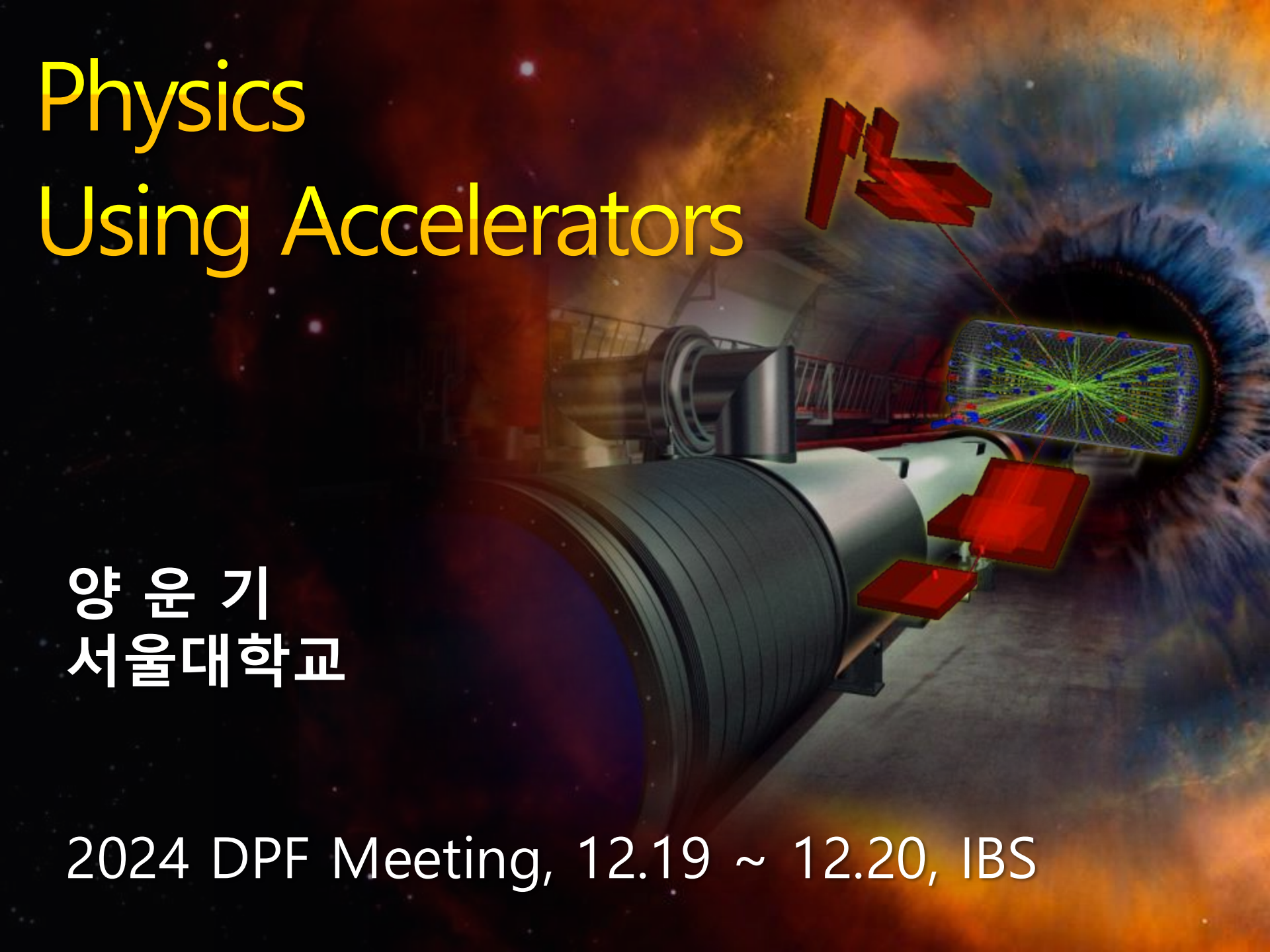
Physics Using Accelerators

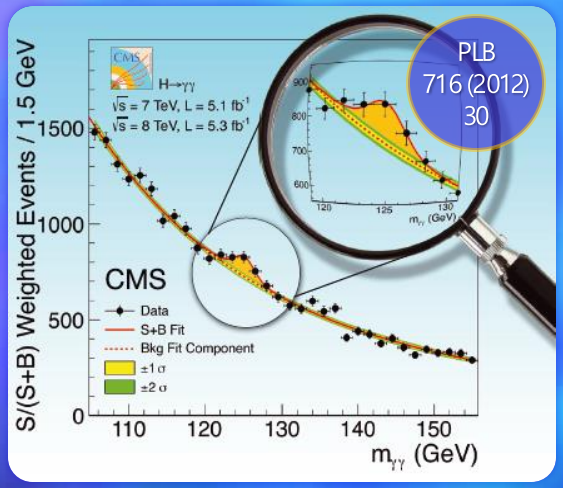


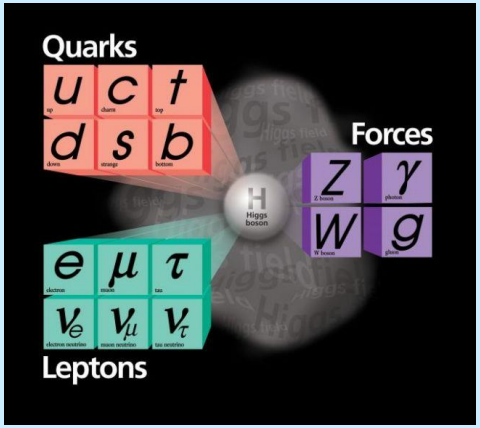
양 운 기
서울대학교

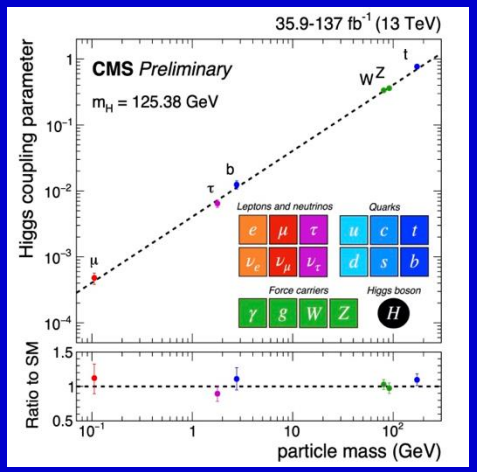
2024 DPF Meeting, 12.19 ~ 12.20, IBS

성공과 도전

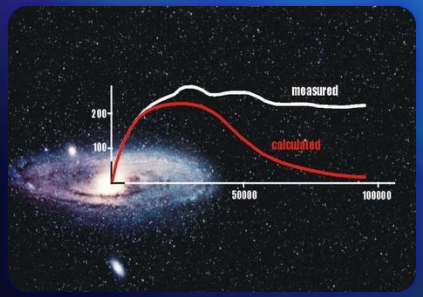
표준모형의 성공과 힉스 발견

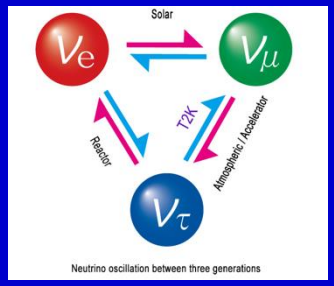


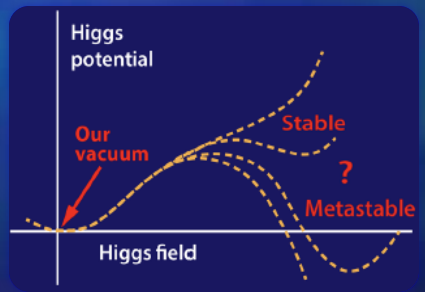


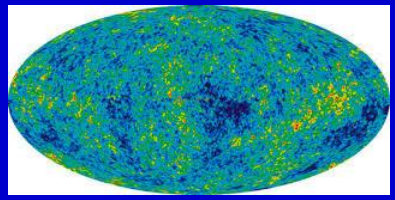


새로운 도전(암흑물질, 중성미자 진동, 힉스 질량, 우주 상수)

