# Korea-CMS (KCMS) Team Activity

**Chang-Seong Moon**

**(Kyungpook National University)**

Meeting of the Division of Particles and Fields of the Korean Physical Society,
(Seoul National University, 2023. 12. 21)

# CMS Physics Goal: Discovery of New Physics

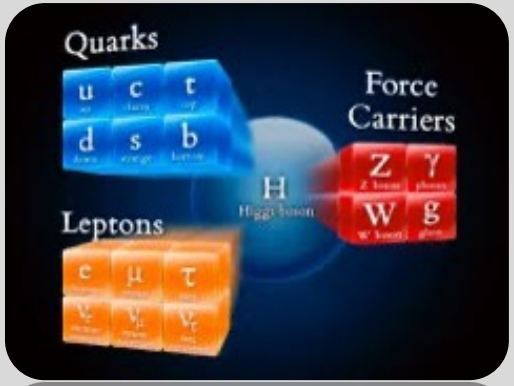
## Discovery of the Higgs boson

▼

Standard model complete?

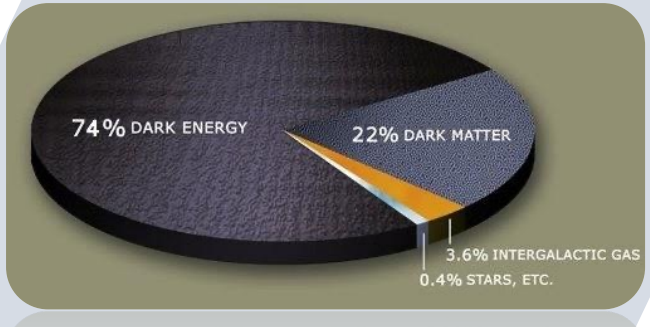
▼

Suggest another way for new physics




## Unsolved problems in the Standard Model (SM)

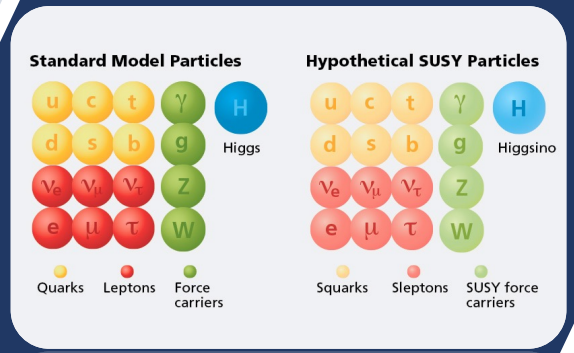
- Dark matter
- Higgs boson mass (naturalness problem)
- Matter-Antimatter asymmetry




## Searching for new physics beyond SM

Search for Supersymmetry

Precision measurement - Anomaly detection



# Korea-CMS (KCMS) Collaboration

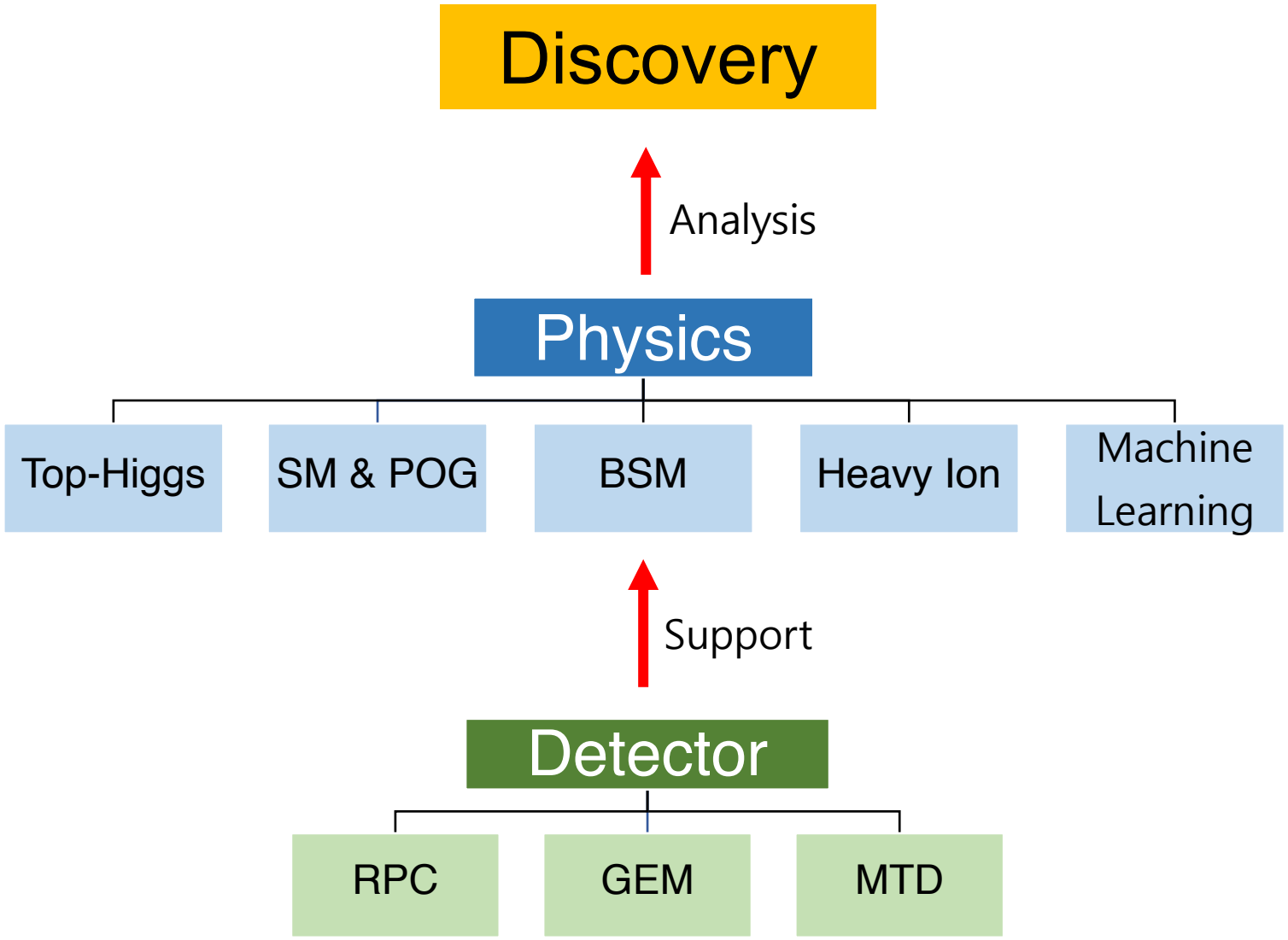
- **World-class research through international cooperation with CERN**
- **Development of detector with CERN**
- **Traininng next generation of researchers**

- **10 Institutes + new institute (Gangneung-Wonju National University)**
  KNU, KHU, KU, SNU, UOS, SKK, SJU, YU, CNU, HYU, GWNU


| Stage | year | budget (100 MKRW) | M&O-A | Prof. | Postdoc | Grad. students | Tech. staff | Total |
|---|---|---|---|---|---|---|---|---|
| 4 | 2016 | 22.5 | 32 | 15 | 20 | 46 | 5 | 86 |
| 5 | 2021 | 30.6 | 36 | 17 | 23 | 73 | 9 | 122 |
| 6 | 2022 | 33.4 | 36 | 17 | 27 | 68 | 8 | 120 |
| 6 | 2023 | 40.1 | 35 | 15 | 23 | 72 | 8 | 118 |

- **Around 2.4% of total CMS collaboration – 10th largest**
- **Annual Budget for 2023 – 4006 MKRW~2.6 MCHF**

# Organization



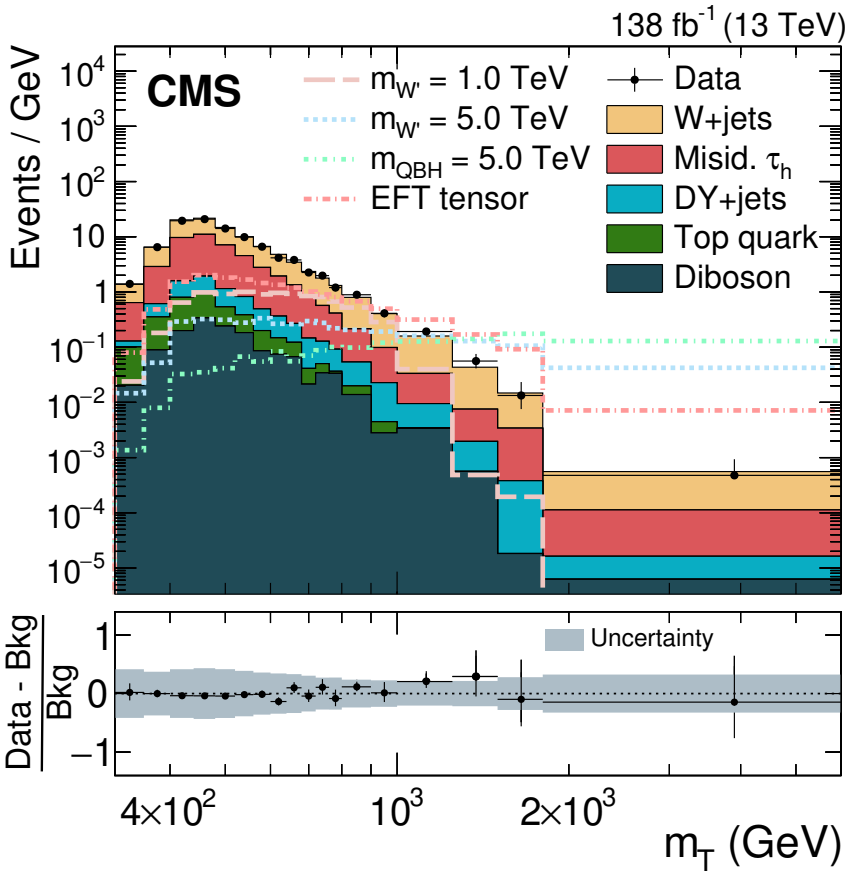

- **Top-Higgs**
  - Precision measurement, search for rare production and decay
- **SM & POG**
  - DY precision measurement, anti-symmetry, Physics Object identification
- **BSM**
  - SUSY, dark matter, heavy neutrino, long lived particle
- **Heavy Ion**
  - Nuclear effect
- **Machine learning**
  - Can use data analysis and trigger

- **Detector**
  - GEM GE2/1,ME0 production and test
  - iRPC production and test
  - MTD R&D

# KCMS physics summary

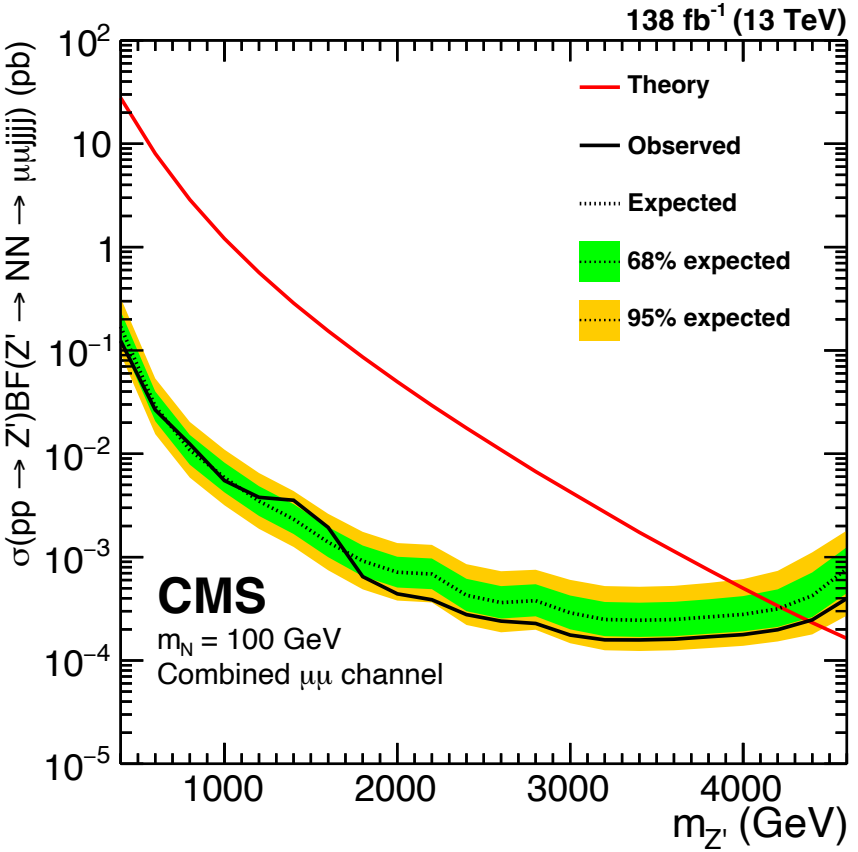
- **Search for new physics in the $\tau$ lepton plus missing transverse momentum final state in pp collisions at 13 TeV**

JHEP 09 (2023) 051: CMS-EXO-21-009




- **Search for $Z'$ bosons decaying to pairs of heavy Majorana neutrinos in pp collisions at 13 TeV**

