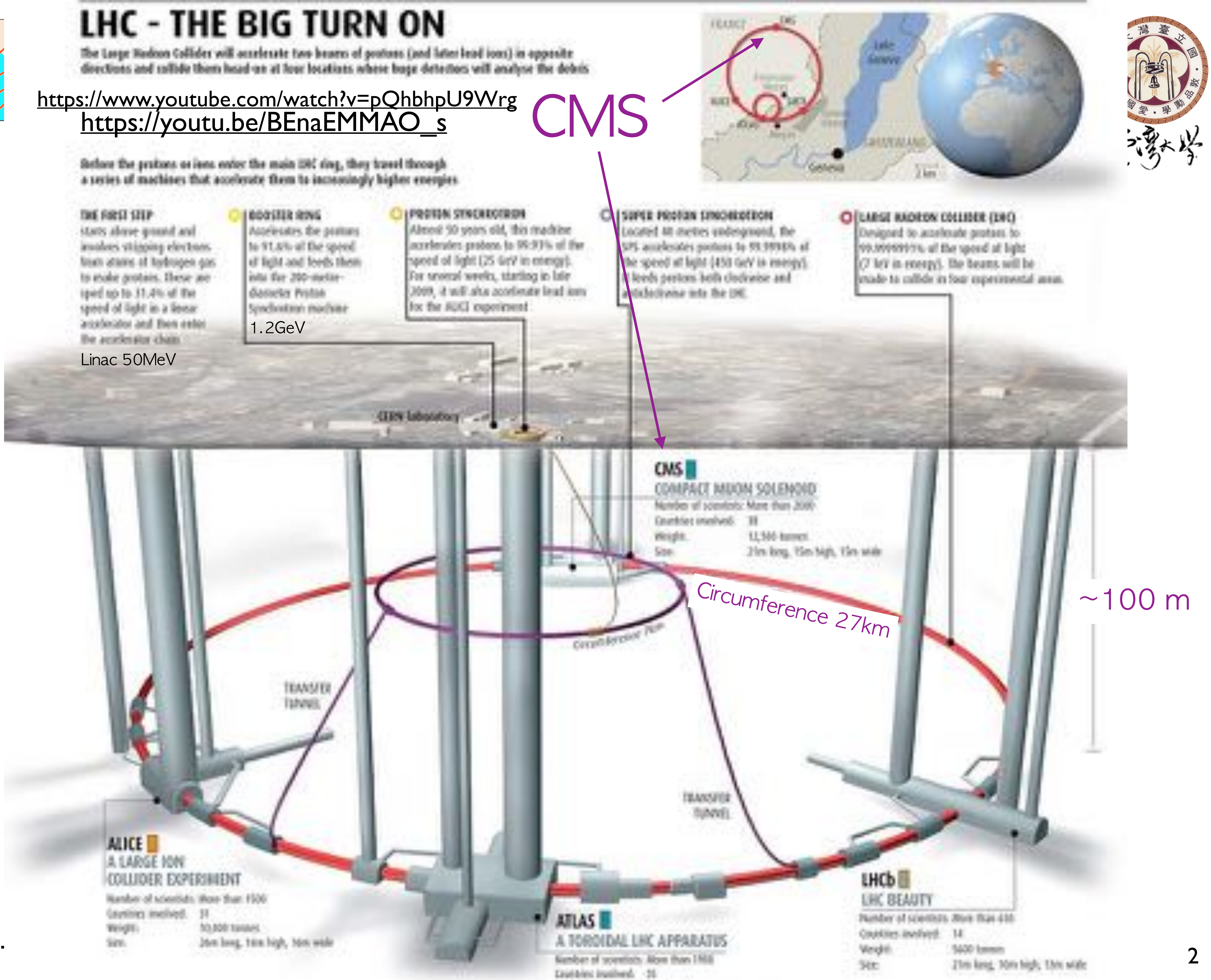
CMS Phase-II upgrade status report

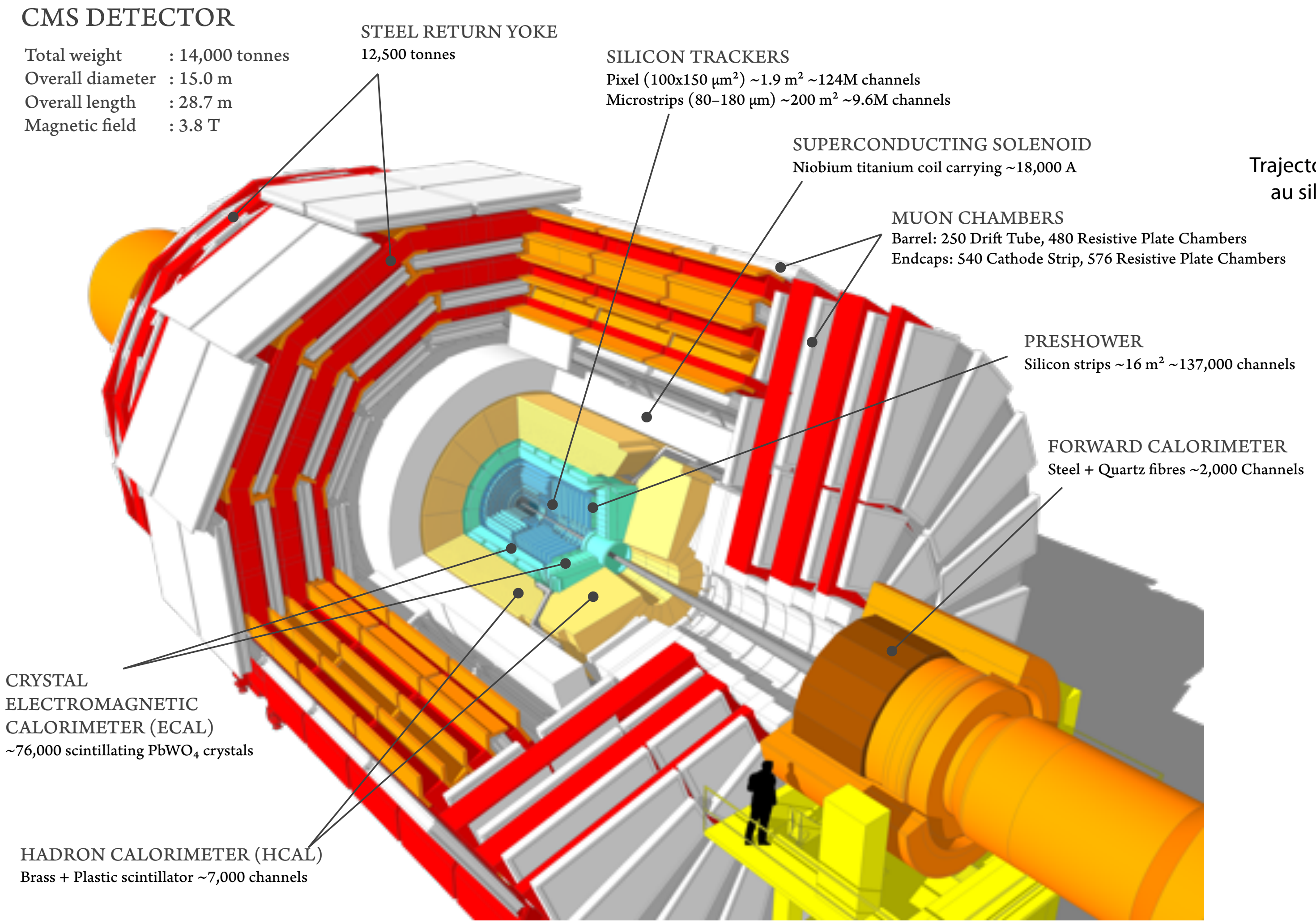
Rong-Shyang Lu
National Taiwan University

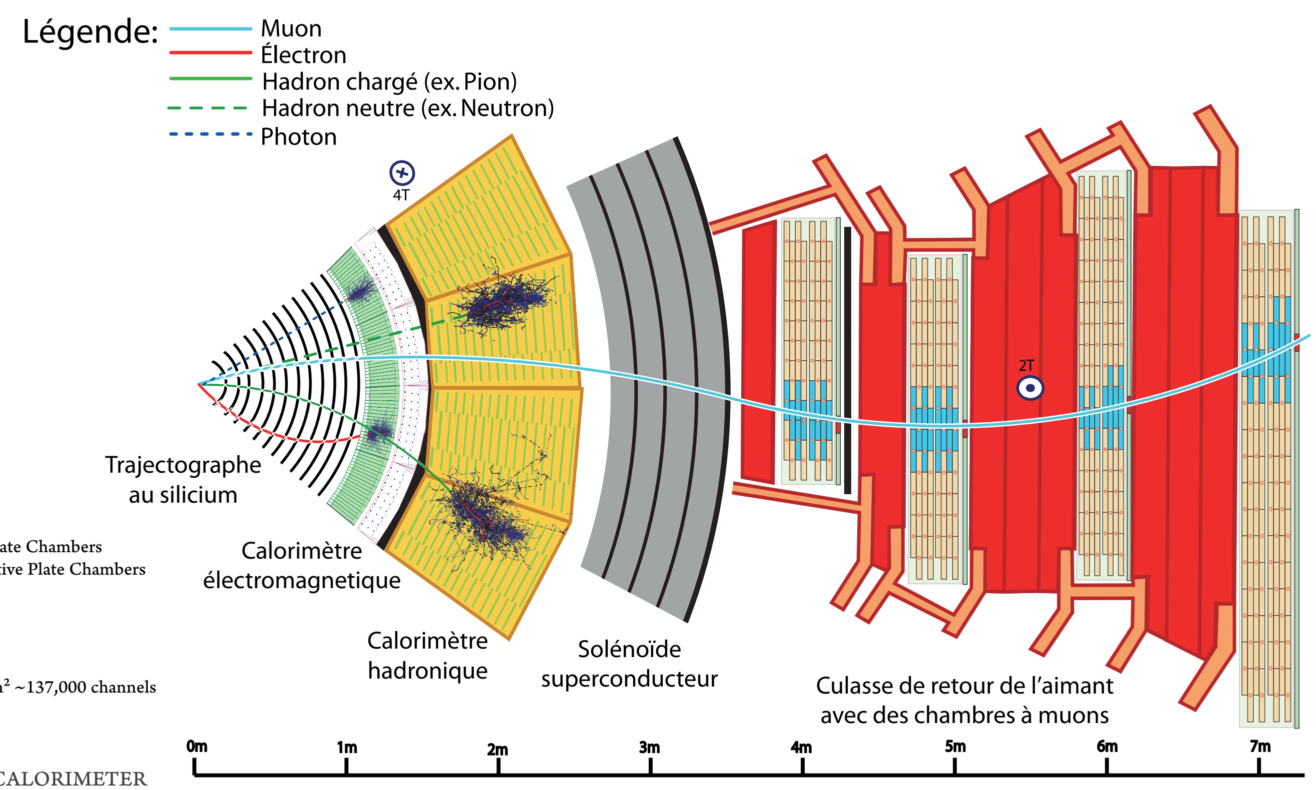
TW HEP meeting
Jan 20-22, 2021

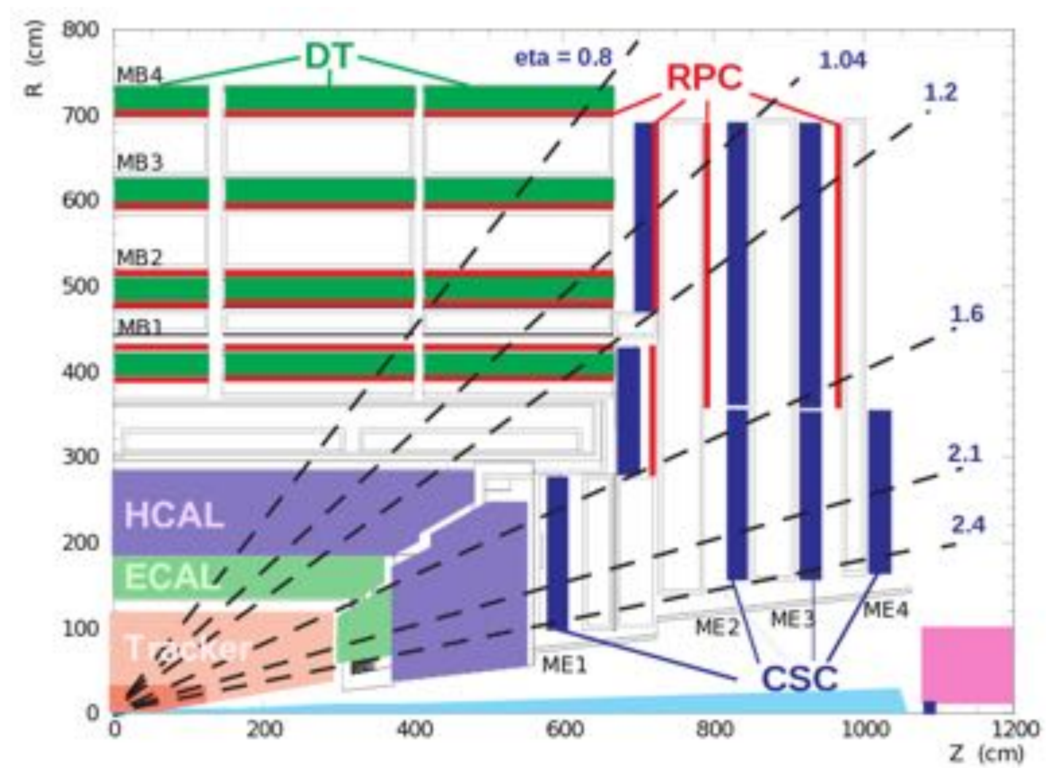
https://www.youtube.com/watch?v=pQhbhpU9Wrg
https://youtu.be/BEnaEMMAO_s



