Search for A to Zh(bb) in ATLAS at 13 TeV

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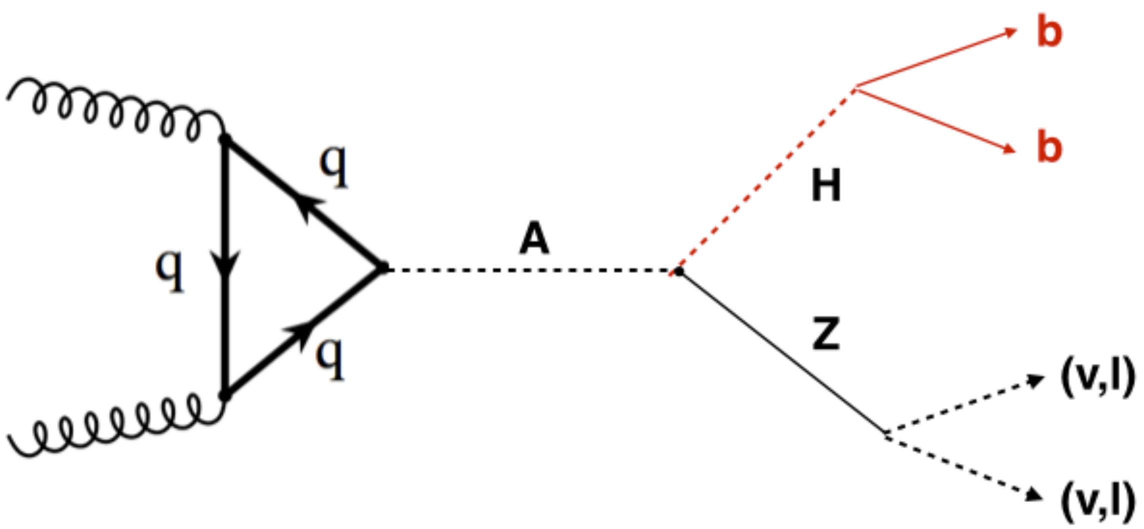
on behalf of the ATLAS collaboration

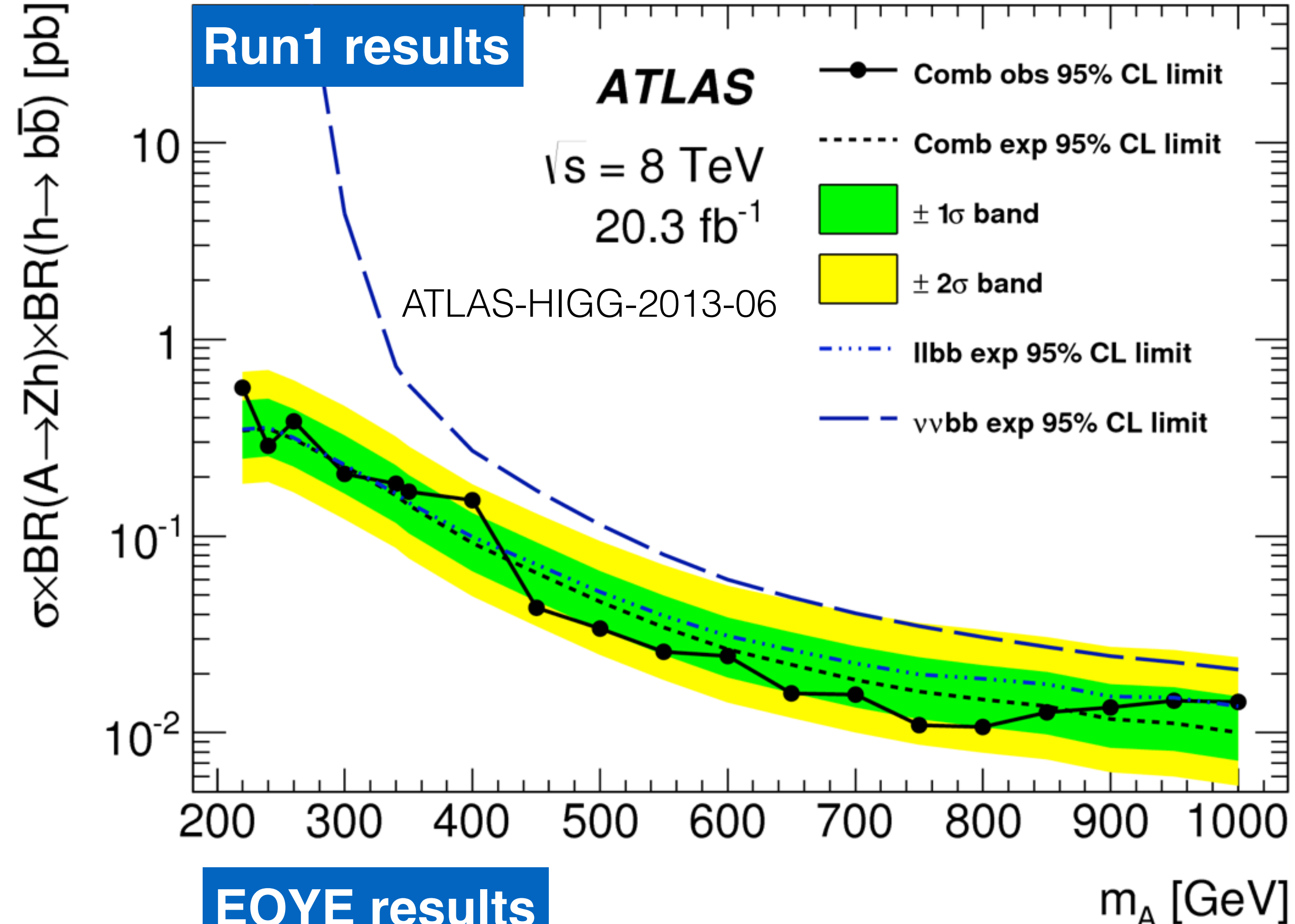
Rencontres de Moriond - Electroweak Session - 16/03/2016

ATLAS-CONF-2016-015

Search for a CP-odd A boson in the Zh(bb) decay channel

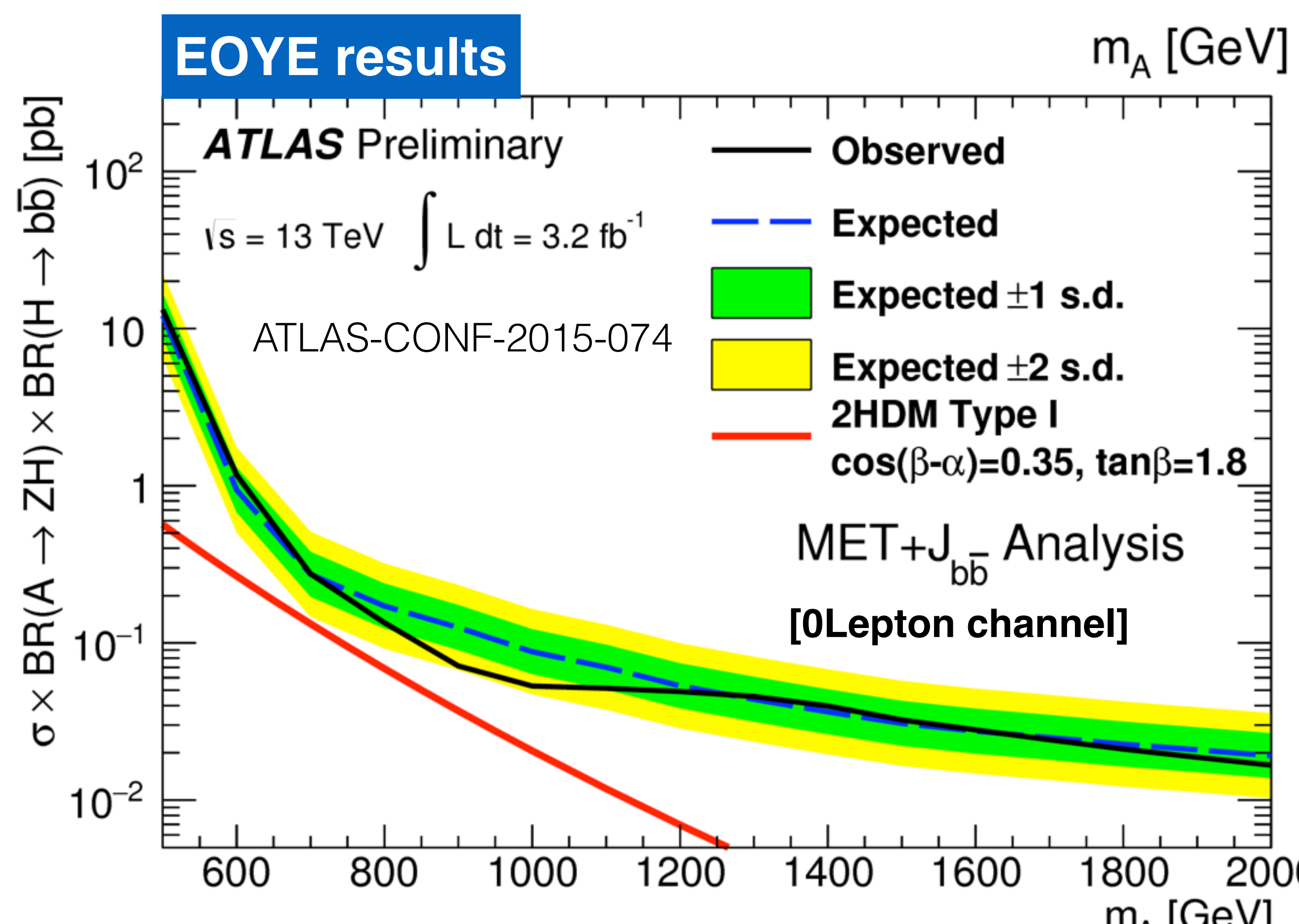


*Search for a CP-odd scalar A boson through ggA and bbA production in the decay channel to Zh, in the context of **2HDMs** with the full 2015 dataset (L=3.2/fb)*



Two main channels combined:

$Zh \rightarrow \nu\nu bb$ (dominant at **high** m_A)
$Zh \rightarrow l^+l^-bb$ (dominant at **low** m_A)

