



Istituto Nazionale di Fisica Nucleare



Looking for excited leptons and dilepton high mass exotic searches in ATLAS

COMPOSE-IT

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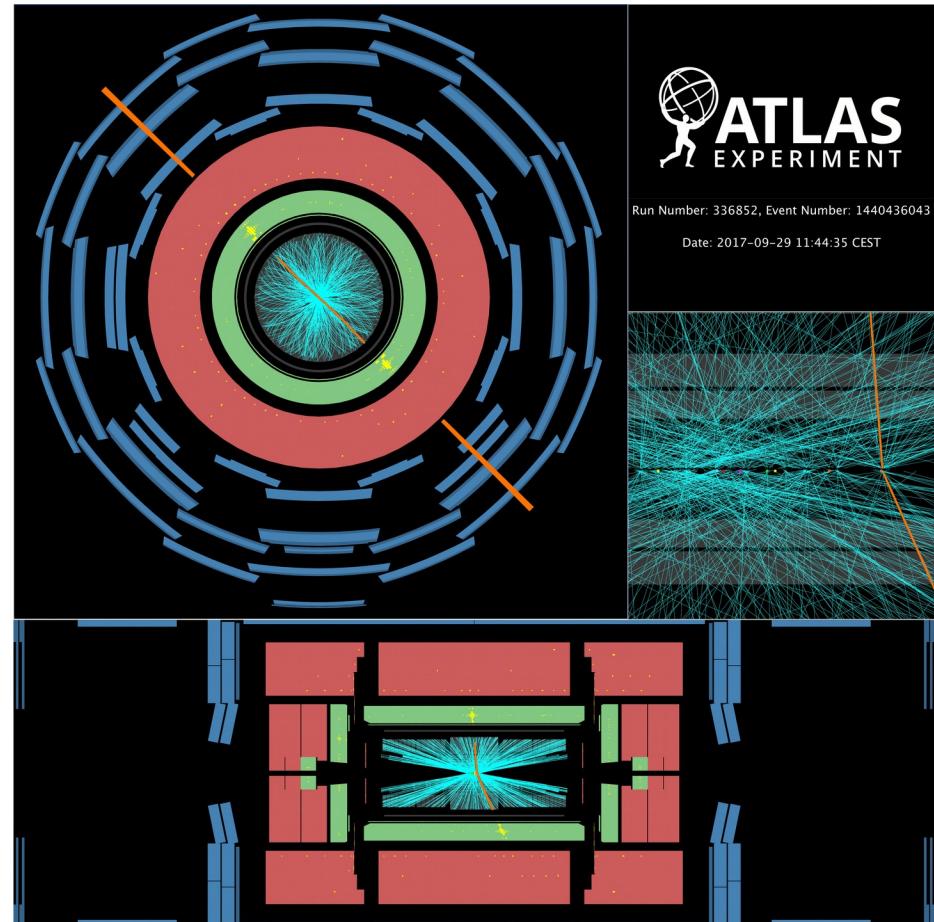
On behalf of the ATLAS Collaboration

A. Sidoti

Introduction

Many Beyond Standard Model extensions predict new phenomena decaying in leptonic final states

- Electrons and muons final states provide low background and high efficiency
- Excellent energy and momentum resolution



Focus on:

- Excited lepton searches [Eur. Phys. J. C 79 \(2019\) 803](#)
- Dilepton resonance searches [Phys. Lett. B 796 \(2019\) 68](#)

Excited lepton searches

Excited leptons appear in composite models:

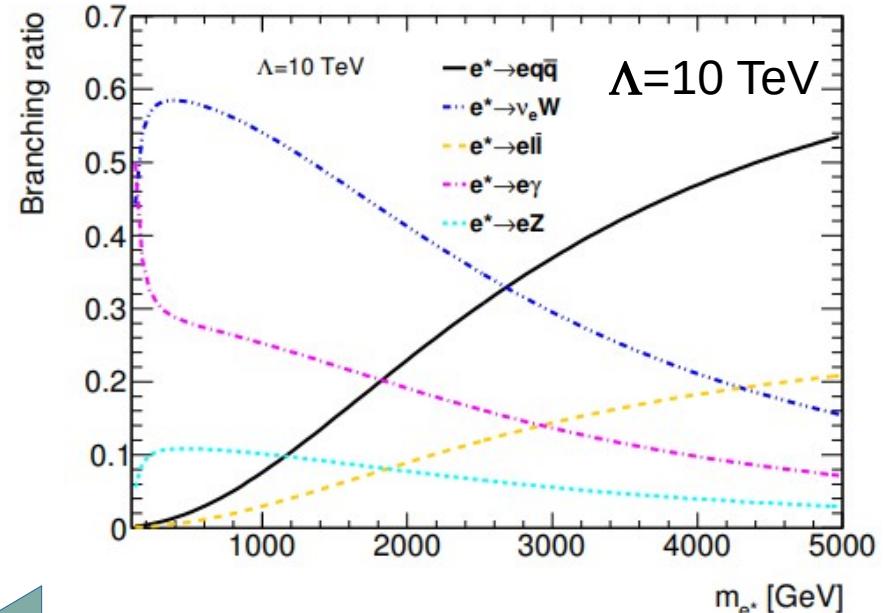
Pati-Salam, Baur-Spira-Zerwas etc.

Preons bind at scale Λ to form SM fermions (ground state) and **excited states**

$$\Delta\mathcal{L}_{\text{CI}} = \frac{2\pi}{\Lambda^2} j^\mu j_\mu$$

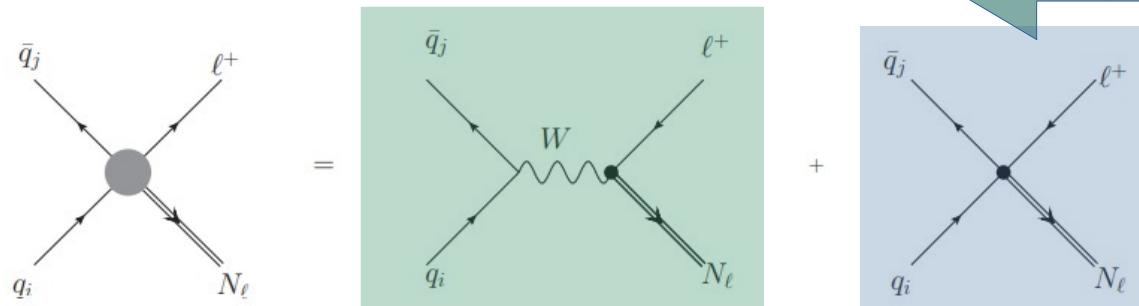
$$j_\mu = \bar{f}_L \gamma_\mu f_L + \bar{f}_L^* \gamma_\mu f_L^* + (\bar{f}_L^* \gamma_\mu f_L + \text{H.C.})$$

$$\Delta\mathcal{L}_{\text{GM}} = \frac{1}{2\Lambda} \bar{f}_R^* \sigma^{\mu\nu} \left[g \frac{\tau}{2} W_{\mu\nu} + g' \frac{Y}{2} B_{\mu\nu} \right] f_L + \text{H.C.}$$



Gauge mediated

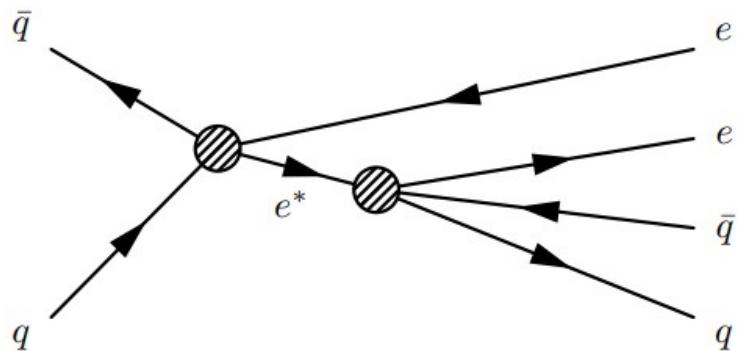
Contact Interaction



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Searches in ATLAS for excited electron in **eejj** and **evJ** final states