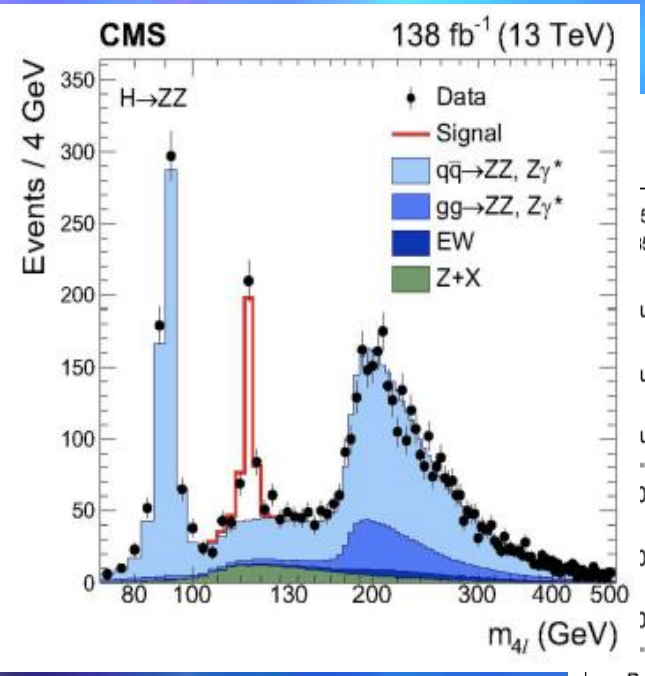




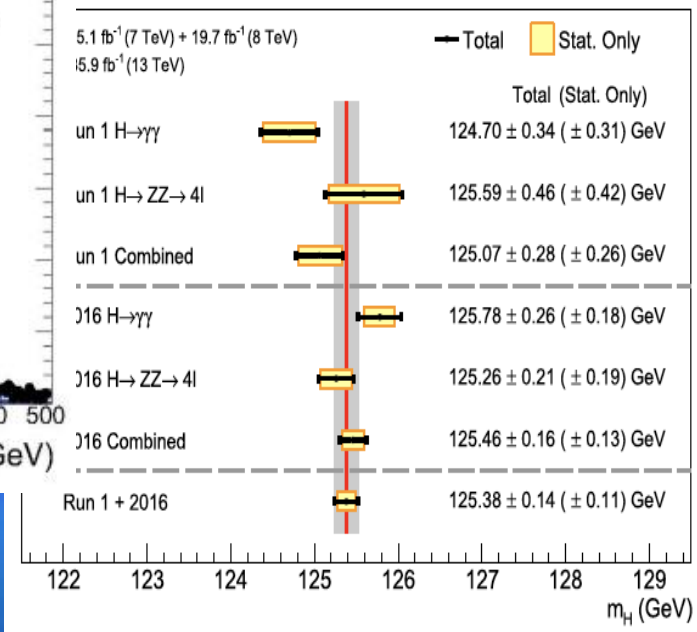


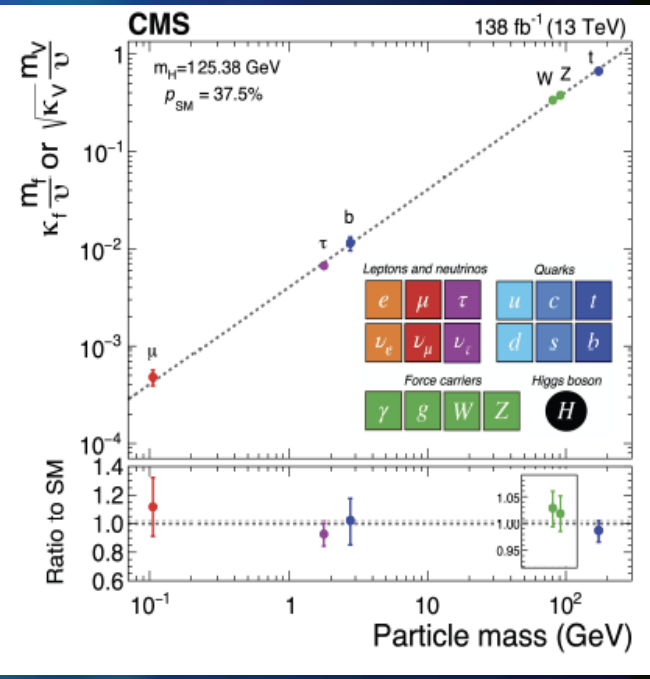


10 years after the Higgs discovery



$m_H = 125.38 \pm 0.14\ GeV$



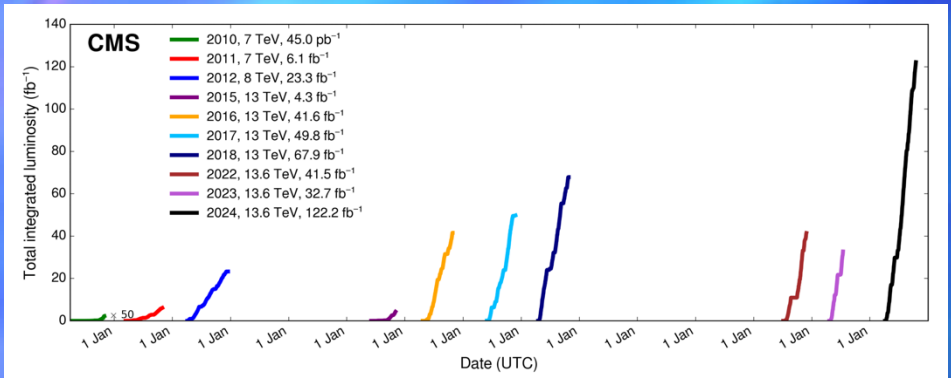


- Higgs mass: 125.38 V with 0.1% precision
- Couplings to the SM particles: consistent with the SM predictions

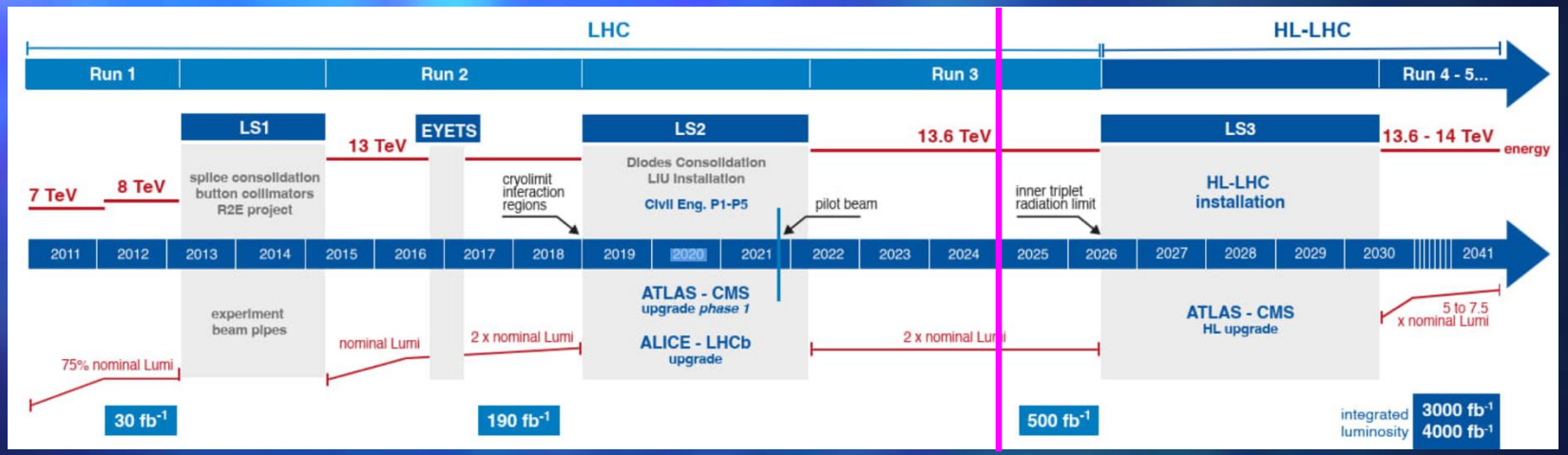
My Apologies

- This review talk will be focused on colliders physics (LHC, Belle II, and future colliders)
- Apologies to DUNE, Hyper-K, JSNS2, SND and DAMSA collaborators

LHC & CMS Performance

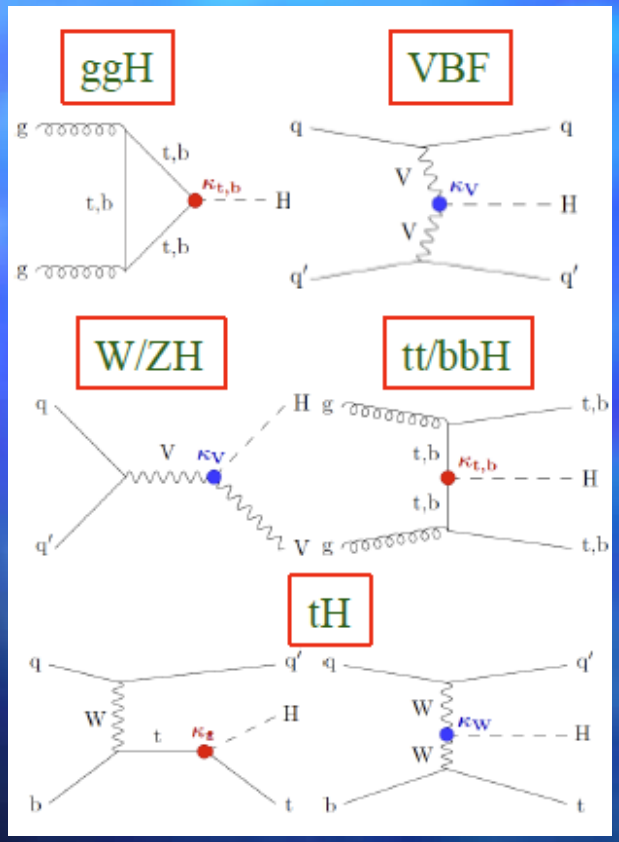


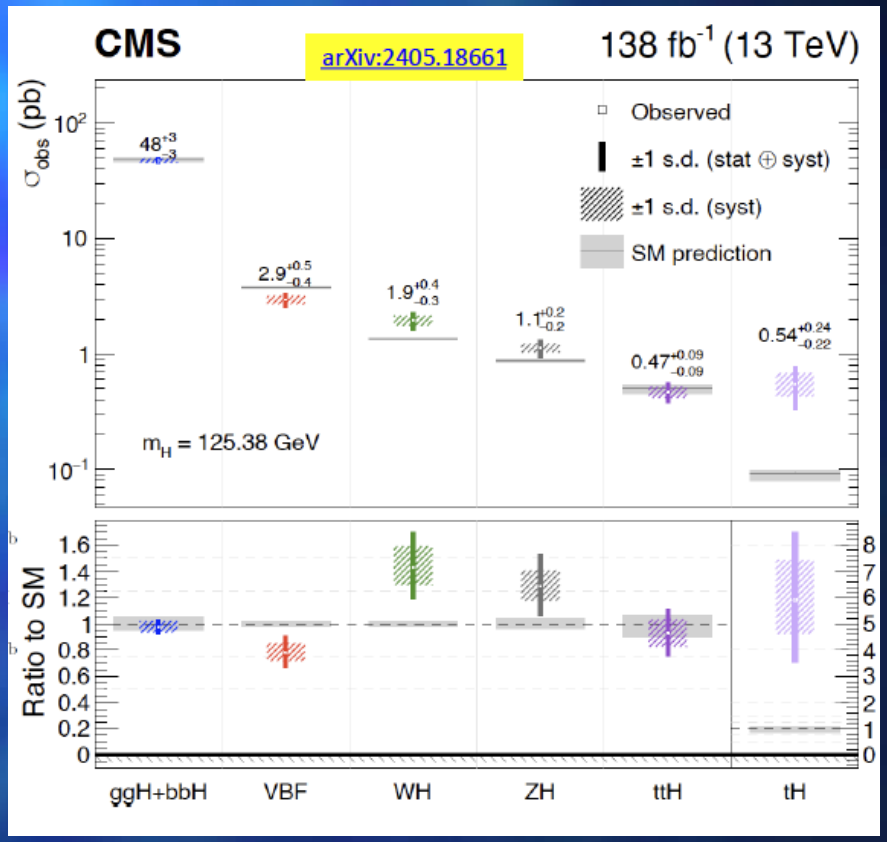
- 350/fb data:
  Run2 + Run3 (~ 14 x Run1)



- Search Machine at Energy Frontier
- EWK precision factory at Intensity Frontier
- Flavor factory (t,b,c,τ) at Intensity Frontier

