Links:
[RunI Results]
[15-only Results]
[15+16 Results]

Search for pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state using proton-proton collisions at 13 TeV with the ATLAS detector

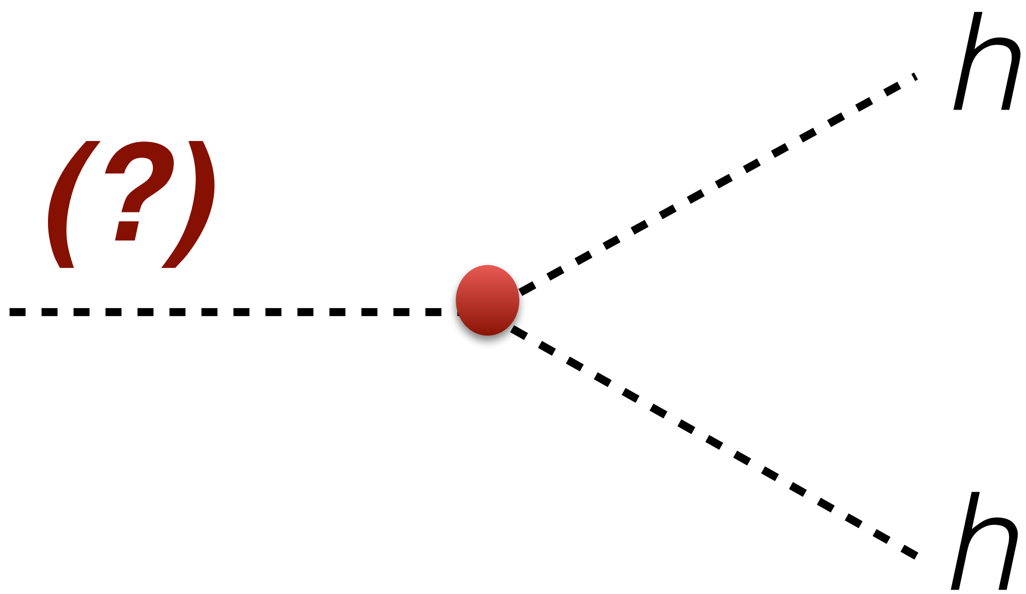
Tony(Baojia)Tong, Harvard University

on behalf of the ATLAS Collaboration

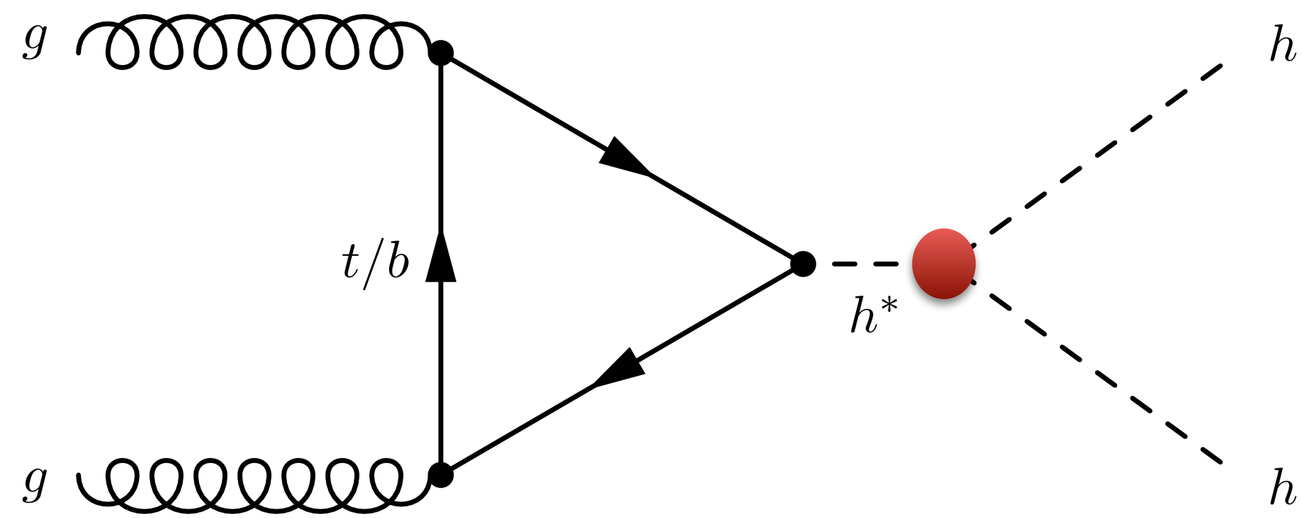
HBSM China, Aug 15-19, 2016

