HL-LHC Data-taking Strategies

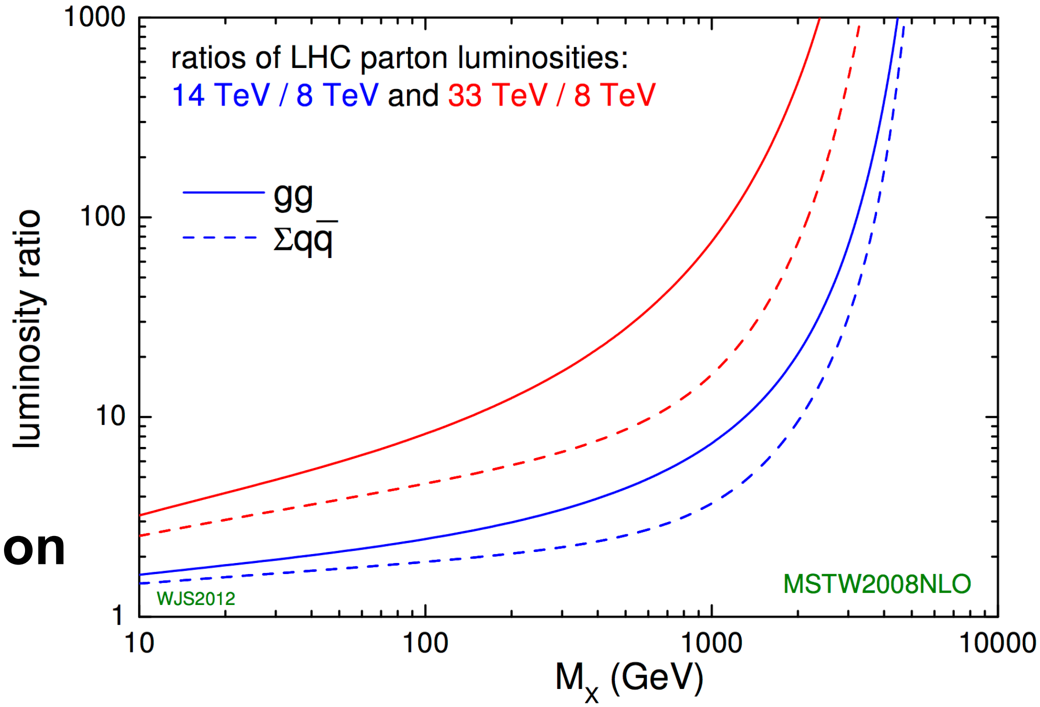
Yuri Gershtein
Graham Kribs
Stéphane Willocq

Preparing for the High-Luminosity Run of the LHC
Perimeter Institute
8-9 June 2015

Further discoveries ahead?

- **LHC Runs 2+3 with 300 fb^{-1} at $\sqrt{s}$ = 14 TeV**
  - **Dramatic increase in sensitivity in multi-TeV region relative to Run 1 at $\sqrt{s}$ = 8 TeV**

Cross section 14 TeV / 8 TeV	gg	$\Sigma q\bar{q}$
M_X = 2 TeV	~20	~10
M_X = 3 TeV	~70	~30
M_X = 4 TeV	~400	~160

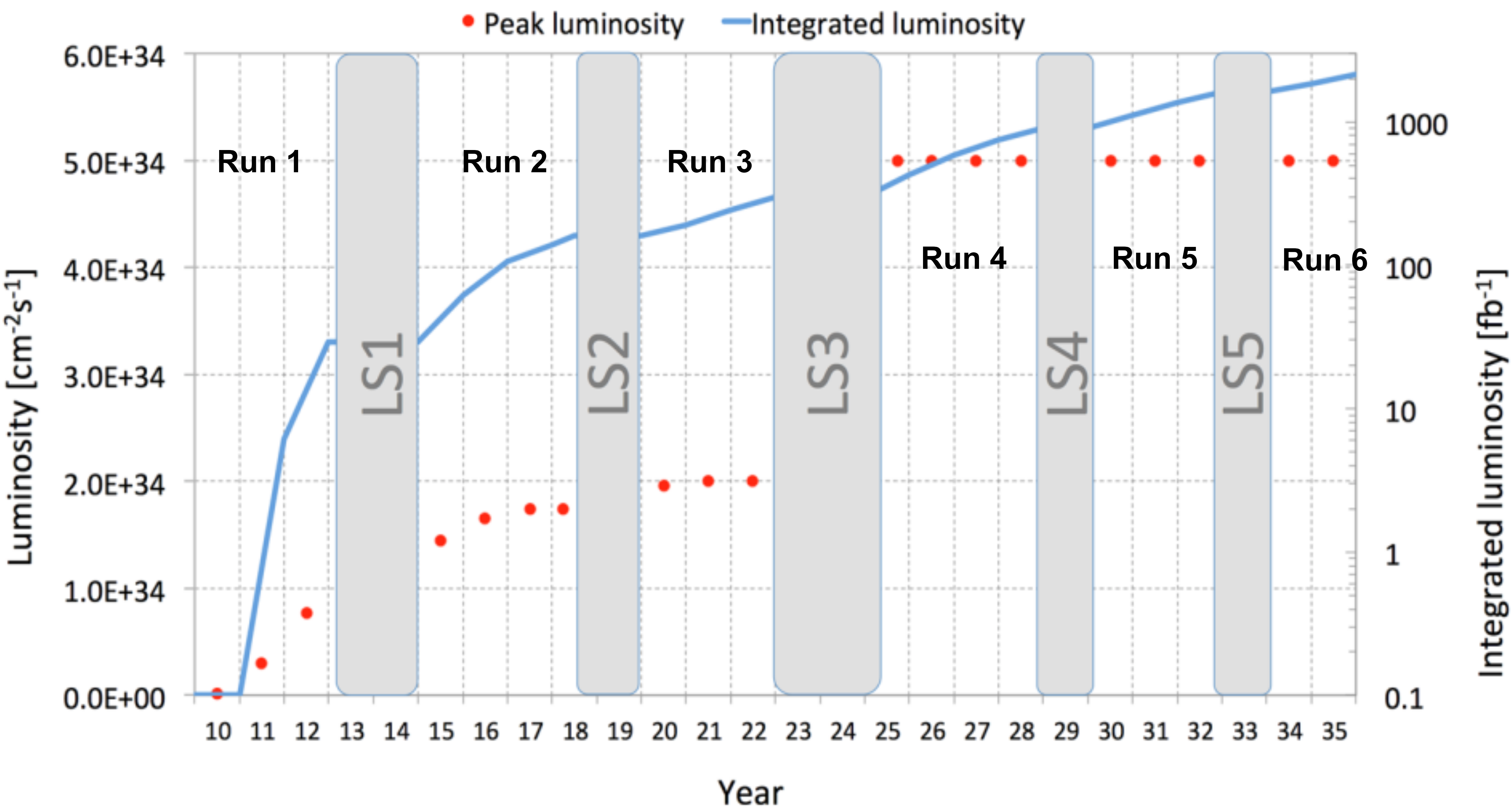


  - **Discovery reach in multi-TeV region benefits the most**

- **HL-LHC with 3000 fb^{-1} at $\sqrt{s}$ = 14 TeV**
  - **x10 luminosity increase to benefit searches for new physics with lower production cross section**
  - **What discoveries are possible only at HL-LHC?**

Future LHC Running

- Expect peak lumi = 5×10^{34} cm^{-2} s^{-1} in 2025 and beyond
  → integrate ~250-300 fb^{-1} / year with HL-LHC
  [note: machine being designed to go up to 7.5×10^{34} cm^{-2} s^{-1}]



Mike Lamont @ Rencontres du Vietnam

HL-LHC Science Case

- Science case based on 3000 fb^{-1} delivered by HL-LHC and "traditional" motivation/arguments
- Precision studies
  - Higgs properties, incl. rare decays (μμ and Zγ) and self coupling?
    → coupling improvements by factor of ~2-3
  - Top properties (couplings, FCNC, rare decays)
  - W and top mass
- BSM searches
  - Extended scalar sector, dark matter, new particles, etc.
  - Extend mass reach of heavy particle searches by ~20%
  - Extend mass reach of weakly-produced new particles by factor up to ~2

HL-LHC Science Case

- **HL-LHC program: a significant challenge for the Standard Model**

Battle of Waterloo

18 June 1815

HL-LHC Scenarios

1. **What if new physics discovered in Runs 2 or 3?**

2. **What if hints of new physics appear at the end of Run 3 or early in Run 4 @ HL-LHC?**

3. **What if NO hints of new physics appear after 1 ab^{-1} @ HL-LHC (or after 300 fb^{-1} in Runs 2+3)?**

→ **Criterion for "hints of new physics"?**

- **At least 1 analysis with 3 σ deviation from SM?**
- **At least 2 such analyses? Same analysis in each ATLAS & CMS?**
- **Higher significance threshold?**

HL-LHC Scenarios

1. **What if new physics discovered in Runs 2 or 3?**
   a. Enhance searches with signatures similar and related to those where new physics appeared
   b. Revisit trigger menu to address potential interpretations of evidence
   c. Modify upgrade detector designs to enhance sensitivity
2. **What if hints of new physics appear at the end of Run 3 or early in Run 4 @ HL-LHC?**
   a. Same as above?
   b. Same as above?
   c. Still time to modify upgrade detectors?
3. **What if NO hint of new physics appears after 1 ab^{-1} @ HL-LHC (or after 300 fb^{-1} in Runs 2+3)?**
   - Focus on precision measurements?
   - Attack less conventional signatures more aggressively?
   - Both impact trigger menu

HL-LHC Scenarios

3. **What if NO hint of new physics appears after 1 ab^{-1} @ HL-LHC (or after 300 fb^{-1} in Runs 2+3)?**
   a. **Precision, precision, precision (Higgs, Electroweak and QCD measmts)**
   b. **Keep same LHC parameters, but open up 1/2 of the HLT rate to triggers for "crazy stuff"**
      → What kind of crazy stuff?
      i. **Hard-to-reconstruct processing**
      ii. **Trigger-level analysis?**
      iii. **Many low-pT particles / compressed scenarios?**
      iv. **What else?**
   c. **Fill a few of the bunches with small number of protons to get some collisions with low lumi. - with tunable fraction of high to low lumi.**
      → What kind of physics benefits from low PU?
      i. **Some crazy diffractive physics?**
      ii. **With the scattered proton detectors in roman pots?**
      iii. **Something with hidden glueballs / soft photon radiation?**
   d. **Add new detectors to the existing ones?**
      e.g. in the spirit of http://arxiv.org/abs/1410.6816 ?

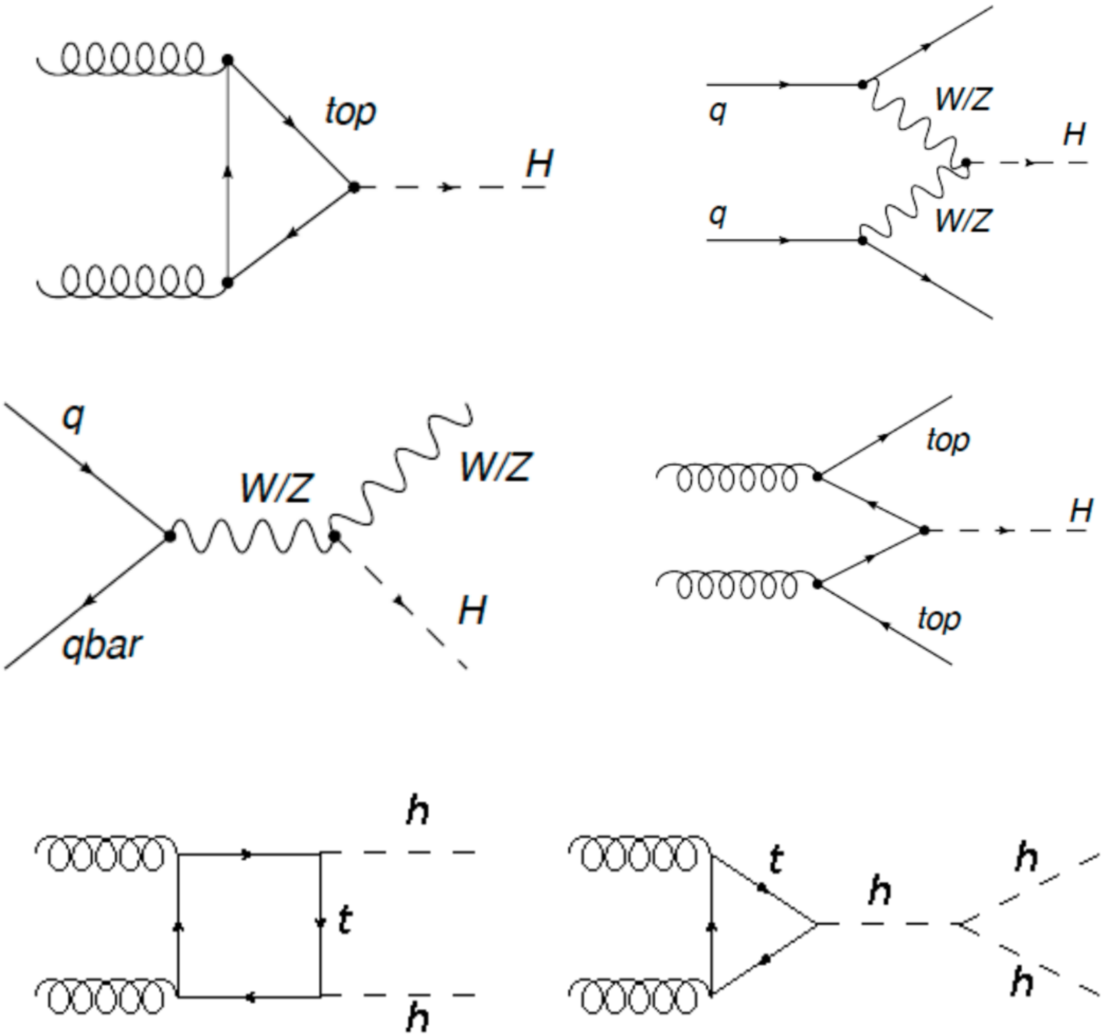
Extras: Higgs and BSM prospects from ECFA HL-LHC workshop 21-23 Oct 2014

https://indico.cern.ch/event/315626/other-view?view=standard

Aram Apyan

Higgs factory: HL-LHC

	Higgs bosons at √s=14TeV
HL-LHC, 3000fb^{-1}	170M
VBF (all decays)	13M
ttH (all decays)	1.8M
H->Zγ	230k
H->μμ	37k
HH (all)	121k



