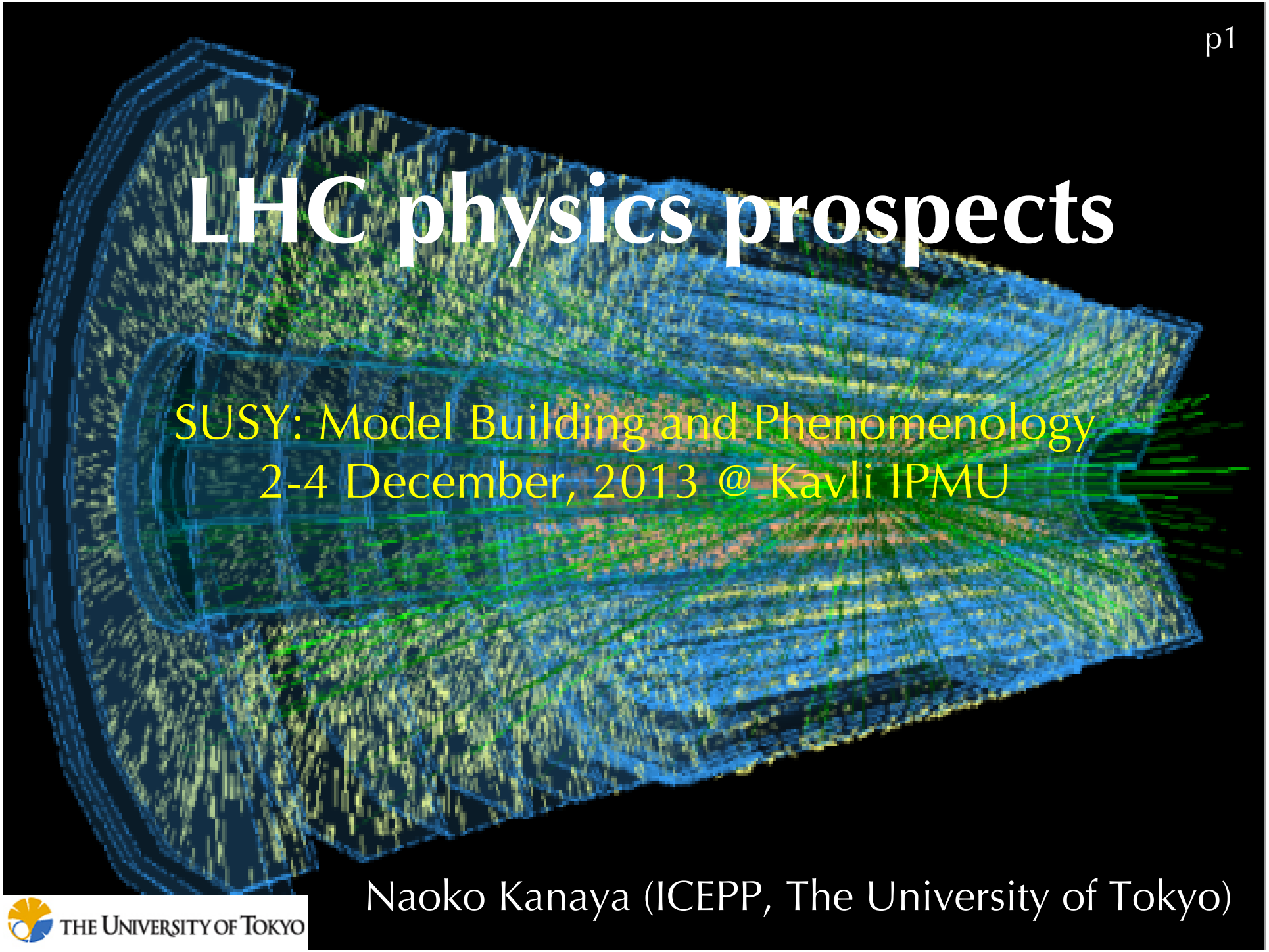
LHC physics prospects

SUSY: Model Building and Phenomenology
2-4 December, 2013 @ Kavli IPMU



Naoko Kanaya (ICEPP, The University of Tokyo)

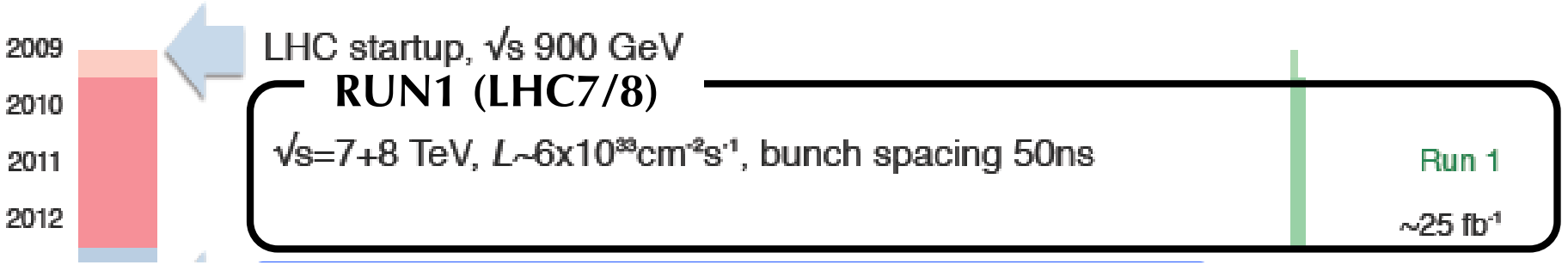
THE UNIVERSITY OF TOKYO

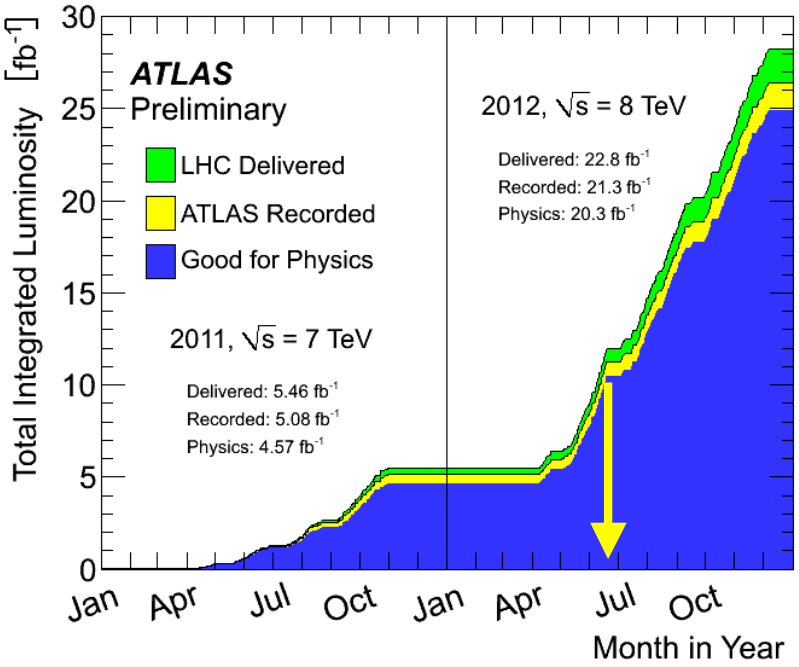
Outline of this talk

- LHC upgrade & environment
- Detector upgrade & physics impact
- ‘New’ Physics prospect
- Summary

Only talk about LHC14 and HL-LHC.
Results for snowmass and ECFA 2013.

LHC approved program



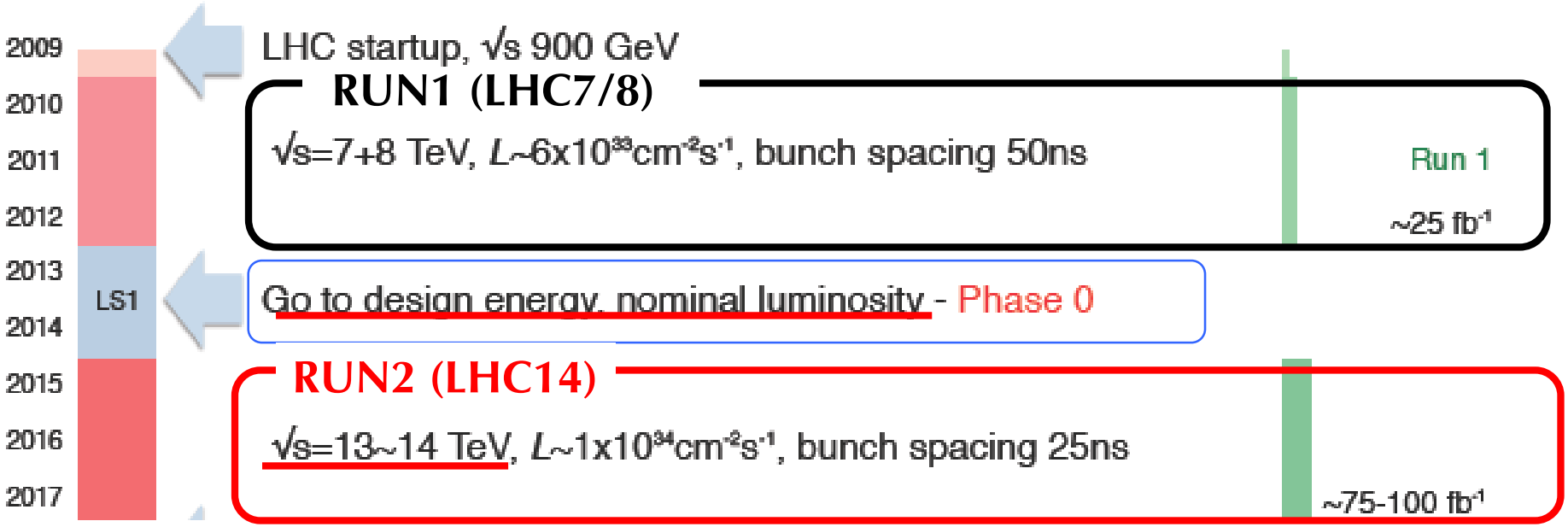


In 2011+2012
Total delivered luminosity : 28.3 fb^{-1}
Total recorded luminosity : 26.4 fb^{-1}
Luminosity for physics : 24.9 fb^{-1} (94%!)

Higgs 5σ discovery on 4 July 2012

Use L=10.7 fb^{-1} data in total collected till June 18!

