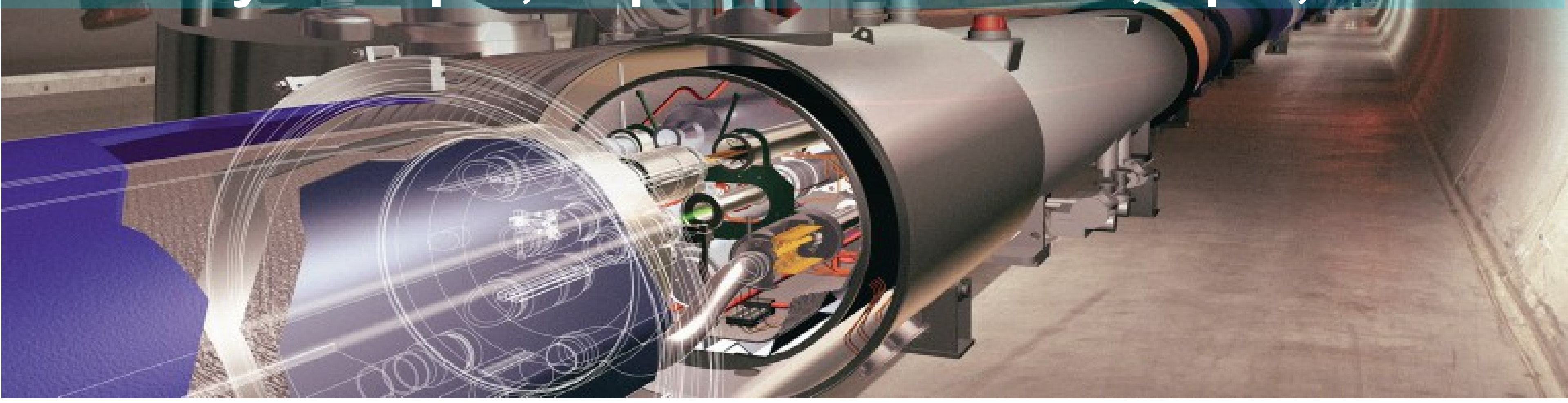
Upgrade and Future of ATLAS

Wei-Ming Yao (LBNL)
For ATLAS Collaboration

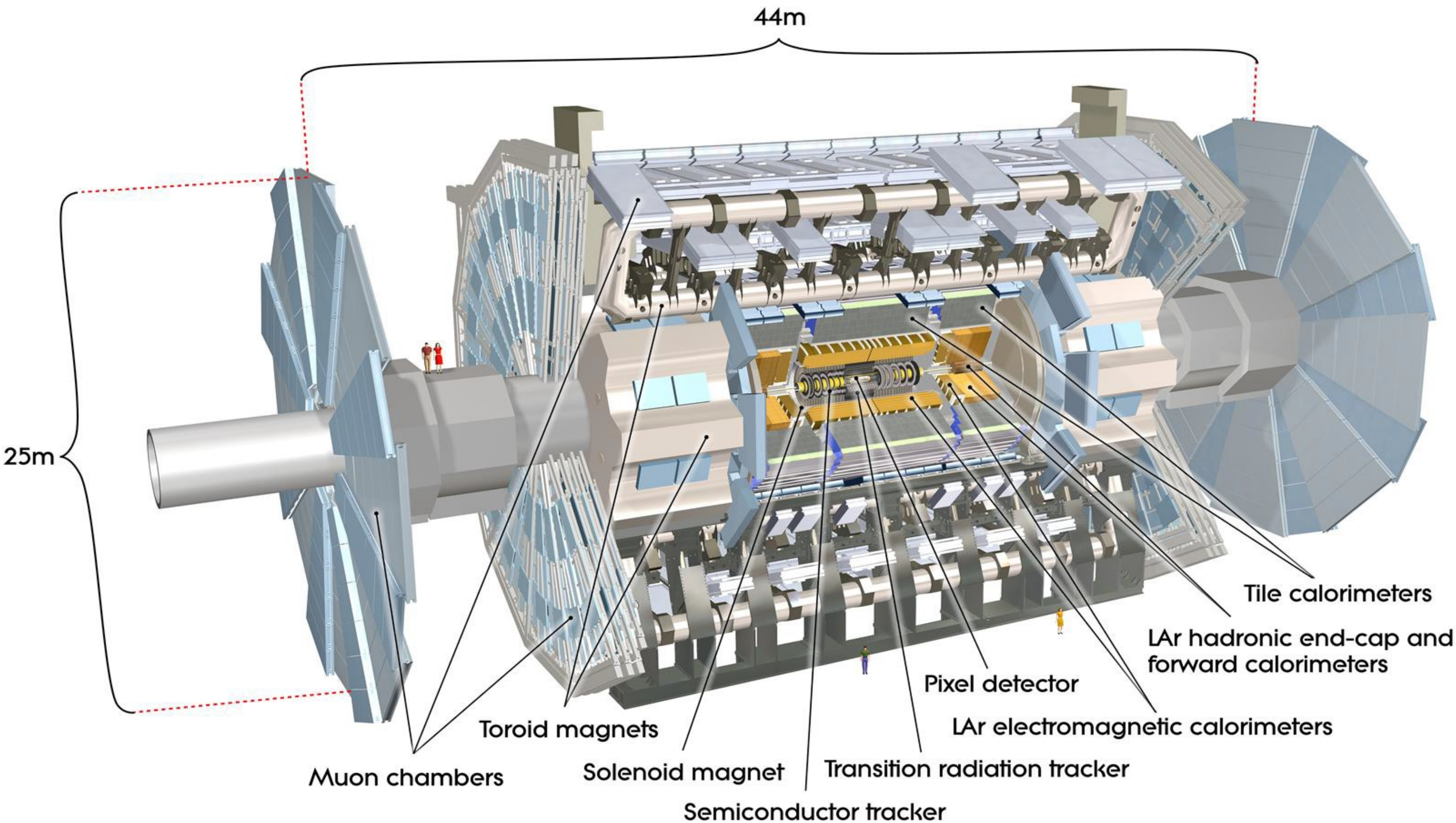
LHC Days in Split, Sept. 29-Oct. 4 2014, Split, Croatia



Outline

- Introduction
- ATLAS Detector Upgrades
- Future Prospects for HL-LHC program
- Conclusion

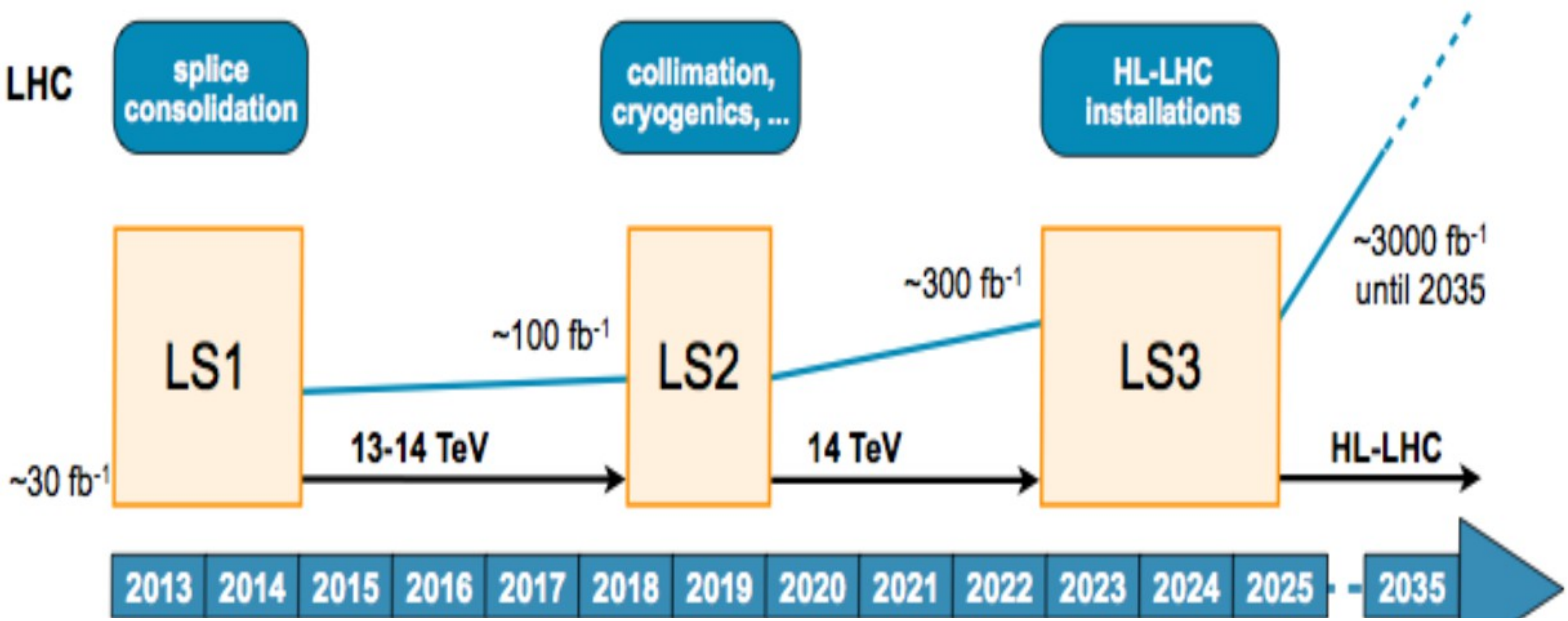
The ATLAS Detector



Physics Case for HL-LHC Program

- The discovery of the Higgs boson has opened the new era of precision Higgs physics for testing the validity of SM and search for new physics beyond SM (BSM) at LHC.
- The data sample of 3000 fb^{-1} at 14 TeV will provide unprecedented and unparalleled physics opportunities such as
  - Measuring the Higgs in many production and decay
  - Extending the mass reach for new particle searches at 1 TeV
  - Probing new physics for longitudinal vector-boson scattering
- The LHC is the only Higgs, top, W, Z factory on the planet for many years to come.

The LHC RoadMap



Go to design energy, nominal luminosity

$L = 1 \times 10^{34} cm^{-2}s^{-1}$

Injector and LHC Phase-1 upgrade for high intensity and ultimate design luminosity

$L = 2\text{-}3 \times 10^{34} cm^{-2}s^{-1}$

HL-LHC Phase-2 upgrade, major intervention in 1.2 Km of LHC

$L = 5 \times 10^{34} cm^{-2}s^{-1}$

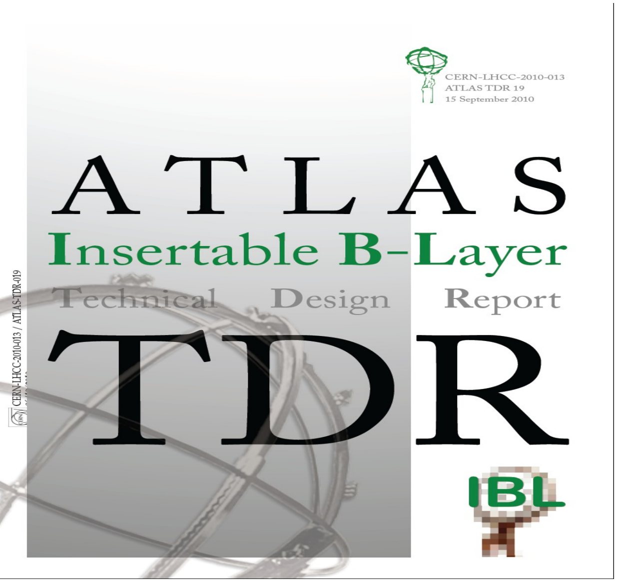
Average pile-up: 28-56 | 56-84 | ~140

Possible ATLAS Upgrade time-line

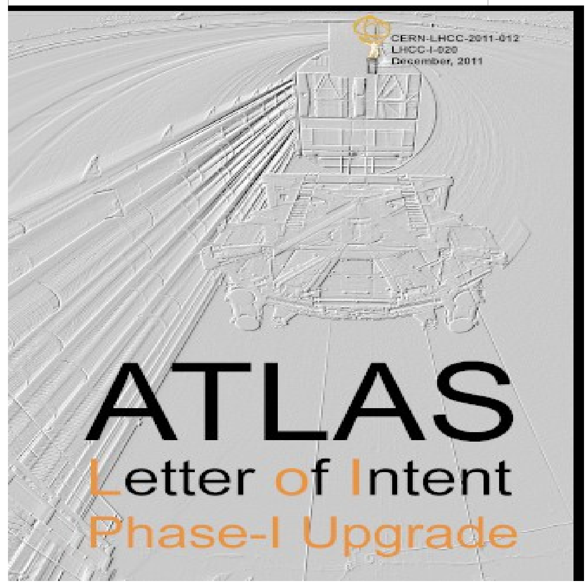
- Detectors need to be upgraded in order to cope with high radiation and pile-up at high luminosity running.
- Phase 0 Upgrade (2013-2014)
  - New inner pixel layer(IBL); and new Diamond Beam Monitor(DBM)
  - Muon system consolidation; new neutron shielding
  - Fast TracKer for high level trigger(HLT), installed, will be ready by ~2015.
- Phase I Upgrade (2018-2019)
  - New muon small wheels
  - Improved granularity of calorimeter trigger at level 1
  - Trigger and data acquisition upgrades
- Phase II Upgrade (2022-2025)
  - Replace inner tracker
  - New trigger & data acquisition system including cal. electronics upgrades
  - New detectors for parts of Muon system

