LHCC Report presented to the LHC Resources Review Boards April 23, 2018

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University and INFN, Pisa

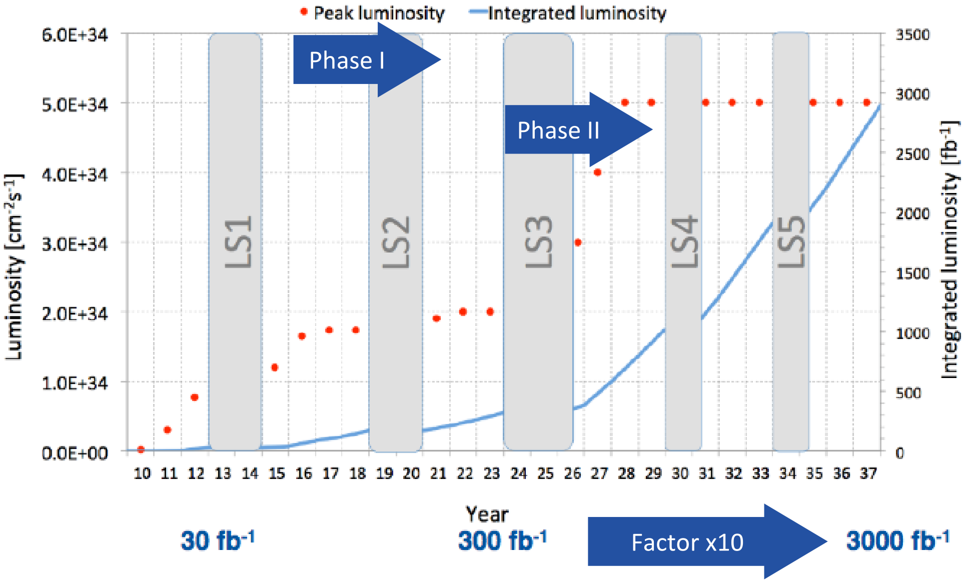
Outline

- Reminder: Phase II upgrades
- Status of the Phase II review process
- Timing Detectors
- Further steps

Reminder, no changes

HL-LHC Goals and Running Conditions

- 3000 fb^{-1} is the target integrated luminosity
- $5x10^{34}$ —> 140 Pile-up is the nominal peak luminosity
- $7x10^{34}$ —> 200 Pile-up is the ultimate peak luminosity (>LS4)



- Phase I Upgrades
  - All approved and funded
  - On-going construction overall on budget and on schedule
- Phase II Upgrades
  - Scoping document presented and approved
  - Technical Design Reports currently being reviewed

Reminder

Phase II Detector Upgrades

Why

- **Maintain detector performance** in the presence of high radiation doses, increased pile-up, and challenging trigger rates.
  - Possibly introduce moderate performance improvements that will allow to take fully advantage of the HL-LHC physics program, e.g. extended coverage
  - Detectors must work well at nominal luminosity (140PU) and only moderately degrade at ultimate luminosity (200PU)

When

- For the most part upgraded detectors will be **installed during LS3**, currently scheduled for 2.5 years starting in 2024
  - Some limited and mature elements may be installed in LS2, with some advantage in terms of schedule: CMS FWD GEM, beam pipes, …

What

- **Many detector elements**, readout electronics, data acquisition system and online computing will require significant upgrades —> part of this review
  - Also distributed offline computing will require significant redesign and improvements —> part of a separate review process

Reminder

Phase II Upgrades Approval Process

- **Document** detailing the process prepared in consultation with DRC and the experiments (CERN-LHCC-2015-007)

DONE

- **Step1**: Approval of preliminary design for the complete set of Phase-II upgrades
  - Concluded in September 2015 —> presented to Oct 2015 RRB
  - Including scoping options
  - Reasonable matching of cost to funding availability

DONE

- **Step2**: Approval of baseline design, cost and schedule
  - TDRs submission foreseen between end 2016 and end 2017
  - Regular monitoring of LHCC and UCG

>2018

- **Step3**: Approval for construction
  - After Engineering Design Review or equivalent

Reminder

Review process

1. Final draft submission (complete and final for the collaboration) - available to all LHCC referees and extended panel members
2. LHCC Scientific and technical review
3. Submission of the UCG cost and schedule package
4. LHCC provisional approval (with comments and requests)
5. Submission of the final public TDR
6. UCG Cost, Schedule and Organizational Review
7. UCG approval
8. Formal LHCC+UCG approval of the TDR
9. Submission to the RB for endorsement

Specific guidelines for reviews
CERN-LHCC-2017-016

Reminder

LHCC Scientific and Technical Review

- The main goals of the LHCC review are the following:
  - Evaluate the scope of the project versus scientific reach and cost and evaluate its methodology
  - Assess the technical readiness of the upgrade project
  - Identify the key technical risks in the project
- The reviews have been conducted with a **mixture of remote and in-person meetings**. A typical structure of the interaction with the experiment is the following:
  - A kickoff remote meeting to clarify the scope of the review and the interaction plan
  - The panel formulates **questions** to the experiment which are communicated in writing
  - An intermediate remote meeting where the experiment presents **answers** to the questions
  - Further questions and requests for information are formulated by the panel
  - A **final in-person meeting** at CERN where the TDR LHCC review is finalized

UCG Cost, Schedule and Management Review

Reminder
See UCG Chair presentation

- The main goals of the UCG review are the following:
  - Evaluate the reliability of the cost estimate for the project
  - Assess the feasibility of the schedule and the availability of the manpower necessary to execute the project
  - Evaluate the project management structure and the risk analysis, including proposed levels of cost realism and schedule contingency.
- The reviews have been conducted with a mixture of remote and in-person meetings. A typical structure of the interaction with the experiment is the following:
  - A kickoff in-person meeting to clarify the scope of the review and the interaction plan
  - The panel formulates questions to the experiment which are communicated in writing
  - An intermediate remote meeting where the experiment presents answers to the questions
  - Further questions and requests for information are formulated by the panel
  - A final in-person meeting at CERN where the TDR UCG review is finalized

Phase II TDRs review status

- Process has been carried out as planned, in the "Fast Forward" mode agreed in April 2017 RRB
- TDR submission closely followed planned schedule
- Large number of panels set-up, to carry out the reviews
  - LHCC members, returning LHCC members, external experts
  - UCG panels are a superset of the LHCC panels, with the addition of scrutiny group experts
- Review process concluded on Apr 13 and final reports produced for the Research Board on Apr 18
  - This process was at the limit of our reviewing bandwidth
  - But thanks to the enthusiastic work of many reviews was carried out in great depth and with extreme attention

TDRs planned submission dates and CORE values (APRIL 2017 RRB presentation)

Experiment	System	Date	CORE MCHF	SOURCE
ATLAS	ITkStrip	Dec-16	61	TDR ITkStrip
ATLAS	Muon	Jun-17	34	SD
ATLAS	LAr	Sep-17	36	SD - sFCal
ATLAS	Tile	Sep-17	9	SD
ATLAS	TDAQ	Dec-17	43	SD
ATLAS	ITkPixel+common	Dec-17	59	SD(2)
CMS	Tracker	Jul-17	112	SD
CMS	Barrel Cal	Sep-17	11	SD
CMS	Muon	Sep-17	25	SD
CMS	Endcap Cal	Nov-17	64	SD
CMS	Trigger DAQ/HLT(1)	>2019	24	SD

SD = Scoping Documents, 2015

ATLAS
Letter of Intent +
Scoping Document
CERN-LHCC-2012-022
CERN-LHCC-2015-020

CMS
Technical Proposal +
Scoping Document
CERN-LHCC-2015-010
CERN-LHCC-2015-019

(1) Interim document in September 2017

(2) As modified in ITkStrip TDR

Timeline detail

Experiment		ATLAS		ATLAS		ATLAS		ATLAS		ATLAS		CMS		CMS		CMS		CMS	
System		Muon		LAr		Tile		TDAQ		ITk-Pixels		Tracker		Barrel Cal		Muon		Endcap Cal	
CORE		34		36		**11**		43		59		112		11		25		64	
Chair		Rob Roser		Claudia Cecchi				Rainer Mankel		Rob Roser		Marcel Demarteau		Franco Bedeschi		Mario Martinez-Perez		Dmitri Denisov	
Week	Comments	LHCC	UCG	LHCC	UCG	LHCC	UCG	LHCC	UCG	LHCC	UCG	LHCC	UCG	LHCC	UCG	LHCC	UCG	LHCC	UCG
26-Jun-17												TDR 1-Jul							
3-Jul-17		TDR 7-jul																	
10-Jul-17												Koff 21-Jul							
17-Jul-17		Koff 27-Jul																	
24-Jul-17																			
31-Jul-17																			
7-Aug-17																			
14-Aug-17												Iter 14-Aug	UCGP 14-Aug						
21-Aug-17													UCGP 26-Aug						
28-Aug-17		Iter 1-Sep	*UCGP 1-Sep*									Iter 1-Sep							
4-Sep-17			*UCGP 4-Sep*																
11-Sep-17	Sep LHCC	Rev 11-Sep App 14-Sep	Koff 12-Sep									Rev 11-Sep App 14-Sep	Koff 12-Sep	TDR 12-Sep		TDR 12-Sep			
18-Sep-17																			
25-Sep-17			UCGP 29-Sep	TDR 30-Sep		TDR 30-Sep													
2-Oct-17																			
9-Oct-17														Koff 12-Oct		Koff 9-Oct			
16-Oct-17				Koff 16-Oct		Koff 16-Oct									UCGP 16-Oct		UCGP 16-Oct		
23-Oct-17	**Oct RRB**		Iter 26-Oct										Iter 27-Oct						
30-Oct-17		TDR+ 3-Nov												Iter 30-Oct		Iter 31-Oct	UCGP 30-Oct		
6-Nov-17				Iter 10-Nov	UCGP 11-Nov	Iter 6-Nov	UCGP 11-Nov												
13-Nov-17															UCGP 13-Nov				
20-Nov-17														Iter 21-Nov	UCGP 21-Nov	Iter 22-Nov			
27-Nov-17	Nov LHCC		Rev 28-Nov	Rev 27-Nov App 30-Nov	Koff 29-Nov	Rev 27-Nov App 30-Nov	Koff 29-Nov						Rev 27-Nov	Rev 28-Nov App 30-Nov	Koff 29-Nov	Rev 28-Nov App 30-Nov	Koff 29-Nov	TDR-Partial 28-Nov	
4-Dec-17	Dec RB	RB 6-Dec										RB 6-Dec							
11-Dec-17								TDR 15-Dec		TDR 15-Dec									
18-Dec-17															Iter 18-Dec		Iter 19-Dec	TDR 22-Dec	
25-Dec-17	Christmas																		
1-Jan-18																			
8-Jan-18					Iter 10-Jan		Iter 10-Jan	Koff 8-Jan		**Koff 12-Jan**					Iter 9-Jan		Iter 9-Jan	Koff 11-Jan	UCGP 8-Jan
15-Jan-18																			UCGP 15-Jan
22-Jan-18	Jan P-II Mtg				Rev 25-Jan		Rev 26-Jan		UCGP 26-Jan		UCGP 26-Jan				Rev 23-Jan		Rev 24-Jan	Rev 22-Jan	
29-Jan-18								Iter 2-Feb											
5-Feb-18										Iter 5-Feb								Iter 8-Feb	
12-Feb-18								Iter 16-Feb											
19-Feb-18																		Iter 21-Feb	
26-Feb-18	Feb LHCC							Rev 26-Feb App 1-Mar	Koff 28-Feb	Rev 27-Feb App 1-Mar	Koff 28-Feb							Rev 26-Feb App 1-Mar	Koff 28-Feb
5-Mar-18				RB 7-Mar		RB 7-Mar								RB 7-Mar		RB 7-Mar			
12-Mar-18																			
19-Mar-18									**Iter 22-Mar**		**Iter 20-Mar**								
26-Mar-18	Easter week																		**Iter 27-Mar**
2-Apr-18																			
9-Apr-18	Apr P-II Mtg								Rev 12-Apr		Rev 10-Apr								Rev 11-Apr
16-Apr-18								RB 18-Apr		RB 18-Apr								RB 18-Apr	

