LHC Experiments: upgrades and HL-LHC (Run IV++)

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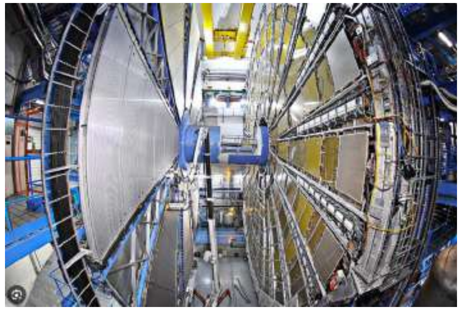
Aristotle University of Thessaloniki

RECFA visit to Greece,

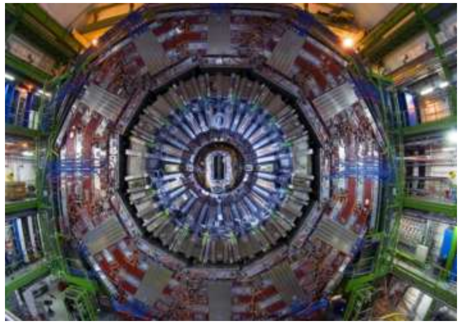
November 10, 2023

LHC Experiments: Upgrades and HL-LHC (Run IV++)

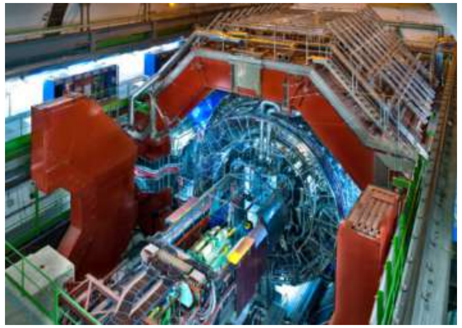
ATLAS
- New Small Wheel (NSW)
- Phase II Upgrade Muon Elx, TDAQ



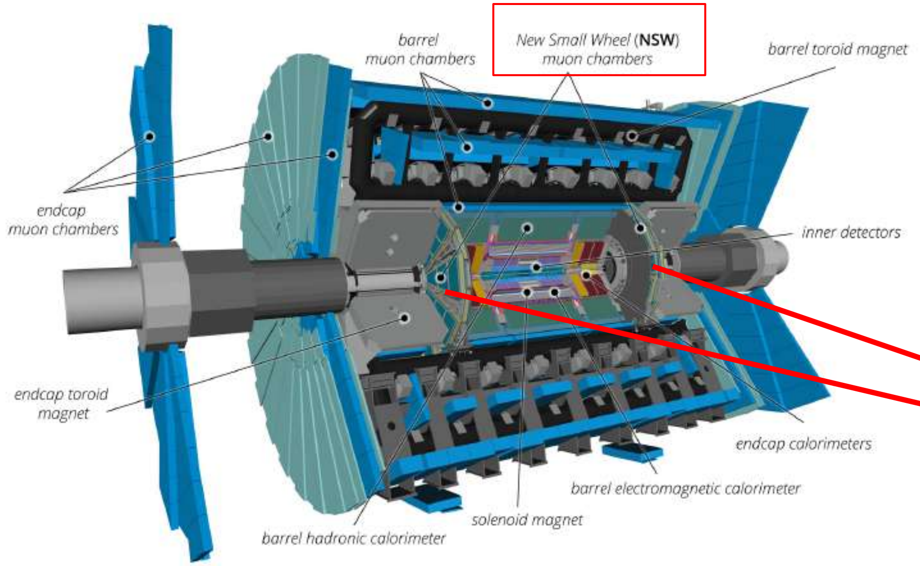
CMS
- Phase II Upgrade:
    - L1 Trigger: muons, global trigger, correlator, 40 MHz scouting
    - Si Tracker: Outer Tracker, Inner Tracker



ALICE
- Upgrade



ATLAS NSW (New Small Wheel)

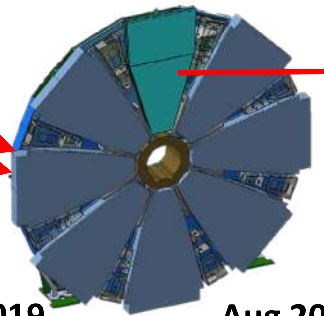


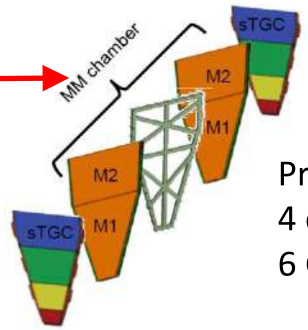
In order to benefit from the expected HL-LHC performance, had to replaced the first station of the ATLAS muon end-cap system (Small Wheel, SW).

New Small Wheel : novel high-rate capable detectors for Run 3 and HL-LHC

• Two technologies:

Small-strip Thin Gas Chambers (sTGCs) and Micromegas Chambers (MM)





Production
4 consortia for MM
6 Consortia for sTGC

2013 TDR

2017 Construction Start

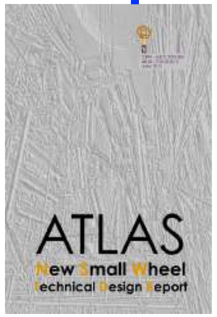
Dec 2018 MM+sTGC integration

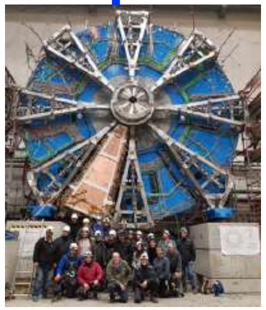
Dec 2019 First sector Installation on JD

Aug 2021 Side A wheel completion

Oct 2021 Side C wheel completion

Commisioning In ATLAS pit





Greek ATLAS in NSW

The Greek teams played a major role in:

- MM Construction : AUTH
- MM Integration and Commissioning : NTUA, AUTH,
- sTGC Commissioning : Demokritos, UNIWA
- NSW Integration and Commissioning : NTUA, NKUA, AUTH, UNIWA
- NSW Trigger Commissioning : Demokritos
- Design RO Electronics (NTUA)

- Electronics cards designed, fabricate assembled and tested by the Greek institutes and Greek industry.
- NSW services design and Micromegas Services.
- Design of the NSW micromegas gas system.
- Design of the NSW Detector Control System (DCS).
- Gas leak validation of the micromegas modules and sectors

- Micromegas integration in BB5
- Micromegas Commissioning in Bat191
- NSW installation in P1
- Validating NSW in the pit
- NSW incorporation in software and performance studies

ARISTOTLE UNIVERSITY OF THESSALONIKI

HELLENIC REPUBLIC
National and Kapodistrian University of Athens

National Technical University of Athens

DEMOKRITOS
NATIONAL CENTRE FOR SCIENTIFIC RESEARCH

UNIVERSITY OF WEST ATTICA
ΠΑΝΕΠΙΣΤΗΜΙΟ ΔΥΤΙΚΗΣ ΑΤΤΙΚΗΣ

Greek ATLAS in NSW

NTUA
NSW integrations & Commisioning
T. Alexopoulos
E.Gazis
S.Maltezos
K. Iakovidis
N. Agapiou
G. Athanasiadis
C. Bakalis
A. Vgenopoulos
C. Kitsaki
I. Fragkos
A. Giokaris
P. Gkountoumis
N. Karagianopoulos
E. Karentzos
E. Koulouris
C. Kourkoutis
E. Lampardaki
P. Lopez Macia
M. Natsios
C. Paraskevopoulos
M. Perganti
P. Tzanis
S. Tzanos
G. Statharas
K. Patrinos

AUTH
LM2 Construction Team :
D. Sampsonidis,
C. Lampoudis,
S. Kompogiannis,
I. Manthos,
I. Maniatis,
I. Karkanias,
T. Koutsosimos,
M.Tsopoulou,
L.Didi,
A.Kallitsopoulou,
P.Paschalias,
I.Maznas,
I.Kalaitzidou,
T.Argysis,
C.Petridou
S.Tzamarias
K.Kordas

NKUA
NSW Wedge Integration and Micromegas commissioning :
D. Fassouliotis,
C.Kourkoumelis
I.Gkialas,
S. Angelidakis,
L. Fountas,
P. Bellos,
V. Lefkovits

UNIWA (Technical Associate Institute)
NSW Micromegas Integration and commissioning :
S. Kyriakis-Bitzaros
K. Zachariadou
I.Mesolongitis
F. Kolitsi
N. Stouras,
G. Stamoulos,
N. Politis
D. Bita

Demokritos
sTGC Wedge Integration Team:
T.Geralis,
O. Zormpa,
M. Prapa,
K. Damanakis,
Y. Kiskiras,
A. Kerezis,
I. Alexopoulos,

LM2 Drift panels production @ AUTH

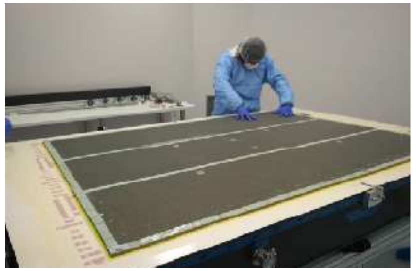

Site Review May 2017


LM2 Drift Panel Construction

MM LM2 Production: Thessaloniki, Dubna and CERN
Thessaloniki: Delivery of 96+spares Drift panels equipped with mesh,
Dubna: 64 RO panels and chambers assembly.

- New Laboratory for detector construction established (360 m^2) based in the Center of Interdisciplinary Research and Innovation of AUTH
- New Clean Room (145 m^2), 2 preparation rooms, a small workshop
- Site was reviewed (May 2017), Production Readiness Review (June 2017)
- QA/QC Procedure : All parts (bars, honeycomb) for the panel were checked.
- Panel QA measurements: Planarity, thickness, Gas tightness, Mesh tension

All Drift panels have shipped to Dubna (Russia) where
the LM2 modules were assembled.

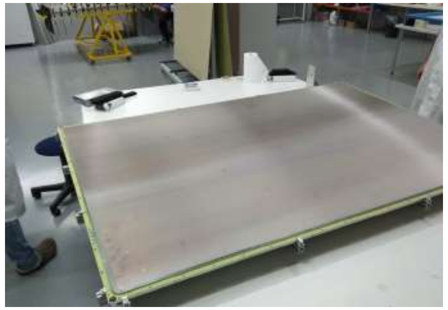

LM2 Drift Panel Construction


Drift Panel Cleaning


Drift Panel Cleaning

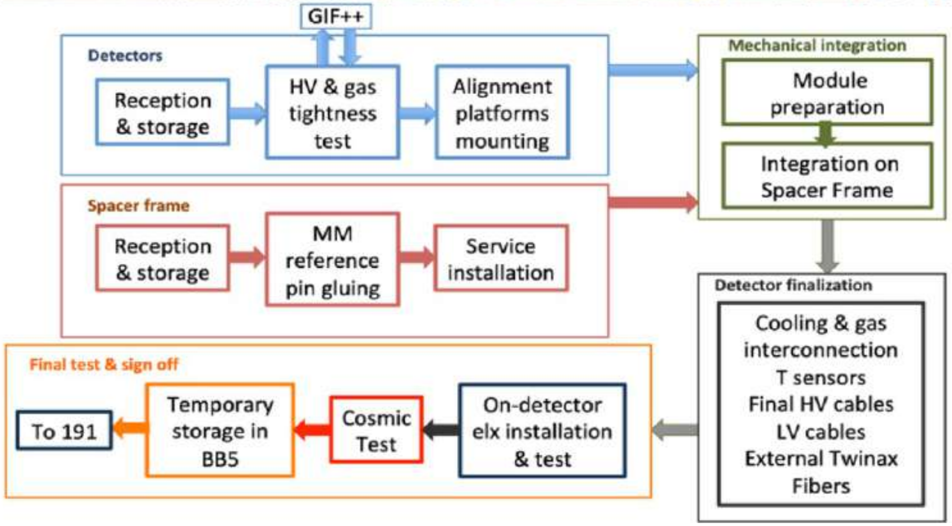

Drift Panel QA measurements


Mesh Stretching

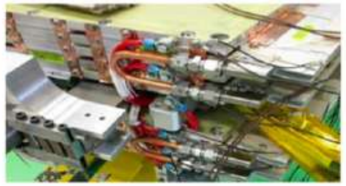

Drift Panel equipped with Mesh


The Team,

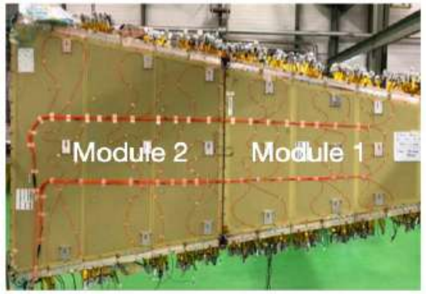
NSW MM Wedge Integration



Integration chambers onto the spacer frame



Cooling interconnections



Optical fibres for alignment system

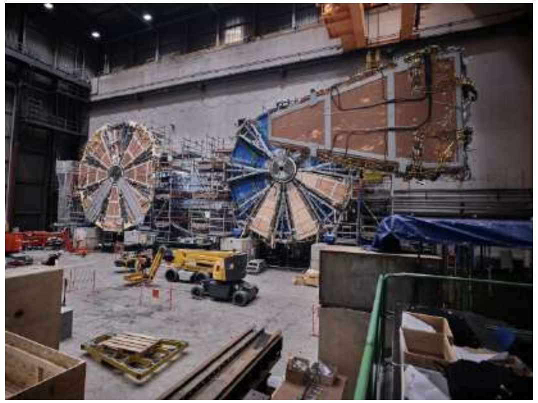
Install electronics cards

- **Assemble the MM modules into wedges, install services and electronics, validate the performance of the wedge with cosmic rays (@CERN)**
  - Wedge production line : About 20 people occupied daily, distributed to the different tasks
- **Optimised throughput for integration and testing of 1 sector every 10 days**
  - Activity parallelisation and testing automation

Integration of the sTGCs

Participation in sTGC Assembly and Integration on Wheels in building 191, (July 2019 – September 2021)




sTGC Trigger Slice system in B180

Build by the Demokritos group (Feb. 2020)

Complete autonomous Trigger Slice ➔ 1 Sector wedge

- Complete FE, Trigger (Pad, strips and Trigger processor) and DAQ system.
- Connections as on the ATLAS detector for proper timing
- Proper cooling

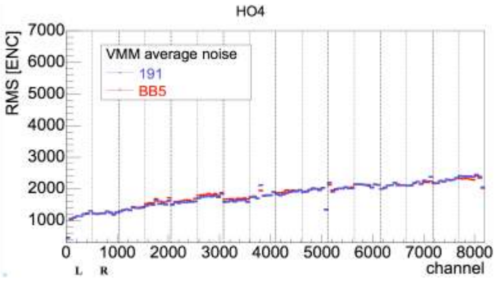
Used for NSW Trigger developments remotely.