Higgs Factory (14M) at LHC



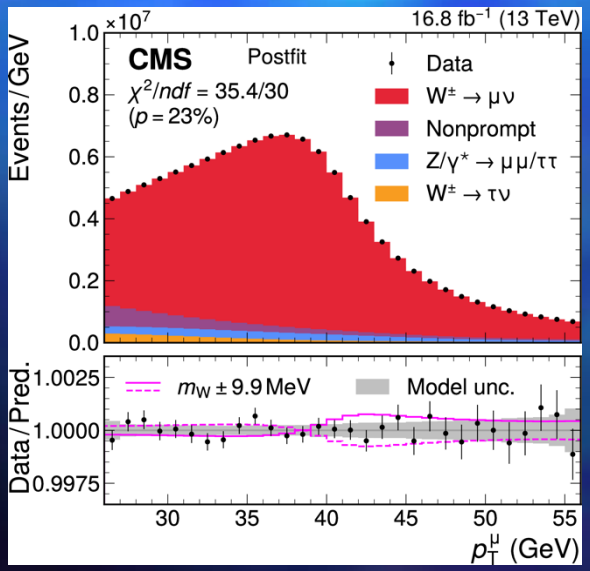


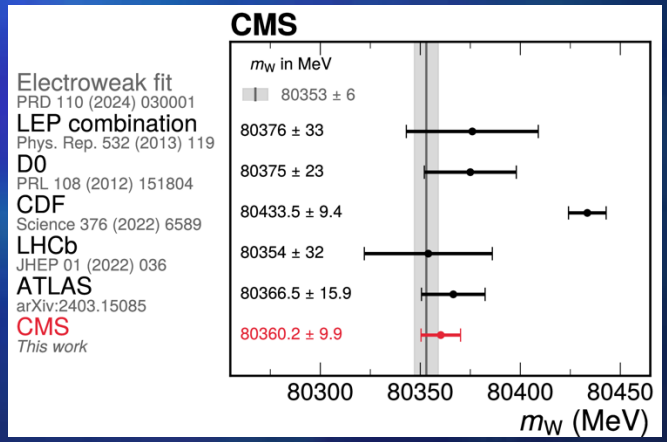
- Good agreement with the Standard Model predictions

W Factory: precise mass

$M_W = 80{,}360 \pm 9.9$ MeV

- **Most precise measurement at the LHC** and comparable the CDF precision using only 10% of the Run2 data
- Agree with the SM prediction
- **In clear tension with the CDF measurement**



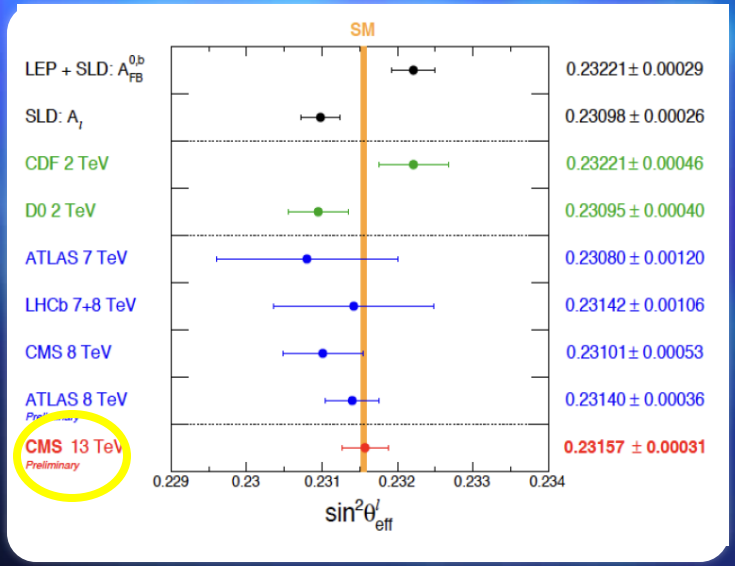


SMP-23-002
Sub. to Nature

Z Factory: precise EWK mixing angle

$$\sin^2\theta^{\ell} = 0.23157 \pm 0.00031$$

- Most precise measurement from hadron colliders, using Z→ll (forward-backward asymmetry)
- Comparable to the LEP/SLD precision
- Good agreement with the SM prediction

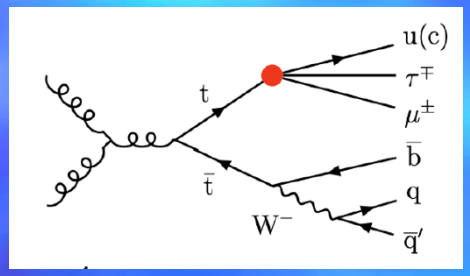


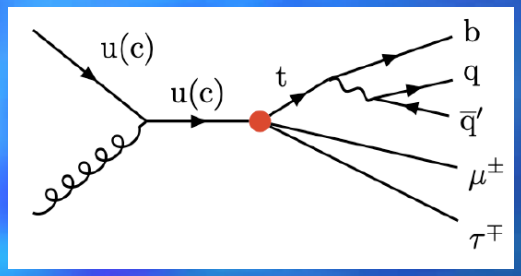
CMS-PAS-SMP-22-010

CERN Press Release: 2024)
(SNU + Rochester + DESY)

Flavor Physics at LHC

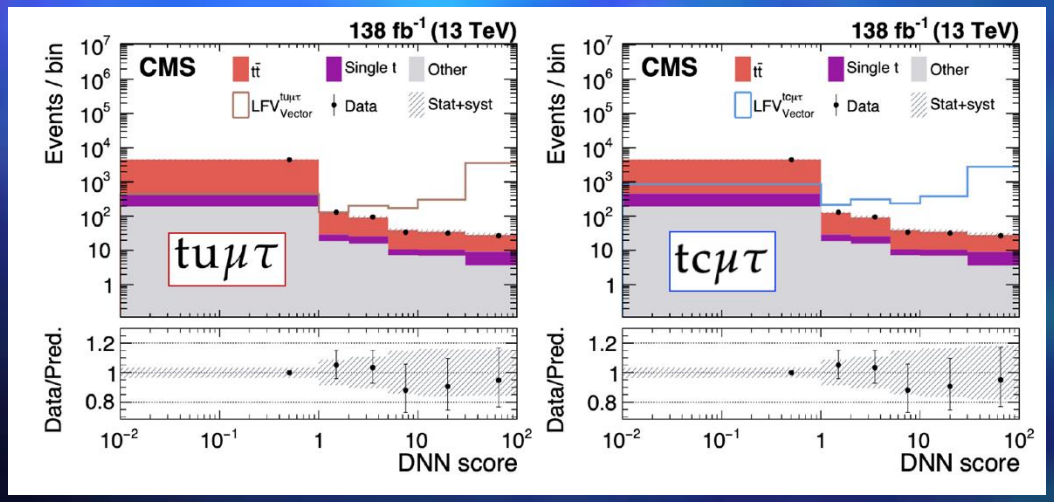
- Search for lepton flavor violation in top quark sector with tau final state using single top or top pair events

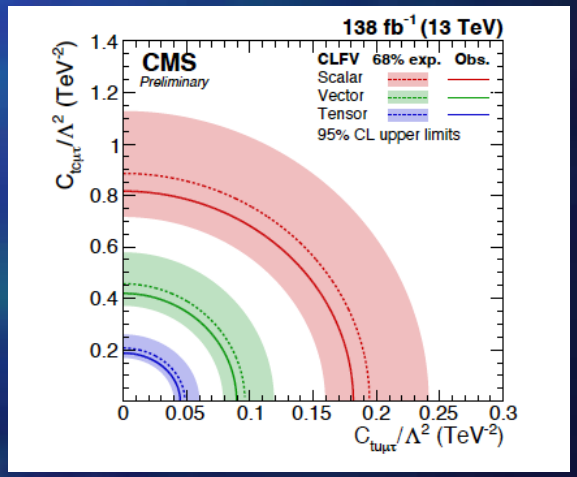




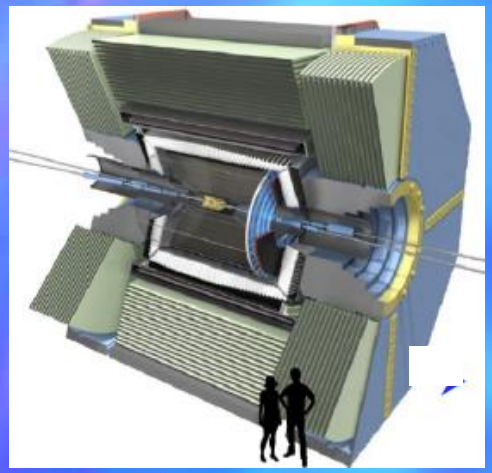
Hanyang U.

