

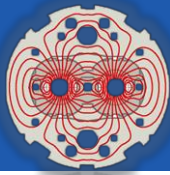
UK CMS Upgrade Oversight Committee

18 November 2015

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

Overview

- Snapshots of LHC & CMS status
 - Reasonably successful commissioning year of operation almost over
 - Finally in the home straight for the Phase I calorimeter trigger upgrade
- Summary of UK upgrade project
 - Recent WP progress
- Finances



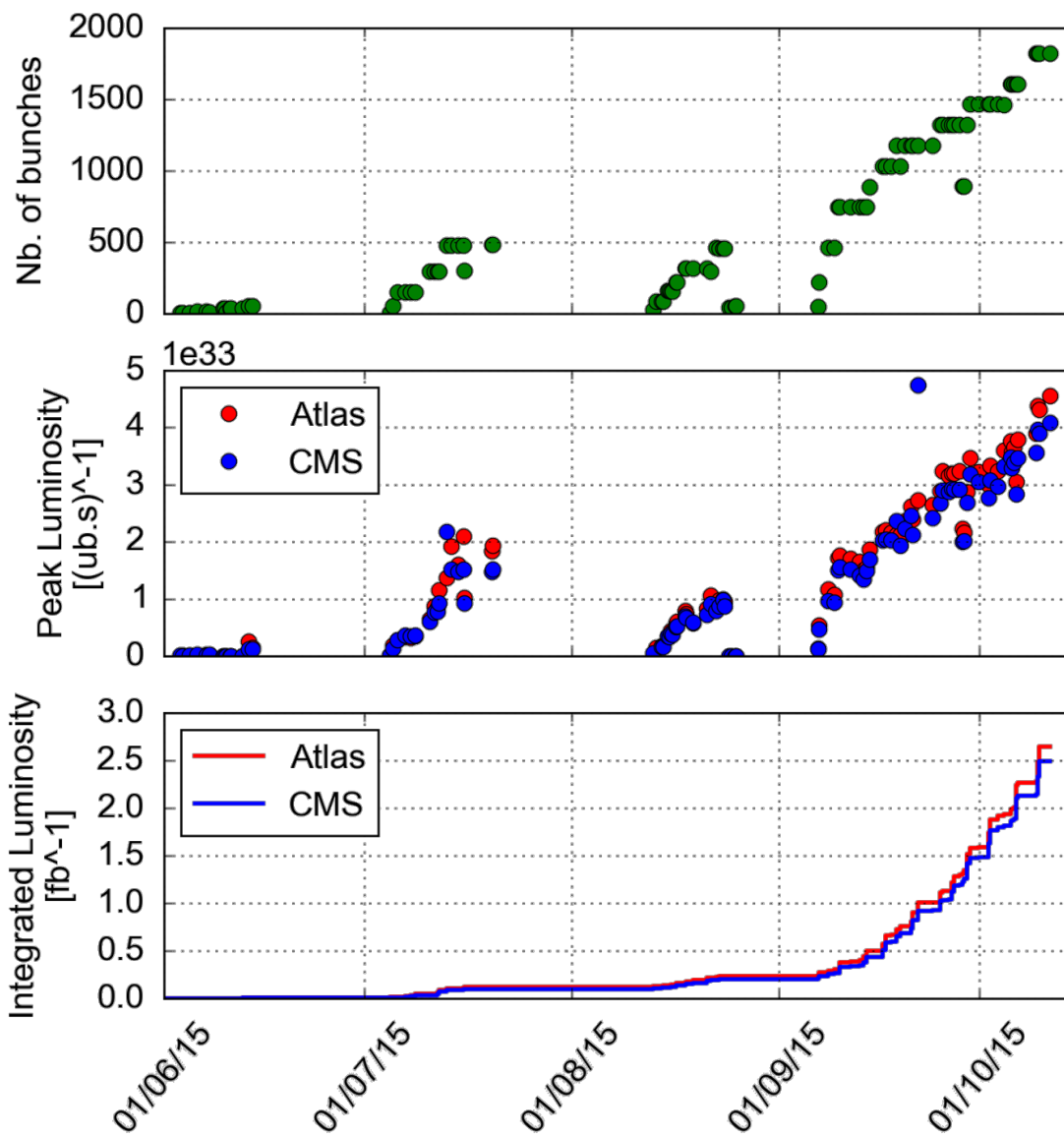
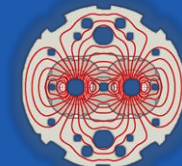
- **Target energy: 6.5 TeV**
 - Limit the magnet training required
 - Small operational margin 100A in 11kA
- **Bunch spacing: 25 ns**
 - strongly favored by experiments, pile-up
- **β^* in ATLAS and CMS: 80 cm**
 - but investigate lower β^* for later

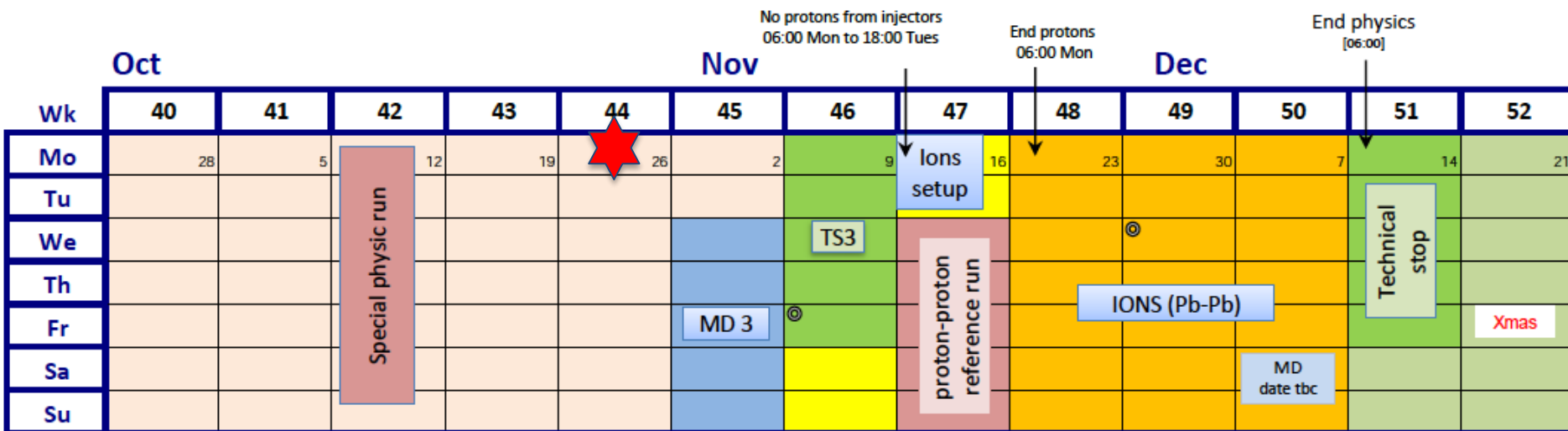
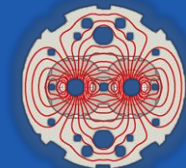
Energy

- Lower quench margins
- Lower tolerance to beam loss
- Hardware closer to maximum (beam dumps, power converters, quenches...)

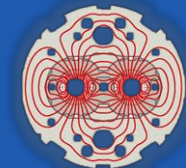
25 ns

- Electron-cloud
- UFOs
- More long range collisions
- Larger crossing angle
- Higher total beam current
- Higher intensity per injection





- 1 week proton running – should make 4 fb⁻¹
- Pb Ion cycle set-up set-up immediately after the Technical Stop (lower β^* in ALICE)
- Reference proton run at 5.02 TeV
- Run Pb-Pb collisions until the end



○ Start 2016 in production mode

- 6.5 TeV, machine scrubbed for 25 ns operation (doublet beam)
- $\beta^* = 40$ cm in ATLAS and CMS
- Rapid intensity ramp up should be possible
- With the beam of today (1825) will reach $1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Hope to push this further in 2016 to $\sim 1.2 \times 10^{34}$.
- Later, with a full machine and higher I_b , can reach $> 1.5 \times 10^{34}$
- Reasonable availability assumed – **usual caveats apply**

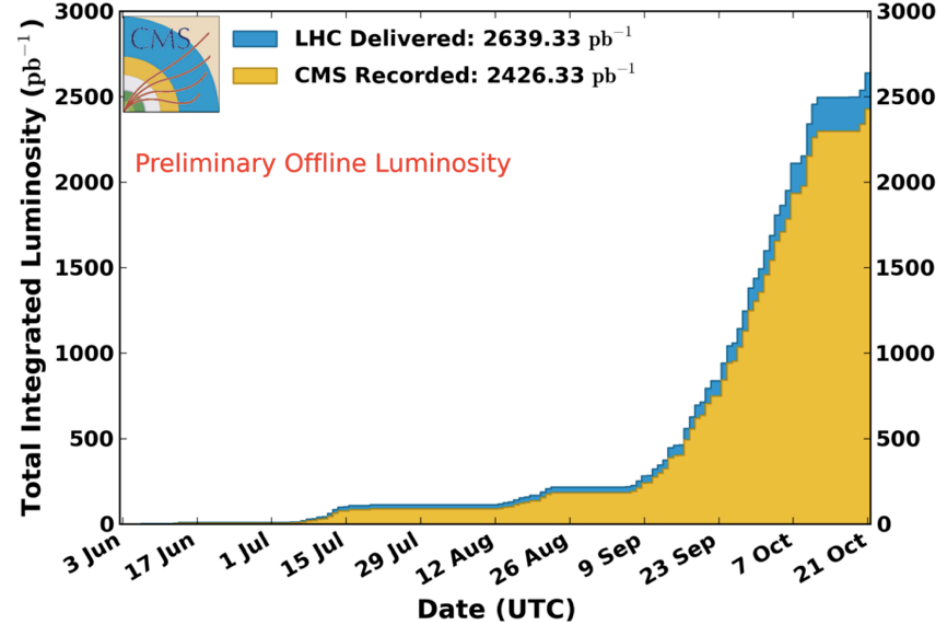
	Peak lumi $\times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	Days proton physics	Approx. int lumi [fb^{-1}]
2015	~ 0.5	65	4
2016	1.2	160	30
2017	1.5	160	36
2018	1.5	160	36