DONE

TODAY

Panels

- Nine full panels setup
- Very strong teams and chairs
- Large contingent of experts
- Cross review model very effective

Count of Status	TDR										
Role	ATLAS ITk-Pixels	ATLAS ITk-Strips	ATLAS LAr+Tile	ATLAS Muon	ATLAS TDAQ	CMS Barrel Cal	CMS End Cap	CMS Muon	CMS Tracker	CMS TDAQ	Grand Total
Chair	1	1	1	1	1	1	1	1	1		9
LHCC-ExpTeam	1	2	2	2	1	1	2	1	2		14
LHCC-OtherTeam	1		1	1	1	1	2	1	1		9
LHCC-Returning				1	1		1	1			4
Technical Expert	8	3	6	5	6	5	7	6	6	2	54
UCG Expert	2	1	2	2	2	2	2	1	2		16
Grand Total	**13**	**7**	**12**	**12**	**12**	**10**	**15**	**11**	**12**	**2**	**106**

Note: CMS TDAQ was not a TDR but interim documents, subject to a preliminary review

Panel chairs

TDR	Last Name	First Name
ATLAS ITk-Pixels	ROSER	Rob
ATLAS LAr+Tile	CECCHI	Claudia
ATLAS Muon	ROSER	Rob
ATLAS TDAQ	MANKEL	Rainer
CMS Barrel Cal	BEDESCHI	Franco
CMS End Cap Cal	DENISOV	Dmitri
CMS Muon	MARTINEZ-PEREZ	Mario
CMS Tracker	DEMARTEAU	Marcel

For UCG reviews:
Stew Smith, Mauro Morandin, Frank Simon

- The UCG Panels were a superset of the LHCC panel
- Addition of Scrutiny Group experts
- Continuity of review process
- Carry forward the complete understanding of the technical issues and the physics basis

CMS Review Panels Members

CMS Tracker

s

Last Name	First Name
Demarteau	Marcel
Denisov	Dmitri
Kajfasz	Eric
Kuze	Masahiro
Casse	Gianluigi
Gemme	Claudia
Riedler	Petra
Stanitzki	Marcel
Riegler	Werner
Stapnes	Steinar

CMS Barrel Cal

s

Last Name	First Name
BEDESCHI	Franco
Kuzmin	Alexander
Eigen	Gerald
Delmastro	Marco
Glenzinski	Doug
Kluge	Alexander
Lanni	Francesco
Danielsson	Hans
Convery	Mary

CMS Muon

Last Name	First Name
MARTINEZ-PEREZ	Mario
Waters	David
Newman	Paul
Dalla Torre	Silvia
Bauer	Florian
Cardini	Alessandro
Polini	Alessandro
Sasaki	Osamu
Kroha	Hubert
Moneta	Lorenzo

CMS End Cap Cal

Last Name	First Name
Denisov	Dmitri
Kajfasz	Eric
Kuzmin	Alexander
Bloise	Caterina
Dunlop	James
Demarteau	Marcel
Heinemann	Beate
Riedler	Petra
Roda	Chiara
Gordon	Howard
Christie	William
Pöschl	Roman

ATLAS Review Panels Members

ATLAS ITk-Strips

s

Last Name	First Name
Burrows	Philip
Kunne	Fabienne
Wisniewski	William
Honma	Alan
Nahn	Steve
Petagna	Paolo
Klempt	Wolfgang

ATLAS Muon

Last Name	First Name
ROSER	Rob
Burrows	Philip
Wisniewski	William
Sfienti	Concettina
RATCLIFF	Blair
Karchin	Paul
Paolucci	Pierluigi
Wood	Darien
Vasseur	George
Danielsson	Hans

ATLAS ITk-Pixels

Last Name	First Name
ROSER	Rob
Calabrese	Roberto
Krueger	Katja
Honma	Alan
Moll	Michael
Musa	Luciano
Nahn	Steve
Petagna	Paolo
Spalding	Jeff
Goldstein	Joel
Moll	Michael

ATLAS LAr+Tile

Last Name	First Name
CECCHI	Claudia
Kunne	Fabienne
Wisniewski	William
Krizan	Peter
Donega	Mauro
Faure	Jean-Louis
Mulders	Martijn
Tschirhart	Robert
Barker	Gary
Lubrano	Pasquale

ATLAS TDAQ

Last Name	First Name
MANKEL	Rainer
Beckmann	Volker
Kuhr	Thomas
Boehnlein	Amber
Gligorov	Vladimir
Huffer	Mike
Newbold	Dave
Vande Vyvre	Pierre
Behrens	Ulf
Convery	Mary
Moneta	Lorenzo

Depth of review

- Very careful scrutiny of the scientific motivation for the technical choices (LHCC)
- In-depth examination of the cost, schedule, and management structure of the project (UCG)
- Literally hundreds of questions have been formulated for each TDR and answers discussed in detail in the various iteration meetings and final review
- In several cases modifications to the TDRs were required to improve the design choices or provide better motivations.
    - In these cases only a provisional approval was granted, pending the clarification of the issues
- The collaborations have been extremely responsive and collaborative to answer questions and put forward the additional work needed

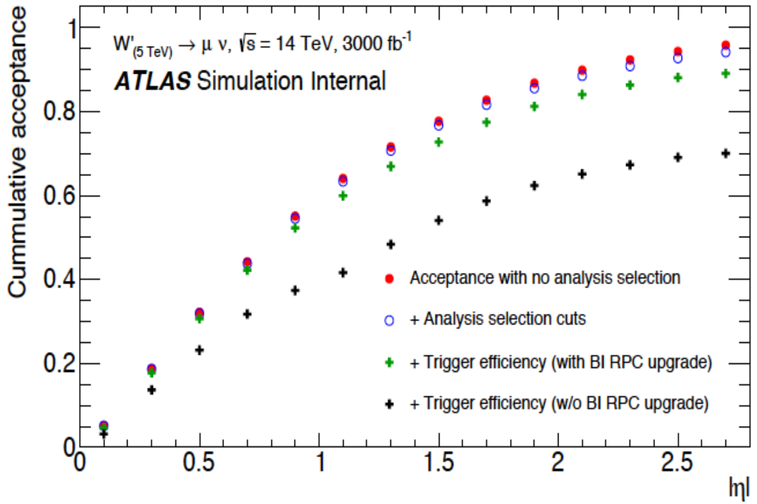
TDR LHCC Reviews

- In the backup there are detailed slides on each TDR
- Excerpts from the LHCC minutes pertaining the Phase II upgrades are attached to the agenda
- I will present here only a few examples on main themes encountered during the review

Scientific motivation

- Scientific motivation has been scrutinized thouroughly
  - Detector performance
  - Effect on the physics reach and sensitivity

Example from ATLAS Muon



With BI RPC
20%
W/out BI RPC

- Benchmark physics channels identified
- Effect of various options examined separately
- Effect on resulting physics sensitivity evaluated

Cross comparison of designs and optimization

Example from Trackers

- Many variations on similar concepts
- No single answer to a very complex problem
- Try to exploit commonalities where advantageous.
- Exploit specificity of each detector
- Large improvements and optimization from Scoping Documents.

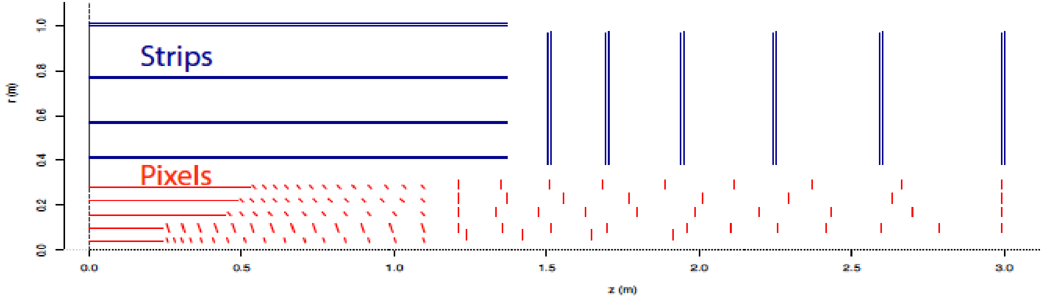
Markus Elsing

Comparison of Phase II Trackers

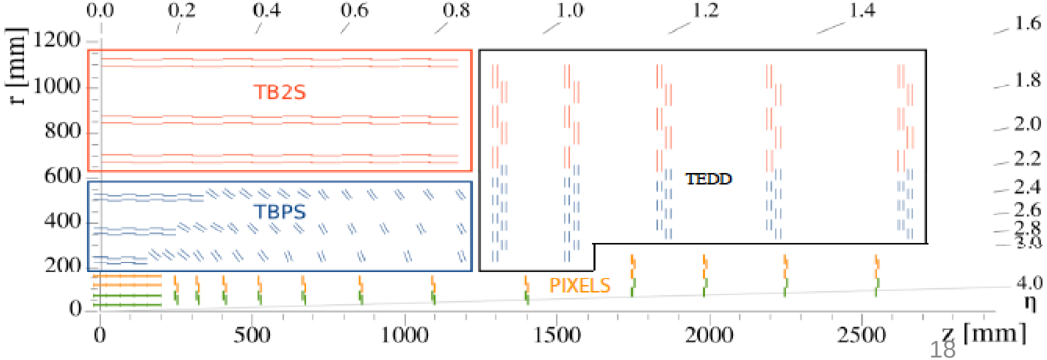
9

- tried scaling layout plots to match dimensions...

