What next at LHC

Mumbai - January 7, 2014

Upgrade of LHC Experiments

D. Contardo - IPN Lyon

Status of the HL-LHC program

Update to the European Strategy for Particle Physics: *"Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030"*

Adopted by the CERN Council in Brussels in May 2013

→ CERN management considers this a strong endorsement of the program

ECFA workshop with ALICE, ATLAS, CMS, LHCb and Theory and Accelerator colleagues

- Address all aspects of the HL-LHC program
- Identify synergies to streamline studies and R&D

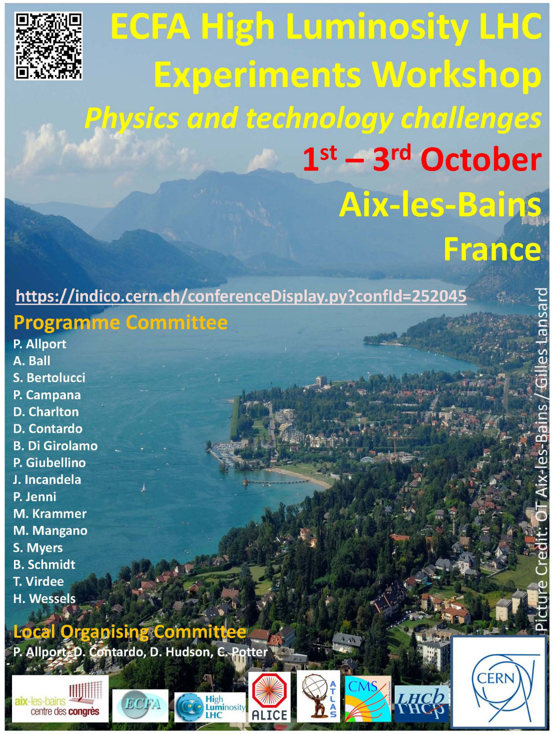
A unique source of information

https://indico.cern.ch/conferenceDisplay.py?confId=252045

And a summary report for ECFA

https://cds.cern.ch/record/1631032/

Material in this presentation is largely borrowed from presentations at the workshop

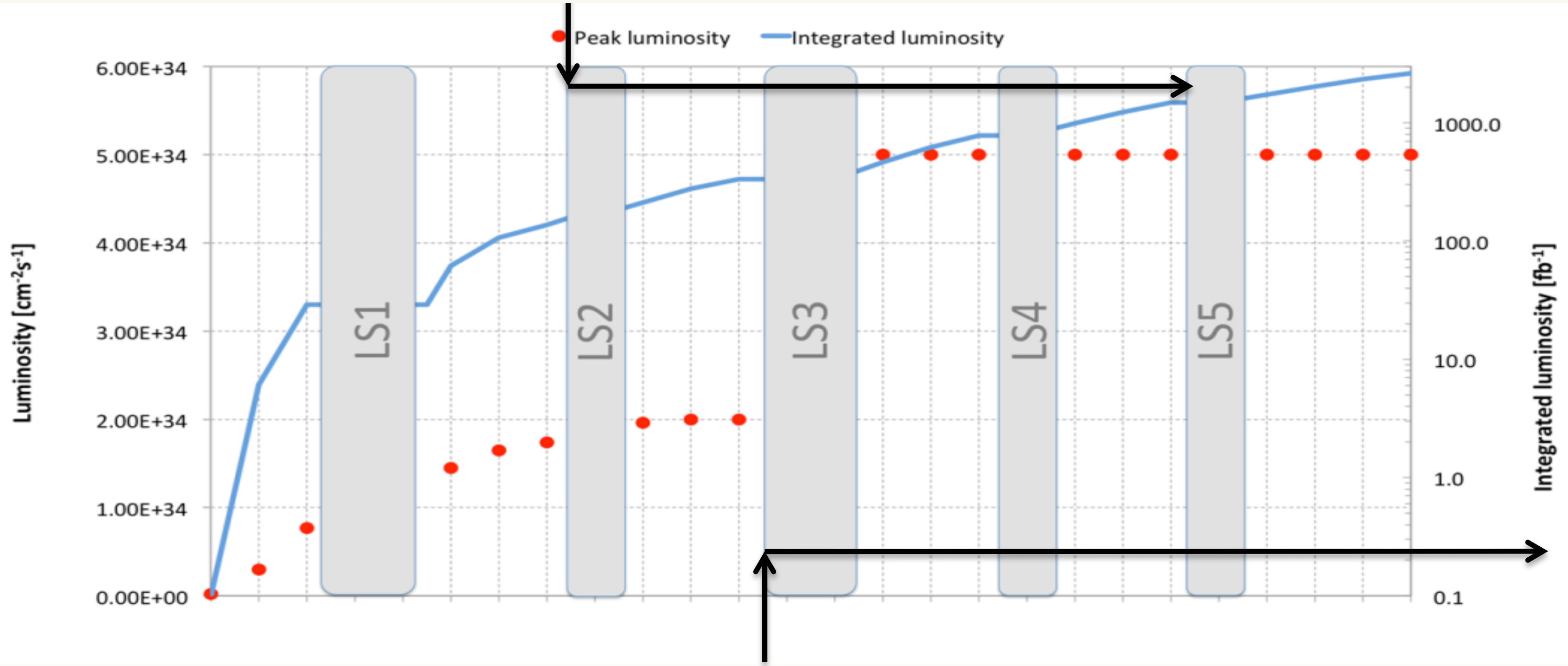


Experiment goals for high integrated luminosity

ALICE and LHCb do not need LHC upgrade they can upgrade in LS2 for a further 8 to 10 years of operation :

ALICE x 2 present luminosity x 100 statistics: Pb-Pb: 6 x 10^{27} $cm^{-2}s^{-1}$ - ~10 nb^{-1}

LHCb x 5 present luminosity x 10 statistics: p-p: 2 x 10^{33} $cm^{-2}s^{-1}$ - 4.5 PU* - ~50 fb^{-1}



ATLAS and CMS Upgrades during LS3 for a further 10 years or more of operation

Target luminosity x 5 nominal: 5 x 10^{34} $cm^{-2}s^{-1}$ (leveled) - 125-140 PU - ~3000 fb^{-1}

* PU = average number of p-p interactions per bunch crossing

Outline

- LHC Upgrade program
  - Accelerator and Experiments upgrade program
  - Physics goals and some performance projections
- Detector Upgrades for HL-LHC
- Concluding remarks

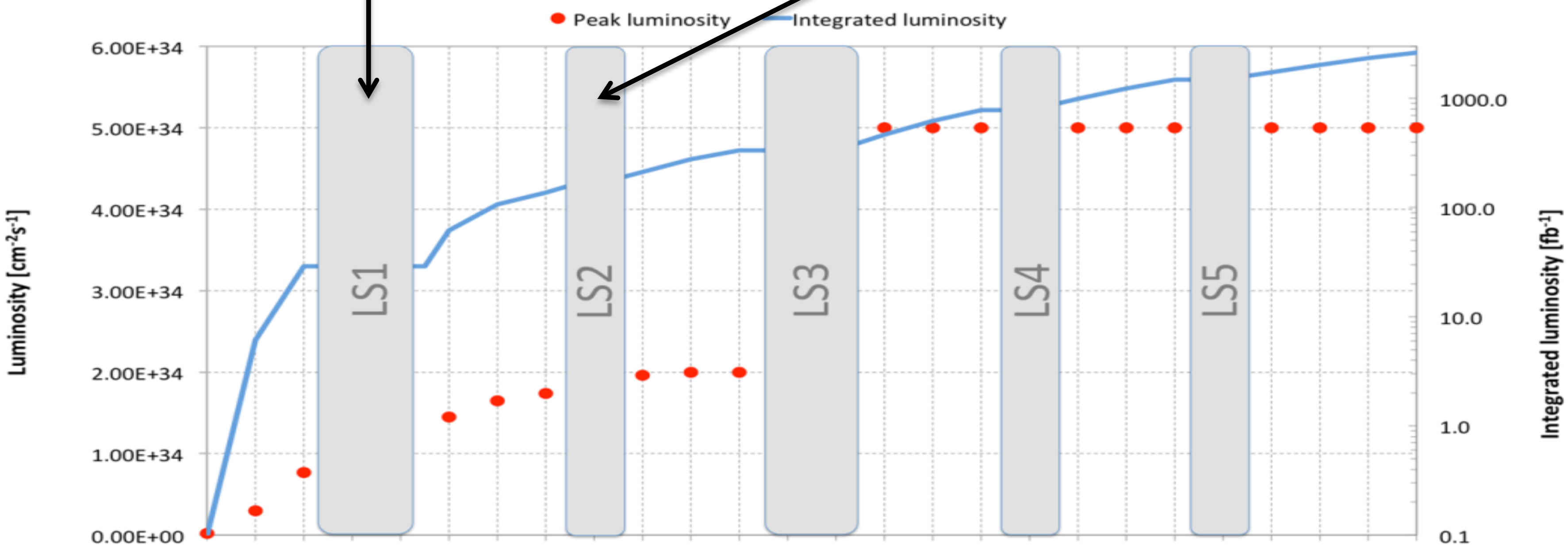
LHC Upgrades in LS1 and LS2

LS1: CM energy: 8 → 13-14 TeV
bunch spacing: 50 → 25 ns

- Batch Compression Merging Splitting
- Scrubbing in SPS (mitigate e-cloud)

LS2: Injection Chain upgrade (LIU)

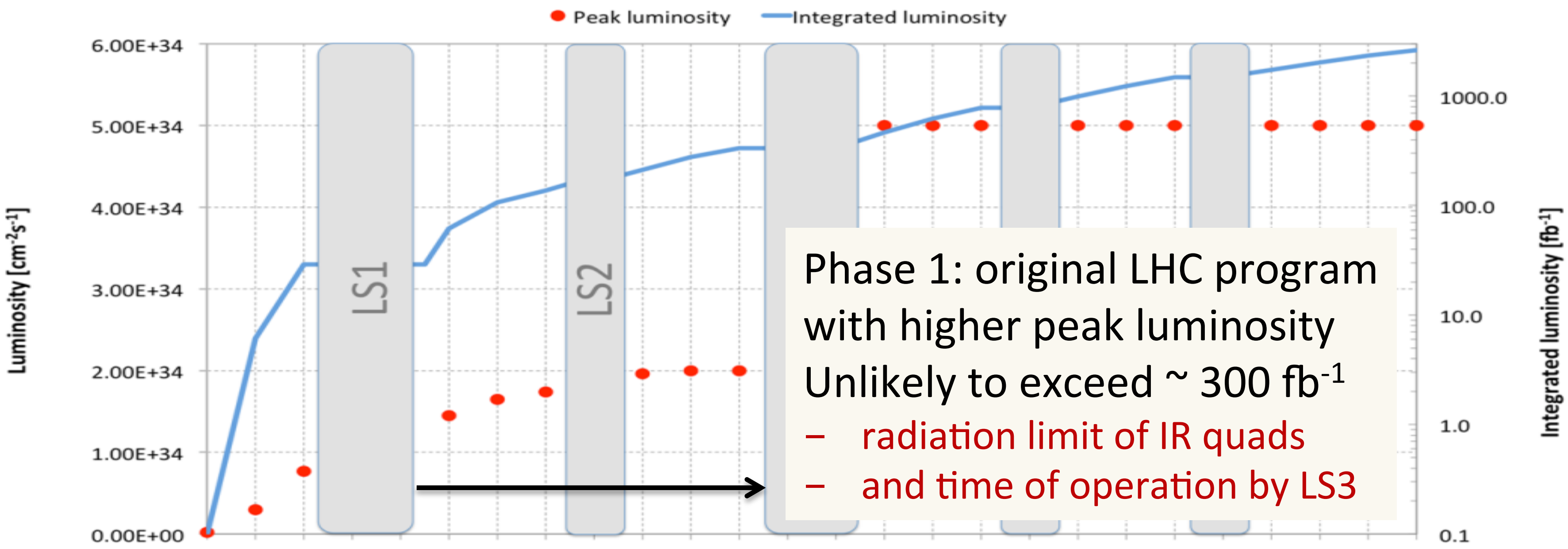
- New Linac
- PSB-PS: 1.4→2 GeV
- RF upgrades in PS and SPS



See E. Tedesco's presentation at this conference
And Review of LHC & Injector Upgrade Plans workshop Oct. 29
https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=260492

LHC Upgrades in LS1 and LS2

- BCMS and LIU provide similar beam brightness of bunch trains at injection of LHC
  - Potential for 2-2.5 x 10^{34} Hz/cm^2 (assuming e-cloud… under control)
  - Leveling ~ 1.75 x 10^{34} cm^{-2}s^{-1} ± 10 - 20% - due to cryogenic limit in IR quads - PU ~ 45
  - 45 to 55 fb^{-1} per year (6.5h fills - 35% stable beam)



Phase 1: original LHC program with higher peak luminosity
Unlikely to exceed ~ 300 fb^{-1}
- radiation limit of IR quads
- and time of operation by LS3

ATLAS & CMS prepare for 50 PU, through LS3, with margin up to 70 PU
Detectors can sustain up to 500 fb^{-1}

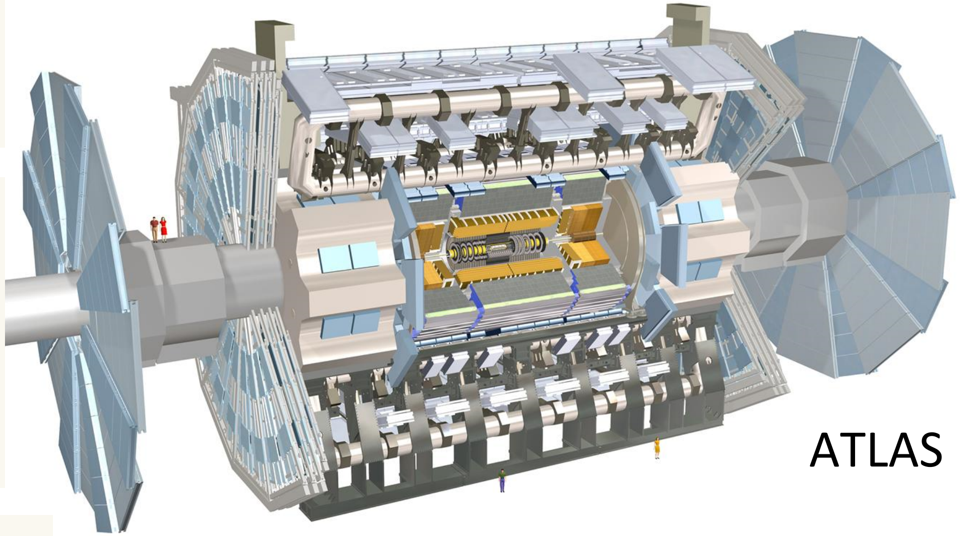
ATLAS and CMS upgrades for Phase 1

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

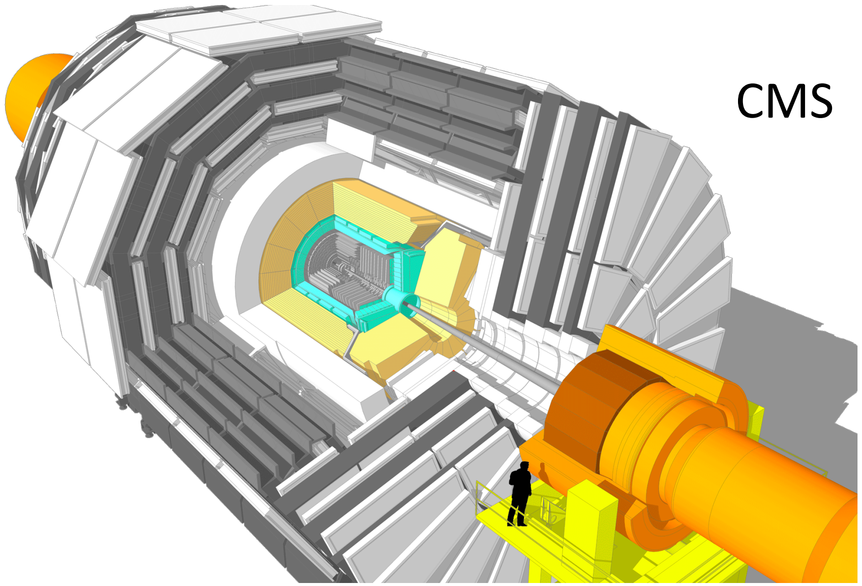
Calorimeters: increase granularity for trigger
ATLAS: new Front End in Liquid Argon (barrel & endcaps) - LS2 (2018)
CMS: New photo-detectors for HF/HE/HB (also reject anomalous signal) - 2015 to LS2

