ATLAS/CMS Upgrades

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on Behalf of the ATLAS and CMS Collaborations

ATLAS EXPERIMENT

CMS

Flavor Physics and *CP* Violation

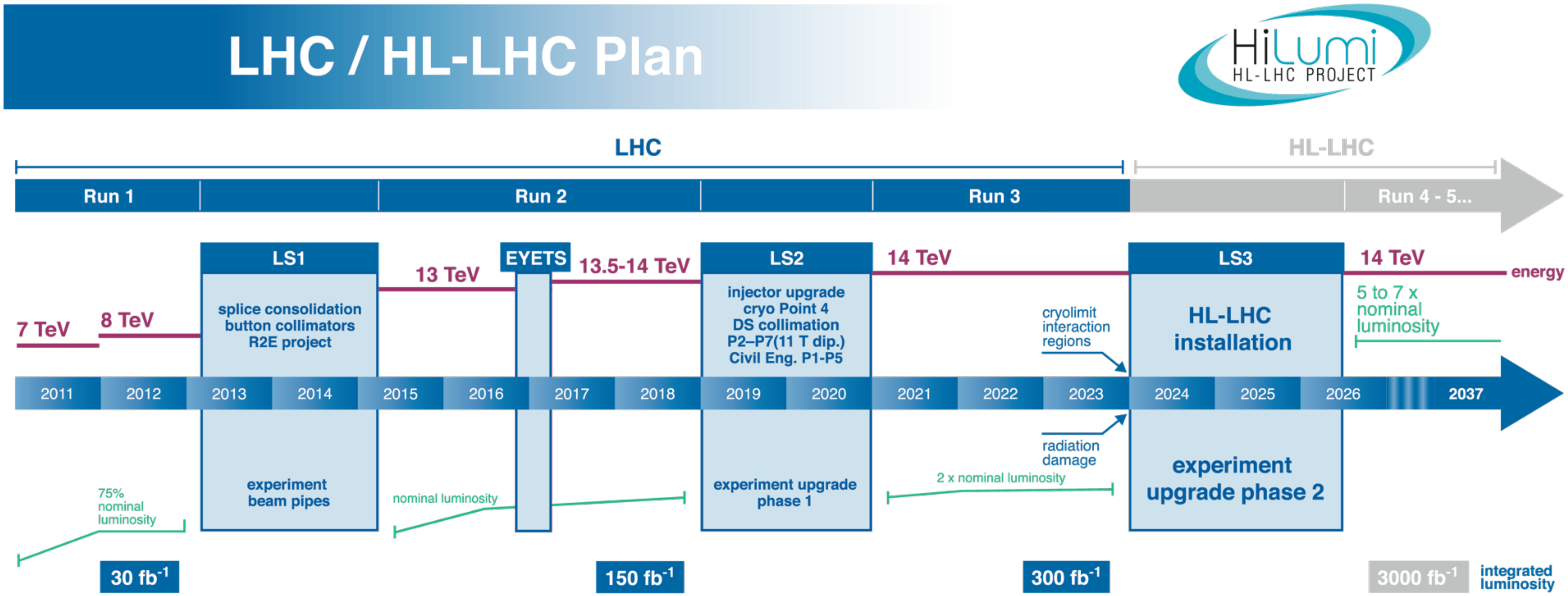
FPC*P* 2016

Outline

- LHC/HL-LHC plan
- ATLAS/CMS upgrades
- Physics prospects

LHC/HL-LHC Plan

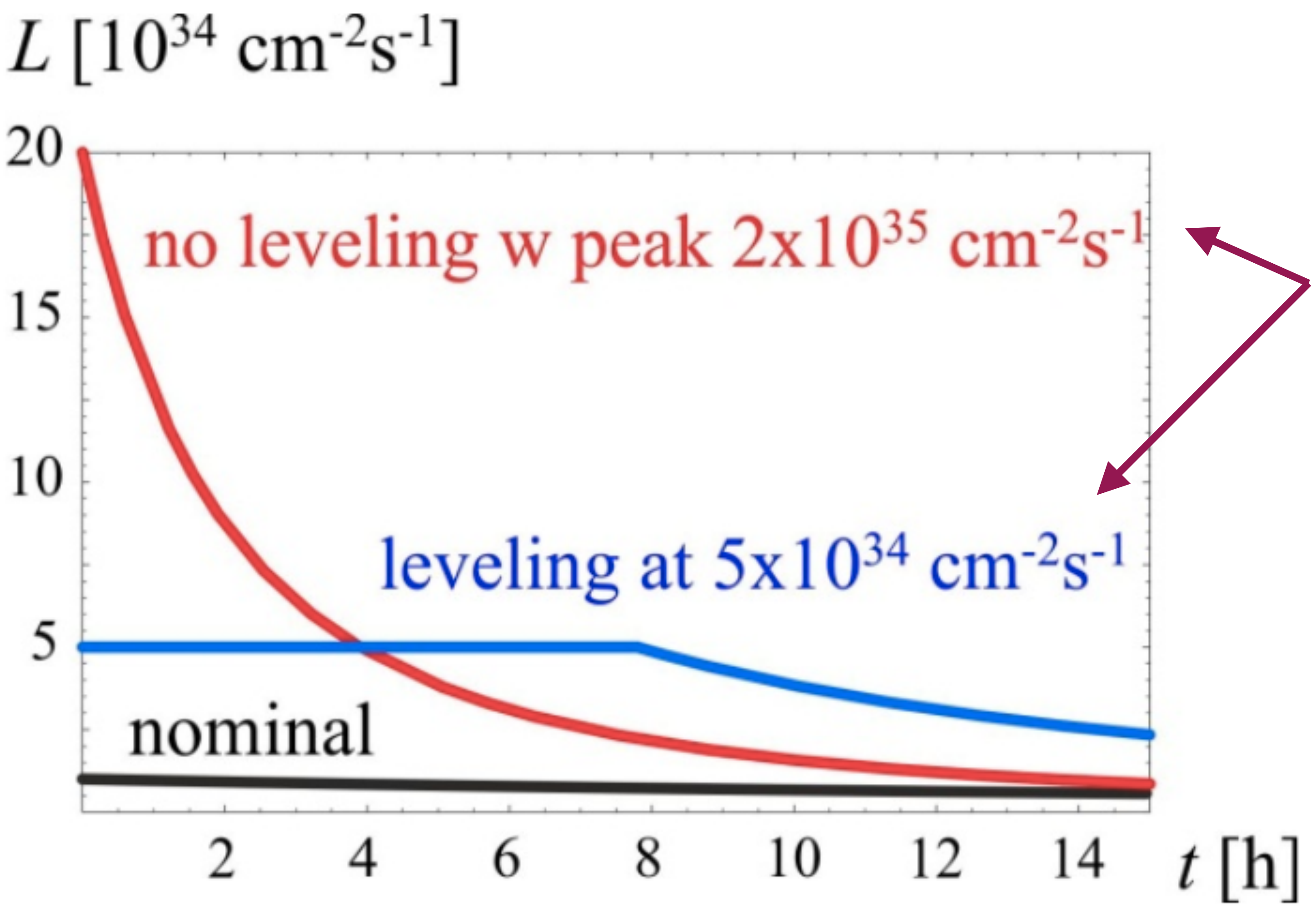
Overview



- SM precision studies and BSM searches with 13-14 TeV and 3000 fb^{-1}.
- Peak instantaneous luminosity: $5\text{-}7 \times 10^{34}\ cm^{-2}s^{-1}$ — a lot of challenges.
- Two upgrade phases: Phase 1 (2019-2020) and Phase 2 (2024-2026).

http://hilumilhc.web.cern.ch/about/hl-lhc-project

Luminosity levelling



The average luminosity is almost the same.

HL-LHC is designed to operate with levelling.

- Lower pileup in the experimental detectors
- Lower energy deposition by the collisions in the interaction region magnets

CERN-ACC-2015-0140

ATLAS/CMS Upgrades

Challenges

Increased luminosity provides a significant challenge for the experiments.

Upgrades are essential to exploit the full potential of LHC and HL-LHC.

- Higher radiation dose
- Higher pileup
- Higher particle rate
- Higher event rate

$\longrightarrow$

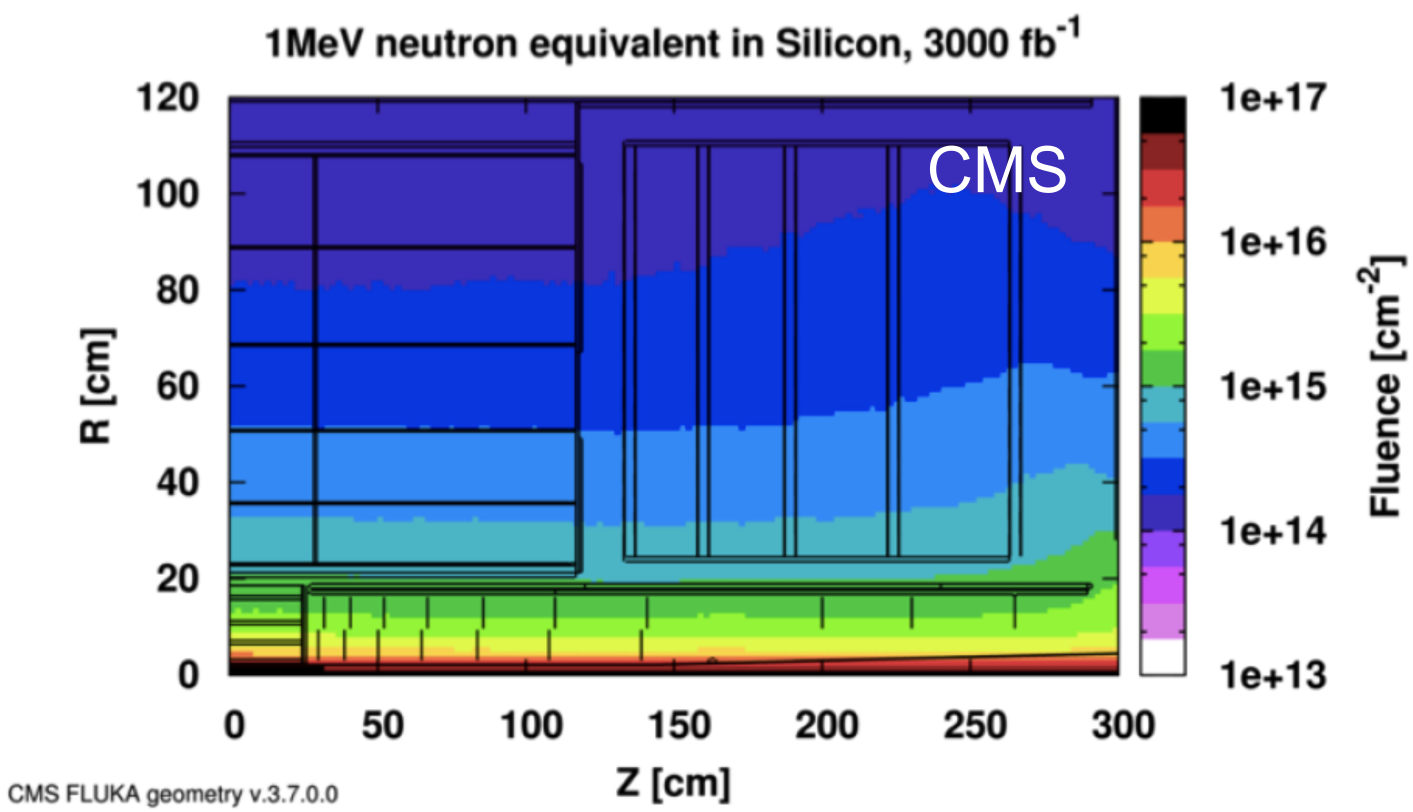
- Replacement of some of the detectors
- Replacement of the electronics
- Overall modifications

  on the trigger and readout scheme

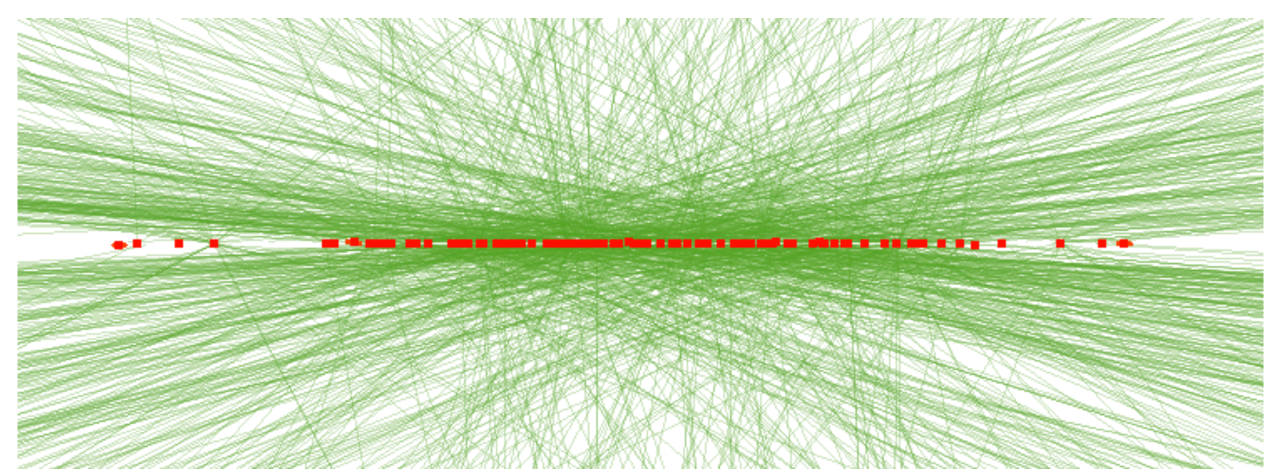
Inner tracker

Inner trackers will be in an extreme environment at HL-LHC.

- 1 MeV neutron equivalent fluence up to 2 x 10^{16} /cm^2.
- Ionisation dose up to 10 MGy.
- Particle rates up to 2 GHz/cm^2 — high occupancy, high bandwidth.



Pileup 140 expected at L = 5 x 10^{34} cm^{-2}s^{-1}

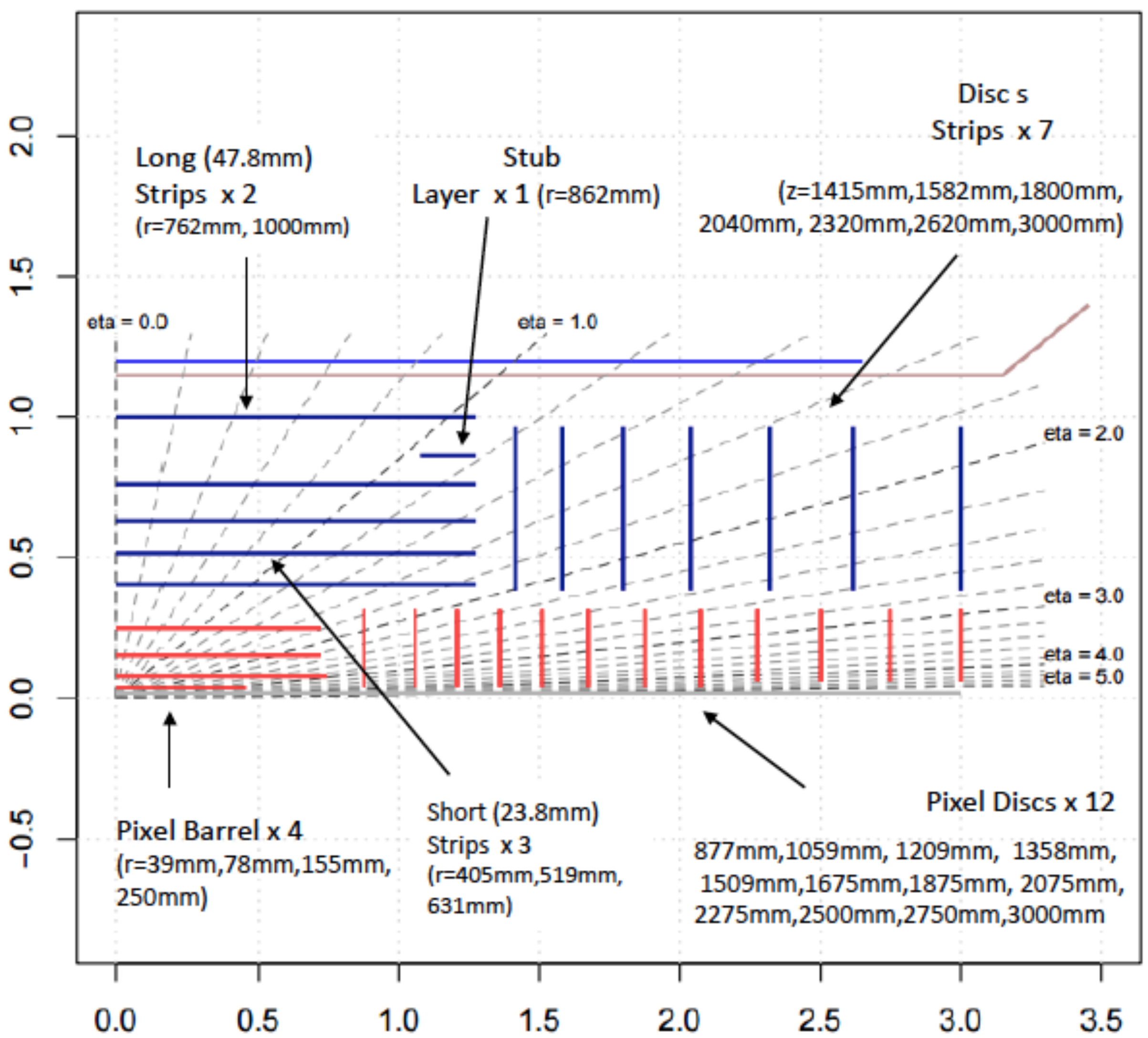


CERN-LHCC-2015-010; LHCC-P-008

Inner tracker

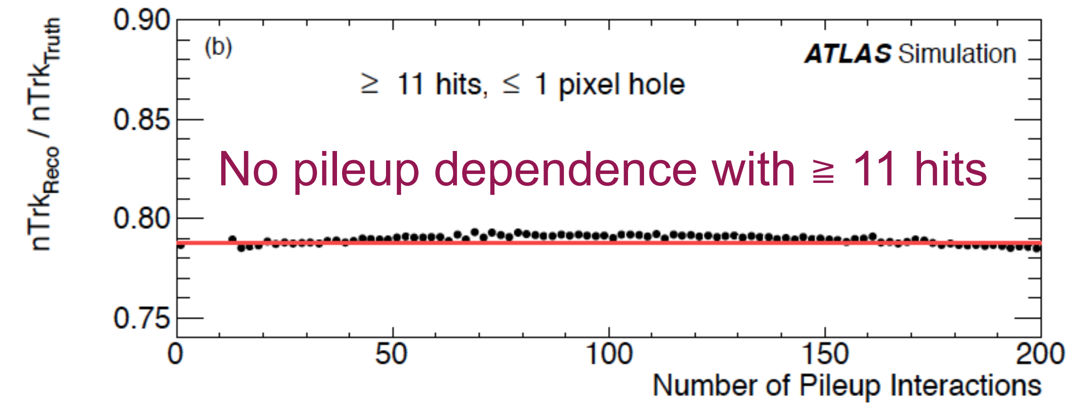
Entire tracker replacement (all-silicon tracker) at the Phase 2 upgrade.