CMS Run II: data taking

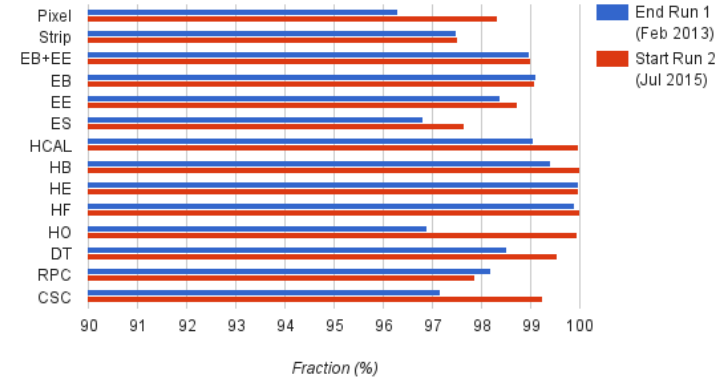
T. Camporesi October RRB

CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13$ TeV

Data included from 2015-06-03 08:41 to 2015-10-21 09:53 UTC



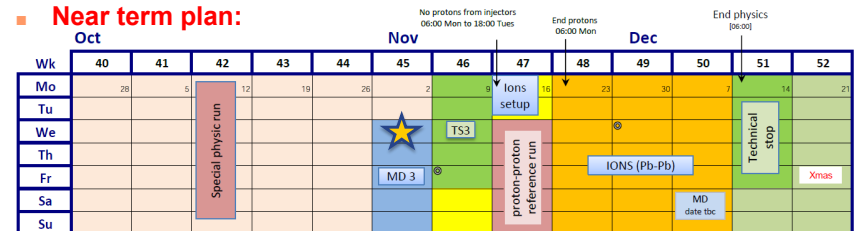
Active Detector Fraction Run 1 to Run 2



LHC and CMS running

- 2015 luminosities $\sqrt{s}=13$ TeV proton collisions:
 - TOTAL: 4105 pb^{-1} / 3675 pb^{-1}
 - B = 3.8T: 3085 pb^{-1} / 2860 pb^{-1} (92.7%)
 - B \neq 3.8T: 1020 pb^{-1} / 815 pb^{-1} (80%)

Near term plan:



- Technical Stop
- Machine development
- Recommissioning with beam
- Special physics runs (indicative - schedule to be established)

Overall data taking efficiency >92%

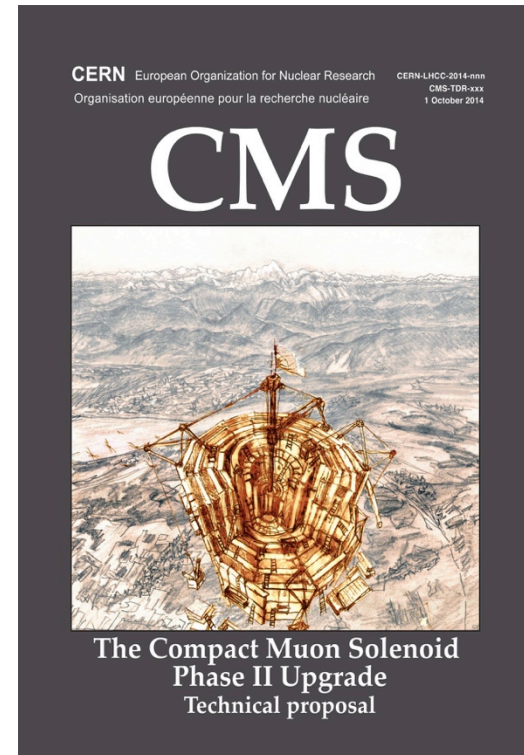
- 18 Nov: special day-long LHC Machine Committee mtg on Year-End Technical Stop planning. Items likely to be discussed include TDI for Beam 2, ULO at 15R8, ATLAS magnet, CMS magnet cryo...

- Since March 2015 the “Cold Box” (CB) that produces liquid He for operation of the CMS magnet has had problems
 - follows compressor oil pollution of the CB circuit.
 - For definitive recovery, the system requires an overall cleanup which takes several months.
- CERN cryogenics group, in collaboration with CMS Technical Coordination, has been trying to find a way to operate the Cold Box with a reasonable Duty Cycle ($> 70\%$) that would allow operation of the magnet synchronized with physics operation of the LHC until the Year End Technical Stop.
 - During TS2: augmented surface filters were installed; in addition, a special “regeneration cycle” has resulted in allowing a continued magnet operation since.
- Some success
 - But about a quarter of the data at $B = 0$

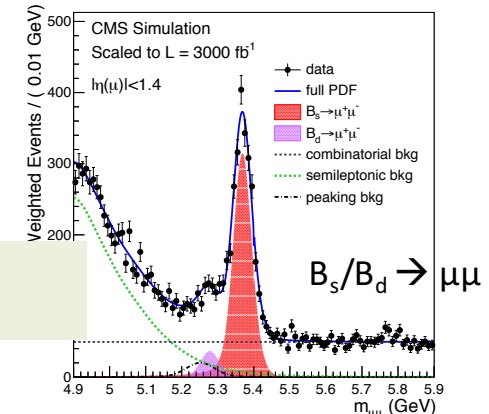
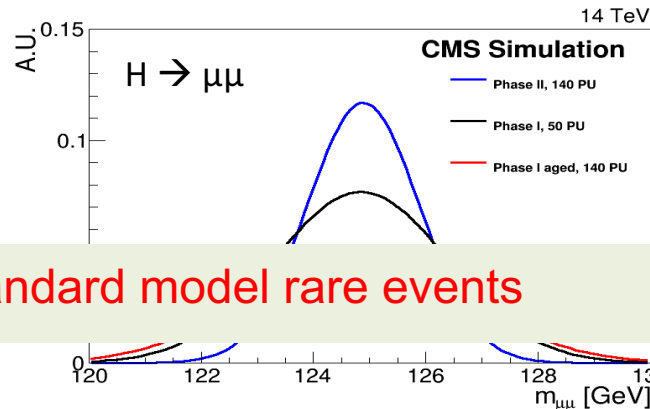
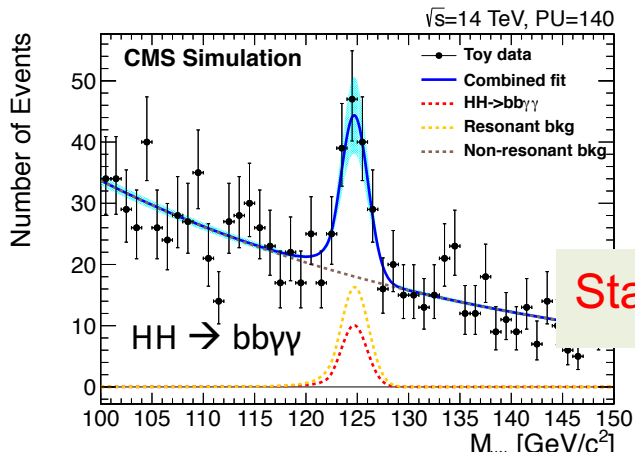
Phase II Technical Proposal

- **Goals of CMS Phase II upgrade**
 - Maintain Phase I detector performance – at 140 PU (the HL-LHC baseline)
 - Enable operation at 200 PU (ultimate), with moderate performance degradation
 - Radiation tolerance: full performance at 3 ab^{-1} , and margin up to 4 ab^{-1}
- **Technical Proposal (TP)**, to LHCC in June 2015.
 - followed by information on effort, R&D and reduced cost options, to RRB in October

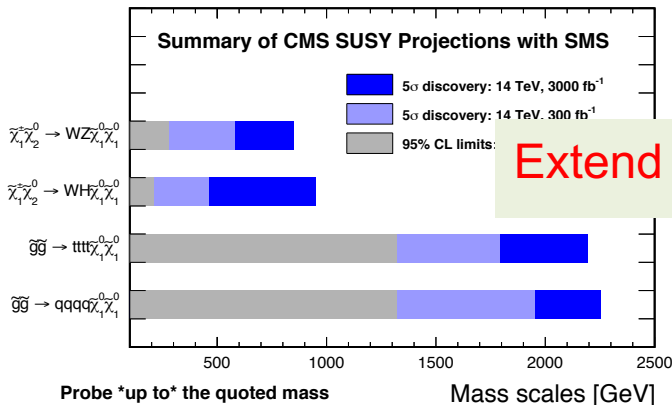
CERN-LHCC-2015-010
<https://cds.cern.ch/record/2020886>



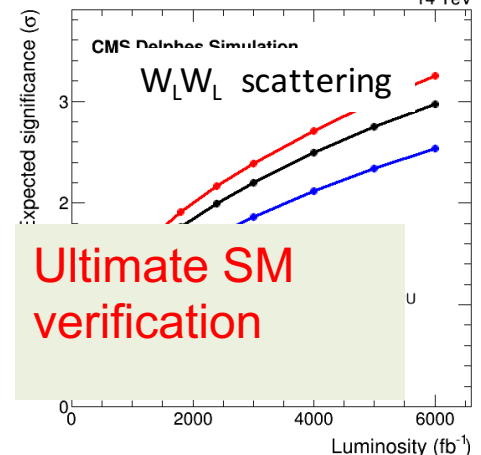
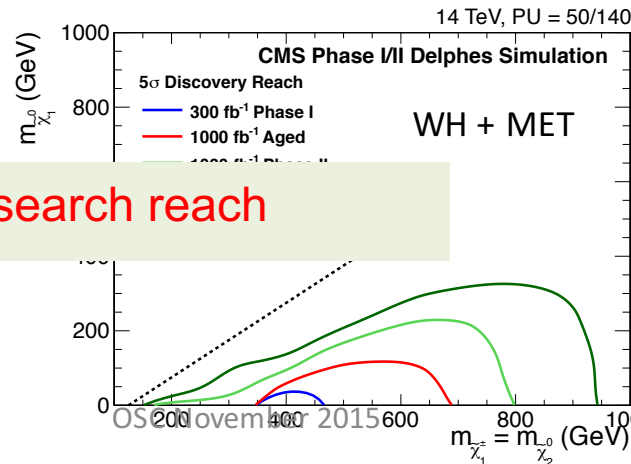
- Studies establish upgrades required due to longevity issues or increased data rates
- Presents physics reach after upgrades in several physics areas



