Physics Prospects with the Upgraded ATLAS Detector

Flera Rizatdinova (Oklahoma State University)
for the ATLAS Collaboration

Overview

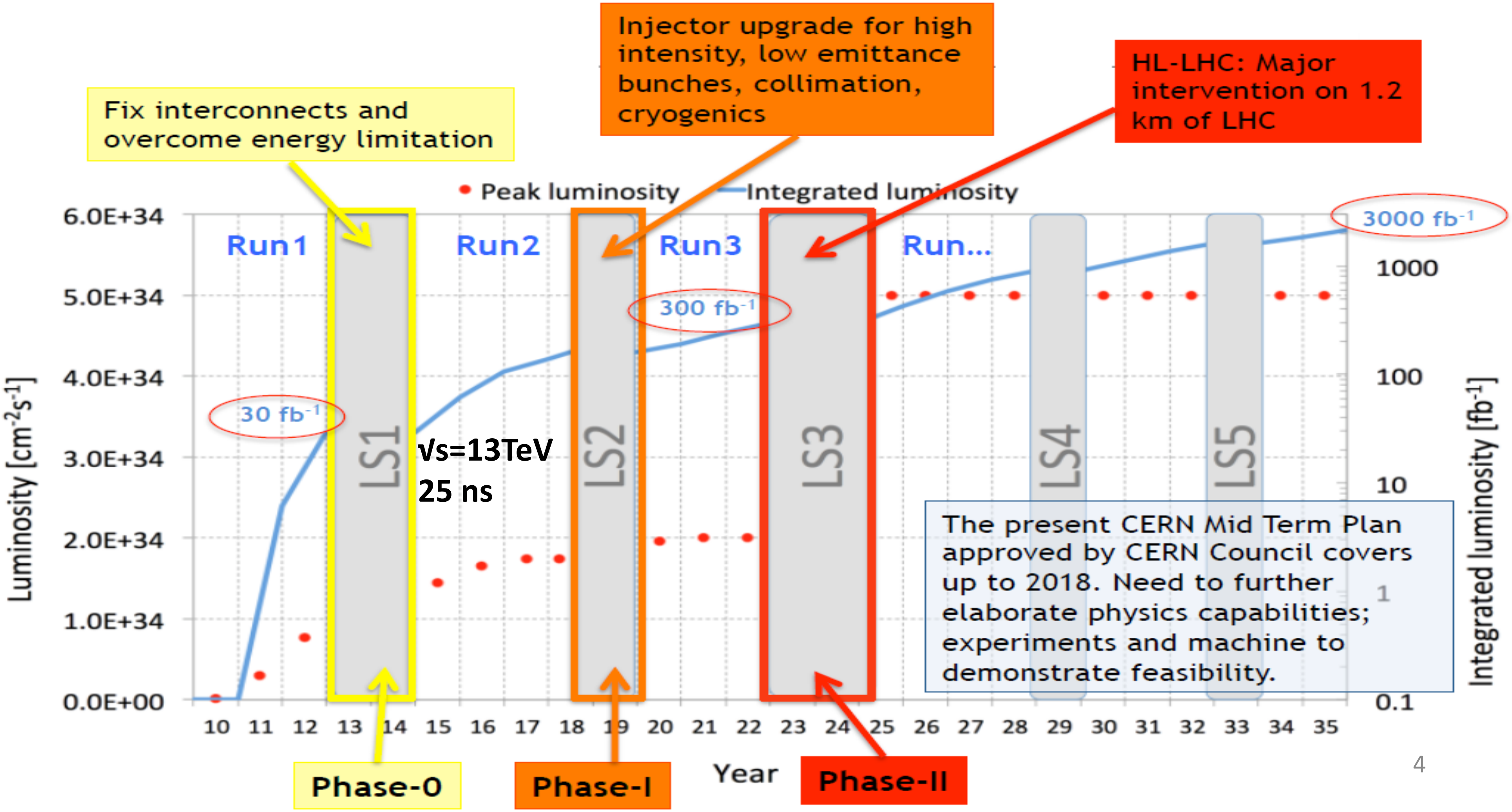
- Introduction
- Prospects for Higgs physics
- Prospects for searches for SuperSymmetry
- Exotic physics search potential
- Conclusions

Physics motivation for LHC upgrade

- Priorities after Higgs discovery:
  - precise measurements of the properties of the new particle
  - search for Higgs rare decays (e.g. $H \rightarrow \mu\mu$)
  - search for partners of the 125 GeV Higgs particle
- Open questions:
  - dark matter candidates
  - naturalness of the Higgs boson
- LHC has been recognized as a natural facility to perform these studies

Luminosity baseline

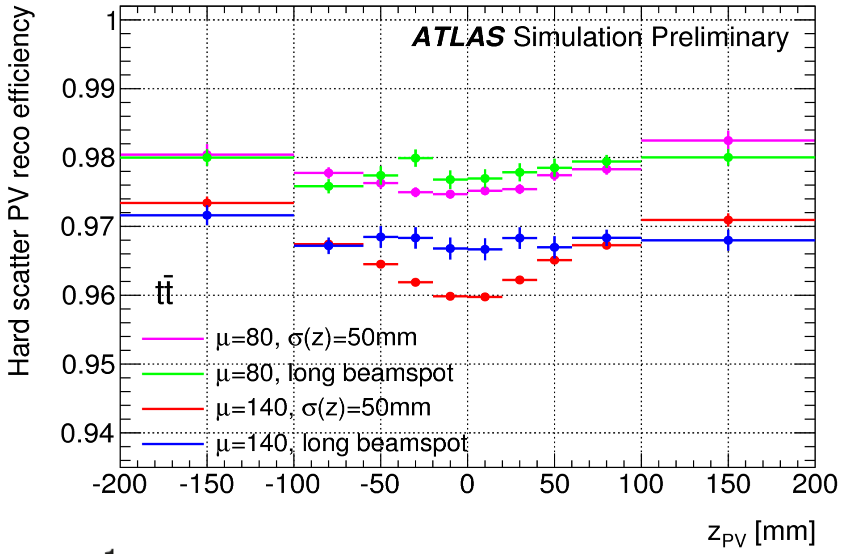
- Run 2 ATLAS upgrade: IBL and trigger
- HL ATLAS upgrade: Inner Tracker will replace the whole current tracking system (expect ~140 pileup events)

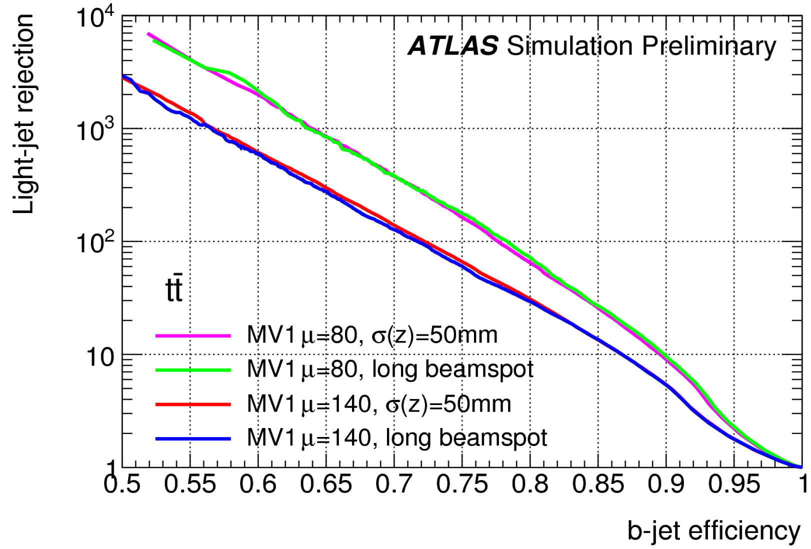


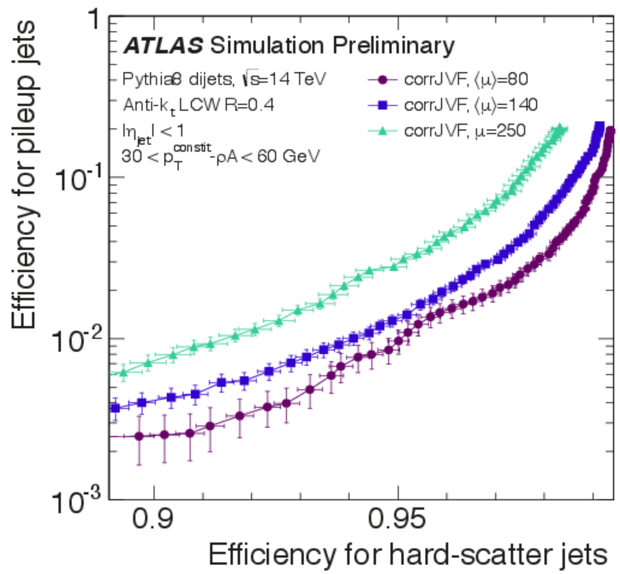
Methodology of evaluation of prospects

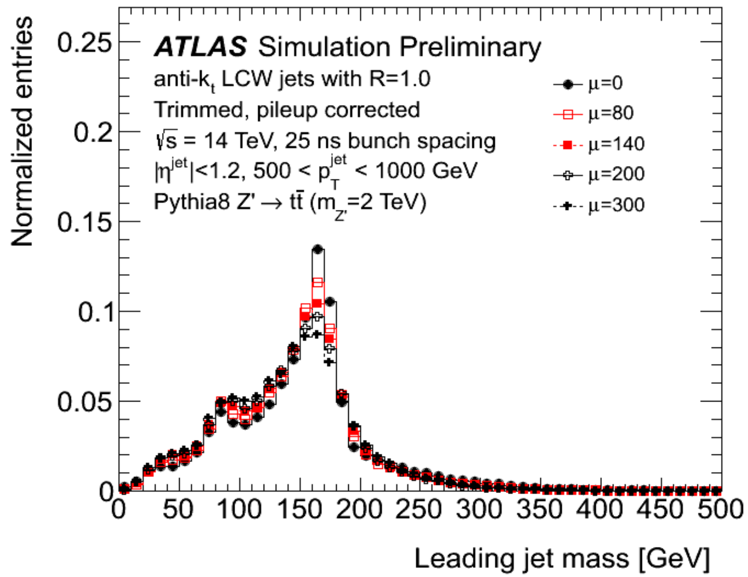
- Prospects in all areas of ATLAS physics program are studied by refining the current analyses and by starting design of new analyses
- Strategy:
  - evaluate the performance using full-simulation studies
  - using smearing functions applied to the truth-level objects
  - consider different scenarios related to the systematic uncertainties (which ones can be reduced)
- Parameterization functions obtained using full simulations:
  - Resolution and reconstruction efficiency for e,μ,γ,τ, jets and E_t^{miss}
  - Rates for light, c and b-quark jets to pass b-tagging criteria