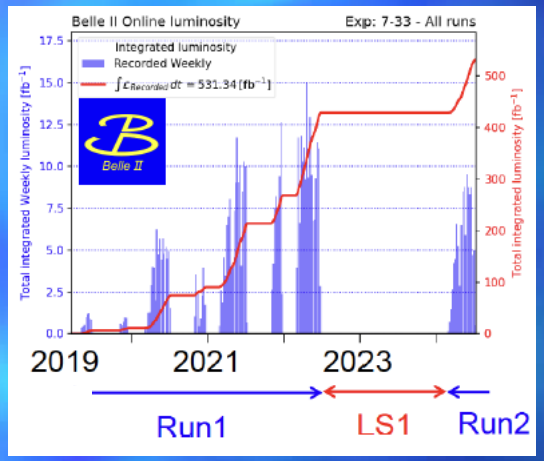
CMS-PAS-Top-22-011

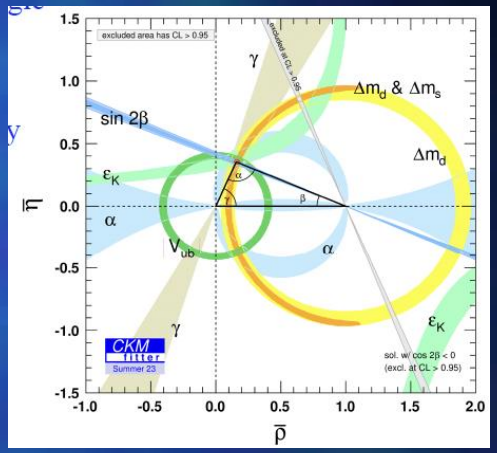


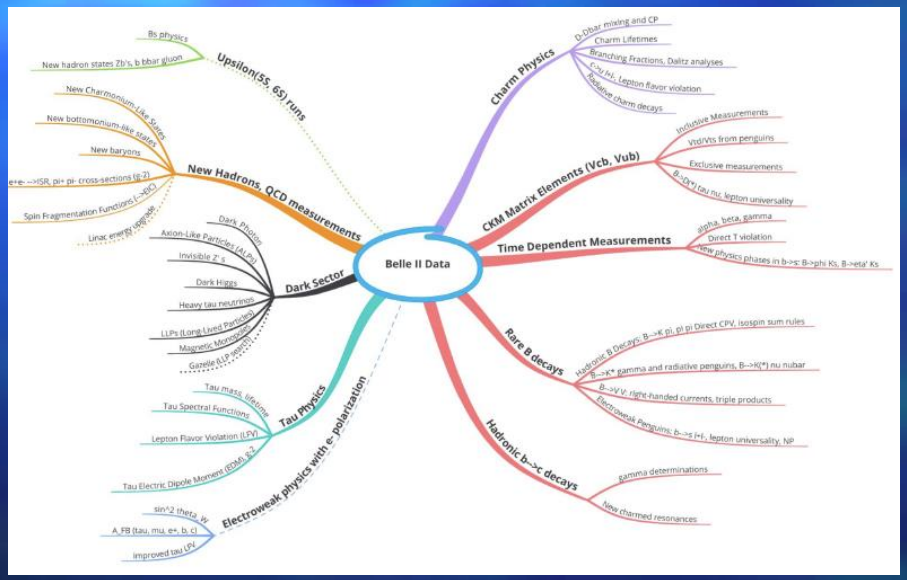


Flavor Factory at Belle II









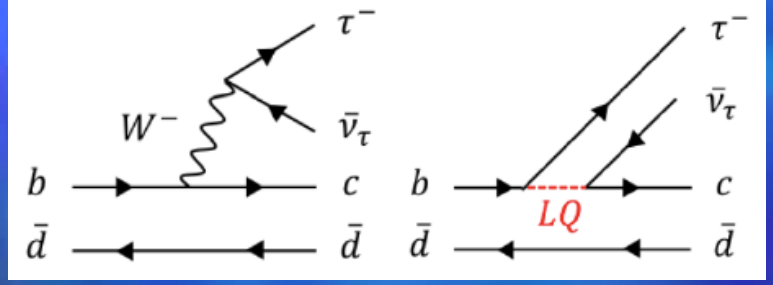
10 institutes (SNU, Yonsei, KU, SKKU, SSU, Hanyang, CAU, KNU, CNU, KISTI)

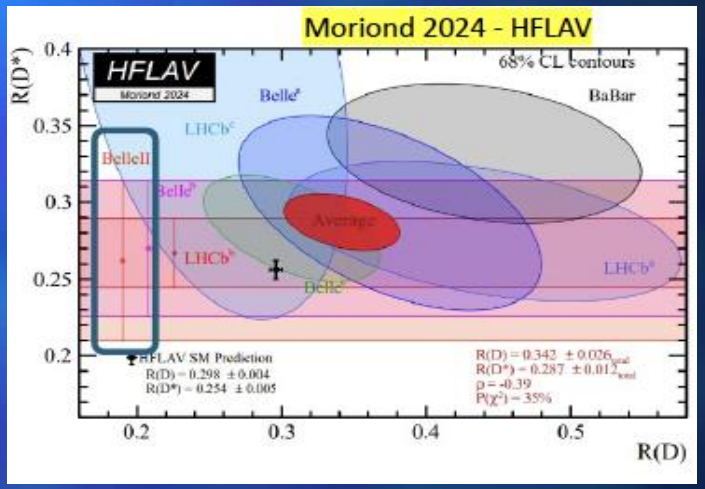
- Belle II started since 2018, Belle (‘99-’10)

LFU at Belle II

- LFU test using R(D*): sensitive to BSM physics
- First measurement using the hadronic B tagging

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)} \tau \nu)}{\mathcal{B}(B \to D^{(*)} \ell \nu)}$$



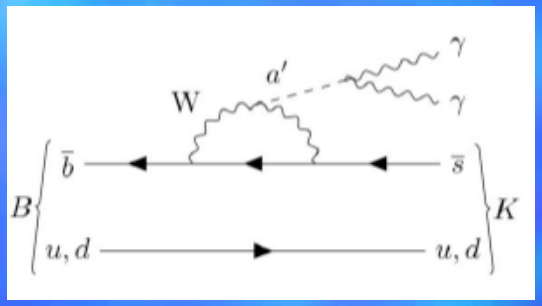


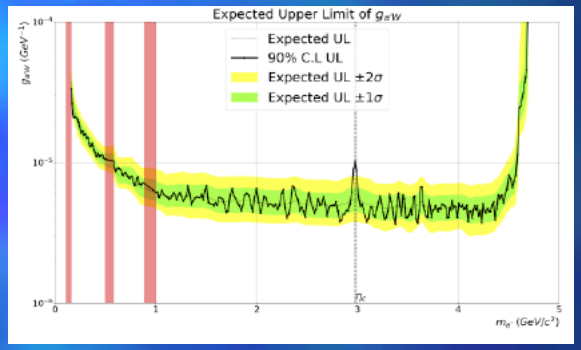
$$R(D^*) = 0.262\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.035}_{-0.032}(\text{syst})$$

- Comparable statistical precision with ¼ Belle data due to much better B tagging

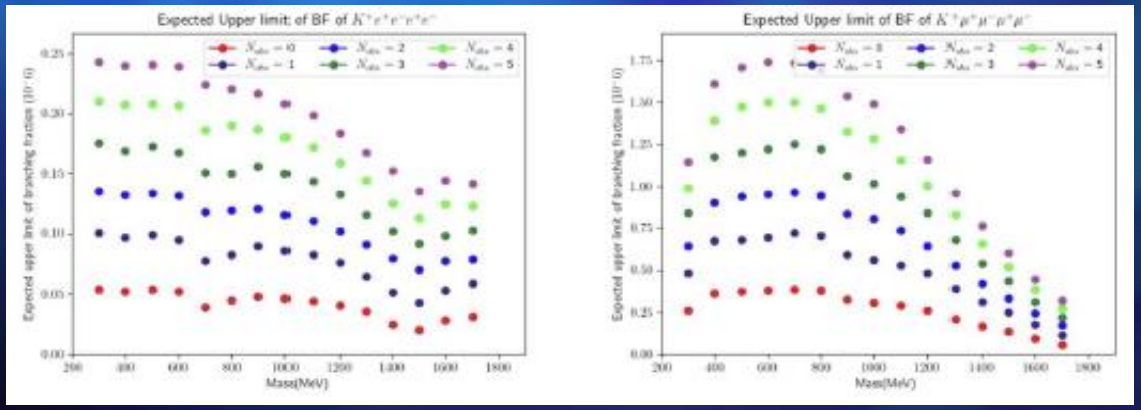
Dark Messengers at Belle II

- Search for ALP in B→K*a' (a'→γγ)





- Search for dark photon in B→K*A'A' (A'→ee,μμ)
  - Upper limits on the BR: 10^{-8}~ 10^{-6}



Yonsei U.

Korean Belle II and Future

- So many ongoing attractive analyses
- Exciting to see coming results soon by Korean group

◆ B meson decay

- LFV $B^0 \to \ell^{\pm}\tau^{\mp}$ with B2BII and FEI (김경호, KISTI)
- DS $B^+ \to K^{(*)+}A'A'(A' \to e^+e^-, \mu^+\mu^-)$ (김용규, 연세대학교)
- ALP $B \to K^{(*)}a'(a' \to \gamma\gamma)$ (조성진, 연세대학교)
- ALP $B^+ \to K^+a'(a' \to \gamma\gamma)$ (김현아, 연세대학교)
- $B^0 \to \tau^+\tau^-$ (김철훈, 한양대학교)

◆ τ^+ decay

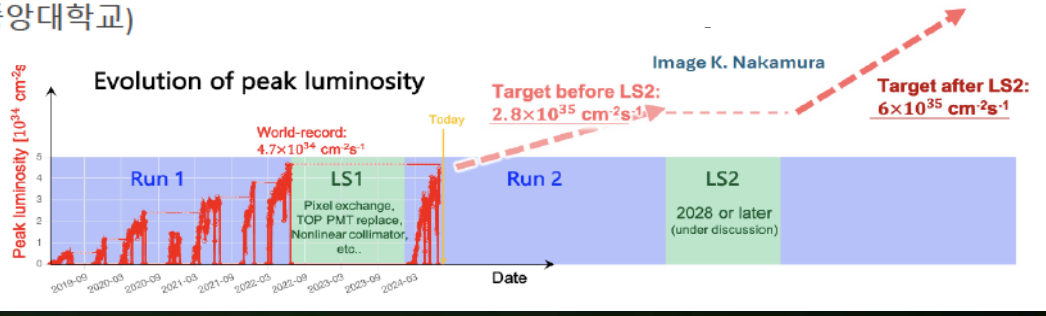
- LFV $\tau^+ \to \ell^+\pi^0$ (조한얼, 한양대학교)
- LFV $\tau^+ \to \ell^+\eta$ (이호빈, 서울대학교)

◆ D meson decay

- $D \to$ invisible with Charm tagger (김찬호, 연세대학교)
- $D^+ \to \eta\pi^+$ (김재영, 연세대학교)

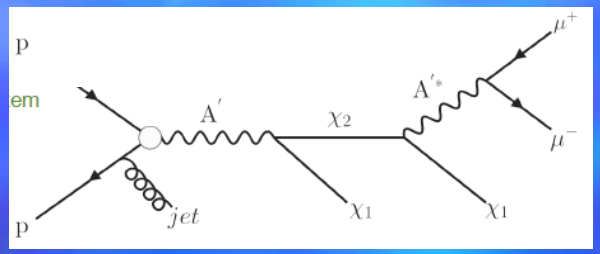
◆ Baryon-involved decay

- $\Lambda_c^+ \to pK_S^0\pi^0$ (김영준, 고려대학교)
- $X(3872) \to \omega J/\psi$, $X(3915) \to \omega J/\psi$ (안용헌, 고려대학교)
- $X(3872) \to J/\psi\,\pi^+\pi^-$, $J/\psi\,\rho(\to \pi^+\pi^-)$ (장은지, 중앙대학교)