eejj channel



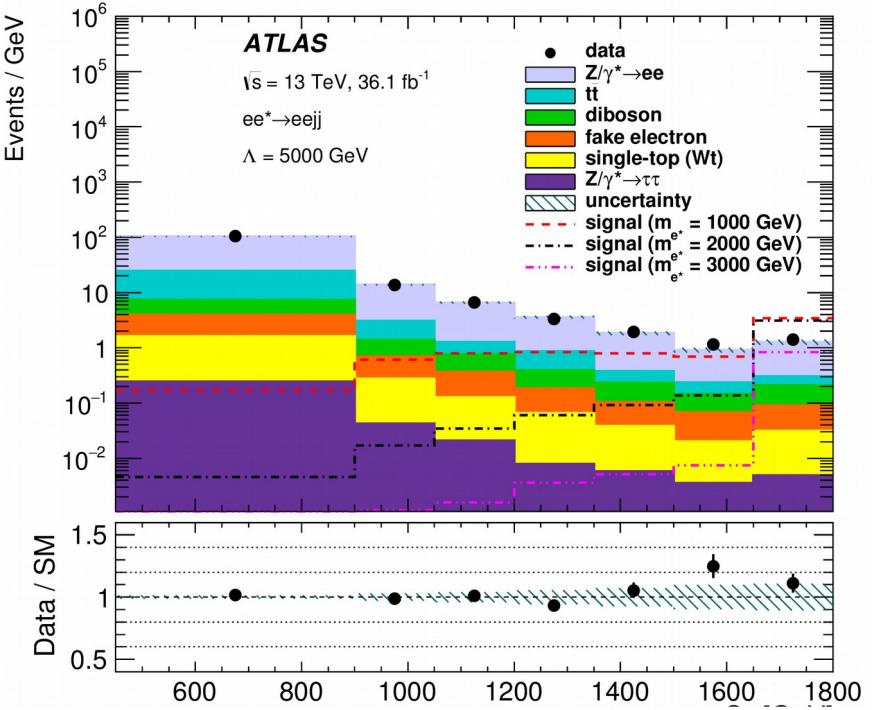
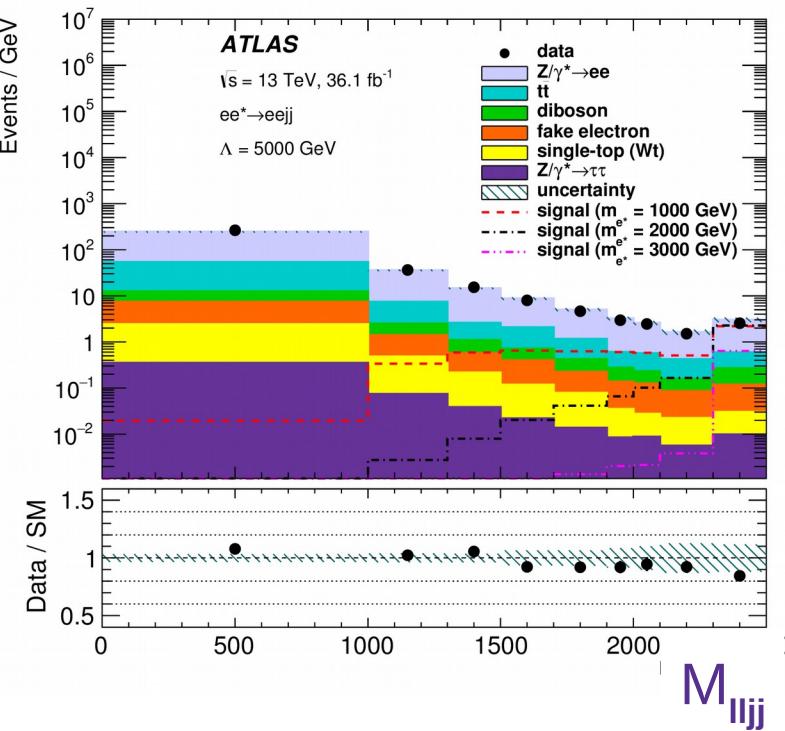
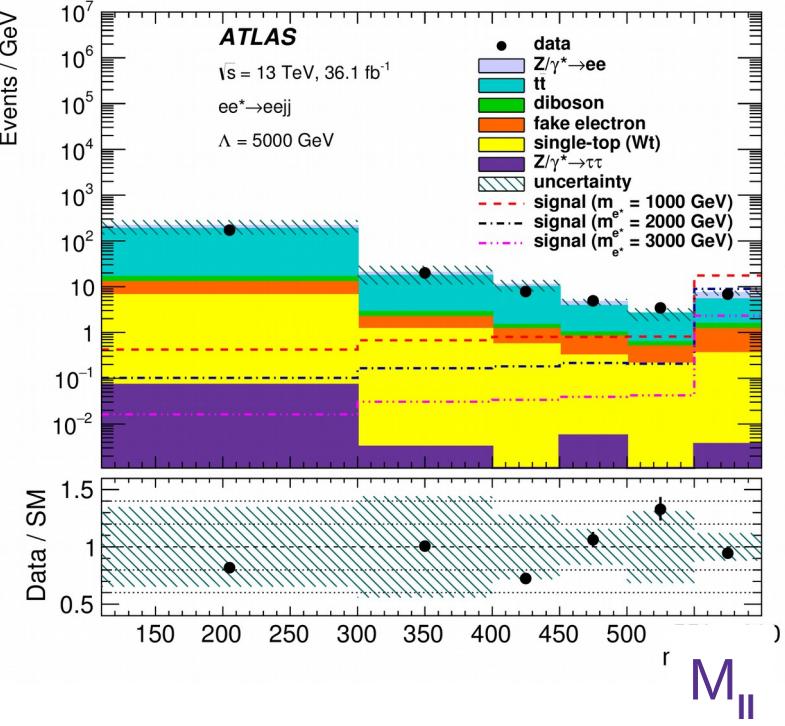
eejj final state

2 High pt electrons ($P_T > 30$ GeV $|y| < 2.47$)
Dielectron trigger ($2e12 \rightarrow 2e17$)
2 or more jets (antiKT R=0.4 and $P_T > 20$ GeV)
Dominant background: Z+jets and tt

Background contribution

	eejj [%]
$Z/\gamma^*(\rightarrow ee) + \text{jets}$	79
$Z/\gamma^*(\rightarrow \tau\tau) + \text{jets}$	< 1
$W(\rightarrow e\nu) + \text{jets}$	—
$W(\rightarrow \tau\nu) + \text{jets}$	—
$t\bar{t}$	16
Single-top	1
Fake electron	2
Diboson	2

Fake electron (+W+jets)
→ Data driven
Z+jets, top and diboson from MC



Discriminating variables for background and signal expectations

Selection

Signal Regions varying with m_{e^*}

M_{\parallel}

S_T : Scalar sum of two electron and two leading jets

$M_{\parallel jj}$:

Modify M_{\parallel} selection (in Z peak) for

CR_N control regions

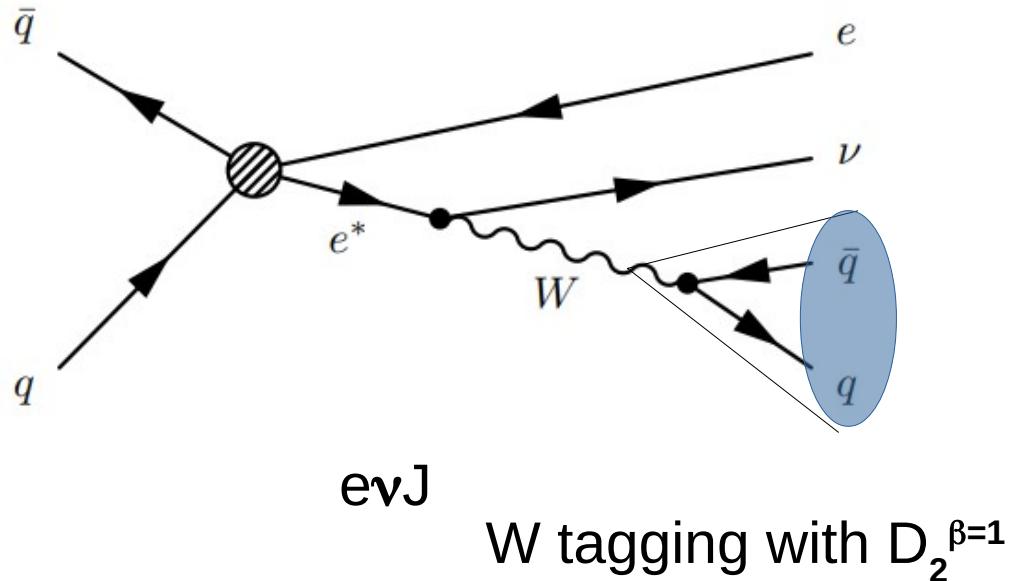
$e\mu$ final state for $t\bar{t}$ CR_N control regions

Mass m_{e^*}	M_{\parallel}	S_T	$M_{\parallel jj}$
200	500	450	none
700	550	900	1000
900	450	900	1300
1000		1050	
1250		1200	1500
1500	400		1700
1750	300	1350	1900
2000			2000
2250		1500	2100
2500	110	1650	2300

Yields
 $t\bar{t}$ CR_N

Yields	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10
Observed	468	71	66	45	30	29	19	17	12	16
Background	470 ± 20	71 ± 8	66 ± 8	45 ± 7	30 ± 6	29 ± 5	19 ± 4	17 ± 4	12 ± 4	16 ± 4
$t\bar{t}$	390 ± 20	49 ± 9	37 ± 9	22 ± 7	17 ± 6	17 ± 6	8 ± 5	7 ± 4	6 ± 4	10 ± 4
Single-top (Wt)	51 ± 2	14.2 ± 1.0	18.7 ± 1.2	15.1 ± 1.1	7.5 ± 0.7	7.5 ± 0.7	6.4 ± 0.7	5.6 ± 0.8	3.5 ± 0.4	2.2 ± 0.2
Diboson	29 ± 8	8 ± 2	10 ± 3	8 ± 2	5.1 ± 1.4	4.8 ± 1.3	4.6 ± 1.3	4.0 ± 1.1	2.8 ± 0.8	3.6 ± 1.0
$Z/\gamma^* \rightarrow \tau\tau$	0.8 ± 1.0	0.07 ± 0.02	0.04 ± 0.02	0.04 ± 0.02	0.020 ± 0.010	0.030 ± 0.010	0.05 ± 0.02	0.06 ± 0.02	0.020 ± 0.010	0.040 ± 0.010