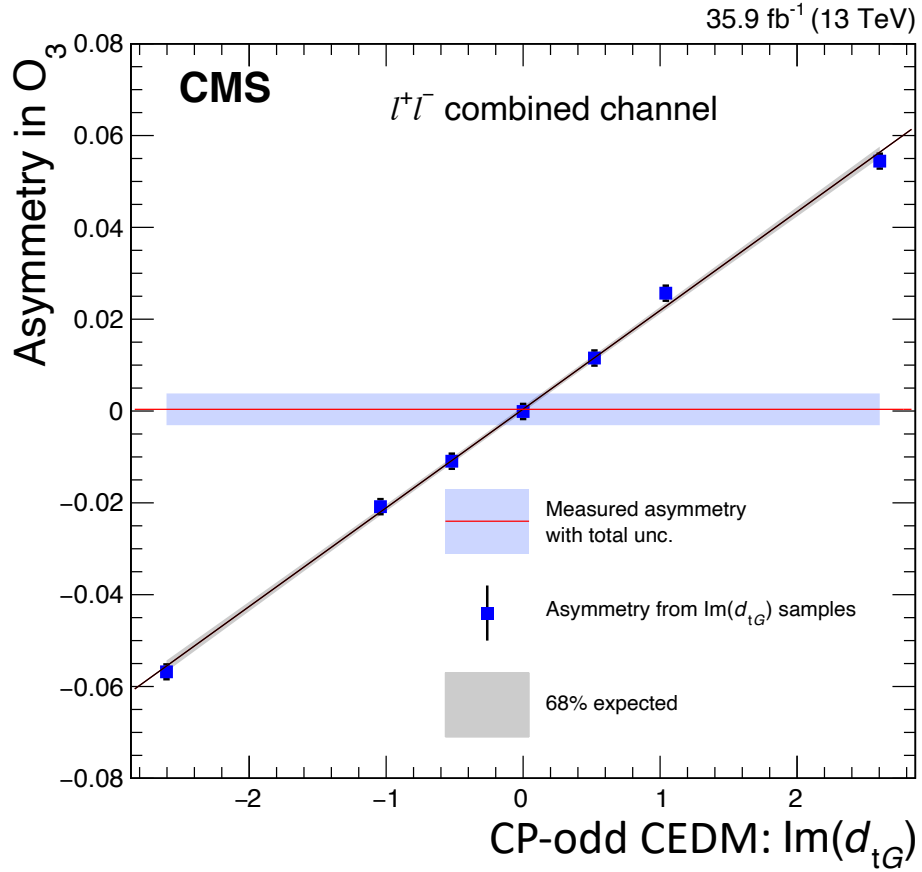
JHEP 11 (2023) 181: CMS-EXO-20-006



# KCMS physics summary

- **Search for CP violation top quark couplings in pp collisions at 13 TeV**

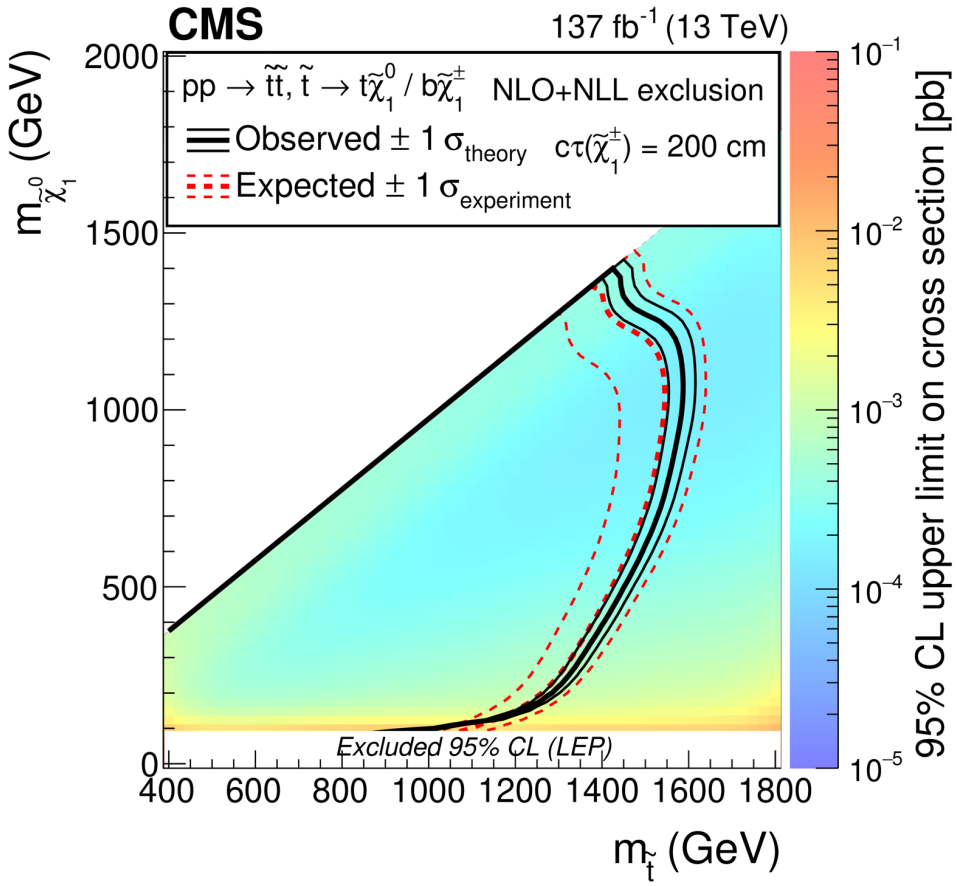
JHEP 07 (2023) 023




searching nonzero chromoelectric dipole moment (CEDM)

- **Search for long-lived SUSY with disappearing track at 13 TeV**

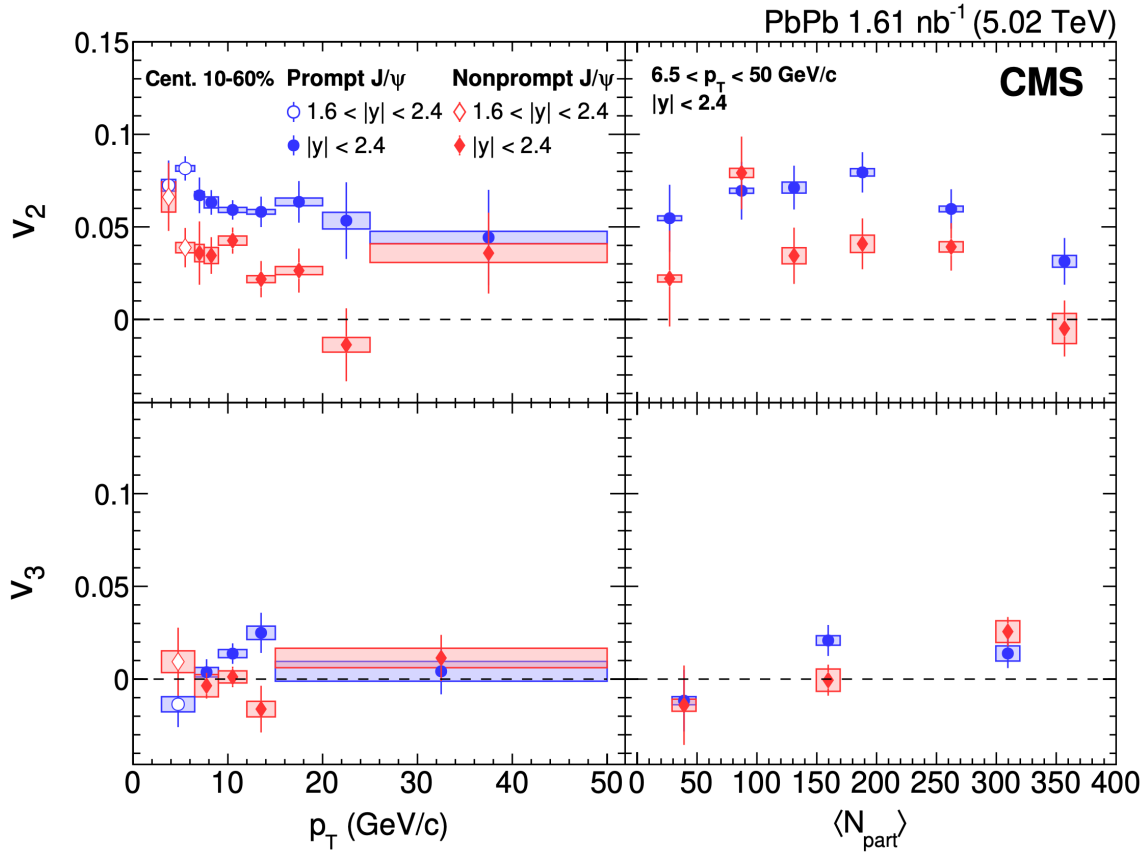
Submitted to Phys. Rev. D (arXiv:2309.16823) : SUS-21-006



# KCMS physics summary

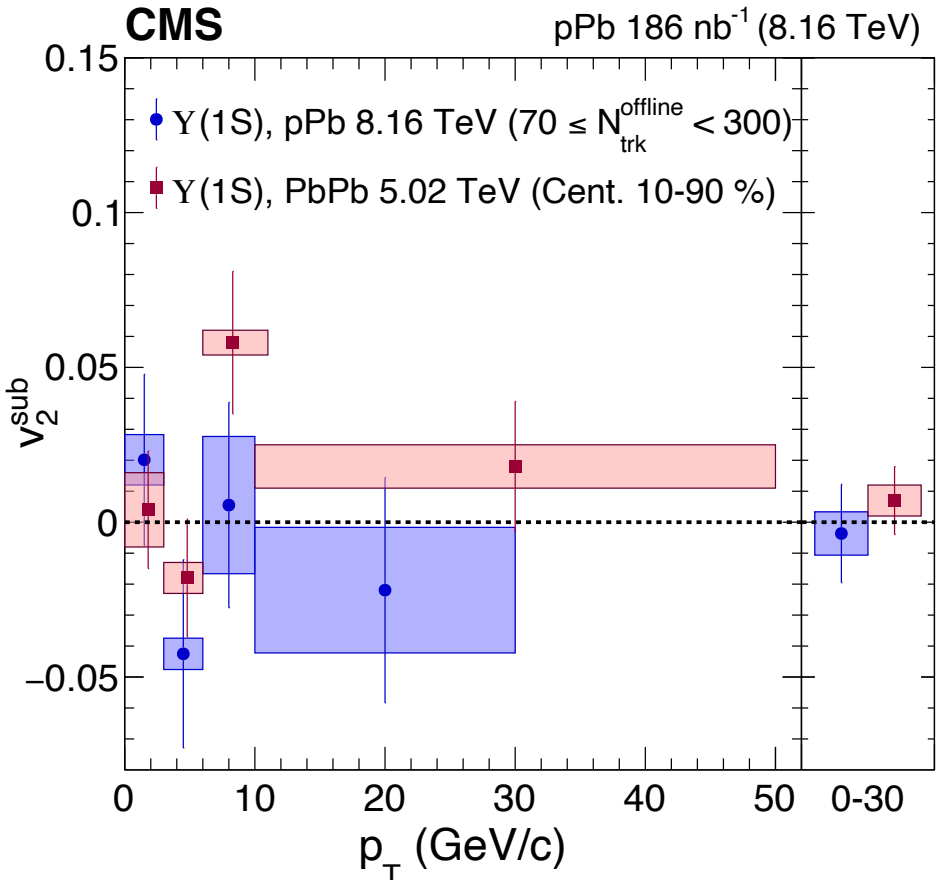
- **Measurements of the azimuthal anisotropy of prompt and non prompt Charmonia in PbPb at 5.02 TeV**

JHEP 10 (2023) 115 : HIN-21-008




- **Study of azimuthal anisotropy of Upsilon(1S) in p+Pb at 8.16 TeV**

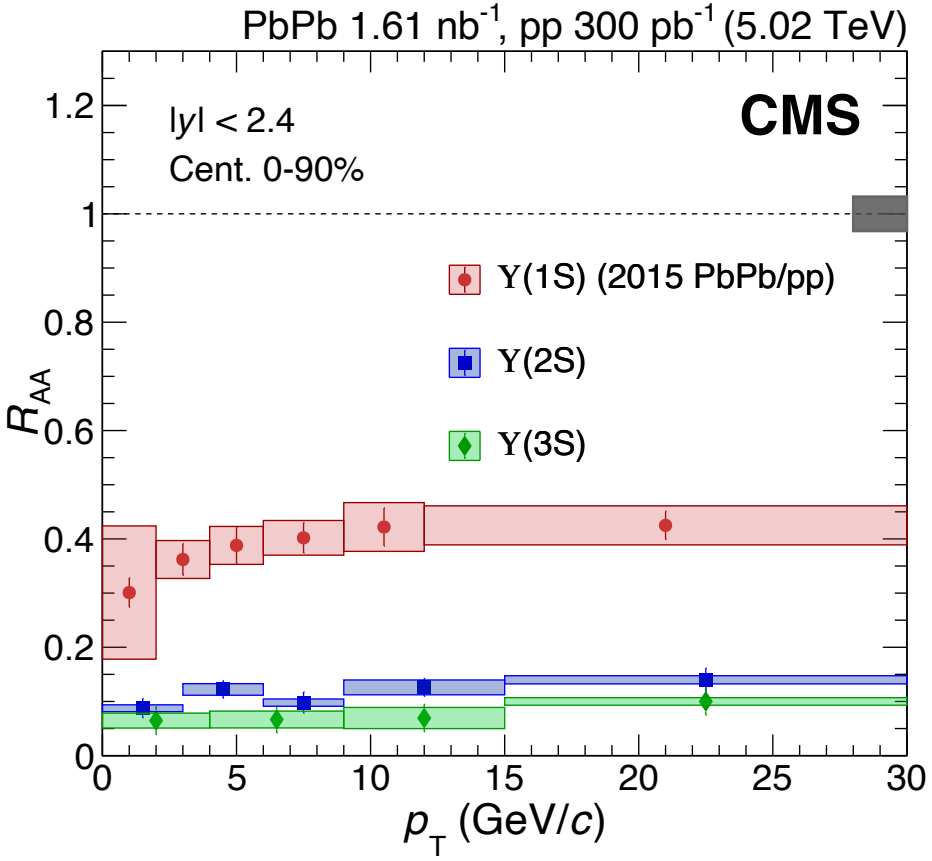
Submitted to PRL (arXiv:2310.03233) : HIN-21-001



# KCMS physics summary

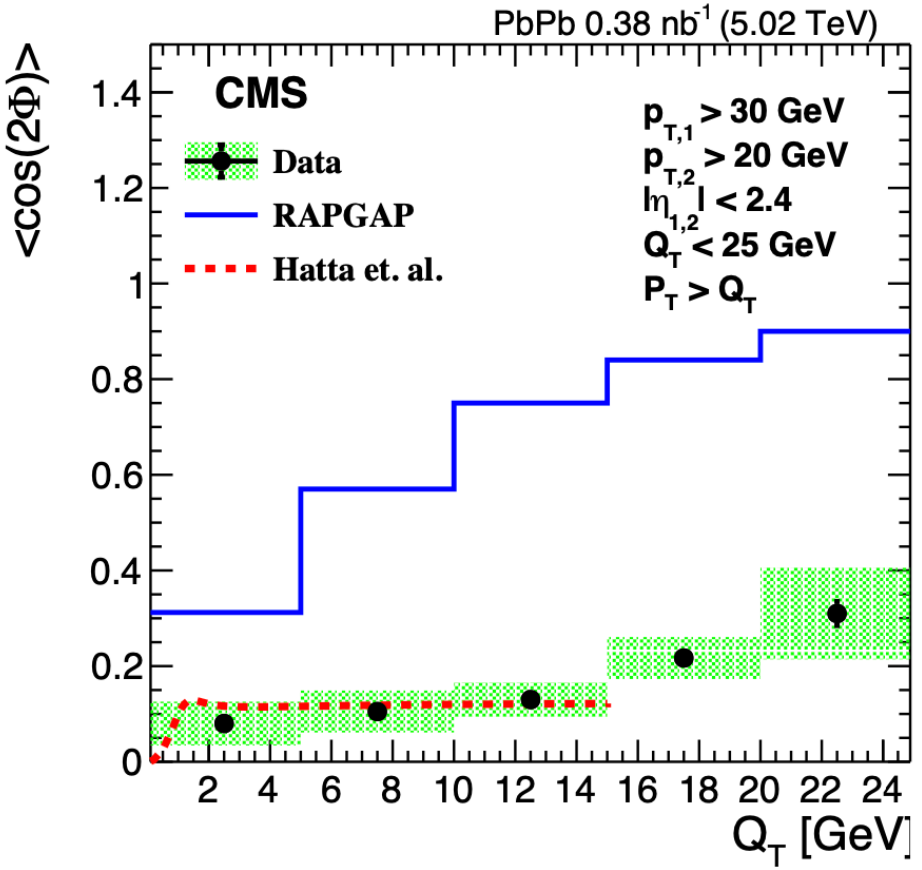
- **Observation of the Upsilon(3S) and suppression in Pb+Pb at 5.02 TeV**