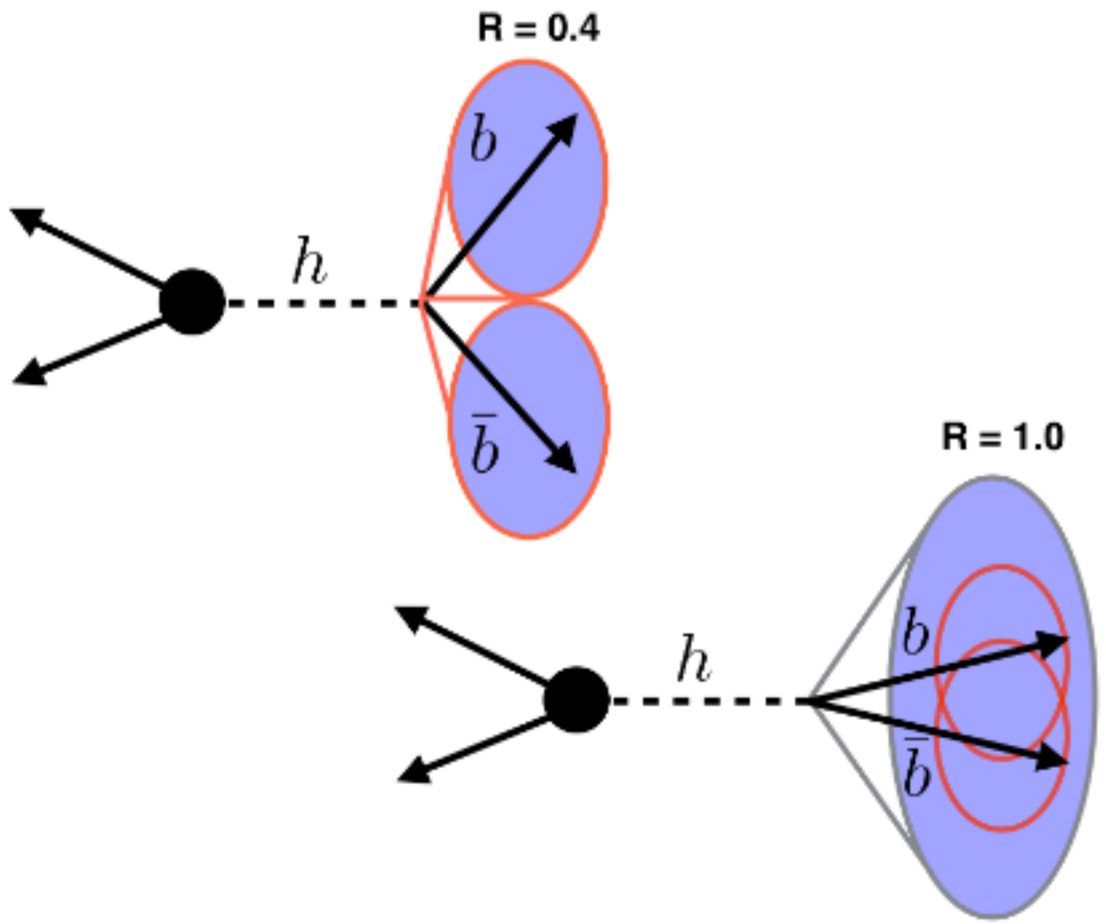


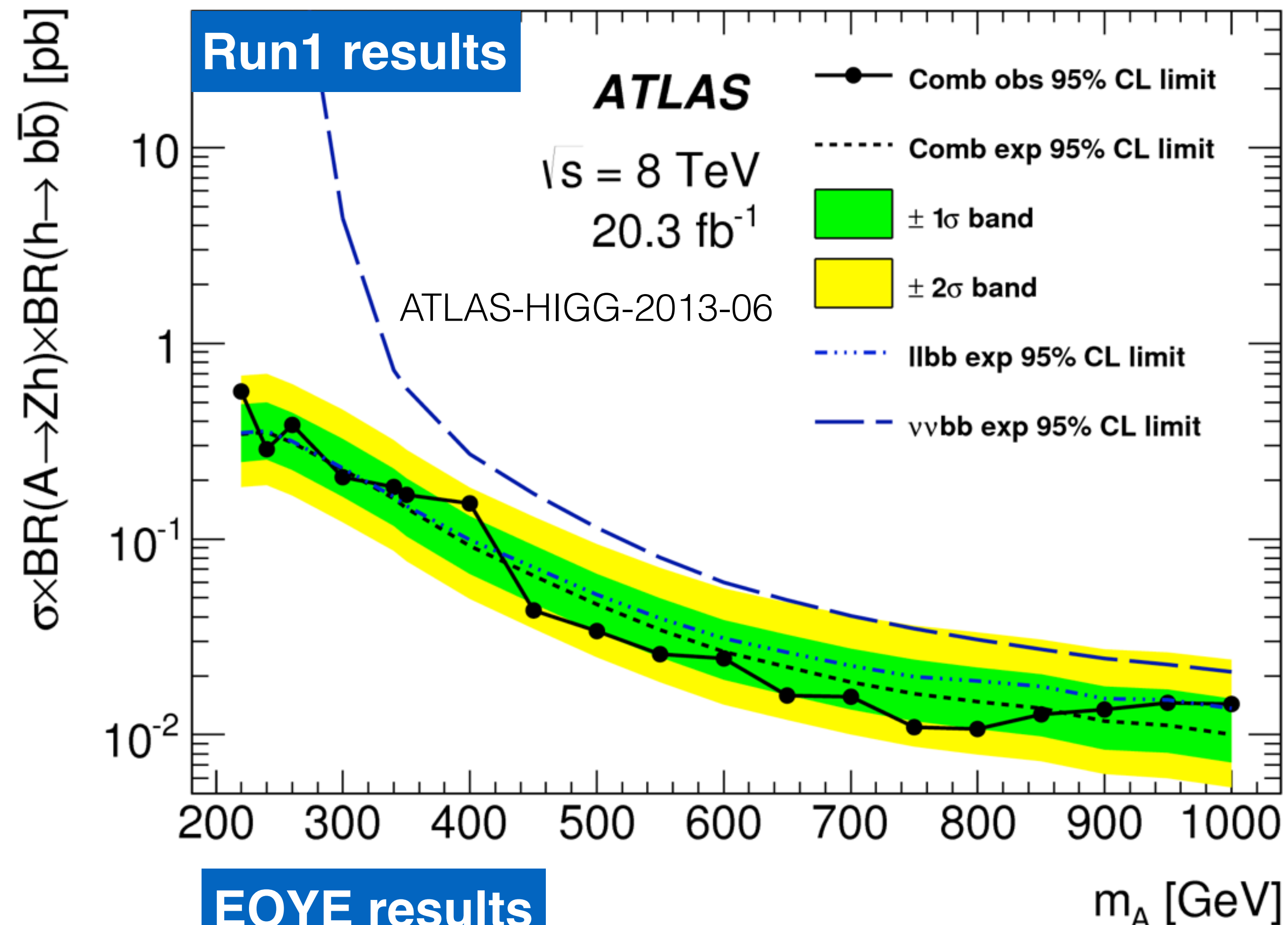
Search strategy: (h→bb) decay

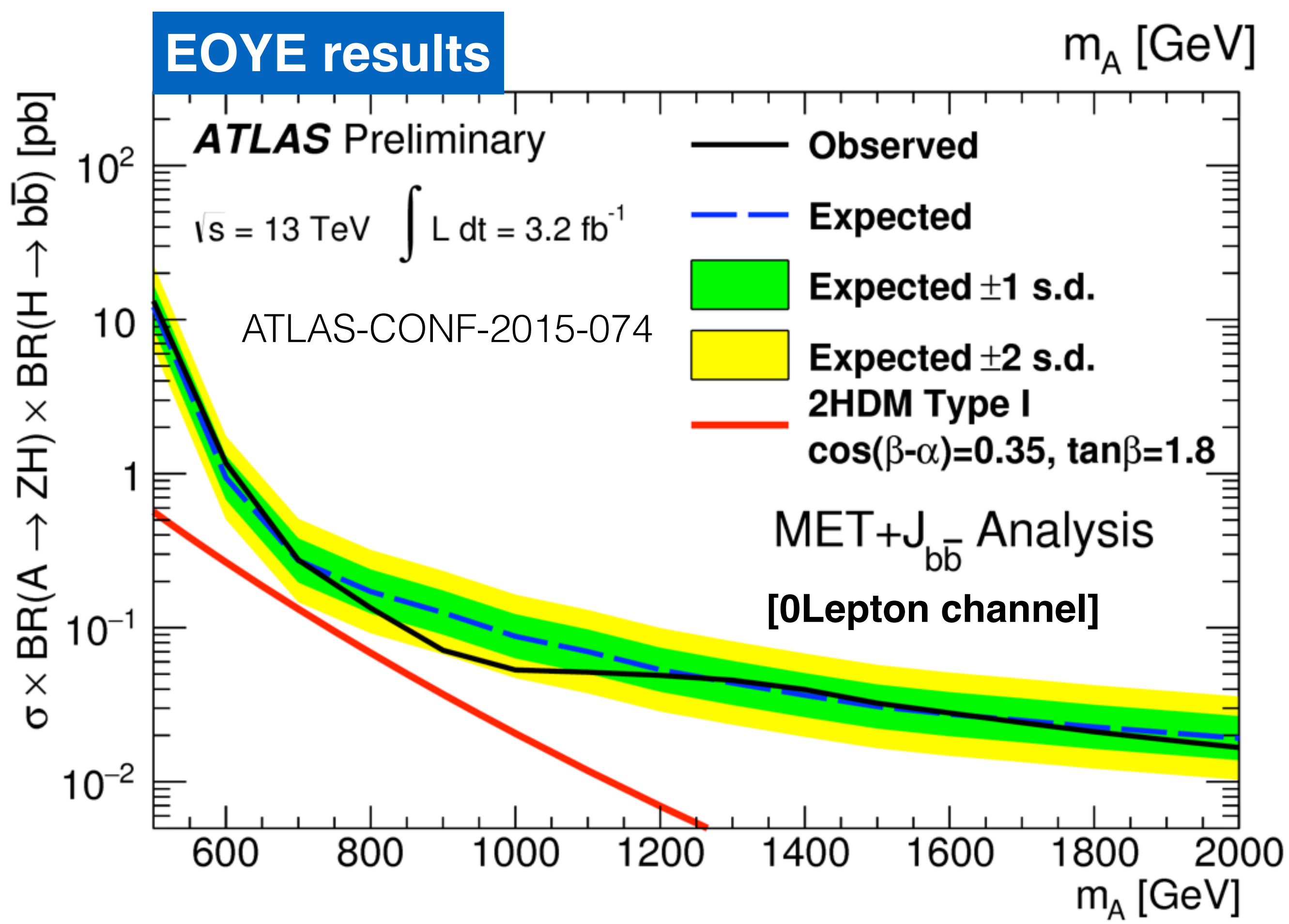
resolved regime ($p_T^Z < 500$ GeV):
calorimeter jets R=0.4 ('small-R')

merged regime ($p_T^Z > 500$ GeV):
calorimeter jet R=1.0 ('large-R')
[b-tagging on *track-jets* R=0.2]

Search for a CP-odd A boson in the Zh(bb) decay channel







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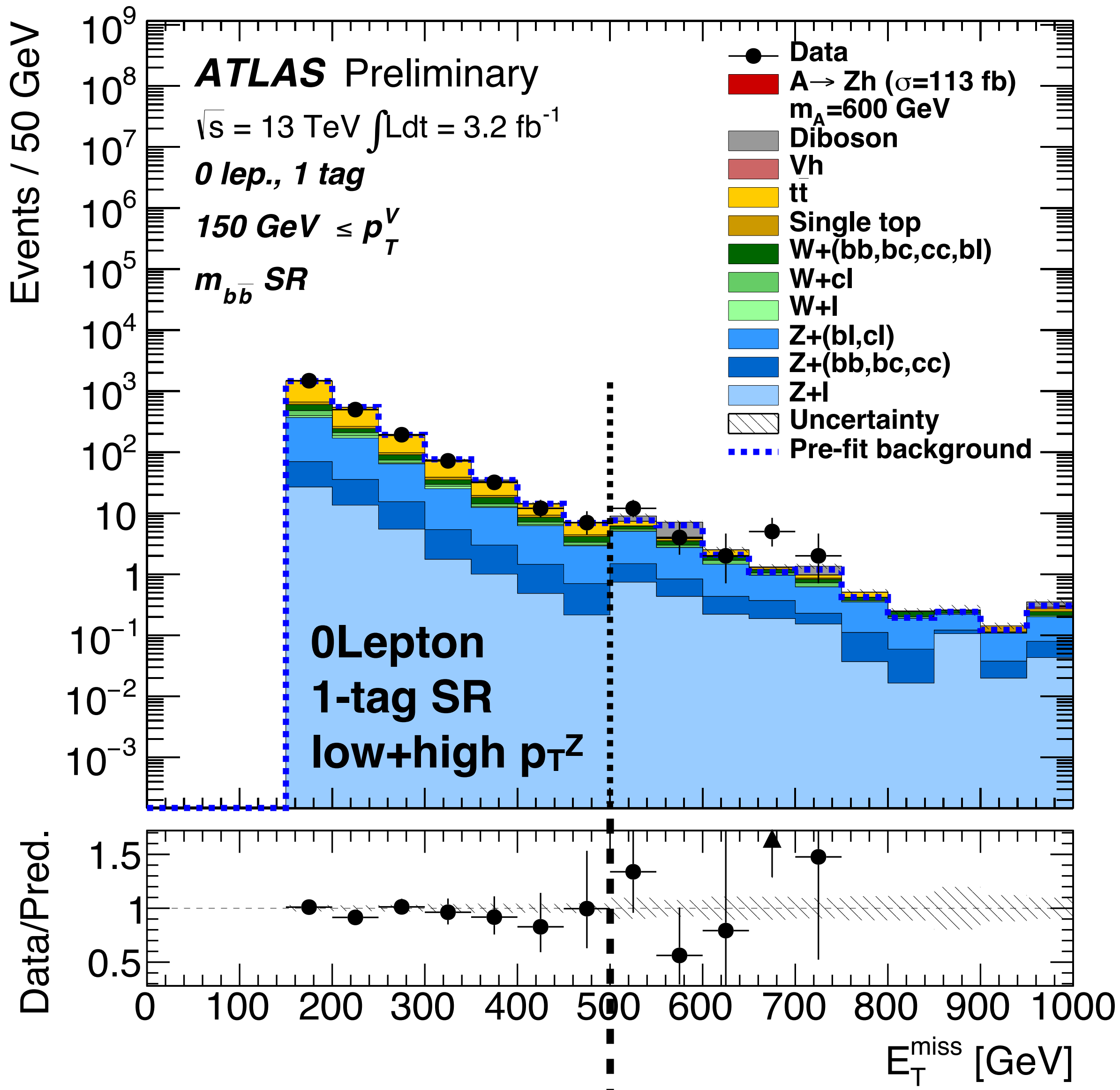
[b-tagging on *track-jets* R=0.2]

Analysis Overview and Selections

SR Common Selection [Zh→(νν,l⁺l⁻)bb]



Low p_T^Z

#small-R jets ≥ 2

#b-tag jets = 1,2

$m_H \in$ [110-140] GeV

Higgs candidate:

2 leading small-R jets (1/2 b-tag)

High p_T^Z

#large-R jets ≥ 1

#b-tag track-jets = 1,2

$m_H \in$ [75-145] GeV

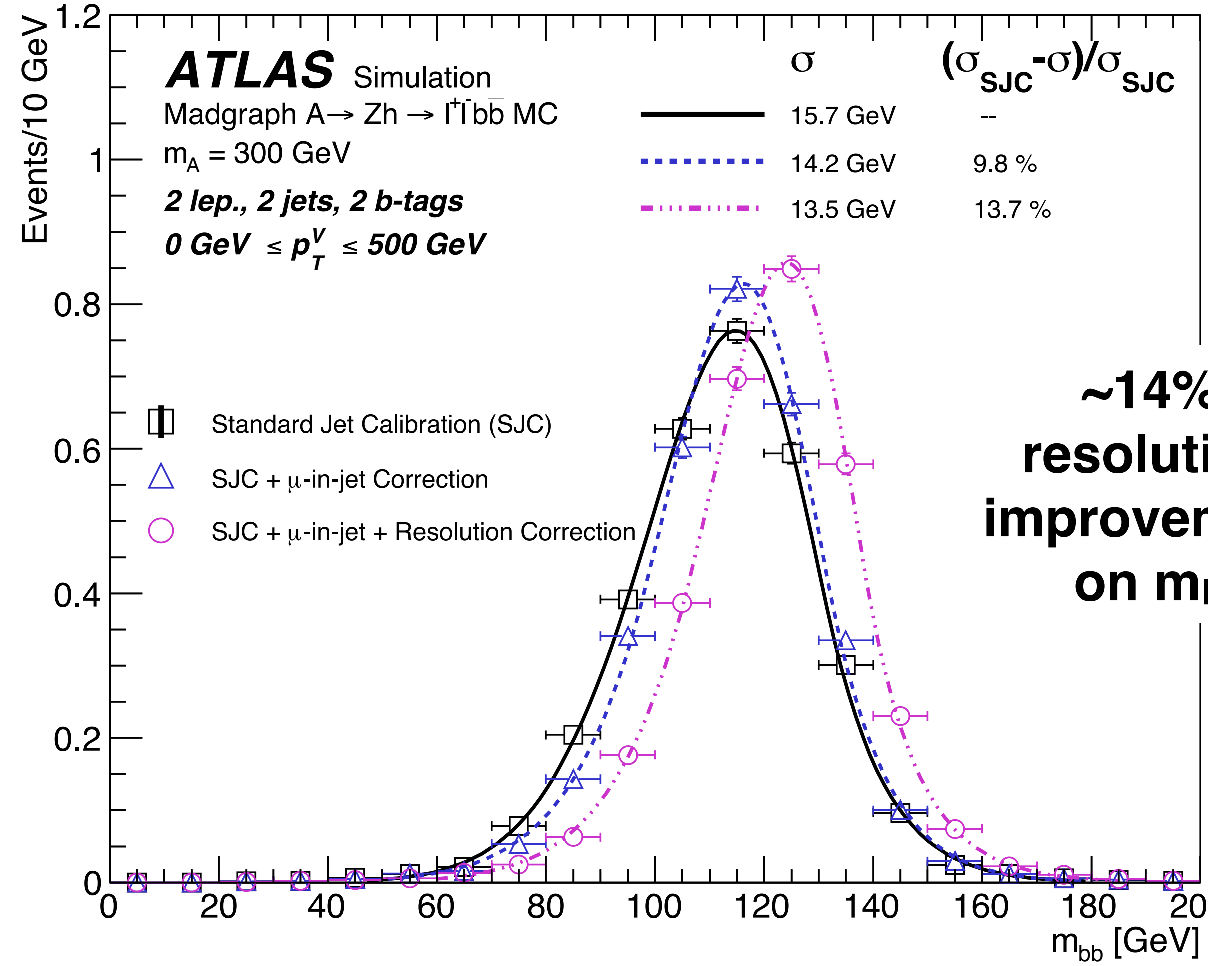
Higgs candidate:

leading large-R jet (1/2 b-tag track-jets)

p_T^Z =500GeV

b-jets Energy Corrections

- **semileptonic b-decays**
  add closest (ΔR) muon's energy to b-tagged jets
- **jet response correction** (small-R jets)
  multiplicative p_T response factor on b-jet 4vector



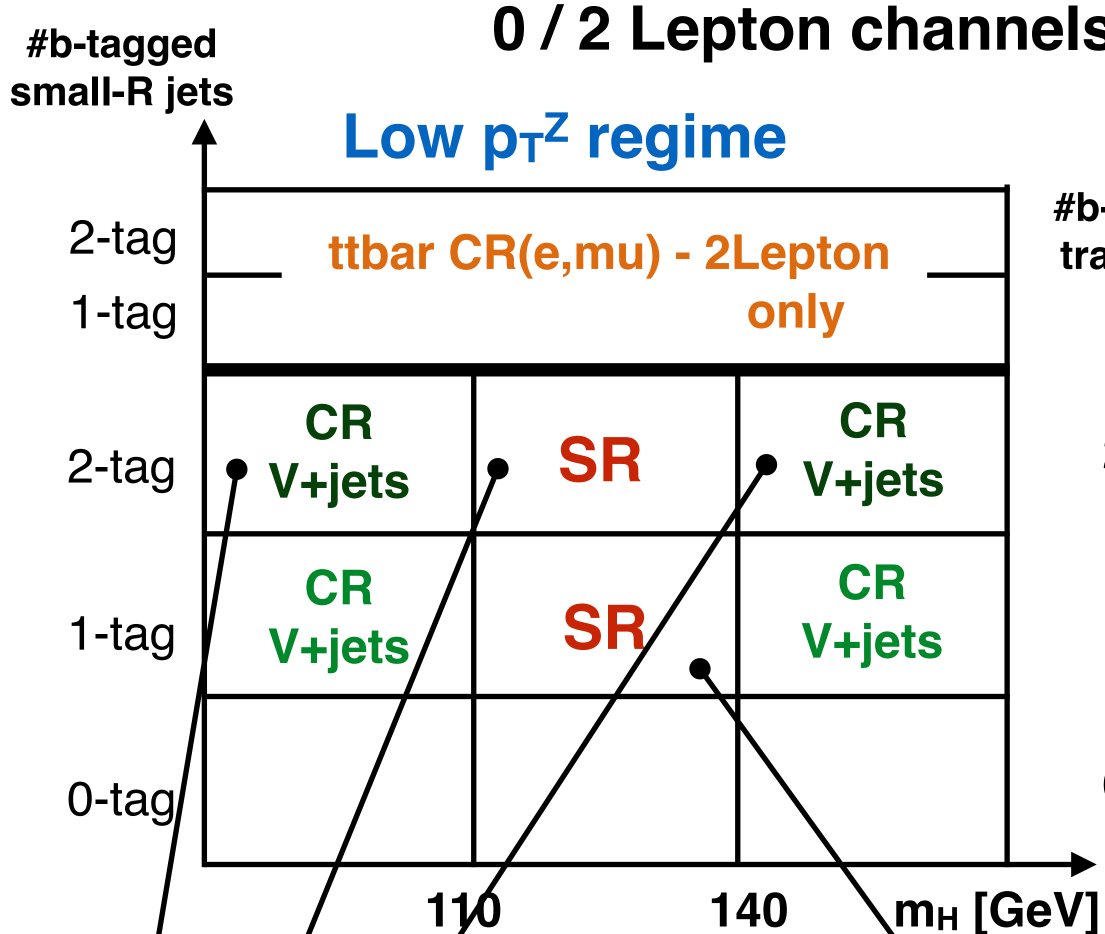
~14% resolution improvement on m_H

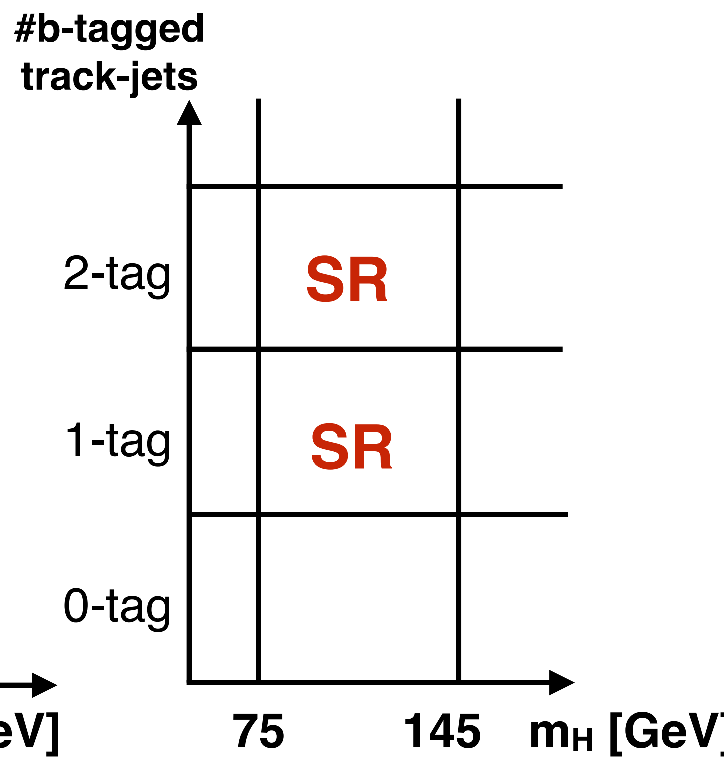
0Lepton:
- high E_T^{miss} (> 150 GeV)
- QCD-rejection cuts (topology + kinematic)

