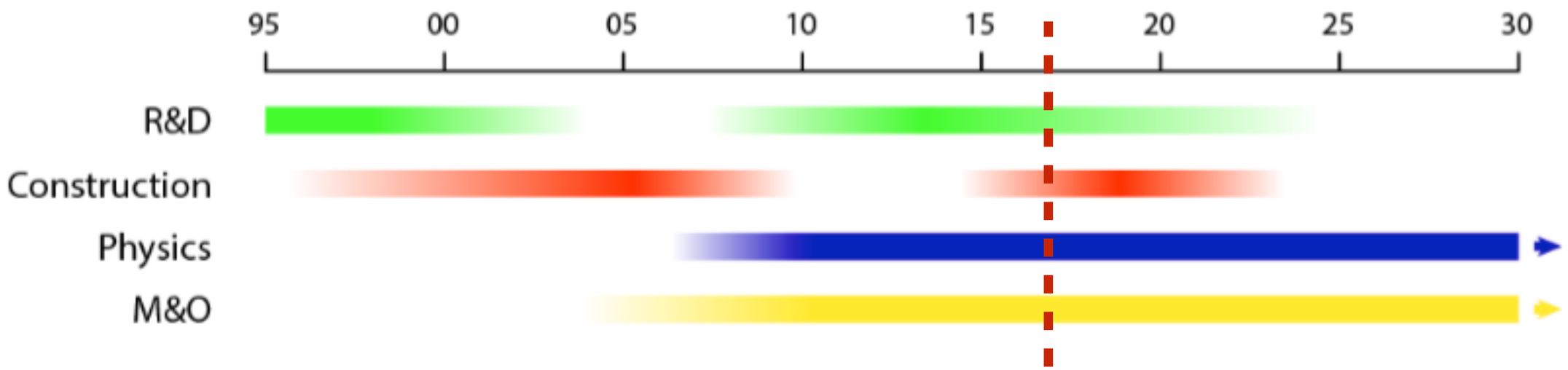
CMS Status & Upgrades

Jim Brooke - for CMS UK

PPAP community meeting, 27 July 2016

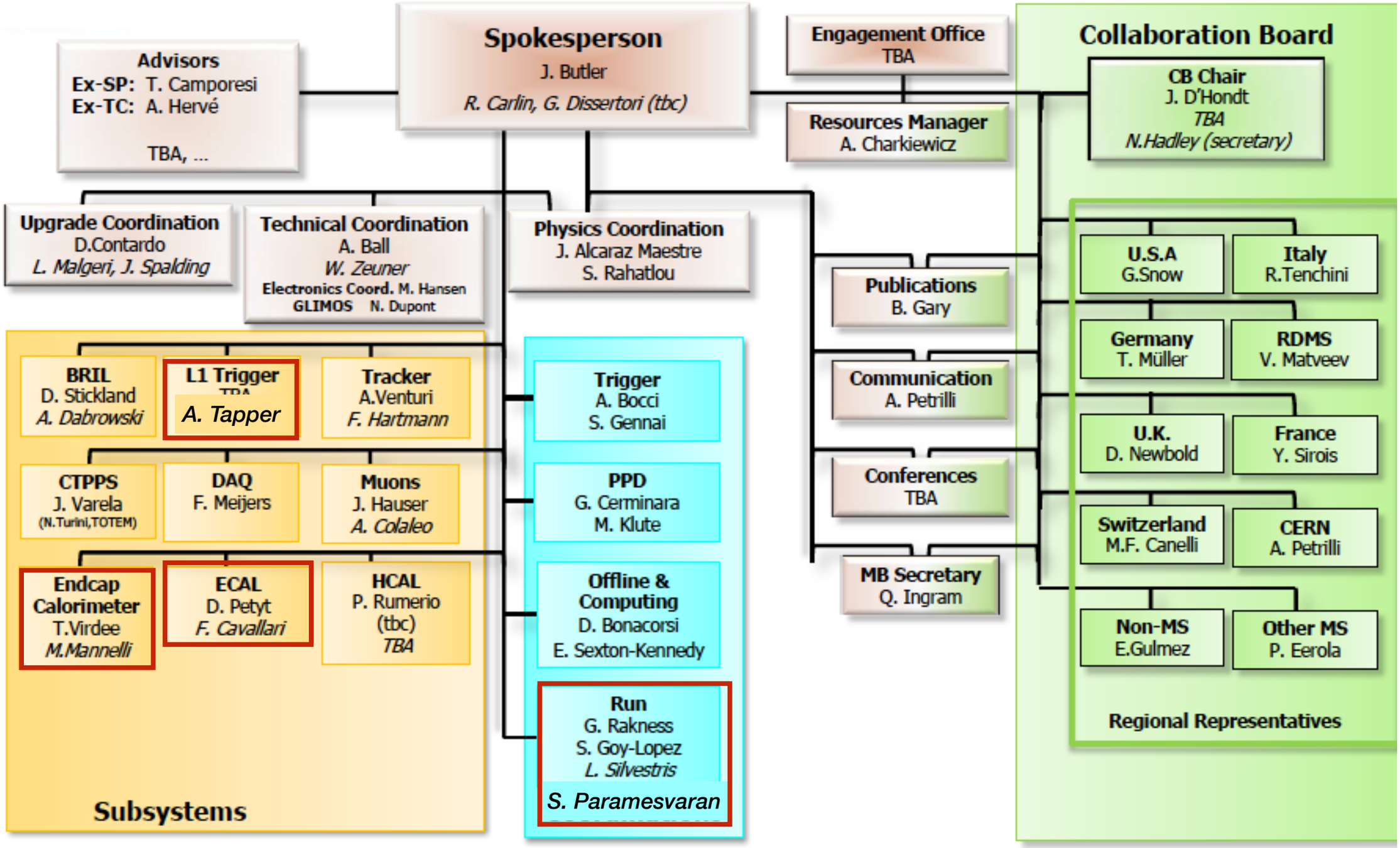
Where are we ?



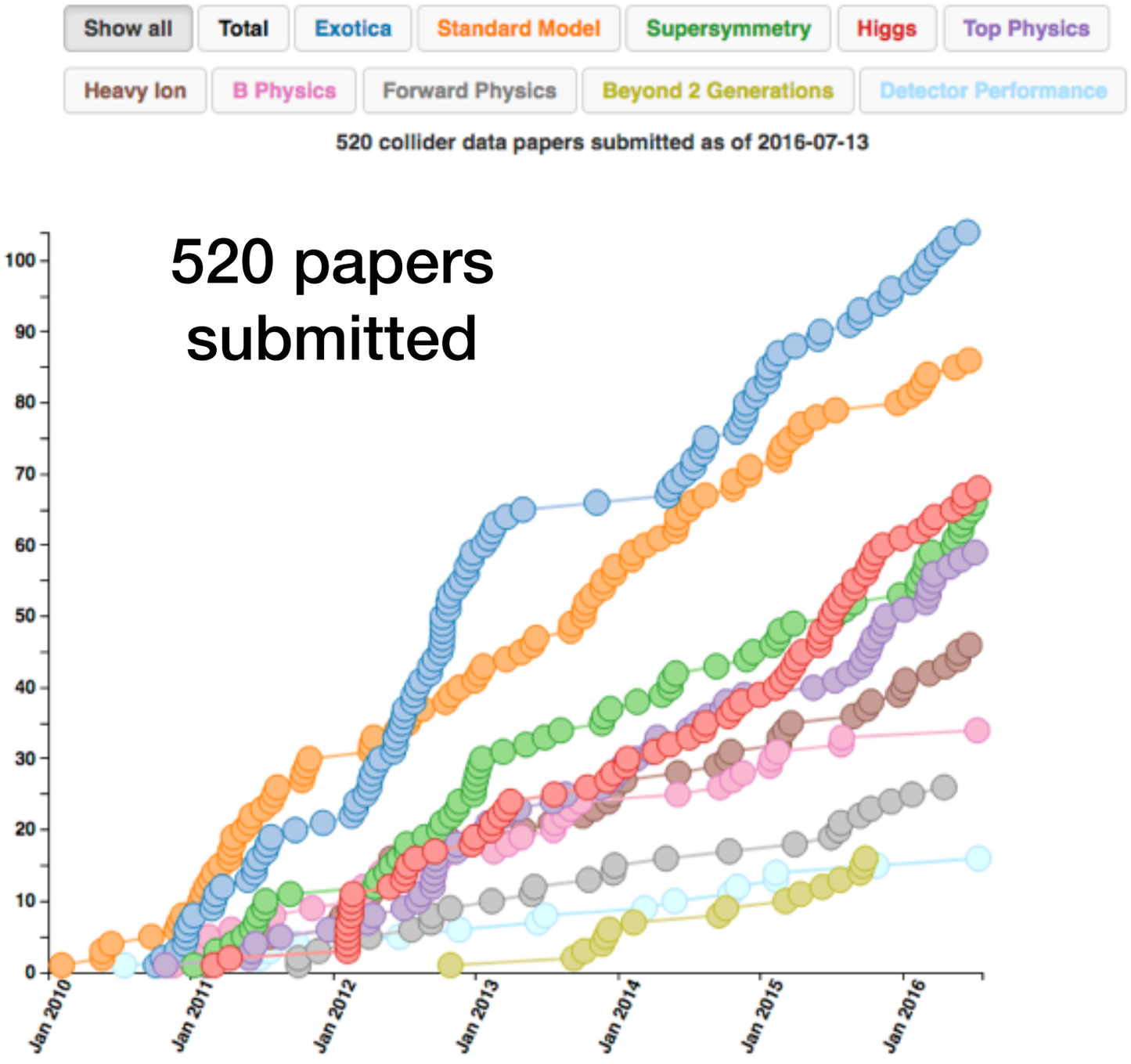
- **Run2 remains potentially *the* crucial era in the LHC programme**
  - Great potential for discovery at 13 TeV
  - Detectors commissioned, techniques well understood; conditions stable

- **However, we are entering a new phase**
  - R&D and construction required in parallel with operations & exploitation

