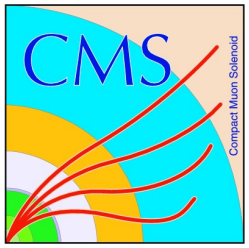

CMS 探测器升级简介

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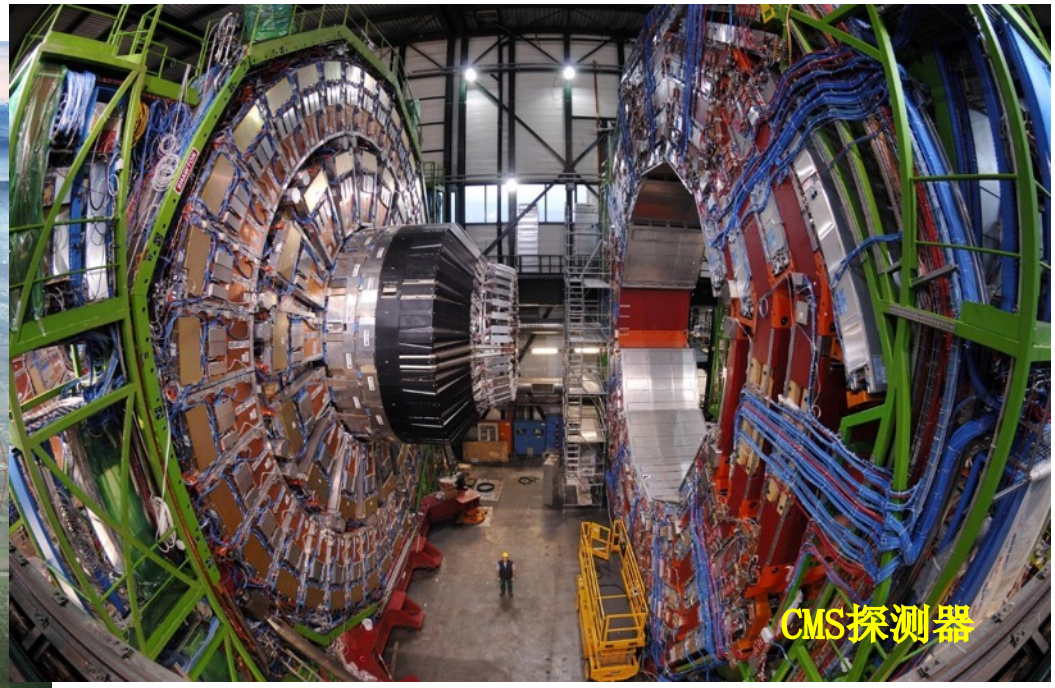
中国CMS冬令营
2021.12.18

LHC项目的成功及其影响



全球上万名科学家与工程师三十多年的努力，是**人类科学工程**的重大成就，其中具有极为丰富的科学、工程、管理、国际合作、文化等内涵

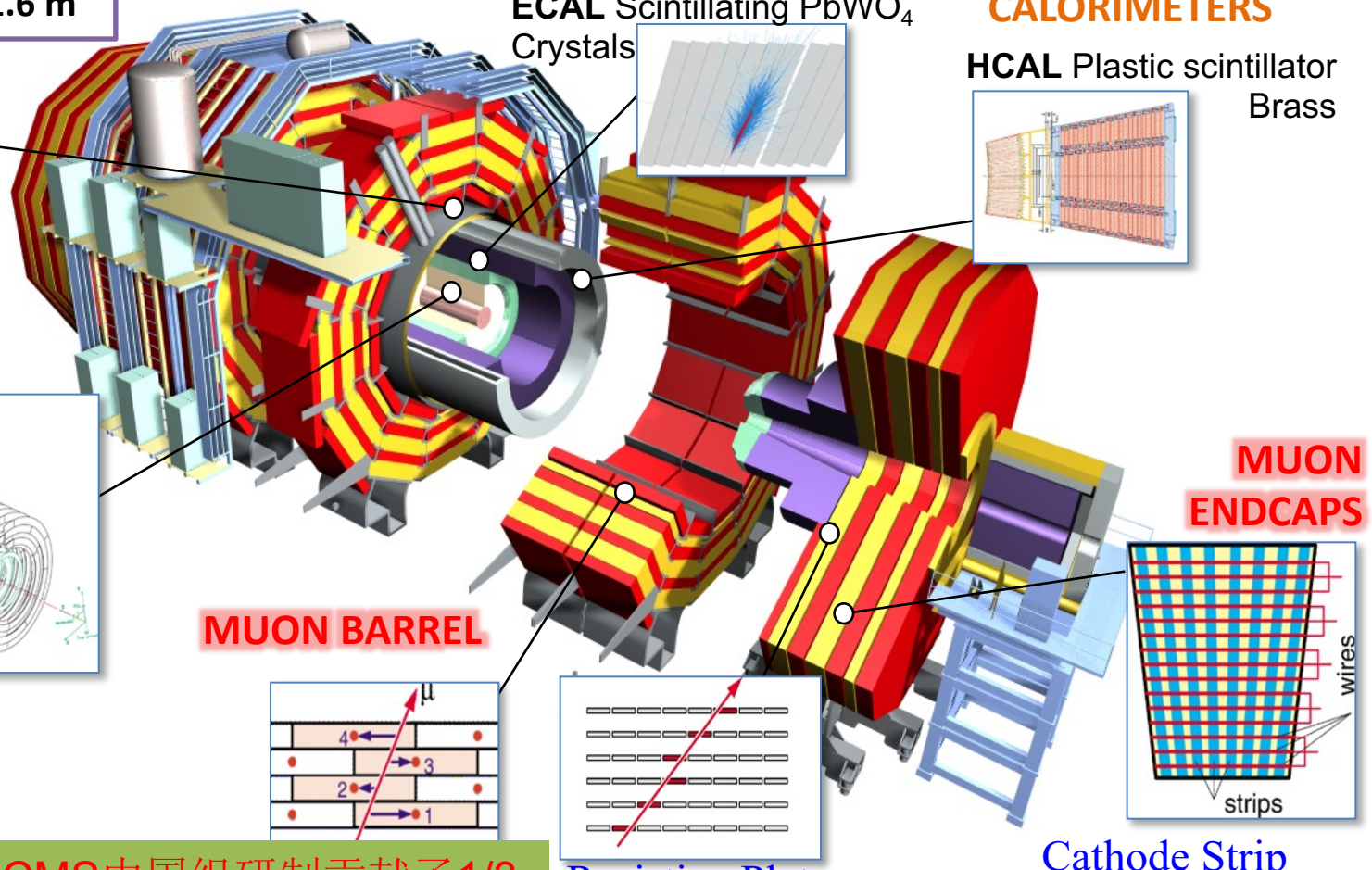
社会影响：

- 全球上千家媒体的报道，诺贝尔奖的肯定；
- 对人类生活和社会发展产生了重大推动作用，推动、发明了**WWW等一系列技术**
- **中国政府首次投入巨资参加重大国际合作实验，在硬件及物理分析中都取得了成就，作出了贡献**

CMS (Compact Muon Solenoid) 探测器

weight: 12500 t
overall diameter: 15 m
overall length: 21.6 m

人类建造最重的对撞机实验粒子探测器

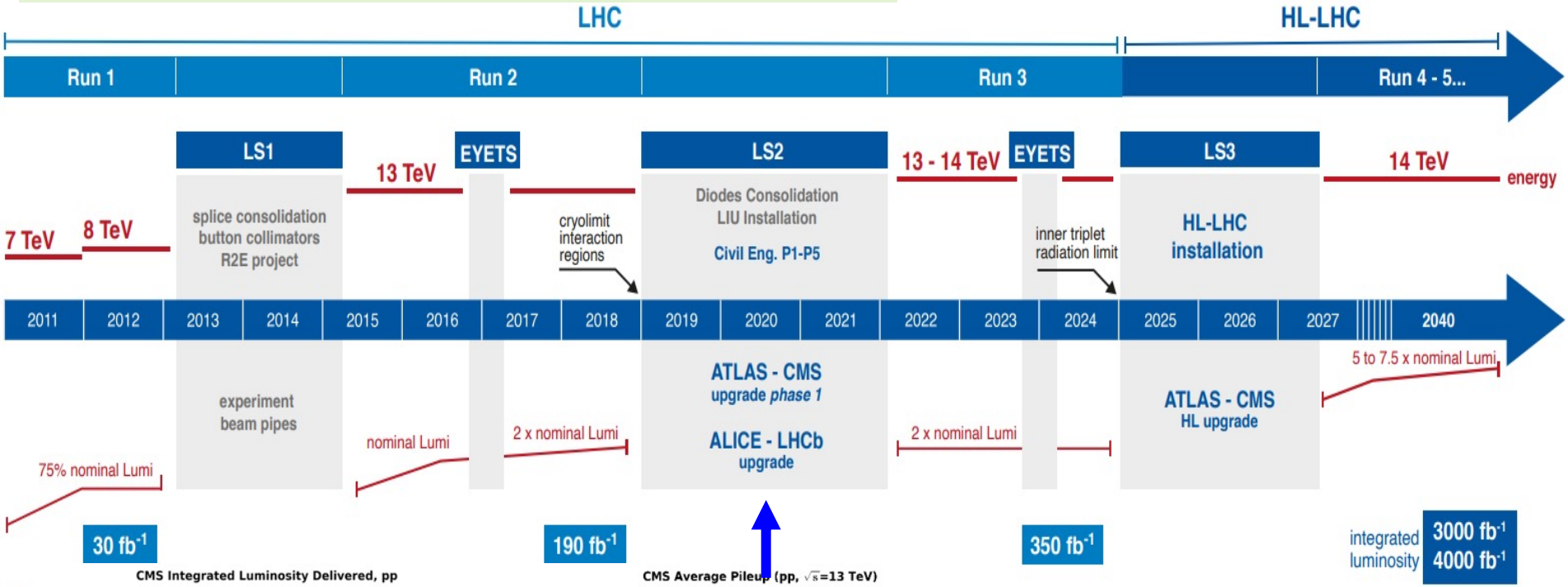


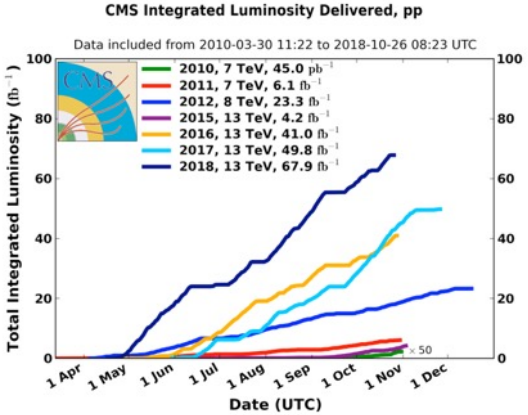
1999— 2006：CMS中国组研制贡献了1/3端盖μ子探测器(CSC/RPC)
2013—2019：参与并圆满完成I期升级

2020/10/22

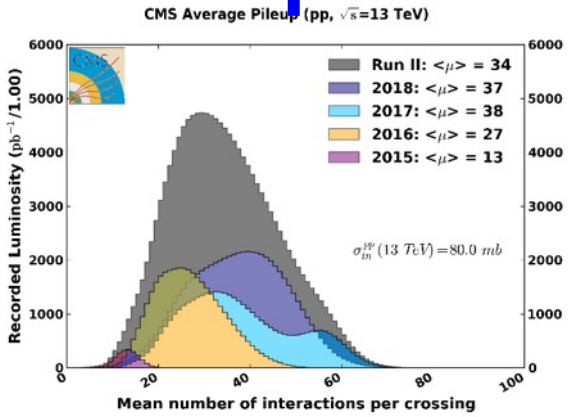
High Lumi-LHC upgrade

So far ~5% of the total planned integrated lumi!

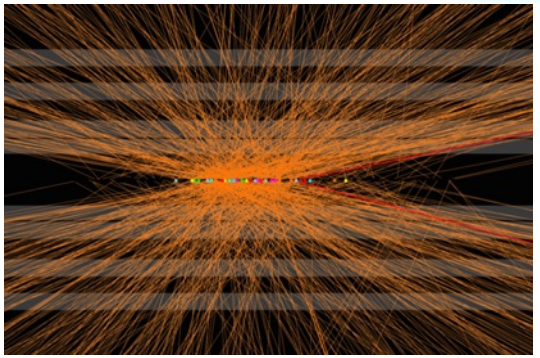




Peak Lumi.
$\sim 2 \times 10^{34} cm^{-2} s^{-1}$

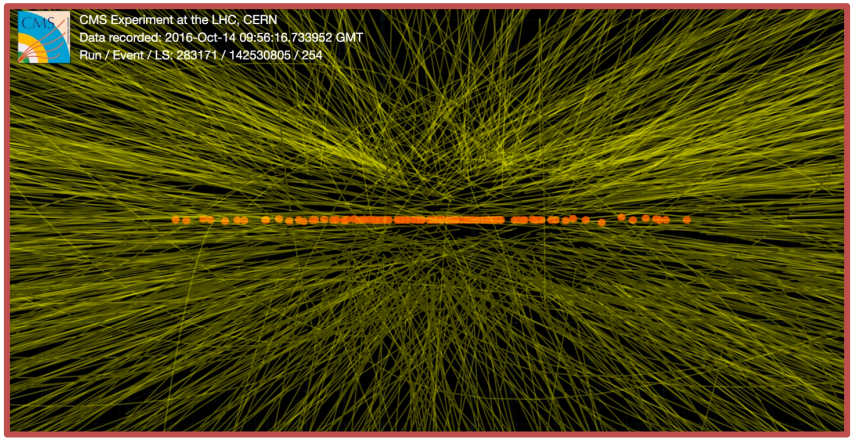


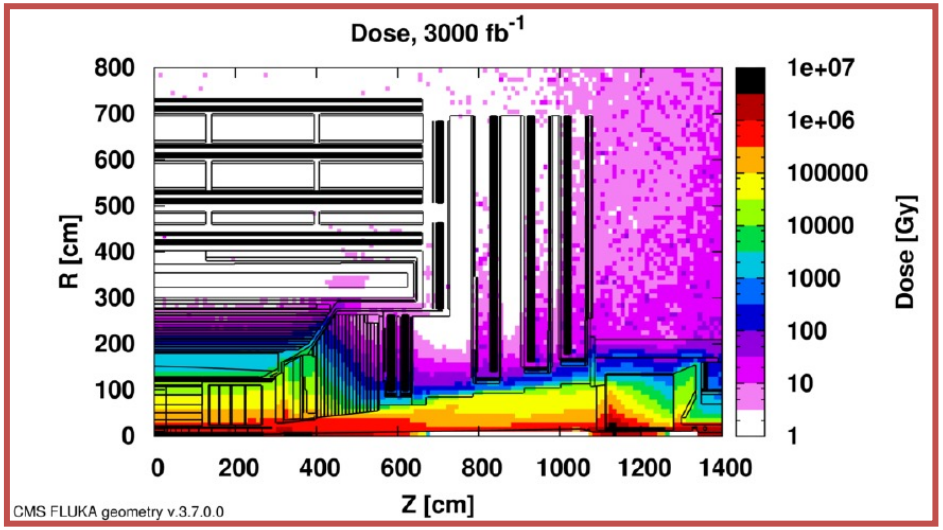
Run II Mean Pileup
34 interactions/Xing



A Z->μμ event with 28 vertices

HL-LHC: challenges and CMS solution





- **Expected pileup** (PU): ~140 -200 (nominal-1.5xnorm)
- Motivates/requires:
  - Improved granularity wherever possible
  - Novel approaches to in-time Pile Up mitigation: Precision Timing detectors (30ps)
  - A complete renovation of the Trigger and DAQ systems for better selectiveness, despite the high PU.

需承受>10^{16}等效MeV中子/cm^2辐照
局部区域吸收剂量~10MGy, 1Gy=1J/kg

- **Radiation damage / accumulated dose** in detectors and on-board electronics may result in a progressive degradation of the performance.
- Maintain detector performance in harsh conditions:
  - The complete replacement of the Tracker and Endcap Calorimeter systems.
  - Major electronics overhaul and consolidation of the Barrel Calorimeters and Muon systems

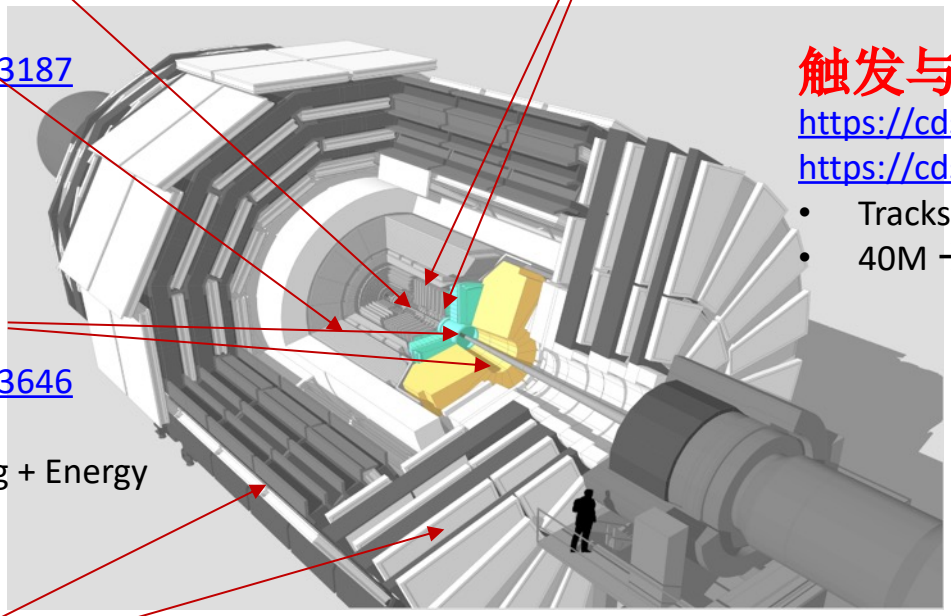
CMS 探测器II期升级: 2019-2026年, 匹配高亮度LHC升级, 是未来物理研究的基础!