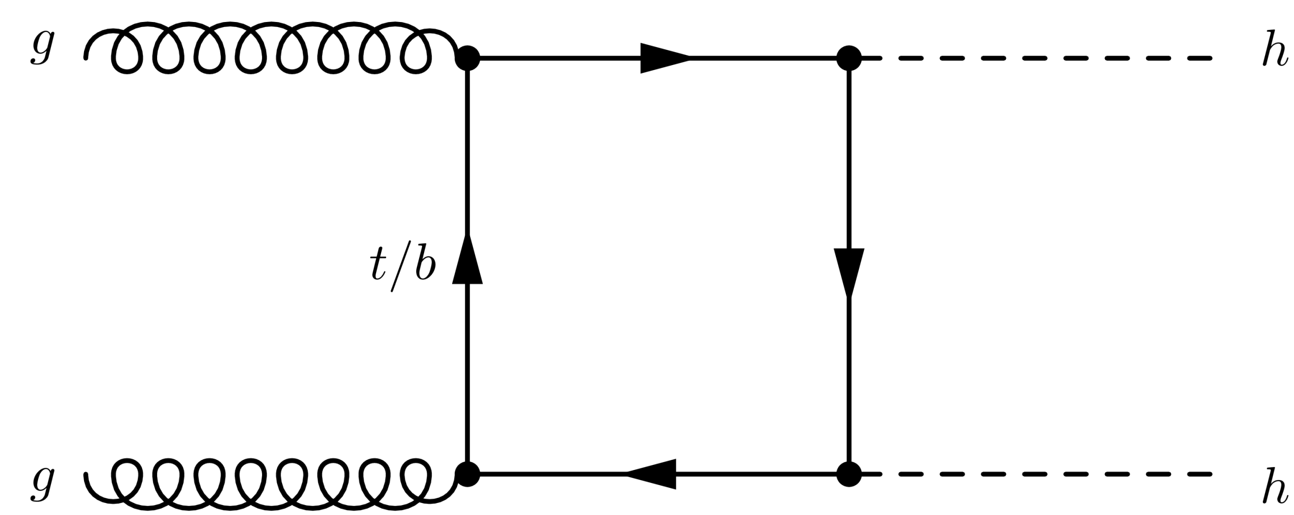
New Physics to hh

Resonance: Graviton, 2HDM …



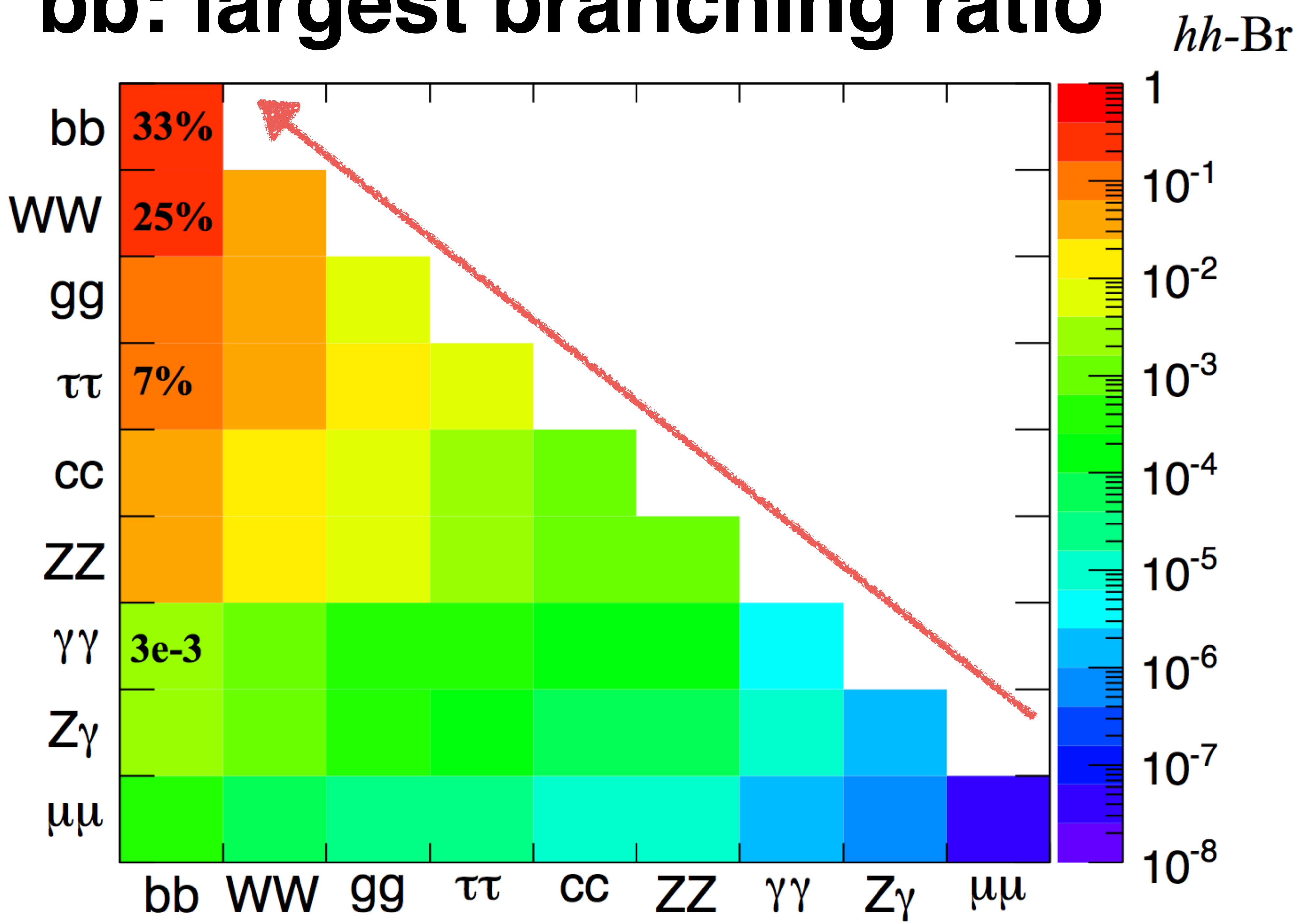
Non-Resonant: (B)SM





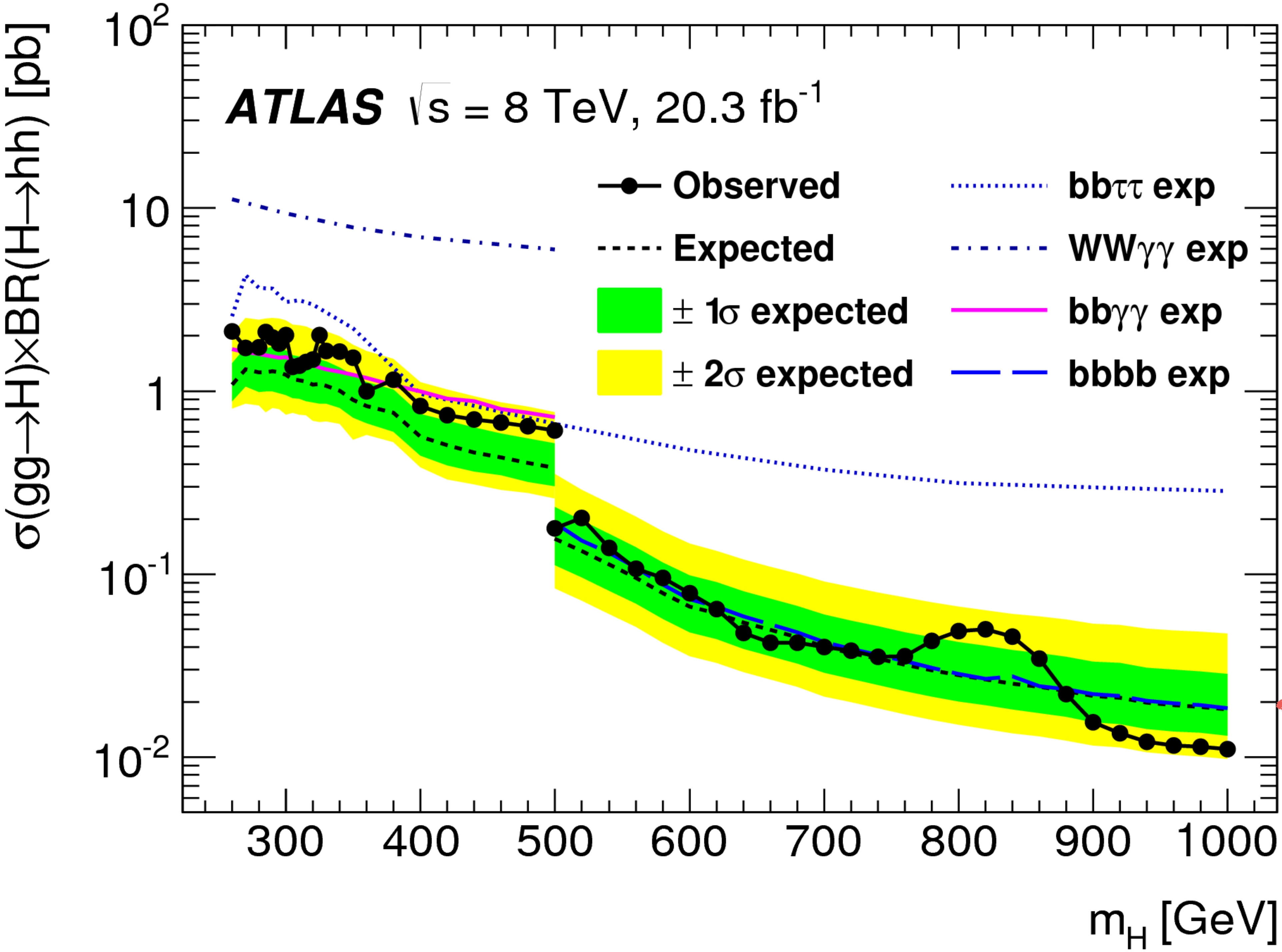
hh to Standard Model Particles

bb: largest branching ratio



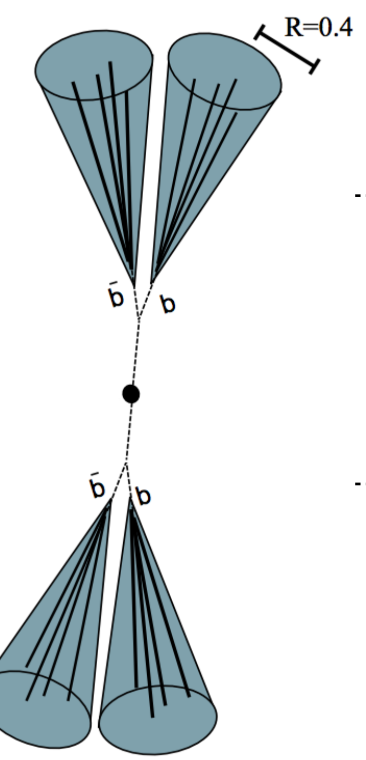
Run1 Limits

4b: hh limit-driver

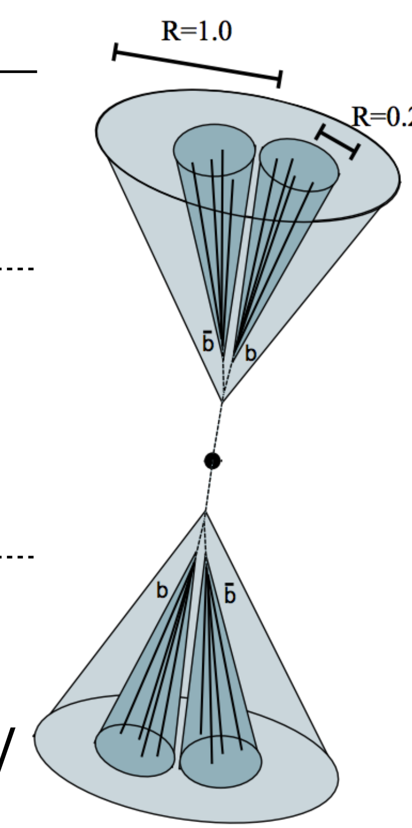


