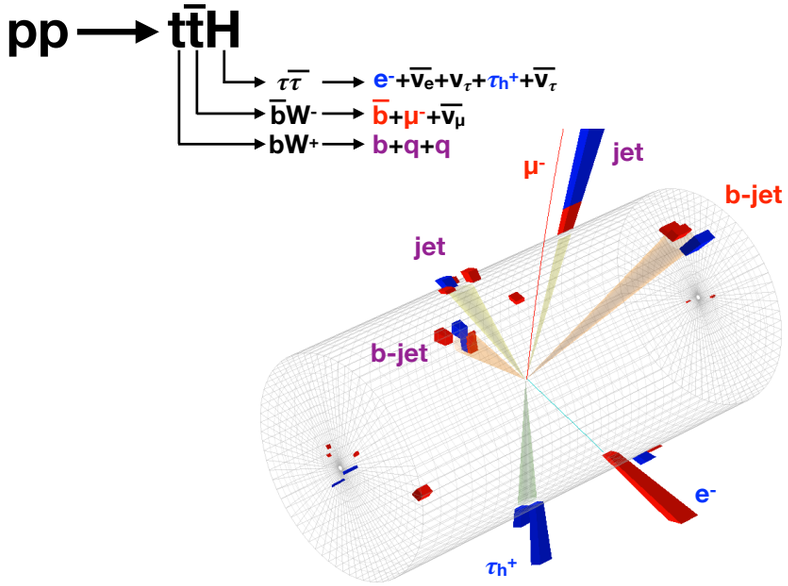
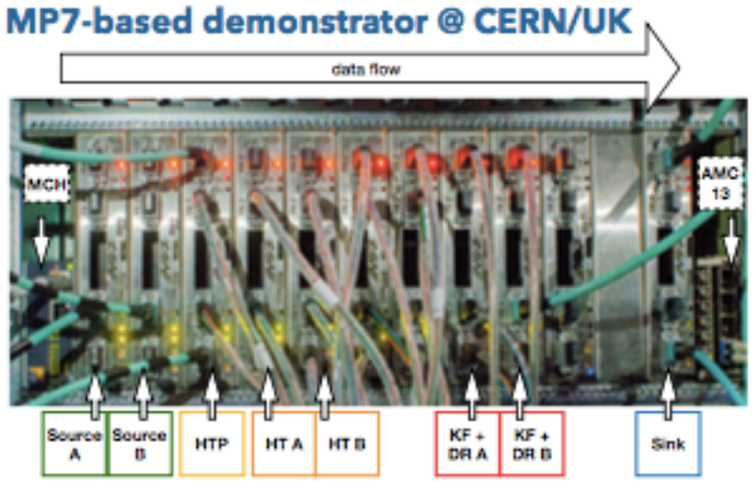
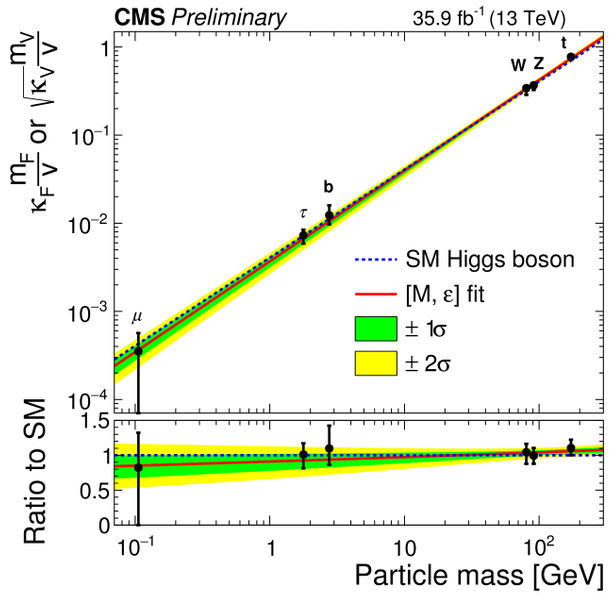
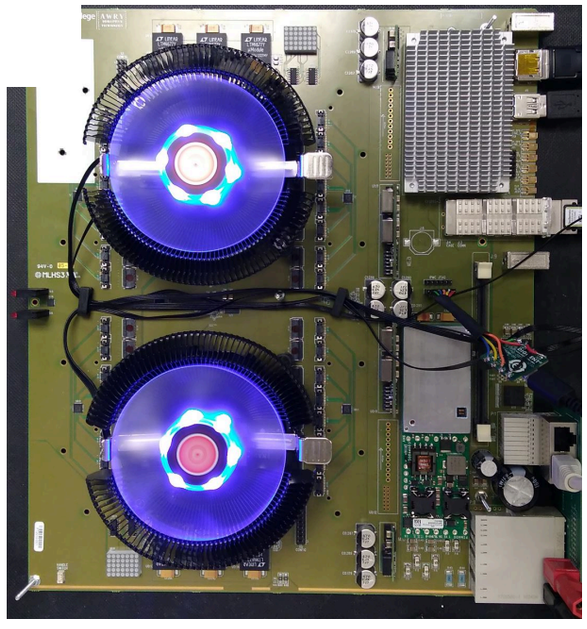
CMSUK – PPAP July 2018









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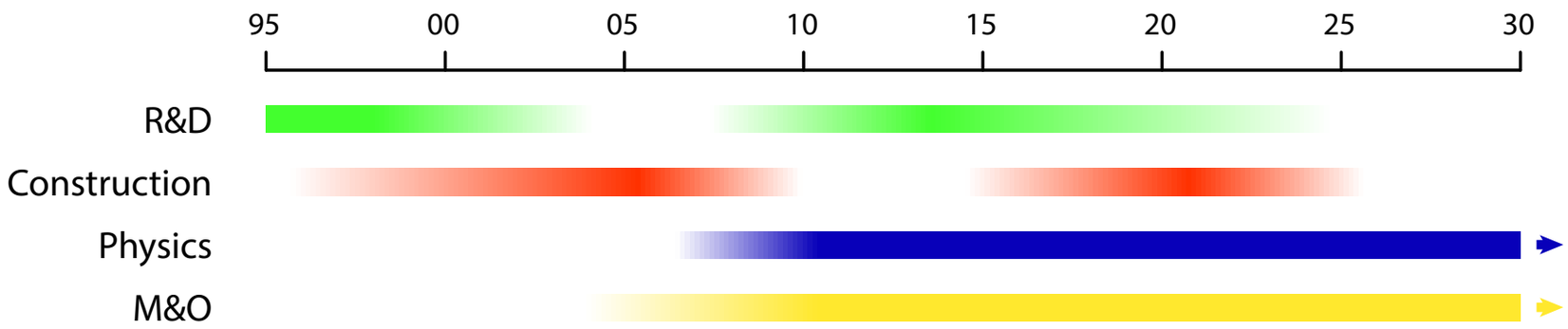
Science & Technology Facilities Council
Rutherford Appleton Laboratory

Gavin Davies

Setting the scene

- 2013 European strategy report:
  - "Europe's top priority should be exploitation of the LHC, including the high luminosity upgrade of the machine and detectors."



- Immensely exciting, but challenging
  - Operate and maintain the ageing detector
  - Exploit the increasingly large data sets with high pile-up
  - Phase 2 upgrades
    - Continue R&D, whilst transitioning into construction phase
- CMSUK critical to all aspects
  - Any reduction in funding requests would have serious impact on CMS
- This talk: illustrate above aspects for CMS & CMSUK
  - Defines present & future activities – natural evolution
    - We are a relatively small number of people, so activities highly integrated

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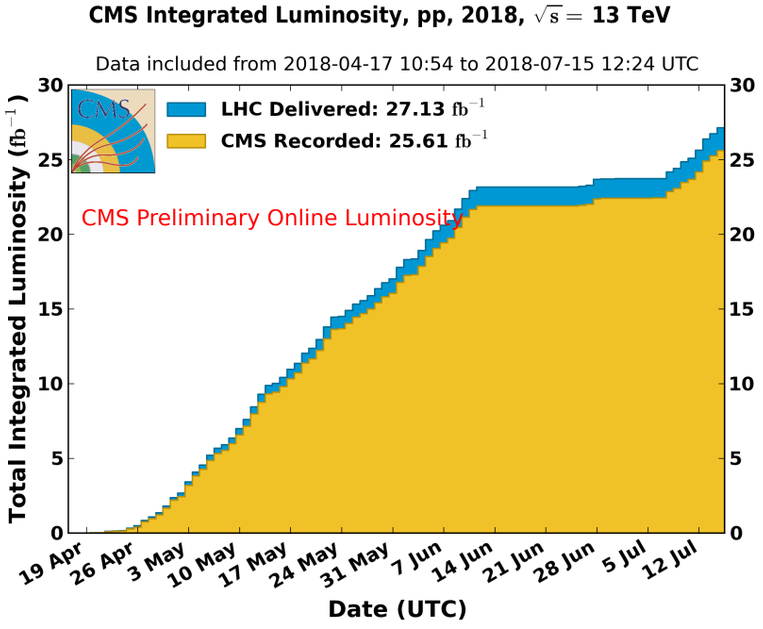
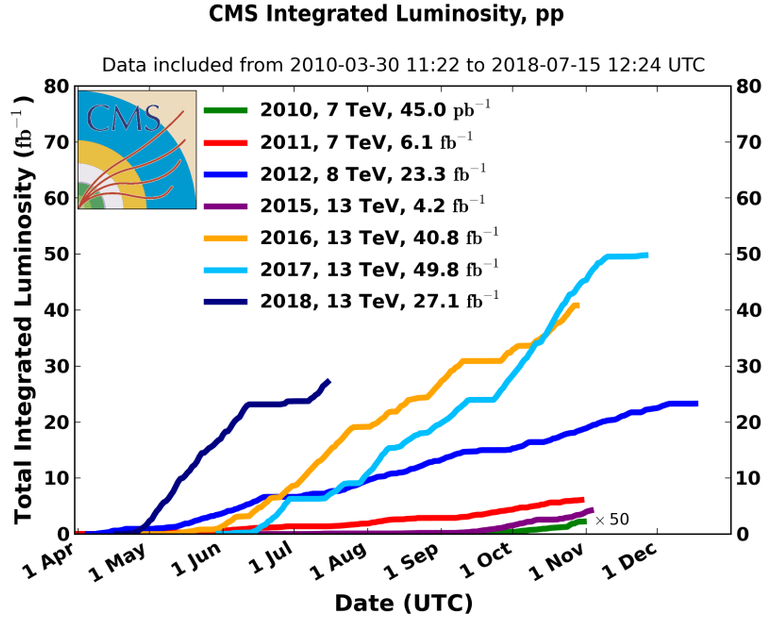
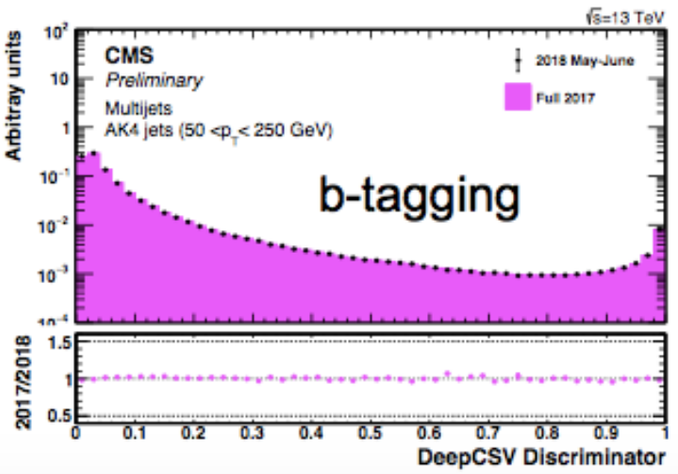
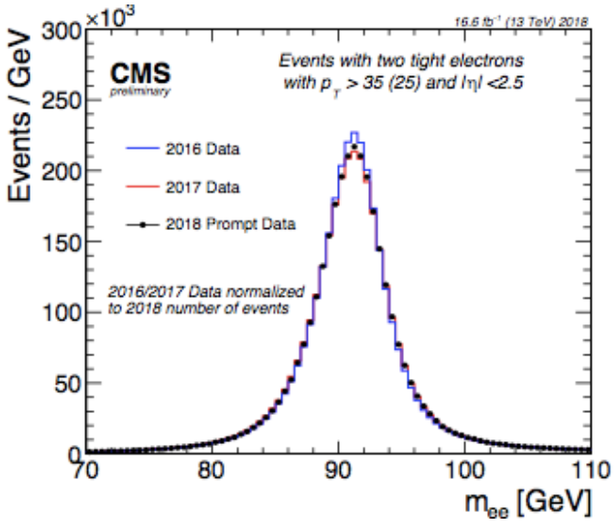
CMS Status