CMS探测器 II期升级项目

硅径迹探测器：
https://cds.cern.ch/record/2272264
- Si-strips and Pixels increased granularity
- Tracking in L1-Trigger
- Coverage extended to |eta|~3.8

MIP 时间探测器：
https://cds.cern.ch/record/2296612
- ~30ps timing resolution
- Barrel: Crystals + SiPMs
- Endcap layer: LG Avalanche Diodes

桶部量能器：
https://cds.cern.ch/record/2283187
- New ECAL/HCAL readout



触发与数据获取系统：
https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193
- Tracks in L1
- 40M → 750k(PF-like) → 7.5k

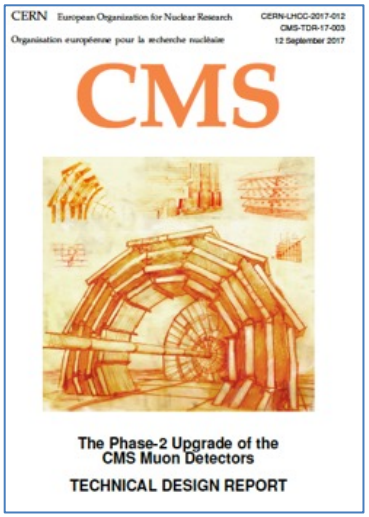
端部量能器：
https://cds.cern.ch/record/2293646
- Si, Scint+SiPM in Pb-W-SS
- 3D position + precise timing + Energy

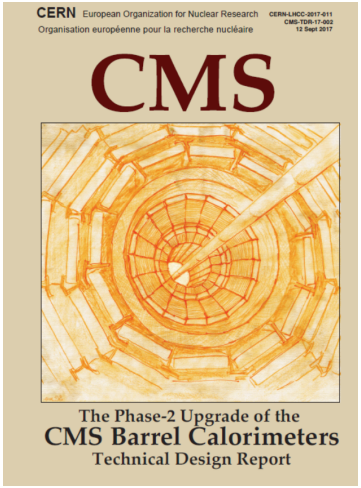
束流、亮度监测与通用设施
https://cds.cern.ch/record/2020886

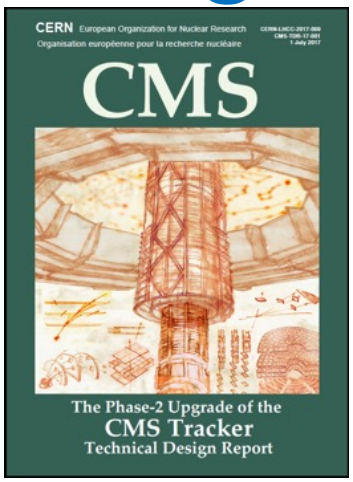
Muon探测器系统：
https://cds.cern.ch/record/2283189
- New FE/BE readout for DT/CSC
- New GEM/RPC 1.4 <|eta|<2.4: GE1/1, GE2/1
- Coverage extended to |eta|~3: ME0

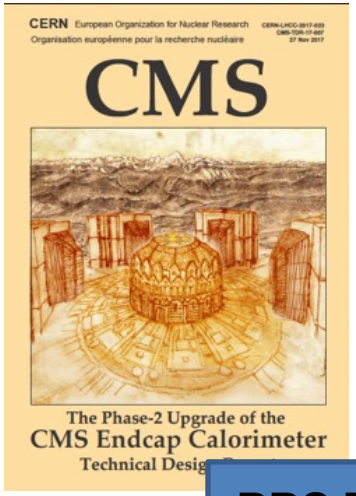
总造价（预算）：2.83亿瑞士法郎

The Phase-II TDR saga

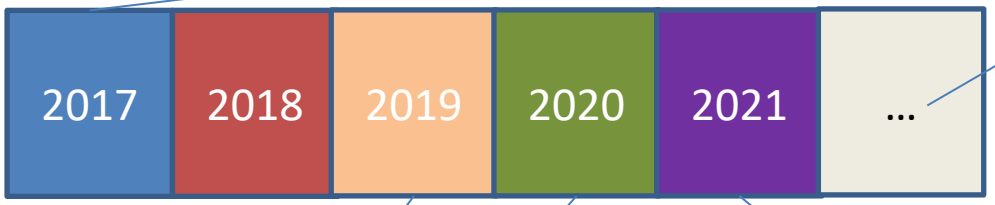




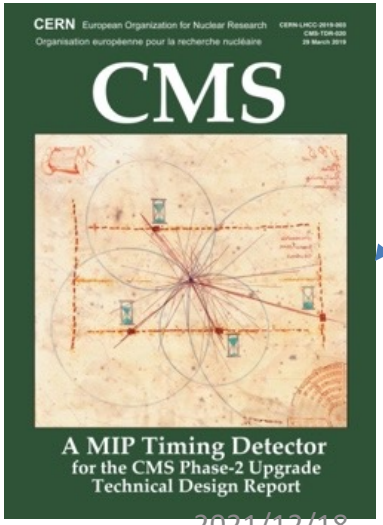


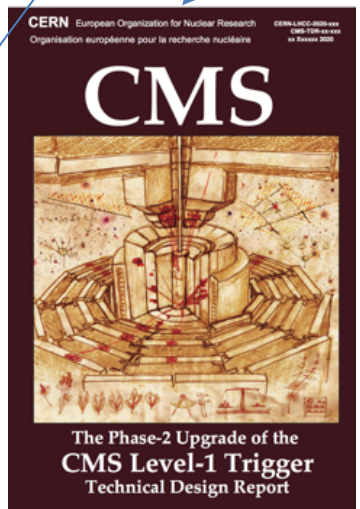


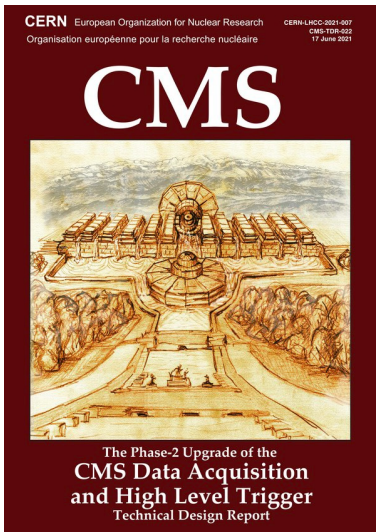
各主要项目TDR背后是>5-10年R&D,都已获LHCC批准

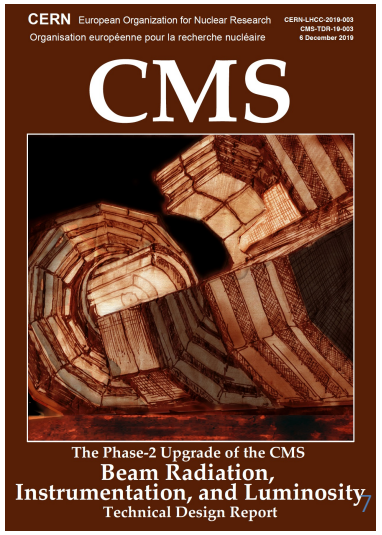


PPS TDR
Offline and Computing TDR ?







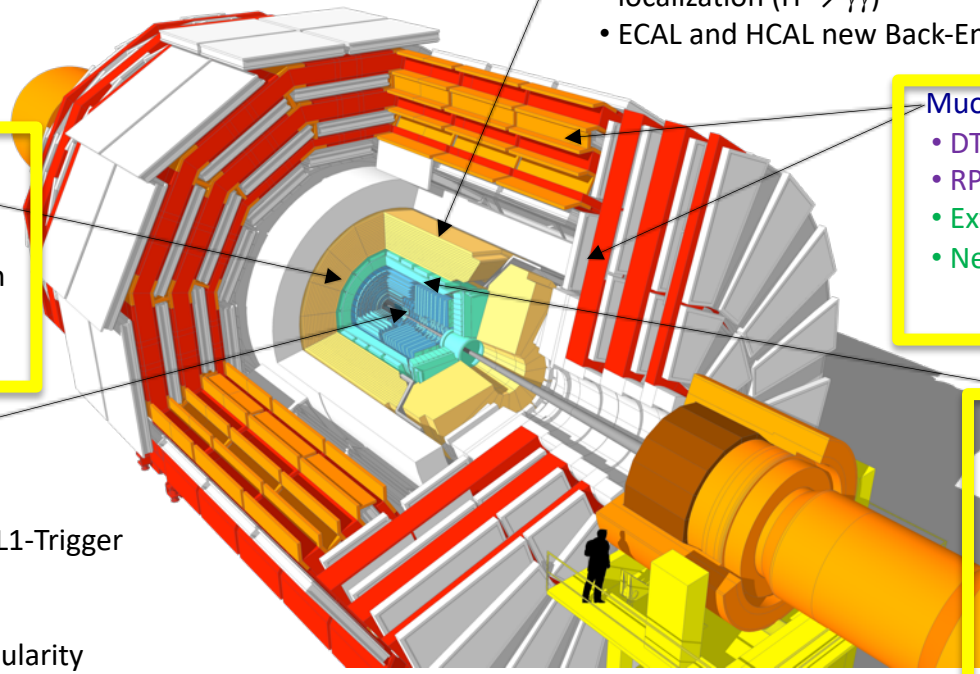


CMS Phase-II upgrade

Replacements of existing system
Electronics upgrade/replacement
New detector

L1-Trigger/HLT/DAQ
- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz

Barrel Calorimeters*
- ECAL crystal granularity readout at 40 MHz
- Precision timing for e/γ at 30 GeV, for vertex localization (H → γγ)
- ECAL and HCAL new Back-End boards



Calorimeter Endcap
- 3D showers imaging for pattern recognition
- Precision timing for PU mitigation
- Si, Scint+SiPM in Pb/W-SS

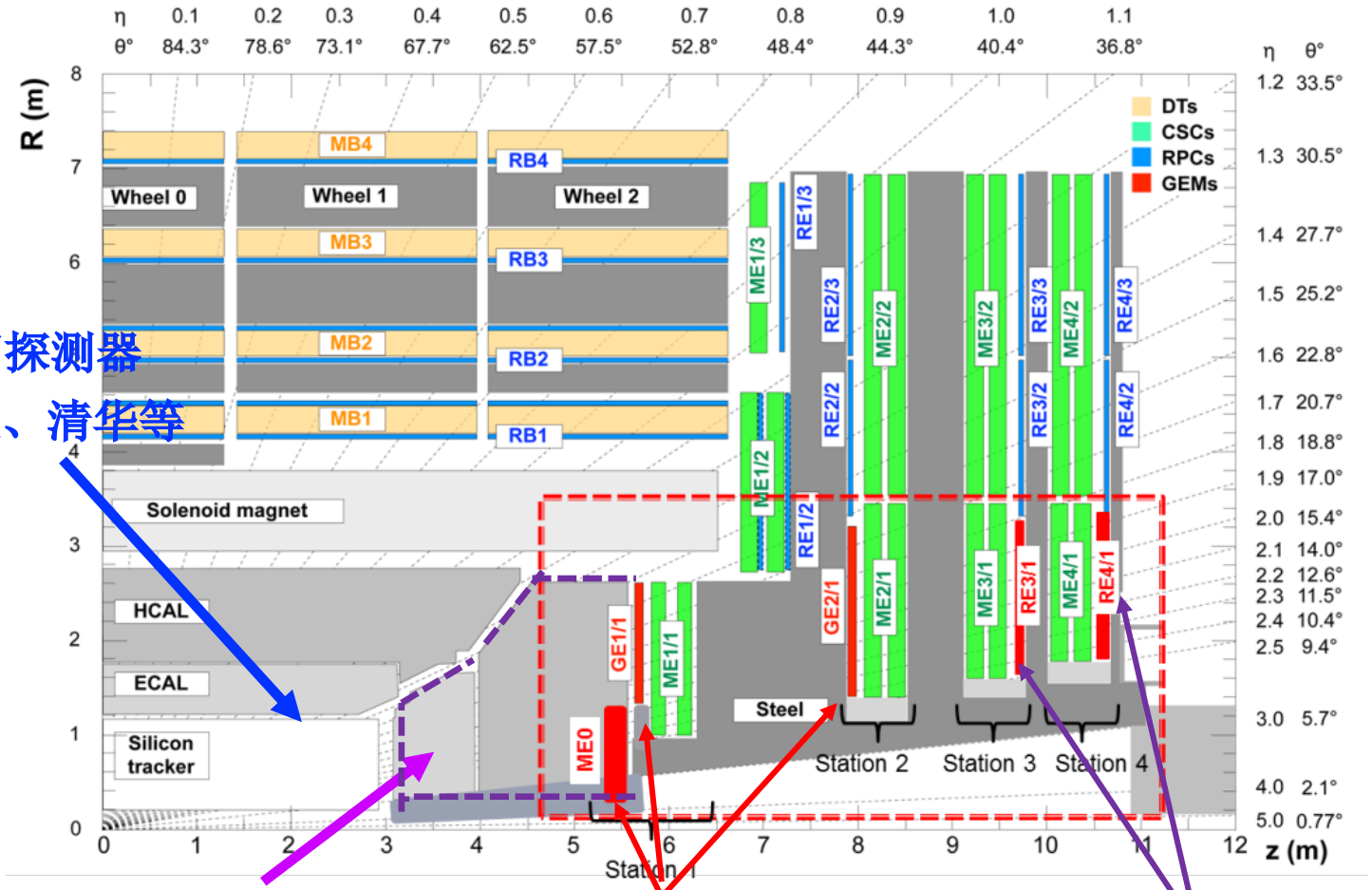
Muon systems
- DT & CSC new FE/BE readout
- RPC back-end electronics
- Extended GEM coverage to $\eta \simeq 3$
- New GEM/RPC $1.6 < \eta < 2.4$

Tracker
- P_T module design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$
- Much reduced material budget
- Si-Strip and Pixels increased granularity

MIP Timing Detector
- Precision timing for PU mitigation
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Projects with major CMS-China contributions

中国组承担的CMS II期探测器升级任务



MTD时间探测器

北大、北航、清华等

端部量能器升级

高能所、浙大、清华、复旦

端盖μ子探测器升级, GEM

北大、清华、中山、北航

iRPC后端电子学及触发

高能所

中国组参加探测器升级的意义

重要升级系统

硅径迹探测器、μ 子探测器、量能器和相关电子学和事例触发等

采用新一代粒子探测技术

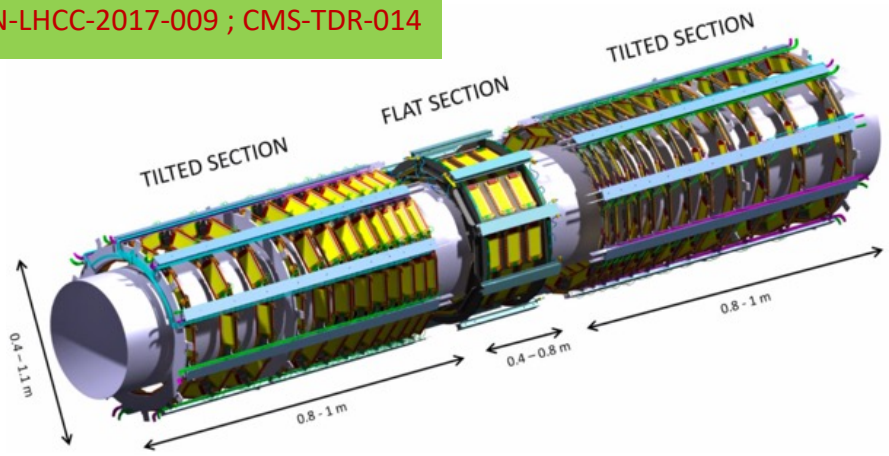
- 大面积的抗辐照、高空间分辨硅探测器
- 大面积、高计数率、高效率的新型μ 子探测器
- 高粒度高能量分辨量能器
- 高致密度ASIC 芯片
- 先进事例触发、数据获取与计算技术

→代表当今世界探测技术最前沿，可以跟踪掌握这些技术、打破禁运、推动我国在这些关键材料、技术和方法的发展，并辐射至其他领域。

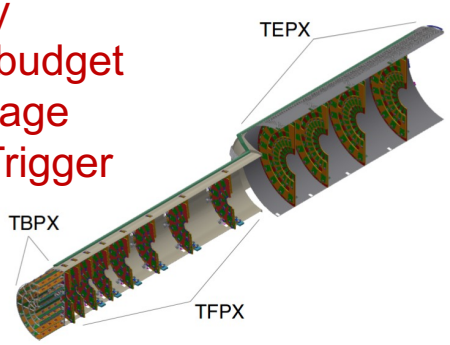
→人才培养和个人发展

Tracker Upgrade: layout and material

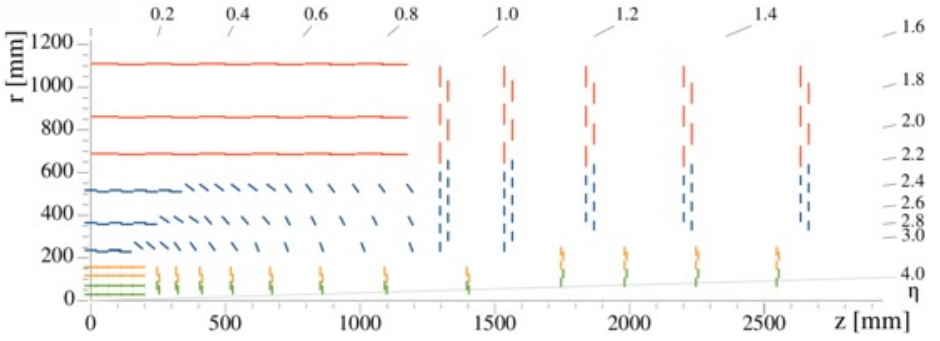
CERN-LHCC-2017-009 ; CMS-TDR-014

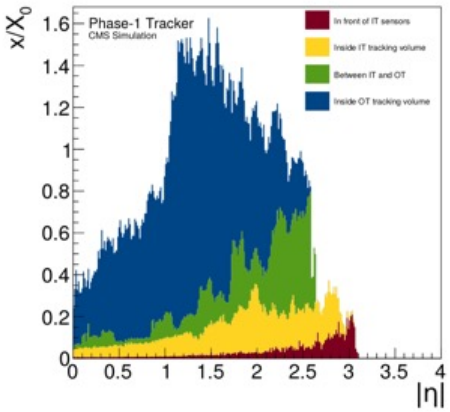


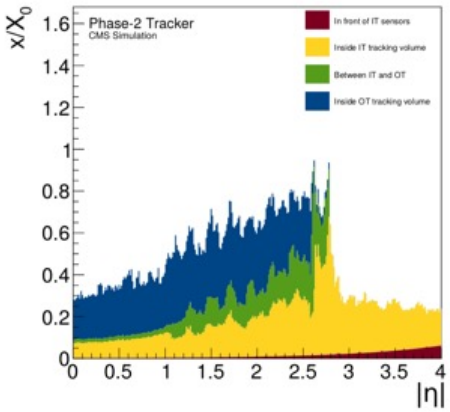
- More granularity
- Lower material budget
- Extended coverage
- Tracking in L1 Trigger



