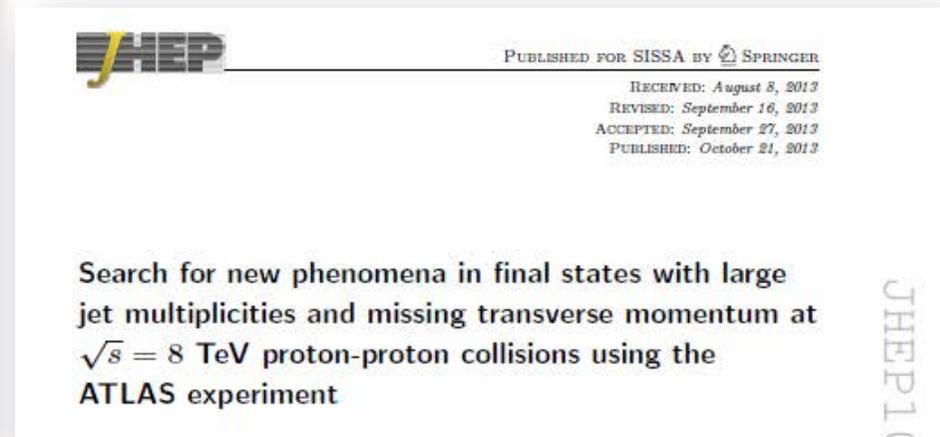


Búsqueda de Nueva Física en el LHC



1. ¿Dónde estamos parados?
2. ¿Más allá del Modelo Estándar?
3. Búsqueda de Supersimetría



Gustavo Otero y Garzón
DDF – Buenos Aires, Julio 7 de 2014



Las partículas fundamentales

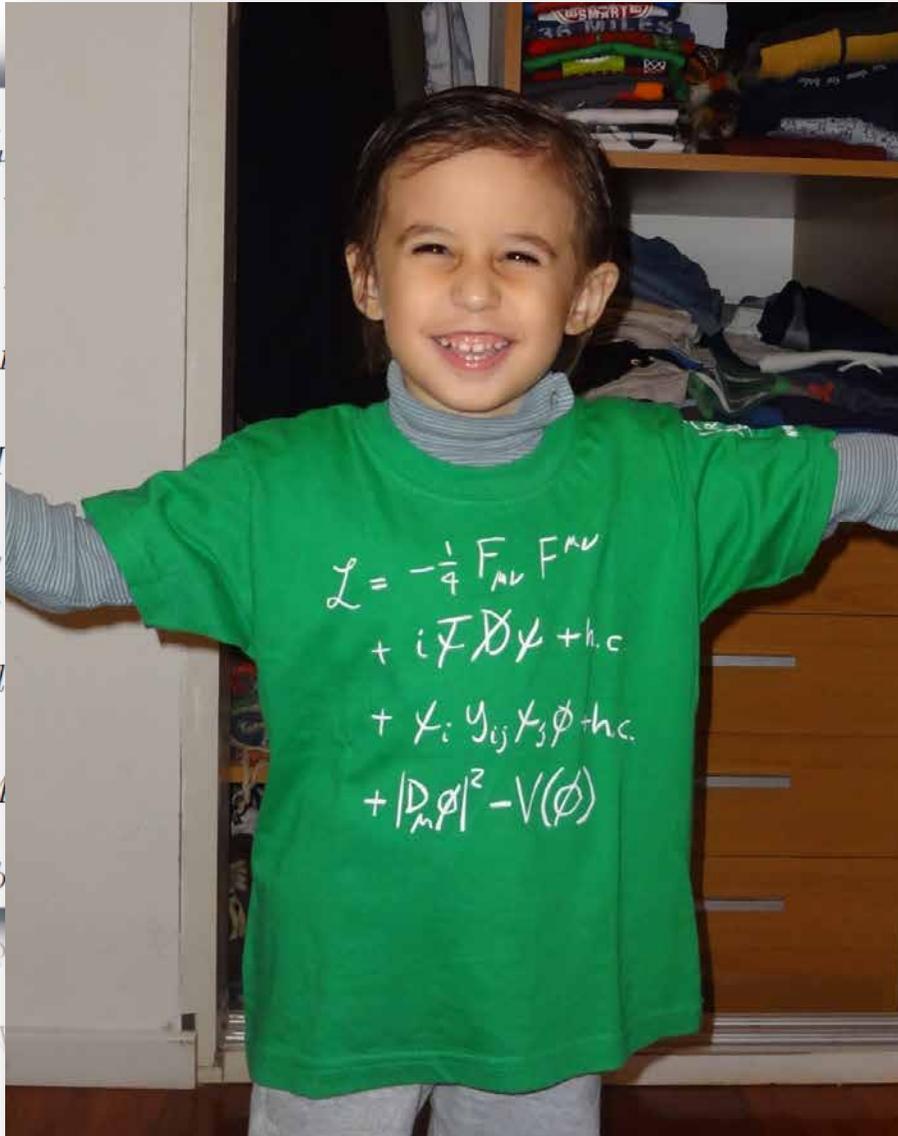
	Fermions			Bosons	
Quarks	u up	c charm	t top	γ photon	Force carriers
	d down	s strange	b bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	
			Higgs* boson		

- Toda la **materia conocida** esta hecha de **fermiones**
 - Quarks y leptones
 - 3 generaciones
- **Fuerzas mediadas por bosones**
 - EM : γ
 - Debil : Z, W^\pm
 - Fuerte : gluones
- **Bosón de Higgs**
 - **Dota de masa a las partículas via interacción**

El Modelo Estándar

Teoría que unifica todo nuestro conocimiento acerca de las partículas fundamentales y sus interacciones **basada en simetrías de la naturaleza**

$$\begin{aligned} \mathcal{L} = & -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{8}\text{tr}(\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu}) \\ & +(\bar{\nu}_L, \bar{e}_L)\tilde{\sigma}^\mu iD_\mu \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \\ & -\frac{\sqrt{2}}{v} \left[(\bar{\nu}_L, \bar{e}_L)\phi M^e e_L \right. \\ & \left. -\frac{\sqrt{2}}{v} \left[(-\bar{e}_L, \bar{\nu}_L)\phi^* M^e \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \right. \right. \\ & \left. +(\bar{u}_L, \bar{d}_L)\tilde{\sigma}^\mu iD_\mu \begin{pmatrix} u_L \\ d_L \end{pmatrix} \right. \\ & \left. -\frac{\sqrt{2}}{v} \left[(\bar{u}_L, \bar{d}_L)\phi M^d d_L \right. \right. \\ & \left. -\frac{\sqrt{2}}{v} \left[(-\bar{d}_L, \bar{u}_L)\phi^* M^d \begin{pmatrix} u_L \\ d_L \end{pmatrix} \right. \right. \\ & \left. +(\overline{D_\mu\phi})D^\mu\phi - m_h^2[\bar{\phi}\phi] \right. \\ & \left. +(\overline{D_\mu\phi})D^\mu\phi - m_h^2[\bar{\phi}\phi] \right. \\ & \left. -\frac{g}{\sqrt{2}} \left[(-\bar{q}_L^c, \bar{q}_L)\phi_* W_\mu^+ \right. \right. \\ & \left. -\frac{g}{\sqrt{2}} \left[(\bar{q}_L, \bar{q}_L^c)\phi_* W_\mu^- \right. \right. \end{aligned}$$



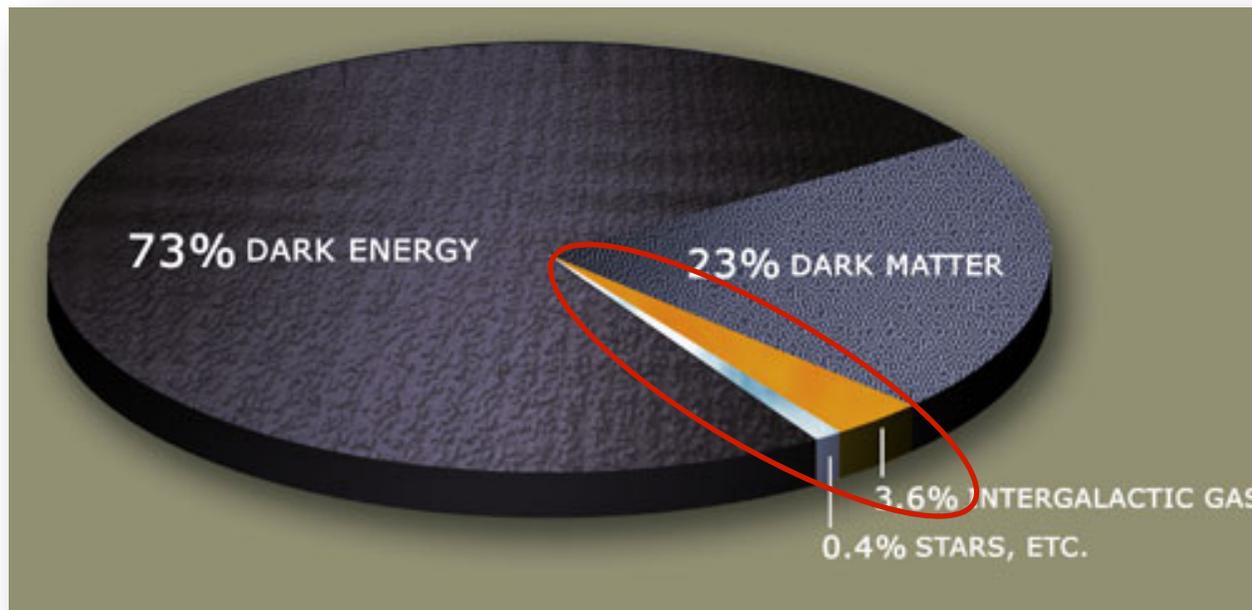
2) and SU(3) gauge terms)
 amical term)
 uon, tauon mass term)
 mass term)
 amical term)
 nge, bottom mass term)
 ed, top mass term)
 amical and mass term)
 and mass term)
 top mass term)
 top mass term)

¿Cuán bueno es este modelo?

- **Pro's:**
 - altamente predictivo
 - no existe aún ningún experimento que esté en desacuerdo!
- **Con's:**
 - No incluye la gravedad

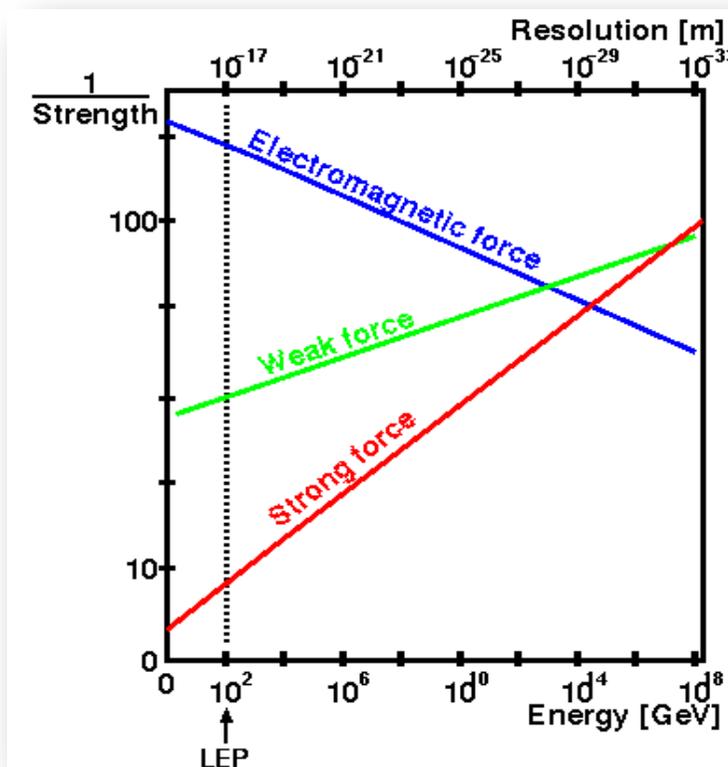
¿Cuán bueno es este modelo?

- **Pro's:**
 - altamente predictivo
 - **no existe aún ningún experimento que esté en desacuerdo!**
- **Con's:**
 - No incluye la gravedad
 - **Describe solo el 4% del universo**



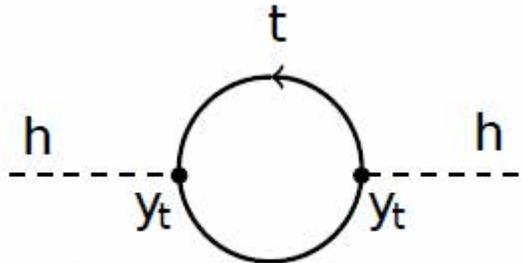
¿Cuán bueno es este modelo?

- Pro's:
 - altamente predictivo
 - no existe aún ningún experimento que esté en desacuerdo!
- Con's:
 - No incluye la gravedad
 - Describe solo el 4% del universo
 - No permite unificación de fuerzas



¿Cuán bueno es este modelo?

- **Pro's:**
 - altamente predictivo
 - **no existe aún ningún experimento que esté en desacuerdo!**
- **Con's:**
 - No incluye la gravedad
 - Describe solo el 4% del universo
 - No permite unificación de fuerzas
 - **No explica la “jerarquía de masas”**


$$-\frac{y_t^2}{8\pi^2} \left[\Lambda^2 - 3m_t^2 \ln \left(\frac{\Lambda^2}{m_t^2} \right) + \dots \right]$$

La masa del Higgs recibe correcciones perturbativas que divergen pero se cancelan “magicamente” (“fine tuning”)

$$\text{¿}1 = 1000000 - 999999\text{?}$$

¿Cuán bueno es este modelo?

- **Pro's:**
 - altamente predictivo
 - **no existe aún ningún experimento que esté en desacuerdo!**
- **Con's:**
 - No incluye la gravedad
 - Describe solo el 4% del universo
 - No permite unificación de fuerzas
 - No explica la “jerarquía de masas”

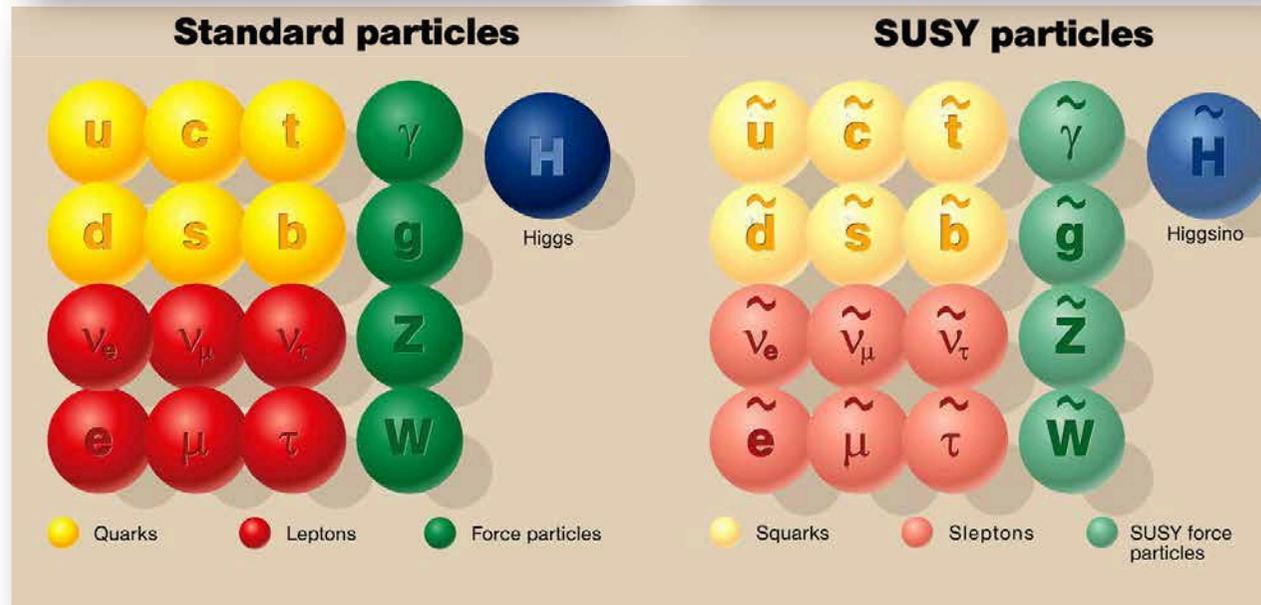
El Modelo Estándar es una teoría efectiva de bajas energías de algo más general

Super Simetría (SUSY)

Única extensión posible del grupo de Poincaré!

$$Q|\text{Boson}\rangle = |\text{Fermion}\rangle$$

$$Q|\text{Fermion}\rangle = |\text{Boson}\rangle$$



- Ninguna partícula SUSY observada aún!
 - **SIMETRÍA ROTA** (al estilo ruptura espontánea de Higgs): nadie vió un selectrón, entonces la degeneración en masa esta rota
- partículas SUSY se crean de a pares
- la **más liviana es estable** (**LSP** = **L**ightest **S**upersymmetric **P**article)

¿Porqué es tan linda SUSY?

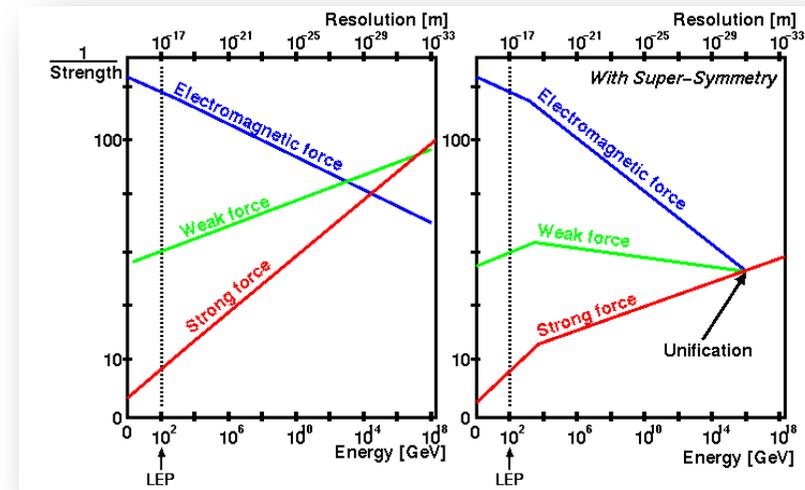
- **Resuelve el “problema de jerarquías”**
 - Las contribuciones de SUSY a la masa del Higgs cancelan las del Modelo Estándar

$$+ \frac{y_S}{16\pi^2} \left[\Lambda^2 - m_S^2 \ln \left(\frac{\Lambda^2}{m_S^2} \right) + \dots \right]$$

$$- \frac{y'_S{}^2}{16\pi^2} \left[\ln \left(\frac{\Lambda^2}{m_S^2} \right) + \dots \right]$$

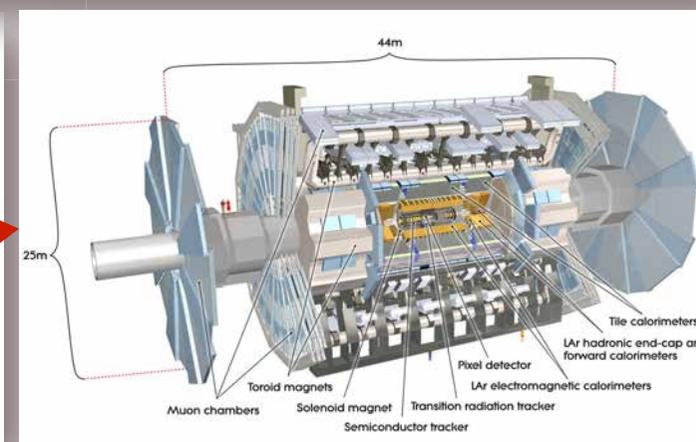
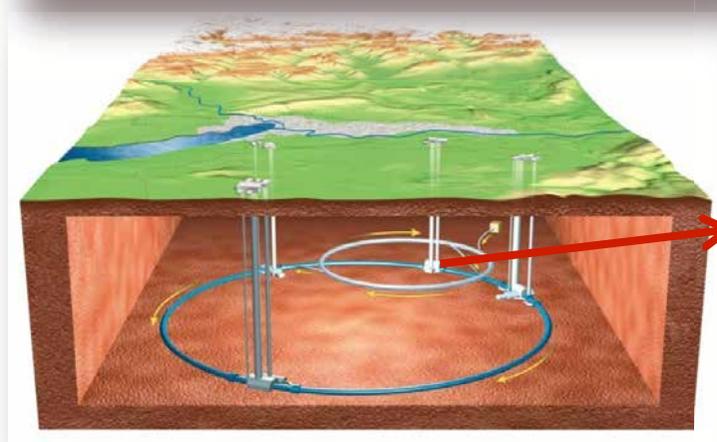
- **Provee un candidato natural de materia oscura: el LSP**

- **Permite una unificación de fuerzas**



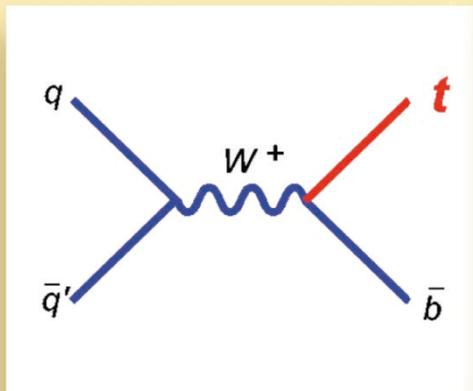
¿Dónde se puede buscar esto?

- **El LHC es el acelerador de partículas más grande y potente del mundo**
 - Anillo de 27 Km de extensión a 100 m bajo tierra cerca de Ginebra, en la frontera entre Suiza y Francia (CERN)
 - Colisiona haces de protones que se mueven a 99.9% de la velocidad de la luz
 - Alimenta de datos a cuatro experimentos

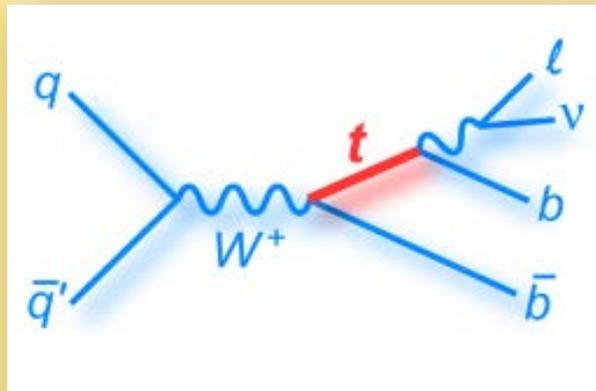


¿Cómo es un evento?

