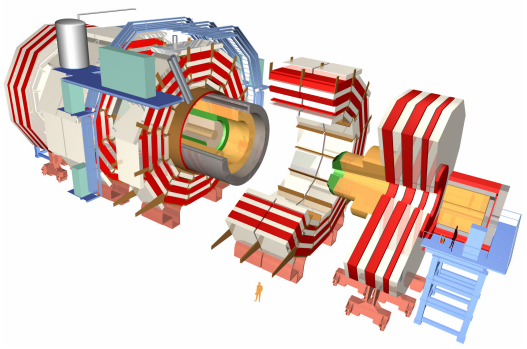
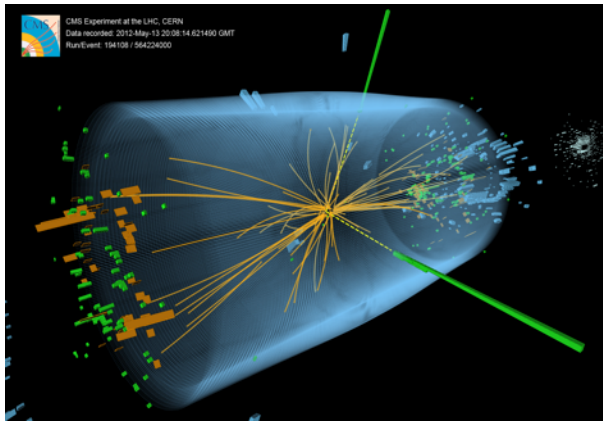




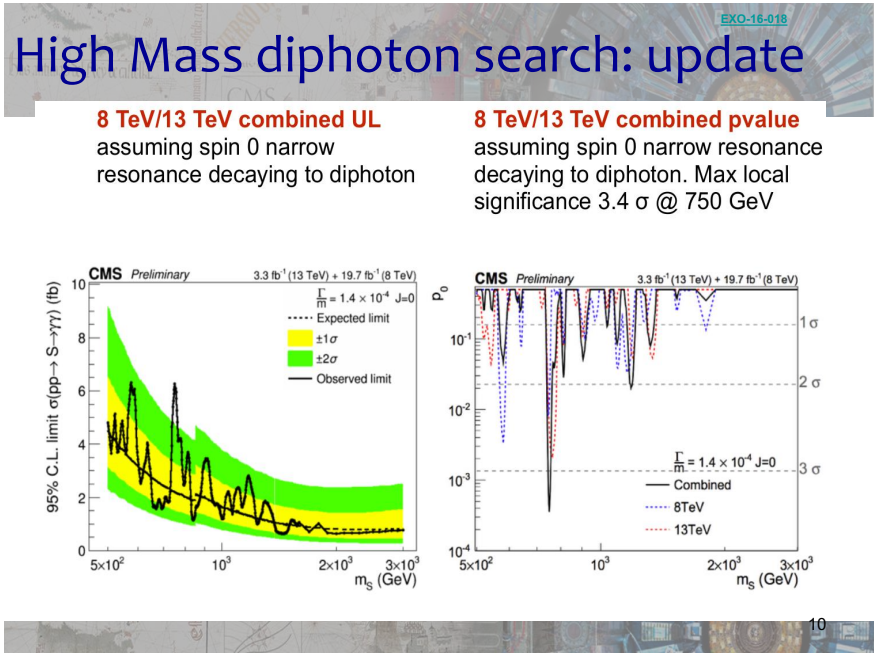
UK CMS Upgrade Oversight Committee

9 May 2016

University of Bristol
Brunel University London
Imperial College London
Rutherford Appleton Laboratory

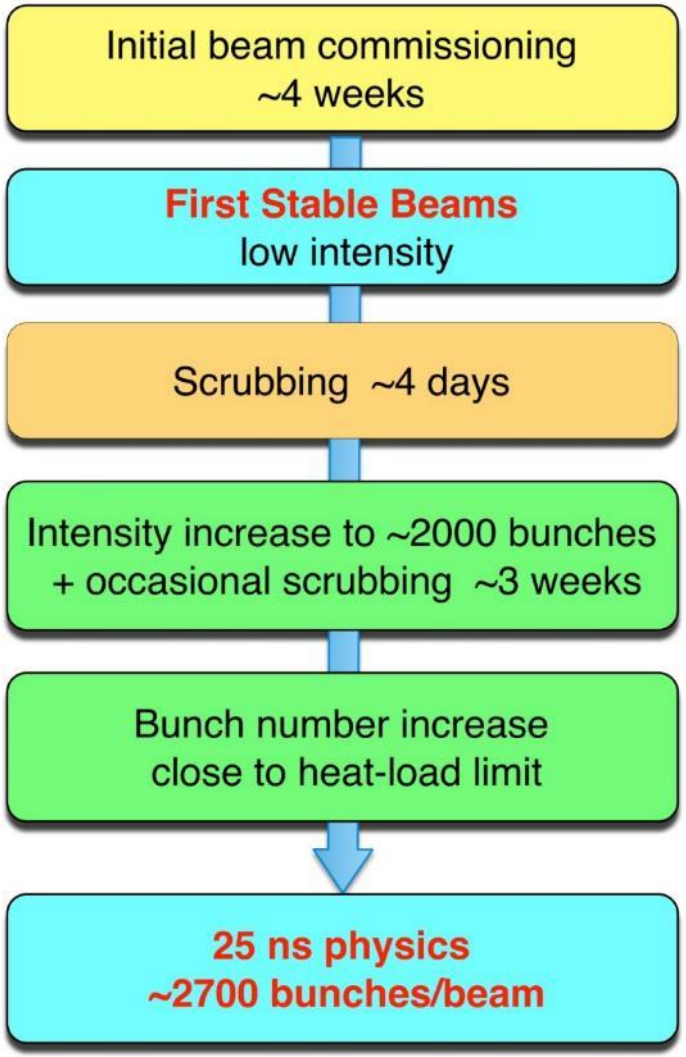
Overview

- Snapshots of LHC & CMS status
  - 2015 was commissioning year with ~4 fb^{-1}
  - 2016 should be production year with 25 fb^{-1} target
    - Hints of new physics?
- Summary of UK upgrade project
  - Recent WP progress
  - Two new WPs
  - Next steps towards construction phase
- Next steps



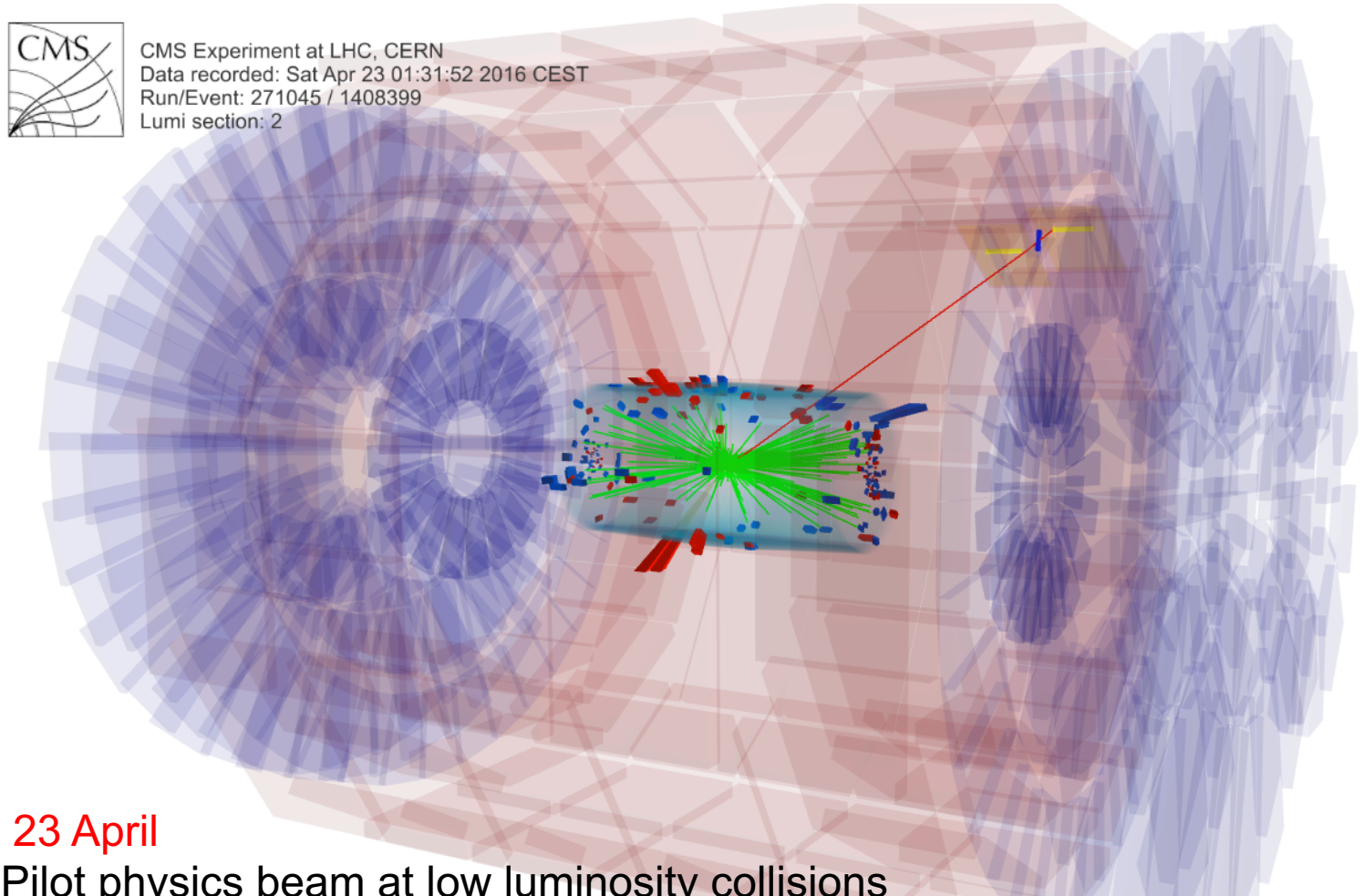
Proton-Proton Plans for 2016

- ✓ **Stable Safe Operations**
  - ➢ Don't compromise on machine safety!
  - ➢ Don't do anything to compromise machine reproducibility
- ✓ **Electron Cloud under control**
  - ➢ Short dedicated scrubbing
  - ➢ Continue during intensity ramp-up
- ✓ **13 TeV, 40 (50) cm β^***
  - ➢ Keep an eye on availability
- ✓ **Nominal 25ns beam, 2748 bunches, 288 bpi**
  - ➢ May push later to shorter bunches & BCMS
- ✓ **Good Availability**
  - ➢ Sustained effort to trace faults
  - ➢ Keep avoidable interruptions to production running to a minimum
- ✓ **Excellent Operational Efficiency**
  - ➢ Combined ramp/squeeze
  - ➢ Work on injection process