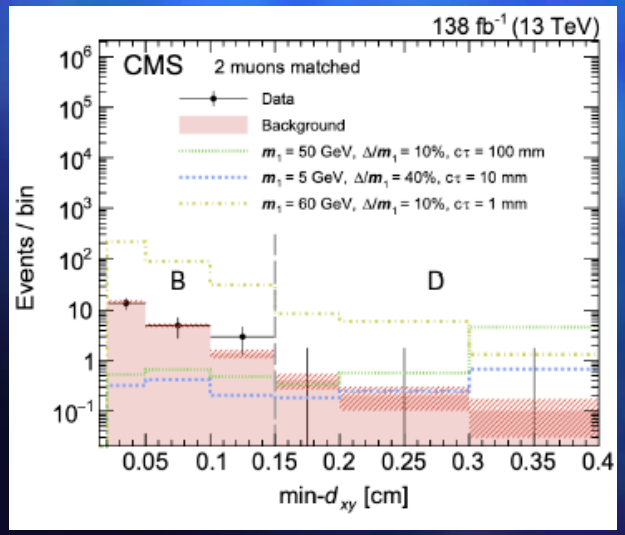
Dark matter at LHC

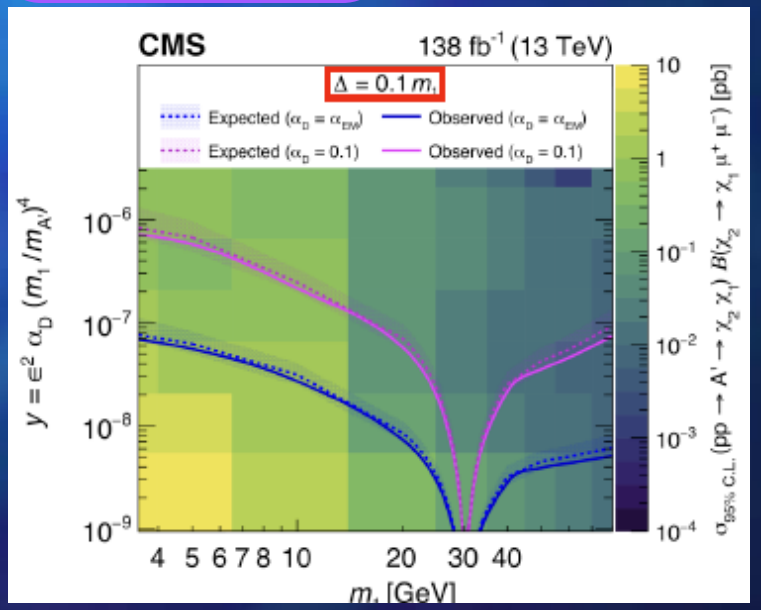
- Events with dark photon, two closely-massed state $\chi 1$ and $\chi 2$
- Search for dark matter using displaced two muons with large MET
- Set the limit on m($\chi 1$) and interaction strength



PRL 132, 041802 (2024)

Kyungpook U.

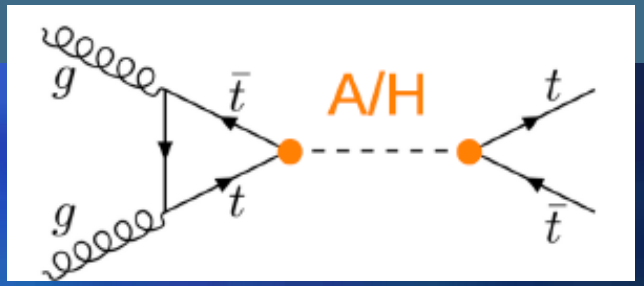


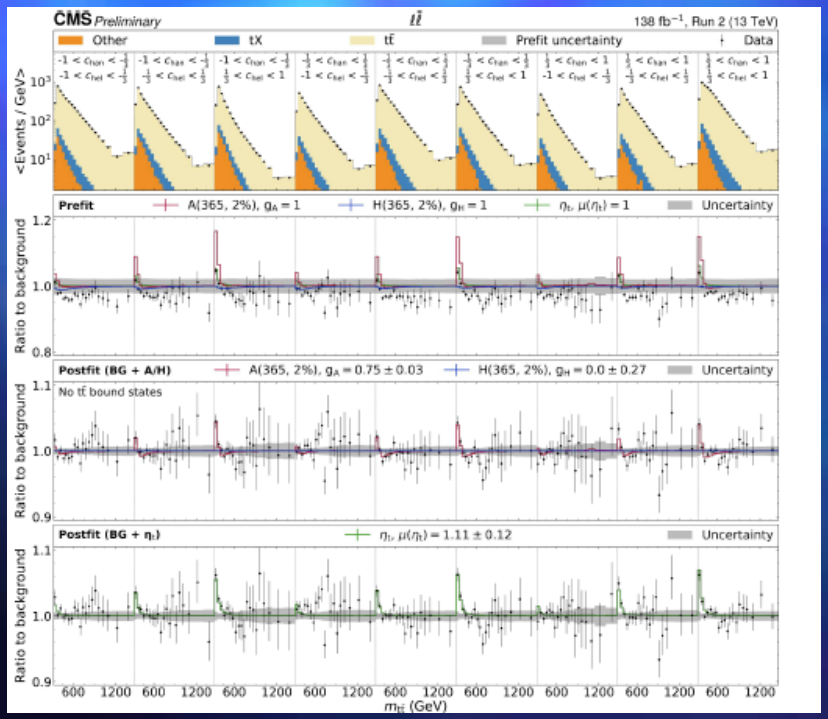


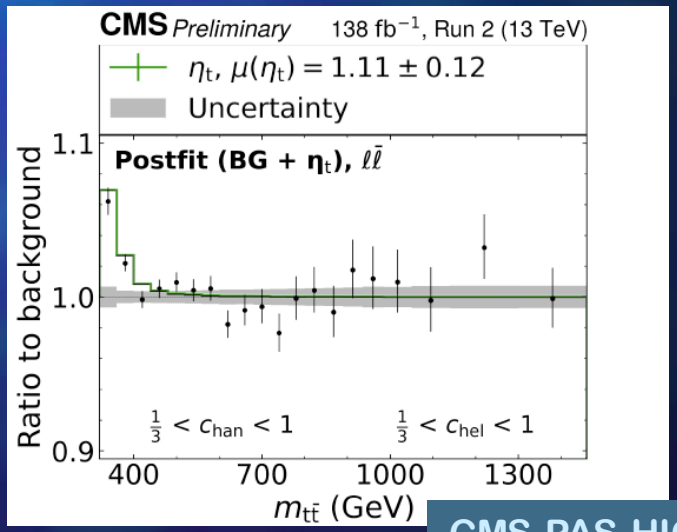
Search for heavy boson

- Search for a resonance in top pair in 1 or 2 leptons channels using M_{tt} and spin correlation observables
- A large excess (>5σ) observed near the tt threshold
- Compatible with tt bound state

  (~7.1 pb with 11% uncertainty)



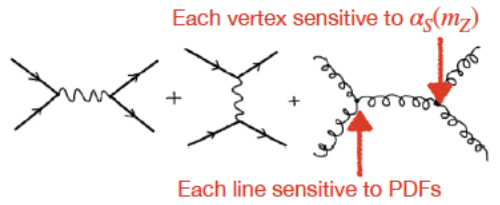


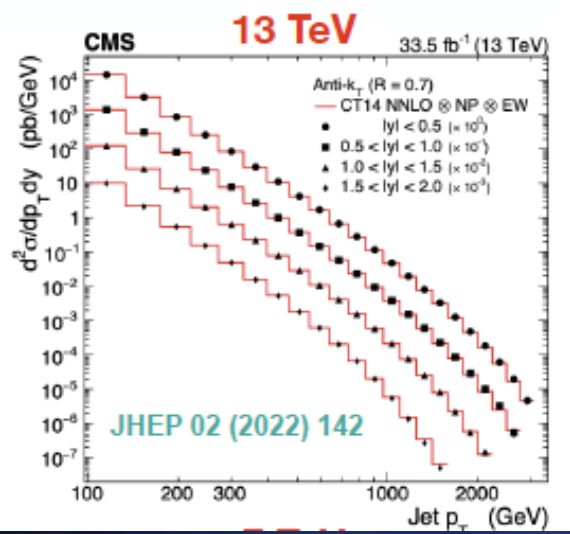


CMS-PAS-HIG-22-013

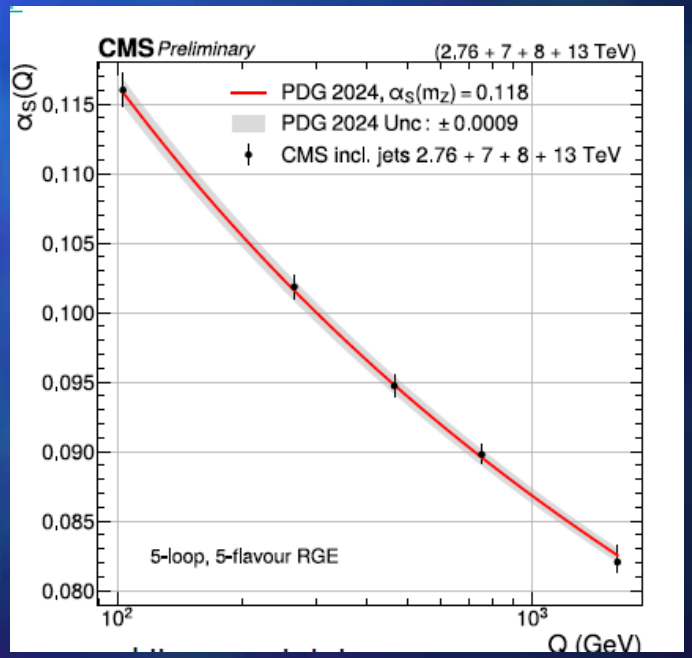
Running Coupling at TeV scale

- Probe α_s up to TeV scale using inclusive jet cross section
- Extract α_s TeV scale in different p_T region
- Good agreement up to 1.6 TeV