➡ ATLAS:
- 4 double-strip
- 5 pixel layers
- total **9 layers**
- total **13 hits**



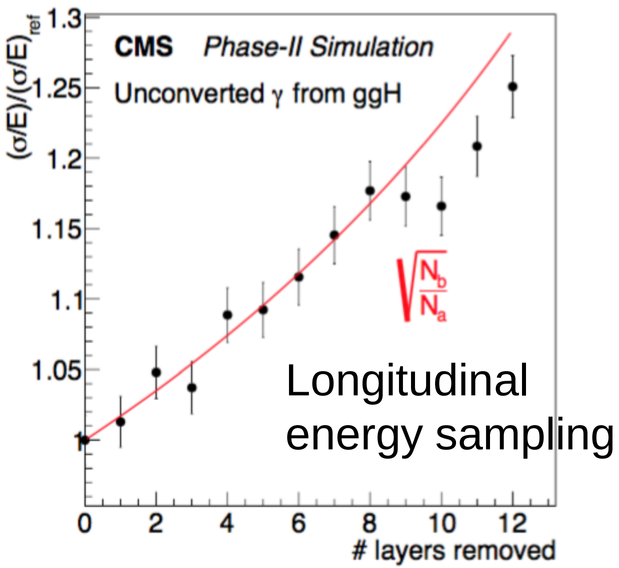
➡ CMS [TDR]:
- 3 double-strip
- 3 strip+pixel
- 4 pixel layers
- total **10 layers**
- total **16 hits**



Cost optimization: physics/buck

Loss of performance → Loss in equivalent running time

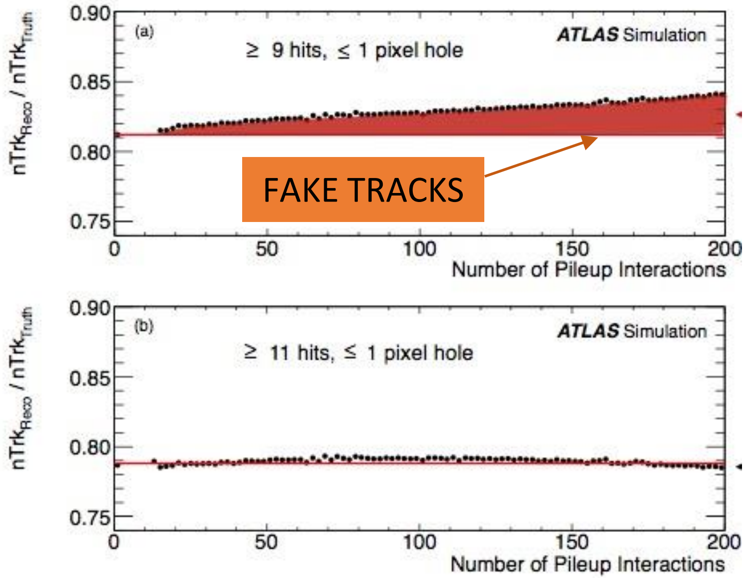
Example from CMS Endcap Cal



Could easily loose 10% equivalent running time

Some redundancy essential to maintain performance at high PU

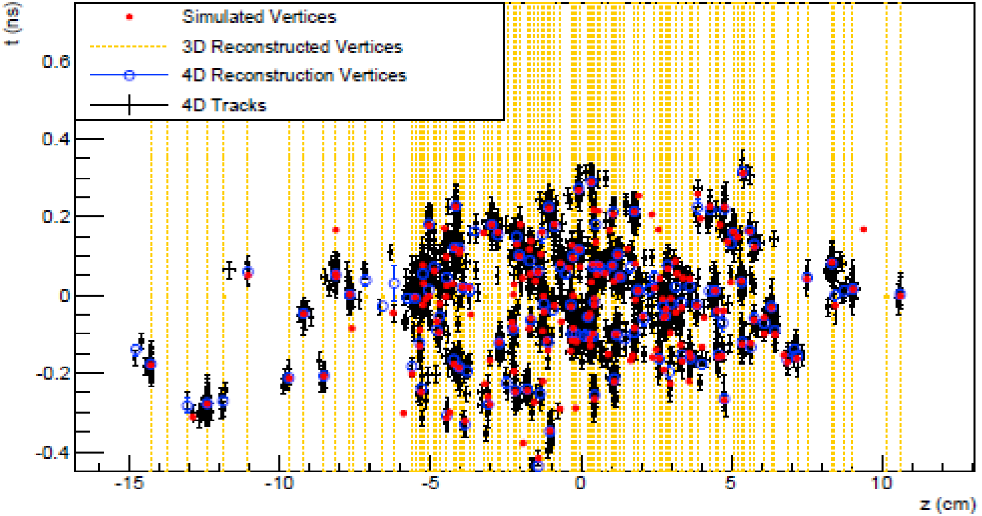
Example from ATLAS ITk

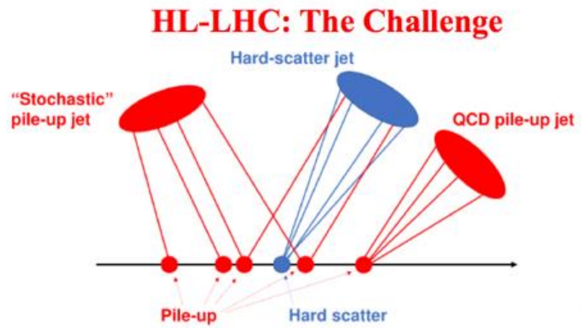


Risk of not fully exploiting the HL of HL-LHC

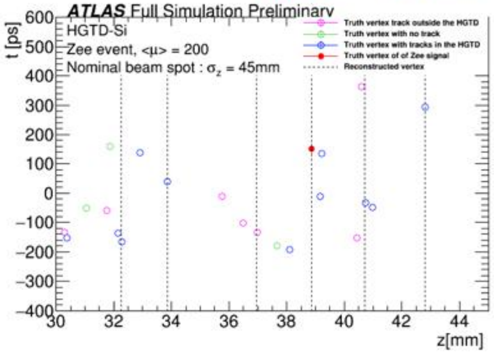
Timing detectors

- Precise MIP timing determination allows to distinguish primary vertices at the same z position, happening at different times.
- Need few tens of ps resolution





Beamspot:
- z ~50mm
- t ~180ps



ITk+HGTD (Full Simulation):
- HS Vertex
- Reconstructed vertices
- Track(s) pT>1GeV in HGTD
- no track pT>1GeV in HGTD
- No track pT>1GeV
- Track(s) pT>1GeV in HGTD (order 50%)

Timing detectors conclusions

- Technical proposals submitted.
- The committee is convinced that the timing detectors provide a useful tool in the high pile- up regime of the HL-LHC.
- Improvements in jet and electron identification and b- tagging will be obtained.
- The detector concept has been reasonably developed for the maturity of the proposals at this time.

For both experiments optimization and system validation work required to arrive at final configuration.

- Expect TDR submission at the end 2018 / beg 2019, when a full cost review can be carried out.

ATLAS Phase II Upgrade Cost Update

ATLAS

Subsystem	TDAQ	ITK-Strips	ITK-Pixels	ITK-Common	Lar	Tile	Muon	Timing Det.	TOTAL	Common fund	Total (incl CF)	Forward	High-eta mu tagger
TDR Date	*Dec-17*	*Dec-16*	*Dec-17*	*Dec-17*	*Sep-17*	*Sep-17*	*Jul-17*	*Dec-18 ?*		*Oct-17*			
SD CostFull	43.3	72.1	32.2	16.1	41.4	8.6	30.6	4.6	**248.8**	17.4	**266.2**	1.3	3.5
SD CostInter	31.9	65.8	31.3	16.1	32.4	8.6	25.3	0.0	**211.3**	15.9	**227.2**	1.3	0.0
SD CostLow	25.1	53.3	27.4	16.1	32.4	8.6	21.3	0.0	**184.1**	14.4	**198.6**	1.3	0.0
TDR	44.9	60.7	46.9	14.4	27.9	11.1	28.2	8.5	**242.6**	24.4	**267.0**	1.3	3.5
		122.0											

Reviewed numbers
In progress
Approved with MOU
Need not established

SD = Scoping Documents

- Funding coverage mismatch at 1% level, although alignment on systems is not perfect.

ATLAS Letter of Intent + Scoping Document
CERN-LHCC-2012-022 CERN-LHCC-2015-020

CMS Phase II Upgrade Cost Update

CMS

Subsystem	Endcap Cal	Barrel Cal	Muon	Tracker	Timing Det.	BRIL	Trigger	TDAQ/HLT	TOTAL	Common fund	Total (incl CF)
TDR Date	*Nov-17*	*Sep-17*	*Sep-17*	*Jul-17*	*Dec-18 ?*	*Jun-20*	*Dec-19*	*2020-2021*		*Oct-17*	
SD CostFull	63.6	11.5	24.4	112.3		4.0	7.3	17.0	**240.1**	25.0	**265.1**
SD CostInter	56.6	11.5	19.9	108.4		4.0	7.3	9.0	**216.7**	25.0	**241.7**
SD CostLow	50.6	11.5	5.3	95.7		4.0	7.3	9.0	**183.4**	25.0	**208.4**
TDR	67.1	13.3	25.2	111.9	15.8	2.6	5.9	12.6	**254.4**	25.0	**279.4**

Reviewed numbers
In progress
Approved with MOU
Need not established

SD = Scoping Documents

- Note that the Muon figure includes 3.75 M for GEM1/1 already approved and in construction
- Funding coverage mismatch at 1% level, although alignment on systems is not perfect.