Submitted to PRL (arXiv:2303.17026)
: HIN-21-007




- **Azimuthal Correlations within Exclusive Dijets with Large Momentum Transfer in p+Pb collisions at 5.02 TeV**

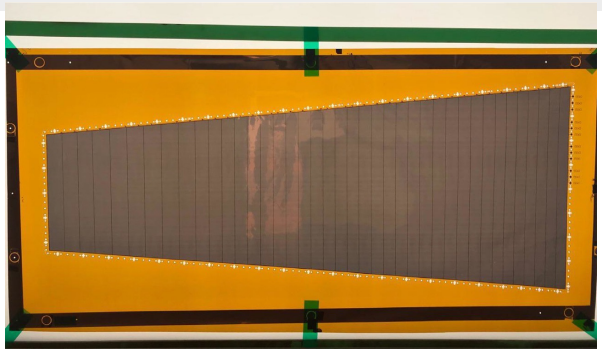
PRL 131 (2023) 051901: HIN-18-011



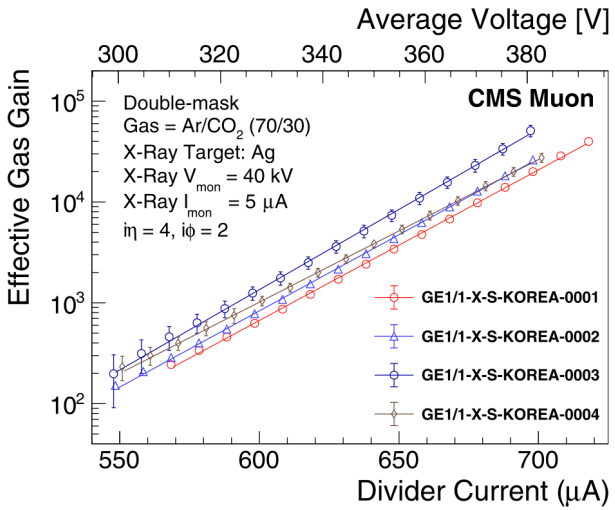
# KCMS physics summary

- **Production and validation of industrially produced large-sized GEM foils for the Phase-2 upgrade of the CMS muon**

Nucl. And Inst. Meth. A 1057 (2023) 168723

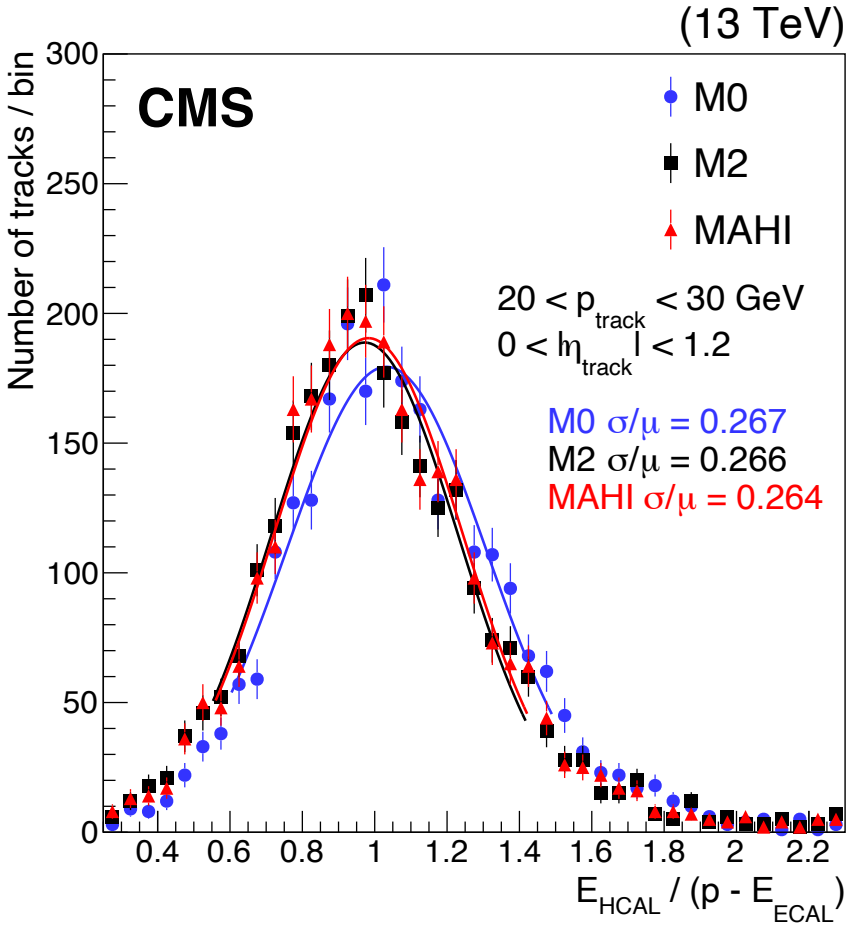


*Nuclear Inst. and Methods in Physics Research, A 1057 (2023) 168723*

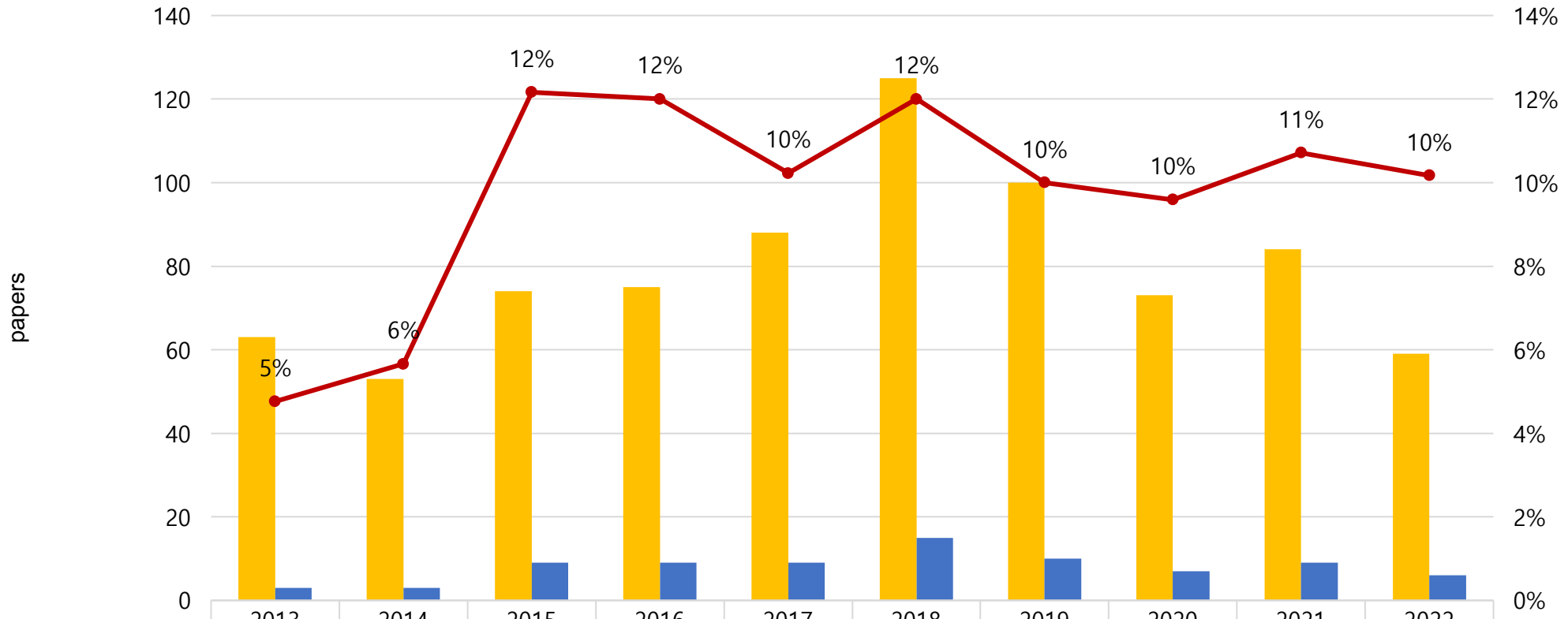



- **Performance of the local reconstruction algorithms for the CMS hadron calorimeter with Run 2 data**

JINST 18 (2023) P11017: CMS-PRF-22-001



# Papers

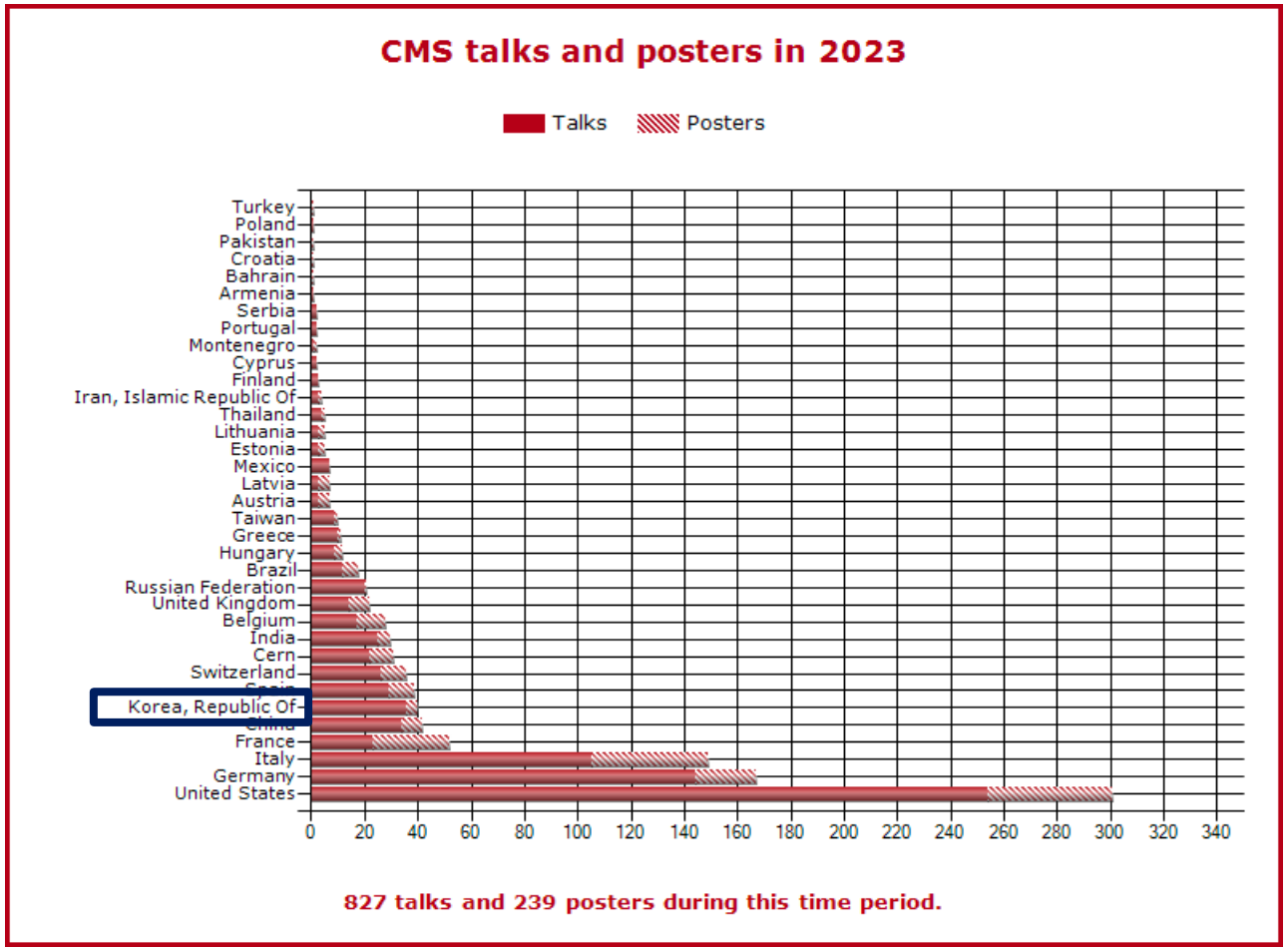



| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|
| CMS papers | 63 | 53 | 74 | 75 | 88 | 125 | 100 | 73 | 84 | 59 |
| KCMS primary | 3 | 3 | 9 | 9 | 9 | 15 | 10 | 7 | 9 | 6 |
| KCMS Ratio | 5% | 6% | 12% | 12% | 10% | 12% | 10% | 10% | 11% | 10% |

- **CMS papers with primary authorship by KCMS**
- **We expect the similar rate in 2023**