ATLAS Upgrade Planning

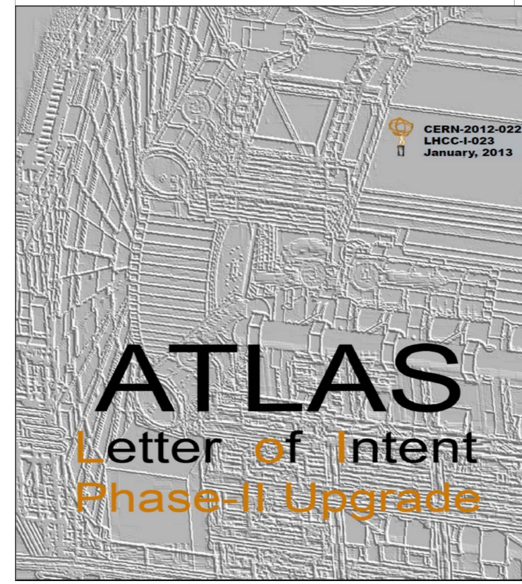
Phase 0 Upgrade TDR



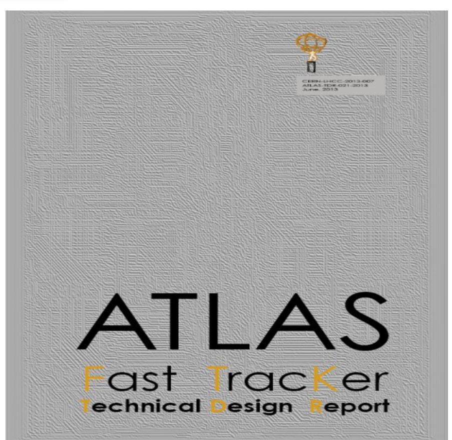
Phase I Upgrade LOI

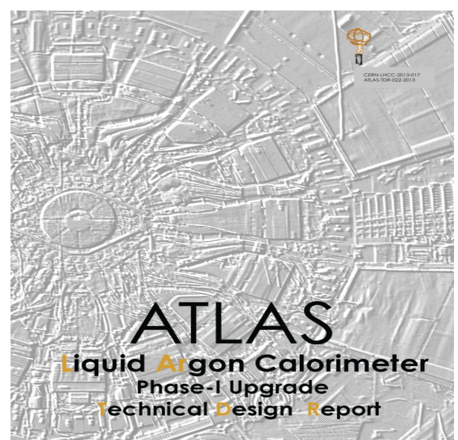


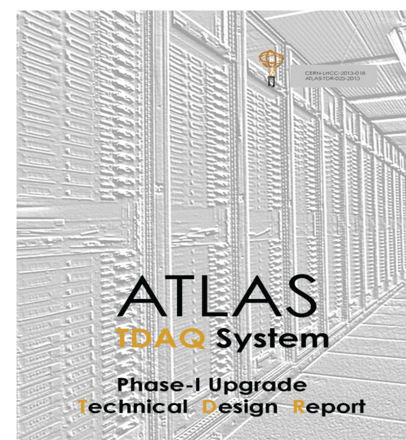
Phase II Upgrade LOI



Phase I Upgrade TDRs

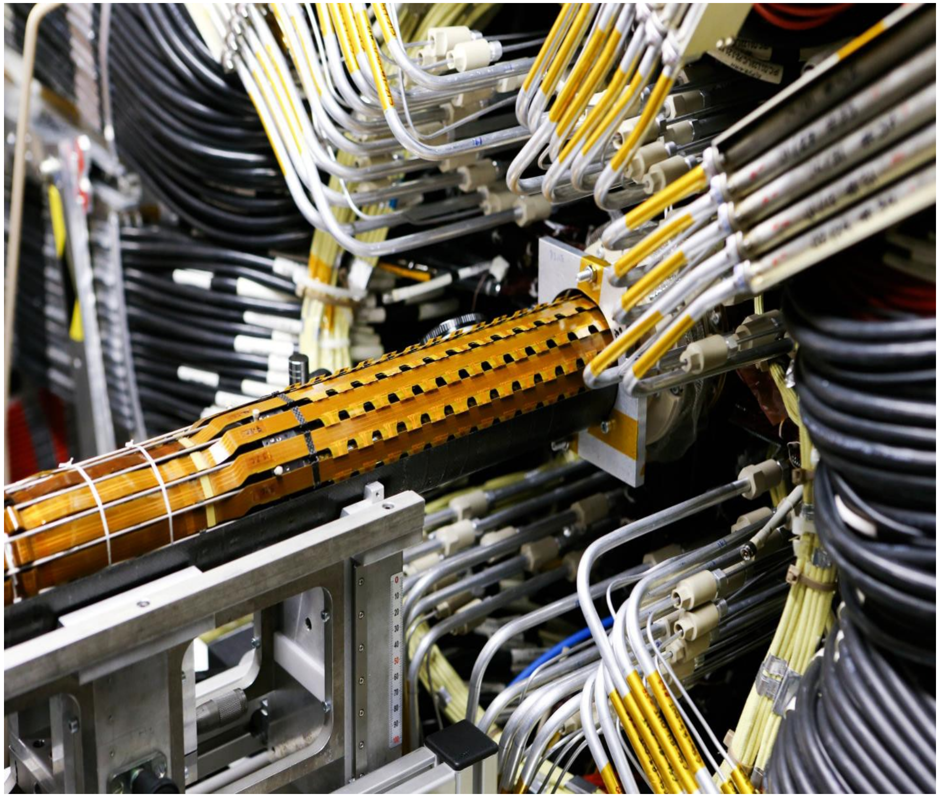


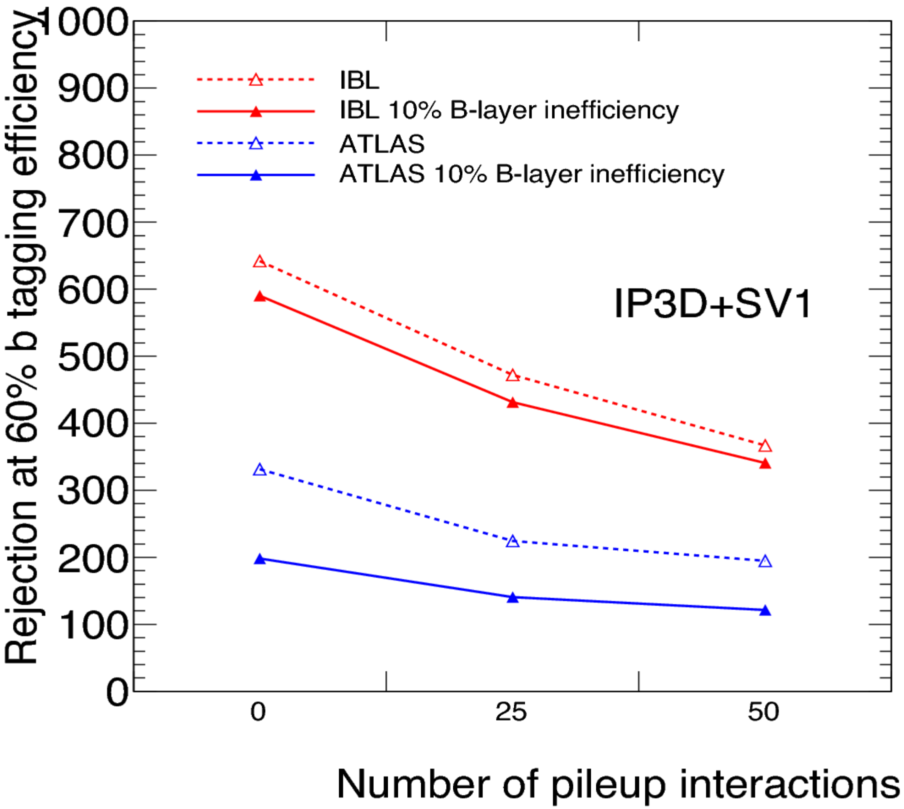




Phase-0: a new pixel layer (IBL)

- ATLAS Run1 Pixel detector has three barrel layers.
- 4th insertable B-layer, close to IP, recently installed, commissioning underway
- Improving tracking, have better impact parameter resolution, vertexing and b-tagging performance.

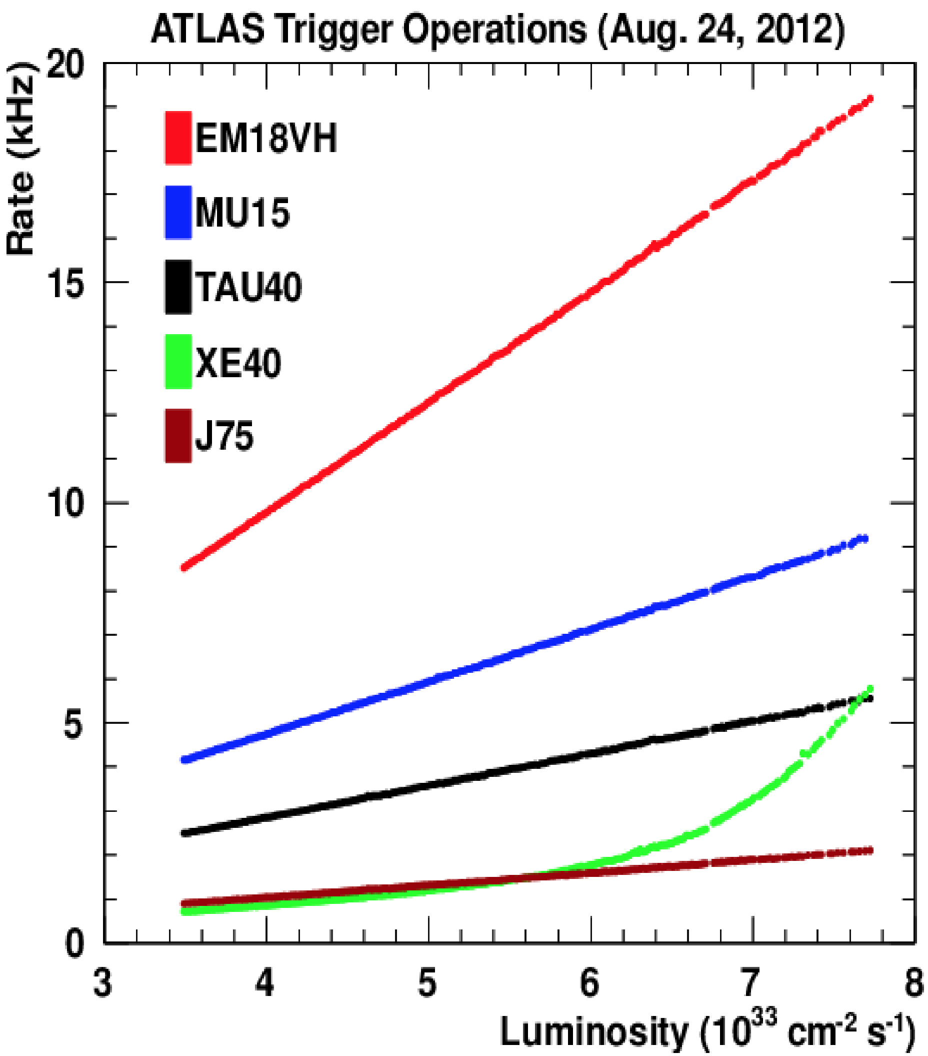




CERN-LHCC-2010-013

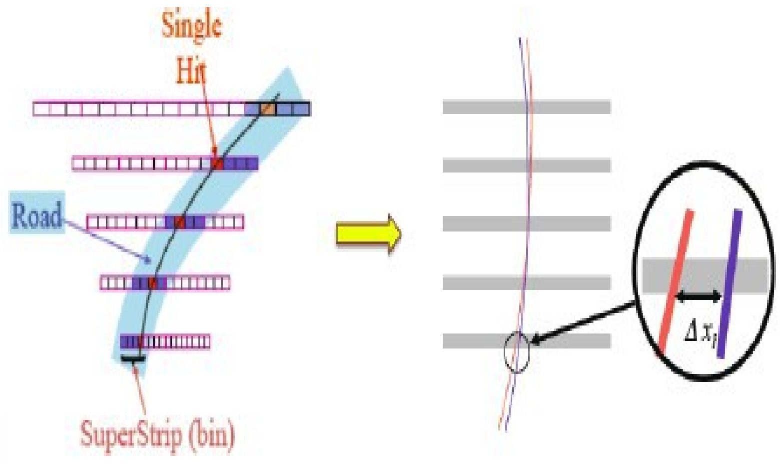
Phase I: Trigger Upgrade

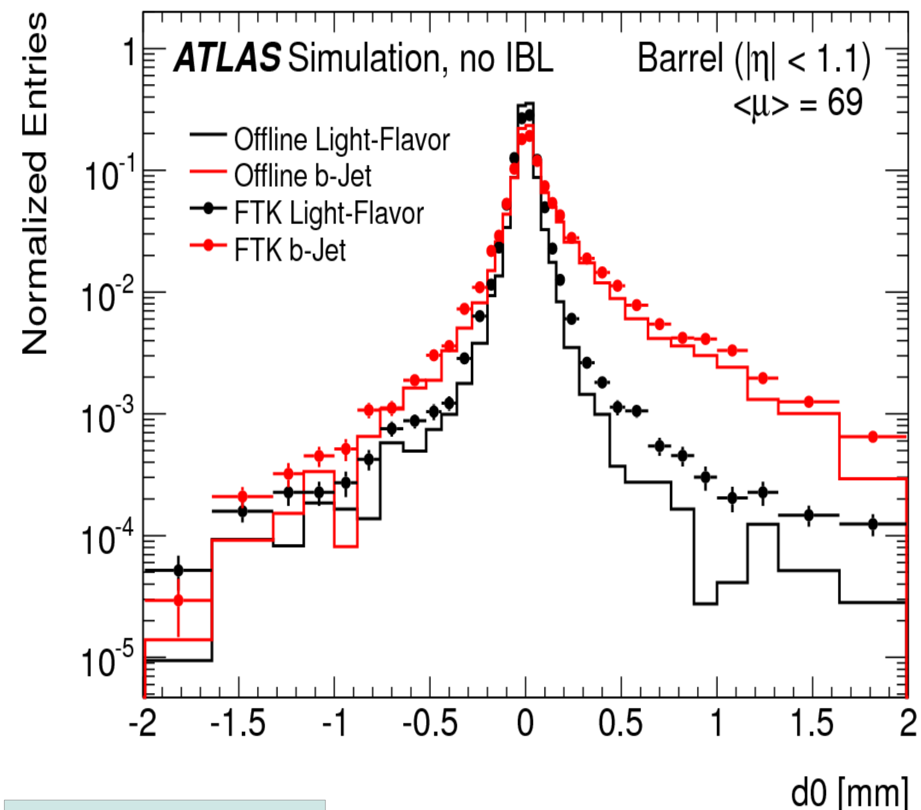
- One of challenges running at high luminosity is able to trigger on lepton at 20 GeV, other interesting events that reduces 40 MHz collision rate to 1kHz storage rate.
- The trigger has to become more selective as luminosity increases.
- Upgrade includes:
  - Fast TracKer (FTK) providing precision tracking for HLT
  - New small wheel muon detector in forward region
  - Improved segmentation in LAr calorimeter trigger

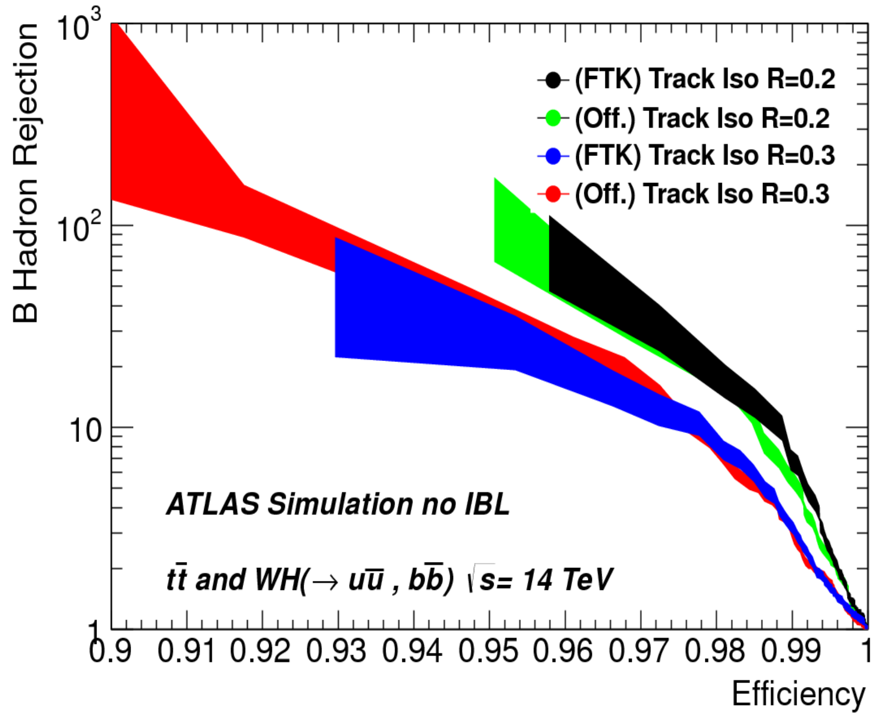


ATLAS New Fast TracKer (FTK)

- FTK does hardware based si-tracking at start of HLT with near offline quality.
- Providing precision tracking(Pt, d0, btag) for HLT to improve triggers.







