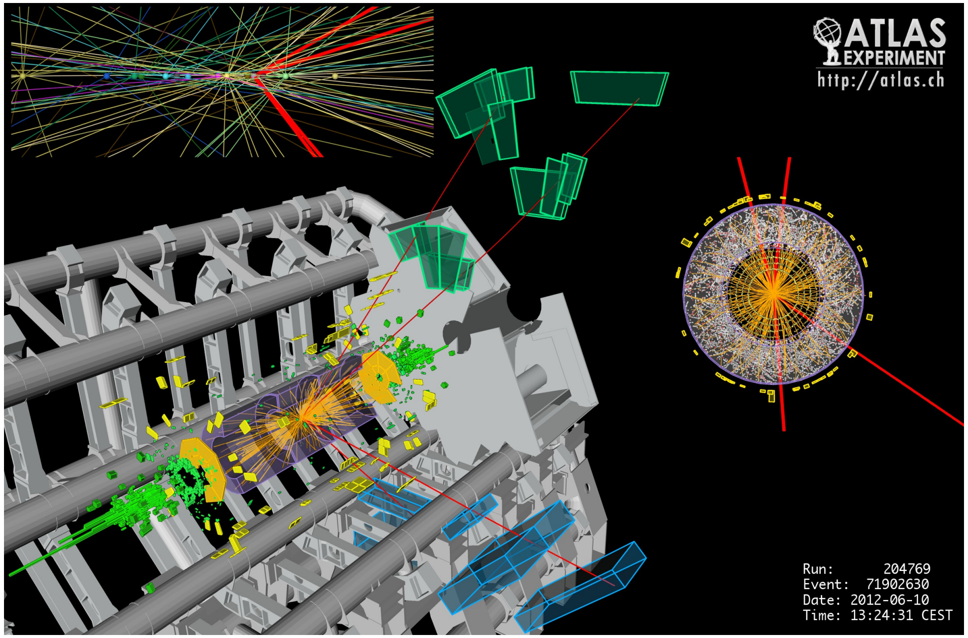
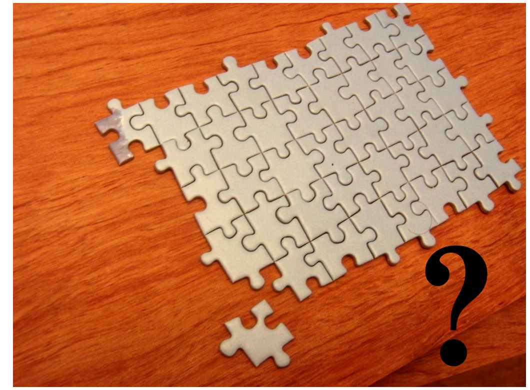




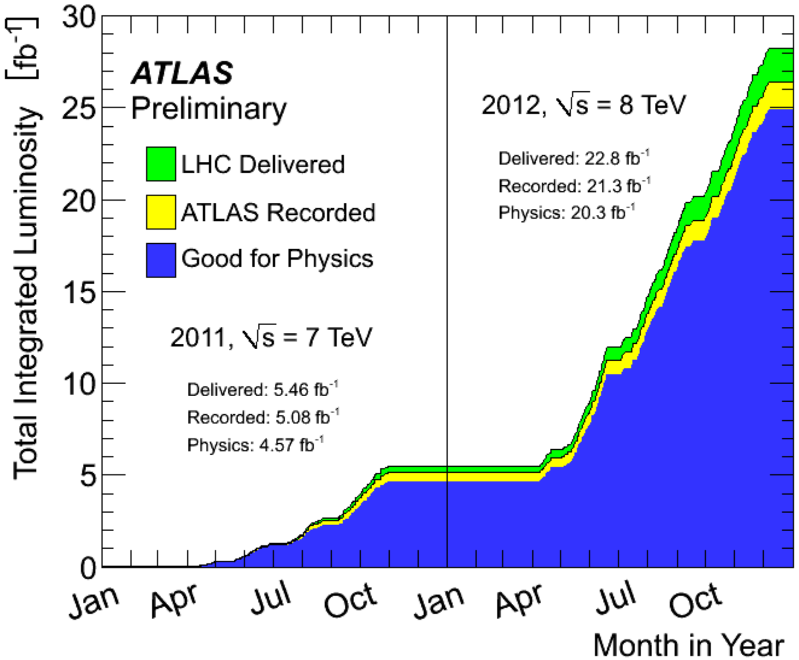
ATLAS Physics Prospects for the High Luminosity LHC

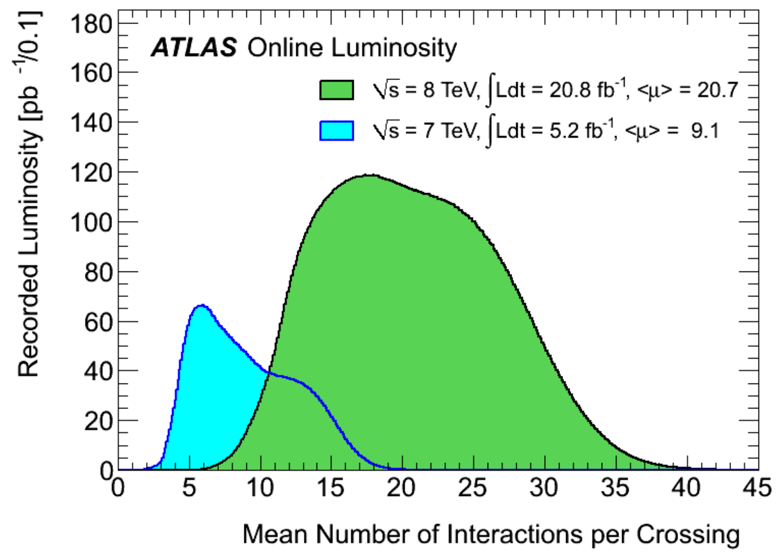
Patricia Conde Muíño
(LIP-Lisboa)

Highlights from the first LHC physics run

- Will show mainly ATLAS results
    - CMS has similar results in most cases

Data taking during LHC Run I

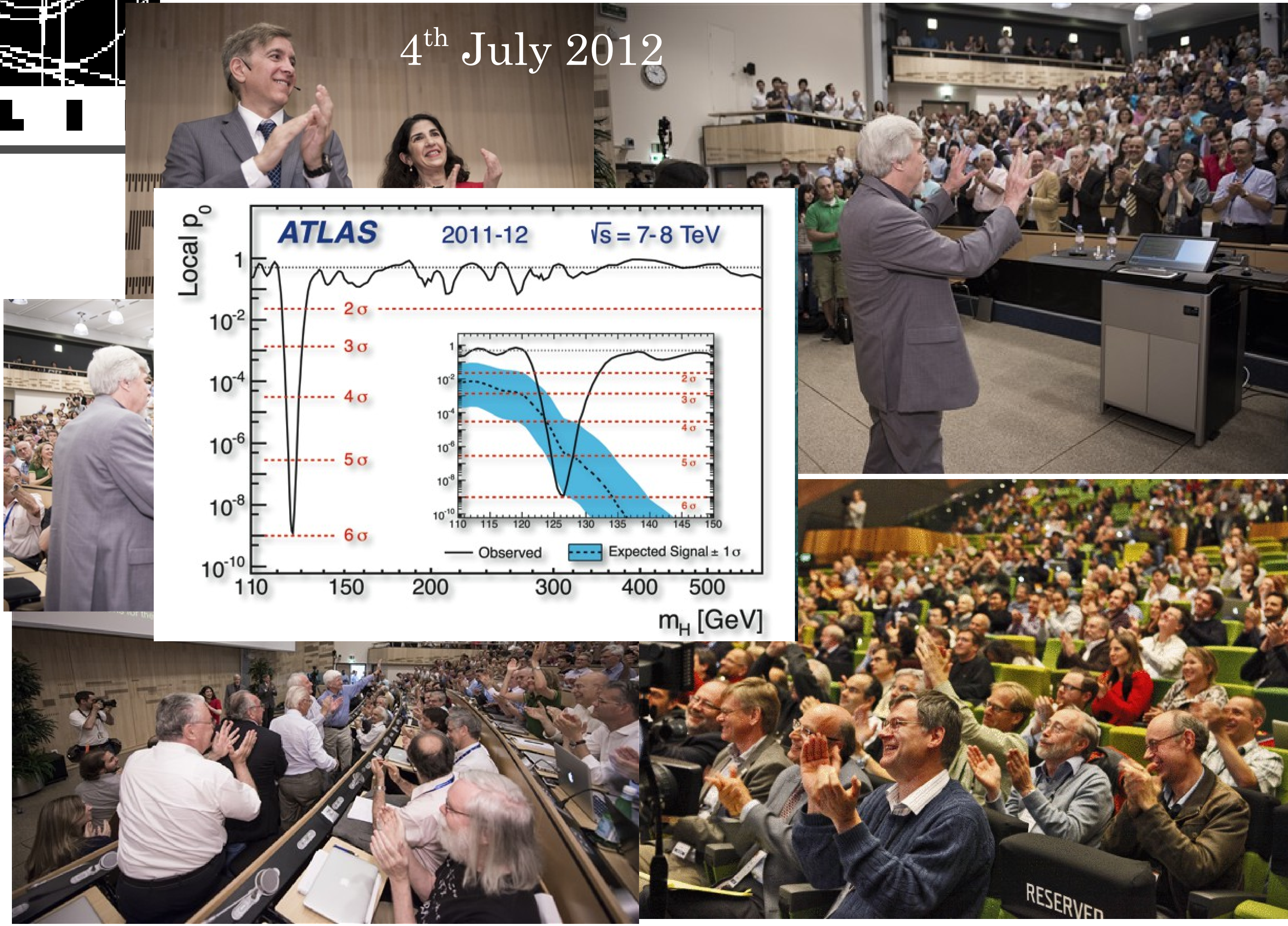




- In addition:
  - 150 μb^{-1} of Pb-Pb collisions @ 2.76 TeV
  - 30 nb^{-1} of p-Pb collisions

- pp collisions recorded at ATLAS
  - 21.3 fb^{-1} @ 8 TeV
  - 5.08 fb^{-1} @ 7 TeV
- ~95% physics quality data!

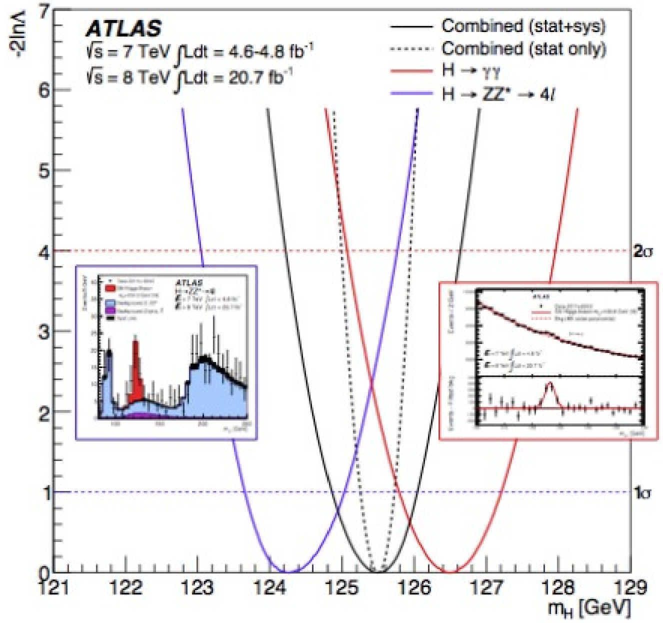
4^{th} July 2012



Higgs mass meassurement

- Measured in the H→γγ and H→ZZ→4l decay channels

  Better mass precision



ATLAS: $M_H = 125.5 \pm 0.2_{stat} \pm 0.6_{sys}$ GeV

Higgs mass meassurement

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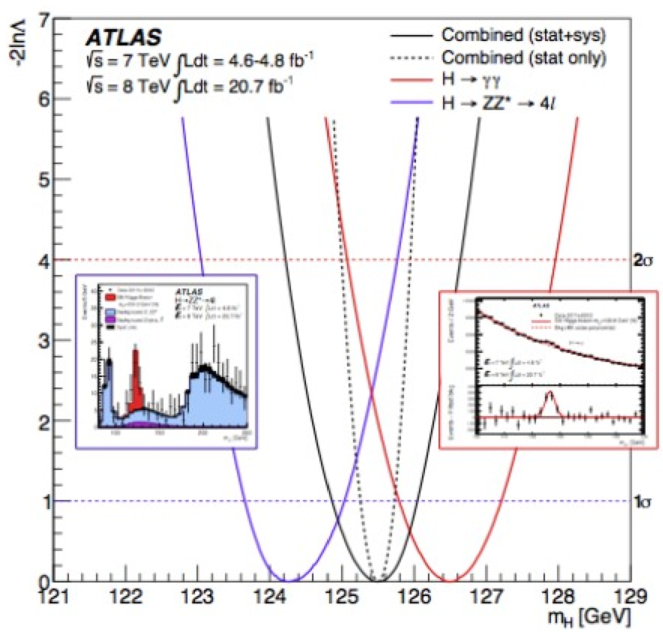
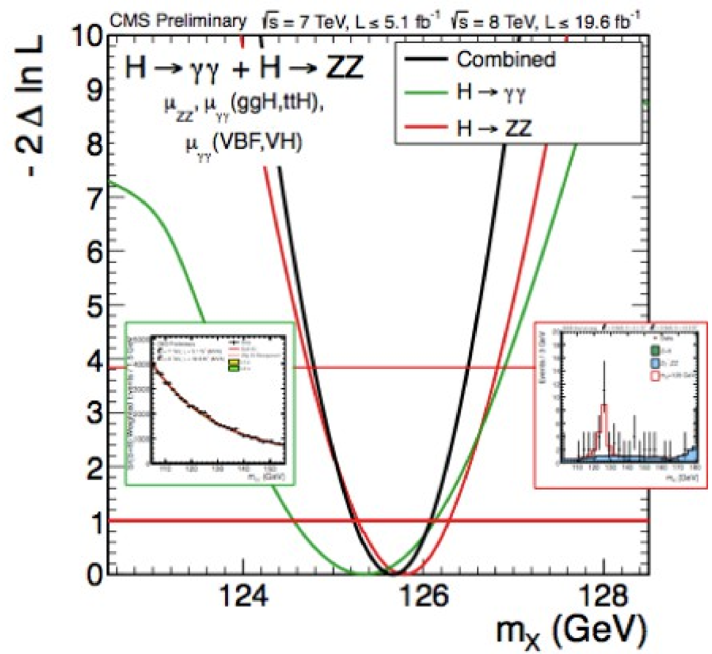


ATLAS: $M_H = 125.5 \pm 0.2_{stat} \pm 0.6_{sys}$ GeV

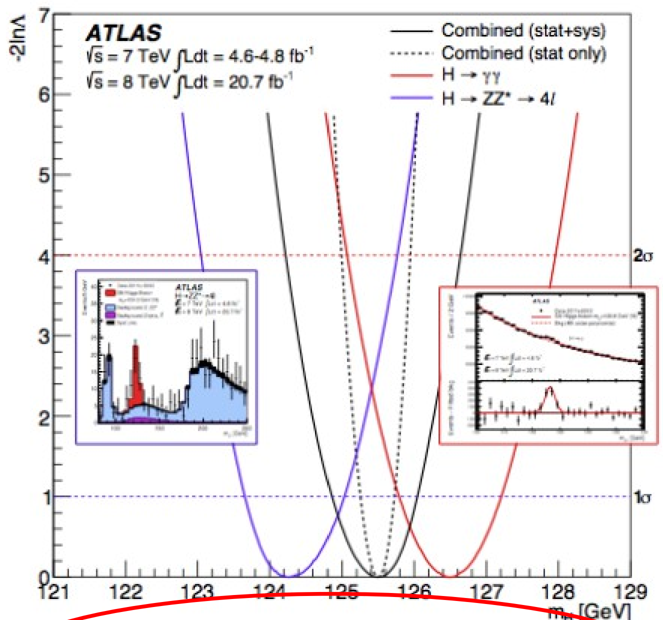


CMS: $M_H = 125.7 \pm 0.3_{stat} \pm 0.3_{sys}$ GeV

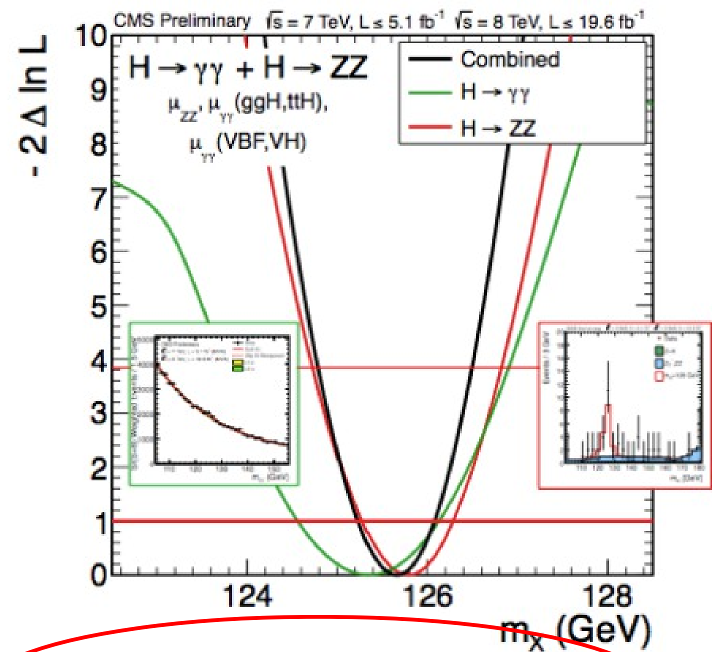
Higgs mass meassurement

- Measured in the $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$ decay channels

