LHC - progetti di upgrade a Roma1

Retreat Fisica Particelle Elementari
16-18 June 2019

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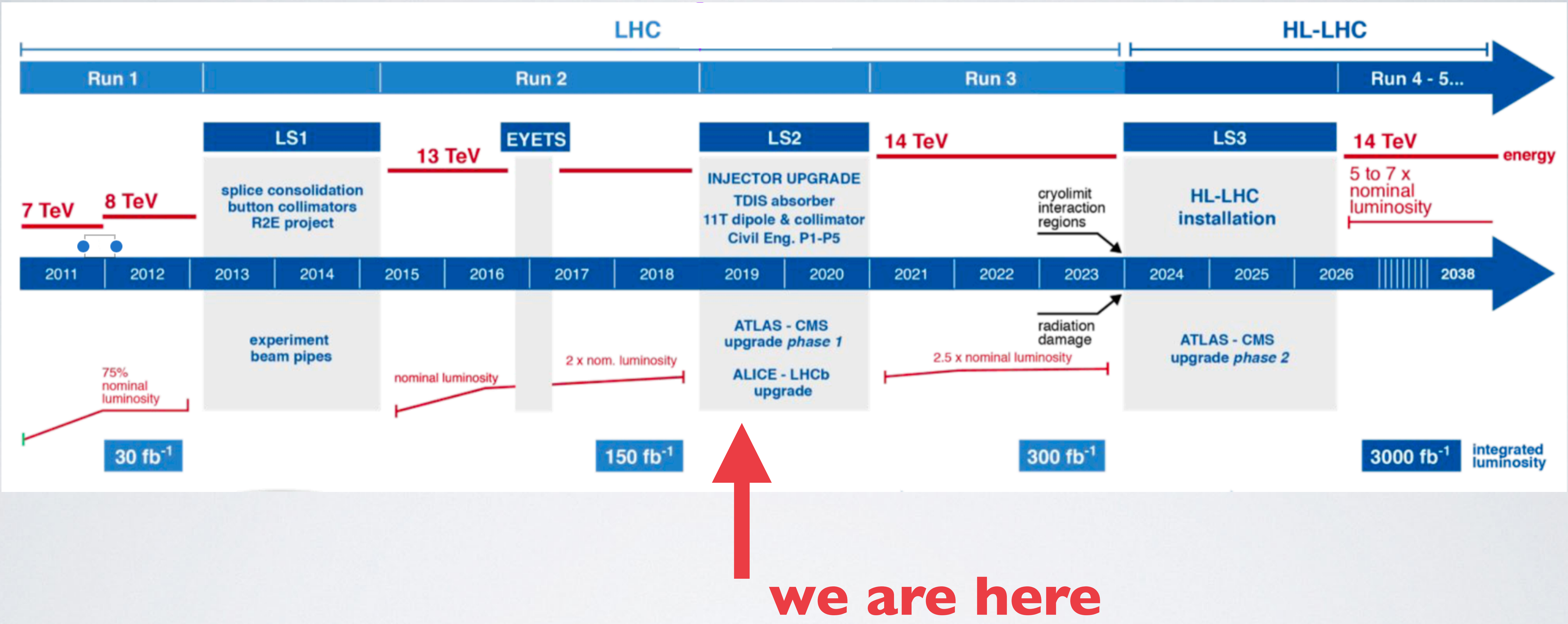
LHC / HL-LHC (I)



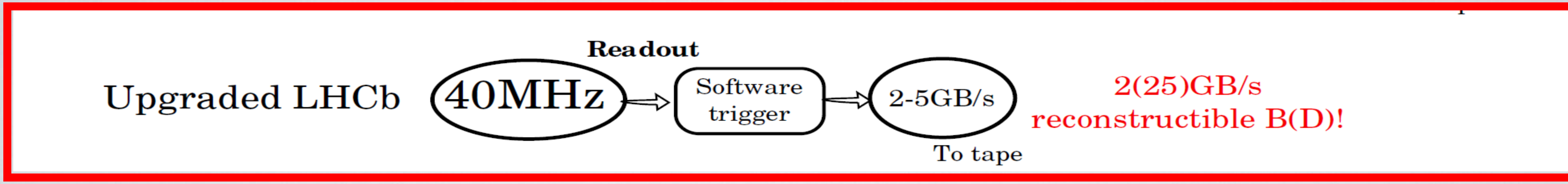
- **Physics goals/opportunities**
  - Precision Higgs Measurements
  - Precision Electroweak Measurements
  - Extend BSM searches to uncovered regions
  - Precision measurements of rare B decays
  - Heavy Ion Physics

LHC / HL-LHC (II)

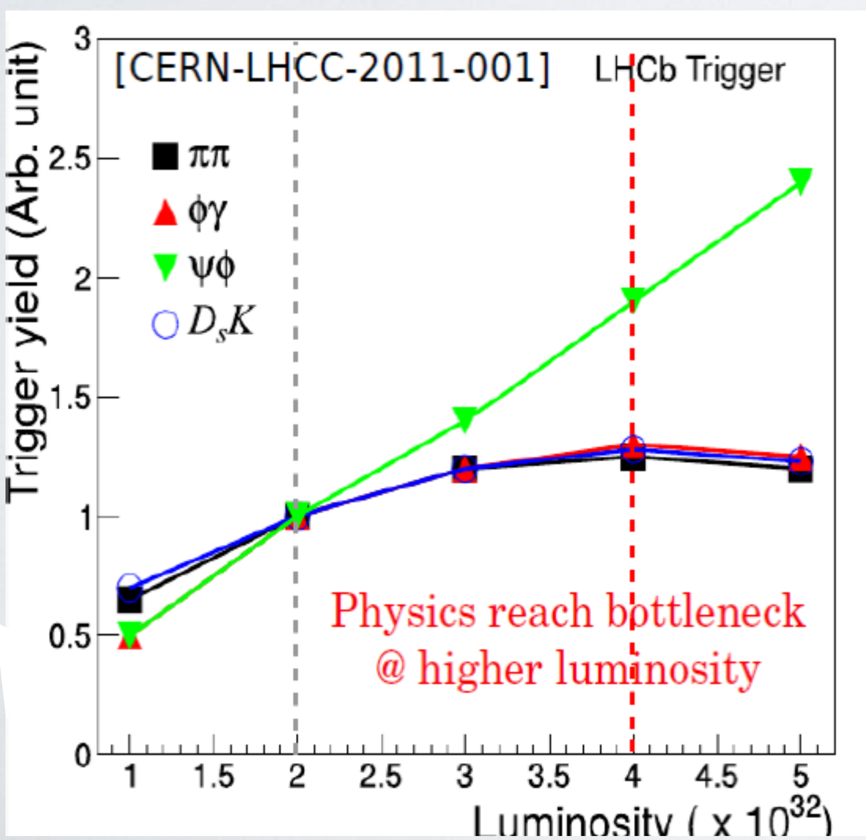
Parameter	LHC Run2	HL-LHC
$\sqrt{s}$ (TeV)	13	14
L ($cm^{-2}s^{-1}$)	2×10^{34}	$>5\times10^{34}$
L_{int} (fb^{-1})	150	3000
γ dose rate (Gy/h)	0.2 ($\|\eta\|=1$) 10 ($\|\eta\|=2.6$)	1.5 ($\|\eta\|=1$) 50 ($\|\eta\|=2.6$)
hadron fluence (cm^{-2})	4×10^{11} ($\|\eta\|=1$) 10^{14} ($\|\eta\|=2.6$)	4×10^{12} ($\|\eta\|=1$) 10^{15} ($\|\eta\|=2.6$)

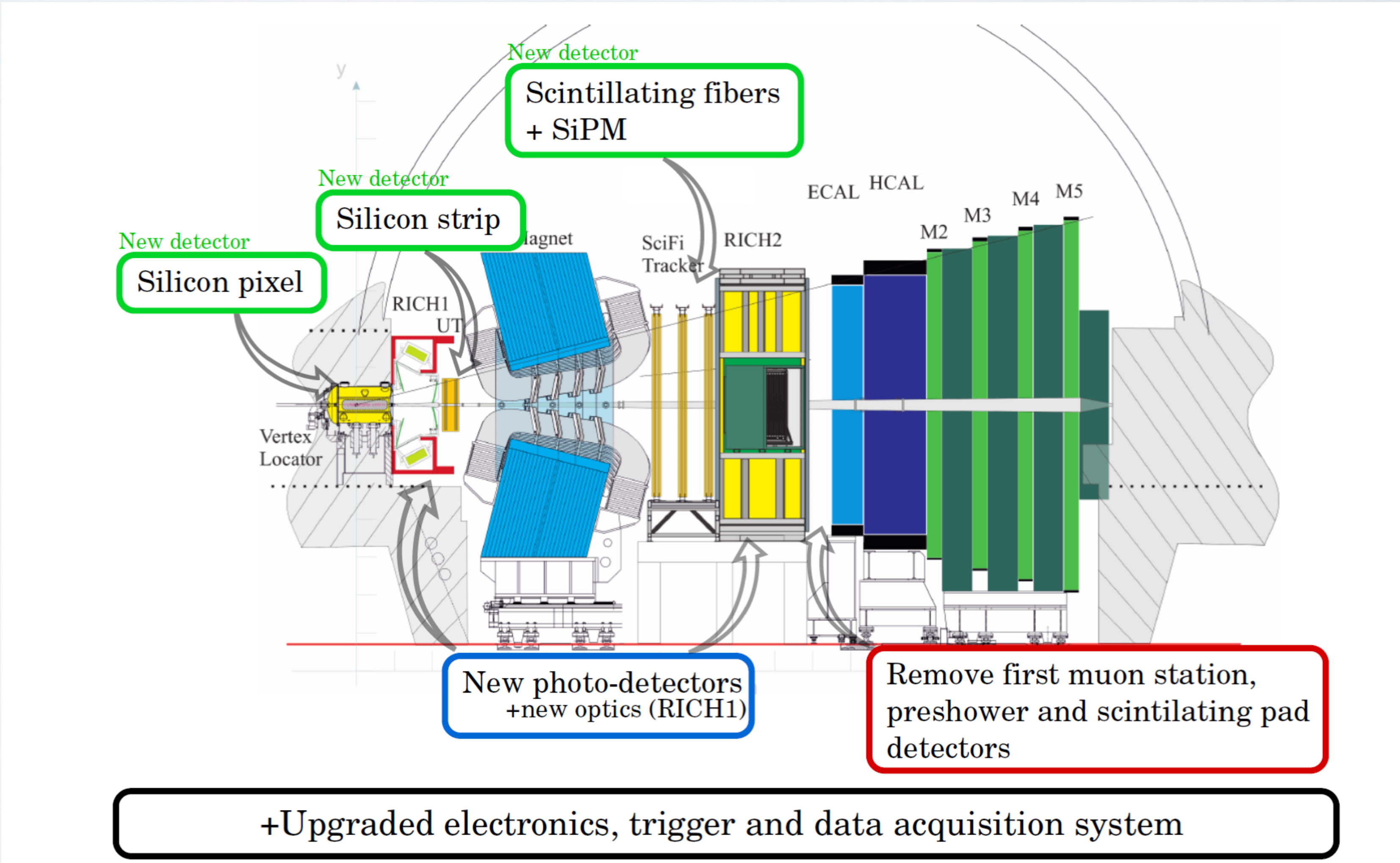
- **Detector challenges**
  - higher particle fluxes, larger event sizes, higher trigger rate
  - higher detector occupancy, increased reconstruction complexity
  - increased fluence → increased radiation damage and activation of materials
- **Detector upgrade**
  - upgrade or complete replacement of various sub-systems, major electronics upgrades
  - new timing detectors
  - new trigger system with augmented capabilities (efficiency and fake rejection) to maintain same acceptance and p_T thresholds: rare and new physics searches require low p_T threshold
  - continuous efforts in consolidation, e.g. new cooling systems, improved power supplies, shielding additions

LHCb upgrade



- New trigger scheme
  - Acquire 40 MHz with a completely new software-based trigger, removing the bottleneck of the hardware based trigger (1 MHz)
  - Reconstruction at the trigger level and online calibration and alignment
  - Save to tape 2-5 GB/s of events ready for analysis
- Upgrade of the detector to keep same high performance @ high 2×10^{33} $cm^{-2}s^{-1}$ luminosity
  - Mainly for Phase I



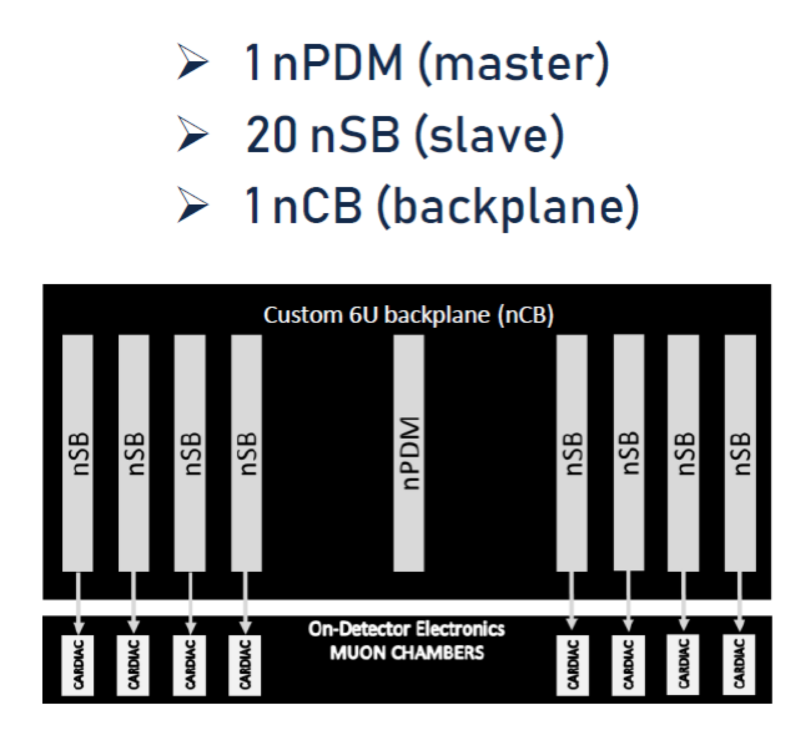


LHCb muon detector upgrade for phase I

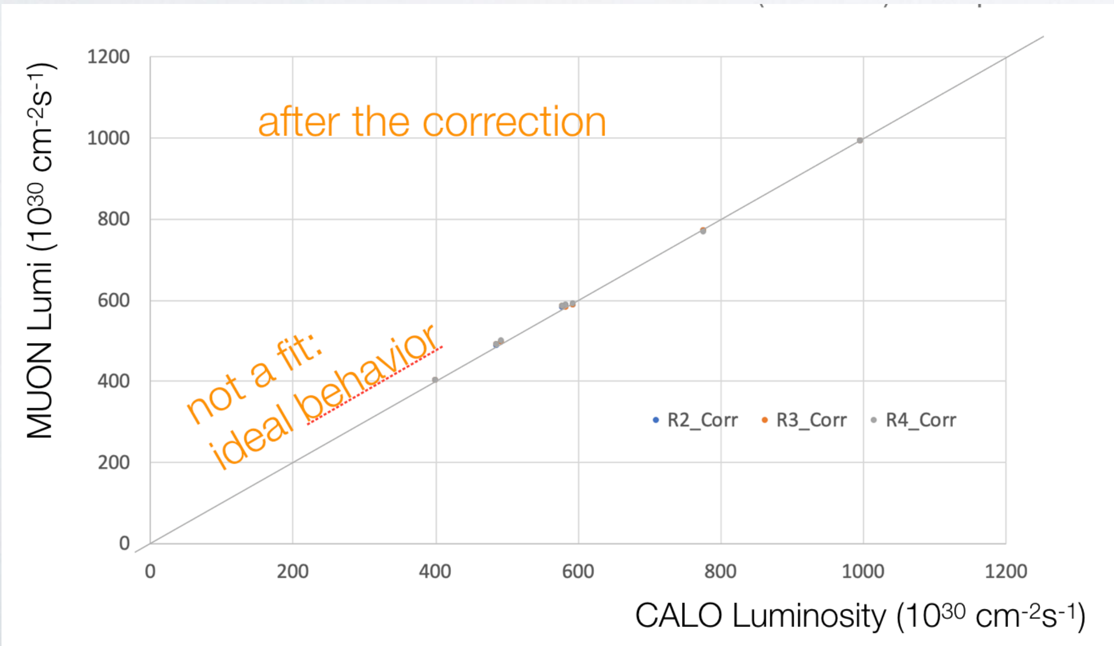
- Upgrade of the detector
  - Remove the first, innermost, muon station M1 (useless at the foreseen detector occupancy)
  - shield around the beam pipe
  - new pad chambers in the innermost region of the second and third muon chambers (to reduce inefficiencies and ghost rate)
- Upgrade of the electronics to 40 MHz

Rome 1 group is responsible of the monitoring electronics and of the front-end configuration and software

- System of 10 crates with:
  - 140 new Service Boards (nSB)
  - 10 new Pulse Distribution Module (nPDM)
  - 10 custom Back Plane (nCB)
- System designed in Rome
- Production of the boards ongoing
- Test stand @ Segré



- Just starting: **On-line luminosity measurement** based on the evaluation and correction of dead time proposed by the Roma 1 group



- INFN-ROMA 1 group
  - Valerio Bocci (original ECS idea)
  - Giuseppe Martellotti
  - Davide Pinci - board test, software for Experiment Control System (Deputy Project Leader of the muon system)
  - Roberta Santacesaria - board test
  - Celeste Satriano - software for Experiment Control System
  - Adalberto Sciubba

LHCb muon detector upgrade for phase 2

- The goal for phase 2 is to raise the luminosity up to 1.5×10^{34} cm^{-2} s^{-1}, with a maximum pile-up of 42

Detector physics requirements:

- **Rate** up to 1 **MHz/cm^2 on detector**
- **Rate up to 700 kHz per electronic channel**
- **Max input capacitance ≤ 100 pF**
- **Efficiency** for single gap **> 97%** within a BX (25 ns)
- **Long stability** up to **2C/cm^2** accumulated charge in **10 y** of operation (M2R1)
- **Pad cluster size < 1.2**