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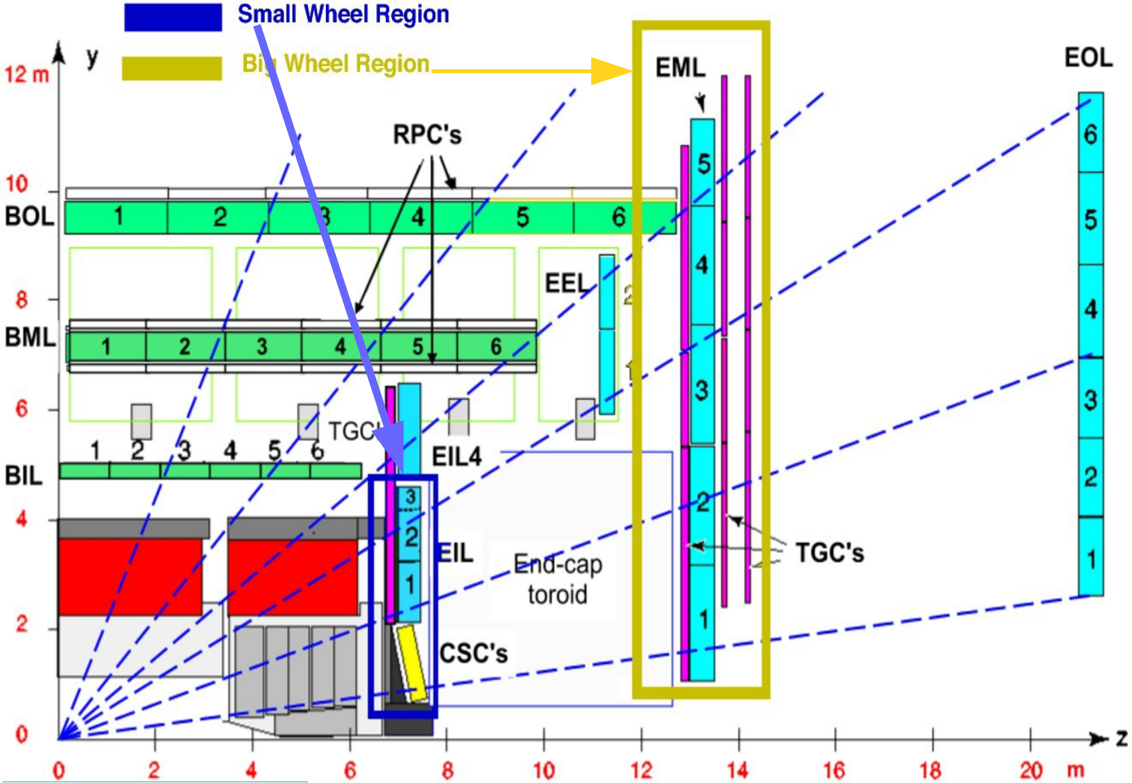
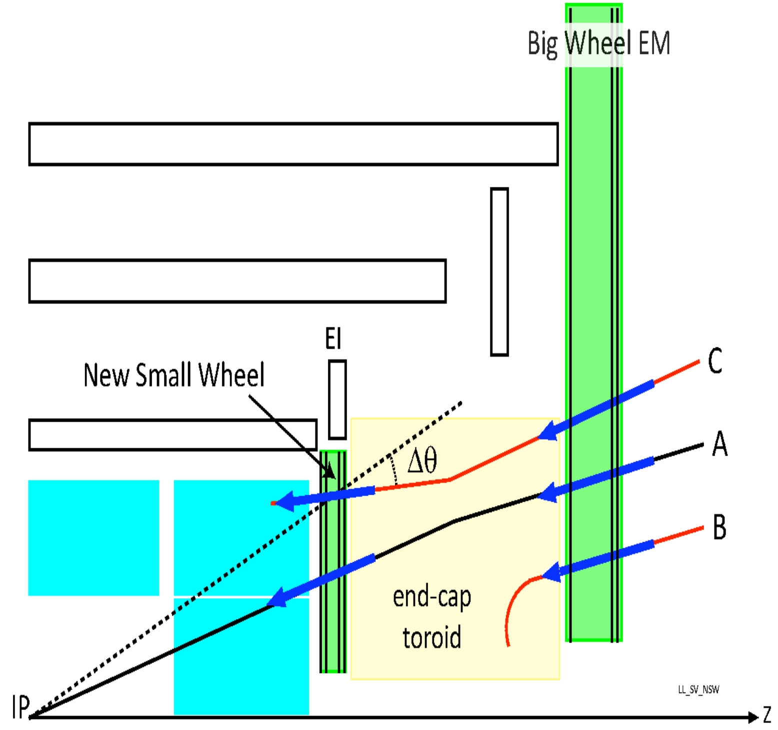
Improving Muon triggers with New Small Wheel

- L1 muon trigger in endcap is based on Big wheel; its performance degrades with increase of inst. Luminosity due to background in endcap toroid.
- New small wheel will add additional hits to reduce fakes by requiring from IP and preserve trigger for low momentum muons up to $5x10^{34}$ for Phase II.





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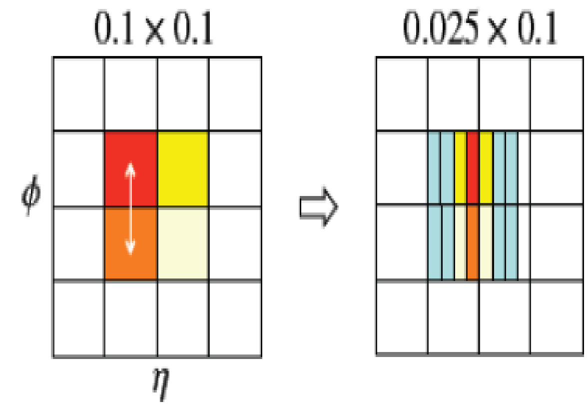
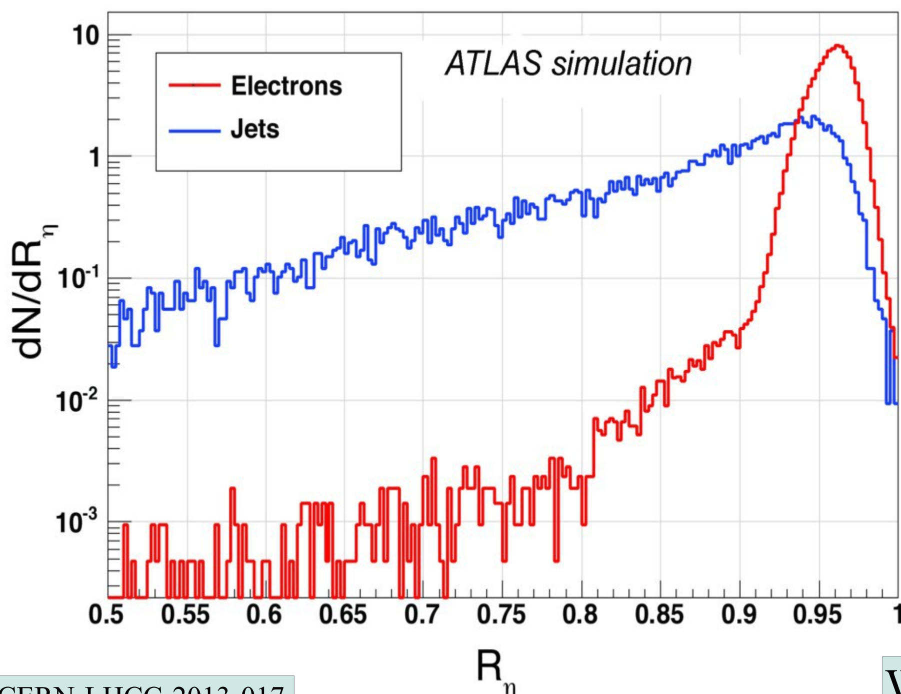
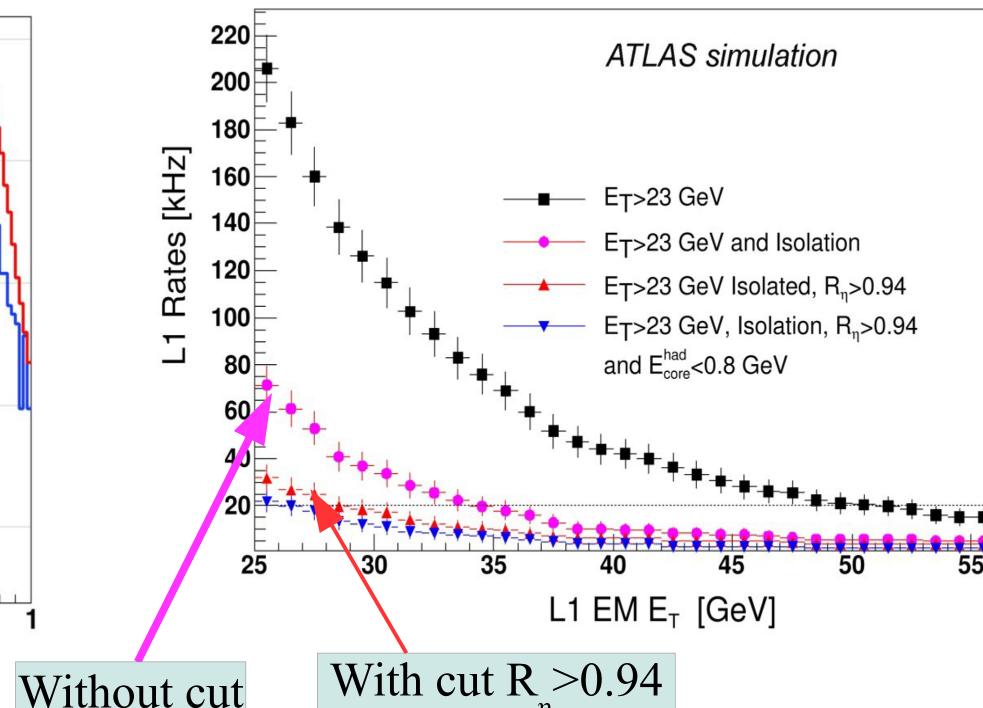
L1 Calorimeter Trigger

- Improve granularity of L1 calorimeter readout to improve e/jet discrimination using shower shape
- Shower shape R_η is defined as ratio of energy in 3x2 over energy in 7x2 cluster at EM calorimeter.
- R_η >0.94 will reduce L1 EM rate by a factor of 2.







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Phase II: Inner Tracker Update

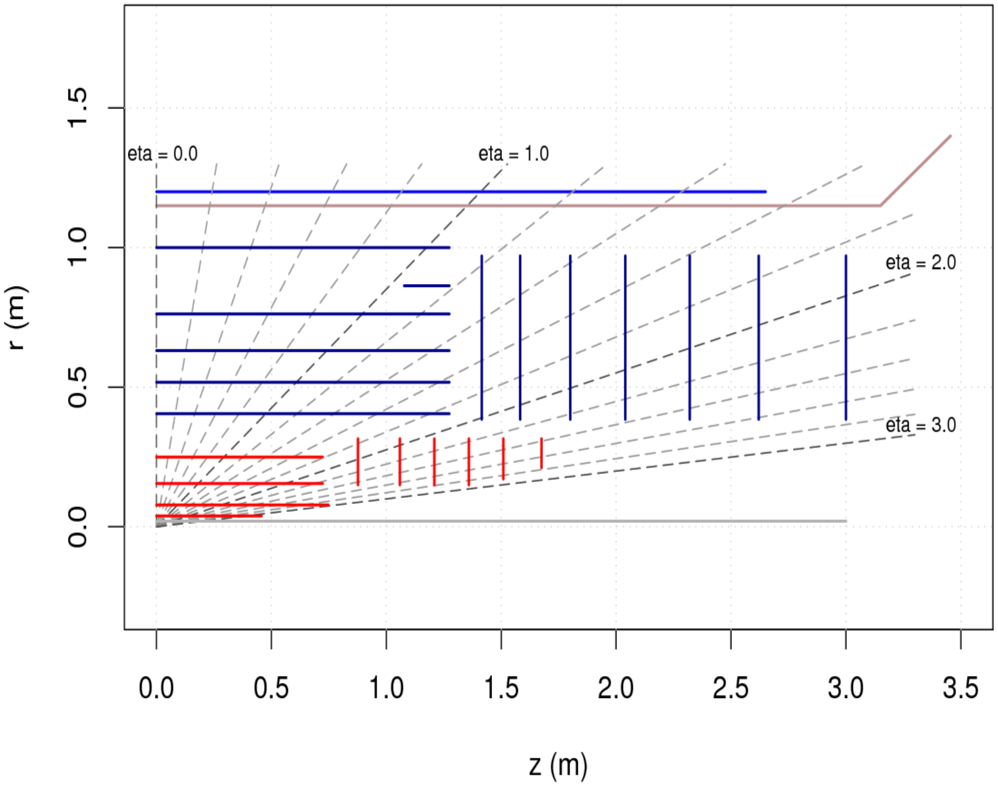
•Radiation damage, occupancy and readout that a new tracker is required.

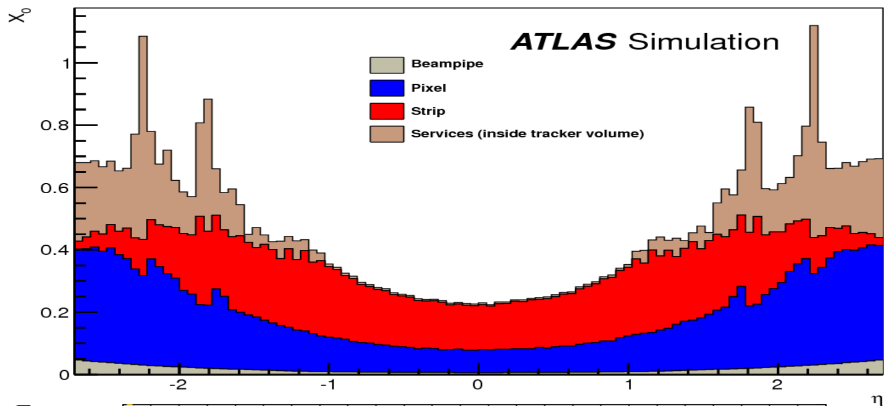
•New tracker need to cope with high luminosity up to 200 pile-up events

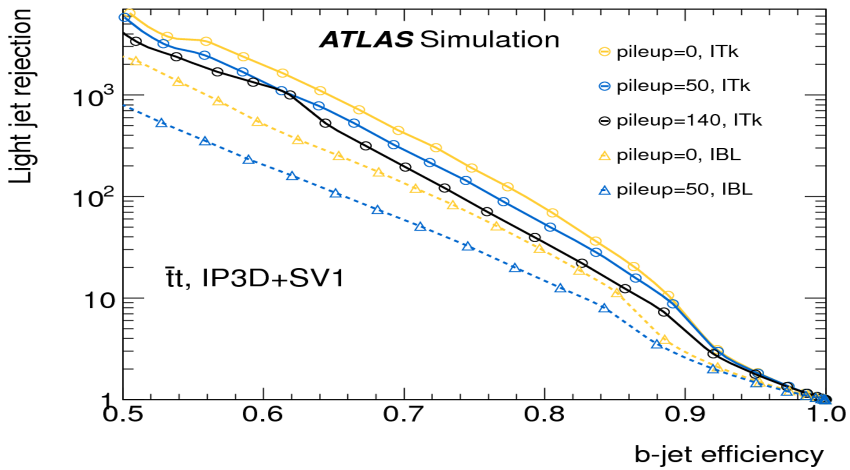
–4 pixel/5 double strip layers in Barrel; 6 pixel/7 strip disks in endcap.

–Much reduced material and better efficiencies than present inner tracker.