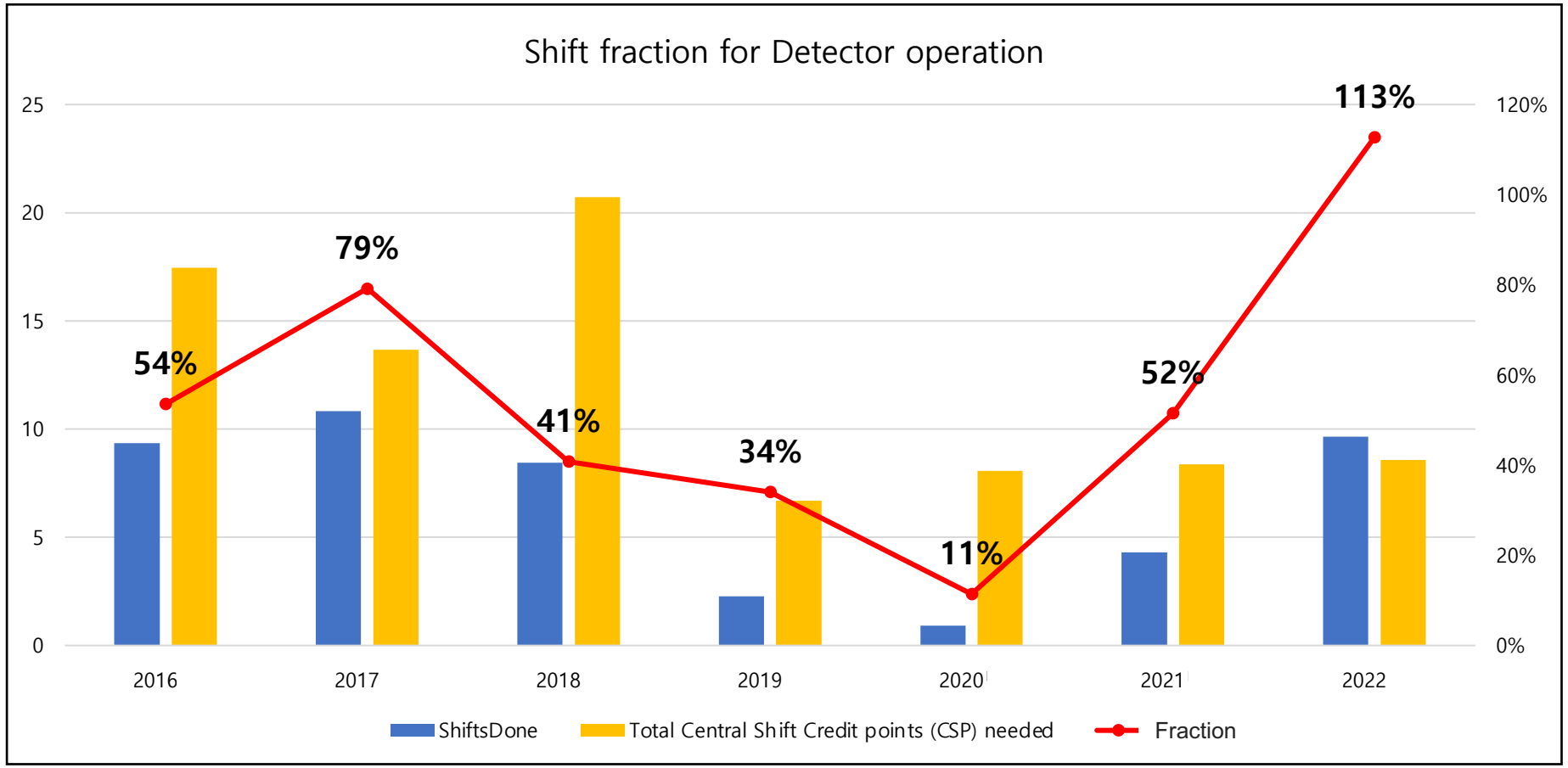
# Conference talks

- In 2023
  - International conference – 21 talks
  - National conference – 37 talks



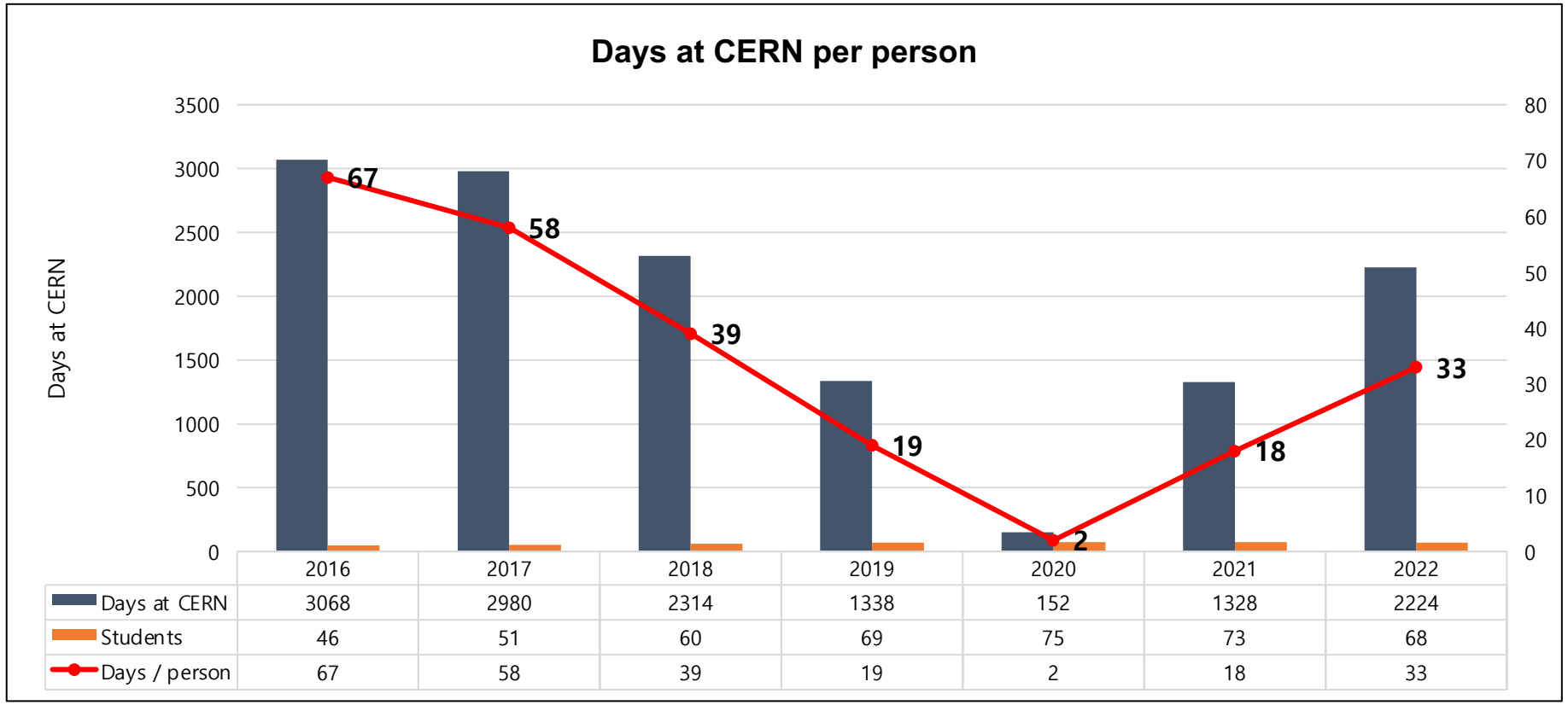
# Detector operations (%)

- Since data taking in July 2022, we started to send more students and postdocs to CERN
- ShiftDone/ShiftNeeded > 100% in 2022
- In 2023, we will reach 100% of the ratio towards the end of the year



# Days of staying at CERN

- With limited budget, it would be difficult to recover the same rate as during Run 2 period (2015~2018)
- We tried to send more students to CERN for long term stay
- Long term stay : three postdocs (Jeremie Alexandre Merlin, Ece Asilar, Sezen Sekmen) and 4 students (Won Jun, Seulgi Kim, Dayoung Gang, Hyejin Kwon, Jieun Choi)




| | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|
| Days at CERN | 3068 | 2980 | 2314 | 1338 | 152 | 1328 | 2224 |
| Students | 46 | 51 | 60 | 69 | 75 | 73 | 68 |
| Days / person | 67 | 58 | 39 | 19 | 2 | 18 | 33 |

# Leaderships – Oct 2023

| Name | Position | CMS leadership | Period |
|---|---|---|---|
| Tae Jeong Kim | Faculty | Muon SM deputy (L1) | 2023.9~ |
| Junghwan Goh | Faculty | RPC DPG Coordinator (L2) | 2017.5~ |
| Ian Watson | Postdoc | GEM DPG Deputy Coordinator (L2) | 2023.9~ |
| Jerime Merlin | Postdoc | GEM production coordinator (L2) | 2021.6~ |
| Ece Asilar | Postdoc | RPC technical coordinator (L2) | 2022.9~ |
| Sezen Sekmen | Postdoc | SUSY Hadronic/photon subgroup convener (L3) | 2022.9~ |
| Sihyun Jeon | Postdoc | Common Analysis Tools (L3) | 2022.9~2023.4 |
| Seungkyu Ha | Postdoc | JME contact for Top PAG (L3) | 2022.9~ |

# Leaderships – Oct 2023

| Name | Position | CMS leadership | Period |
|---|---|---|---|
| Hyejin Kwon | Student | Combine contact in SUS PAG (L3) | 2023.9~ |
| Won Jeon | Student | Muon HLT convener (L3) | 2022.9~ |
| Jieun Choi | Student | B2G HLT contact (L3) | 2023.9~ |
| Seulgi Kim | Student | GEM production convener (L2) | 2023.3~ |
| Dayoung Kang | Student | GEM PreProd Manager (L3) | 2022.9~ |
| Junbin Lee | Student | GEN MC Validation convener (L3) | 2022.9~ |
| Sanghyun Goh | Student | EXO high-Et electron contact (L3) | 2022.9~ |
| Jin Choi | Student | GEN MC & Interpretation convener(L3) | 2022.9~ |
| Soohwan Lee | Student | HIN Dilepton Physics Interest Group convener (L3) | 2022.9~ |
| Changgi Huh | Student | SUSY JME contact (L3) | 2023.3~ |

# Achievement

- 4 PhD graduated (Boston Univ., DESY, KCMS) in 2023
- 3 Master graduated (moved to army and PhD)
- International collaboration
  - Join PhD degree - Lyon (Jieun Choi), VUB (Juhee Song)
- “First place” award in poster session at the top quark conference (USA)
  - Juhee Song (KCMS student)
- CMS award
  - Ece Asilar (KCMS postdoc)

# High-Luminosity LHC (HL-LHC) at CERN

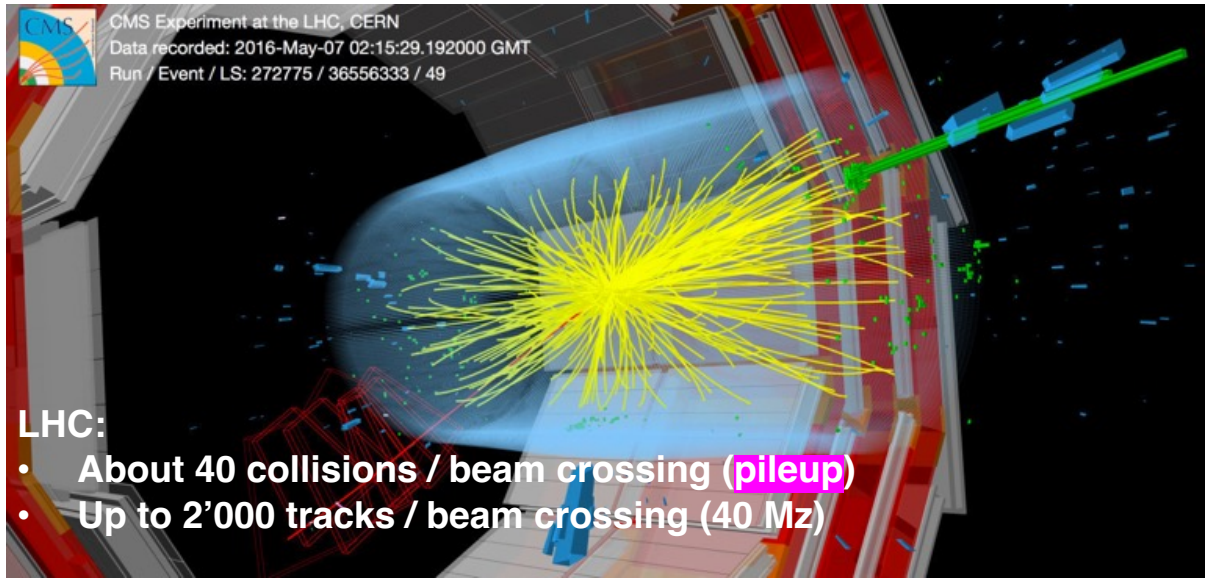
Goal: precision tests of the standard model and Higgs physics, and searches for (rare) BSM phenomena

- **Precision measurement of Higgs boson couplings** (few percent)
- Measurement of the **Higgs boson self-coupling** via direct observation of the di-Higgs boson production
- Search for heavy **dark matter candidates, SUSY particles, new gauge bosons, Long-Lived Particles**, …

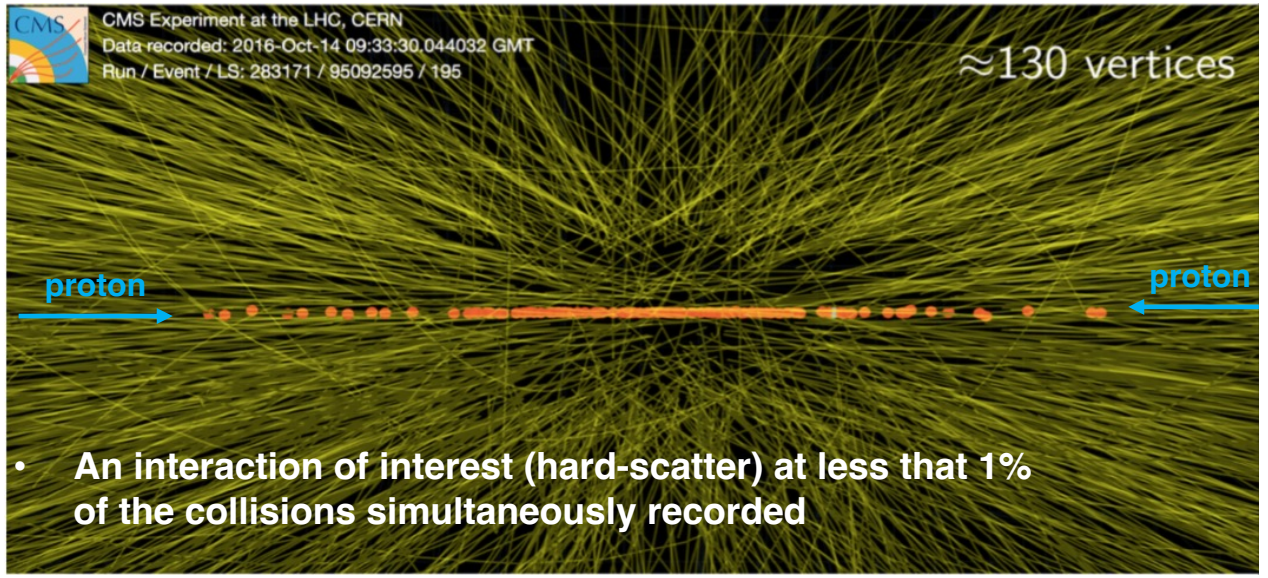
Means: upgrade of the LHC optics and injectors to increase the beam intensity