2Lepton:
- low E_T^{miss} ($E_T^{miss}/\sqrt{H_T}$ < 3.5)
- m_{ll}-window around Z peak (l=e,mu)

Analysis Phase Space: Signal and Control Regions

0 / 2 Lepton channels separately





8 Signal Regions (SR)

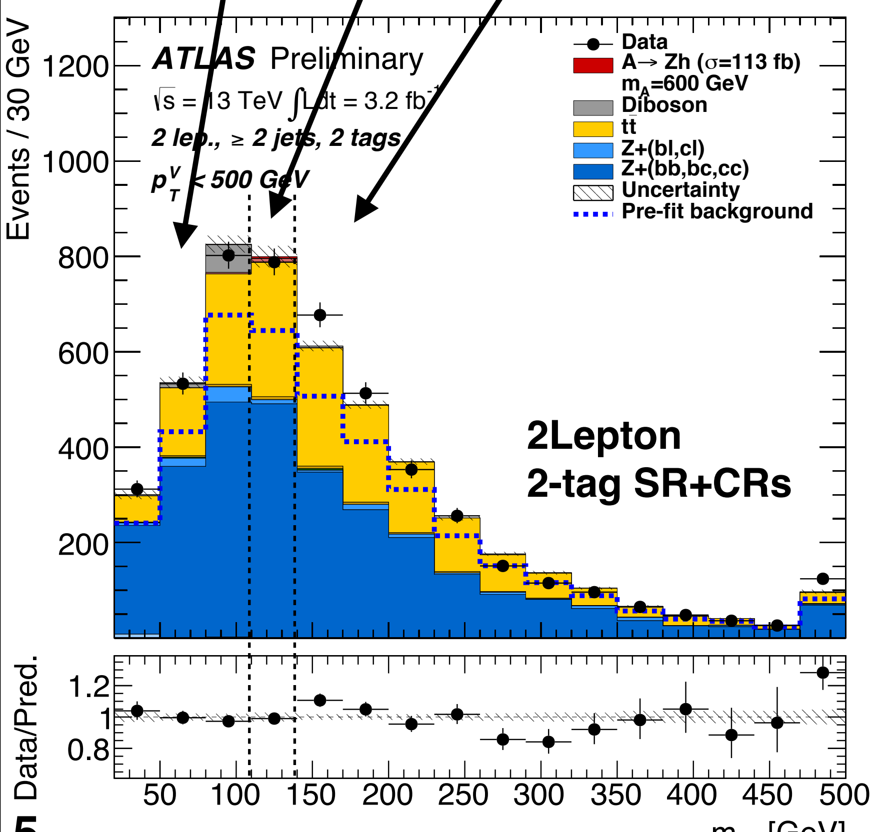
- 4 SRs x 2 leptonic channels

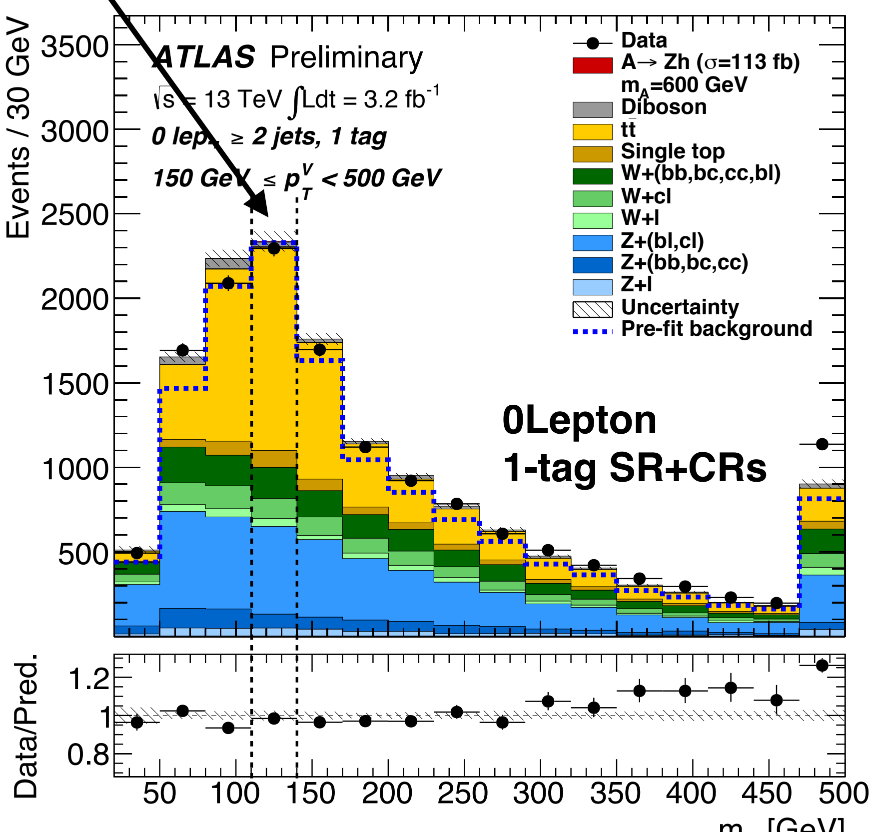
6 Control Regions (CR)

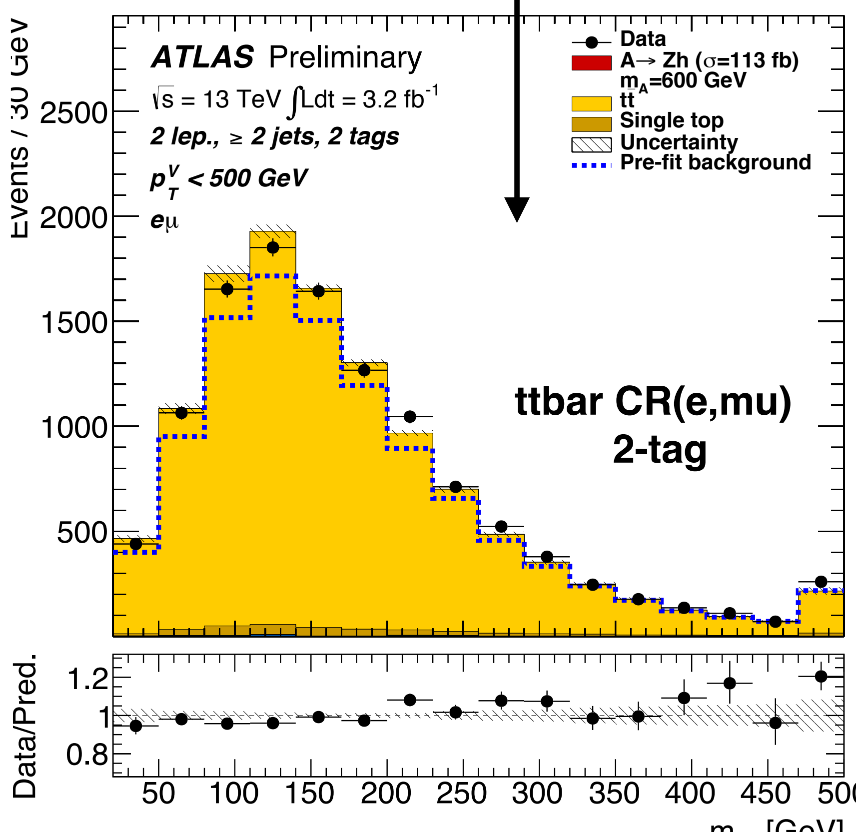
- 2 CRs for 0Lepton
- 4 CRs for 2Lepton (including ttbar (1,2)-tag CR)

low and high m_H sidebands merged together

- **V+jets** modelling from m_H sidebands
- **ttbar** modelling from 2Lepton CR(e,mu) [relaxed m_{ll} cut]

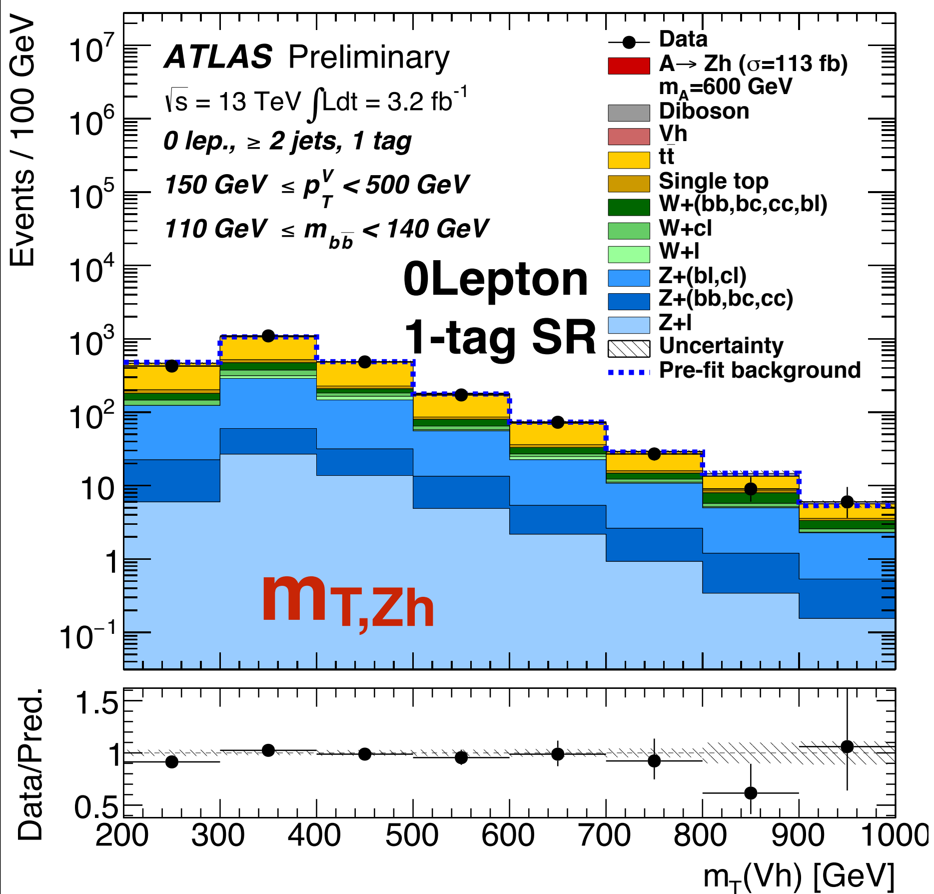


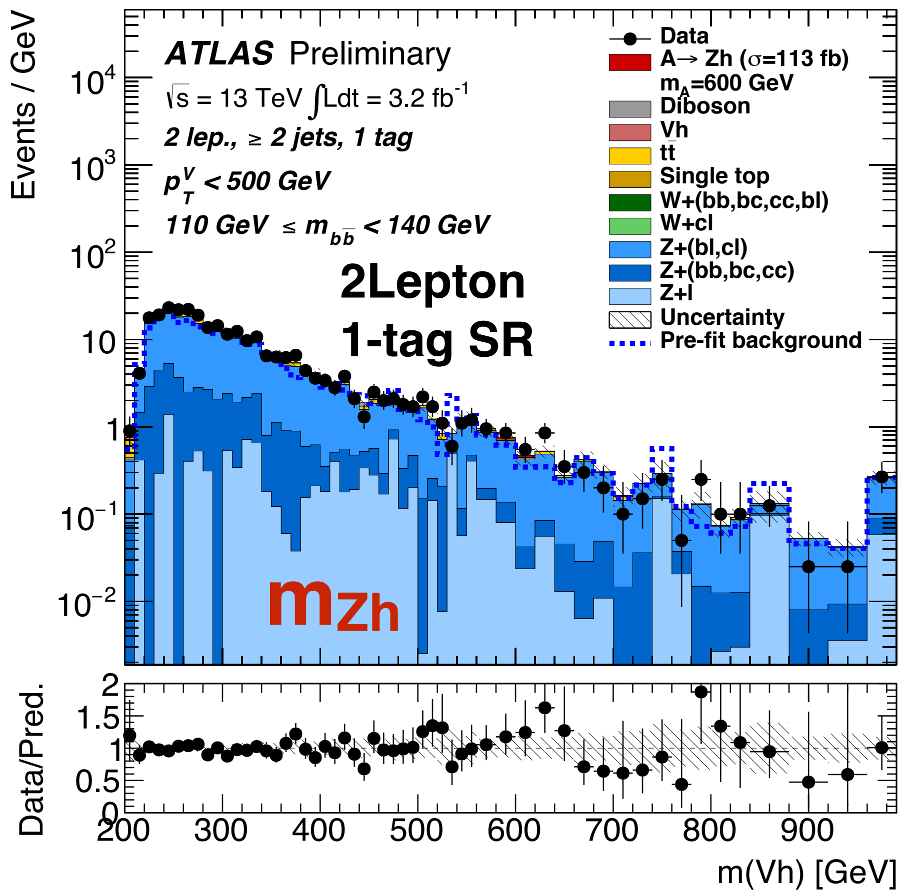




Systematic Uncertainties and Fit Model

Data fitted to MC prediction with binned profile likelihood ratio test statistic





Discriminating variable:

m_{Zh} invariant mass (2Lepton)

$m_{T,Zh}$ transverse mass (0Lepton)

$$m_{T,Zh} = \sqrt{(E_T^h + E_T^{\text{miss}})^2 - (\vec{p}_T^{\,h} + \vec{E}_T^{\text{miss}})^2}$$

- **dominant experimental systematics**:
  calibration/resolution of small-R and large-R jets energy, large-R jets mass (high p_T^Z), b-tagging efficiency and mistag rate

- **theoretical systematics & background normalisation**:

ttbar (0Lepton / 2Lepton)
Z+(bb,bc,cc) / Z+(bl,cl) / Z+l
W+(bb,bc,cc,bl) / W+cl / Z+l

