Inclusive SUSY search in the single-lepton final state at HL-LHC with $\sqrt{s} = 14$ TeV in CMS.

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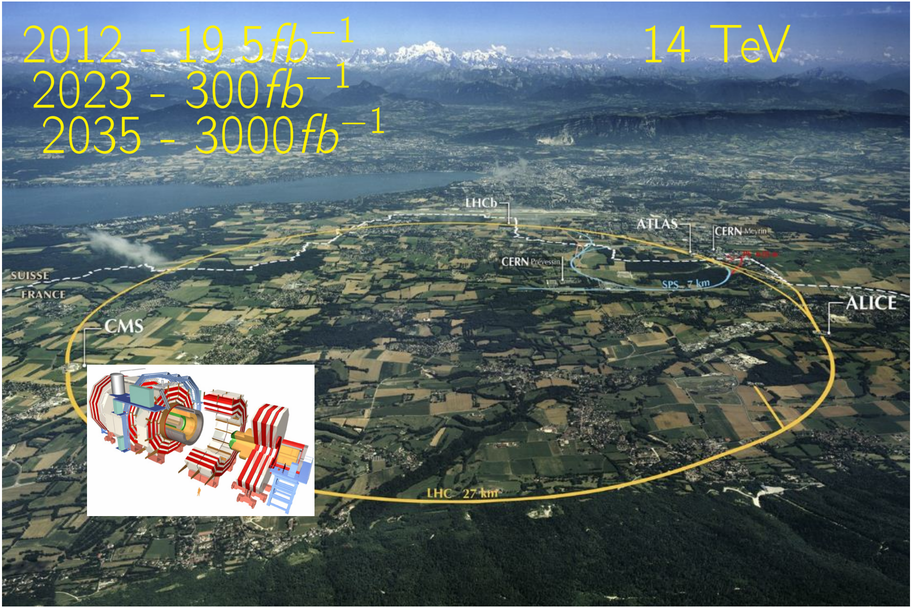
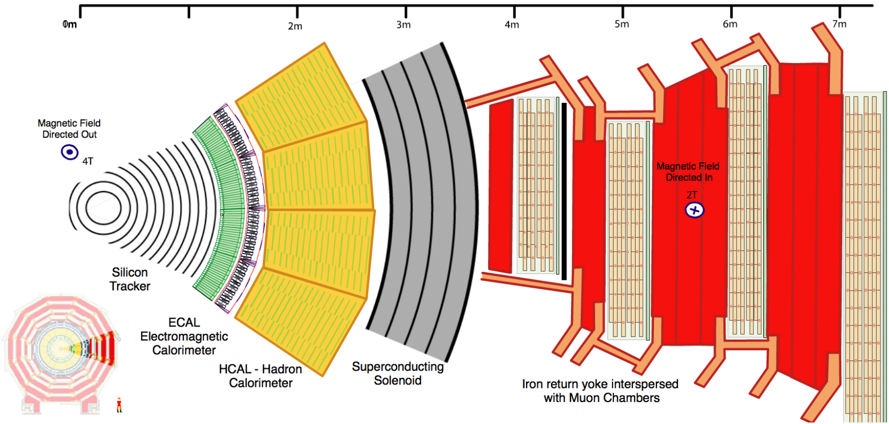
8 September, 2014, DESY

Outline

- Future of LHC and CMS experiment.
- Preparation for the next LHC run.
- SUSY production models.
- Single lepton final state.

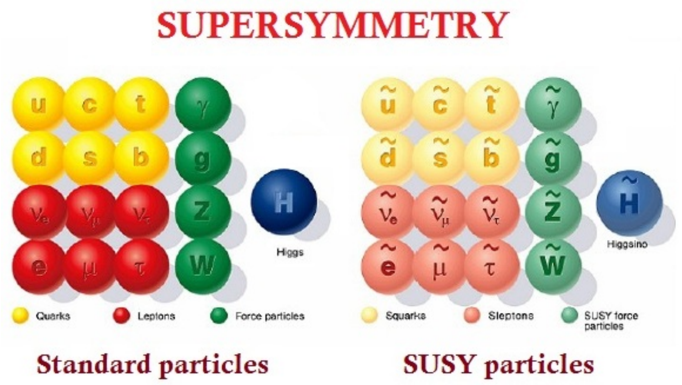

2012 - 19.5 fb^{-1}
2023 - 300 fb^{-1}
2035 - 3000 fb^{-1}
14 TeV
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

CMS detector



SUSY

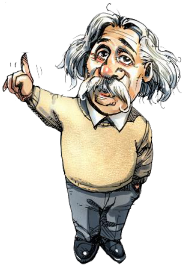
Standard model can't describe everything.



Too many free parameters. BUT we hope to see SUSY production at next LHC run at $\sqrt{s} = 14$ TeV.