CMS Organisation

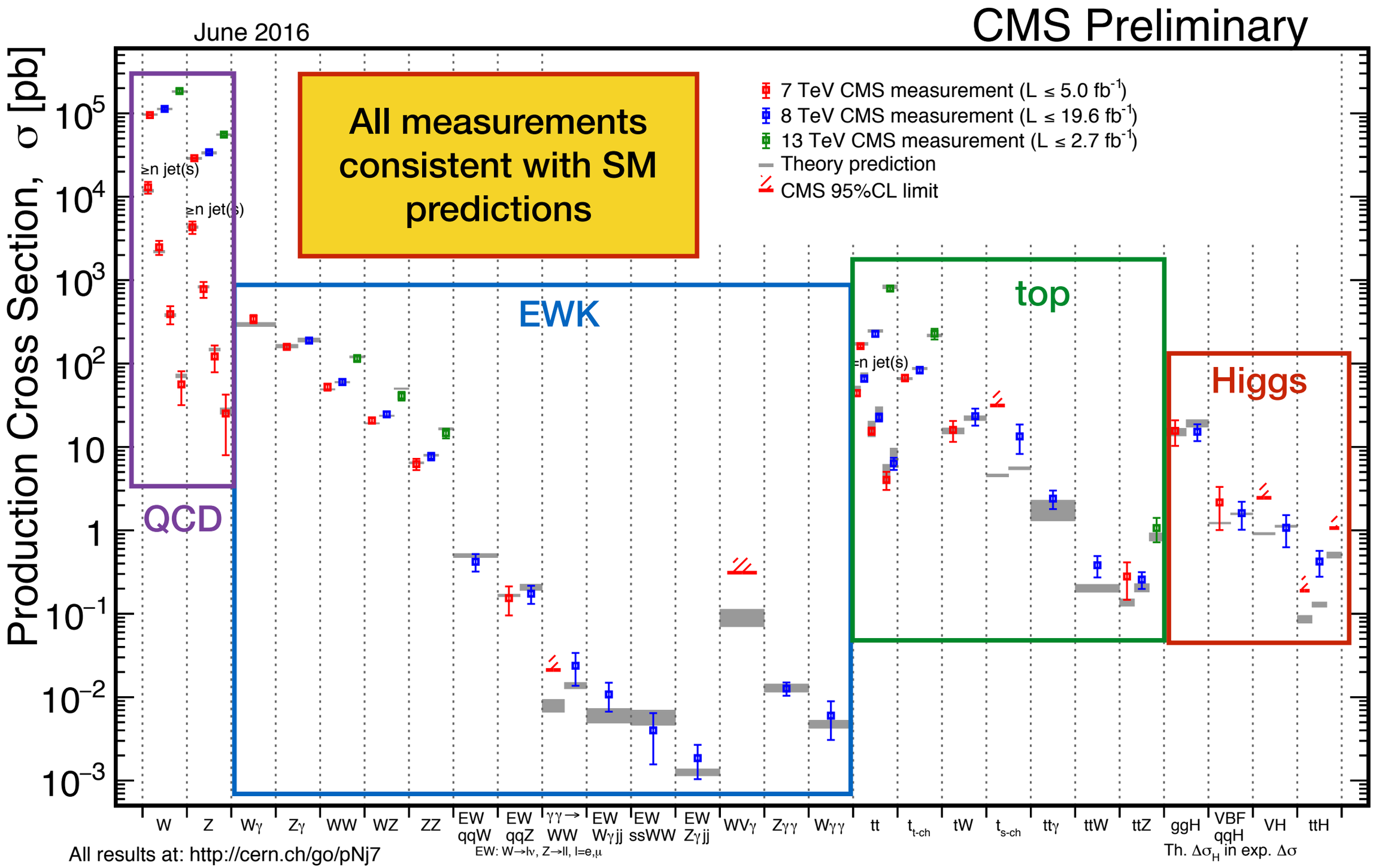


Publications

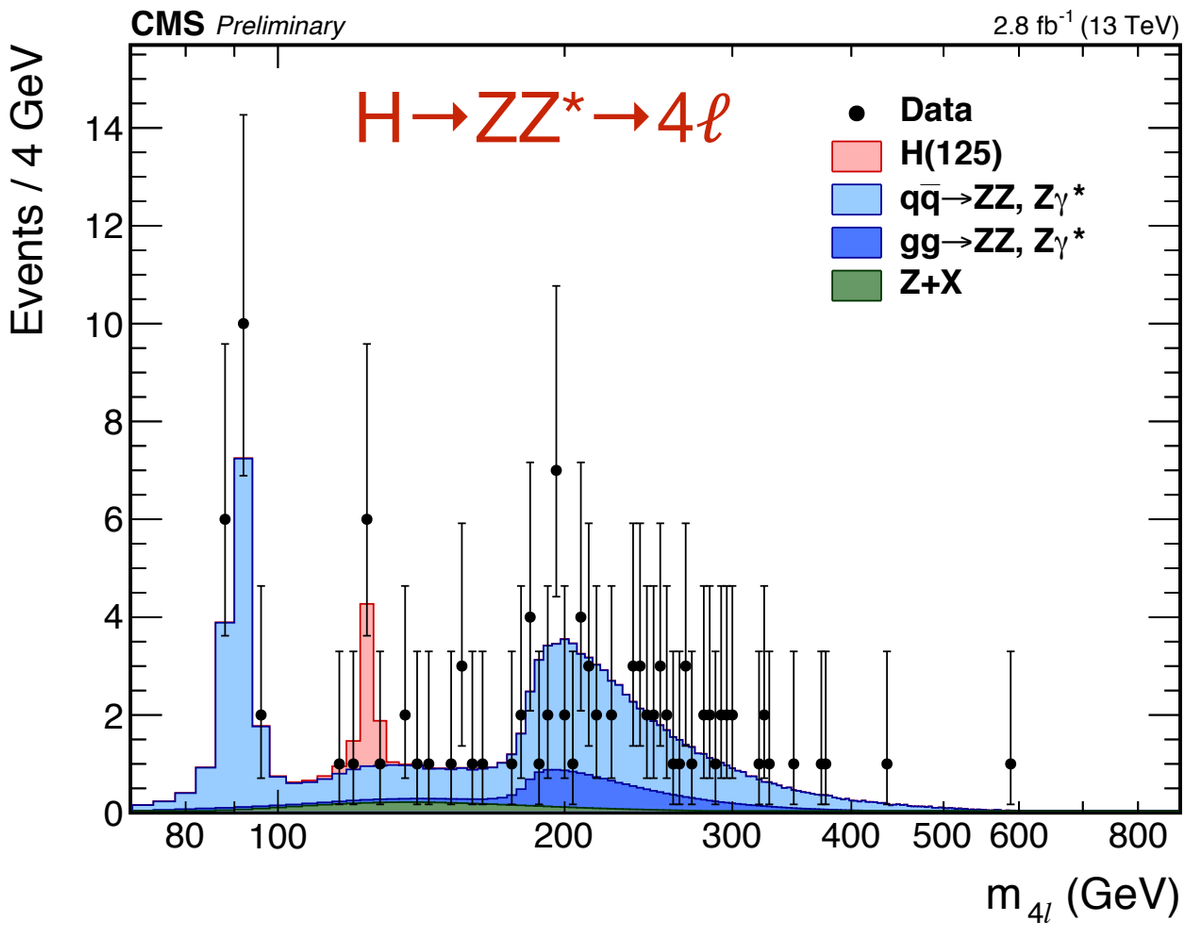


http://cms-results.web.cern.ch/cms-results/public-results/publications/

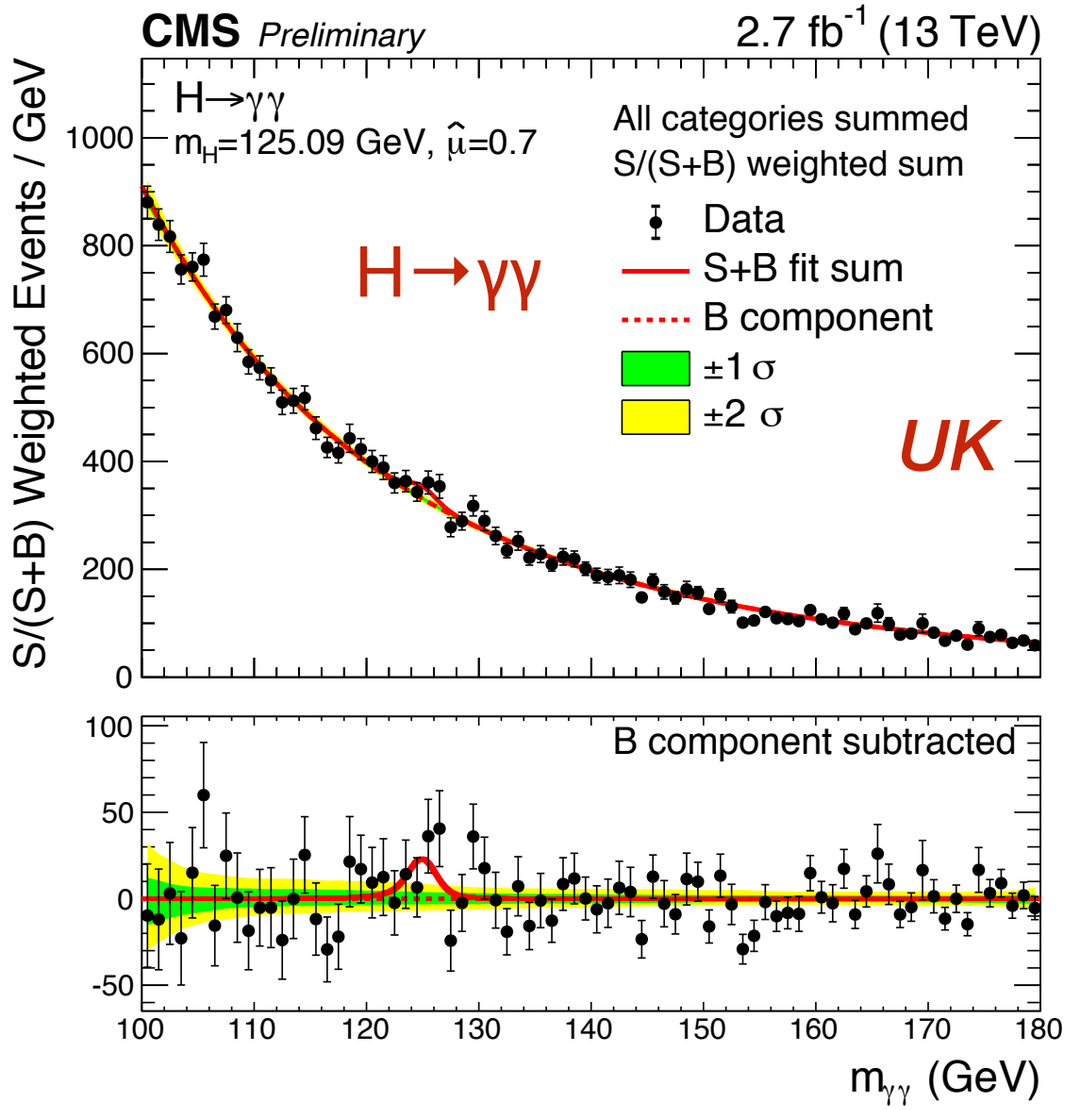
Physics at 13 TeV : SM



Physics at 13 TeV : Higgs



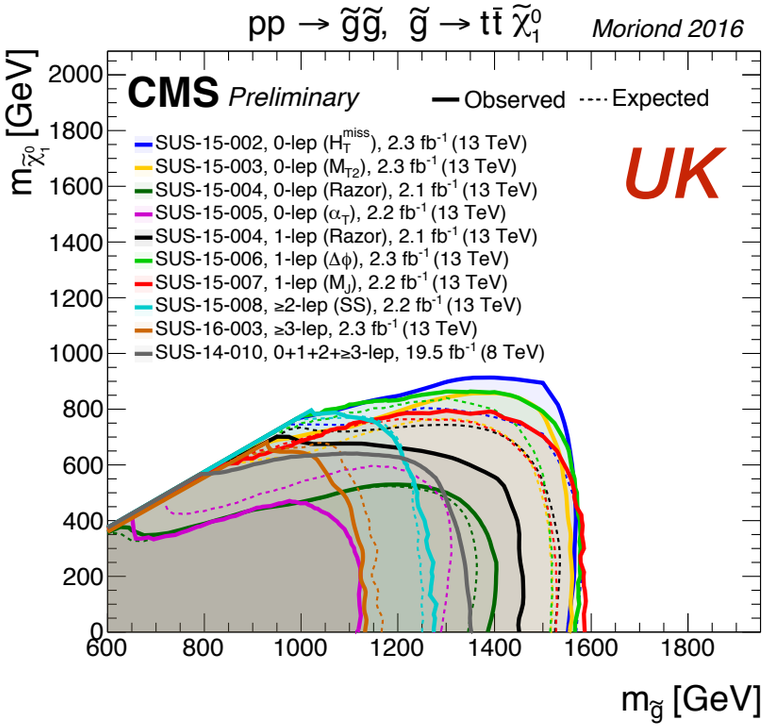
2015 dataset

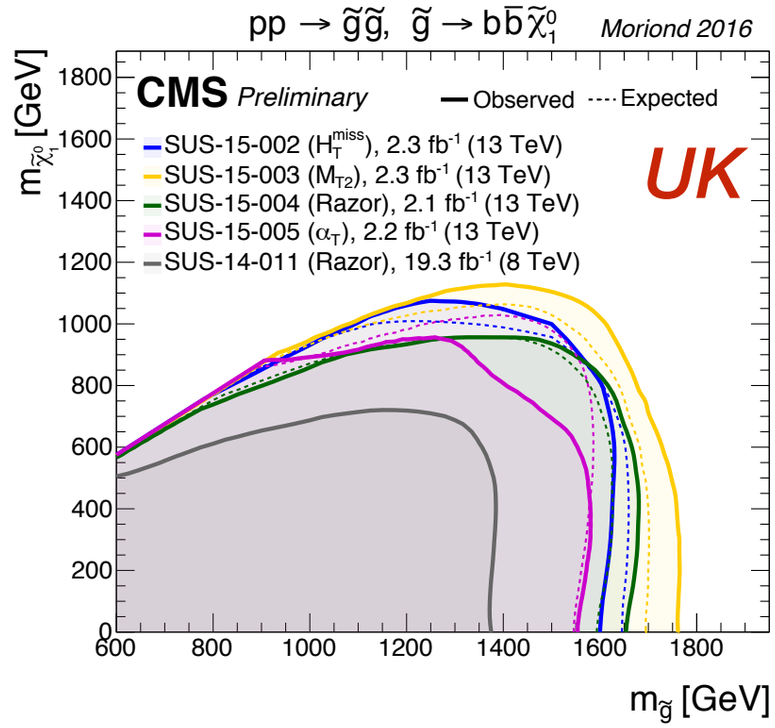


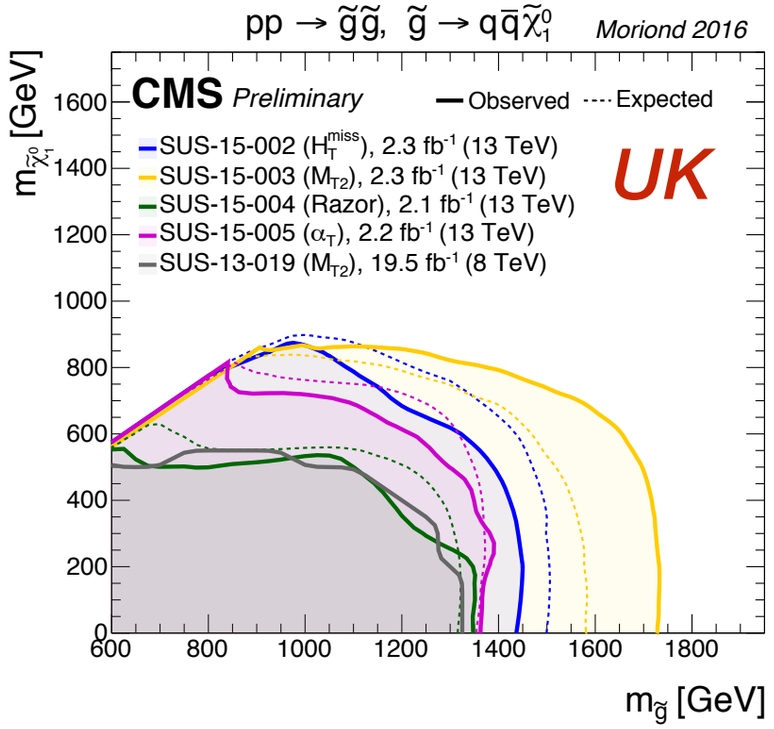
- Anticipate transition to focussed precision measurements in future
- Fewer incremental updates

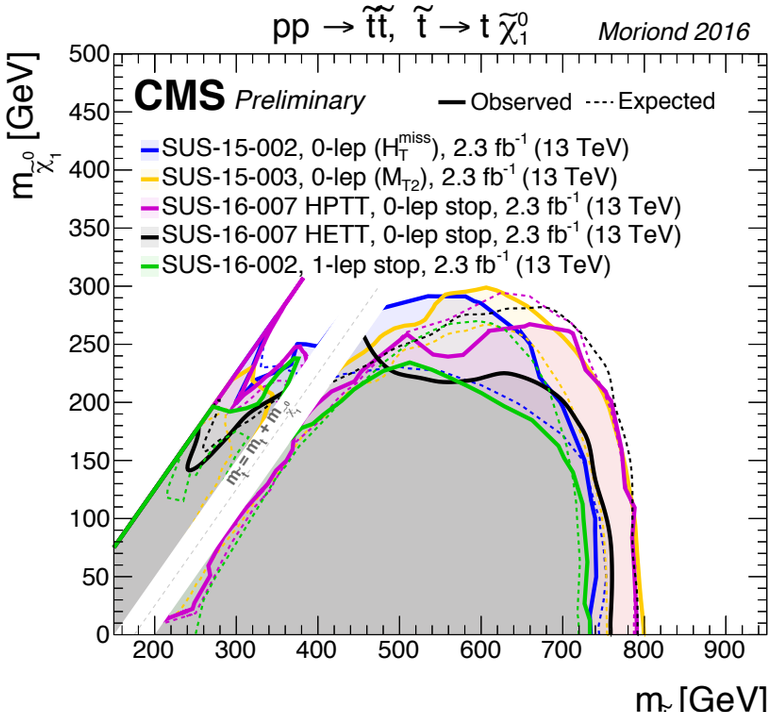
Physics at 13 TeV : SUSY

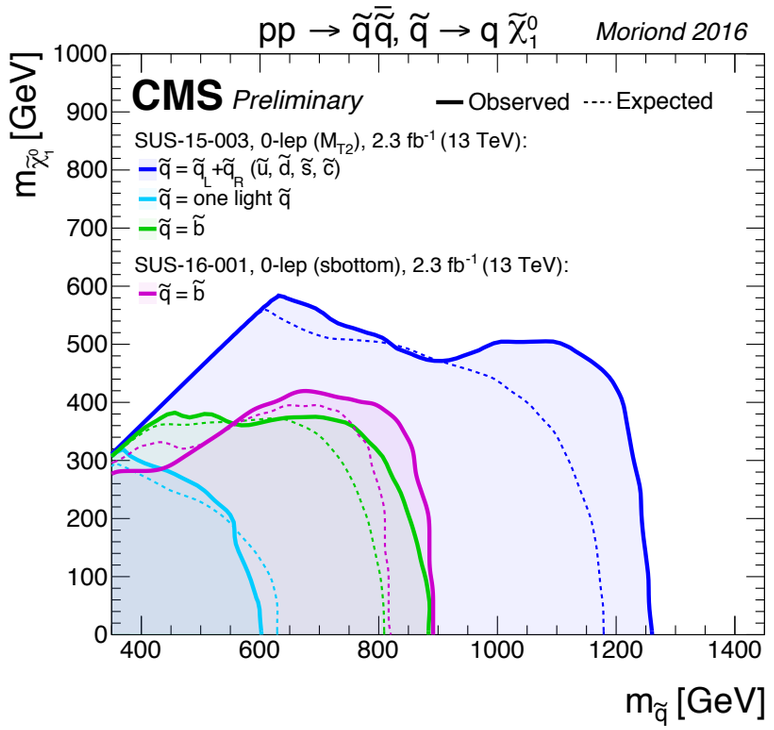
- 2015 dataset
- Significant increase in sensitivity with ICHEP dataset





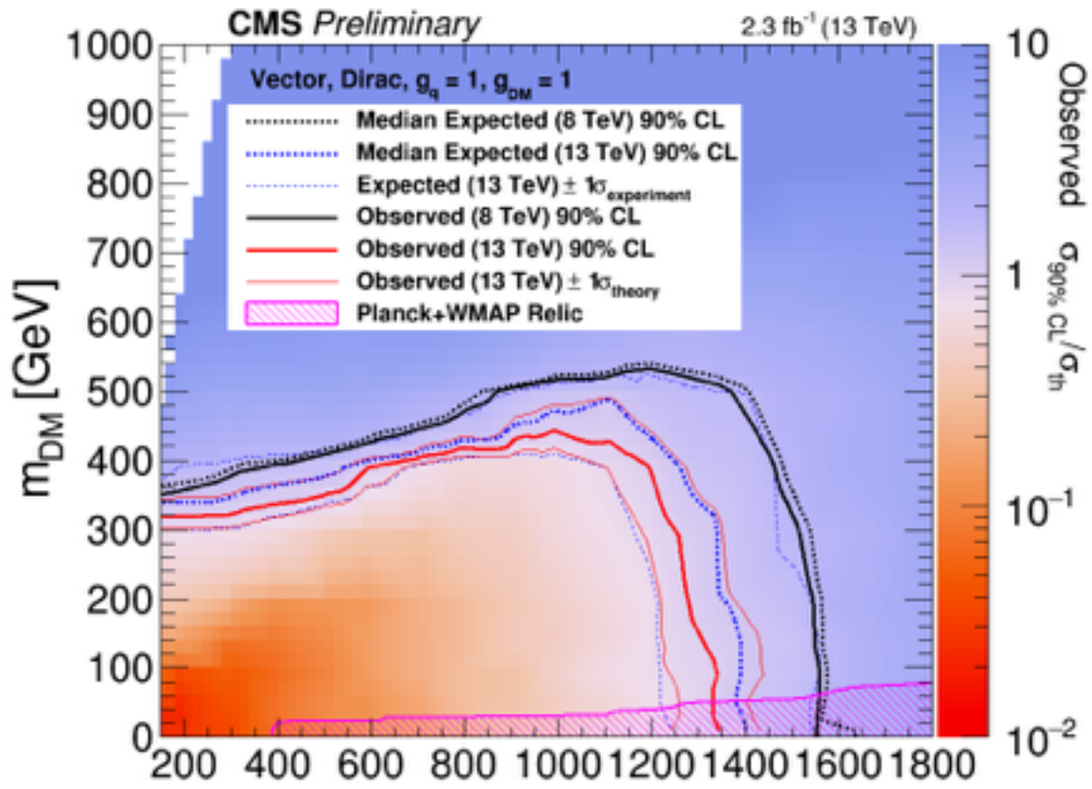




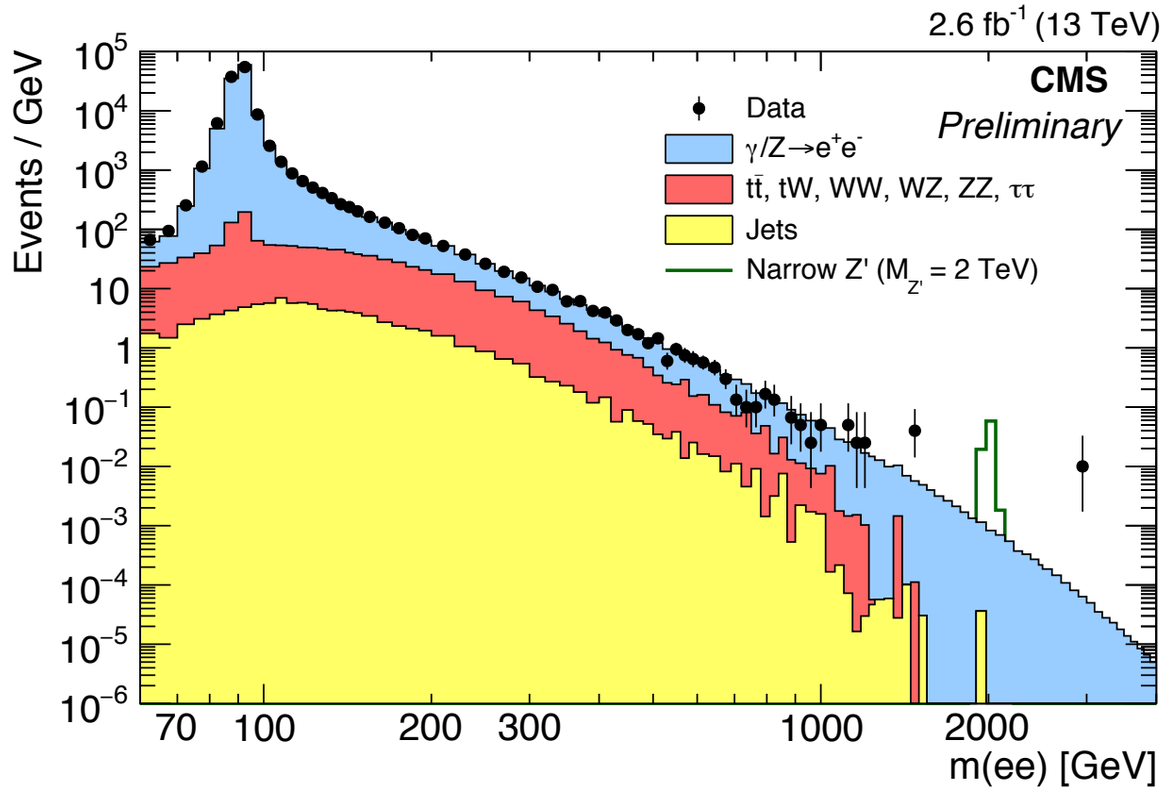


Physics at 13 TeV : Exotica

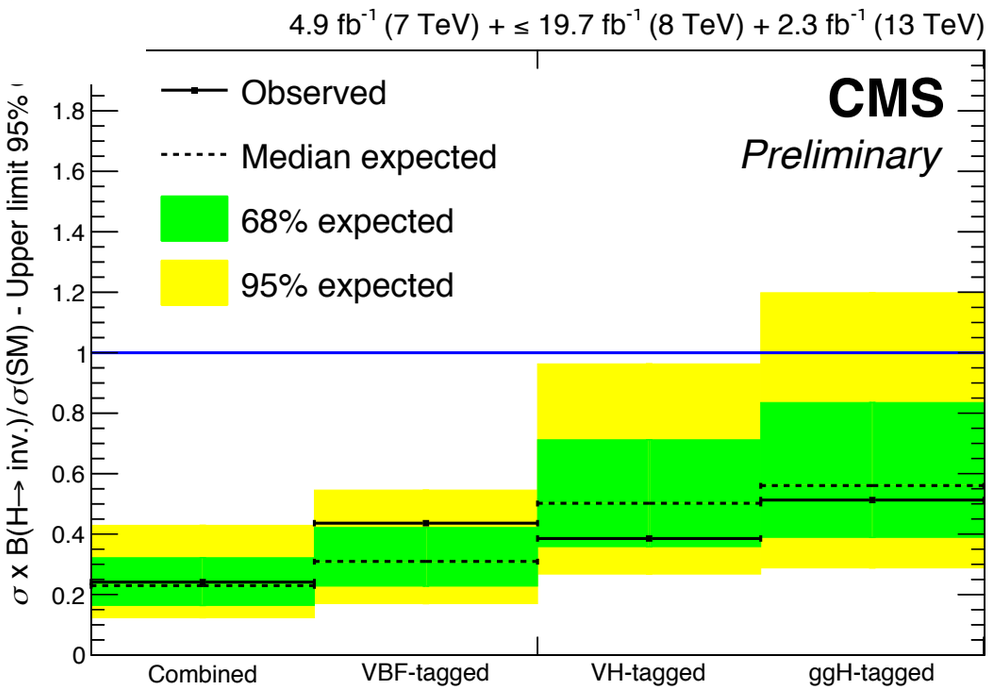
UK



pp→DM+jet(s)