Particularly useful during Covid pandemic

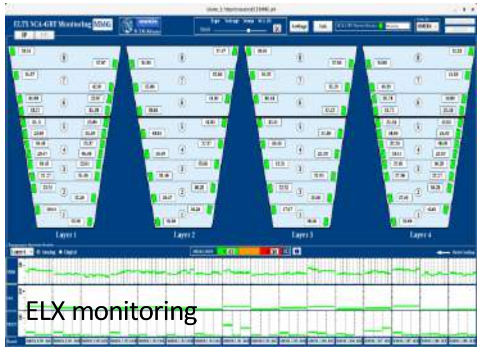

ATLAS – NSW surface commissioning

Micromegas surface commissioning

- Installation, verification of infrastructure
- Definition of commissioning protocol
- Problem identification, solution proposal
- Connections and sectors verification



Example of the RMS of a baseline in ENC for a sector layer (Blue B191, Red BB5)



Pre-installation connections and tests

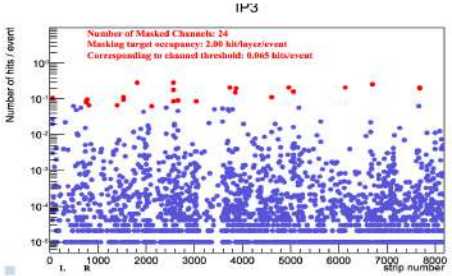
- *On the wheel*
- *On the mm quadruplets*

Post-installation parallel work stream 1

- *Gas flushing*
- *HV connection*
- *HV operation*

Post-installation parallel work stream 2

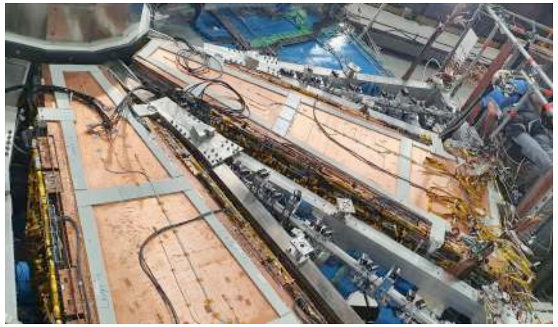
- *Sensor connections*
- *Temperature reading*
- *Cooling operation*
- *Read out connection*
- *LV operation*
- *Configuration of electronics*
- *DCS monitoring of electronics*



Example of noisy channel mapping

Data taking and sign-off at B 191

- *Baselines - threshold estimation*
- *Pulsing electronics*
- *Dead and Noisy channel mapping*
- *Trigger path validation*

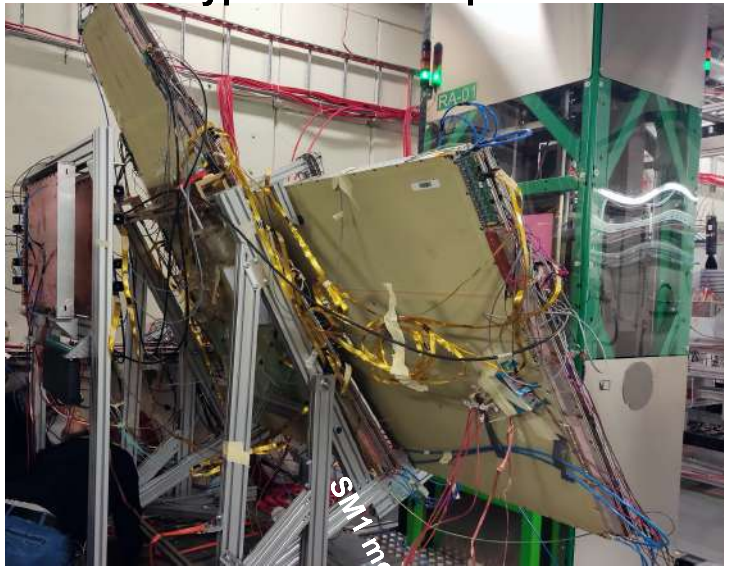


Working in very dense conditions … often w/o visual contact … facing and resolving a variety of challenges

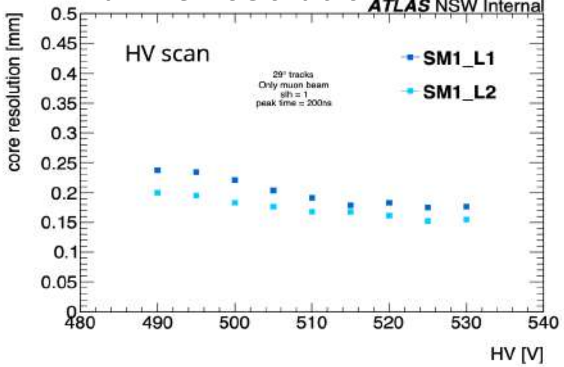
Micromegas R&D program

- Long R&D program (under ATLAS experiment) on micromegas technology **started in 2008** extending **up to date**.
- Greek participation from the beginning at the level of co-coordination (T. Alexopoulos, NTUA) and analyzing data from the various testbeam periods, in average three periods per year.
- Long irradiation periods at GIF++ facility of spare NSW-ATLAS micromegas modules for longevity studies.
- Performance studies of micromegas using muon beam in a high gamma radiation enviroment.
- Several years of HL-LHC equivalent have been accumulated so far for all the types of sectors (>20y for LM2); no general “decease” in performance was observed.
- The results of this detector R&D program have been documented in six PhD thesis and in more than 60 journal papers.

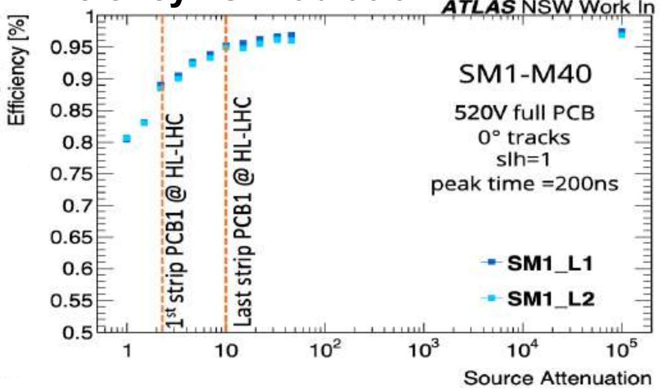
Typical MM setup at GIF++



uTPC resolution



Efficiency vs irradiation



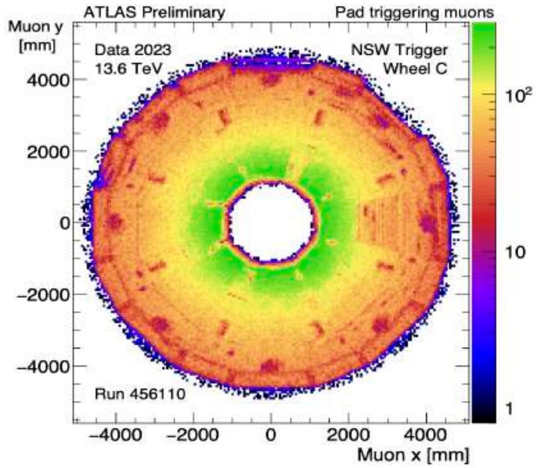
NSW Trigger Commissioning and Integration to ATLAS

NSW Trigger aim: Reject fake muons

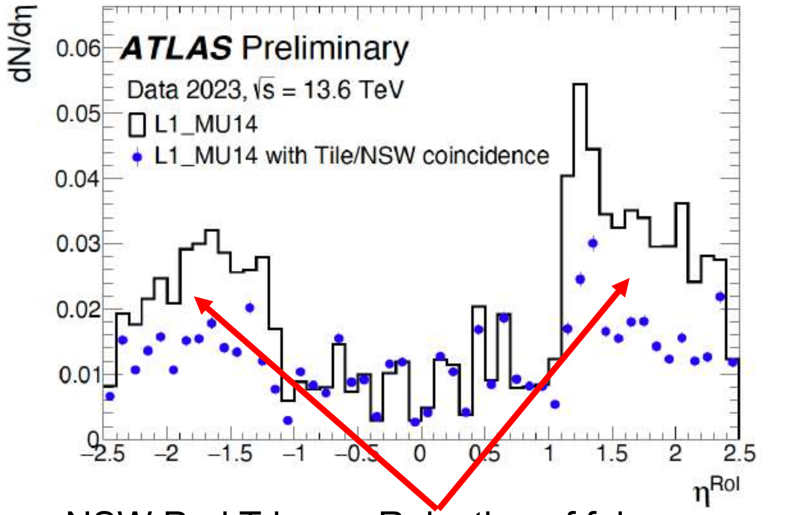
Major achievement in 2023

sTGC Pad Trigger: Demokritos (Coordination), Univ. of West Attica

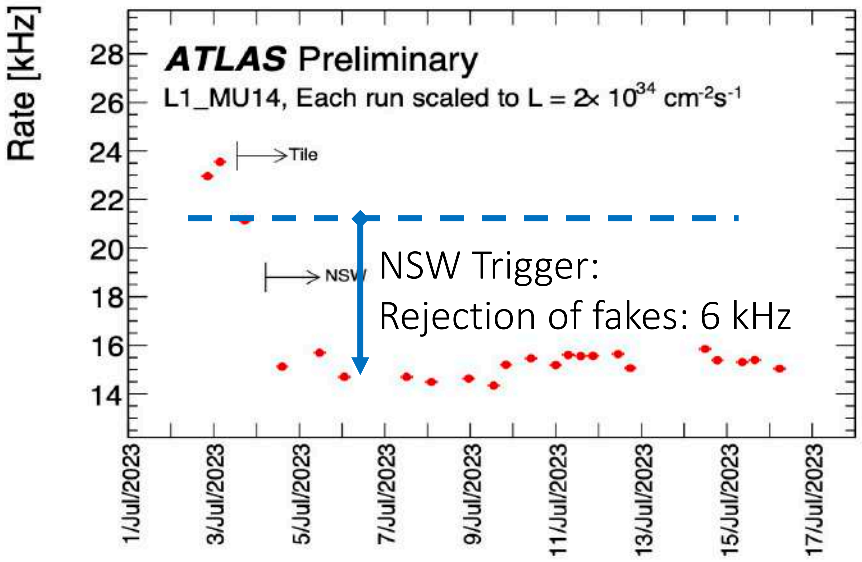
- Commisioning of the sTGC Trigger on all 32 sectors on surface (2020 – 2021) and in P1 after NSW integration to ATLAS (2022)
- Integration of NSW sTGC Trigger in ATLAS
- Successful integration of the NSW Pad Trigger into ATLAS
- 4th of July 2023: NSW in ATLAS trigger ➔ Rejection of 6 kHz fakes
- Allowed low deadtime readout in ATLAS



NSW Pad Trigger Hitmap



NSW Pad Trigger- Rejection of fake muons



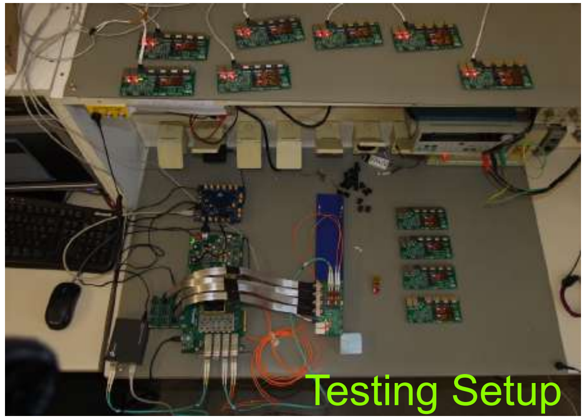
NSW Electronics

Electronics cards designed, fabricated and assembled (by GR industry) and tested by Greek institutes:

- Micromegas L1DDC (L1 Data Driver Card)
- sTGC L1DDC
- Rim L1DDC (sTGC trigger readout)
- LVDB (micromegas Low Voltage Distribution Card)
- Clean clock card

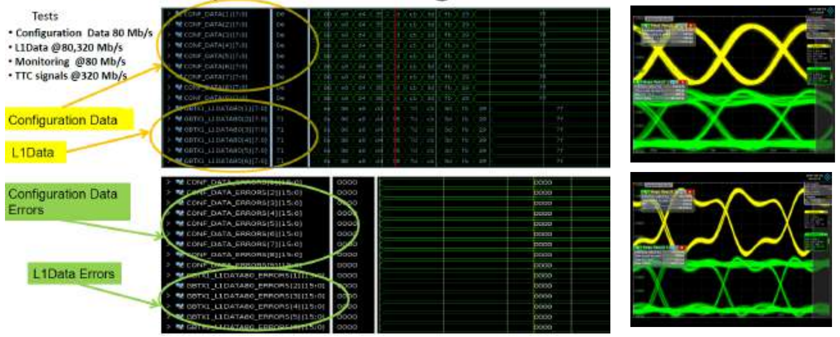
L1DDC Quality Control

NTUA – UNIWA – NKUA – Demokritos



1024 L1DDC cards for Micromegas and sTGC were tested and quality assured in 2019

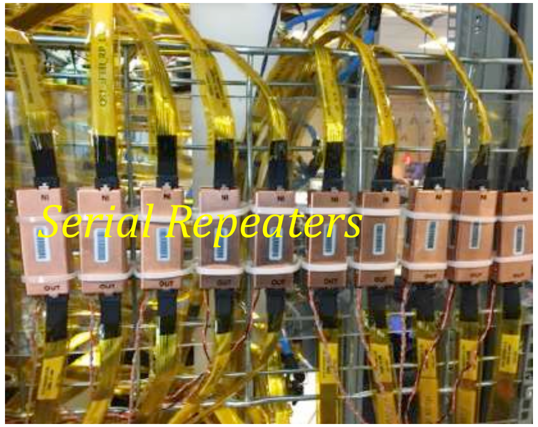
Results for preproduction boards @ ECTLab UNIWA



sTGC Trigger Repeaters boards

Restoring attenuated trigger signals **Demokritos**

- Repeaters design, construction and testing
- Commissioning and integration on detector
- *880 Serial and 150 LVDS repeater boards* build in collaboration with the **Greek industry**
- Cooling/Faraday cages by Greek industry
- Development of test bench (VC707) – yield 99.5%