  Better mass precision

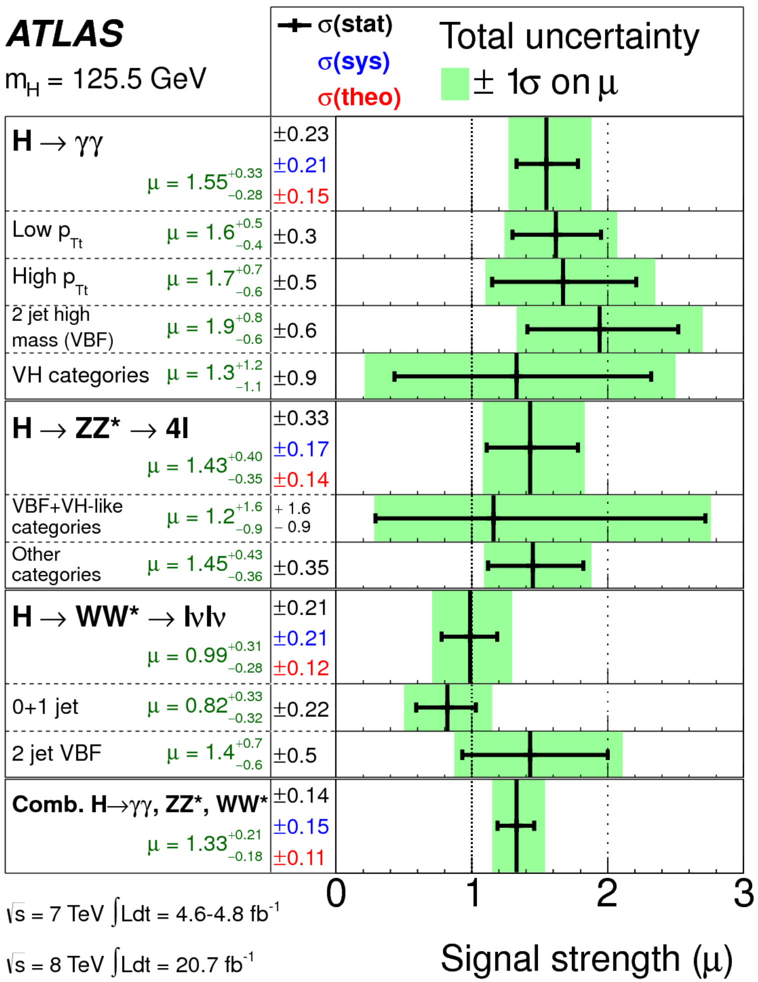


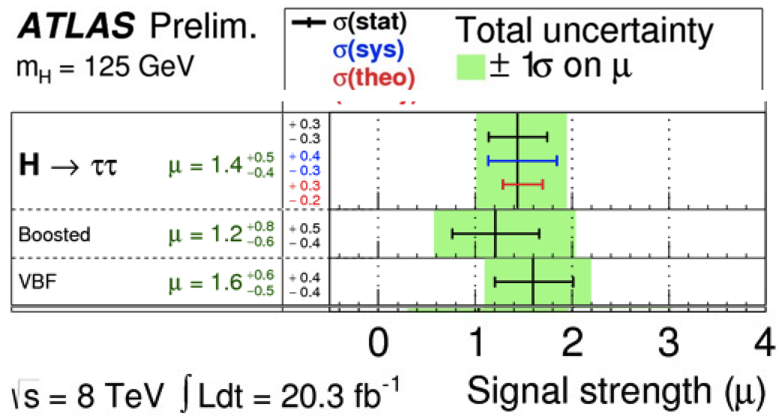
ATLAS: $M_H = 125.5 \pm 0.2_{stat} \pm 0.6_{sys}$ GeV

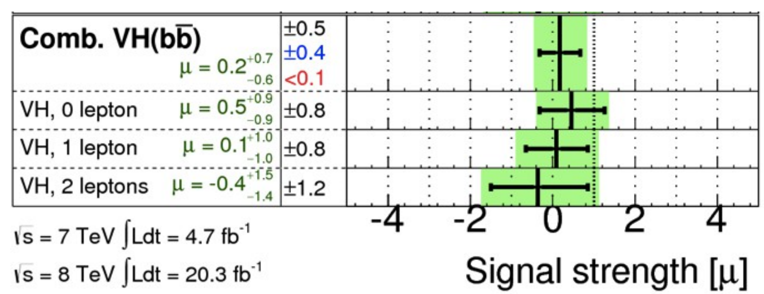


CMS: $M_H = 125.7 \pm 0.3_{stat} \pm 0.3_{sys}$ GeV

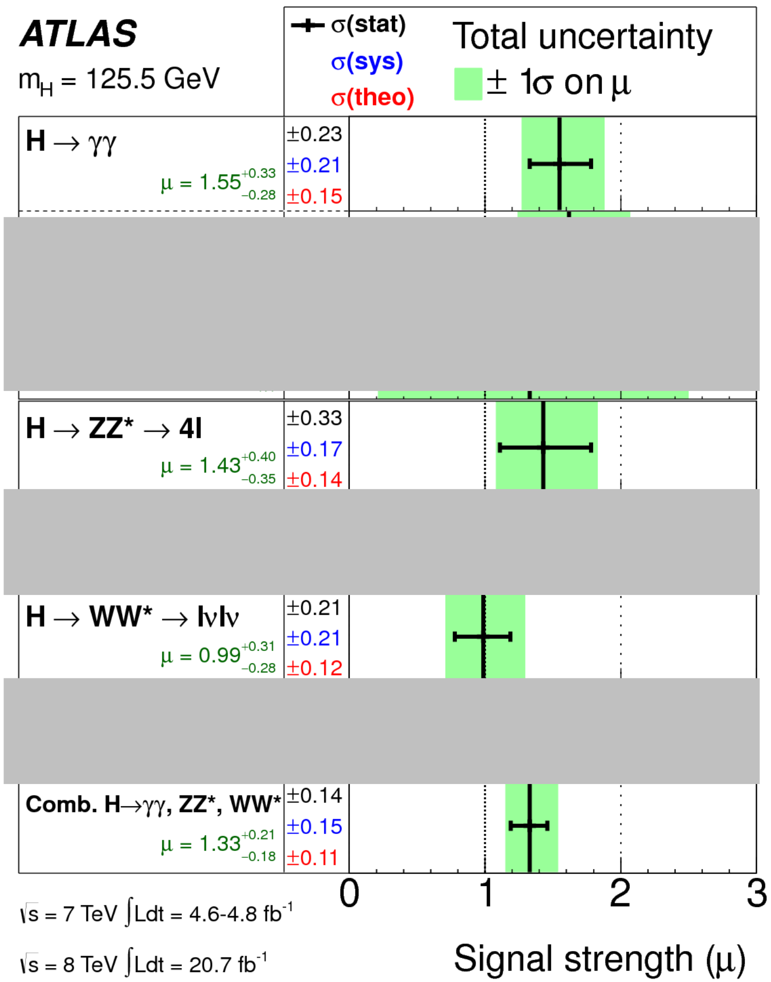
Higgs signal strength

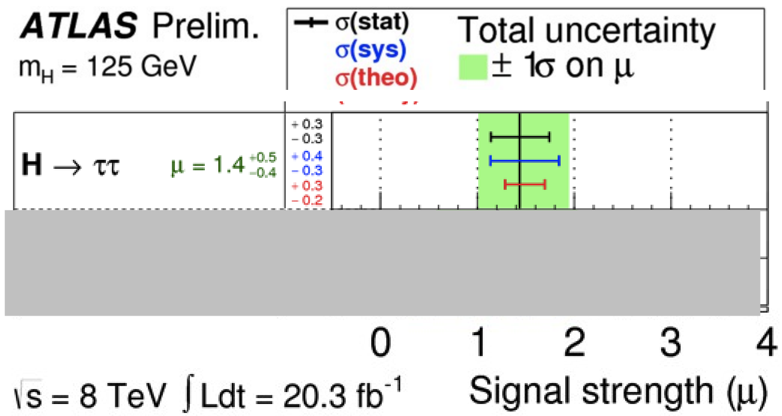


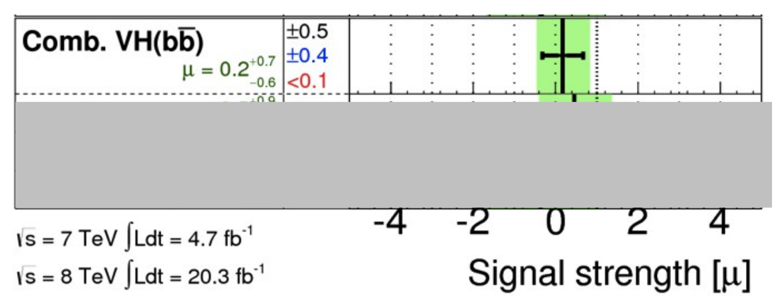




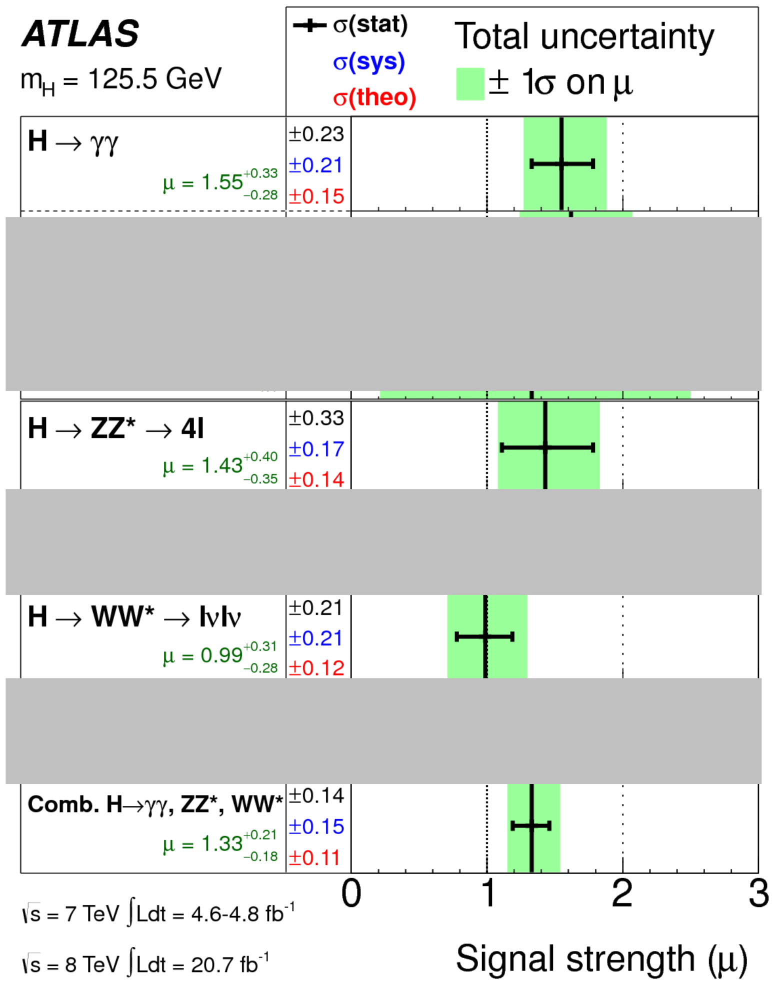
Higgs signal strength

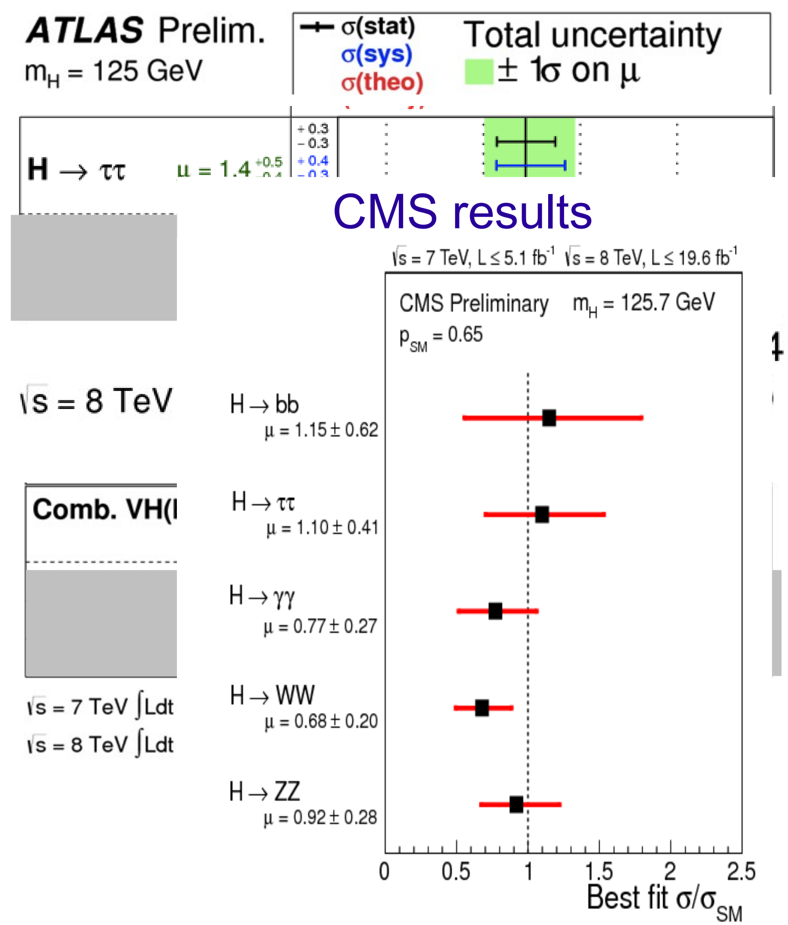






Higgs signal strength





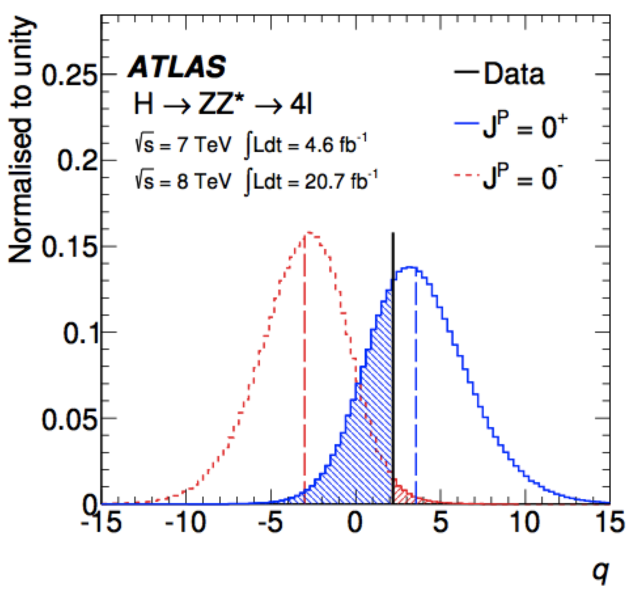
Higgs spin combination

- Three channels combined:

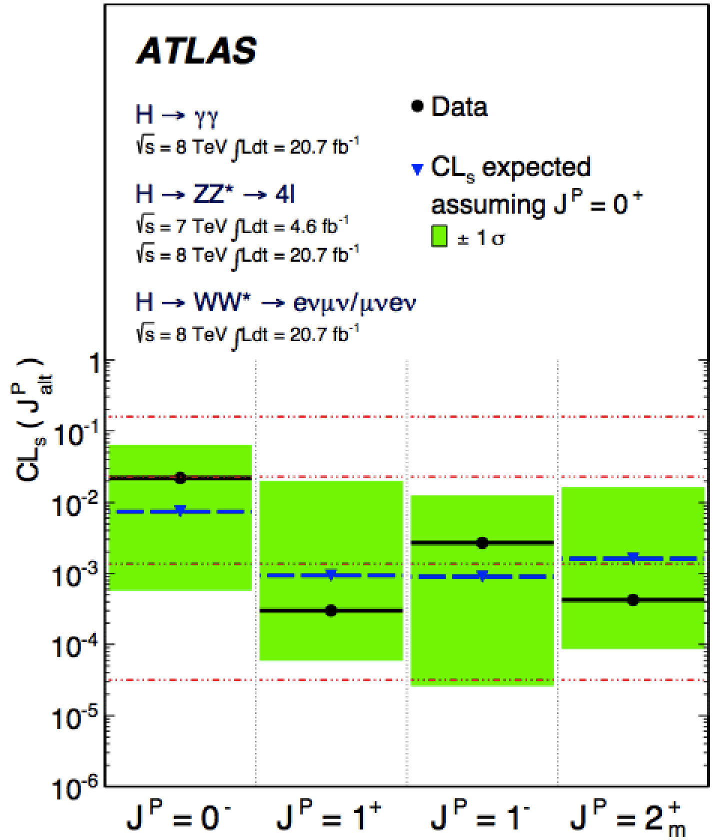
  H→γγ, H→ZZ, H→WW

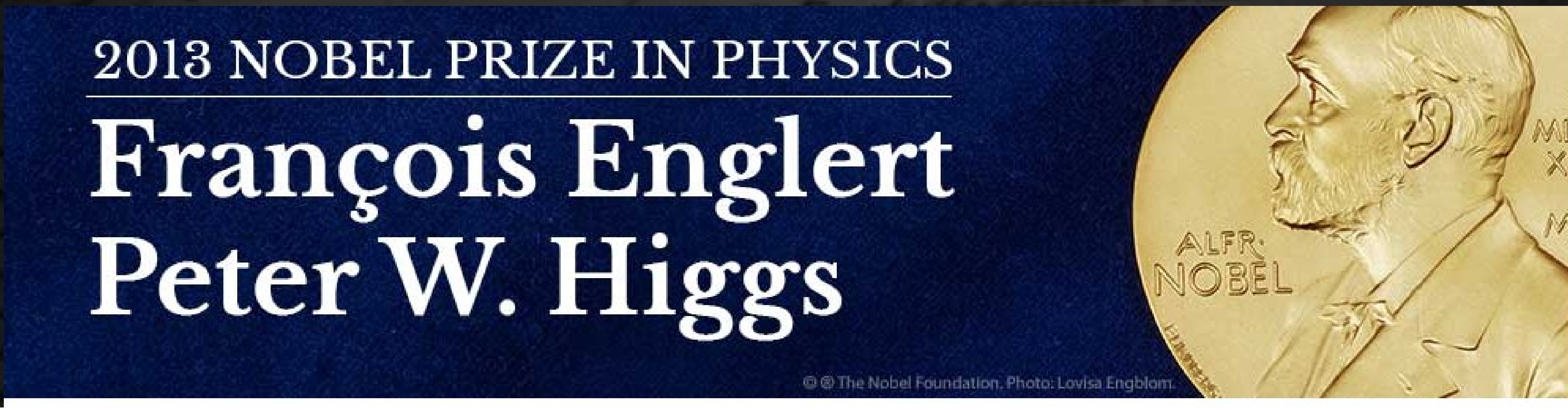
- Combine J^p sensitive variables
- Combined in a likelihood fit

$$q = \log \frac{\mathcal{L}(J^P = 0^+, \hat{\mu}_{0^+}, \hat{\hat{\theta}}_{0^+})}{\mathcal{L}(J^P_{\rm alt}, \hat{\mu}_{J^P_{\rm alt}}, \hat{\hat{\theta}}_{J^P_{\rm alt}})}, \qquad \mathrm{CL_s}(J^P_{\rm alt}) = \frac{p_0(J^P_{\rm alt})}{1 - p_0(0^+)}.$$



