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Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

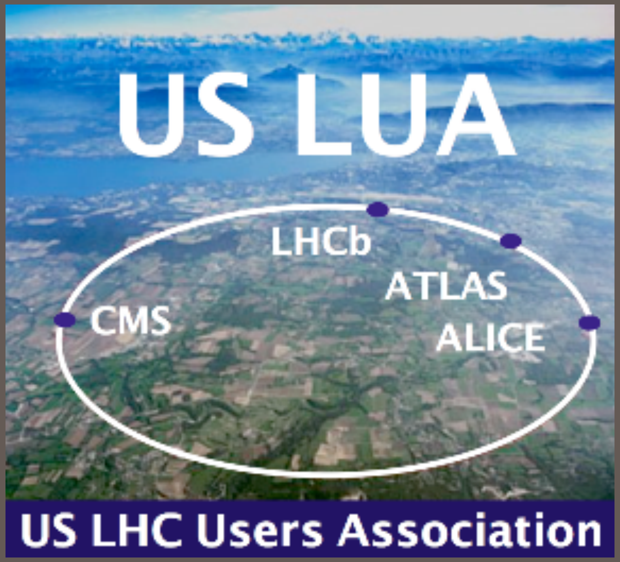
ATLAS Upgrade Program

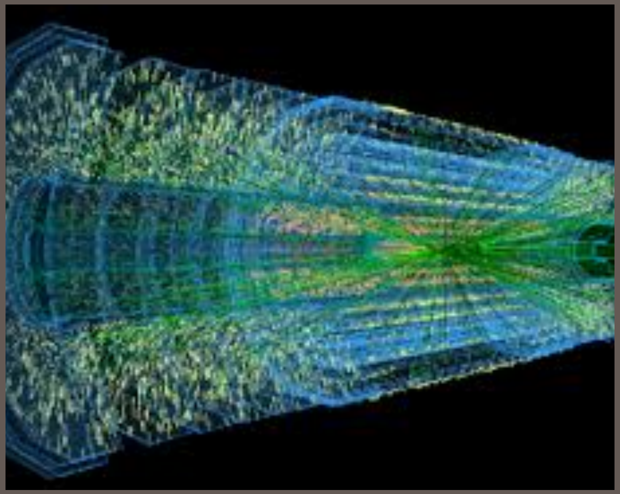
US LHC Users Association Annual Meeting

November 12th-14th, 2014

Argonne National Laboratory, Chicago

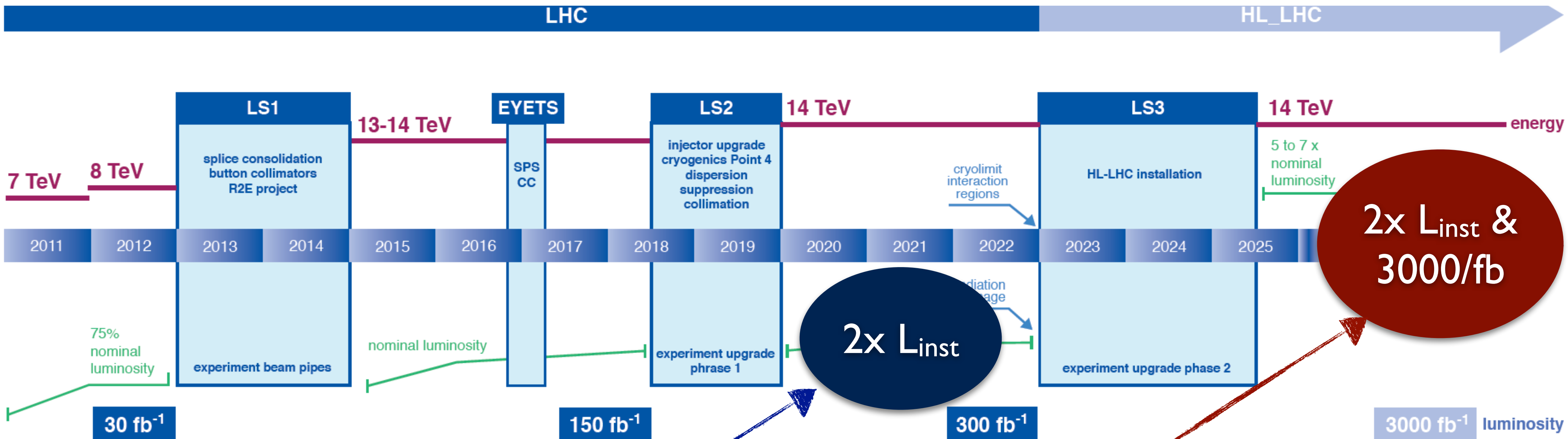
Anadi Canepa | TRIUMF





Overview

- ATLAS upgrades are planned to adapt to the challenges of the LHC accelerator in all its phases and take full advantage of the LHC physics potential
  - to also account for detector aging (lifetime of Run 1-2 ATLAS ~10 years)



- **Phase I**
  - New Small Wheel (trigger)
  - Fast Track Trigger
  - Liquid Argon Calorimeter Trigger
  - TDAQ System

- **Phase II**
  - New all-Si inner tracker (ITK)
  - Forward Calorimeter
  - TDAQ system
  - Electronics for Liquid Argon calorimeter
  - Muon trigger electronics and L1 Track Trigger
  - Software and Computing

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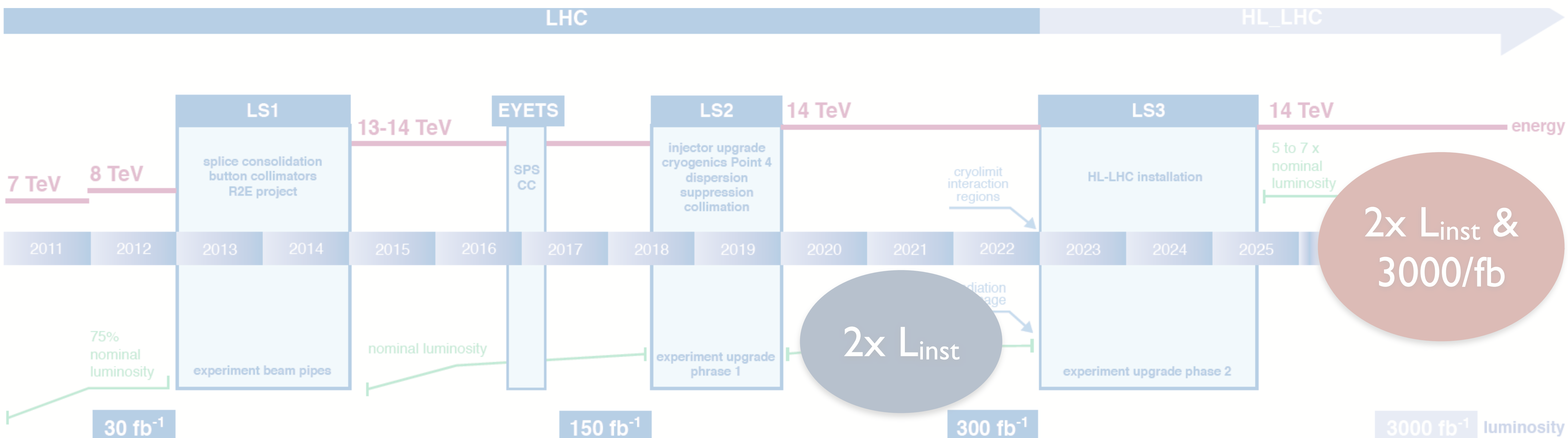

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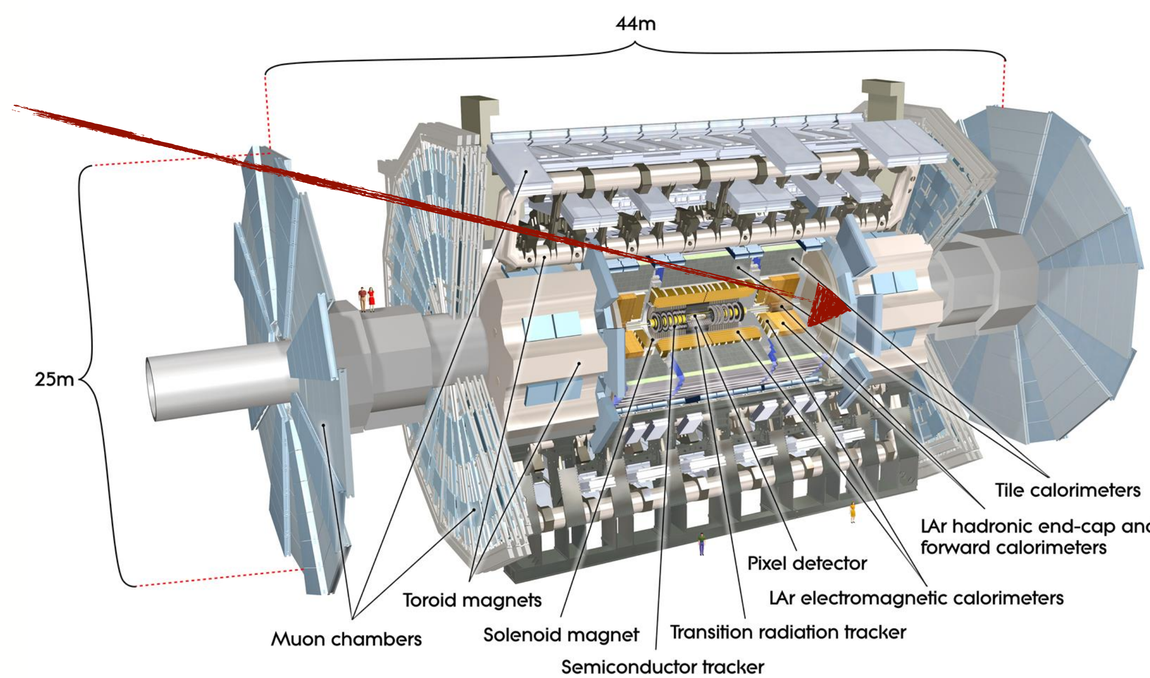
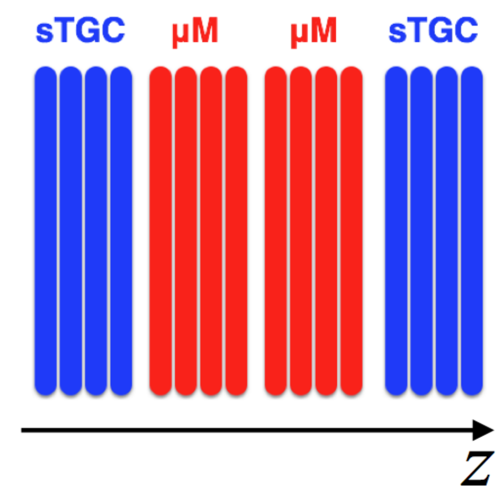
Phase 1 : New Small Wheel

- Muon Small Wheel is located between EC-calo and EC-toroid
  - in high luminosity condition, background rate exceeds ~15 kHz and tracking performance deteriorates
- **New Small Wheel (NSW)** is based on a two-chamber technology:
  - Small gap chamber (sTGC): primary trigger
  - MicroMega (MM): primary tracker
- Expected performance:
  - Level-1 trigger segment reconstruction and matching with angular resolution better than 1mrad
  - precision tracking up to 7 x $10^{34}/cm^2s^1$ with spacial resolution better than 100µm



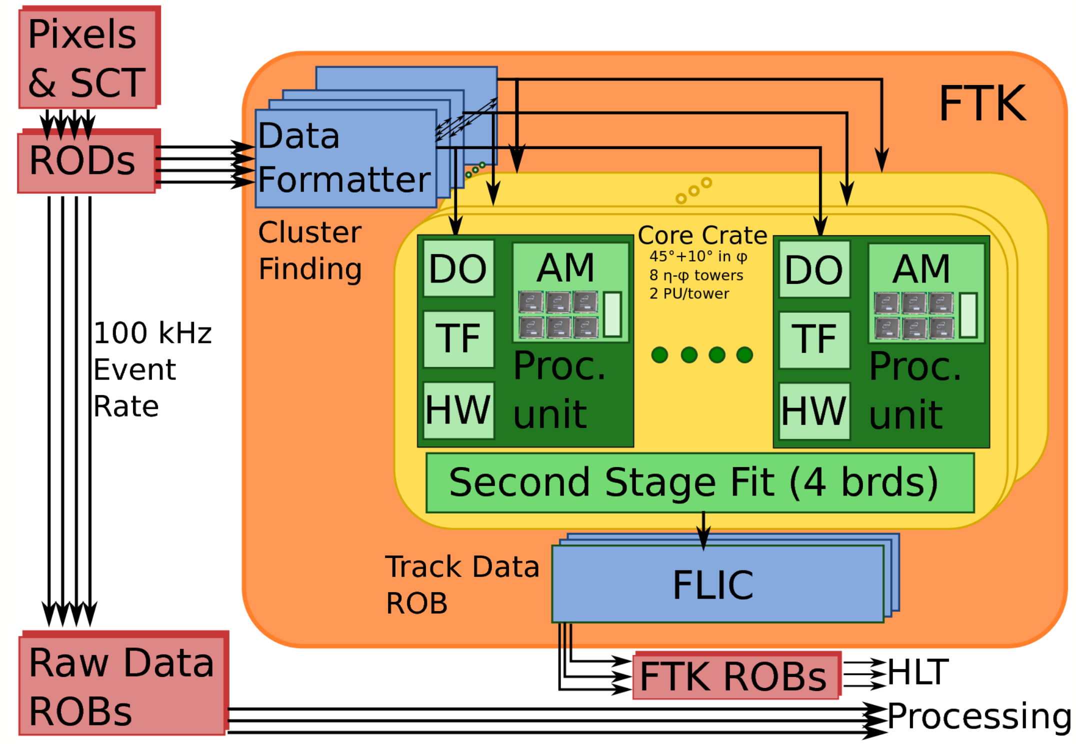


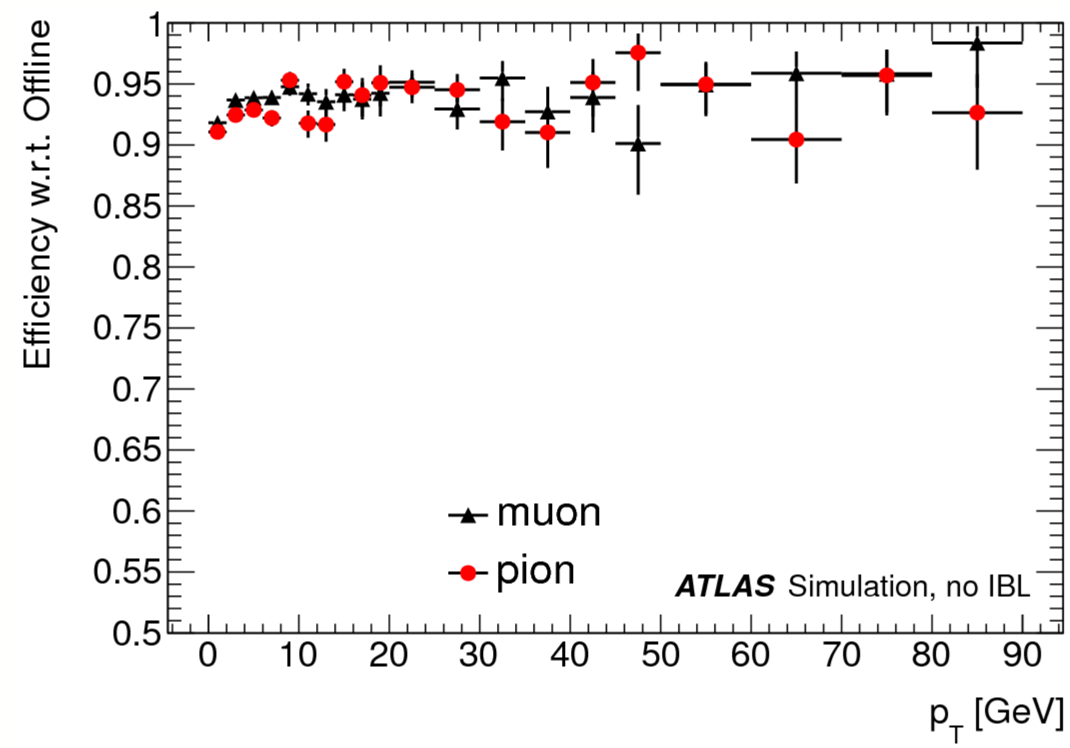
L1MU threshold (GeV)	Level-1 rate (kHz)
$p_T > 20$	60 ± 11
$p_T > 40$	29 ± 5
$p_T > 20$ barrel only	7 ± 1
$p_T > 20$ with NSW	22 ± 3
$p_T > 20$ with NSW and EIL4	17 ± 2

ATLAS-TDR-020

Phase I : Fast Tracker Trigger (FTK)