CMS





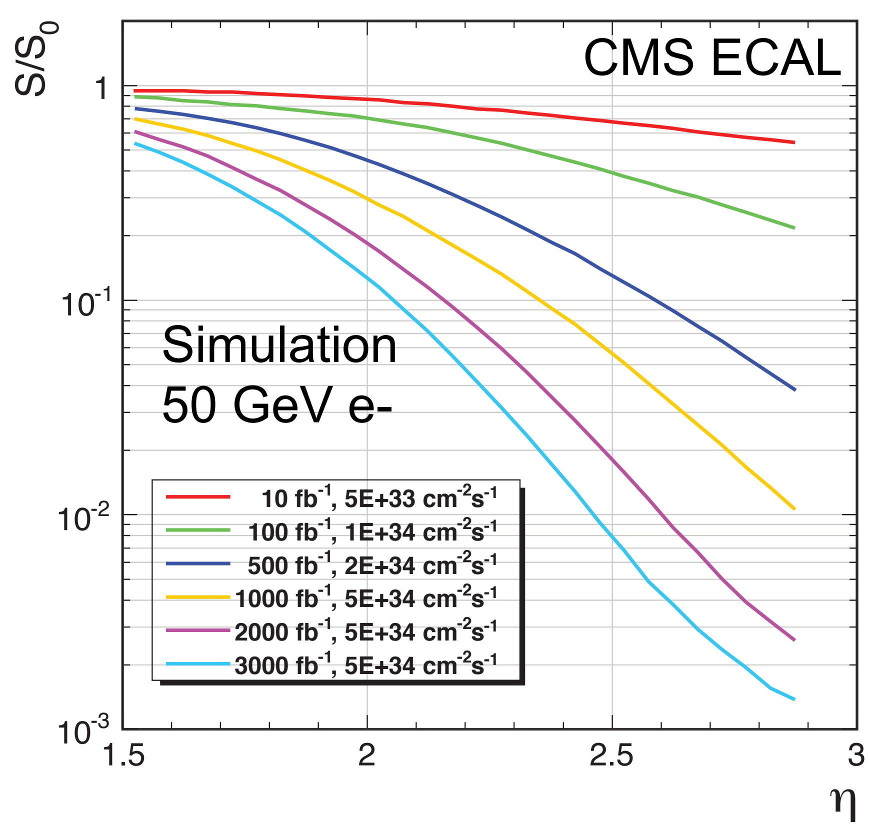


Total weight : 12500 tone
Overall diameter : 15m
Overall length : 21.5m
Magnetic field : 3.8 Tesla

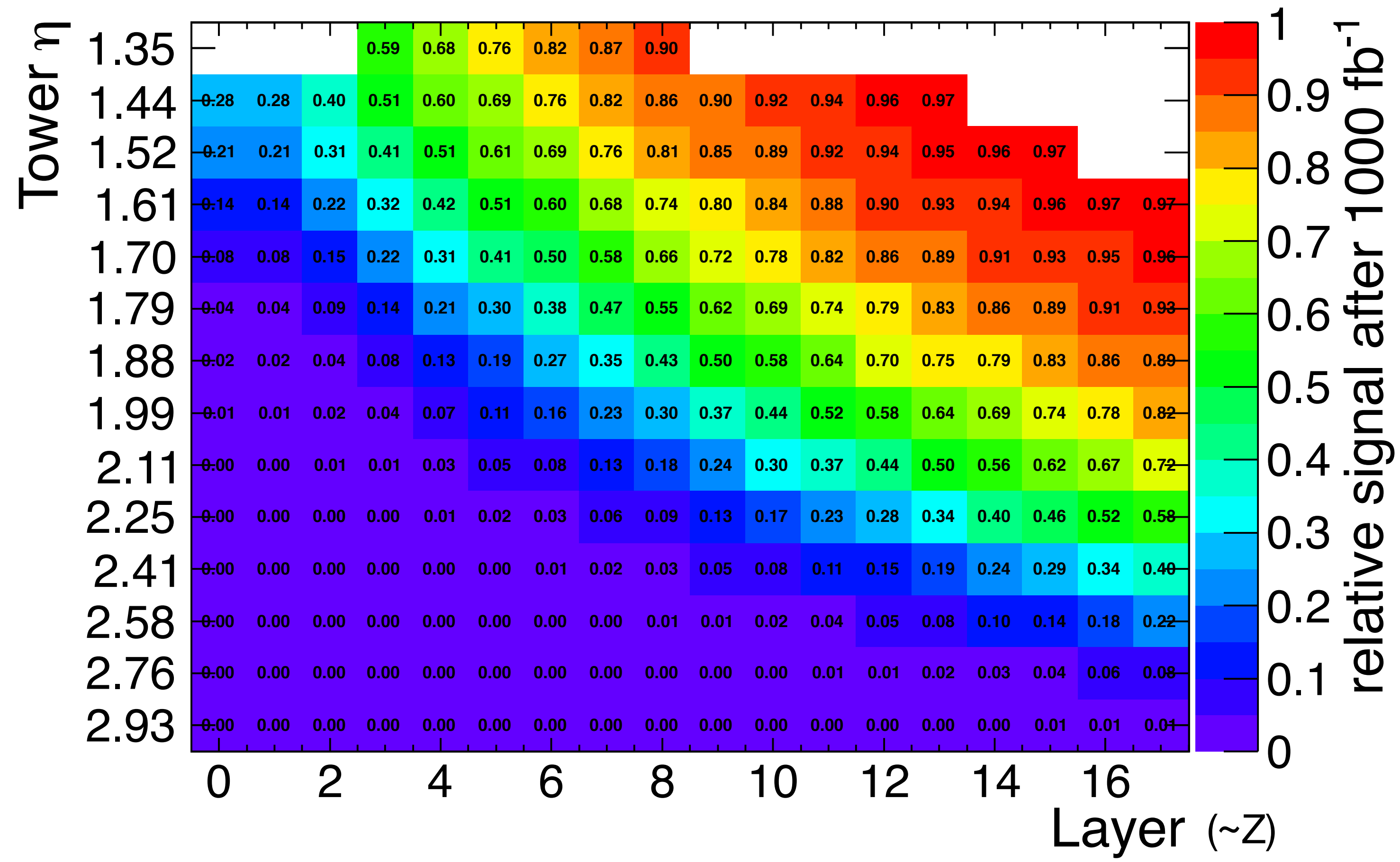
Why Upgrade

- The replacement of CMS Endcap calorimeters is required due to radiation-induced effects.
  - The relative responses of crystals in EE and also HE are low during the HL-LHC period.
  - The resolution of EE will worsen to the O(10%)
- Better angular and lateral resolution, plus fast timing-〉 a futuristic detector

CERN-LHCC-2015-010



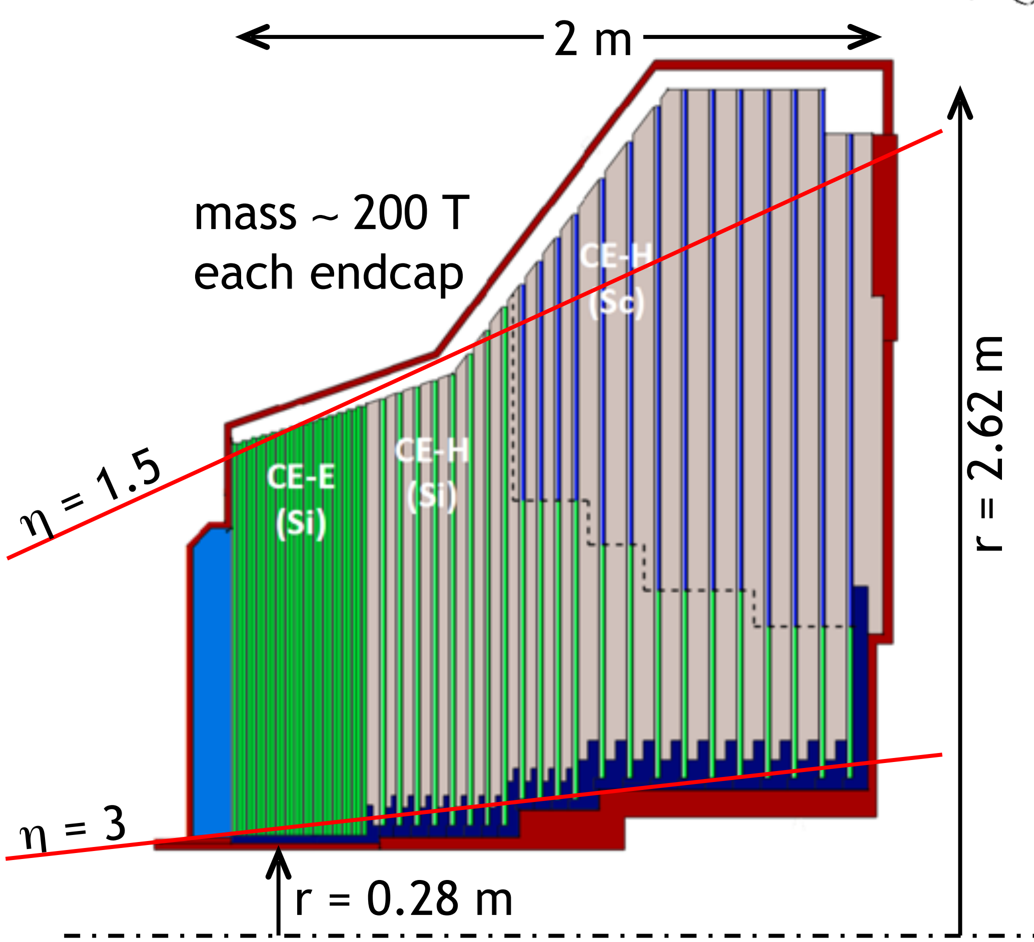
CERN-LHCC-2015-010



HGCAL Overview

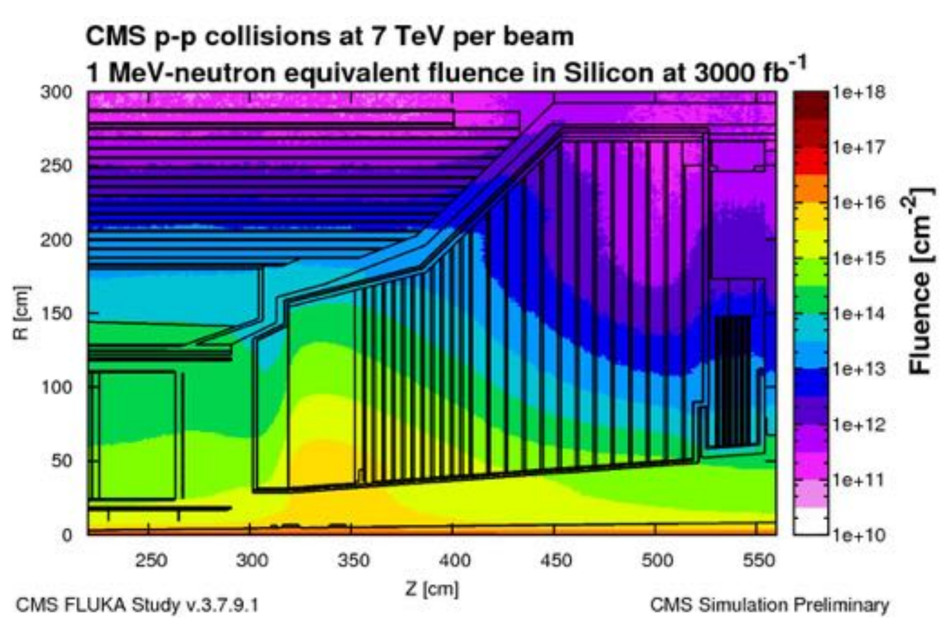
Key Parameters (updated from the TDR):