Coupling fit I

- New: VH->bb included in ATLAS, updates for H->Zγ, VH/ttH->γγ (*)
- No BSM Higgs decay modes assumed
- Comparable numbers for κ_W,κ_Z, κ_t, and κ_γ between the experiments
- Couplings can be determined with 2-10% precision at 3000fb^{-1} for CMS Scenario 2

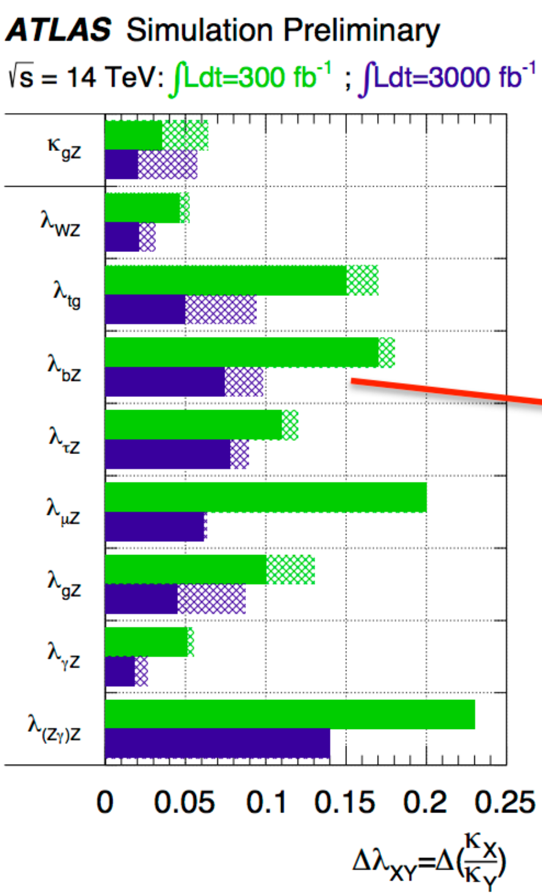
		κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	κ_μ
300fb^{-1}	ATLAS	[9,9]	[9,9]	[8,8]	[11,14]	[22,23]	[20,22]	[13,14]	[24,24]	[21,21]
300fb^{-1}	CMS	[5,7]	[4,6]	[4,6]	[6,8]	[10,13]	[14,15]	[6,8]	[41,41]	[23,23]
3000fb^{-1}	ATLAS	[4,5]	[4,5]	[4,4]	[5,9]	[10,12]	[8,11]	[9,10]	[14,14]	[7,8]
3000fb^{-1}	CMS	[2,5]	[2,5]	[2,4]	[3,5]	[4,7]	[7,10]	[2,5]	[10,12]	[8,8]

- ATLAS: [no theory uncert., full theory uncert.]
- CMS: [Scenario 2, Scenario1]

(*)
ATL-PHYS-PUB-2014-011
ATL-PHYS-PUB-2014-006
ATL-PHYS-PUB-2014-012
ATL-PHYS-PUB-2014-016

Coupling fit II

- Remove the assumption on the total width
  - Only ratios of the coupling scale factors can be determined at LHC
  - Use given process as a reference



CMS[Scenario2,Scenario1]

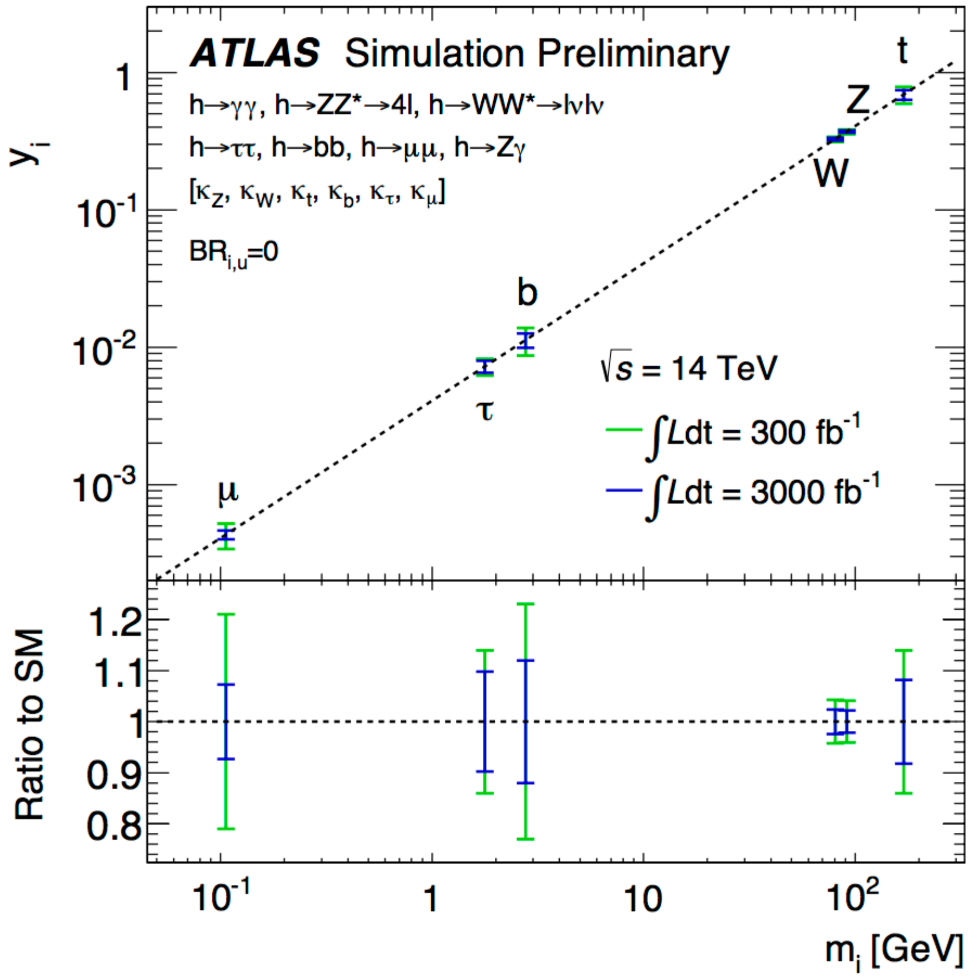
L (fb^{-1})	$\kappa_g \cdot \kappa_Z / \kappa_H$	κ_γ/κ_Z	κ_W/κ_Z	κ_b/κ_Z	κ_τ/κ_Z	κ_Z/κ_g	κ_t/κ_g	κ_μ/κ_Z	$\kappa_{Z\gamma}/\kappa_Z$
300	[4,6]	[5,8]	[4,7]	[8,11]	[6,9]	[6,9]	[13,14]	[22,23]	[40,42]
3000	[2,5]	[2,5]	[2,3]	[3,5]	[2,4]	[3,5]	[6,8]	[7,8]	[12,12]

5.7	2.6	3.1	9.8	8.9	8.7	9.4	6.3	14

- 2-3% accuracy on few coupling constants at HL-LHC
  - Reduced theoretical uncertainties needed

Mass dependence of couplings

- Higgs boson couplings versus the SM particle masses
- Define 'reduced' coupling parameters



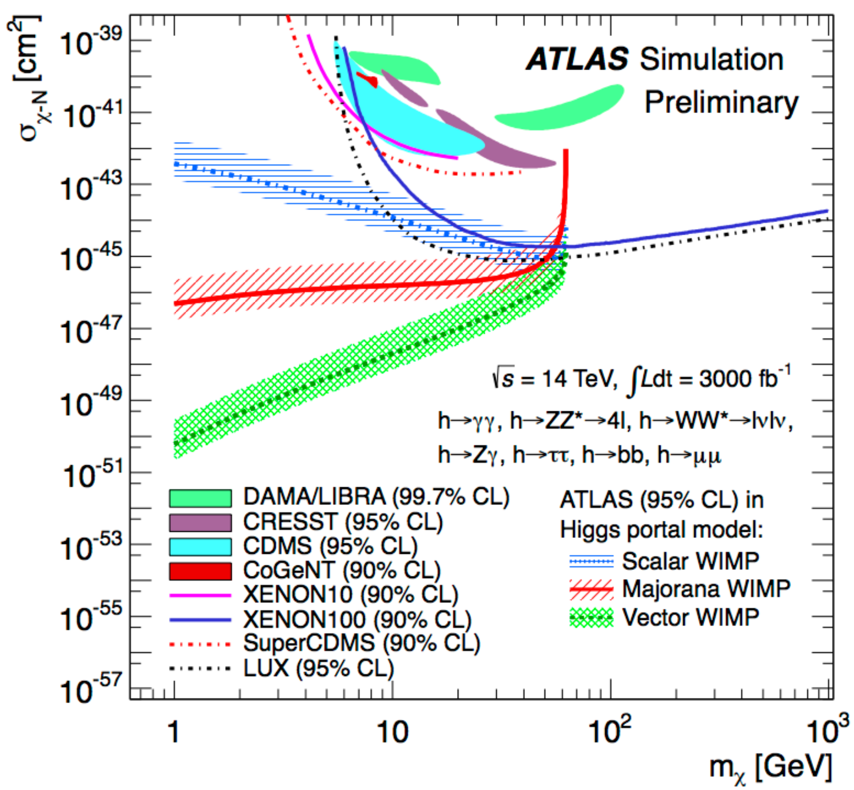
$$y_{V,i} = \sqrt{\kappa_{V,i}\frac{g_{V,i}}{2v}} = \sqrt{\kappa_{V,i}}\frac{m_{V,i}}{v}$$

$$y_{F,i} = \kappa_{F,i}\frac{g_{F,i}}{\sqrt{2}} = \kappa_{F,i}\frac{m_{F,i}}{v}$$

[redacted]

Higgs portal to Dark Matter

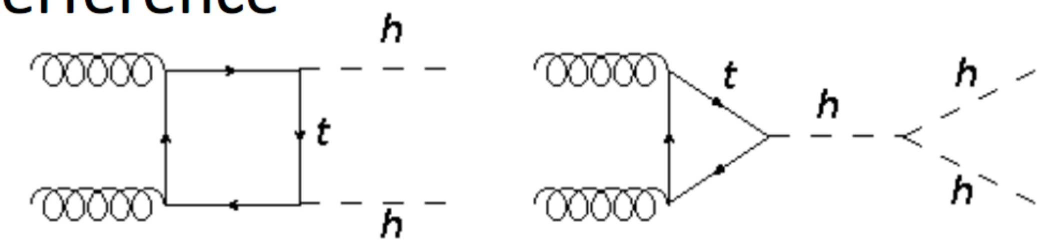
- BR of Higgs decays to invisible final states
  - ATLAS: $BR_{inv} < 0.13$ (0.09 w/out theory uncertainties) at $3000 fb^{-1}$
  - CMS: $BR_{inv} < 0.11$ (0.07 in Scenario 2) at $3000 fb^{-1}$
- The coupling of WIMP to SM Higgs taken as the free parameter
- Translate limit on BR to the coupling of Higgs to WIMP



