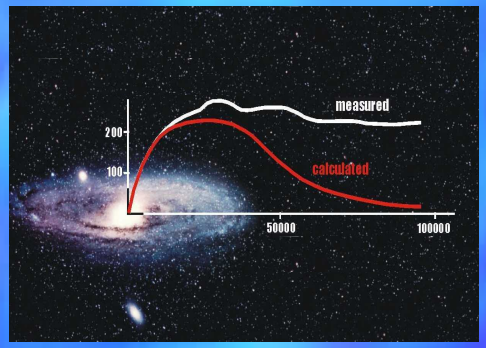
CMS: Recent Results and Prospects

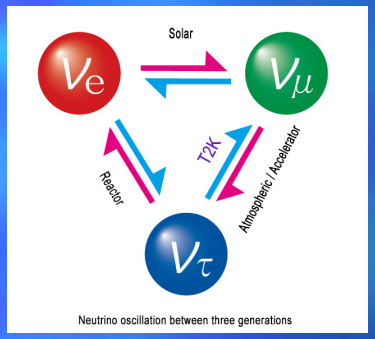
양운기 (서울대)

2021 KPS-DPF MEETING,
2021.12.17-18

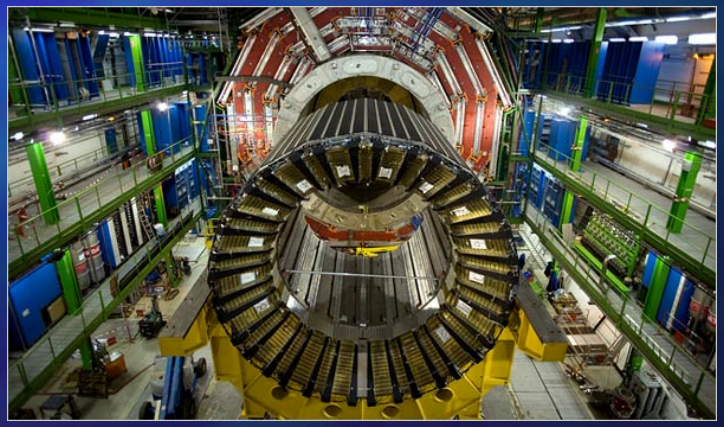
에너지 프란티어에서 새로운 물리 탐사

CMS at LHC

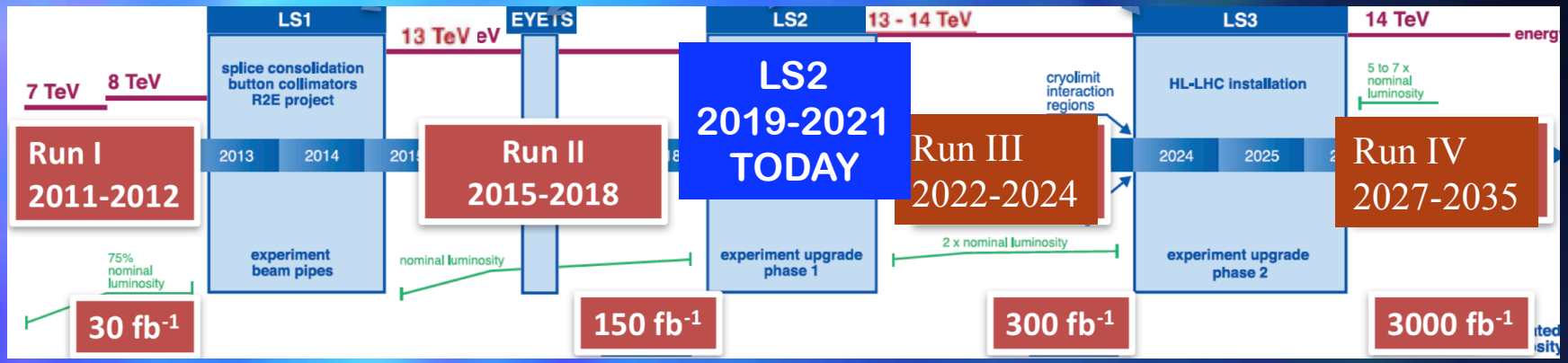




- 힉스입자 발견으로 표준모형은 완성이 되었으나, 암흑물질, 중성미자 진동, 우주의 물질과 반물질의 비대칭성은 더 근본적인 물리법칙을 증거하고 있음



LHC Status



- Despite of the difficulties, CMS keeps physics program and detector upgrade
  - Between 3~11 months delays in LS2 and Upgrade activities
  - Beam tests for Run 3 in Oct. 2021 done successfully
  - Physics publications reasonably well
  - KCMS are performing great jobs.

LS2 Activities

LS2 = Long Shutdown 2 since 2019
Collisions to return mid 2022

Strip tracker
- kept cold to avoid reverse annealing (but warmed during beam pipe bake-out)

HCAL
- completion of Phase-I upgrades

Pixel detector
- replace first barrel layer
- replace all DCDC converters

Magnet
- at room temperature since mid 2020
- maintenance work: free wheel thyristor, cryo-cooling, power, pumps, etc.

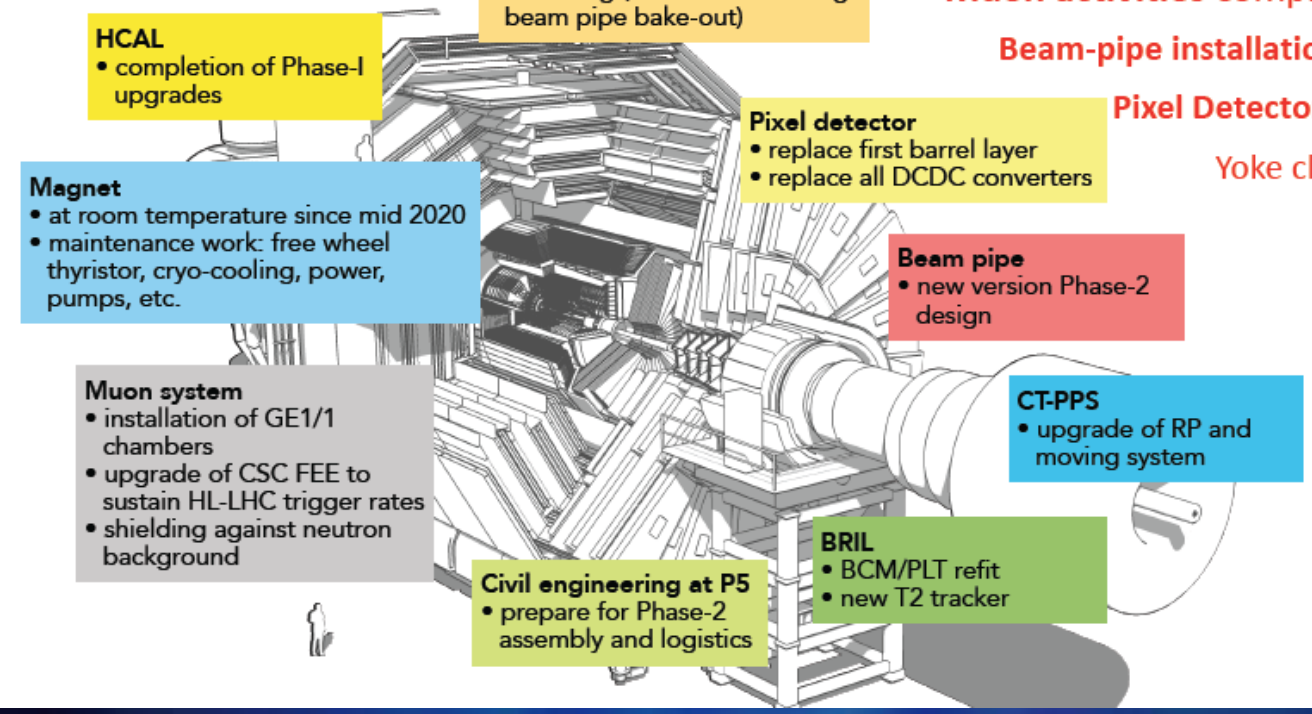
Beam pipe
- new version Phase-2 design

Muon system
- installation of GE1/1 chambers
- upgrade of CSC FEE to sustain HL-LHC trigger rates
- shielding against neutron background

CT-PPS
- upgrade of RP and moving system

BRIL
- BCM/PLT refit
- new T2 tracker

Civil engineering at P5
- prepare for Phase-2 assembly and logistics



Work on HCAL Barrel (SiPM readout) completed in Oct. 2019

Muon activities completed in Dec. 2020

Beam-pipe installation and bake-out completed in May 2021

Pixel Detector installation completed in June 2021

Yoke closed end of Sep 2021 (with some delays)

Magnet restart (3.8T) and commissioning (beg. Oct 2021)
CRAFT - 24/7 (mid of Oct).

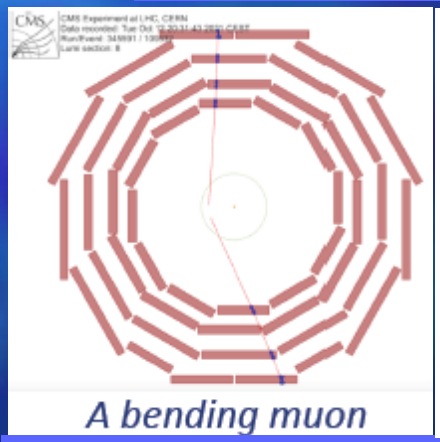
CMS was ready for the pilot beam test in October!

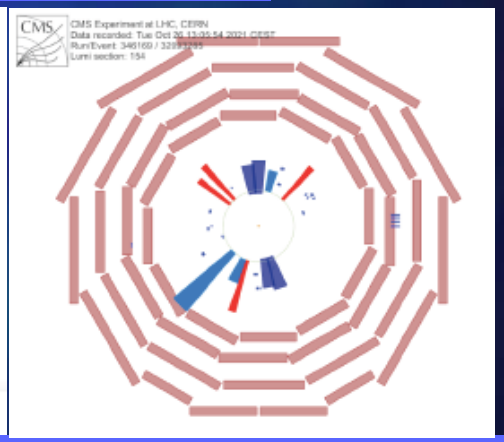
After Pilot Beam Test in Oct 2021
- Phase-II muon demonstrators installation

LS2 Activities

➢ GE1/1 detector

➢ Fully-refurbished pixel det.

