Новые результаты эксперимента АТЛАС

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НИИЯФ МГУ

Сессия СЯФ ОФН РАН, Протвино, 5-8.11.2013

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- **поиск тяжёлых двух-лептонных резонансов**
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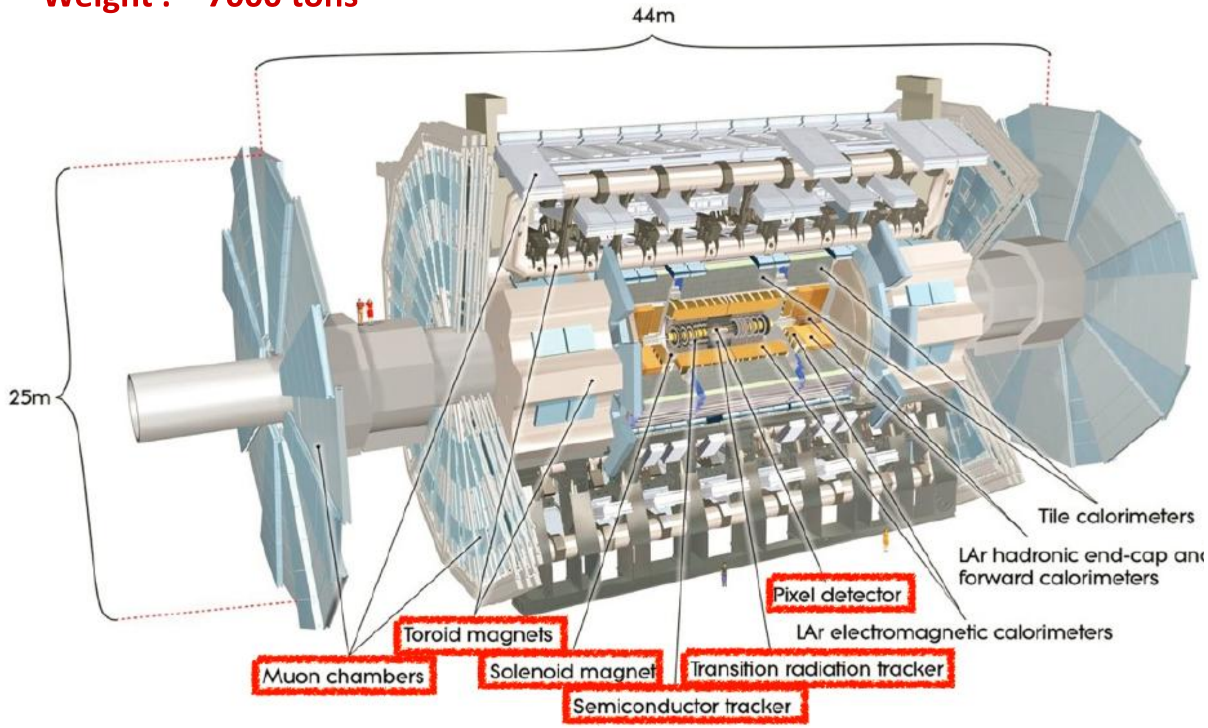
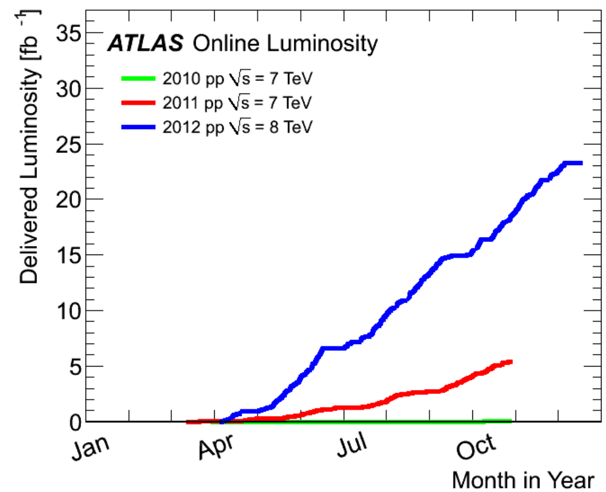
новые результаты ATLAS по электро-слабой физике в докладе Александра Солодкова сегодня в 15:00

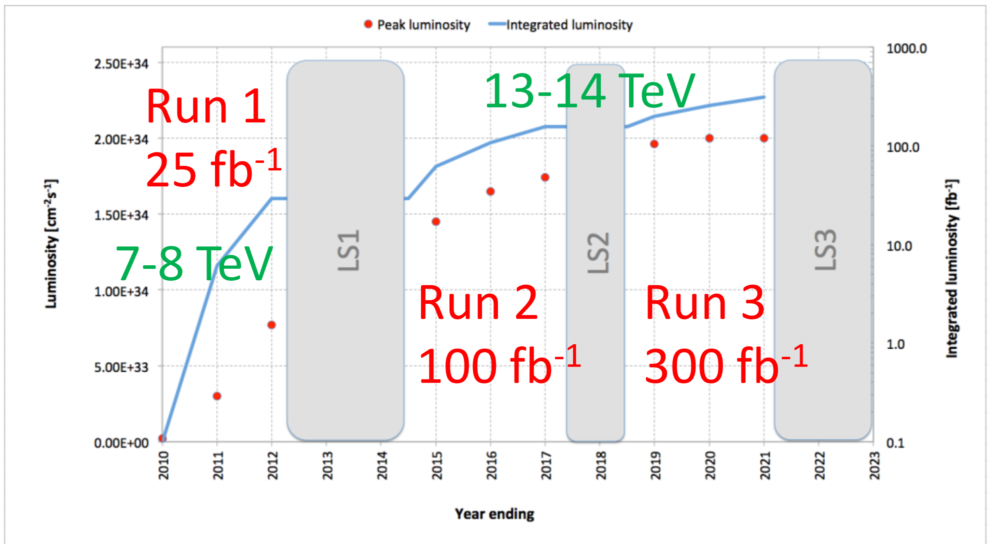
ATLAS @ LHC

Weight : ~ 7000 tons





Peak Lumi: 6.76×10^{33} cm^{-2} s^{-1}

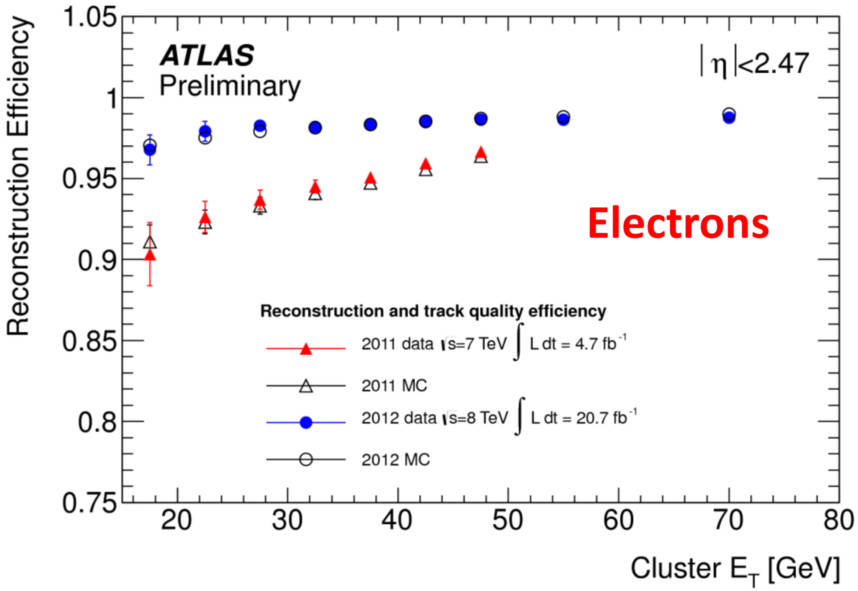


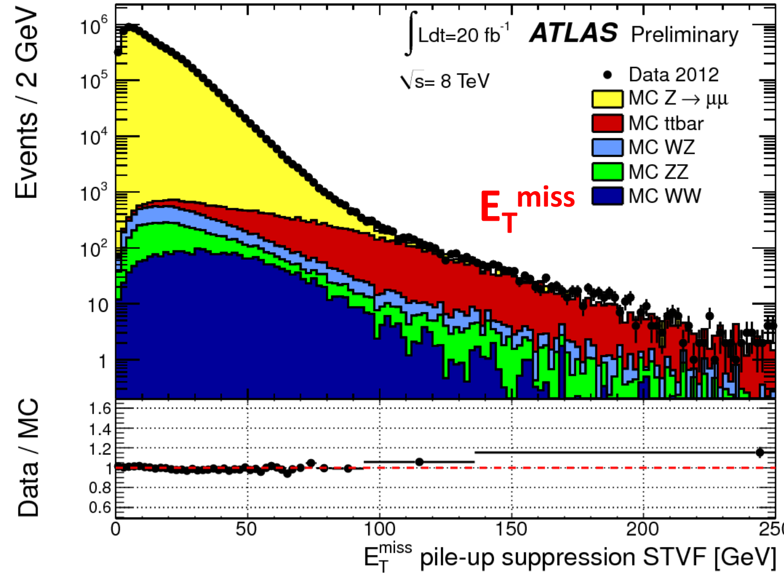
Run 4

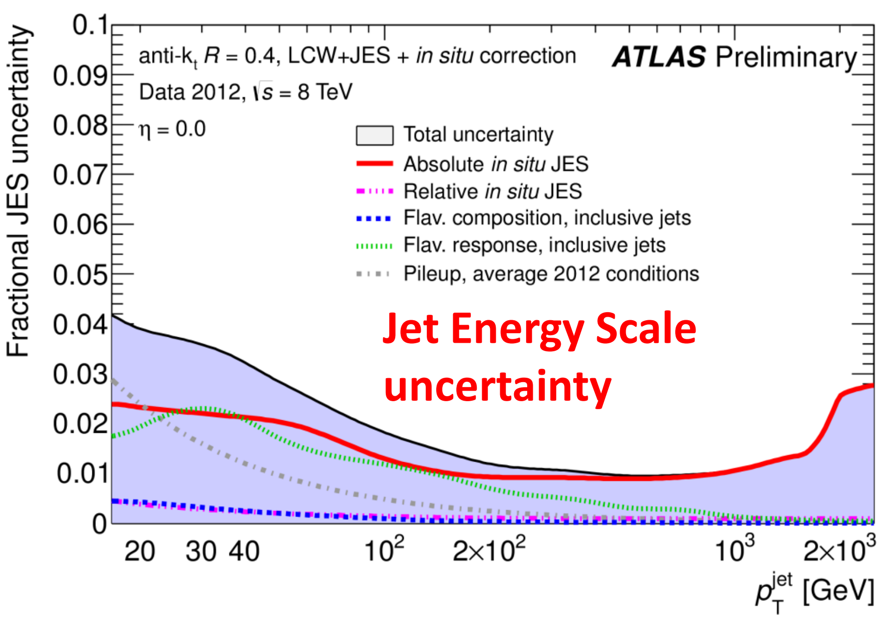
HL-LHC

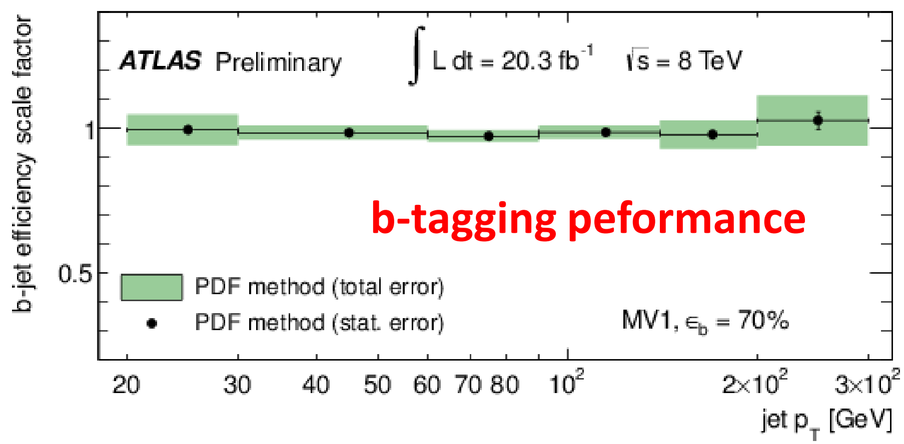
3000 fb^{-1}

Реконструкция и моделирование объектов



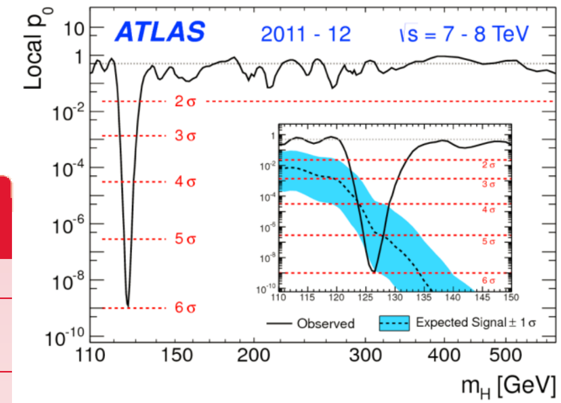




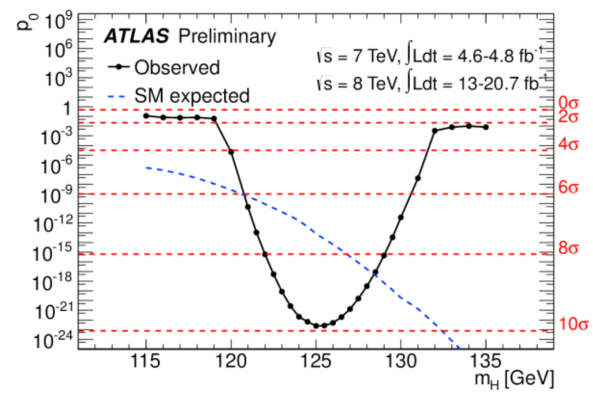


Бозон Хиггса на LHC - картина ATLAS'а

Higgs Decay	Sub. Decay	Sub-Channels	$\int L\,dt\,[\text{fb}^{-1}]$
		2011 $\sqrt{s} = 7$ TeV	
$H \to ZZ^*$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu$, 2-jet VBF, ℓ-tag$\}$	4.6
$H \to \gamma\gamma$	-	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{$2-jet VBF$\}$	4.8
$H \to WW^*$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{$0-jet, 1-jet, 2-jet VBF$\}$	4.6
$H \to \tau\tau$	$\tau_{\text{lep}}\tau_{\text{lep}}$ $\tau_{\text{lep}}\tau_{\text{had}}$ $\tau_{\text{had}}\tau_{\text{had}}$	$\{e\mu\} \otimes \{$0-jet$\} \oplus \{\ell\ell\} \otimes \{$1-jet, 2-jet, $p_{T,\tau\tau} > 100$ GeV, $VH\}$ $\{e,\mu\} \otimes \{$0-jet, 1-jet, $p_{T,\tau\tau} > 100$ GeV, 2-jet$\}$ $\{$1-jet, 2-jet$\}$	4.6 4.6 4.6
$VH \to Vbb$	$Z \to \nu\nu$ $W \to \ell\nu$ $Z \to \ell\ell$	$E_T^{\text{miss}} \in \{120-160, 160-200, \geq 200\text{ GeV}\} \otimes \{$2-jet, 3-jet$\}$ $p_T^W \in \{<50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$ $p_T^Z \in \{<50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	4.6 4.7 4.7
		2012 $\sqrt{s} = 8$ TeV	
$H \to ZZ^*$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu$, 2-jet VBF , ℓ-tag$\}$	20.7
$H \to \gamma\gamma$	-	14 categories $\{p_{Tt} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{$2-jet VBF$\} \oplus \{\ell$-tag, E_T^{miss}-tag, 2-jet $VH\}$	20.7
$H \to WW^*$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{$0-jet, 1-jet, 2-jet VBF$\}$	20.7
$H \to \tau\tau$	$\tau_{\text{lep}}\tau_{\text{lep}}$ $\tau_{\text{lep}}\tau_{\text{had}}$ $\tau_{\text{had}}\tau_{\text{had}}$	$\{\ell\ell\} \otimes \{$1-jet, 2-jet, $p_{T,\tau\tau} > 100$ GeV, $VH\}$ $\{e,\mu\} \otimes \{$0-jet, 1-jet, $p_{T,\tau\tau} > 100$ GeV, 2-jet$\}$ $\{$1-jet, 2-jet$\}$	13 13 13
$VH \to Vbb$	$Z \to \nu\nu$ $W \to \ell\nu$ $Z \to \ell\ell$	$E_T^{\text{miss}} \in \{120-160, 160-200, \geq 200\text{ GeV}\} \otimes \{$2-jet, 3-jet$\}$ $p_T^W \in \{<50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$ $p_T^Z \in \{<50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	13 13 13



July 2012



March2013

October 2013

Рождение бозона Хиггса на LHC

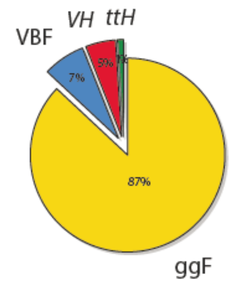
Dominant process is gluon-gluon fusion (ggF)

- Proceeds mainly through the top quark loop

→ Indirect probe of Higgs-fermion coupling

Vector Boson Fusion (VBF)

- Direct probe of vector boson coupling
- Signature includes two forward high-pT jets with a large rapidity-gap

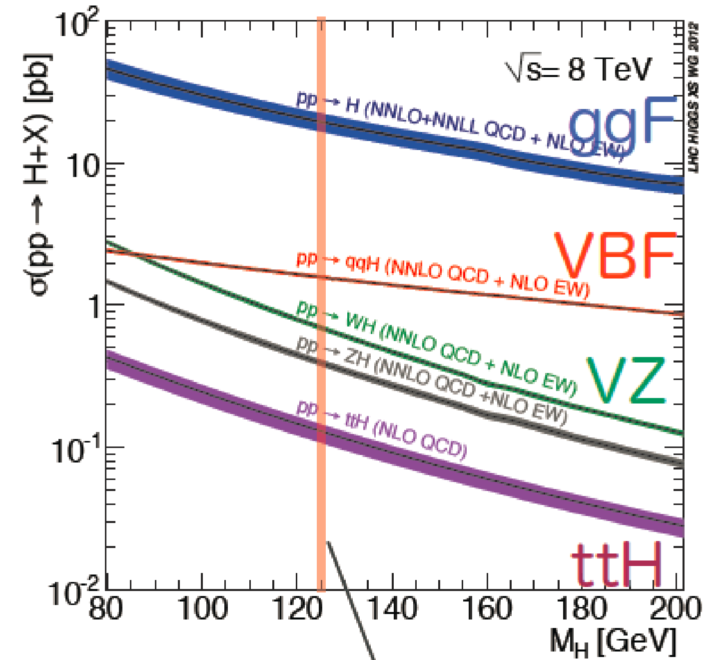


Associated production with W/Z (VZ)

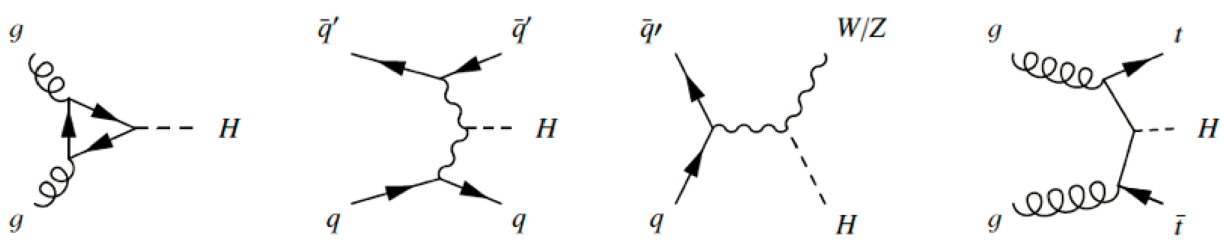
- Direct probe of vector boson coupling
- Signature includes high-pT leptons

Associated production with a top quark pair (ttH)

- Direct probe of Higgs-top quark coupling



σ (pb)	7TeV	8TeV
ggF	15	19
VBF	1.2	1.6
WH	0.57	0.70
ZH	0.33	0.41
ttH	0.09	0.13

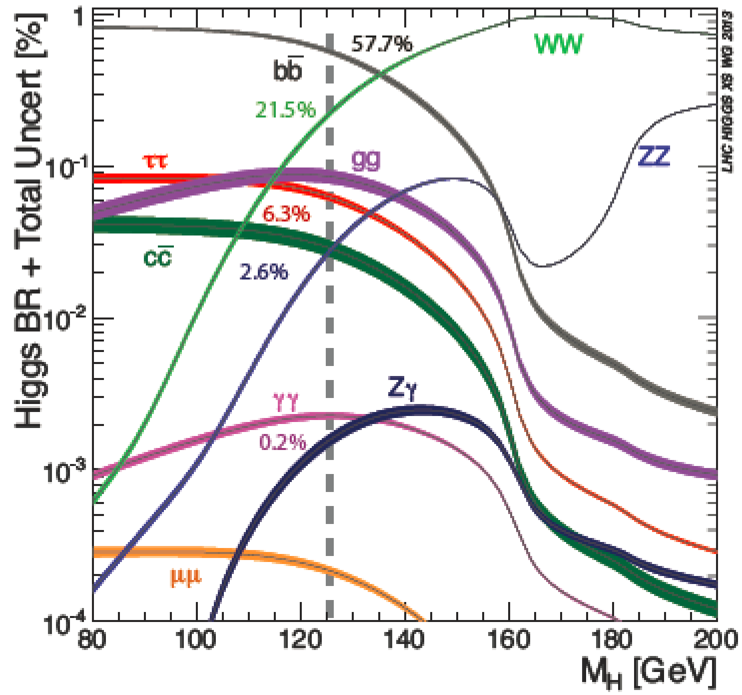


(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$

Распады бозона Хиггса на LHC

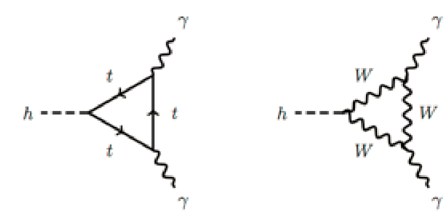
m_H=125.5GeV	BR(%)
H→γγ	0.23
H→ZZ	2.8
H→WW	22
H→ττ	6.2
H→bb	57

	BR(%)
H→Zγ	0.16
H→μμ	0.02



Higgs boson can decay into a photon pair via W or t-quark loop.

