Searches for new phenomena in final states involving leptons and jets using the ATLAS detector

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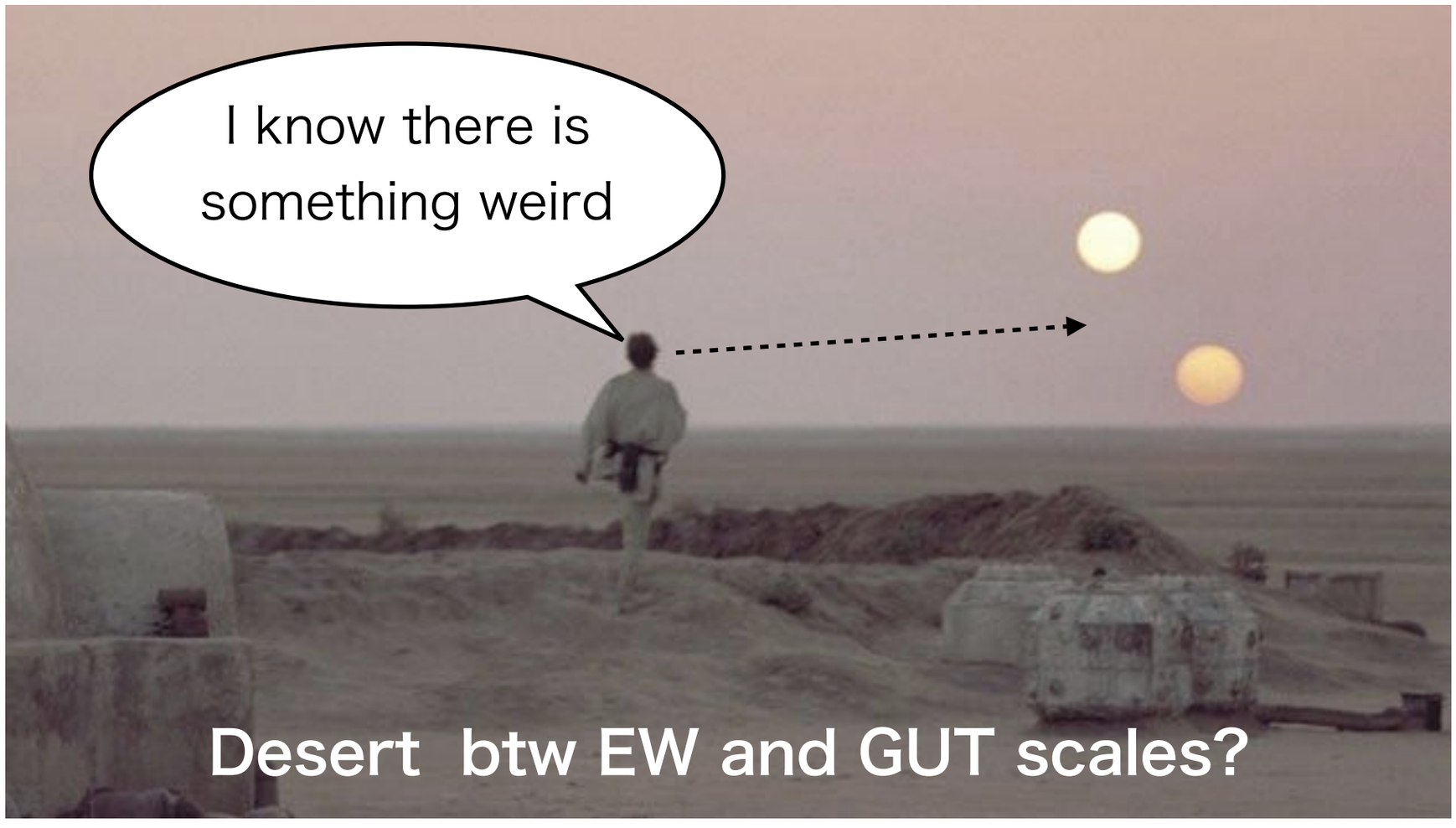
Is the Standard Model perfect?

- Great description of physics at EW scale O(100)GeV but what is **Dark Matter**? **Hierarchy problem**? **GUT**? etc.



M_{EW} M_{GUT} M_{Planck}

O(100) $O(10^{16})$ $O(10^{19})$

Energy Scale [GeV]

Model-independent ‘Exotics’ searches

Based on final state signatures,

- Diboson
- Diphoton
- Dilepton
- Dijet
- ISR+E_T^{miss}
- lepton+jet
- ⋮

- SUSY/ 2HDM
- Extended SU(2)
- Dark Matter
- Extra Dimension
- GUT
- ⋮

Give a constraint on models.

Search for TeV-scale gravity signatures

PLB 760 (2016) 520-537

(Large) Extra Dimension

- Introduce *n* additional (flat) space-time dimensions
- Extra dimensions are compactified on a torus with radius *R*

$$M^2_{\mathrm{Planck}} = M_D^{n+2} R^n$$

Scale of gravity in the *n*-dimensional space-time;
which can be O(1)TeV = one of the solutions for hierarchy problem

- An interesting feature of extra dimension models: non-perturbative gravitational states such as **microscopic black holes** (BH)
  - Mass of the BH is assumed to be much higher than M_D
  - BHs “evaporate” immediately by Hawking radiation
  - Radiates SM particles “democratically”

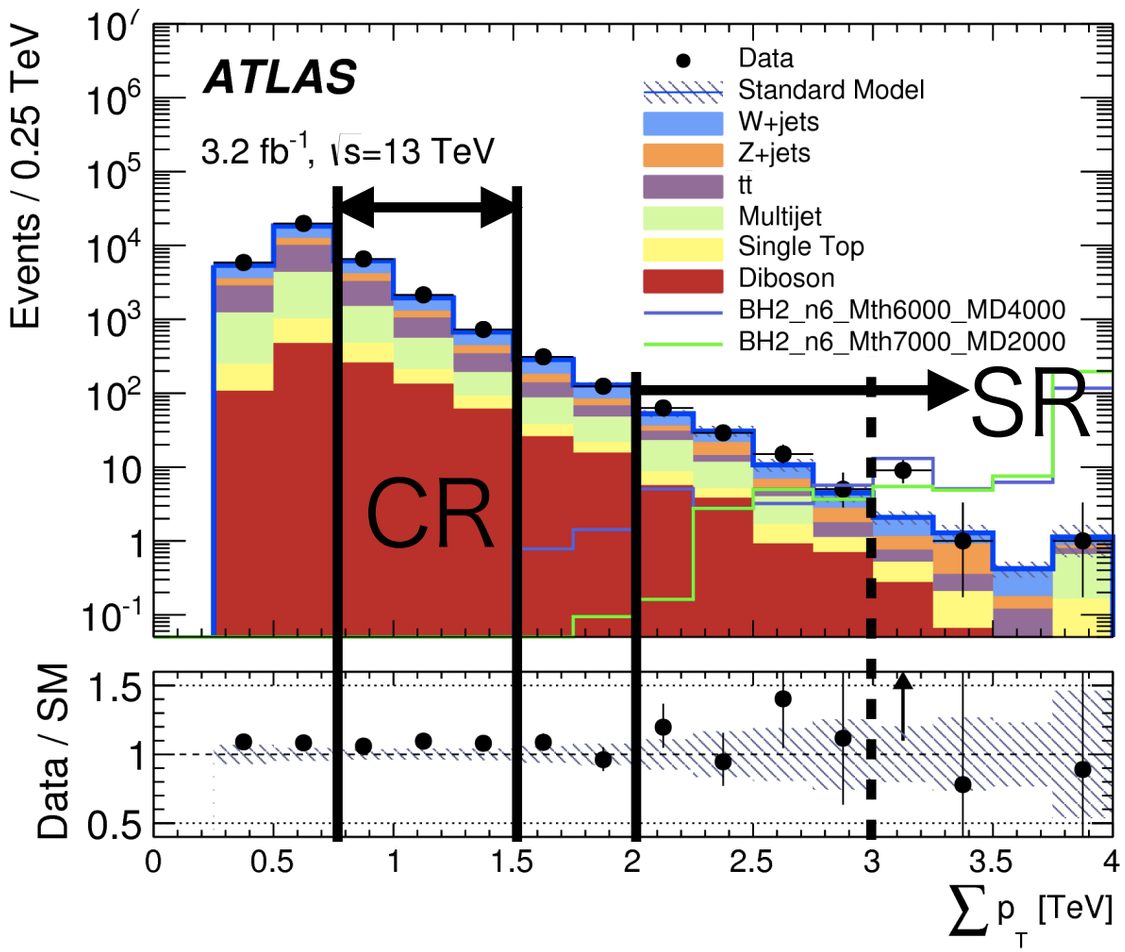
Target final state: **multi high-p_T SM particles**
including at least one leptons to suppress the b.g.

Analysis strategy

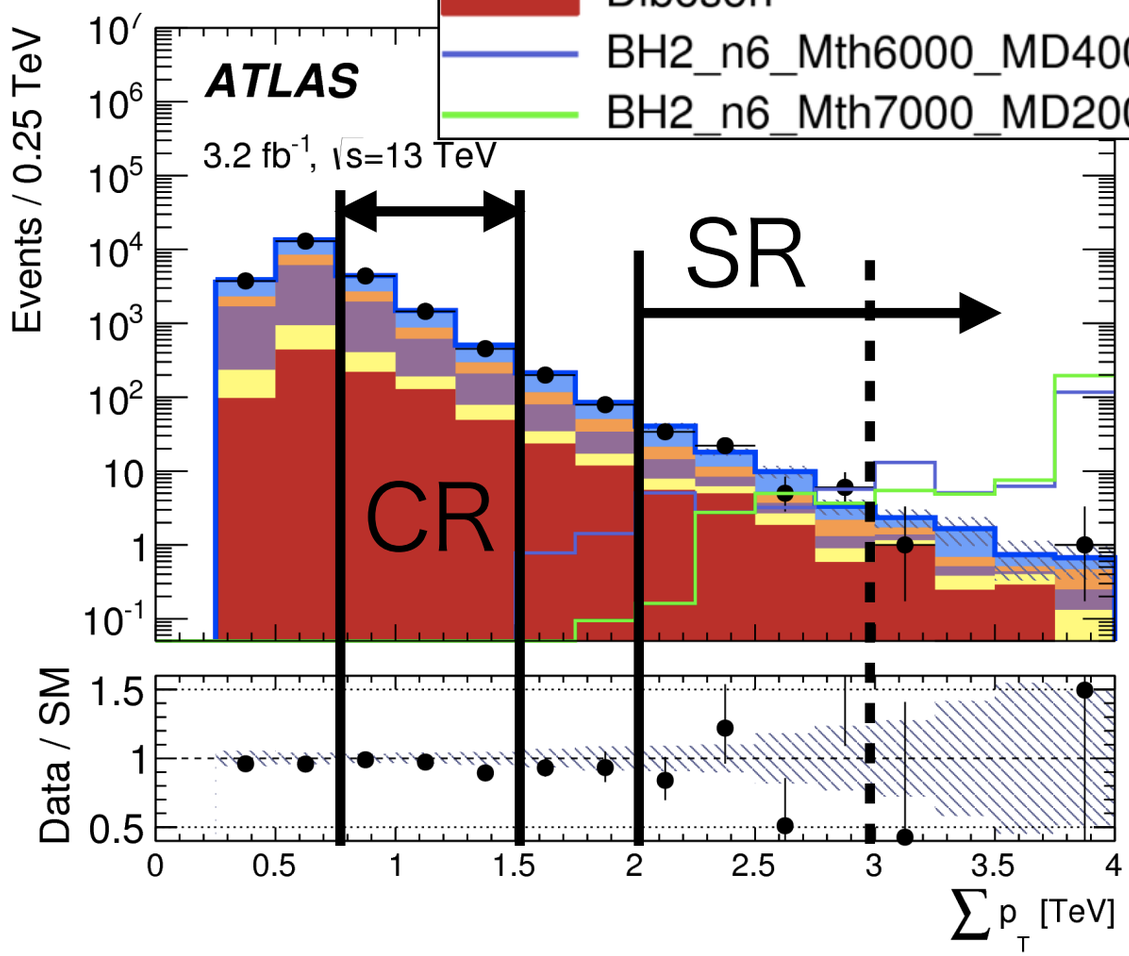
- As a benchmark, simplified rotating BH signals generated by CHARYBDIS2 are used
  - Number of extra dimensions: n=2, 4, and 6
  - The range of M_D : [2, 5]TeV
  - BHs are assumed to be produced over a continuous range of mass above a threshold M_{th}
  - Multiplicity of the final state is drawn from a Poisson distribution
- Require >=3 reconstructed leptons or jets with p_T>100GeV in the event (including at least one leptons)
- No further selection cuts are applied. General search for new physics at high-mass and involving the EW sector

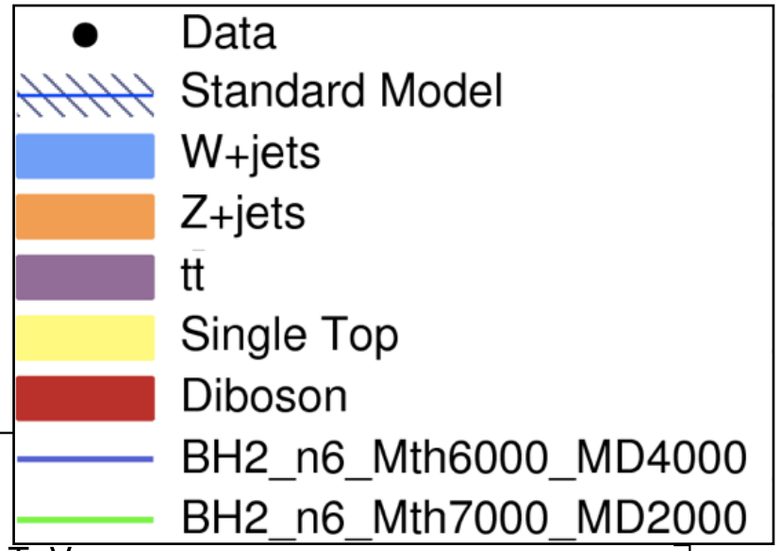
Σp_T distributions

e channel



μ channel





- 2 signal regions (SRs) are defined by Σp_T>2TeV and >3TeV (not orthogonal between each other)
- Lower Σp_T region is used as control region (CR) for main sources of b.g.
- CR is separated into 3 sub-categories dedicated to W+jets, Z+jets and ttbar