Following a severe power cut on 28 April, no beam until 5 May

First collisions 2016



23 April

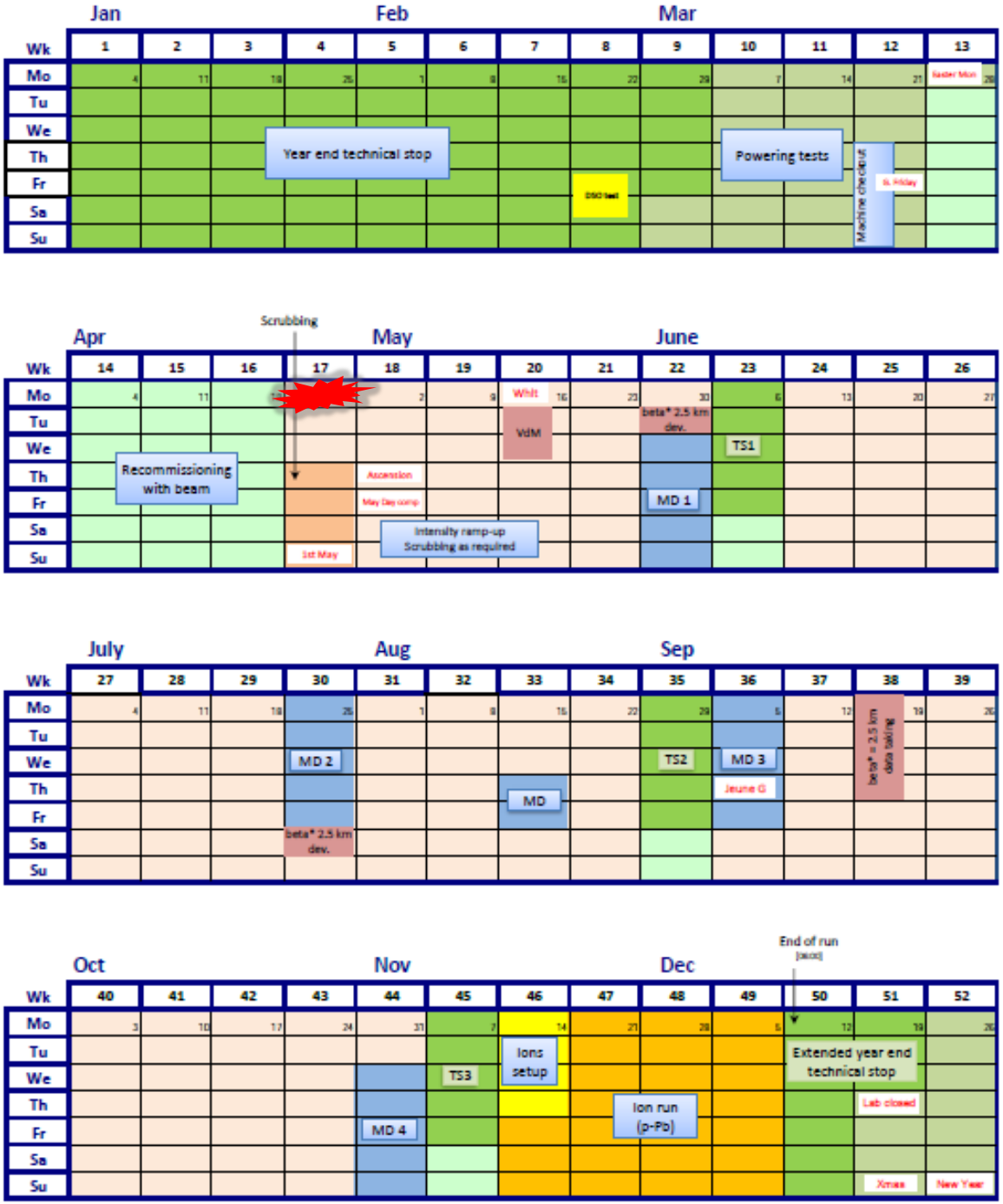
Pilot physics beam at low luminosity collisions

3x3 nominal bunches, 2 colliding. β^*= 40cm and I(B1)= 2.21e11, IB(2)=2.53e11

Online value of luminosity: ~3.7μb^{-1}.

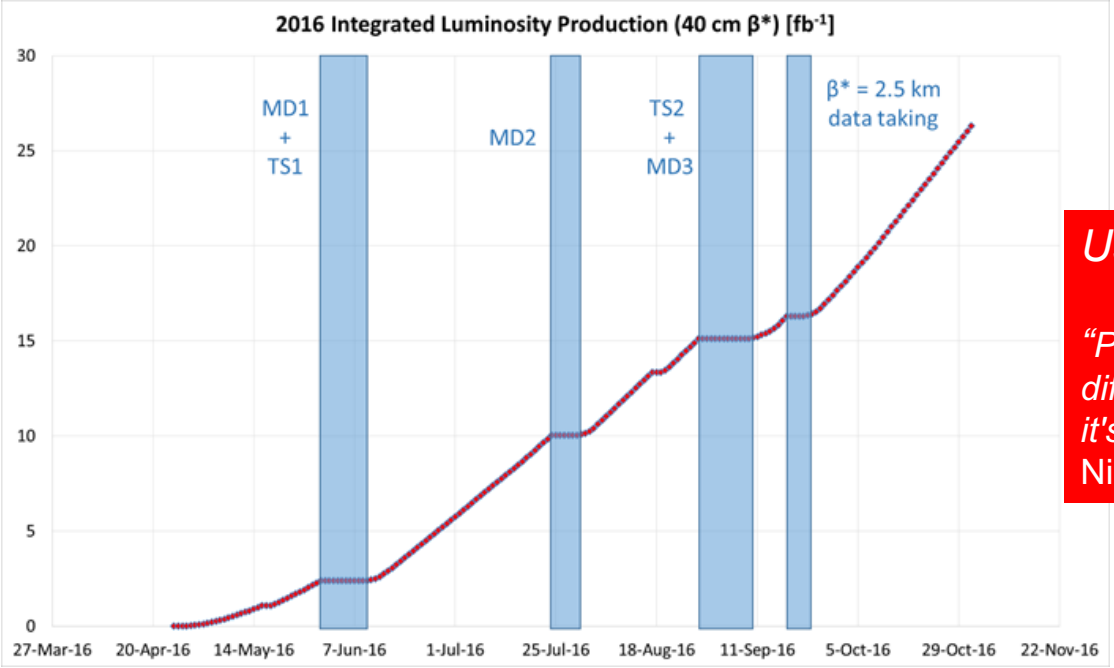
LHC schedule 2016

2016: a production year



LHC goal for **2016**

Integrated luminosity goal:
2016 : ~ 25 fb^{-1} at 13 TeV c.m



Usual caveat …

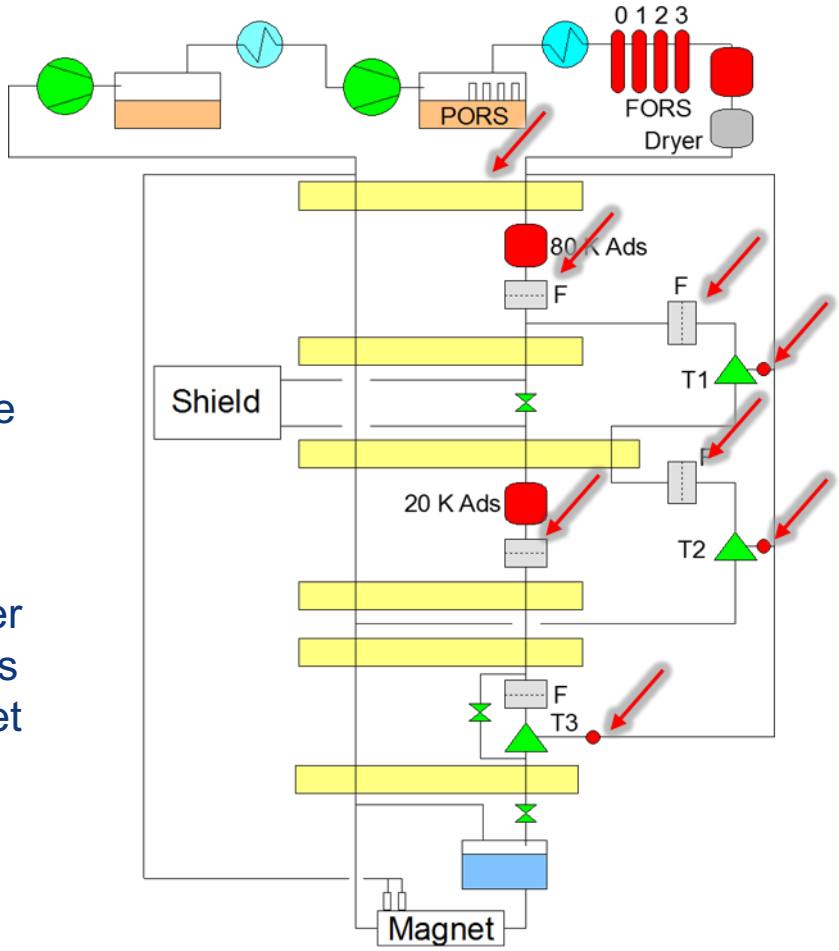
"Prediction is very difficult, especially if it's about the future." - Niels Bohr

CMS Cold-Box Contamination 2015

- Breox® (compressor oil) was found on
  1. Outlet filter 80K and 20 K adsorbers
  2. Inlet filter T1
  3. Inlet filter T2
  4. Turbine gas bearing inlet filters

- Breox® is thought to diminish the heat exchange surface of the first heat-exchanger.

Normally a cold-box having suffered such a Breox® pollution is stopped to be cleaned. This was however impossible in the CMS case, and the installation was kept alive with regular 80K adsorber and turbine inlet filters regenerations. When judged necessary the turbine filters were exchanged for new ones.



Of the integrated (p-p) luminosity delivered to CMS in 2015, about 73% of the data is taken under nominal field conditions.

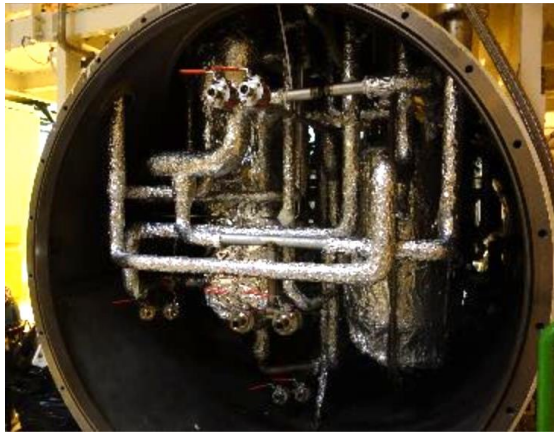
Cold box cleaning: USC

350+10+8 grams of Breox

Cold box shunts & taps

Warm-end of cold box modifications

Heat exchanger tapings (taken out)



Cold-end of cold box modifications

Cleaning machine components

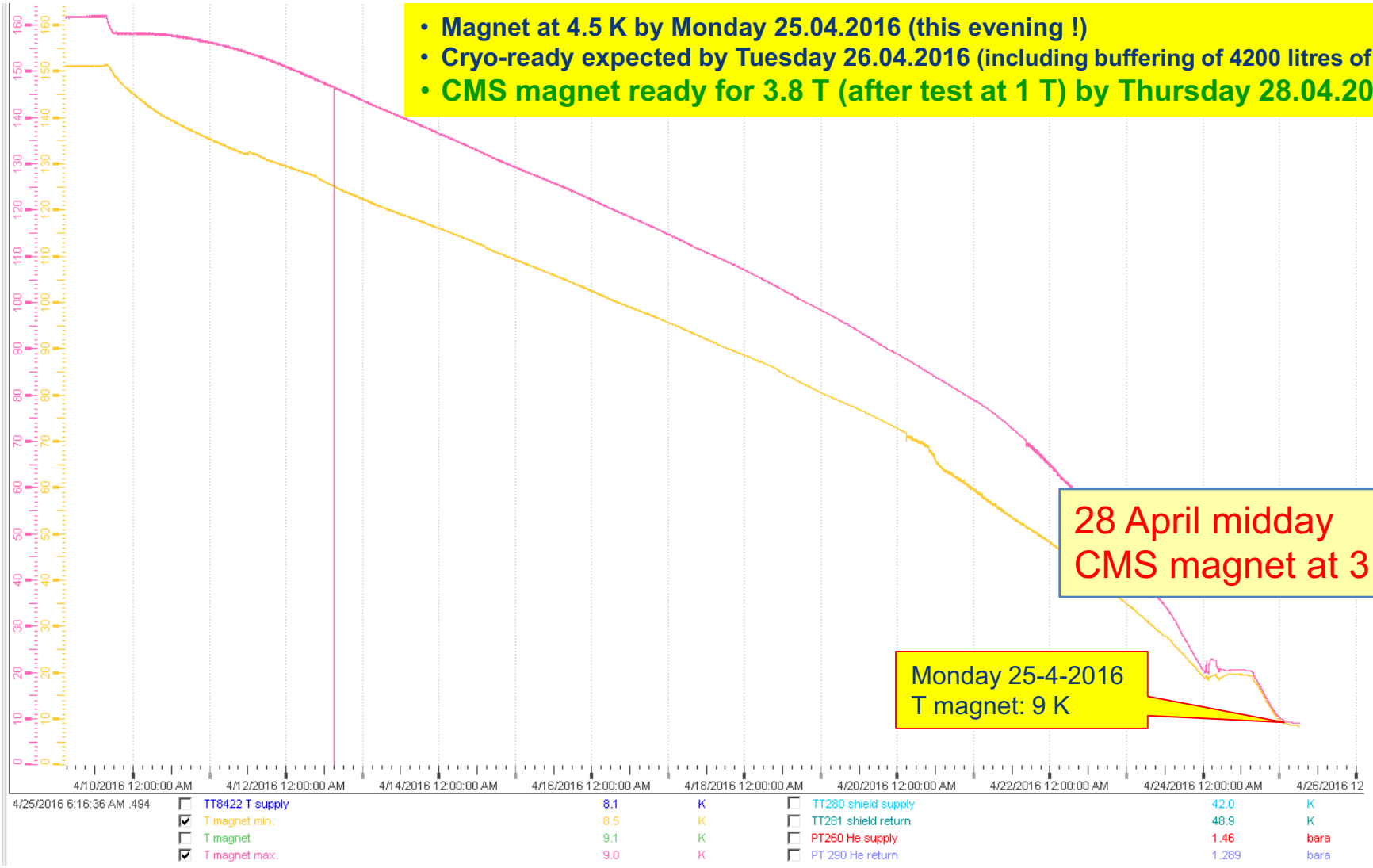
Commissioning finished 25 Jan.