- Negative interference between W-boson loop and t-quark loop helps the indirect measurement of the coupling to fermions



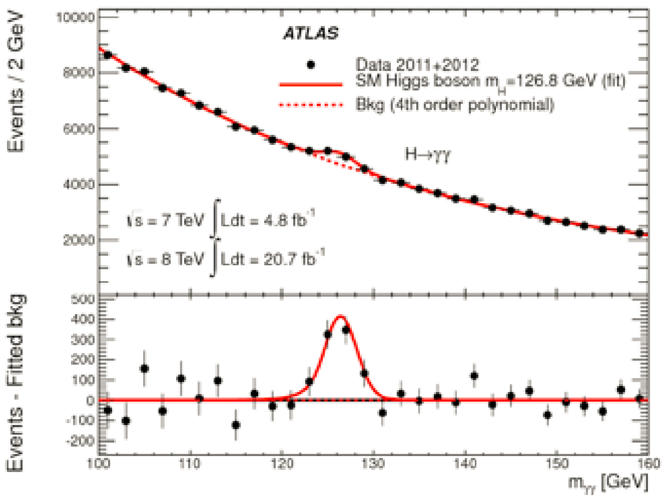
Final states with leptons or photons are easier to measure

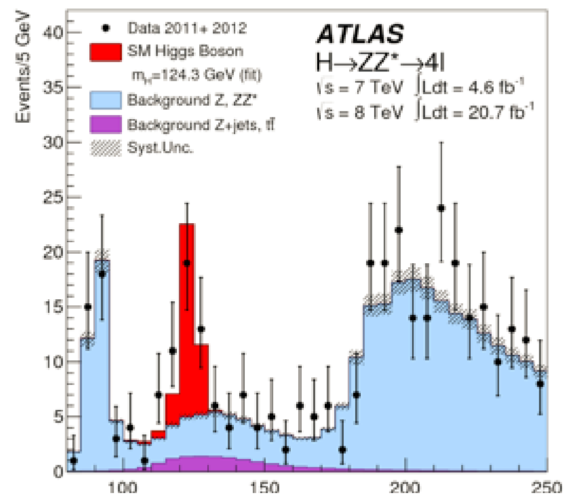
- Discovery channels : H→γγ, ZZ(→4ℓ), WW(→ℓνℓν)

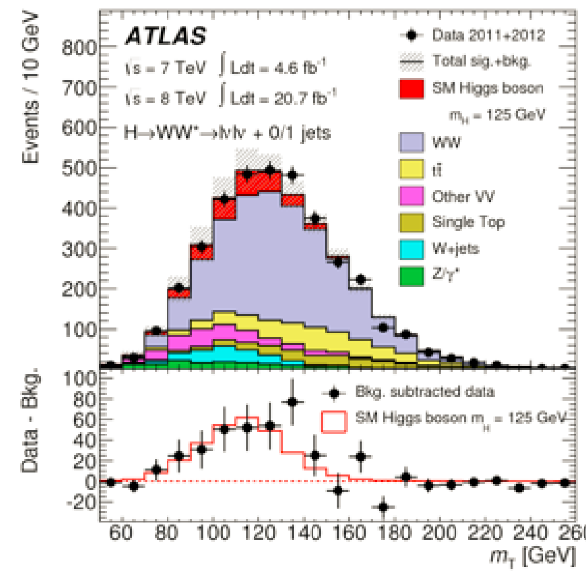
Decays to jets or τs are more difficult to separate from QCD background, but they are very important for the direct measurement of the coupling to fermions.

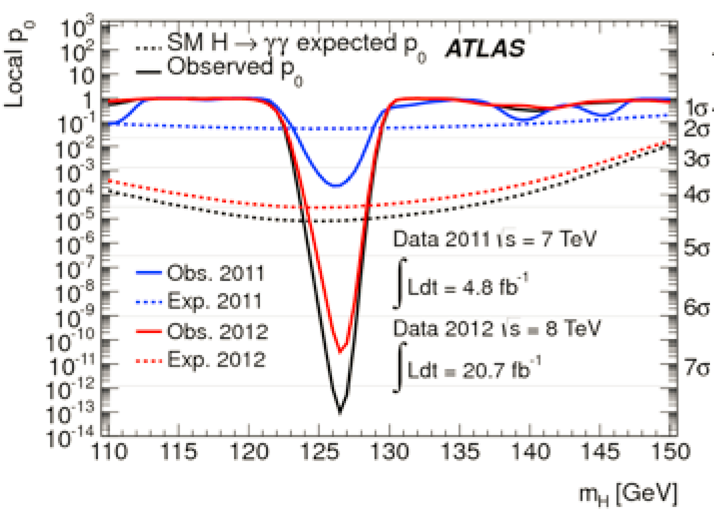
Основные каналы наблюдения *H*

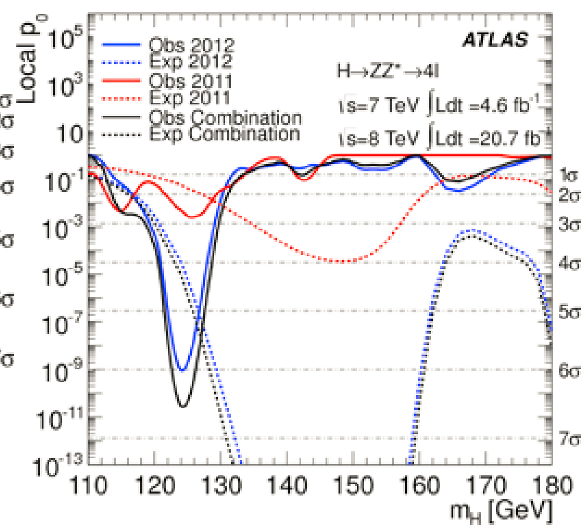
$H \to \gamma\gamma$ | $H \to ZZ$ | $H \to WW$

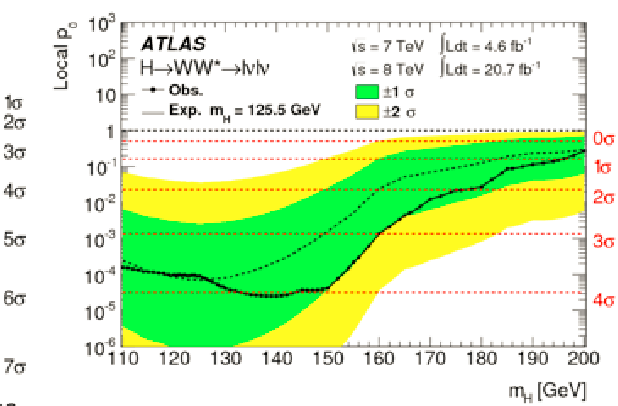








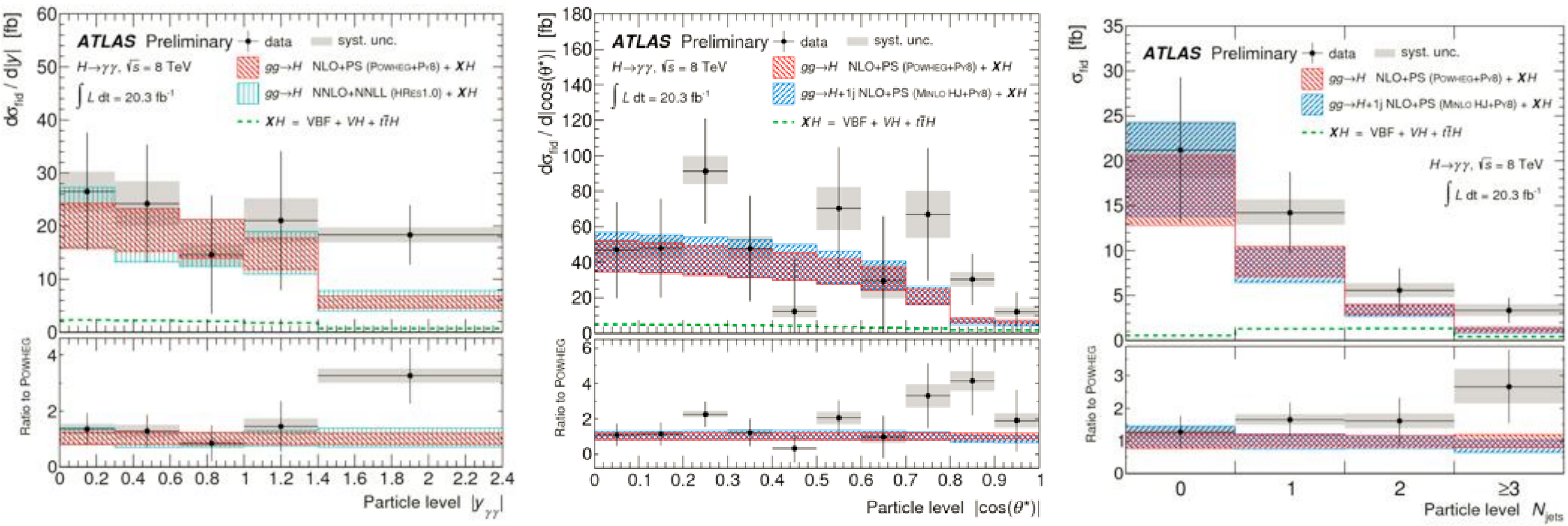




Дифференциальные сечения $H \to \gamma\gamma$

ATLAS-CONF-2013-072

- 8 observables : $p_T^{\gamma\gamma}$, $|y^{\gamma\gamma}|$, $|\cos\theta^*|$, N_{jets}, Φ_{jj}, ...,
- The distributions are unfolded to particle level and compared with MC generators
- Sensitive to PDF, radiative correction, relative rate of Higgs production, spin,...



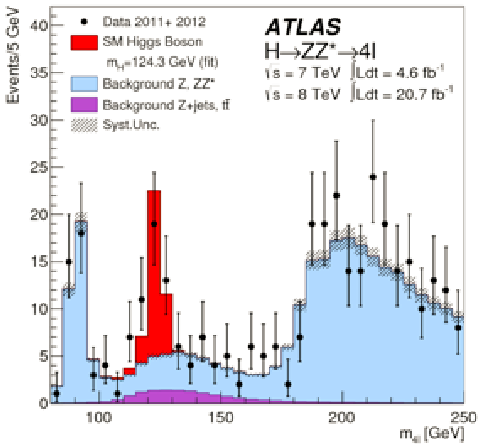
Probability of χ^2 test

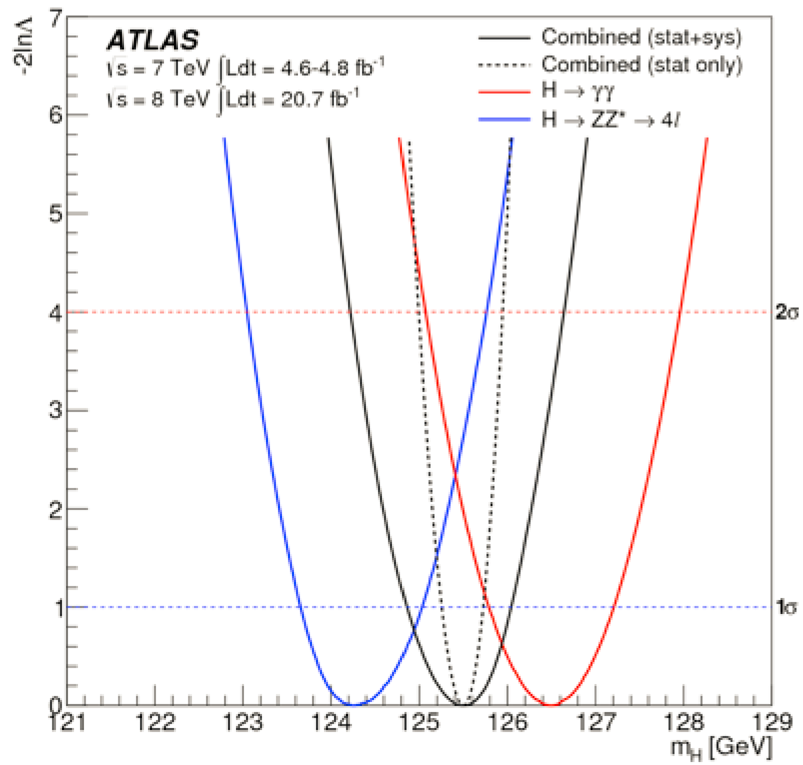
	N_{jets}	$p_T^{\gamma\gamma}$	$\lvert y^{\gamma\gamma}\rvert$	$\lvert\cos\theta^*\rvert$	$p_T^{j_1}$	$\Delta\phi_{jj}$	$p_T^{\gamma\gamma jj}$
POWHEG	0.54	0.55	0.38	0.69	0.79	0.42	0.50
MINLO	0.44	–	–	0.67	0.73	0.45	0.49
HRES 1.0	–	0.39	0.44	–	–	–	–

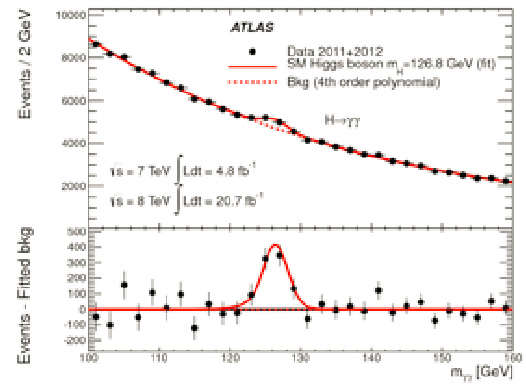
No significant deviation from SM (POWHEG, MINLO, HRES1.0) is observed.

Масса бозона Хиггса

arXiv:1307.1427







Combined $m_H = 125.5 \pm 0.2\ (\text{stat})\ {}^{+0.5}_{-0.6}\ (\text{sys})\ \text{GeV}$

$$\Delta m_H = m_H^{\gamma\gamma} - m_H^{ZZ} = 2.3\ {}^{+0.3}_{-0.7}\ (\text{stat}) \pm 0.6\ (\text{sys})\ \text{GeV}$$

Mass difference ~2.4σ - not a problem yet

to be clarified with Run2 data

“Сила” сигнала бозона Хиггса

arXiv:1307.1427

$$\mu = \frac{\sigma \times \mathrm{BR}}{(\sigma \times \mathrm{BR})_{\mathrm{SM}}}$$

μ=1 (if SM Higgs), μ=0 (if no SM Higgs)

combined

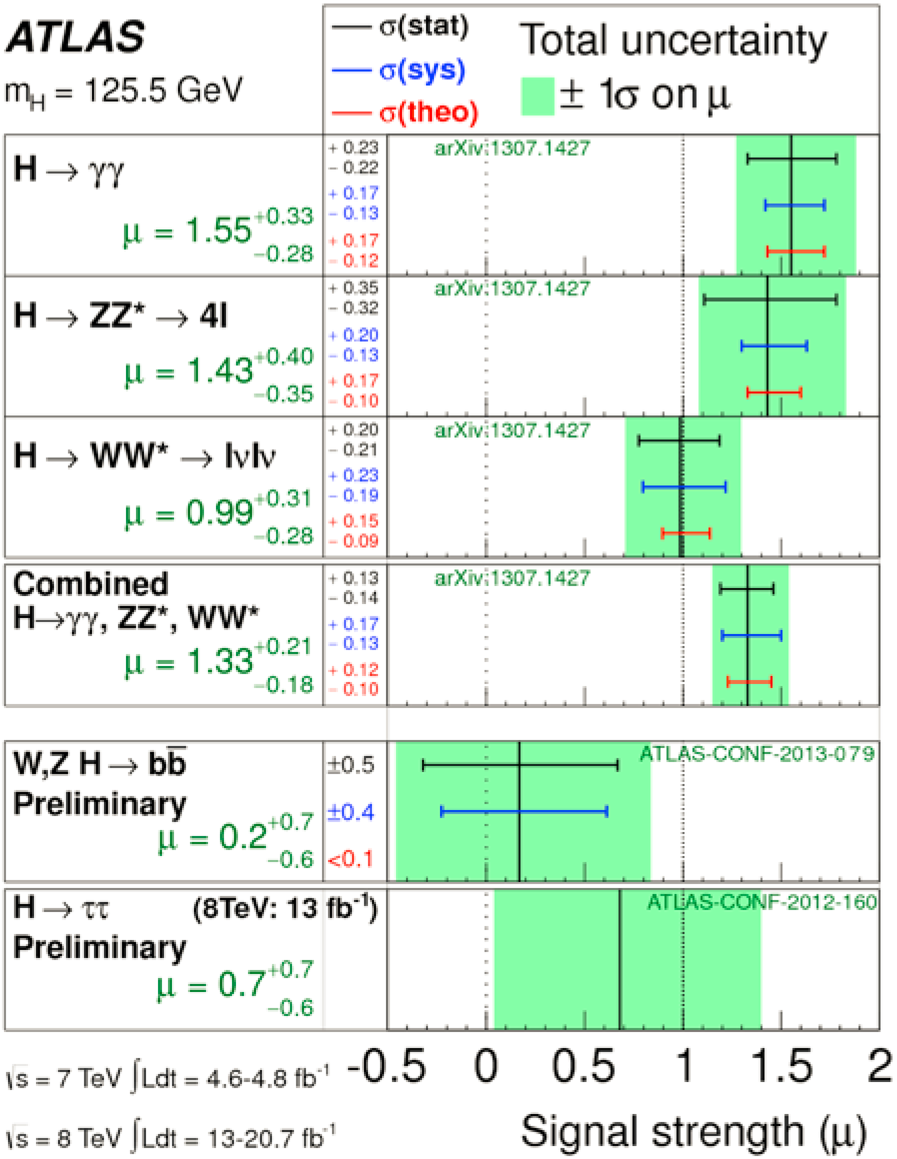
$$\mu = 1.33 \pm 0.14(\mathrm{stat}) \pm 0.15(\mathrm{sys})$$

(m_H=125.5GeV)

Result is consistent with the SM prediction with 15% precision.

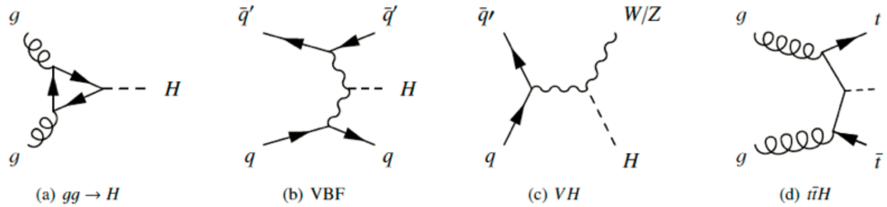
H→bb and H→$\tau\tau$ not in the combination

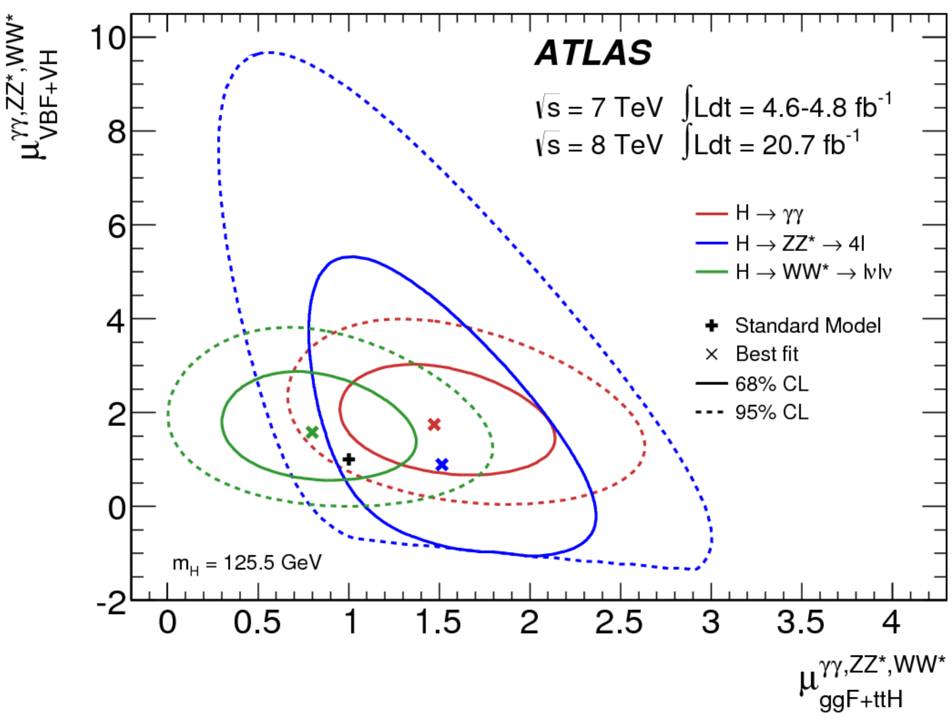
Statistical, systematic and theory (QCD scale, PDF) uncertainties are already comparable.

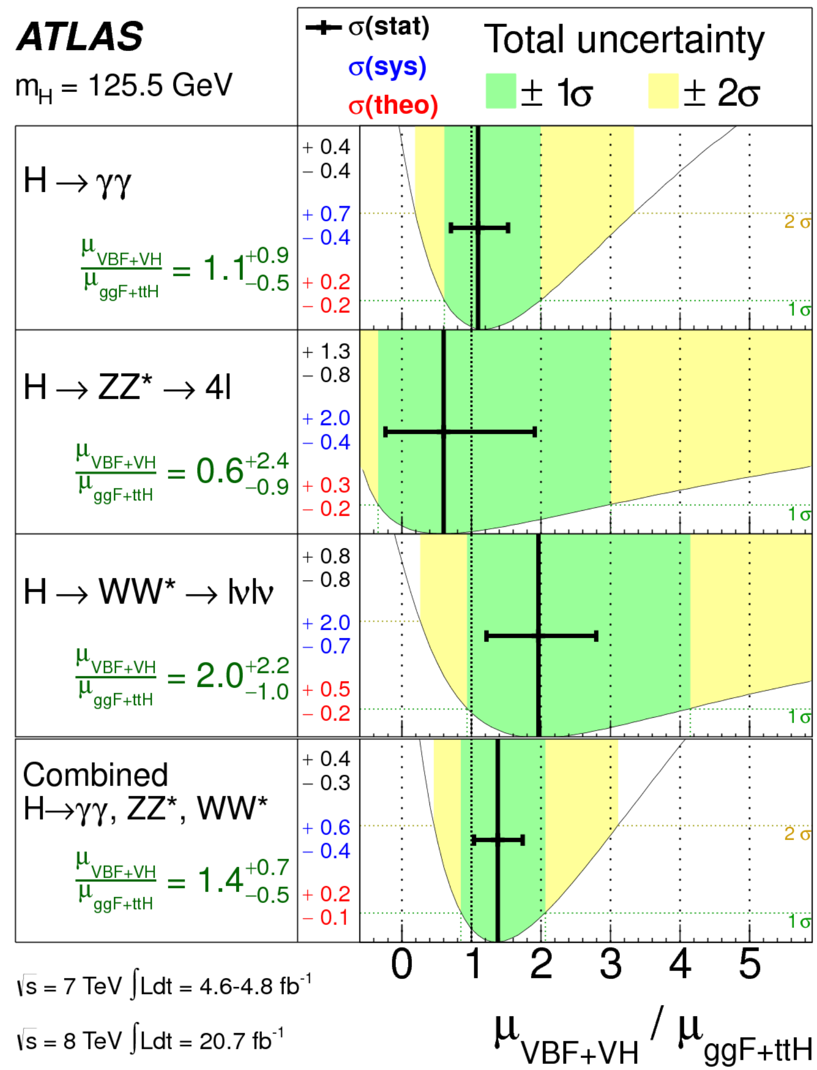


Наблюдение VBF рождения бозона Хиггса

arXiv:1307.1427





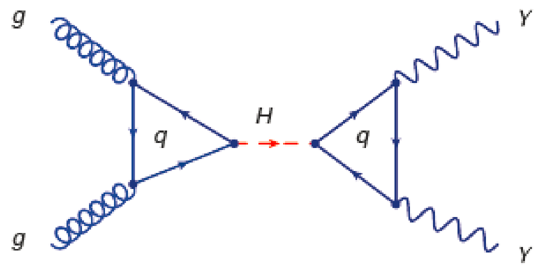


3.3 σ evidence that a fraction of Higgs boson production occurs through VBF

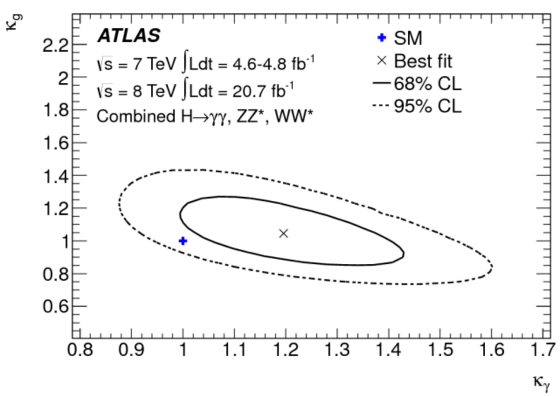
Константы связи бозона Хиггса

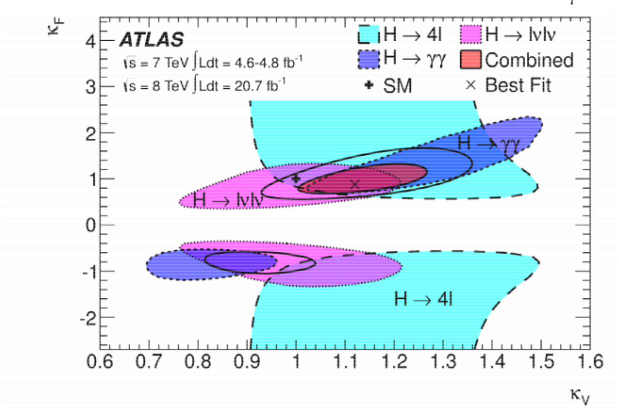
arXiv:1307.1427

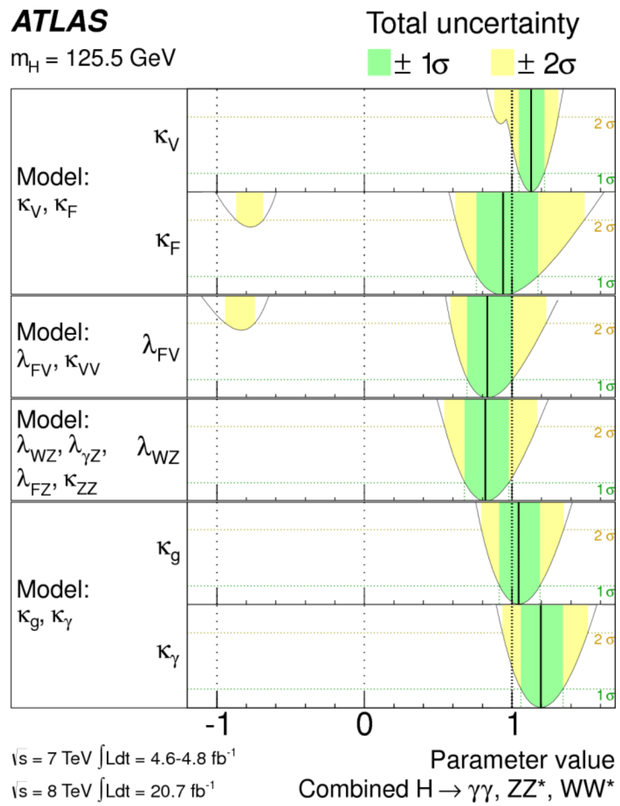
coupling scale factors are considered



$$\frac{\sigma \cdot \mathrm{B}\,(gg \to H \to \gamma\gamma)}{\sigma_{\mathrm{SM}}(gg \to H) \cdot \mathrm{B}_{\mathrm{SM}}(H \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$