- Excellent start-up: ~95% data-taking efficiency
  - All DCDC converters replaced
    - No DCDC problems; issue understood
  - Recent issue with 2 sectors in one HCAL endcap
- Much activity required to maintain 95% data taking
  - CMSUK provides current Run Coordinator





2018 Data taking

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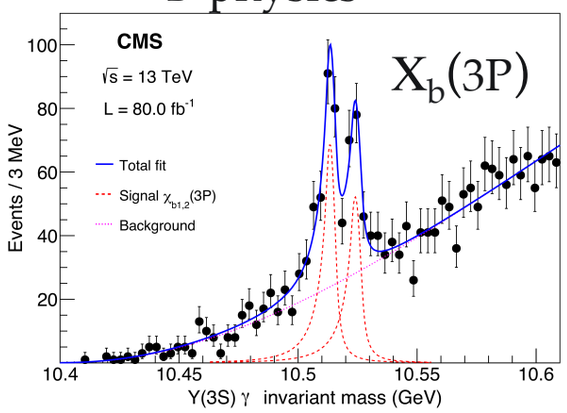
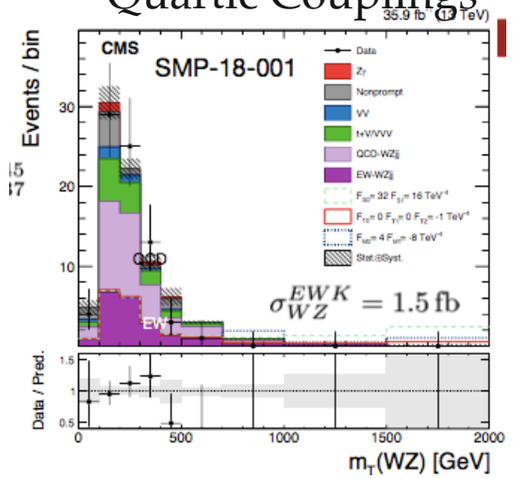
CMS Physics

- Very broad programme
  - Risen to challenge of high pile-up

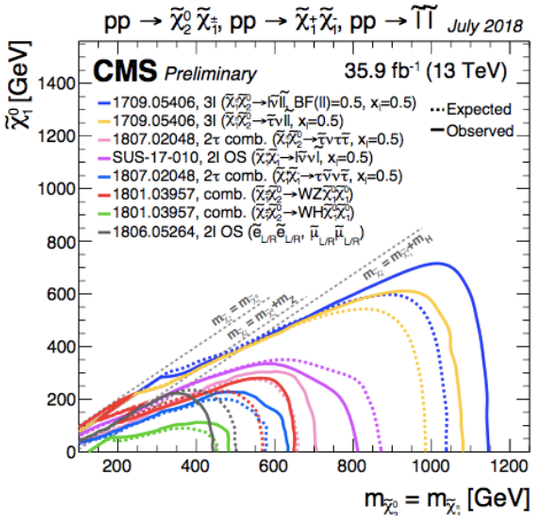
B-physics



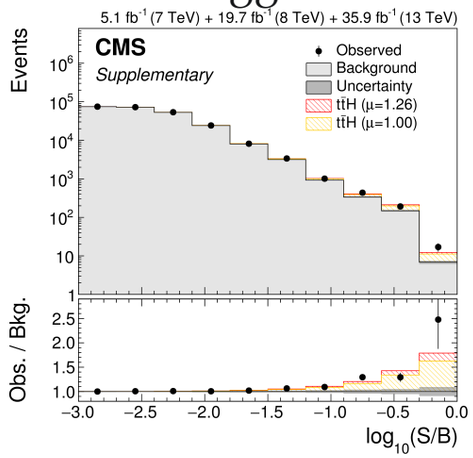
Quartic Couplings



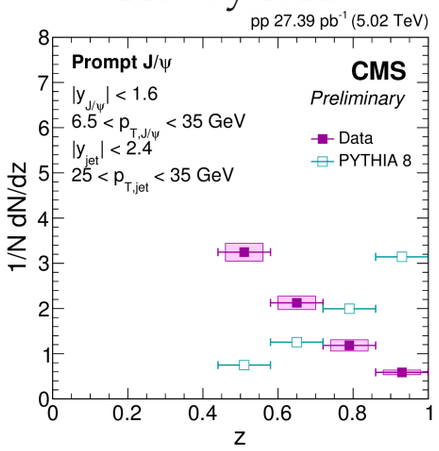
EW SUSY

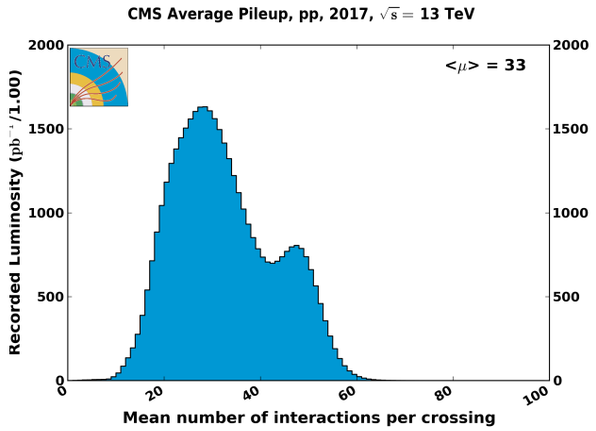


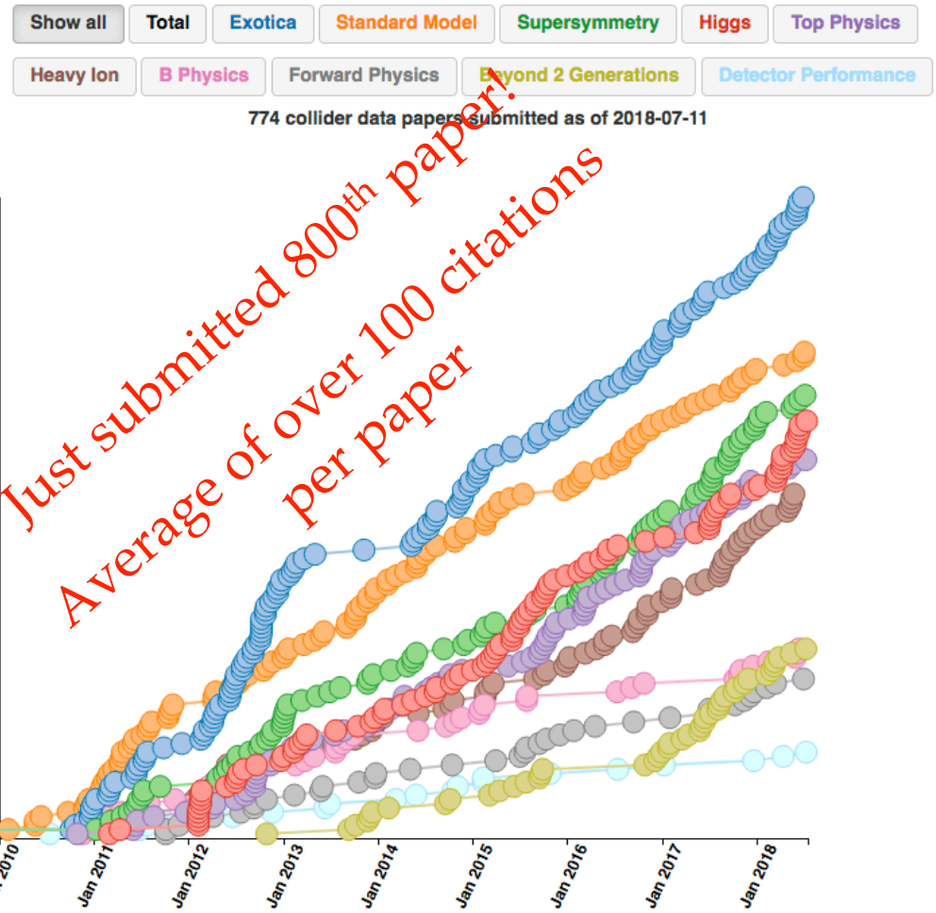
Higgs



Heavy ions







- Enjoying the larger data sets
  - Access to a wealth of physics
  - Increased publication rate

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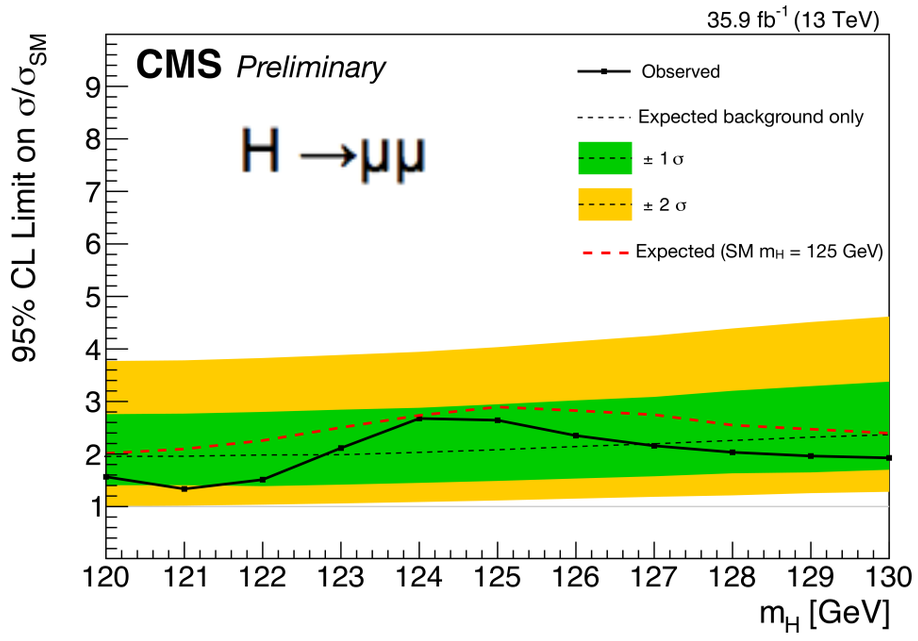
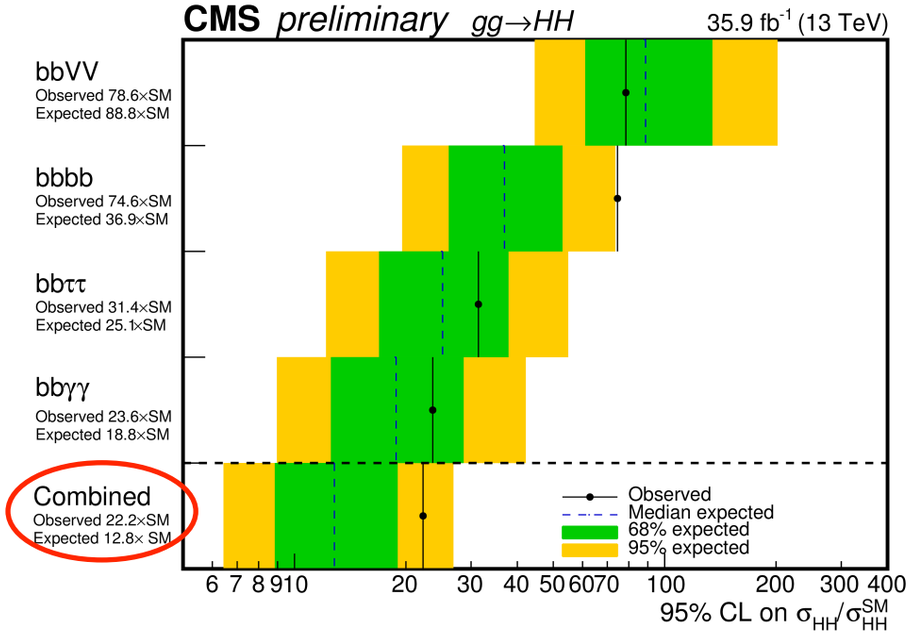
CMS Physics

- Larger data sets open a wealth of opportunity
  - More sophisticated techniques
  - Increased precision, access to rarer decays, lower cross sections…
  - e.g. evolution in Higgs sector (e.g H⟶μμ or self-coupling)