Fluid circulation in cct 1 started 25 Jan

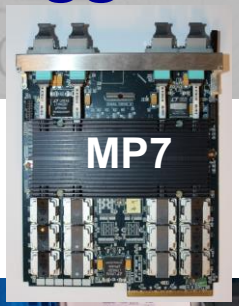
Following the drying procedure, the outgassing rate of the cleaning liquid is very low (less then 100 ppm over several days). Most of the contaminated items (O-rings etc.) are replaced

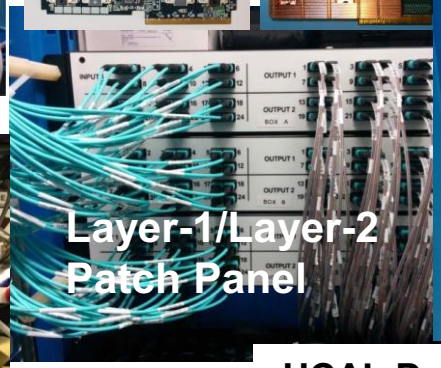
CMS Magnet cooling down progress

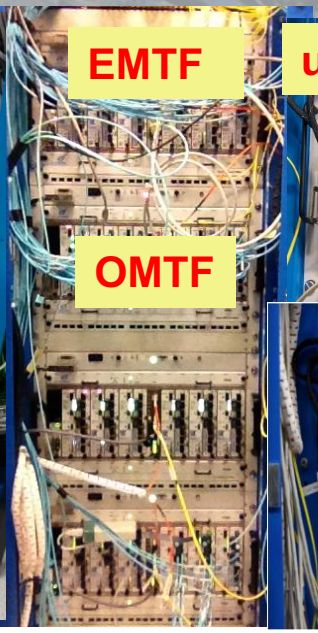
- **Magnet at 4.5 K by Monday 25.04.2016 (this evening !)**
- **Cryo-ready expected by Tuesday 26.04.2016 (including buffering of 4200 litres of LHe)**
- **CMS magnet ready for 3.8 T (after test at 1 T) by Thursday 28.04.2016**

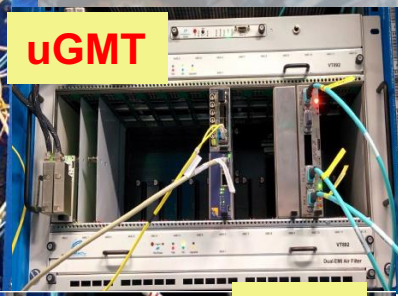


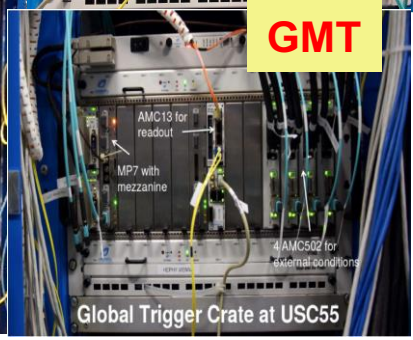
The Level-1 Trigger Upgrade Commissioned at CMS

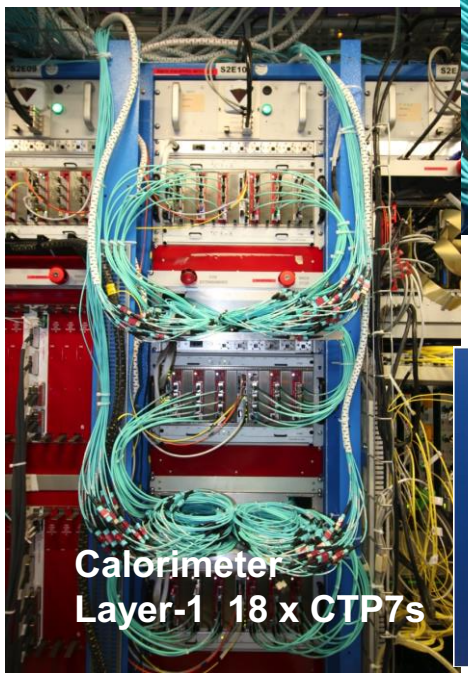












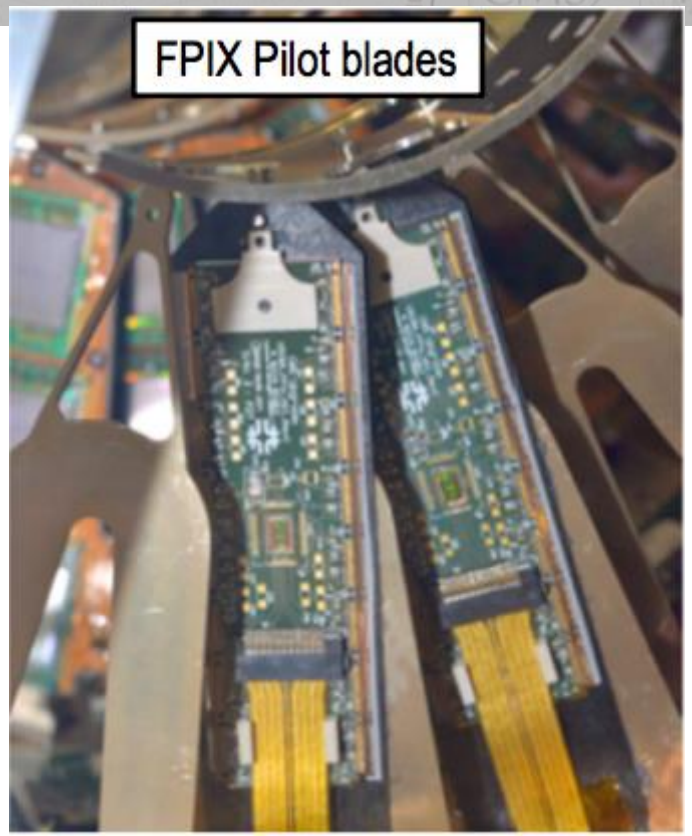
ECAL Data Input

HCAL Data Input

- **The Level-1 Trigger Upgrade is now commissioned at P5 and ready to collect data.**
- Online software stable and ready for data taking.
- Final tuning of the algorithm parameters and performance (being validated with beams)
- The sustained effort from the Institutes involved in the trigger over the last 24 months is coming to fruition!
- **The funding agencies involved have invested resources when needed to ensure delivery: we are very thankful!**

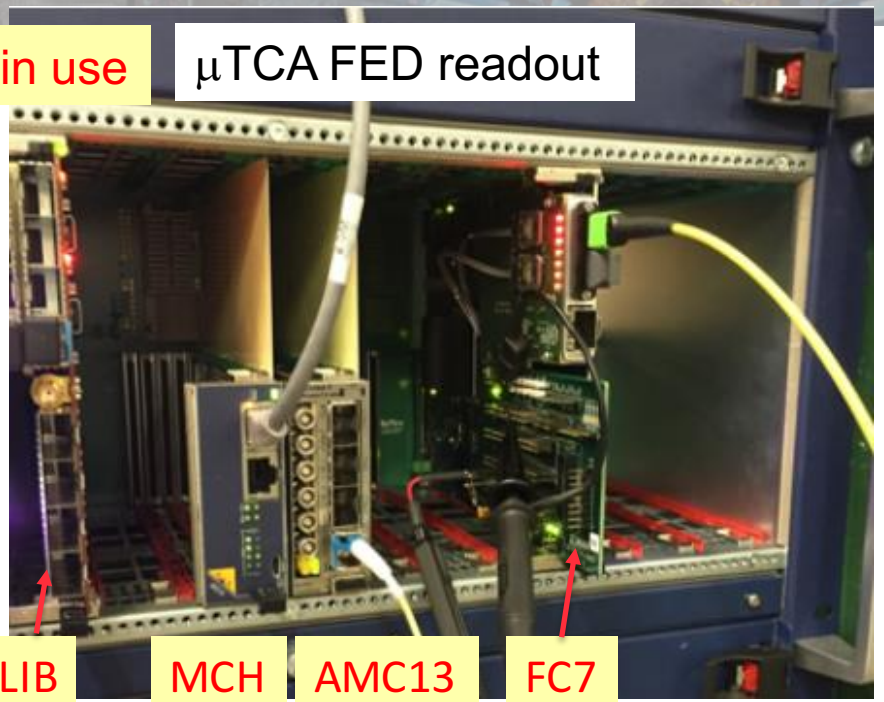
T Camporesi 25 April RRB report

Pixel Phase I Readout



FC7 in use

μTCA FED readout



As the system is meant to be ready to take data on day 1 of the 2017 run a pilot blade system readout by the new μTCA Back End is being integrated as part of the standard configuration for 2016 and will be used to debug/commission the full readout chain

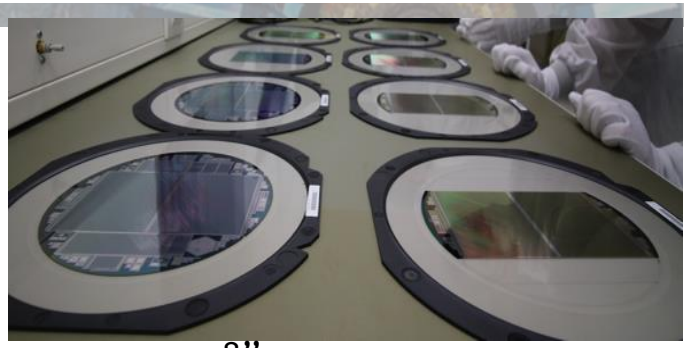
T Camporesi 25 April RRB report

Outer tracker progress

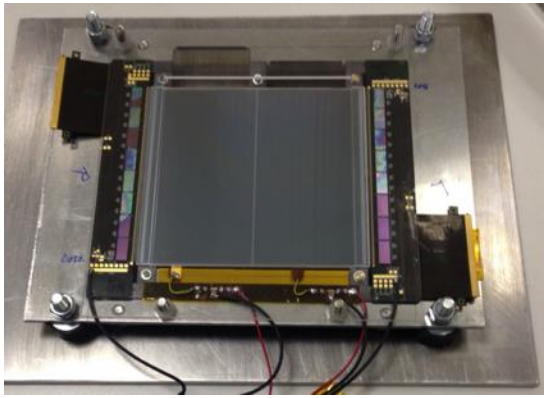
T Camporesi 25 April RRB report

Several initial milestones presented in the TP met on schedule

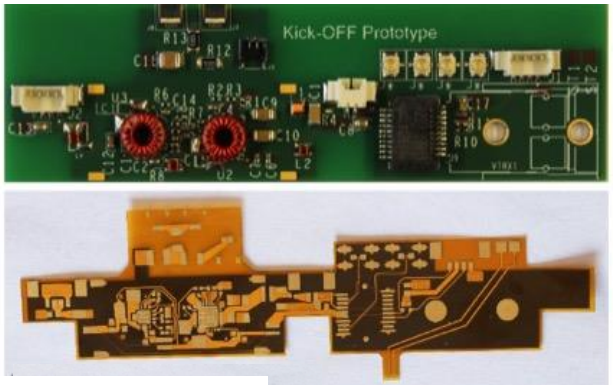
- Si-Sensors: 200 μm thick & produced on 8" by INFINEON with very good quality - Market Survey launched
- ASIC chips: all front-end ASIC designs completed
- Power chain: demonstrator operational
- Modules: prototypes assembled and tested in beam
- Mechanical structures: prototyping with improved designs
- Track Trigger: demonstrators operational