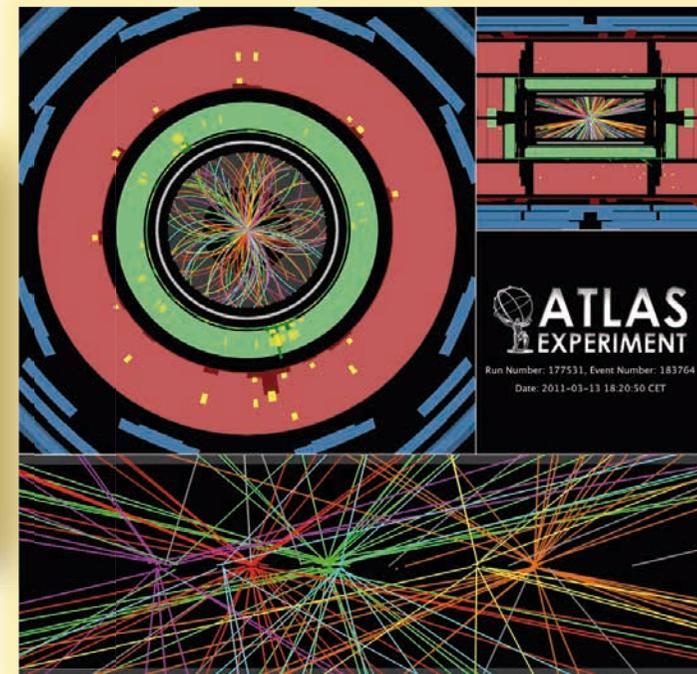
Sería fantástico si viésemos esto:



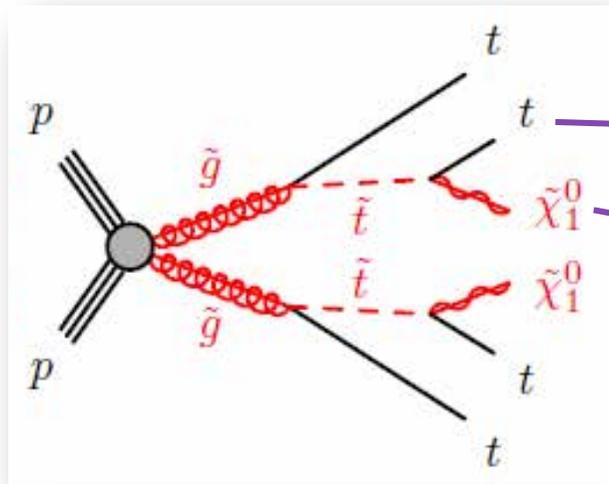
O bueno, esto:



En fin, nos contentamos con:



Sólo vemos estados finales



SEÑAL

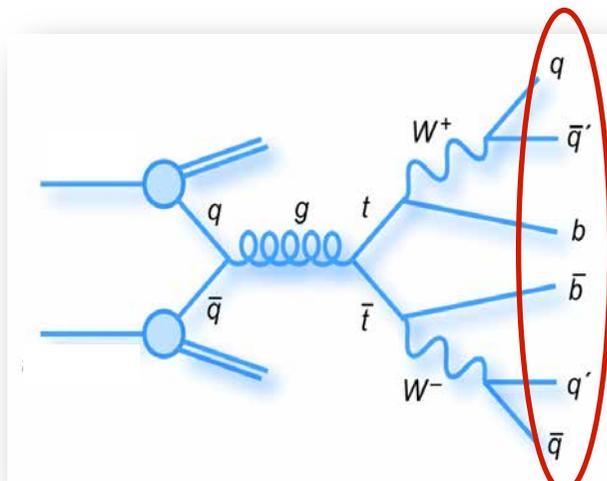
quarks → jets

LSP → Energía Faltante (MET)

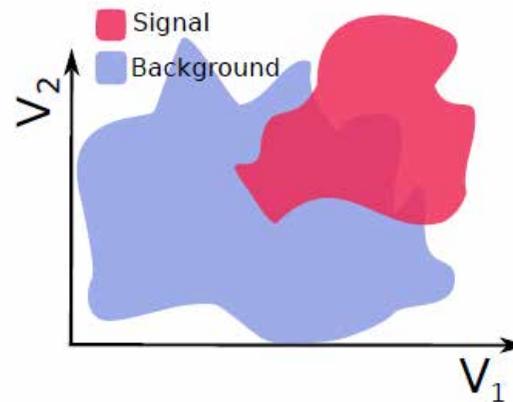
Jets + MET

Jets + MET

Selección de eventos que maximice señal / fondo, por ejemplo:



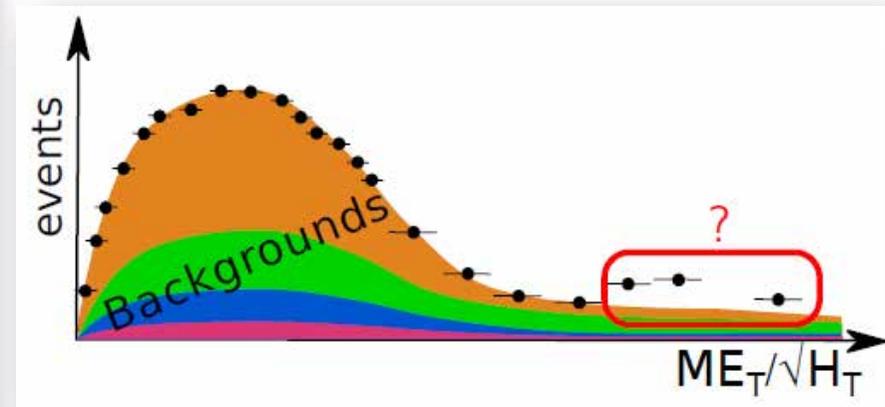
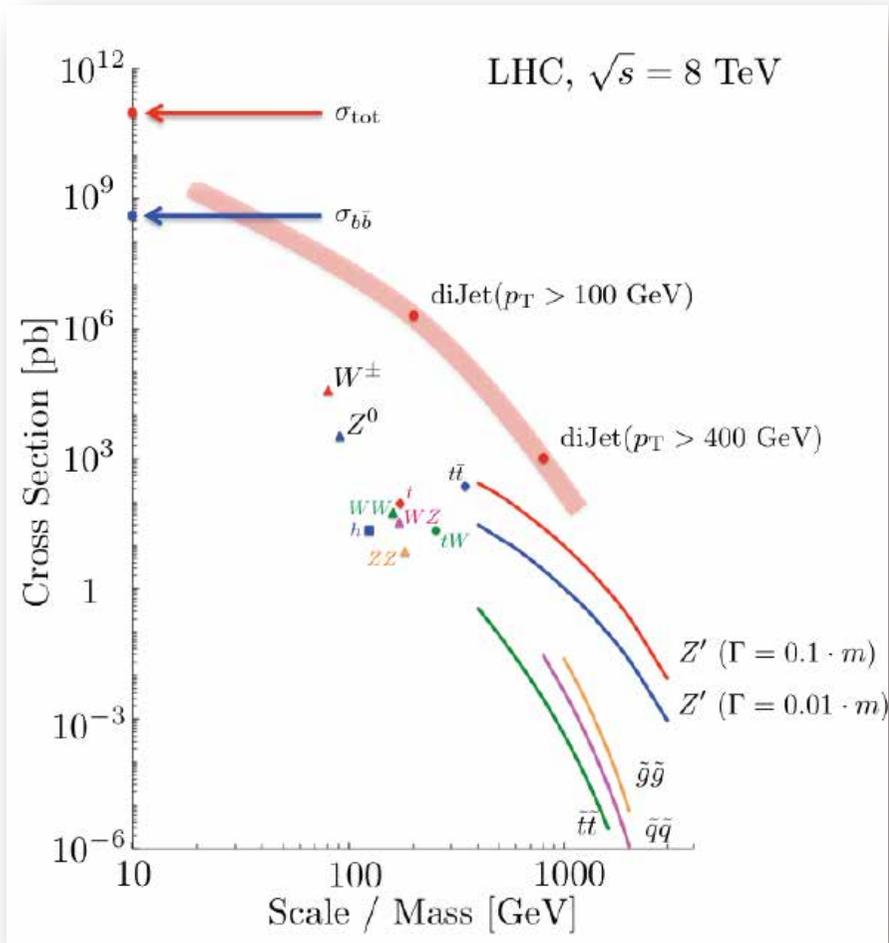
FONDO



$$E_T^{\text{miss}} / \sqrt{H_T} > 4\text{GeV}^{1/2}$$

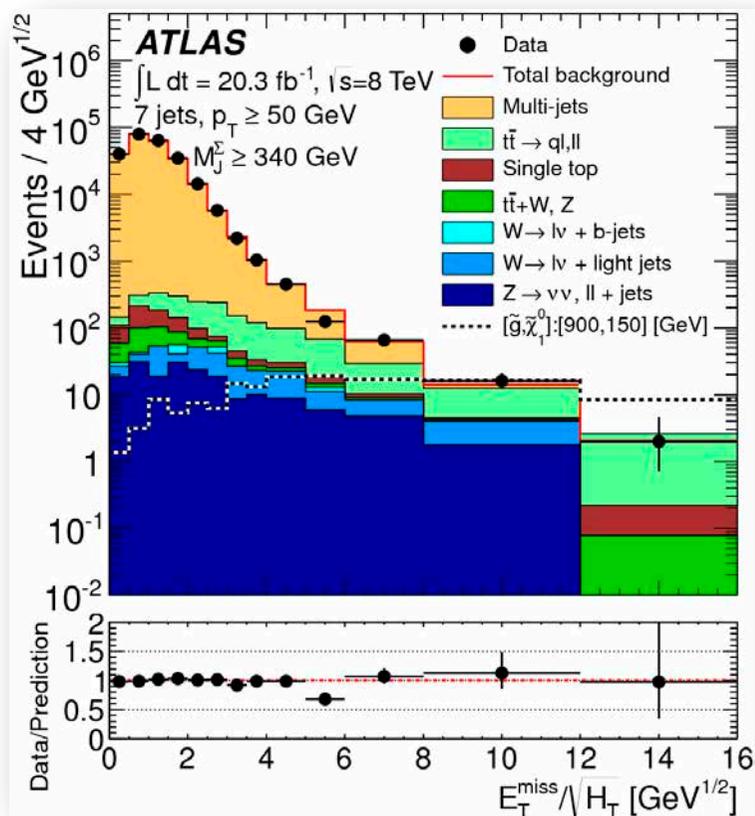
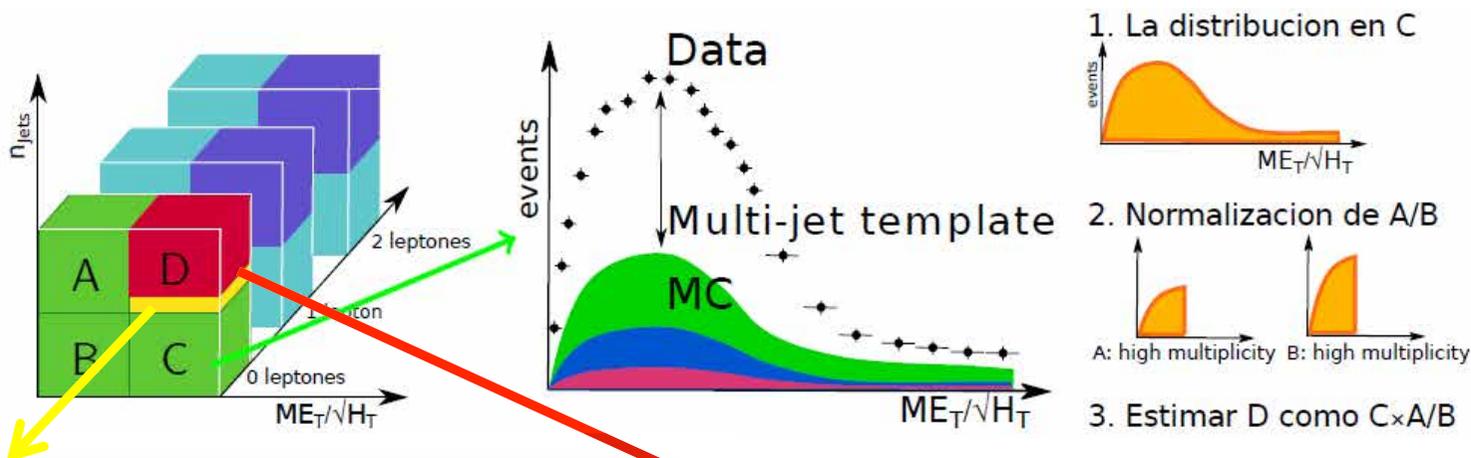
$$M_J^\Sigma = \sum_{\text{fat-jets}} m_{\text{jet}}^{R=1.0}$$

Determinación de los fondos



Búsqueda de SUSY = búsqueda de un **exceso significativo de los datos sobre el fondo esperado en tails de distribuciones sensibles**

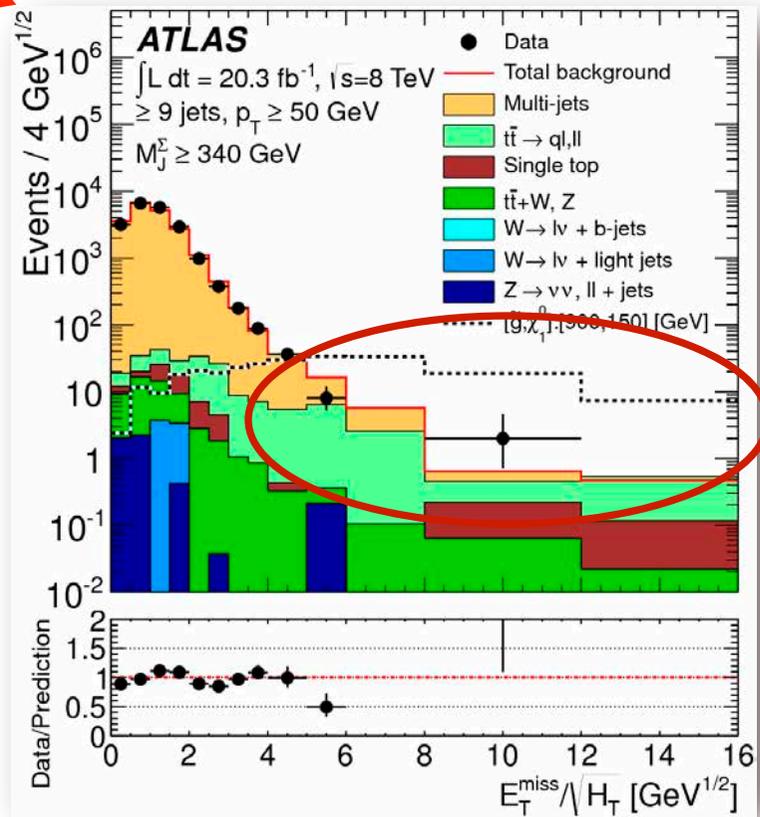
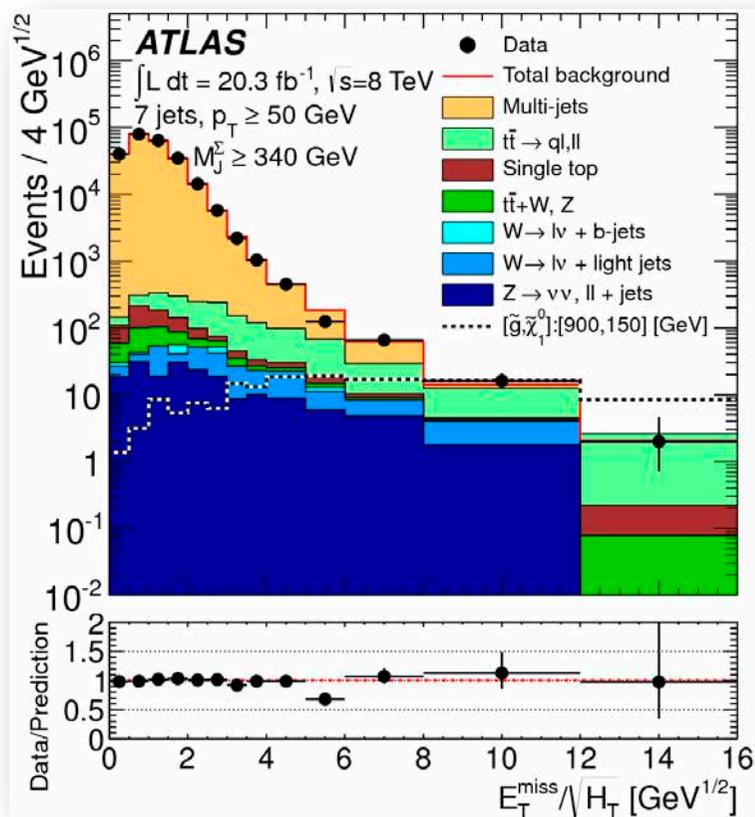
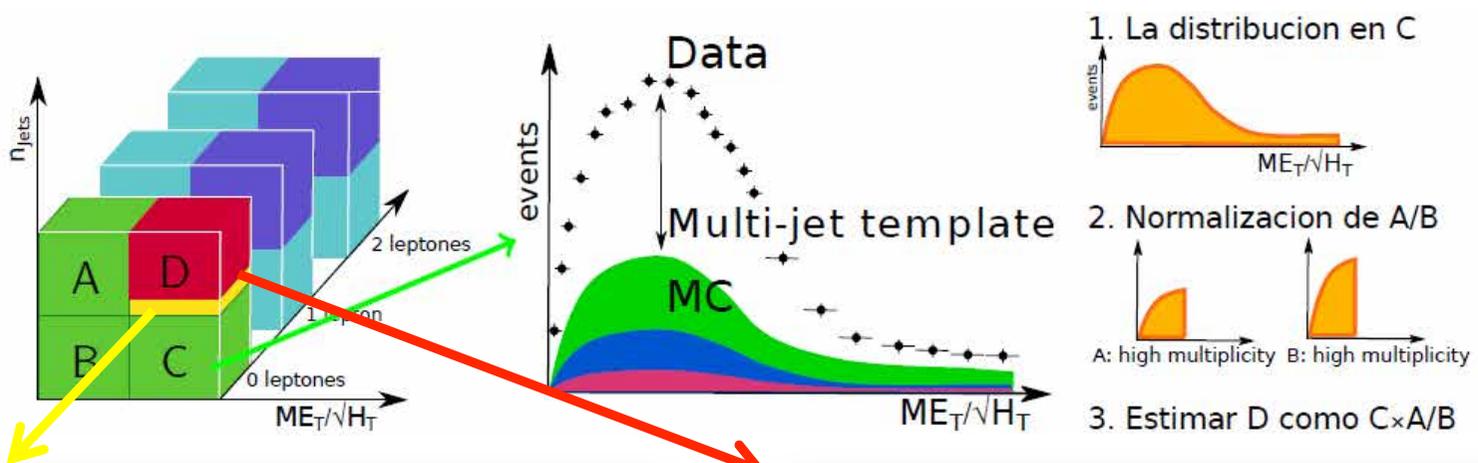
Estrategia del análisis



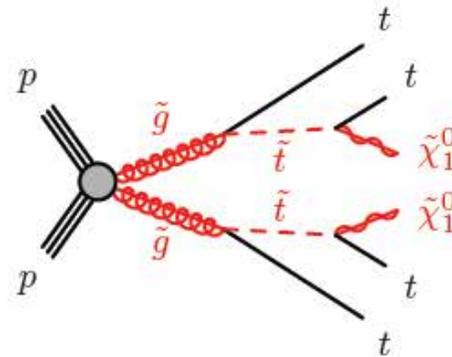
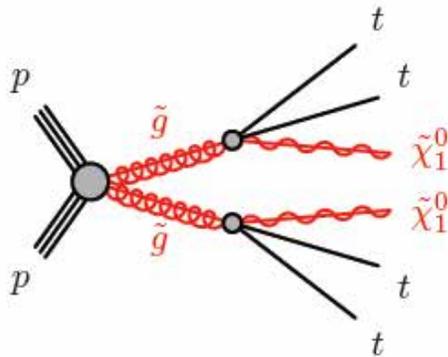
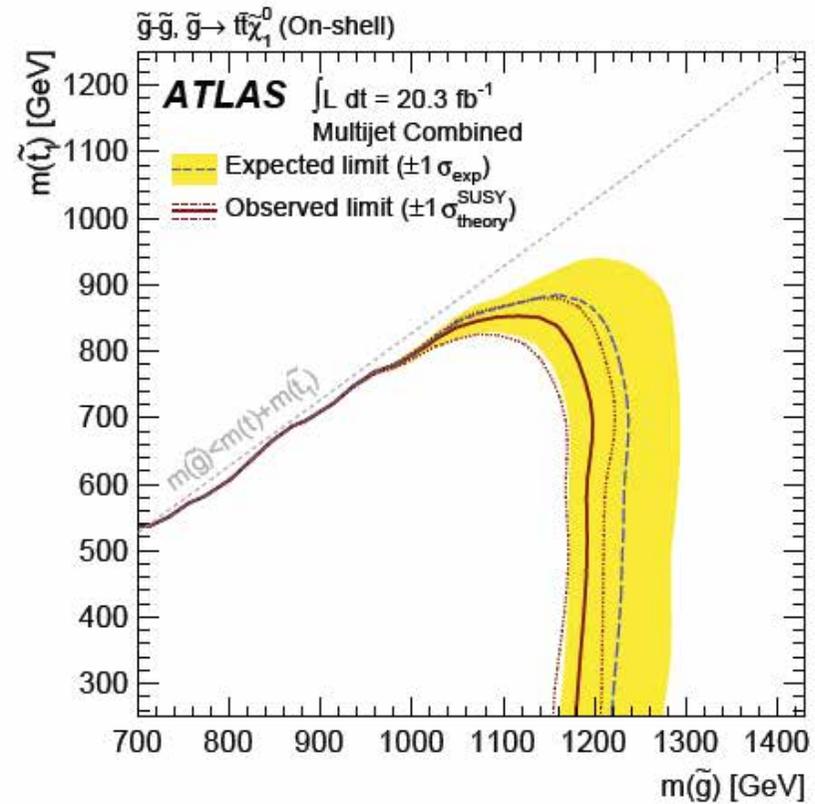
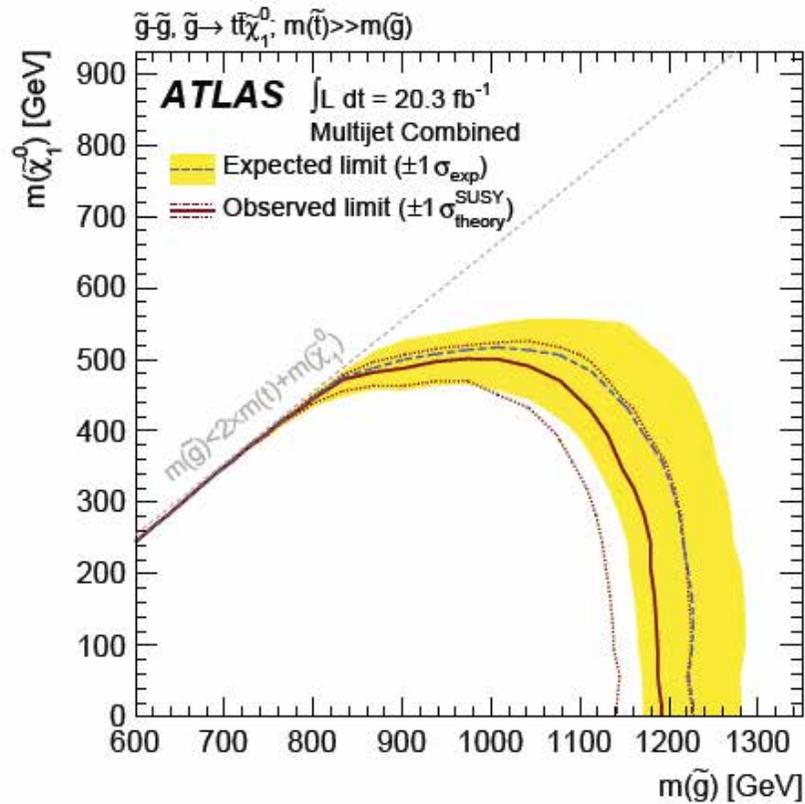
“Abrir la caja” (mirar los datos en la región de señal)