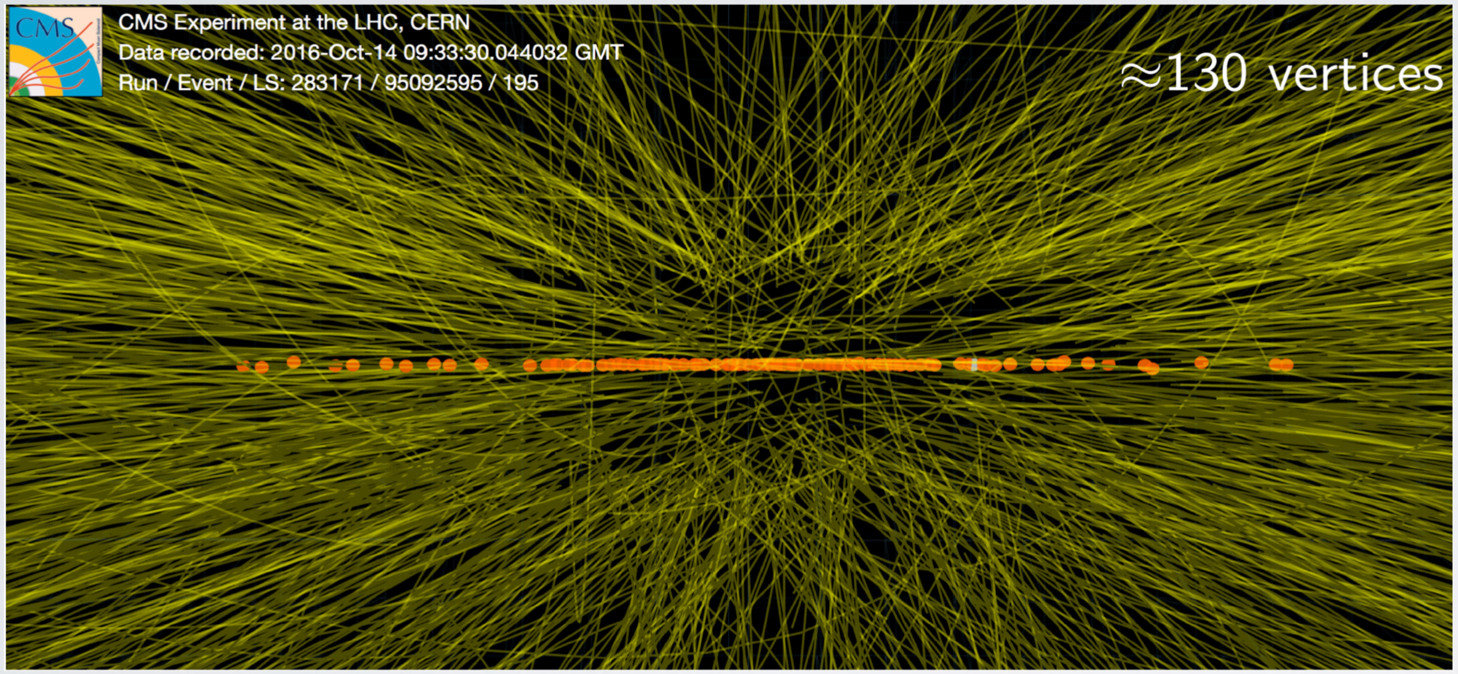
- The MWPCs of the muon detector will not support the expected rate in the central regions → replace chambers with a new detector technology
  - **μRwell chambers** have been proposed as a possible choice (more details on this detector in Davide Pinci's talk)

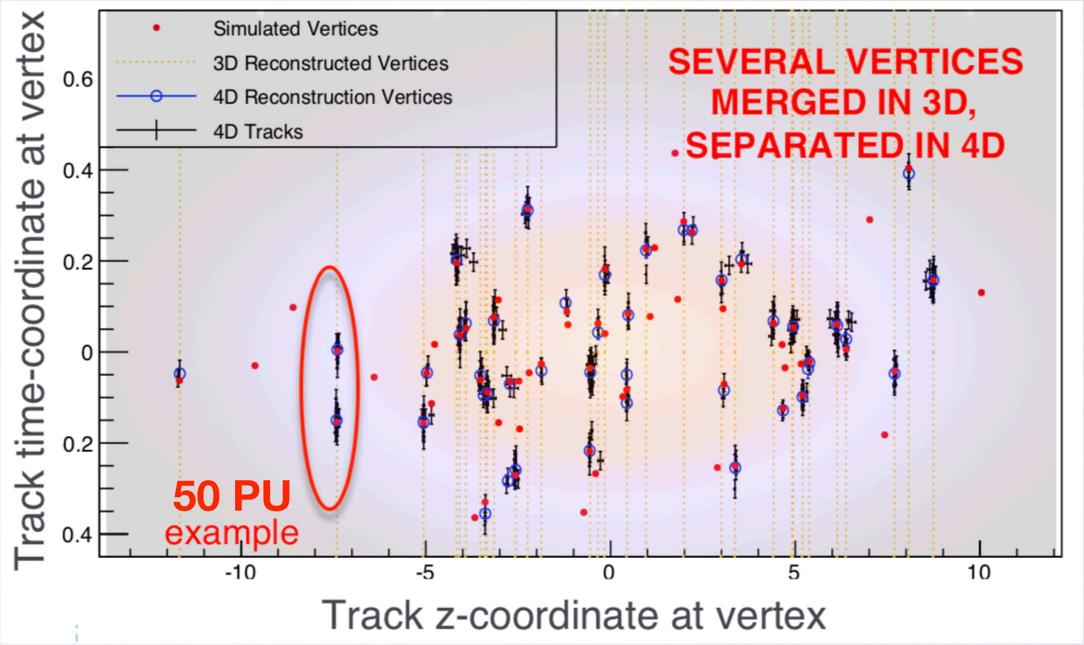
The LHCb-ROMA1 group, given its experience with MWPC and GEM would participate at the production and test phase

CMS - MIP TIMING DETECTOR FOR PHASE 2

- At high pileup, interaction vertices may be merged in space

Basic idea:
vertexes overlapping in z might not overlap in time



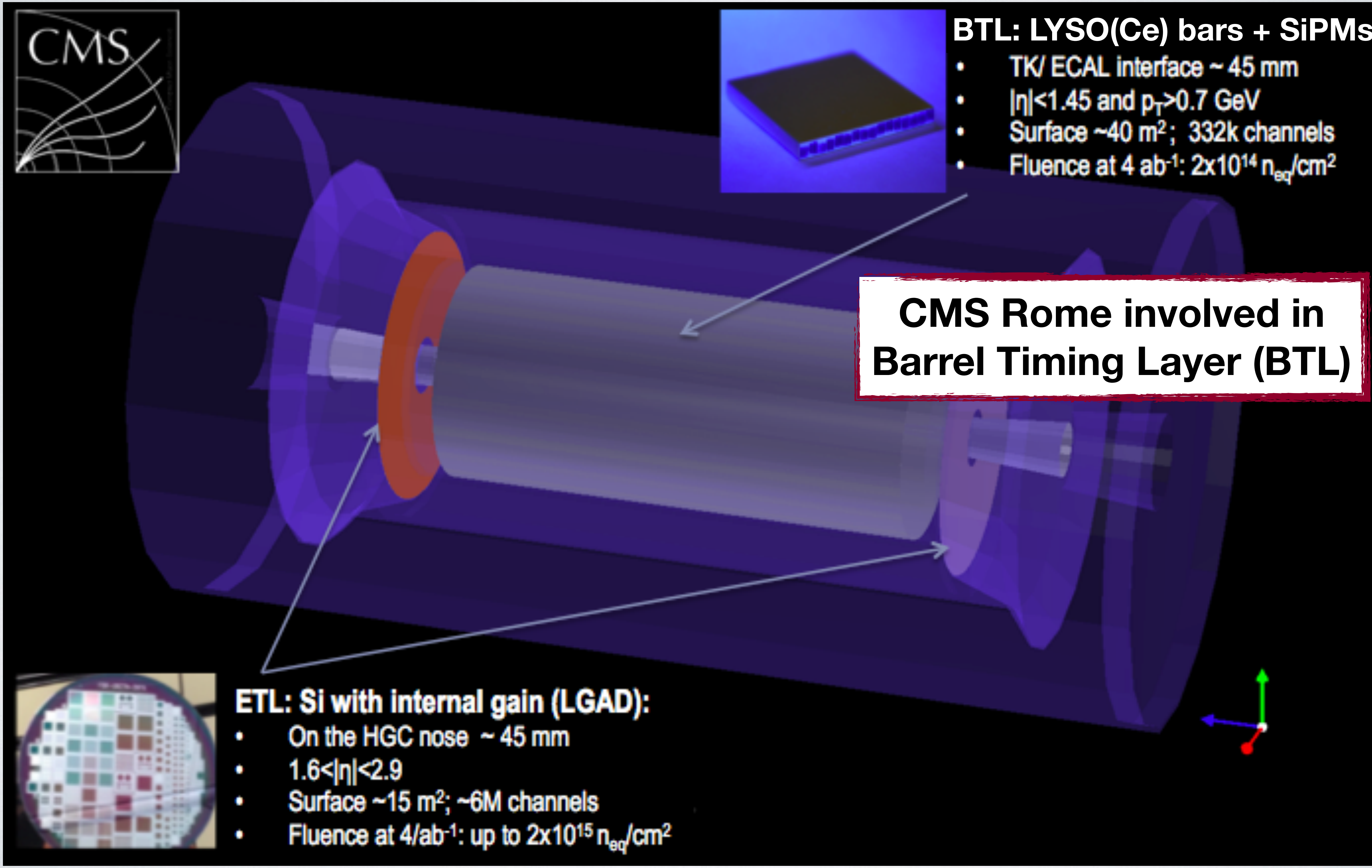


- New timing detectors with excellent time resolution are proposed
- Luminous region has time RMS ~ 180 ps
- Better time resolution → better separation
  - Can be used to effectively **reduce PU**
  - and opens **new** search possibilities! (e.g. long-lived particles)

σ(t)	Effective PU
None	200
30 ps	33
45 ps	50
60 ps	70

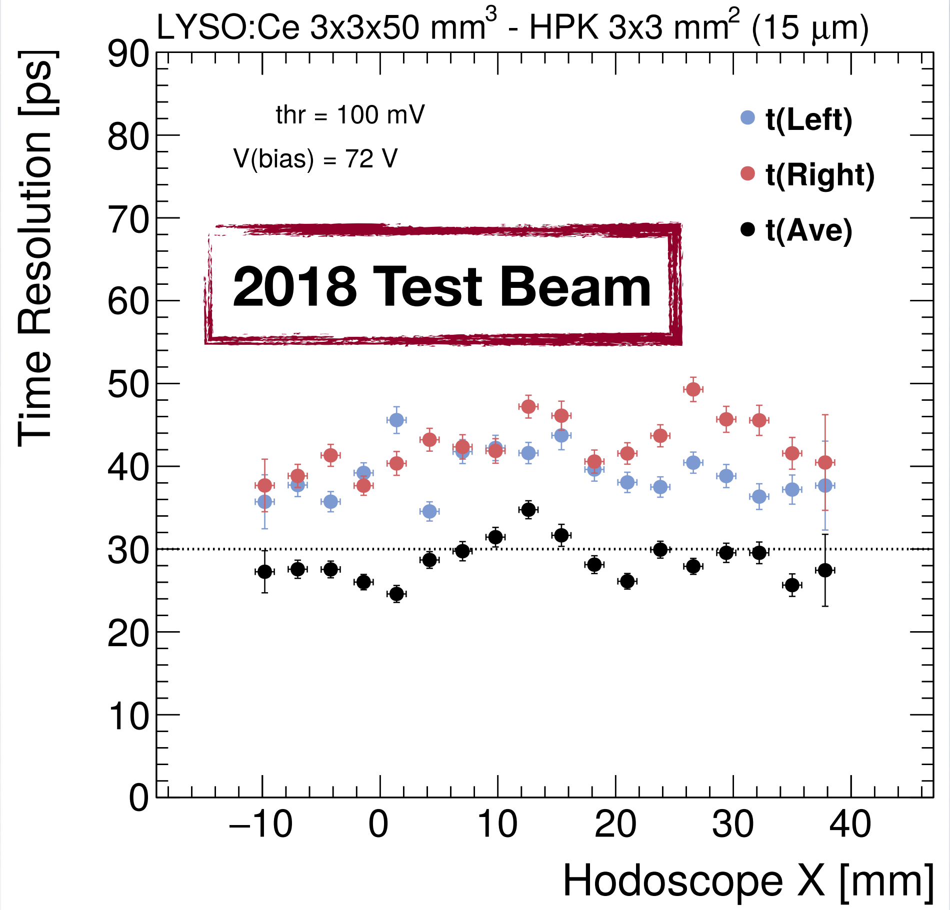
Target:
σ_t = 30 ps @ startup

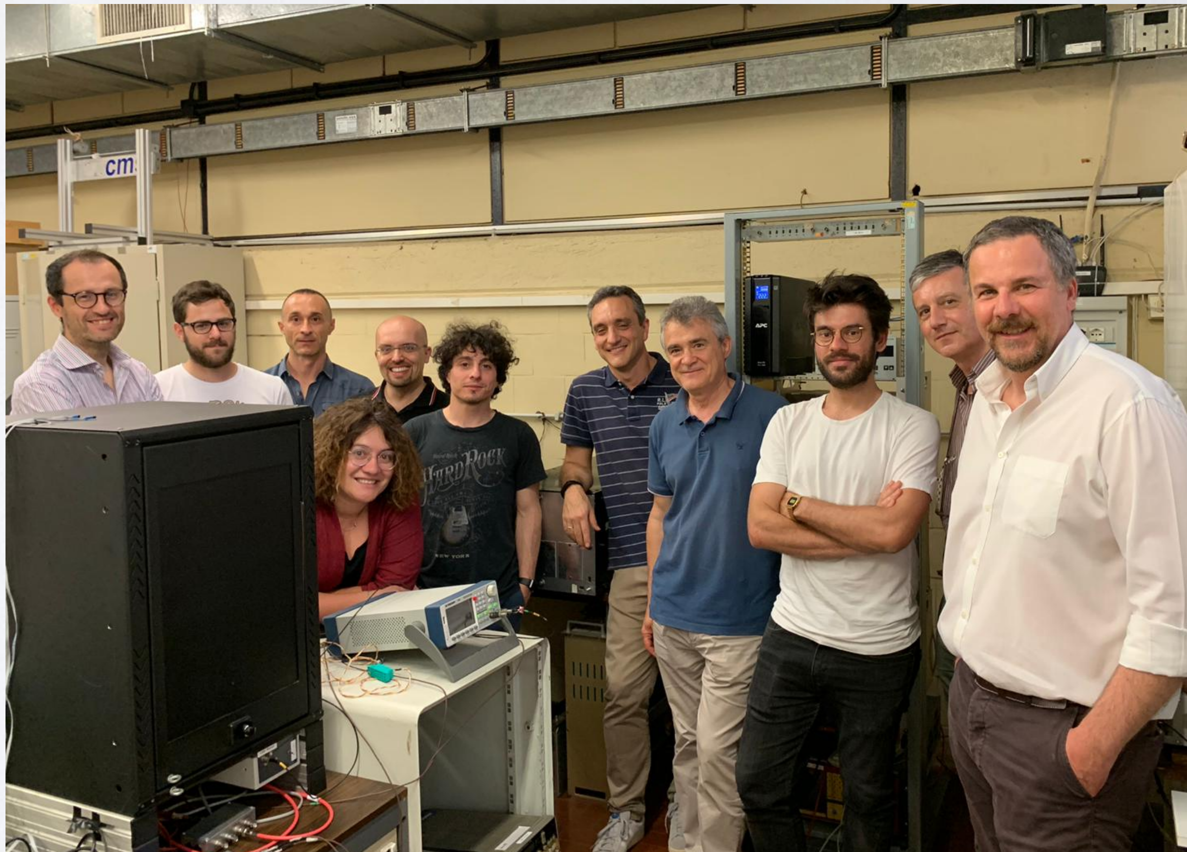
TWO TIMING DETECTORS: BTL AND ETL



ACTIVITIES IN ROME

- **Participated to many test beams in 2016-2018**
  - Proved that σ_t < 30 ps is **achievable**
- **Rome in charge of choosing crystal producer**
  - 8 producers (China, Taiwan, Canada, US)
  - Will do extensive QA campaign
- **Full-fledged crystal characterization @ Sapienza (Segré Labs)**
  - Light yield and energy resolution
  - Time resolution and decay time
  - xyz dimensions, planarity, density
  - Radiation resistance (Casaccia - ENEA)





ECAL PHASE 2 UPGRADE: BARREL HV

- CMS ECAL barrel ($|\eta|<1.4$): **substantial** upgrades
  - Front-end electronics
    - need replacement to comply with trigger requirements
      - all cells available at L1, 0.75 MHz at L1
    - operate from 18° C to 9°C to mitigate Avalanche Photo Diode aging
  - Current HV boards reaching end-of-life
- **Rome historically in charge of barrel HV system**
  - In charge of testing, ordering and maintaining **new** HV system
  - New CAEN boards **already** being tested

ECAL PHASE 2 UPGRADE: ENFOURNEUR

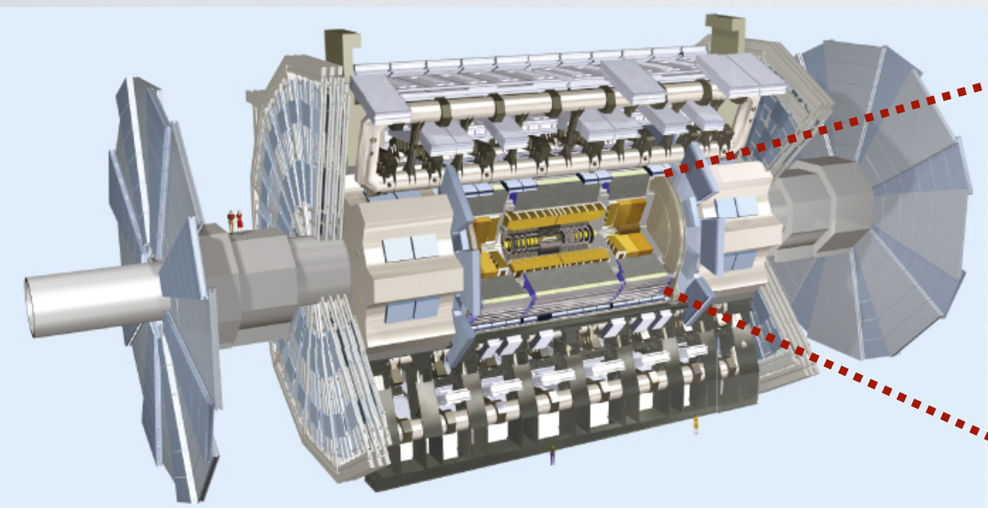
- Tool to insert/extract ECAL supermodules
  - Only **one** at the moment
  - Takes ~8 months to extract full detector (**too long!** shut-down is only two years)
- **Rome will contribute to designing and building second enfourneur**
  - Technical drawings being **finalized**
  - Construction will begin **soon** at CERN
  - Will be used in LS3 to extract ECAL