Radiation tolerance, increased granularity, reduced material, extension to forward, …

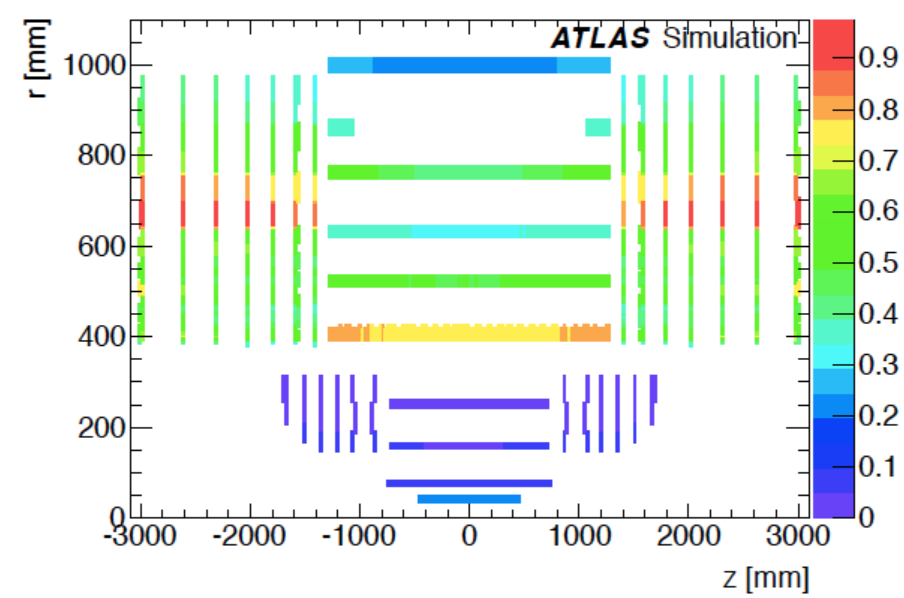


Pixel thickness possibly 150 μm, pixel size possibly 50 x 50 μm^2

Ratio of reconstructed to generated tracks



Channel occupancy [%] for 200 pileups

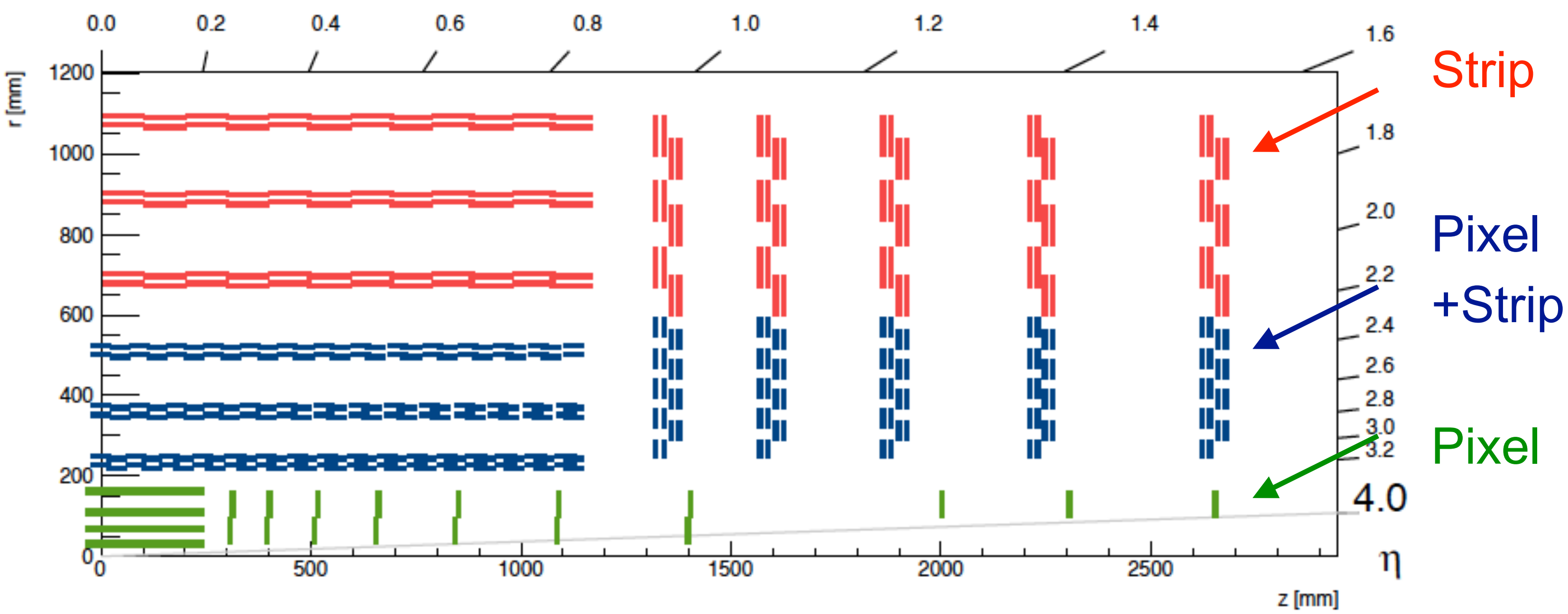


CERN-LHCC-2012-022; LHCC-I-023. CERN-LHCC-2015-020; LHCC-G-166.

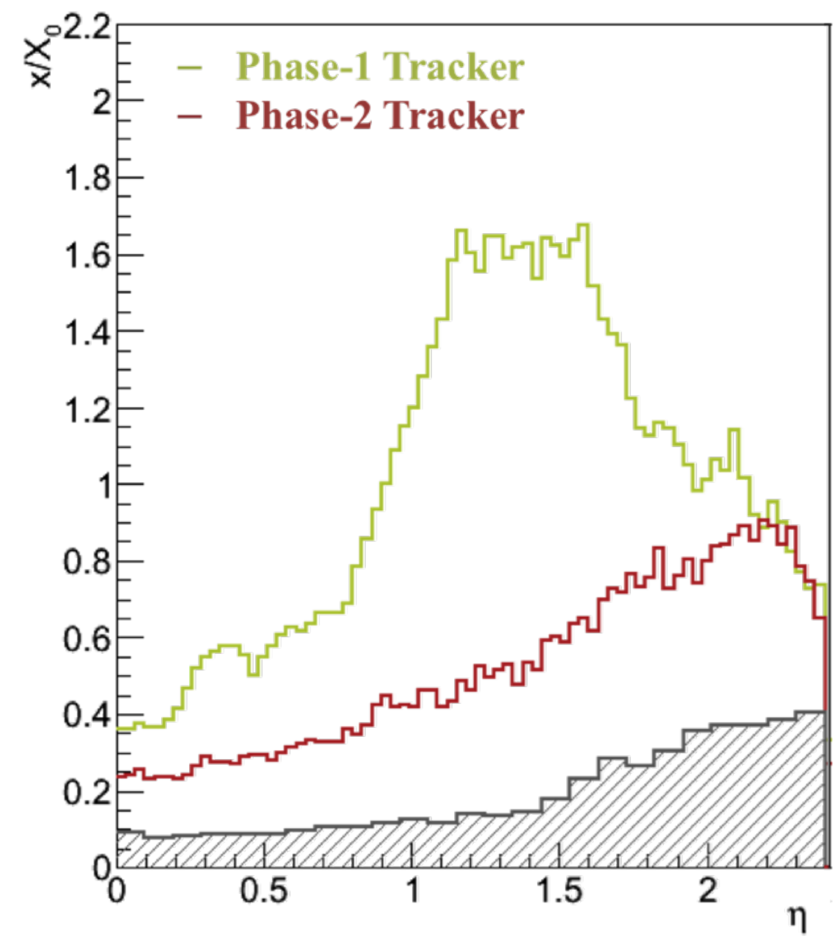
Inner tracker

Pixel detector replacement in the end of 2016 (as a Phase 1 project).

Entire tracker replacement at the Phase 2 upgrade.



Pixel size considered: 25x100 μm² and 50x50 μm²



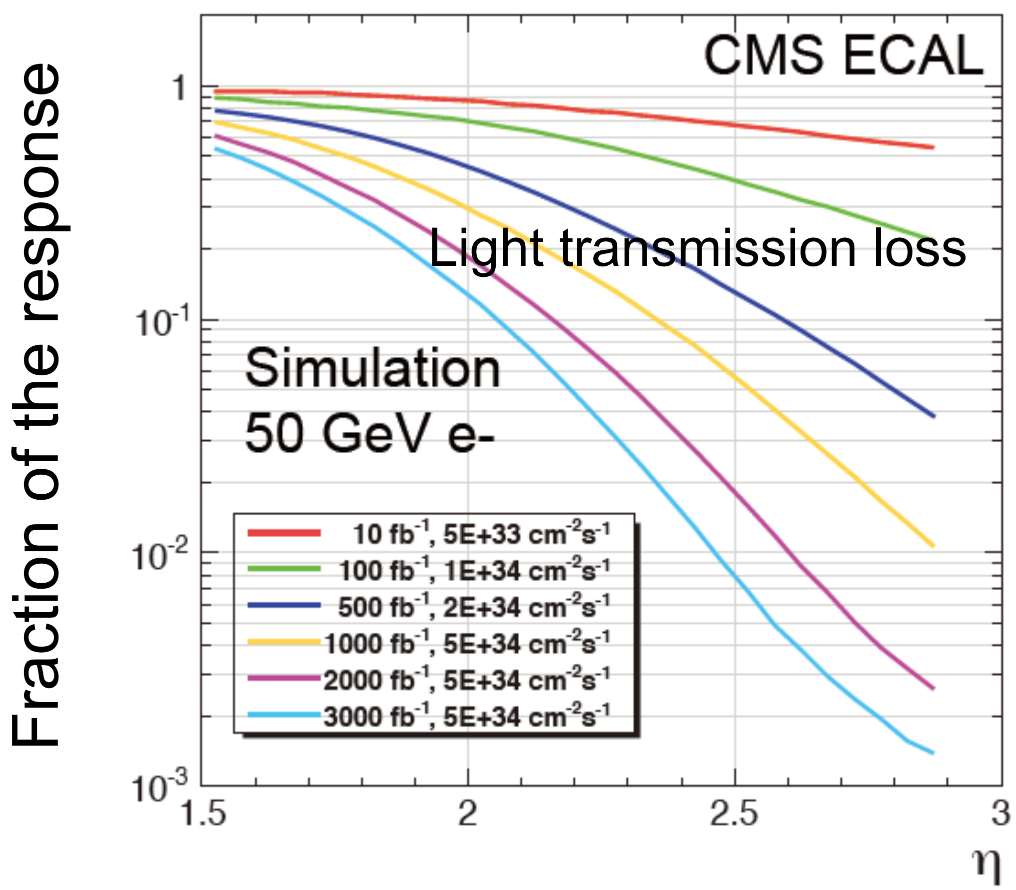
Radiation tolerance, increased granularity, reduced material, extension to forward, …

CERN-LHCC-2015-010; LHCC-P-008

Calorimeter

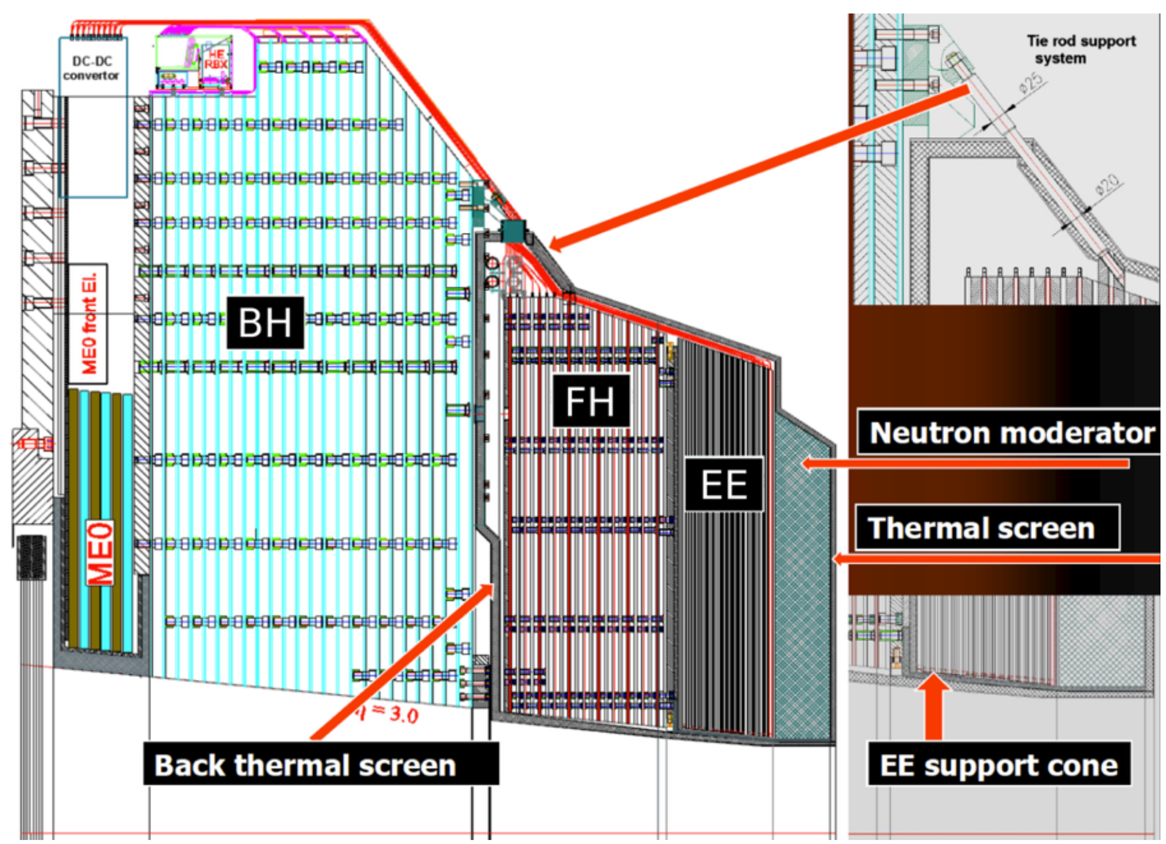
Endcap calorimeter will be replaced — longevity and performance issues.

Hadron fluence 2 x 10^{14} /cm^2 at |η| = 2.6.
Defects in lead tungstate scintillating crystal of the electromagnetic calorimeter.



Response degradation also expected for the hadron calorimeter.

A high-granularity sampling calorimeter with a tungsten/silicon electromagnetic part (EE) followed by brass/silicon (FH) and brass/scintillator (BH) hadronic parts.

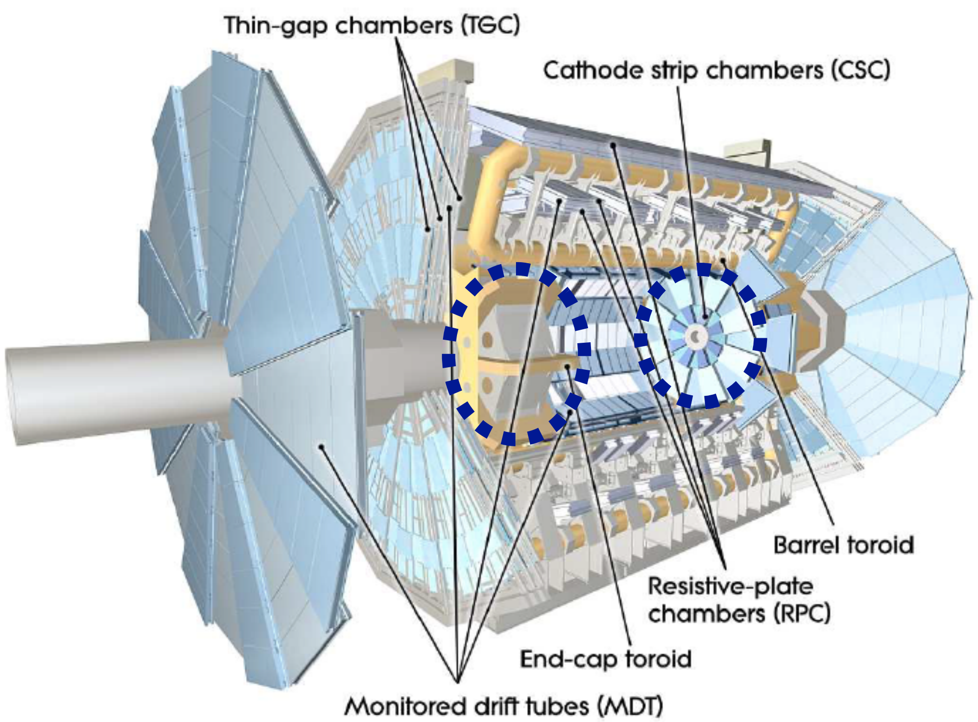


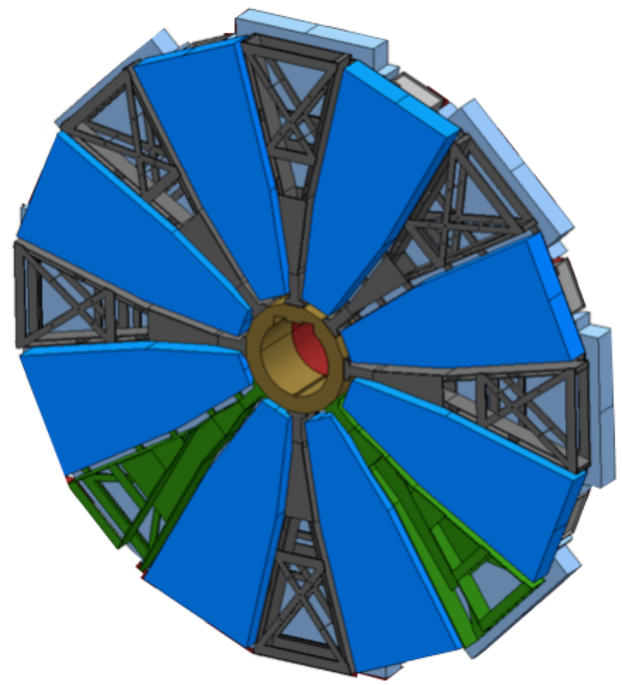
High performance at high pileup

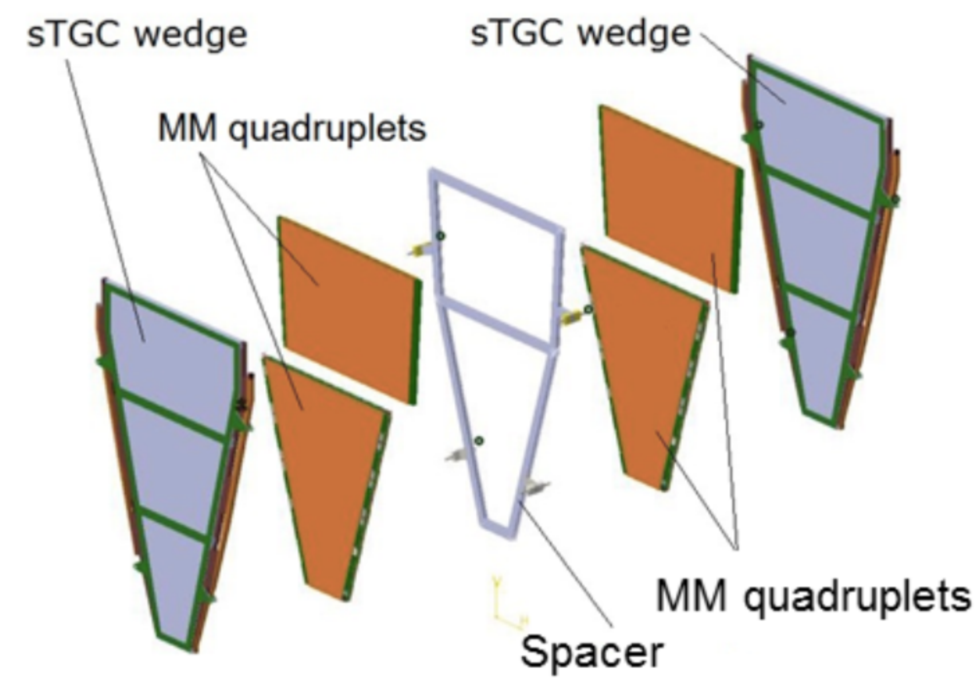
CERN-LHCC-2015-010; LHCC-P-008

Muon spectrometer

New Small Wheel will be installed to cope with a relatively high hit rate (~15 kHz/cm^2 at L = 7 x 10^{34} cm^{-2}s^{-1}) and also to improve muon trigger.