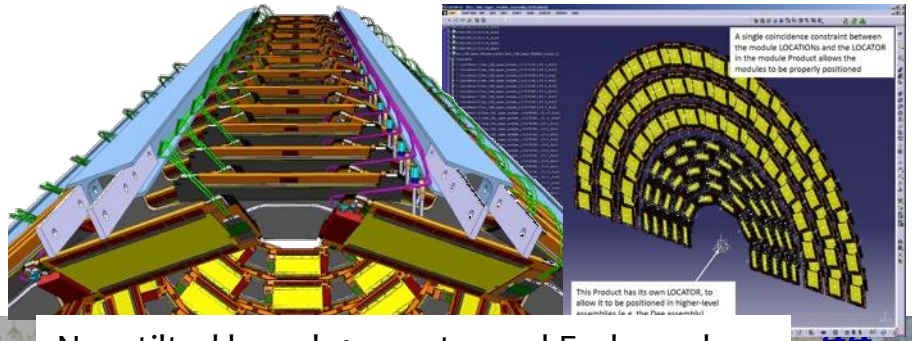
8" sensors



Full-size 2S module with CBC ASICs



Power hybrids

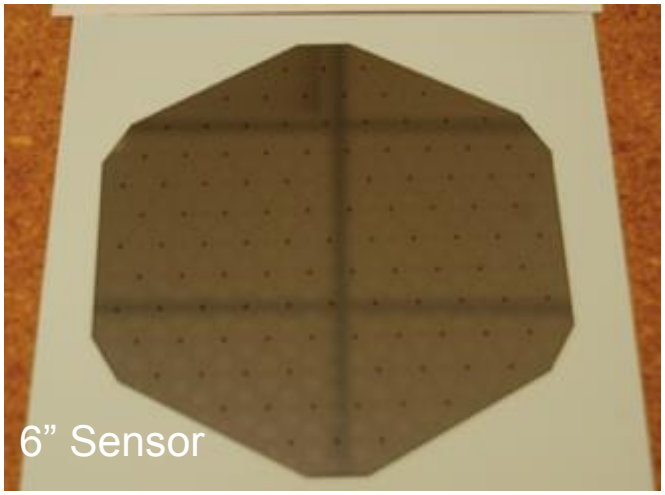


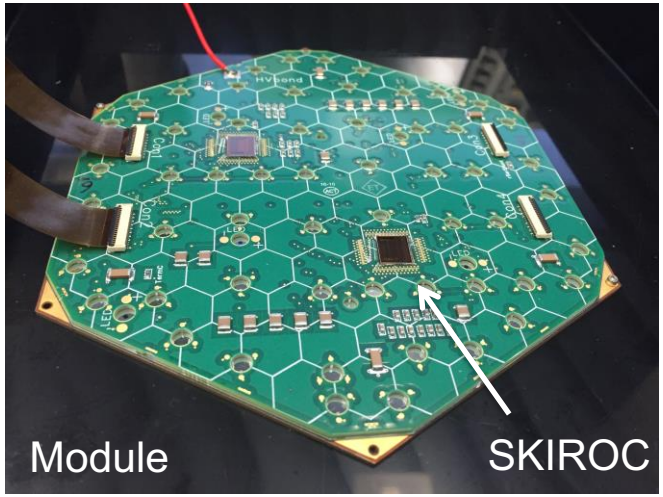
New tilted barrel geometry and End cap dees

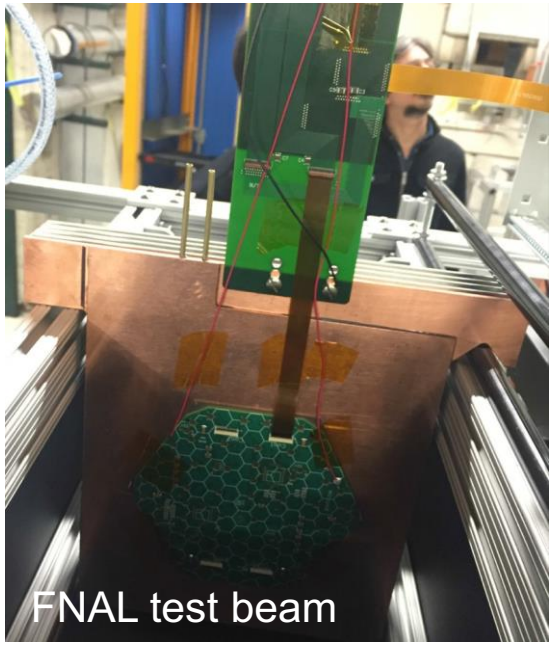
Endcap Calo R&D progress

Several initial milestones presented in the TP met on schedule

- Si-Sensors: first high quality pad sensors in 6” produced by HPK - production/order of other required geometries proceeding at three vendors (type, thickness, pad size, 8”)
- Modules: first assembled with SKIROC FE ASIC in test beam a FNAL







- ASIC chips: SKIROC2-CMS ASIC demonstrator submitted (test beam at CERN fall 2016) - ASIC blocks in 130 nm submitted

T Camporesi 25 April RRB report

UK R&D status

Last 6 months

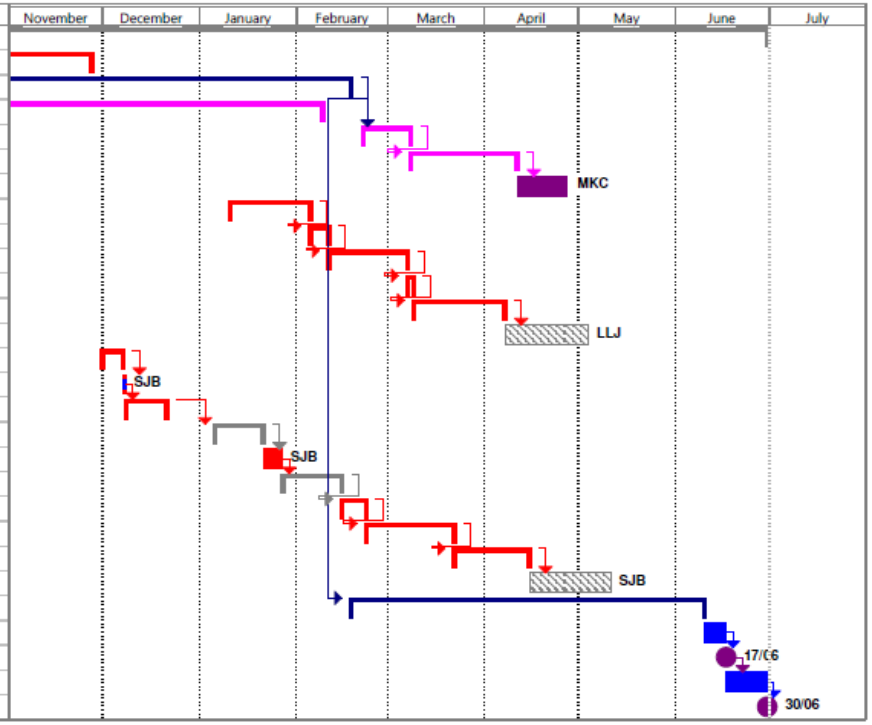
- WP2:
  - Further progress with CBC3 design – some delay
    - expect CBC3 submission mid-2016, shared with GBT-SCA
      - substantial cost saving
  - FC7 R2 production fully validated, and now baseline
    - Accelerated lifetime tests: 5 FC7-R2 x 5 years equivalent – 0 faults
- WP3: TDR trigger complete
  - 2016 trigger has been commissioned with parallel data taking
  - MP-Ultra submitted
- WP4: HGC
  - Report for first time
- WP5: L1 track-finder
  - Good progress with demonstrator
  - Important milestones this year: reviews May/Dec for architecture decision

Overview of CBC activities

- CBC2 based module tests continue
  - first full-size module in November test beam
  - further beam test of irradiated mini-module currently underway
- Outer tracker system progress
  - 3 potential suppliers of flex hybrids identified
  - first prototypes of concentrator and LP-GBT ASICs expected ~ end of year
  - DC-DC powering scheme prototypes also expected by ~ end of year
  - working group now looking at production QA and testing procedures
- CBC3 design close to completion
  - delayed w.r.t. previous plan (February)
    - loss of RAL TD engineer
    - some underestimation of remaining tasks
  - extra effort allocated and plan revised (next slide)

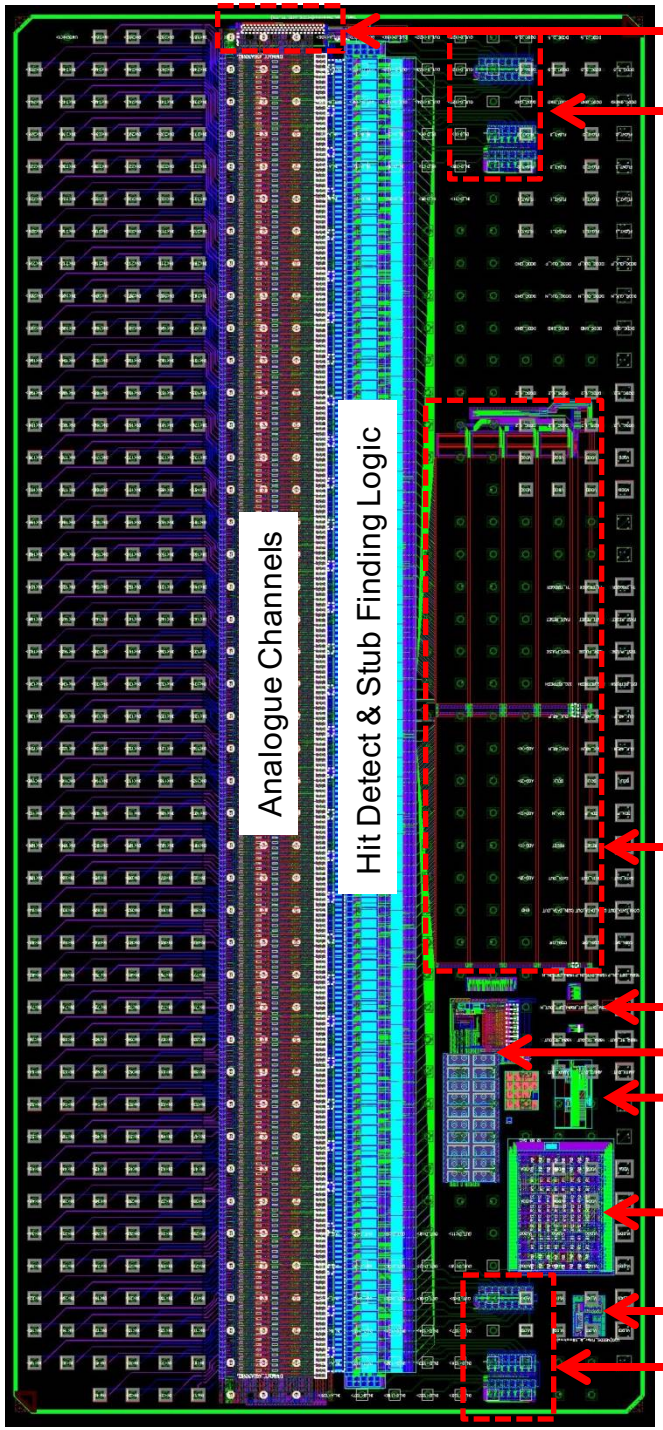
CBC3 plan to completion

ID	Task Name	Duration	Start	Finish	Resource Names
1	**CBC3 Design**	**406.97 days**	**Wed 21/01/15**	**Thu 30/06/16**	
2	**Modify IPRE1 for 3x Full scale**	**240.68 days**	**Wed 21/01/15**	**Fri 27/11/15**	
6	**Modify the Pipeline RAM**	**108.66 days**	**Thu 01/10/15**	**Thu 18/02/16**	
11	**Modify the Pipeline Control Logic**	**107.97 days**	**Tue 22/09/15**	**Tue 09/02/16**	**MKC**
16	**Re-layout the Serial Data Shift Reg**	**12.59 days**	**Mon 22/02/16**	**Tue 08/03/16**	**MKC**
19	**Layer Swap & Hit Detect Multiplexers**	**26.03 days**	**Tue 08/03/16**	**Mon 11/04/16**	**MKC**
23	**I2C Compatability Check**	8 days	Mon 11/04/16	Wed 27/04/16	MKC
24	**Modify Front End (Pre, Post Amp & Comp)**	**21 days**	**Mon 11/01/16**	**Fri 05/02/16**	**LLJ**
27	**LDO modification**	**4 days**	**Fri 05/02/16**	**Thu 11/02/16**	**LLJ**
30	**Modify I2C Configuration Registers**	**19 days**	**Thu 11/02/16**	**Mon 07/03/16**	**LLJ**
34	**Modify Analogue Mux**	**2 days**	**Mon 07/03/16**	**Wed 09/03/16**	**LLJ**
37	**CHIP ID eFuses & supporting circuitry**	**23 days**	**Wed 09/03/16**	**Thu 07/04/16**	**LLJ**
41	**A/L, S/L & R3B support**	20 days	Thu 07/04/16	Wed 04/05/16	LLJ
42	**New 4 Bit DAC for VPLUS/VPLUS2 (1)**	**5 days**	**Tue 01/12/15**	**Mon 07/12/15**	**SJB**
44	**Beta Multiplier Circuit schematic**	1 day	Mon 07/12/15	Tue 08/12/15	SJB
45	**New 10 Bit VCTH DAC (1)**	**10 days**	**Tue 08/12/15**	**Mon 21/12/15**	**SJB**
47	**New 4 Bit DAC for VPLUS/VPLUS2 (2)**	**12 days**	**Wed 06/01/16**	**Thu 21/01/16**	**SJB**
50	**Beta Multiplier Circuit layout**	5 days	Thu 21/01/16	Wed 27/01/16	SJB
51	**New 10 Bit VCTH DAC (2)**	**14 days**	**Wed 27/01/16**	**Mon 15/02/16**	**SJB**
54	**Comp Current Balancing Ref**	**6 days**	**Mon 15/02/16**	**Tue 23/02/16**	**SJB**
57	**New Bandgap and trimming**	**22 days**	**Tue 23/02/16**	**Tue 22/03/16**	**SJB**
61	**DLL for Hit Detect Synchronisation**	**19 days**	**Tue 22/03/16**	**Fri 15/04/16**	**SJB**
65	**A/L, S/L & CFI support**	**20 days**	**Fri 15/04/16**	**Wed 11/05/16**	**SJB**
66	**TOP LEVEL**	**87.64 days**	**Thu 18/02/16**	**Fri 10/06/16**	**MLP**
68	Review Preparation	5 days	Fri 10/06/16	Fri 17/06/16	
69	**Pre-submission Project Review**	0 days	Fri 17/06/16	Fri 17/06/16	
70	Post Review Actions	10 days	Fri 17/06/16	Thu 30/06/16	
71	**Ship GDS File**	0 days	Thu 30/06/16	Thu 30/06/16	