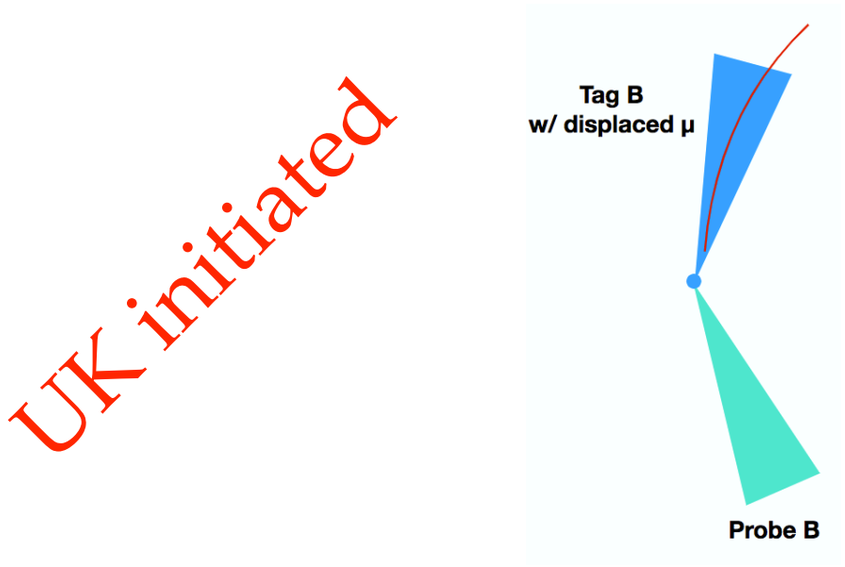


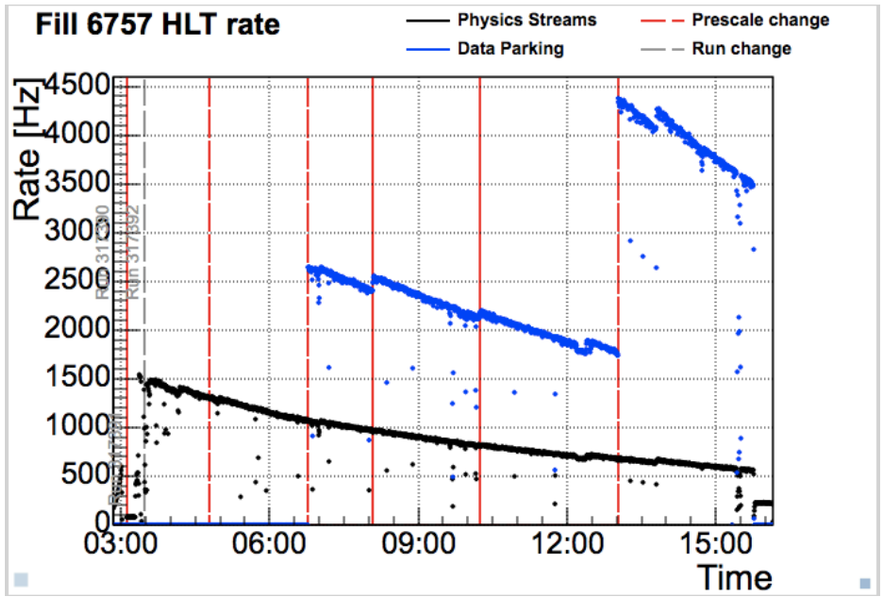


- Run 2 data should provide first hint for 2nd generation
- First results paving the way for Run3 and HL-LHC program

CMS Physics

- Larger data sets open a wealth of opportunity
  - More sophisticated techniques
  - Increased precision, access to rarer decays, lower cross sections…
  - e.g. exploit data-parking





  - Collect large sample of unbiased B decays
  - Enable broad programme of B physics during LS2
  - Use ‘old’ opposite side tag method, turning-on L1 seeds as rate falls

- Legacy Run 2 & Run 3: Evolution to rarer processes, more complete coverage of parameter space, and precision measurements with tighter constraints on NP

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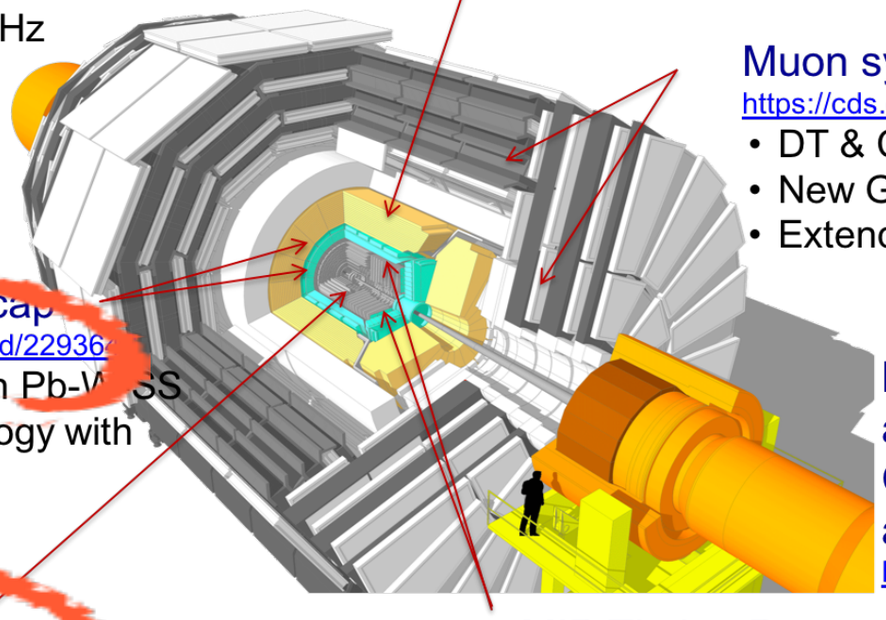
CMS Upgrade

L1-Trigger/HLT/DAQ
https://cds.cern.ch/record/22831
https://cds.cern.ch/record/2283193
- Tracks in L1-Trigger at 40 MHz for 750 kHz PFlow-like selection rate
- HLT output 7.5 kHz

Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

Calorimeter Endcap
https://cds.cern.ch/record/22936
- Si, Scint+SiPM in Pb-W-SS
- 3D shower topology with precise timing



Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure
https://cds.cern.ch/record/2020886

Tracker https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

MIP Timing Detector
https://cds.cern.ch/record/2296612
- $\simeq$ 30 ps resolution
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

- High statistics needed to explore high masses, small couplings, rare decays
- Need high lumi, high trigger acceptance, high reconstruction efficiency
  - Acceptance for W/Z/γ, and jet / energy flow resolution, must be as good or better than Run 2
- The UK programme addresses these points *directly*
- Global reconstruction requires a balanced approach to sub-detector upgrades

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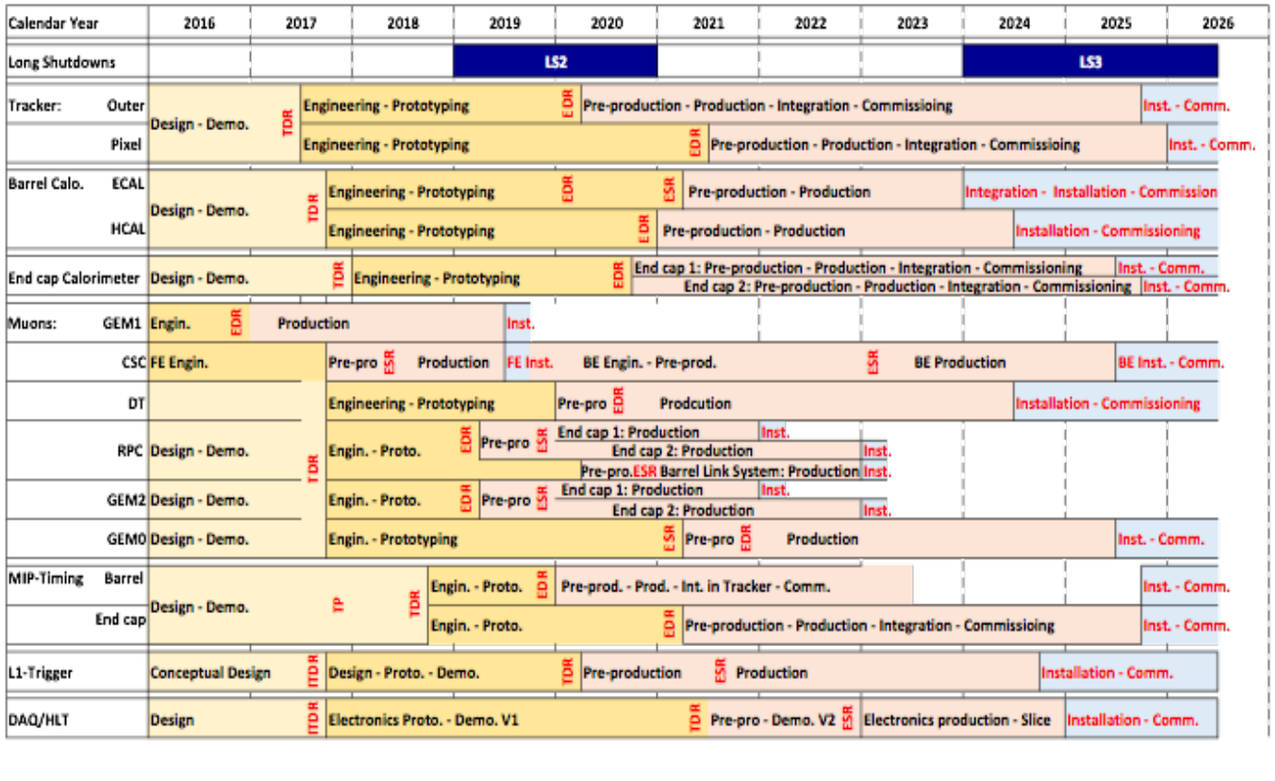
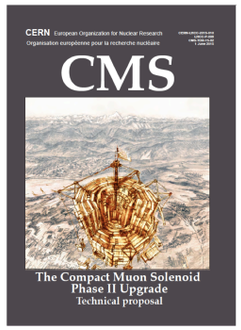
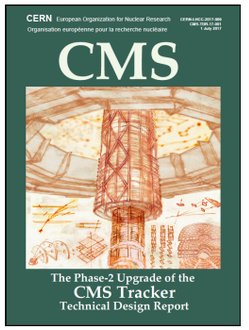
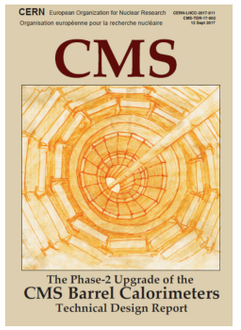
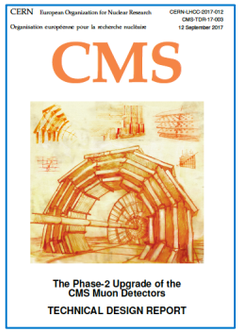
CMS Upgrade

