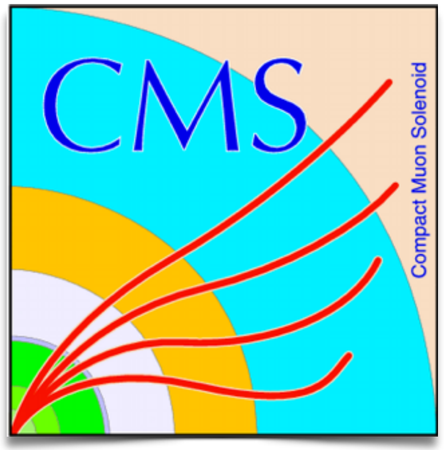
SUSY Searches at CMS

Carsten Hensel, CBPF, Rio de Janeiro
for the CMS Collaboration



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WHAT'S NEXT?

SUPERSYMMETRY INTRODUCTION

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PREFERRED ENERGY THRESHOLD FOR NEW PHYSICS

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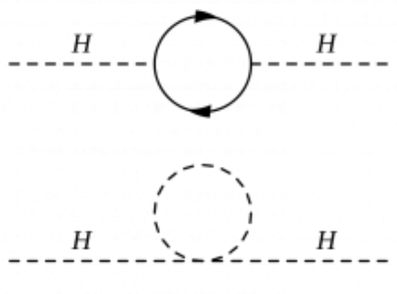

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ADDITIONAL LOOPS CANCEL QUADRATIC DIVERGENCIES

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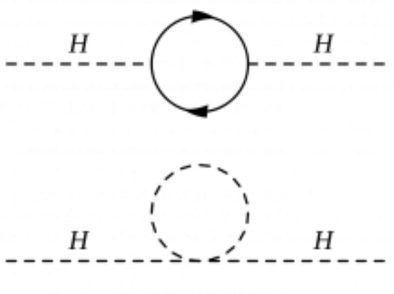

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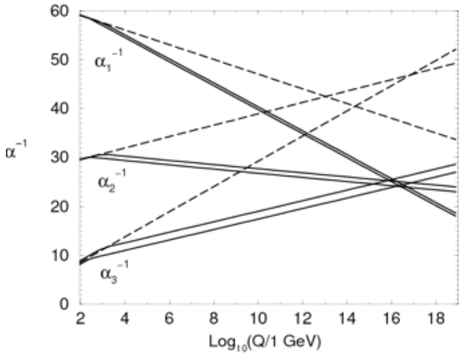

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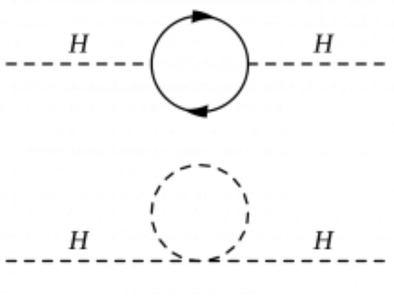

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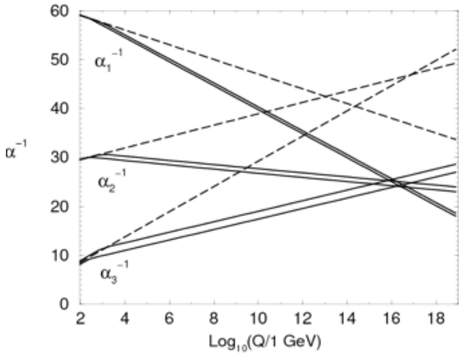

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LIGHTEST SUSY PARTICLE (LSP) (IF R-PARITY IS CONSERVED)

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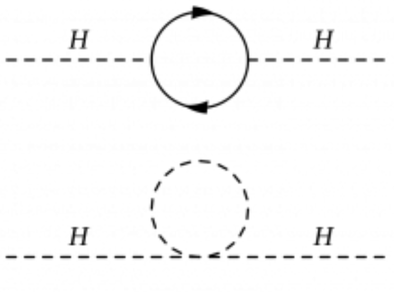

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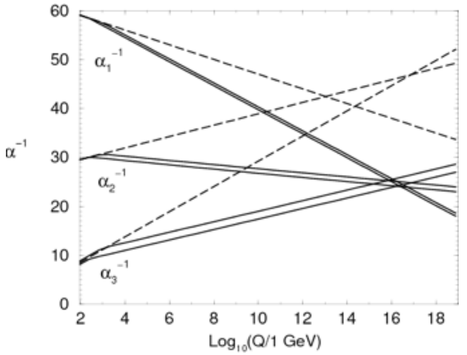

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SUSY has to be a broken symmetry

PARAMETRIZE SUSY BREAKING: 124 PARAMETERS

Minimal Supersymmetric Extension to the Standard Model

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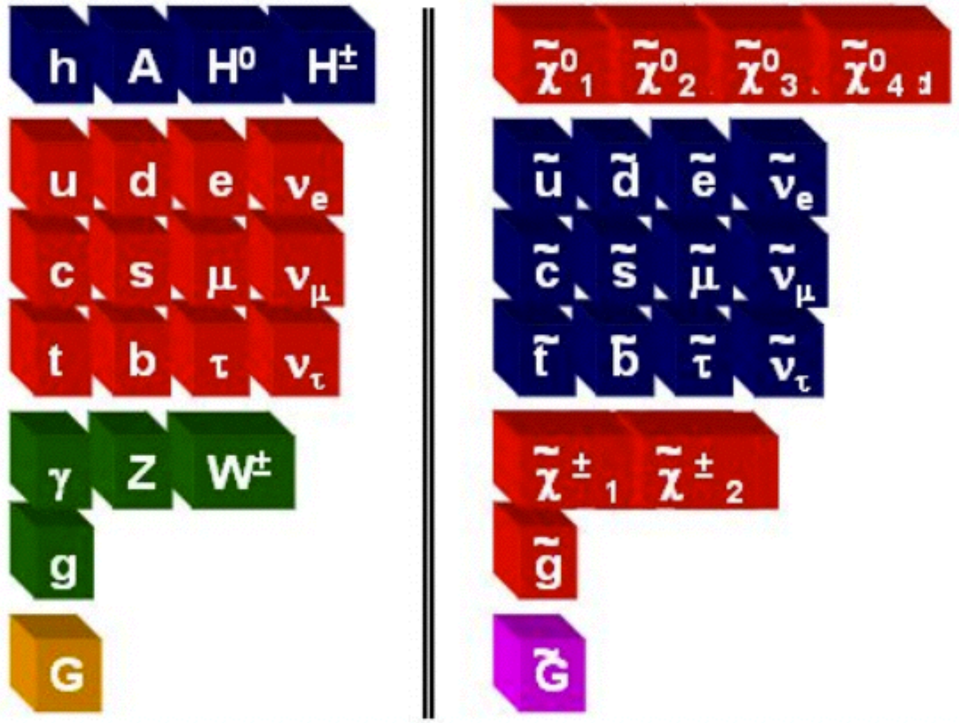

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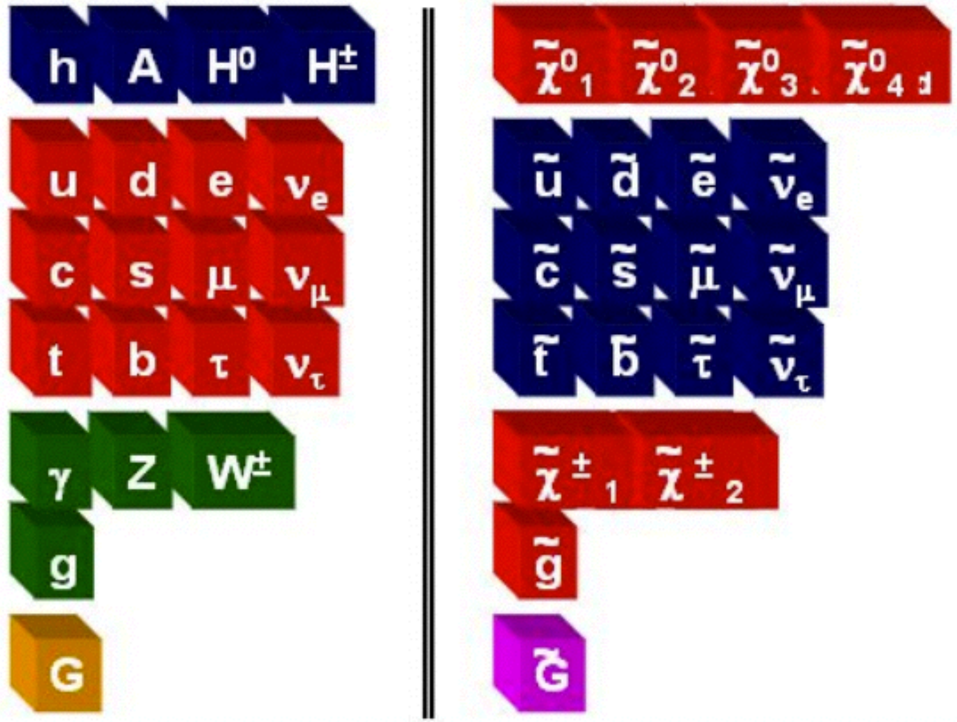

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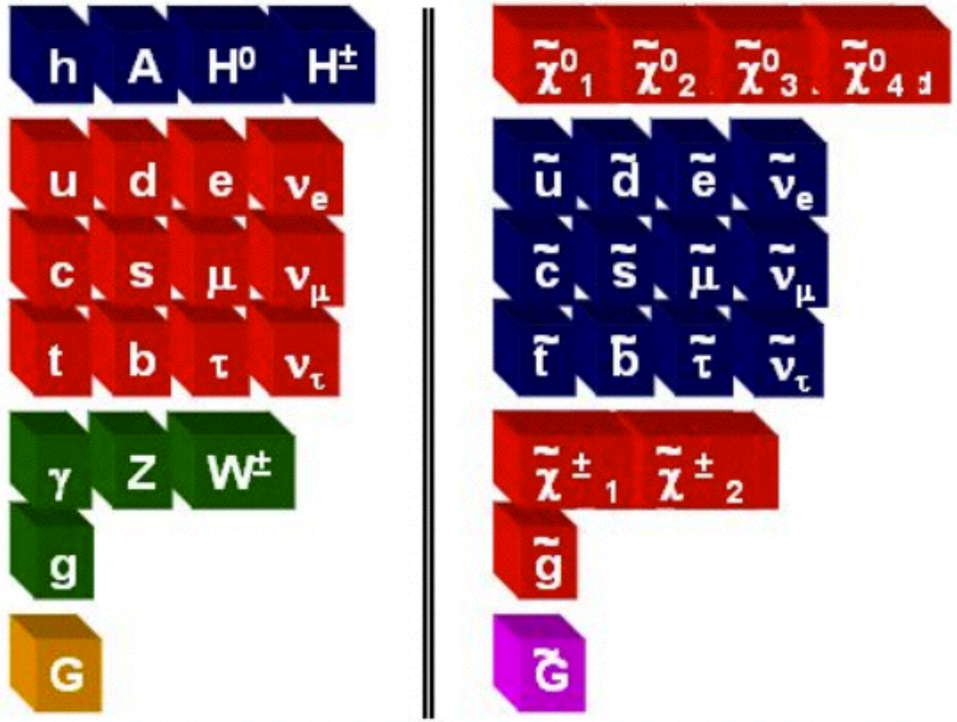

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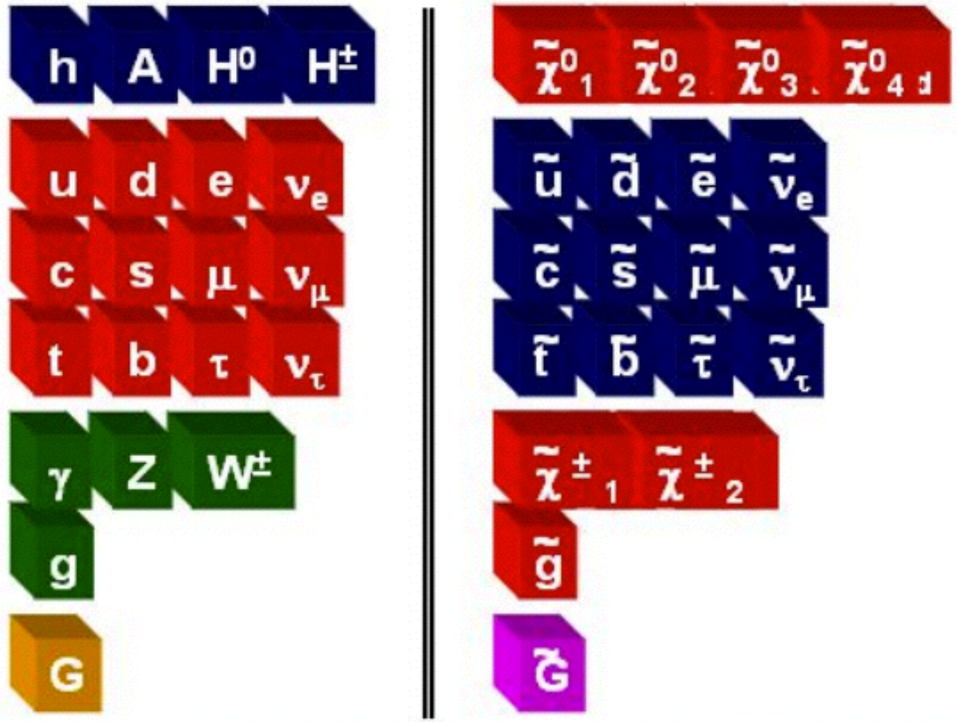

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SIMPLIFIED MSSM

- effective models with minimal particle content
- parametrized directly in terms of particle masses
- complementary to pMSSM

The CMS Experiment

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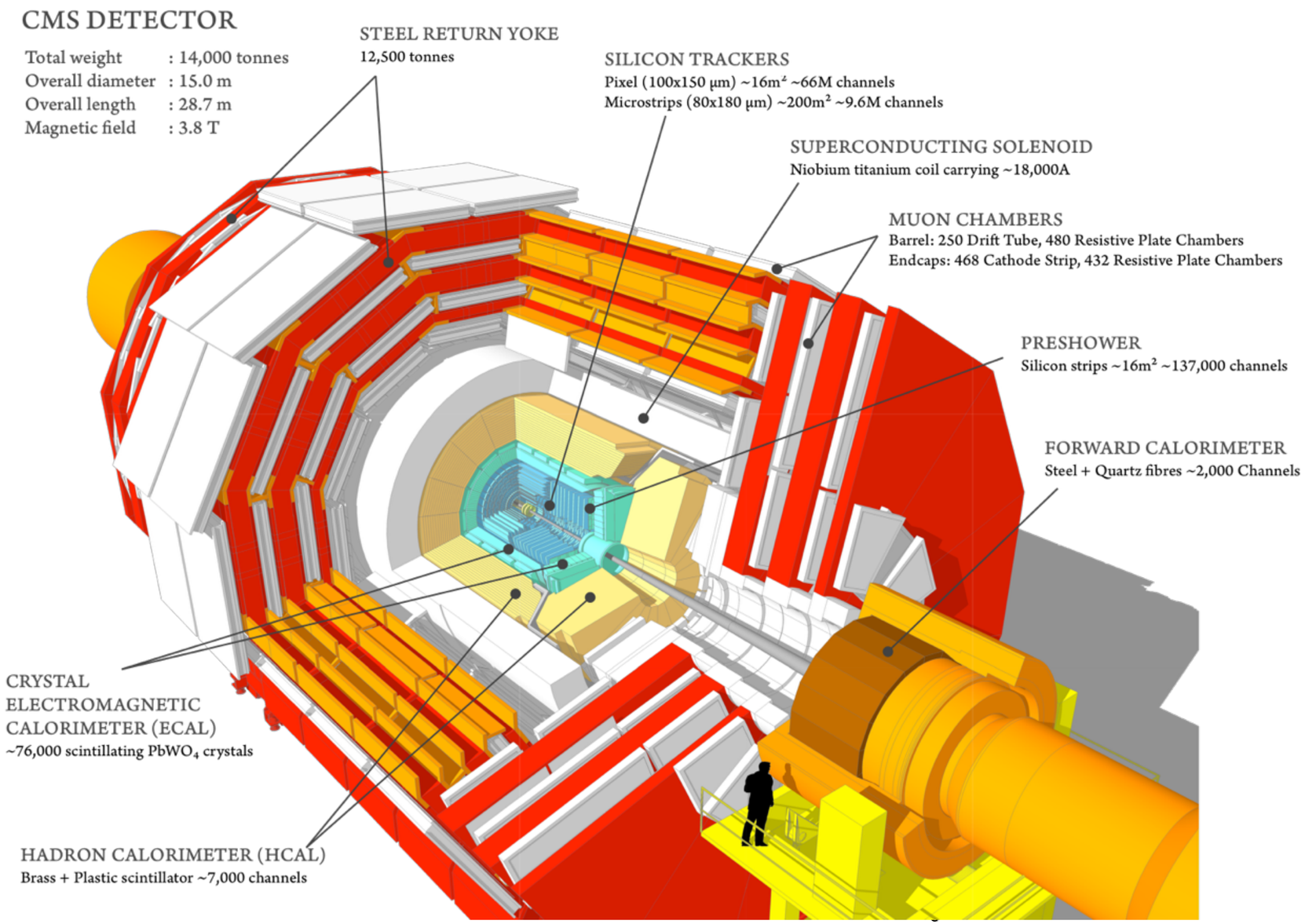

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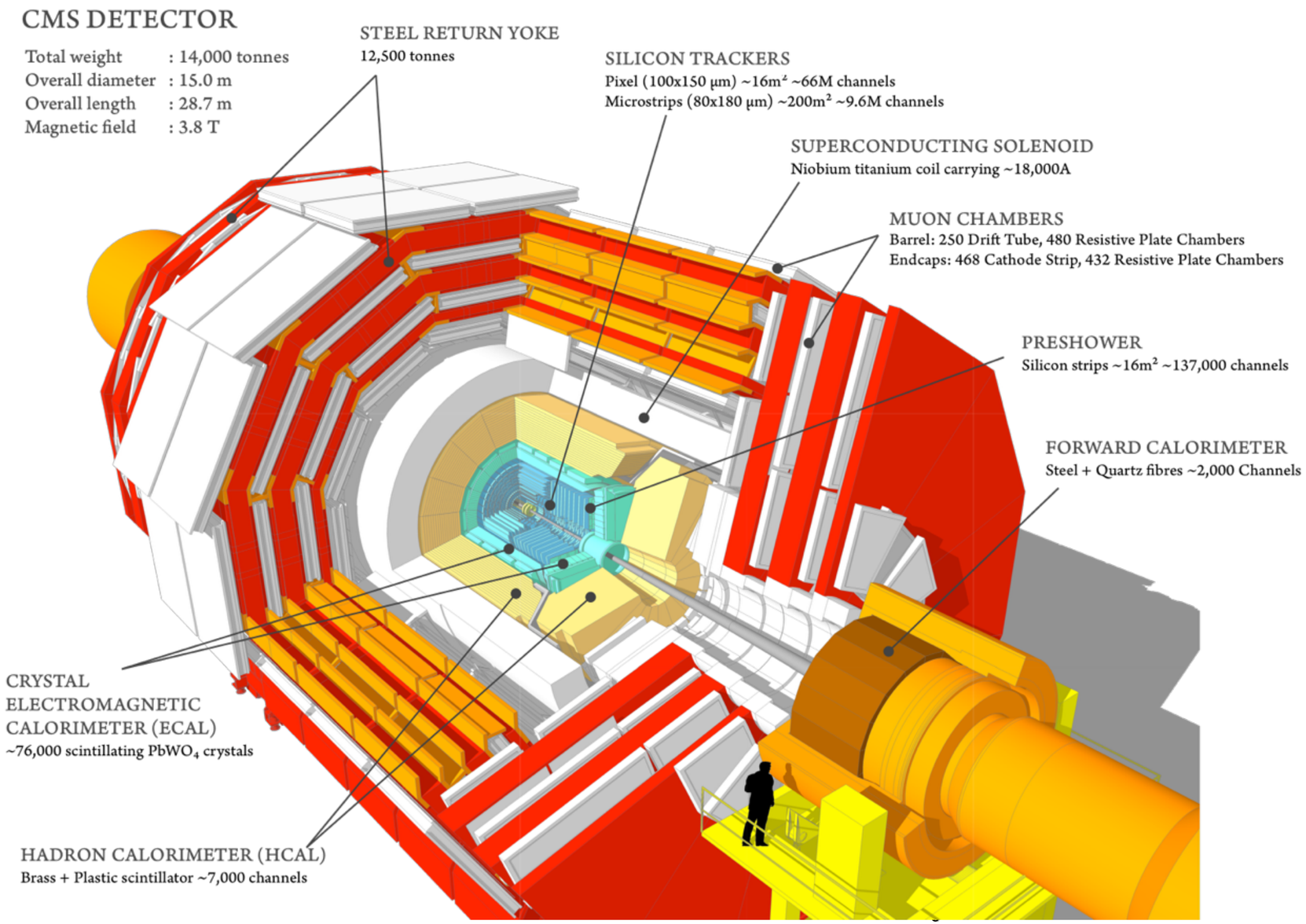

