ATLAS and CMS Upgrades and the future physics program at the LHC

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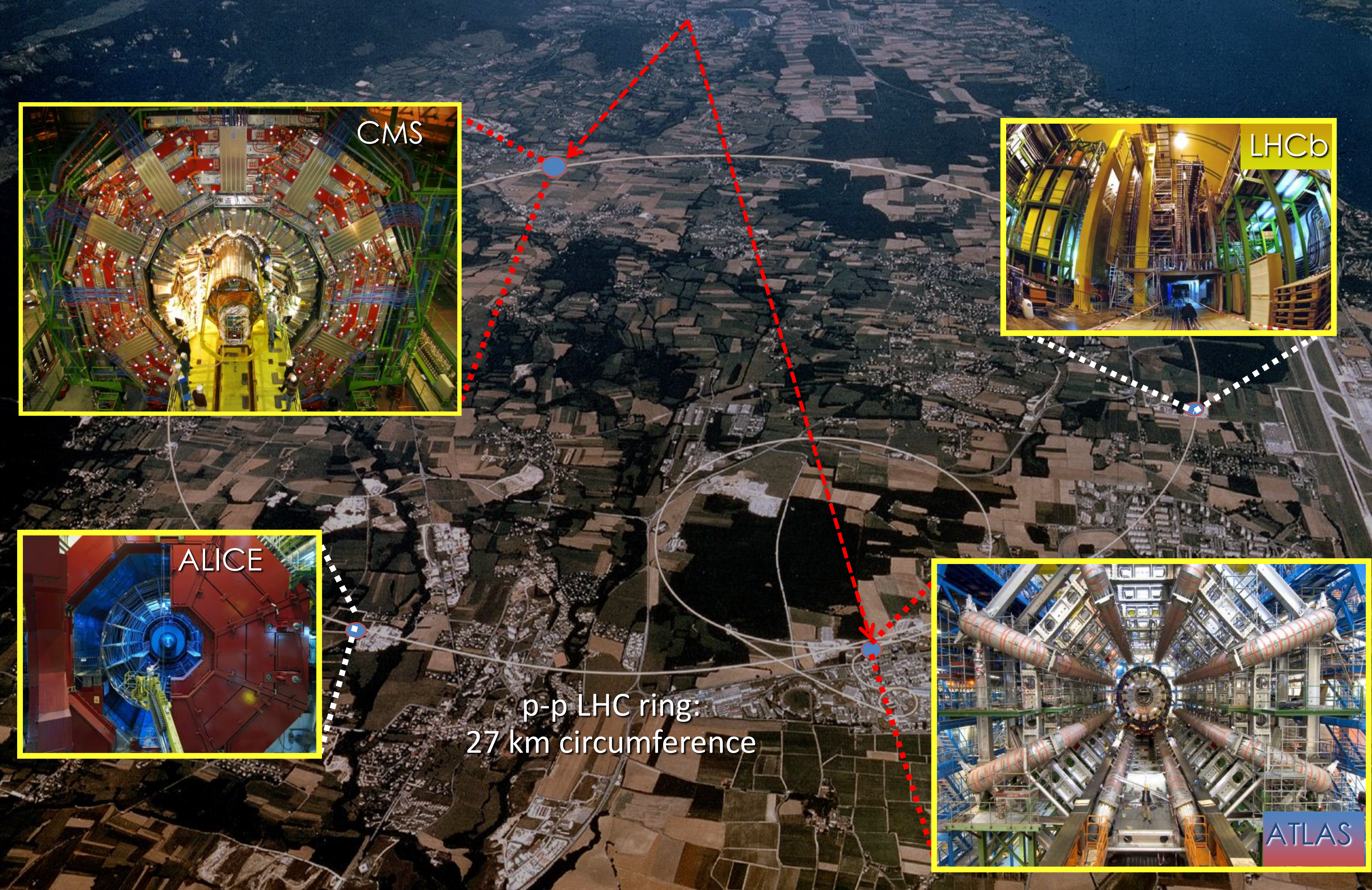


Outline

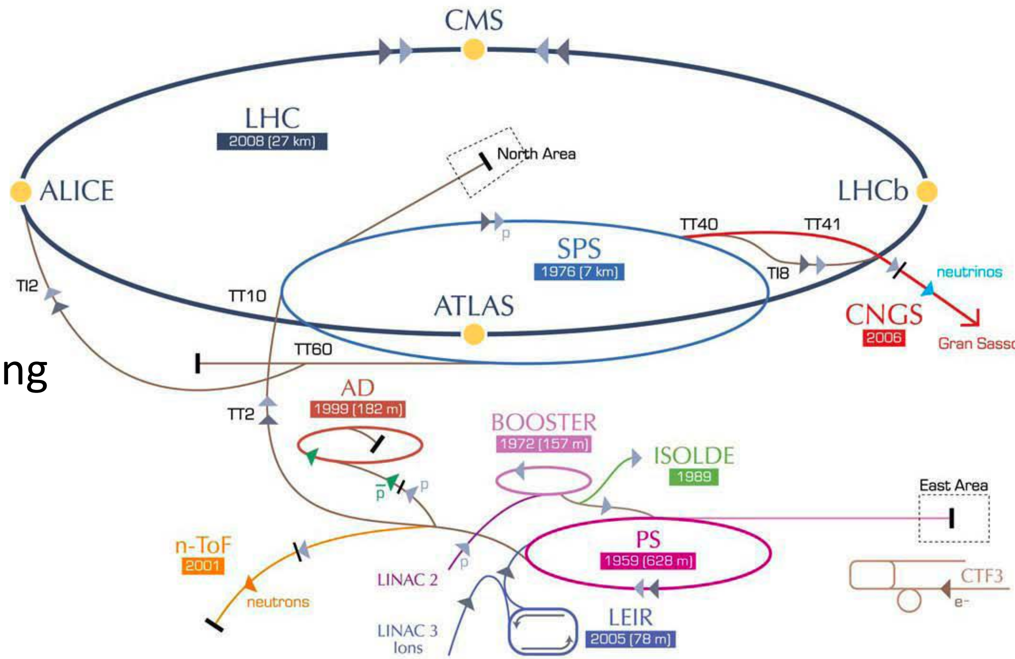
- First run at the LHC 2010 - 2012
  - Beam conditions and data taking
  - Higgs discovery
- LHC Upgrade and physics goals
- ATLAS and CMS present detectors
- Detector Upgrades for Phase 1
- Detector Upgrades for Phase 2 - HL-LHC

First run at the LHC (2010 - 2012): Beams and Data

Proton beams are injected in LHC in bunch trains prepared in the injection chain

In 2012

- 1368 bunches of ~ 1-2 x10^{11} protons spaced by 50 ns
- CM energy of 8 TeV
- Luminosity reach 8x10^{33} Hz/cm^2
  ~ 20 p-p interactions per bunch crossing
- Mean fill length ~ 6 hours
- Stable beam 35% of time in 2012



Data registered in ATLAS and CMS

- ~ 98% of detector in operation
- ~ 94% of delivered luminosity recorded ~ 30 fb^{-1} (5 fb^{-1} in 2011 and 25 fb^{-1} in 2012)

$L = n_b N_b^2 f_{rev} / 4\pi\beta^* \varepsilon_n \times R$

- Maximize brightness: N_b/ε_n
- Focus beams : $\beta^* \varepsilon_n$
- Improve overlap: $R(\Phi, \beta^*, \varepsilon_n, \sigma_n)$

Production Rate = Luminosity x Cross-section

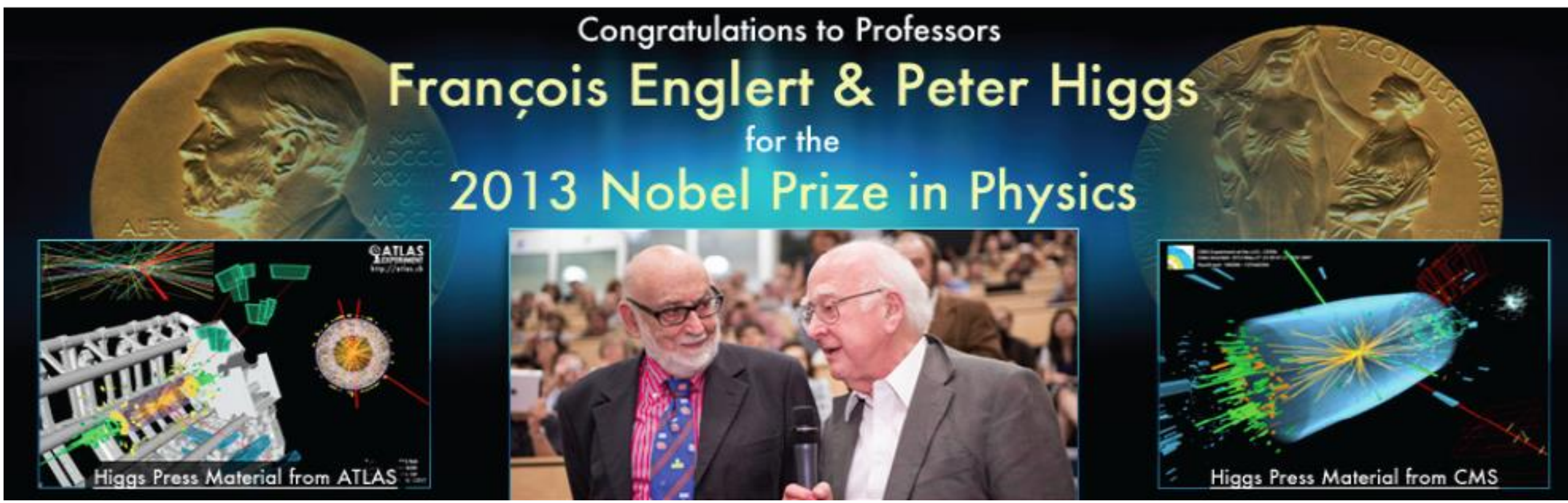
First run at the LHC: A Higgs boson discovery

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2013 to

François Englert
Université Libre de Bruxelles, Brussels, Belgium

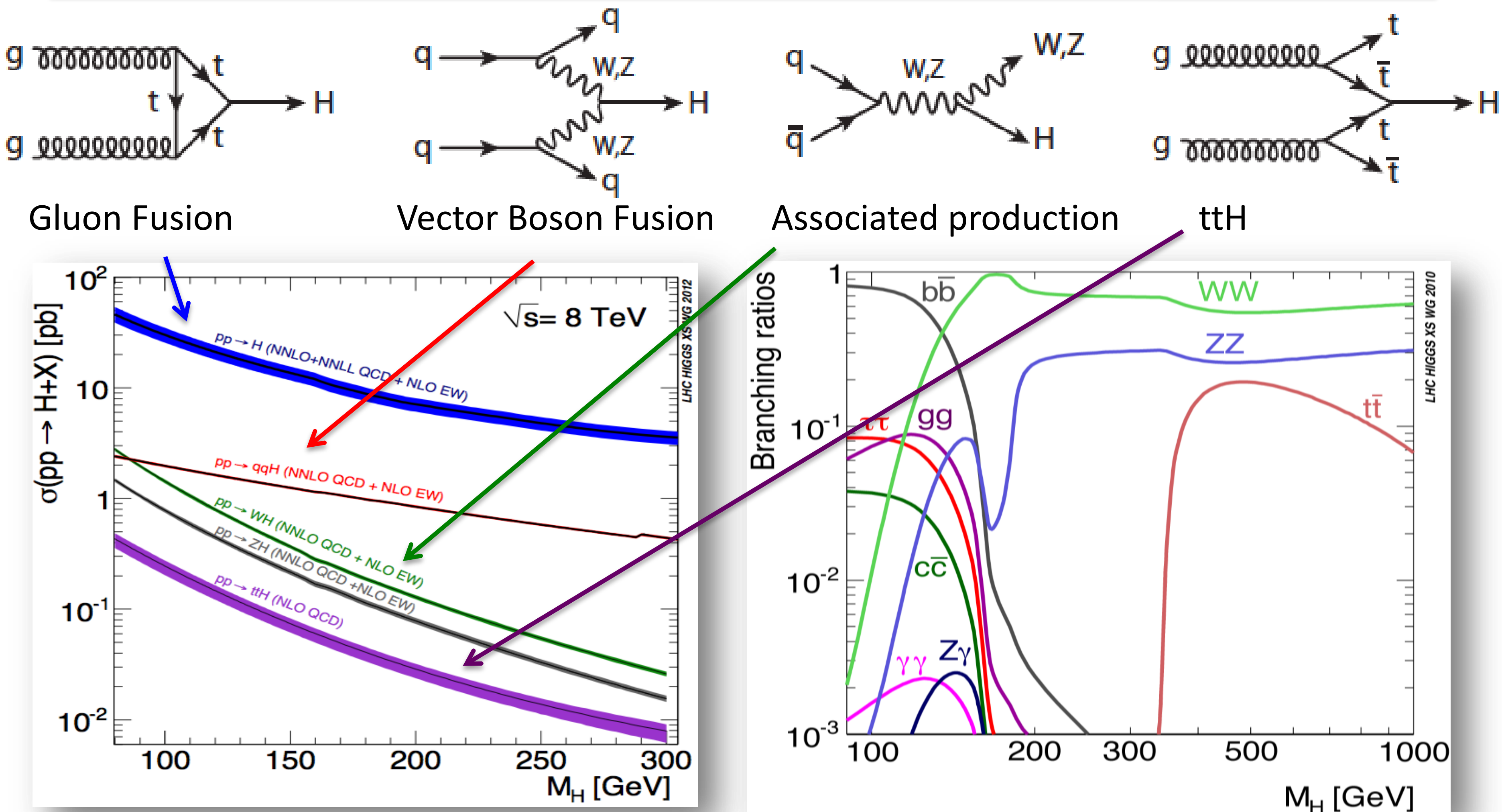
Peter W. Higgs
University of Edinburgh, UK

"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"



And consolidation of the Standard Model but no evidence for new physics yet

Higgs boson: Standard Model prediction

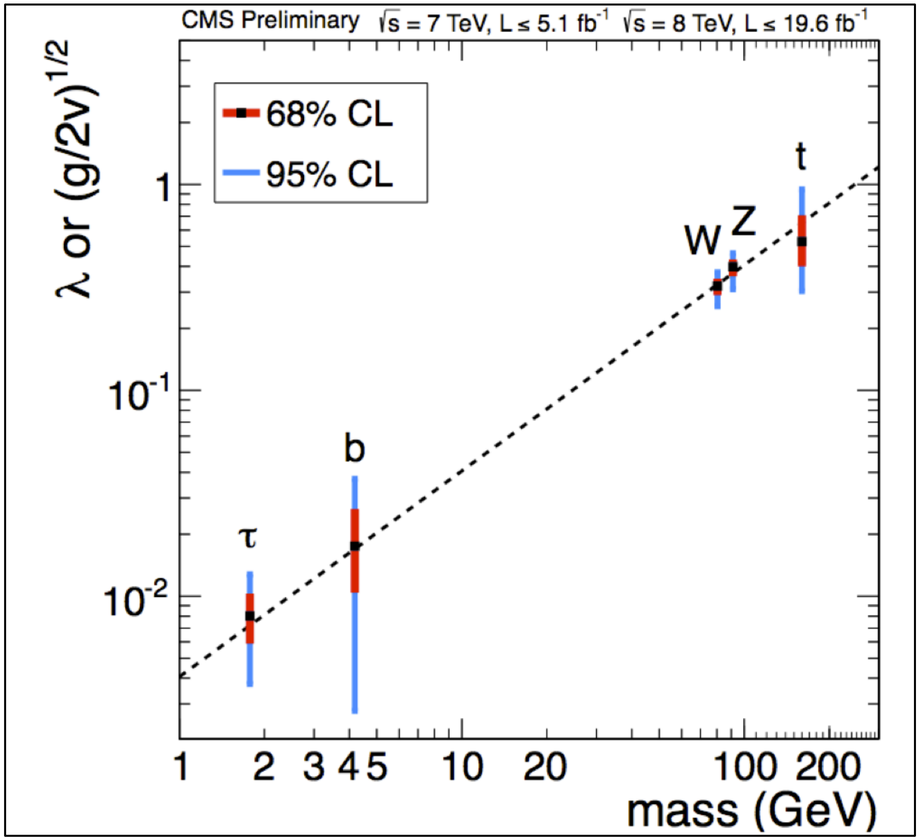


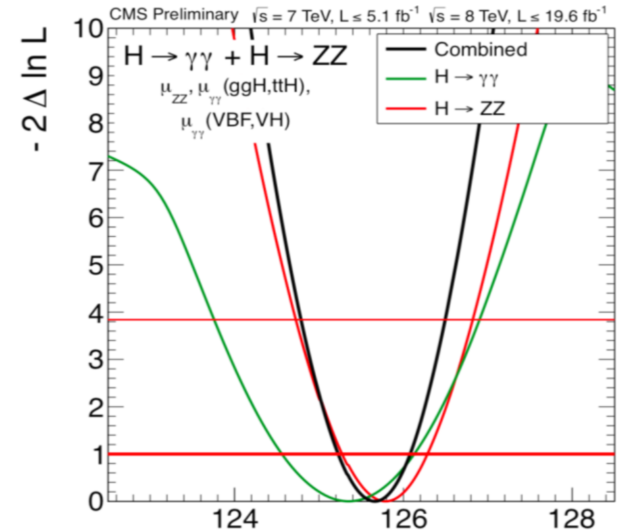
Discovery channels: $H \rightarrow \gamma\gamma$ - $H \rightarrow ZZ \rightarrow 4l$ (very good mass resolution ~ 1%) - $H \rightarrow WW$

Others channels: bb, ττ decays hard to identify in huge background

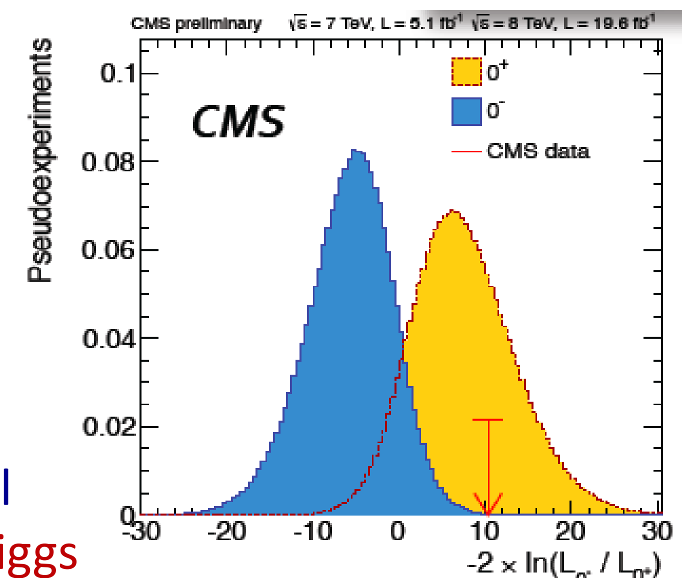
Higgs boson: Measured properties so far (30 fb^{-1})

Today ATLAS+CMS have ~ 1400 Higgs events





M = 125.7 ± 0.3 ± 0.3 GeV



Spin 0+ it is a scalar particle

Strength of coupling is proportional to the mass and spin/parity = 0^{+} as expected in Standard Model

It is a Higgs but it doesn't exclude it is a non-SM Higgs

Outline

- First run at the LHC 2010 – 2012
- LHC Upgrade and physics goals
  - Steps in the luminosity increase
  - Physics goals and few performance projections (see more in ESPG- Snowmass and recent ECFA workshop references below)
- ATLAS and CMS present detectors
- Detector Upgrades for Phase 1
- Detector Upgrades for Phase 2 - HL-LHC

link to Krakow: http://espp2012.ifj.edu.pl/
link to Snowmass: http://www.snowmass2013.org/tiki-index.php
Link to ECFA workshop: https://cms-docdb.cern.ch/cgi-bin/PublicDocDB//ShowDocument?docid=12141
https://indico.cern.ch/conferenceDisplay.py?confId=252045