$\kappa_F \in [0.76, 1.18]$

$\kappa_V \in [1.05, 1.22]$

$\lambda_{FV} \in [0.70, 1.01]$

$\lambda_{WZ} = 0.82 \pm 0.15$

$\kappa_g = 1.04 \pm 0.14$

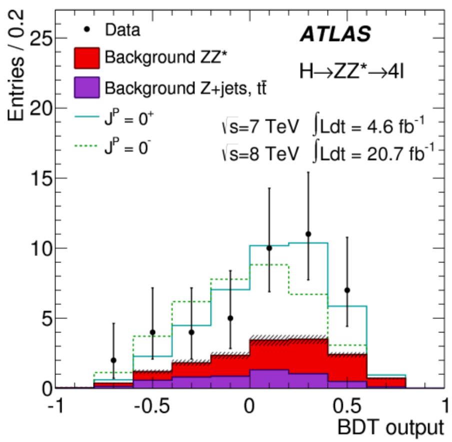
$\kappa_\gamma = 1.20 \pm 0.15$

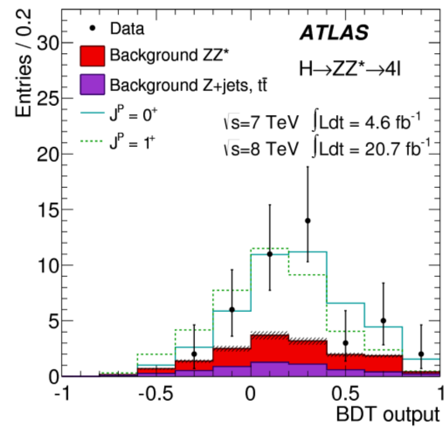
good agreement with SM expectations

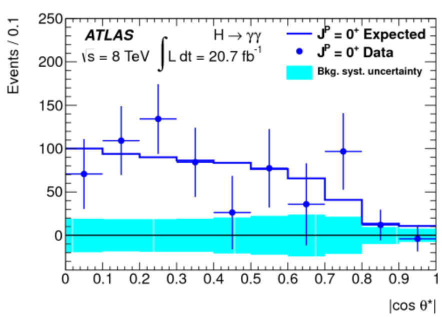
Спин-чётность бозона Хиггса

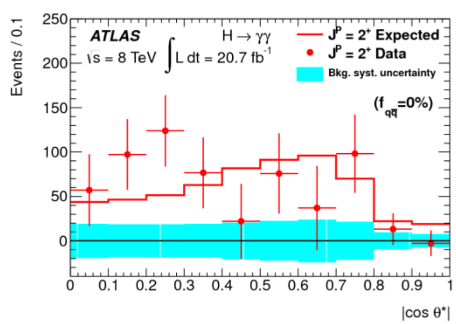
arXiv:1307.1432

0^+ is expected; test it vs 0^-, 1^+, 1^-, 2^+

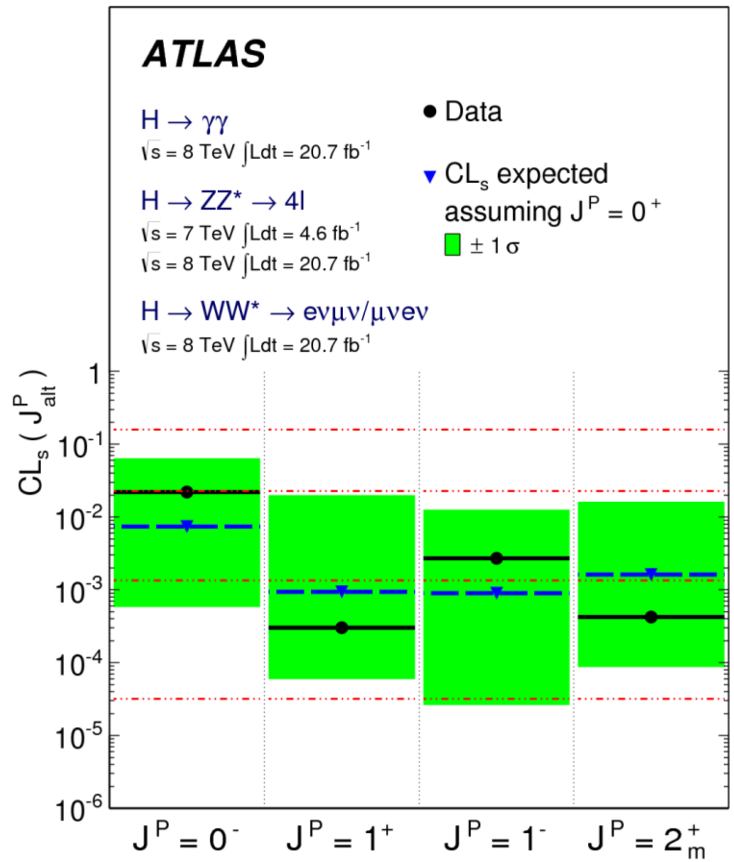








$$|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+(p_T^{\gamma\gamma}/m_{\gamma\gamma})^2}}\frac{2p_T^{\gamma 1}p_T^{\gamma 2}}{m_{\gamma\gamma}^2}$$



Spin-Parity 0^+ confirmed

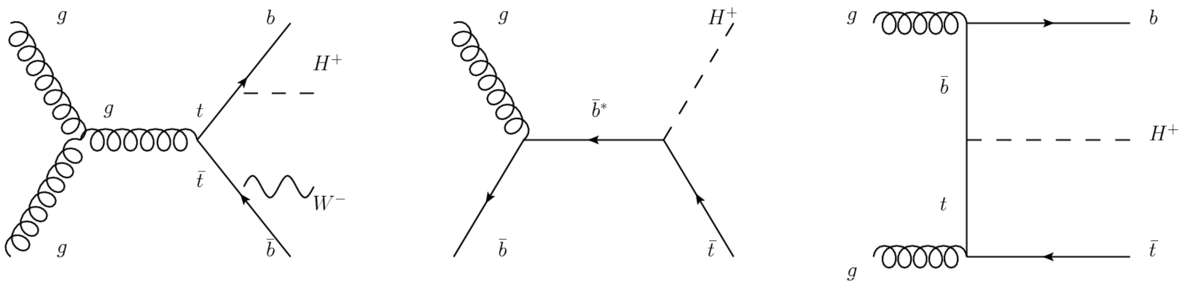
J^P hypo	Exclusion CL	Source
0^-	97.8%	$H \to ZZ^* \to 4l$
1^-	99.7%	Combined ZZ^*/WW^*
1^+	99.97%	Combined ZZ^*/WW^*
2^+	99.9%	Combined $\gamma\gamma/ZZ^*/WW^*$

Поиск заряженного бозона Хиггса $H^+ \to \tau^+ \nu$

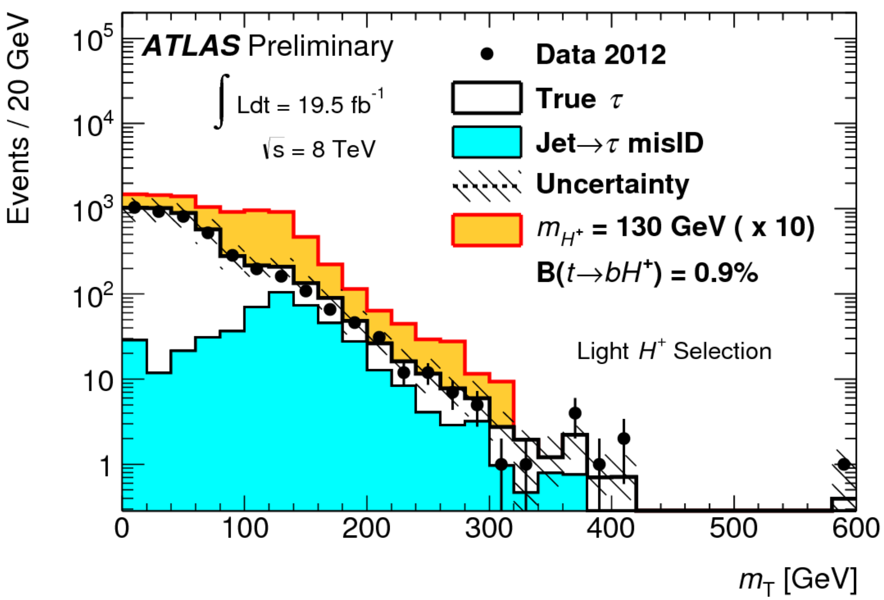
ATLAS-CONF-2013-090

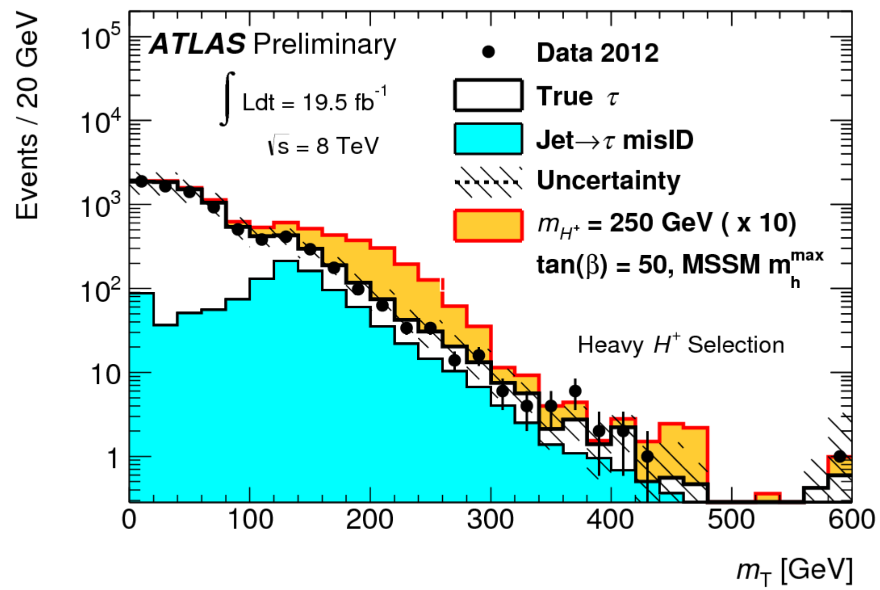
лёгкий

тяжёлый



Signature: 3-4 jets, at least one jet b-tagged, exactly one τ (narrow jet), E_T^{miss}



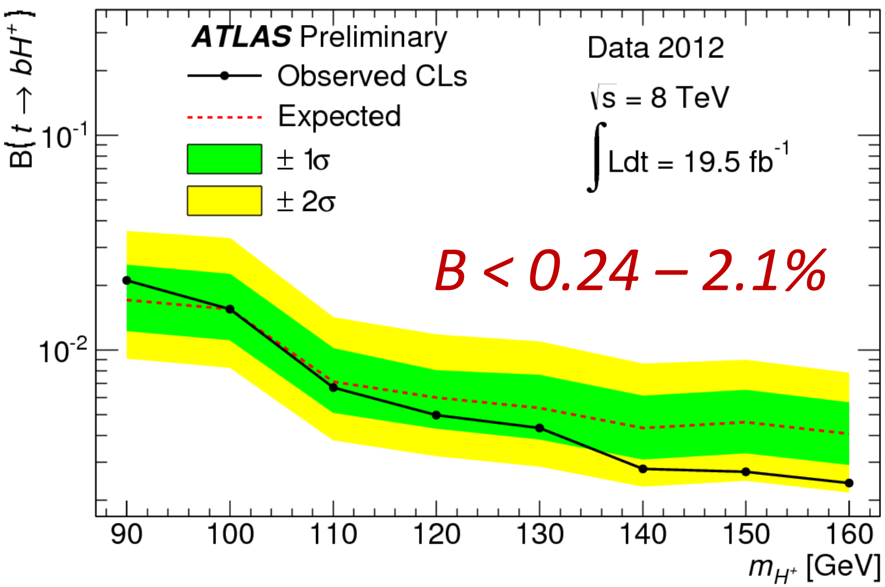


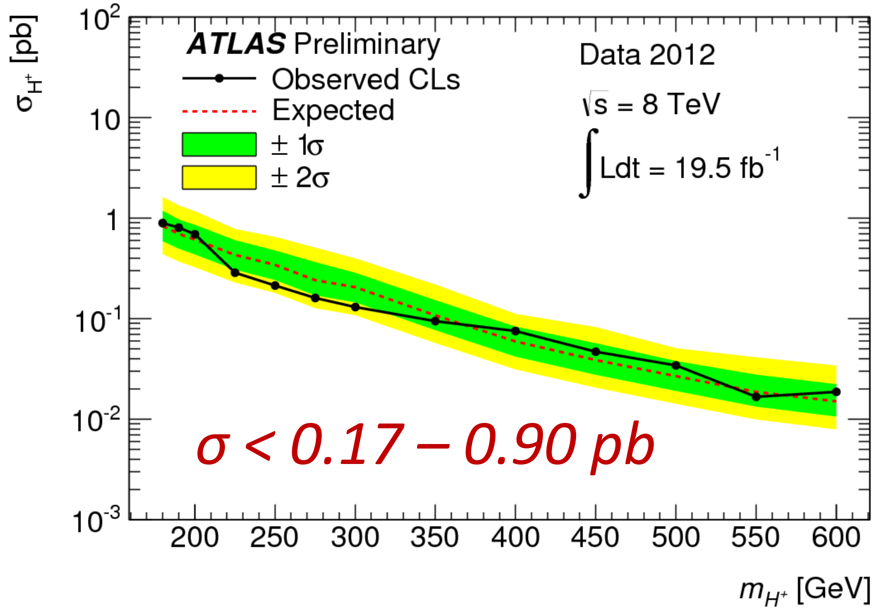
$$m_T = \sqrt{2 p_T^{\tau} E_T^{\text{miss}} (1 - \cos \Delta\phi_{\tau,\text{miss}})}$$

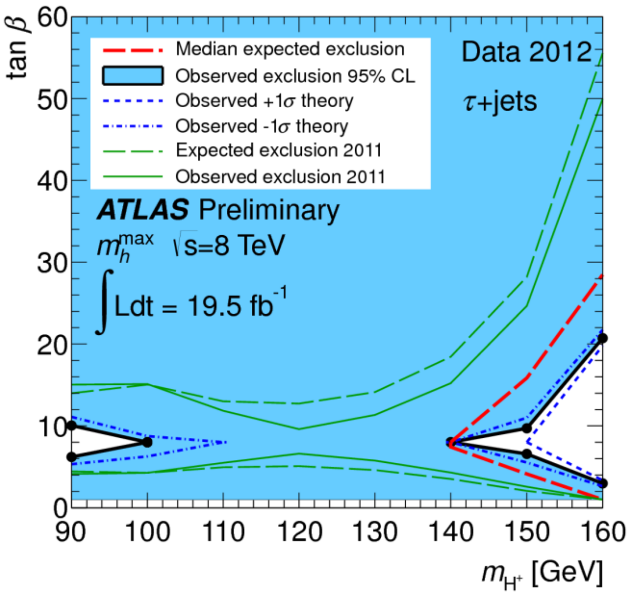
Ограничения на характеристики заряженного бозона Хиггса $H^+ \to \tau^+ \nu$

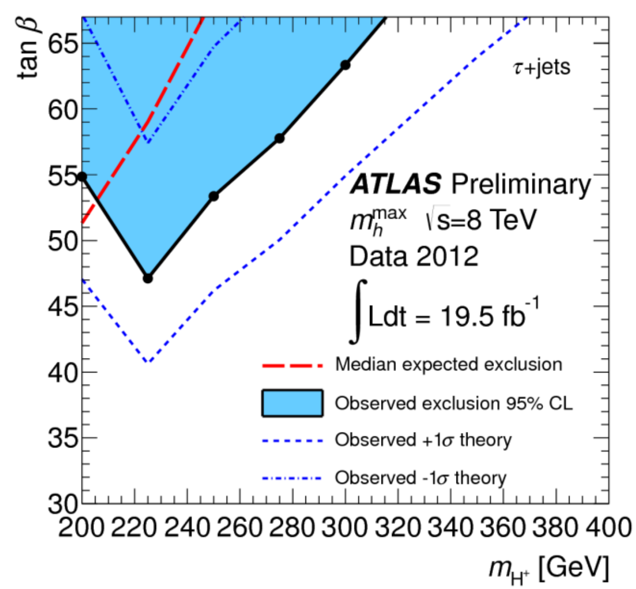
ATLAS-CONF-2013-090

лёгкий $B(H^+ \to \tau\nu) = 100\%$ **тяжёлый**



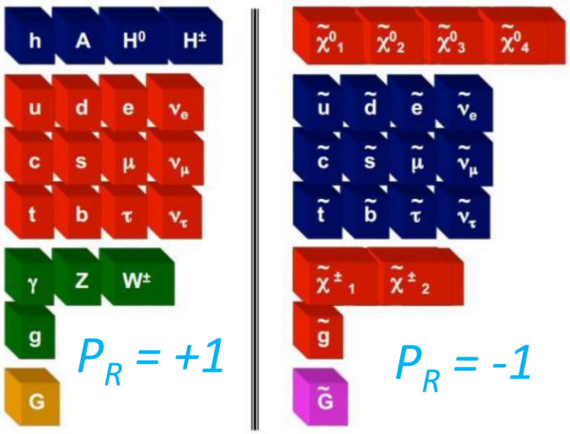






MSSM (m_h^{max} scenario) interpretation

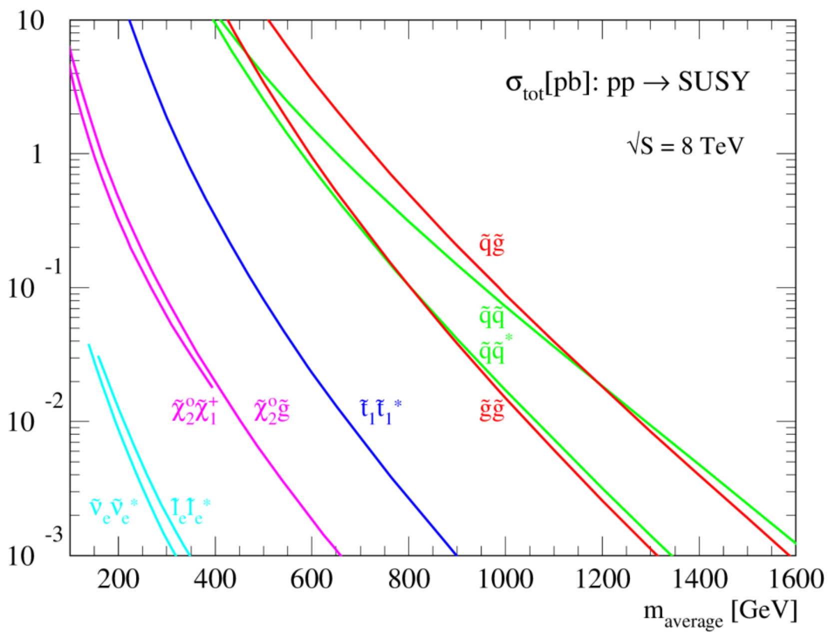
Поиски Суперсимметрии в эксперименте ATLAS

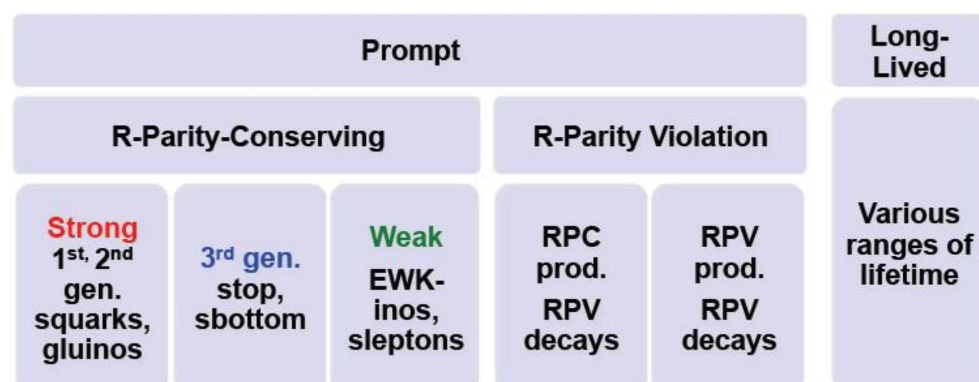


SUSY can
- eliminate quadratic divergences in Higgs mass corrections
- unify forces at high scales
- explain nature of Dark Matter (if LSP stable or long-lived)