- ¿Exceso significativo de los datos sobre el background predicho?
- **NO** → estimar límites al 95% CL
- **SI** → comprar boleto de avión a Estocolmo

Estrategia del análisis



Límites (Gtt model)



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Moriond 2014

ATLAS Preliminary

$$\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV}$$

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{g}, \tilde{g} 1.7 TeV	$m(\tilde{g})=m(\tilde{g})$ ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	\tilde{g} 1.2 TeV	any $m(\tilde{g})$ ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	\tilde{g} 1.1 TeV	any $m(\tilde{g})$ 1308.1841
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	\tilde{q} 740 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$ ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	\tilde{g} 1.3 TeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$ ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{\chi}_1^0 \rightarrow q\tilde{W} \rightarrow \tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	\tilde{g} 1.18 TeV	$m(\tilde{\chi}_1^0) < 200 \text{ GeV}, m(\tilde{\chi}_2^0)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$ ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{\chi}_1^0 \rightarrow q\tilde{W} \rightarrow \tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	\tilde{g} 1.12 TeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$ ATLAS-CONF-2013-089
	GMSB (\tilde{t} NLSP)	2 e, μ	2-4 jets	Yes	4.7	\tilde{t} 1.24 TeV	$\tan\beta < 15$ 1208.4688
	GMSB ($\tilde{\tau}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{\tau}$ 1.4 TeV	$\tan\beta > 18$ ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	20.3	\tilde{g} 1.28 TeV	$m(\tilde{\chi}_1^0) > 50 \text{ GeV}$ ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	\tilde{g} 619 GeV	$m(\tilde{\chi}_1^0) > 50 \text{ GeV}$ ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	\tilde{g} 900 GeV	$m(\tilde{\chi}_1^0) > 220 \text{ GeV}$ 1211.1167
GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	\tilde{g} 690 GeV	$m(\tilde{H}) > 220 \text{ GeV}$ ATLAS-CONF-2012-152	
Gravitino LSP	0	mono-jet	Yes	10.5	\tilde{g} 645 GeV	$m(\tilde{g}) > 10^{-1} \text{ eV}$ ATLAS-CONF-2012-147	
3 rd gen. \tilde{g} med.	$\tilde{g} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	\tilde{g} 1.2 TeV	$m(\tilde{\chi}_1^0) < 600 \text{ GeV}$ ATLAS-CONF-2013-061
	$\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	\tilde{g} 1.1 TeV	$m(\tilde{\chi}_1^0) < 350 \text{ GeV}$ 1308.1841
	$\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	\tilde{g} 1.34 TeV	$m(\tilde{\chi}_1^0) < 400 \text{ GeV}$ ATLAS-CONF-2013-061
	$\tilde{g} \rightarrow b\tilde{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	\tilde{g} 1.3 TeV	$m(\tilde{\chi}_1^0) < 300 \text{ GeV}$ ATLAS-CONF-2013-061
3 rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	\tilde{b}_1 100-620 GeV	$m(\tilde{\chi}_1^0) < 90 \text{ GeV}$ 1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow t\tilde{\chi}_1^0$	2 e, μ (SS)	0-3 b	Yes	20.7	\tilde{b}_1 275-430 GeV	$m(\tilde{\chi}_1^0)=2 m(\tilde{\chi}_2^0)$ ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^0$	1-2 e, μ	1-2 b	Yes	4.7	\tilde{t}_1 110-167 GeV	$m(\tilde{\chi}_1^0)=55 \text{ GeV}$ 1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow W\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	\tilde{t}_1 130-210 GeV	$m(\tilde{\chi}_1^0) = m(\tilde{t}_1) - m(W) - 50 \text{ GeV}, m(\tilde{t}_1) < m(\tilde{\chi}_2^0)$ 1403.4853
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	\tilde{t}_1 215-530 GeV	$m(\tilde{\chi}_1^0)=1 \text{ GeV}$ 1403.4853
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	\tilde{t}_1 150-580 GeV	$m(\tilde{\chi}_1^0) < 200 \text{ GeV}, m(\tilde{\chi}_1^+) - m(\tilde{\chi}_2^+) = 5 \text{ GeV}$ 1308.2631
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	\tilde{t}_1 200-610 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$ ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	\tilde{t}_1 320-660 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$ ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$	0	mono-jet/ c -tag	Yes	20.3	\tilde{t}_1 90-200 GeV	$m(\tilde{t}_1) - m(\tilde{\chi}_1^0) < 85 \text{ GeV}$ ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	\tilde{t}_1 150-580 GeV	$m(\tilde{\chi}_1^0) > 150 \text{ GeV}$ 1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.3	\tilde{t}_2 290-600 GeV	$m(\tilde{\chi}_1^0) < 200 \text{ GeV}$ 1403.5222
	EW direct	$\tilde{\chi}_{1,2}^0\tilde{\chi}_{1,2}^0, \tilde{\chi} \rightarrow \tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\chi}$ 90-325 GeV
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 + \tilde{\nu}(\tilde{\nu})$		2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-465 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\chi}_1^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{\nu}))$ 1403.5294
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow \tilde{\tau}(\tilde{\tau}) + \tilde{\nu}(\tilde{\nu})$		2 τ	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 180-330 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\chi}_1^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{\nu}))$ ATLAS-CONF-2013-028
$\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0 + \tilde{\nu}(\tilde{\nu}), \tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow \tilde{\nu}(\tilde{\nu})$		3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^+, \tilde{\chi}_2^0$ 700 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, m(\tilde{\chi}_1^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{\nu}))$ 1402.7029
$\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow W\tilde{\chi}_1^0\tilde{\chi}_2^0$		2-3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^+, \tilde{\chi}_2^0$ 420 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0$, sleptons decoupled 1403.5294, 1402.7029
$\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow W\tilde{\chi}_1^0\tilde{h}\tilde{\chi}_1^0$		1 e, μ	2 b	Yes	20.3	$\tilde{\chi}_1^+, \tilde{\chi}_2^0$ 285 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0$, sleptons decoupled ATLAS-CONF-2013-093
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	$m(\tilde{\chi}_1^0) - m(\tilde{\chi}_1^\pm) = 160 \text{ MeV}, \tau(\tilde{\chi}_1^\pm) = 0.2 \text{ ns}$ ATLAS-CONF-2013-069
	Stable, stopped \tilde{g} R-hadron	0	1-5 jets	Yes	22.9	\tilde{g} 832 GeV	$m(\tilde{\chi}_1^0)=100 \text{ GeV}, 10 \mu\text{s} < \tau(\tilde{g}) < 1000 \text{ s}$ ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{\tau}, \tilde{\mu}) + \tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde{\tau}$ 475 GeV	$10 < \tan\beta < 50$ ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	$0.4 < \tau(\tilde{\chi}_1^0) < 2 \text{ ns}$ 1304.6310
$\tilde{q}\tilde{q}, \tilde{\chi}_1^0 \rightarrow q\tilde{q}$ (RPV)	1 μ , displ. vtx	-	-	20.3	\tilde{q} 1.0 TeV	$1.5 < c\tau < 156 \text{ mm}, \text{BR}(\mu)=1, m(\tilde{\chi}_1^0)=108 \text{ GeV}$ ATLAS-CONF-2013-092	
RPV	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	$\lambda'_{311}=0.10, \lambda'_{132}=0.05$ 1212.1272
	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	$\lambda'_{311}=0.10, \lambda'_{12333}=0.05$ 1212.1272
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	\tilde{g}, \tilde{g} 1.2 TeV	$m(\tilde{g})=m(\tilde{g}), c\tau_{LSP} < 1 \text{ mm}$ ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^+ \rightarrow e\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 760 GeV	$m(\tilde{\chi}_1^0) > 300 \text{ GeV}, \lambda'_{121} > 0$ ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^+ \rightarrow \tau\tilde{\nu}_\tau, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 350 GeV	$m(\tilde{\chi}_1^0) > 80 \text{ GeV}, \lambda'_{133} > 0$ ATLAS-CONF-2013-036
	$\tilde{g} \rightarrow q\tilde{q}$	0	6-7 jets	-	20.3	\tilde{g} 916 GeV	$\text{BR}(\tilde{t})=\text{BR}(\tilde{b})=\text{BR}(\tilde{c})=0\%$ ATLAS-CONF-2013-091
	$\tilde{g} \rightarrow \tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{s}$	2 e, μ (SS)	0-3 b	Yes	20.7	\tilde{g} 880 GeV	ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon $\rightarrow q\tilde{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693 1210.4826
	Scalar gluon pair, sgluon $\rightarrow \tilde{t}\tilde{t}$	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	$m(\chi) < 80 \text{ GeV}$, limit of $< 687 \text{ GeV}$ for D8 ATLAS-CONF-2012-147

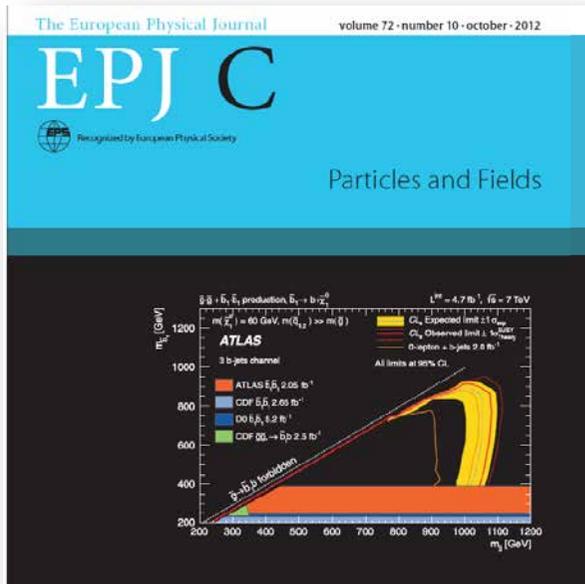
$\sqrt{s} = 7 \text{ TeV}$ full data
 $\sqrt{s} = 8 \text{ TeV}$ partial data
 $\sqrt{s} = 8 \text{ TeV}$ full data

10⁻¹ 1 Mass scale [TeV]

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

Conclusiones

- El Modelo Estándar goza de buena salud ... aún
- Búsqueda de SUSY en la UBA



HEP

PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: August 8, 2013
REVISED: September 16, 2013
ACCEPTED: September 27, 2013
PUBLISHED: October 21, 2013

Search for new phenomena in final states with large jet multiplicities and missing transverse momentum at $\sqrt{s} = 8$ TeV proton-proton collisions using the ATLAS experiment

JHEP10(2013)130



The ATLAS collaboration

E-mail: atlas.publications@cern.ch

ABSTRACT: A search is presented for new particles decaying to large numbers (7 or more) of jets, with missing transverse momentum and no isolated electrons or muons. This analysis uses 20.3 fb^{-1} of pp collision data at $\sqrt{s} = 8$ TeV collected by the ATLAS experiment at the Large Hadron Collider. The sensitivity of the search is enhanced by considering the number of b -tagged jets and the scalar sum of masses of large-radius jets in an event. No significant deviation from the Standard Model is observed.



G. Romeo (tesis doctoral) H. Reisin (tesis doctoral)

- Contribuciones en otras áreas:
 - Hardware (Forward Detector)
 - Software (trigger, algoritmos)
 - Performance (calibración del calorímetro, física con jets)
 - Análisis (SUSY, Modelo Estándar)

El entusiasmo por Nueva Física



201



2015?



201

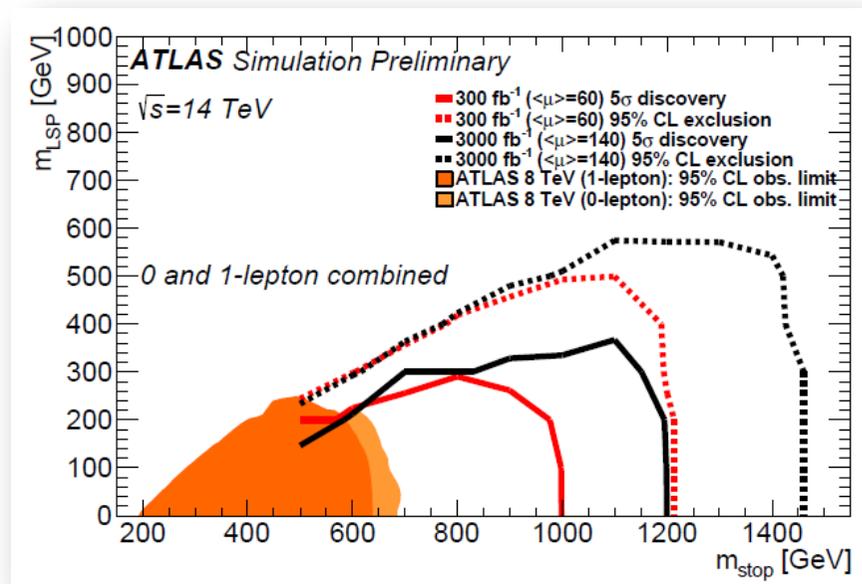


Perspectivas

- Preparados con **nuevas ideas y mejores detectores**

- **Run II comienza en 2015 (de 8 a 14 TeV y más luminosidad):**

- Aumento en las secciones eficaces de producción de SUSY (mas que el fondo!)
- 5 veces más datos en el mismo período de tiempo



- **Nueva Física a la vuelta de la esquina**
 - está muy bien escondida
 - pero en un rango de energías accesibles en el LHC!

¿Sorpresas para el próximo DDF?

HEP-EX UBA ¿quiénes somos?