ATLAS performance under HL LHC conditions

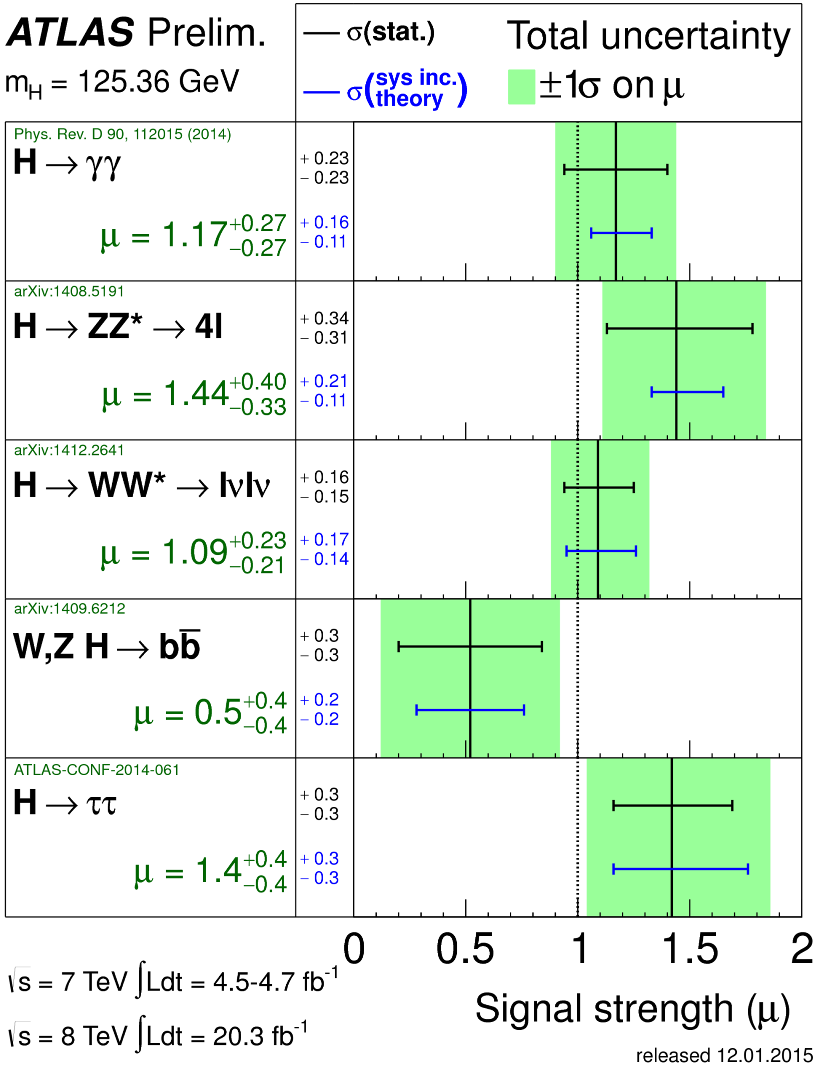


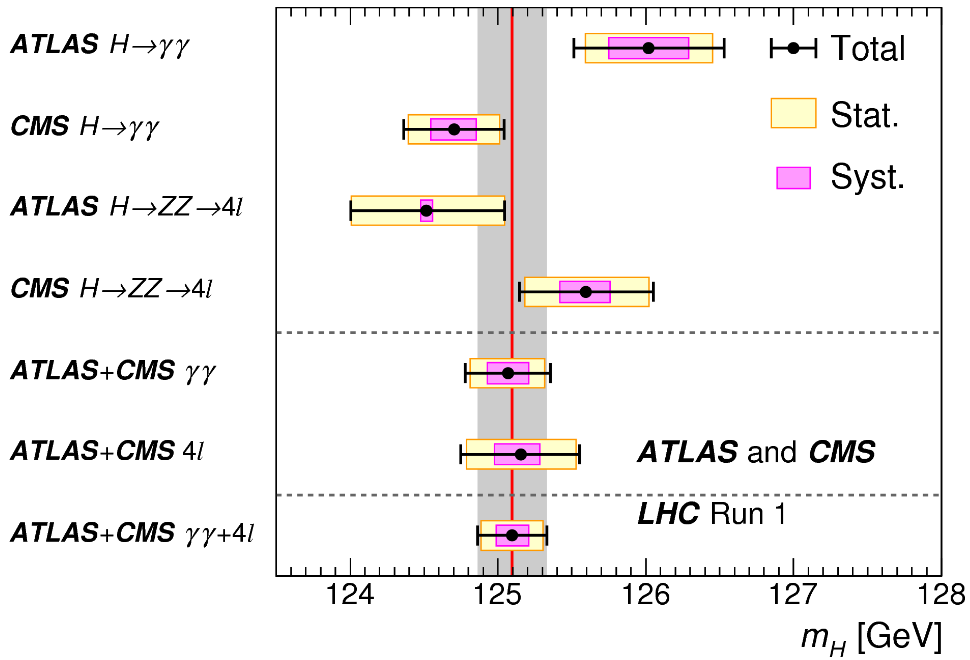






SM Higgs boson: current status



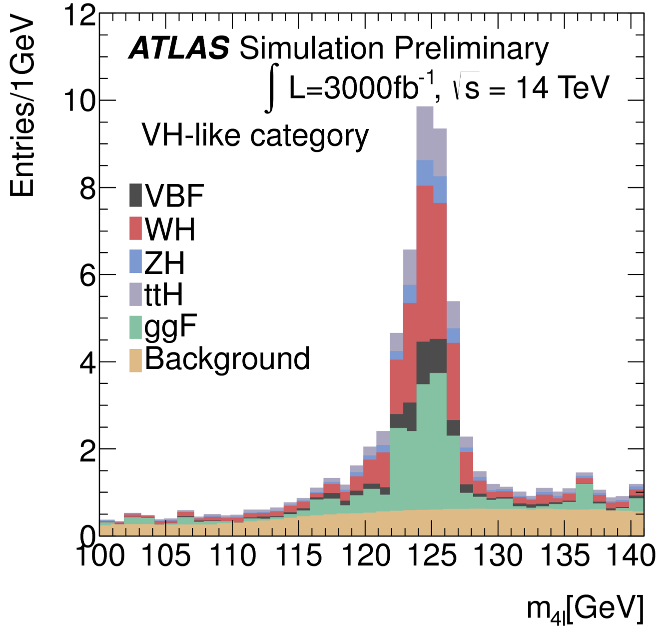


- $M_H = 125.09 \pm 0.24$ GeV

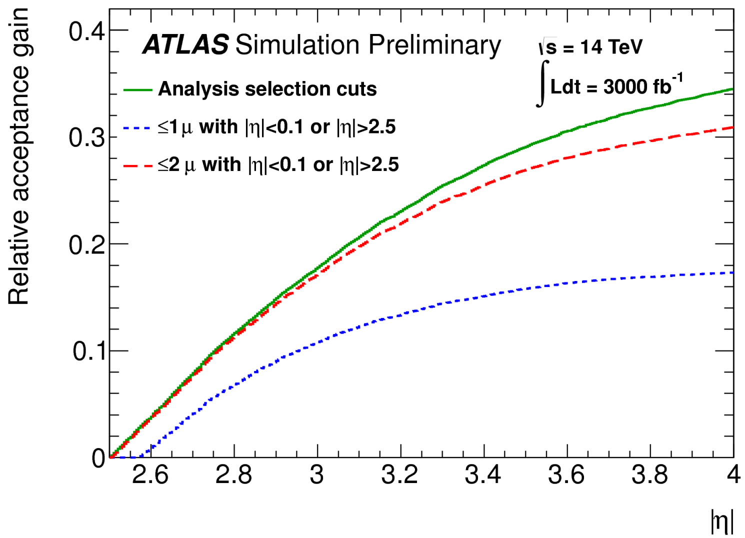
Prospects of observation of Higgs→ ZZ final state at HL

- Experimentally, very clean signal

$\Delta\mu/\mu$	Total	Stat.	Expt. syst.	Theory
Production mode			300 fb^{-1}	
ggF	0.152	0.066	0.053	0.124
VBF	0.625	0.545	0.233	0.226
WH	1.074	1.064	0.061	0.085
$t\bar{t}$H	0.535	0.516	0.038	0.120
Combined	0.125	0.042	0.044	0.108
			3000 fb^{-1}	
ggF	0.131	0.025	0.040	0.124
VBF	0.371	0.187	0.225	0.226
WH	0.390	0.375	0.061	0.085
ZH	0.532	0.526	0.038	0.073
$t\bar{t}$H	0.224	0.184	0.034	0.120
Combined	0.100	0.016	0.036	0.093