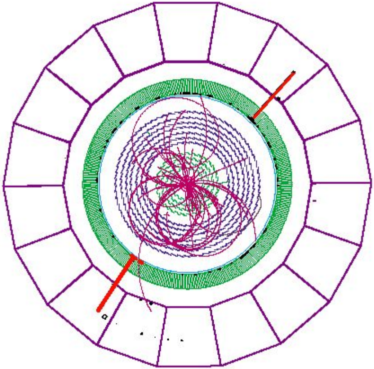
Preparation for the next LHC run. 4 main steps.

Theoretical model



Generating the data

Run detector simulation



Now we have several million genarated data. What is the next step?

Analyse it!

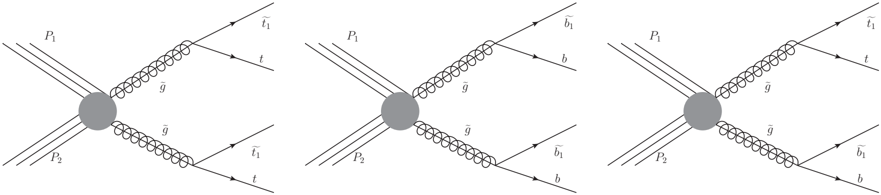
Only $\tilde{g}$ production

Pileup scenarios: 50PU and 140PU.

Natural models: NM1, NM2, NM3

- low 3^{rd} genaration squarks masses$\rightarrow$ cancel Higgs mass divergence.
- low $\widetilde{\chi}$ masses.

99% $\widetilde{g}\widetilde{g}$ production.We are interested in the single lepton final state.

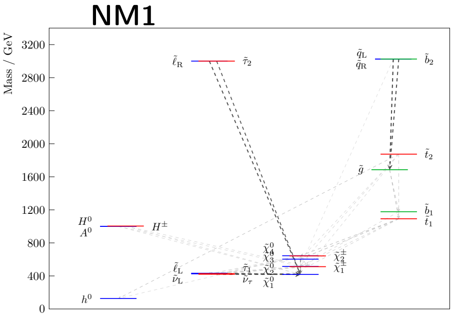


$$\widetilde{g} \longrightarrow \widetilde{t}_1 \overline{t},\ 60\ \%$$

$$\widetilde{g} \longrightarrow \widetilde{b}_1 \overline{b},\ 40\ \%$$

Mass spectrum

In NM1, NM2, NM3: $m(\widetilde{g}) = 1.7$ TeV, $m(\widetilde{t}_1) = 1$ TeV, $m(\widetilde{b}_1) = 1.2$ TeV
$\widetilde{\chi}^0_1$ - Lightest Supersymmetric Particle (LSP).



- $m(\widetilde{\chi}^1_0) = 419$ GeV,
- $m(\widetilde{\chi}^0_4) = 644$ GeV,
- $m(\widetilde{\chi}^{\pm}_1) = 512$ GeV,
- $m(\widetilde{\nu}) = 425$ GeV.

$\widetilde{t}_1 \rightarrow \widetilde{\chi}^0_4 t$, 30 %,

$\widetilde{\chi}^0_4 \rightarrow \widetilde{\chi}^{\pm}_1 W^{\pm}$, 16 %,

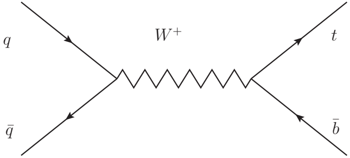
$\widetilde{\chi}^{\pm}_1 \rightarrow \widetilde{\nu} l^{\pm}$, 58 %,

$\widetilde{\nu} \rightarrow \widetilde{\chi}^0_1 \nu$, 100 %.

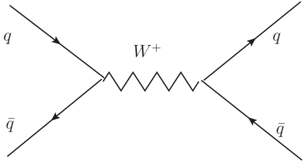
Main background processes

Main background:

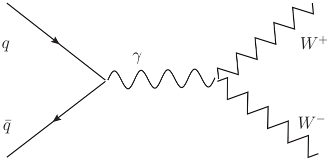
top-jet



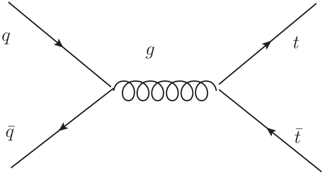
Boson+jets



DiBoson



$t\bar{t}$

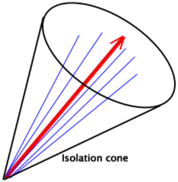


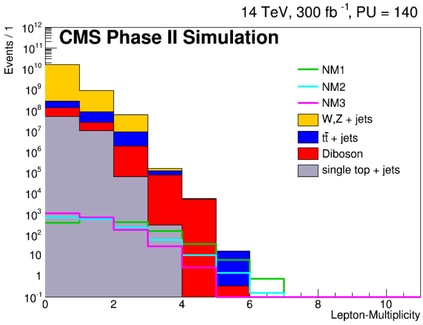
Lepton.