Gino Marceca



Pablo Pieroni



Sabrina Sacerdoti



Jonathan Bossio

Becarios

Gracias



Ricardo Piegaia



Hernán Reisin

Postdoc



Florencia Daneri



Roberta Devesa

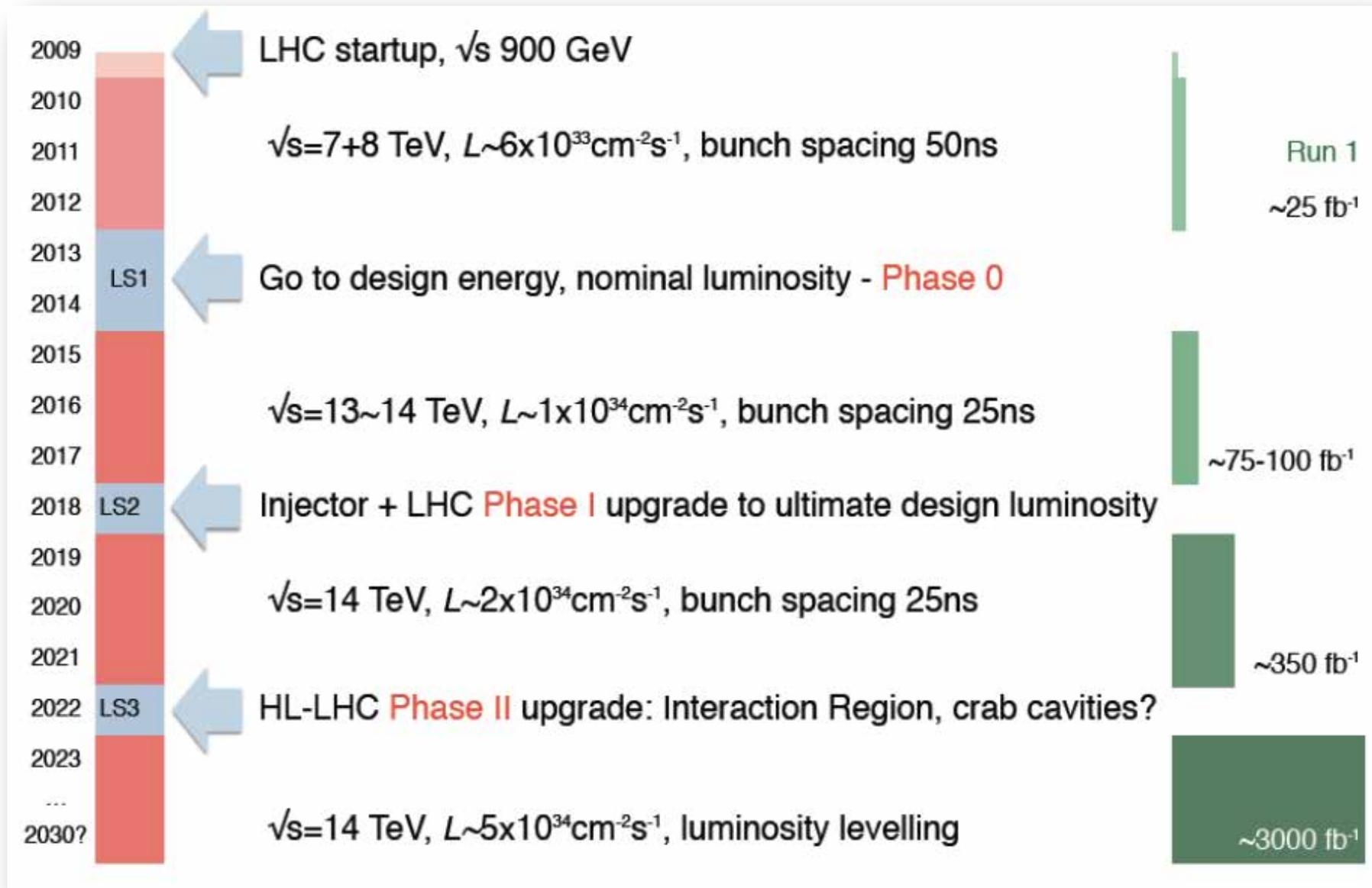
Tesistas



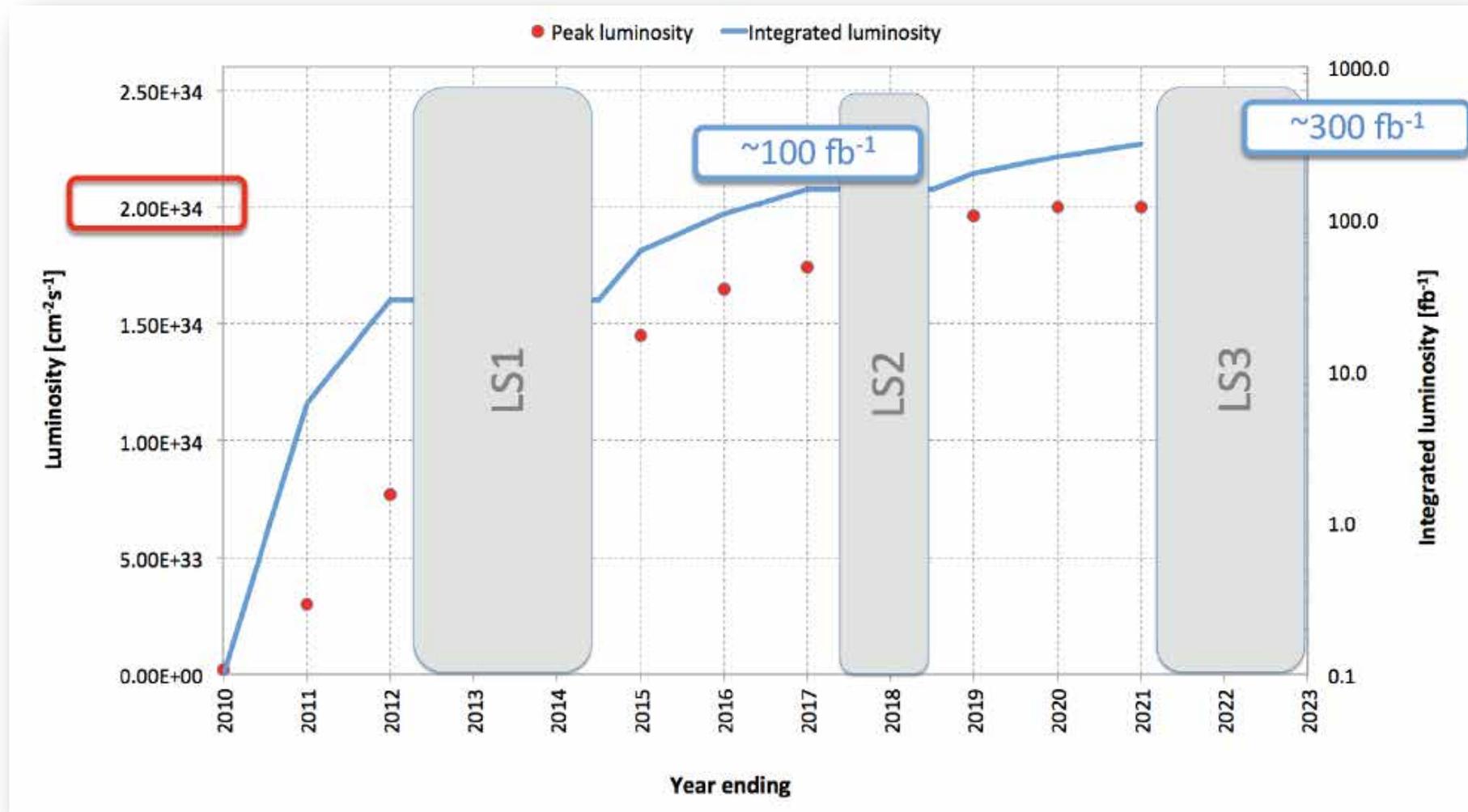
Martín Milano

Back Up

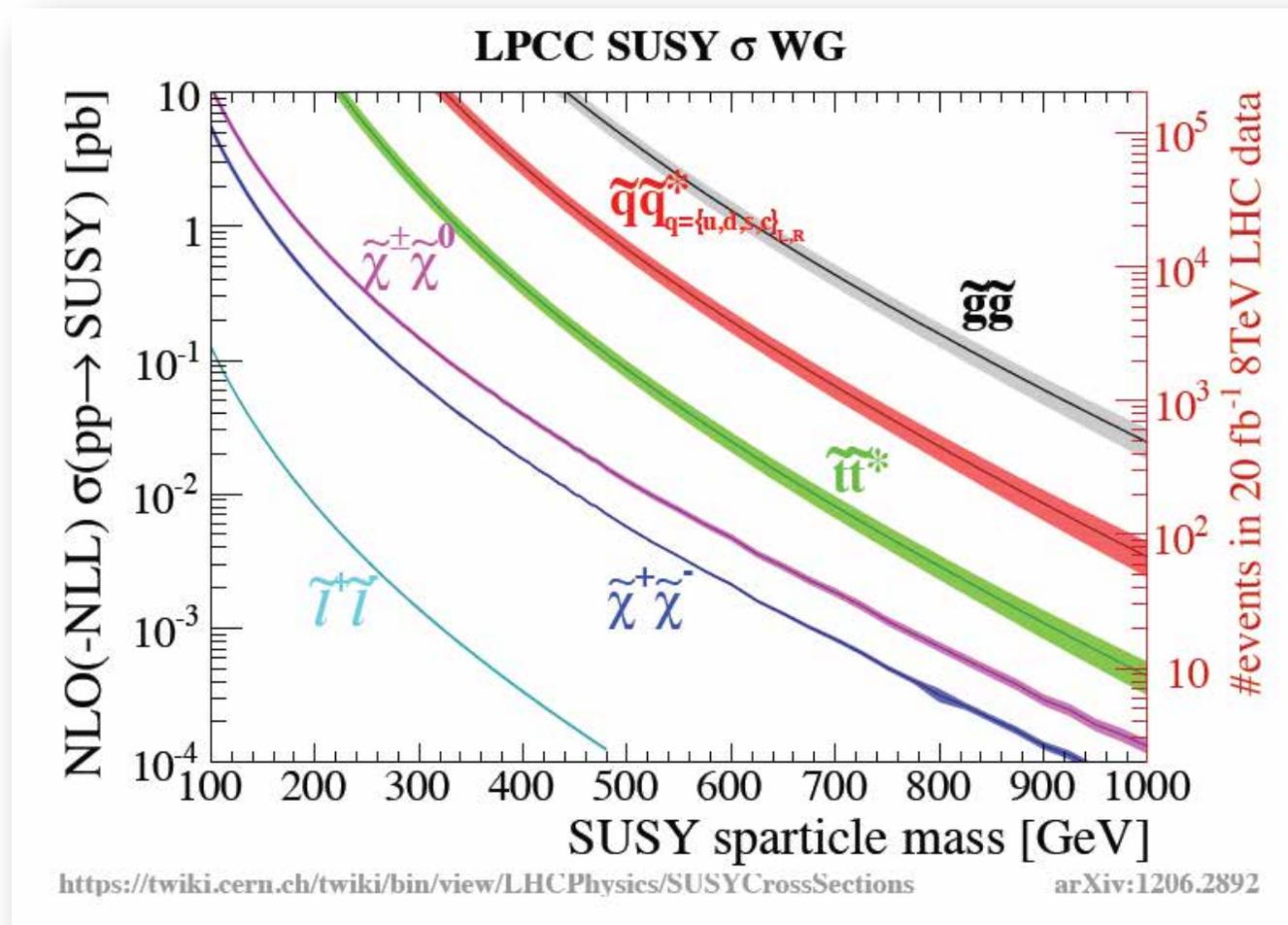
Vida del LHC



Vida del LHC

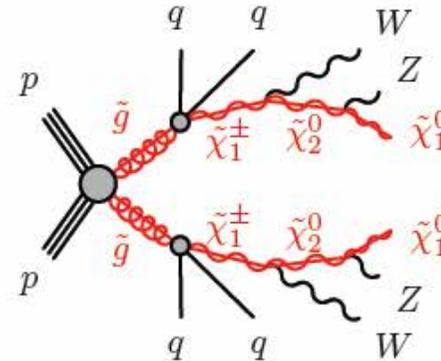
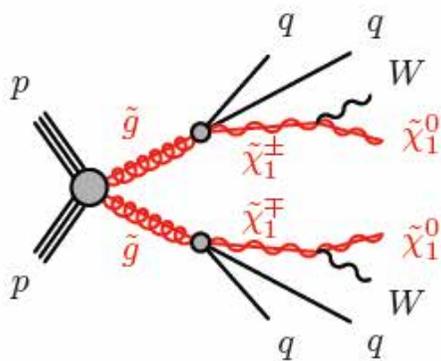
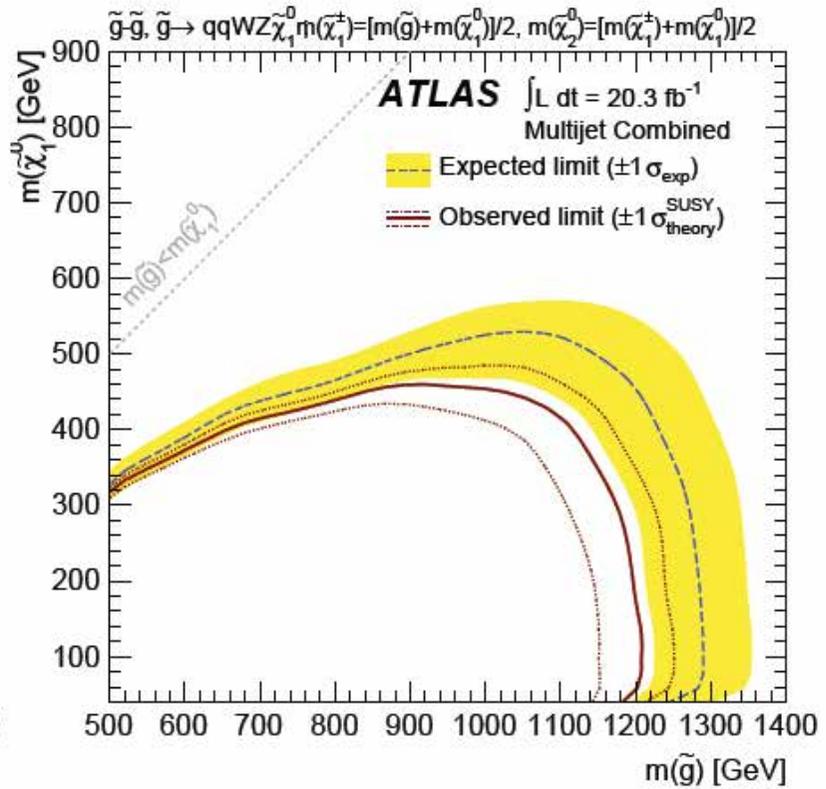
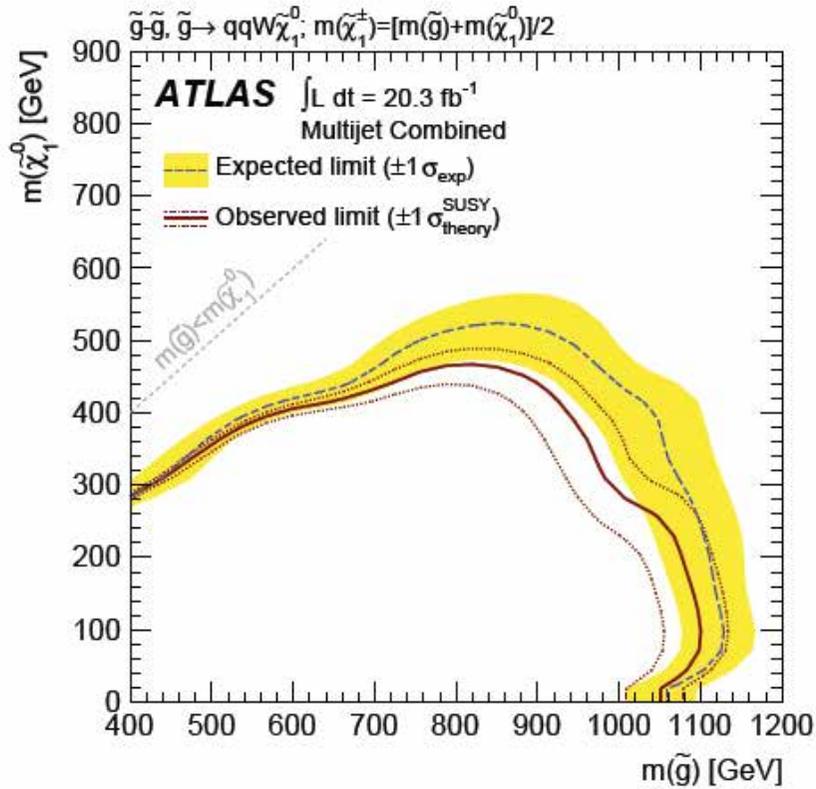


Producción de SUSY en el LHC

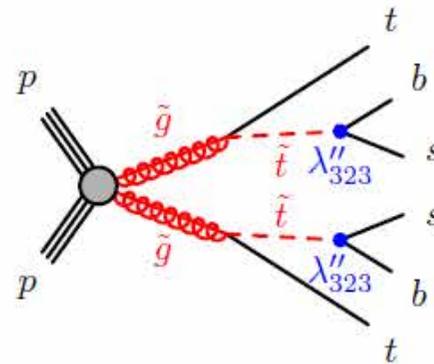
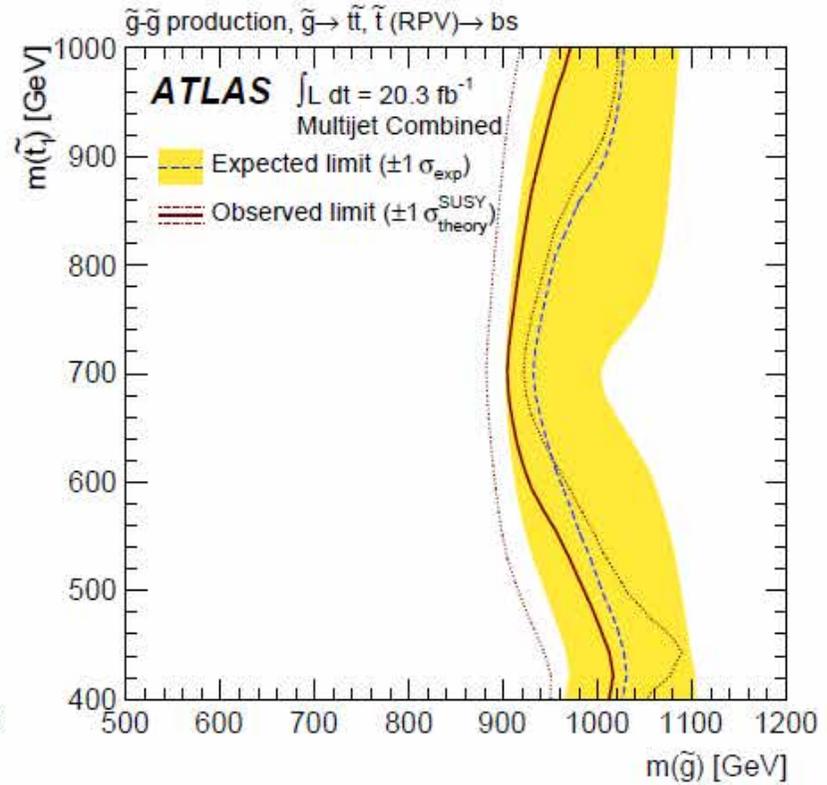
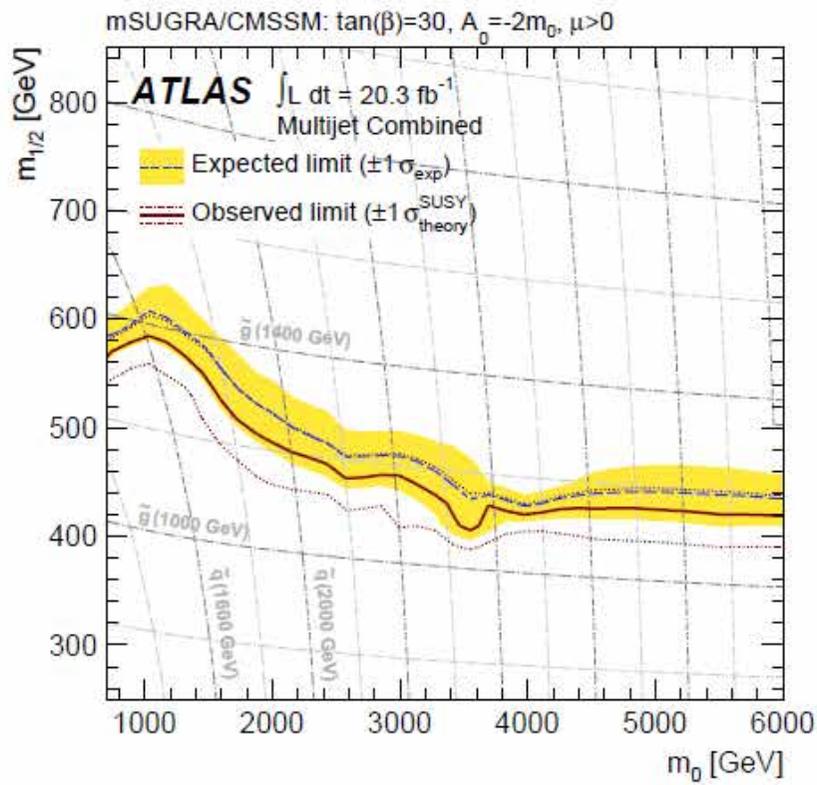


- Si $m(\text{gluino}) \sim 800$ GeV, el LHC ya fabricó 5000 pares de gluinos
- “Natural” SUSY: los squarks de la 3^{er} generación son los más livianos

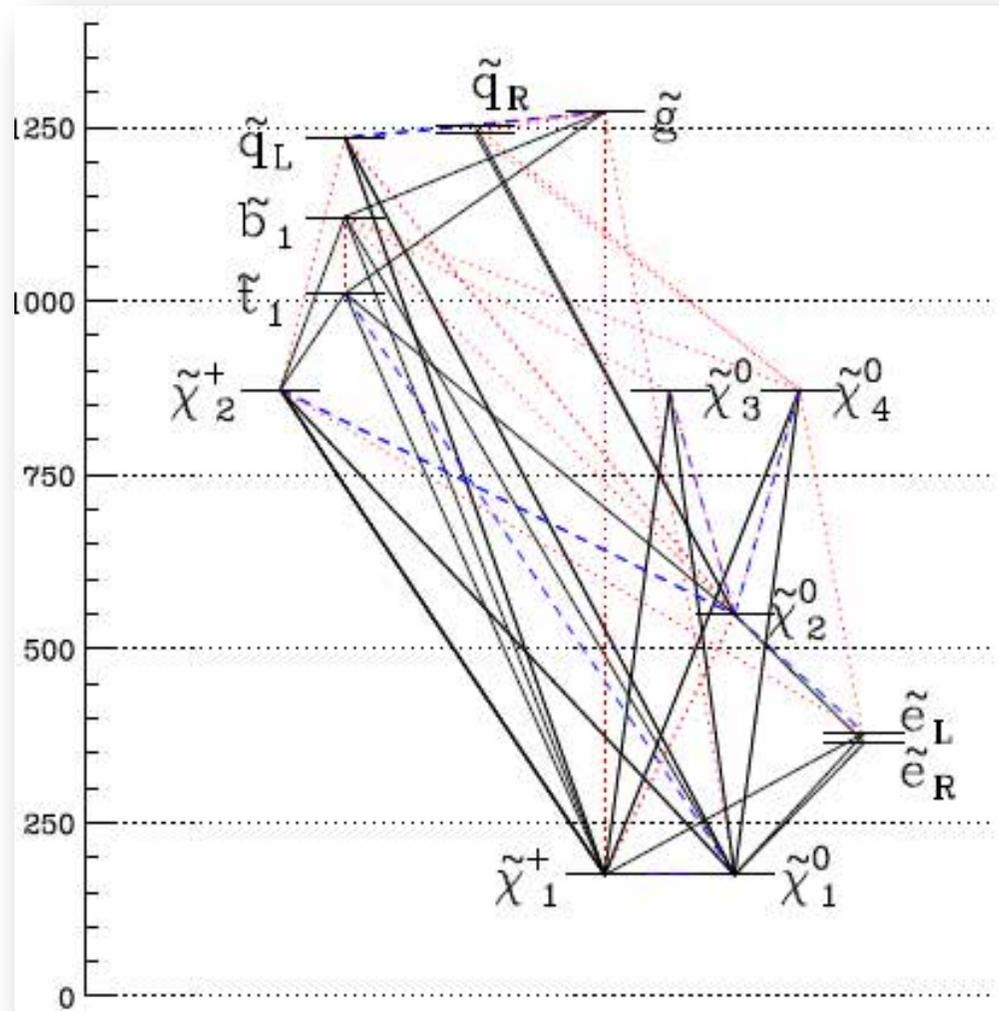
Límites (1 y 2 etapas)



Modelos interpretados

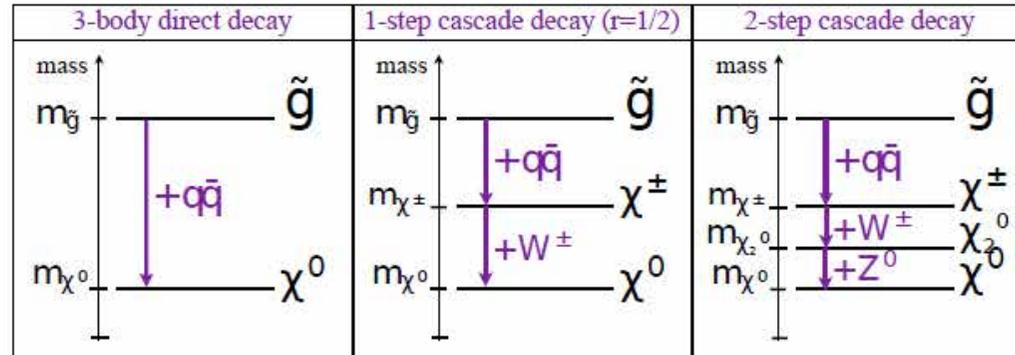


Espectro de masas (MSSM)

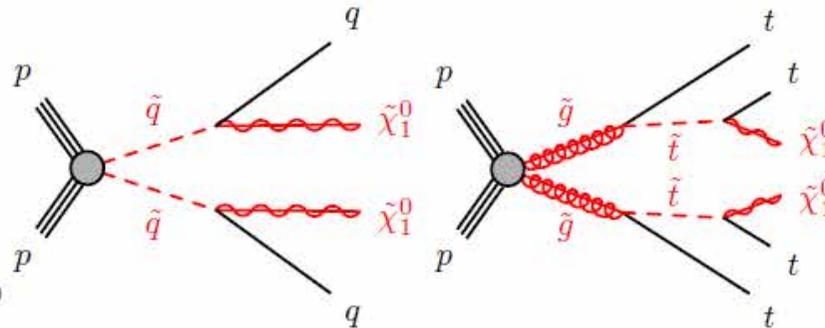
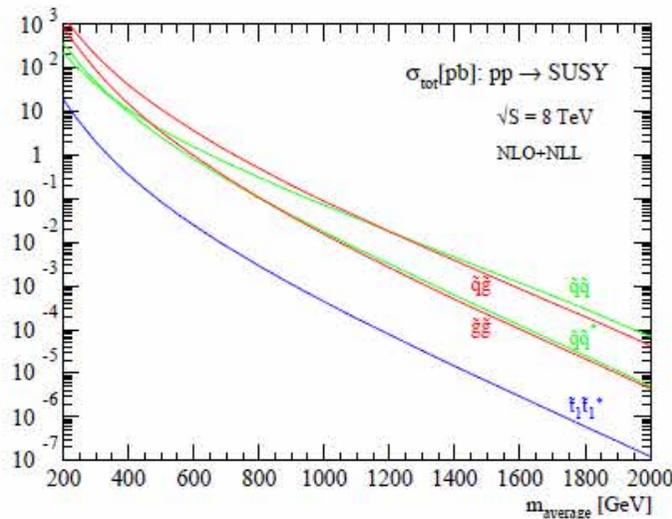


Modelos simplificados

- Pocas partículas, y branching ratios fijos

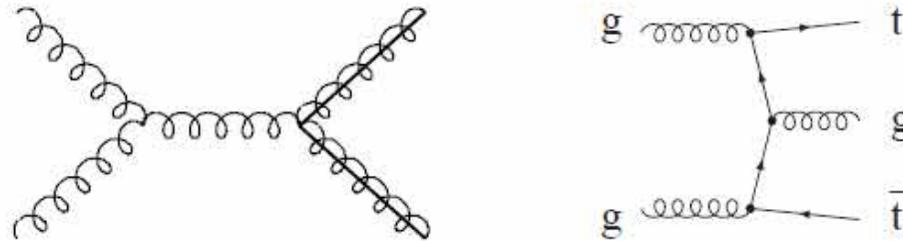


- A diferencia del cMSSM las masas de las partículas son parámetros libres, lo que permite el estudio de un amplio espacio de parámetros de modelos SUSY.
- Se considera producción de pares de gluinos, pues da lugar a un mayor número de jets que la producción de squarks.