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: increase 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 - by end 2015



ATLAS

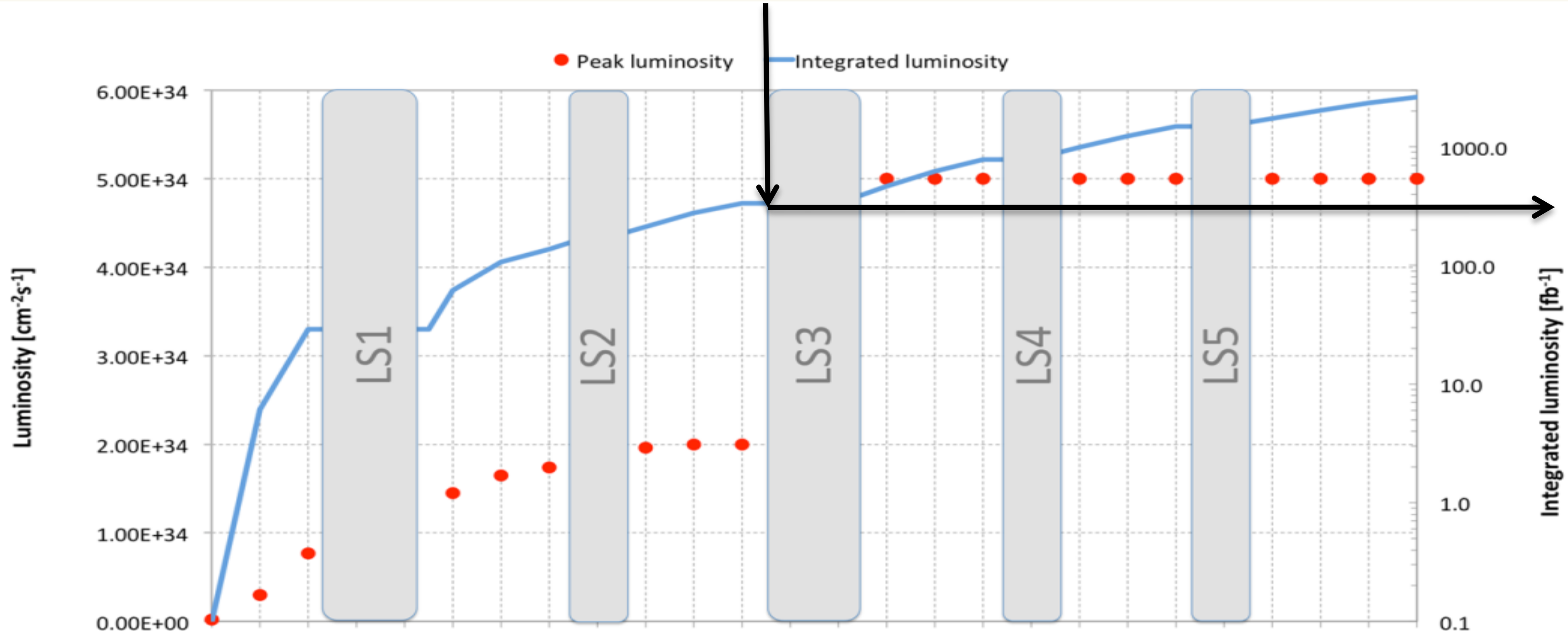


CMS

High Luminosity LHC Upgrades in LS3

Upgrades at Interaction Regions assuming leveling at 5 x 10^{34} Hz/cm^2, PU~ 125-140

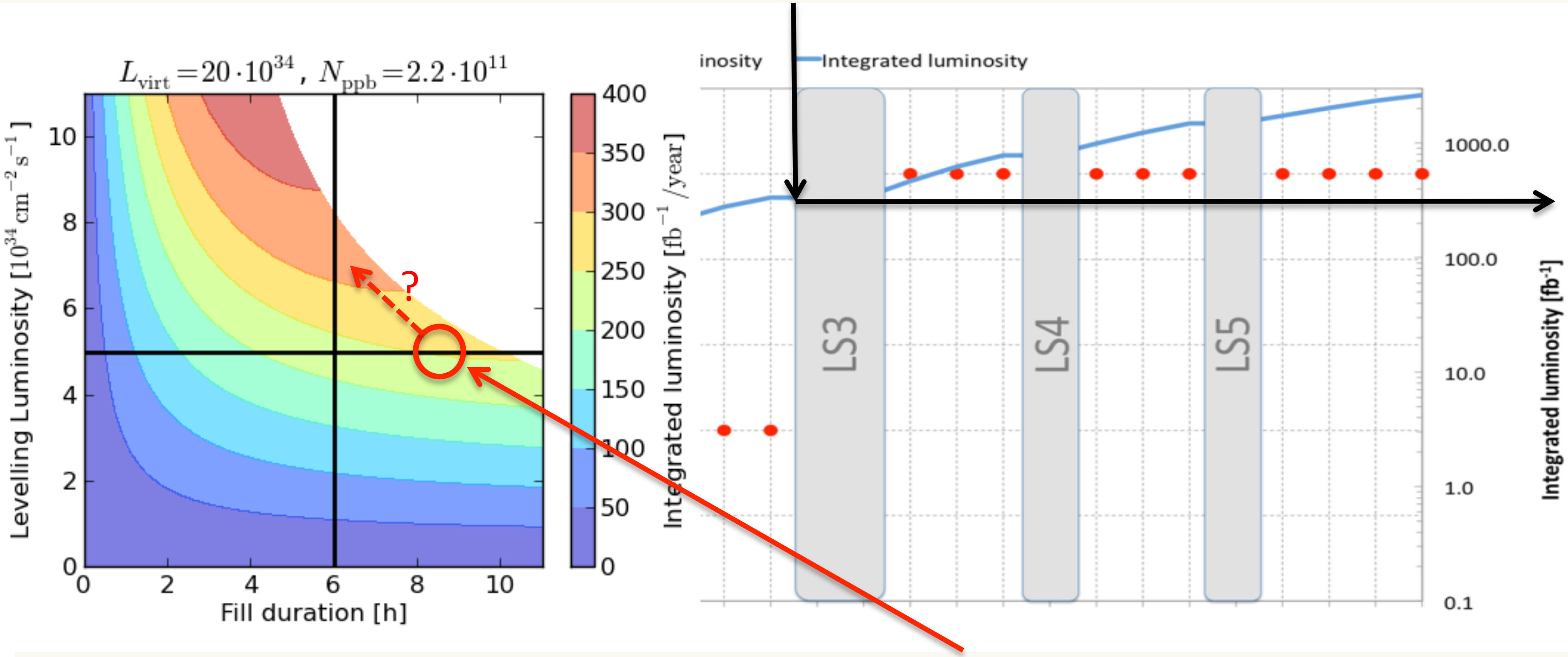
- New low-β quadrupoles - improve beam focus → ~ 80 fb^{-1} /year
- & Beam-Beam Wire Compensation - reduce long range BB effects → ~ 170 fb^{-1} /year
- & Matching sections & Crab Cavities - lower β, compensate crossing angle ≥ 250 fb^{-1} /year
- & CC kissing scheme - reduce PU density, 200 MHz RF - longer/more intense bunches



Phase 2: ATLAS & CMS target performance at 125-140 PU (cross section uncertainty and bunch to bunch fluctuations) - but prepare operation margin up to 200 PU - limit will be set by physics performance

High Luminosity LHC Upgrades in LS3

Upgrades at Interaction Regions assuming leveling at 5 x 10^{34} Hz/cm^2, PU~ 125-140
- New low-β quadrupoles - improve beam focus → ~ 80 fb^{-1} /year
- & Beam-Beam Wire Compensation - reduce long range BB effects → ~ 170 fb^{-1} /year
- & Matching sections & Crab Cavities - lower β, compensate crossing angle ≥ 250 fb^{-1} /year
- & CC kissing scheme - reduce PU density, 200 MHz RF - longer/more intense bunches



Phase 2: ATLAS & CMS target performance at 125-140 PU (cross section uncertainty and bunch to bunch fluctuations) - but prepare operation margin up to 200 PU - limit will be set by physics performance

New Long Shutdowns Schedule (Dec. 2013)

EYETS 19 weeks -16/17
CMS Pixel and prepare LIU

LS2 18 months - mid18/19
LIU, ALICE and LHCb upgrades

LS3 30 months - 23/mid25
LHC, ATLAS and CMS upgrades

Reaching 3000 fb^{-1} by 2035 will be challenging

Outline

- LHC Upgrade program
  - Accelerator and Experiments upgrade program
  - Physics goals and performance projections
- Detector Upgrades for HL-LHC
- Concluding remarks

Physics goals and some performance projections

- Preliminary projections where performed for ESPG and Snowmass*

- Further studies for ECFA workshop targeted to include:
  - Common assumptions for physics process generation
  - Improved description of detectors upgrades in simulation
  - Better understanding of analysis tools to handle large PU

- Program of studies was developed with theory colleagues covering:
  - Precision measurement of Higgs properties and search beyond Standard Model
  - Direct searches for other Beyond-the-Standard Model physics,
  - Precision tests of the SM in heavy flavour physics and rare decays
  - Precision measurements of the properties of the Quark-Gluon Plasma

- About 30 studies were performed for ECFA - some need significant work to adapt to new detector configurations and PU condition → work is continuing

See P. Giacomelli's and S. Padhy's presentations at this conference

* ESPG: http://espp2012.ifj.edu.pl/
Snowmass: http://www.snowmass2013.org/tiki-index.php

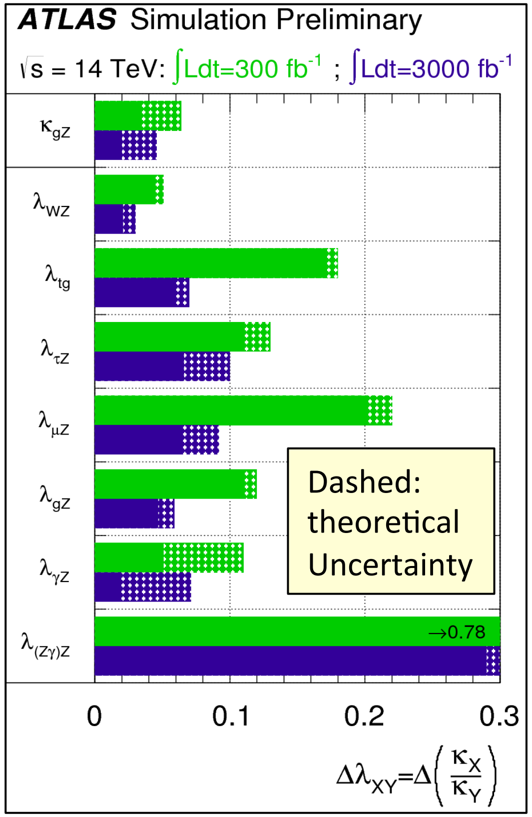
Higgs coupling precision projections

HL-LHC (3000 fb^{-1}) > 3M Higgs for 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]

Importance of theory and systematic errors
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 HL-LHC

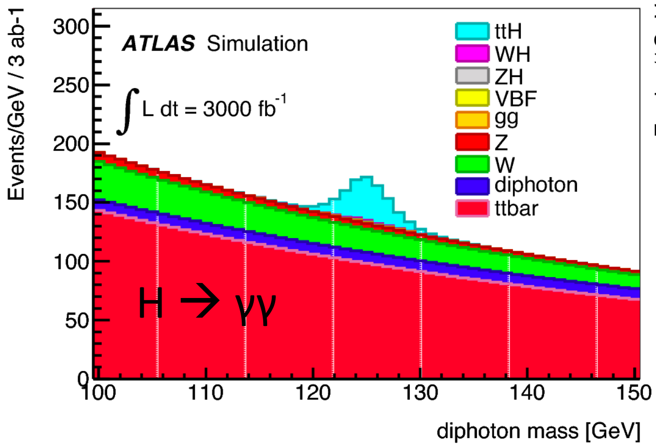
	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim -3\%$

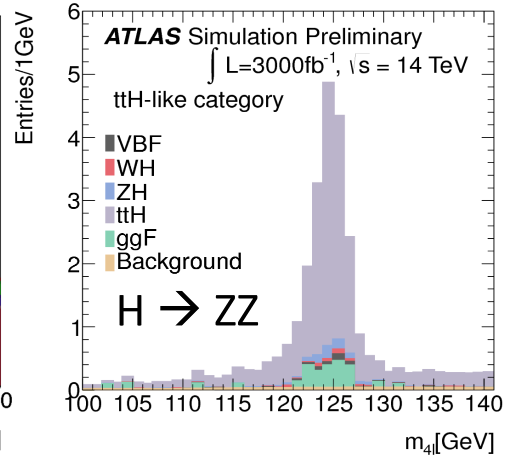


Higgs rare process/decay projections

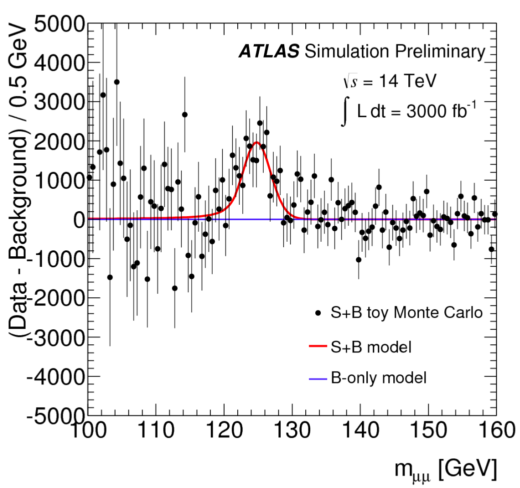
Signals only accessible with 3000 fb^{-1} with errors limited by statistics