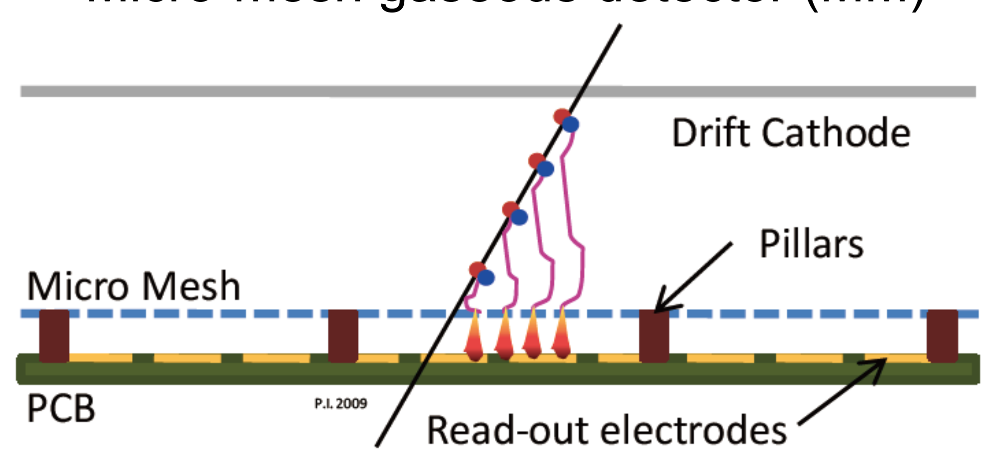
Both MM and sTGC for precision tracking and trigger.

Position resolution per layer: ~100 μm.

Segment angle resolution at first-level trigger: ~1 mrad.

Coverage: 1.3 < |η| < 2.7.

Micro-mesh gaseous detector (MM)

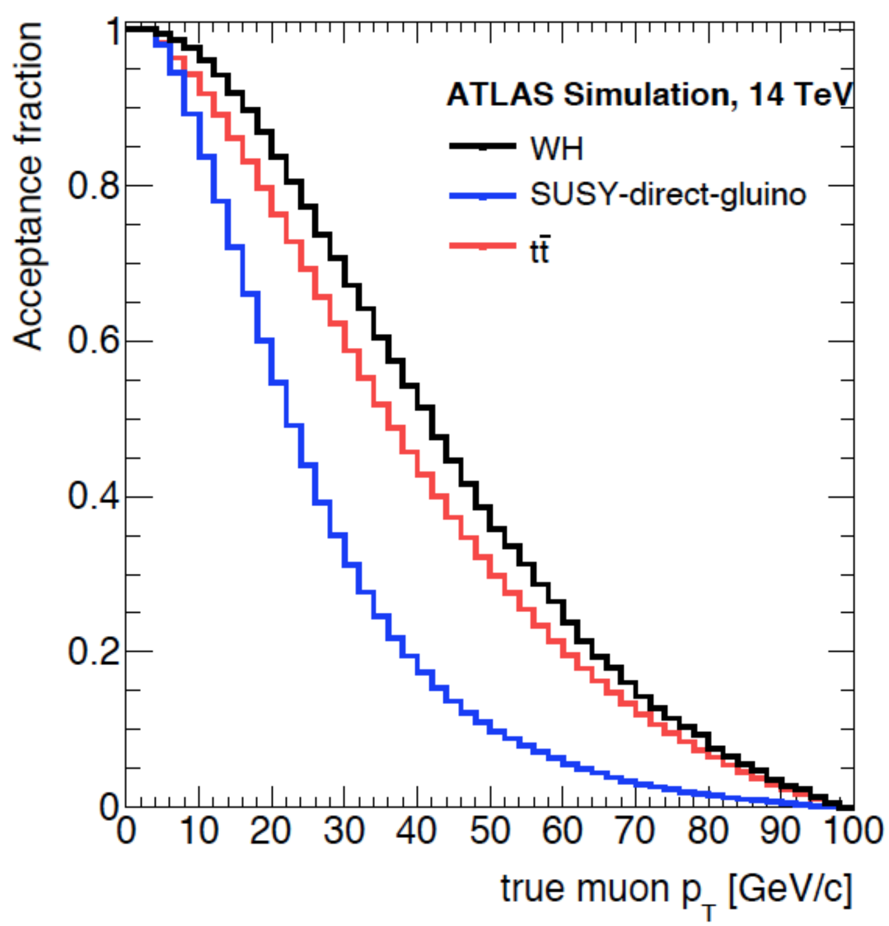


CERN-LHCC-2013-006; ATLAS-TDR-020

Trigger

More luminosity — more interesting events but also more background.

Without changes, trigger rates exceed the limits of trigger/readout system.



Simply increasing the threshold would kill the signal.

Choice of ATLAS and CMS at Phase 2 upgrades

Increase trigger rates.
First level: ~100 kHz → 750-1000 kHz
Storage level: ~1 kHz → 5-10 kHz

Increase latency — improve algorithm.
First level: ~3 μs → 6-12.5 μs

Electronics replacements for all sub-systems.

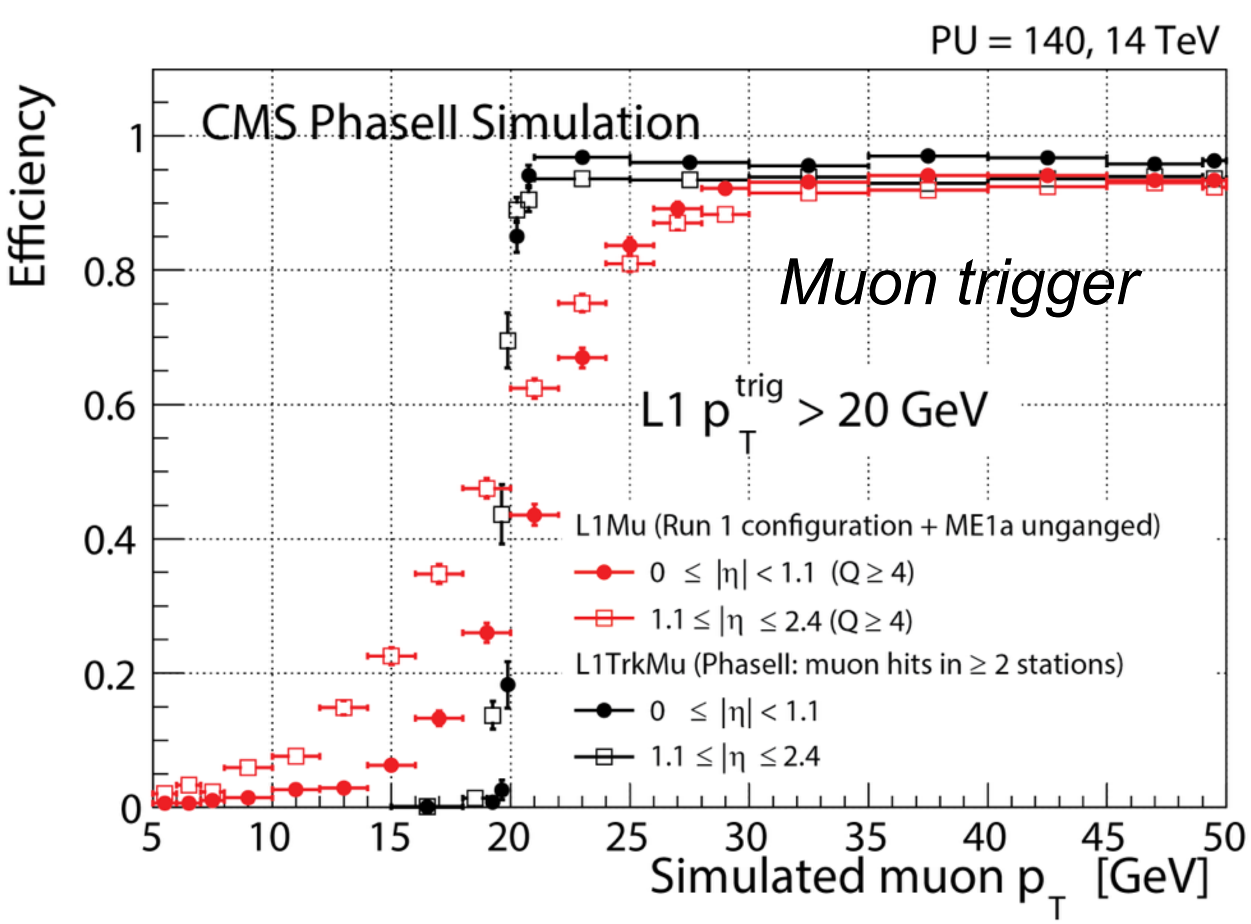
CERN-LHCC-2012-022; LHCC-I-023. CERN-LHCC-2015-019; LHCC-G-165. CERN-LHCC-2015-020; LHCC-G-166.

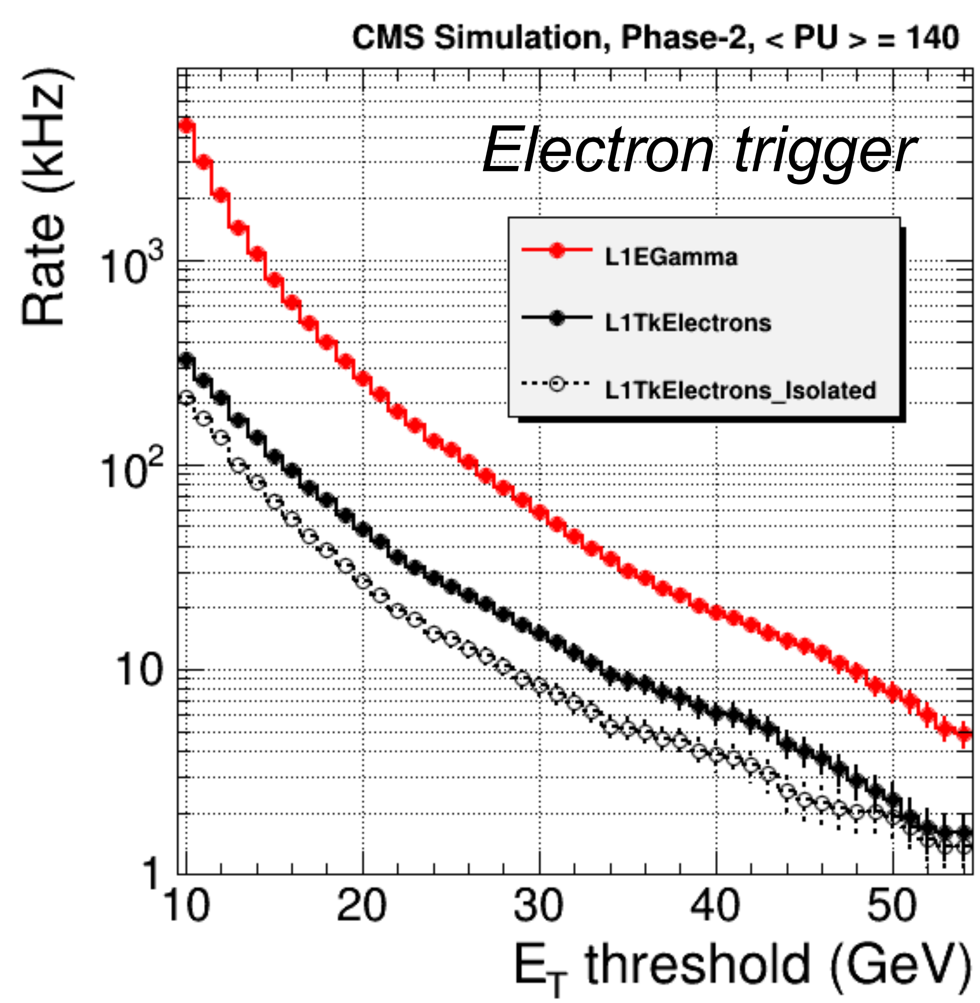
Trigger

Track trigger implementation in the first-level trigger.

Benefits: improved p_T determination, better identification of charged leptons, …

Technologies: studies ongoing for Associative Memories, FPGA, …





CERN-LHCC-2015-010; LHCC-P-008.

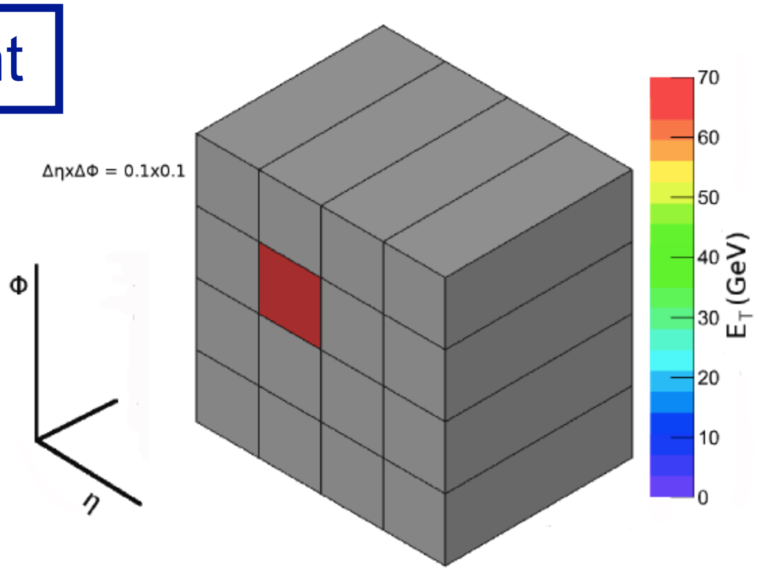
Trigger

ATLAS

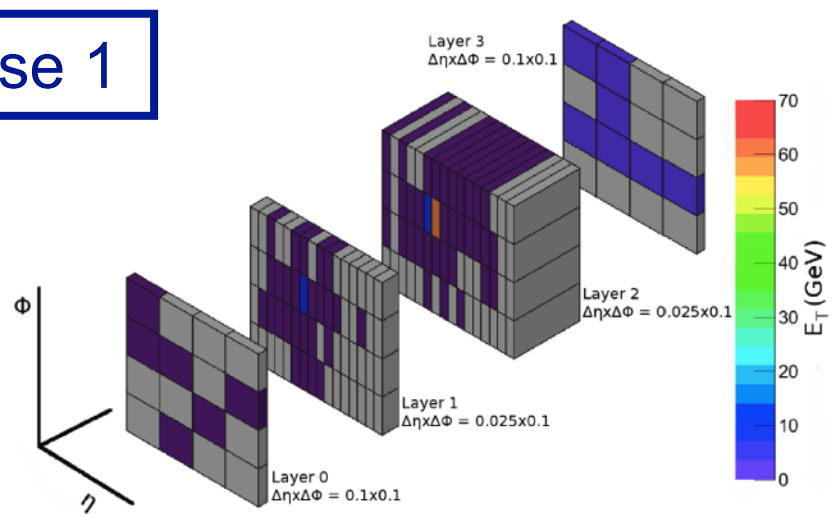
Calorimeter trigger upgrade

Higher granularity information provided at first-level trigger.
Less sensitive to pileup.

Current

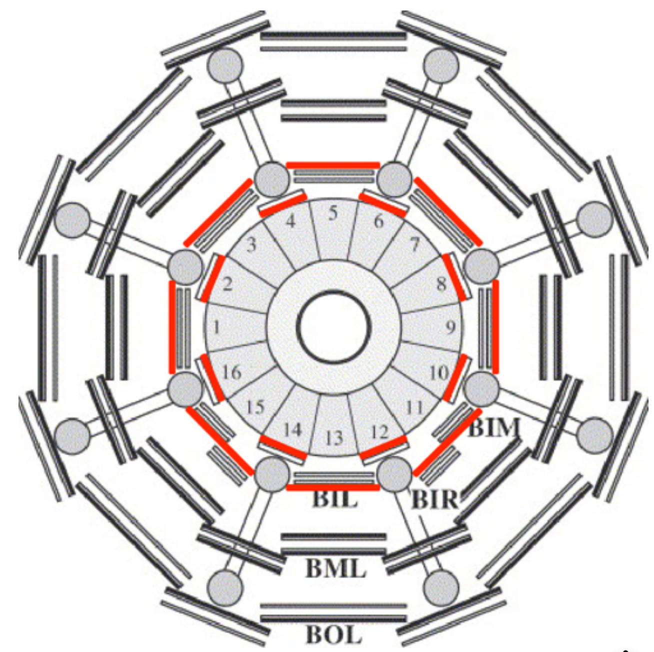


Phase 1



Muon trigger upgrade

Extend muon trigger acceptance in the barrel by additional chambers.