ATL-PHYS-PUB-2014-017

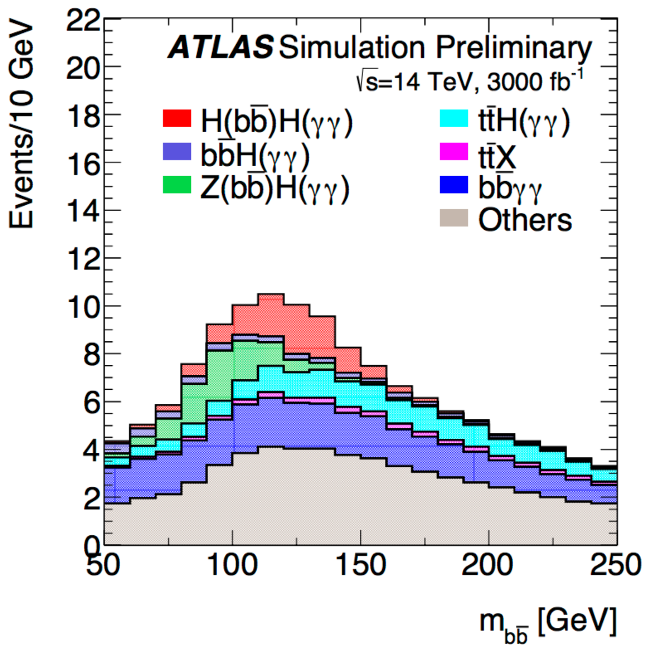
Di-Higgs Production

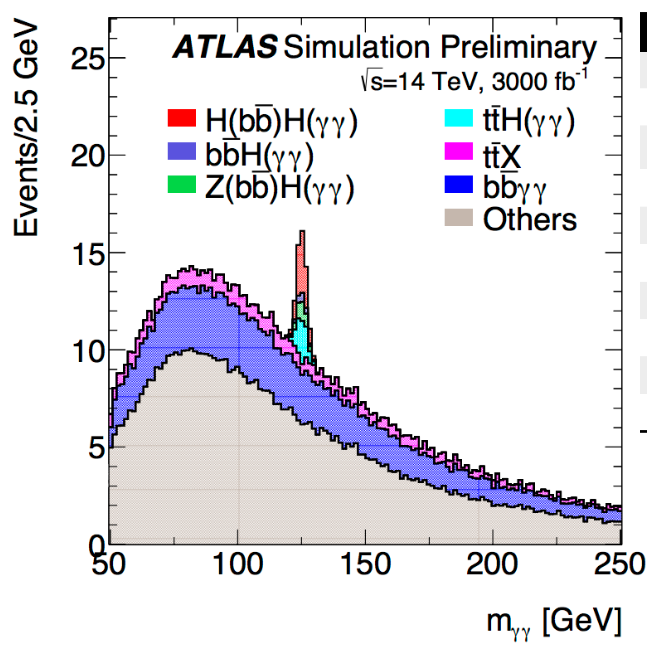
- One of the exciting prospects of HL-LHC
  - Cross section at √s=14 TeV is 40.2 fb [NNLO]
  - Challenging measurement
    - New preliminary results from ATLAS and CMS
- Destructive interference



- Final states shown today
  - bbγγ [320 expected events at HL-LHC, 3000fb^{-1}]
    - But relatively clean signature
  - bbWW [30000 expected events at HL-LHC, 3000fb^{-1}]
    - But large backgrounds
- bbbb and bbττ final states under consideration

Higgs Projections: di-Higgs



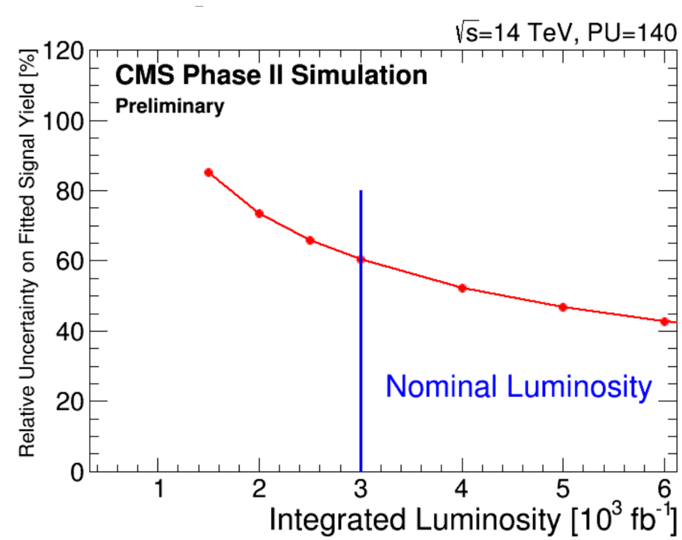


process	Expected events in 3000 fb^{-1}
SM HH→bbγγ	8.4± 0.1
bbγγ	9.7 ± 1.5
ccγγ, bbγj, bbjj, jjγγ	24.1 ± 2.2
top background	3.4 ± 2.2
ttH(γγ)	6.1 ± 0.5
Z(bb)H(γγ)	2.7 ± 0.1
bbH(γγ)	1.2 ± 0.1
Total background	47.1 ± 3.5
S/√B (barrel+endcap)	1.2
S/√B (split barrel and endcap)	1.3

CMS results

Process / Selection Stage	HH	ZH	$t\bar{t}H$	$b\bar{b}H$	$\gamma\gamma$+jets	γ+jets	jets	$t\bar{t}$
Object Selection & Fit Mass Window	22.8	29.6	178	6.3	2891	1616	292	113
Kinematic Selection	14.6	14.6	3.3	2.0	128	96.9	20	20
Mass Windows	9.9	3.3	1.5	0.8	8.5	6.3	1.1	1.1

Table 3: The expected event yields of the signal and background processes for 3000 fb^{-1} of integrated luminosity are shown at various stages of the cut-based selection for the both photons in the barrel region. Mass window cuts are 120 GeV to 130 GeV for $M_{\gamma\gamma}$ and 105 GeV to 145 GeV for M_{bb}. A large fit mass window, 100 GeV to 150 GeV for $M_{\gamma\gamma}$ and 70 GeV to 200 GeV for M_{bb}, is used for the likelihood fit analysis. The statistical uncertainties on the yields are of the order of percent or smaller.

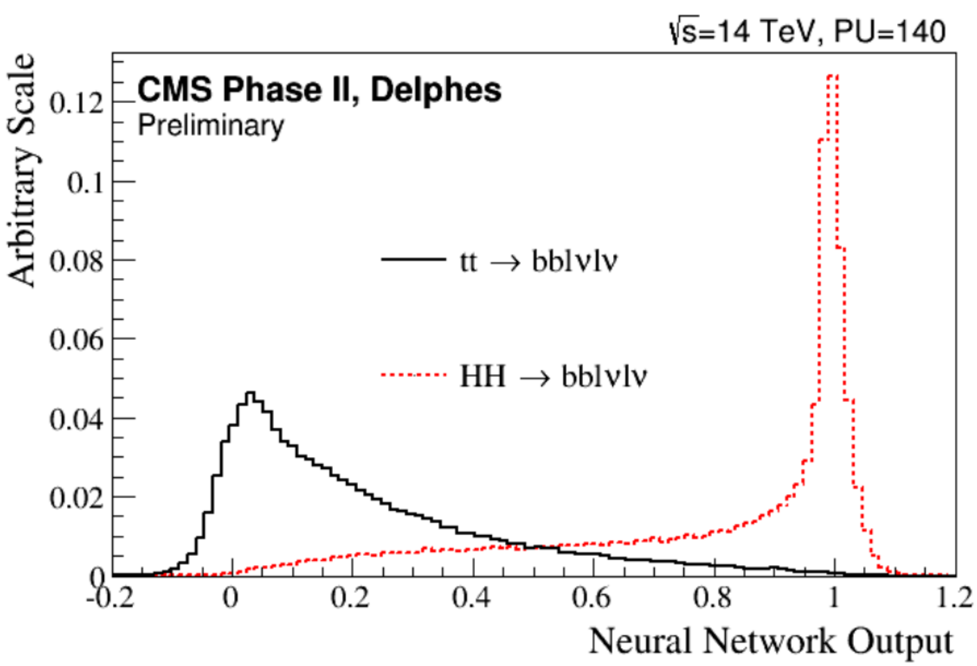


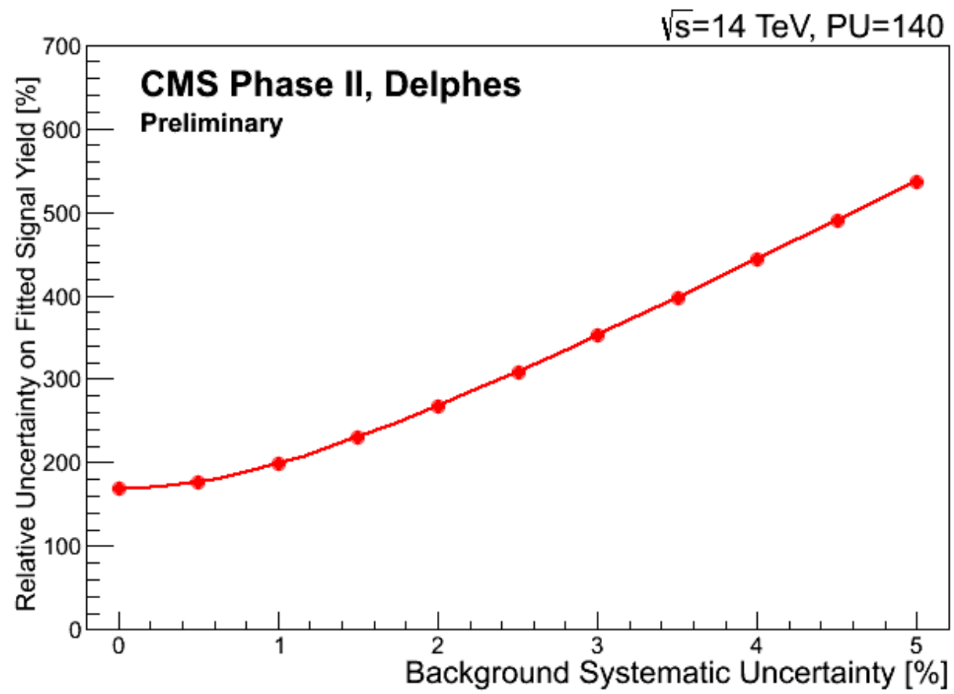
Higgs Projections: di-Higgs

HH->bbWW analysis

Search for HH → bbWW → bblvlv

- Based on Delphes fast simulation tuned to CMS Phase II detector
- Considering only the main tt background
- The rest of the SM processes are negligible
- Neural Network discriminant to suppress tt
  - Signal region: Neural Network output > 0.97





Scenarios

Stephane Willocq

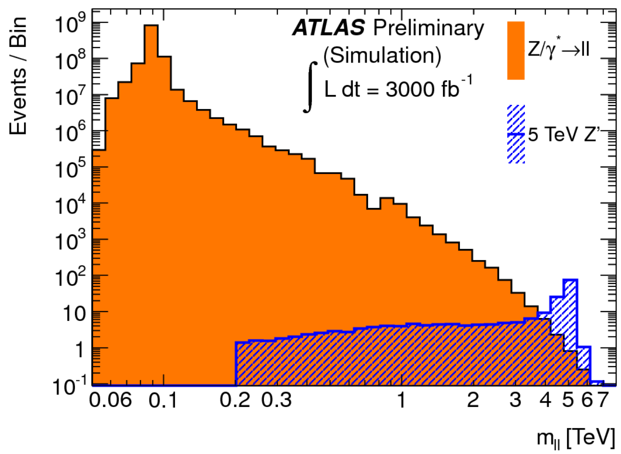
- **Scenarios**
  - **LHC Run 3 after Phase 1 upgrade: 300 fb^{-1} at $\sqrt{s}$ = 14 TeV, μ = 50**
  - **HL-LHC after Phase 2 upgrade: 3000 fb^{-1} at $\sqrt{s}$ = 14 TeV, μ = 140**
- **MC simulation**
  - **Effect of pile-up taken into account**
  - **Parameterization of upgraded ATLAS / CMS detector response**
    - **Resolution and reconstruction efficiency for e, mu, tau, photon, (b-tag) jets**
    - **Rates for light- and c-jets to pass b-tag requirements**
    - **Parameterization depends on pileup**
- **Systematic uncertainties**
  - **Generally based on completed 8 TeV data analyses**
  - **Improvement from higher luminosity in case of statistical limitation (CR)**
- **Analysis techniques**
  - **Simple approaches used → sensitivity can be further improved**

Dilepton Resonances

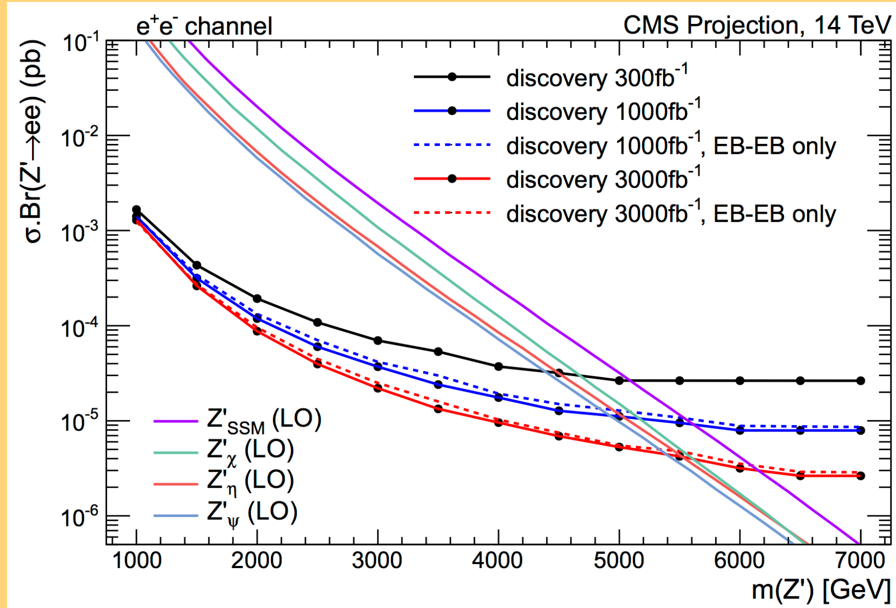
- **Many extensions of the SM predict new resonances**
  - **Heavy gauge bosons W' and Z'**
  - **KK excitations of vector bosons**
- **Clean decay channels**

