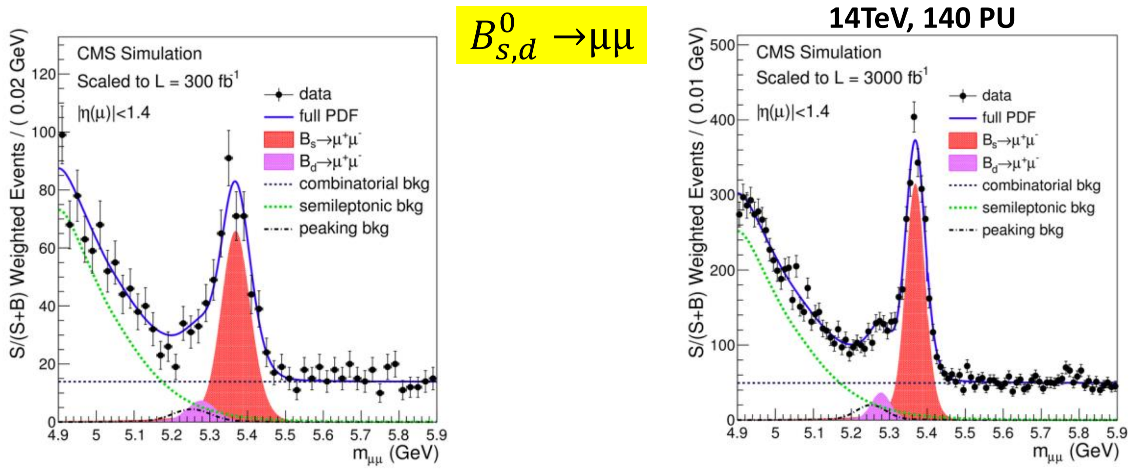




Dimuon mass fit projections for an integrated luminosity of *300*fb^{-1} (*3000*fb^{-1})
[assuming expected performance of Phase-1 (Phase-2) CMs detector] [from TDR]

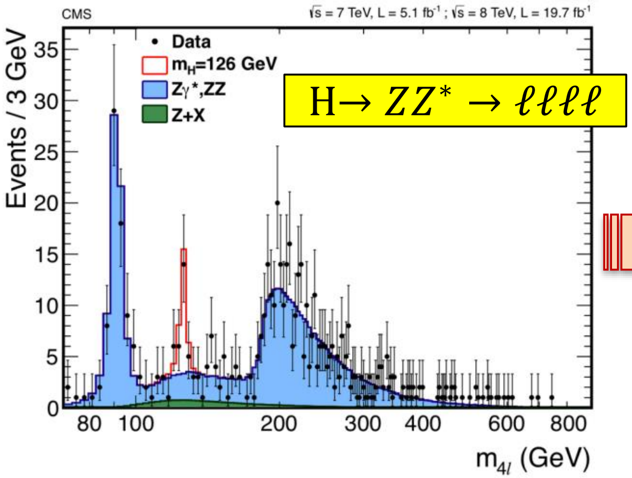
Upgraded Muon system performances - II

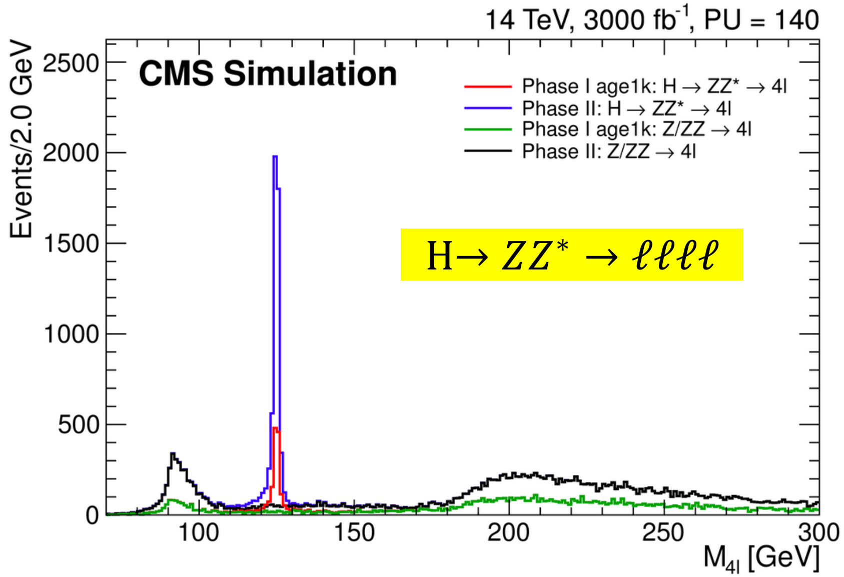




Dimuon mass fit projections for an integrated luminosity of *300*fb^{-1} (*3000*fb^{-1})
[assuming expected performance of Phase-1 (Phase-2) CMs detector] [from TDR]

- **The acceptance increase is particularly rewarding for multi-μ final states (ex.: $H \to ZZ^* \to 4\mu$) & searches (ex.: $\tau \to 3\mu$)**





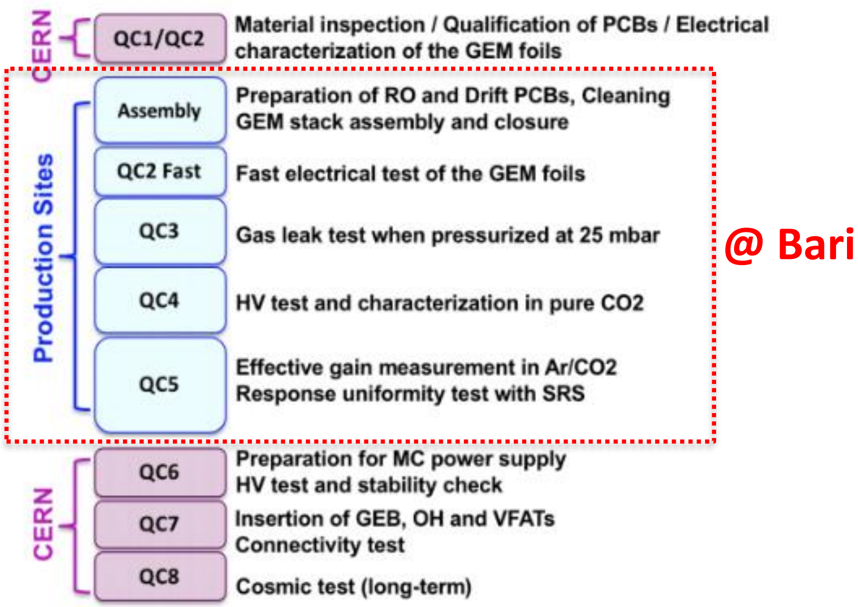
Four lepton mass distributions for the full Phase-2 integrated luminosity (*3000*fb^{-1})
[assuming 2 cases: the aged Phase-1 detector & the Phase-2 detector] [from TDR]

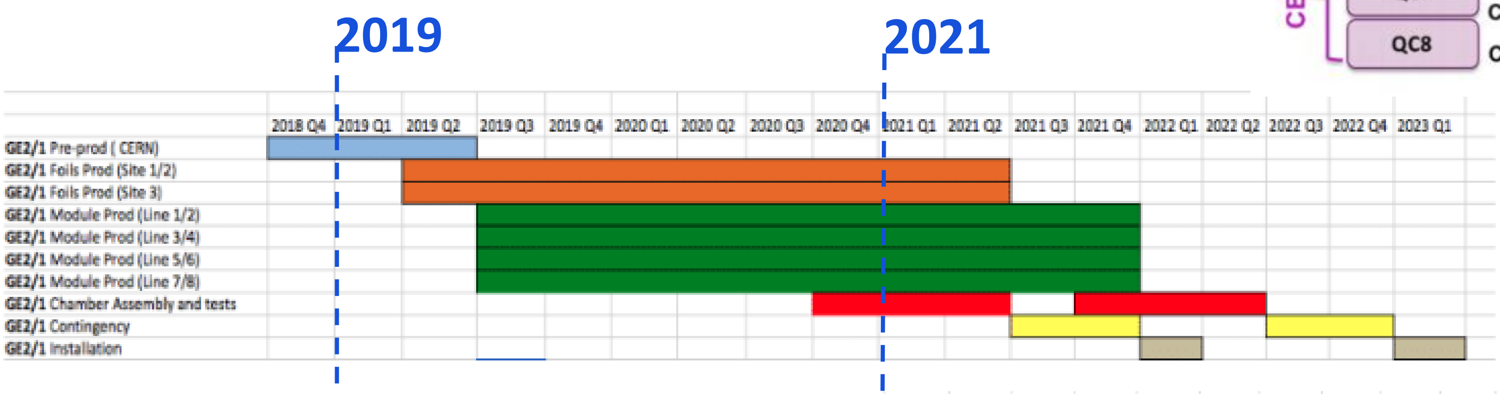
INFN(-Bari) commitments in GEM construction

- **INFN will deliver for the upgraded Muon system a part of the designed Triple-GEM detector** (see backup) **:**

  - **72/288 GE2/1 detectors (36 chambers @ Bari**; 36@ LNF**)**
    - to be installed/commissioned/analyzed in YETS 2022/23