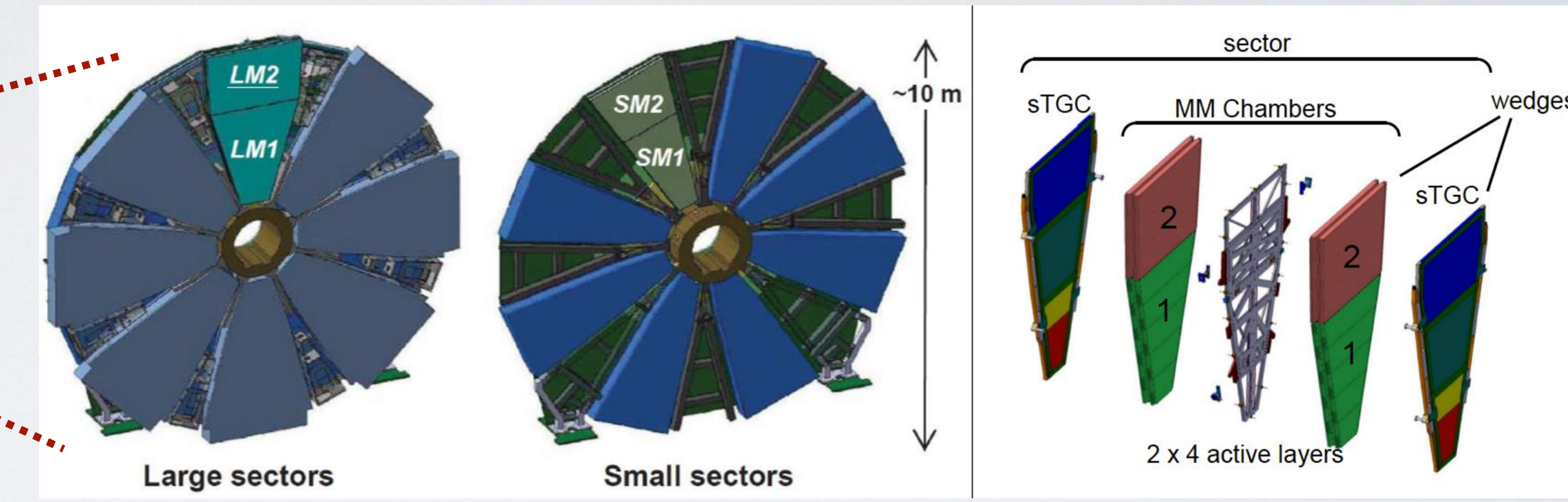
CMS UPGRADE: SCHEDULE AND PERSONPOWER

	FTE/yr	Years
Timing	2-3	2018-2026
ECAL HV	1.5-2	2018-2022
Enfourneur	1-1.5	2018-2021

ATLAS: NEW SMALL WHEEL (NSW)- PHASE 1

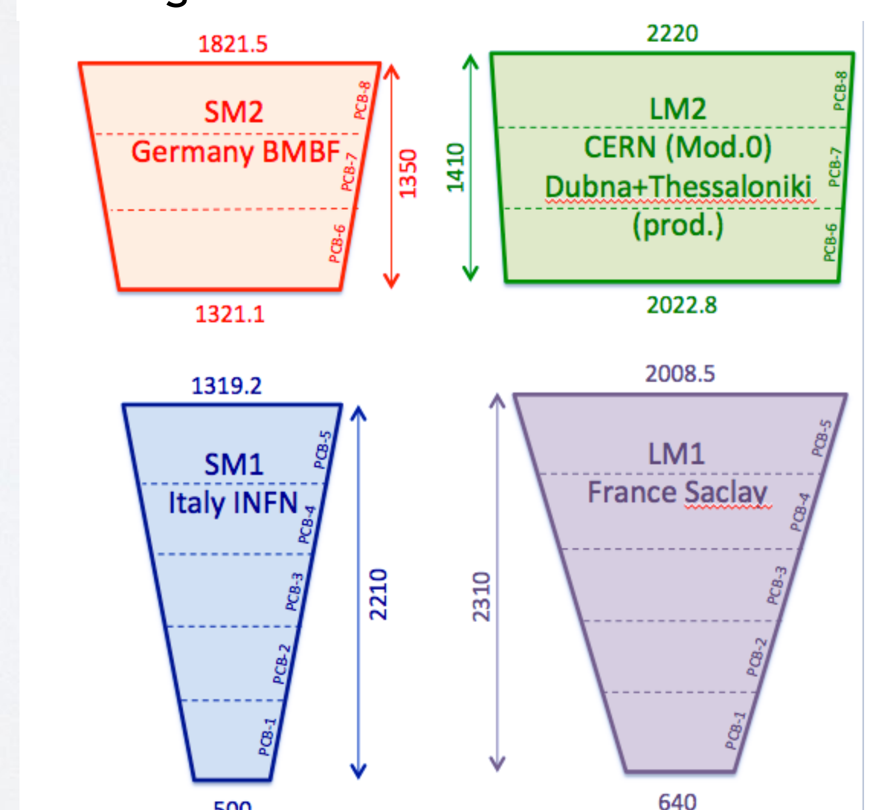
Upgrade of the innermost forward stations of the Muon Spectrometer to preserve same trigger and reconstruction capabilities also at the HL-LHC conditions → **MicroMegas** (MM) and **sTGC** chambers





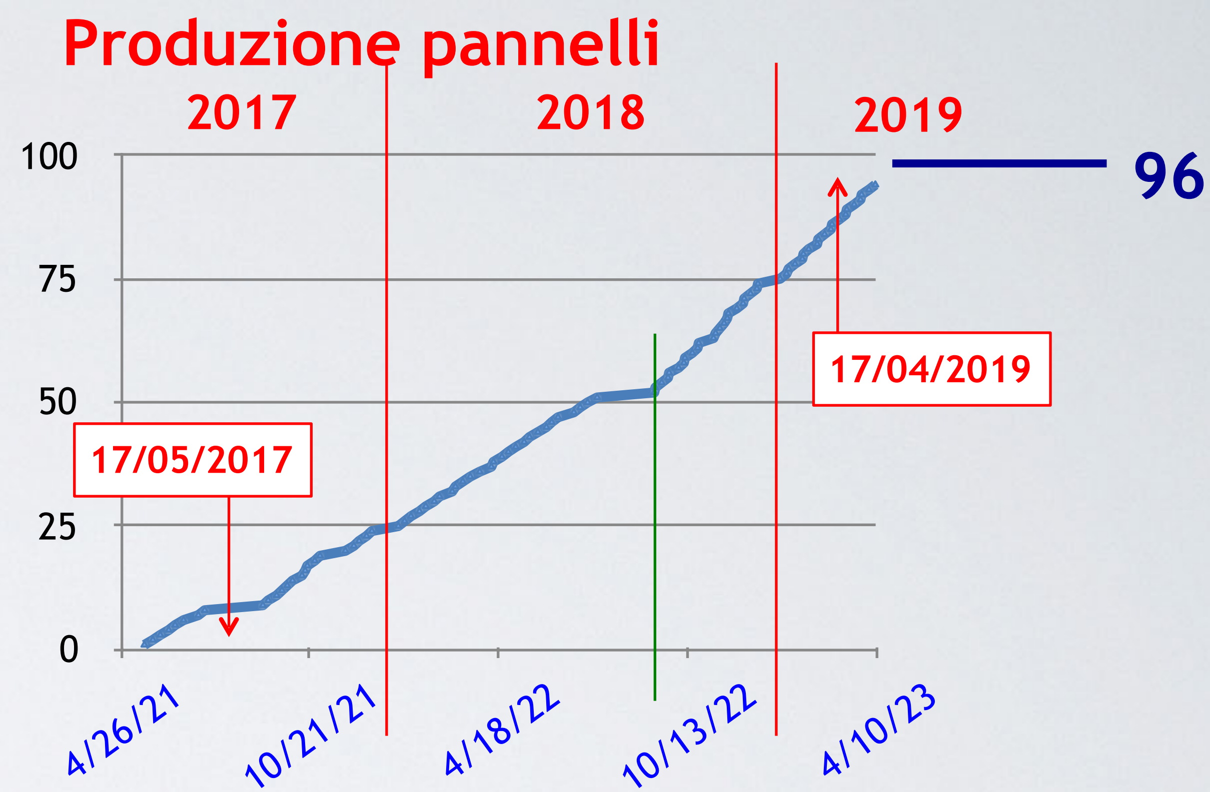
INFN (MoU 2014)	
Construction of 32 SM1 MM chambers	25%
Integration Test & Commissioning	12.8%
Trigger - sTGC PAD coincidence logic	100%
LV power (incl. cables to detector)	28.3%

Sharing of the MM chamber construction



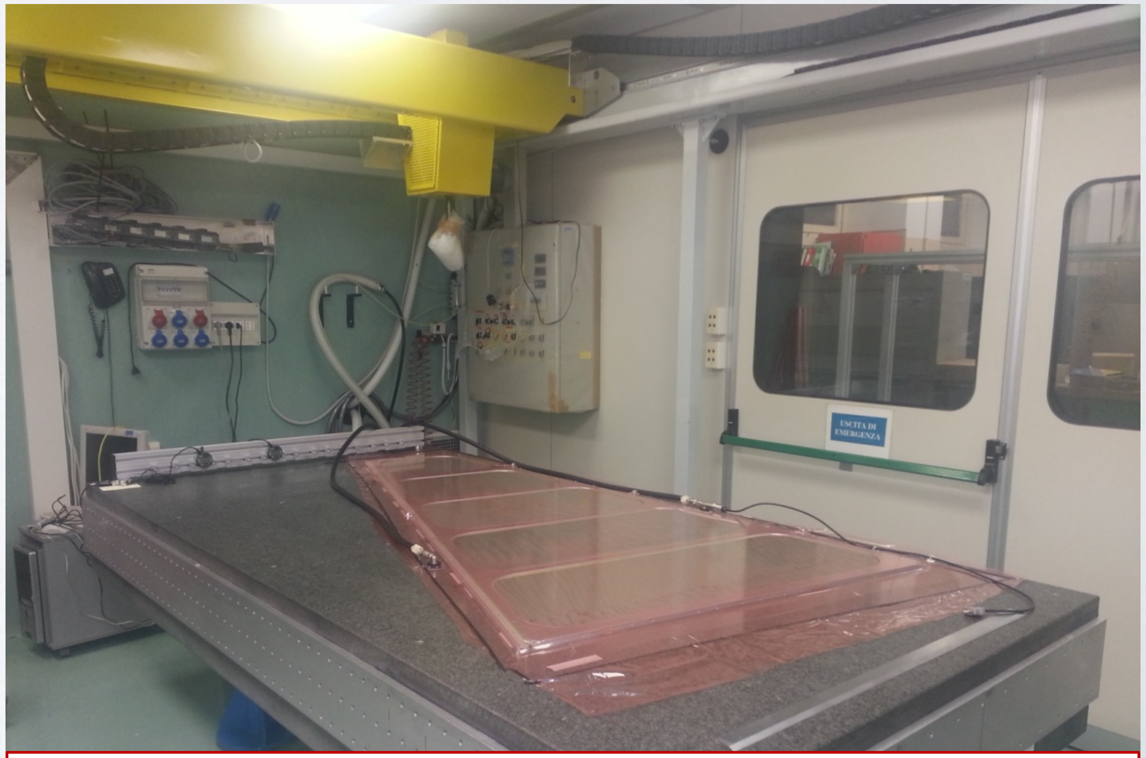
MICROMEGAS - ACTIVITY @ ROMA I

- **Construction of the drift panel of the MM chambers** in the ***Clean Room*** of the ***mechanical workshop***
  - development of the ***Vacuum Bag Technique***
  - production and QA/QC of 96 panels completed in April
  - production of a few spares in July, then the activity will finish



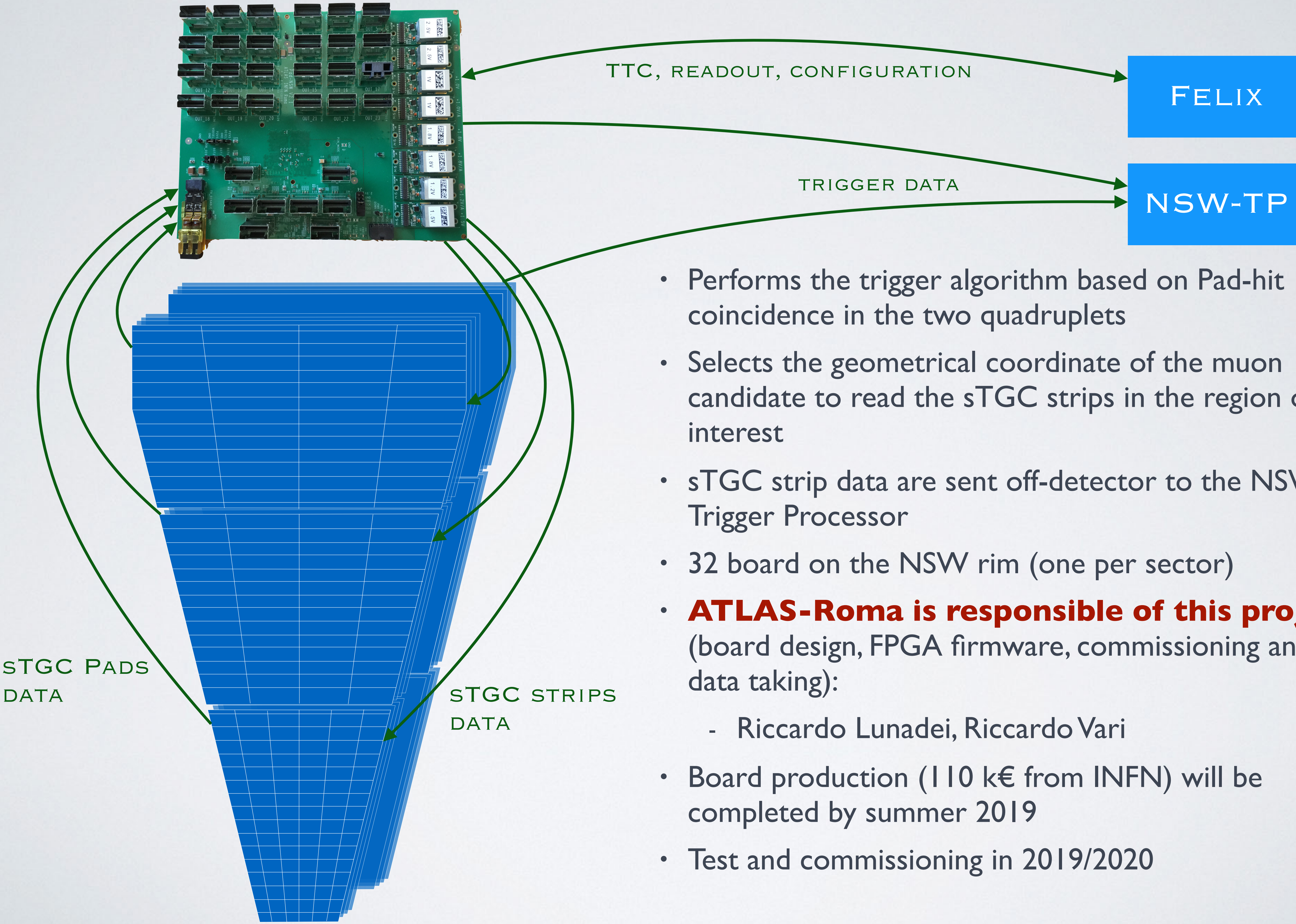
- **Rome I group also contributes to the MM assembling at LFN**
  - tooling
  - mesh gluing
  - cleaning and preparation of the panels for the MM assembling

- INFN-ROMA I group
  - Cesare Bini - MM Italian coordinator
  - Franco Lacava - responsible of activity in the mechanical workshop
  - Fabio Anulli - activity at LNF
  - + contributions from ~ 10 physicists, 3 technicians, 1 mechanical designer



vacuum bag for drift panel assembling

DESIGN AND REALIZATION OF THE TRIGGER BOARDS FOR THE PADS OF THE sTGC CHAMBERS

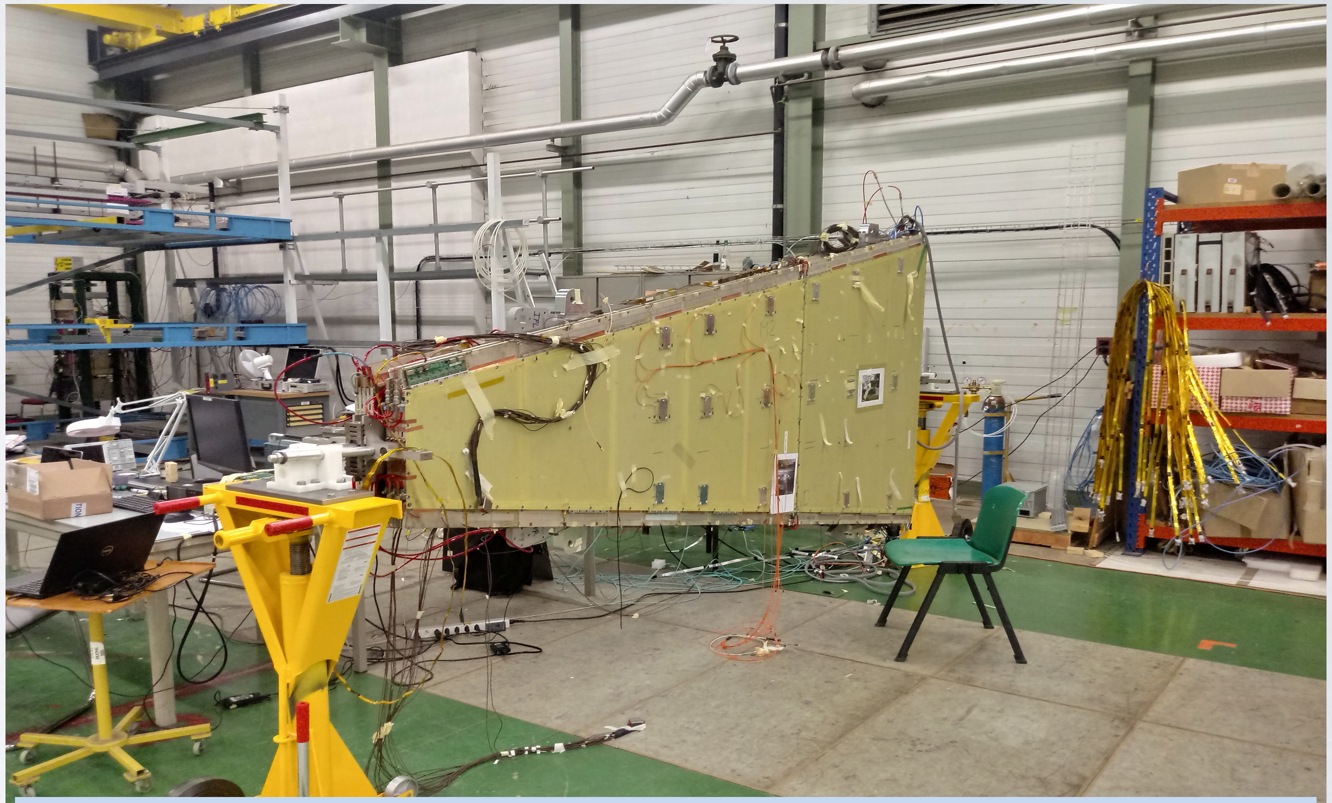


- Performs the trigger algorithm based on Pad-hit coincidence in the two quadruplets
- Selects the geometrical coordinate of the muon candidate to read the sTGC strips in the region of interest
- sTGC strip data are sent off-detector to the NSW Trigger Processor
- 32 board on the NSW rim (one per sector)
- **ATLAS-Roma is responsible of this project** (board design, FPGA firmware, commissioning and run data taking):
  - Riccardo Lunadei, Riccardo Vari
- Board production (110 k€ from INFN) will be completed by summer 2019
- Test and commissioning in 2019/2020