  $Z' \rightarrow e^+e^-$ or $\mu^+\mu^-$

ATL-PHYS-PUB-2013-003



arXiv:1307.7135



Discovery up to 6.2 TeV (for SSM Z')

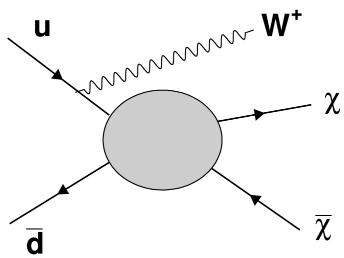
Z' mass lower limit @ 95% CL in SSM [ATLAS]	Run 1 @ 8 TeV (20 fb^{-1})	Run 3 @ 14 TeV (300 fb^{-1})	HL-LHC @ 14 TeV (3000 fb^{-1})
Z' mass (ee)	Up to 2.79 TeV	Up to 6.5 TeV	Up to 7.8 TeV
Z' mass (μμ)	Up to 2.53 TeV	Up to 6.4 TeV	Up to 7.6 TeV

No systematic uncertainties included

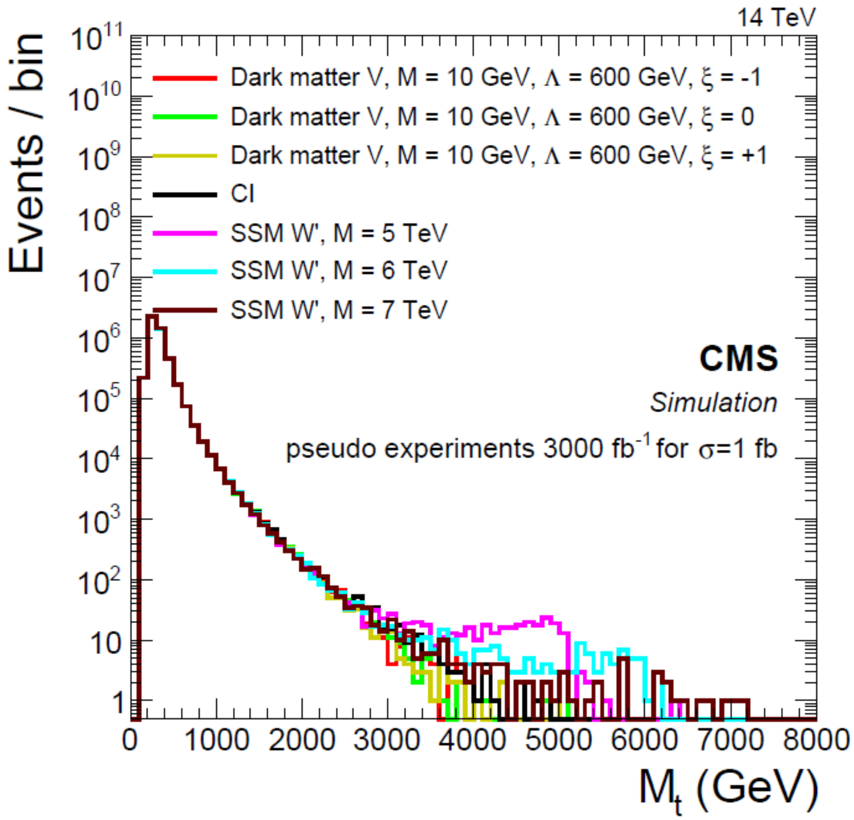
Non-resonant signatures

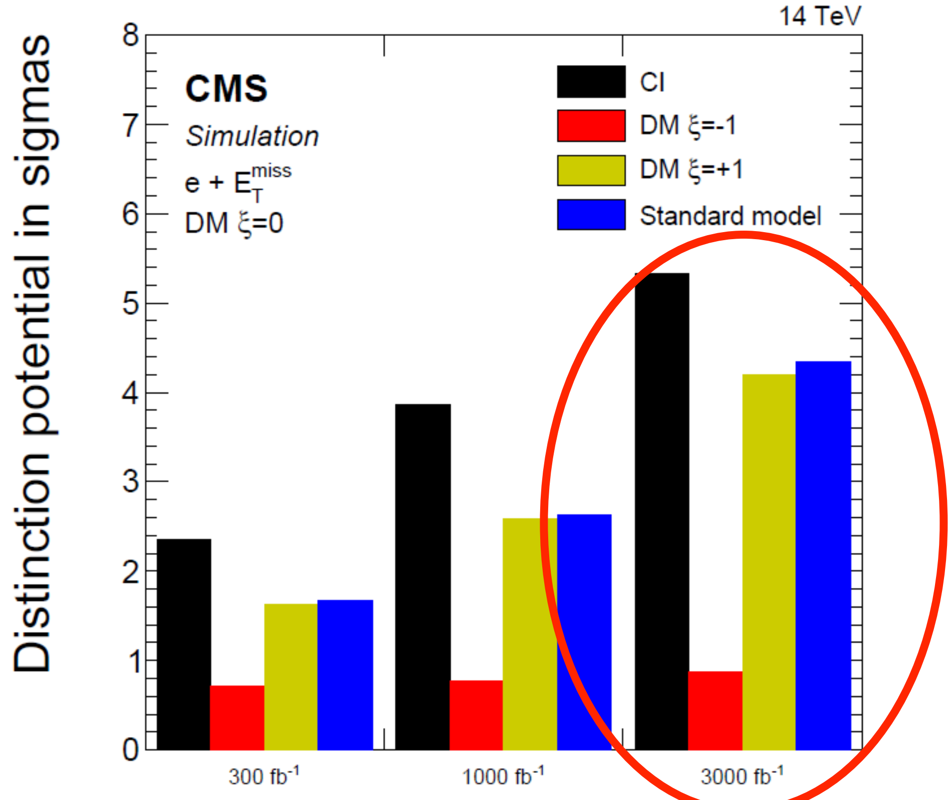
NEW

- **Models**
  - **Contact interactions in charged-current process q q → l ν**
  - **Dark matter in p p → W DM DM and W → l ν ("mono-lepton")**



- **Shape discrimination in transverse mass distribution**
  - **Compare SM W → l ν with 1 fb signal from CI or dark matter**
  - **Significant separation from SM shape only achieved at HL-LHC**



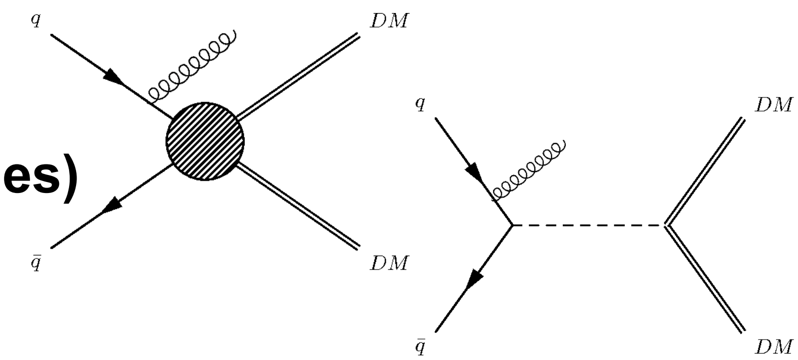


NEW

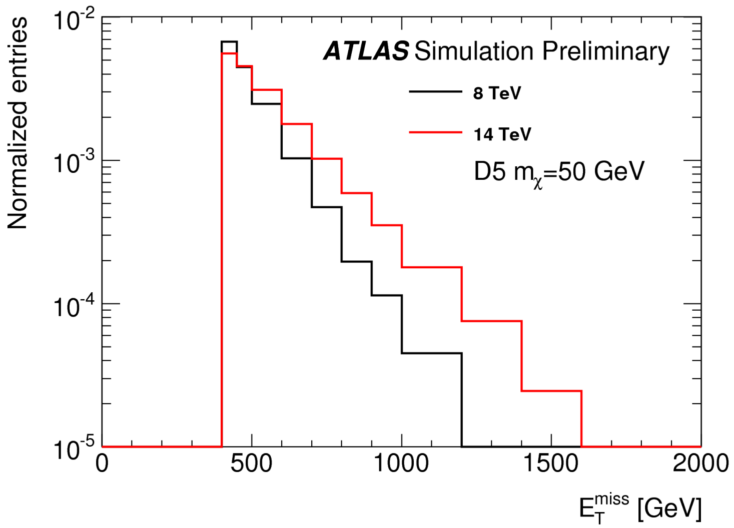
Dark matter

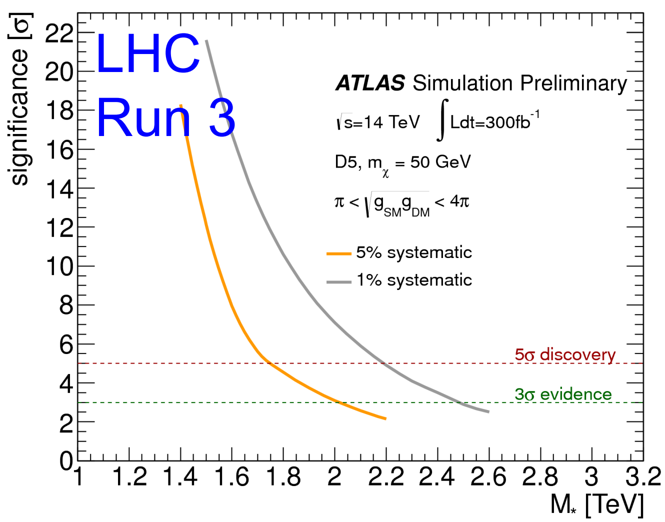
ATL-PHYS-PUB-2014-007

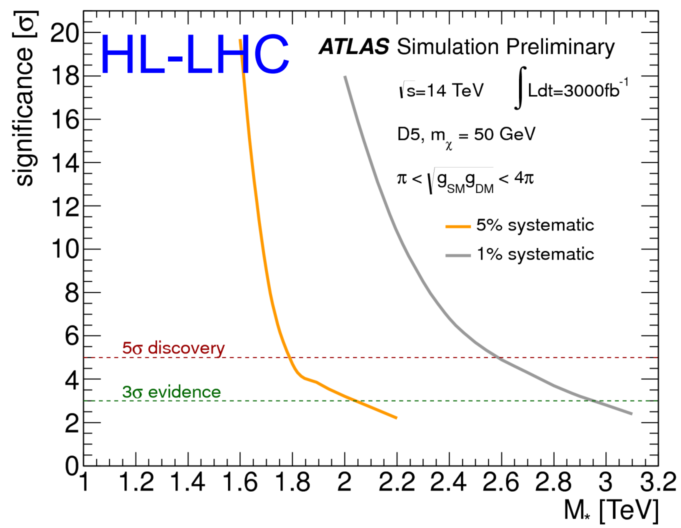
- **Models**
  - **Effective Field Theory (contact interaction btw SM and DM particles)**
  - **Simplified models with explicit mediator**



- **Signature ("mono-X")**
  - **Initial state radiation or direct coupling via mediator particle**
  - **Mono-jet: high-p_T leading jet (≤ 2 jets), large E_T^{miss}, e/μ veto**



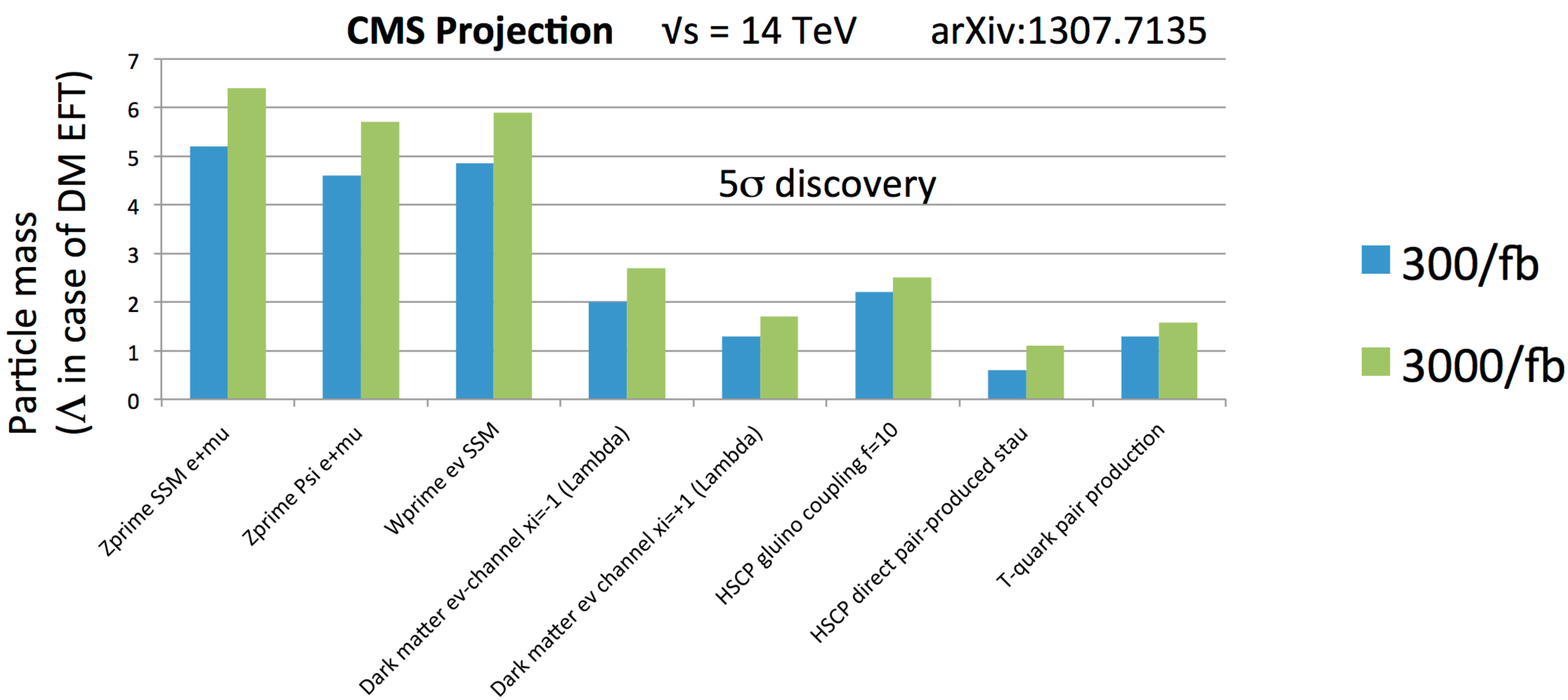




- **5σ discovery up to suppression scale M* of 2.2 (2.6) TeV for 300 (3000) fb^{-1} (assuming 1% systematic uncertainty)**