Standard model rare events



Extend search reach



Ultimate SM verification

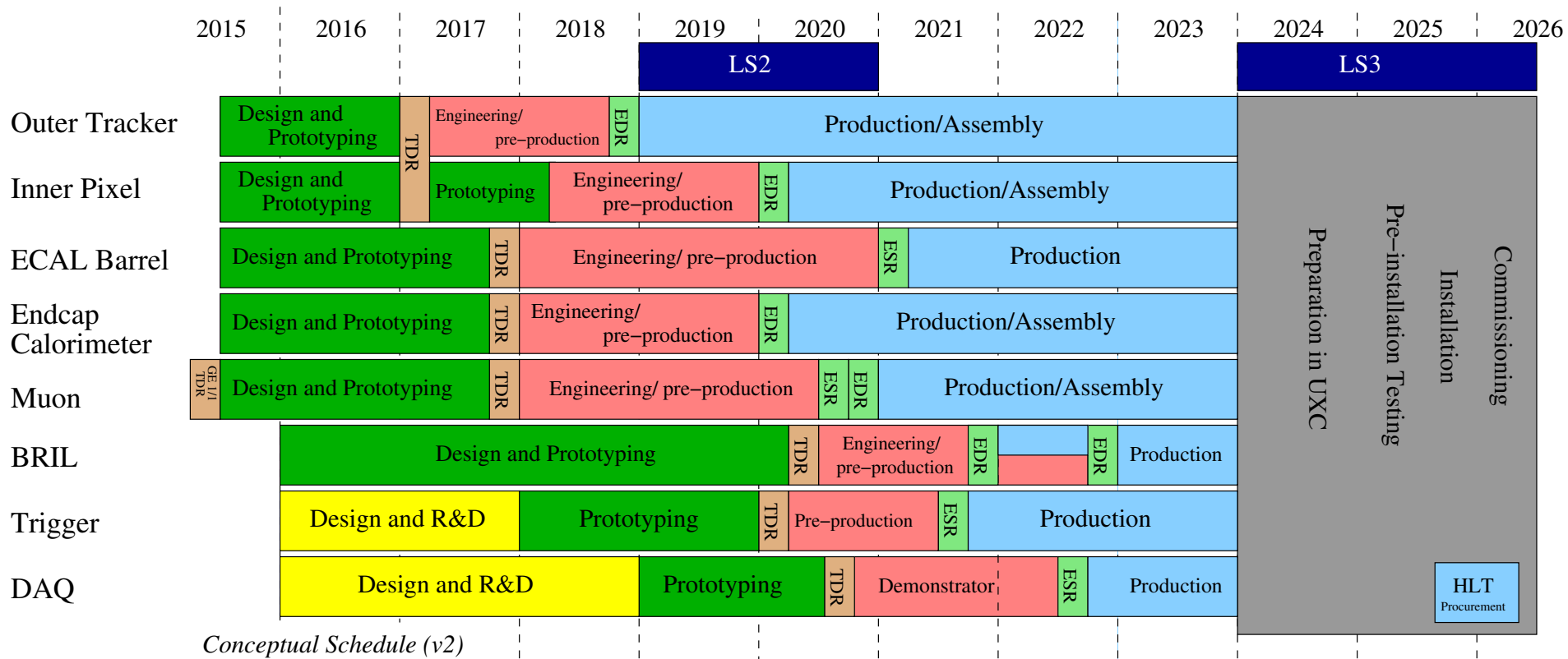
Cost estimate

- Reference design: 265 MCHF
 - uses vendor information for major cost drivers, present knowledge of comparable systems (eg MP7), scaling from original
- Also considered descoped versions
 - 242 MCHF
 - lose performance under extreme pileup (200) but smooth degradation
 - 208 MCHF
 - significant impact on physics and increased risk to performance

CORE cost estimate	MCHF (2014)
Pixel Detector	23
Outer tracker	89
Tracking System	112
EB electronics	10
HB scintillators	1
Endcap HGC+BHE	64
Calorimeters	75
DT and CSC electronics	10
Muon stations:GE11,GE21, RE31 and RE41	10
Muon extension ME0	5
Muon Systems	25
Beam Monitors and Luminosity	4
Hardware trigger	7
HLT	11
DAQ	6
Trigger and DAQ	24
Infrastructure, Systems and Support, Installation	25
Total	265

Project planning

- TDRs for large construction projects are foreseen year 2017



UK R&D status

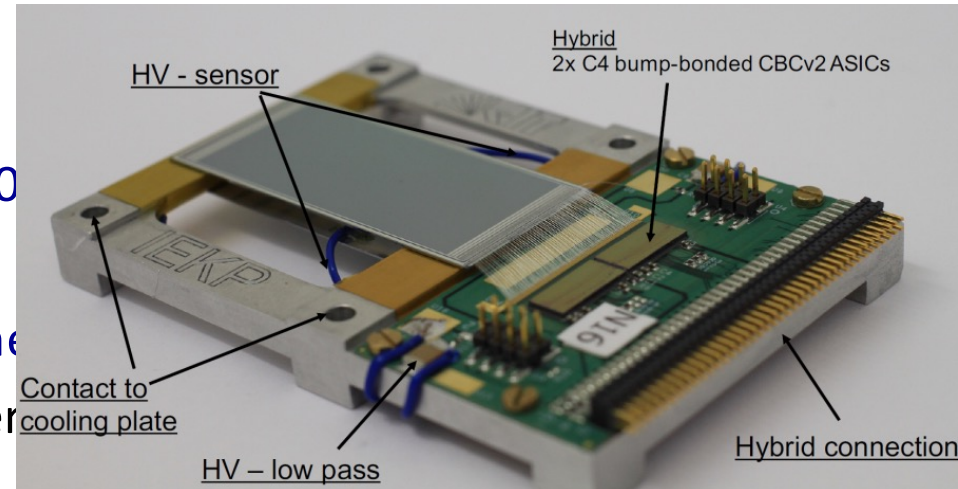
Last 6 months

- WP2:
 - continued steady progress with CBC3 design
 - expect CBC3 submission Feb 2016, but probably MPW run, not MOSIS
 - Latest FC7 production confirms quality of new manufacture(r)
- WP3: progress towards installation of TDR trigger
 - Stage-1 operating as CMS trigger since September
 - 2016 trigger has been commissioned with parallel data taking
 - quite close to last schedule
 - now evaluating (apparently excellent) results in detail
- shared: L1 track finder studies and demonstrator
 - somewhat later than anticipated but otherwise progressing well
 - timely to plan new WP to harness and steer all the effort

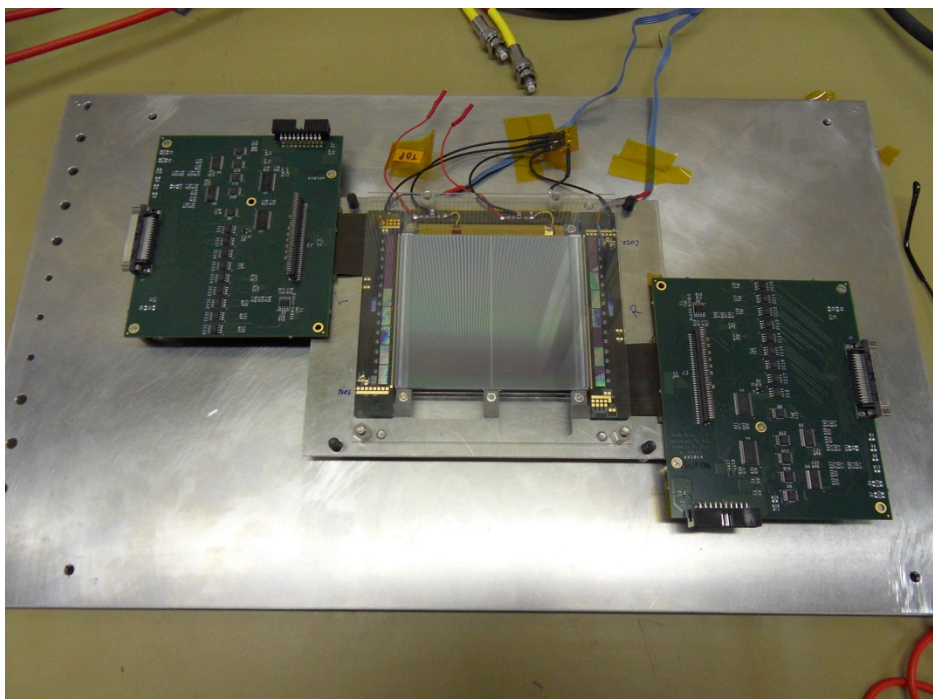
Overview of CBC activities

- CBC2 based module tests continue
 - first full-size module recently constructed in time for November test beam
 - mini-module with irradiated sensors in test beam in June

- CBC3 design continuing
 - target submission date still February 2016
 - can expect wafers in middle of year
 - plan now to share submission with other groups
 - many more chips & possibly cheaper



- CBC3 test
 - starting to think about CBC3 readout
 - much more data to handle (6 x 360 Mbps data streams)
 - FC7 based