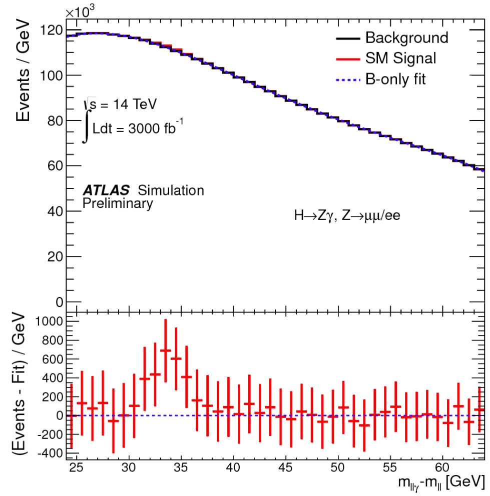
ttH → γγ or ZZ
30 fb^{-1}: 6xSM cross-section
3000 fb^{-1}: expect > 5σ sensitivity - Higgs-top coupling can be measured to about 10%



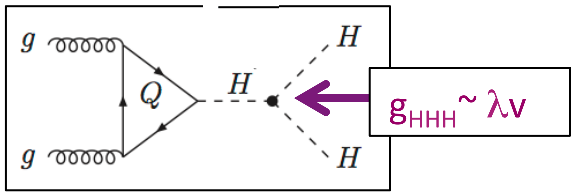


H → μμ (coupling to fermions of second generation) ~ 10% precision on production
H → Zγ (compositeness) ~ 20% precision on production



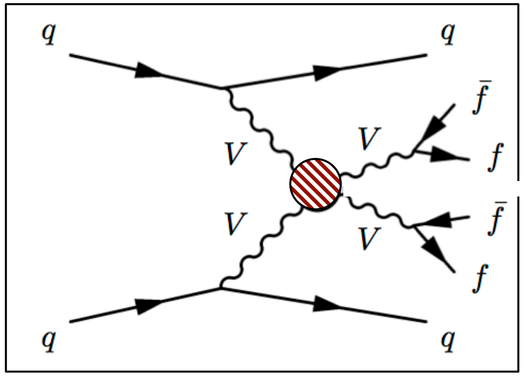


HH production (probe Higgs potential)
HH→bbγγ - HH→bbττ… studies on going tens of events expected ~ 30% precision per experiment

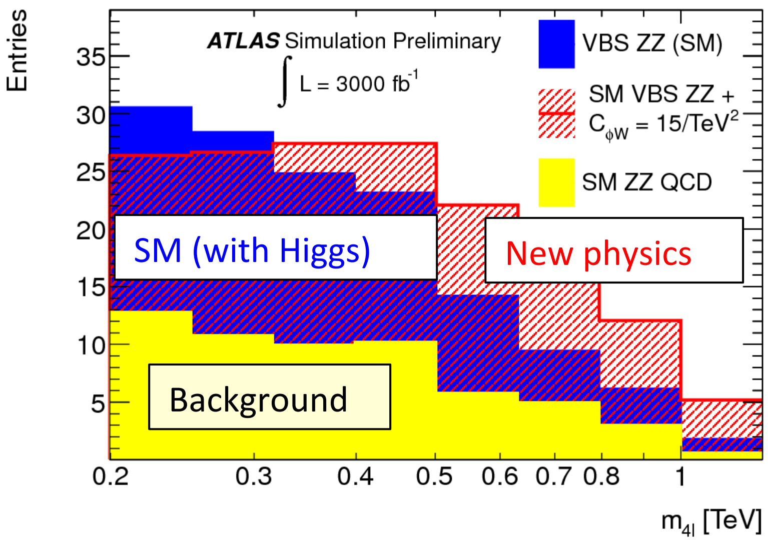


Vector Boson Scattering

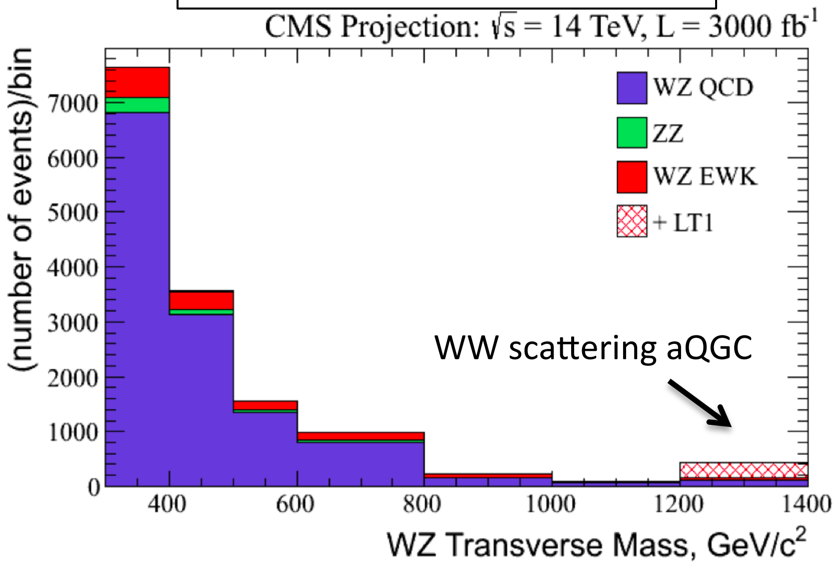
- Test of Higgs role in cancelling VBS divergence in SM can be measured to 30% (10%) with 300 (3000) fb^{-1}
- If new physics exists: sensitivity to anomalous triple or quartic couplings increases by factor of ~ 2 from 300 to 3000 fb^{-1}



VBS ZZ→ 4l

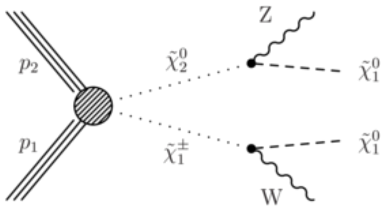


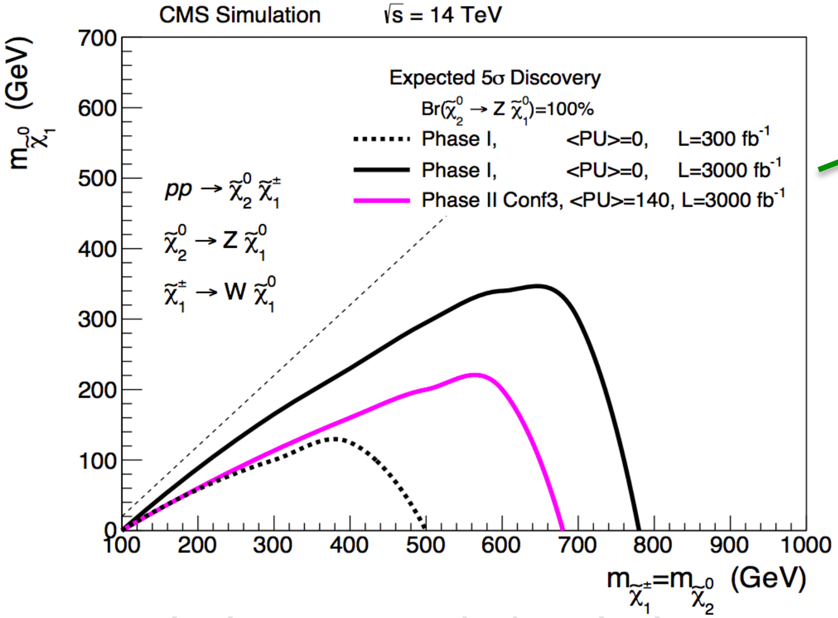
VBS WZ→ 3l + Etmiss

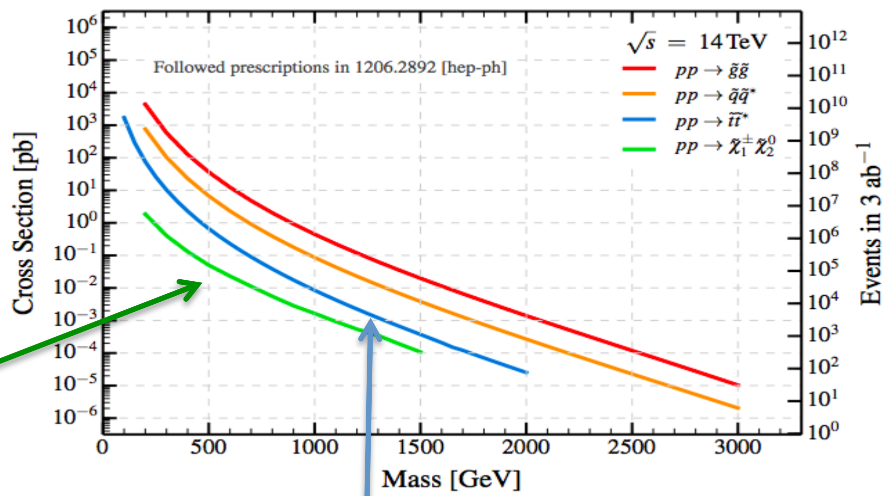


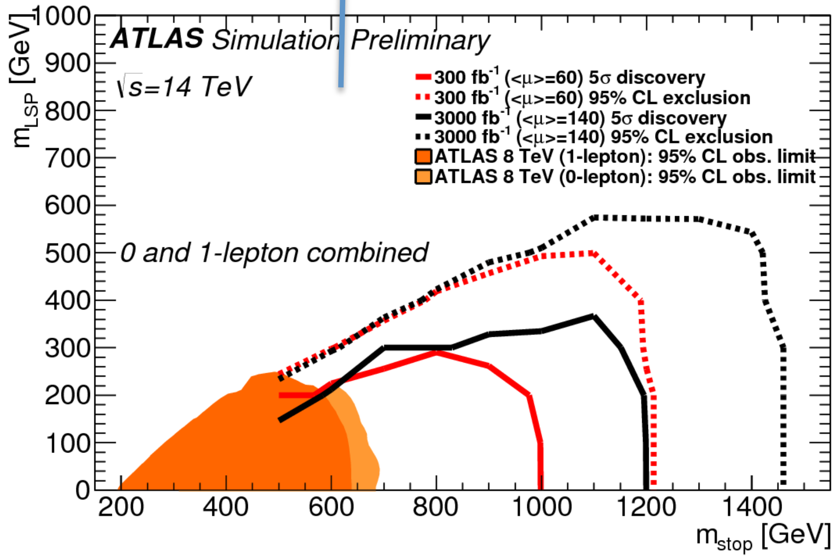
Search for SUperSYmmetry particles

Direct production of chargino/neutralino

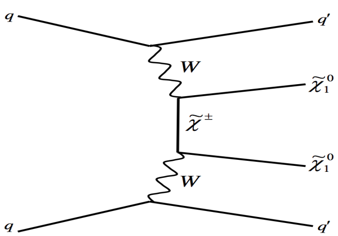




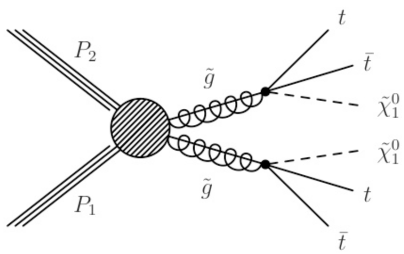




And also:

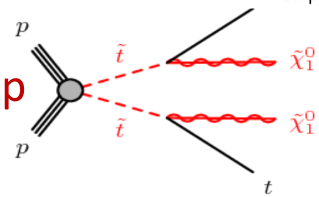


VBF Dark matter



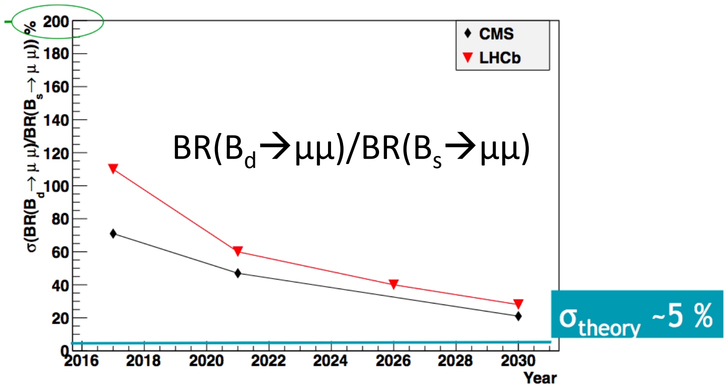
production of gluinos

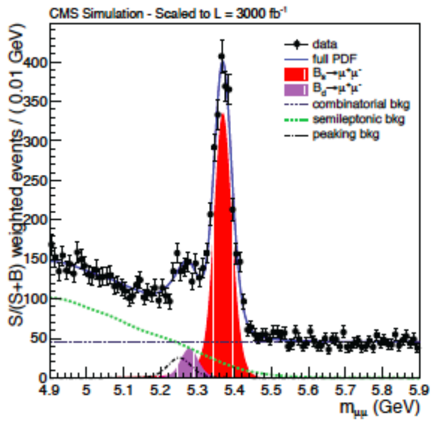
Production of stop

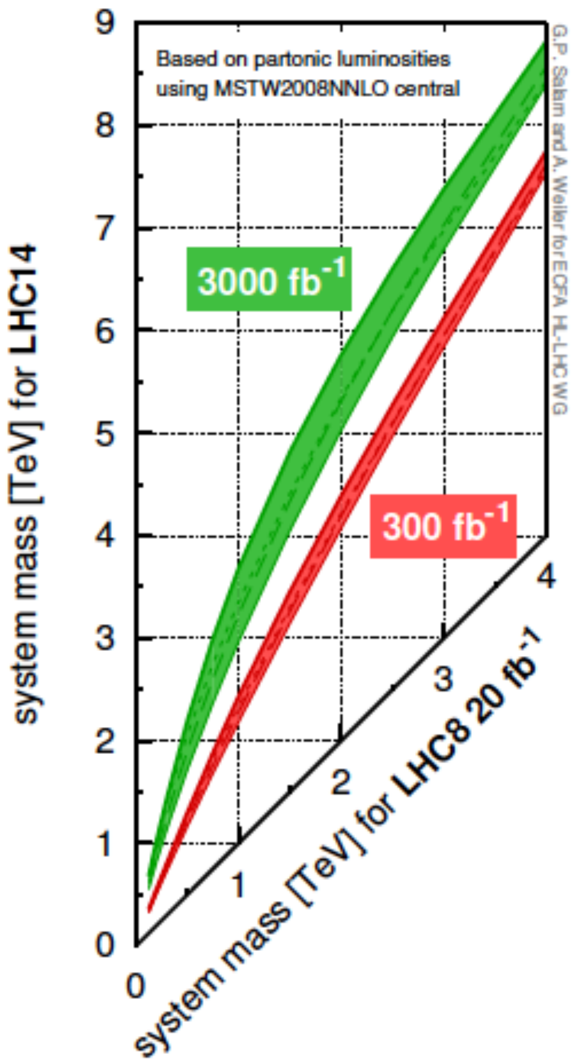


And many other studies

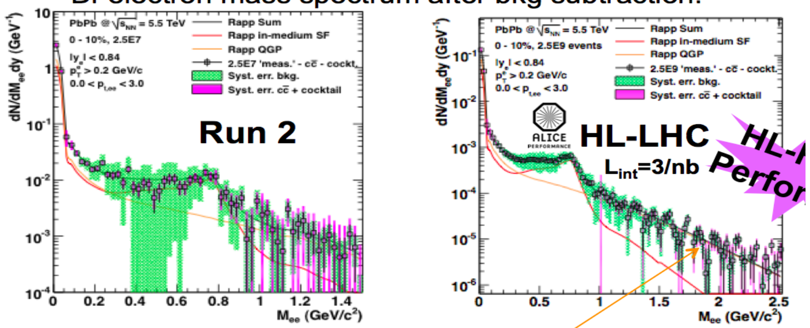
- Overall mass reach for BSM new particles
- Direct search of BSM Higgs (2HDM description)
- Heavy vector-like quarks
- Indirect searches in flavor physics
- FCNC decays
- Quark Gluon Plasma physics