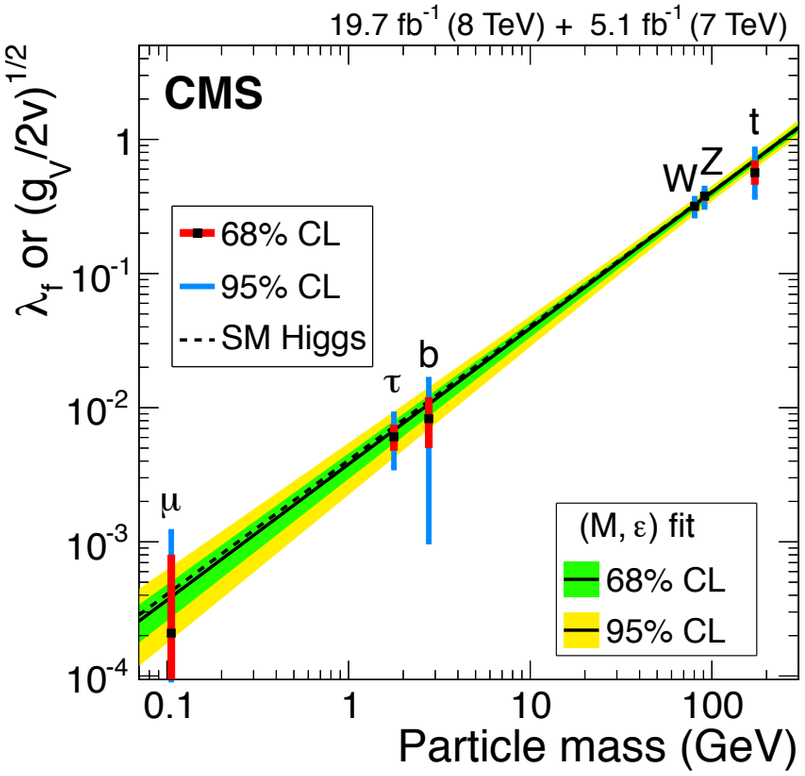


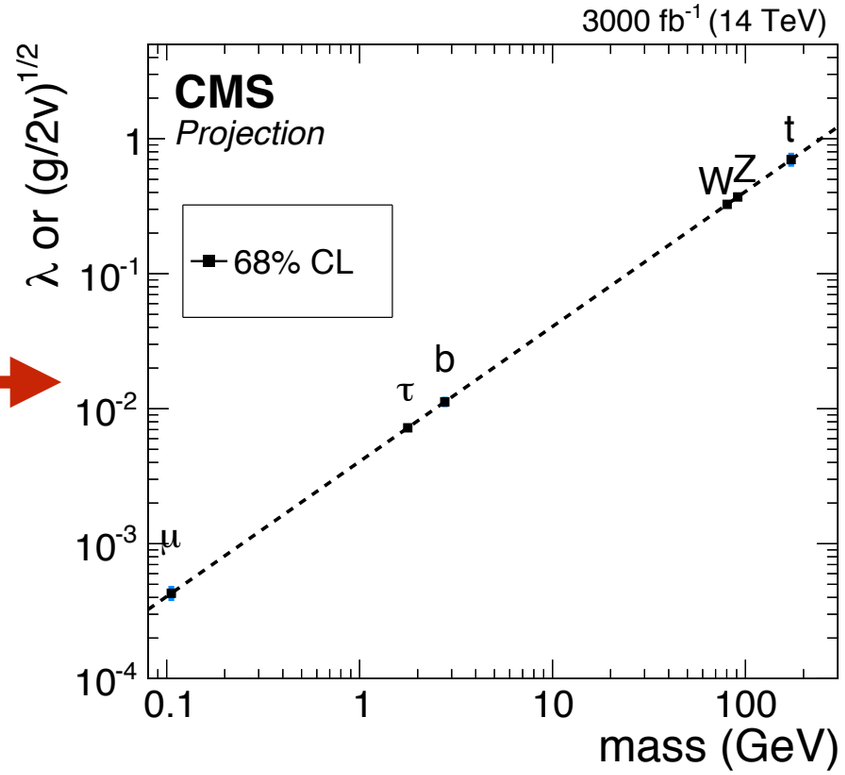
Z'→ee



H→inv

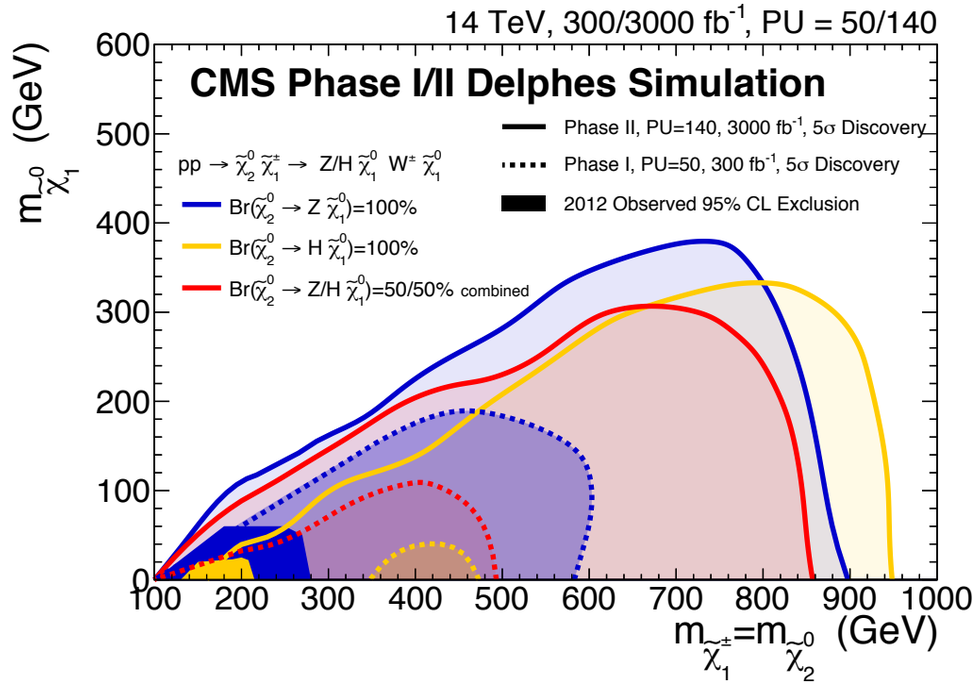
Prospects - 3000fb^{-1}

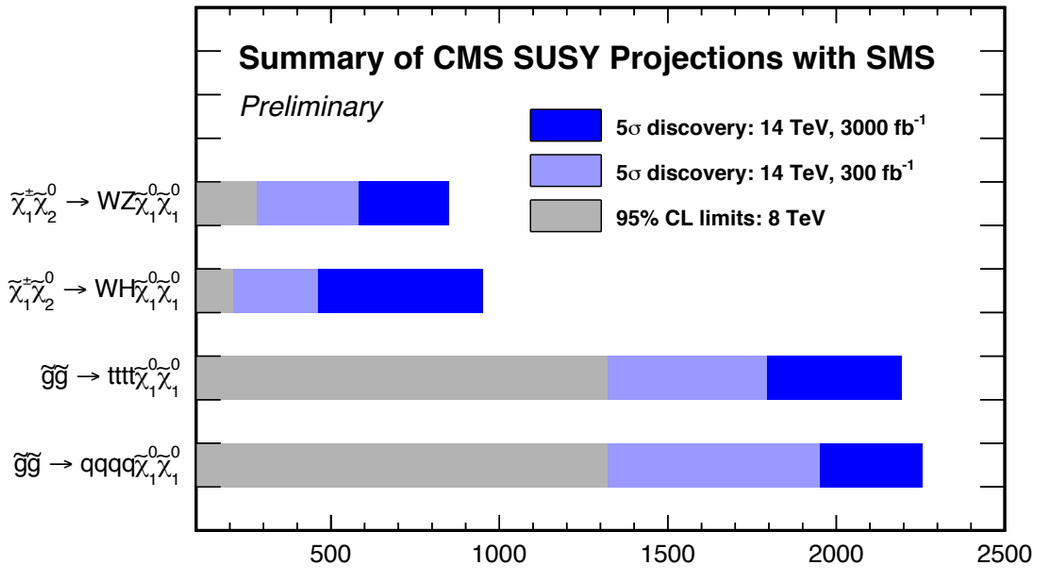




HL-LHC Higgs factory
Precision measurement of Higgs couplings

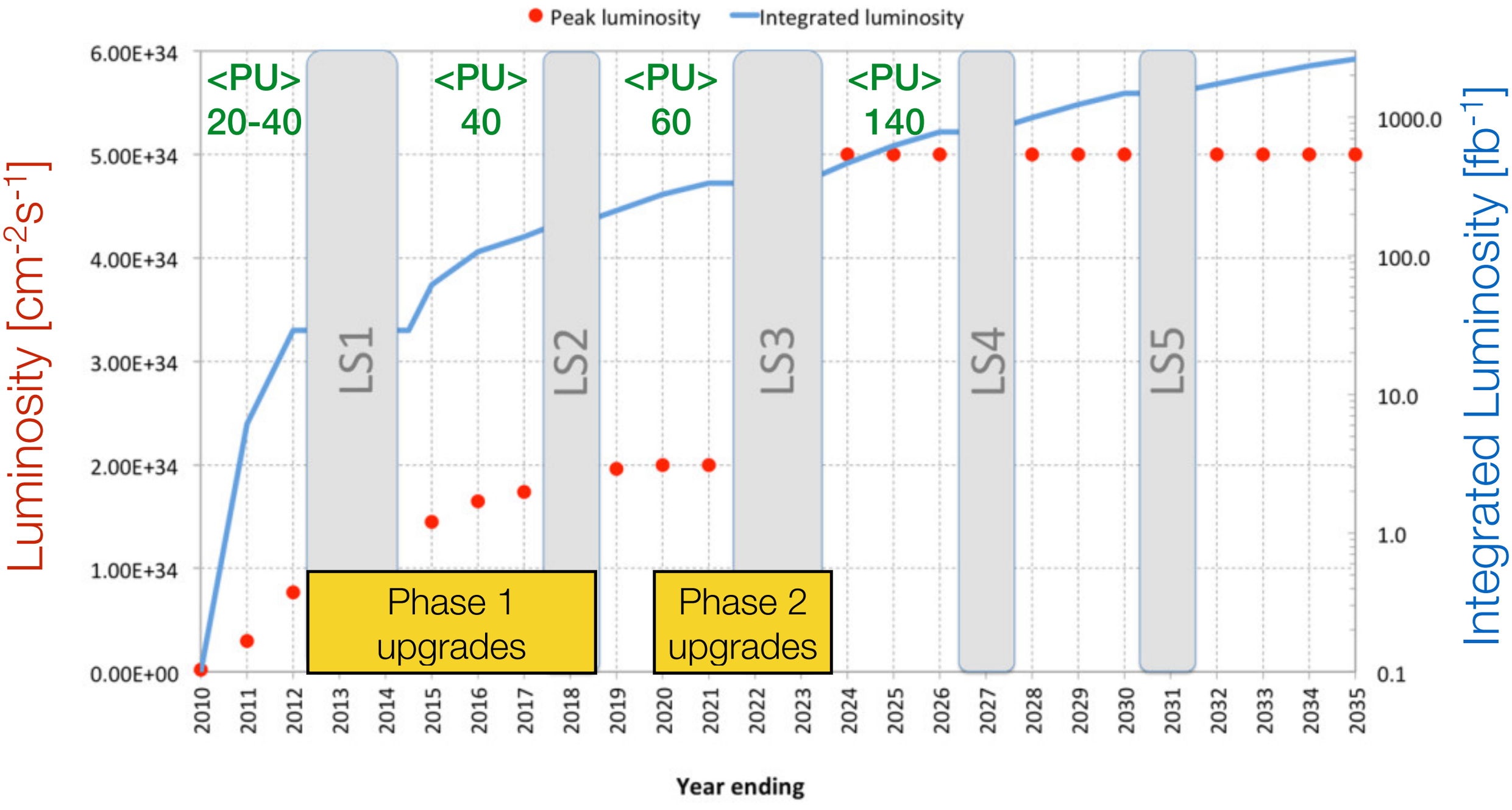
SUSY
EWK production
Other difficult scenarios



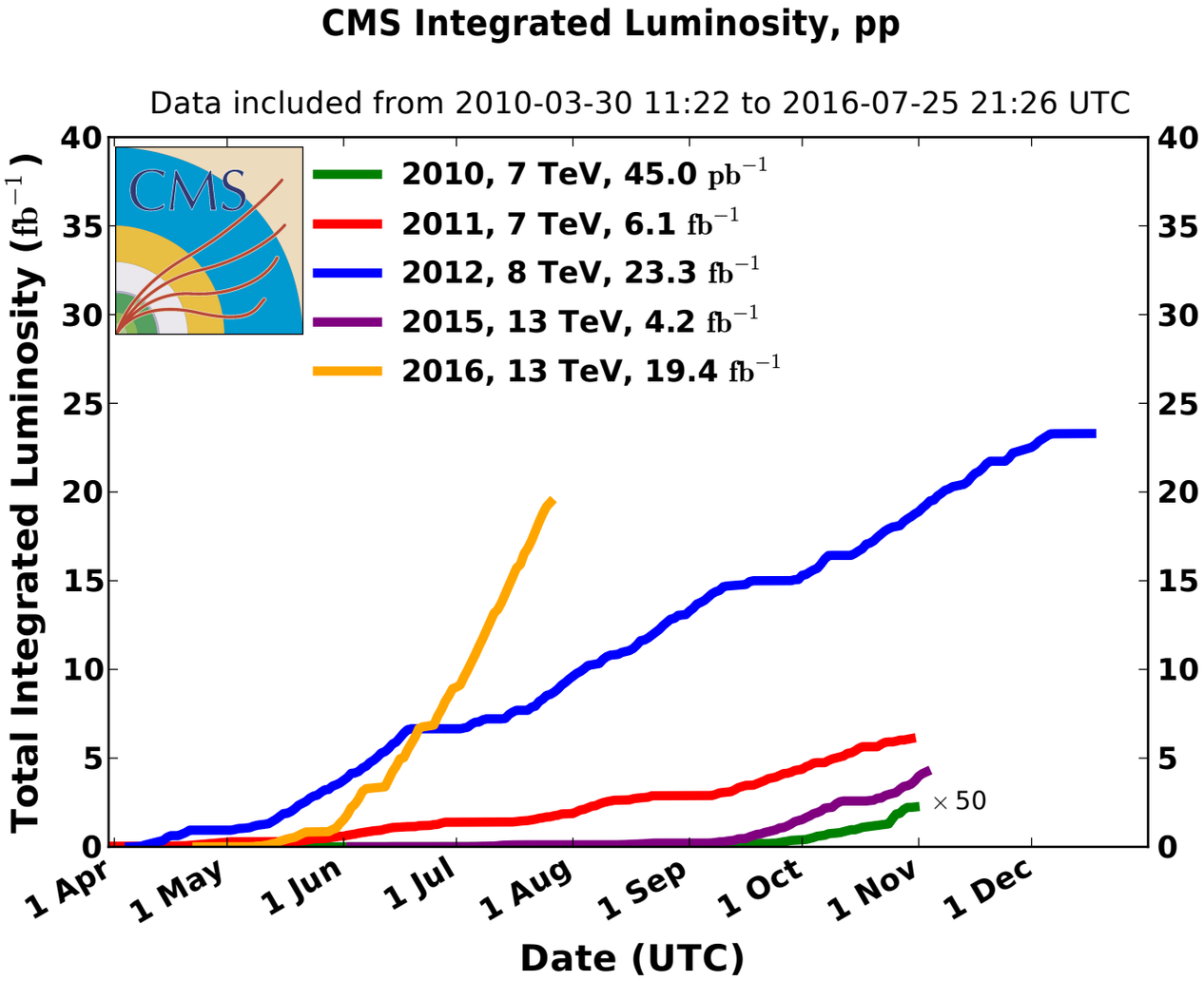


Probe *up to* the quoted mass

LHC Schedule



CMS Status



LHC :

peak L_{inst} ~ 1.2E10^{34} cm^{-2}s^{-1}

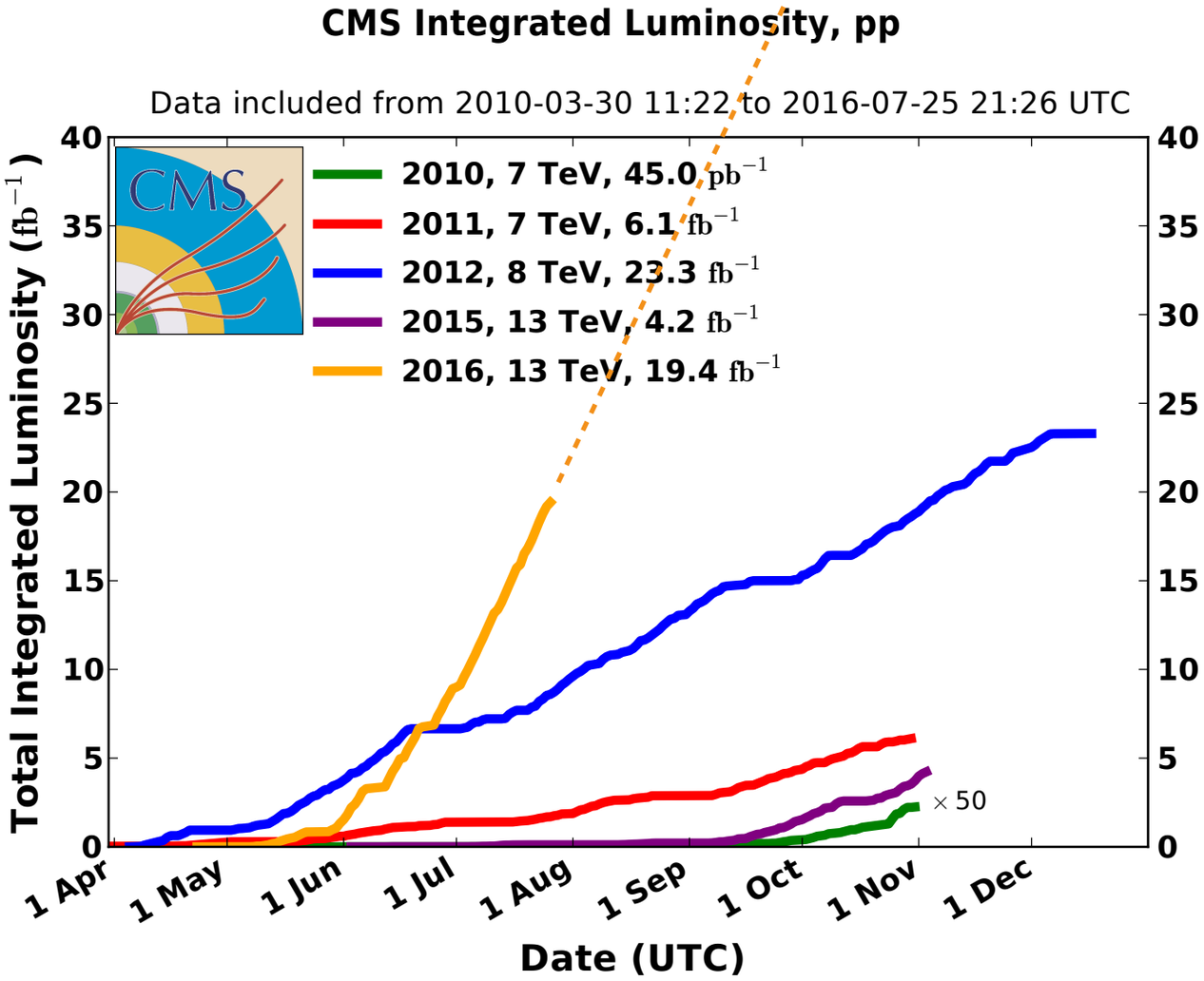
CMS :

Data-taking efficiency ~ 92.2%

- **Main activities during 2015 end of year stop**
  - Refurbishment and cleaning of magnet cryogenics
  - Full upgrade of L1 Trigger

CMS Status

???



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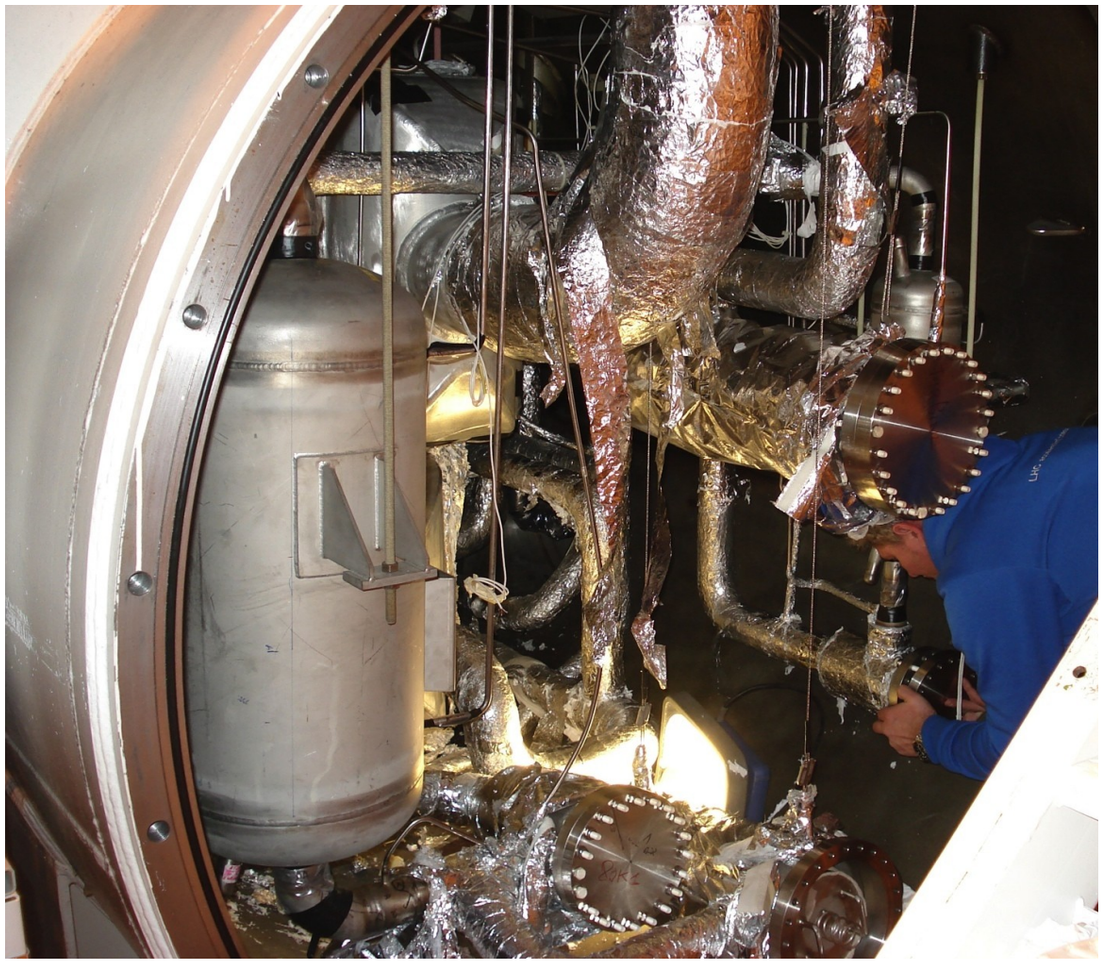
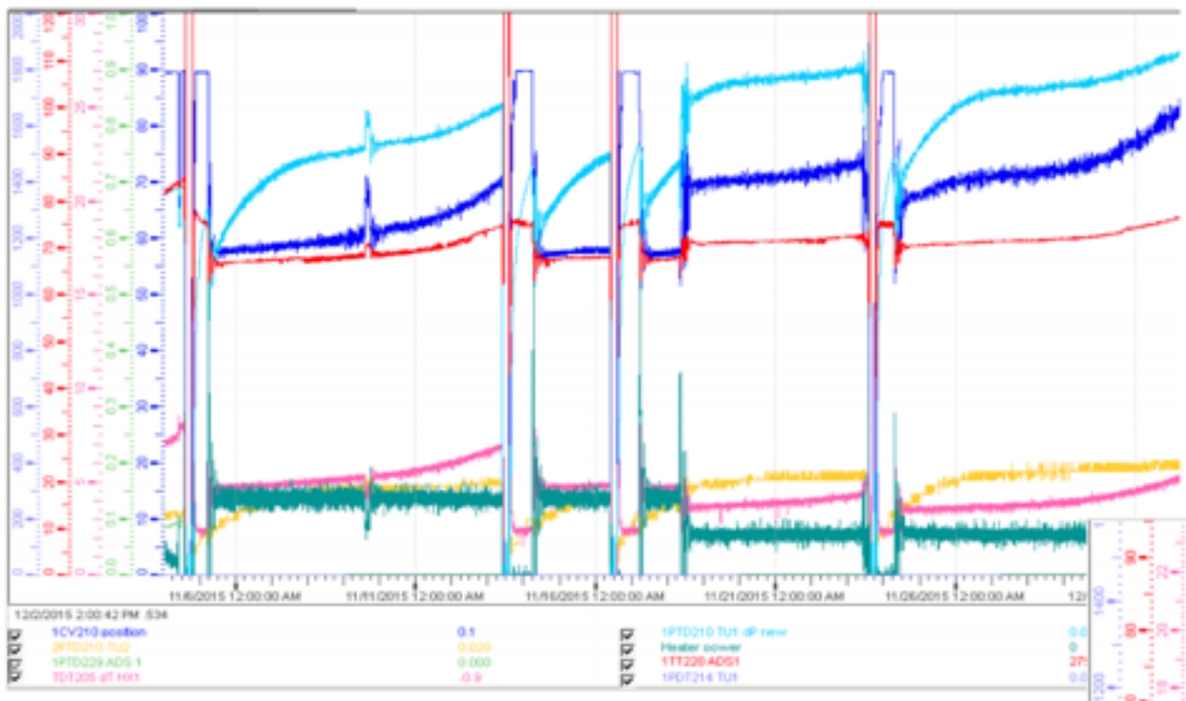
Magnet Status



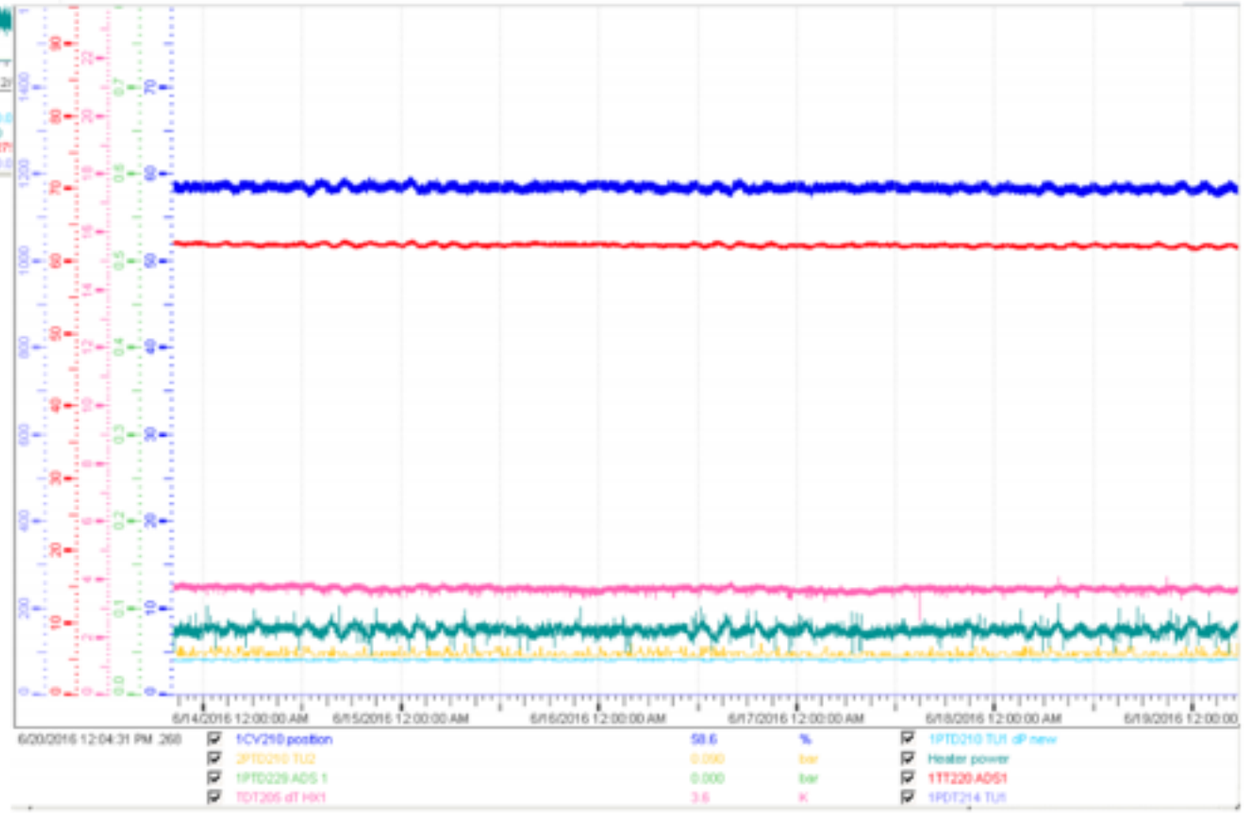
- **CMS magnet suffered during 2015**
  - Oil contamination of liquid He
  - Source of contaminant confirmed with mass spectrometry shortly after end of 2015 data-taking
- **Refurbishment of “cold box” during 2015/16 year end stop**
  - Primary oil removal system replaced
  - System cleaned to remove all contaminant