- Under high luminosity conditions, extensive tracking is expensive in terms of processing time per event or computing cores needed
- A dedicated, hardware-based track finder (FTK) is proposed to provide *global* tracking information after Level-1 trigger FTK:
  - receives the hits at full rate following a Level-1 accept
  - computes the helix parameters:
    - Associative Memory finds track candidates in coarse resolution 'roads' using pre-loaded patterns and information from 8/12 silicon layers
    - A full 12-layer fit is carried out for good tracks outputting hits on the track, track χ^2, helix parameters, track quality word
  - operates at 100 kHz, with latency compatible with Level-2 (<100μs)

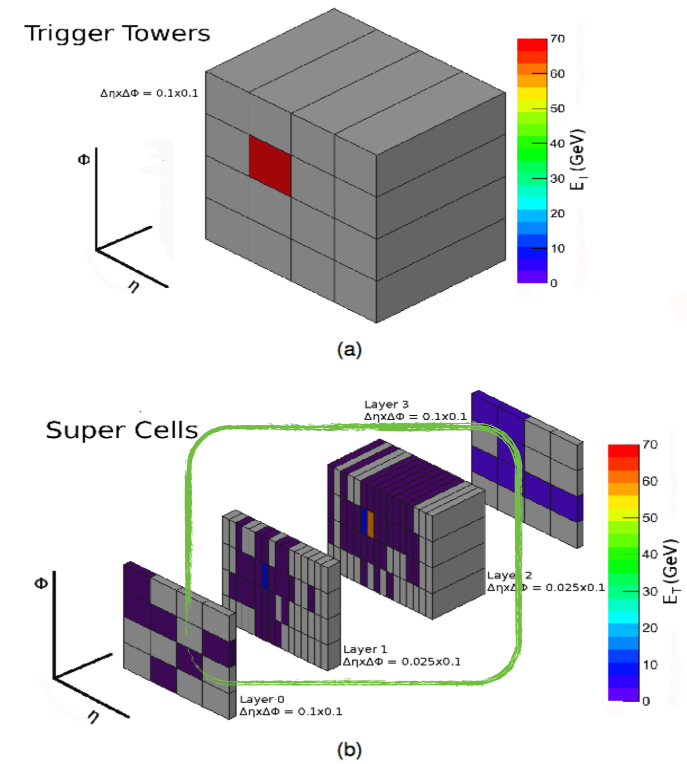


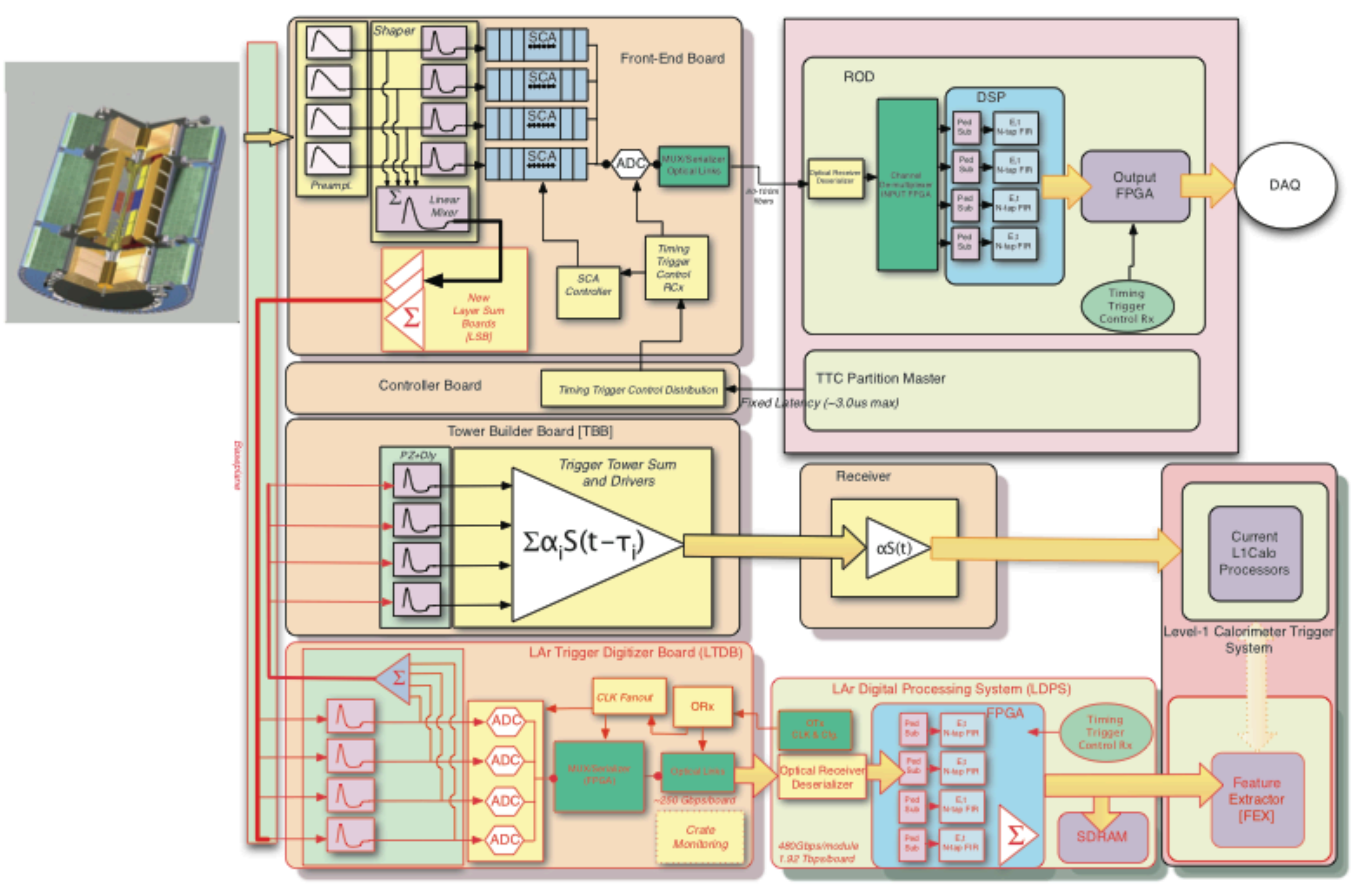


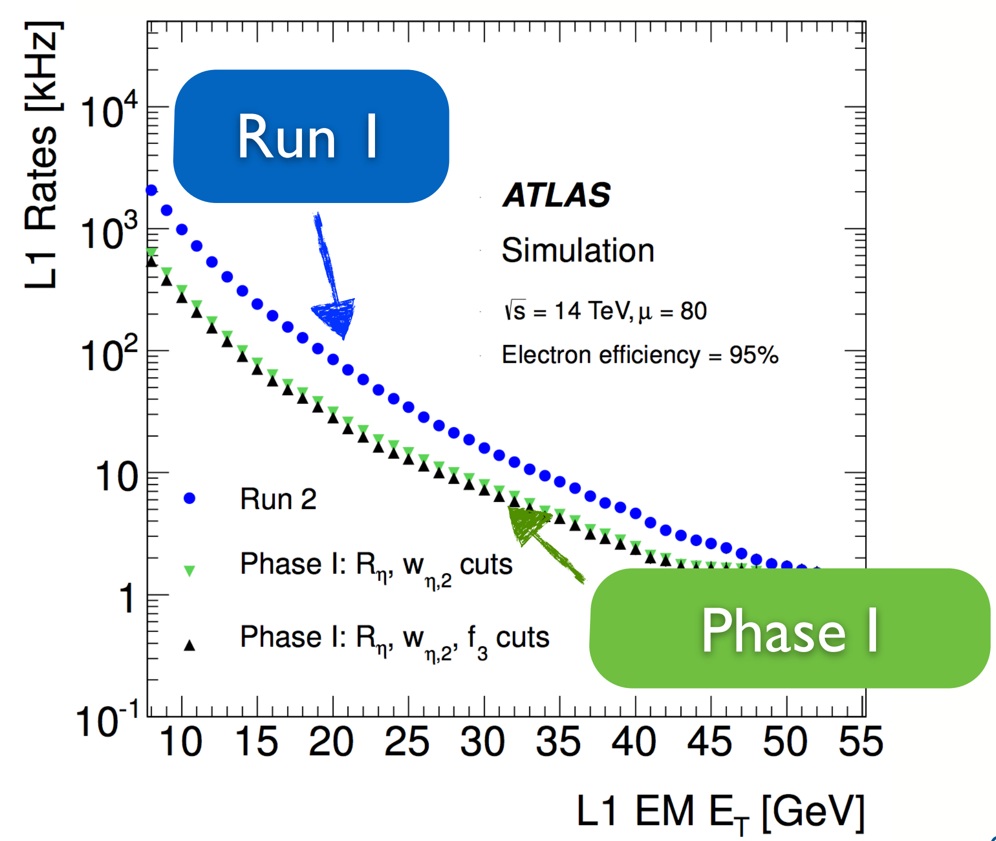
ATLAS-TDR-021

Phase I : Liquid Argon Calorimeter Trigger

- The Run I Level-I calorimeter trigger input was based on $\Delta\eta\times\Delta\varphi$=0.1x0.1 'towers'
  - Used to compute object energy and isolation
  - Leading to triggers rate ~ 270kHz @ 3x10^{34}cm^{-2}s^{-1}
- The upgrade will make higher-granularity and longitudinal shower information available to the Level-I trigger processors, expected improvement of energy resolution and object identification efficiency







ATLAS-TDR-022

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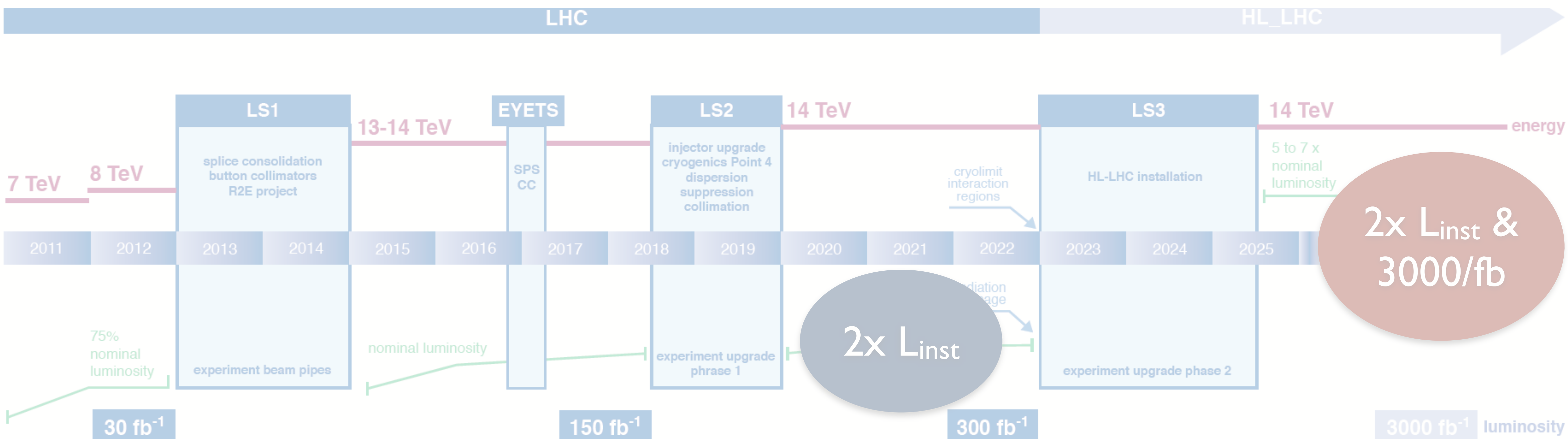

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Tracker for HL-LHC

Radiation hard sensors and electronics to cope with 250-300/fb/year

High granularity to achieve low occupancy and perform efficient pattern recognition

Low material to perform precision tracking especially at low transverse momentum

Small average pitch to achieve good performances at high transverse momentum

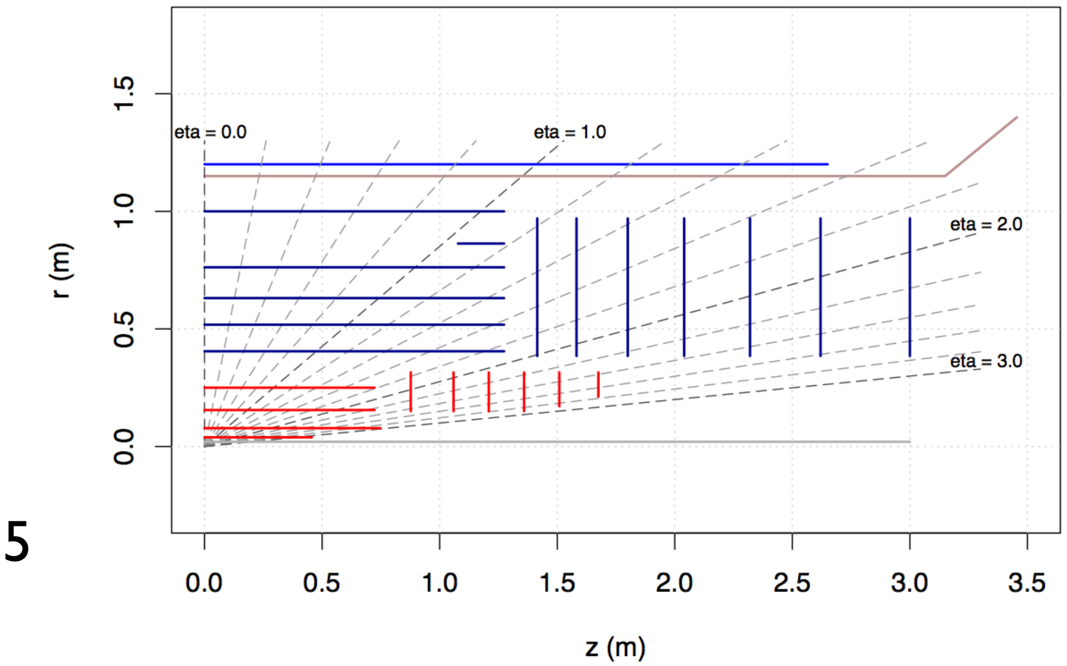
Phase II : Inner Tracker (ITK)

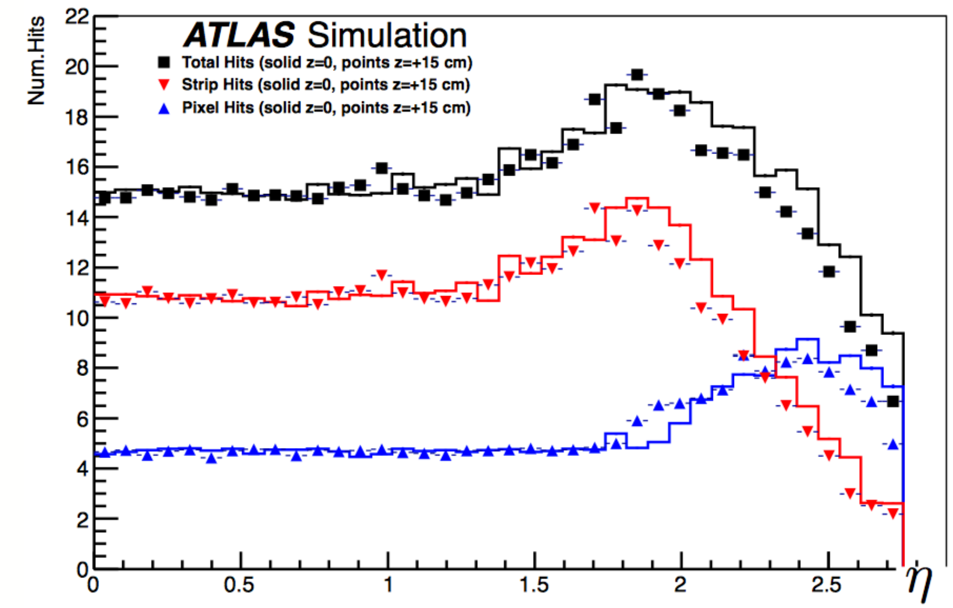
- Various designs (including extension to high η) are considered for a new all silicon-tracker with high granularity and large bandwidth read-out links

- Basic layout is based on:
  - Strip tracker: 5 layers, stubs, 7 disks on each side, |η| < 2.5
    - AC-coupled double-sided n-in-p sensors
  - Pixel tracker: 4 layers, 6 disks
    - n-in-n/p planar sensor, 3D sensors, diamond sensors considered for inner pixels; CMOS approach investigated for larger radii