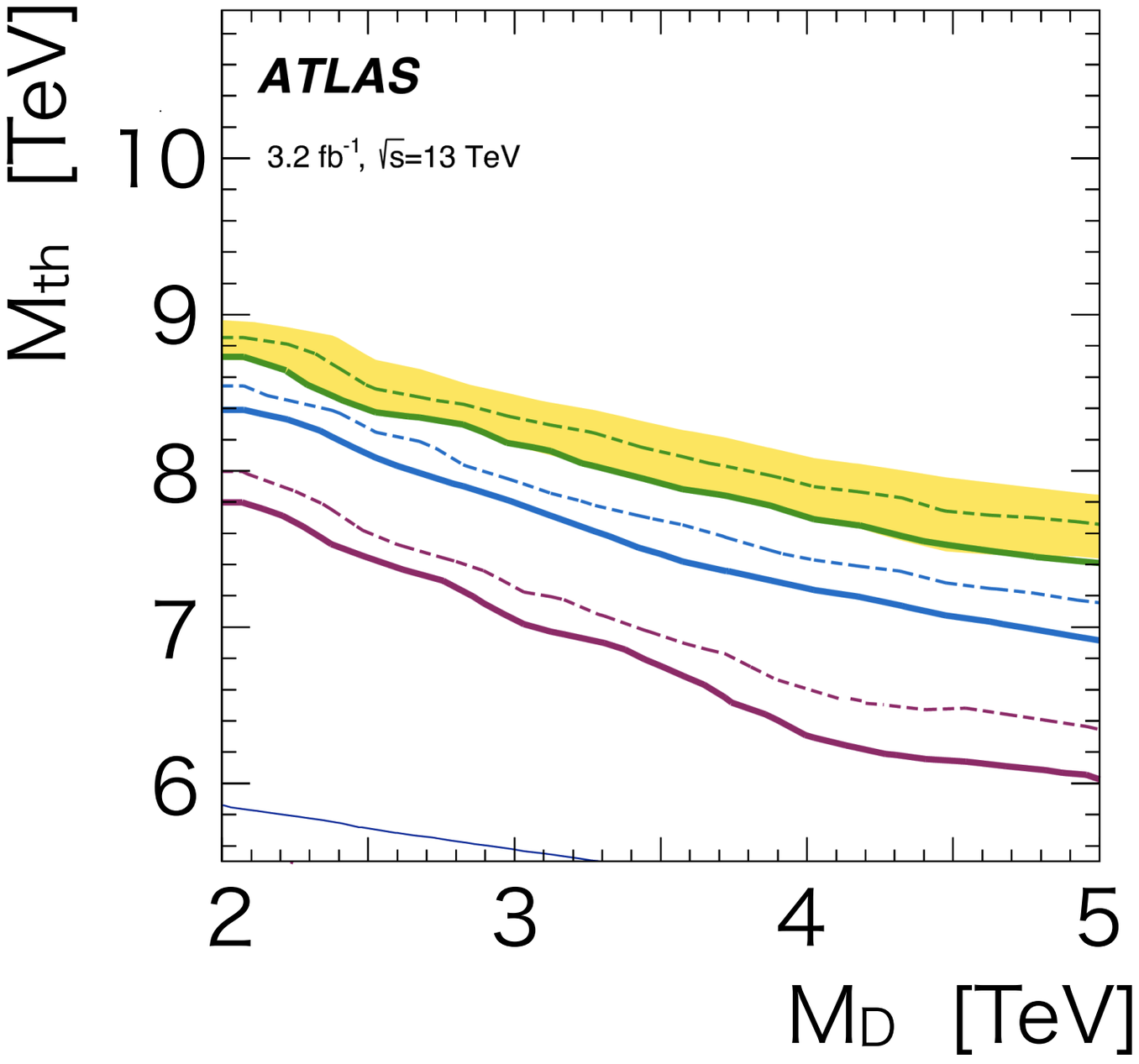
$\sum p_T = \sum p_T$ (all leptons and jets with p_T>60GeV)

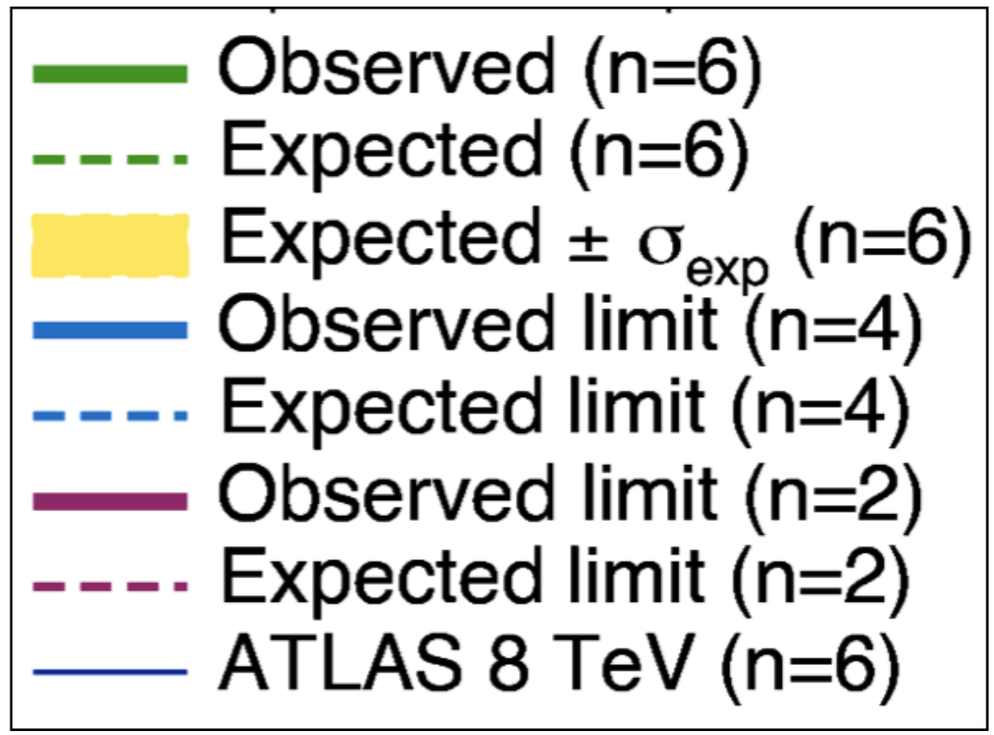
Observed event yields in SRs

	SR-2TeV (e)	SR-2TeV (μ)	SR-3TeV (e)	SR-3TeV (μ)
Data	123	69	11	2
Total b.g.	104 ± 9	78 ± 6	4.6 ± 0.8	5.3 ± 1.2
Top	13.8 ± 3.1	11.4 ± 2.5	0.65 ± 0.18	0.55 ± 0.15
W+jets	32.0 ± 3.5	33.9 ± 3.2	1.76 ± 0.31	2.0 ± 0.4
Z+jets	16.6 ± 1.5	12.6 ± 1.4	1.09 ± 0.18	0.77 ± 0.24
Single-t	6.1 ± 0.9	5.2 ± 0.7	0.59 ± 0.18	0.54 ± 0.14
Diboson	11.4 ± 1.4	14.5 ± 1.5	0.22 ± 0.18	1.5 ± 0.5
Multijet	24 ± 7	-	0.32 ± 0.24	-

- Simultaneous fit to SR and CR with background-only hypothesis; Systematic uncertainties are treated as nuisance parameters
- A mild excess is observed in electron channel only in SR-3TeV; Observed p-value is ~1% (~2σ)
- Model-independent upper limit on fiducial cross-section is 12.1 (3.4) fb from SR-2TeV (SR-3TeV), allowed for any form of new physics which produces a lepton in conjunction with at least 2 objects each with p_T>100GeV

Limits on simplified signal model





- Fit with signal+b.g. hypothesis to SR-3TeV and get limits on the parameters
- Great improvement from run-1 analysis; Limit on M_{th} is more stringent by ~3TeV at M_D=2TeV and by ~2TeV at M_D=4TeV

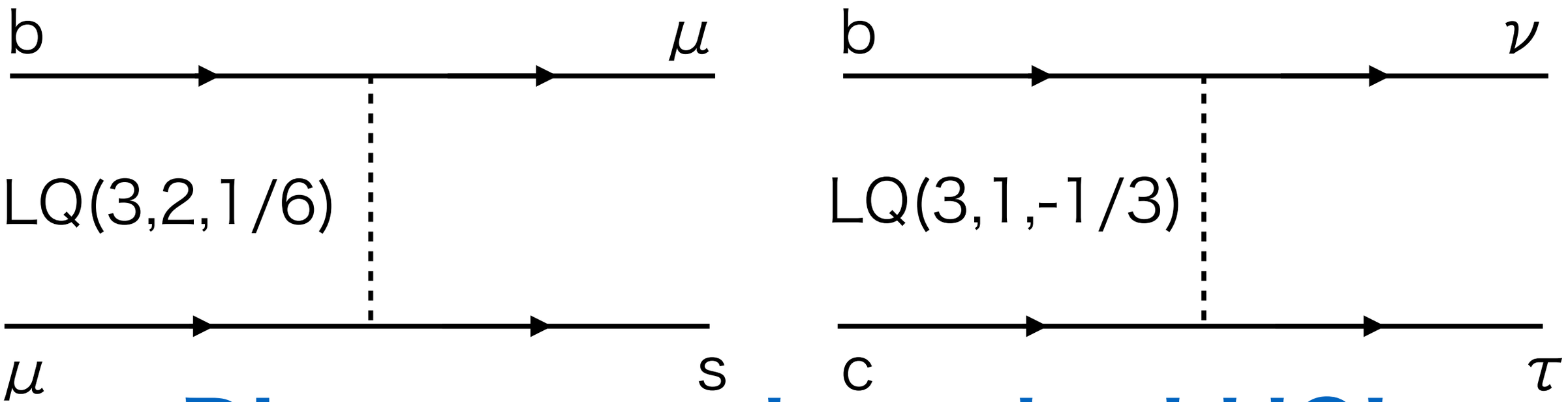
Search for leptoquarks

New J. Phys. 18 (2016) 093016

A hint of new physics?

- Recently, three (very) different experiments LHCb, Belle and Babar reported consistent results of:
  - disagreement of $\beta(b\to c\tau\nu)/\beta(b\to c\mu\nu)$ from the SM prediction ($\sim 4\sigma$)
  - non-unity $\beta(b\to s\mu\mu)/\beta(b\to see)$ ($\sim 2.5\sigma$ deviation from the SM)

  (detail in backup)
- Scalar leptoquarks (LQs) with certain set of quantum numbers can increase and/or decrease these branching fractions
- LQ is naturally connected to GUT



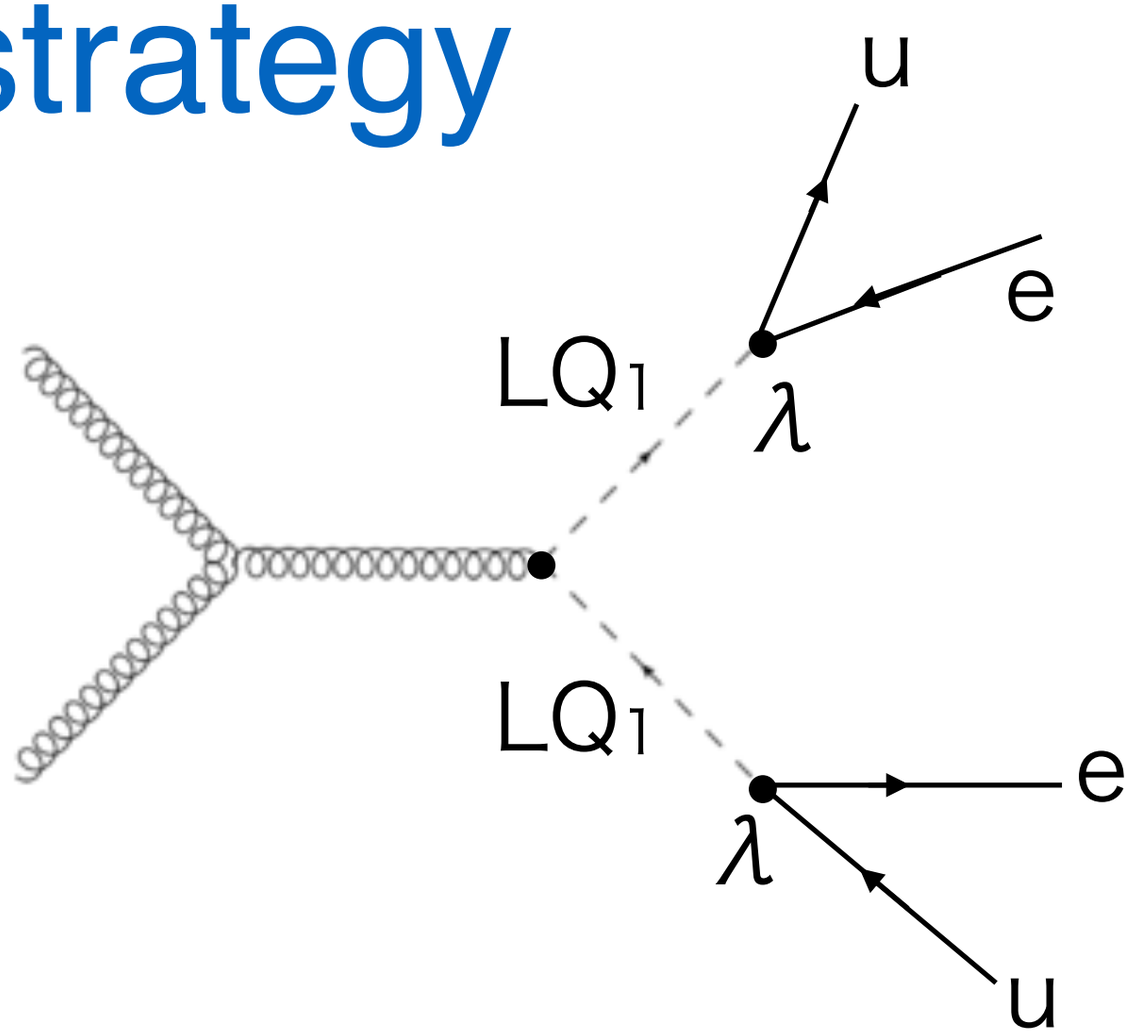
Direct search at the LHC!