LHC approved program



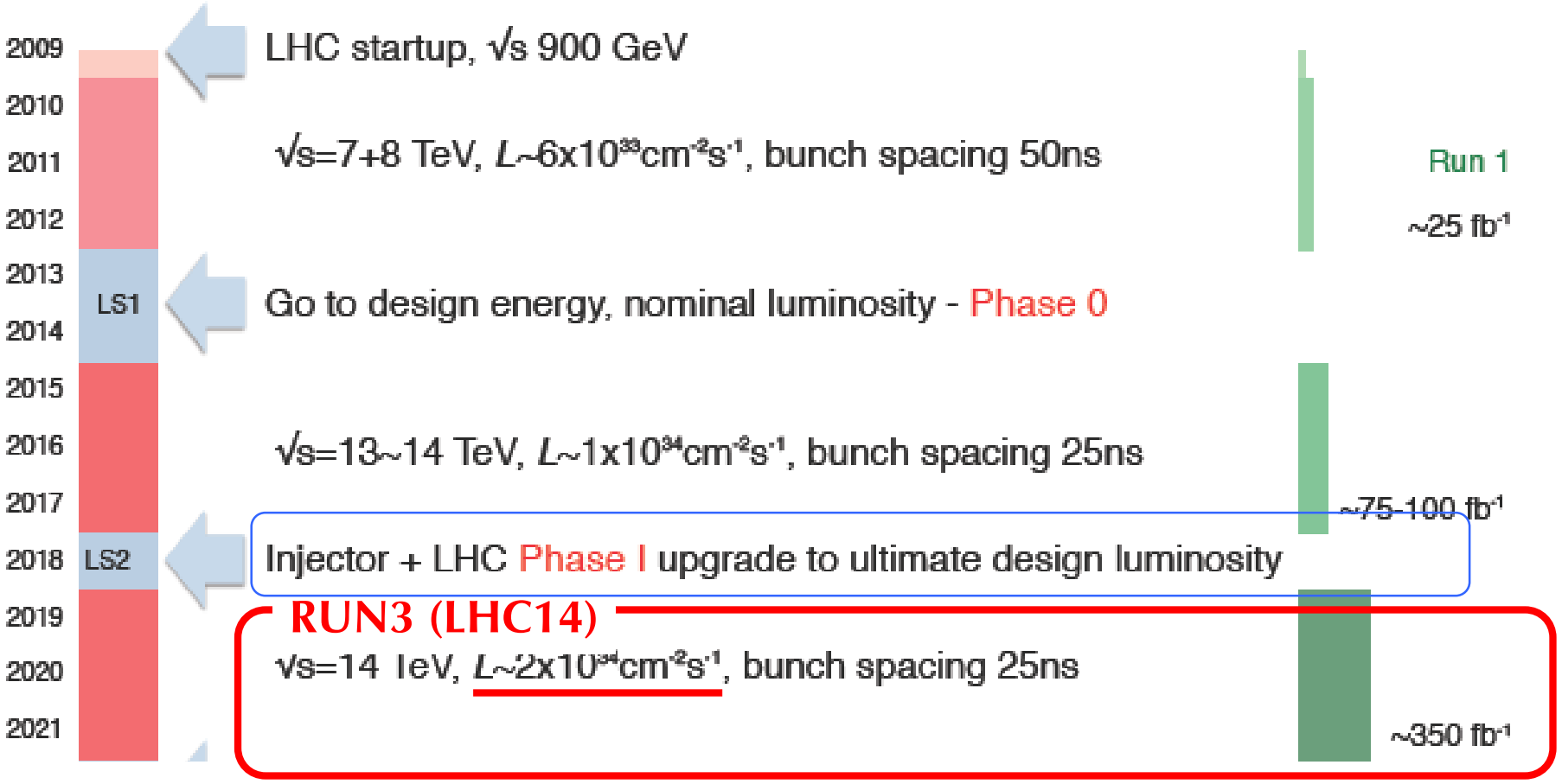
We're here: Long Shutdown 1 (2013-2014) for RUN2

LS1 (Phase-0 upgrade) for increasing of the beam energy and repairing/replacement of some detector elements.

ATLAS

- The 4th pixel layer (IBL) with new beam pipe.
- Fast Tracker trigger (FTK)…

LHC approved program

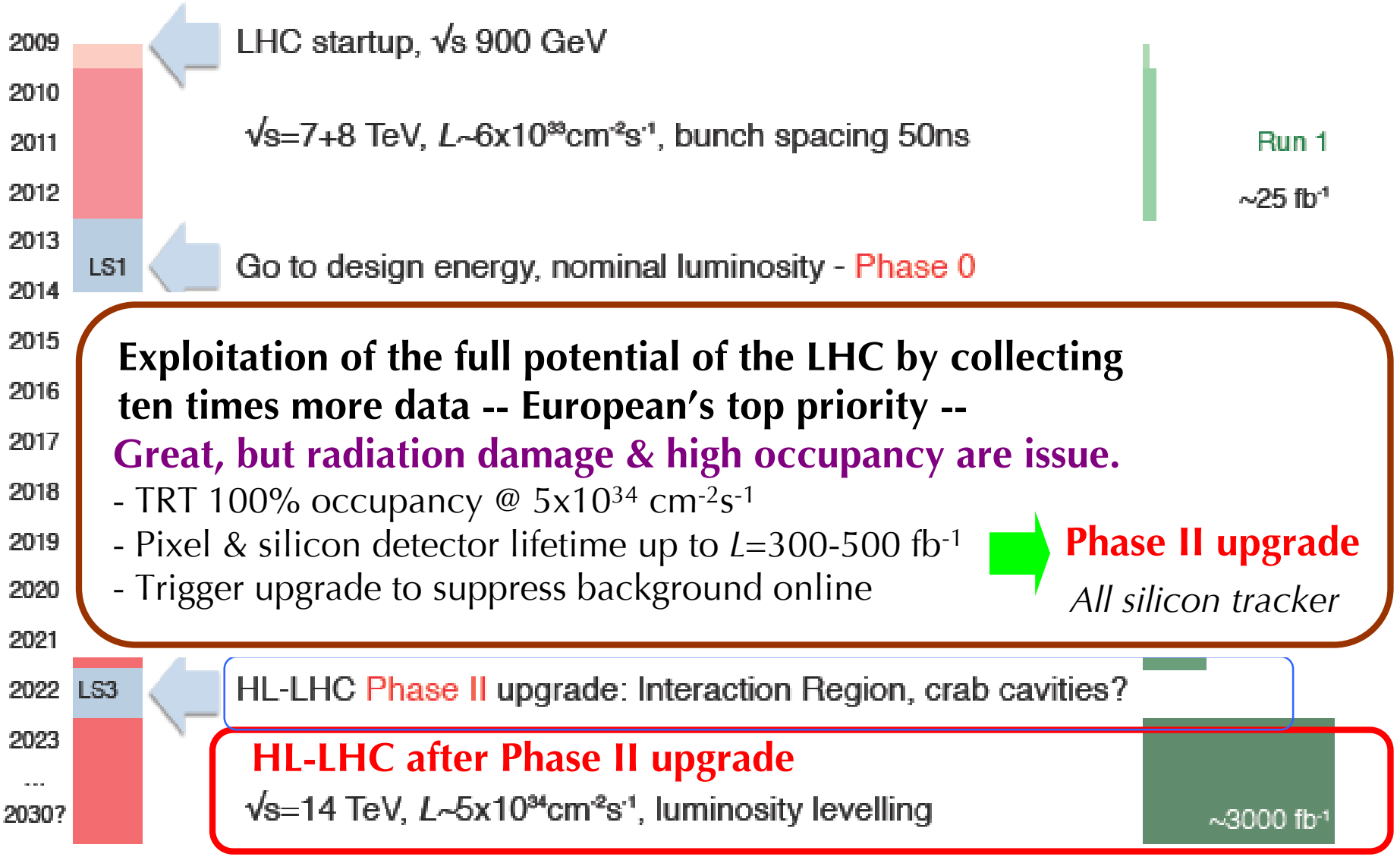


Phase-I upgrade (2018)

Trigger upgrade. Maintain lower threshold
- finer granularity for calorimeter trigger
- new muon trigger detector in the endcap

for lepton trigger with p_T>20-35 GeV

High-luminosity run (HL-LHC)



A few words on Pile-Up…

:) Great to have more luminosity(L), Rate=σL

:(More pileup (# of interactions/crossing)

Luminosity

$$L = \frac{N^2 \cdot f \cdot n_b}{4\pi \cdot \varepsilon \cdot \beta^*}$$

No. of pileups

$$\mu = \frac{L \times \sigma_{inel}}{f \cdot n_b}$$

N : # of protons/bunch
f : *revolution frequency*
n_b : # of bunches
ε=emittance
β*=beta function @IP
σ_{inel}=81mb

RUN2 ~ LHC design : L=1x10^{34}cm^{-2}s^{-1}, μ~23

	RUN3	HL-LHC
Sqrt(s_{pp})	14	14
n_b	2808	2808
N	1.2x10^{11}	2x10^{11}
β* [m]	0.55	0.15
Peak L [cm^{-2}s^{-1}]	2x10^{34}	5x10^{34}
μ (pileup)	~60	~140

Start-up 2015: under discussion

- <μ>=25, *L*/year=24 fb^{-1}
- <μ>=52, *L*/year=45 fb^{-1}

….

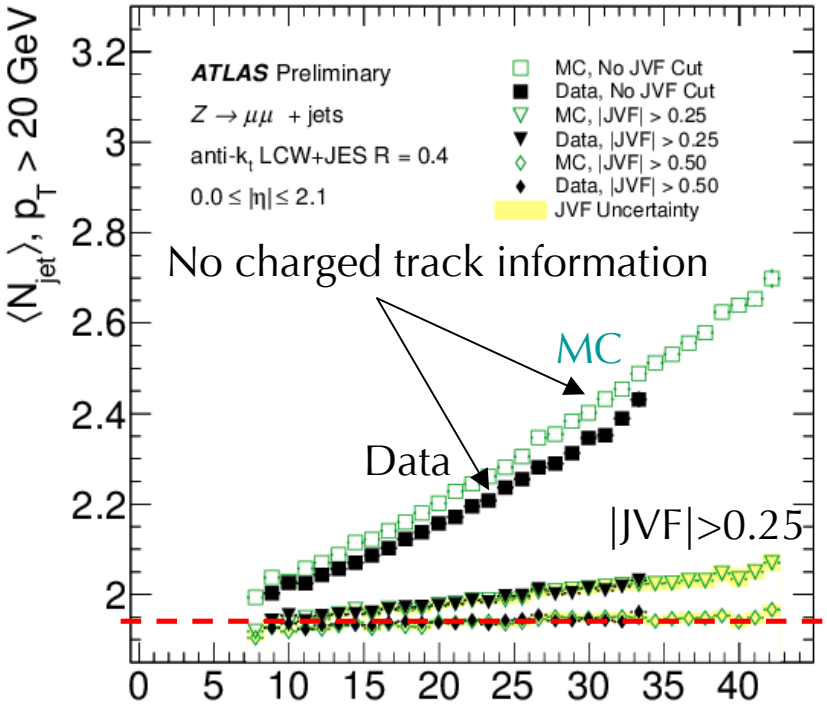
L.Ponce LHC-France 2013

Need to adopt the detector, trigger and analysis for this hash environment!

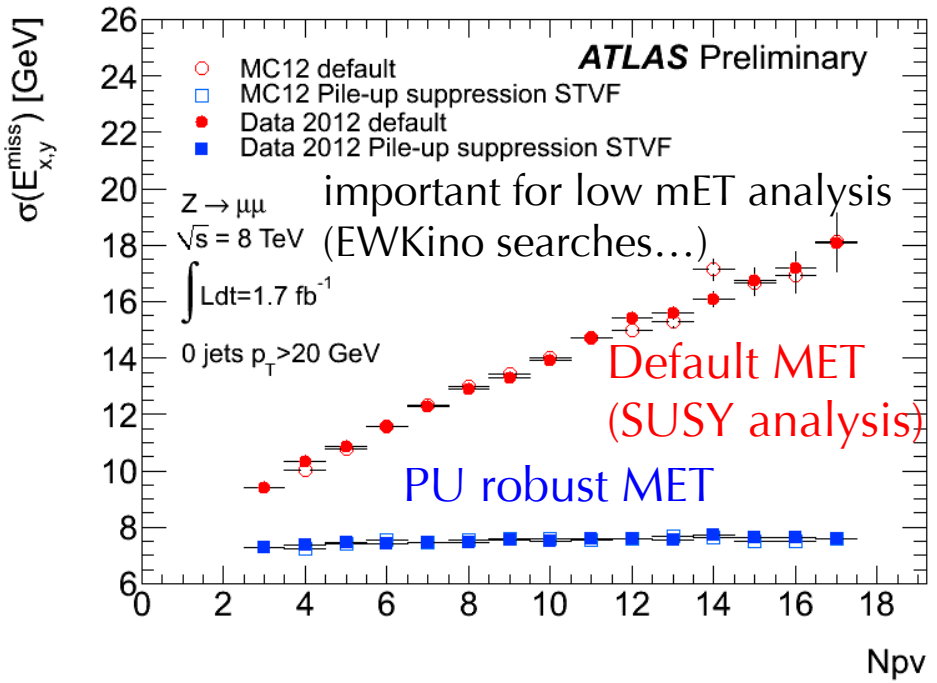
A few words on Pile-Up…

Jet/mET systematic uncertainty is often the largest detector-related uncertainty in most of BSM searches.