STATUS OF THE NSW PROJECT AND PROSPECTS FOR THE ROMA 1 GROUP

- Installation of the NSW-A during LS2 and of the NSW-C during the EYETS 2020-2021
- Tight schedule
- Delivery of MM chambers to CERN: INFN 8/32, other sites are behind (some critical issues)

Mechanical structures of the two wheels


The first Double-Wedge (4 chambers) at BB5

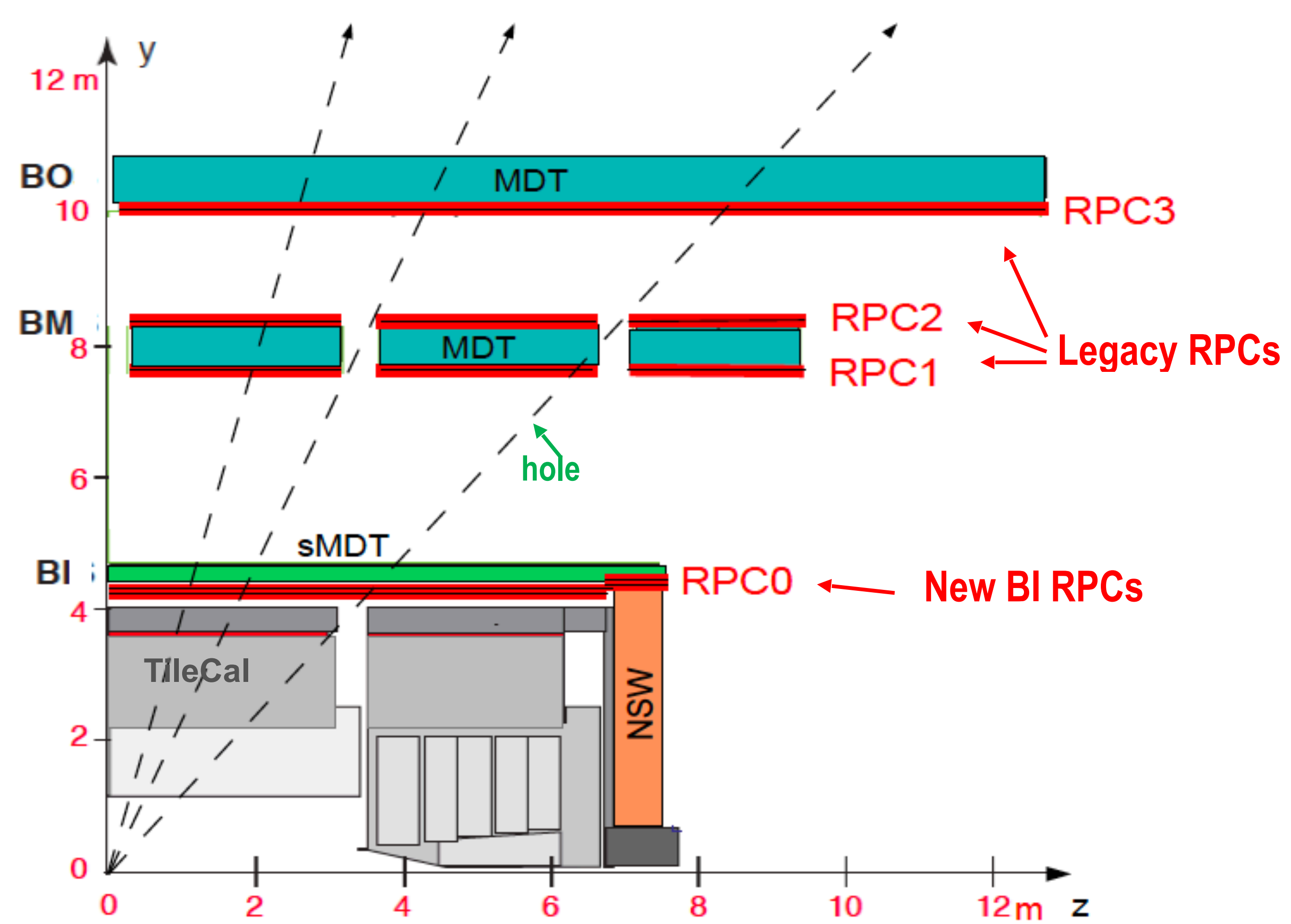
- **<u>Rome 1 group intends to intensify its participation to the following activities:</u>**
  - chamber assembling and validation at LNF → summer 2020
  - chamber integration at CERN → ~ summer 2021
  - detector and trigger commissioning → Run3

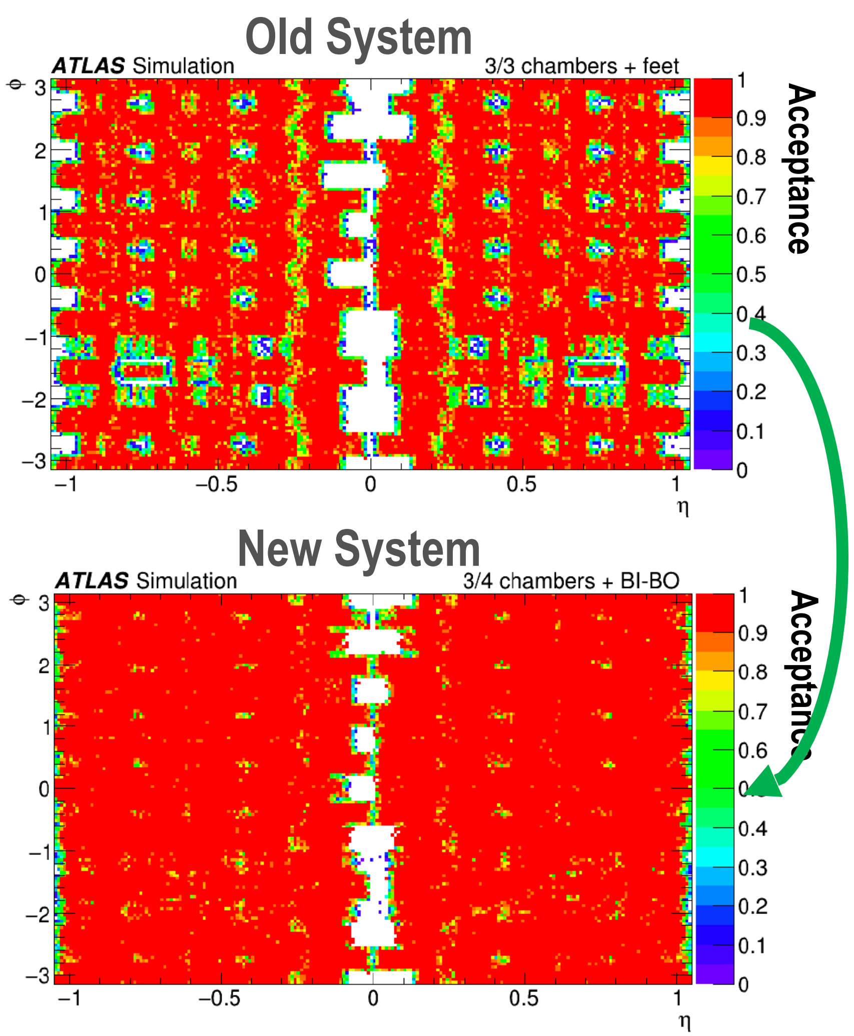
ATLAS: L0 MUON BARREL TRIGGER UPGRADE - PHASE 2

ATLAS will rebuild completely the trigger system, building a single hardware trigger level (L0) with 1 MHz output.

The new L0 Muon Barrel trigger will have three main new features:

- A new Barrel-Inner (**BI**) layer of **RPC** triplet chambers, to recover **acceptance** holes caused by support structures and to add **robustness** against reduced efficiency of the legacy RPCs (that will be operated at reduced HV to avoid ageing limitations)
- All the hits will be sent off-detector to the FPGA-based processors, to allow for more sophisticated algorithms (see e.g. **NN implementation on FPGA** in backup) and more **flexible** logic to adapt to running conditions and physics requirements (e.g. **triggers for Long Lived Particles**).
- Hits from the precision **MDT** chambers (Drift Tubes) and the Tile Calorimeter will also be used in the L0 trigger to confirm candidates from RPCs and improve the **momentum resolution** (sharper p_T thresholds, possibility to cut on invariant mass for di-muons)

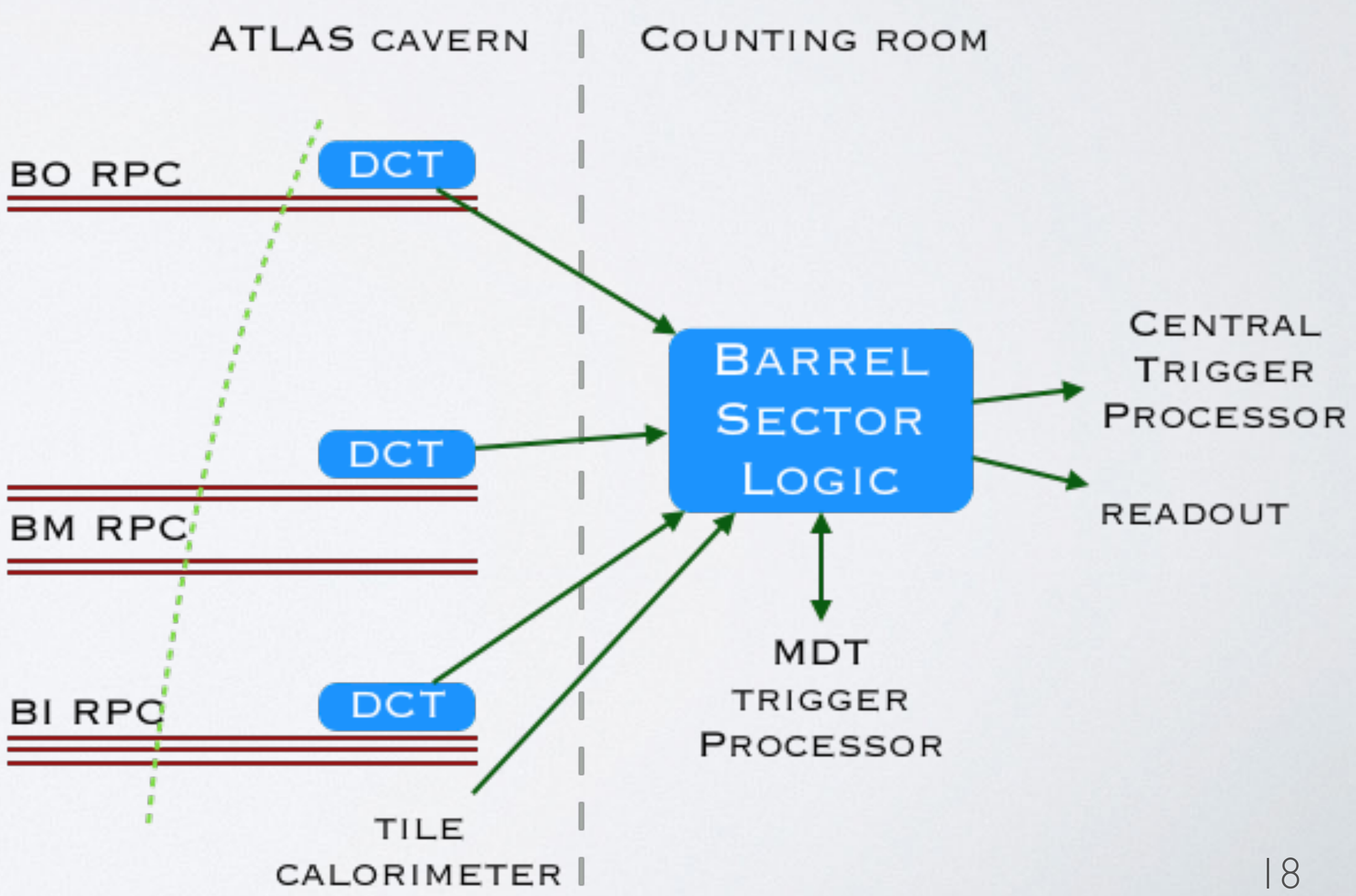




ATLAS L0 MUON BARREL TRIGGER SYSTEM

- The 32 Sector Logic (SL) boards (one per each sector), 1096 Data Collector and Transmitter (DCT) boards (~35 per sector)
- DCT total cost: 3.75 MCHF (75% INFN, 25% Greece)
- SL total cost: 1.02 MCHF (100% INFN)
- **Roma 1 is responsible of the full L0 Muon Barrel project**
  - Trigger algorithm simulation and performances studies
  - Boards design and production
  - FPGA firmware development
  - Installation and commissioning
  - DAQ and monitoring software and run data taking
  - Offline software

- A small part of the BI RPC layer will be installed in the current shutdown (phase 1): the BI7/8 chambers (<10% of the total BI)



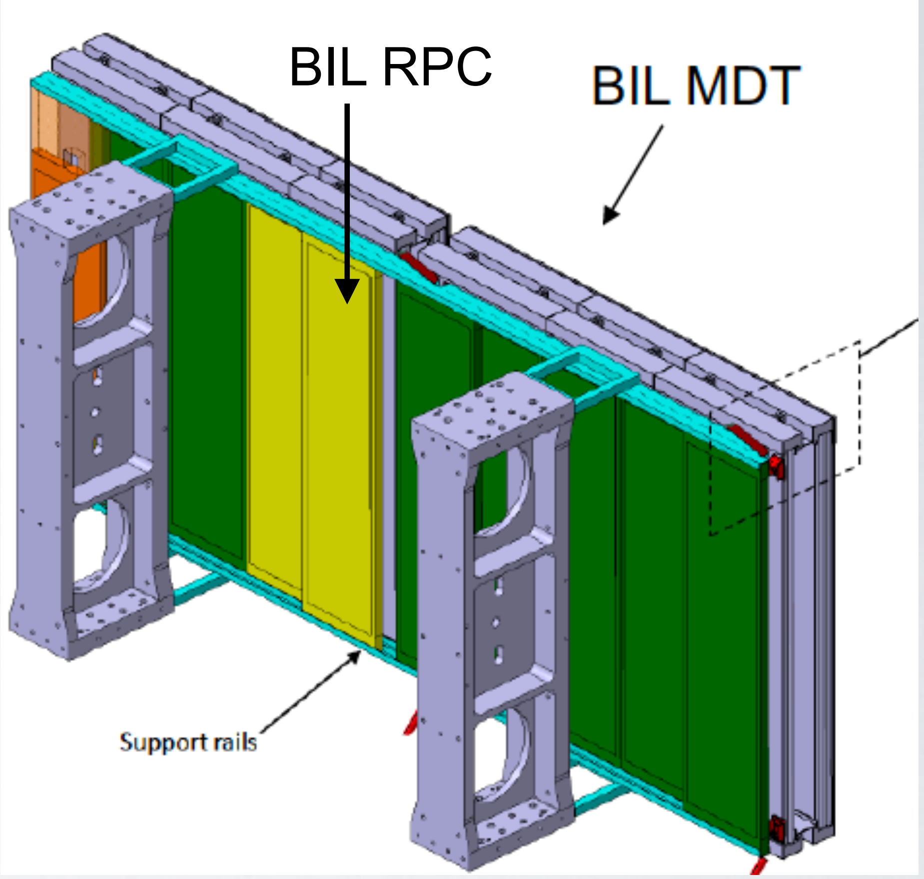
ATLAS L0 MUON BARREL TRIGGER - RESPONSIBILITIES, RESOURCES AND WORK PLAN

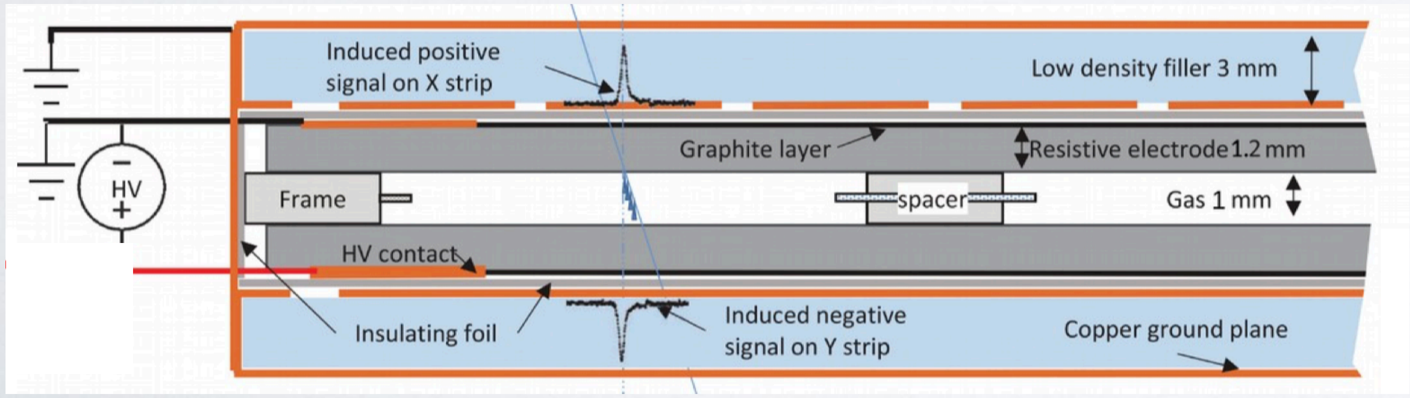
- DCT and SL Specification Documents ready by summer 2019
- DCT and SL prototypes and Preliminary Design Review by early 2020
- Production completed in 2023
- DCT Installation time is 2 years, can be done if 50 DCTs per month are installed, requires at least two people full time in the cavern
- INFN - Roma 1 people:
  - Massimo Corradi - Simulation, performance studies (+ Muon Upgrade Project Leader)
  - Simone Francescato (PhD) - Barrel Sector Logic firmware and simulation
  - Stefano Giagu - Artificial Intelligence algorithms, offline SW
  - Iacopo Longarini (PhD) - DCT firmware and simulation
  - Federica Riti (thesis) - Artificial Intelligence trigger algorithms
  - Claudio Luci - DCT design, services (+ L1 Muon Barrel responsible, Muon Run Coordinator)
  - Riccardo Lunadei (technician) - Electronics design, testing, installation BIS78
  - Antonio Policicchio - Simulation and offline SW
  - Stefano Rosati - Offline SW (+ Muon Software Coordinator)
  - Luigi Sabetta (PhD) - Artificial Intelligence trigger algorithm studies
  - Francesco Safai - DAQ software
  - Cristiano Sebastiani (PhD) - DCT firmware and simulation
  - Riccardo Vari - L0 Muon Trigger responsible, electronics design, firmware BIS78 (+ NSW Pad Trigger responsible)
  - Stefano Veneziano - (+ TDAQ Project Leader)

	Bologna	Napoli	Roma1	Roma2	Greece	Japan
Simulation & Performances	x		x			
Design & production			x	x		x
Firmware		x	x			
Installation & Commissioning			x			
Testing			x		x	
DAQ & Run data taking	x		x			
Monitoring		x	x			
Offline software	x		x			