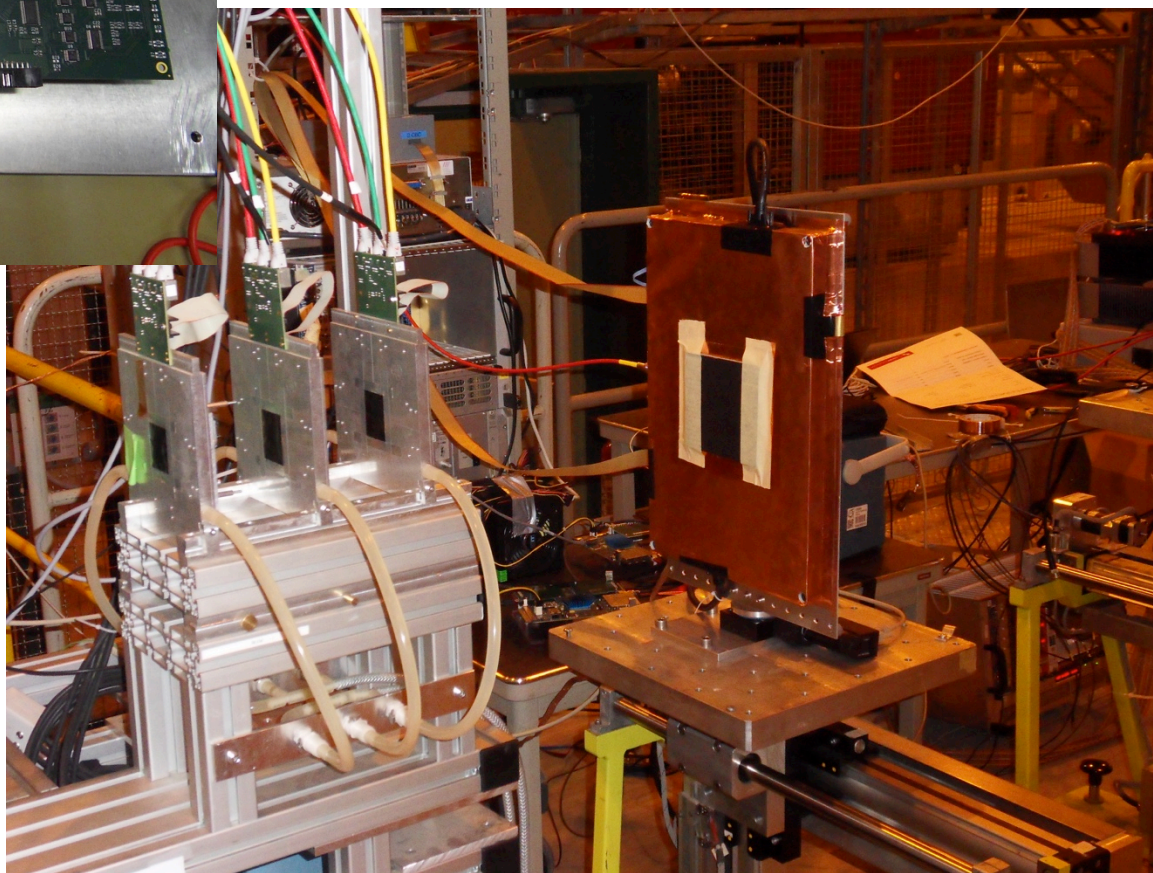
2S-module in test beam

full size $\sim 10 \times 10 \text{ cm}^2$ sensor area

2 x 8CBC2flex hybrids

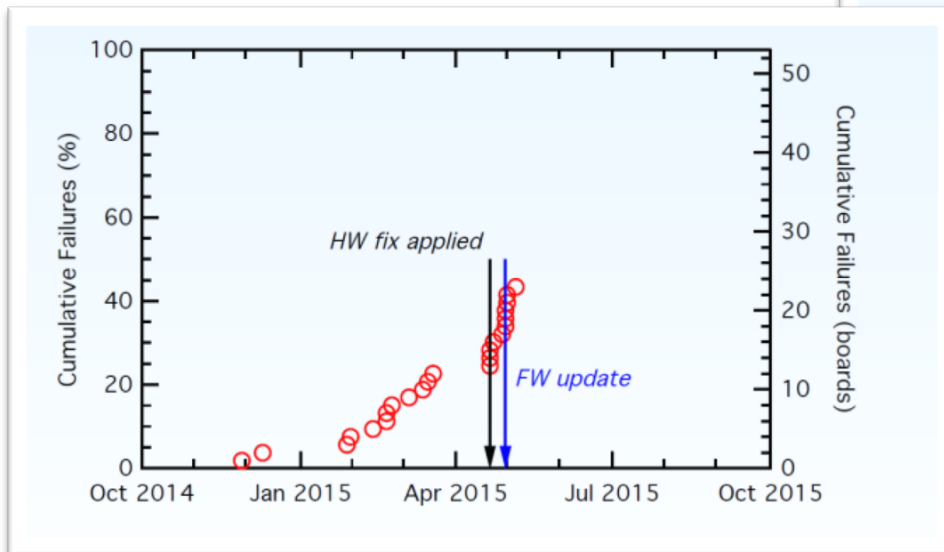
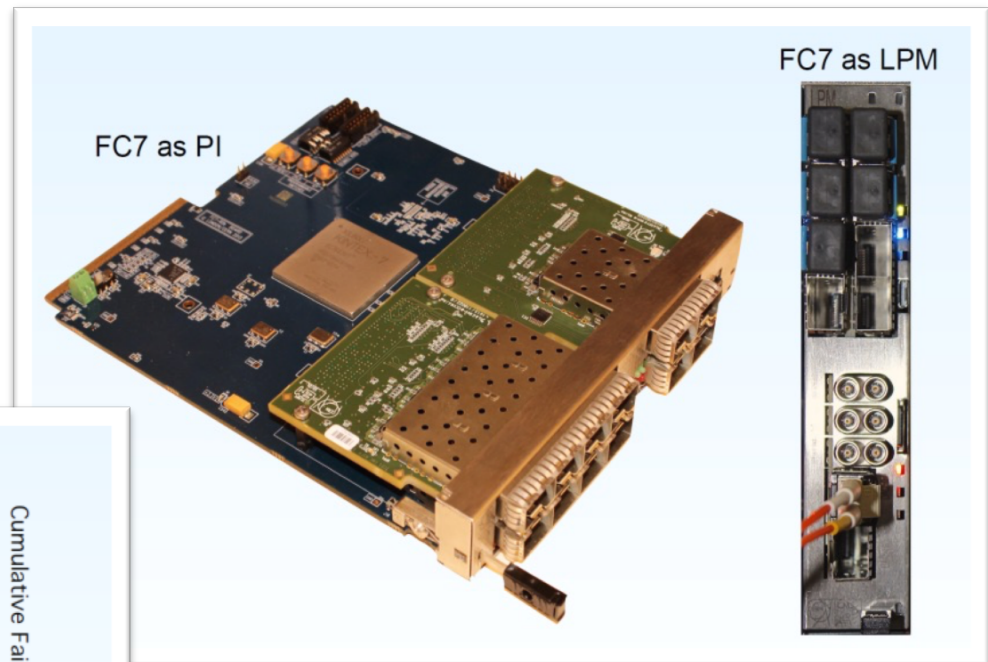
CERN H6 beam area
4 – 15 November

early online results look
very promising



FC7 history

- Problems discovered in prototype (R0) boards built for TCDS project
 - upgraded CMS TTC system, on tight schedule
 - hardware (wire) fix applied has stemmed the failures
 - survival of the fittest



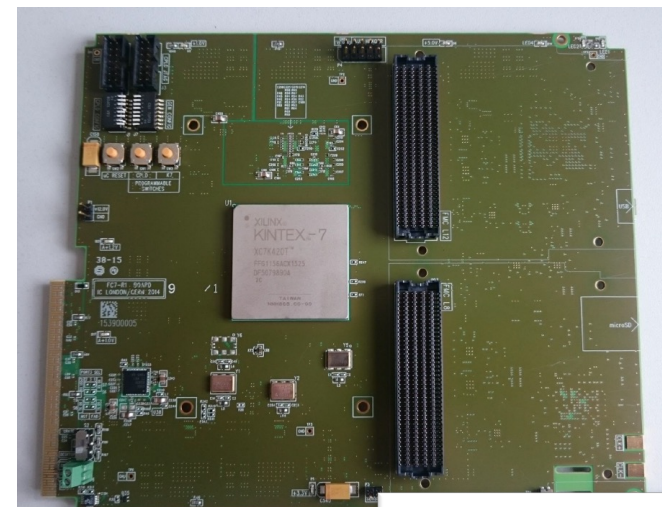
- fix included on next design revision (R2)

- manufacturing problems with HAPRO
 - PCB (FastPrint) does not meet spec, cf. MP7
 - PCB failure during inspection/assembly twice
 - (~3 month delay, still awaiting delivery)

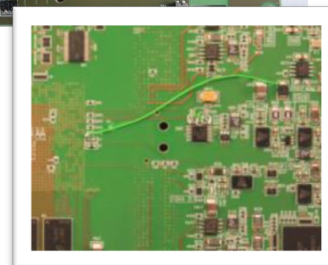
- in parallel, trial manufacture with new suppliers
 - assembly (BB Electronics) who manufactured CERN GLIB card over many years
 - PCB (Somacis,IT), cf. MP7

- 35 new boards from BBE (R1 variety) delivered in October
 - 2.5 month turnaround
 - outstanding yield (97%)

- R2 production with BBE underway
 - batches of 5 + 60 + 135 + 50 + options till 2017



BBE R1 with wire-fix at assembly

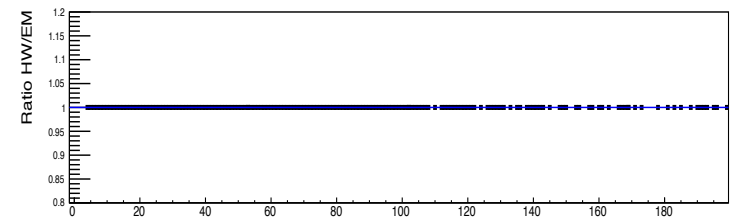
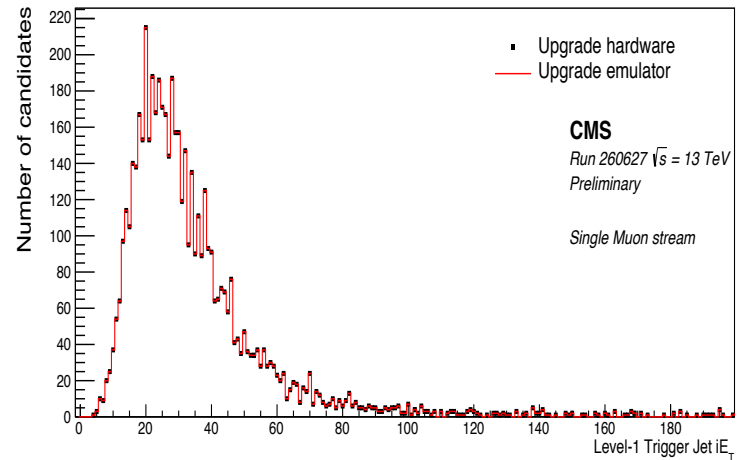


WP3: Phase I trigger progress

- Commissioning for 2015 (Stage-1) completed with 50ns data and operational for CMS data taking with 25ns data
- Commissioning for 2016 underway (next slide)
- Two small outstanding hardware items:
 - Power supplies did not operate as expected – solved with help of manufacturer
 - Final fibre installation between processing nodes and demux – fibres received and will be installed before Xmas at a convenient time
- General lack of manpower for online software
 - UK already contributing significantly – no new effort from us
 - Trigger Project Managers trying to solve with help from CMS management

Phase I trigger status

- Commissioning of the system has progressed significantly
 - Collected more than 7bn events, smoothly with CMS central DAQ
- Data allow us to:
 - Validate the simulation of the trigger – **done** (see figure; many other examples)
 - Measure rates and efficiencies – **ongoing**
 - Allows tuning of trigger conditions for the start-up of the LHC next year
- Expect to complete data analysis early December
 - **decision by CMS for 2016**