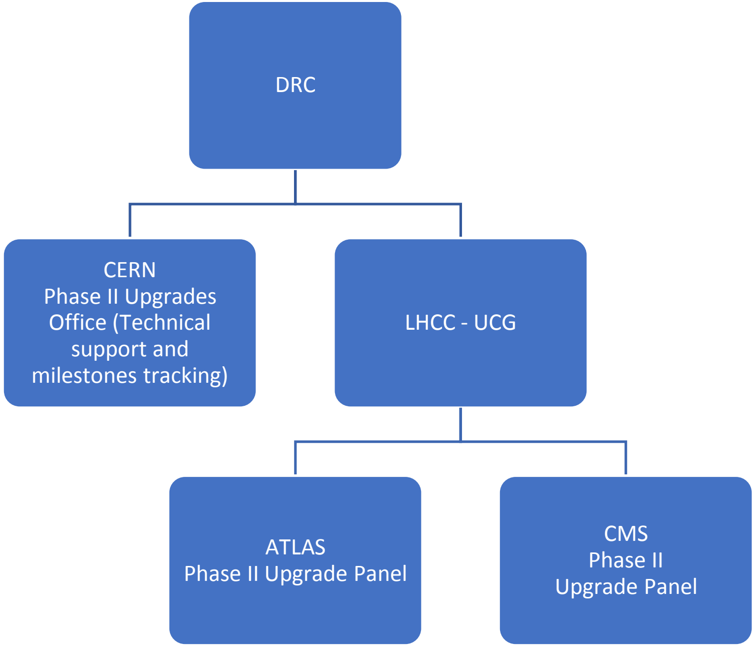
CMS Technical Proposal + Scoping Document
CERN-LHCC-2015-010 CERN-LHCC-2015-019

Money matrix

- The financial coverage of the upgrade costs is at this time very good for both experiments.
- The robustness of the numbers is continuously improving
- Many Funding Agencies are processing the requests and will be able to provide solid number during the course of 2018, with the aim of arriving at full closure in October.
- Alignment between expected funding and systems is good, but requires further optimization
  - Ongoing negotiations with groups and funding agencies

Phase II Project execution tracking

- Considering the complexity and dimension of the Phase II upgrades, a special structure is required to monitor project execution
- Each panel will be formed by experts from the TDR Review Panels
- Each panel will meet about 2-3 times/year, providing oversight and project tracking
  - Including endorsing the Engineering Design Reviews convened by the experiments before major spending



Outlook

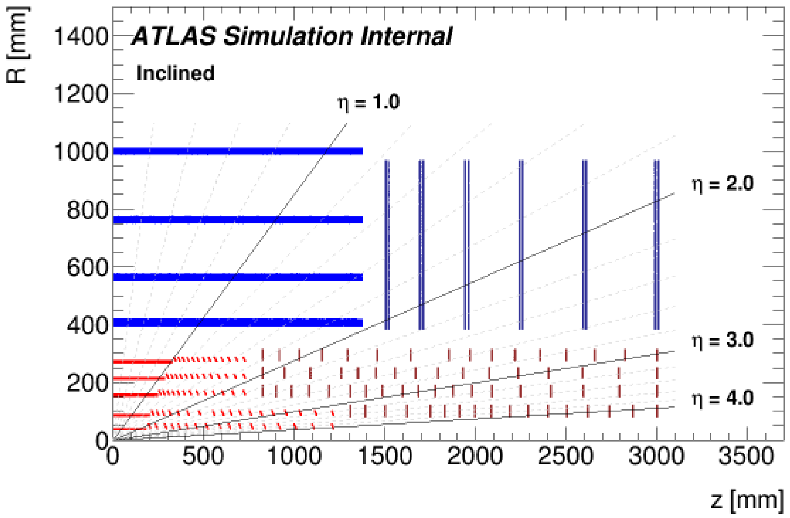
- The Phase II upgrade plan put forward in **2015** is still holding, both technically and cost-wise.
- Nearly all the TDRs have been approved and the full envelope of the Phase II upgrades can be defined
  - Nearly final money matrix are available for discussion with Funding Agencies
  - Timing Detectors have shown great physics potential. TDRs will be submitted later in 2018/2019.
  - CMS TDAQ/HLT TDR planned for Q1-2020/Q2-2021
- We can consider the Step 2 concluded, and by **Oct 2018** we expect to have the final money matrix.

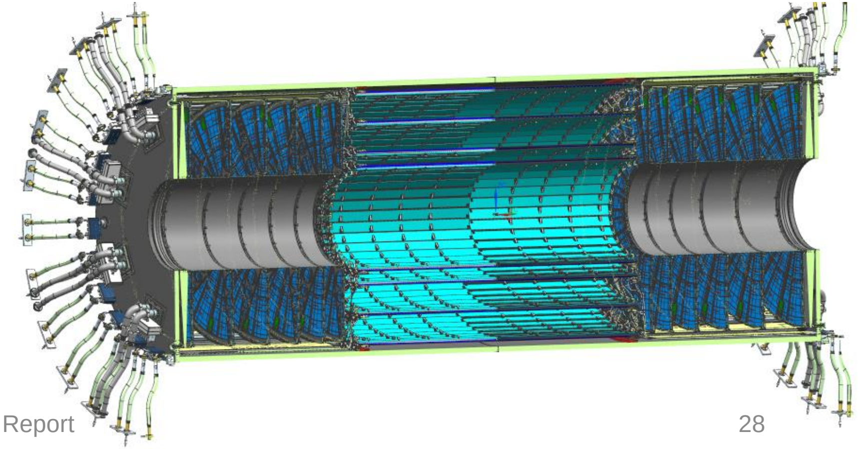
Details on each TDR

ATLAS Itk strips TDR

- Submitted at the end 2016
- Settled on 5 pixel + 4 strip points system
- Only the strips are described in detail now
- The pixel TDR followed at the end of 2017
- Large document (>500 pages)

60 MCHF





The ATLAS Itk-Strip TDR Chronicles I

- 20/11/16: An internal ATLAS TDR draft version was shared with the LHCC ATLAS referee team. Though largely complete, several chapters were missing from the document at that stage.
- 29/11/16: The ATLAS referees provided informal feedback on the internal draft at their regular LHCC Week meeting with the ATLAS management.
- Several external experts were added to the LHCC ATLAS referee team for the purpose of reviewing the TDR. The LHCC is grateful to Alan Honma, Steve Nahn and Paolo Petagna for serving in this capacity. The LHCC Chair and UCG Chair were also included to complete the membership of the LHCC ITk Strip TDR Review Team (the 'Review Team').
- 16/12/16: An updated draft TDR version was submitted to the Review Team. This was complete in layout with the exception of the chapter on Performance & Physics.
- 20/12/16: The Review Team met to agree the timetable for the subsequent review and to assign responsibilities among the Team members.
- 20/1/17: A complete draft TDR version, including the chapter on Performance & Physics, was submitted to the Review Team.
- 30/1/17: The Review Team met to discuss the draft TDR and identify a first round of issues requiring clarification and/or discussion. A list of questions was subsequently supplied to ATLAS.

The ATLAS Itk-Strip TDR Chronicles II

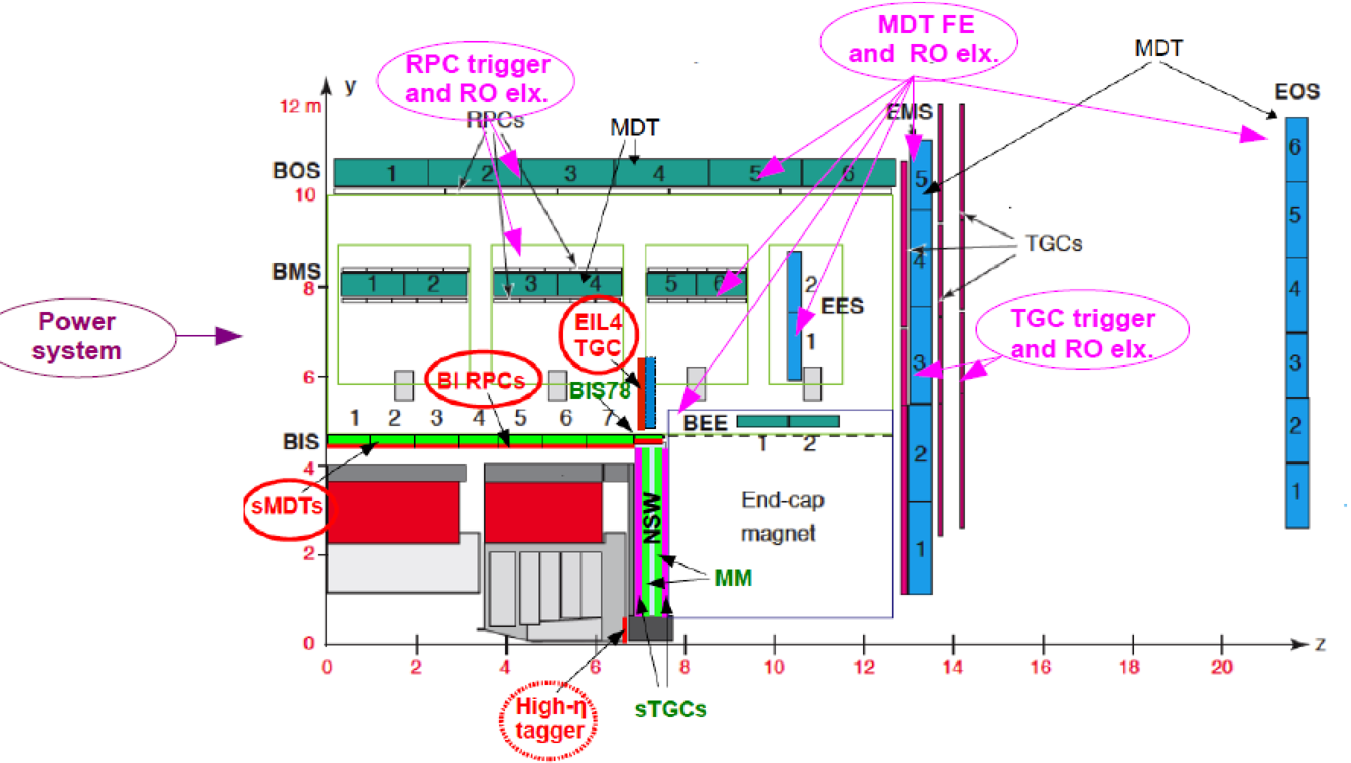
- 8/2/17: The Review Team met with ATLAS ITk system representatives and ATLAS management to discuss the issues raised and the ATLAS responses, and to identify further items requiring clarification. A subsequent list of topics and suggestions for the format and scope of the formal LHCC review, was sent to the ATLAS management.
- 21/2/17: The Review Team conducted a formal review of the draft TDR. Detailed presentations were received from ATLAS on: 1) overview and rationale for the Strips (and implications for the Pixels) system layout; 2) performance and physics; 3) sensors and modules; 4) mechanics and cooling; 5) electronics, power supplies and cables; 6) integration and installation; 7) [with the UCG] management, schedule, risks, and finance.
- **23/2/17**: The Review Team findings were presented to the LHCC in closed session. It was found that the TDR is a monumental document that contains a wealth of detail and represents the reference design for the ITk Strips system. The Strip tracker as proposed was found to be of a sound design. In conjunction with the proposed Pixel system the complete tracker will address the tracking performance required to do physics in the high-luminosity LHC era. The design will maintain the current tracker performance levels in an environment with event-pileup values as large as 200, as well as extending tracking coverage into the forward regions. While there are many technical issues and associated risks to be overcome, no ‘show-stoppers’ were identified.
- However, **a number of presentational issues were identified** and ATLAS was requested to make corresponding improvements for incorporation into the final TDR. The most important of these was a request for a clearer presentation of the performance in terms of measurement capability in benchmark physics channels and in the context of representative models of Beyond-SM physics.
- LHCC gave its provisional approval of the draft TDR and recommended that the UCG review should proceed. It was agreed that, subject to satisfactory completion of the LHCC’s requests, and subject to the findings of the UCG, the final TDR would be considered for approval at the May LHCC meeting.
- 7/4/17: The final version of the Strip TDR was made publicly available by ATLAS.