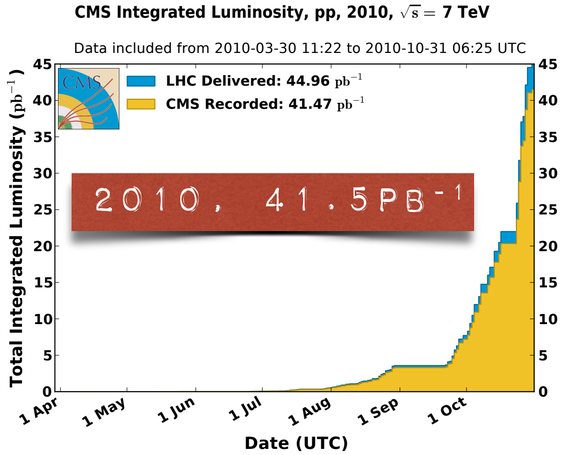

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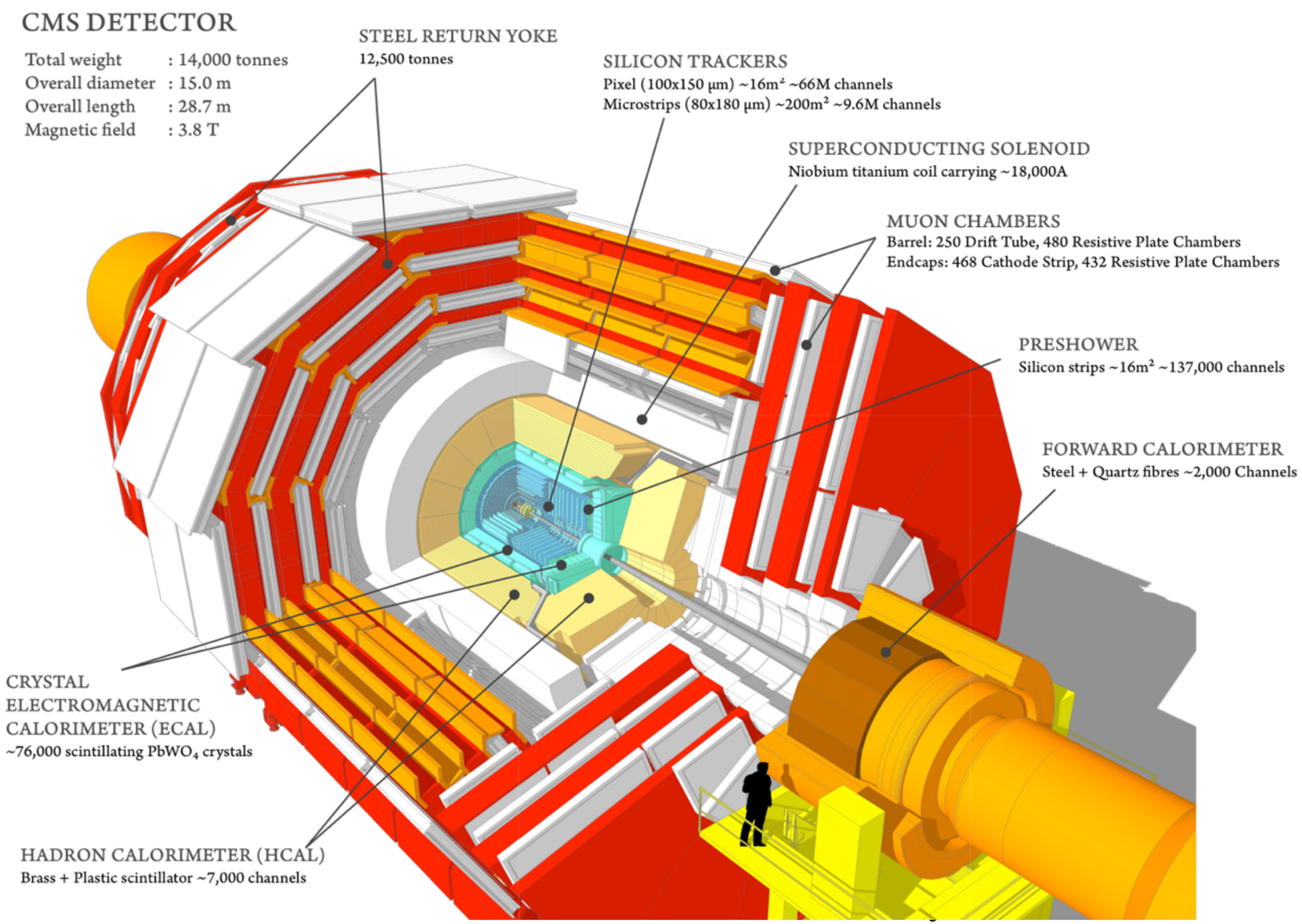

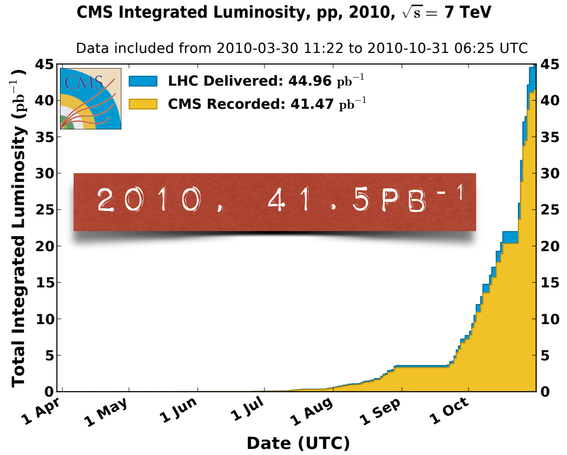

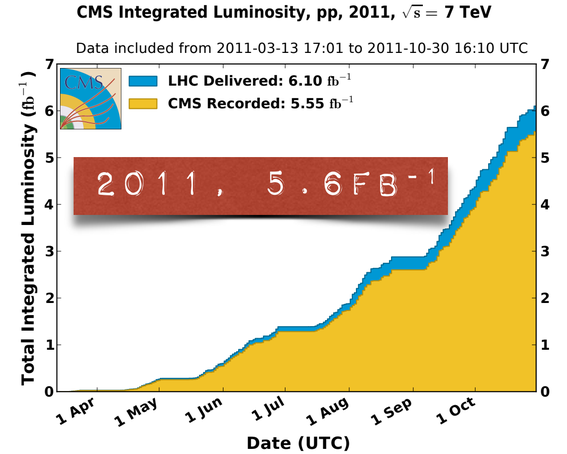

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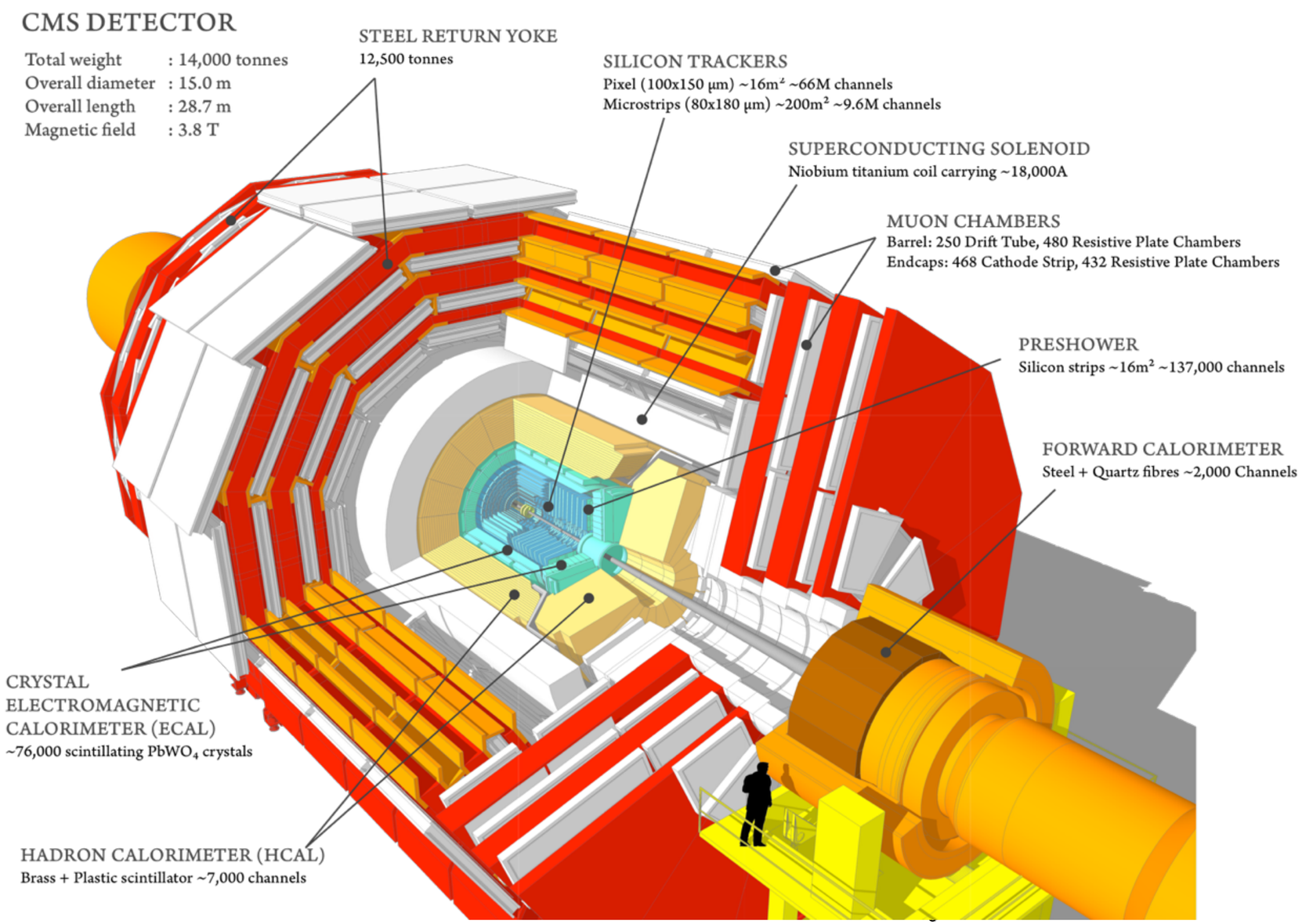

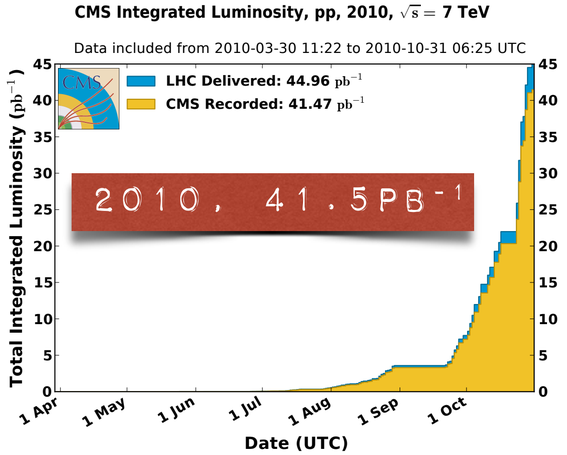

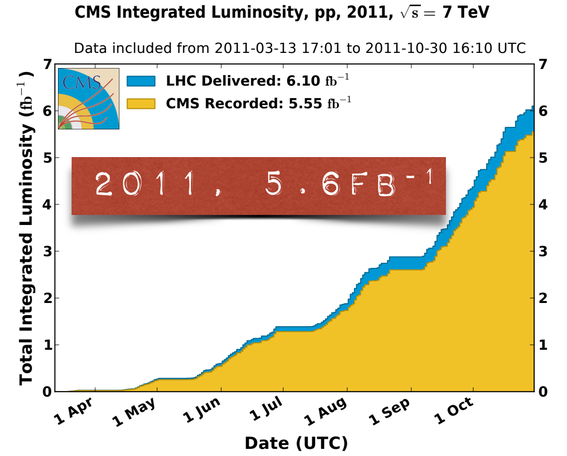

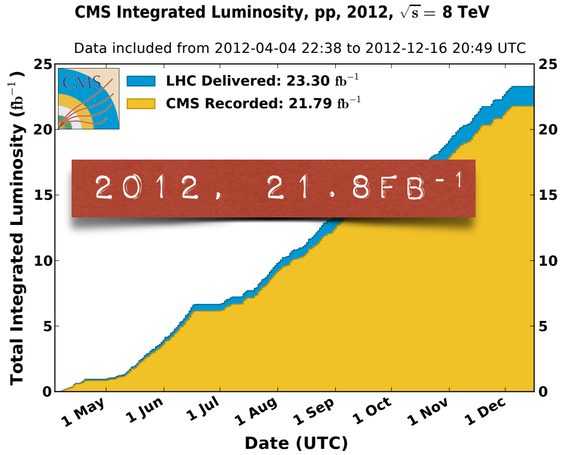

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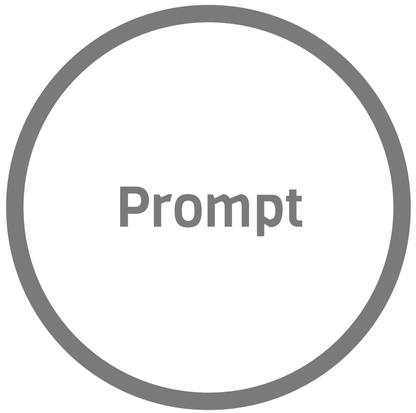

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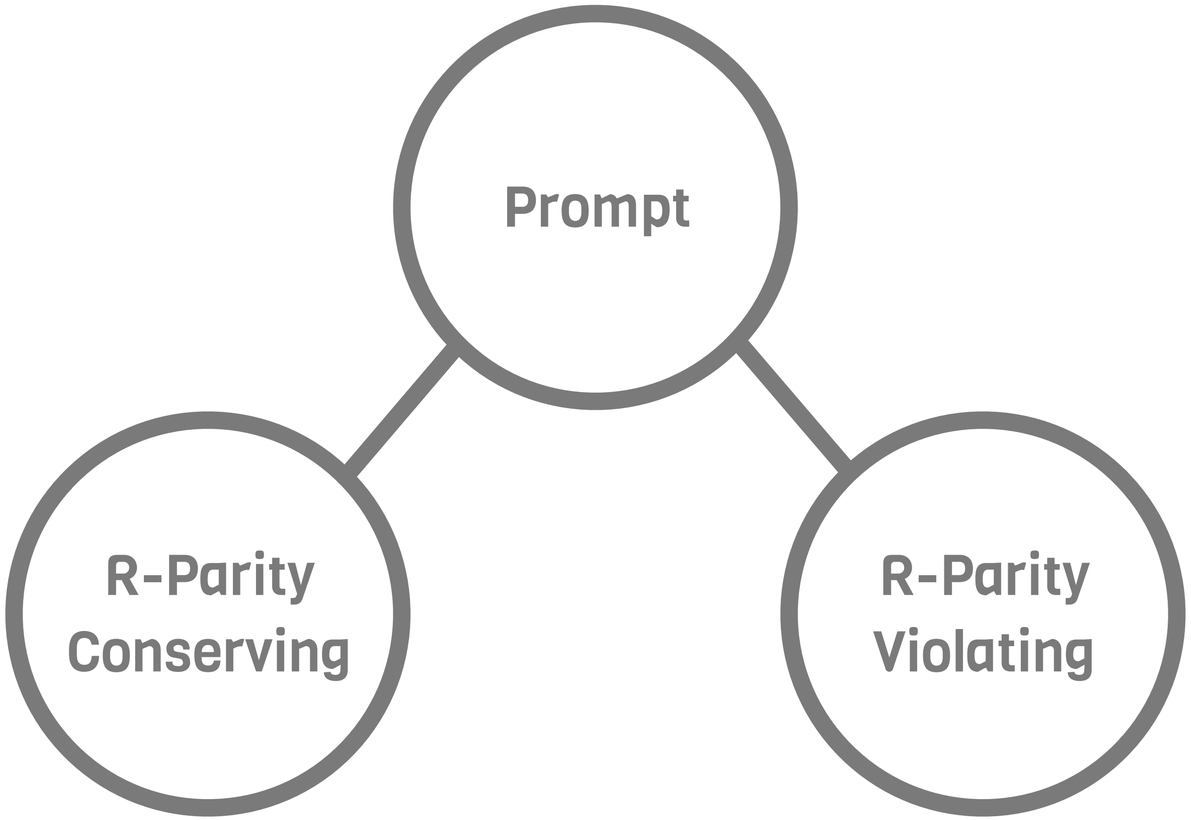

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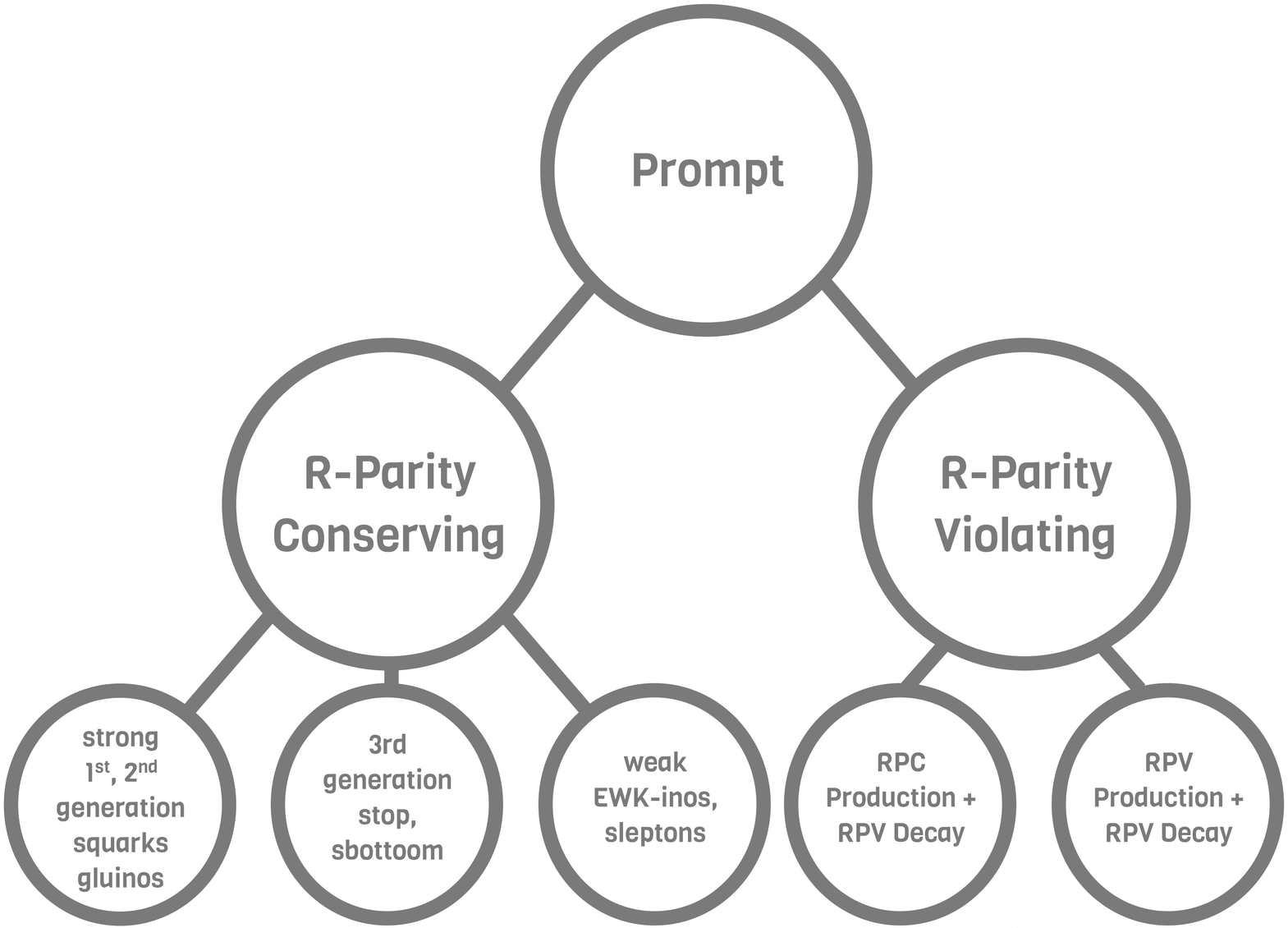