Summary of Exotics Prospects

- **Sensitivity in multi-TeV range increases by ~20% with HL-LHC**

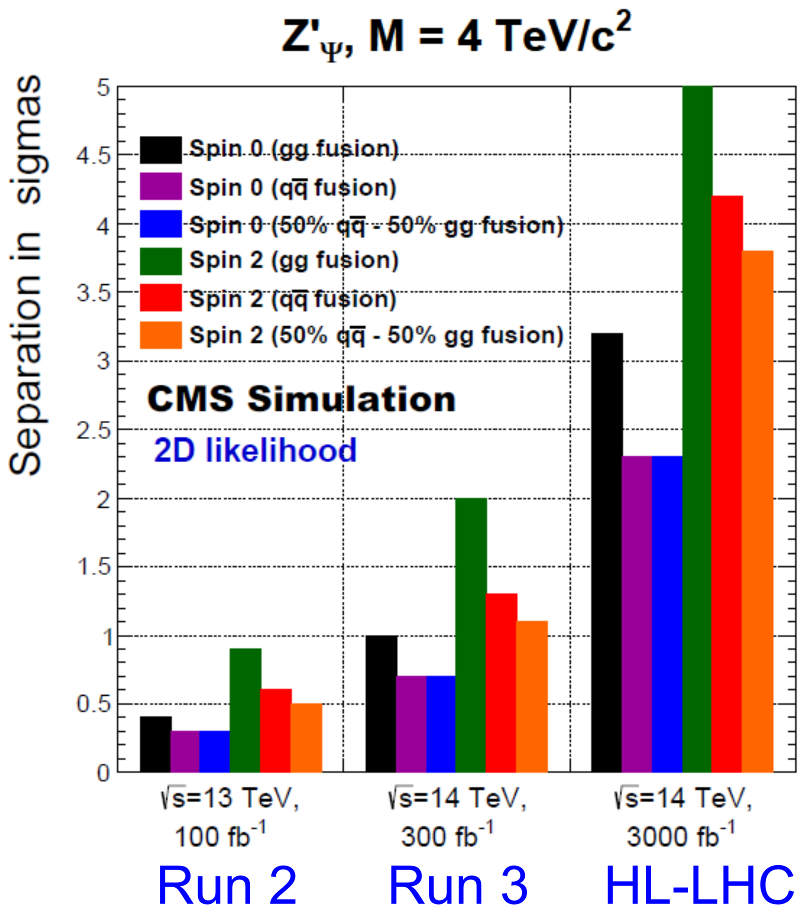


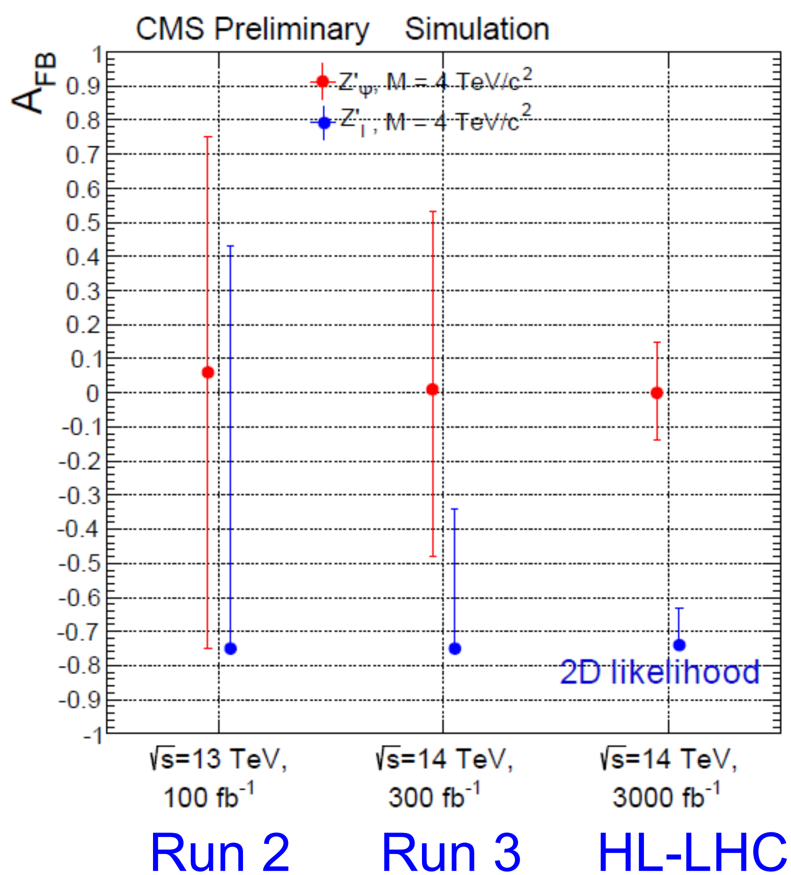
ATLAS Projection	**Z' → ee SSM 95% CL limit**	**g_{KK} → t t RS 95% CL limit**	**Dark matter M* 5σ discovery**
Run 3 @ 14 TeV ($300\ fb^{-1}$)	6.5 TeV	4.3 TeV	2.2 TeV
HL-LHC @ 14 TeV ($3000\ fb^{-1}$)	7.8 TeV	6.7 TeV	2.6 TeV

Model discrimination after discovery

NEW

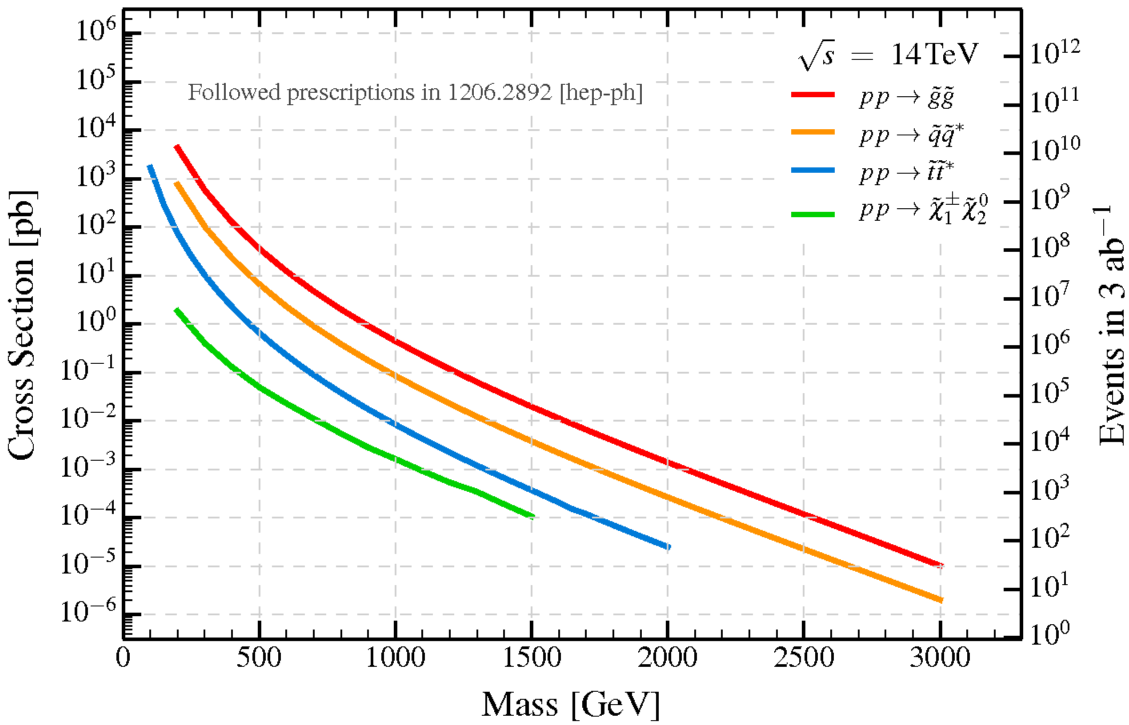
- **Ability to discriminate improves dramatically with HL-LHC**
  - **Separation between spin-1 (Z') or spin-2 (G_{KK}) interpretation and other interpretations ranges from ~2 to 5 σ**
  - **2D likelihood with dilepton angular and rapidity distributions or forward-backward asymmetry**



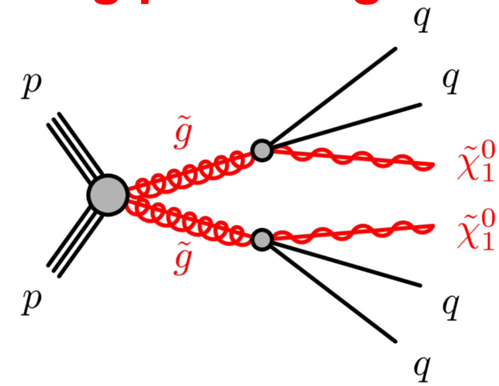


SUSY

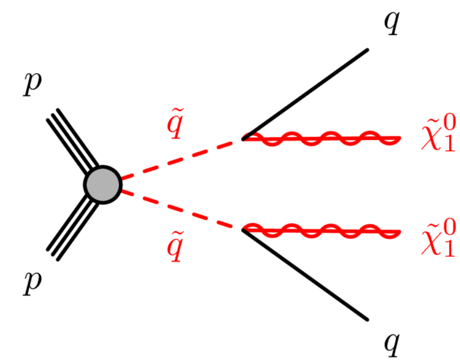
- **Motivated by naturalness, dark matter, …**



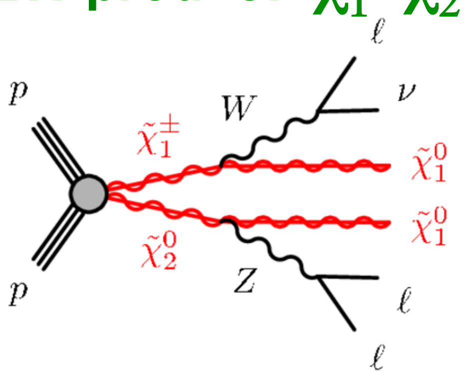
Strong prod. of gluinos



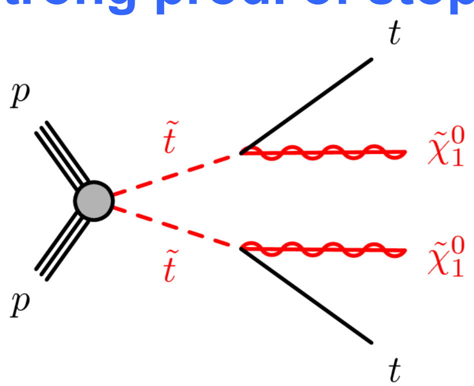
Strong prod. of squarks



EW prod. of $\chi_1^+\chi_2^0$



Strong prod. of stops

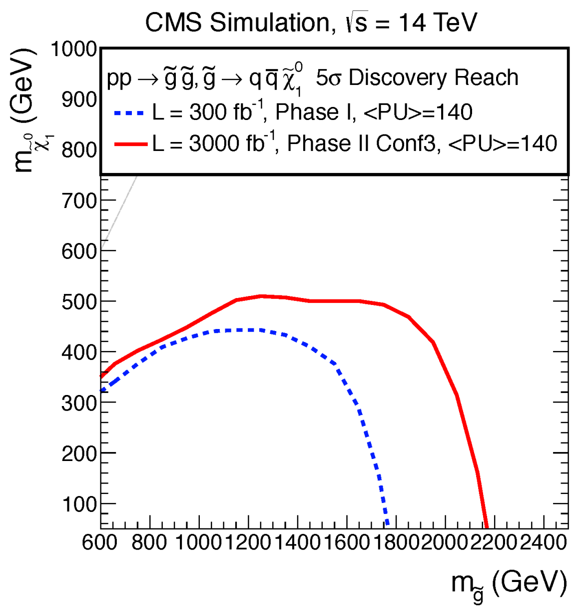


Gluinos not necessarily first to be discovered (many different mass spectra possible)