Analysis strategy

- Assuming pair production of scalar LQs via strong interaction;
  x-section not depend on coupling of LQ, λ (Yukawa-type coupling)

- As a benchmark, we assume interaction of LQs to lepton and quark within the same generation only i.e.

  $pp \rightarrow LQ_1 LQ_1 \rightarrow eueu$
  $pp \rightarrow LQ_2 LQ_2 \rightarrow \mu c \mu c$



- However we don't require flavor tagging to jets to keep the analysis model-independent as much as possible (possibility of LQ→bμ and be is not excluded)

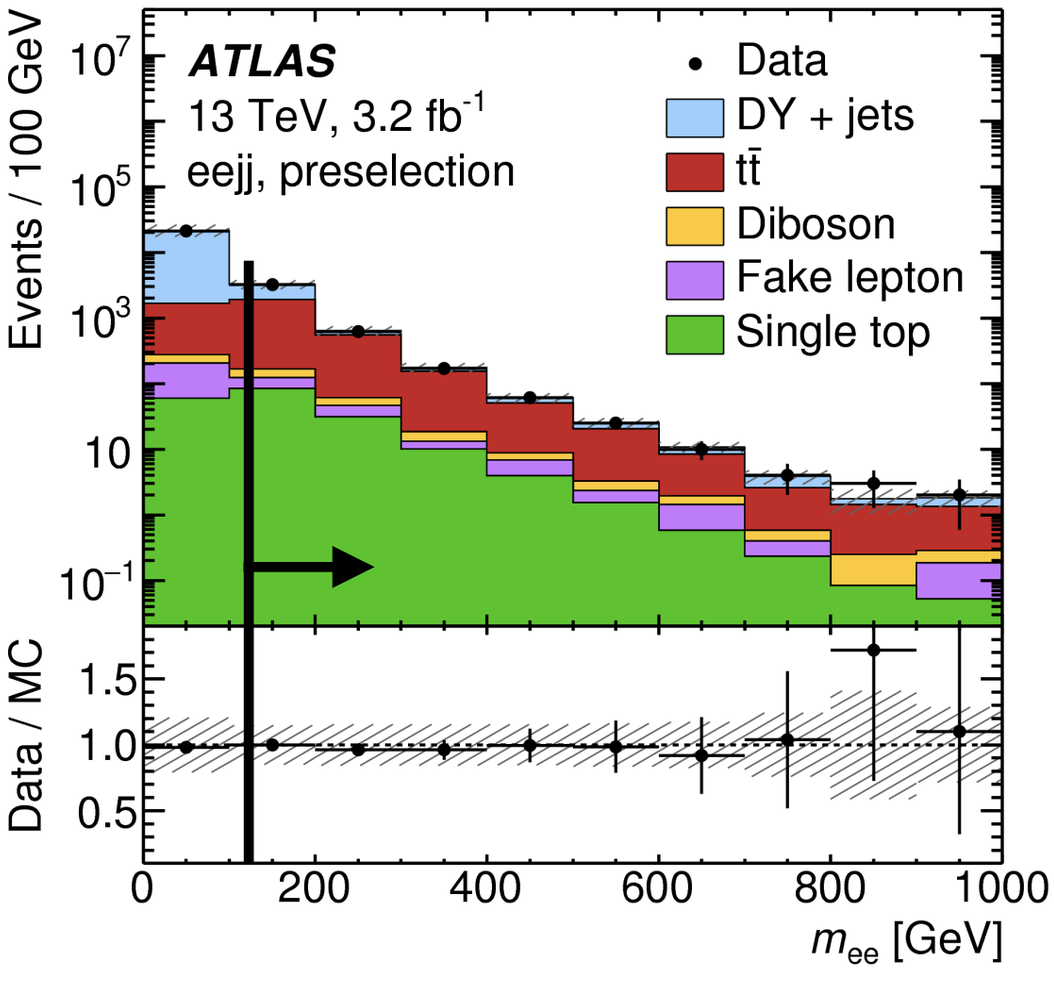
- Generated LQ masses are varied in [500, 1500]GeV and width is set to narrow enough w.r.t. detector resolution

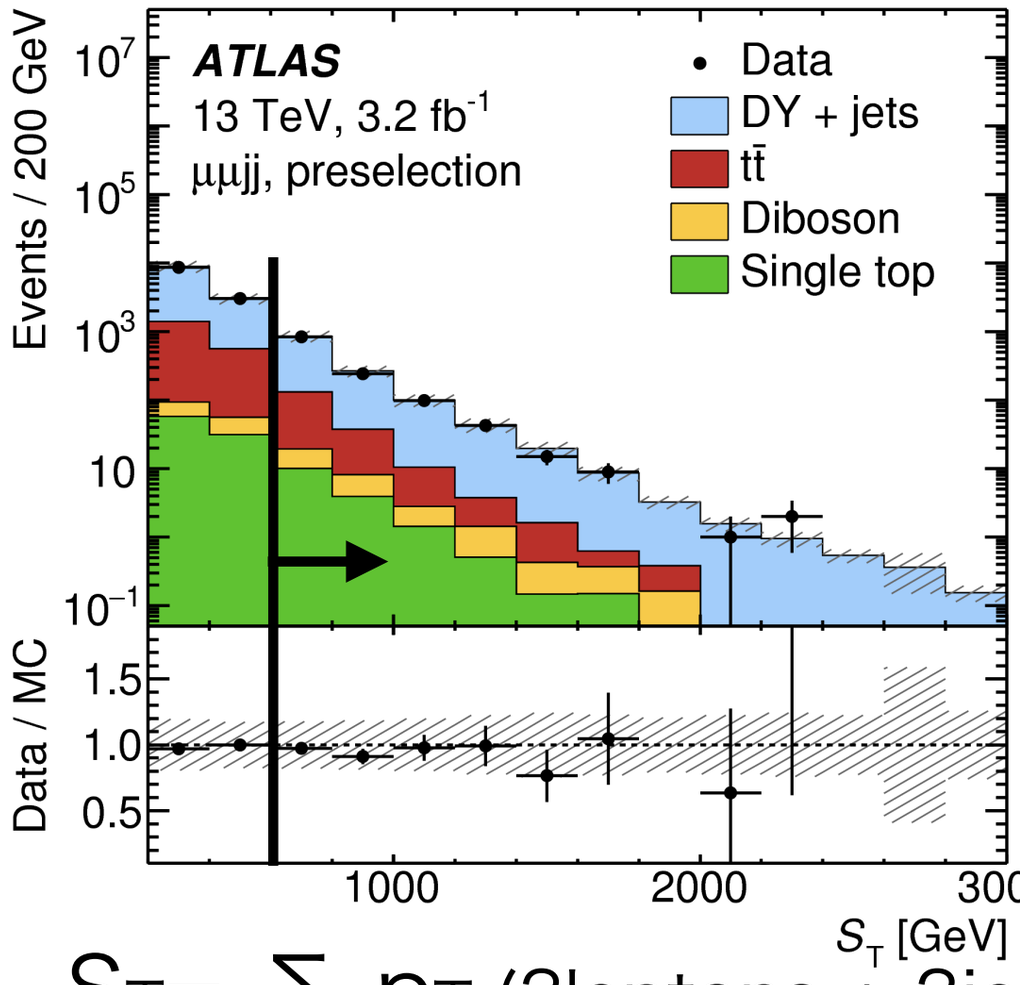
- Dedicated searches for LQ_3-like signature (i.e. SUSY $\tilde{t} \rightarrow t\tilde{\chi}^0_1$ and RPV $\tilde{t} \rightarrow l^{\pm}b$) will be presented in the other ATLAS talks

S. K. Strandberg, Searches for direct pair production of stops and sbottoms with the ATLAS detector
F. Ungaro, Searches for stops in scenarios with R-parity violating sparticle decays, or long-lived sparticles with ATLAS

Event selection and categorization

- Signal region is defined by m_{ll} > 130GeV and S_T>600GeV
  - 2 leptons with same flavor
  - Selection efficiency is ~60% for eueu and ~40% for μcμc signals
- ttbar CR: exactly 1 electron and 1 muon in the event; no S_T cut for stat
- Z+jets CR: $m_{ll} \in [70, 110]$GeV; no S_T cut for stat

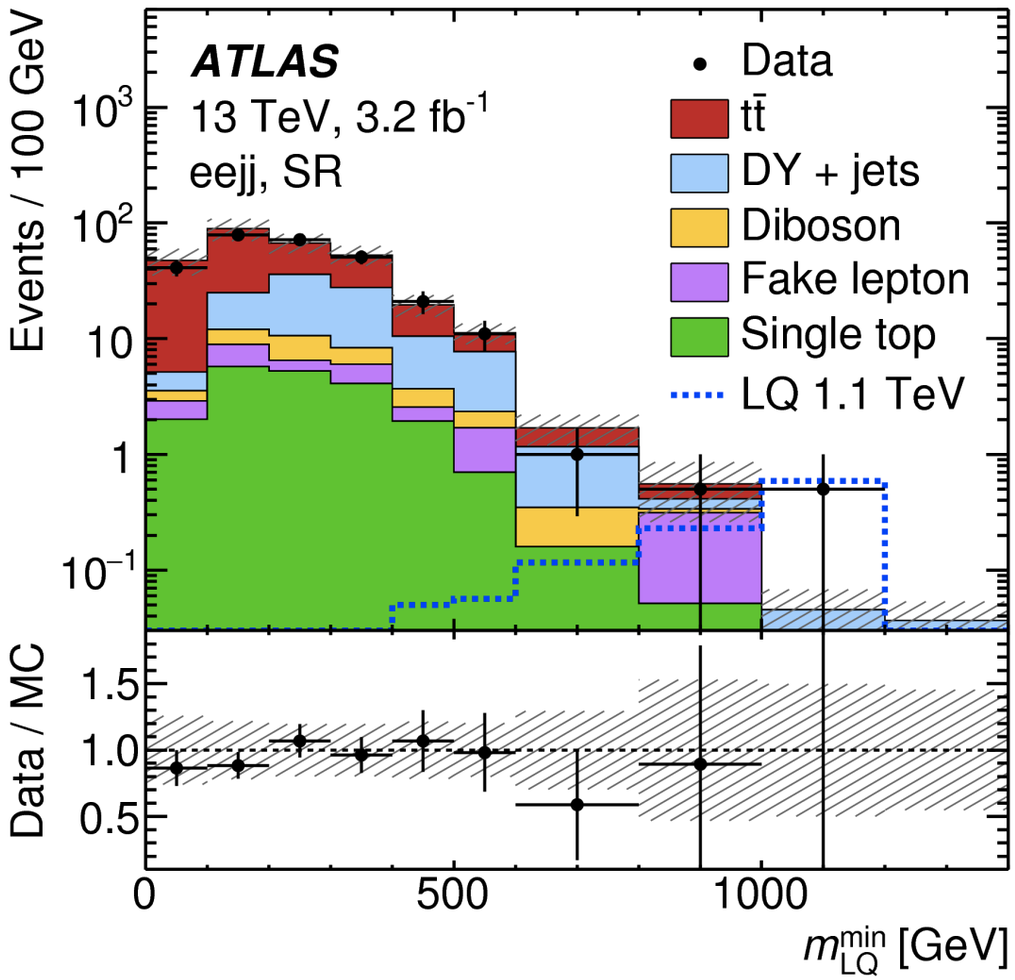




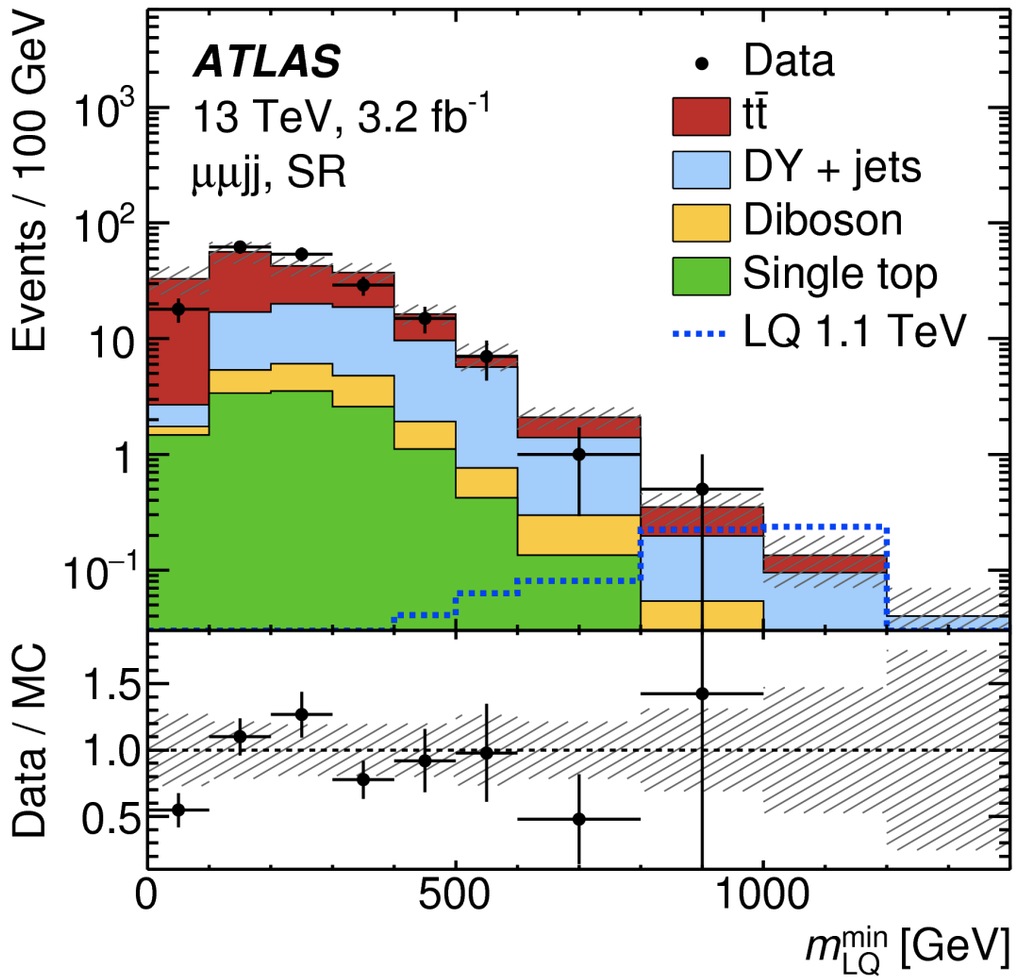
$S_T = \sum p_T$ (2leptons + 2jets)