LOI layout







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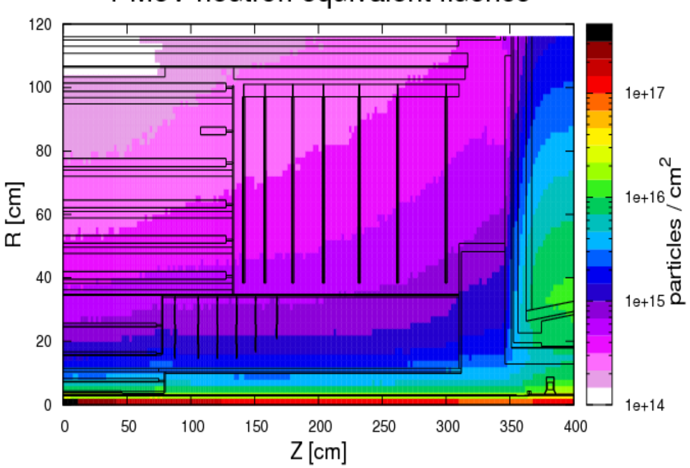
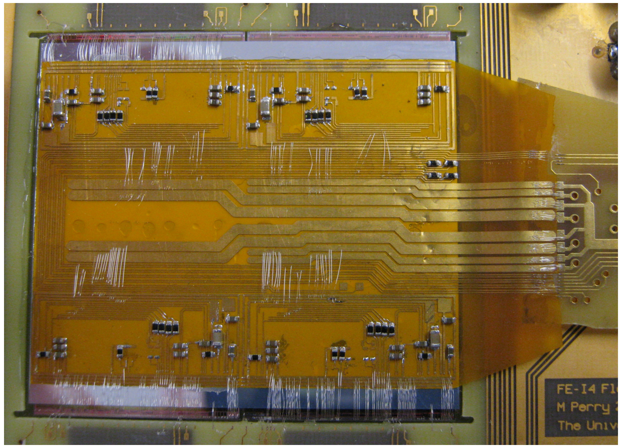
Detector R&D

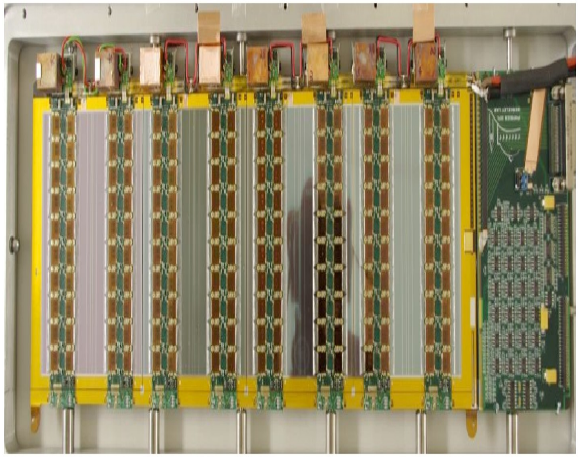
- Phase II upgrade are technically challenging and require lots of R&D.
  - Hermetic, high efficiency covering the full solid angle
  - Good space resolution and lower power
  - High radiation tolerance, detection close to IP
  - Material budget including sensor, cooling, cabling
  - Fast triggable up to 40 MHz,
  - Reliability for several years



Pixel Quad-module



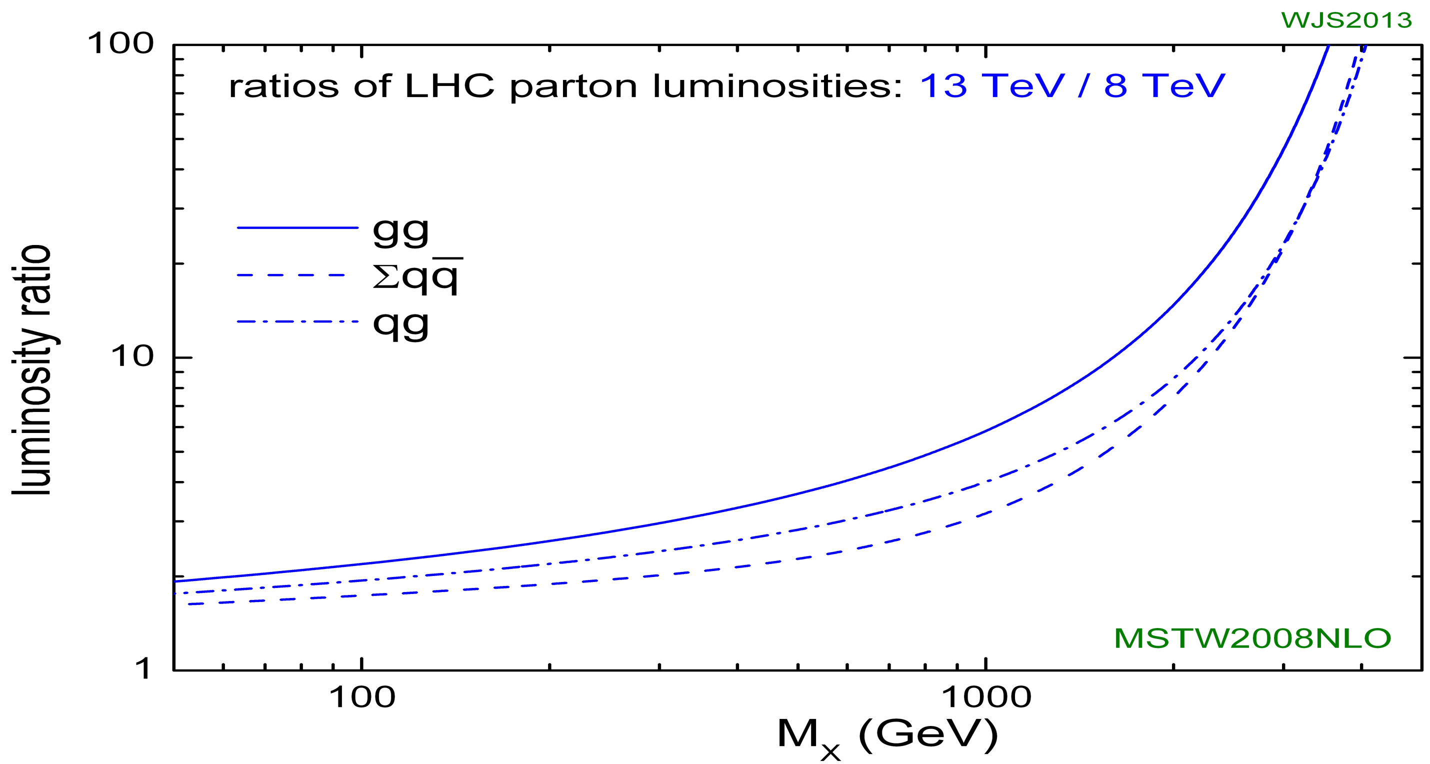
Double Strip module



CERN-LHCC-2012-022

Near Future: Run 2 at 13 TeV

- Increase in cross section by factor ~10 for new particle M~ 2TeV
  - Discovery of TeV scale particle possible with a few fb^{-1}
- Higgs measurement will improve significantly with 100 fb^{-1} .



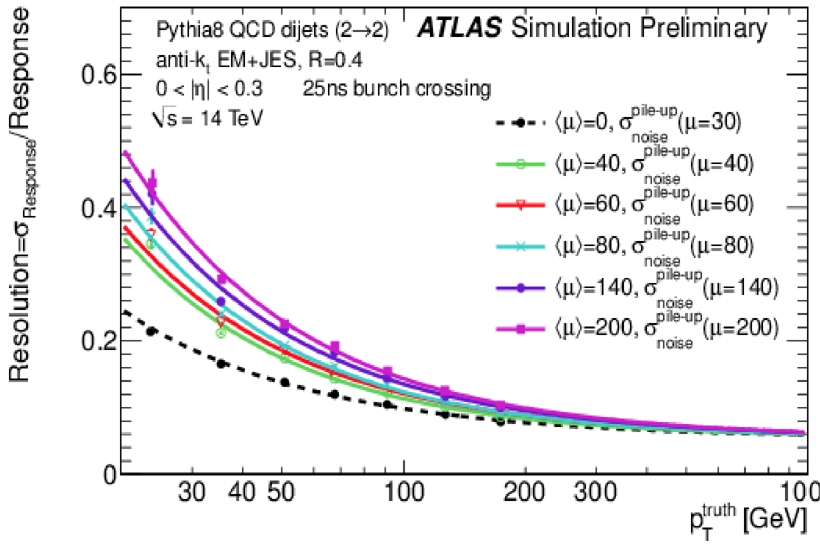
Physics Prospects after Run2

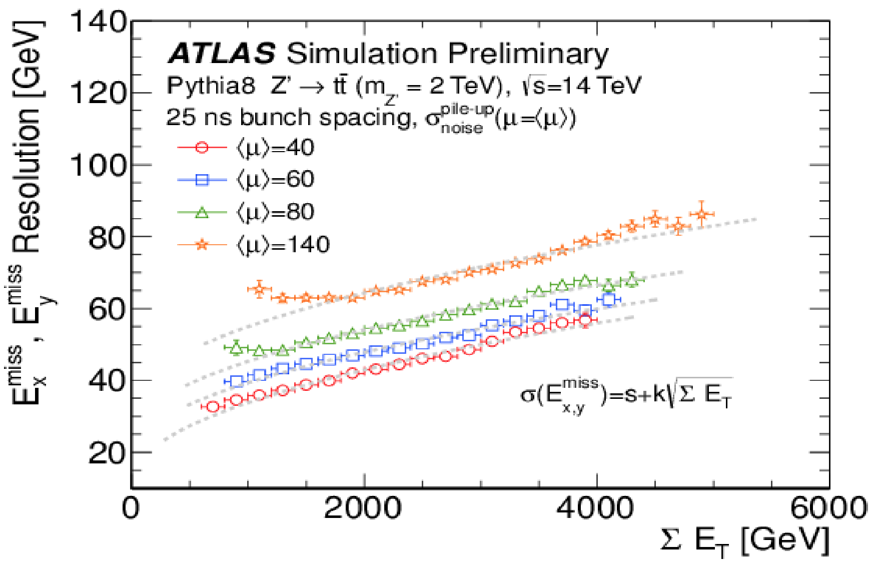
•Studies are done for 14TeV for 300 fb^{-1} (LHC) and 3000 fb^{-1} (HL-LHC)

•Studies based on smearing functions applied to truth level based on realistic/pessimistic assumptions for detector performance (ECFA).

•The pile-up assumed to be 140 interactions and 25 ns beam crossing.

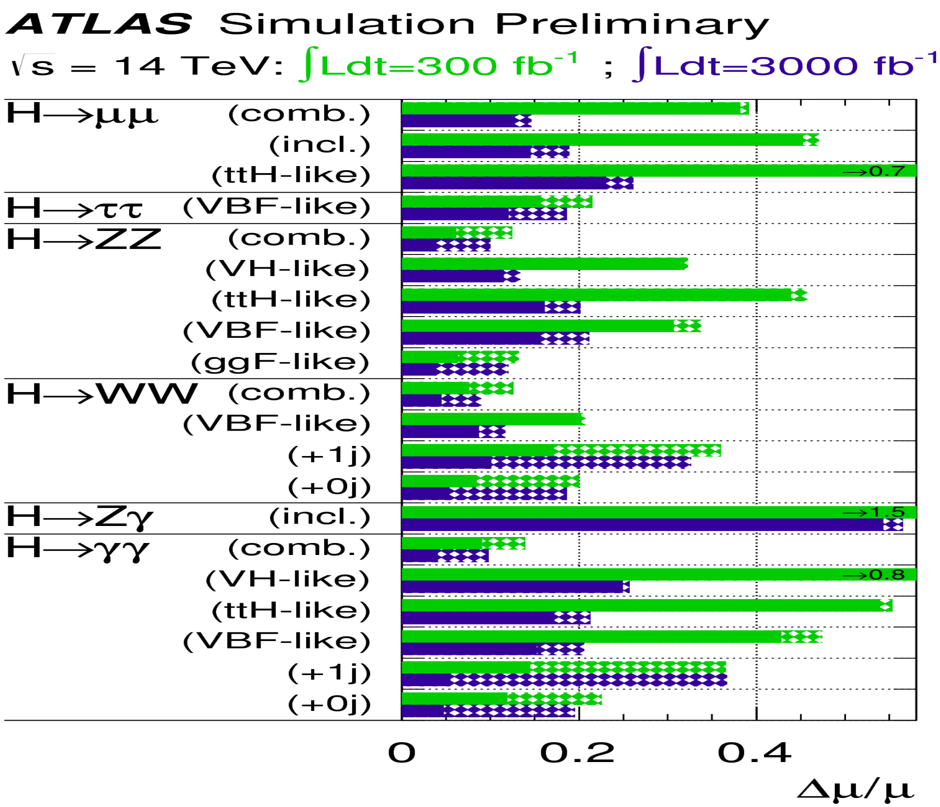
•Most reconstruction algorithms are based on Run1, could be further improved at high luminosity with new detectors.



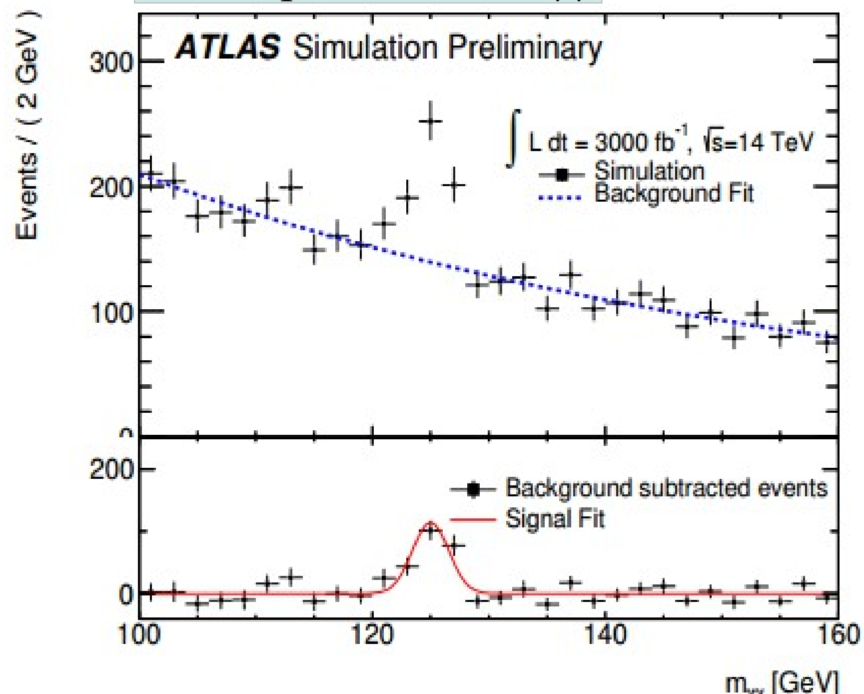


Improvement of Higgs Measurement

- ΔM_H will be ~0.1GeV after run-2, difficult to improve.
- Width expected to be narrow for SM H, can not be measured directly.
- Spin/parity already established as 0+, will search for extra H and CPV.
- Coupling can be constrained via $\mu = (\sigma x B)^{data}/(\sigma x B)^{SM}$.