Phase 2

Additional RPCs

Muon $\mathcal{A}$ x ε in barrel could be improved from ~70% to ~95%.

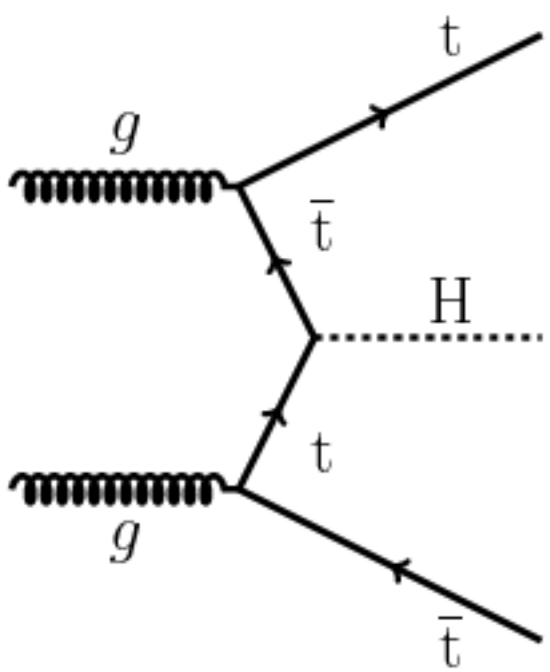
Trigger rate reduction for e, γ, …

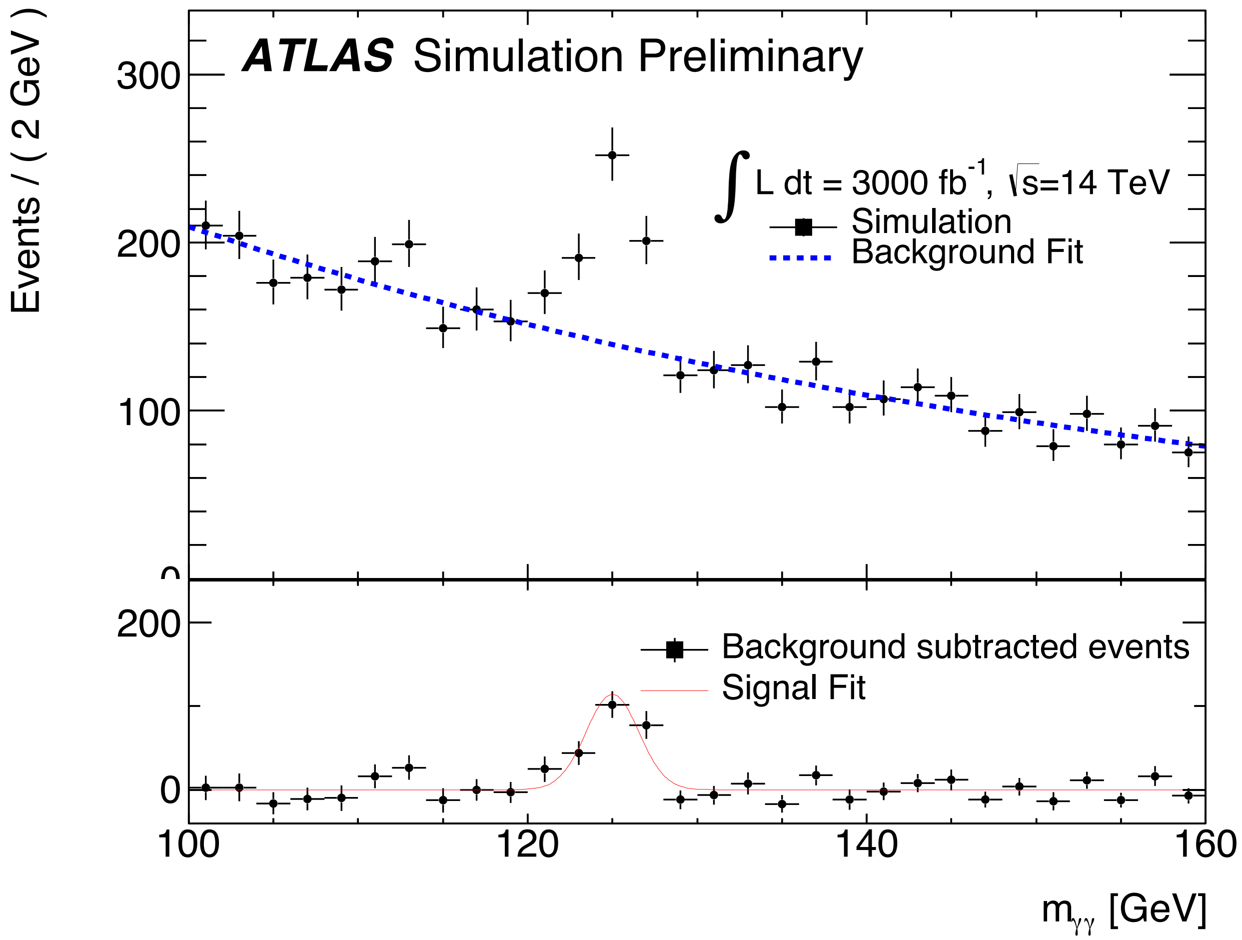
CERN-LHCC-2013-017; ATLAS-TDR-022-2013. O. Kortner, VCI 2016.

Physics Prospects — Examples

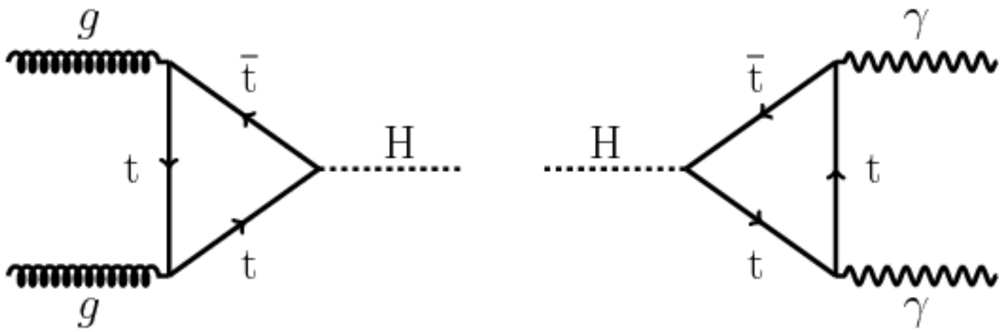
ttH

Direct probe of Higgs-top coupling.





gg→H and H→γγ indirect (loops).



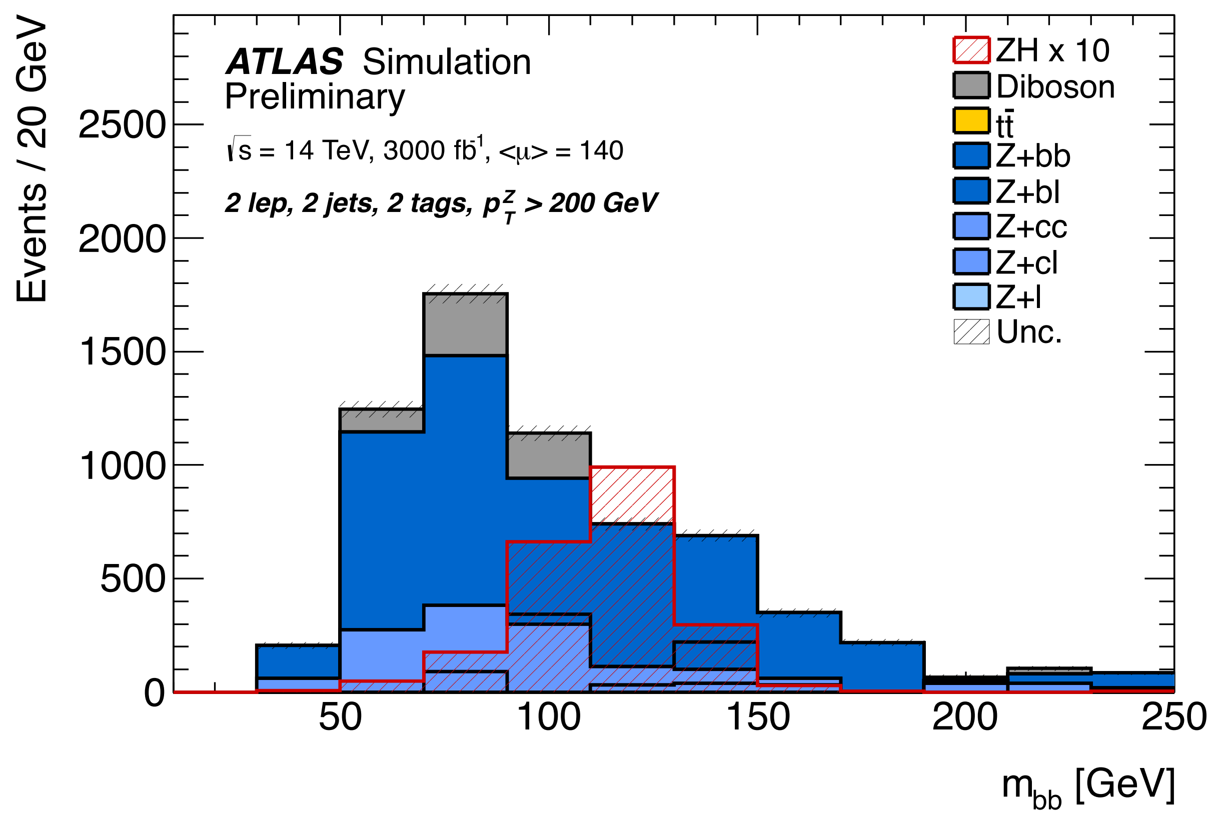
Observation expected for ttH, H→γγ.

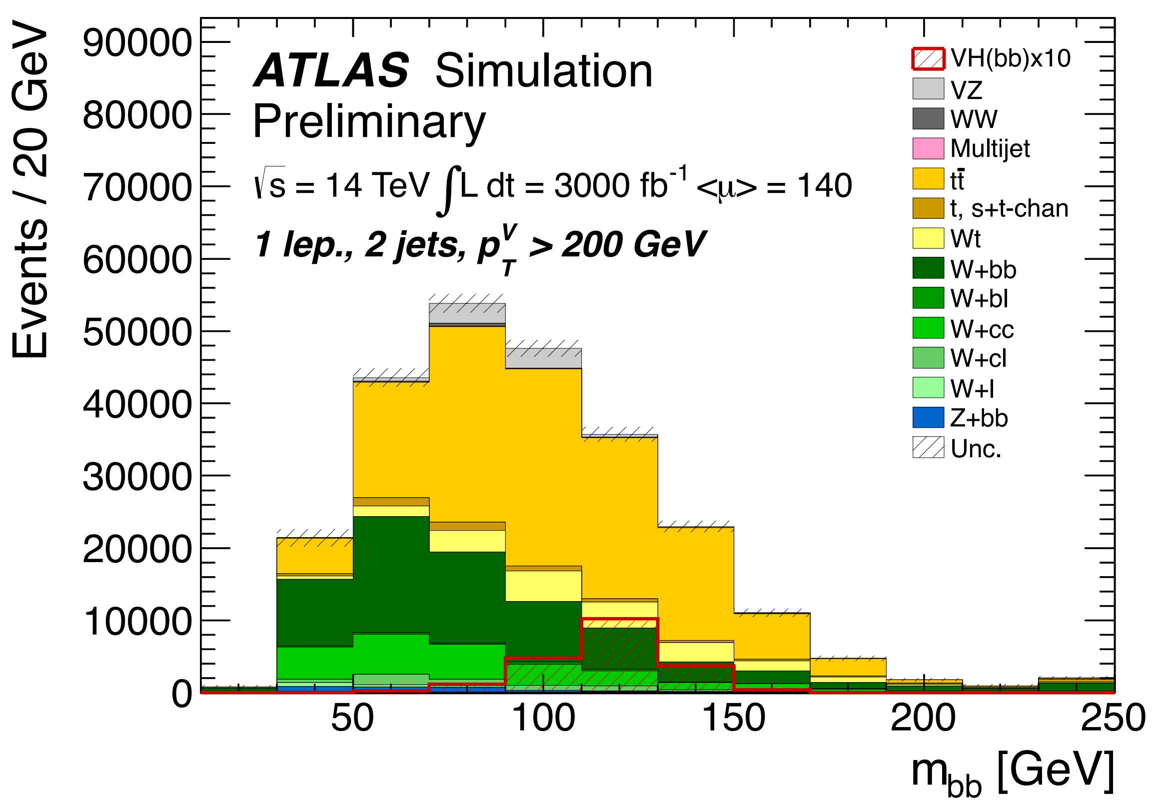
ATLAS expected: 8.2σ (3000 fb^{-1}).

ATL-PHYS-PUB-2014-012

H→bb

Access to Higgs-bottom coupling.





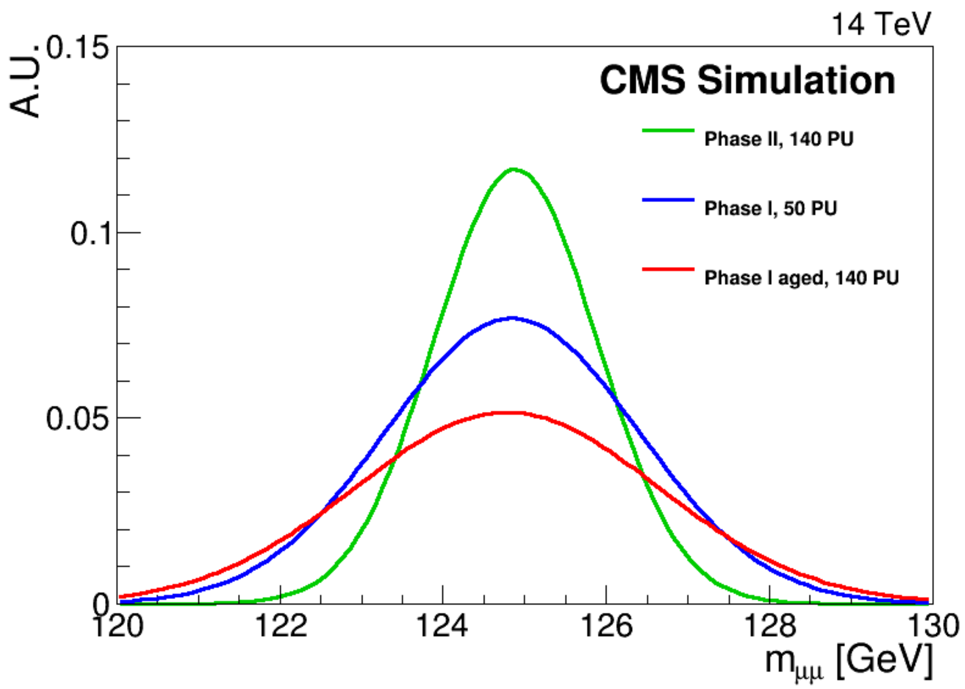
Observation expected for VH, H→bb (V = Z or W).

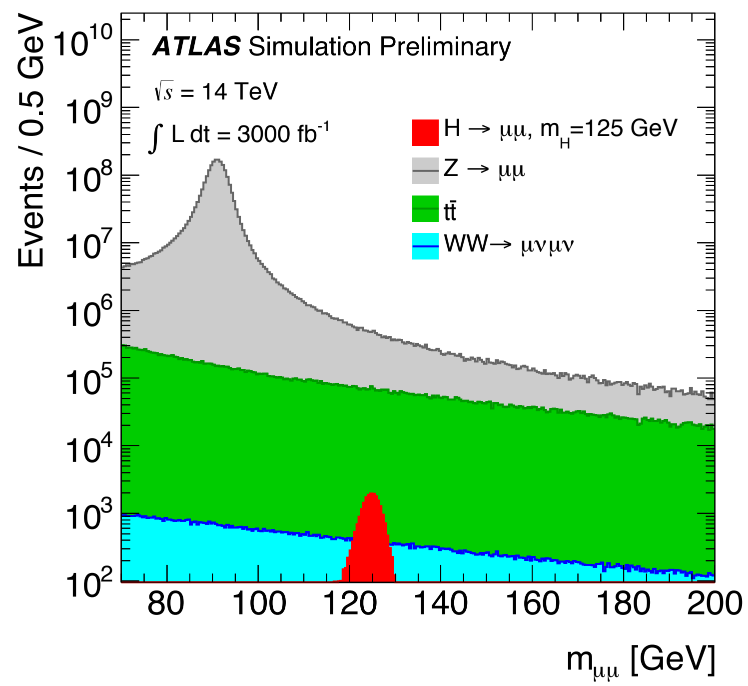
ATLAS expected significance at 3000 (300) fb^{-1}: 8.8σ (3.9σ).

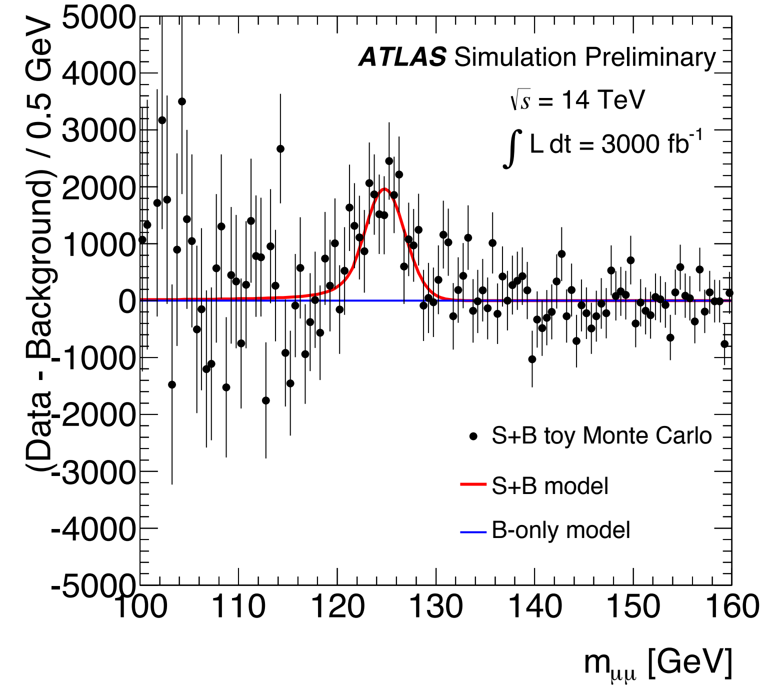
ATL-PHYS-PUB-2014-011

H→μμ

Access to Higgs-muon coupling.