NEW RPC CHAMBERS

- Contributing to the design of the layout of the new BI RPC chambers with the help of the mechanical design service (M. Corradi, T. Zullo)
    - the challenge is to fit new RPCs in the small gaps left free in the original system
- **Evaluating the possibility to take a responsibility in the construction of the new BI RPC chambers**
    - The BI upgrade involves Institutes from Italy, Germany, China, Hong Kong, Russia and Turkey
    - INFN has a 33% share, most of the know-how and of the project responsibility, but relatively limited human resources (Roma-2, Bologna, Cosenza)
        - a contribution from us would be very welcome… And of course we are very interested that these chambers work well, as they are the basis of the trigger system



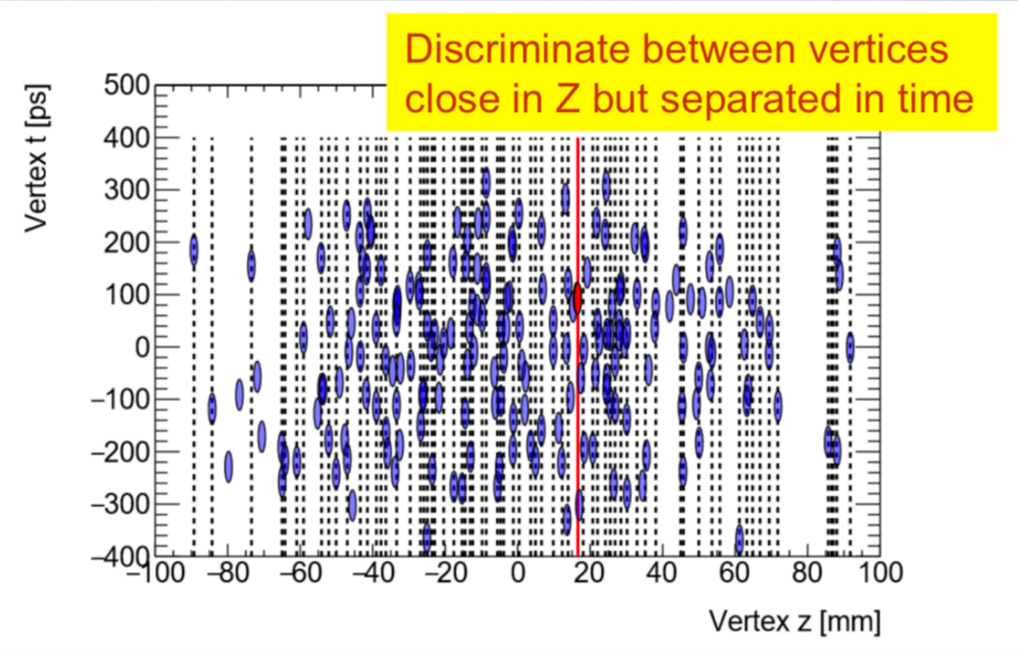


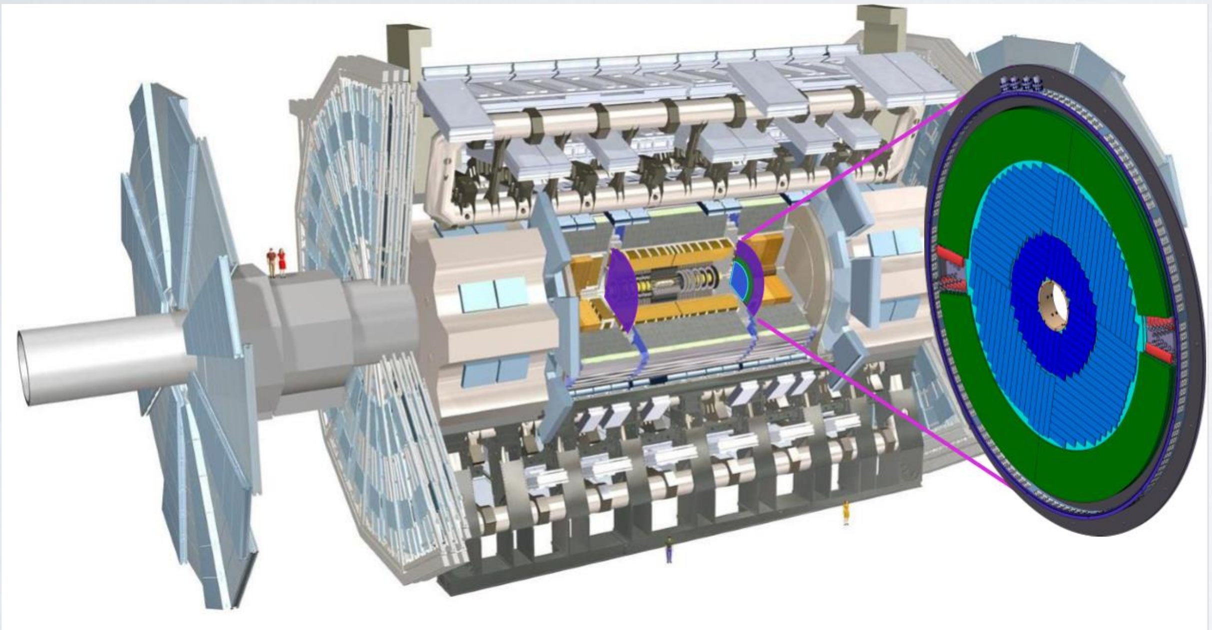
1mm gap bakelite RPCs that exploit modern low-noise FE electronics to gain in rate capability, spatial and timing resolution (~1 mm, ~400 ps)

A very interesting technology that has been proposed for experiments at future colliders

ATLAS: HIGH GRANULARITY TIMING DETECTOR - PHASE 2

- The pileup density is larger than the longitudinal resolution of ITk (the new ATLAS tracker) in the end-cap region (pseudo rapidity > 2.4)
    - ITk longitudinal track impact parameter resolution in this region from 0.5 to 2 mm for a 5 GeV track: insufficient to assign tracks to vertices in an unambiguous way





- An innovative detector with low occupancy <10% (*High Granularity*) and time resolution < 30 ps per track (*Timing Detector*) is proposed in the forward region
    - LGAD (Low Gain Avalanche Detector) silicon sensors, 1.3x1.3 mm^2 size with intrinsic time resolution of ~50ps (before irradiation)
    - Two(three) hits per track in the 2.4 <|η|<3.1 (3.1<|η|<4.0) region
    - Time resolution < 30 ps per track

- Italian groups already involved in R&D and performance studies: Milano, LNF
- **Expression of interest from Rome 1 in module assembling and test**
    - 2020 - join the project
    - 2022-2023 - production
    - resources: 3 physicists + 2 technicians, 1 engineer (possible outsource), clan room, automatic wire-bonding machine (possible outsource)

SUMMARY

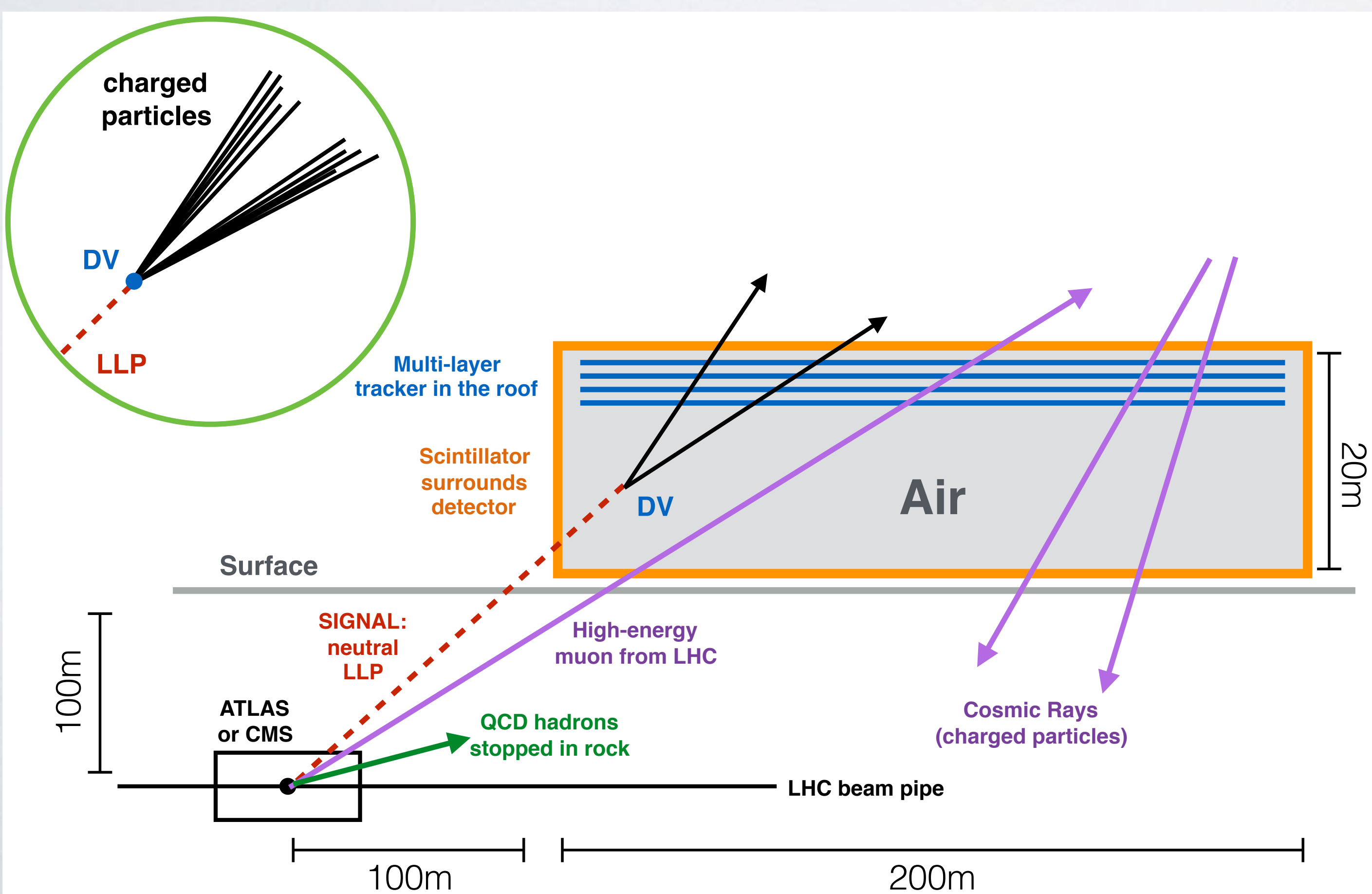
	Phase 1	Phase 2
LHCb	Monitoring electronics and FE configuration and software for muon spectrometer upgrade	Test and construction of µRwell chambers
	Online luminosity measurement	
CMS		Barrel timing detector: in charge of choosing crystal producer; full-fledges crystal characterization @ Segré
		Barrel ECAL: in charge of testing, ordering and maintaining new HV system; contribute to designing and building second enfourneur
ATLAS	NSW: construction of the drift panels for the SM1 module of the MM chambers and assembling activity at LNF; design and realization of the pad trigger board for the sTGC chambers	L0 Muon Barrel project: responsible of the project
	NSW: chamber integration at CERN, test of the trigger boards at CERN, software and firmware development; detector and trigger commissioning	New BI RPCs: take a responsibility in the construction of the chambers
		HGTD: contribute to module assembling and test

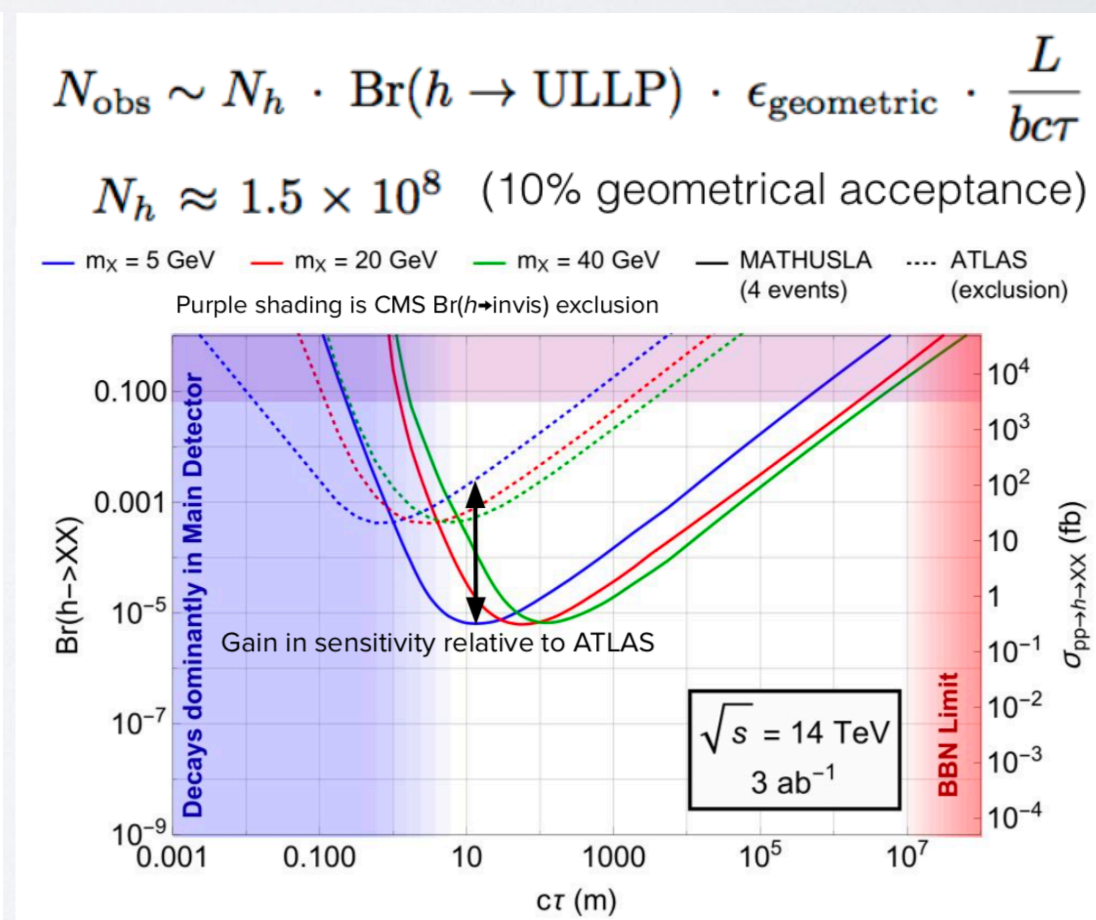
*expression of interest

EXTRA

MATHUSLA

- Use HL-LHC to explore the lifetime frontier set by Nucleosynthesis after Big Bang (BBN) at $c\tau \lesssim 10^{7\text{-}8}$ m
- With LHC detectors after HL-LHC (~3ab^{-1}) reachable upper limit is ~10^3m → **need a detector really far away from interaction point, with no background** to access lifetimes at the BBN limit
- **MATHUSLA**: **MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutra**L** p**A**rticles
  - a large **surface (10% geometrical acceptance), 20m hight detector to be installed at the ground level over ATLAS/CMS detector**
  - **top surface instrumented with a tracking system (RPC or polystyrene scintillator strips, with ~1cm and <1ns resolution), scintillators surround the detector**
  - observe tens of long-lived neutral particles decaying in the detector volume with lifetime at the BBN limit in ~3ab^{-1}
- **Proposal presented to LHCC and European Strategy** (CERN-LHCC-2018-025 and arXiv:1901.04040)
  - Roma2 and Lecce involved in the project
  - Roma 1: Antonio Policicchio (tracking, RPC data unpacking for test stand)
  - Henry Lubatti is currently visiting professor @ Sapienza





BACKUP

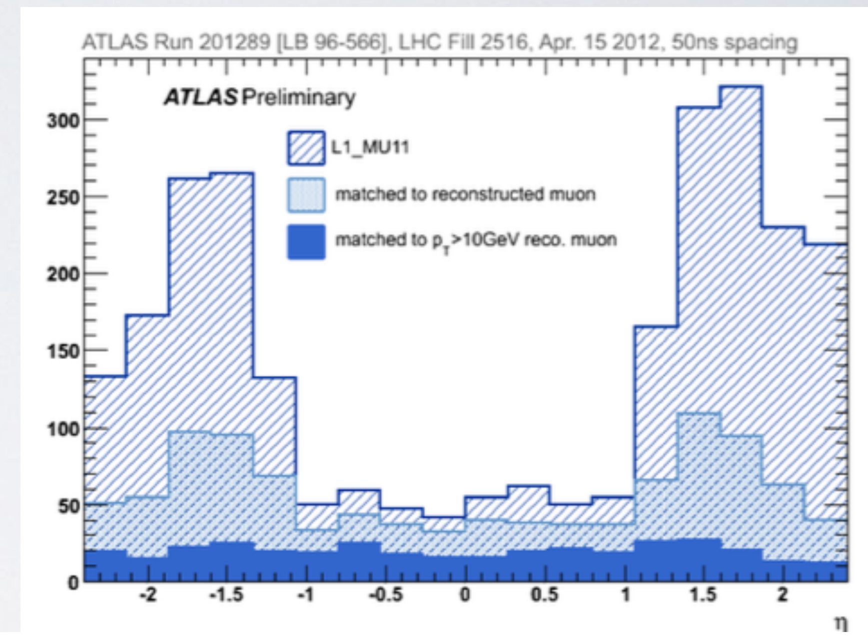
ATLAS - NSW

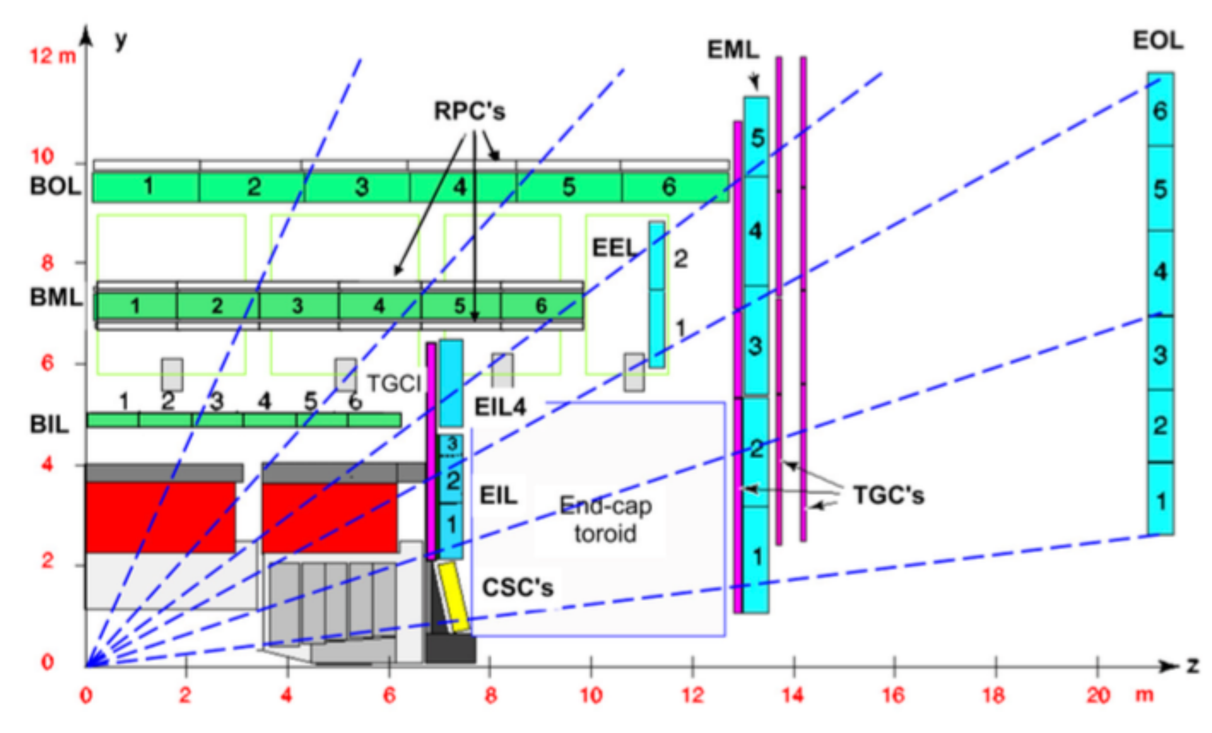
ATLAS MUON SPECTROMETER UPGRADE

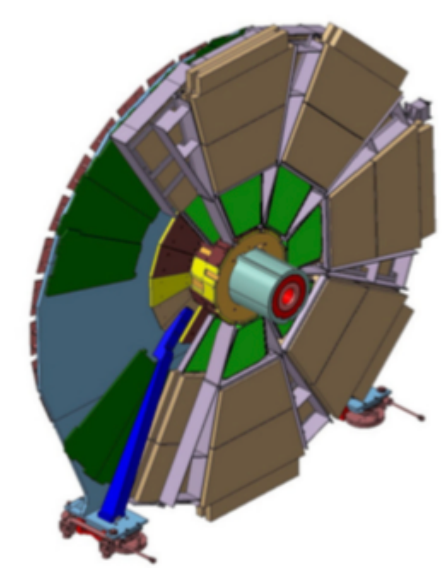
- Muons in final state → distinctive signature for many physics processes which led to the discovery of the **Higgs boson** and searches for **new phenomena**
- High background rate as high as ~15 kHz/cm^2 s can be reached in the most forward region at luminosities between 2 and 7×10^{34}cm^{-2}s^{-1}, during LHC Run-3 and HL–LHC → new detector technologies needed as MDTs can support rate of 510-770 Hz/cm^2
- Moreover fake muon trigger rate needs to be reduced (it is as high as 60Hz (75Hz allowed at L1!): add a second trigger measurement in endcap will reduce enormously the fake rate