# of pileups <μ> ~ 21 @ LHC8.
Also take some high brightness fill with <μ> up to 69.



Tagging soft jets is useful for the compressed mass scenario.



Well under control by considering tracks from the hard collision vertex.

Detector upgrade & Physics Impact

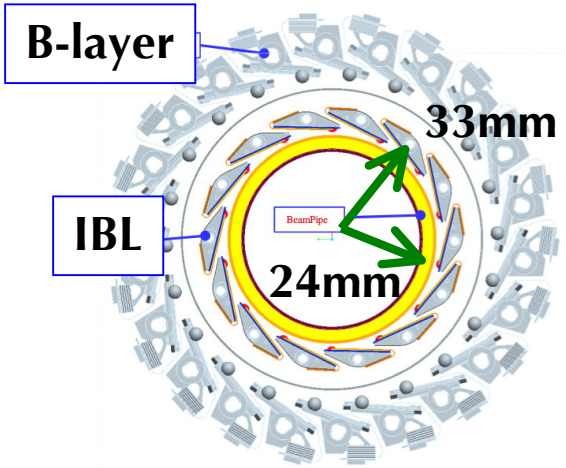
A few examples

(RUN2 ATLAS)

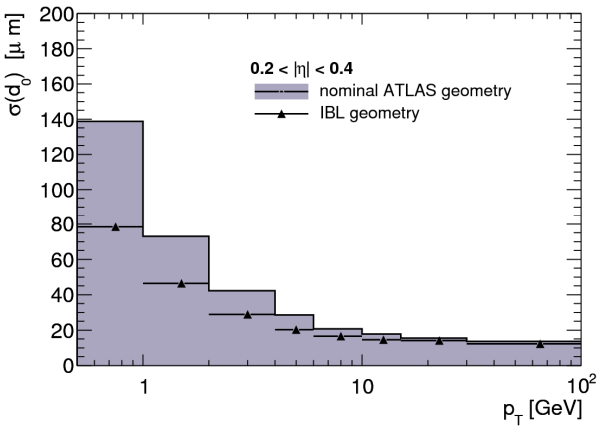
Insertable B-Layer (IBL)

4th inner pixel-layer + new beam pile

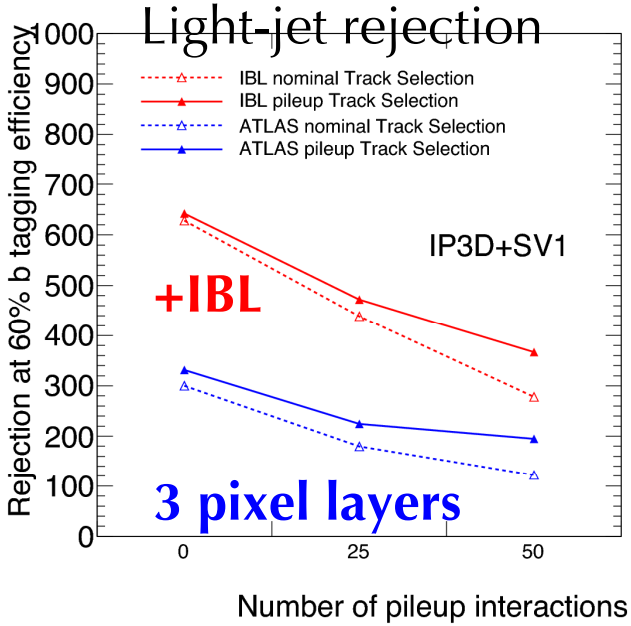
Current inter-most B-layer (R=51mm)
First hit @ 55mm -> 33mm!
Significant improvement for b-tagging performance



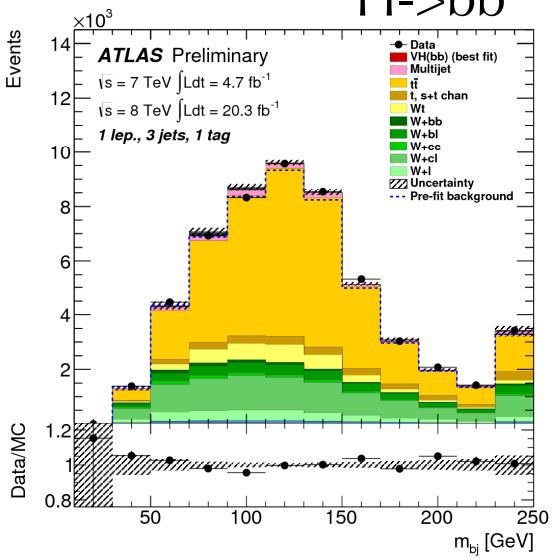
Impact parameter



Light-jet rejection



H->bb



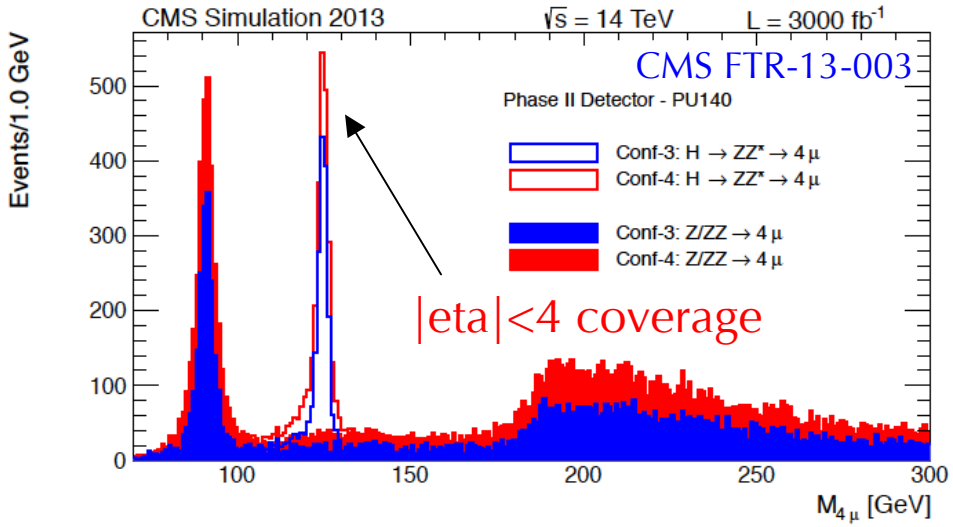
Detector upgrade & Physics Impact

A few examples

(CMS HL-HLC) muon/trackers up to |eta|<4

H->ZZ(4mu)

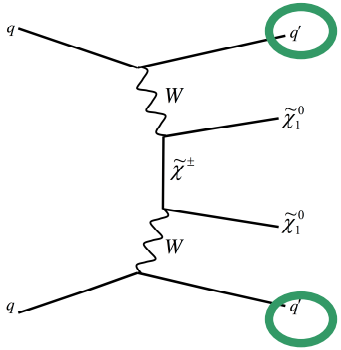
Acceptance gain +45%



- Lepton acceptance
- pileup jet/partilces subtraction, MET
- Lepton veto for background rejection

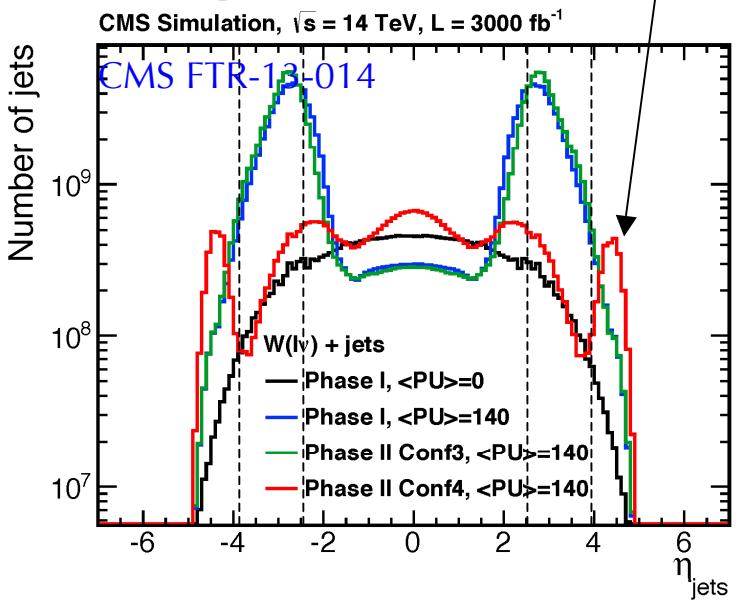
e.g. W(lv)+jets for mono-jet analysis

LSP/DM in VBF



MET +forward jets

|eta|<4 coverage

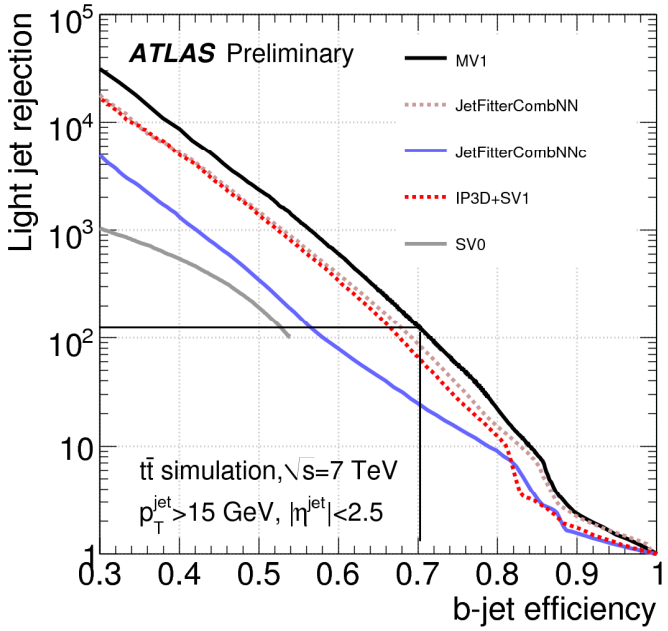


Detector upgrade & Physics Impact

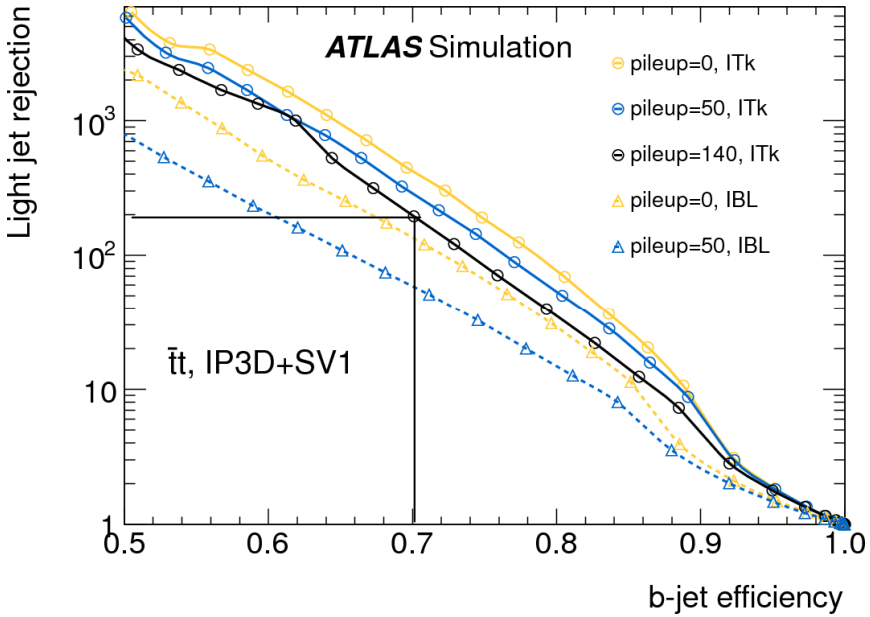
A few examples

Maintain or even improve the performance by phase1/2 upgrade despite of high pile-up!