Jets Merging and The Two Channels

- Final search variable: **sums** of decay products' **invariant mass**
- **1.5 TeV** resonance → ~ 600 GeV pT Higgs → $\Delta R_{bb} \sim 2m_h/pT$ ~ **0.4**

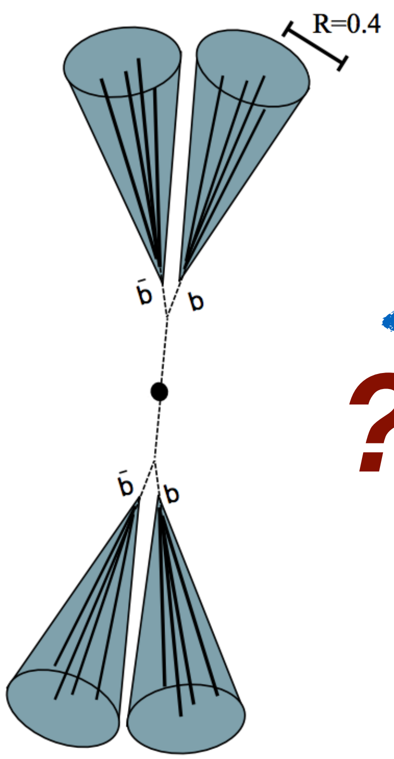


Objects/ Final State	**Resolved** (250–1200 GeV)	**Boosted** (1100-3000 GeV)
Trigger	Mixed Trigger	Large R-jet Trigger
Jets	Four **0.4** Anti-kt Jets	Two **1.0** trimmed Anti-kt Jets
pT cuts	Jet pT > **30** GeV	Leading > **450** GeV Subleading > 250 GeV
B-tagging	70% WP on EM Jets	77% WP on Anti-kt R=**0.2** track jets



Moriond Limits

Constraints	Resolved	Boosted
Low Mass Constraint	**high pT cuts/combinatorics**	R=1.0 jet not big enough
High Mass Constraint	resolved jets merging	**R=0.2 track jet merging**



