Characterizing New Physics with Polarized Beams at High Energy Hadron Colliders

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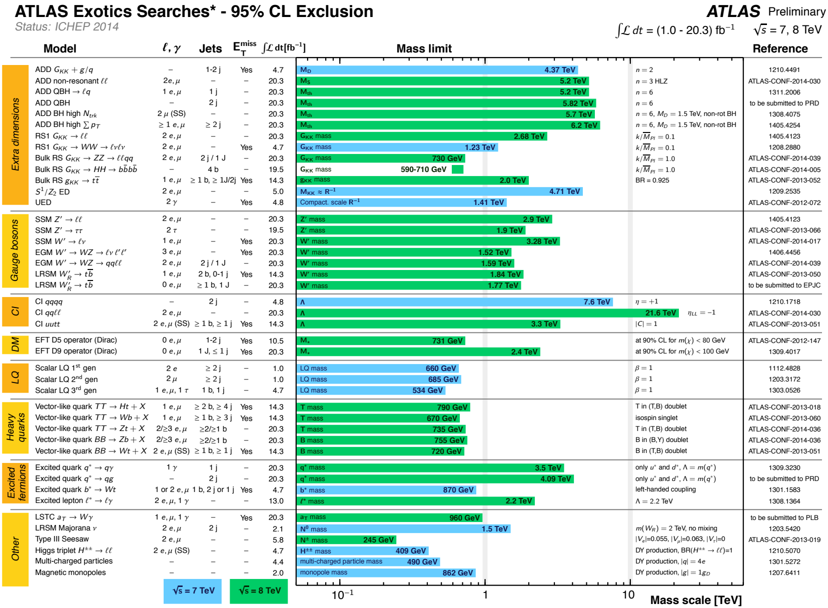
Outline

1. Motivations
2. Physics at polarized hadron colliders
3. Physics case: Monotop signature
4. Conclusions

Status of New Physics searches at the LHC

- **After 3 years of data taking at the LHC:**
    - **No experimental evidence** of **New physics has been found**
    - **ATLAS and CMS have probed extensively** the **TeV region**
    - **Significant portions** of the **parameter space (ps)** of **many BSM simplified models** have been **excluded**.
    - **Mass exclusion limits** of many **BSM particles** have been **pushed higher and higher in energy**
- ***e.g.* Summary plots for ATLAS:**