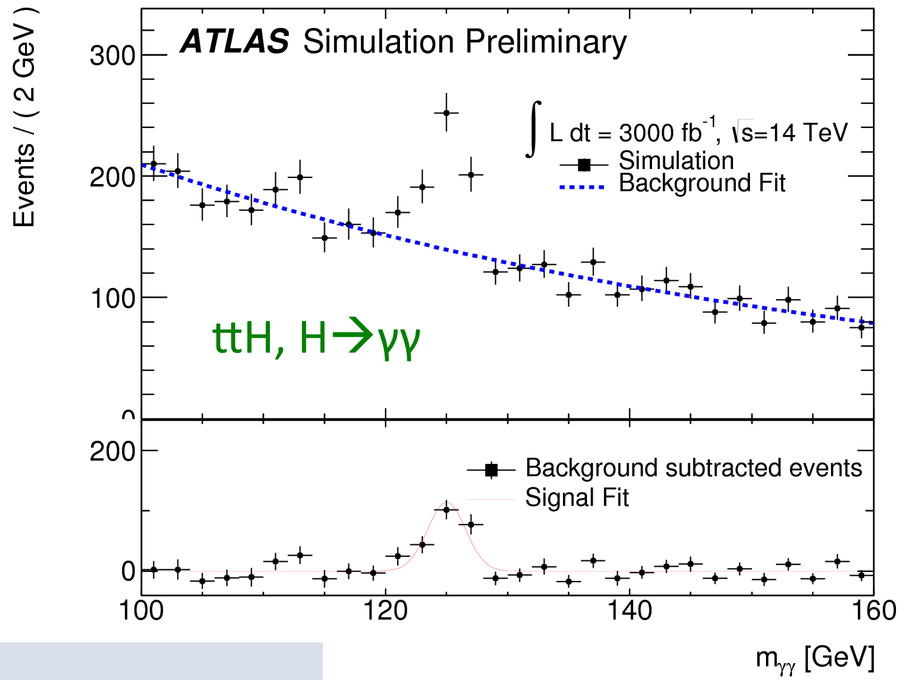


- Significant acceptance gain is expected due to extension of muon η coverage



Higgs measurements in γγ final state

- Important for tH Yukawa coupling measurements
- ATLAS studied different channels; theoretical uncertainties are leading
- Combined signal strength uncertainty is ~3.5% (if drop theoretical uncertainties)



	Δμ/μ (%)			
Production mode	Total	Statistical	Experimental	Theoretical
ttH	+21 −17	+13 −12	+5 −4	+17 −11
WH	+26 −25	+21 −20	+13 −12	+10 −8
ZH	+35 −31	+32 −29	+7 −7	+12 −8
ggF	+19 −14	+3 −3	+1 −1	+19 −14
VBF	+29 −29	+18 −18	+1 −1	+23 −23

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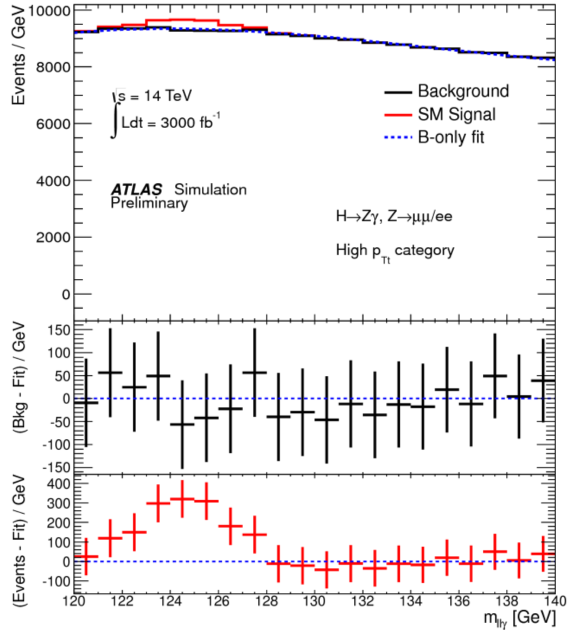
Rare Higgs boson decays

- H→Zγ is sensitive to potential new particles in the loop. ATLAS expects to observe H→Zγ decay at ~4σ level on 3000 fb^{-1} dataset.
- Expected uncertainty on signal strength: 0.46 at 300 fb^{-1} →0.30 at 3000 fb^{-1}



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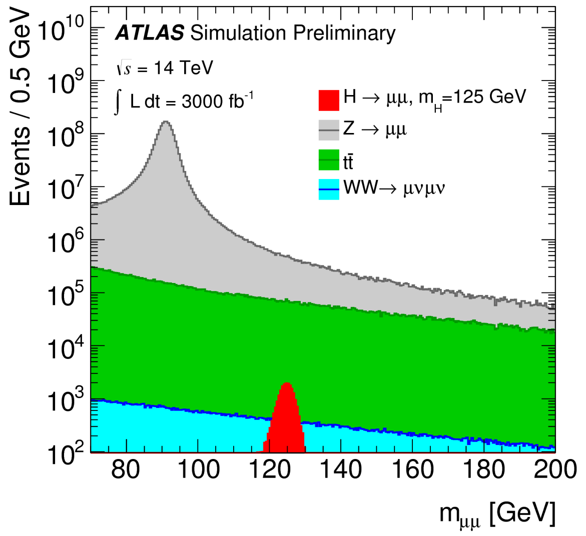
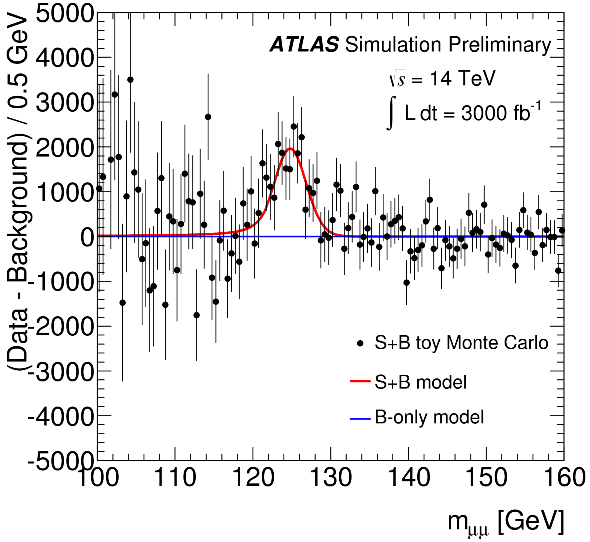
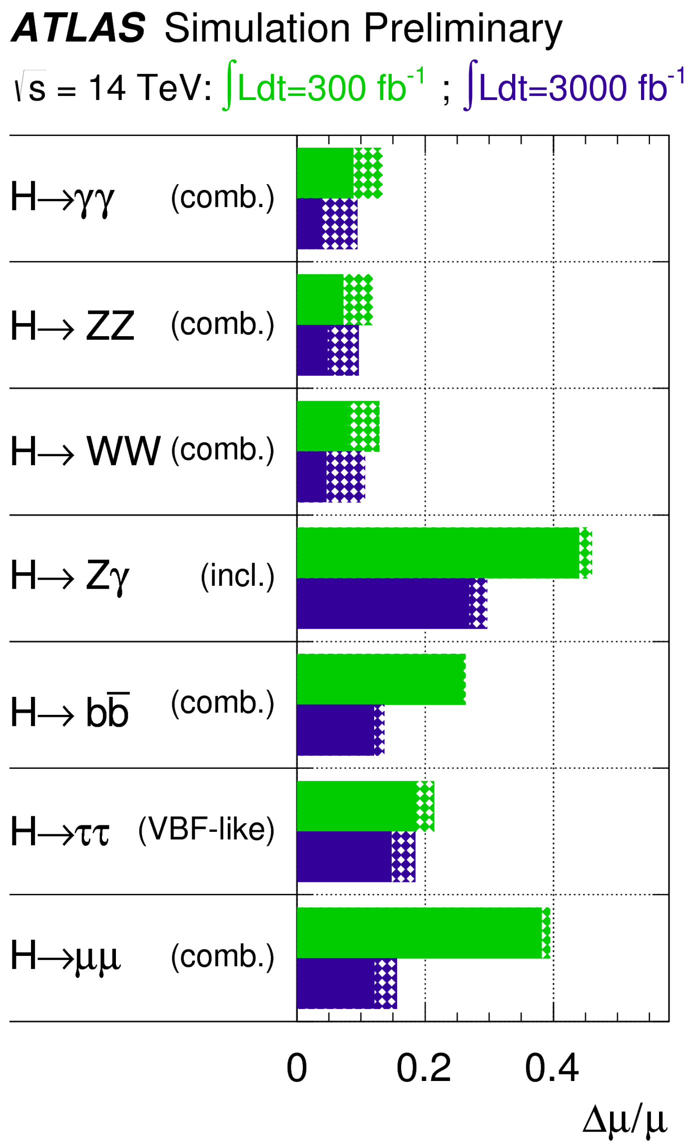