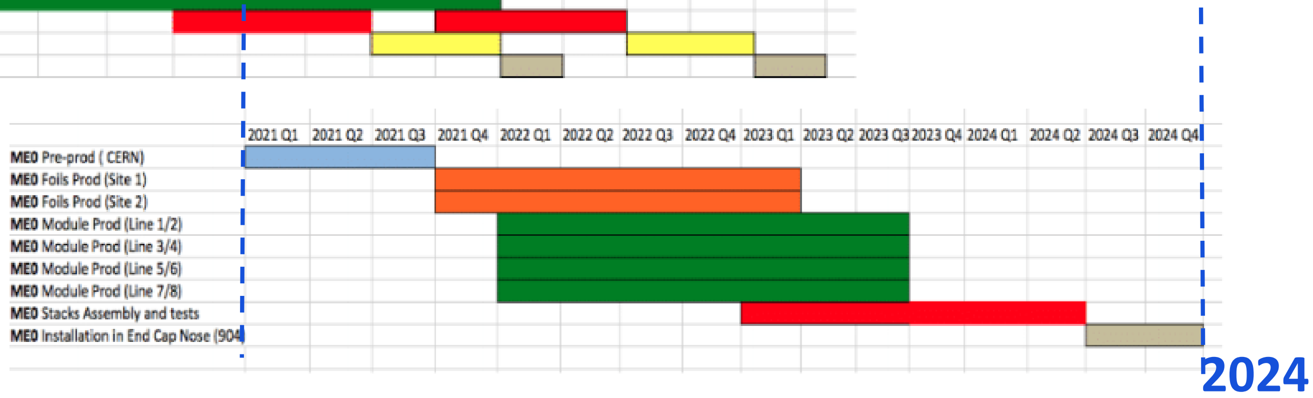
  - **54/216 ME0 detectors (27 chambers @ Bari**; 27@ LNF**)**
    - to be installed/commissioned/analyzed in LS3





Schedule GE2/1

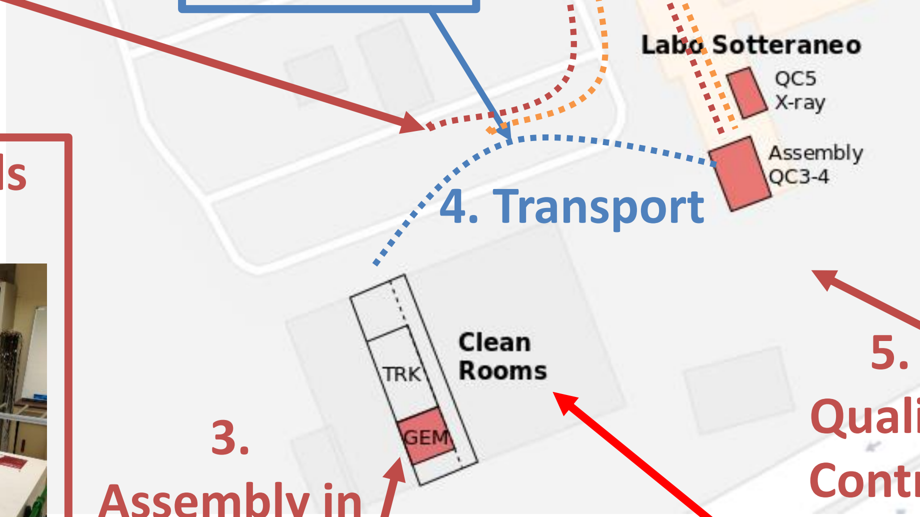
Schedule ME0



- **This will be in addition to the current (2017/8) production activity of 18 GE1/1 chambers @ Bari :**
  13 chambers already constructed & tested (5 to be done) [next slide]; **installation+commissioning in LS2**

Current Production @ Bari of GE1/1 chambers

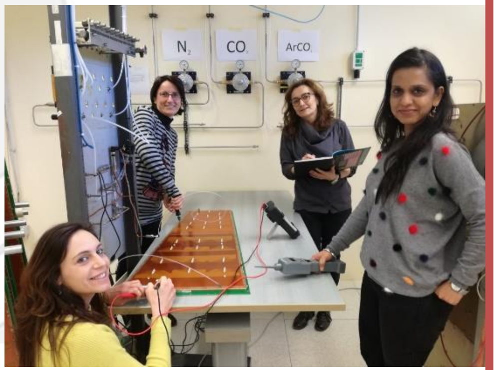
1. Arrival of materials



6. Transport to CERN

2. Check Materials Pre-Assembly

5. Quality Control



3. Assembly in Clean Room

Assistance by technicians:

- officina mecc.
- design CAD
- serv. elettronico

Manpower of INFN/CMS-BARI for GEM commitments

INFN/CMS-Bari manpower involved in the activities for the new GEM detectors :

Institue	2018 FTE	Task	Avergae Manpower (without request)			Request of manpower (FTE)						
			Physicist and Engineer	Technicians	PhD/Temporary	2019	2020	2021	2022	2023	2024	2025
Bari	3,3	ME0.RD.DET.6, ME0.PR.DET.1,ME0.PR.DET.2,	2,8	0,5	1,3	1,00	1,00	1,00	1,00	1,00	1,00	
		GE.RD.FE.5, ME0.RD.FE.5, ME0.RD.DET.6				0,50	0,50					
Bologna	1,2		1,1	0,4	0,2							
Frascati	1,2	GE21.RD.DET.2, GE21.RD.DET.4, GE21.PR.DET.2	0,9	0,8	0	1,00	1,00	1,00				
		ME0.PR.FE.1, ME0.PR.DET.4							1,00	1,00	1,00	
Napoli	1,7		1,7	0,5	0,5							
Pavia	1,4		2,0	0,4	1,0		1,00	1,00				

Manpower of INFN/CMS-BARI for GEM commitments

INFN/CMS-Bari manpower involved in the activities for the new GEM detectors :

Institue	2018 FTE	Task	Avergae Manpower (without request)			Request of manpower (FTE)						
			Physicist and Engineer	Technicians	PhD/Temporary	2019	2020	2021	2022	2023	2024	2025
Bari	3,3	MEO.RD.DET.6, MEO.PR.DET.1,MEO.PR.DET.2,	2,8	0,5	1,3	1,00	1,00	1,00	1,00	1,00	1,00	
		GE.RD.FE.5, MEO.RD.FE.5, MEO.RD.DET.6				0,50	0,50					

Name	Profile	Status	Project	2018	2019	2020	2021	2022	2023	2024	2025	2026	Total	Task	Caratteristiche	Sede
BARI																
Colaleo Anna	Physicist	Staff	GEM	0,40	0,40	0,70	0,70	0,70	0,70	0,60	0,60	0,60	5,40	GE21.PR.DET.2, GE21.PR.DET.4, MEO.PR.DET.1, MEO.PR.DET.2, MEO.PR.DET.3, MEO.PR.DET.4	QC camere / commissioning detector	Bari
Maggi Marcello	Physicist	Staff	GEM	0,70	0,70	0,70	0,70	0,70	0,70	0,70	0,70	0,70	6,30	GE.RD.FE.5, GE21.PR.DET.3, MEO.RD.FE.5, MEO.RD.DET.6	Cosmic-Stand/commissioning/operations	Bari
Nuzzo Salvatore	Physicist	Staff	GEM	0,10	0,40								0,50	GE21.RD.DET.2, GE21.RD.DET.4, MEO.RD.DET.6	costruzione e QC camere	Bari
Ranieri Antonio	Physicist	Staff	GEM	1,00	1,00	0,10							2,10	GE21.RD.DET.2, GE21.RD.DET.4, MEO.RD.DET.6	costruzione e QC camere	Bari
Verwilligen Piet Omer J	Physicist	Staff	GEM	0,40	0,70	0,70	0,70	0,70	0,70	0,70	0,70	0,70	6,00	GE21.RD.DET.2, GE21.RD.DET.4, GE21.PR.DET.2, GE21.PR.DET.4, MEO.RD.DET.6, MEO.PR.DET.1,MEO.PR.DET.2, MEO.PR.DET.3, MEO.PR.DET.4	costruzione e QC camere & commissioning	Bari
De Robertis Giuseppe	Engineer	Staff	GEM	0,30	0,30	0,30	0,30	0,30	0,30	0,20			2,00	GE21.RD.FE.2, GE21.RD.FE.3, MEO.RD.FE.2, MEO.RD.FE.4	progettazione elettronica	Bari
Loddo Flavio	Engineer	Staff	GEM	0,20	0,20	0,20	0,20	0,20	0,10	0,10			1,20	GE21.RD.FE.2, GE21.RD.FE.3, MEO.RD.FE.2, MEO.RD.FE.4	progettazione elettronica	Bari
Engineer (now AdR)	Engineer	Staff	GEM	0,20	0,20	0,20	0,20	0,20	0,20	0,20			1,40	GE21.RD.FE.2, GE21.RD.FE.3, MEO.RD.FE.2, MEO.RD.FE.4		Bari
Post-doc 1	AdR	Temp	GEM	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	4,50	GE21.RD.DET.2, GE21.RD.DET.4, GE21.PR.DET.2, GE21.PR.DET.4, MEO.RD.DET.6, MEO.PR.DET.1,MEO.PR.DET.2, MEO.PR.DET.3, MEO.PR.DET.4	costruzione e test	Bari
PhD student 1	PhD student	Temp	GEM	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	3,60	GE21.RD.DET.2, GE21.RD.DET.4, GE21.PR.DET.2, GE21.PR.DET.4, MEO.RD.DET.6, MEO.PR.DET.1,MEO.PR.DET.2, MEO.PR.DET.3, MEO.PR.DET.4		Bari
PhD student 2	PhD student	Temp	GEM	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	3,60	GE21.RD.DET.2, GE21.RD.DET.4, GE21.PR.DET.2, GE21.PR.DET.4, MEO.RD.DET.6, MEO.PR.DET.1,MEO.PR.DET.2, MEO.PR.DET.3, MEO.PR.DET.4		Bari
Technician 2	Technician	Staff	GEM	0,20	0,40	0,60	0,60	0,60	0,60	0,60	0,20	0,20	4,00	GE21.RD.DET.2, GE21.RD.DET.4, GE21.PR.DET.2, GE21.PR.DET.4, MEO.RD.DET.6, MEO.PR.DET.1,MEO.PR.DET.2, MEO.PR.DET.3, MEO.PR.DET.4	costruzione & installazione camere-Technician meccanico	Bari
Technician 5	Technician	Staff	GEM	0,10	0,10	0,10	0,10	0,10	0,10	0,10			0,70	GE21.RD.FE.2, GE21.RD.FE.3, MEO.RD.FE.2, MEO.RD.FE.4	elettronico	Bari
Physicist 1	AdR	Request	GEM		1,00	1,00	1,00	1,00	1,00	1,00			6,00	GE21.RD.DET.4, GE21.PR.DET.2, GE21.PR.DET.4, MEO.RD.DET.6, MEO.PR.DET.1,MEO.PR.DET.2, MEO.PR.DET.3		Bari
Engineer 2	AdR	Request	GEM		0,50	0,50							1,00	GE.RD.FE.5, MEO.RD.FE.5, MEO.RD.DET.6	competenze elettronica per front-end	Bari
TOTAL FTE /YEAR				4,90	7,20	6,40	5,80	5,80	5,70	5,50	3,50	3,50				