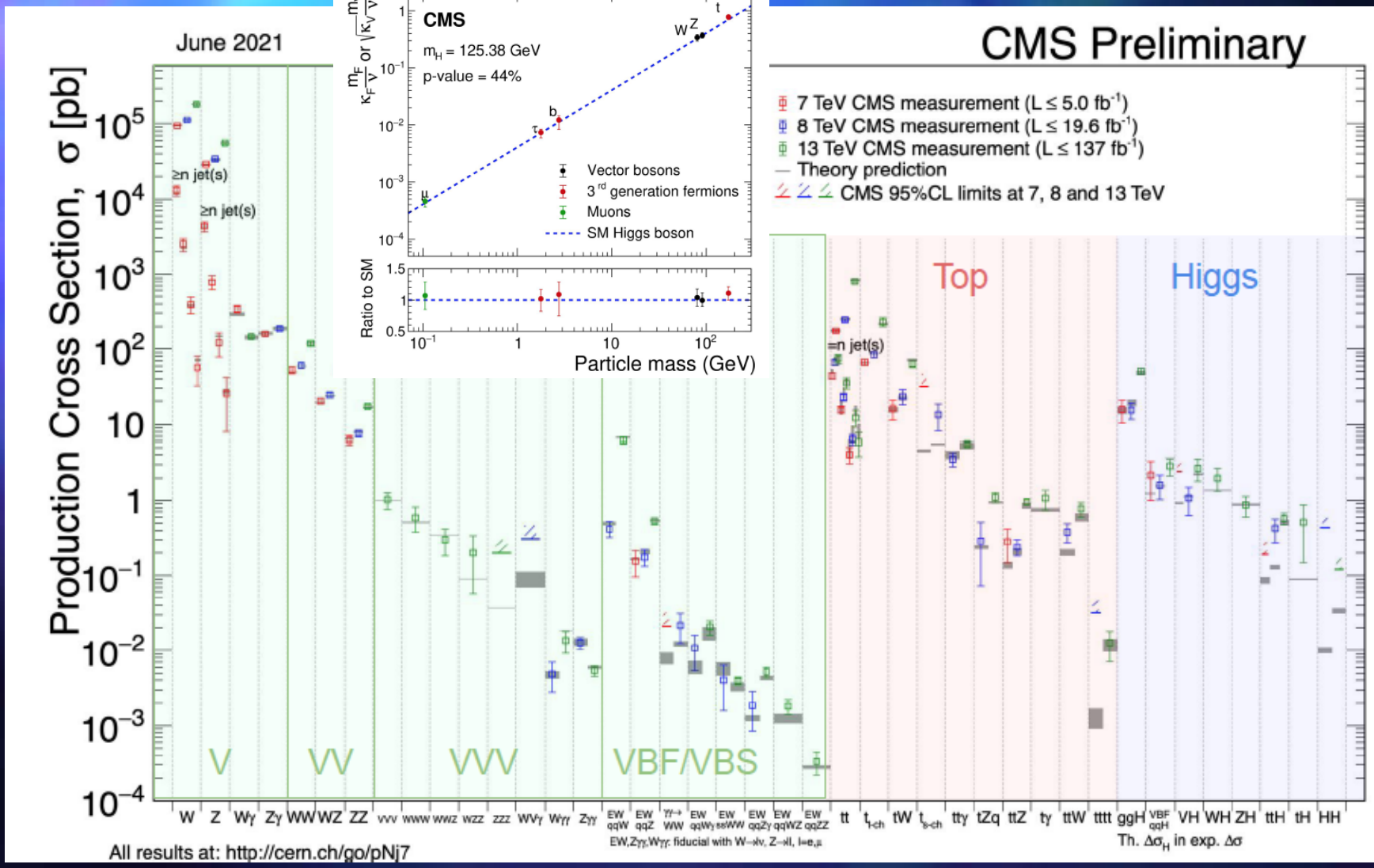




➢ Cosmic Run in July (~1M muons)

➢ Beam test in Oct. 2021

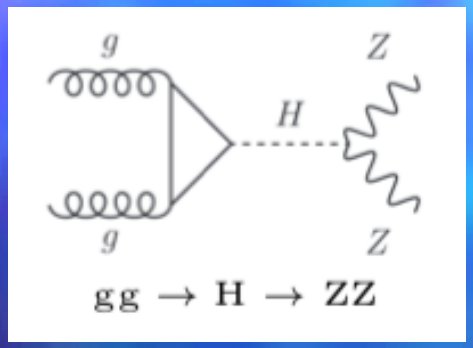
Status with SM

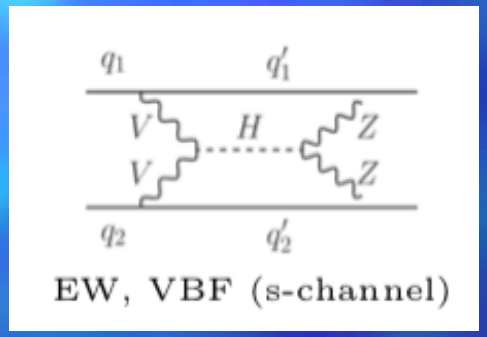


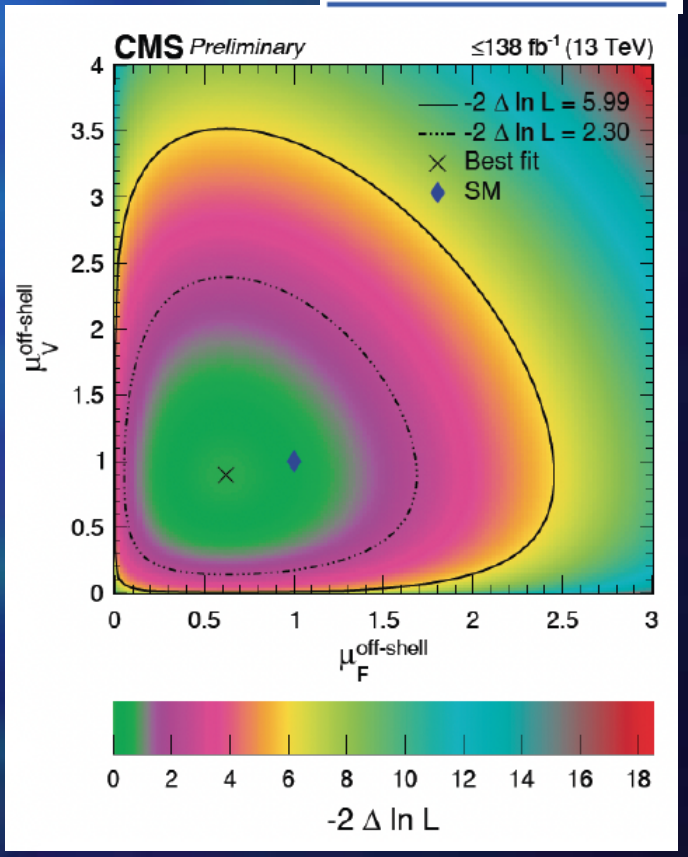
Off-shell Higgs

- Evidence of off-shell Higgs production to ZZ in 2l2ν and 4l
  - 10% events: off-shell production for $m(H^*)>2m_{W/Z}$
- The first measurement of the Higgs boson width
  - To be submitted to Nature

HIG-21-013





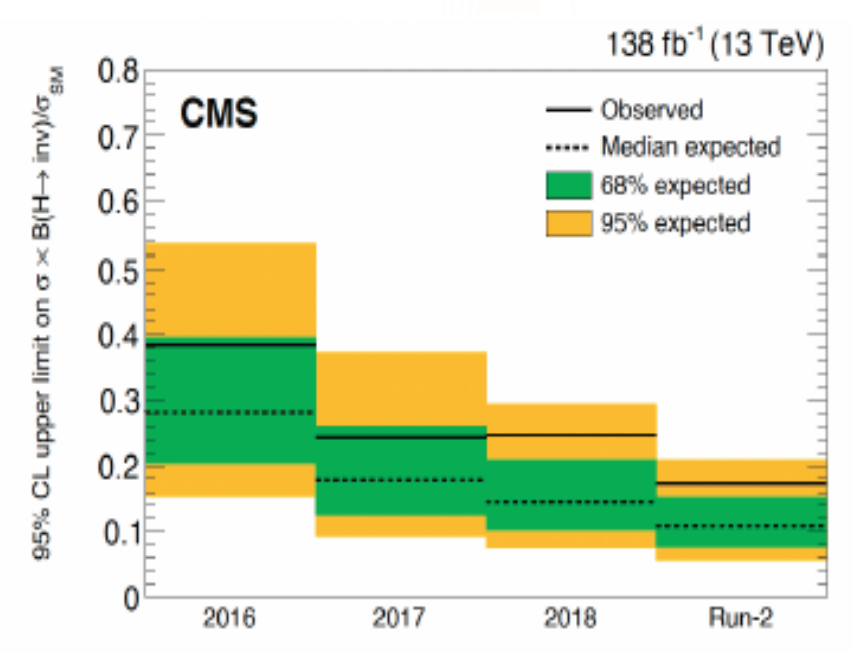


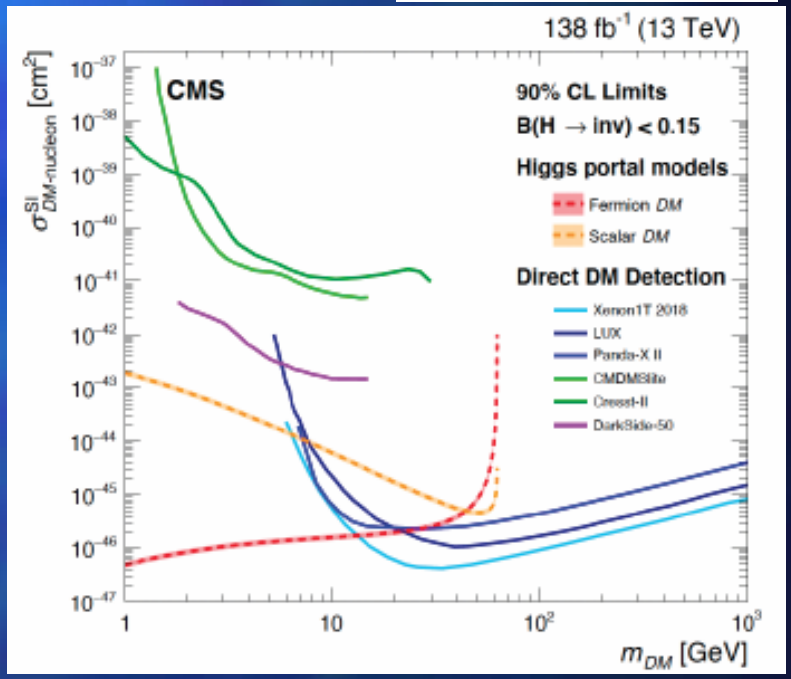
Higgs total width: $\Gamma_H = 3.2^{+2.4}_{-1.7}$ MeV

Higgs decaying invisibly

- Search Higgs → invisible in the VBF Higgs production
- Observed (exp.) upper limit on the Br: 0.17 (0.11)

HIG-20-003

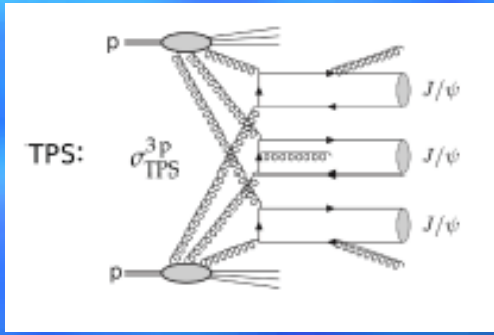


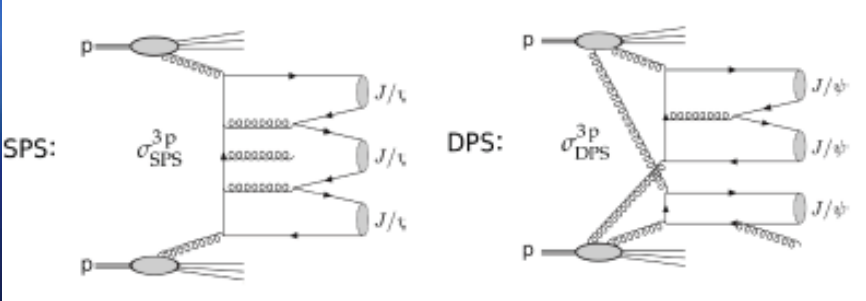


- The most stringent limits on Br(H→inv)
- Interpreted within Higgs-portal models