Di-electron mass spectrum after bkg subtraction:



Precision of ~10% on the inverse slope → T

Outline

- LHC Upgrade program
- Detector Upgrades for HL-LHC
  (Focus on ATLAS and CMS)
  - Driving requirements and overview
  - Sub-detectors and systems
  - Accelerator - Experiments interface
  - Infrastructures and LS3 logistics
- Concluding remarks

Driving requirements and overview ALICE & LHCb upgrades

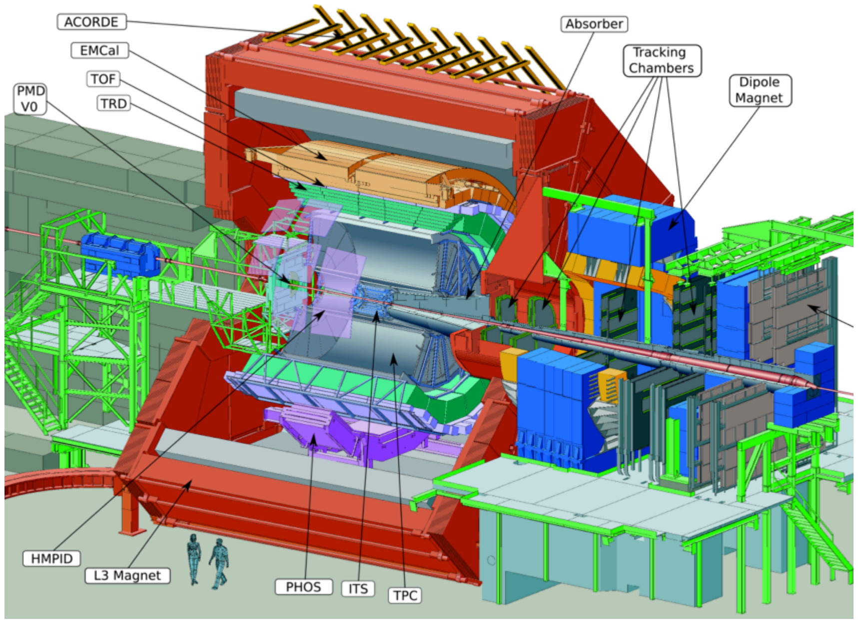
- Limitations in readout bandwidth and trigger capability
  - Goal is to register all Pb-Pb collisions in ALICE (50 kHz of data registered)
  - Goal is to move trigger functions to computing in LHCb (40 MHz readout)

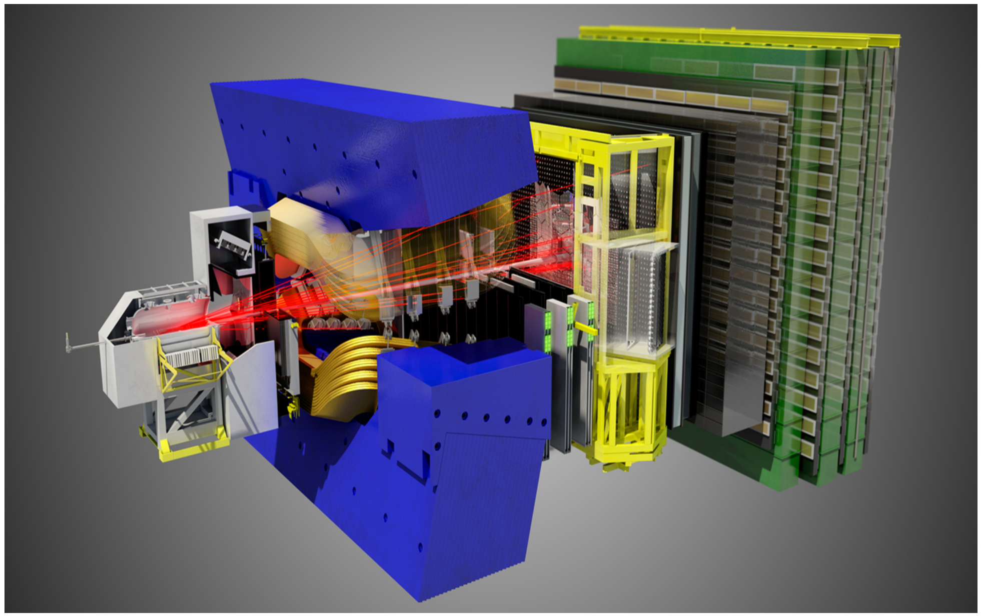
ALICE

- New Pixel detector (ITS)
- TPC with GEM readout
- New Muon Forward Tracker (Pixels)
- New read-out for all detectors

LHCb

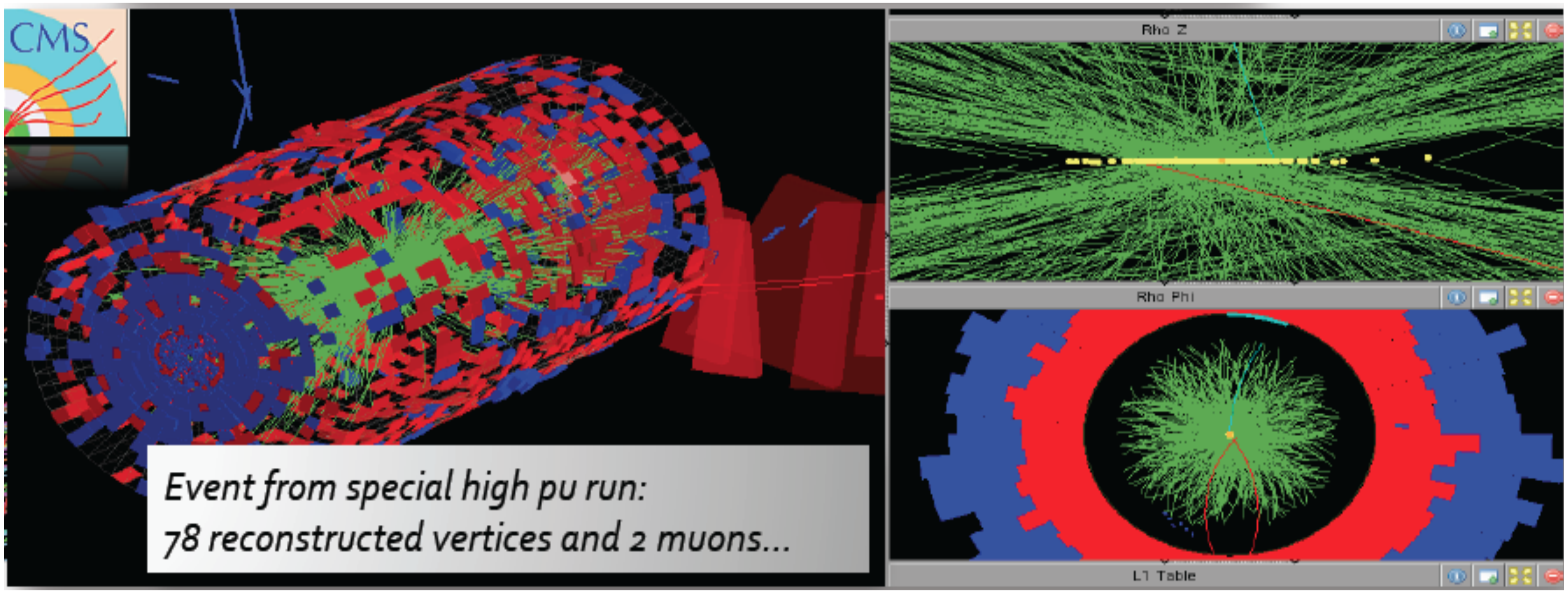
- New Pixel detector (VELO)
- New tracker with scintillating fibers
- RICH with new MAPMT
- New readout for all detectors





Driving requirements for ATLAS & CMS upgrades at HL-LHC

- Radiation tolerance:
  - New detector technologies
- Mitigation of PU effect - fully exploit High Luminosity potential:
  - High granularity and precision - concerns especially the tracker
- Acceptance of physics event - critical to measure rare processes:
  - Improved trigger inputs and algorithms and increased detector coverage
- Data flow:
  - High readout bandwidth and fast processing



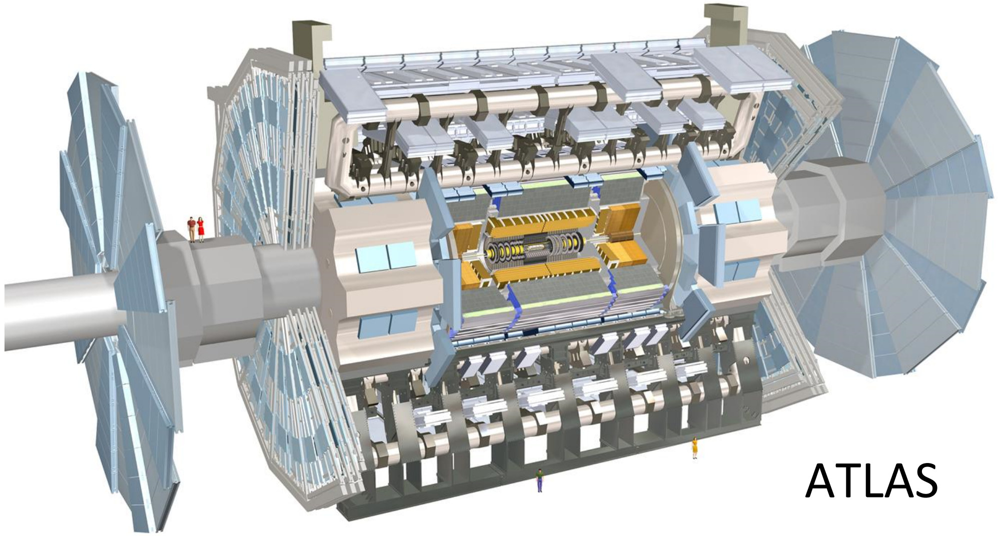
ATLAS and CMS upgrades for HL-LHC overview

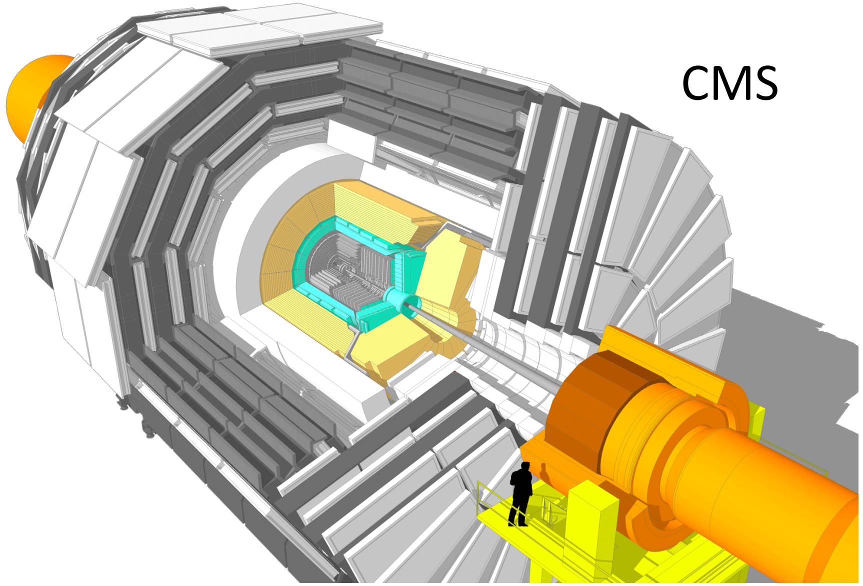
Tracker replaced both in ATLAS and CMS:
Radiation tolerant - higher granularity
Extended coverage in forward region

Calorimeters:
ATLAS: new FE electronics for trigger - investigate rates effect in FCAL & PreAmp aging in HEC
CMS: replace full endcaps (longevity)
FE electronics in ECAL barrel for trigger

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

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





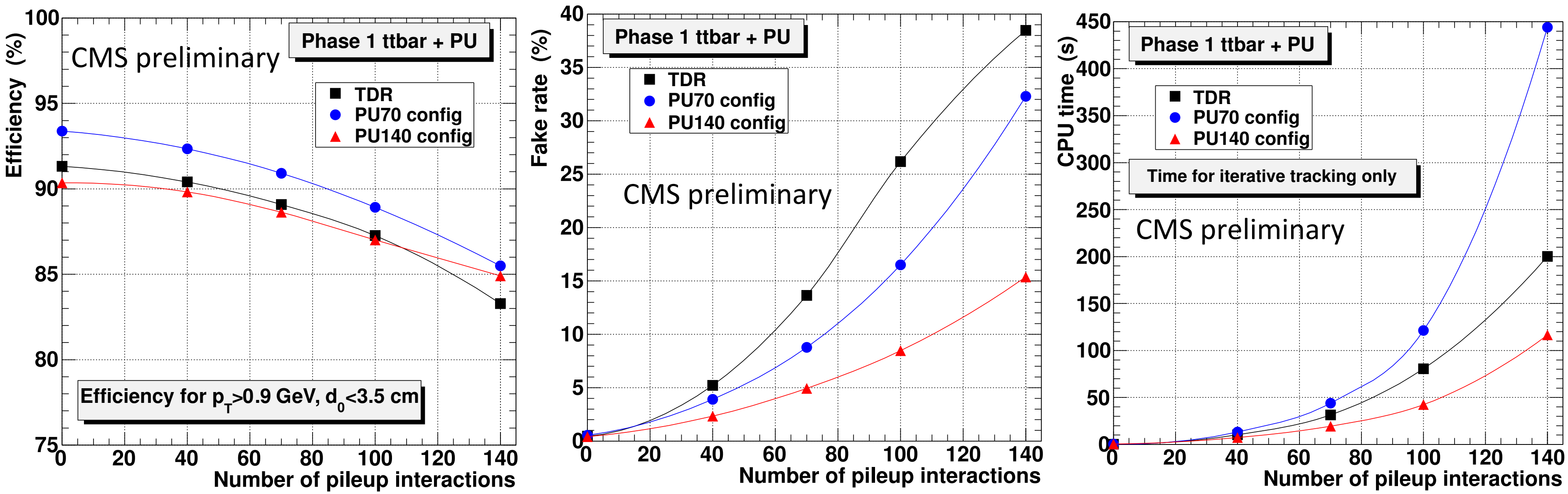
ATLAS and CMS Trackers replacement for HL-LHC

- Present detectors not designed for the higher trigger rate and <PU> and will become inoperable beyond 500 fb^{-1} due to radiation damage