Magnet Status

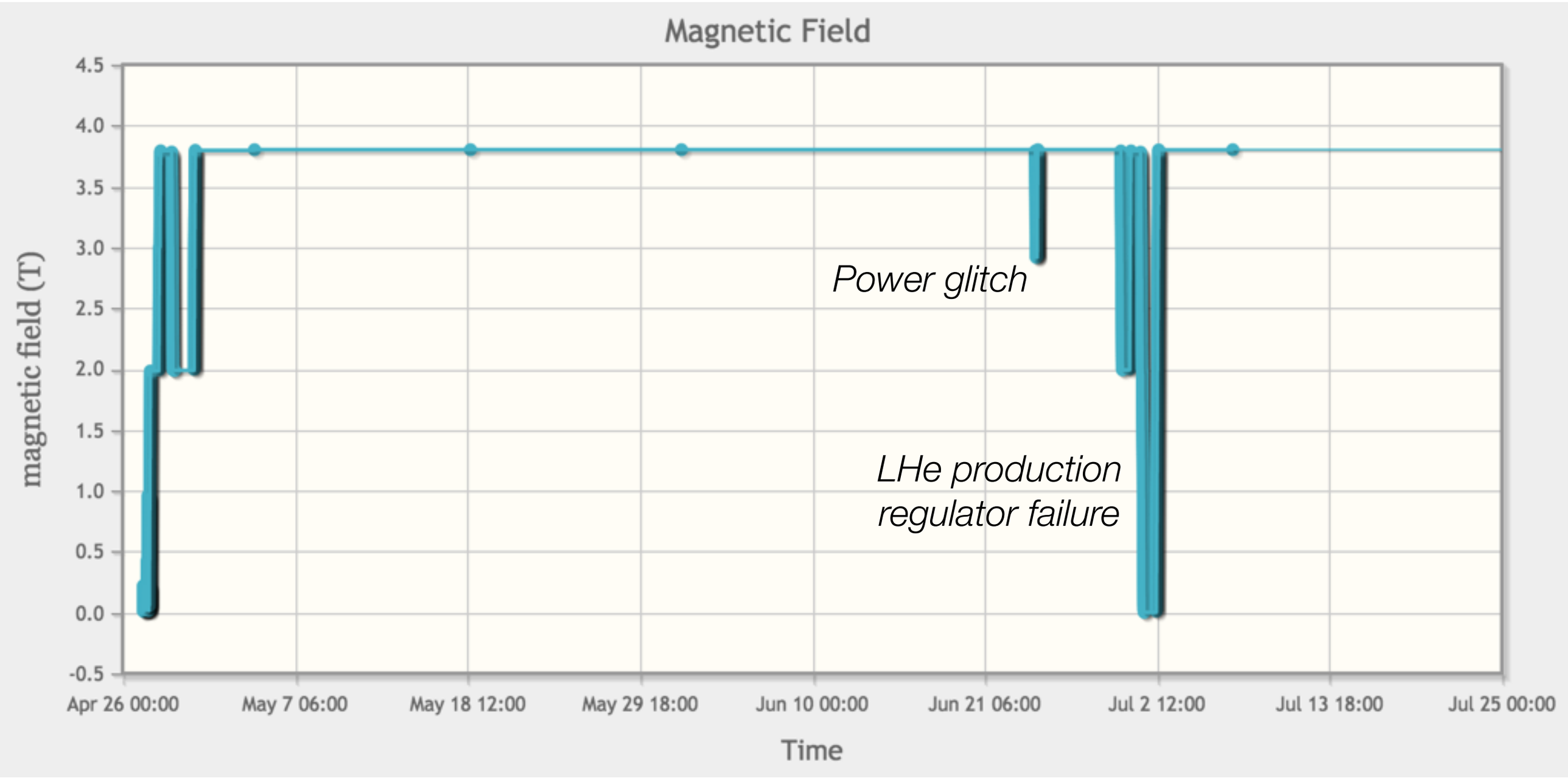


November 2015

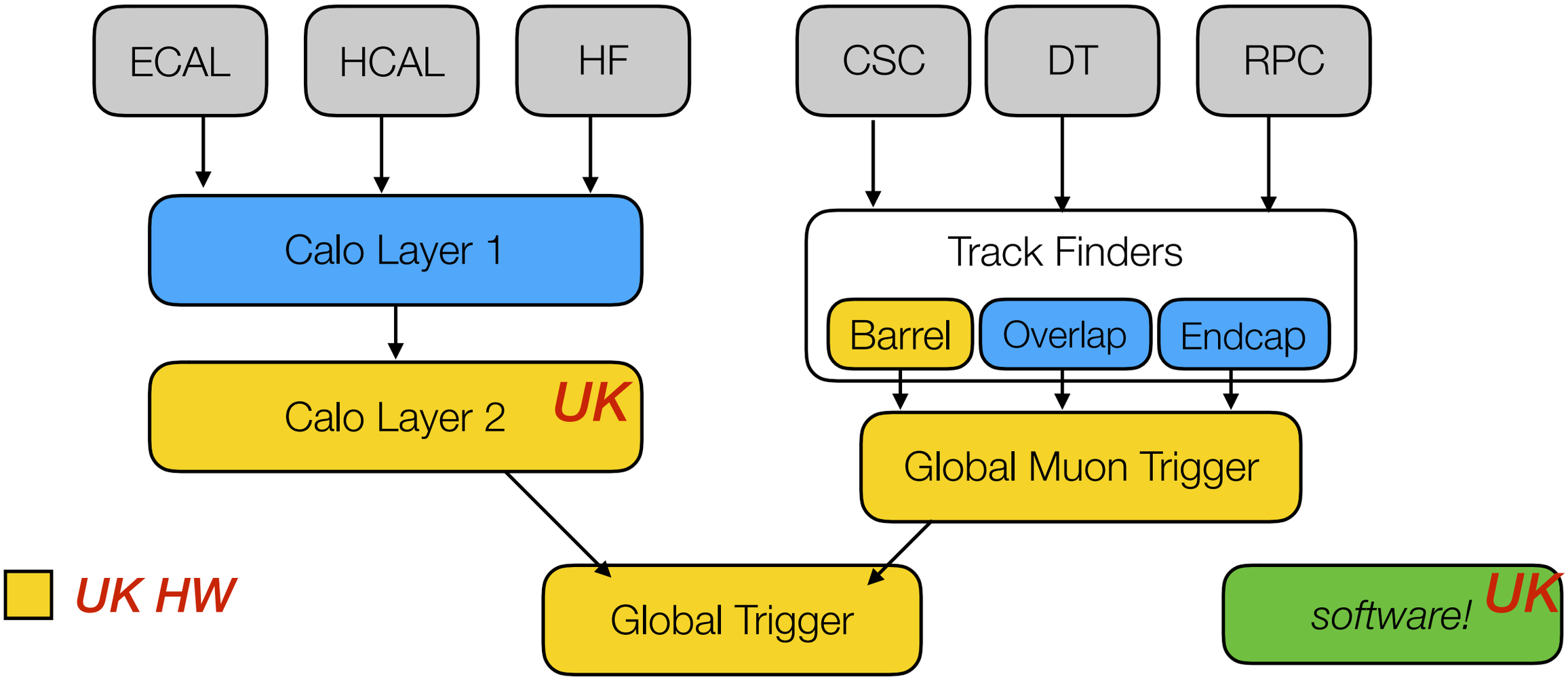
June 2016



Magnet Status



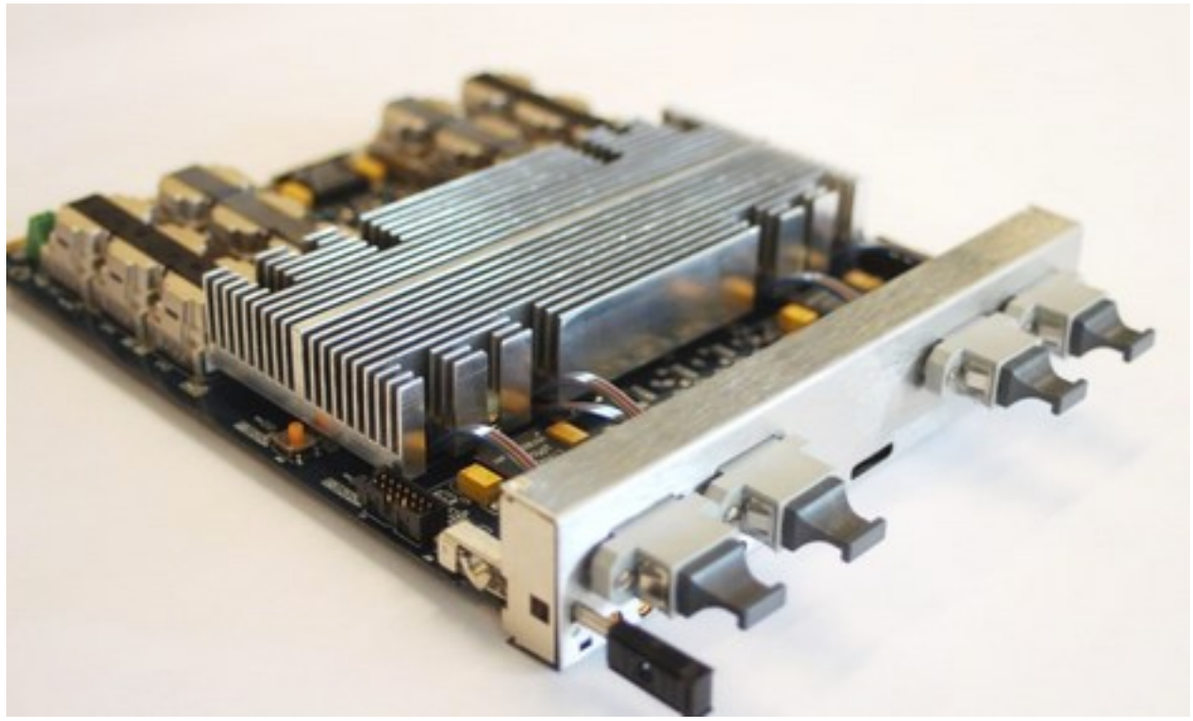
Phase 1 Trigger Upgrade



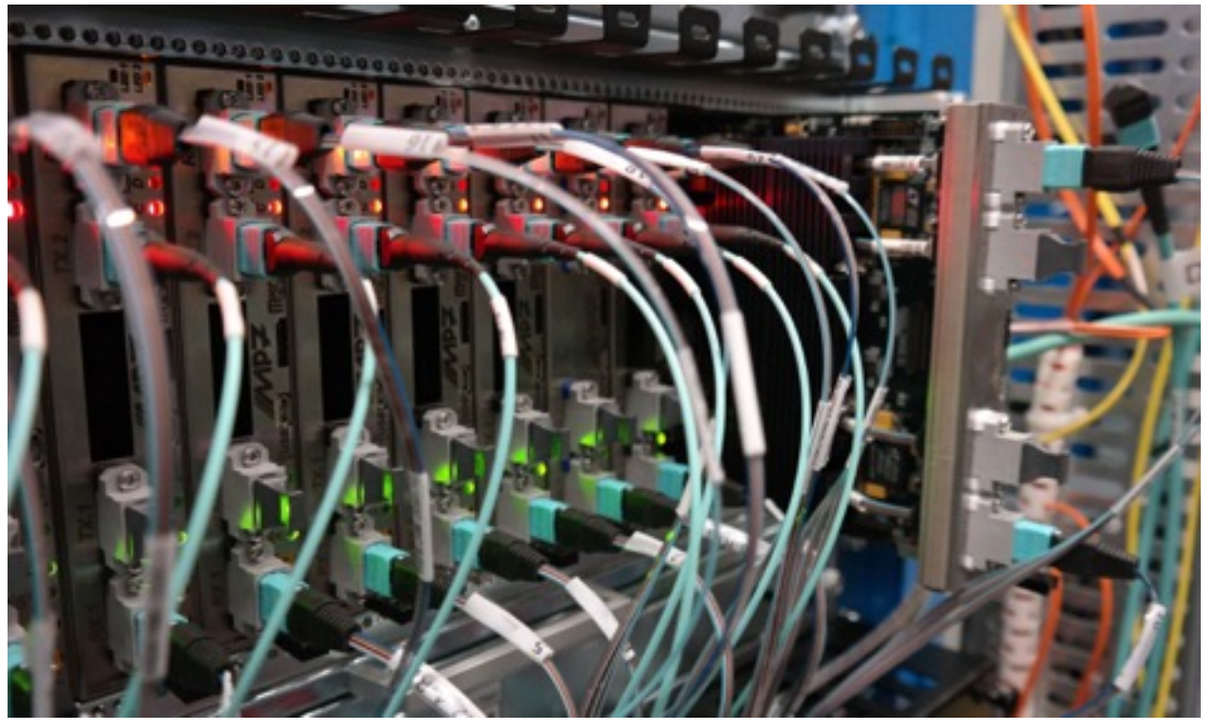
- Successfully deployed calo trigger interim upgrade (one board) in 2015
- Fully replaced entire L1 Trigger during 2015/16 year end stop
- In operation for 2016 data taking, supplying triggers to CMS

Phase 1 Trigger Upgrade

UK



MP7 Processor

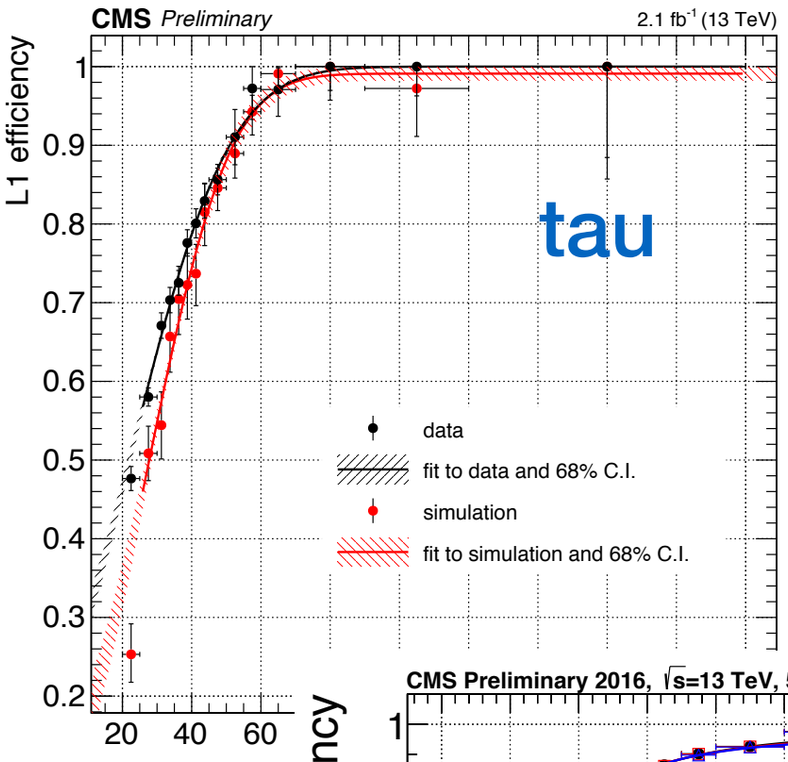


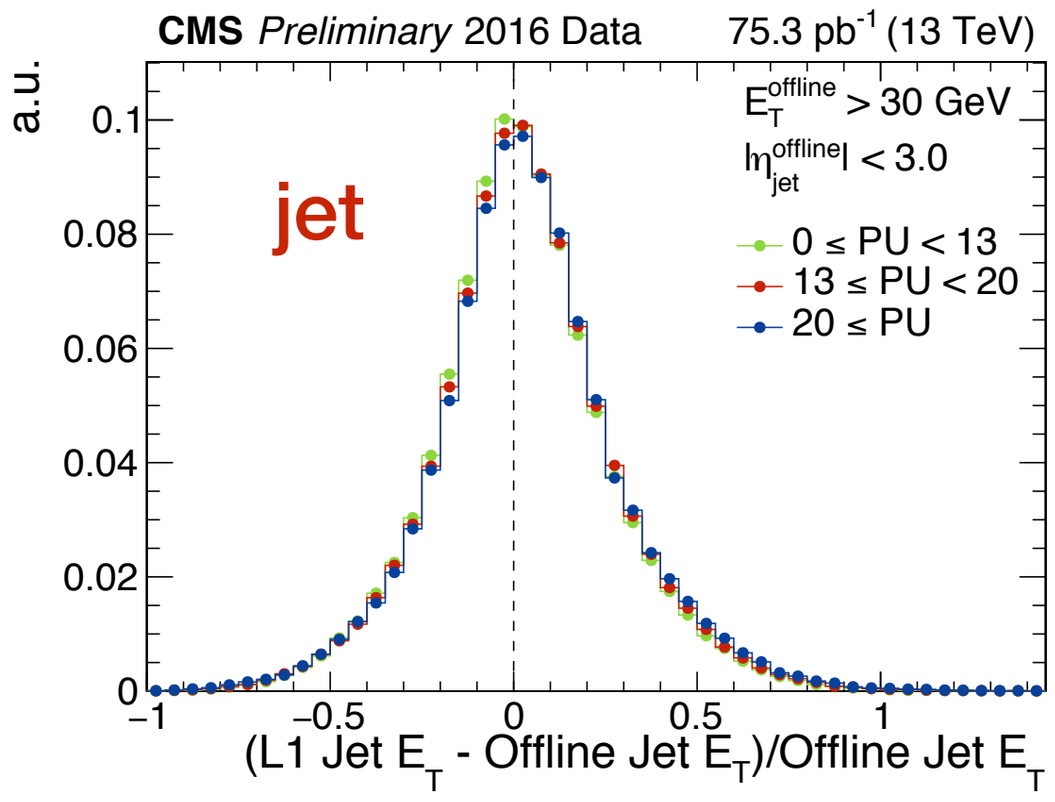
Layer 2 Calo Trigger

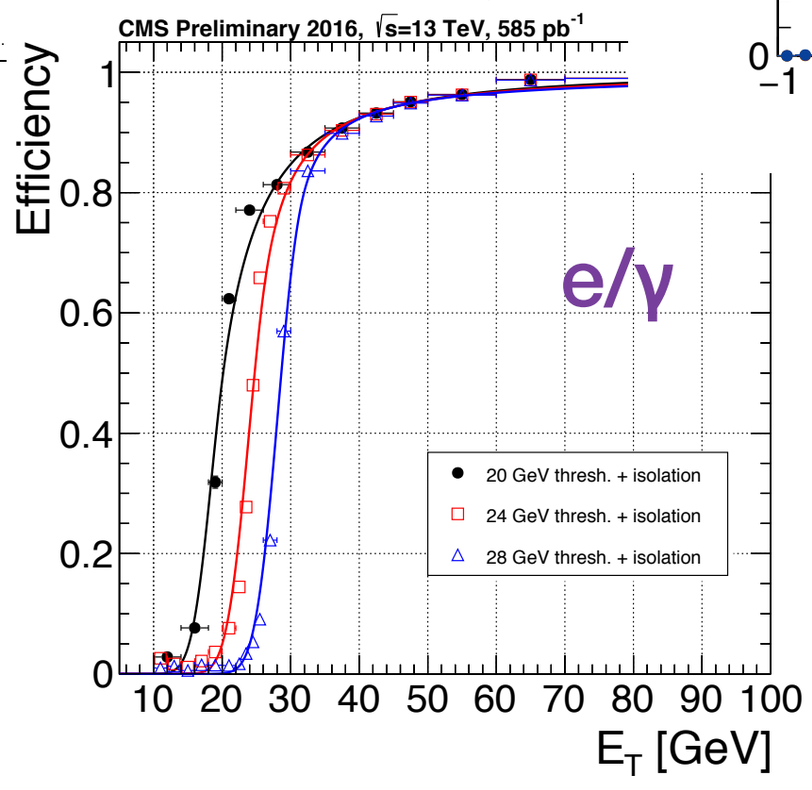
- **Layer 2 calorimeter trigger - UK deliverable**
- **UK hardware supplied to multiple CMS L1 Trigger subsystems**
- **Supplied package of hardware + “core” firmware and software**
- **“Users” provide algorithm firmware + software**