Comparing jet E_T for hardware and simulation

MP7 order status

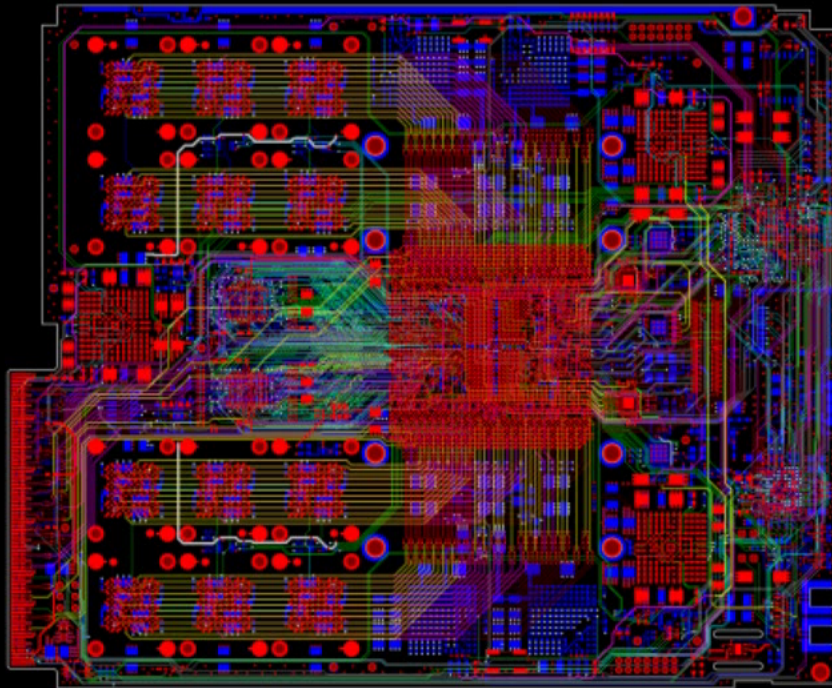
- Following pre-production, two orders of 16 boards completed (see table)
 - Prod-1: Hapro (No) + Exception (UK) , and Supp Prod-1: 8 boards at Hapro
 - Prod-2: Hapro orders of 32 launched in 2014
 - Production failure with PCB supplier (FastPrint, CN)
 - Three production failures with UK PCB supplier (Exception, UK)
 - Poor QA at both PCB companies despite adhering to international standards.
 - Discussions with CERN PCB experts & purchasing, two new suppliers
 - SOMACIS (IT): Delivery 30 Oct – quality looks very good (cf. FC7)
 - TTM (US): Delivery due 11 Nov

<i>Project</i>	<i>Pre-prodn</i>	<i>Prod-1</i>	<i>Supp. Prod-1</i>	<i>Prod-2</i>	<i>Future req</i>	<i>Prod Total</i>
<i>Calo Trig Layer-2 & demux</i>	9	25	5	4	12?	34-46
<i>GT & GMT</i>	1	4	0	14	0	18
<i>Barrel Muon Track finder</i>	1	3	0	14	0	17
<i>Stage-1</i>	2	0	2	0	0	2
<i>LLR</i>	1	0	1	0	0	1
<i>Total required</i>	14	32	8	32	0	72-84
<i>Orders</i>	14	32	8	32	12?	72-84
<i>Delivery</i>	Done	Aug-Oct	Dec	Apr?	?	

Next generation: MP-ultra

- Technology demonstrator and development board for future trigger and readout applications
- All board infrastructure (power, clocking, control, optical fitments) designed to stay the same as part of a roadmap of future developments
- First generation: MP-ultra K
 - Xilinx Kintex Ultrascale FPGA
 - 48 optical links at 16 Gbps
 - 8 Gbit low-latency RAM (reserved address bits routed for future capacity expansions)
- Should be easier to manufacture than MP7
- First prototypes expected ~January 2016

From MP7 to MP-ultra



MP7XE_R0_v19 - 11 March 2014, 14:37:57
OSC November 2015

Track-trigger progress

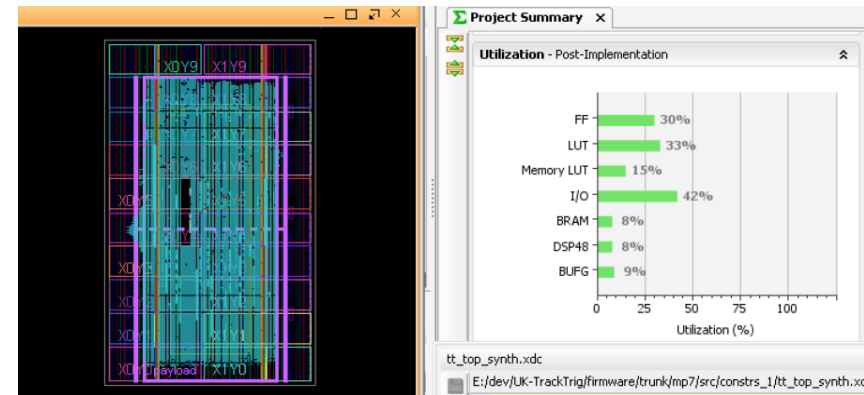
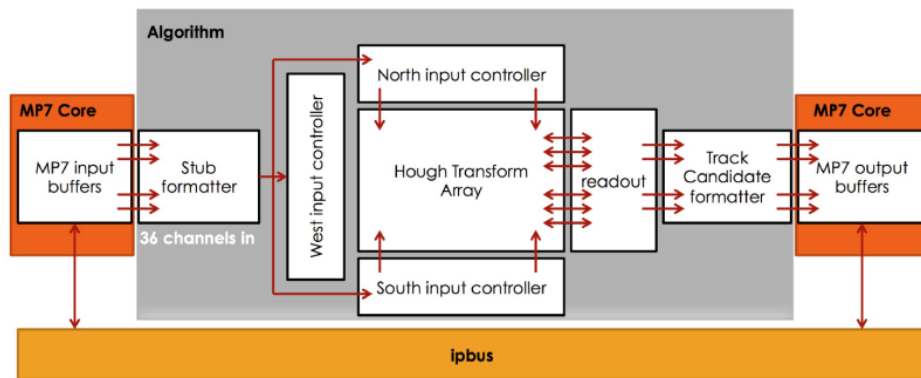
- Recent focus on assembling and testing MP7 demonstrator system
 - 1D scalable track finder based on Hough Transform (HT)
 - beginning with single board demonstrators and a scaled down HT
 - firmware and software now being debugged
- Other work
 - optimization studies on HT array (MC)
 - investigations of new algorithms and alternative HT implementations
 - Track Fitting simulations to enable comparisons on performance
 - development of generic software tool for simulating algorithm data flow



demonstrator crate at RAL, 2 MP7XEs

Firmware and software development

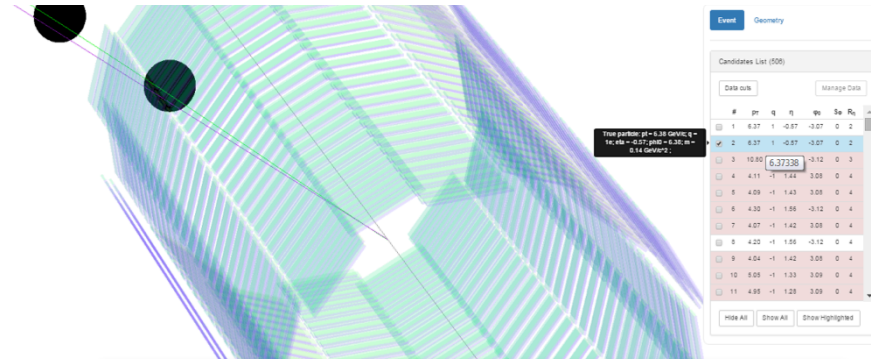
- Firmware based on systolic array complete
 - includes recent improvements to reject fake combinations
 - integrated with MP7 infrastructure firmware
 - algorithm implements ~10% of final array, with ~30% V690 resources



- Software infrastructure ready, and under test in demonstrator
 - track finder emulator
 - pattern writer/reader for MP7 input and output capture
 - board control and array configuration scripts

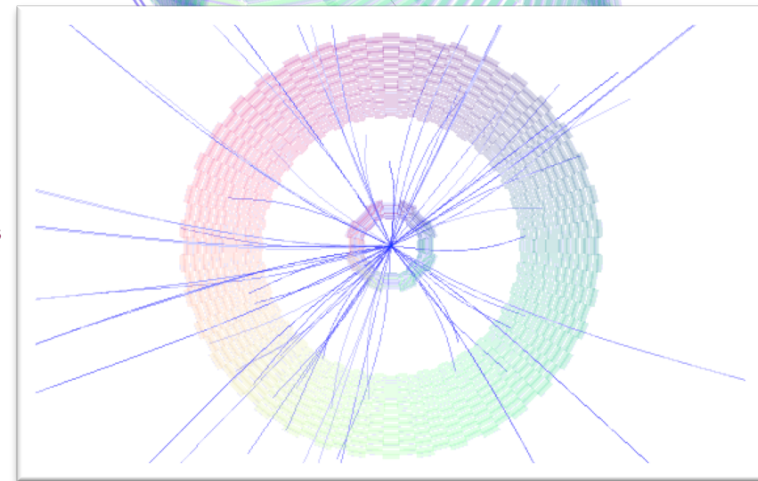
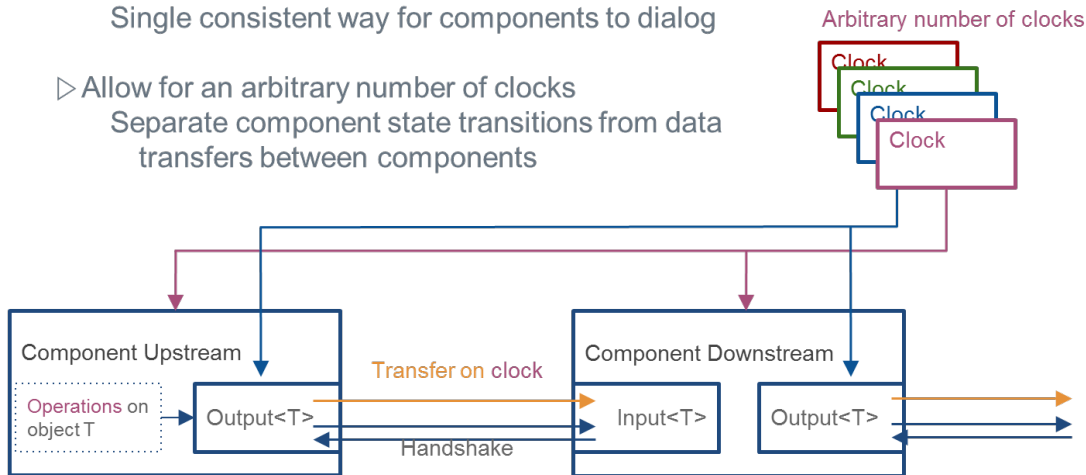
Common software tools