$e\nu J$ (Large jet) channel



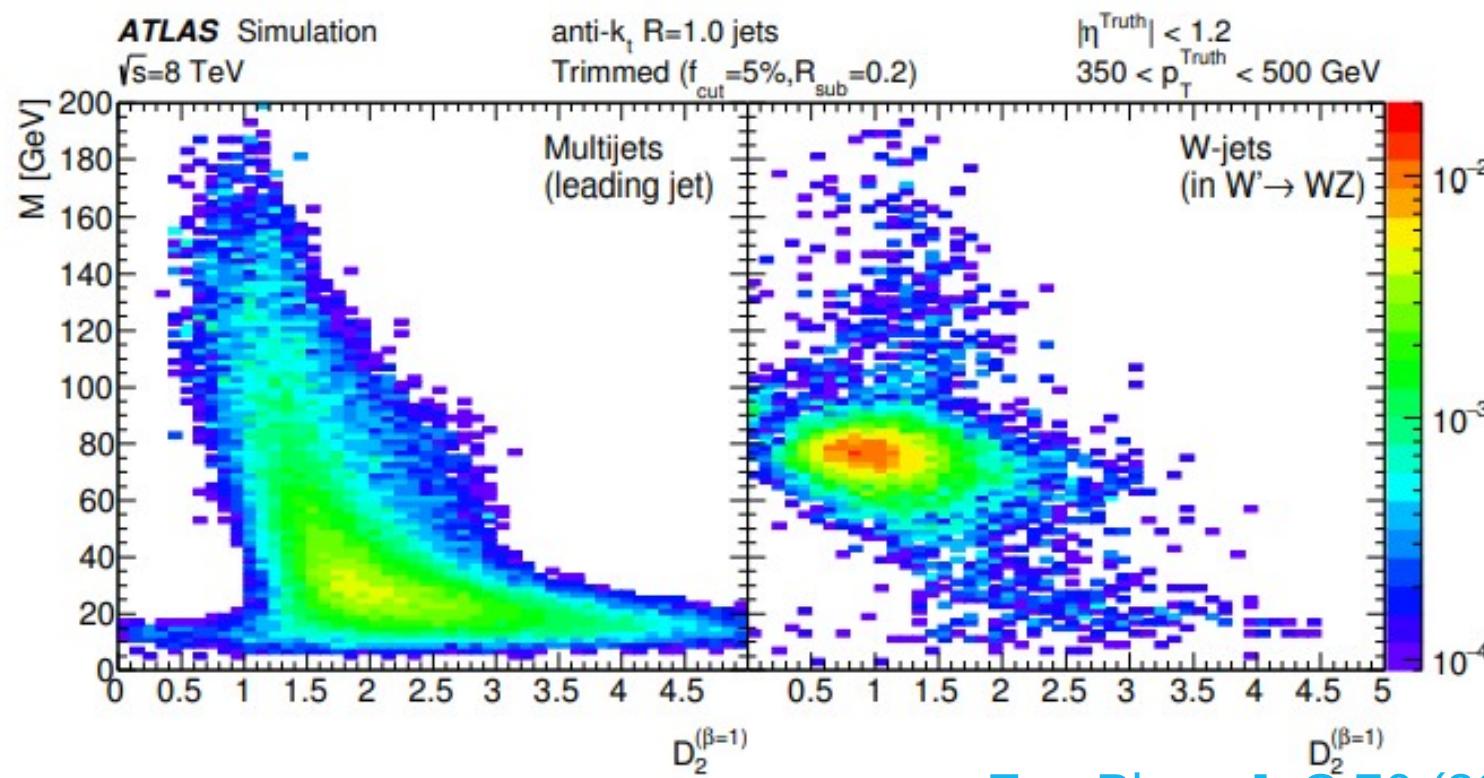
Background contribution

	$e\nu J$ [%]
$Z/\gamma^*(\rightarrow ee) + \text{jets}$	< 1
$Z/\gamma^*(\rightarrow \tau\tau) + \text{jets}$	< 1
$W(\rightarrow e\nu) + \text{jets}$	27
$W(\rightarrow \tau\nu) + \text{jets}$	3
$t\bar{t}$	58
Single-top	6
Fake electron	2
Diboson	4

- 1 High P_T -electron (single electron trigger and $P_T > 65$ GeV)
- 1 Large-R Jet (from boosted W) $P_T > 100$ GeV
- Missing Energy: MET > 100 GeV
- Dominant background: W+jet

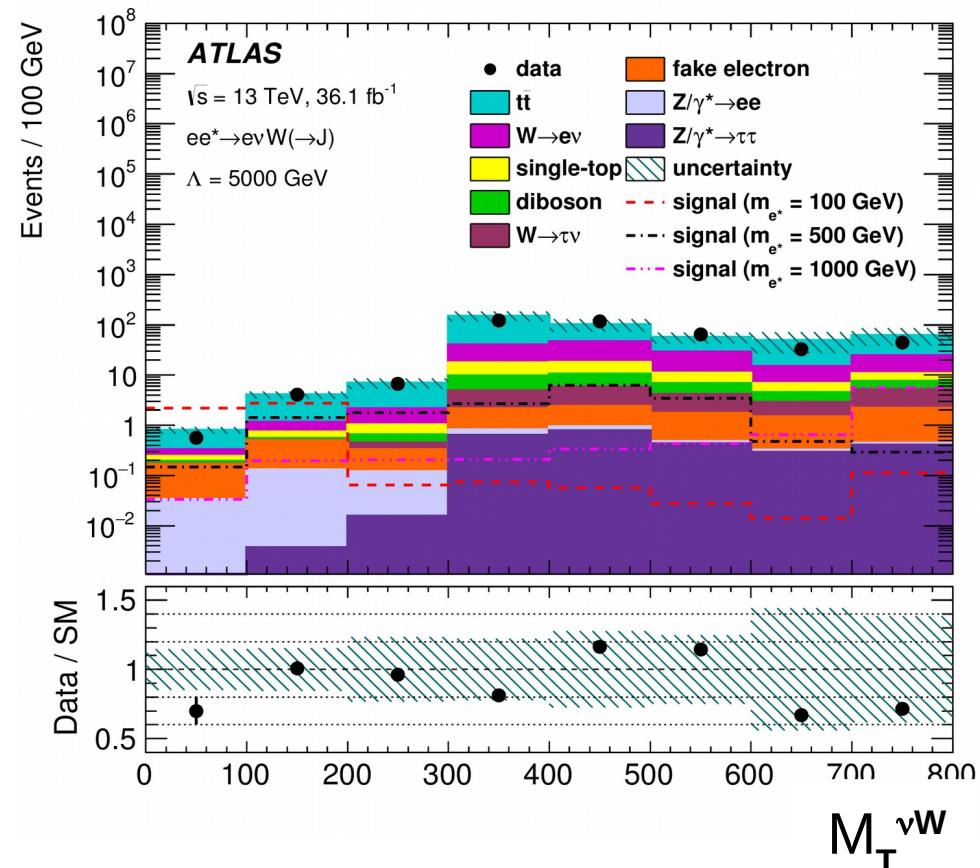
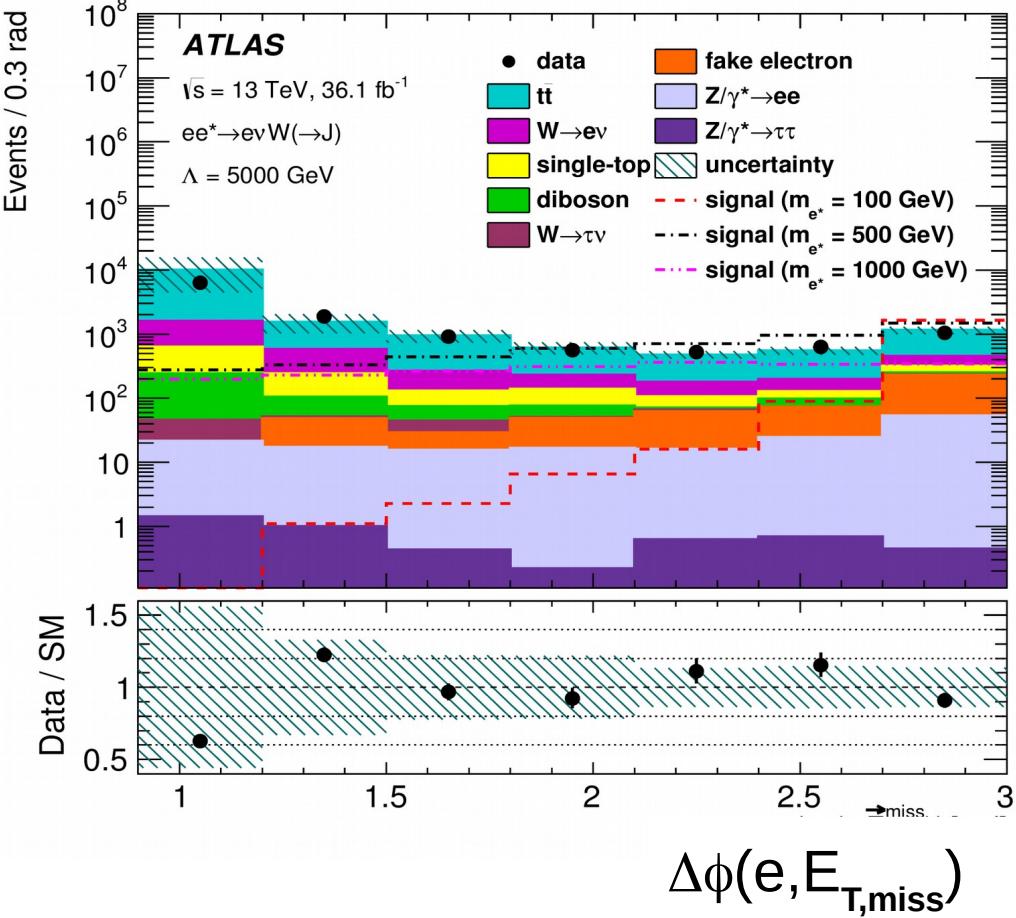
W Boson Tagger

SmoothWZTagger → Combination of m_{comb} and $D_2^{\beta=1}$ Energy correlator
Two working points: 50% and 80% efficiency



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Discriminating variables for background and signal expectations



evJ (Large jet) channel

Signal Regions varying with m_{e^*}
hypothesis

M_T^{vW} : Transverse Mass of W
tagged Large R Jet and MET
 $\Delta\phi(e, E_{T,\text{miss}})$.