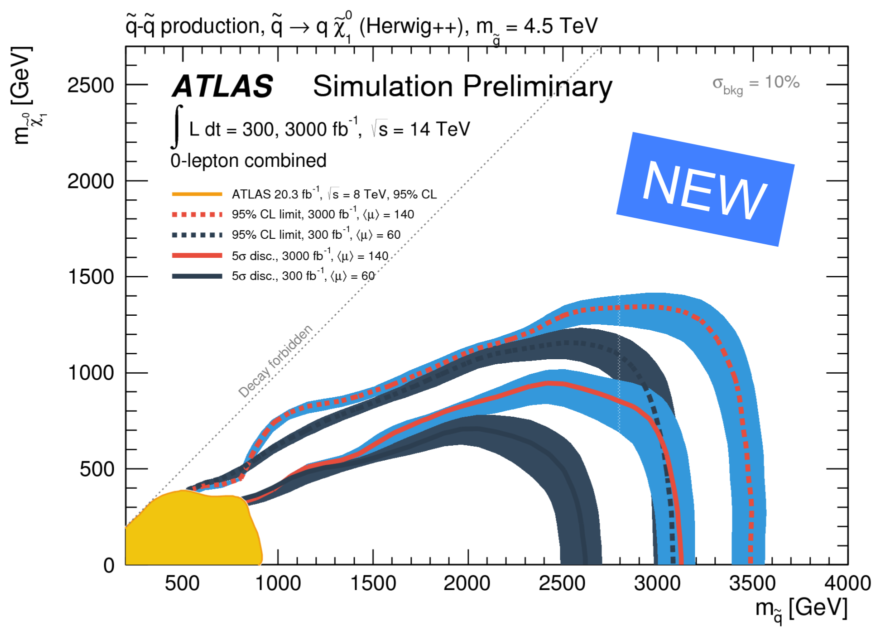
SUSY: Strong production of gluinos & squarks

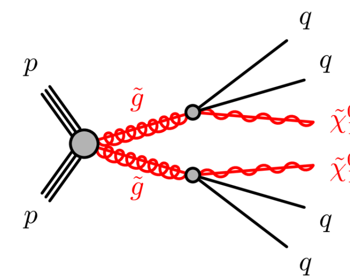
- **Largest cross section: ~1 fb at M = 2 TeV**
  - **0 lepton + 2-6 jets + E_T^{miss}**

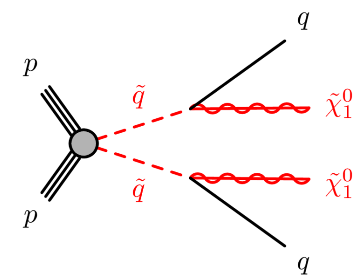
CMS PAS FTR-13-014



ATL-PHYS-PUB-2014-010





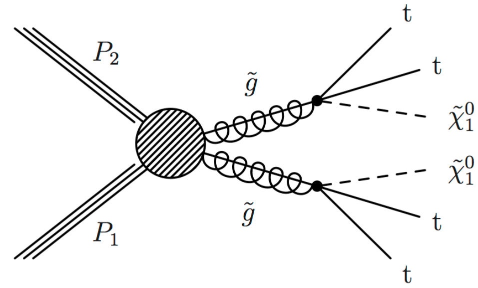


Interpretation in context of simplified model

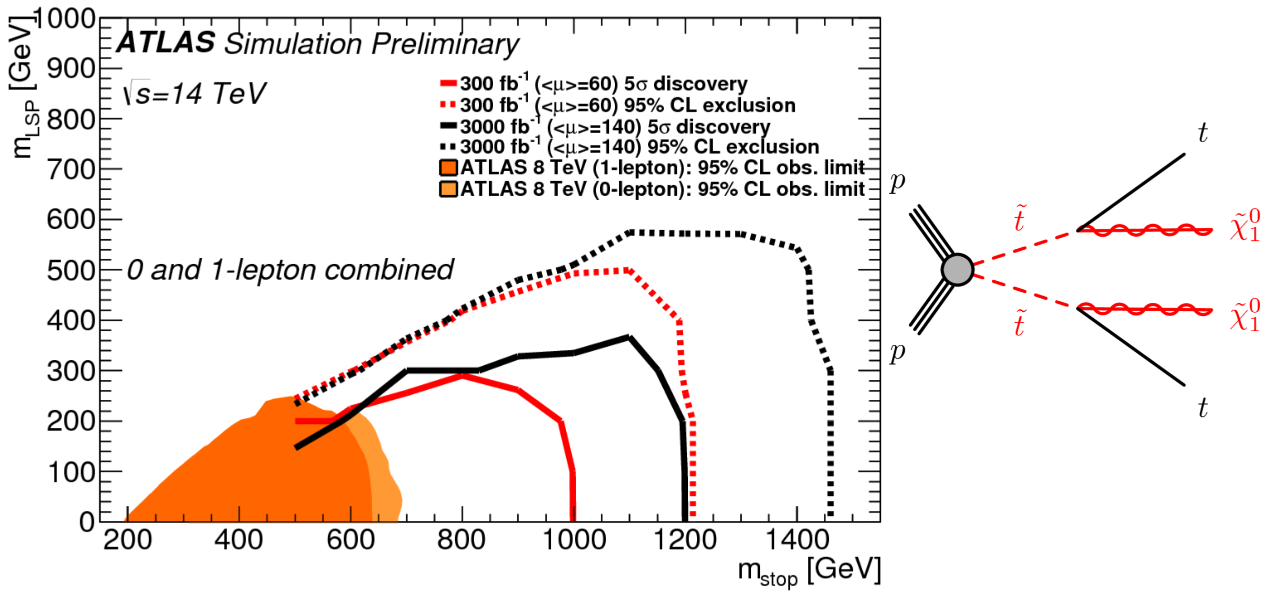
5σ discovery Simplified model	**Run 3 @ 14 TeV ($300\ fb^{-1}$)**	**HL-LHC @ 14 TeV ($3000\ fb^{-1}$)**
gluino mass [ATLAS]	Up to 2.0 TeV	Up to 2.4 TeV
gluino mass [CMS]	Up to 1.8 TeV	Up to 2.2 TeV
squark mass for m(gl) = 4.5 TeV [ATLAS]	Up to 2.6 TeV	Up to 3.1 TeV

SUSY: Strong production of top squarks

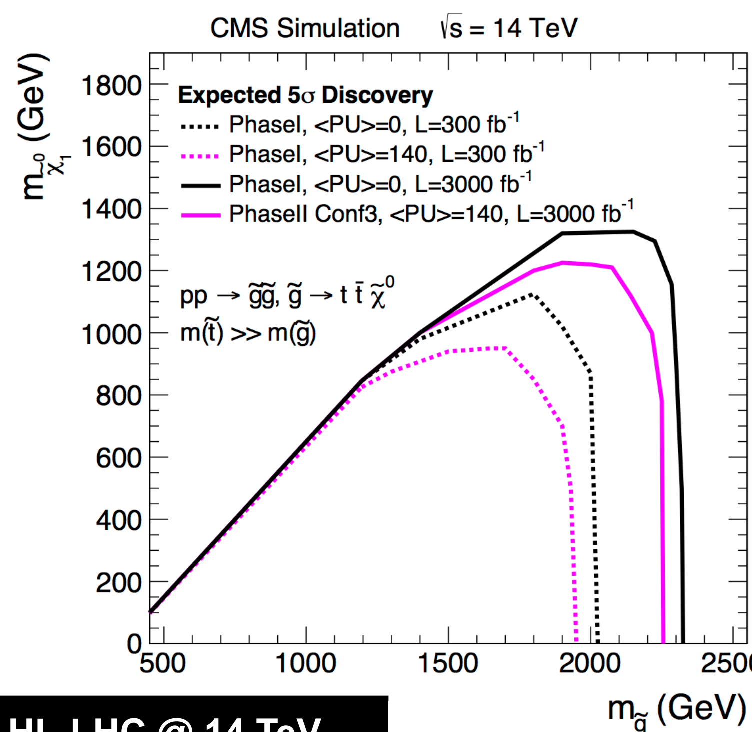
- **Naturalness: requires stop mass < ~1 TeV**
  - **ATLAS: 0/1 lepton + ≥ 4 jets + ≥ 1 b-tag + E_T^{miss}**
  - **CMS: 1 lepton + ≥ 6 jets + ≥ 1 b-tag + E_T^{miss}**



ATL-PHYS-PUB-2013-011



CMS PAS FTR-13-014



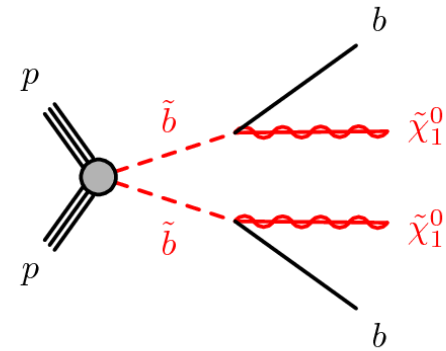
5σ discovery Simplified model	**Run 3 @ 14 TeV (300 fb⁻¹)**	**HL-LHC @ 14 TeV (3000 fb⁻¹)**
stop mass from direct production [ATLAS]	Up to 1.0 TeV	Up to 1.2 TeV
gluino mass with decay to stop [CMS]	Up to 1.9 TeV	Up to 2.2 TeV

NEW

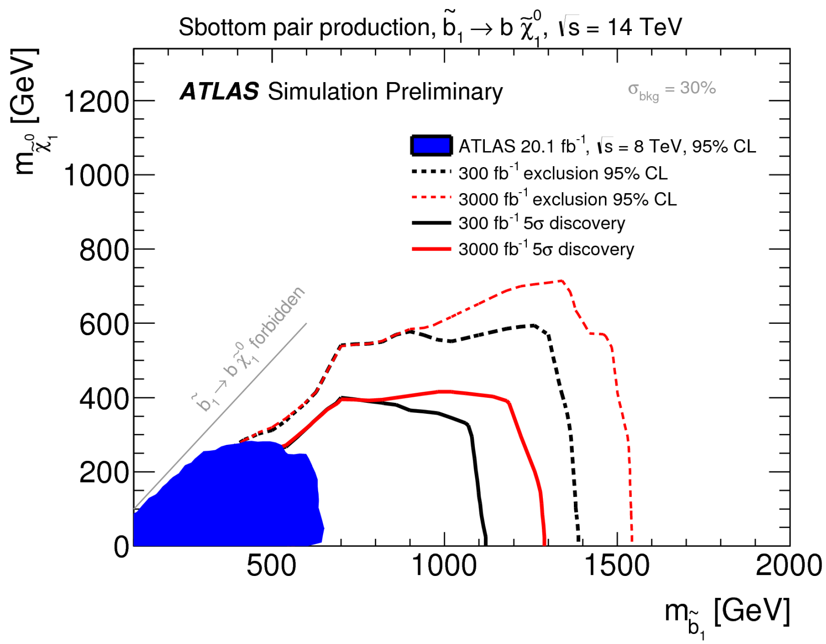
SUSY: Strong production of bottom squarks

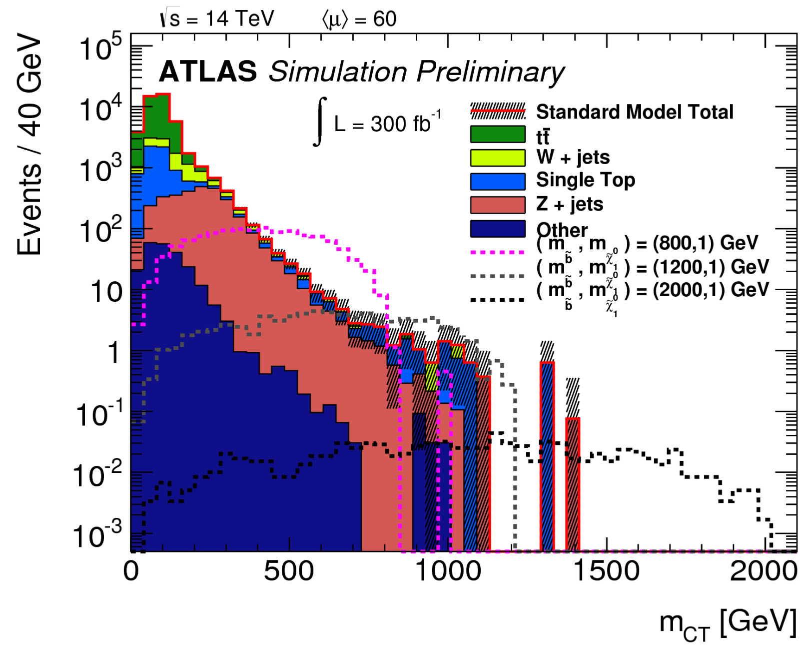
- **Naturalness motivation**
  - **ATLAS: 0 lepton + 2 b-tags + E_T^{miss}**
  - **Use contransverse mass m_{CT}**

$$m_{CT}^{max} = \frac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$$



ATL-PHYS-PUB-2014-010



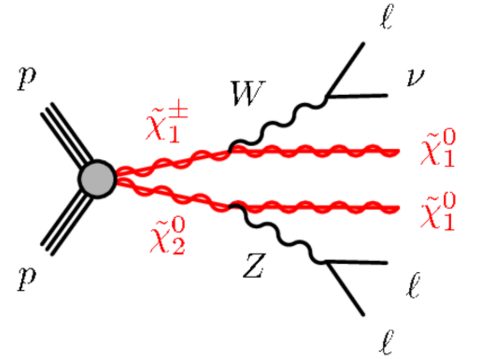


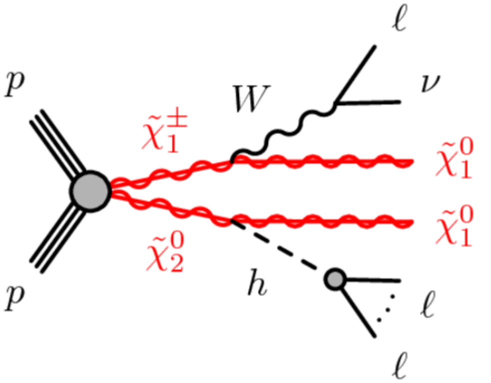
5σ discovery Simplified model	Run 3 @ 14 TeV (300 fb^{-1})	HL-LHC @ 14 TeV (3000 fb^{-1})
Sbottom mass from direct production [ATLAS]	Up to 1.1 TeV	Up to 1.3 TeV