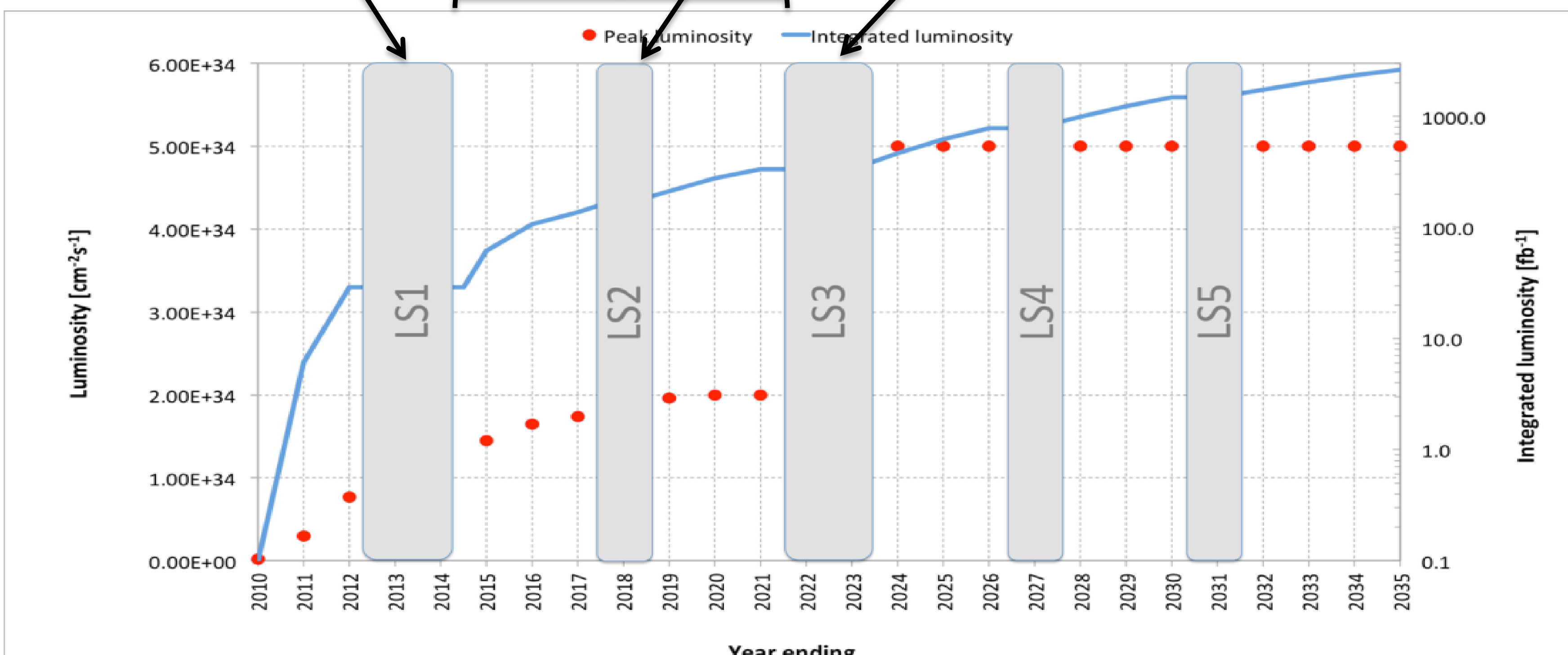
LHC Upgrade program: Reach nominal - increase luminosity

CM energy: 8 → 13-14 TeV
bunch spacing: 50 → 25 ns

Injection Chain upgrade
- New Linac
- PSB-PS: 1.4→2 GeV
- RF upgrades in PS and SPS

HL-LHC upgrade
Improve beam focus and overlap at Interaction Points
- New low-β quadrupoles
- Beam-Beam wire compensation
- Crab Cavities

Improve beam brightness

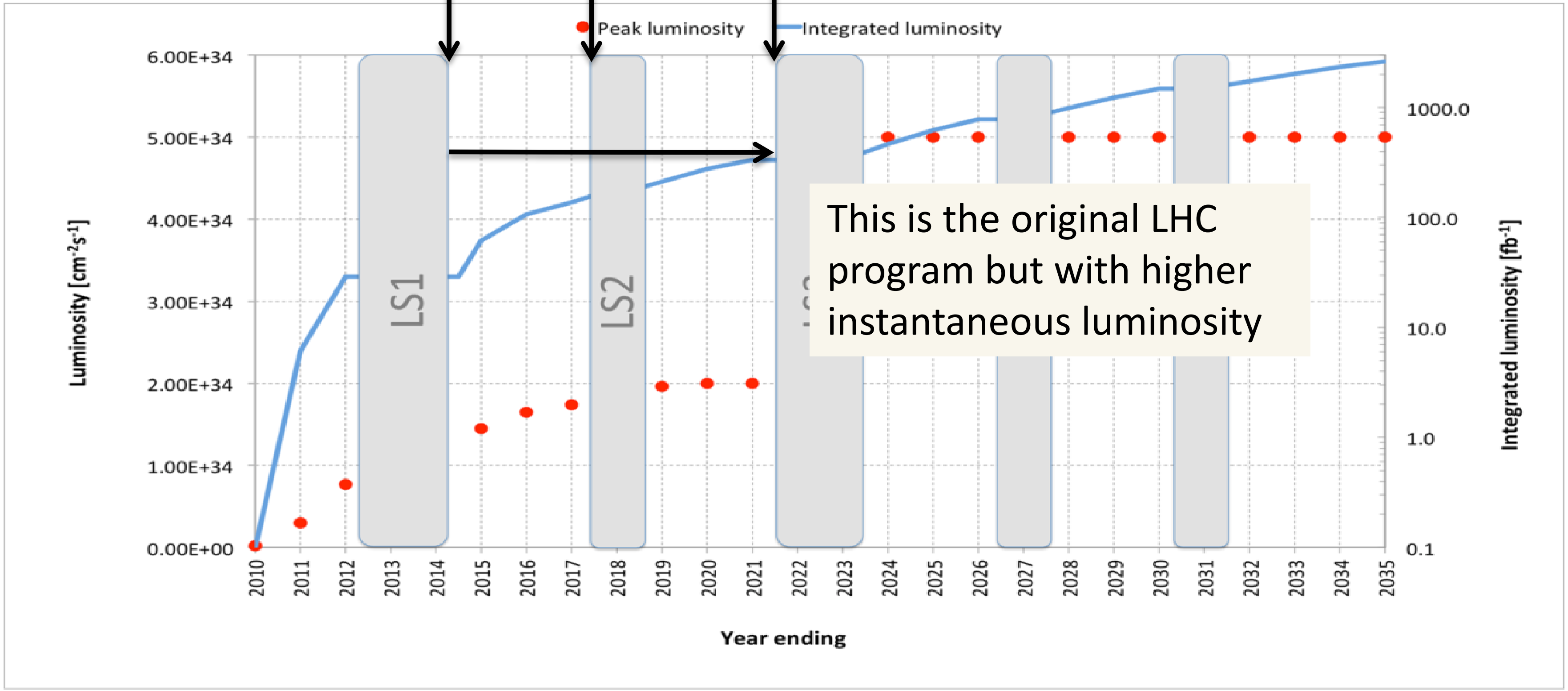


Schedules of Long Shutdown 2 and 3 presented in this slide are still under discussion

ATLAS & CMS Upgrade program: Phase 1

LS1 through LS2:

- Complete original detectors and consolidate operation for nominal LHC
  - ➢ 1 x 10^{34} Hz/cm^2 , <PU> ~ 25
- Prepare detector to maintain physics performance for
  - ➢ 1.6 x 10^{34} Hz/cm^2 , <PU> ~ 40, ~ 100 fb^{-1}
  - ➢ 2.5 x 10^{34} Hz/cm^2, <PU> ~ 60, ~ 200 fb^{-1}

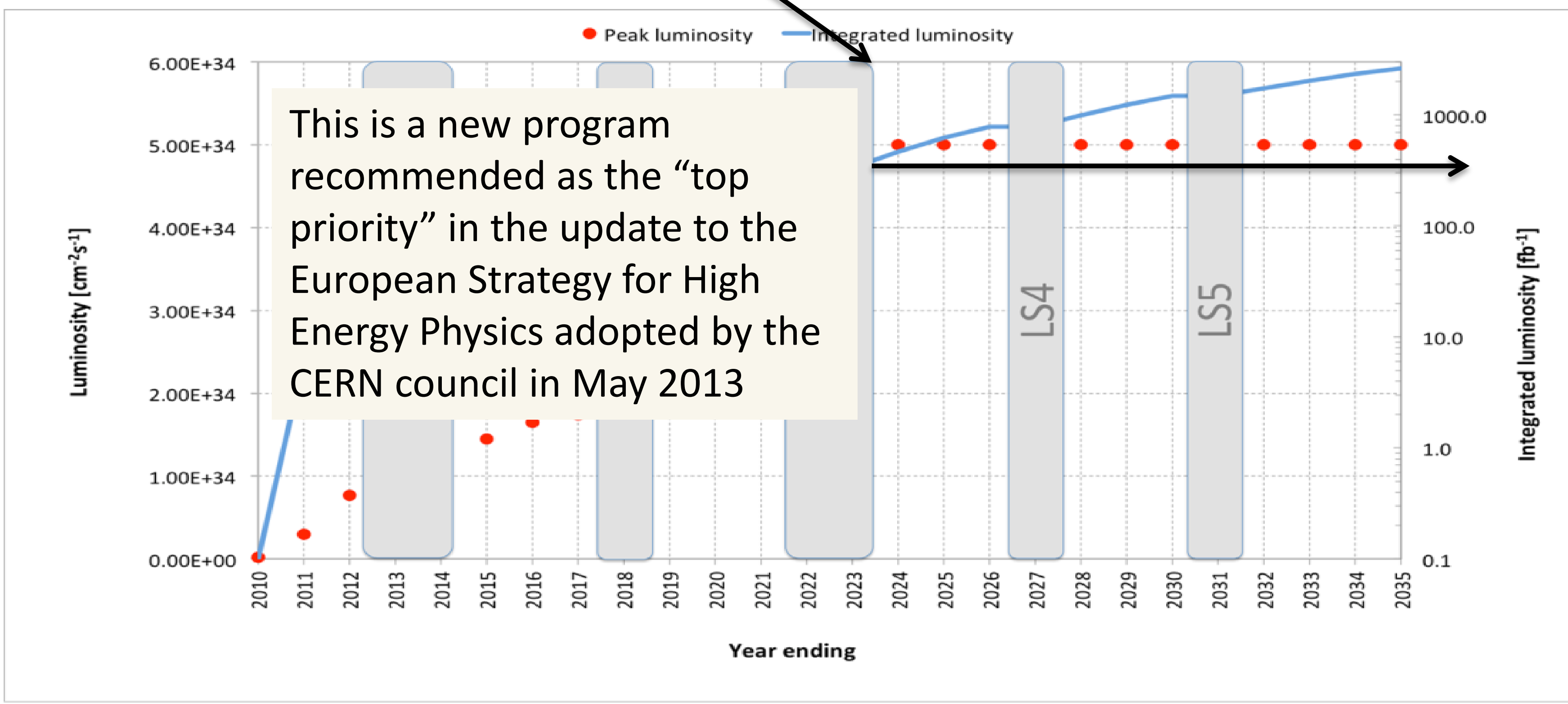


This is the original LHC program but with higher instantaneous luminosity

ATLAS & CMS Upgrade program: Phase 2 - HL-LHC

LS3:

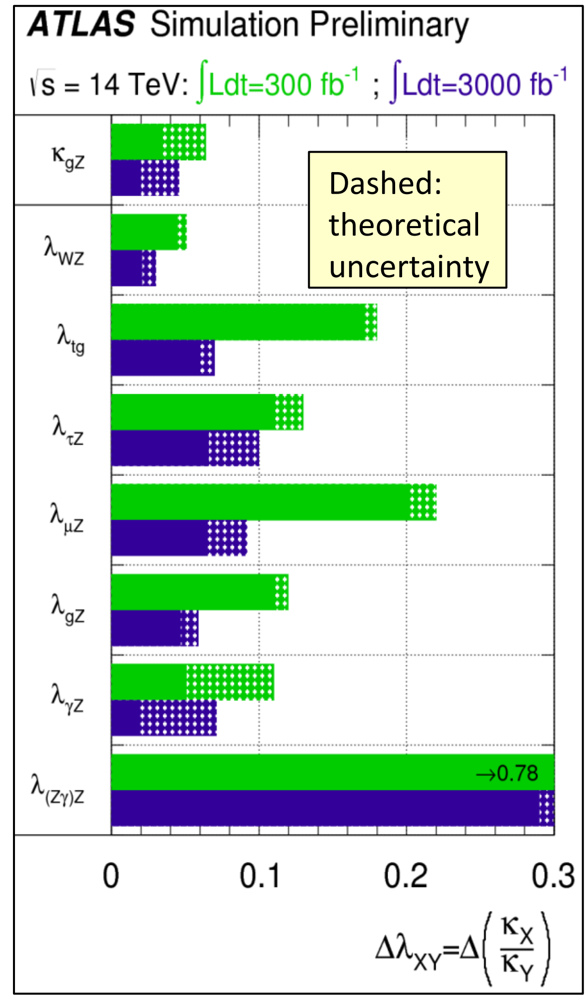
- Replace subsystems inoperable due to radiation damage or aging
- Prepare for 10 years of operation
- Maintain physics performance at least up to
  - ➢ 5 x 10^{34} Hz/cm^2 (with leveling), <PU> 125, ~ 3000 fb^{-1}



High luminosity program: Higgs couplings precision

HL-LHC (3000 fb^{-1}) > 170M Higgs events produced > 3M precise measurements

L(fb^{-1})	Exp.	$\kappa_g \cdot \kappa_Z / \kappa_H$	κ_γ/κ_Z	κ_W/κ_Z	κ_b/κ_Z	κ_τ/κ_Z	κ_Z/κ_g	κ_t/κ_g	κ_μ/κ_Z	$\kappa_{Z\gamma}/\kappa_Z$
300	ATLAS	[3,6]	[5,11]	[4,5]	N/a	[11,13]	[11,12]	[17,18]	[20,22]	[78,78]
	CMS	[4,6]	[5,8]	[4,7]	[8,11]	[6,9]	[6,9]	[13,14]	[22,23]	[40,42]
3000	ATLAS	[2,5]	[2,7]	[2,3]	N/a	[7,10]	[5,6]	[6,7]	[6,9]	[29,30]
	CMS	[2,5]	[2,5]	[2,3]	[3,5]	[2,4]	[3,5]	[6,8]	[7,8]	[12,12]



Range of coupling ratio precision (ECFA workshop Oct. 1-3) depending on progress of theory and systematic uncertainties

With 3000 fb^{-1}: typical precision 2-8% per experiment

→ ~ 2x better than with 300 fb^{-1}

Sensitivity to new physics scenarios with no new particles observable at LHC

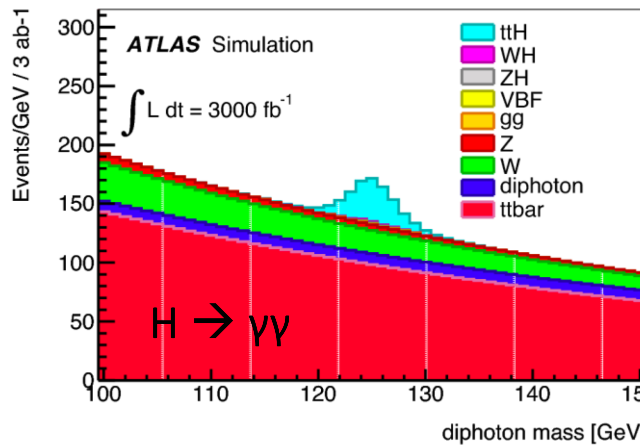
	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim -3\%$

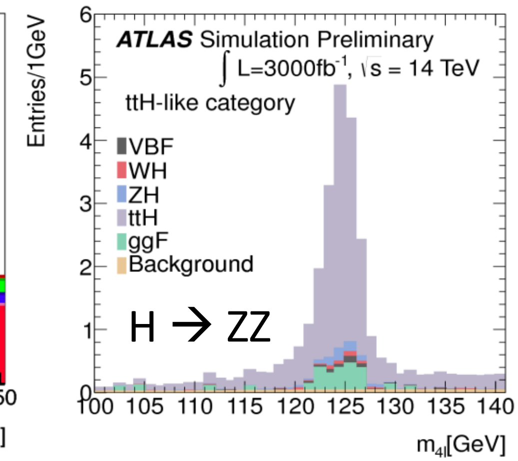
High luminosity program: Higgs rare processes/decays

ttH → γγ or ZZ

30 fb^{-1}: 6xSM cross-section

3000 fb^{-1}: expect 200 events > 5σ sensitivity - Higgs-top coupling can be measured to about 10%

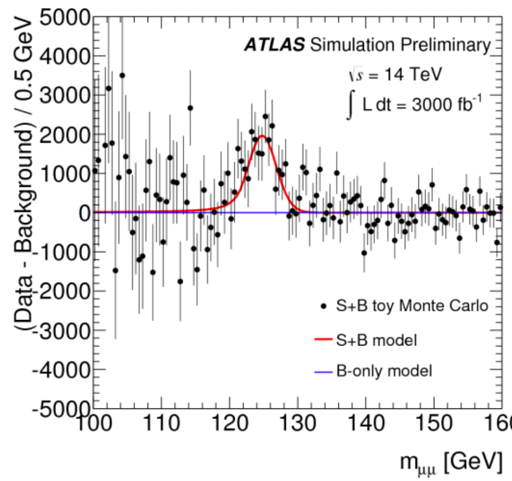


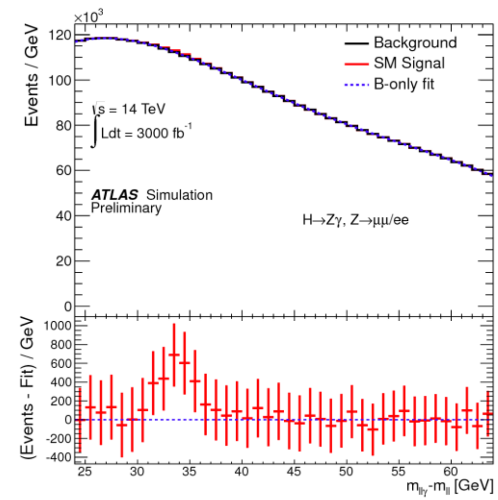


Signals only accessible with 3000 fb^{-1} with errors limited by statistics

H → μμ (coupling to fermions of second generation) ~ 10% precision on production

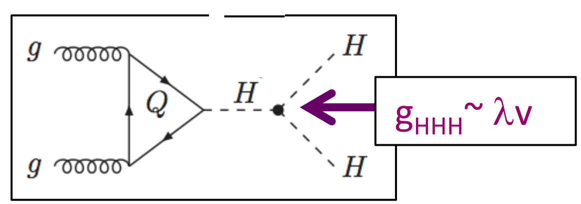
H → Zγ (compositeness) ~ 20% precision on production





HH production (probe Higgs potential)

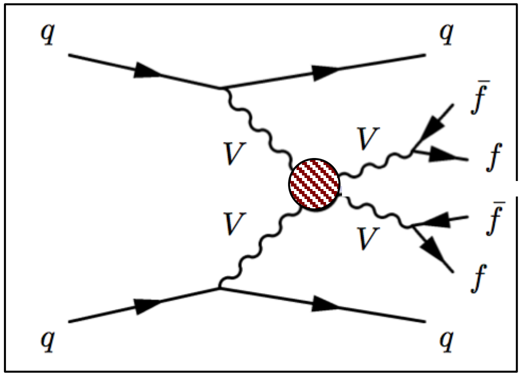
HH→bbγγ - HH→bbττ studies on going tens of events expected ~ 30% precision per experiment



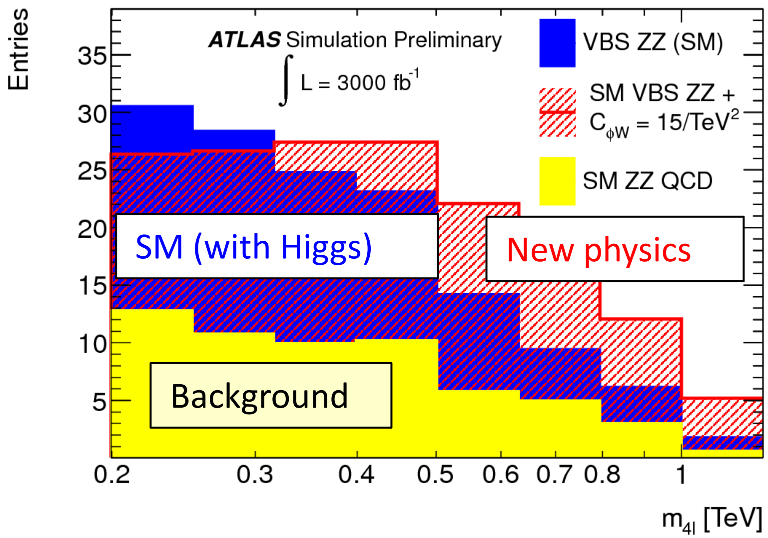
High luminosity program: Vector Boson Scattering