- CLs of alternative J^p hypothesis assuming 0^+




2013 NOBEL PRIZE IN PHYSICS
François Englert
Peter W. Higgs
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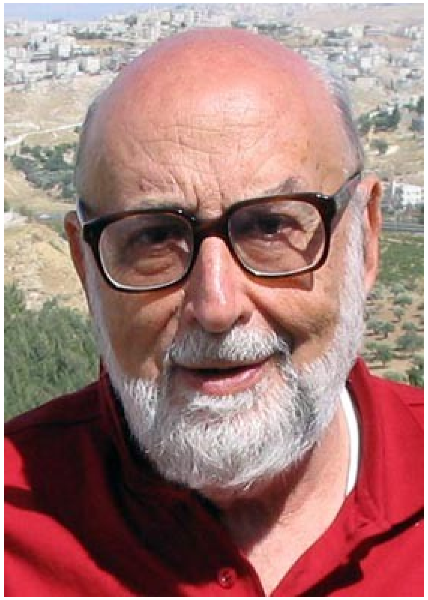
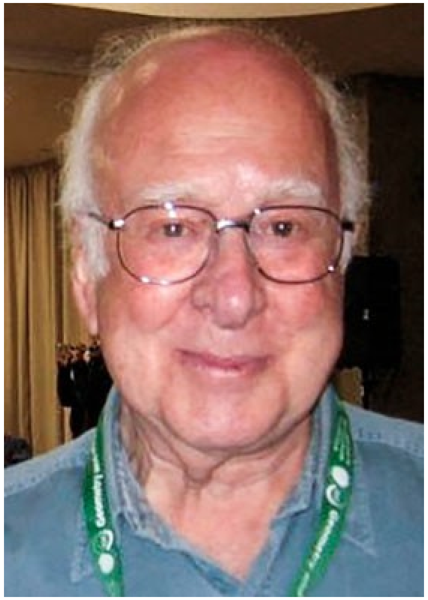
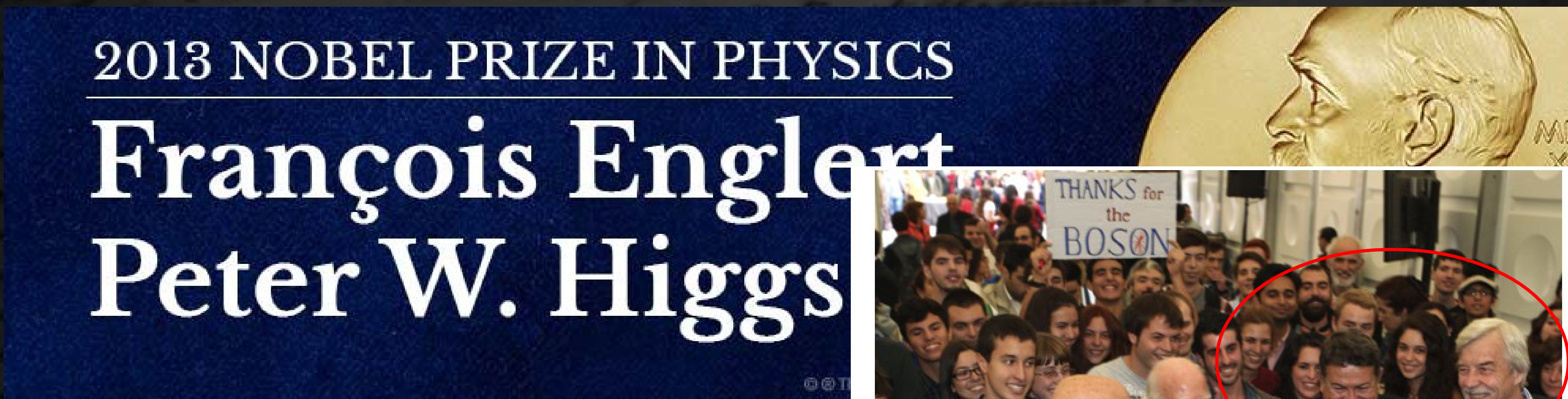
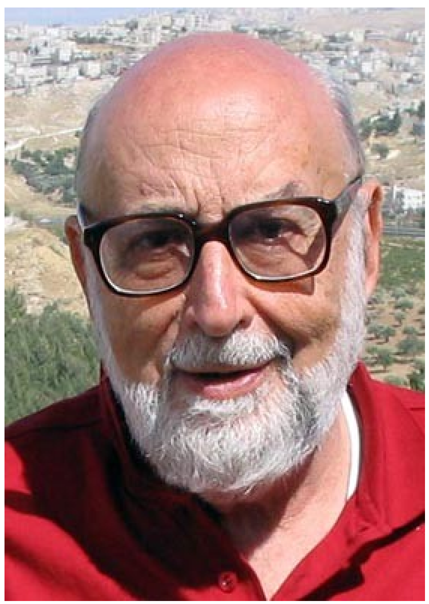








Fundación
Príncipe de Asturias

SUSY searches up to now

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

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

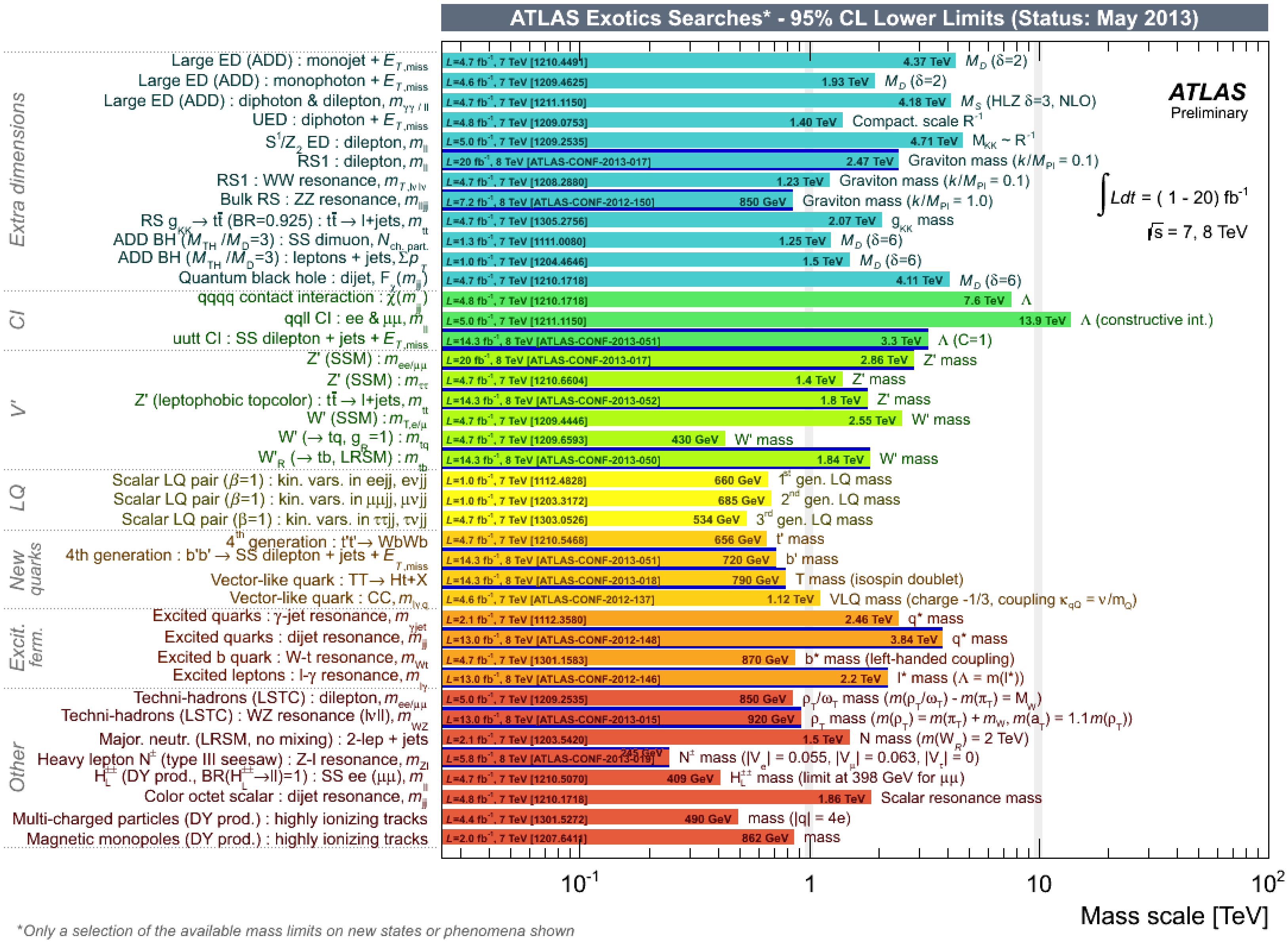
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$		Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any $m(\tilde{q})$	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	$\tilde{q}$	740 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	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	$\tan\beta$<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	$\tan\beta$ >18	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	4.8	$\tilde{g}$	1.07 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	1209.0753
	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	$m(\tilde{H})$>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	$\tilde{g}$	1.2 TeV	$m(\tilde{\chi}_1^0)$<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	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	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	ATLAS-CONF-2013-061
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	20.7	$\tilde{b}_1$	275-430 GeV	$m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(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), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-220 GeV	$m(\tilde{\chi}_1^0)$ =$m(\tilde{t}_1)$-$m(W)$-50 GeV, $m(\tilde{t}_1)$<<$m(\tilde{\chi}_1^\pm)$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$	225-525 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-065
	$\tilde{t}_1\tilde{t}_1$(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	20.7	$\tilde{t}_1$	200-610 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$	500 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$	271-520 GeV	$m(\tilde{t}_1)$=$m(\tilde{\chi}_1^0)$+180 GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	85-315 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$	125-450 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell}, \tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	180-330 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau}, \tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	600 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell}, \tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	315 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	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
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	22.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	ATLAS-CONF-2013-057
	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<$\tan\beta$<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	1 e, μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$	1.2 TeV	$m(\tilde{q})$=$m(\tilde{g})$, $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	760 GeV	$m(\tilde{\chi}_1^0)$>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$	350 GeV	$m(\tilde{\chi}_1^0)$>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	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	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
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)	1 b	Yes	14.3	sgluon	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

10^{-1} 1 Mass scale [TeV]

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

*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.

Exotics

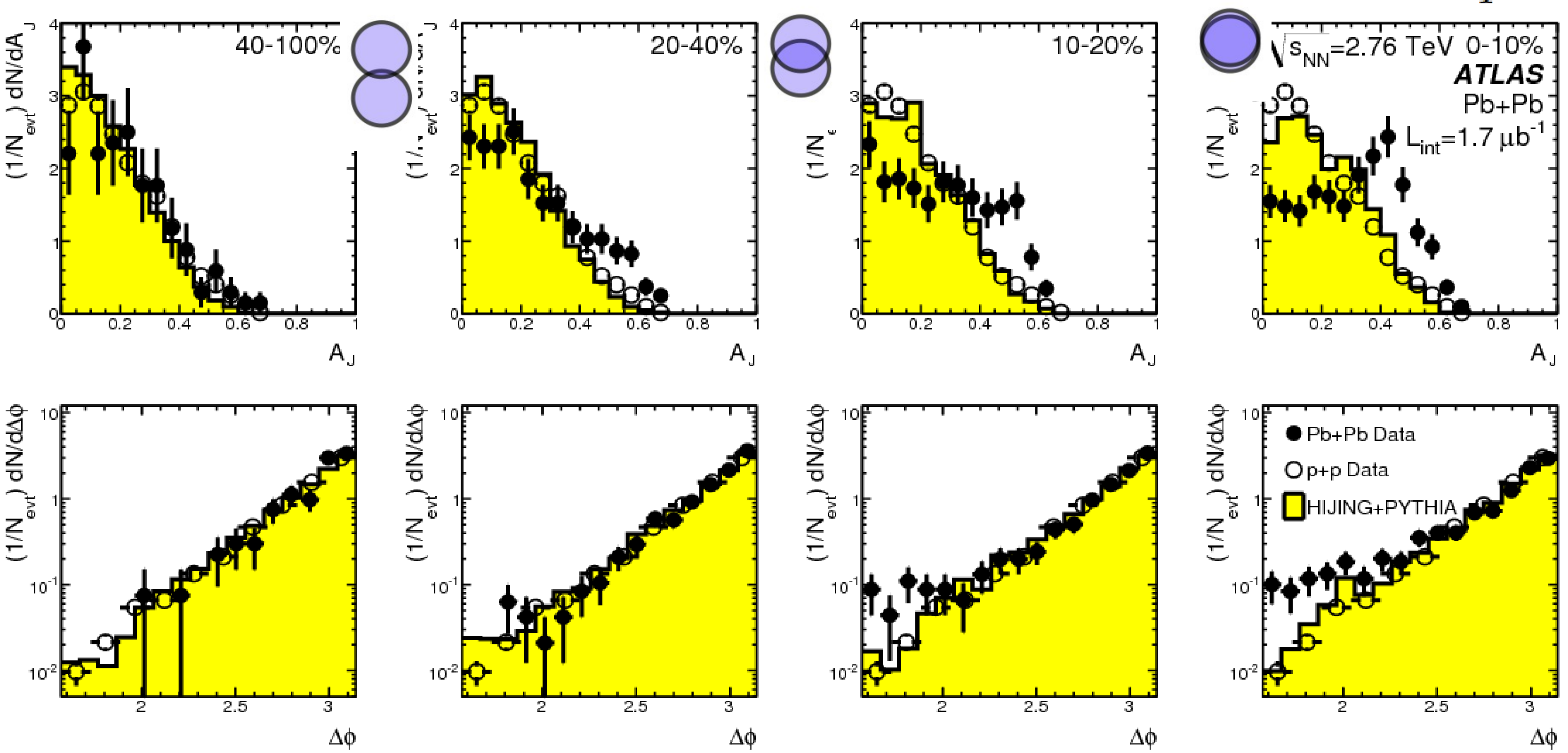


*Only a selection of the available mass limits on new states or phenomena shown

Heavy Ion Physics highlights in Run I

- Jet suppression in central Pb-Pb collisions:

$$A_J = \frac{E_T^1 - E_T^2}{E_T^1 + E_T^2}$$



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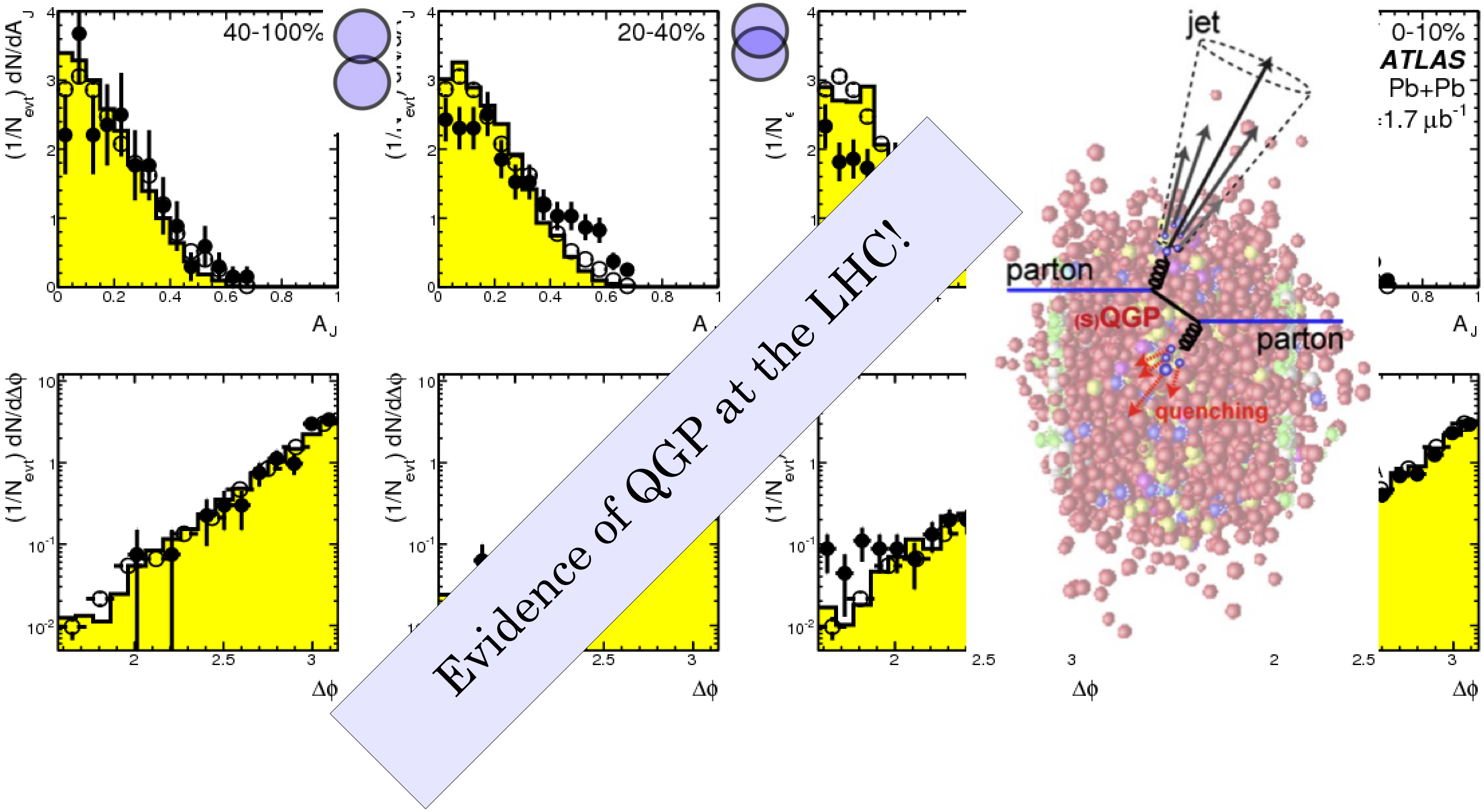
- Jet suppression in central Pb-Pb collisions:

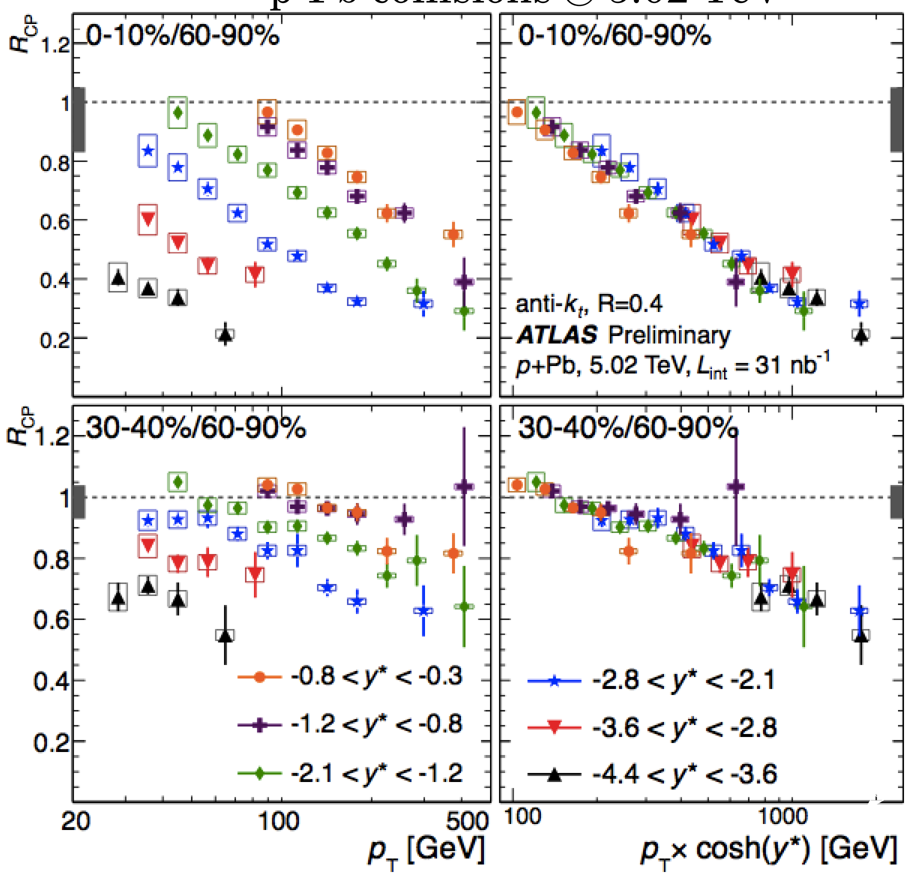
$$A_J = \frac{E_T^1 - E_T^2}{E_T^1 + E_T^2}$$



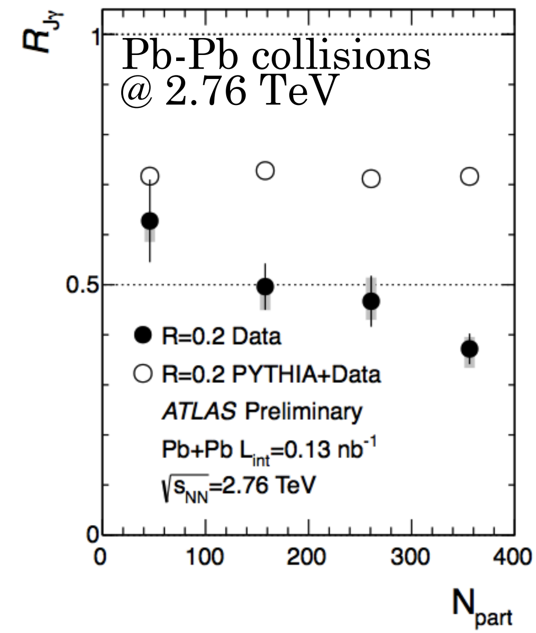
Heavy Ions highlights during Run I

- Central to periferal jet production ratio

p-Pb collisions @ 5.02 TeV



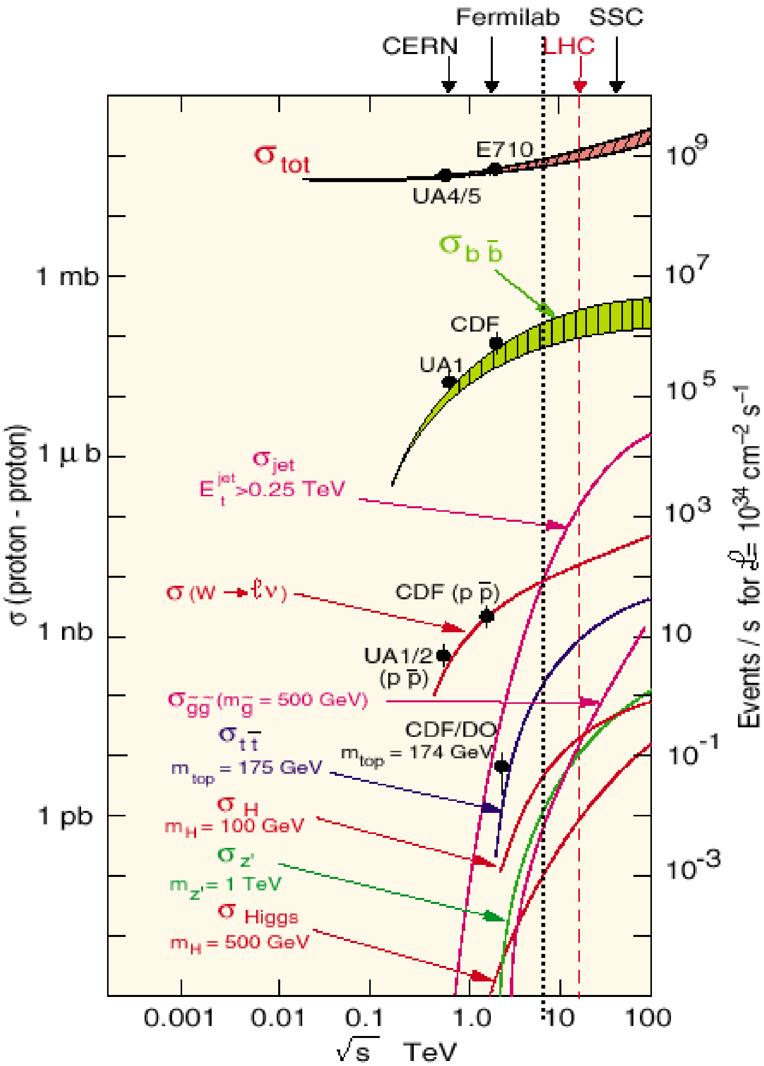
- Jet suppression in γ-jet events:



Jet suppression increases with pT and y*!

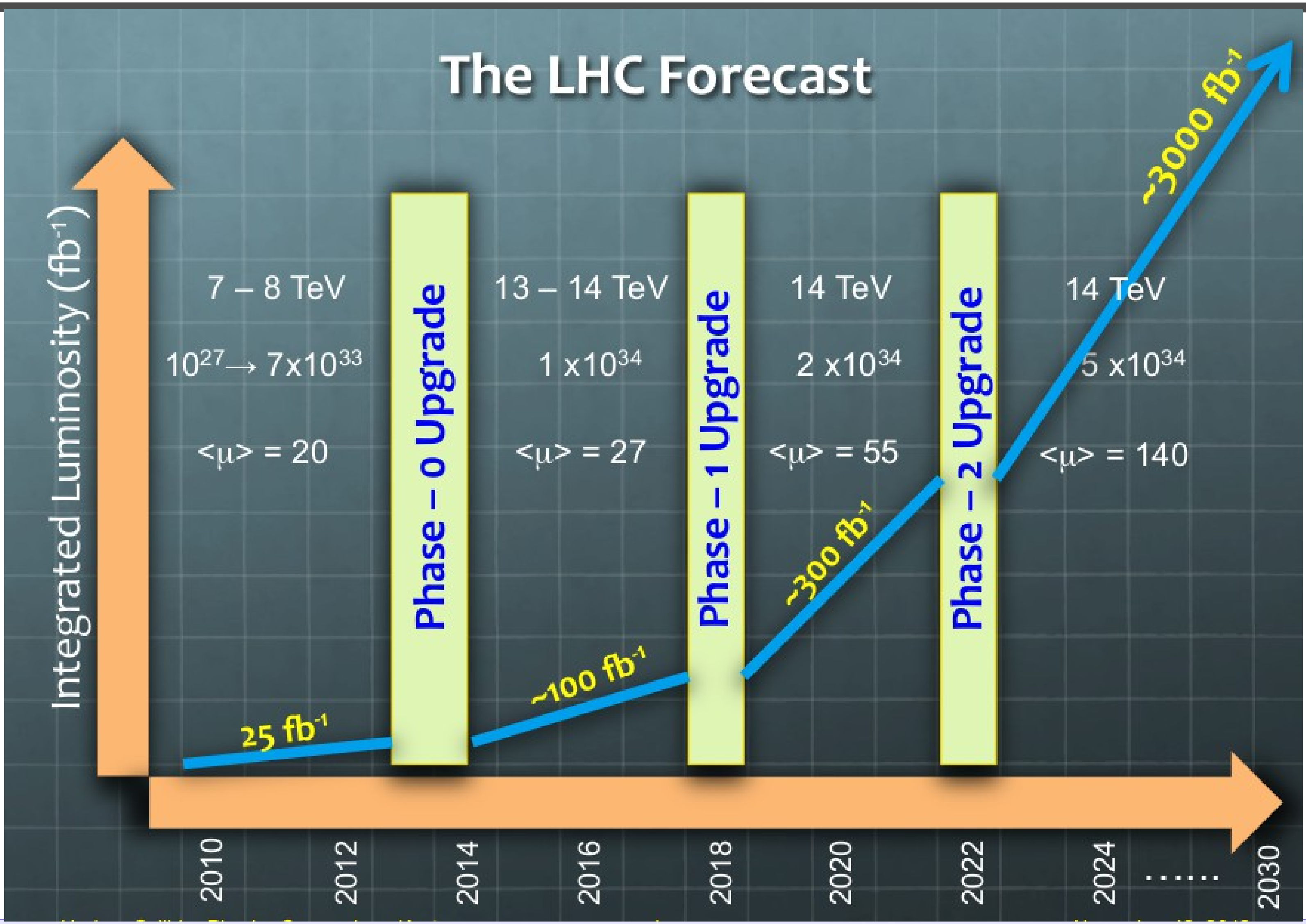
Same dependence in p!

Physics at √s=14 TeV



- Moving from 8 TeV to 14 TeV the cross sections of the following processes increase by
  - Top quark production ~ a factor 4
  - Low mass Higgs boson ~ factor 3
  - Exotic heavy particles, like Z', up to a factor 10
- Background processes, like W/Z boson production or jet cross sections increase more slowly
- The sensitivity improves considerably!

LHC Upgrade Schedule



Why do we need so much luminosity?

The SM is incomplete

96% of the universe dominated by dark matter/energy ?

- What are they?

- Why is the universe dominated by matter? ?

- Why is the Higgs mass so low? ?

- Neutrino masses? ?

- Why is gravity so weak? ?

SUSY?

Compositeness?

Tecnicolor?

Hidden sector?

Extra-dimensions?

Extended Higgs sector?

Some of the Upgrade Physics Topics

SUSY

Exotics searches

Quark Gluon Plasma

Standard Model

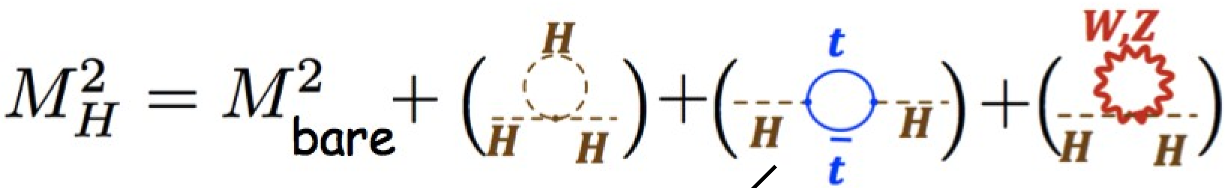
?

Higgs

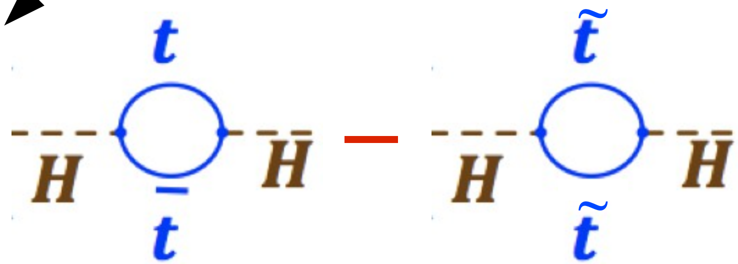
Quartic Gauge Boson Couplings

Top quark physics

The stability of the Higgs mass



$\sim m_t^2 \Lambda^2$



- Cancel out large terms:

  Stop → SUSY

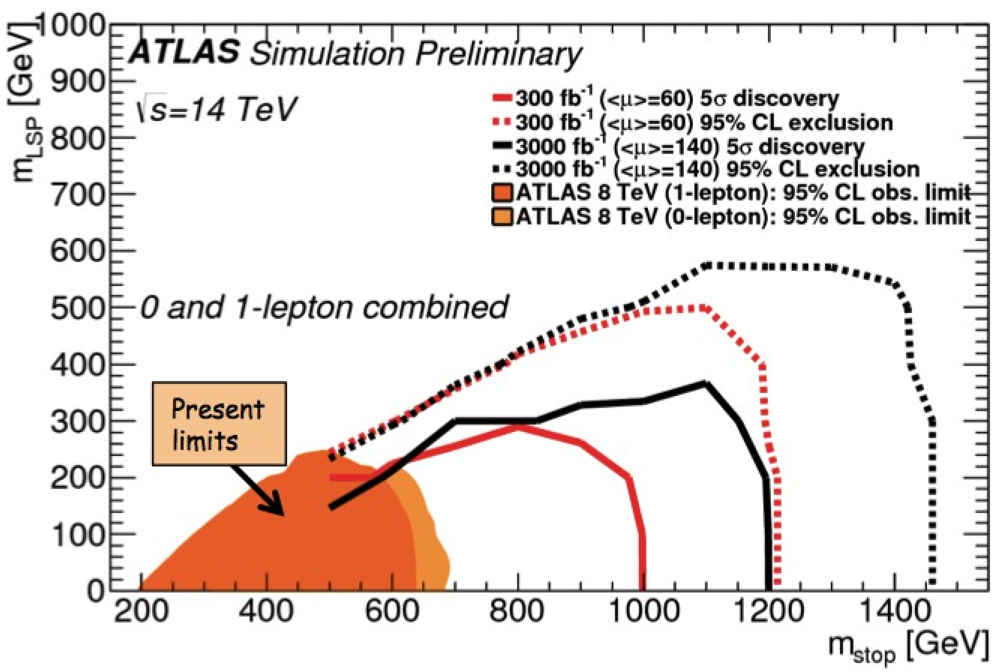
  But... stop mass cannot be much larger than the top mass

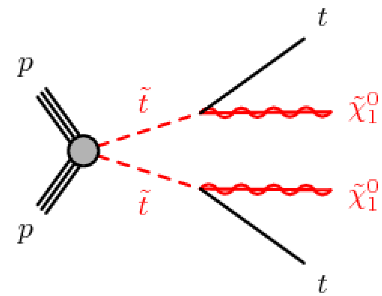
  Avoid fine tunning!