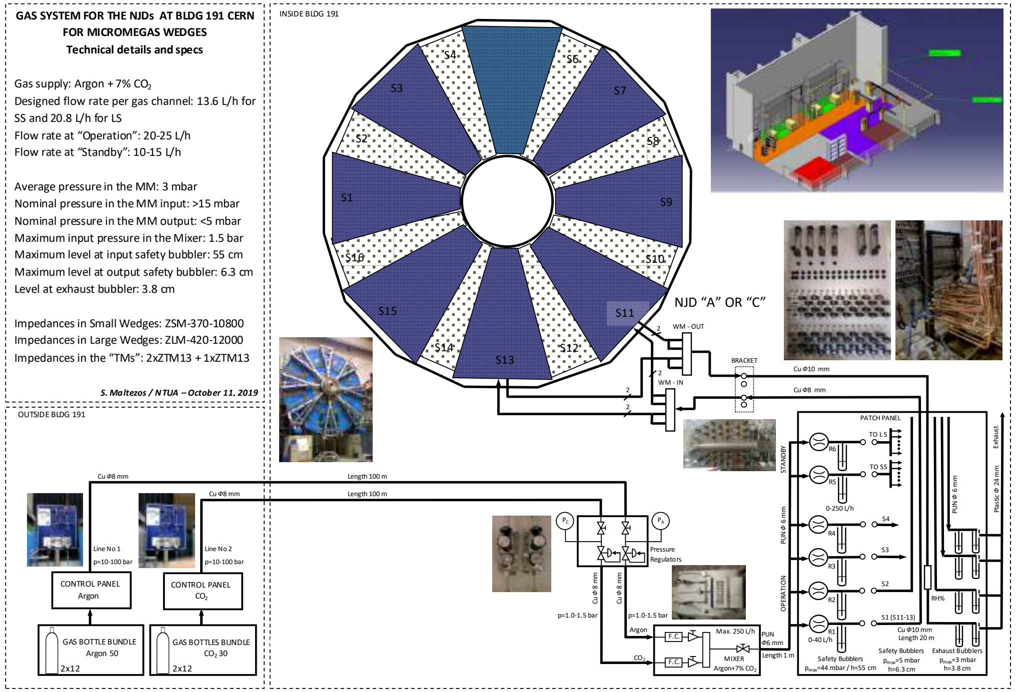
Operating in ATLAS since Jan. 2022 without any problems

Some of the Elx will be replaced for trigger bandwidth extension @ HL-LHC

NSW (DCS) and Gas System

NTUA

- NSW Detector Control System & NSW Micromegas Gas System was designed by NTUA team.

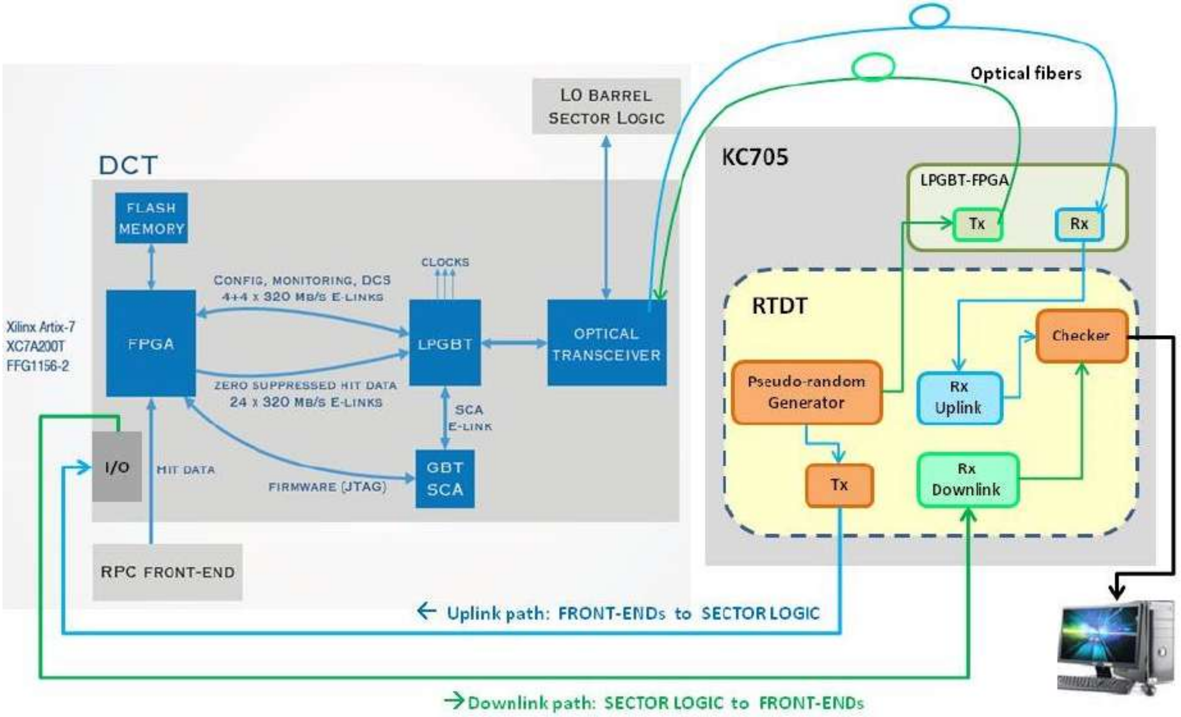


ATLAS Phase II Upgrade

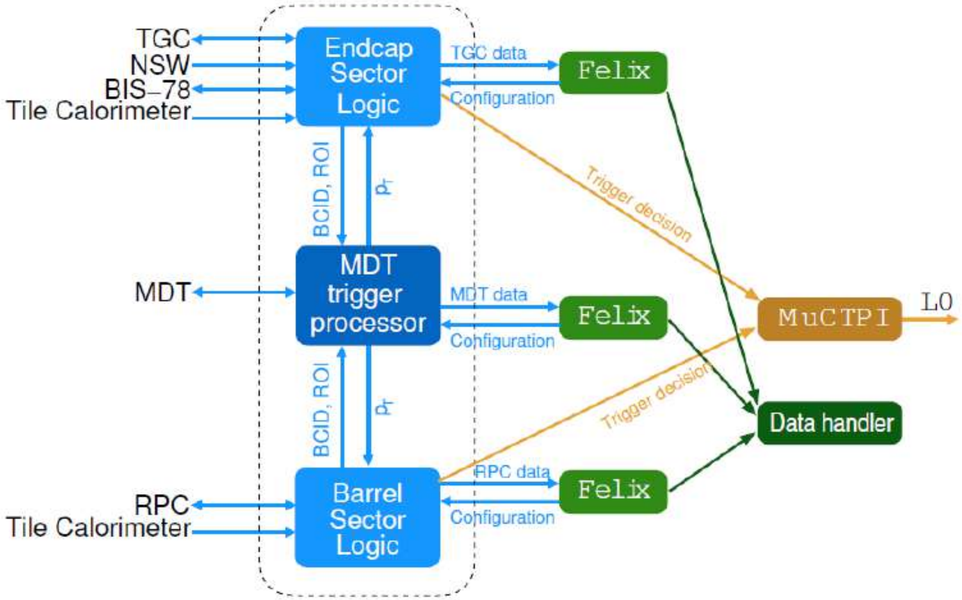
(Demokritos – NKUA – NTUA – UNIWA)

Elx design and testing

RPC DCT testing setup block diagram



Barrel Sector Logic: RPC & Tile Barrel trigger



Main Group Contributions:

- ❑ Development of DCT testing hardware/firmware/software
- ❑ Evaluation of several prototypes
- ❑ Testing and quality assurance of production cards

Main Group Contributions:

- ❑ Firmware for DCT ↔ SL and SL ↔ FELIX communication
- ❑ Trigger Processor Algorithms and Implementation

ATLAS TDAQ & Tracking for Phase-II

- Tracking in the High-level Trigger (= Event-Filter, "EF"): in "EF tracking" & "EF muon
- Trigger algorithms for Muon Barrel Sector Logic board

• Initially, worked with the "Hardware Tracker for the Trigger" (HTT), a hardware *co-processor* for the EF farm (re-configurable to be able to provide tracks to the hardware Level-1 trigger).

• Worked in the *Associative Memory chips for pattern recognition* (verification & power simulations) , in control and tracking firmware on the *"Pattern Recognition Mezzanine"*, & in *Z/H trigger studies for the potential L1 tracking*.

• ATLAS decided in 2021 to abandon L1 tracking and go for 1MHz L1 accept rate and move to custom solution for the EF farm.

•Group played key role in preparing the custom hardware option for this decision.

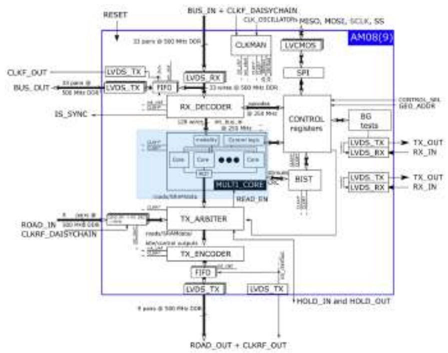
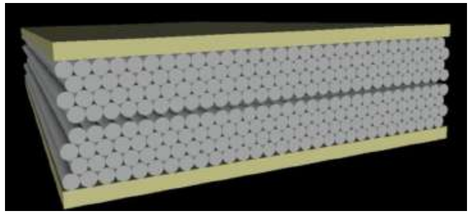
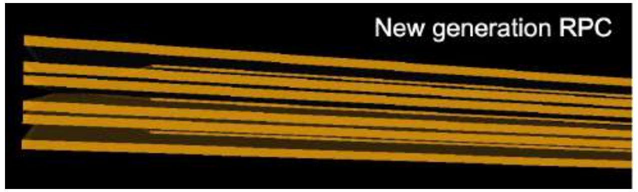
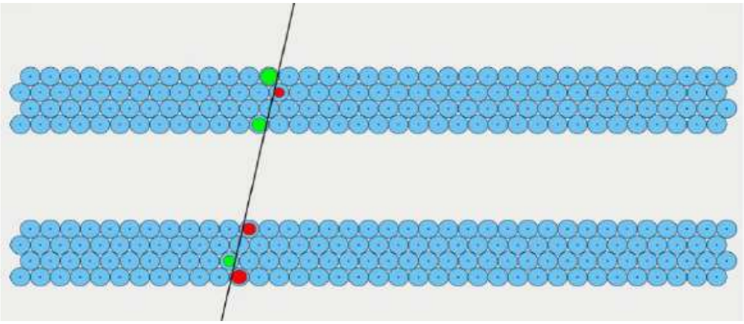


Fig. 1. Functional Block Diagram of the AM08 ASIC

• Now *implementing the tracking in the new "ACTS" framework (mainly muon)* which is common with the offline (C++ in CPUs, with plugins for GPUs as co-processors and potentially FPGAs, 2 PhDs on going).







• Readout DAQ firmware of the pilot "BIS 7/8" chambers already installed (in preparation for phase-II)

• *Trigger algorithms for Muon Barrel Sector Logic board*

Coordination positions in ATLAS HL-LHC upgrade projects

- Micromegas testbeam co-coordinator (T. Alexopoulos 2015 – 2019)
- Micromegas integration co-coordinator (T. Alexopoulos 2015 – 2022)
- NSW DCS coordinator (T. Alexopoulos 2016 – 2020)
- Micromegas Analysis co-coordinator (T. Alexopoulos 2016 – 2019)
- LM2 Production Co-coordinator (D. Sampsonidis 2016-2020)
- NSW Electronics Steering group (T. Alexopoulos 2017-2023)
- Micromegas Coordination Group Member (D. Sampsonidis 2017- today)
- NSW surface commissioning Coordinator (D. Fassouliotis, 2019 – 2020)
- NSW commissioning coordination (E. Koulouris 2019-2022)
- NSW services coordinator in commission (K. Iakovidis 2019 – 2022)
- NSW Steering Group, (T. Geralis 2017 – today)
- NSW Electronics Steering group, (T. Geralis 2017 – today)
- NSW Trigger Coordinator, (T. Geralis 2021 – today)
- Micromegas represetative in Muon SG (T. Alexopoulos 2022 - today)
- NSW DCS coordinator (P. Tzanis 2021 – 2022)
- Vertical Slice Laboratory responsible, (T. Geralis 2022 – today)
- Upgrade Advisory Board Member (E. Gazis, 2015 - 2023)
- Upgrade Advisory Board Member (D. Sampsonidis, 2015 - 2023)

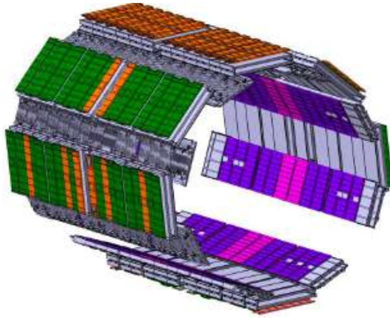
ATLAS Phase II Upgrade Funding

New Small Wheel

GR funds through RRB

ATLAS Phase I Upgrade **_350 kCHF_**

Other R&D funds	Funding Source	Amount (€)
DeTANet (Development of Detectors, High-Tech Electronics & their Applications)	ESPA	245 k€
Construction & Test of Micromegas	AUTH, NTUA	150 k€
Construction & Test of Micromega	ATLAS Experiment	300 k€
Open R&D calls	ELIDEK, KRIPIS, Min. of Educ.	370 k€
Total		**_1.065 M€_**