The ATLAS Itk-Strip TDR Chronicles III

- 14/4/17: A package of additional materials to support the UCG review was made available by ATLAS to the UCG review team.
- 24/4/17: The UCG review team met with ATLAS ITk system representatives and ATLAS management for first-round discussions. Questions and comments were fed back to ATLAS in preparation for the formal review at the May LHCC week.
- 8-9/5/17: The UCG review team held a formal review of the Strip TDR. They concluded that the cost estimate, resources, schedule, and risk level are reasonable for the current stage of the project. They recommended Step 2 approval by the RB and RRB to allow resources to become available and MOUs to be signed. They recommended that, to ensure success, ATLAS, the LHCC and CERN management must closely monitor the funding situation and technical progress of this extremely complex project.
- 11/5/17: The LHCC, having satisfied itself that its requests for clarifications had been incorporated into the final TDR version, and noting that the UCG review had not identified any additional issues beyond those normal for a large project at this stage, formally **recommended for approval the ITk-Strip TDR**. The LHCC thanked and congratulated ATLAS for their achievement and for their prompt and constructive engagement with the review process.

ATLAS Muon Upgrade Scope

34 MCHF



Three semi-independent projects: (s)MDT; RPC, and TGC, with supporting electronics, power supplies

ATLAS Muon Sept LHCC Comments

- The TDR document detailed the physics motivation for such an upgrade, the electronics modifications to all three subsystems (RPC, MDT and TGC), as well as the addition of a fourth layer to the RPC system. Furthermore, included is a description of the power systems, impact of a potential shift to an environmentally friendly gas mixture, as well as the installation plan and description of the project management.
- The goal of this upgrade is to preserve the ability of the muon system to trigger at current thresholds in a much higher luminosity environment and maintain muon acceptance at today's values. We concluded that the muon upgrade **is well motivated** as an appropriate response to the challenges of running at the HL-LHC, and is properly matched to the physics goals.
- The committee felt that at this stage, we can only provide **conditional approval**. The TDR, as presented, identified a number of R&D efforts underway that can impact final design. Thus, it is unclear to the reader what is the "baseline" system that is being proposed for approval.
- For final approval, please identify clearly what is the baseline plan. The R&D described should be presented as possible options. If this R&D is successful and can be adopted, describe what the impact to the overall project would be in shifting the baseline.

ATLAS Muon Nov LHCC Approval

- Based on the committee's guidance, the ATLAS muon group produced an **updated version of the TDR** with several improvements for LHCC review.
  - They provided updated performance plots and improved clarity on how simulation was used for physics prospects.
  - A detailed discussion on greenhouse gas impact and plans was added.
  - A refined RPC discussion clarifying what is in the baseline design and R+D opportunities to improve performance was also added.
  - The power supply chapter was modified to include more modules than was originally described.
  - Finally, the management chapter was significantly updated with much more detail than the original version.
- The committee was pleased with added clarity provided in the updated version of the TDR and **fully approve** this version. The committee was also quite impressed with the latest round of presentations and information.
- In a few short months, it seemed that this upgrade project is functioning much more like a coherent team with significantly improved communications and ownership of the project that did not come across in the first review.

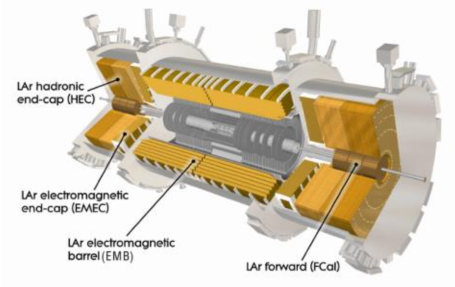
ATLAS LAr

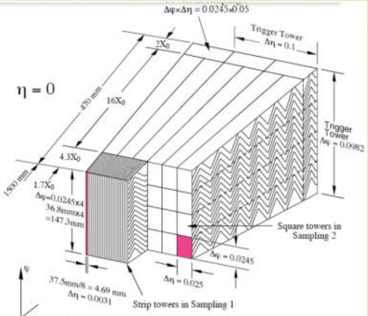
- Electronics upgrade

Role	Last Name	First Name
Chair	CECCHI	Claudia
LHCC-ExpTeam	Kunne	Fabienne
	Wisniewski	William
LHCC-OtherTeam	Krizan	Peter
Technical Expert	Donega	Mauro
	Faure	Jean-Louis
	Mulders	Martijn
	Tschirhart	Robert
UCG Expert	Barker	Gary
	Lubrano	Pasquale

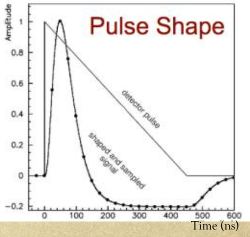
28 MCHF

The LAr Phase2 Upgrade

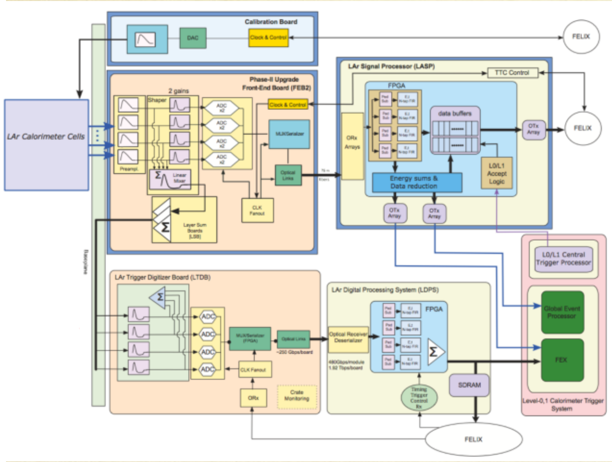




- Fine-grained lead (EM)/copper (HEC & FCal)/tungsten (FCal) - liquid argon sampling calorimeter
  - At shower maximum ("middle layer"), $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$
  - ~180,000 cells



LAr readout post-upgrade



- Pile-up mitigation at HL-LHC
- Limited radiation tolerance
  - On detector electronics qualified up to 700-1000 fb^{-1}
- Incompatibility with Trigger upgrade (Phase1 2019)
  - 2.5 μs latency, 100KHz ✎ 35 μs, 1MHz

C. Cecchi 30/11/2017

ATLAS LAr LHCC Conclusions

- The electronic upgrade of the detector is well justified in view of the High Luminosity running.
  - The motivations of the upgrade have been clearly presented going from pile-up mitigation, to radiation tolerance issues and compatibility with the Phase-I Trigger upgrade.
  - The necessity for the LAr upgrade is well defined, even if many design choices have to be finalized. Some parts of the upgrade have, from the technical point of view, stringent requirements, but they have been shown to be feasible on the proper time scale.
- Detector performances have been discussed starting from the assumption of reaching, with the upgraded calorimeter, the same performance as in the run 2 data taking.
  - At the present stage, this goal has not always been achieved, but there is clear room for improvement.
  - The review panel asked to explicitly highlight and quantify in the TDR the benefits arising from the availability of the full granularity and history of energy deposits in a bunch crossing for triggering and PU (pile-up) filtering.
- **Based on the technical and scientific review, approval is given for the project to proceed to the UCG review.**

ATLAS Tile

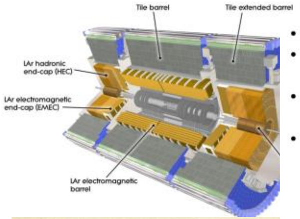
- Electronics upgrade

Role	Last Name	First Name
Chair	CECCHI	Claudia
LHCC-ExpTeam	Kunne	Fabienne
	Wisniewski	William
LHCC-OtherTeam	Krizan	Peter
TechnicalExpert	Donega	Mauro
	Faure	Jean-Louis
	Mulders	Martijn
	Tschirhart	Robert
UCGExpert	Barker	Gary
	Lubrano	Pasquale

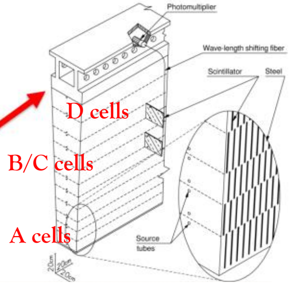
11 MCHF

The TileCal Phase2 Upgrade

- ATLAS central (|η|<1.7) hadronic calorimeter; made of plastic scintillator tiles and steel.
  - Measures hadrons and jet energy and direction.
  - Contribute to the ETMiss measurement, e/ϒ and μ identification.
  - Measure/monitor the LHC luminosity.
- One barrel and two extended-barrel cylinders made of 64 trapezoidal modules each.



- The scintillators are readout on both sides by two PMTs using WLS fibres.
- PMTs and Front-End (FE) electronics are mounted on 3m long drawers (super-drawer) at the outer radius of the modules
- The super-drawer is the smallest read-out units in the current system and cover a region ΔηxΔφ =0.7x0.1
- 256 super-drawers are used to readout the Tile.