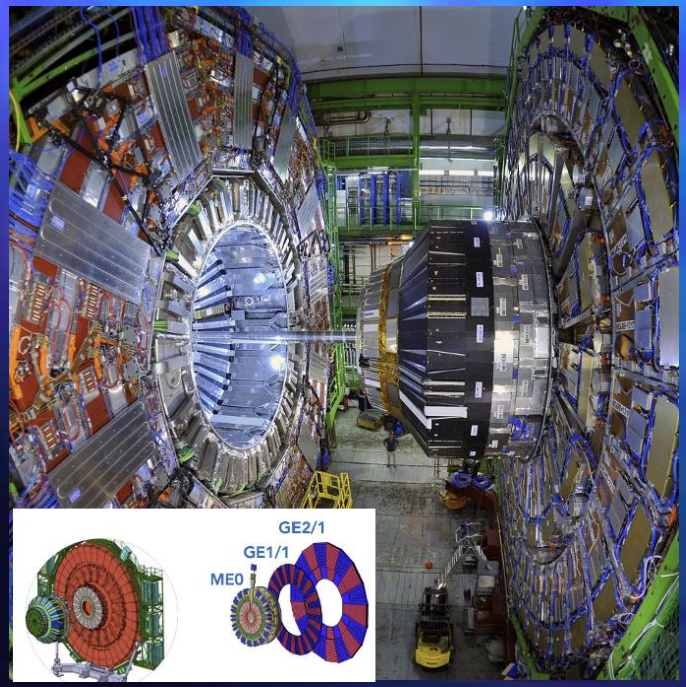


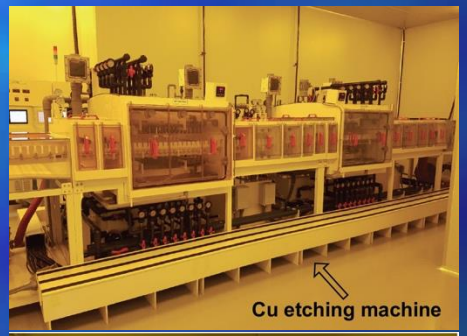
CMS-PAS-SMP-24-007



GEM Detector

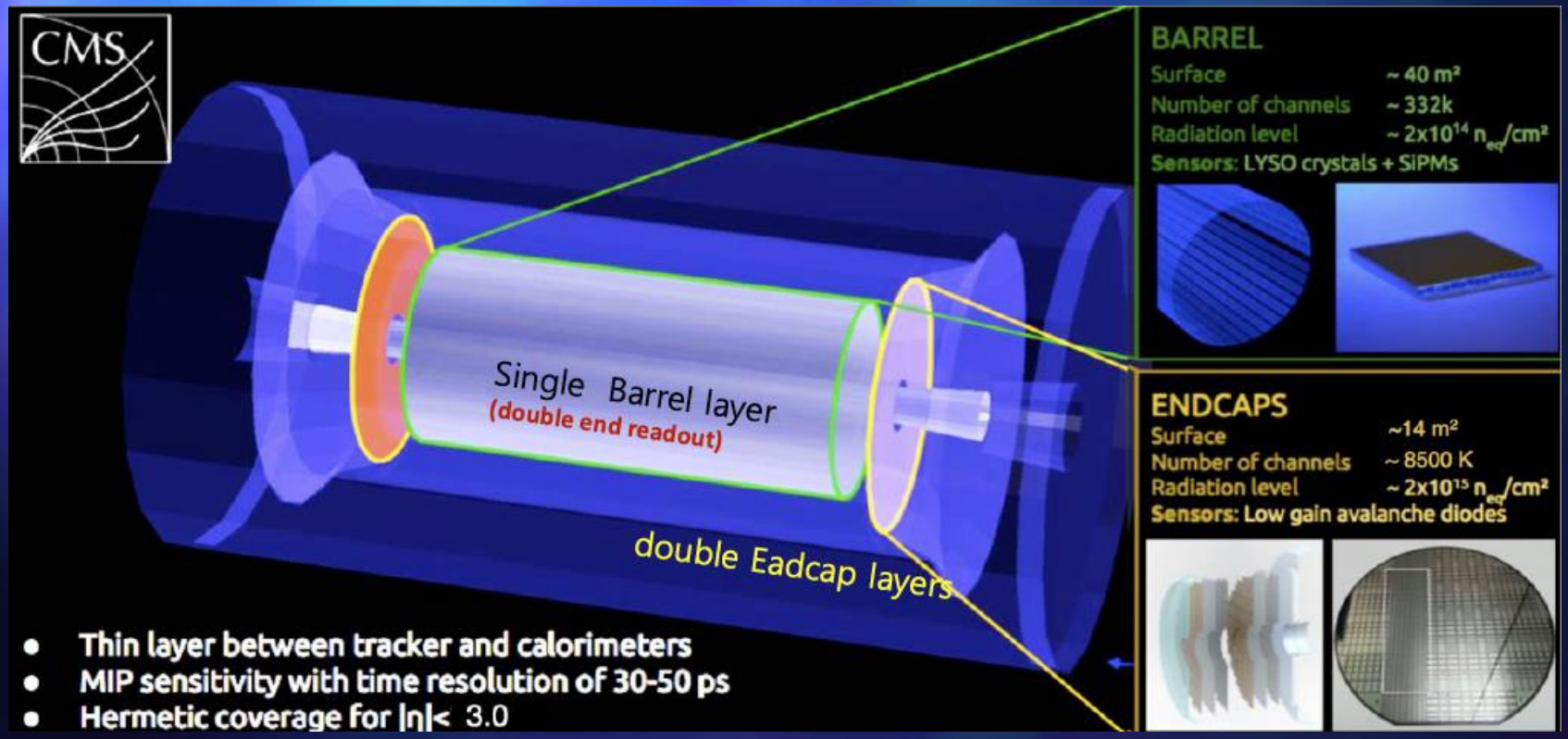
- GEM Foil Production
  - 350 ME0 GEM foils produced at IBS by Oct 2024,
  - Will be completed by 2025 (~660 foils)
- ME0 GEM detector will be installed in 2026





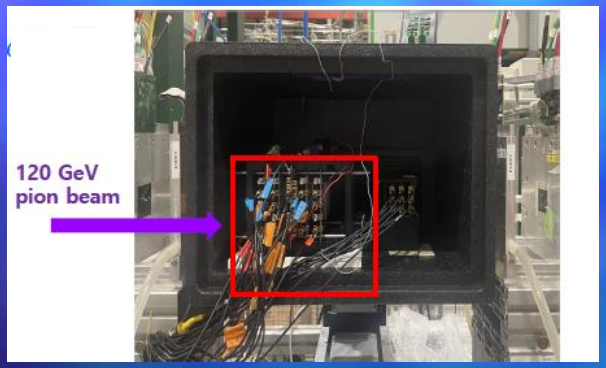
MTD Detector

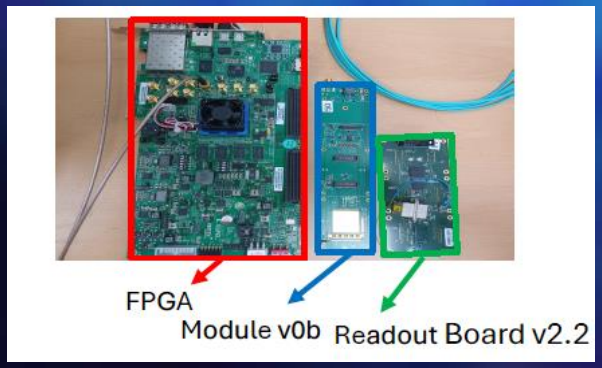
- MTD (MIP Timing Detector): 30~50ps timing resolution to remove extra pp interactions
  - BTL: crystal scintillator + SiPM readout
  - ETL: silicon based sensor (LGAD)+ASIC readout (25% by KCMS)

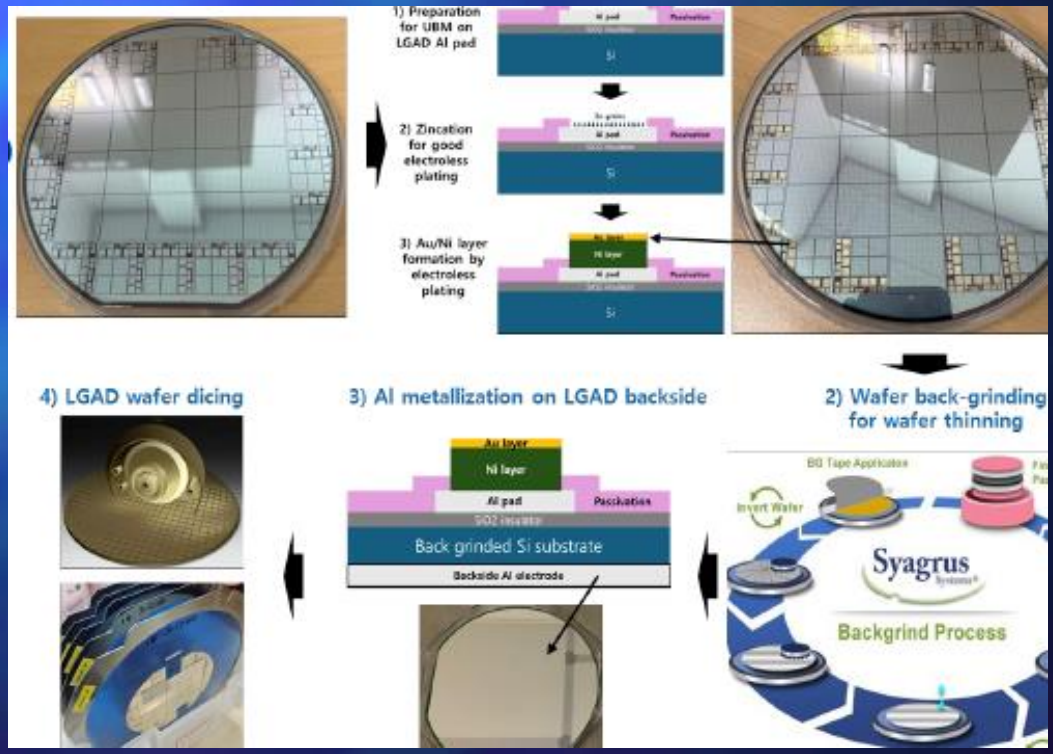


MTD Detector

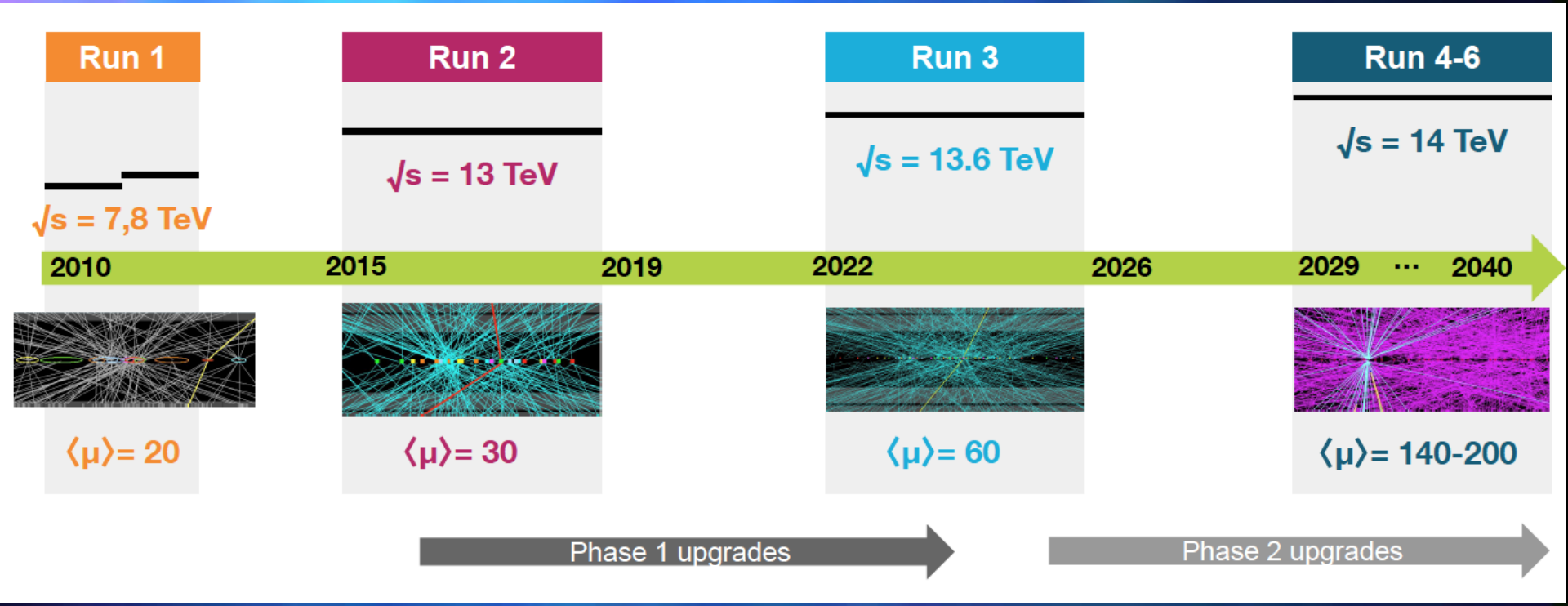
- Beam test at CERN: 35ps timing resolution achieved
- Built up the timing test setup in Korea
- R&D for wafer postprocessing in Korea
- Bump-bonding test with dummy chips