- Expected performance:
  - 14 hits/track for |η| < 2.3
  - occupancy <1% for μ ~200

with $0.7X_0$ *for* $|\eta| \leq 2.7$



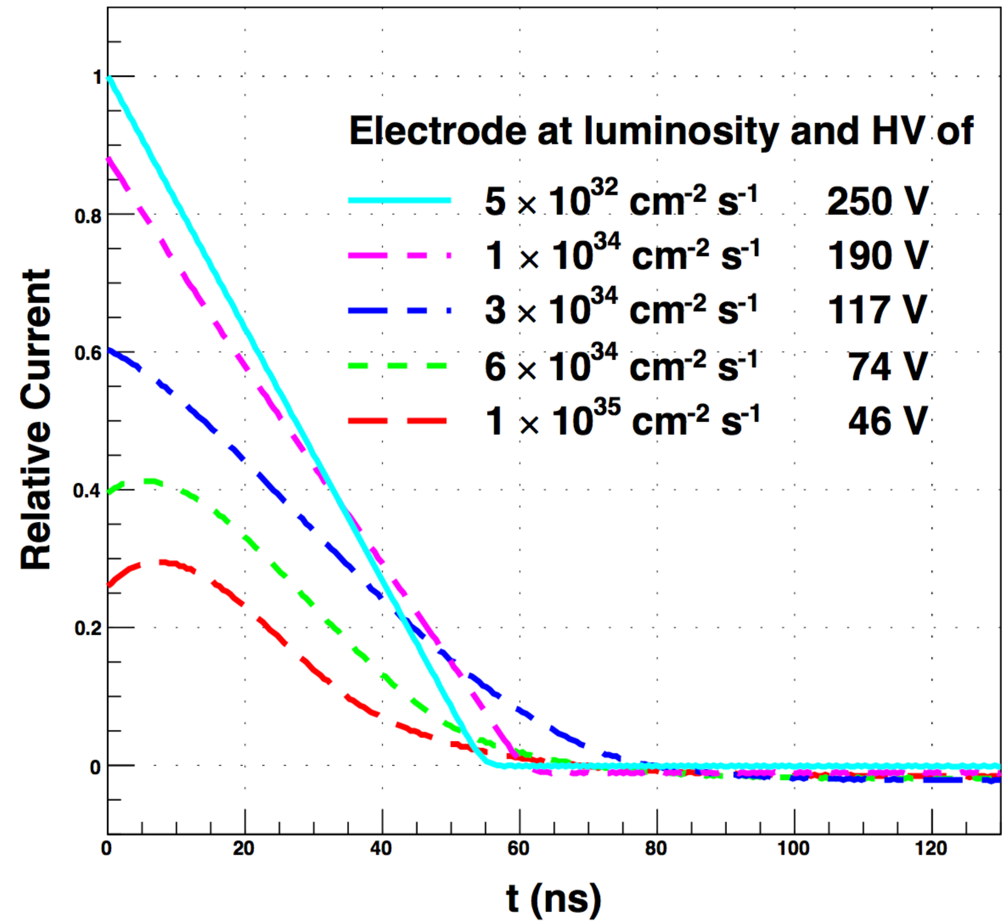


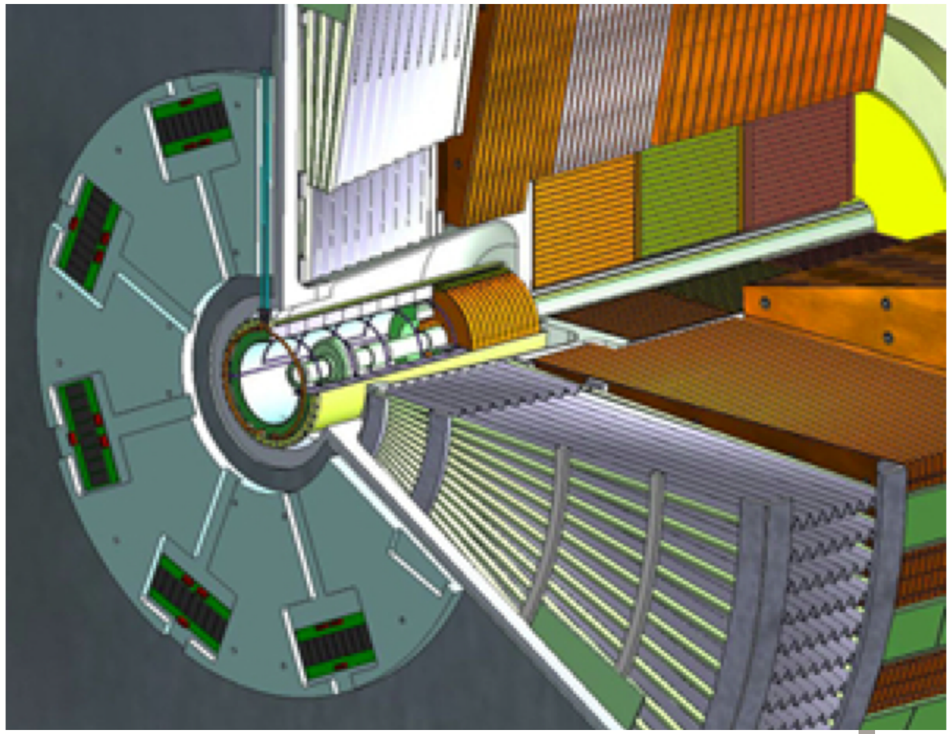
Track parameter $|\eta| < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum (q/p_T) [/TeV]	0.3	0.2
Transverse impact parameter (d_0) [μm]	8	8
Longitudinal impact parameter (z_0) [μm]	65	50

LHCC-I-023

Phase II : Forward Calorimeter

- Current FCAL consists of 3 modules with FCAL1 closest to the interaction point
  - as luminosity increases, performance degrades due to space charge effects, HV drop and possibly heating up of the liquid argon.
- Two options (three when including no upgrade)
  - new sFCAL
    - has same design, smaller LAr gaps, new summing boards; requires cooling down of the cryostat
  - additional miniFCAL in front of the FCAL
    - 3 technologies are explored: diamond, High Pressure Xenon gas, and liquid argon
    - planned to use copper absorber
    - impact on the cryostat is limited but modification to the beam pipe is required

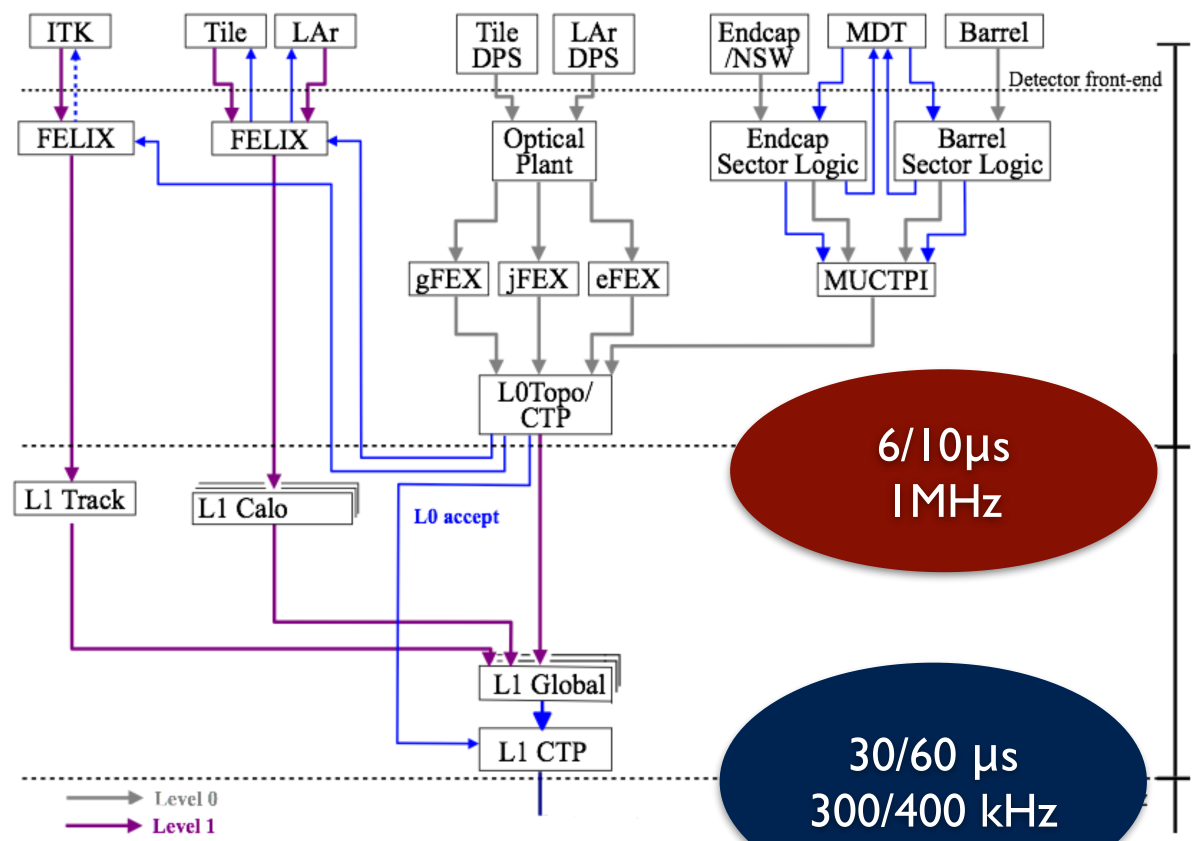


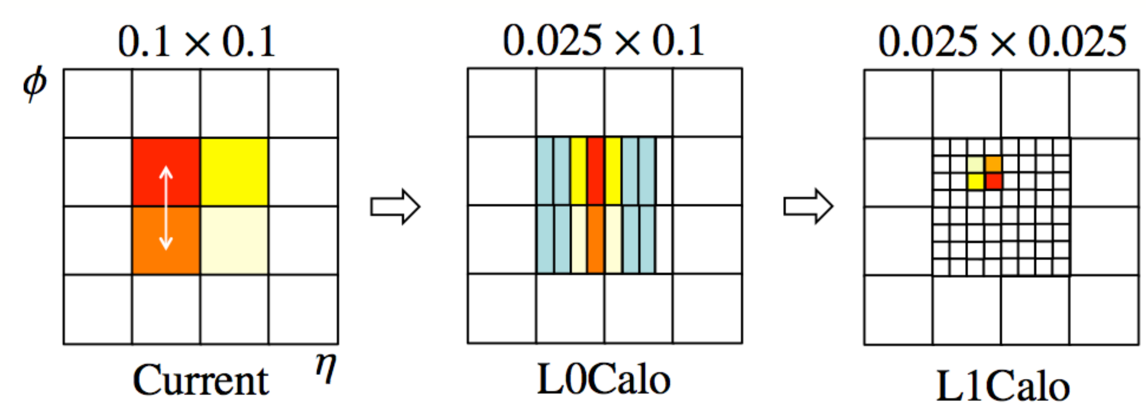


LHCC-I-023

Phase II : Trigger System

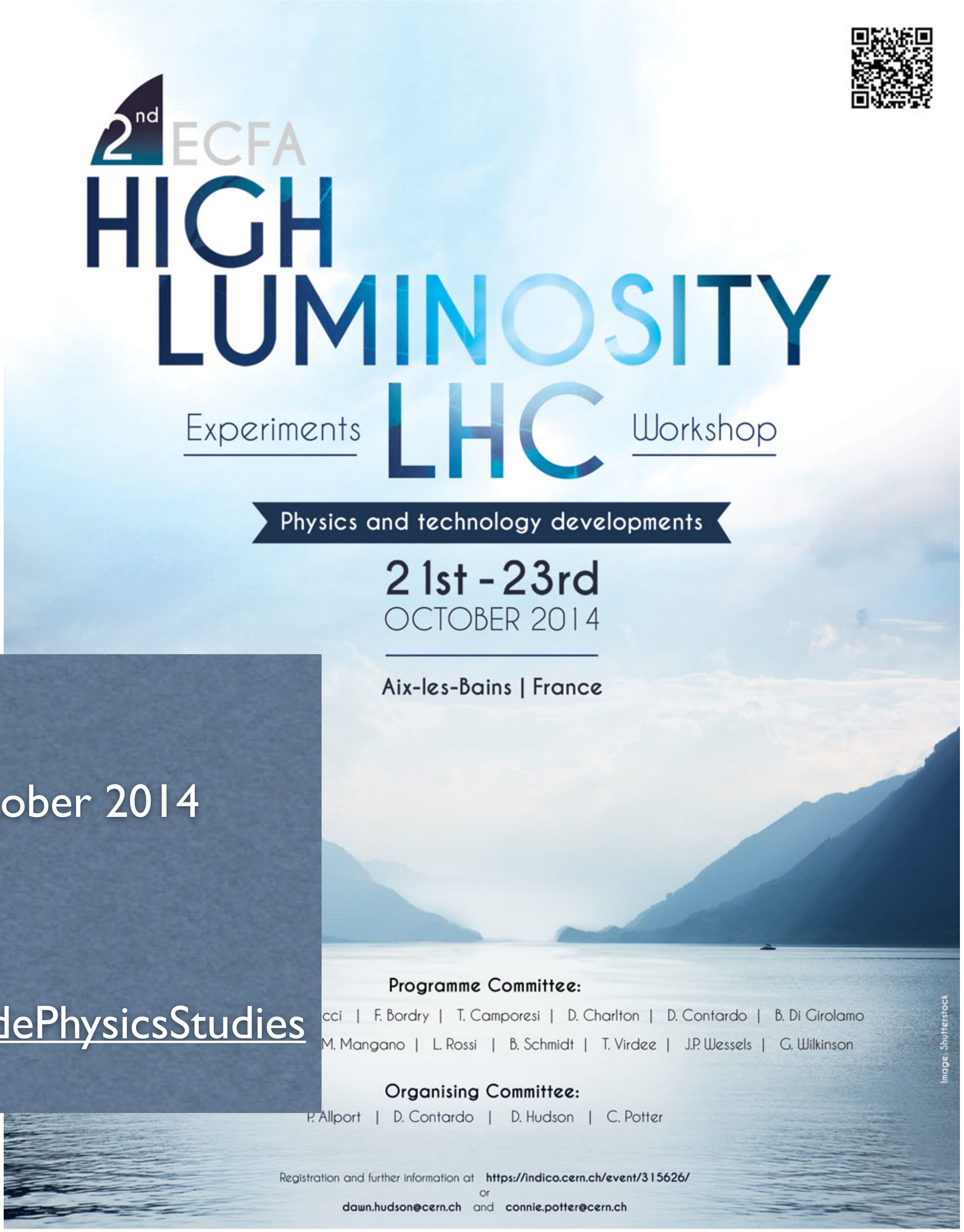
- HL-LHC will provide L_{inst} of 5-7 x10^{34} 1/cm^{2} s
- To maintain low thresholds, a new trigger system is proposed with a 2-step first level hardware trigger:
  - **1st step, Level-0**: calorimeter and muon information (functionally the same as the Phase I Level-1)
  - **2nd step, Level-1**: regional tracking information, regional full calorimeter granularity, refined muon selection using muon precision tracking chambers
    - within latency, processing time available to further refine EM, tau, jet and energy sum trigger objects.
- Offline-like algorithms will be used at the High-Level Trigger (software) with a readout rate of 5-10 kHz





LHCC-I-023

Physics and Performance Results



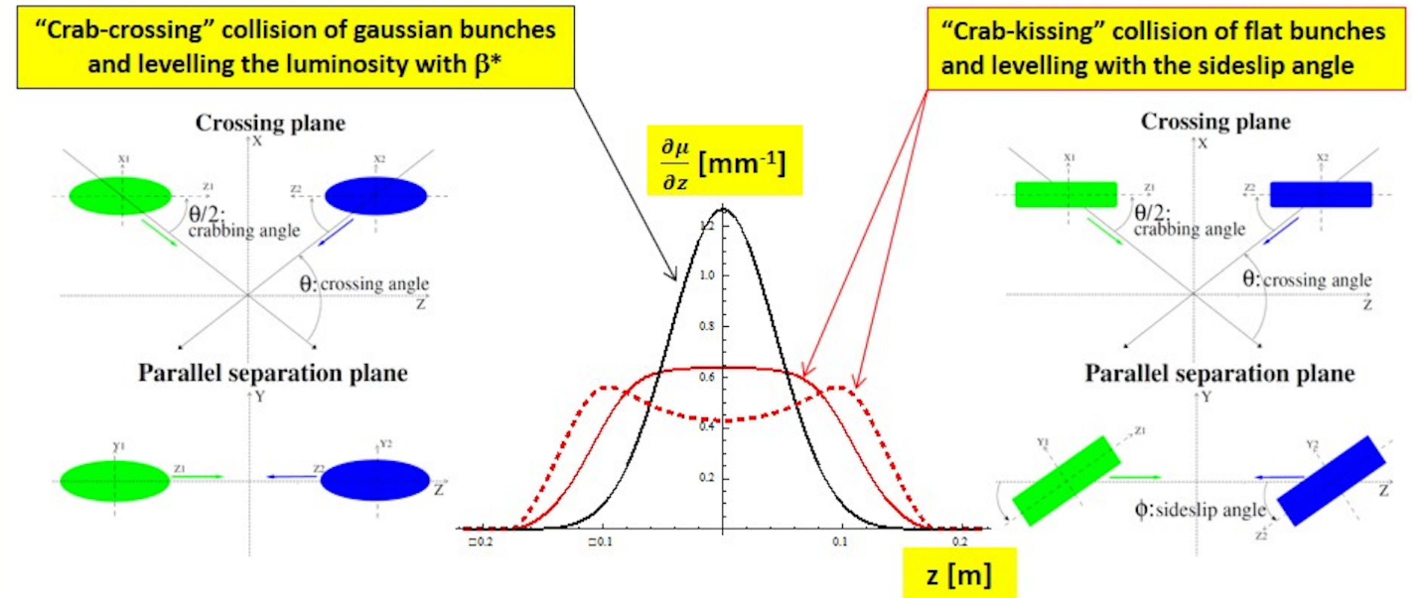
Summary of the results presented at ECFA, October 2014