Observation of triple J/Ψ

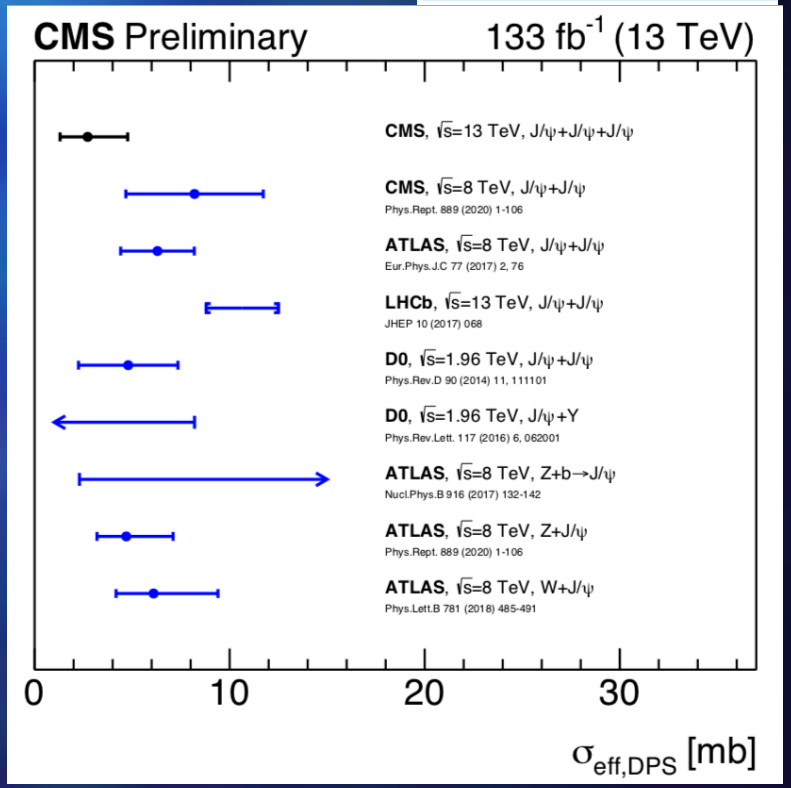
- The first observation of triple parton scattering process
  - Extraction of double parton scattering cross section
  - Underlying dynamics of N-Parton scattering process





$\sigma_{eff}(DPS) = 2.7\ ^{-1.0}_{+1.4}(exp)\ ^{-1.0}_{+1.5}(theo)$ mb

BPH-21-004



한국-CMS (KCMS) 사업팀

- CMS: 55개국, 239개 기관, 5373명 참여 (저자수 2096명)
- KCMS: 10개의 참여기관
  - 경북대, 경희대, 고려대, 서울대, 서울시립대
  - 성균관대, 세종대, 연세대, 전남대, 한양대

- 예산 및 연구인력: 총 30.59억원, 122명
- 세계에서 10번째 규모의 사업팀 (2.4%)

단계	연도	총 예산 (억원)	교수	연구원	대학원생	기술, 행정	총인원
3	2013	22.0	13	18	36	10	77
4	2016	22.5	15	20	46	5	86
5	2019	26.1	18	20	69	9	116
	2020	28.86	18	19	75	9	121
	2021	30.59	17	23	73	9	122

KCMS 업적 (‘21.01~)

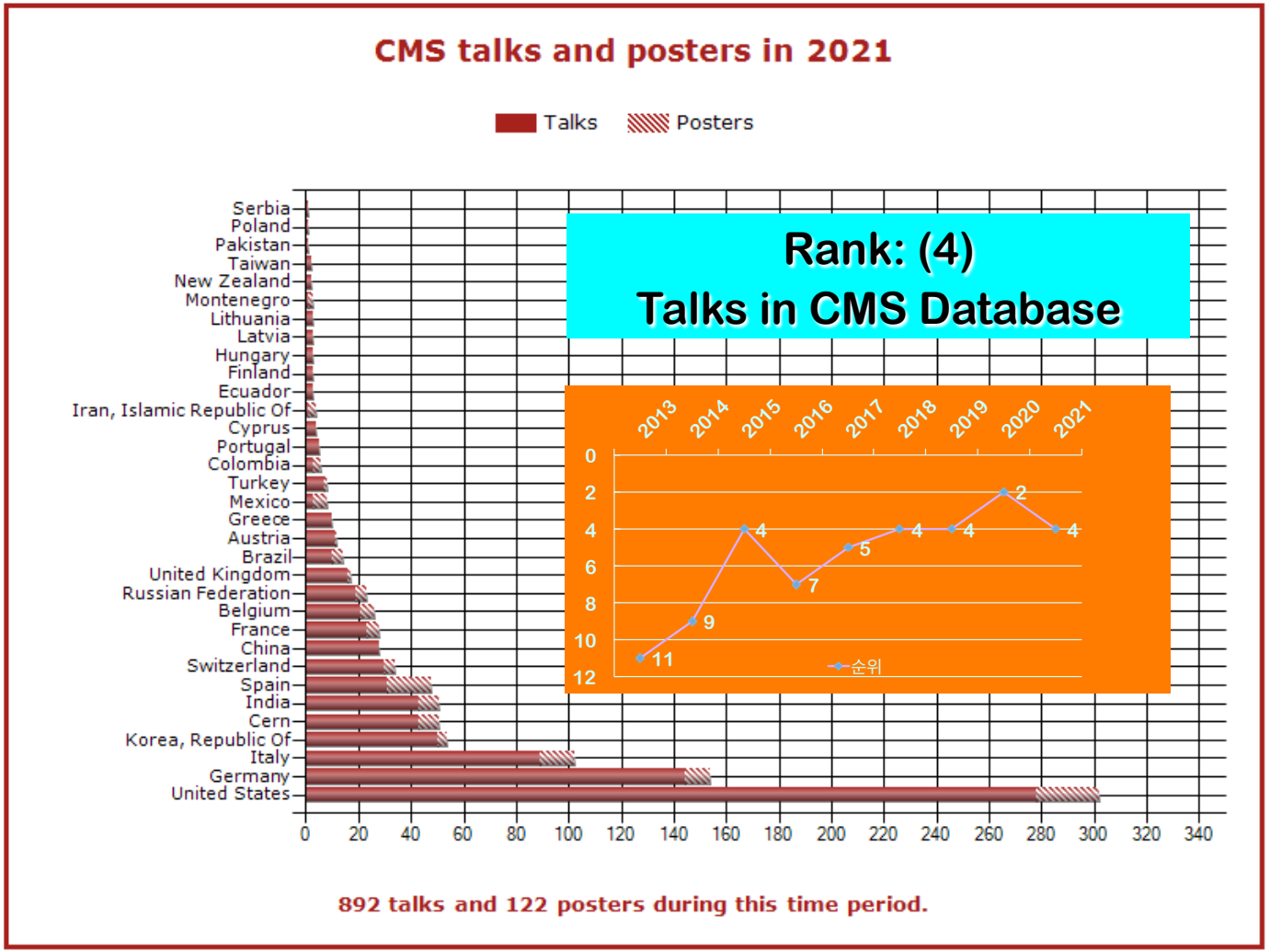
- CMS 논문 (총 62편중 주저자 논문 9편, 15%)
- 국제+국내 학술발표: ~52편 (4위권, 목표치 7위권)
- ‘20년에 설치 완료한 GE11 뮤온 검출기를 성공적으로 시운전함
- GE21 대형 호일 생산을 2월부터 생산 시작
- 학위배출: 박사 4명, 석사 6명
- CMS Award 2명 수상, 한국물리학회 우수 발표상 7명
- 주요 리더쉽
  - 최수용 교수: 비회원국 Representative
  - 김태정 교수: Muon RPC 이사회 Chair
  - 김용선 교수: HIN Physics Group convener (L2)
  - S. Sekman: Upgrade Performance Studies Group (L2)
  - 유재혁 교수: SUSY Leptonic group convener (L3)
  - 고정환 교수: RPC DPG Deputy Coordinator (L3)
  - Jason Lee 교수: GEM DPG Coordinator (L3)
  - 전시현 학생: EXO MC & Interpretation convener (L3)
  - 오민석 학생: MUON HLT convener (L3)
  - 고상현 학생: GEN Validation convener (L3)

논문 발표 성과

- **CMS papers with primary authorship by KCMS:**
  9 papers (total 62: 15%) + 3 ML papers

	2013	2014	2015	2016	2017	2018	2019	2020	2021
CMS papers	68	53	74	75	88	125	100	73	62
KCMS primary	3	3	9	9	9	15	10	8	9
KCMS Ratio	4%	6%	12%	12%	10%	12%	10%	11%	15%

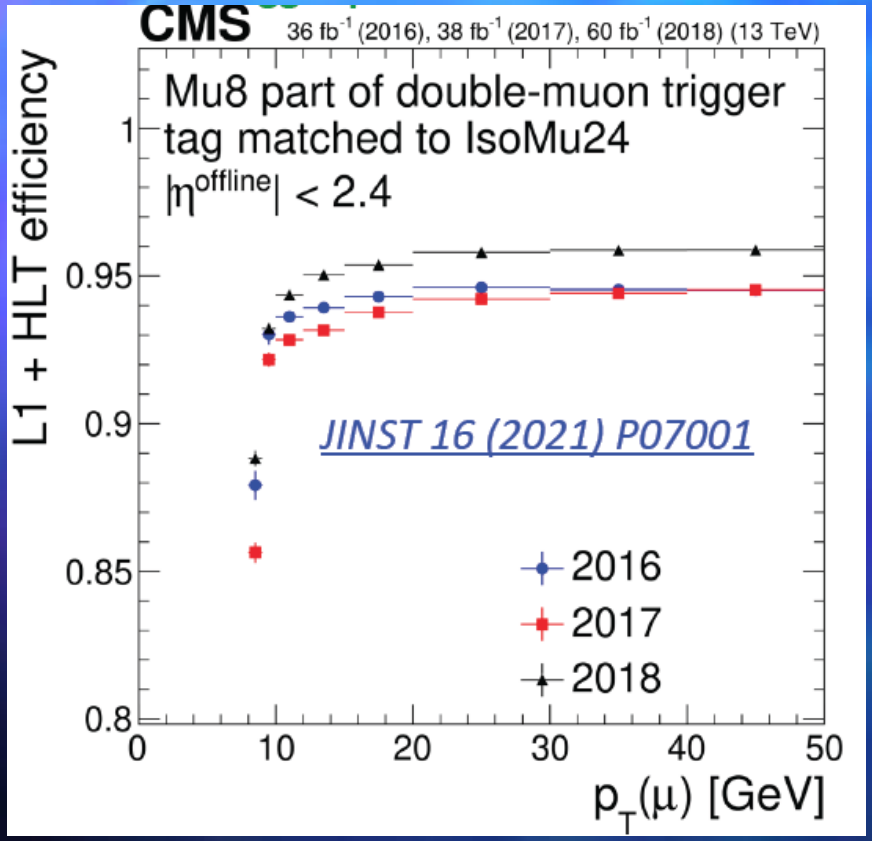
학술 발표 성과 ('21)