RUN1 ATLAS
MV1 (IP3D+SV1+JetFitter)



Phase2 ATLAS
IP3D+SV1



Not only detector, but DAQ/Trigger is also very important.
Maintain efficiency for low p_T objects as in RUN1…

LHC 'New' Physics Prospect

LHC back to Physics in April 2015 with $\sqrt{S_{pp}}$=13 TeV

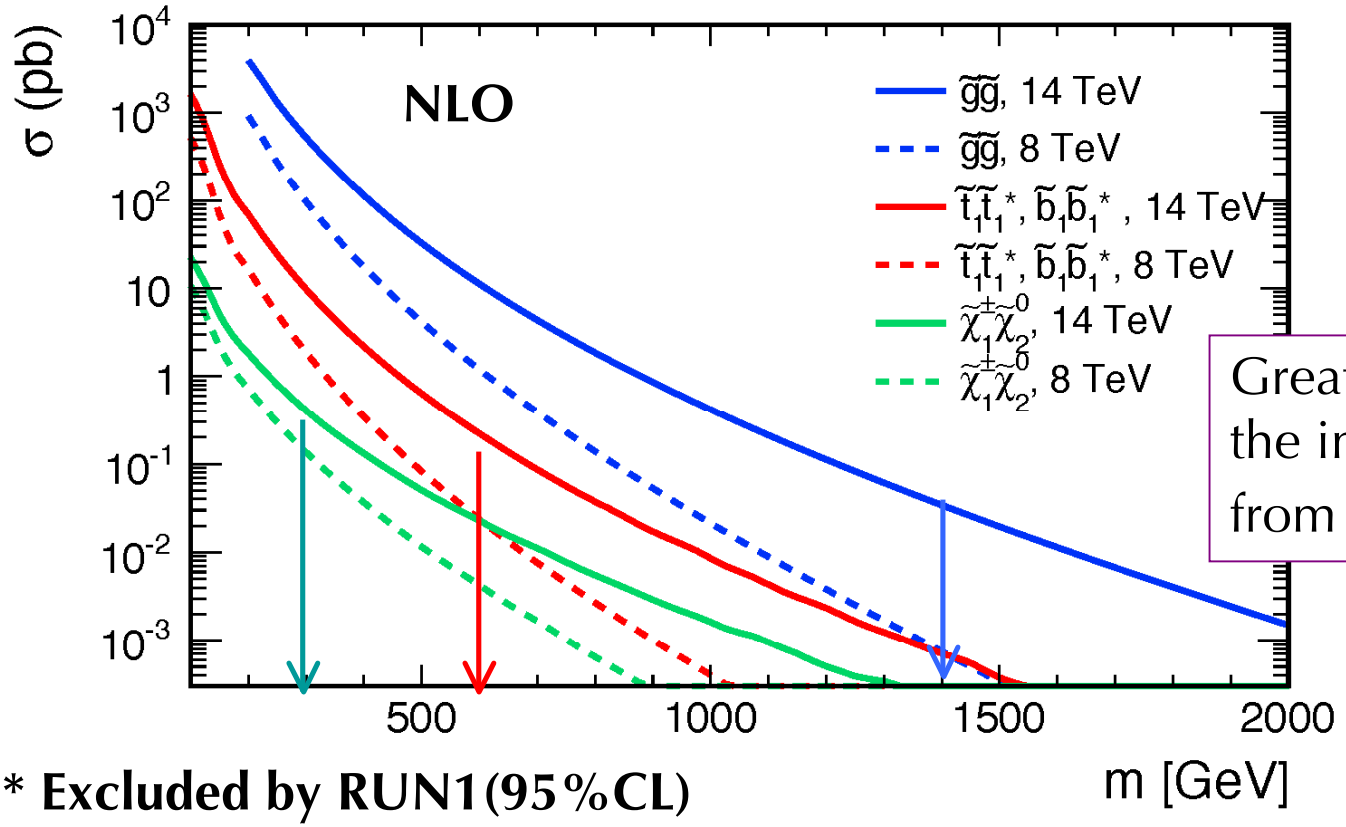
- ECFA HL-LHC workshop, Aix-les-Bains 2013
- Snowmass on the Mississippi 2013

Reference : Upgrade and Future physics

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

CMS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP

SUSY Cross-section @ 14TeV



Great benefit from the increase in energy from 8TeV to 13/14TeV.

* Excluded by RUN1(95%CL)

SUSY mass	Ratio(14/8)
Chargino (~300GeV)	~2
Stop (~600GeV)	~10
Gluino (~1.4TeV)	~43

SM backgroud : x2-4

Sensitivity gain is ~10 @ TeV scale

SUSY Analysis

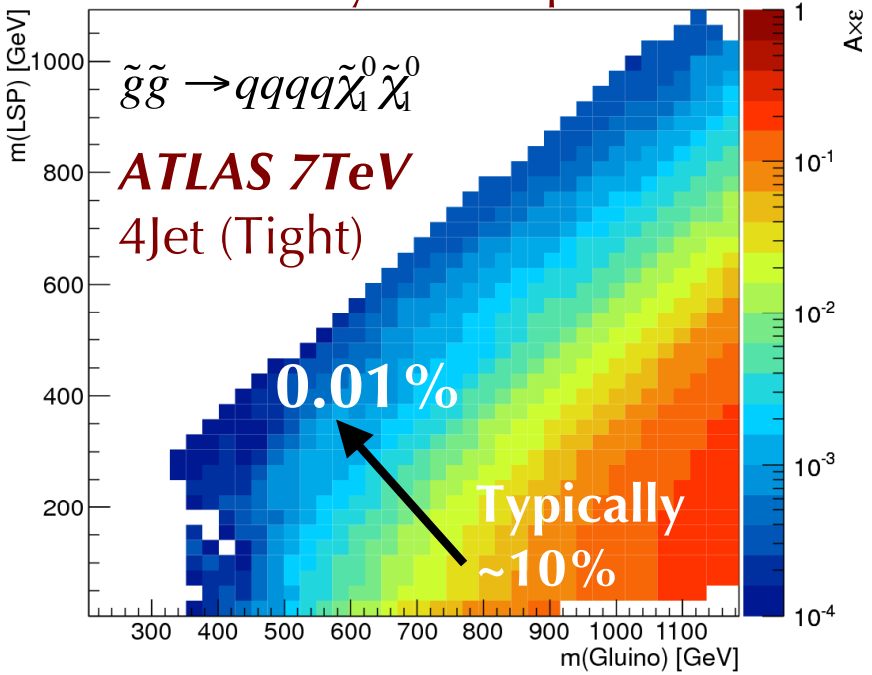
- Categorize by production x final state wth multiple SRs.
- Optimization based on available luminosity.

e.g. 0-lepton analysis for gluino/squark search, nJet=2-6 (~5x3 SRs)

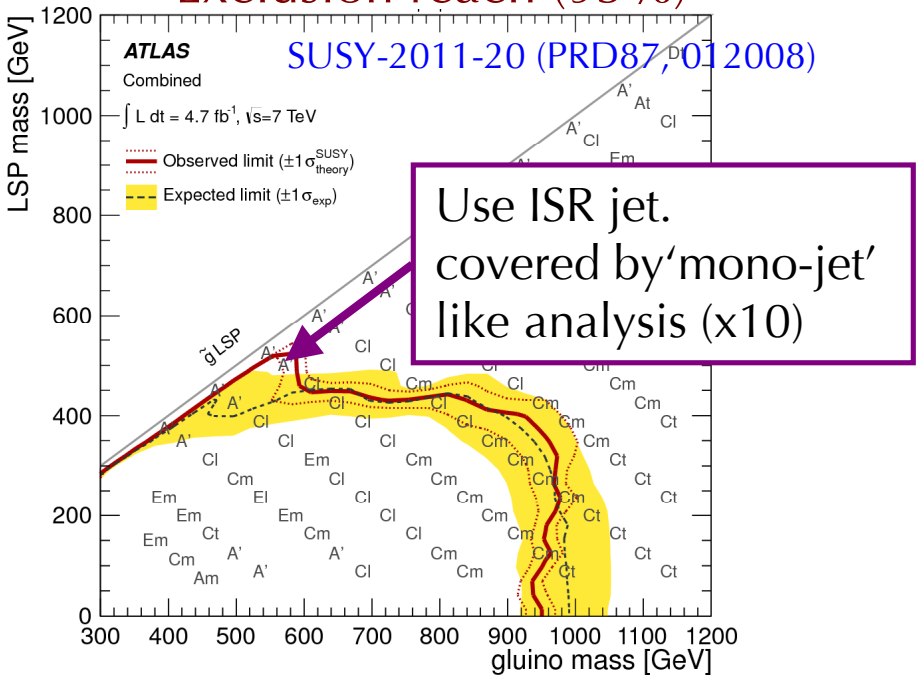
Discriminant: Meff (= mET + $\Sigma|p_T|$)

4Jet tight SR	7TeV (4.7fb^{-1})	8TeV (5.8fb^{-1})	8TeV (20fb^{-1})
Meff cut	1.5TeV	1.9TeV	2.2TeV

Efficiency x Acceptance



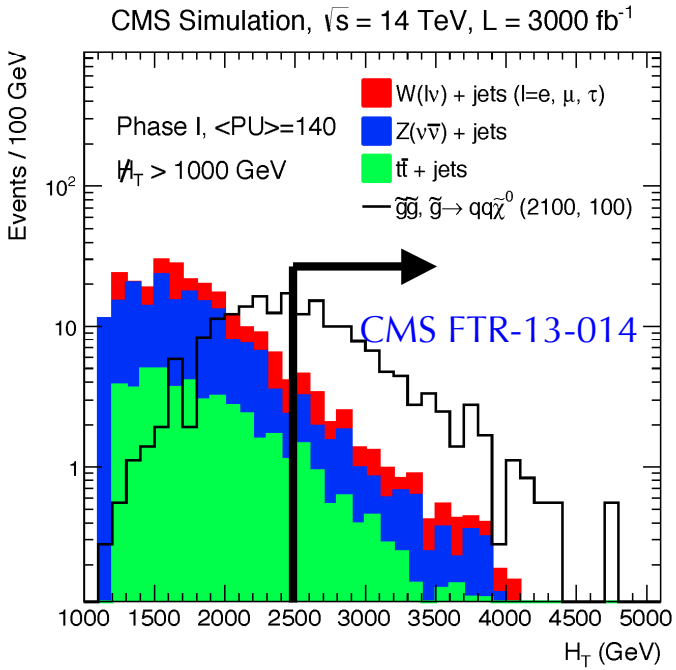
Exclusion reach (95%)



Gluino production

$\tilde{g} \rightarrow qq\tilde{\chi}_1^0$

Most interesting channel at the beginning of RUN2!