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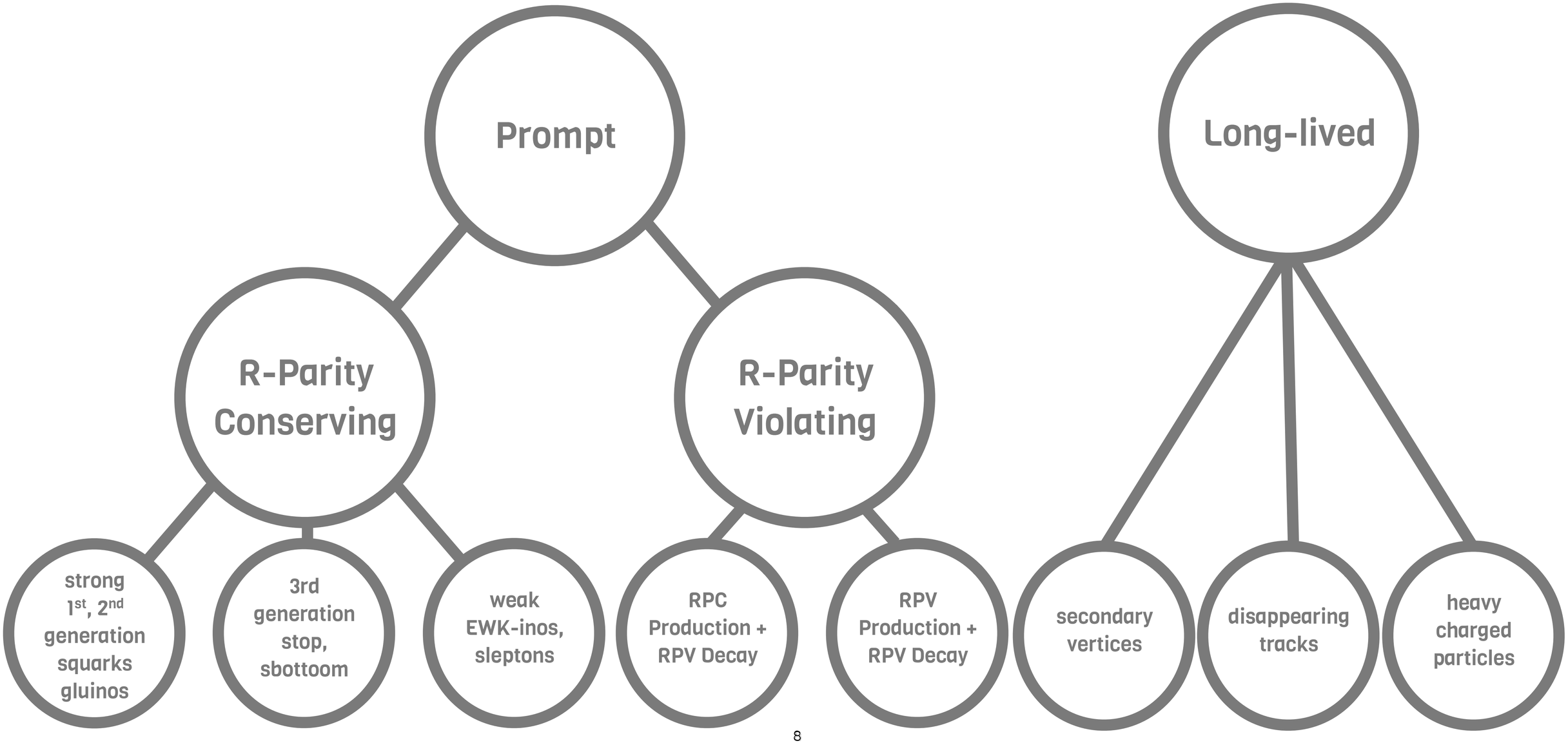
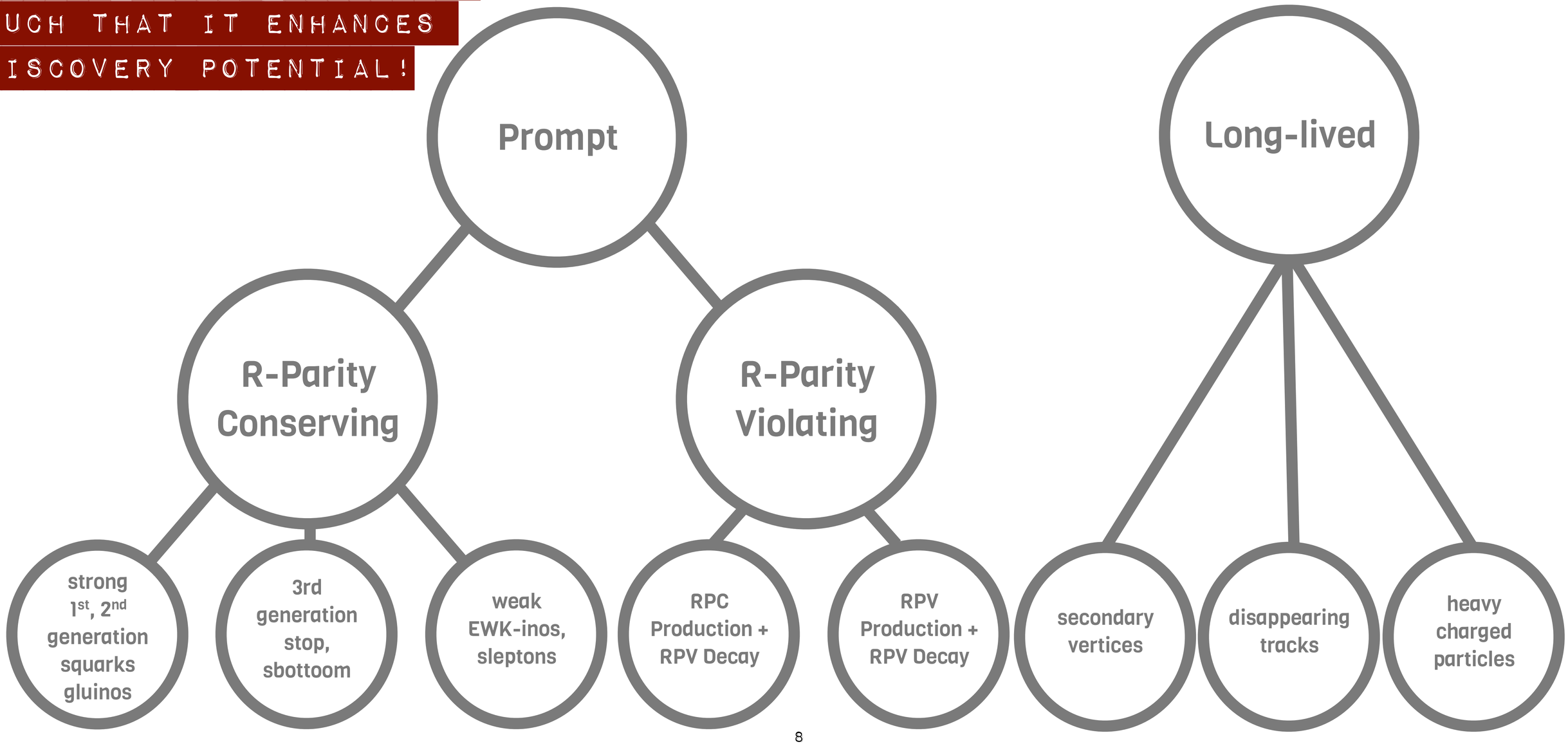


SUSY Signatures

DESIGN SEARCH STRATEGY SUCH THAT IT ENHANCES DISCOVERY POTENTIAL!



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- don't forget detector backgrounds

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Results I

'STANDARD' SEARCHES

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BACKGROUND CONTROL

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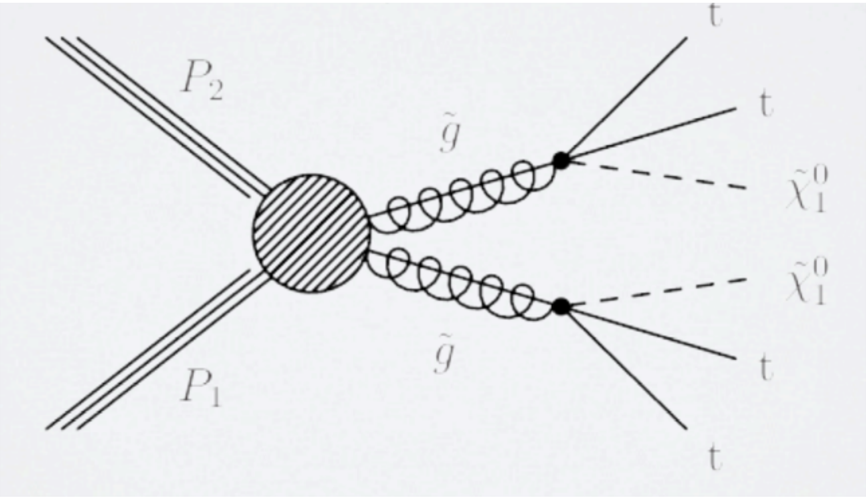

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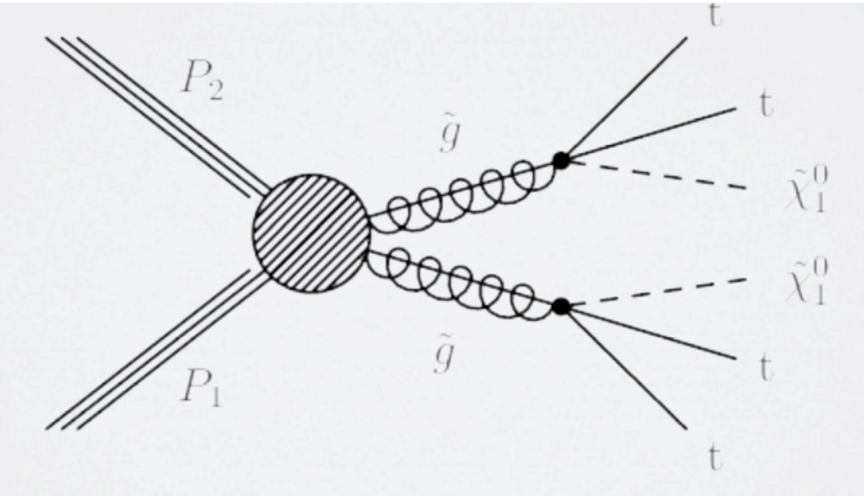

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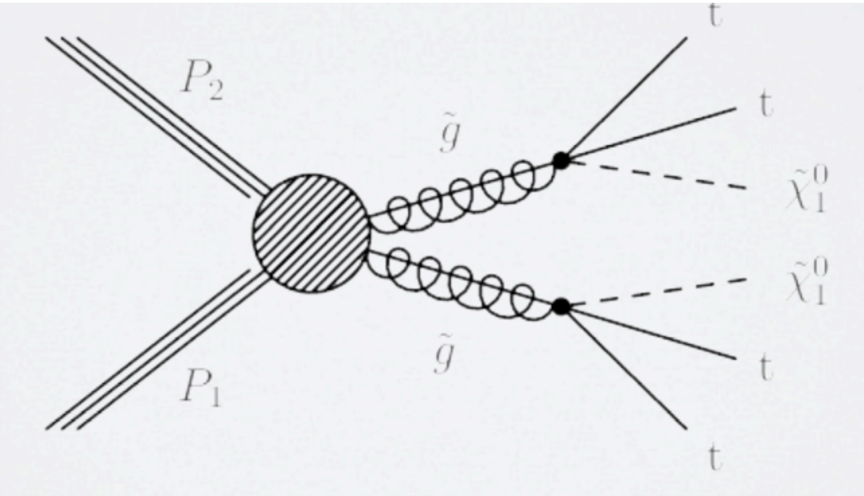

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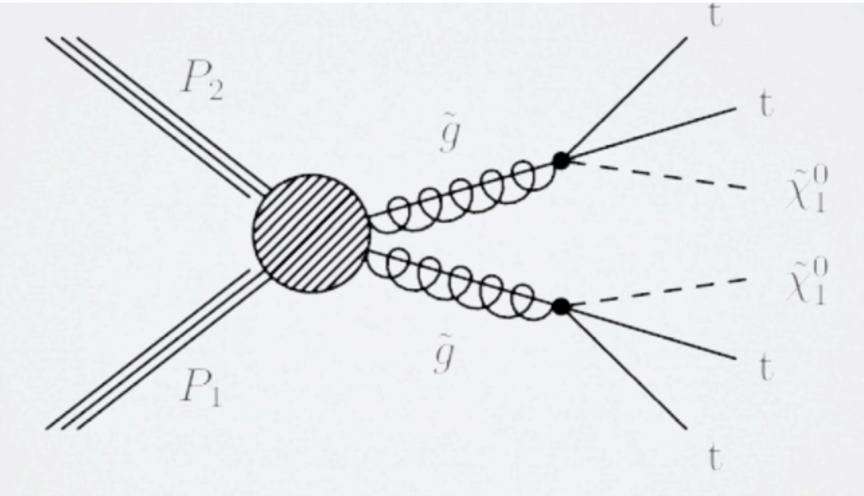

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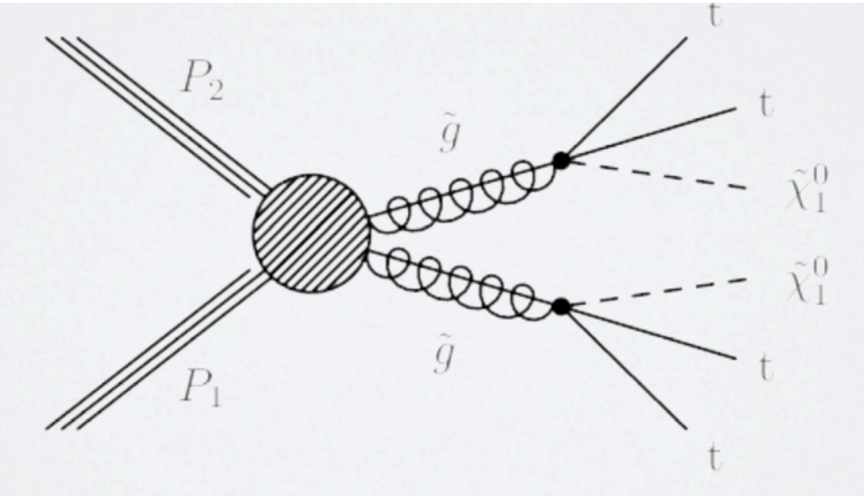

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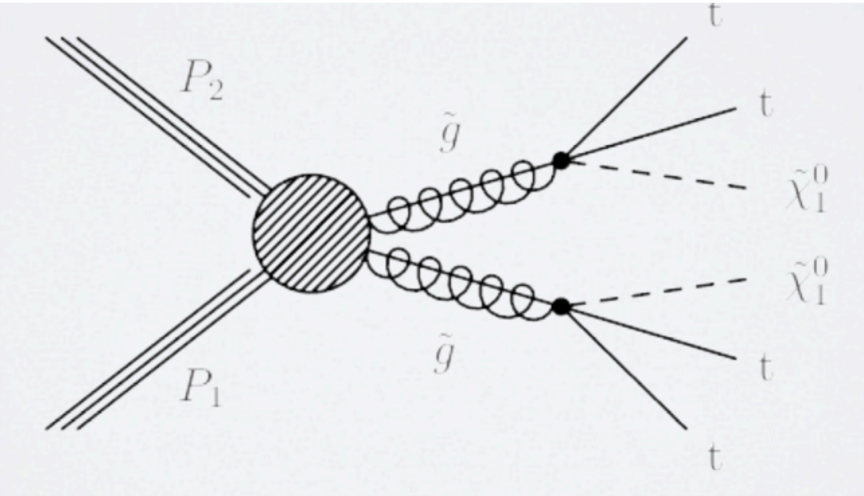

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- require at least 3 jets with p_T > 40 GeV
- HT > 500 GeV
- backgrounds: ttbar, W + jets, single top, diboson, DY + jets

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Single Lepton Final States: Results

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two methods for bkg estimation:

- lepton spectrum method
- $\Delta\Phi$ method

PLB 733 328 (2014)

Single Lepton Final States: Results

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- ΔΦ method

no significant excess found:

			$3 \leq N_j \leq 5$			$N_j \geq 6$		
		S_T^{lep} [GeV]	Control	Pred.	Obs.	Control	Pred.	Obs.
$N_b = 2$	e	[250, 350]	548	34.2±5.4	30	112	3.8±1.8±0.6	9
		[350, 450]	174	5.1±1.9	8	28	2.7±1.9±0.8	2
		>450	61	5.6±2.1	1	9	0.0±0.4±0.2	0
	μ	[250, 350]	632	41.9±5.6	59	141	6.0±2.2±0.9	9
		[350, 450]	188	8.5±2.4	11	24	1.4±1.1±0.4	2
		>450	71	2.5±1.3	1	9	0.0±0.7±0.2	0
$N_b \geq 3$	e	[250, 350]	70	3.9±0.9	2	45	1.9±0.9±0.4	4
		[350, 450]	12	0.3±0.2	2	7	0.9±0.7±0.4	0
		>450	4	0.3±0.2	0	0	0.0±0.1±0.03	0
	μ	[250, 350]	59	3.9±0.8	5	28	1.9±0.8±0.4	0
		[350, 450]	25	1.1±0.4	0	13	0.6±0.5±0.3	0
		>450	7	0.3±0.2	0	2	0.0±0.2± 0.1	0

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Single Lepton Final States: Results

two methods for bkg estimation:

- lepton spectrum method
- ΔΦ method

limits for simplified model with gluino pair production

no significant excess found:

			$3 \leq N_j \leq 5$			$N_j \geq 6$		
		S_T^{lep} [GeV]	Control	Pred.	Obs.	Control	Pred.	Obs.
$N_b = 2$	e	[250, 350]	548	34.2±5.4	30	112	3.8±1.8±0.6	9
		[350, 450]	174	5.1±1.9	8	28	2.7±1.9±0.8	2
		>450	61	5.6±2.1	1	9	0.0±0.4±0.2	0
	μ	[250, 350]	632	41.9±5.6	59	141	6.0±2.2±0.9	9
		[350, 450]	188	8.5±2.4	11	24	1.4±1.1±0.4	2
		>450	71	2.5±1.3	1	9	0.0±0.7±0.2	0
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PLB 733 328 (2014)