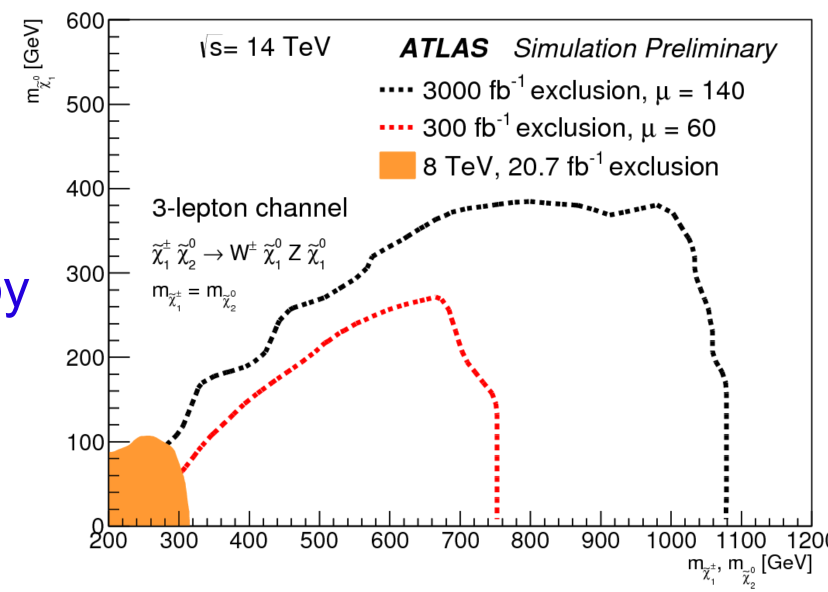
- Given the observed mass of the Higgs boson, the stop mass should not be much larger than 1-1.5 TeV

  Accessible at the LHC?

SUSY at high luminosity



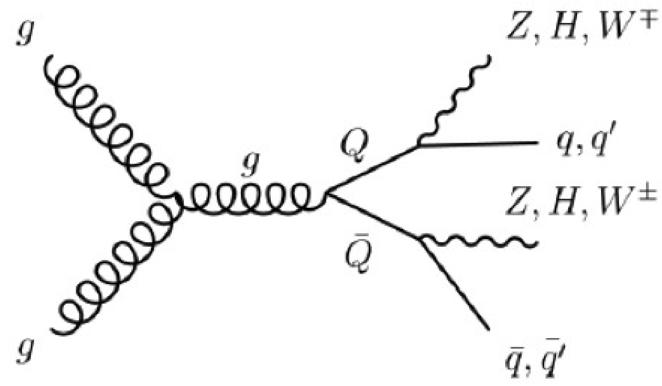


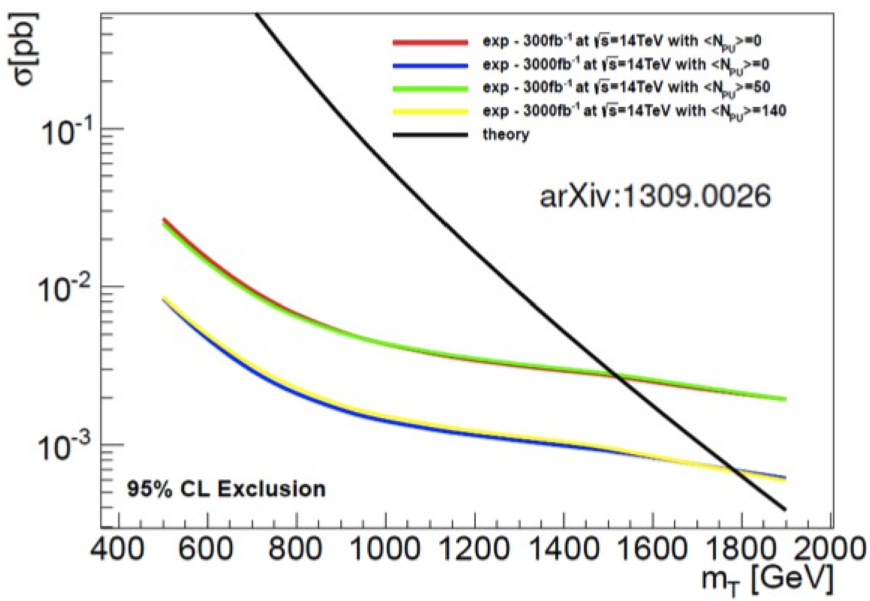


- With 3000 fb-1 we increase the reach by
  - ~200 GeV for the stop searches
  - ~300 GeV for the chargino neutralino searches

Vector-like quarks

- Vector-like quarks appear in certain models to cancel Higgs mass divergencies
  - Little Higgs, extra-dimensions
- Left-handed and right-handed components transform in the same way under SU(2)





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Quark Gluon Plasma

Standard Model

Higgs ?

Quartic Gauge Boson Couplings

Top quark physics

Higgs physics in the next 10 years

In the absence of direct evidence for new physics, the Higgs will be

- Fundamental to test the validity of the SM!
- Probe of new physics

With 10 times more data:

- Precise measurements of Higgs production/decay rates, couplings and mass.
- Search for rare/ new/ invisible decay modes.
- Measurements of tensor structure of Higgs couplings and possible CP violating contributions.
- Search for additional Higgs bosons beyond the Standard Model.

With 100 times more data

- Measurement of Higgs self-coupling becomes possible

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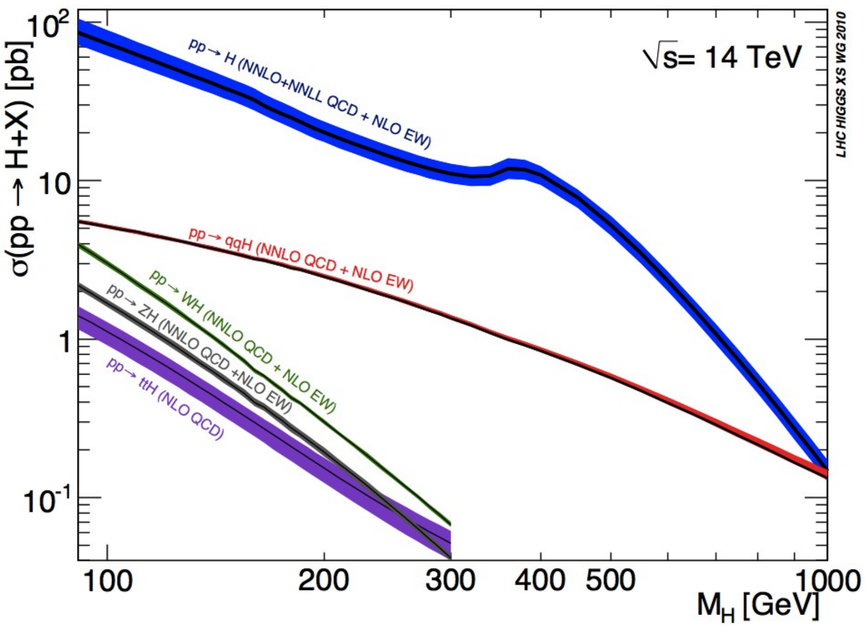
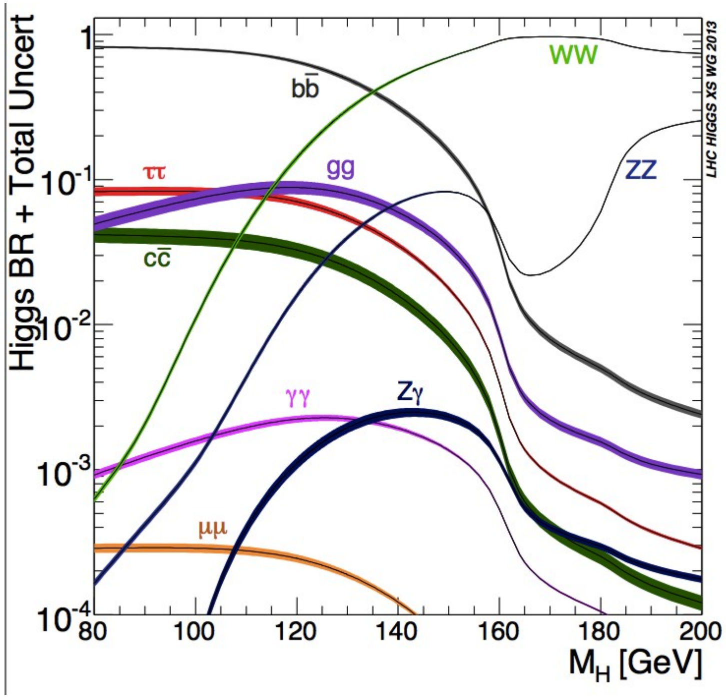
Higgs @ 14 TeV

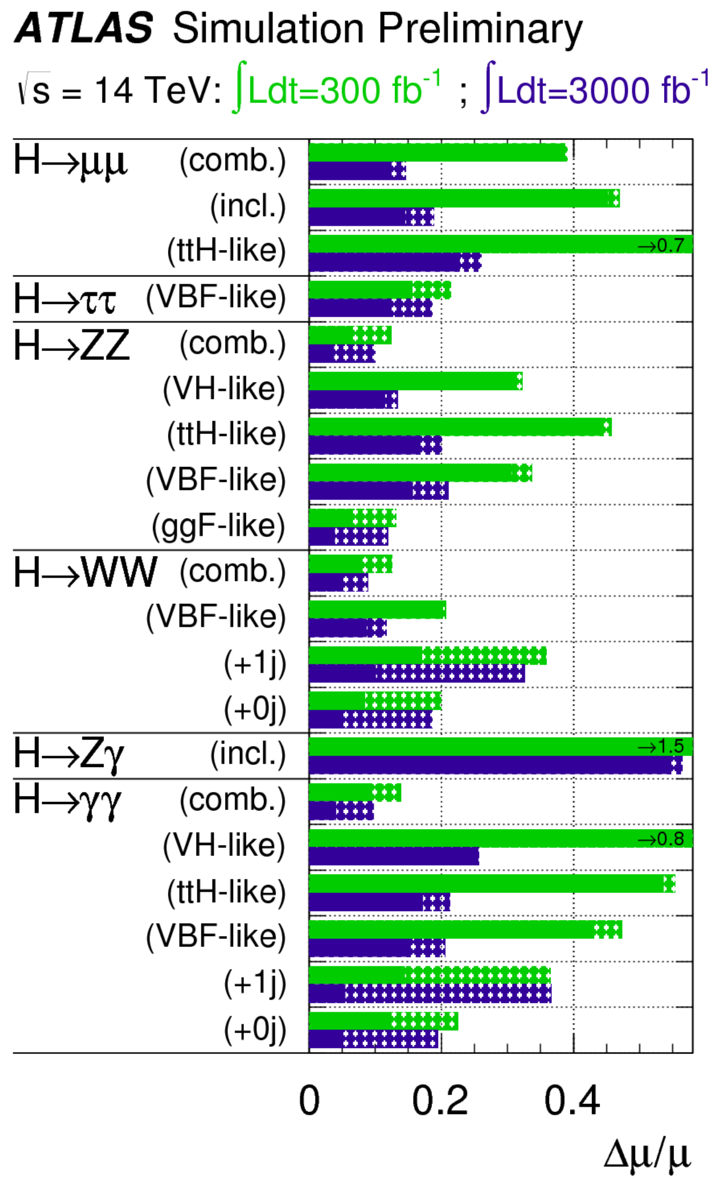




- With more data
  - Rare decays
  - Rare production mechanisms

Become accessible

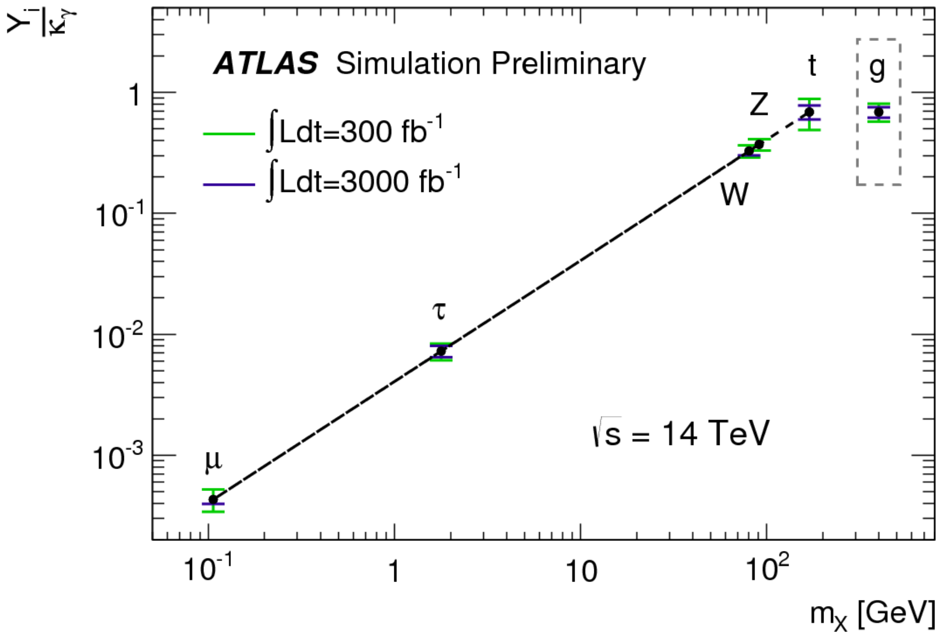
Higgs signal strength projections

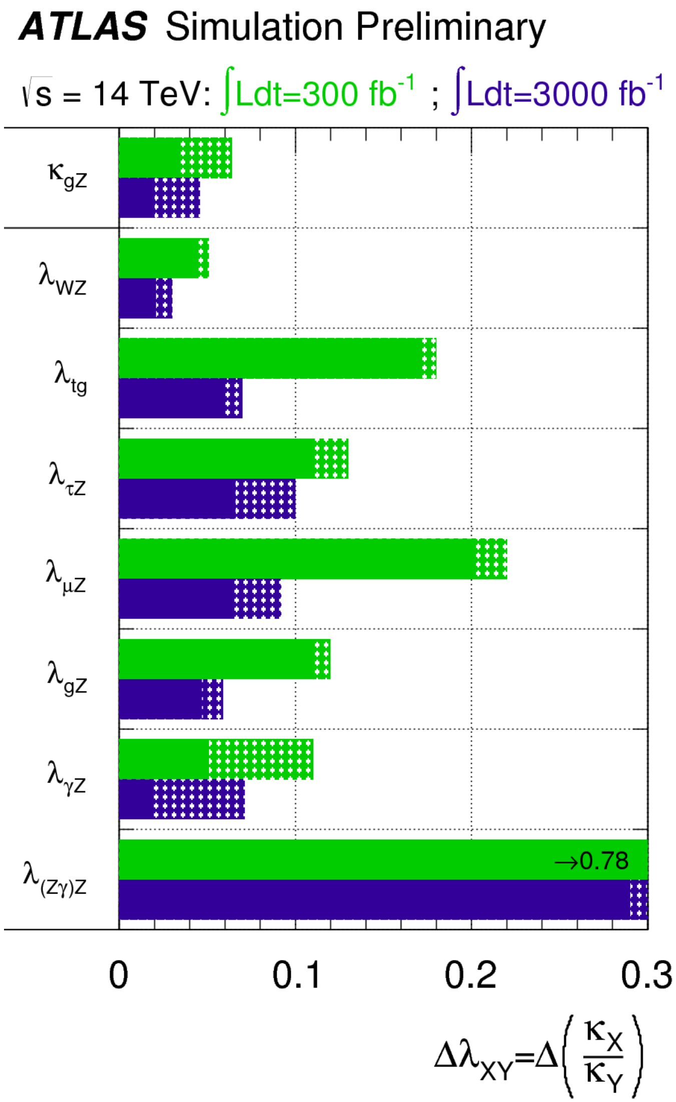


ATL-PHYS-PUB-2013-014

- Observe different production modes in each decay channel!
  - Even for $H\to\mu\mu$!
- Many channels will have uncertainties at the 10% level with 3000 fb^{-1}

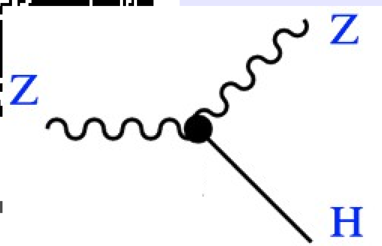
Higgs couplings projections





Snowmass 2013

Model	$\Delta\kappa_V$	$\Delta\kappa_\gamma$	$\Delta\kappa_b$
Singlet mixing	6%	6%	6%
2HDMs	1%	1%	10%
Composite Higgs	−3%	−9%	−(3-9)%
Vector top partner	−2%	1%	−2%
Decoupling MSSM	−0.0013%	<1.5%	1.6%



H→ZZ vertex tensor structure

- Generic Higgs coupling vertex to a vector boson

$$A(X \to VV) = v^{-1} \Big(g_1^{(0)} m_V^2 \epsilon_1^* \epsilon_2^*$$
$$+ g_2^{(0)} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3^{(0)} f^{*(1),\mu\nu} f_{\mu\alpha}^{*(2)} \frac{q_\nu q^\alpha}{\Lambda^2}$$
$$+ g_4^{(0)} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \Big)$$