Vector Boson Scattering:

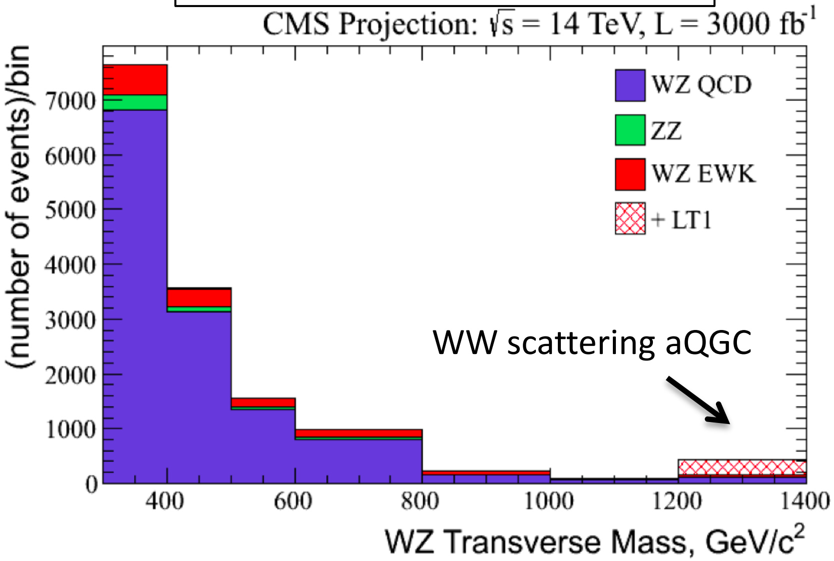
- Test of Higgs role in cancelling VBS divergence in SM can be measured to 30% (10%) with 300 (3000) fb^{-1}
- If new physics exists: sensitivity to anomalous triple or quartic coupling increases by factor of ~ 2 between 300 and 3000 fb^{-1}



VBS ZZ→ 4l

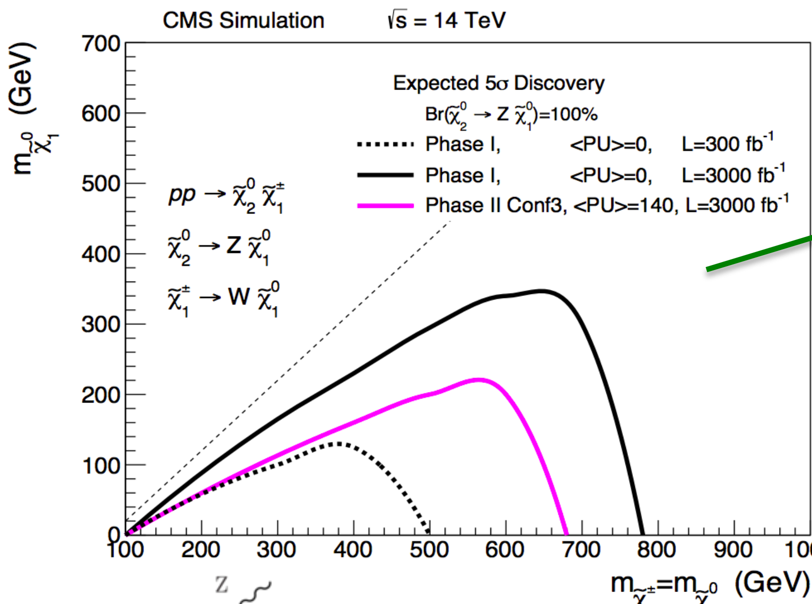


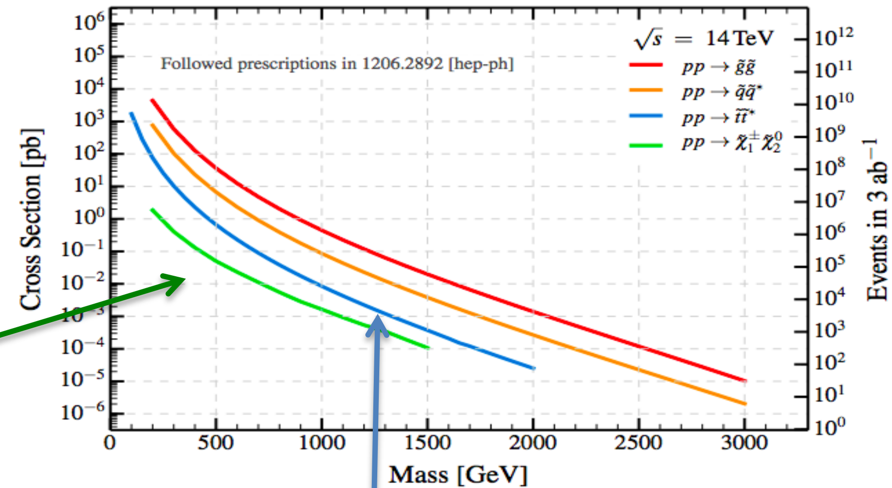
VBS WZ→ 3l + Etmiss

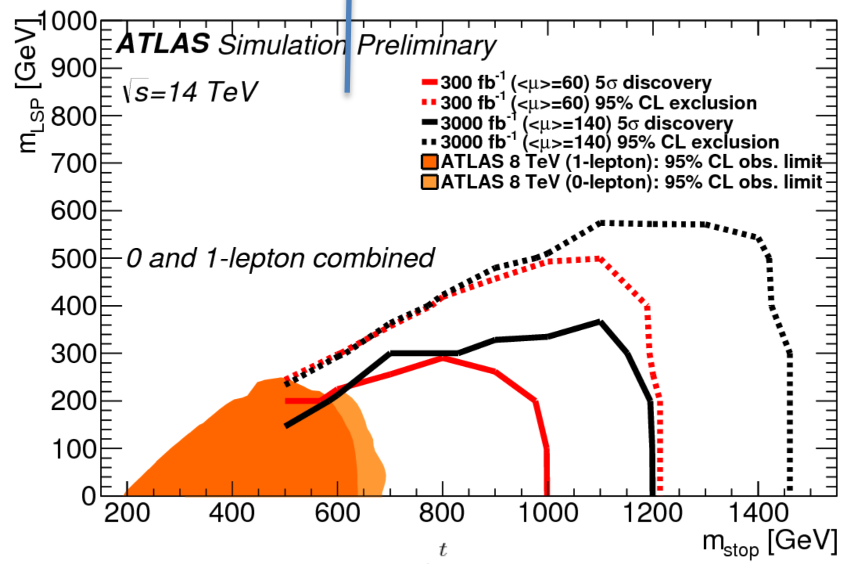


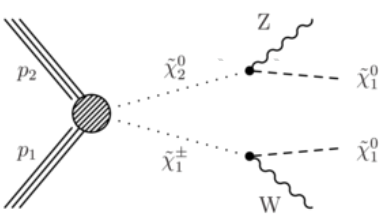
New physics: SUperSYmmetry at high luminosity

Stabilize Higgs mass - dark matter

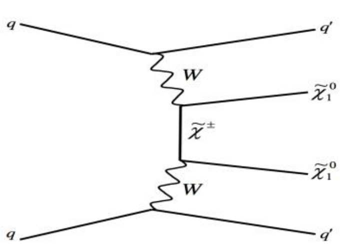




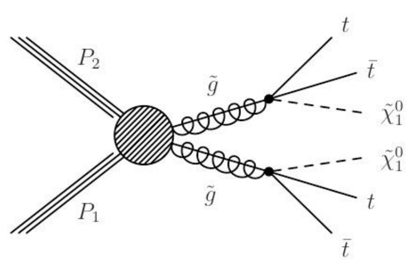




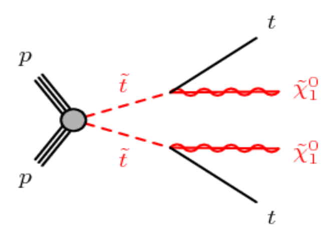
Direct chargino/neutralino



VBF Dark matter



Direct gluinos



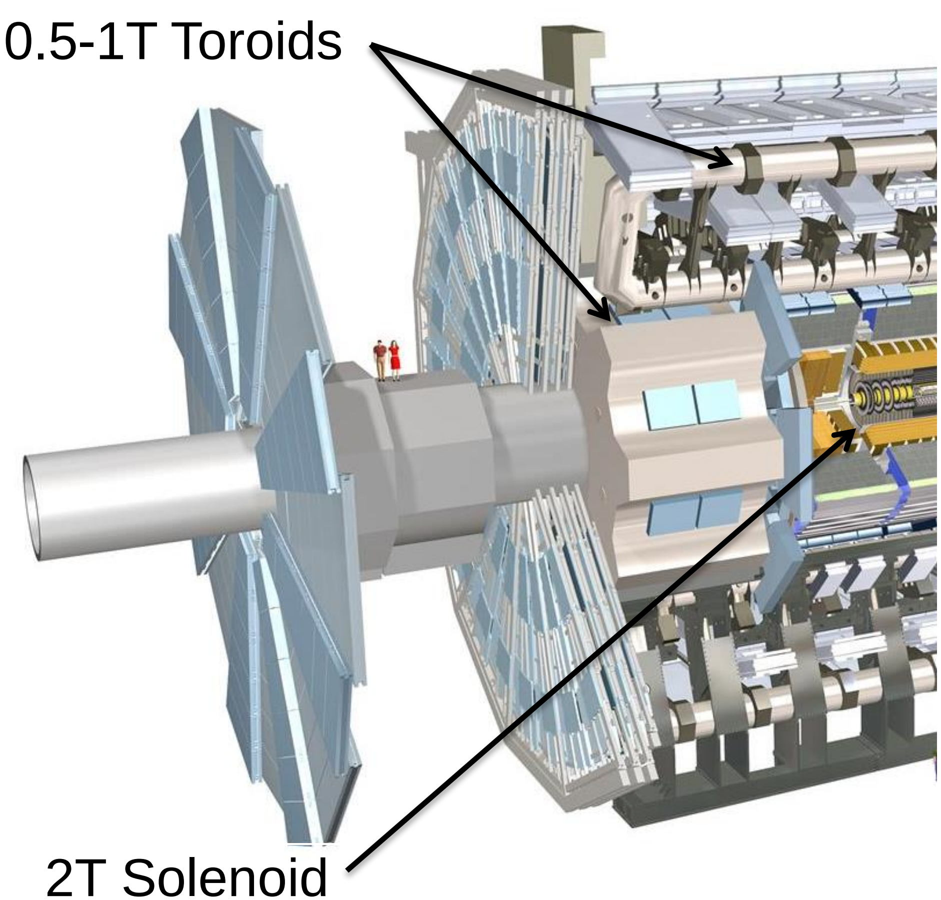
Direct stop

Outline

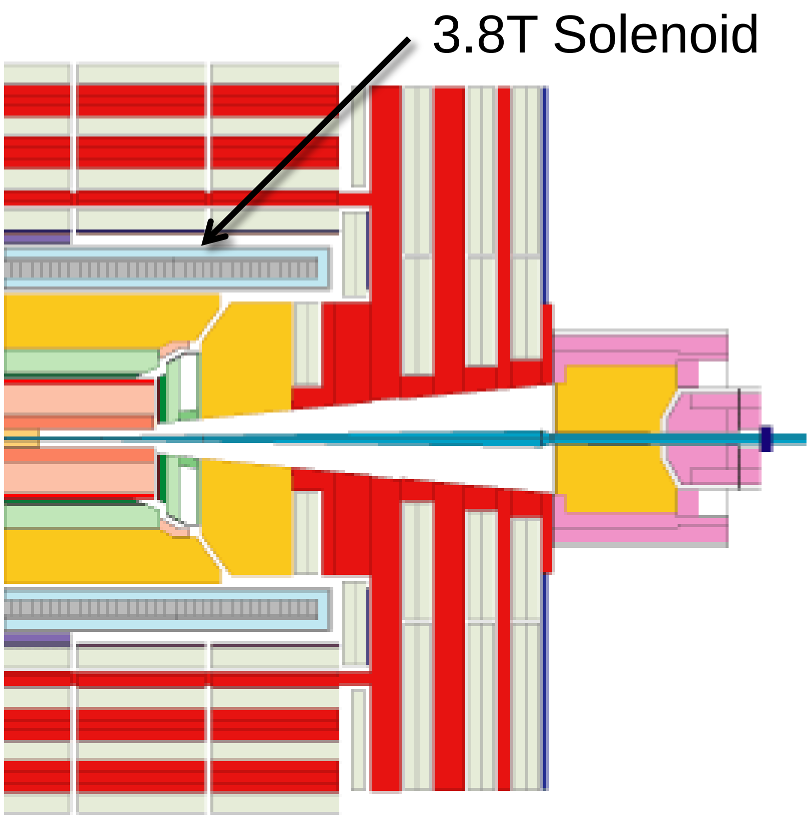
- First run at the LHC 2010 – 2012
- LHC Upgrade and physics goals
- ATLAS and CMS present detectors
  - Sub-systems
  - Challenges at high luminosity
- Detector Upgrades for Phase 1
- Detector Upgrades for Phase 2 - HL-LHC

The ATLAS and CMS Detectors today: Magnets

ATLAS (half)



CMS (half)

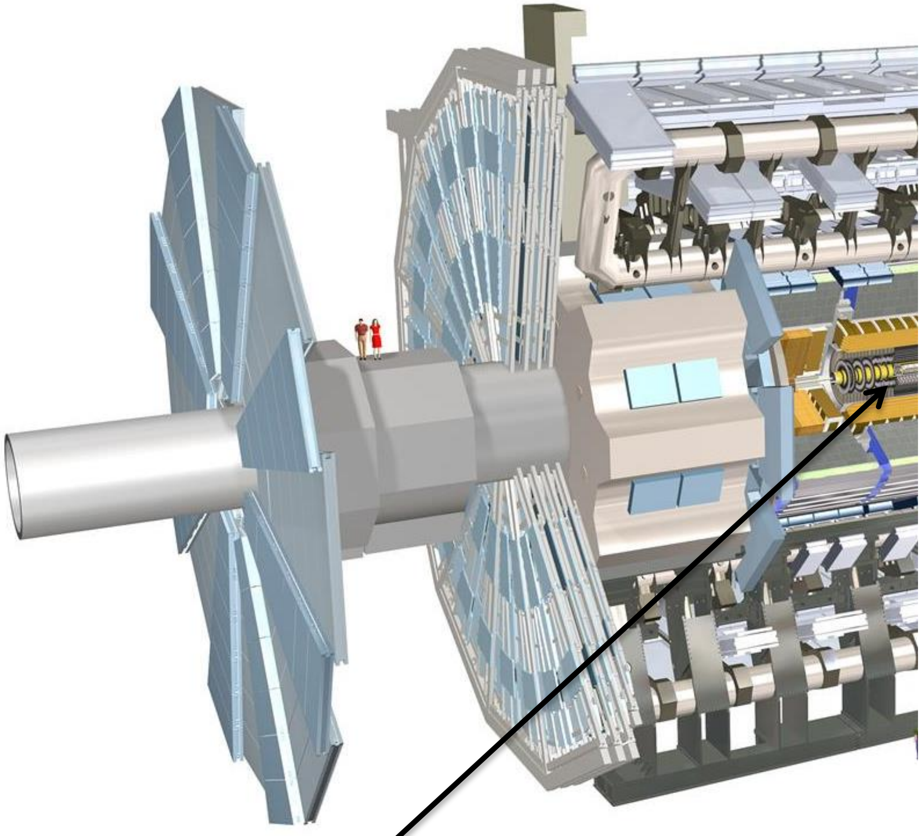


Total weight 7000 t
Overall diameter 25 m
Overall length 45 m

Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m

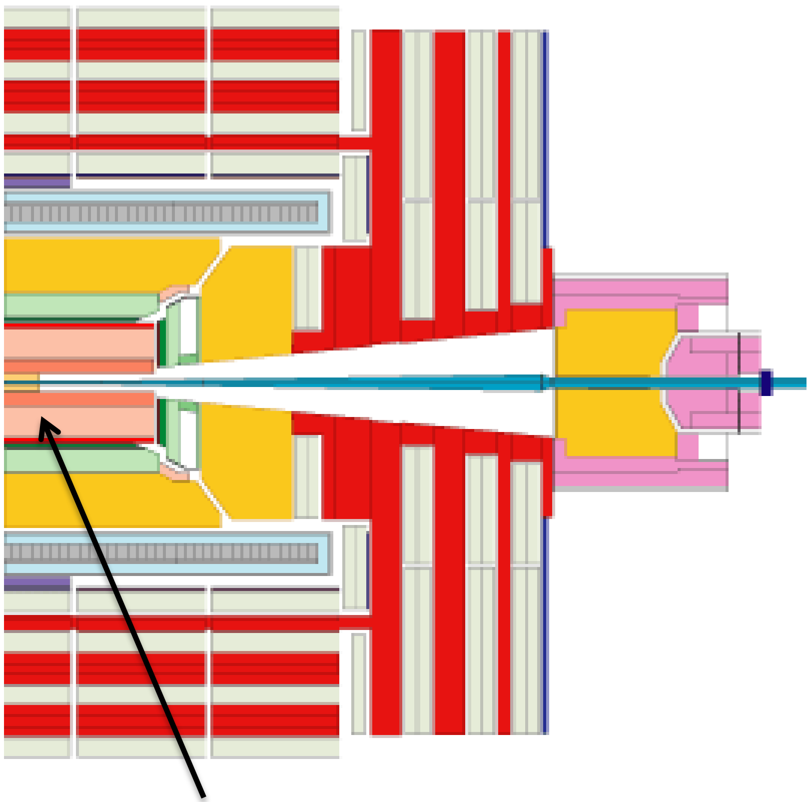
The ATLAS and CMS Detectors today: Tracker

ATLAS (half)



- Silicon Pixels 50 x 400 μm^2 ~ 1. m^2 ~ 80 Mch
- Silicon Strips (SCT) 80 µm ~ 60 m^2 ~ 6 Mch
- Transition Radiation Tracker (TRT)

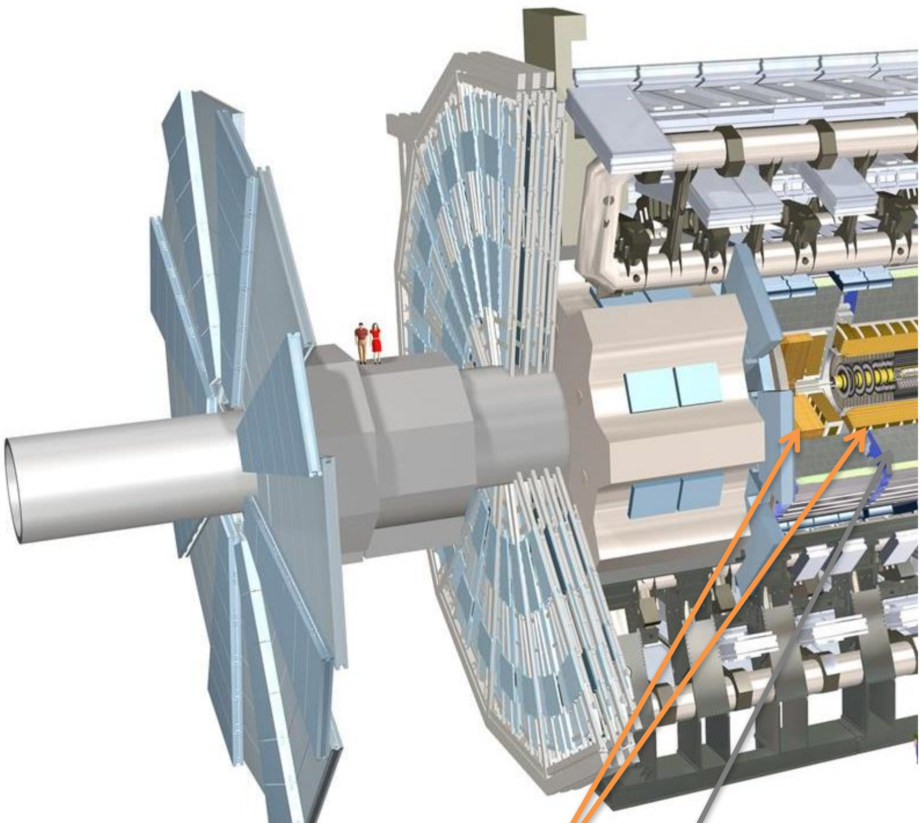
CMS (half)



- Pixels 100x150μm^2 ~ 1 m^2 ~ 66 Mch
- Strips 80-180 µm ~ 200 m^2 ~ 9.6 Mch

The ATLAS and CMS Detectors today: Calorimeters

ATLAS (half)



- Electromagnetic Calorimeter

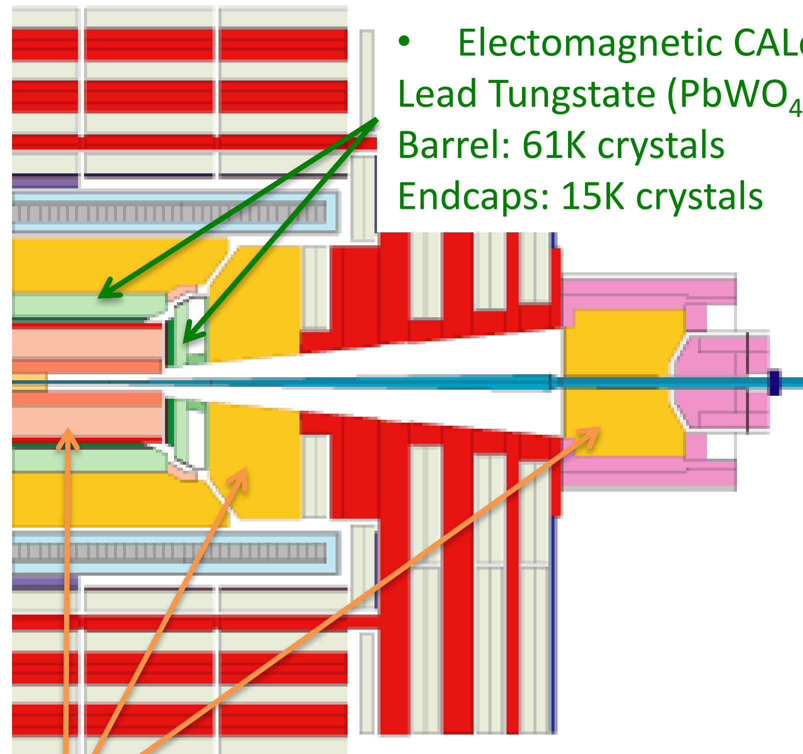
Liquid Ar (LAr) barrel and endcaps 110 kCh

- Hadronic Calorimeter

Barrel: Tile calorimeter (Iron/scintillator)

Endcaps LAr Hadronic

CMS (half)



- Electomagnetic CALo.