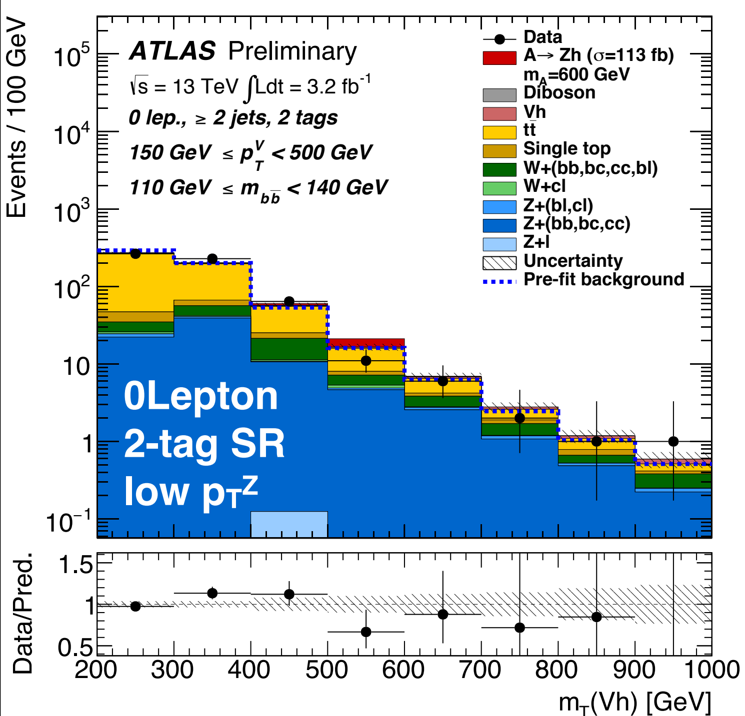
→

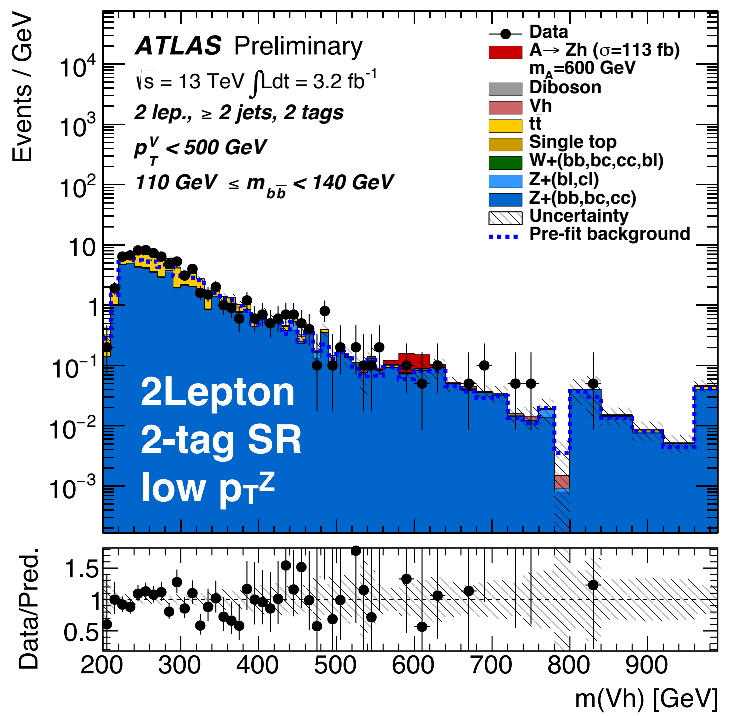
- overall normalisation freely floating
  (gaussian prior for the smaller contributions: Z+l, W+jets)
- relative acceptance variations across analysis categories
- systematic variation on the shape of **m_{Zh}** (or **$m_{T,Zh}$**)

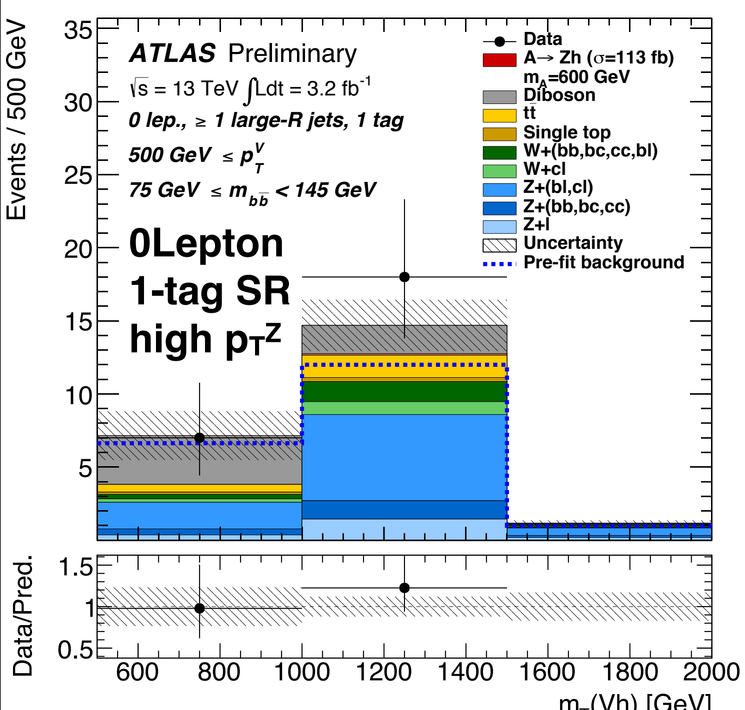
Acceptance and/or shape systematics for the smaller backgrounds (diboson, single-top) and signals

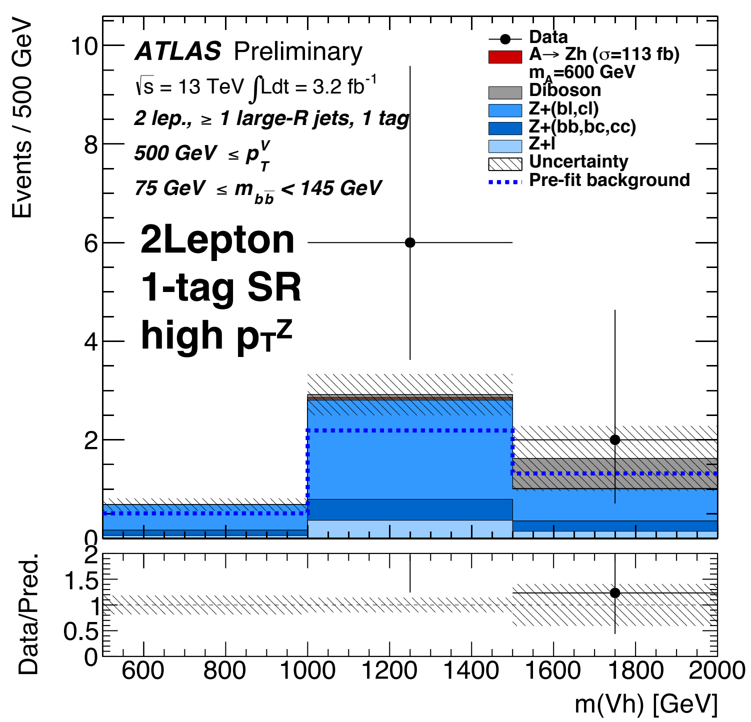
After the maximum likelihood fit to data, the total uncertainty on the signal cross-section (m_A=600GeV) is dominated by data statistics (~80%)

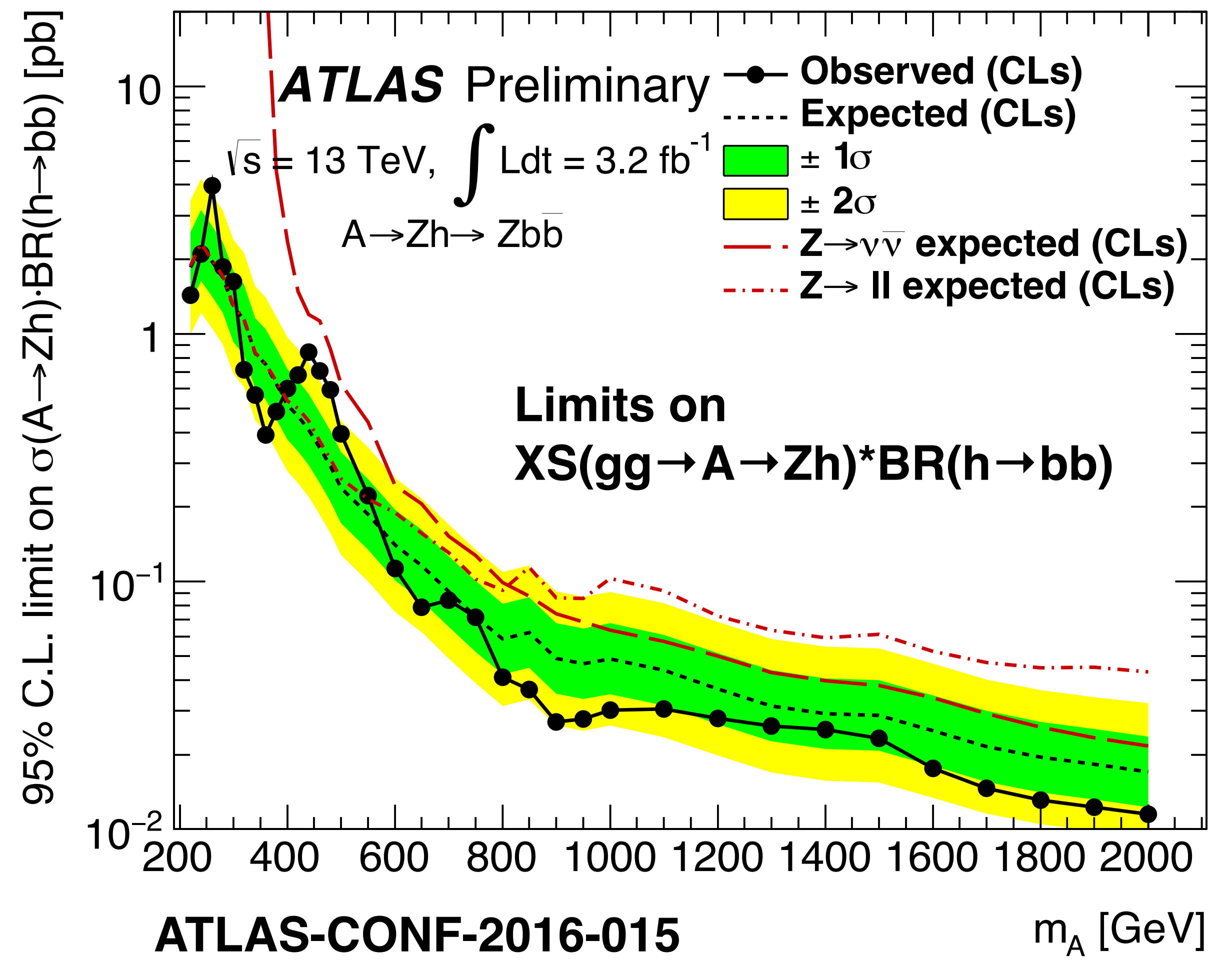
Results & Conclusions: Cross-Section Limits











No significant excess over the background prediction is observed

exclusion limits set on the A →Zh XS

First Run2 combined result

(low+high p_T^Z, 0+2Lepton channels)

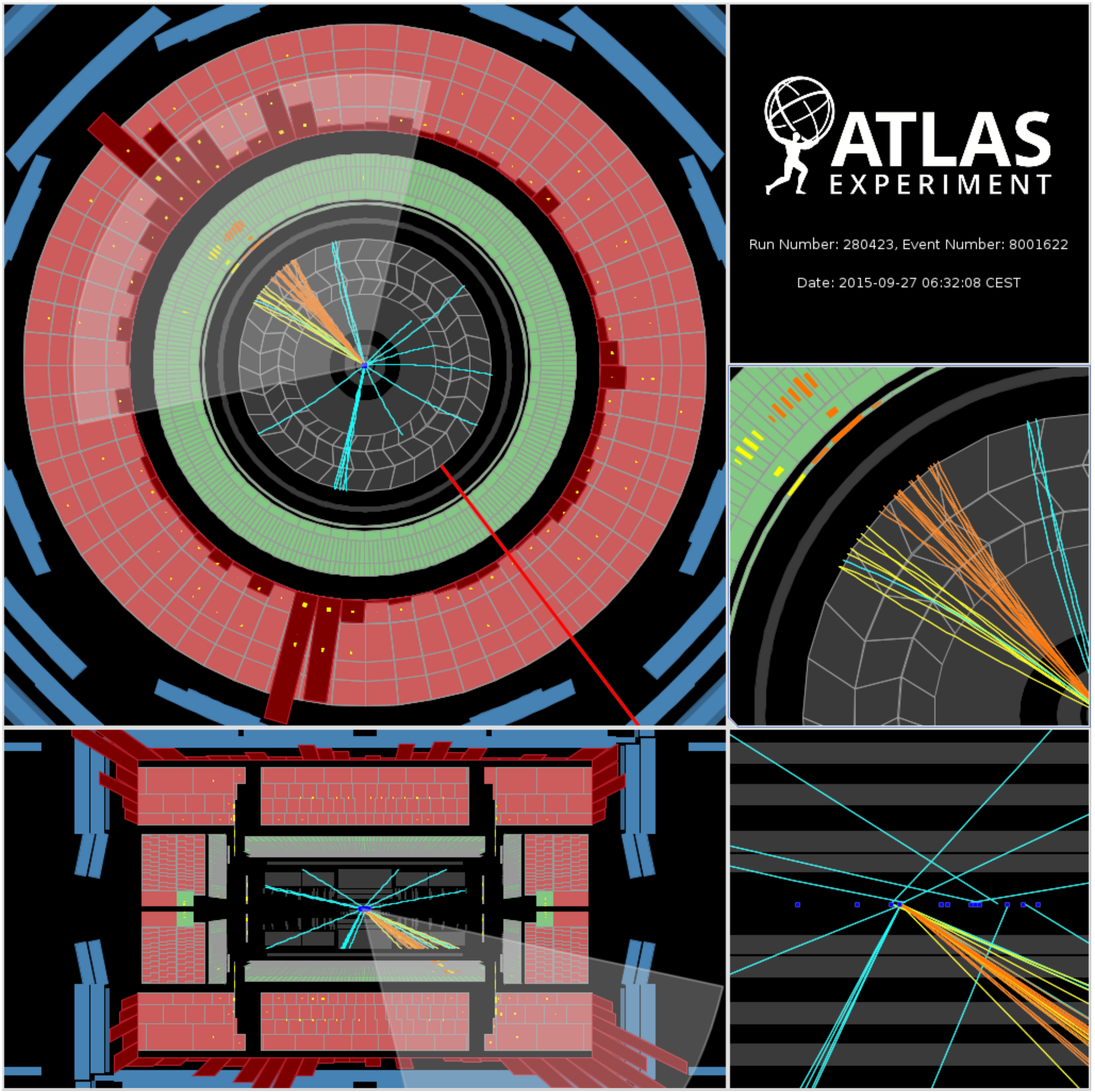
Run1 exclusion limits improved for $m_A \gtrsim$ 800 GeV

Two upward deviations from the background-only hypothesis m_A=260,440 GeV

[local significance ~ 2σ]

Looking forward to the 2016 LHC run for more data!