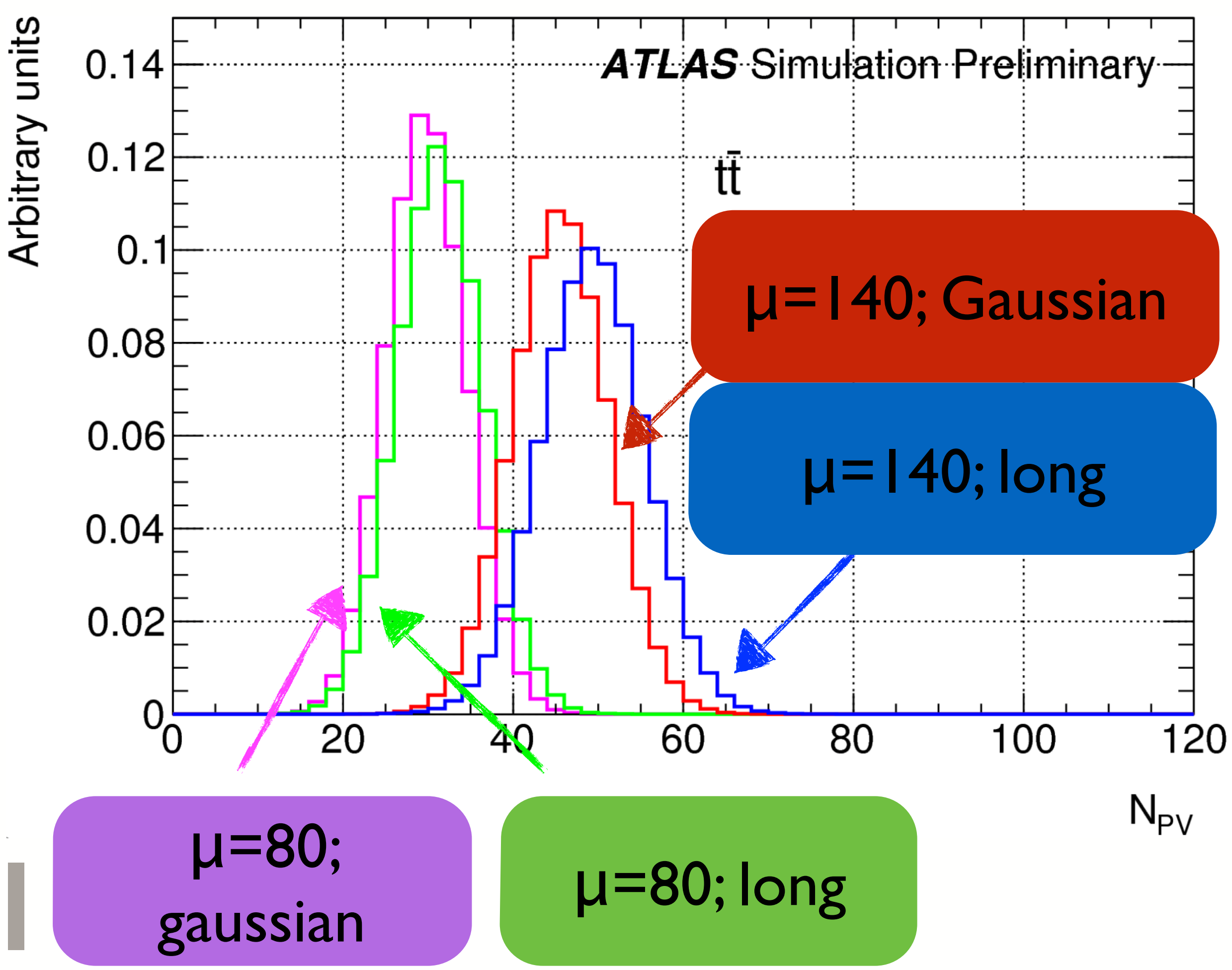
Full program at:

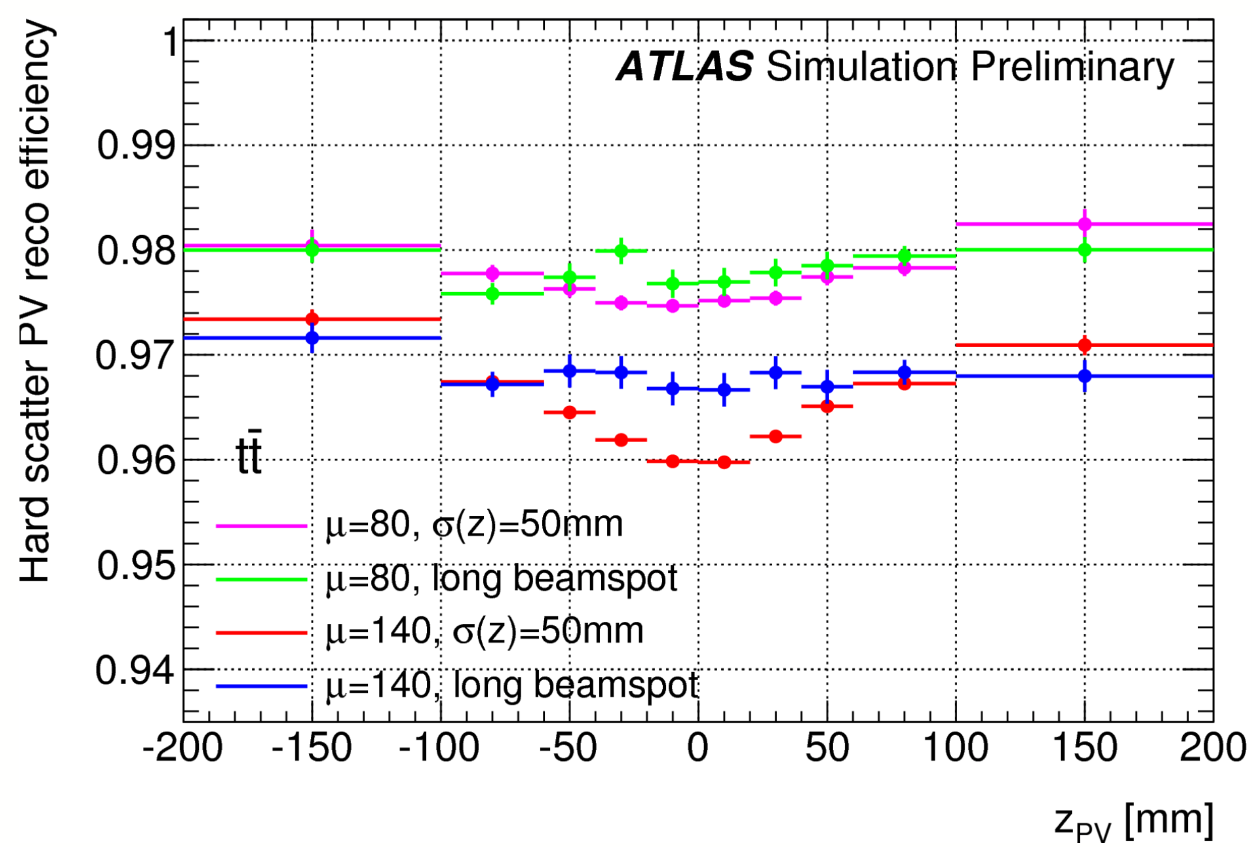
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

Beam Configuration at the HL-LHC

- A peak luminosity of $5\times10^{34}/cm^2s^1$ corresponds to an average pileup <μ> ~ 140 events
  - Poisson distribution with a sigma of about 12 events
- A long-flat beam configuration is under investigation as a way to mitigate the effect of high-pile up







PLOT-UPGRADE-2014-003

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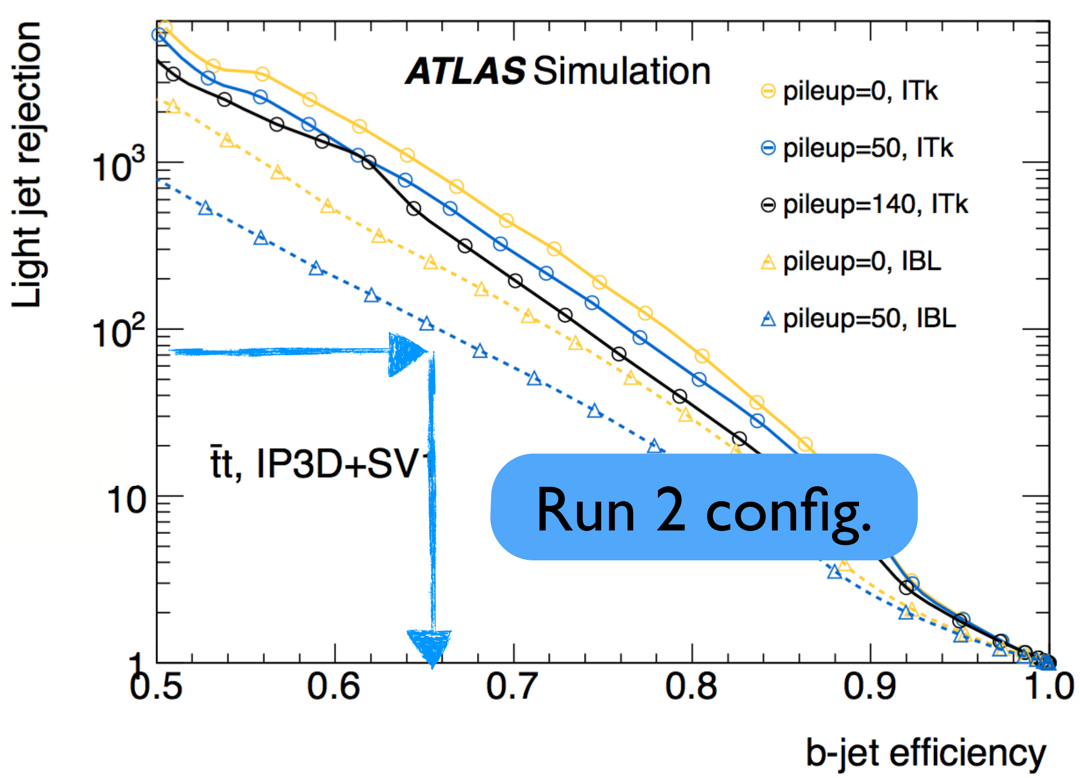
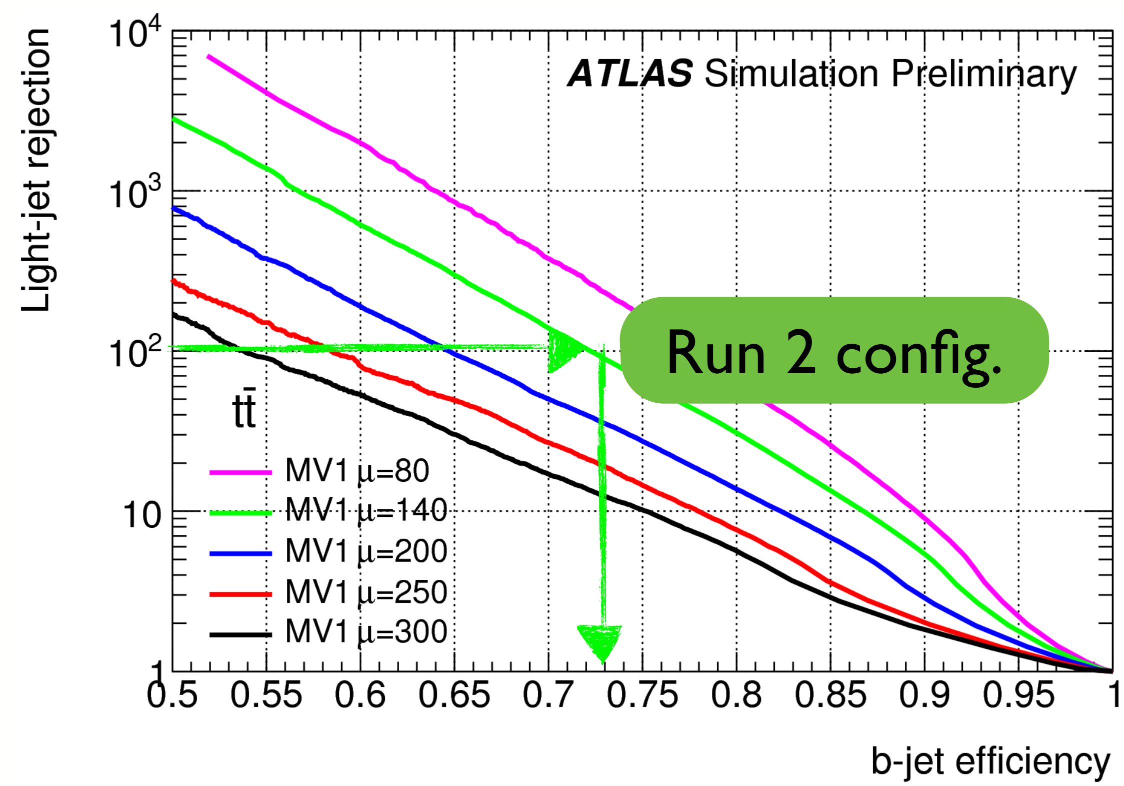
Tagging b-jets at the HL-LHC

- The capability of tagging b-jets is critical to the success of the Higgs and BSM programs at the HL-LHC
- Performance of (yet to be re-optimized!) Run 1/2 b-taggers is assessed in events where the hard-scatter vertex is assigned based on the scalar sum of the tracks' momentum
- ATLAS Phase II at μ=140 performs better than ATLAS Run 2 with μ=50