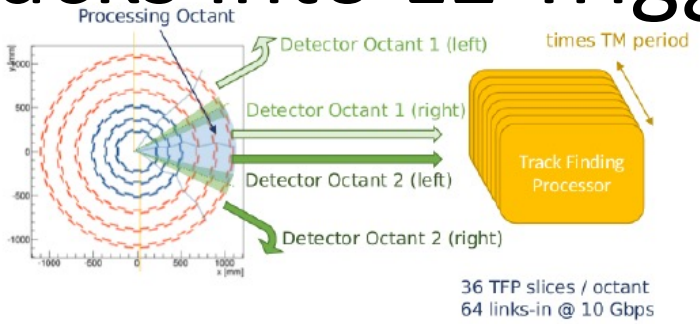
- **Inner tracker**:
  - Increased granularity with occupancy at per mille level: pixel size ~ 25 × 100 μm² or 50 × 50 μm²
  - Coverage up to η ~ 4, with ~4.9 m² active area
  - Layout: 4 barrel layers, 8 small disks, 4 large discs per side
  - Mechanics and support: simple structure for easy installation and removal → potential replacement of inefficient parts possible!
- **Outer tracker**:
  - Layout: 6 barrel layers, 5 discs per endcap
  - 9.5 million channels:
    - ~ 200 m² of active silicon sensors → 44M strips and 174M macro pixels (r < 60 cm)
  - Vastly **reducing** material:
    - light-weight mechanics and modules
    - improved routing of services
    - tilted barrel section

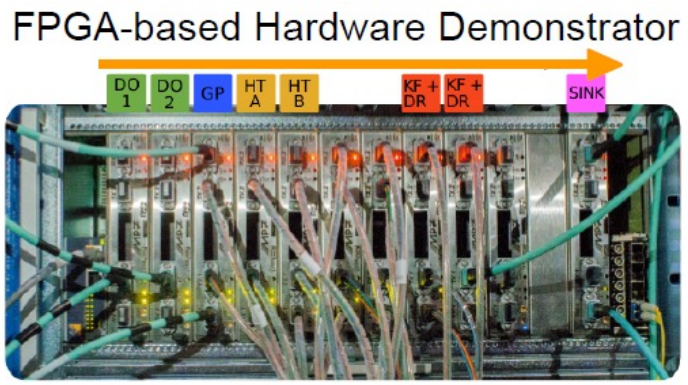






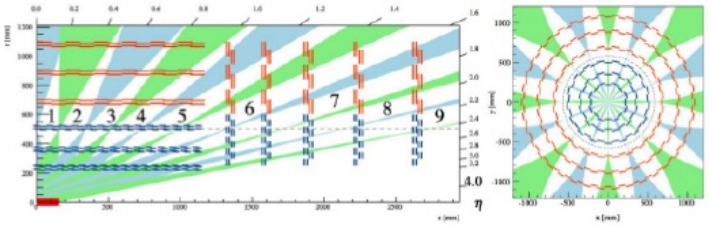
Tracks into L1 Trigger





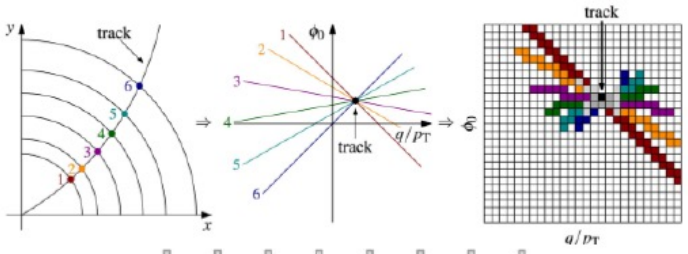
Geometric Processor GP

Processes stub data, sub-divides octant into 36 sub-sectors



Hough Transformation HT

Track finder, identifies groups of stubs consistent with a track in r-φ

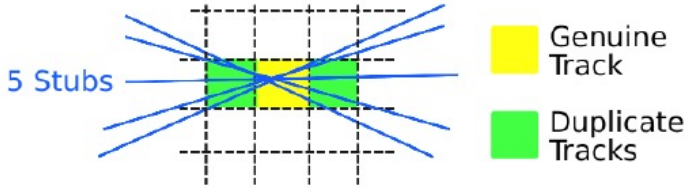


Kalman Filter KF

Candidate cleaning and precision fitting

Duplicate Removal DR

Uses fit information to remove duplicate tracks generated by the HT



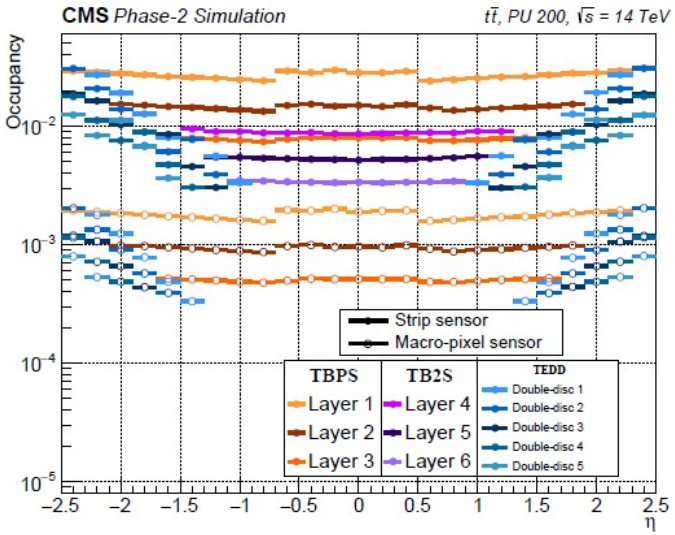
Data flow

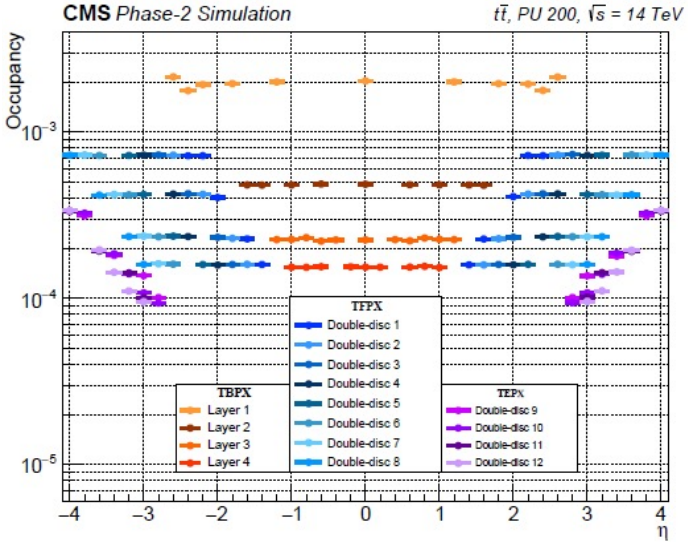
Expected performance

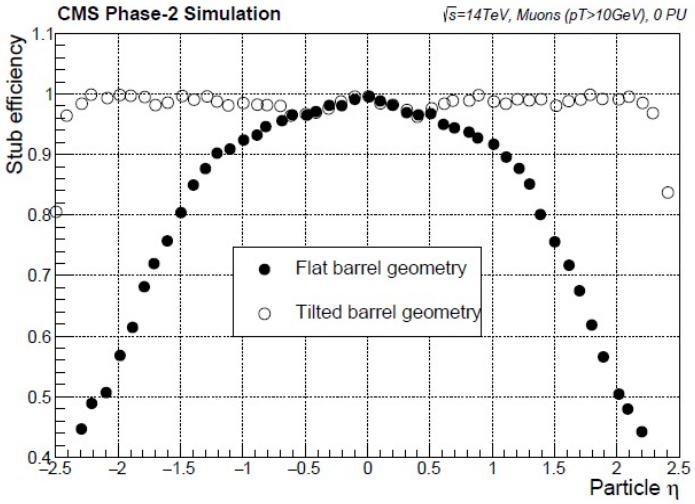
Occupancy will not exceed 3%

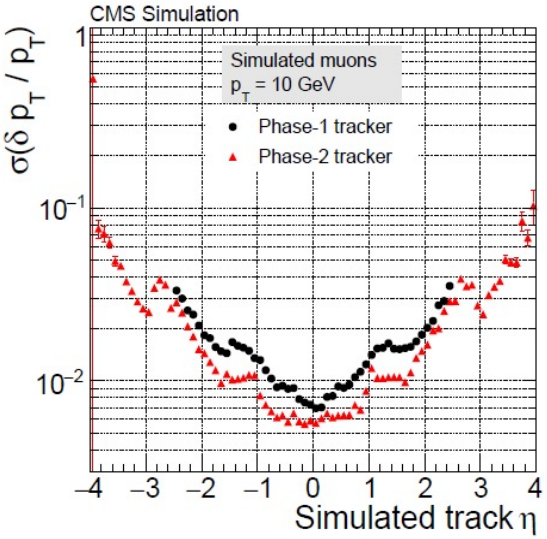
Resolution:

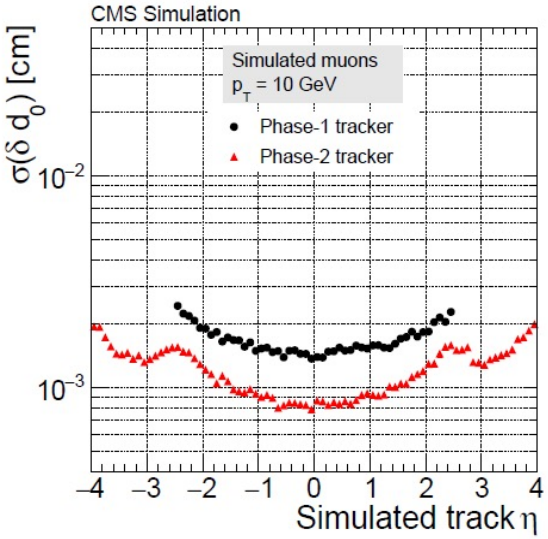
- ✓ Deteriorates at higher η due to shorter lever arm
- ✓ Below 10μm in centre, 20μm at edge







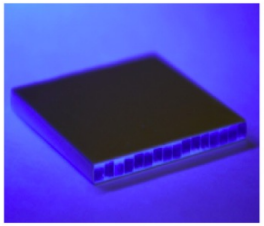




MIP Timing Detector

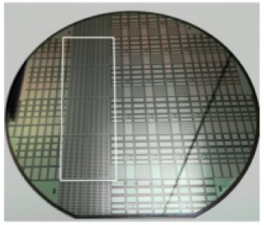
BTL: LYSO bars + SiPM readout:

- TK / ECAL interface: $|\eta| < 1.45$
- Inner radius: 1148 mm (40 mm thick)
- Length: ±2.6 m along z
- Surface ~38 m^2; 332k channels
- Fluence at 4 ab^{-1}: $2x10^{14}$ n_{eq}/cm^2



ETL: Si with internal gain (LGAD):

- On the CE nose: $1.6 < |\eta| < 3.0$
- Radius: $315 < R < 1200$ mm
- Position in z: ±3.0 m (45 mm thick)
- Surface ~14 m^2; ~8.5M channels
- Fluence at 4 ab^{-1}: up to $2x10^{15}$ n_{eq}/cm^2



Thin layer between tracker and calorimeters

Hermetic coverage for $|\eta| < 3.0$

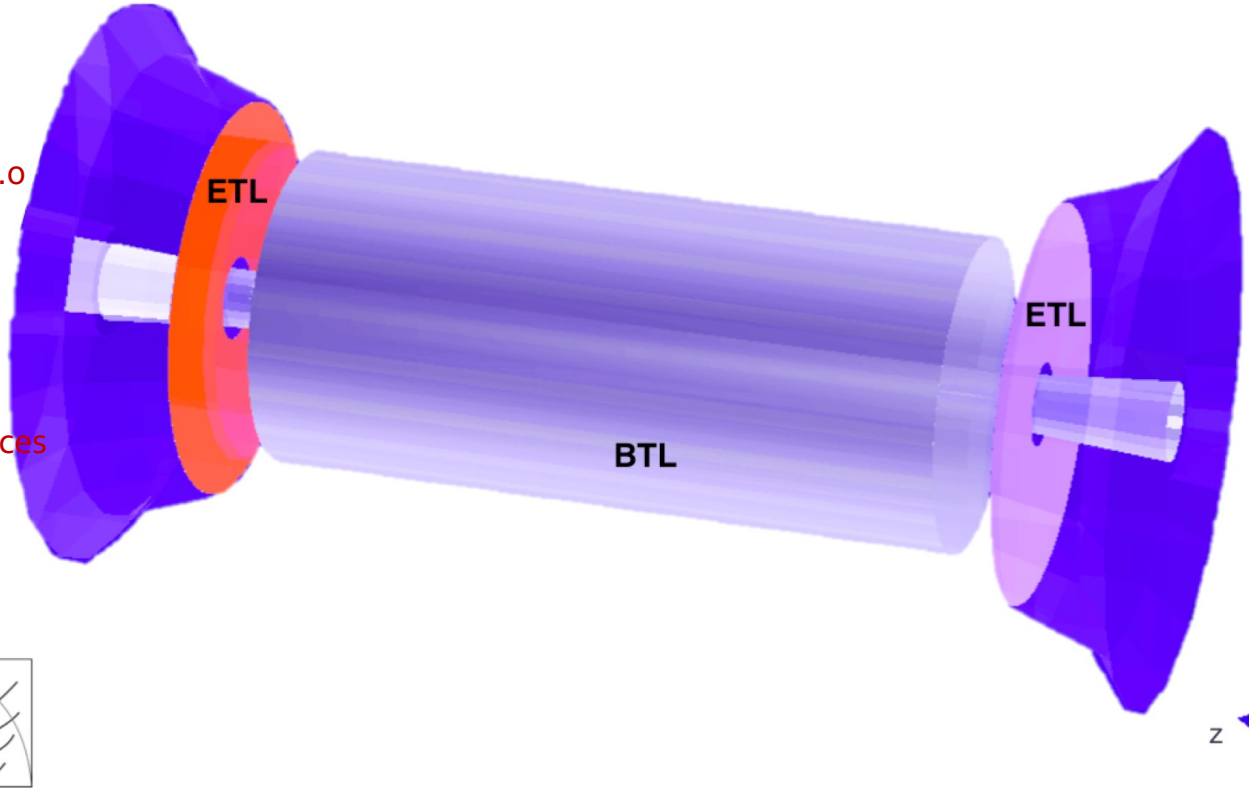
Feature:

MIP Time resolution 30-50 ps

4D vertex reconstruction

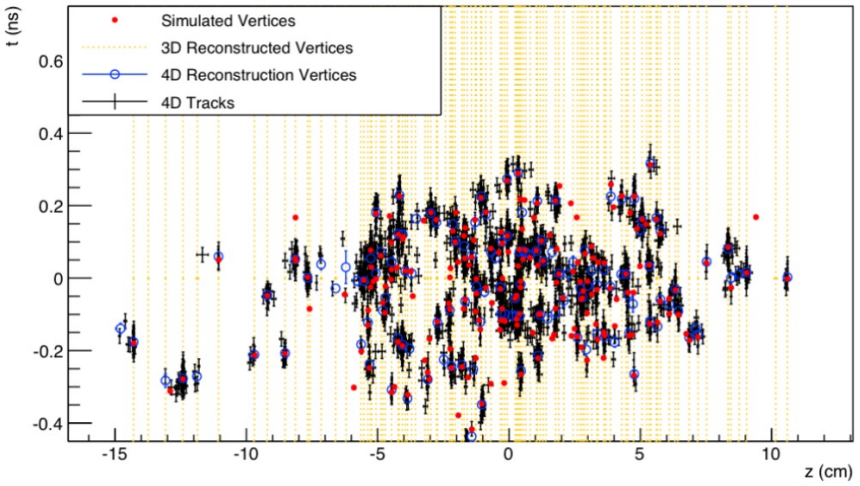
Expand physics at HL-LHC:

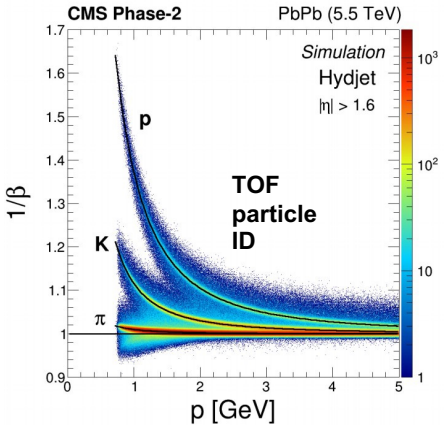
- Reduction of pile-up enhances quality of reconstruction
- Mass reconstruction of the long-lived particle

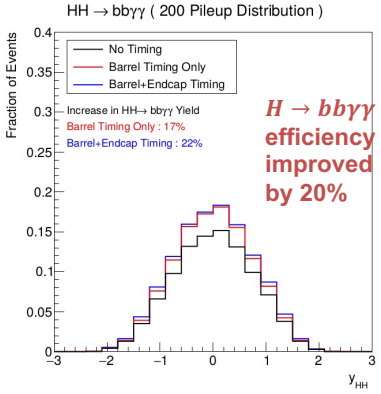


MIP Timing Detector

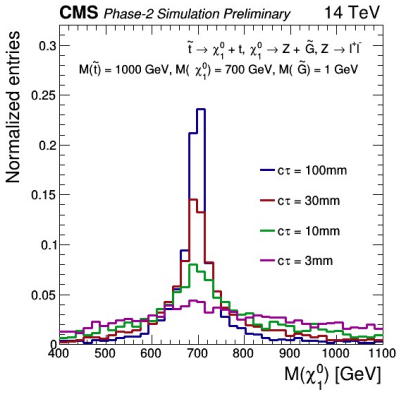
- **Time information** improves the quality of the reconstruction of physics objects.
  - Track time association allows to remove spurious pile-up tracks from reconstruction,
  - Impact on fake jet reconstruction, lepton isolation and ID, b-tagging, p_T^{miss} resolution.
  - Also adding the possibility to perform Time-Of-Flight particle identification
- Impact on the reach of physics analysis: both SM and BSM