- HGCAL covers $1.5 < \eta < 3.0$
- **Full system maintained at -30°C**
- **~640 m²** of silicon sensors
- **~370 m²** of scintillators
- 6.1M Si channels, 0.5 or 1.1 cm² cell size *(6M)*
  240k scint-tile channels (η–ϕ)
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all in CE-H
- ~31000 Si modules (incl. spares)



Active Elements:

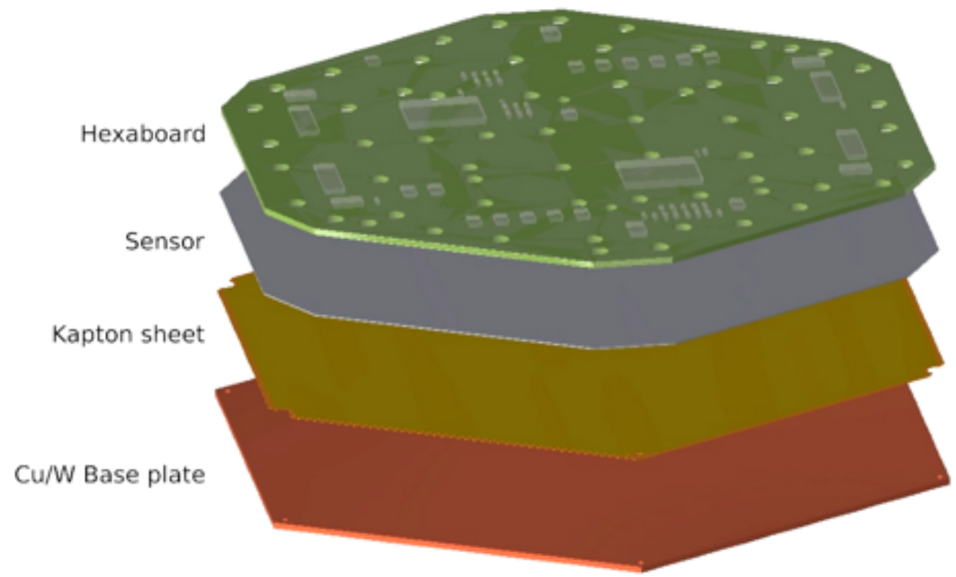
- Si sensors (full and partial hexagons) in CE-E and high-radiation region of CE-H.
- SiPM-on-Scintillating tiles in low-radiation region of CE-H

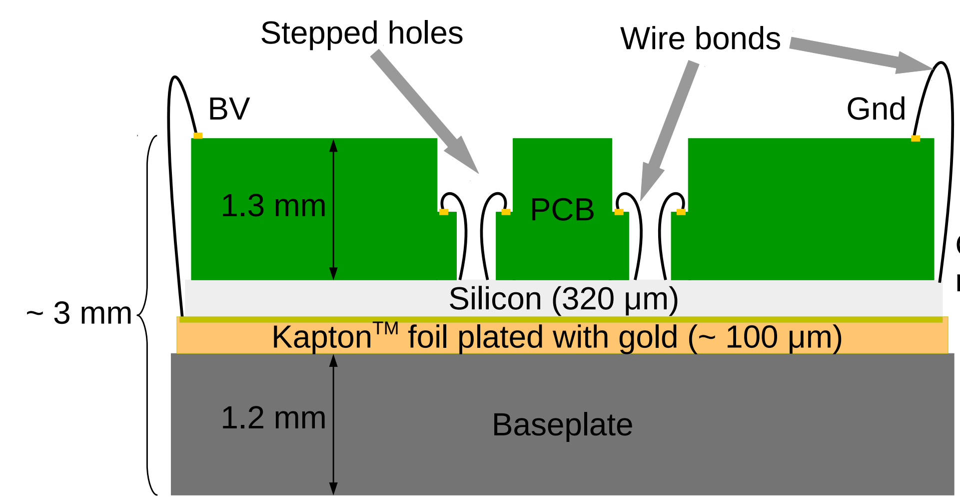


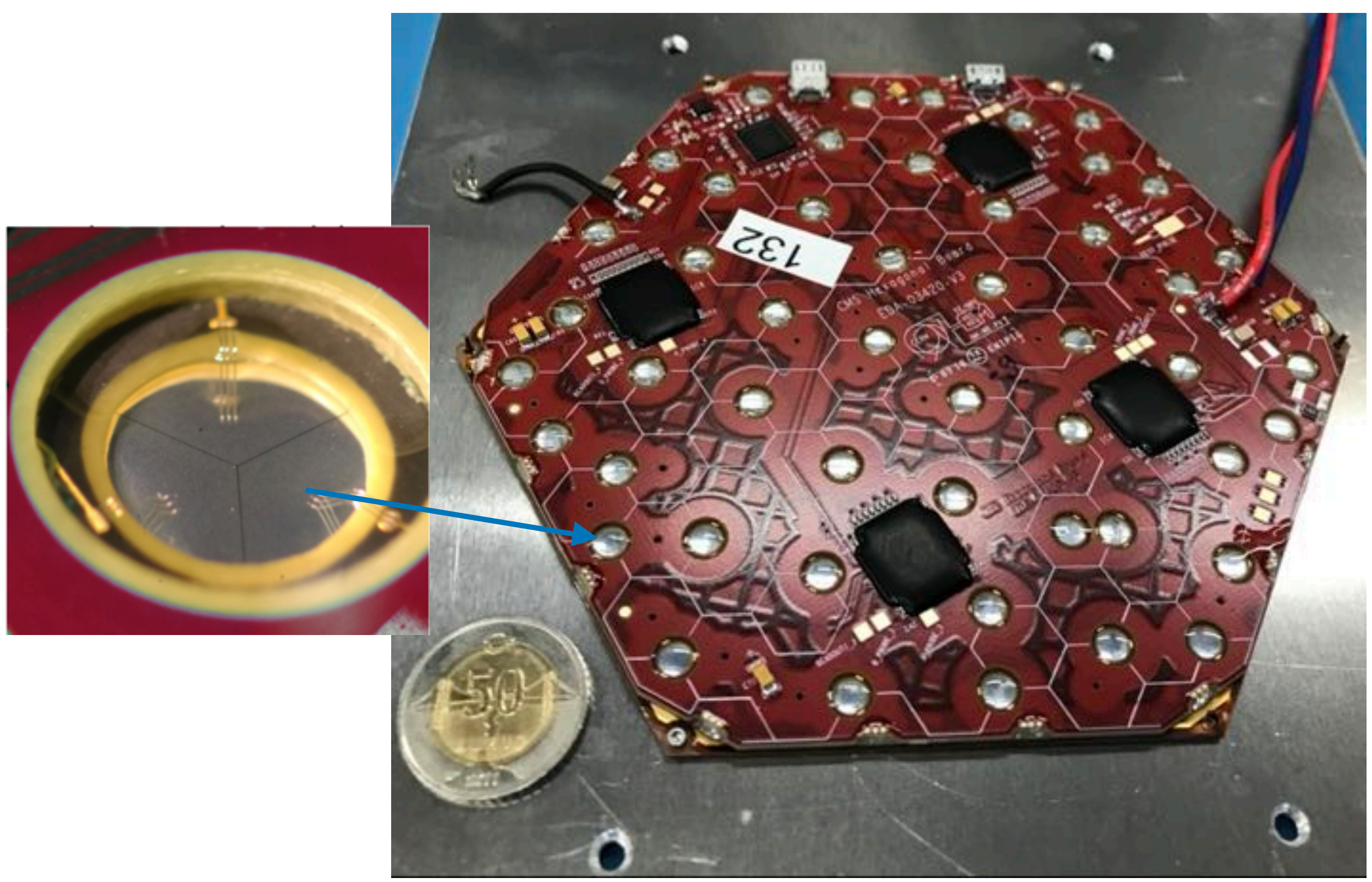
✦ Electromagnetic calorimeter (**CE-E**): **Si**, Cu/CuW/Pb absorbers, 28 layers, 25.5 X_0 & ~1.7λ

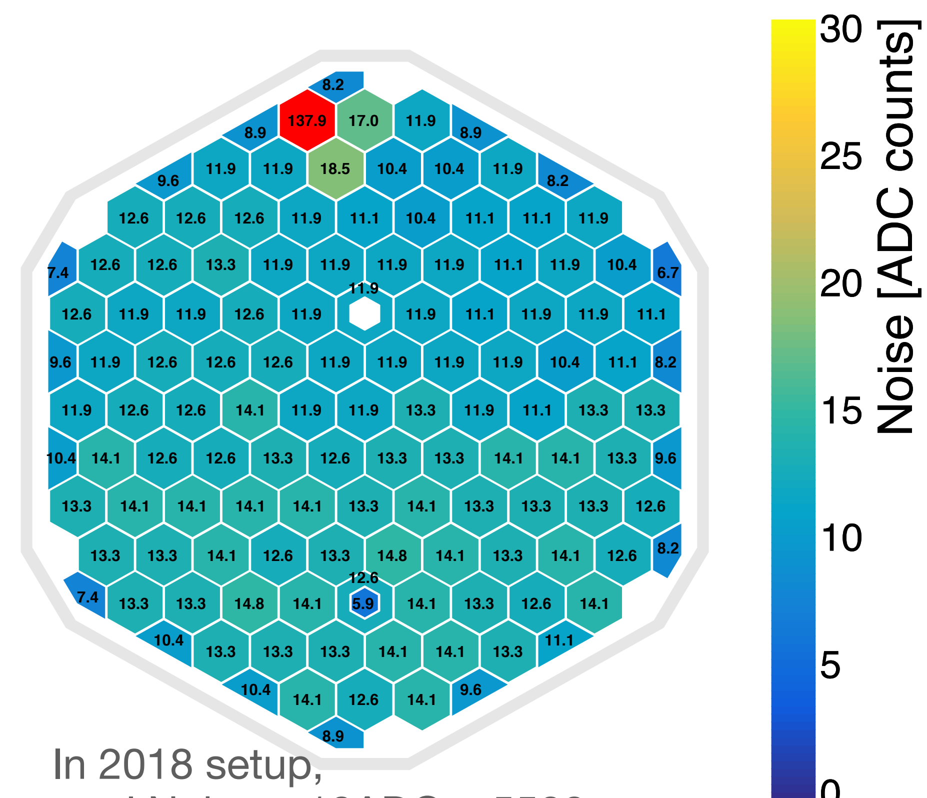
✦ Hadronic calorimeter (**CE-H**): **Si & scintillator**, steel absorbers, 22 layers, ~9.5λ (including CE-E)

Silicon module









In 2018 setup,
total Noise ~ 10ADC ~ 5500 e-
Intrinsic noise ~ 5ADC
MIP ~ 40 ADC

HL-LHC plan


LHC / HL-LHC Plan
HiLumi
LARGE HADRON COLLIDER
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
LS3
7 TeV
8 TeV
13 TeV
13 - 14 TeV
14 TeV
energy
splice consolidation
button collimators
R2E project
cryolimit
interaction
regions
Diodes Consolidation
LIU Installation
11 T dipole coll.
Civil Eng. P1-P5
HL-LHC
installation
5 to 7.5 x nominal Lumi
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
radiation
damage
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
30 fb-1
190 fb-1
350 fb-1
integrated
luminosity
3000 fb-1
4000 (ultimate)
Today
HL-LHC TECHNICAL EQUIPMENT:
DESIGN STUDY
PROTOTYPES
CONSTRUCTION
INSTALLATION & COMM.
PHYSICS
HL-LHC CIVIL ENGINEERING:
DEFINITION
EXCAVATION / BUILDINGS