Reconstructed LQ mass distributions

Electron channel

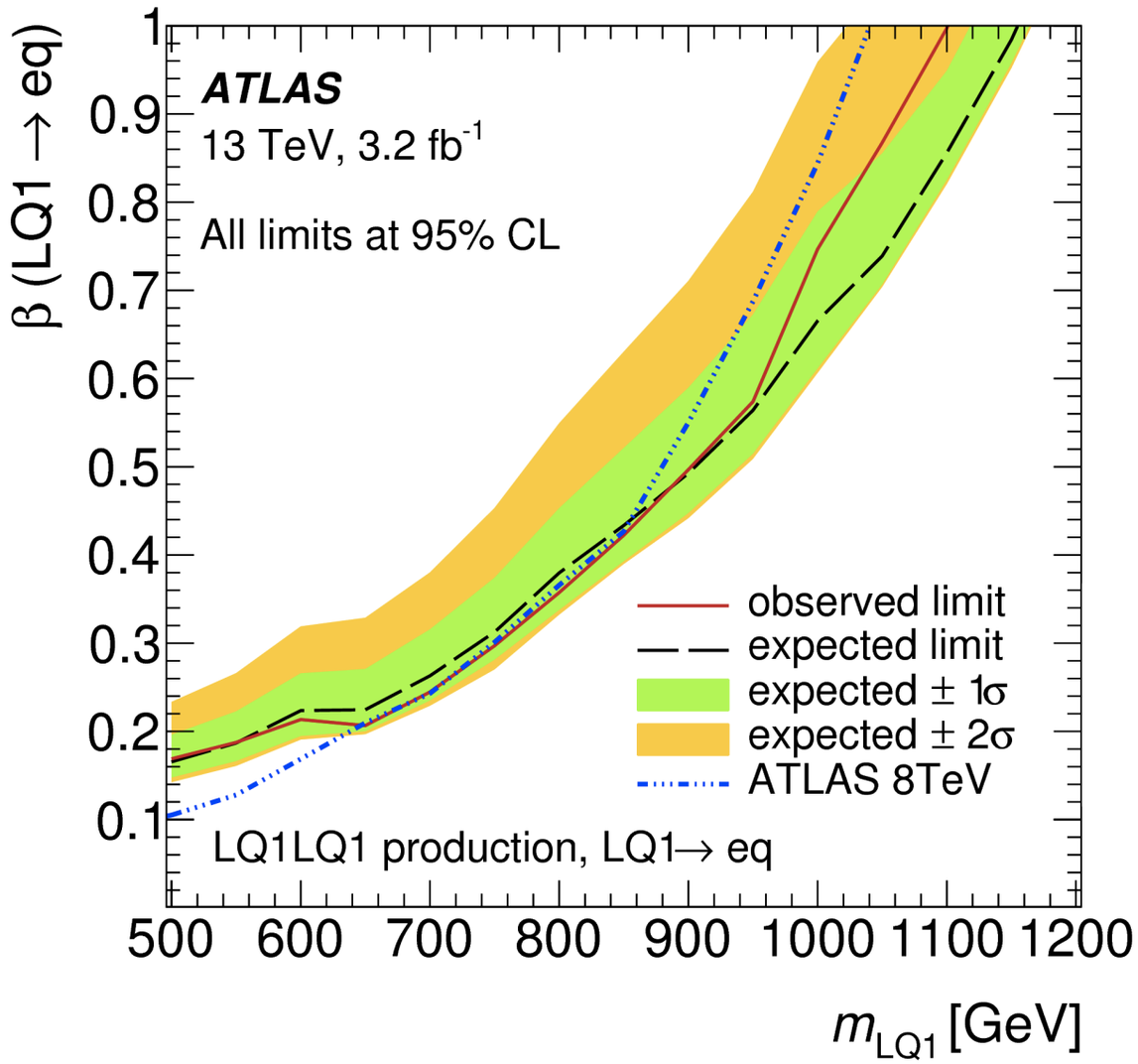


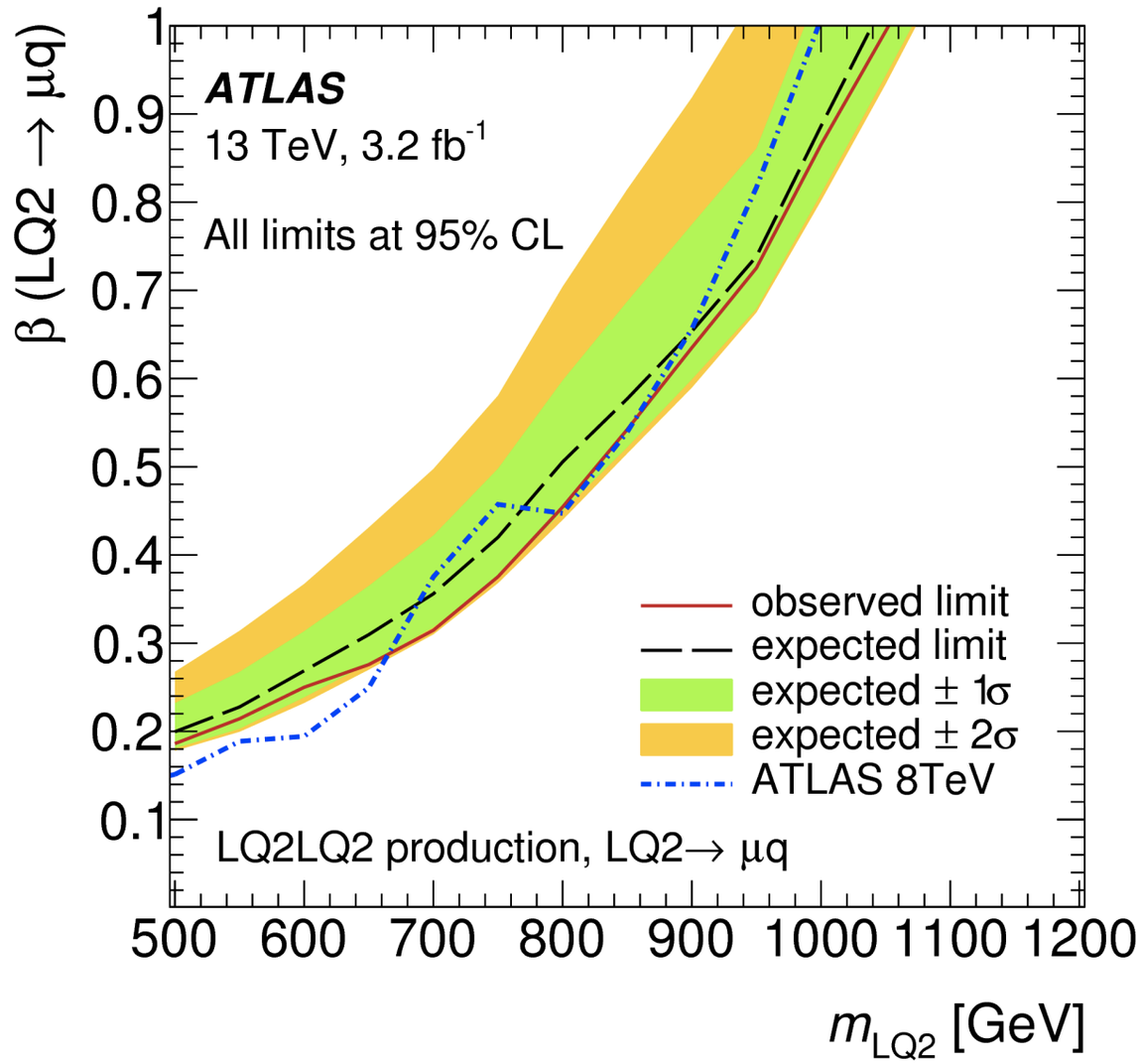
Muon channel



- Two pairs of (lepton, jet) are selected to minimize the mass difference between them
- Minimum invariant mass reconstructed by lepton and jet is used as final discriminant
- Data agree well with the estimated SM background

Limits on benchmark signals





- Ratio of branching fractions β(LQ→lq) and β(LQ→νq) is scanned in [0, 1]
- Only with 3/fb data at 13TeV, sensitivity at m>900GeV is already greater than run-1 (8TeV, 20/fb)