CP-Even tree level component

CP-Even loop induced

CP-Odd contributions

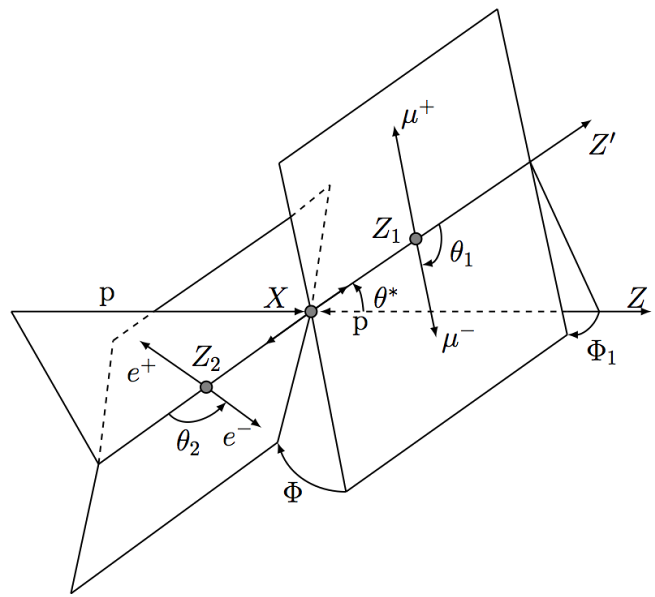
- CP-conserving tree level SM:

  g1=1, g2=g3 = g4 = 0

- CP violation in the Higgs sector:

  g4$\neq$ 0, either g1 or g2, g3 $\neq$0

- Sensitivity to new vertex contributions through angular distributions of the Higgs decay products



H→ZZ vertex tensor structure (II)

- 8D fit to distributions of kinematic variables (m_{4l}, $m_{Z_{1,2}}$, $\theta_{1,2}$, φ, φ_1, θ^*)
- Free parameters: real and imaginary part of g2, g4 relative to g1

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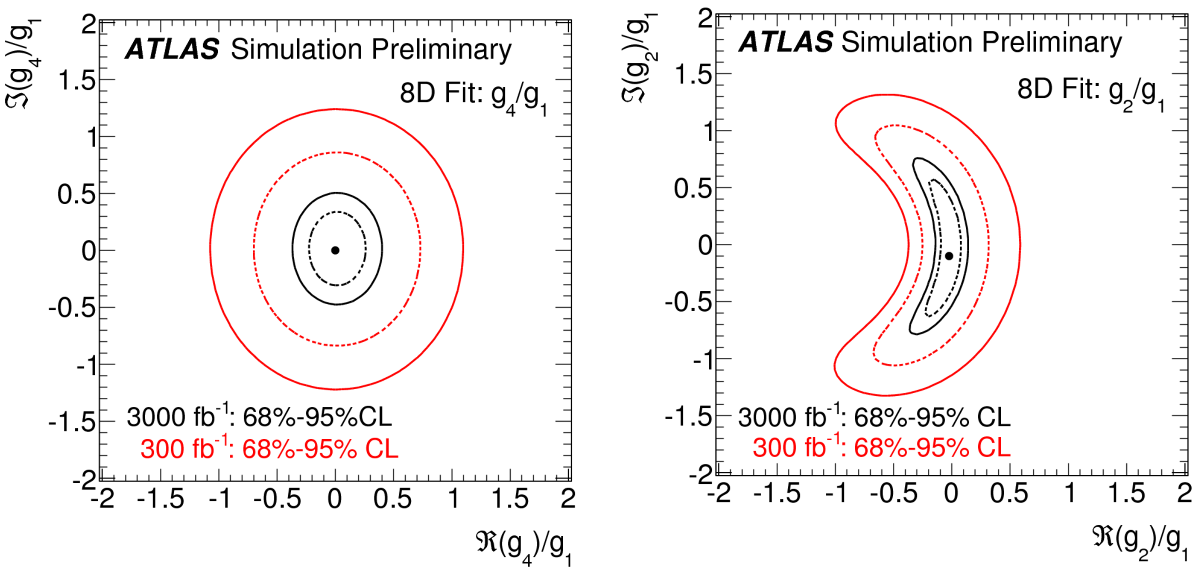


Sensitive test of the tensor structure at the HL-LHC!

Luminosity	$\lvert g_4\rvert/g_1$	$\Re(g_4)/g_1$	$\Im(g_4)/g_1$	$\lvert g_2\rvert/g_1$	$\Re(g_2)/g_1$	$\Im(g_2)/g_1$
300 fb^{-1}	1.20	(-0.88, 0.91)	(-1.02, 1.05)	1.02	(-0.84,0.44)	(-1.19, 1.18)
3000fb^{-1}	0.60	(-0.30, 0.33)	(-0.39, 0.42)	0.60	(-0.30,0.11)	(-0.71, 0.68)

High mass Higgs searches

- Many extensions of the SM predict more than one Higgs
- 2 Higgs Doublet Model

  Add one more complex doublet

  Predicts 5 Higgs bosons:

    2 CP-even (h, H)

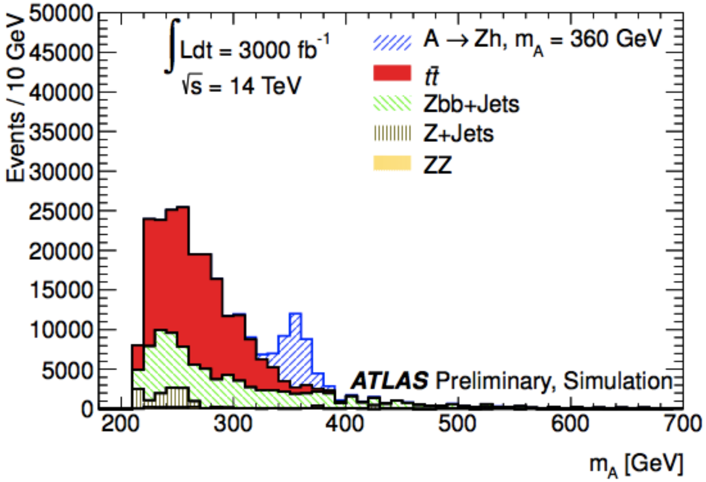
    1 CP-odd (A),

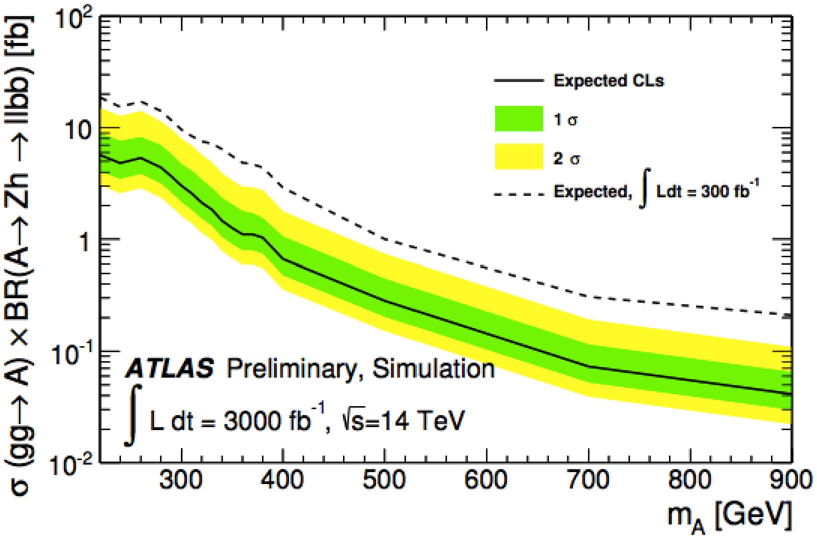
    2 charged ($H^{\pm}$)
- Parameterized in terms of $\tan\beta \equiv v_2/v_1$ and α = mixing angle CP even bosons
- Modified couplings to h (SM-like Higgs boson):

Coupling strength	Type I	Type II	Type III	Type IV
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
κ_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$

High mass Higgs searches: A→Zh→llbb

ATLAS-PHYS-PUB-2013-016





- 95% CL upper limits on σ×BR:

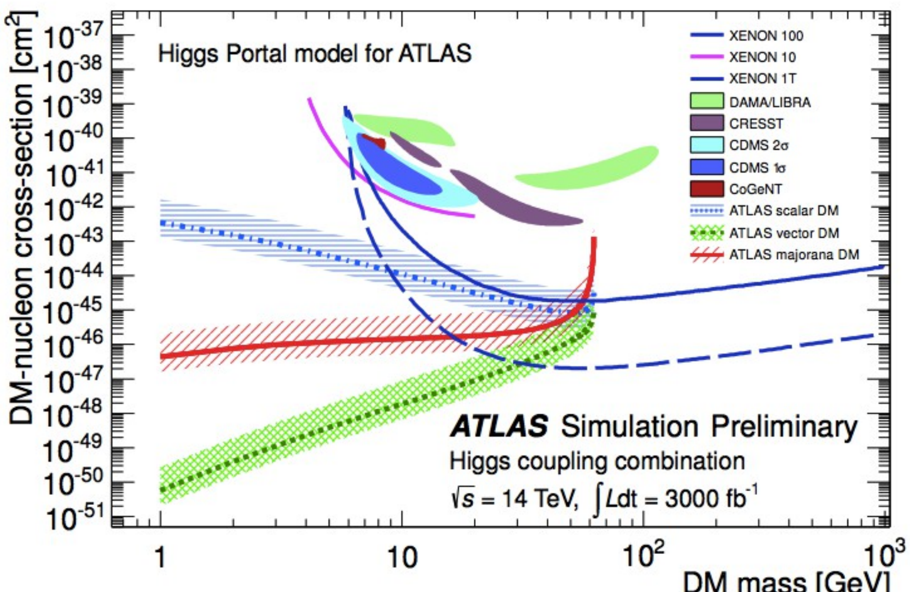
  Between 5-0.07 fb in the mass range between 200-900 GeV

  with 3000 fb^{-1} of integrated luminosity

- 3-4 worse limits with only 300 fb^{-1} of accumulated luminosity

Higgs as a portal to dark matter

- WIMP: assumed to interact very weakly with visible matter, except for the Higgs boson
- Search for invisible Higgs decays
  - Assume couplings to other known particles as in SM
- Interpreted in terms of dark matter particles coupling only to Higgs sector
  - Exclusion limits dependent on WIMP spin
  - WIMP mass < $2m_H$



ATL-PHYS-PUB-2013-015

Some of the Upgrade Physics Topics

SUSY

Exotics searches

Quark Gluon Plasma

Higgs

?

Standard Model

Quartic Gauge Boson Couplings

Top quark physics

Quartic Gauge Boson Couplings

- Non-abelian structure of the Electroweak interaction in the SM implies the existence of triple and quartic gauge boson couplings

Weak force

$$L_{WEAK} = -1/4F^{(a)}{}_{\mu\nu}F^{(a)\mu\nu} + i\bar{\Psi}_L(\gamma^\mu(D_\mu) - m)\Psi_L$$

where:

$D_\mu = \partial_\mu + igT^aW^a{}_\mu$

a is sum over 3 gauge bosons

T^a = 0.5*Pauli spin matrices (PDG!)

$W^a{}_\mu$ is weak gauge boson field

$F^{(a)}{}_{\mu\nu} = \partial_\mu W^a{}_\nu - \partial_\nu W^a{}_\mu - g_s\varepsilon_{abc}W^b{}_\mu W^c{}_\nu$

ε_{abc} = SU(2) structure constants

$F_{\mu\nu}F^{\mu\nu}$ contains triple, quartic couplings

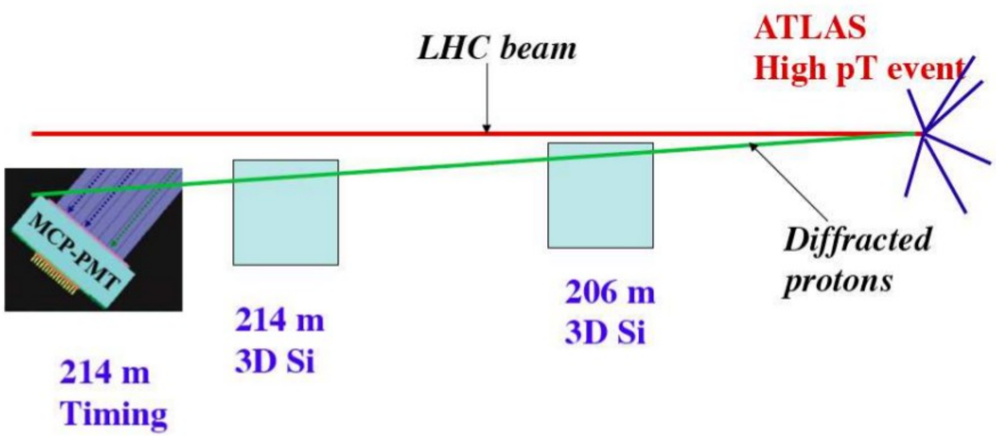
Quartic Gauge Boson Couplings

- In the SM, triple and quartic gauge boson couplings constrained by the symmetries of the Lagrangian
- Very precise predictions:
  - WWWW, γγWW, WWZZ exist
  - ZZZZ not present as quartic gauge boson coupling, but mediated by the Higgs at tree level
  - γγZZ: only at loop level
- WWWW:
  - Related to the EW Symmetry Breaking mechanism:
    - Longitudinal modes are Goldstone bosons

Beyond the SM physics can modify the quartic gauge boson couplings

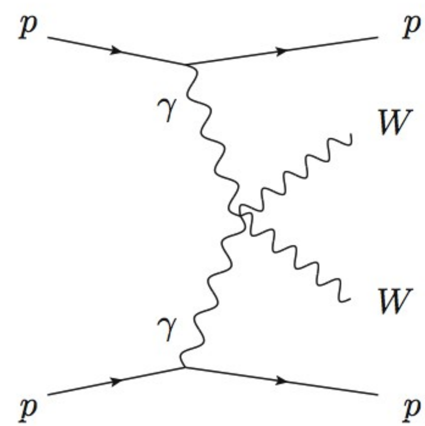
- Extra-dimensions

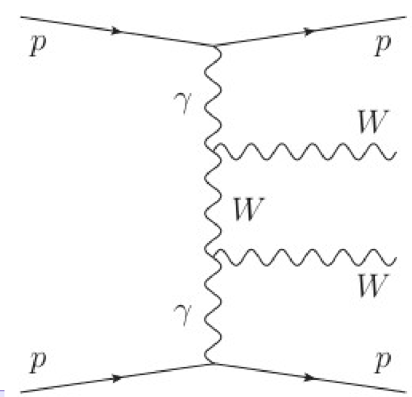
AFP



- Tag and measure protons at ±210 m
- Radiation hard edgeless 3D Silicon detectors
- 10 ps timing detectors
    - Allow running in high pile up conditions
    - Associate protons with correct primary vertex

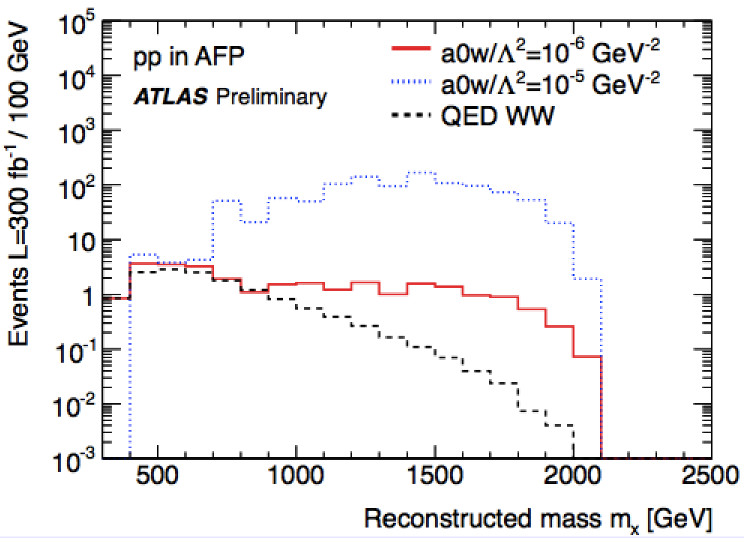
- Forward proton tagging converts the LHC in a γγ collider!