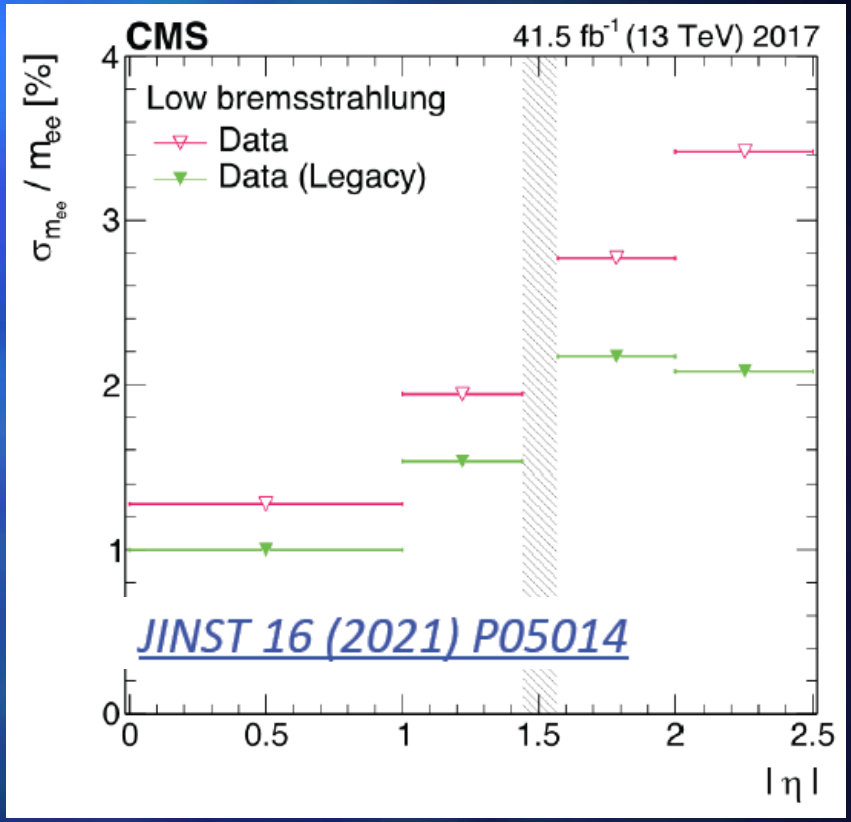
➢ 52 talks (7.2% vs M&O-A 2.4%)

Run 2 Performance

- Muon Trigger Efficiency



- Electron energy resolution



- Big improvements made: CMS Award

Search for high mass resonances in dilepton

- With full Run 2 data, produced combined limits and model independent results
- Explored LFUV anomalies

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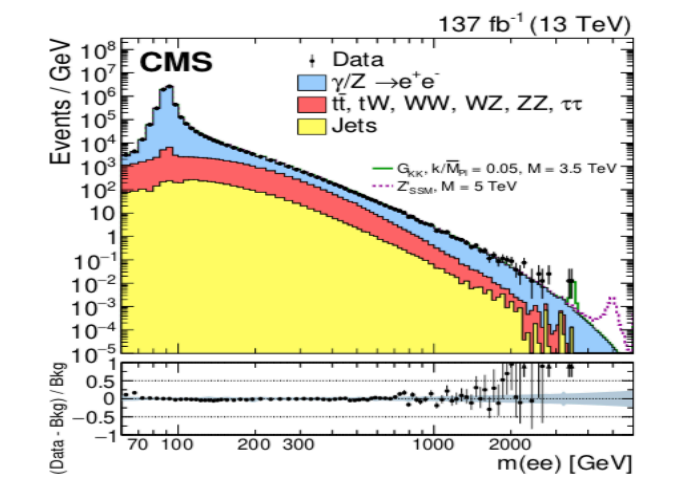
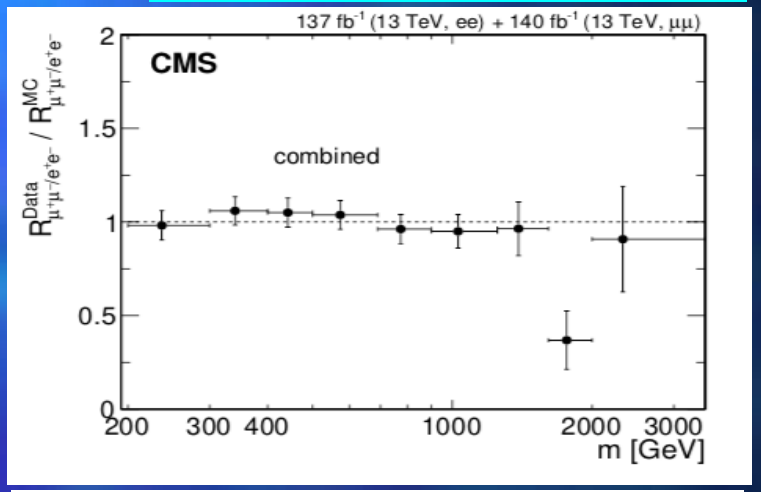
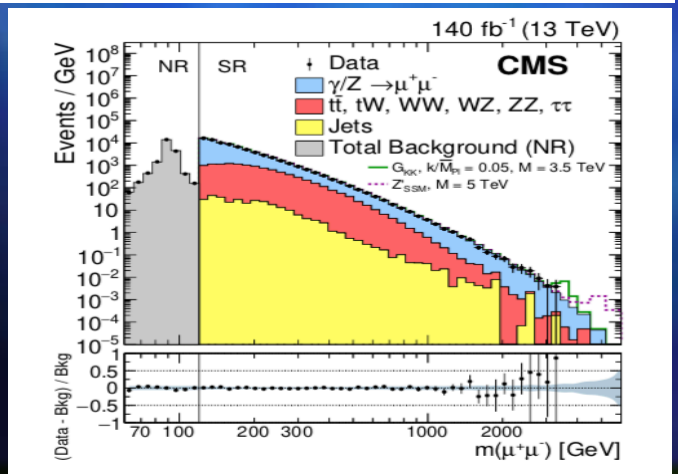
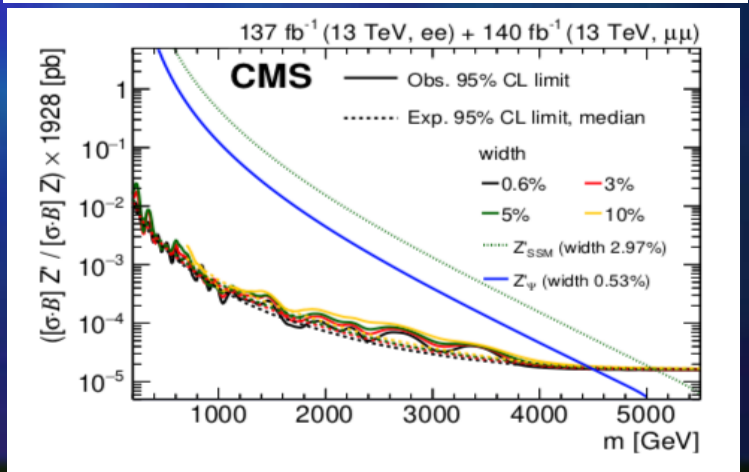


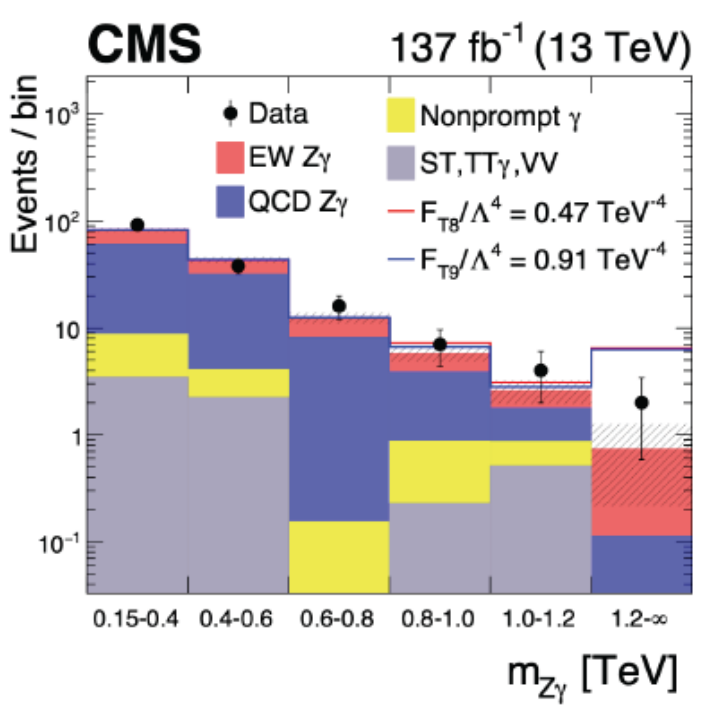




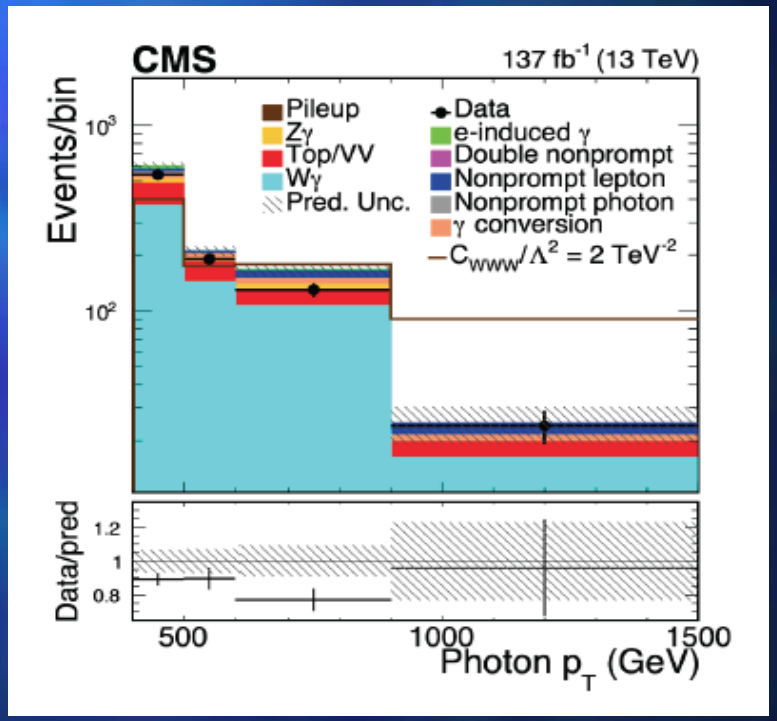


W / Z production with photon

- Wγ and Zγ production can be used to constrain anomalous triple gauge couplings
- Allow to probe the region of hi-pt photon and Vγ mass