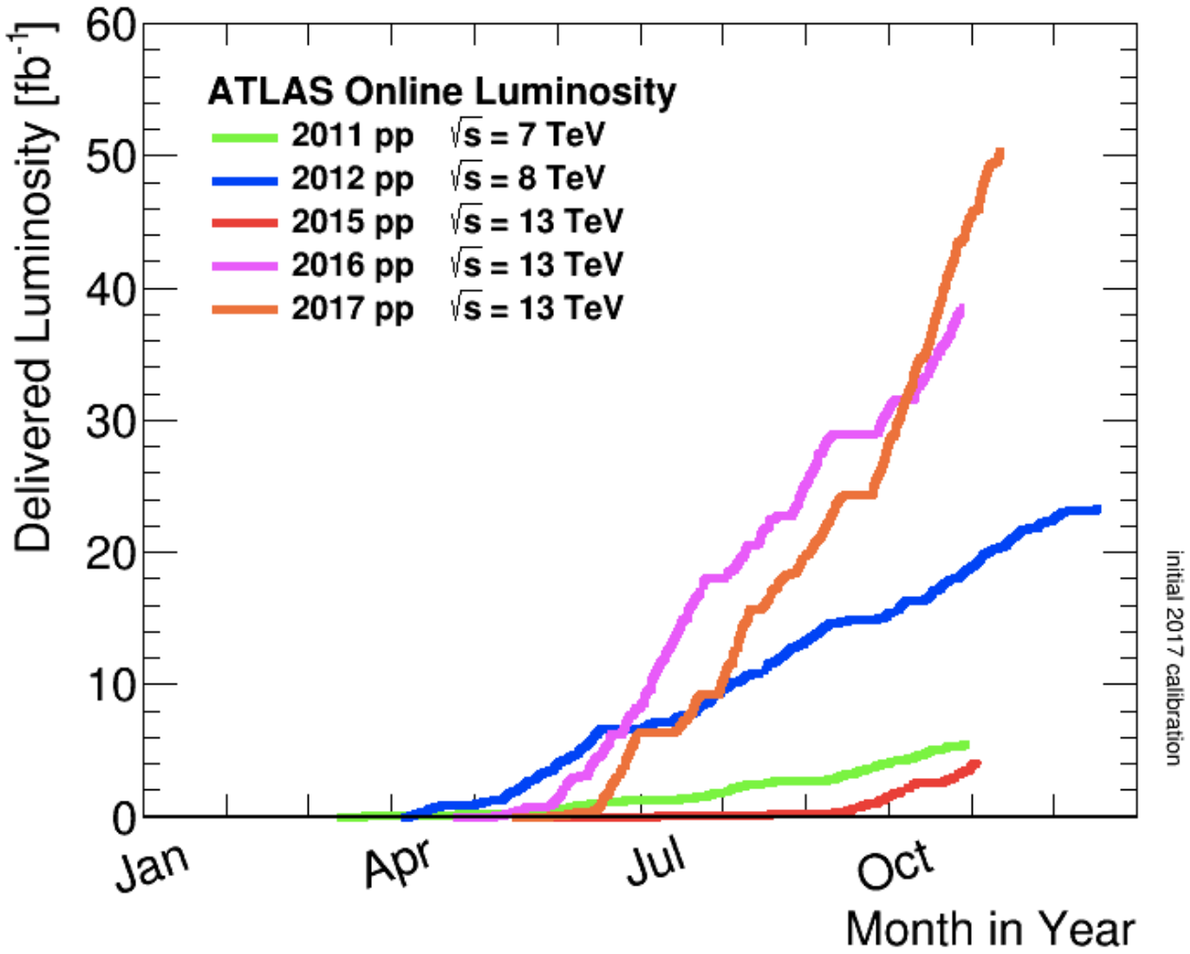
Summary

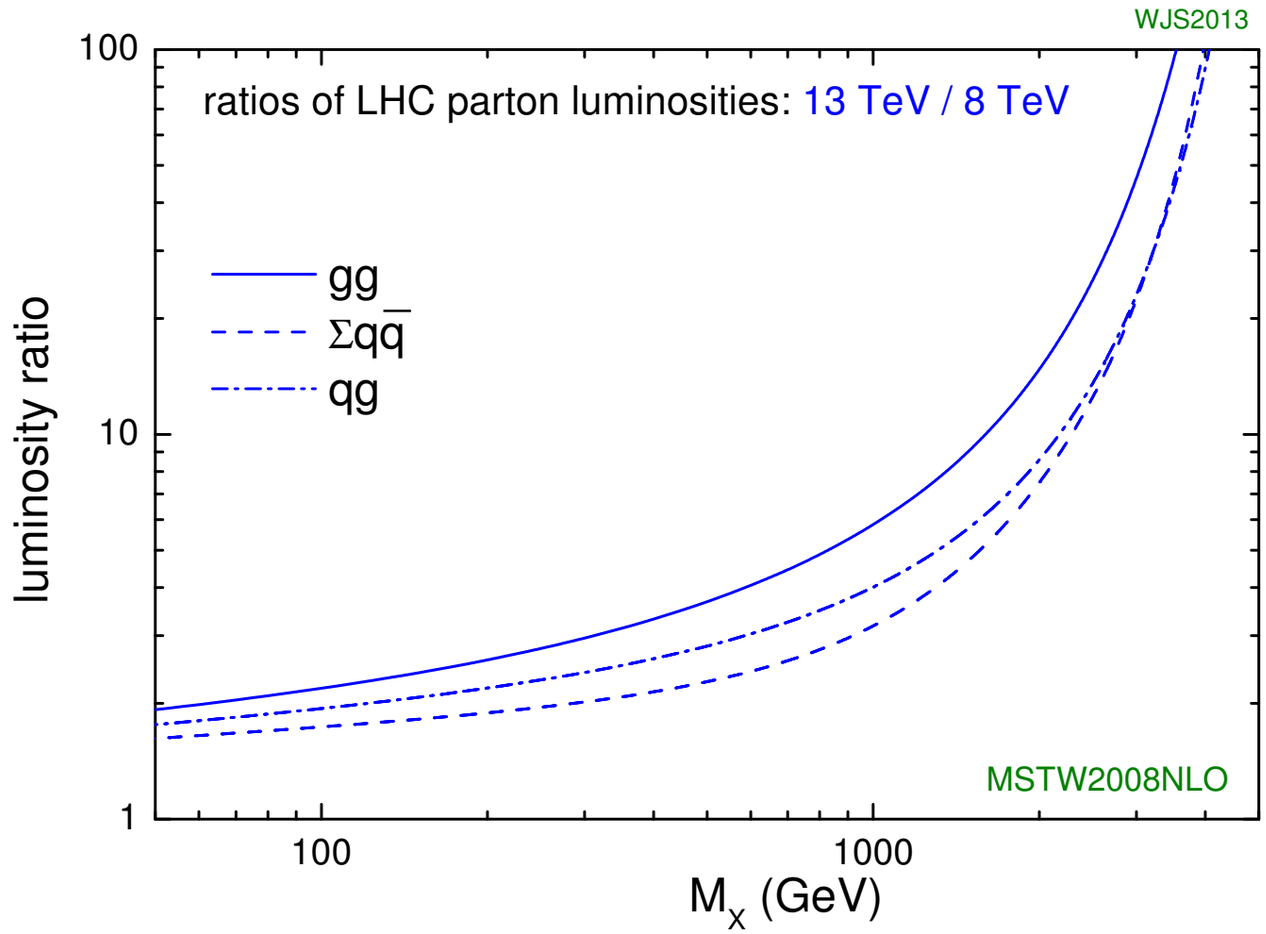
- The latest ATLAS results using lepton(s) and jet(s) have been presented
- **Multi production of high-p_T SM particles** (incl. leptons) for general search for new physics involving EW sector
  - Benchmark: micro BH production expected from **extra dimension** models
  - Great improvement in sensitivity from run-1 analysis
  - Keep an eye on ~2σ excess in e-channel
- **Lepton+jet resonance** is naively expected from observed **anomalies in flavor physics**; and also interesting from a view point of **GUT**
  - Model-independent search for LQ pair production decaying to eq and μq
  - Better sensitivity than run-1 analysis at m>900GeV
- Only 3.2fb^{-1} data collected in 2015 are shown today.
  Analysis using more data is on-going (we already collected ~80fb^{-1} until today!)

Stay tuned:)

Aux materials

ATLAS data taking in run-2





- Total ~80/fb collected at 13TeV during 2015-2017
- Full run-2: ~120/fb is expected

Physics of micro BH production

- If stars satisfy R<R_g, black hole is formed; R_g is the Schwarzschild radius

- In our 4-dimensional universe, it is

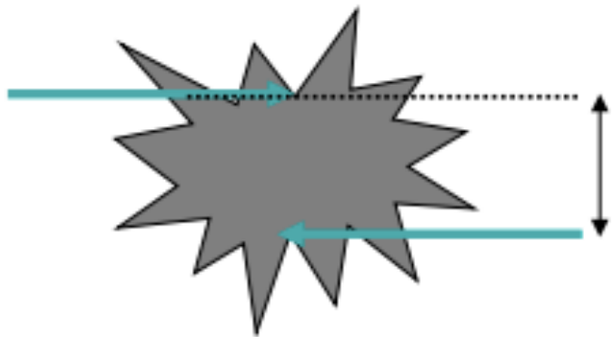
$$R_g = \frac{2GM}{c^2}$$

- If *n* extra dimensions are added, it becomes to:

$$R_g = \frac{1}{\sqrt{\pi} M_{\mathrm{Planck}}} \left[\frac{M_{\mathrm{BH}}}{M_{\mathrm{Planck}}} \left(\frac{\Gamma\left(\frac{n+3}{2}\right)}{n+2} \right) \right]^{\frac{1}{1+n}}$$

(*R_g* increases as a function of *n*)

- If impact parameter is smaller than 2R_g, micro BH is produced at the LHC

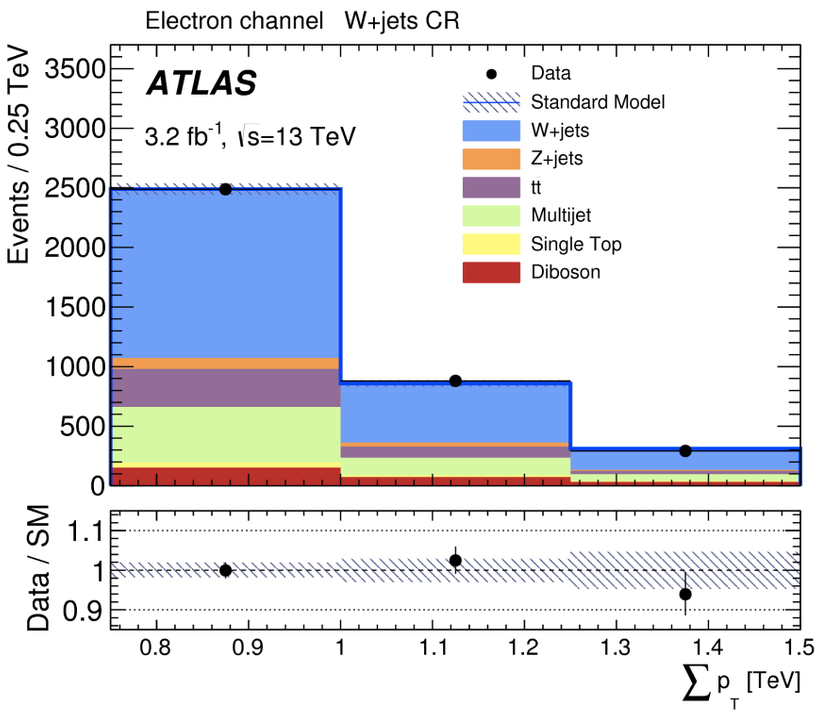


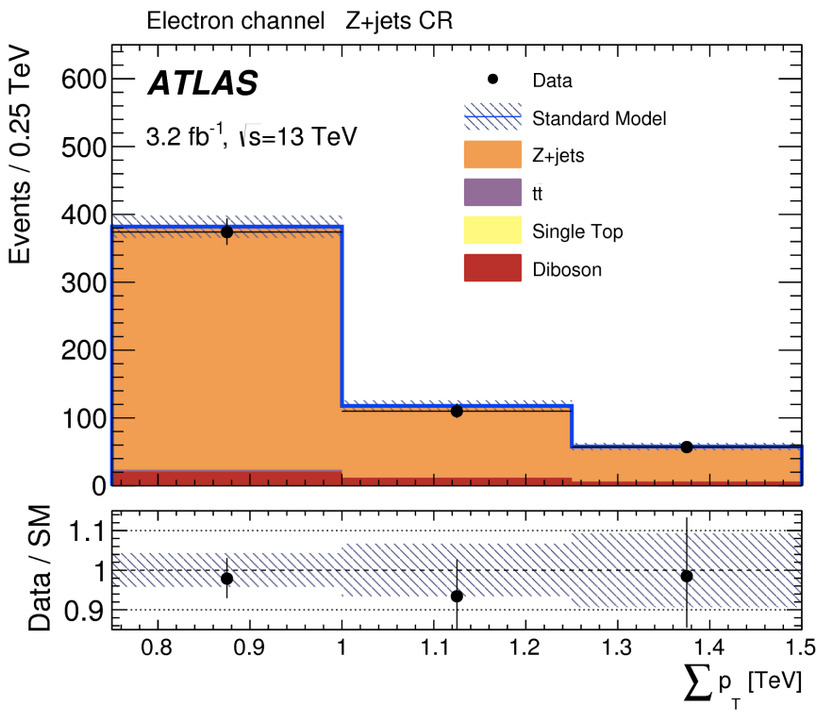
- Cross section of micro BH at the LHC is increased if we assume larger number of extra dimensions!

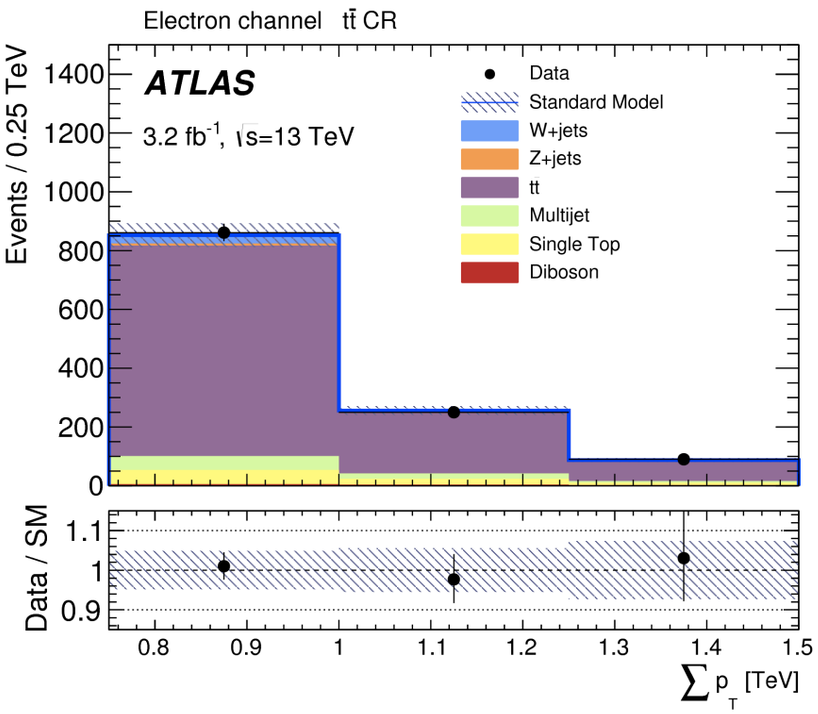
Event selection BH search

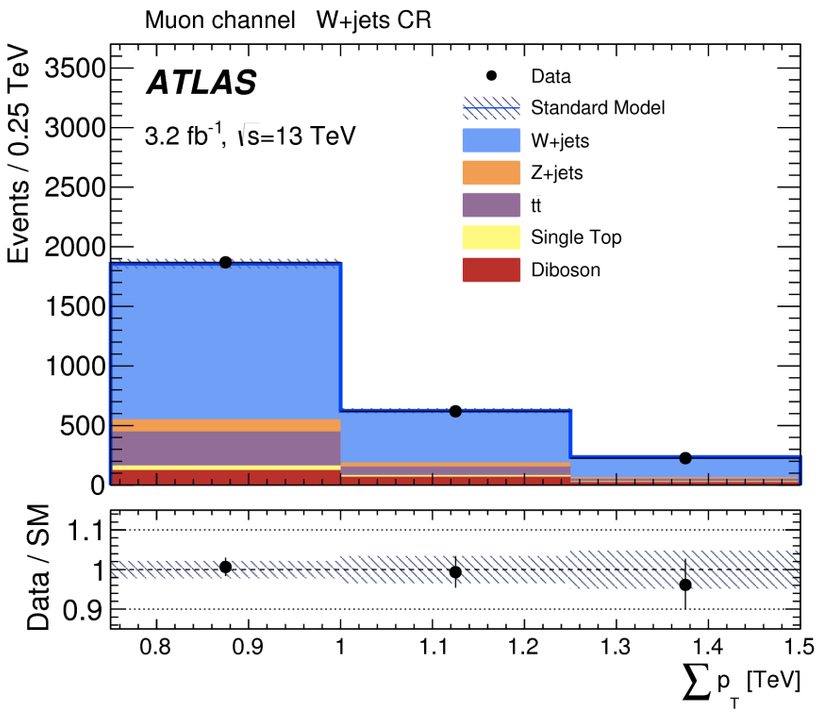
Selection	**Control Regions**			**Signal regions**
	Z**+jets**	W**+jets**	$t\bar{t}$	
$\sum p_{\mathrm{T}}$	750–1500 GeV			$>$ 2000(3000) GeV
Number of objects (leptons or jets)	$\geq$ 3 objects with $p_{\mathrm{T}} > 60$ GeV			$\geq$ 3 objects with $p_{\mathrm{T}} > 100$ GeV
Leading lepton (electron or muon)	Isolated with $p_{\mathrm{T}} > 60$ GeV			Isolated with $p_{\mathrm{T}} > 100$ GeV
$m_{\ell\ell}$	80–100 GeV	n/a		n/a
$E_{\mathrm{T}}^{\mathrm{miss}}$	n/a	> 60 GeV	n/a	
Number of leptons	$= 2$, opposite sign same flavour	$= 1$		≥ 1
Number of b-tagged jets	n/a	$= 0$	≥ 2	n/a
Number of jets	n/a		≥ 4	