- Luminosity delivered by **LHC** (2009-2025): **~ 400 fb$^{-1}$ / experiment** *[~250 fb$^{-1}$ collected so far]*
- Target luminosity for **HL-LHC** (2029-2042): **>3000 fb$^{-1}$ / experiment** ***[one year of HL-LHC equivalent to ~10 years of LHC]***

**Collision event with 35 reconstructed vertices**

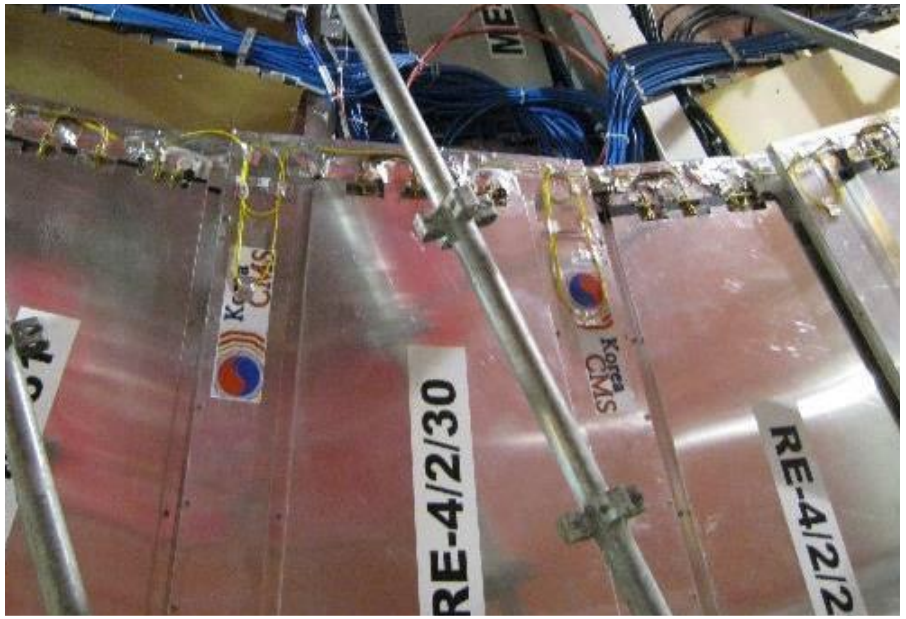



**Real life event at the LHC emulating HL-LHC conditions**



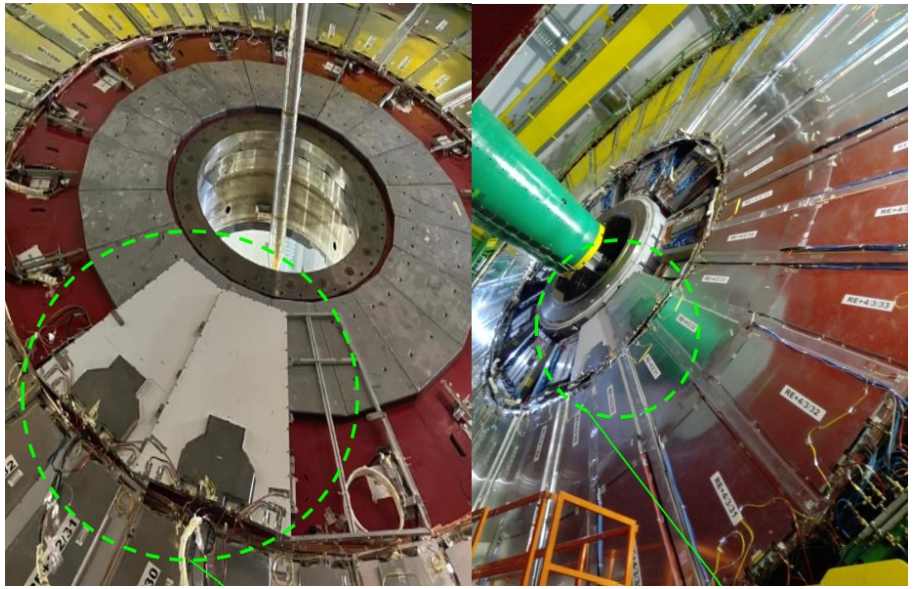
# Contribution to Phase-2 Upgrade

- **GE11: 592 kCHF (Complete)**
- **GE21, ME0 (2024~2026): 2.262 MCHF**
  - 456(GE21), 666(ME0) foils:2064kCHF
  - Glass mask (5 pairs):198kCHF
  - MoU(done)
- **iRPC Upgrade: 400 kCHF**
  - RPC GAP: 286 kCHF (in-kind)
  - Shipping + chammber compoents (114kCHF)
  - MoU (done)
- **Common Fund (MoU:done)**
  - 560 kCHF(2018-2026)
- **MTD upgrade: 2.2 MCHF (MoU: Oct. 26, 2023)**
- **Total contribution with MTD on the Phase 2: 6 MCHF**




# RE3/1 and RE4/1 (iRPC)

- Installation of four demonstrator iRPC@P5 completed in January 2021
- Since then, 120 iRPC gaps were already delivered to CERN for assembly
- All gaps for the 72 RE3/1 and RE4/1 chambers will be produced by April 2024



# Korea GEM foil production

- A relocation of GEM foil production was needed due to decision of Mecaro company (in Aug. 2022) to stop production
- MoU between RAON in IBS and CMS collaboration signed with Prof. Seung-Woo Hong, Director of RAON on April 14

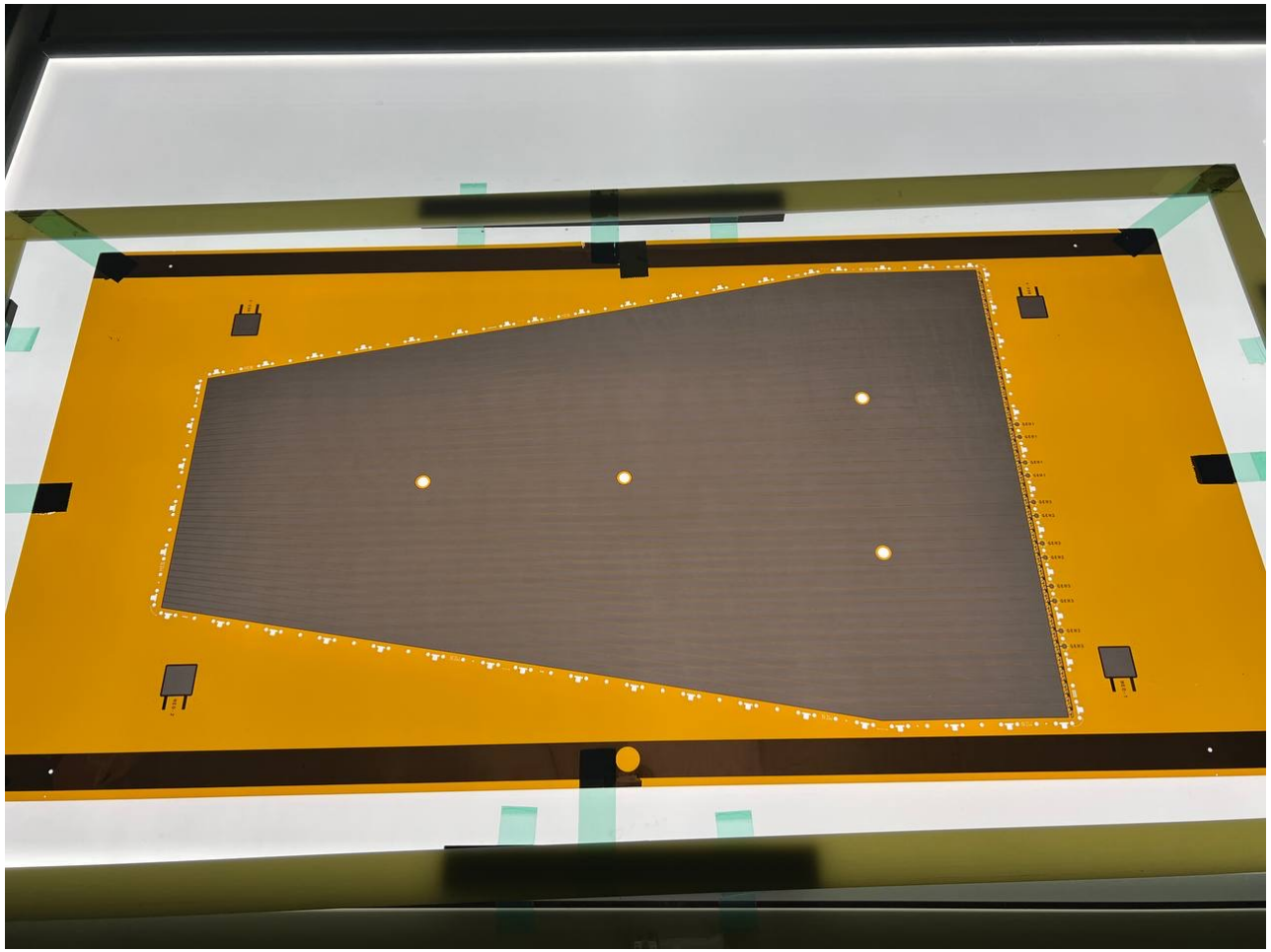
- Relocation successfully completed and distributed in 2 sites
  - IBS for dry process
    (laminate, photolithography, QA/QC, packing)
  - ANSAN for wet process
    (etching and cleaning)

# Cleanroom (before)

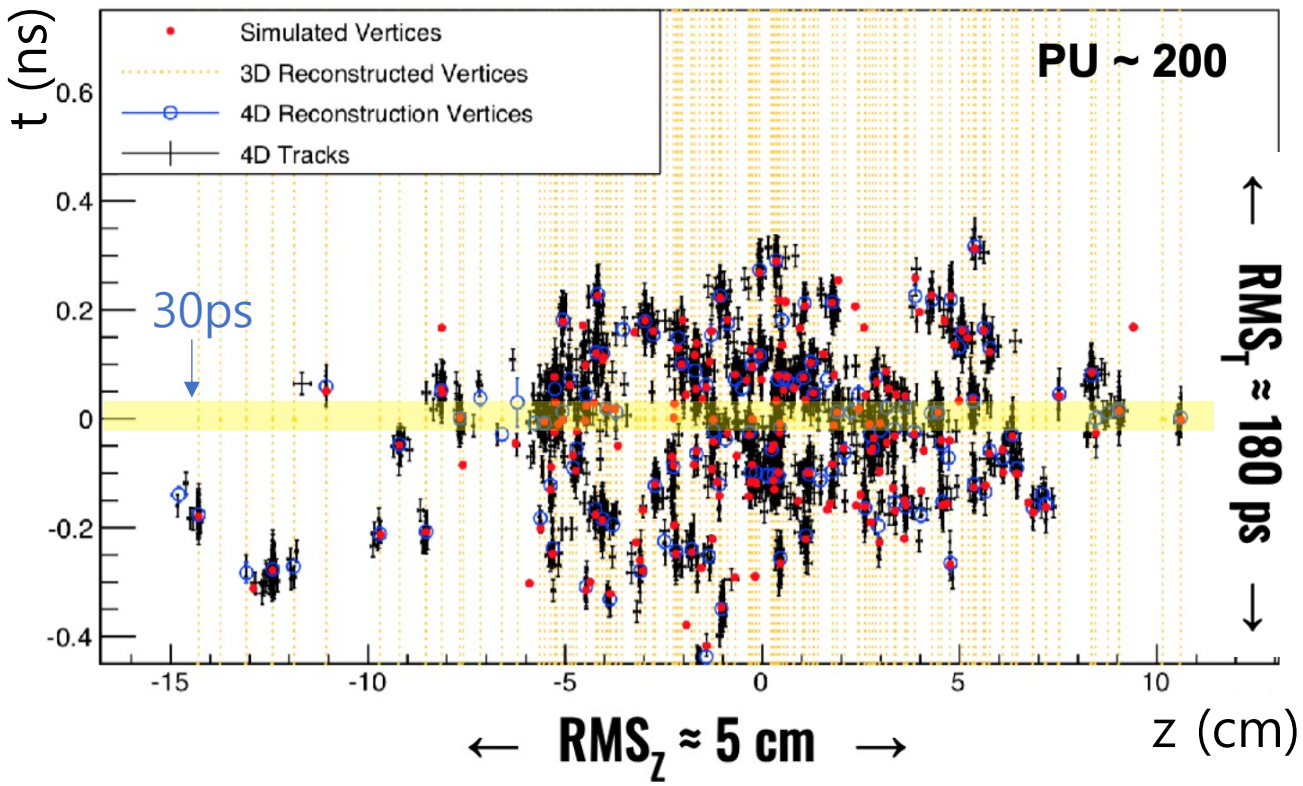
# Cleanroom (after)

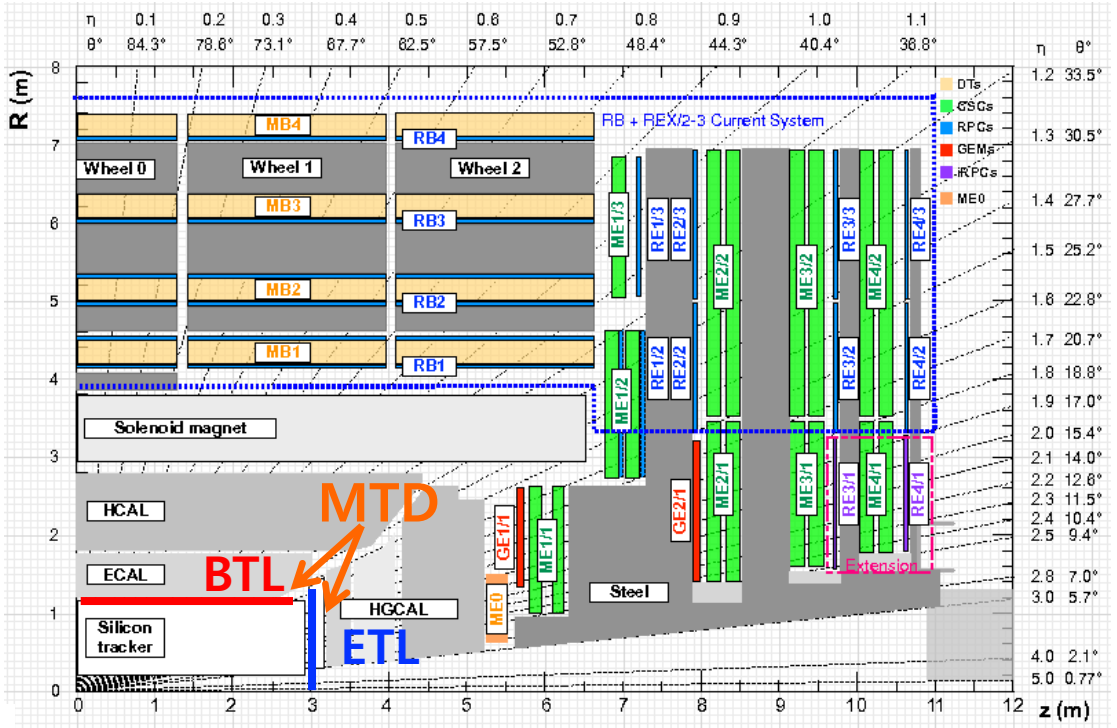
# First GEM foils after relocation

- 13 ME0 foils (passed QC) were delivered already to CERN
- First ME0 GEM foils from Korea now sitting at b.904