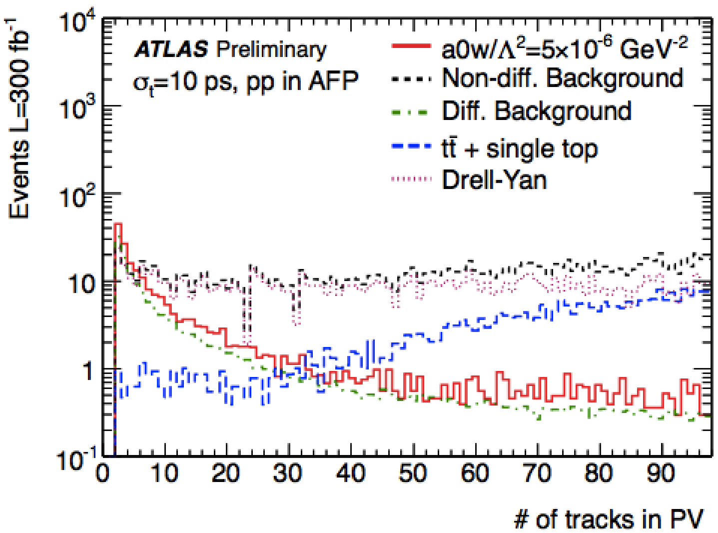




Search for γγWW anomalous couplings

- Reach on anomalous couplings studied using a full simulation of the ATLAS detector, including all pile-up effects; only leptonic decays of Ws are considered
- Signal appears at high lepton p_T and dilepton mass (central ATLAS) and high diffractive mass (reconstructed using forward detectors)
- Cut on the number of tracks fitted to the primary vertex: very efficient to remove remaining pile-up after requesting a high mass object to be produced (for signal, we have two leptons coming from the W decays and nothing else)



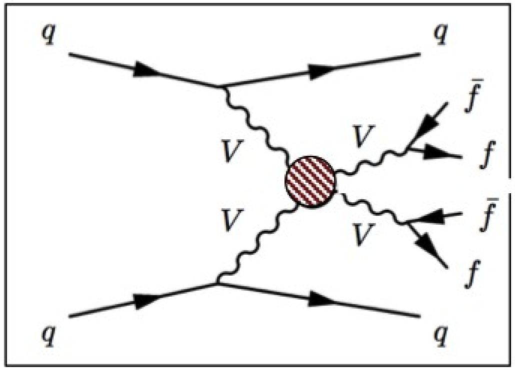


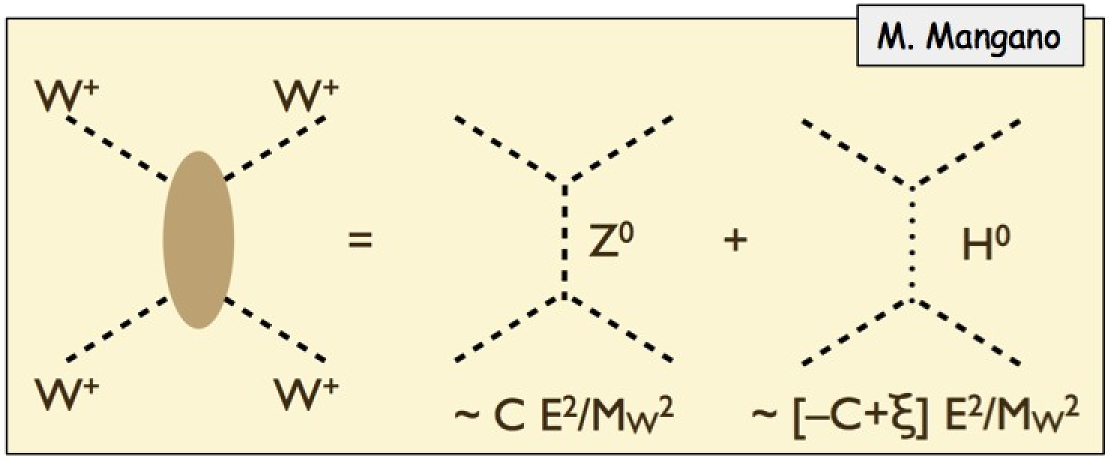
Expected limits in QGBC

Couplings	OPAL limits [GeV^{-2}]	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1} 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	5.4 10^{-6} (2.7 10^{-6})	2.6 10^{-6} (1.4 10^{-6})
a_C^W/Λ^2	[-0.052, 0.037]	2.0 10^{-5} (9.6 10^{-6})	9.4 10^{-6} (5.2 10^{-6})
a_0^Z/Λ^2	[-0.007, 0.023]	1.4 10^{-5} (5.5 10^{-6})	6.4 10^{-6} (2.5 10^{-6})
a_C^Z/Λ^2	[-0.029, 0.029]	5.2 10^{-5} (2.0 10^{-5})	2.4 10^{-5} (9.2 10^{-6})

- Improve LEP sensitivity by more than 4 orders of magnitude with 30/200 fb^{-1} at LHC, and of D0/CDF results by ~2 orders of magnitude
- AFP improves the results obtained with central detector only by 2 orders of magnitude
- Reaches the sensitivity needed for extra-dimensions models!!

Vector boson scattering

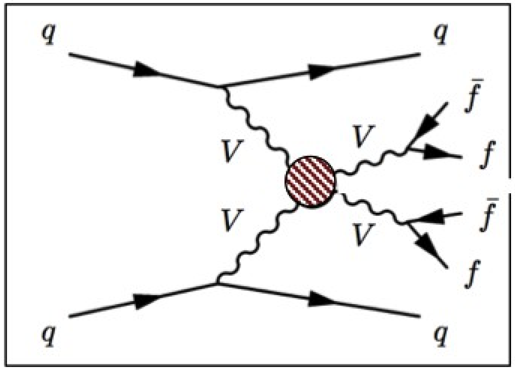




- Divergence in WWWW scattering was the original motivation to introduce the Higgs mechanism
- Measure this process: *closure* test of the SM

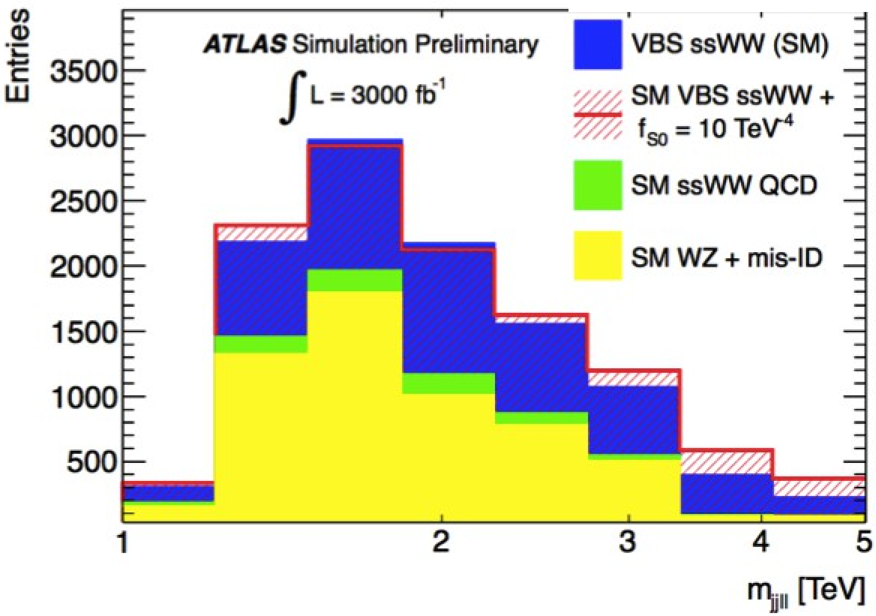
  Sensitive also to new physics: additional Higgs bosons, other scalars, new heavy bosons, ...

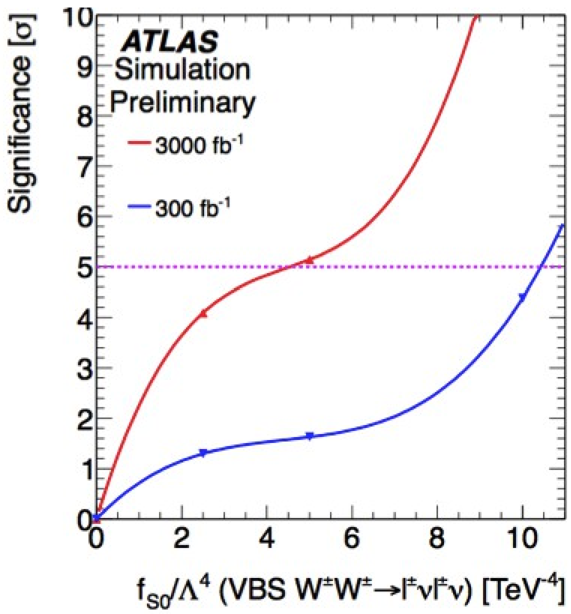
Same sign WW scattering



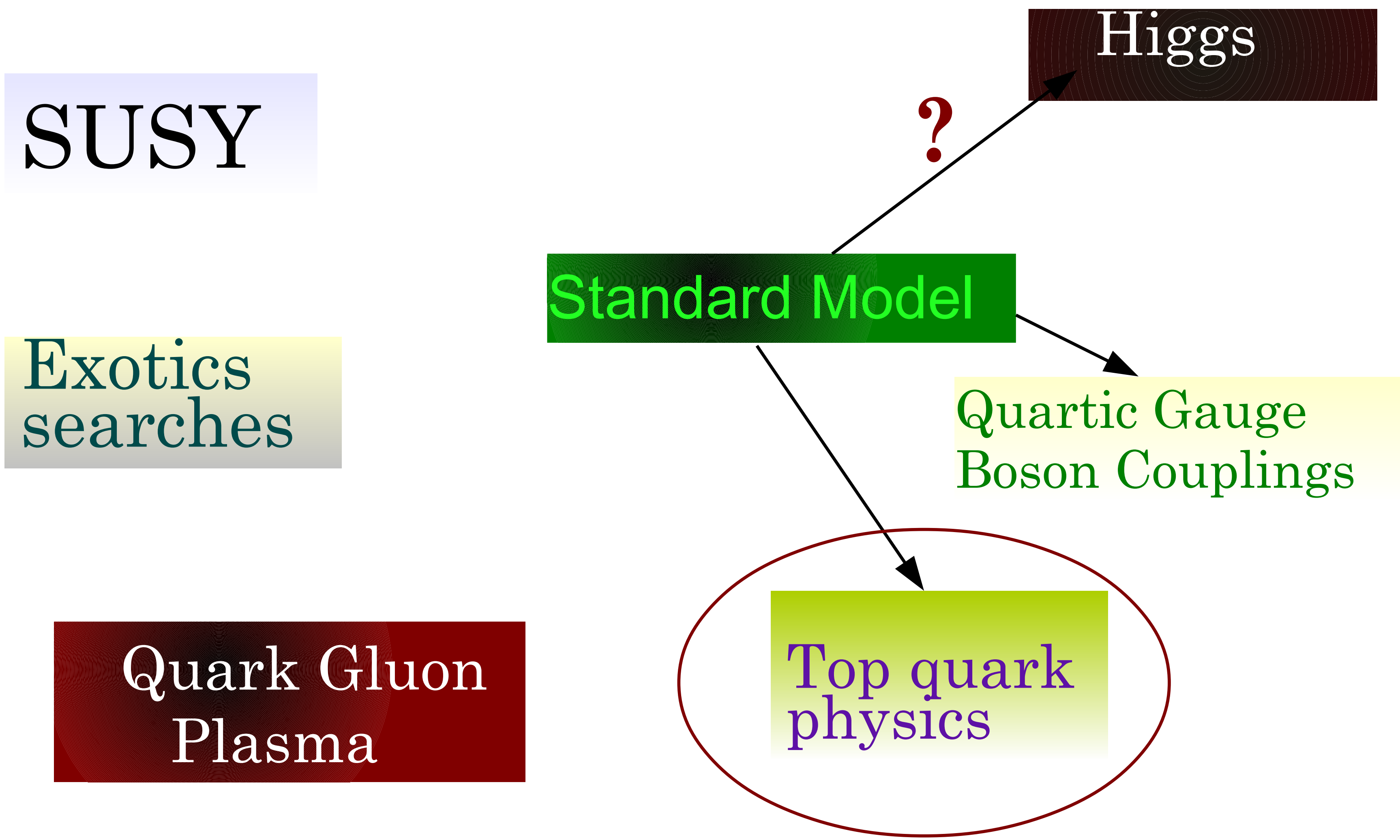
- Experimental signature
  - Two leptons (same sign), large missing E_T
  - Two forward/backward jets with m_{jj} > 1 TeV
- Sensitive to dimension 8 operators

$$\mathcal{L}_{S,0} = \frac{f_{S0}}{\Lambda^4}[(D_\mu\phi)^\dagger D_\nu\phi)] \times [(D^\mu\phi)^\dagger D^\nu\phi)]$$

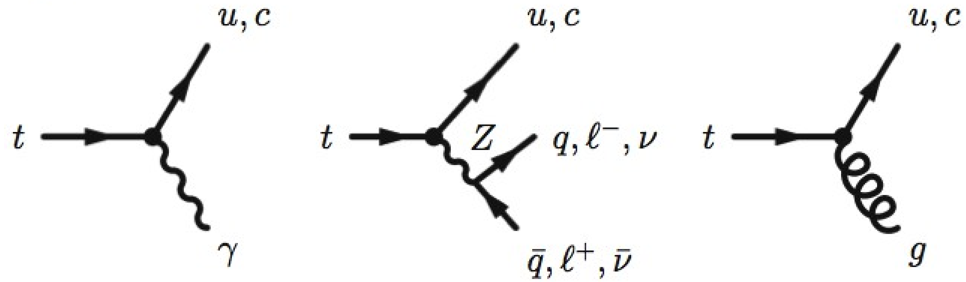




Some of the Upgrade Physics Topics



FCNC in top quark decays



BR($t \to$ FCNC) in several models:

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY	TC2	RS
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-9}$
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-4}$	$\sim 10^{-5}$
$t \to qg$	$\sim 10^{-12}$	$\sim 10^{-7}$	$\sim 10^{-4}$	$\sim 10^{-8}$	$\sim 10^{-5}$	$\sim 10^{-4}$	$\sim 10^{-4}$	$\sim 10^{-9}$

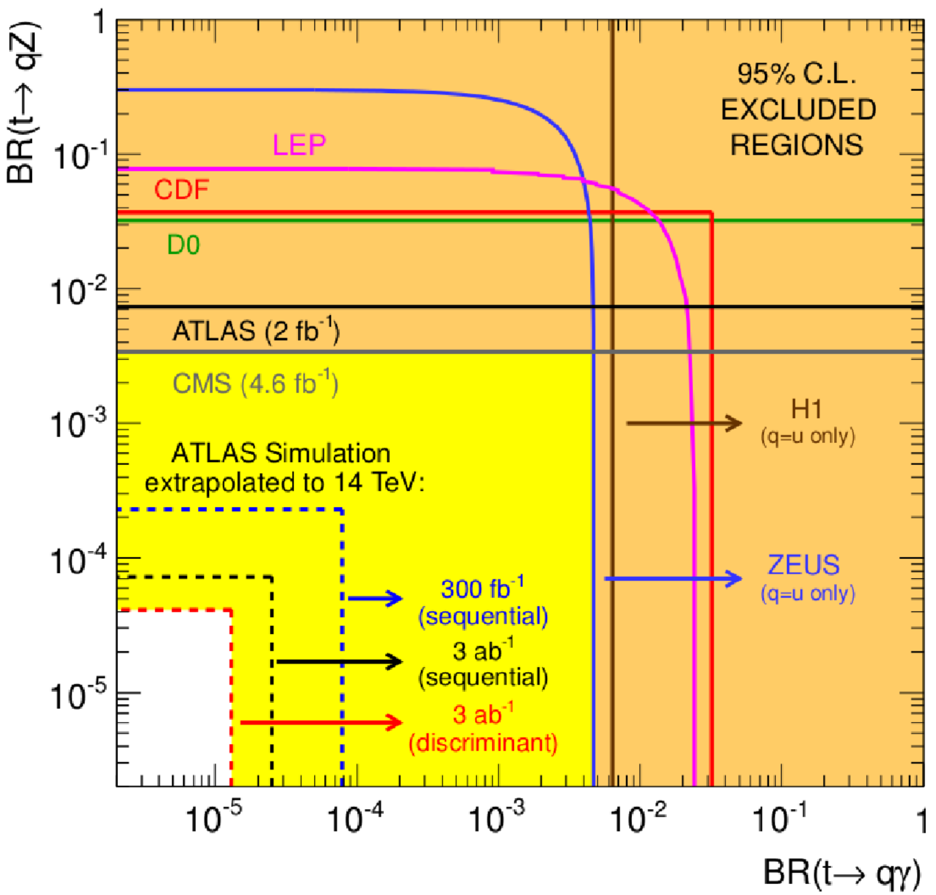
Acta Phys. Polon. B35 (2004) 2695–2710; Phys. Rev. D68 (2003) 015002; Phys. Rev. D 75 (2007) 015002

present experimental limits:

	LEP	HERA	Tevatron	LHC
BR($t \to q\gamma$)	2.4%	0.47 %	3.2 %	—
BR($t \to qZ$)	7.8%	30%	3.2 %	0.05%
			2.0×10^{-4} (tug)	5.7×10^{-5} (tug)
BR($t \to qg$)	17%	13%	3.9×10^{-3} (tcg)	2.7×10^{-4} (tcg)

FCNC in top quark decays

- With 300 fb^{-1} ATLAS will improve the sensitivity to FCNC in top quark decays by ~ two orders of magnitude
- With 3000 fb^{-1} limits in the BR can reach ~10^{-5}-5×10^{-5}



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Heavy Ion Physics during the Upgrade

- Not only the pp physics will benefit from the Upgrade!

Run I:

year	system	$\sqrt{s_{NN}}$ (TeV)	L_{int}
2010	**Pb-Pb**	**2.76**	**~ 10 μb^{-1}**
2011	pp	2.76	~ 250 nb^{-1}
2011	**Pb-Pb**	**2.76**	**~ 150 μb^{-1}**
2013	p-Pb	5.02	~ 30 nb^{-1}
2013	pp	2.76	~ 5 pb^{-1}

- Run II: 5-10 times higher stats!