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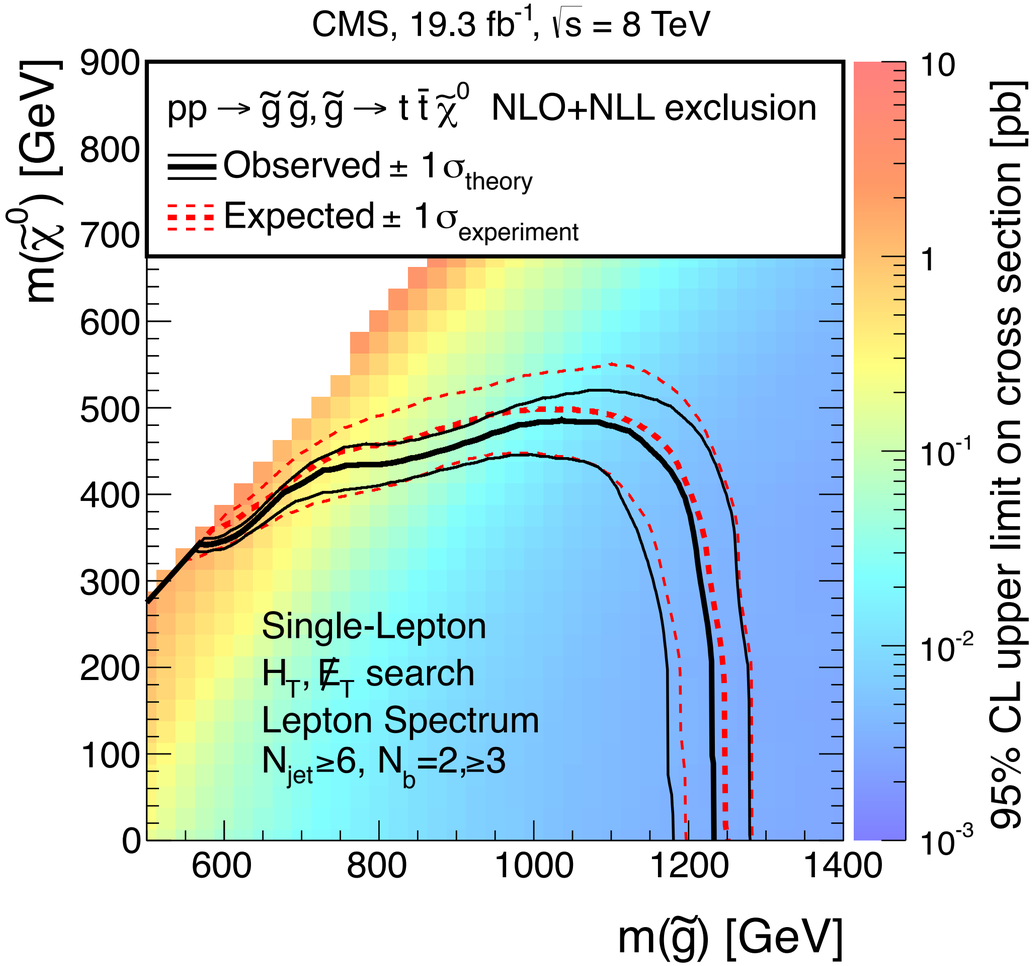

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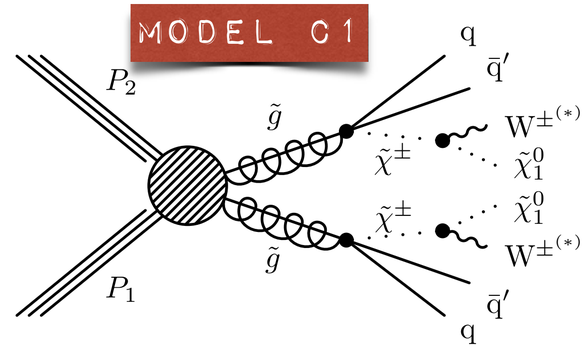

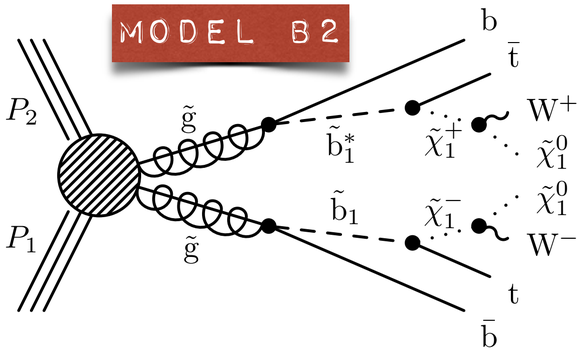

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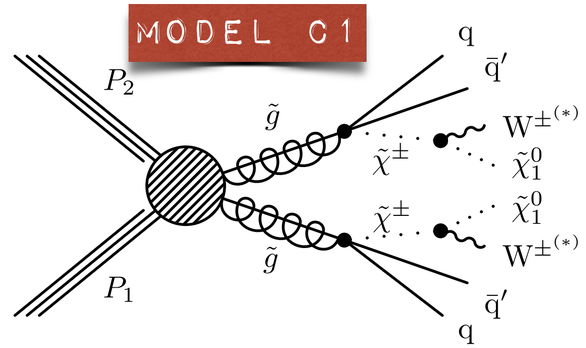

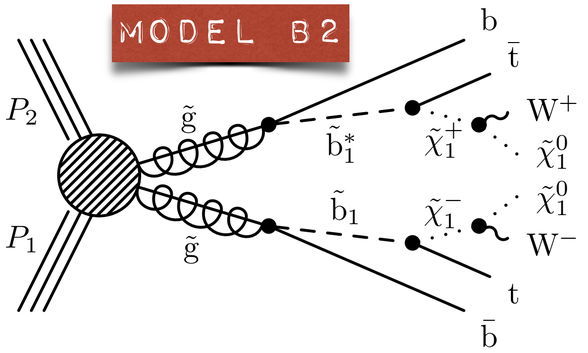

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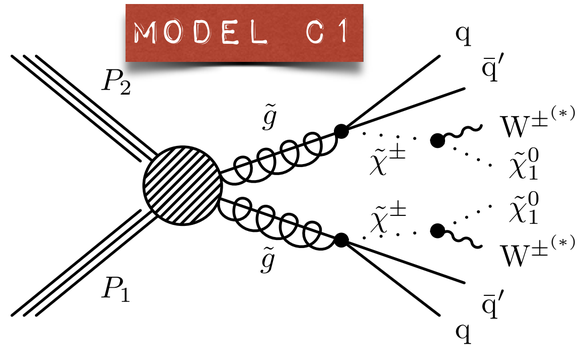

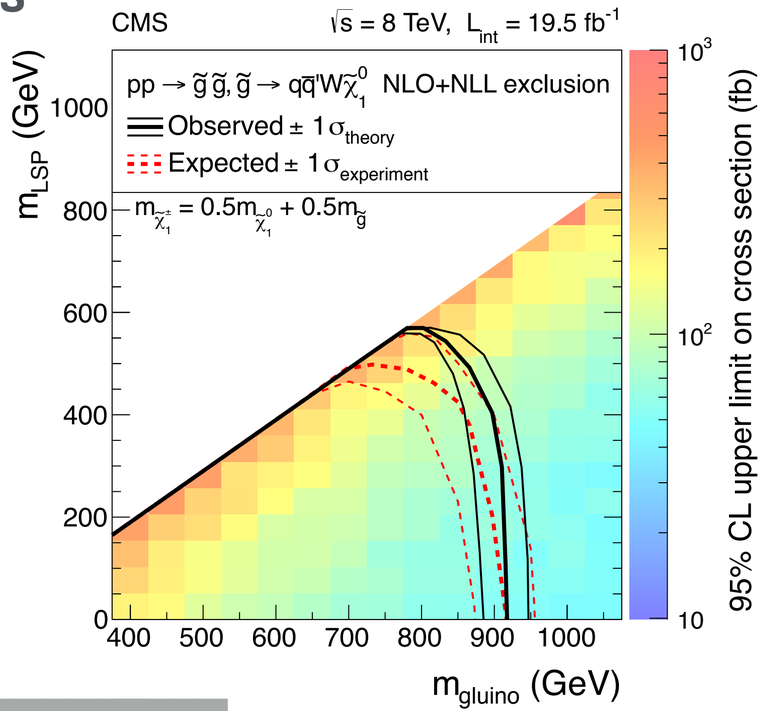

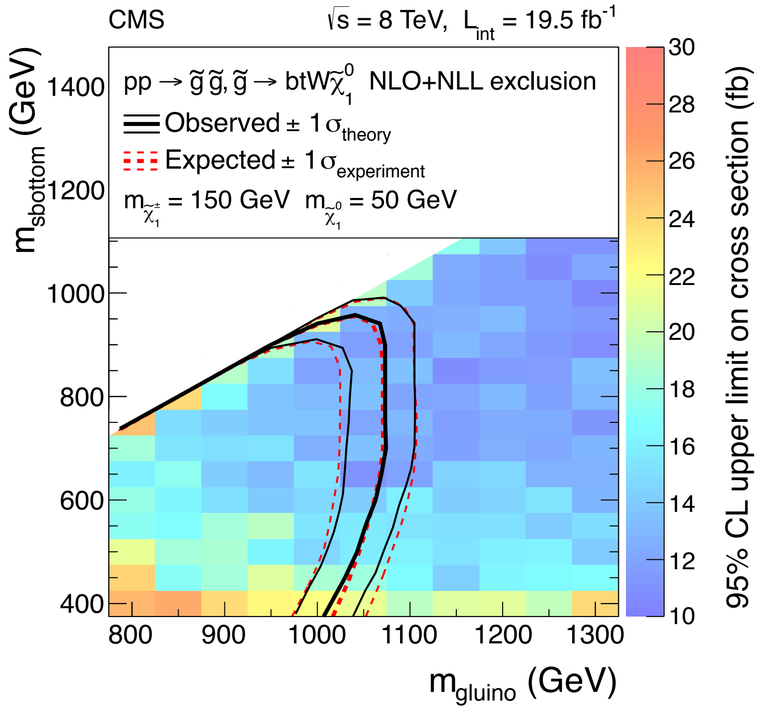

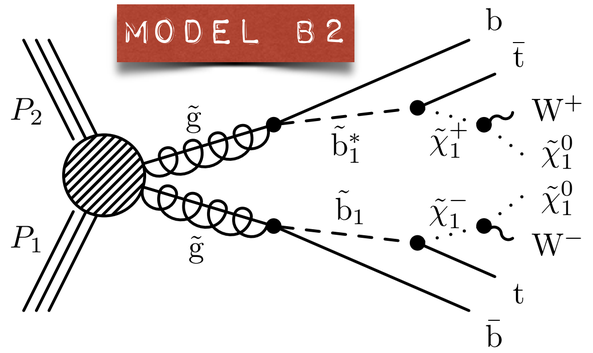

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3 LEPTON EXAMPLE

3 leptons $H_T > 200$ GeV	$m_{\ell^+\ell^-}$	E_T^{miss} (GeV)	$N_{\tau_h}=0, N_b=0$ Obs.	$N_{\tau_h}=0, N_b=0$ Exp.	$N_{\tau_h}=1, N_b=0$ Obs.	$N_{\tau_h}=1, N_b=0$ Exp.	$N_{\tau_h}=0, N_b\geq 1$ Obs.	$N_{\tau_h}=0, N_b\geq 1$ Exp.	$N_{\tau_h}=1, N_b\geq 1$ Obs.	$N_{\tau_h}=1, N_b\geq 1$ Exp.
OSSF0	—	(100, ∞)	5	3.7 ± 1.6	35	33 ± 14	1	5.5 ± 2.2	47	61 ± 30
OSSF0	—	(50, 100)	3	3.5 ± 1.4	34	36 ± 16	8	7.7 ± 2.7	82	91 ± 46
OSSF0	—	(0, 50)	4	2.1 ± 0.8	25	25 ± 10	1	3.6 ± 1.5	52	59 ± 29
OSSF1	Above-Z	(100, ∞)	5	3.6 ± 1.2	2	10.0 ± 4.8	3	4.7 ± 1.6	19	22 ± 11
OSSF1	Below-Z	(100, ∞)	7	9.7 ± 3.3	18	14.0 ± 6.4	8	9.1 ± 3.4	21	23 ± 11
OSSF1	On-Z	(100, ∞)	39	61 ± 23	17	15.0 ± 4.9	9	14.0 ± 4.4	10	12.0 ± 5.8
OSSF1	Above-Z	(50, 100)	4	5.0 ± 1.6	14	11.0 ± 5.2	6	6.8 ± 2.4	32	30 ± 15
OSSF1	Below-Z	(50, 100)	10	11.0 ± 3.8	24	19.0 ± 6.4	10	9.9 ± 3.7	25	32 ± 16
OSSF1	On-Z	(50, 100)	78	80 ± 32	70	50 ± 11	22	22.0 ± 6.3	36	24.0 ± 9.8
OSSF1	Above-Z	(0, 50)	3	7.3 ± 2.0	41	33.0 ± 8.7	4	5.3 ± 1.5	15	23 ± 11
OSSF1	Below-Z	(0, 50)	26	25.0 ± 6.8	110	86 ± 23	5	10.0 ± 2.5	24	26 ± 11
OSSF1	On-Z	(0, 50)	*135	130 ± 41	542	540 ± 160	31	32.0 ± 6.5	86	75 ± 19
3 leptons $H_T < 200$ GeV	$m_{\ell^+\ell^-}$	E_T^{miss} (GeV)	$N_{\tau_h}=0, N_b=0$ Obs.	$N_{\tau_h}=0, N_b=0$ Exp.	$N_{\tau_h}=1, N_b=0$ Obs.	$N_{\tau_h}=1, N_b=0$ Exp.	$N_{\tau_h}=0, N_b\geq 1$ Obs.	$N_{\tau_h}=0, N_b\geq 1$ Exp.	$N_{\tau_h}=1, N_b\geq 1$ Obs.	$N_{\tau_h}=1, N_b\geq 1$ Exp.
OSSF0	—	(100, ∞)	7	11.0 ± 4.9	101	111 ± 54	13	10.0 ± 5.3	87	119 ± 61
OSSF0	—	(50, 100)	35	38 ± 15	406	402 ± 152	29	26 ± 13	269	298 ± 151
OSSF0	—	(0, 50)	53	51 ± 11	910	1035 ± 255	29	23 ± 10	237	240 ± 113
OSSF1	Above-Z	(100, ∞)	18	13.0 ± 3.5	25	38 ± 18	10	6.5 ± 2.9	24	35 ± 18
OSSF1	Below-Z	(100, ∞)	21	24 ± 9	41	50 ± 25	14	20 ± 10	42	54 ± 28
OSSF1	On-Z	(100, ∞)	150	150 ± 26	39	48 ± 13	15	14.0 ± 4.8	19	23 ± 11
OSSF1	Above-Z	(50, 100)	50	46.0 ± 9.7	169	140 ± 48	20	18 ± 8	85	93 ± 47
OSSF1	Below-Z	(50, 100)	142	130 ± 27	353	360 ± 92	48	48 ± 23	140	133 ± 68
OSSF1	On-Z	(50, 100)	*773	780 ± 120	1276	1200 ± 310	56	47 ± 13	81	75 ± 32
OSSF1	Above-Z	(0, 50)	178	200 ± 35	1676	1900 ± 540	17	18.0 ± 6.7	115	94 ± 42
OSSF1	Below-Z	(0, 50)	510	560 ± 87	9939	9000 ± 2700	34	42 ± 11	226	228 ± 63
OSSF1	On-Z	(0, 50)	*3869	4100 ± 670	*50188	50000 ± 15000	*148	156 ± 24	906	925 ± 263

PRD 90, 032006 (2014)

Three(+)-lepton Final States: Interpretation

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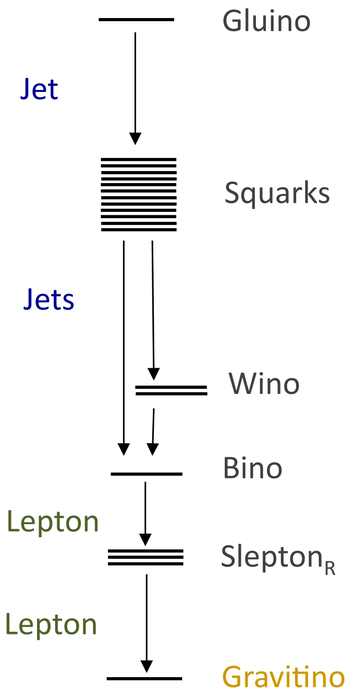

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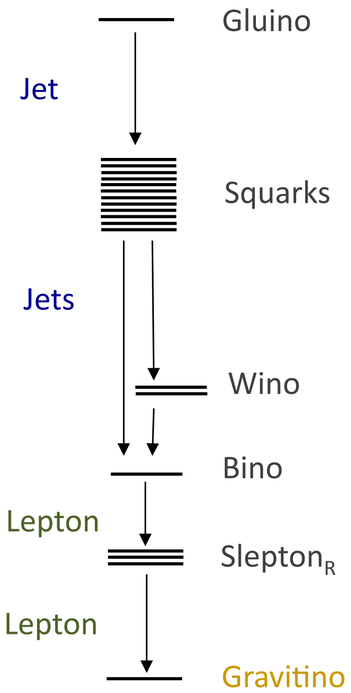

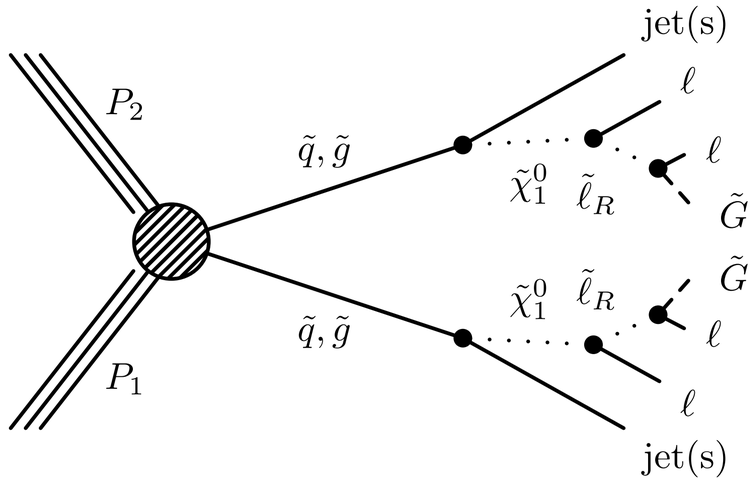

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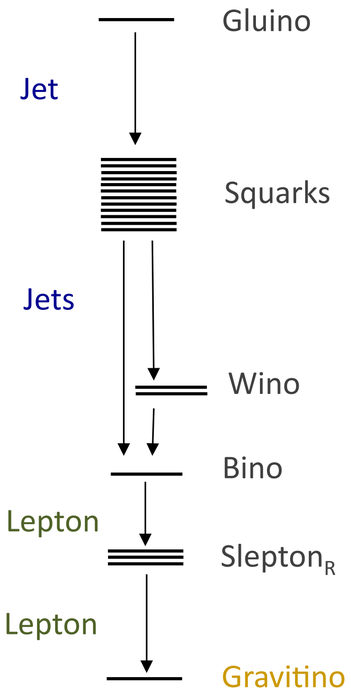

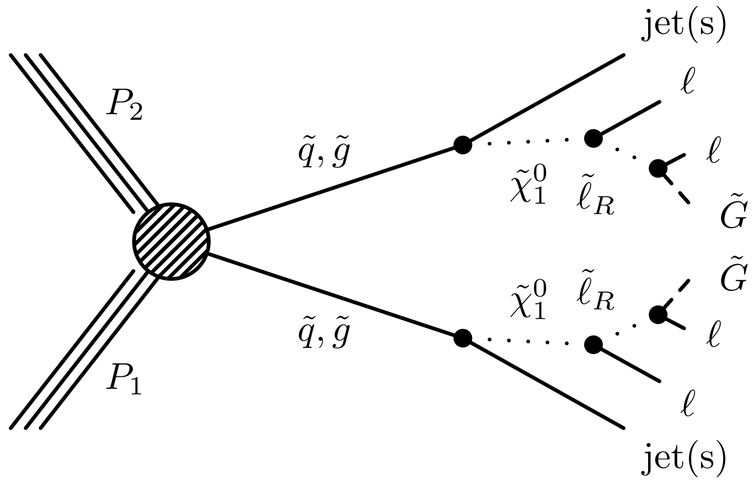

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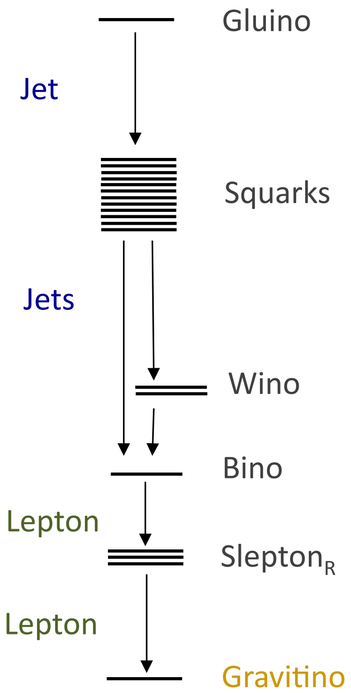