Lead Tungstate ($PbWO_4$)

Barrel: 61K crystals

Endcaps: 15K crystals

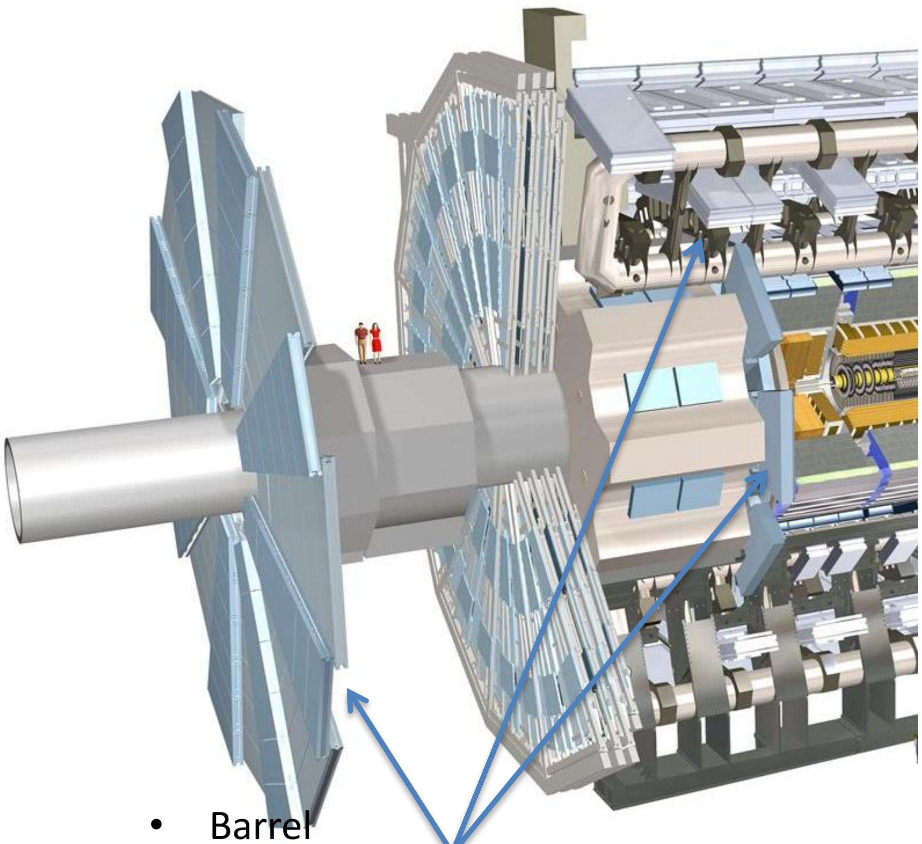
- Hadronic CALorimeter

Barrel and endcaps: Brass/Plastic scintillator tiles and WLS fiber 7kCh

HF: Steel/Quartz fiber Cerenkov calo. 2kCh

The ATLAS and CMS Detectors today: Muons

ATLAS (half)



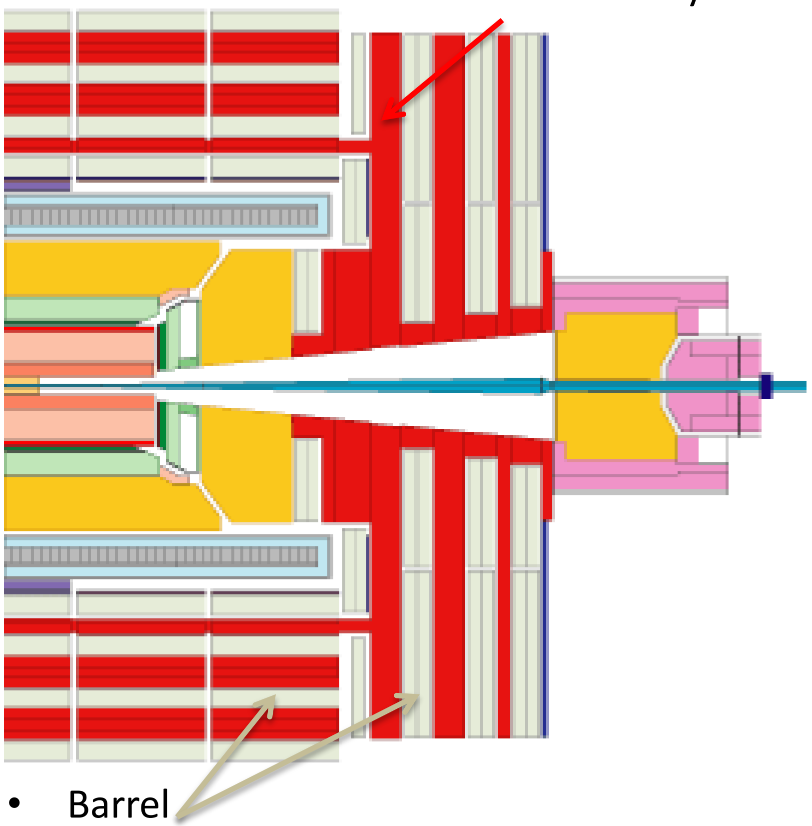
- Barrel

MDT (Muon drift tubes)
RPC (Resist. Plate Ch.)

- Endcaps

CSC (Cathode Strip Ch.)
TGC (Thin Gap Ch.)

CMS (half)



- Barrel

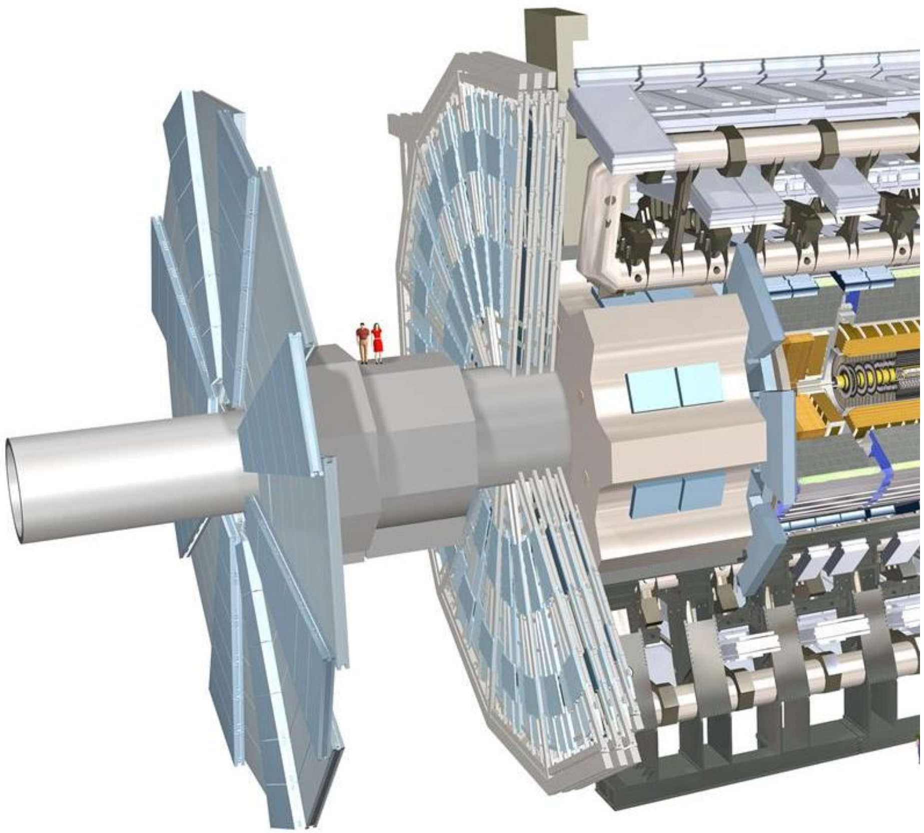
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)

- Endcaps

473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)

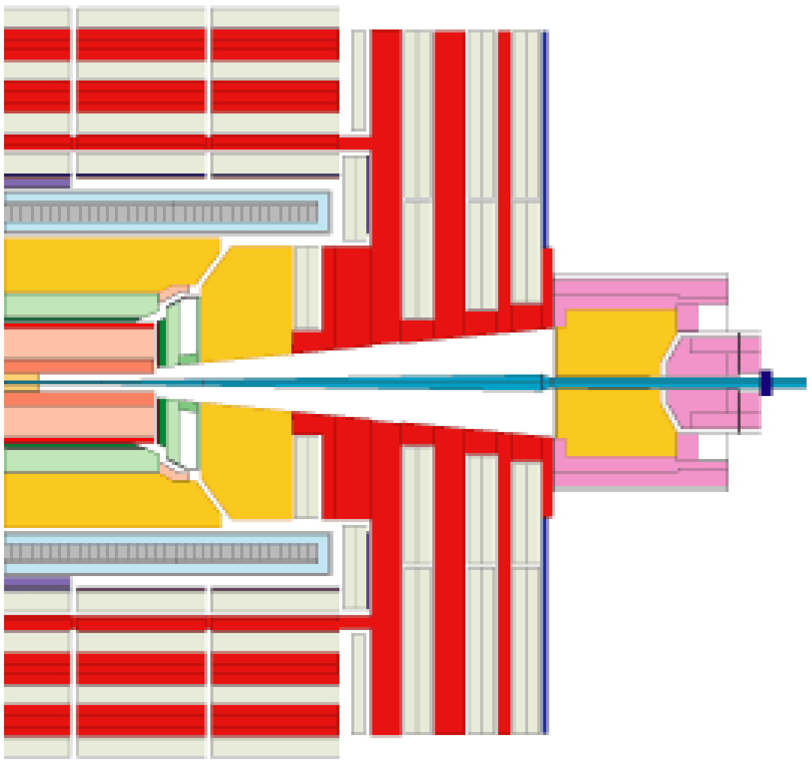
The ATLAS and CMS Detectors today: Trigger

ATLAS (half)

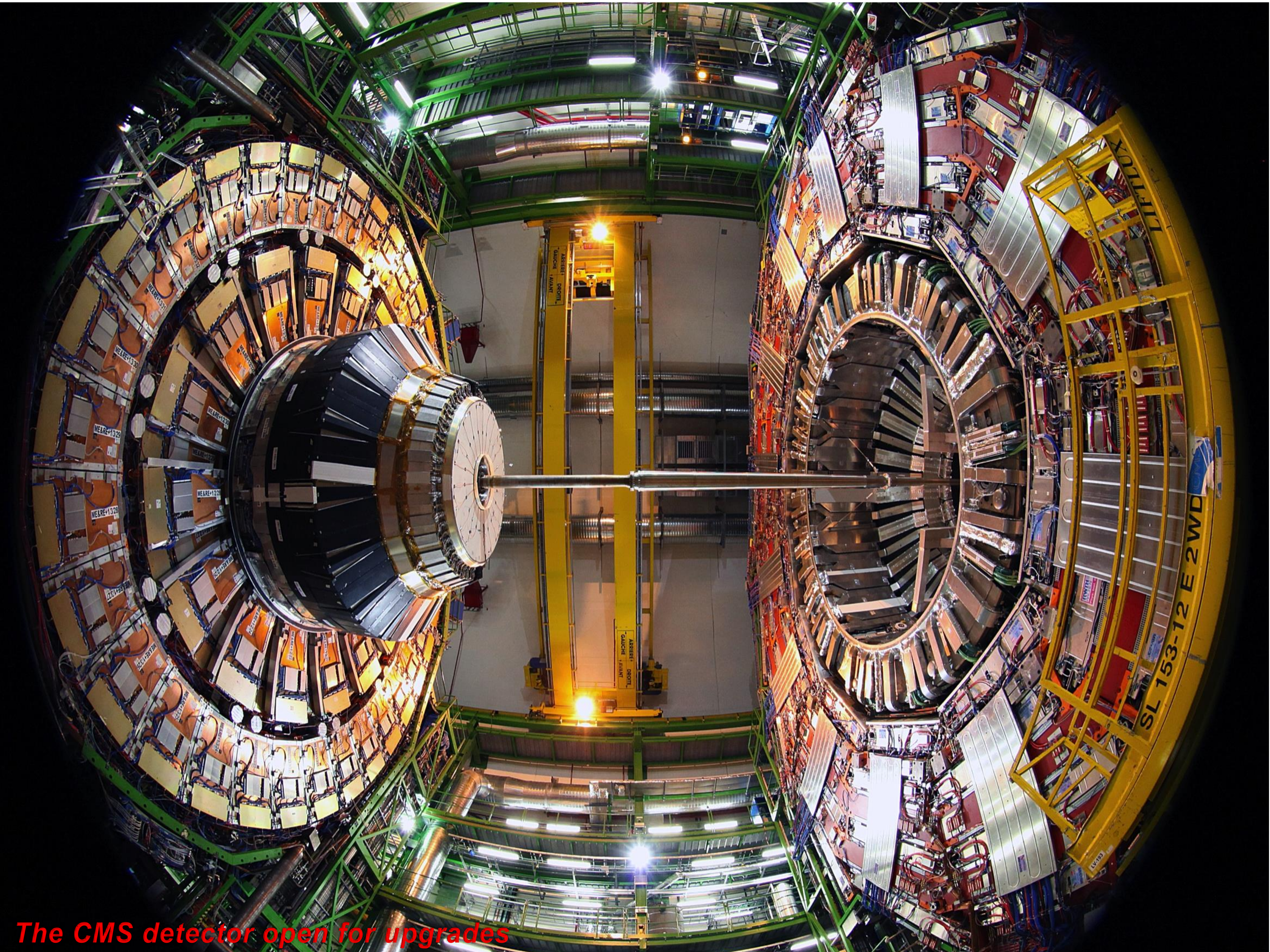


- Level 1 in hardware, < 2.5 µs, 100 kHz
  Calorimeter and Muon information
- HLT processor farm, 1 kHz:
  track reconstruction, proc. time: ~ 550 ms

CMS (half)

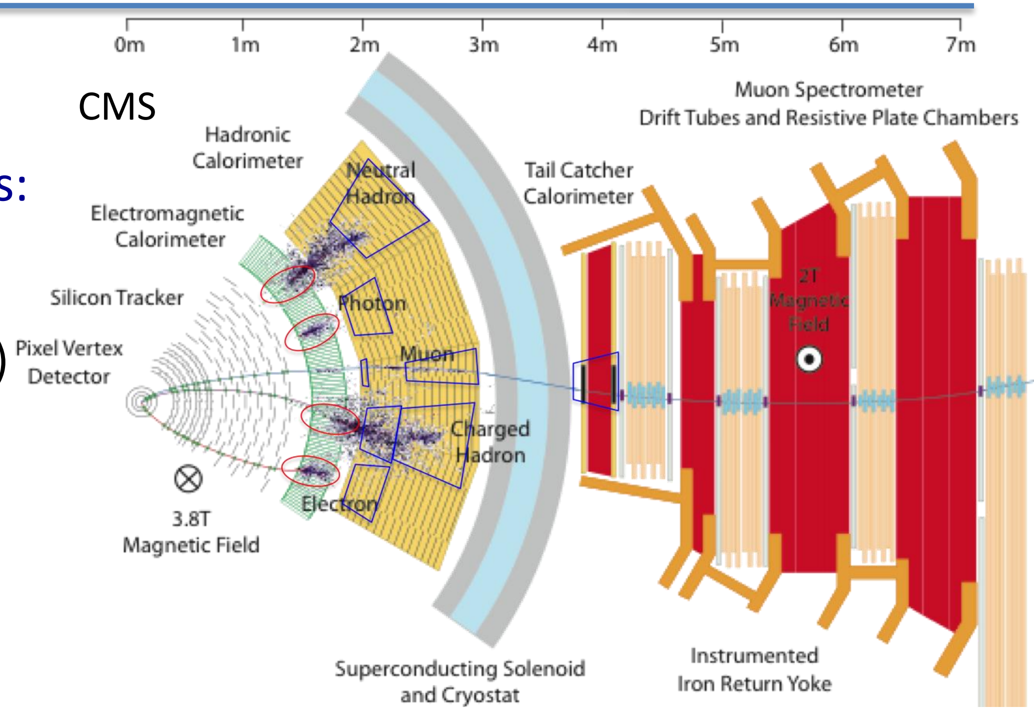


- Level 1 in hardware, 3.2µs latency ,100 kHz
  Calorimeter and Muon information
- HLT processor farm, 1 kHz:
  track reconstruction, proc. time: ~ 200 ms