- H→μμ is sensitive to the 2nd generation coupling
- Expect to see at 7σ level

Higgs signal strengths

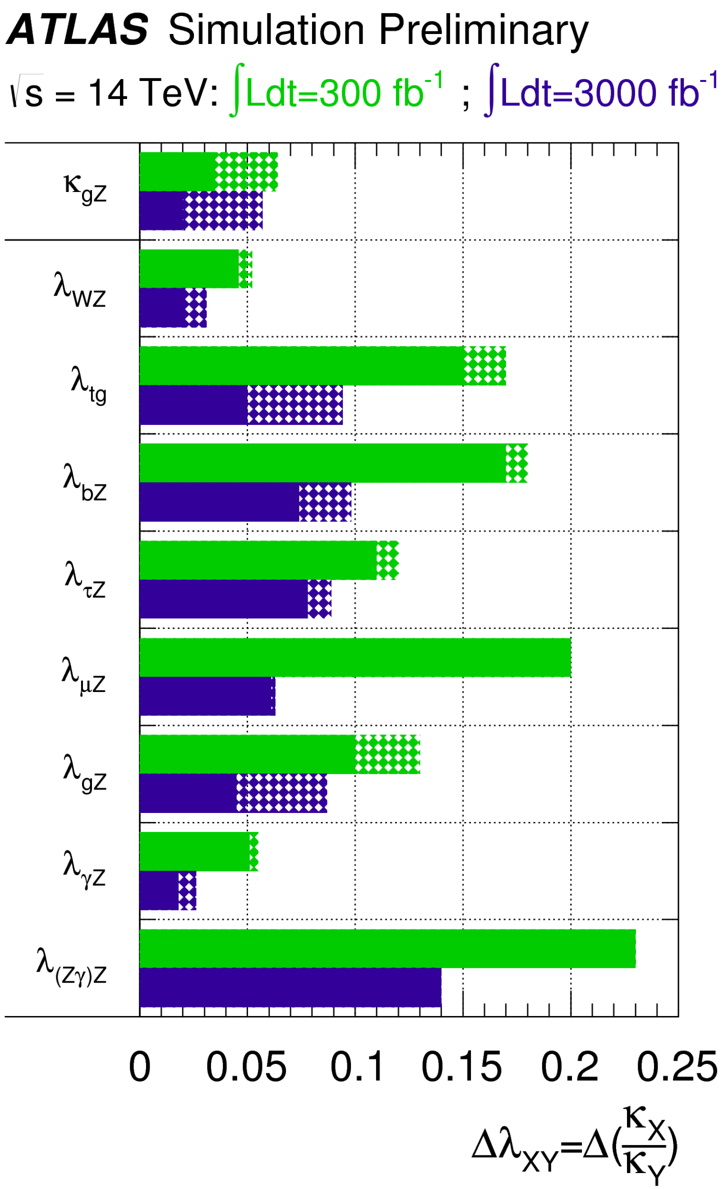
- Signal strength $\mu=\sigma xBR/(\sigma xBR)_{SM}$
- Separation by production modes
  - Important for coupling measurements
- Projection assumptions:
  - 300/fb: μ=60, 3000/fb: μ=140
  - Used dedicated 14 TeV samples
- Systematics:
  - Conservative estimation (including propagation of the large statistics in control regions)
  - Large impact from theory uncertainties (shown by dashed areas), like QCD scale, PDFs



Higgs coupling ratios

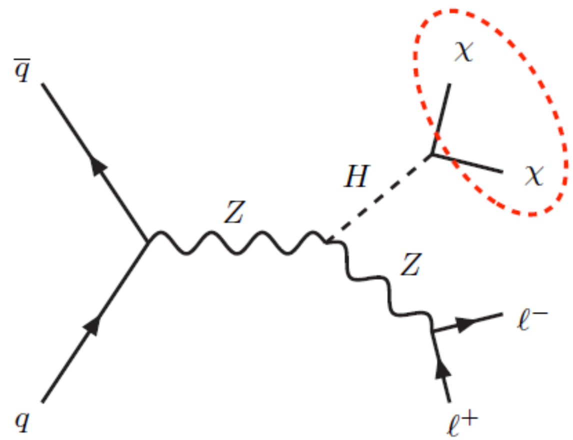
- Ratios:
  - $\lambda_{ij} = k_i/k_j$; $k_{ij} = k_i k_j/k_h$
  - k_i are modifiers of the SM couplings, k_h is the width scale factor
- Overall, ~5% accuracy is achievable
  - don't rely on assumptions on total width
  - Free couplings to SM particles
  - Allow for BSM in loops and undetected final states
- Expected precision of couplings (assuming that theoretical uncertainties will be reduced by factor of 2)

k(%)	k_Z	k_W	k_t	k_b	k_τ	k_μ	k_g	k_γ	$k_{Z\gamma}$
300 fb^{-1}	8	9	21	22	14	21	14	9	24
3000 fb^{-1}	4	4.5	9	11	9	7	7	4	14

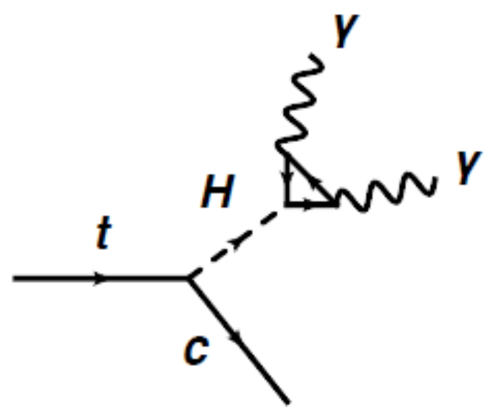


BSM Higgs searches

- Invisible Higgs: ZH→ll+X
  - sensitivity Br(H→invisible): 20-30% at 300/fb, 10% at 3000/fb
  - similar to sensitivity from couplings



- Top rare decays t→cH (FCNC)
  - SM: 3×10^{-15}, BSM: up to 10^{-5}
  - expected sensitivity at 3000/fb: 1.5×10^{-4}



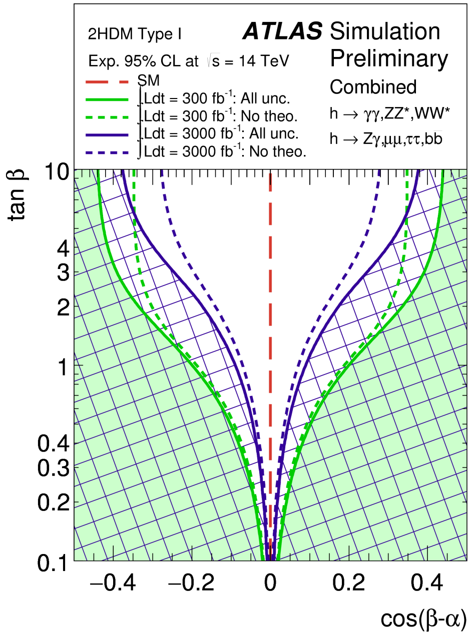
BSM Higgs couplings

- Additional electroweak singlet (H)
  - precision on κ_H: 2.5% at 300/fb, 1.6% at 3000/fb (w/o theor. uncertainties)

$$\kappa_h^2 + \kappa_H^2 = 1$$

SM-like Higgs (125 GeV)

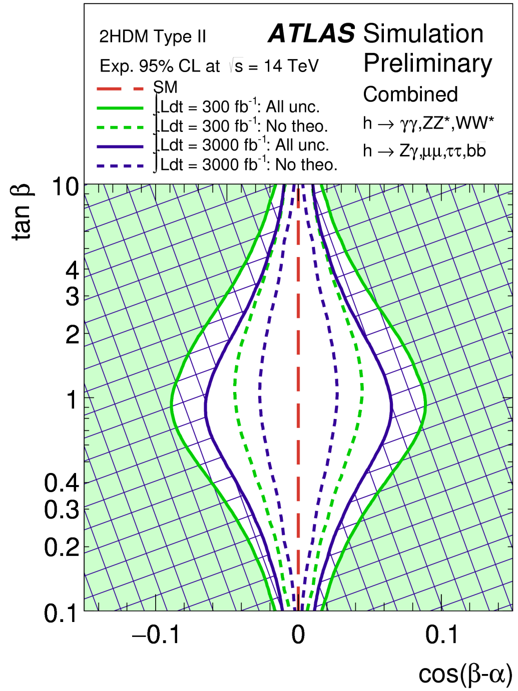
- 2HDM for Type I and Type 2



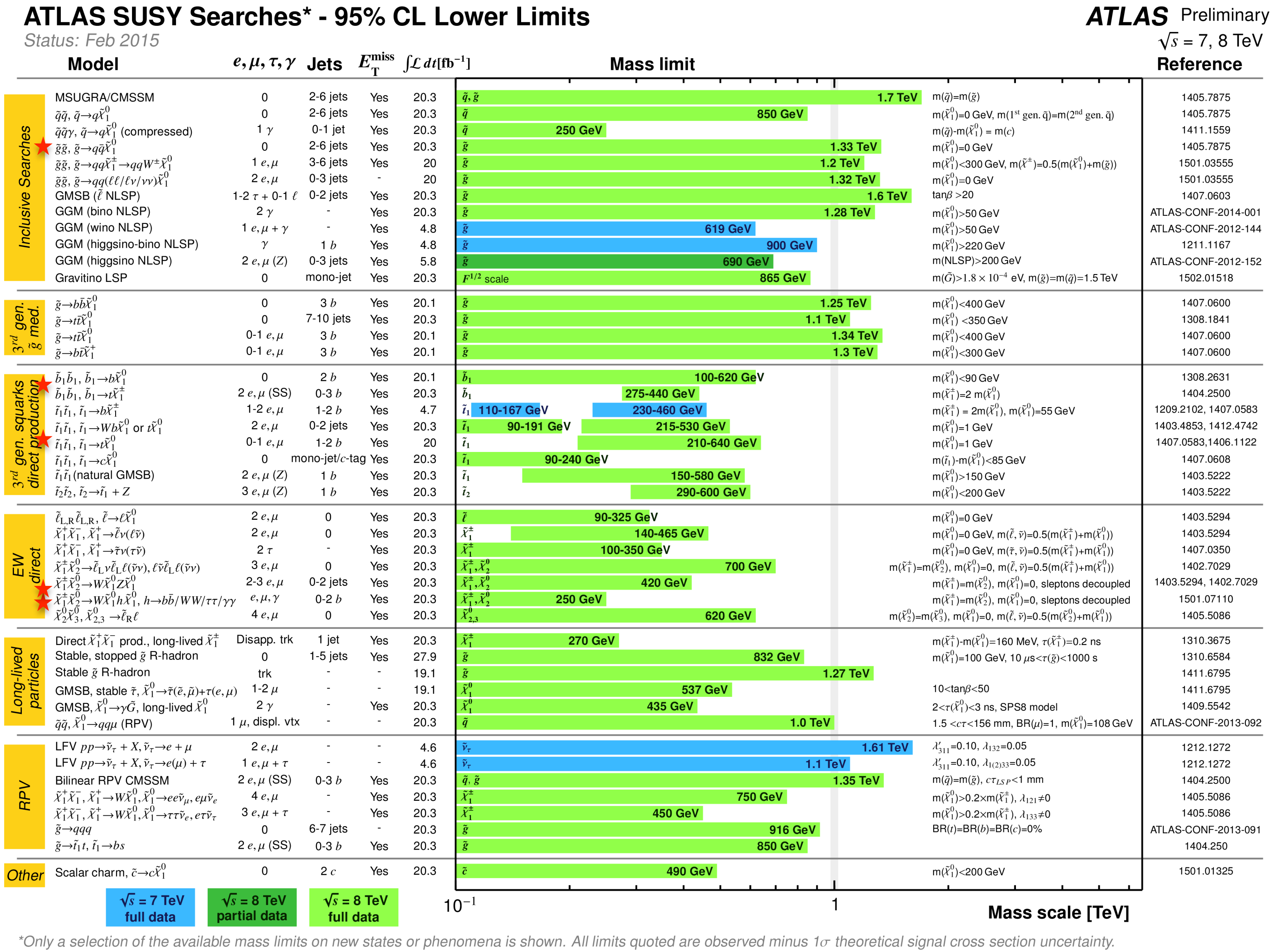
α – angle between 2 CP-even Higgs states.