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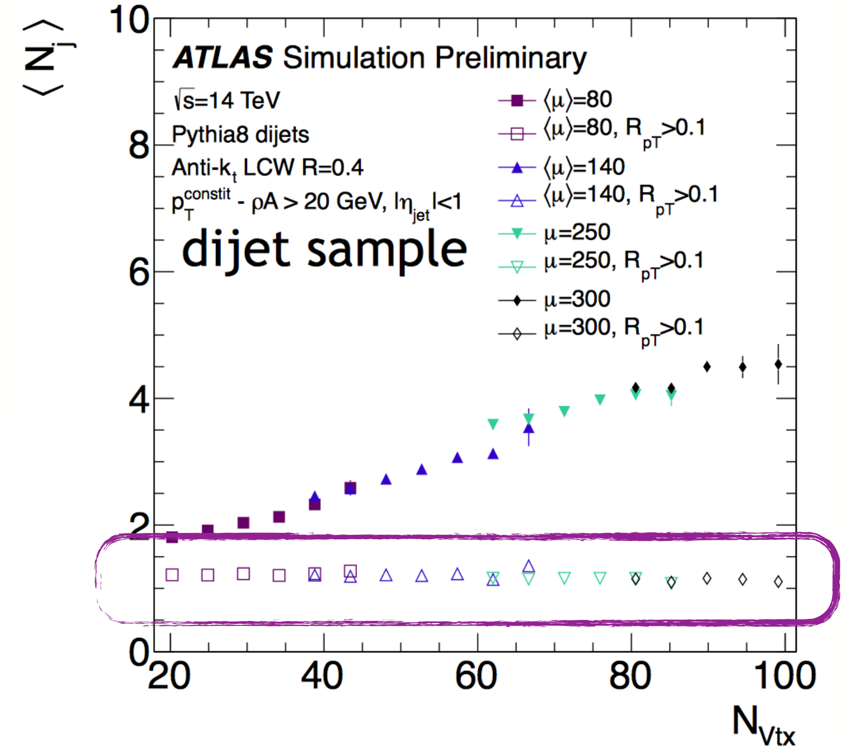
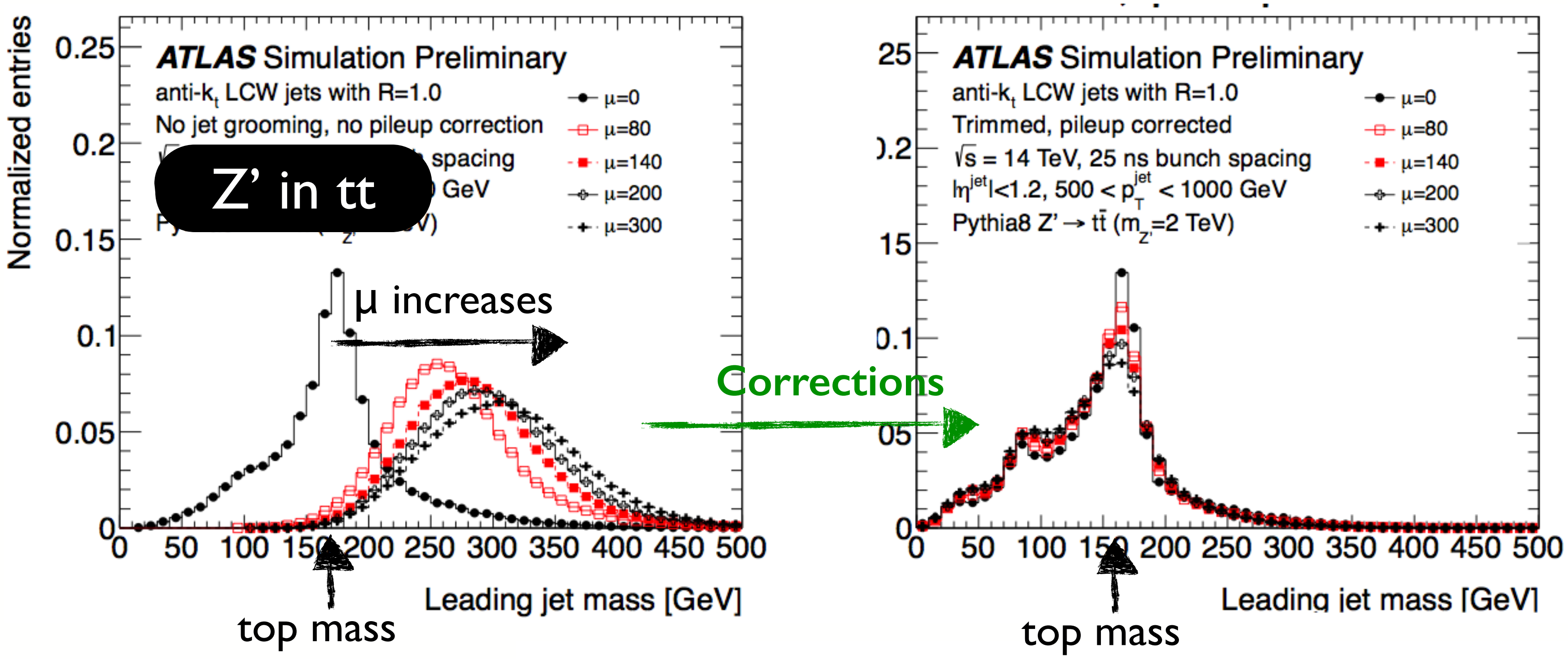
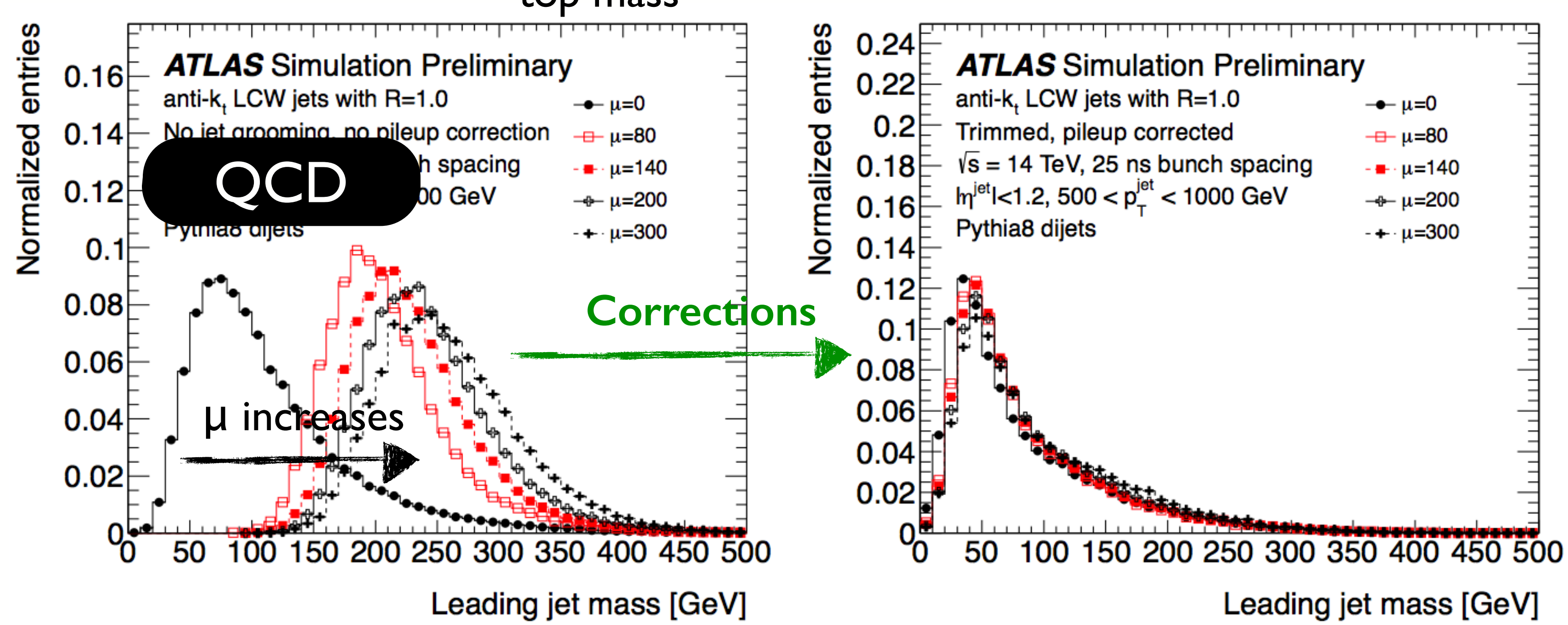
Reconstructing Jets at HL-LHC

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

- Jets from the hard scatted vertex and pile-up jets are efficiently distinguished using a jet charged-fraction based selection
- Removal of low-pT subjects and pile-up corrections applied to hard-scatter jets restore scale and improve energy resolution

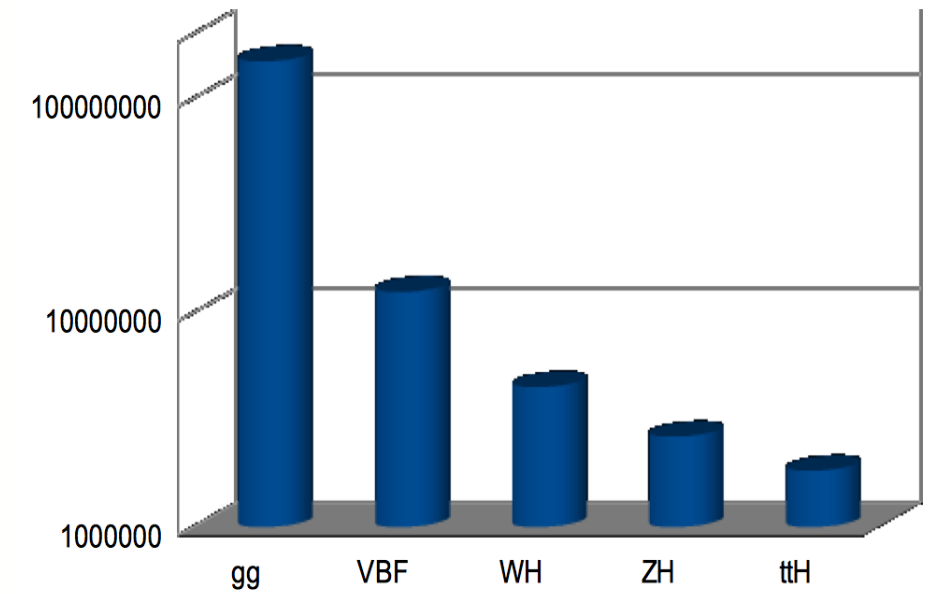


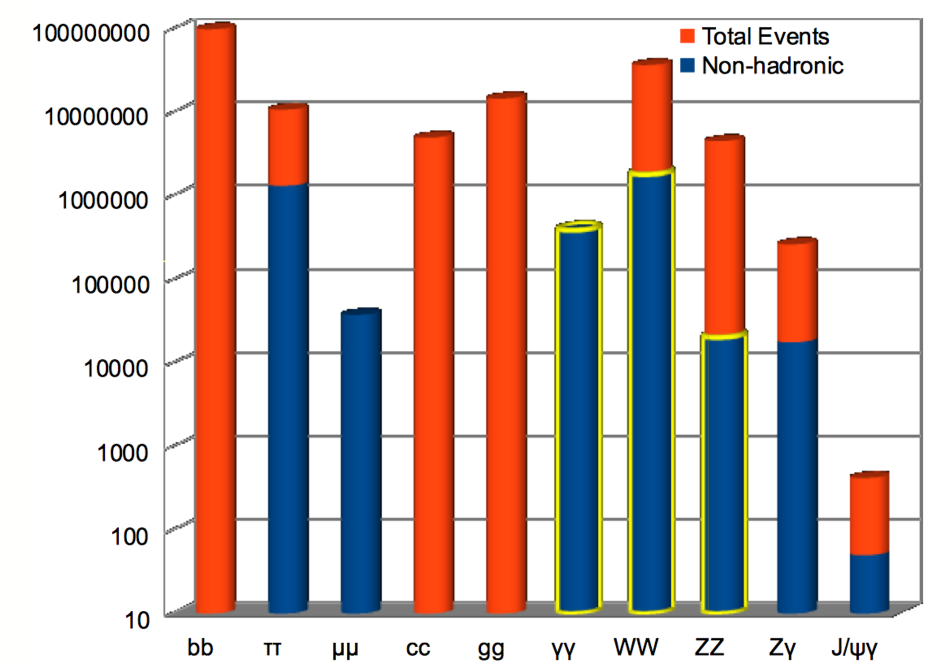




The Higgs Program at Run 3 and HL-LHC

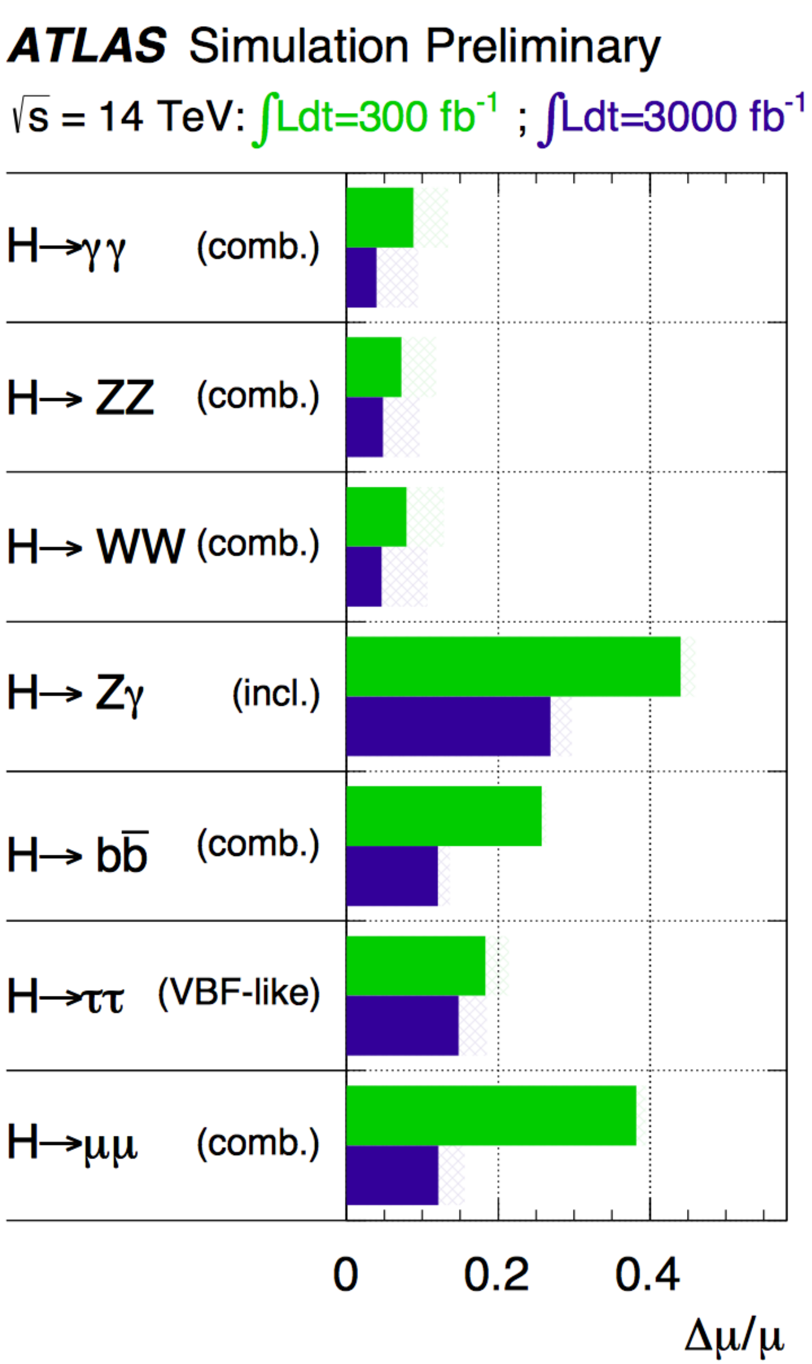
- **The HL-LHC will be a Higgs Factory!**
  - Over 100 million SM Higgs bosons in total
  - Observation of rare processes
    - Sensitivity to $H \rightarrow \mu\mu$ at 5σ with 3000/fb
    - Measurement of $H \rightarrow Z\gamma$, ttH
  - Precision measurement of all dominant production and decay modes
  - Indirect searches for New Physics through precision measurements of couplings
  - Direct searches for additional Higgs bosons





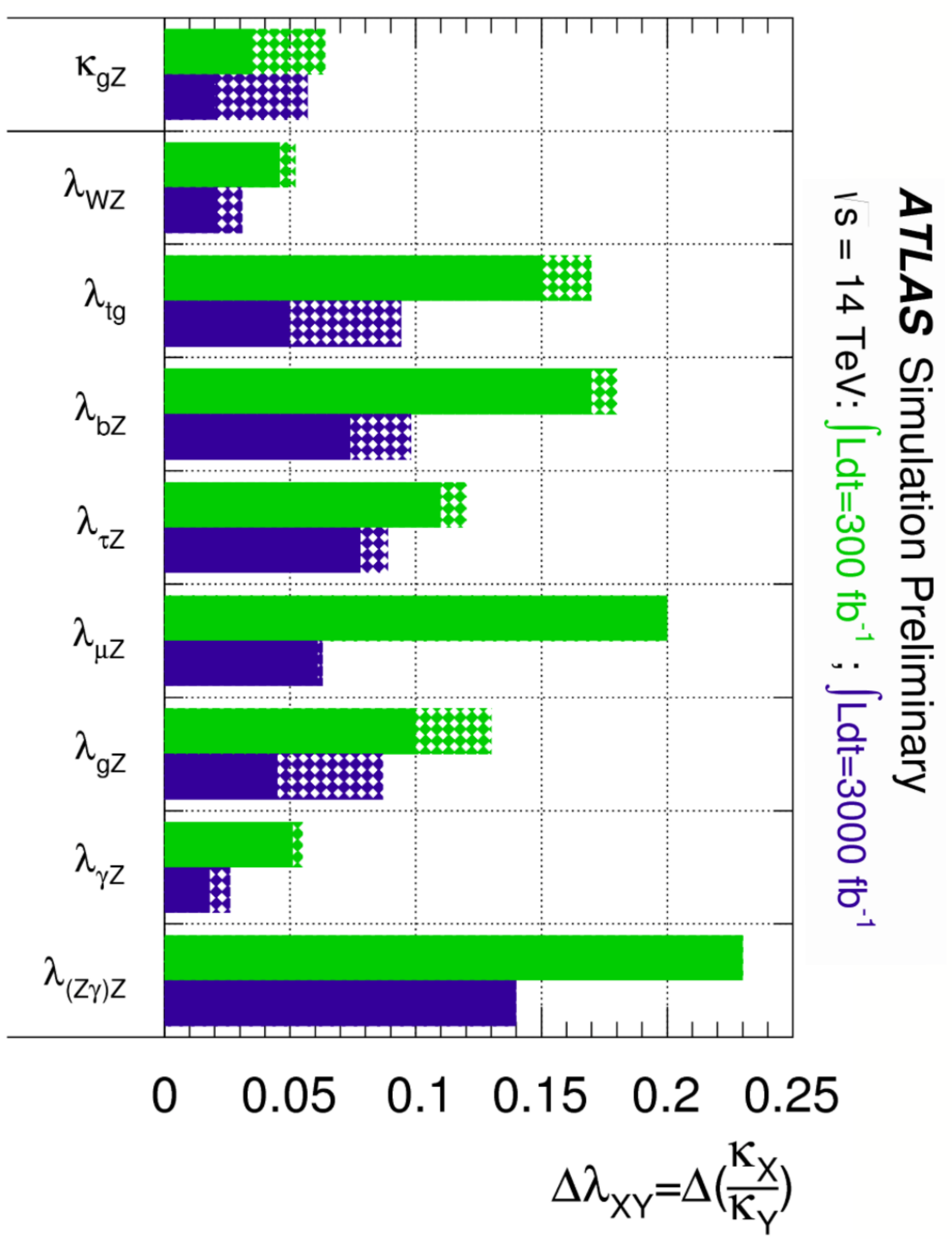
Coupling Measurements

- High precision on signal strength achieved by combining various production modes