Brief history of NCU+NTU joining HGCAL

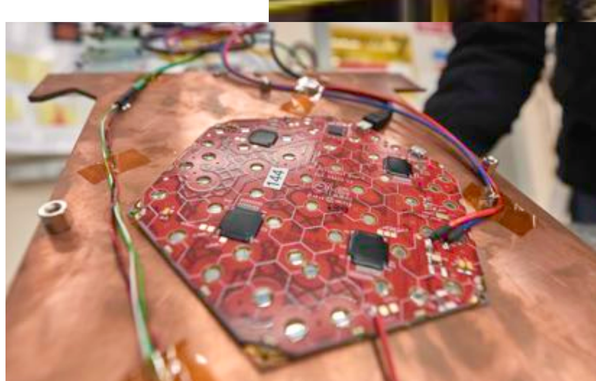
- Phase 2 competition between HGCAL and Shashlik-EM(W+Lyso)+HE-rebuilt. HGCAL was chosen. NTU and NCU were contacted for HGCAL collaboration based on on experience on silicon detectors.
- NTU and NCU participated R&D of prototypes and became one of the 6 detector assembly centers (NTU+NCU Taiwan, IHEP China, TIFR India, UCSB US, TTU US, CMU US)
- NTU hosts main assembly lab and NCU hosts Sensor Qualification Center (SQC, the others are HEPHY Vienna, CERN, FSU and TTU)
- TDR approved in 2017
- MoST/NTU/NCU signed phase-2 MoU with CERN on 2018

NTU/NCU involvement

- R&D
  - Testbeam exp. with silicon-module prototype
  - System test with ASIC and hexaboard designers on front-end development
  - DC-DC converter design
- Module Assembly Center (MAC)
  - Setup Sensor Qualification Center (SQC)
  - jig designs and assembly procedures
  - 6/8-inch prototype assembly for system test
- Detector Performance Group (DPG) toward analysis

Testbeam exp.

- R.-S. Lu was (L2) co-convener during 2017-2018.
- Several beam-test @CERN, FNAL and DESY between 2016 and 2018 studying prototype 6-inch silicon modules.
- NTU-NCU led the effort on setup, DAQ and data analyses.



Testbeam exp.

- 2016 results are published on JINST 13, P10023(2018)
- 2018 results will be published in several papers. Two papers submitted to JINST on Dec. 2020. More drafts on the performance in preparation.

Available on CMS information server CMS DN -2020/018

The Compact Muon Solenoid Experiment
Detector Note
The content of this note is intended for CMS internal use and distribution only

08 April 2020 (v7, 02 December 2020)

Submitted to JINST

Construction and commissioning of CMS CE prototype silicon modules

J inst PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *April 19, 2018*
REVISED: *August 23, 2018*
ACCEPTED: *September 20, 2018*
PUBLISHED: *October 18, 2018*

First beam tests of prototype silicon modules for the CMS High Granularity Endcap Calorimeter

N. Akchurin,[r] A. Apreysan,[o] S. Banerjee,[o] D. Barney,[g,1] B. Bilki,[t] A. Bornheim,[m] J. Bueghly,[q] S. Callier,[c] V. Candelise,[h] Y.-H. Chang,[h] Y.-W. Chang,[h] R. Chatterjee,[u]

2018 JINST 13 P10023

Available on CMS information server CMS DN -2020/023

The Compact Muon Solenoid Experiment
Detector Note
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21 April 2020 (v5, 02 December 2020)

Submitted to JINST

The DAQ system of the 12,000 Channel CMS High Granularity Calorimeter Prototype

Available on the CMS information server CMS DN-19-019

The Compact Muon Solenoid Experiment
CMS Draft Note
Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

2020/09/09
Archive Hash: 191f091-D
Archive Date: 2020/09/08

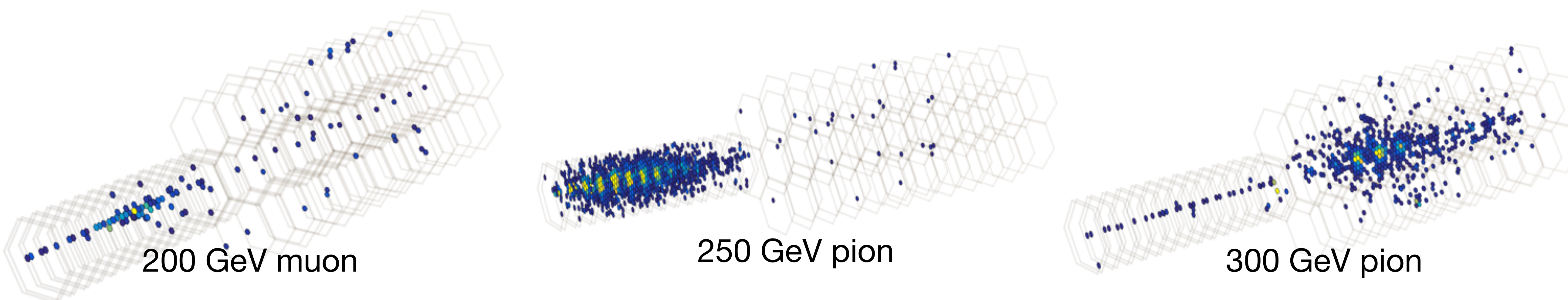
In preparation

Measurement of the response of a CMS HGCAL silicon-pad calorimeter prototype to electrons at the 2018 beam tests

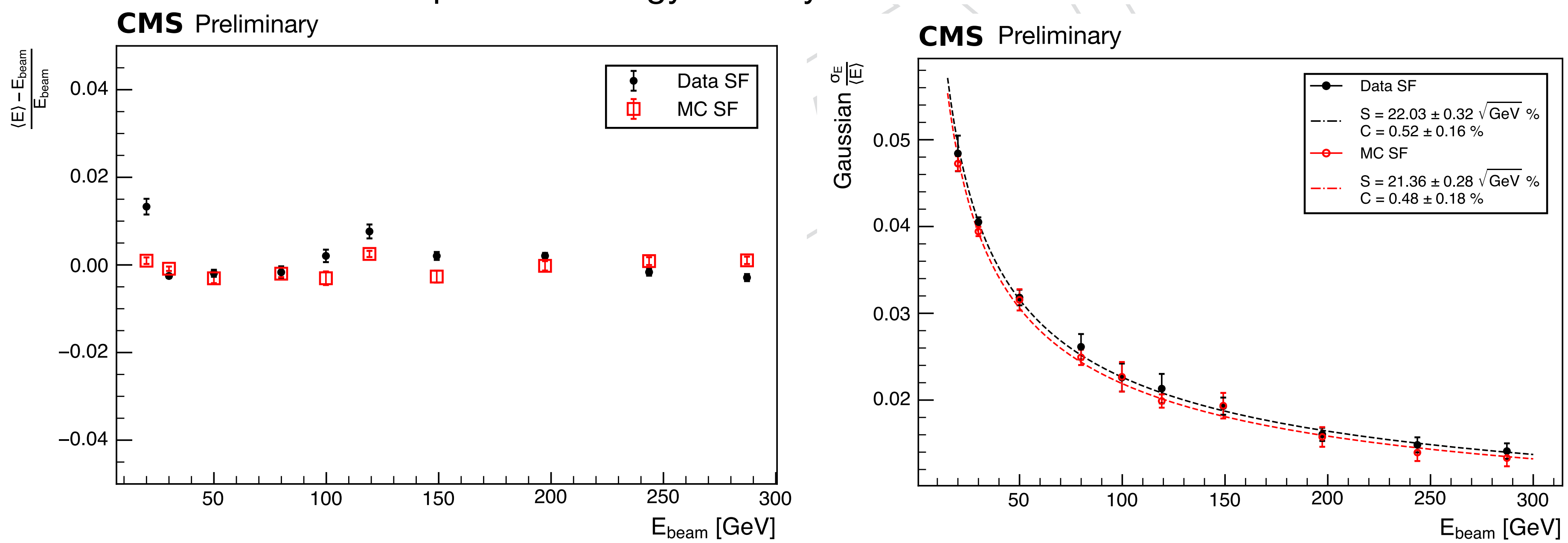
[i] *National Taiwan University, Taipei, Taiwan*
[j] *Çukurova University, Adana, Turkey*

Testbeam exp.

- 2016 results are published on JINST 13, P10023(2018)
- 2018 results will be published in several papers. Two papers submitted to JINST on Dec. 2020. More drafts on the performance in preparation.