Type 1: One Higgs doublet couples to vector bosons, the other – to fermions.

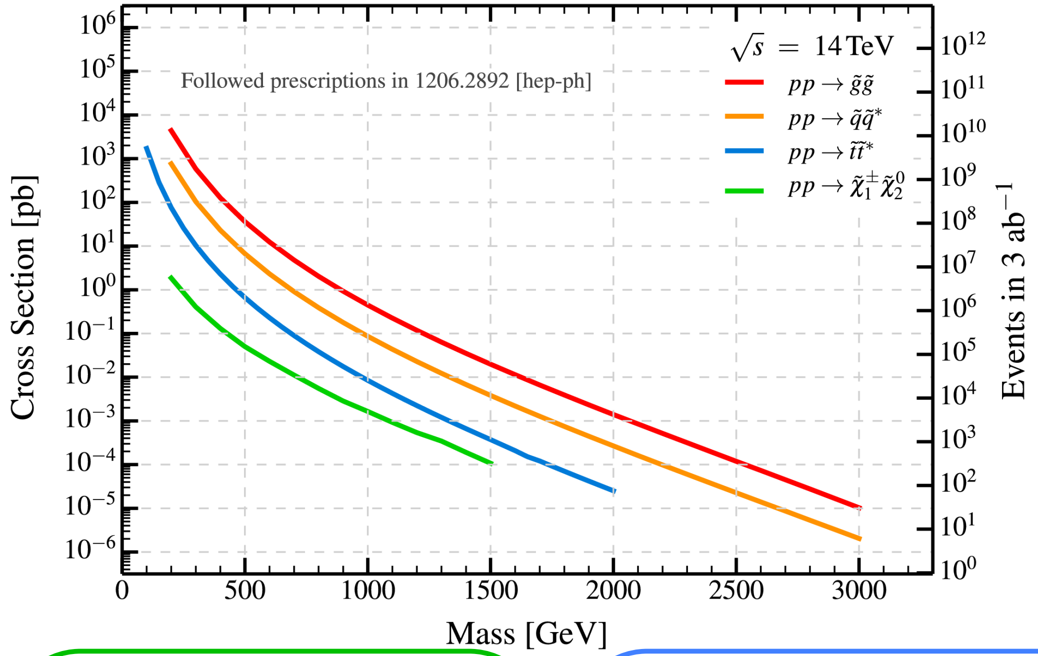
Type 2: One Higgs doublet couples to up-type quarks, the other – to down-type quarks.



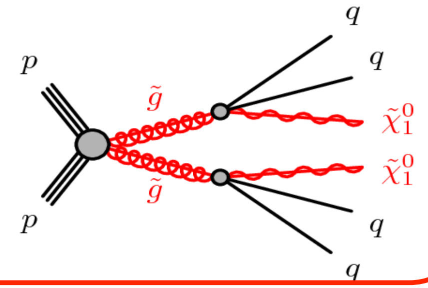
SUSY: Current Status



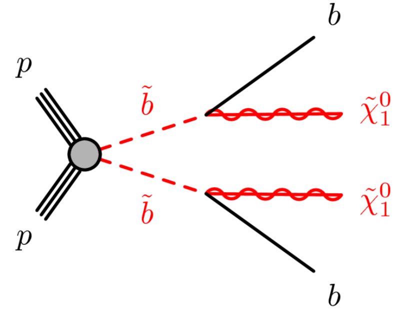
SUSY searches strategy at HL LHC



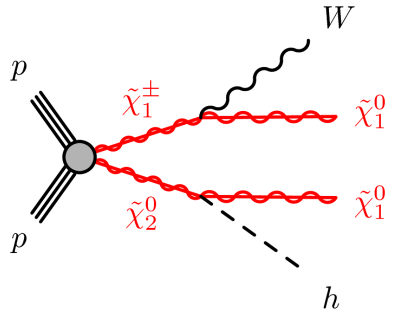
Strong prod. of gluinos



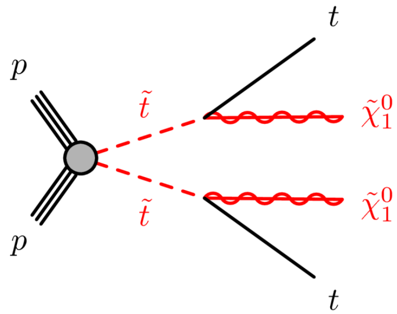
Strong prod. of sbottoms



EW production of $\chi_1^+\chi_2^0$



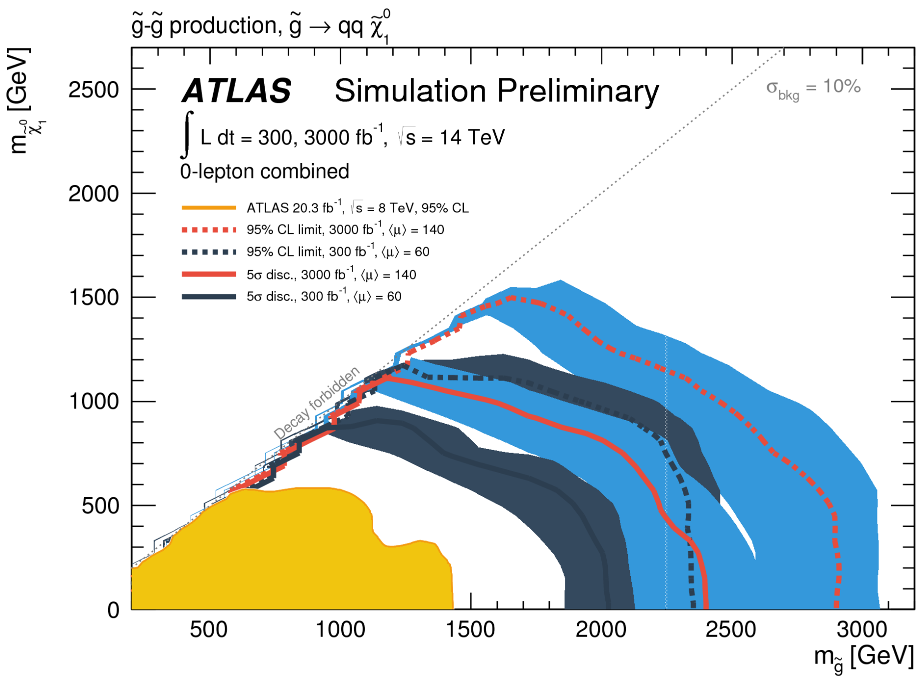
Strong prod. of stops

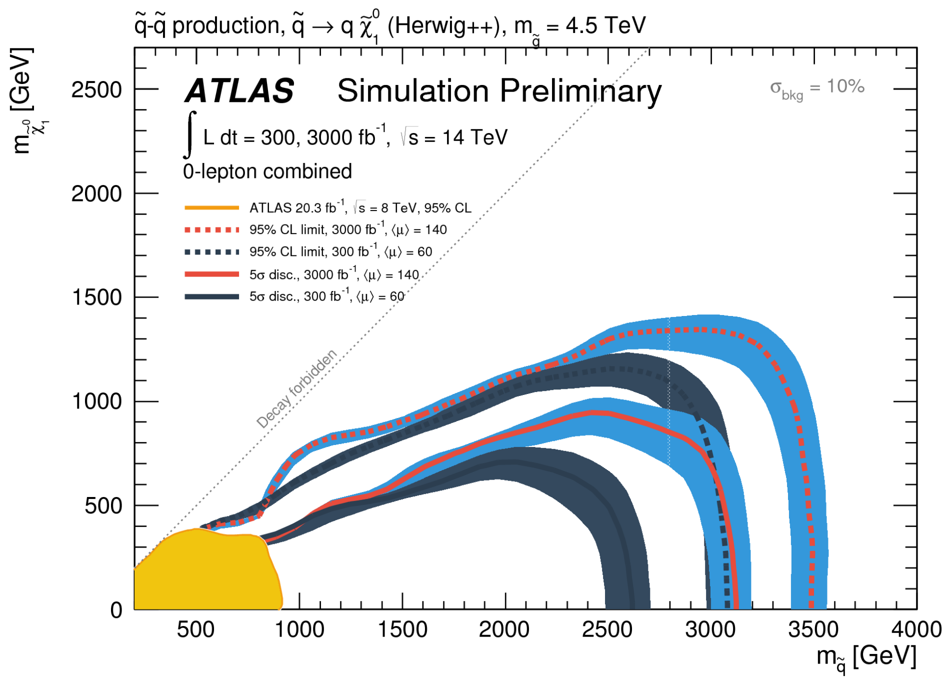


- Mass constraints depend on the assumed SUSY mass spectrum

Strong production of gluinos/squarks

- Search in 0 lepton + multiple b-jets + Etmiss channel
- Current lower limit on gluino mass (1.4 TeV) can be extended to 2.3 TeV with 300 fb^{-1} and 3 TeV with 3000 fb^{-1}