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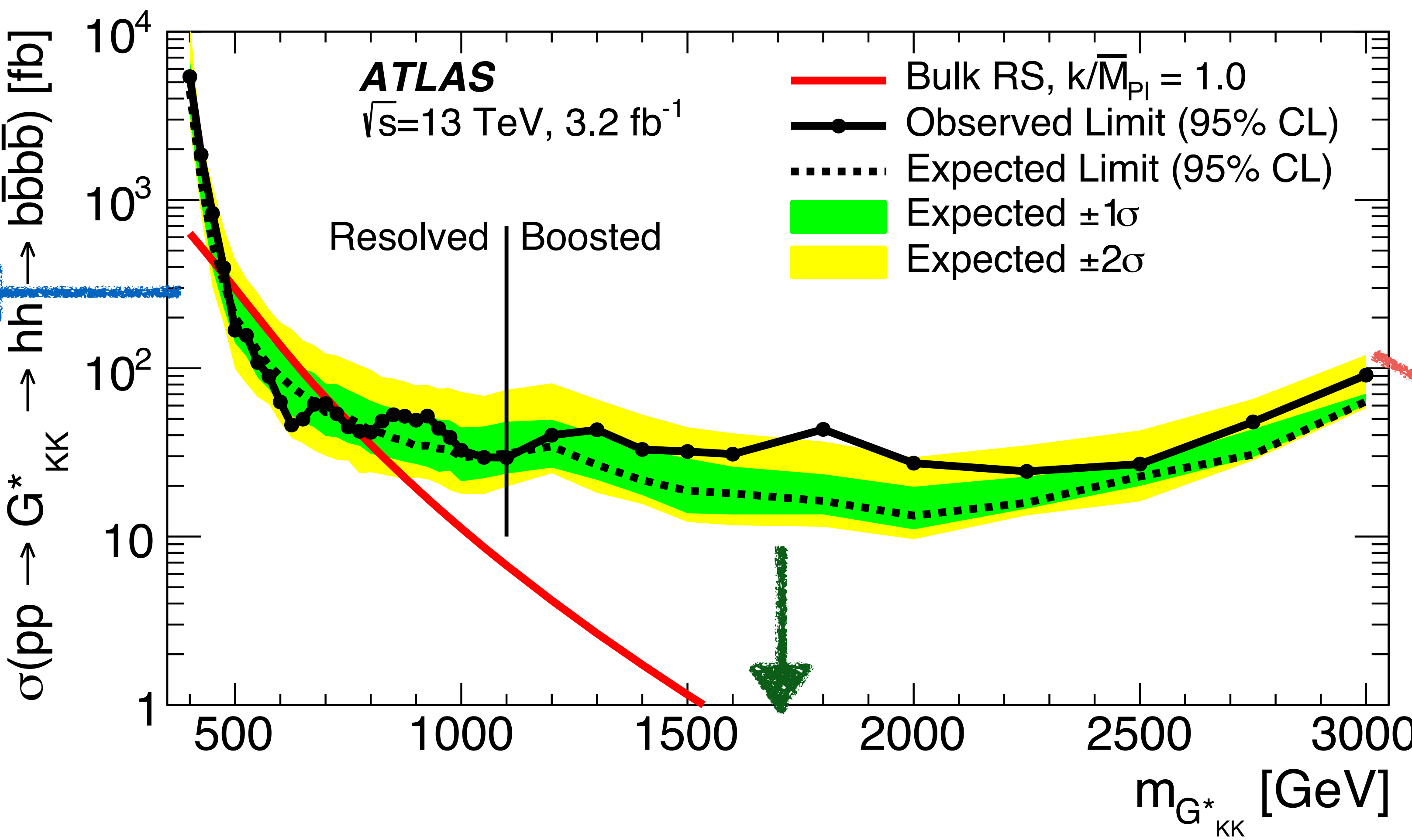

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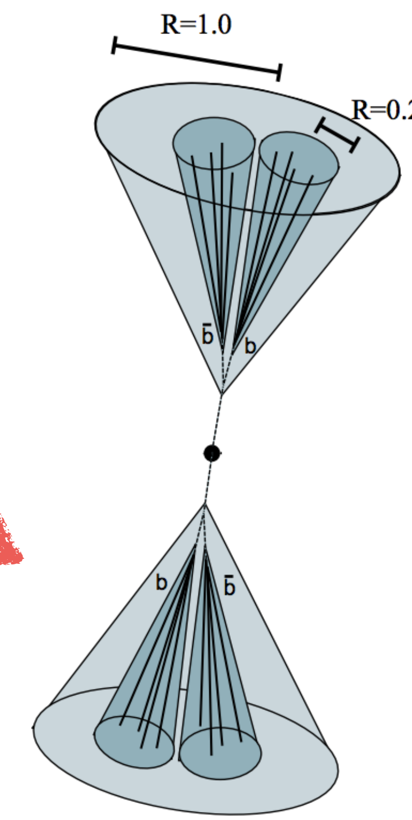
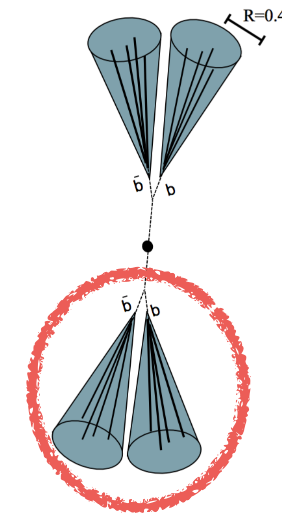
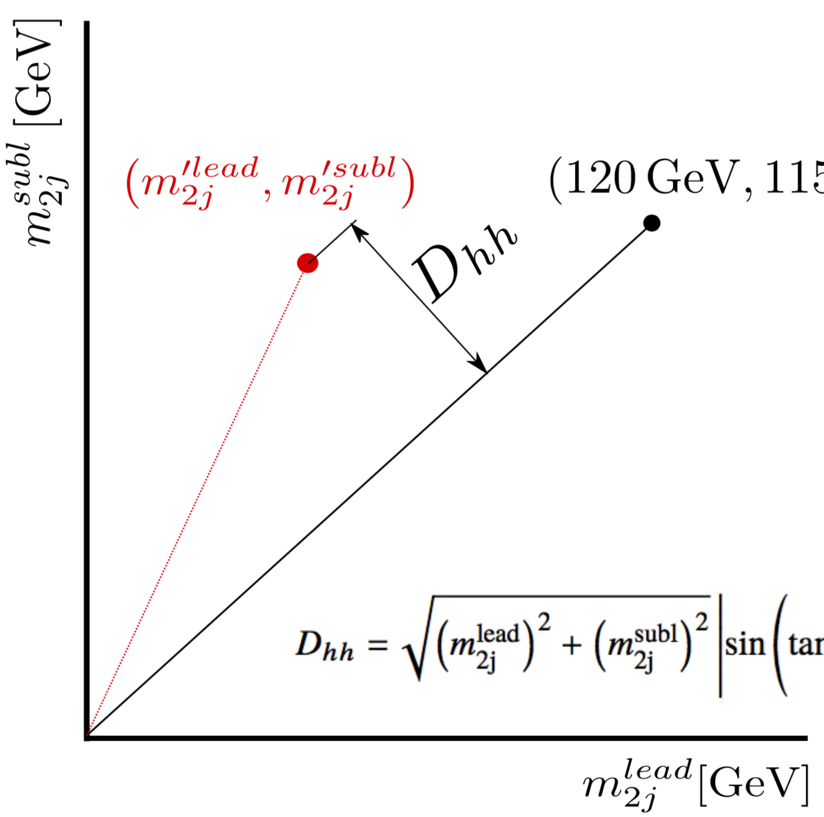