- Detailed plan monitored by weekly progress meetings
  - finishing end June, still compatible with joint submission with CERN chip
- Top level tasks now remaining
  - assembly of complete chip, connecting up, lots of checking

CBC3 Top Level



- all (almost) functional blocks present
  - not in precise final locations
- some congestion evident
  - chip will grow by one column of pads
    - extra logic and longer pipeline
    - 250 µm wider than CBC2

WP3: Phase I trigger progress

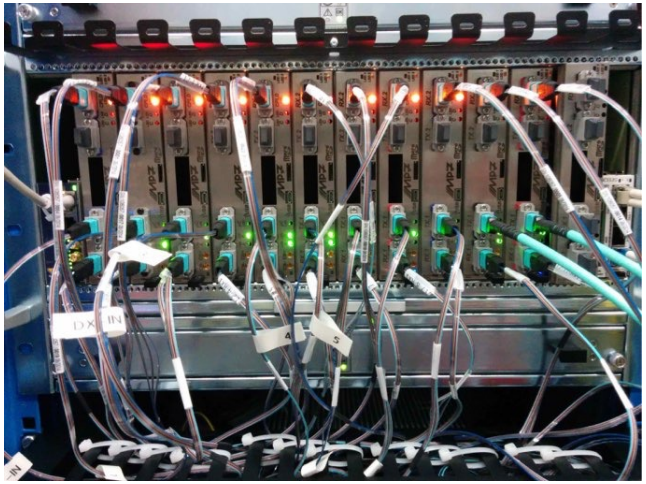
- UK designed Time Multiplexed Trigger for L1 Calorimeter fully installed and operational
  - Parallel operation in Nov-Dec 2015
  - Final commissioning for 2016 underway

- MP7 orders complete, with high yield
  - Spares in use for track-finder demonstrator

- SWATCH online software system for entire trigger now operational
  - UK devised and led
  - Substantial effort under great pressure

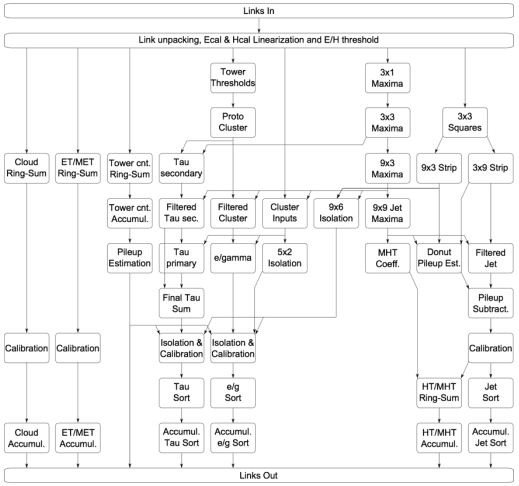
Calorimeter trigger upgrade

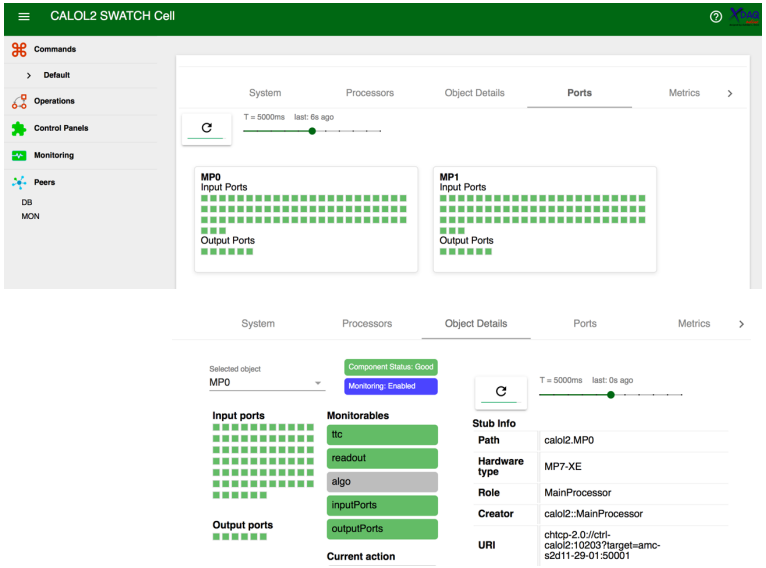
- System installed at P5 in 2014
  - 10 MP7 boards + spares installed ✓
  - Fibre connections installed and validated ✓
- Commissioning
  - Interconnection tests ✓
  - Pattern test campaign in 2015 ✓
  - Data taken in CMS global running in 2015 ✓
    - Over 7 billion events in pp running
  - Cosmic runs and splashes in 2016 ✓
  - First collisions in 2016 ✓
  - **Start physics run** ✓
- Miscellaneous
  - Additional MP7s for project delivered ✓



Calorimeter trigger upgrade

- Algorithms implemented and tested ✓
- Final preparations for run
  - System running stably with new SWATCH control system (UK designed) ✓
  - Additions and testing of DQM ✓
  - Final calibrations and tuning ✓

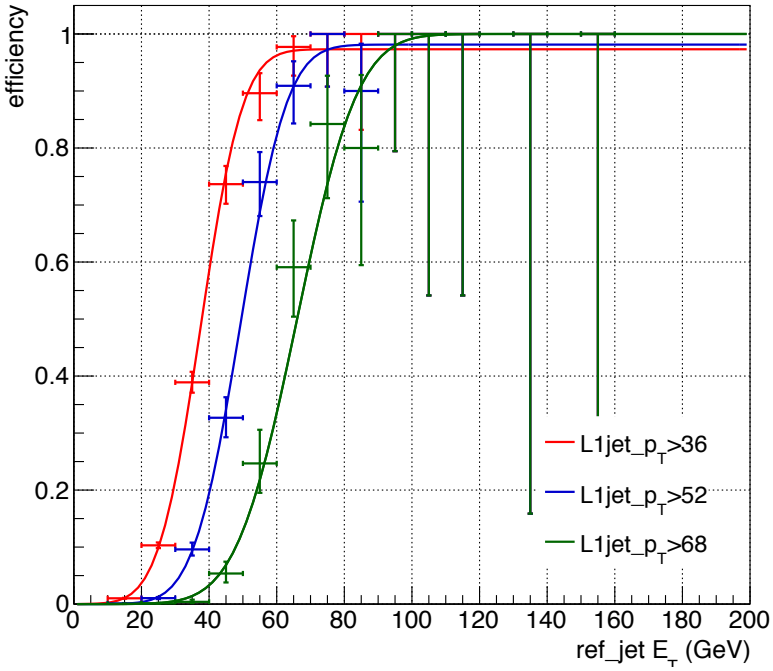


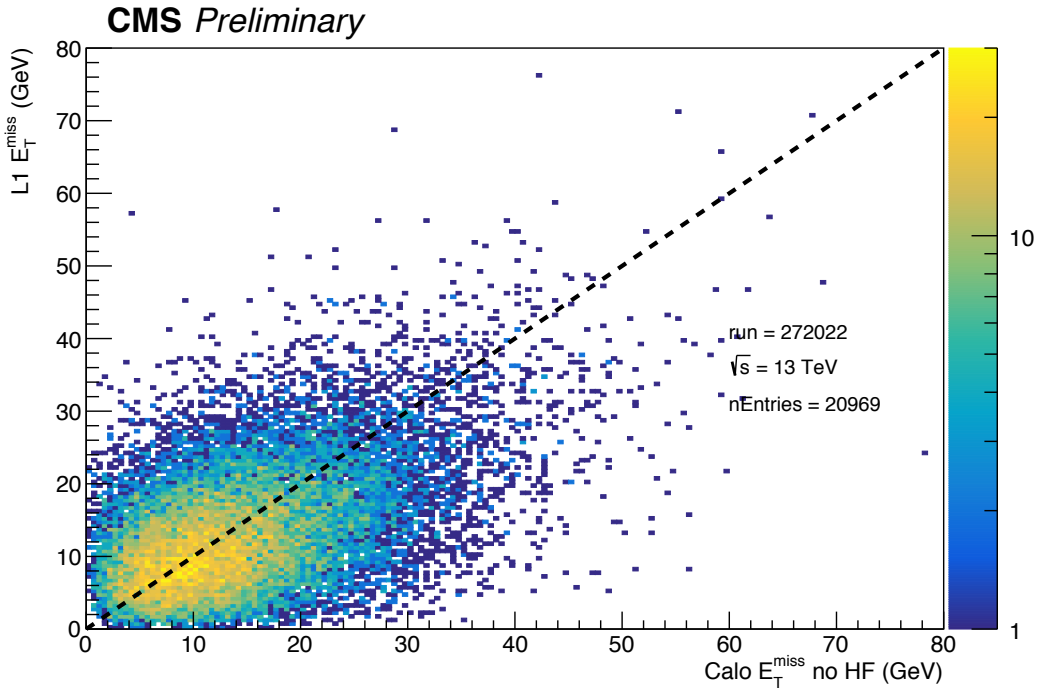


Calo trigger performance

- Evaluation already under way

Online MET vs offline MET

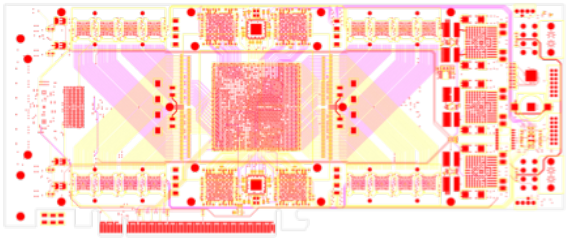


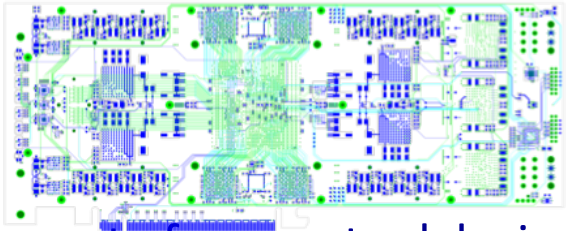


jet trigger efficiency

WP3: Future plans

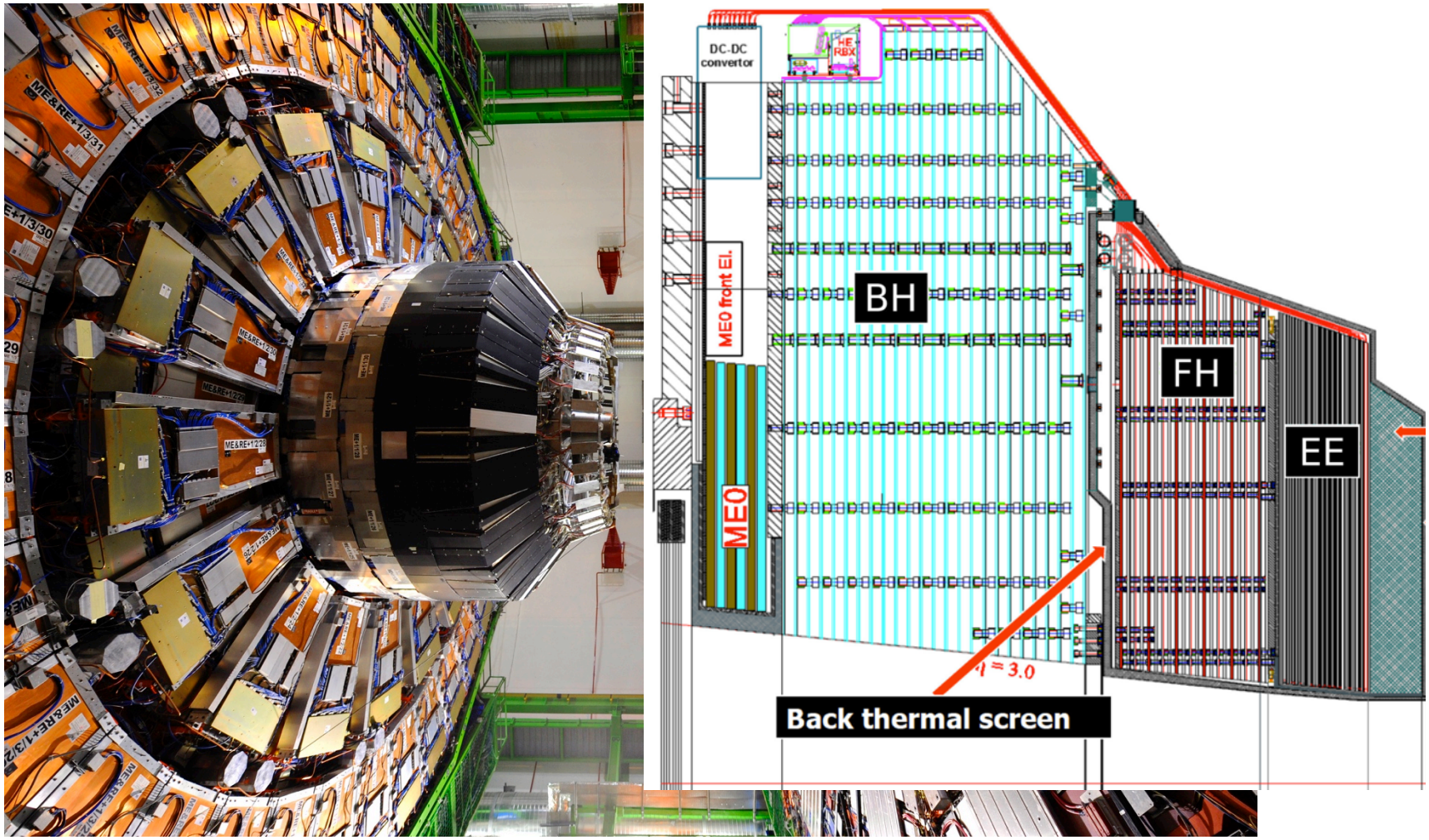
- Next generation hardware: MP-Ultra
  - Based on Xilinx Kintex Ultrascale FPGA
    - More details in previous report
  - Prototypes expected end May