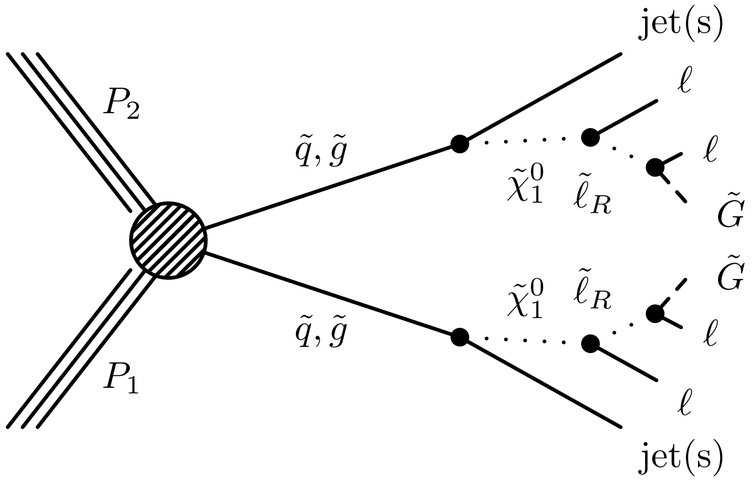

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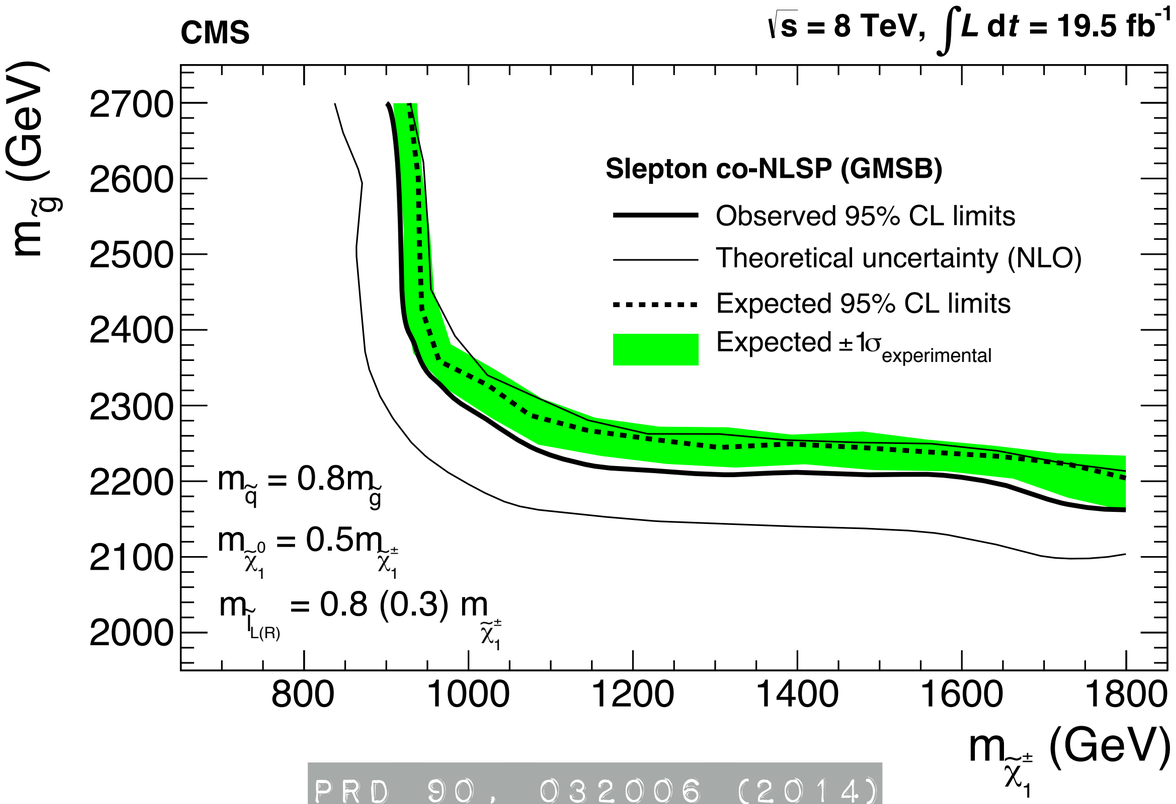
exclusion limits in the lightest chargino-gluino mass plane



PRD 90, 032006 (2014)

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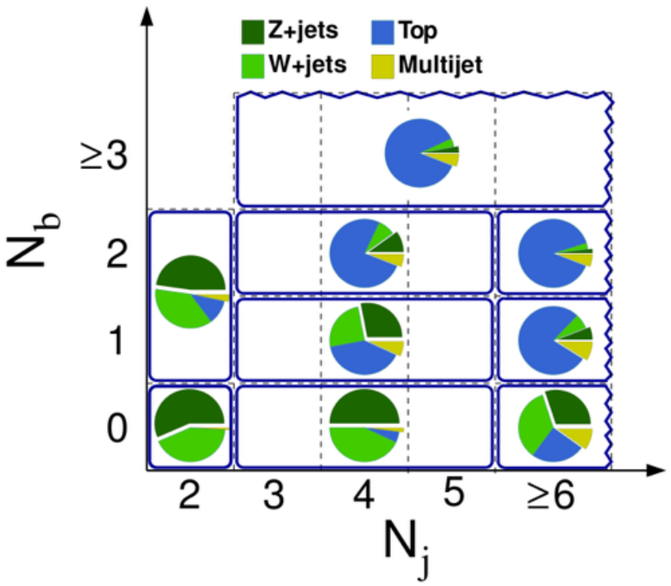

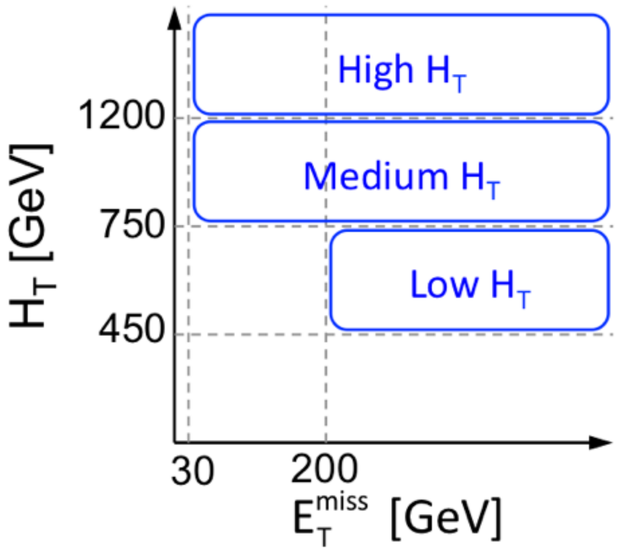

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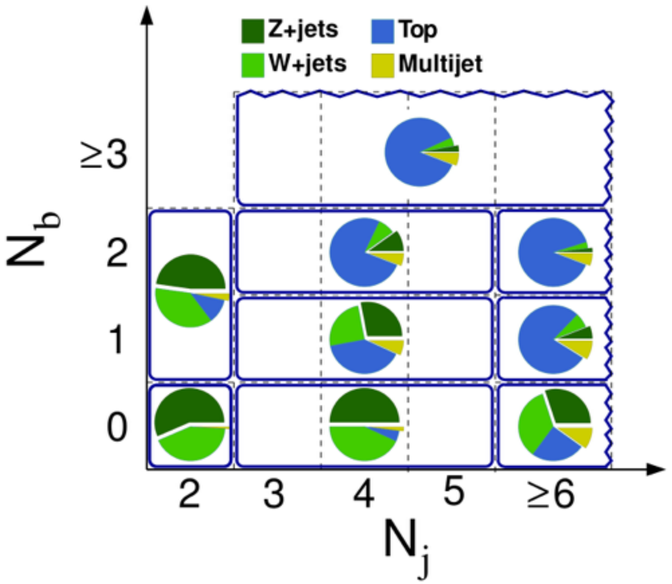

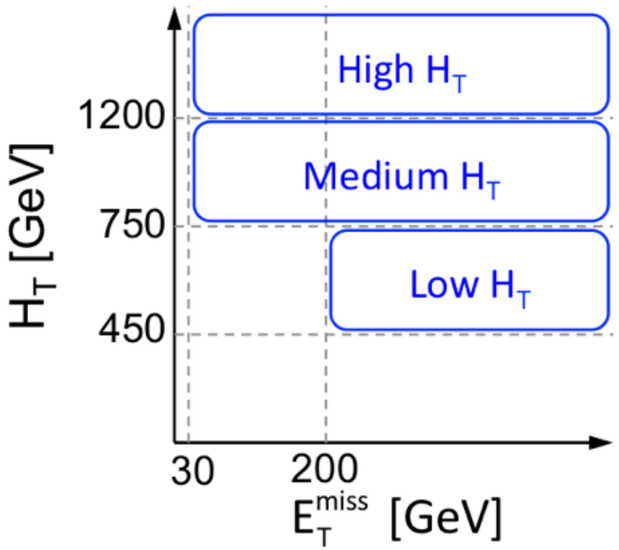

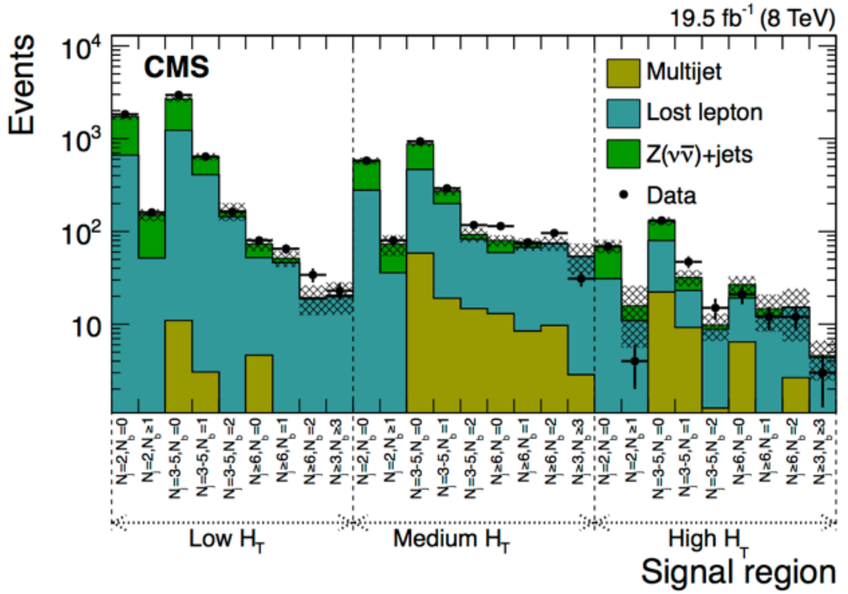

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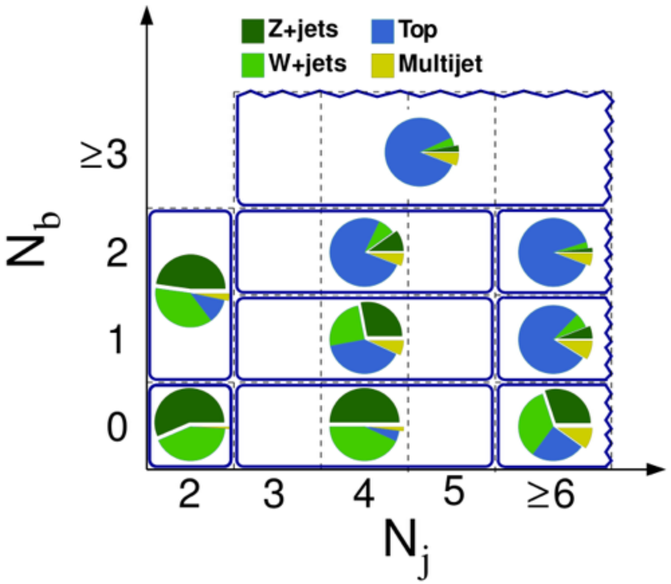
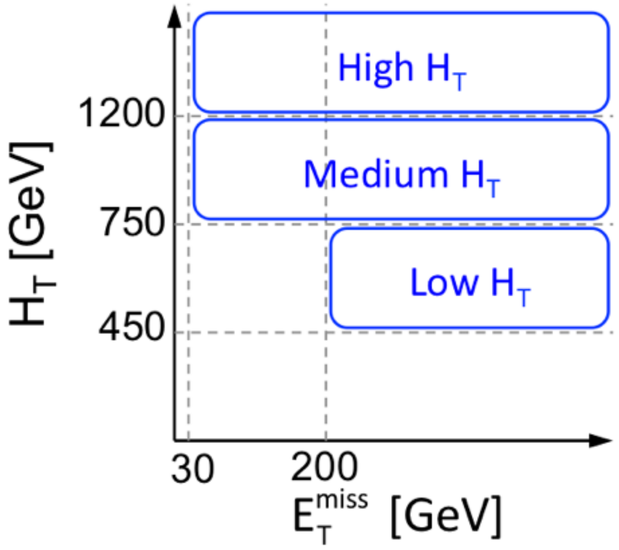
VERY STRONG SBOTTOM LIMITS





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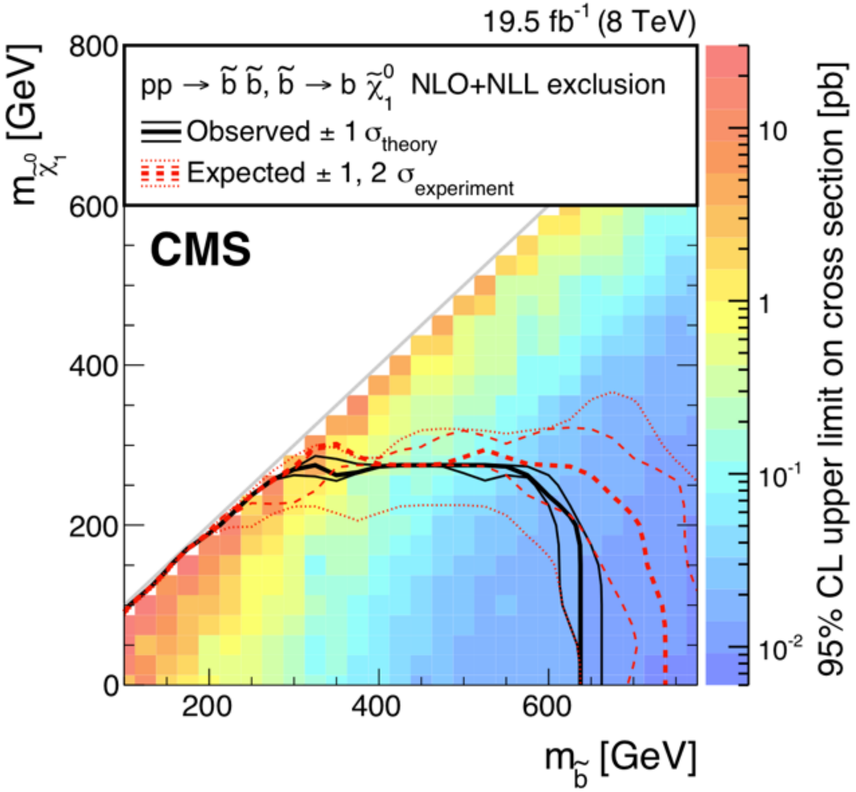

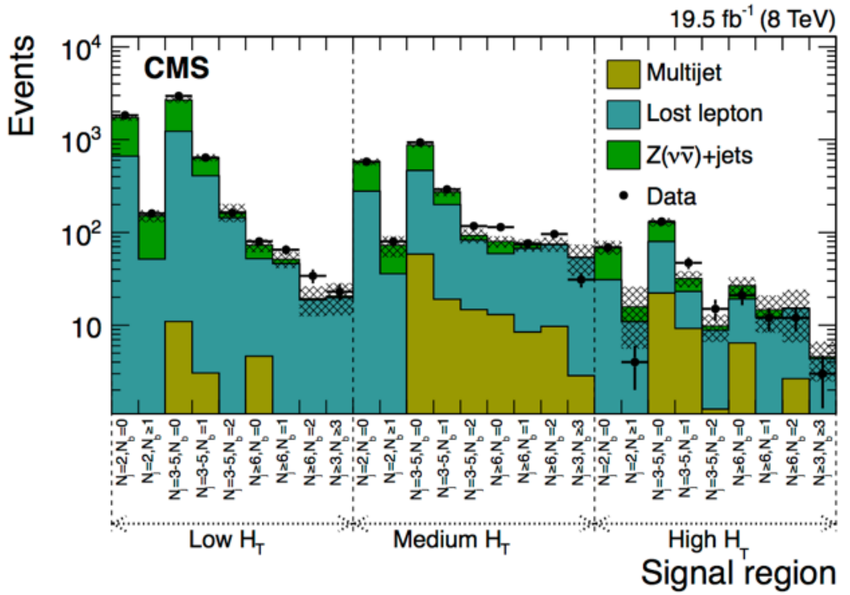

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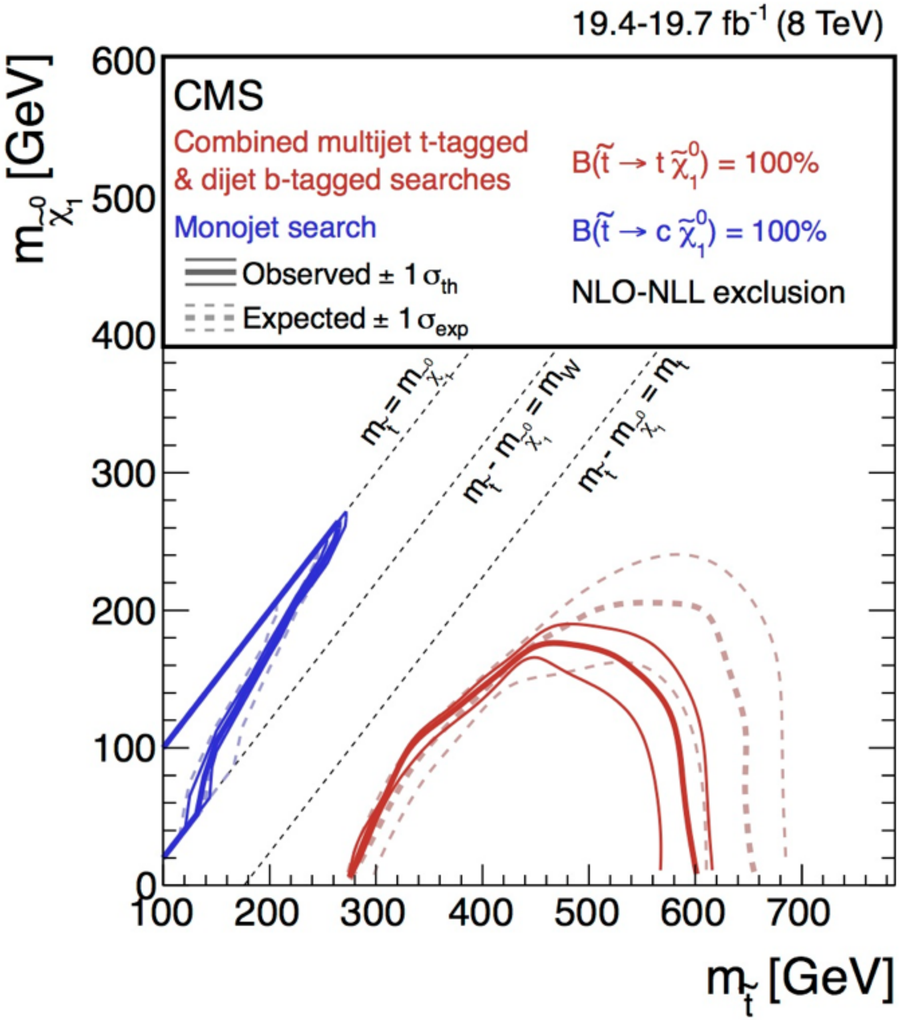

ARXIV 1503.08037

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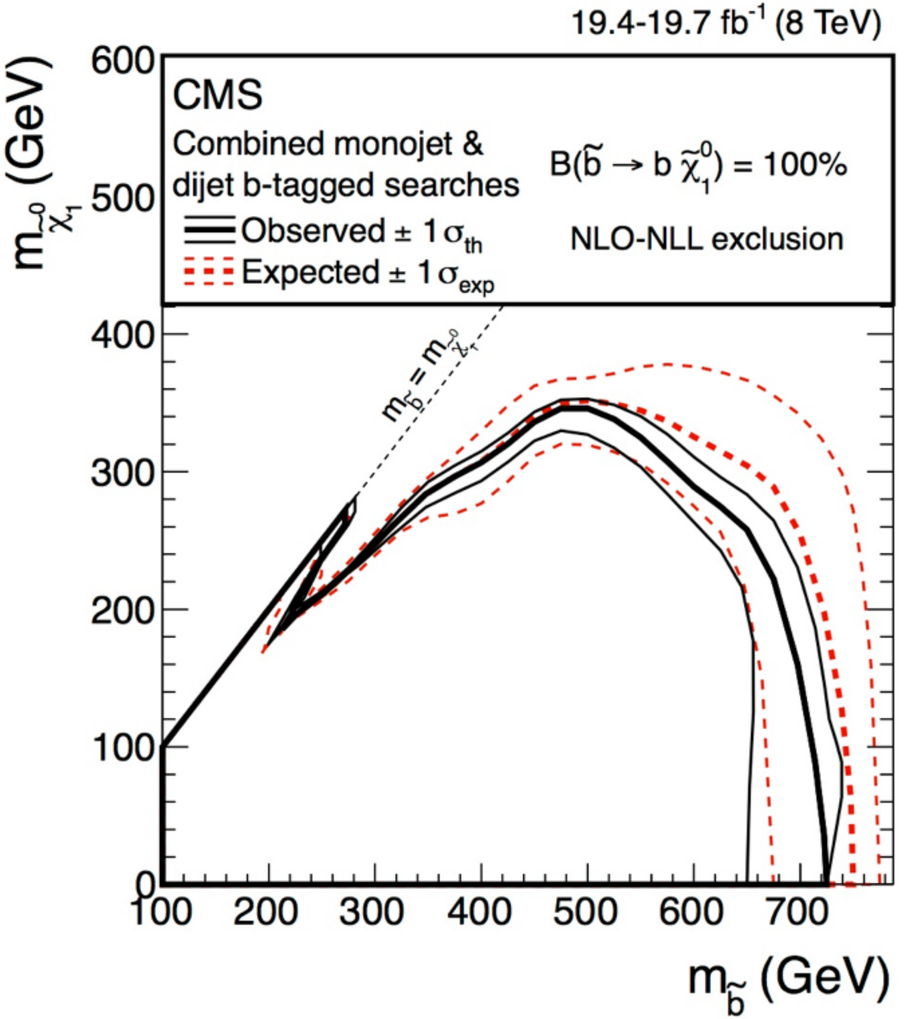

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Outline

Intro

SUSY CMS

Setup

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Results I

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- SUSY masses/cross-section out of reach (for now) — WAIT FOR MORE DATA TO ROLL IN
- SUSY scenario is sitting in a niche — HAVE TO COME UP WITH NEW ANALYSIS IDEAS

Where Could SUSY ‘Hide’?