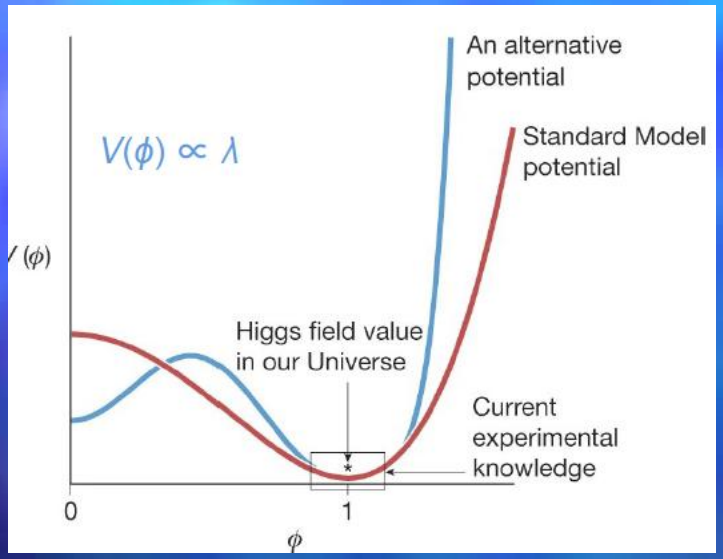


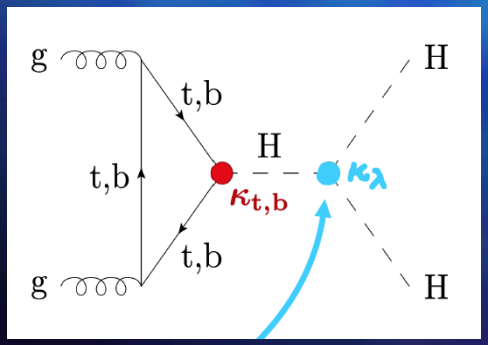
Present and Future of LHC

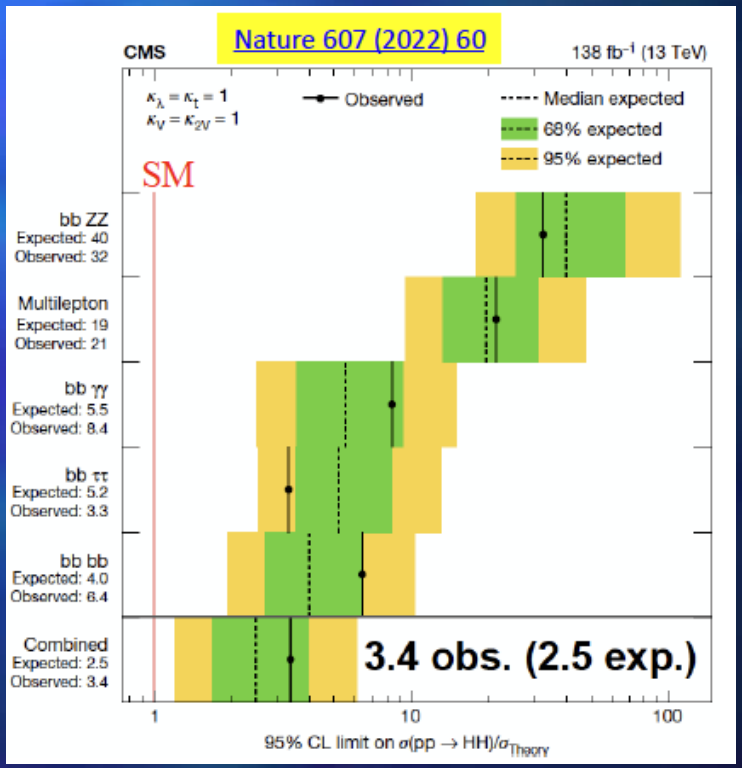


Can be the BSM Higgs world?

- Unstable Higgs mass, stability of our vacuum depending on Higgs potential

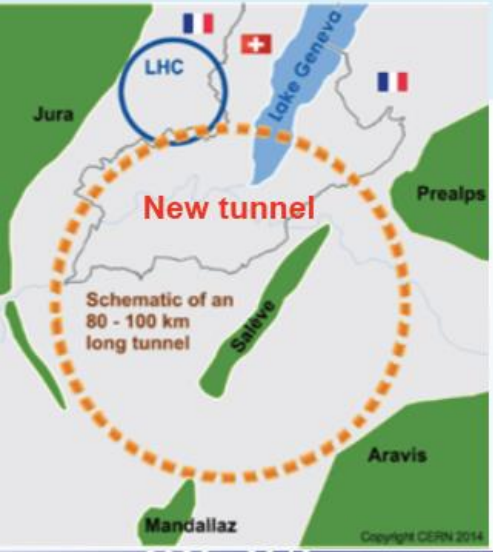




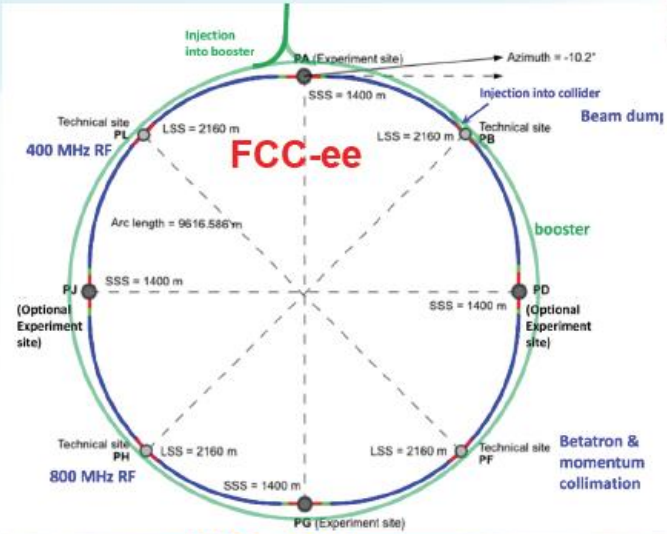


Future Collider

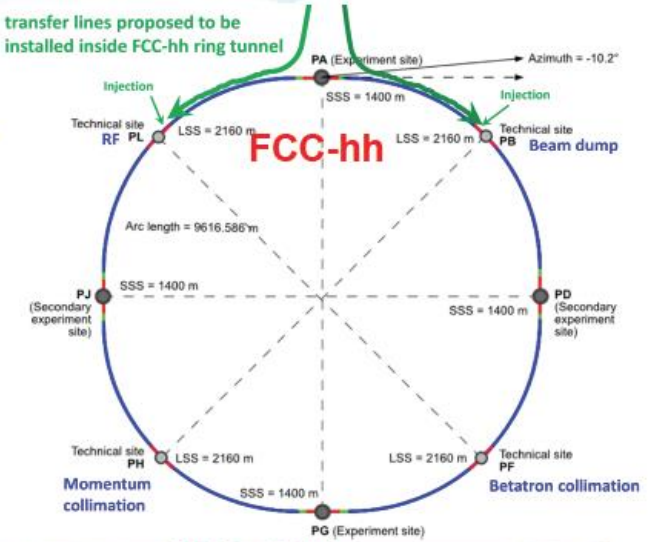
- More Sensitivity, more Precision, more Energy
  - Highest luminosity
  - Highest parton energy
  - Synergy between lepton and hadron colliders



2020 - 2040



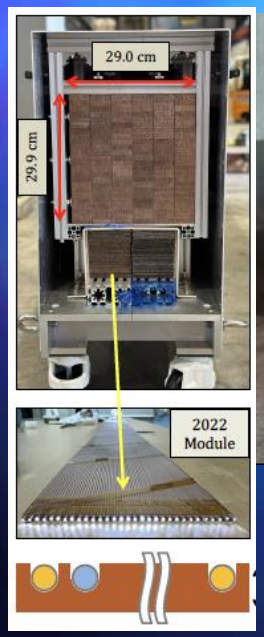
2045 - 2060

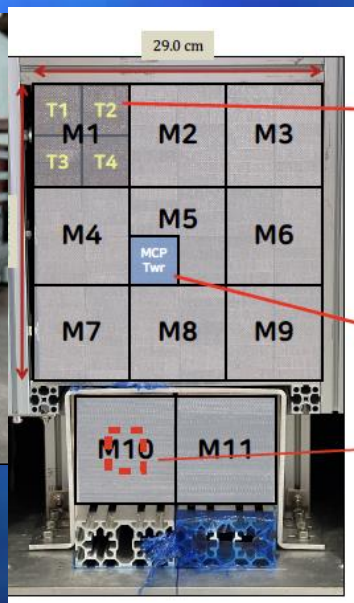


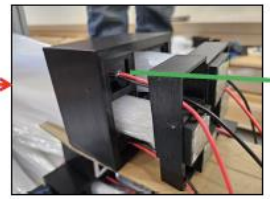
2065 - 2090

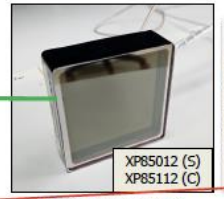
Dual-Readout Calorimeter (DRC)