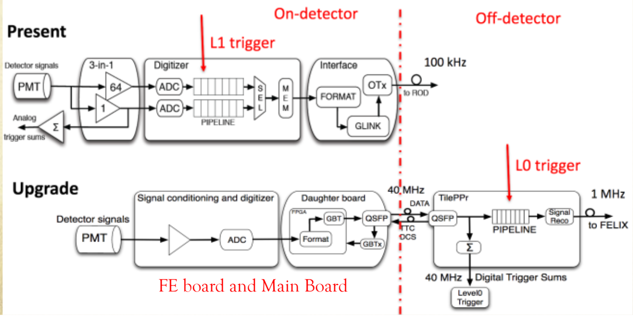


Motivations

New ATLAS trigger and readout architecture
- Digital trigger ✎ better precision and granularity
- Higher trigger rate and latency
- Higher bandwidths readout
- New sensitivity to LLP new physics

Radiation hardness
- Will exceed components lifetime in most cases

Improve reliability of the system and access to electronics
- Smaller independent minidrawers
- Redundancy



ATLAS Tile LHCC Conclusions

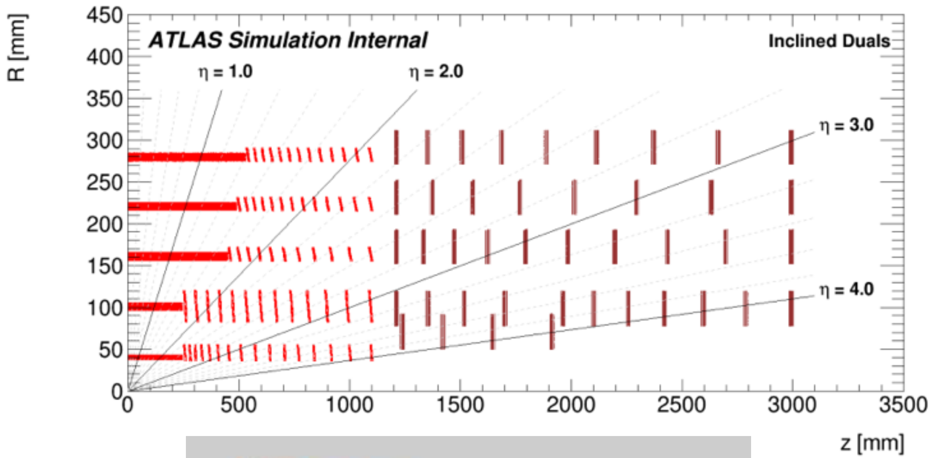
- Motivations of the electronic upgrades, very well justified, are mainly based on the new ATLAS trigger and readout architecture (higher latency and trigger rates), radiation tolerances, and improvements of the reliability of the system by implementing redundancies on the new electronic boards.
- The physics case and detector performance have been presented but only up to a maximum value of pile-up of 40, while the expected pile up for HL-LHC is of the order of 200, and only in the central part of the detector.
  - The review panel has explicitly asked for a more extended study up to pile-up of 200, and including also the region of the extended barrel, which has neither been presented nor described in the reviewed version of the TDR.
  - → Studies have been performed and presented in January
- **Based on the technical and scientific review, approval is given for the project to proceed to the UCG review.**

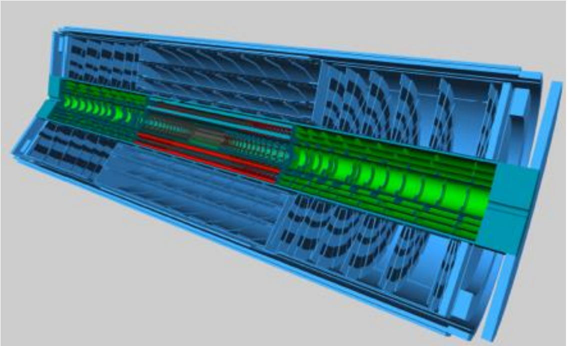
ATLAS ITk-Pixels

Role	Last Name	First Name
Chair	ROSER	Rob
LHCC-ExpTeam	Calabrese	Roberto
LHCC-OtherTeam	Krueger	Katja
Technical Expert	Honma	Alan
	Moll	Michael
	Musa	Luciano
	Nahn	Steve
	Petagna	Paolo
	Spalding	Jeff
UCG Expert	Goldstein	Joel
	Moll	Michael

Strips: 60.7 MCHF (approved)
Pixels: 46.9 MCHF
Common systems: 13.7 MCHF
TOTAL: 121.3 MCHF

- 5 Layer Pixel Detector
  - Inner two layers are replaceable
  - Leveraging Planar and 3D designs
  - Designed to be much more rad hard than before as well as handle the expected higher data rates (one-time replacement of inner two layers foreseen)
  - Extended eta coverage, now goes out to 4
  - Combined with strip detector – potential of at least 9 measurement points on every track.
  - Serial power to keep number of cables to an acceptable layer
  - New front end chip – based on RD53 project





ATLAS ITk-Pixels LHCC Conclusions

- Still need to make a number of decisions – encouraged to do this as soon as is sensible and to fix dates when these decisions will be made (milestones)
- A new Layout Task Force has been appointed to further optimize the layout with conclusions by July 2018.
- Serial power scheme -- long serial power chains are needed (up to 13 modules)
- Option of monolithic CMOS (layer 4) – not well motivated to the committee and could be a distraction
- ATLAS timing layer space budget needs to be folded into future layout
- Plan for module assembly: 10 assembly sites and 15 testing sites requires significant logistics when it comes to handling.
- **The review panel finds physics goals and technical implementation of the Phase-II ATLAS Inner Tracker Pixel Detector well matching with the HL-LHC programme and recommends the TDR to proceed to the UCG review of the project.**

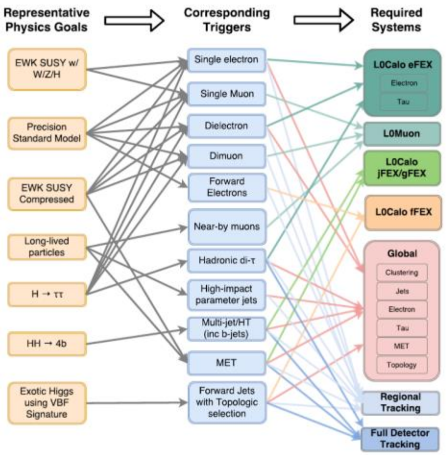
ATLAS TDAQ

Role	Last Name	First Name
Chair	MANKEL	Rainer
LHCC-ExpTeam	Beckmann	Volker
LHCC-OtherTeam	Kuhr	Thomas
LHCC-Returning	Boehnlein	Amber
Technical Expert	Gligorov	Vladimir
	Huffer	Mike
	Newbold	Dave
	Vande Vyvre	Pierre
	Behrens	Ulf
UCG Expert	Convery	Mary
	Moneta	Lorenzo

Level-0 trigger: 10.4 MCHF
Data acquisition: 13.6 MCHF
Event filter: 20.8 MCHF
TOTAL: 44.8 MCHF

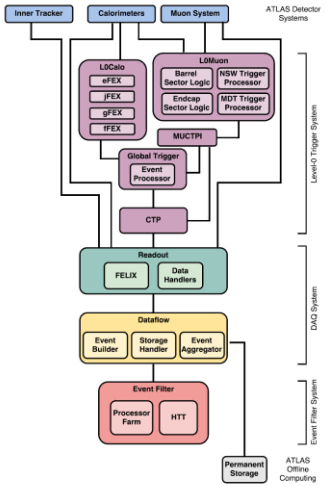
Goals of TDAQ Upgrade

- Accommodate the ultimate HL-LHC conditions at <μ>=200
- Enable a broad and challenging physics program
  - precision measurement of Higgs properties
  - precision SM measurements
  - searches for BSM signatures
  - flavor physics, heavy ion physics
- Maintain low thresholds e.g. for leptons → precision measurements in SM and Higgs areas
- Also hadronic (multijet + MET) triggers essential → BSM physics searches
  - many more…



Run II TDAQ System Overview

- Three TDAQ systems:
  - Level-0 trigger
  - Data acquisition
  - Event filter
- Hardware-based Level-0 trigger system designed for 1 MHz trigger rate and a maximum latency of 10μs
  - using full granularity of calorimeters in L0
  - re-using also the Phase I hardware (L0Calo)
  - benefit from muon NSW and barrel inner stations
  - no ITk information used at this level
- Data acquisition system provides common readout interface and can handle input readout bandwidth of 5.2 TB/s
- Event filter includes processing farm plus regional & full-scan hardware-based tracking (HTT)
  - maximum output event rate: 10 kHz

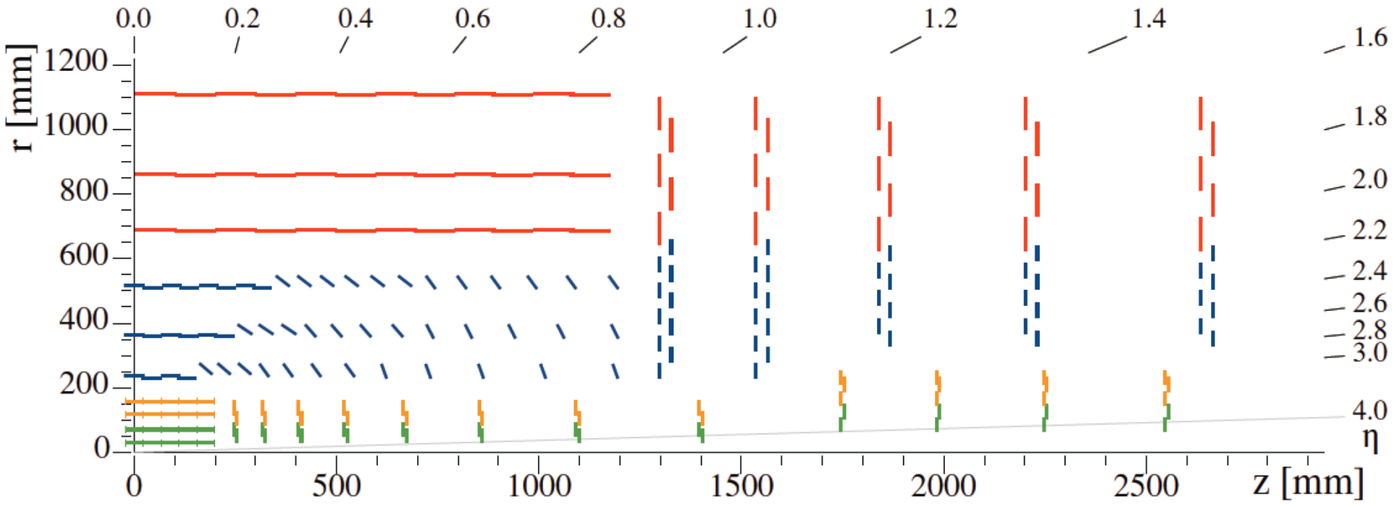


ATLAS TDAQ LHCC Conclusions

- The review panel is satisfied with the findings concerning the ATLAS TDAQ Phase II Upgrade TDR.
- Both scientifically and technically, we consider the TDR a fully convincing document.
- Well-motivated design driven by physics goals, and found suitable to keep the thresholds for key physics processes reasonably low even under HL-LHC pileup conditions
- In many areas the project relies critically on timely development of the firmware. Advance evaluation of performance and resource usage is of high importance.
- The HTT is a particularly challenging part of the project. Both the implementation and the commissioning deserve highest attention. The allocation of adequate resources is crucial.
- **The panel recommends the LHCC to approve the TDR, and proceed with the UCG review**