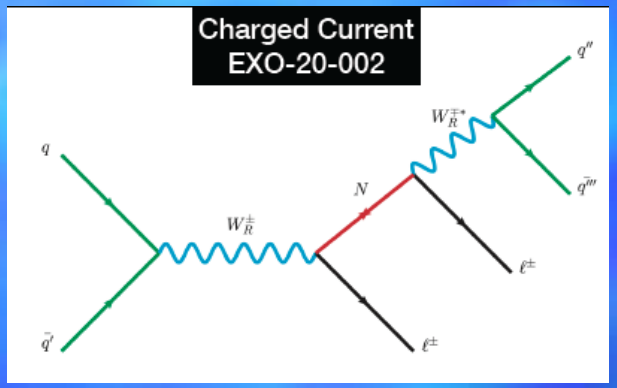
PRD 104 (2021) 072001

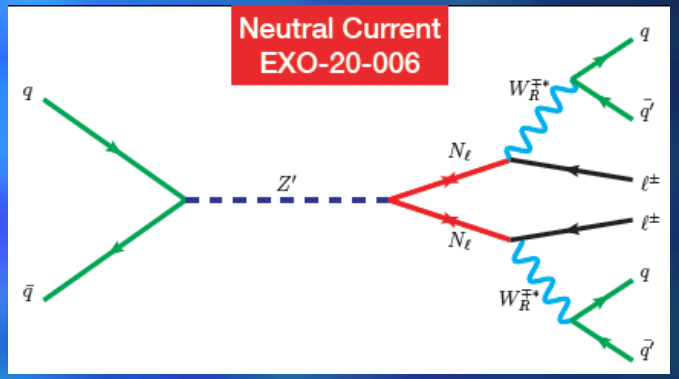


PRL 126 (2021) 252002

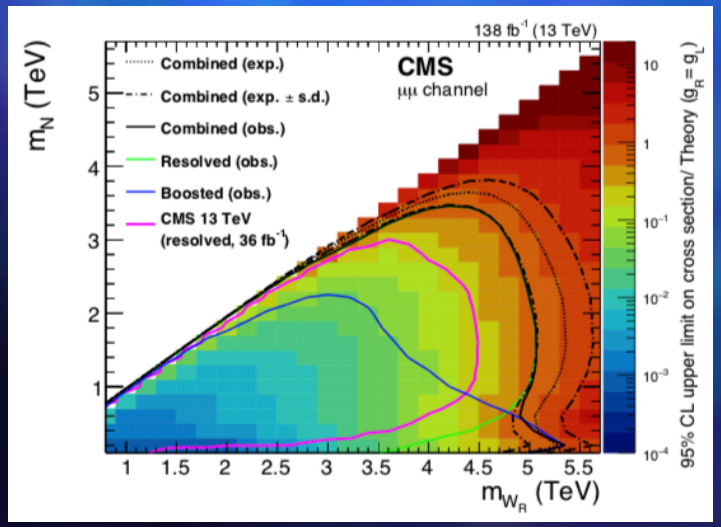
Heavy Neutrinos

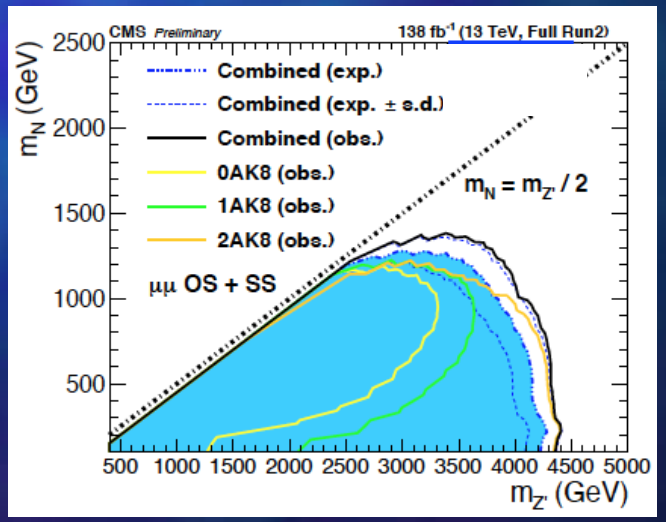
- Search for heavy Majorana neutrinos in LRSM





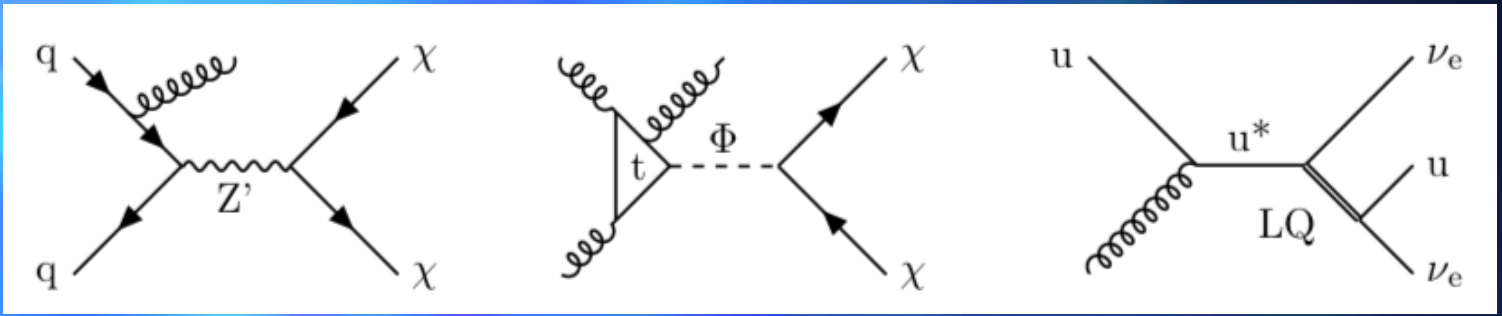
- Set upper limits on WR, ZR and heavy N





Searches for new particles with jets and MET

- Searches for dark matter in MET channel with large MET



- Set limits on the dark matter and mediator

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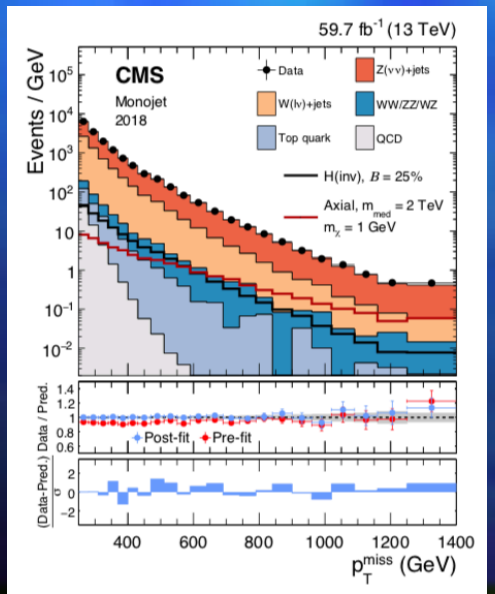
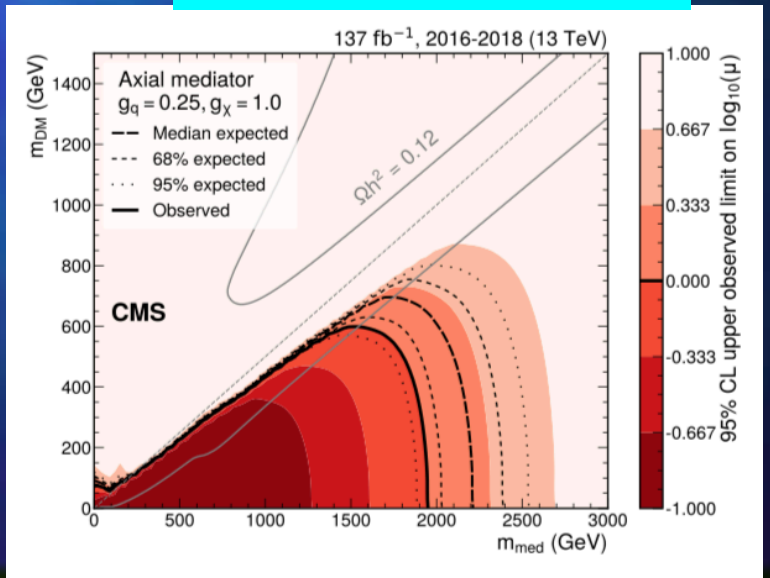
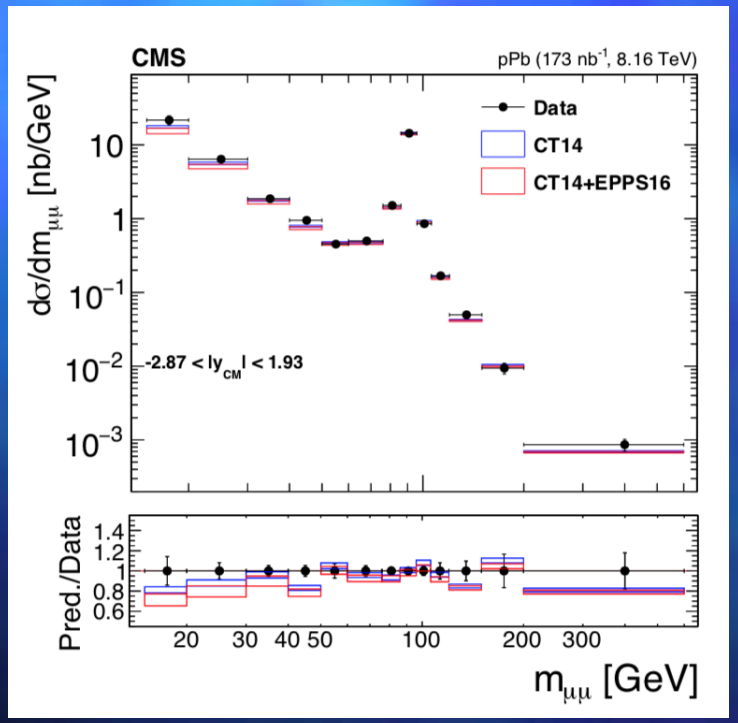
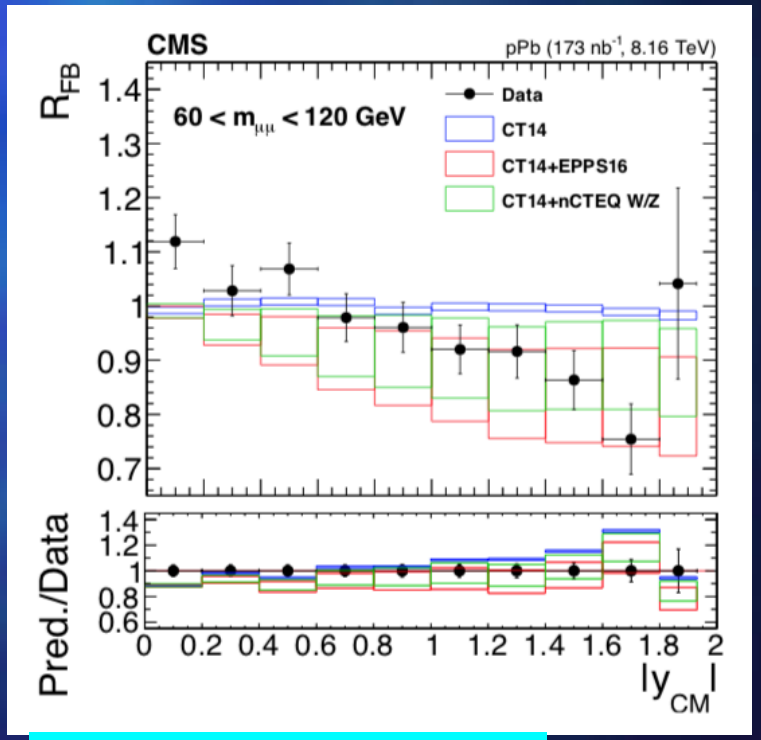