NEW

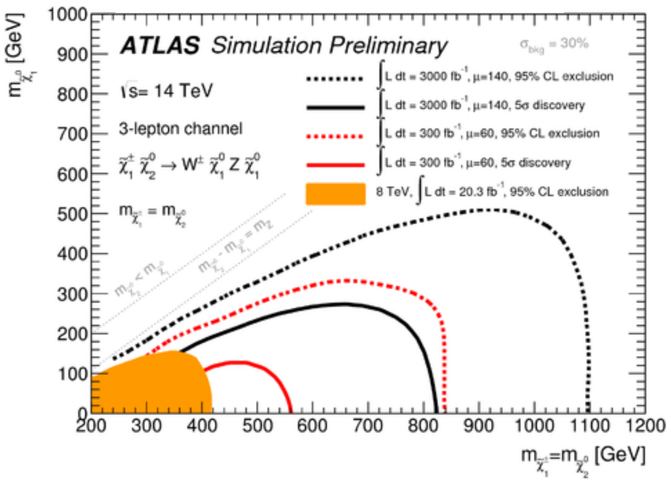
SUSY: Electroweak production of $\chi_1^+\chi_2^0$

- **EW prod. lower by 2 orders of magnitude but can dominate SUSY production if squarks and gluinos heavy**
  - WZ: 3 leptons + E_T^{miss}
  - WH: 3 leptons + E_T^{miss} [ATLAS]
    1 lepton + E_T^{miss} + 2 b-tags [CMS]

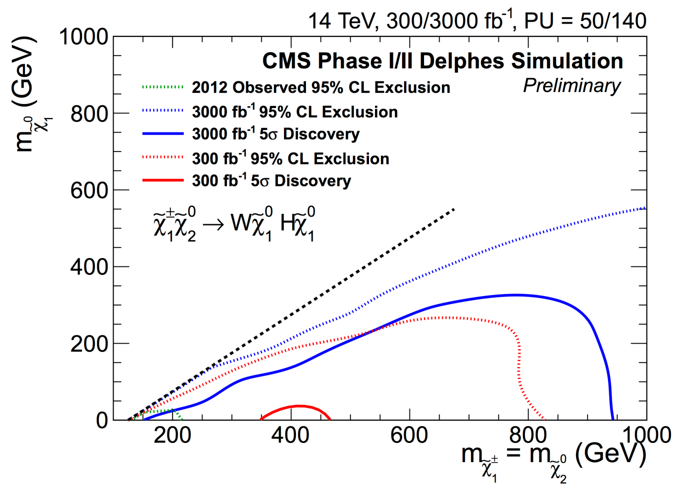




ATL-PHYS-PUB-2014-010



CMS PAS SUS-14-012



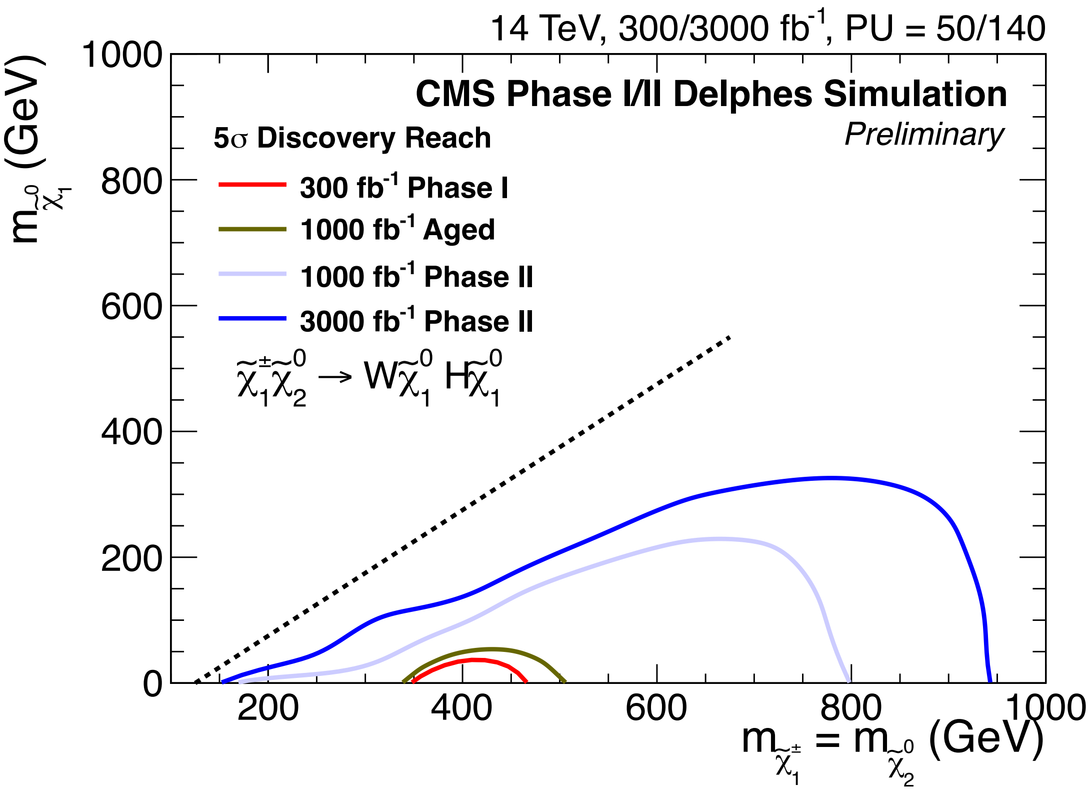
Chargino mass 5σ discovery Simplified model	Run 3 @ 14 TeV (300 fb^{-1})	HL-LHC @ 14 TeV (3000 fb^{-1})
WZ (3l analysis) [ATLAS]	Up to 560 GeV	Up to 820 GeV
WZ (3l analysis) [CMS]	Up to 600 GeV	Up to 900 GeV
WH (3l analysis) [ATLAS]	None	Up to 650 GeV
WH (bb analysis) [CMS]	350-460 GeV	Up to 950 GeV

Assume $m(\chi_1^+) = m(\chi_2^0)$

NEW

SUSY: Electroweak production of $\chi_1^+\chi_2^0$

- **Importance of Phase II detector upgrade** — CMS PAS SUS-14-012
  - **WH: 1 lepton + E_T^{miss} + 2 b-tags [CMS]**



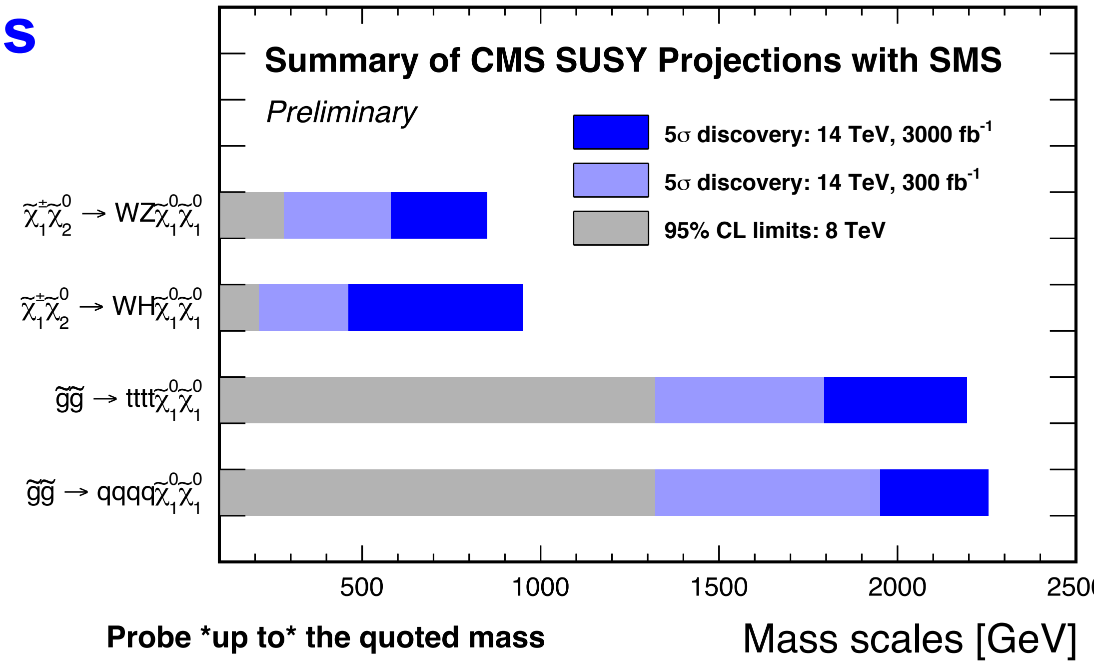
- **950 GeV discovery** reach with 3000 fb^{-1}, μ=140, and **upgraded detector**
- 450 GeV discovery reach with 300 fb^{-1}, μ=50, existing detector

- **Continued running with degraded detector increases the physics reach only marginally for this SUSY signature**

NEW

SUSY: Simplified models summary

- **Focus on production of a reduced set of sparticles**
  - **Assume decoupled spectrum**
  - **Decay BR generally assumed to be 100%**
- **Discovery potential increases by ~20% in terms of gluino, squark and stop masses**
- **More substantial gains for $\chi_1^+\chi_2^0$ EW production**
  - **At least 50% increase in mass reach**
    DOUBLES in case of WH final state



ATLAS projection	gluino mass	squark mass	stop mass	sbottom mass	χ_1^+ mass WZ mode	χ_1^+ mass WH mode
Run 3 300 fb^{-1}	2.0 TeV	2.6 TeV	1.0 TeV	1.1 TeV	560 GeV	None
HL-LHC 3000 fb^{-1}	2.4 TeV	3.1 TeV	1.2 TeV	1.3 TeV	820 GeV	650 GeV

5σ discovery up to quoted mass

NEW

SUSY: Full-spectrum models

CMS PAS SUS-14-012

- **3 pMSSM models motivated by naturalness, different LSP**
  - **NM1(2): bino-like χ_1^0 with low(high) slepton mass; NM3: higgsino-like χ_1^0**
- **2 p(C)MSSM models, DM relic density, different coannihilation**
  - **STC: stau + χ_1^0 coann.**
  - **STOC: stop + χ_1^0 coann.**
- **Explored:**
  - **9 different experimental signatures**
  - **5 different types of SUSY models**

Exploring SUSY model space →

Exploring experimental signature space ↓

Analysis	Luminosity (fb^{-1})	Model				
		NM1	NM2	NM3	STC	STOC
all-hadronic (HT-MHT) search	300					
	3000					
all-hadronic (MT2) search	300					
	3000					
all-hadronic $\tilde{b}_1$ search	300					
	3000					
1-lepton $\tilde{t}_1$ search	300					
	3000					
monojet $\tilde{t}_1$ search	300					
	3000					
$m_{\ell^+\ell^-}$ kinematic edge	300					
	3000					
multilepton + b-tag search	300					
	3000					
multilepton search	300					
	3000					
ewkino WH search	300					
	3000					

$< 3\sigma$ | $3-5\sigma$ | $> 5\sigma$

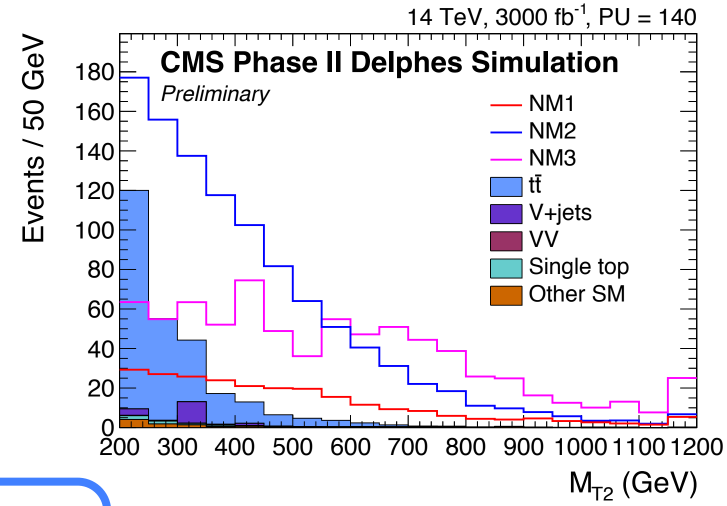
Different types of SUSY models lead to different patterns of discoveries in different final states after different amounts of data