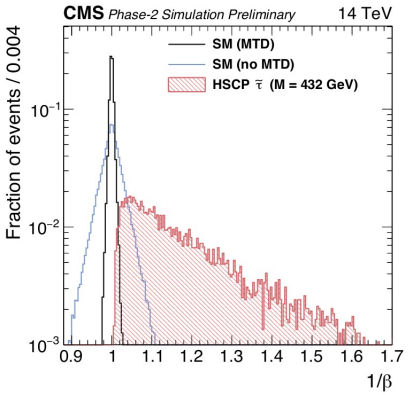




LLP



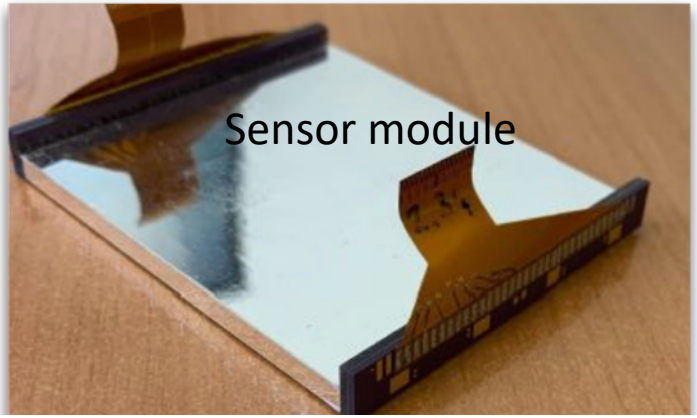
HSCP

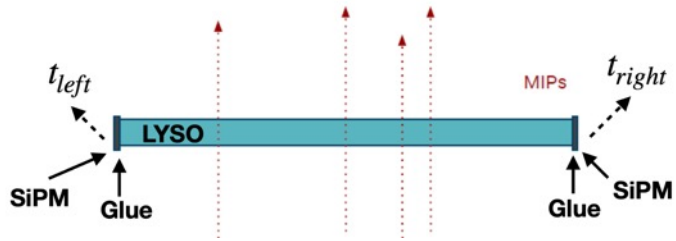


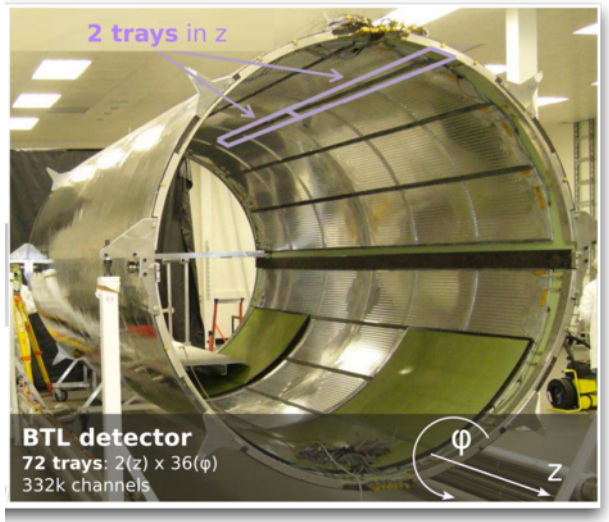
Improve HH sensitivity by 20%

Improve single Higgs precision by 20-30%

CMS timing detector MTD

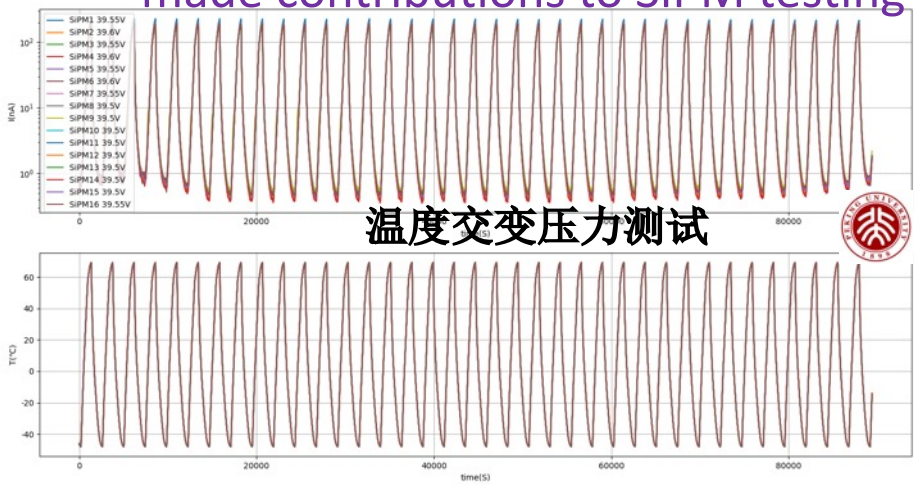






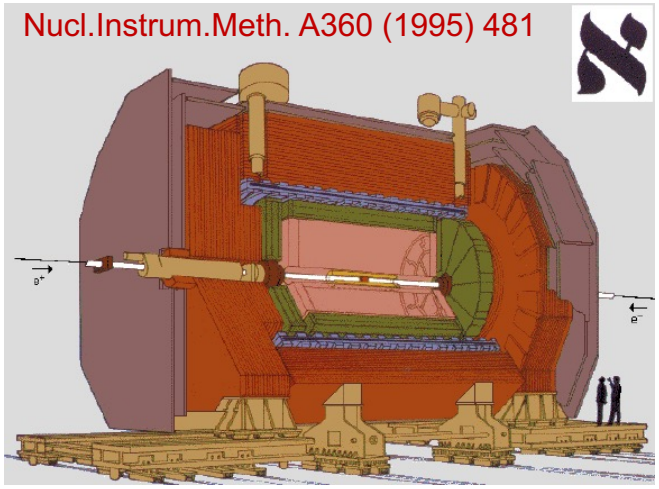
CMS-China officially joined MTD in 2021

- PKU, BUAA and THU joined MTD barrel (BTL) studies which uses LYSO+SiPM
- USTC plans to join the MTD endcap (ETL) studies which uses LGAD
- Actively communicated with MTD collaboration, built local labs, set up testing bench, and already made contributions to SiPM testing

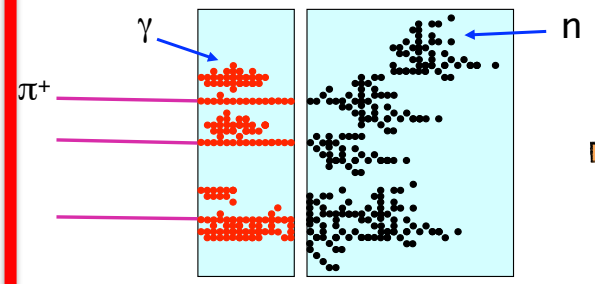


CMS端部量能器升级

Nucl.Instrum.Meth. A360 (1995) 481



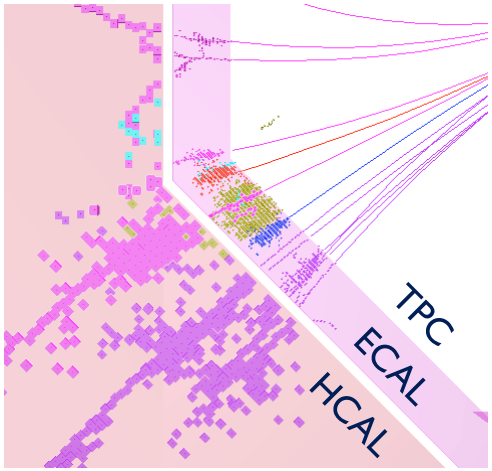
传统事例重建vs粒子流算法



$E_{JET} = E_{ECAL} + E_{HCAL}$

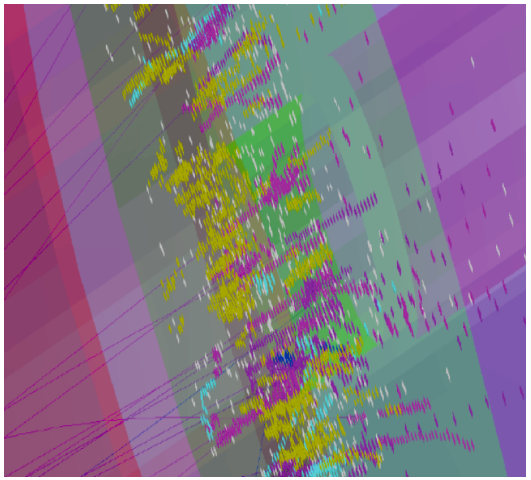
$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

NIMA.2009.09.009, NIMA.2012.10.038



arXiv:1307.7335, 1506.05348

LHCC-P-008

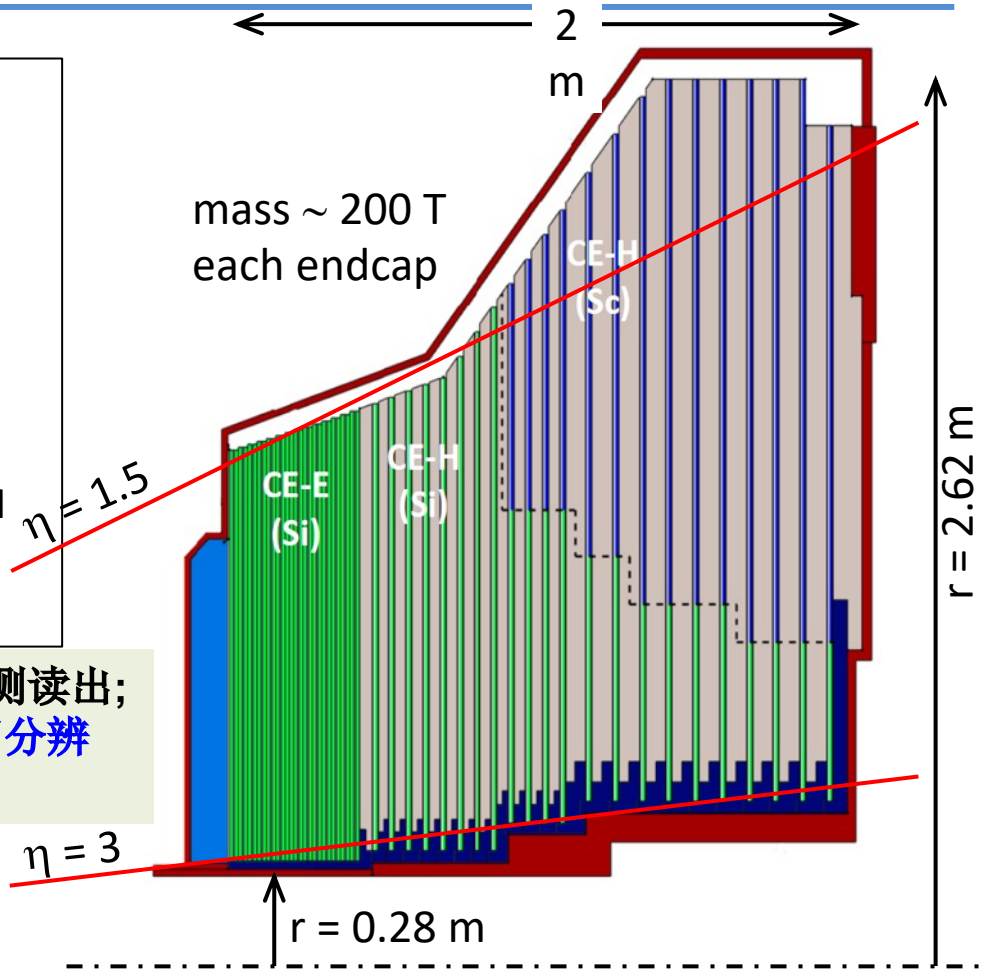


JINST 12 (2017) no.10, P10003

高粒度量能器HGCal

Key Parameters :

- HGCAL covers $1.5 < \eta < 3.0$
- Full system maintained at -30°C
- ~640 m^2 of silicon sensors
- ~370 m^2 of scintillators
- 6.1M Si channels, 0.5 or 1.1 cm^2 cell size (6M)
  240k scint-tile channels ($\eta-\phi$)
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all in CE-H
- ~31k Si modules (incl. spares)



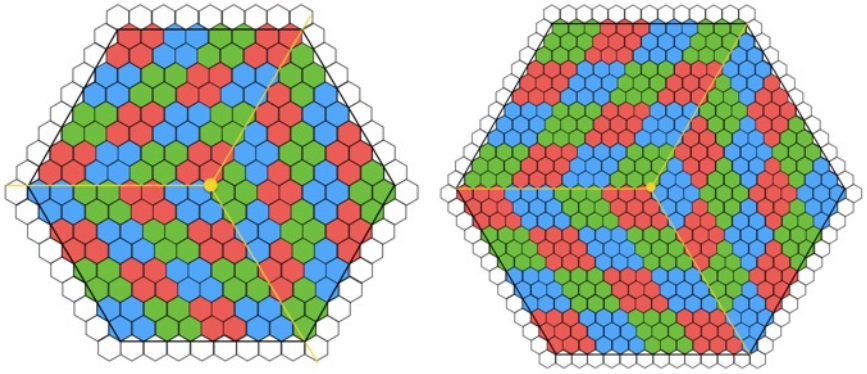
challenges：
2MGy does
140 pileup
220kW heat load
640m^2 silicon sensor
…

1立方厘米单个探测读出;
能量，位置，时间分辨
5D量能器

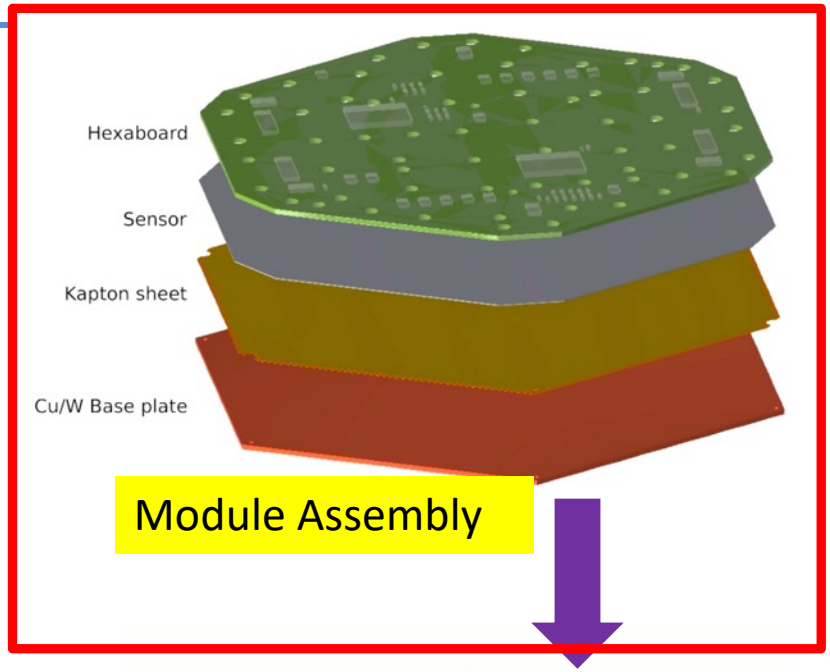
Electromagnetic calorimeter (CE-E): Si, Cu/CuW/Pb absorbers, 28 layers, 25.5 X_0 & ~1.7λ
Hadronic calorimeter (CE-H): Si & scintillator, steel absorbers, 22 layers, ~9.5λ (including CE-E)

高粒度量能器的设计

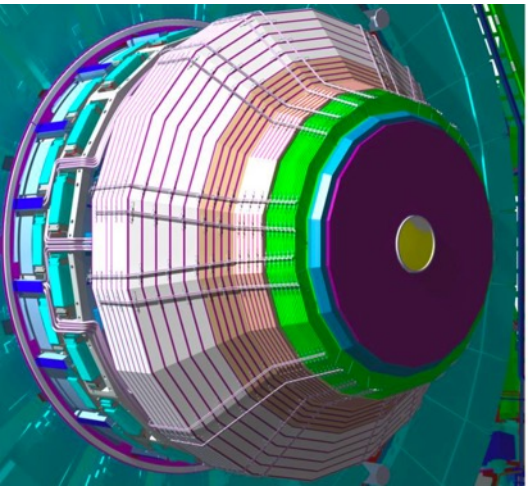
8inch， 1.18cm²（192） / 0.52cm²（432）



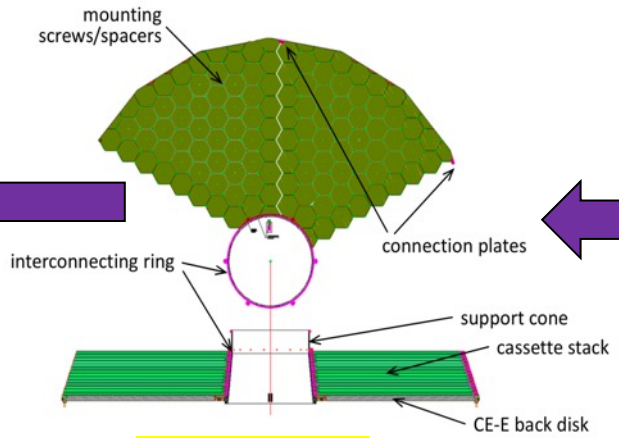
Sensors (Hexagon)