Heavy Ions

- Drell-Yan production in pPb collisions
  - Measure the differential Xsection: provides nuclear PDFS
  - PDF with nuclear effect shows an agreement with data





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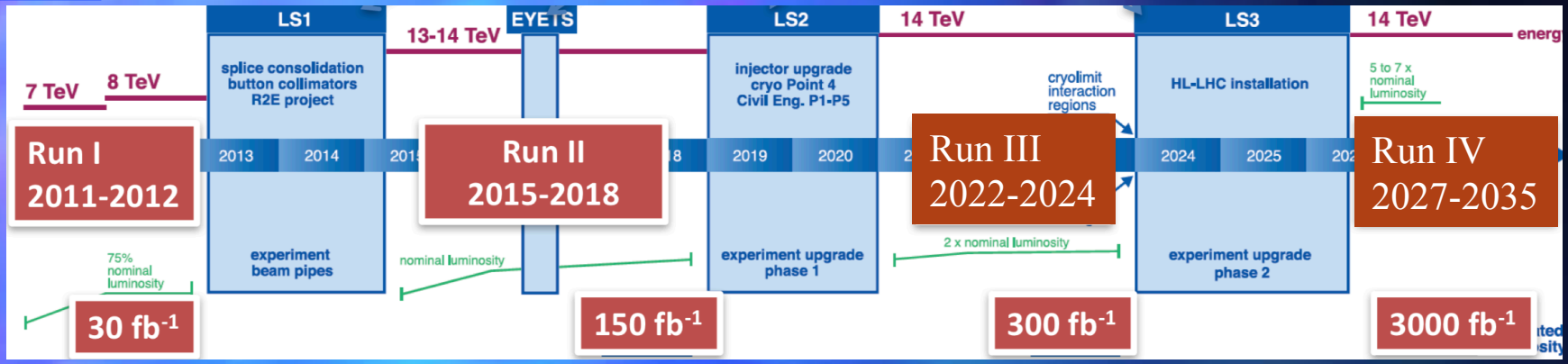
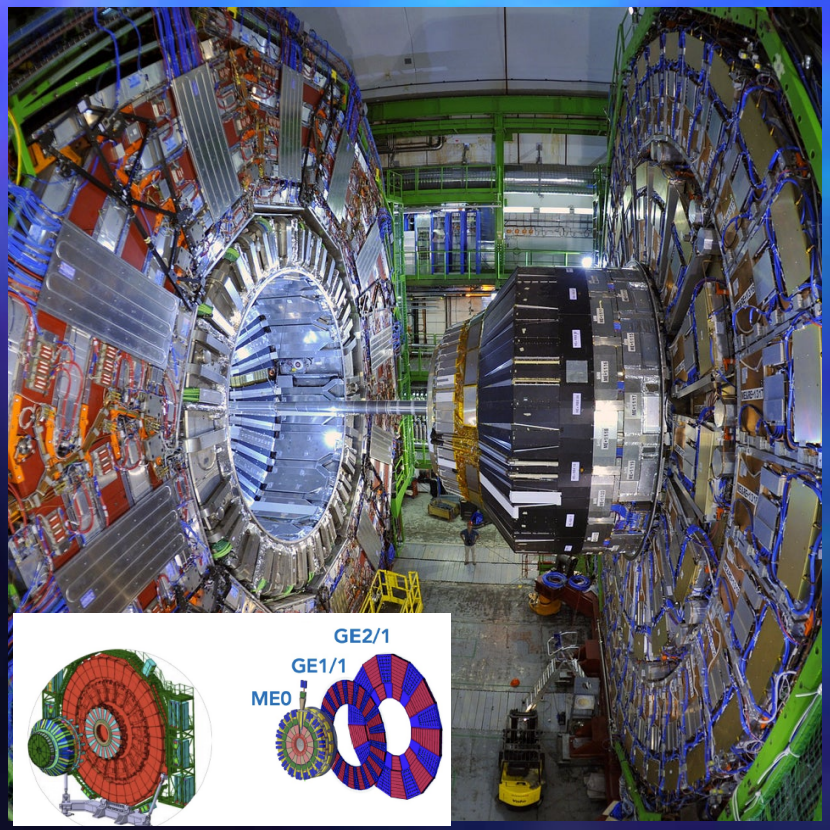
CMS Detector Upgrade





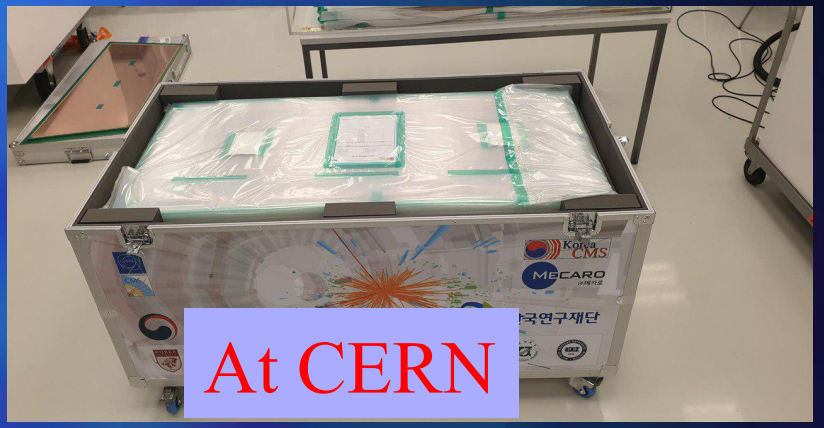
- LS1 : RPC ('13~'14): 550kCHF
  - RPC Gap & chamber
  - Phase-1 RE4/2 installed (done)
- LS2 : GE11 : 592K
  - GE11 construction (done)
- LS3: GE21, ME0 ('21~'24): 2,262K
  - GE21 foil prod. (underway)
- LS3: RE3/1, RE4/1 RPC gap: 400K (underway)
- LS3: MTD ('21~'26):1,000K(started)

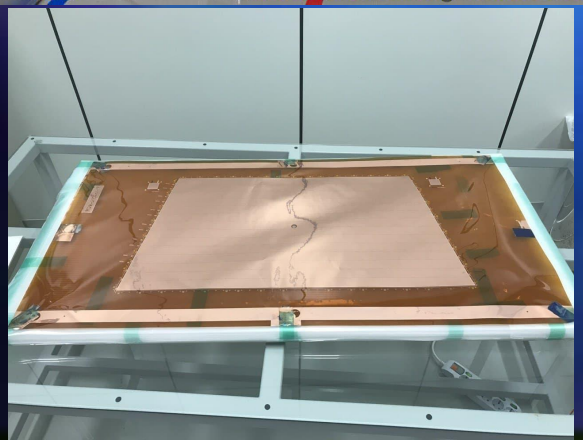
GEM GE21 production

- Mass production started since the 1st batch of the Korean GE 21 foils were produced in this Spring.