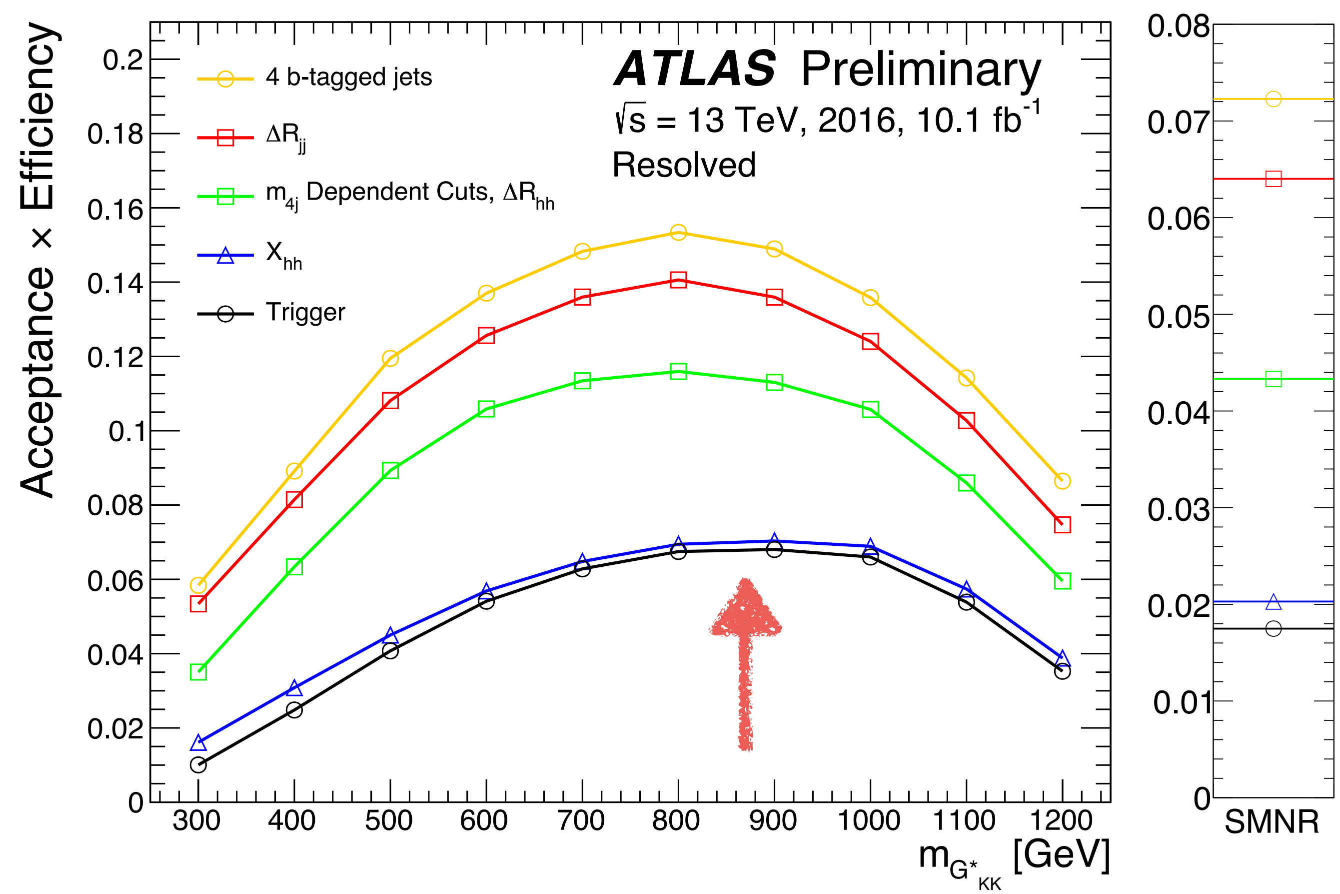
Jets Pair Combinatorics and Cuts

- Select hh pair that has the **minimal distance** to the diagonal line
- m_{4j} dependent requirements on h **pT, eta, and dR_{jj}**
- Good signal efficiency across **large** mass ranges

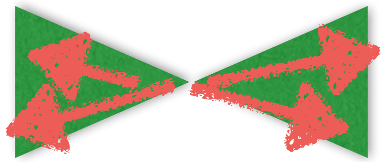
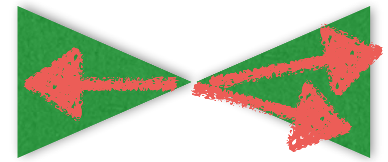