- Measurements of the couplings is interpreted in the leading-order tree level *k* framework, for example:

$$\frac{\sigma \cdot B\,(gg \to H \to \gamma\gamma)}{\sigma_{SM}(gg \to H) \cdot B_{SM}(H \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

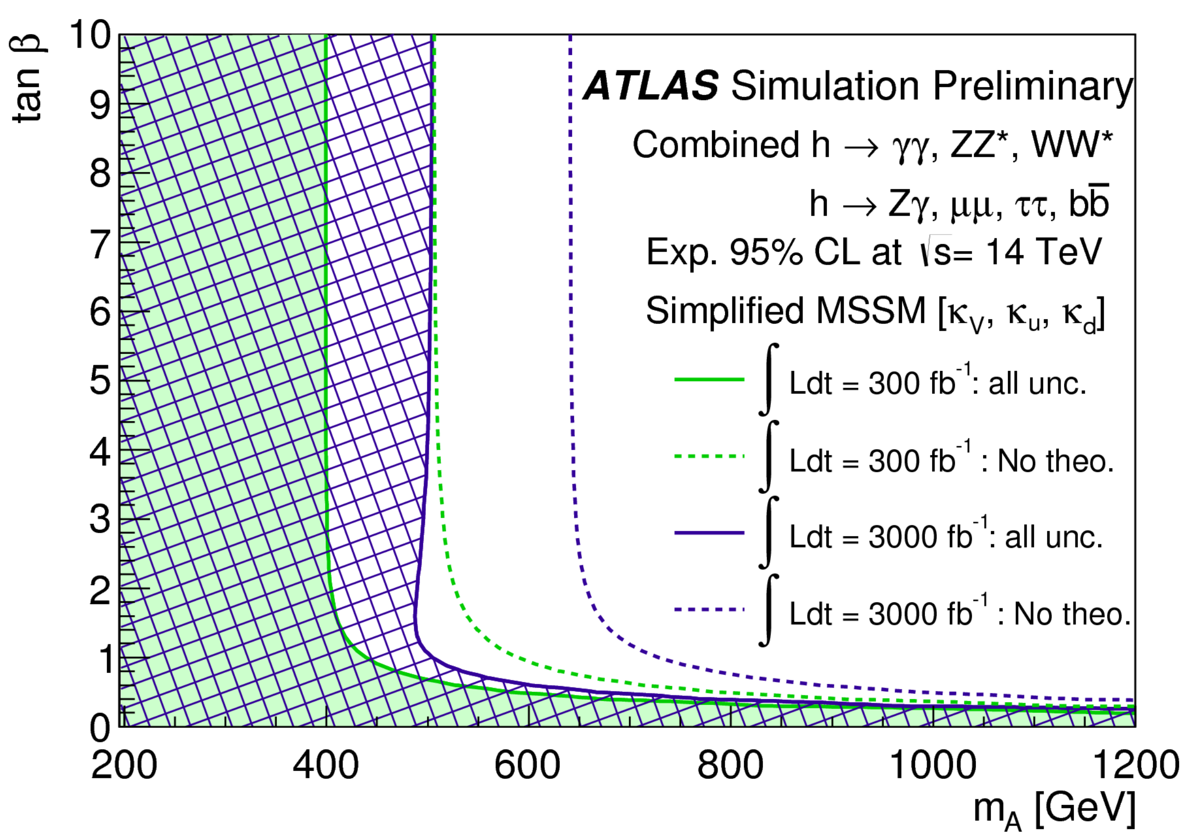


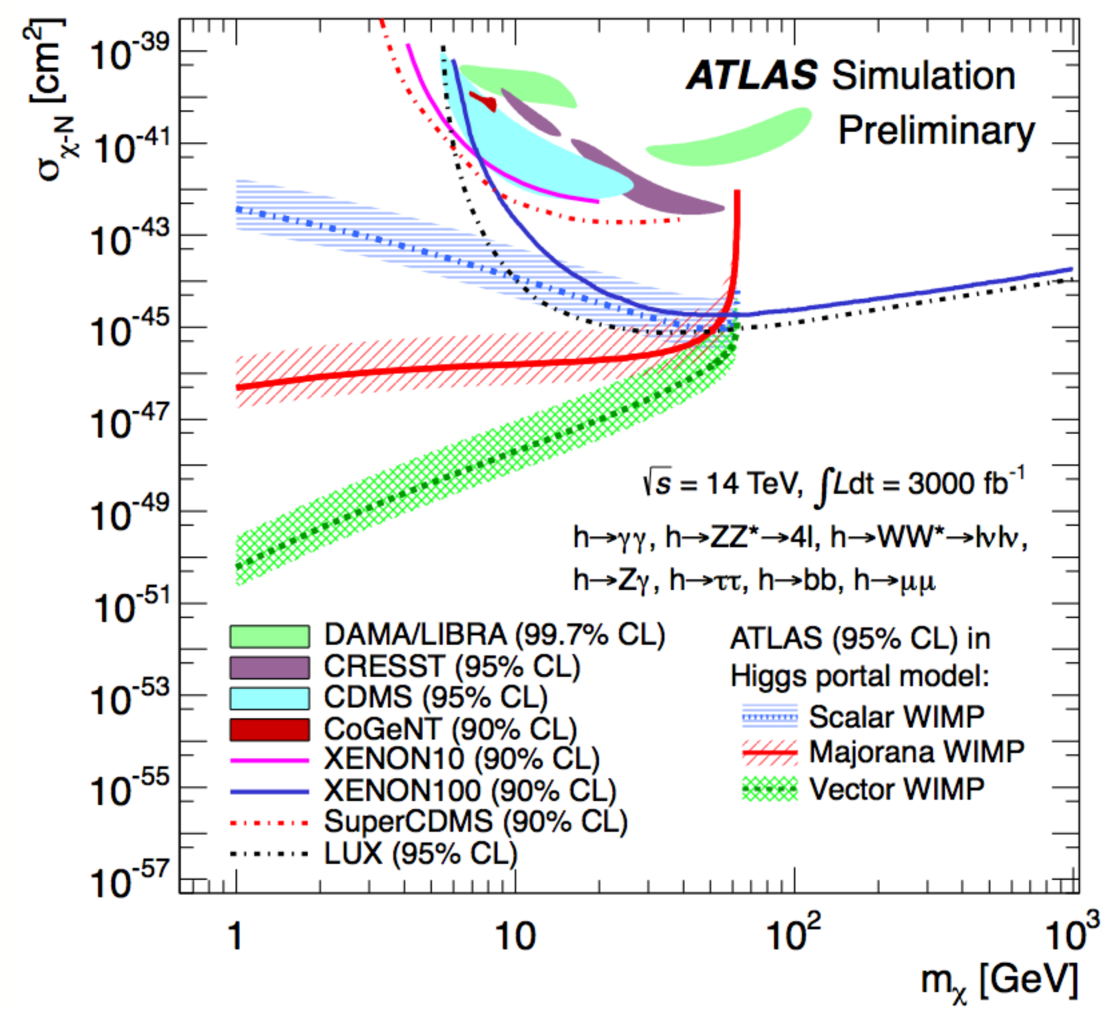
ATL-PHYS-PUB-2014-016

Sensitivity to New Phenomena

- The combination of measurements from multiple production and decay channels is used to probe to determine the sensitivity to
  - composite Higgs models
    - couplings are modified with a scaling parameter $\xi = v^2/f^2$
  - Minimal Supersymmetric Standard Model
  - decay of Higgs to dark matter candidates

Model	$300\ fb^{-1}$ All unc.	$300\ fb^{-1}$ No theory unc.	$3000\ fb^{-1}$ All unc.	$3000\ fb^{-1}$ No theory unc.
MCHM4	620 GeV	810 GeV	710 GeV	980 GeV
MCHM5	780 GeV	950 GeV	1.0 TeV	1.2 TeV





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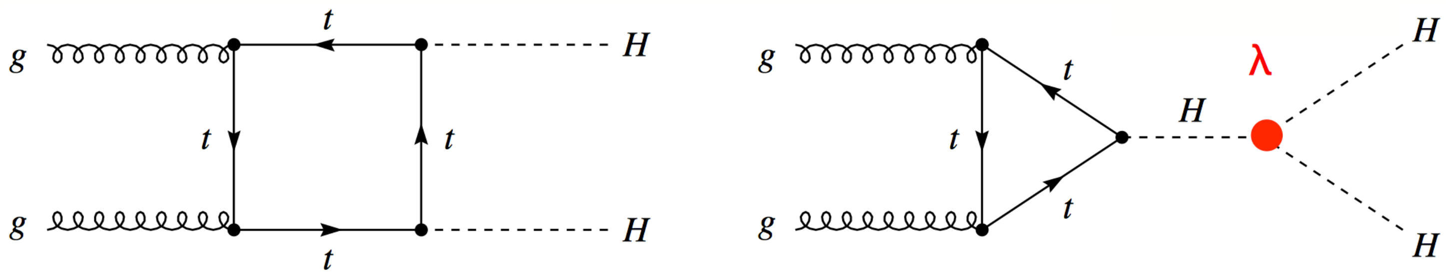
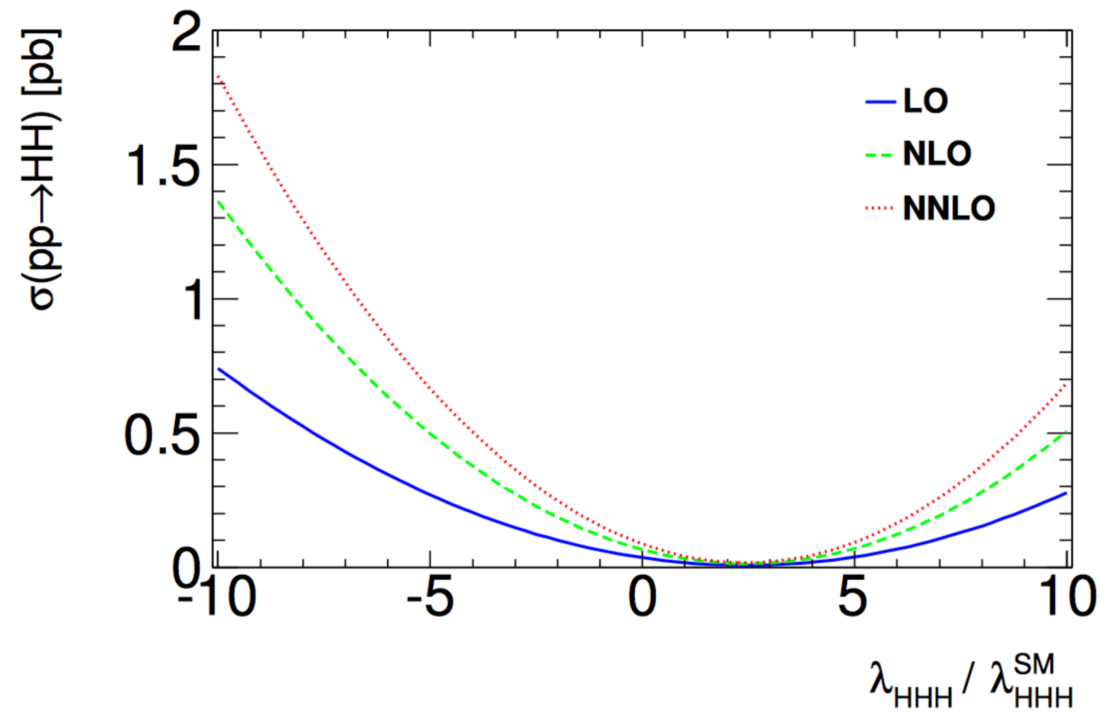
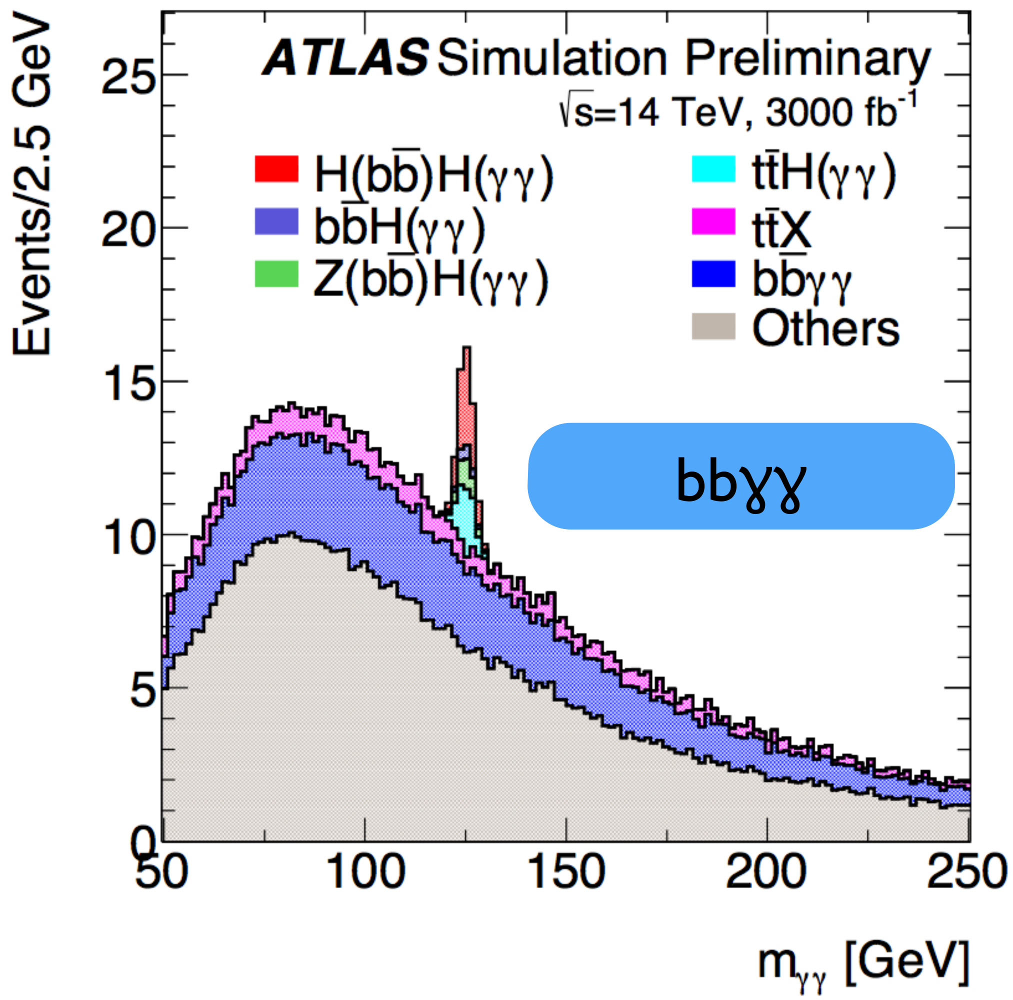
Higgs Pair Production at the HL-LHC

- Measurement of the Higgs pair production can probe the trilinear coupling and thus the Higgs potential
- The negative interference between the box and s-channel lead to suppression of event yield