2018 TB results on positron energy linearity and resolution

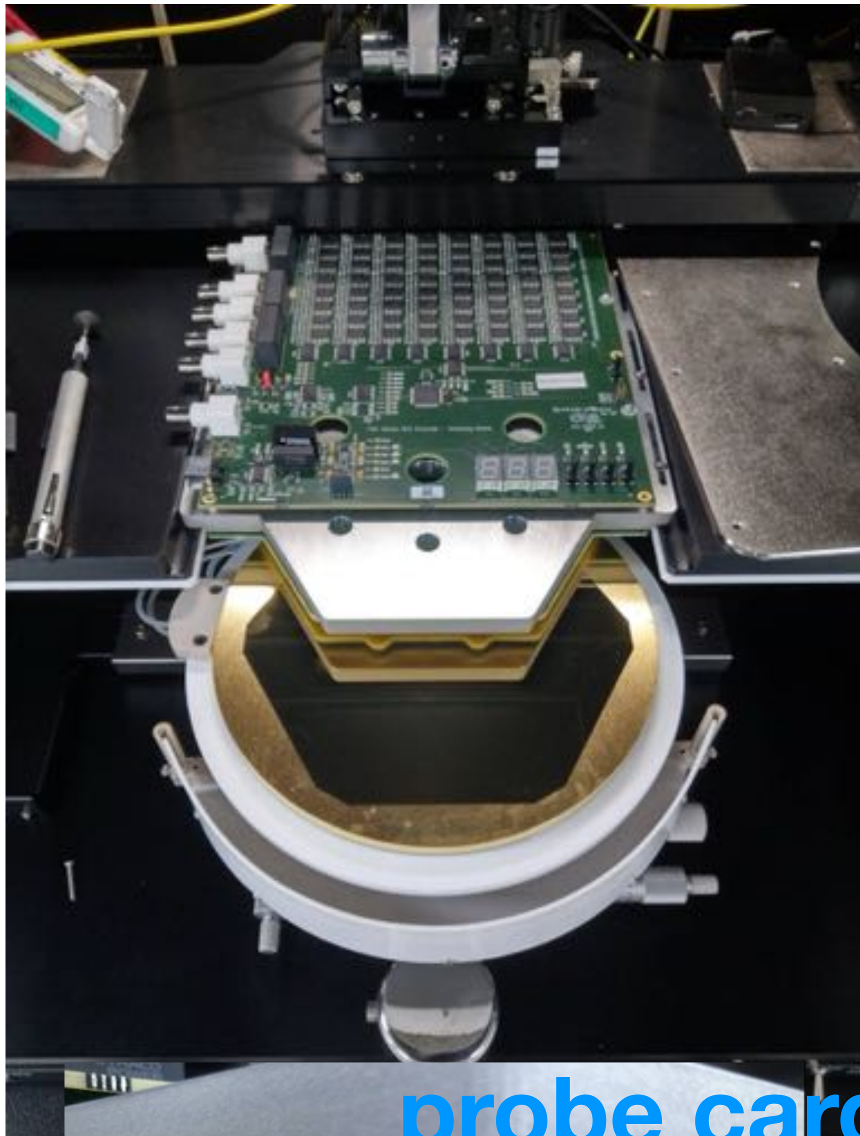


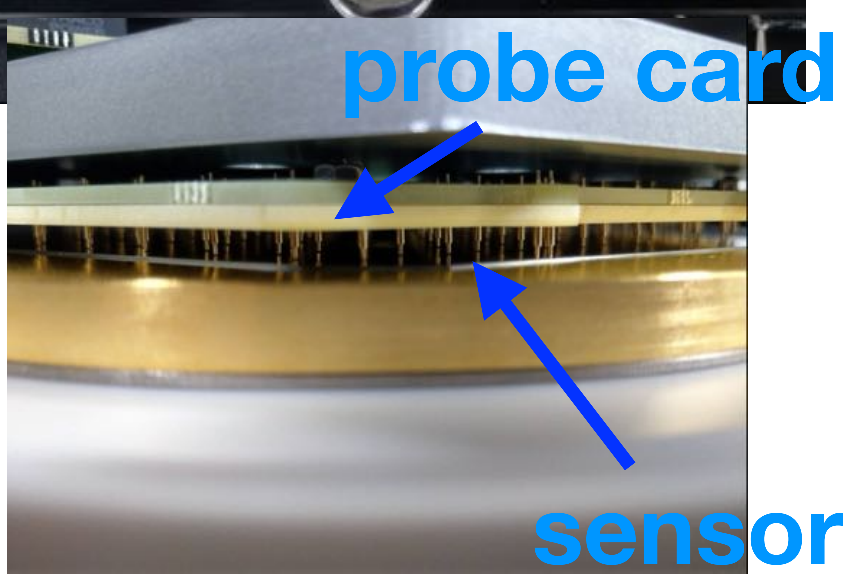
MAC Taiwan

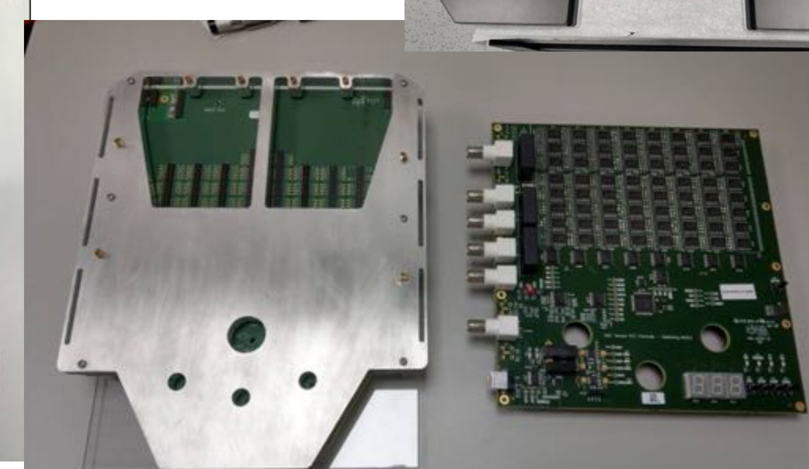
- Taiwan Module Assembly Center (MAC) will build 5,000 out of 30,000 silicon modules between Aug. 2022 and Dec. 2024.
- NCU will be in charge of silicon sensor qualification (SQC) and NTU will perform the assembly of modules.

SQC @NCU

- Sensor tests using the ARRAY system (full wafer probe card with pogo-pins) using front-side biasing
- NCU equips a semi-automatic probe station in the renovated clean-room
- Received Probe-card, switch-card and 4 8-inch sensors from CERN
- Switch card adapter and platon were produced in Taiwan. System, combining above cards, was installed recently

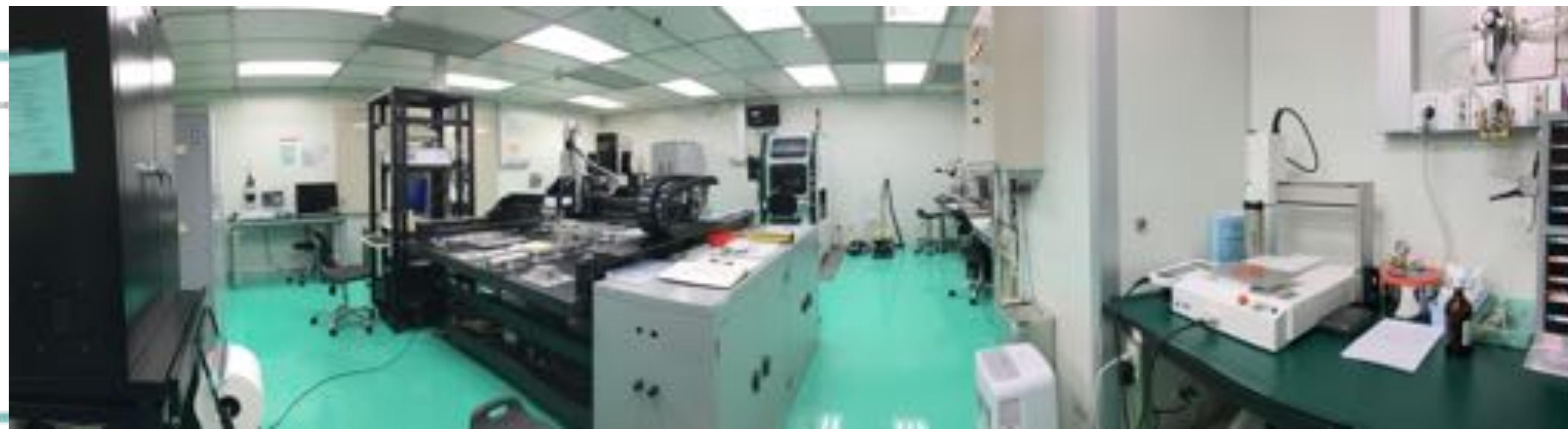




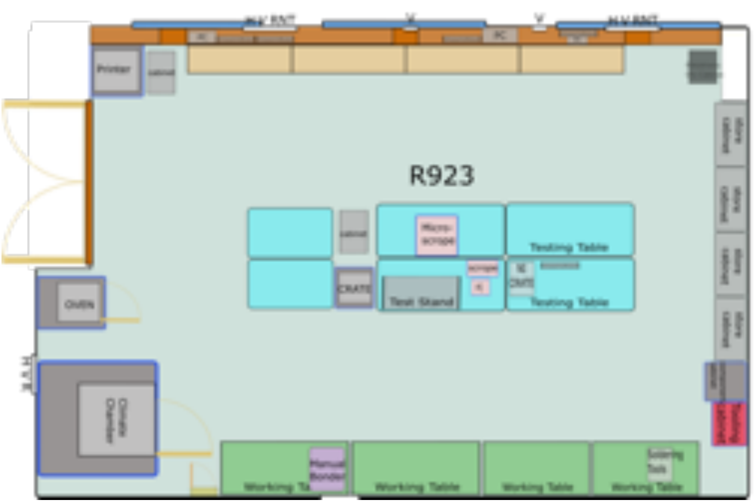


MAC setup @NTU

- Led by Prof. E. Paganis and Prof. R.-S. Lu
- Complete the cleanroom (915) setup including robotic gantry, wire-bonder, probe station and services in spring 2019.
- Setup testing lab (923) with test-stand, climate chamber in early 2020.

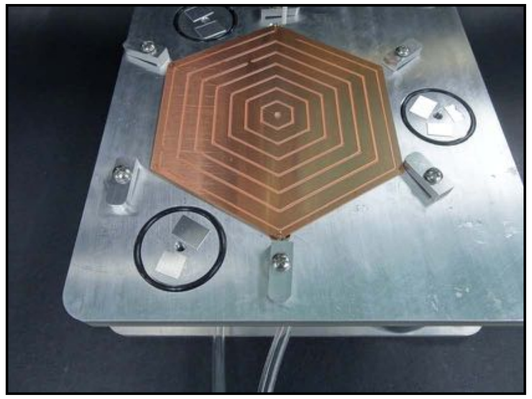
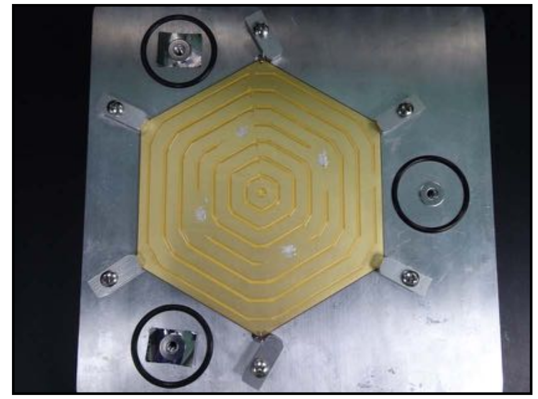
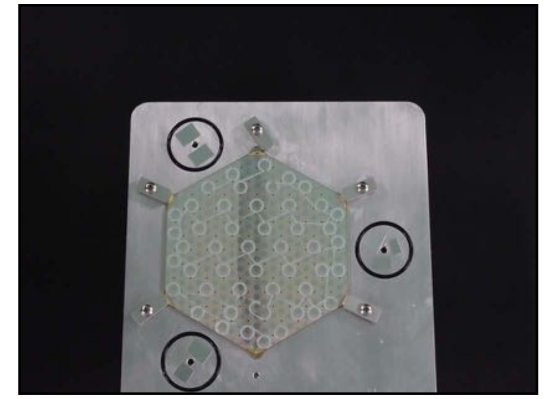
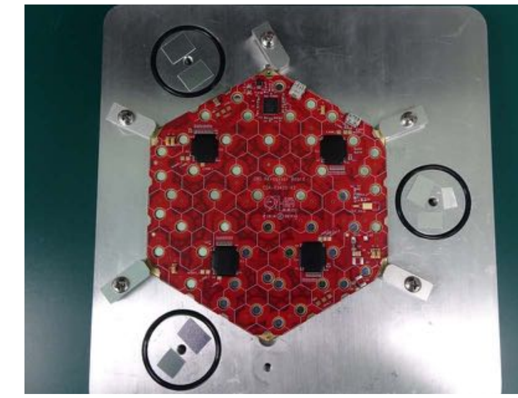
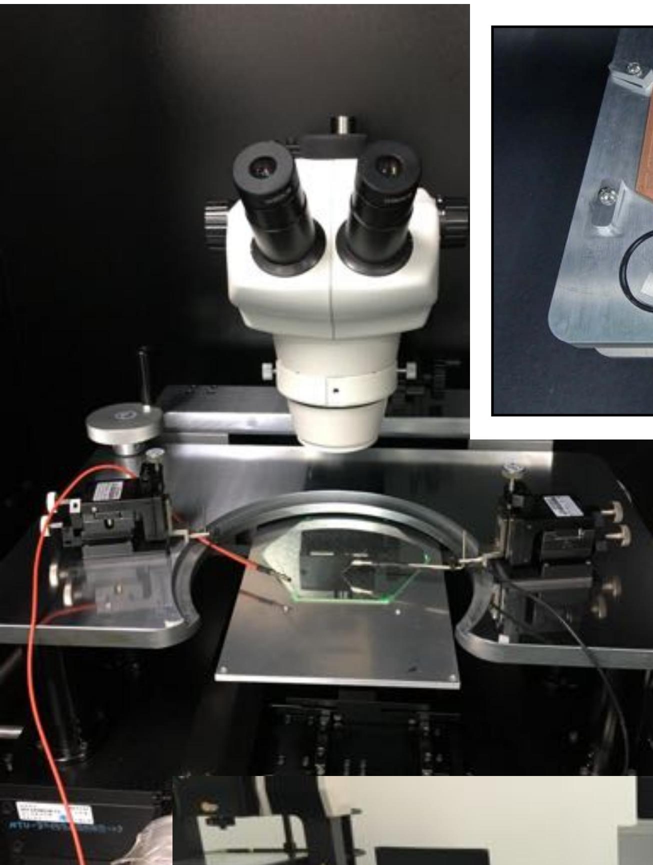
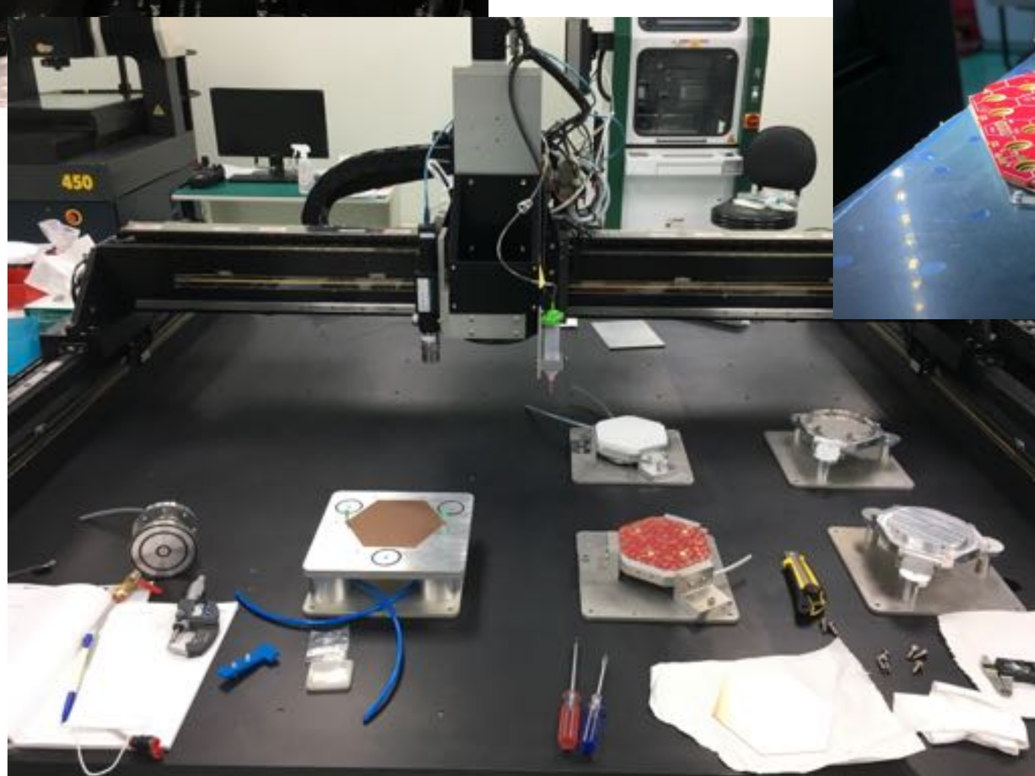