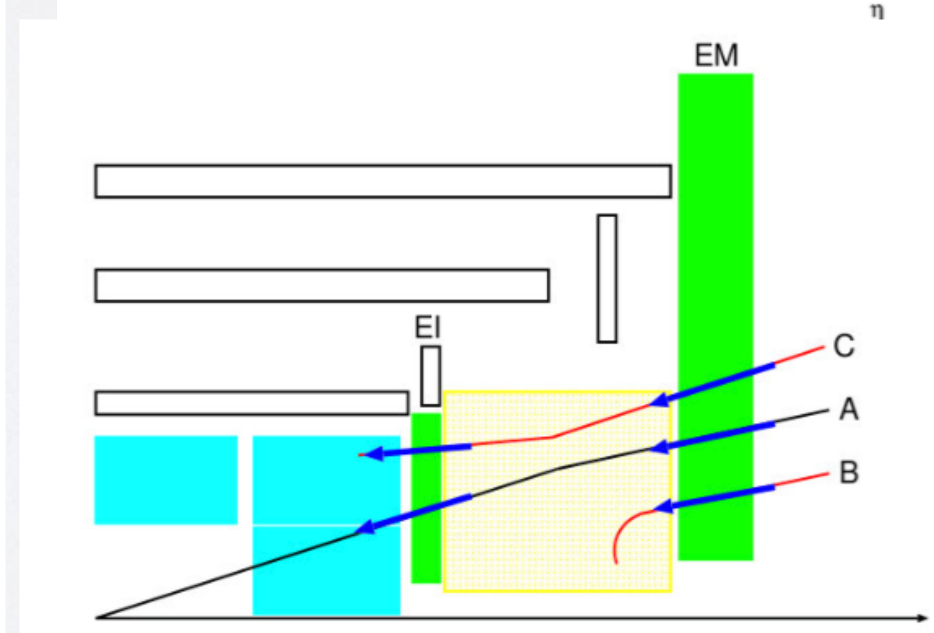
- Characteristics of the replacement detectors:
  - cope with high charged particle flux (15kHz/cm^2) in variable magnetic field
  - <100μm spatial resolution (with incidence angle of 45°)
  - good time resolution ~4-5 ns
  - able to provide online (trigger) segments with a 1 mrad accuracy
  - high radiation hardness

→ Combination of sTGC and MicroMegas detector planes









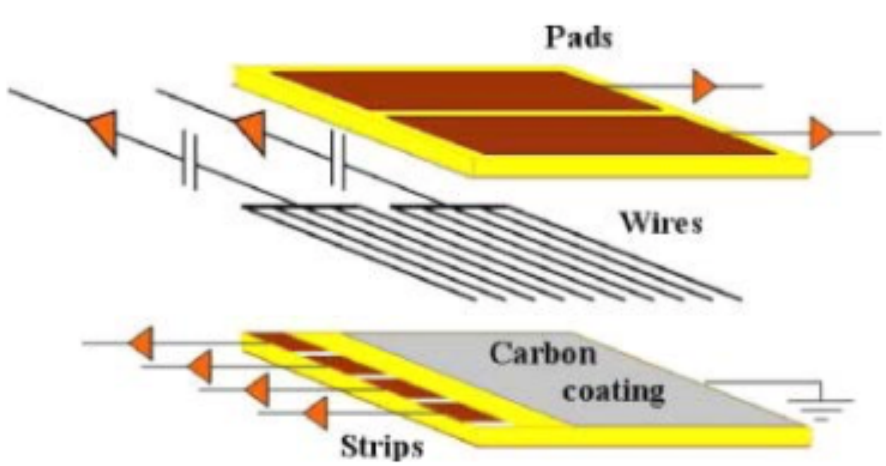
sTGC and MicroMegas

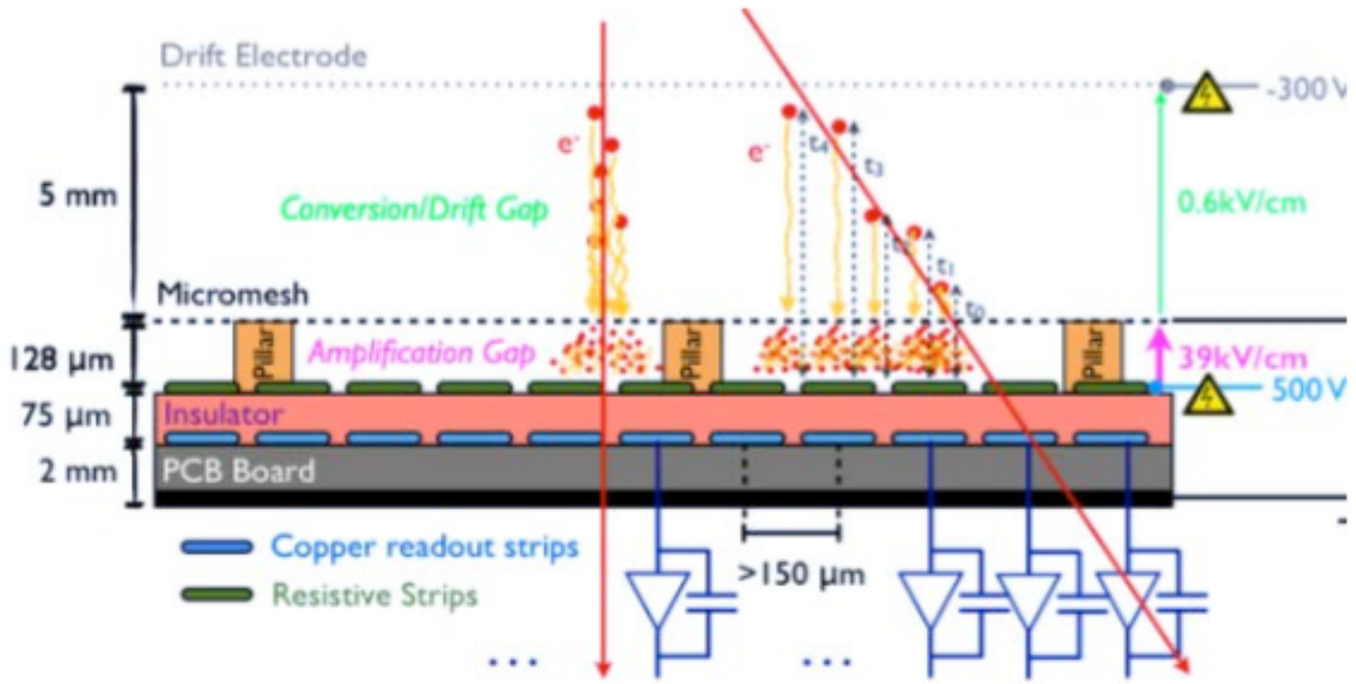
Small Strips TGC (sTGC)
primary trigger detector

- Bunch ID with good timing resolution
- Online track vector
  with <1 mrad angle resolution
- pads: region of interest
- strips: track info (strip pitch 3.2 mm)
- wire groups: coarse azimuthal coordinate

MicroMegas (MM)
primary precision tracker

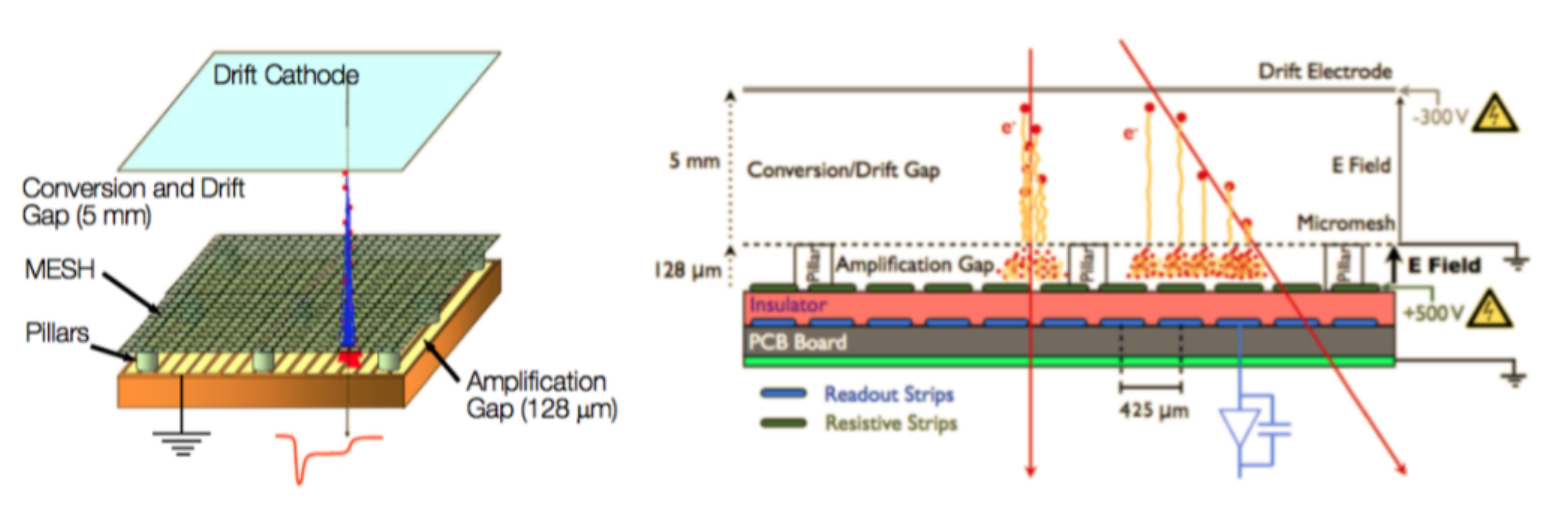
- Good Spatial resolution < 100 µm
- Good track separation (0.4 mm readout granularity)
- Resistive anode strips → suppress discharge influence on efficiency
- Provide also online segments for trigger





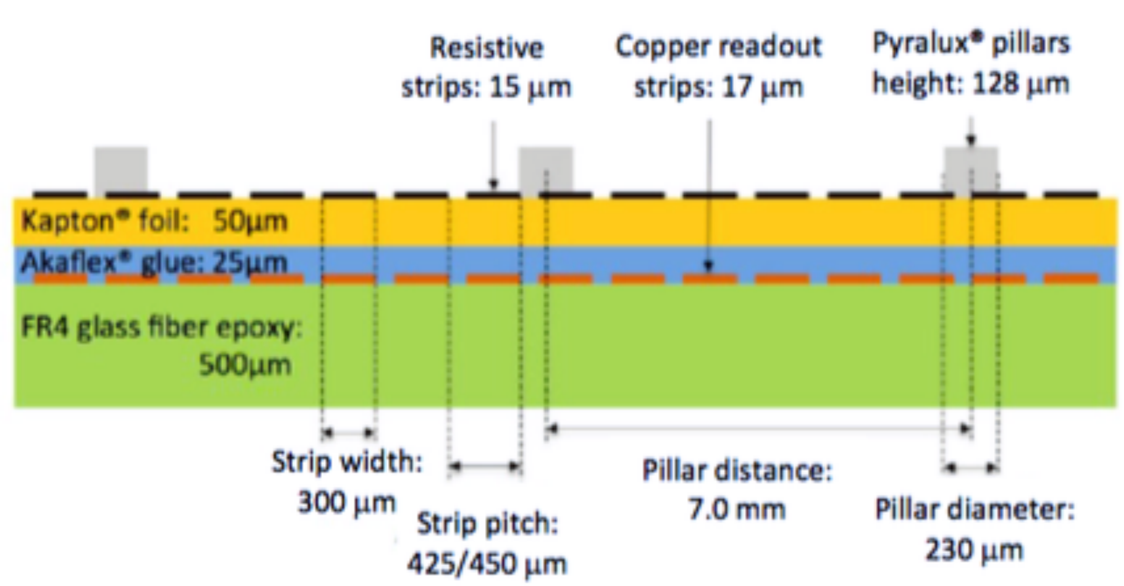
MicroMegas (I)

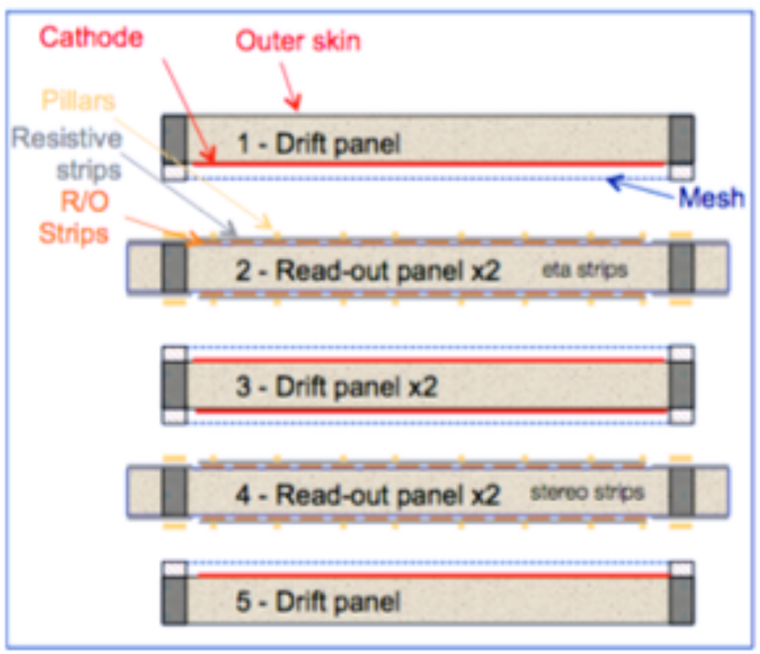
- A MM consists in two gas gaps electrically separated by a metallic mesh: a few mm conversion and drift gap, where charged particles ionize the gas (Ar:CO_2,93:7), and a very thin gap (128 μm) for the amplification, where the avalanche of electrons is produced and collected on the resistive strips
- The resistive strips serve as protection to minimize the effect of sparks by limiting the spark currents
- Signals are induced via capacitive coupling to the readout strips

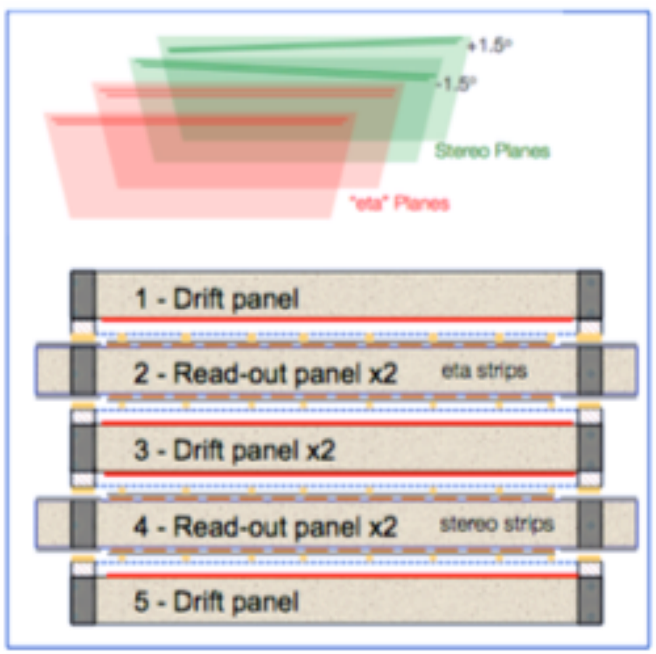


MicroMegas (II)

- The basic element of the resistive MM structure is the anode (or readout) board.
- This is produced starting from a 0.5 mm thick FR4 printed circuit board (PCB) with etched copper strips, on which a 50 μm thick Kapton^R foil is glued, comprising carbon resistive strips deposited by screen printing
- Typical values of the local resistivity are in the range of 10-20 MΩ/cm
- A pattern of 128 μm high pillars with a diameter of 300 μm is created using photolithography
- The pillars are required to hold the metallic mesh at the correct distance from the strips, in order to form the amplification gap
- All readout boards have trapezoidal shapes. Depending on the module type and PCB position, the readout board dimensions vary from 40 cm up to 2 meters, with a constant height of about 45 cm. There are 1022 strips per board, with a pitch of 425 (450) μm for small (large) modules
- To form the MM quadruplets, the readout boards are assembled on two readout panels
- A MM quadruplet consists of three drift panels, two readout panels and four gas gaps, created by spacer bars around the detector perimeter
- The readout boards are disposed in a “back-to-back” configuration on the readout panels: one of them is equipped with eta-strips (parallel to the bases of the trapezoid), while the readout boards with stereo strips are assembled in the second panel
- The drift panels integrate the copper cathode plane, the meshes, and the gas distribution system; one central double sided and two external drift panels, sustaining the stainless steel mesh, are coupled to the two readout panels to form the four gas gaps. In each gas gap the mesh separates the drift and amplification gaps, of 5 mm and 128 μm, respectively