NEW

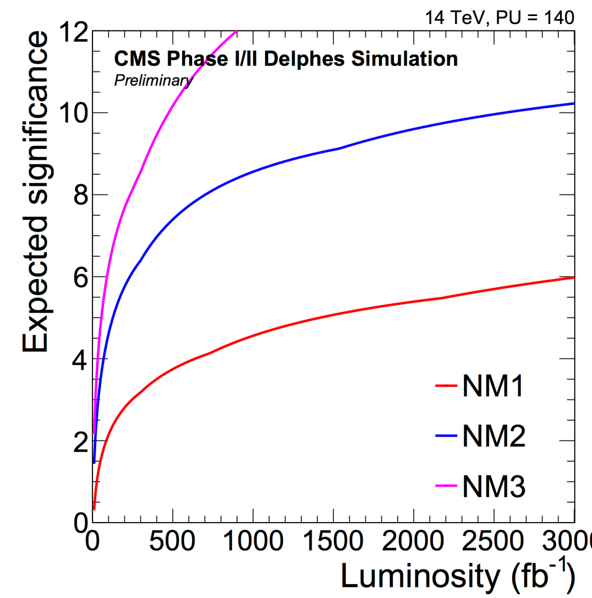
SUSY: Full-spectrum models

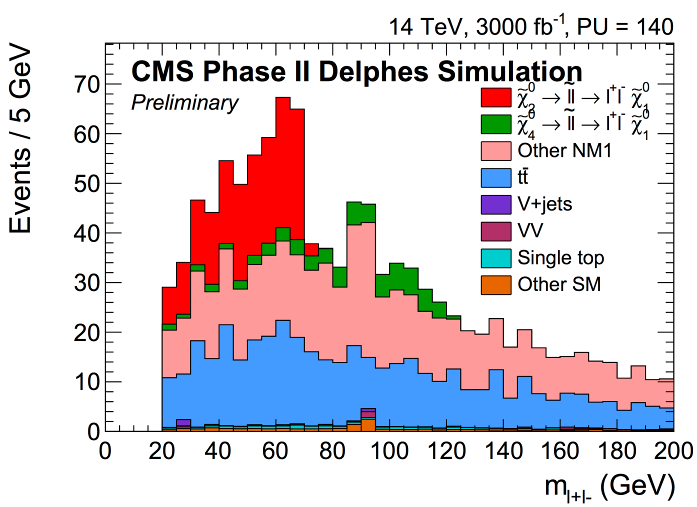
CMS PAS SUS-14-012

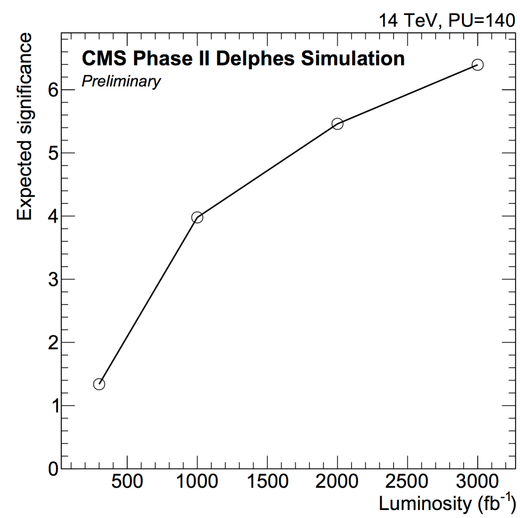
- **All hadronic (0 lepton) MT2 analysis**
  - **Targets natural SUSY with gluino pair production and 2 LSPs → use stransverse mass MT2**
  - **Gluino decay through stop and sbottom → large # b-jets and jets, E_T^{miss}**



- **Dilepton kinematic edge**
  - **NM1: gluino decay with** $\tilde{\chi}_2^0 \rightarrow \tilde{\ell}\ell \rightarrow \ell\ell\tilde{\chi}_1^0$
  - **Dilepton + ≥ 6 jets + ≥ 1 b-tag + E_T^{miss}**
  - **Edge significance > 5σ at HL-LHC**





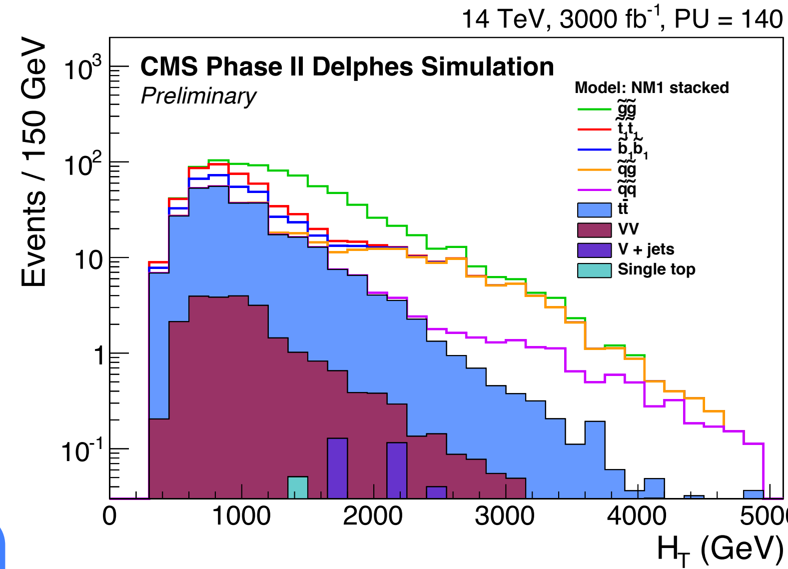


NEW

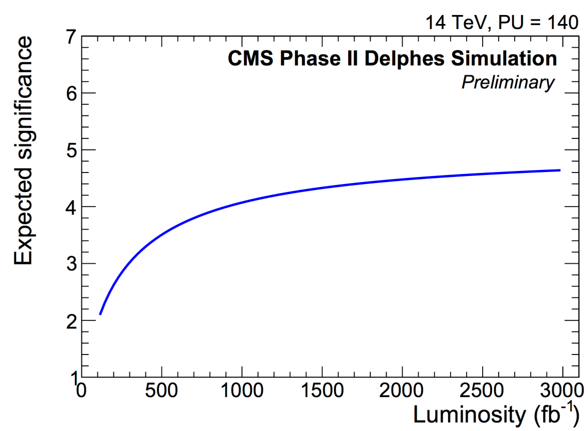
SUSY: Full-spectrum models

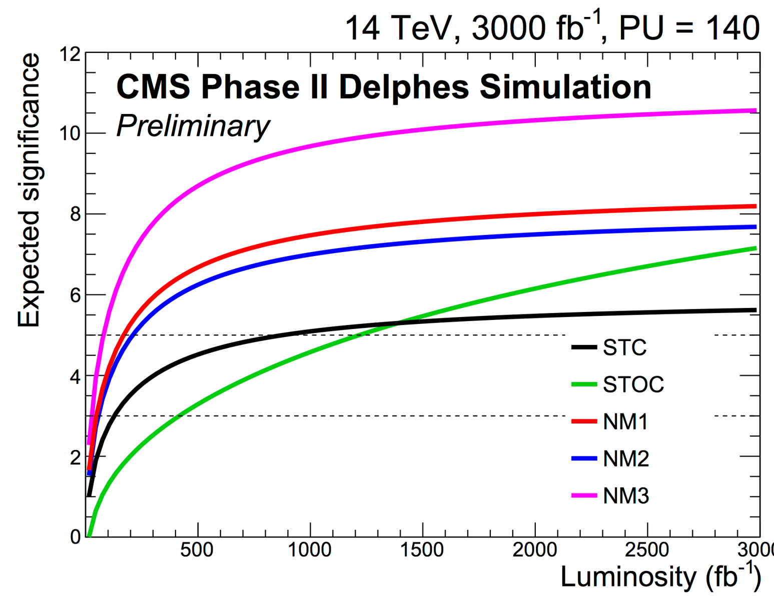
CMS PAS SUS-14-012

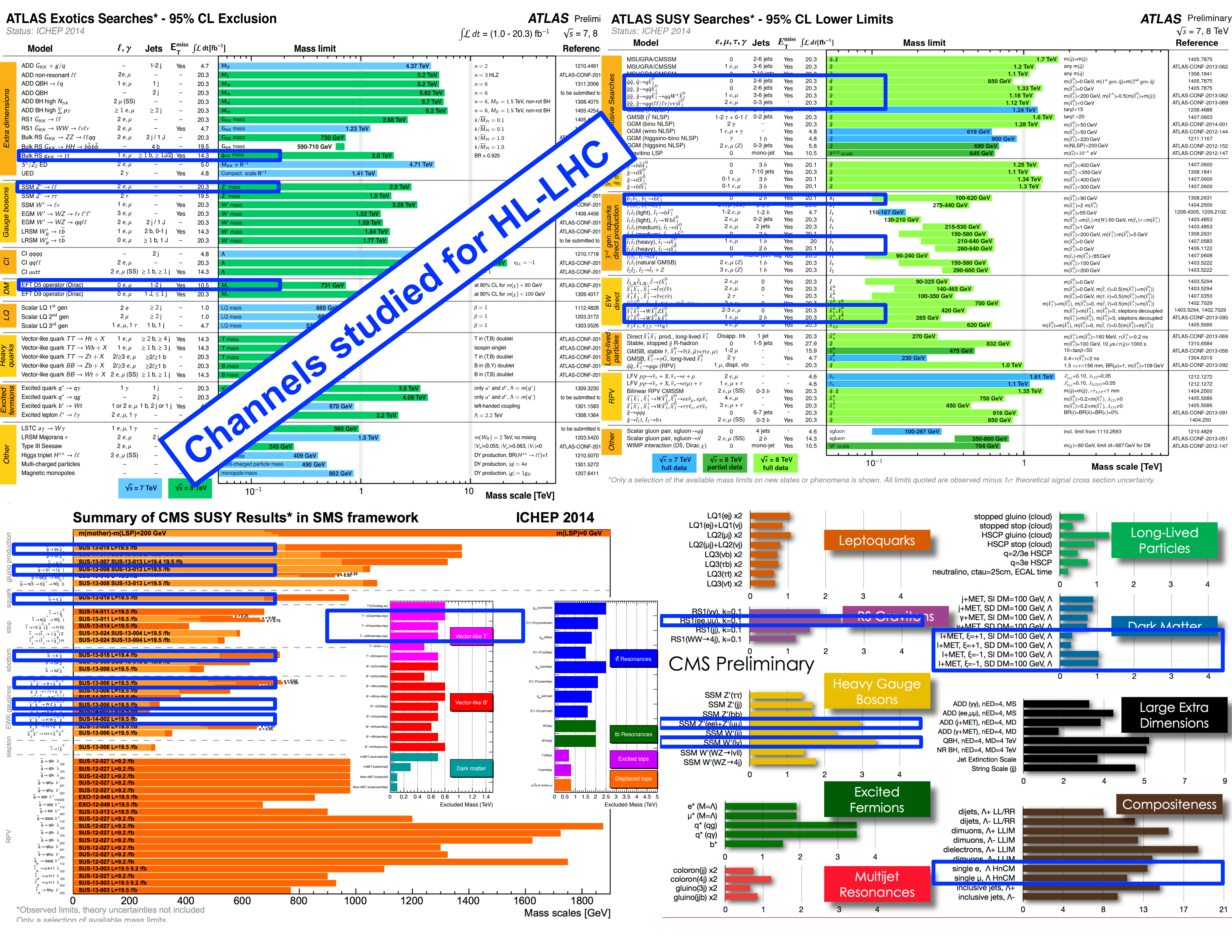
- **Direct stop pair in 1 lepton+jets**
  - **Wide range of production processes**
  - **Moderate 1.7 TeV gluino mass scale allows sensitivity to 3 TeV squark**
  - **Discovery only possible at HL-LHC for STC and STOC models**



- **Compressed spectra**
  - **If stop and χ_1^0 masses close, dominant decay is stop → c χ_1^0 in STOC**
    ➔ use mono-jet signature
  - **Just below 5σ at HL-LHC but complementary to HT-MHT analysis in STOC**






ATLAS Exotics Searches* - 95% CL Exclusion
Status: ICHEP 2014
ATLAS Preliminary
Model
Jets
Mass limit
Reference
Extra dimensions
Gauge bosons
CI
DM
LQ
Heavy quarks
Excited fermions
Other
√s = 7 TeV
√s = 8 TeV
Mass scale [TeV]
ATLAS SUSY Searches* - 95% CL Lower Limits
Status: ICHEP 2014
ATLAS Preliminary
√s = 7, 8 TeV
Model
Jets
Mass limit
Reference
Inclusive Searches
EW direct
Long-lived particles
RPV
Other
√s = 7 TeV full data
√s = 8 TeV partial data
√s = 8 TeV full data
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.
Channels studied for HL-LHC
Summary of CMS SUSY Results* in SMS framework
ICHEP 2014
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
Vector-like T'
Vector-like B'
tt Resonances
tb Resonances
Excited tops
Displaced tops
Dark matter
Excluded Mass (TeV)
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Leptoquarks
Long-Lived Particles
RS Gravitons
Dark Matter
CMS Preliminary
Heavy Gauge Bosons
Large Extra Dimensions
Excited Fermions
Compositeness
Multijet Resonances