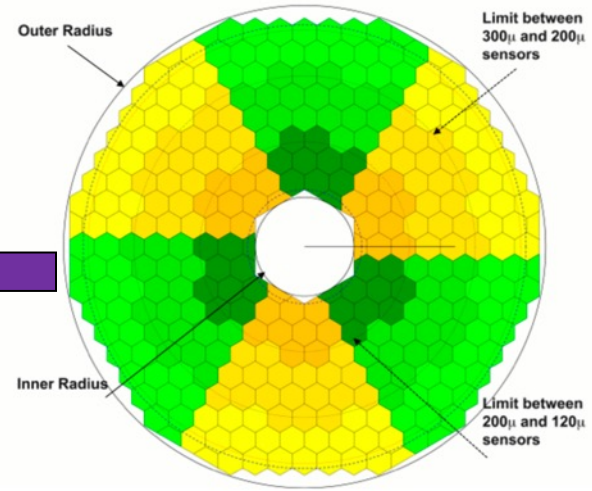
Module Assembly



28层Ecal，24层HCal

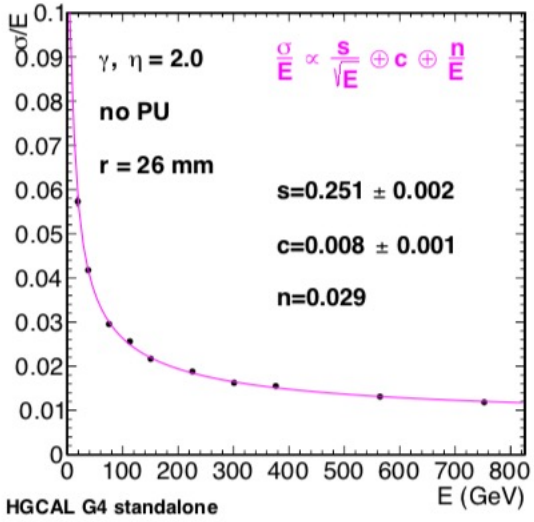


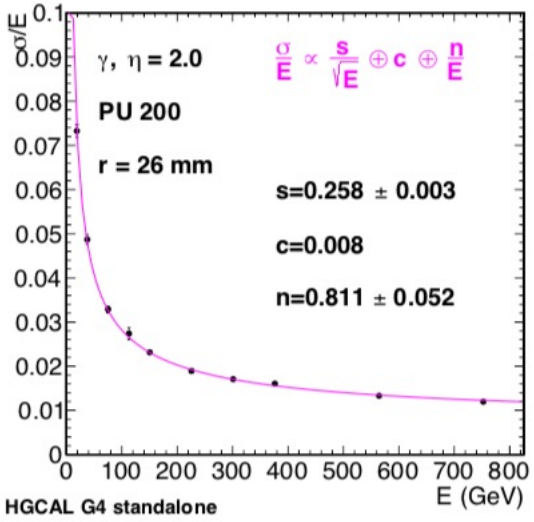
Stacking

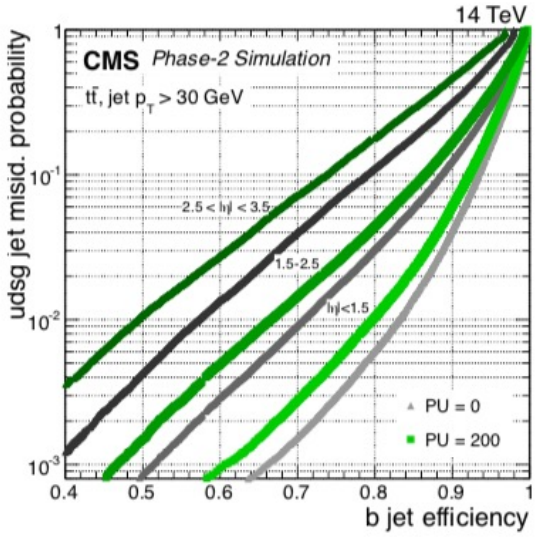


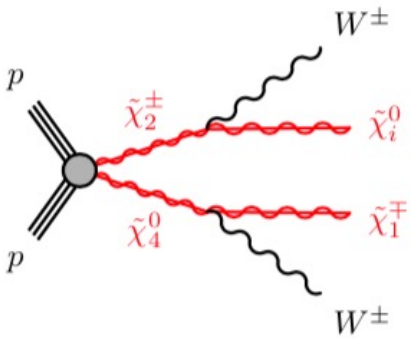
Tiling

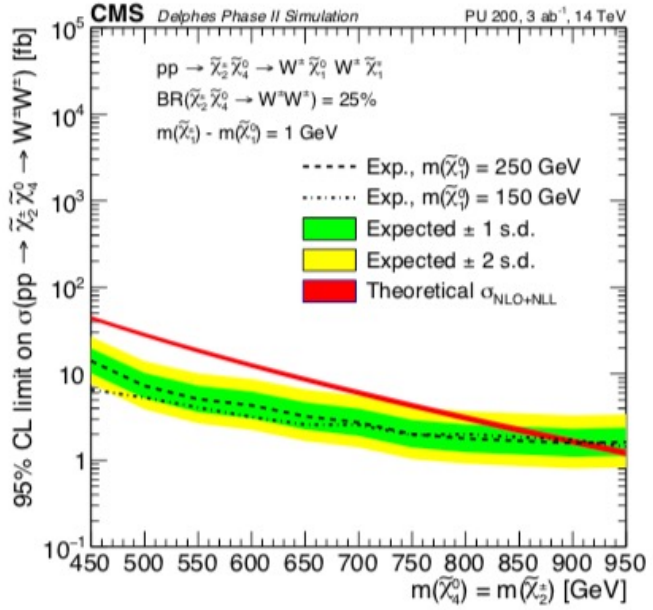
CMS-HGCAL预期性能与物理











改善光子和喷注末态重要物理：

- H → γγ, H → ττ in the VBF
- HH→ bbττ
- Search for electroweakinos with SS leptons
- Search for FCNC in t→qγ
- Physics with boosted objects

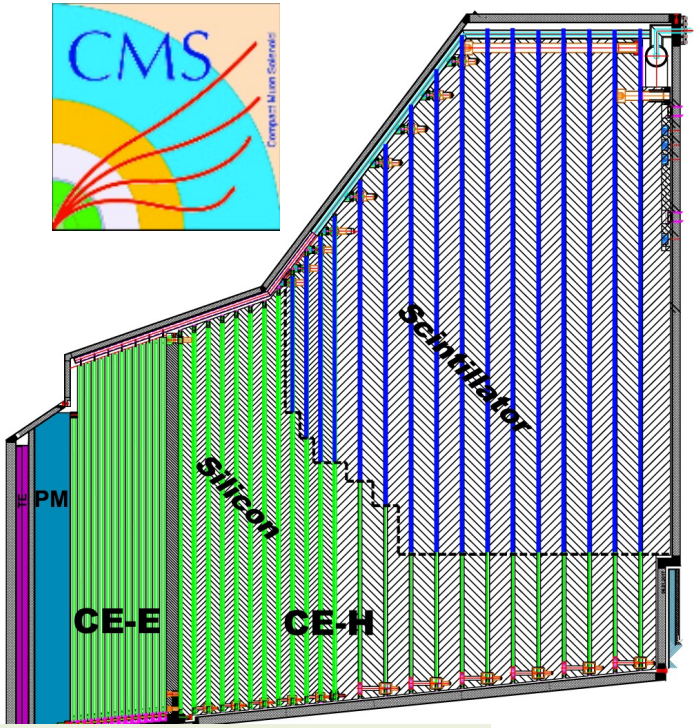
CMS 高粒度量能器HGCAL

Similar idea

CMS HGC
Approved 2015

Years of R&D，
Application Not yet approved

空间项目等

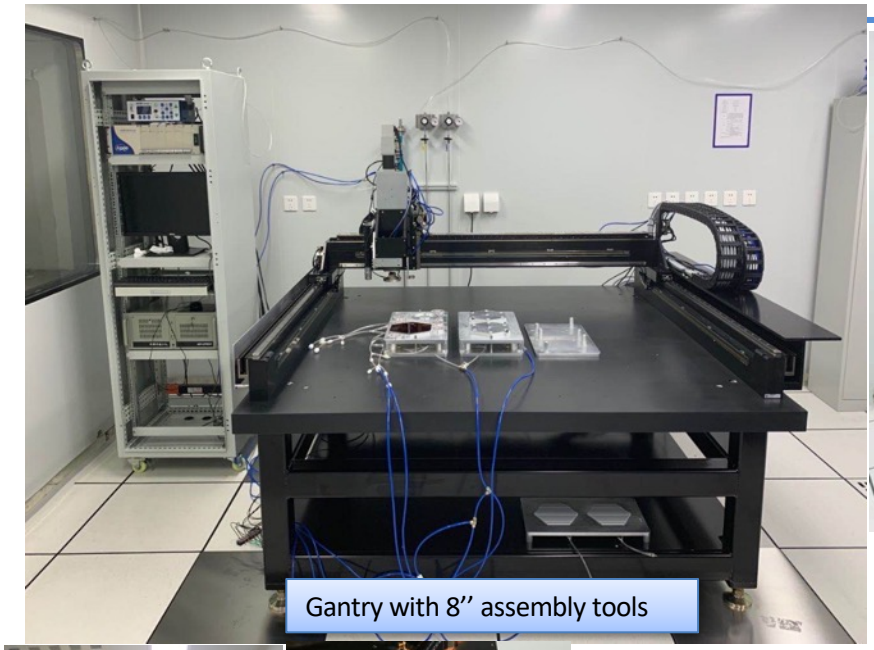


Other future HEP experiments

中国组任务：

- 参与硅传感器的测试；硅模块的设计，性能的束流测试；
- 建设高粒度量能器量能器硅模块生产中心（共 6个），并承担部分模块生产任务

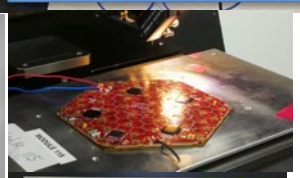
IHEP MAC Lab ready: apparatus and training

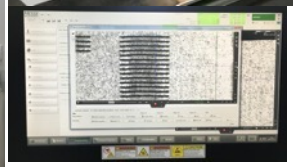


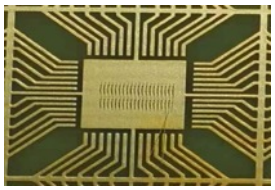
Gantry with 8'' assembly tools

OGP operating

Probe station

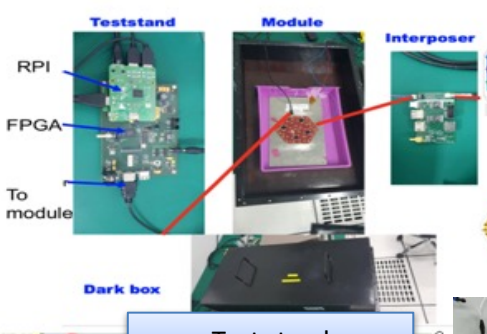






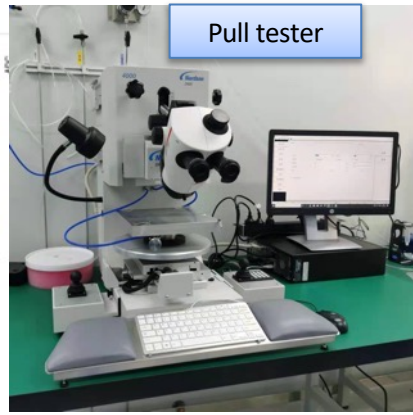
Bonder and test

Mini gantry training



Test stand

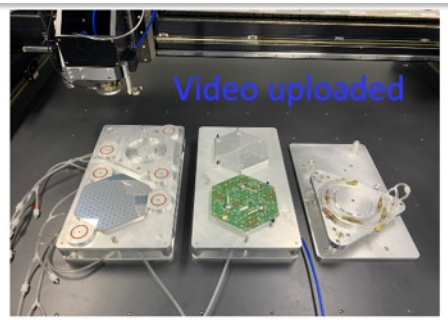
Cosmic ray test



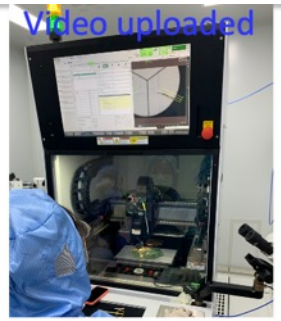
Pull tester

Production chain at IHEP MAC set up and qualified

componat tests

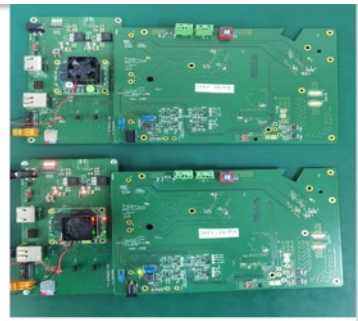


Module assembly

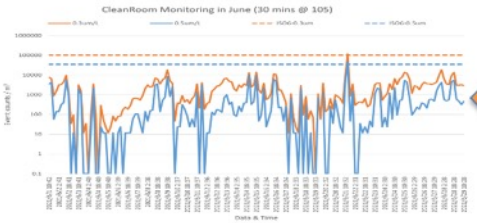


Wire bonding

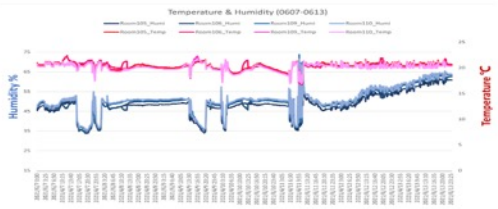
encapsulation



Module testing



Cleanroom status
- Cleanness
- Temperature
- Humility



Ship back to CERN

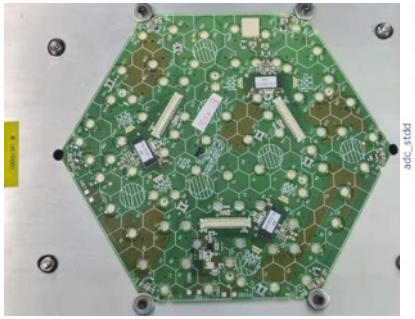
- Clean room and major equipment are installed, operator trained
- Fixture for gantry, wire bonder, pull tester, encapsulation are fabricated
- Glue parttern for assemly, encapsulation and wire bonding code are tested
- Go through full production chain for the first time on real componats (next slide)

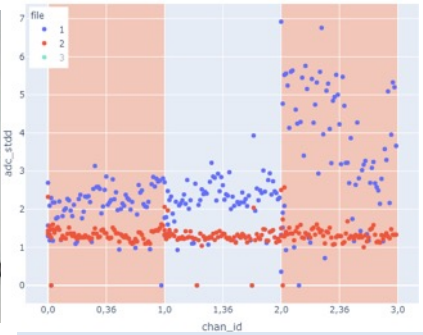
HGC project manager's site qualification report to P2UG

- Silicon module assembly centres: MACs qualified (UCSB, IHEP, and NTU), are close (CMU and TTU), and TIFR now has a green light to order a g
- SiPM market survey closed. Moulded tile prototyping well advanced. Machined cast tile prototypes made and under test, and tileboards development and test advancing well
- SiPM-on-Tile light yield results consolidated from different tests. Inputs collected for the optimization of the overall layout, and calibration procedure being studied for end-of-life with lower S/N
- Tilemodule assembly: automated tile wrapping and tilemodule assembly equipment is working in the TACs
- HGCROCv3 is under test and the analogue results very encouraging, some issues with new digital elements to be understood, and packaging has suffered delays
- ECON-T-P1 submitted. ECON-D design well advanced and reviews being planned. Schedule updated to be more realistic. ECON-T-P2 planned. ECON design and verification team stable. Looking how to further consolidate the depth of the team

Production of 2 functional 8 inch module

- Successfully build 2 8 inch HGCal silicon module
  - HGC first functional 8″ silicon module
  - Latest HGCROC ASICs
  - Low noise（~2-3ADC）
  - IHEP news report
- Both modules tested by test beam
  - 2021-9 test first module at CERN beam: IHEP module001
  - 2021-10 test second module at CERN beam: IHEP module 002

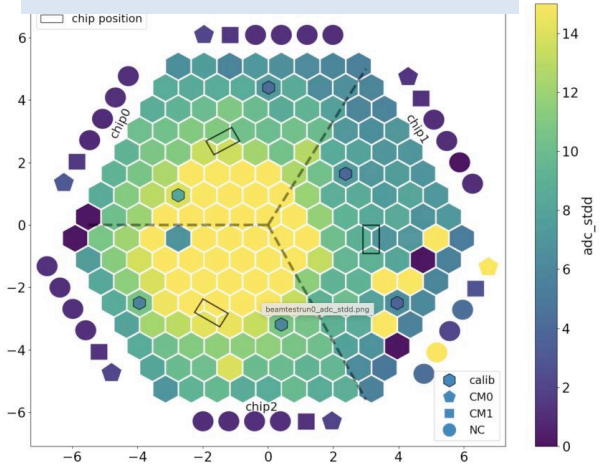




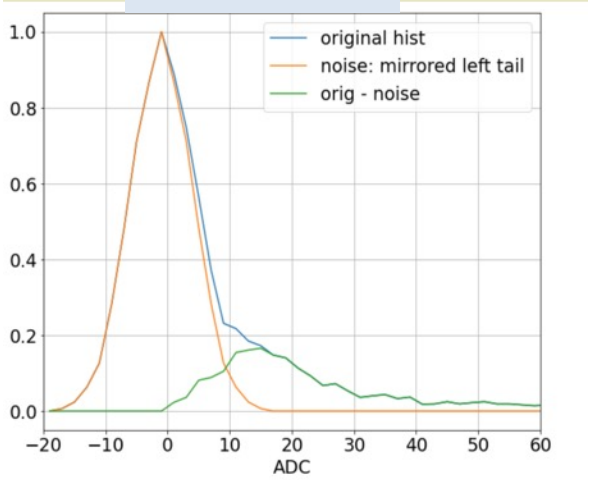
Noise with/w.o. sensor

First time see beam in 8″ silicon module

Beam shower event



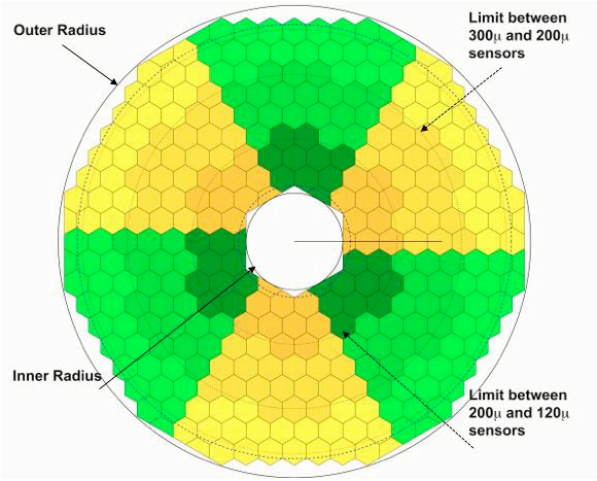
MIP signal

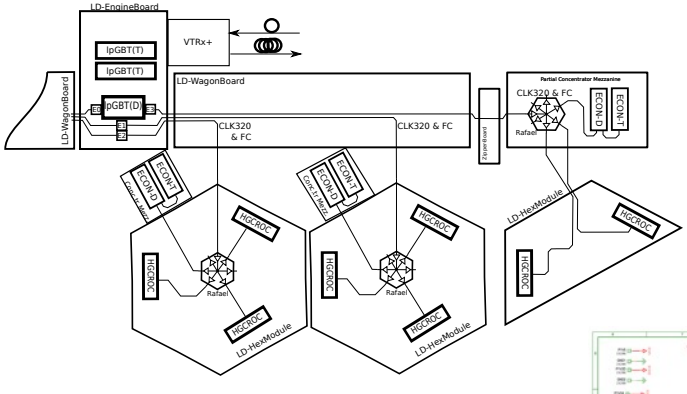


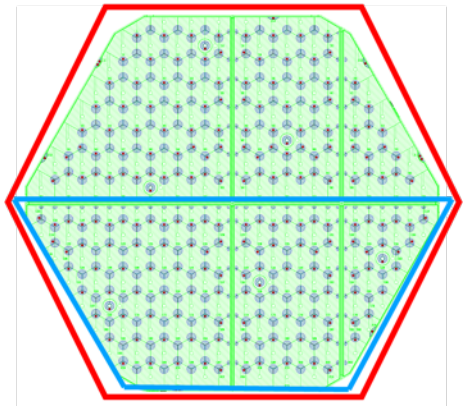
Half-hexaboard design

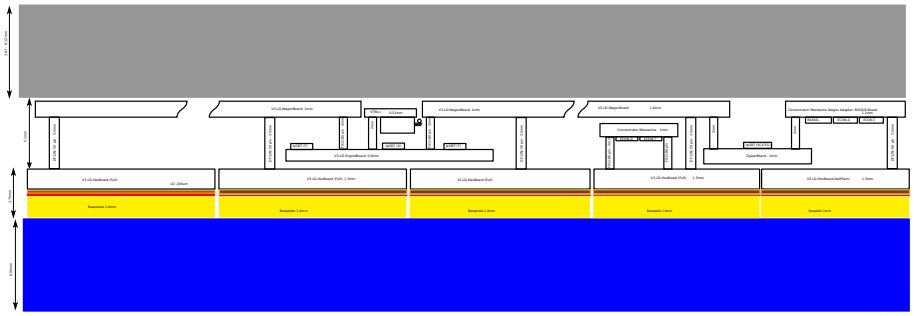
ZJU

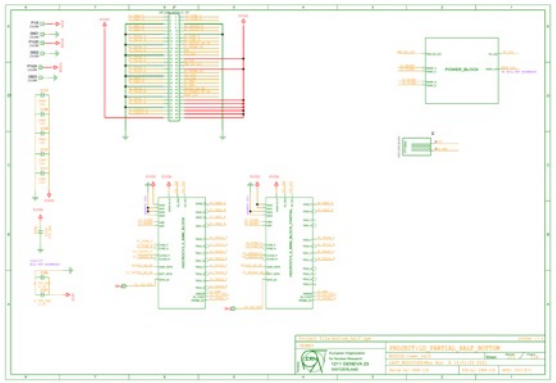
- Complex HGCAL geometry at CMS endcap regions: extra challenges
  - Equipped with both full (hexagonal) modules and partial modules
  - Zhejiang University team: design half modules
    - Schematics done, now working on the layout