ATLAS Phase II Upgrade

GR funds through RRB

Muon Spectrometer:

- MDT Front End Mezzanine boards (QA/QC)
- MDT Optical Cabling (QA/QC)
- DCS System (Development) — *GR contribution 500 kCF*
- RPC DCT Boards (Development – next slides)
- RPC DCT secvices — *GR contribution 850 kCF*
- Micromegas L1DDC bandwidth extension (Design, construction)
- sTGC L1DDC bandwidth extension (Design, construction) — *GR contribution 200 kCHF*
- MDT HV/LV
- RPC HV/LV, DCS (Development) — *GR contribution 950 kCHF*

TDAQ :

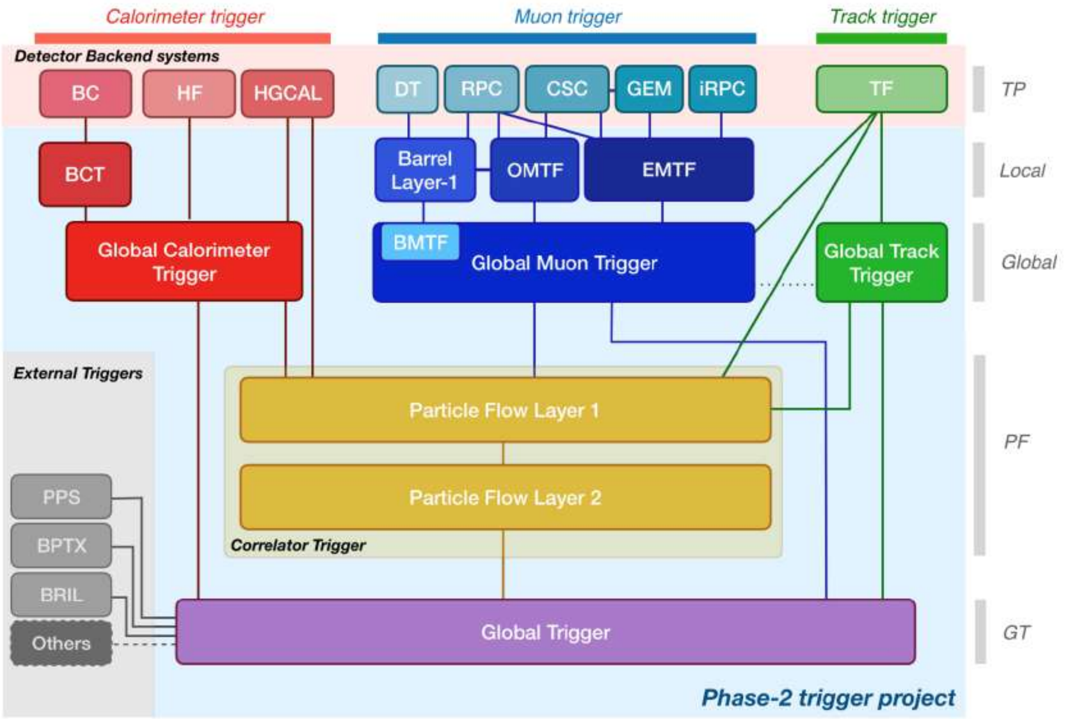
- EF Servers / EF tracking & EF Muon (Development) — *GR contribution 800 kCHF*

Total estimated ATLAS/Greek Contribution: **_3.5 MCHF_** **_(MOU is pending)_**

CMS Phase II

The CMS L1-Trigger at HL-LHC

- Latency: 12.5 μsec, Maximum Rate: 750 KHz
- The L1-Trigger decision processes data from the Calorimeters, the Muon detectors, as well as the Silicon Tracker.
- The CMS stacked tracker design allows low momentum tracks to be rejected at the detector level and this reduces the Track Trigger input rate by two orders of magnitude.
- The introduction of tracks at the L1-Trigger allows for significant rate reduction (without this the maximum L1-Trigger rate would have been 1.5 MHz).
- The Barrel Muon Trigger uses track information to improve muon candidate P_T resolution.
- The Correlator Trigger uses track information for particle flow algorithms to improve calorimeter object resolution and subtract contributions for Pile-up events.
- The Global Track Trigger calculates the event vertex.

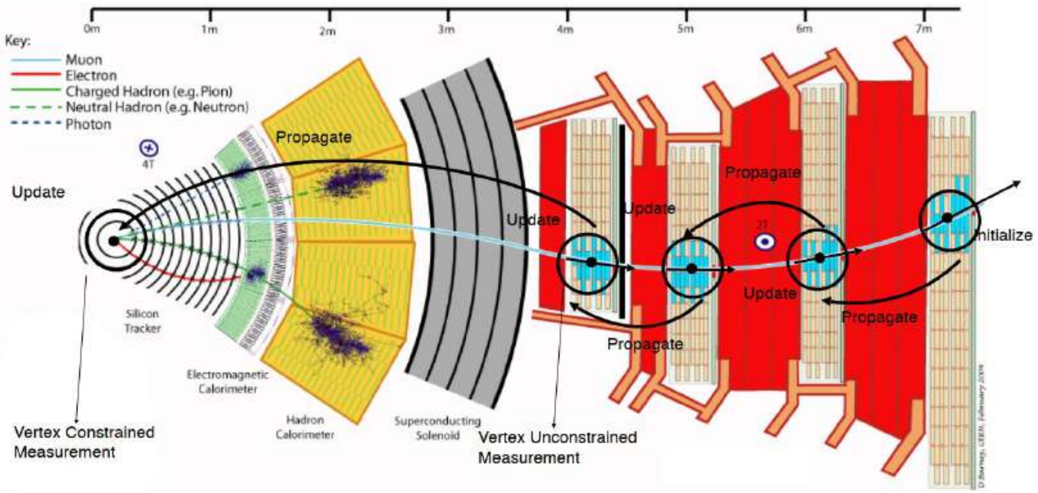


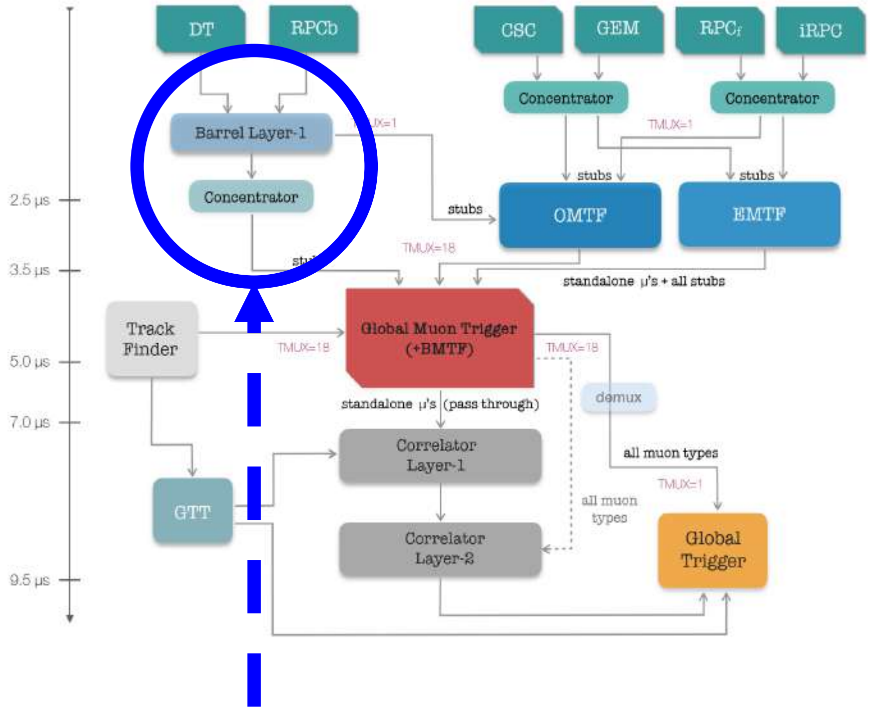
CMS Greece is making key contributions at the Barrel Muon Trigger (Barrel Layer-1) and the Correlator Trigger – Particle Flow Layer-2)

CMS L1 Trigger Team:

P. Sphicas, K. Vellidis, K. Theofilatos (UoA), C. Foudas, N. Manthos, I. Evangelou, I. Papadopoulos, K. Adamidis, I. Bestintzanos, S. Liontos (Ioannina)

The CMS Barrel Muon Trigger (BMT) for HL-LHC





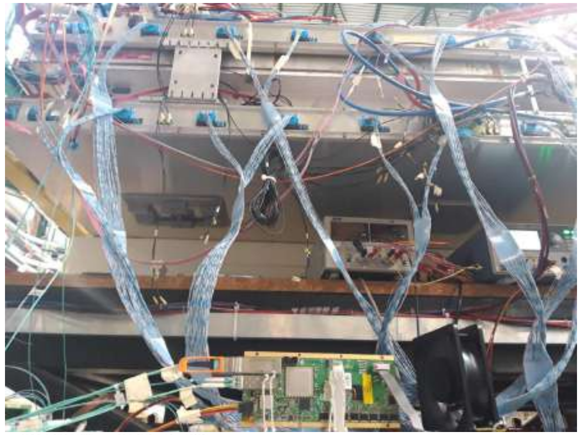
- BMT processes DT and RPC data to search for muon candidates in the CMS Barrel region (η<0.8)
- BMT Layer-1 and Concentrator reconstructs tracklets (subs) at the 4 muon detector stations of each of the 12 muon detector wedges.
- The Kalman Filter-based track finder reconstructs tracks starting from the outermost muon station, propagating inwards and updating the track parameters at each station. At the innermost station it provides a vertex constrained and an unconstrained measurement, allowing for triggering on prompt and displaced muons
- The novelty of this design is that it uses for the first time the tracks from the Track Trigger and matches them in the Global Muon Trigger with tracks from the muon trigger to produce muon candidates of the highest resolution and performance

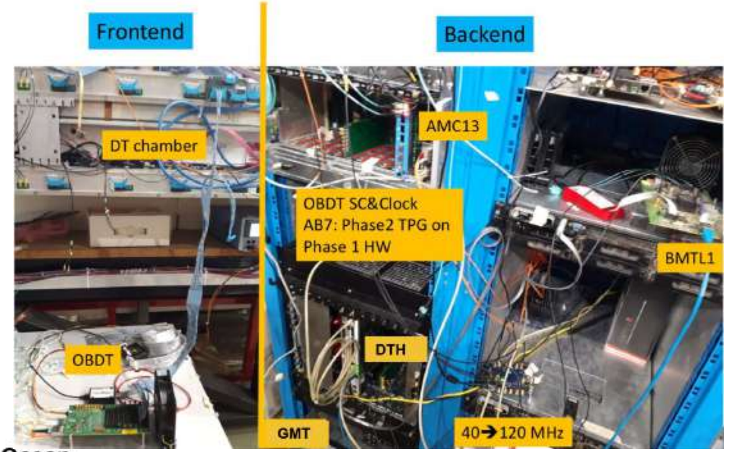
BMT Layer-1 + Concentrator joint responsibility of : Athens, Ioannina (GR) and CIEMAT (Spain): P. Sphicas, K. Vellidis (Athens), C. Foudas, N. Manthos, I. Evangelou, K. Adamidis, I. Bestintzanos, S. Liontos (Ioannina), C. Fernandez Bedoya, A. Navarro, I. Redondo (CIEMAT)

BMT Layer-2 (Global Muon Trigger) responsibility of : UCLA, M. Bachtis

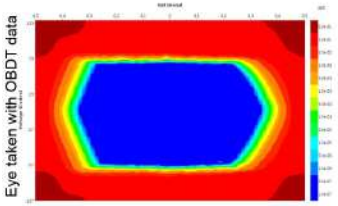
Trigger Processor Technology Demonstrator

2017-2021

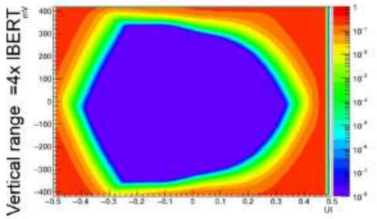




OBDT -> BMTL1 Demo
- 2 Tx GBT Links @ 4.8 Gb/s
- Counter data running for 7 days
- No Errors



BMTL1 Demo -> Ocean
- Using CMS Standard Protocol (CSP)
- 4Tx & 4Rx Links @ 16 Gb/s
- Running 2 days
- No CRC Errors

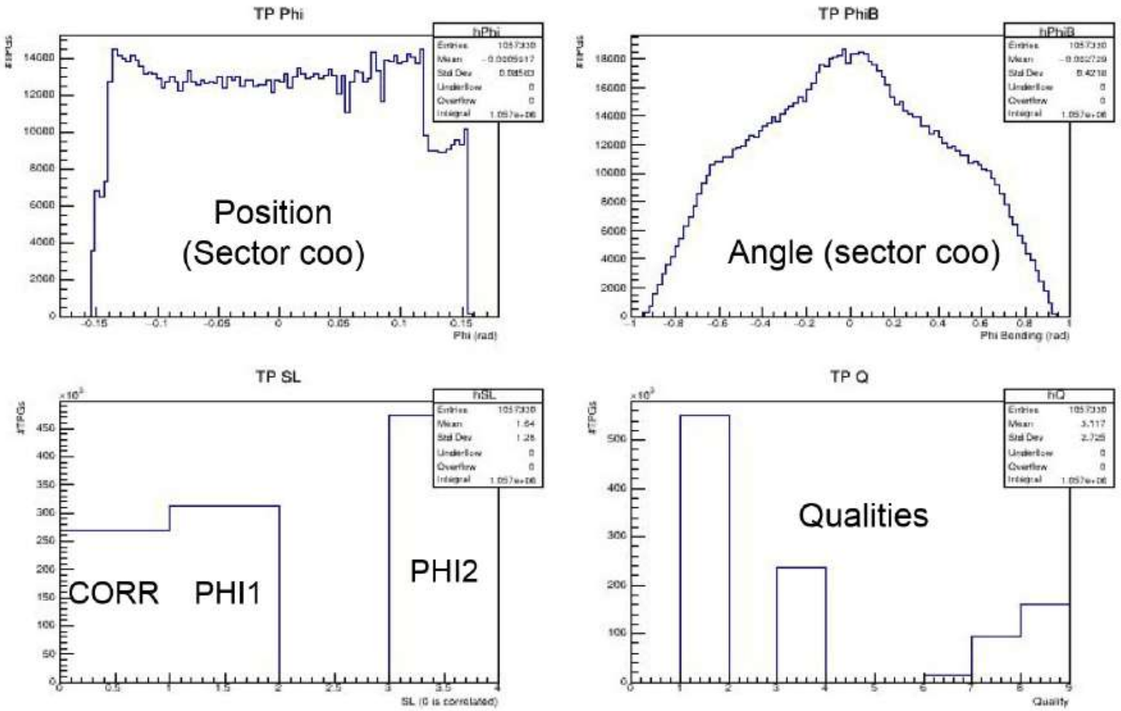


The optical link design for the CMS L1 Trigger was part of the PhD thesis of K. Adamidis (Ioannina). These tests demonstrate that the links perform as required.