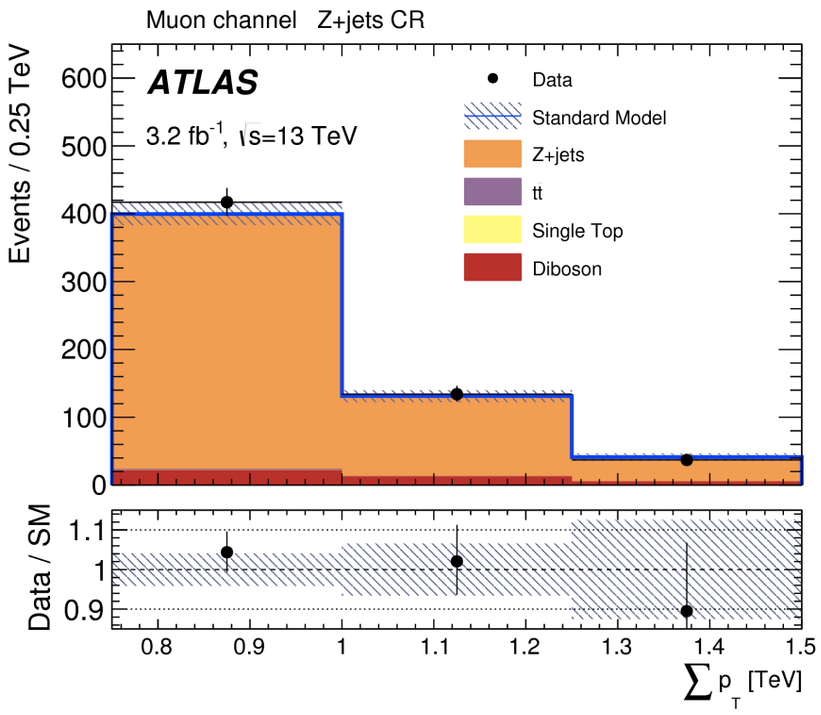
CRs for BH search

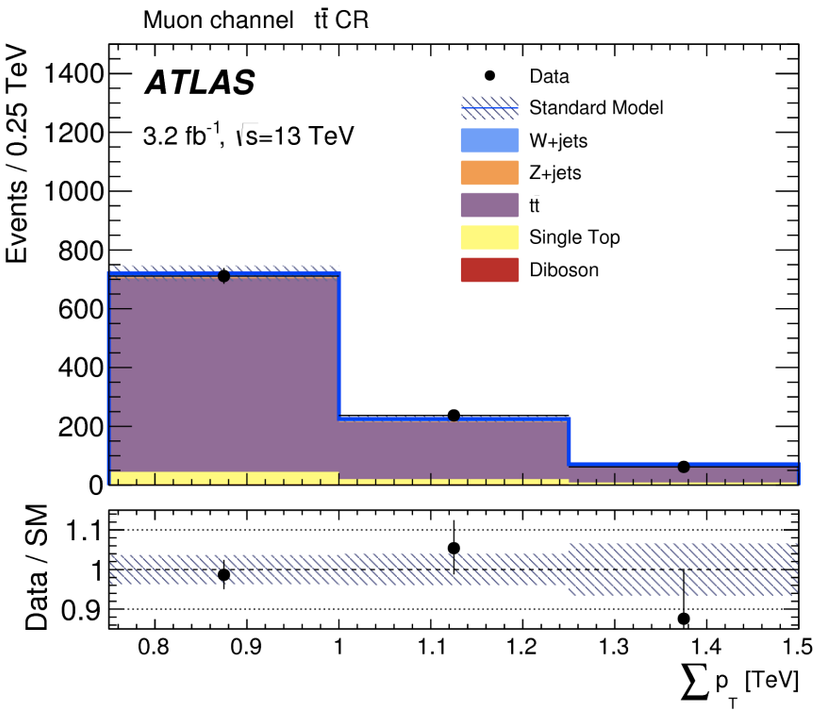






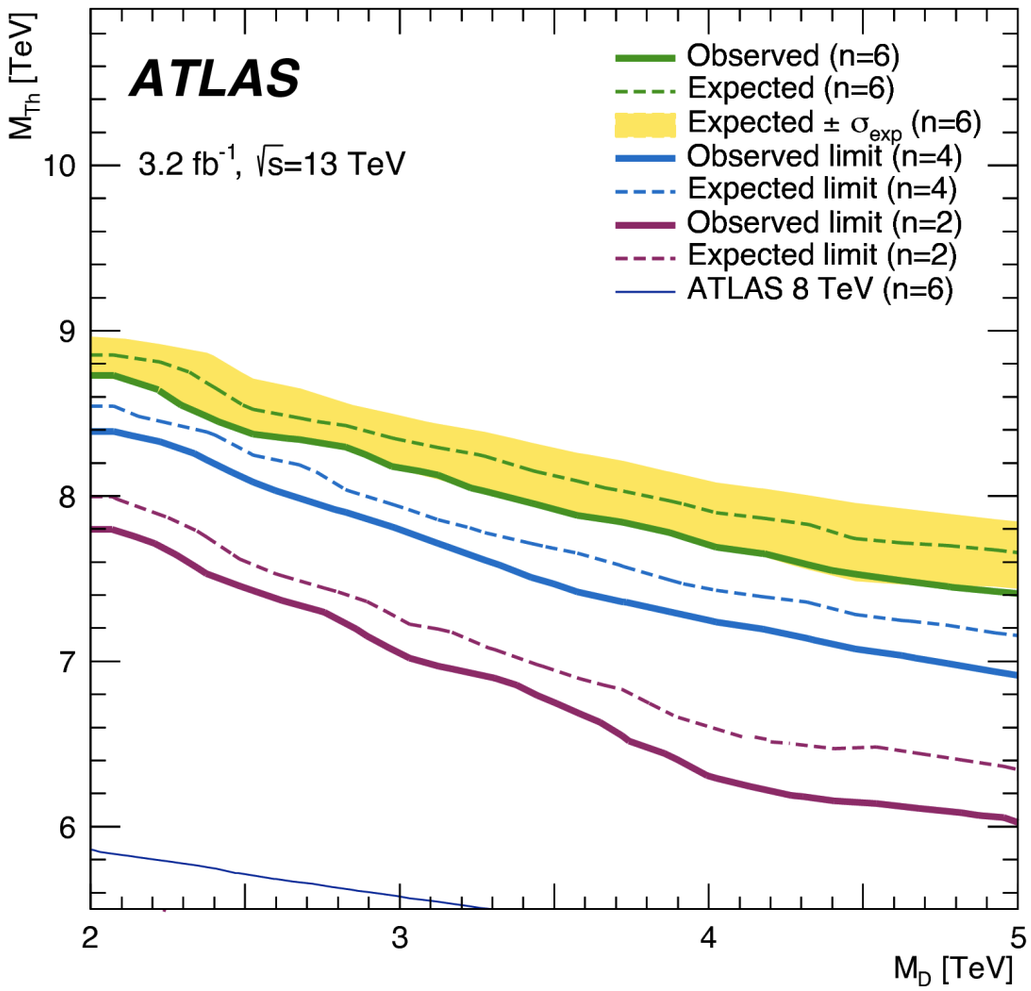




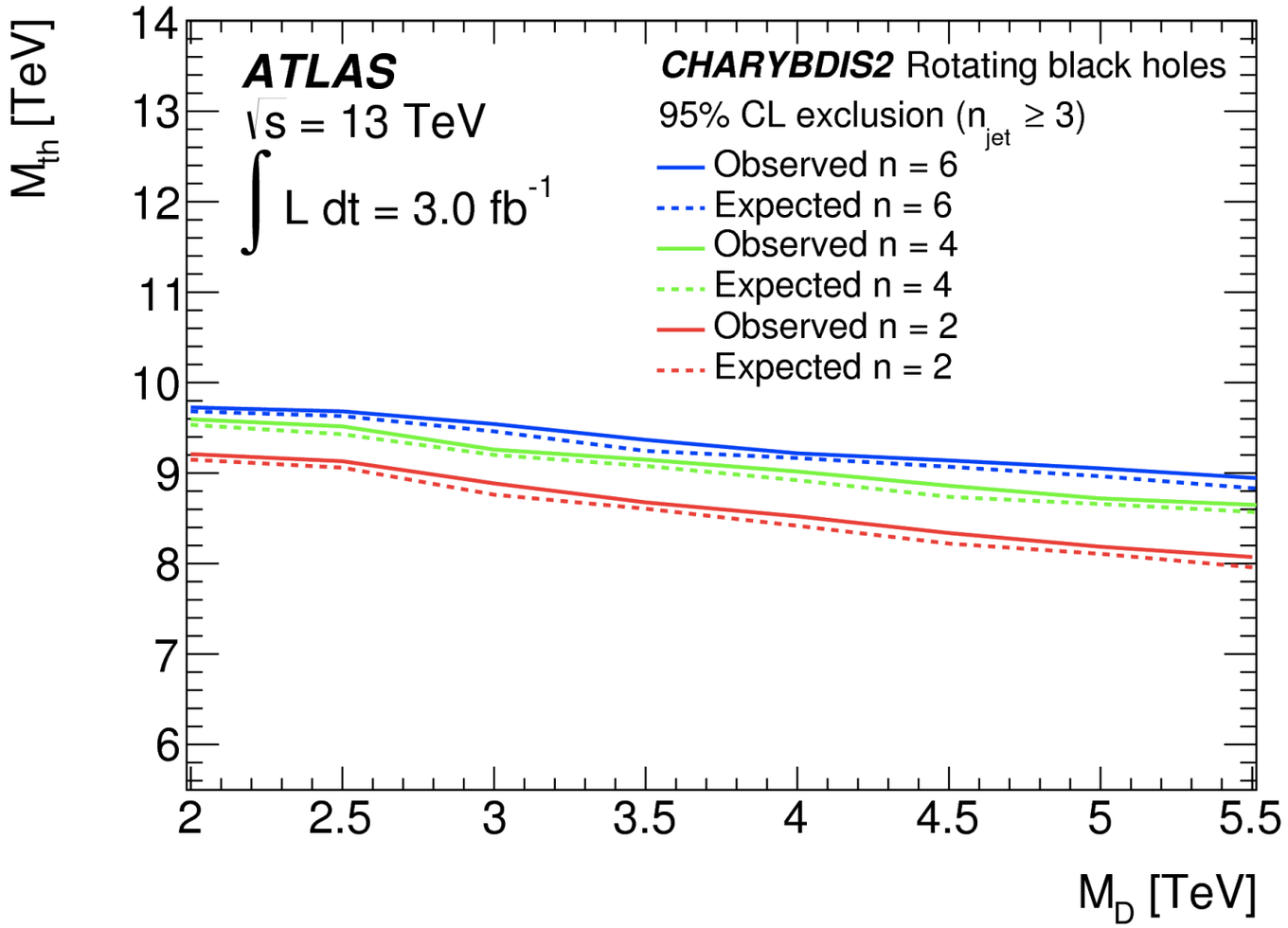


Comparison with full-hadronic final states

at least 1 leptons

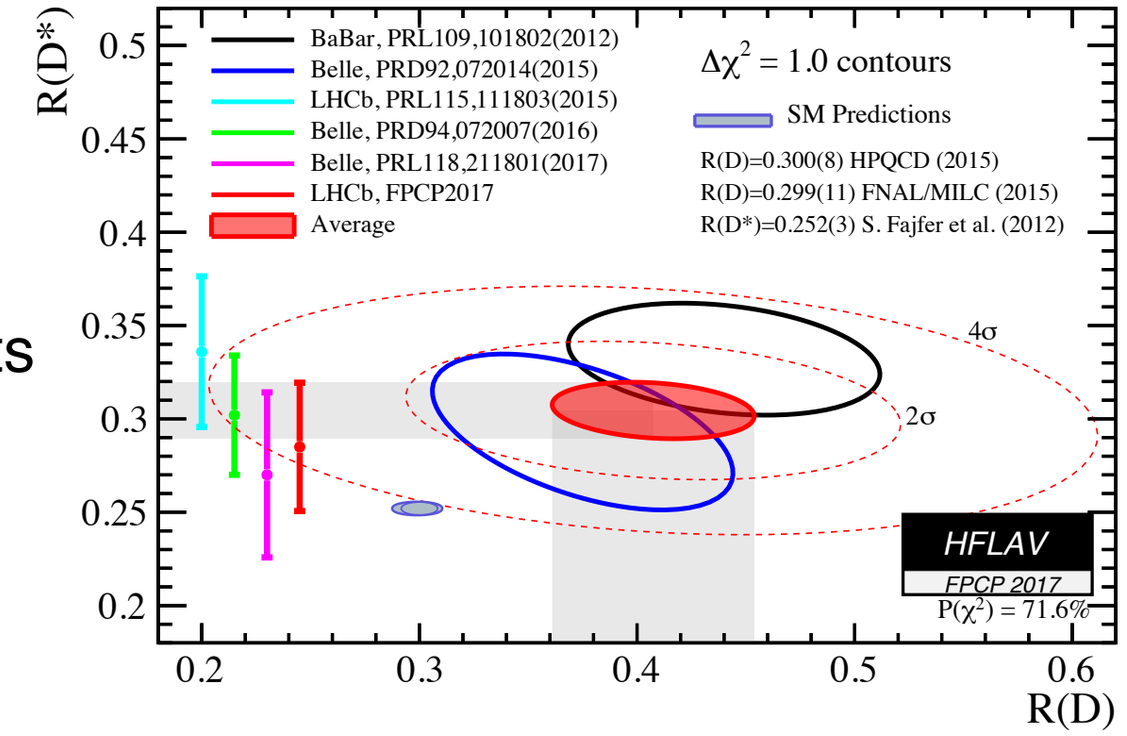


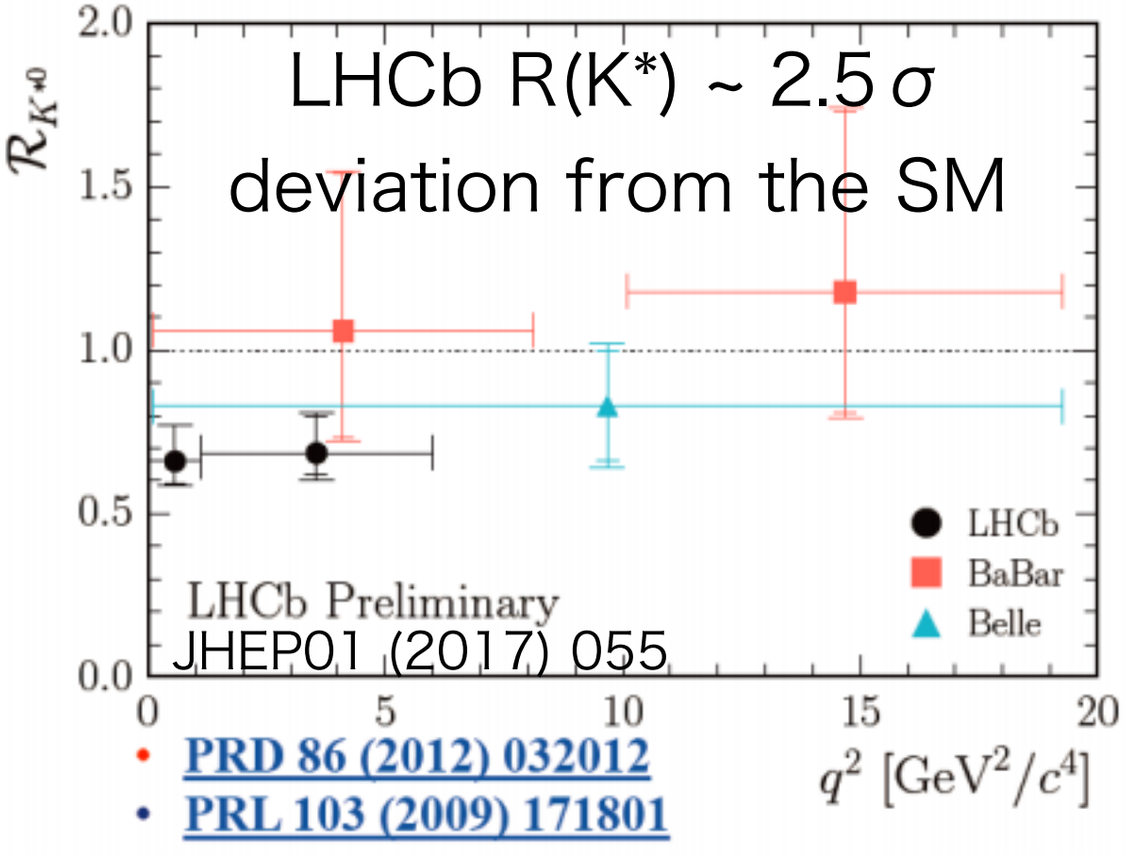
all hadronic

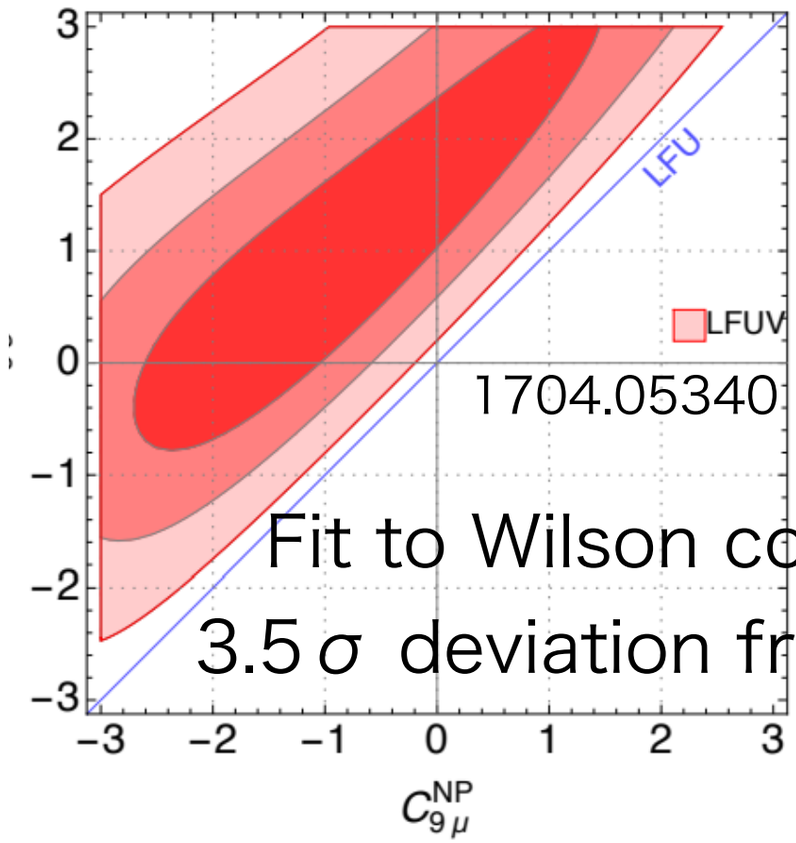


Lepton flavor non-universalities

- LHCb and B-factories reported consistent results