  → Need to be replaced in LS3

- At 140 PU Phase 1 track reconstruction performance degrades significantly
  - Efficiency drops while fake rate increases - even with tuning and improvements in reconstruction algorithms

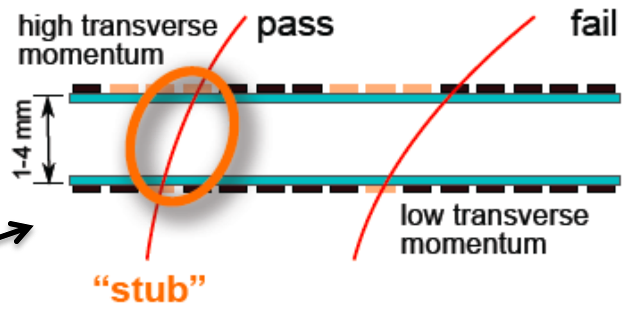
  → Need higher granularity - goal for performance up to 200 PU - and improved processing



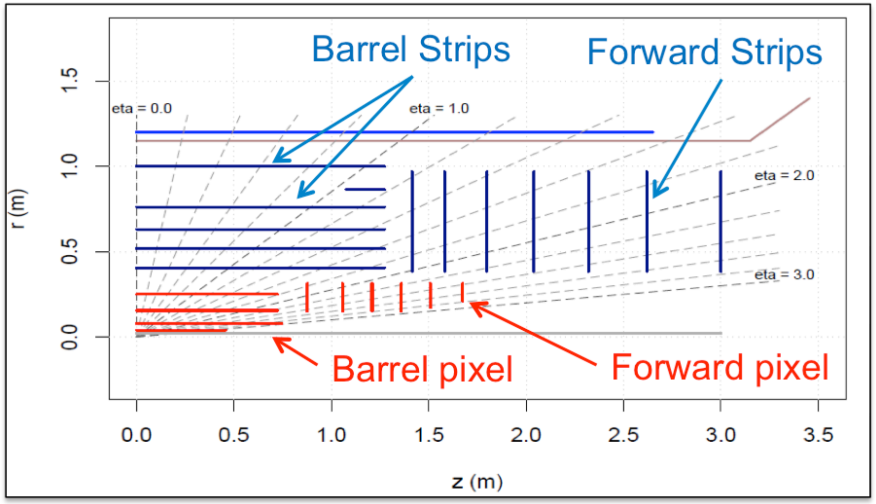
Track reconstruction with CMS Phase 1 detector at 140 PU

ATLAS and CMS Tracker designs for HL-LHC

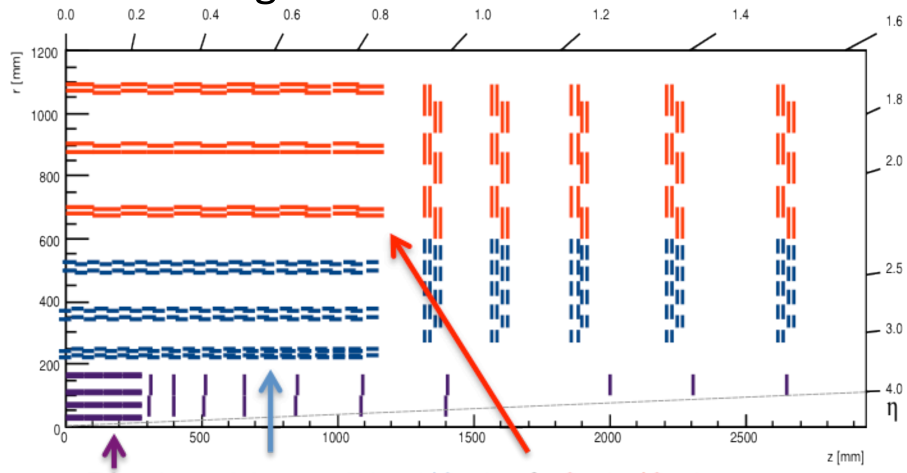
- Similar Granularity
  - Strip pitch ~ 80-90 µm & length ~ 2.5 to 5 cm
  - Pixel pitch ~ 25-30 µm and ~ 100 µm length
- Light materials
- Different configurations
  - CMS: module concept to select "stubs" of Pt≥2GeV for trigger readout at 40MHz
    - Strip-Strip modules in outer layers and macro Pixel-Strip in inner (z measurement)
  - ATLAS: read-out tracker region of interest at ≥500kHz for trigger
    - Strip stereo modules (z measurement)



ATLAS design



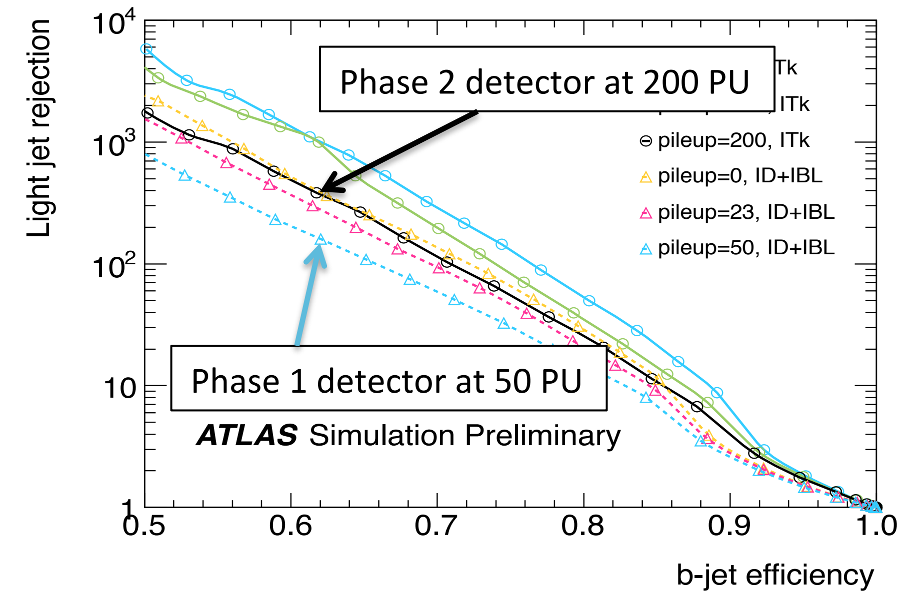
CMS design



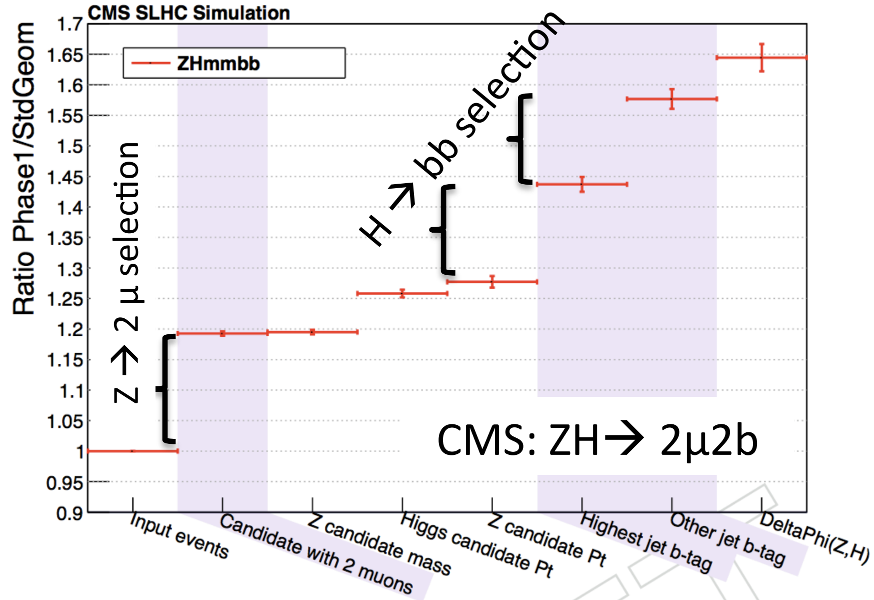
ATLAS and CMS Tracker performance enhancement

- Pixel detectors with thinner sensors and finer granularity
  → Improve resolution on track origin - association at primary & secondary vertices

b-tagging performance from ATLAS simulation



Example of improvement with CMS phase 1



~ 65% gain in statistics

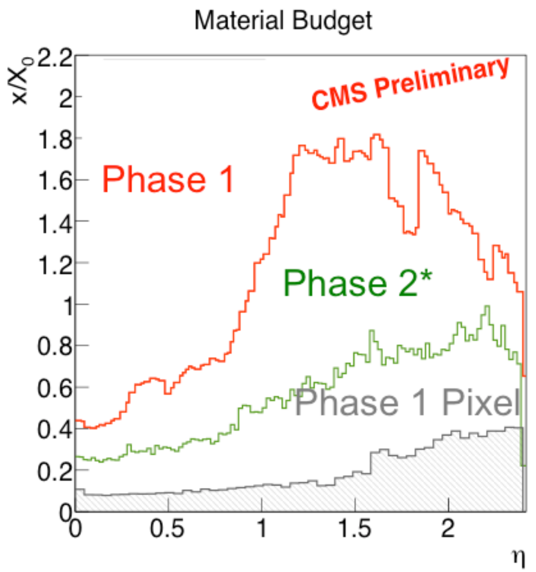
Expect significant improvements for key physics channels (studies will continue) :
ex. HH→bbγγ - and rare process with multi-leptons…

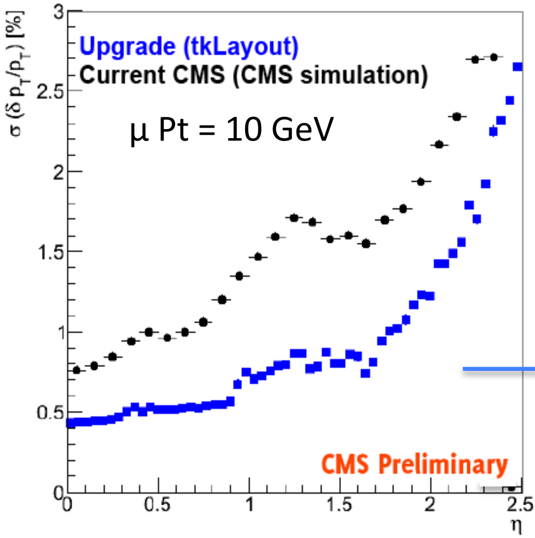
ATLAS and CMS Tracker performance enhancement

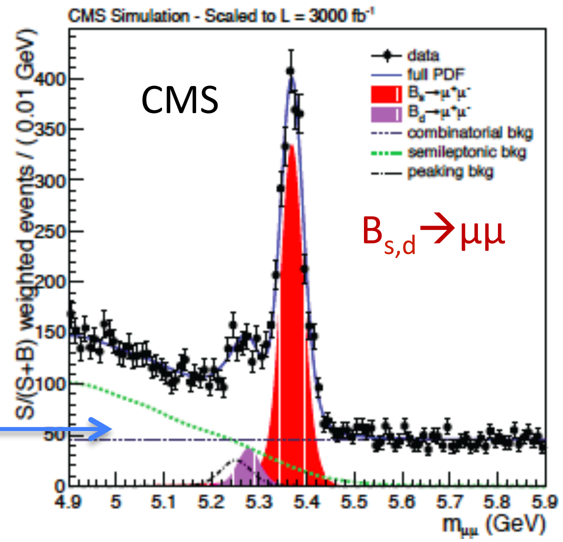
- **Light materials**

  Improved track Pt resolution & reduce rate of γ conversion

  ex. HH→ bbγγ - ttH → γγ - H → μμ - $B_{s,d}$→ μμ…



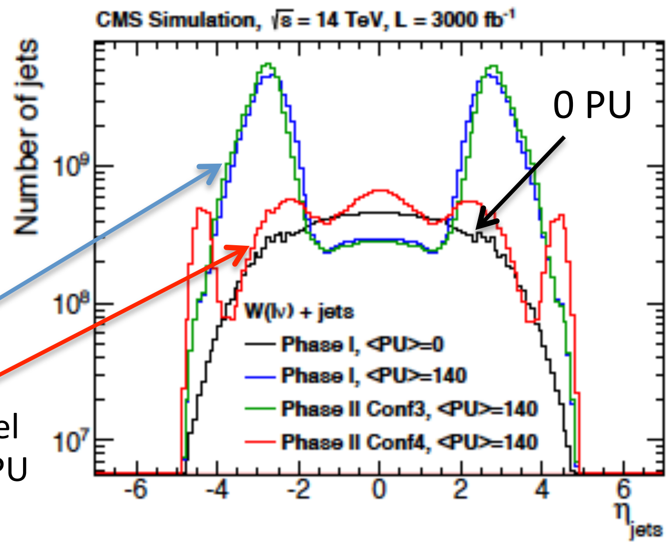




- **Extension of pixel coverage up to |η| ~ 4**

  Associate jets to tracks - vertex to mitigate pile-up effect

  Expect significant improvements for all VBF processes: Higgs - BSM dark matter & for VBS



Jet rate without & with pixel coverage extension at 140 PU

ATLAS and CMS Silicon Tracker R&D

All components need to be radiation tolerant

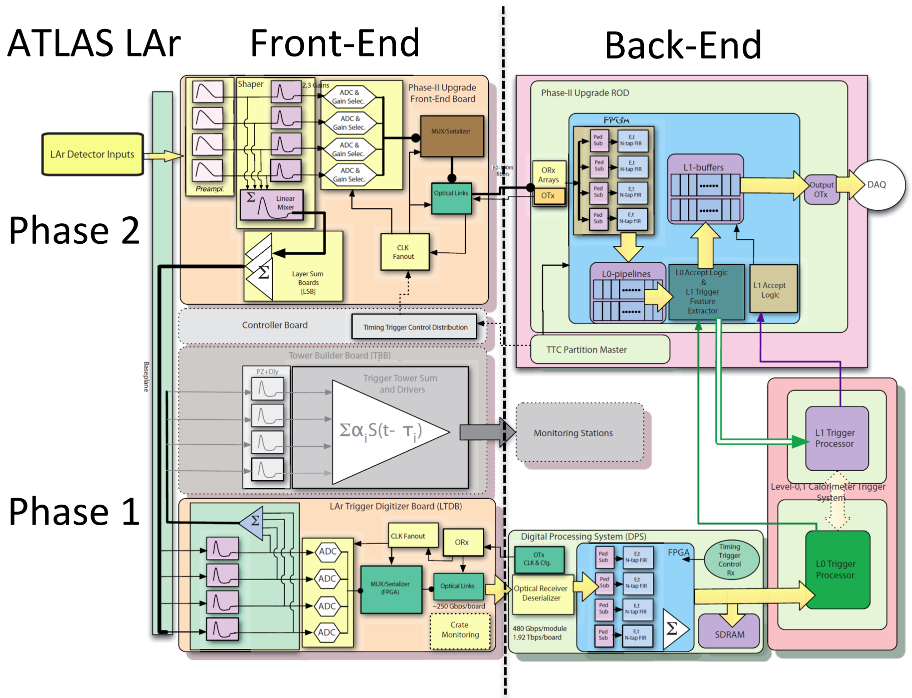
Upgrades	Area	sensor type
ALICE ITS	12 m^2	CMOS
LHCb VELO	0.15 m^2	tbd
LHCb UT	5 m^2	n-in-p
ATLAS Strips	193 m^2	n-in-p
CMS Strips	218 m^2	n-in-p
ATLAS Pixels	8.2 m^2	tbd
CMS Pixels	4.6 m^2	tbd