- To speed up testing and debugging of new algorithms and concepts
 - data flow simulator
 - event display tool



CIDAF: **C**ircuit **D**ata **F**low simulator

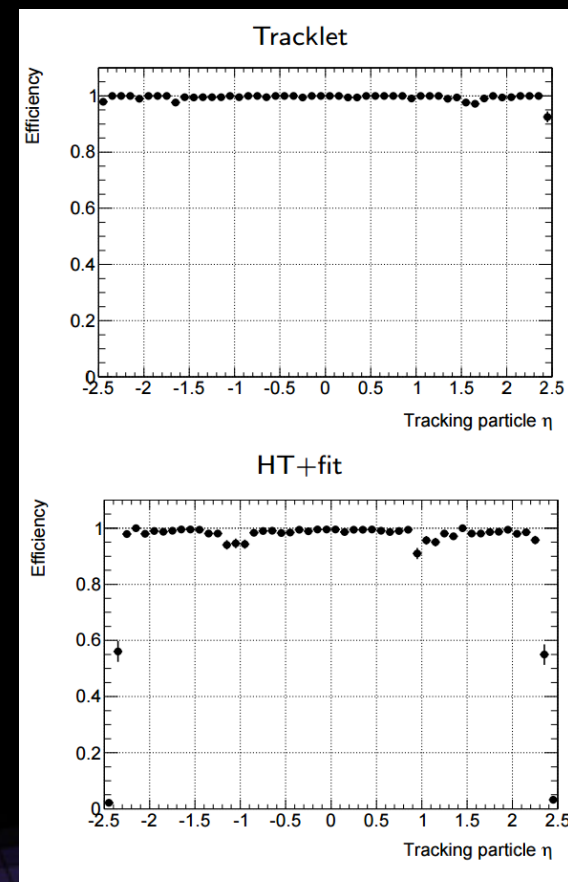
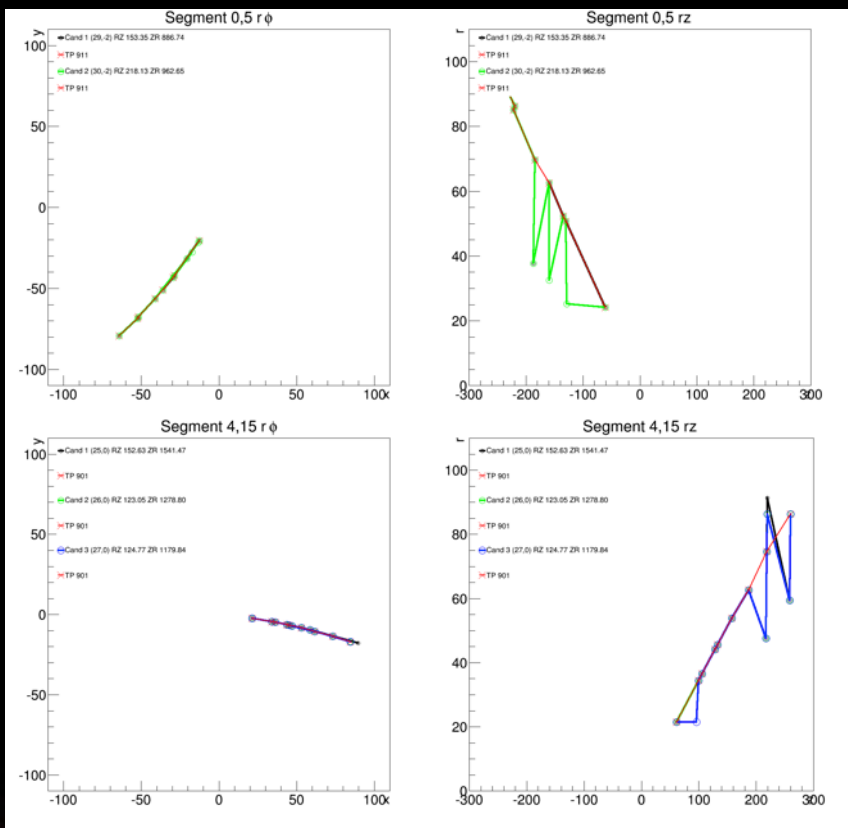
- ▷ Connections between user-created components at runtime
 - Single consistent way for components to dialog
- ▷ Allow for an arbitrary number of clocks
 - Separate component state transitions from data transfers between components



event display of found tracks using HT + track fit in a ttbar +140 pileup MC sample



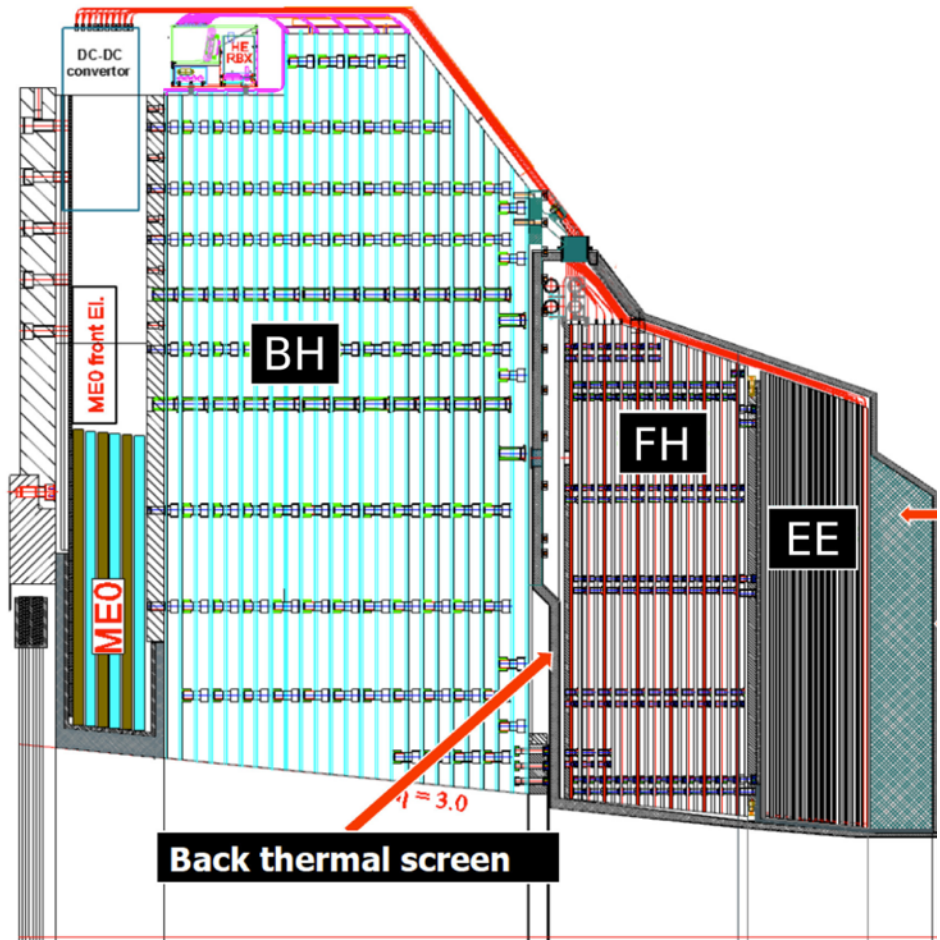
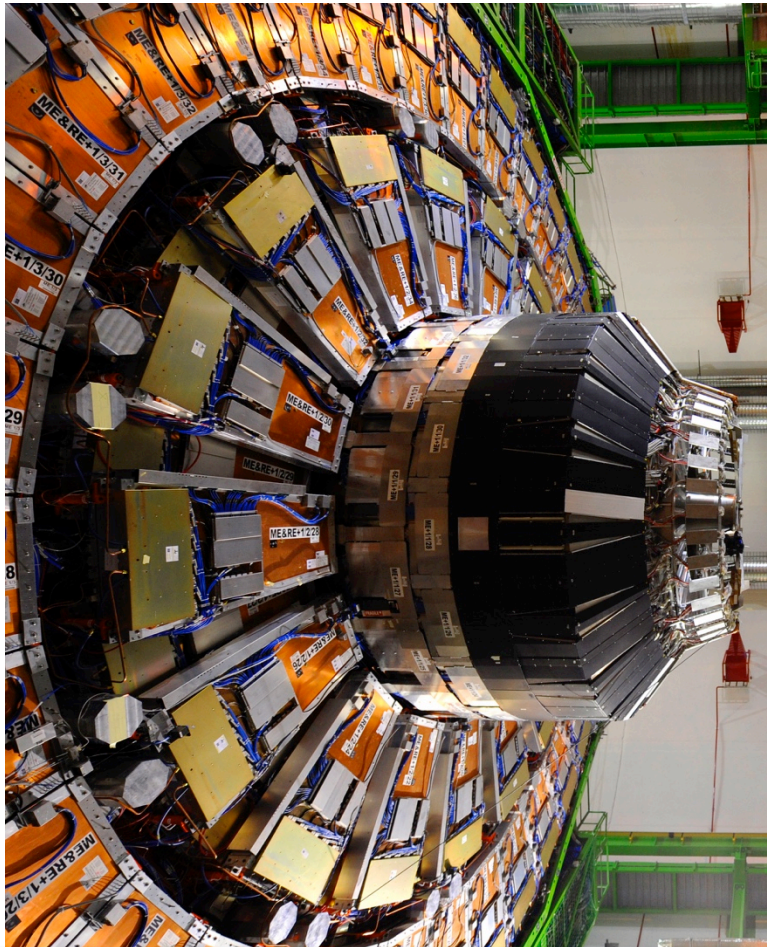
Track quality and fitting analysis



Track fit studies in collaboration with OAW (Vienna)

Candidates (circles) with associated Tracking Particles (red lines and crosses). Note rogue outliers which fit the r - ϕ track projection but not the 3-D track.