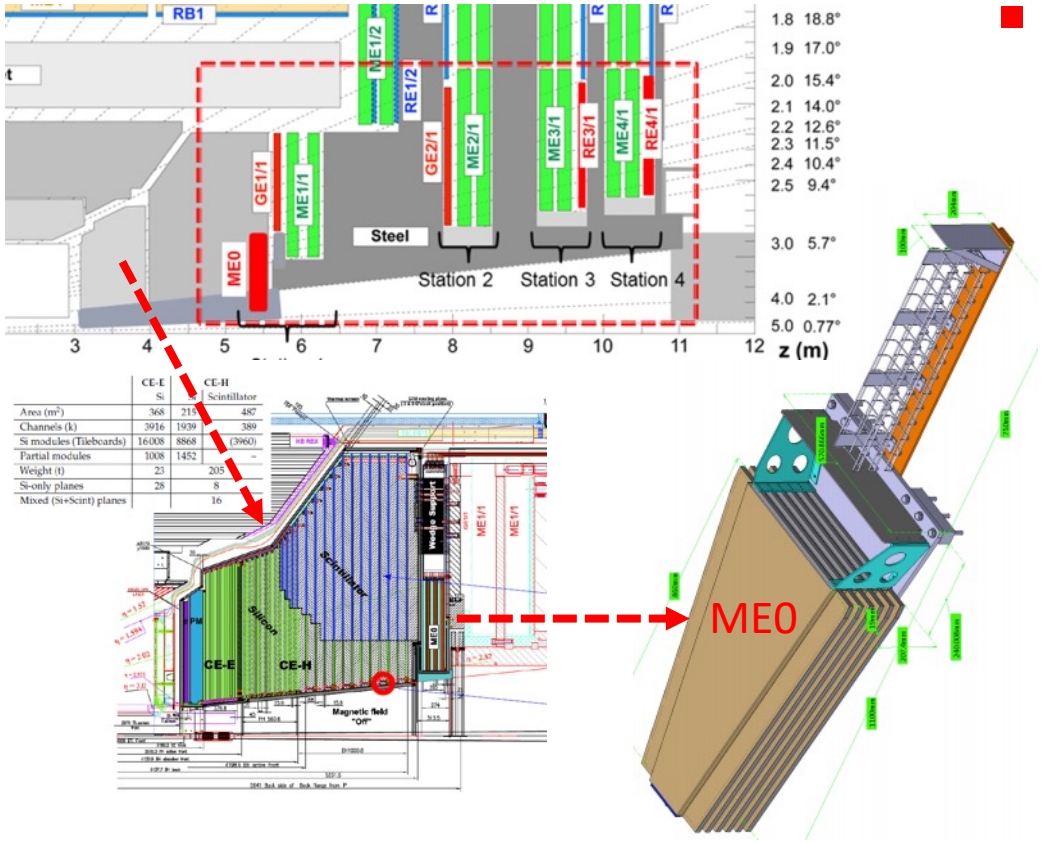








Muon Challenges: ME0 as example

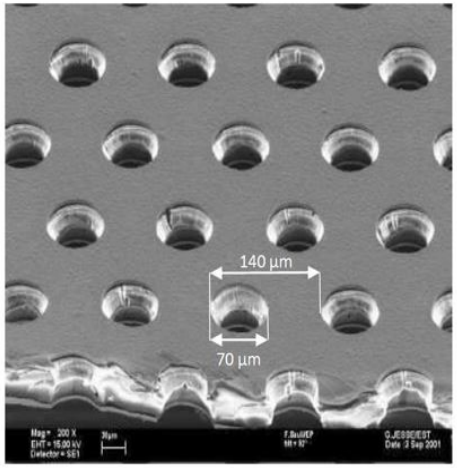


- 6-Layer Triple-GEM stack installed behind HGCAL (complex environment)

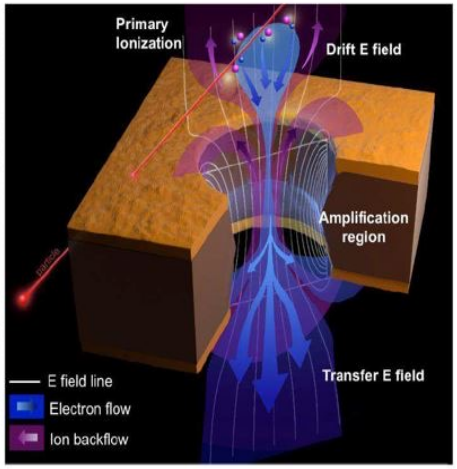
  $2\ x\ 18$ stacks (20°) covering $2.0 < \eta < 2.8$

- Requirements:
  - 97% module efficiency
  - $< 500 \mu$rad resolution
  - 8-10 ns time resolution
  - $\leq 15\%$ gain uniformity
  - *Work in high rate environment: 50kHz/cm²*
  - *Survive harsh radiation environment: 280mC/cm²*
  - *Discharge rate that does not impede performance or operation*

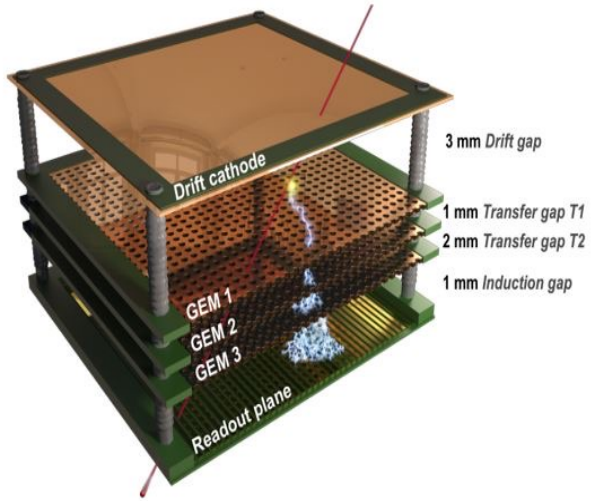
CMS 端盖μ子探测器 GEM



GEM 微孔膜结构



在电场中的气体放大机制



三层膜GEM探测器结构

GEM工作机制：

粒子射入探测器，在漂移区产生的电离电子在电场作用下，穿过多层强电场微孔膜，在收集电极产生级联放大的信号。

GEM: Gaseous Electron Multiplier (气体电子倍增器)

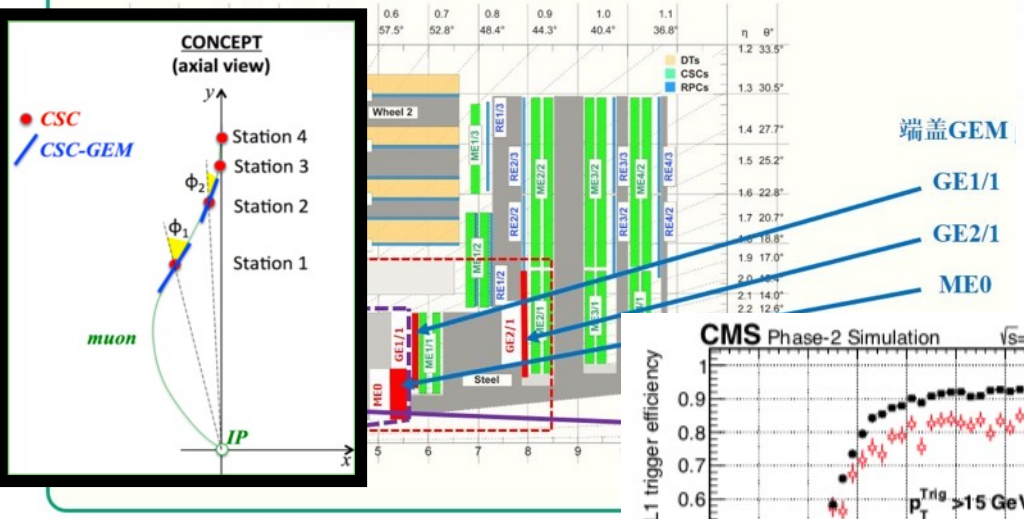
- CMS内圈μ子探测器工作在极强辐照环境中，将采用**GEM（气体电子倍增器）技术**。优点：结构简单，时间、空间、计数率性能优异。

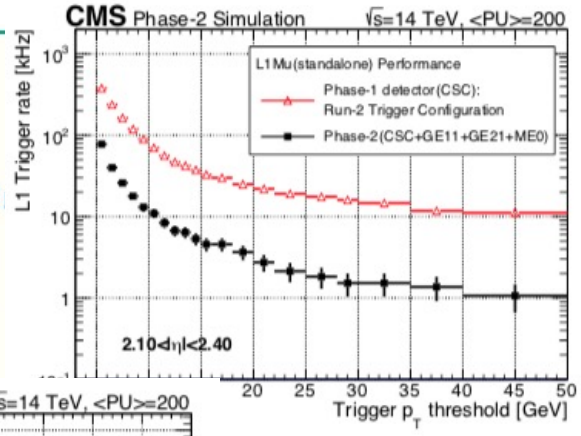
→大面积GEM技术在高能对撞实验中的首次大规模应用

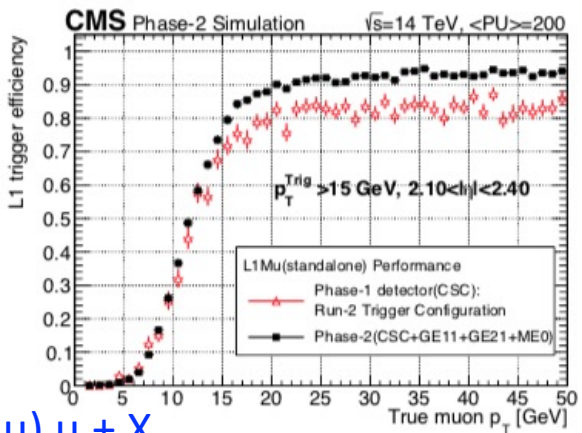
CMS-GEM性能与未来物理研究

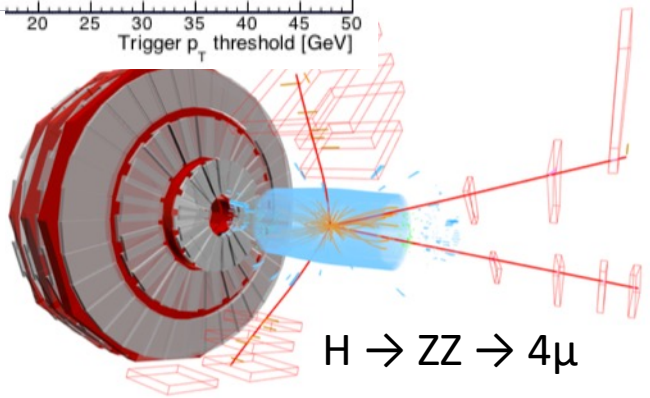
- CMS-GEM不仅提供触发，且高空间分辨能力可提供μ子径迹重建。

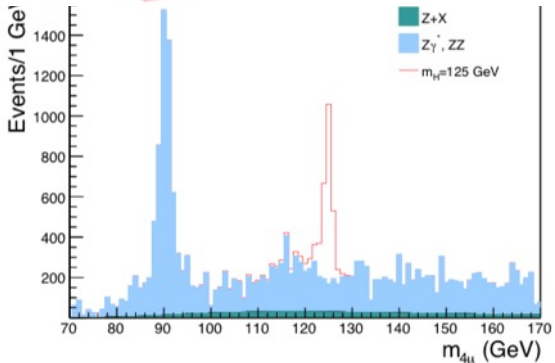
→保证高亮度运行时μ子触发效率，且大大提高新物理发现潜力。







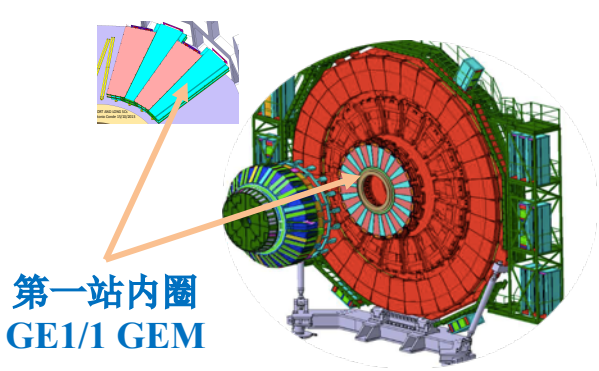


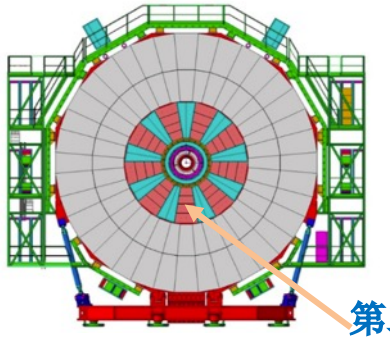


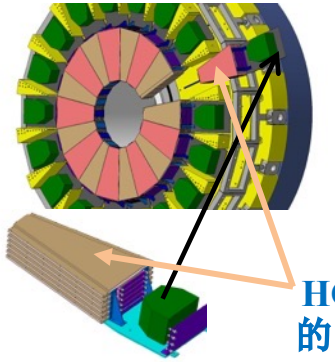
改善多μ子末态重要物理：

- H → ZZ → 4μ，H → 2μ
- Top quark mass in t → J/ψ(μμ) μ + X
- Double-parton scattering in pp → W+W+
- $B_{(s)}$→ μ μ，LFV decays τ → 3μ
- Precise electroweak mixing angle with Drell-Yan events
- BSM with two SS leptons, displaced muons, HSCP

CMS-GEM探测器分阶段项目与中国组贡献







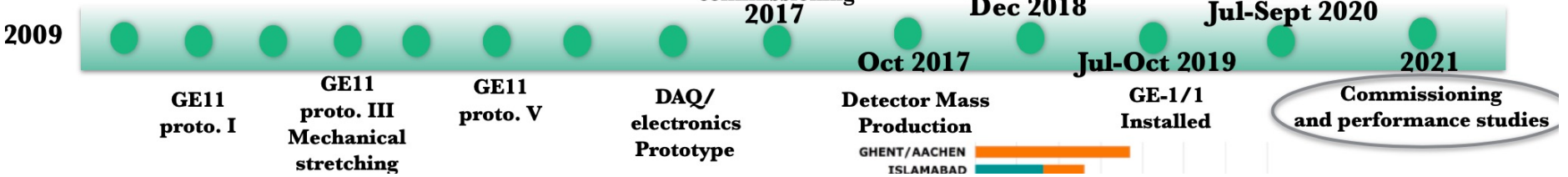
升级探测器		GE1/1	GE2/1	ME0
探测器个数*		288（=2×36×4）	288（=2×18×8）	216（=2×18×6）
计划	预研	2013-2017	2014-2020	2014-2021
	批量生产	2017-2019	2020-2022	2022-2024
	安装调试	2018-2021	2022-2024	2024-2026
中国组任务		全部前端电子板GEB生产测试，在CERN的探测器组装测试、安装调试	设计研发及生产测试全部GEB，在北大生产1/8 GEM探测器，在CERN进行组装测试、安装调试	设计研发及生产测试全部GEB，在北大生产~1/5 GEM探测器，在CERN进行组装测试、安装调试