Selección de eventos de señal

- ▶ Regiones de señal están definidas en términos de la **multiplicidad de jets**, $E_T^{\text{miss}}/\sqrt{H_T}$ y otros observables.
- ▶ Los jets se eligen en la zona central del detector (no gran η)

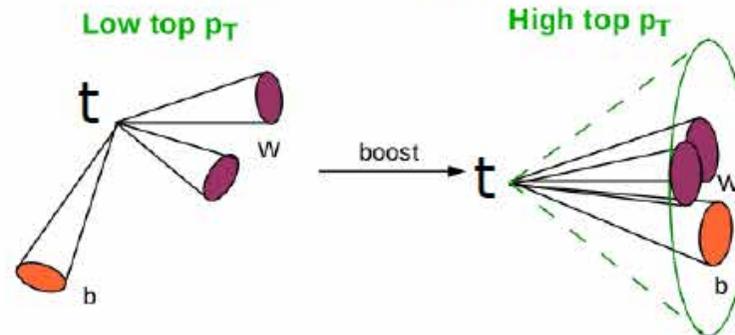


- ▶ El análisis está dividido en dos variantes según cortes en **el número de b -jet** y la **masa total de los fat-jets**, $M_J^\Sigma = \sum_{\text{fat-jets}} m_{\text{jet}}^{R=1.0}$.

Regiones de señal	Multijet + flavour						Multijet + M_J^Σ					
$ \eta $ de jets	< 2.0						< 2.8					
multiplicidad de jets & p_T ($R = 0.4$ jets)	8j50		9j50		10+j50	7j80		8+j80		8+j50	9+j50	10+j50
# b -jets o M_J^Σ	0	1	2+	0	1	2+	Inclusivo	0	1	2+	>340 y >420 GeV	
$E_T^{\text{miss}}/\sqrt{H_T}$	> $4\text{GeV}^{1/2}$											

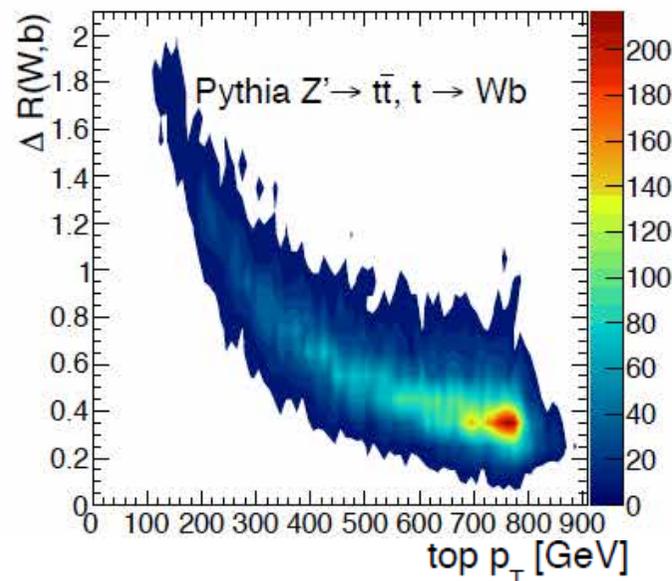
Fat jets

- ▶ El régimen de energía alcanzado en el LHC permite producir partículas masivas con un considerable momento transverso.



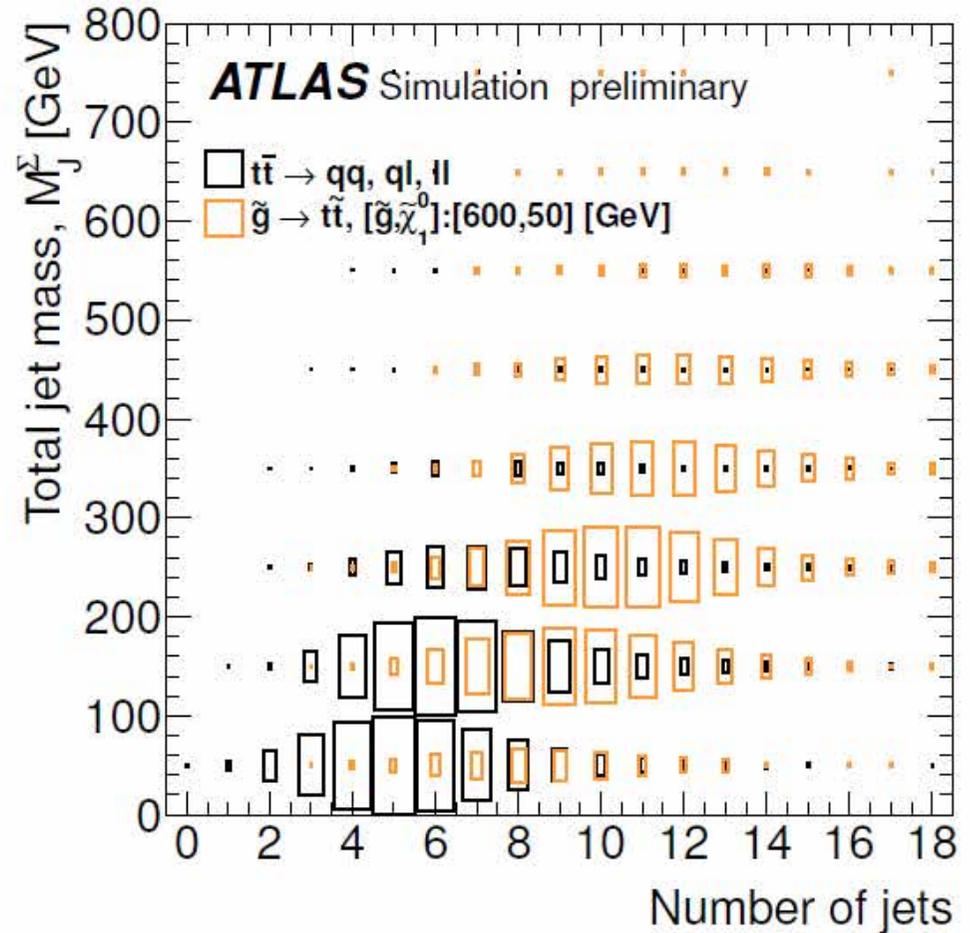
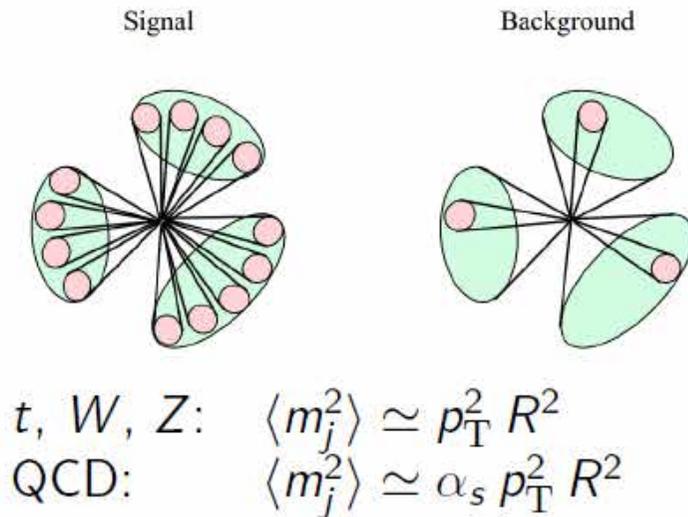
- ▶ La reconstrucción de una partícula masiva requiere jets de gran tamaño tal que se engloben los productos del decaimiento.

$$A \rightarrow B + C, \quad \Delta R(B, C) \simeq \frac{2m_A}{p_T^A}$$



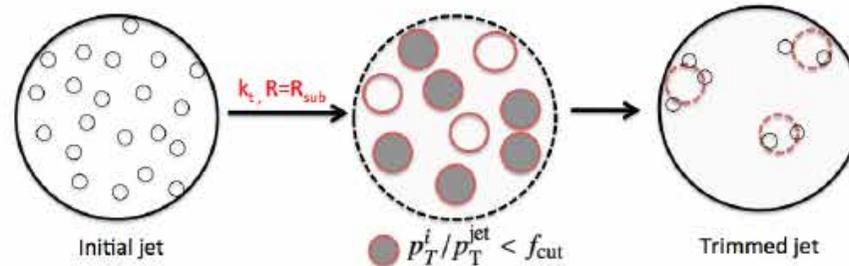
Total Jet Mass

- ▶ M_J^Σ incorpora la subestructura de 'fat-jets' para discriminar eventos de señal que se esperan con más jets de mayor masa que los del background.

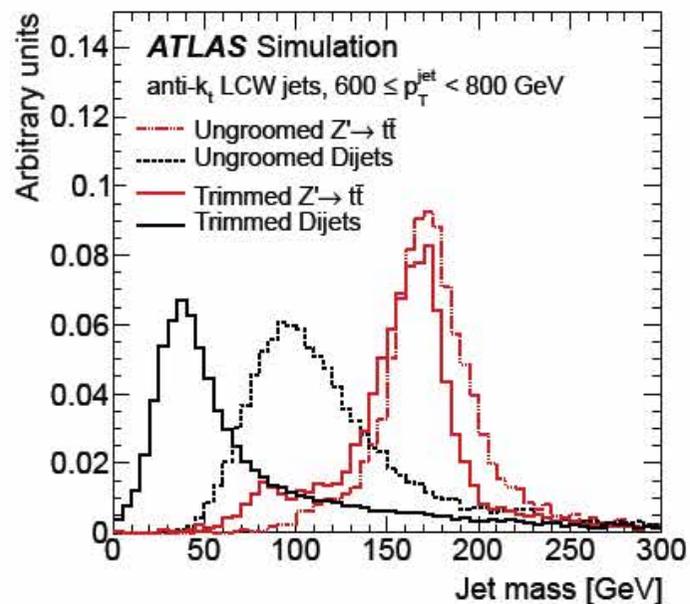


Grooming

- ▶ Jets de gran tamaño son más susceptibles a ISR/FSR/pile-up/MPI \implies afecta la resolución de la masa.
- ▶ *Grooming* de jets, técnicas que eliminan componentes soft del jet.

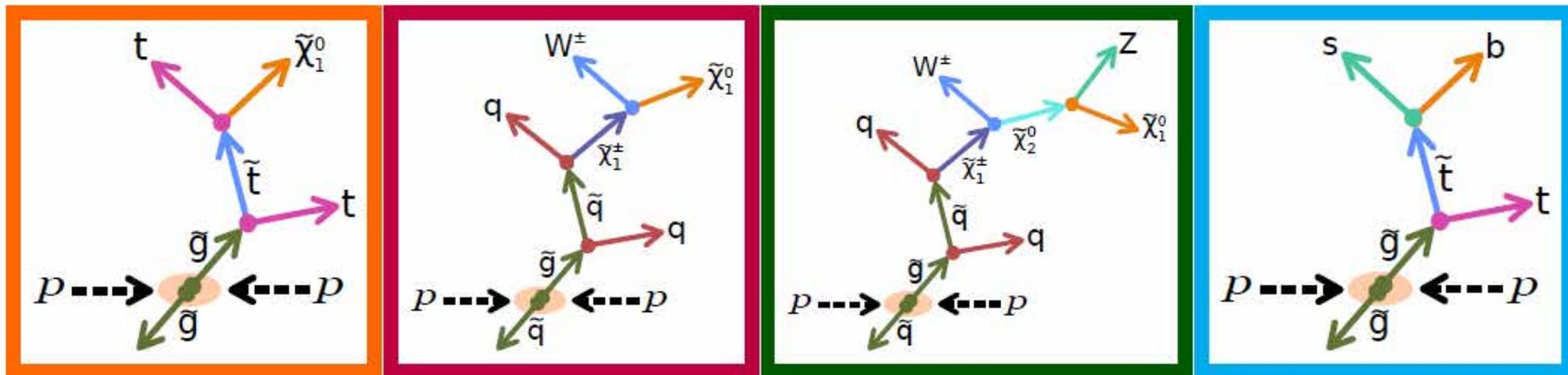


- ▶ Elimina la dependencia del jet con el pile-up, mejora la resolución de masa y aumenta la discriminación de señal.



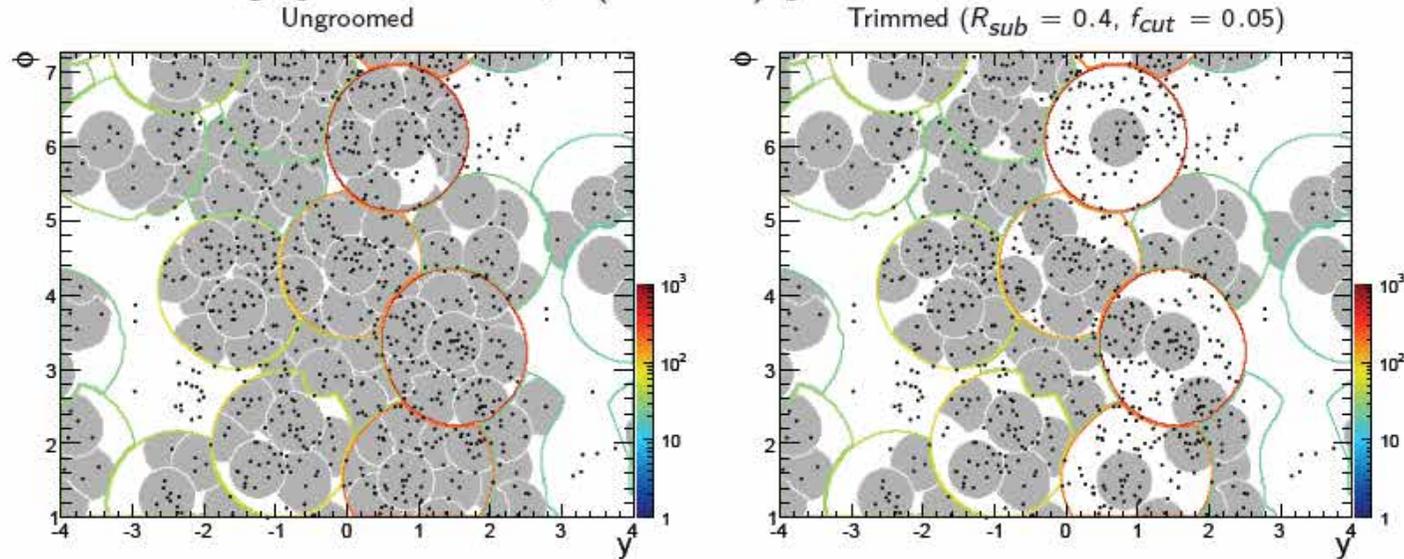
Modelos SUSY

- ▶ Modelos con paridad R conservada,
 - ▶ **Gtt** con on-shell y off-shell stop
 - ▶ Cascada **gluino-gluino 1-step**
 - ▶ Cascada **gluino-gluino 2-steps**
 - ▶ cMSSM
- ▶ Modelo con paridad-R rota
(LSP es inestable)
 - ▶ **RPV-UDD**

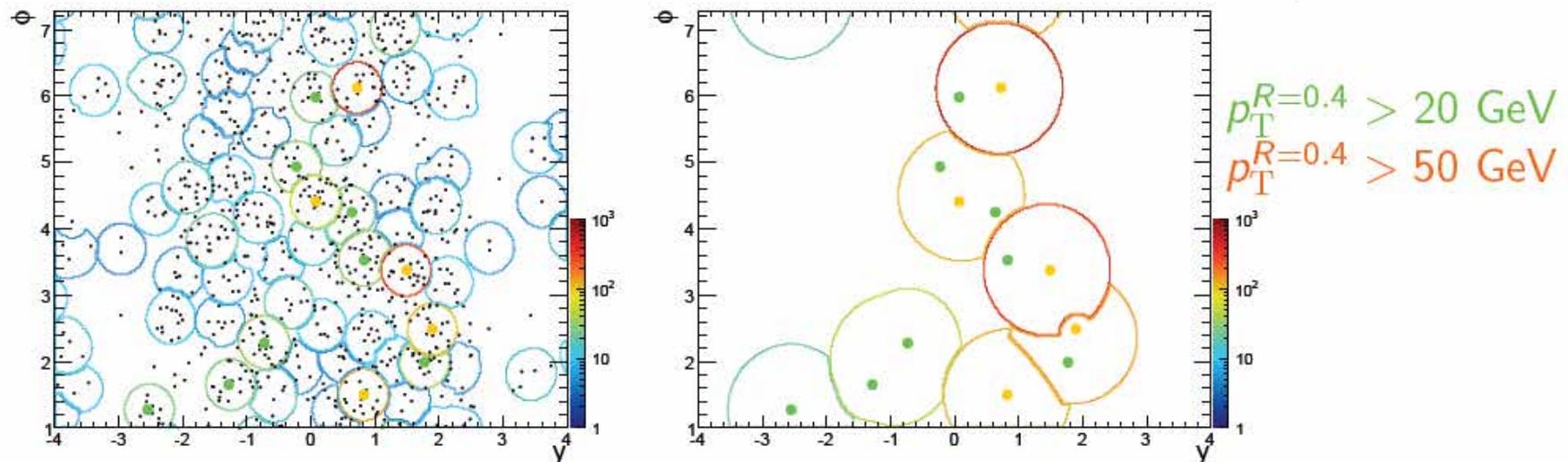


Jet Compuestos

1. 'Trimming' jets: anti- k_T ($R=1.0$) jets built from calorimeter clusters.



2. 'composite jets' built from the 'skinny'-jets (anti- k_T with $R=0.4$)

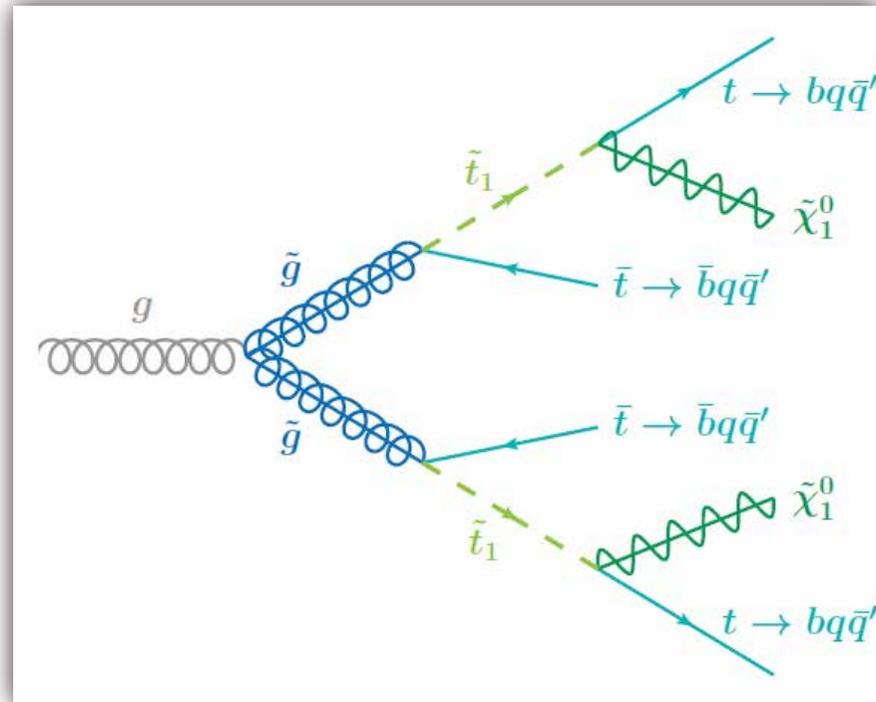


Producción de stop mediante gluinos

- Buscar $pp \rightarrow \tilde{g} \tilde{g}$
con $\tilde{g} \rightarrow \tilde{t}_1 \bar{t}$ y $\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$
y tops hadrónicos $t \rightarrow b q \bar{q}'$

- Esto significa buscar:

$\tilde{\chi}_1^0$: E_T^{miss}
 q : 12 jets
 b : 4 b -jets
 ~~e~~ : e veto
 ~~μ~~ : μ veto



- Pero no hay ningun evento con 12 jets (4 b-jets) => relajar requisitos
 - E_T^{miss} , al menos 6 jets, 3 b-jets
 - E_T^{miss} , multijets (8, 9 10+)

Resumen de un análisis

- Identificar regiones enriquecidas de señal

- Buscar variables que discriminen entre SUSY y Background
- Optimizar cortes para maximizar la significancia

$$S = \text{Signal} / \Delta B$$

$$12 \text{ quarks (4 } b) + 2 \tilde{\chi}_1^0 \left\{ \begin{array}{l} \Rightarrow E_T^{\text{miss}}, \text{ at least 6 jets, 3 } b\text{-jets} \\ \Rightarrow E_T^{\text{miss}}, \text{ multijets (8, 9, 10+)} \end{array} \right.$$

- Estimar el Background

- QCD, ttbar, W+jets, Z+bbbar, single top, Higgs ... (“data-driven” y MC)

- Incertezas Sistemáticas

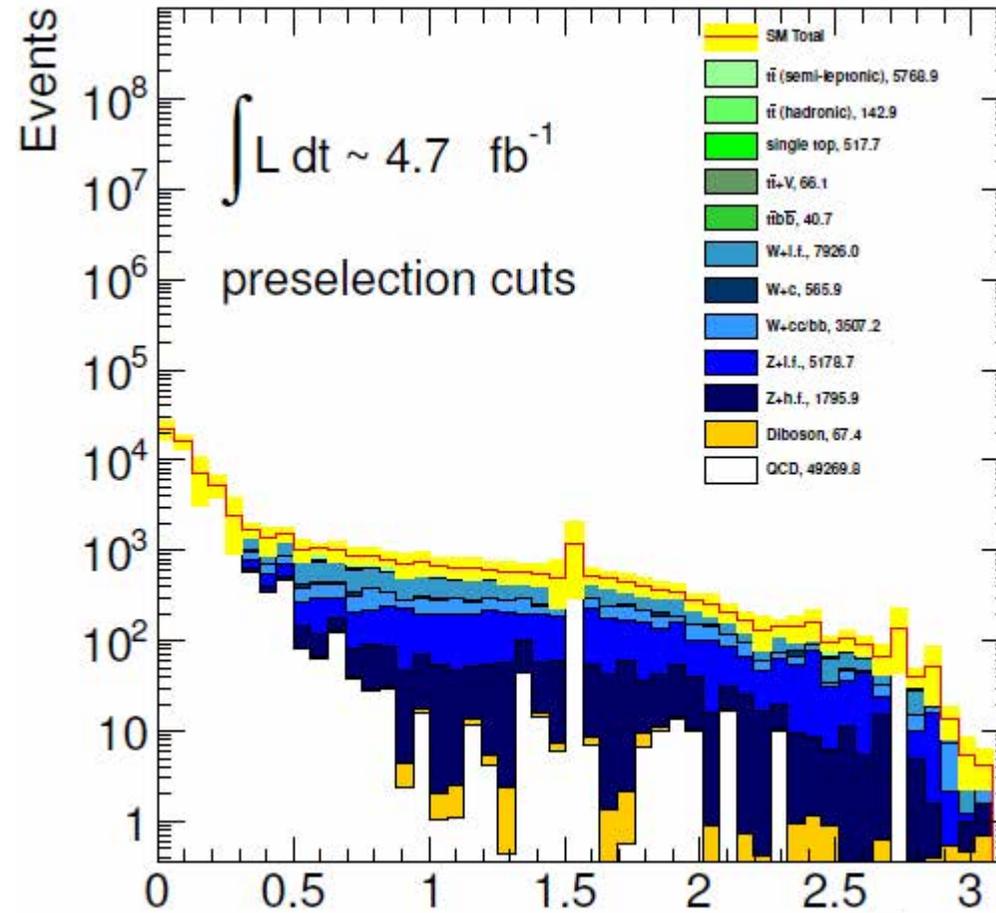
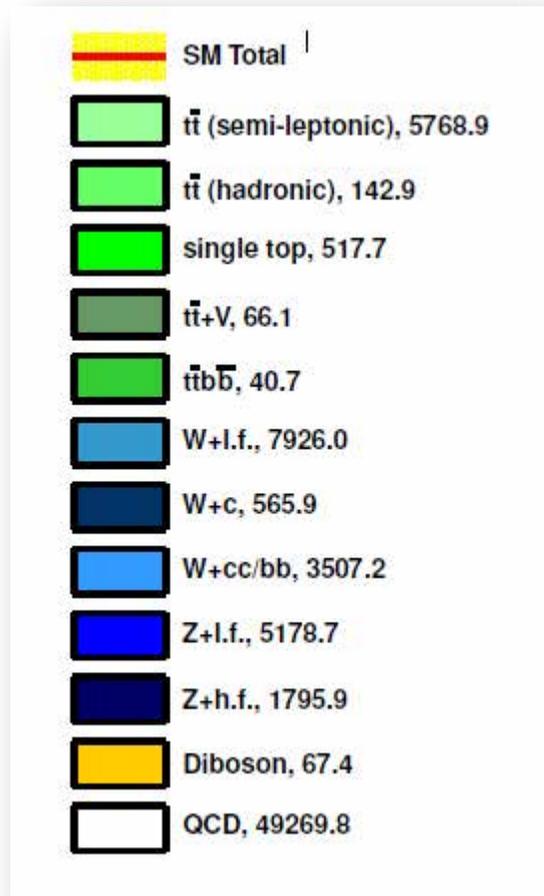
- Detector: calibración, resolución, eficiencias, acceptance, ...
- Teóricas: MC, pdf, escalas de factorización/renormalización ...