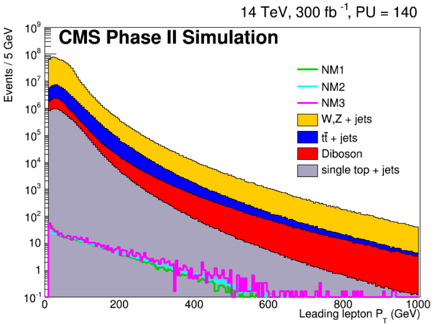
Lepton multiplicity after applying requirements:
$p_T > 10$ GeV, $|\eta_\mu| < 2.1$, $|\eta_{el}| < 2.4$, $I_{rel} < 0.15$, where

$$I_{rel} = \frac{\sum p_T}{p_T(lep)} \text{ in cone } \Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.3,$$

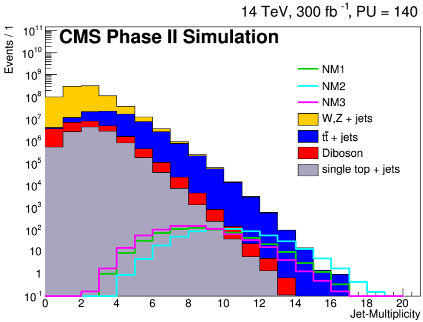
NM1 sample has the highest lepton multiplicity.

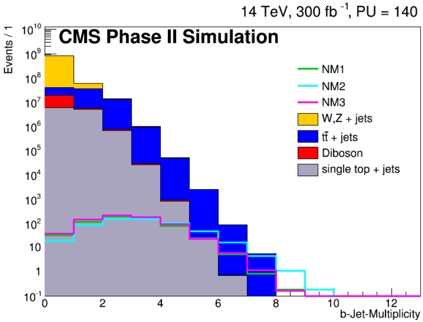






Jet and b-jet multiplicity after applying 1 lepton requirement and $p_T(jet) > 40$ GeV, $|\eta(jet)| < 2.5$:





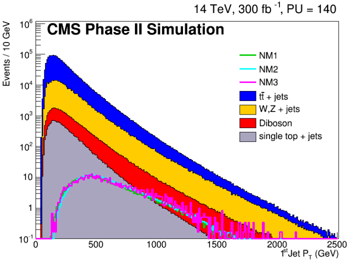
Signals have higher jet multiplicity than background.

Preselection

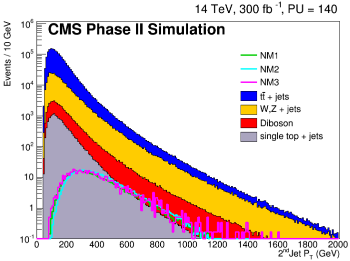
- Only one lepton : $p_T > 10\text{GeV}$, $|\eta_\mu| < 2.1$, $\||eta_{el}| < 2.4$, $rel.Iso < 0.15$
- Jet multiplicity ≥ 6
- $p_T > 40$ GeV, $|\eta| < 2.5$.
- Cleaning all the jets $\Delta R(jet, lep) > 0.3$, where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

Event Selection. Jets

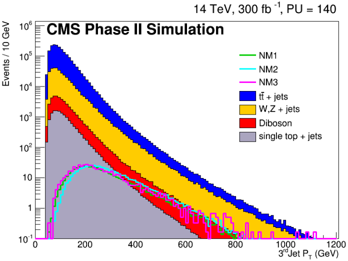
$P_T(1jet) > 300 GeV$



$P_T(2jet) > 200 GeV$



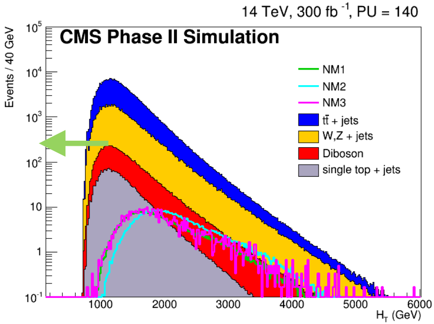
$P_T(3jet) > 75 GeV$

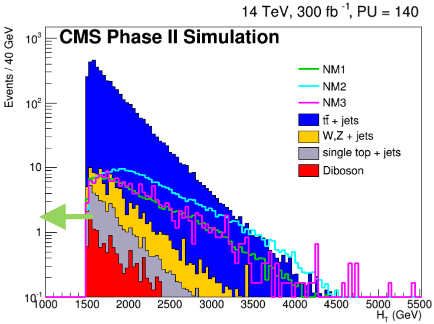


H_T after 1 lepton, jets preselection

$H_T = \sum_{all\ jets} |\vec{p_T}|$

$H_T > 1500$ GeV can supress background by two orders of magnitude.