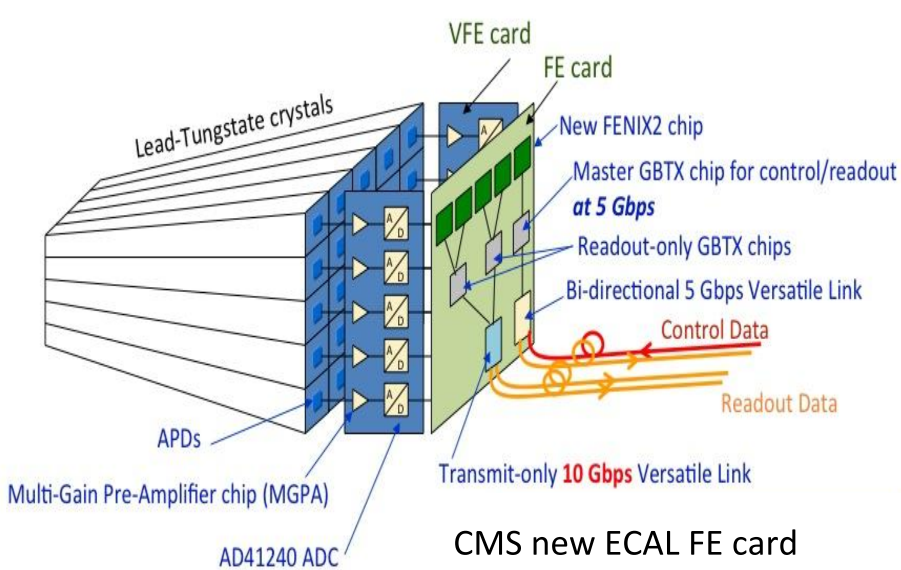
- Sensor technology
  - Hybrid pixels - radiation up to > 10^{16} neq cm^{-2}
    - n-in-p planar for outer layers at -20°
    - Thin planar, 3D, diamond - innermost layers
  - CMOS MAPS for ALICE could be of interest with enhanced radiation tolerance & rate capabilities
- FE ASICS chips (low power)
  - Process in 130 nm (strips) and 65 nm (pixels)
- Optical links
  - GBTx and Versatile link (low power)
- High Density Interconnection
  - Bump-bonding - Through Silicon Vias light assemblies (important cost)
- Low powering scheme
  - DC/DC converters or serial powering (increase efficiency - reduce material)
- Light materials
  - Thermal properties for low temperature
- Cooling
  - Two phase CO_2 cooling for all experiments with high power devices (100kW)

Calorimeter upgrades

- All experiments need new read-out electronics to access full granularity and/or increase data transfer bandwidth and/or allow higher trigger/DAQ rates
  - Front-end chips depend on calo technology, but needs are similar for large dynamic range and analog to digital conversion
  - Choice of technology ASICs or Custom Off The Shelf components has common interest
  - Transfer of data at interaction rate - need high bandwidth links 10 Gbps or higher

ATLAS and CMS calorimeter electronics upgrades in Phase1 anticipate Phase 2 need



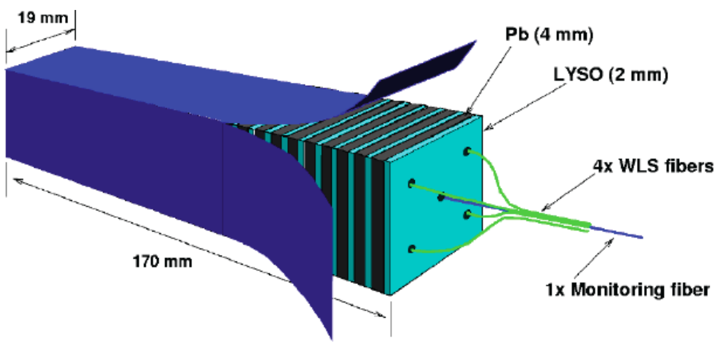


CMS new ECAL FE card
for trigger/latency/rate

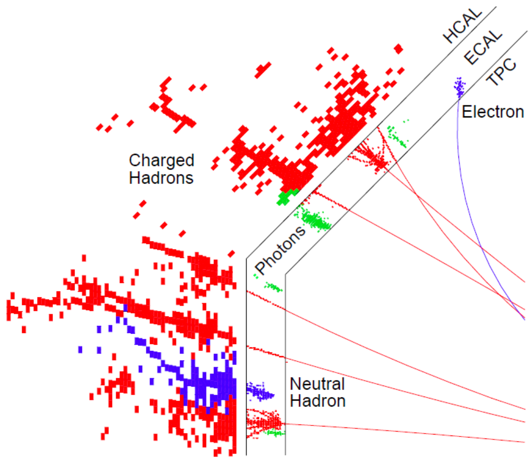
CMS Endcap Calorimeters for HL-LHC

- Tower geometry (as in present detectors)
  - Shashlik ECAL with crystals (resolution) & radiation tolerant HCAL with scintillators finer transverse granularity for both ECAL and HCAL for PU mitigation
- 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 |η| ~ 4 (avoid transition to Hadron Forward Calo)
- Consider precise timing measurement (≤ 30 ps) to mitigate PU effects of neutrals

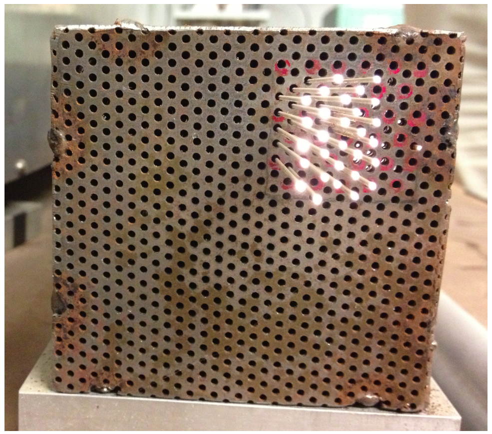
→ R&D on radiation tolerant Crystals/WLS fibers/Photo-detectors, but also MPGDs - silicon detectors, and precise timing measurement devices



Shashlik concept



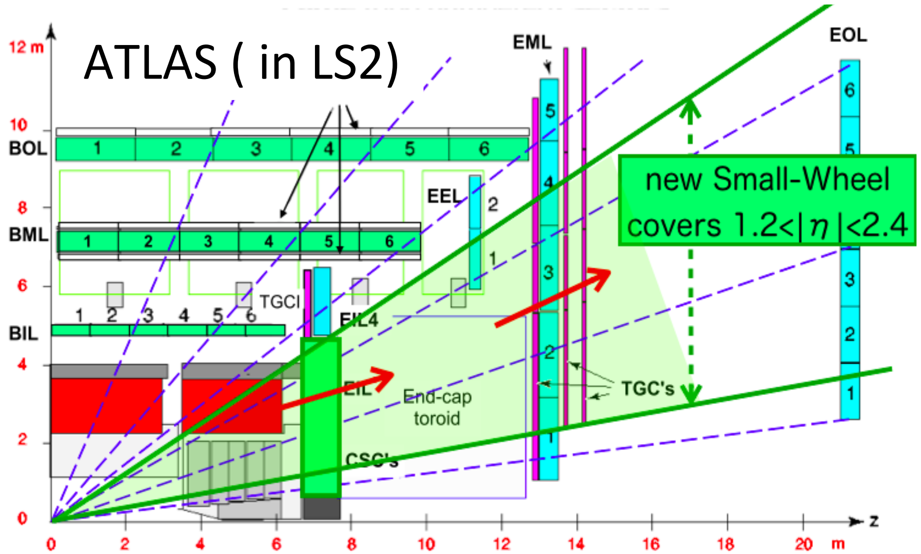
CALICE concept

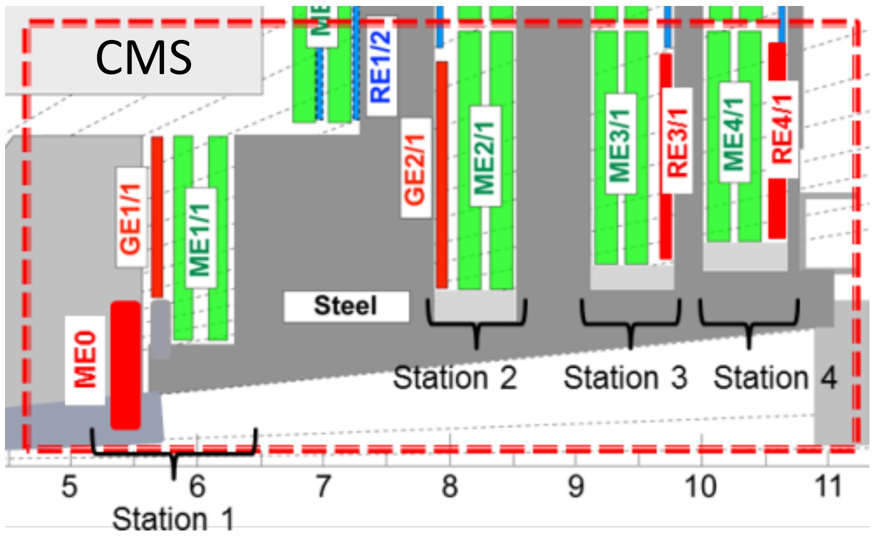


DREAM concept

ATLAS and CMS Muon system upgrades

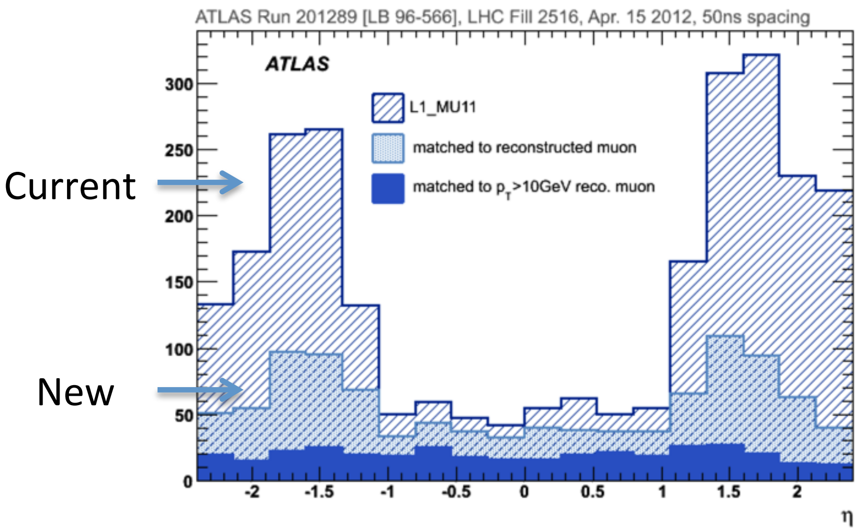
- Muon Chambers are expected to sustain 3000 fb^{-1}
  - Studies of long term operation and aging mitigations are ongoing
- Main R&Ds are for new forward detectors in ATLAS and CMS
  - Increased rate capabilities 1 to ≥ 10 kHz/cm^2 and radiation hardness
  - Improved resolution 1 to 0.1 mm for online trigger and offline analyses
  - Improved timing precision ≤ 100 ps for background rejection
  - ➢ GEM detectors CMS forward muons chambers but also ALICE TPC upgrade and interest for high granularity forward calorimetry in CMS
  - ➢ Micromegas and sTGCs (ATLAS forward chambers)
  - ➢ RPCs - low resistivity glass for rate capability - multi-gap for high precision timing in CMS forward chambers

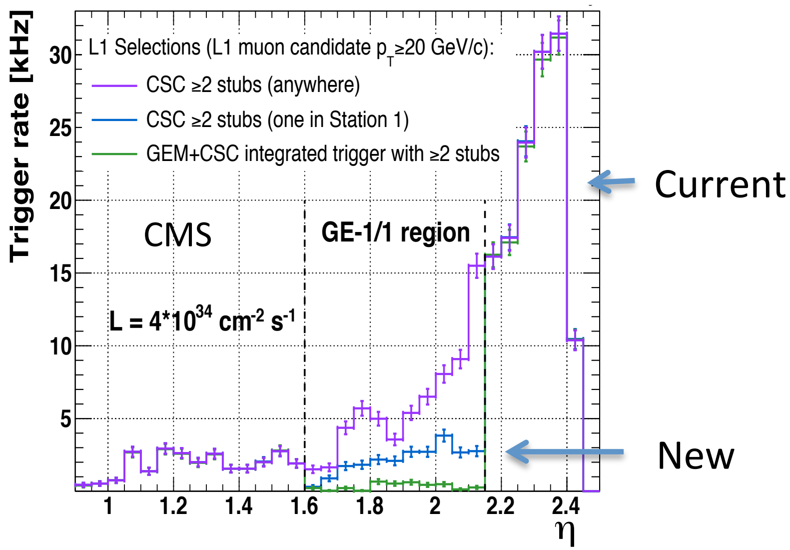


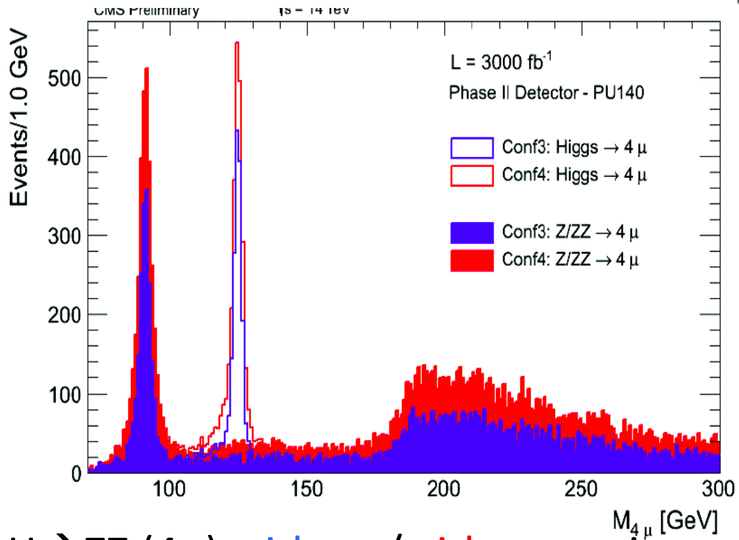


ATLAS and CMS Muon systems upgrades

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







H→ZZ (4μ) without/with extension

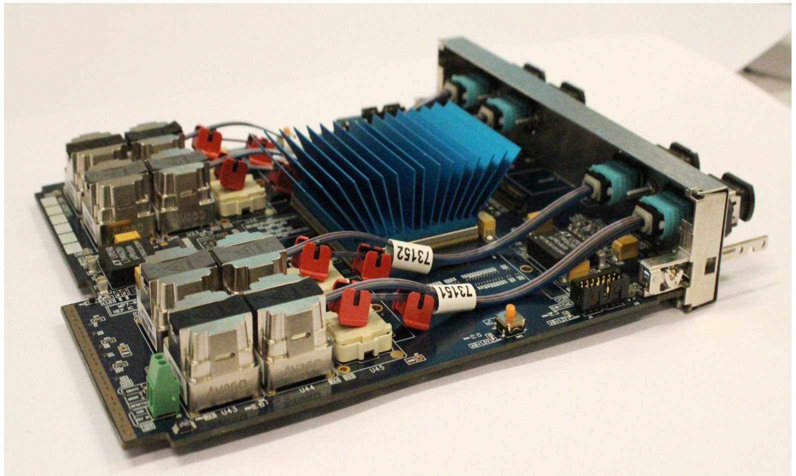
CMS considers muon tagging extension up to |η|~4 coupled with extension of endcap calorimeters & pixel disks