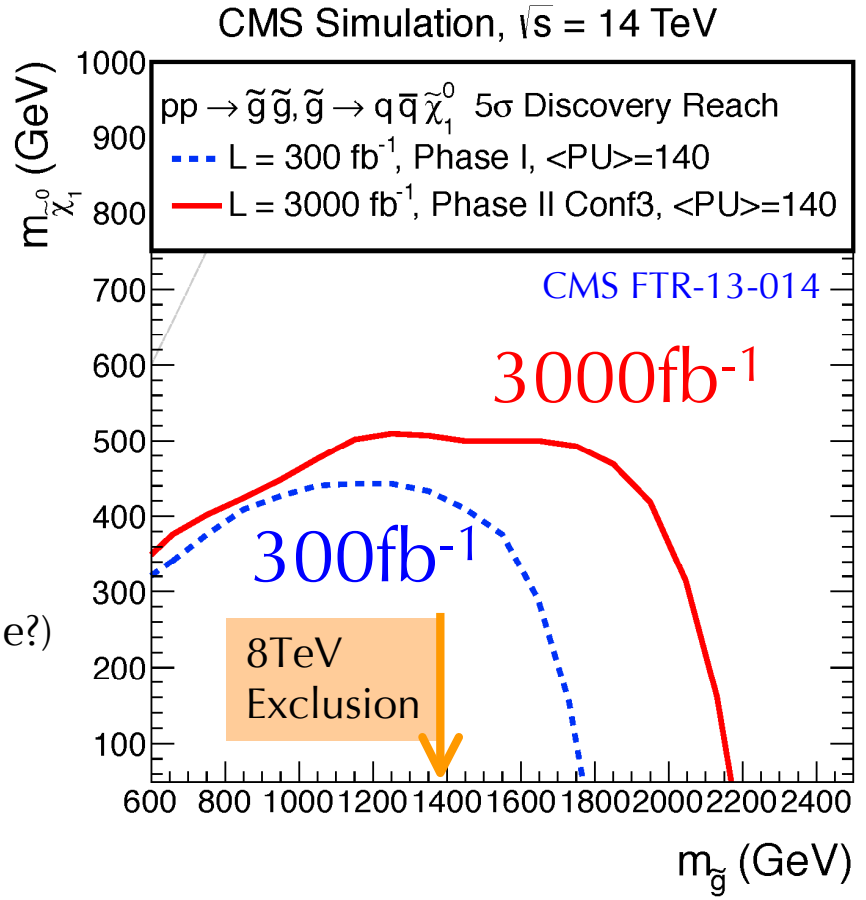
W/Z+jet is main background (MC is reliable?)
Almost no impact of pileup.

5σ discovery
m(gluino)=1.8 ~ 2.2 TeV

6Jet HT (=Σ|p_T|) Analysis

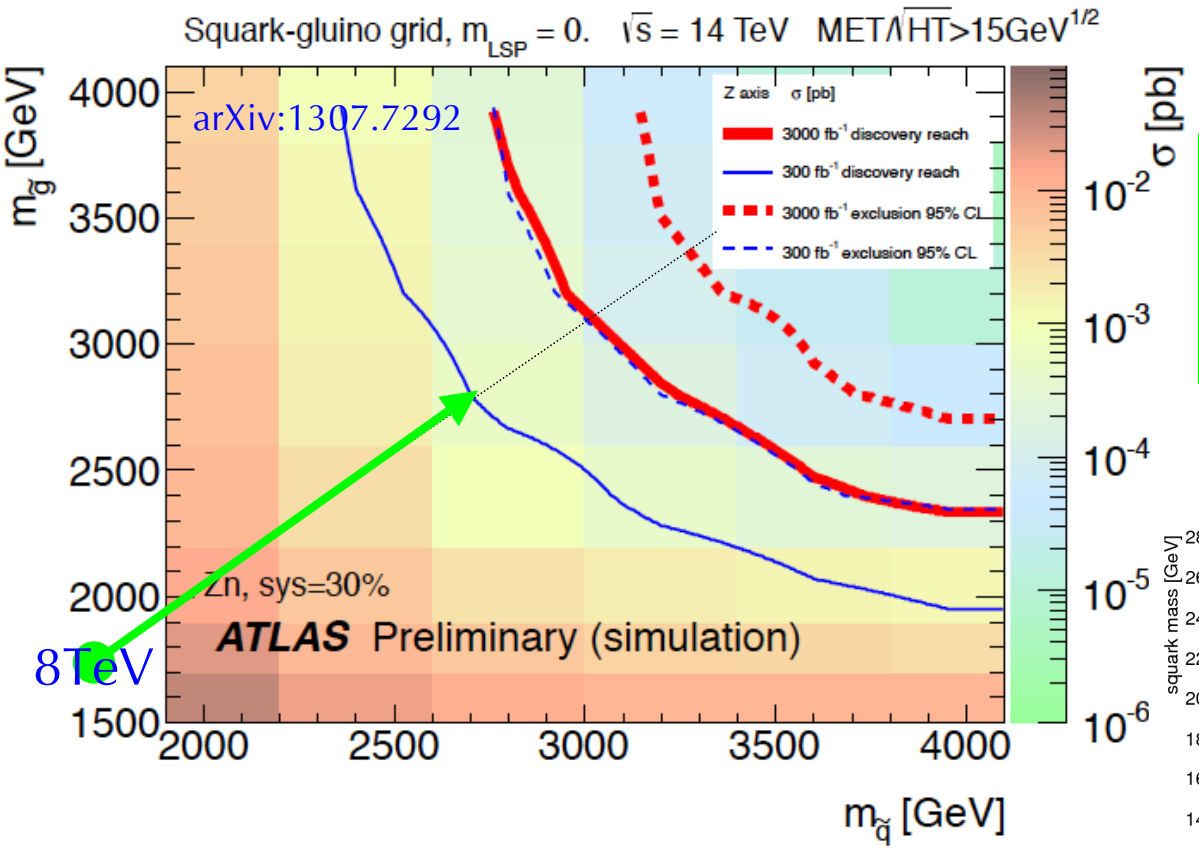
SR for High gluino mass

HT>2100GeV, ~~H~~T>700 GeV(300 fb^{-1})
HT>2500GeV, ~~H~~T>1000 GeV(3000 fb^{-1})



Gluino/Squark production

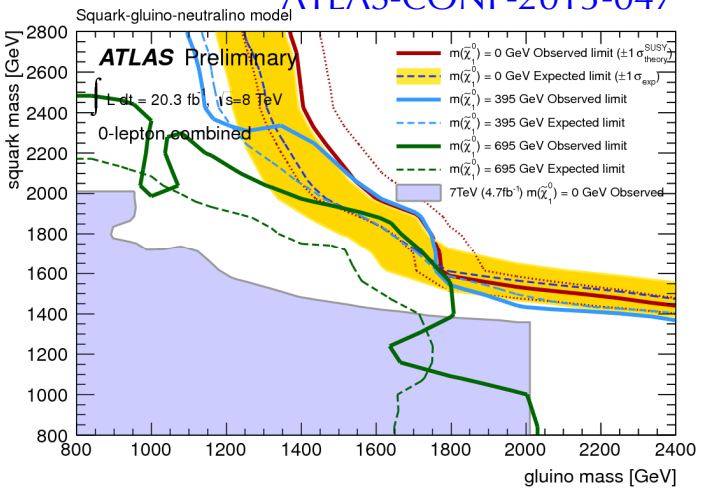
Very optimistic case ? squark is also light, m_{LSP}~0GeV
(no pileup suppression for mET, use mET/√HT)



5σ discovery(mg̃~mq̃)
2.7TeV (300 fb^{-1})
3TeV (3000 fb^{-1})

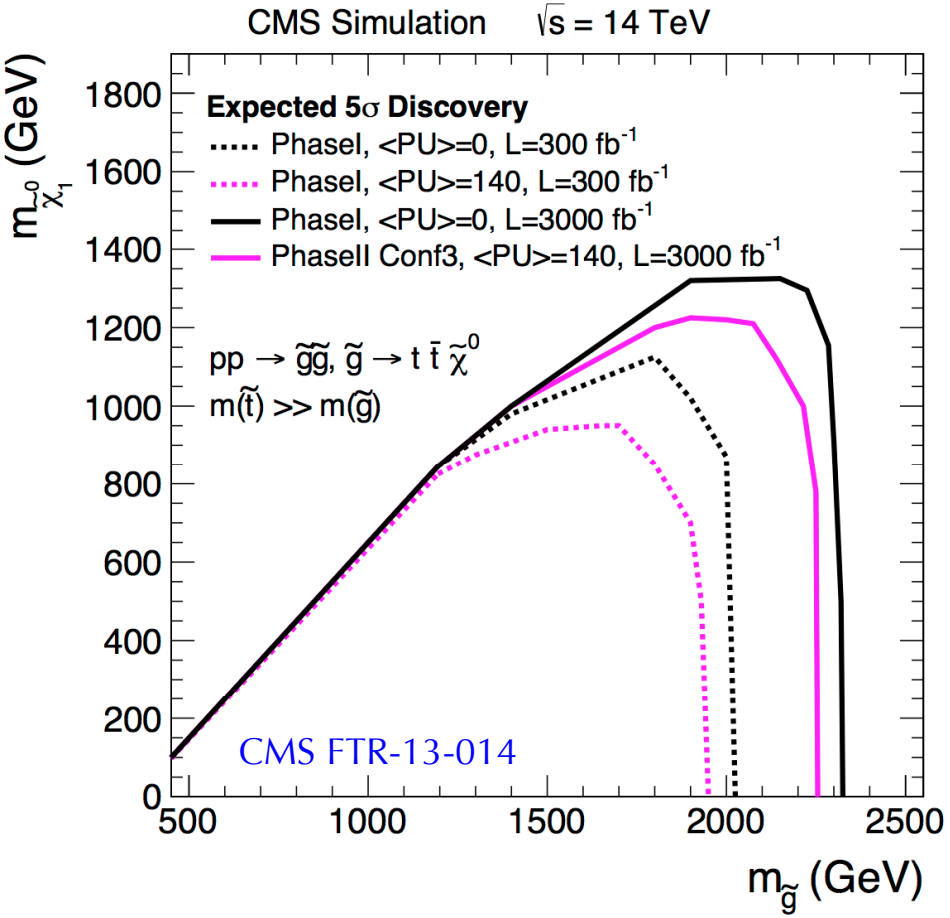
ATLAS 8TeV result

ATLAS-CONF-2013-047



Gluino production $\tilde{g} \rightarrow tt\tilde{\chi}_1^0$ (3body-decay)

Very characteristic, 4-tops in the final state.
ttbar background is highly suppressed by nbjet>=4 requirement



1Lep+6Jet (n_b==3, >=4)

8TeV result (95% excl)