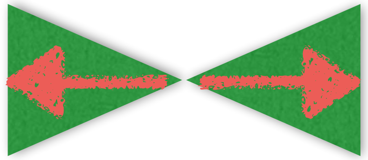


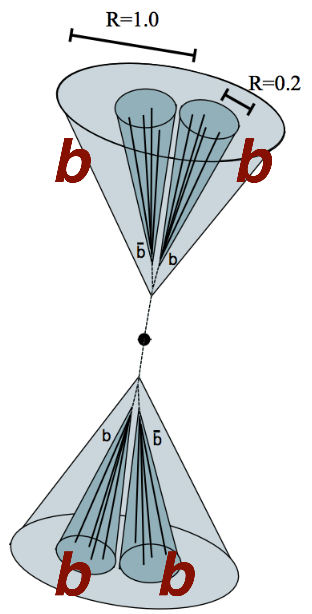


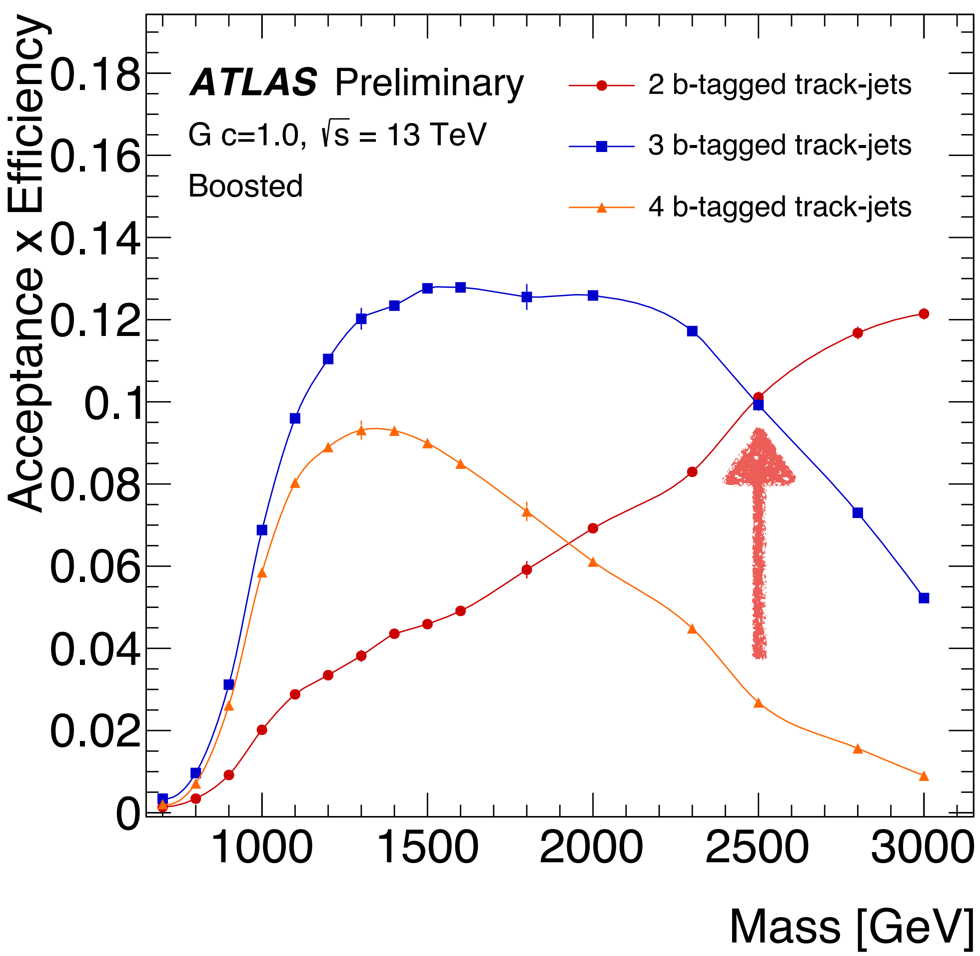
$$D_{hh} = \sqrt{\left(m_{2j}^{\text{lead}}\right)^2 + \left(m_{2j}^{\text{subl}}\right)^2} \left|\sin\left(\tan^{-1}\left(\frac{m_{2j}^{\text{subl}}}{m_{2j}^{\text{lead}}}\right) - \tan^{-1}\left(\frac{115}{120}\right)\right)\right|$$