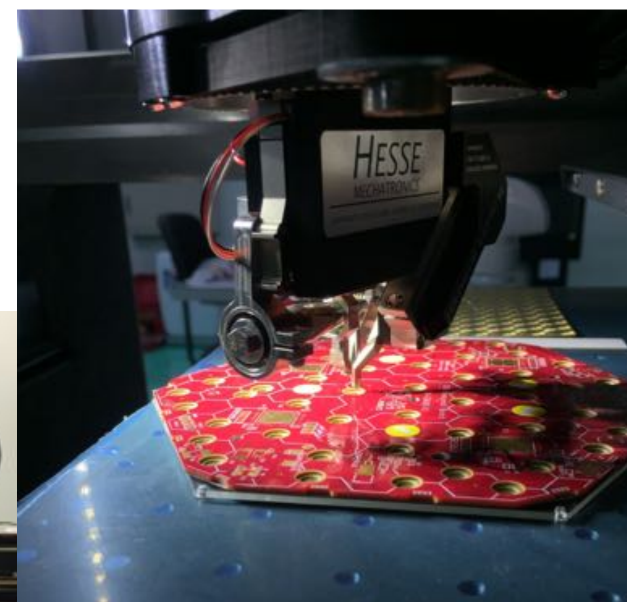
923 Outlets
T : Telephone
N : Net
R : UPS
V : 110V
Area:990 * 660 cm2
~64 m2

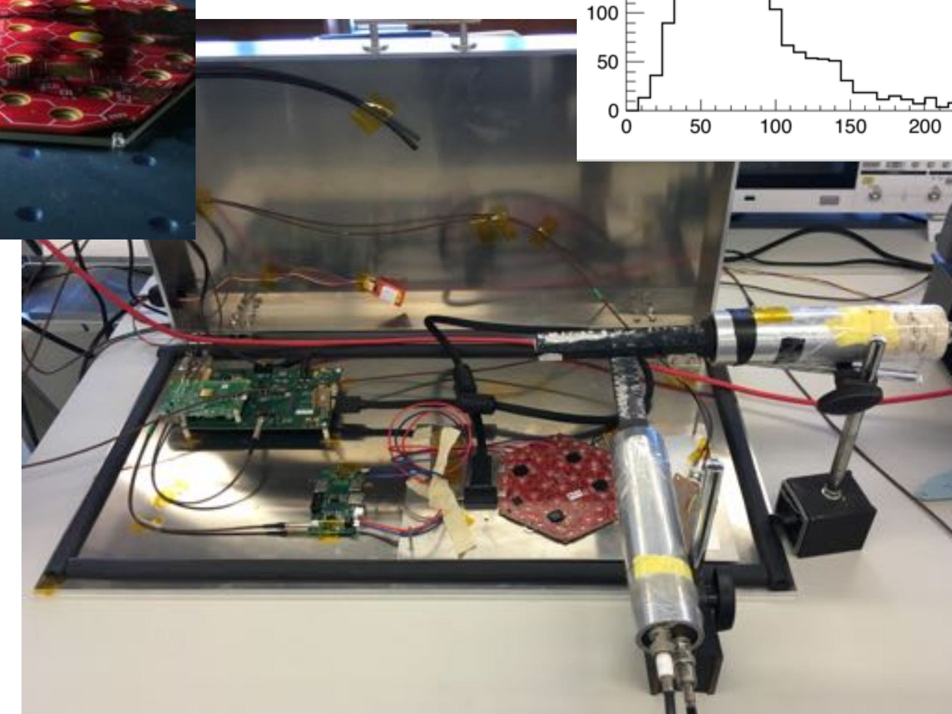
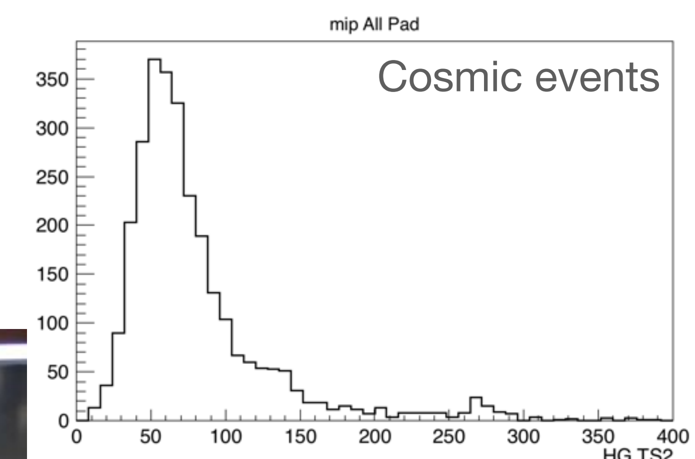


6-inch prototype assembly

- 1.2 mm Cu BasePlate + 70μm gold-Kapton + 400μm Silicon Sensor + V3 PCB



https://www.ntu.edu.tw/spotlight/2019/1670_20190412.html 108年4月12日

臺灣大學將成為新型國際粒子實驗偵測器製造中心

位於臺大天文數學大樓由科技部經費補助的臺灣矽基偵測器設施（Taiwan Silicon Detector Facility，TSIDF）已於2019年三月正式營運。臺灣研究團隊包含了臺灣大學、中央大學、中央研究院、清華大學及成功大學，由臺大物理系裴思達教授及呂榮祥教授、中大物理系郭家銘教授及中研院物理所侯書雲研究員共同領導。

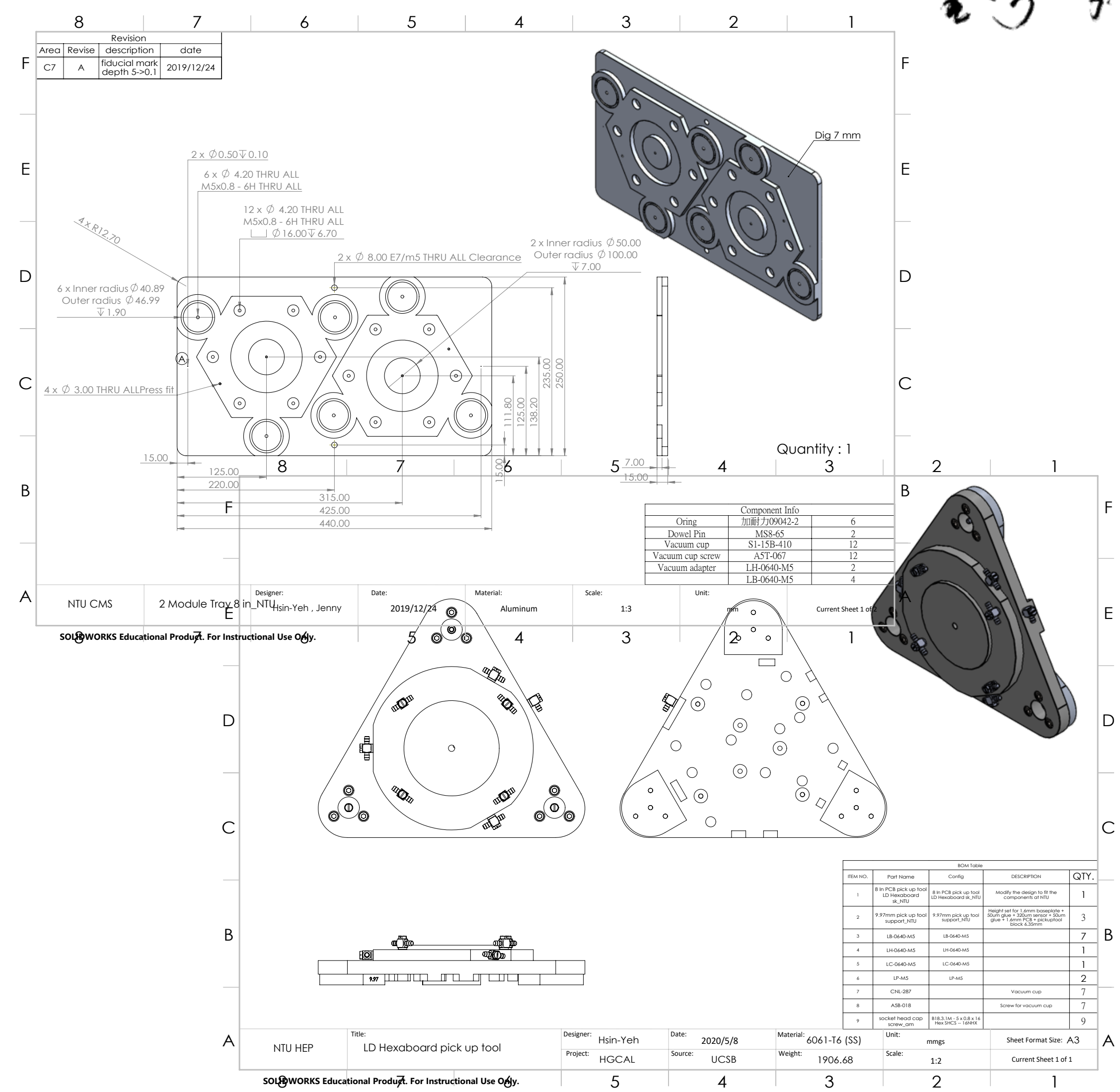
這項設施包含具有視域功能的自動機械手臂，以
打線服務。此設施已由歐洲核物理研究中心的CMS 實驗
粒子成像量熱器偵測器（此偵測器於2012年發現希格斯
產基地，將在此地製作5000個感測器模組。臺大學生及
正與其他合作機構的學生和科學家一起製作第一台原型
有元件皆是由臺灣製造。

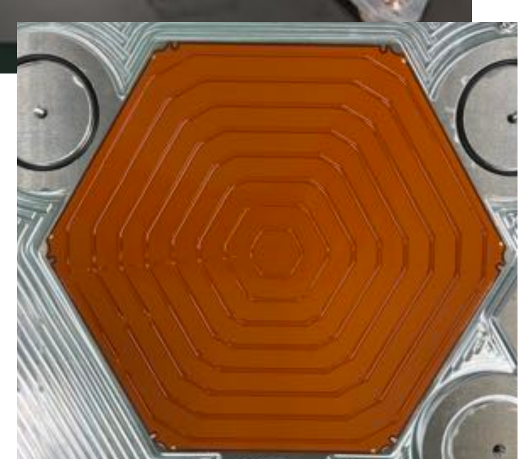
來自日本最大型的綜合研究機構之理化學研究所
（RIKEN）、美國布魯克赫文國家研究所（BNL）及麻省
（MIT）的20位的科學家，於3月26日參觀臺灣矽基偵測
觀完後他們表達強烈的期望，希望此設施能為布魯克赫文
（BNL）之sPHENIX實驗的追蹤裝置提供生產空間。