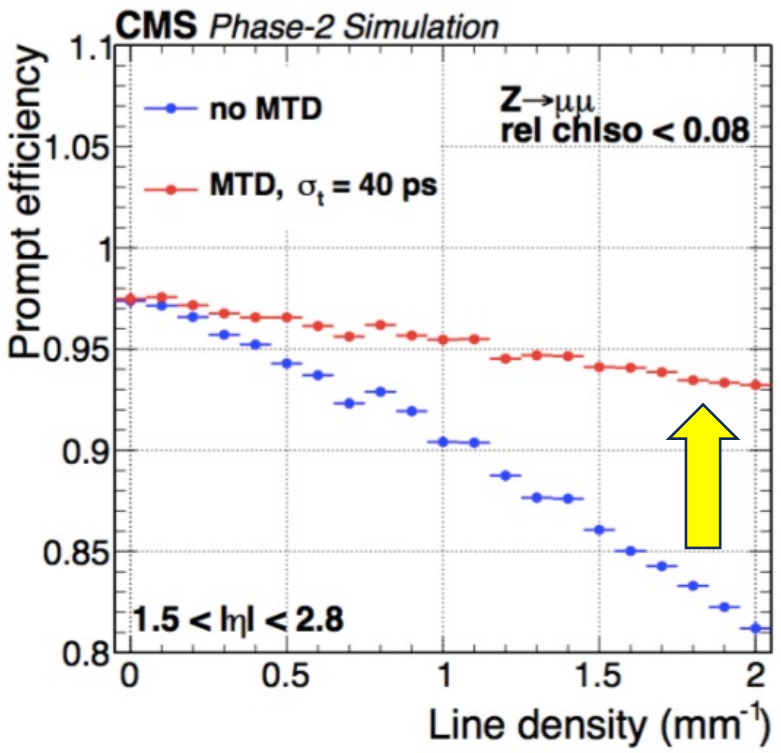
# MIP Timing Detector (MTD) for CMS Phase-2 Upgrade

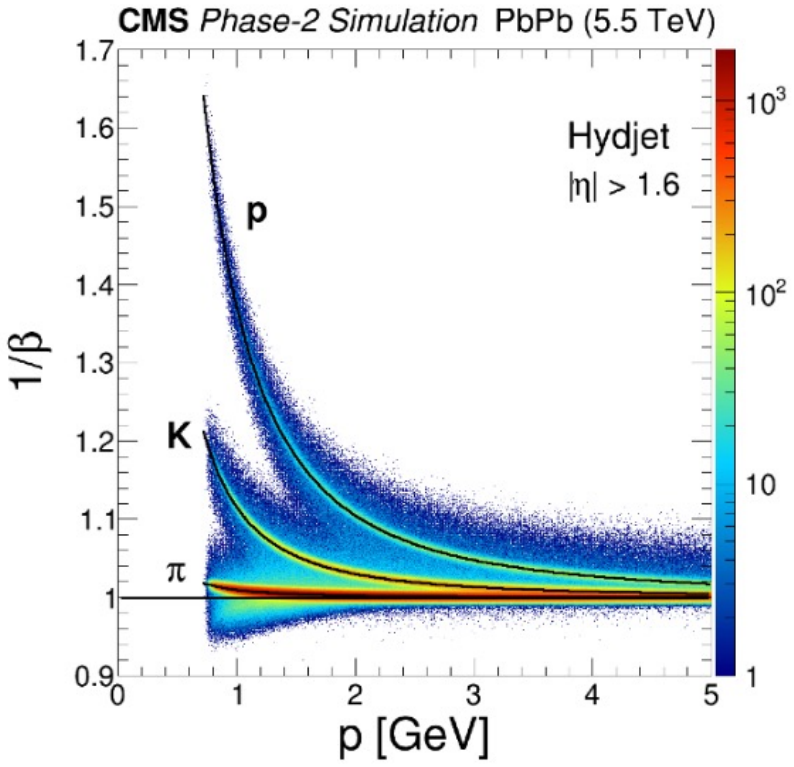


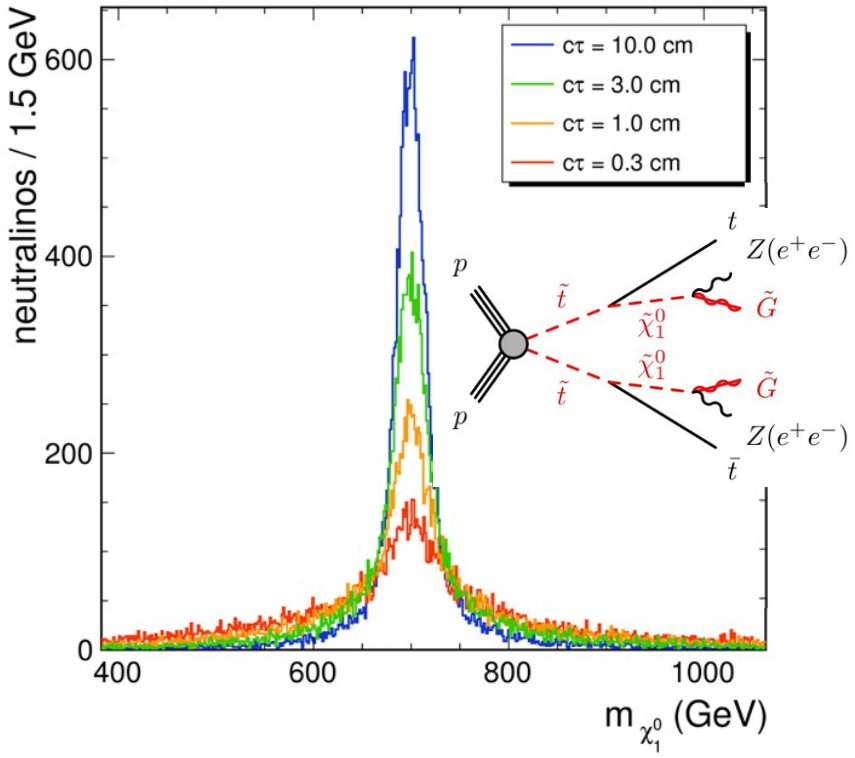




- Important to maintain detector performance during HL-LHC running
  - Time information will help to reduce pileup effects from approximately 200 simultaneous interactions
- MIP timing detector (MTD) consists of barrel timing layer (BTL) and endcap timing layer (ETL), providing 30-50 ps time resolution per track
  - BTL: LYSO crystal scintillator + SiPM readout
  - ETL: Silicon based sensor (LGAD) + ASIC readout
  - Two different detector technologies for radiation hardness and costs

# MTD Physics motivation: pile-up mitigation

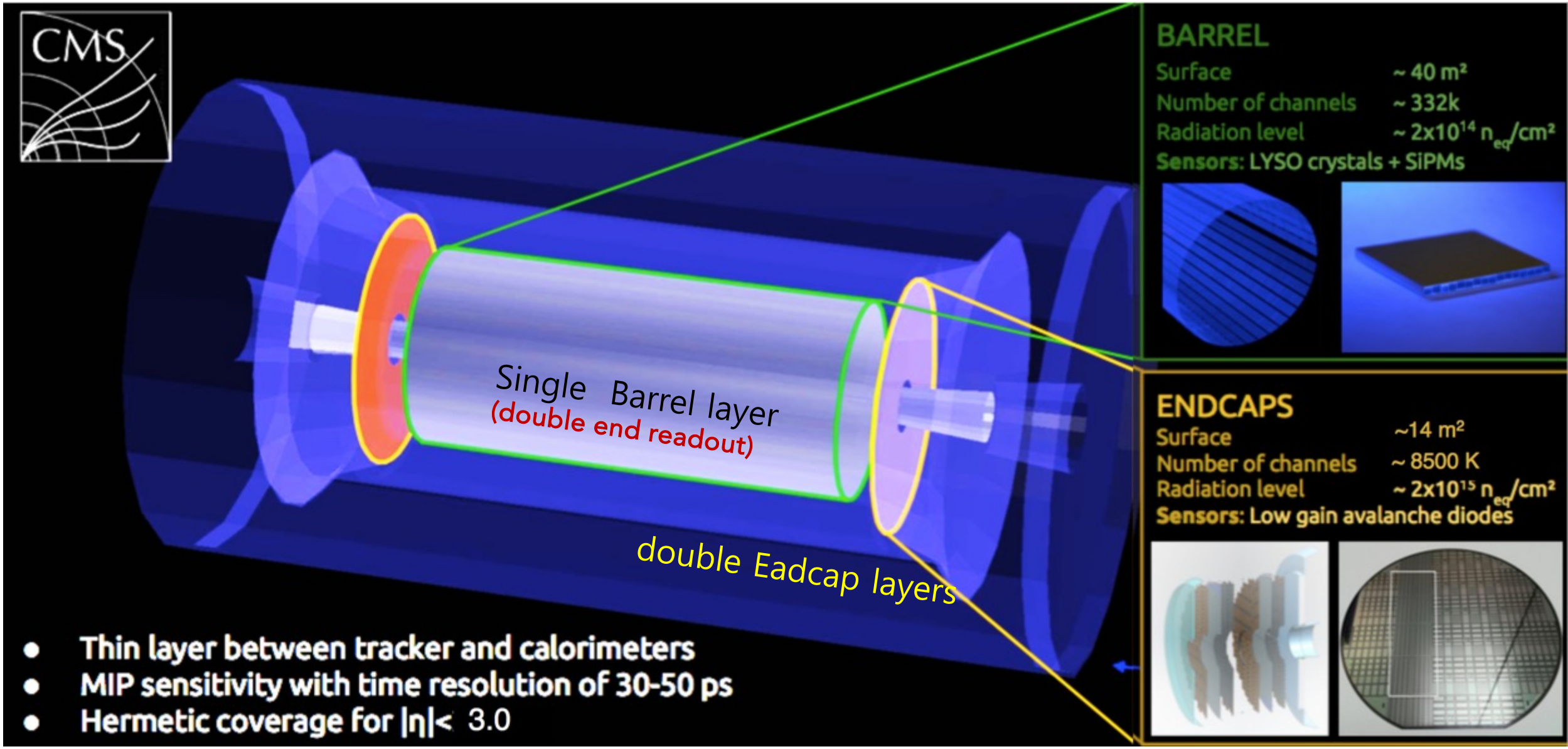


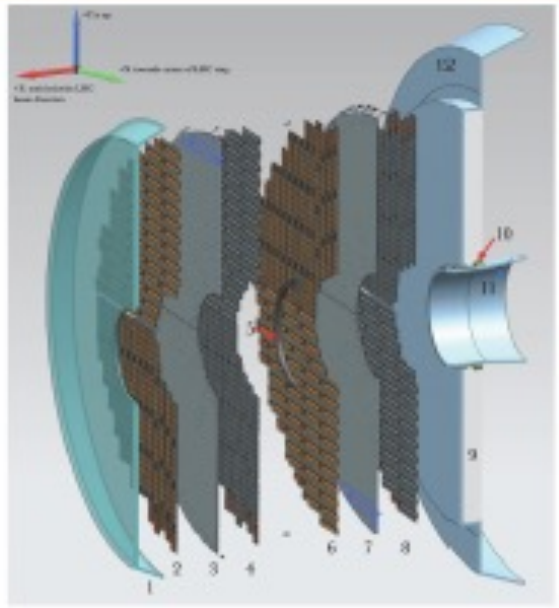

- The mitigation of pile up effect improves all physics objects
- 4D vertexing (position + time) can remove
  - Spurious pileup tracks from “isolation cone” around leptons
  - Spurious jets formed from pileup particles.
- MTD can provide significant improvement for particle ID: Heavy ion charm tag
- Significant gains for searches for long-lived new particles

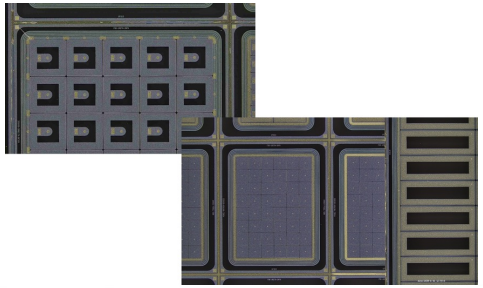
# Mip Timing Detector (MTD)

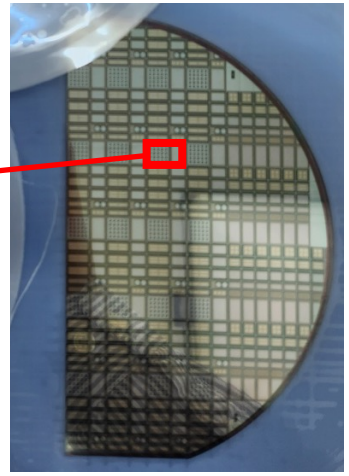


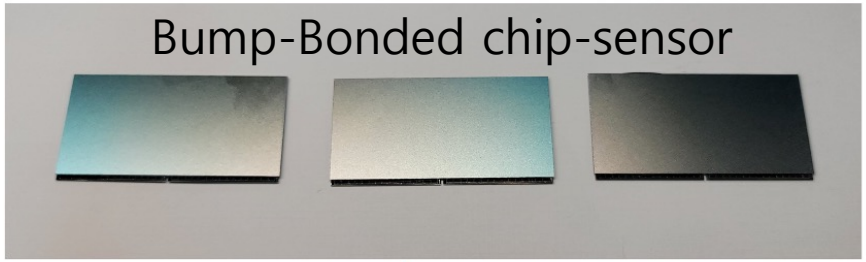
# Plan for MIP Timing Detector (MTD) contribution