ATLAS Exotics Searches* - 95% CL Exclusion

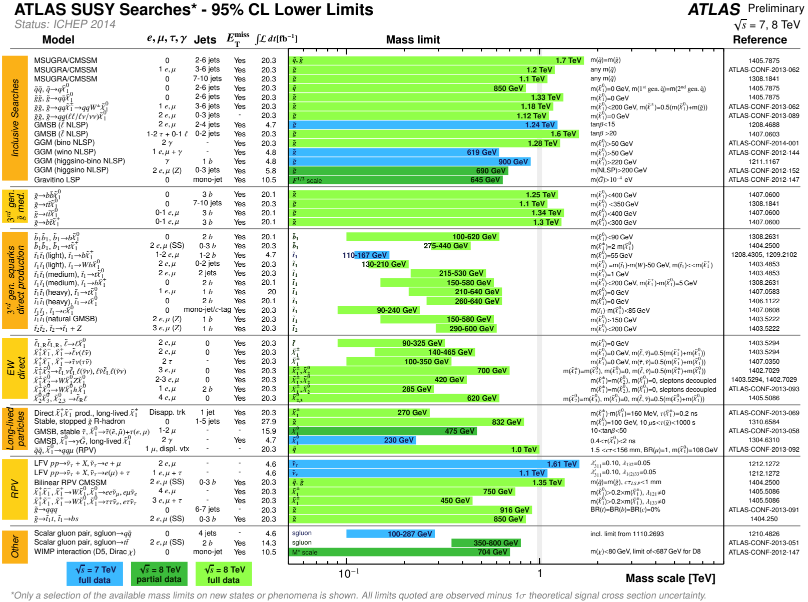
Status: ICHEP 2014

ATLAS Preliminary

$\int\mathcal{L}\,dt = (1.0 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	ℓ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Extra dimensions	ADD $G_{KK}+g/q$	–	1-2 j	Yes	4.7	M_D 4.37 TeV	$n=2$	1210.4491
	ADD non-resonant $\ell\ell$	$2e,\mu$	–	–	20.3	M_S 5.2 TeV	$n=3$ HLZ	ATLAS-CONF-2014-030
	ADD QBH $\to \ell q$	$1\ e,\mu$	1 j	–	20.3	M_{th} 5.2 TeV	$n=6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n=6$	to be submitted to PRD
	ADD BH high N_{trk}	$2\ \mu$ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n=6$, $M_D=1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	$\geq 1\ e,\mu$	≥ 2 j	–	20.3	M_{th} 6.2 TeV	$n=6$, $M_D=1.5$ TeV, non-rot BH	1405.4254
	RS1 $G_{KK}\to\ell\ell$	$2\ e,\mu$	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl}=0.1$	1405.4123
	RS1 $G_{KK}\to WW\to\ell\nu\ell\nu$	$2\ e,\mu$	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl}=0.1$	1208.2880
	Bulk RS $G_{KK}\to ZZ\to\ell\ell qq$	$2\ e,\mu$	2 j / 1 J	–	20.3	G_{KK} mass 730 GeV	$k/\overline{M}_{Pl}=1.0$	ATLAS-CONF-2014-039
	Bulk RS $G_{KK}\to HH\to b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl}=1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK}\to t\bar{t}$	$1\ e,\mu$	≥ 1 b, $\geq$ 1J/2j	Yes	14.3	g_{KK} mass 2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	$2\ e,\mu$	–	–	5.0	$M_{KK}\approx R^{-1}$ 4.71 TeV		1209.2535
	UED	$2\ \gamma$	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z'\to\ell\ell$	$2\ e,\mu$	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z'\to\tau\tau$	$2\ \tau$	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W'\to\ell\nu$	$1\ e,\mu$	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W'\to WZ\to\ell\nu\,\ell'\ell'$	$3\ e,\mu$	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM $W'\to WZ\to qq\ell\ell$	$2\ e,\mu$	2 j / 1 J	–	20.3	W' mass 1.59 TeV		ATLAS-CONF-2014-039
	LRSM $W'_R\to t\bar{b}$	$1\ e,\mu$	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
	LRSM $W'_R\to t\bar{b}$	$0\ e,\mu$	≥ 1 b, 1 J	–	20.3	W' mass 1.77 TeV		to be submitted to EPJC
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta=+1$	1210.1718
	CI $qq\ell\ell$	$2\ e,\mu$	–	–	20.3	Λ 21.6 TeV	$\eta_{LL}=-1$	ATLAS-CONF-2014-030
	CI $uutt$	$2\ e,\mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C\rvert=1$	ATLAS-CONF-2013-051
DM	EFT D5 operator (Dirac)	$0\ e,\mu$	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi)<80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator (Dirac)	$0\ e,\mu$	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi)<100$ GeV	1309.4017
LQ	Scalar LQ 1^{st} gen	$2\ e$	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta=1$	1112.4828
	Scalar LQ 2^{nd} gen	$2\ \mu$	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta=1$	1203.3172
	Scalar LQ 3^{rd} gen	$1\ e,\mu,\ 1\ \tau$	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta=1$	1303.0526
Heavy quarks	Vector-like quark $TT\to Ht+X$	$1\ e,\mu$	≥ 2 b, ≥ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT\to Wb+X$	$1\ e,\mu$	≥ 1 b, ≥ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $TT\to Zt+X$	$2/\geq 3\ e,\mu$	$\geq 2/\geq 1$ b	–	20.3	T mass 735 GeV	T in (T,B) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB\to Zb+X$	$2/\geq 3\ e,\mu$	$\geq 2/\geq 1$ b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB\to Wt+X$	$2\ e,\mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	B mass 720 GeV	B in (T,B) doublet	ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^*\to q\gamma$	$1\ \gamma$	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1309.3230
	Excited quark $q^*\to qg$	–	2 j	–	20.3	q^* mass 4.09 TeV	only u^* and d^*, $\Lambda=m(q^*)$	to be submitted to PRD
	Excited quark $b^*\to Wt$	1 or 2 e,μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^*\to\ell\gamma$	$2\ e,\mu,\ 1\ \gamma$	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda=2.2$ TeV	1308.1364
Other	LSTC $a_T\to W\gamma$	$1\ e,\mu,\ 1\ \gamma$	–	Yes	20.3	a_T mass 960 GeV		to be submitted to PLB
	LRSM Majorana ν	$2\ e,\mu$	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R)=2$ TeV, no mixing	1203.5420
	Type III Seesaw	$2\ e,\mu$	–	–	5.8	$N^\pm$ mass 245 GeV	$\lvert V_e\rvert$=0.055, $\lvert V_\mu\rvert$=0.063, $\lvert V_\tau\rvert$=0	ATLAS-CONF-2013-019
	Higgs triplet $H^{\pm\pm}\to\ell\ell$	$2\ e,\mu$ (SS)	–	–	4.7	$H^{\pm\pm}$ mass 409 GeV	DY production, BR($H^{\pm\pm}\to\ell\ell$)=1	1210.5070
	Multi-charged particles	–	–	–	4.4	multi-charged particle mass 490 GeV	DY production, $\lvert q\rvert=4e$	1301.5272
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g\rvert=1g_D$	1207.6411

*Only a selection of the available mass limits on new states or phenomena is shown.