ttH-1lep:8.2σ in H→γγ

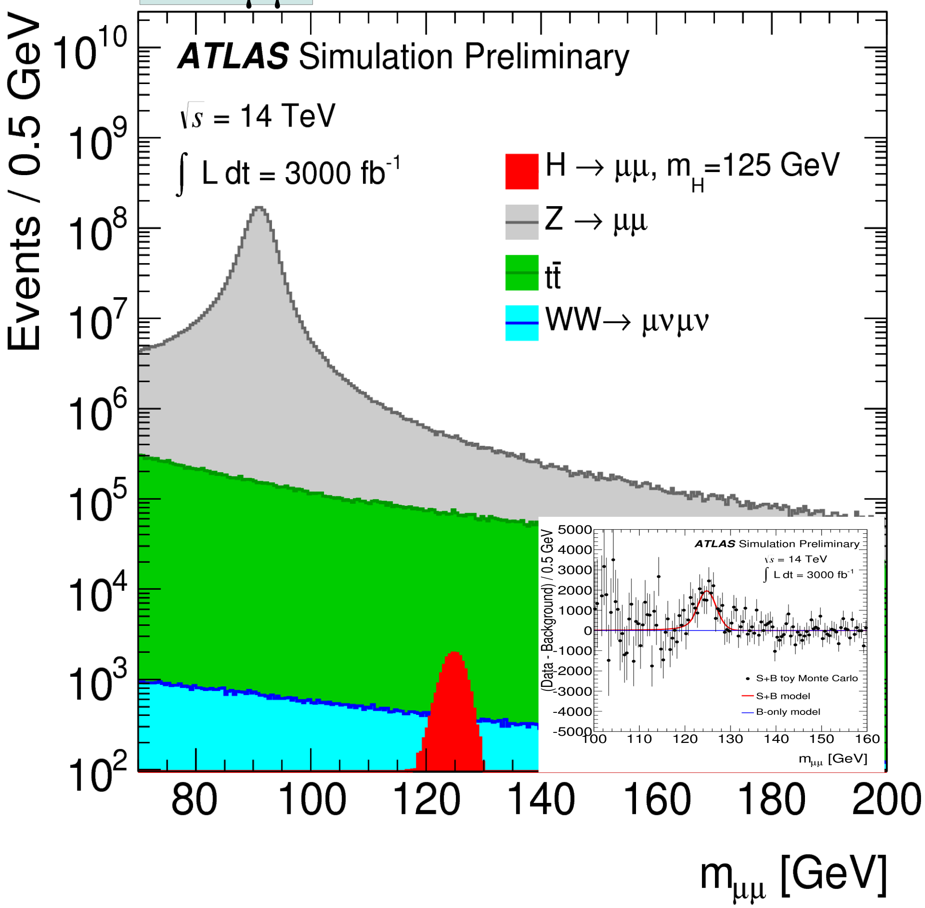


ATL-PHYS-PUB-2014-012/011

Search for H→μμ, Zγ Rare Decay

- HL-LHC provides large Higgs sample for rare decay studies
- Expect >5σ and 3.9σ significance for H→μμ and Zγ with 3000 fb^{-1} data

H→μμ



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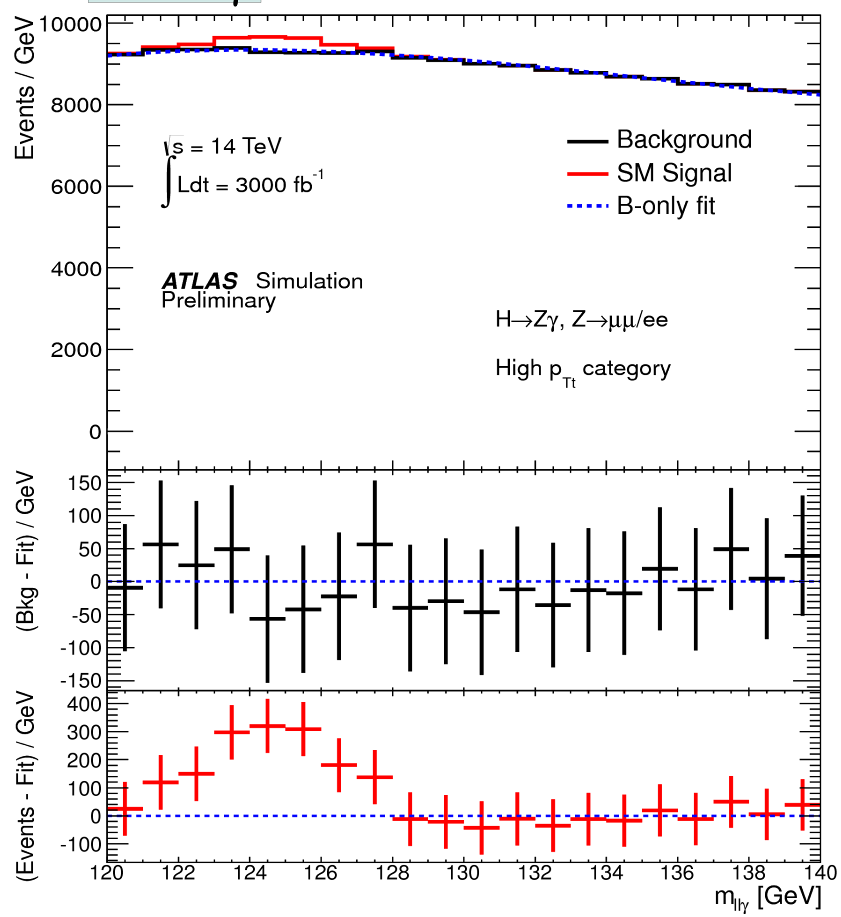
H→Zγ



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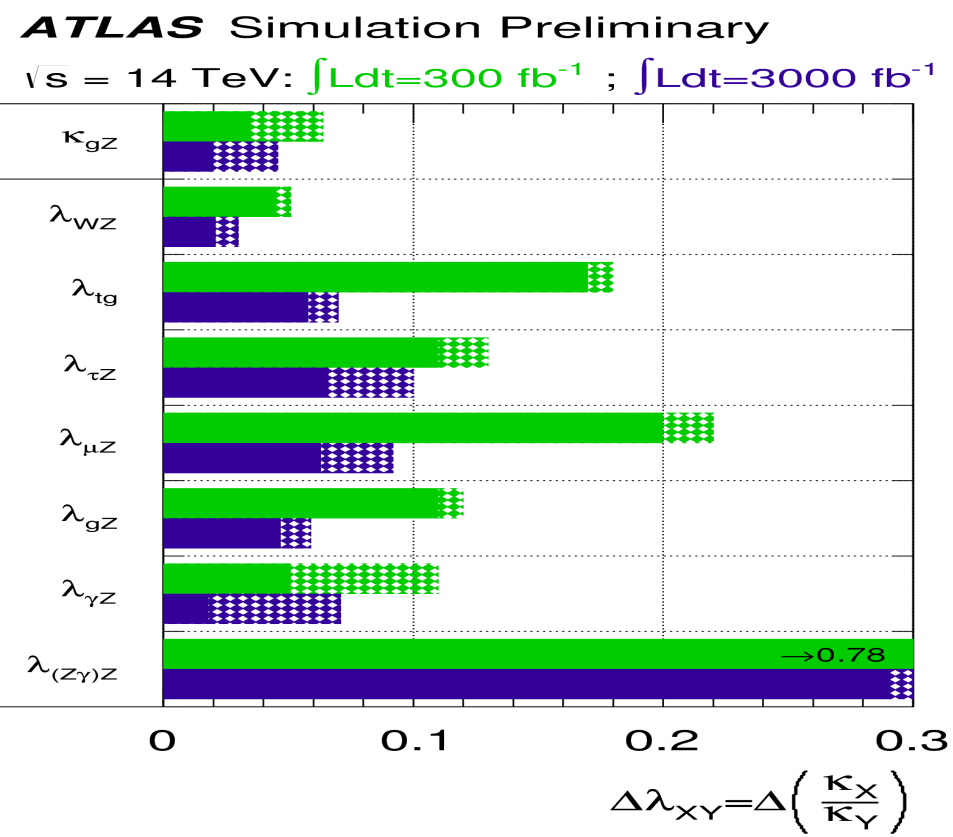
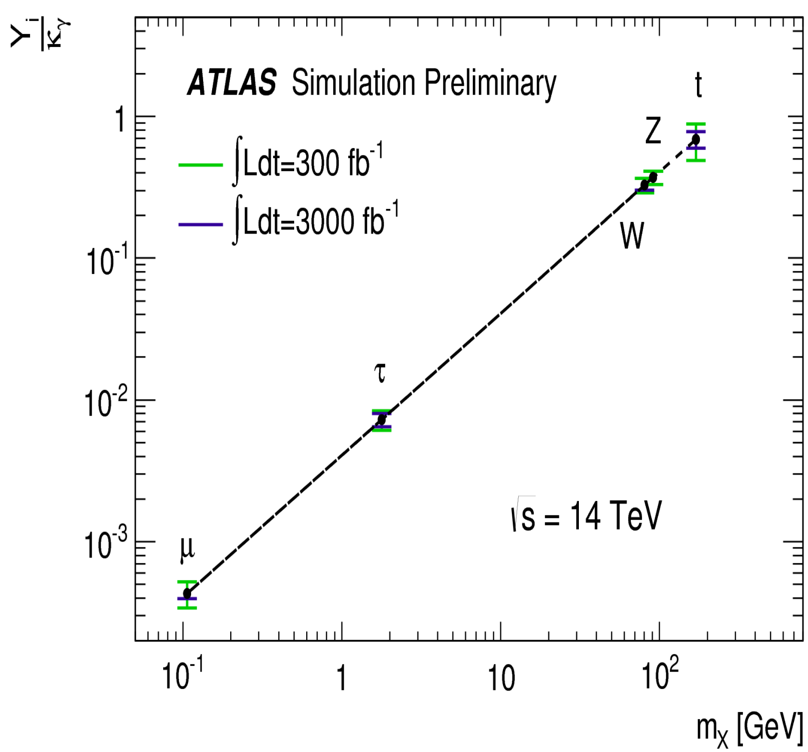
Higgs boson coupling

- Some uncertainties cancel in ratio of partial widths:
  - Sensitive probe expecting new physics to affect couplings differently
- Expected precision ~3-10% for HL-LHC, a factor of 2-3 better than LHC.
- Theory uncertainty becomes more important in most cases.

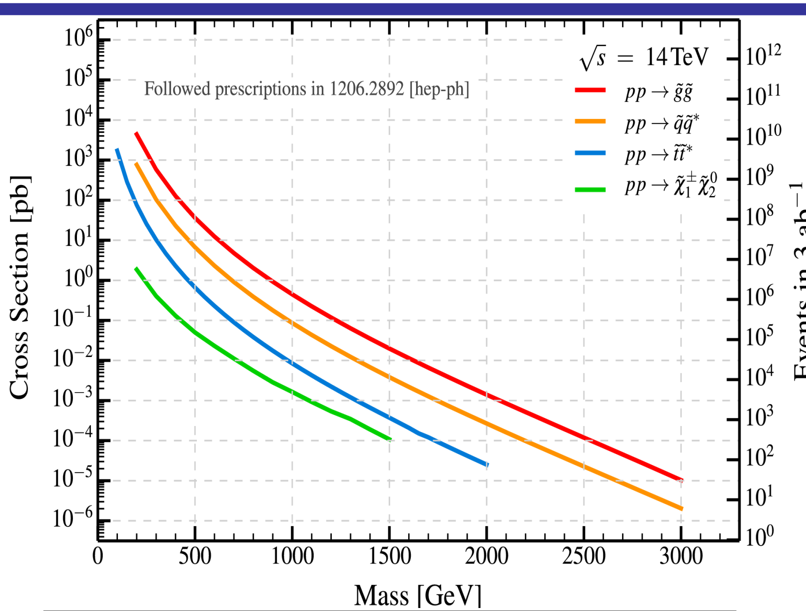


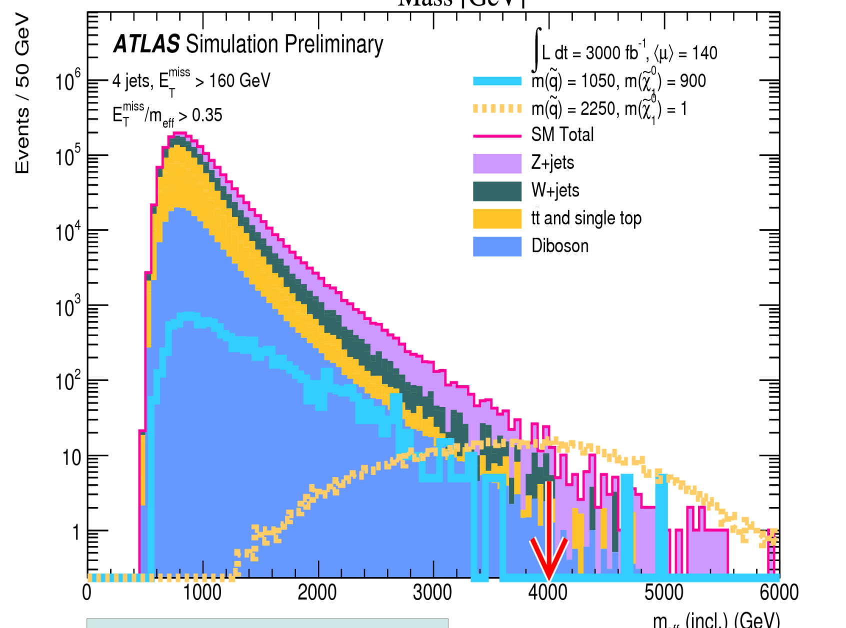


ATL-PHYS-PUB-2013-014

Search for Supersymmetric Particle

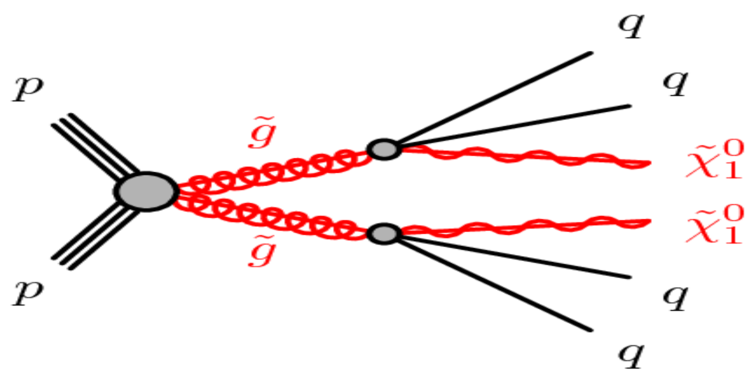
- SUSY can provide a solution to naturalness and dark matter candidate.
- SUSY particles can be either strongly or weakly produced at LHC and limits will be extended significantly by HL-LHC.
- They will produce an experimental signature of multi-jets, leptons, missing Et.
- A useful variable is the effective mass
- Typical selections for strongly produced sparticles:
  – Njet>=4, with Et>100,50,50,50
  – Lepton veto with Et>25,Met>160 GeV