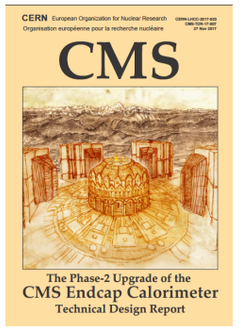


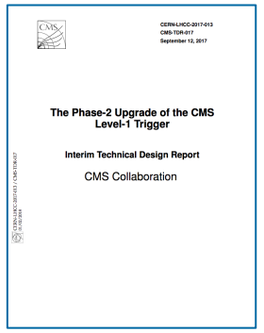








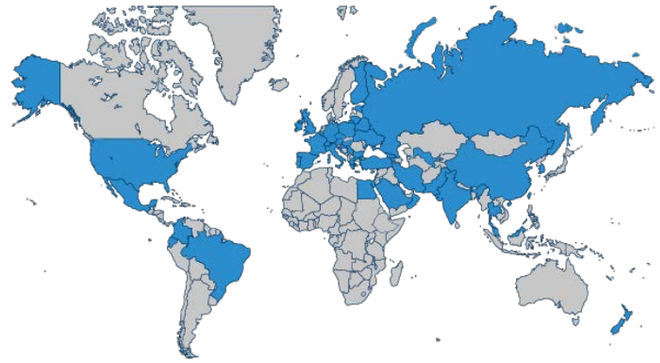


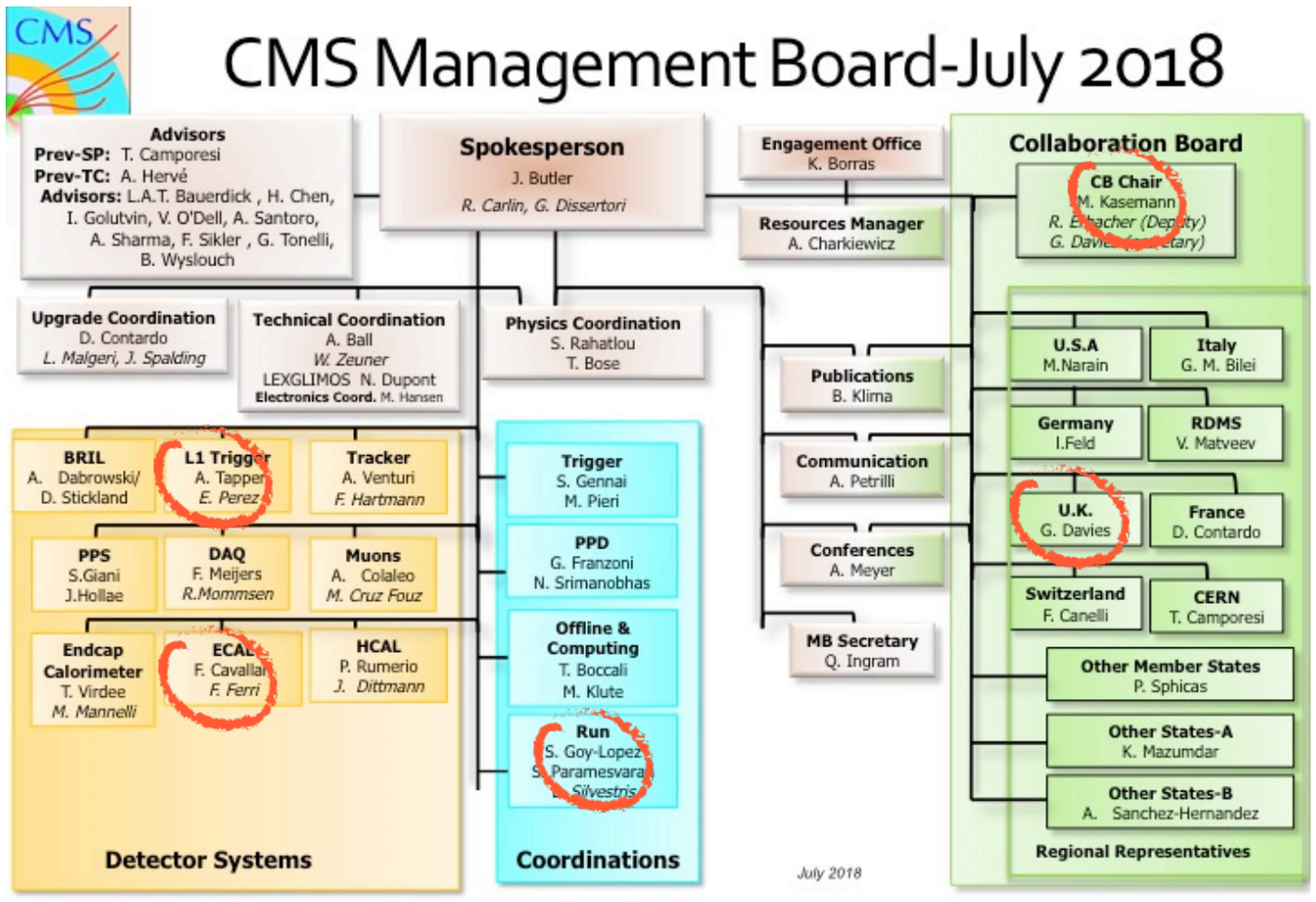


- Overall, and individual TDR's approved by LHCC
  - Capital cost ~275MCHF (~50% of original cost), covered by FA indicated budgets
  - Negotiation of deliverables largely complete, documented in TDRs
  - Moving towards signing of MoU's later this year
- CMSUK responsible for key aspects
  - Our continued leadership integral to overall CMS plan
  - Looking forward to UKRI swiftly processing our construction bid

UK in CMS

- Continue to punch above our weight (only ~4% of the Collaboration)
  - Key roles & responsibilities in operations, physics and upgrade
  - Management roles:
    - Three current (or ex) system managers: L1 trigger, HGCAL, ECAL
    - Run coordination
    - Exotic Physics group
    - MB & XEB members, CB secretary, Diversity Office Chair
    - Numerous L2 positions: L1 Trigger, data preparation, computing, physics, upgrades (L1 trigger, tracker, HGCAL)
    - Lead most analysis groups in which we participate





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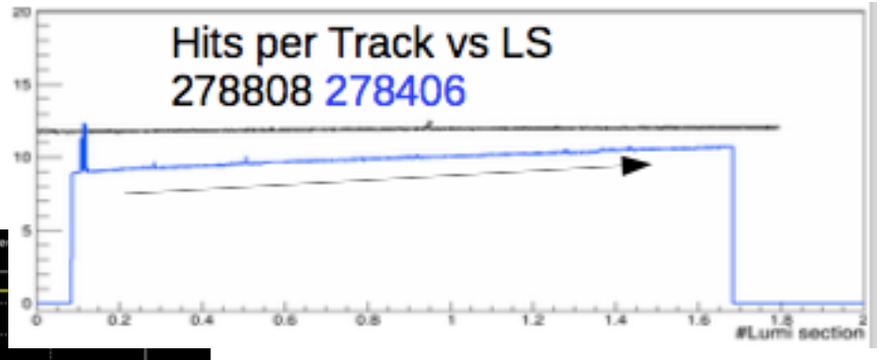
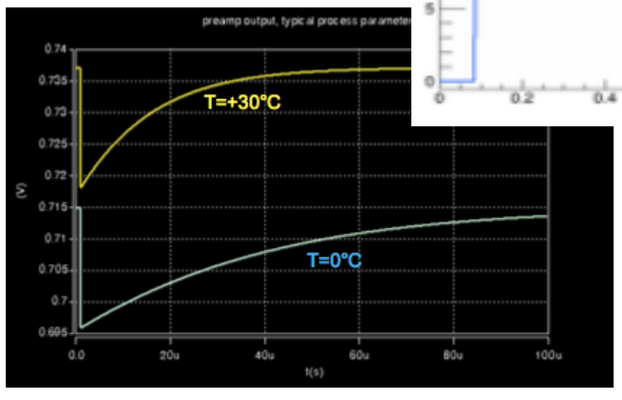
CMSUK Operations

- UK mission-critical M&O responsibilities
  - ECAL endcaps, Tracker readout, Level-1 Trigger
    - Also software for reconstruction and analysis, and computing
  - Commitments remain throughout lifetime of the experiment
    - Increased pile-up, firmware /software evolution, detector ageing

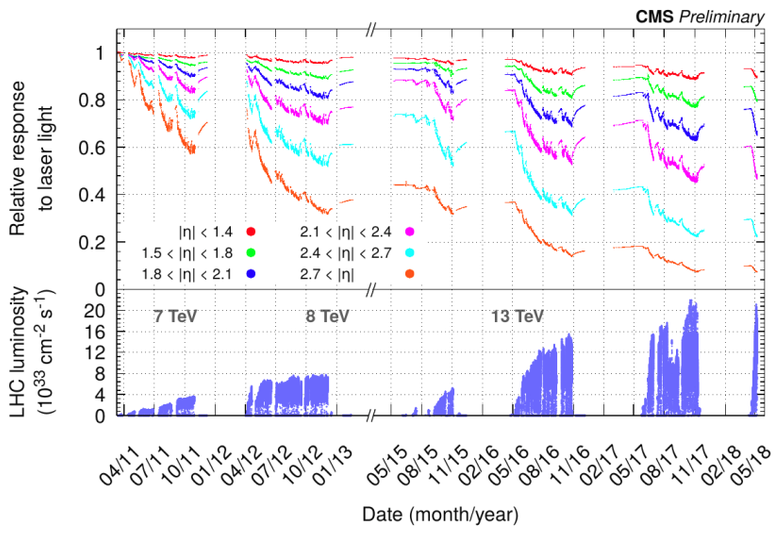
- e.g. Tracker readout
  - Loss of tracking efficiency with increasing luminosity
  - Finally understood to be slower recovery time of APV at low temperatures
  - New APV settings fixed issue



Pre-amp recovery



- e.g. Maintaining ECAL performance
  - Led evaluation studies
  - Took action to recover and preserve 2018 trigger efficiency
  - Most crucial in forward regions



- Effort essential for Run 3 & beyond

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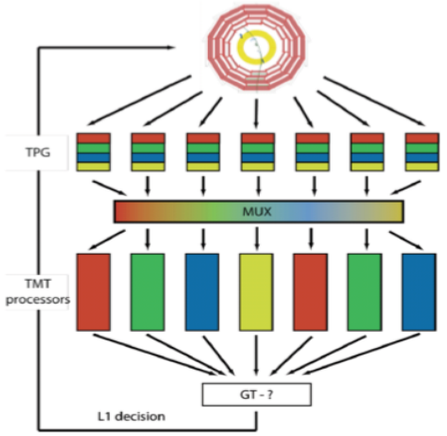
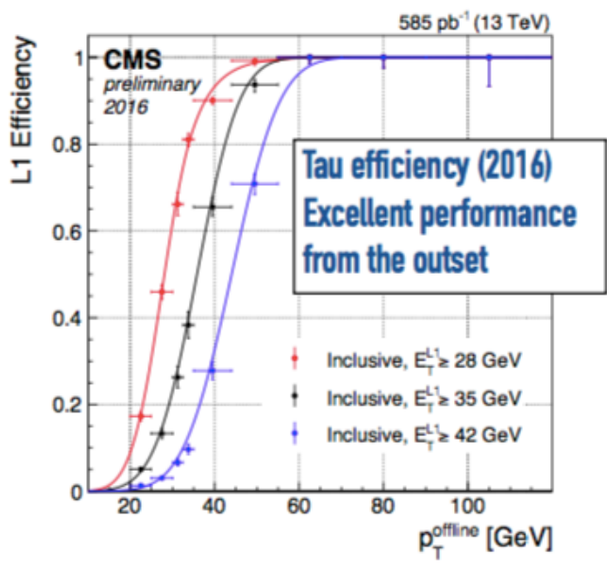
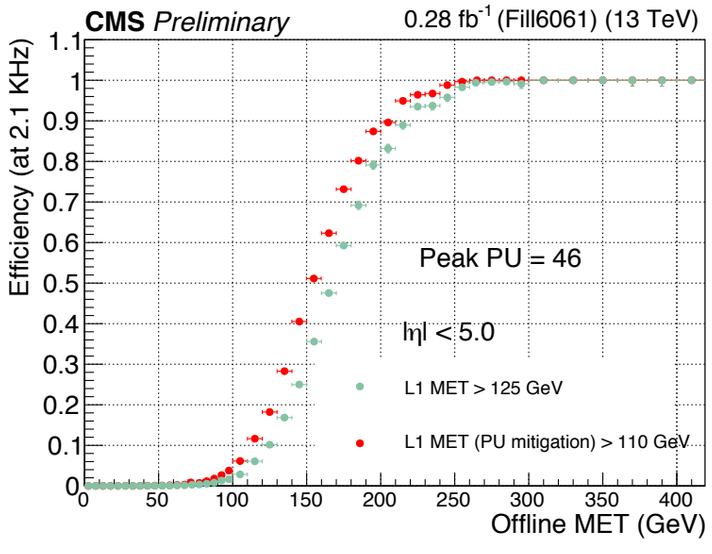
CMSUK Operations

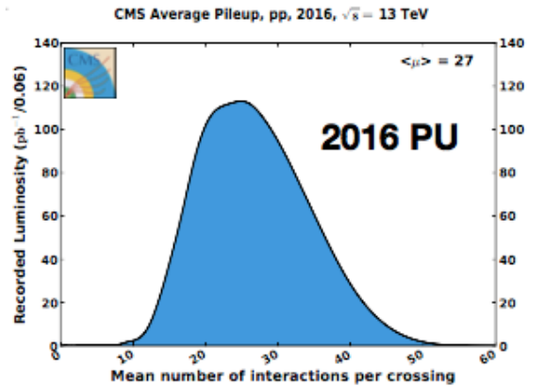
- Phase 1 Trigger Upgrade
  - UK: leading role in ambitious replacement of entire L1 Trigger
    - Novel time-multiplexed architecture
    - Common hardware / software platform (MP7, FC7)

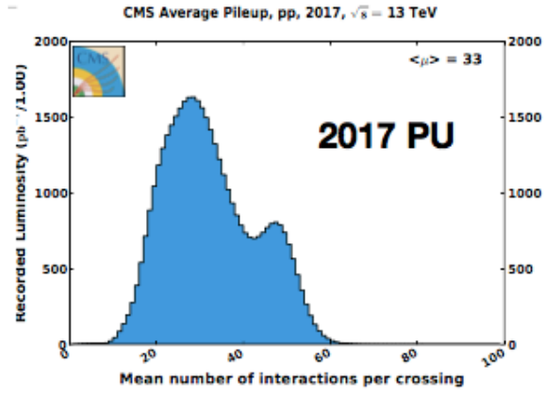




- Highly successful
- 2017: Changing beam conditions tested flexibility
  - Object reconstruction and menus re-optimised for high pile-up
  - MET trigger rate particularly sensitive to high PU
  - PU mitigation algorithm studied, implemented & optimised
  - Factor of 2 reduction in rate (= ~15GeV in threshold)