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Strong production of stop quarks

- Naturalness requires stop/sbottom mass to be < ~1 TeV
- Studies performed only for standard cases t+LSP
- Final state: 0/1 lepton + ≥6/4 jets + ≥2/1 b-jets + Etmiss
- 5σ discovery potential up to 1 TeV with 300 fb^{-1} and 1.2 TeV with 3000 fb^{-1}.

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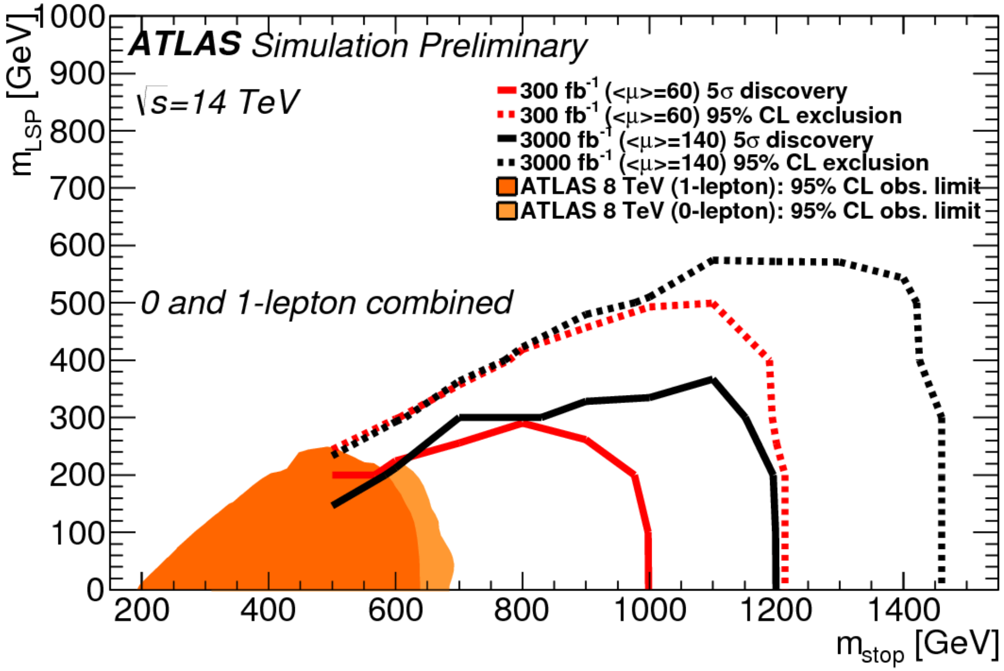

Strong production of sbottom quarks

- Feasibility studies performed for direct production and decay (b+LSP)
- Discriminator between signal and main background (ttbar): boost-corrected contransverse mass $$m_{CT} = \frac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$$
- 5σ discovery potential up to 1.1 TeV with 300 fb^{-1} and 1.3 TeV with 3000 fb^{-1}.

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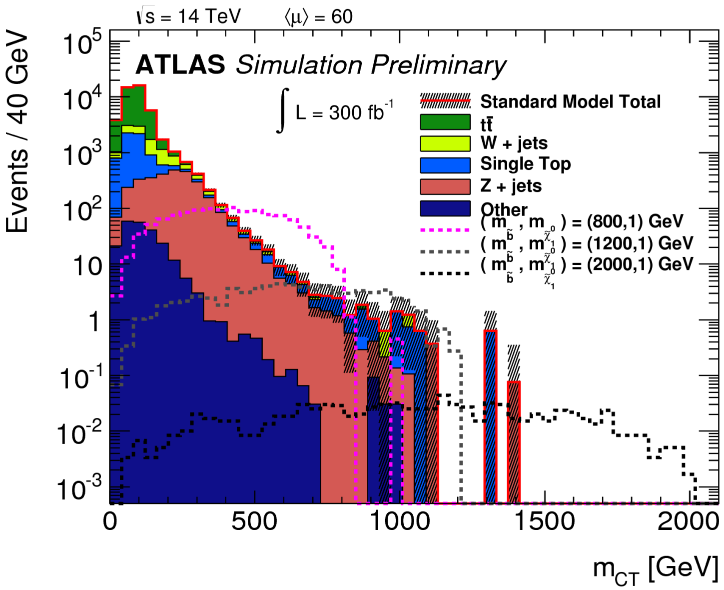
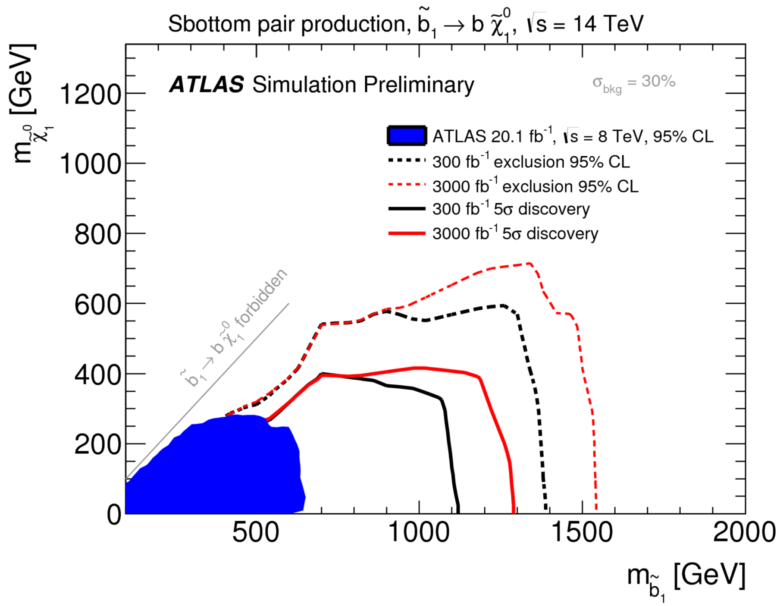
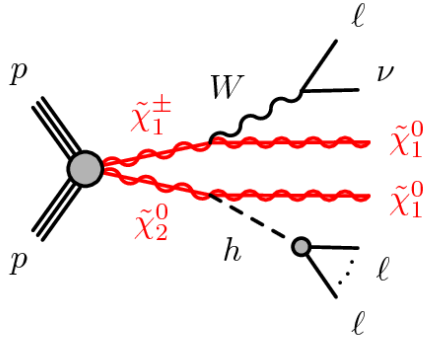


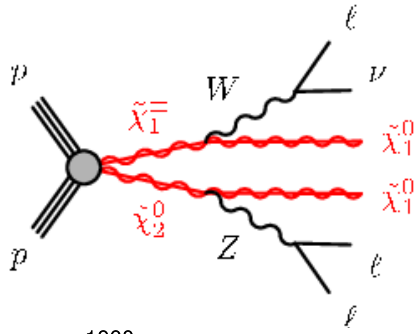


Electroweak production of charginos/ neutralinos

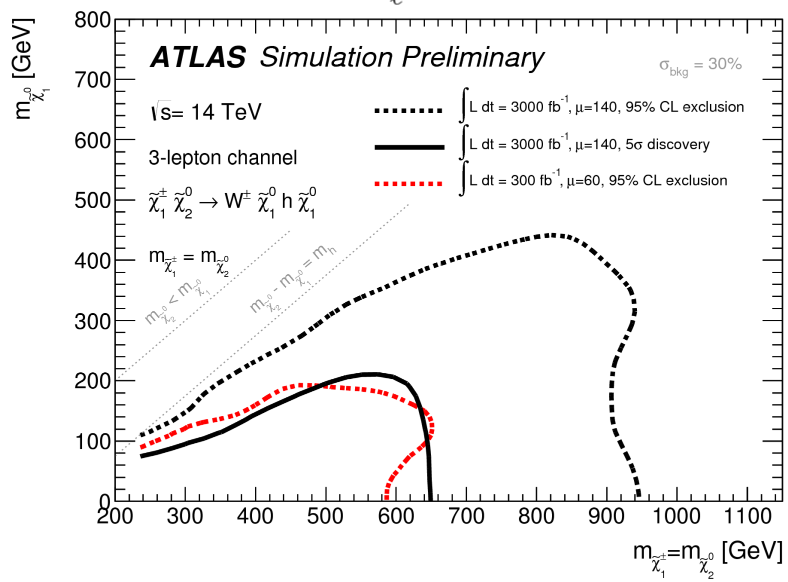
- Increase of integrated luminosity from 300/fb to 3000/fb extends the sensitivity potential of $\chi_1^{\pm}\chi_2^0$ production by 300—350 GeV