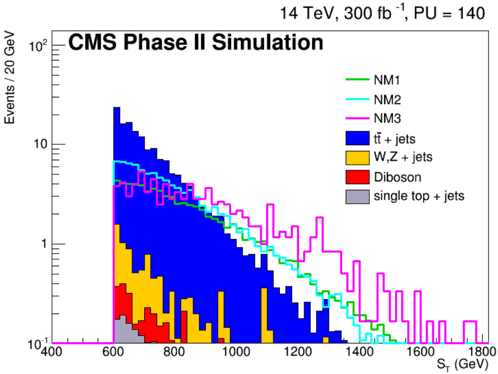


S_T after 1 lepton, jets preselection

$E_T^{miss} = | - \sum_{all \ particles} \vec{p}_T |$

$S_T = E_T^{miss} + p_T(l)$

$S_T > 600$ GeV:



L_P, $\Delta\phi$, $p_T(W)$

$$L_P = \frac{\vec{P_T}(l)\vec{P_T}(W)}{P_T(W)^2} = \frac{P_T(l)}{P_T(W)}\cos(\Delta\phi)$$

$$P_T(W) = \sqrt{(E_T^{\text{miss}})^2 + P_T^2(l) + 2 \cdot P_T(l) \cdot E_T^{\text{miss}} \cdot \cos(\Delta\phi(l, E_T^{\text{miss}}))}$$

$$\phi(W) = atan\frac{P_y}{P_x} = atan\frac{P_y(\nu) + P_y(l)}{P_x(\nu) + P_x(l)}$$

Preselection and event selection

Preselection and Event Selection to be applied :

Preselection:

- Only one lepton : $p_T > 10 GeV, |\eta_\mu| < 2.1, |\eta_{el}| < 2.4, Iso < 0.15$
- Cleaning all the jets $\Delta R(jet, lep) < 0.3$
- Jet multiplicity ≥ 6
- $p_T > 40$ GeV, $|\eta| < 2.5$.
- $p_T(1jet) > 300$GeV, $p_T(2jet) > 200$GeV,$p_T(3jet) > 75$GeV

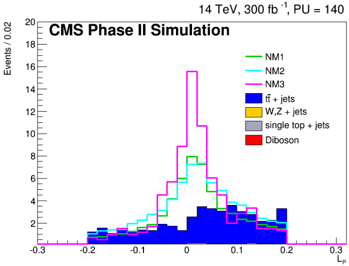
Event Selection:

- $H_T > 1500$ GeV
- $|L_P| < 0.2$
- 6 different search bins using S_T threshold and b-jet multiplicity:

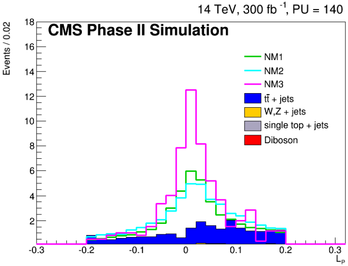
SR	Selection	SR	Selection
1	$\geq$ 3 b-jets, $S_T > 600$ GeV	4	$\geq$ 4 b-jets, $S_T > 600$GeV
2	$\geq$ 3 b-jets, $S_T > 700$ GeV	5	$\geq$ 4 b-jets, $S_T > 700$GeV
3	$\geq$ 3 b-jets, $S_T > 800$ GeV	6	$\geq$ 4 b-jets, $S_T > 800$GeV

Lp in 4 different search bins, PU = 140

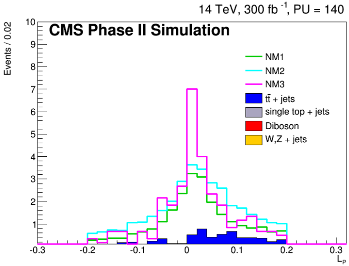
B-jet ≥ 3, HT $>$ 1500GeV, $S_T > 600$GeV



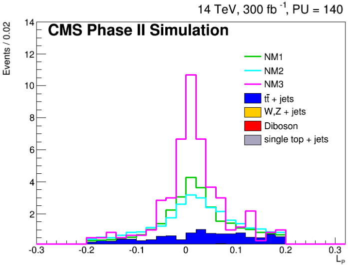
B-jet ≥ 4, HT $>$ 1500GeV, $S_T > 600$GeV



B-jet ≥ 3, HT $>$ 1500GeV, $S_T > 700$GeV



B-jet ≥ 3, HT $>$ 1500GeV, $S_T > 800$GeV



6 search bins, 300 fb^{-1}, PU = 140

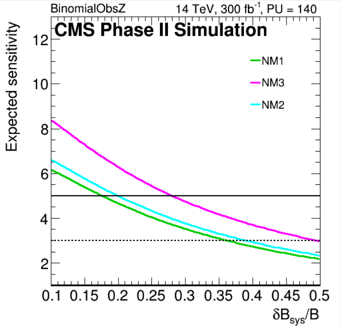
Number of events after cut |Lp|<0.2						
Sample	3B-jet,S_T>600	3B,S_T>700	3B,S_T>800	4B,S_T>600	4B,S_T>700	4B,S_T>800
TTbar	42	20	10	6	3	1
BosonJets	1	1	1	0	0	0
DiBoson	0	0	0	0	0	0
TopJets	0	0	0	0	0	0
Total SM	44	21	11	6	3	1
NM1	56	41	28	23	17	11
NM2	67	45	28	33	22	14
NM3	76	60	48	30	22	18