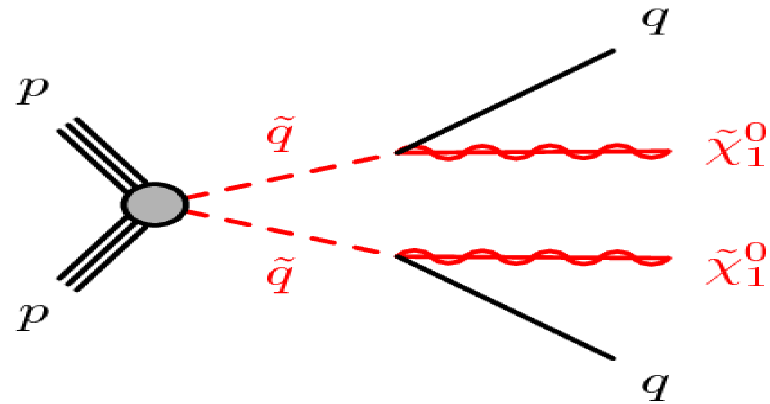


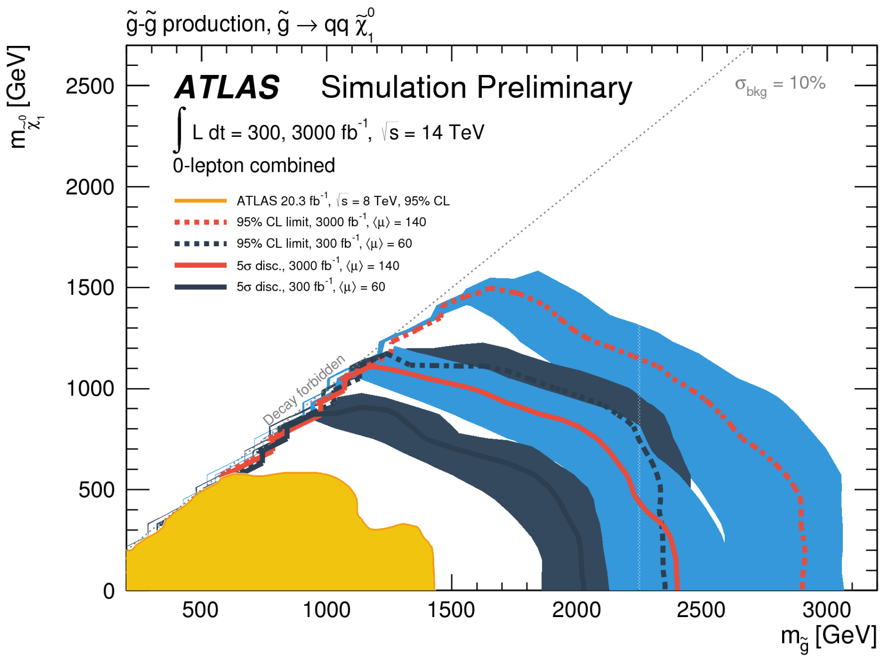


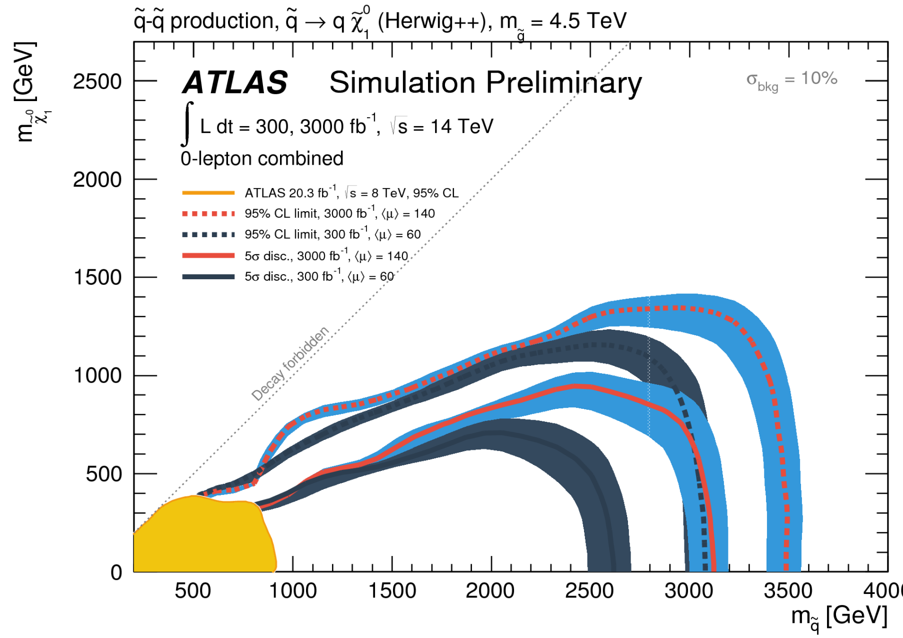
ATL-PHYS-PUB-2014-010

Gluino and squark discovery potential









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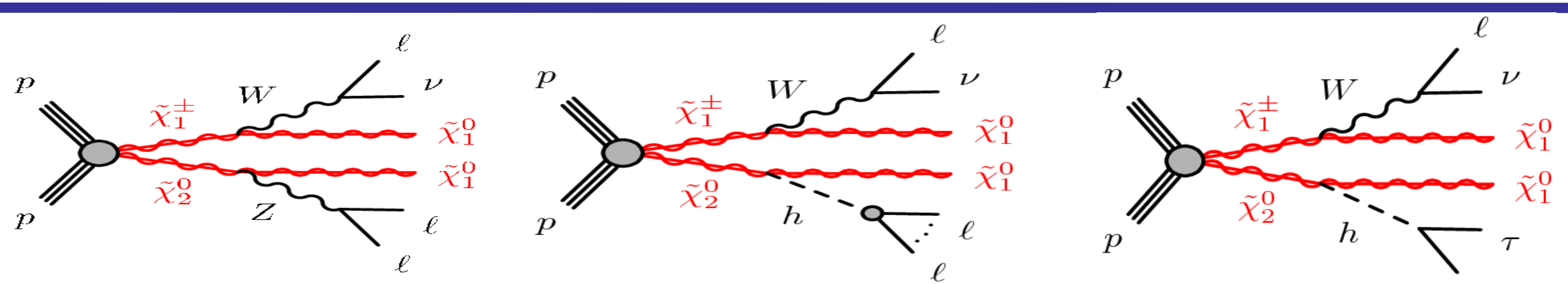
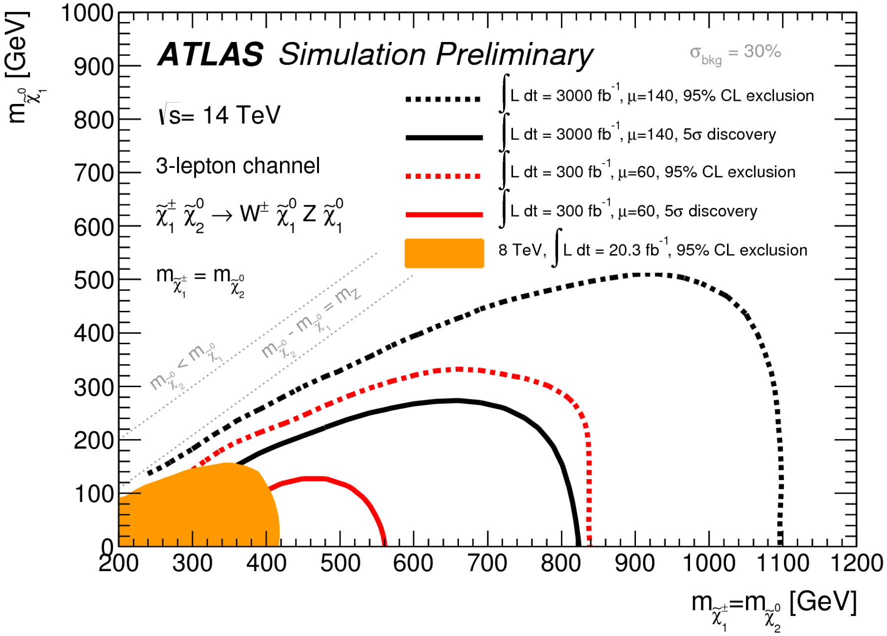
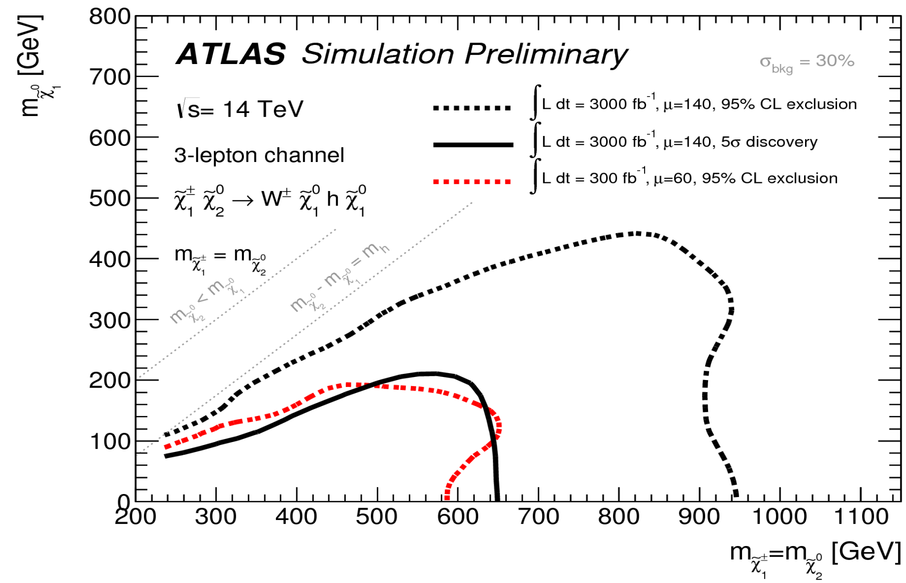
- Gluino mass reach 2.95 TeV at 95% CL with 3000 fb^{-1} data
- Squark mass reach 3.5 TeV at 95% CL with Gluino mass =4.5 TeV

Direct Production of Electro-Weakino





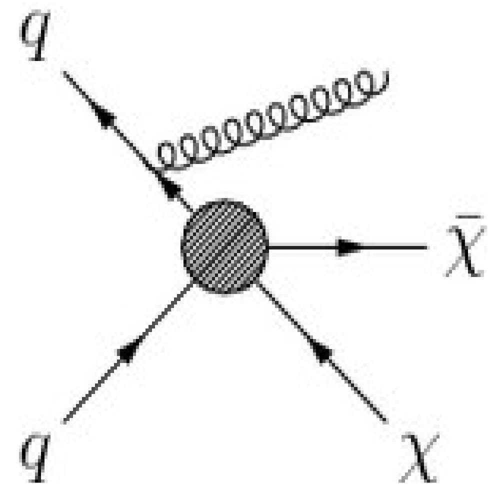


ATL-PHYS-PUB-2014-010

- Neutralinos/chargino is superposition of Higgino, Wino, and Zino
- Chargino mass reach 1.1 TeV at 95% CL via WZ with 3000 fb^{-1}.
- Chargino mass reach 0.95 TeV at 95% CL via Wh in final states.

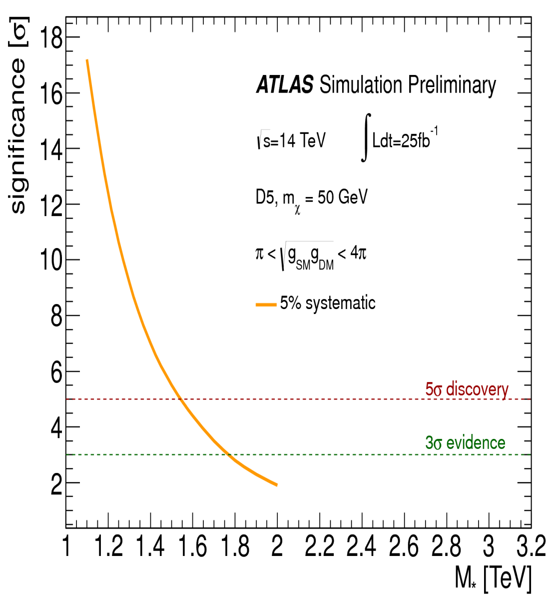
Search for WIMP Dark Matter

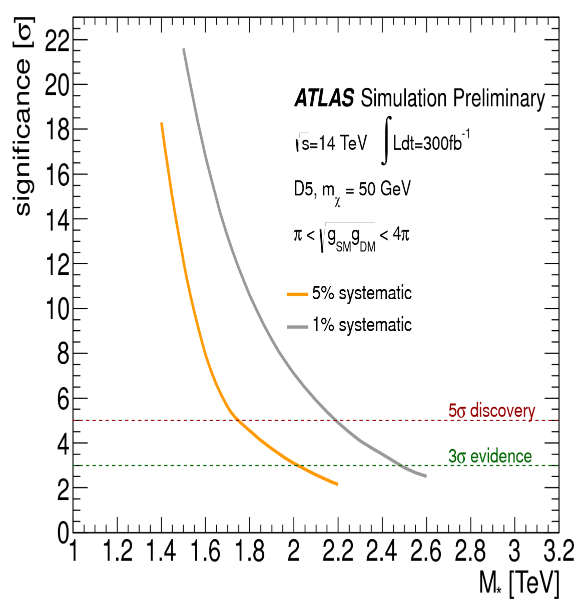
- The mono-jet search is one of most sensitive and general searches for WIMP that relies on ISR jets to tag the production of invisible particles as large missing Et.

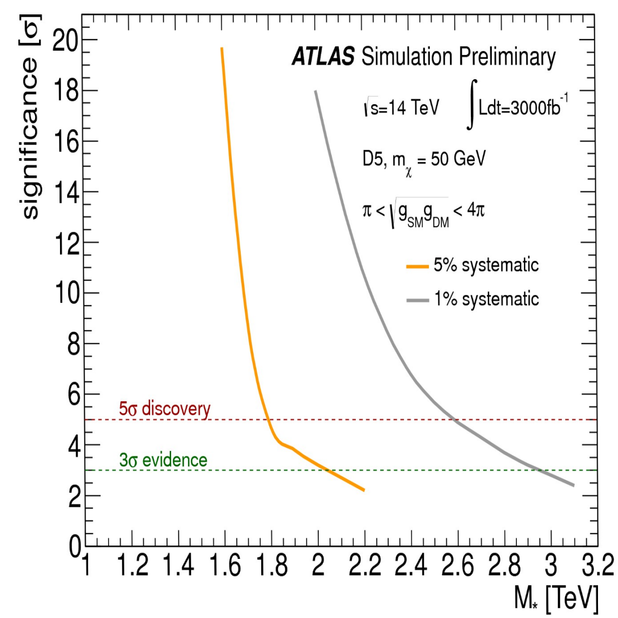


- Assuming SM-DM couples via contact interactions ($M_{mediator} >> M_{DM}$): $M^* = M_{mediator}/\sqrt{(g_{SM} g_{DM})}$.

- No improvement above 300 fb^{-1}.



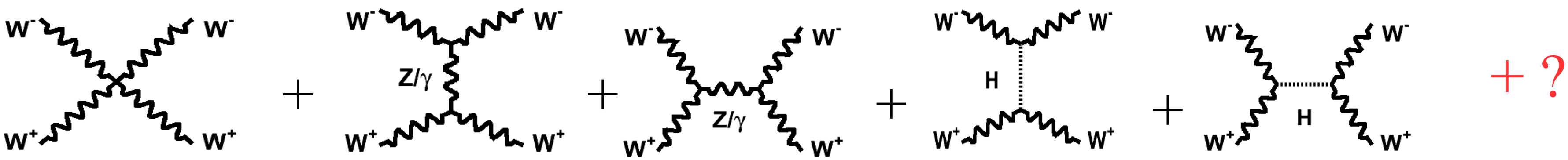


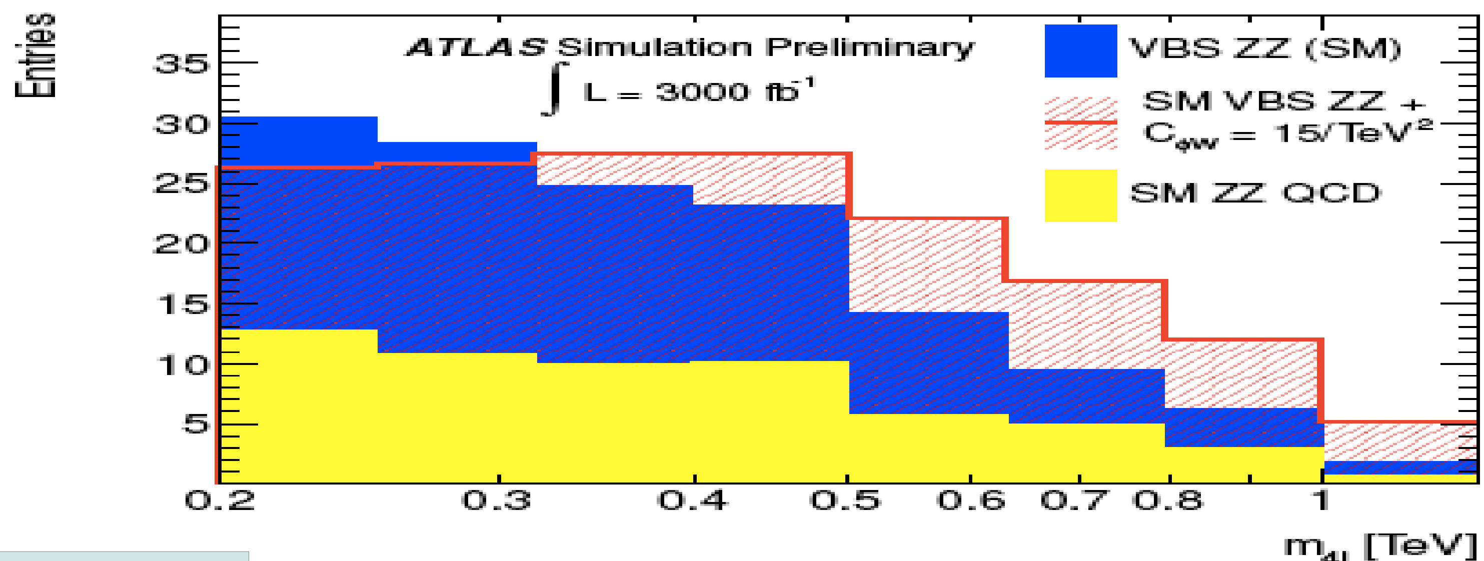


ATL-PHYS-PUB-2014-007

Vector Boson Scattering

- Given Higgs discovery, focus on its impact in electroweak sector.
- Confirm that Higgs boson cancels divergence at high energy in SM.
- Any strong dynamics contributions could enhance the high mass production of ZZ, WW, and WZ di-boson pairs.