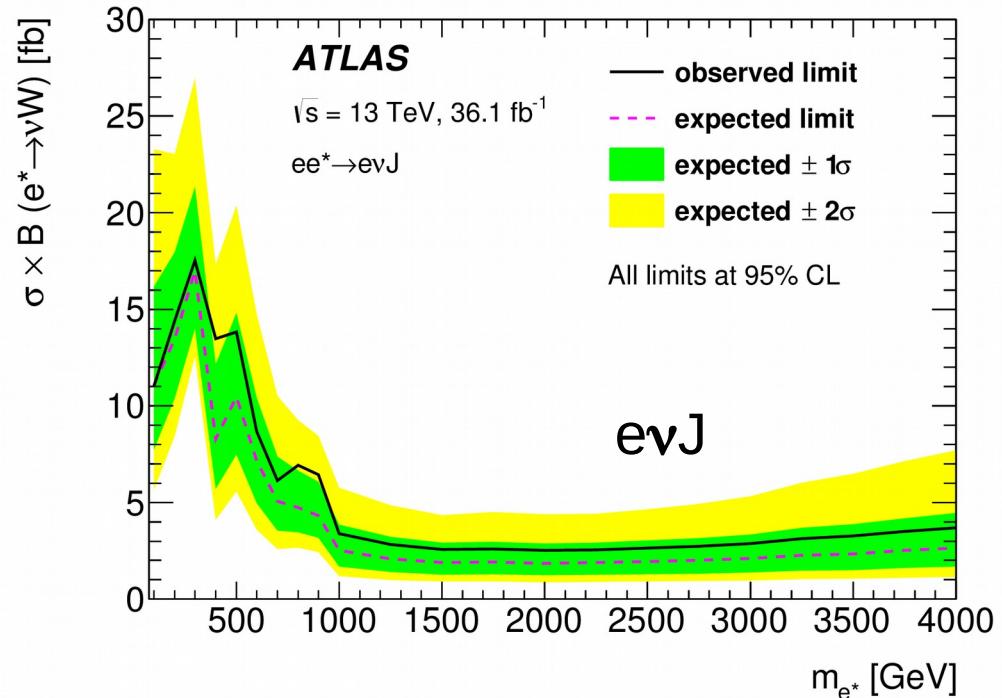
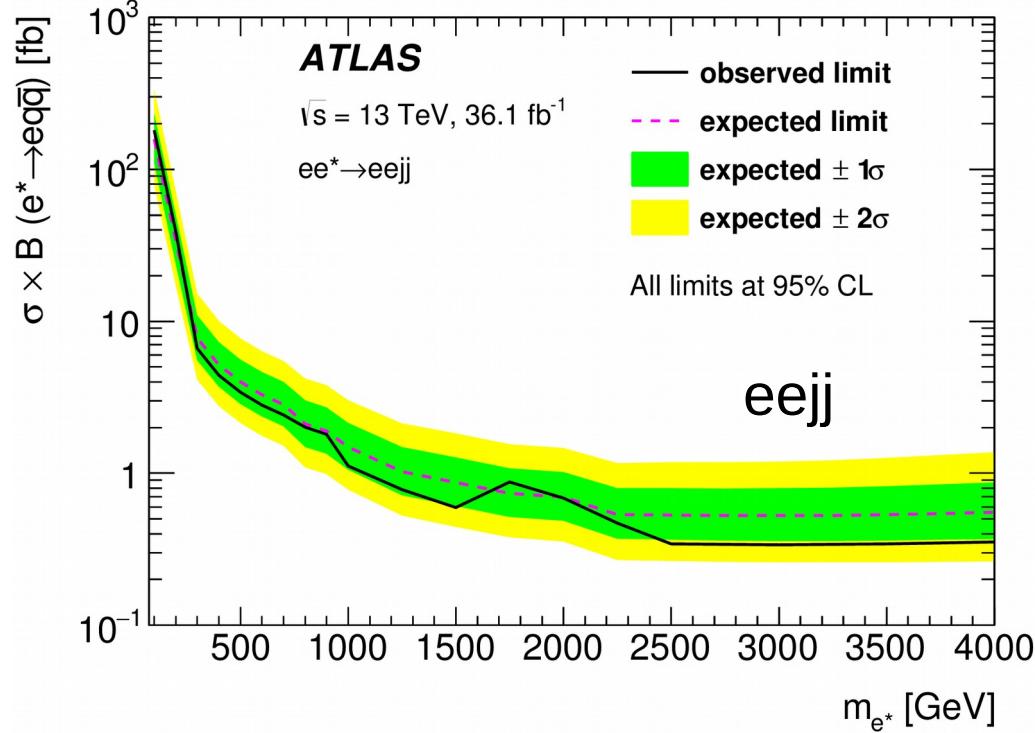
CR_N Control Regions

Region	m^J interval	$N^{b\text{-jets}}$	m_T^{vW}	$ \Delta\varphi(e, \vec{E}_T^{\text{miss}}) $
SR	W-tag50 pass	0	pass	pass
W CR	W-tag80 fail	0	pass	N/A
$t\bar{t}$ CR	W-tag50 pass	>1	pass	pass
VR	W-tag50 fail W-tag80 pass	N/A	pass	pass

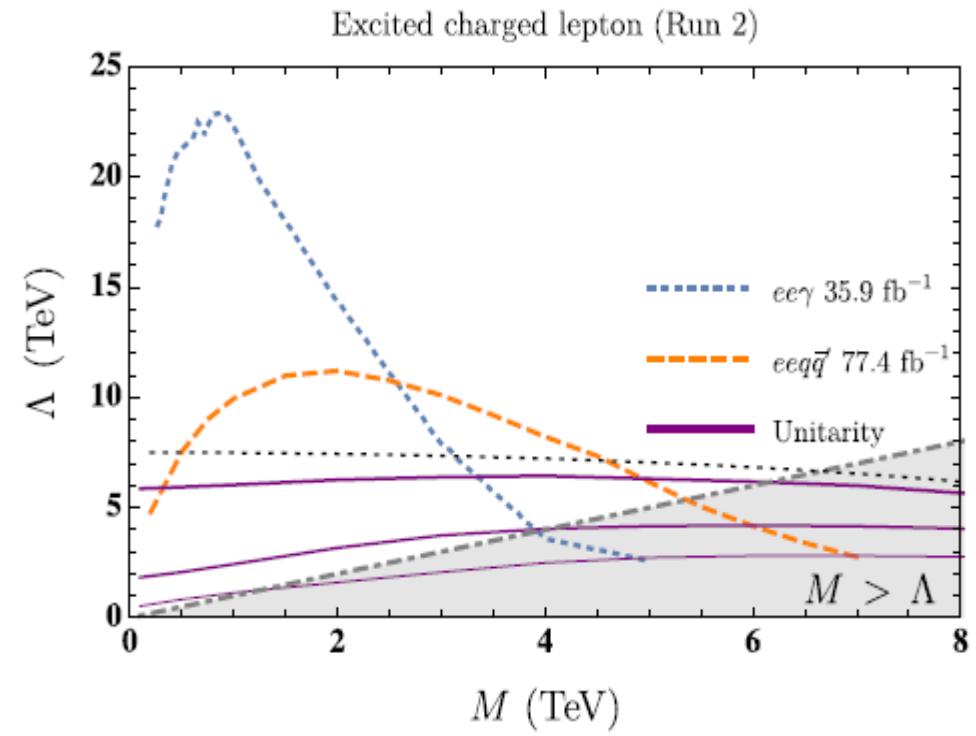
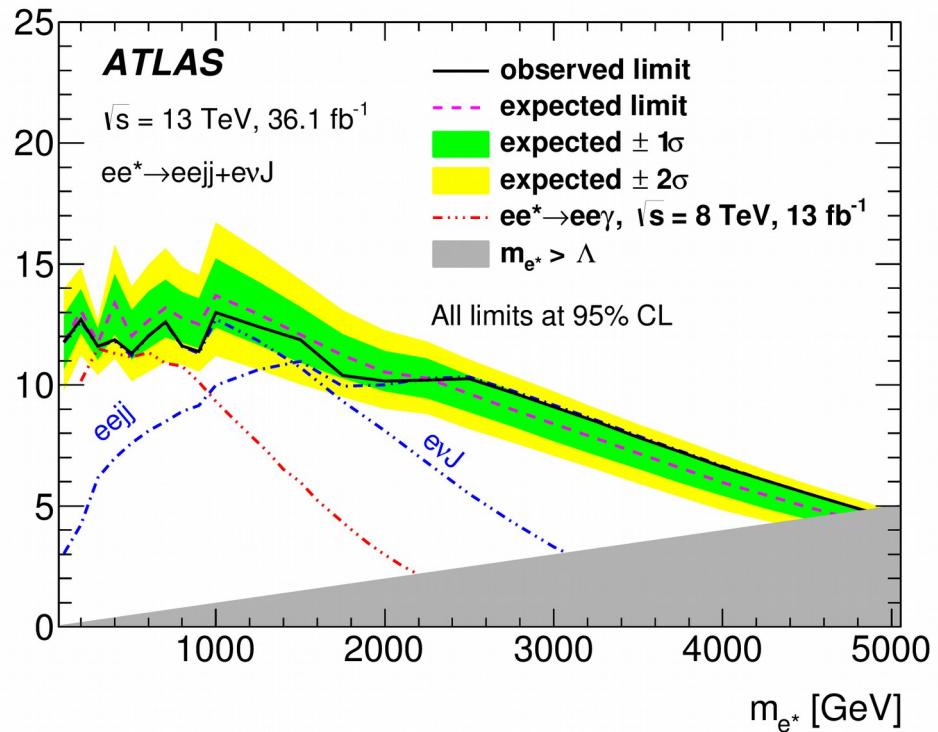
Mass m_{e^*}	Min M_T^{vW}	Min $\Delta\phi(e, E_{T,\text{miss}})$
100	200*(Max)	2.7
200	100	2.4
300		2.1
400	200	1.8
500	300	1.5
600	400	1.2
700	500	
800	600	0.9
1000	700	