To increase physics acceptance for physics channels with multi lepton final state

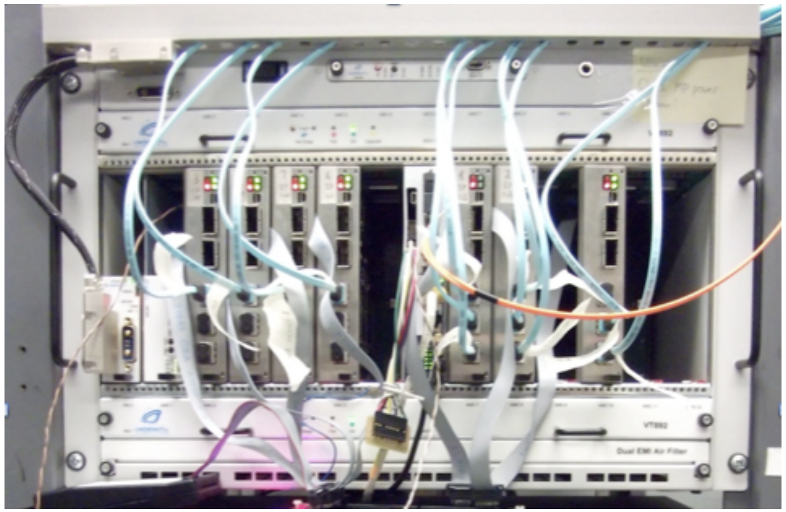
ATLAS and CMS L1-Trigger, hardware upgrades

Example of Phase 1 upgrade

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



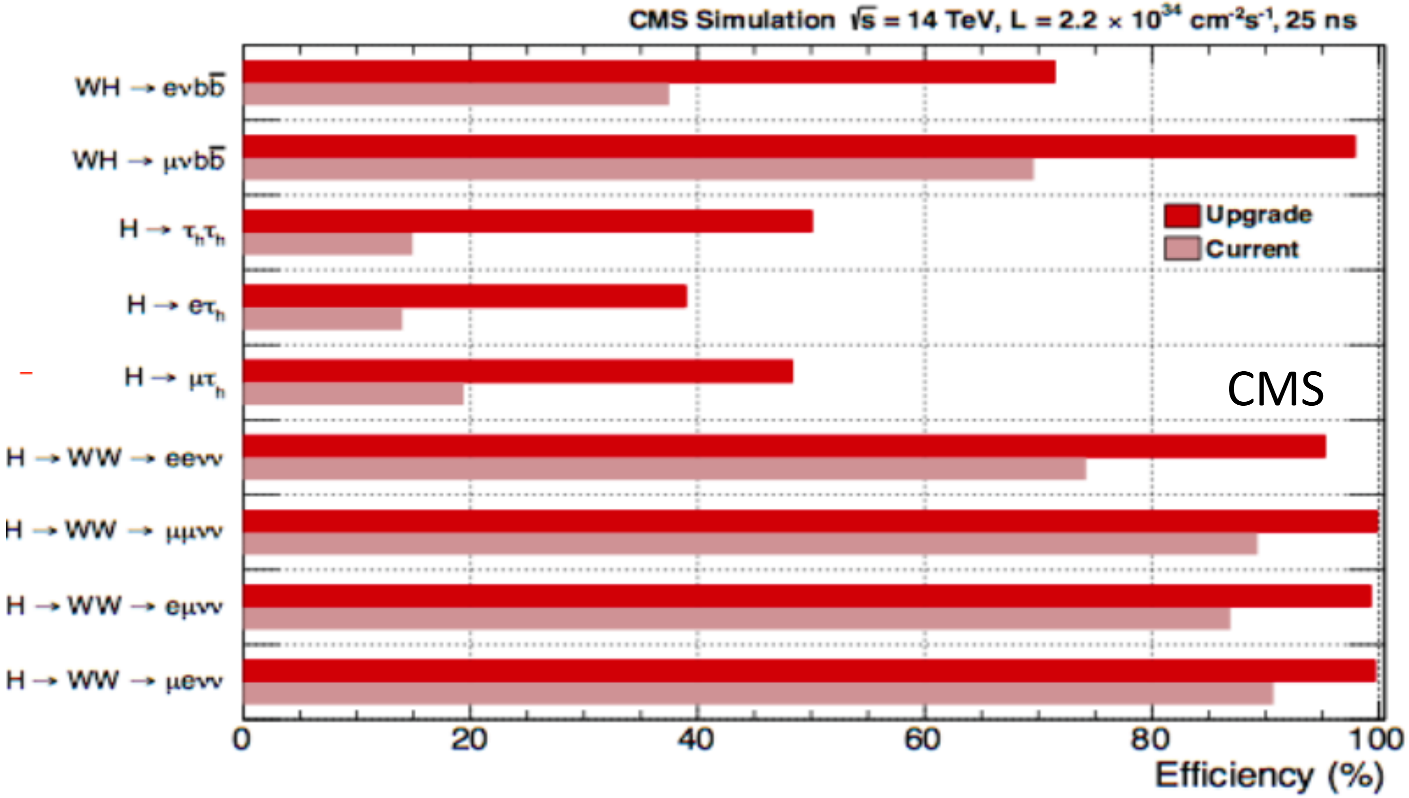
CMS: MP7 calorimeter trigger board & µTCA crate



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

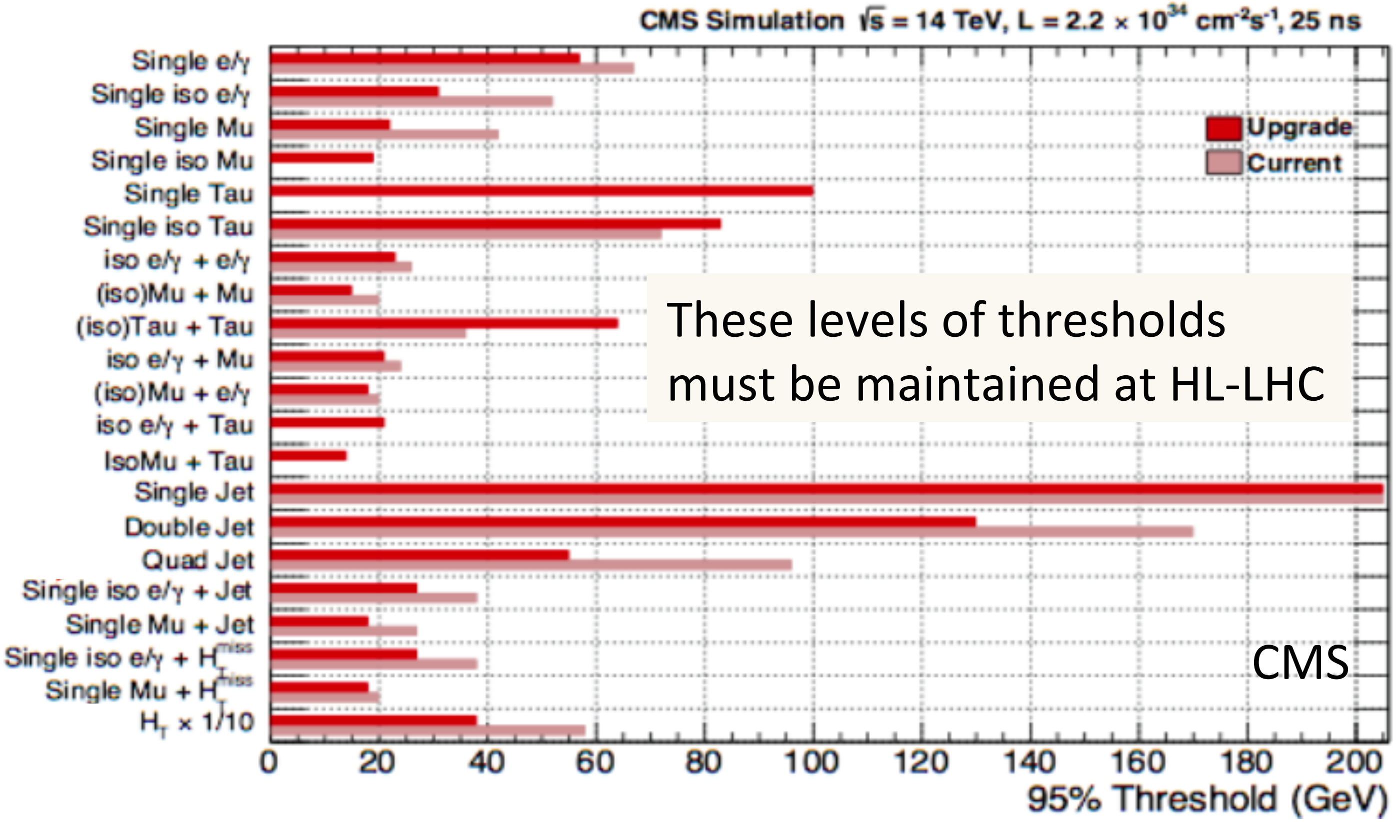
ATLAS and CMS L1-Trigger, hardware upgrades

- Example of Performance in phase 1
  (higher calorimeter granularity - improved muons - improved algorithms)
  - e and γ isolation with PU subtraction
  - Jet finding and Et missing with PU subtraction
  - Improved τ identification (small cone jets)
  - μ momentum and implementation of isolation



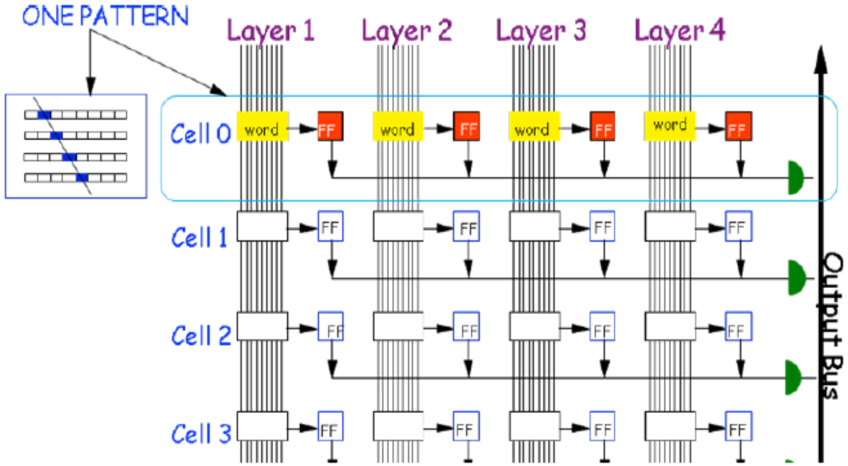
ATLAS and CMS L1-Trigger, hardware upgrades

- Example of Performance in phase 1
  (higher calorimeter granularity - improved muons - improved algorithms)
  - e and γ isolation with PU subtraction
  - Jet finding and Et missing with PU subtraction
  - Improved τ identification (small cone jets)
  - μ momentum and implementation of isolation



Trigger system upgrades for HL-LHC

- L1-trigger, Hardware
  - ATLAS
    - Level 0 in 5 μs - 500 kHz to readout tracker in Region of Interest
    - Level 1 in 20 μs - up to 200 kHz input to computing level (HLT)
  - CMS
    - Tracker information (Pt≥2) at 40 MHz - crystal granularity in ECAL
    - Level 1 in ≥ 10 μs - up to 1 MHz input to computing level (HLT)
- ➢ Track Trigger implementation
  - Pattern recognition with Custom ASIC Associative Memory chips (as developed for ATLAS FTK in phase 1) followed by a track fit in a FPGA
- Computing trigger level
  - ATLAS & CMS output up to 10 kHz
  - LHCb 40 MHz input - 20 kHz output
  - ALICE 50 kHz output with online reconstruction to reduce data bandwidth



PRAM chip architecture for ATLAS FTK

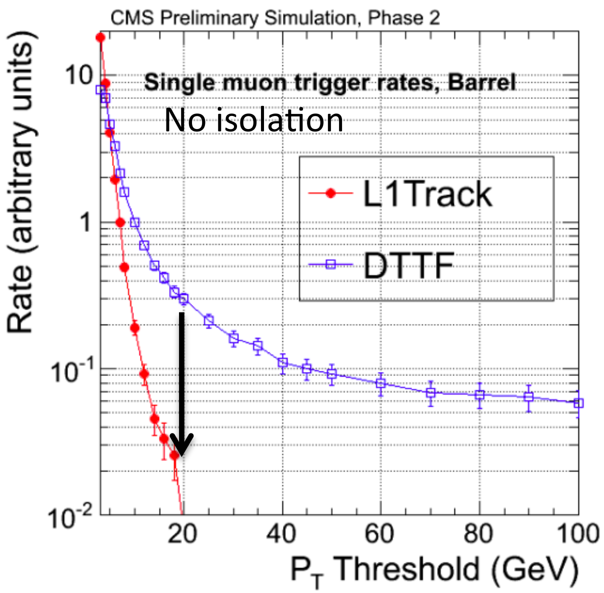
	Event size [kB]	L1 Rate [kHz]	Bandwidth [Gb/s]	Year [CE]
ALICE	20000	50	8000	2019
ATLAS	4000	>200	6400	2022
CMS	4000	<1000	32000	2022
LHCb	100	40000	32000	2019

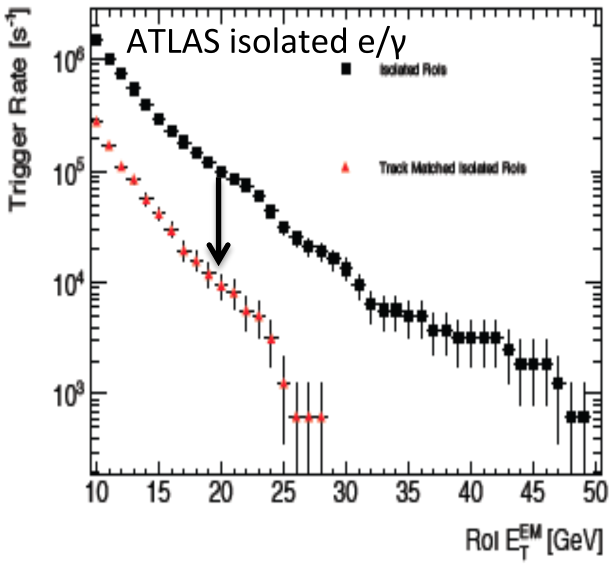
ATLAS and CMS L1-trigger upgrade for HL-LHC