VFAT3 bench-tests

VFAT3 Packaging & Test

(construction & installation)

(PCB preparation)

GE2/1

ME0

[shared with RPC in same 2 years]

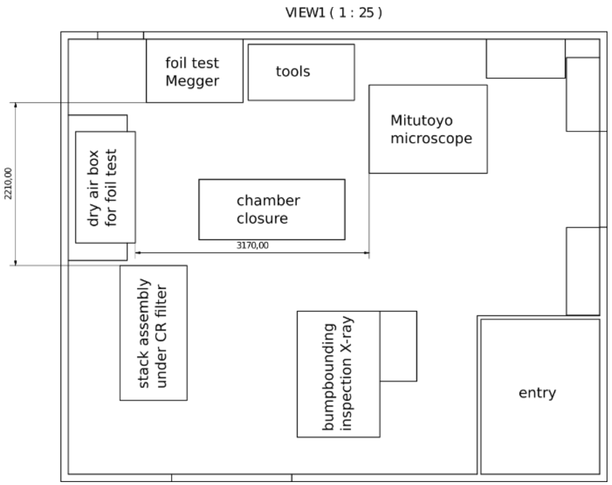
VFAT3 QC & Test

Chamber construction & test

Lab space of INFN-Bari for GEM commitments

- **Currently used** laboratory space (Clean Room + 2 Labs) **confirmed** & **saturated** for the period 2019/23

Clean Room (CP3)



2 Laboratories:

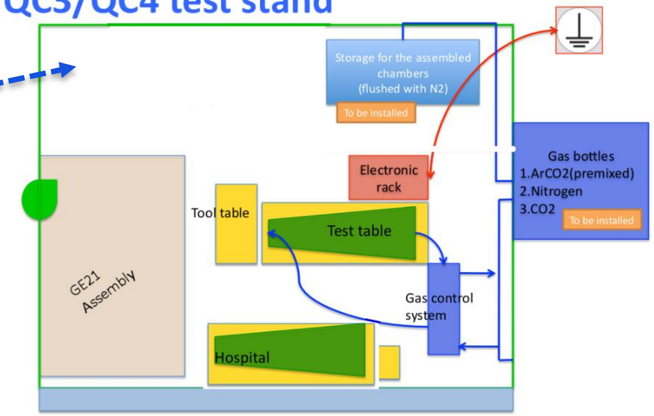
S-01 (ex-BC2S) :

- Material inspection
- GEM Chamber Pre-Assembly
- Gas leak test (QC3)
- HV-test (QC4)
- "Hospital"

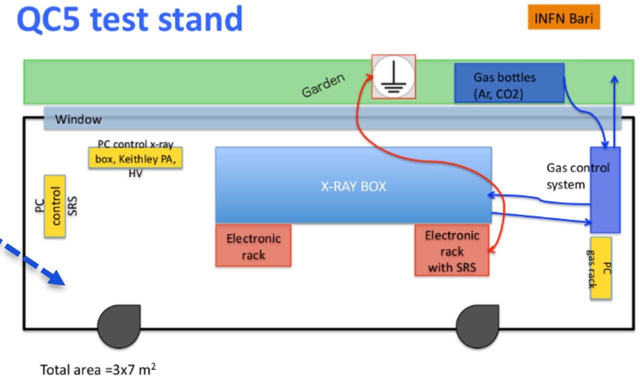
S-06-08 (ex BC2S) :

- GEM Gain Measurement
- GEM Gain Uniformity

QC3/QC4 test stand



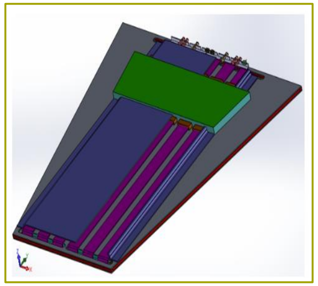
QC5 test stand



INFN(-Bari) commitments into RPC upgrade

- **Activities for the RPC upgrade are foreseen to be carried out @CERN :**
  - **ongoing longevity tests @ GIF++, to be continued & completed by 2018/9**
  - **in LS2 (2019-20) : RPC leak repairs & installation of services for RE3/1, RE4/1**
  - **in YETS/22 & /23 : installation of iRPC chambers (RE3/1, RE4/1) [36 & 36] & commissioning**
  - **in LS3 (2024-25) : re-installation & re-commissioning of ME1 RPC chambers**

18 & 18 (x2 endcaps)



double-gap RPC
wedge-shaped with
- HPL electrodes,
- pick-up strips in the middle,
- improved FE electronics

- **Front-End board electronics**

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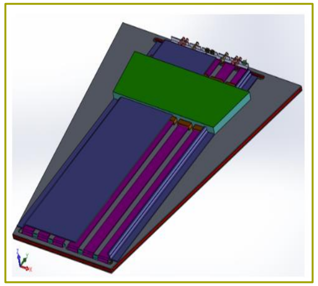


double-gap RPC
wedge-shaped with
- HPL electrodes,
- pick-up strips in the middle,
- improved FE electronics

- **Front-End board electronics**

The new iRPC chambers will need to be instrumented with a new a Front-End (FE) board electronics.

The **baseline** for the FE electronics is developed in Lyon (PETIROC).

A **back-up choice** is represented by a - currently under study - ASIC chip developed in Bari & Roma-TorVergata (synergy with ATLAS);
a 16-channel version has been successfully tested on a double-gap RPC @GIF++ during summer 2017.

Final decision on the electronics will be taken after suitable test-beams and within 2018 [*].

[*] for testing & integration activity a technological contract for an electronics expert (in 2019-2020) has been required for INFN-Bari

Manpower of INFN/CMS-BARI for RPC commitments

INFN/CMS-Bari manpower involved in the activities for the RPC detectors :

INSTITUTE	TOT FTE 2018	TOT FTE 2018 Fase2	Construction Tasks	Average Manpower (2018-2026) w/out requests in FTE: Physicist&Engineers	Technicians	PhD/Temp	Requests of Manpower: Type	2018	2019	2020	2021	2022	2023	2024	2025	TOT contracts Person Year	TOT Cost (Keu) 25Keu/year
			chamber tests at CERN													0	0
Bari	5,1	2,6	front end electronics	1,6	0,36	0,8	AT		0,5	0,5						1	25
			commissioning													0	0
																0	0
			Eco-gas studies													0	0
LNF	3,5	1,8	chamber tests at CERN	1,4	0,2	_										0	0
																0	0
			Power system													0	0
Napoli	7,9	1,8	bachelite production and QC	1,25	0,3	0,5										0	0
			integration,commissioning													0	0
			Longevity													0	0
Pavia	1,8	0,9		0,6	_	_										0	0
																0	0
Total FTE	18,3	7,1					TOT (PY)	0	0,5	0,5	0	0	0	0	0	1	
							TOT (Keu)	0	12,5	12,5	0	0	0	0	0		25
Legenda								2018	2019	2020	2021	2022	2023	2024	2025	TOT contracts	TOT Cost (Keu)

Request of manpower (FTE)

Assegno Tecnologico

Manpower of INFN/CMS-BARI for RPC commitments

INFN/CMS-Bari manpower involved in the activities for the RPC detectors :

INSTITUTE	TOT FTE 2018	TOT FTE 2018 Fase2	Construction Tasks	Average Manpower (2018-2026) w/out requests in FTE: Physicist&Engineers	Technicians	PhD/Temp	Requests of Manpower: Type	2018	2019	2020	2021	2022	2023	2024	2025	TOT contracts Person Year	TOT Cost (Keu) 25Keu/year
			chamber tests at CERN													0	0
Bari	5,1	2,6	front end electronics	1,6	0,36	0,8	AT		0,5	0,5						1	25
			commissioning													0	0
																0	0

Request of manpower (FTE)
Assegno Tecnologico

Name	Profile	Status	Project	2018	2019	2020	2021	2022	2023	2024	2025	2026	Total	Task
Bari														
M.Abbrescia	Physicist	Staff	RPC	0,2	0,4	0,4	0,5	0,5	0,3	0,3	0,3	0,3	3,2	RPC.PP.DET1, RPC.PR.DET.2, RPC.PR.DET.3, RPC.PR.DET.4, RPC.PR.DET.5, RPC.PR.DET.6, RPC.PR.DET.7
N.De Filippis	Physicist	Staff	RPC	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,9	RPC.PP.DET1, RPC.PR.DET.2, RPC.PR.DET.3, RPC.PR.DET.4, RPC.PR.DET.5, RPC.PR.DET.6, RPC.PR.DET.7
G.Iaselli	Physicist	Staff	RPC	0,6	0,6	0,6	0,6	0,6	0,3	0,3	0,2	0	3,8	RPC.PP.DET1, RPC.PR.DET.2, RPC.PR.DET.3, RPC.PR.DET.4, RPC.PR.DET.5, RPC.PR.DET.6, RPC.PR.DET.7
G.Pugliese	Physicist	Staff	RPC	0,5	0,5	0,5	0,6	0,6	0,6	0,8	0,8	0,8	5,7	RPC.PP.DET1, RPC.PR.DET.2, RPC.PR.DET.3, RPC.PR.DET.4, RPC.PR.DET.5, RPC.PR.DET.6, RPC.PR.DET.7
Engineer (now AdR)	Engineer	Staff	RPC	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,9	
PhD student 1	PhD student	Temp	RPC	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	7,2	RPC.PP.DET1, RPC.PR.DET.2, RPC.PR.DET.3, RPC.PR.DET.4, RPC.PR.DET.5, RPC.PR.DET.6, RPC.PR.DET.7
Technician 1	Technician	Staff	RPC	0,2	0,2	0,2	0,2	0,4	0,4	0,4	0,2	0,2	2,4	RPC.PP.DET1, RPC.PR.DET.2, RPC.PR.DET.3, RPC.PR.DET.4, RPC.PR.DET.5, RPC.PR.DET.6, RPC.PR.DET.7
Technician 2	Technician	Staff	RPC	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,9	RPC.PP.DET1, RPC.PR.DET.2, RPC.PR.DET.3, RPC.PR.DET.4, RPC.PR.DET.5, RPC.PR.DET.6, RPC.PR.DET.7
	Engineer	Request	RPC		0,5	0,5								
			TOTAL FTE /YEAR	2,60	3,30	3,30	3,00	3,20	2,70	2,90	2,60	2,40		

[shared with GEM in same 2 years]

iRPC FE electronics

Recent/current Contributions/Responsibilities within CMS

Contributions to MUON TDR :

Official editors :

C. Calabria (Cap.6: New GEM detectors)

A. Colaleo (Cap.9: Organization, schedule, cost)

Contributions (plots, ...)