	$eejj$				$e\nu J$			
	$N_{\text{sig}}^{\text{obs}}$	$N_{\text{sig}}^{\text{exp}}$	$\sigma_{\text{vis}}^{\text{obs}} [\text{fb}]$	$\sigma_{\text{vis}}^{\text{exp}} [\text{fb}]$	$N_{\text{sig}}^{\text{obs}}$	$N_{\text{sig}}^{\text{exp}}$	$\sigma_{\text{vis}}^{\text{obs}} [\text{fb}]$	$\sigma_{\text{vis}}^{\text{exp}} [\text{fb}]$
SR1	120.3	$107.9^{+38.1(81.6)}_{-29.1(48.8)}$	3.34	$2.99^{+1.06(2.27)}_{-0.81(1.35)}$	11.2	$11.3^{+4.6(10.5)}_{-3.1(5.2)}$	0.31	$0.31^{+0.13(0.29)}_{-0.09(0.14)}$
SR2	30.7	$35.0^{+12.7(27.8)}_{-9.3(15.6)}$	0.85	$0.97^{+0.35(0.77)}_{-0.26(0.43)}$	21.4	$19.9^{+5.9(13.3)}_{-4.2(7.1)}$	0.59	$0.55^{+0.16(0.37)}_{-0.12(0.20)}$
SR3	27.5	$28.7^{+11.1(24.7)}_{-8.0(13.3)}$	0.76	$0.80^{+0.31(0.69)}_{-0.22(0.37)}$	31.6	$30.9^{+7.1(15.9)}_{-5.1(6.6)}$	0.88	$0.86^{+0.20(0.45)}_{-0.14(0.21)}$
SR4	18.1	$23.3^{+9.1(20.4)}_{-6.5(10.7)}$	0.50	$0.64^{+0.25(0.57)}_{-0.18(0.30)}$	23.5	$15.9^{+6.6(14.8)}_{-4.6(7.5)}$	0.65	$0.44^{+0.18(0.41)}_{-0.13(0.21)}$
SR5	13.0	$16.7^{+6.9(15.7)}_{-4.8(7.9)}$	0.36	$0.46^{+0.19(0.44)}_{-0.13(0.22)}$	26.9	$21.1^{+7.9(17.4)}_{-5.7(9.5)}$	0.75	$0.58^{+0.22(0.48)}_{-0.16(0.26)}$
SR6	11.1	$15.8^{+6.6(15.0)}_{-4.6(7.5)}$	0.31	$0.44^{+0.18(0.42)}_{-0.13(0.21)}$	19.9	$17.0^{+6.8(15.4)}_{-4.9(8.0)}$	0.55	$0.47^{+0.19(0.43)}_{-0.13(0.22)}$
SR7	17.0	$14.5^{+6.1(13.9)}_{-4.2(6.9)}$	0.47	$0.40^{+0.17(0.39)}_{-0.12(0.19)}$	13.8	$11.9^{+4.8(10.9)}_{-3.2(5.4)}$	0.38	$0.33^{+0.13(0.30)}_{-0.09(0.15)}$
SR8	14.0	$14.1^{+5.9(13.4)}_{-4.0(6.7)}$	0.39	$0.39^{+0.16(0.37)}_{-0.11(0.18)}$	17.1	$11.9^{+4.6(10.5)}_{-3.1(5.2)}$	0.47	$0.33^{+0.13(0.29)}_{-0.09(0.14)}$
SR9	9.7	$10.9^{+4.8(11.1)}_{-3.2(5.2)}$	0.27	$0.30^{+0.13(0.31)}_{-0.09(0.15)}$	9.4	$7.5^{+3.5(8.3)}_{-2.3(3.7)}$	0.26	$0.21^{+0.10(0.23)}_{-0.06(0.10)}$
SR10	7.3	$11.1^{+4.9(11.4)}_{-3.3(5.4)}$	0.20	$0.31^{+0.14(0.32)}_{-0.09(0.15)}$	N/A	N/A	N/A	N/A

Observed and expected model-independent limits at 95% CM on number of signal events and visible cross section

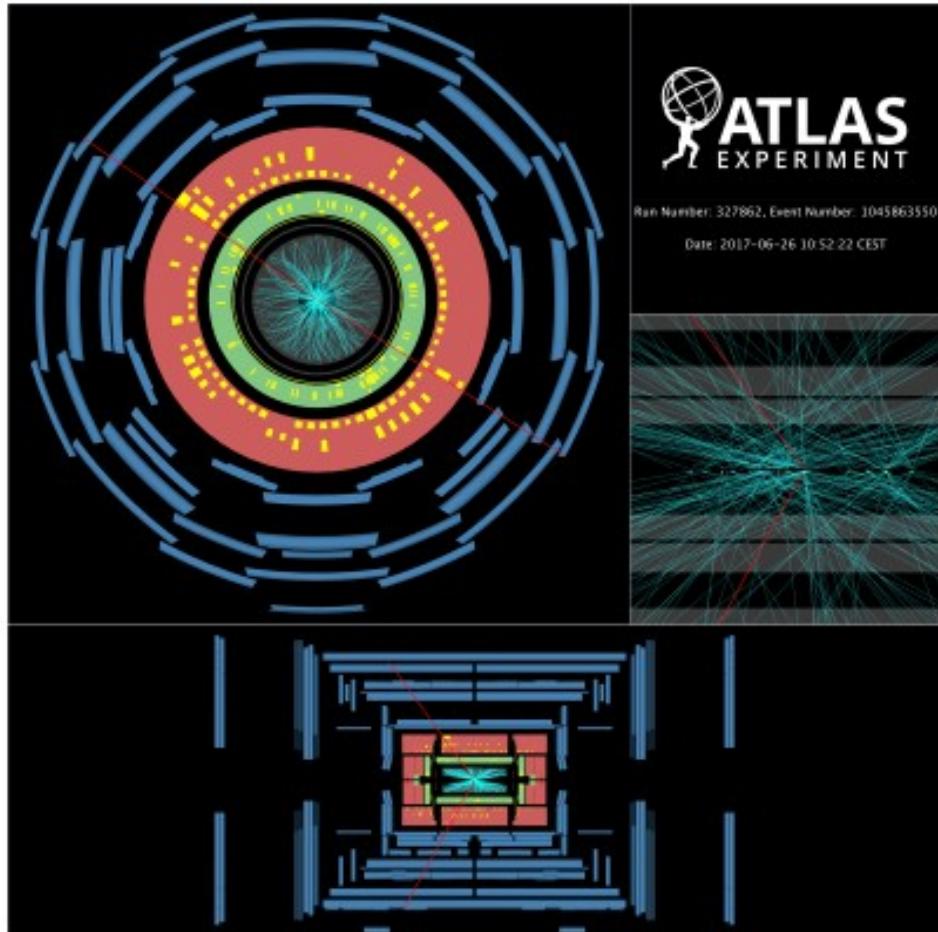


Upper limit on $\sigma \times B$ as a function of m_{e^*}

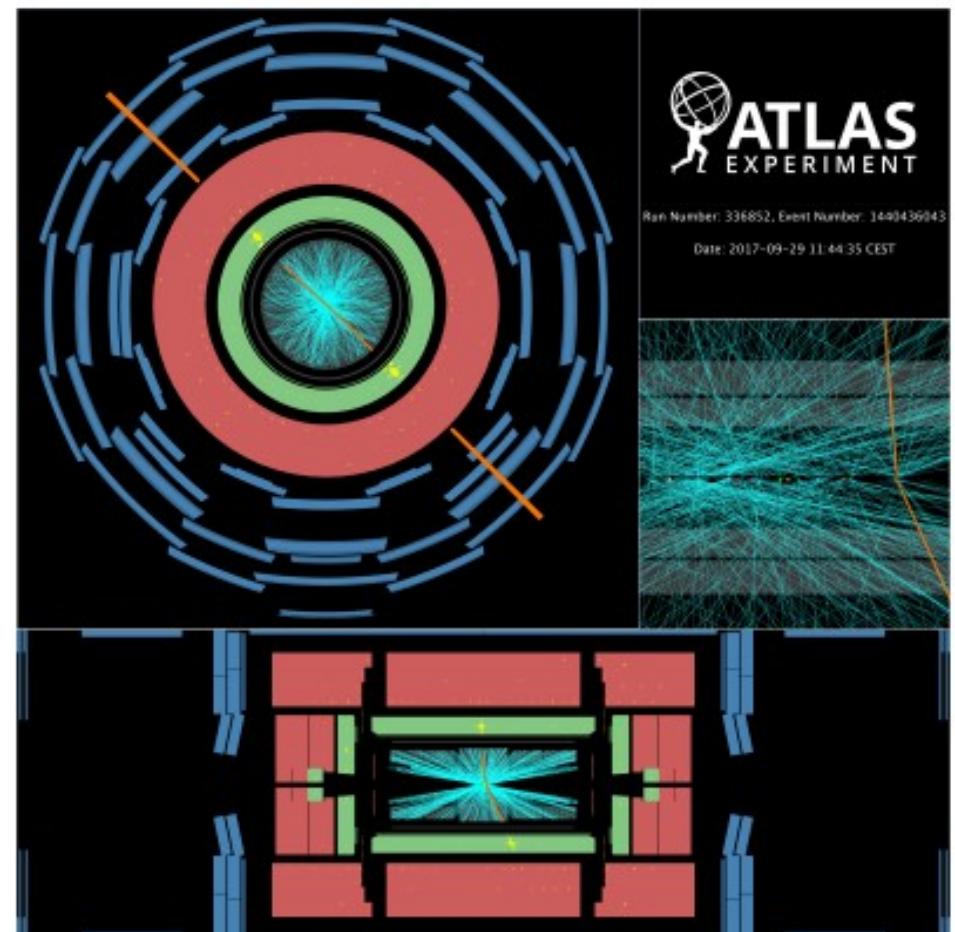


From PhysLettB799(2019)134990

Lower limits on Λ as a function of m_{e^*} combined for the eejj and the evJ channels.



$$m_{\mu\mu} = 2.75 \text{ TeV}$$



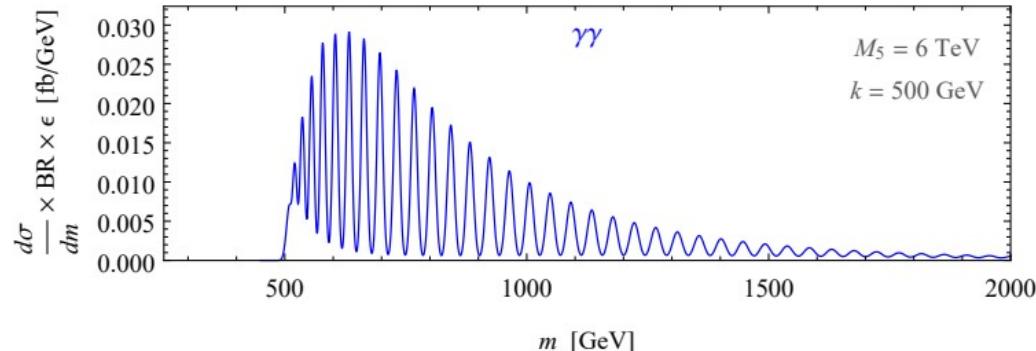
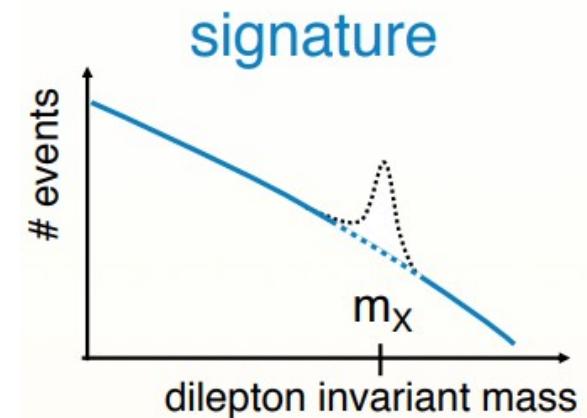
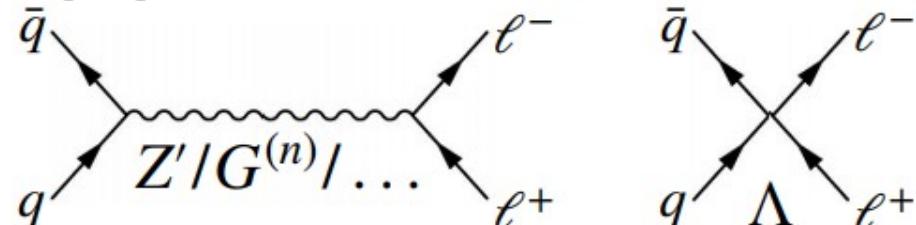
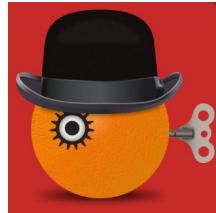
$$m_{ee} = 4.06 \text{ TeV}$$