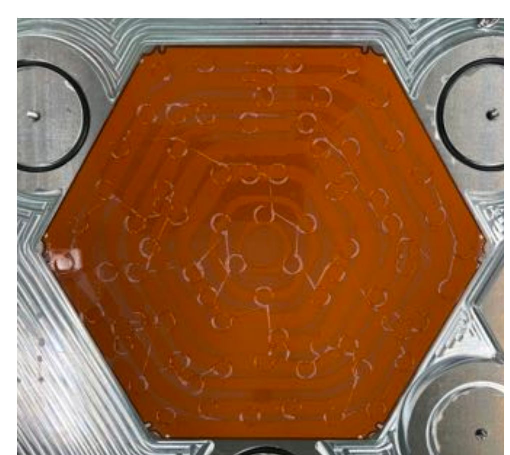
此計畫的發起人裴思達教授指出，替世界上一些
驗團隊建造偵測器的核心元件且整個製程均在臺灣進行，
史無前例的。一直以來，我們與美國，英國，中國和印度
競爭，現在我們的技術與工藝水準就算沒有超越他們至少
站在同一水平。但最重要的是，有了這個矽基偵測器設施
與大型國際合作計畫時不再需要將我們所有的資源（人員
拿去用於海外的實驗室。我們可以將經費留在臺灣，利用

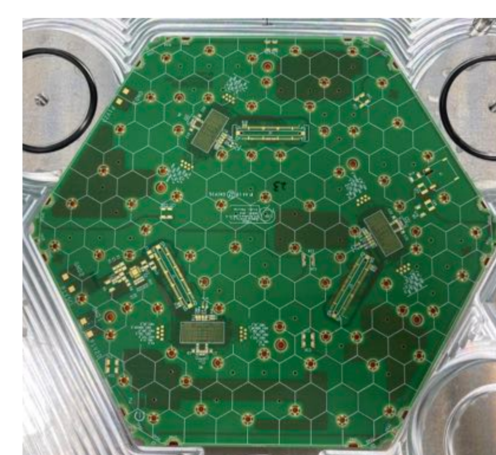
8-inch setup

- Jigs designed @NTU and fabricated @AS. Assembling dummy modules for deformation study during thermal cycles

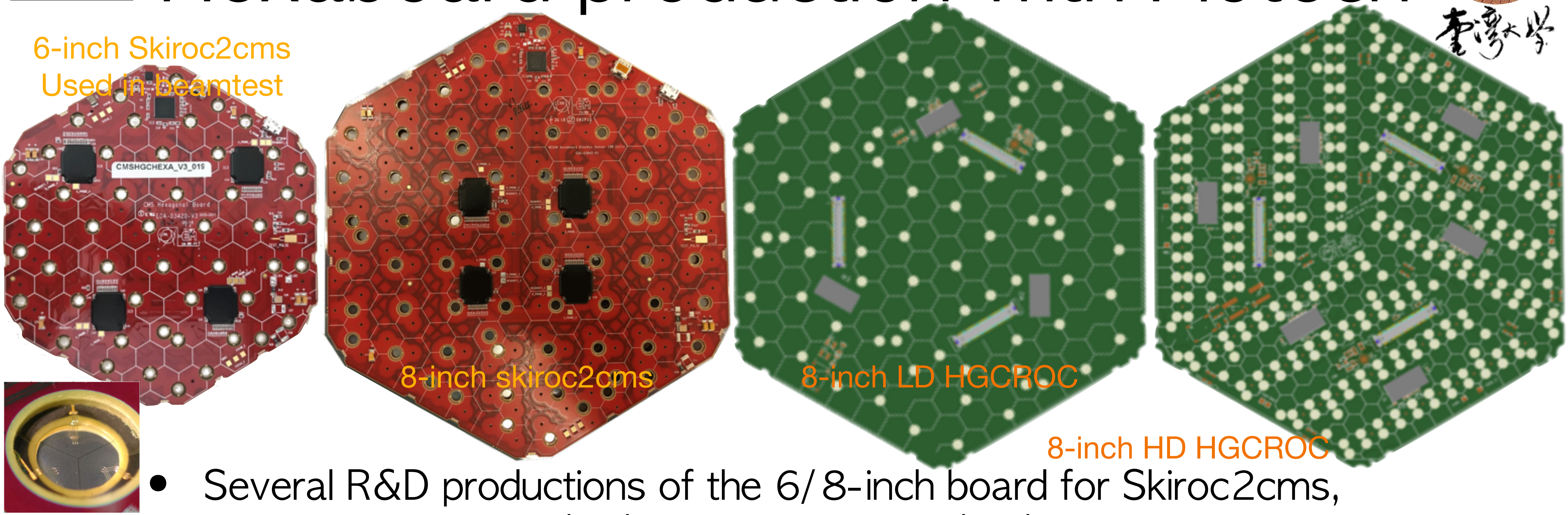








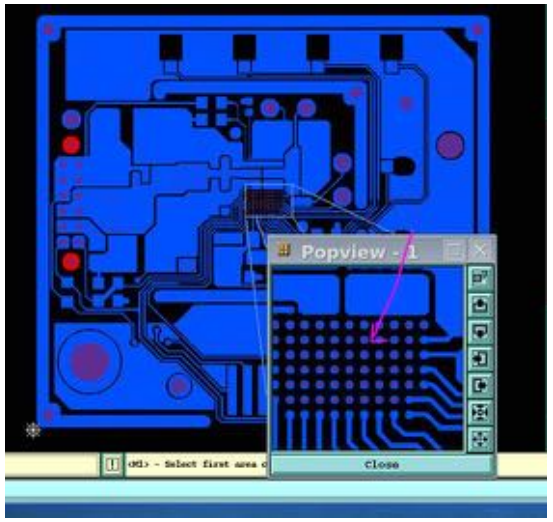
Hexaboard production with Plotech



- Several R&D productions of the 6/8-inch board for Skiroc2cms, HGCROC low density (LD) and high density (HD) hexaboards were done by Plotech. Contact through Prof. C.M. Kuo (NCU)
- Plotech team has been very helpful in producing these highly complex boards (dense traces and vias, step holes) and is willing to discuss with us (Only 3 PCB manufactures can produce this kind of boards in the world)
- All boards meet CMS's requirements so far
- Hopefully at least all (~4000) HD boards and some peripheral boards can be produced, mounted and tested in Taiwan

DC-DC converters

- Stefano Caregari (NCU), an electrical engineer, has been playing a very important role in the design of the DC-DC converters for HGCal
- The project actually aims at the development of DC-DC converters for applications in HEP, targeting the upgrade of LHC detectors
- The converters are based on ASICs. They are designed to withstand large magnetic field (up to 4T), and radiations up to ultra-high doses (TID > 150 Mrad)

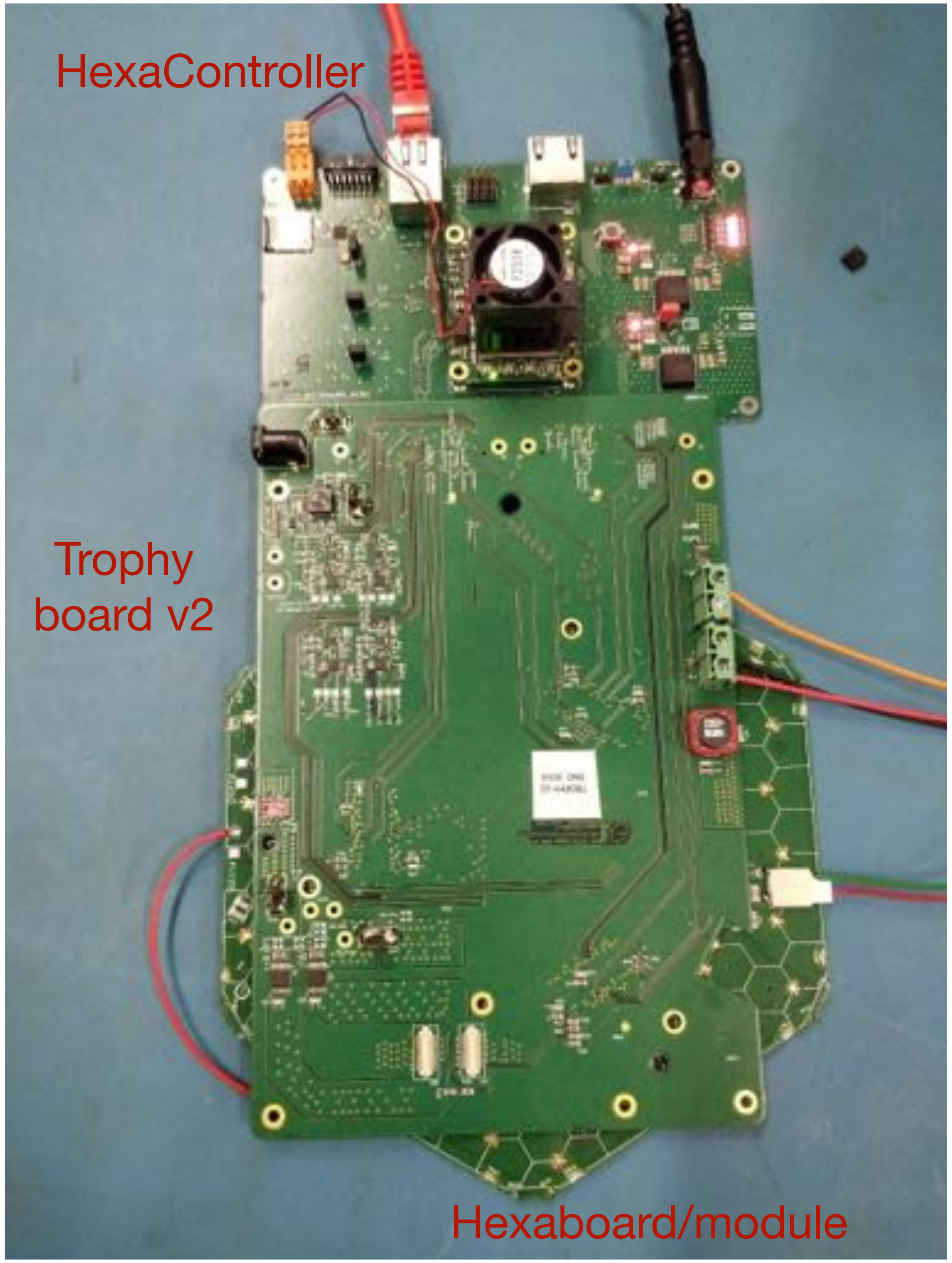


rPOL2V5 module

- rPOL2V5 chip prototypes arrived at CERN
- Discussing with Plotech to produce test boards in Taiwan. Hopefully all rPOL2V5 boards will be produced, mounted and tested in Taiwan