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\text{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde q, \tilde g$ 1.7 TeV	$m(\tilde q)=m(\tilde g)$	1405.7875
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde g$ 1.2 TeV	any $m(\tilde q)$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde g$ 1.1 TeV	any $m(\tilde q)$	1308.1841
	$\tilde q \tilde q, \tilde q \to q \tilde\chi_1^0$	0	2-6 jets	Yes	20.3	$\tilde q$ 850 GeV	$m(\tilde\chi_1^0)$=0 GeV, m(1^{st} gen. $\tilde q$)=m(2^{nd} gen. $\tilde q$)	1405.7875
	$\tilde g \tilde g, \tilde g \to q \bar q \tilde\chi_1^0$	0	2-6 jets	Yes	20.3	$\tilde g$ 1.33 TeV	$m(\tilde\chi_1^0)$=0 GeV	1405.7875
	$\tilde g \tilde g, \tilde g \to q q \tilde\chi_1^\pm \to q q W^\pm \tilde\chi_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde g$ 1.18 TeV	$m(\tilde\chi_1^0)$<200 GeV, $m(\tilde\chi^\pm)$=0.5($m(\tilde\chi_1^0)$+$m(\tilde g)$)	ATLAS-CONF-2013-062
	$\tilde g \tilde g, \tilde g \to qq(\ell\ell/\ell\nu/\nu\nu)\tilde\chi_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde g$ 1.12 TeV	$m(\tilde\chi_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde\ell$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde g$ 1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde\ell$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde g$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde g$ 1.28 TeV	$m(\tilde\chi_1^0)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde g$ 619 GeV	$m(\tilde\chi_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde g$ 900 GeV	$m(\tilde\chi_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde g$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde G)>10^{-4}$ eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde g$ med.	$\tilde g \to b \bar b \tilde\chi_1^0$	0	3 b	Yes	20.1	$\tilde g$ 1.25 TeV	$m(\tilde\chi_1^0)$<400 GeV	1407.0600
	$\tilde g \to t \bar t \tilde\chi_1^0$	0	7-10 jets	Yes	20.3	$\tilde g$ 1.1 TeV	$m(\tilde\chi_1^0)$ <350 GeV	1308.1841
	$\tilde g \to t \bar t \tilde\chi_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde g$ 1.34 TeV	$m(\tilde\chi_1^0)$<400 GeV	1407.0600
	$\tilde g \to b \bar t \tilde\chi_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde g$ 1.3 TeV	$m(\tilde\chi_1^0)$<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde b_1 \tilde b_1, \tilde b_1 \to b \tilde\chi_1^0$	0	2 b	Yes	20.1	$\tilde b_1$ 100-620 GeV	$m(\tilde\chi_1^0)$<90 GeV	1308.2631
	$\tilde b_1 \tilde b_1, \tilde b_1 \to t \tilde\chi_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde b_1$ 275-440 GeV	$m(\tilde\chi_1^\pm)$=2 $m(\tilde\chi_1^0)$	1404.2500
	$\tilde t_1 \tilde t_1$ (light), $\tilde t_1 \to b \tilde\chi_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde t_1$ 110-167 GeV	$m(\tilde\chi_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde t_1 \tilde t_1$ (light), $\tilde t_1 \to W b \tilde\chi_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde t_1$ 130-210 GeV	$m(\tilde\chi_1^0)$ =$m(\tilde t_1)$-$m(W)$-50 GeV, $m(\tilde t_1)$<<$m(\tilde\chi_1^\pm)$	1403.4853
	$\tilde t_1 \tilde t_1$ (medium), $\tilde t_1 \to t \tilde\chi_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde t_1$ 215-530 GeV	$m(\tilde\chi_1^0)$=1 GeV	1403.4853
	$\tilde t_1 \tilde t_1$ (medium), $\tilde t_1 \to b \tilde\chi_1^\pm$	0	2 b	Yes	20.1	$\tilde t_1$ 150-580 GeV	$m(\tilde\chi_1^0)$<200 GeV, $m(\tilde\chi_1^\pm)$-$m(\tilde\chi_1^0)$=5 GeV	1308.2631
	$\tilde t_1 \tilde t_1$ (heavy), $\tilde t_1 \to t \tilde\chi_1^0$	1 e, μ	1 b	Yes	20	$\tilde t_1$ 210-640 GeV	$m(\tilde\chi_1^0)$=0 GeV	1407.0583
	$\tilde t_1 \tilde t_1$ (heavy), $\tilde t_1 \to t \tilde\chi_1^0$	0	2 b	Yes	20.1	$\tilde t_1$ 260-640 GeV	$m(\tilde\chi_1^0)$=0 GeV	1406.1122
	$\tilde t_1 \tilde t_1, \tilde t_1 \to c \tilde\chi_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde t_1$ 90-240 GeV	$m(\tilde t_1)$-$m(\tilde\chi_1^0)$<85 GeV	1407.0608
	$\tilde t_1 \tilde t_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde t_1$ 150-580 GeV	$m(\tilde\chi_1^0)$>150 GeV	1403.5222
	$\tilde t_2 \tilde t_2, \tilde t_2 \to \tilde t_1 + Z$	3 e, μ (Z)	1 b	Yes	20.3	$\tilde t_2$ 290-600 GeV	$m(\tilde\chi_1^0)$<200 GeV	1403.5222
EW direct	$\tilde\ell_{\text{L,R}} \tilde\ell_{\text{L,R}}, \tilde\ell \to \ell \tilde\chi_1^0$	2 e, μ	0	Yes	20.3	$\tilde\ell$ 90-325 GeV	$m(\tilde\chi_1^0)$=0 GeV	1403.5294
	$\tilde\chi_1^+ \tilde\chi_1^-, \tilde\chi_1^+ \to \tilde\ell \nu(\ell \tilde\nu)$	2 e, μ	0	Yes	20.3	$\tilde\chi_1^\pm$ 140-465 GeV	$m(\tilde\chi_1^0)$=0 GeV, $m(\tilde\ell, \tilde\nu)$=0.5($m(\tilde\chi_1^\pm)$+$m(\tilde\chi_1^0)$)	1403.5294
	$\tilde\chi_1^+ \tilde\chi_1^-, \tilde\chi_1^+ \to \tilde\tau \nu(\tau \tilde\nu)$	2 τ	-	Yes	20.3	$\tilde\chi_1^\pm$ 100-350 GeV	$m(\tilde\chi_1^0)$=0 GeV, $m(\tilde\tau, \tilde\nu)$=0.5($m(\tilde\chi_1^\pm)$+$m(\tilde\chi_1^0)$)	1407.0350
	$\tilde\chi_1^\pm \tilde\chi_2^0 \to \tilde\ell_{\text{L}} \nu \tilde\ell_{\text{L}} \ell(\tilde\nu\nu), \ell \tilde\nu \tilde\ell_{\text{L}} \ell(\tilde\nu\nu)$	3 e, μ	0	Yes	20.3	$\tilde\chi_1^\pm, \tilde\chi_2^0$ 700 GeV	$m(\tilde\chi_1^\pm)$=$m(\tilde\chi_2^0)$, $m(\tilde\chi_1^0)$=0, $m(\tilde\ell, \tilde\nu)$=0.5($m(\tilde\chi_1^\pm)$+$m(\tilde\chi_1^0)$)	1402.7029
	$\tilde\chi_1^\pm \tilde\chi_2^0 \to W \tilde\chi_1^0 Z \tilde\chi_1^0$	2-3 e, μ	0	Yes	20.3	$\tilde\chi_1^\pm, \tilde\chi_2^0$ 420 GeV	$m(\tilde\chi_1^\pm)$=$m(\tilde\chi_2^0)$, $m(\tilde\chi_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde\chi_1^\pm \tilde\chi_2^0 \to W \tilde\chi_1^0 h \tilde\chi_1^0$	1 e, μ	2 b	Yes	20.3	$\tilde\chi_1^\pm, \tilde\chi_2^0$ 285 GeV	$m(\tilde\chi_1^\pm)$=$m(\tilde\chi_2^0)$, $m(\tilde\chi_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
	$\tilde\chi_2^0 \tilde\chi_3^0, \tilde\chi_{2,3}^0 \to \tilde\ell_{\text{R}} \ell$	4 e, μ	0	Yes	20.3	$\tilde\chi_{2,3}^0$ 620 GeV	$m(\tilde\chi_2^0)$=$m(\tilde\chi_3^0)$, $m(\tilde\chi_1^0)$=0, $m(\tilde\ell, \tilde\nu)$=0.5($m(\tilde\chi_2^0)$+$m(\tilde\chi_1^0)$)	1405.5086
Long-lived particles	Direct $\tilde\chi_1^+ \tilde\chi_1^-$ prod., long-lived $\tilde\chi_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde\chi_1^\pm$ 270 GeV	$m(\tilde\chi_1^\pm)$-$m(\tilde\chi_1^0)$=160 MeV, $\tau(\tilde\chi_1^\pm)$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde g$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde g$ 832 GeV	$m(\tilde\chi_1^0)$=100 GeV, 10 μs<$\tau(\tilde g)$<1000 s	1310.6584
	GMSB, stable $\tilde\tau, \tilde\chi_1^0 \to \tilde\tau(\tilde e, \tilde\mu) + \tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde\chi_1^0$ 475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde\chi_1^0 \to \gamma \tilde G$, long-lived $\tilde\chi_1^0$	2 γ	-	Yes	4.7	$\tilde\chi_1^0$ 230 GeV	0.4<$\tau(\tilde\chi_1^0)$<2 ns	1304.6310
	$\tilde q \tilde q, \tilde\chi_1^0 \to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde q$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde\chi_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp \to \tilde\nu_\tau + X, \tilde\nu_\tau \to e + \mu$	2 e, μ	-	-	4.6	$\tilde\nu_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp \to \tilde\nu_\tau + X, \tilde\nu_\tau \to e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde\nu_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde q, \tilde g$ 1.35 TeV	$m(\tilde q)$=$m(\tilde g)$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde\chi_1^+ \tilde\chi_1^-, \tilde\chi_1^+ \to W \tilde\chi_1^0, \tilde\chi_1^0 \to ee\tilde\nu_\mu, e\mu\tilde\nu_e$	4 e, μ	-	Yes	20.3	$\tilde\chi_1^\pm$ 750 GeV	$m(\tilde\chi_1^0)$>0.2×$m(\tilde\chi_1^\pm)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde\chi_1^+ \tilde\chi_1^-, \tilde\chi_1^+ \to W \tilde\chi_1^0, \tilde\chi_1^0 \to \tau\tau\tilde\nu_e, e\tau\tilde\nu_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde\chi_1^\pm$ 450 GeV	$m(\tilde\chi_1^0)$>0.2×$m(\tilde\chi_1^\pm)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde g \to qqq$	0	6-7 jets	-	20.3	$\tilde g$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde g \to \tilde t_1 t, \tilde t_1 \to bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde g$ 850 GeV		1404.250
Other	Scalar gluon pair, sgluon$\to q\bar q$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar t$	2 e, μ (SS)	2 b	Yes	14.3	sgluon 350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