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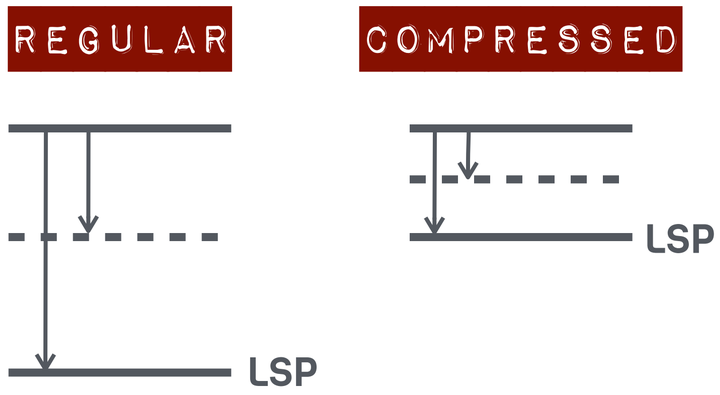

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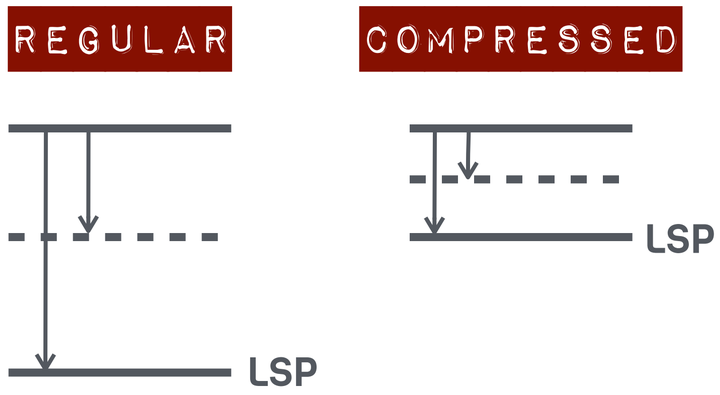

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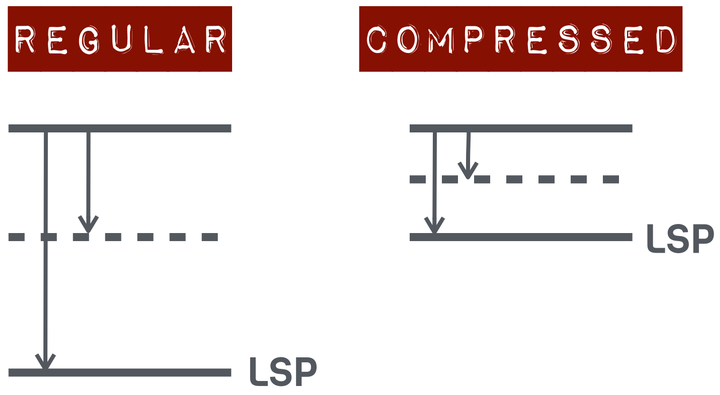

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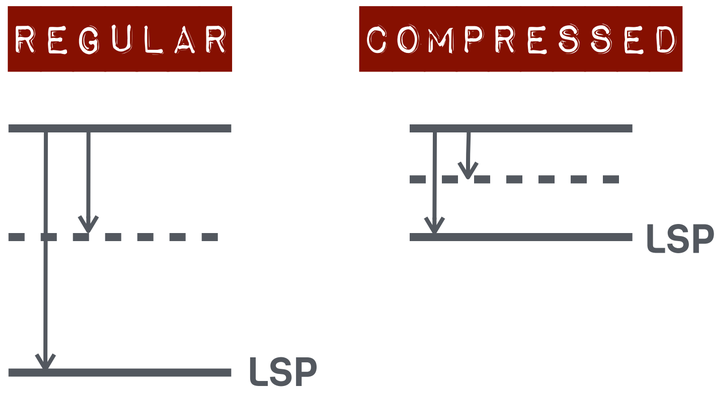

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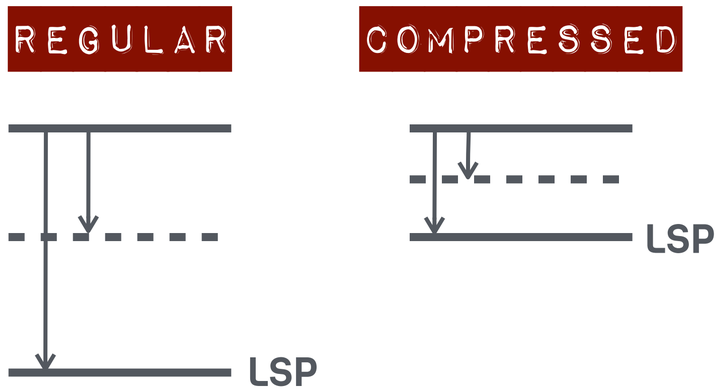

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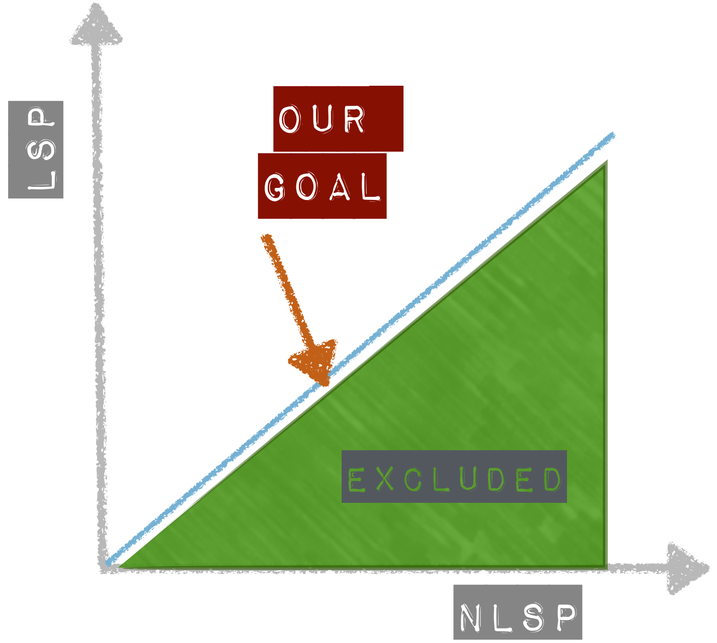

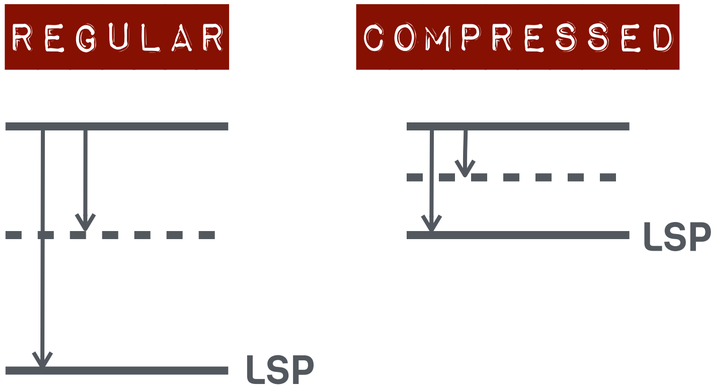

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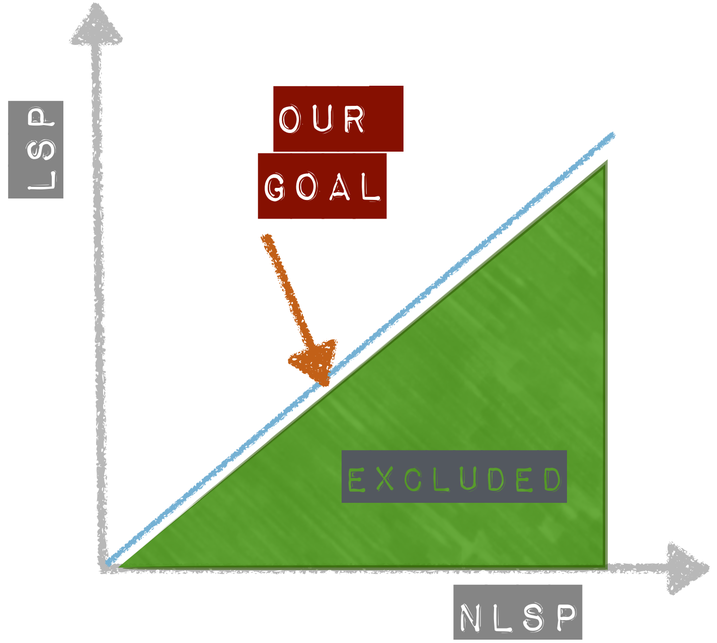

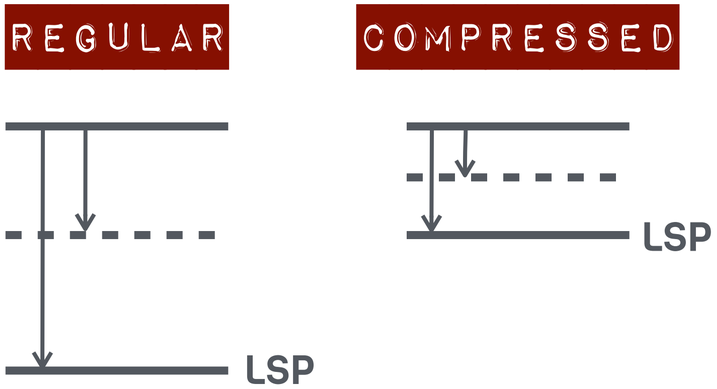

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- reconstruction might fail
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=> requires dedicated analyses

Compressed Scenario I

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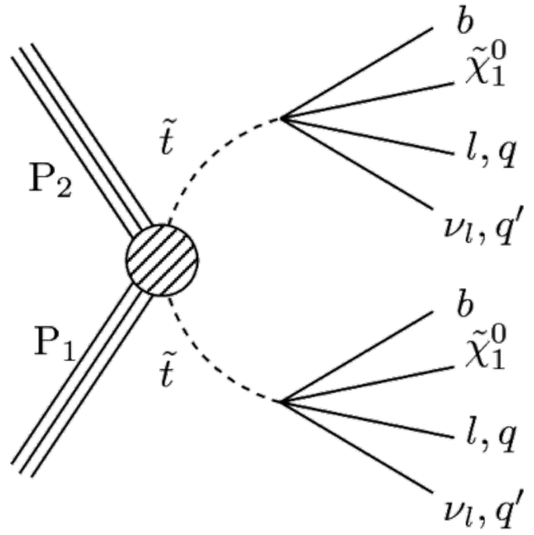

Compressed Scenario I

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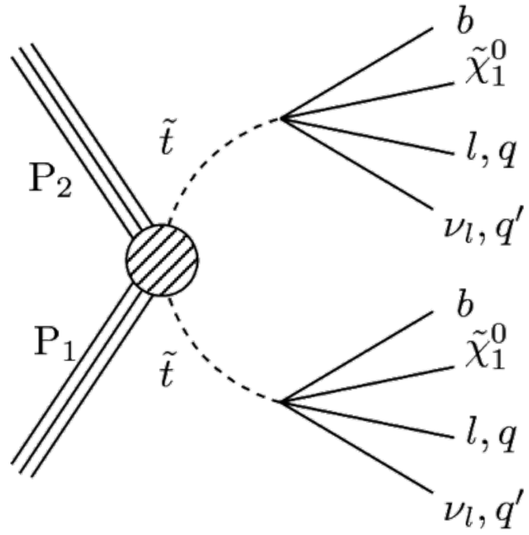

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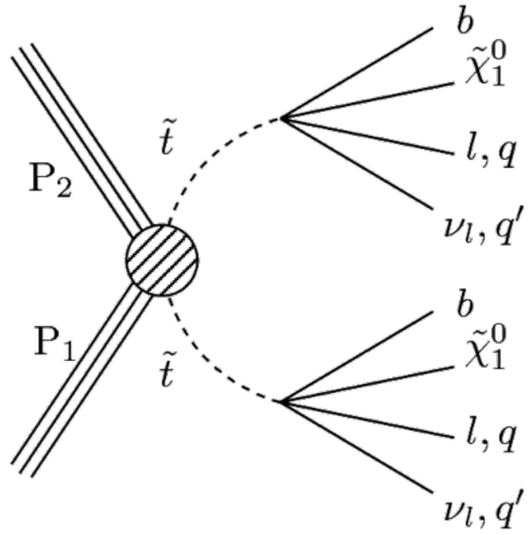

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- 3 decay channels (W decays)
  - 0 lepton: BR 55%, huge irreducible bkg Z -> νν, W -> $l\nu_{miss}$
  - 1 lepton: BR 38%, bkg from W -> lν
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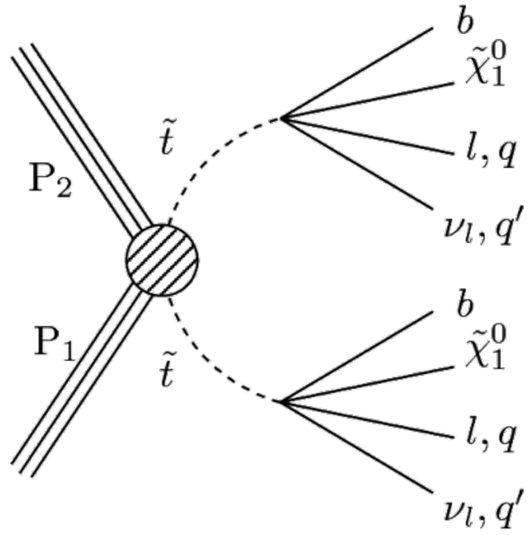

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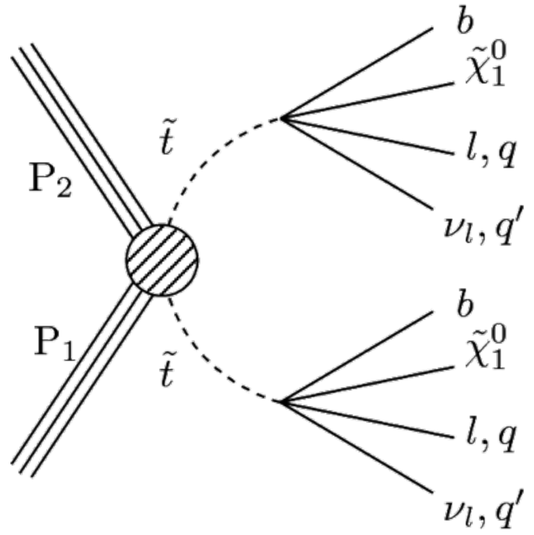
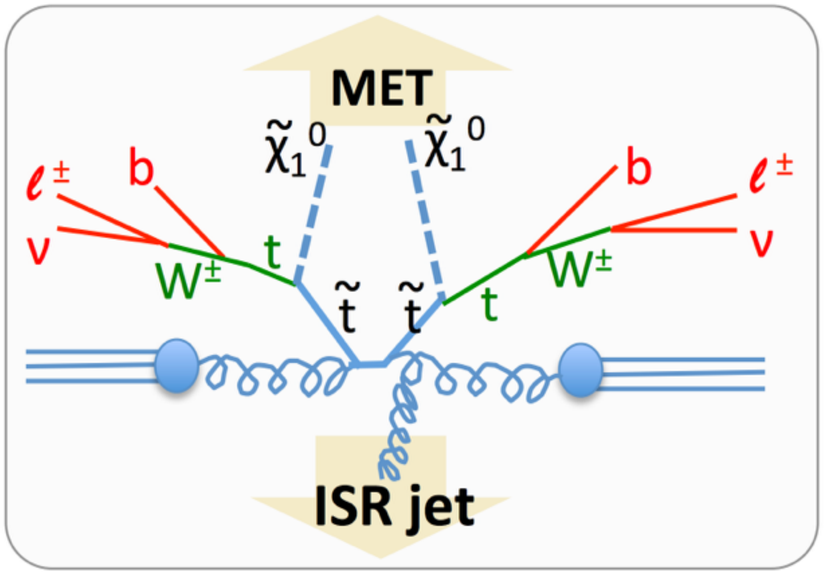
  - => require ISR jet(s)





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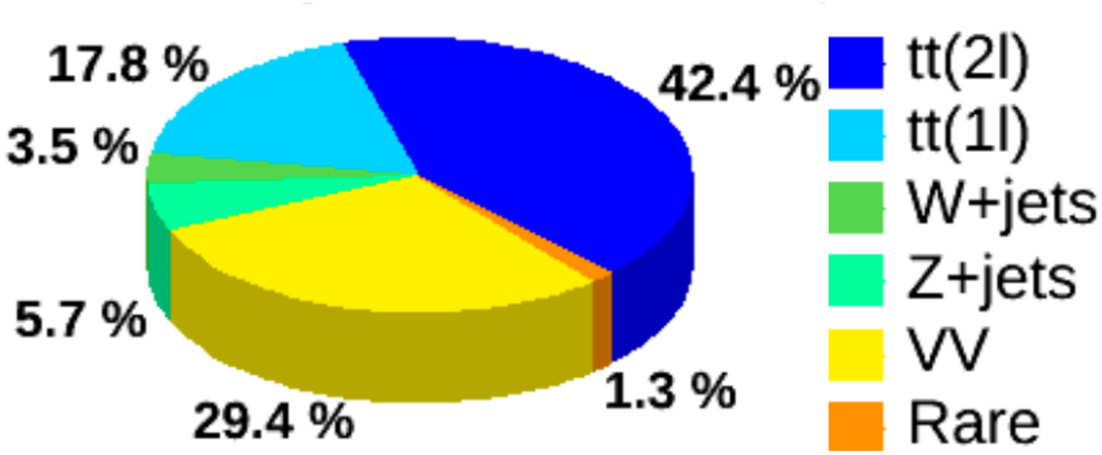
- SR region: 8 events (simulation)
- background composition