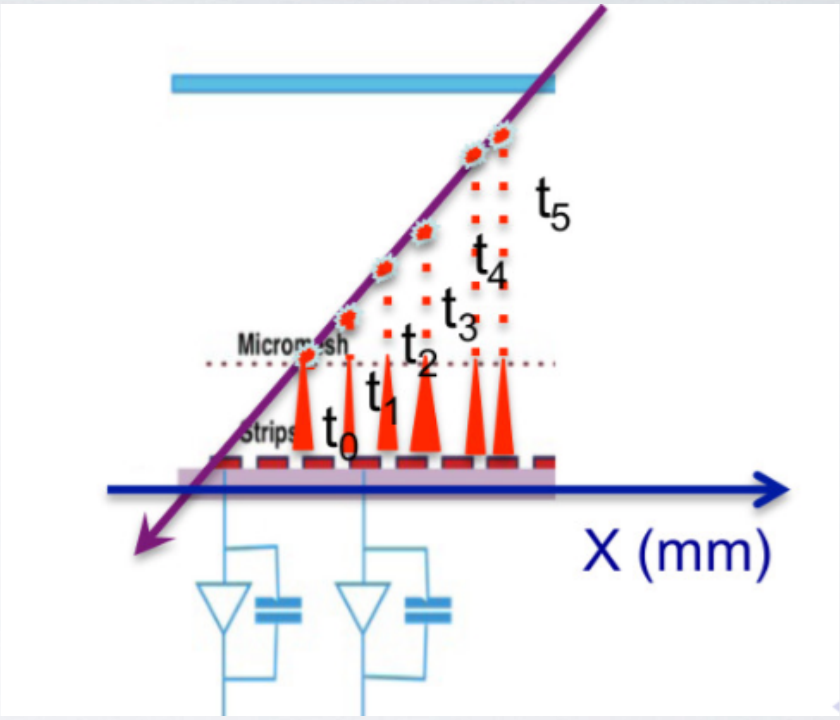


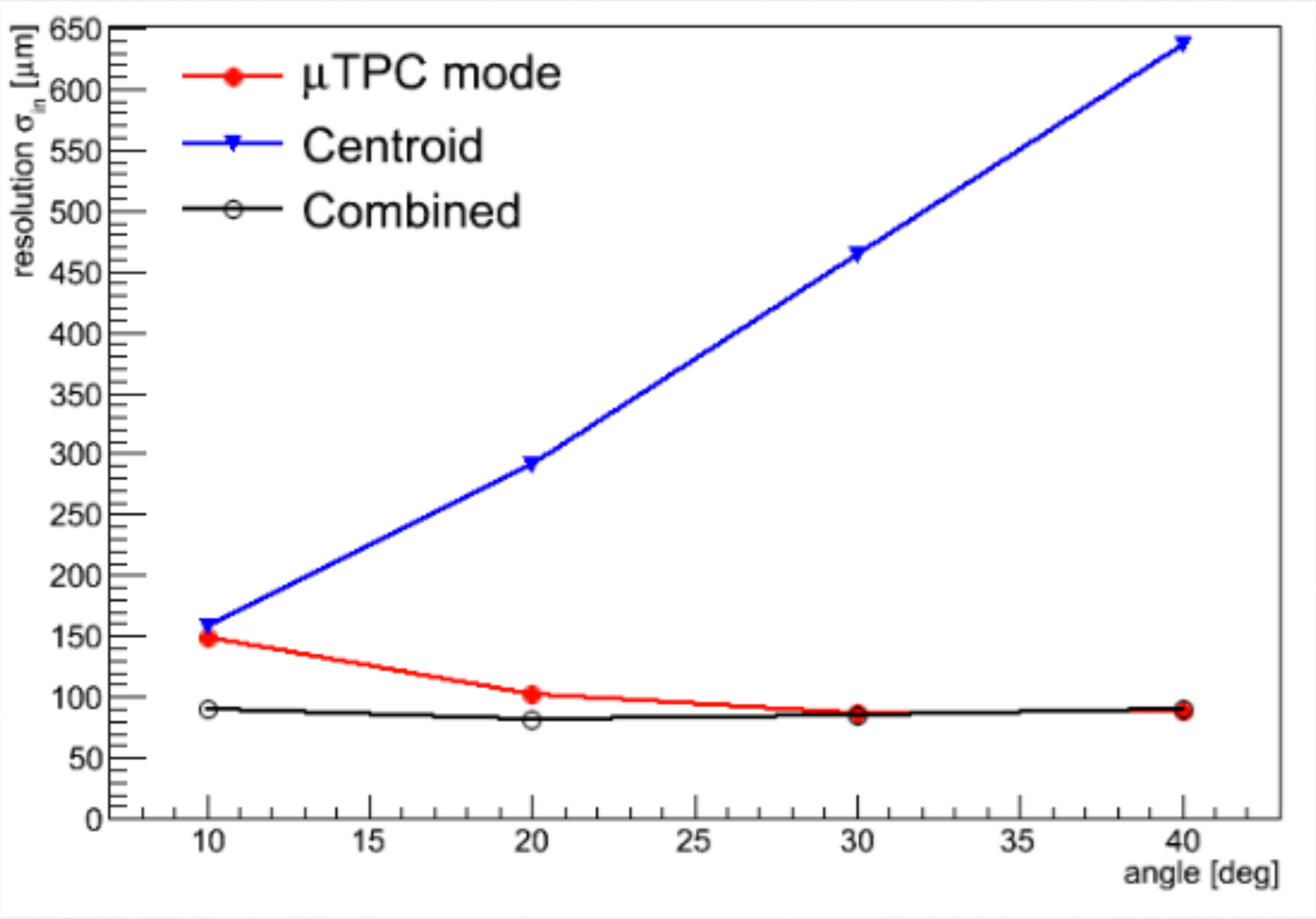




MicroMegas: PERFORMANCE

- High radiation hardness
- Time resolution: 2-5 ns
- Space resolution: <100 μm for 90° crossing particles
- For different angle the micromegas can be used as a micro-TPC (μ-TPC)





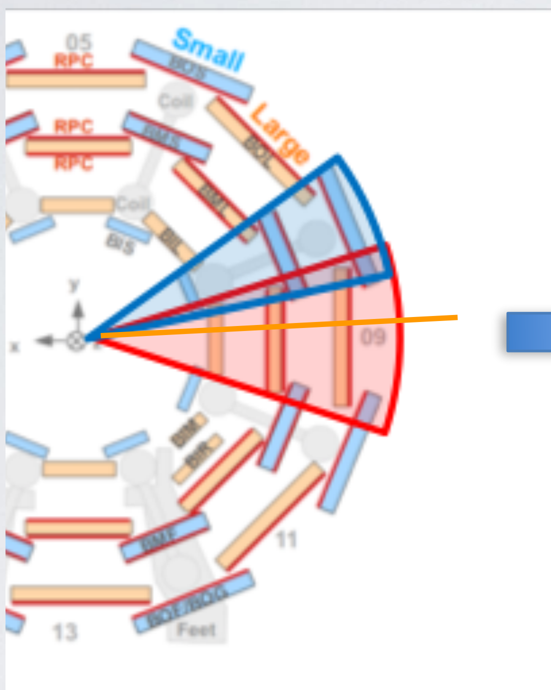
ATLAS - L0 TRIGGER

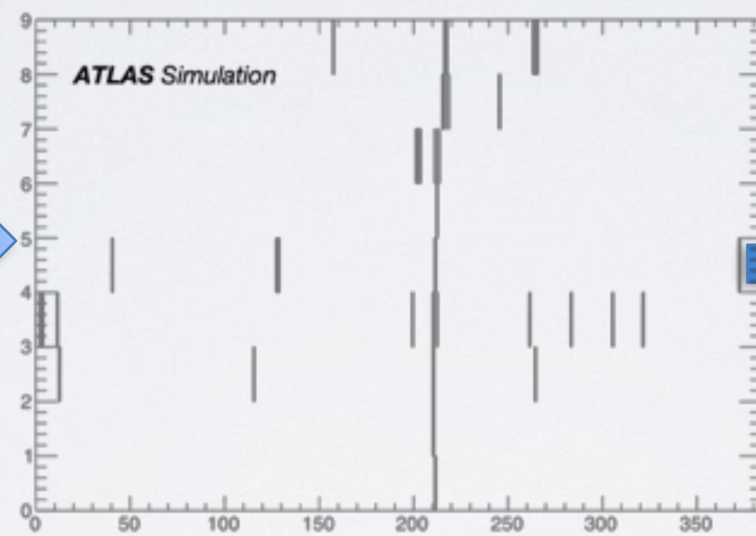
ATLAS L0 MUON BARREL TRIGGER - USE CASE

Neural Networks on FPGA

- Exploiting the new **FPGA** processor is possible to use a fast **ternary Convolutional Neural Network (tCNN)** for the **Level-0 muon trigger**

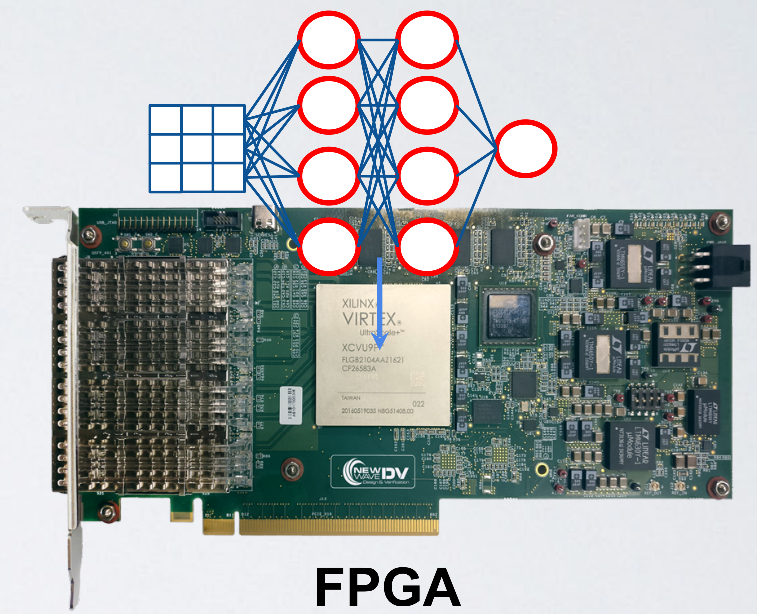
Input
RPC strips arranged in an image-like matrix
(9 gas gaps x 384 η intervals)





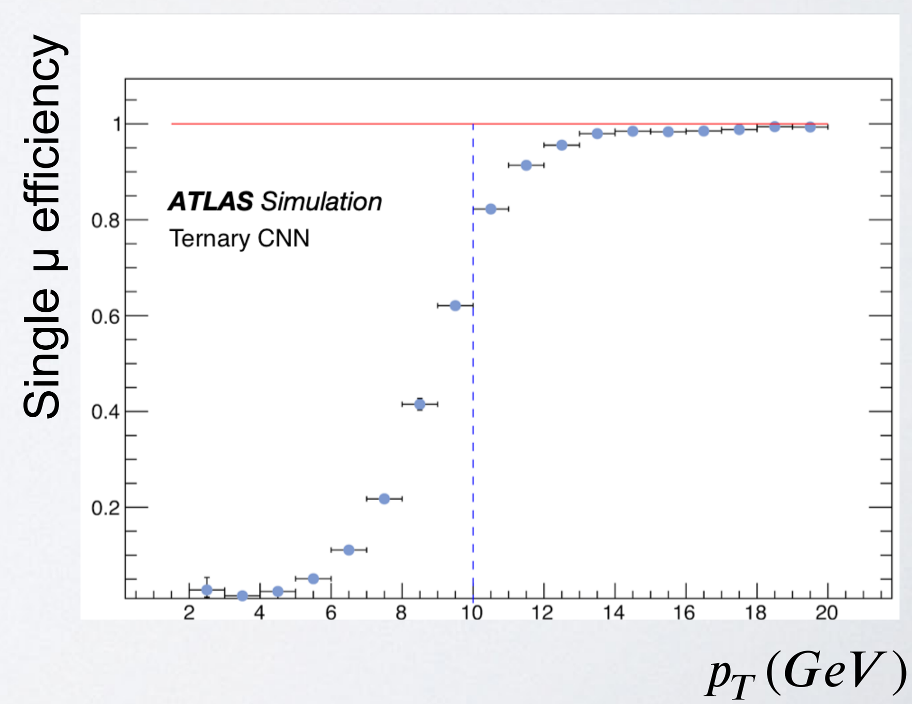
η sector image

Output
Regression on
- p_T of leading and subleading muons
- η of leading and subleading muons
- number of muons



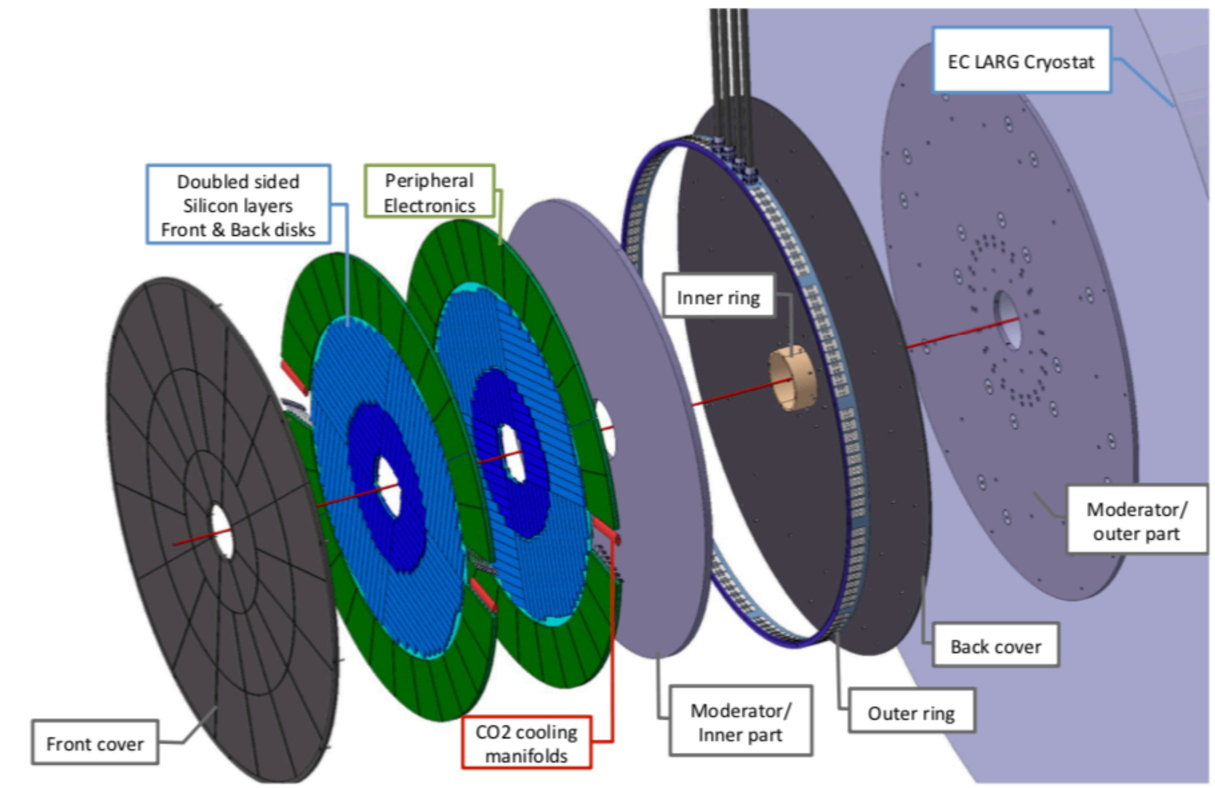
FPGA

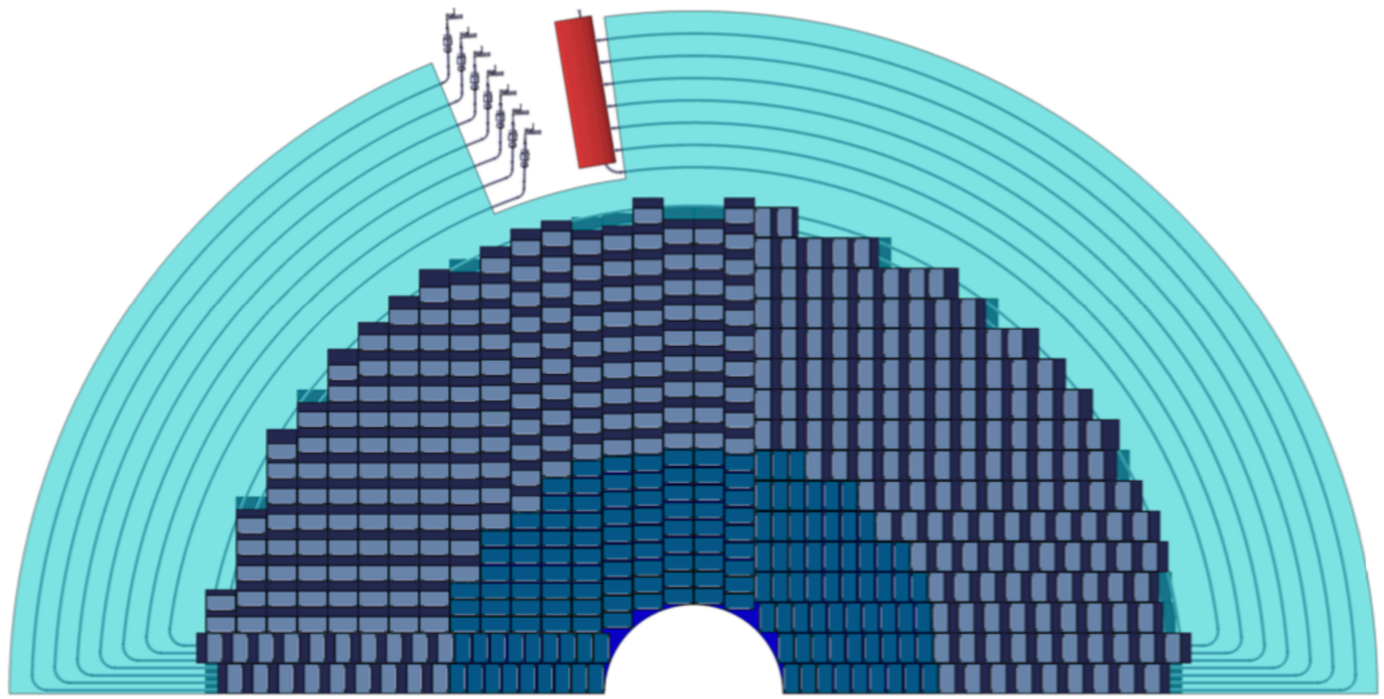
- Good performance on physical quantities obtained
- Working on synthesis and implementation of FPGA firmware