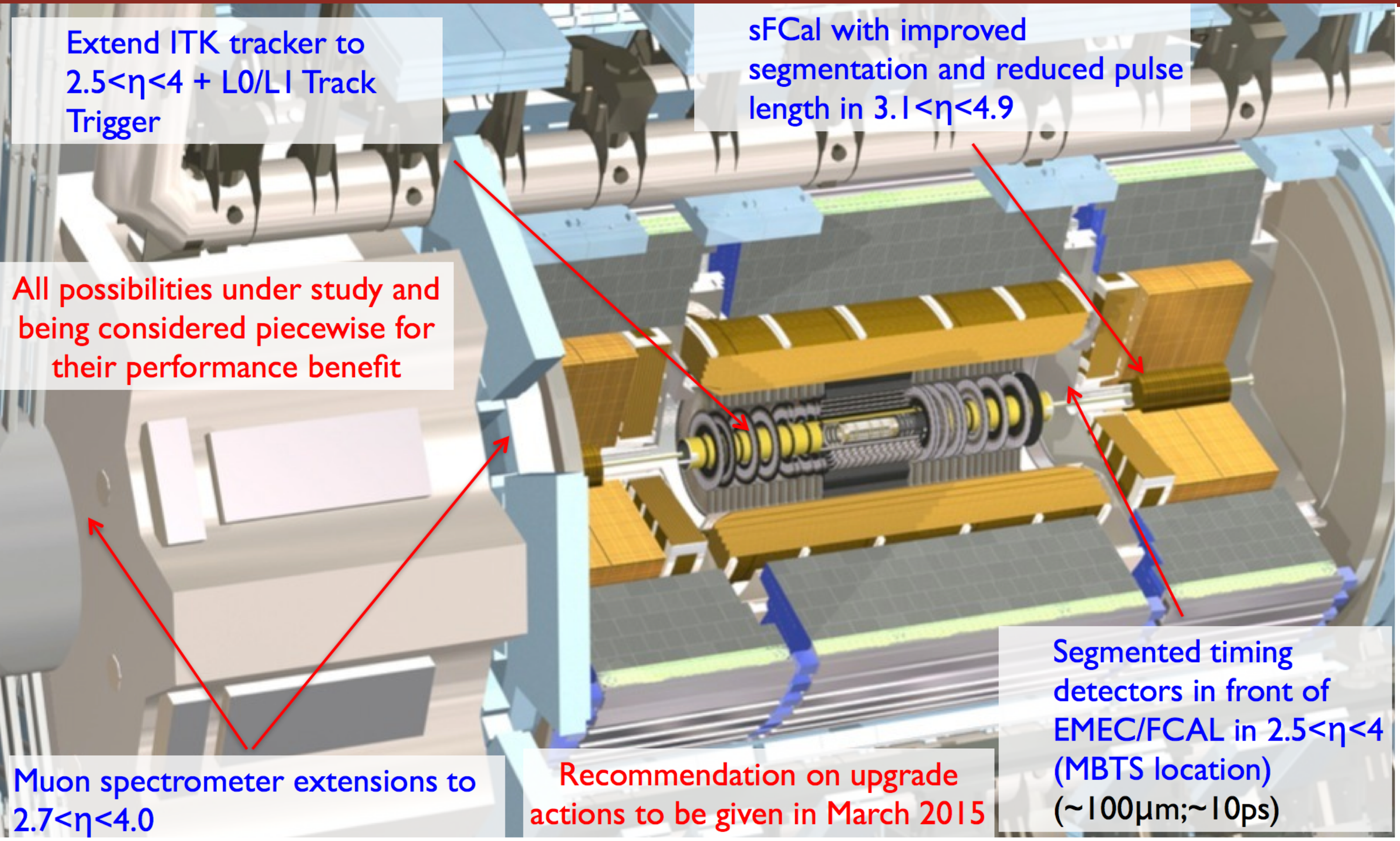


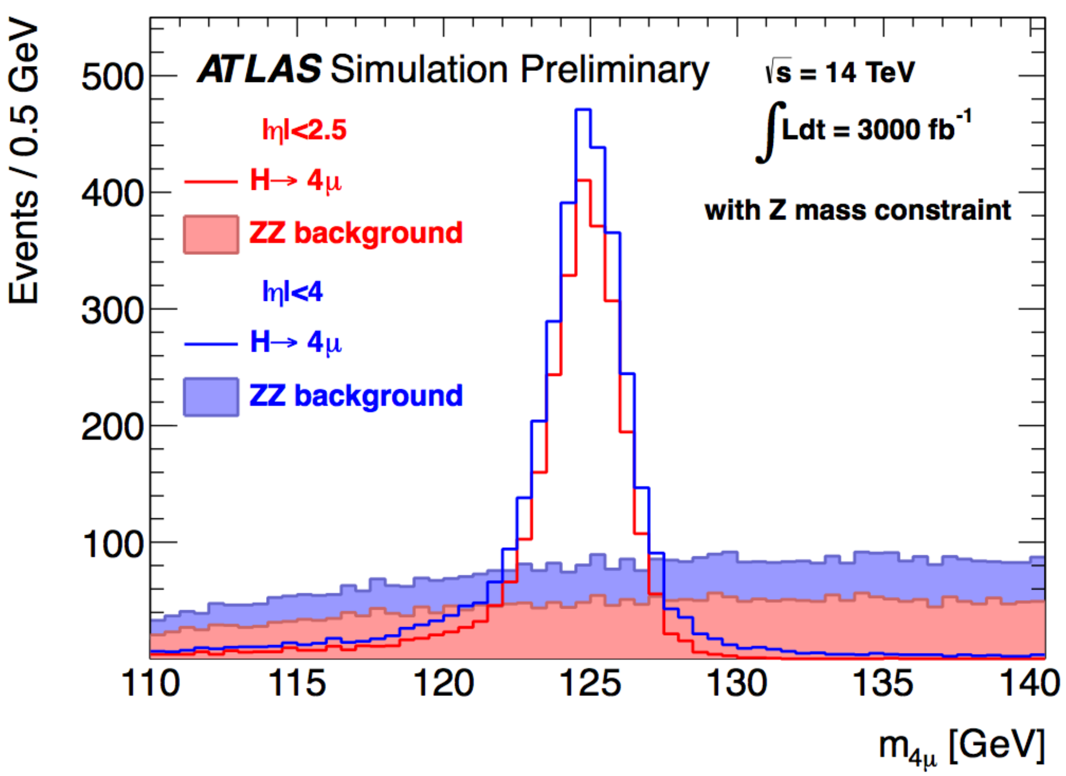


process	Expected events in 3000 fb^{-1}
SM HH→bbγγ	8.4± 0.1
bbγγ	9.7 ± 1.5
ccγγ, bbγj, bbjj, jjγγ	24.1 ± 2.2
top background	3.4 ± 2.2
ttH(γγ)	6.1 ± 0.5
Z(bb)H(γγ)	2.7 ± 0.1
bbH(γγ)	1.2 ± 0.1
Total background	47.1 ± 3.5
S/√B (barrel+endcap)	1.2
S/√B (split barrel and endcap)	1.3

ATL-PHYS-PUB-2014-019

Extension of ATLAS to large η: Impact on Higgs Physics





- The acceptance of H→ZZ in 4μ final states increases by ~35% assuming 100% muon reconstruction efficiency

- The expected signal strength error of the VBF $H\tau_l\tau_{had}$ signal improves by 2.25x if 90% pile up jet rejection probability

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

BSM at Run 3 and HL-LHC

- The Run 3 and HL-LHC at 14 TeV provide significant discovery potential in multi-TeV region with respect to reach at 7-8 TeV

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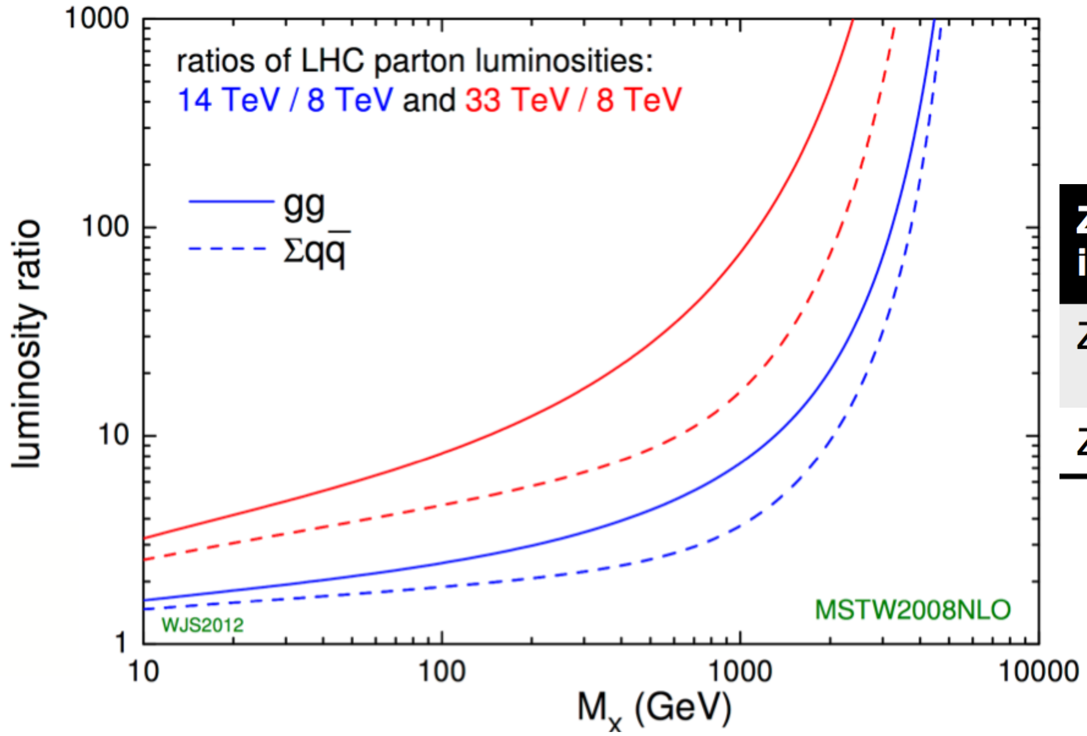
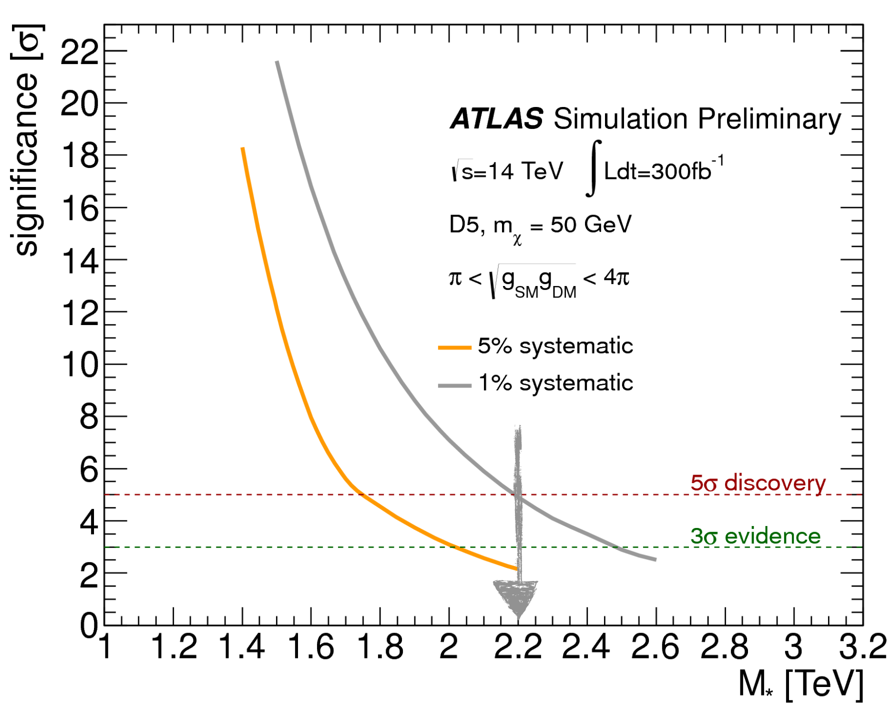
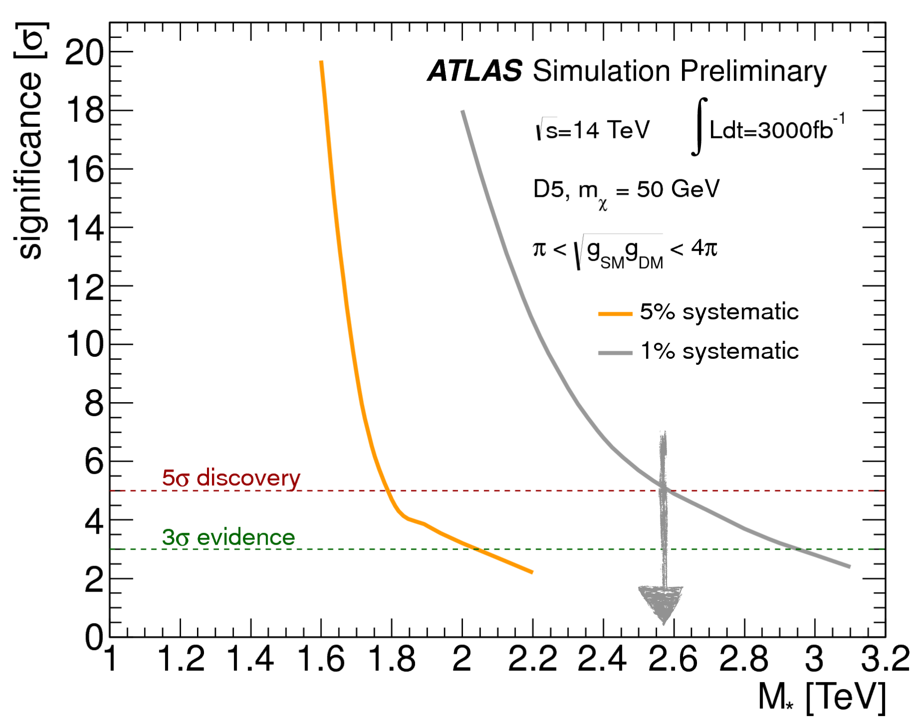


SSM Z'

Z' mass lower limit @ 95% CL in SSM [ATLAS]	Run 1 @ 8 TeV (20 fb^{-1})	Run 3 @ 14 TeV (300 fb^{-1})	HL-LHC @ 14 TeV (3000 fb^{-1})
Z' mass (ee)	Up to 2.79 TeV	Up to 6.5 TeV	Up to 7.8 TeV
Z' mass (μμ)	Up to 2.53 TeV	Up to 6.4 TeV	Up to 7.6 TeV