Significance

BinomialObsZ

$$Z = \frac{x-\mu}{\sigma}, Z = \Phi^{-1}(p)$$

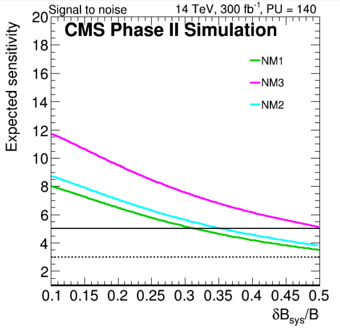
Binomial propability p-value.



Signal to noise ratio

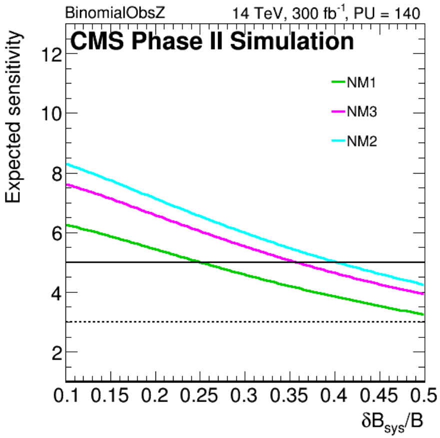
$$Z = \frac{S}{B + (\delta B)^2}$$

Too high values.

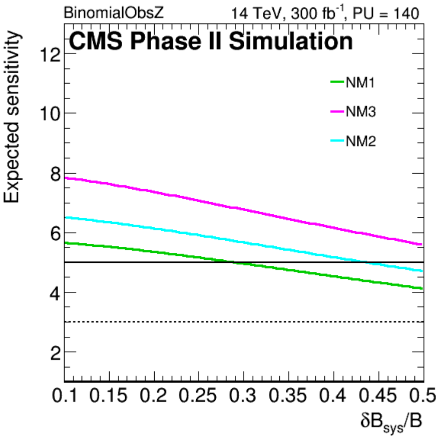


Significance using BinomialObsZ, 300 fb^{-1}

B-jet ≥ 4, $S_T > 600$GeV



B-jet ≥ 4, $S_T > 800$GeV



Significance dependence on luminosity, $\delta B/\mathrm{B} = 0.2$ and $\delta B/\mathrm{B} = 0.3$

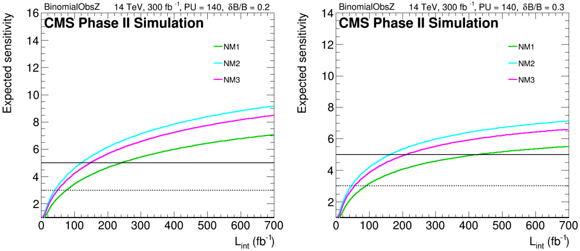
Calculated using binomial probability p-value, BinomialObsZ in RooStats

NM3 would be discovered with 150 fb^{-1} data.

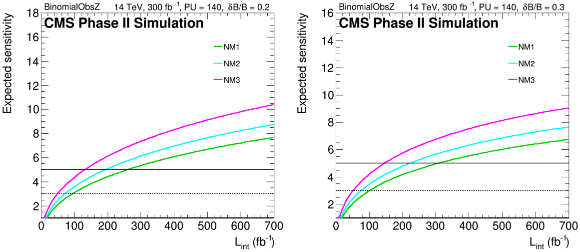
NM2 would be discovered with 220 fb^{-1} data.

NM1 would be discovered with 300 fb^{-1} data.

B-jet $\geq$ 4, H_T > 1500GeV, S_T > 600GeV



B-jet $\geq$ 4, H_T > 1500GeV, S_T > 800GeV



Summary

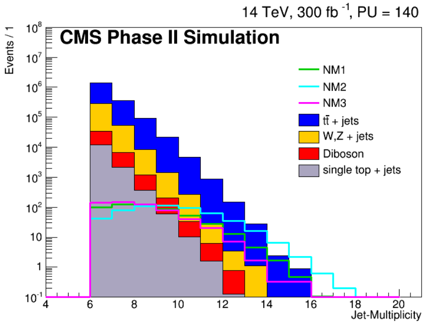
- NM1,NM2,NM3 models were investigated.
- 6 different search bins were found to reach sensitivity in 5 σ for NM1,NM2,NM3 for 300 fb^{-1}.
- Sensitivity dependence on a background uncertainty and integrated luminosity were presented.
- We are looking forward for the next LHC run and ... patiently waiting for SUSY discovery :)