1L6J (CMS/8TeV) < 1.2TeV
3B (ATLAS/8TeV) < 1.4TeV

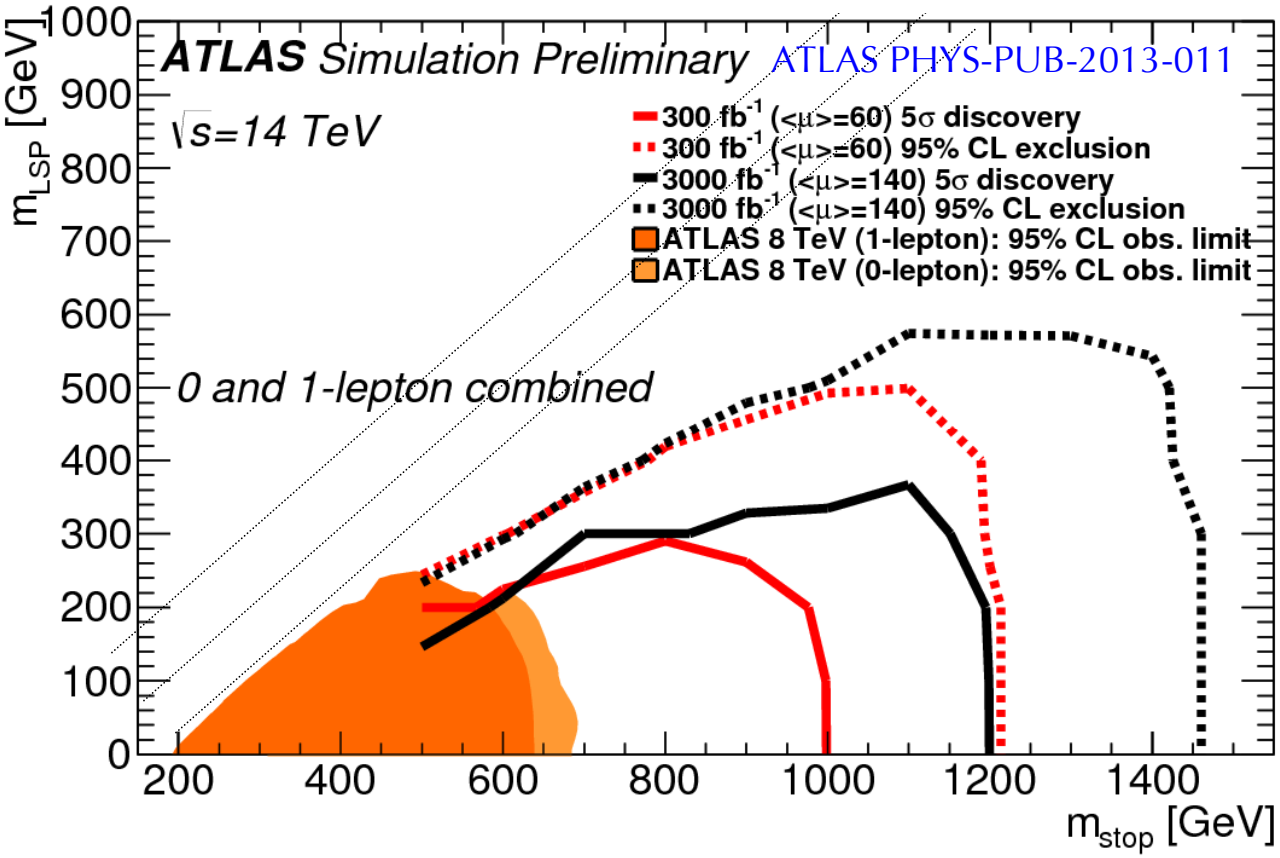
5σ discovery
1.9-2.0TeV (300 fb^{-1})
2.2-2.3TeV (3000 fb^{-1})

Pileup effect due to degraded b-tagging performance

Stop production

$\tilde{t} \rightarrow t\tilde{\chi}_1^0$

Stop mass with 500-600GeV was excluded by RUN1.
(m_{LSP}~100-200GeV, large mass difference)



Background

$(m_{\tilde{t}}, m_{\tilde{\chi}})$	(800,100)	(1100,100)
$t\bar{t}$	69±13	5.7±3.4
$t\bar{t}+W$	5±1	0.8±0.6
$t\bar{t}+Z$	38±5	3.9±1.5
W+jets	3±3	negligible
Z+jets	14±4	1.8±1.3
Total bkg	129±15	12.2±3.9
Signal	457±13	46.0±1.4

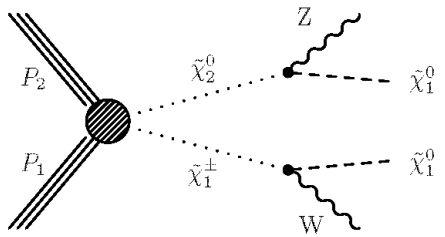
ttbar+ vector-boson becomes sub-dominant background.
(cross-check by ttbar+γ?)

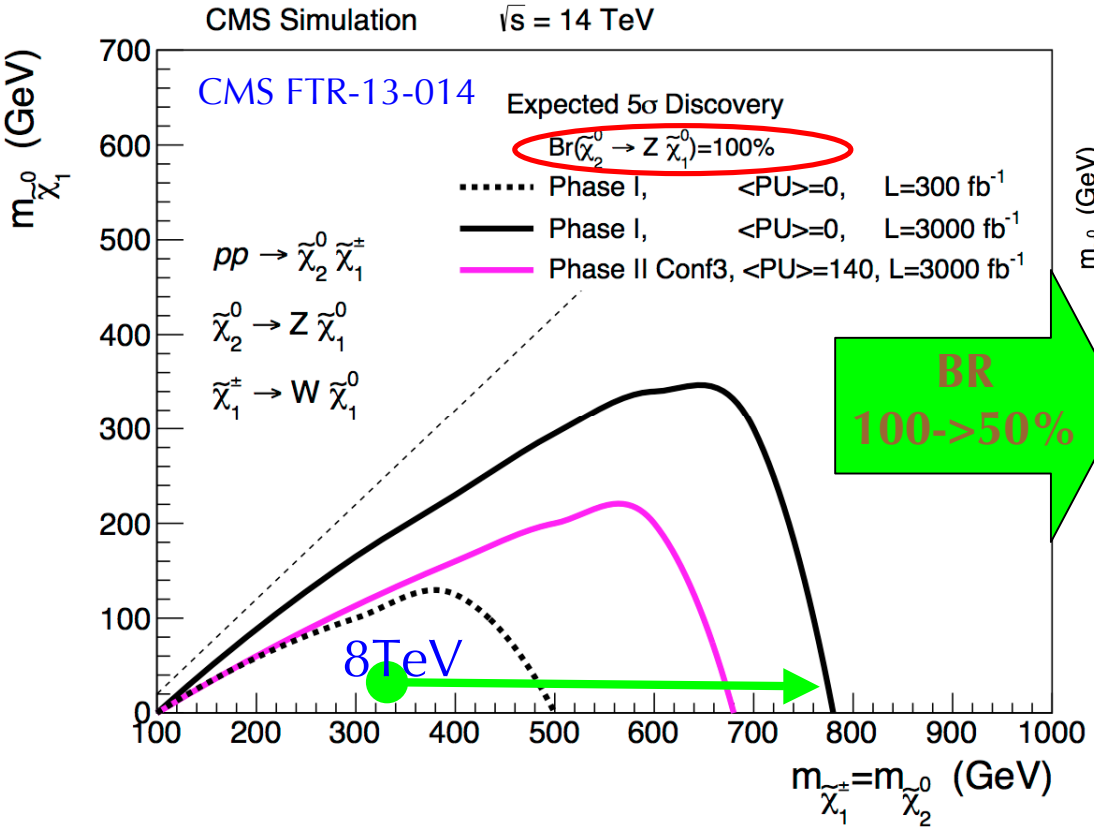
Discovery could be possible for stop mass~1-1.2 TeV!

EWKino production

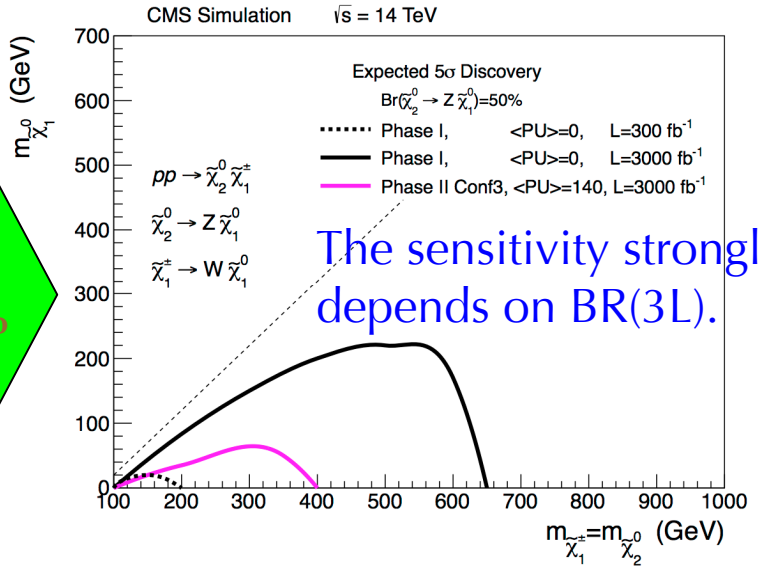
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (W^{\pm}\tilde{\chi}_1^0)(X^{\pm}\tilde{\chi}_1^0)$

3Lepton analysis is a golden channel for EWKino searches.





BR 100->50%



The sensitivity strongly depends on BR(3L).

Compressed mass spectrum case could be covered by MVA analysis.

Explored up to $m(\tilde{\chi}^{\pm})$=500-800GeV!

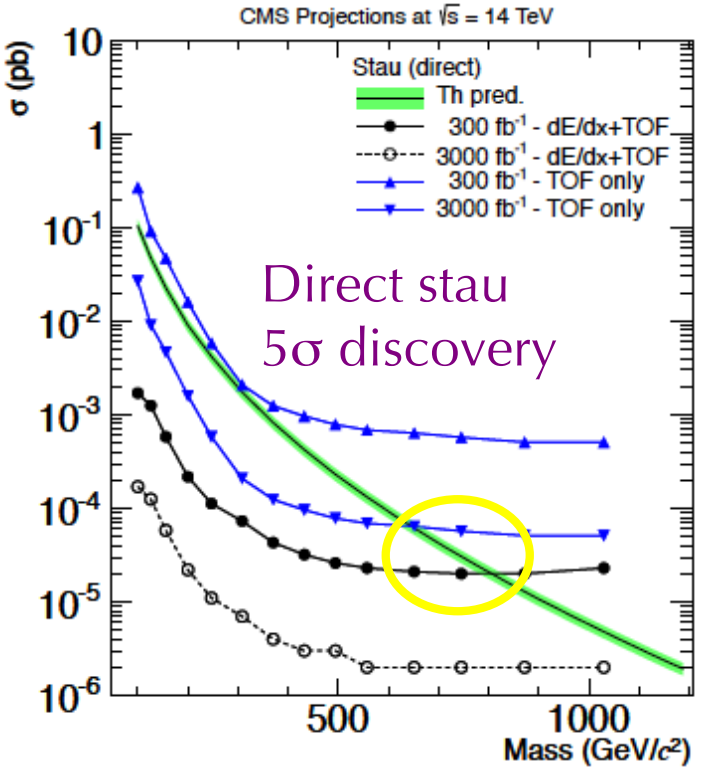
If nothing, chargino is excluded up to ~1TeV…

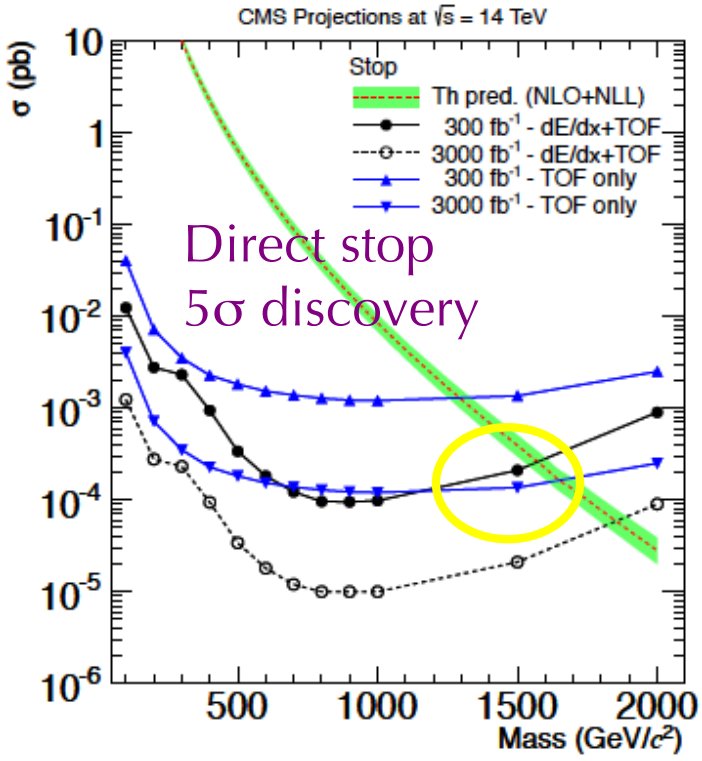
Long-lived charged particle

Heavy stable charged particles can be identified by

- ToF measurement (β<1) by the muon trigger
  → RUN2~ : Lower efficiency due to narrower trigger window (50->25ns)
- Large dE/dx by silicon trackers
  → HL-LHC~ : not-available

N_b (instrumental bkg) signal acceptance are scaled by luminosity.