G. Pugliese, A.Gelmi
(Cap.4: RPC upgrades and new RPC detectors)

C. Calabria, A.Sharma, F.Errico
(Cap.7: Muon trigger and reconstruction)

N. De Filippis, R.Venditti
(Cap.7: Muon trigger and reconstruction)

Contributions to TRACKER upgrade :

- N. De Filippis (plots for TRACKER TDR)
- A. Di Florio (studies in ML group / workshops)
(Deep Learning for Pixel doublets filtering @ HL-LHC)

Responsibilities in years 2017-18 :

Gruppo	Livello in CMS	Nome	Responsabilità
MUON	L1	Anna Colaleo	Muon System Manager
RPC	L2	Gabriella Pugliese	RPC Project Manager
RUN	L1	Lucia Silvestris	Run Coordinator
TK	L2	Flavio Loddo	RD53 Project Engineer
GEM	L2	Marcello Maggi	Operation & Online System Coordinator
PHYS	L3	Alexis Pompili	B-Phys Spectroscopy Convener
COMP	L3	Giorgio Maggi	Bari Tier2 Coordinator
GEM	L3	Rosamaria Venditti	Upgrade Physics Coordinator
MUON	L3	Raffaella Radogna	High-pt muon sub-convener
GEM	L3	Piet Verwilligen	Phase 2 Simulation Coordinator
GEM	L3	Archana Sharma	Reconstruction & Validation Coordinator
GEM	L3	Cesare Calabria	Software & Online Contact for Upgrade
		Mauro de Palma	Career Committee
		Nicola De Filippis	Schools Committee co-chair, MuIB Advisory Group, CMS Thesis Award Comittee
PHYS	L4	Leonardo Cristella	B-Phys Muon contact

In red squares those related to the Upgrade tasks

CONCLUSIONS

- **The HL-LHC & CMS Phase-2 are widespread & complex projects that will allow to perform Physics research** (@CERN) **for other 15 years, going from the Energy Frontier to the Intensity Frontier** **(**by increasing luminosity rather than energy scale**) and looking for New Physics signs while performing precision measurements.**

- **CMS-Bari has been, is and will be heavily involved in activities for the CMS Phase-2 upgrade.**

In particular into:

- new Tracker construction & commissioning

- new GEM detectors construction, test & commissioning

- new iRPC test & commissioning

Construction activities imply intense efforts from physicists & technicians highly committed

in INFN-Bari properly equipped laboratories, till LS3 (2024-26).

Limited amount of temporary but fully dedicated experts need to be hired on specific tasks.

Further efforts, also from technicians, will be requested in test & commissioning activities @CERN.

NOTE: all quoted numbers are those proposed to Comm. Naz. GR.I & directors of Sezioni INFN, discussed with referees and provided for scrutiny by the INFN-Comitato Tecnico-Scientifico

BACKUP

CMS-Bari manpower plan in a nutshell

Institute	2018FTE	TASK	Average Man Power (without request) Physicists & Engineers	Technicians	PhD /Temporary	REQUEST of MANPOWER [FTE] 2018	2019	2020	2021	2022	2023	2024	2025
Bari	3,9	IT FE Hybrid QC/QA	3	0,9	0,2			1	1	1	1		
		OTPS Module construction						1	1	1	1		

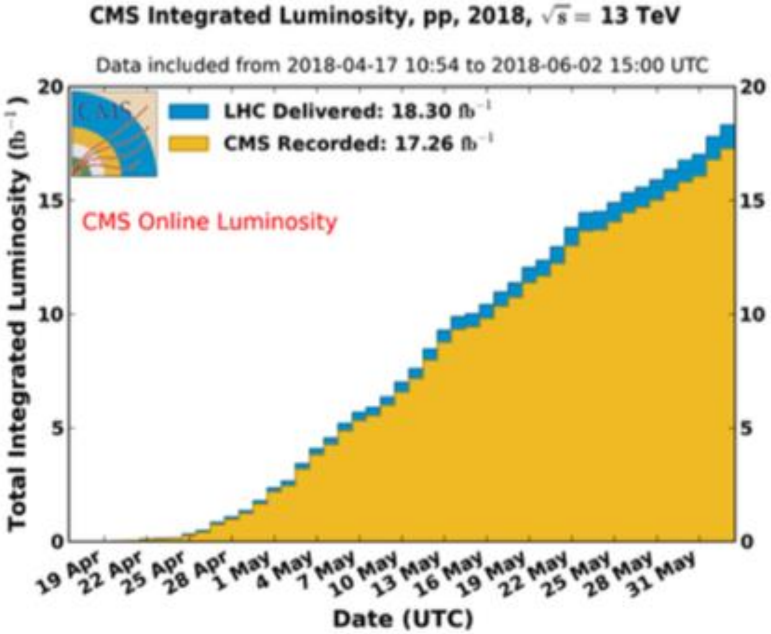
Institue	2018 FTE	Task	Avergae Manpower (without request) Physicist and Engineer	Technicians	PhD/Temporary	2019	2020	2021	2022	2023	2024	2025
Bari	3,3	ME0.RD.DET.6, ME0.PR.DET.1,ME0.PR.DET.2,	2,8	0,5	1,3	1,00	1,00	1,00	1,00	1,00	1,00	
		GE.RD.FE.5, ME0.RD.FE.5, ME0.RD.DET.6				0,50	0,50					

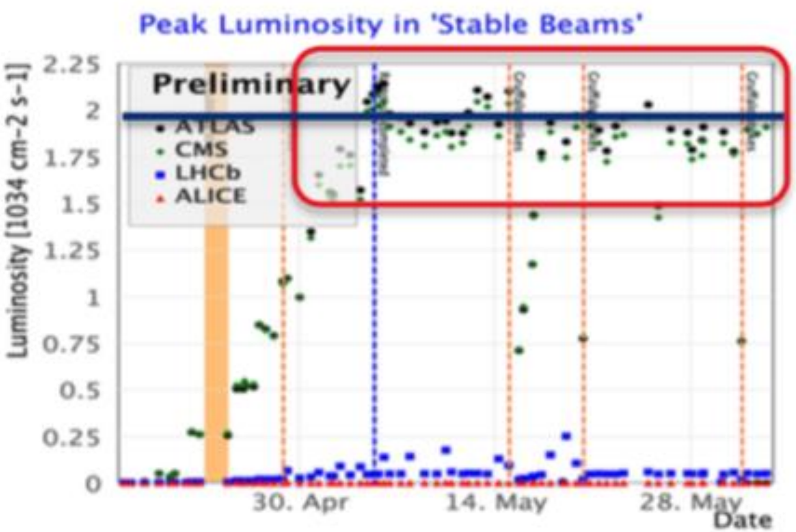
INSTITUTE	TOT FTE 2018	2018 Fase2	Construction Tasks	Average Manpower (2018-2026) w/out requests in FTE Physicist&Engineers	Technicians	PhD/Temp	Type	Requests of Manpower 2018	2019	2020	2021	2022	2023	2024	2025
Bari	5,1	2,6	chamber tests at CERN front end electronics commissioning	1,6	0,36	0,8	AT		0,5	0,5					

Request of manpower (FTE) :

- **1 Assegno Tecnologico (2019-2020) x GEM+RPC [2 anni]**
- **1 Assegno di Ricerca (2019-2024) x GEM (**GEM2/1+ME0**) [3+3 anni]**
- **1 Assegno di Ricerca (2020-2023) x Tracker (**IT3**) [4 anni]**
- **1 Tecnico (2020-2023) x Tracker (**OT5**) [4 anni]**