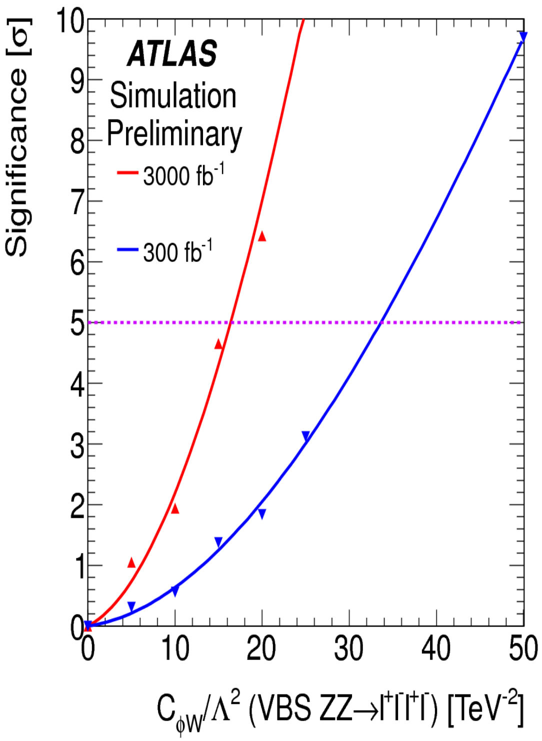


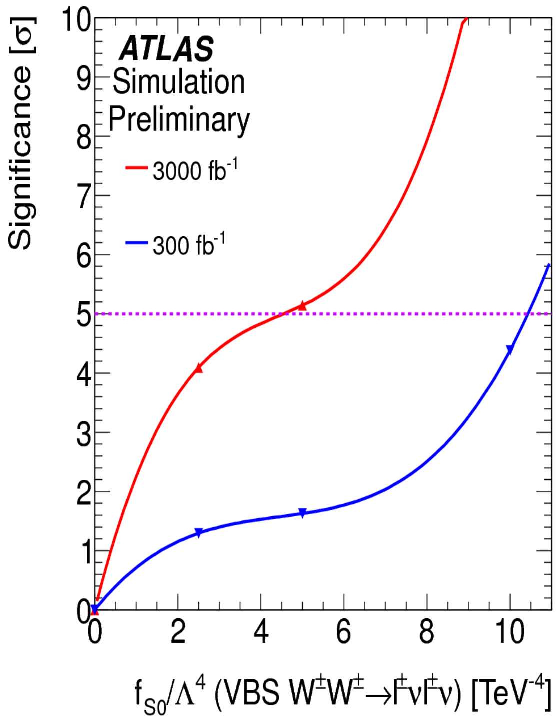


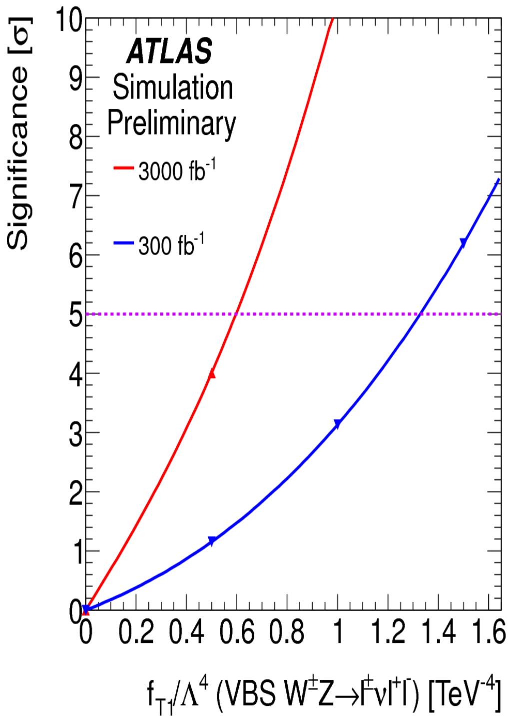
ATL-PHYS-PUB-2013-006

Vector Boson Scattering

- Parameterize BSM using higher dimensional operator in Lagrangian:
  - ZZ dimension-6 operator $\mathcal{L}_{\phi W} = \frac{c_{\phi W}}{\Lambda^2}\mathrm{Tr}(W^{\mu\nu}W_{\mu\nu})\phi^\dagger\phi$
  - $W^\pm W^\pm$ dimension-8 operator: $\mathcal{L}_{S,0} = \frac{f_{S0}}{\Lambda^4}[(D_\mu\phi)^\dagger D_\nu\phi)] \times [(D^\mu\phi)^\dagger D^\nu\phi)]$
  - WZ dimension-8 operator: $\mathcal{L}_{T,1} = \frac{f_{T1}}{\Lambda^4}\mathrm{Tr}[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times \mathrm{Tr}[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}]$
- Discovery reach for operators extended by a factor of 2 at HL-LHC

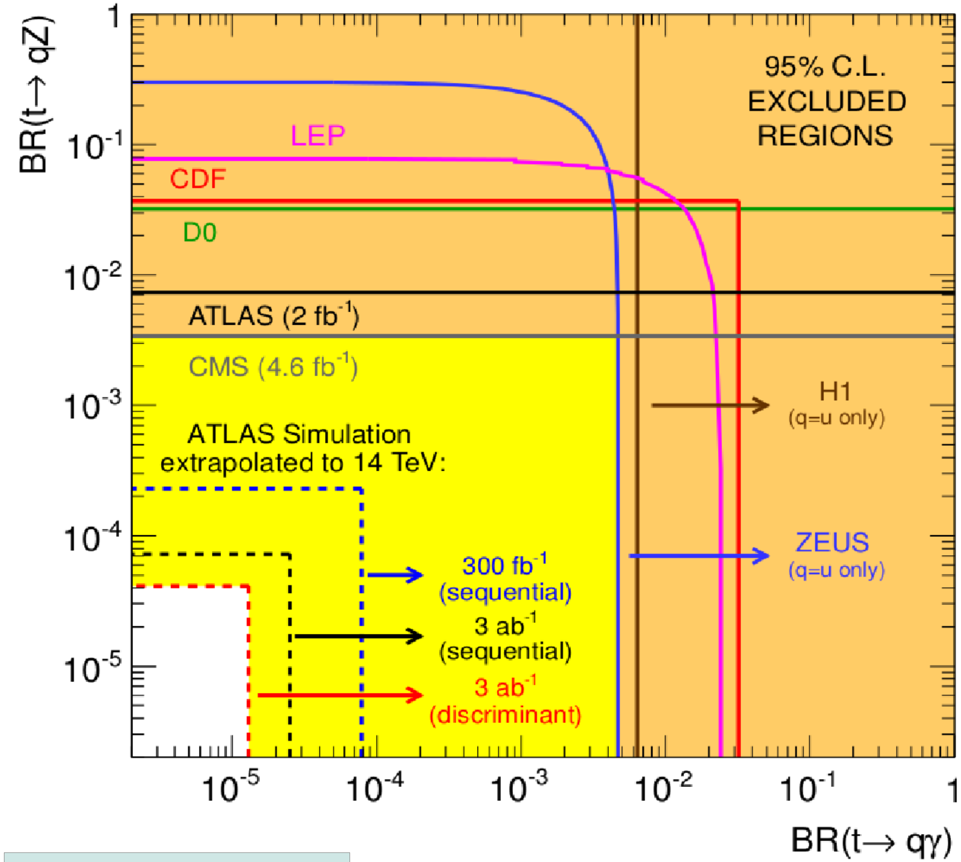






FCNC with Top Quarks

- HL-LHC would provide large top samples for rare decay studies
- FCNC level in SM is 10^{-14}, but BSM can enhance it to 10^{-4}.
- Extrapolation to 14 TeV based on 2 fb^{-1} results, limits @3ab^{-1} up to 10^{-5}



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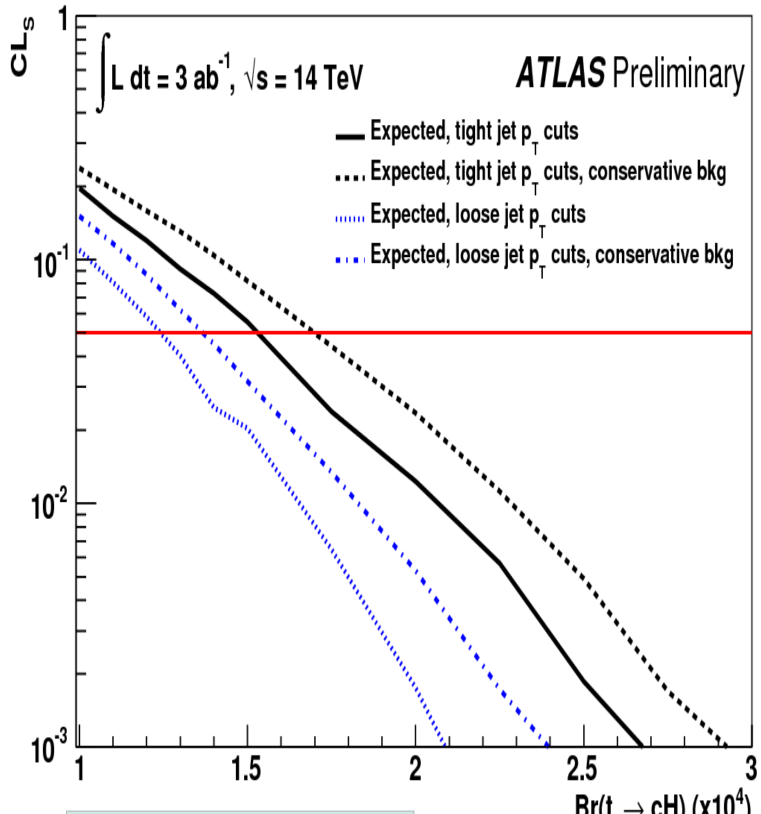

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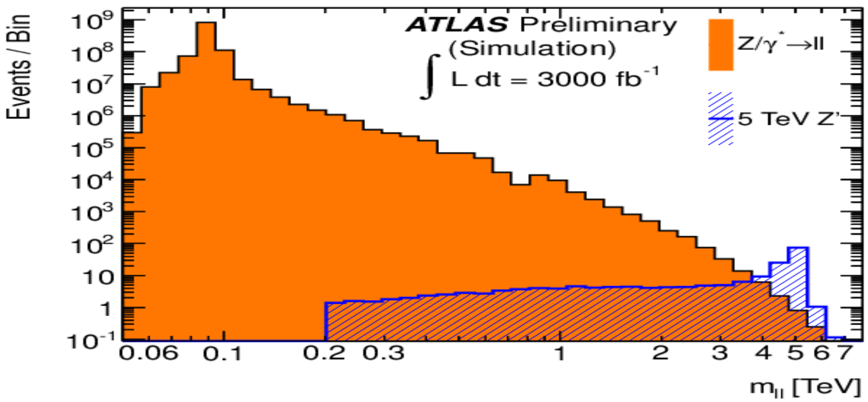
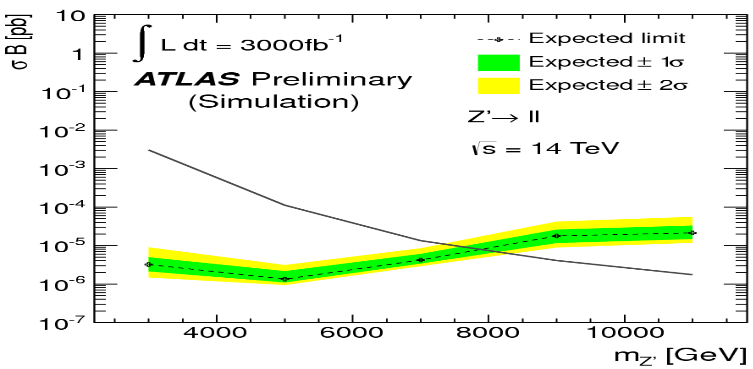
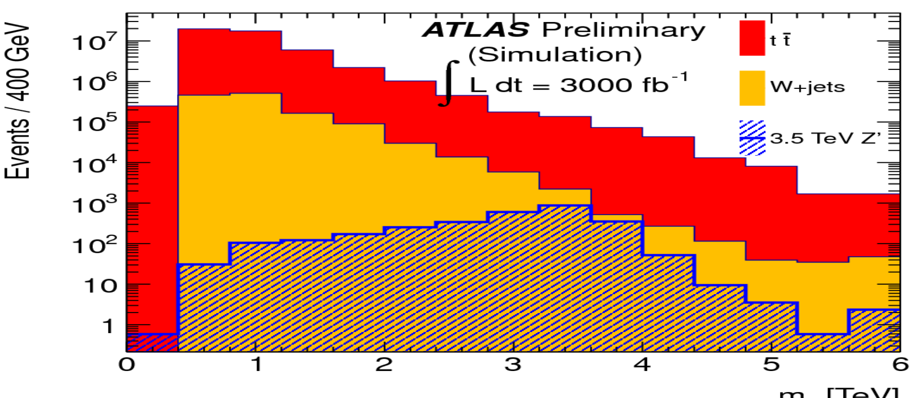
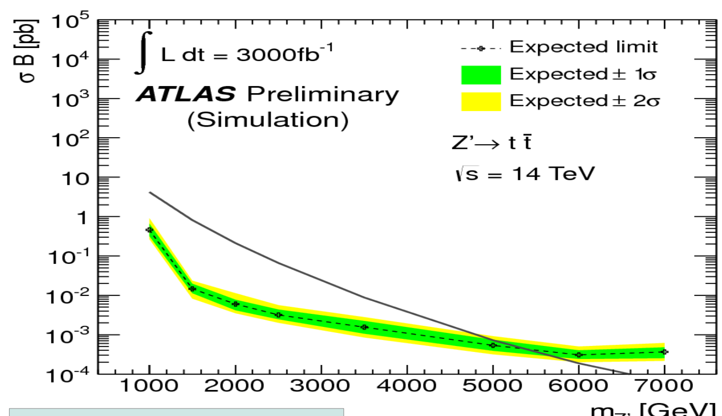
Exotic Resonances