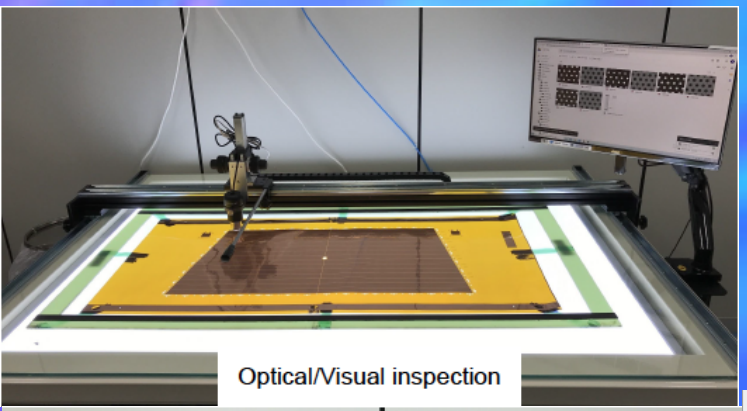
Korea

2 GEM papers: Triple-GEM
DN-2021-007 (JINST)
DN-2020-035 (JINST)

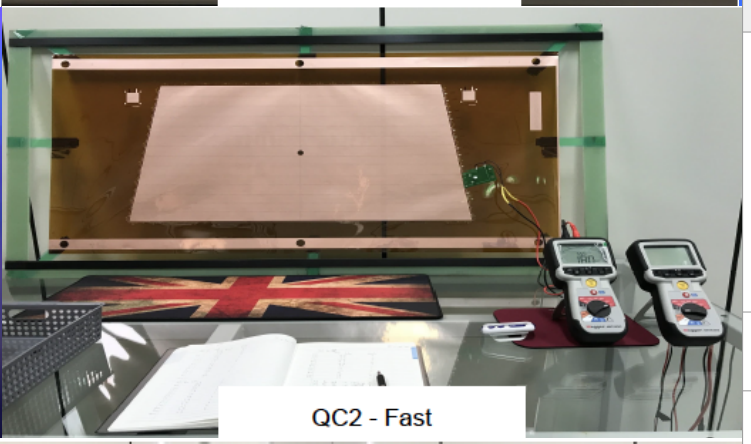




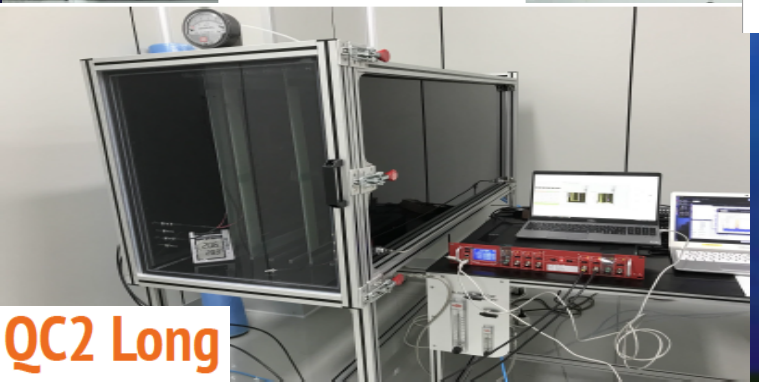
GEM Foil Tests at Mecaro



Optical/Visual inspection

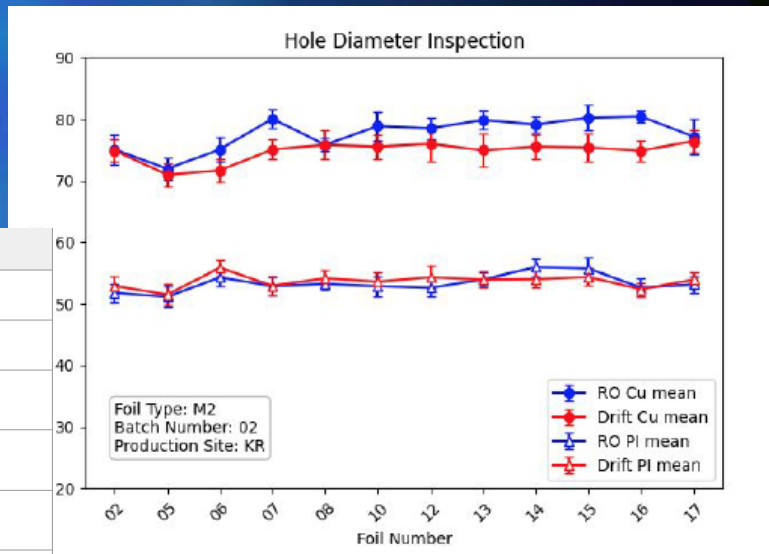


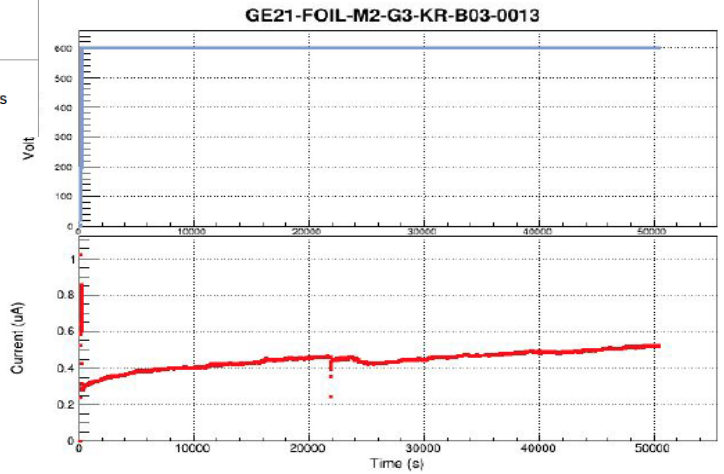
QC2 - Fast



QC2 Long

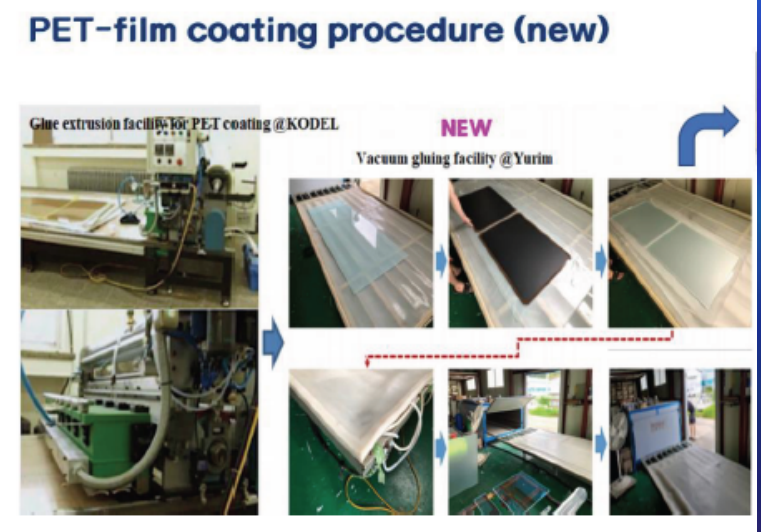
Step	Test Section	
1	Optical/Visual	Surface Condition - Stain
		SMD Resistor values
		HV Line open or closed
		Defects size and ppm
		Hole diameter inspection
2	QC2-Fast	Impedance and Sparks check at 550 Volts
3	QC2-Long	Current measurement at 610 Volts

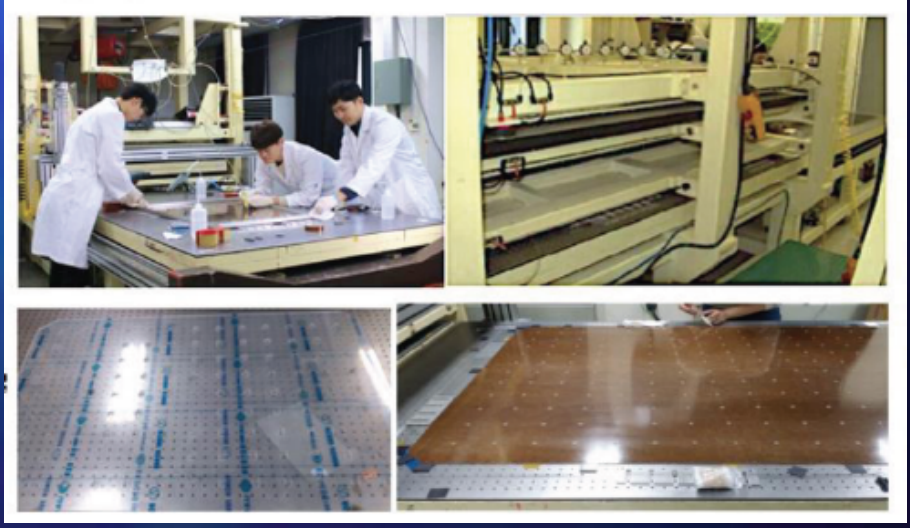




RPC Upgrade

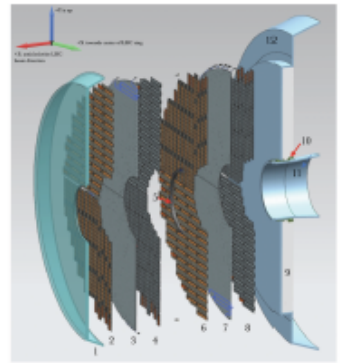
- 8 RE3/1 and RE4/1 demo-chambers will be installed during LS2 for a performance study
- Demonstrator production started after Jan. 2021
- Gaps were produced and Quality Controls at Korea Univ.
- New procedures for electrode washing, graphite and films were performed in Korean companies

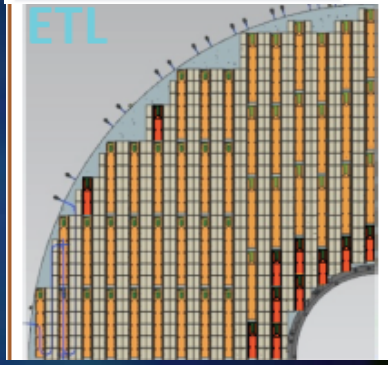




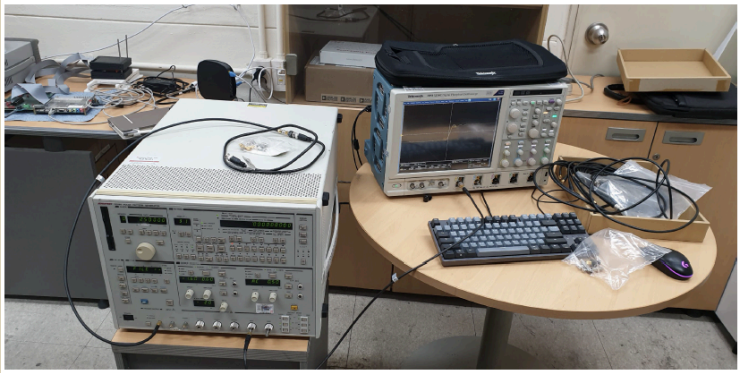
New MTD Project

- MTD fund, 300K for 2022 is allocated from NRF
  - Plan to contribute at the level of 1,000k CHF
- Korea plans to make in three different area.
  - Low Gain Avalanche Detector (LGAD) sensor development & test
  - ASIC readout chip (ETROC) development & test





ETROC1 Test set up at KNU

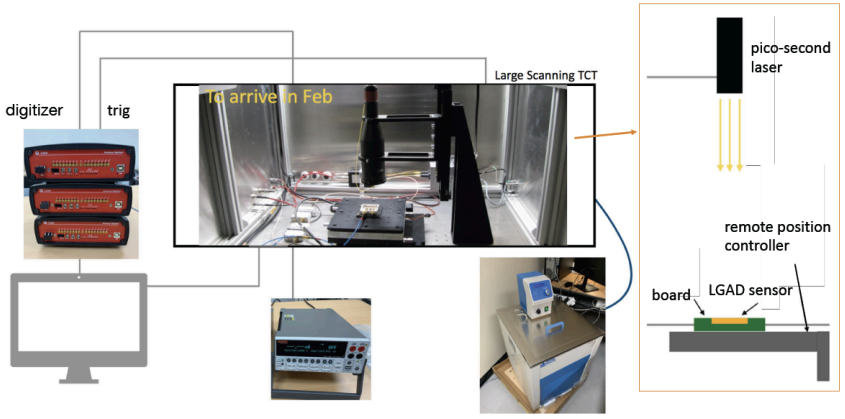


- ETROC1
  - 4x4 clock tree, preamp + discriminator + TDC
  - Goal: full chain front-end with TDC, 4x4 clock tree
  - This is the first full chain precision timing prototype

- Full array full chain ETROC1 charge injection testing at FNAL → results good
- ETROC1 and 5x5 LGAD sensor bump-bonded
  - Laser testing will be done
  - Test Beam (Dec – Apr 2021)