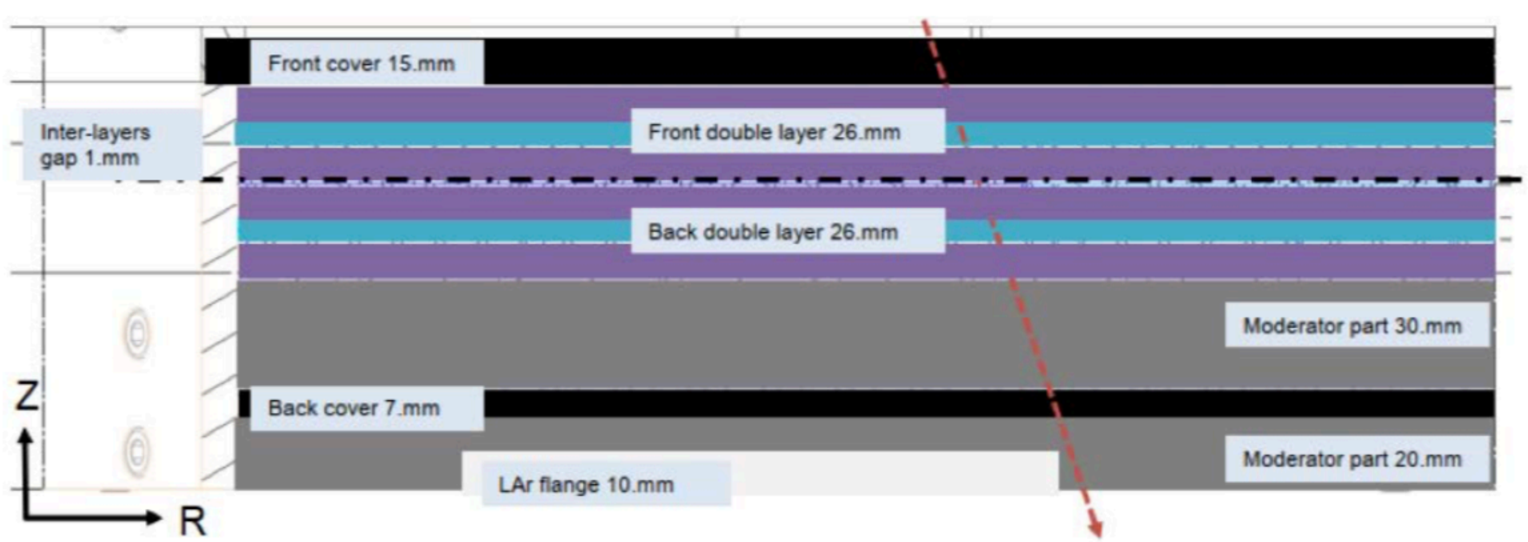
ATLAS - HIGH GRANULARITY TIMING DETECTOR

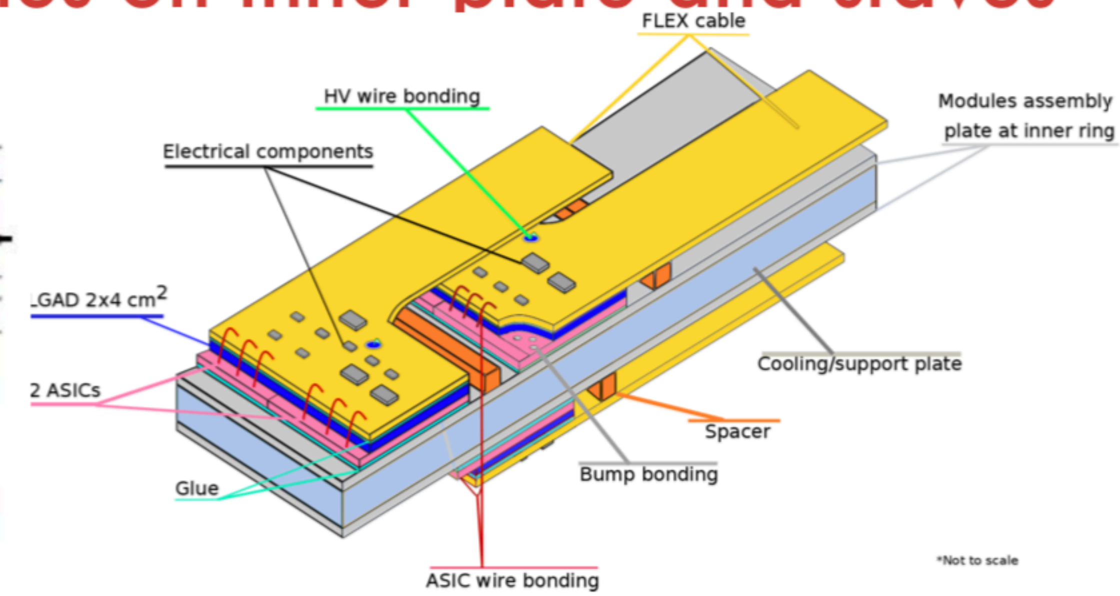
DETECTOR DESIGN





Modules on inner plate and staves

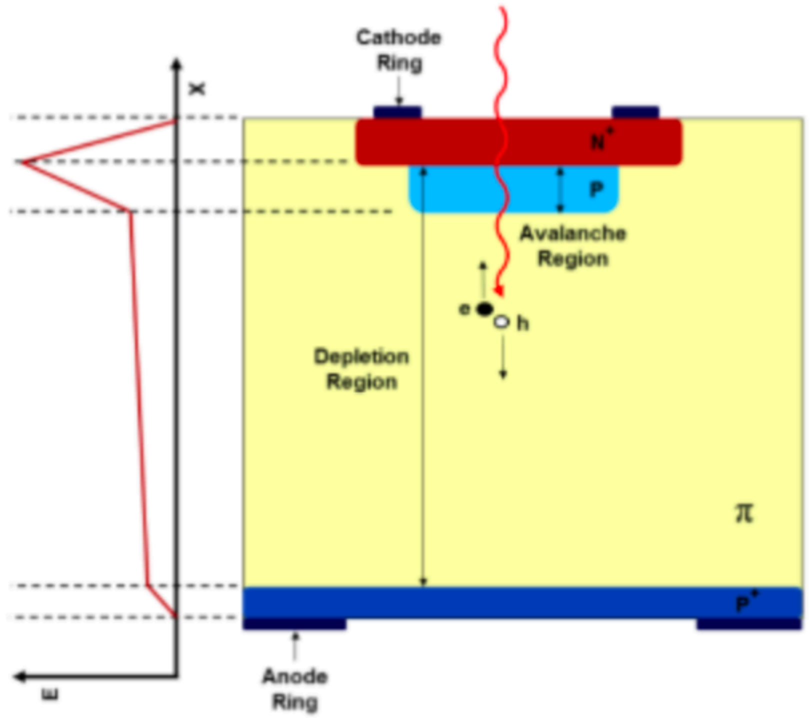


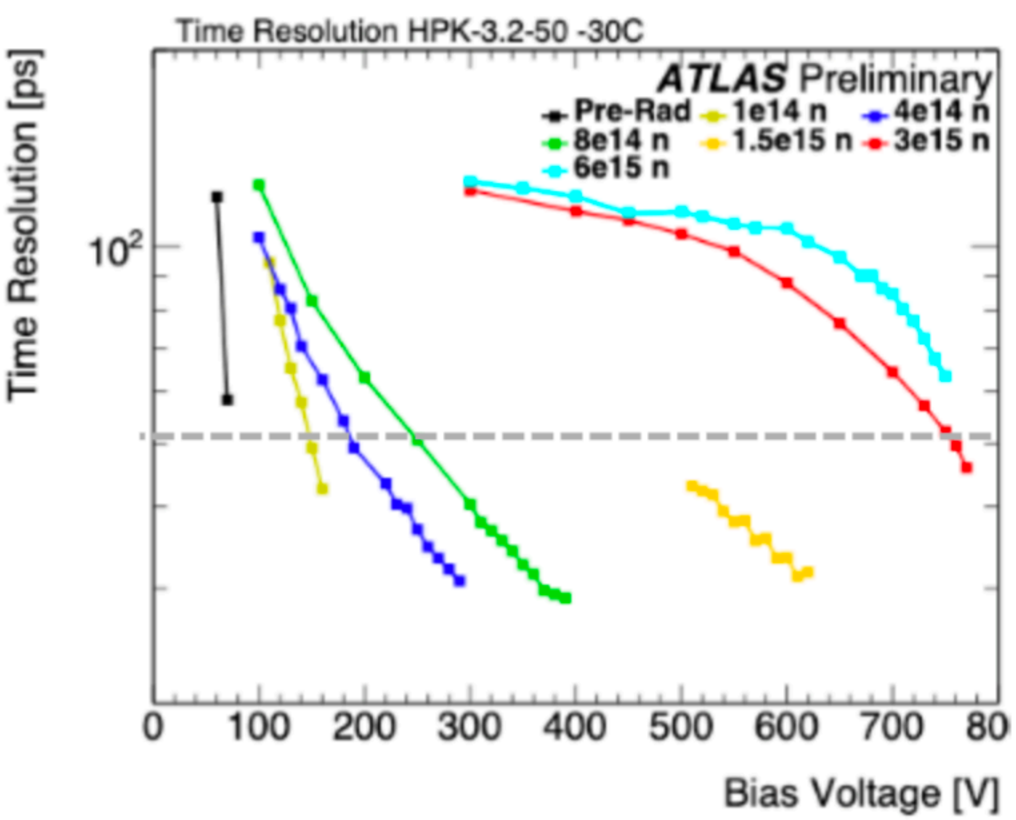


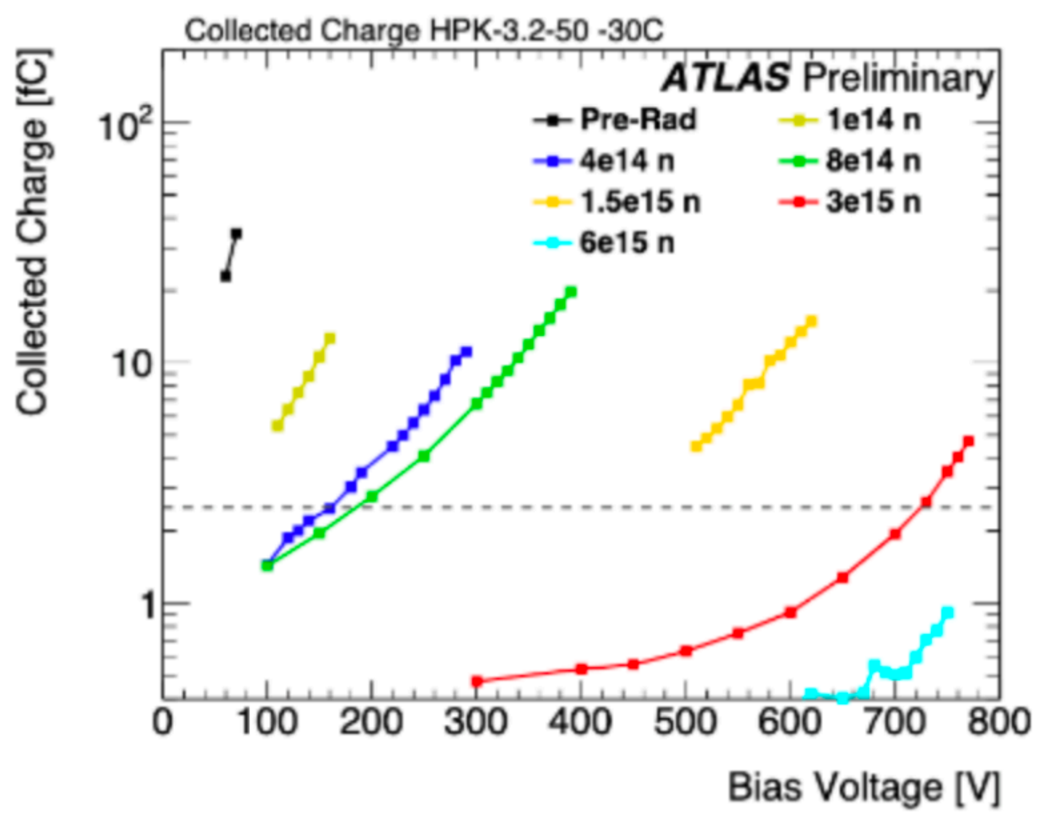
9k moduli da produrre, assemblare e integrare

SENSORS

- LGAD: silicon detector with a thin (<5μm) and highly doped (~10^{16} p++) multiplication layer
  - High electric field in the multiplication layer
- LGADs have intrinsic modest internal gain (10-50)
  - Better signal to noise ration, sharp rise edge

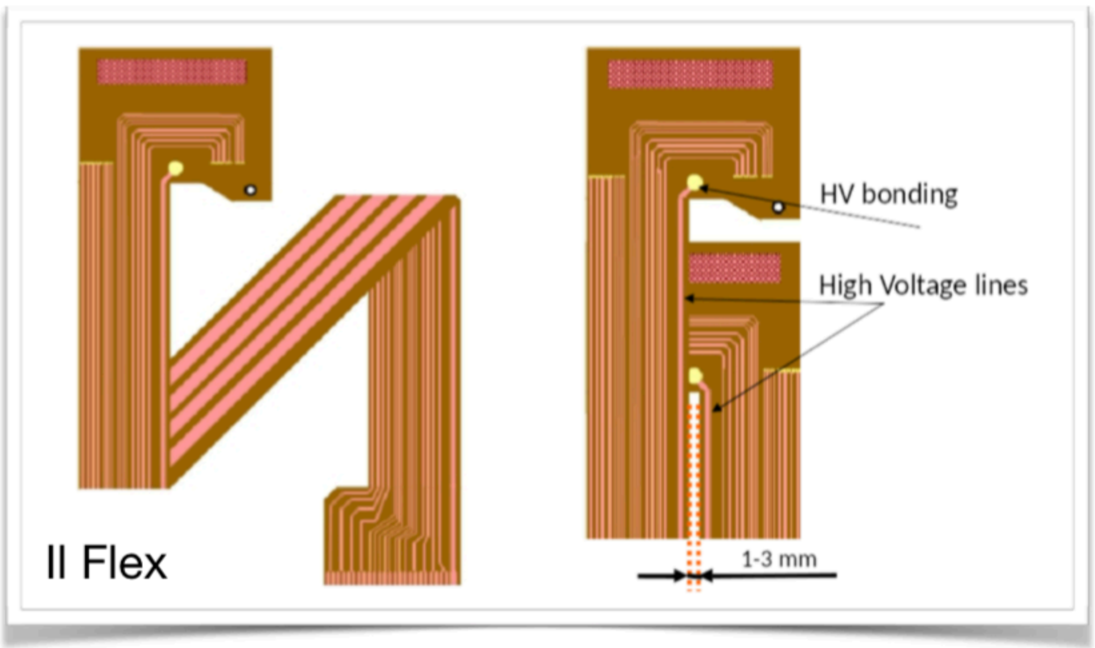


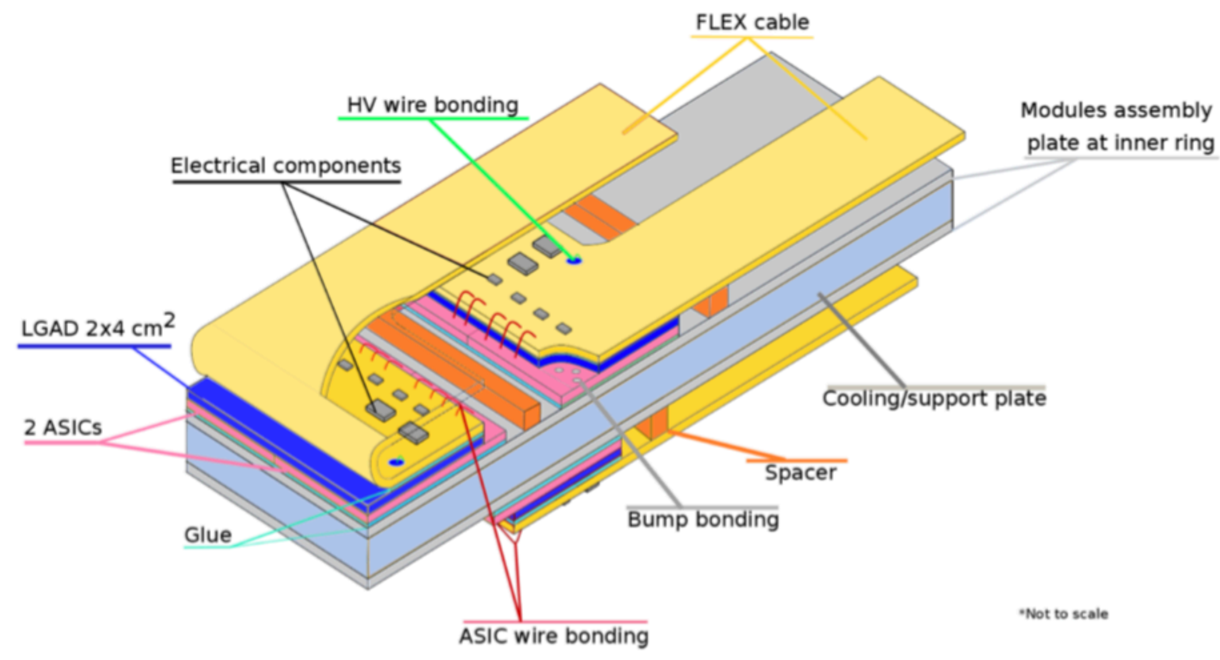




- Sensors qualified in terms of collected charge and time resolution up to 3×10^{15} neq /cm^2

INCOLLAGGIO E WIRE BONDING





- Incollatura del Flex sul sensore.
- Wire bonding dei cavi ASIC I/O con il Flex.
- Wire bonding (o anche saldatura semplice del cavo HV).
- Prove del modulo.
- Incollatura moduli sul supporto. Assemblaggio della mezza stave intera (per support plate).
- Prova del wire bonding per sensore e per la stave intera.

Non comprende assemblaggio del supporto sul cooling plate.

In almeno 5 o 6 siti per imaginare produrre circa 1500 moduli wire bonded per sito in due anni.

Altri gruppi potenziali candidati per questa fase di costruzione:

- CERN (con l'assemblaggio completo)
- Mainz
- Barcelona IFAE
- LPNHE/LAL
- Brookhaven

from Marumi Kado

LHCB

µRWELL CHAMBERS

- The µ-RWELL is composed of only two elements: the µ-RWELL_PCB and the cathode defining the gas gap
- The µ-RWELL_PCB, the core of the detector, is realized by coupling:
  - a WELL patterned foil acting as amplification stage
  - a resistive layer for discharge suppression w/surface resistivity ~ 10 100 MΩ/□- different current evacuation schemes can be implemented
  - a standard readout PCB
- Applying a suitable voltage between the top Cu-layer and the Diamond Like Carbon (DLC), the "WELL" acts as a multiplication channel for the ionization produced in the drift gas gap
- The main effect of the introduction of the resistive stage is the suppression of the transition from streamer to spark, with a consequent reduction of the spark-amplitude
- The µ-RWELL seems to be a valuable option for the upgrade of R1-R2- R3 regions of the Muon apparatus