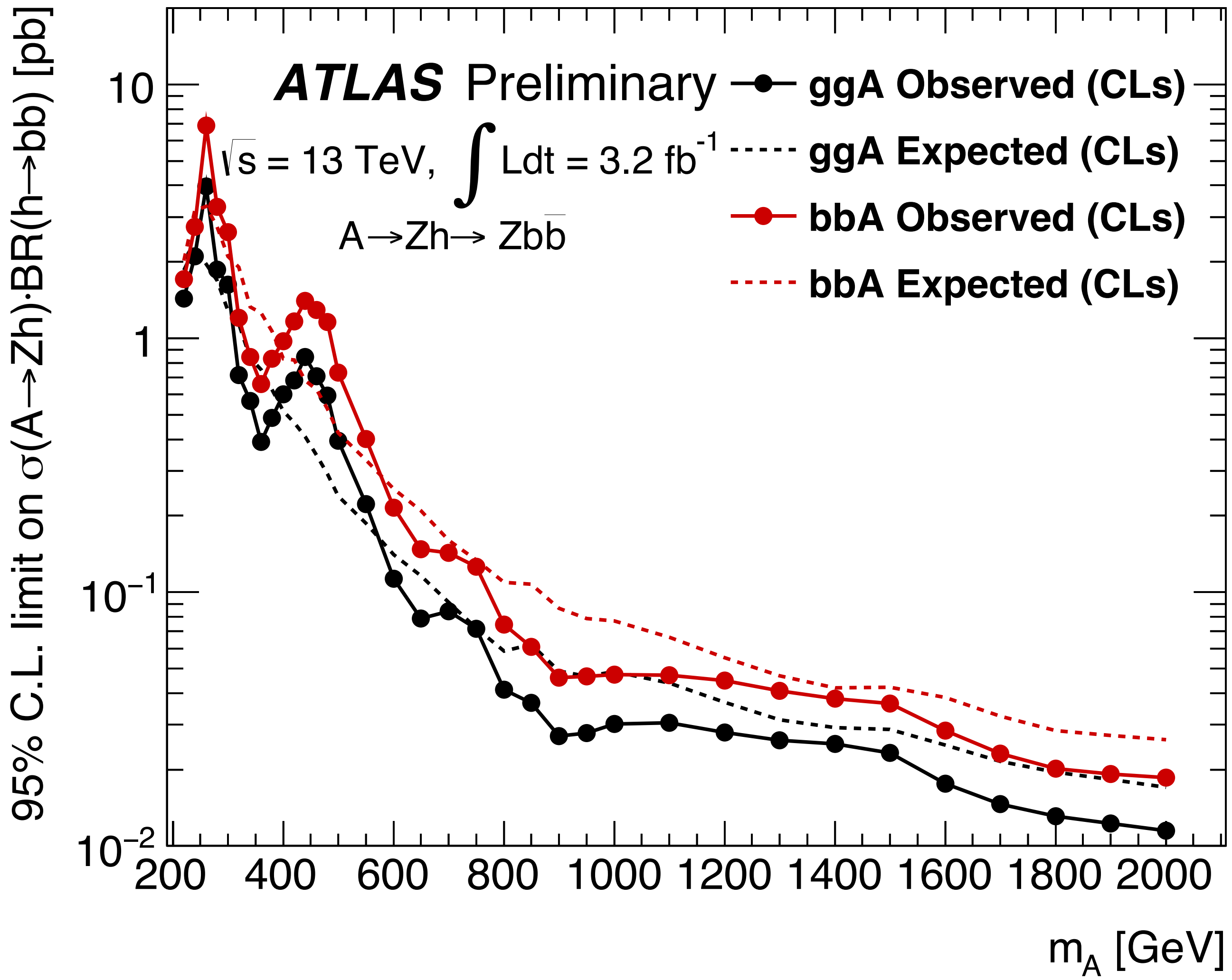
Back-Up



0Lepton
2-tag SR
high p_T^Z event

$m_{T,Zh}$ = 985 GeV

Cross-Section Limits: bbA vs ggA production

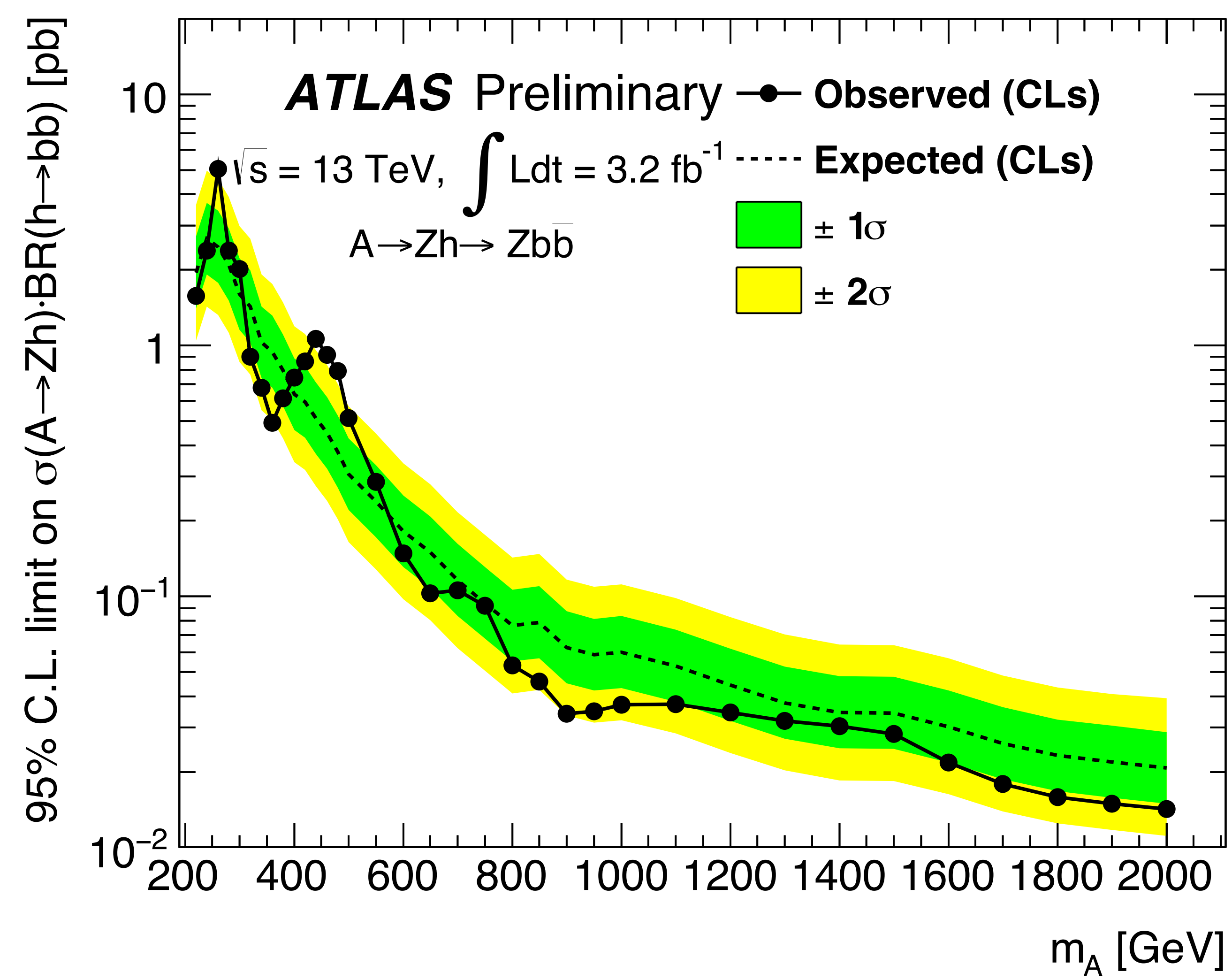


Limits on

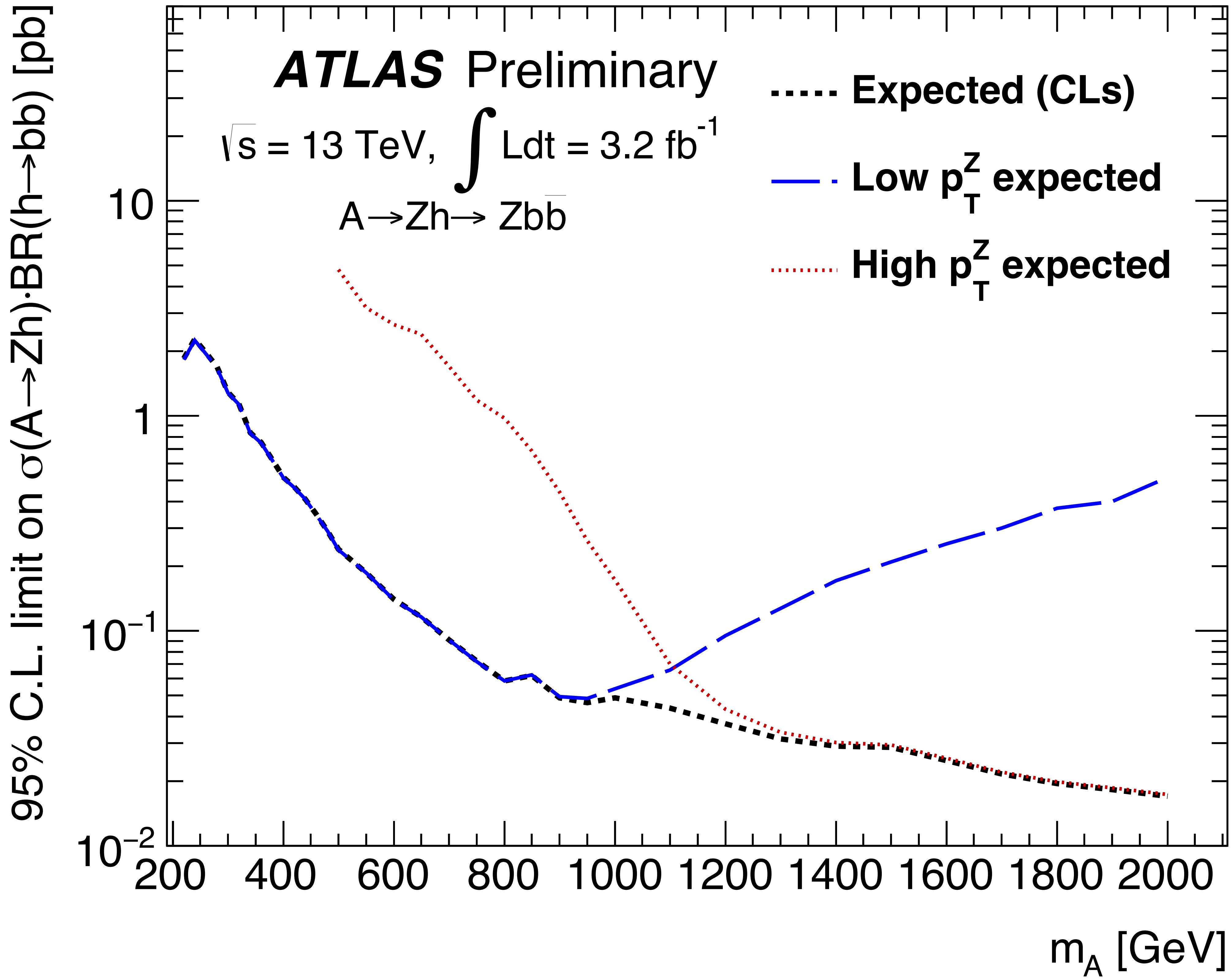
- **XS(bb→A→Zh)*BR(h→bb)**
- **XS(gg→A→Zh)*BR(h→bb)**

Limits on an equal mixture of gluon-fusion and b-quark associated production

- **50%[bb→A→Zh] + 50%[gg→A→Zh]**



Cross-Section Limits: resolved vs merged regimes



Results: 2 Higgs Doublet Models Interpretation

The results can be interpreted in the framework of **Type-I** and **Type-II** 2HD models:

exclusion limits are shown for m_A=600 GeV in the tan(β) / cos(β-α) plane, for points in the parameter space with $\Gamma_A/m_A < 5\%$

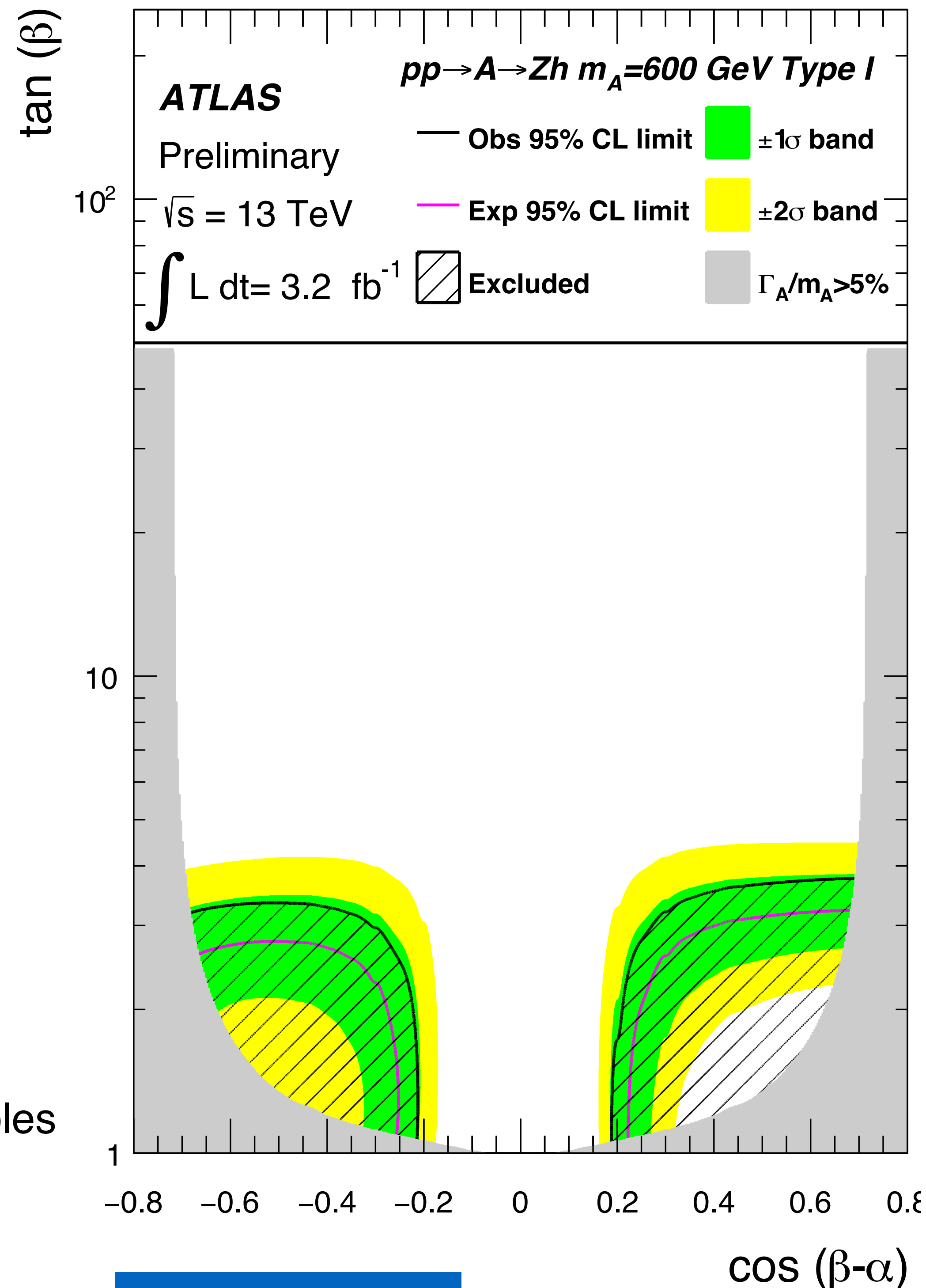
2HDMs
1 charged-scalar
1 pseudo-scalars
2 neutral-scalars

tan(β) = v2/v1
(β = rotation angle that diagonalises the squared mass matrices of charged scalars and pseudo scalars)

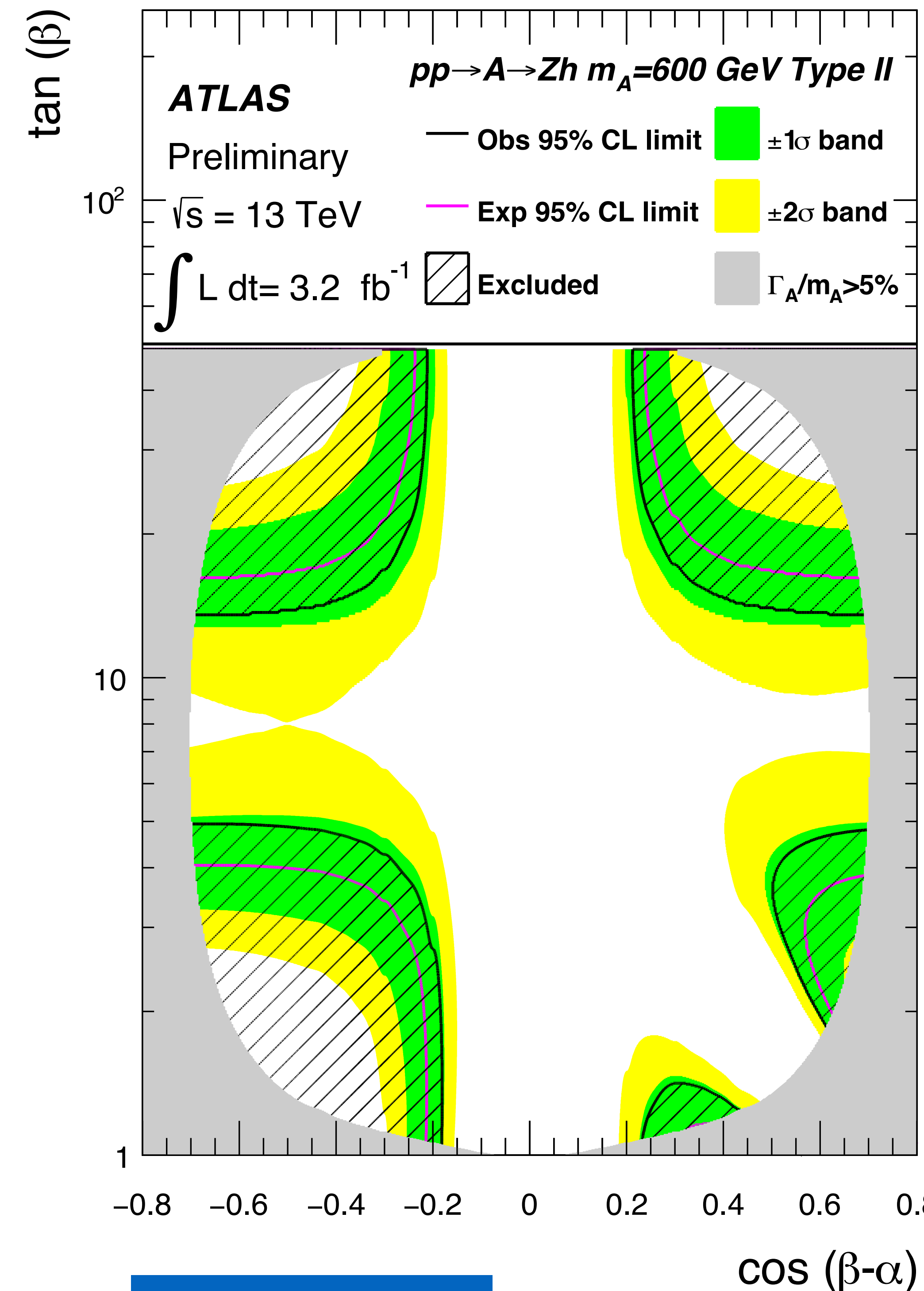
cos(β-α)
(a = rotation angle that diagonalises the squared mass matrix of the scalars)