- “Abrir la caja” (mirar los datos en la región de señal)

- ¿Exceso significativo de los datos sobre el background predicho?

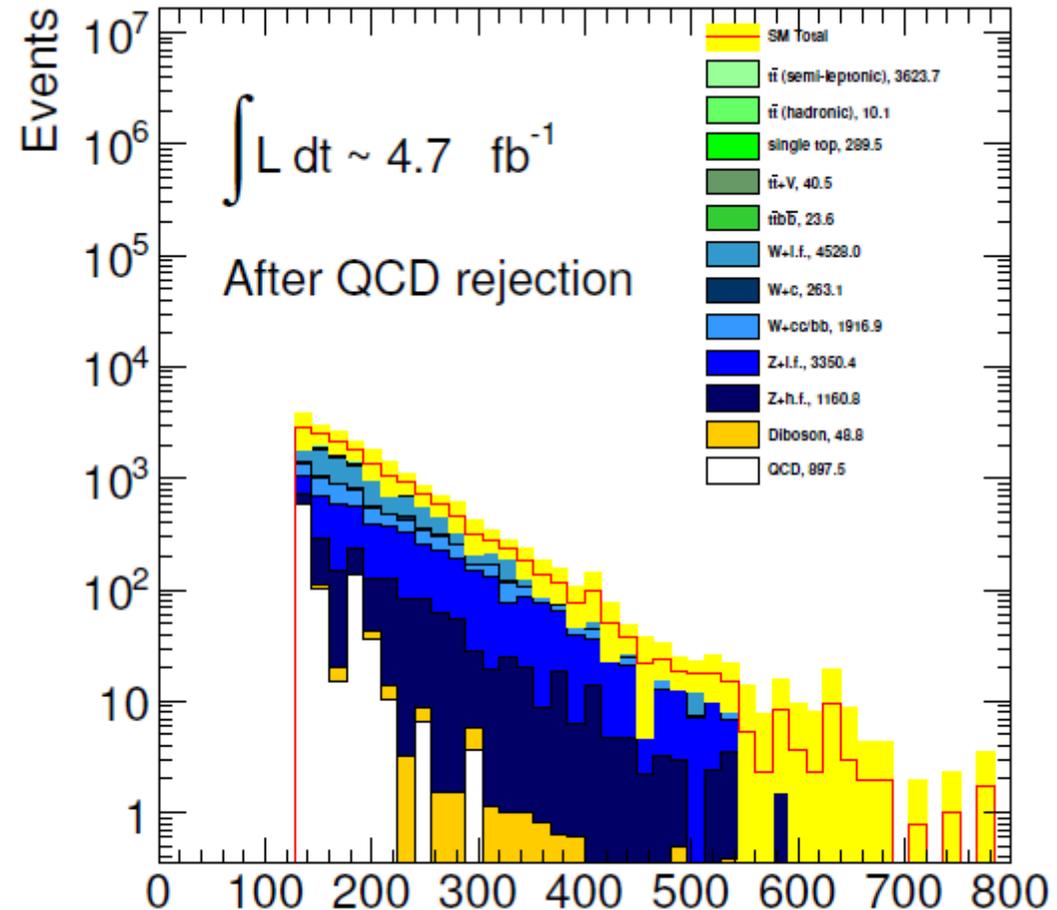
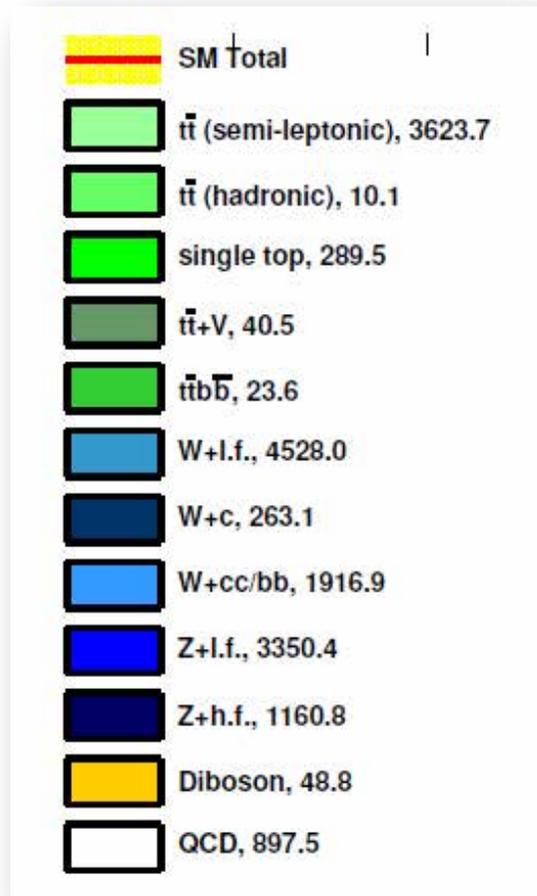
- **NO** -> estimar límites al 95% CL
- **SI** -> comprar boleto de avión a Estocolmo

Eliminar QCD



- ▶ QCD: E_T^{miss} comes from a mismeasured jet $\rightarrow \phi(E_T^{\text{miss}}) \approx \phi(\text{jet})$ $\Delta\phi_{\min}$
- ▶ Define $\Delta\phi_{\min}$: closest $\Delta\phi$ between E_T^{miss} and a jet $\Rightarrow \Delta\phi_{\min}^{\text{QCD}} \approx 0$
- ▶ SUSY, W/Z, $t\bar{t}$: genuine E_T^{miss} \rightarrow uniform $\Delta\phi_{\min}$
- ▶ $\Delta\phi_{\min} > 0.4$ requirement selectively suppresses QCD

Eliminar QCD

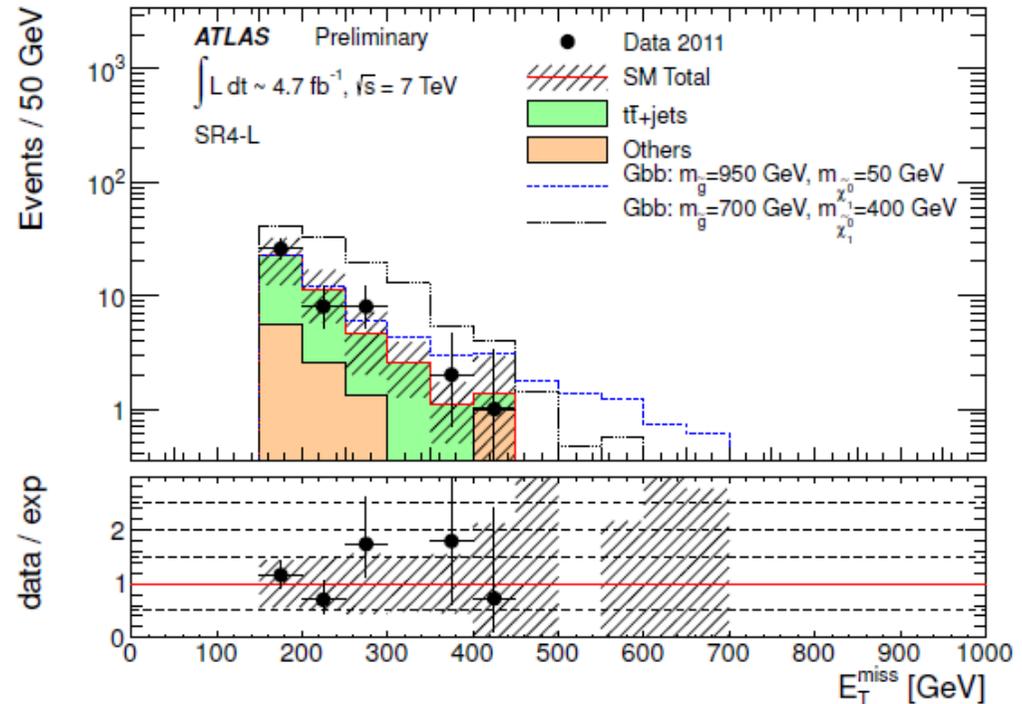


- ▶ QCD: E_T^{miss} comes from a mismeasured jet $\rightarrow \phi(E_T^{\text{miss}}) \approx \phi(\text{jet})$ E_T [GeV]
- ▶ Define $\Delta\phi_{\text{min}}$: closest $\Delta\phi$ between E_T^{miss} and a jet $\Rightarrow \Delta\phi_{\text{min}}^{\text{QCD}} \approx 0$
- ▶ SUSY, W/Z, $t\bar{t}$: genuine E_T^{miss} \rightarrow uniform $\Delta\phi_{\text{min}}$
- ▶ $\Delta\phi_{\text{min}} > 0.4$ requirement selectively suppresses QCD

Otros Backgrounds

$t\bar{t}$ +jets, W/Z +jets, $t\bar{t}+b\bar{b}$, $t\bar{t}+W/Z$, ...

- Requerir b-tagged jets
 - SM background tiene muchos menos que la señal
- Empezamos con # b-jets = 0
- # b-jets = 1
 - Reducir W/Z
- # b-jets = 2
 - Reducir W/Z
 - Bkg dominante: top
- # b-jets ≥ 3
 - Suprimir $t\bar{t}b\bar{b}$
 - Señal visible!



Datos consistentes con la prediccion del background, no vemos SUSY.

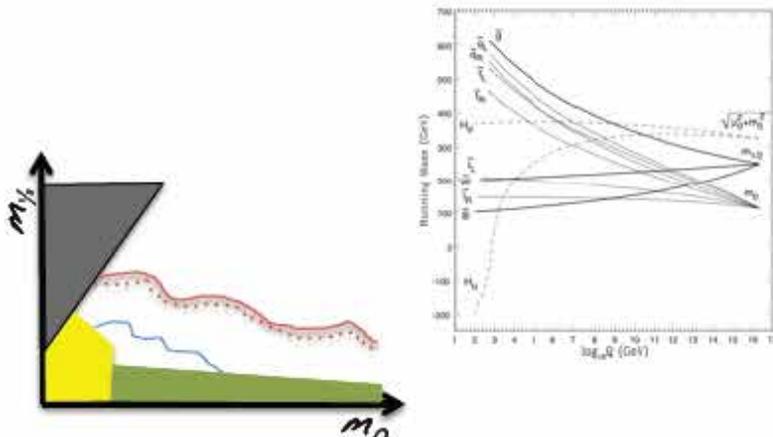
Modeling SUSY

Top-down approach:

- Model of SUSY breaking:
 - Gravity mediated (mSUGRA, cMSSM)
 - Gauge mediated (GMSB)
 - ...
- Assume GUT scale parameters (few)

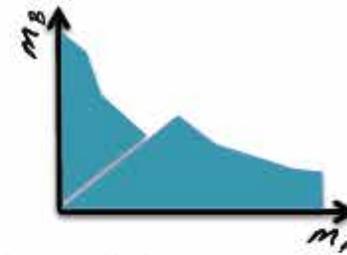
- m_0 : scalar mass parameters
- $m_{1/2}$: gaugino mass parameter
- A_0 : trilinear Higgs-sfermion-sfermion coupling
- $\tan\beta$: ratio of Higgs vacuum expectation values
- $\text{sign}(\mu)$: sign of SUSY Higgs parameter

- Predict phenomenology at the EWK scale

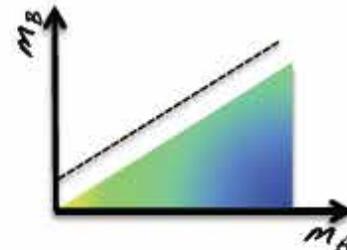


Bottom-up approaches:

- Phenomenological models:
 - Assume mass & hierarchy for SUSY particles



- Simplified models:
 - Well define production & decay
 - Assume simple decay chain



Model Independent limits:

- Provide:
 - $\sigma \times \text{selection efficiency} \times \text{detector acceptance}$

Expected Signatures

General MSSM Lagrangian violates leptonic and baryonic numbers in the superpotential



Introduce new symmetry to suppress proton decay

R-Parity

$$R = (-1)^{3(B-L)+2s}$$

$$R_p^{SM} = +1$$

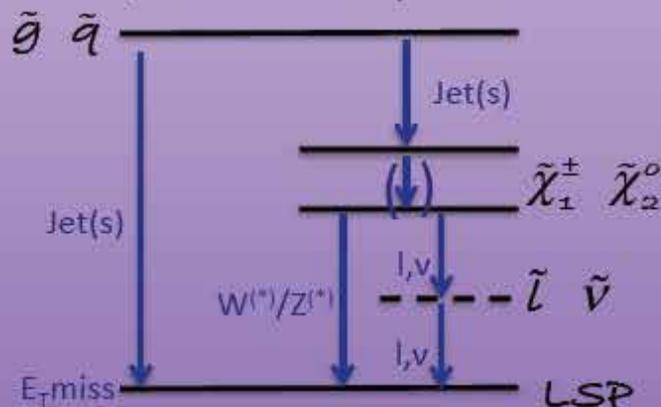
$$R_p^{SUSY} = -1$$

Impact on expected phenomenology

R-Parity Conservation (RPC)

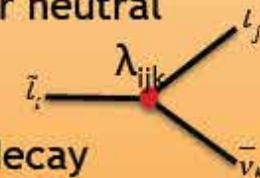
- ✓ SUSY particles created in pairs
- ✓ Lightest Supersymmetric Particle (LSP) is stable. DM candidate.
 - ✓ Missing transverse momentum ($E_{T\text{-miss}}$)
 - ✓ No mass peak: SUSY evidence in tails of distributions

Simplified Decay Chains



R-Parity Violation (RPV)

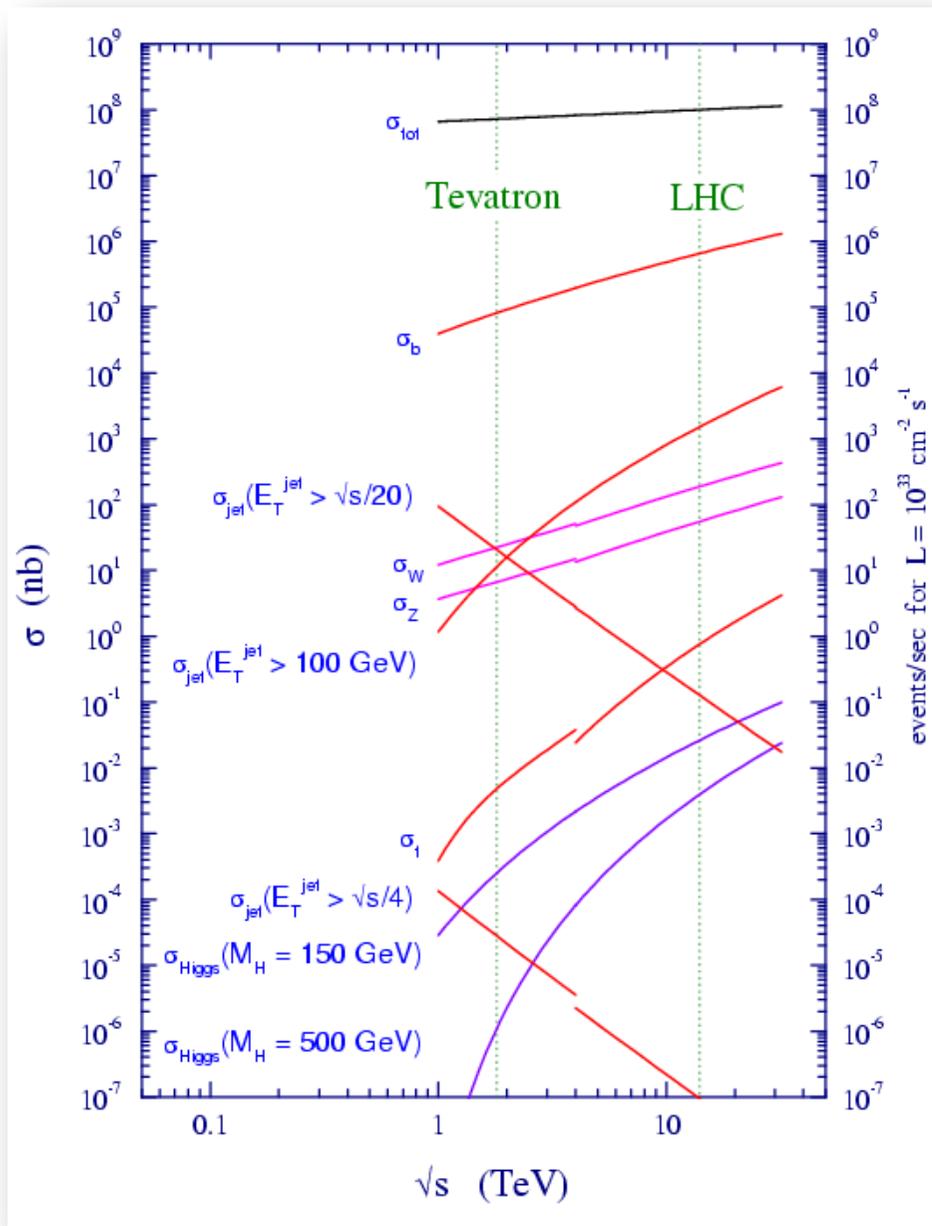
- ✓ LSP: not need to be stable nor neutral
 - ✓ Not DM candidate
- ✓ LSP decays:
 - ✓ Exploit invariant mass, decay properties
- ✓ Sparticle can be produced singly
- ✓ $E_{T\text{-miss}}$ can also be expected (e.g neutrinos) but can be relaxed



Other more exotic situations

- ✓ Depending on the mass splitting/hierarchy
 - ✓ Displaced vertices
 - ✓ Slow moving ionizing particles
 - ✓ Delayed decay
 - ✓ ...