R-Parity $P_R = (-1)^{3(B-L)+2S}$

Search strategy designed to provide coverage for a broad class of SUSY models

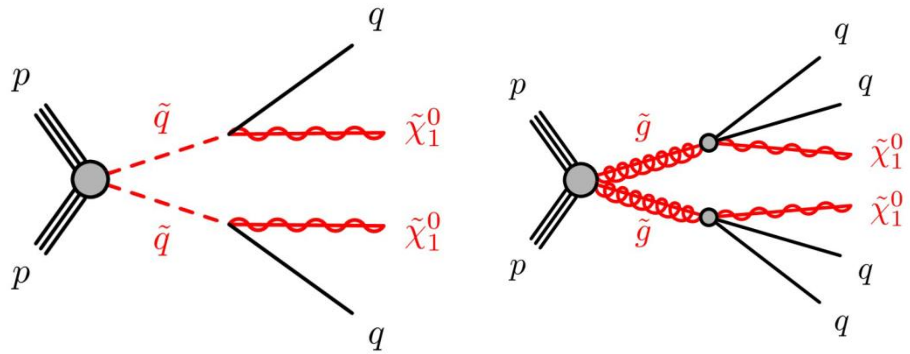




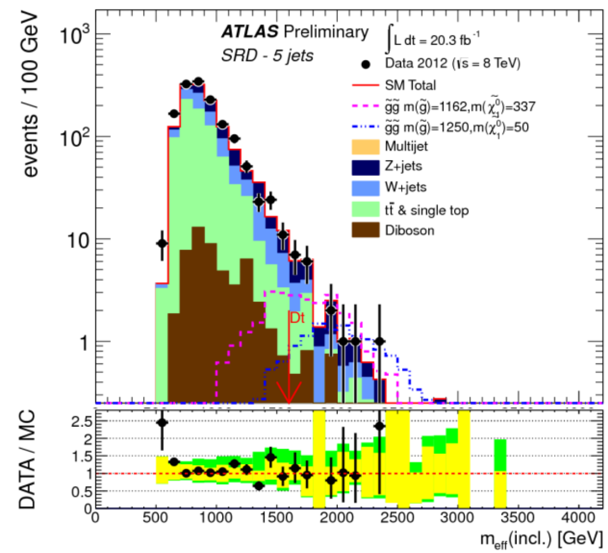
For each search, a number of signal regions is optimized based on a variety of models

Поиски $\tilde{q}$ и $\tilde{g}$ в событиях без лептонов, с 2- 6 струями и большим E_T^{miss}

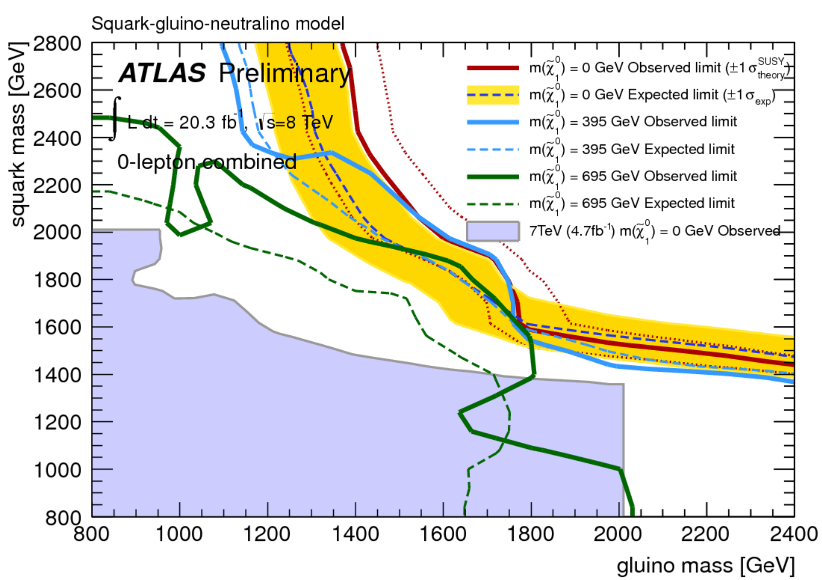
ATLAS-CONF-2013-047

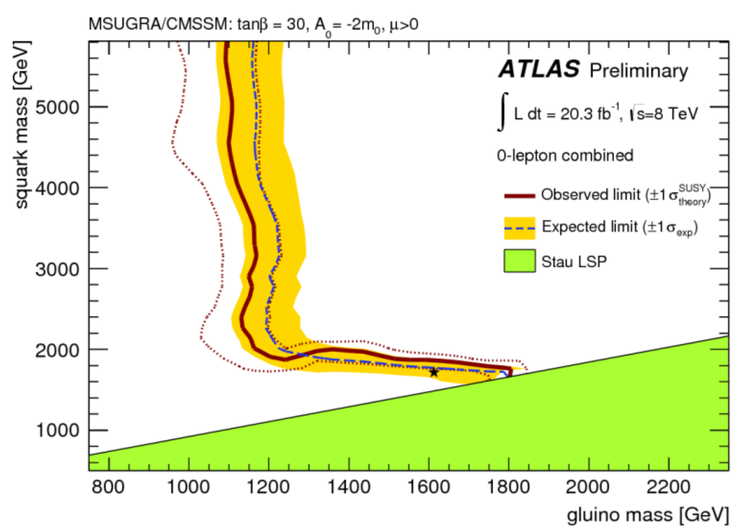


$$m_{eff} = E_T^{miss} + \Sigma\, p_T^{jets}$$



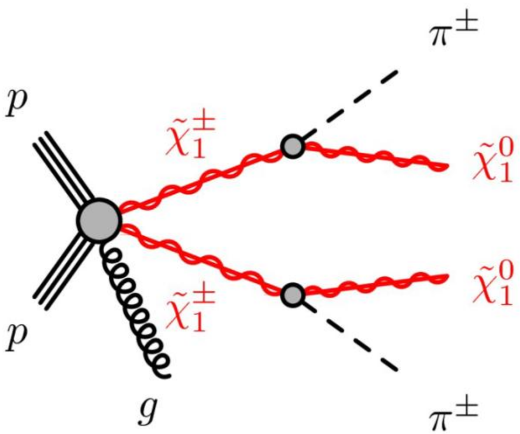
simplified phenomenological MSSM scenario with only strong production of gluinos and first- and second-generation squarks (of common mass), with direct decays to jets and lightest neutralinos

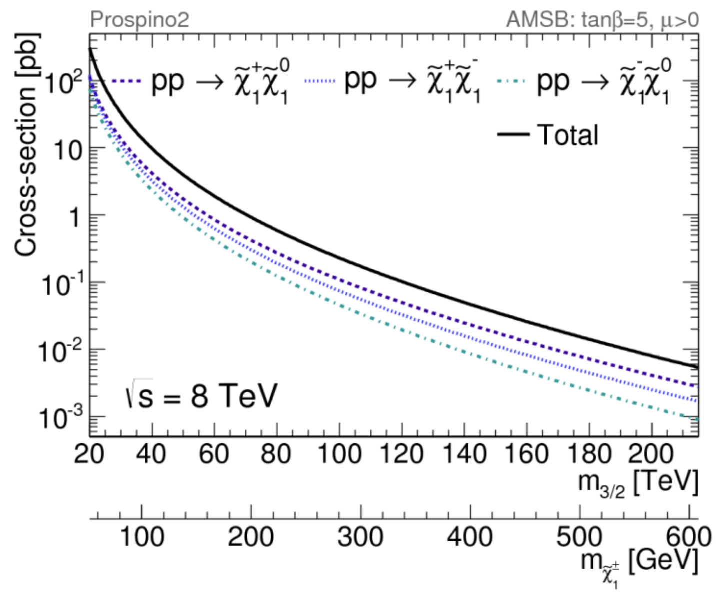




Поиск $\tilde{\chi}_1^{\pm}$ с $m(\tilde{\chi}_1^{\pm}) \approx m(\tilde{\chi}_1^{0})$ в событиях с большим E_T^{miss} и "исчезающим" треком

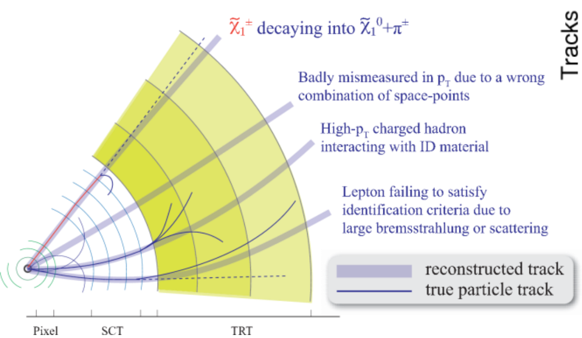
arXiv:1310.3675

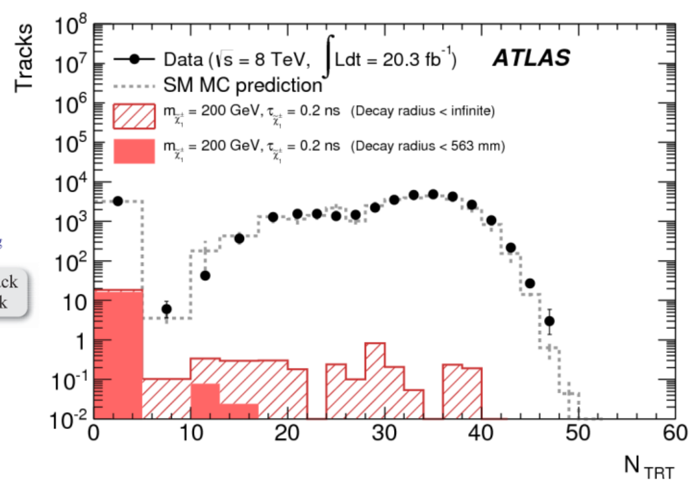


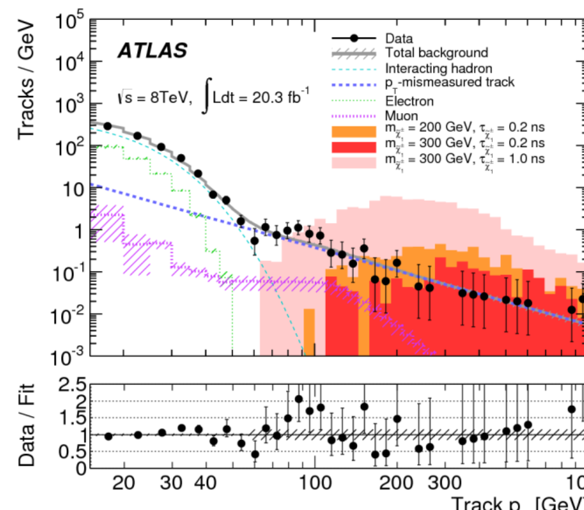


Many SUSY model e.g. AMSB have almost mass degenerate chargino and LSP → long-lived chargino

$\Delta m \sim 160$ MeV





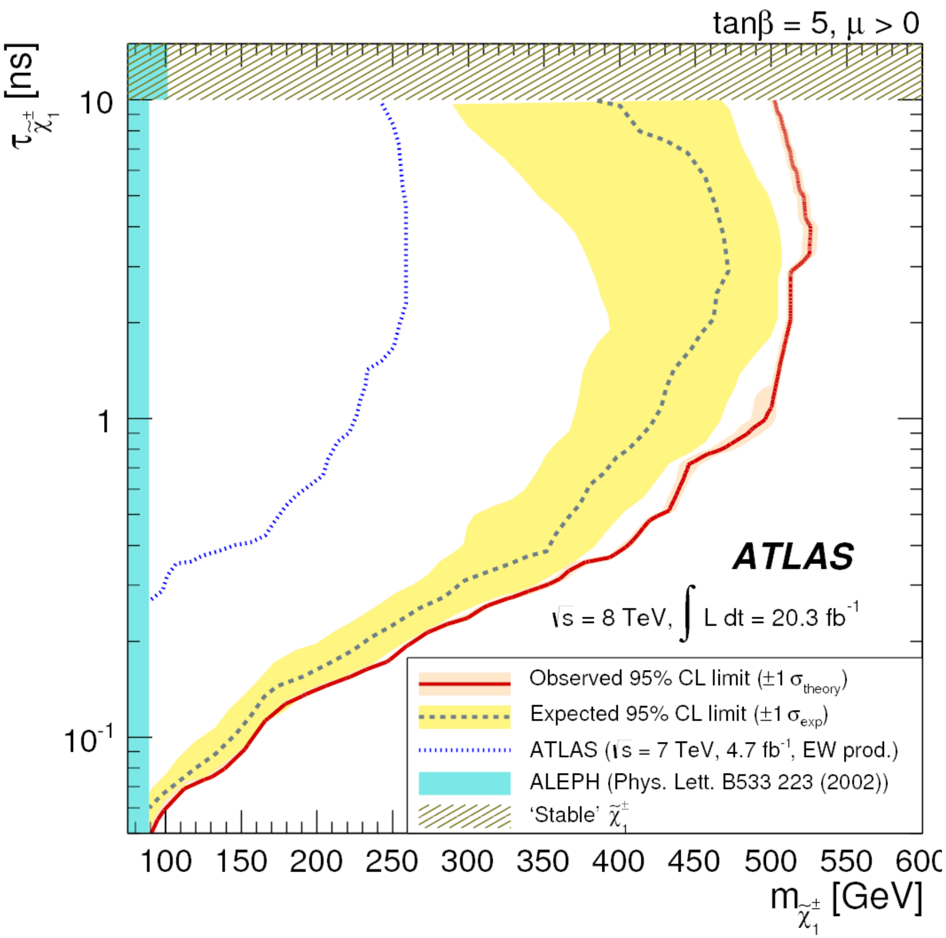


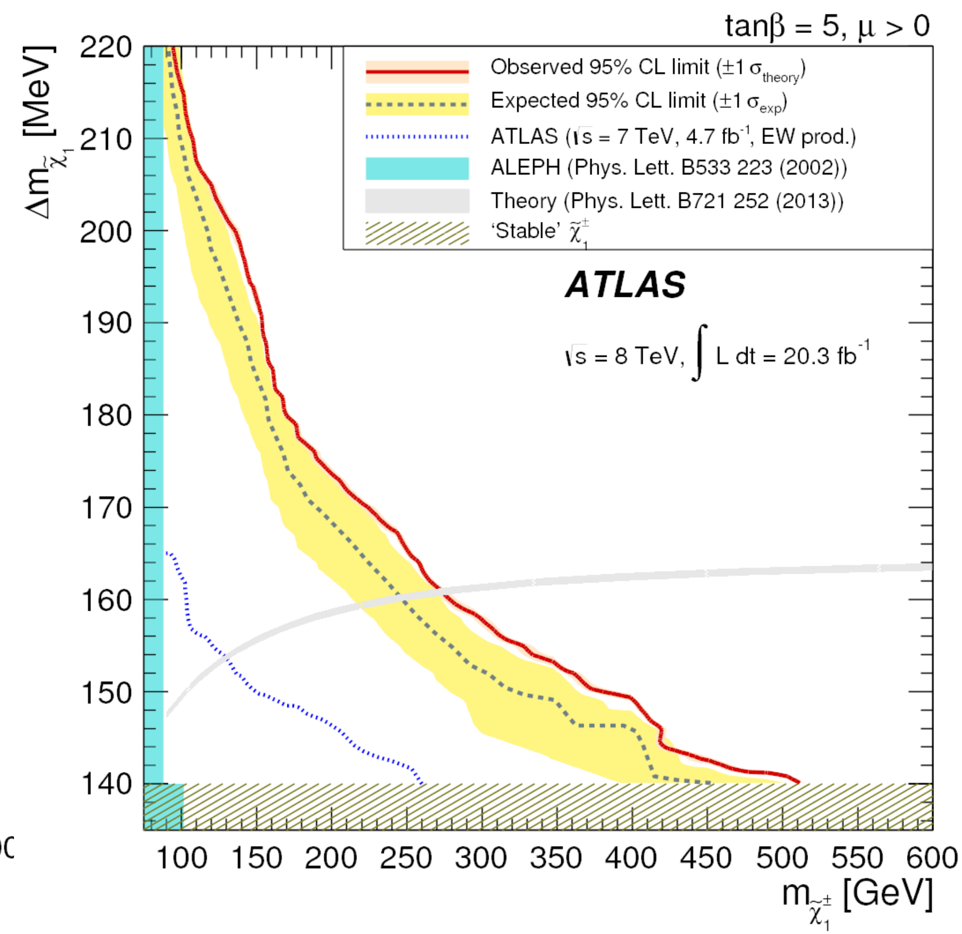
$N_{TRT} < 5$

$p_T^{track} > 75, 100, 150, 200$ GeV

Ограничения на $m(\tilde{\chi}_1^{\pm})$, $\tau(\tilde{\chi}_1^{\pm})$ и $m(\tilde{\chi}_1^{\pm})$-$m(\tilde{\chi}_1^{0})$ в событиях с большим E_T^{miss} и "исчезающим" треком

arXiv:1310.3675





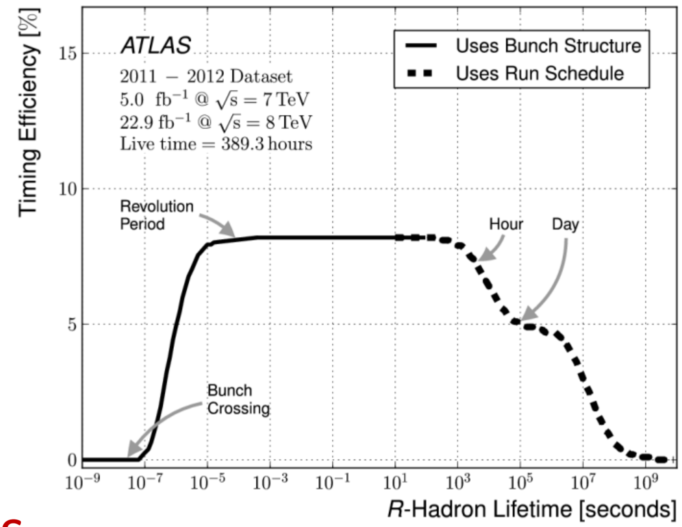
For τ ~ *0.2* ns, charginos excluded up to 270 GeV

For τ ~ *1–10* ns, chargino excluded up to 520 GeV

Поиск долгоживущих остановившихся R-адронов
"decaying out of time with pp collisions" arXiv:1310.6584

long-lived gluino: $(\tilde{g}q\bar{q})$, $(\tilde{g}qqq)$, $(\tilde{g}g)$

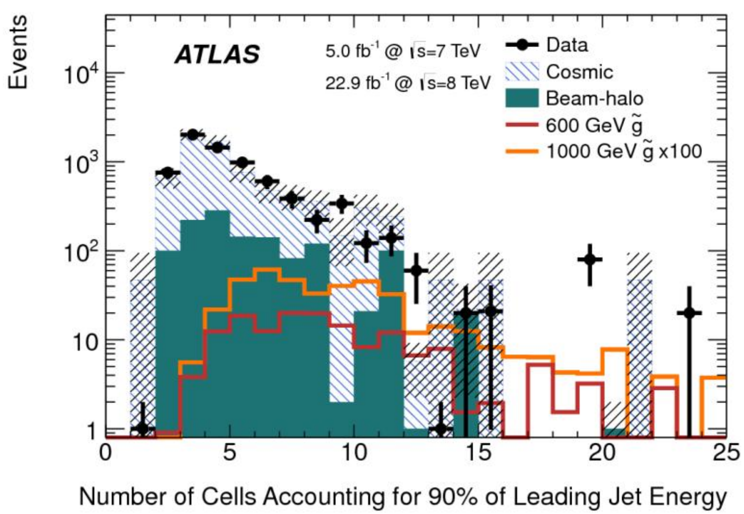
long-lived squark: $(\tilde{t}\bar{q})$, $(\tilde{b}\bar{q})$



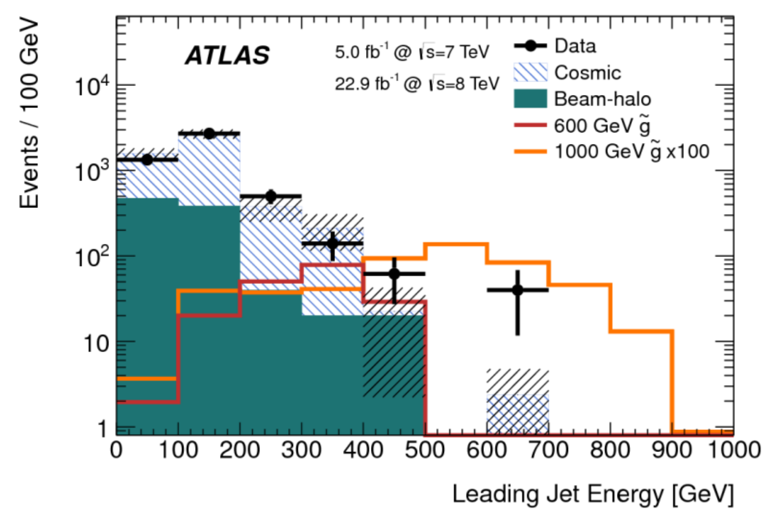
$R_{hadron} \longrightarrow \tilde{\chi}^0$ + *hadronic jets* at a later time

signature: large E_T^{miss} and jet activity in empty bunch crossings

E_T^{miss} / $E_T^{leading\ jet}$ > 0.5, no muons segments



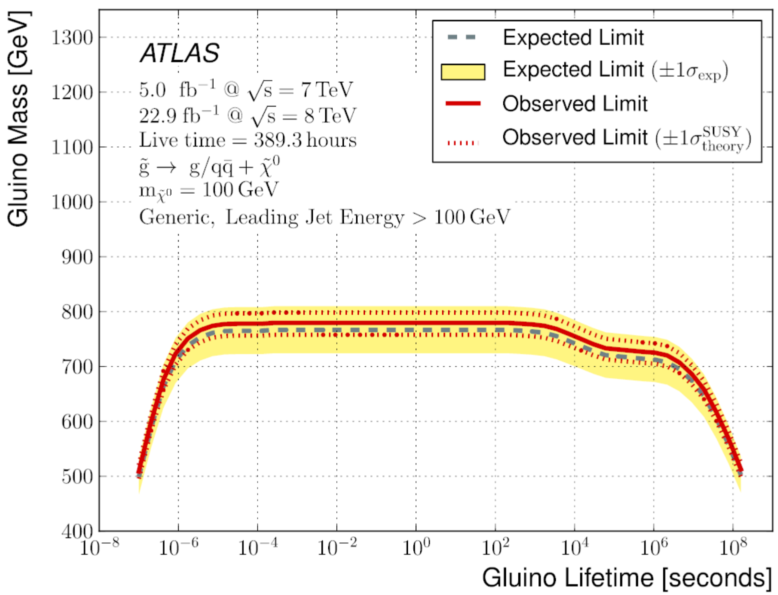
> 3

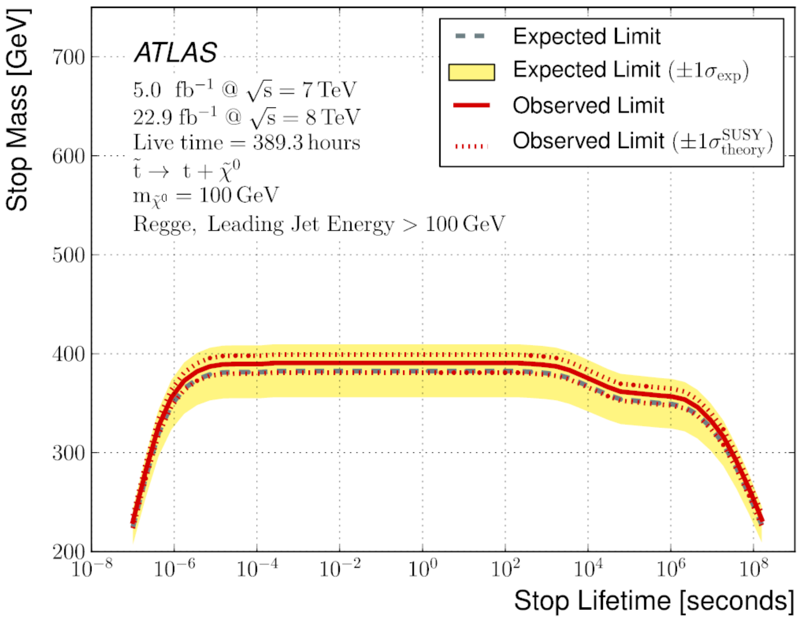


> 100, 300 GeV

Ограничения на характеристики $\tilde{g}$, $\tilde{t}$ и $\tilde{b}$ из долгоживущих остановившихся R-адронов