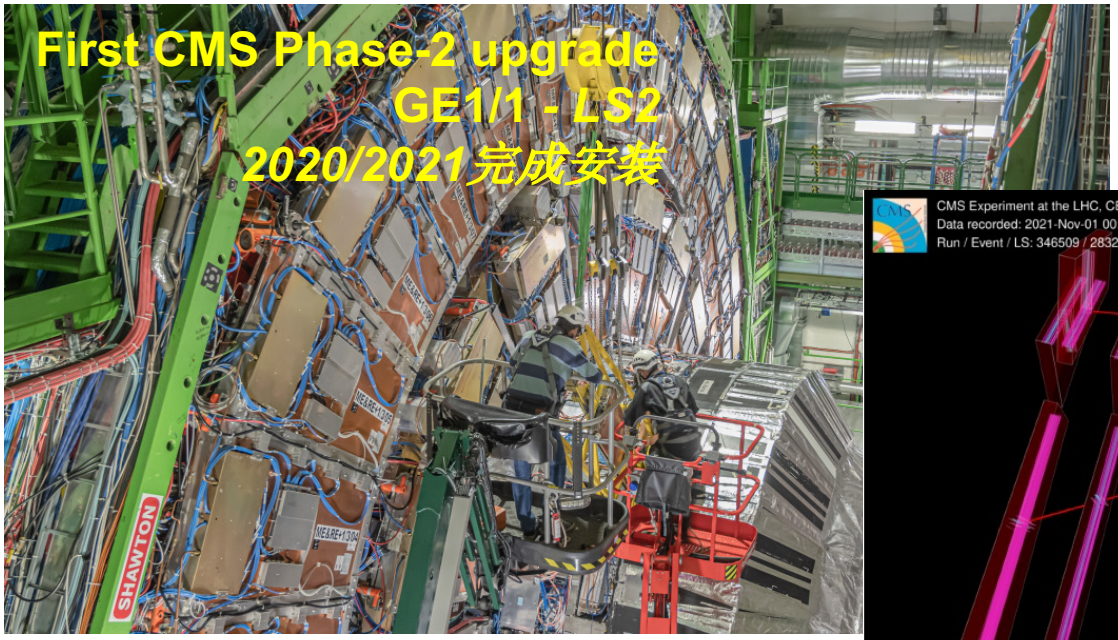
*（总探测器个数=端部数×每个端部module数×每个module探测器个数）

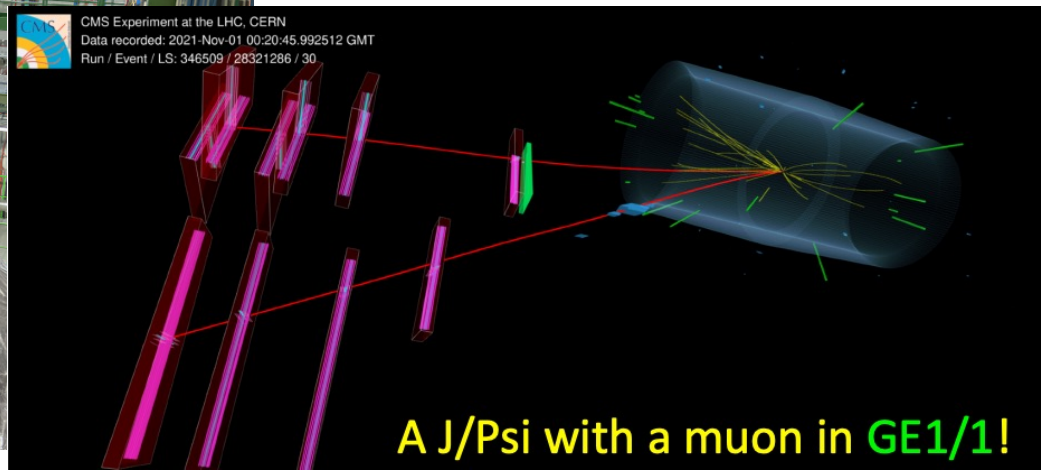
中国组还将负责**GEM-FR4框架**和**超级模块结构部件**生产

GE1/1 探测器已经成功运行

NIMA 972 (2020) 164104



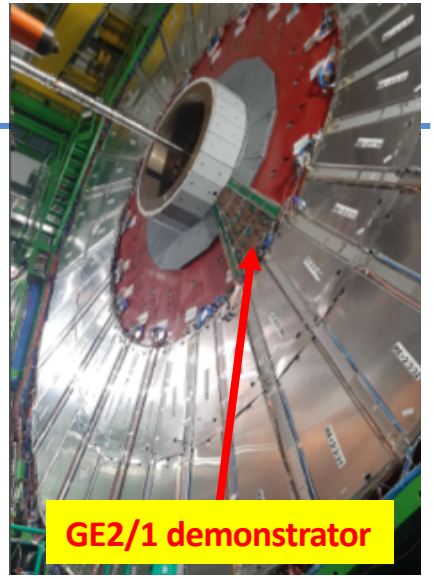




Muon upgrade: new detectors

New stations:

- GEM: **GE1/1, GE2/1**, iRPC: **RE3/1, RE4/1**, $1.6 \leq \eta \leq 2.4$
- GEM: **ME0** extended coverage $1.15 \leq \eta \leq 3$



GE2/1 (EYETS 23/24)

- **Demonstrator chamber:** installed in November
- **Production:** 16 modules assembled, 40 in early 2022; enough for 10/144 chambers

RE3/1 + RE4/1 (EYETS 23/24)

- **Demonstrator chambers:**
  - 2 RE4/1 (with FEB_v2.1, Petiroc-2B) installed in November
  - 2 RE3/1 to be installed in mid-January

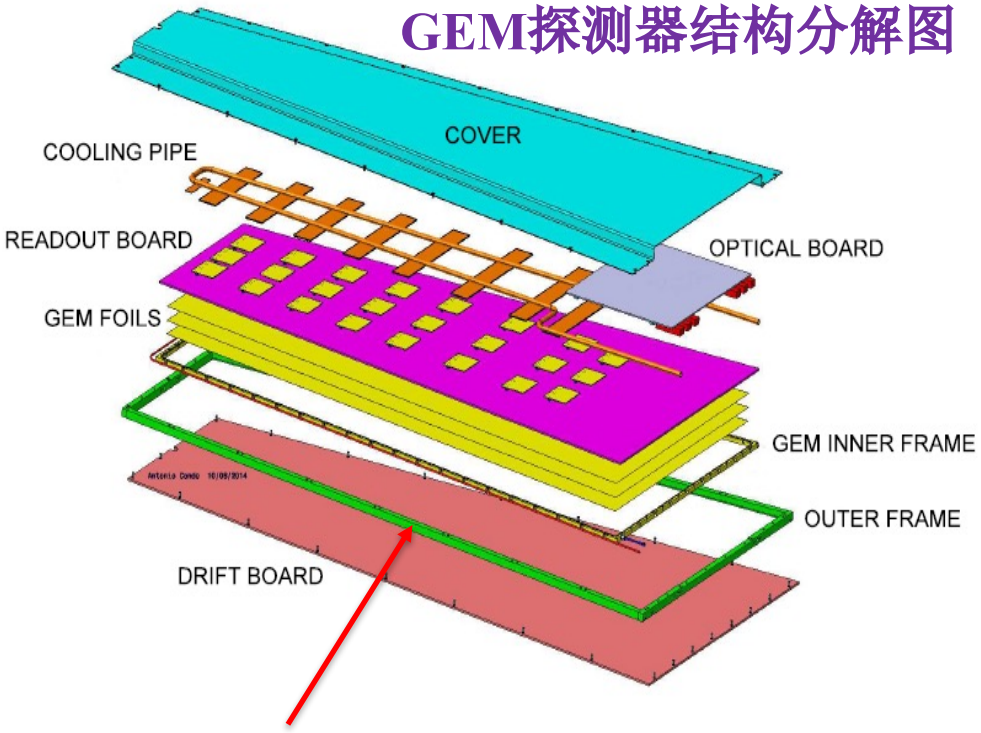
ME0 (LS3)

- **Prototypes:** tested in the beam, all looks good

CMS-GEM系统组成

CMS-GEM探测器系统包括**气体室、读出板、前端电子学板、读出芯片、光电转换板、机械结构、冷却系统、信号及控制传输系统及后端电子学、触发系统**等。

GEM探测器结构分解图

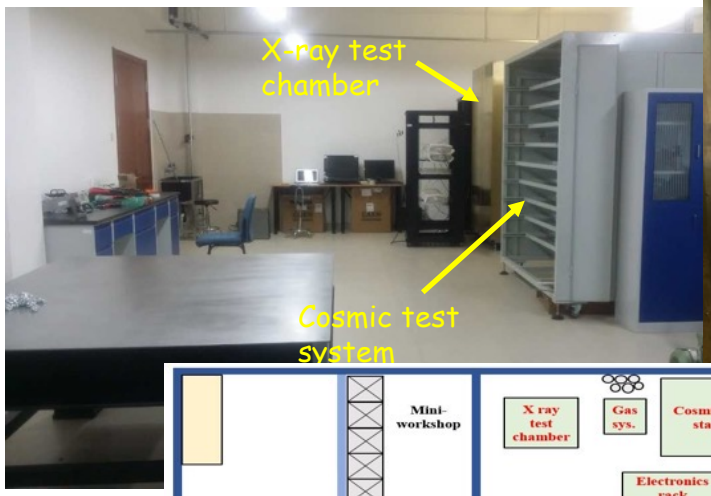


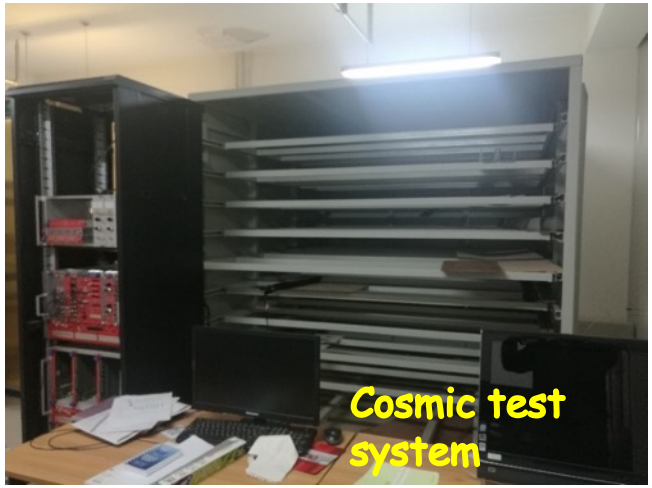
GEM-FR4框架

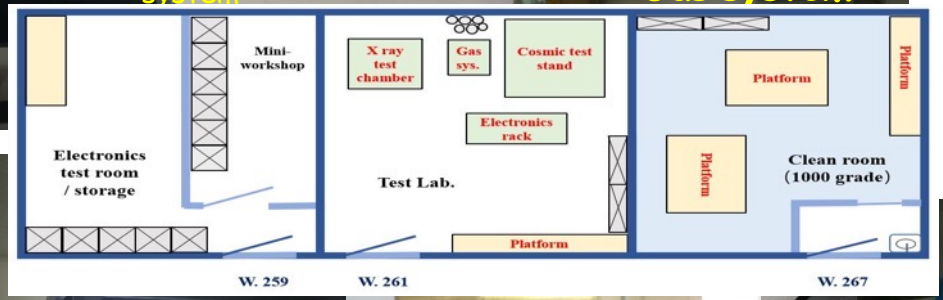
机械性能和公差要求极高

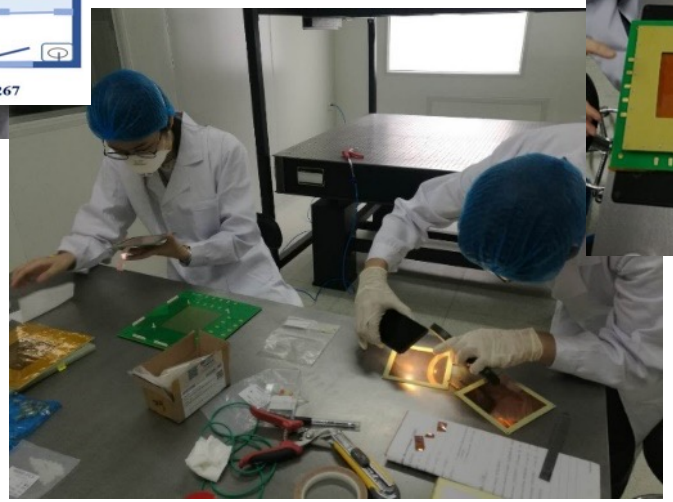
CMS-GEM项目： GEM生产基地

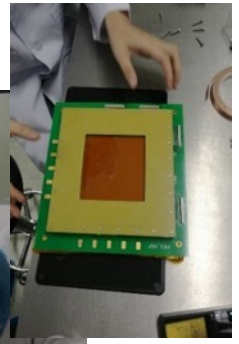
北京大学GEM组装测试实验室（~120 m^2）









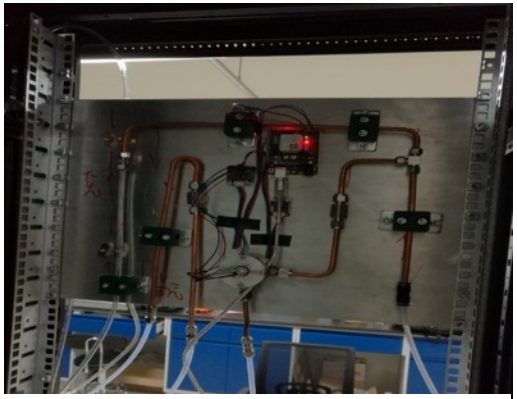


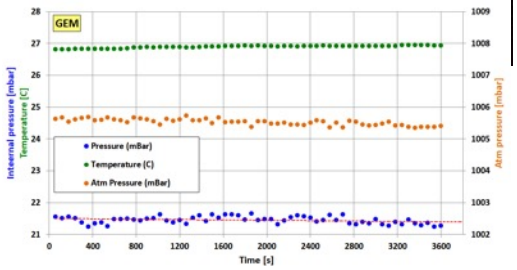
在洁净室组装10×10 GEM探测器

CMS-GEM项目：GEM生产基地

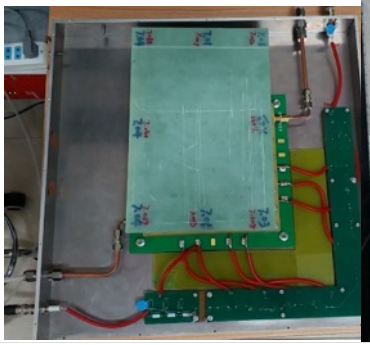
GEM探测器组装、测试、质量控制流程准备：

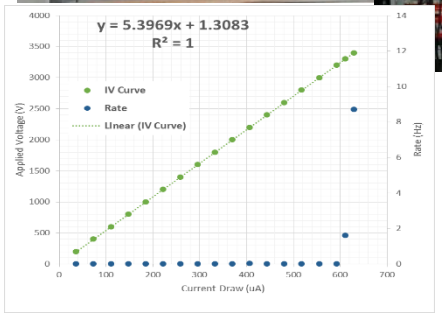
QC3: 探测器气密性检测



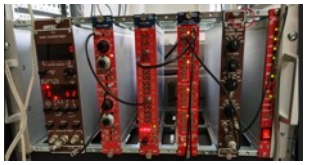


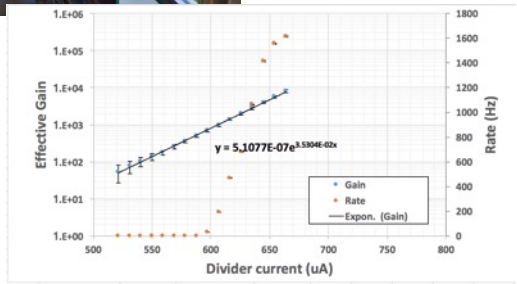
QC4: 高压-电流性能检测:





QC5: X射线增益检测

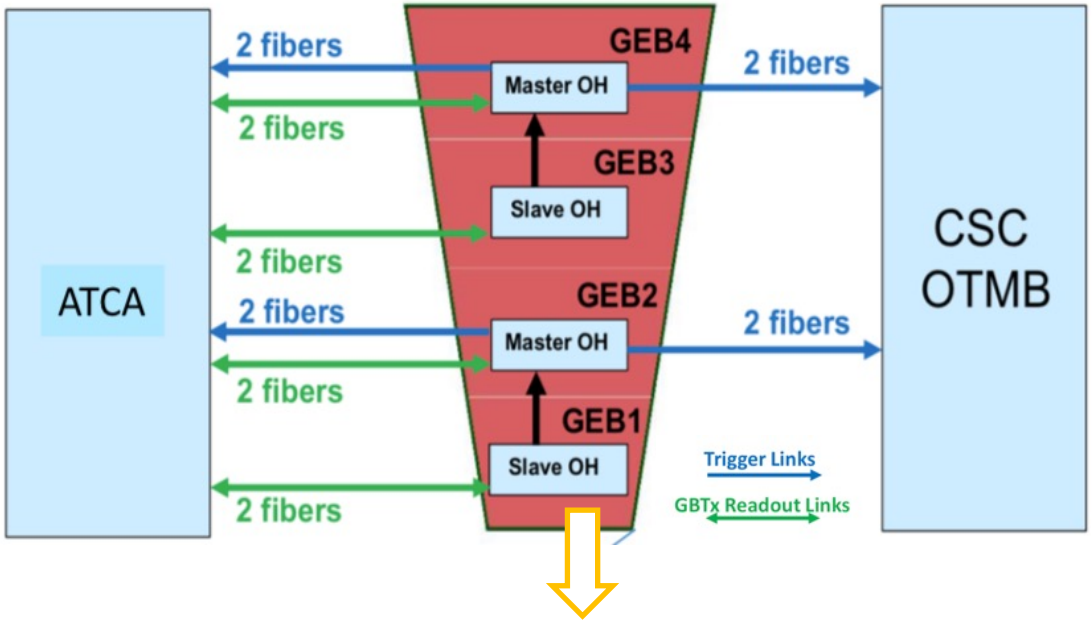




北京大学CMS-GEM组装测试基地建设进展顺利，各组装测试各步骤所需硬件及测试平台已建立，对小尺寸GEM及原尺寸CMS-GEM探测器的测试结果表明，各测试步骤及结果达到要求，已经获得了CMS-GEM合作组认证。

→ GEM探测器批量组装测试的条件具备,2022年开始生产。

GE2/1探测器前端电子学系统

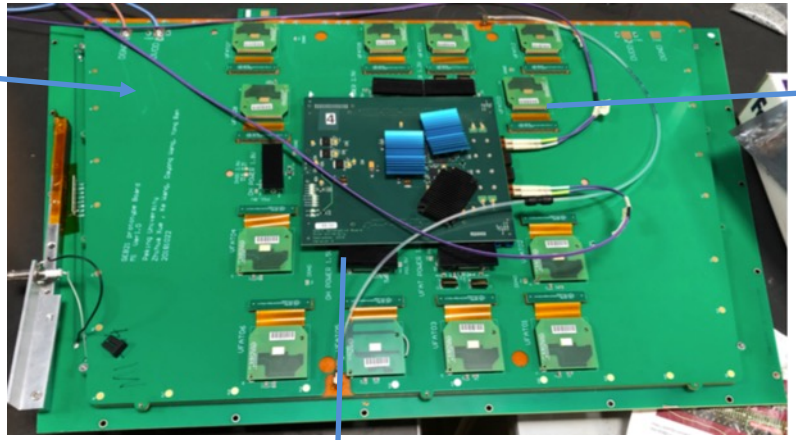


GE2/1探测系统：

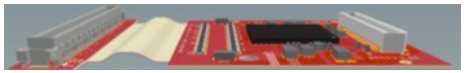
- 共有72个探测器
  - 每个探测器由48个VFAT3读出
- 共有288个OH板
- 共有288个GEB
- 288 光纤连接OTMB (3.2 Gbps)
- 288光纤传输至 ATCA (trigger信号)
- 576 光纤传输至ATCA (GBTx links)