Discovery
Stau
700-800GeV
Stop
1.5-1.6 TeV

Higgs, other BSM…

BSM Higgs?

28/11/2013
ATLAS-CONF-3013-108

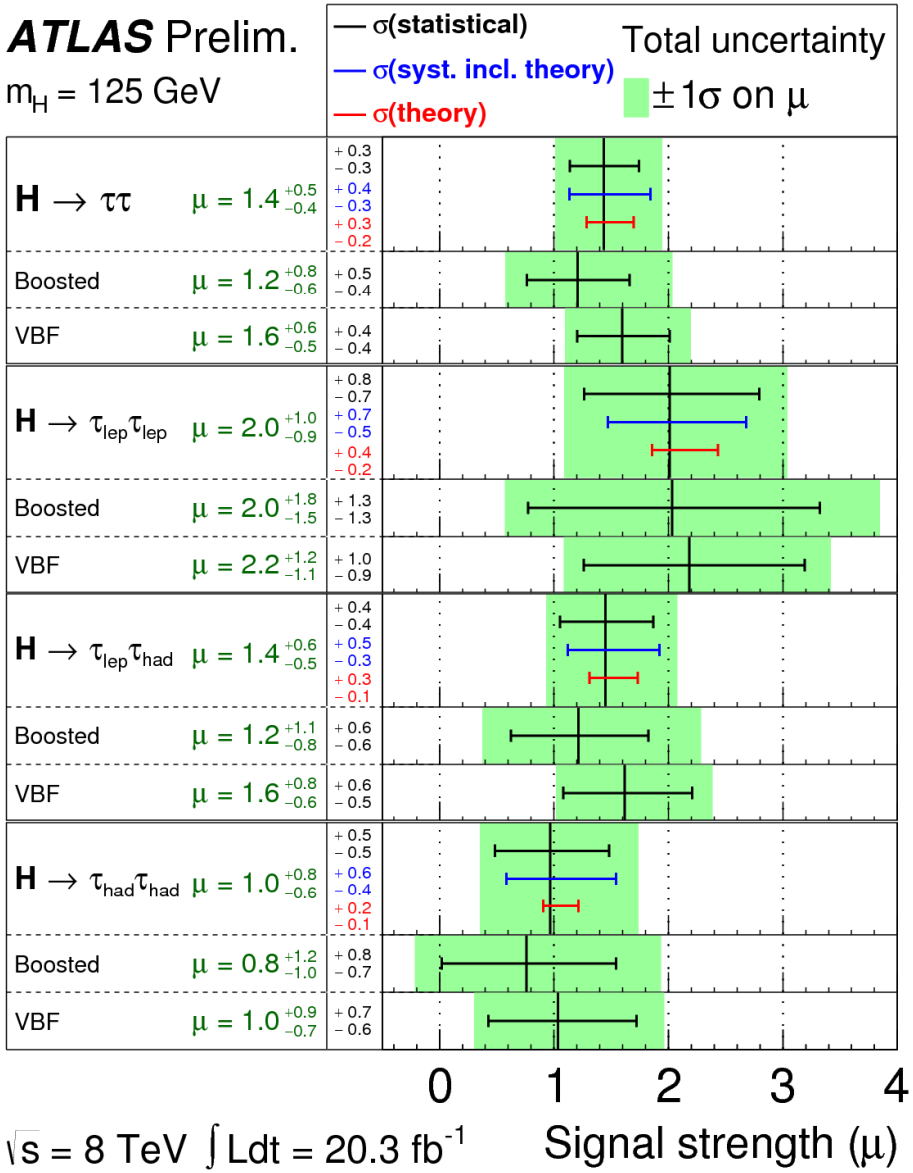
Higgs Naturalness problem?

ATLAS/CMS 8TeV measurements are consistent with the SM prediction, but the error is still large.

HL-LHC is Higgs factory!

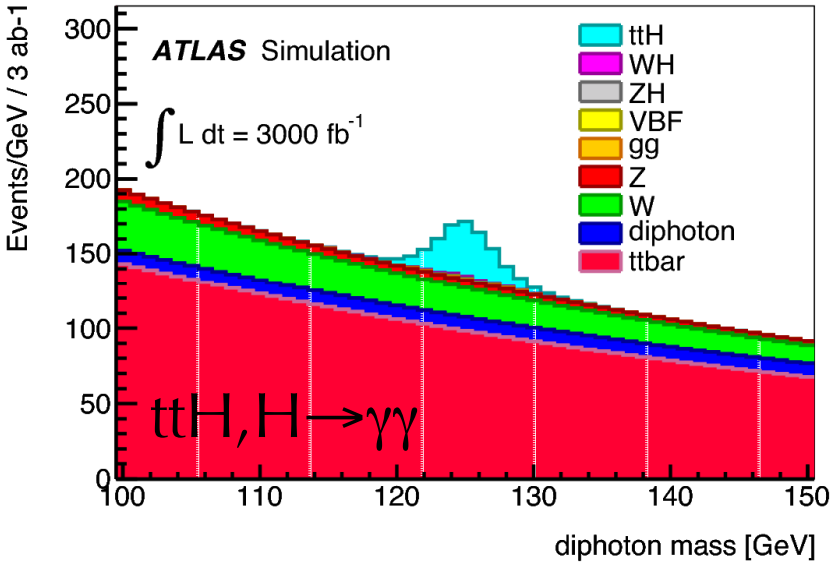
Higgs@3000fb^{-1}	
H->WW->lvlv	1M
H->ZZ->4l	20K
H->γγ	400K

(1) non SM-like couplings?
(2) Heavy Higgs?