- β(b→cτν)/β(b→cμν) is larger than theory (~4σ deviation from the SM)
- β(b→sμμ)/β(b→see) is smaller than theory



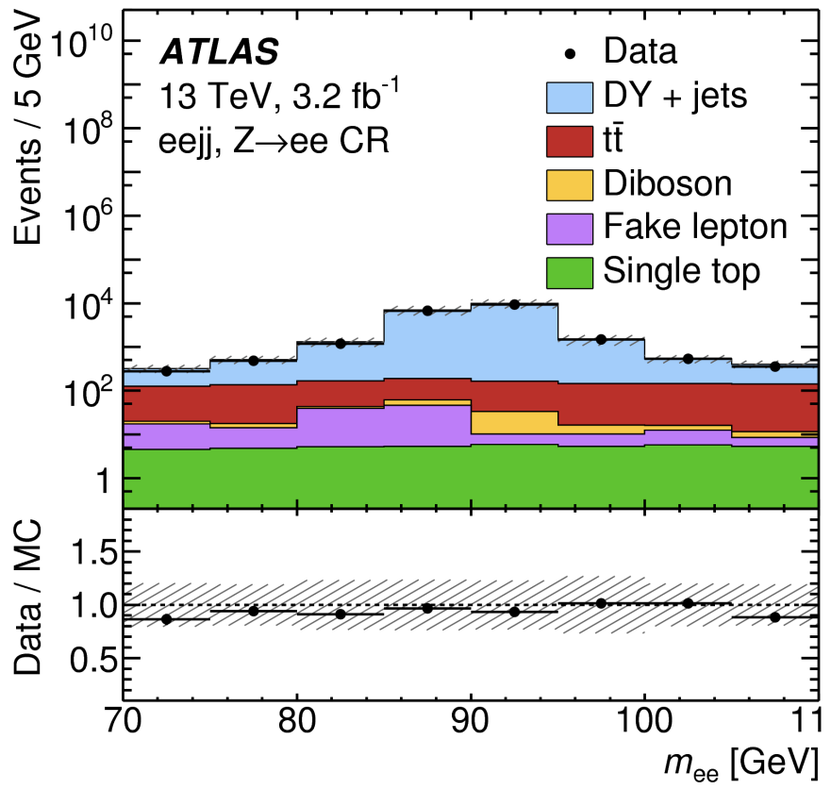


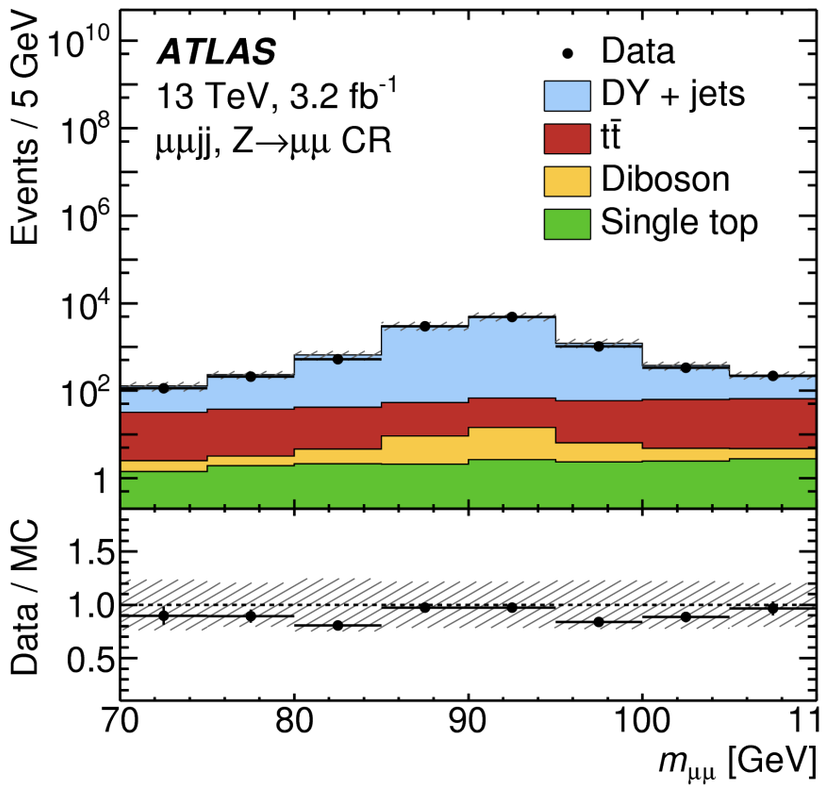


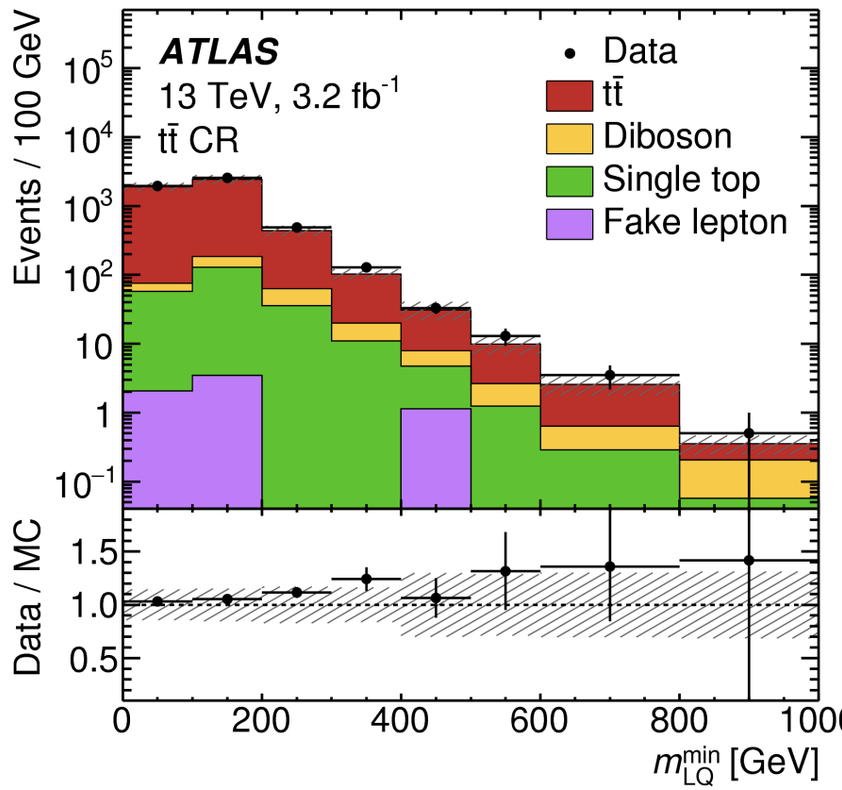
Event selection LQ search

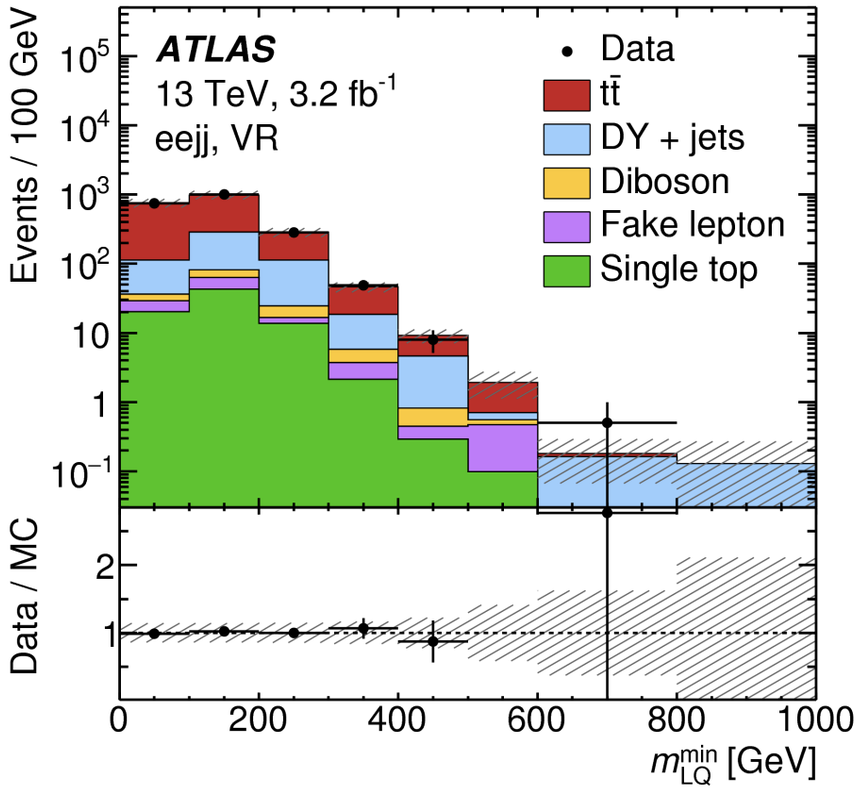
Region	Channel	#e	#μ	$m_{\ell\ell}$ [GeV]	S_{T} [GeV]
$t\bar{t}$ CR	both	1	1	–	–
DY+jets CR	$eejj$	2	0	[70, 110]	–
	$\mu\mu jj$	0	2		
SR	$eejj$	2	0	>130	>600
	$\mu\mu jj$	0	2		
VR	$eejj$	2	0	>130	<600
	$\mu\mu jj$	0	2		