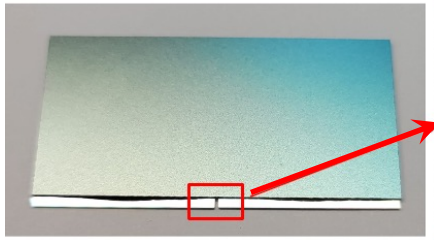
- **Need to mitigate the pileup events in HL-LHC using timing information to recover our detector performance**
- **Main contributions from KCMS**
  - Low Gain Avalanche Detector (LGAD) sensor development & test
  - Bump-Bonding devlopment & test
- **Required budget for MTD ETL (Endcap Timing Layer) : 2.2 MCHF**
- **Total contribution with MTD on the Phase 2 will be ~6 MCHF**

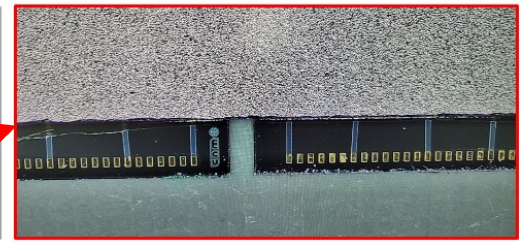


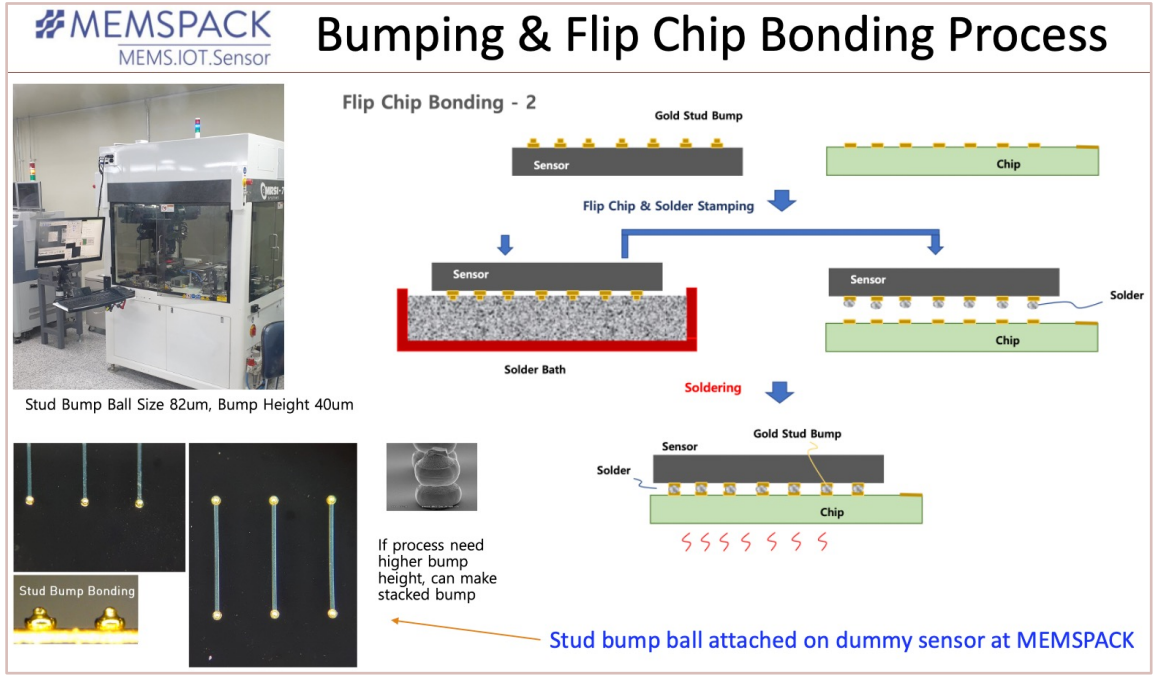




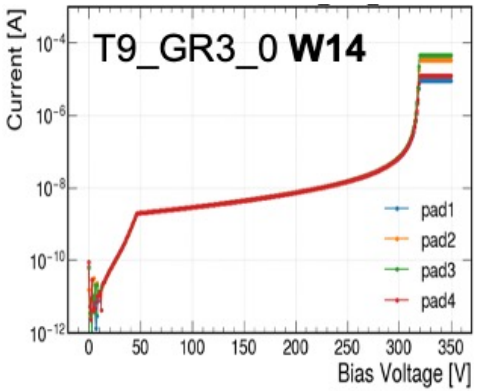


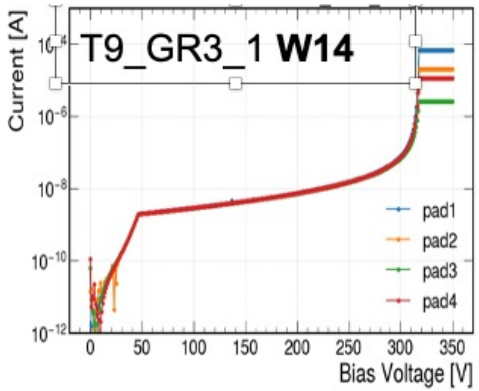



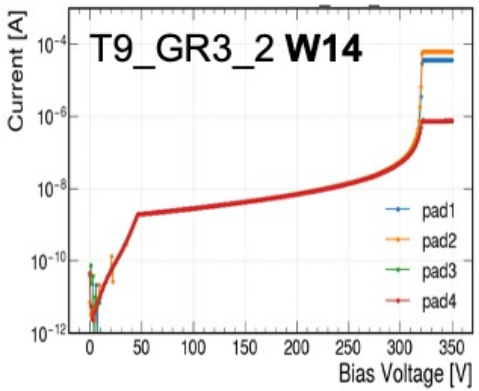


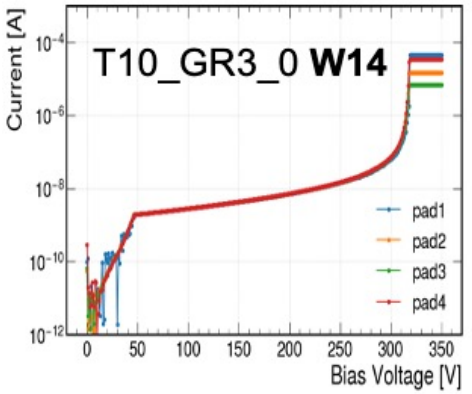


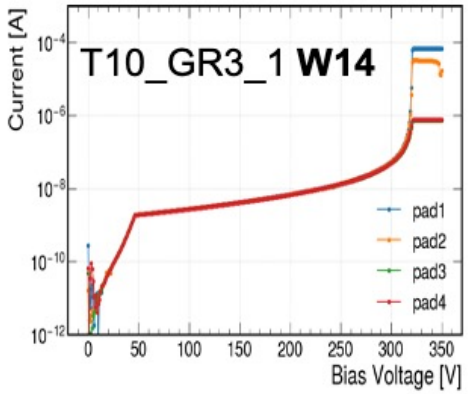
# I-V measurement of 2x2 sensors in wafer level (UFSD4 W14) at KNU

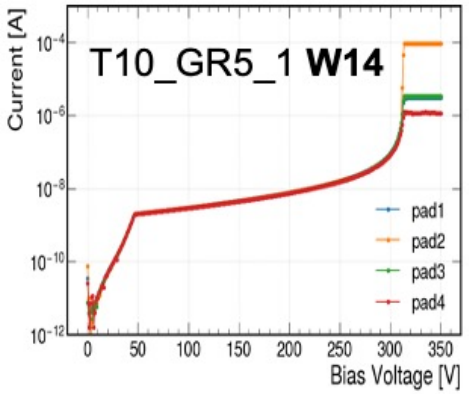


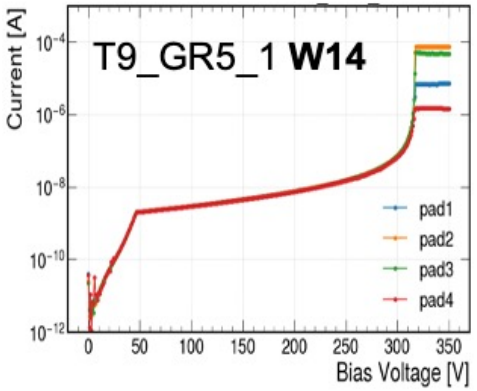



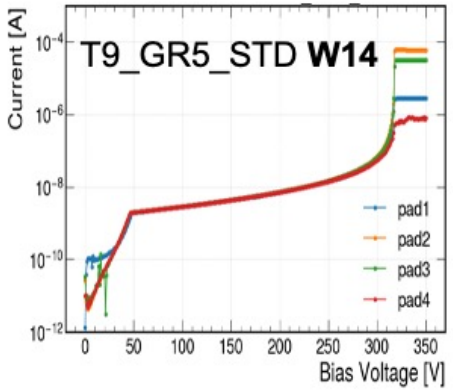



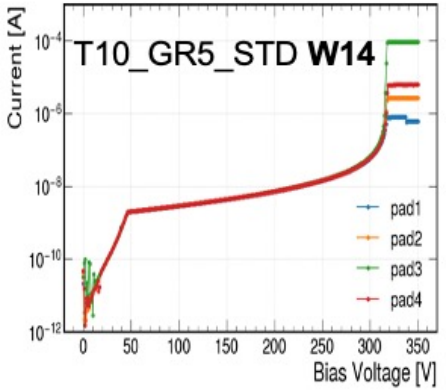



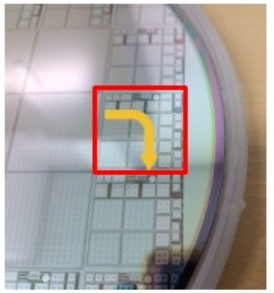



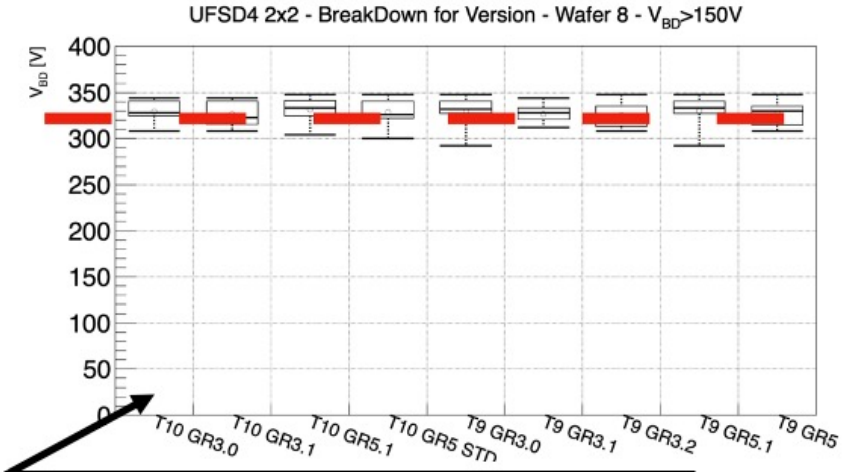



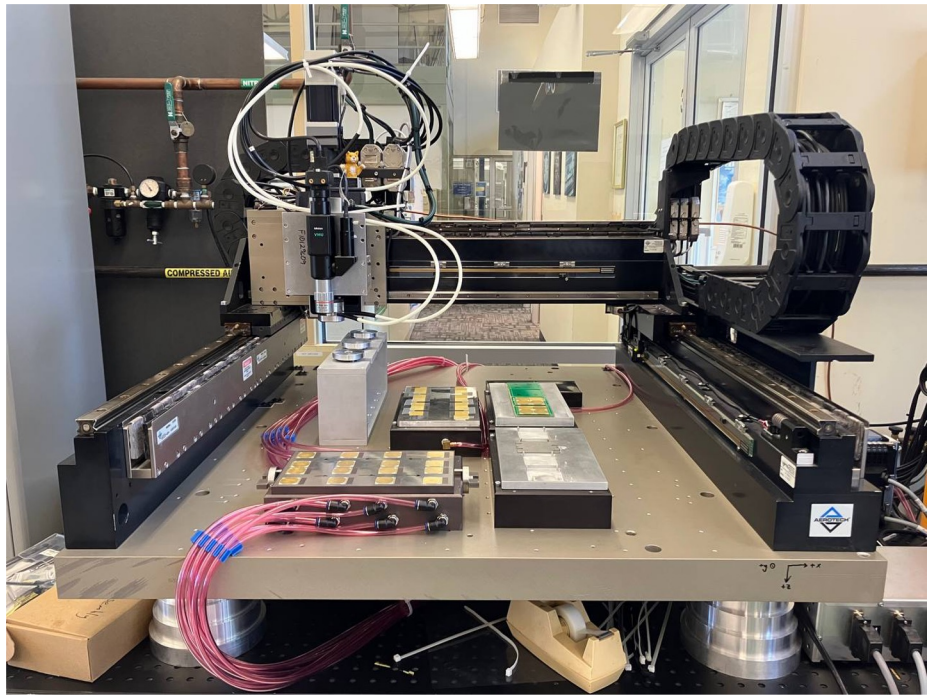

- Bias Voltage applied from 0 V to -350 V (ΔV = 1 V)
- Room temperature
- **Breakdown Voltage**
  - $V_{BD}$ ~ 320 V
  - The breakdown voltages are consistent in 2x2 sensors