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Background	$p_T(\ell_1)$: 5–15 GeV	$p_T(\ell_1)$: 15–25 GeV	Inclusive
$t\bar{t}(2\ell)$	0.75 ±0.19	2.08 ±0.37	2.84 ±0.42
$t\bar{t}(1\ell)$,W+jets	0.60 ±0.33	1.32 ±0.69	1.92 ±0.76
Z/γ^*+jets	<0.30	0.48 ±0.45	0.48 ±0.45
VV	0.74 ±0.27	1.61 ±0.48	2.35 ±0.55
Rare backgrounds	0.03 ±0.01	0.08 ±0.04	0.11 ±0.04
Total SM	2.12 ±0.47	5.6 ±1.0	7.7 ±1.1
$\tilde{t}\tilde{t}$ signal (250,230)	10.0 ±1.5	3.41 ±0.90	13.5 ±1.8
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Systematic effect	$p_T(\ell_1)$: 5–15 GeV	$p_T(\ell_1)$: 15–25 GeV
Statistical uncertainty	21.9	18.3
Jet energy scale	1.0	2.8
b tagging	1.5	1.4
Electron efficiency	1.3	1.1
Muon efficiency	6.0	4.5
$t\bar{t}$ background	5.1	5.4
NP background	10.1	5.6
Z/γ^* background	0.0	2.3
VV background	8.0	2.6
Rare backgrounds	3.7	3.3
Total uncertainty	26.9	21.1

RELATIVE SYST. UNCERTAINTIES

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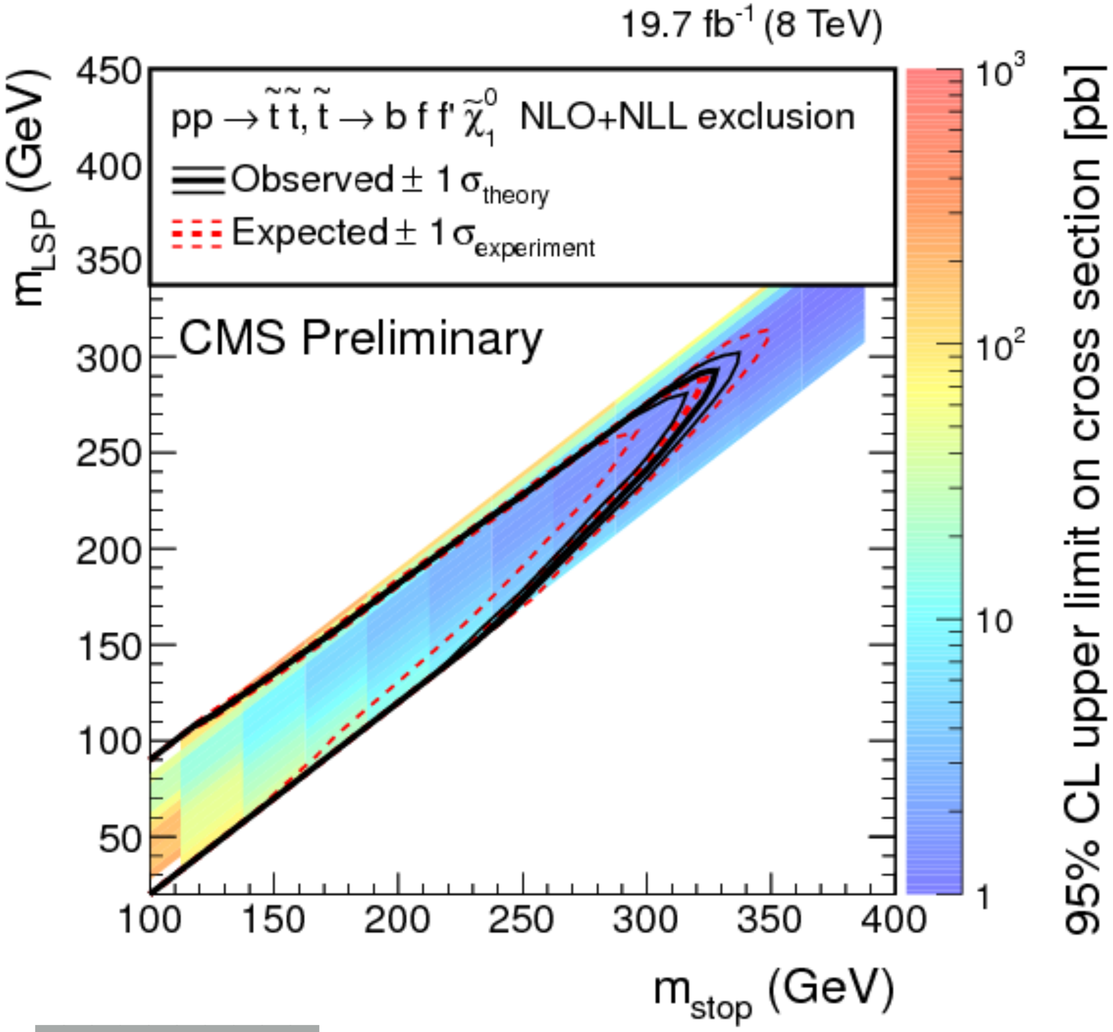

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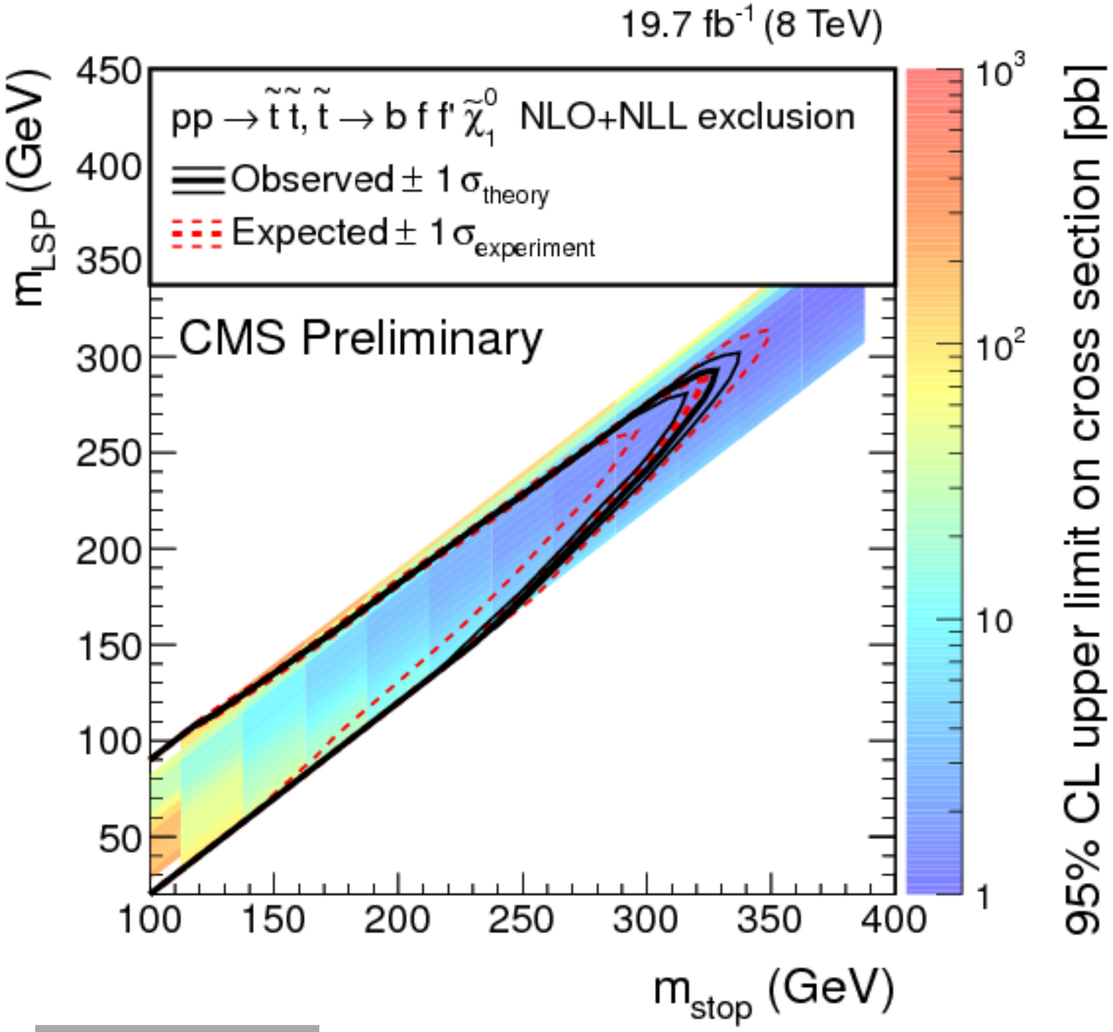

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- limits covering unexplored region!

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Compressed SUSY Scenario II

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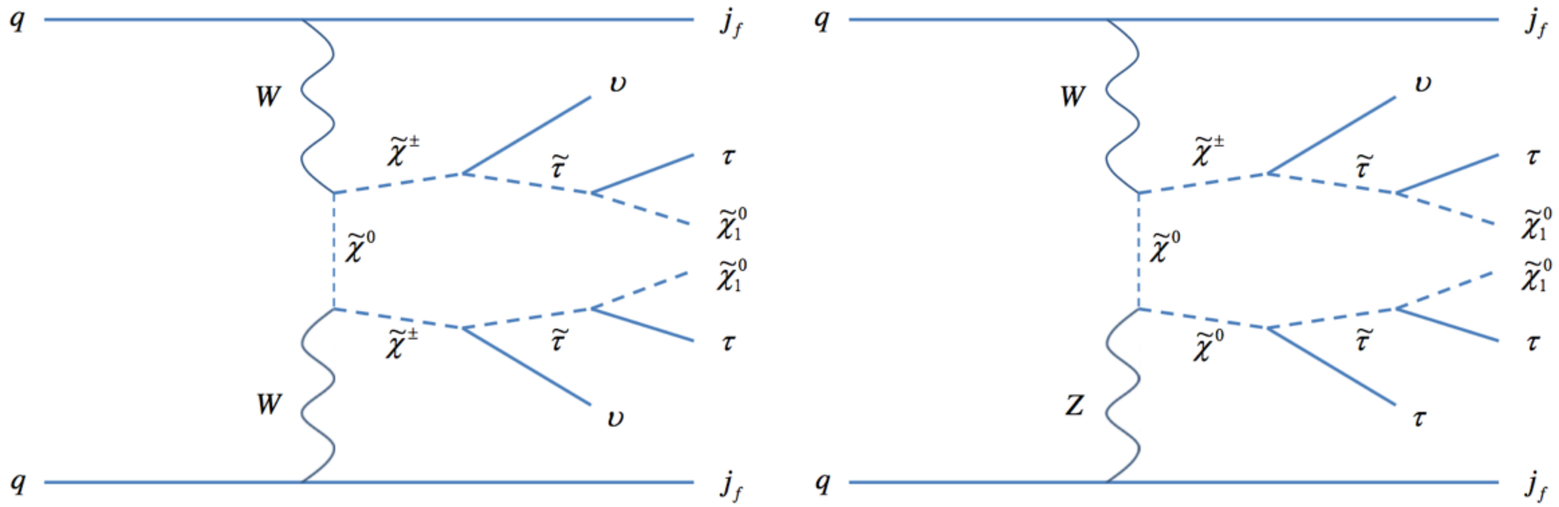

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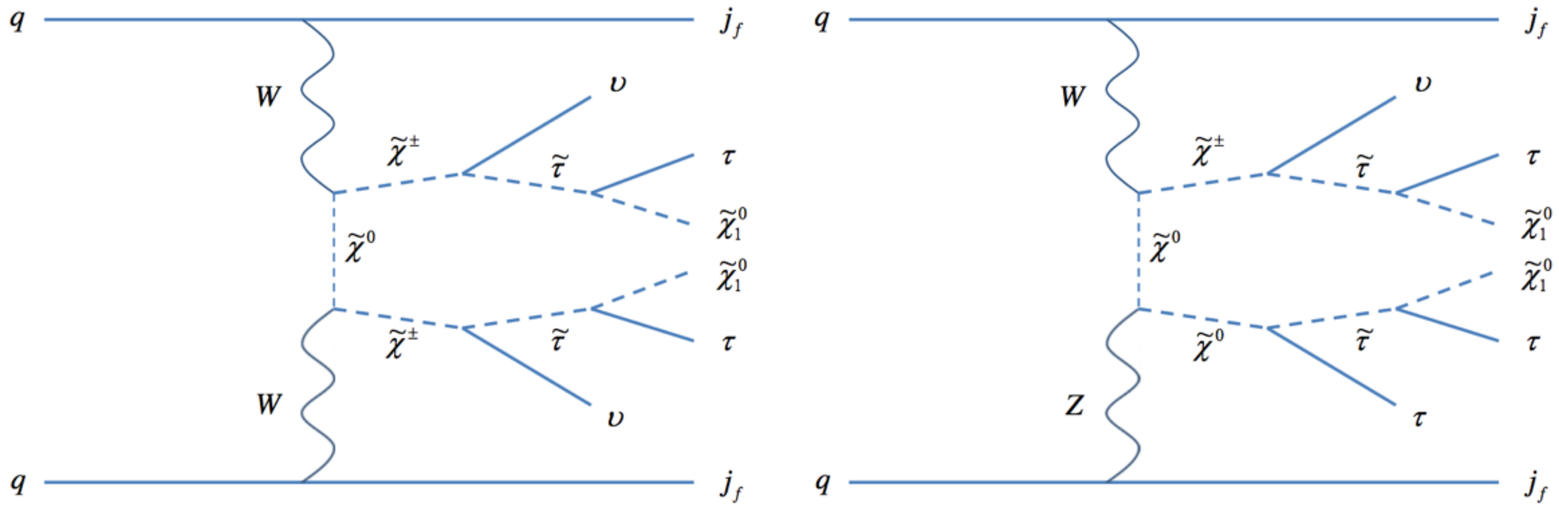

- VBF production (2 example diagrams shown) yields 2 high p_T jets in opposite hemispheres of the detector with large separation in η
- search performed in opposite sign (os) and same sign (ss) $\mu\mu$,$e\mu$,$\mu\tau_h$,$\tau_h\tau_h$ channels

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Compressed SUSY Scenario II: Background Estimation

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- backgrounds vary with os or ss and lepton flavour

Process	$\mu^{\pm}\mu^{\mp}jj$	$e^{\pm}\mu^{\mp}jj$	$\mu^{\pm}\tau_h^{\mp}jj$	$\tau_h^{\pm}\tau_h^{\mp}jj$
DY + jets	4.3 ± 1.7	$3.7 \pm^{2.1}_{1.9}$	19.9 ± 2.9	12.3 ± 4.4
W + jets	< 0.01	$4.2 \pm^{3.3}_{2.5}$	17.3 ± 3.0	2.0 ± 1.7
VV	2.8 ± 0.5	3.1 ± 0.7	2.9 ± 0.5	0.5 ± 0.2
$t\bar{t}$	24.0 ± 1.7	$19.0 \pm^{2.3}_{2.4}$	11.7 ± 2.8	–
QCD	–	–	–	6.3 ± 1.8
Higgs	1.0 ± 0.1	1.1 ± 0.5	–	1.1 ± 0.1
VBF Z	–	–	–	0.7 ± 0.2
Total	32.2 ± 2.4	$31.1 \pm^{4.6}_{4.1}$	51.8 ± 5.1	22.9 ± 5.1
Observed	31	22	41	31

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OS

Process	$\mu^{\pm}\mu^{\pm}jj$	$e^{\pm}\mu^{\pm}jj$	$\mu^{\pm}\tau_h^{\pm}jj$	$\tau_h^{\pm}\tau_h^{\pm}jj$
DY + jets	< 0.01	$0 \pm^{1.7}_{0}$	0.5 ± 0.2	< 0.01
W + jets	$0.1 \pm 8.2 \times 10^{-4}$	$0 \pm^{3.0}_{0}$	9.3 ± 2.3	0.5 ± 0.1
VV	2.1 ± 0.3	$1.9 \pm^{0.4}_{0.2}$	1.1 ± 0.2	$0.1 \pm 6.5 \times 10^{-2}$
$t\bar{t}$	3.1 ± 0.1	$3.5 \pm^{0.7}_{0.9}$	6.7 ± 2.8	$0.1 \pm 1.2 \times 10^{-2}$
Single top	–	–	–	< 0.1
QCD	–	–	–	7.6 ± 0.9
Higgs	–	–	–	< 0.01
Total	5.4 ± 0.3	$5.4 \pm^{3.5}_{0.9}$	17.6 ± 3.8	8.4 ± 0.9
Observed	4	5	14	9

SS

Compressed SUSY Scenario II: Interpretation

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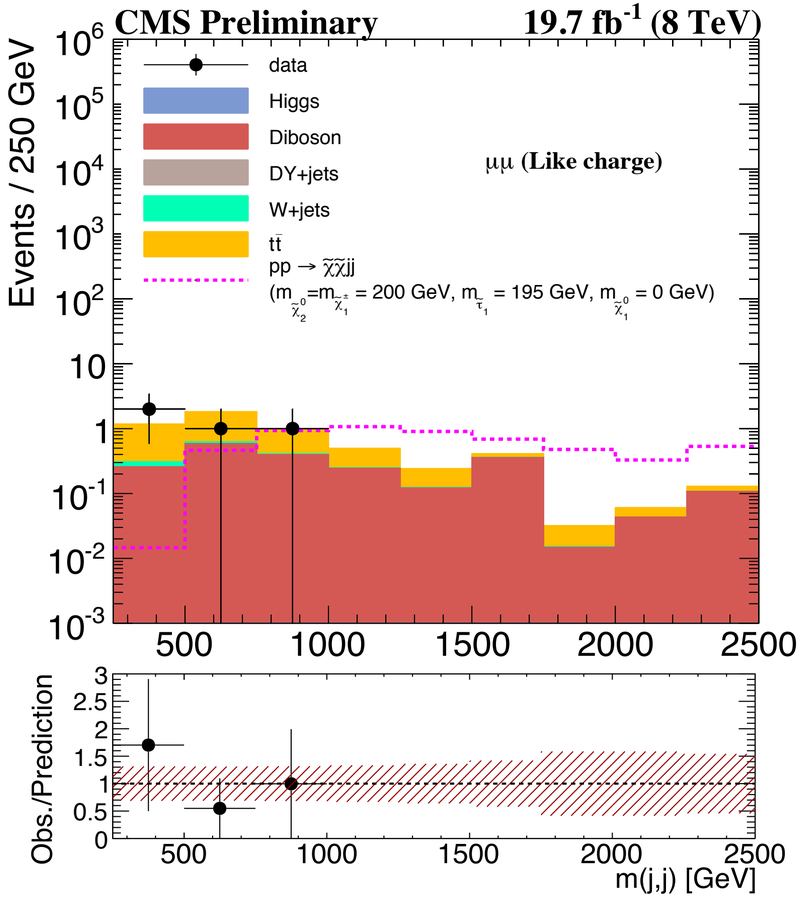

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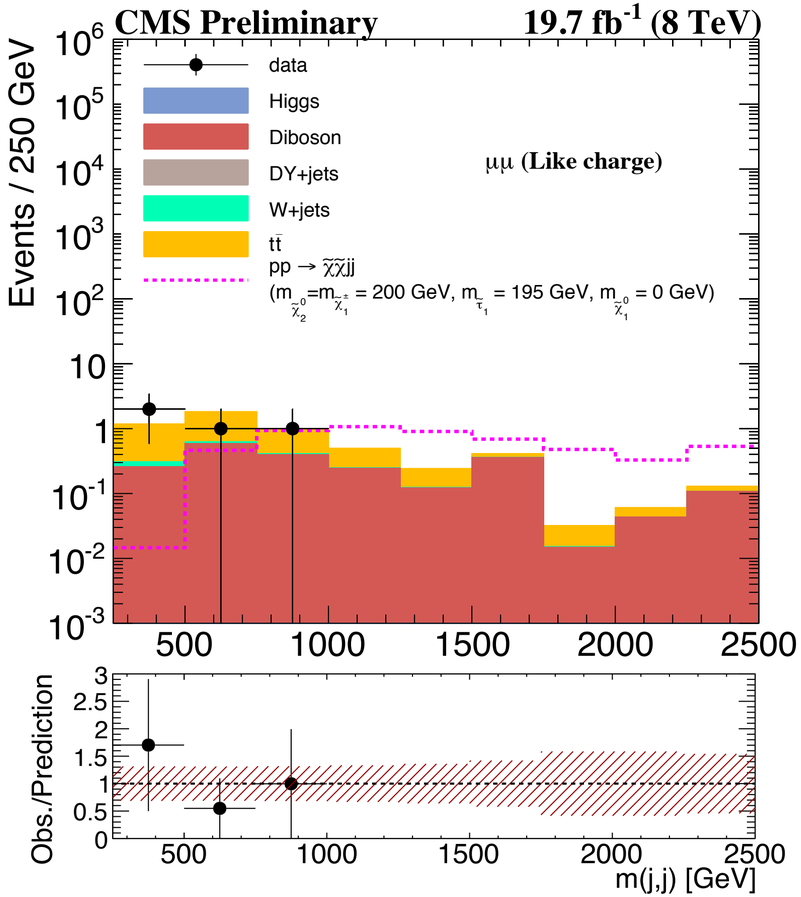