Avoid tree-level FCNC imposing discrete symmetries:

- **Type I**: all quarks couples to 1 of the doublets
- **Type II**: Q=2/3 RH and Q=-1/3 RH couple to different doublets



Type-I 2HDM



Type-II 2HDM

Detailed analysis selection

SR Common Selection [Zh→(νν,l+l-)bb]

Variable	Low-p_T^Z	High-p_T^Z
p_T^Z [GeV]	<500	$\geq$ 500
$N_{b\text{-tag jet}}$	1,2	1,2
$N_{\text{small-}R\text{ jet}}$	$\geq$2	$\geq$0
$N_{\text{large-}R\text{ jet}}$	$\geq$0	$\geq$1
m_{dijet} or m_{jet} [GeV]	110–140	75–145

0Lepton specific cuts [Zh→ννbb]

Variable	Low-p_T^Z	High-p_T^Z
E_T^{miss} [GeV]	> 150	–
$\sum_{i=1}^{N_{\text{jet}}=3(2)} p_T^{\text{jet}_i}$ [GeV]	$> 150\ (120)(*)$	–
p_T^{miss} [GeV]	> 30	> 30
$\Delta\phi(\vec{E}_T^{\text{miss}}, \vec{p}_T^{\text{ miss}})$	$< \pi/2$	$< \pi/2$
$\Delta\phi(\vec{E}_T^{\text{miss}}, h)$	$> 2\pi/3$	$> 2\pi/3$
$\min[\Delta\phi(\vec{E}_T^{\text{miss}}, \text{small-}R\text{ jet})]$	$> \pi/9(*)$	$> \pi/9(*)$
$\Delta\phi(j,j)$	$< 7\pi/9$	–

2Lepton specific cuts [Zh→l+l-bb]

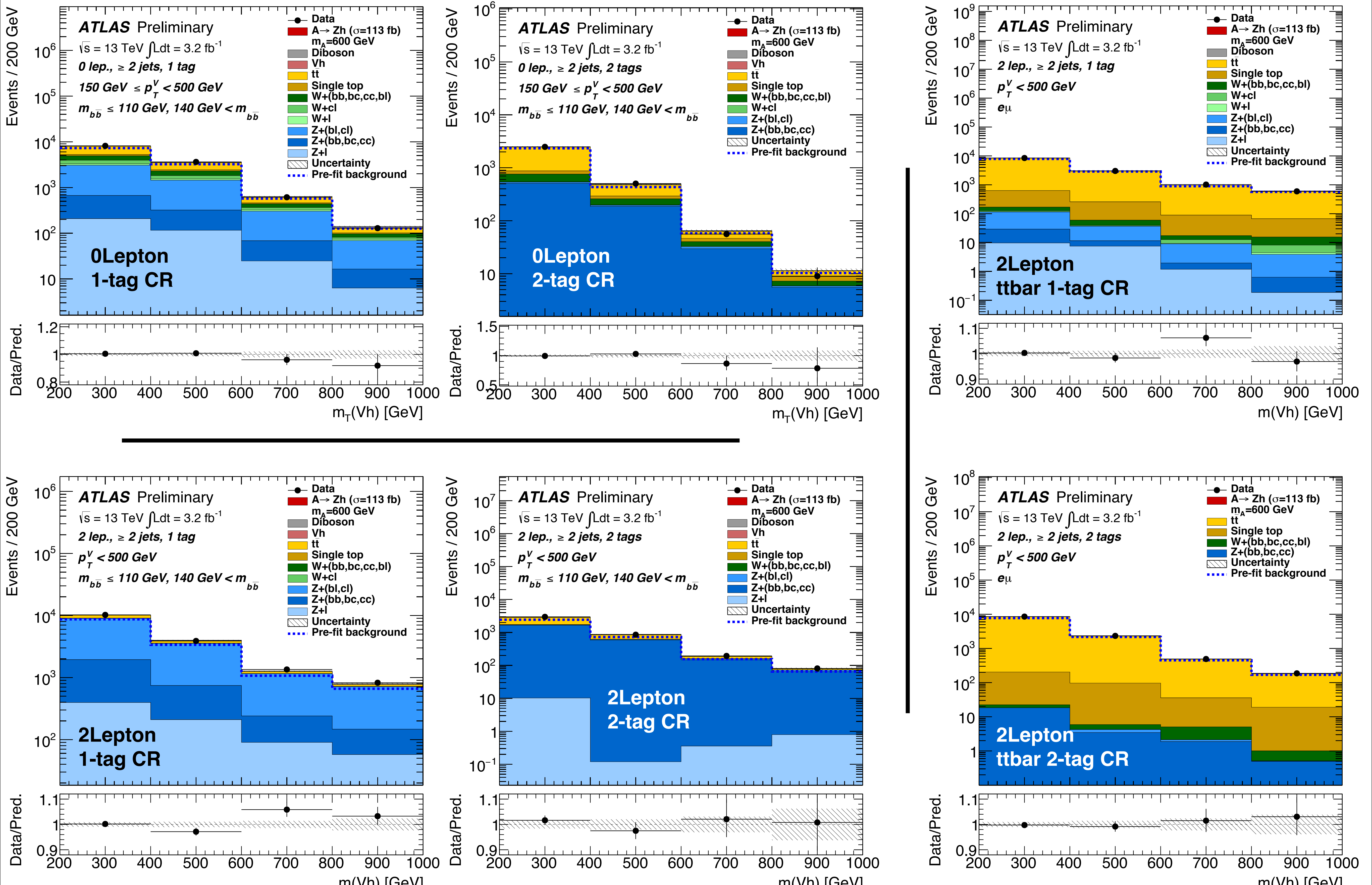
m_{ee} [GeV]	70–110	70–110
$m_{\mu\mu}$ [GeV]	70–110	55-125
$E_T^{\text{miss}}/\sqrt{H_T}$ [$\sqrt{\text{GeV}}$]	< 3.5	–

Event Yields

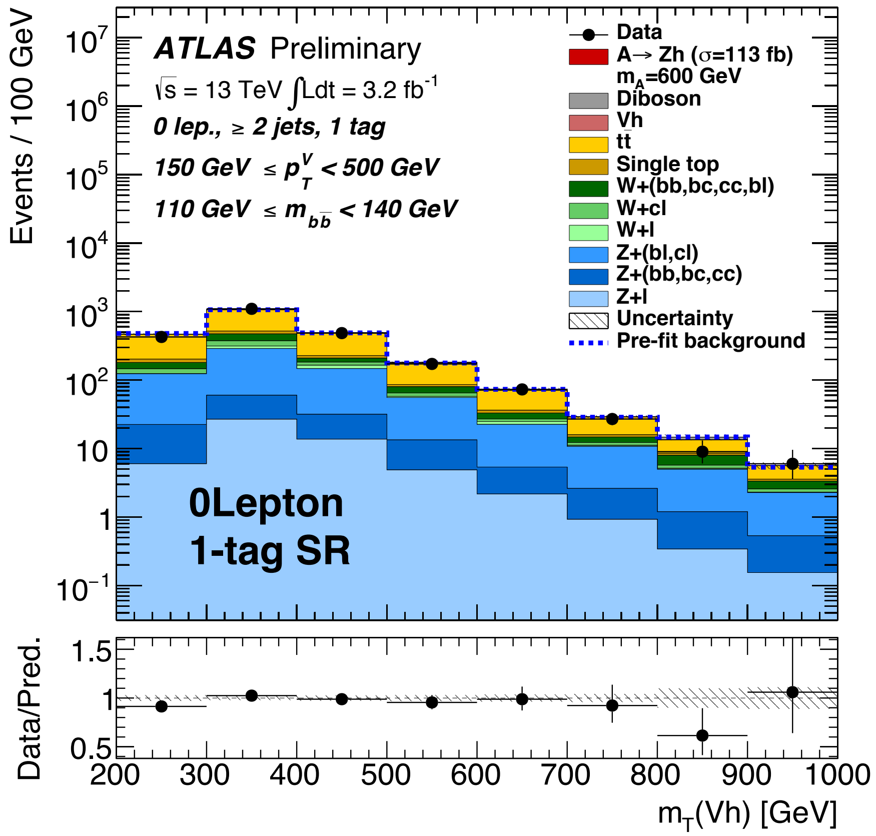
One b-tag				
	0-leptons low-p_T^Z	0-leptons high-p_T^Z	2-leptons low-p_T^Z	2-leptons high-p_T^Z
$Z+l$	55 ± 31	2.0 ± 1.0	118 ± 38	0.57 ± 0.28
$Z+(cl,bl)$	518 ± 54	8.2 ± 1.8	1943 ± 65	3.18 ± 0.65
$Z+(bb,bc,cc)$	82 ± 13	1.82 ± 0.35	391 ± 23	0.74 ± 0.13
$W+l$	48 ± 22	–	–	–
$W+cl$	111 ± 42	1.17 ± 0.45	0.67 ± 0.28	–
$W+(bb,bc,cc,bl)$	185 ± 71	1.80 ± 0.63	10.1 ± 4.2	–
$t\bar{t}$	1202 ± 77	2.05 ± 0.72	276 ± 22	–
single top	99 ± 10	0.49 ± 0.11	15.3 ± 1.6	–
diboson	27.2 ± 4.6	5.3 ± 1.0	26.3 ± 6.1	0.67 ± 0.32
$(W/Z)h$	3.3 ± 1.6	0.16 ± 0.08	3.7 ± 1.8	0.04 ± 0.02
total background	2332 ± 45	23.0 ± 2.6	2784 ± 47	5.2 ± 0.9
expected $A \to Zh$ (gluon-fusion)	5.00 ± 0.41	–	1.73 ± 0.12	–
expected $A \to Zh$ (b-quark-associated)	3.05 ± 0.26	–	1.01 ± 0.08	–
data	2295	25	2769	8
Two b-tags				
	0-leptons low-p_T^Z	0-leptons high-p_T^Z	2-leptons low-p_T^Z	2-leptons high-p_T^Z
$Z+l$	0.13 ± 0.44	0.01 ± 0.01	–	–
$Z+(cl,bl)$	4.7 ± 1.8	0.06 ± 0.03	9.6 ± 4.0	0.02 ± 0.01
$Z+(bb,bc,cc)$	81 ± 13	0.75 ± 0.15	490 ± 22	0.36 ± 0.05
$W+l$	–	0.02 ± 0.01	–	–
$W+cl$	3.6 ± 2.1	0.04 ± 0.02	–	–
$W+(bb,bc,cc,bl)$	37 ± 14	0.28 ± 0.09	0.42 ± 0.20	–
$t\bar{t}$	392 ± 24	0.22 ± 0.11	284 ± 22	–
single top	27.8 ± 2.9	–	6.39 ± 0.60	–
diboson	6.1 ± 3.1	0.05 ± 0.03	0.57 ± 0.23	–
$(W/Z)h$	5.4 ± 2.6	0.10 ± 0.05	7.6 ± 3.7	0.03 ± 0.01
total background	557 ± 18	1.53 ± 0.25	799 ± 23	0.42 ± 0.05
expected $A \to Zh$ (gluon-fusion)	9.21 ± 0.76	–	3.65 ± 0.29	–
expected $A \to Zh$ (b-quark-associated)	5.85 ± 0.47	–	2.21 ± 0.17	–
data	577	0	788	0

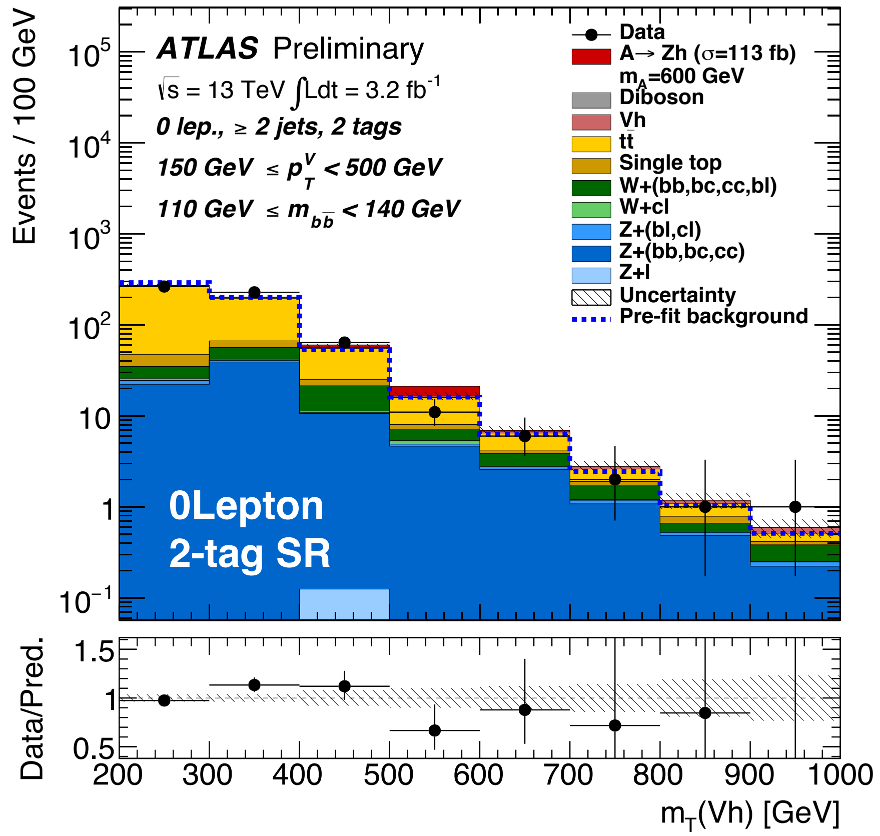
Table 2: The numbers of expected and observed events for all the signal regions. The expectation is shown after the maximum likelihood fit to the data. The quoted uncertainties are the combined systematic and statistical uncertainties. The numbers predicted for a $A \to Zh$ signal process in gluon-fusion and b-quark-associated production assume that $\sigma(gg \to A) \cdot \text{BR}(A \to Zh) \cdot \text{BR}(h \to b\bar{b}) = \sigma(pp \to b\bar{b}A) \cdot \text{BR}(A \to Zh) \cdot \text{BR}(h \to b\bar{b}) = 113$ fb, for $m_A = 600$ GeV. This cross section corresponds to the 95% CL upper limit on these effective cross sections at this mass. A dash indicates a negligible yield of events.