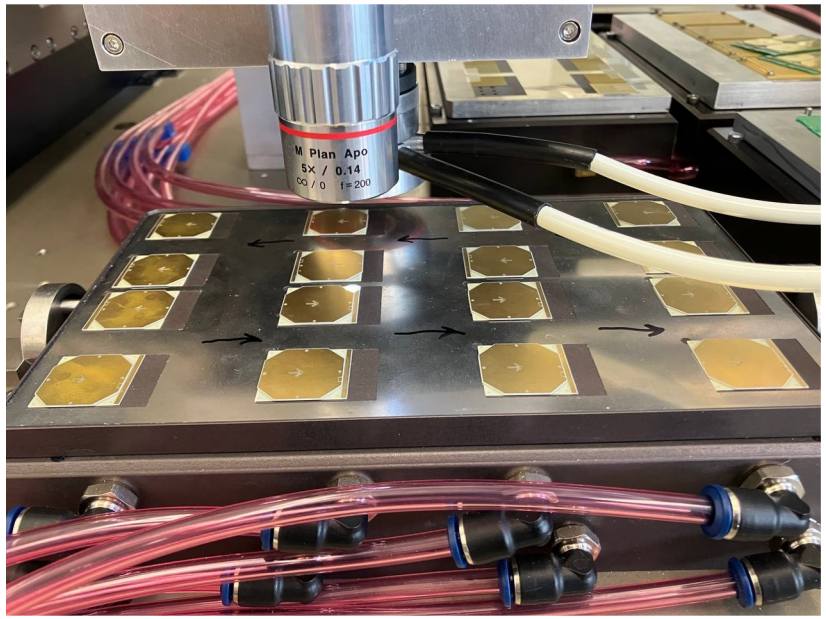


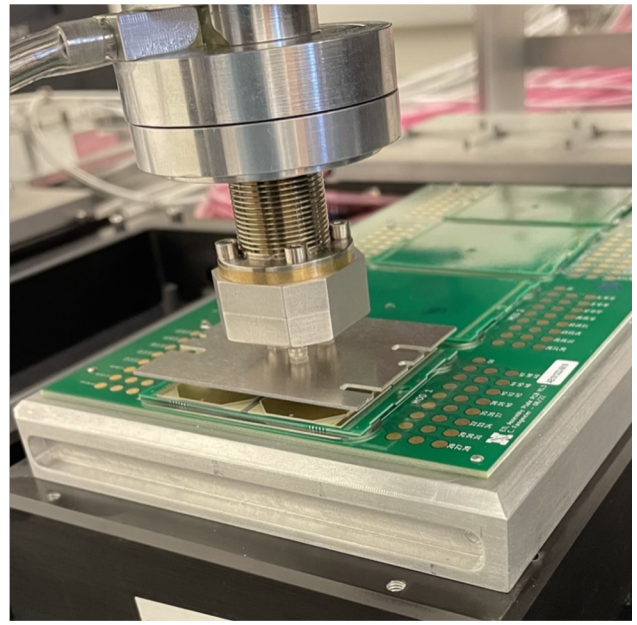



From Marta Tornago's talk,
https://indico.cern.ch/event/1141394/

# ETL Module assembly with Gantry at Fermilab



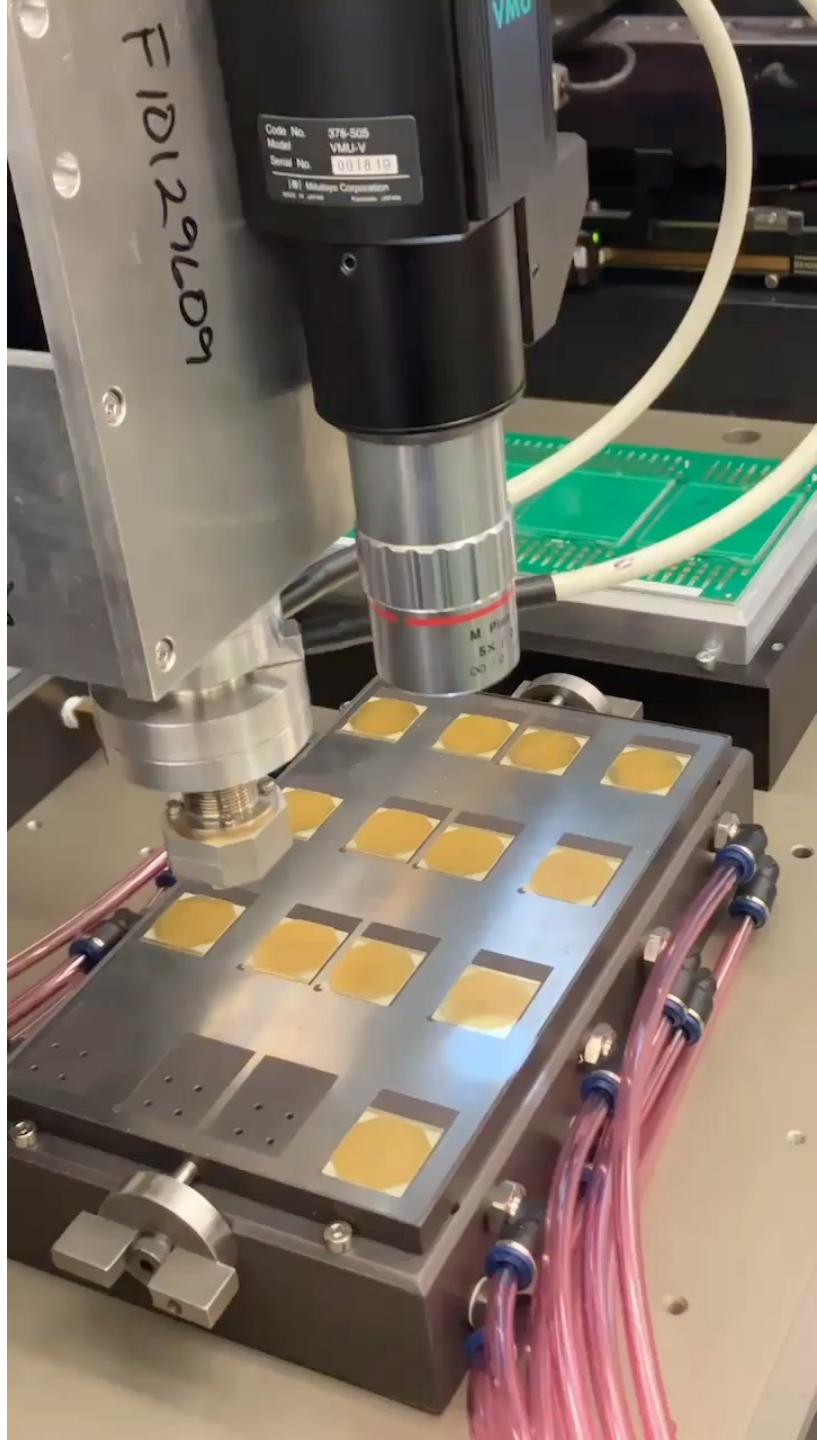


- Aerotech 3+1 axis gantries were used for ETL module assembly.
- Based on a vacuum pump
  - Modules PCBs and sensors are securely fixed.
  - Vacuum arm is used for picking and moving sub-assembly.
- The robot arm rail is moved using magnetic force, enabling precise operations at the 10µm level
- The camera measures and automatically corrects the position, rotation, and tilt of the sensors
- Checking production capacity of 100 modules per week

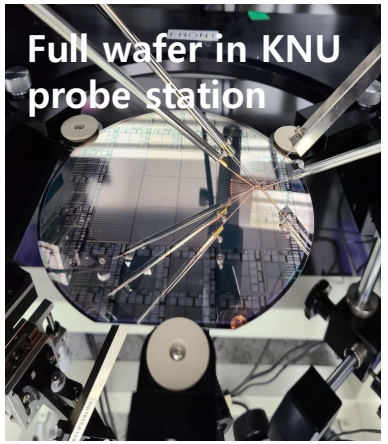

Mitutoyo
VMU
F1D129L09

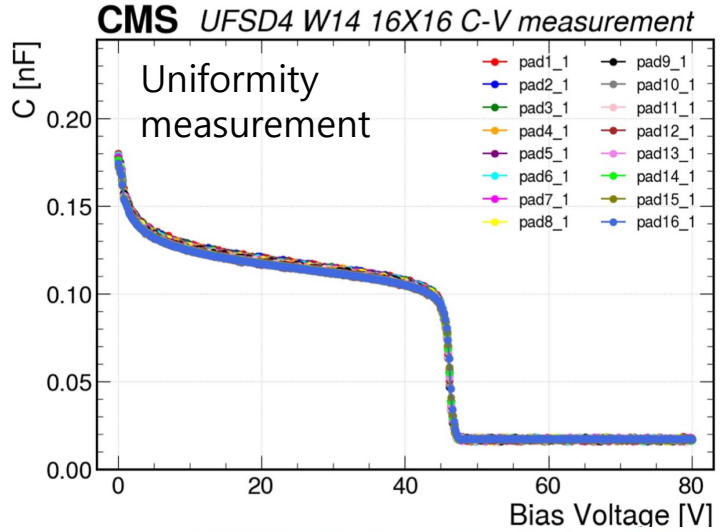

Mitutoyo
VMU
F1D129L09

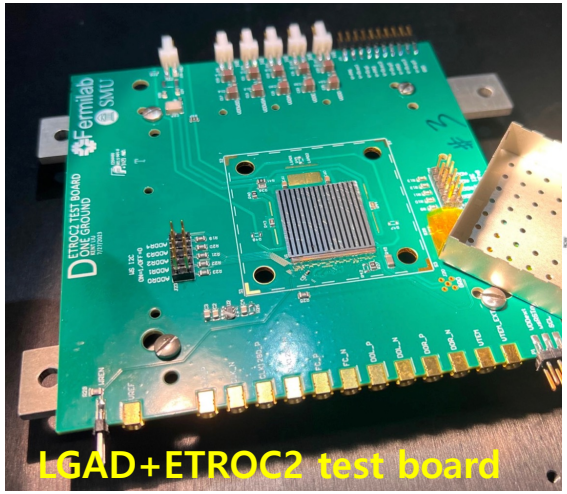

VMU
F1D129L09
Code No. 378-505
Model VMU-V
Serial No. 0018 10
Mitutoyo Corporation

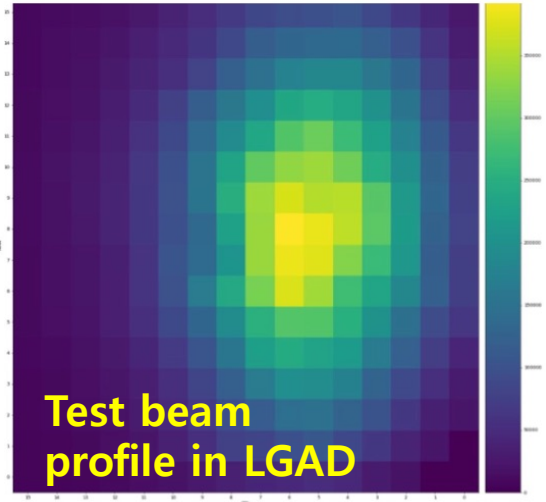
# Korea contribution to the MTD

- **KCMS responsible for the delivery of one layer of ETL sensors!**
  - **25% of the total endcap coverage**
- **Significant contributions to prototyping towards production:**
  - **LGADs prototyping and validation:**
    - Detailed testing of prototype LGADs informed vendor qualification
    - Probe station measurements to verify quality and uniformity of full-size wafers
  - **ETROC2 testing**
    - Active in ETROC testing, including test beam campaigns for validation of the performance of the LGADs + ETROC chain
  - **Wafer processing:**
    - Exploring wafer processing with one of the qualified LGADs vendors for wafer thinning, dicing, and surface preparation at Korean companies for the production phase
  - **Bump-bonding:**
    - Exploring options with Korean companies for LGAD-to-ETROC bump-bonding during production



# MOU draft for MTD (to be signed today and tomorrow)



## Memorandum of Understanding (MoU) for Korea-CMS contribution towards the MIP timing detector (MTD) for the Phase-2 CMS Upgrade

between

The CMS Collaboration at CERN, hereafter referred to as CMS, on the one hand

and

The CMS Korea Institutes, hereinafter referred to as KCMS, on the other hand and hereinafter collectively referred to as Parties

- The specific contributions, and their estimated costs, are itemized below:
  - A contribution to procurement of 7,330 LGAD sensors to provide coverage of one layer per end cap, which corresponds to one quarter of the ETL surface. This production could be done with a Korean vendor as an in-kind contribution. KCMS should carry out the R&D work necessary to demonstrate the viability of this option, or otherwise provide sensors using vendors already qualified by the MTD project with an estimated cost of 905 kCHF.
  - A contribution to procurement of one quarter of the front-end ASICs, which corresponds to an estimated cost of 468 kCHF, together with continued contributions to the testing of prototype front-end ASICs, both as bare chips and as modules after bump-bonding to LGAD sensors and assembly in modules.
  - A contribution to the bump bonding of ETROC ASICs and LGAD sensors, corresponding to one half of the ETL, which corresponds to an estimated cost of 355 kCHF. This production could be done with a Korean vendor as an in-kind contribution, with viability demonstrated through prototyping in collaboration with the MTD groups that have committed to deliver the remainder of the bump bonding.
  - A contribution to procurement of one quarter of the module structures used to support the bump-bonded LGAD sensors and front-end ASICs. This contribution could be done with a Korean vendor as an in-kind contribution, with viability demonstrated through prototyping in collaboration with the MTD groups that have committed to deliver the remaining module structures. This corresponds to an estimated cost of 89 kCHF.
- KCMS will contribute to the assembly of the fourth layer, with personnel participating in the module assembly centers established by the MTD collaboration.
- KCMS shall provide a contribution to shared costs, which include the cooling infrastructure for the endcap timing layer operation and for the installation test stand. This entails procuring components for the CO2-based two-phase cooling system in collaboration with the CMS Technical Coordination team, corresponding to one quarter of the cooling infrastructure costs. This will correspond to a procurement contribution of 357 kCHF.

Therefore, the total contributions from KCMS shall be valued at 2,174 kCHF. A contingency of 15-30% should be considered for potential cost increases.

# CERN-Korea CMS Sign-up Ceremony for the MTD project



- **Korea CMS group** will contribute the **LGAD production (25%), bump bonding process, front-end ASICs and module structures**, etc.
- Total budget: **2.2M CHF** supported by National Research Foundation of Korea (NRF)

# Workshops and conference

- 3rd KCMS Workshop @ RAON, June 26-28 in 2023
- We will have an annual workshops in January 2024


- Korean Physics Society, Changwon, Oct 24-27 in 2023
- Pioneer session
  - Present and Future of the LHC programs at CERN

KPS Pioneer session - Present and Future of the LHC Program at CERN

Thursday 26 Oct 2023, 14:00 → 20:00 Asia/Seoul

Room: 602 (Changwon Exhibition Convention Center)

Chang-Seong Moon (Kyungpook National University (KR)), Hyung Do Kim (Seoul National University (KR)), Min Jung Kweon (Inha University (KR)), Tae Jeong Kim (Hanyang University (KR))

Description LHC started more than 10 years ago, and CERN will turn 70 years old soon. Ever since then, the Higgs boson was discovered, and the properties of the fundamental particles has been measured precisely. The standard model seems to be complete. However, nature such as dark matter and matter-antimatter asymmetry is still out there to be discovered. Furthermore, through heavy-ion collision experiments, we have confirmed the existence and basic properties of quark-gluon plasma, known as the primordial matter of the universe. However, understanding its characteristics from various perspectives is still necessary. LHC is the unique machine that allows us to probe these unknown phenomena. We will discuss the present and future of the LHC in this session.

# Thank you