Dilepton Searches

BSM extensions predict:

- heavy resonances decaying in dileptons
 - Results with 139 fb^{-1} (Full Run2 statistics)
 - Look for resonances in m_{ee} and $m_{\mu\mu}$
- non resonant searches phenomena
- even more weird predictions (e. clockwork [JHEP 1806\(2018\) 00](#))

28/01/2020



Analysis Strategy

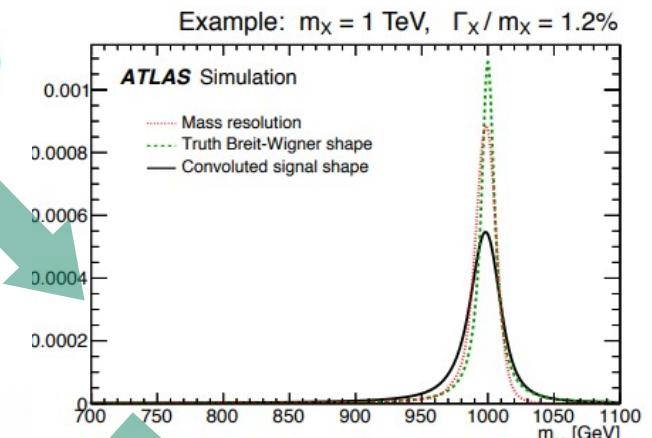
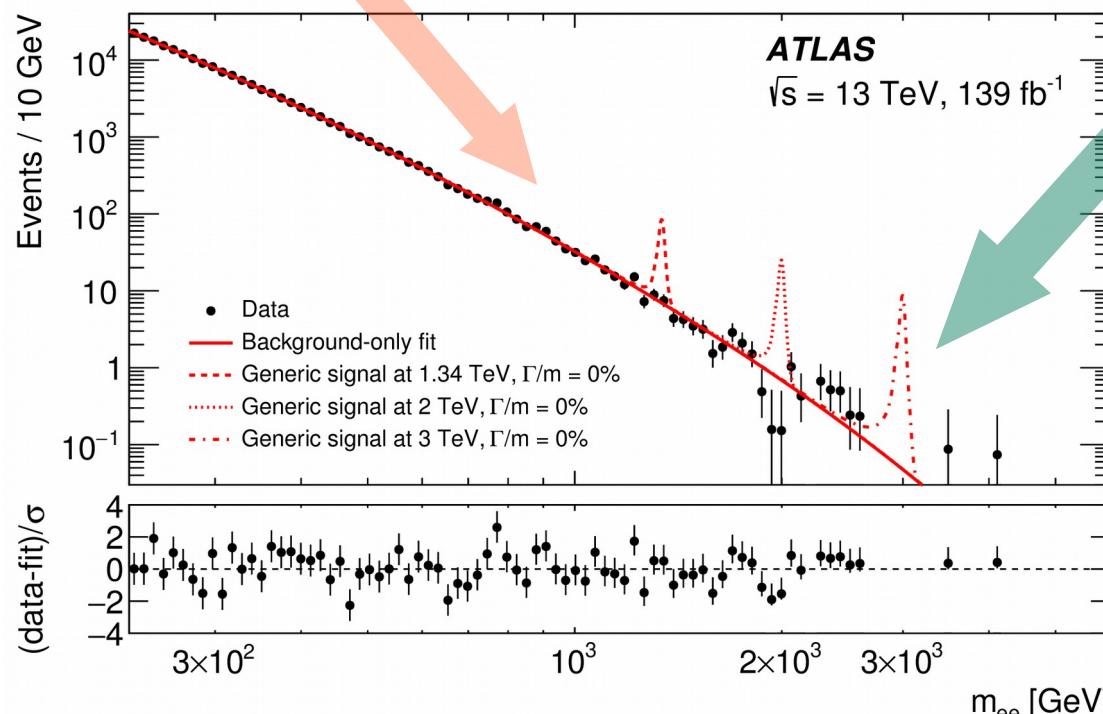
- Event selection

Two same flavor leptons $225 \text{ GeV} < m_{\ell\ell} < 6000 \text{ GeV}$

$$\text{data distribution} = \underbrace{f_{\text{bkg}}(m_{\ell\ell})}_{\text{Background}} + \underbrace{f_{\text{sig}}(m_{\ell\ell})}_{\text{Signal}}$$

$$\mathcal{F} = Z_0(m_{\ell\ell}) \cdot (1 - x^c)^b \cdot x^{\sum p_n \log^n(x)}$$

$$x = m_{\ell\ell}/\sqrt{s}, \quad n = 0, \dots, 3$$

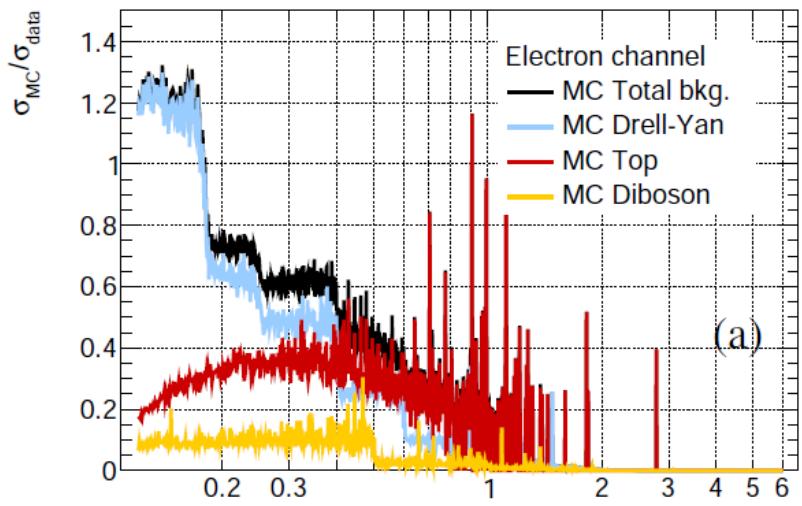


Breit-Wigner \otimes $m_{\ell\ell}$ resolution

Analysis Strategy

Main improvement wrt first Run2 Result
([36 fb-1](#))

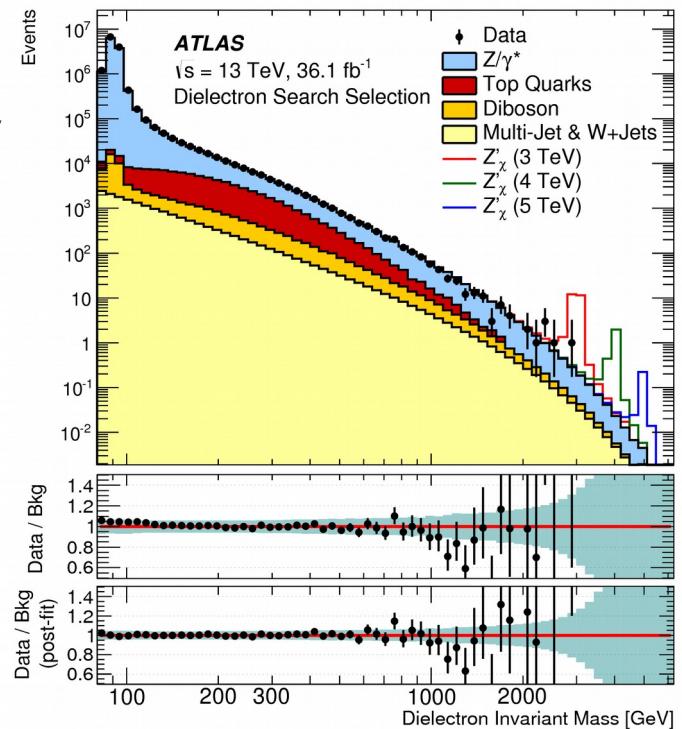
Using data driven background estimate
instead of MC based



Huge relative stat uncertainty from
MC in low mass region

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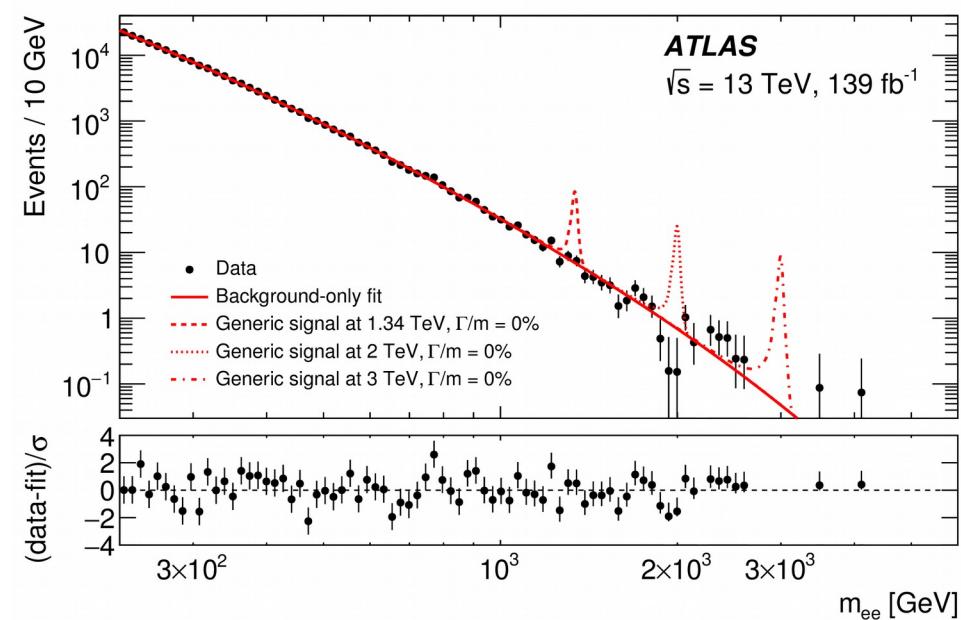
A. Sidoti