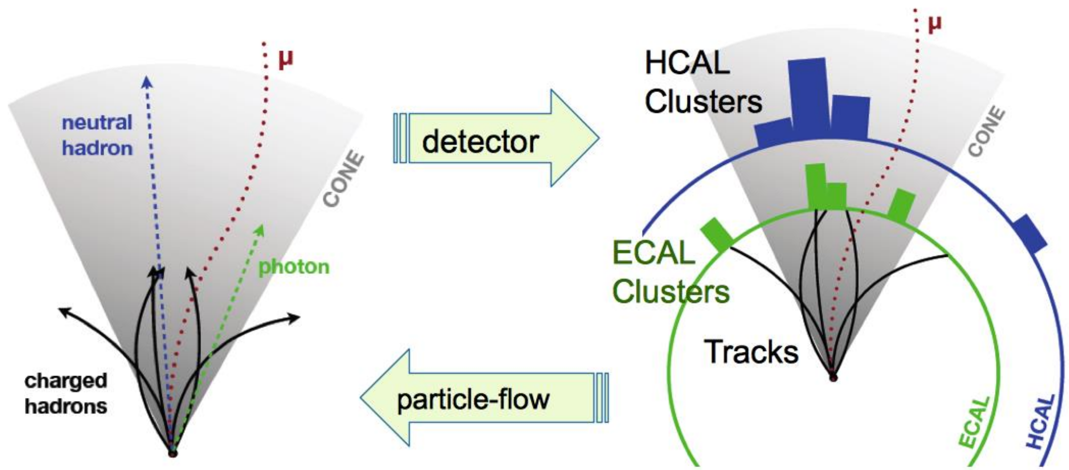
The CMS detector open for upgrades

From measurement to physics results

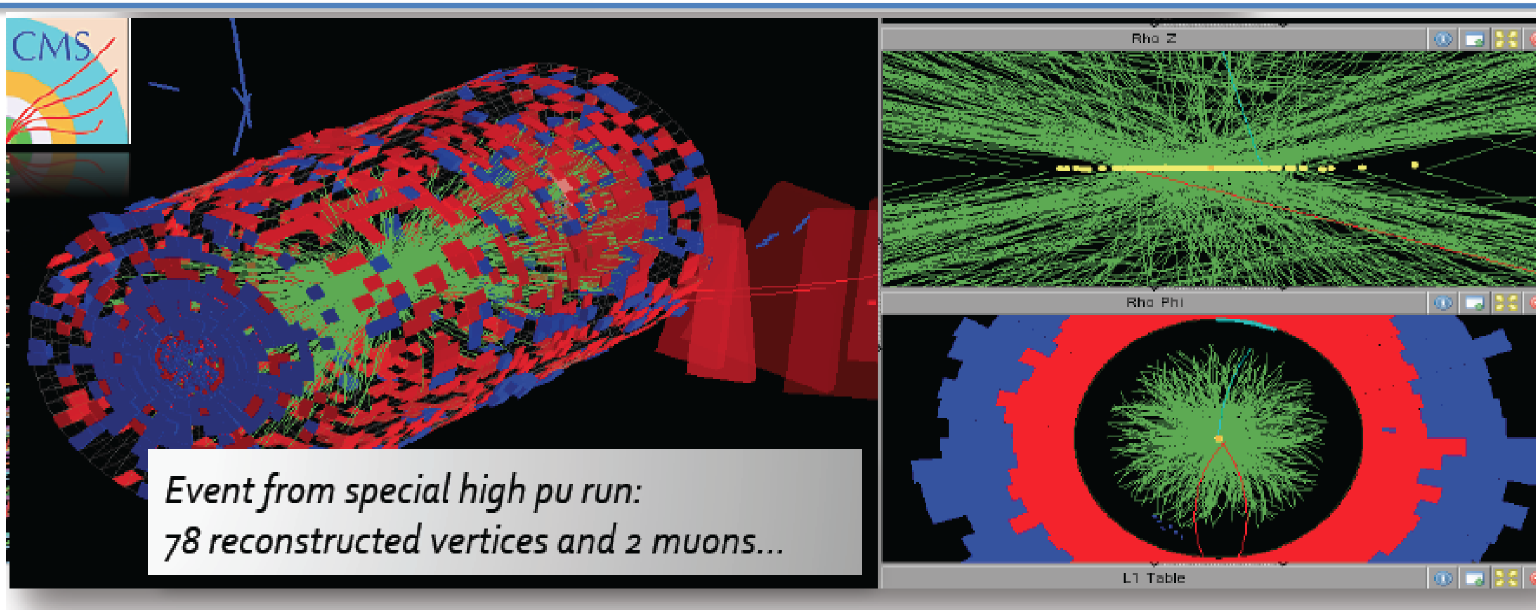


- Detector measures charge deposits:
  - Charged particles (tracker)
  - e/γ (electromagnetic calorimeter)
  - Hadrons π … (hadronic calorimeter)
  - μ (gas chambers)

- Sophisticated algorithms combine all information to reconstruct:
  - Physics objects
    - Identified and isolated particles
      - Jets - total and missing energy
  - Decay of fundamental particles
    - W, Z, H, t …
  - Correct apparatus effect with Monte-Carlo simulation



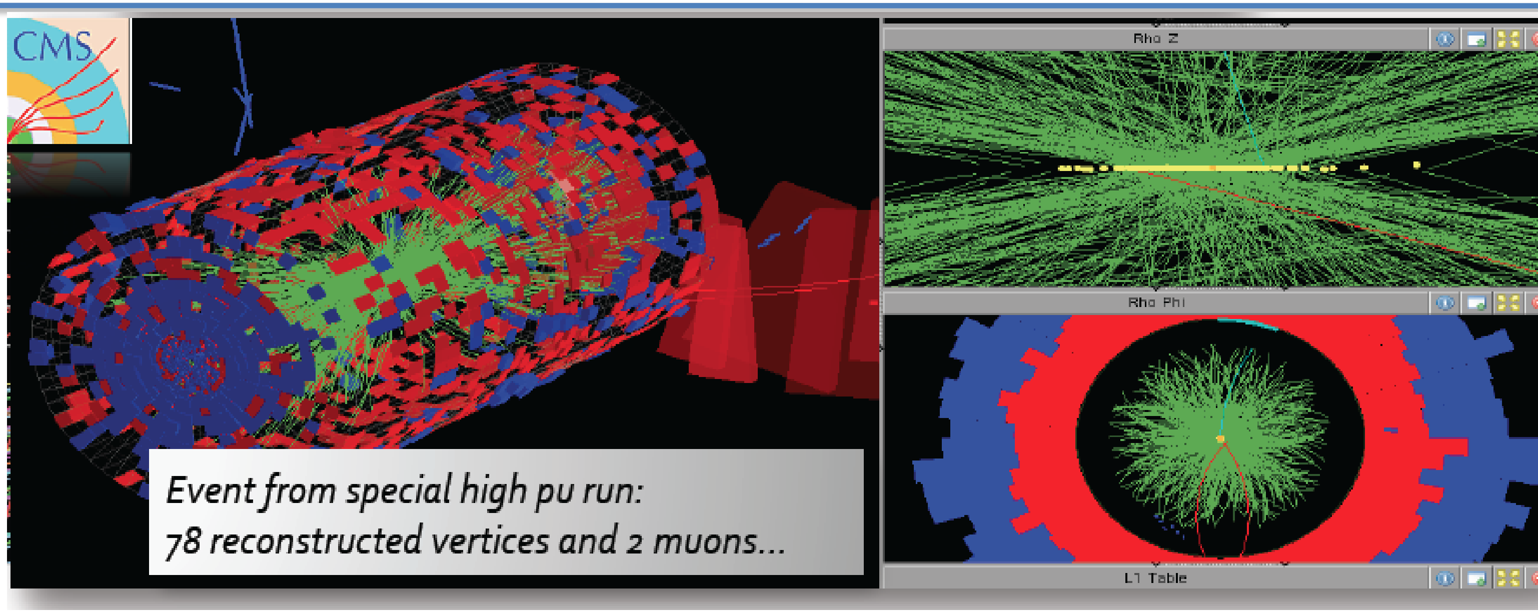
High luminosity: The experimental challenges



- Operational issues
  - Data volume increases - detector read-out bandwidth becomes insufficient
    → Loss of information
- Performance issues
  - Number of event passing selection for data acquisition increases
    → Need to raise threshold losing acceptance for physics
  - Occupancy increases and detector granularity becomes insufficient
    → Reconstruction efficiencies drop and fake rates increase
  - Assignment of particles to vertices degrades
    → Resolutions degrade and backgrounds increase

➢ Modify readout chain - mitigate PU effect with high tracking performance

High luminosity: The experimental challenges



- Operational issues
  - Data volume increases - detector read-out bandwidth becomes insufficient
    → Loss of information

Use new technologies (not available at construction time)

→ Increased processing power and high bandwidth links for data transfer (mostly commercial)

→ Develop radiation hard components (needs specific R&Ds)

  - Assignment of particles to vertices degrades
    → Resolutions degrade and backgrounds increase

➢ Modify readout chain - mitigate PU effect with high tracking performance

Outline

- First run at the LHC 2010 – 2012
- LHC Upgrade and physics goals
- ATLAS and CMS present detectors
- Detector Upgrades for Phase 1
  - Maintain performance up to PU 70
  - These upgrades are already at execution level
- Detector Upgrades for Phase 2 - HL-LHC

Link to LHCC documentation https://cds.cern.ch/collection/LHCC%20Public%20Documents?ln=en

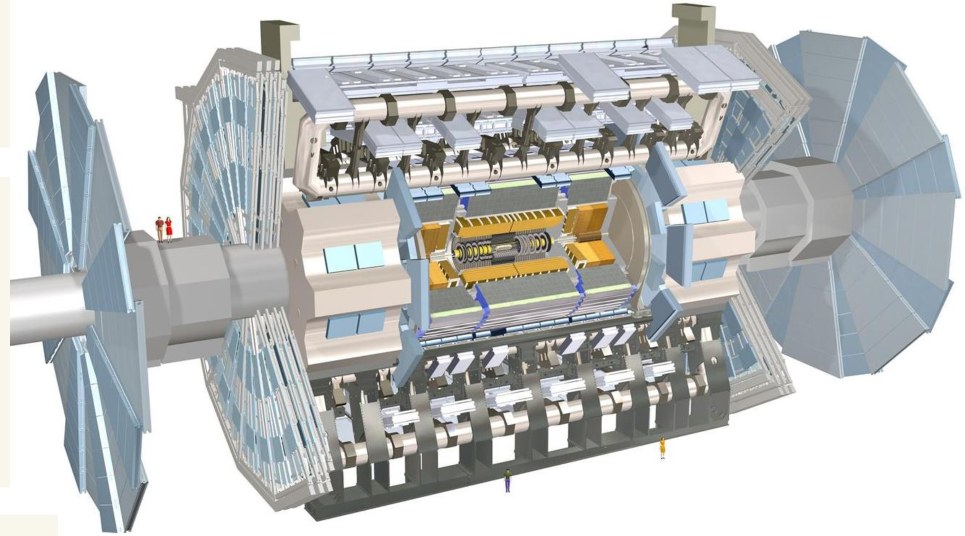
ATLAS and CMS upgrades: Phase 1

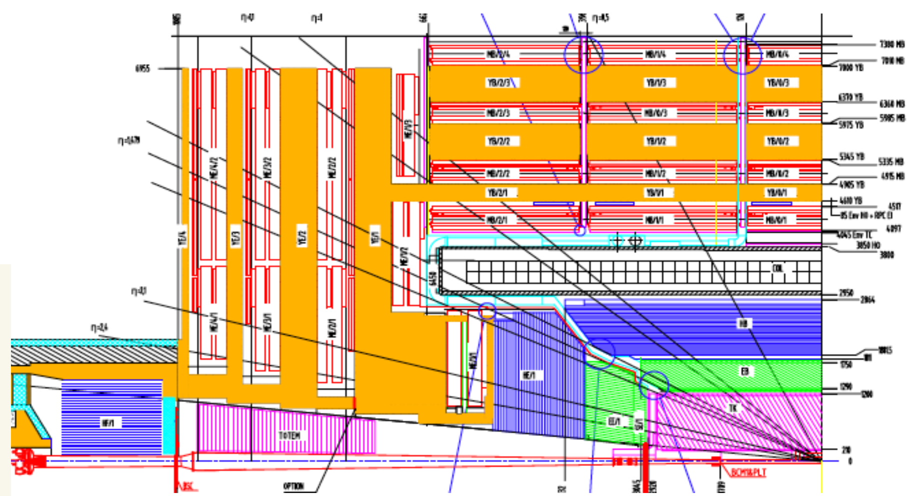
Pixel detectors : add 1 measurement point
ATLAS: Insertable Barrel Layer - 2015 (LS1)
CMS: Full replacement - end 2016

Calorimeters: increase granularity for trigger
ATLAS: new Front End in Liquid Argon (barrel & endcaps) - LS2 (2018)
CMS: New photo-detectors for HF/HE/HB (also anomalous signal) - From 2015 to LS2

Muon systems: complete coverage - improve forward resolution for trigger
ATLAS: coverage - 2015 New forward disks - LS2
CMS: Complete coverage of CSCs and RPCs
Increase CSC read-out granularity - 2015

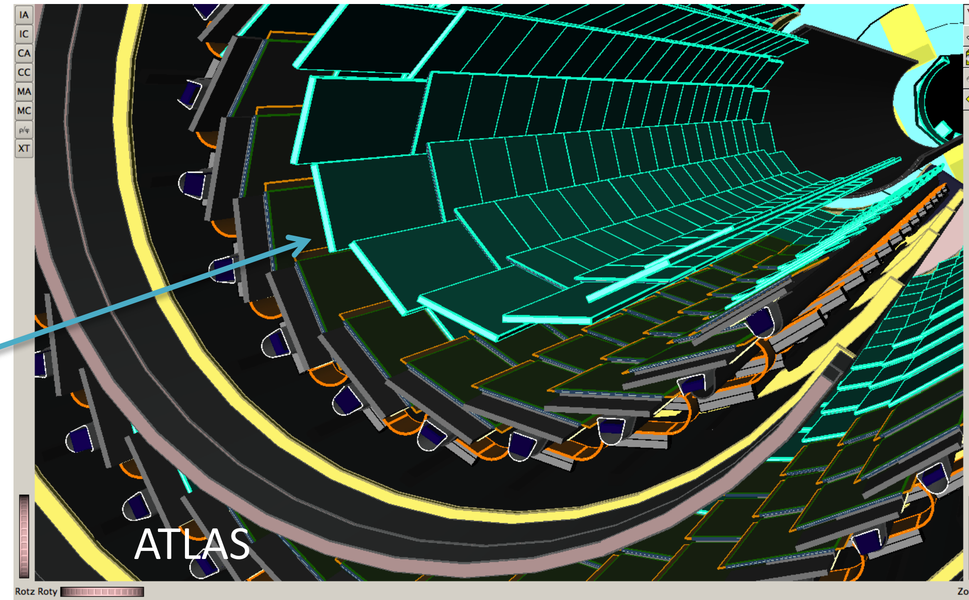
Trigger/DAQ: improve bandwidth & processing
ATLAS: New Back-End electronics - LS2
and Fast Track Trigger (FTK) input at High Level Trigger - before LS2
CMS: New Back-End electronics - end 2015





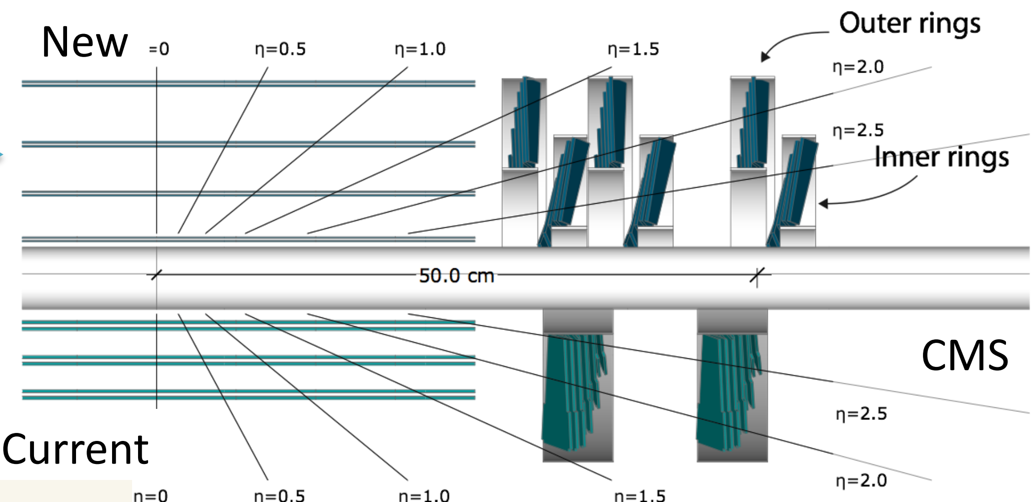
ATLAS and CMS Phase 1: Pixel detector designs

- Common ATLAS & CMS features
  - 4 space points over coverage acceptance (η = 2.5)
  - Smaller inner radius (3 cm)



- ATLAS Insertable Barrel Layer
  - Use planar at smaller eta and new 3D technology at higher eta (improved radiation hardness)

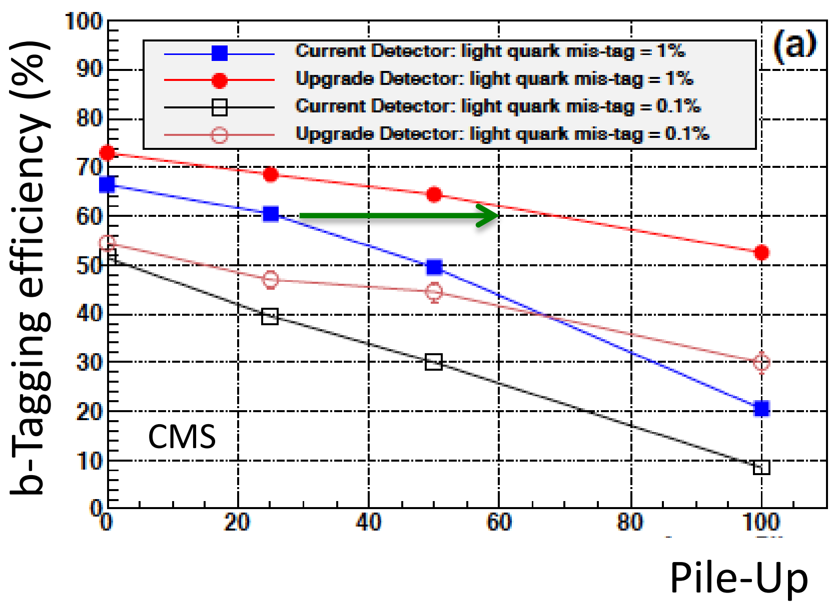
- CMS new detector
  - 1 additional layer and disk
  - Similar technology as present - inner layer (5%) will be exchanged after ~ 250 fb^{-1}
  - Lighter detector

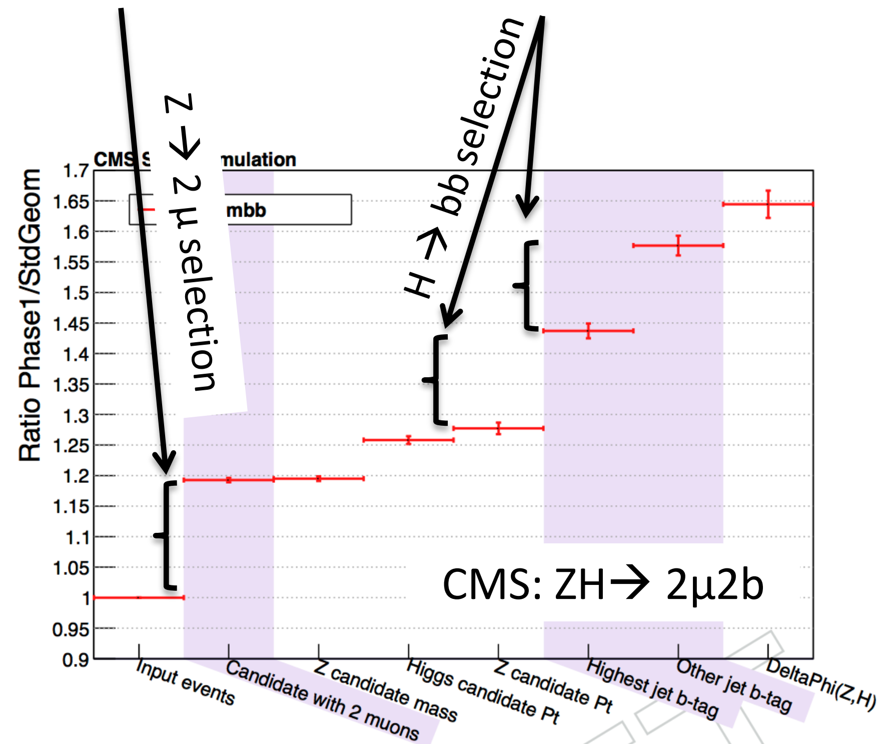


Significant DESY contribution to build layer 4

ATLAS and CMS Phase 1: Pixel detector performance

- Additional layer with smaller radius and lighter material
  - → Improves track reconstruction efficiency and resolution on origin
  - → Improves association of tracks at primary vertex and secondary vertices