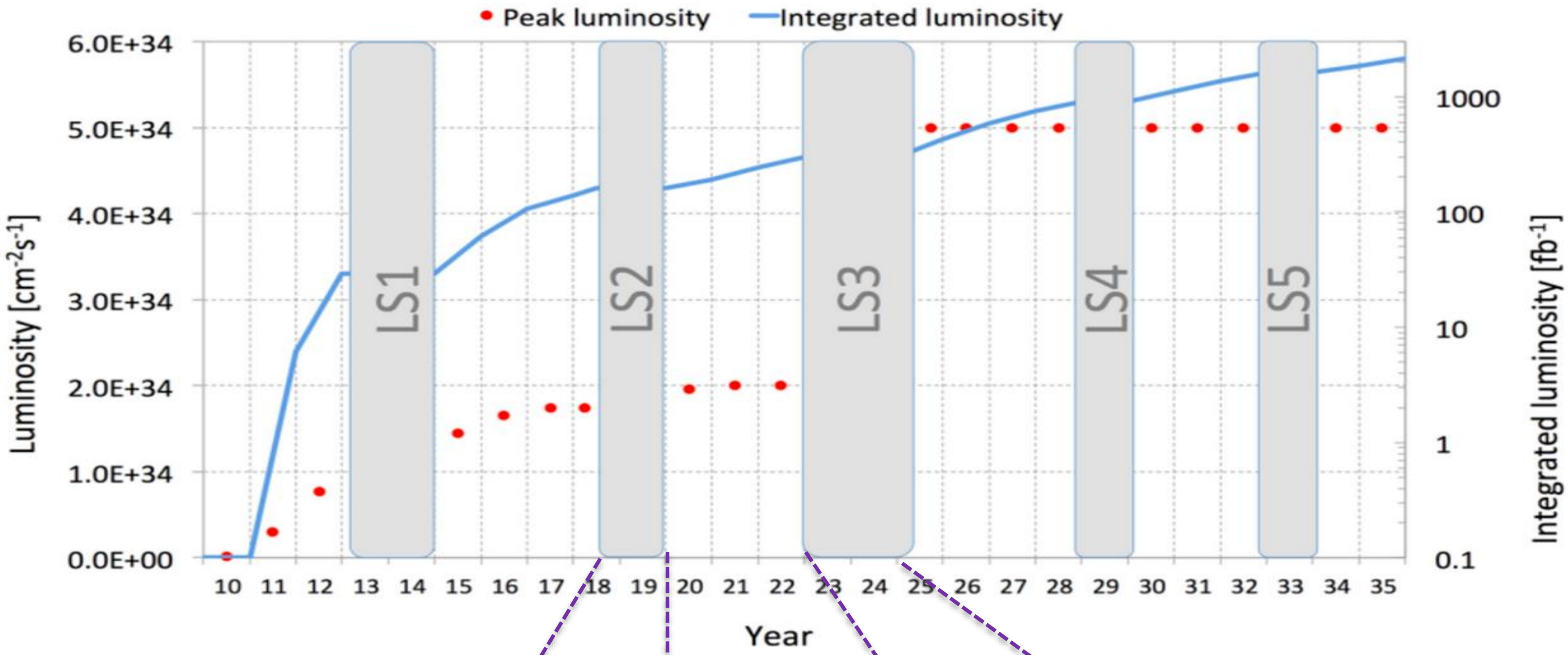
CMS is running very well in 2018

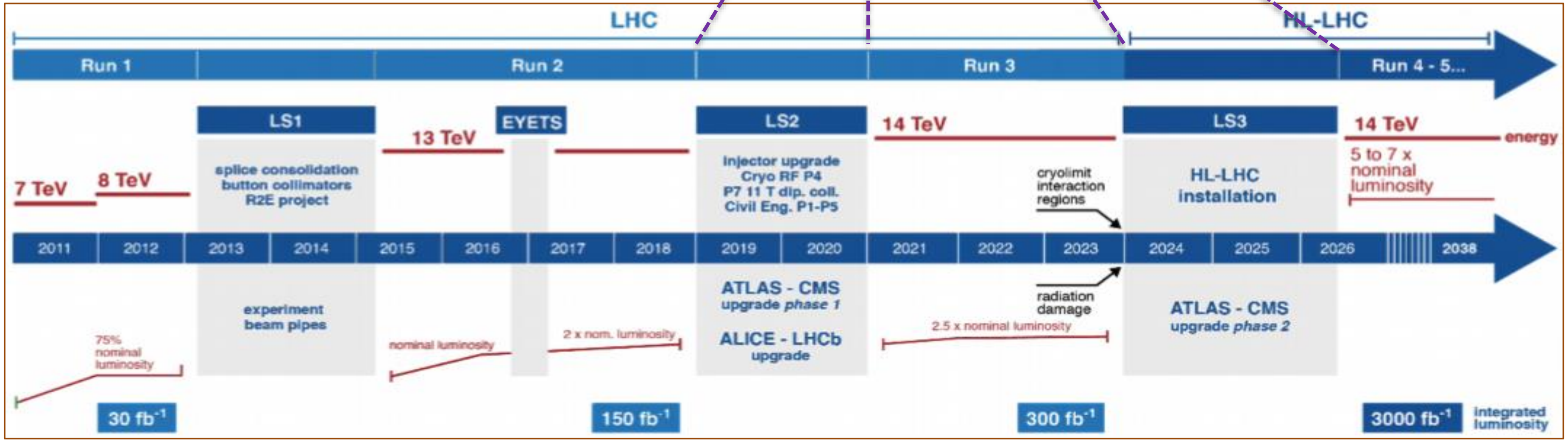




- Very fast commissioning of CMS, matching the fast ramp-up of LHC
  - Despite the tight technical stop with unplanned Pixel detector refurbishment
- Very good recording efficiency, above 94%
- Peak luminosity ~ $2 \cdot 10^{34}\ Hz/cm^2$
  - Corresponding to Pile-Up > 55
  - Deadtime negligible also at the highest luminosity (factor 2 higher than design)
- Fraction of active channels is high and stable

Projected LHC performance through 2035





rz cross section of a CMS detector quadrant

The layout of the upgraded MUON system is shown in Fig. 8. New detectors added specifically for the HL-LHC Phase-2 upgrade and located in the endcaps (GEM, additional RPCs) are indicated.

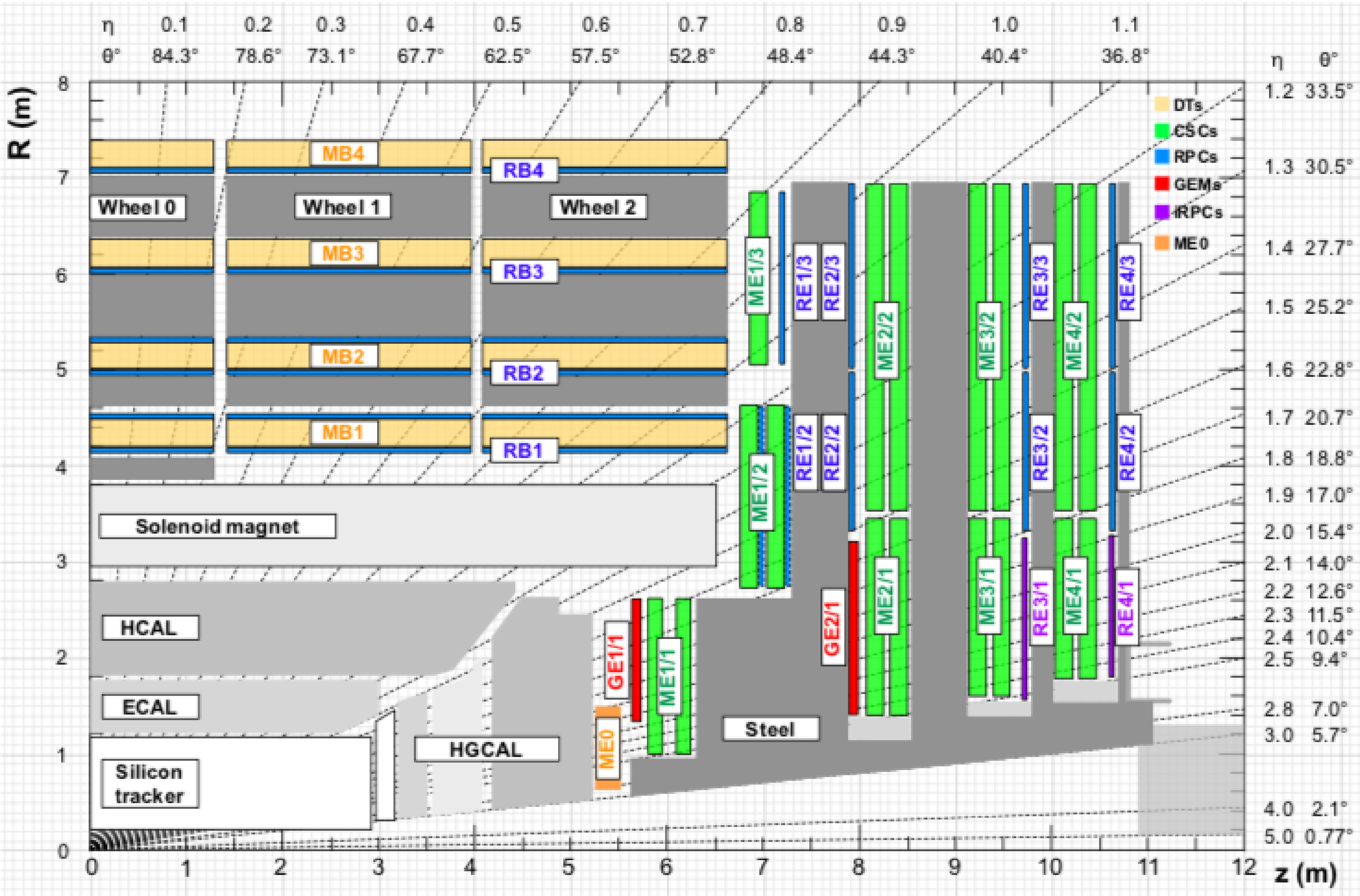
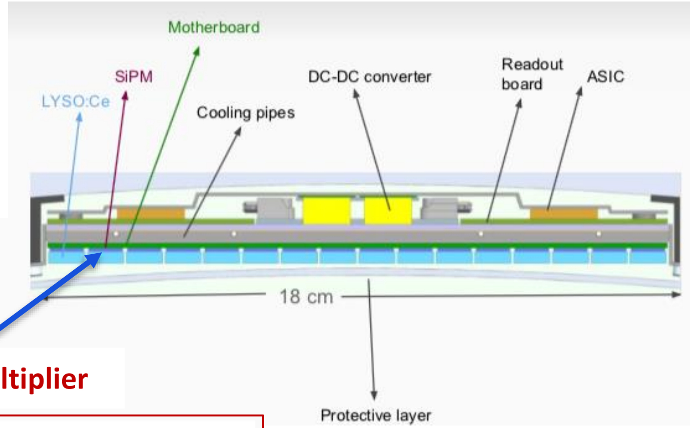


Figure 8: An R-z cross section of a quadrant of the CMS detector, including the new Phase-2 components (RE3/1, RE4/1, GE1/1, GE2/1, ME0). The interaction point is at the lower left corner. The locations of the various muon stations are shown in color (MB = DT = Drift Tubes, ME = CSC = Cathode Strip Chambers, RB and RE = RPC = Resistive Plate Chambers, GE and ME0 = GEM = Gas Electron Multiplier). M denotes Muon, B stands for Barrel and E for Endcap. The magnet yoke is represented by the dark gray areas.