- Greece is responsible for designing the BMT Layer-1 processor as well as all the *Service Firmware* (Optical Links, Monitoring and Run-control FW etc). The stub finding algorithm is the responsibility of CIEMAT. Both Groups are responsible of commissioning and running BMT.
- Production of the Layer-1 processors (42 units + spares are needed) will occur in Greece and Spain.
- A first prototype of BMT Trigger processor was designed (Athens, Ioannina) and **manufactured in Greece (Prisma-Alexandroupolis GR)**. Mostly a technology demonstrator but could also host stub-finding algorithms form to DT chambers.
- Data collection started in 2019 using it but it was interrupted early in 2020 due to COVID-19 and resumed in 2021.

Results using the BMT processor demonstrator

2021-2022



- Data were collected in 2021 using the BMT processor demonstrator connected with electronics from the entire chain of the DT trigger (slice test) which demonstrated and validated the Barrel Muon Trigger design.
- The Level-1 trigger optical link design was a join program between Ioannina and Imperial College London. The design has been published. Modifications were made afterwards to make them compatible with certain CMS Trigger components and are currently under use by the entire CMS L1-Trigger upgrade.

JINST
Published by IOP Publishing for SISSA Medialab
Received: October 24, 2021
Accepted: February 25, 2022
Published: June 14, 2022

Topical Workshop on Electronics for Particle Physics 2021
20–24 September, 2021
Online

Hermes — a robust, low latency, optical link protocol for synchronous data transfer at commercial asynchronous line rates

K. Adamidis,[a,*] I. Bestintzanos,[a] C. Foudas,[a] A. Howard,[b] G.M. Iles,[b] S. Mallios[c] and T. Williams[d]

[a] University of Ioannina, Ioannina, Greece
[b] Blackett Laboratory, Imperial College, Prince Consort Road, London, SW7 2BW, U.K.
[c] European Organization for Nuclear Research (CERN), Geneva, Switzerland
[d] STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot, OX11 0QX, U.K.

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2022 JINST

PROCEEDINGS OF SCIENCE

Upgrade of the CMS Barrel Muon Track Finder for HL-LHC featuring a Kalman Filter algorithm and an ATCA Host Processor with Ultrascale+ FPGAs

M. Bachtis[a], C. Foudas[b], P. Katsoulis[b], T. Lam[a], S. Mallios[b], G. Karathanasis[c,*], I. Papavergou[c], S. Regnard[a], M. Tepper[a], P. Sphicas[c,d], C. Vellidis[c]

[a] University of California, Los Angeles
[b] University of Ioannina, Greece
[c] University of Athens, Greece
[d] European organization of Nuclear Research (CERN)

On behalf of the CMS Collaboration

The Barrel Muon Track finder of the CMS experiment at the Large Hadron Collider uses custom processors to identify muons and measure their momenta in the central region of the CMS detector. An upgrade of the L1 tracking algorithm is presented, featuring a Kalman Filter in FPGAs, implemented using High Level Synthesis tools. The matrix operations are mapped to the DSP cores reducing resource utilization to a level that allows the new algorithm to fit in the same FPGA as the legacy one, thus enabling studies during nominal CMS data taking. The algorithm performance has been verified in CMS collisions during 2018 operations. The algorithm is also proposed for standalone muon tracking at the High Luminosity LHC. The algorithm development is complemented by ATCA processor R&D featuring a large ZYNQ Ultrascale+ SoC with high speed optical links.

PoS(TWEPP2018)139

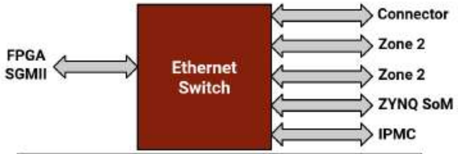
The BMT Layer-1 ATCA Processor

(2022-2023)

Optical connectivity

- 40 RX @ 25 Gbps
- 40 TX @ 25 Gbps ⇨ 10 x BiDir FireFly Modules 25G
- 80 RX @ 16 Gbps ⇨ 7 x Rx FireFly Modules 16G
- 36 TX @ 16 Gbps ⇨ 3 x Tx FireFly Modules 16G

- 120 RX + 76 TX ~ **3.9 *Tbps*** → *~200.000 ADSL connections, ~100.000 VDSL connections, ~4000 Gbit connections*

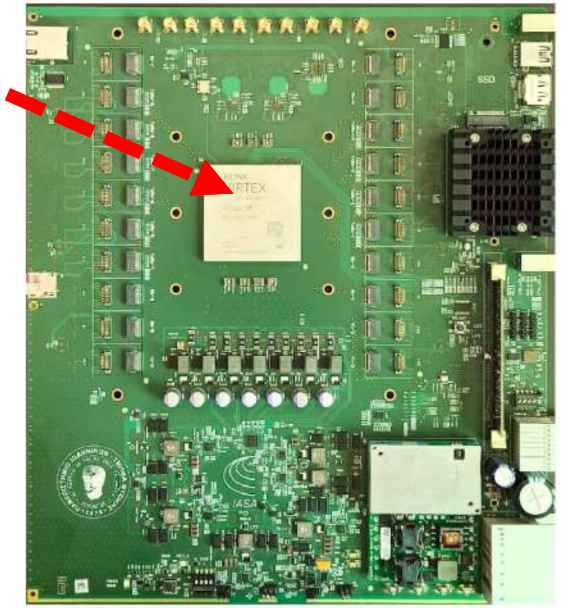


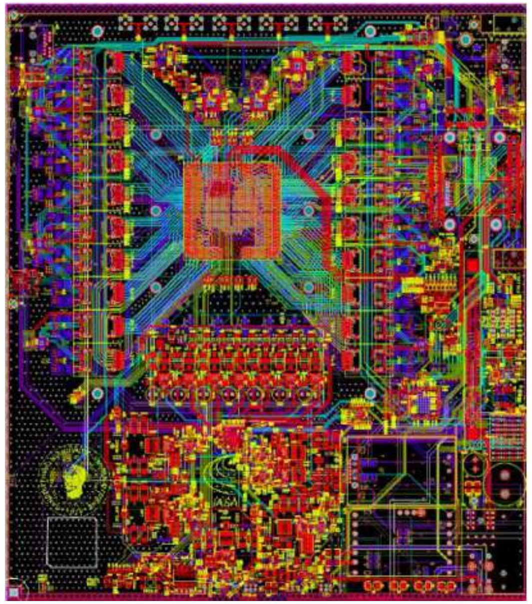
Onboard Ethernet switch circuitry provides access to many subsystems on board

Samtec FireFly optical modules

Xilinx XCVU13P FPGA
- *Ultrascale+ architecture*
- *16 nm lithography*
- *4 SLRs (Super Logic Regions)*
- *1,728,000 LUTs*
- *3,456,000 Flip Flops*
- *12,288 DSP slices*
- *128 GTY transceivers @ 28G*
- *2577 ball BGA package*
- *-1 speed grade*

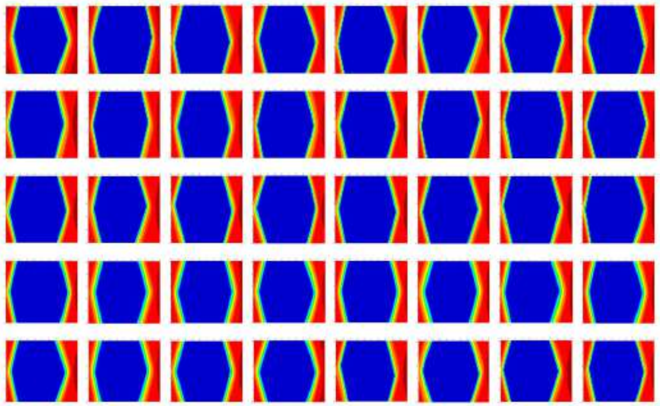
38.3 TOP/s (DSP)
- Simultaneous usage of 12228 DSPs





- Two full scale BMT Layer-1 processor cards in ATCA format have been manufactured. Detailed testing has demonstrated that are fully functional.
- Both satisfy all requirements of the CMS L1-trigger upgrade TDR.
- 3 more Processor will be produced in the next 12 months.
- One of the processor cards was used to collect data from proton-proton collisions

Optical Link Performance at 25 Gbps

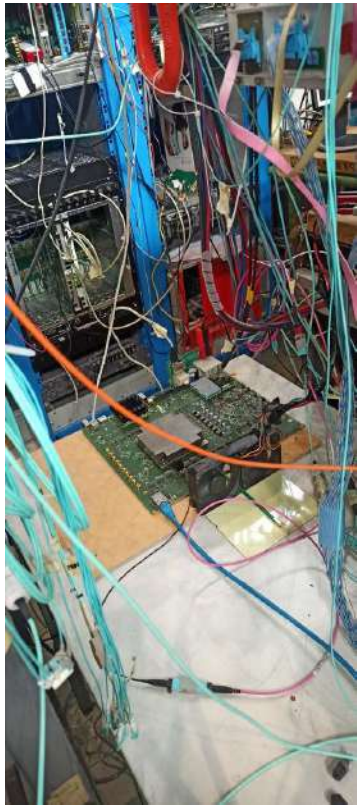


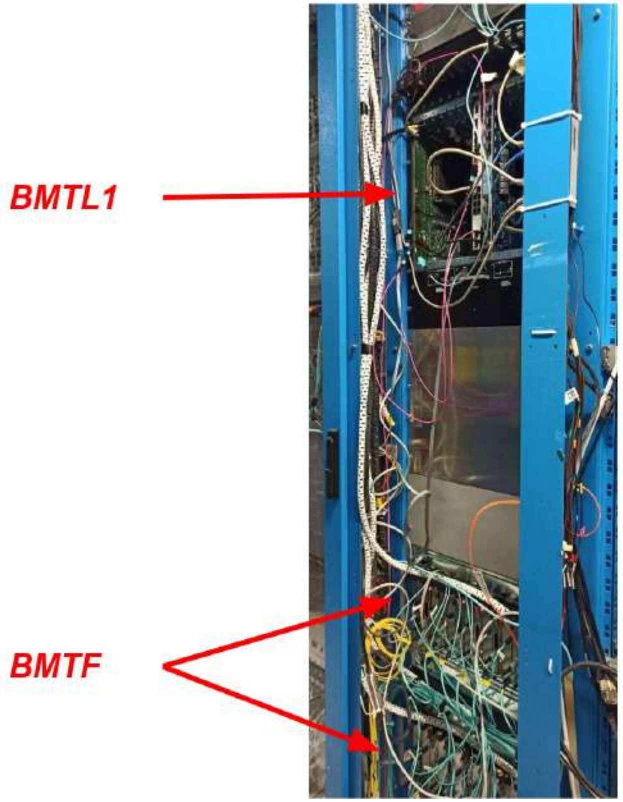
IBERT with all 40 25G MGTs instantiated and operating simultaneously

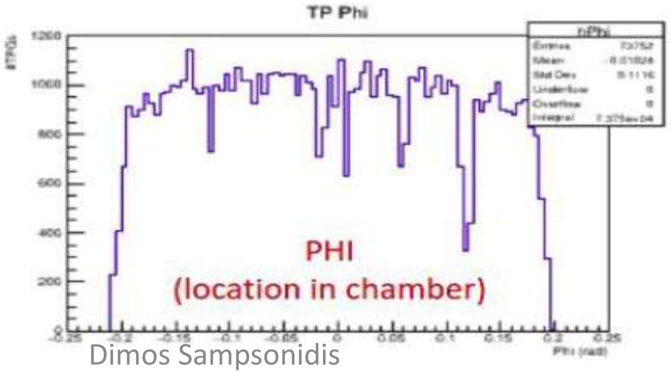
- 2 meter optic fiber
- 25.6 Gb/s
- PRBS7
- Resolution 1
- Eyescan BER 1e-8

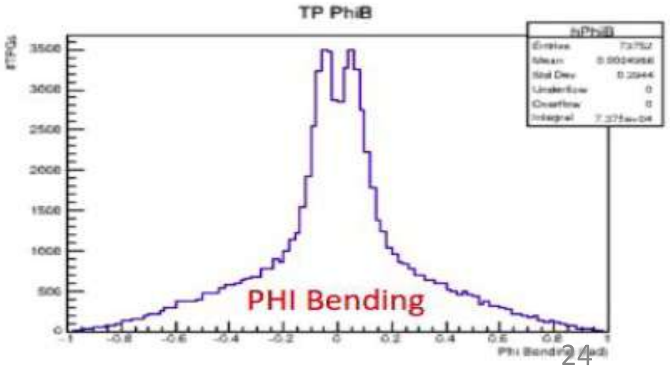
BMT Slice tests with proton-proton collisions

- Slices of the DT detector have been instrumented with Phase-II electronics (OBDT).
- The BMT Layer-1 Trigger Processor was taken to P5 (Nov 2022) and was connected to fibers coming from the OBDT detector electronics as well as to the Phase-1 DAQ.
- Data was collected during proton-proton collisions which demonstrated the functionality of the BMT processor card.