GEB：

1. 在前端VFAT和OH板之间传输电信号
2. 分配功率
3. GEB被放置在GEM读出板的顶部，对探测器提供电屏蔽



VFAT3芯片+柔性板



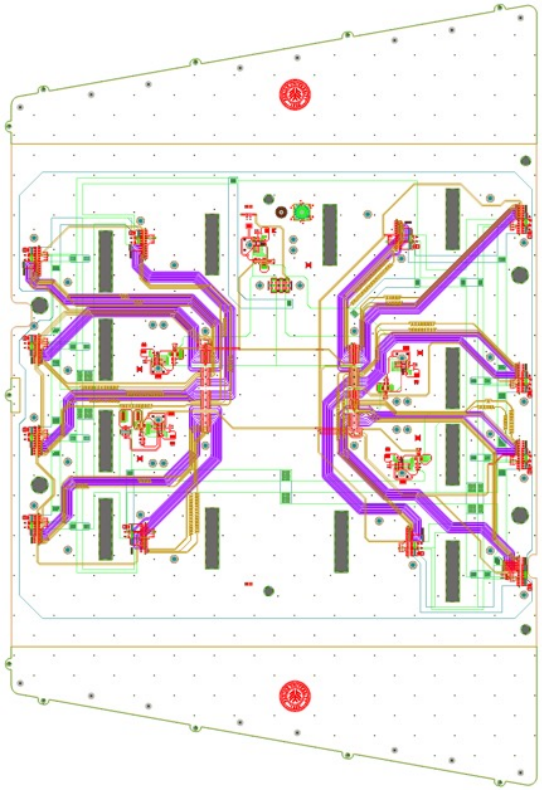
- 有利于减轻GEB上对应接头的压力，便于安装

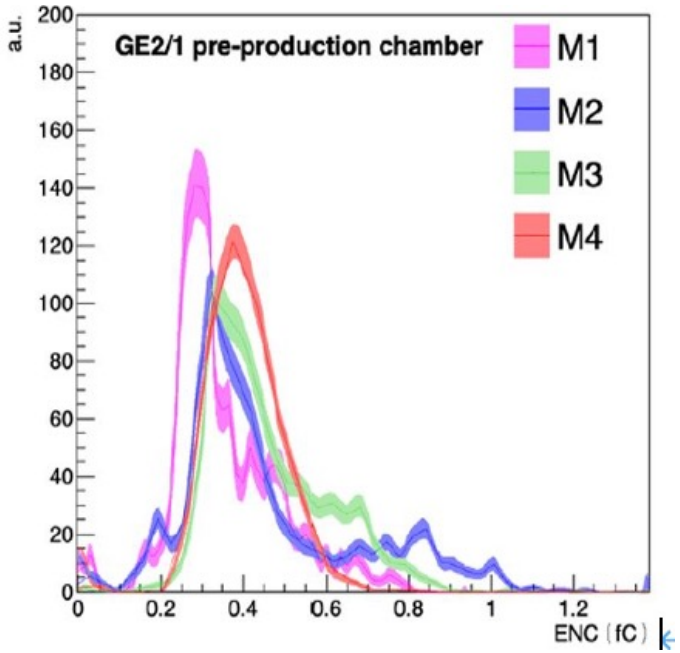
OH板：接收来自GEB的信号，并传输给后端电子学

CMS-GEM项目：前端电子学板GEB

- GE1/1 GEB：中国组负责全部GEB的批量生产和测试，目前已经按质按期完成，安装在CMS上。
- GE2/1 GEB: 负责独立设计、研发和生产全部8种型号GEB。样机经过CERN及美国方面的初步测试达到要求。目前生产测试进行之中。
- ME0 GEB：样机预研究已经开始，完成了第一版样机生产，2022年ESR。

四种型号(M1-M4)
GEB 2/1样机。





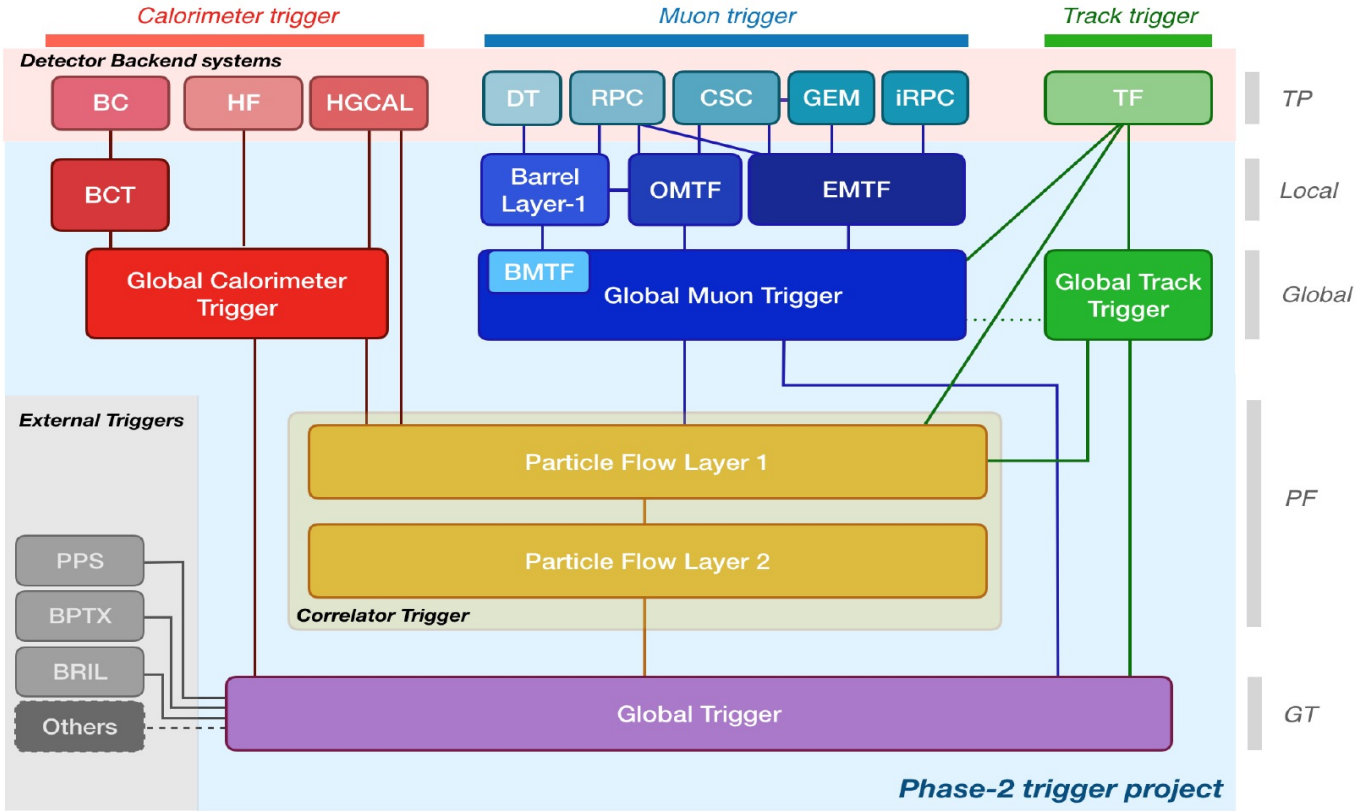
GE2/1 GEB原型M1-M4的噪声测试结果

Phase-II trigger upgrade

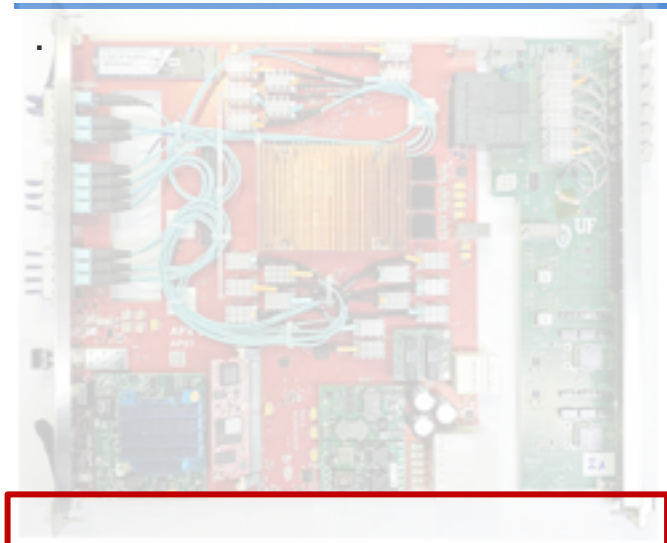
- Retain two-level trigger approach
  - Level-1 + High-Level Trigger
- L1 Key parameters
  - Rate: 100 kHz ⟶ 750 kHz
  - Latency: 3.8 μs ⟶ 12.5 μs
- Inputs
  - Calorimeters
  - Muon System
  - Outer Tracker

Four independent trigger processing paths

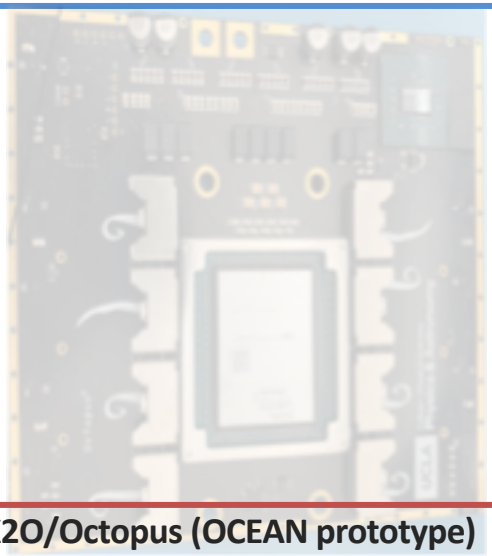
Sophisticated FPGA-based algorithms: using particle-flow (PF) or ML approaches.
Increase trigger acceptance&physics sensitivity, while maintaining Run-2 thresholds.
Scouting into HL-LHC data @ 40 MHz: storing only high-level information



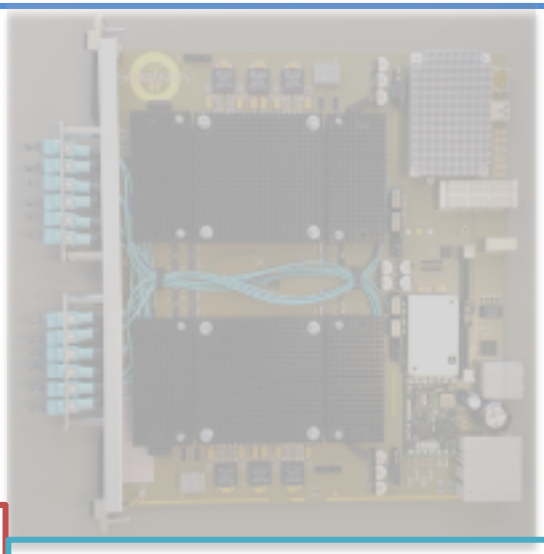
L1 hardware prototype



APx:
- Powered by a VU9P FPGA with 2.5M logic cells
- 100 bidirectional links up to 28 Gb/s
- Control, management, and monitoring by an embedded linux mezzanine (ELM) (ZYNQ SoC)
- Shelf management via custom IPMI mezzanine (OS)



X2O/Octopus (OCEAN prototype)
- Modular design (x2 FPGA)
- Optical Module
- Up to 28 QSFP cages (112 links)
- Compatible with 25G and 10G transceivers
- Power Module: Off-the-shelf ZYNQ mezzanine, DC-DC converters, IPMC running on the ZYNQ
- Inter-module connections with cables

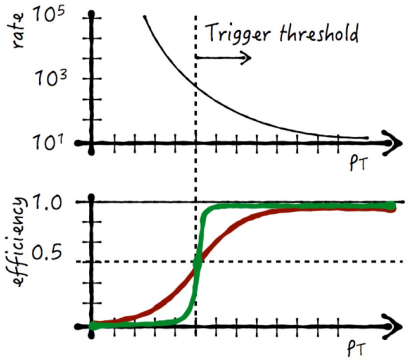


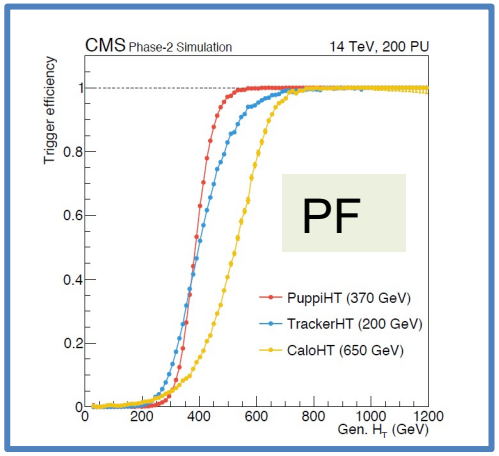
Serenity:
Carrier board w/ 2 sites hosting daughter cards (any combination of FPGA)
Up to 144 bidirectional links (extendable to 192)
Control & Monitoring: COM express (x86 processor)
IPMI management through CERN IPMC

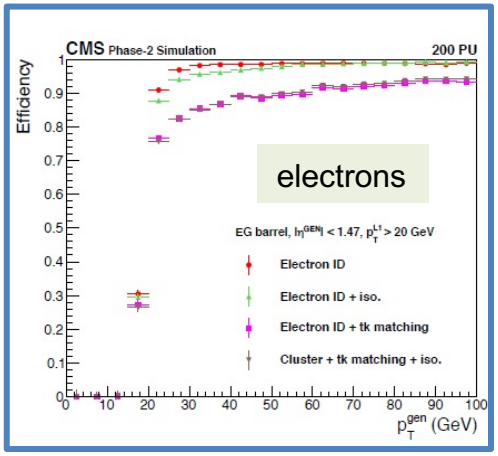
Design philosophy: Generic Processing Engines → I/O, FPGA
- FPGA : Xilinx Virtex Ultrascale / Ultrascale+
- Optics : Samtec Firefly x4 /x12 flyover
- Processors on board running commercial linux for flexible configuration and monitoring

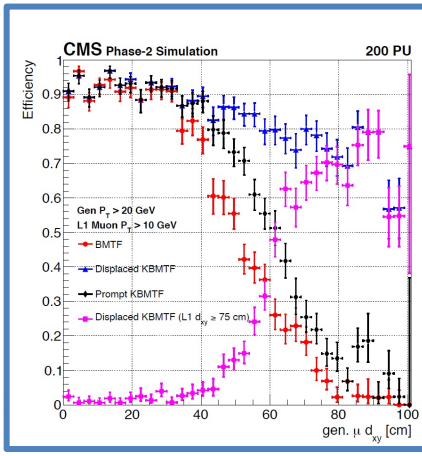
L1T: algorithms

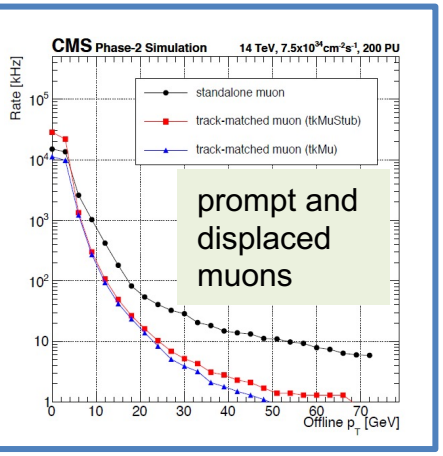
- **Extensive use of tracking** to reach near offline performance (sharper efficiency turn-on curves) + reconstruction of Primary Vertex.
- Exploit **complementarity of different object flavor**:
  - Standalone objects: robust triggers based on independent sub-detectors
  - Track-matched objects: tracking used to confirm standalone objects, significant improvement with simple design
  - Particle-flow (PF) objects: ultimate performance improvement, combine all information to match offline algorithms, require most processing time and resources for calculation





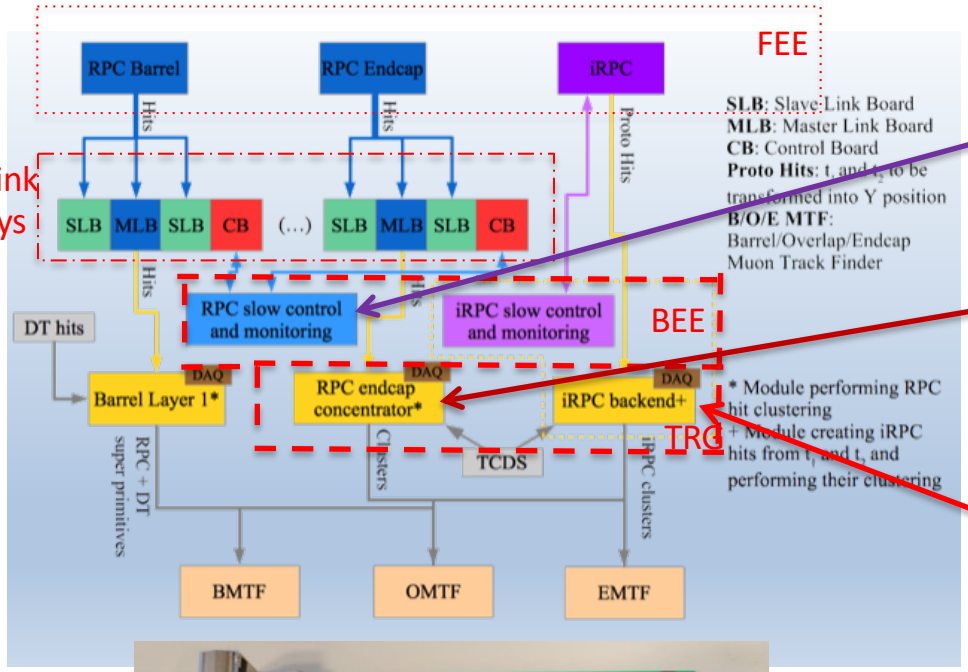






RPC/iRPC TRIG/Backend Electronics

IHEP



Exiting RPC Backend(|η| < 1.9),Barrel and End cap

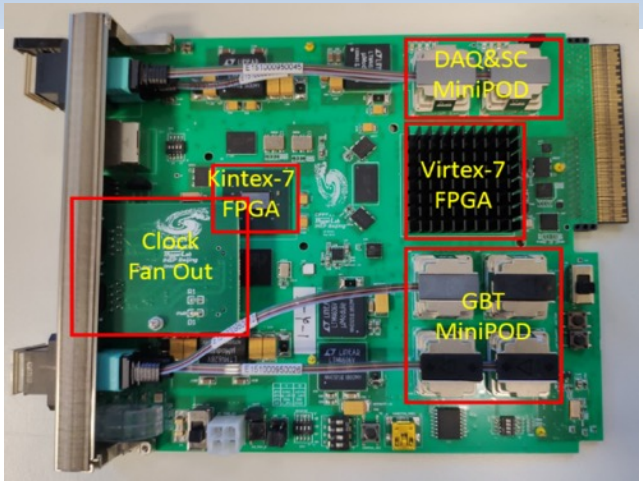
- Communication with LBS/CB
- Monitoring
- Slow Control

RPC Endcap Concentrator/Trigger

- Concentrator
- Trigger primitive(Cluster)
- Readout(DAQ)

iRPC(RE3/1,RE4/1) Backend/Trigger

- Slow Control
- Monitoring
- Fast Control
- Trigger primitive (Cluster)
- Readout(DAQ)



Demonstrator 2021/2022 and Interim 2023/2024 Installation

Backend electronic and trigger board by IHEP is key hardware component for backend and trigger

Summary

- To meet the challenges of HL-LHC and maintain physics potential, CMS needs upgrade
- CMS Phase-II upgrade projects progress well, with important contributions from CMS-China
  - MTD
  - HGCAL
  - GEM
  - PRC electronics

Building the future for CMS