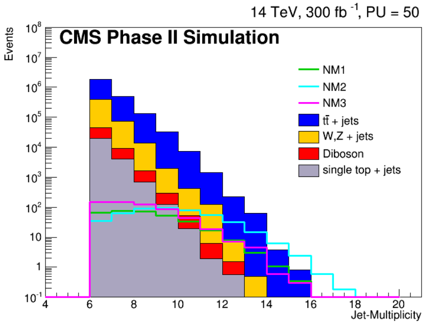
"If I have ever made any valuable discoveries, it has been owing more to patient attention, than to any other talent.", ***Isaac Newton***

Thank you for your attention!

BACK UP

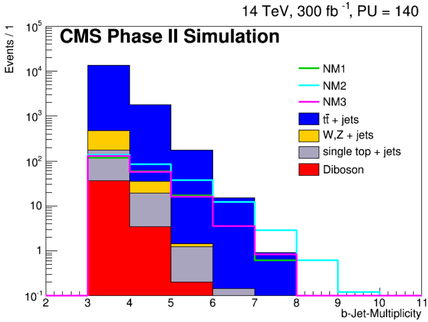
Preselection. Jets

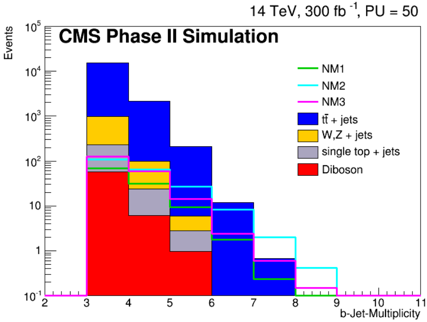




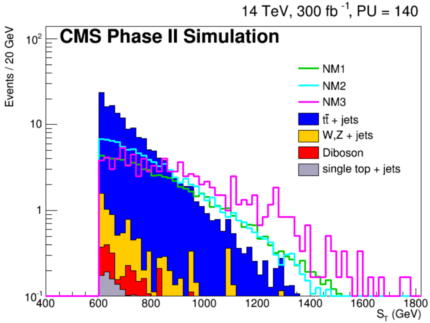
Preselection. B-jets

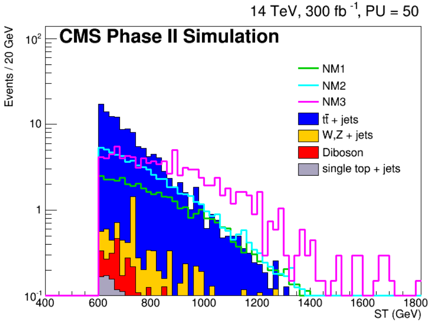
B-jets multiplicity after lepton and jets preselection.



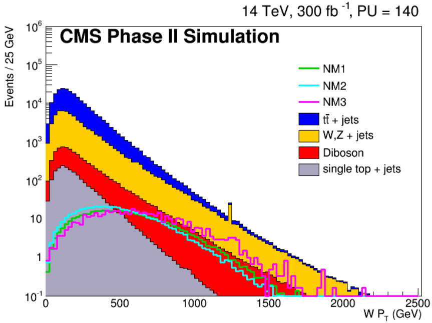


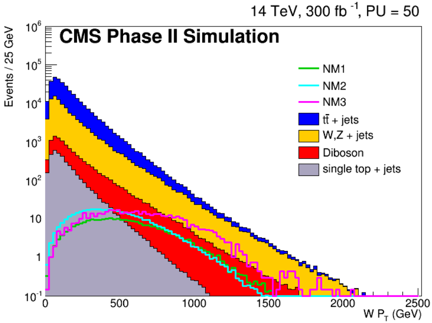
ST after preselection and HT>1500



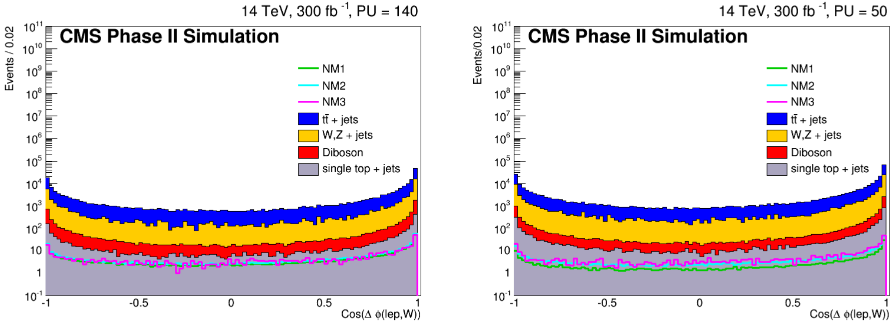


$p_T(W)$


14 TeV, 300 fb -1, PU = 140
CMS Phase II Simulation
Events / 25 GeV
W P_T (GeV)
NM1
NM2
NM3
tt̄ + jets
W,Z + jets
Diboson
single top + jets