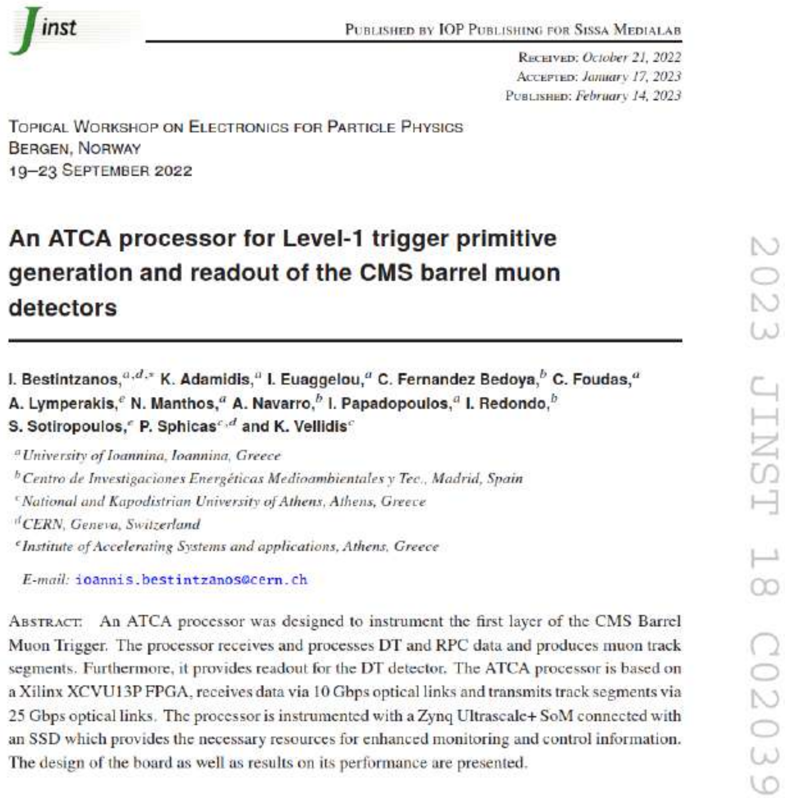


Current BMT L1 Trigger Project status

BMT Layer-1 Milestones

BMT Production Board Design and Firmware Specification Complete (LHCC)	March 19th 2023
BMT Production Pilot Board and Firmware Ready (LHCC)	October 2nd 2023
BMT Production Final Board and Firmware Ready for testing (LHCC)	December 24th 2024
BMT Production Complete (LHCC)	August 20th 2025

- The project is proceeding in a very satisfactory way and has met its milestones so far.
- The BMT Processor design is the PhD topic of I. Bestintzanos (Ioannina) and has been published.
- The design of a revision of the BMT processor is under way. It will be based on halogen free PCB, will be instrumented with a Kria System in Chip processor for monitoring and control (new CMS standard) and parts that have become obsolete will be replaced.



JINST — Published by IOP Publishing for SISSA Medialab

Received: October 21, 2022
Accepted: January 17, 2023
Published: February 14, 2023

Topical Workshop on Electronics for Particle Physics
Bergen, Norway
19–23 September 2022

An ATCA processor for Level-1 trigger primitive generation and readout of the CMS barrel muon detectors

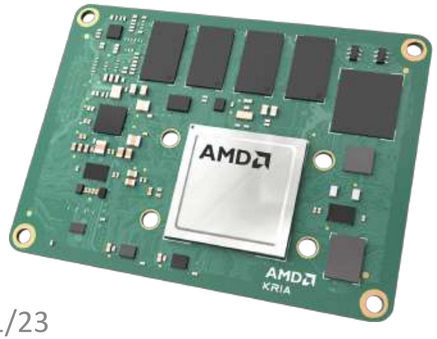
I. Bestintzanos,[a,d,*] K. Adamidis,[a] I. Euaggelou,[a] C. Fernandez Bedoya,[b] C. Foudas,[a] A. Lymperakis,[e] N. Manthos,[a] A. Navarro,[b] I. Papadopoulos,[a] I. Redondo,[b] S. Sotiropoulos,[e] P. Sphicas[c,d] and K. Vellidis[c]

[a] University of Ioannina, Ioannina, Greece
[b] Centro de Investigaciones Energéticas Medioambientales y Tec., Madrid, Spain
[c] National and Kapodistrian University of Athens, Athens, Greece
[d] CERN, Geneva, Switzerland
[e] Institute of Accelerating Systems and applications, Athens, Greece

E-mail: ioannis.bestintzanos@cern.ch

Abstract: An ATCA processor was designed to instrument the first layer of the CMS Barrel Muon Trigger. The processor receives and processes DT and RPC data and produces muon track segments. Furthermore, it provides readout for the DT detector. The ATCA processor is based on a Xilinx XCVU13P FPGA, receives data via 10 Gbps optical links and transmits track segments via 25 Gbps optical links. The processor is instrumented with a Zynq Ultrascale+ SoM connected with an SSD which provides the necessary resources for enhanced monitoring and control information. The design of the board as well as results on its performance are presented.

2023 JINST 18 C02039

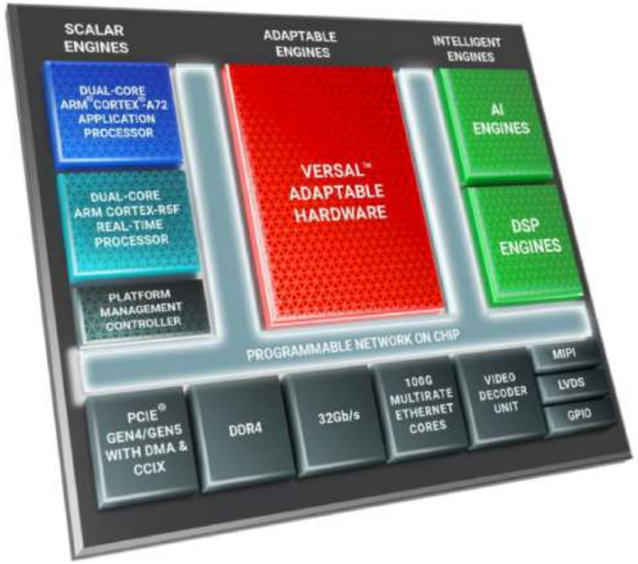


Contributions to the Layer-2 of the Correlator Trigger

- The Layer1 of the Correlator Trigger uses L1-Trigger data processed by particle flow and pile-up subtraction algorithms to produce L1 trigger objects of the highest possible resolution.
- CMS Greece (Bestintzanos, Foudas, Sphicas) has started working on this project and have made in developing firmware for a seeded-cone jet-finder for jets with a wide cone (R=0.8). The code has been tested successfully and a lower latency has been achieved.
- In collaboration with the CERN CMS L1-Trigger group have been investigating new technologies which could be useful to the CMS Trigger and perhaps elsewhere. Namely we have been experimenting with the new Versal parts (VC1902) which employ Adaptive Intelligence (AI) engines which are ideal for high through-put systems.

<u>VCK5000</u>

- Versal AI Core ACAP
  - VC1902
- 145 TOPS
  - 400 AIE @ 1.25 GHz
  - 1968 DSPs
  - 900k LUTs
  - 1.8M FFs
  - 191 Mb PL memory
- PCI Express
  - Programmed & I/O through XRT
- Processor System
  - Dual core Cortex-A72 APU
  - Dual core Cortex-R5F RPU
- 16GB DDR4
- 44 GTY transceivers
  - 2 x QSFP28 (100 GbE)

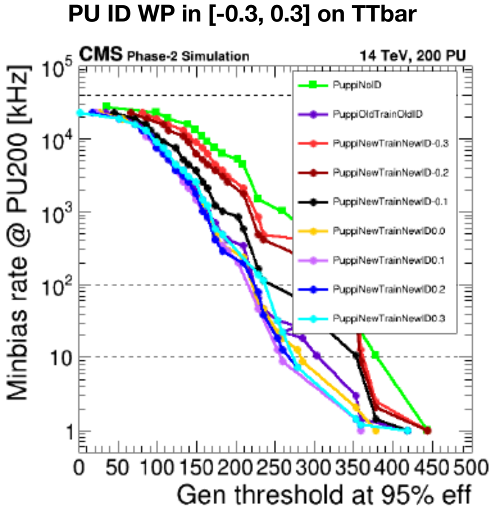


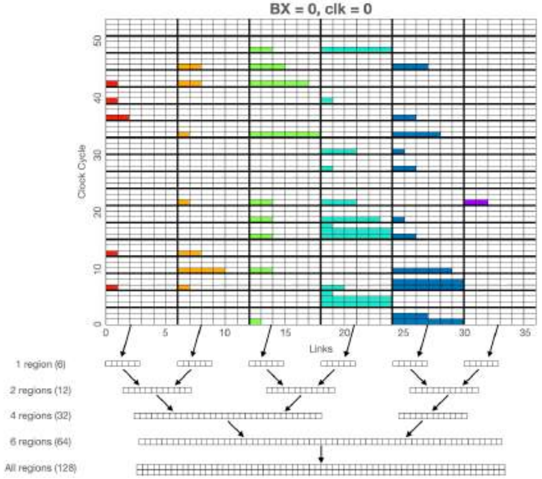
Level-1 Trigger: phase II (HL-LHC)

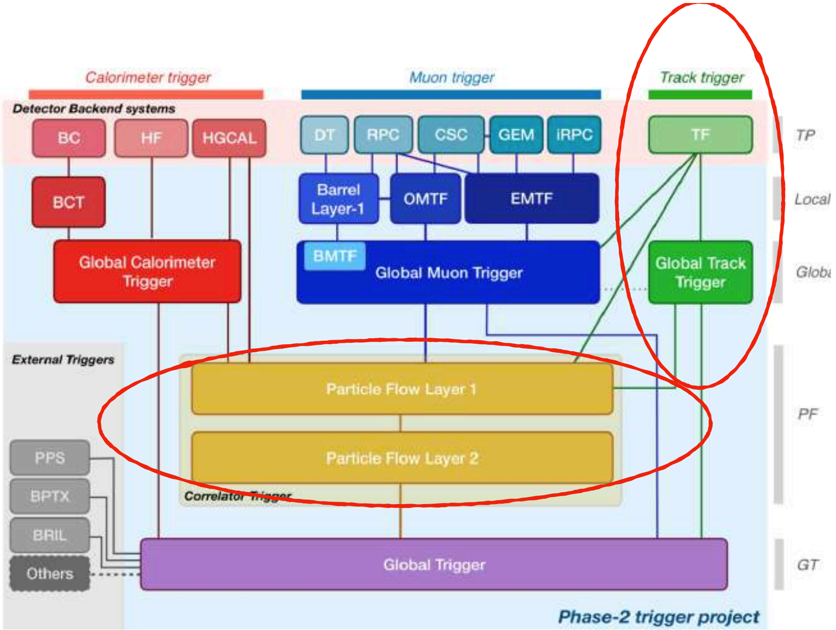
Other responsibilities:

- Global Trigger (with CERN and Estonia)
- Participation in Correlator

Algorithms & Correlator Deregionizer Emulator (for FPGA)



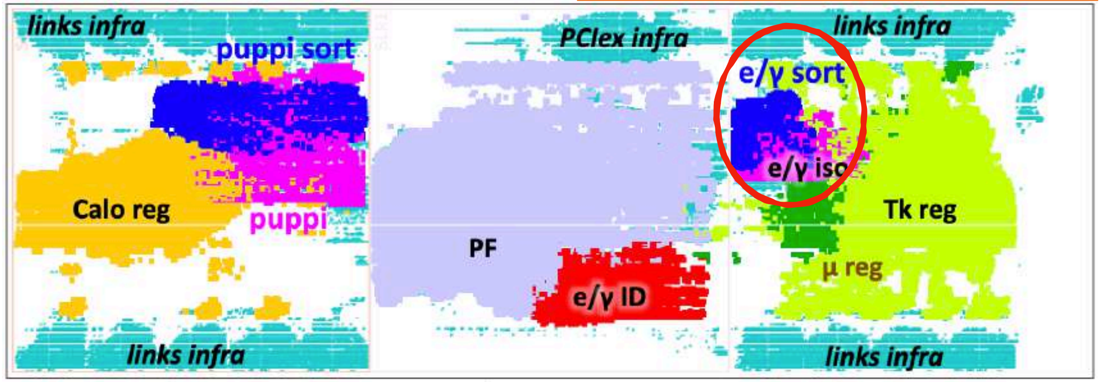




Also:

- L1 pflow contributions
  (reconstruction algo)
- L1 correlator e/g performance studies
- 40 MHz scouting at Level-1 trigger