- Looking ahead for CMSUK M&O
  - LS2: Consolidation & preparation for Run 3
  - Run 3 operation

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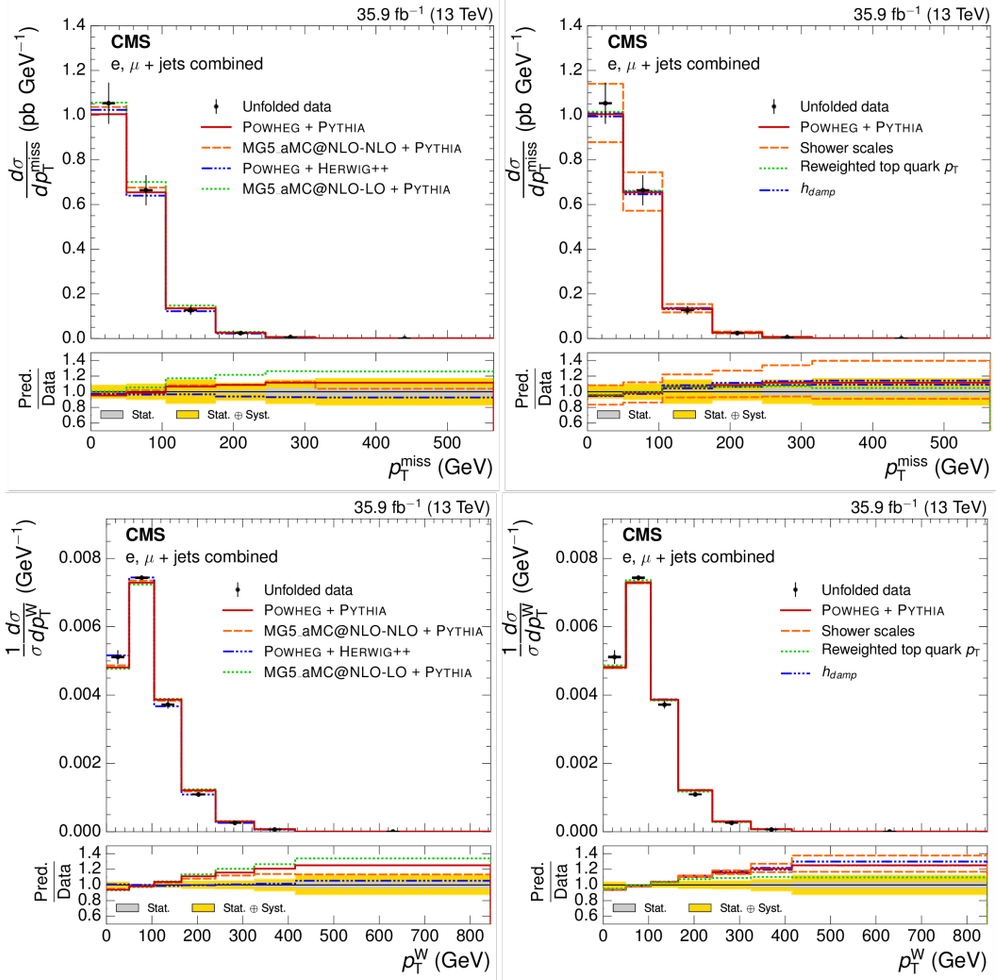
CMSUK Physics

- UK: Leading roles SM (top), Searches (SUSY, DM, Z', exotics) & Higgs
  - Evolution to rarer processes, precision measurements & constraints on NP
  - Significant phenomenological activity
    - SUSY (Mastercode), DM searches at LHC / interplay with others, long-lived particles, Z' bosons, NMSSM Higgs, heavy neutrinos

- Top
  - ttbar differential cross section measurements
    - Results consistent with all NLO generators
  - ttbar spin studies
  - tZq – rare SM single top production
  - Larger datatsets
    - SM measurements & contraints on NP
    - Top modelling – inc Sherpa tuning

- Increasing V+jets effort
  - Intrinsic interest & as background in searches



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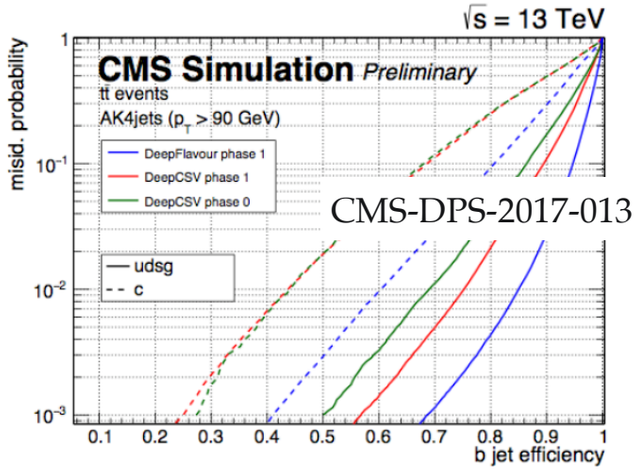
CMSUK Physics - searches

- "α_T" – inclusive jets + MET
  - First published SUSY search from LHC
    - Seven publications so far, >1000 citations
  - Sensitive to broad range of SUSY & generic DM models
    - Focus on extension to wider models
    - Develop dedicated LLP tagger – motivated by deep learning b-tagger



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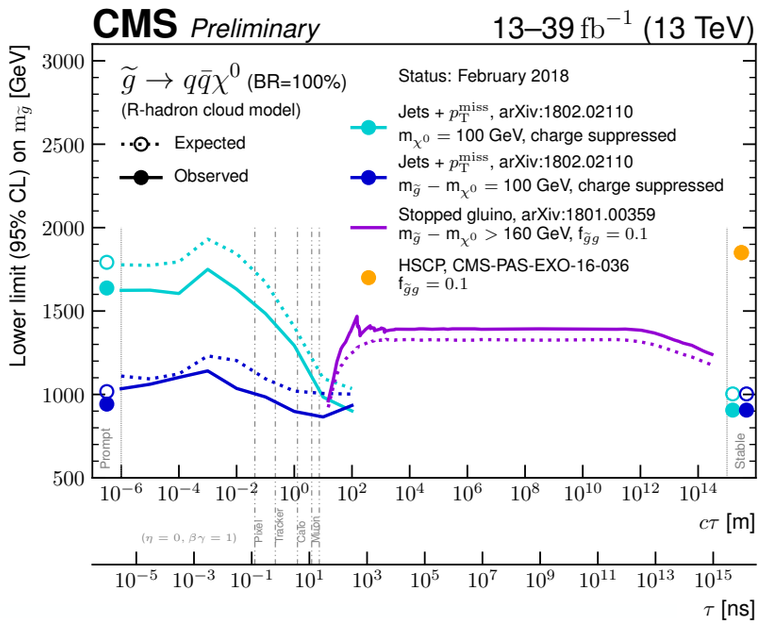

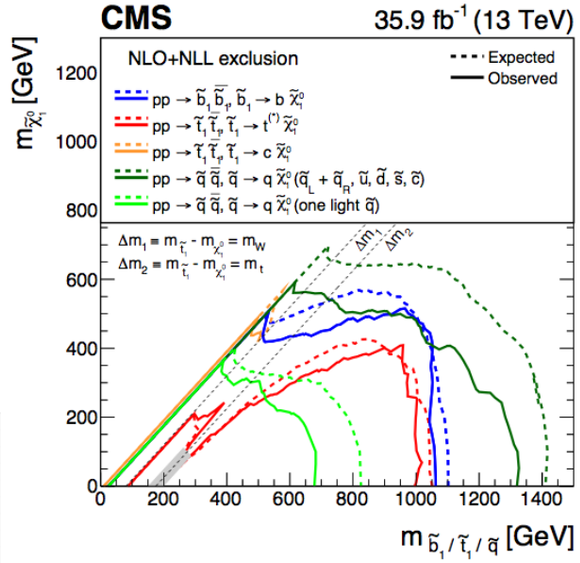

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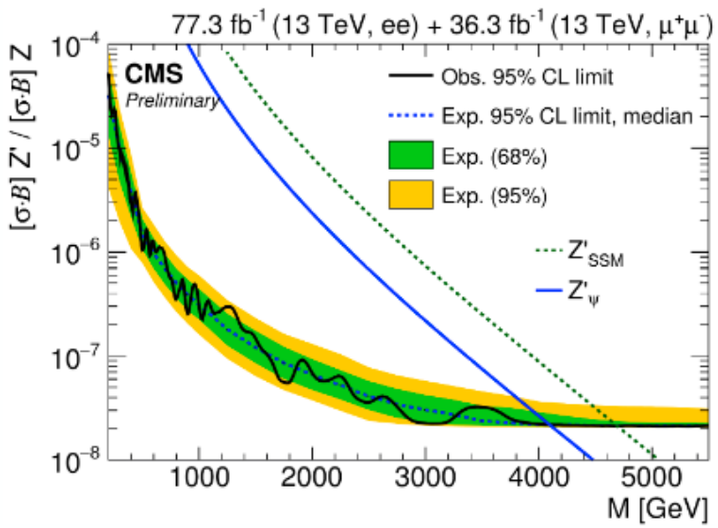
Long-lived coverage

- Other Searches…
- Other extensions..
  - Semi-visible jets, Boosted Higgs in NMSSM decays



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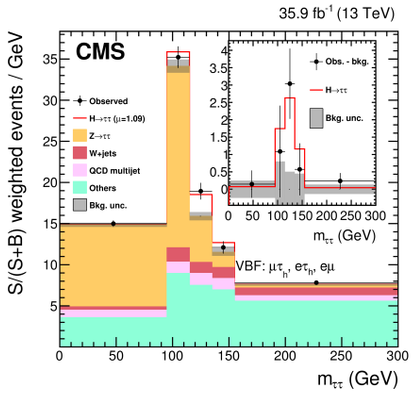
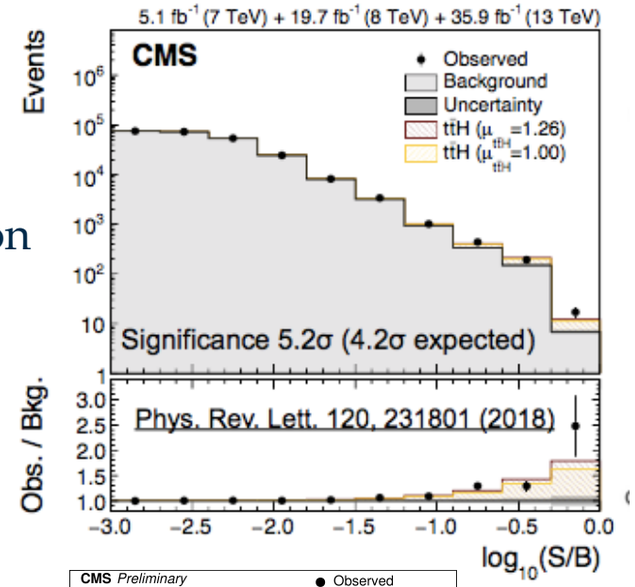
CMSUK Physics - Higgs

From observation to characterisation

Last year: ττ Observation



Earlier this year: ttH Observation

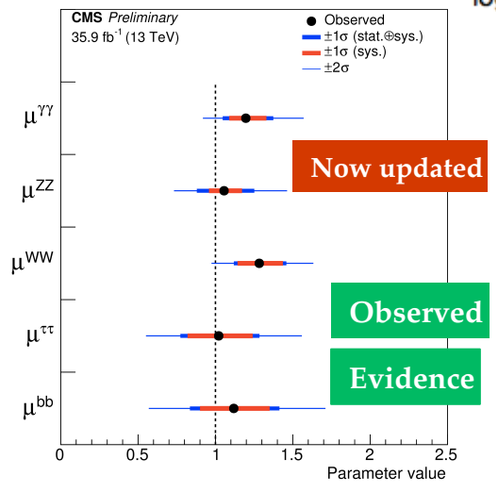


- Rapid evolution in combination

$$\mu = 1.17^{+0.10}_{-0.10} = 1.17^{+0.06}_{-0.06}\,(\text{stat.})\,^{+0.06}_{-0.05}\,(\text{sig. th.})\,^{+0.06}_{-0.06}\,(\text{other sys.})$$

- Differential distributions
- Search for NP – Higgs to invisible

	ggF	VBF	VH	ttH
H→ZZ→4l	•	•	•	•
H→γγ	•	•	•	•
H→WW	•	•	•	•
H→bb	•		•	•
H→ττ	•	•		•
H→μμ	•	•		
H→inv	•	•	•	