ATL-COM-PHYS-2014-549

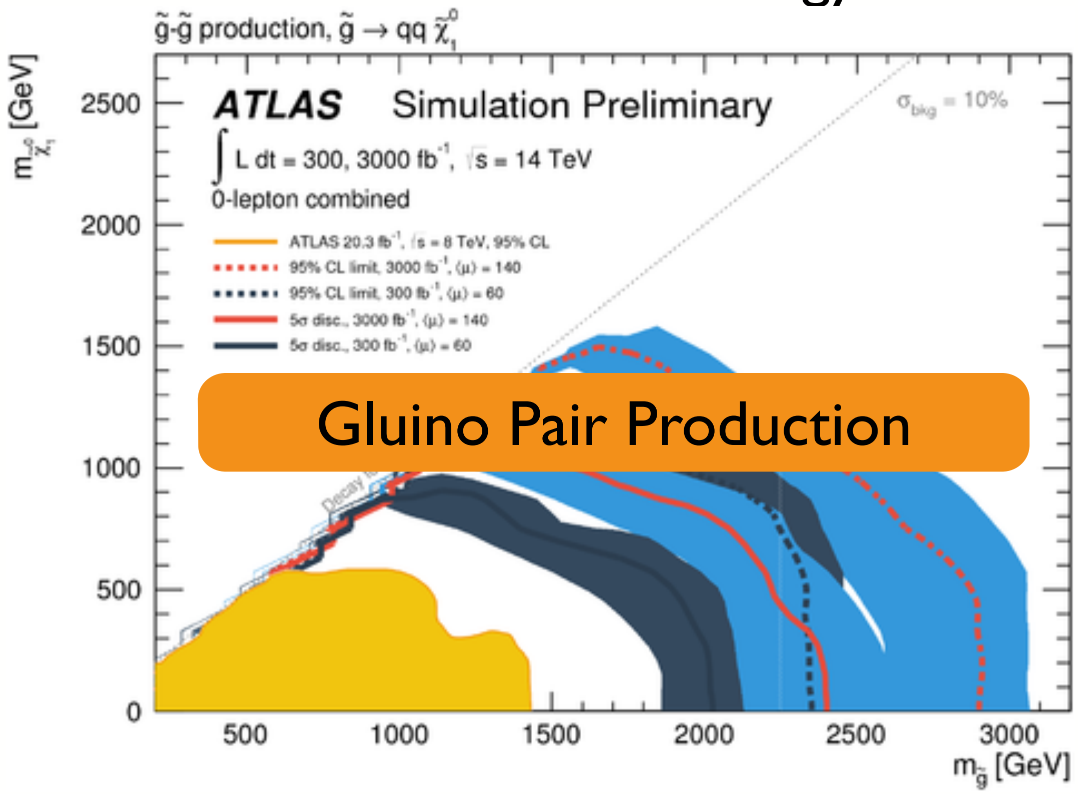


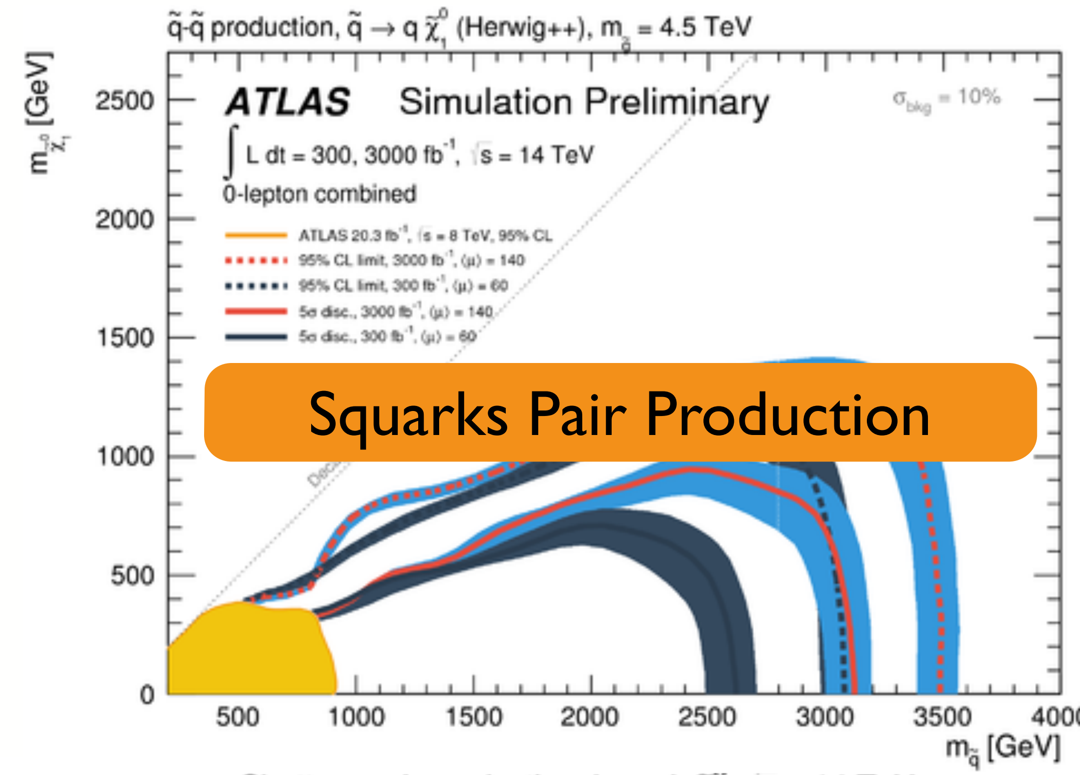


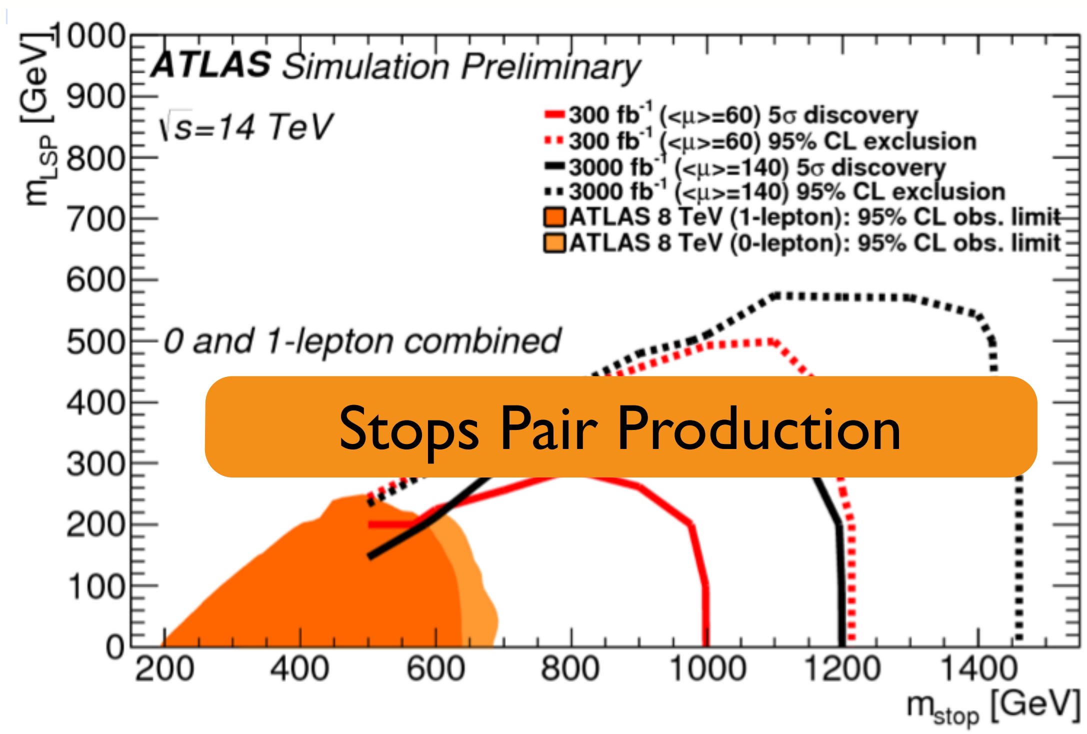
Search for Dark Matter in EFT framework

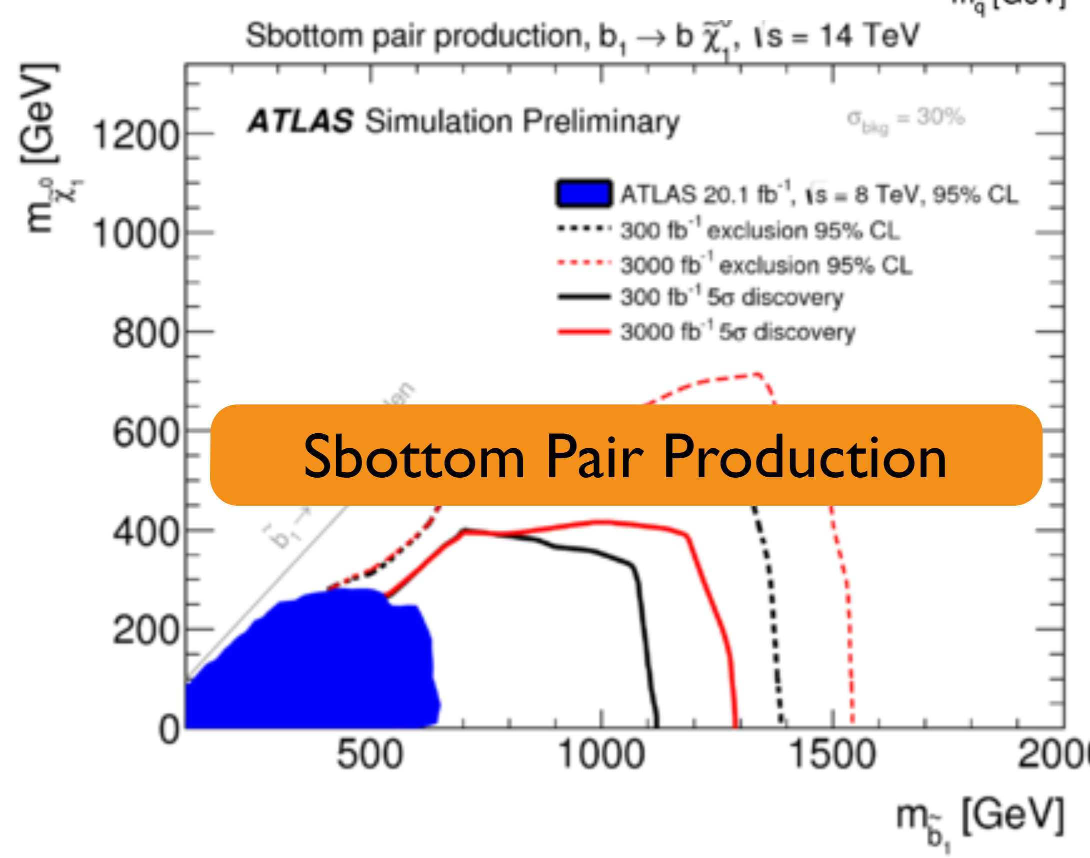
SUSY at Run 3 and HL-LHC

- Significant increase of discovery potential for strongly produced sparticle originates from the increase in center of mass energy









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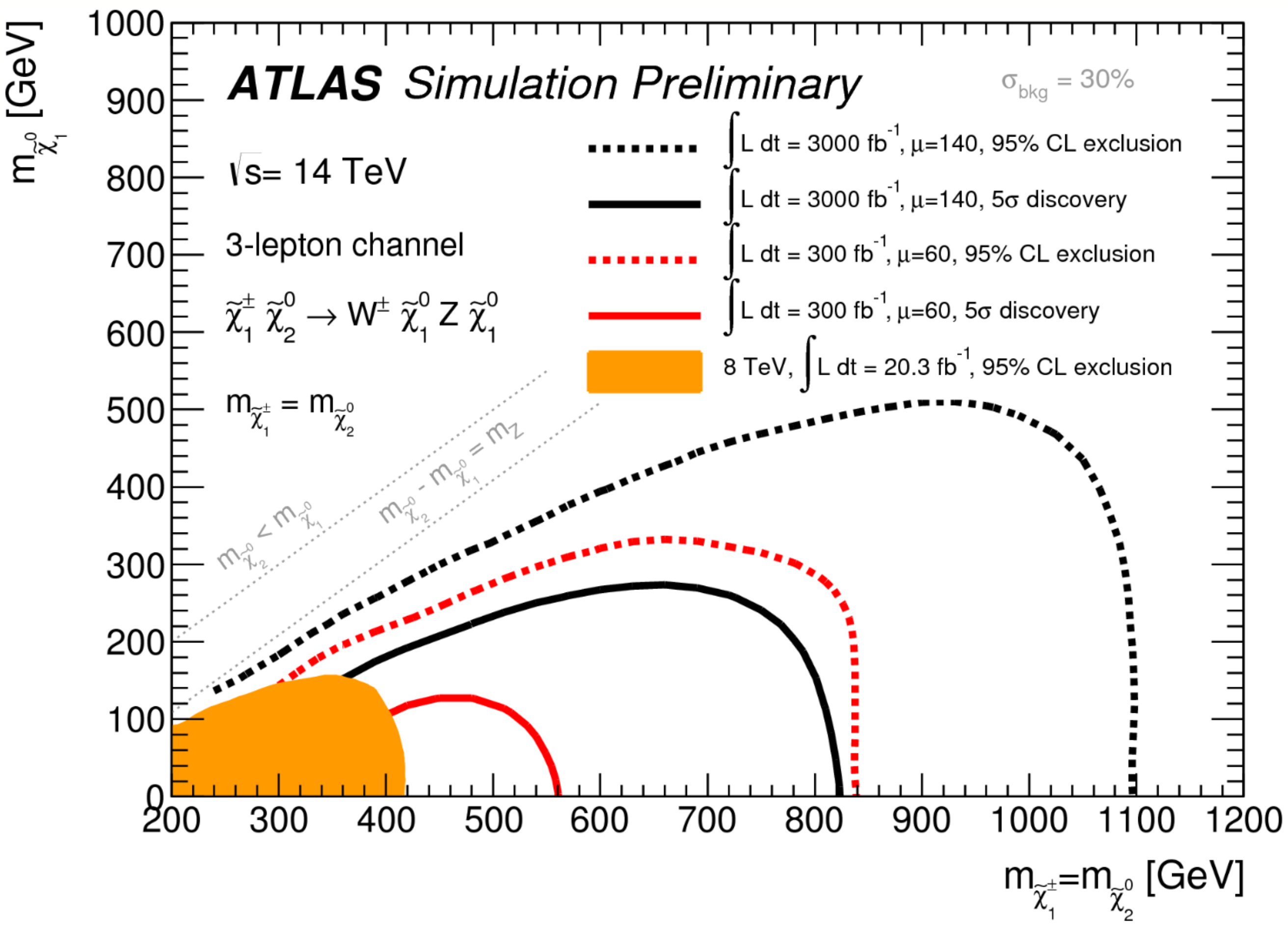
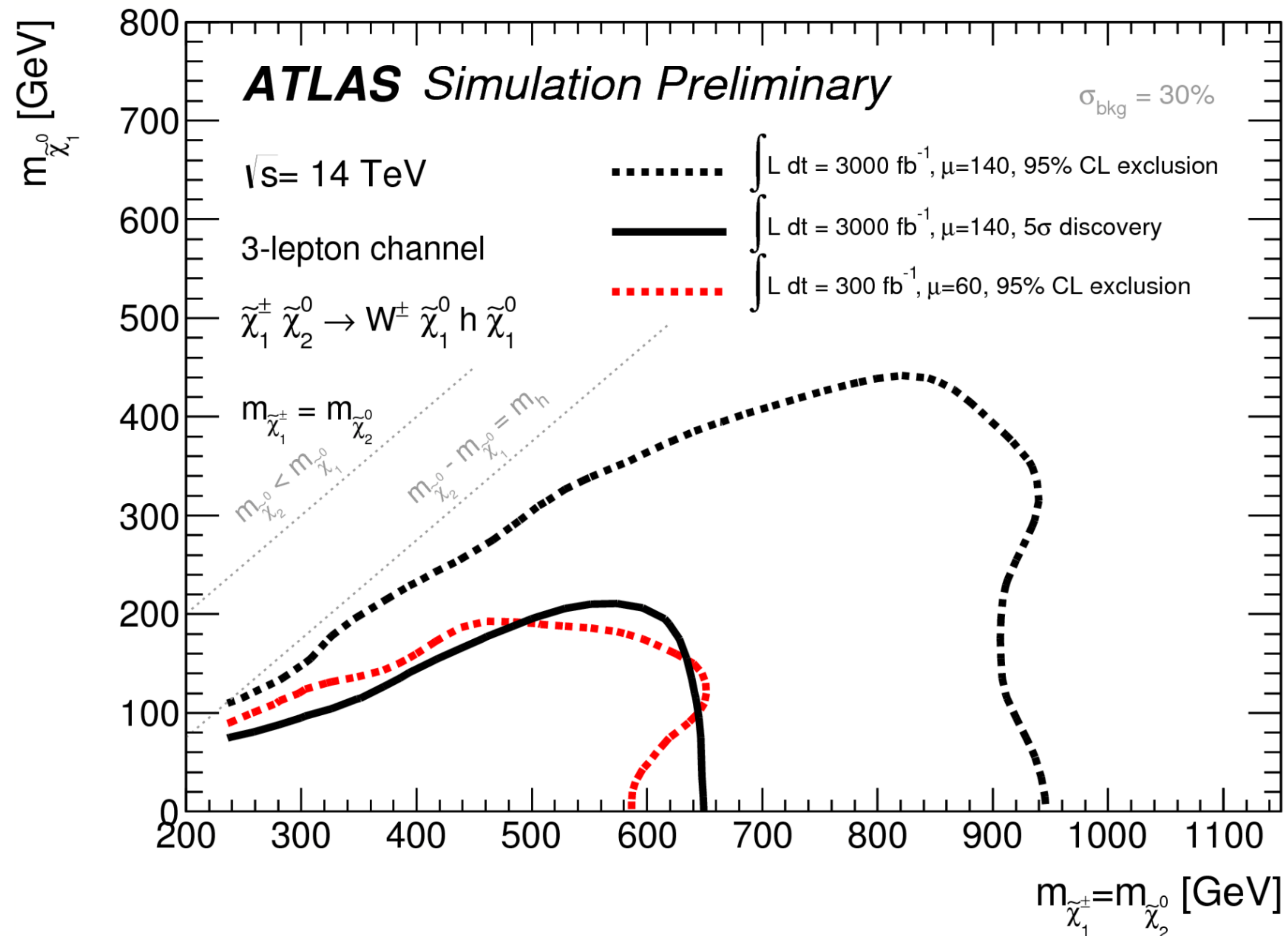
ATL-COM-PHYS-2013-011

EWK-SUSY at Run 3 and HL-LHC

- Factor 10x in cumulated luminosity is essential to probe rare SUSY processes, e.g. the pair production of EWK-inos expected to be light from naturalness arguments





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TRIUMF

Summary

- The ATLAS detector will be upgraded to fully exploit the discovery potential at the LHC Run 3 and HL-LHC
  - Phase I: upgrade of the muon, tracking and calorimeter triggers
  - Phase II: new tracking detector, upgrade of the TDAQ system, calorimeter and muon electronics.
- The combination of an upgraded detector and improved experimental techniques guarantee good performances even in high luminosity conditions
- The HL-LHC provides precision measurement of the Higgs couplings, access to rare processes, and it probes the Higgs pair production process
- The HL-LHC extends discovery reach in strongly motivated areas via direct and indirect searches