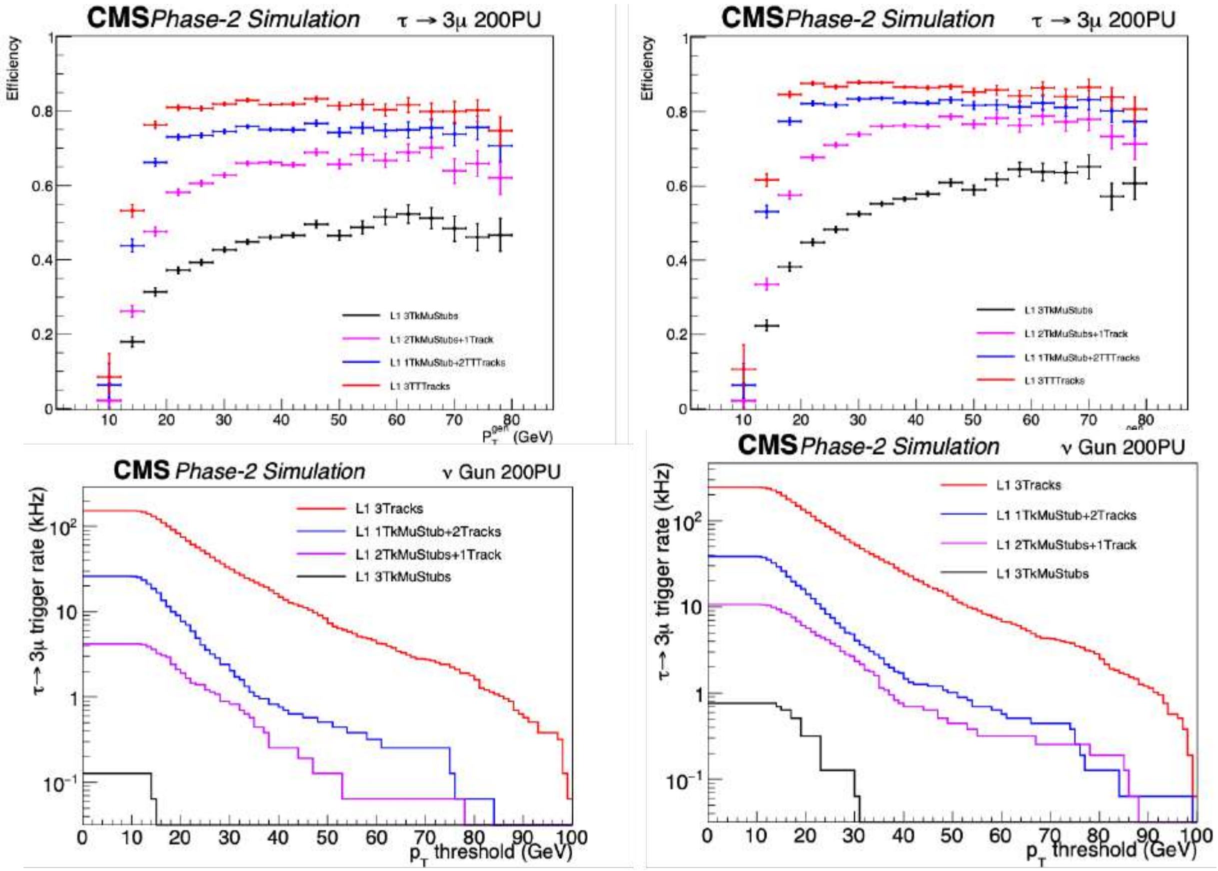
Correlator FPGA Firmware



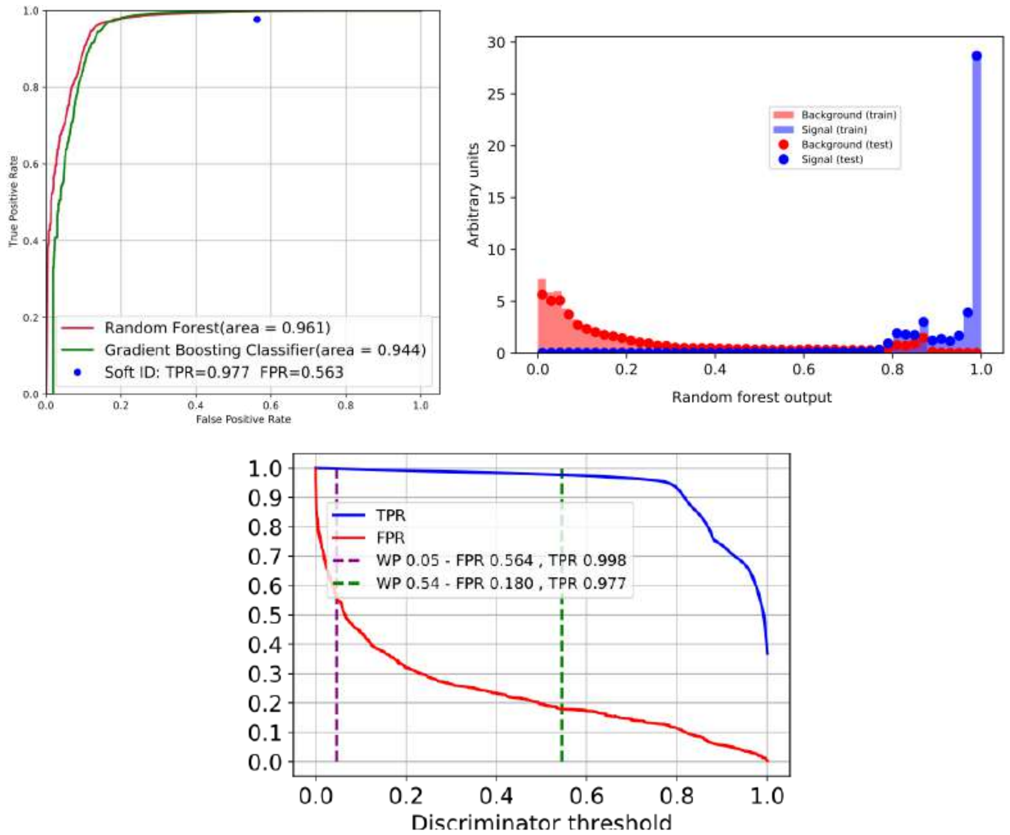
Level-1 Trigger: phase II (HL-LHC)

- Simulations of new triggers for Phase II signals (including scouting)

τ→μμμ



MVA soft muon ID (reduce PU rate, but retain high ε(signal)



C. Vellidis & students

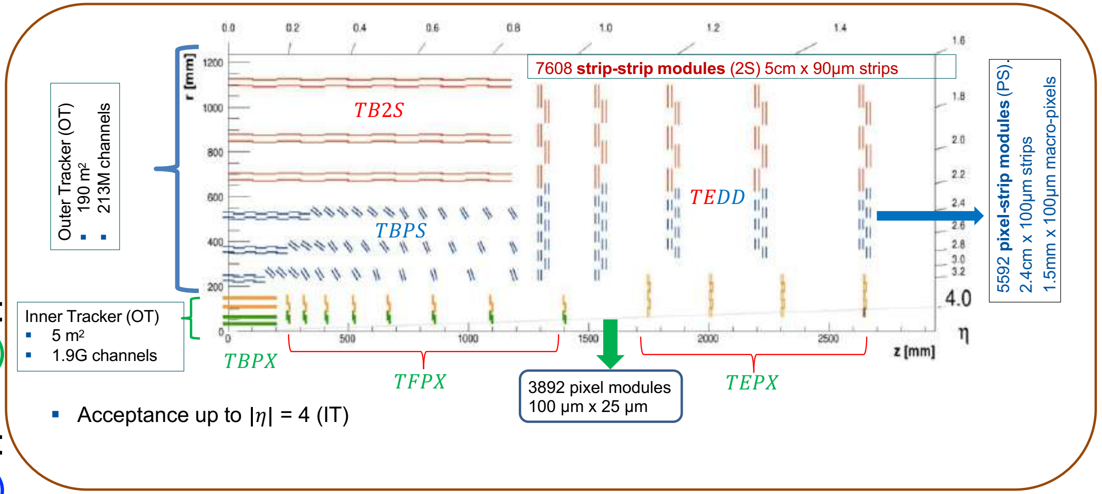
The CMS Phase II Tracker

Main areas of contribution to the CMS Phase-2 Tracker

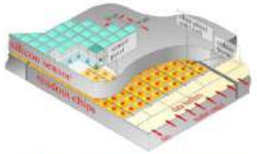
- ➢ **Development of Silicon Sensors**
- ➢ **Quality Control of Si Sensors Production**
- ➢ **Firmware & Middleware for the Inner Tracker**
- ➢ **TCAD Simulations**
- ➢ **Radiation tests with ^{60}Co**

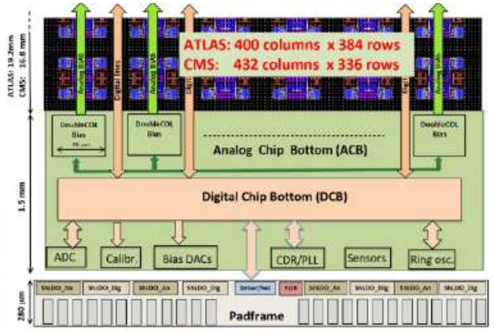
- Two major components based on Si sensors: Outer Tracker (OT) & Inner Tracker (IT)
  - ➢ OT: with P_t modules for L1 trigger: Strip-Strip (2S) and Pixel-Strip(PS)
  - ➢ IT : Pixels 25 x 100 μm^2

One quarter of the Phase-II CMS silicon Tracker detector



- ➢ Hybrid Module Design:
  - ○ Separate Sensor and readout chip
  - ○ Flip chip assembly with bump bonding





- ➢ Readout chip developed by the RD53 Collaboration (CMS + ATLAS)
  - ○ 65nm process (TSMC)
  - ○ **RD53A:** Half-sized demo version, extensively tested
  - ○ **CROCv1**: Full-sized (336 x 432 pixels) pre-production prototype, Sep '21
  - ○ Final version (CROCv2) submitted in October '23

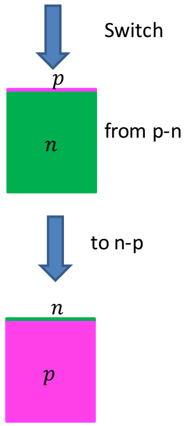
CMS - Phase II TrackerTeam:
I. Kazas, A. Kyriakis, D. Loukas (Demokritos)

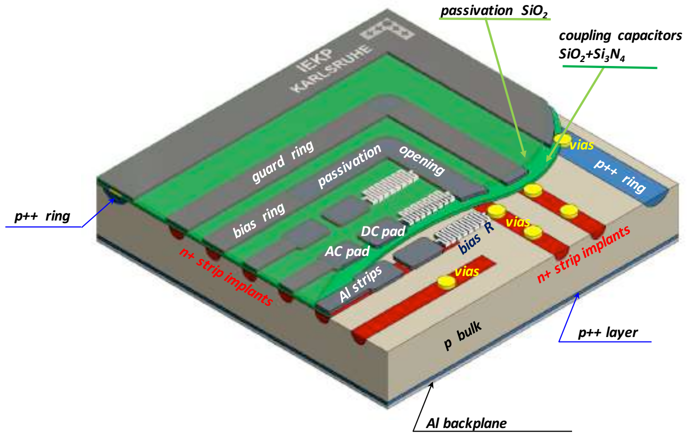
GR Contribution to R&D for the Phase II OT CMS Tracker

- Development of Si Sensors :

  For almost a decade, the CMS experiment has been conducting a campaign that ultimately led to the choice of ***n on p*** *silicon sensors. Demokritos group joint this effort in 2015.*

  - Our group contributed to the development and evaluation of prototypes.



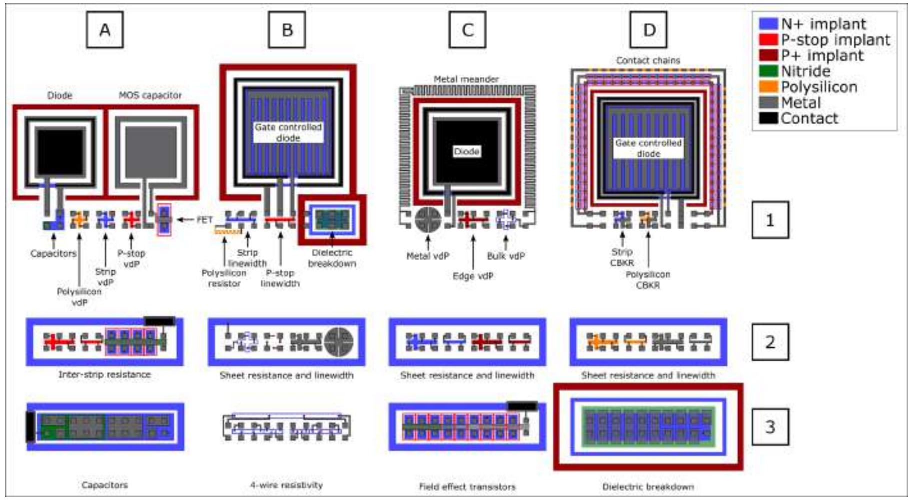


- Process Quality Control of Si Sensors Production (PQC)

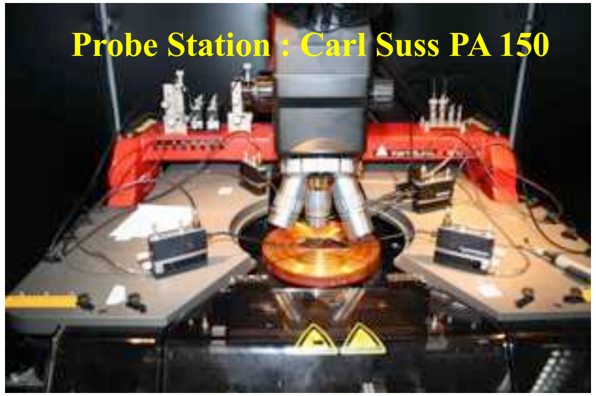
  A quality assurance plan to ensure the full compliance of all sensors with the technical specifications and to monitor their production procedure and fabrication stability with Test Structures:
  (Diodes, MOS, Van der Pauw, , metal meaders, gated diodes etc)