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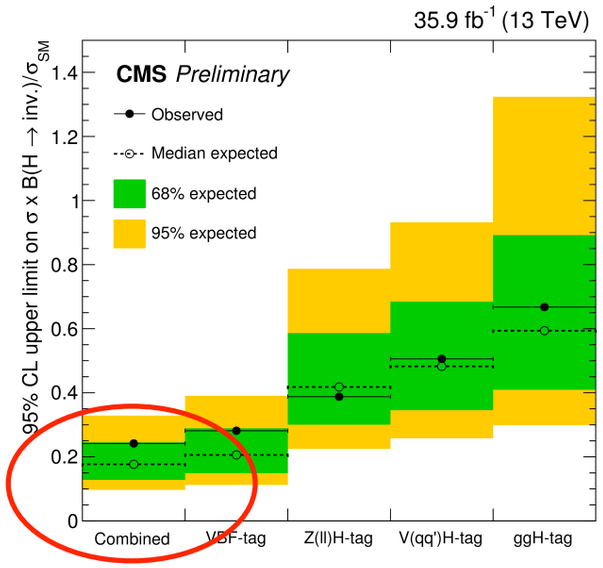

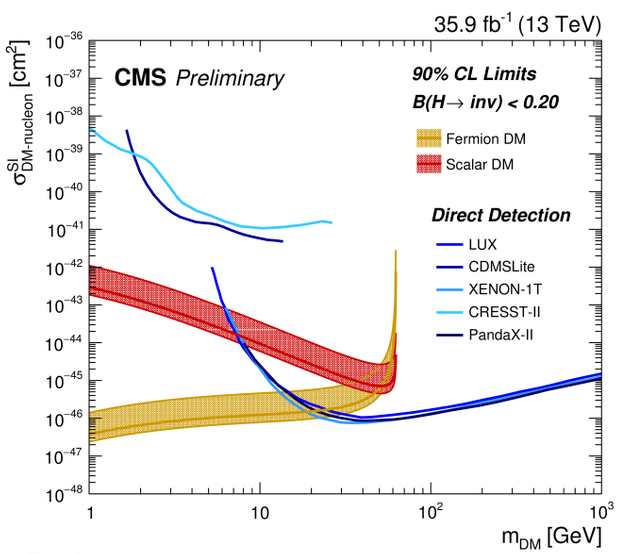

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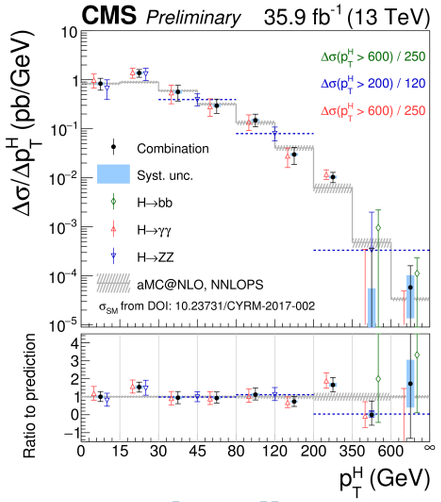
HIG-17-028



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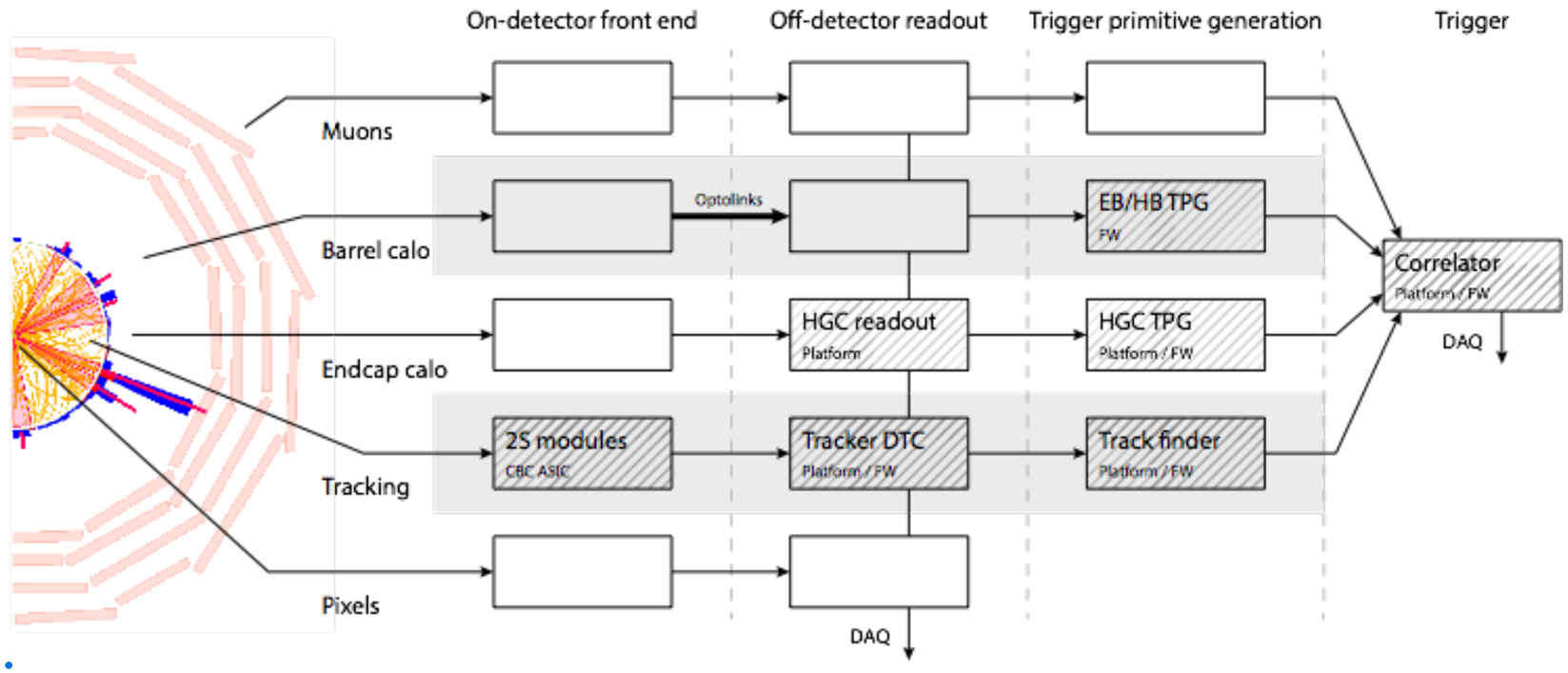
CMSUK Upgrade

- Strategy
  - Build on success of original and Phase-1 projects
    - In particular off-detector electronics
  - Create common technology WP
    - Enables us to broaden our leadership / influence within sub-detectors
    - Clear potential for wider use
  - Maintain crucial contribution to trigger – major factor in physics performance

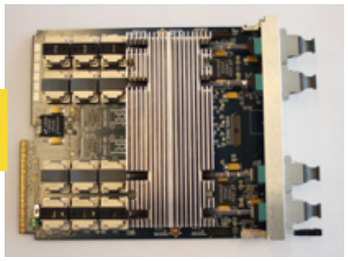


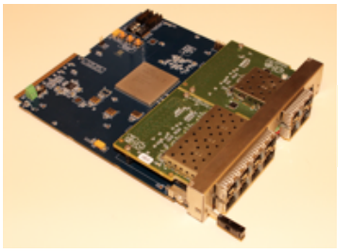
- Objectives:
  - Common readout and trigger electronic module for use across subsystems
  - Outer tracker readout ASIC
  - Tracker off-detector readout electronics and L1 track-finding system [New at HL-LHC]
  - Trigger electronics for the CMS calorimeters
  - Level-1 trigger correlator

CMSUK Upgrade: Common Technology

- New back-end electronics necessary

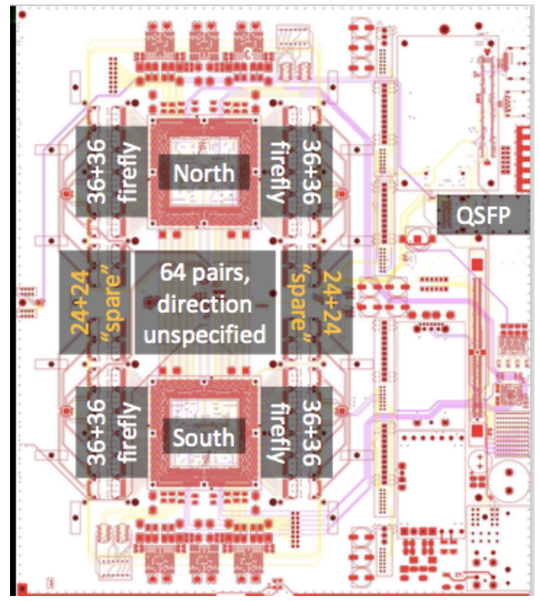
MP7

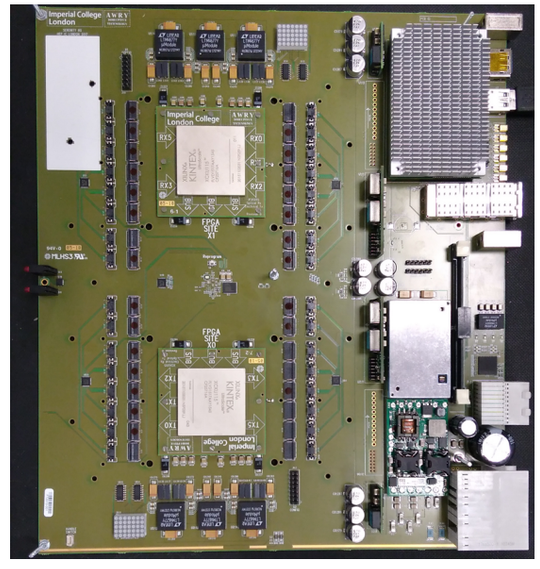


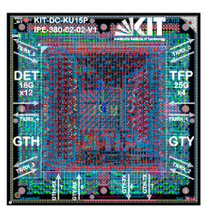


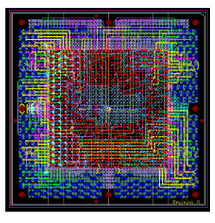
FC7

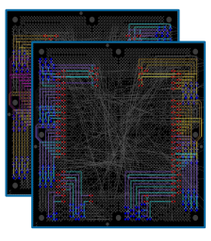
- Common approach
  - Covers hardware, firmware, software
  - Manpower savings
    - Both in construction & operation
  - Builds on success of Phase 1 project (MP7,FC7)
- "Serenity" – first full prototype now in hand
  - ATCA development platform
    - Carrier card (services), Daughter cards (data processing FPGAs), Firmware & software
  - Flexibility & adaptability
  - Pragmatic approach, with collaborators, to de-risk complex development, reducing costs & simplifying future operations

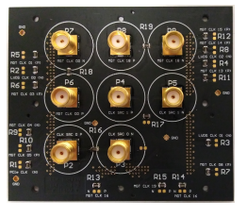












- Complete generic development & then tailor to sub-detector needs

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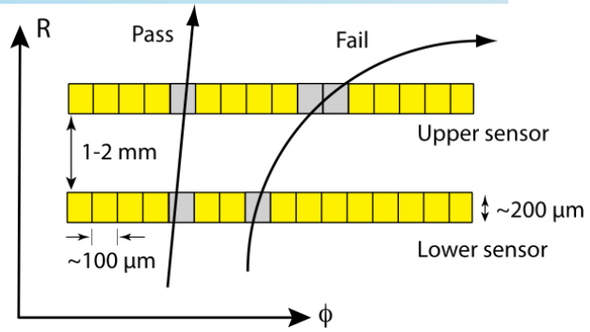
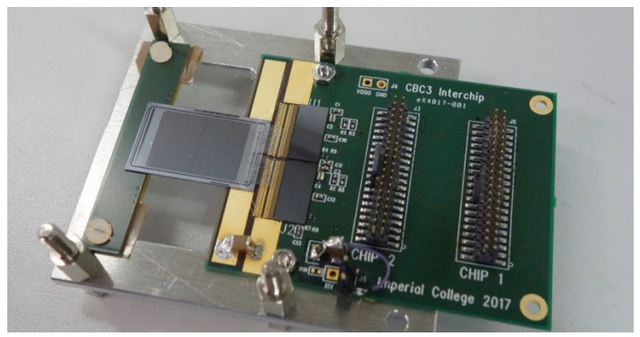
CMSUK Upgrade: Tracker