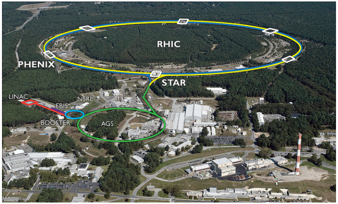
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

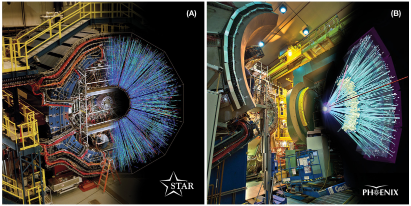
What's next?

- **The range of those searches will be increased by:**
  - The **upcoming run** at **13** and **14 TeV**
  - The **proposed** (and **very popular**) **High-Luminosity upgrade**
- **If New Physics has to be discovered in the coming years:**
  - **Goal** will be to **characterize** the **properties** of the new **d.o.f.**
    - e.g. masses, couplings and spins
- **However in most studies at hadron colliders...**
  - **Experimental analyses motivated** by theoretical arguments
    - Imply **key-final state signatures** that should be looked for
  - **Signatures not typical** of a given **theory/scenario**
    - **Famous example**: MSSM and UED models
- **Disentangling BSM theories with same signature is hard**

Why using polarized beams for New Physics searches?

- **Because it precisely solves the previous issue**





- **Because the technology is already there and working:**
  - c.f. **RHIC** (Relativistic Heavy Ion Collider) in **BNL**
    - **Polarization rate** of proton beams at RHIC ∼ **70-80%**
- **Because we have the theoretical knowledge:**
  - **A few BSM** phenomenological **studies** were **lead** at **RHIC**
  - **Most** of those **studies** were also **considering**
    - **Polarization upgrades** of the TeVatron and/or the LHC

Future Accelerators & Polarized beams

- **A polarized LHC is now quite unlikely to be realized**
  - **Technologically** **feasible** but...
    - Would **require** to **replace** the **full injector chain**

- **The situation is different for the recently proposed FCC**
  - **If** **New physics** is **discovered** at the **LHC**
    - ➟ **Strong motivation** for a **polarized mode** of the **FCC**

1. Motivations
2. Physics at polarized hadron colliders
3. Physics case: Monotop signature
4. Conclusions

Polarized Parton Distribution Functions

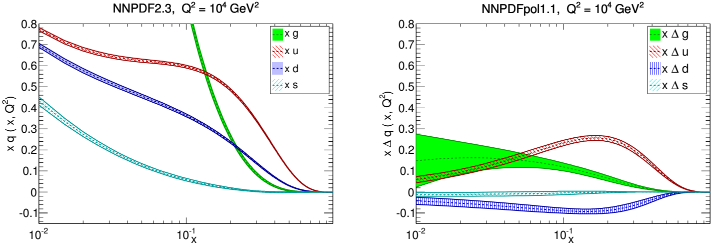
- **Unpolarized and polarized PDFs defined as:**

$$\begin{aligned} f_{a/p}(x, Q^2) &= f^+_{a/p}(x, Q^2) + f^-_{a/p}(x, Q^2) \\ \Delta f_{a/p}(x, Q^2) &= f^+_{a/p}(x, Q^2) - f^-_{a/p}(x, Q^2) \end{aligned}$$

With $f^+_{a/p}(x, Q^2)$ $[f^-_{a/p}(x, Q^2)]$ at Leading Order:

> The probability of finding a parton a with a **momentum fraction** x at a given **energy scale** Q, with a **spin aligned** $\big[$**anti-aligned**$\big]$ **with** the **spin of the proton** p

Polarized Parton Distribution Functions



- **Polarized PDFs are smaller than unpolarized ones**
- **At small-x polarized PDFs are largely suppressed**
- **Polarized distributions Δu and Δd have opposite signs**
- **Important consequences for spin asymmetries:**
  - **Sizable only** at **medium** and **large-x**
    - i.e. for final-state with large invariant masses (New Physics)
  - Behave **differently** depending on the **initial partonic state**
    - i.e. give discriminating power between BSM scenarios

Parton luminosities & cross sections

- **Parton luminosities are defined from the PDFs as:**

$$
\begin{aligned}
\mathcal{L}_{ij} &= \frac{1}{S}\int_{\tau}^{1}\frac{dx}{x}\frac{1}{1+\delta_{ij}}\left[q_i\left(x,m_X\right)q_j\left(\frac{\tau}{x},m_X\right)+q_i\left(\frac{\tau}{x},m_X\right)q_j\left(x,m_X\right)\right]\\
\mathcal{L}_{ij}^{L} &= \frac{1}{S}\int_{\tau}^{1}\frac{dx}{x}\frac{1}{1+\delta_{ij}}\left[q_i\left(x,m_X\right)\Delta q_j\left(\frac{\tau}{x},m_X\right)+q_i\left(\frac{\tau}{x},m_X\right)\Delta q_j\left(x,m_X\right)\right]\\
\mathcal{L}_{ij}^{LL} &= \frac{1}{S}\int_{\tau}^{1}\frac{dx}{x}\frac{1}{1+\delta_{ij}}\left[\Delta q_i\left(x,m_X\right)\Delta q_j\left(\frac{\tau}{x},m_X\right)+\Delta q_i\left(\frac{\tau}{x},m_X\right)\Delta q_j\left(x,m_X\right)\right]
\end{aligned}
$$