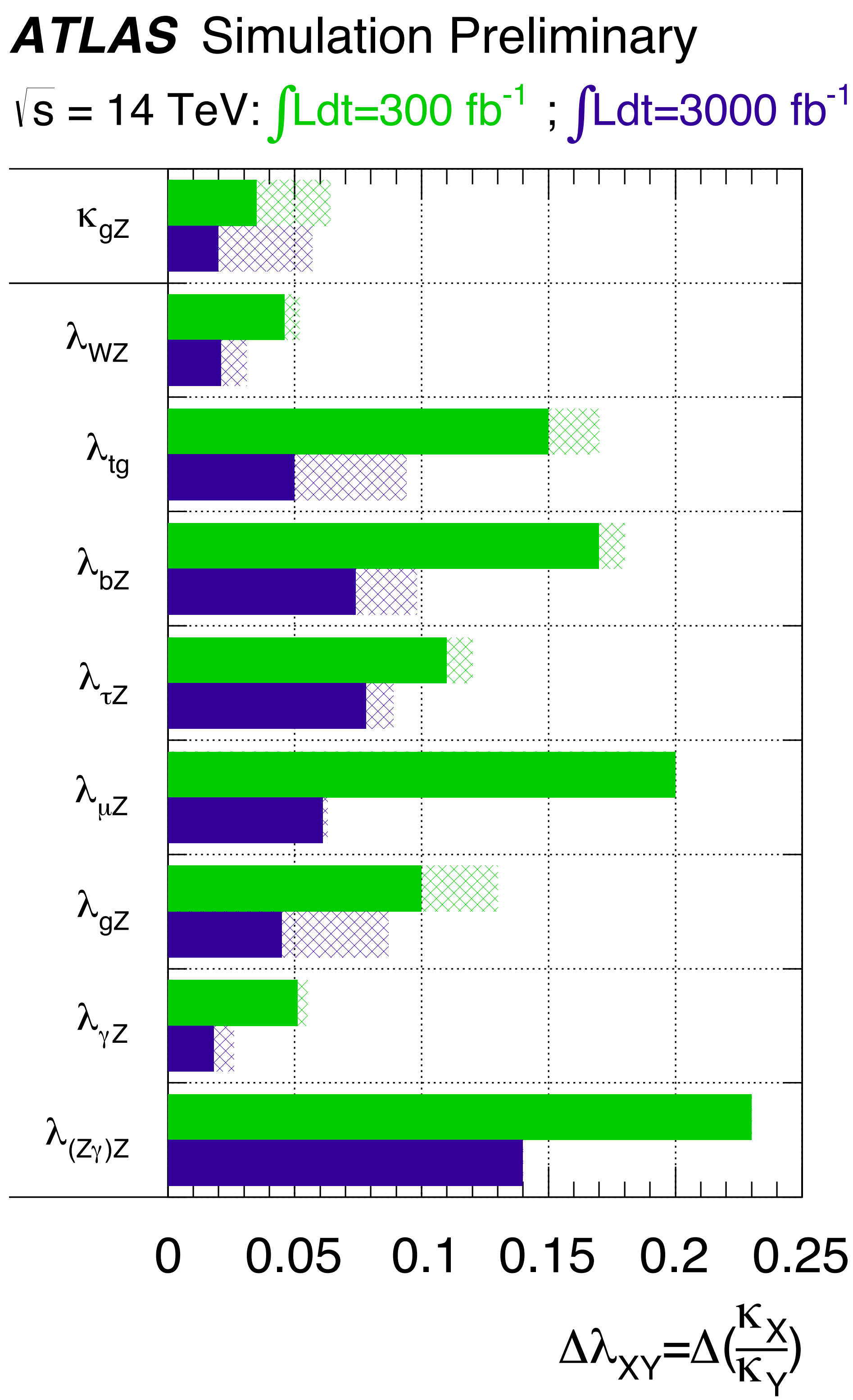


- Reduction of the material and better spacial resolution for tracking at Phase 2.
- Mass resolution expected: 40% better with respect to 'Phase 1 aged' (radiation damage for 1000 fb^{-1} assumed).

- Observation expected for H→μμ.
- ATLAS expected: 7.0σ (3000 fb^{-1}).

CERN-LHCC-2015-010; LHCC-P-008. ATL-PHYS-PUB-2013-014.

Higgs couplings



Fit with a fully generic parametrisation

- No assumption on the total width
  - κ_{gZ} (= $\kappa_g\kappa_Z/\kappa_H$) overall scale parameter common to all signal channels
- No assumption on new particle contribution through loops

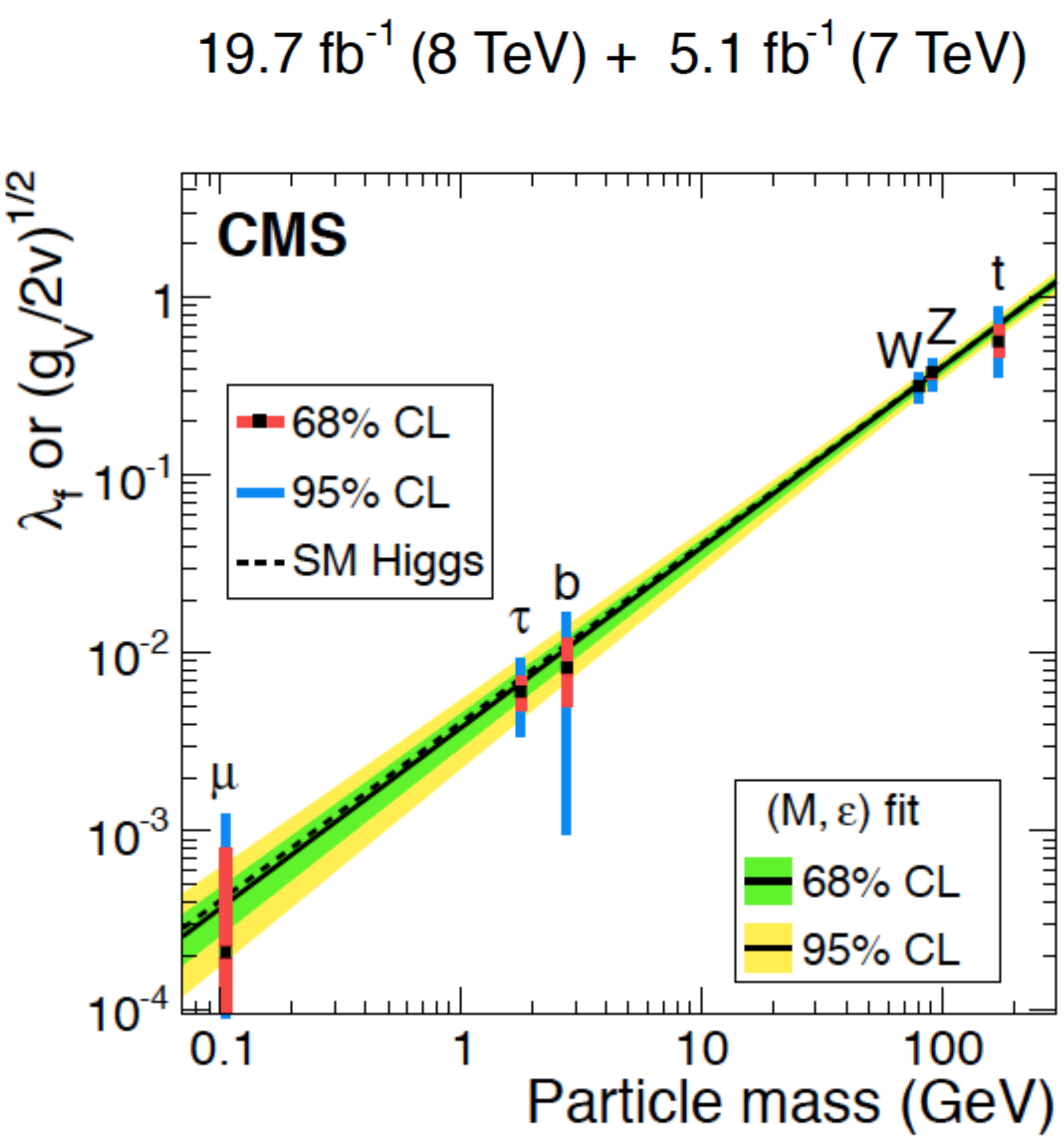
Hashed areas: current theory systematic uncertainties

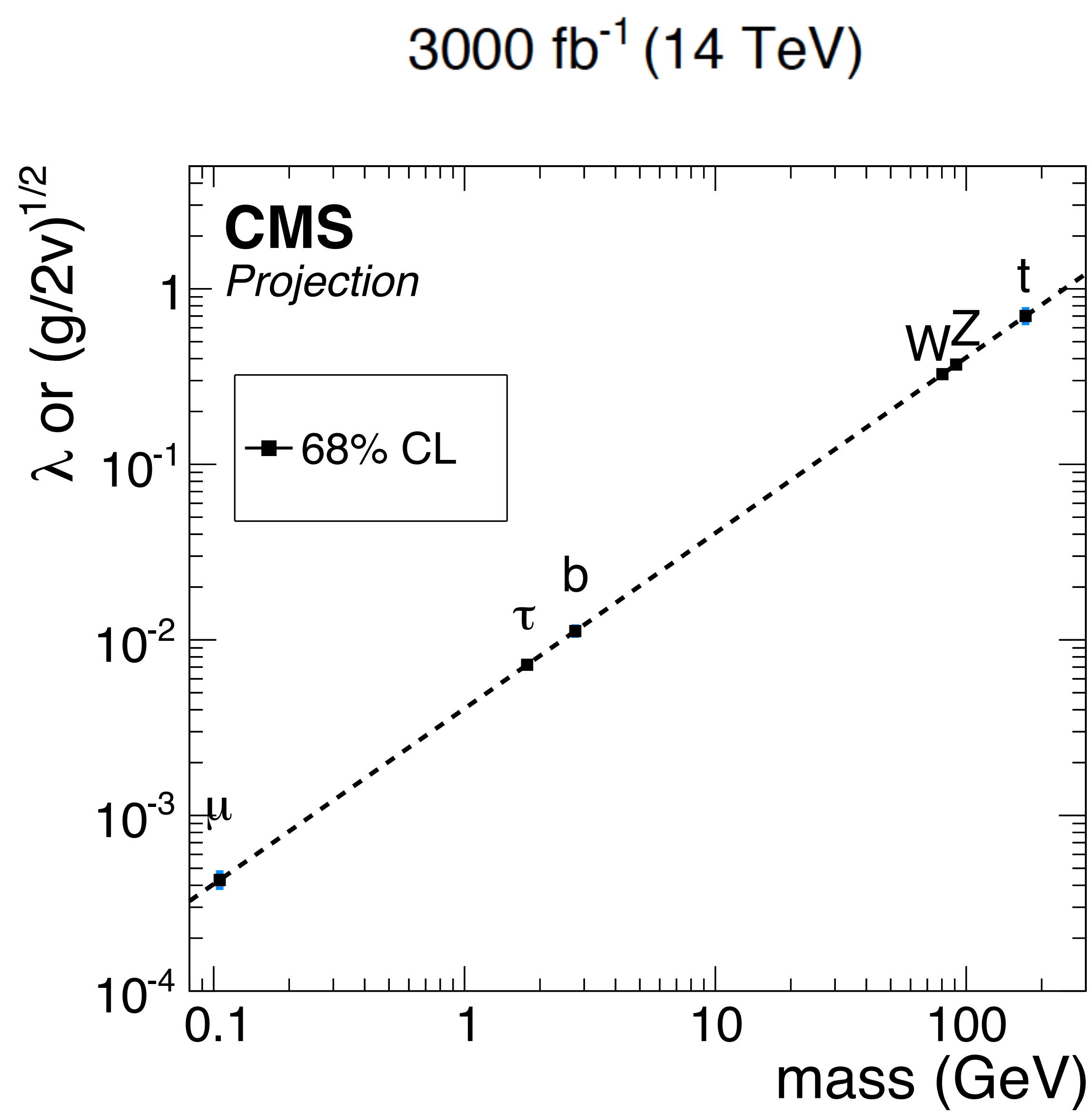
For various coupling scale factor ratios, the precision of % level expected at 3000 fb^{-1}.

Similar precision expected for ATLAS and CMS.

ATL-PHYS-PUB-2014-016. arXiv:1307.1347 [hep-ph].

Higgs couplings





Significant improvement expected with 14 TeV, 3000 fb^{-1}.

Precision test of Yukawa terms for various ‘flavors’: t, b, τ, and μ.

CERN-LHCC-2015-019; LHCC-G-165

$B_{s,d} \to \mu\mu$

$B_{s,d} \to \mu\mu$ decays are only proceed through FCNC processes and are highly suppressed in SM.

CMS and LHCb, Nature 522, 68 (2015)

$\mathcal{B}(B_s \to \mu\mu) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$

$\mathcal{B}(B_d \to \mu\mu) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$

C. Bobeth, et al., PRL 112, 101801 (2014)

$\mathcal{B}(B_s \to \mu\mu) = (3.65 \pm 0.23) \times 10^{-9}$

$\mathcal{B}(B_d \to \mu\mu) = (1.06 \pm 0.09) \times 10^{-10}$

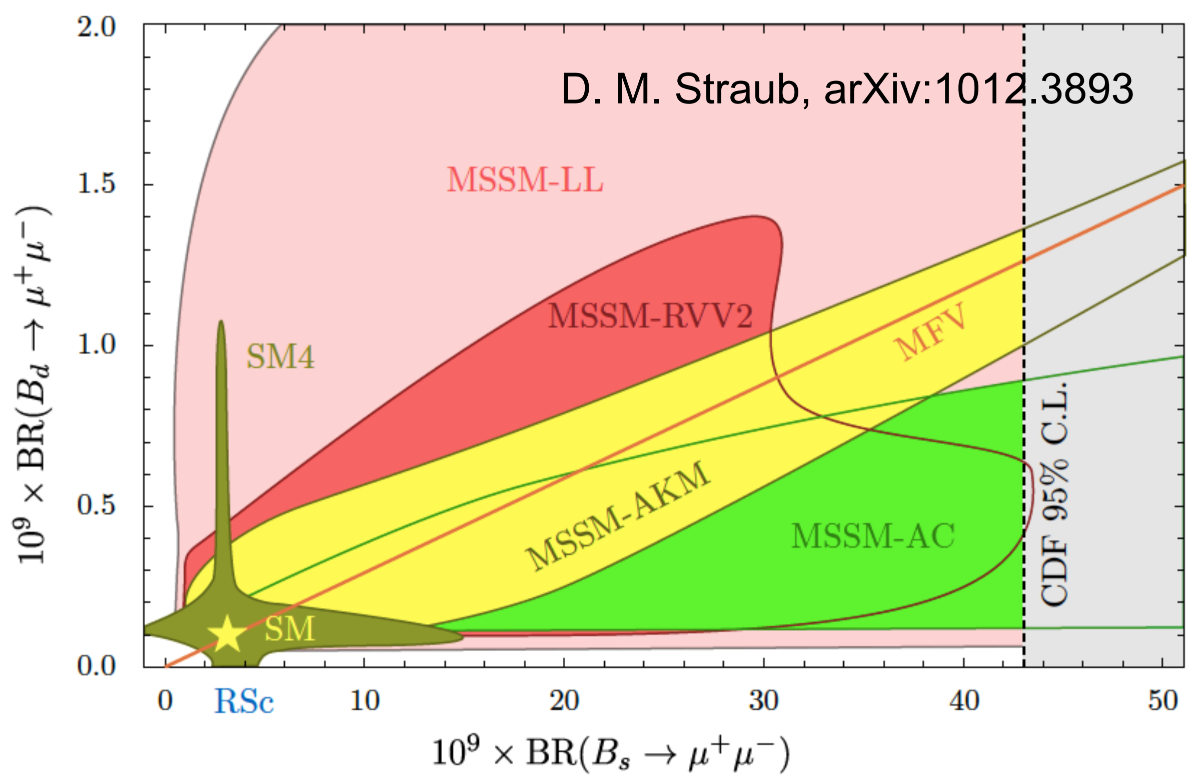
ATLAS, arXiv:1604.04263 [hep-ex]

$\mathcal{B}(B_s \to \mu\mu) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$

$\mathcal{B}(B_d \to \mu\mu) < 4.2 \times 10^{-10}$ (95% CL)

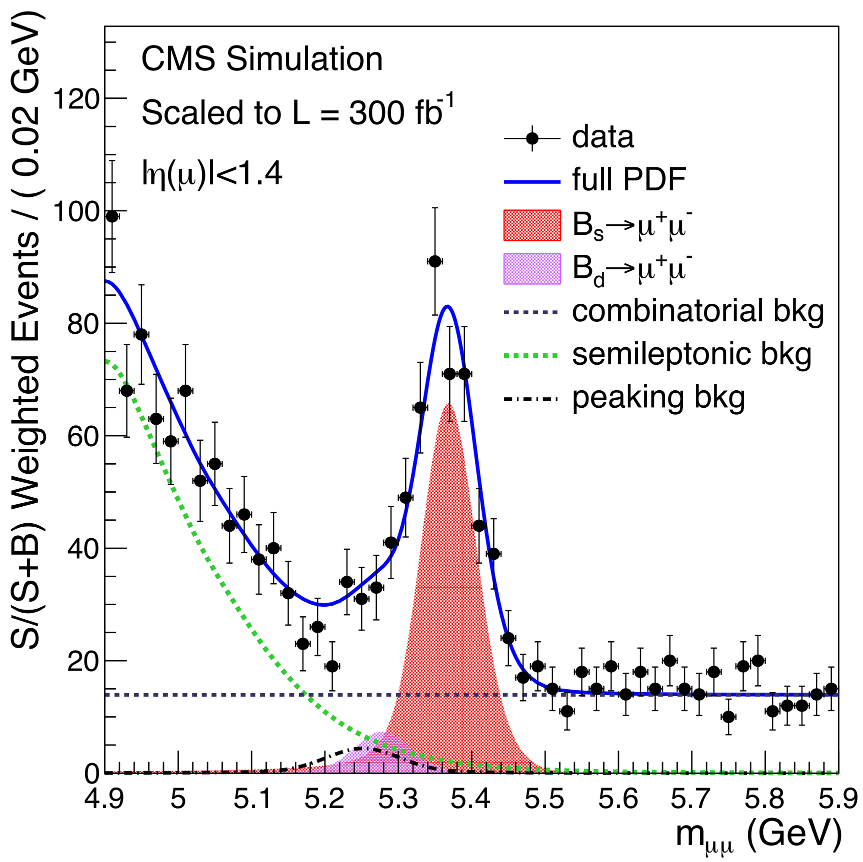
Some of new physics scenarios may boost the $B_{s,d} \to \mu\mu$ decay rates.

B_s/B_d ratio provides a stringent test of various models beyond SM.