Phase II Endcap Calorimeter Upgrade High Granularity and Backing Calorimeter



46 CMS Institutions involved of which 3 are from the UK

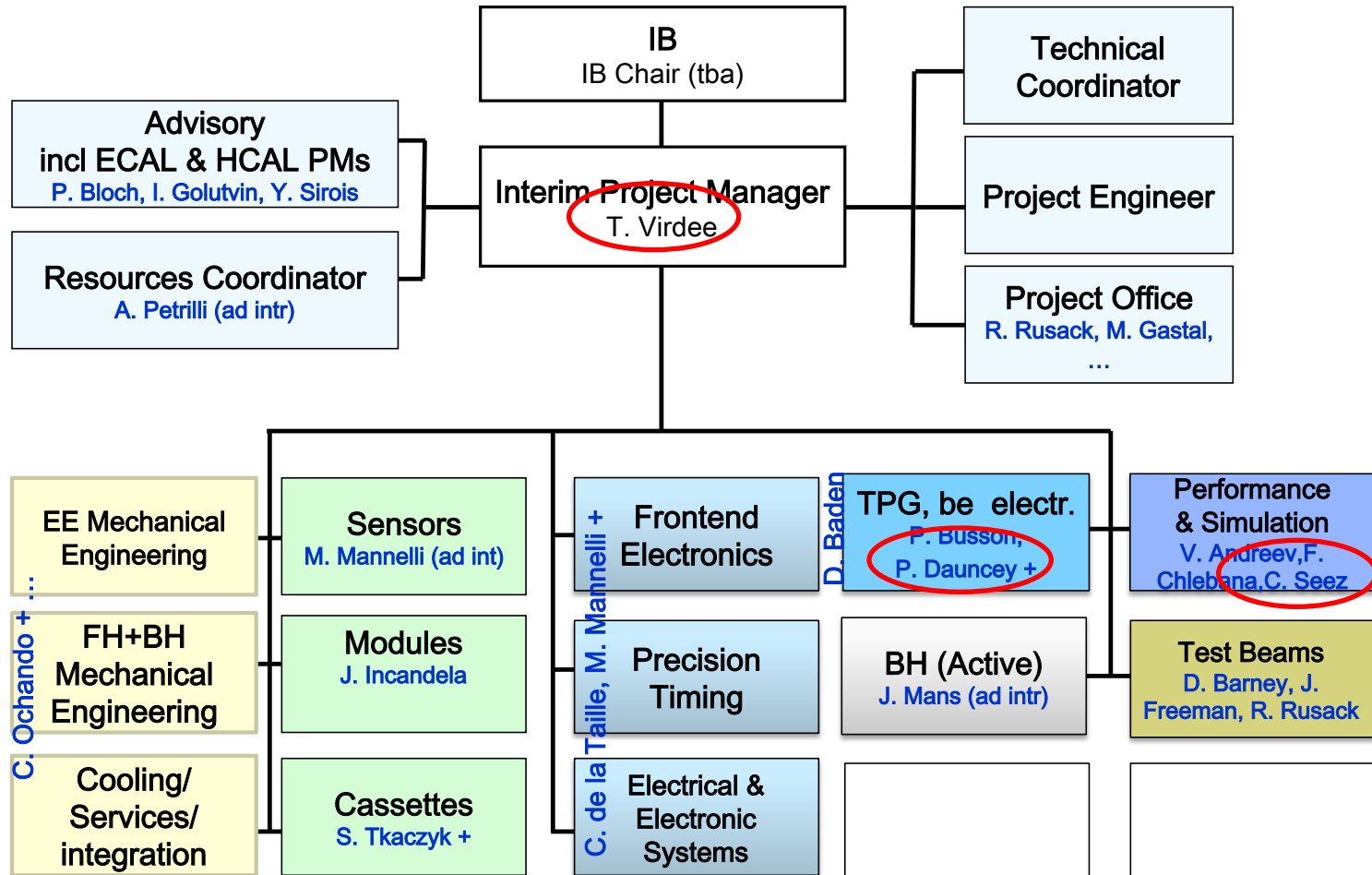
Case for UK Involvement

- Endcap calorimetry must be replaced
 - HGICAL improves physics capability in areas of interest (eg VBF $\tau\tau$)
 - Continuation of historical UK role in ECAL
 - focused on endcaps for construction contribution
 - UK (again) proposed the concept, and promoted the R&D
 - as with many of the ideas for original high resolution em calorimetry
 - Coherence of likely contributions with track-trigger work
 - New ERC grant (3M€) and 2-year PRD post just starting
 - plus £70k (capital) contribution in 2013 for prototyping
 - Significant contributions to project already
 - including performance and optimisation simulations, and steering it
- Propose to add a new work package to this project
 - Organisation, milestones, deliverables, resources etc to be presented in next OSC report

Interim organisation



HGC Interim Steering Committee



Future planning

- Expenditure – no special issues
 - Staff expenditure close to foreseen
 - TD expenditure increase to ~£210k, for CBC3 completion (but NB recent personnel changes)
 - Travel spend on target
- Materials & equipment
 - WP2: CBC3 manufacture early 2016
 - WP3: purchases via CERN (FC7 & MP7); invoicing to Imperial still working well
- Risks - a few revisions to take note of
 - With hindsight, a few were retired early
- Maintenance and Operation
 - Trigger is now entering a new phase; probably must be supported by project effort
 - Reductions in CG support leave CMS with no dedicated tracker M&O effort, yet long term commitment to crucial hardware and system
 - ECAL currently well covered, mainly by PPD.
 - recovered 50% of J Fulcher upgrade post for online DAQ
 - rebalancing of UK activities is now essential

Conclusions

- Milestones
 - reported in document
- Trigger Phase I upgrade appears to have converged
 - Operational phase from 2016
- Some new work packages proposed to begin in coming months, enabled by
 - new resources into project for HGC (WP4)
 - ramp down of Phase I trigger effort, and steady progress with WP2 for track-finder (WP5)
- Need to review the balance of activities to ensure M&O delivered

Further information

Magnet cryo: longer term

T. Camporesi October RRB

Primary Oil Removal System (PORS)

- ordered, delivery 1 Jan 2016
(coalescers will be later – mid March), but can be installed in parallel

300m warm He transfer line (surface to underground)

- surface pipe done, work started in PM 54 shaft

80K Ads tank spares

- first one ready in CERN shops
- second one in order from Air Ilquide

Cold box cleaning

- cleaning machine ordered, delivery Dec 2015
- selecting solvent –
- and defining cleaning sequence

Thermal Shield cleaning

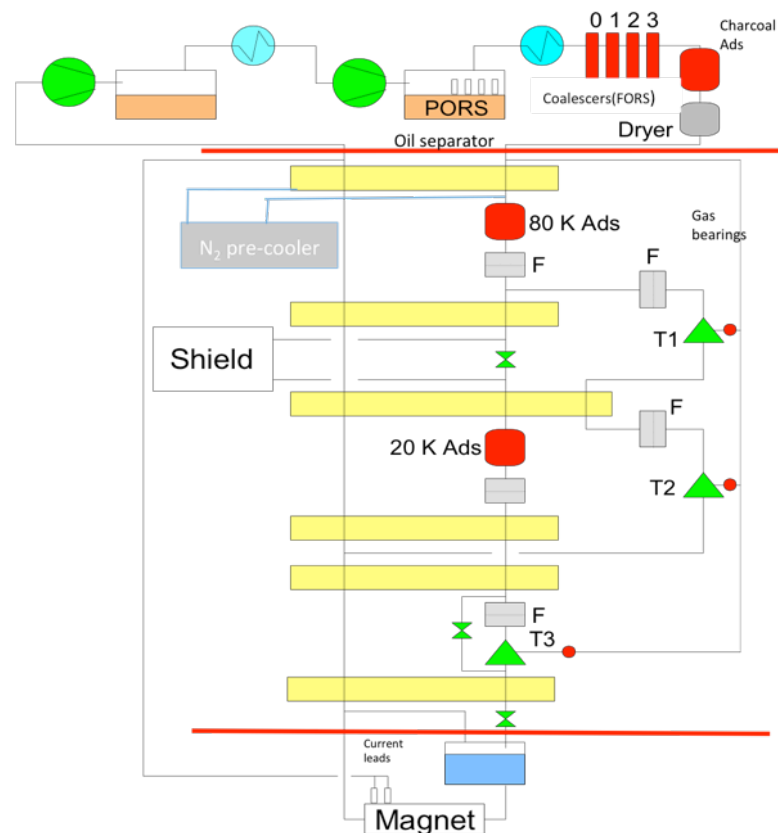
- examining options & risk

Direct contacts with other victims:

- “Elbe” plant in Dresden, “ALICE” in UK, investigating “Cello” at PETRA (not documented).

Risk analysis review (all risks to magnet)

- mandate being drafted



Phase II upgrade: Baseline Design in the TP

Trigger/HLT/DAQ

- Track information in Trigger (hardware)
- Trigger latency $12.5 \mu\text{s}$ - output rate 750 kHz
- HLT output 7.5 kHz

Barrel EM calorimeter

- New FE/BE electronics
- Lower operating temperature (8°)

Muon systems

- New DT & CSC FE/BE electronics
- Complete RPC coverage $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