- **Cross sections can be defined using parton luminosities:**

$$
\begin{aligned}
\sigma_0 &= q_i\otimes q_j\otimes\hat{\sigma}_{0,ij}=\mathcal{L}_{ij}\otimes\left[\hat{s}\ \hat{\sigma}_{0,ij}\right],\\
\sigma_L &= q_i\otimes\Delta q_j\otimes\hat{\sigma}_{L,ij}=\mathcal{L}_{ij}^{L}\otimes\left[\hat{s}\ \hat{\sigma}_{L,ij}\right],\\
\sigma_{LL} &= \Delta q_i\otimes\Delta q_j\otimes\hat{\sigma}_{LL,ij}=\mathcal{L}_{ij}^{LL}\otimes\left[\hat{s}\ \hat{\sigma}_{LL,ij}\right]
\end{aligned}
$$

Longitudinal spin asymmetries

- **Spin asymmetries are defined as ratios of cross sections:**

$$A_L = \frac{\sigma_L}{\sigma_0} \qquad A_{LL} = \frac{\sigma_{LL}}{\sigma_0}$$

- **Why is it is useful to compute spin asymmetries?**
  - From the **experimental point of view:**
    - Because **systematic uncertainties cancel in ratios**
  - Because of their **sensitivity** to the **initial partonic state**
  - Because $\hat{s}\hat{\sigma}_{ij}$ are often constants
    - Far above the production threshold
    - In the case of a narrow s-channel resonance

➡ A_L and A_{LL} re-write as ratios of parton luminosities

$$A_L^{ij} = \frac{\mathcal{L}_{ij}^L}{\mathcal{L}_{ij}} \qquad \text{and} \qquad A_{LL}^{ij} = \frac{\mathcal{L}_{ij}^{LL}}{\mathcal{L}_{ij}}$$

1. Motivations
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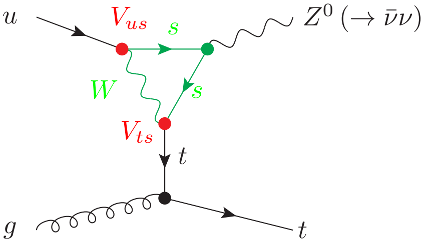
Monotop production in the Standard model

[Fuks, Andrea, Maltoni arXiv:11066199]

- Final state signature : $t + \not{E}_T \longrightarrow bjj + \not{E}_T$
- Production mode $\longrightarrow$ **subdominant contribution**
  - **GIM suppressed:** $V_{us} \simeq 0.23$, $V_{ts} \simeq 0.04$
  - **Loop-suppressed**
  - **Branching ratio**: $\mathrm{BR}(Z \to \nu\bar{\nu}) \simeq 0.2$
- **Observing monotop means observing New Physics**

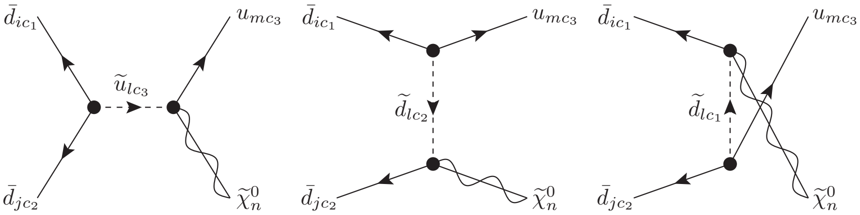


Monotop production in the RPV-MSSM

- **Production @ tree-level through squark exchange**

$$pp \to \widetilde{q} \to \widetilde{\chi}_1^0 + t$$

  - **6 diagrams** in the **flavor conserving case**
  - $\not{E}_T$ associated to the lightest neutralino
    - Kinematic condition: $m_t > m_{\chi_1^0} \Rightarrow$ Long-lived neutralino
    - Decay far outside of the detector due to its long lifetime

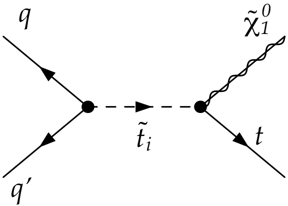


Monotop production in the RPV-MSSM

- **Production @ tree-level through $\widetilde{t}_1$ exchange**

$$pp \to \widetilde{t}_1 \to \widetilde{\chi}_1^0 + t$$

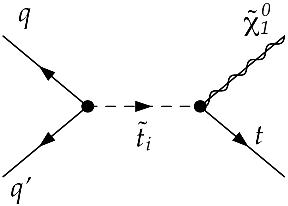
  - **Assume $\widetilde{t}_2$ contribution** is **negligible**
  - **Only one resonant diagram** (NWA)



$$\hat{\sigma}^{h_1 h_2}_{RPV}(\bar{q}_j \bar{q}_k \to t\tilde{\chi}_1^0) = \frac{(1-h_1)(1-h_2)\pi \left| \lambda''_{3jk} \sin\theta_{\tilde{t}} \right|^2}{6} \times \mathrm{BR}\left(\tilde{t} \to t\tilde{\chi}_1^0\right) \times \delta\left(\hat{s} - m_{\tilde{t}}^2\right)$$

Monotop production in the RPV-MSSM

- **Dominant channels are ds and $\bar{d}\bar{s}$**



Spin asymmetries for the process + charge conjugate

$$A_L^{\bar{d}\bar{s}+ds} = \frac{\mathcal{L}_{ds}^{L} - \mathcal{L}_{\bar{d}\bar{s}}^{L}}{\mathcal{L}_{ds} + \mathcal{L}_{\bar{d}\bar{s}}} \quad \text{and} \quad A_{LL}^{\bar{d}\bar{s}+ds} = \frac{\mathcal{L}_{ds}^{LL} + \mathcal{L}_{\bar{d}\bar{s}}^{LL}}{\mathcal{L}_{ds} + \mathcal{L}_{\bar{d}\bar{s}}}$$

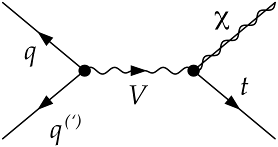
Monotop production in the Hylogenesis model

[arXiv:1008.2399], [arXiv:1106.4320]

- **Provides a theoretical mechanism for generating:**
  - **Baryon Asymmetry in the Universe** (BAU)
  - **Dark Matter** (DM)
- **Lagrangian:**

$$\mathcal{L}_{\text{hylo}} = \frac{1}{2}\kappa_{ij}\ \bar{d}_i^c \gamma^\mu d_j V_\mu + \text{h.c.}\ ,$$