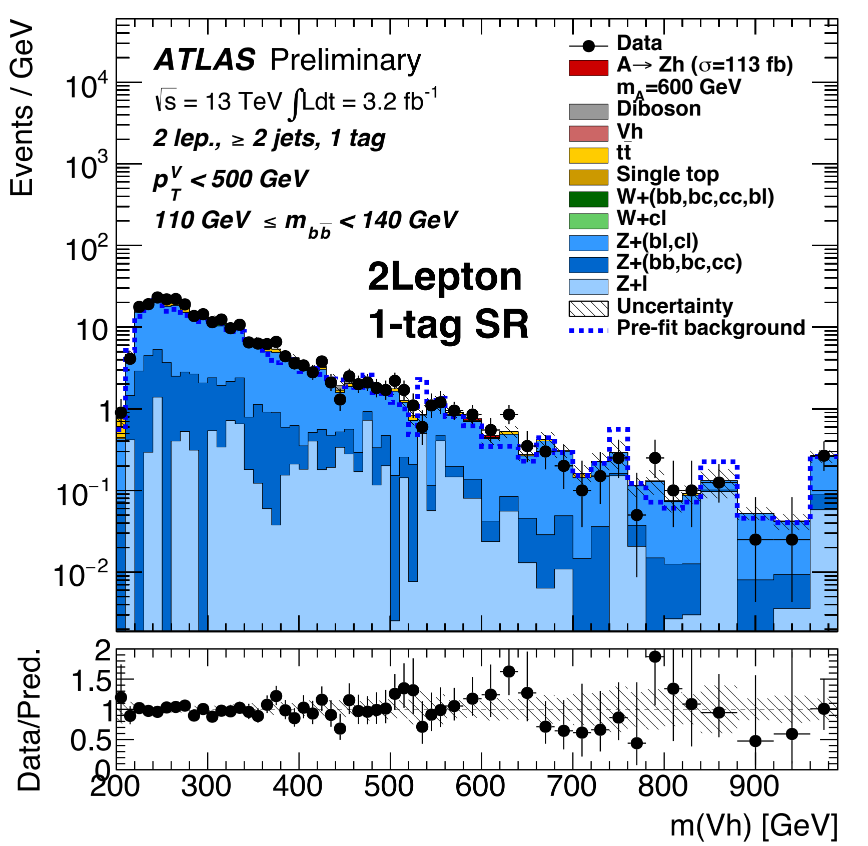
Control Regions: low p_T^Z

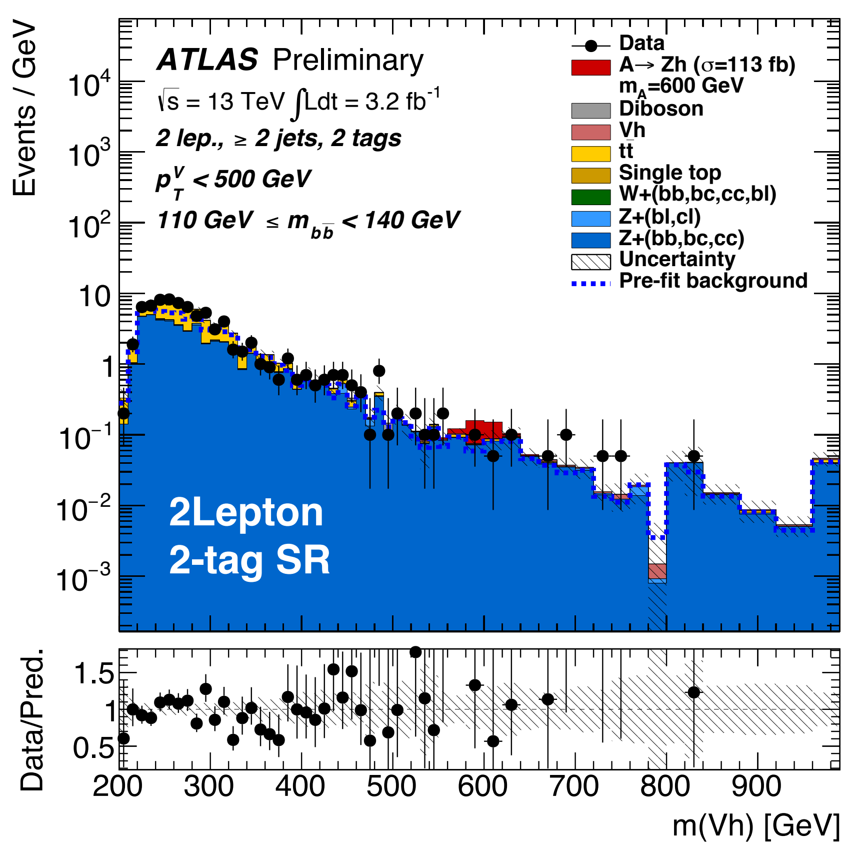


Signal Regions: low p_T^Z

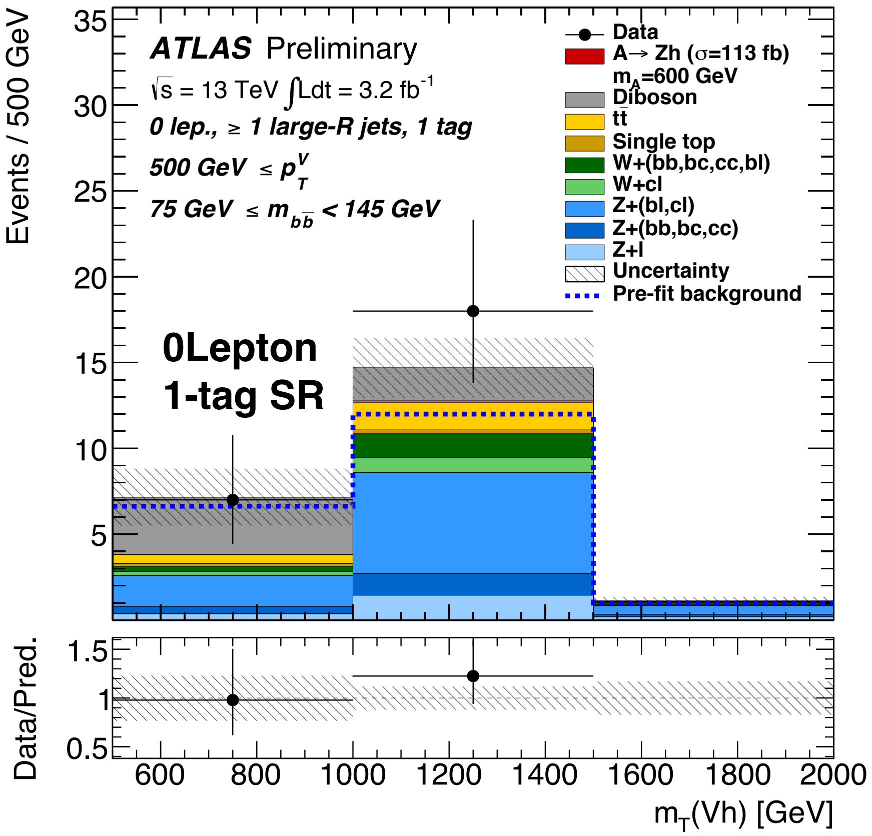


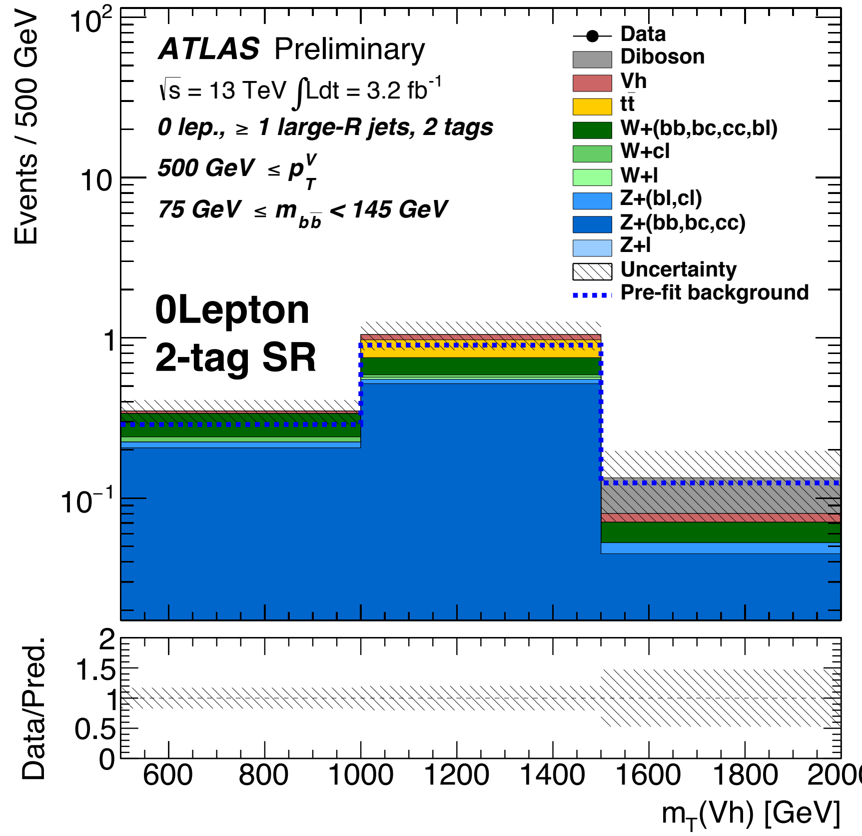


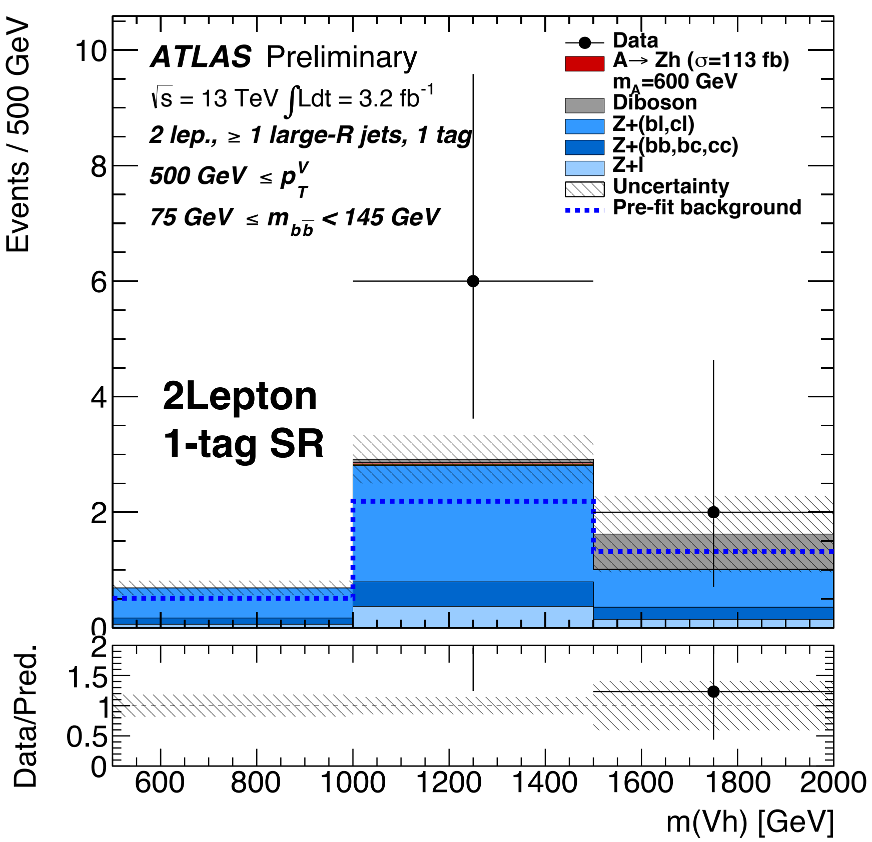


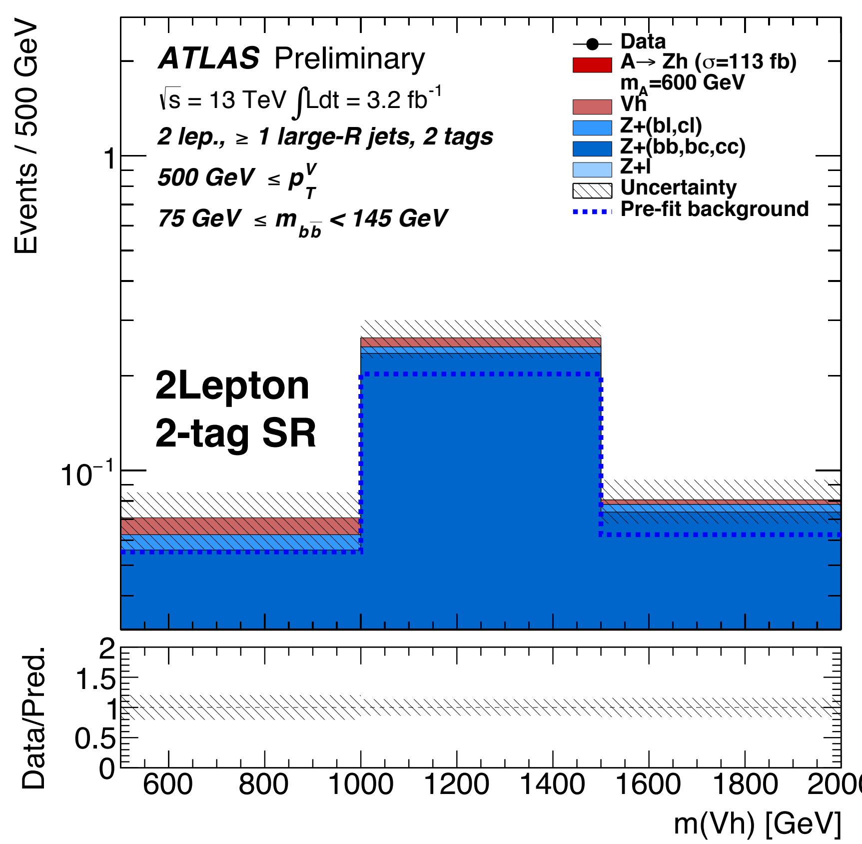


Signal Regions: high p_T^Z