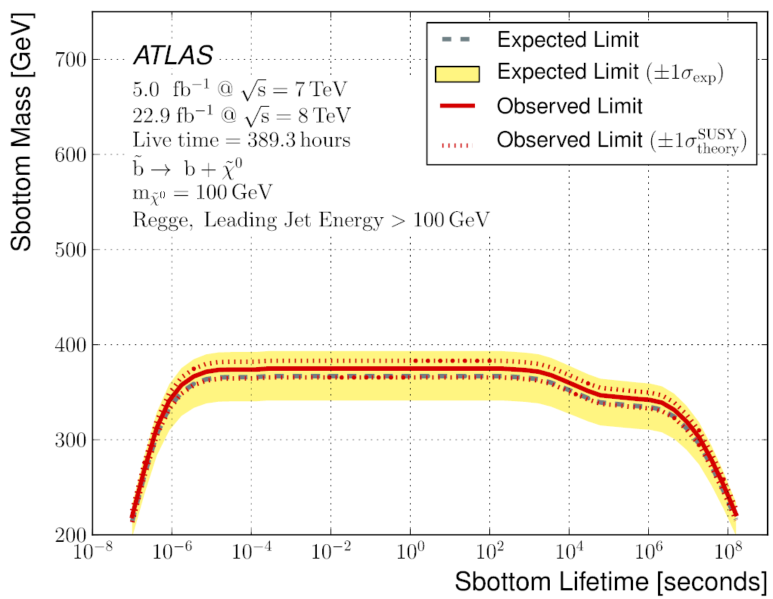
arXiv:1310.6584



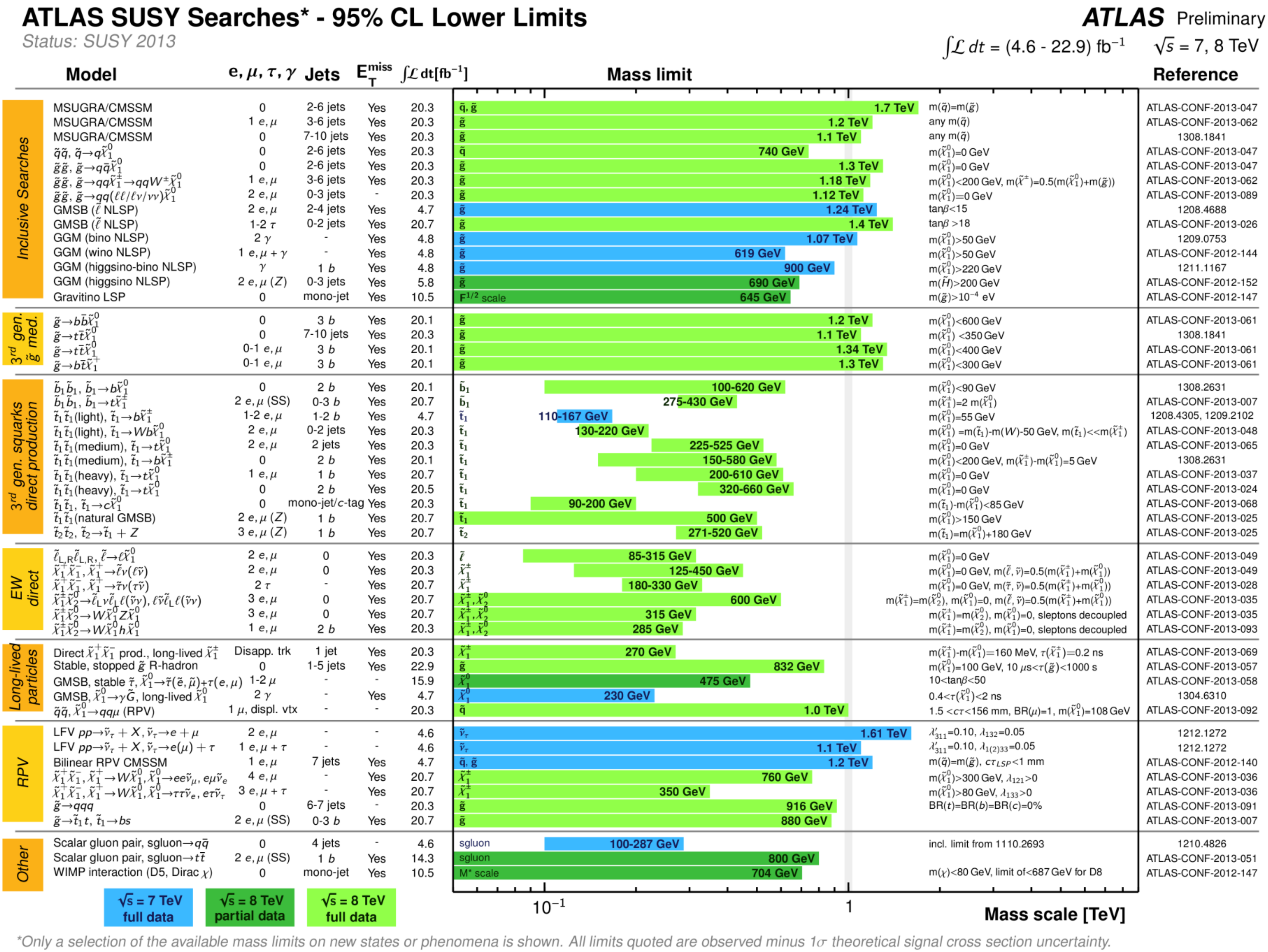


Limits are somewhat model dependent

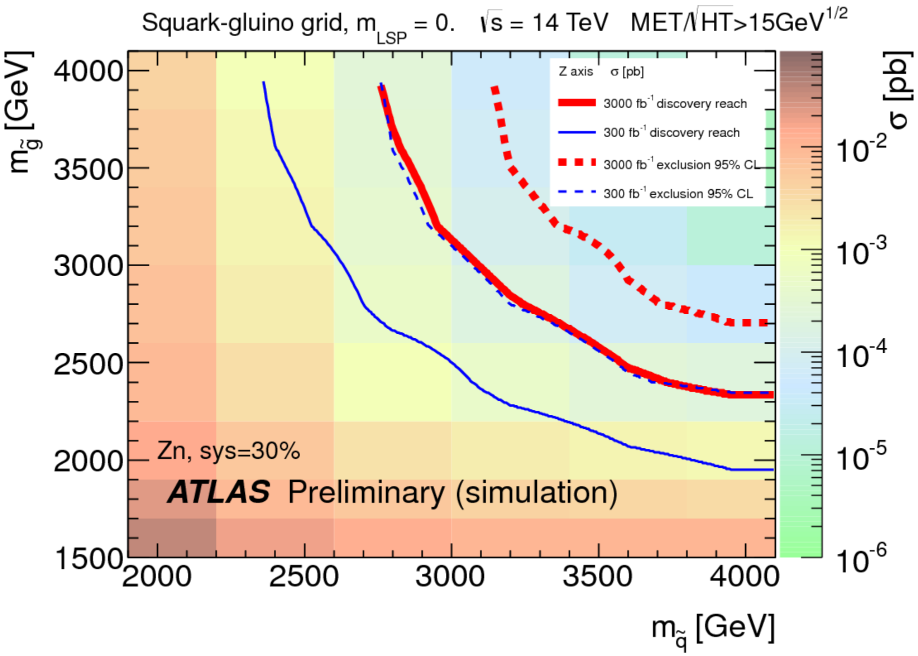
Conclusion is general –
No SUSY signature (yet?)

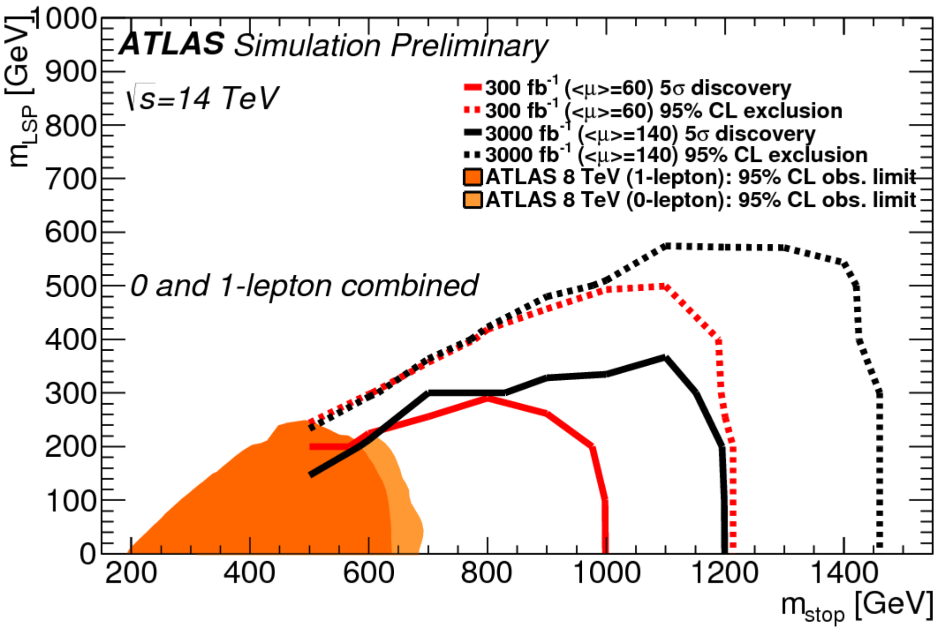


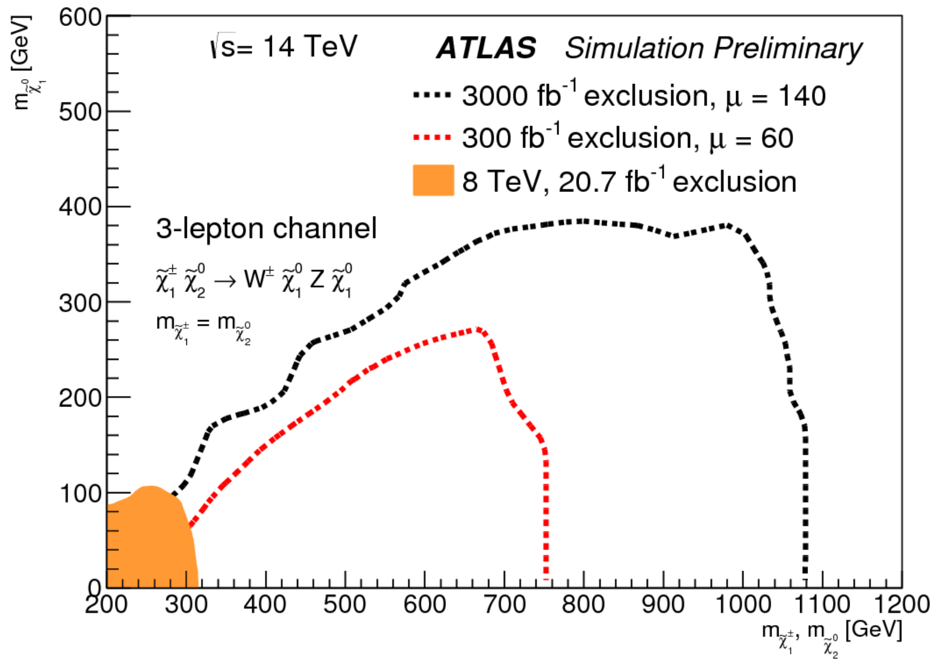
Ограничения на массы суперсимметричных партнёров



Перспективы обнаружения SUSY в эксперименте ATLAS

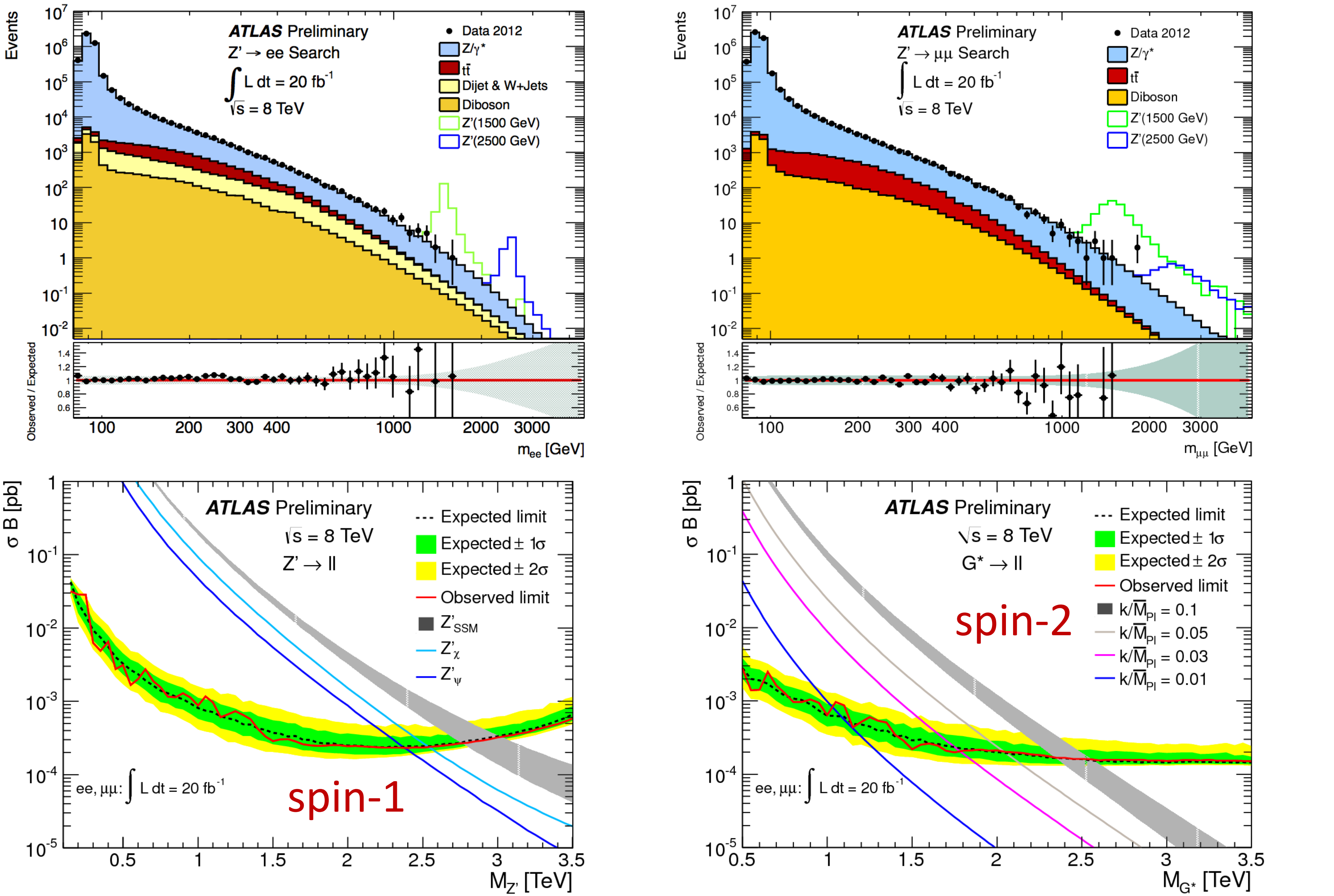






Поиск тяжёлых двух-лептонных резонансов

ATLAS-CONF-2013-017

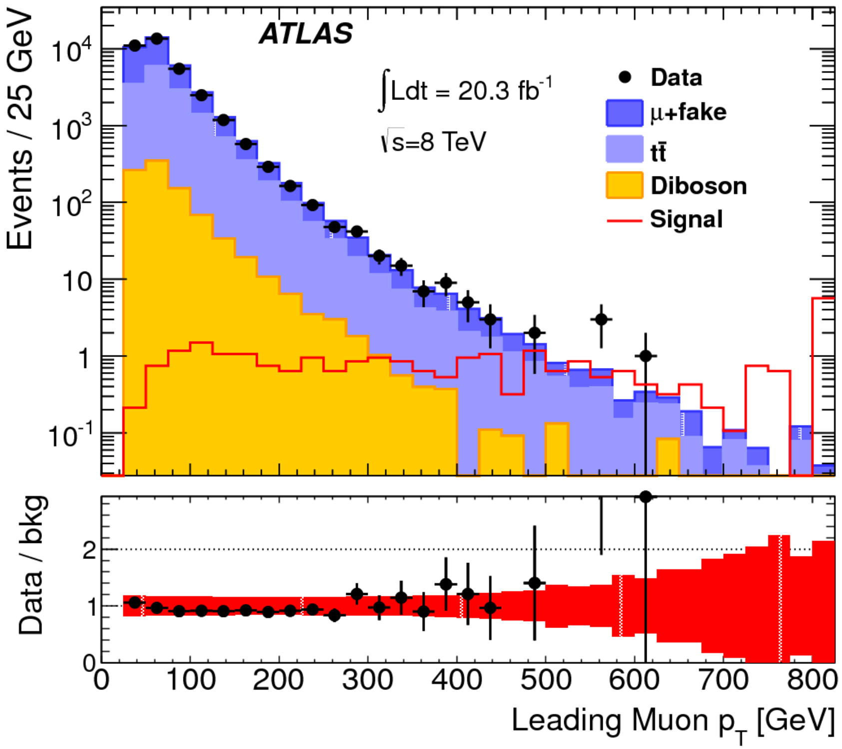


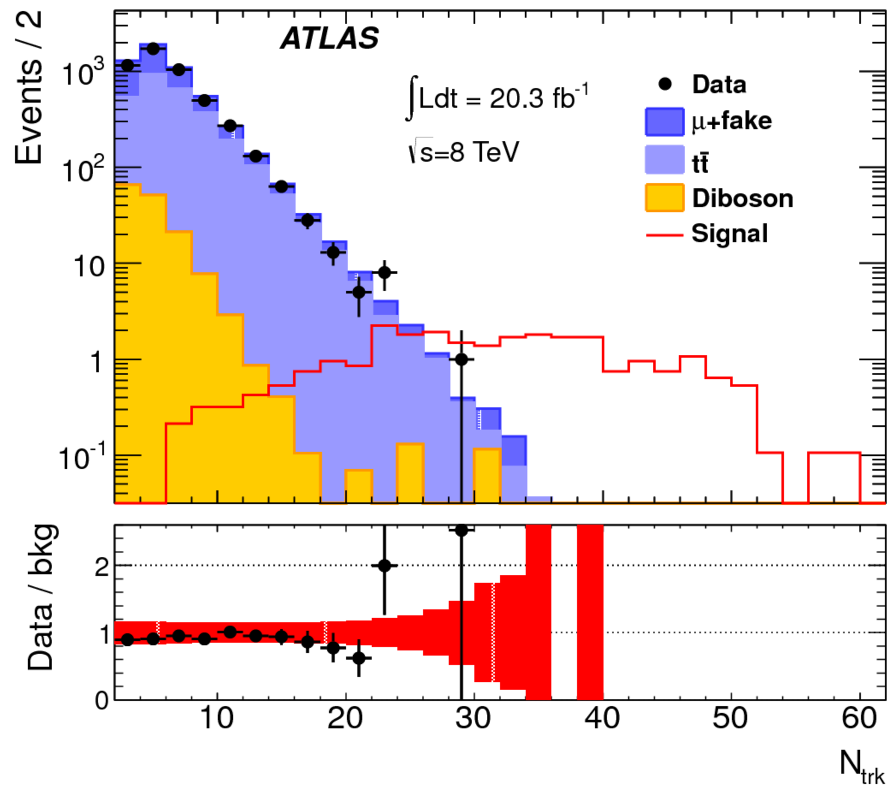
limits on *m(Z')* (SSM and GU E6)

limits on *m(G*)* (RS graviton)

Поиск микроскопических чёрных дыр в событиях с большой множественностью и двумя мюонами одного знака

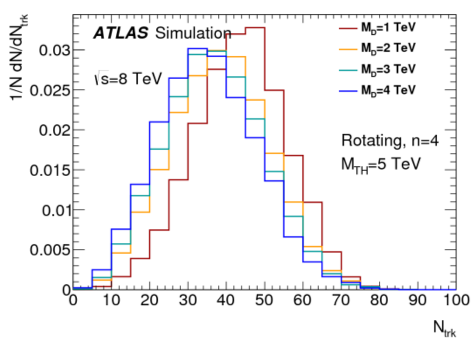
arXiv:1308.4075





$p_T(\mu) > 100$ GeV

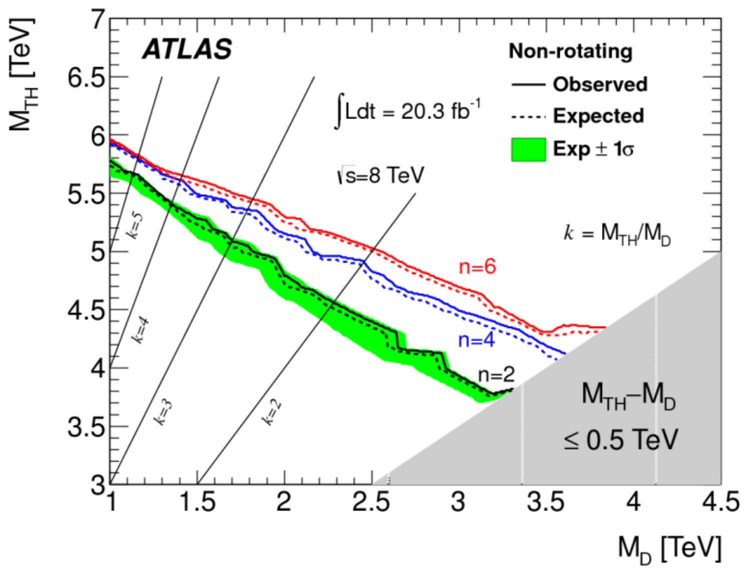
$N_{trk} > 30$ ($p_T^{track} > 10$ GeV)