- Physics goals necessitate use of track information in L1 trigger
  - Never been done before
- New concept for silicon tracking
  - Detector comprises 'p_T modules', producing 'stubs'
  - CBC ASIC correlates hits in outer layers
- UK leadership
  - Original concept of stacked tracking
  - CBC ASIC; hardware track finder, BE boards
- Hardware track finder
  - UK proposed FPGA based solution – using Hough transform and Kalman filter track fitter
  - Result: Adoption of UK technology & project leadership
  - Now need to turn system into reality
  - Off-detector electronics
    - Largest of new CMS electronics systems
    - ~400 boards with large FPGAs

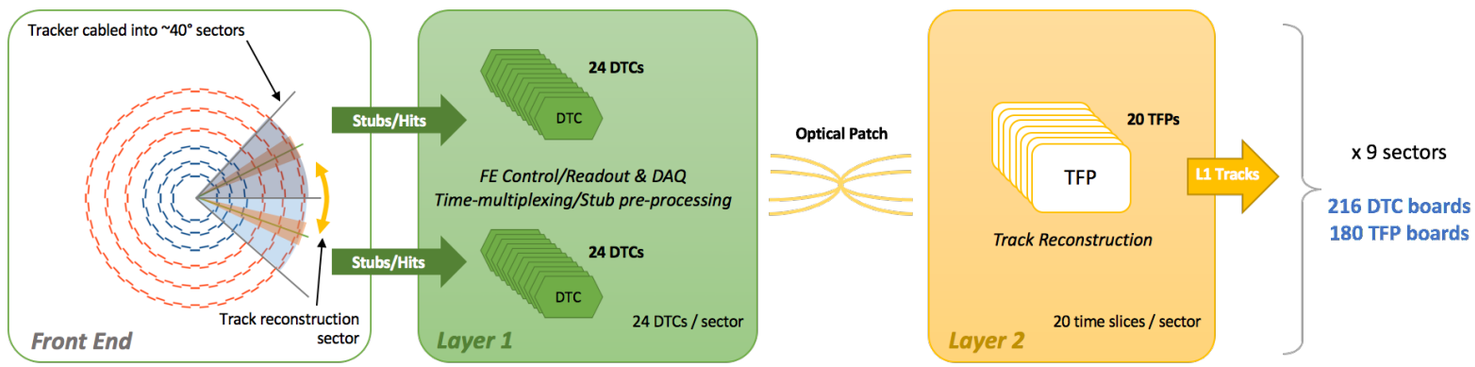


CBC3 module



CBC3.1 (final version)

- Submitted



- Continued optimisation of TF algorithms
- Hardware specialisation for BE boards, inc DTC and TF

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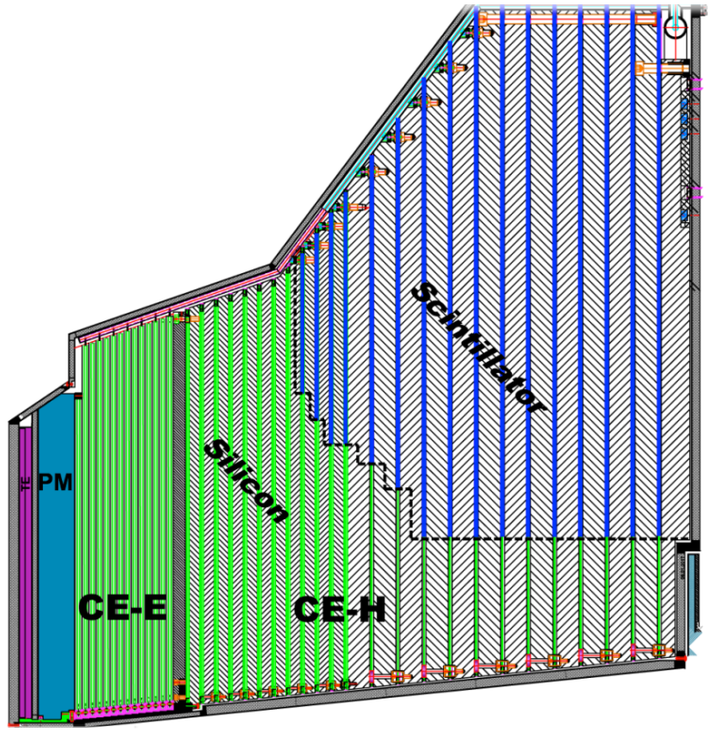
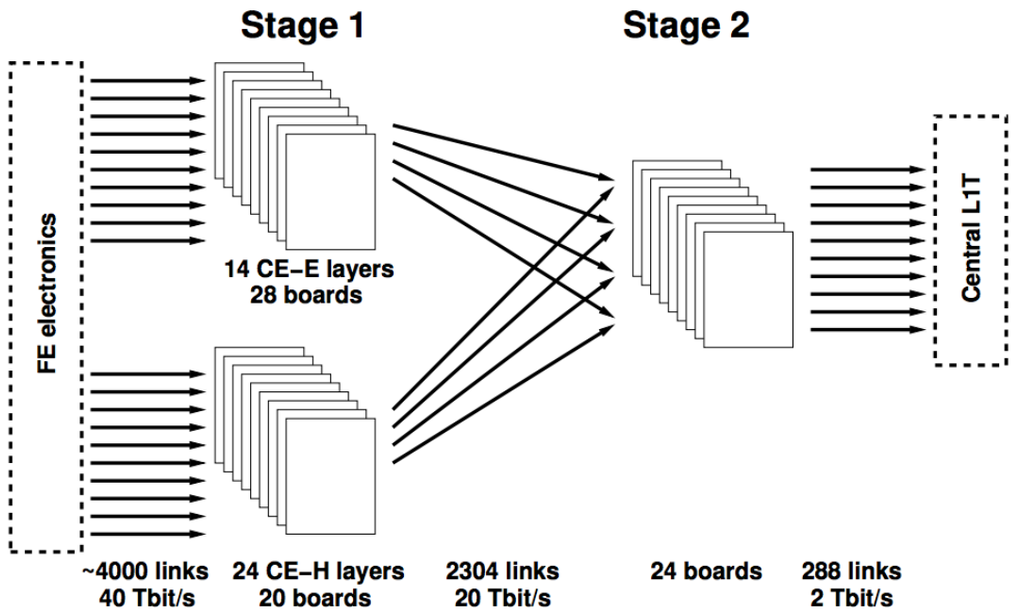
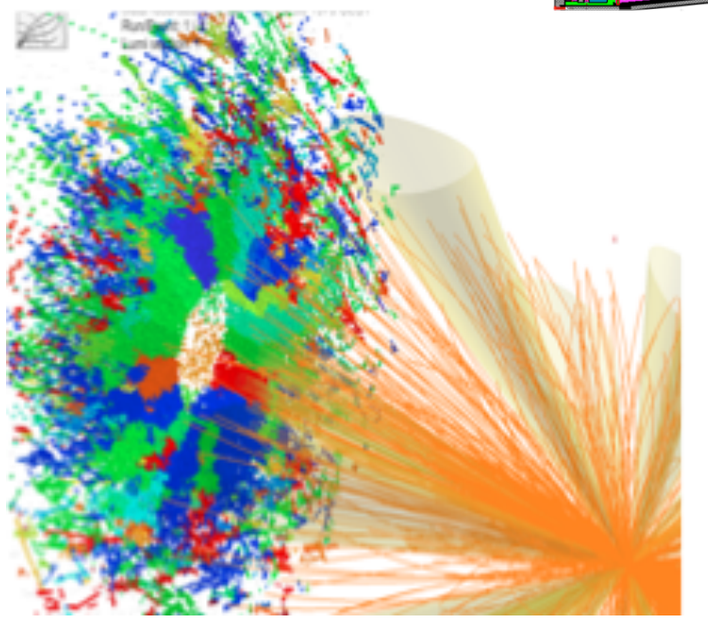
CMSUK Upgrade: Calorimetry

- UK leadership:
  - Project managers: ECAL, HGCAL; HGCAL trigger and simulation conveners
  - Barrel ECAL
    - UK Role: Trigger primitive development (full granularity at L1) & detector optolinks
  - HGCAL
    - Radically new approach
    - UK Role: Trigger primitive development and electronics, and simulation







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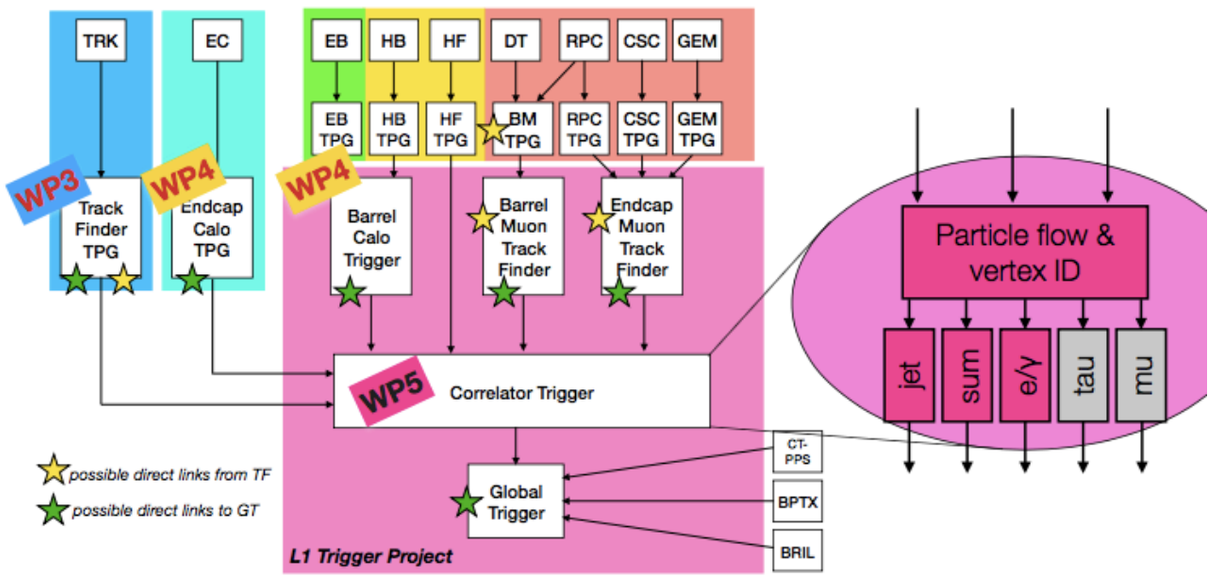
CMSUK Upgrade: L1 Trigger

- UK leadership:
  - L1 PM and L1 Phase 2 upgrade convener
  - Built on highly successful 'time-multiplexed' Phase-1 project
- Challenge: Maintain acceptance for physics with high pile-up
  - Use more information from the detectors
    - Addition of tracking information, increased granularity of calorimeter data – HGCAL
    - Particle flow at L1 with next generation FPGAs possible – never been done before
    - Current focus on defining architecture and algorithm development



- Directly re-use specialised board from tracker or HGCAL UK activities

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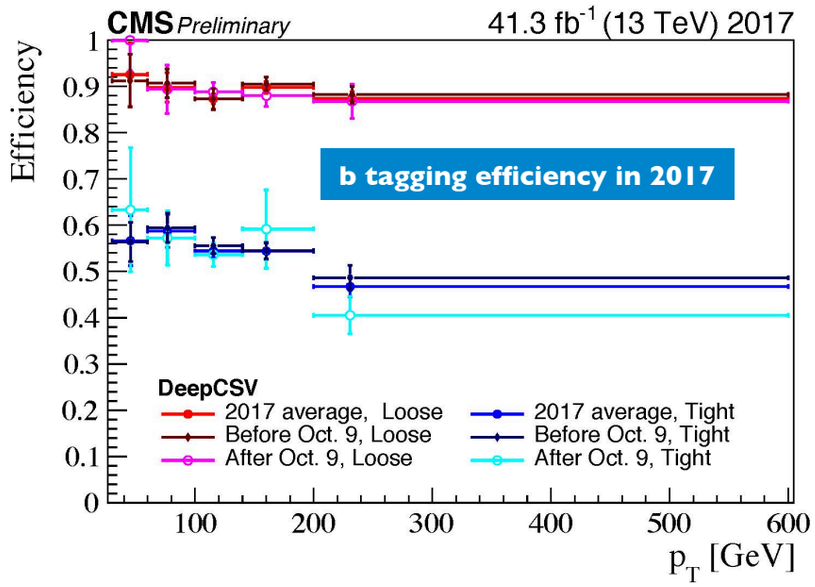
Summary