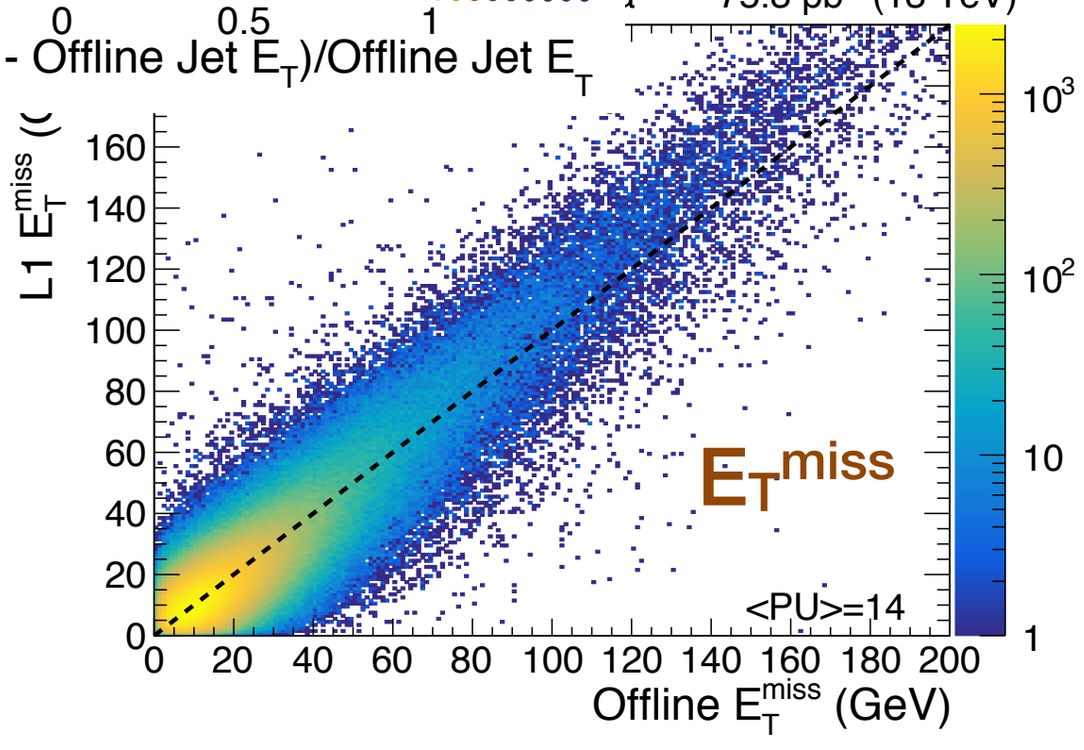
Phase 1 Trigger Upgrade

UK

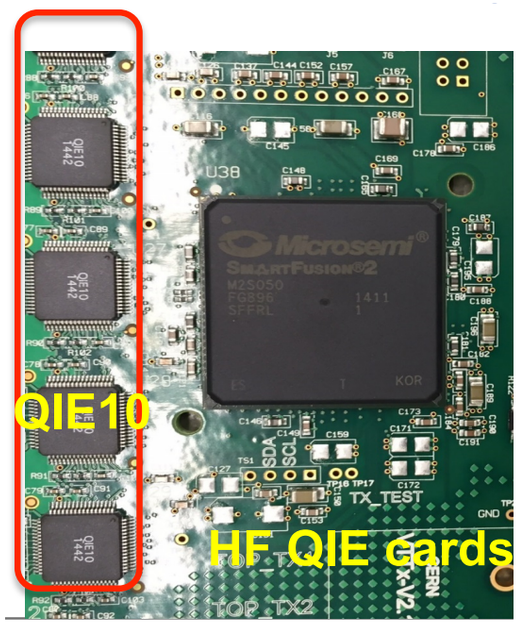


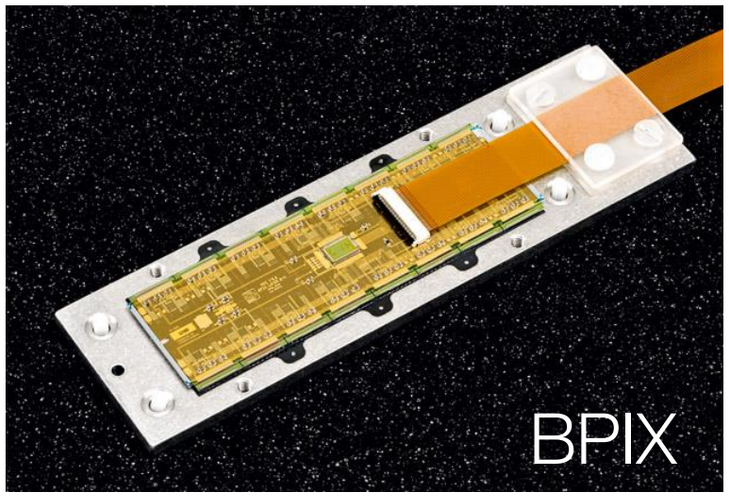




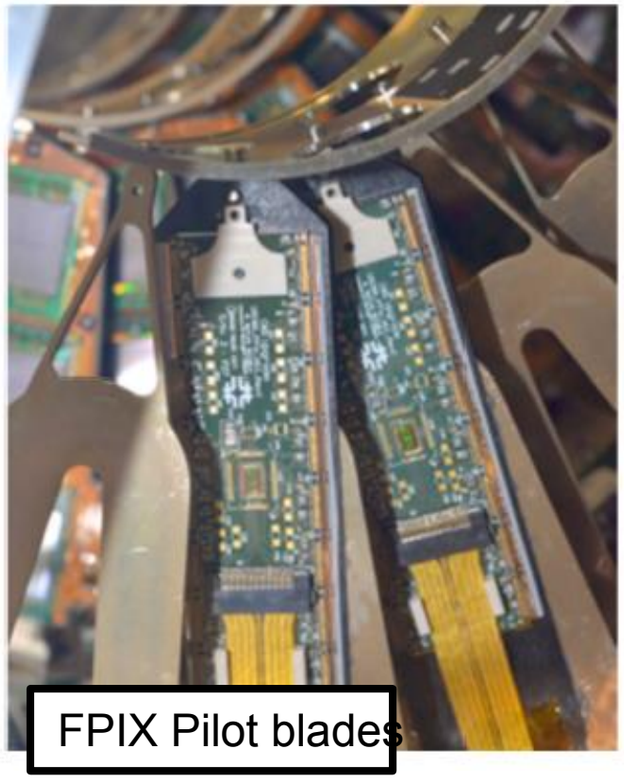


Phase 1 Upgrades : Pixels & HCAL

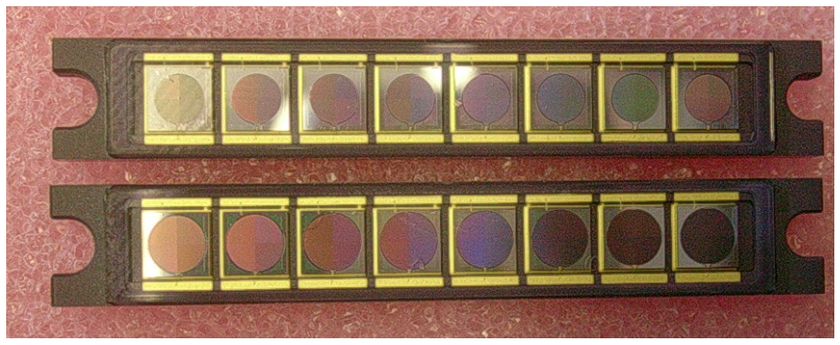




>100% required modules assembled



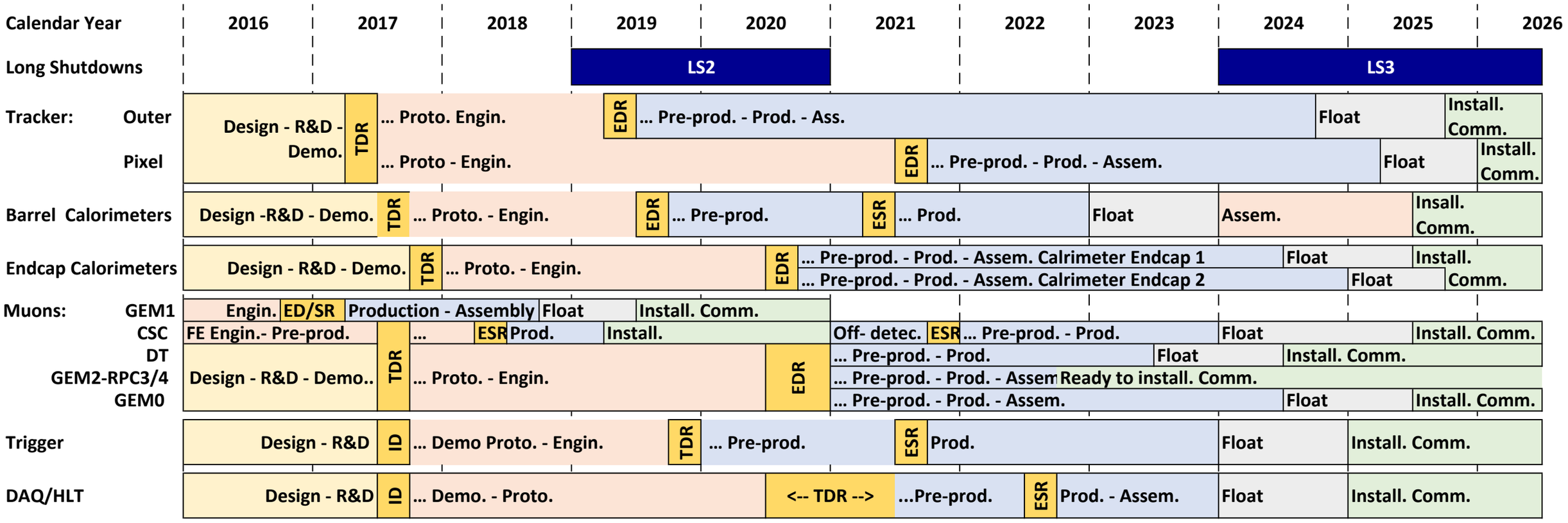
~70% required modules assembled



HCAL endcap Si-PMs

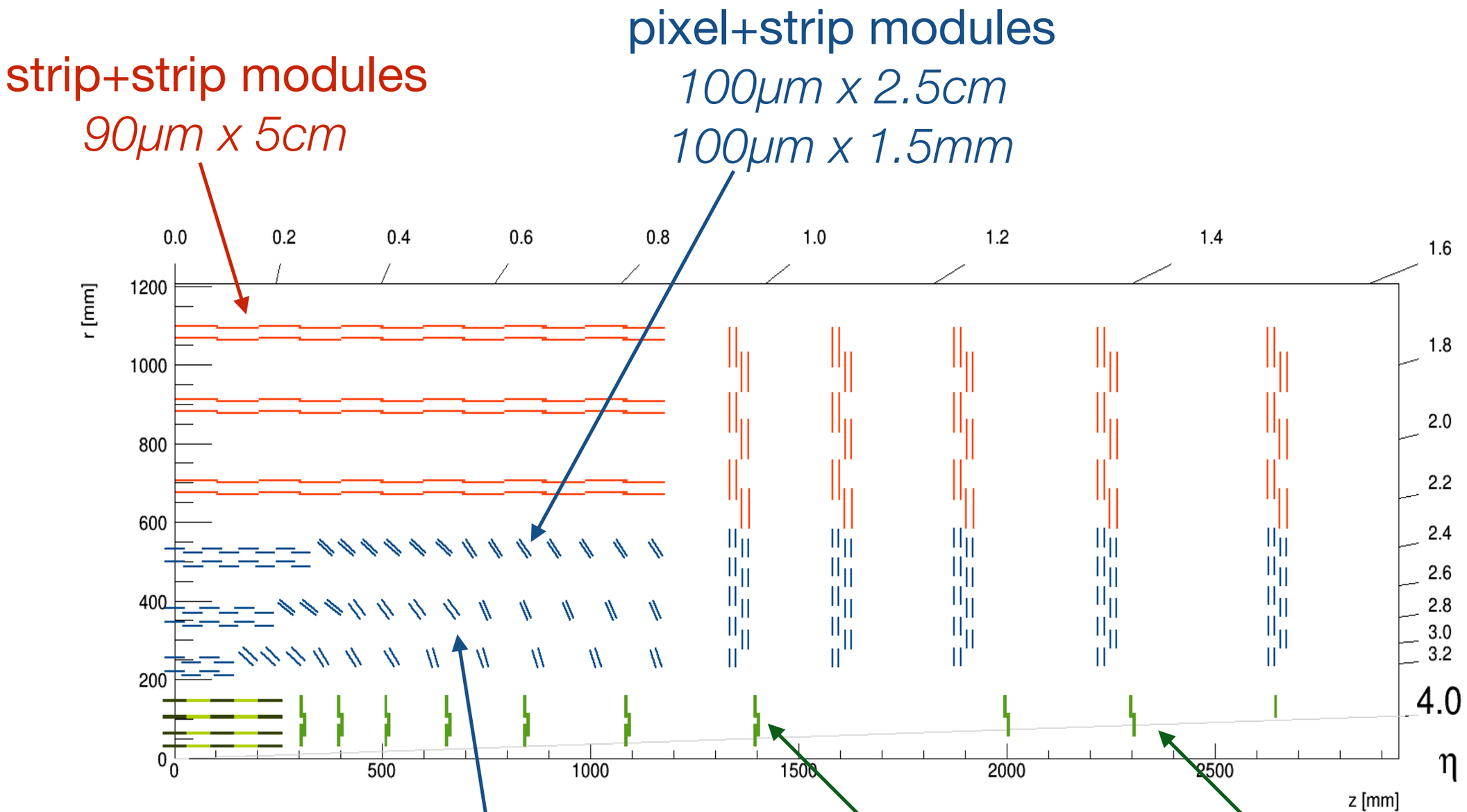
- **Extended year end stop (EYETS) 2016/17**
  - Replace pixel detector
  - Replace HCAL endcap photodetectors and FE electronics
  - Replace HCAL forward electronics

Phase 2 Upgrades



- Substantial detector upgrades required during LS3
  - *Tracking, calorimetry, muon systems, trigger, DAQ*
- Ongoing R&D and design studies converging
- Sub-detector TDRs planned in 12-18 months; Trigger & DAQ follow in 2019

Phase 2 : Tracking



Phase 2 : Tracking

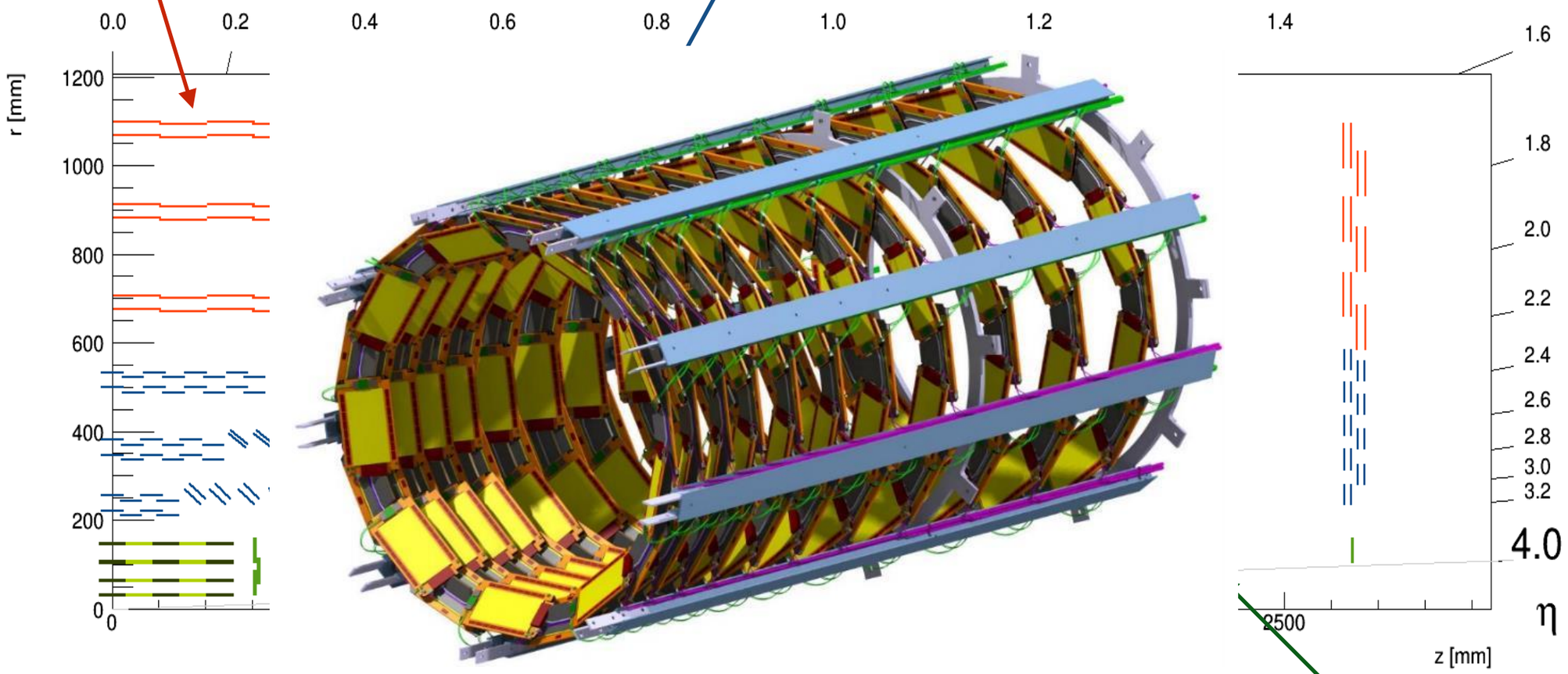
strip+strip modules

90µm x 5cm

pixel+strip modules

100µm x 2.5cm

100µm x 1.5mm



tilted modules ?