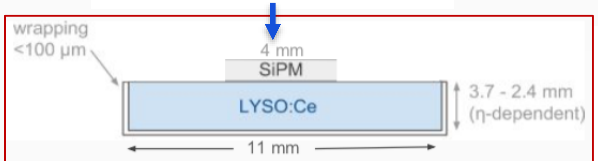
New MIP Timing Detector



Barrel Timing Layer (LYSO+SiPM)

- Larger surface area
- Lower radiation dose
- Mature readout ASIC technology

Silicon photomultiplier

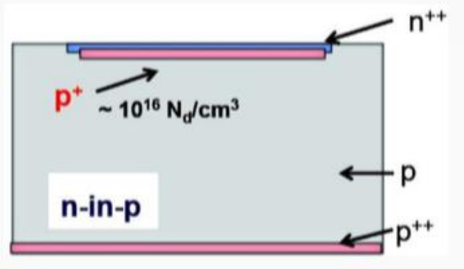


- $11x11\ mm^2$ LYSO tiles
- $4x4\ mm^2$ SiPM
- 250 k channels

Endcap Timing Layer (LGAD)

- Larger radiation dose
- More flexible installation schedule →time for R&D
- R&D synergies with ATLAS

- Low-gain avalanche diode (LGAD) are silicon sensor with a special avalanche gain-layer
- Typical gain: 10-30



Detailed Muon system upgrade schedule

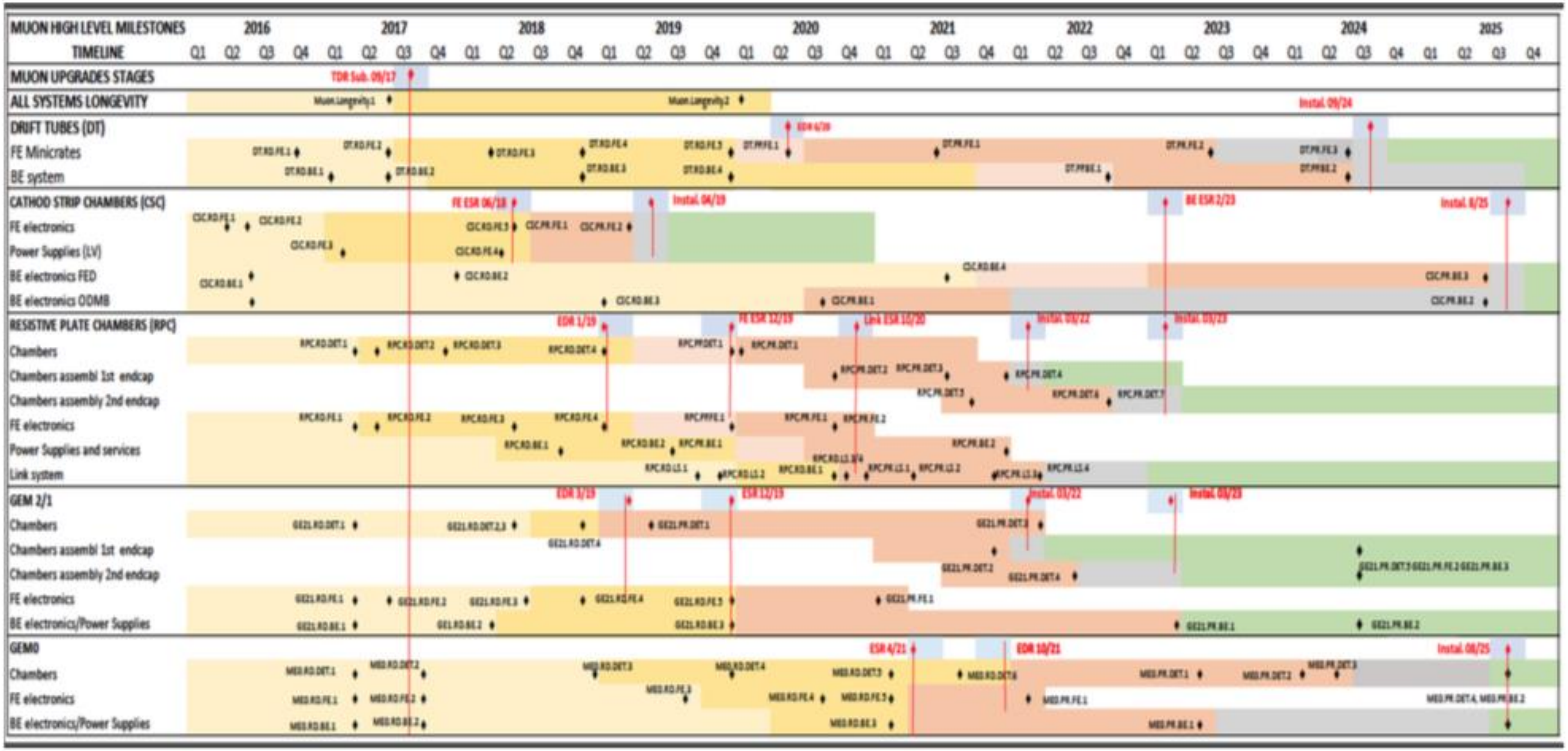
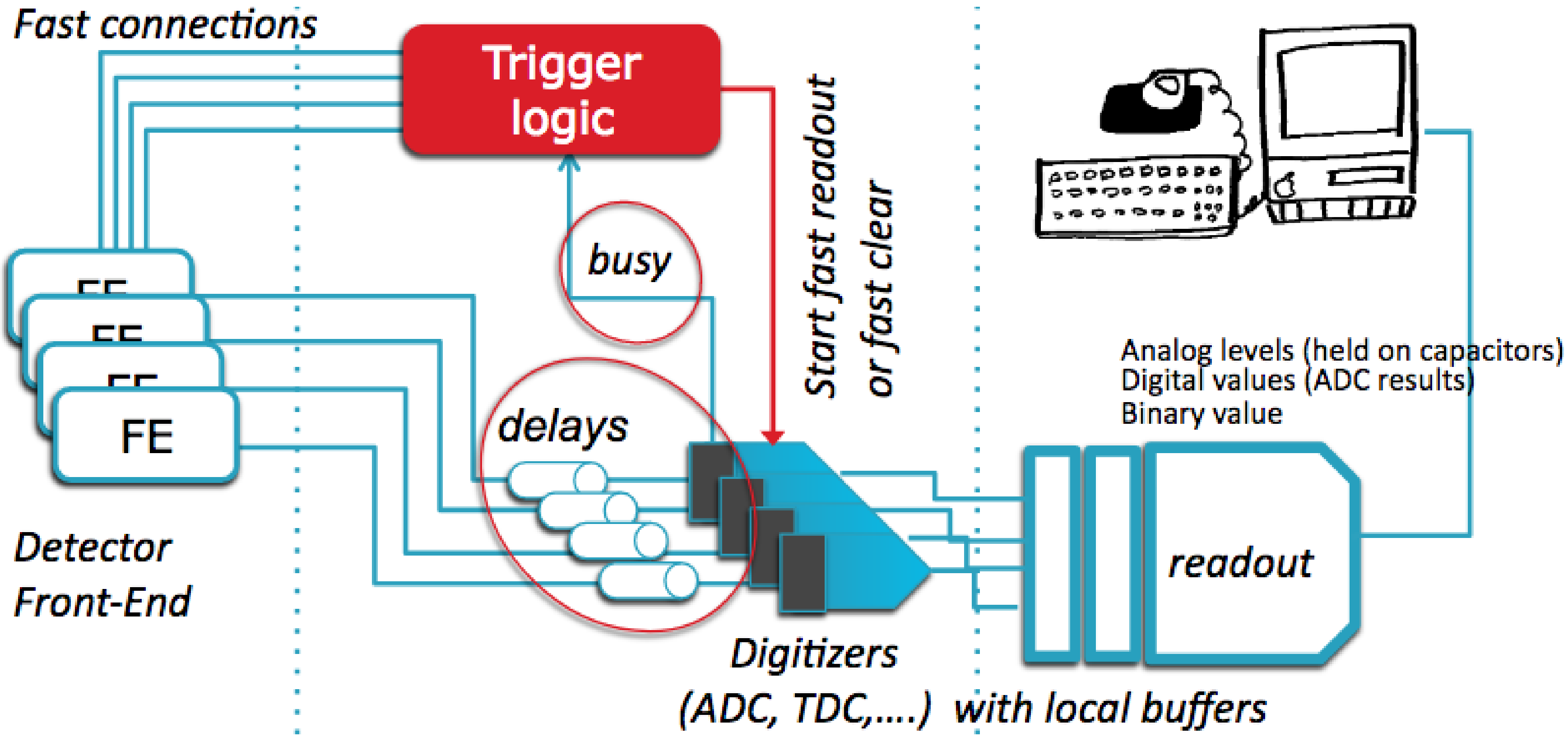


Fig. 33: detailed schedule with information of the milestones, with their tag as reported in the tables below.