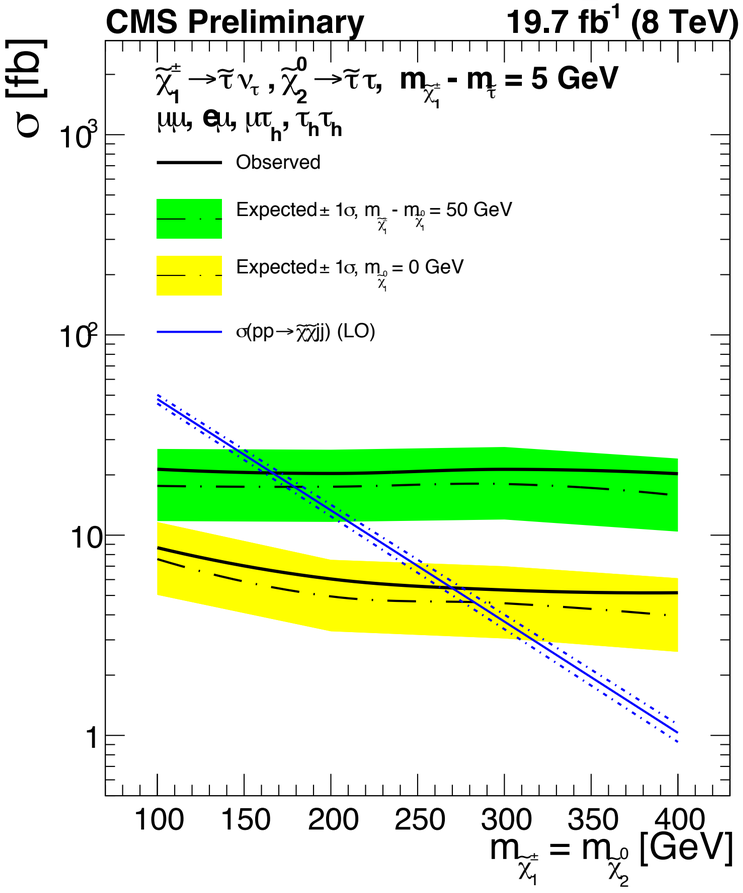

- interpretation with light stau for compressed spectra and light LSP
- especially ss channels have large signal to background ratios
- results compatible with SM, limits have been set for compressed (green) and large mass gap (yellow) scenarios

SUS-14-005

Outline

Intro

SUSY
CMS

Setup

WHAT ARE
WE LOOKING
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Results I

'STANDARD'
SEARCHES

Results II

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Outline

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There's More...

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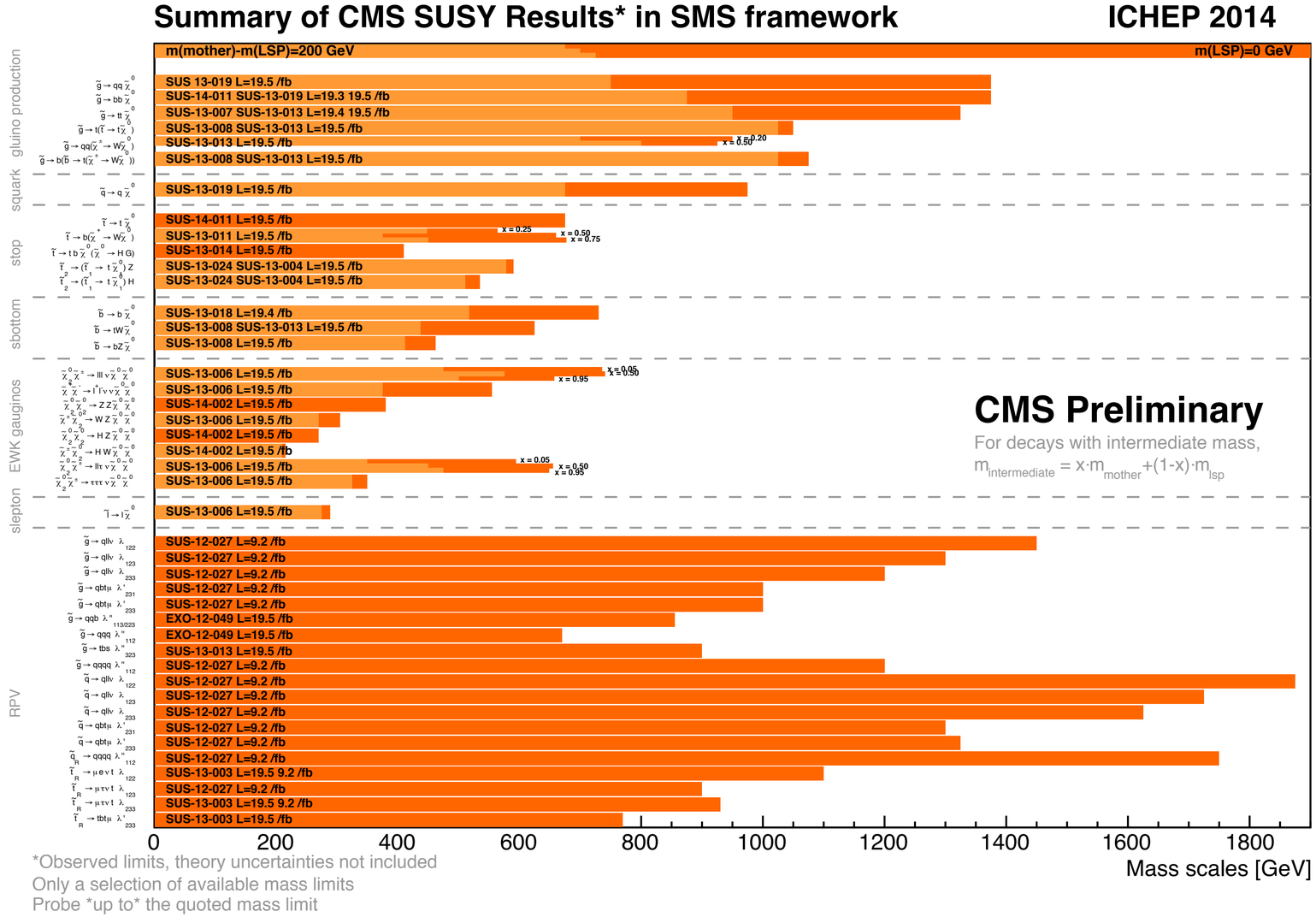
Summary of CMS SUSY Results* in SMS framework
ICHEP 2014
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
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SUS-13-006 L=19.5 /fb
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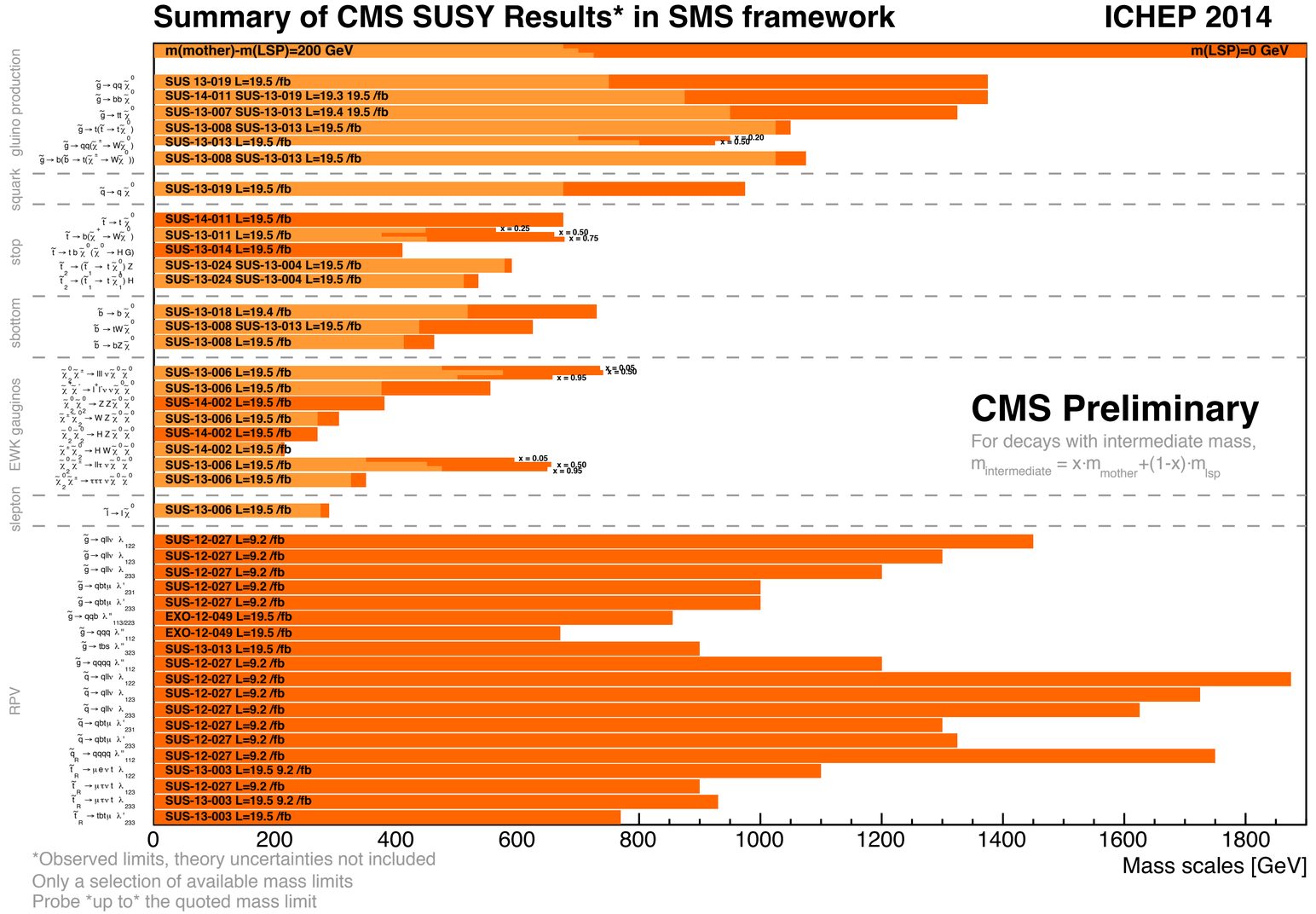
SUS-13-003 L=19.5 9.2 /fb
SUS-13-003 L=19.5 /fb
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother+(1-x)·m_lsp
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

There's More...

- probing the 1 TeV mass scale
- 'classic' SUSY scenarios in classic final states become less interesting
- trying to close holes where SUSY might be hiding
- there's still a lot of work ahead!



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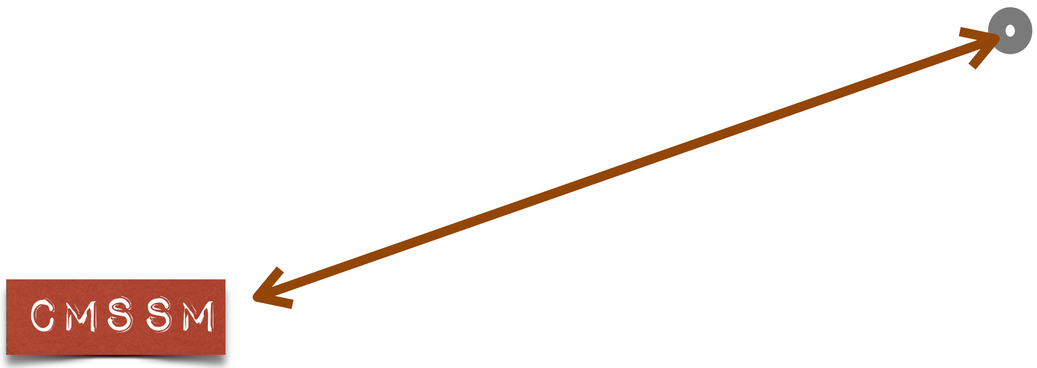

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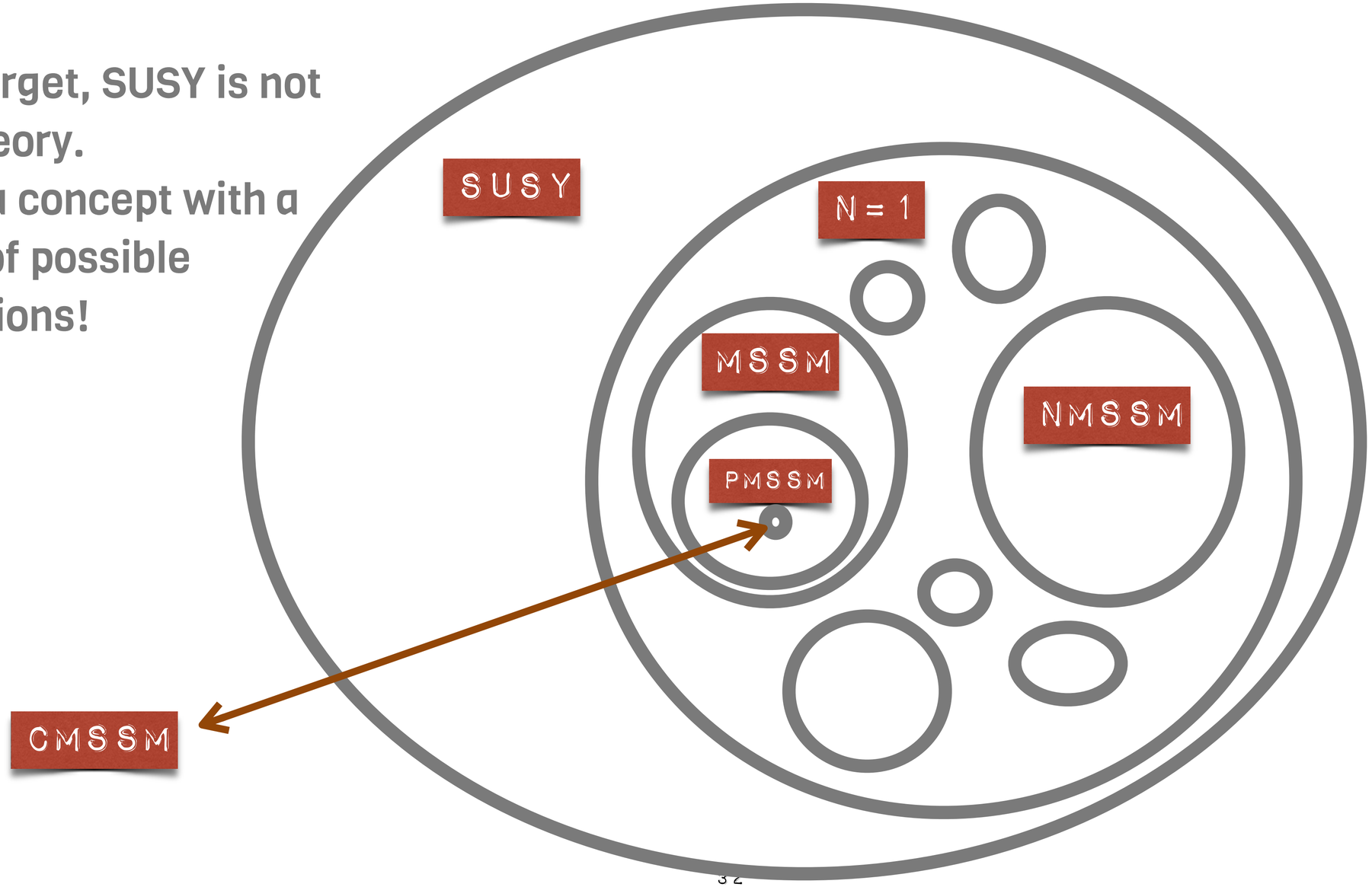

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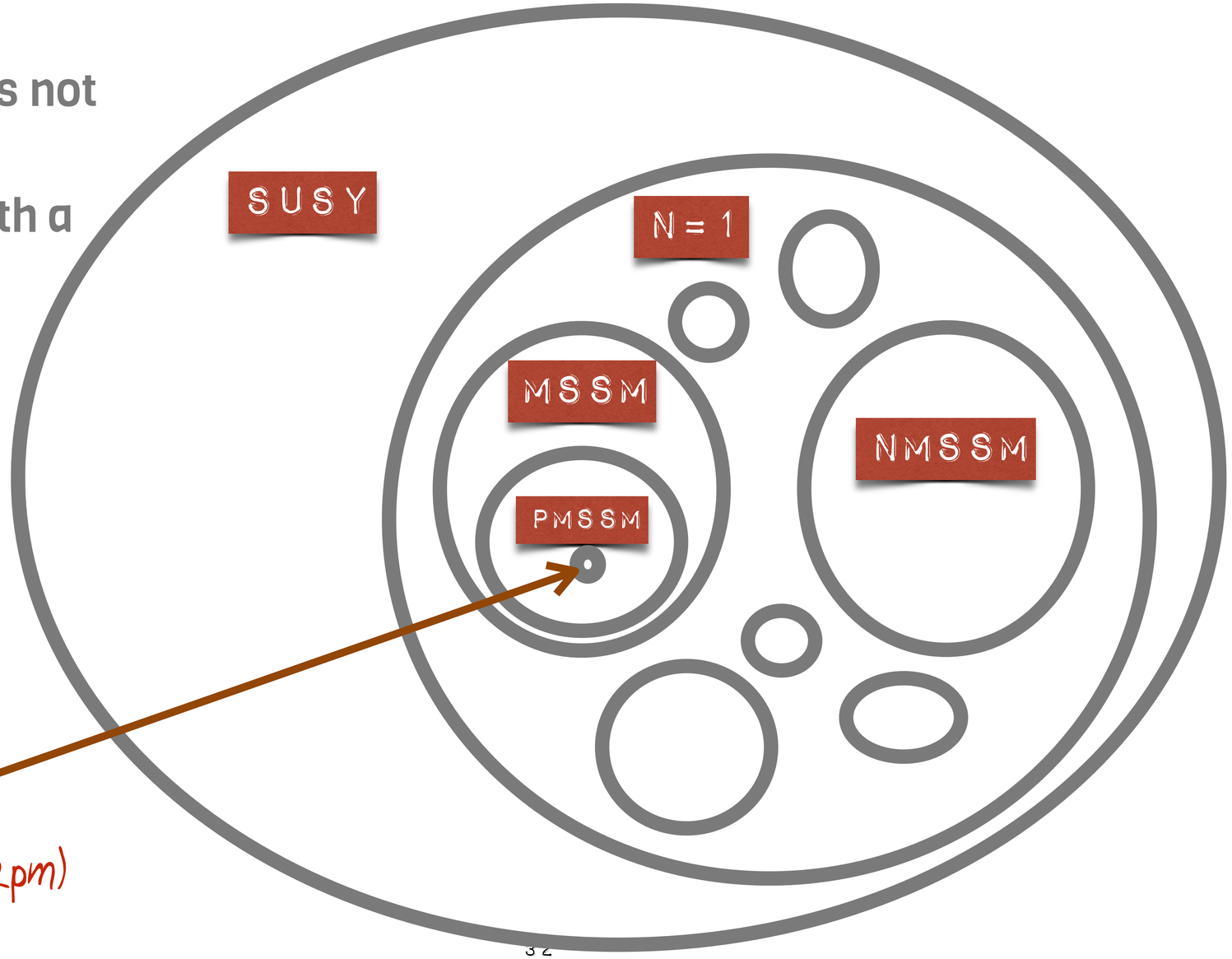

(see Matthias' talk @2pm)

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- … and is far from being ruled out