- High-quality energy measurement of both e/γ & hadrons:
  - EM fraction in hadronic shower can be measured
- Korean group (8 institutes) does all aspects of the DRC R&D
  - Module building, electronic & DAQ system, GEANT studies
  - Test-beam experiments and performance studies









MCP-PMT (talk J2.07)

- The DRC module is divided to '**tower**' unit, each tower is bundled to single readout channel. (Square type PMT, Hamamatsu R11265-100)
- On M5-T3, **MCP-PMT** is attached, which provides high granularity, dividing single tower into 64 channels. (XP85012, XP85112)

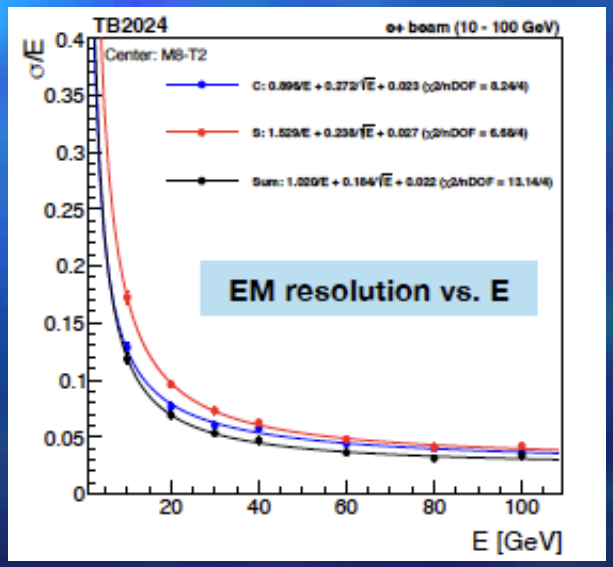
S-ch: 200
C-ch: 200
on the center of M10

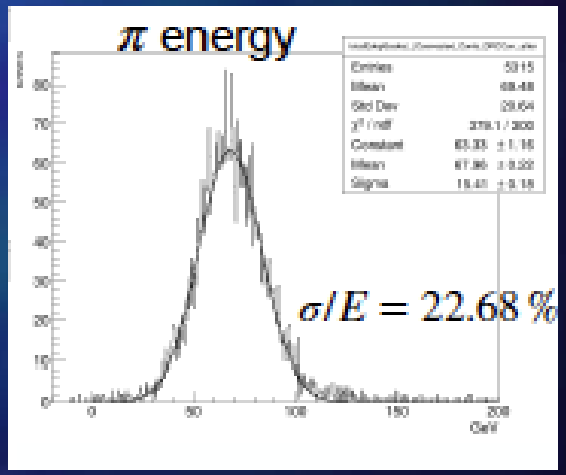
Module Building ('24)

Electronics

DRC Test Beam at CERN SPS

- Good results are obtained
  - EM energy resolution: $\sigma/E \sim 1.020/E + 0.184/\sqrt{E} + 0.022$
  - Pion energy: $\sigma/E \sim 22.68\%$
- Research activities for FCC were expanded for EIC

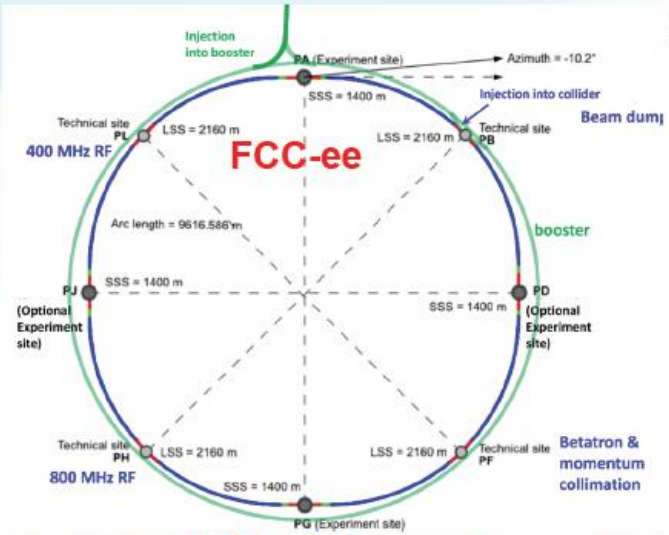




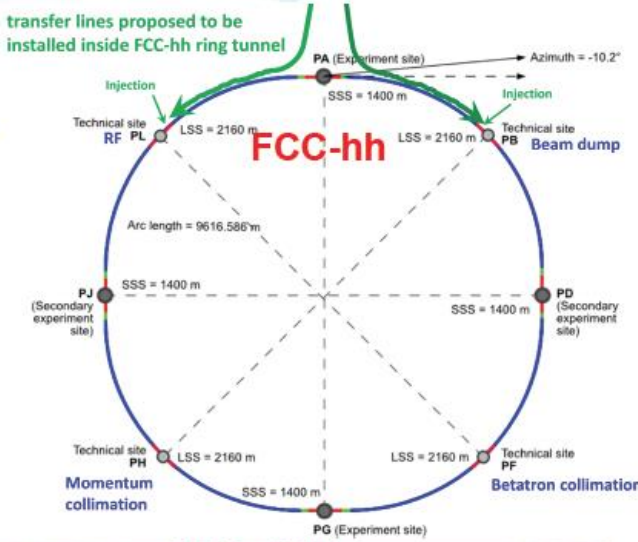
Future Colliders at Energy Frontier

- More Sensitivity, more Precision, more Energy
  - Highest luminosity
  - Highest parton energy
  - Synergy between lepton and hadron colliders
- FCC (or CEPC) is the only option? 50 yrs from now?

2020 - 2040



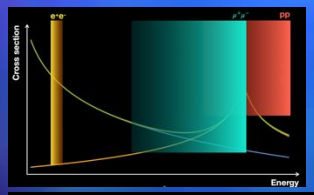
2045 - 2060

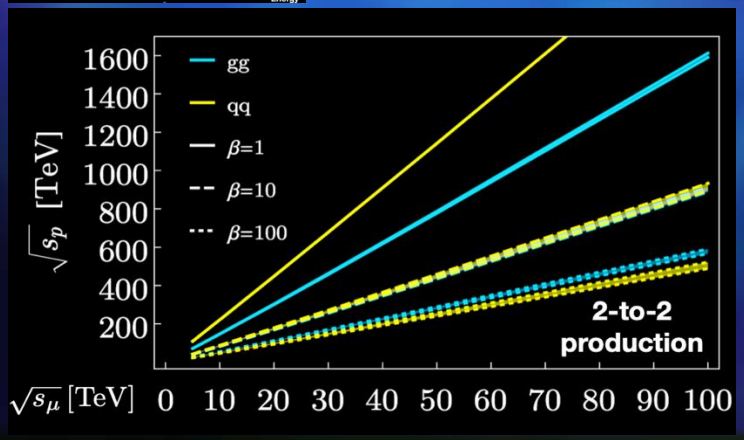


2065 - 2090

Muon Colliders at Energy Frontier

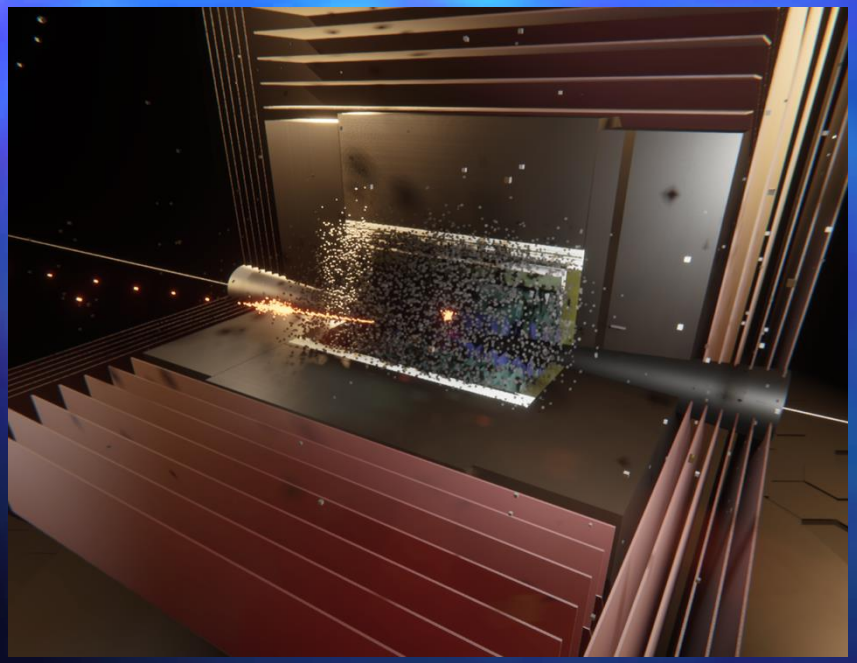
- 10 TeV mu collider: equivalent to 100 TeV pp collider
- Can be realized before 2050 with less money?
- More thrilling project?

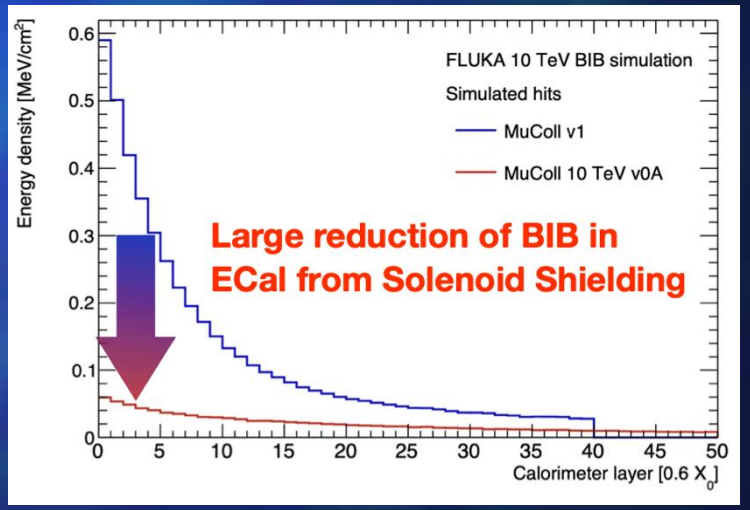




Muon Colliders at Energy Frontier

- Muon beam cooling
- Detector: huge beam induced bkgd (BIB) radiations from n,γ,e and even ν





Summary & Discussions

- Both LHC and Belle II experiments have done much better than expected in understanding detectors and analysis techniques
- We have verified the Standard Model and have searched for new physics at the Energy Frontier and Intensity frontier, but no new physics evidence
- LHC and Belle II started new runs, we will continue our exploration to look for physics beyond the SM
- How can we do better at present and future?
- And how shall we prepare our future?