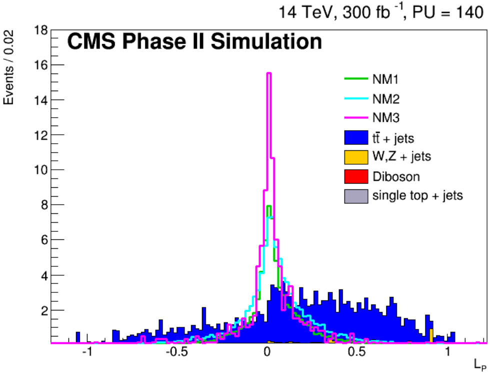

14 TeV, 300 fb -1, PU = 50
CMS Phase II Simulation
Events / 25 GeV
W P_T (GeV)
NM1
NM2
NM3
tt̄ + jets
W,Z + jets
Diboson
single top + jets

$\cos\Delta\phi(W, lep)$

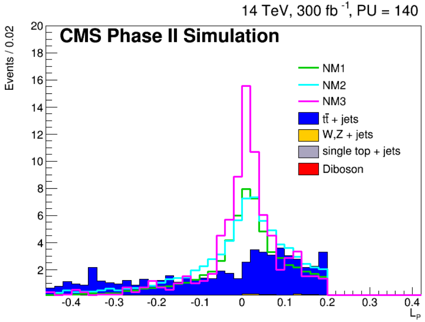


Lp after loose cut

Number of B-jets ≥ 3, $H_T > 1500$ GeV, $S_T > 600$ GeV

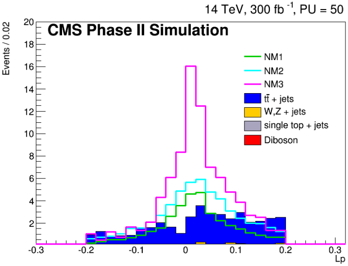


Number of B-jets ≥ 3, HT > 1500, ST > 600, Lp < 0.2, $|\text{Lp}| < 0.2$

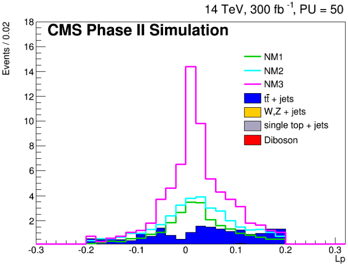


Lp in 4 serch bins, PU = 50

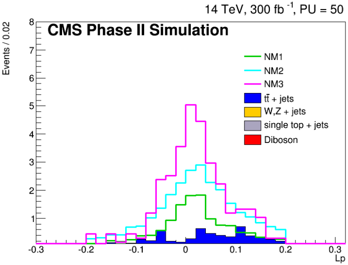
B-jet $\geq$ 3, HT $>$ 1500GeV, ST $>$ 600GeV