  - **Demokritos** is one of the four CMS centers for PQC during sensor production

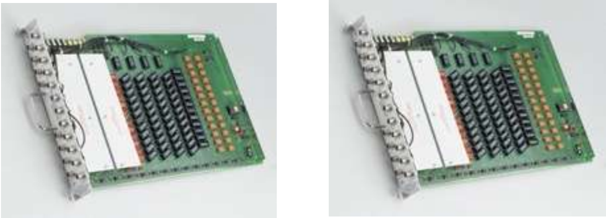
Test Structures



Local Instrumentation



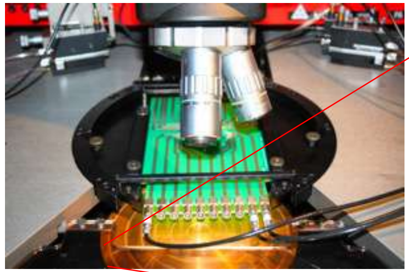

switching matrix

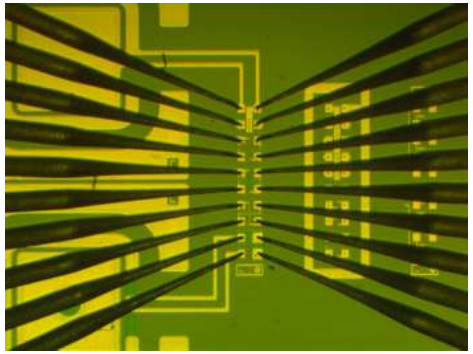

matrix cards

Climatic Chamber

Test Structures

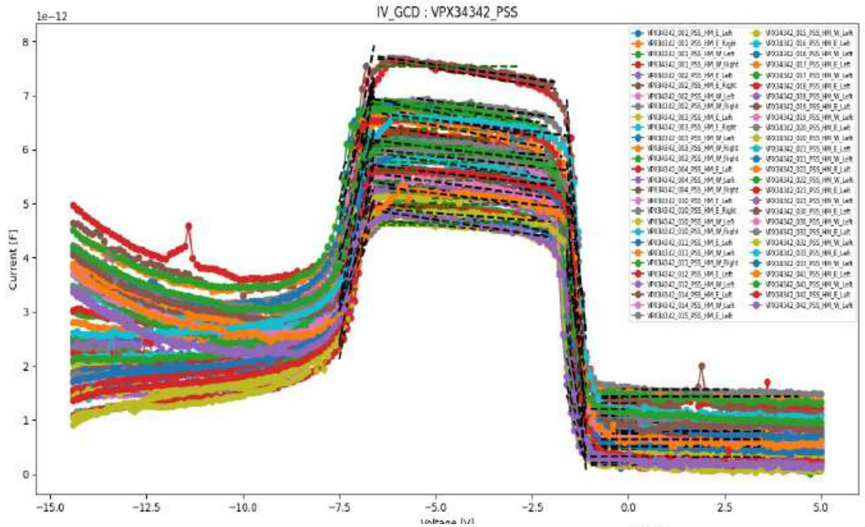
Probe Station Custom Card

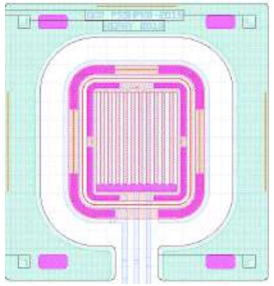

probe card

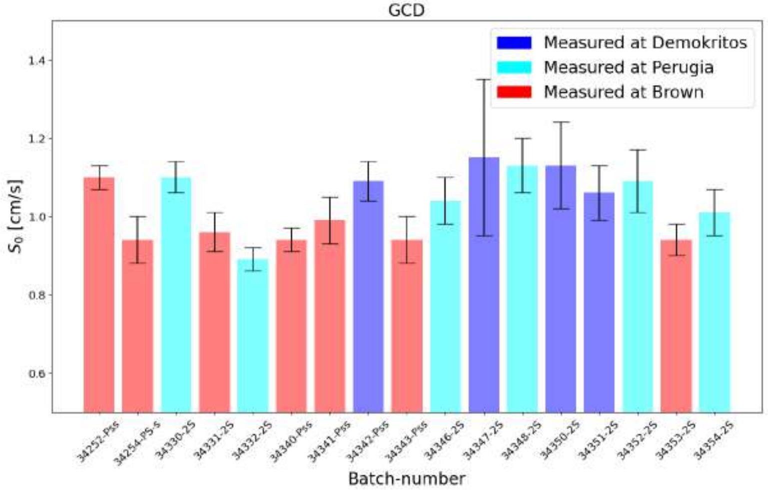


PQC Example - TCAD Simulations

Summary of Gate Condrolled Diode Measurements
in three CMS Process Quallity Centers

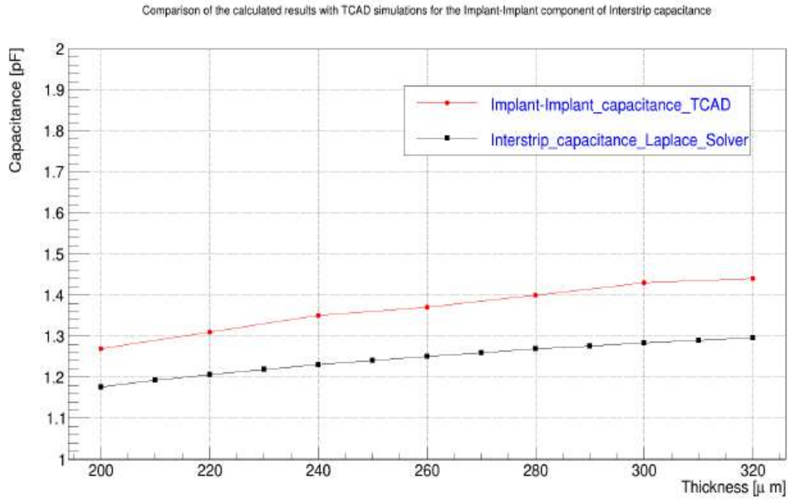


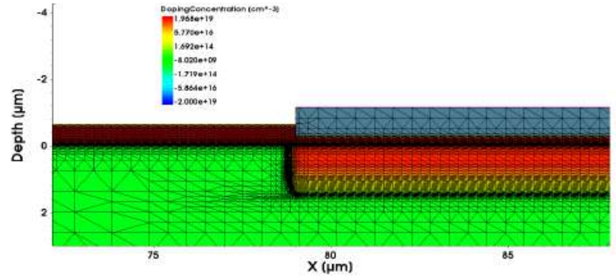




EDA Tools : Access via Europractice to EDA design tools (Cadence, Synopsys TCAD, OrCad)

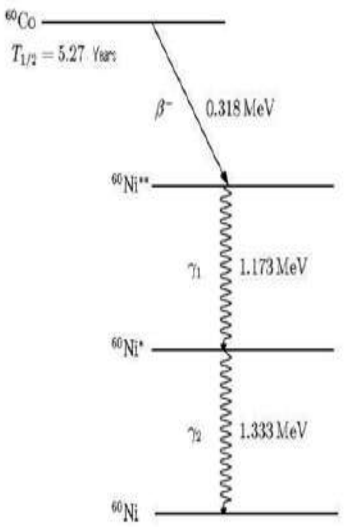
Implant-Implant TCAD Simulation of Interstrip Capacitance of 2S sensors vs sensor thickness. TCAD results compared to those obtained with a Laplace Solver developed by our group[1]

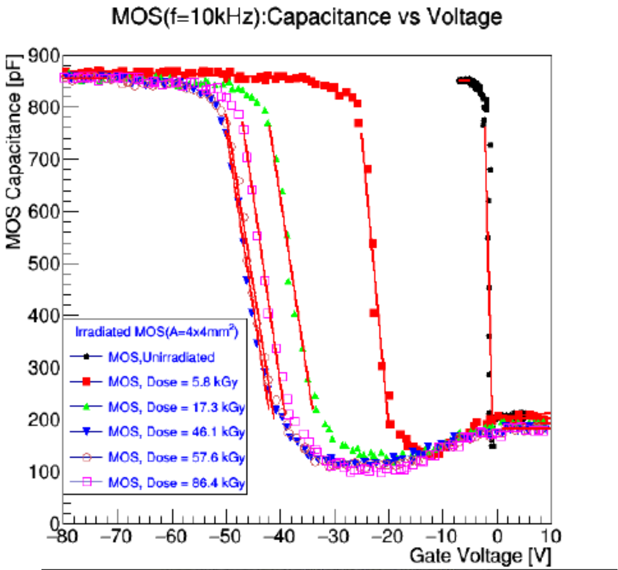


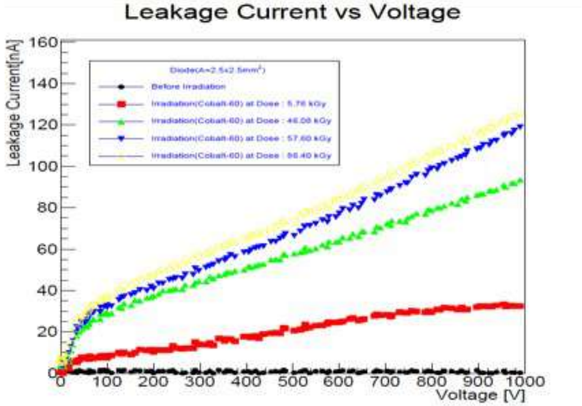


[1] P. Assiouras, et al. *"Fast calculation of capacitances in silicon sensors with 3d and 2d numerical solutions of the laplace's equation and comparison with experimental data and TCAD simulations".* Journal of Instrumentation, 15(11):P11034–P11034, nov 2020.

MOS and Diode irradiation studies for Phase 2 CMS Tracker Upgrade







^{60}Co source: Picker therapy unit 30 TBq (March 2012) horizontal orientation (~11 TBq October 2019) Greek Atomic Energy Commission (GAEC),

diodes

Coordination positions in CMS HL-LHC upgrade projects

- Muon trigger upgrade group coordinator (C. Vellidis)
- Main Firmware Developer for the Inner Tracker, (I.Kazas)
- CMS Annual Review Committee for the DAQ (I. Bestintzanos)
- L1 TDR chapter co-editors: K. Theofilatos, C. Vellidis, M. Vourliotis (PhD student)

CMS Phase II Upgrade Funding

R&D funds	Funding Source	Amount (€)
DeTANet (Development of Detectors, High-Tech Electronics & their Applications)	ESPA	30 k€
ARISTEIA	Min. of Education	40 k€
Highly Miniaturized ASIC Radiation Detector	EU	43 k€
New Generation of sensors and electronics for LHC	ELIDEK	41 k€
Total		***154 k€***

CMS Phase II Upgrade

GR funds through RRB

Si-Tracker	GR contribution	1.4 MCF
L1 – Trigger	GR contribution	1.0 MCF
EndCap Calorimeter HG-CAL	GR contribution	0.35 MCF
Common Fund	GR contribution	0.305 MCF

Total estimated CMS / Greek Contribution: ***3.055 MCHF*** ***(MOU is pending)***

ALICE Phase II

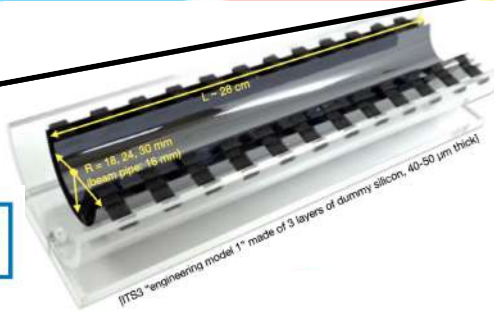
ALICE upgrades

Run 1 2009 - 2013 | Run 2 2015 - 2018 | Run 3 2022 - 2025 | Run 4 2029 - 2032 | Run 5 | Run 6

ALICE 1 | ALICE 2 | ALICE 2.1 upgrade | ALICE 3 upgrade

ITS3
FOCAL

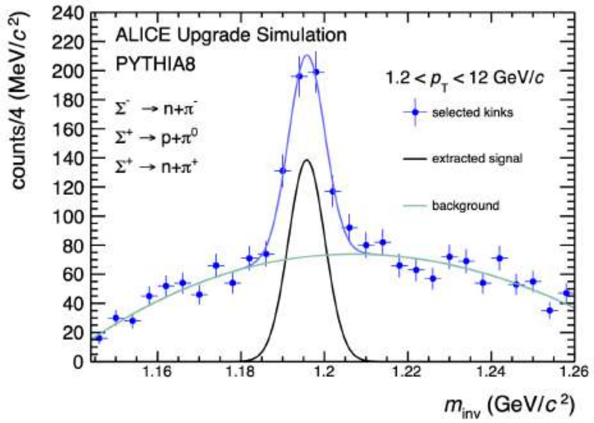
Letter of Intent: CERN-LHCC-2019-018



CERN-LHCC-2022-009

ALICE3

Studies for strange particles identification, especially the charged Σ-baryons via their topological decays to one charged and one neutral daughter (kink)

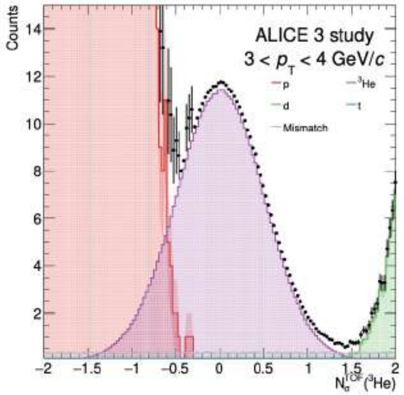


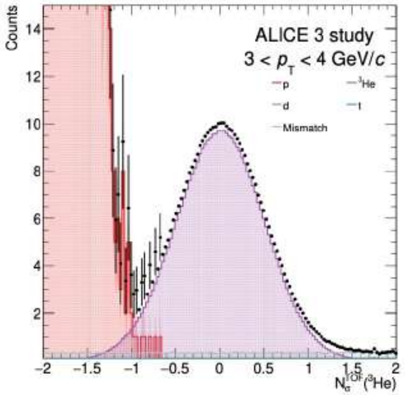
Replacing the 3 innermost layers of ITS2 with **new ultra-light, truly cylindrical layers**:

- **Reduced material budget** (from 0.35% to 0.05% X0)
- **Closer to the interaction point** (from 23 to 18 mm)
- **Improved vertexing performance** and reduced backgrounds for heavy-flavour signals and for low-mass dielectrons

Planned contributions to ALICE3 topics:

- Simulations for Tracker layout specifications
- Strangeness: strange particles measurements will benefit form the Tracker layers closest to the IP (access to lower p_T)
- Search for exotic anti-, hyper- and super-nuclei with TOF detector + shower shape techniques in the Tracker (anti-nuclei and anti-hyper-nuclei with A ≥ 5 have yet to be discovered)





Left: TOF nσ-distribution for the ^{3}He hypothesis without selection on the cluster size in the tracking layers.

Right: After applying an additional selection for tracks with large average cluster size

Summary

- The Greek teams (ATLAS-CMS- ALICE) are strongly involed in the Upgrade projects for the HL-LHC.
- It is very important to have the upgrade MoUs signed asap after their review by GGEK.
- R&D funding, which is so necessary for supporting Greek teams working on Upgrade projects have been lacking
- Most of the funding obtained through the years has been through independent, often different types of calls for research projects or infrastructures, with no regular frequency, sometimes with long gaps between calls.
- It has been, and remains to be, very difficult to formulate any kind of long-term R&D plan.

Thank you