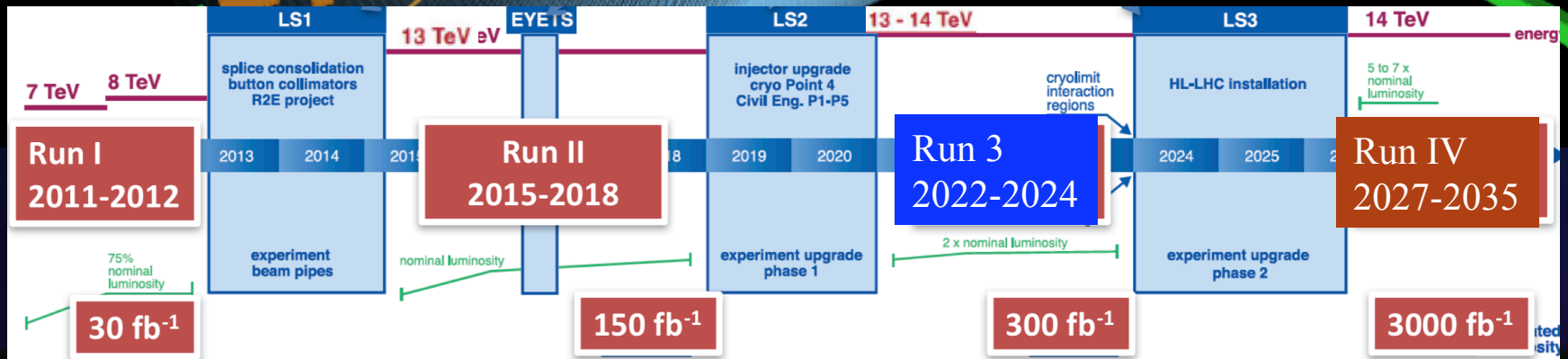
- 1 NIM, 1 JINST papers

LGAD Sensor testing using laser at KU



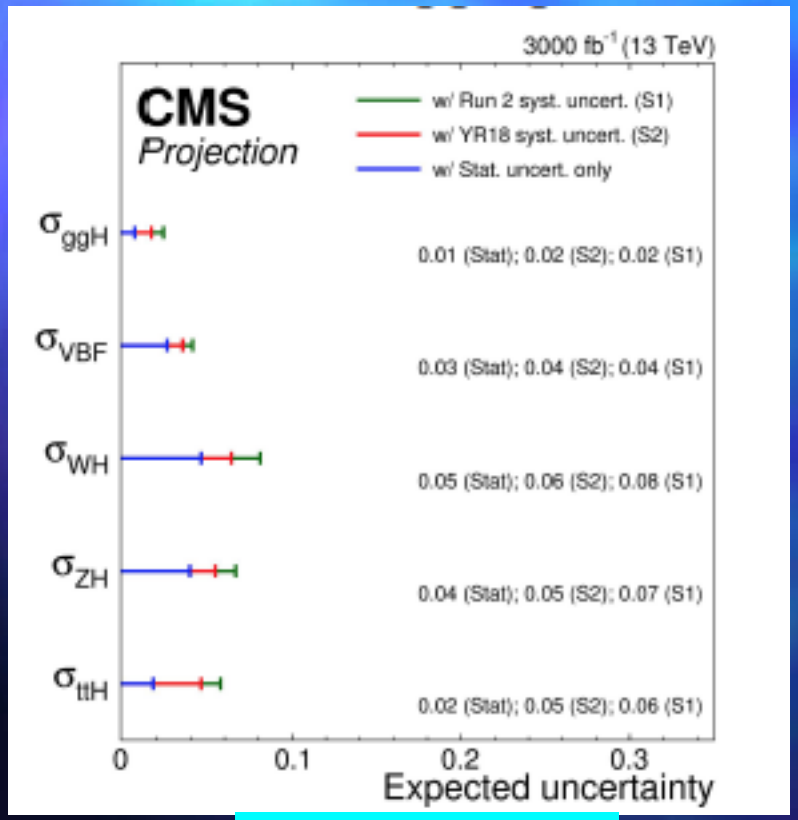
Run/Event: 194108 / 564224000

After a Higgs Discovery, Run 3 + HL-LHC

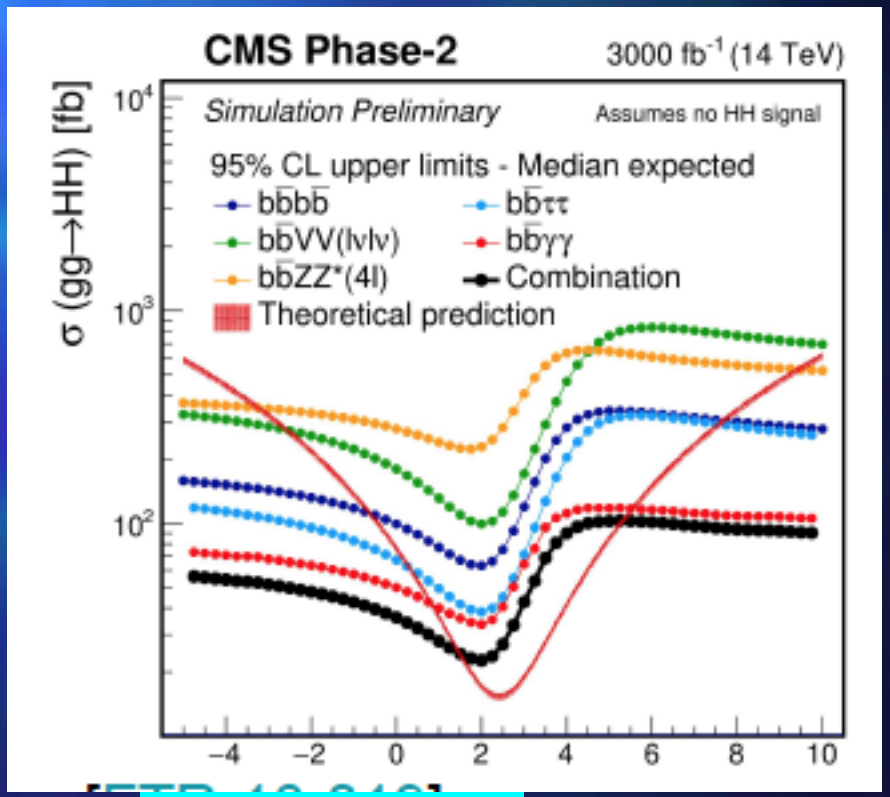


Higgs Physics @ High-Lum

- Coupling to Higgs < 10%
- Observation of di-Higgs production: 3σ



FTR-18-011



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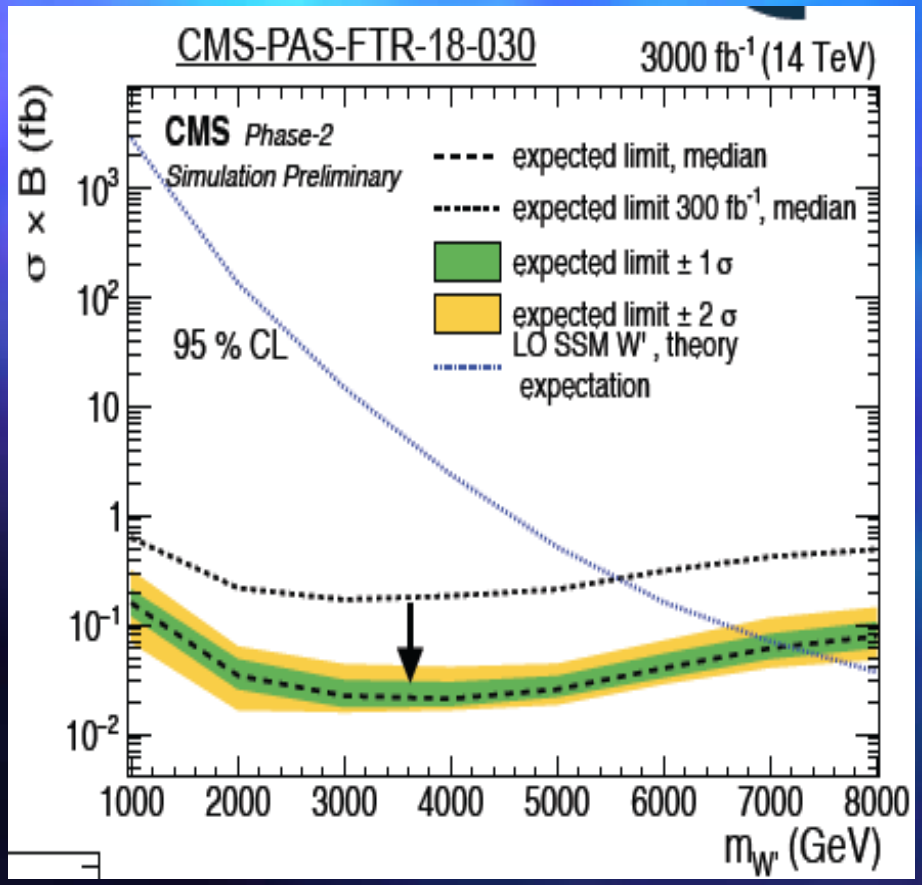
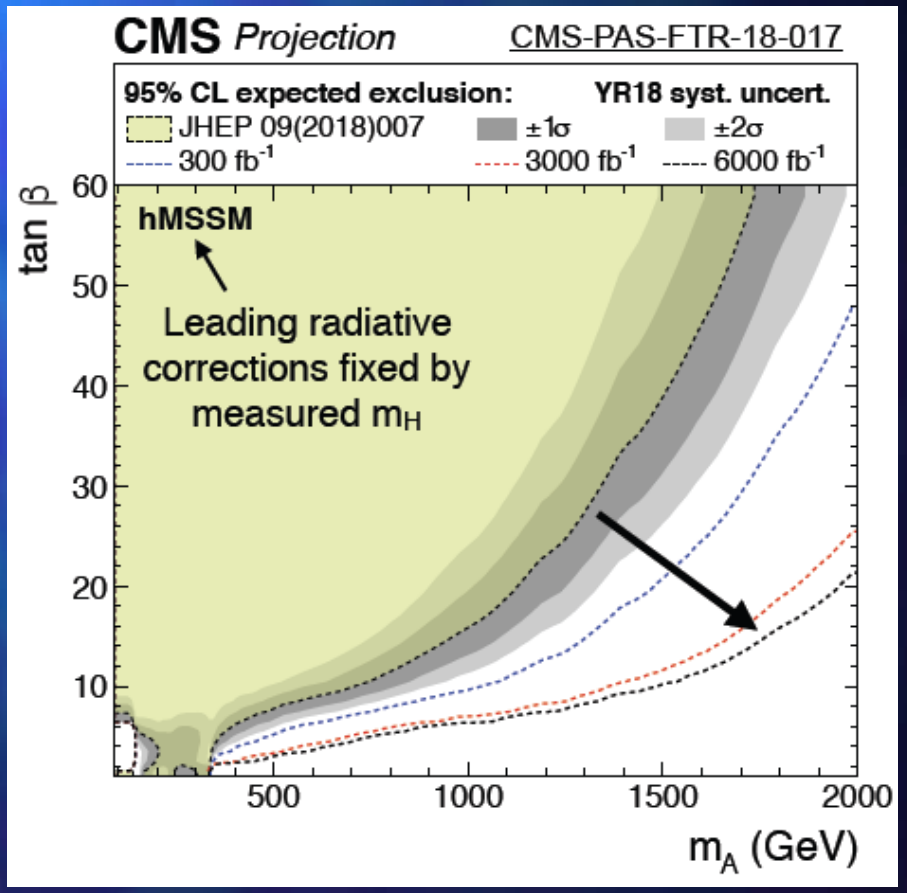
BSM Physics @ High-Lum

- Z'/W'
- Heavy Higgs





Summary

- **LHC CMS**
  - After Higgs discovery, many precisions and searches results with Run 2 data
  - HL-LHC projections show the large gains expected with the upgraded detector and a luminosity of 3000 fb^{-1}
- **Korea-CMS**
  - Very productive in physics analysis under pandemic
  - Major contributions to muon detectors (RPC, GEM, and MTD), and on the right track for the upgrade project
  - Very successful in training students and postdocs
  - Finishing Run2 analyses and preparing Run3 and HL-LHC
  - Very Bright Future with New Leader: 김태정 교수


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-27 23:35:47.271030 GMT
Run/Event: 195099 / 137440354
감사합니다