- Direct discovery at HL-LHC will probe of new physics at highest mass scales.
  - Narrow weak resonances: Z', W' in extended electroweak sectors
  - Broad strong resonances: KK gluons in model of extra dimensions
- Assuming Z' SM coupling, dielectron reach at ~8TeV, ttbar at 5TeV@95% CL









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Conclusion

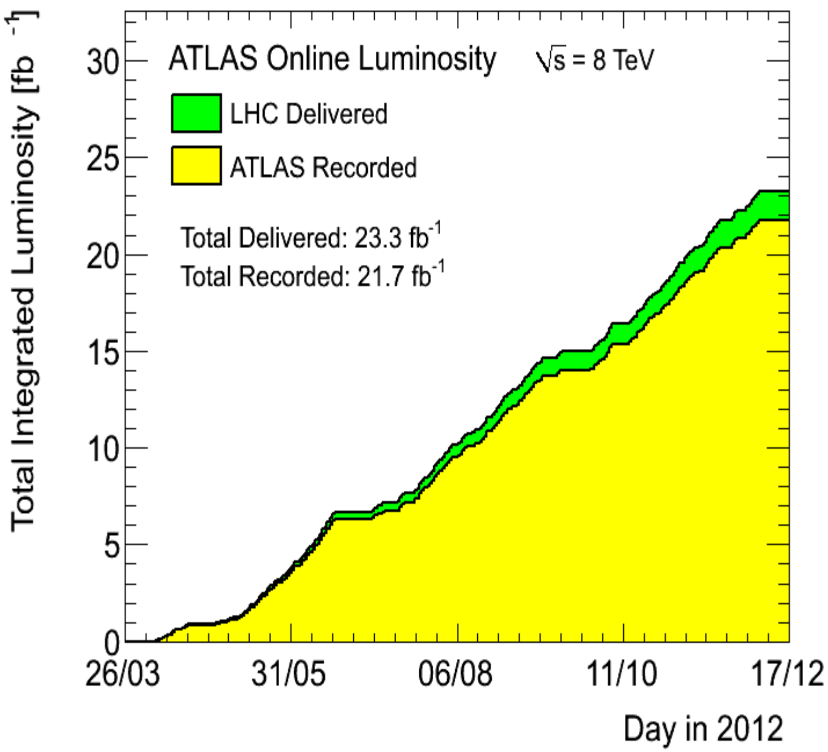
- Run-1 has been great success to discover a Higgs boson and set tight constrains on physics beyond SM.
- ATLAS has a rich and exciting physics program for higher energy running at 13 TeV with 10 times more luminosity.
- Proposed HL-LHC program will exploit full potential of LHC
- Significant physics reach with 3000 fb^{-1} relative to 300 fb^{-1}
  - Higgs couplings will be measured to 3-10% precision
  - Searches for new particles will extend mass reach by a factor of 2-3.
- Energy frontier at LHC remains open to discovery and exploration of unexpected physics at the highest energy scales.

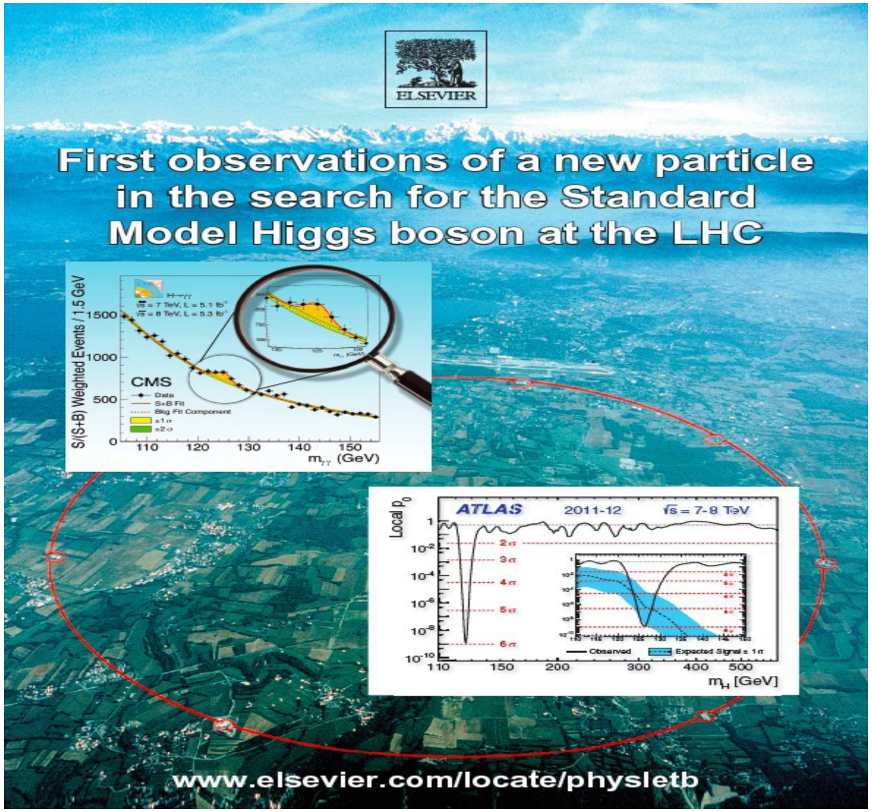
More details can be found at
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome#Upgrade_Projects_and_Physics_Pro

BACKUP

Introduction

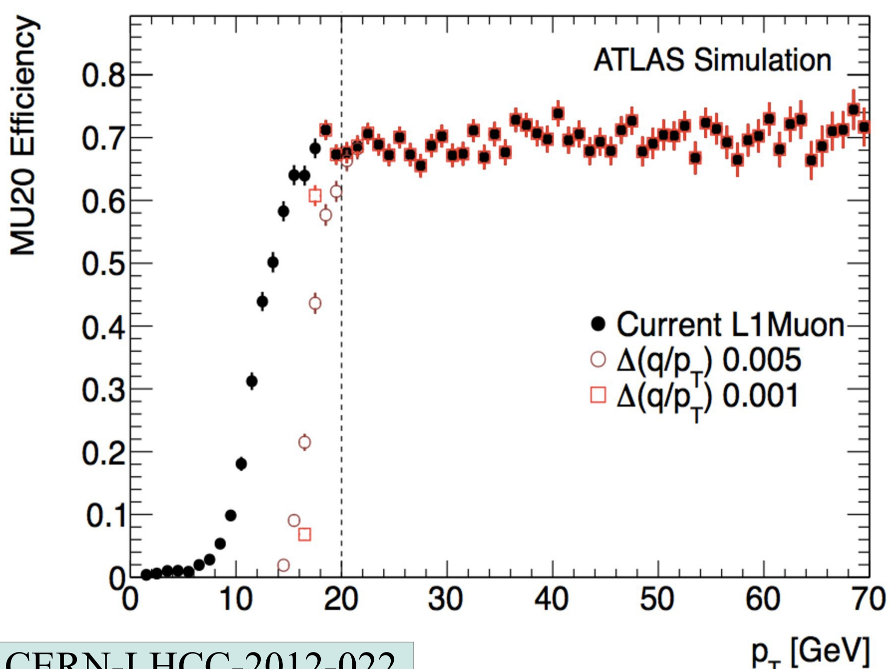
- LHC run1 (2010-2012) was a great success.
- Excellent performance and recorded 5.3 +21.7 fb^{-1} data at 7+8 TeV
- A new boson was discovered at 125 GeV that looks like SM
- But there are still no sign of physics beyond SM yet.

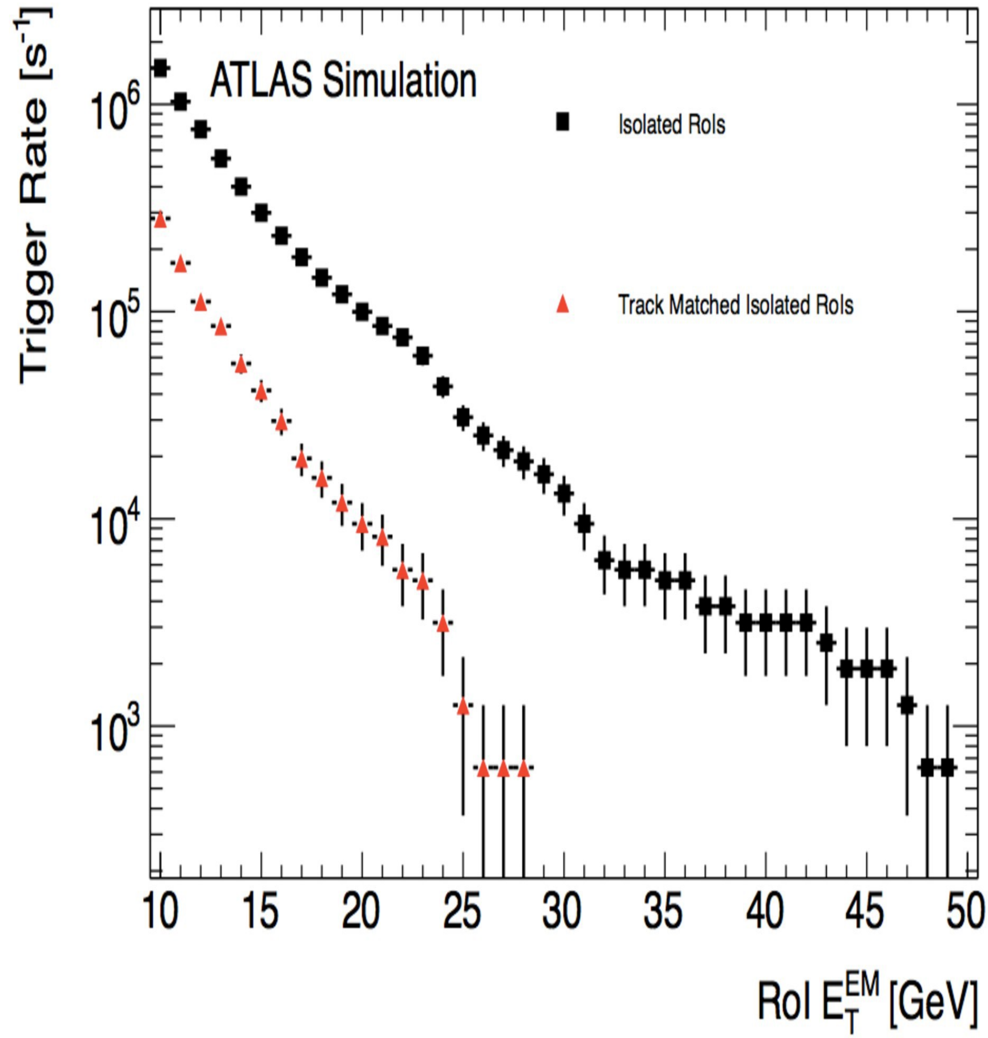




L1 Track Trigger

- New trigger architecture@Phase-II
  - L0→MHz, latency<6 μs
  - L1→400kHz, latency<20 μs
- Two options investigated
  - Data pull: ROI seeded L1track
  - Data push: self seeded L1track

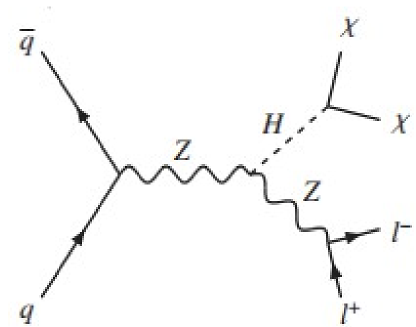


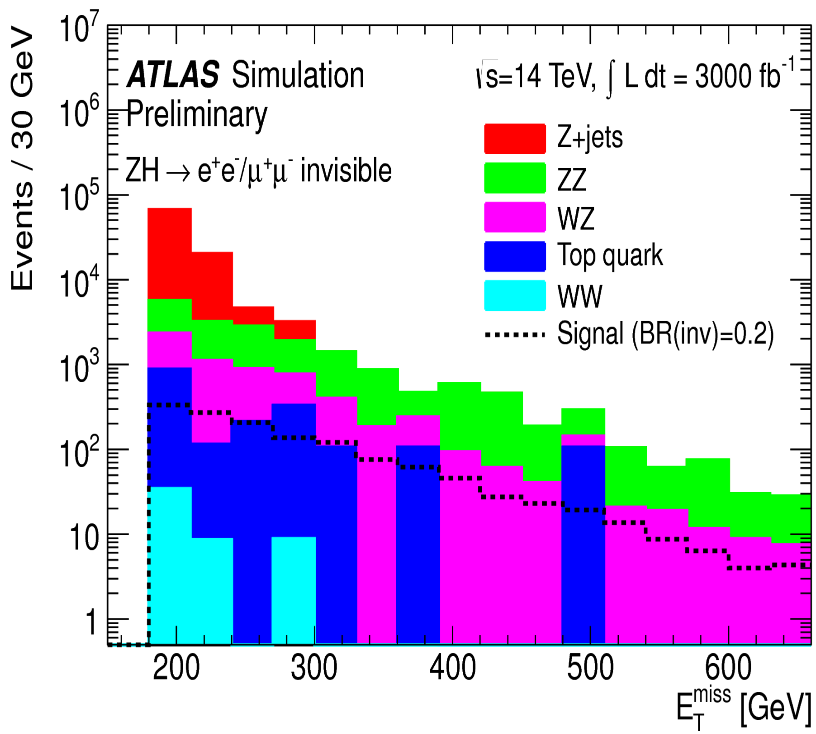


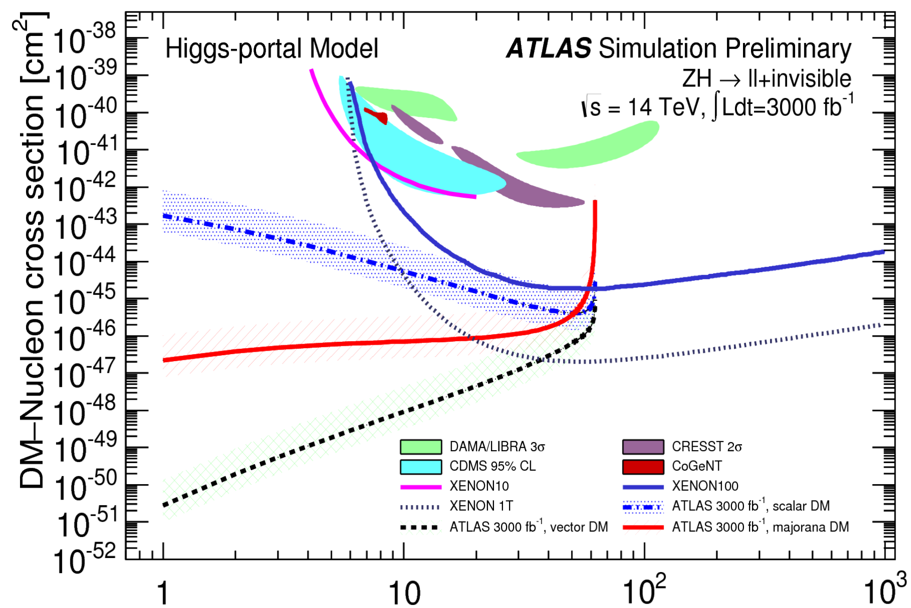
CERN-LHCC-2012-022

Invisible Higgs Branching Fraction

- ZH→l⁺l⁻ +met offers searching for H→invisible directly.
- B(H→invisible) can be interpreted in Higgs-portal models.







ATL-PHYS-PUB-2013-014/015

BR(H →inv.) limits at 95% (90%) CL	300 fb^{-1}	3000 fb^{-1}
Realistic scenario	23% (19%)	8.0% (6.7%)
Conservative scenario	32% (27%)	16% (13%)