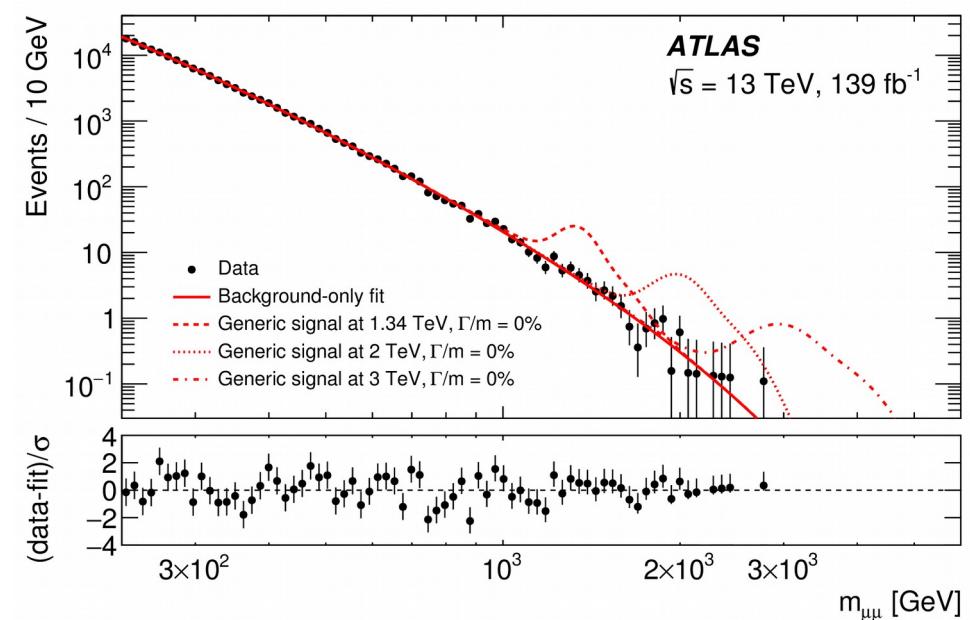
Mass [GeV]	Sensitivity loss [%]
150	35
200	18
300	13
500	6

Potential sensitivity loss
without fixing the problem by
smoothing MC bkg predictions

17 / 27



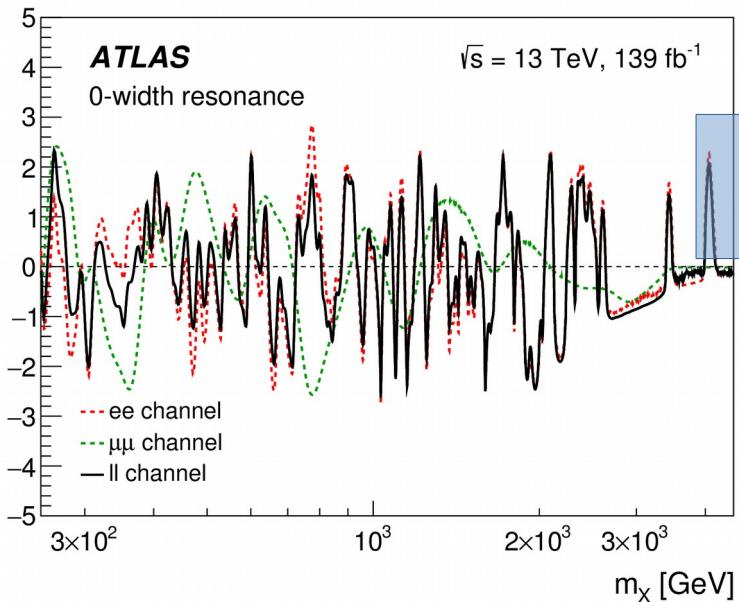
ee channel



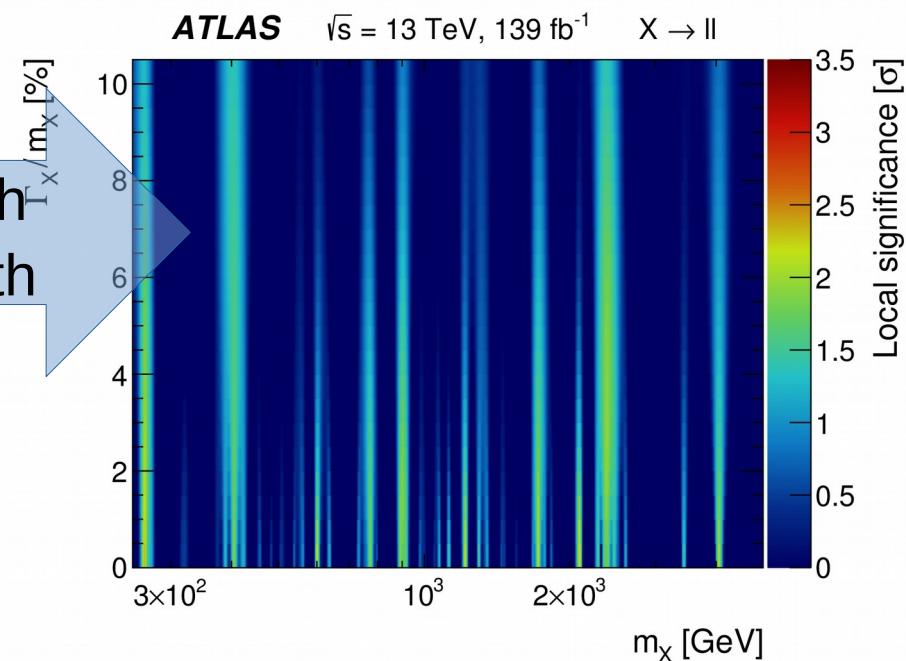
μμ channel

Results

Local significance [σ]



From 0 width
to finite width

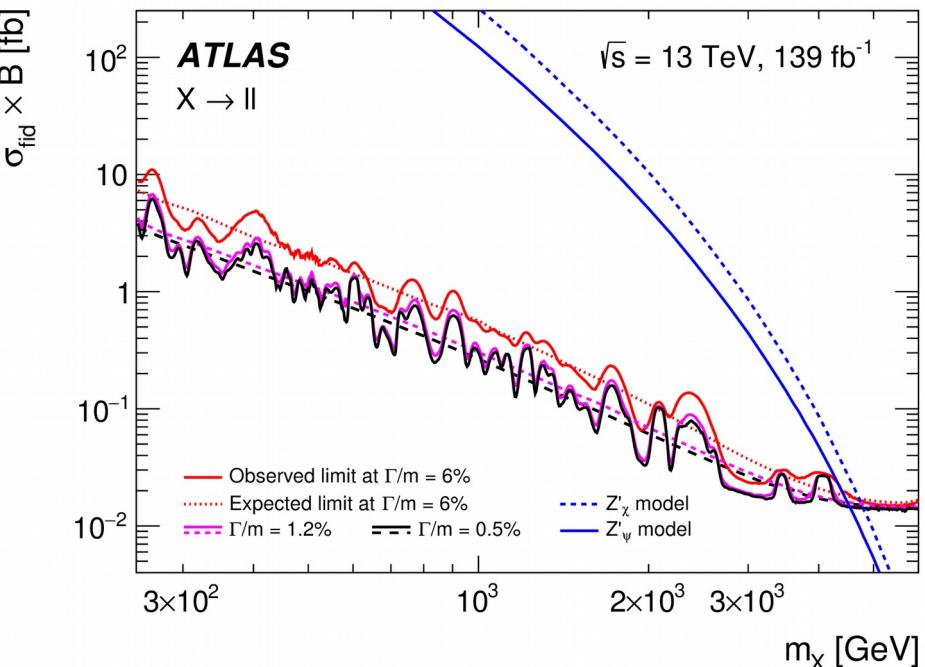
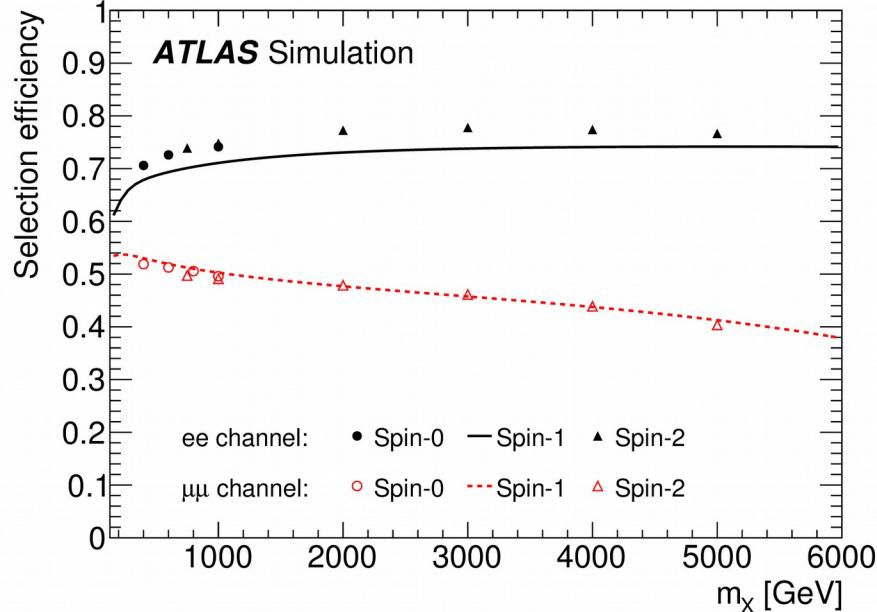


Channel	Excess			Deficit		
	$p_0 [\sigma]$	$m_X [\text{GeV}]$	$\Gamma_X/m_X [\%]$	$p_0 [\sigma]$	$m_X [\text{GeV}]$	$\Gamma_X/m_X [\%]$
ee	3.0	773	2.5	-3.2	1957	4.0
$\mu\mu$	2.5	268	2.5	-2.8	349	8.5
$\ell\ell$	2.3	264	0	-2.9	1958	3.0

Interpretation of non resonant
search on going

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Limits



Generic limits for various widths, signal shapes and spin hypothesis
 Generic cross section limits at $\Gamma/m=0.5\%$, 1.2% and 3.0% compared with predictions of Z'_ψ , Z'_χ and Z'_{SSM}

Limits are interpretable for various models - there's a framework to make it easy!