- Planning for Phase II trigger
  - CMS group set up for performance studies, development of conceptual design and necessary R&D
  - Led by J. Brooke (Bristol) and R. Cavanaugh (FNAL/UIC)
  - Close connection to tracker and HGC projects → UK synergy
  - Workshop planned for June

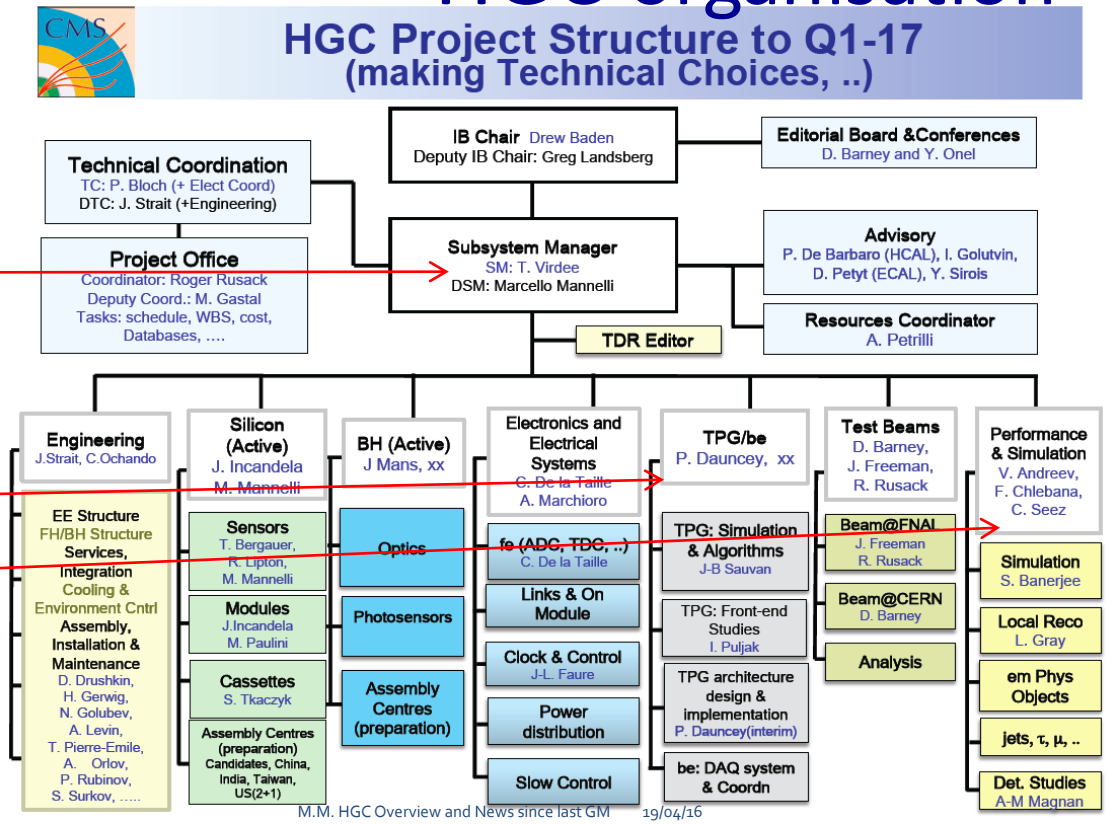
WP4: Phase II Endcap Calorimeter Upgrade



46 CMS Institutions involved of which 3 are from the UK

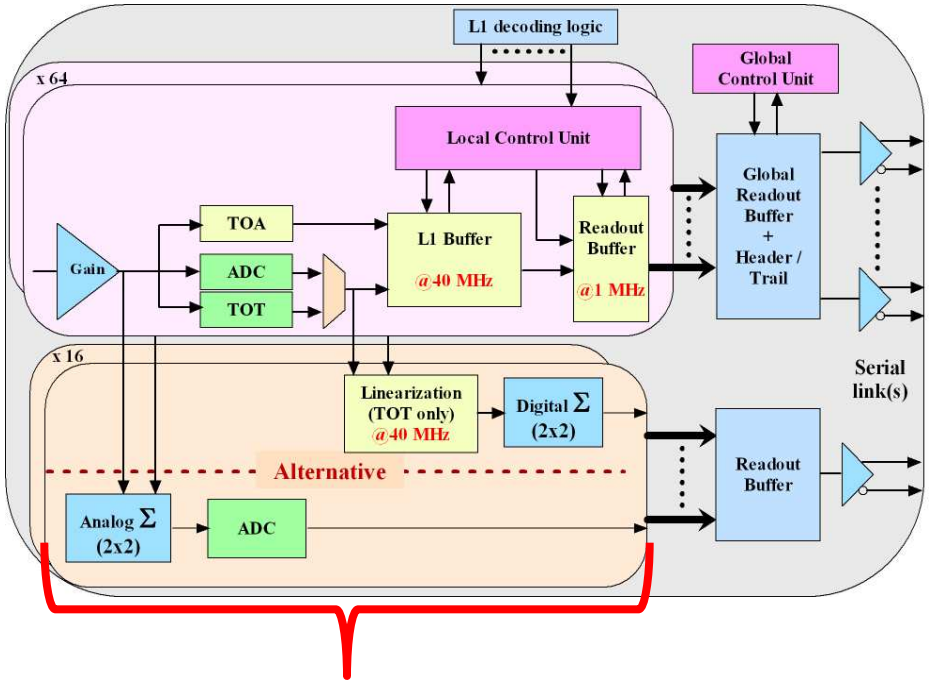
HGC organisation

- UK has strong role
  - Subsystem manager (L1)
    - Jim Virdee
  - Two subproject coordinators (L2)
    - Paul Dauncey
    - Chris Seez



- Current areas of activity
  - Front-end electronics design/testing
  - L1 trigger primitive generator (TPG) design
  - Simulation and performance studies

FE electronics design

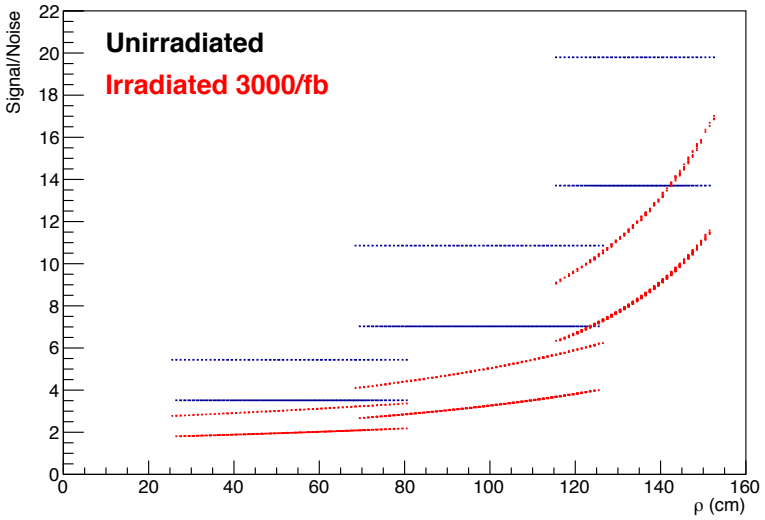


- Dynamic range of 17 bits
  - From MIP to high energy EM shower core
  - ADC and TOT paths
- Timing to < 100ps
  - Pileup rejection
- Provide four-cell sums
  - For TPG inputs

- Two alternative paths for TPG calculation
  - Digital or analogue summing
- UK will contribute to some part of ASIC design
  - Not yet decided, but the TPG summing would be interesting area and obvious choice given our leadership of TPG

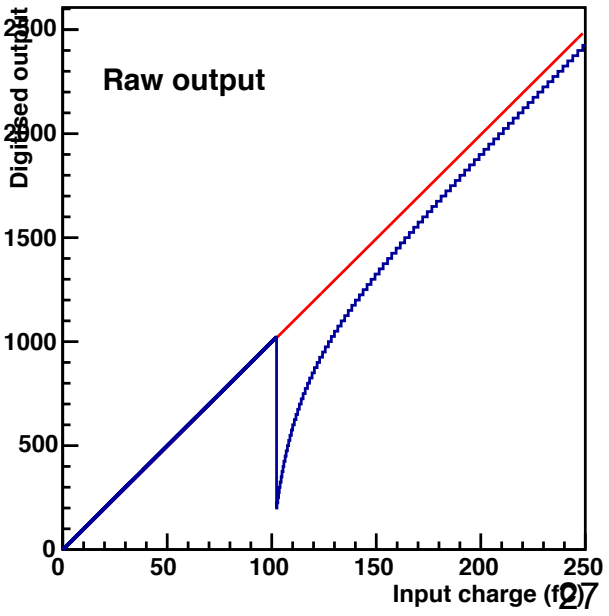
Trigger primitives

- Short-term goal is to fix requirements for FE electronics
  - Performance of trigger; FE noise, digitisation, non-linear effects
  - Selection of trigger sums; TX-limited due to bandwidth



- Modelling noise
  - Initial conditions and long-term

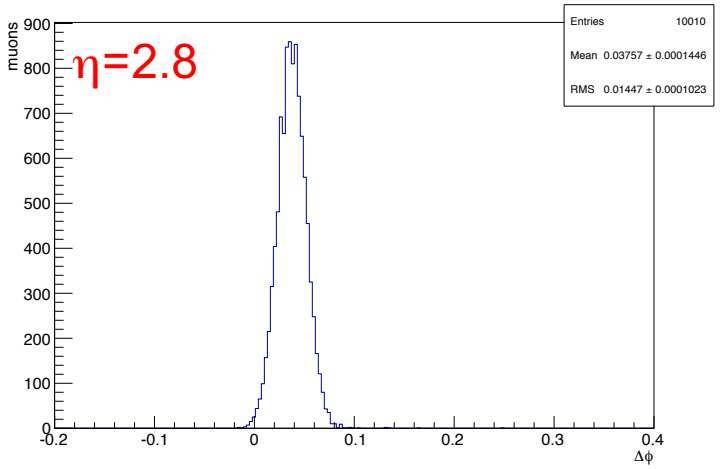
- Modelling non-linearities from TOT path
  - Correction methods studied

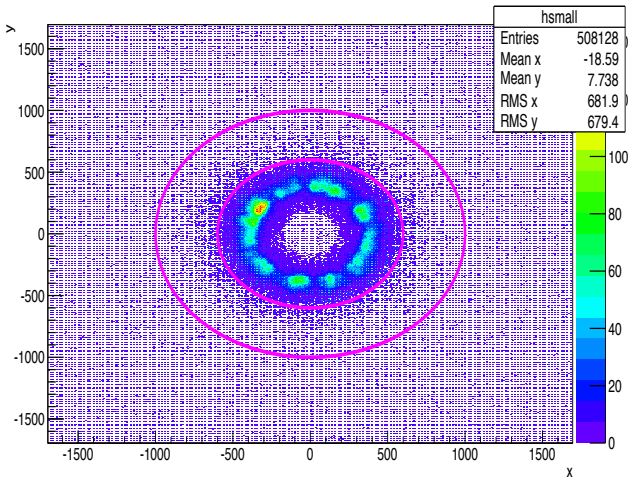


Simulation and performance

- Several areas of study in the UK
  - Geometry verification, detector optimisation, clustering and reconstruction
  - Mostly with UK-developed “standalone” simulation