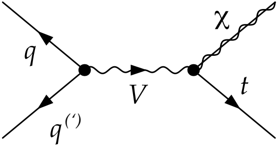
- **Monotop originates from the decay of a vector resonance**



$$\hat{\sigma}^{h_1 h_2}_{\text{hylo}}(\bar{q}_j \bar{q}_k \to t\chi) = \frac{2(1-h_1h_2)\pi\left|\kappa_{jk}\right|^2}{3} \times \text{BR}\Big(V \to t\chi\Big) \times \delta\Big(\hat{s} - m_V^2\Big)$$

Monotop production in the Hylogenesis model

- **Dominant channels are dd and $\bar{d}\bar{d}$**



Spin asymmetries for the process + charge conjugate

$$A_L^{\bar{d}\bar{d}+dd} = 0 \,, \qquad A_{LL}^{\bar{d}\bar{d}+dd} = -\frac{\mathcal{L}_{dd}^{LL} + \mathcal{L}_{\bar{d}\bar{d}}^{LL}}{\mathcal{L}_{dd} + \mathcal{L}_{\bar{d}\bar{d}}}$$

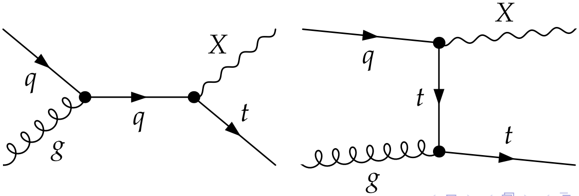
Monotop production in the X-model

[arXiv:1107.0623], [arXiv:1310.7600]

- **Provides a candidate for Dark matter**
  - **Top quark couple** to a new **neutral heavy resonance X**
  - X **resonance strongly couples** to some **new hidden sector**
  - X **resonance** decays into **particles** of the **hidden sector**
  - X **resonance** mediates **FCNCs at tree-level**
- **Lagrangian:**

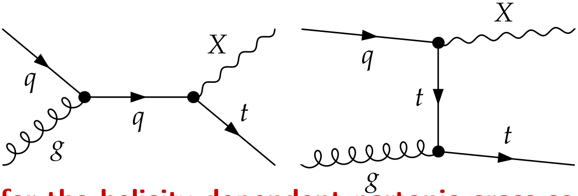
$$\mathcal{L}_X = g_X^i \bar{u}_i \gamma^\mu P_R t X_\mu + \text{h.c.}$$

- **Monotop originates from non-resonant diagrams**



Monotop production in the X-model

- **Non-resonant diagrams ⇒ Cannot apply the NWA**



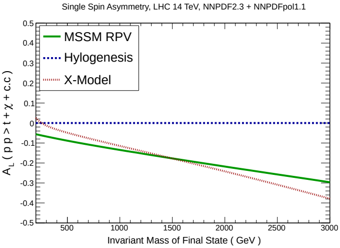
- **Result for the helicity-dependent partonic cross-section:**

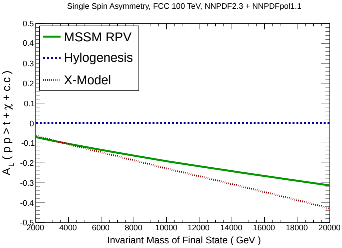
$$\frac{\mathrm{d}\hat{\sigma}_X^{h,\lambda}}{\mathrm{d}t}(u_i g \to tX) = \quad \frac{1}{16\pi s^2}\frac{g_s^2 g_X^{i2}}{12 s m_X^2 (t-m_t^2)^2}(1+h)\Big[C_1 + C_2\lambda\Big]$$

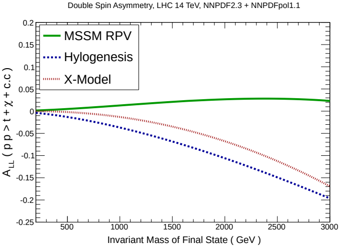
  - No simple expression for A_L and A_{LL}

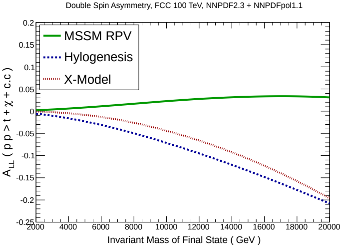
- **Dominant channel ⇒ ug**

Numerical Results









Conclusions

Conclusions

- ➢ **Polarized beams are technologically feasible**
- ➢ **If New Physics** is discovered at the LHC or at the HL-LHC
  - ➠ Provide **strong motivation** for a **polarized FCC**
- ➢ **Polarized beams** allow to disentangle **BSM theories** with the **same final-state signature**
  - ➠ Because of the of the **properties** of the **polarized PDFs**
- ➢ **Polarization effects** at a **100 TeV FCC** are **unavoidable**
  - ➠ Because at high energy the Z and W are effectively massless, and should be included into the DGLAP equations

Thanks for your attention

Back-up slides

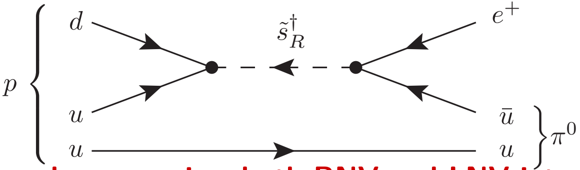
Motivations for beyond Minimal SUSY searches

- **Non-observations of SUSY particles @ the LHC:**
  - **Rekindled the interest** for **non-minimal SUSY models**
- **Idea behind non-minimal SUSY models**
  - **It could be that we are missing an additional ingredient**
    - **R-Parity Violating (RPV) MSSM**
    - NMSSM, Left-Right MSSM, MRSSM, Vector-like MSSM
- **Price to pay for non-minimal SUSY**
  - **More interactions** ⇒ **New free parameters**
  - **Phenomenological analyses** ⇒ **More complicated**
- **Attractive feature of non-minimal SUSY**
  - **May solve problems that minimal SUSY does not**
    - Baryon Asymmetry in the Universe **(BAU)** [Barbier et al.]
    - **Neutrino mass generation** [Barbier et al.]
    - μ **problem**

Motivations for R-Parity Violating SUSY

R-Parity

- **Forbids both BNV** and **LNV interactions** in the MSSM
- **Imposed** to avoid **fast proton decay:** $\tau_p \gtrsim 10^{33}$ years



- **Proton decay requires both BNV and LNV interactions**
  - **R-parity conservation** is **too restrictive**
  - **Either BNV** or **LNV** are **allowed** ⇒ **No proton decay**
- **RPV-MSSM with BNV model features**
  - **BNV** + lepton number conservation **compatible** with a **GUT**
  - **Provides** the **third Sakharov condition** ⇒ **BAU**
- **Price to pay:** Extremely difficult to accommodate DM