Current performance is maintained up to ~ 70 PU

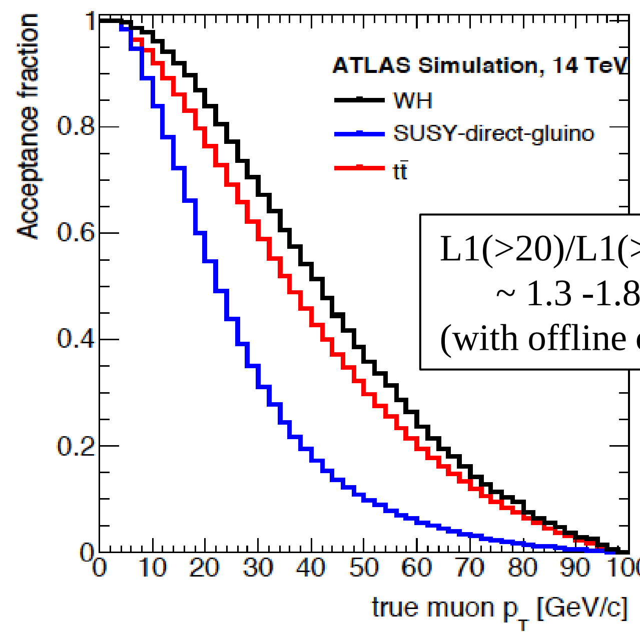
~ 65% gain in statistics

ATLAS and CMS Phase 1: L1-Trigger, hardware systems

- In Phase 1 ATLAS and CMS L1-Trigger bandwidth is limited to 100 kHz
- Hardware event selection is based on calorimeter and muon information
- Interactions rate is ~ GHz compared to mHz for Higgs - relatively low mass of Higgs or multiple decay of new particles implies low momentum in final states

CMS simplified menu	8 TeV 7E33 ~25 PU		14 TeV 2E34 50 PU	
	Thresh (GeV)	Rate (kHz)	Thresh (GeV)	Rate (kHz)
Single EG	22	10	46	10
Single IsoEG	18	9	31	9
DoubleEG	13, 7	9	22, 12	9
Single Muon	16	9	50	9
Dble Muon	10, open	5	35, open	5
EG+Mu	12, 3.5	3	21, 6	3
Mu+EG	12, 7	2	25, 15	2
SingleJet	128	2	188	2
DoubleJet	56	10	132	10
QuadJet	36	2	96	10
Double Tau	44	2	56	2
MET	36	7	84	7
HTT	150	2	511	2

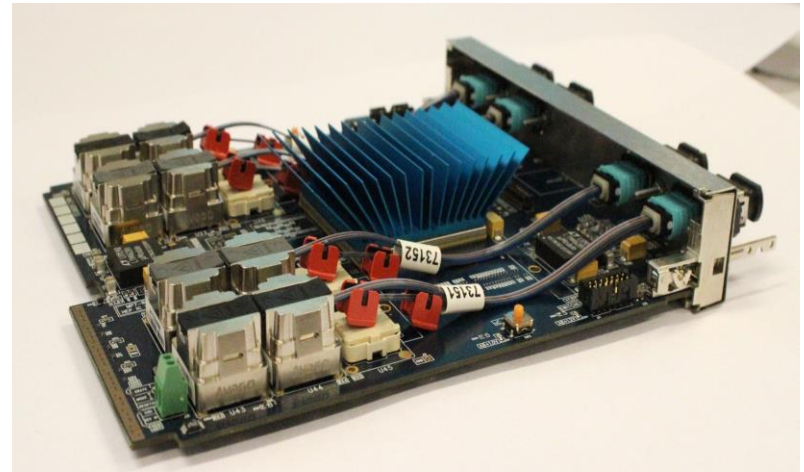
Threshold increase without upgrades will significantly limit physics acceptance



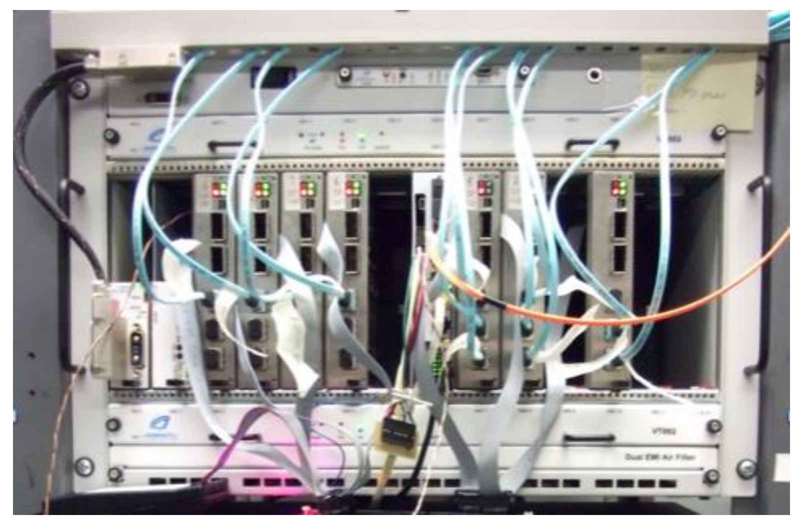
L1(>20)/L1(>30) ~ 1.3 -1.8 (with offline cuts)

ATLAS and CMS Phase 1: L1-Trigger, hardware systems

- Common ATLAS & CMS features
  - Higher bandwidth and processing power with modern FPGAs and high band width xTCA back-plan
    - Improved calorimeter and muon inputs
    - Improved algorithms ex. topological triggers (mass cut angular correlations…)



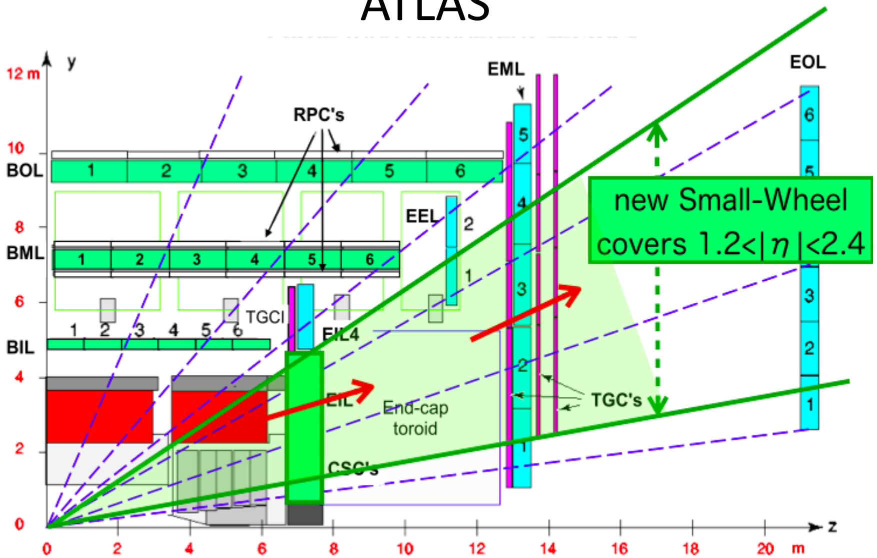
CMS: MP7 calorimeter trigger board & µTCA crate



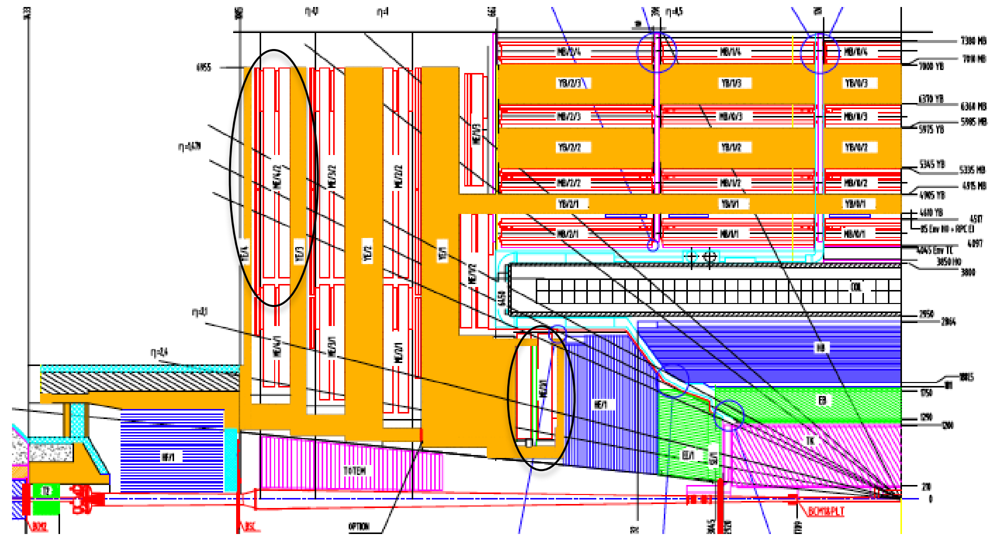
- ATLAS
  - Fats Track Trigger input at HLT
- CMS
  - New architecture (Time Multiplexed Trigger) with full event in 1 Processor

ATLAS and CMS Phase 1: Muon Trigger

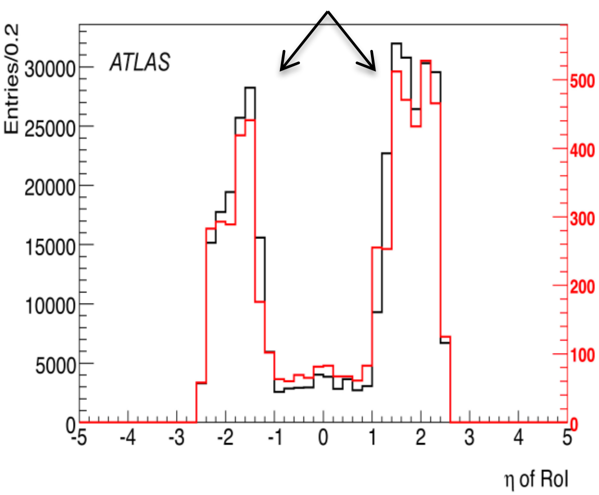
ATLAS

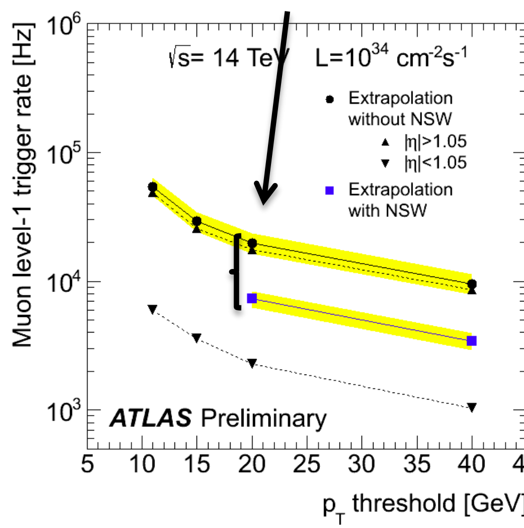


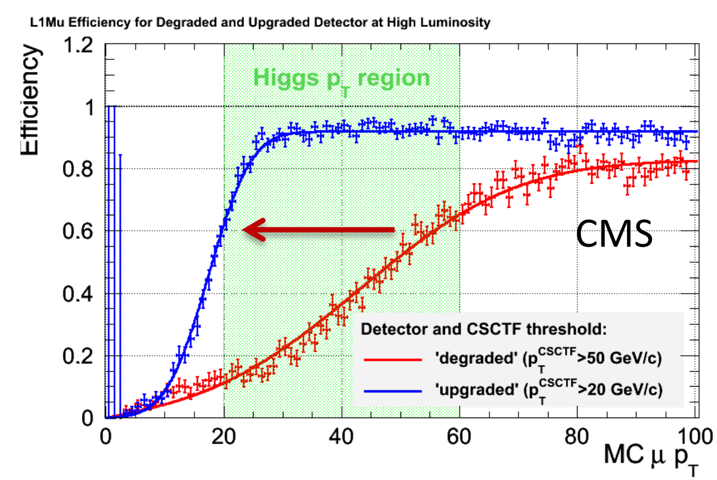
CMS



New chambers and electronics upgrades improves momentum resolution to reduce high trigger rates in endcaps regions by 1/3 → single μ threshold remains at ~ 20 GeV



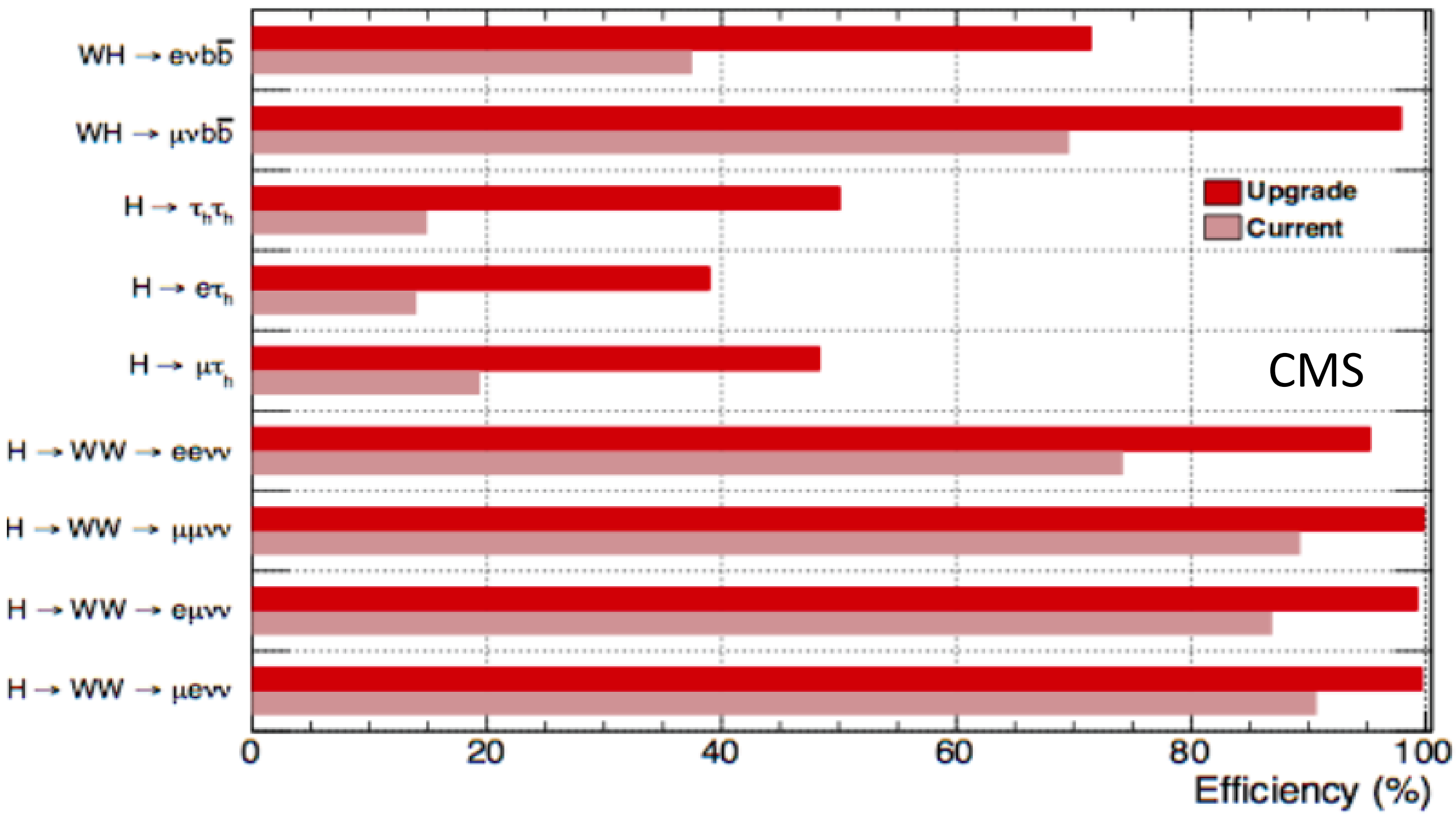




ATLAS and CMS Phase 1: Calorimeter Trigger

- Use of finer calorimeter granularity for more efficient identification algorithms
  - e and γ isolation with PU subtraction
  - Jet finding and Et missing with PU subtraction
  - Improved τ identification (small cone jets)
  - μ isolation

Overall benefit of Phase 1 trigger upgrades on key physics channels



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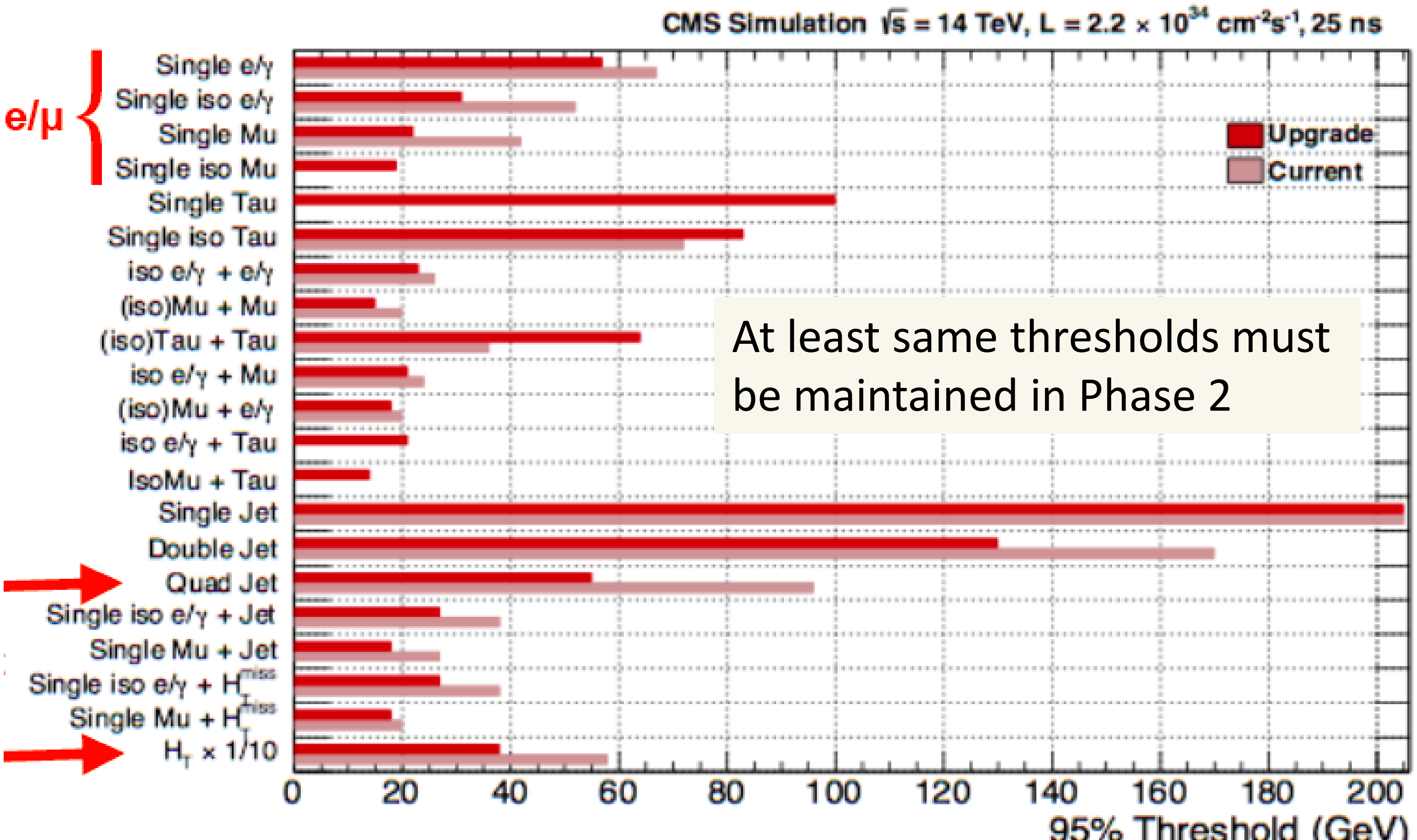