pixel modules

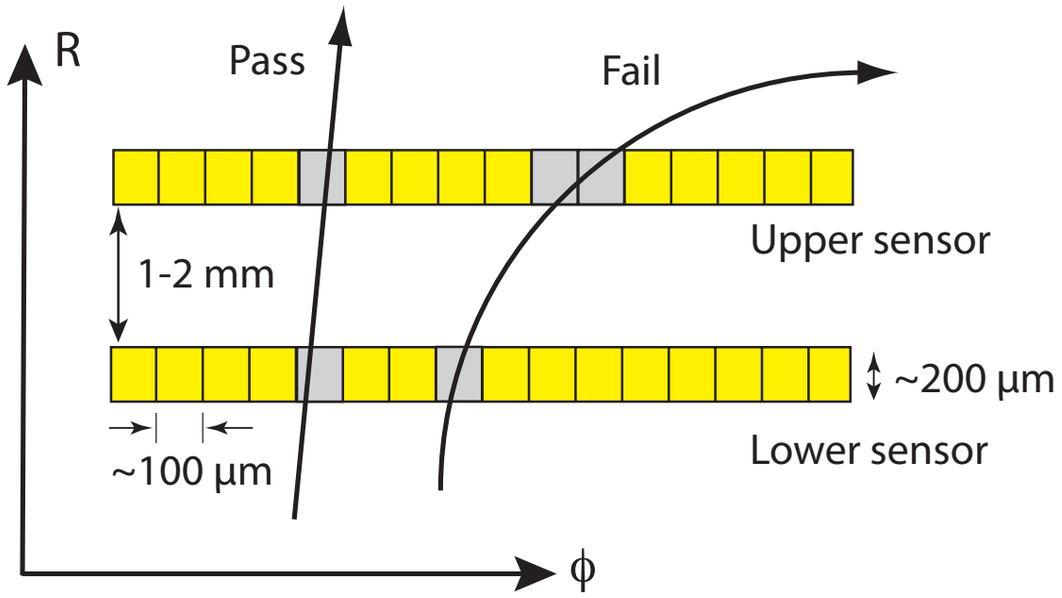
25µm x 100µm

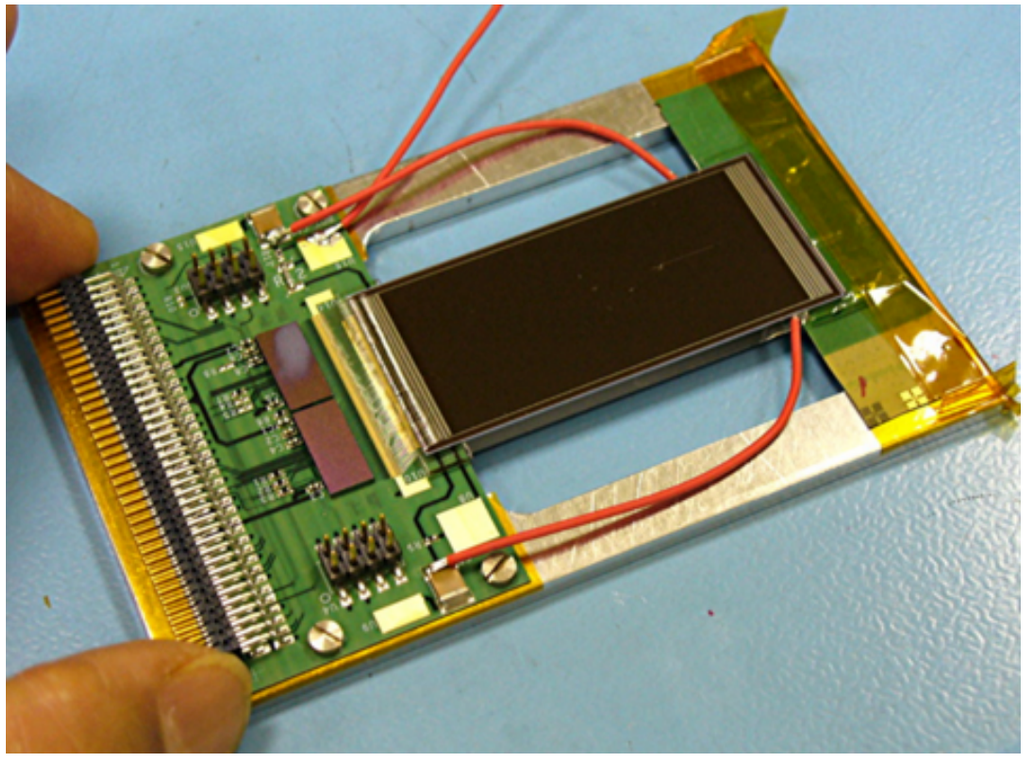
or 50µm x 50µm

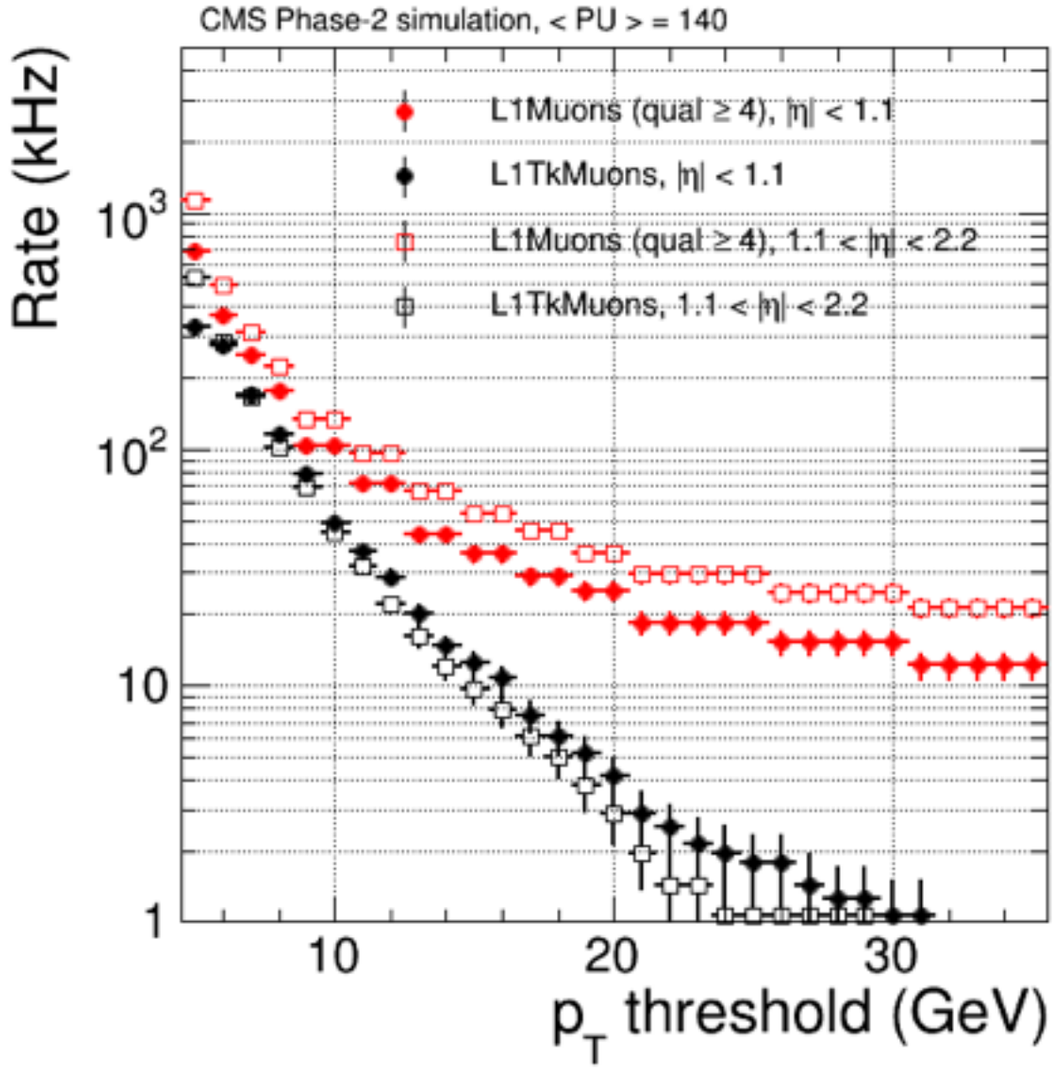
pixel coverage up to eta<4

Phase 2 : Tracking

UK







2S Module

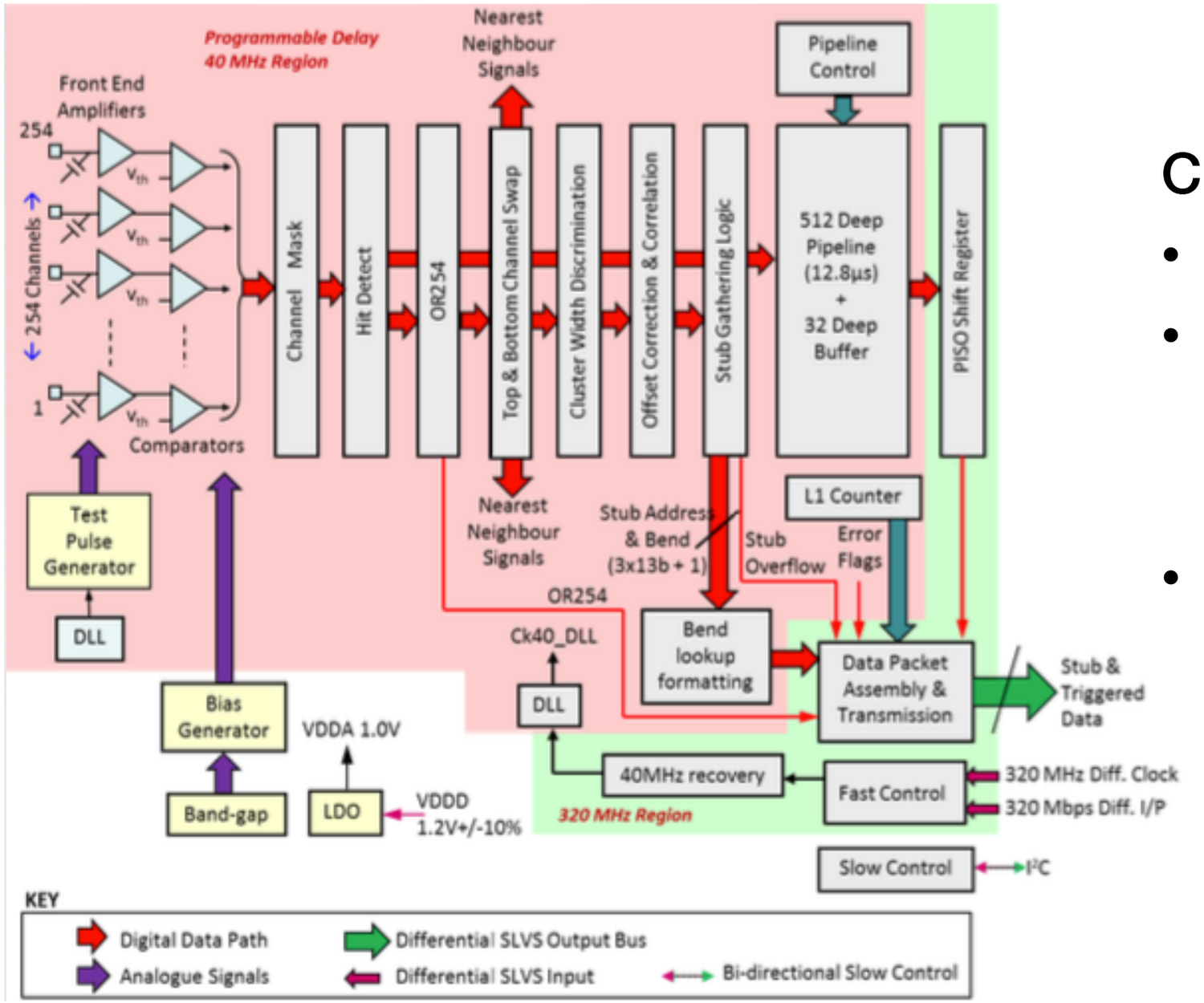
Double layer Si strips

90µm pitch x 5cm length

Track stub identification for L1 Trigger

Phase 2 : Tracking

UK

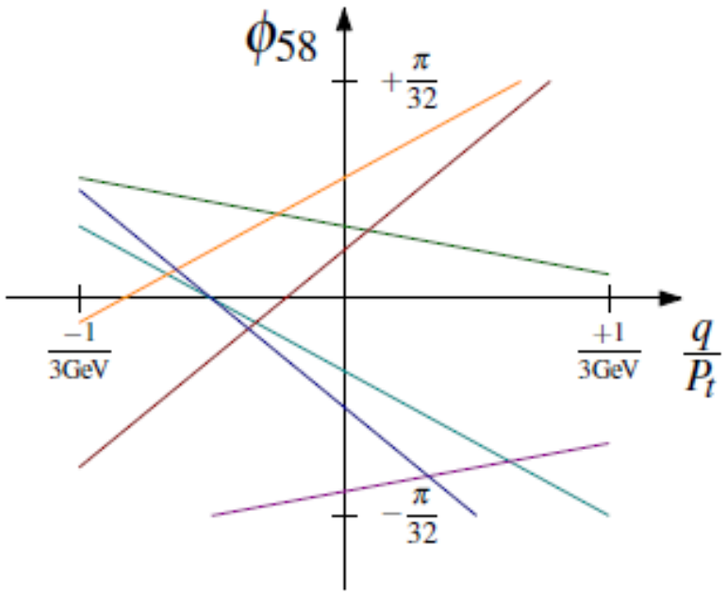


CBC

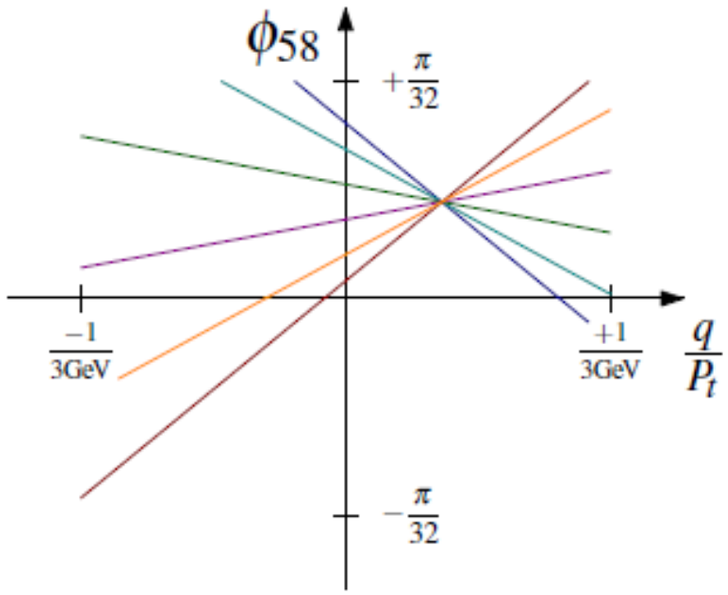
- Binary FE readout ASIC
- v2 demonstrated
  - 2S module prototypes
  - successful beam tests
- v3 design nearing completion
  - modified analogue FE
  - full pipeline depth
  - final logic (?)

Phase 2 : Tracking

UK



6 random stubs

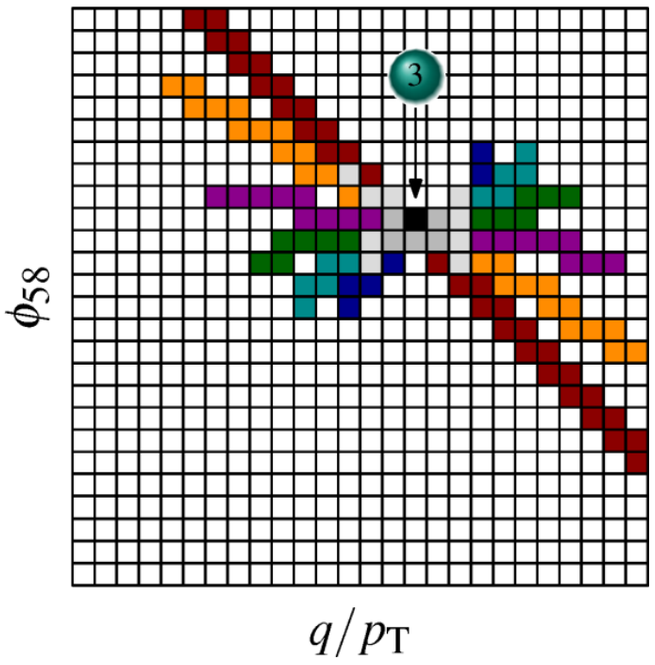


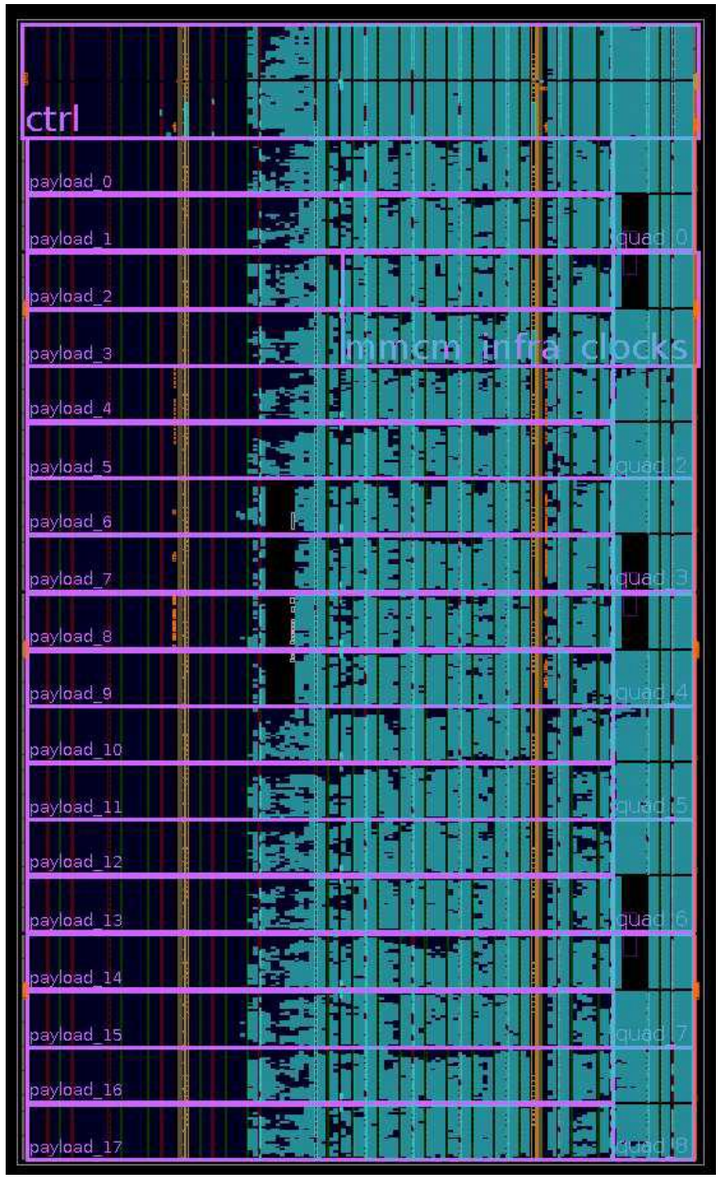
6 stubs from same particle

Track finding for L1 trigger

FPGA implementation of a Hough Transform

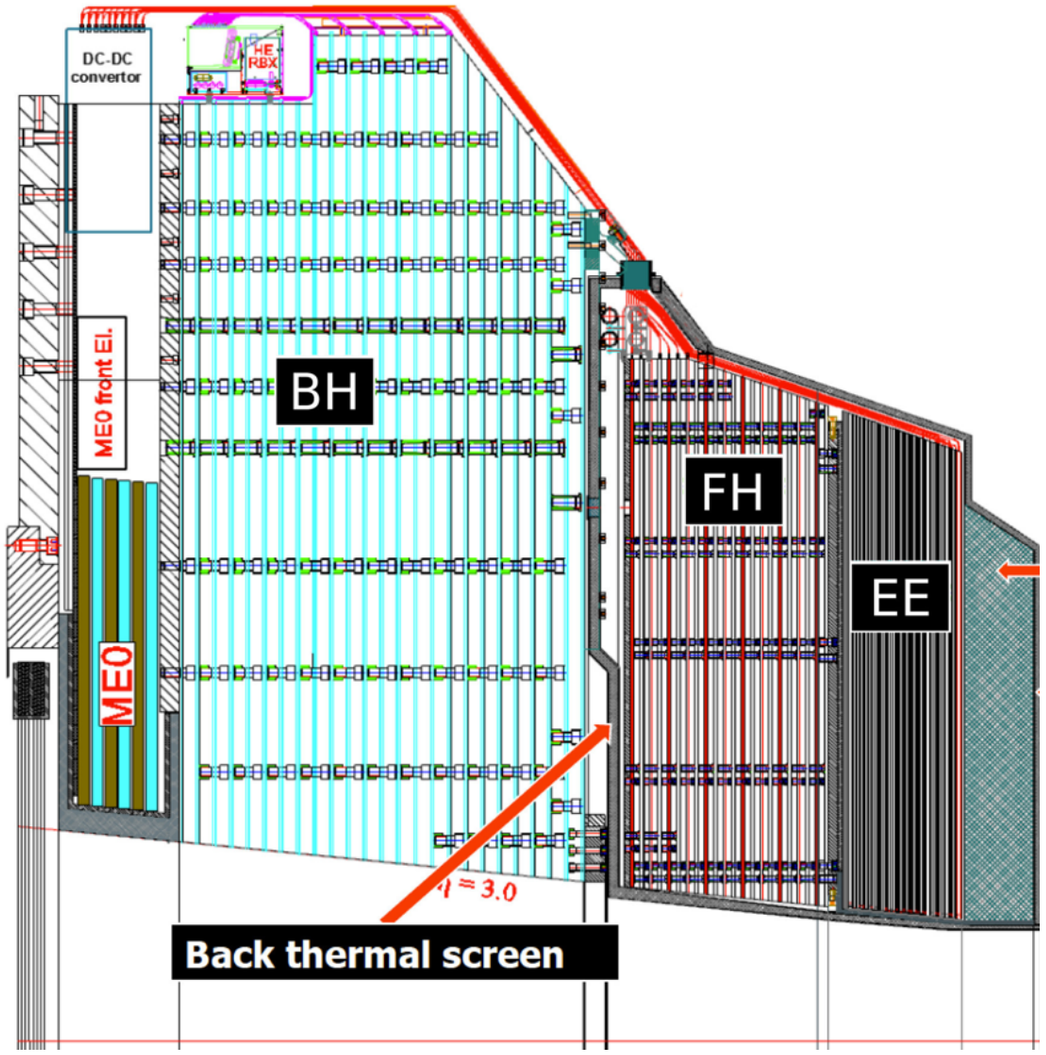
Demonstrated in hardware using MP7-based system





Phase 2 : Endcap Calorimeter

UK

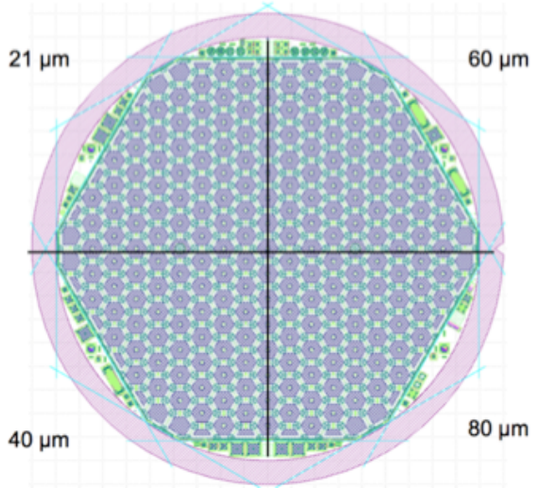


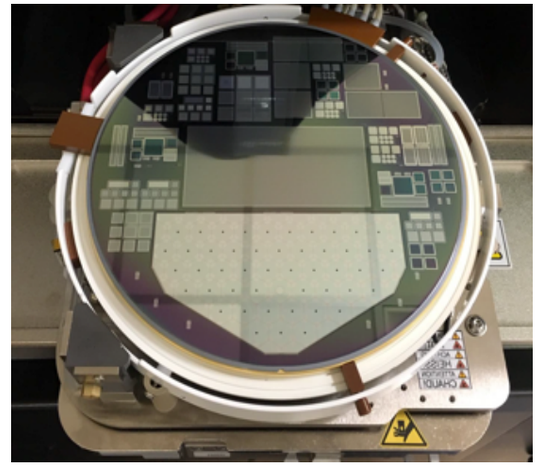
- **Current calorimeter will not remain performant after LS3**
  - Due to radiation damage and high pileup
- **Hexagonal silicon sensors**
- **Modules arranged into wedge-shaped cassettes and inserted into absorber**
- **593 m^3 silicon, 6M channels**
- **UK initiation & leadership**

EE - Silicon + tungsten absorber, 28 layers, 25 X_0 (~1.3λ)
FH - Silicon + steel absorber, 12 sampling layers, 3.5λ
BH - Scintillator + steel absorber, 11 layers, 5λ

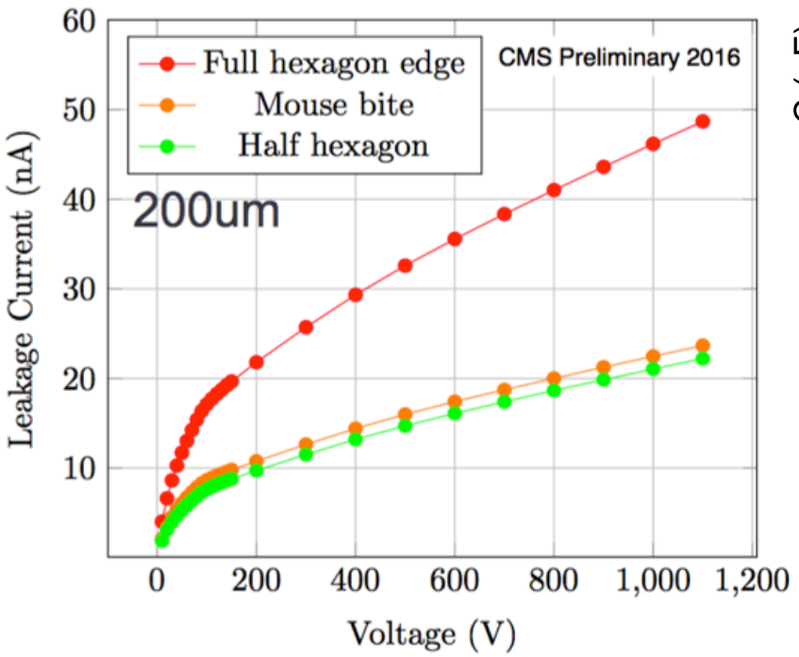
Phase 2 : Endcap Calorimeter

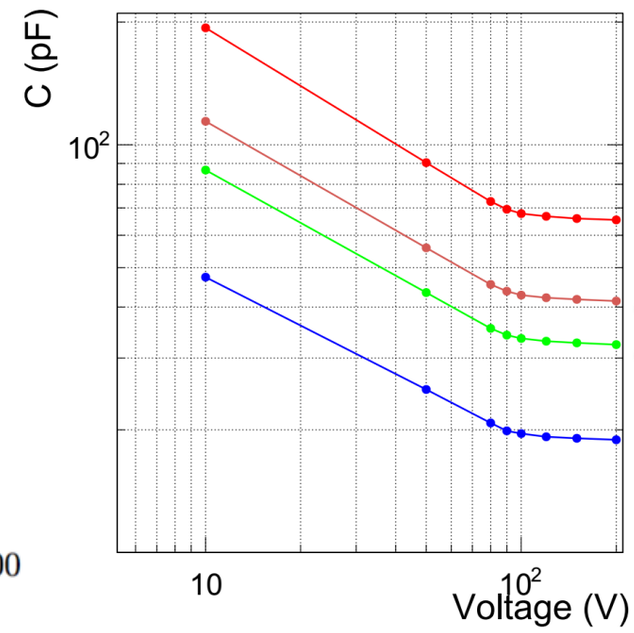
- **Hamamatsu : 6” sensors delivered**
- **Infineon : 8” design submitted**
- **Novati : 8” half-hexagon delivered**