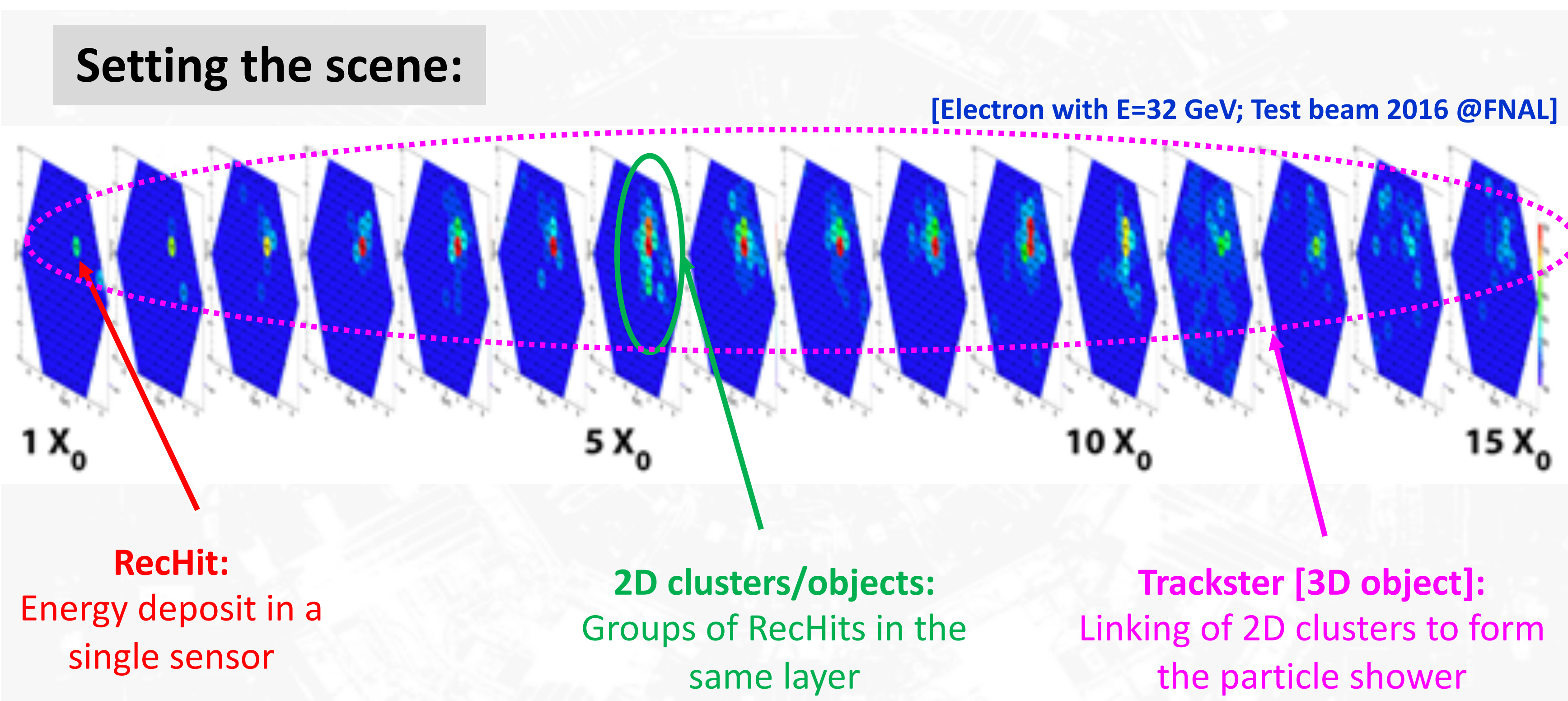
System test

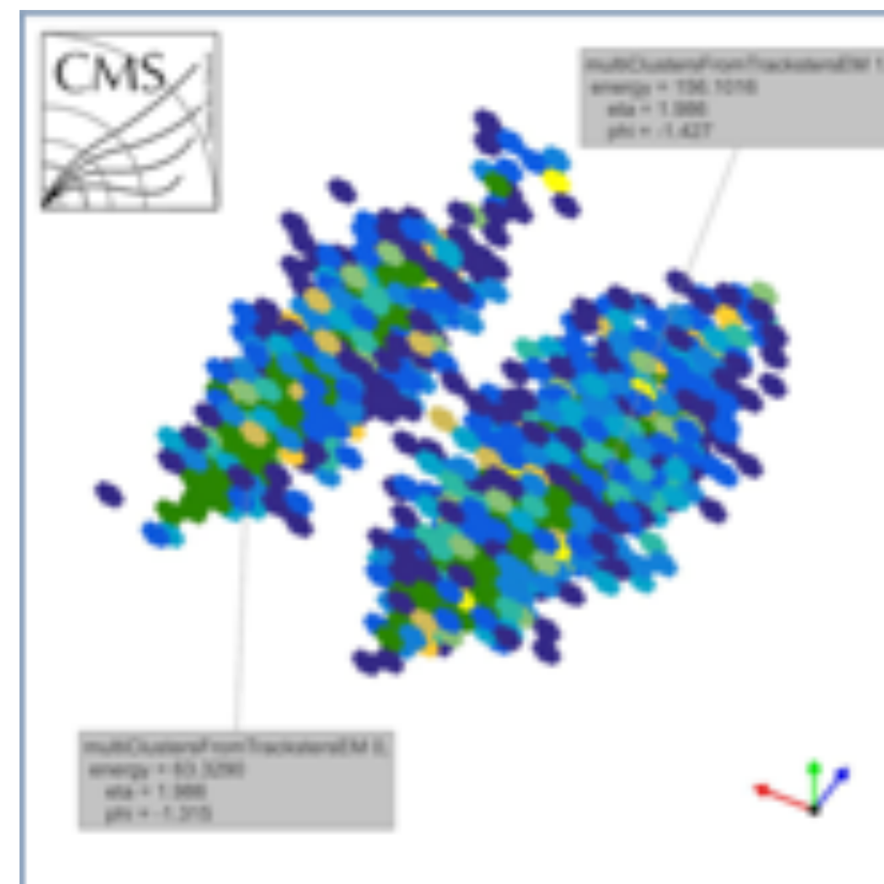
- A. Steen(NTU) co-lead the group (L2 convener)
- System on R&D of front-end system
- Developing software to test firmware(on zynq FPGA of trend module) and custom-made hardware (Controller and Trophy board) with engineers
- Basic system to grow into parallel test-stands for MAC testing



DPG activities

- A. Psallidas (NTU) in charge of software release and sample validation (L3 convener).
- Also investigating on The Iterative CLustering (TICL) algorithm on jet and tau reconstruction





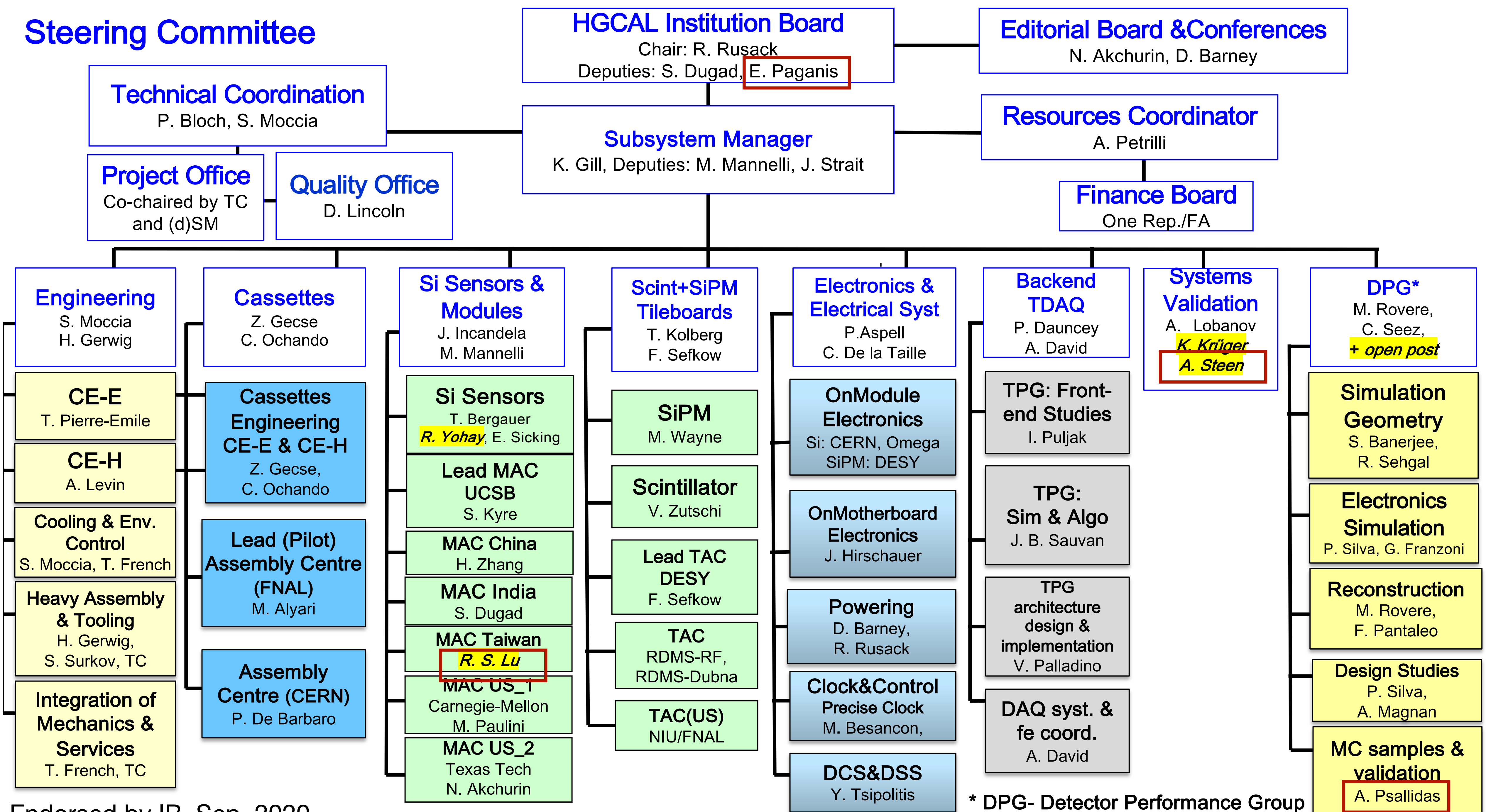
Milestones

242	**7**	**Silicon Modules**		**4 Jan 16**	**1 Dec 24**
243	7.1	Module for SKIROC2		4 Jan 16	3 May 16
244	7.2	Module for SKIROC2-CMS		3 May 16	30 Sep 16
245	7.3	Module design and specs defined for TDR baseline choice (HL)		15 Dec 16	15 Dec 16
246	**7.4**	**Assembly setup**		**28 Nov 17**	**1 Mar 21**
247	7.4.1	Silicon Module assembly pilot site and procedures setup 6" (HL)	CE.MO.2	28 Nov 17	28 Nov 17
248	7.4.2	Setup module pilot assembly site		28 Nov 17	21 Jun 19
249	7.4.3	Silicon Module assembly pilot site and procedures setup 8" (HL)	CE.MO.3	21 Jun 19	21 Jun 19
250	7.4.4	Setup modules assembly sites and proceedures		21 Jun 19	1 Mar 21
251	7.4.5	All Silicon module assembly sites and procedures qualified (HL)	CE.MO.4	1 Mar 21	1 Mar 21
252	**7.5**	**Silicon Module qualification**		**25 Dec 19**	**25 Jun 22**
253	7.5.1	Test module with HGCROC-V2		25 Dec 19	31 Jan 20
254	7.5.2	Silicon module tested with HGCROC-V2 (HL)	CE.MO.5	31 Jan 20	31 Jan 20
255	7.5.3	Evaluate full performance of HGCROC-V2 module		31 Jan 20	29 Jul 20
256	7.5.4	Assemble and test of module with HGCROC-V3		28 Jun 21	27 Aug 21
257	7.5.5	Evaluate full performance with HGCROC-V3 module		27 Aug 21	11 Oct 21
258	7.5.6	HGCROC-V3 silicon module validated (HL)	CE.MO.6	11 Oct 21	11 Oct 21
259	7.5.7	Qualify Final Modules (pre-series)		2 Jun 22	25 Jun 22
260	7.5.8	Final silicon module qualified (HL)	CE.MO.8	25 Jun 22	25 Jun 22
261	**7.6**	**Silicon Module Production**		**27 Aug 21**	**1 Dec 24**
262	7.6.1	Tender for all Silicon Modules components		27 Aug 21	8 Feb 22
263	7.6.2	Silicon Module components orders placed (HL)	CE.MO.7	4 Feb 22	4 Feb 22
264	7.6.3	Silicon Modules Pre-Production		1 Aug 22	29 Dec 22
265	7.6.4	Silicon Modules production 5% complete (HL)	CE.MO.9	29 Dec 22	29 Dec 22
266	7.6.5	Silicon Modules Production first half		29 Dec 22	24 Dec 23
267	7.6.6	Silicon Modules production 50% complete (HL)	CE.MO.10	24 Dec 23	24 Dec 23
268	7.6.7	Silicon Module production second half		24 Mar 24	1 Dec 24
269	7.6.8	Silicon Module production 100% complete (HL)	CE.MO.11	1 Dec 24	1 Dec 24

upcoming milestone

Will be delayed and coupled with 256.

HGCAL Organization



Endorsed by IB. Sep. 2020

NTUers

Summary

- NCU and NTU have joined HGCAL project, part of phase 2 upgrade of CMS, and actively participating beamtest and R&D tasks.
- Taiwan MAC will produce 5,000 of 30,000 silicon modules within 2.5 years before HGCAL is installed in 2025.
- We have also participated HGCAL data analysis in testbeam, detector level performance and phase 2 simulation events (DPG).