Secciones Eficaces



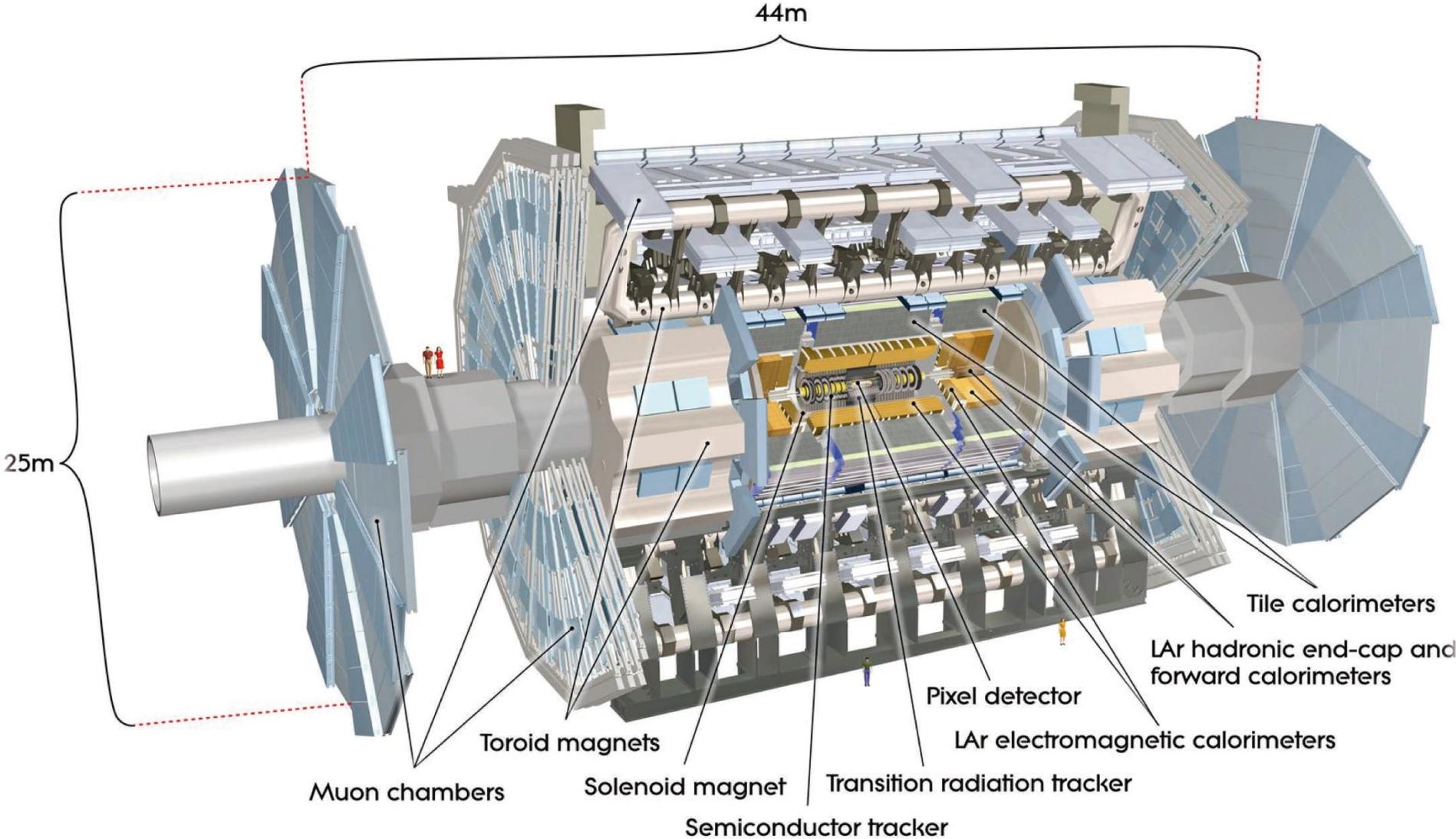
Las secciones eficaces de producción expanden 13 órdenes de magnitud

— Inundados de procesos “mundanos”

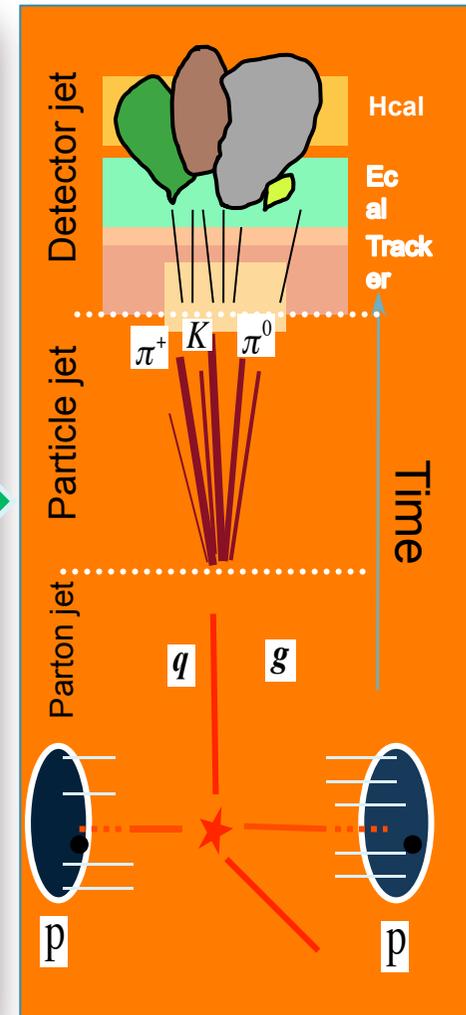
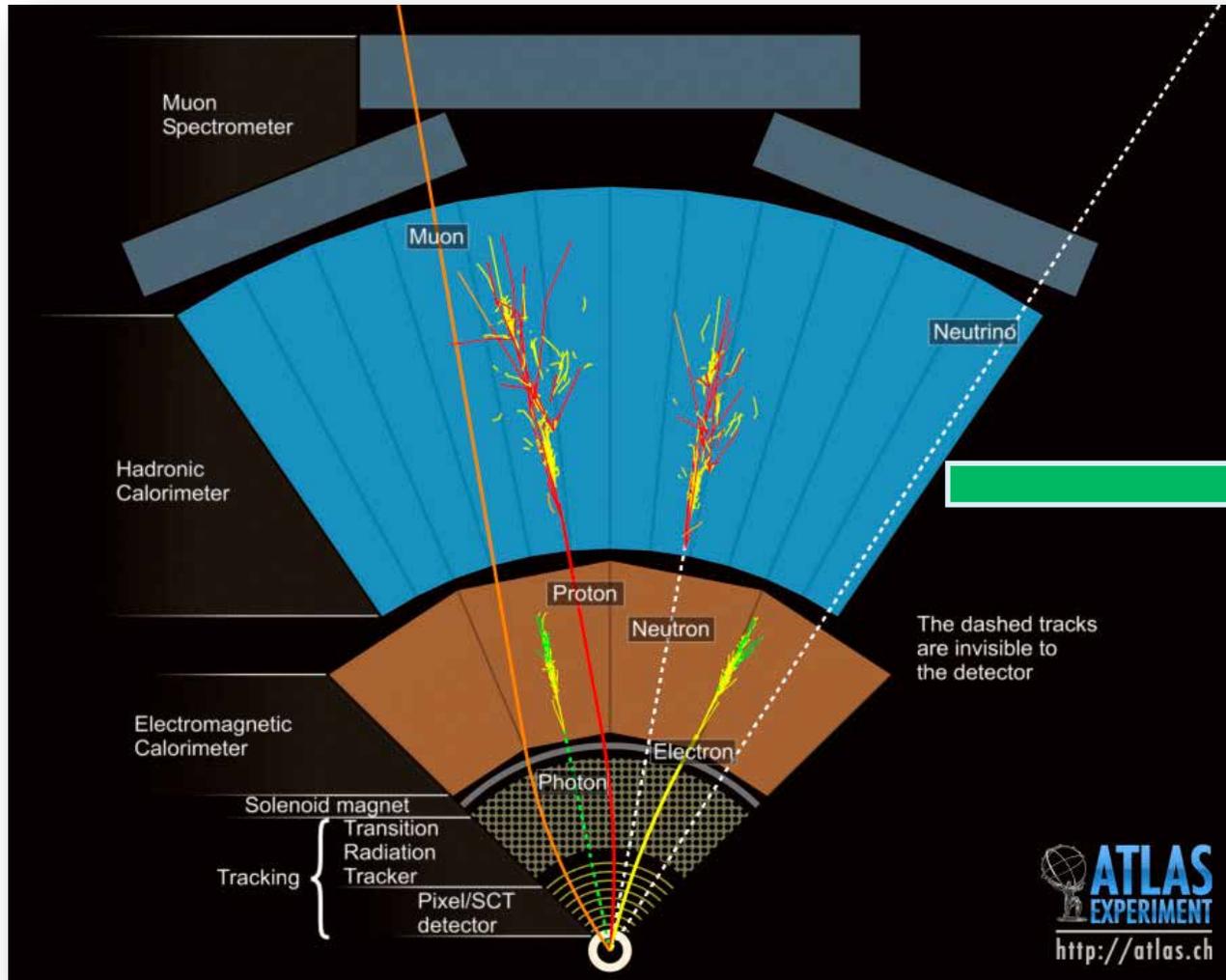
Gran variedad de procesos

— Programa Físico muy “rico”

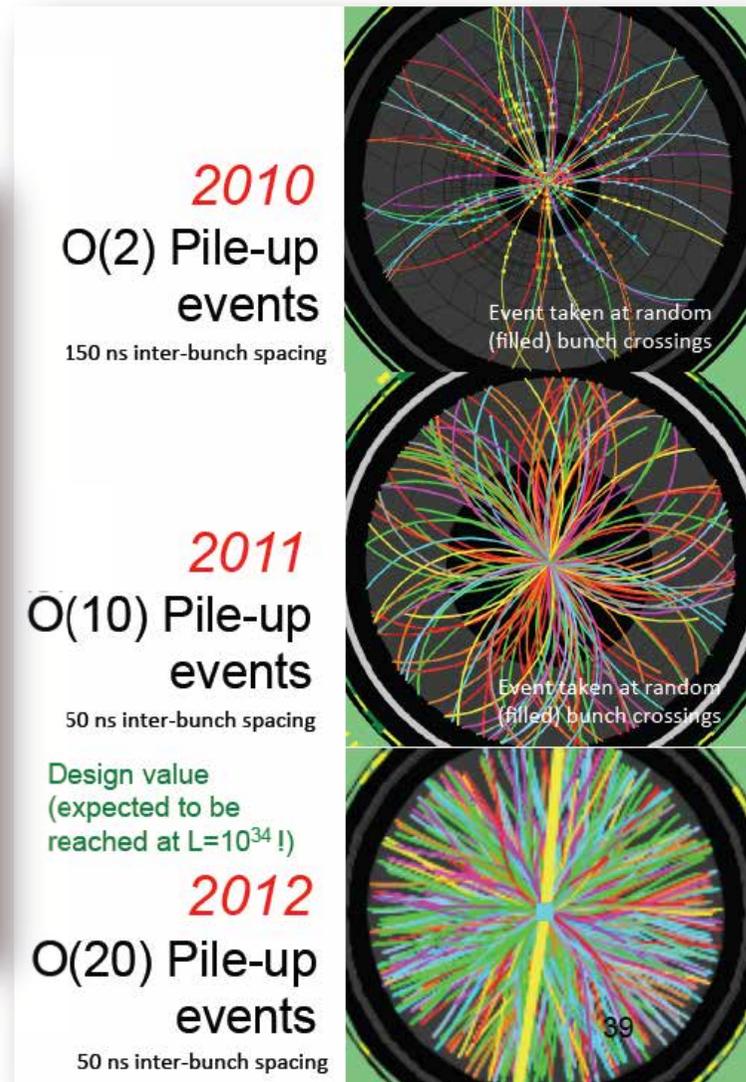
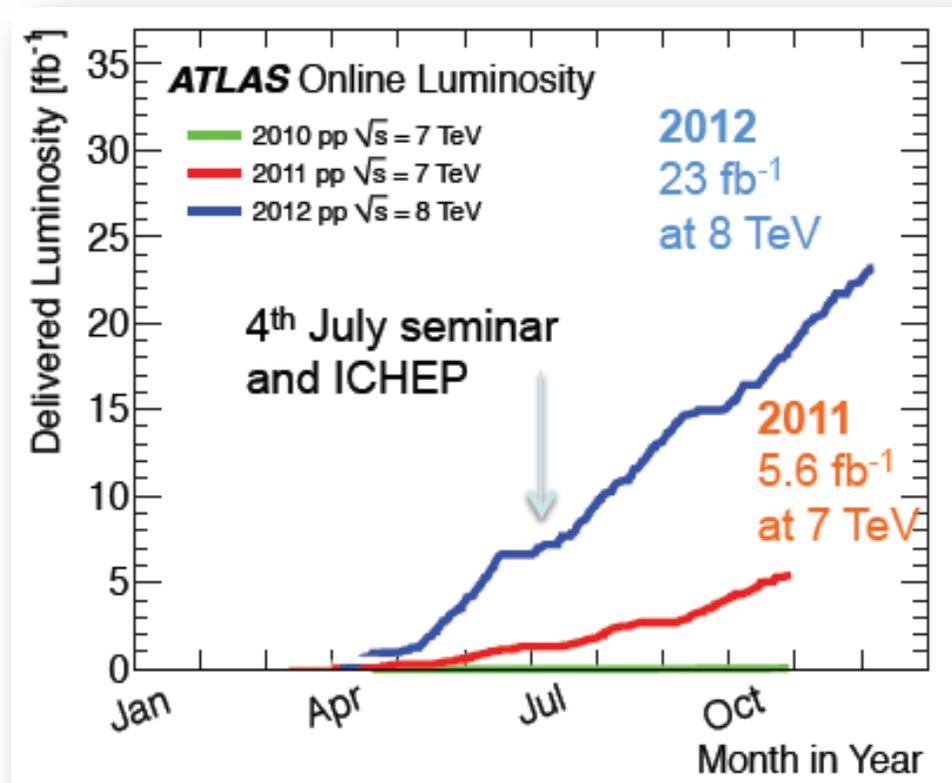
El detector ATLAS



¿Qué detectamos?



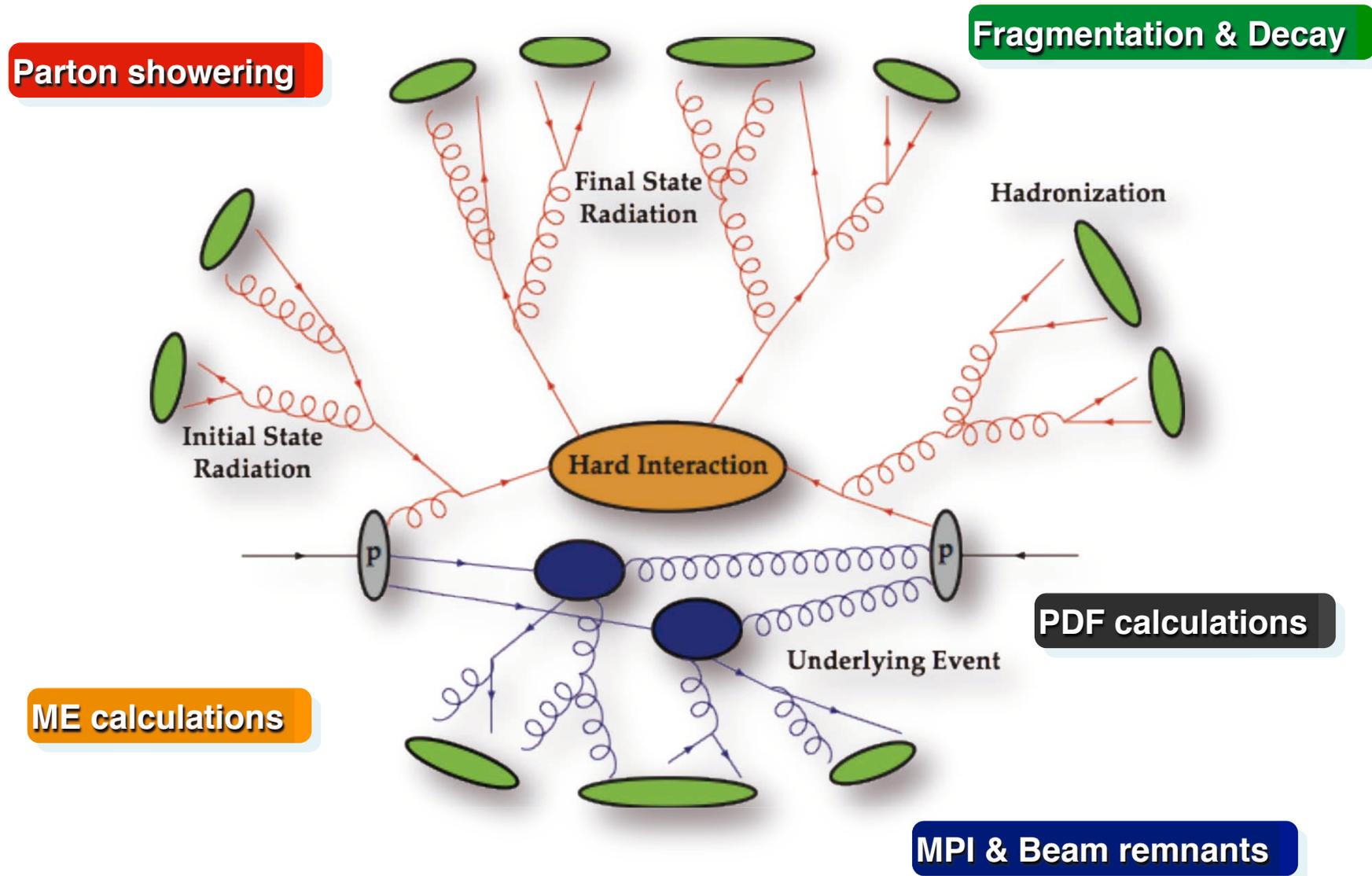
Luminosidad (L) y sección eficaz (σ)



$$N_{\text{Higgs}} = L \times \sigma = 11 \text{ fb}^{-1} \times 12 \text{ pb} = 132.000 (!)$$

El LHC es una “Fábrica de Higgses”

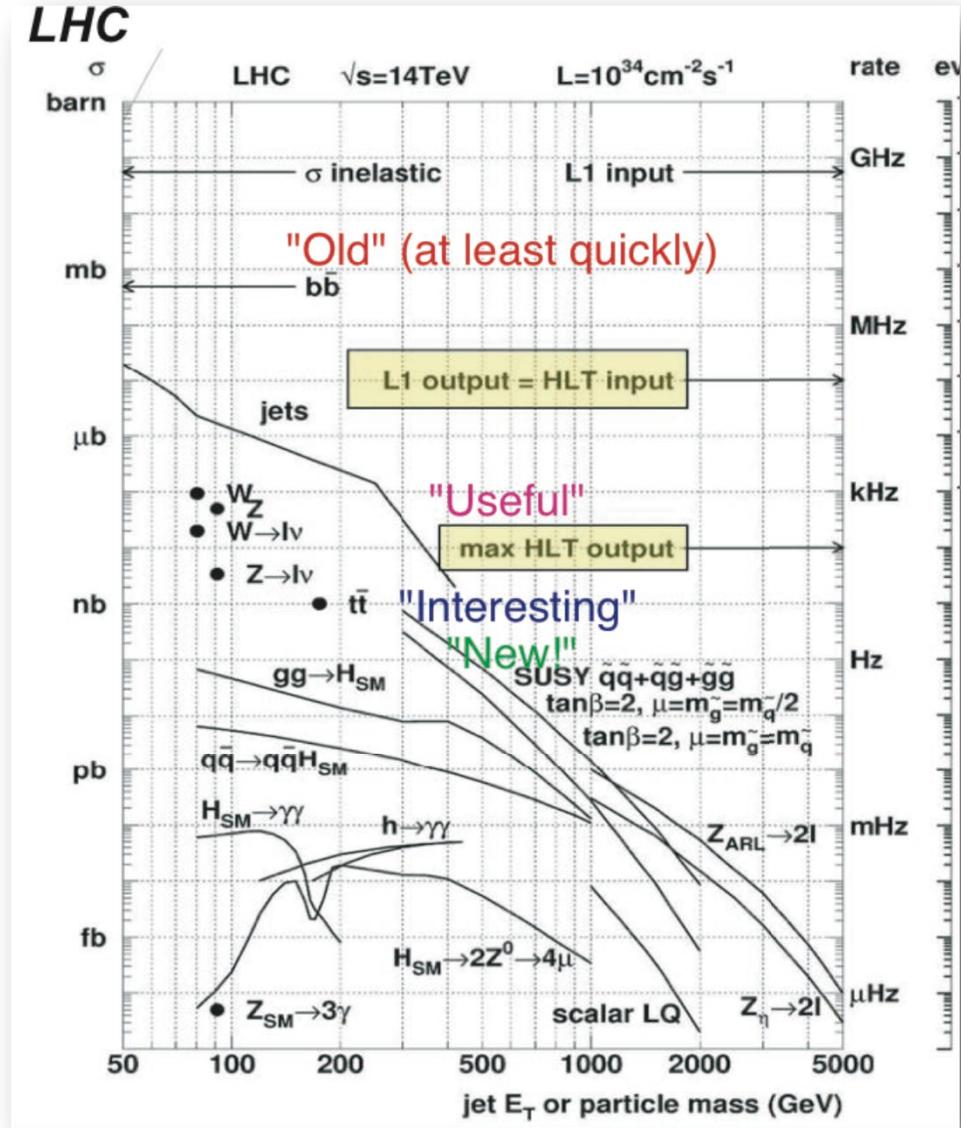
Simulación de Eventos



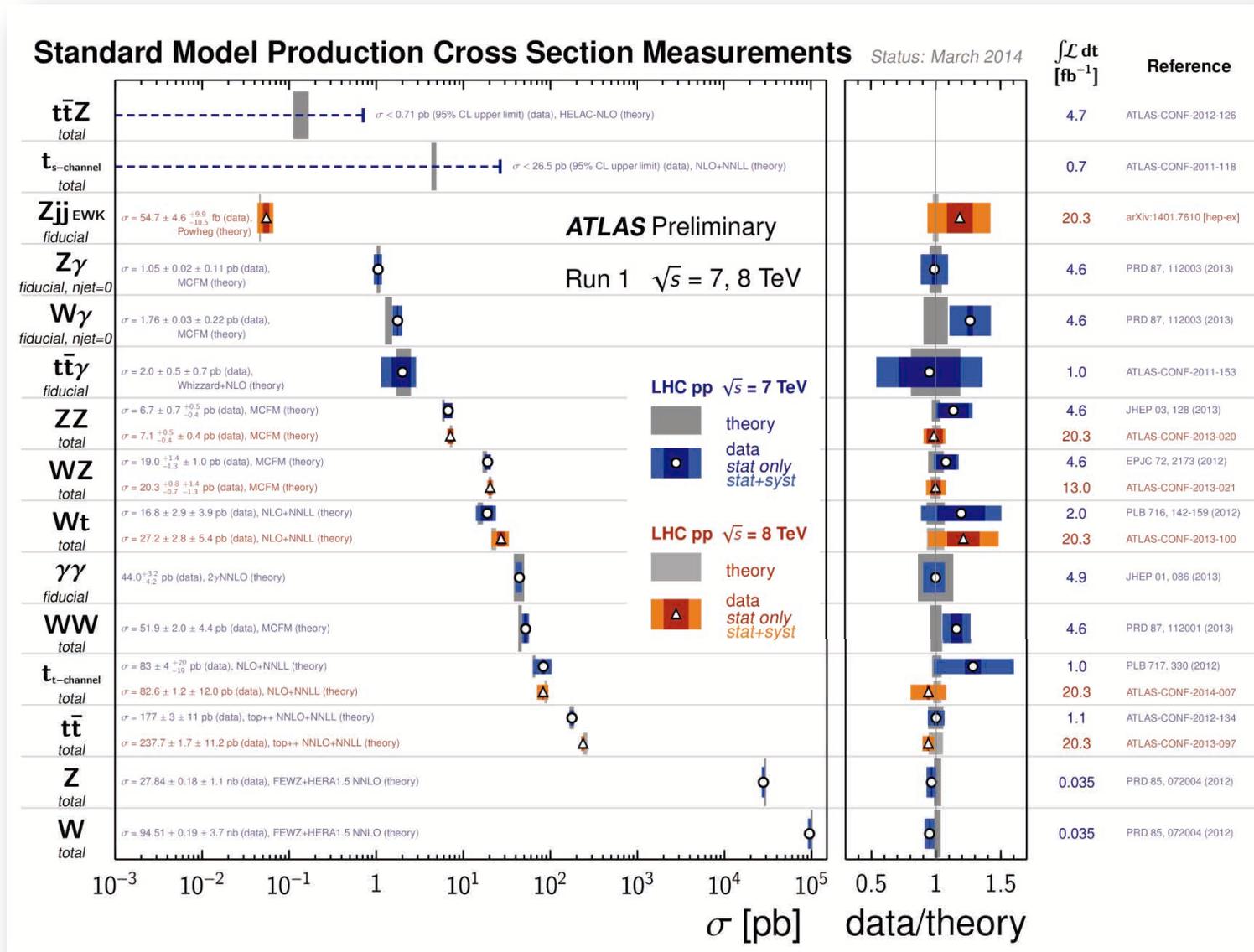
Triggering

- Lo "interesante" tiene *rates* entre 1 y 10^{-3} Hz
- Guardar los eventos interesantes, tirar el resto
- Solo podemos guardar ~600Hz

Eventos no seleccionados por el trigger se pierden para siempre!