The model

- **BNV superpotential:**

$$W_{BNV} = \frac{1}{2}\lambda''_{ijk} U^i D^j D^k + W_{MSSM}$$

  - λ''_{ijk}: BNV couplings ⇒ 9 new free independent parameters
  - U, D: Superfields
  - i, j and k : Flavor indices

- **BNV Lagrangian:**

$$\begin{aligned}\mathcal{L}_{U_i U_j D_k} &= -\frac{1}{2}\lambda''_{ijk}\varepsilon^{c_1 c_2 c_3}\Big(\widetilde{u}^{0\dagger}_{lc_3} R^u_{l(k+3)} \bar{\Psi}^d_{Dic_1} P_L \Psi^{d\;\;C}_{Djc_2} \\ &+ \widetilde{d}^{0\dagger}_{lc_2} R^d_{l(k+3)} \bar{\Psi}^u_{Dic_1} P_L \Psi^{d\;\;C}_{Dkc_2} + \bar{\Psi}^u_{Dic_1} P_L \Psi^{d\;\;C}_{Djc_2} R^d_{l(k+3)} \widetilde{d}^{0\dagger}_{lc_3}\Big) + \text{h.c.}\end{aligned}$$

Constraints on BNV couplings

Present experimental constraints on λ''_{ijk} couplings:

- Neutron dipole moment [Slavich arXiv:0008270]
- Antinucleon oscillations, double nucleon decays
- Rare hadronic decays of B-mesons, K-K systems
- **Observed flux of cosmic rays antiprotons :** [Gondolo arXiv:9704411]

$$\lambda''_{ijk} < 10^{-19} - 10^{-24}$$

- **Yet... Not applicable** to λ''_{3jk} if the **top quark** is **heavier than the Lightest Supersymmetric Particle (LSP)**
  - λ''_{3jk} is left **almost unconstrained** [Barbier et al.]
- **Enforce MFV** $\Rightarrow$ **Only** λ''_{312} is **sizable** $\sim \mathcal{O}(0.1)$

Analytical expressions of the charges

$$\begin{aligned}
Q^{ss}_{lo} &= s\ C_{d_i d_j \tilde{u}_l} C^*_{d_i d_j \tilde{u}_o} \Bigg[\left(s - m^2_{q_m} - m^2_{\tilde{\chi}^0_n} \right) \left(L_{u_m \tilde{u}_l \tilde{\chi}^0_n} L^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} \right. \\
&+ \left. R_{u_m \tilde{u}_l \tilde{\chi}^0_n} R^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} \right) - 2 m_{u_m} m_{\tilde{\chi}^0_n} \left(L_{u_m \tilde{u}_l \tilde{\chi}^0_n} R^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} + R_{u_m \tilde{u}_l \tilde{\chi}^0_n} L^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} \right) \Bigg] \\
Q^{tt+}_{lo} &= C_{u_m d_i \tilde{d}_l} C^*_{u_m d_i \tilde{d}_o} \left(t - m^2_{u_m} \right) \left(t - m^2_{\tilde{\chi}^0_n} \right) \left(L_{d_j \tilde{d}_l \tilde{\chi}^0_n} L^*_{d_j \tilde{d}_o \tilde{\chi}^0_n} \right) \\
Q^{tt-}_{lo} &= C_{u_m d_i \tilde{d}_l} C^*_{u_m d_i \tilde{d}_o} \left(t - m^2_{u_m} \right) \left(t - m^2_{\tilde{\chi}^0_n} \right) \left(R_{d_j \tilde{d}_l \tilde{\chi}^0_n} R^*_{d_j \tilde{d}_o \tilde{\chi}^0_n} \right) \\
Q^{uu+}_{lo} &= C_{u_m d_j \tilde{d}_l} C^*_{u_m d_j \tilde{d}_o} \left(u - m^2_{u_m} \right) \left(u - m^2_{\tilde{\chi}^0_n} \right) \left(L_{d_i \tilde{d}_l \tilde{\chi}^0_n} L^*_{d_i \tilde{d}_o \tilde{\chi}^0_n} \right)
\end{aligned}$$

Analytical expressions of the charges

$$
\begin{aligned}
Q^{uu-}_{lo} &= C_{u_m d_j \widetilde{d}_l} C^*_{u_m d_j \widetilde{d}_o} \left(u - m^2_{u_m}\right)\left(u - m^2_{\widetilde{\chi}^0_n}\right)\left(R_{d_i \widetilde{d}_l \widetilde{\chi}^0_n} R^*_{d_i \widetilde{d}_o \widetilde{\chi}^0_n}\right) \\
Q^{st}_{lo} &= 2m_{\widetilde{\chi}^0_n} m_{u_m} s\Re\left(C_{d_i d_j \widetilde{u}_l} L_{u_m \widetilde{u}_l \widetilde{\chi}^0_n} C^*_{u_m d_i \widetilde{d}_o} R^*_{d_j \widetilde{d}_o \widetilde{\chi}^0_n}\right) \\
&+ 2st\Re\left(C_{d_i d_j \widetilde{u}_l} R_{u_m \widetilde{u}_l \widetilde{\chi}^0_n} C^*_{u_m d_i \widetilde{d}_o} R^*_{d_j \widetilde{d}_o \widetilde{\chi}^0_n}\right) \\
Q^{su}_{lo} &= -2m_{\widetilde{\chi}^0_n} m_{u_m} s\Re\left(C_{d_i d_j \widetilde{u}_l} L_{u_m \widetilde{u}_l \widetilde{\chi}^0_n} C^*_{u_m d_j \widetilde{d}_o} R^*_{d_i \widetilde{d}_o \widetilde{\chi}^0_n}\right) \\
&- 2us\Re\left(C_{d_i d_j \widetilde{u}_l} R_{u_m \widetilde{u}_l \widetilde{\chi}^0_n} C^*_{u_m d_j \widetilde{d}_o} R^*_{d_i \widetilde{d}_o \widetilde{\chi}^0_n}\right) \\
Q^{ut}_{lo} &= 2\left(m^2_{\widetilde{\chi}^0_n} m^2_{u_m} - ut\right)\Re\left(C_{u_m d_i \widetilde{d}_l} R_{d_j \widetilde{d}_l \widetilde{\chi}^0_n} C^*_{u_m d_j \widetilde{d}_o} R^*_{d_i \widetilde{d}_o \widetilde{\chi}^0_n}\right)
\end{aligned}
$$