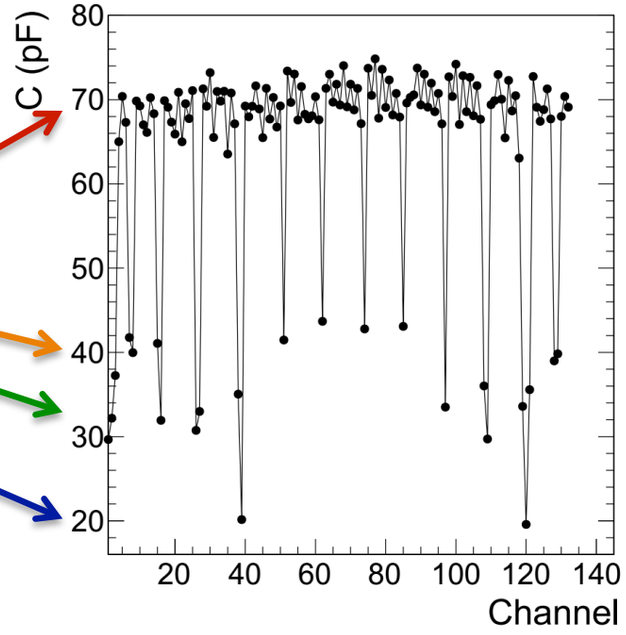




Infineon design Novati half-hexagon

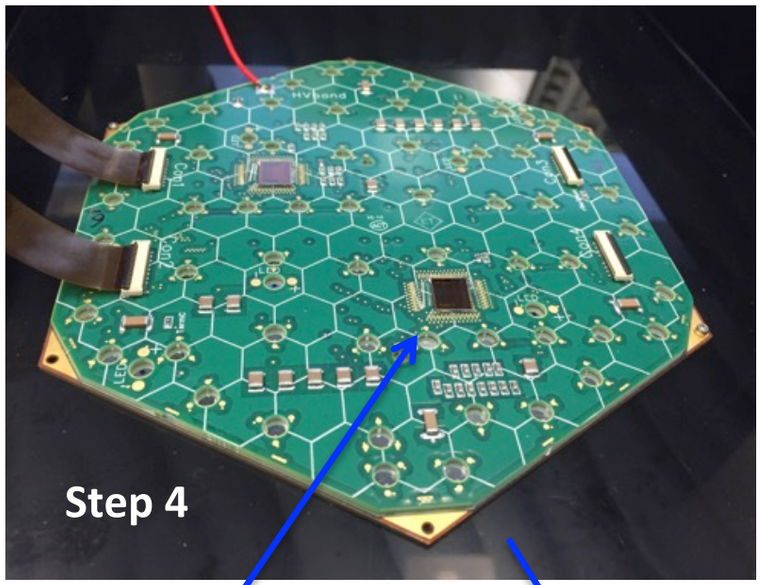


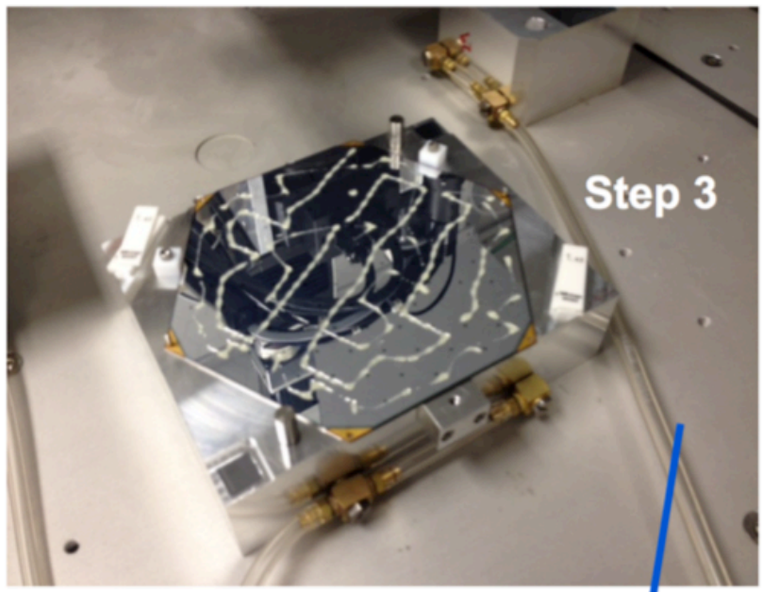


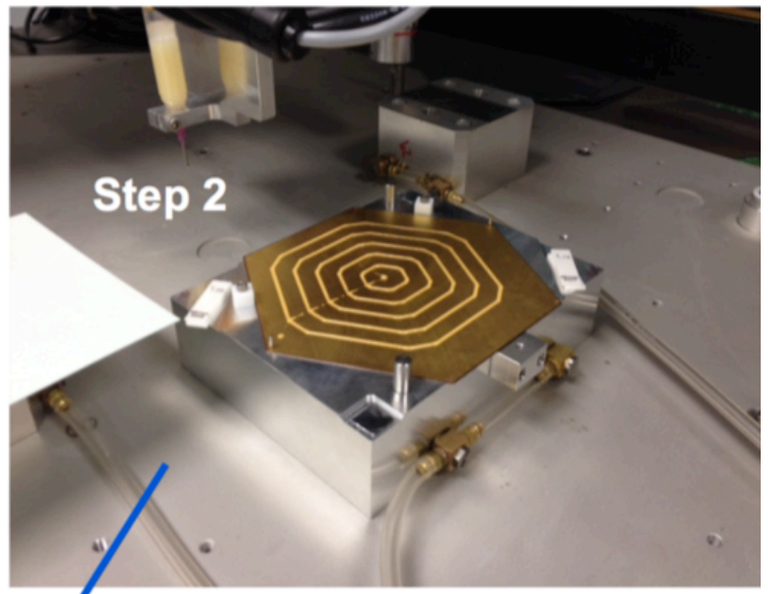


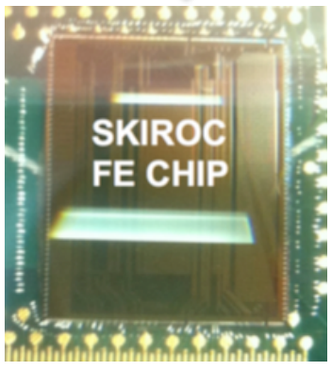
Measurements of Hamamatsu sensor

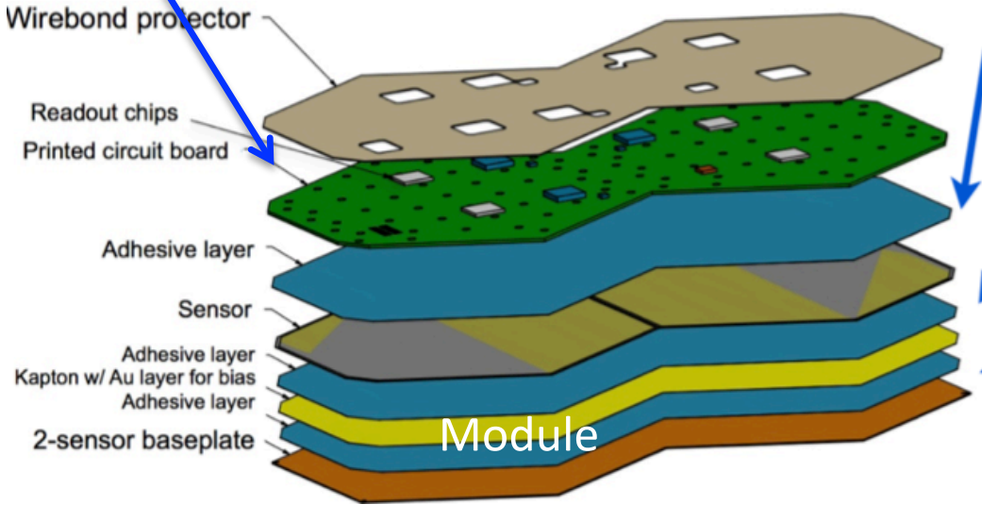
Phase 2 : Endcap Calorimeter

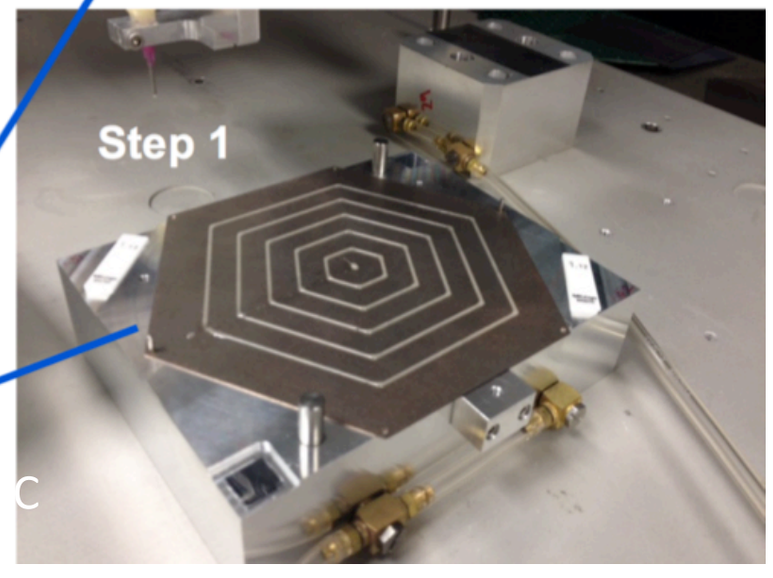






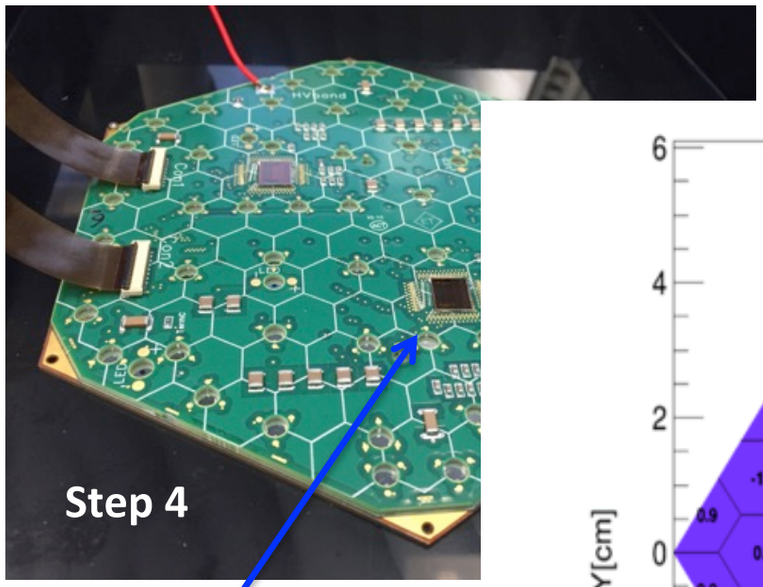


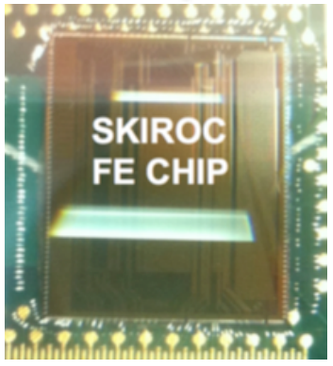


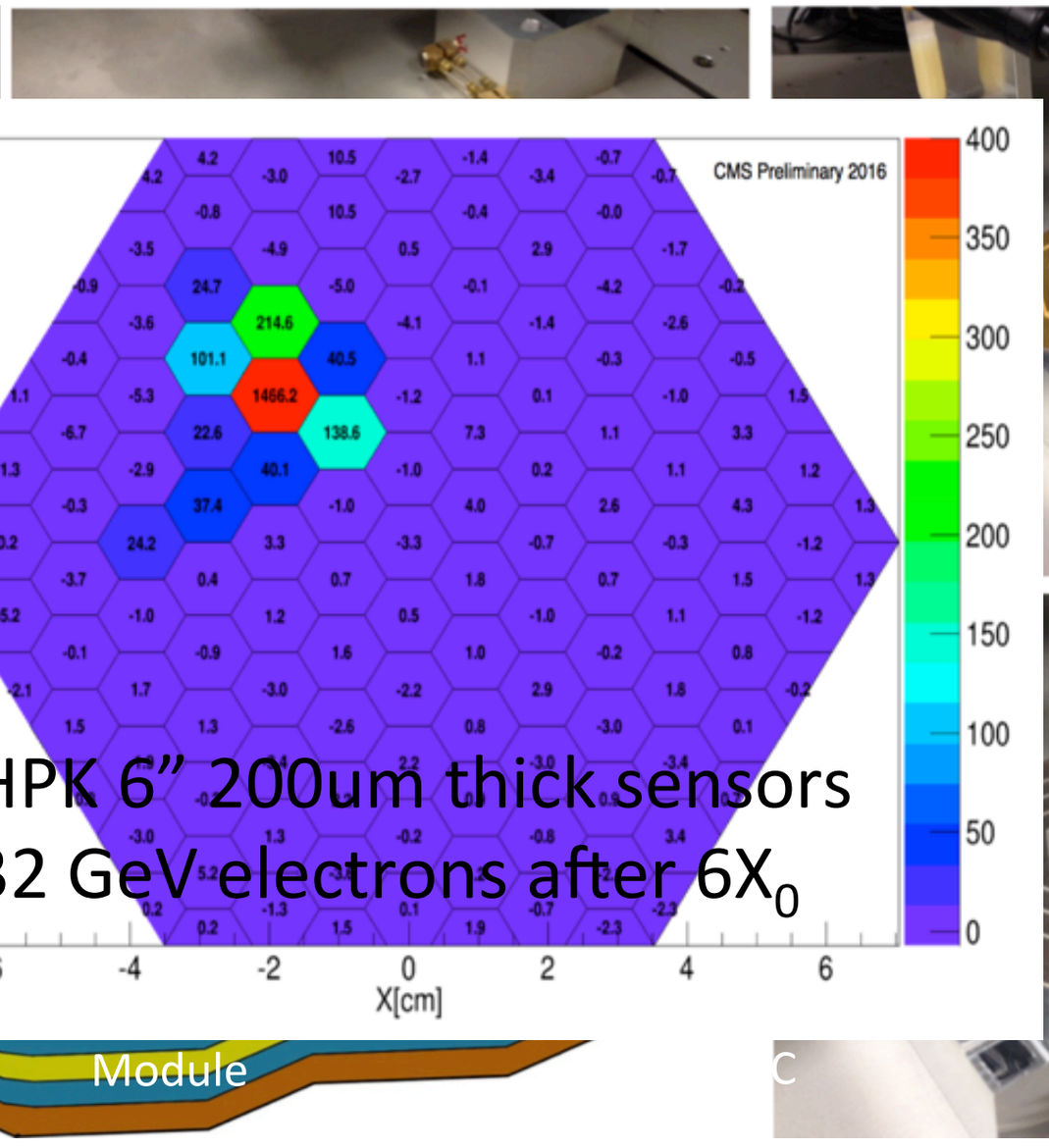


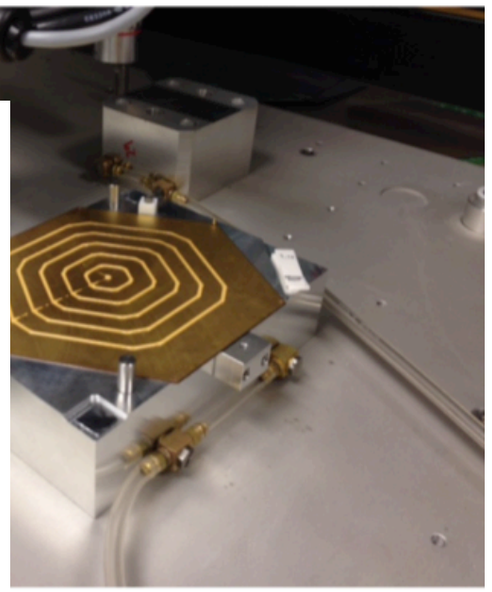
Successful module assembly for Fermilab test beam

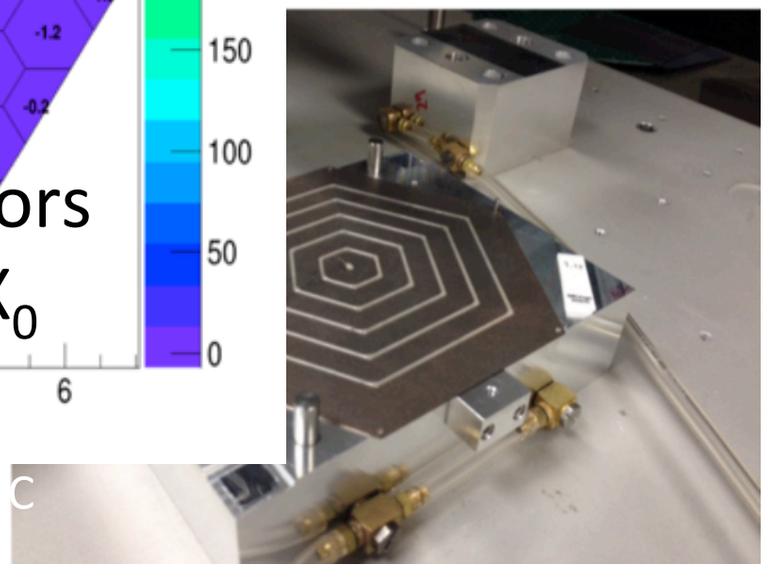
Phase 2 : Endcap Calorimeter







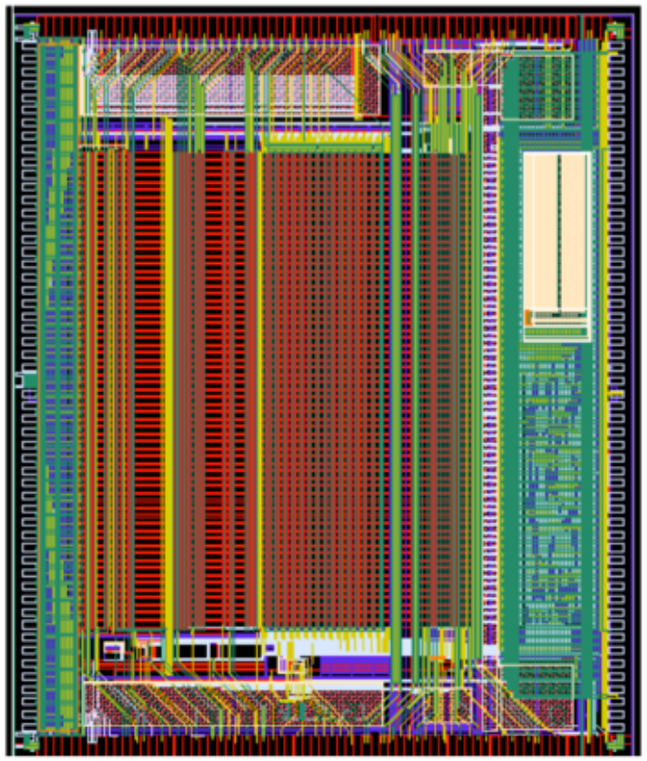




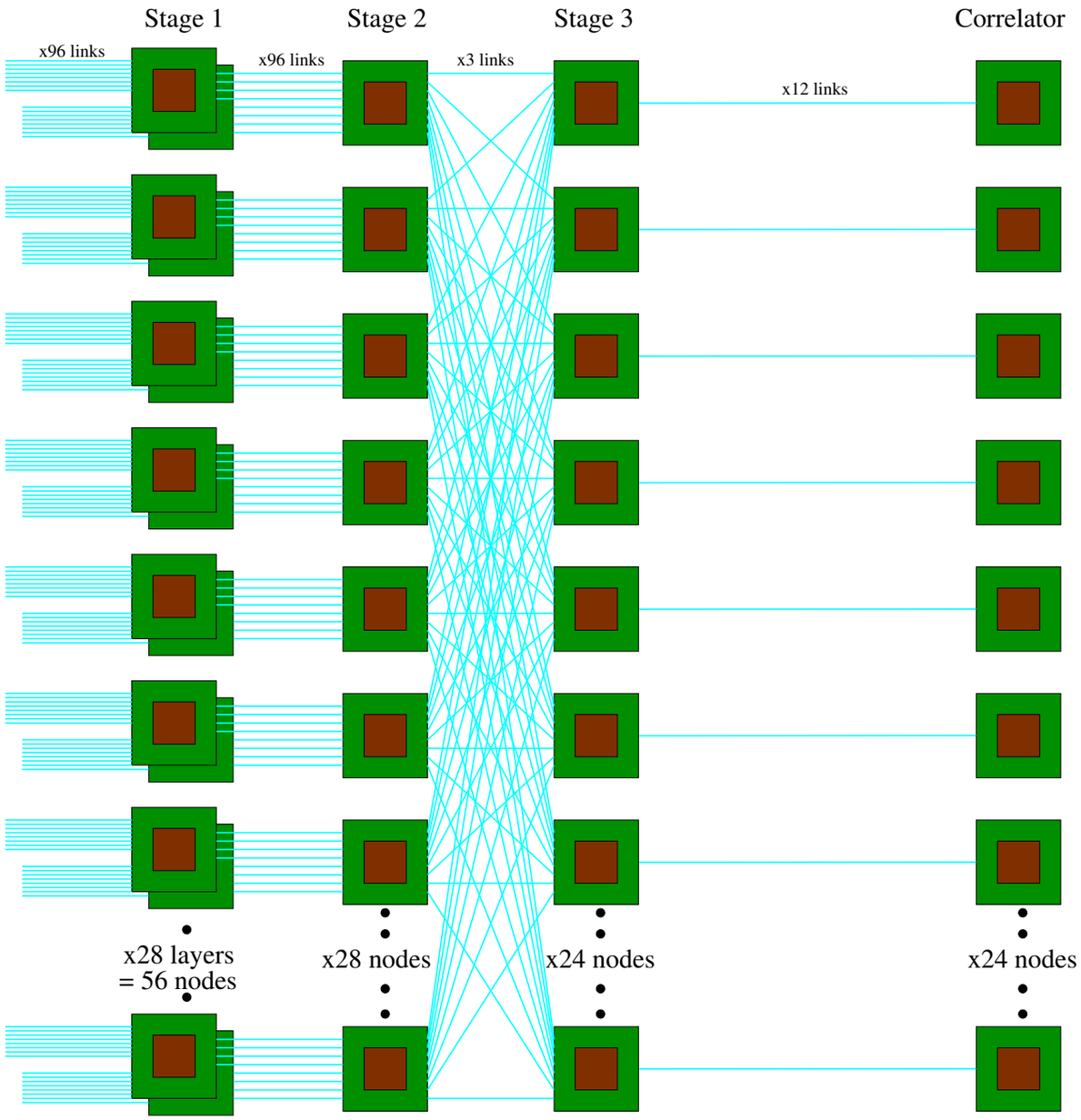
Successful module assembly for Fermilab test beam