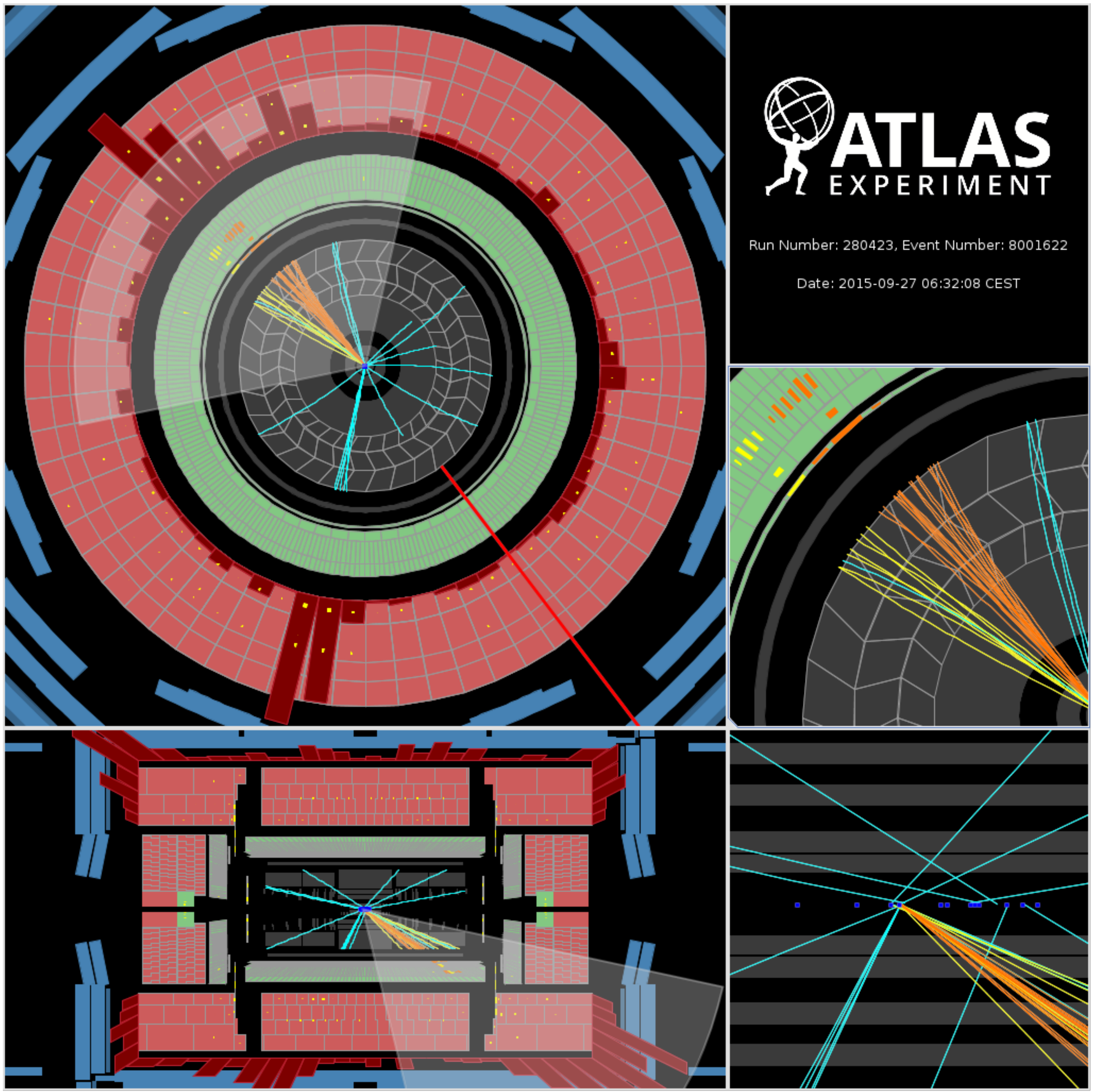


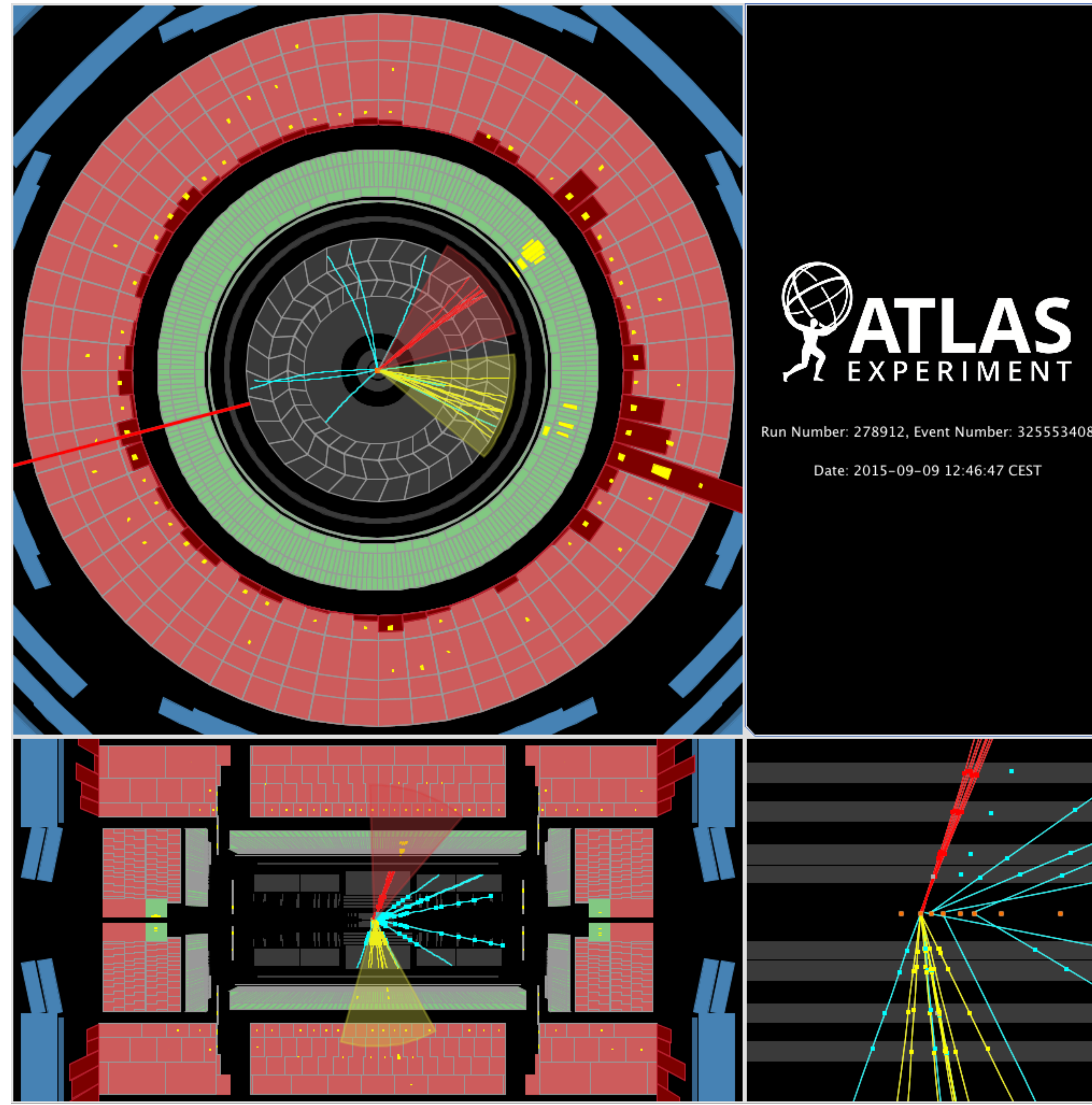






0Lepton Event Displays

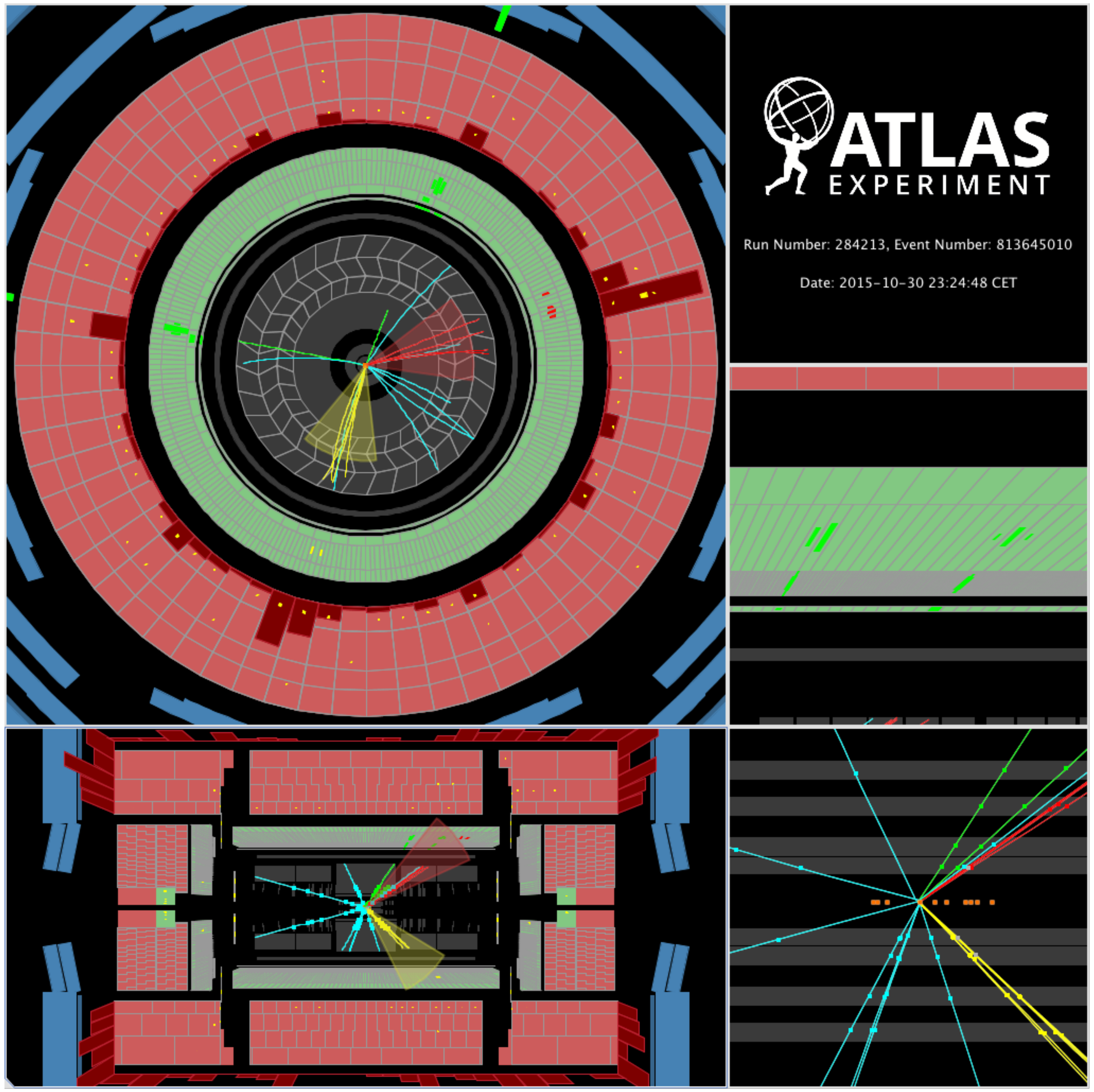




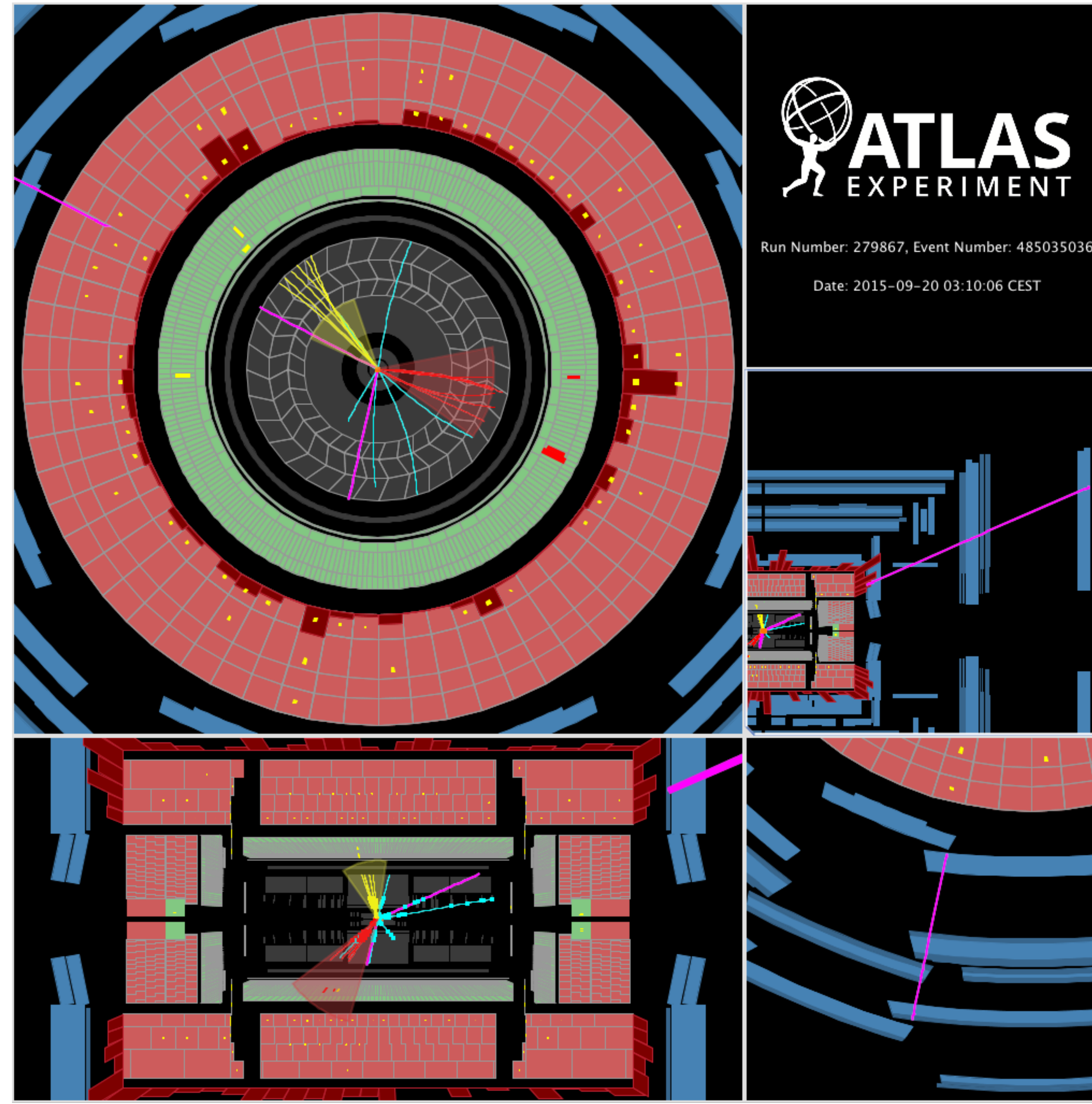
High p_T^Z

Low p_T^Z

2Lepton Event Displays

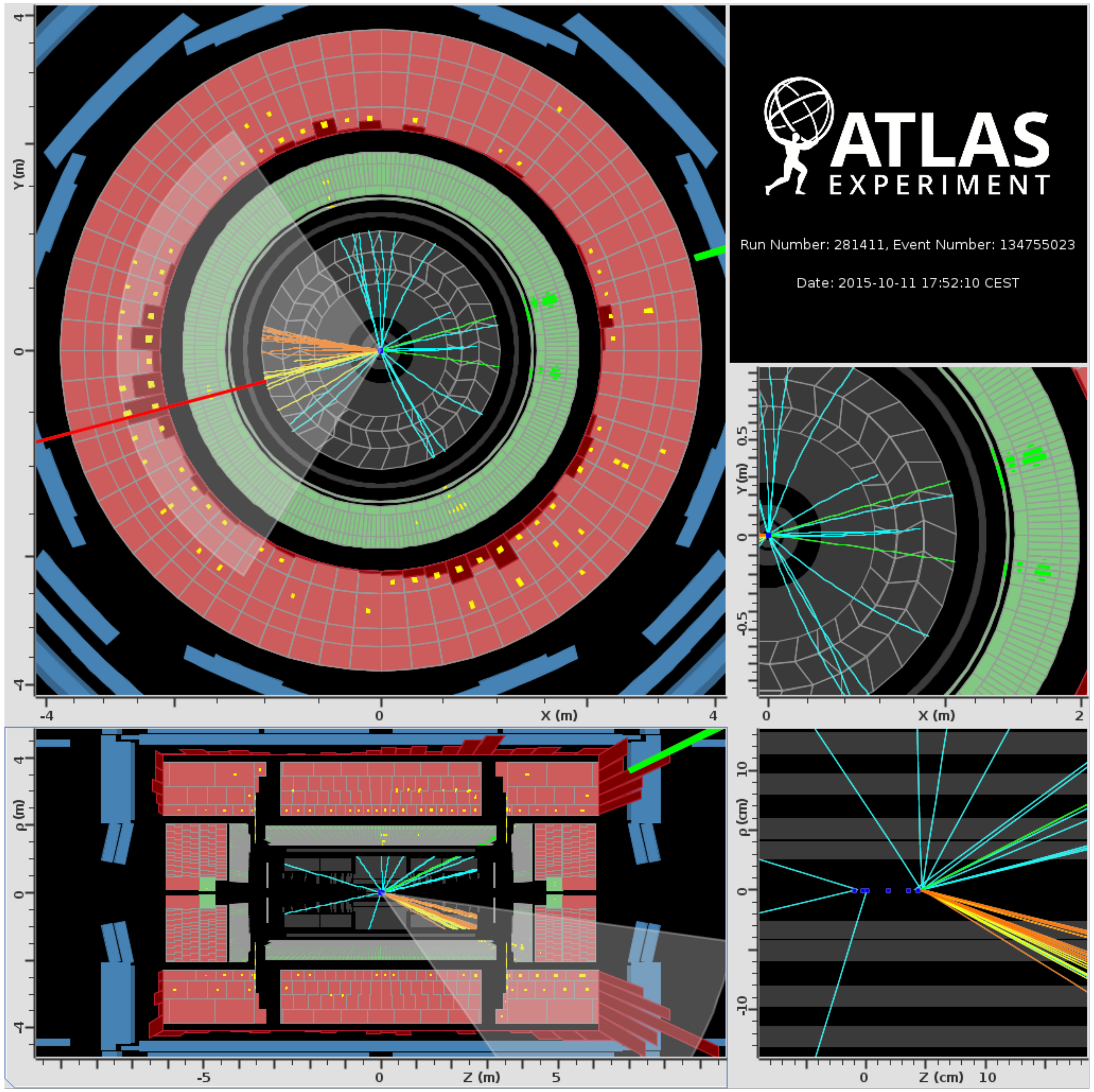


Low p_T^Z



Low p_T^Z

2Lepton Event Displays



High p_T^Z