$B_{s,d} \to \mu\mu$

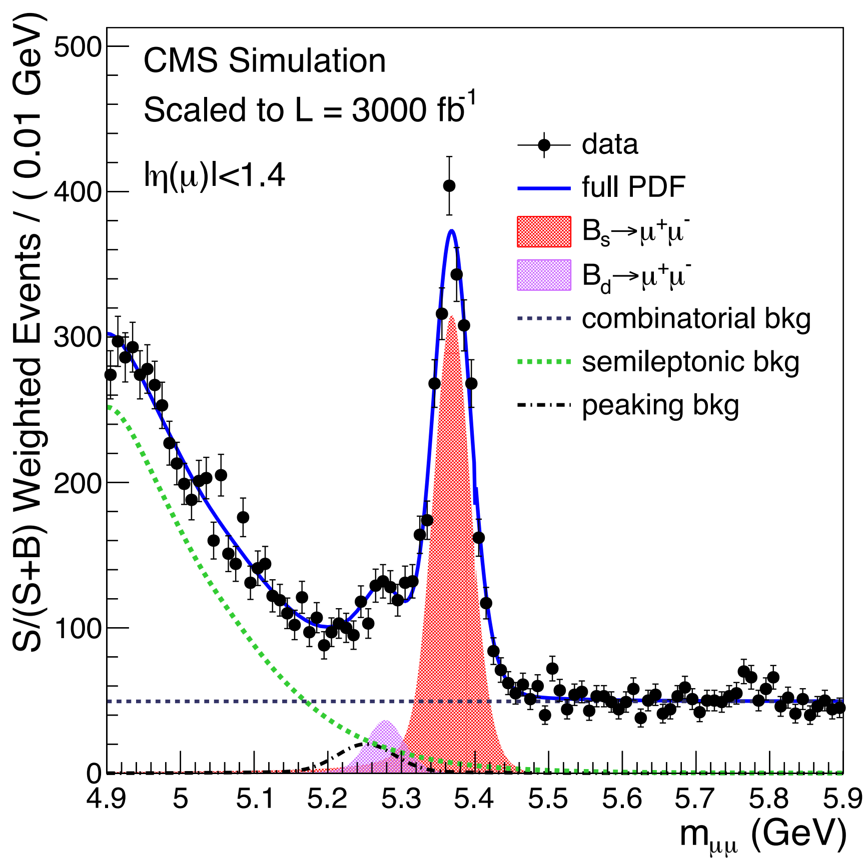
300 fb^{-1}



$\mathcal{B}$ ($B_s \to \mu\mu$) precision: 13%

$\mathcal{B}$ ($B_d \to \mu\mu$) precision: 48% (2.2σ)

3000 fb^{-1}



$\mathcal{B}$ ($B_s \to \mu\mu$) precision: 11%

$\mathcal{B}$ ($B_d \to \mu\mu$) precision: 18% (6.8σ)

σ x $\mathcal{B}$ predicted by SM assumed.

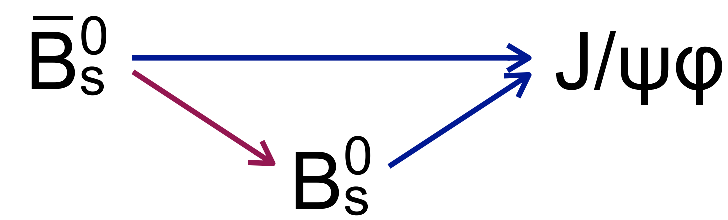
CERN-LHCC-2015-010; LHCC-P-008. K. F. Chen, EPS-HEP 2015.

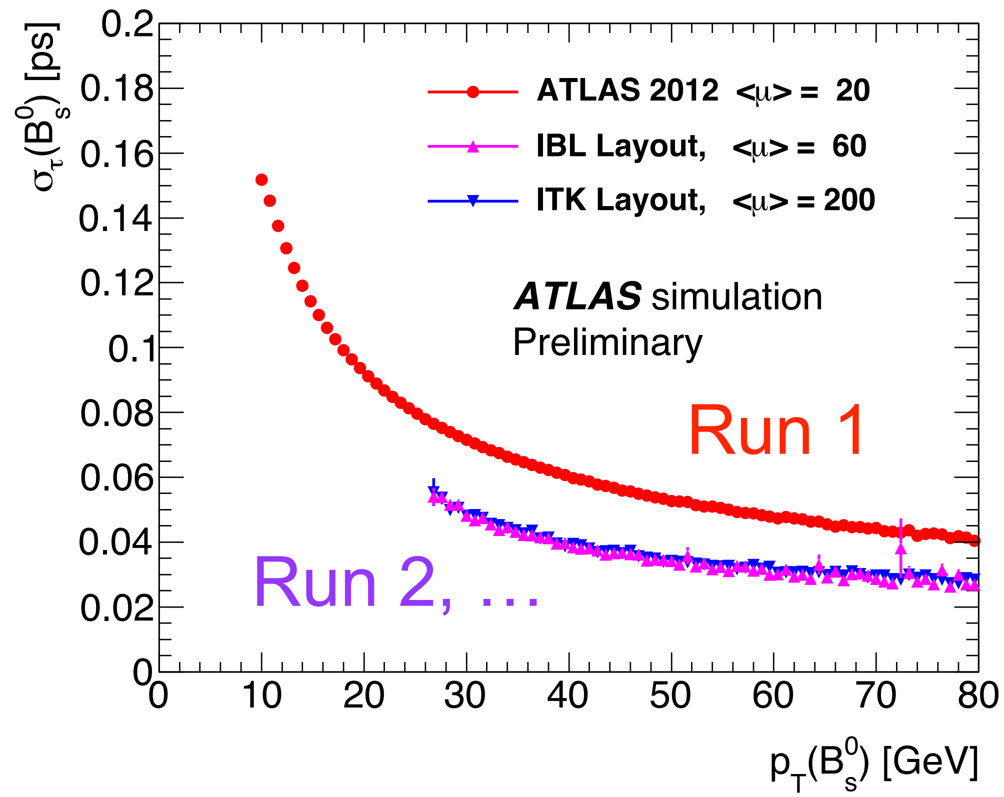
$B_s \rightarrow J/\psi\varphi$

- CP violation due to interference between direct decay and decay with B_s^0-$\bar{B}_s^0$ mixing.
- New physics can show up in the mixing.
- Phase difference between interfering amplitudes φ_s extracted from decay time defined on the transverse plane: $t = \frac{L_{xy} M_B}{c\, p_{T_B}}$.
- Improve decay time resolution σ_τ by 30% with respect to Run 1 at ATLAS.

Luminosity	250 fb^{-1}	3000 fb^{-1}
$\sigma(\varphi_s)$ (Stat.)	0.064 rad	0.022 rad

Method improvement in arXiv:1601.03297 [hep-ex].





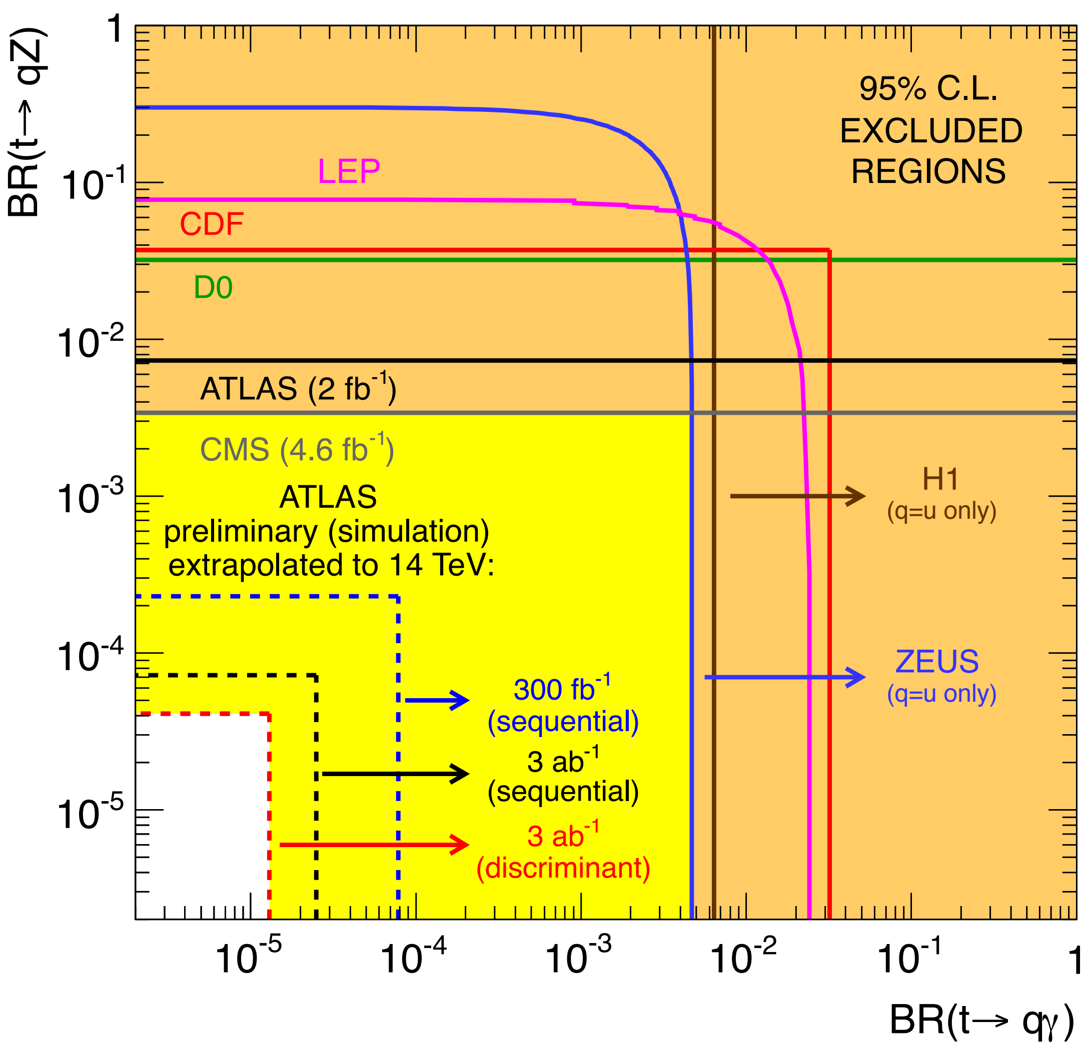
SM global fit by CKMfitter

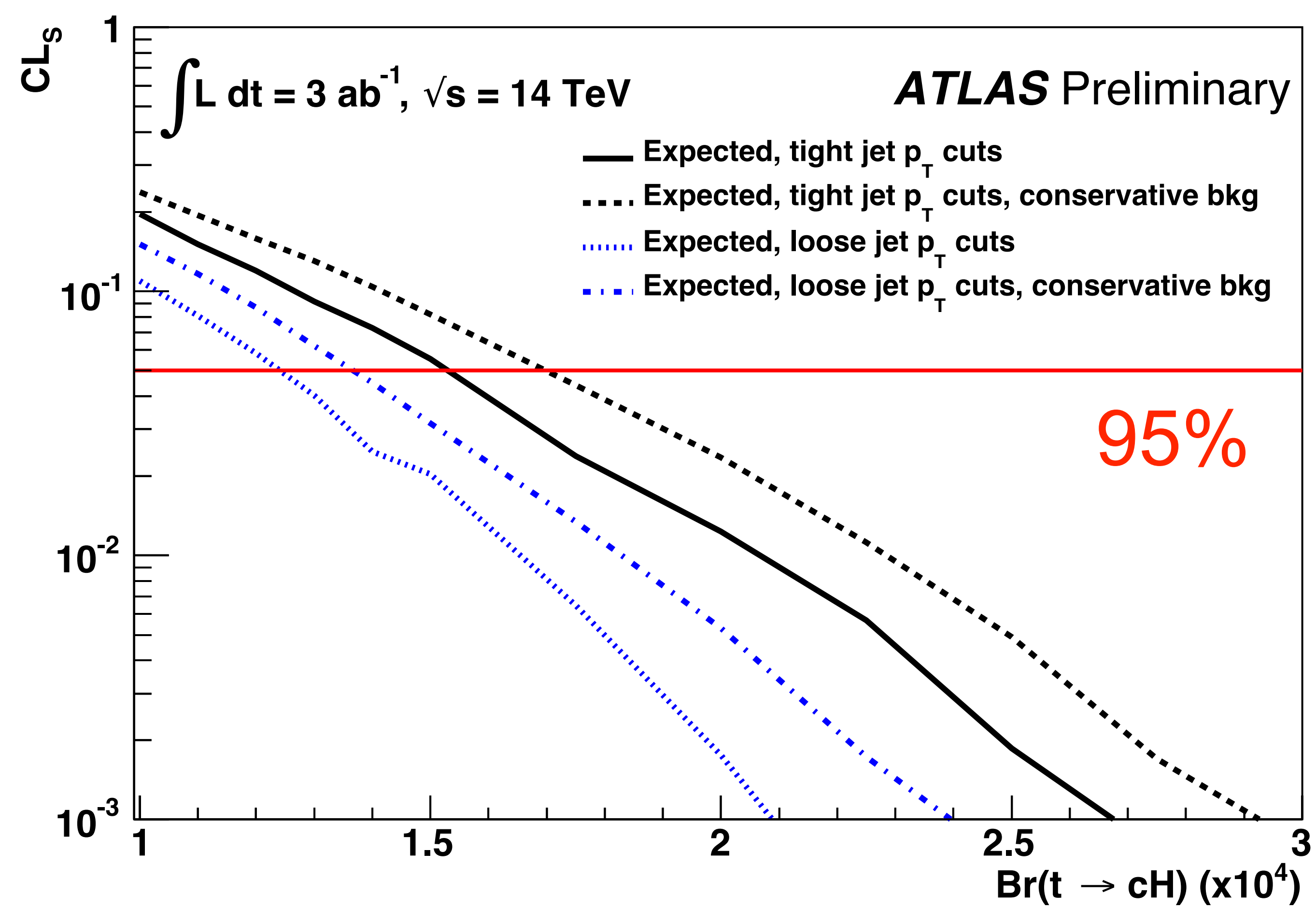
$$\varphi_s = -0.0365^{+0.0013}_{-0.0012}\ \text{rad}$$

ATL-PHYS-PUB-2013-010. PRD 91, 073007 (2015).

t→qγ, qZ, and qH

- FCNC top quark decays are highly suppressed in SM: $\mathcal{B} < 10^{-13}$.
- New physics scenarios may enhance the rate up to $\mathcal{B} \sim 10^{-4}$.
- HL-LHC expected limits at 95% CL are $\mathcal{B} = 10^{-4}$–10^{-5}.





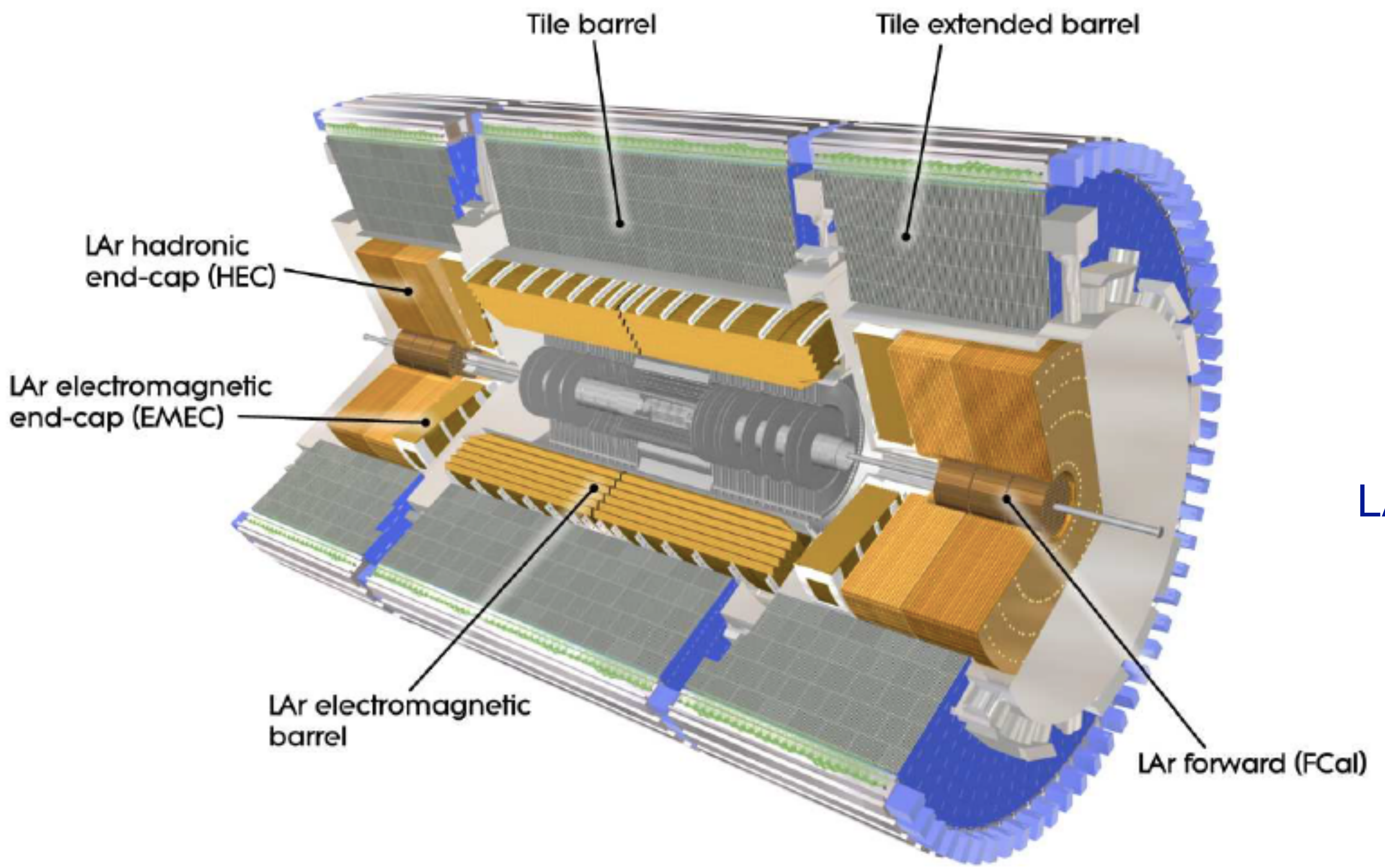
ATL-PHYS-PUB-2013-007. ATLAS-PHYS-PUB-2013-012. CMS PAS FTR-13-016.

Conclusion

- Aim for SM precision studies and BSM searches with 300 fb^{-1} (LHC) and 3000 fb^{-1} (HL-LHC) at ATLAS and CMS.
- Potential observation of the processes related with 'flavors': ttH, $H \to bb$, $H \to \mu\mu$, $B_d \to \mu\mu$, …
- Potential CP-violation measurement of $B_s \to J/\psi\varphi$, …
- Increased luminosity (5-7 x 10^{34} $cm^{-2}s^{-1}$) provides a significant challenge for the experiments.
  - High radiation dose, pileup, particle rate, and event rate.
- Overcome the difficulties by the upgrades in various aspects.