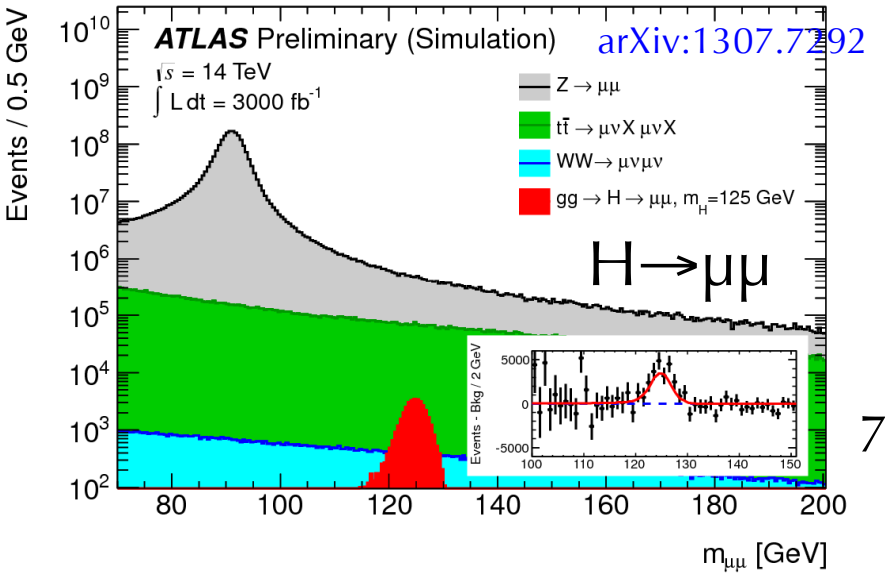


New Higgs channels…

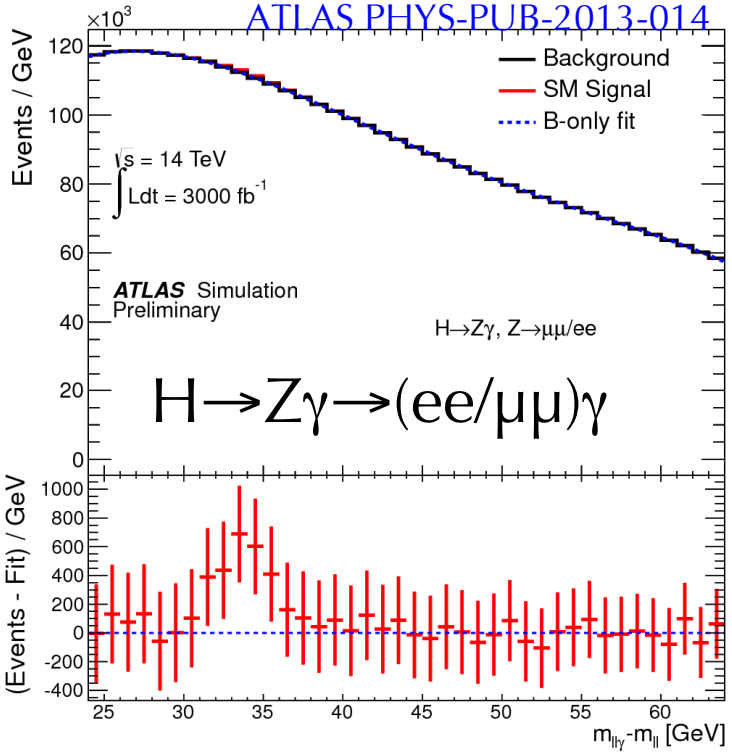
arXiv:1307.7292



ttH,H→γγ : clean signature S/B~20%



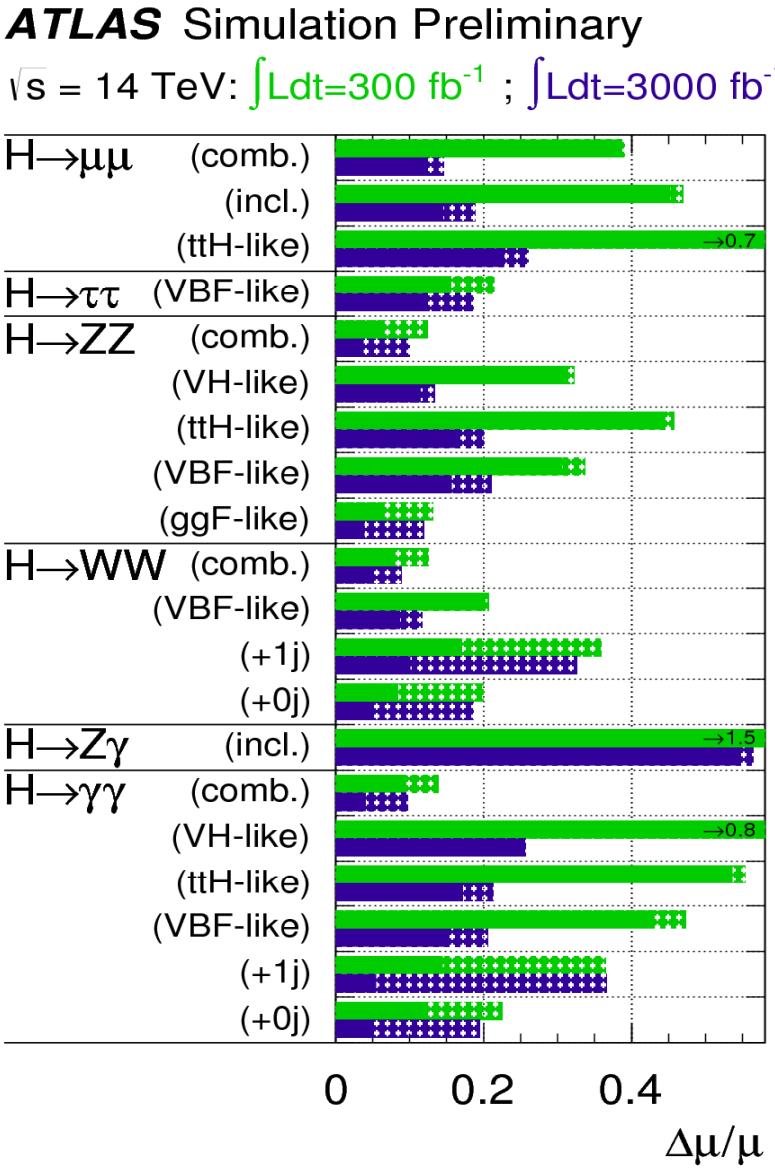
arXiv:1307.7292



7σ observation (inclusive)

Higgs signal strength

ATLAS PHYS-PUB-2013-014



Signal strength $\mu = \sigma_{obs}/\sigma_{SM}$

Δμ/μ(H->bb) from CMS

300fb^{-1} : 7-11%

3000 fb^{-1} : 5-7%

NB: not comparable with the ATLAS result

with 3000 fb^{-1}

H→μμ : 15%

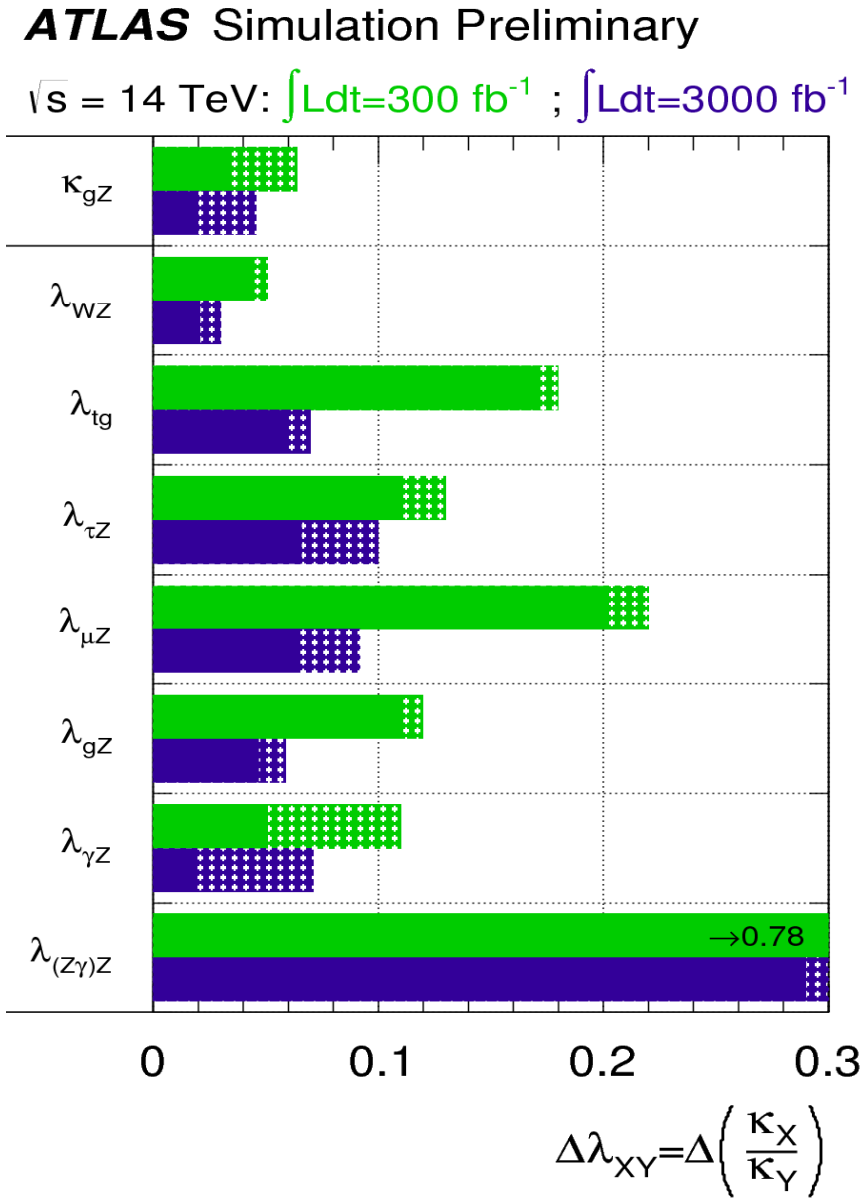
H→Zγ : 57%

Theory uncertainty also dominates

(comb)	total	w/o thr.
H->WW	9%	5%
H->ZZ	10%	4%
H->γγ	10%	4%

Higgs coupling ratios

ATLAS PHYS-PUB-2013-014



Extract Higgs couplings

ratio of H-couplings to aa/bb

$$\lambda_{ab} = \kappa_a / \kappa_b$$

$$\sigma \cdot Br(i \to H \to f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H}$$

$$\kappa_a^2 = (\sigma_{obs}/\sigma_{obs})_a = (\Gamma_{obs}/\Gamma_{obs})_a$$

Assumption
- $\Gamma_H = \Gamma_{SMtotal}$
- No Br(H→invisible/NP)
- cc scale with ττ

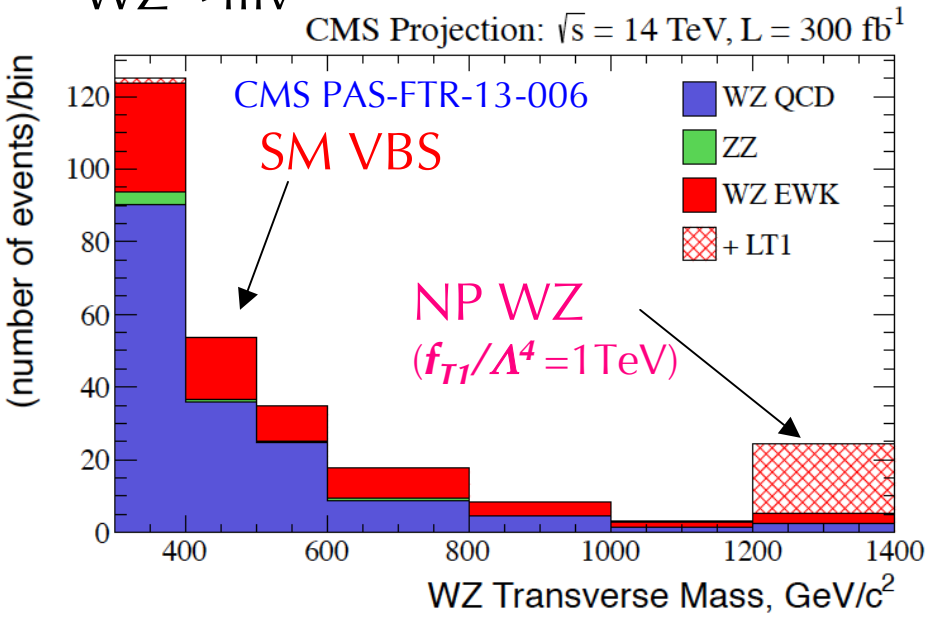
ττ is used to fix H->fermions.

Coupling ration becomes better by a factor 2~3 with HL-HLC run.

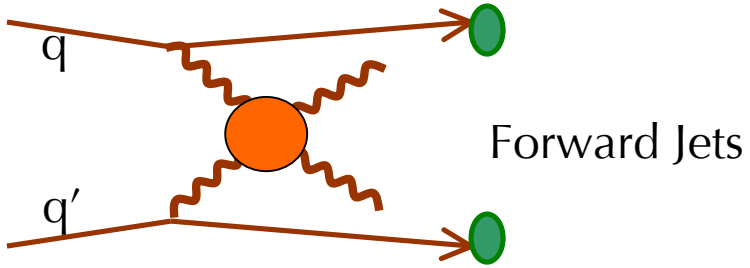
Vector boson scattering

Observation of VBS and possibly associated new physics.

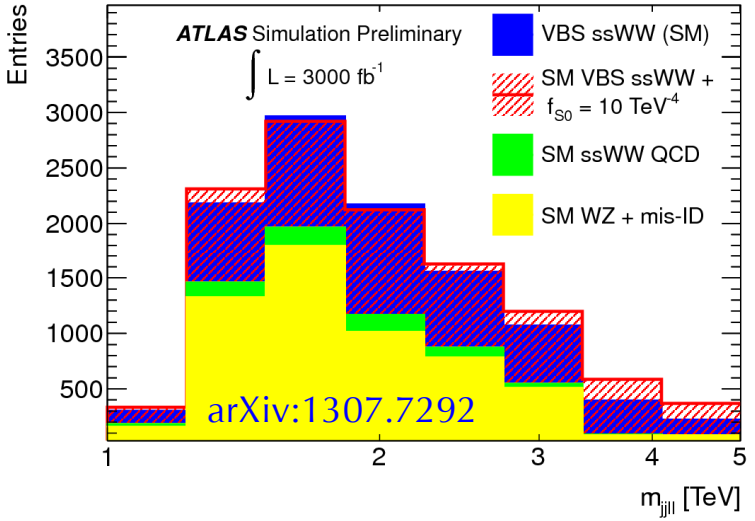
WZ→lllν



significance	3σ	5σ
SM VBS	**75fb^{-1}**	**185fb^{-1}**
f_{T1}/Λ^4 (300fb^{-1})	**0.8TeV^{-4}**	**1.0TeV^{-4}**
f_{T1}/Λ^4 (3000fb^{-1})	**0.45TeV^{-4}**	**0.55TeV^{-4}**



$W^{\pm}W^{\pm} \rightarrow l^{\pm}\nu l^{\pm}\nu$



$W^{\pm}W^{\pm}$ is also sensitive..
Main (conservative) background is SM WZ/Wγ with mis-identified lepton.
(2x N_b from RUN1 result)

Summary

Successful operation of LHC at 7-8TeV in 2009-2012.

No sign of the existence of NP/SUSY…

But, many inputs for SUSY model building and hope SUSY driven into a corner…

We hope to(should) find SUSY-like signature in RUN2!

Even SUSY within the LHC reach, the discovery could be tough. Make doubly sure!!

Great sensitivity is expected in RUN2

	LHC8 95%CL exclusion		**LHC14 5σ discovery (300fb^{-1})**
Gluino	**: ~1.4TeV**	→	**~1.8TeV**
Stop	**: ~600GeV**	→	**~1TeV**
Chargino	**: ~300GeV**	→	**~500GeV**