CMS Tracker Upgrade Scope

112 MCHF



- Acceptance up to |η| ~ 4
- Inner Tracker:
  - 4.9m^2, 2 x 10^9 pixels, two types of hybrid pixel modules: 1x2 chips and 2x2 chips
- Outer Tracker
  - 192m^2, 42M strips, 170M macro-pixels (25m^2)
  - 13296 modules; two types: **S**trip **S**trip (2S) and macro-**P**ixel **S**trip (PS)
  - Innovative tilted geometry in inner barrel

LHCC Conclusions on CMS Tracker

- The **scope** of the project is justified in terms of technical realization as well as physics performance.
- The project is **technically** very demanding but deemed feasible. No technical showstoppers have been identified.
- Successful delivery of the **RD53 readout chip** is crucial to the success of the overall project
- It is critical that the **remaining R&D** be supported as strongly as possible; appropriate funding for the R&D efforts has to be provided.
- The next two years will require an intense R&D phase in order to validate the various technical choices and to be ready for production; strong oversight is required to keep the schedule.
- Technical solutions should be finalized as quickly as possible.
- The project is demanding and needs strong overall management to keep the aggressive schedule.
- → **Proceeding to the UCG review**

CMS BarrelCal

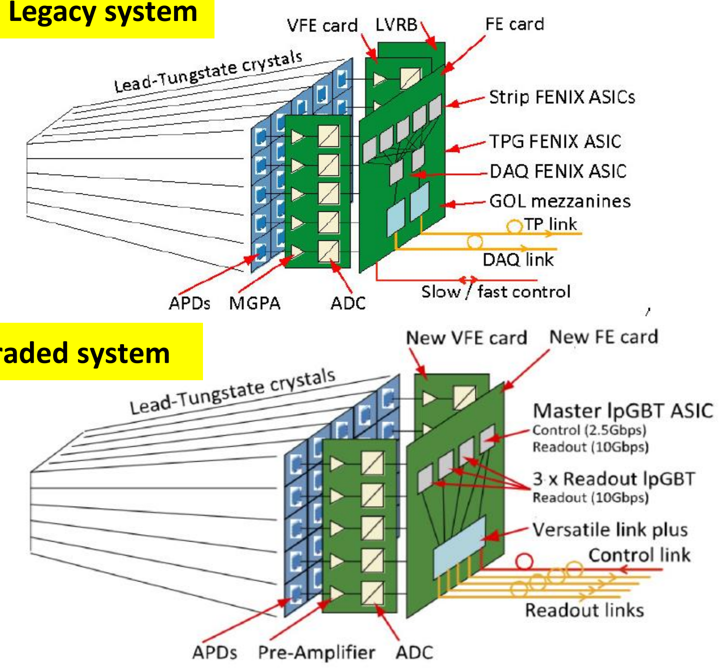
15 MCHF → 13.3MCHF

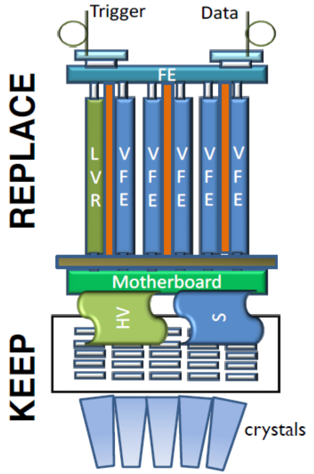
Role	Last Name	First Name
Chair	BEDESCHI	Franco
LHCC-ExpTear	Kuzmin	Alexander
LHCC-OtherTe	Eigen	Gerald
Technical Expe	Delmastro	Marco
	Glenzinski	Doug
	Kluge	Alexander
	Lanni	Francesco
UCG Expert	Danielsson	Hans
	Convery	Mary

- Electronics upgrade

Legacy system

Upgraded system





ECAL barrel trigger tower (25 crystals)

- HL CMS L1 trigger goals
  - Output rate 100 kHz → 750 kHz
    - Scale with luminosity
  - Max latency 4 → 12.5 μs/ 5x5 → 1x1 trigger granularity
    - Allow for more complex triggers (including L1 tracks)
  - 30 ps timing resolution for improved vertex association at high PU
- Spikes
  - APD photo-sensors occasionally record anomalously large charge depositions from the direct ionization of bulk-silicon from through going particles
  - Current spike rejection insufficient
- Radiation damage
  - Reduce temperature to 9C to mitigate effect

CMS BarrelCal Conclusions

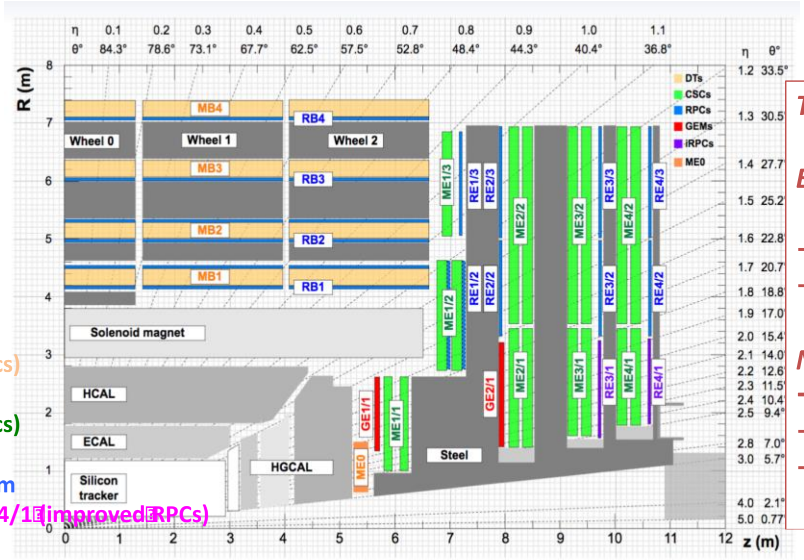
- The main motivations for the upgrade are the need to significantly reduce the noise in the APDs and their rate of "spikes", and to make the calorimeter compatible with the higher Level 1 trigger rates and increased trigger complexity demanded by the high luminosity operation. The panel found these motivations very solid.
- Additional findings are that the project appears to be in a very good stage of advancement for the TDR phase and is well organized and managed by a competent and experienced team. Moreover, most studies done in the TDR cover a range of integrated luminosity up to 4500 fb^{-1}, in excess of the 3000 fb^{-1} planned for the whole HL-LHC running period. This demonstrates that the proposed upgrades have adequate performance margins.
- The review panel finds physics goals and technical implementation of the CMS barrel calorimeter upgrade well matching with the HL-LHC programme and **recommends the TDR to proceed to the UCG review of the project.**
- In Jan 2018 CMS decided NOT to replace the scintillator megatiles, greatly simplifying the HCAL upgrade and reducing the cost

CMS Muon

Role	Last Name	First Name
Chair	MARTINEZ-PEREZ	Mario
LHCC-ExpTeam	Waters	David
LHCC-OtherTeam	Newman	Paul
LHCC-Returning	Dalla Torre	Silvia
Technical Expert	Bauer	Florian
	Cardini	Alessandro
	Polini	Alessandro
	Sasaki	Osamu
	Kroha	Hubert
	Moneta	Lorenzo

GEM 1/1 : 3.75 MCHF
Muon: 21.4 MCHF
Total: 25.1 MCHF

Outline of Upgrades



1. DT Upgrades (only electronics)
1. CSC upgrades (only electronics)
1. RPC upgrades
   1. Link system
   2. RE3/1, RE4/1 (improved RPCs)
2. GEM upgrades
   1. [*GEM 1/1 already approved, upgrade ongoing]
   2. GE2/1
   3. ME0

(no GEM detectors in CMS before the upgrades)

Two main components of the upgrade:

Electronics upgrade, needed for the increased luminosity
→ mandatory to cope with L1 trigger rates and latency at HL-LHC
→ Will provide new trigger capabilities and maintain low pT thresholds
→ Will help in protecting physics against aging in chambers

New enhanced muon coverage at large rapidity up to |eta| < 2.8
→ More redundancy and then a better trigger efficiency
→ Larger acceptance for multilepton final states
→ New stand-alone trigger capacities for most exotic signatures

10

CMS Muon LHCC Conclusions

- Different elements of the read-out electronics for the muon chambers: Drift Tubes (DT), Cathode Strip Chambers (CSC) and Resistive Plate Chambers (RPC) need to be replaced in order to cope with the expected Level 1 trigger rate of 750 kHz and the Level 1 trigger latency of 12.5 microseconds.
  - The proposed upgrade of the DT and CSC read-out electronics is mandatory, in order to maintain the detector performances over the entire HL-LHC period. The improved trigger capacities will preserve the physics program.
- Two new sets of GEM chambers are proposed, ME0 and GE2/1, which will cover the pseudorapidity regions 2.0 – 2.8 and 1.6 – 2.4, respectively. Two improved RPC chambers are proposed, RE3/1 and RE4/1, in the pseudorapidity region 1.8 – 2.4.
  - The committee finds that the physics case was not presented in enough detail and, in particular, it is not completely clear what the gain of the additional pseudorapidity coverage is in terms of physics output.
  - We recommend CMS to continue to work on the physics motivation, and provide clear evidence of the separate impact of each muon upgrade and not just the combined impact of all upgrades taken together.
- The review committee finds the CMS muon system TDR technically sound and satisfying the specifications of the HL-LHC programme. The committee therefore **approves** the TDR (**pending information** of the individual upgrades on the physics reach) **to proceed to the UCG review** of the project.