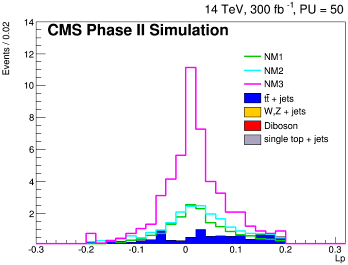
B-jet $\geq$ 4, HT $>$ 1500, ST $>$ 600



B-jet $\geq$ 3, HT $>$ 1500GeV, ST $>$ 700GeV

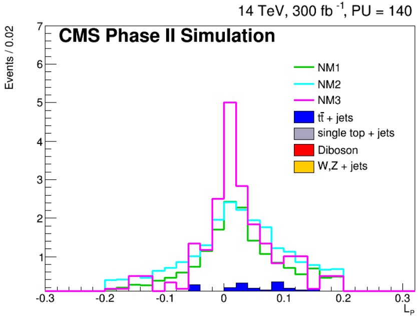


B-jet $\geq$ 3, HT $>$ 1500, ST $>$ 800

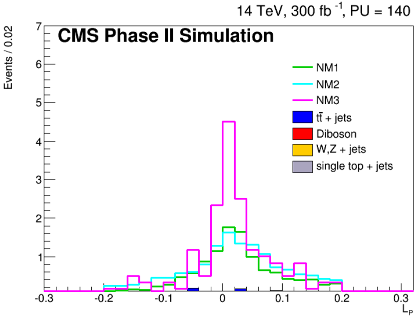


Lp in 2 different search bins, PU = 140

B-jet $\geq$ 4, HT $>$ 1500, ST $>$ 700

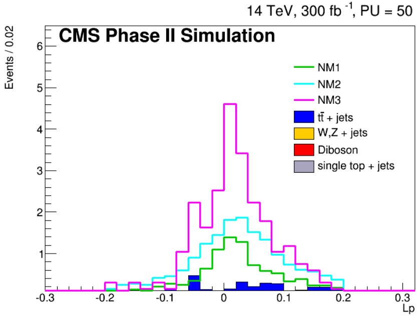


B-jet $\geq$ 4, HT $>$ 1500, ST $>$ 800

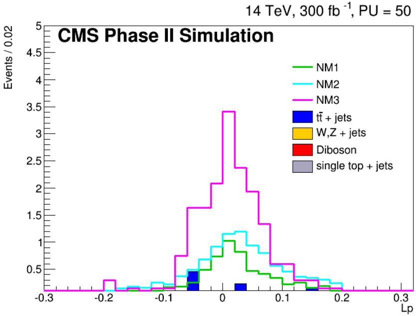


Lp in 2 different search bins, PU = 50

B-jet $\geq$ 4, HT $>$ 1500, ST $>$ 700



B-jet $\geq$ 4, HT $>$ 1500, ST $>$ 800



CutFlow

Number of events after cuts, 300 fb^{-1}, PU = 140						
Sample	pre	$\geq$3 B-jets	H_T>1500	S_T>600	L_P<0.2	$\|L_P\|$<0.2
TTbar	159400	14954	3845	144	69	42
BosonJets	54615	309	64	7	3	1
DiBoson	5495	40	13	2	1	0
TopJets	2082	155	31	2	1	0
Total SM	221592	15459	3952	154	73	44
NM1	444	198	158	71	61	56
NM2	509	275	255	94	76	67
NM3	482	208	164	95	83	76

Number of events after cuts, 300 fb^{-1}, PU = 50						
Sample	pre	$\geq$3 B-jets	H_T>1500	S_T>600	L_P<0.2	$\|L_P\|$<0.2
TTbar	220862	16683	5114	118	58	37
BosonJets	85618	808	209	5	3	1
DiBoson	6603	65	21	2	0	0
TopJets	3600	193	54	1	1	0
Total SM	316683	17748	5398	127	62	38
NM1	273	112	93	41	36	33
NM2	426	213	203	67	57	52
NM3	500	203	172	100	91	85

Number of events, 300 fb^{-1}, PU = 50

Number of events after cut |Lp|<0.2					
Sample	4B-jet,ST>600	3B-jet,ST>700	3B-jet,ST>800	4B-jet,ST>800	4B-jet,ST>800
TTbar	6	19	9	3	2
BosonJets	0	1	0	0	0
DiBoson	0	0	0	0	0
TopJets	0	0	0	0	0
Total SM	6	20	9	3	2
NM1	23	41	28	16	11
NM2	33	44	28	22	14
NM3	33	65	49	26	19

Signal Samples

$\tilde{\chi}_1^0$ - Lightest Supersymmetric Particle (LSP) in all models.

NM1

- $m(\tilde{g}) = 1.69$ TeV,
- $m(\tilde{t}_1) = 1.08$ TeV,
- $m(\tilde{b}_1) = 1.18$ TeV,
- $m(\tilde{\chi}_0^1) = 419$ GeV,
- $m(\tilde{\chi}_4^0) = 644$ GeV,
- $m(\tilde{\chi}_1^\pm) = 512$ GeV,
- $m(\tilde{\nu}) = 425$ GeV.

$\tilde{t}_1 \to \tilde{\chi}_4^0 t$, 30 %,

$\tilde{\chi}_4^0 \to \tilde{\chi}_1^\pm W^\pm$, 16 %,

$\underline{\tilde{\chi}_1^\pm \to \tilde{\nu} l^\pm, 58\ \%,}$

$\tilde{\nu} \to \tilde{\chi}_1^0 \nu$, 100 %.

NM2

- $m(\tilde{g}) = 1.69$ TeV,
- $m(\tilde{t}_1) = 1.08$ TeV,
- $m(\tilde{b}_1) = 1.18$ TeV,
- $m(\tilde{\chi}_0^1) = 199$ GeV ,
- $m(\tilde{\chi}_4^0) = 654$ GeV,
- $m(\tilde{\chi}_1^\pm) = 534$ GeV.

$\tilde{t}_1 \to \tilde{\chi}_4^0 t$, 30 %,

$\tilde{\chi}_4^0 \to \tilde{\chi}_1^\pm W^\pm$, 36 %,

$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^\pm$, 100 %.

NM3

- $m(\tilde{g}) = 1.69$ TeV,
- $m(\tilde{t}_1) = 1.14$ TeV,
- $m(\tilde{b}_1) = 1.16$ TeV,
- $m(\tilde{\chi}_0^1) = 195$ GeV,
- $m(\tilde{\chi}_4^0) = 837$ GeV,
- $m(\tilde{\chi}_1^\pm) = 201$ GeV.

$\tilde{t}_1 \to \tilde{\chi}_2^0 t$, 41 %,

$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 q\bar{q}$, 35 %.