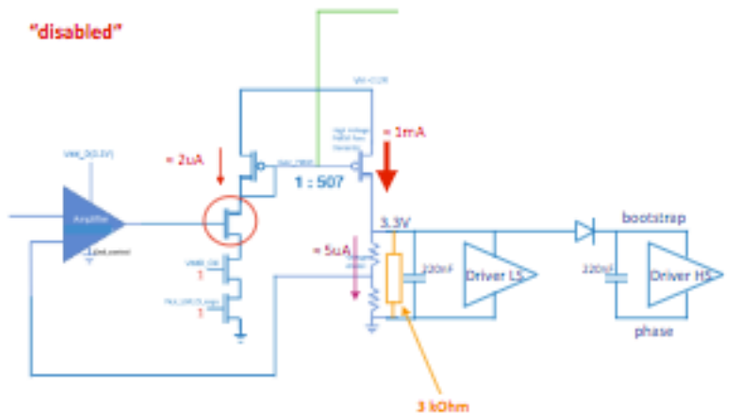
- LHC: A highly exciting present & future programme
  - Have analysed less than 5% of total data sample
    - Need to deal with high pile-up
  - Dynamic technical evolution underway for Phase 2 upgrades
    - Major activities: ~ 1/2 scale of the original construction
- CMS: At the cutting edge
  - Continues to show its versatility & creativity in both physics & upgrades
- Challenge:
  - Continued operation of detector in parallel with exploitation & upgrades
- CMSUK
  - Essential part of all aspects
    - Many mission-critical activities
  - Focused, integrated effort far in excess of numerical contribution
    - CMS relying upon our full participation
  - Full funding – both CG and upgrade – as requested is critical
    - Need to learn to access wider sources of funding

Backup

Comment on DCDC Converters

- ~5% of DCDC power units on newly installed pixel detector failed late 2017
- Impact on 2017 data quality marginal
  - 4 layers – redundancy, modified tracking
- All 1200 converters removed & replaced
  - Also 6 sensor modules in inner layer
- Operating as at start of 2017, no failures
- Problem localised and understood
  - Combination of integrated radiation & disable-enable cycle
  - Radiation induced leakage current in 1 specific transistor amplified by a current mirror
  - When a cycle occurs, for an instant there is no path for current and it builds up charge, eventually breaking circuit
- Modified operations for 2018 run – expect no impact
- Problem easily resolved
- Required significant effort from many – solution a major relieve to many!





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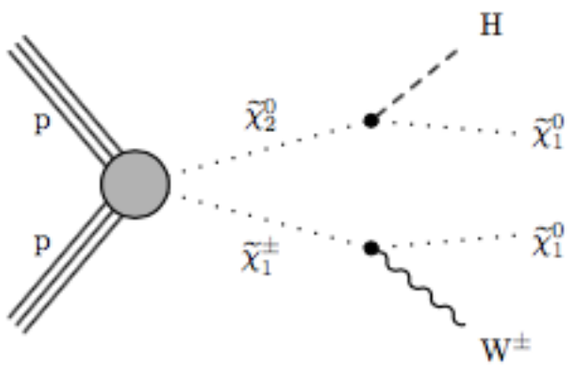
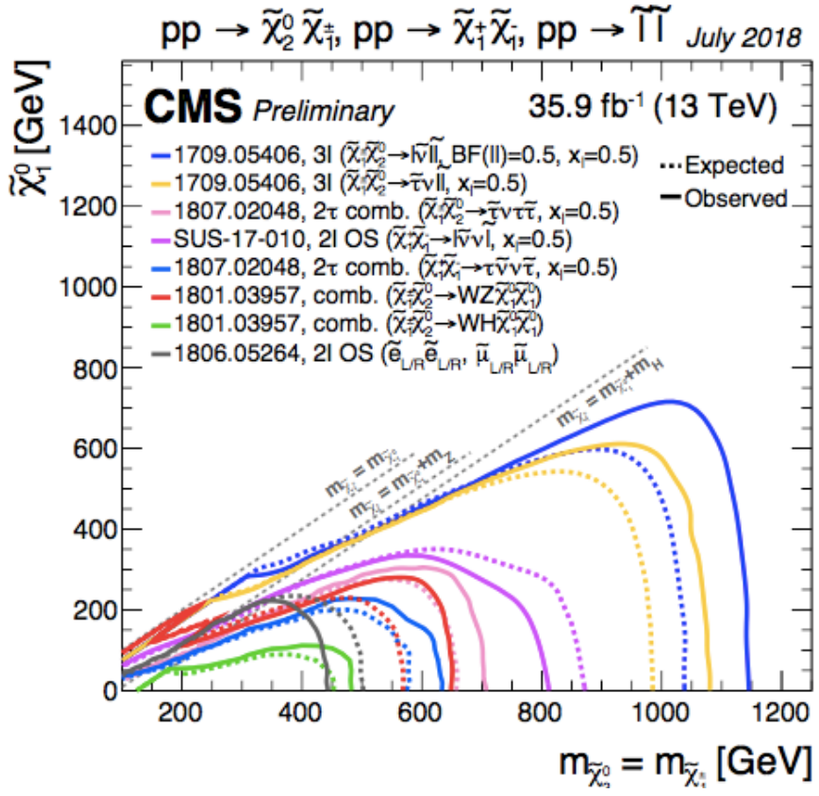
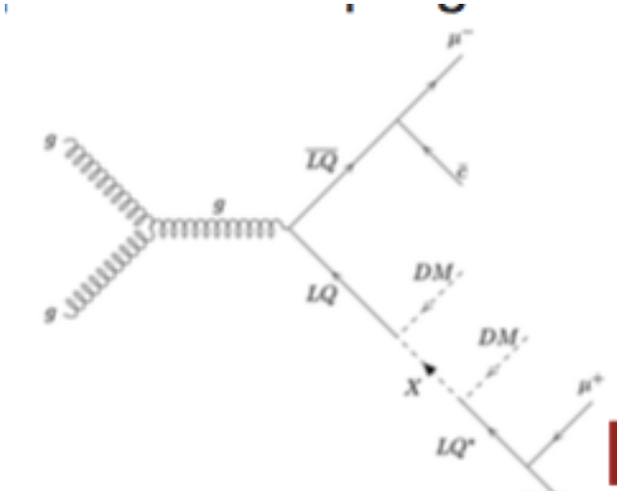
CMS Physics

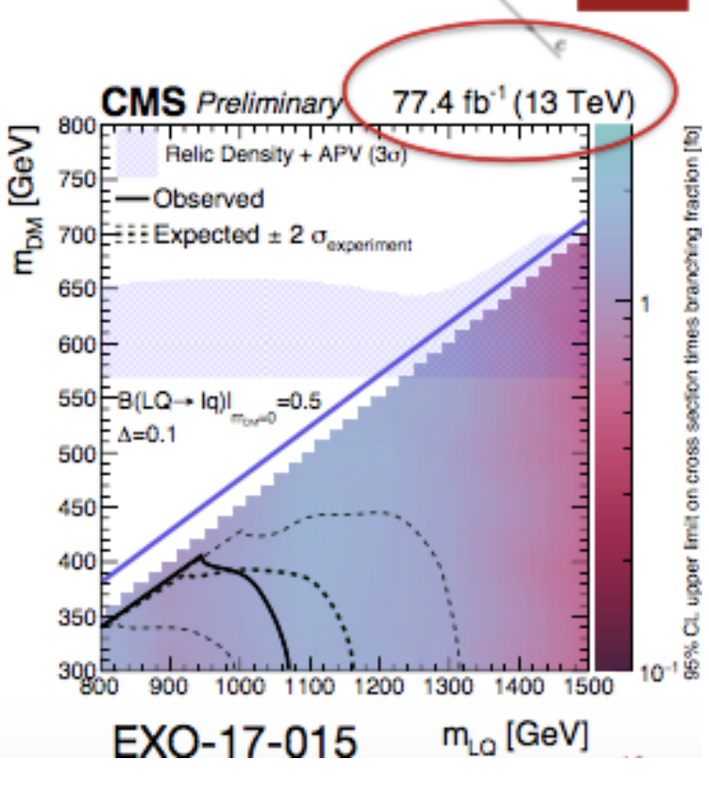
- Larger data-sets – a wealth of opportunity
- Electroweak SUSY
  - Using Higgs tagging





- Probing the B-anomalies
  - Leptoquarks





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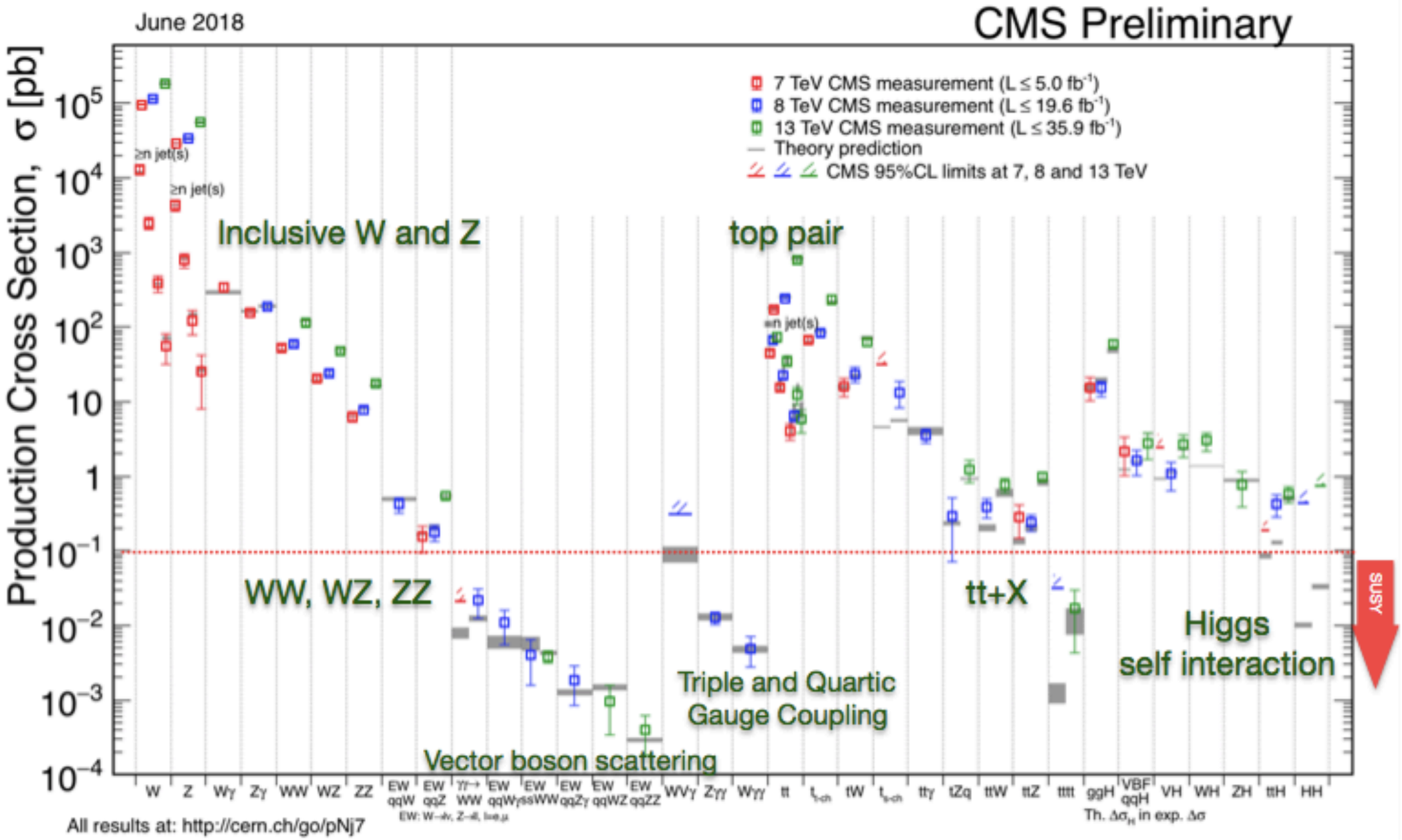
CMS Physics

- The onward march….



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UK Detector Leadership

- Original construction
  - Physics-driven detector simulation and optimisation
  - Tracker front-end ASIC and off-detector readout
  - Endcap ECAL construction, ECAL front-end ASIC
  - L1 calorimeter trigger; Software and computing
- Phase-1 upgrades
  - Calorimeter trigger (UK leadership - Tapper)
  - UK common hardware / software platform for trigger (MP7) and readout (FC7)
- Phase-2 R&D
  - Low power front-end ASIC for silicon tracker (UK leadership – Hall)
  - Hardware track-finding system and trigger primitives (UK leadership – Pesaresi)
  - ECAL front-end electronics and data processing (UK leadership – Petyt)
  - L1 trigger final correlator unit (UK leadership – Brooke)
- ERC / STFC HGCAL project
  - Design and optimisation of highly granular endcap calo (UK leadership – Virdee)
  - Design of readout electronics and trigger primitives (UK leadership – Dauncey)
- Well-supported R&D has placed the UK in an exceptionally strong position

CMS Evolution