Backup Slides

Calorimeter



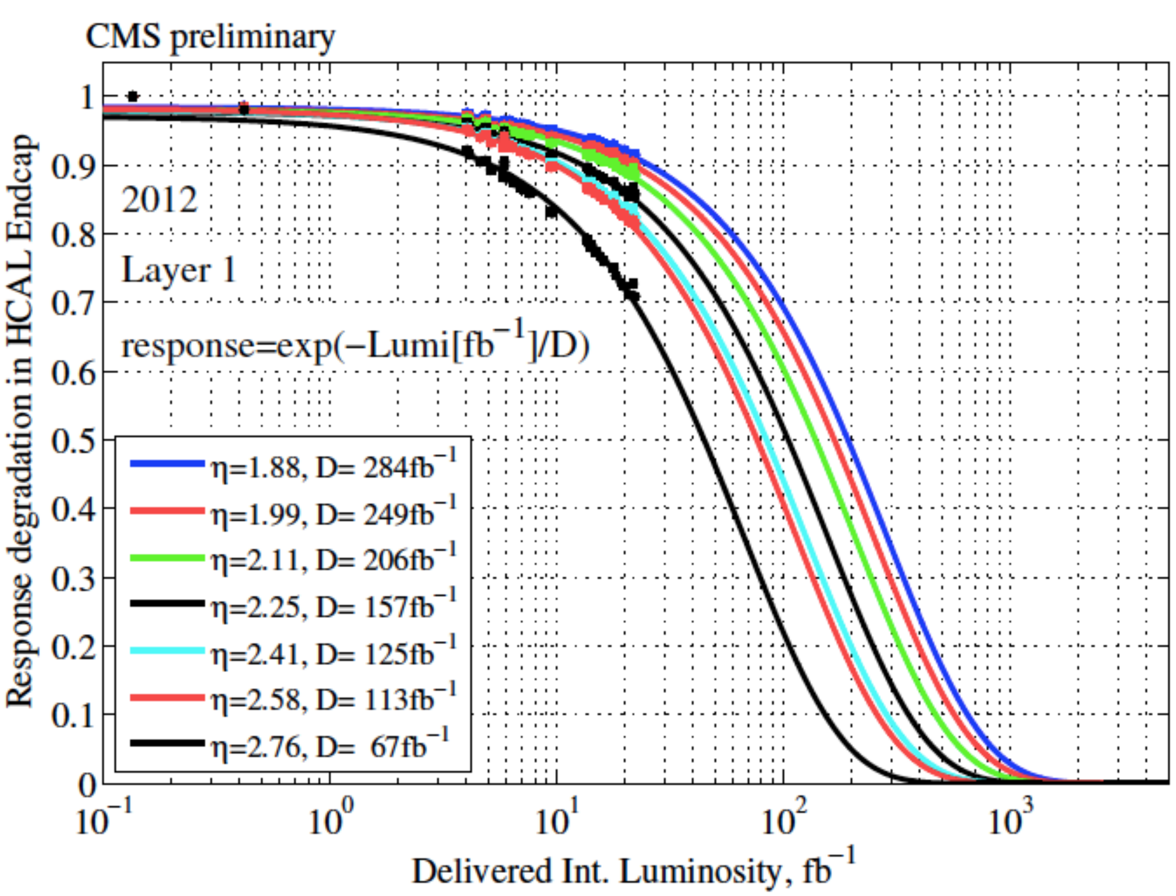
LAr: radiation hardness

- Maintain required performance under HL-LHC conditions and therefore do not need replacement with possible exception for FCal.
- FCal replacement with high-granularity one (100 μm gap) under discussion.
- Addition of timing detector (intrinsic resolution O(10) ps) under discussion.

CERN-LHCC-2015-020; LHCC-G-166

Calorimeter

Radiation dose at 3000 fb^{-1}
for the scintillating tiles
of the endcap hadron calorimeter
will reach up to 300 kGy
— response degradation expected.



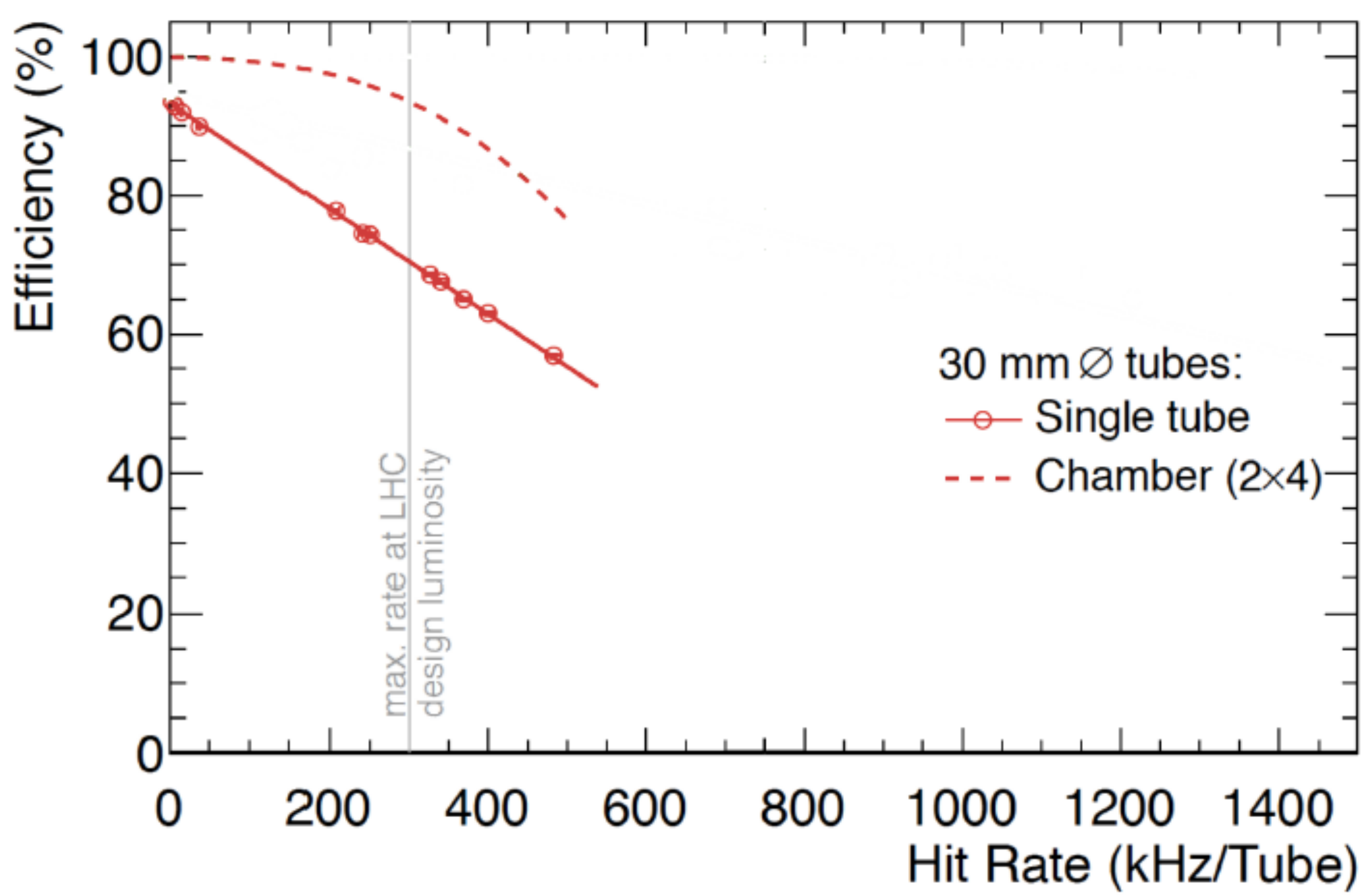
For the new endcap calorimeter,
exploit advances in silicon detectors
in terms of cost per unit area
and radiation tolerance.
The silicon sensors to be used
will be simple, large area, and
single-sided.

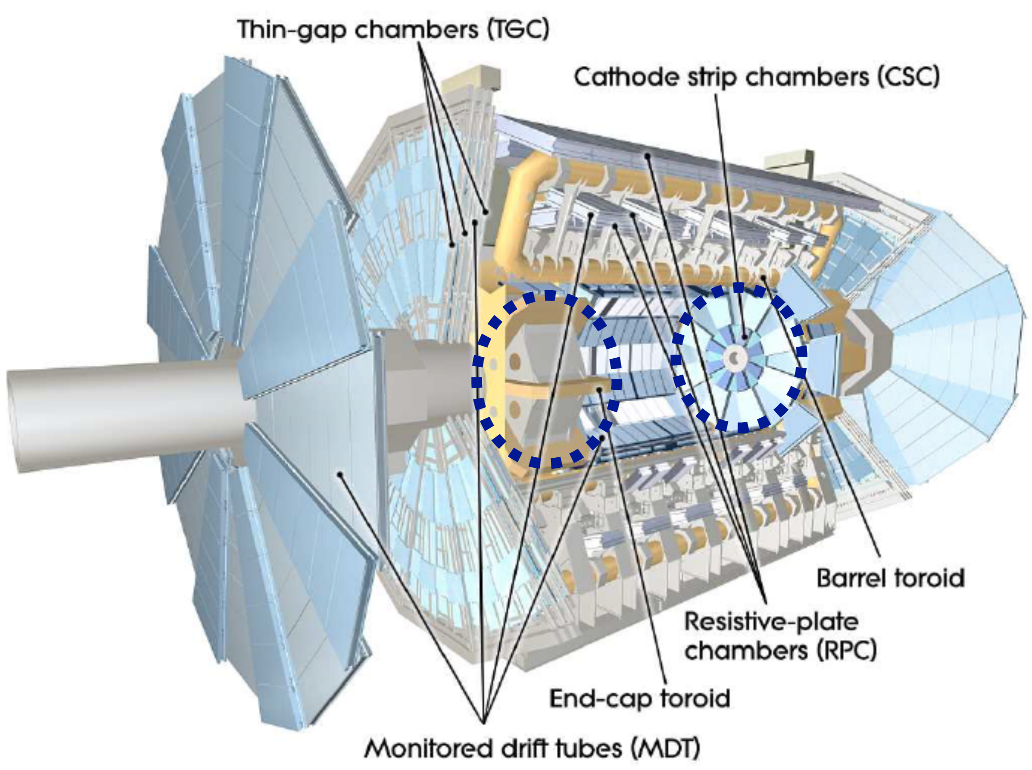
Thickness	300 μm	200 μm	100 μm
Maximum dose (Mrad)	3	20	100
Maximum n fluence (cm^{-2})	6×10^{14}	2.5×10^{15}	1×10^{16}
EE region	$R > 120$ cm	$120 > R > 75$ cm	$R < 75$ cm
FH region	$R > 100$ cm	$100 > R > 60$ cm	$R < 60$ cm
Si wafer area (m^2)	290	203	96
Cell size (cm^2)	1.05	1.05	0.53
Cell capacitance (pF)	40	60	60
Initial S/N for MIP	13.7	7.0	3.5
S/N after 3000 fb^{-1}	6.5	2.7	1.7

CERN-LHCC-2015-010; LHCC-P-008

Muon spectrometer

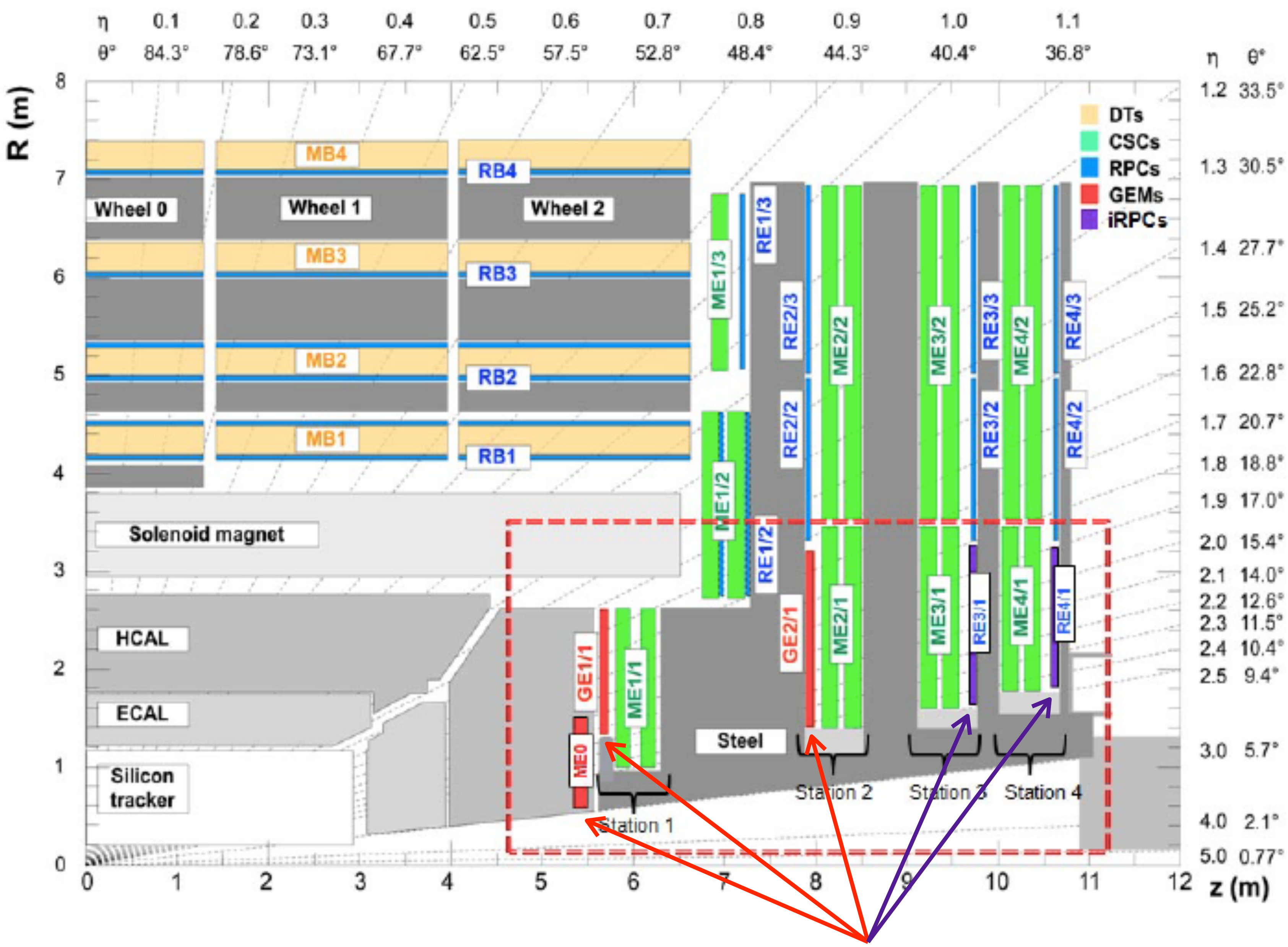
- Current drift tube chambers: inefficiency and resolution degradation with hit rate above 300 kHz/tube.
- Impact on the endcap inner layer with $L > 10^{34}$ $cm^{-2}s^{-1}$.





CERN-LHCC-2013-006; ATLAS-TDR-020

Muon spectrometer



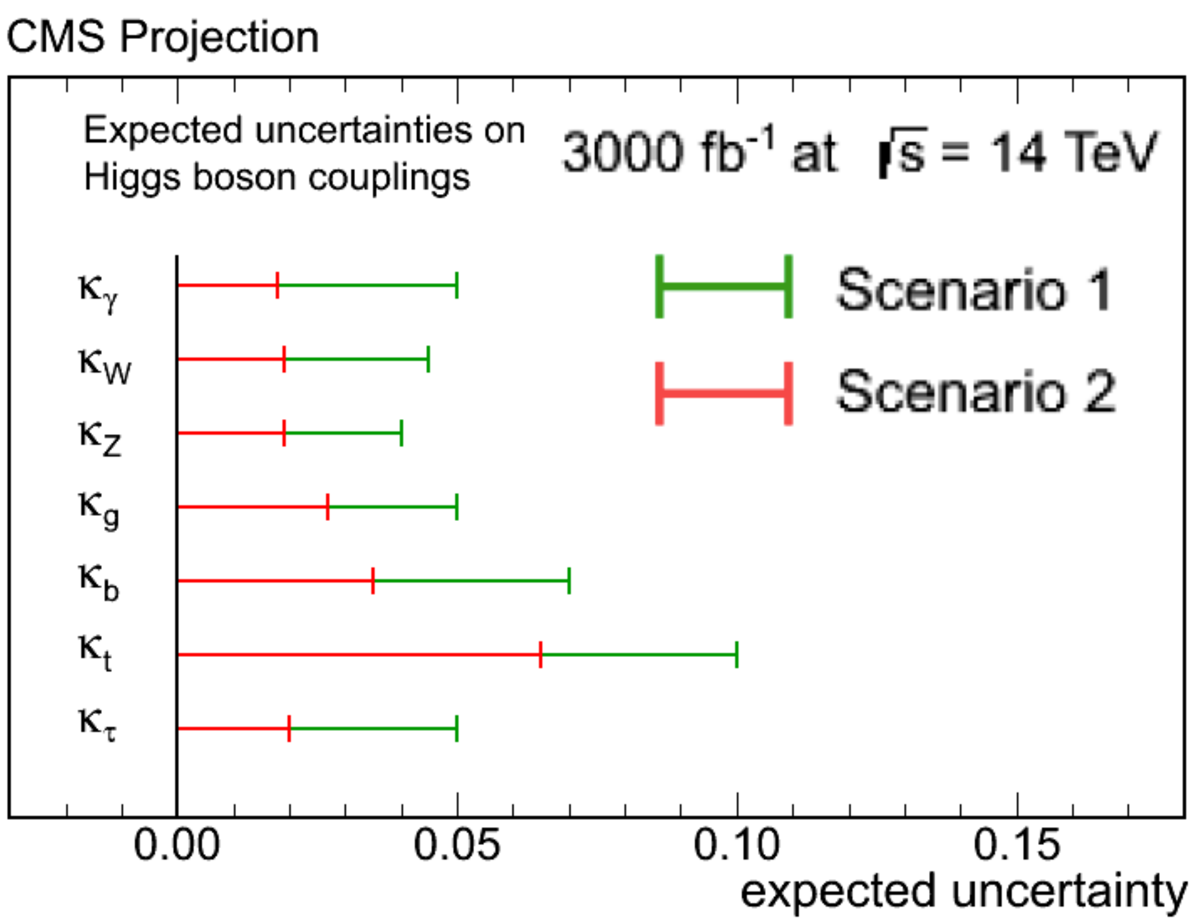
Possible additional chambers

- GEM — micro-pattern gas amplification detector
- RPC — time resolution of ~100 ps for pileup mitigation

(i) new irradiation tests must be performed to confirm that all types of existing muon detectors will survive the harsher conditions.
(ii) additional muon detectors in the forward region 1.6 < |η| < 2.4 to increase redundancy and enhance the trigger and reconstruction capabilities.
(iii) extension of muon coverage up to |η| = 3 or more behind the new endcap calorimeter to take advantage of the pixel tracking coverage extension.