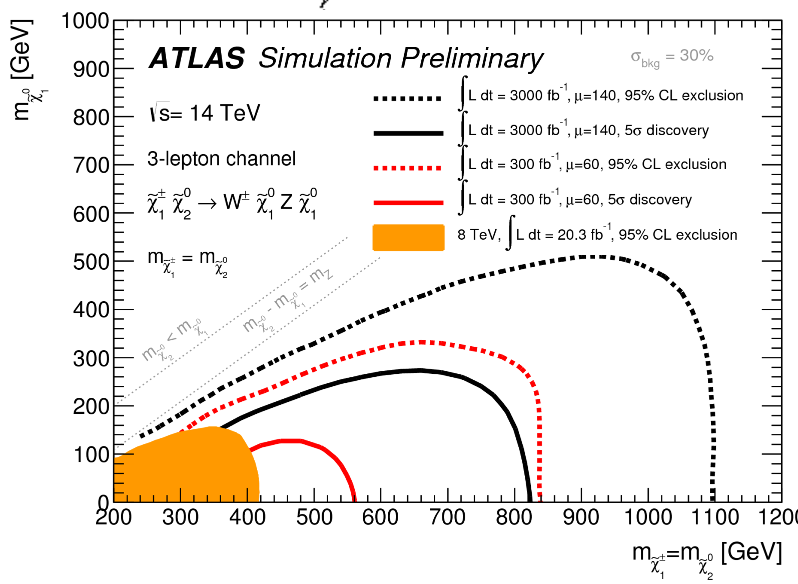


sensitivity in the 3 lepton channel for the Wh-mediated mode



sensitivity in the 3 lepton channel for the WZ-mediated mode





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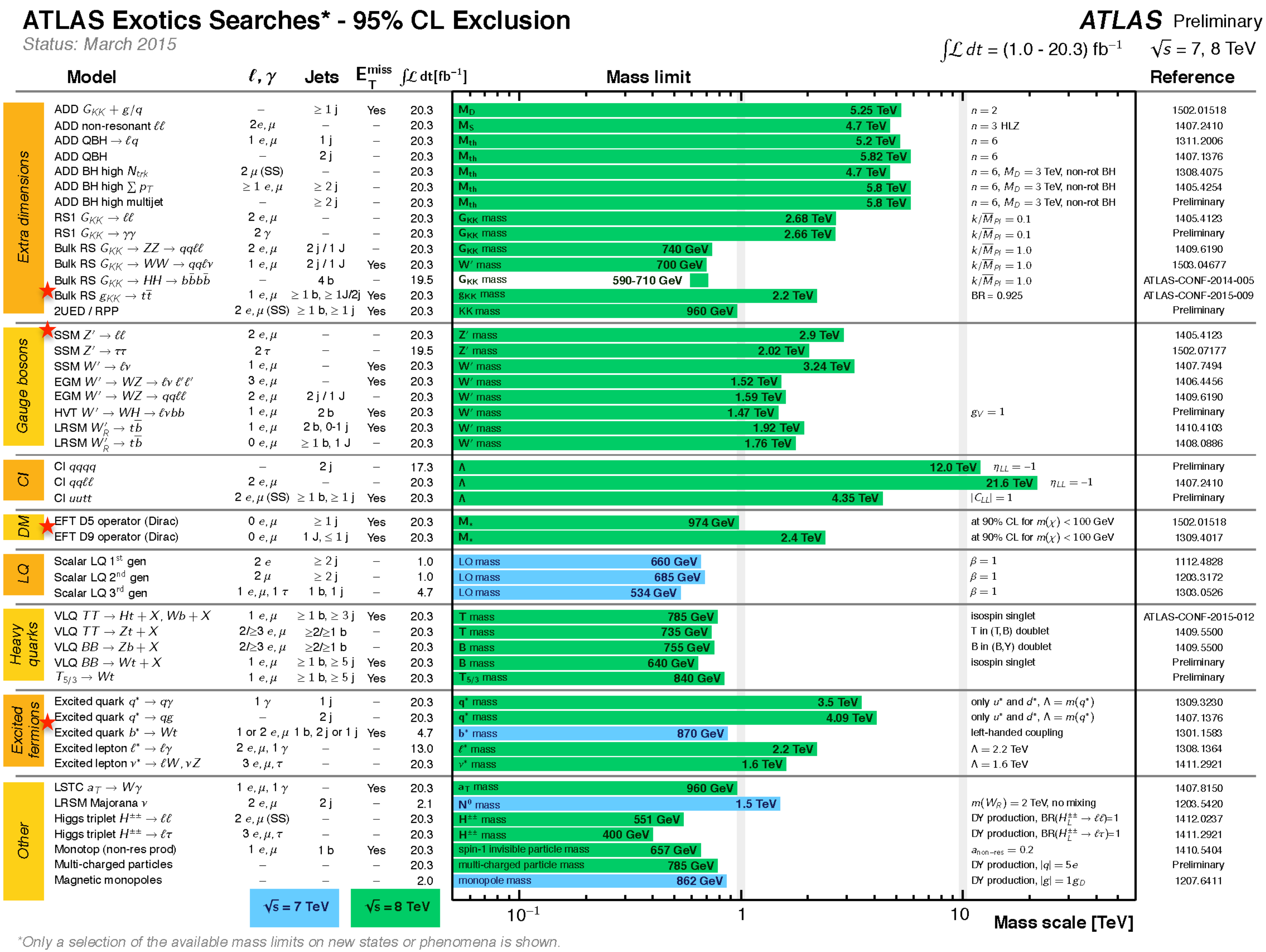
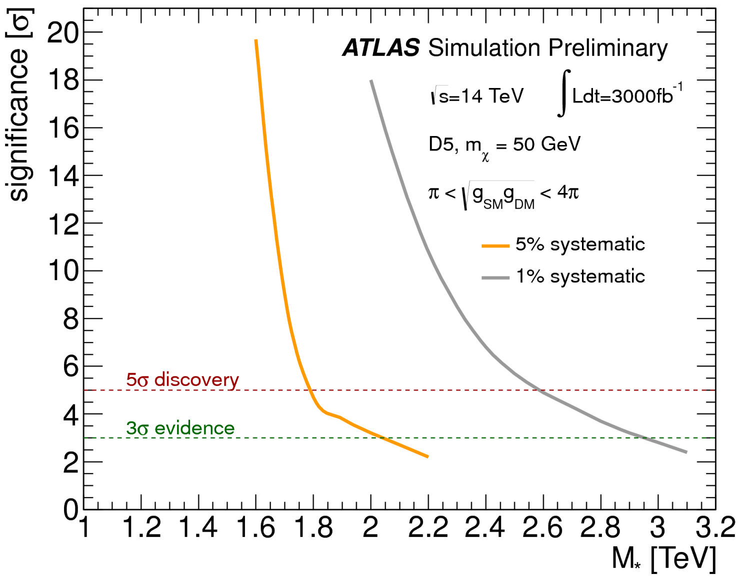
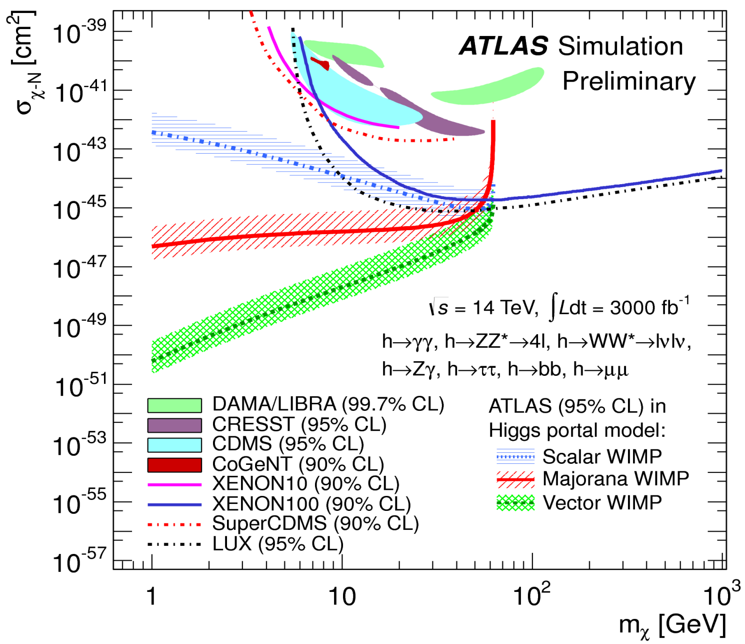
Exotic physics: current status



Searches for WIMP Dark Matter

- Models:
  - contact interactions between SM and DM particles – EFT
  - simplified models with mediators (e.g. Z')
  - Higgs portal models – weak interaction with SM particles except the Higgs boson
- Signatures: mono-jet + Etmiss   any higgs-like event





Search for Dilepton/ditop resonances

- Characterization of ATLAS high mass reach
  - strongly produced wide resonances: Kaluza-Klein gluons (g_{KK}) in extra-dimensional models
  - weakly produced narrow resonances: Z'→tt/ll
- With 3000/fb, can probe tt resonances up to 6.7 TeV, dilepton resonances up to 7.8 TeV