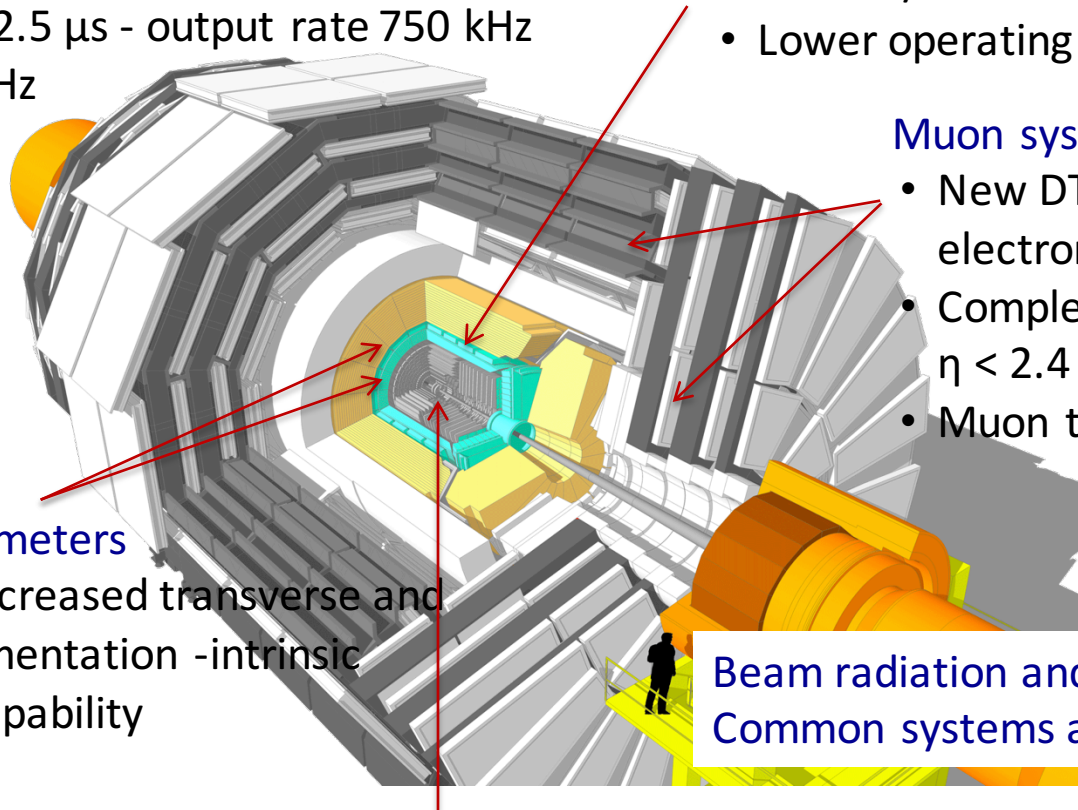
New Endcap Calorimeters

- Rad. tolerant - increased transverse and longitudinal segmentation -intrinsic precise timing capability

Beam radiation and luminosity
Common systems and infrastructure

New Tracker

- Rad. tolerant - increased granularity - lighter
- 40 MHz selective readout ($P_t \geq 2 \text{ GeV}$) in Outer Tracker for Trigger
- Extended coverage to $\eta \approx 3.8$



Phase II upgrade: Descoped Scenarios

Descoped item	Impact on performance	Cost reduction MCHF Scenario 1/2	Recov.
Tilted modules in outer tracker	Track-trigger resolution	3.9	no
Muon endcap 2 last stations	Redundancy, efficiency, resolution	2.0	yes
CSC readout in 2 last stations	Efficiency at Trigger rate ≥ 500 kHz	2.5	yes
HLT/DAQ power	Trigger rate $\lesssim 300$ kHz	8.0	yes
HGC 5/13 layers scenario 1/2	Energy resolution, object ID, pointing and timing resolutions	7.0/13	no
Scenario 1		242 MCHF	
Muon Encap station 2	Redundancy, efficiency, resolution	4.0	yes
Muon extension to $\eta \approx 3$	Muon acceptance	4.5	no
Pixel extension to $\eta \approx 4$	Acceptance, jet-tagging, Missing E_T	7.7	yes
DT readout	Efficiency, trigger rate $\lesssim 300$ kHz	6.1	yes
Layer 4 in outer tracker	Track trigger efficiency	5.0	no
Scenario 2		208 MCHF	

Phase II upgrade: combined performance effect of descoped scenarios

The effect of the descoped scenarios on the physics reach for predefined benchmarks signals expressed as a luminosity loss factor (studies performed for the baseline luminosity, i.e. 140 PU or $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$)

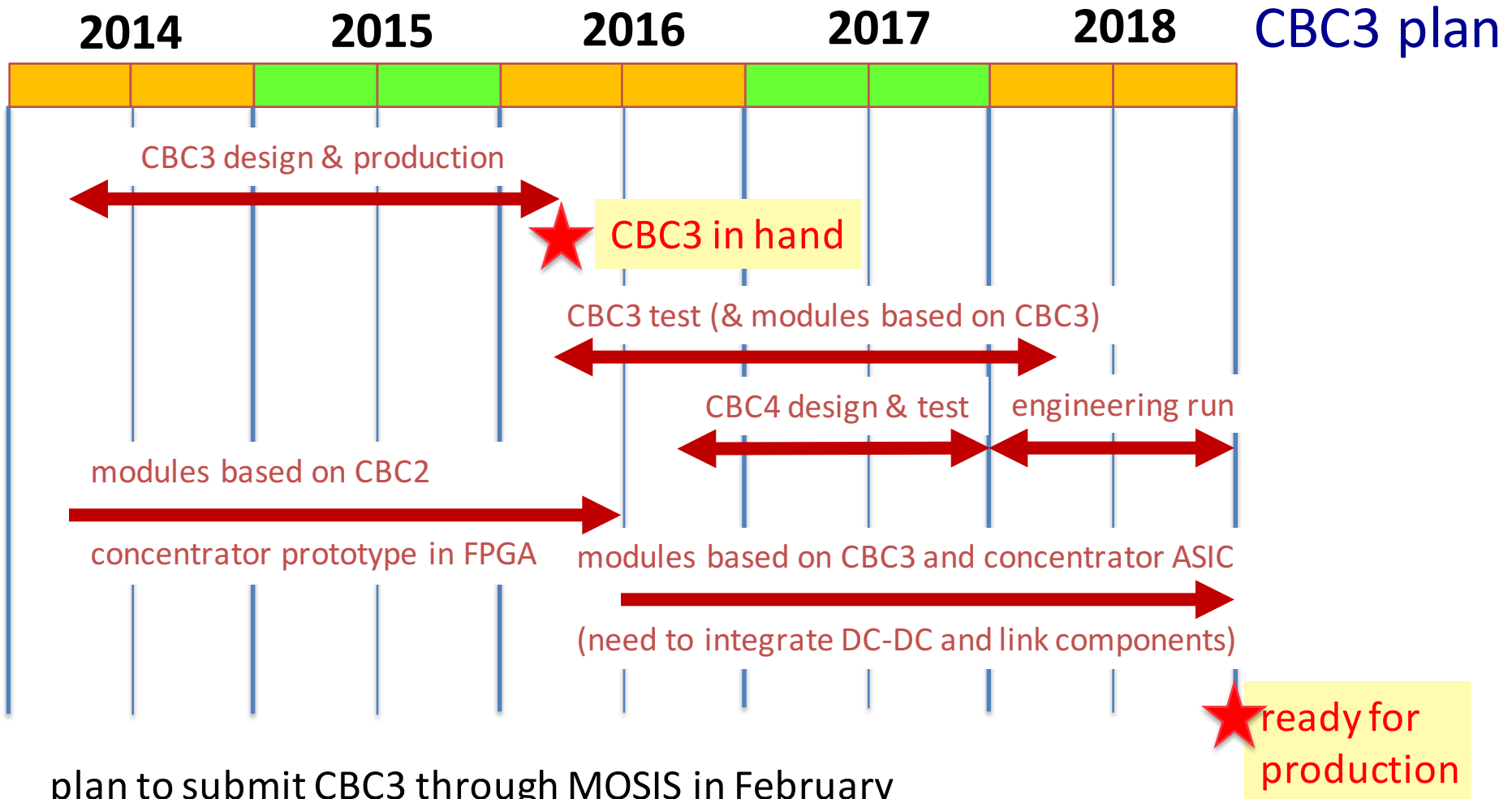
Effect much worse for 200 PU

Scenario 1

Process	Descoped items	Effects considered	Impact
VBF $H \rightarrow \tau\tau$	trigger	trigger acceptance	1.25
$H \rightarrow \mu\mu$	RPC	muon ID	1.02
$H \rightarrow 4e$	HGCAL (24/11)	electron resolution and ID	1.3

Scenario 2

Process	Descoped items	Effects considered	Impact
VBF $H \rightarrow \tau\tau$	trigger, tracker ext.	trigger acc., E_T^{miss} res., jet counting	4.2
$H \rightarrow \mu\mu$	muon system	muon ID	1.25
$H \rightarrow 4\mu$	tracker ext.	muon acceptance	1.25
$H \rightarrow 4e$	HGCAL (18/9), tracker ext.	electron res., ID, and acc.	2.0
$W^\pm HE_T^{\text{miss}}$	tracker ext.	E_T^{miss} resolution	6.7



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)

WP3 objectives and status

- Calorimeter trigger – now in final commissioning stage
 - quite close to planned schedule

- **Milestones related to commissioning of the trigger**

- 22.12.2014 Layer-2 – Patch Panel – Layer-1 Commissioned
- 16.01.2015 oSLB and HF uHTR systems commissioned
- 19.01.2015 Layer-2 – Patch Panel – Layer-1 Connected to uGT
- 25.11.2014 First Version of CTP7 firmware (incl. input playback)
- 09.03.2015 Final Version of CTP7 firmware (except DAQ link)
- 17.02.2015 Final design of Algorithms and data format defined
- Decision to upgrade 2016 trigger inputs from ECAL and HCAL
- 17.06.2015 B/E uHTR system connected to the trigger - Commissioned
- **02.09.2015 System ready for parallel data taking**

Phase 1 trigger parallel running

Run	No. of L1 triggers (M events)	Time (hours)	Lumi (pb ⁻¹)	Notes
258741	1.9	0.5	4.7	ECAL
258742	1236	4.5	59	ECAL
259884	215	1	6.7	ECAL & HCAL
260424	1240	4.3	63	ECAL
260490	94	0.5	5.3	ECAL & HCAL
260493	79	0.3	3.7	ECAL & HCAL
260576	948	3	48	ECAL
260627	3316	12	179	ECAL & HCAL & HF
All	7279	26.1	369.4	

MP7 PCBs

– PCB Procurement changes

- Additional internal manufacturer QA now specified & agreement required
 - i.e. signed and stamped by the company
- Additional thermal “real world” shock tests, beyond IPC standard
- Search for suppliers involved capability agreements and factory visits to
 - (a) discuss technical aspects with experts
 - (b) judge whether the company was really capable of delivering.
- 2 new suppliers
 - SOMACIS (IT): Delivery 30/10/15
 - TTM (US): Delivery 11/11/15

– All SOMACIS PCBs delivered on schedule and to specification

- Visually inspected @ HAPRO 3/11/15.
- Additional thermal shock & solder-ability tests @ HAPRO before assembly.
- Assembly 10/11 /15 – 12/11/15 followed by preliminary in-situ test @ HAPRO
- Will be closely monitored during assembly.