→ additional information clarifying the physics case has been presented and included in the TDR

CMS EndCap Cal

Role	Last Name	First Name
Chair	Denisov	Dmitri
LHCC-ExpTeam	Kajfasz	Eric
	Kuzmin	Alexander
LHCC-OtherTeam	Bloise	Caterina
	Dunlop	James
LHCC-Returning	Demarteau	Marcel
Technical Expert	Heinemann	Beate
	Riedler	Petra
	Roda	Chiara
	Gordon	Howard
UCG Expert	Christie	William
	Pöschl	Roman

67.1 MCHF

Design Criteria

- Existing CMS endcap calorimeter will not withstand HL-LHC conditions
  - Based on crystals (electromagnetic) and scintillator/WLS (hadron)
- This region of calorimetry (eta between ~1.5 and ~2.5) is critical for both missing energy and various objects reconstruction - leptons, photons, jets
- Main design goals set by CMS
  - Radiation hard to 3 ab^{-1} +50% (= 4.5 ab^{-1})
  - Stable performance during HL-LHC running
  - Dense to provide good photons/electron discrimination, and high precision in measuring VBF and boosted jets
  - Reasonable power budget and cost
- Set of benchmark physics processes selected
  - Simple construction, cost effective
  - Margin and redundancy for long term operation without access
- CMS, internally, went over comparison of various options
  - Which culminated in the submission of the TDR to LHCC

CMS 5

Endcap calorimeter is a silicon sensor sampling calorimeter
(absorber material – W, Pb, Stainless Steel)

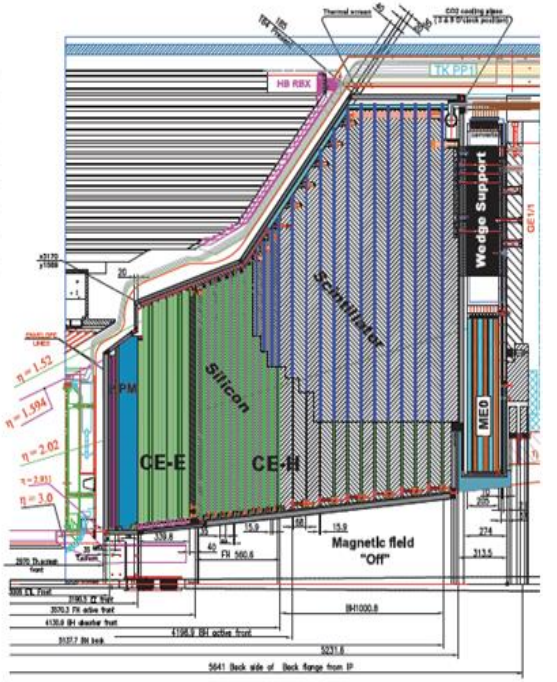
followed by plastic scintillator tiles
with direct SiPM readout for the volume with lower radiation levels (absorber material – Stainless Steel)

CE-E: ECAL

Active thickness (μm)	300	200	120
Area (m^2)	245	181	72
Largest lifetime dose (Mrad)	3	20	100
Largest lifetime fluence (n_{eq}/cm^2)	0.5×10^{15}	2.5×10^{15}	7×10^{15}
Largest outer radius (cm)	≈180	≈100	≈70
Smallest inner radius (cm)	≈100	≈70	≈35
Cell size (cm^2)	1.18	1.18	0.52
Initial S/N for MIP	11	6	4.5
Smallest S/N(MIP) after 3000 fb^{-1}	4.7	2.3	2.2

CE-H: HCAL

	Scintillator	Si	Si
Sensor thickness	3 mm	300 μm	200 μm
Area (m^2)	480	71	15
Largest lifetime dose (Mrad)	<0.3	30	100
Largest lifetime fluence (n_{eq}/cm^2)	8×10^{13}	5×10^{14}	2.5×10^{15}
Largest outer radius (cm)	≈235	≈160	≈100
Smallest inner radius (cm)	≈90	≈80	≈45
Cell size (cm^2)	2×2 to 5.5×5.5	1.18	1.18
Initial S/N for a MIP	≫5	11	6
Smallest S/N(MIP) after 3000 fb^{-1}	5	4.7	2.3



CMS EndCap Cal LHCC Conclusions

Some requests from the panel

- Large number of activities to be completed for EDR (June 2020): careful monitoring by LHCC and CMS is required
- Optimization of longitudinal segmentation is important and needs to receive further studies
- Specifications/performance of the hadron calorimeter needs to be finalized
- Proceed expeditiously making remaining technical choices to finalize technical design by the time of the EDR in June 2020
- System integration is important for this new detector type and every effort should be made to perform relevant tests as soon as various sub-systems will become available
- Study most probable failure modes in the fully assembled and operating detector
- Update TDR based on the results of the LHCC review

Recommendation

- The proposed design of the high granularity endcap calorimeter for the CMS upgrade is expected to satisfy requirements of the HL-LHC running while continuing R&D and simulation studies remain to verify and optimize the design choices.
- **We recommend to approve the TDR and proceed toward UCG review of the project.**

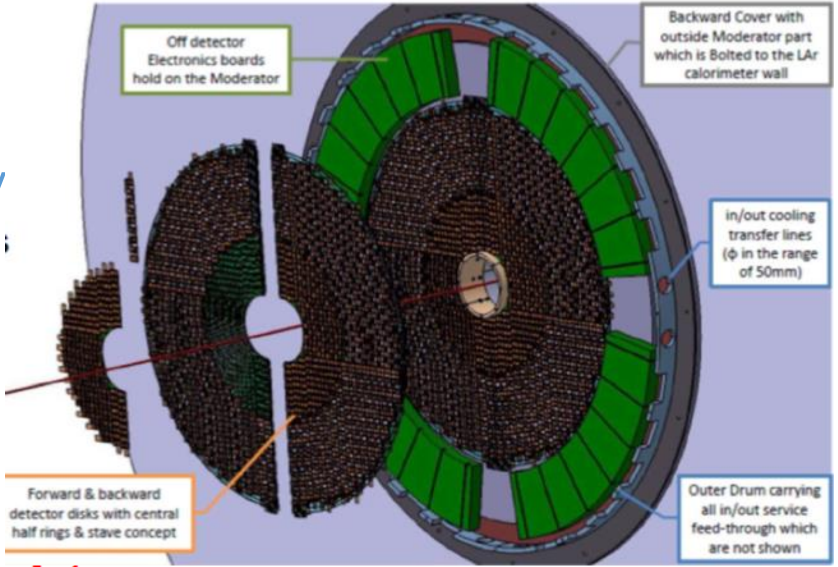
CMS Intermediate documents for L1 Trigger and DAQ

6 + 12.6 MCHF

- Interim TDRs on the Level 1 and HLT/DAQ Phase-II upgrades have been submitted to the LHCC in September. While the full review will only take place once the TDRs have been submitted at a later date, the interim documents serve to understand the overall scope, feasibility, and cost of the systems in the context of the full Phase-II upgrade. In both cases design, schedule and cost estimate were found to be reasonable.
- Based on the interim TDRs submitted, the **LHCC finds** the design, schedule and cost estimates of the Level 1 and HLT/DAQ systems for Phase-II reasonable, and encourages CMS to proceed to develop the full TDRs, planned for 2020 and 2021 respectively.

ATLAS HGTD

- Endcaps only (LAr barrel allow already good PU suppression)
- Thing LGAD (Low Gain Avalanche Silicon Detector) technology
- Resolution 25-35ps
- Cost about 7.5M (+1M for TDAQ)



Benefits

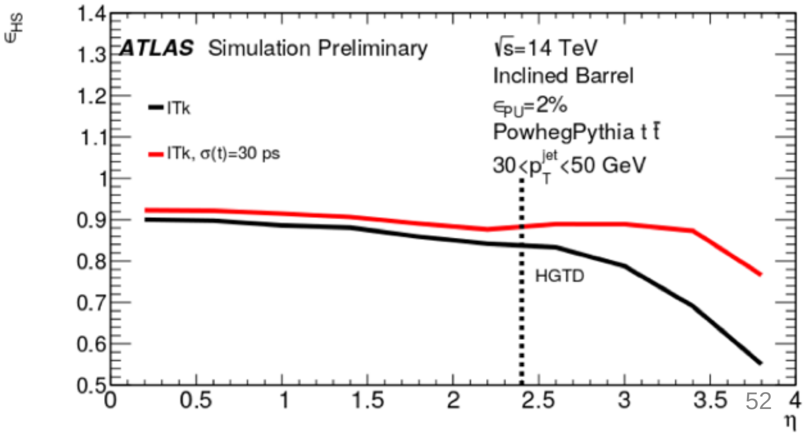
Physics channels:	Relative improvement
Z→ ee to measure $\sin^2\theta_W$	5%
VBF Higgs to WW	8%
VBF Higgs→ττ	10%
tH with H → b bbar	11%

Luminosity

Order 1% error on luminosity measurement important for many physics analyses:

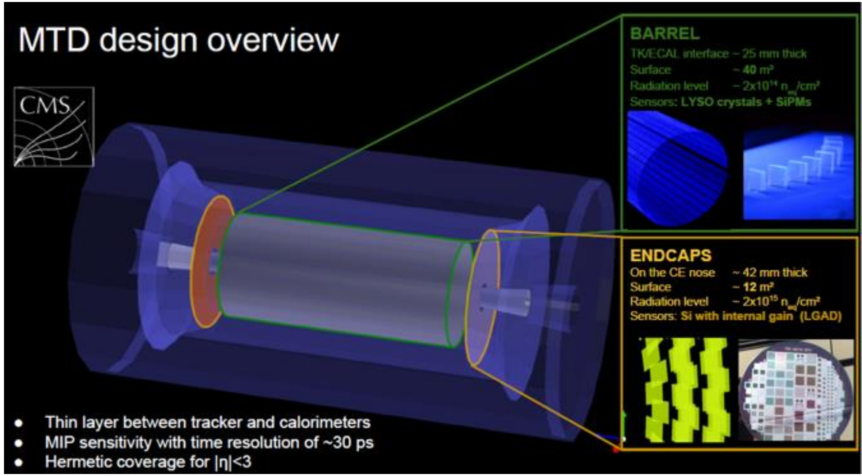
- **HGTD will provide 40MHz bunch by bunch measurements**

Jets



CMS MIP Timing detector

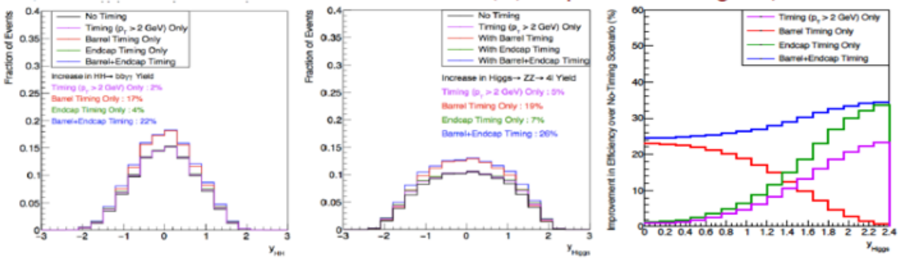
- Barrel (LYSO+SiPM) and endcaps (LGAD)
- Resolution about 30 ps
- Cost about 8M for barrel, 7.8M for endcaps



Gain in signal yields (i.e. effective luminosity): 18-26% (*)

	HGC	ETL	BTL	MTD	Localized observables
HH→bbbb	+2%	+4%	+14%	+18%	b-tagging
HH→bbγγ	+2%	+4%	+17%	+22%	b-tagging + photon identification
H→4l	+5%	+7%	+19%	+26%	Lepton isolation (**)

(**) No precision timing for μ's in HGCal



HH→bbγγ **H→4l: more than 50% from ETL at $|y_{HI}| > 1.4$** rt