Full expressions for the couplings

$$
\begin{aligned}
L_{\tilde{u}_j u_k \tilde{\chi}^0_i} &= \left[(e_q - T^3_q)\, s_W\, N_{i1} + T^3_q\, c_W\, N_{i2} \right] R^{u*}_{jk} + \frac{m_{u_k}\, c_W\, N_{i4}\, R^{u*}_{j(k+3)}}{2\, m_W\, \sin\beta} \\
R_{\tilde{u}_j u_k \tilde{\chi}^0_i} &= -e_q\, s_W\, N^*_{i1}\, R^{u*}_{j(k+3)} + \frac{m_{u_k}\, c_W\, N^*_{i4}\, R^{u*}_{jk}}{2\, m_W\, \sin\beta} \\
L_{\tilde{d}_j d_k \tilde{\chi}^0_i} &= \left[(e_q - T^3_q)\, s_W\, N_{i1} + T^3_q\, c_W\, N_{i2} \right] R^{d*}_{jk} + \frac{m_{d_k}\, c_W\, N_{i4}\, R^{d*}_{j(k+3)}}{2\, m_W\, \sin\beta} \\
R_{\tilde{d}_j d_k \tilde{\chi}^0_i} &= -e_q\, s_W\, N^*_{i1}\, R^{d*}_{j(k+3)} + \frac{m_{d_k}\, c_W\, N^*_{i4}\, R^{d*}_{jk}}{2\, m_W\, \sin\beta}
\end{aligned}
$$

$$
C_{d_i d_j \widetilde{u}_l} = \lambda''_{ijk} R^u_{l(k+3)} \quad \text{and} \quad C_{u_i d_j \widetilde{d}_l} = \lambda''_{ijk} R^d_{l(k+3)}
$$

With

$$
\widetilde{\chi}^0_i = N_{ij} \psi^0_j \quad \text{with} \quad i = 1, 2, 3, 4
$$

Monotop production in the RPV-MSSM

- **Helicity-dependent partonic cross section**

Full 2 → 2 process

$$\frac{d\hat{\sigma}_{h_a h_b}}{dt} = \frac{\alpha}{12 s_W^2 c_W^2 s^2} \sum_{l,o=1,2}^{6} \Bigg[(1-h_a)(1-h_b) \left(\frac{Q_{lo}^{ss}}{s_l s_o} + \frac{Q_{lo}^{tt-}}{t_l t_o} + \frac{Q_{lo}^{uu-}}{u_l u_o} + \frac{Q_{lo}^{st}}{s_l t_o} + \frac{Q_{lo}^{su}}{s_l u_o} + \frac{Q_{lo}^{tu}}{t_l u_o} \right) + (1-h_a)(1+h_b) \frac{Q_{lo}^{tt+}}{t_l t_o} + (1+h_a)(1-h_b) \frac{Q_{lo}^{uu+}}{u_l u_o} \Bigg]$$

- **Compactified expression** of the **cross section**
- h_a and h_b $\Longrightarrow$ **helicities** of **incoming particles**
- Q^{ss}: interferences between diagrams in the s-channel

Tool chain

- **SLHA2 input file:** [Allanach et al.]
  - Model and parameters specification

⇓

- **SUSY-spectrum:** `SPheno-3.2.1`: [Porod, Staub]
  - Compute **RGEs** at the **two loop level**

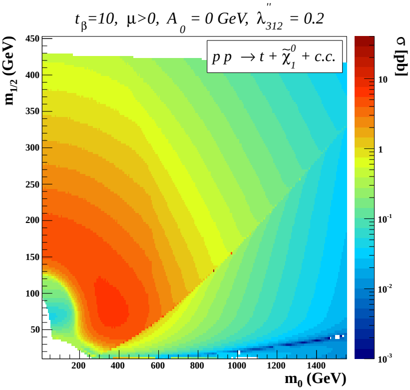
⇓

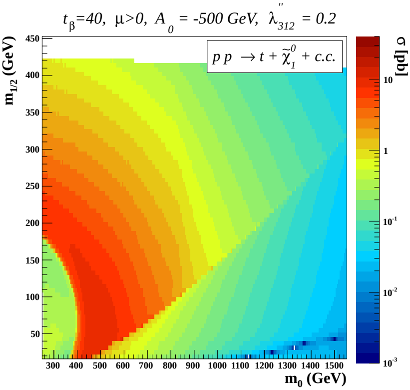
- **Decay Width an Branching Ratios:** `SUSY-HIT-1.3` [Djouadi, Mullheitner,Spira]
  - **Width** and **BRs** of the **MSSM Higgs bosons**: `HDECAY`
  - **Width** and **BRs** of the **SUSY particles**: `SDECAY`

⇓

- **Cross section & scans:** `XSUSY-1.9.23` (**Private code**)
  - Original `C++` **code** developed by **B. Fuks** & **B. Herrmann**
  - **Numerical integration** performed using `VEGAS`

Numerical results





- **Demanding from the computational point of view**
- **Is there a way to simplify the computations?**

The Narrow Width Approximation

- **The Narrow Width Approximation (NWA):**
  - **Reduction** of the **complexity of scattering amplitudes**
  - **Assumes peaked resonance** with a **Breit-Wigner lineshape**
  - **For small** Γ, **off-shell effects are suppressed**
    - ➟ **Intermediate resonance** can be **approximated** to be **on-shell**
  - **Production** and **decay** of **unstable particles** $\Rightarrow$ **factorized**
  - **Non-resonant contributions** are **neglected**
  - **Introduction** of an **error** of $\mathcal{O}(\Gamma/M)$ for each **Breit-Wigner**

Requirements for the NWA

1. **Total width** of the particle way **smaller** than its **mass**: $\Gamma \ll M$
2. **Propagator separable** from the **matrix element**
3. **No significant interferences** from **non-resonnant processes**
4. **Scattering energy larger** than mass of the **resonance**: $\sqrt{s} \gg M$
5. Mass of **resonance larger** than masses of the **daughter** particles

Narrow Width Approximation & New Physics

[Kauer, Rainwater, Berdine arXiv:0703058]

- **Narrow Width Approximation features:**
  - **Drastically** **simplifies calculations** $\Rightarrow\ \sigma_p \times \mathrm{BR}$
  - **Reduce CPU time** required **for computations**
  - **Works pretty well** in the **case** of the **SM**
  - **Extensively used** for **BSM searches**

- **Is the NWA reliable in the context of BSM searches?**
  - **NWA** **assumes** **Breit-Wigner resonance**
    - In the vicinity of kinematical bounds like $\sqrt{s} \sim M$
    - For near-degenerate parent-daughter masses $m \sim M$
  - **Breit-Wigner lineshape** is **distorted** by threshold factors
    - phase space factors e.g. $\beta = \sqrt{1-(m/M)^2}$

Validity of the NWA