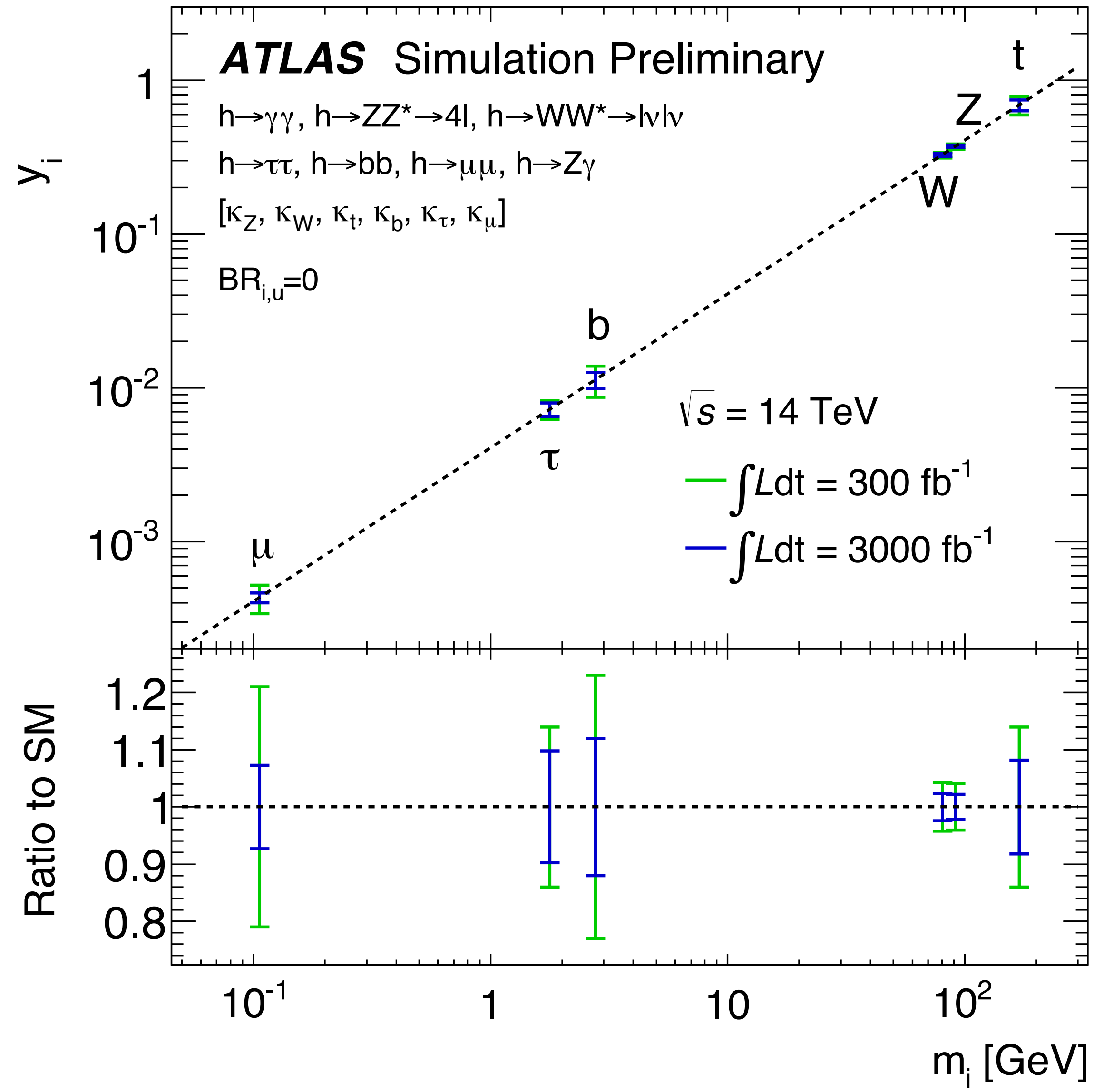
CERN-LHCC-2015-010; LHCC-P-008

Higgs couplings



Scenario 1: all systematic uncertainties unchanged.

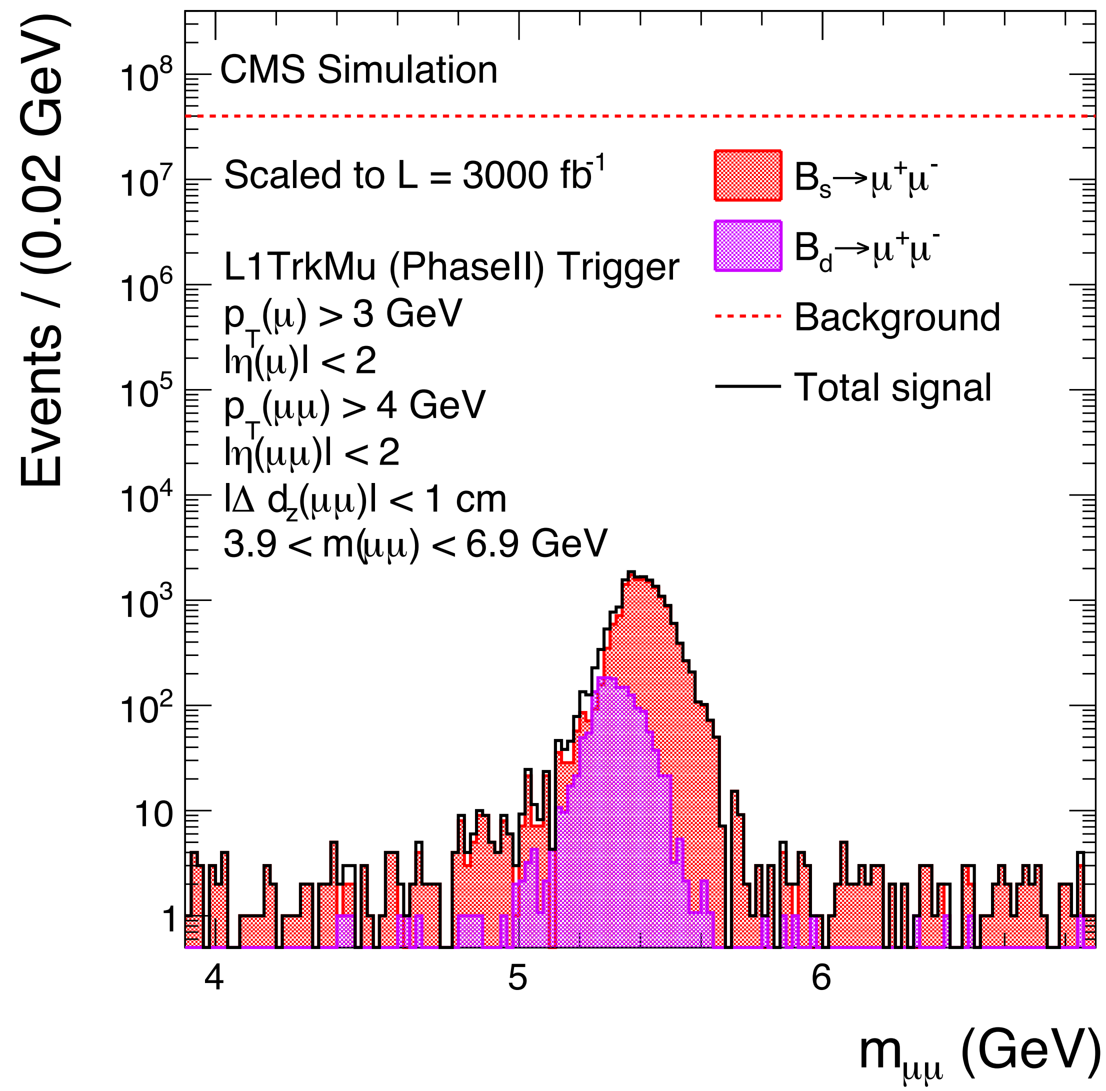
Scenario 2: improved theoretical/systematic uncertainties.



CERN-LHCC-2015-010; LHCC-P-008. ATL-PHYS-PUB-2014-016.

$B_{s,d} \to \mu\mu$

- Without trigger upgrade, unsustainable event rate at HL-LHC.
- Track trigger with upgraded CMS detector plays an essential role.
- Invariant mass $m_{\mu\mu}$ resolution at Level-1 trigger expected: ~70 MeV.
- Level-1 trigger rate expected: a few hundred Hz (<< 1 MHz).



at Level-1 trigger

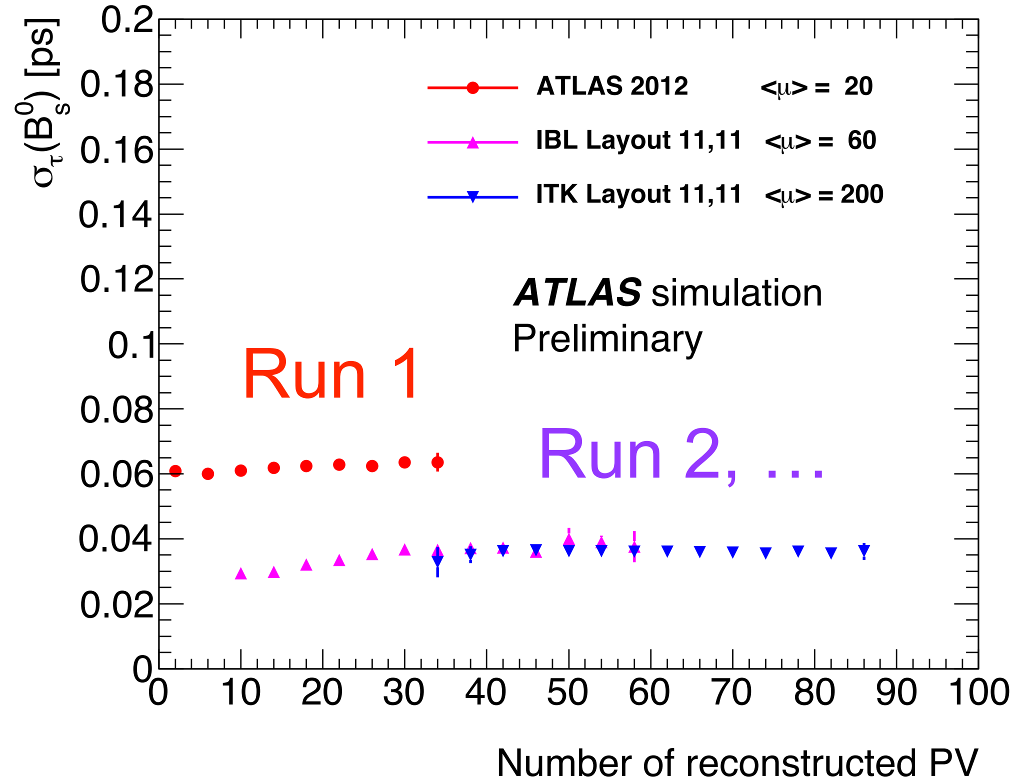
CERN-LHCC-2015-010; LHCC-P-008. K. F. Chen, EPS-HEP 2015.

$B_s \to J/\psi\varphi$

- Opposite-side tagging studied and calibrated by $B^\pm \to J/\psi K^\pm$ (flavor provided by kaon charge).
- Di-muon trigger with $p_T > 11$ GeV (both muons) assumed at ATLAS at HL-LHC.
- Systematic error of Run 1 analysis:
  - uncertainties in flavor charge tagging,
  - likelihood fit modelling,
  - trigger efficiency determination,
  - contribution of $B \to J/\psi K^*$ decays,
  - inner tracker alignment

— will benefit from the larger data samples.

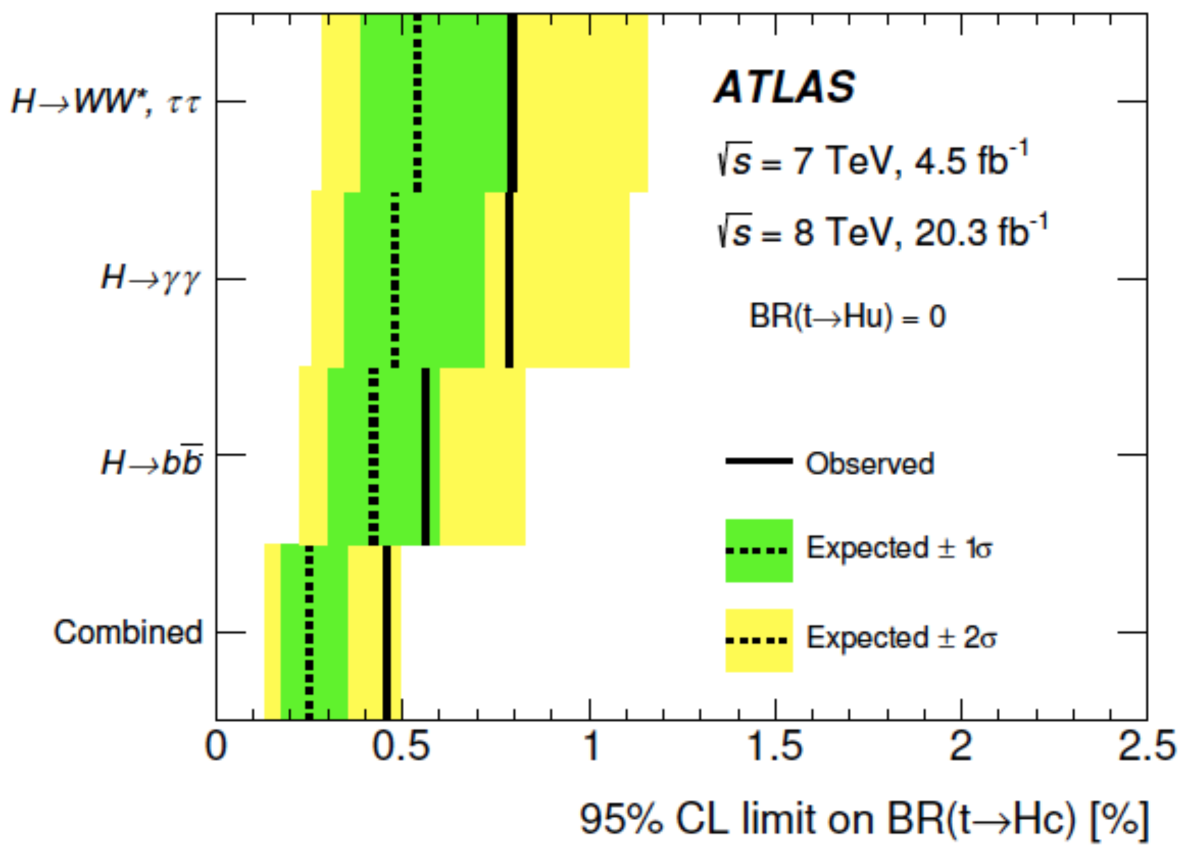
Slight σ_τ increase (14%) in Run 2 with number of primary vertices — but stable at > 40.

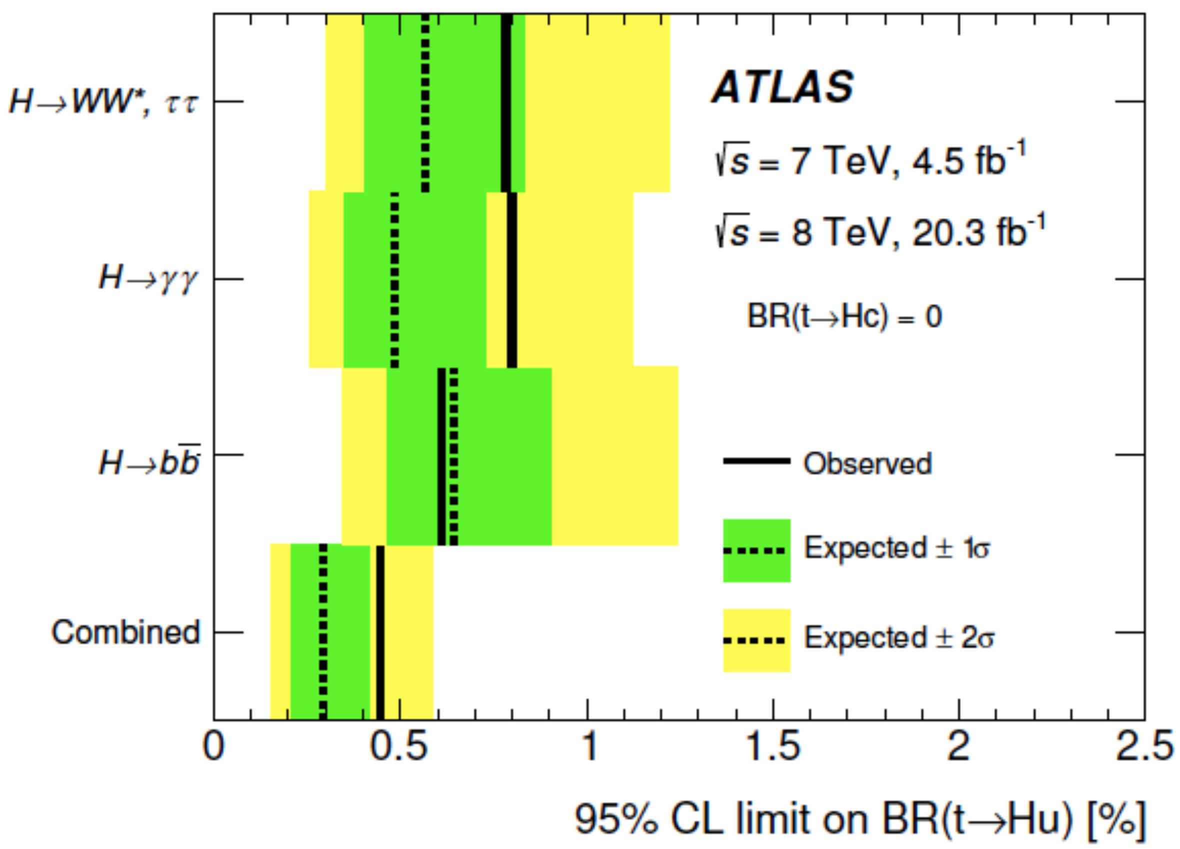


ATL-PHYS-PUB-2013-010

$t \to qH$

Current 95% CL upper limit on the branching ratio at the order of 10^{-3}.





arXiv:1509.06047v2 [hep-ex]