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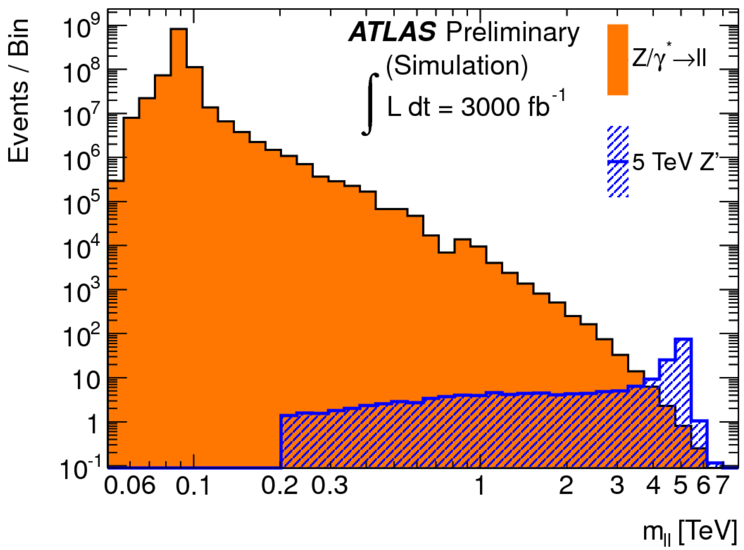
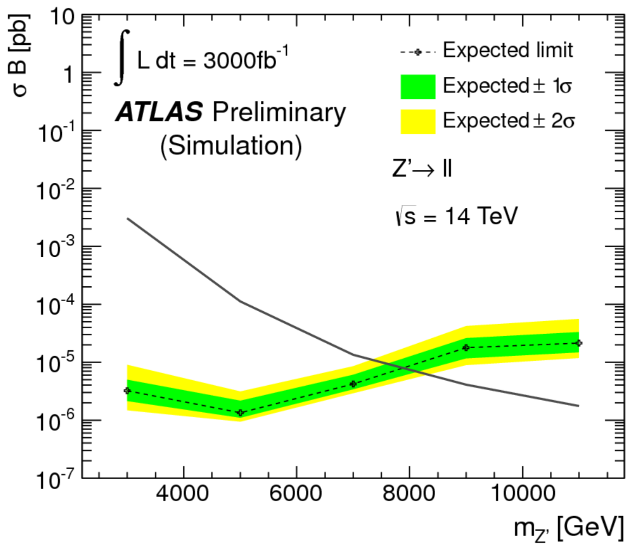
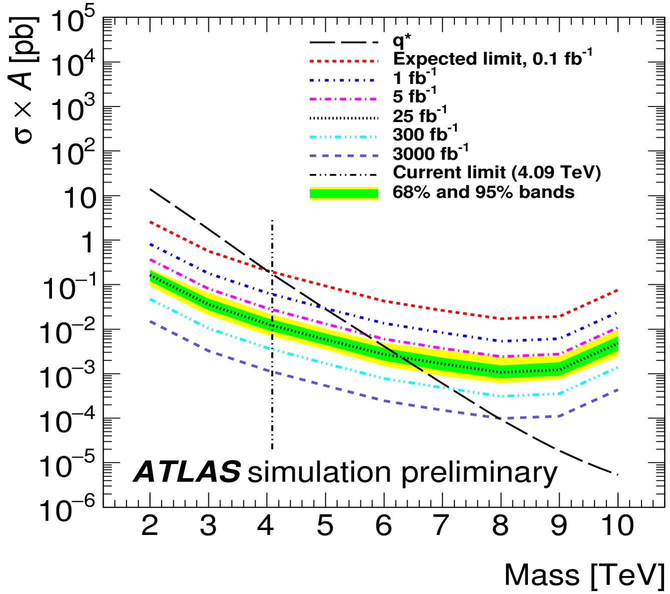


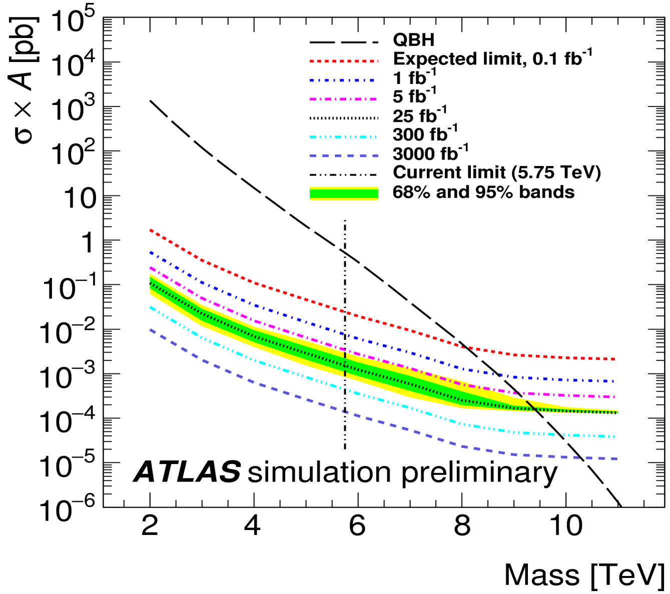


shown: dielectrons similar results obtained for dimuons

Search for Dijet resonances

- Benchmark processes: excited quarks q* and Quantum Black Holes (QBH)
  - the signals are expected to surpass the backgrounds by an order of magnitude
- Sensitivity scans show that approx. 1/fb of data is sufficient for 5σ discovery of q* up to 4 TeV and QBH up to 7 TeV
  - at 3000/fb discover q* up to 7 TeV and QBH up to 10 TeV





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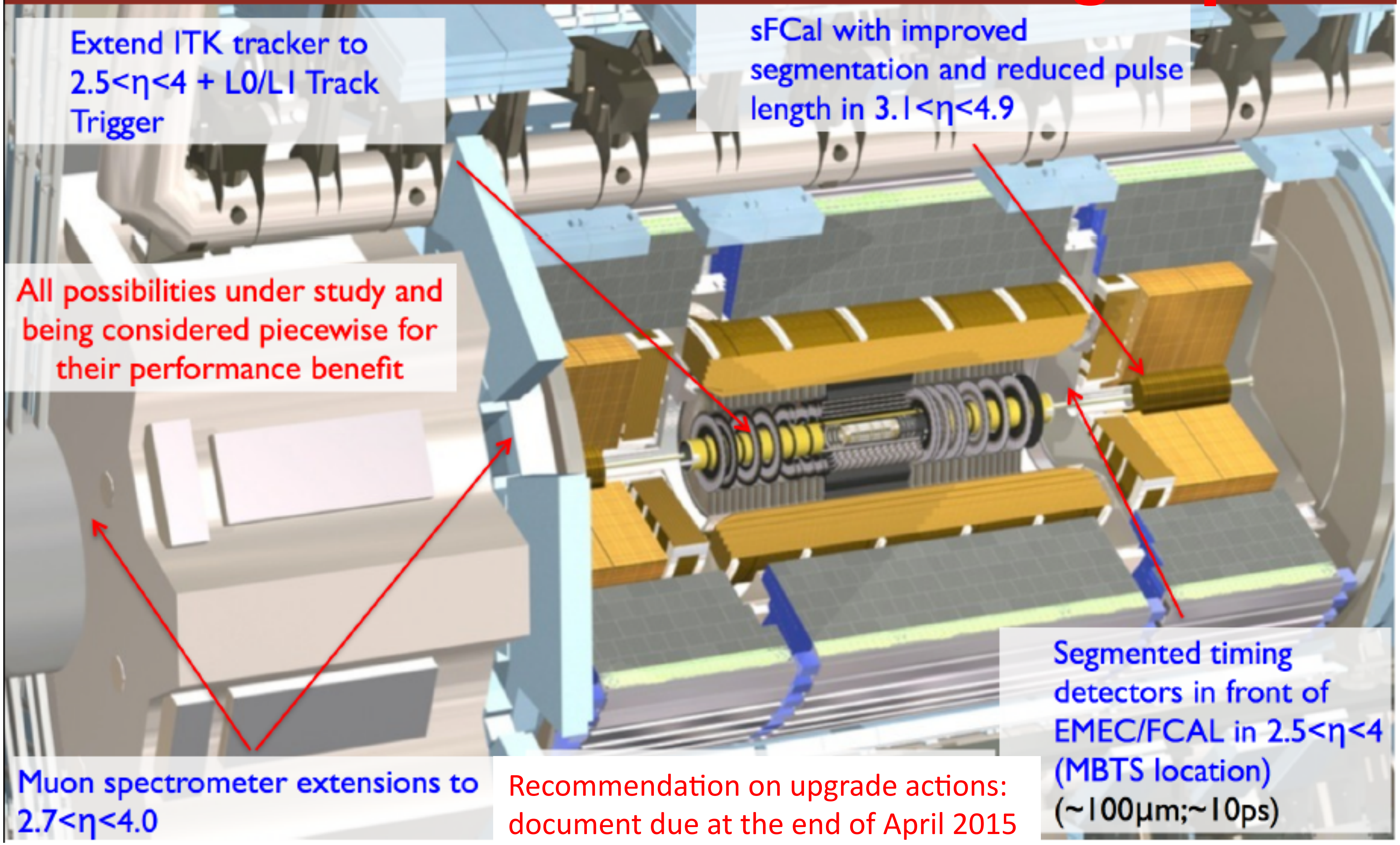
Conclusions

- ATLAS had very fruitful Run 1, resulted in the Higgs boson discovery, measurements of some of its properties, and wide searched for new physics
- After the HL LHC upgrade and the matching ATLAS upgrade, the ATLAS detector will collect up to 3000 fb^{-1} of data at higher CM energy, 14 TeV
- High luminosity upgrades will significantly increase achievable parameter measurement precision and enhance the BSM reach
- It will provide the HEP community an opportunity to shed light on the fundamental questions about Dark Matter candidates, hierarchy, and to significantly expand searches for new physics scenarios

Backup

Extension of ATLAS to large η



Recommendation on upgrade actions: document due at the end of April 2015

Higgs signal strengths

- Signal strength $\mu = \sigma x BR / (\sigma x BR)_{SM}$
- Separation by production modes
  - Important for coupling measurements
- Projection assumptions:
  - 300/fb: μ=60, 3000/fb: μ=140
  - Used dedicated 14 TeV samples
- Systematics:
  - Same as Run 1
  - Large impact from theory uncertainties (shown by dashed areas), like QCD scale, PDFs