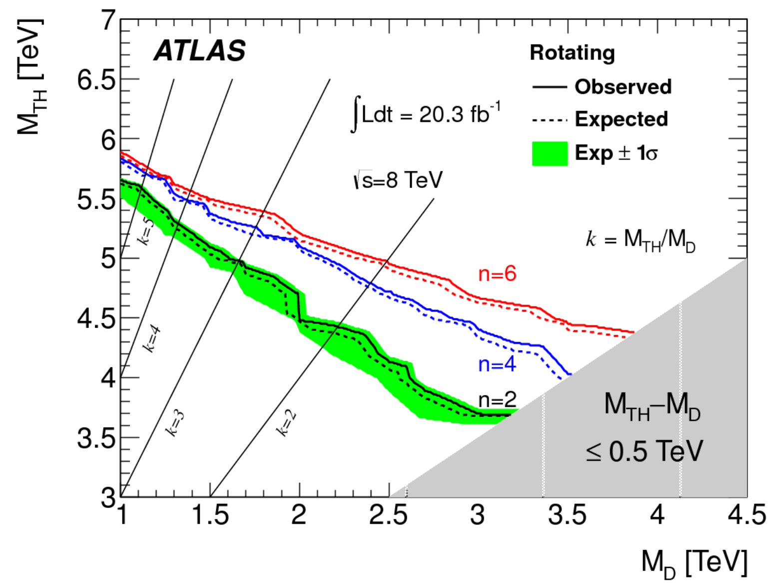


"Signal" – rotating black hole for *$n=4$, $M_{TH}=5$ TeV, $M_D=1.5$ TeV*

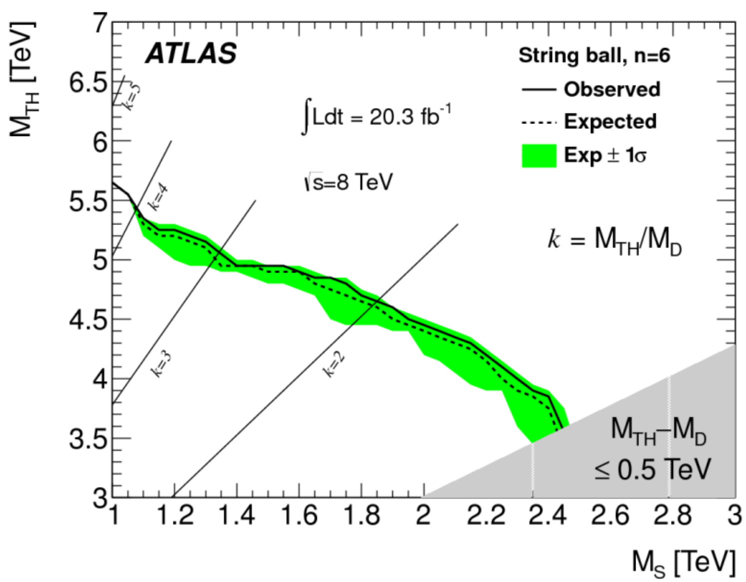
Ограничения на рождение микроскопических чёрных дыр и “струнных клубков” (BlackMax)

arXiv:1308.4075





$k = M_{TH}/M_D$, $k >> 1$ corresponds to physical models



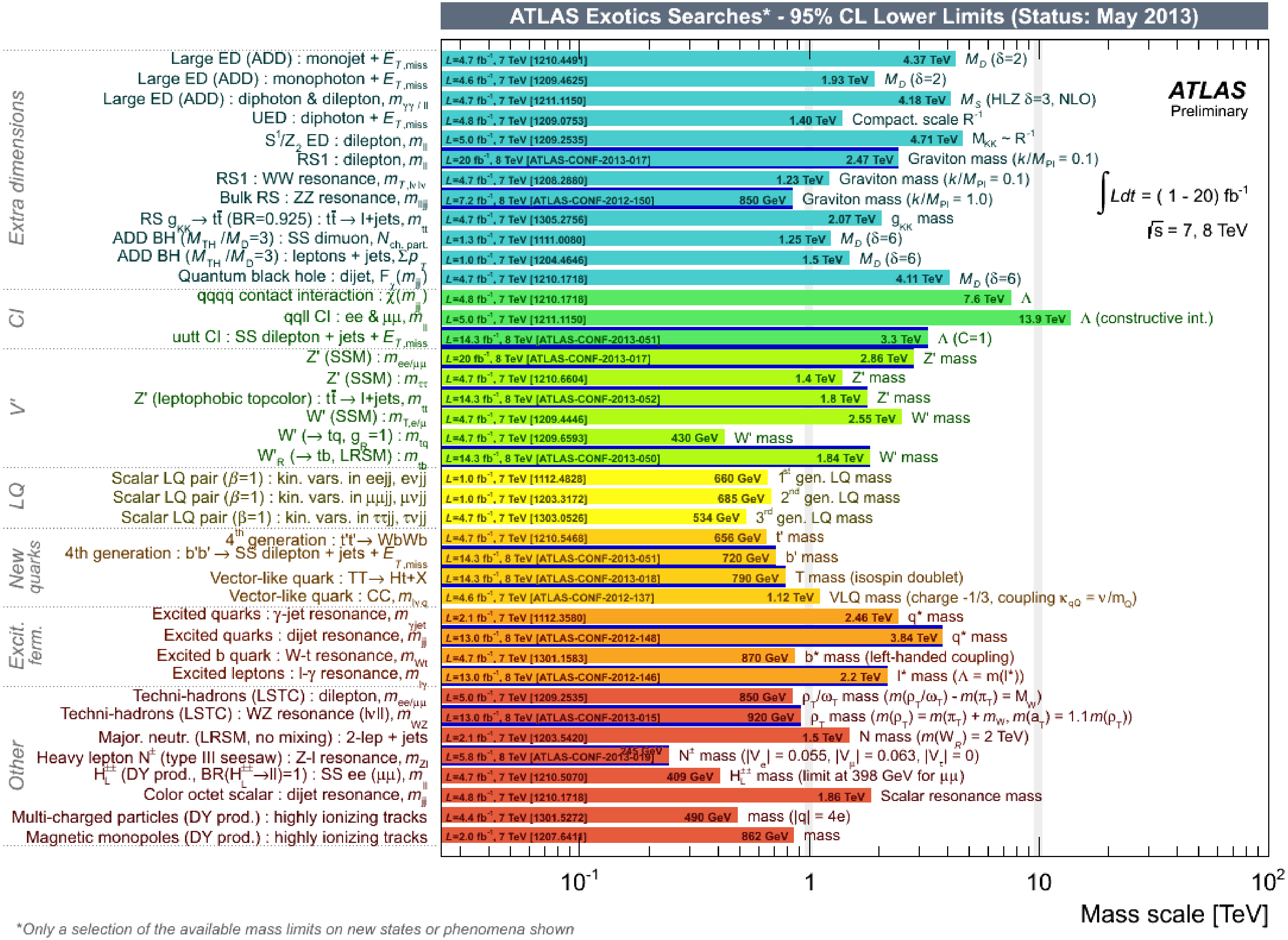
Weakly-coupled string model

$M_D = 5^{1/(n+1)}\, M_S$

$g_S^2 = 1/5^{(n+2)/(n+1)}$

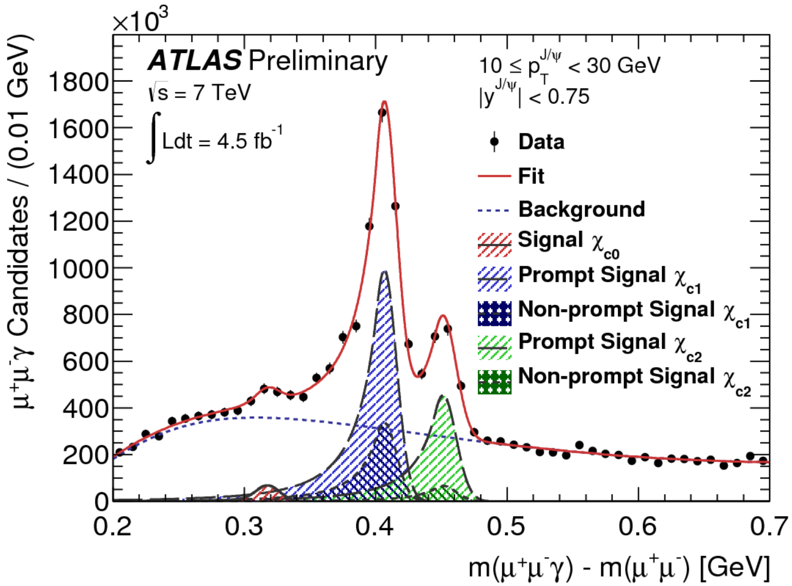
Model	n	M_{TH}[TeV]$\geq$
Non-rotating black hole	2	5.3
Non-rotating black hole	4	5.6
Non-rotating black hole	6	5.7
Rotating black hole	2	5.1
Rotating black hole	4	5.4
Rotating black hole	6	5.5
String ball	6	5.3

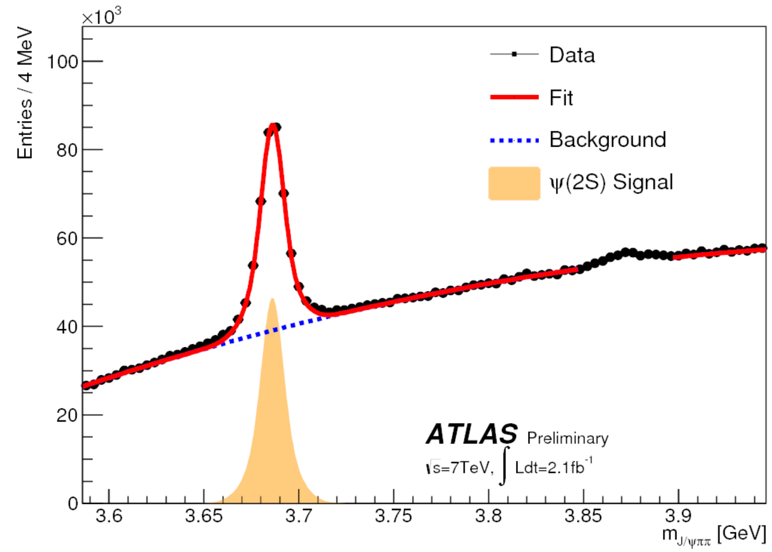
Ограничения на массы “новых” частиц (не SUSY)



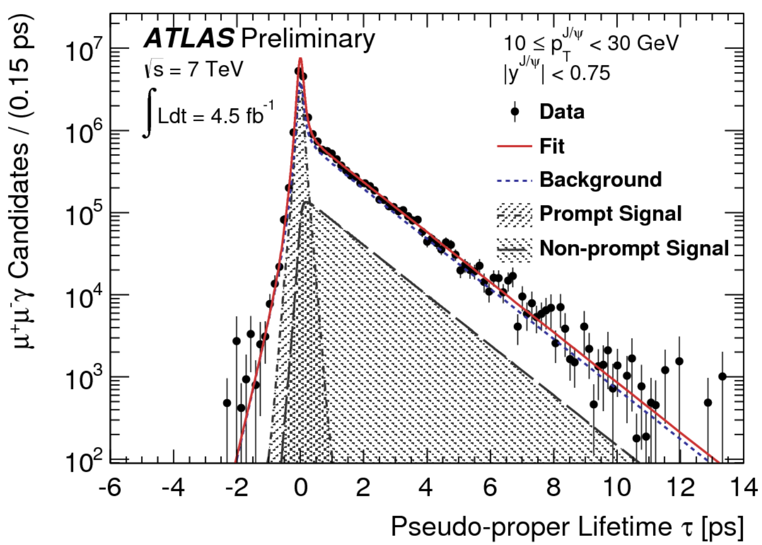
Измерение рождения кваркониев $\chi_{c1}, \chi_{c2}, \psi(2S)$

ATLAS-CONF-2013-094, ATLAS-CONF-2013-095





only photon conversions are used

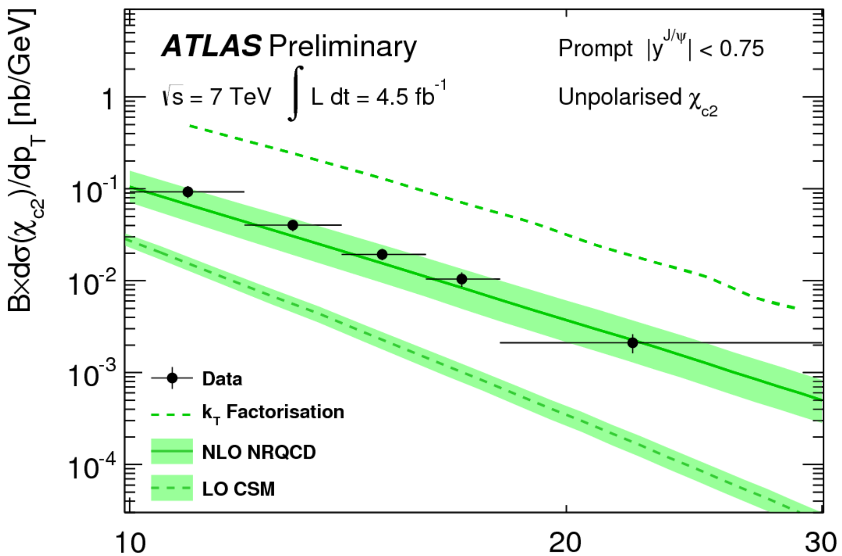


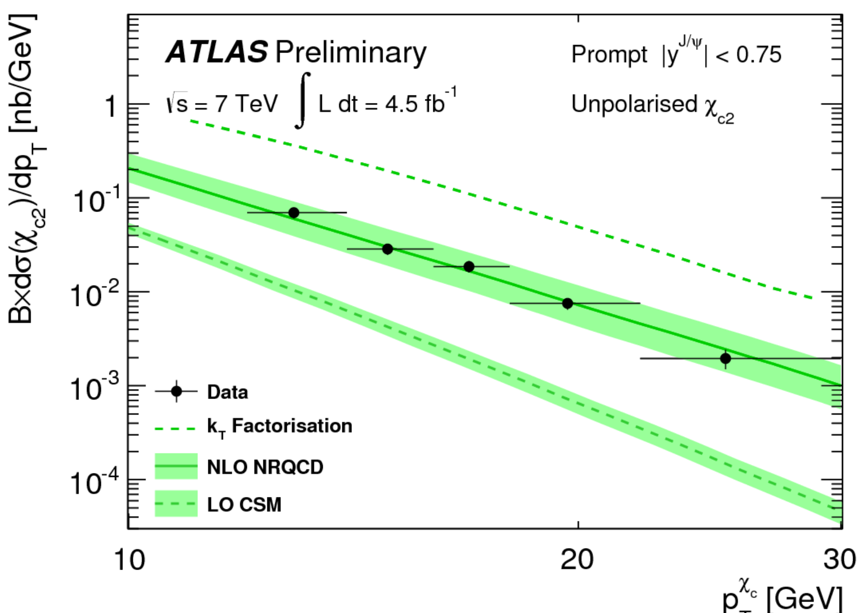
To separate prompt and non-prompt (from B decays) production pseudo-proper lifetime is used

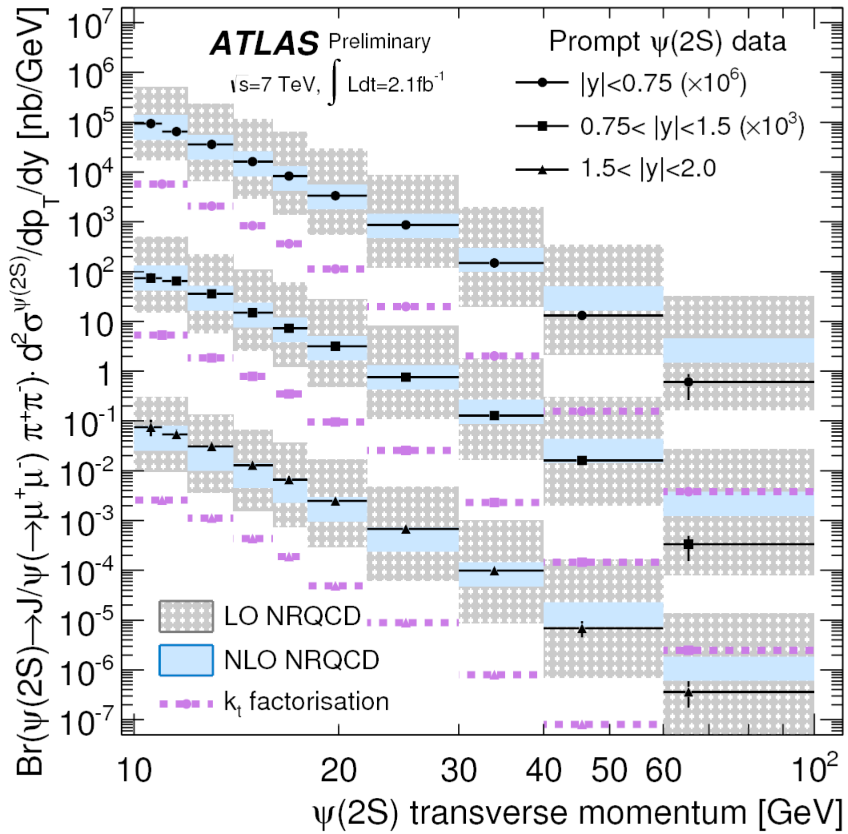
$$\tau = \frac{L_{xy} \cdot m_{J/\psi}}{|\vec{p_T}|} \qquad L_{xy} = \frac{\vec{L} \cdot \vec{p_T}}{|\vec{p_T}|}$$

Сечения прямого рождения кварткониев $\chi_{c1}, \chi_{c2}, \psi(2S)$

ATLAS-CONF-2013-094, ATLAS-CONF-2013-095







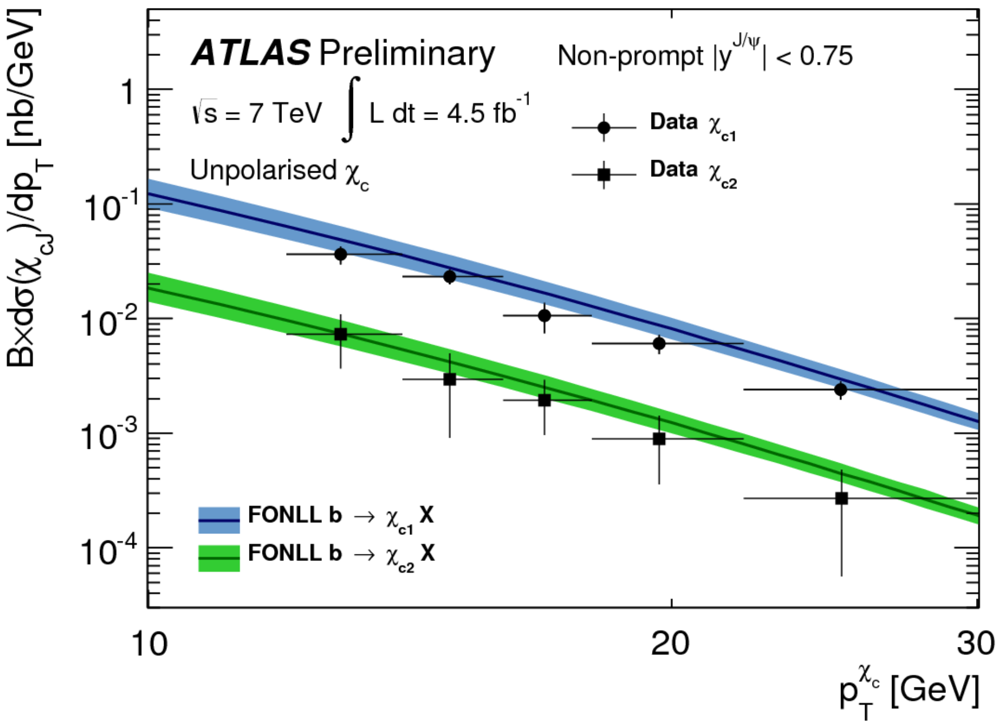
LO CSM - too low

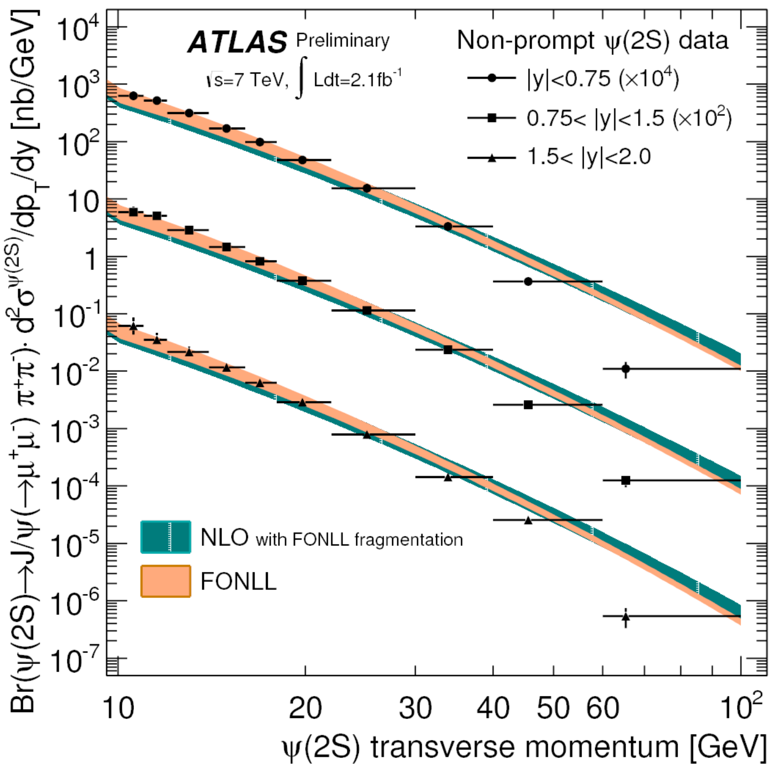
NLO NRQCD - o.k. (somewhat harder)

k_T factorisation - problems?