Concept of Trigger latency



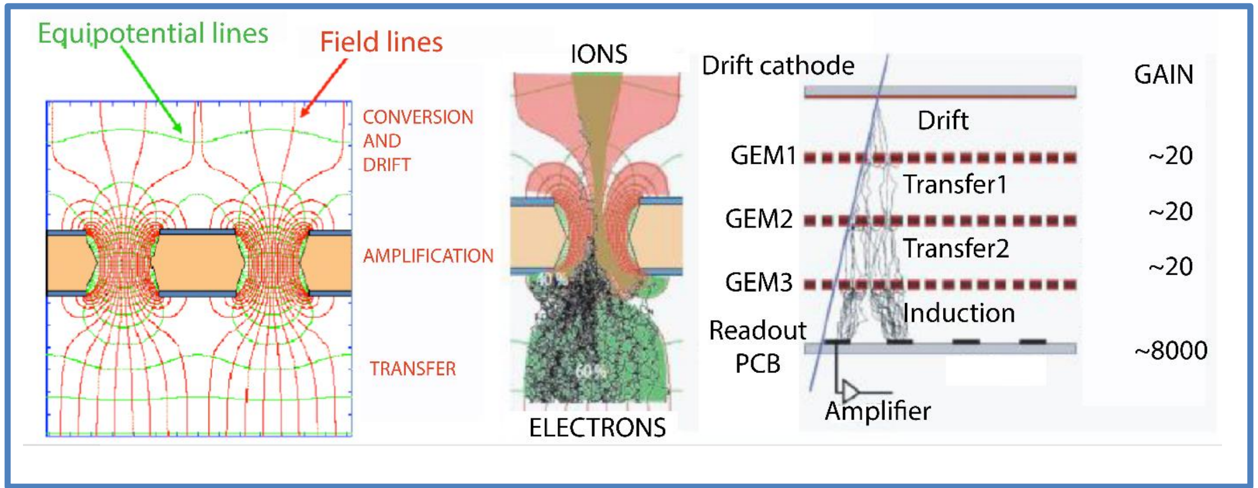
- **Trigger latency** = finite time to form the trigger decision and distribute it to the digitizers
  - More complex is the selection, longer the latency
  - Signals have to be delayed until the trigger decision is available at the digitizers
- Valid interactions are rejected due to **system busy** during digitization/readout
  - **Dead-time** is source of inefficiency

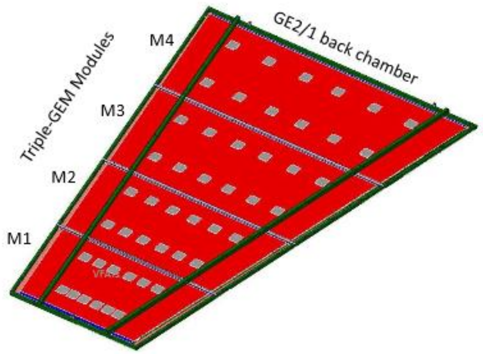
Credits: F. Pastore

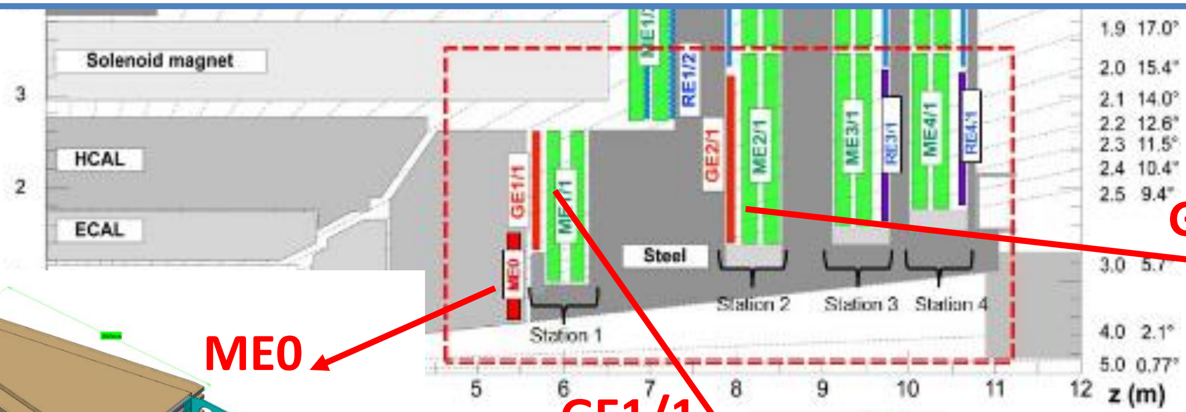
CMS Triple-GEM detector - I

CMS Triple-GEM

Figure 4.5:
Left) Electric fields and equipotentials across the GEM foil. Within the holes the amplifying field ranges from 50 – 80kV/cm. Center) A simulation of electron multiplication in the vicinity of the hole in a GEM foil. Right) Arrangement of the triple-GEM detector with three foils, a drift electrode on the top and a readout electrode at the bottom defining drift and induction fields.



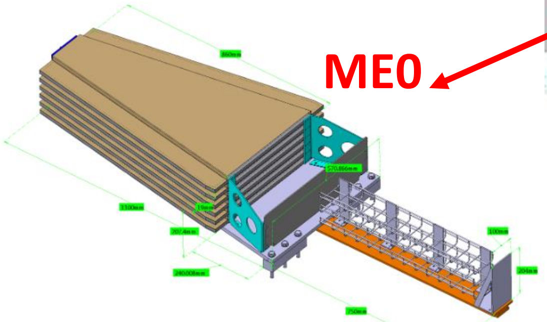




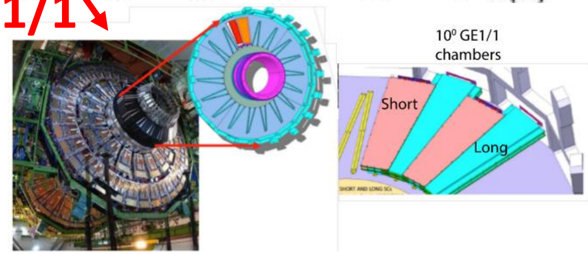
ME0

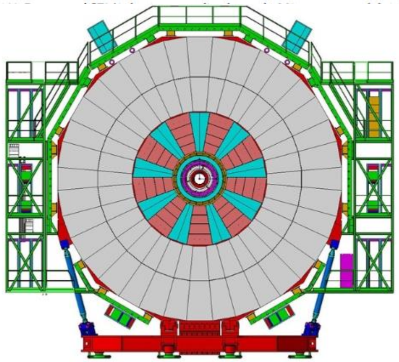
GE1/1

GE2/1



Stack of 6 triple GEMs

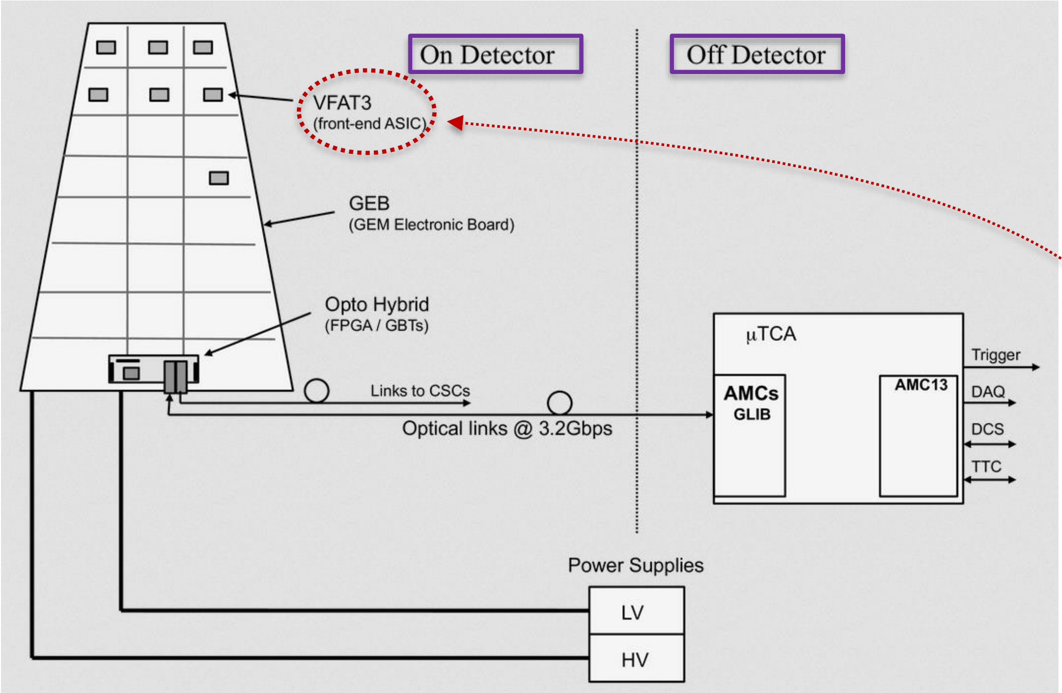




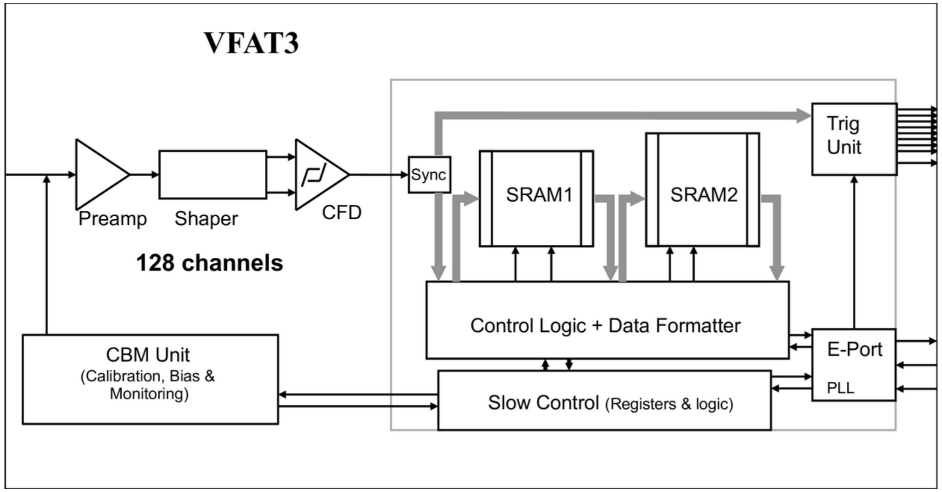
Stack of 2 triple GEMs

CMS Triple-GEM detector - II

Diagram of the GEM electronics readout system for CMS



VFAT3 block diagram



GEM activities @Bari – RECAP

Past activities in 2018:

- Build & Test 18 GE1/1 chambers (spring-summer 2018) + Build GE2/1 prototypes (fall 2018)
- VFAT3 design, bench-tests & tests with full GE1/1 chambers @ CERN
- Analysis of Slice Test data, Run Coordination

Activities in 2019-2020 (LS2):

- Install & commissiong GE1/1 chambers + Detector Performance Analysis
- Build & Test 72 GE2/1 chambers (2019-2020) together with LNF
- VFAT3 Packaging & Test

Activities 2021-2025 (EYTS + LS3):

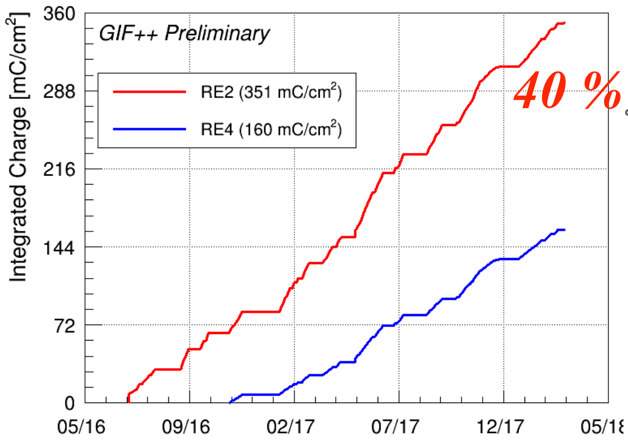
- Build & Test 54 ME0 chambers (2021-2022) together with LNF
- Install GE2/1 in YETS 2022 & 2023 + Commissioning & Detector Performance
- Install ME0 in 2024-2025 (LS3) + Commissioning & Detector Performance

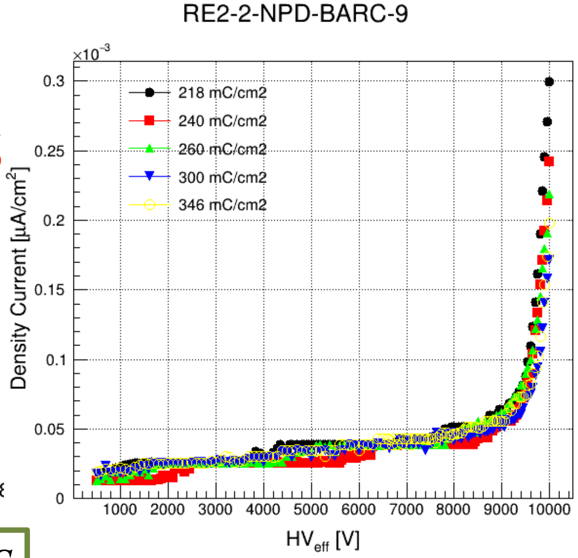
GEM milestones

	ID	Milestone title	Date
Design	GE21.RD.DET.1 GE21.RD.FE.1 GE21.RD.BE.1	GE2/1 R&D: Key detector system design parameters are defined based on performance requirements	21.Mar.17
	GE21.RD.FE.2	GE2/1 R&D: On-chamber electronics preliminary design completed and interfaces defined	19.Jun.17
	GE21.RD.BE.2	GE2/1 R&D: Off-chamber electronics preliminary design completed and interfaces defined	12.Mar.18
	GE21.RD.DET.2	GE2/1 R&D: A full size chamber prototype with partially instrumented readout built, tested and performance validated	1.May.18
	GE21.RD.DET.3	GE2/1 R&D: Detector design parameters optimization completed, final chamber design is selected for the demonstrator	8.May.18
	GE21.RD.FE.3	GE2/1 R&D: On-chamber electronics prototypes engineering design complete	1.Jun.18
Prototyping	GE21.RD.FE.4	GE2/1 R&D: On-chamber electronics prototype electronics manufacturing and testing is complete	9.Oct.18
	GE21.RD.DET.4	GE2/1 R&D: Performance of the demonstrator chamber with prototype electronics is validated	12.Mar.19
	GE21.RD.FE.5 GE21.RD.BE.3	GE2/1 R&D: On-chamber and off-chamber prototype electronics integration and performance studies completed	12.Dec.19
		GE2/1 PRR for the On-Detector Services	3.Aug.2018
		GE2/1 PRR for the Foil Production	13.Nov.2018
		GE2/1 Detector EDR	12.Mar.2019
		GE2/1 ESR	12.Dec.2019
Production	GE21.PR.DET.1	GE2/1 On-Disk Services Installation Complete	20.May.2019
	GE21.PR.FE.1	GE2/1 On-Chamber Electronics Manufacturing and Testing is Completed	3.Mar.2021
	GE21.PR.DET.2	GE2/1 Chambers for Disk-1 are assembled, tested, and ready for installation	16.Nov.2021
	GE21.PR.DET.3	GE2/1 Module manufacturing and testing is complete	8.Feb.2022
	GE21.PR.DET.4	GE2/1 Chambers for Disk-2 are assembled, tested, and ready for installation	5.Apr.2022
	GE21.PR.BE.1	GE2/1 Off-Chamber Electronics Manufacturing & Testing completed and ready for installation	5.May.2023
		GE2/1 Full Detector Commissioning Starts	15.Mar.2024

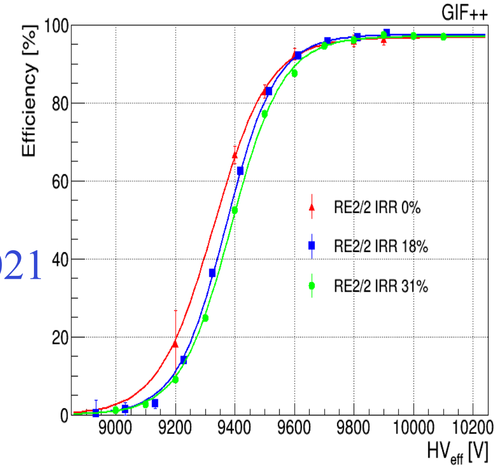
RPC system Longevity test @ GIF++(Cern)

To certify the RPC system at HL-LHC conditions a new LONGEVITY STUDY started @ ***Gamma Irradiation Facility (GIF++)*** *in 2016*





Expected integrated charge @ HL-LHC
840 mC/cm²



Setup @ GIF++:

- *2* ***RE2 chambers*** *(Irrad & Ref)*
- *2* ***RE4 chambers*** *(Irrad & Ref)*

Detectors performance are stable so far.
Plan to complete the irradiation test on these chambers & with standard gas mixture by 2021

RPC activities @Bari – RECAP

Past activities in 2018:

- Longevity tests RPC in GIF++ Operation & Analysis: RPC system ok up to $0.6kHz/cm^2$

Activities in 2019-2020 (LS2):

- Longevity tests RPC in GIF++ to be continued
- Gas Leak Repairs + services iRPC
- FE electronics tests
  (ATLAS chip as backup for PETIROC)

Activities 2021-2025:

- iRPC chamber validation @ CERN + installation in YETS 2022-2023
  + Commissioning & Detector Performance

RPC milestones

	ID	Milestone title	Date
Design	ME0.RD.DET.1 ME0.RD.FE.1 ME0.RD.BE.1	ME0 R&D: Key detector system design parameters are defined based on performance requirements	21.Mar.17
	ME0.RD.DET.2	ME0 R&D: Irradiation studies and assessment of performance and longevity with small prototypes completed	11.Jul.2017
	ME0.RD.FE.2 ME0.RD.BE.2	ME0 R&D: On-chamber & off-chamber electronics preliminary principal design complete and interfaces defined	25.Jul.17
	ME0.RD.DET.3	ME0 R&D: Chamber (stack) prototype mechanical design completed	18.Dec.2018
	ME0.RD.FE.3	ME0 R&D: On-chamber electronics engineering design completed and validated	23.Aug.2019
Prototyping	ME0.RD.DET.4	ME0 R&D: Chamber (stack) prototype mechanical prototype testing and validation complete	24.Dec.2019
	ME0.RD.FE.4	ME0 R&D: On-chamber electronics prototype electronics manufacturing and testing is complete	21.Aug.2020
	ME0.RD.BE.3	ME0 R&D: Integration of the on-chamber and off-chamber electronics and performance assessment complete	8.Jan.2021
	ME0.RD.DET.5 ME0.RD.FE.5	ME0 R&D: Assessment of the electronics performance and integration with the demonstrator chamber completed	30.Mar.2021
	ME0.RD.DET.6	ME0 R&D: Beams and Cosmics testing of the demonstrator chamber and performance qualification completed	31.Aug.2021
		ME0 PRR for the Foil Production	14.Jun.2021
		ME0 ESR	27.Apr.2021
		ME0 Detector EDR	28.Oct.2021
Production	ME0.PR.FE.1	ME0 On-Chamber Electronics Manufacturing and Testing complete, ready for chamber (stack) assembly	29.Mar.2022
	ME0.PR.DET.1	ME0 Chambers for Disk-1 are assembled, tested, and ready for installation	4.May.2023
	ME0.PR.BE.1	ME0 Off-Chamber Electronics Manufacturing & Testing complete	8.June.2023
	ME0.PR.DET.2	ME0 Chambers for Disk-2 are assembled, tested, and ready for installation	7.Mar.2024
	ME0.PR.DET.3	All ME0 Stacks Installed in the New Nose. Detector is ready for installation as part of the endcap at Pt. 5	23.May.2024
	ME0.PR.DET.4 ME0.PR.FE.2 ME0.PR.BE.2	Construction Project Complete. Ready for Global System Commissioning	12.Sep.2025