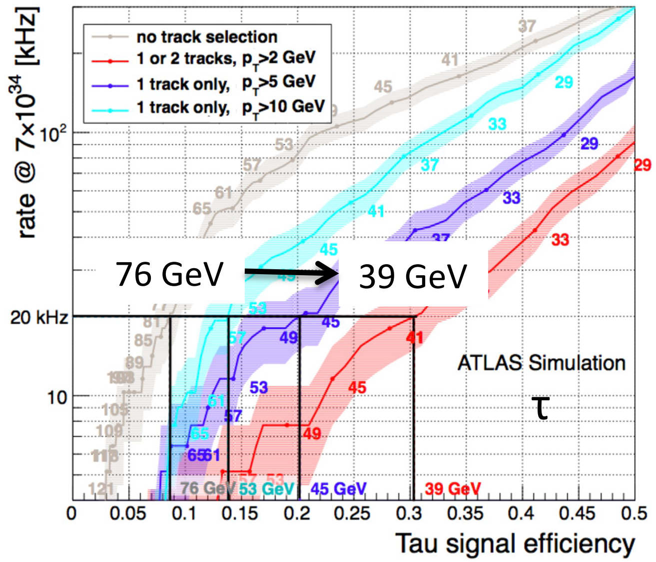
- Track trigger will reduce rates through
  - High momentum resolution of leptons - sharp thresholds
  - Isolation for e/γ/μ/τ - reduce background
  - Association of particles to same primary or secondary vertex - reduce combinatorial effect of PU in multi-particle/jet triggers

  → Gain ~ 10 for lepton triggers - will allow maintaining low trigger thresholds
- Increase of L1 bandwidth will provide flexibility
  - Allocate bandwidth to specific triggers - driven by physics or lower track-trigger efficiency

  → Preliminary ~ 20-40% threshold reduction - may also allow to tolerate higher PU

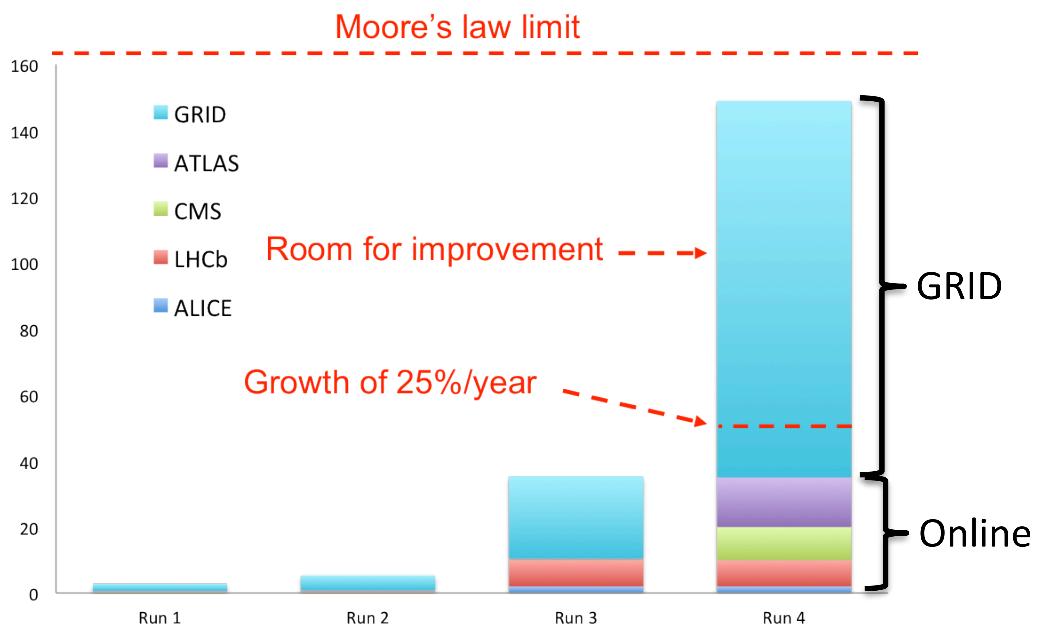


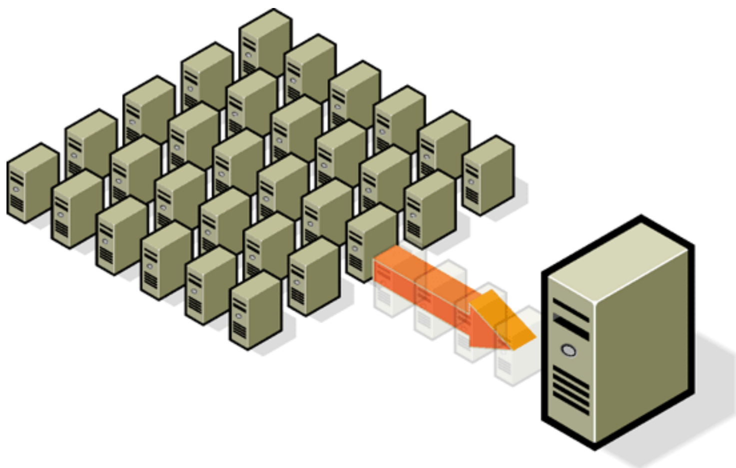




ATLAS and CMS Computing and Software for Phase 2

- 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

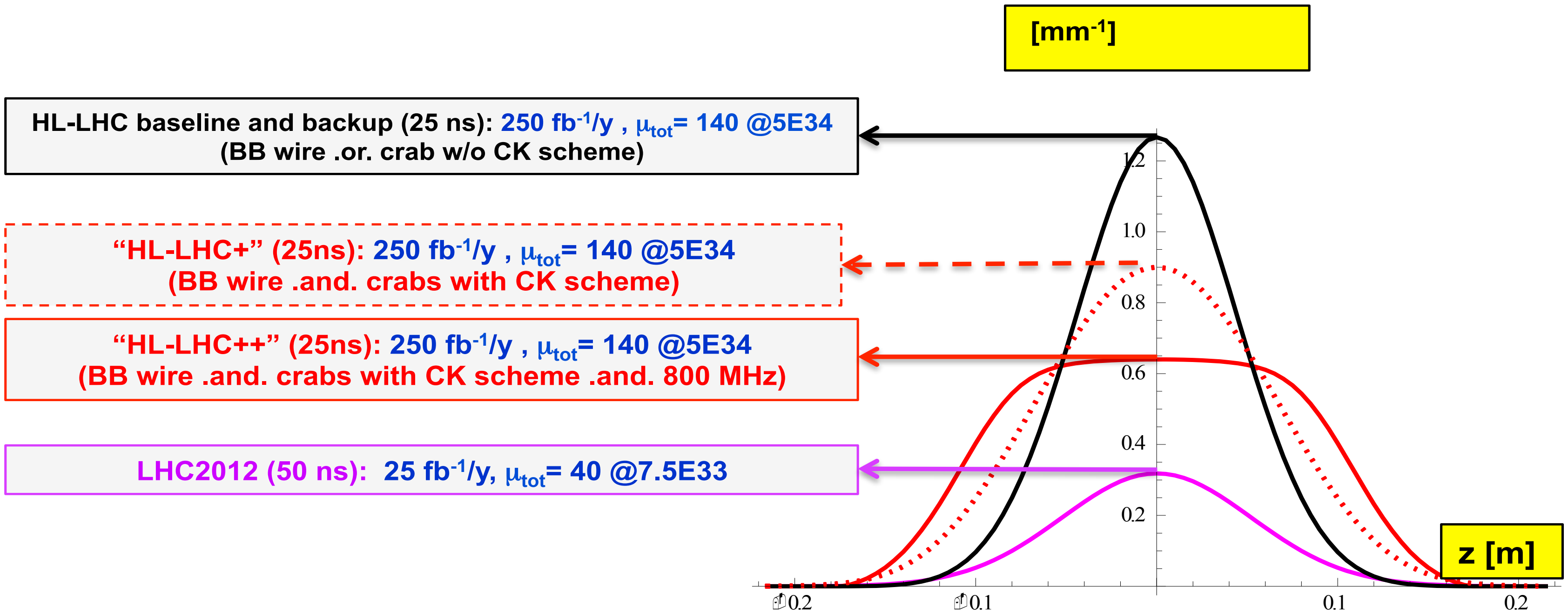




Virtualization is the key technology behind the Cloud

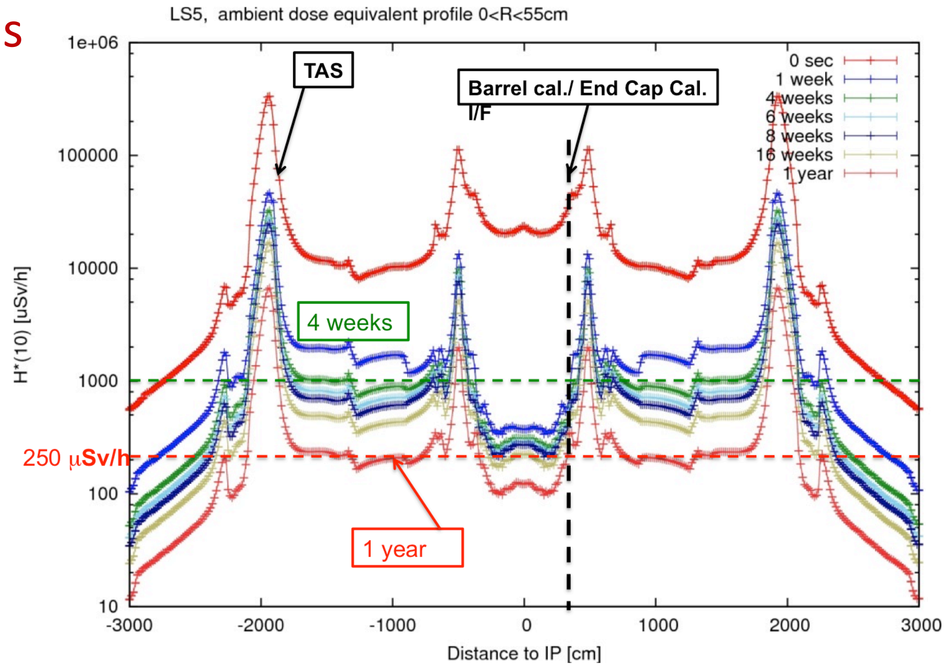
Accelerator and Experiment interface (ATLAS & CMS)

- Different upgrade scenarios lead to options for luminous region (see below)
  - With possibility to lower the PU density → ATLAS and CMS to evaluate benefit
- New quadrupoles at IR will have twice the present aperture
  - Requires modification of absorbers (TAS) in the IR - appear compatible with small radius beam pipe - highly desirable to anticipate work in LS2 (lower activation - time gain in LS3)
- Beam loss risks (for new crab cavities and experiments)
  - No show stopper from preliminary studies - more work is needed



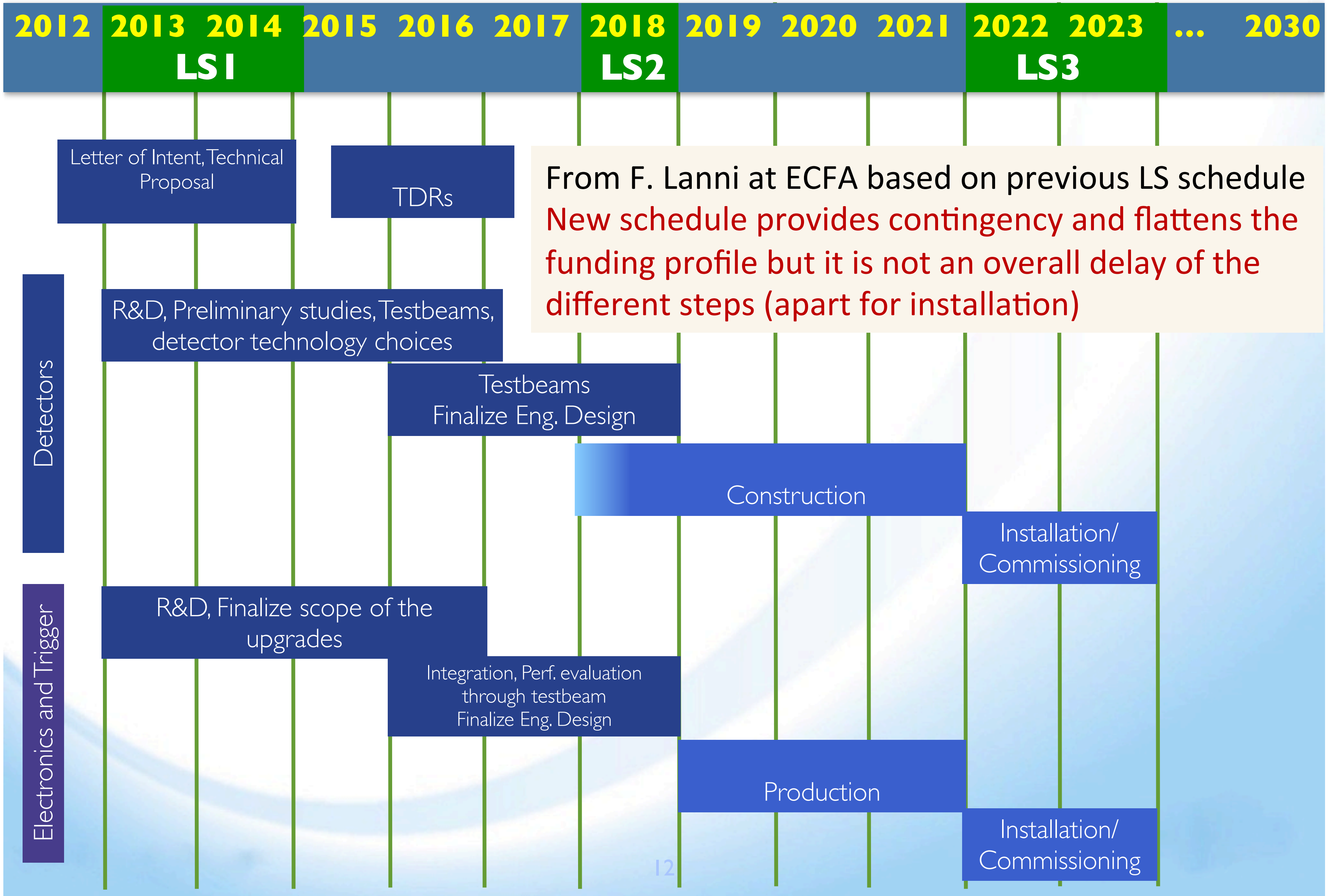
ATLAS and CMS Infrastructure upgrades and installation

- Infrastructure
  - 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
- Radiation and activation issues will become more and more challenging
  - Work in LS3 will need to satisfy safety rules:
    - Personal dose < 2mSv/month and < 20mSv/year
    - 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
  - Sufficient ant and skilled manpower
  - Present estimates 30 - 36 months

ATLAS and CMS Phase 2 upgrades technical schedule



From F. Lanni at ECFA based on previous LS schedule

New schedule provides contingency and flattens the funding profile but it is not an overall delay of the different steps (apart for installation)

Concluding remarks

- The LHC at 300 fb^{-1} and then 3000 fb^{-1} will be a unique facility for particle physics in the next decades, for search of new particles and precise measurements of Higgs properties

- Preparing detectors for high precision measurements at the highest luminosity and radiation levels is critical and will be a challenge

- Collaborations are analyzing data and already upgrading for phase 1, but the timescale for HL-LHC upgrades is tight and we need strong efforts to optimize detector designs for physics performance and to rapidly proceed with R&D to develop cost effective technical solutions