At least same thresholds must be maintained in Phase 2

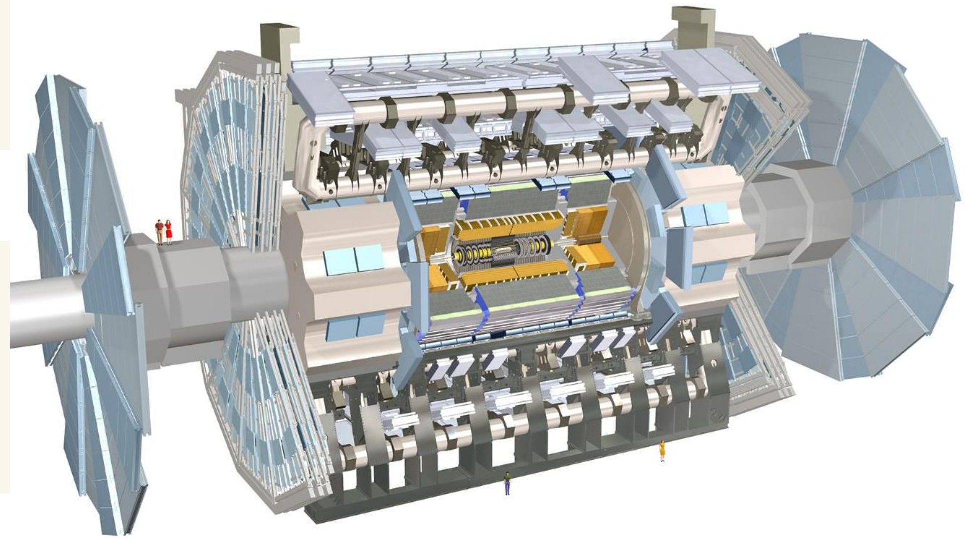
Outline

- First run at the LHC 2010 – 2012
- LHC Upgrade and physics goals
- ATLAS and CMS present detectors
- Detector Upgrades for Phase 1
- Detector Upgrades for Phase 2 - HL-LHC
  - Replace detectors that will not survive radiations
  - Mitigate PU effect - critical since it limits ability to benefit from high luminosity
  - Maintain improve physics acceptance to measure the very rare processes - trigger and coverage acceptance are critical
  - These upgrades are at conceptual design and R&D level

Link to LHCC documentation https://cds.cern.ch/colle&tion/LHCC%20Public%20Documents?ln=en

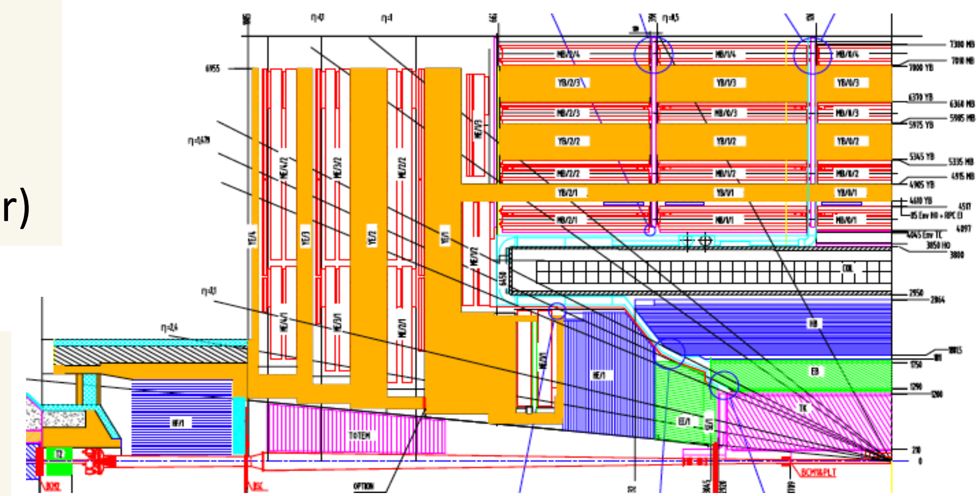
ATLAS & CMS Upgrade program: Phase 2 - HL-LHC

Tracker replacement both in ATLAS and CMS:
Radiation tolerant - higher granularity
Extended coverage in forward region



Calorimeters:
ATLAS: new FE electronics for all calo. trigger
CMS: replace full endcaps (longevity) - and FE electronics in ECAL barrel for trigger

Muon systems
ATLAS: new FE electronics for trigger
CMS: new chambers in forward - new FE electronics in DT chambers (longevity & trigger)

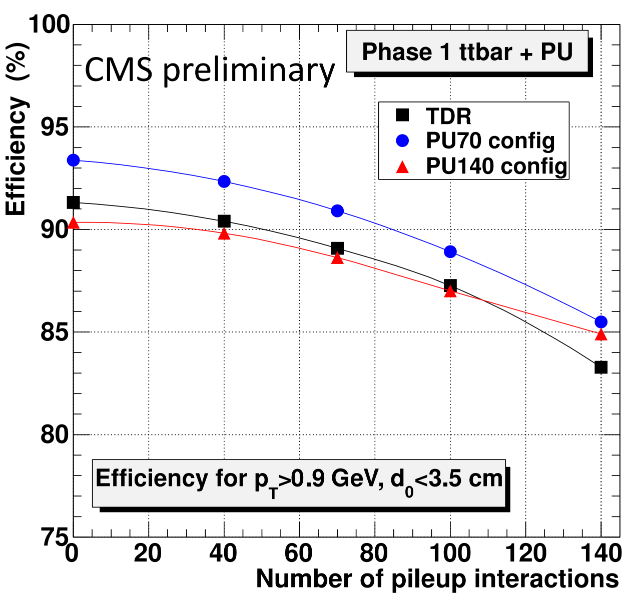


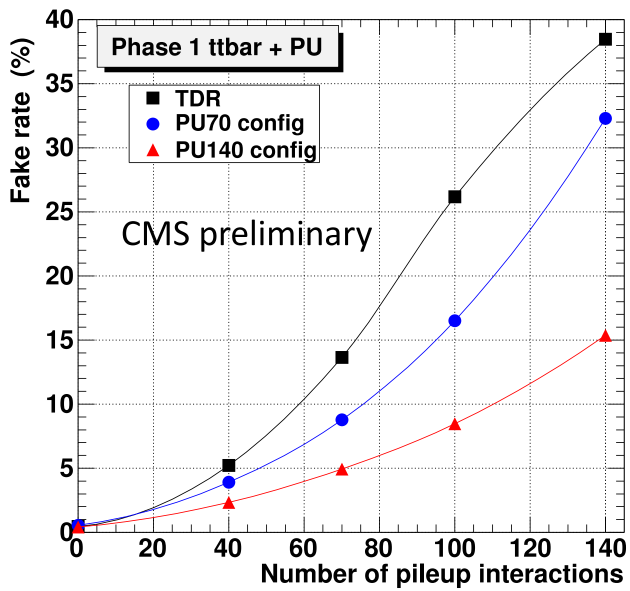
Trigger/DAQ both ATLAS and CMS:
Add tracking at Level 1, hardware
New BE electronics

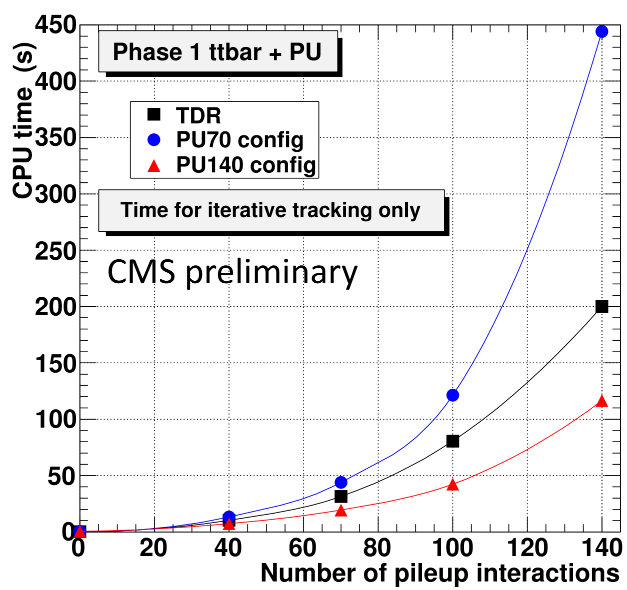
ATLAS and CMS Phase 2: Tracker replacement

- Present detectors not designed for the higher trigger rate and <PU> and will become inoperable beyond 500 fb^{-1} due to radiation damage
- At 140 PU Phase 1 track reconstruction performance degrades significantly
  - Efficiency drops while fake rate increases - despite tuning and improvements in reconstruction algorithms

→ Higher granularity for efficient track reconstruction is needed with goal for performance at 200 PU - processing needs improvements





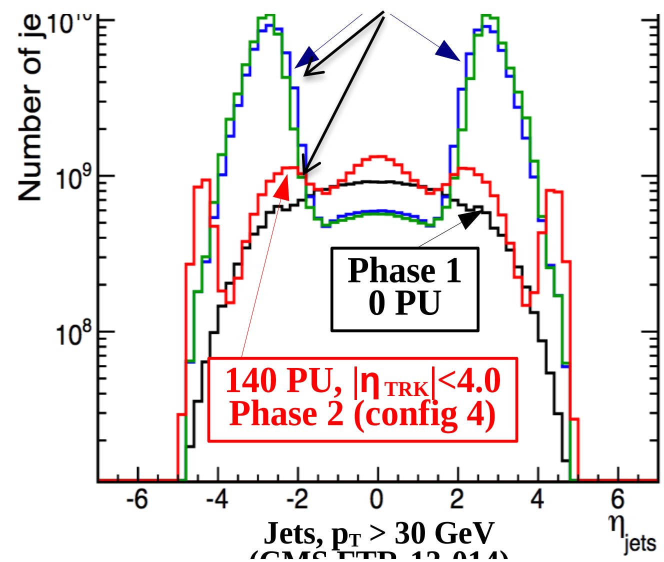


ATLAS and CMS Phase 2: Tracker designs

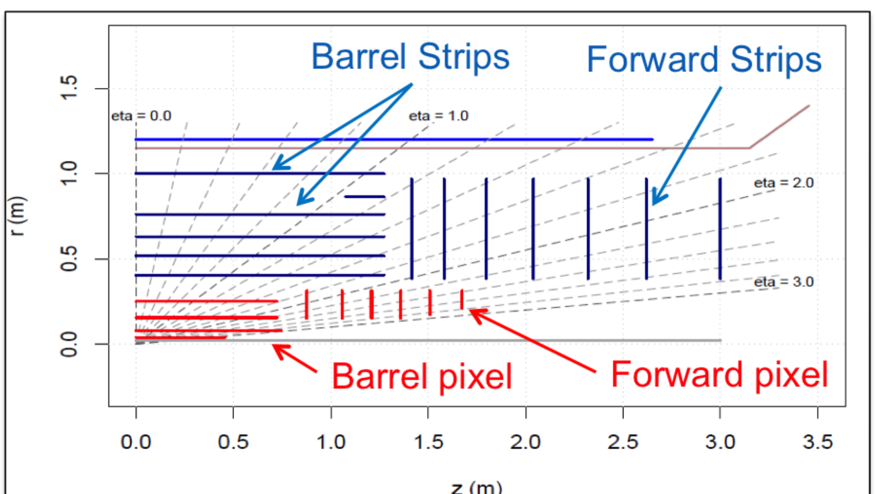
- Different configurations
  - CMS module concept to select tracks of Pt≥2GeV for trigger readout at 40 MHz
  - ATLAS read-out tracker region of interest at ≥ 500 kHz for trigger
- Proposal to extend Pixel coverage up to |η|~ 4
  - Associate jets to tracks and then vertex to mitigate pile-up effect

    → VBF Higgs - BSM dark mater & VBS

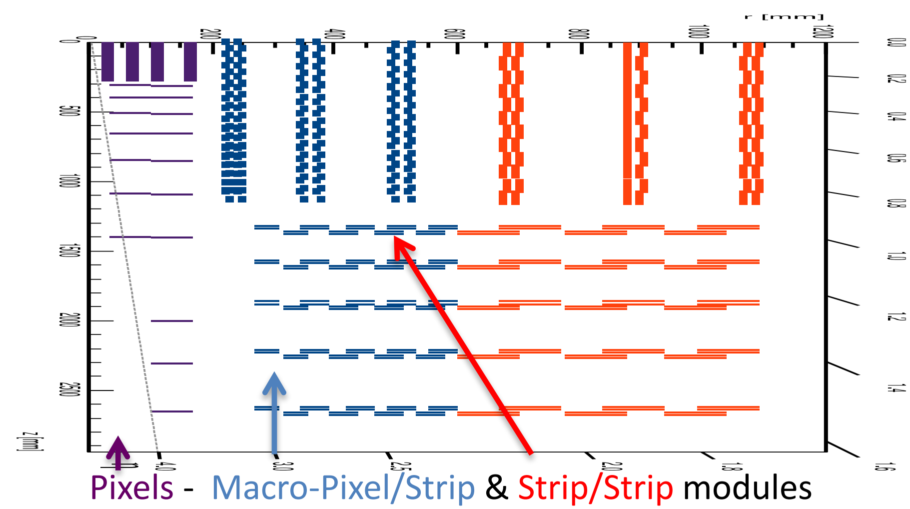
Jet rate with & without pixel coverage extension at 140 PU



ATLAS design



CMS design

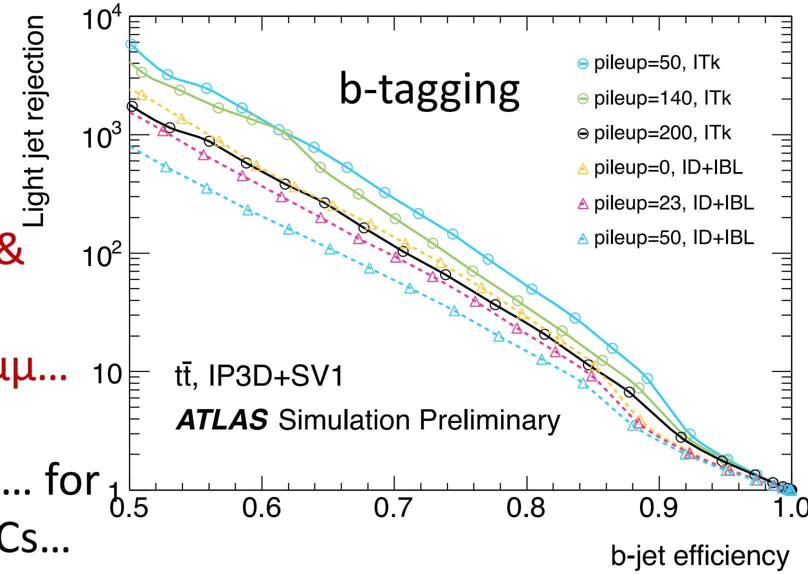


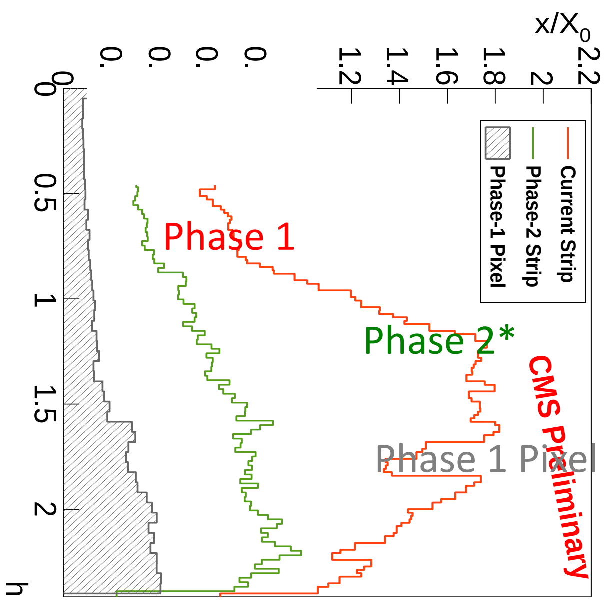
ATLAS and CMS Phase 2: Tracker features

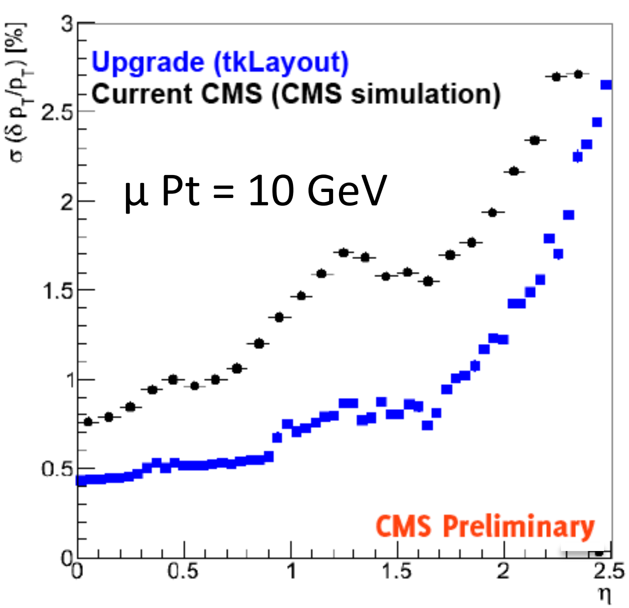
- Granularity
  - Strip pitch ~ 80-90 µm & length ~ 2.5 to 5 cm
  - Pixel pitch ~ 25-30 µm and ~ 100 µm length
- Lighter materials

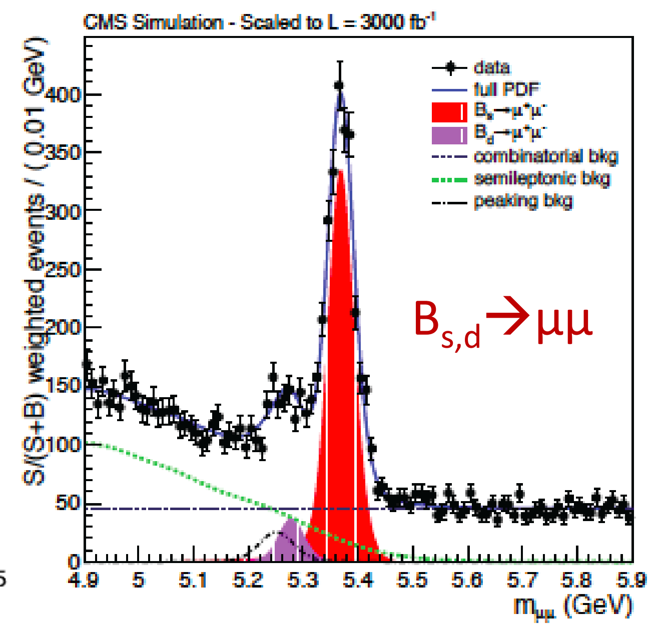
→ Improved vertex association: mitigate pile-up effect & improve b-tagging - improved track Pt resolution & reduce rate of γ conversion ex. HH→bbγγ - $B_{s,d}$→µµ…

- Sensor and electronics Technology R&Ds
  - n-in-p planar for outer layers - n-in-n, 3D, diamond… for innermost layers - thin 100 µm - 65nm process ASICs…





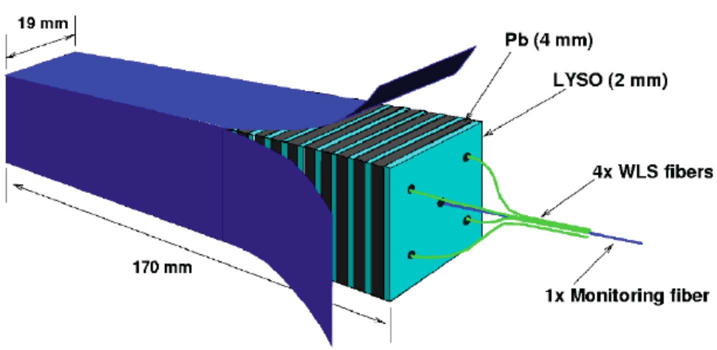




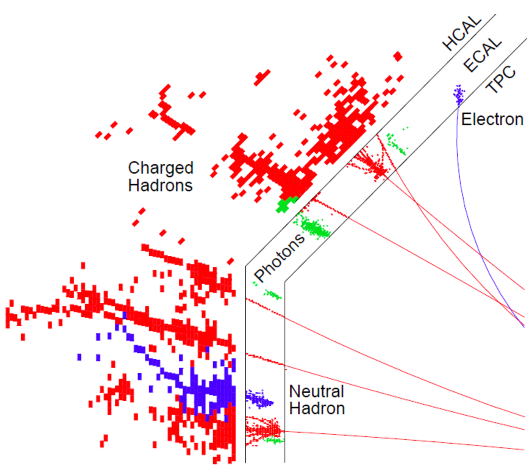
CMS Endcap Calorimeters for Phase 2: Alternatives

- Tower and tile geometry (as in present detectors)
  - Shashlik ECAL with crystals (high resolution) & radiation tolerant HCAL with scintillators
- Integrated calorimetry (opportunity to improve performance at high PU?):
  - High granularity & longitudinal segmentation (shower topology) - CALICE (ILC)
  - Dual readout scintillating & cerenkov light (e/h compensation) - DREAM
- Consider extending up to $|\eta| \sim 4$ (avoid transition to Hadron Forward Calo)
- Consider precise timing measurement ($\sim$ 20 ps) to mitigate PU effects for neutrals