- Muon reconstruction in HGC
  - Resolution ~40% for p_T = 10 GeV
  - Limited by multiple scattering





- Study of ~3 TeV jets at high η
  - Determine dynamic range of FE in “HCAL” layers of HGC

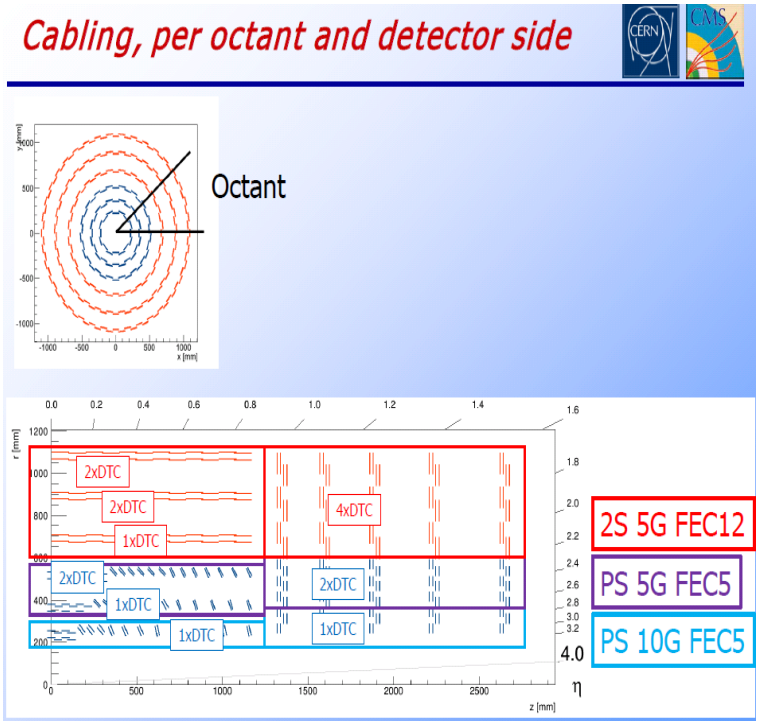
HGC schedule and milestones

- Currently focused on TDR
  - Due for submission in Nov 2017
- FE:
  - Results from ASIC V1 for TDR; design submission in Mar 2017
  - Studies of performance of test structures made with TSMC 130nm process during 2016
- TPG:
  - Need to show there is at least one feasible solution by TDR; no need to be optimised on this timescale
  - Architecture, rates and efficiencies, FPGA resource estimates
- Physics:
  - Show performance for e/γ, taus, and jets (in high pileup conditions)
  - Optimization will be limited by TDR timescale

WP5: L1 track-finder

- MP7-based demonstrator system operational in CERN
  - Appears to be most advanced of three options (review later this week)
    - Profit from a lot of expertise in the group, especially from L1 trigger
  - Second, complementary, small system operational in RAL
- Large multi-institute team now collaborating intensively
  - A lot of interesting work, as well as operating and optimising demonstrator
    - See report for most of the names - includes CERN, KIT, Vienna
  - Track finding in high pileup conditions already working
  - 2 workshops held – Jan, April
- Review process for architecture recommendation by end 2016
  - Process largely defined, with first meeting with panel 12-13 May
    - Introduce concept, planning, results to date
  - Final review December, where full slice to be demonstrated
    - Plus cost, resource and other information

System Architecture - Our aims

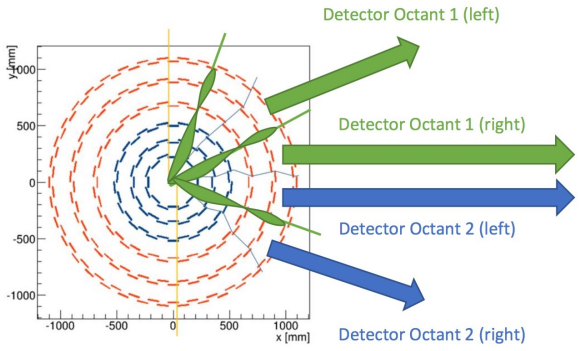


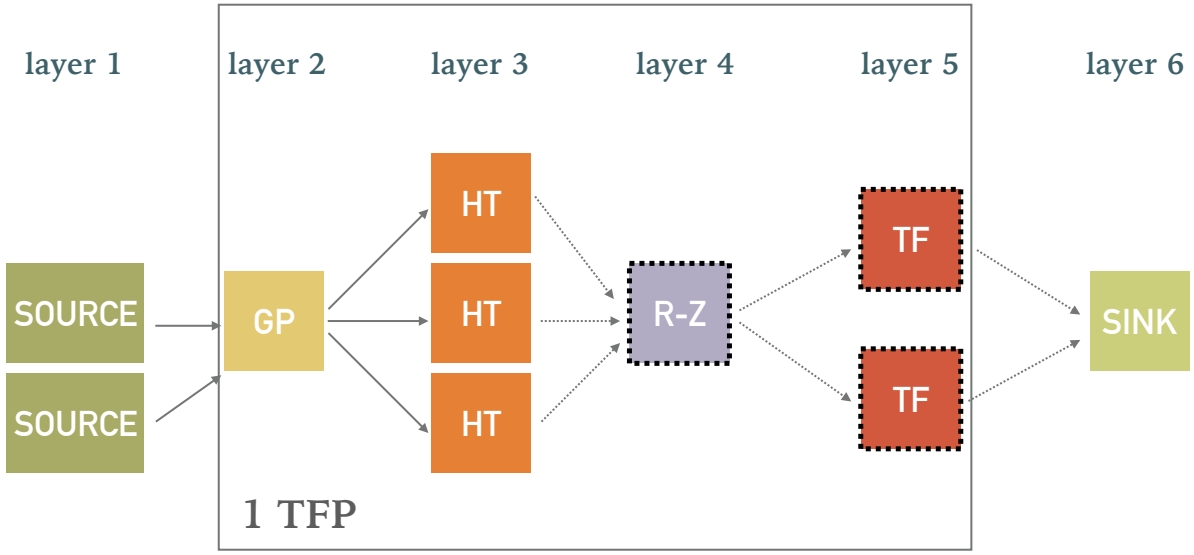
- Must ensure full scale & demonstrator systems conform to new realistic cabling scheme
  - Our TM system should be flexible enough to handle this
- Compartmentalise Track Finder from DTC layer
  - Separate the geometry from algorithm
  - Important if system is to retain its flexibility
- Verify # links/bandwidth from DTCs are compatible with full scale/demo system

- hardware emulates one quarter of the CMS tracker
  - stubs at 40MHz, time multiplexed, from Monte Carlo simulations
  - demonstrates track finding in 1/8 of detector, for 1/36 events

Architecture - Mapping to demonstrator slice

- TFP is **internally divided into logical elements**, each on separate boards (MP7s)
- Simplifies division of labour and algorithm development/testing
- Present-day **FPGA resources** is **no longer a limit** to the scale/performance of algorithms we want to implement





CERN Demonstrator hardware status

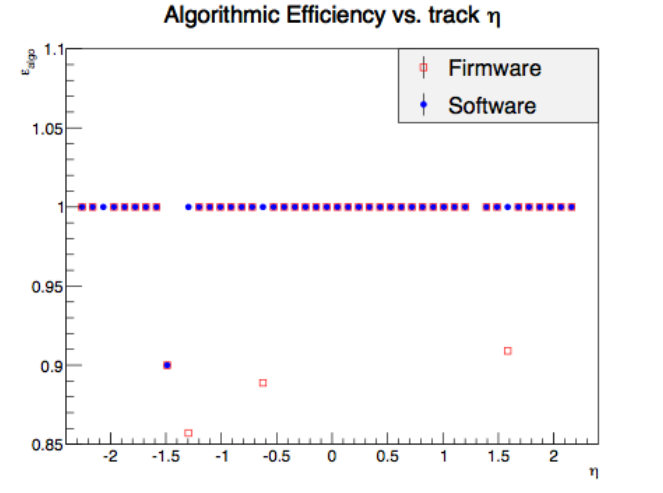
- CERN Tracker Integration Facility
  - B186
- Standard CERN blue rack
  - Turbine, 3-phase power, air deflector, water cooling/heat exchangers
  - 1 Schroff (MP7-XE) crate
    - 1 Vadatech (MP7-R1s or Xes) backup/expansion
  - Each with MCH + AMC13
  - PowerEdge R620 CMS rack PC
  - 8 MP7-Xes installed in Schroff

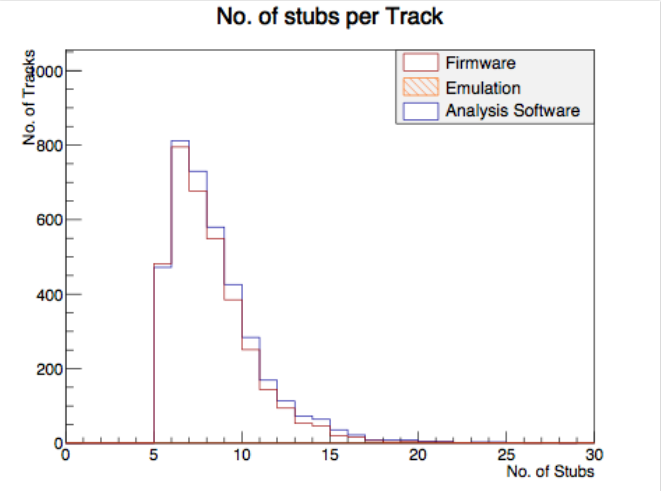
Demonstrator status

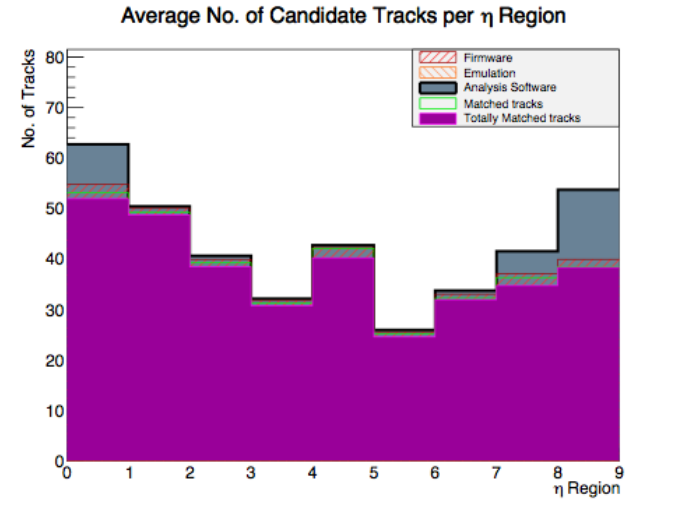
- Software - Full TMTT analysis software suite running
  - Pattern writer
  - Simulation software
  - Unpacker
  - Comparison software
- All board to board communication and synchronisation validated
  - Patterns injected into layer 2, and passed through layer 3
  - 3 simultaneous HTs, data from GP board
  - Results validated against single board tests at RAL
  - Sink/Source fw & sw tested & validated on single board

Demonstrator status

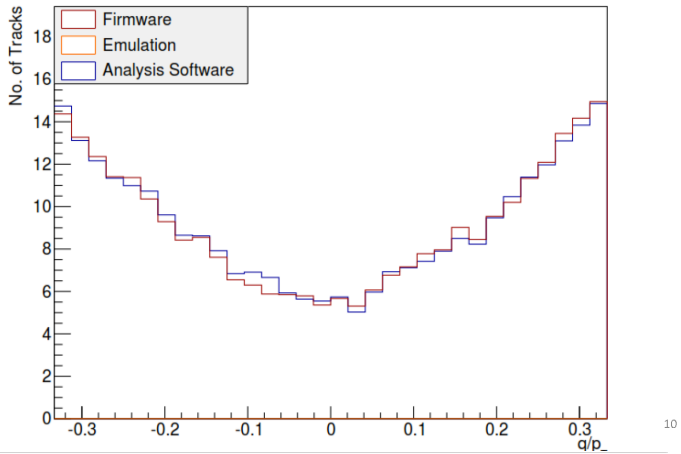
- Results coming in





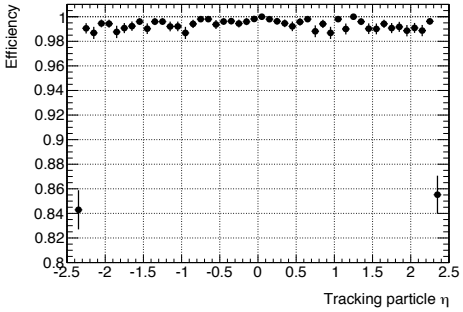


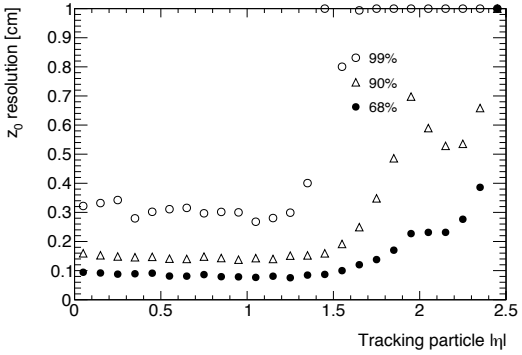
Average No. of Candidate Tracks per q/p_T



Simulated performance

- Early days yet… but exploring details





Muons, p_T = 10 GeV, 140 PU

Emyr Clement

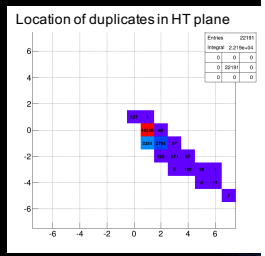
…y does tracking efficiency fall at high Pt?