Phase 2 : Endcap Calorimeter

UK



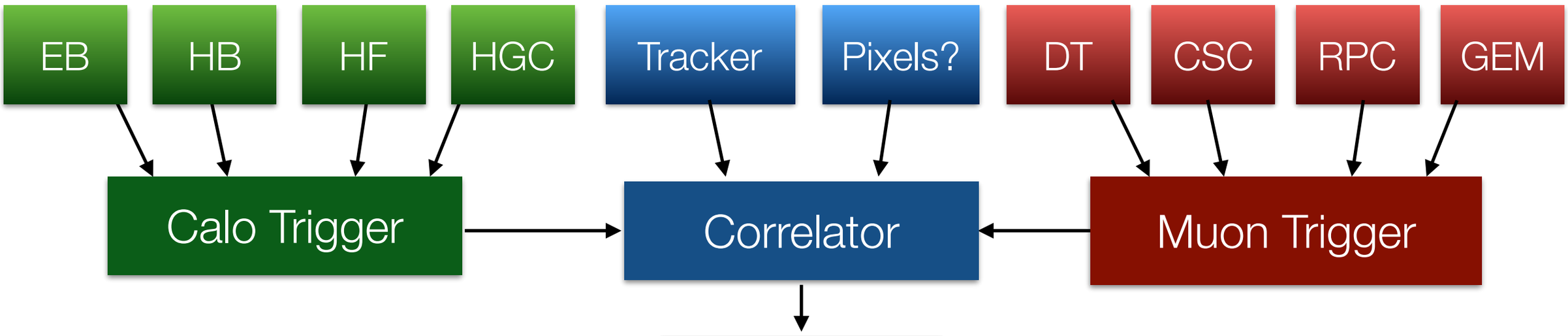
FE ASIC prototype
SKIROC2-CMS
Testing in UK



Trigger primitive generation
3D shower reconstruction in hardware/firmware

Phase 2 : Trigger

UK



- **State of the art offline reconstruction: “particle flow” technique**
  - Can we achieve (something like) this in L1 trigger hardware ?
- **Interim Document to accompany Tracker/Calo/Muon TDRs**
  - Trigger/DAQ TDRs follow in 2019
- **UK leadership**

Summary

- **LHC and CMS both performing extremely well in 2016**
  - Great potential for discovery with incoming 13 TeV dataset
  - Results so far use 1% of the total envisaged LHC dataset !

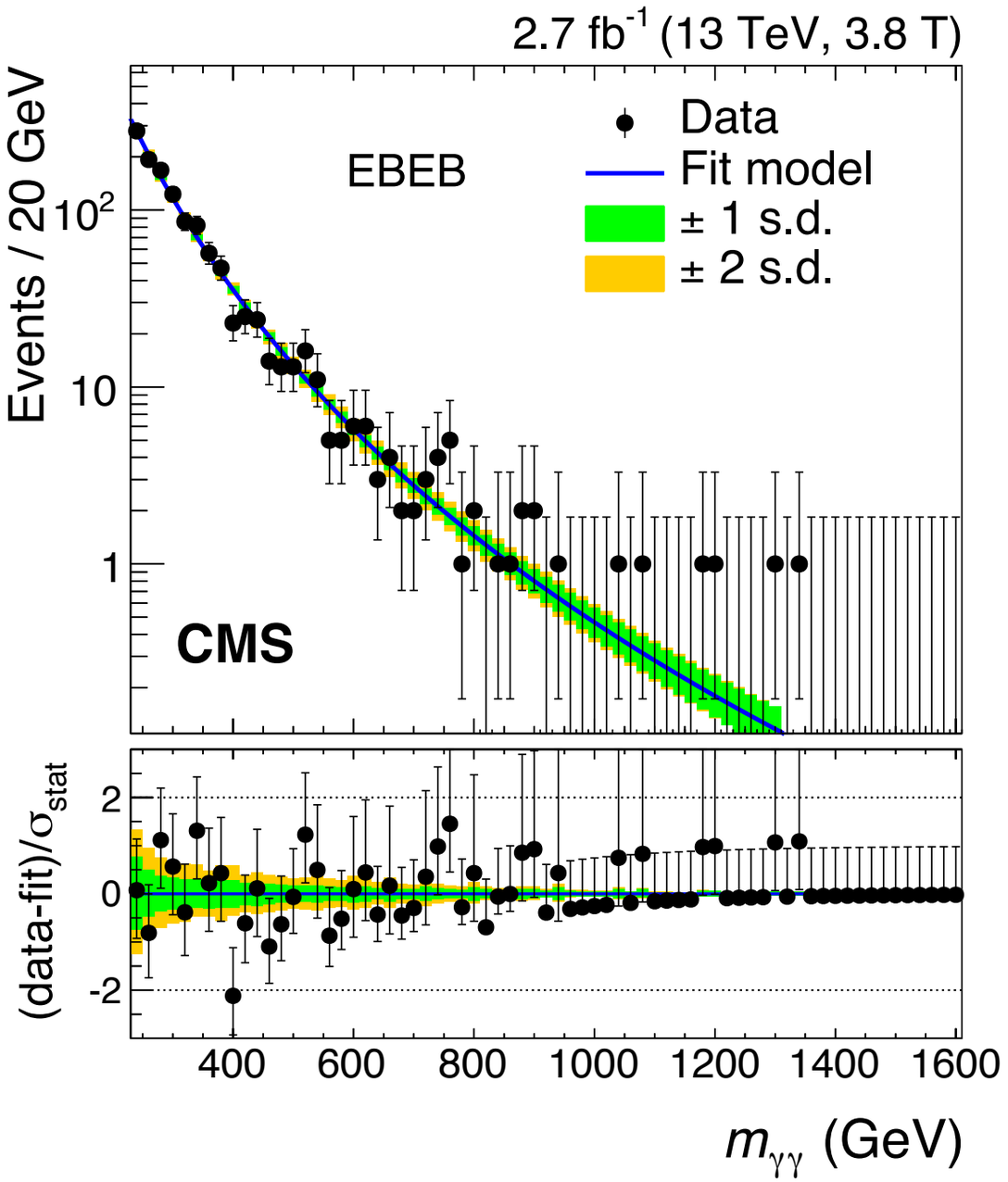
- **Successfully balancing operations, exploitation, upgrades**
  - Maintaining expert effort is critical in achieving this

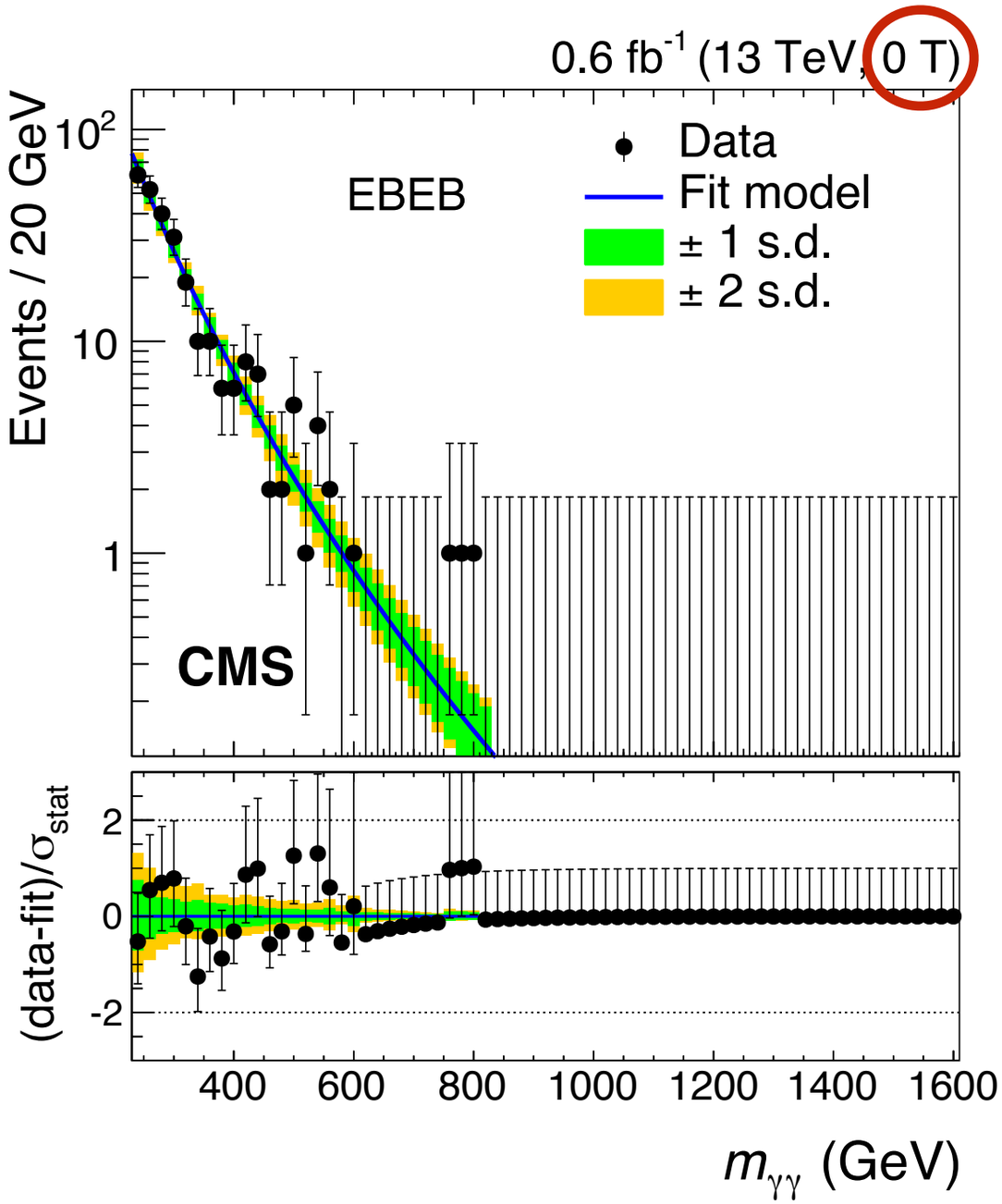
- **Upgrade programme is well underway**
  - Phase 1 Trigger successful - (very) substantial UK involvement
  - Phase 2 activities now coming to the fore
    - R&D, design studies, detailed planning
    - UK highly active in Tracking, Calorimetry, Trigger

Bonus Slides

750 GeV Excess

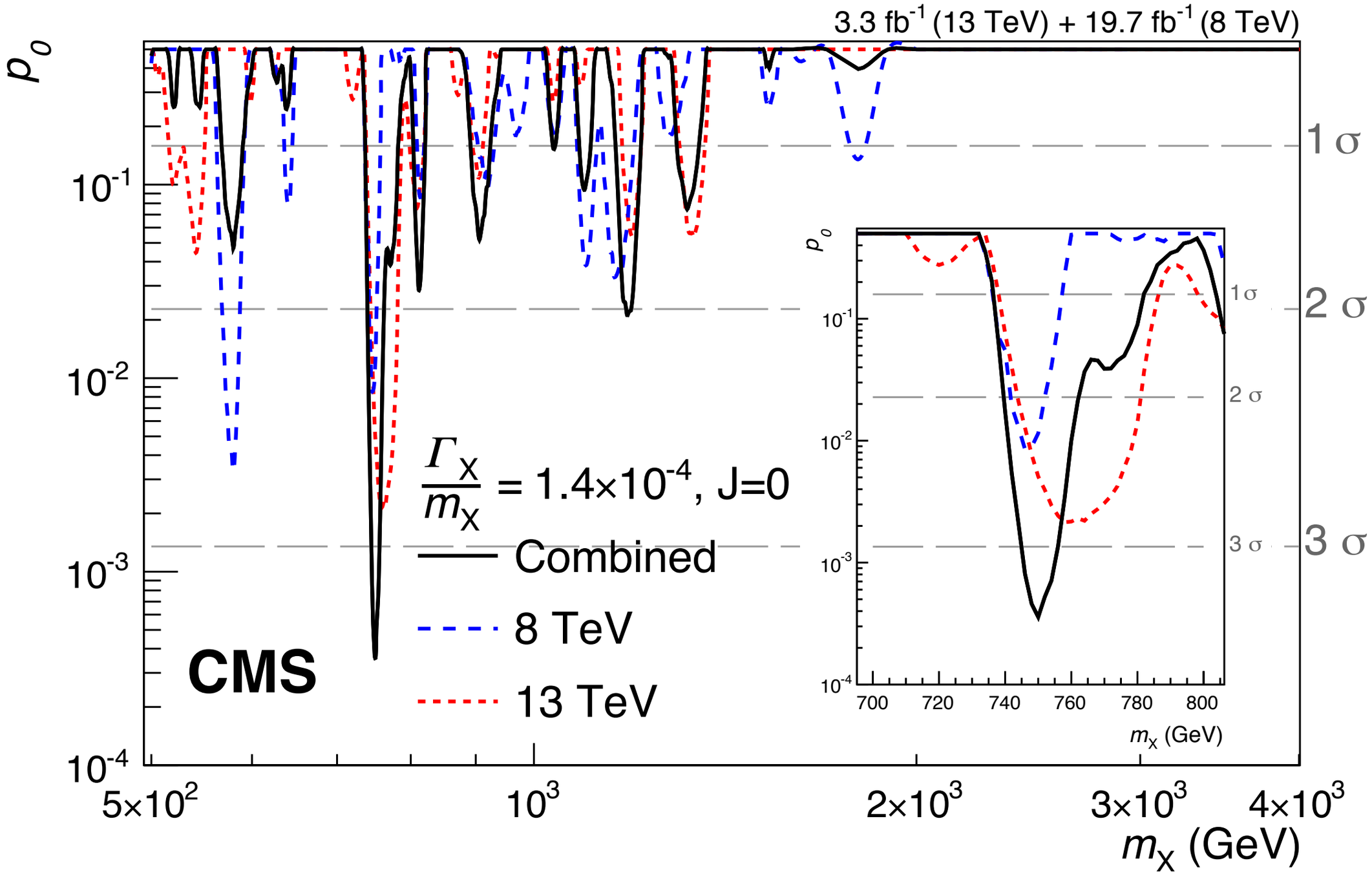
UK



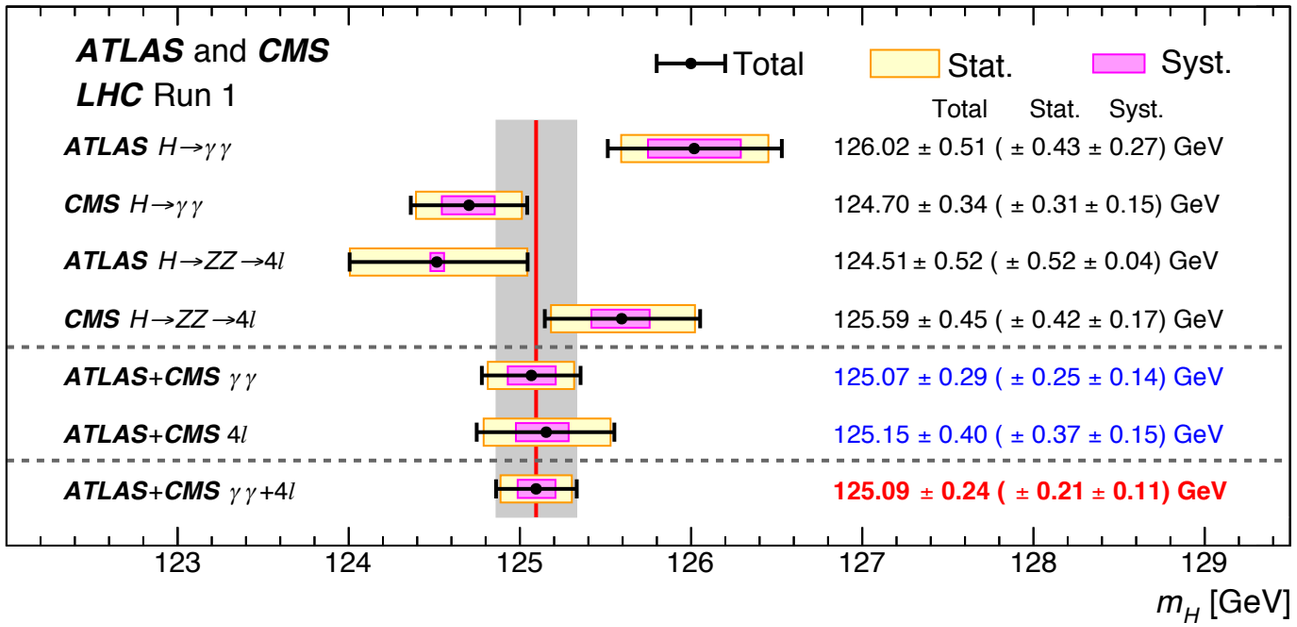


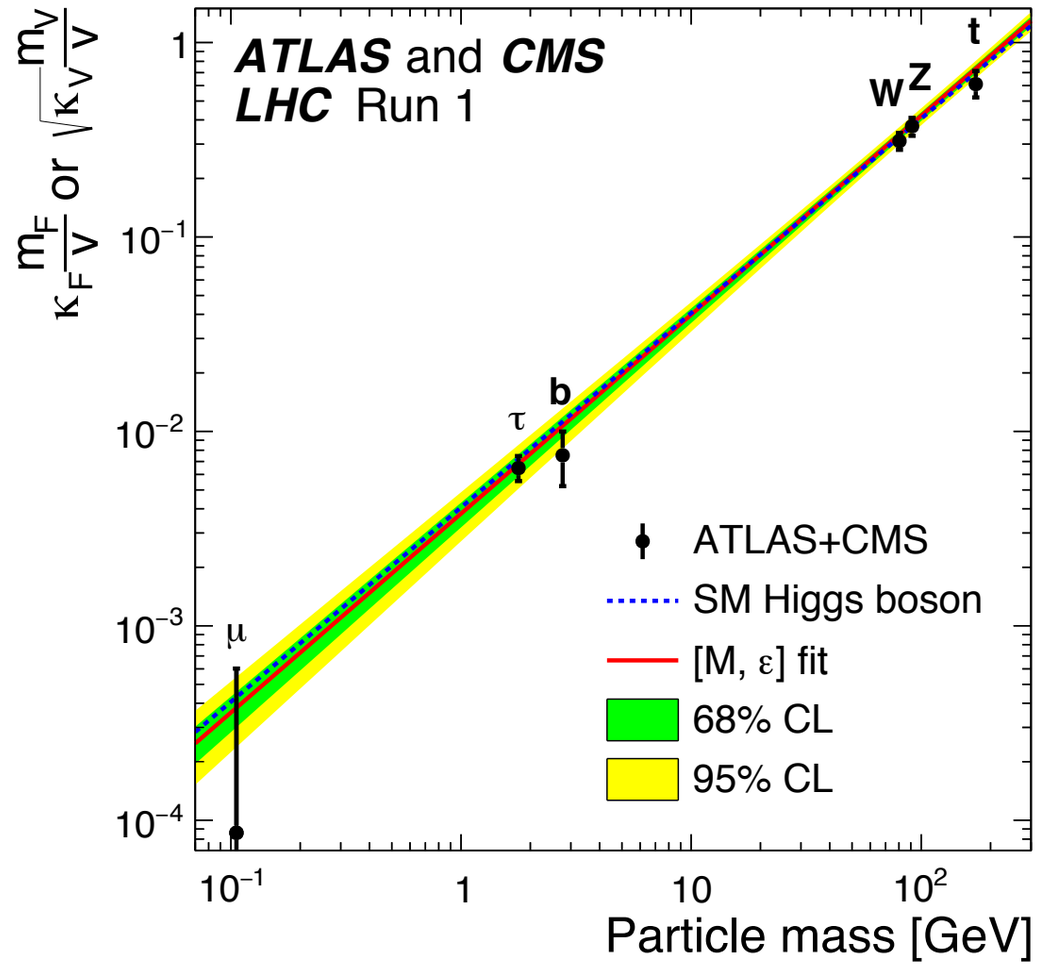
750 GeV Excess

UK



Physics : Higgs





Final Run 1 measurements