28/01/2020

A.

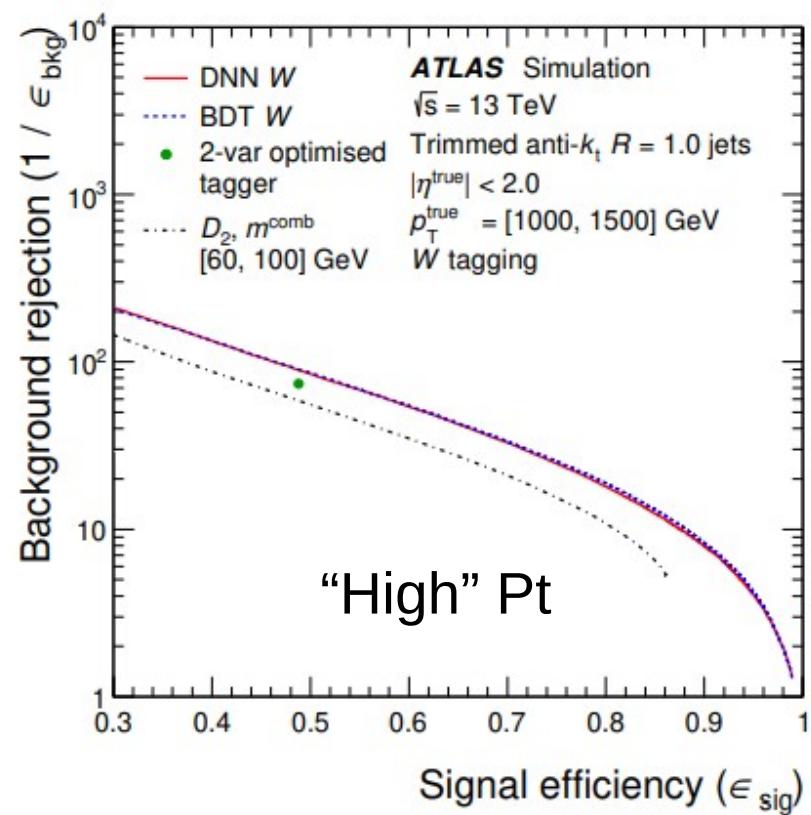
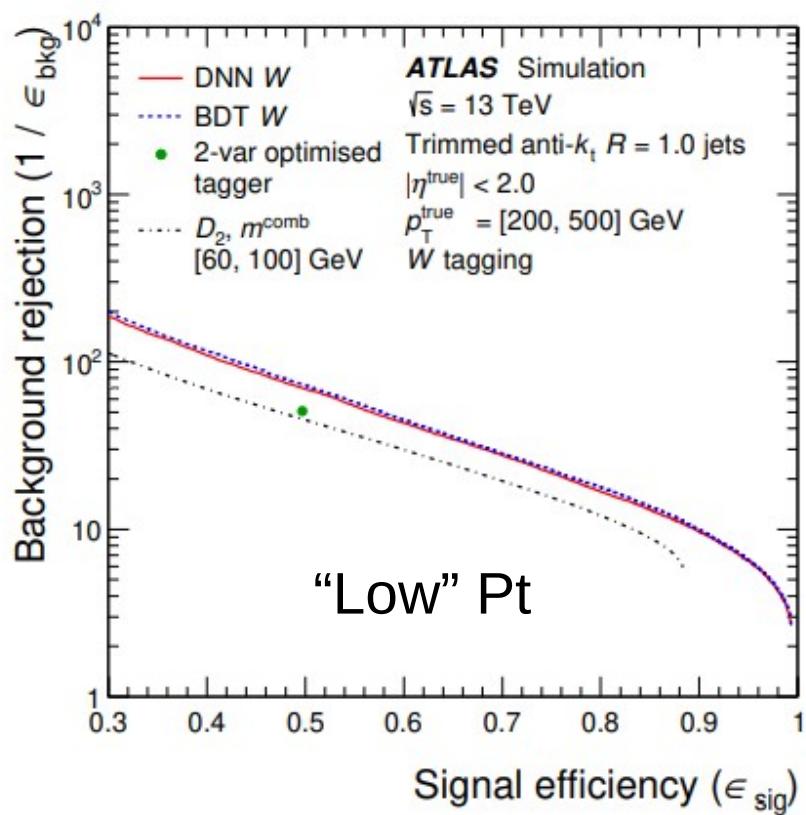
Model	Lower limits on $m_{Z'}$ [TeV]					
	ee		$\mu\mu$		ll	
	obs	exp	obs	exp	obs	exp
Z'_ψ	4.1	4.3	4.0	4.0	4.5	4.5
Z'_χ	4.6	4.6	4.2	4.2	4.8	4.8
Z'_{SSM}	4.9	4.9	4.5	4.5	5.1	5.1

Prospects

How to improve? (1)

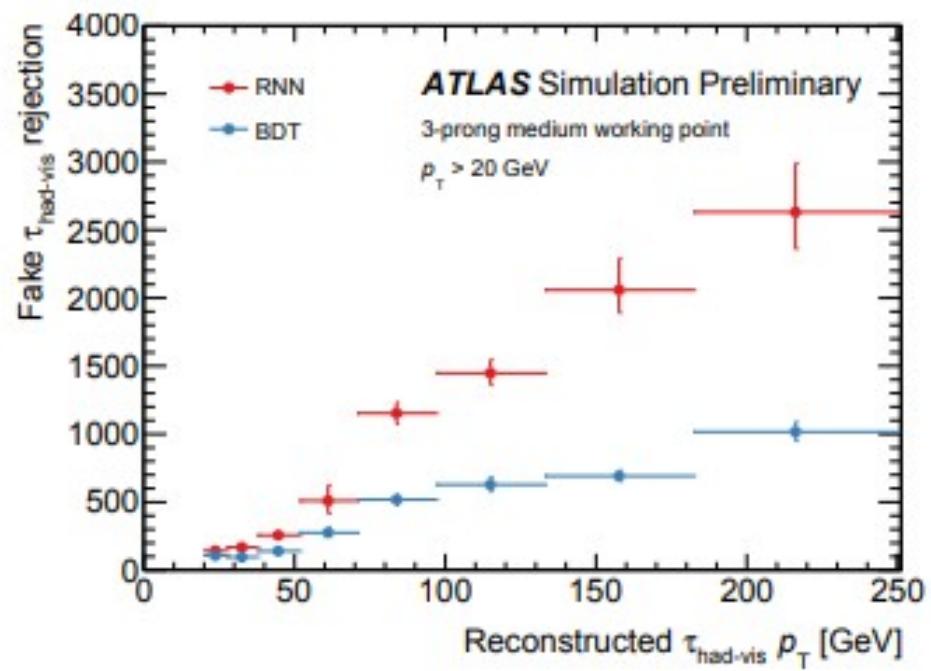
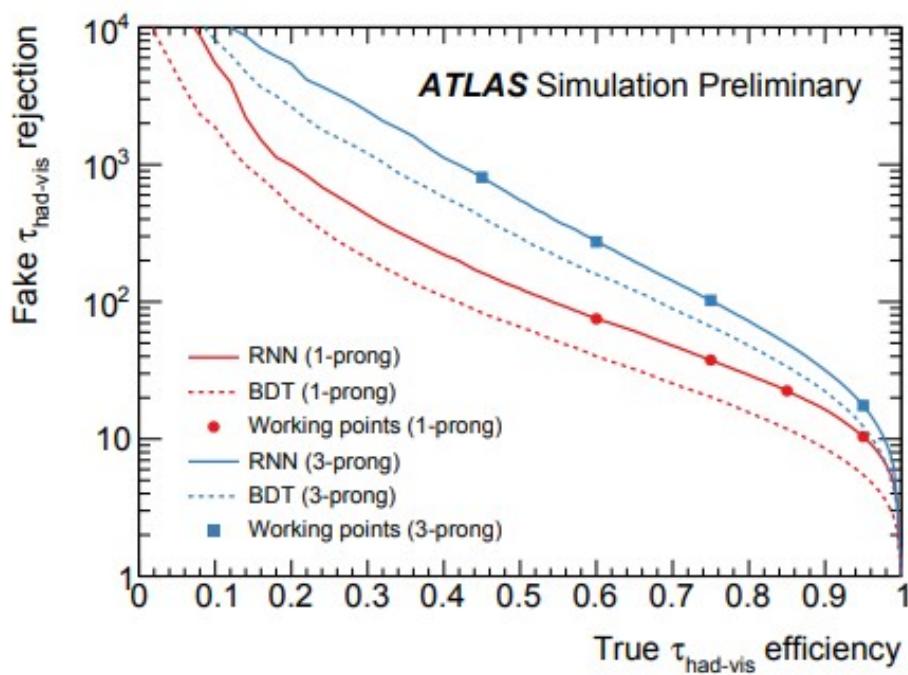
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Improving W boson tagger using ML techniques



How to improve? (2)

Looking for tau in final states. More efficient tau id algorithms are available (RNN) → Combine track inputs, cluster inputs and high level inputs



Conclusion

- No evidence of BSM physics in leptonic signature in ATLAS so far
- Analysis with leptons are pushing further the search area in the TeV region
- Going from simple to more difficult BSM models
- Increased collected data need change in analysis strategy
- Get ready for Full Run2 results and Run3! → Several improvements
 - ▶ Better W boosted W tagger
 - ▶ Tau final states (hadronic and leptonic)

BackUp