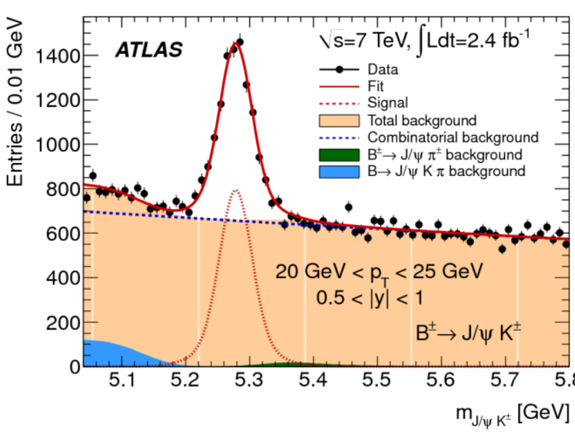
Сечения непрямого рождения $\chi_{c1}, \chi_{c2}, \psi(2S)$

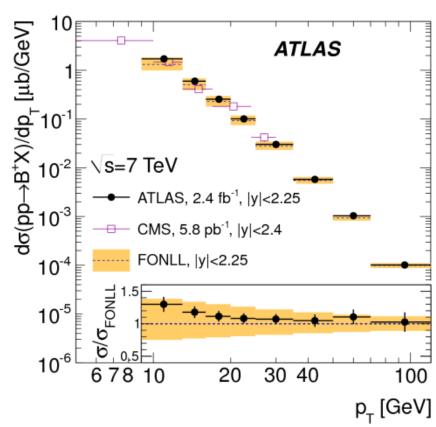
ATLAS-CONF-2013-094, ATLAS-CONF-2013-095





сечение рождения $B^{\pm}$ arXiv:1307.0126

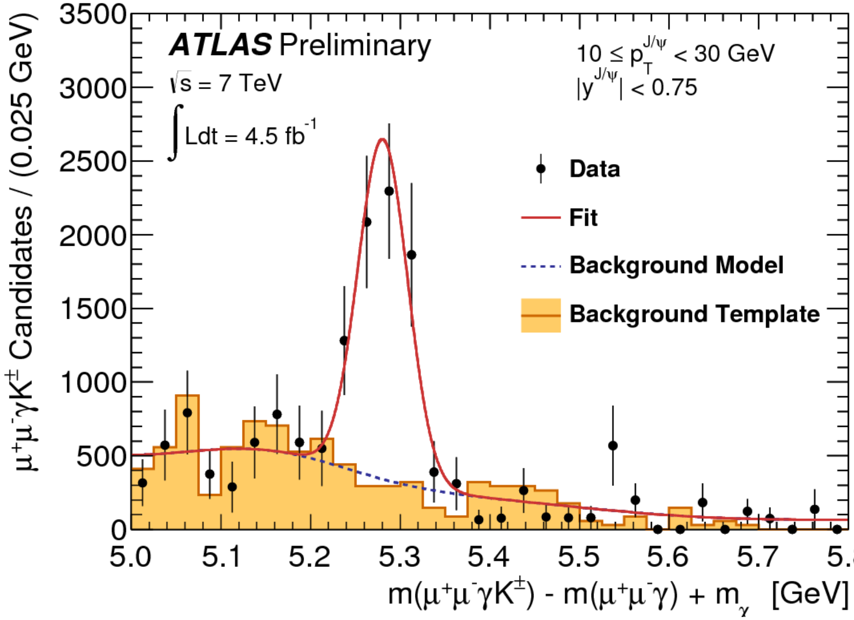




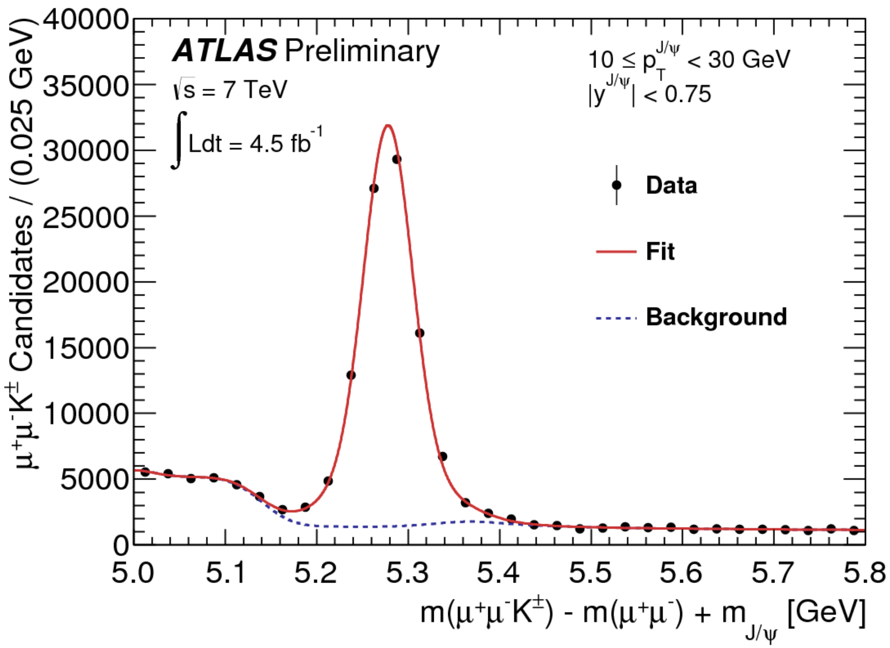
FONLL – o.k. within uncertainties (somewhat harder)

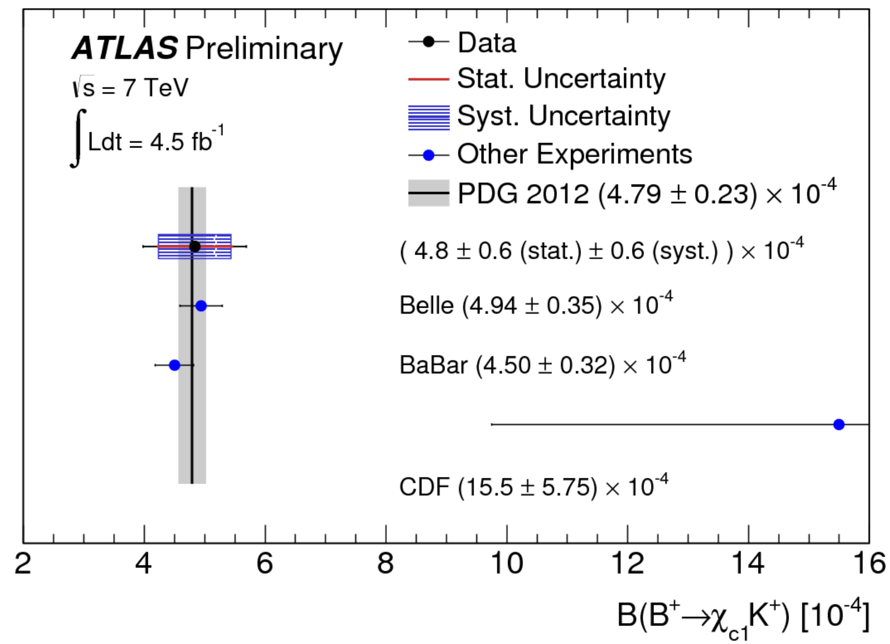
Парциальная ширина распада $B^{+} \longrightarrow \chi_{c1} K^{+}$

ATLAS-CONF-2013-095



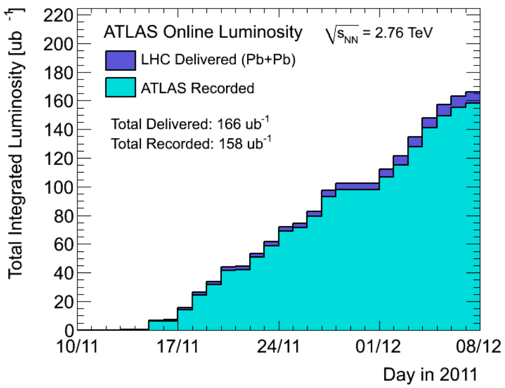
$$\mathcal{B}(B^{\pm} \to \chi_{c1} K^{\pm}) = \mathcal{A}_B \cdot \frac{N^B_{\chi_{c1}}}{N^B_{J/\psi}} \cdot \frac{\mathcal{B}(B^{\pm} \to J/\psi K^{\pm})}{\mathcal{B}(\chi_{c1} \to J/\psi\, \gamma)}$$

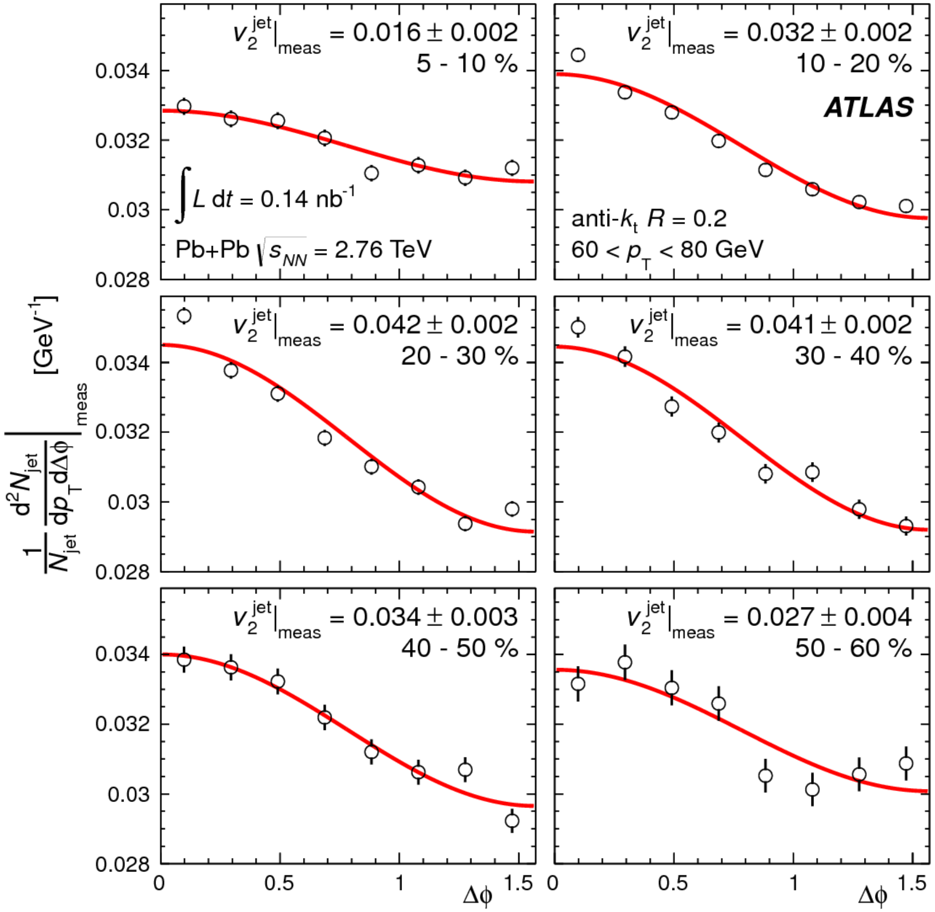




Азимутальная зависимость инклюзивного рождения струй в Pb+Pb столкновениях

PRL 105(2010)252303, PLB 719(2013)220,
PRL 111(2013)152301 (arXiv:1306.6469)





Azimuthal angle distribution parametrized by:

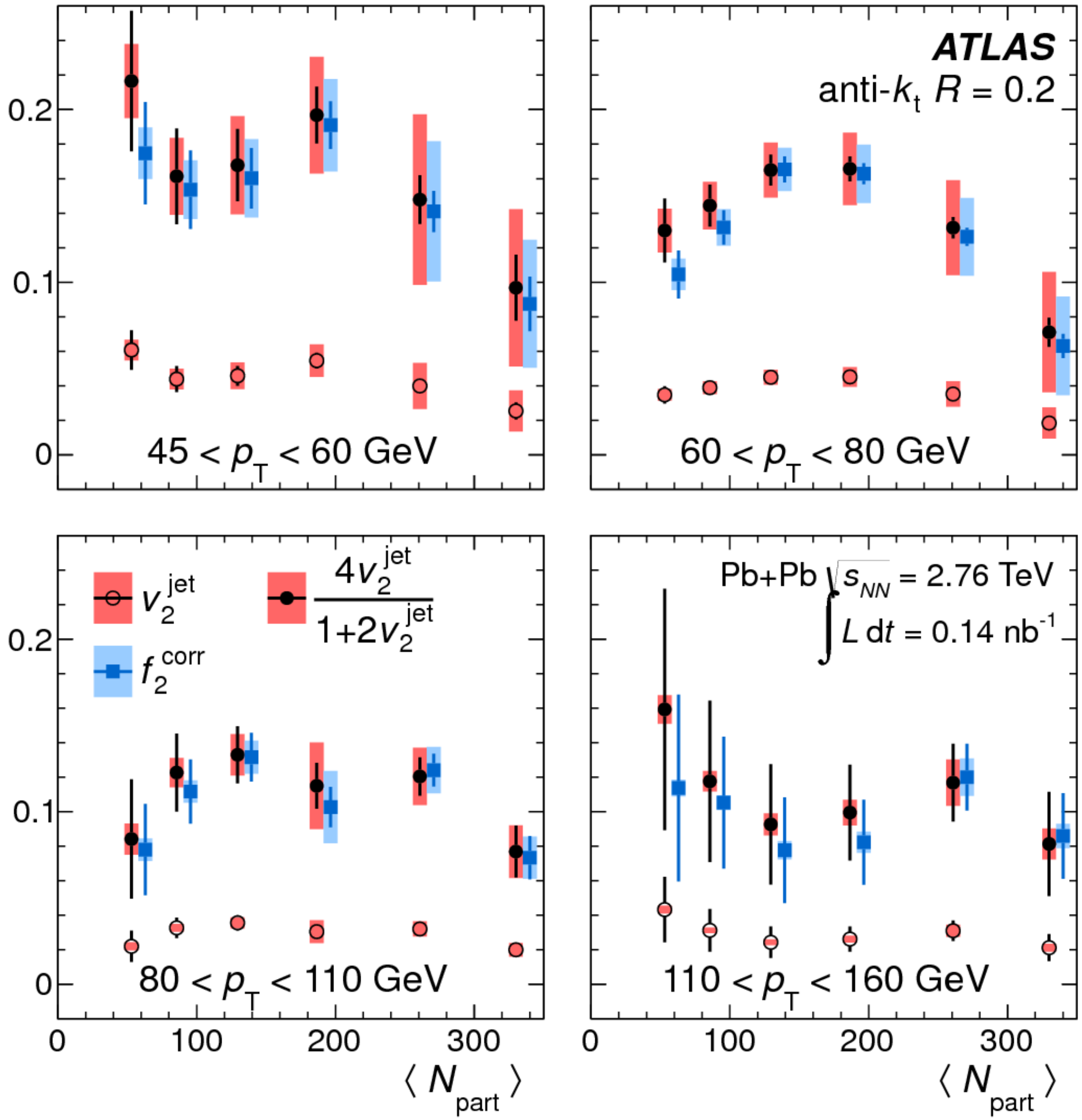
$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos 2(\phi - \Psi_2)$$

Ψ_2 is the elliptic event plane angle

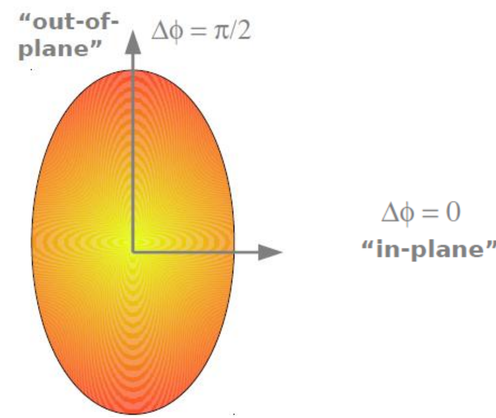
v_2 is the magnitude of the modulation

Significant $\Delta\phi$ variation in the jet yield is observed for all centrality intervals

Азимутальная зависимость инклюзивного рождения струй в Pb+Pb столкновениях



PRL 111(2013)152301
(arXiv:1306.6469)



a suppression by as much as 20% seen for out-of-plane jets comparing to in-plane jets

smaller suppression in the peripheral (small quenching) and the most central (small eccentricity) collisions for *60 < p_T < 110* GeV

$$f_2 = 1 - d^2N_{\rm jet}/dp_{\rm T}d\Delta\phi\big|_{\rm out} \,/\, d^2N_{\rm jet}/dp_{\rm T}d\Delta\phi\big|_{\rm in}$$

Заключение

Higgs boson established

$m_H = 125.5 \pm 0.2\ ^{+0.5}_{-0.6}$ GeV

$J^P = 0^+$

production and decay properties consistent with SM expectations

Searches for new physics ($H^{\pm}$, SUSY, extra dimensions, heavy resonances, …) performed

no new physics observed

limits are set

Many new measurements in QCD and B-physics areas, in particular

measurements of prompt and non-prompt χ_{c1}, χ_{c2}, $\psi(2S)$ *production*

measurement of $B^+ \to \chi_{c1} K^+$ decay branching

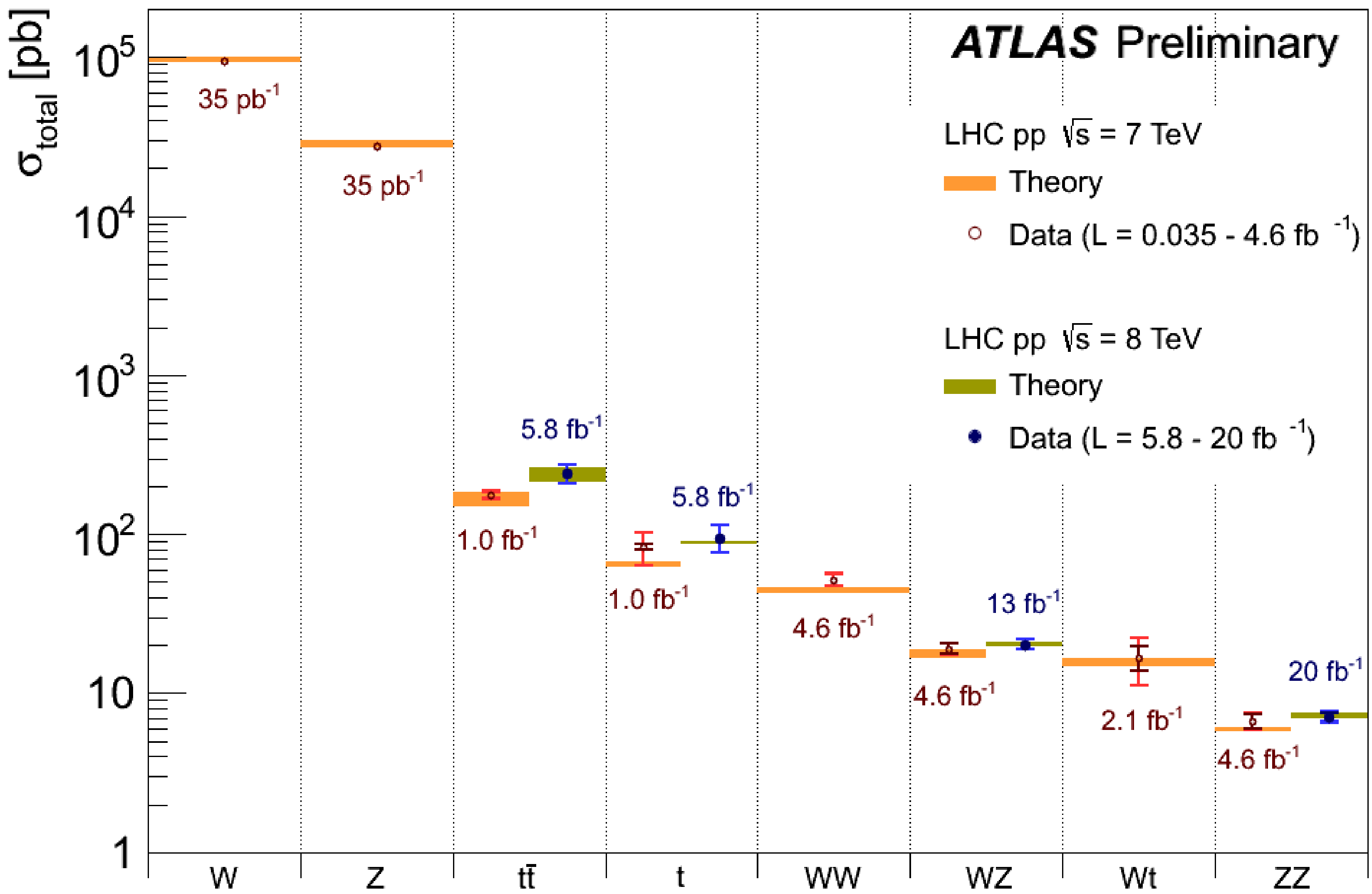
New measurement with Pb+Pb collisions, in particular

azimuthal angle dependence of inclusive jet yields

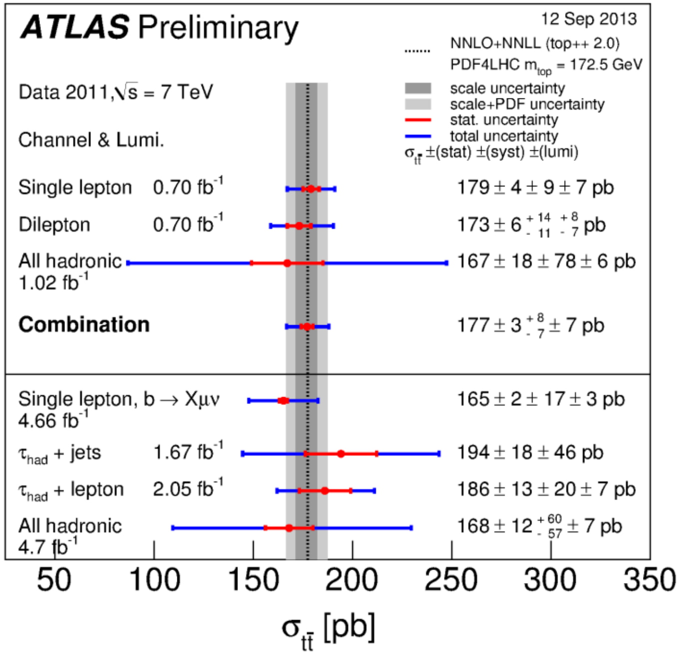
(varied up-to 20% between in-plane and out-of-plane directions)