Hough Transform duplicate candidate removal (WP5)

- The output from the $r\phi$ Hough Transform contains many candidates that are overlapping, subsets, or duplicates of others. The challenge is to reduce these extraneous candidates to reduce the effort needed further downstream in the track finding.
- Four methods were tried:
  - Alg11: *remove* any candidate found in *adjacent* $r\phi$ HT cells
  - Alg12: *remove* any candidate found in the $(\delta x=1, \delta y=0)$ $r\phi$ HT
  - Alg13: *merge** any candidate found in the $(\delta x=1, \delta y=0)$ $r\phi$ HT
  - Alg14: *merge** all candidates found in *adjacent* $r\phi$ HT

  * *merge* = combine all stubs at master cell location

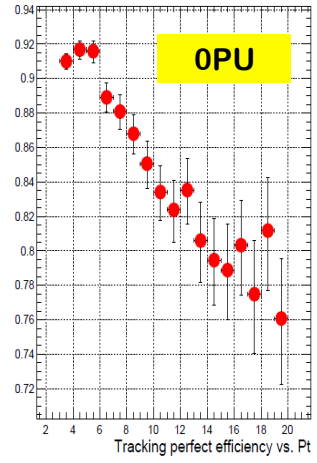
CONCLUSION: Merging with all adjacent candidates (Alg14) reduces candidates by 41%, with only a 0.5% loss of algorithmic efficiency.

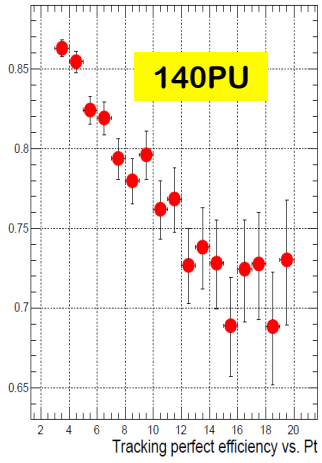


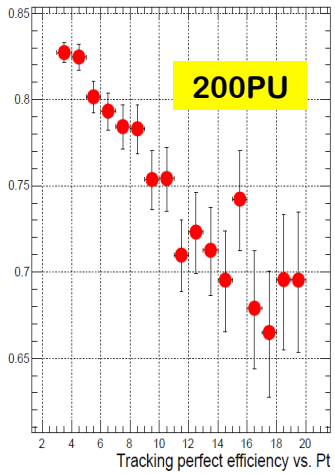
Brunel University London

Ivan D Reid

- But demanding no incorrect hits on L1 track ("perfect reco") when measuring algorithmic efficiency yields ~30% efficiency loss at high Pt!
- This efficiency loss has little dependence on PU, so must be caused by jets from ttbar system itself.
- **We need to improve further our tracking algorithm !**







Future planning

- Expenditure – no special issues
  - Most expenditure close to foreseen
- Materials & equipment
  - WP2: CBC3 manufacture mid-2016, with CERN invoice
  - Invoicing to Imperial still working well
- Steps towards construction project
  - Recent request from STFC for update on science case and resource requests
  - Now preparing update on last submission in 2014
    - Requirements yet to be fully defined

Some comments on future plans

- Mainly related to this R&D project, which is currently at the half-way stage
  - Funding runs to March 2019, and have built on predecessor period
- Several outcomes now visible =>firm foundations for construction project
  - CBC – most advanced ASIC – and 2S-module (key to demonstrate track-trigger concept)
    - Only full size Phase II ASIC, with most of final features
  - MP7 – most advanced board of its type, challenge to manufacture, but succeeded
    - May be compared to CTP7, but no other comparable hardware
  - FC7 – successful collaboration with CERN on design and manufacture
    - General purpose board, already widely deployed, including outside CMS
  - Ipbus – only(?) common firmware/software infrastructure
  - Established record of advanced (& difficult!) firmware development
    - Nearly all open access
  - Online software – significant DAQ expertise, both from past and R&D
    - Created new SWATCH system rapidly, under time pressure
  - System implementation – with capability to cover all aspects

Towards construction project

- Several major ideas pioneered by UK
  - Track-trigger pT module concept and demonstration in simulation, and hardware
  - Time multiplexed trigger, and related firmware in single FPGA
  - Ipbus - invented elsewhere, but implementation done by us
  - Full system implementation
  - High Granularity Calorimeter concept
- Additionally, we now have developed much expertise
  - Firmware, software, board design, ASIC design and qualification, manufacturing (and procurement) experience
  - Important management expertise, locally and within CMS
  - With a very good collaborative (internal & external) spirit, which is proving effective
- Without undue modesty, this is a unique record in CMS
- We think both we and CMS can profit significantly from this
  - Even if capital resources are limited (not too much, we hope!)
  - There is now a lot of coherence and overlap in our overall activities

Conclusions

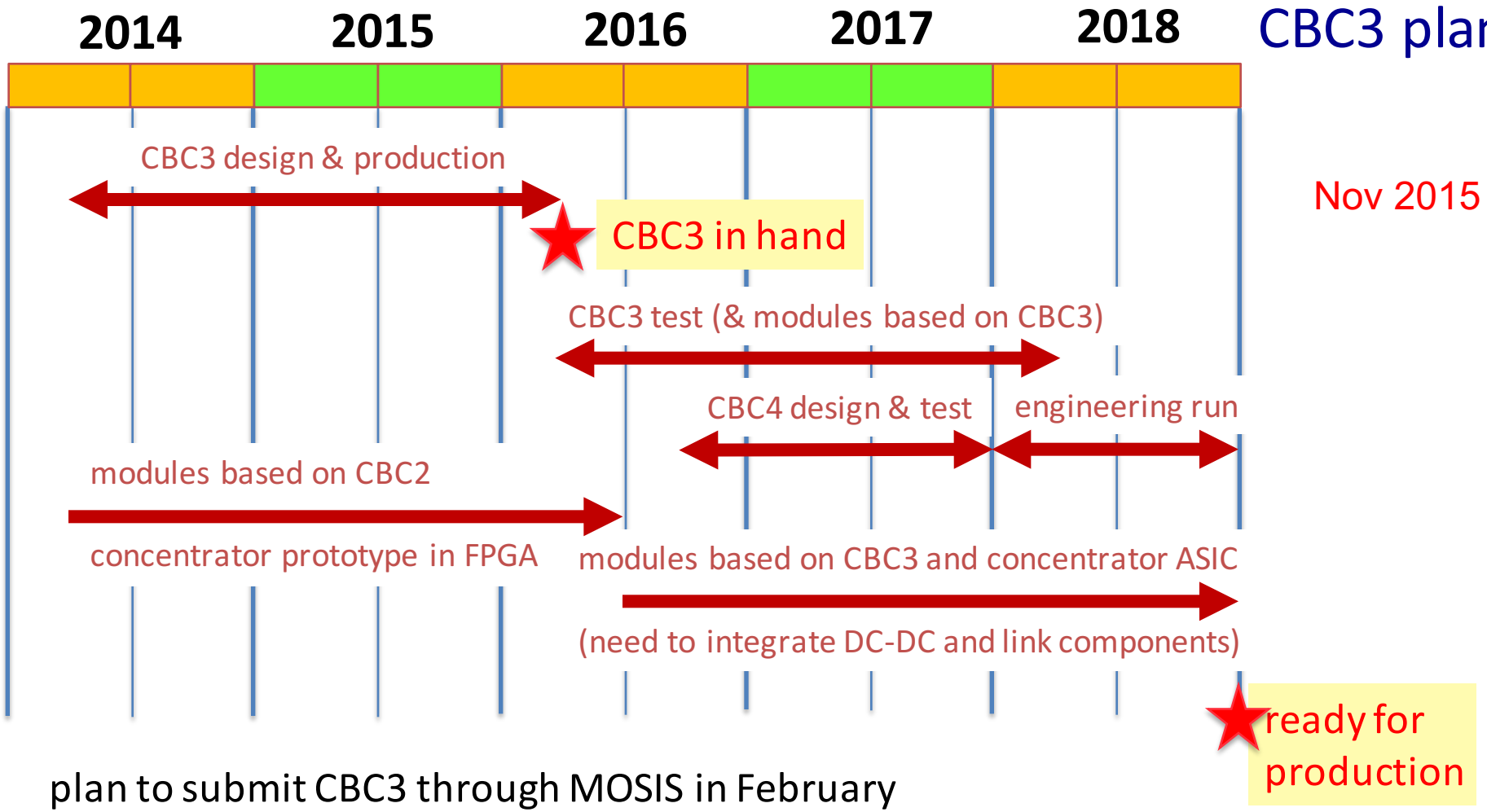
- Successful completion of L1 Trigger Phase I upgrade
  - Operational phase from 2016

- New work packages under way
  - No change in scope compared to original proposal
    - New resources from ERC for HGC activities
    - Overall focus on science-driven, trigger-related tasks in all areas
      - Potential flexibility in future deployment
  - Important decision-making milestone at end 2016
    - With influence over future UK activities

- Planning for construction project urgent

Further information

CBC3 plan



plan to submit CBC3 through MOSIS in February

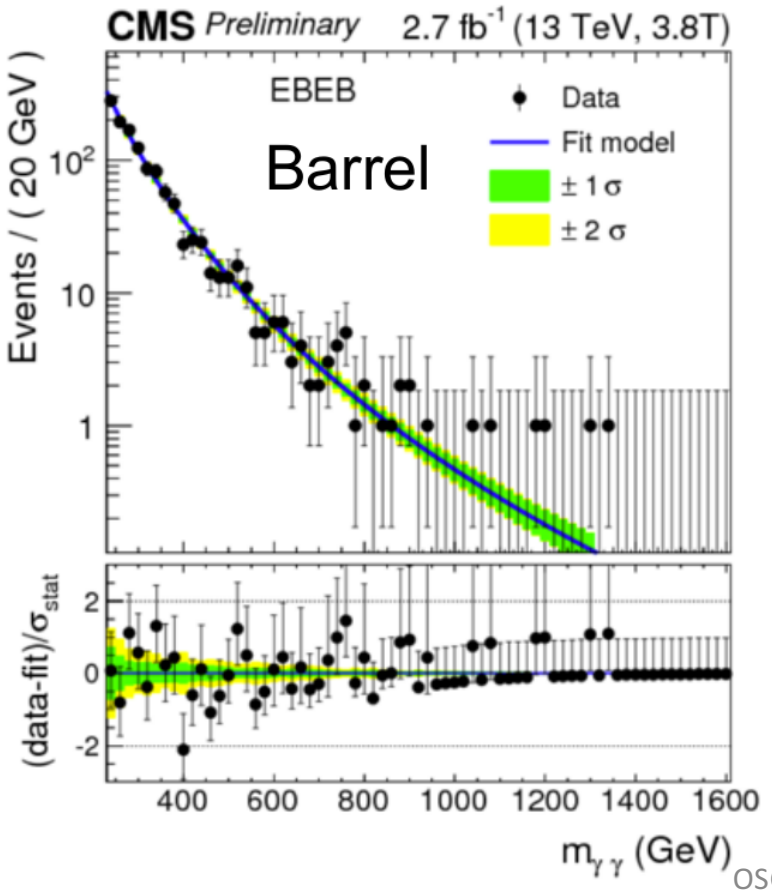
limited number of chips but ~ half the cost of full wafer run

can expect chips in hand ~ May

(small schedule slippage but have to comply with fixed submission dates)

High Mass diphoton search: update

3.8 T data after re-reco
(improved detector calibration): expect 10% improvement in performance (w.r.t. Jamboree) due to better resolution



0 T data:
new analysis, expect another 10% improvement when added