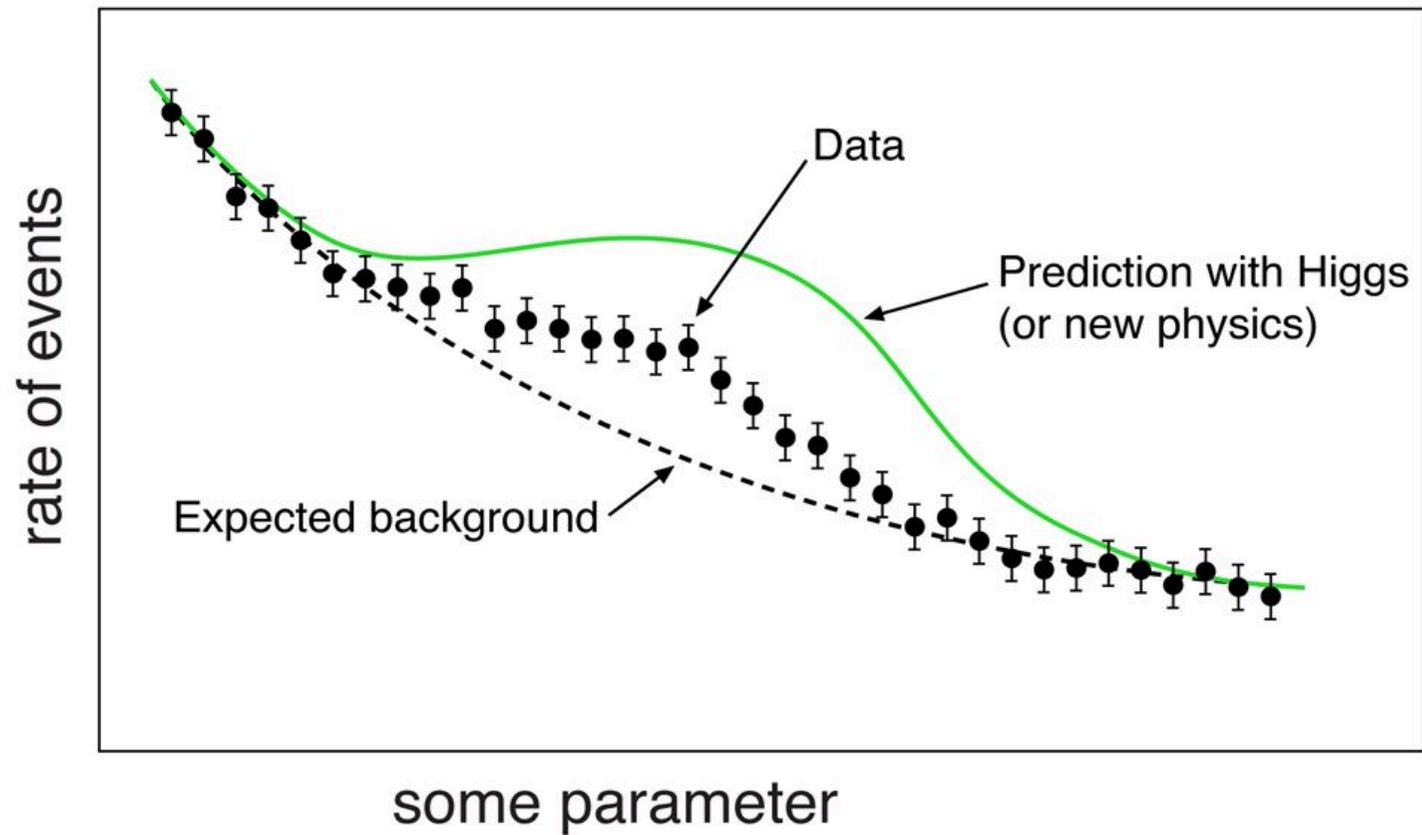


¿Dónde estamos parados?

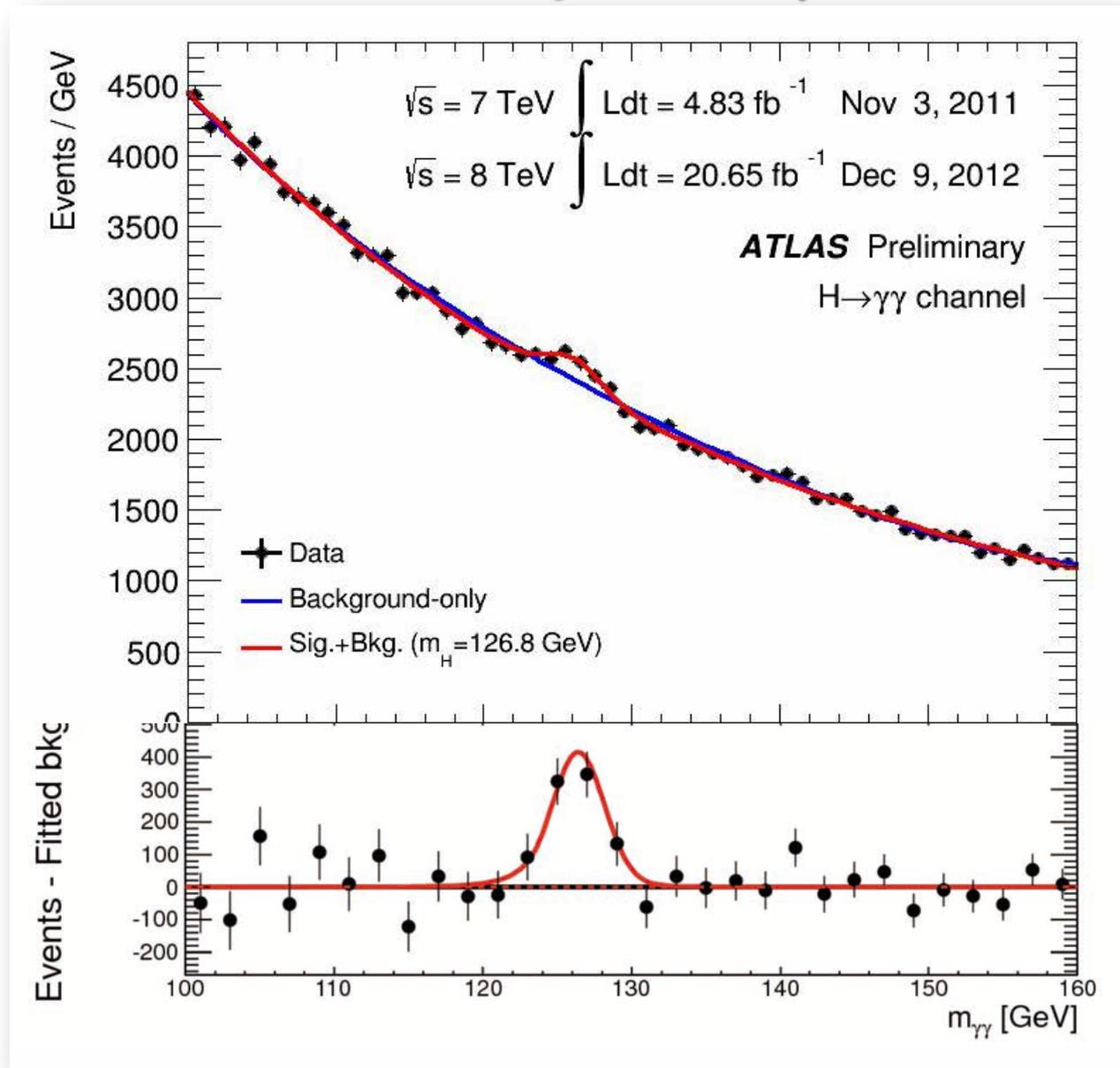


Antes de buscar BSM tenemos que entender el SM!

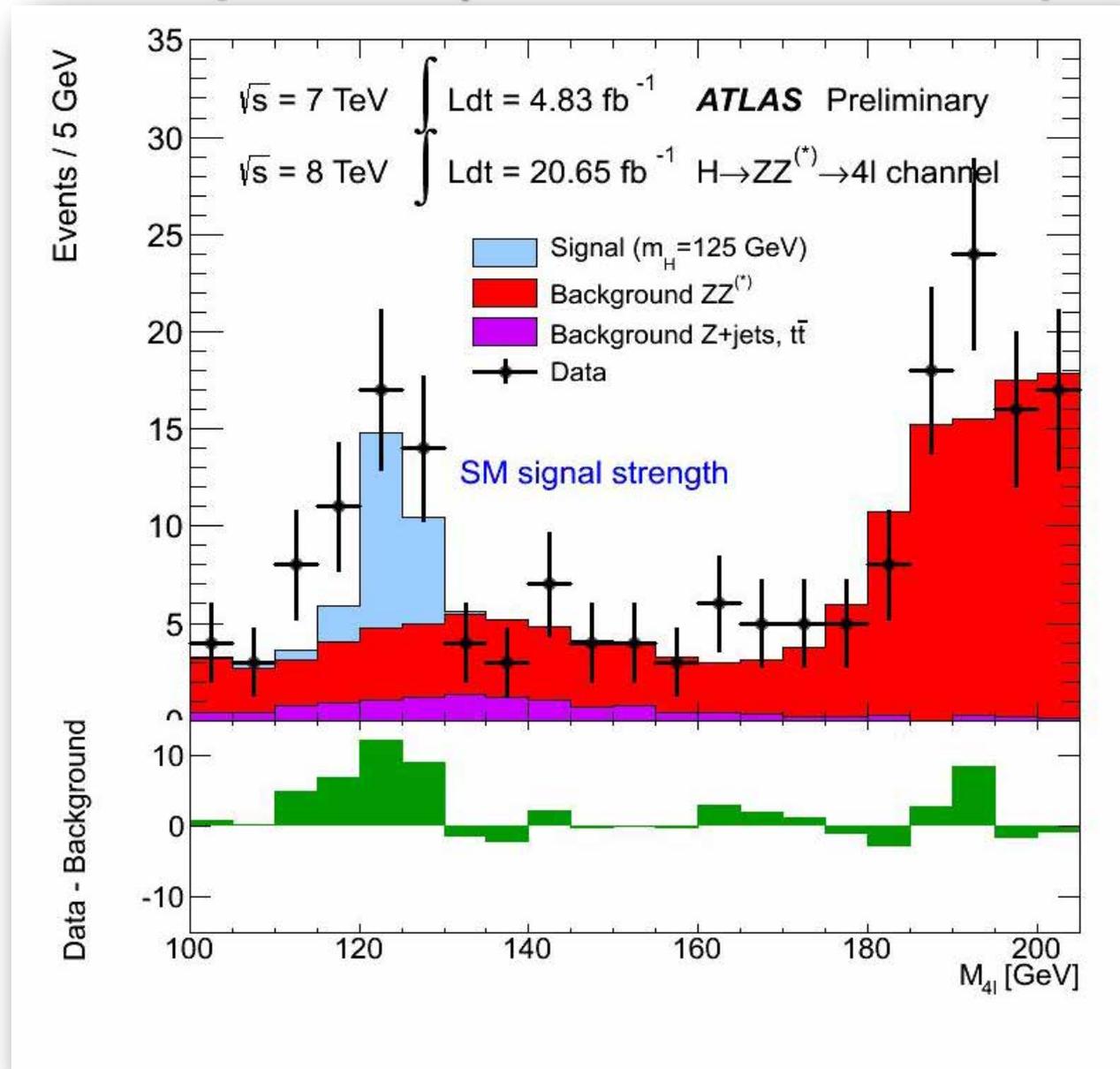
La búsqueda: a contar ...



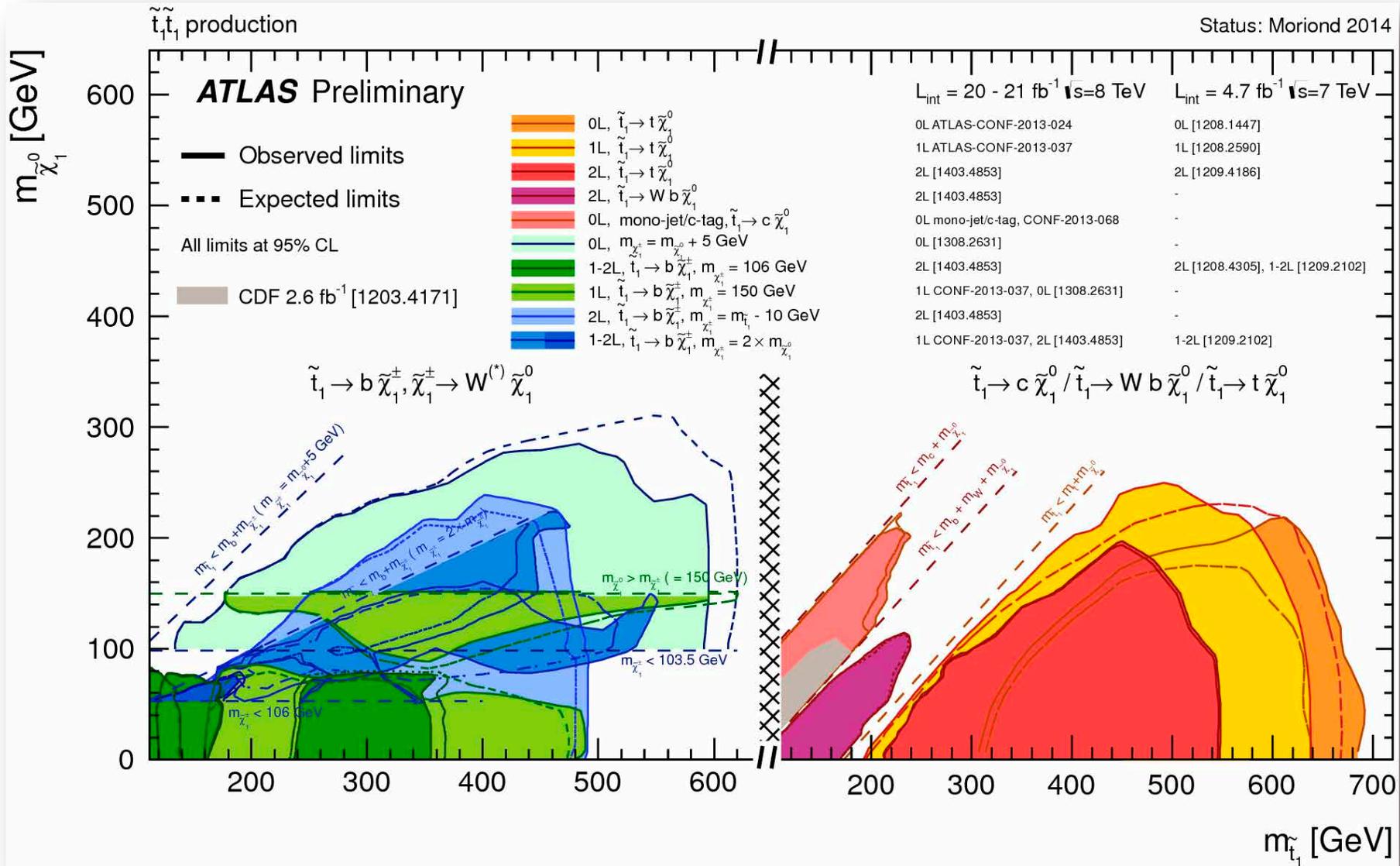
Un análisis de búsqueda ($H \rightarrow 2$ fotones)



Otra búsqueda ($H \rightarrow ZZ \rightarrow 4 \text{ leptones}$)



Búsqueda de partículas SUSY



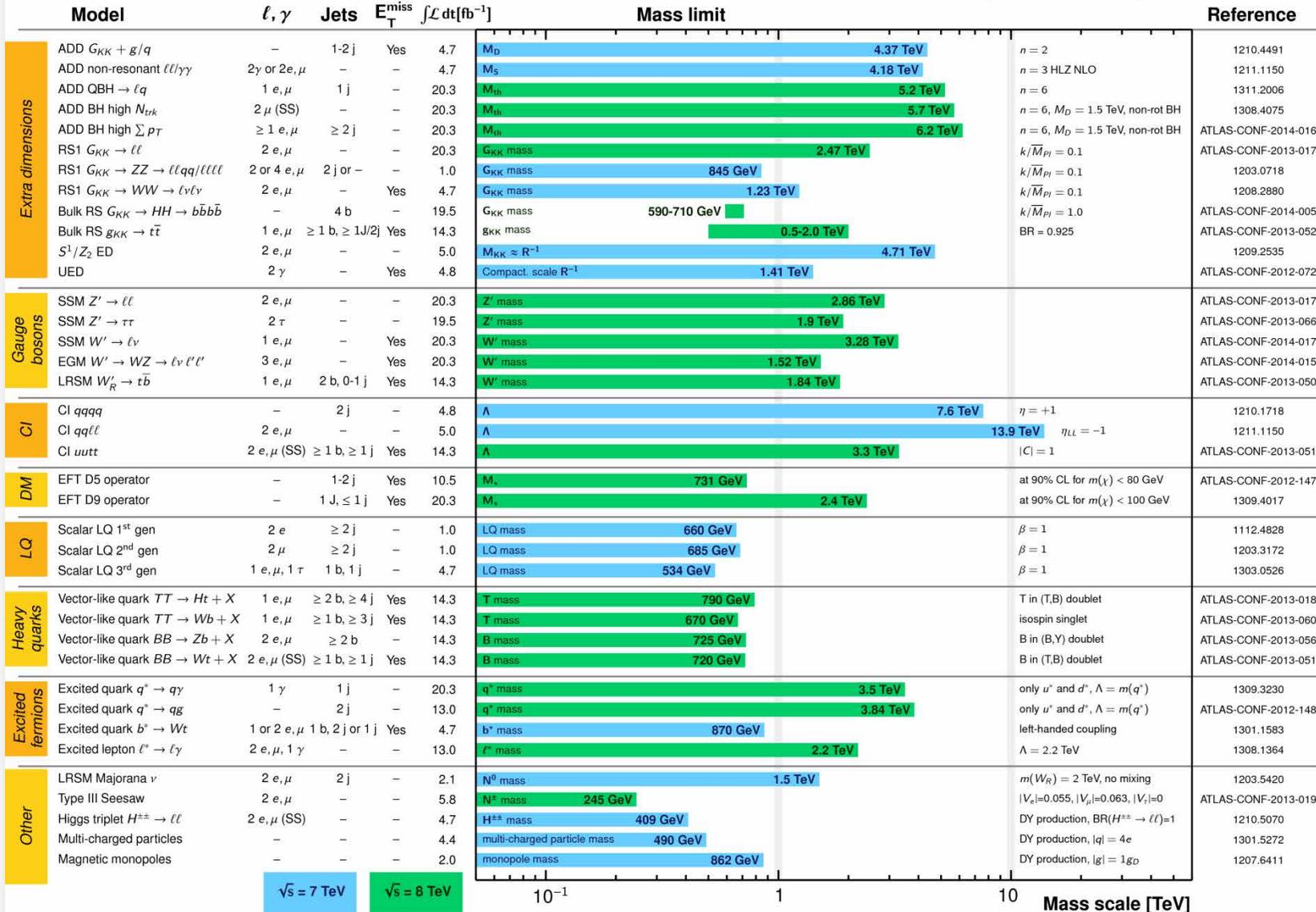
Búsqueda de Física "Exótica"

ATLAS Exotics Searches* - 95% CL Exclusion

Status: April 2014

ATLAS Preliminary

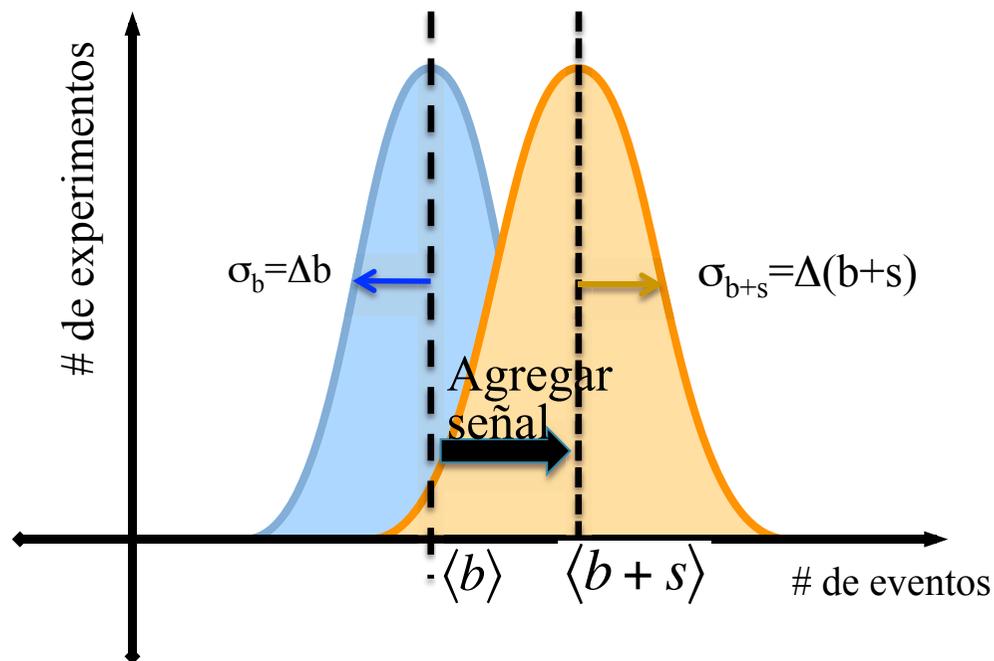
$\int \mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1}$ $\sqrt{s} = 7, 8 \text{ TeV}$



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

Límite Esperado

- Generar un ensemble de N experimentos usando la distribución medida de $\langle b \rangle + \Delta b$ ($\langle b \rangle$ es la media poissoniana, Δb es gaussiana)
- “Límite Esperado”: máximo # de eventos de señal en la muestra tal que $b+s$ C.I. contenga la predicción del background, $\langle b \rangle$, 95% de las veces.



Límite Observado:

máximo # de eventos de señal en la muestra tal que $b+s$ C.I. contenga N_{obs} 95% de las veces

El límite se traduce en la medición de un observable usando modelos teóricos y acceptance/efficiency de señal

La masa de los quarks