  Pb-Pb ~1nb^{-1} @ $\sqrt{s_{NN}}$ ~ 5.1 TeV

  p-Pb (at increased luminosity?)

  pp reference at Pb-Pb energy (5.1 TeV)

- Extend current results to larger energies. Explore new observables

- Run III, IV: experiments request

  >10 nb^{-1} Pb-Pb

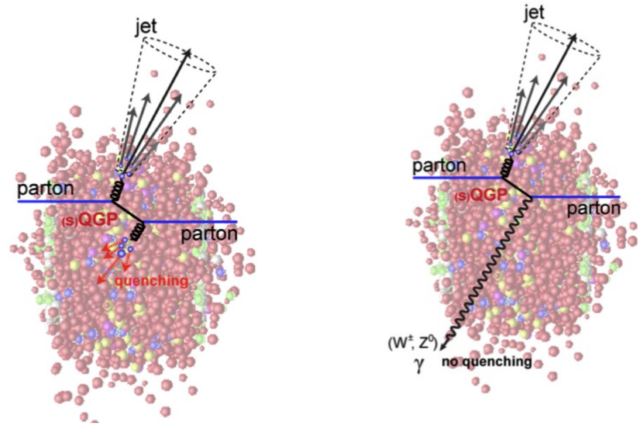
  p-Pb high luminosity, pp reference 5.5 TeV,

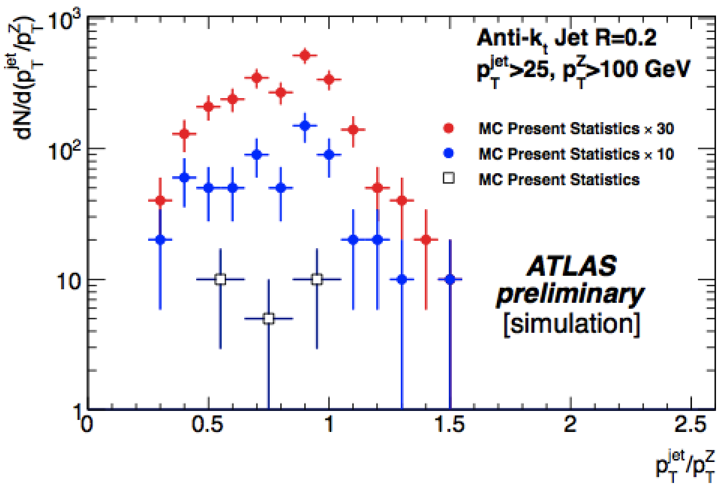
  possibly light ions (e.g. Ar-Ar)

Heavy Ion Physics @ high lumi

Focus on rare probes, study their coupling with QGP medium and their (medium-modified) hadronization process

- Jets: characterization of energy loss
  - testing ground for the multi-particle aspects of QCD
  - probe of the medium density
- Heavy flavour:
  - mass dependence of energy loss
- Quarkonium dissociation pattern and regeneration
  - probe of deconfinement and medium temperature





Summary and conclusions

- Very successful LHC Run I
  - Higgs discovery
  - But no new physics observed
- We know there is something more
  - The SM is not the end of the story
- We will use the LHC to try to find the answer to many of the unknown questions
  - Precision studies of the Higgs sector and SM predictions
  - Searches for deviations from predictions
  - Direct searches for SUSY or other new physics

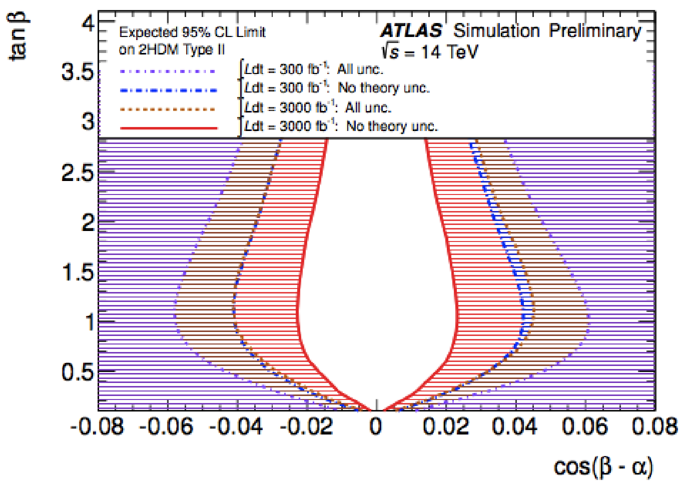
Backup

Indirect limits on 2HDM

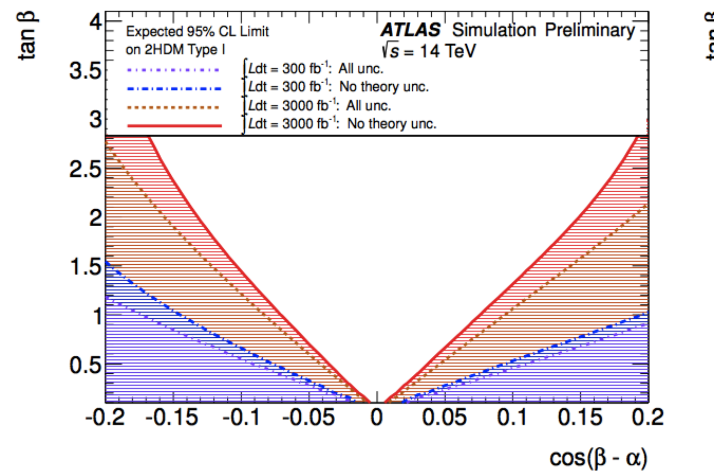
- Use Higgs rate measurements in different production and decay modes to set limits in the tan β, cos (β−α) plane

    Limits depends on the 2HDM type

- Considerable improvements in the limits after 3000 fb^{-1} of integrated luminosity



(b) Type II



(a) Type I

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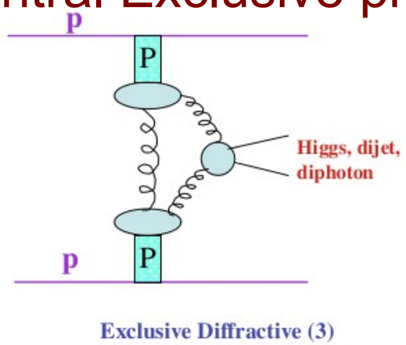
Selection conditions

Cuts	Top	Dibosons	Drell-Yan	W/Z+jet	Diffr.	$a_0^W/\Lambda^2 = 5 \cdot 10^{-6}$ GeV^{-2}
timing < 10 ps $p_T^{lep1} > 150$ GeV $p_T^{lep2} > 20$ GeV	5198	601	20093	1820	190	282
M(ll)>300 GeV	1650	176	2512	7.7	176	248
nTracks ≤ 3	2.8	2.1	78	0	51	71
$\Delta\phi < 3.1$	2.5	1.7	29	0	2.5	56
$m_X > 800$ GeV	0.6	0.4	7.3	0	1.1	50
$p_T^{lep1} > 300$ GeV	0	0.2	0	0	0.2	35

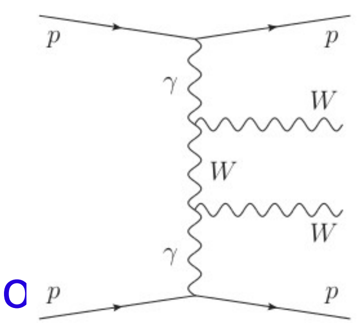
Table 9.5. Number of expected signal and background events for 300 fb^{-1} at pile-up $\mu = 46$. A time resolution of 10 ps has been assumed for background rejection. The diffractive background comprises production of QED diboson, QED dilepton, diffractive WW, double pomeron exchange WW.

Diffractive physics with AFP

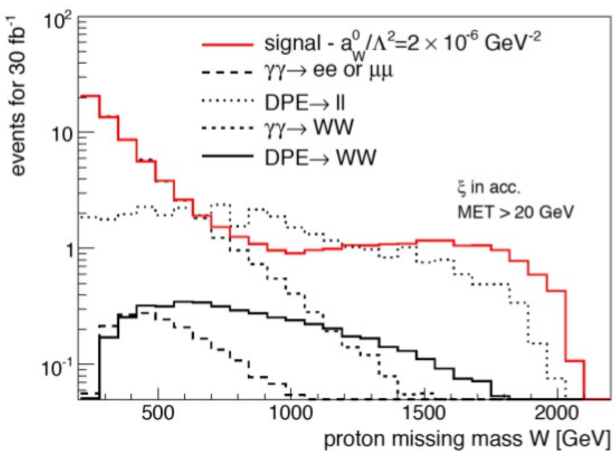
Central Exclusive production



- Higgs
    - Good mass resolution from p energy loss (~2-3%)
    - Tests J^{CP} & improve b-Higgs coupling measurement
- Di-jets
    - Test QCD calculations

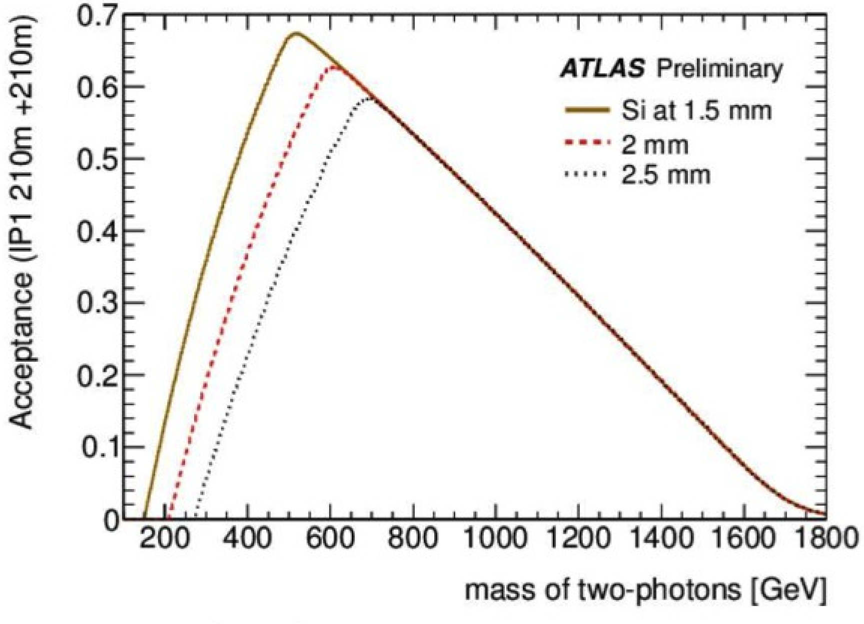


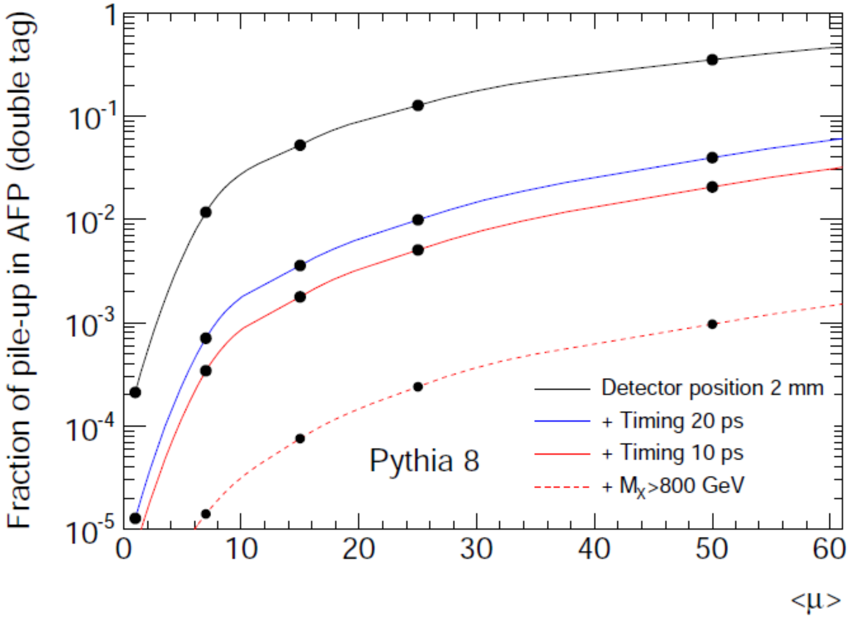
Triple and quartic anomalous gauge boson couplings



- Exclusive production of WW via photon exchange ($\sigma_{WW\to WW}$ well kno
- Diffractive mass computed from p energy loss
    - Large mass tails sensitive to anomalous couplings
- Improvement of LEP sensitivity by more than 4 orders of magnitude with 30-200 fb^{-1}

AFP background suppression and acceptance

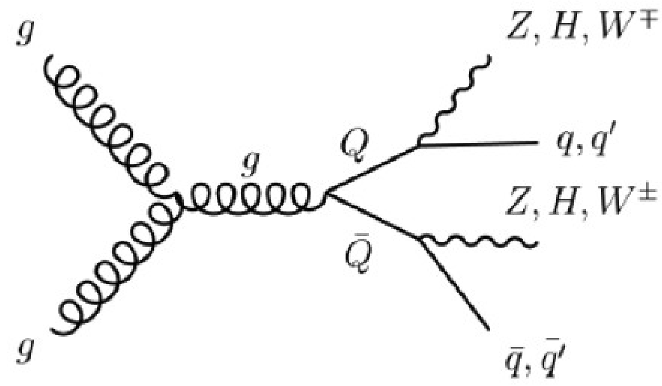


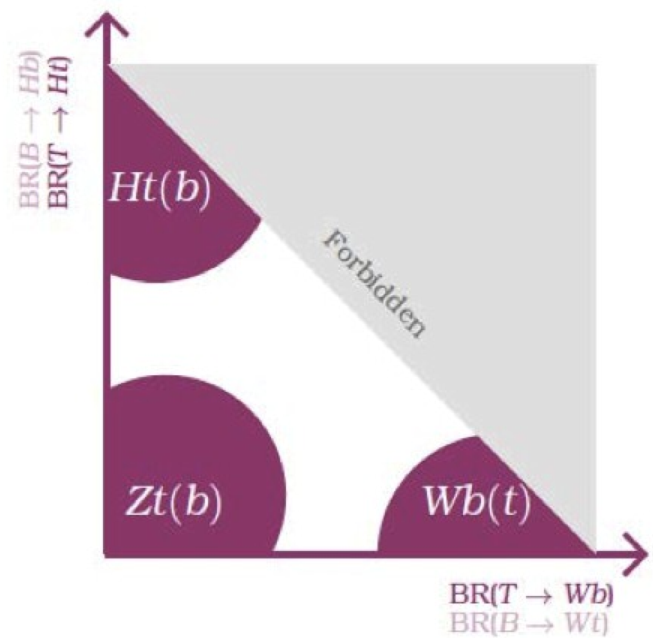


- Very good mass resolution (few %)

Vector-like quarks

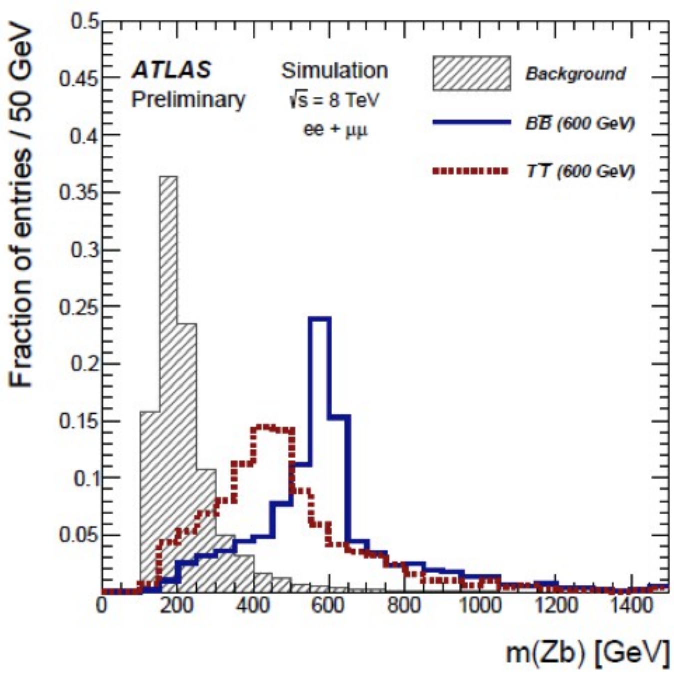
- Vector-like quarks appear in certain models to cancel Higgs mass divergencies
  - Little Higgs, extra-dimensions
- Left-handed and right-handed components transform in the same way under SU(2)
- In some models, they interact mainly with third generation quarks
  - Model independent search:
    - Scan over BR's in a 2D plane
    - Assume sum BR = 1

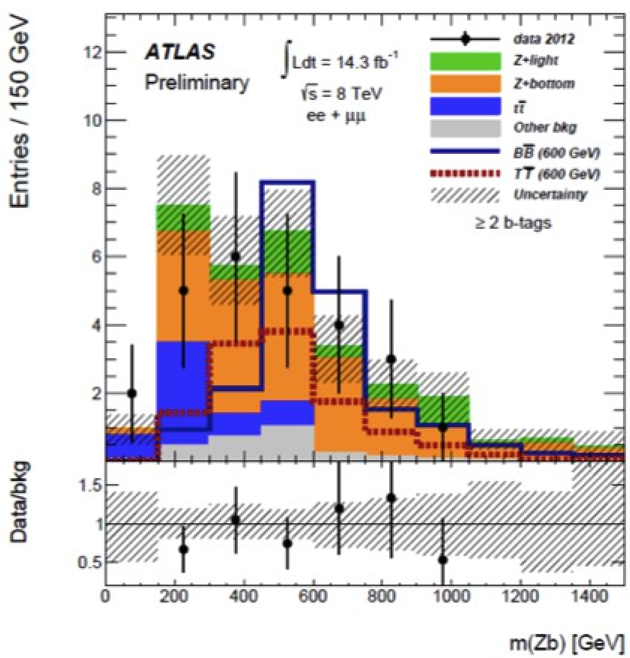




Vector-like quark searches

- Use sensitive variables to discriminate against SM backgrounds
- Example of the T→Zt+X channel





Vector-like quark limits