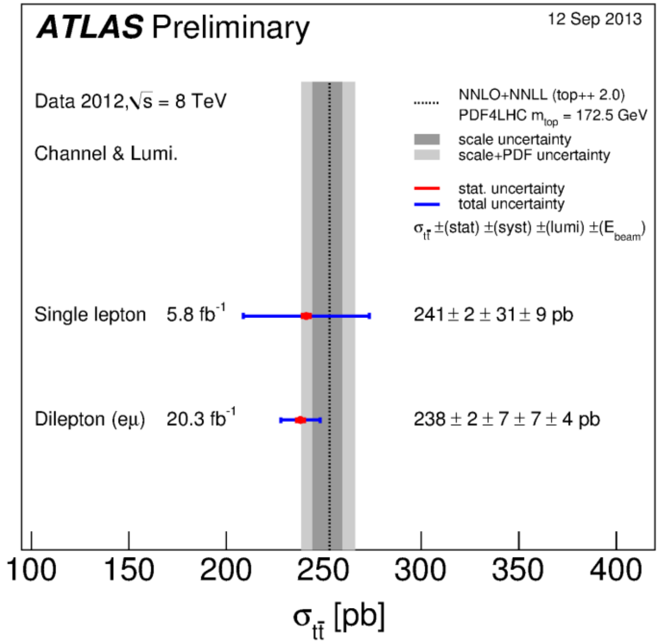
Back-up

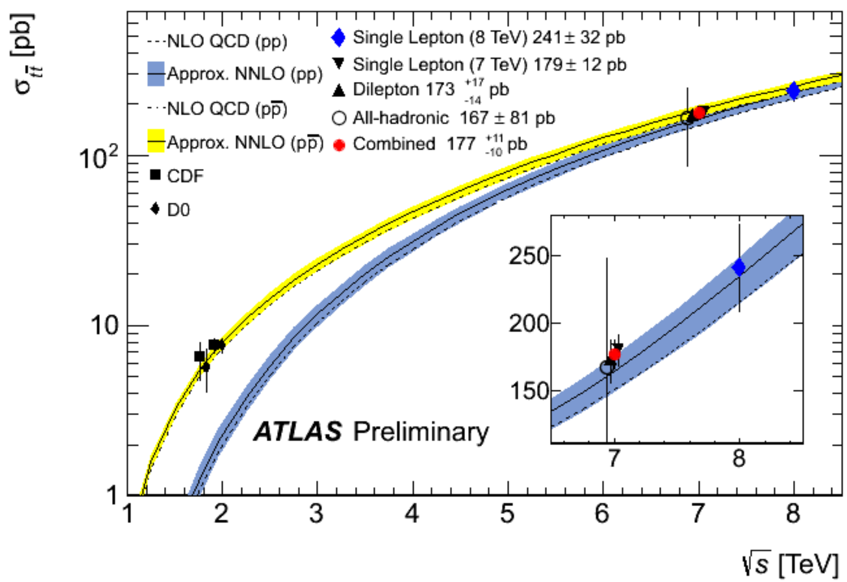
SM measurements



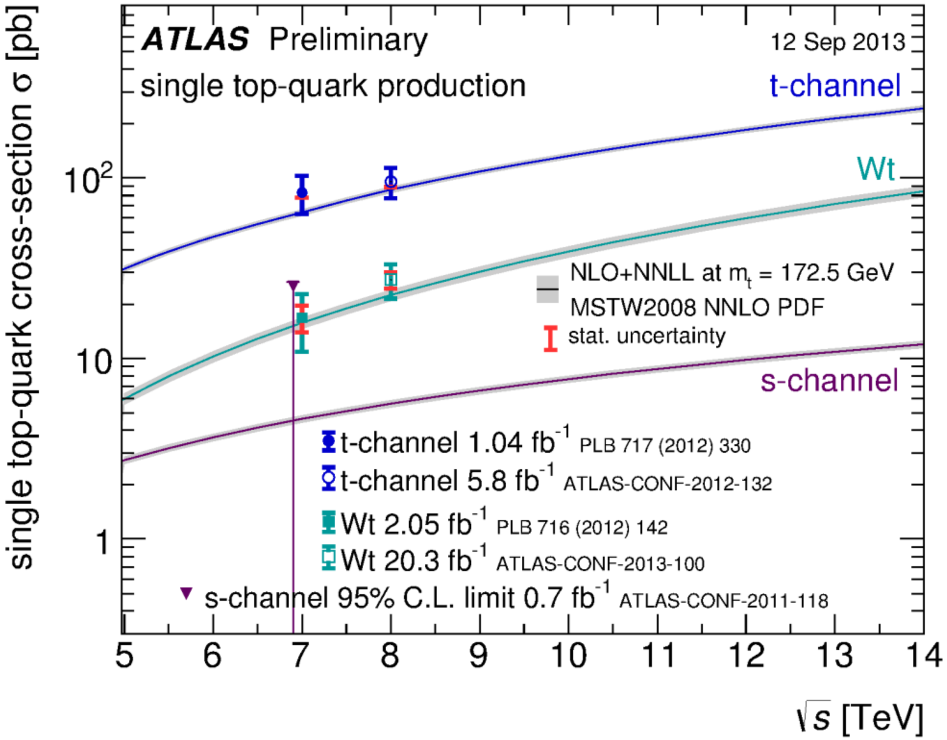
$t\bar{t}$ production

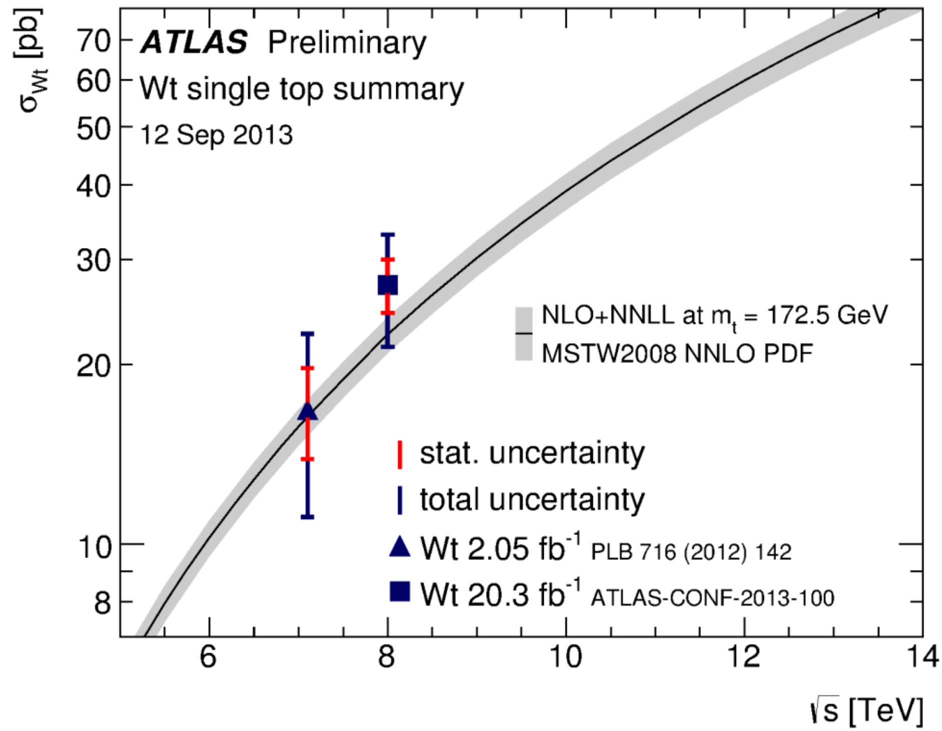




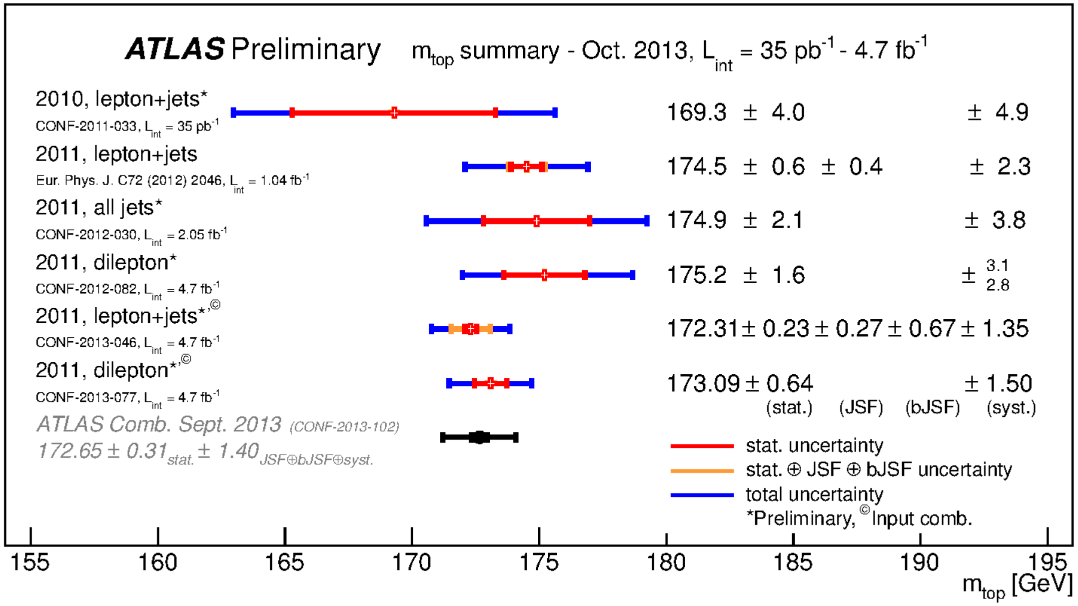


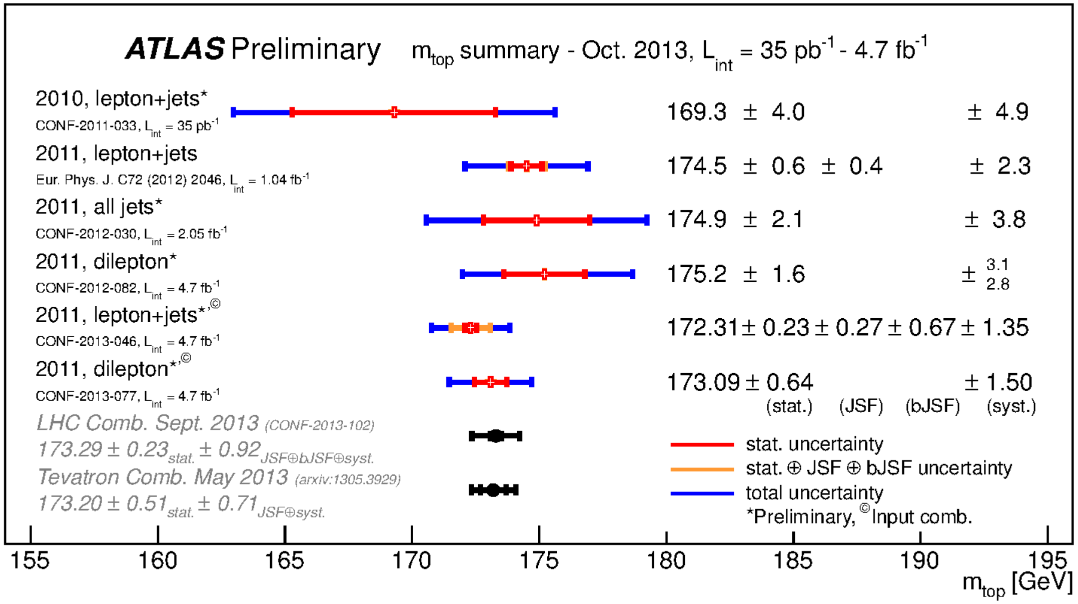
single top production



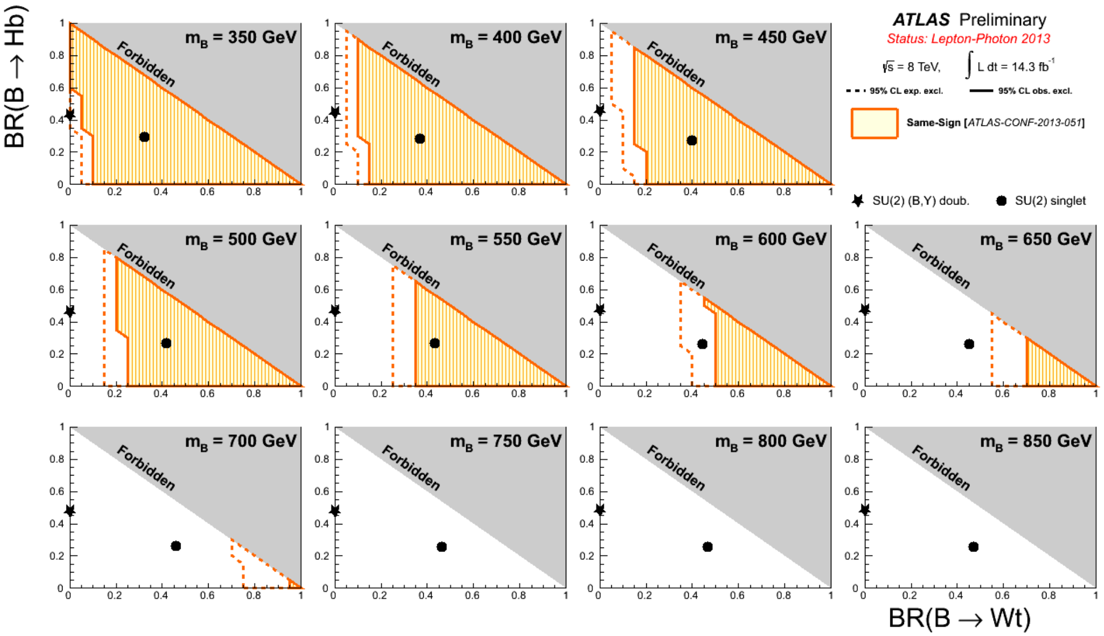


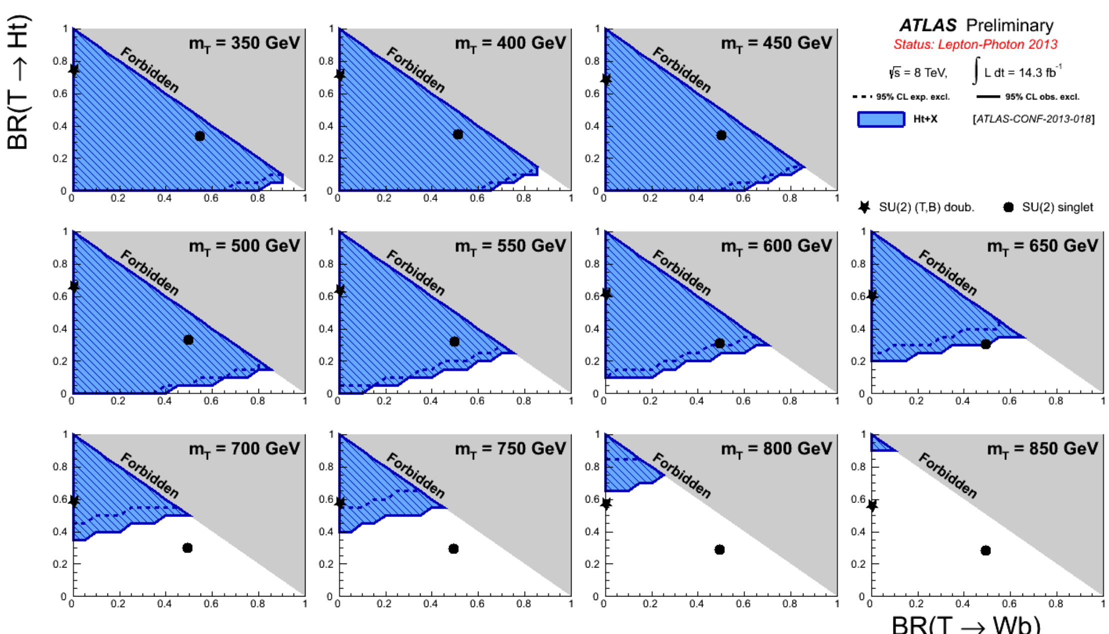
m(t) measurements



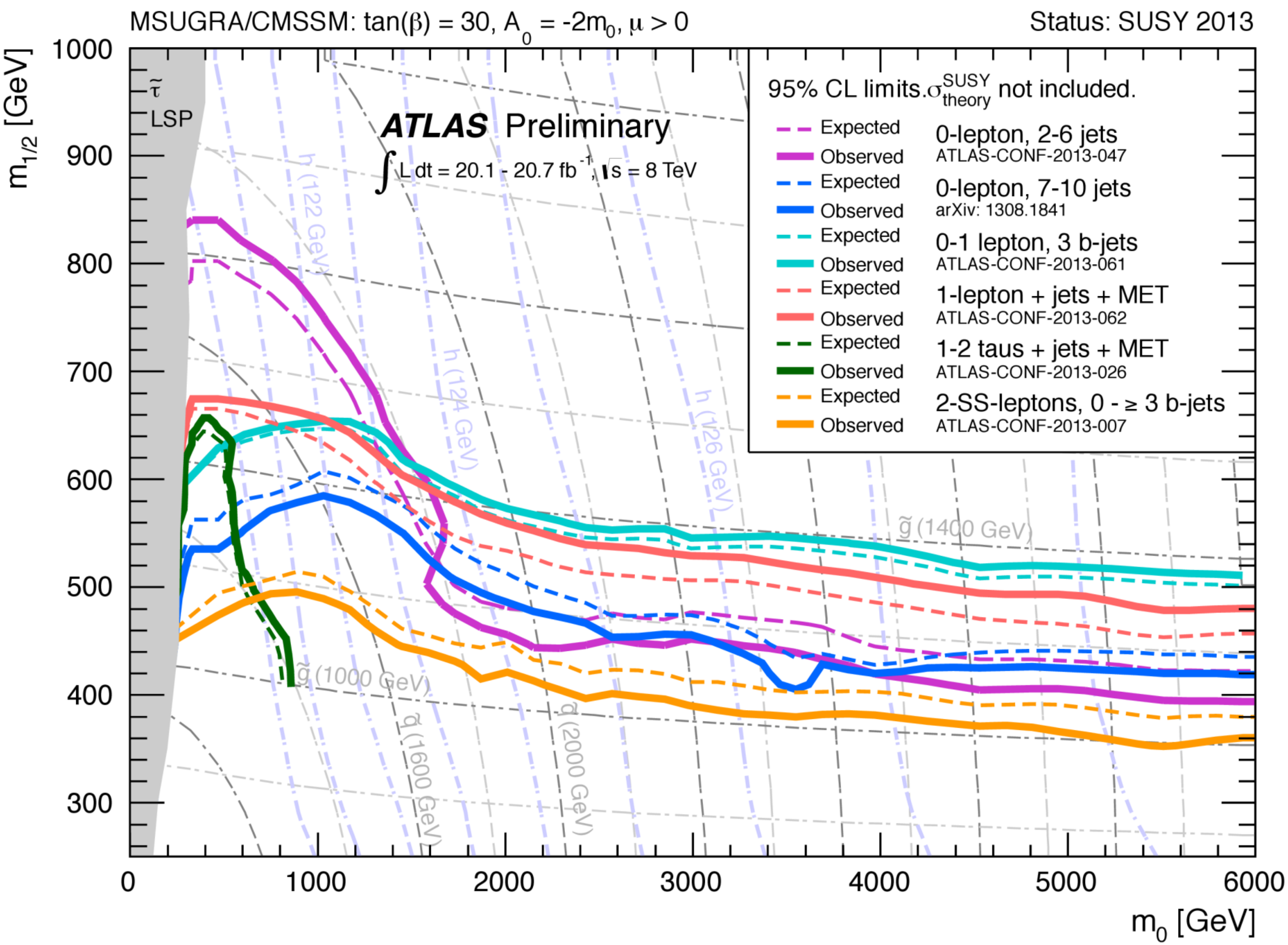


Searches for vector-like B and T quarks

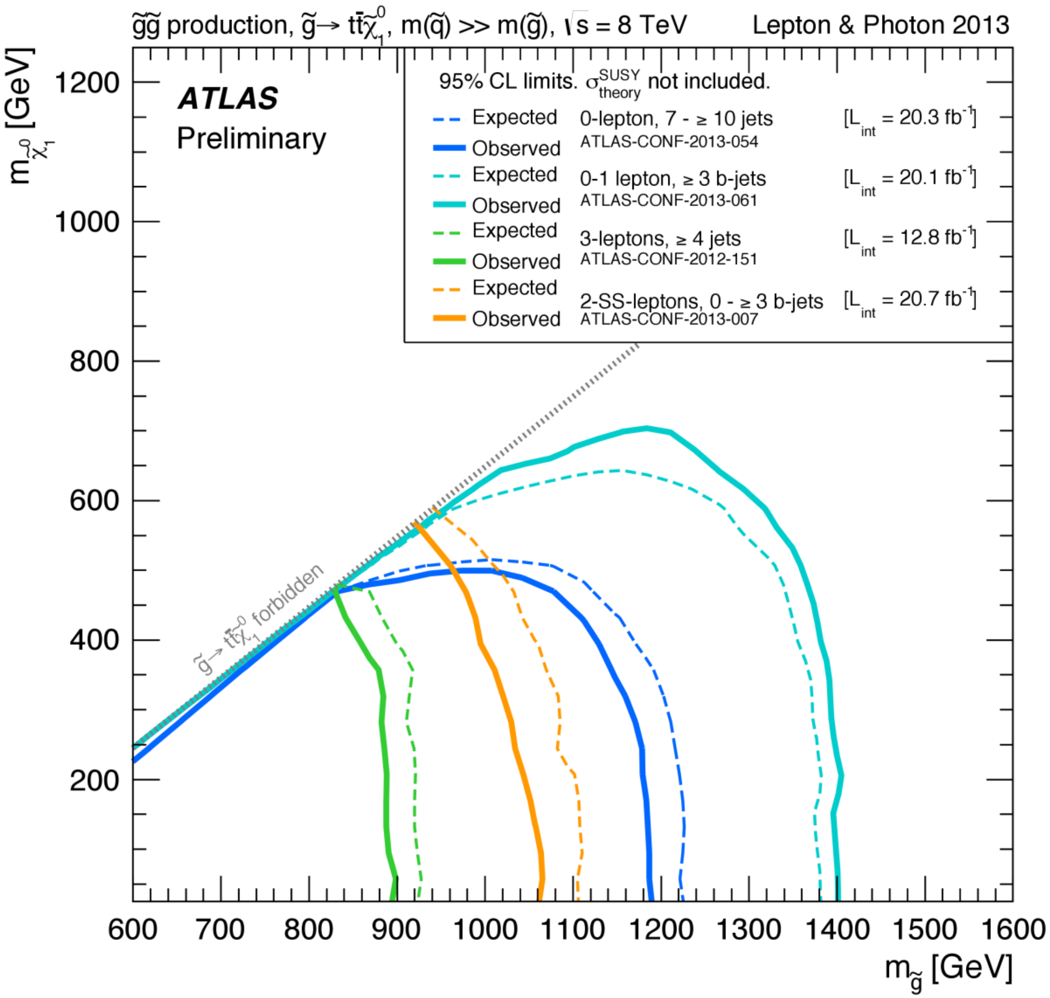


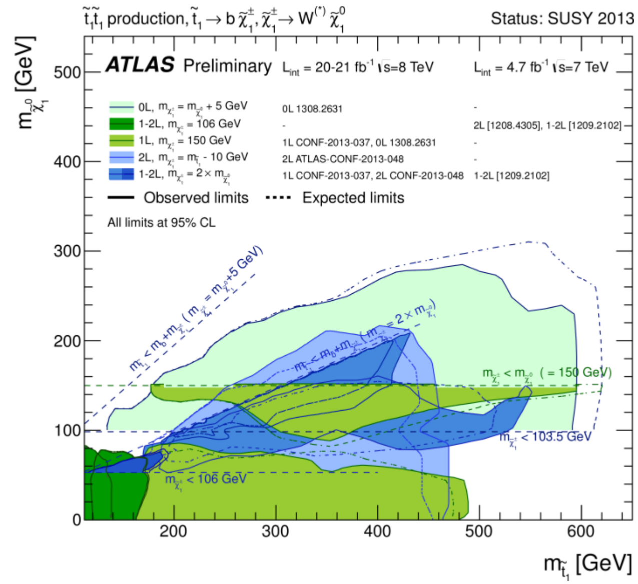


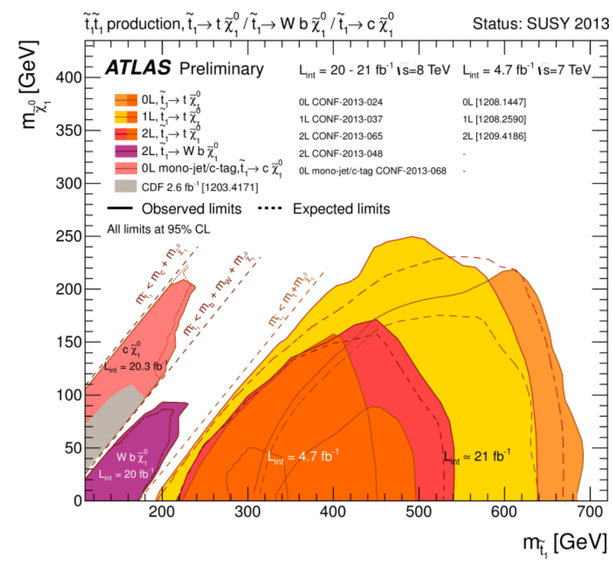
MSUGRA/CMSSM limits



Limits for gluino and stop







Future Higgs measurements