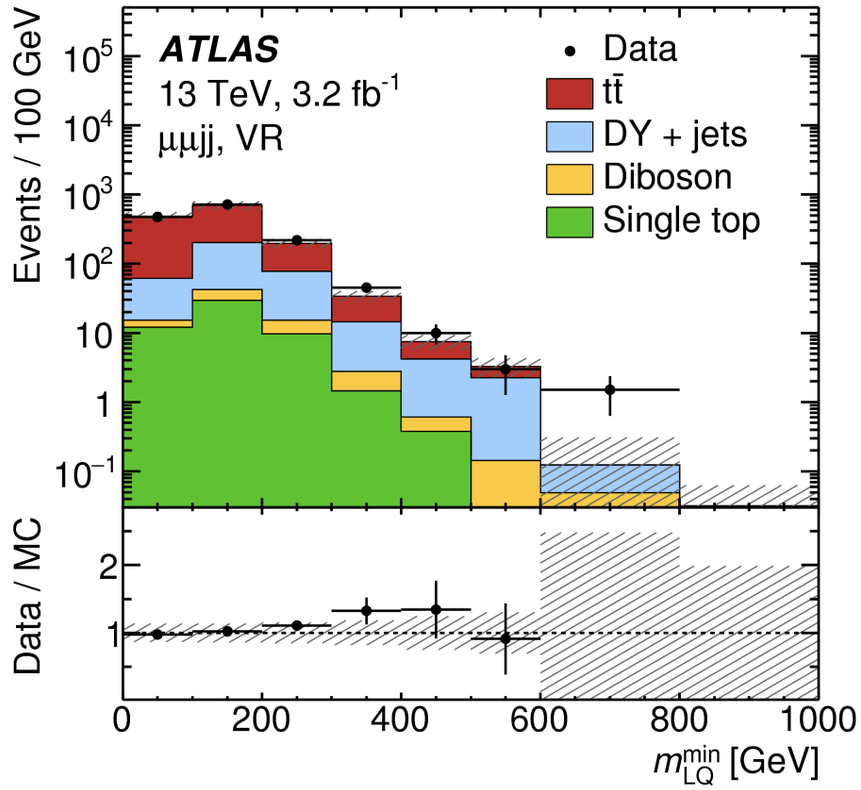
CRs for LQ search











Yield tables LQ search

electron channel

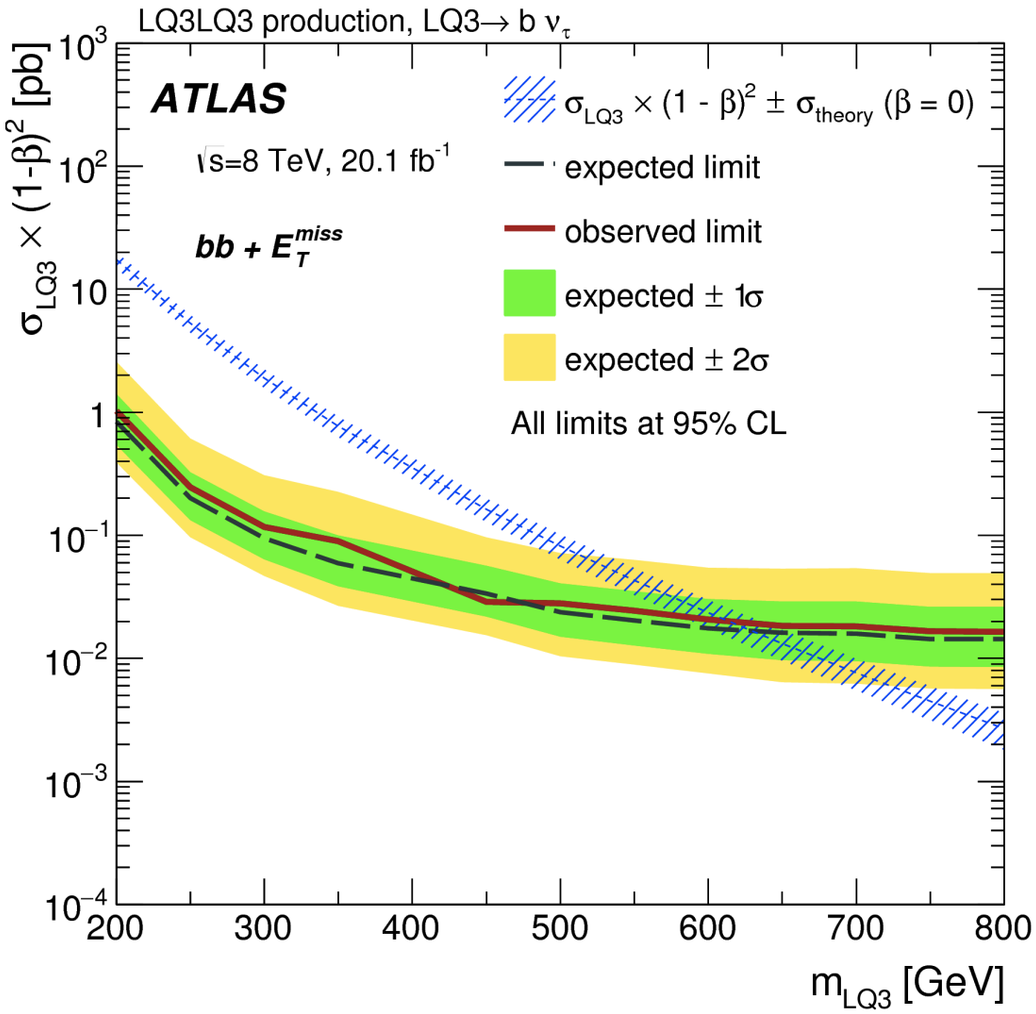
	SR	CR DY+jets	CR ttbar
Data	279	20328	5194
Total b.g.	300 ± 30	20300 ± 200	5200 ± 50
DY + jets	74 ± 7	19100 ± 200	<0.01
ttbar	190 ± 30	1060 ± 10	4840 ± 40
Diboson	12.5 ± 0.6	63 ± 3	115 ± 6
Single-t	20 ± 1	42 ± 2	230 ± 10
Multijet	9 ± 4	120 ± 10	6 ± 3

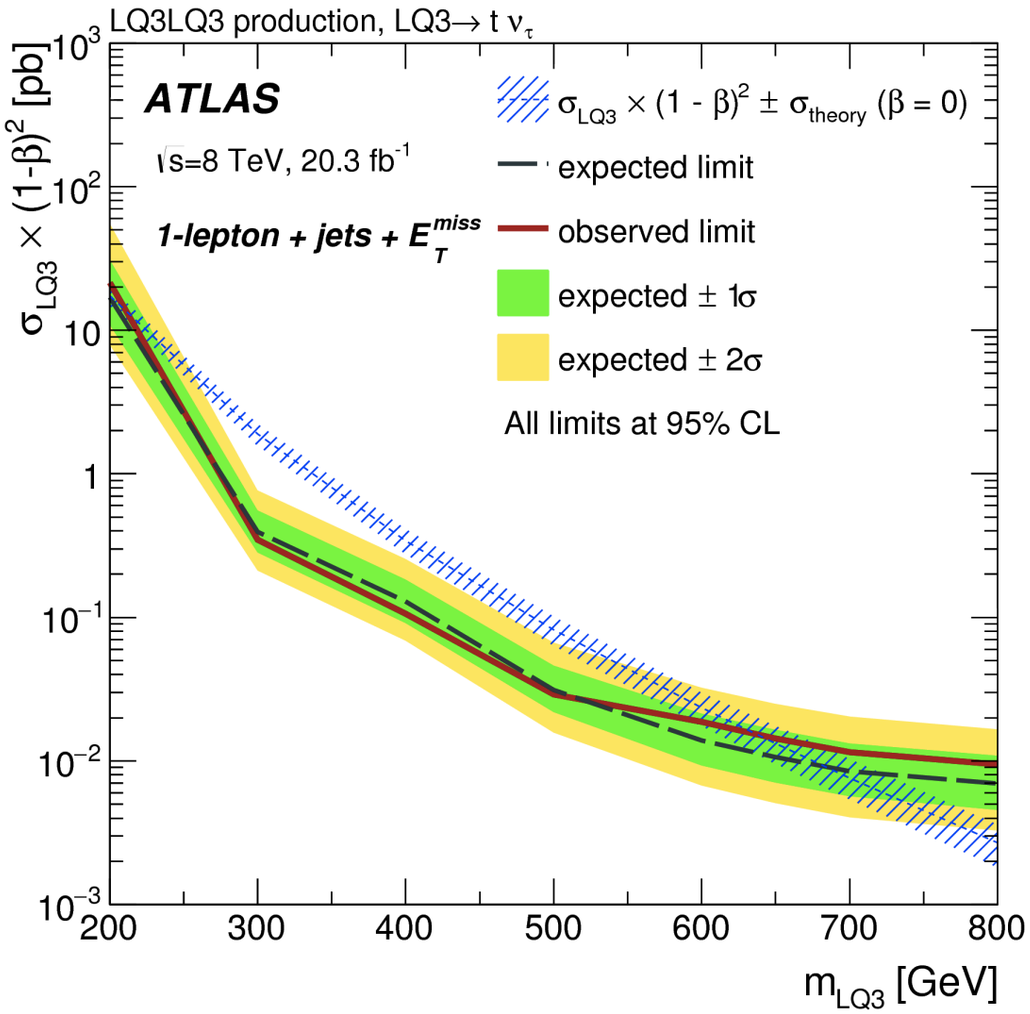
muon channel

	SR	CR DY+jets	CR ttbar
Data	188	10233	5194
Total b.g.	200 ± 30	10200 ± 100	5200 ± 70
DY + jets	56 ± 8	9800 ± 100	9 ± 1
ttbar	120 ± 30	400 ± 20	4840 ± 80
Diboson	8.6 ± 0.6	32 ± 3	115 ± 10
Single-t	12.8 ± 0.9	18 ± 2	230 ± 20
Multijet	-	-	-

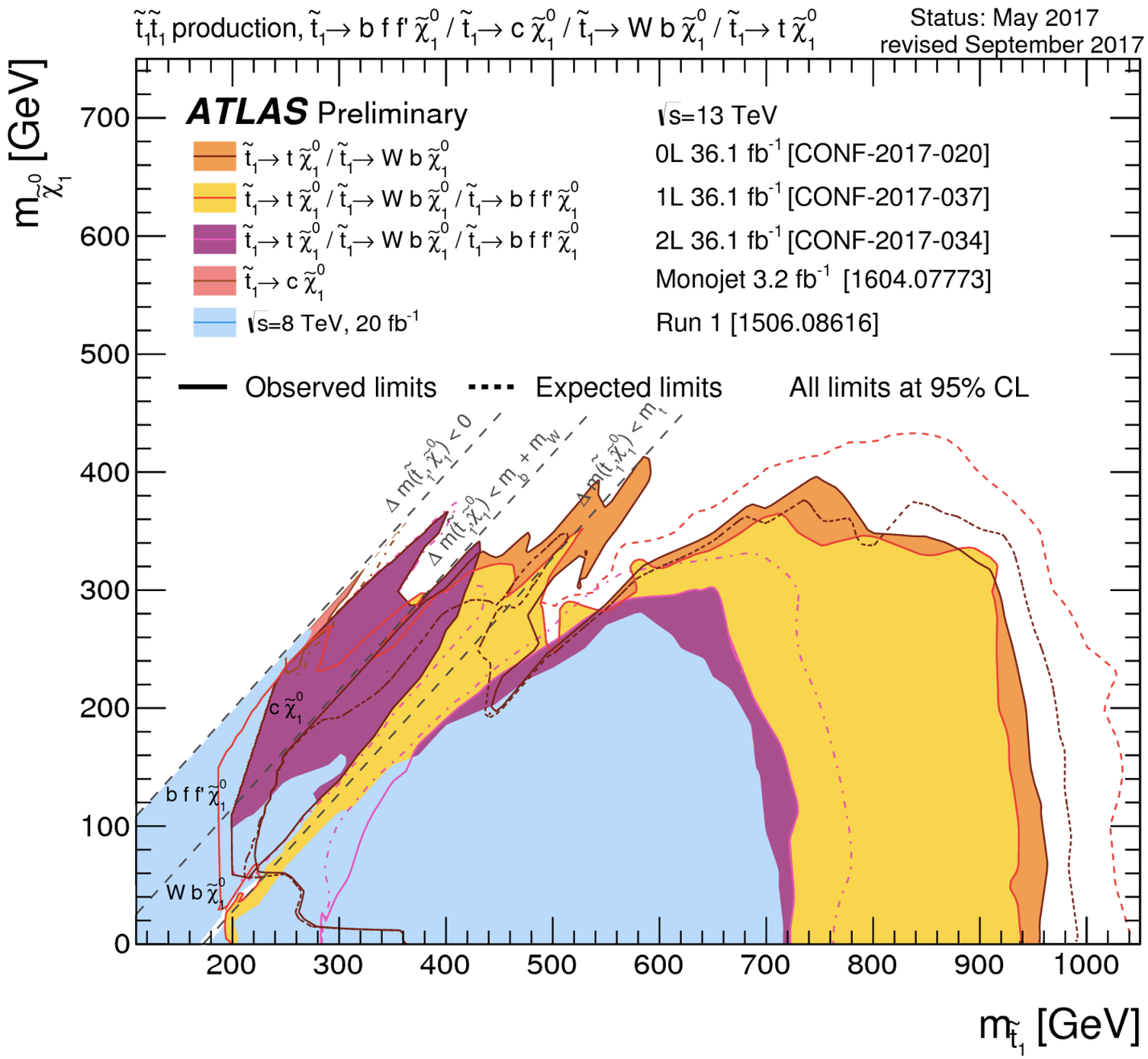
LQ_3 search

- 8TeV data rejected m<625GeV in bvbv channel and [200, 640]GeV in tvtv channel (EPJC76 (2016) 1-28)
- Some SUSY signals ($\tilde{t}\to t\tilde{\chi}^0_1$ and RPV $\tilde{t}\to l^{\pm}b$) have similar topologies to LQ_3. 13TeV results will be presented in the other ATLAS talks





ATLAS stop search results



- Line at m_{LSP}=0GeV indicates the limit on scalar LQ_3 decaying to top and neutrino