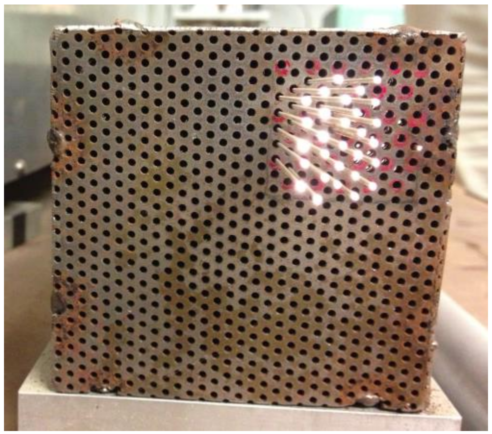
→ R&D on radiation tolerant components - Crystals - WLS fibers - Photo-detectors - MPGDs - Silicon detectors - precise timing measurement devices



Shashlik concept



CALICE concept

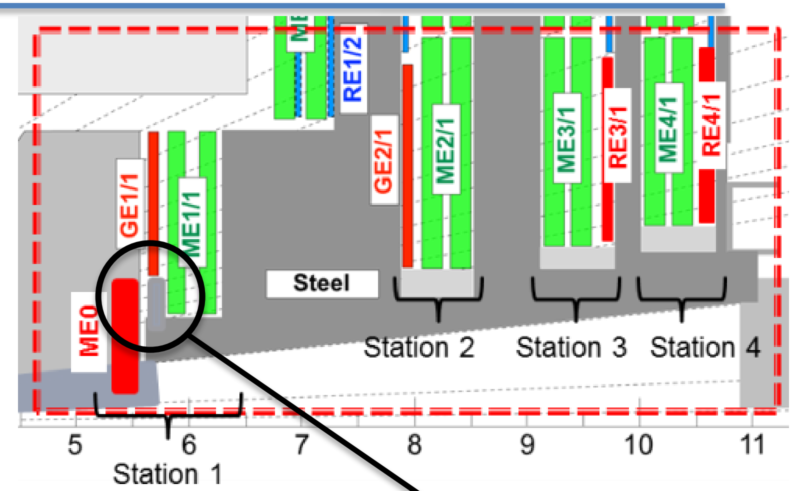


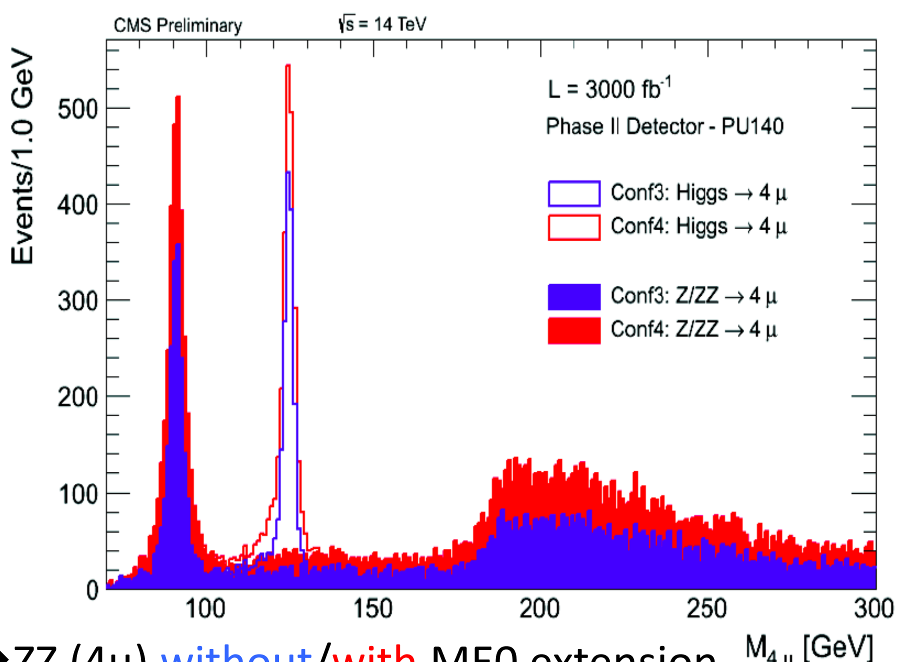
DREAM concept

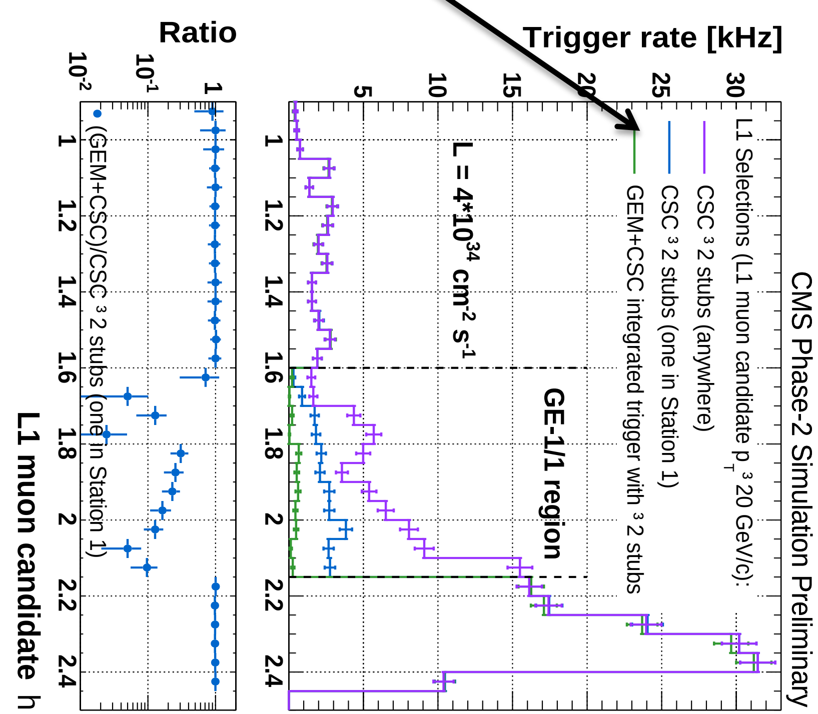
CMS Muon system for Phase 2: Concept

- Complete muon stations at $1.6 < |\eta| < 2.4$ to reduce trigger rates
  - GEMs in 2 first stations (improve Pt resolution)
  - RPCs in 2 last (timing resolution to reduce bgd)
- Consider increase of the muon coverage up to $|\eta| \sim 4$ coupled to extension of new calorimeter and pixel

→ Increase physics acceptance for physics channels with multi-lepton final state



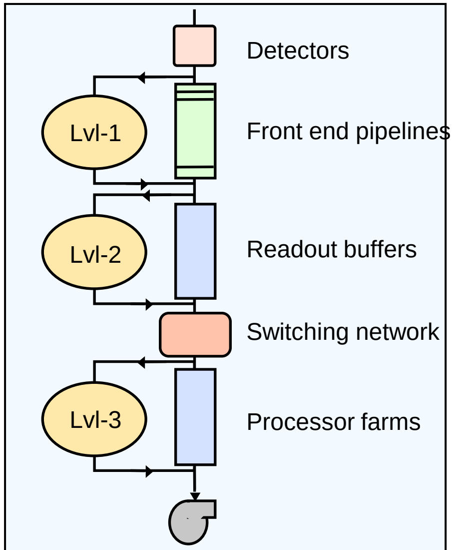




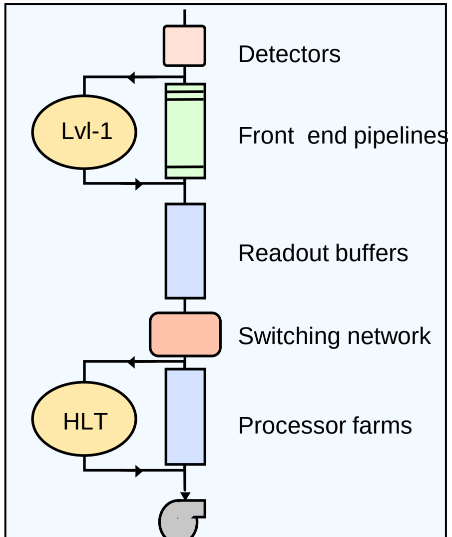
H→ZZ (4μ) without/with ME0 extension

ATLAS and CMS Phase 2: Trigger/DAQ concept

- ATLAS
  - Increase Level 0 bandwidth to at least 500 kHz with 5 μs latency
  - Readout tracker information in Region of Interest at 500 kHz
  - Level 1 up to 200 kHz with 20 μs latency
  - 6.4 Tbps at HLT input and output up to 10 kHz
- CMS
  - Selective readout of Tracker information at 40 MHz
  - Readout crystal granularity in ECAL
  - Level 1 up to 1 MHz - latency ≥ 10 μs
  - 32 Tbps at HLT input and output up to 10 kHz (keep present HLT rejection factor)
- Track Trigger implementation
  - Based on pattern recognition with Custom ASIC Associative Memory chips (as developed for FTK) followed by a track fit in FPGA



ATLAS: 3 physical levels



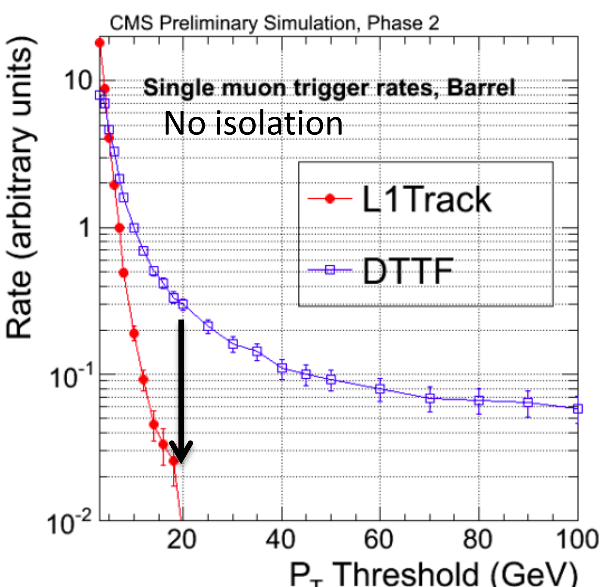
CMS: 2 physical levels

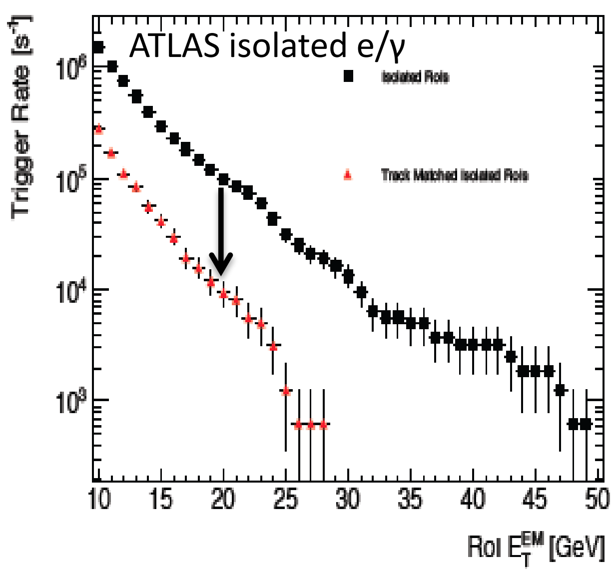
ATLAS and CMS Phase 2: Trigger/DAQ performance

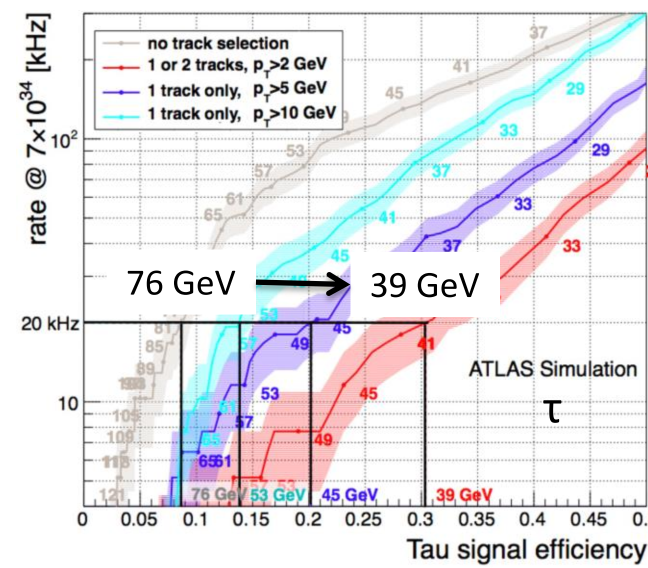
- Track trigger will reduce rates through
  - High momentum resolution of leptons (sharp thresholds)
  - Isolation for e/γ/μ/τ (select fundamental particle decays)
  - Association of particles to same primary or secondary vertex to reduce combinatorial effect of PU in multi-particle/jet triggers

  → Gain is ~ 10 for lepton triggers - allowing to maintain low trigger thresholds
- Increase of L1 bandwidth will provide flexibility
  - Allocation of bandwidth to triggers where track-trigger is less efficient

  → Indication of ~ 20-40% reduction of threshold - may allow to tolerate higher PU

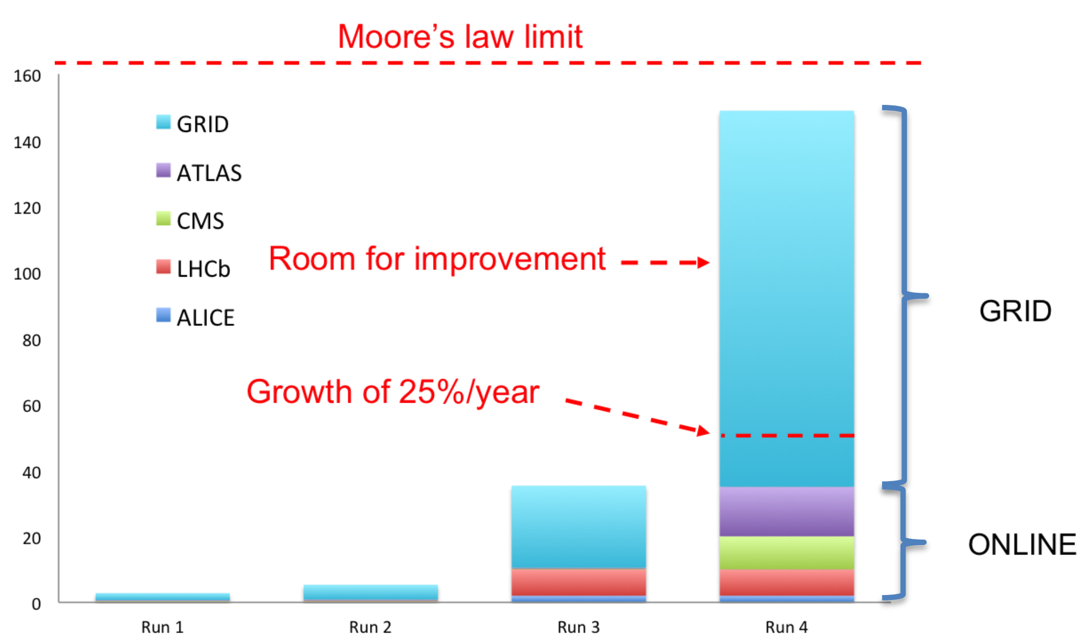


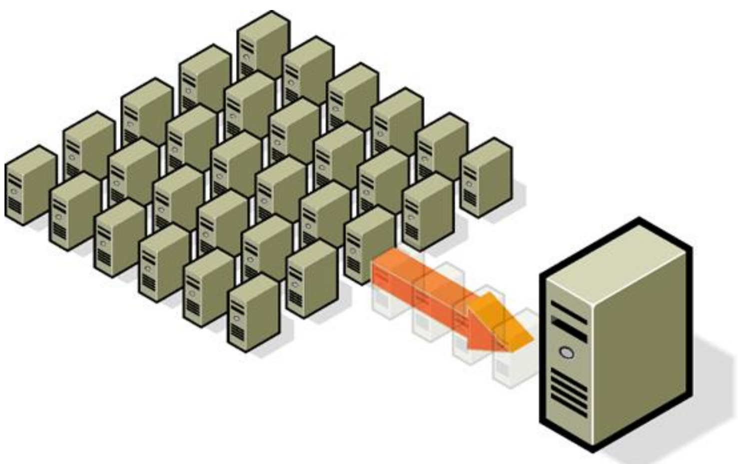




ATLAS and CMS Computing and Software for Phase 2

- Resources needed for computing at HL-LHC are large - but not unprecedented
  - Flat resources will only allow ½ to 10 times less CPU power than needed
  - → Cloud federation may be a way to build our next Grid
  - → Will need major software developments for proper usage of specialized track processing (GPUs) and/or multi-core processors



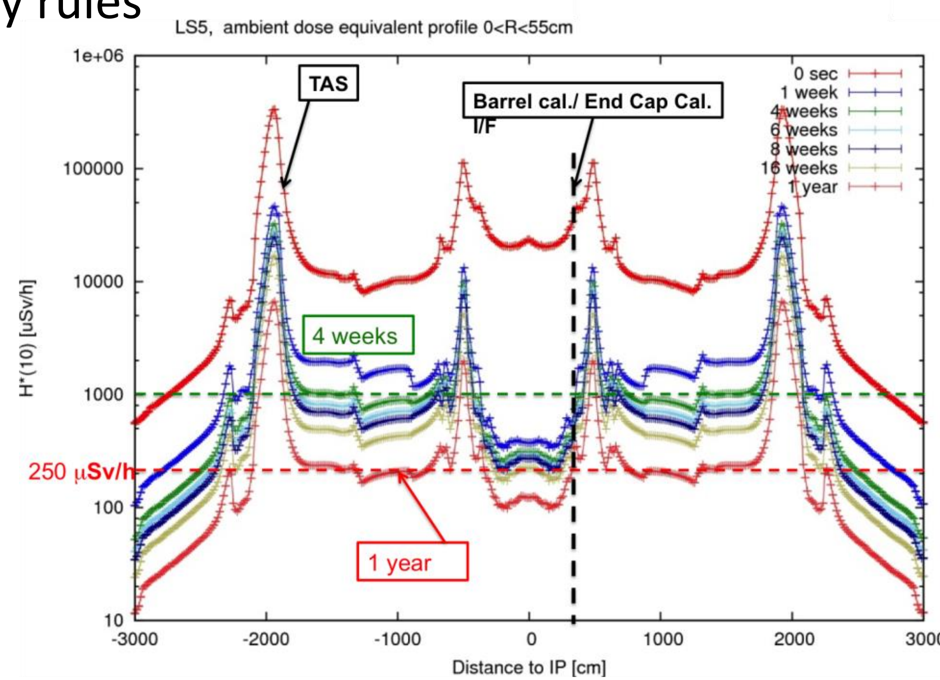


Virtualization is the key technology behind the Cloud

ATLAS and CMS upgrades: Infrastructure and installation

- Infrastructure
  - Replacement of quadrupoles at Interaction Region will need new shielding
  - After 15 years of operation many systems will be inoperable or unmaintainable
  - Capacity of services for new detectors might not be sufficient
    - Cooling systems - electrical power
  - Civil engineering needed on surface should be planed in advance

- Radiation and activation issues will become more and more challenging
  - Work in LS3 will need to satisfy safety rules
    cooling time - specific procedures
    - shielding & handling tools
  - First estimates indicate that LS at HL-LHC will be ~ LS1 x 30 in dose



- Duration of LS3 must be minimized
  - Need careful preparation of sequence of intervention and important and skilled manpower
  - Present estimates 2 - 3 years

Concluding remarks

- The discovery of a Higgs boson is a giant leap in our understanding of fundamental physics

- However, we know that the SM is not an ultimate theory of particle physics and there is compelling reason to believe that new physics should manifest at the TeV scale

- The LHC at 300 fb^{-1} and then 3000 b^{-1} will be the unique facility to explore the Higgs properties and search for new particles in the next decades

- Preparing detectors for the highest luminosity and radiation levels will be a challenge - the HL-LHC schedule is already tight at the same time the collaborations are analyzing data and upgrading for phase 1

We have a lot of exciting work ahead of us!
The upgrade activities must ramp-up