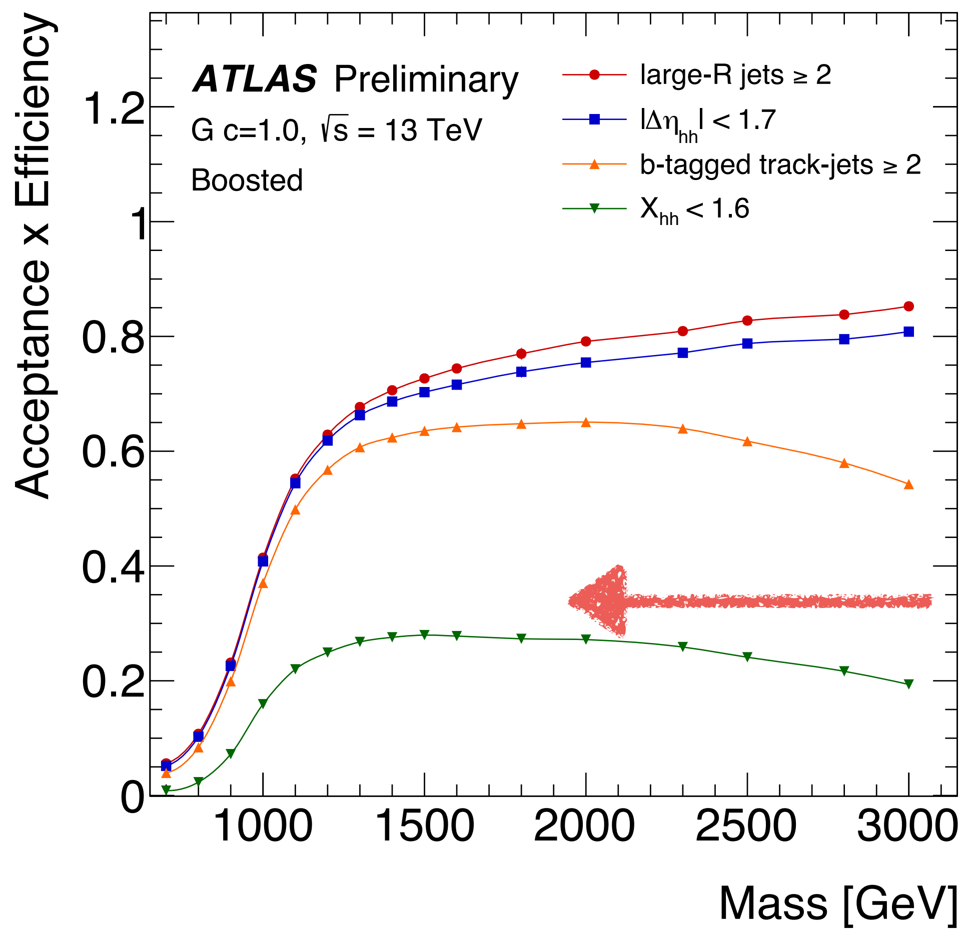


Track Jets Merging and Signal Regions

- 4Tag:  3Tag: 
- 2Tag Split: one b Tag in each large R jet 
- **Three** Signal Regions**: 4Tag, 3Tag and 2Tag Split**

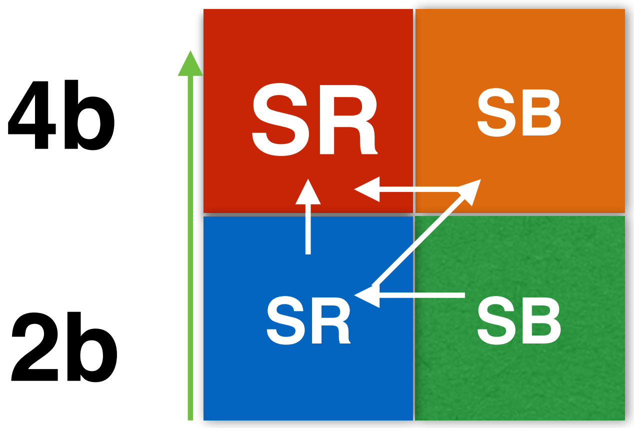


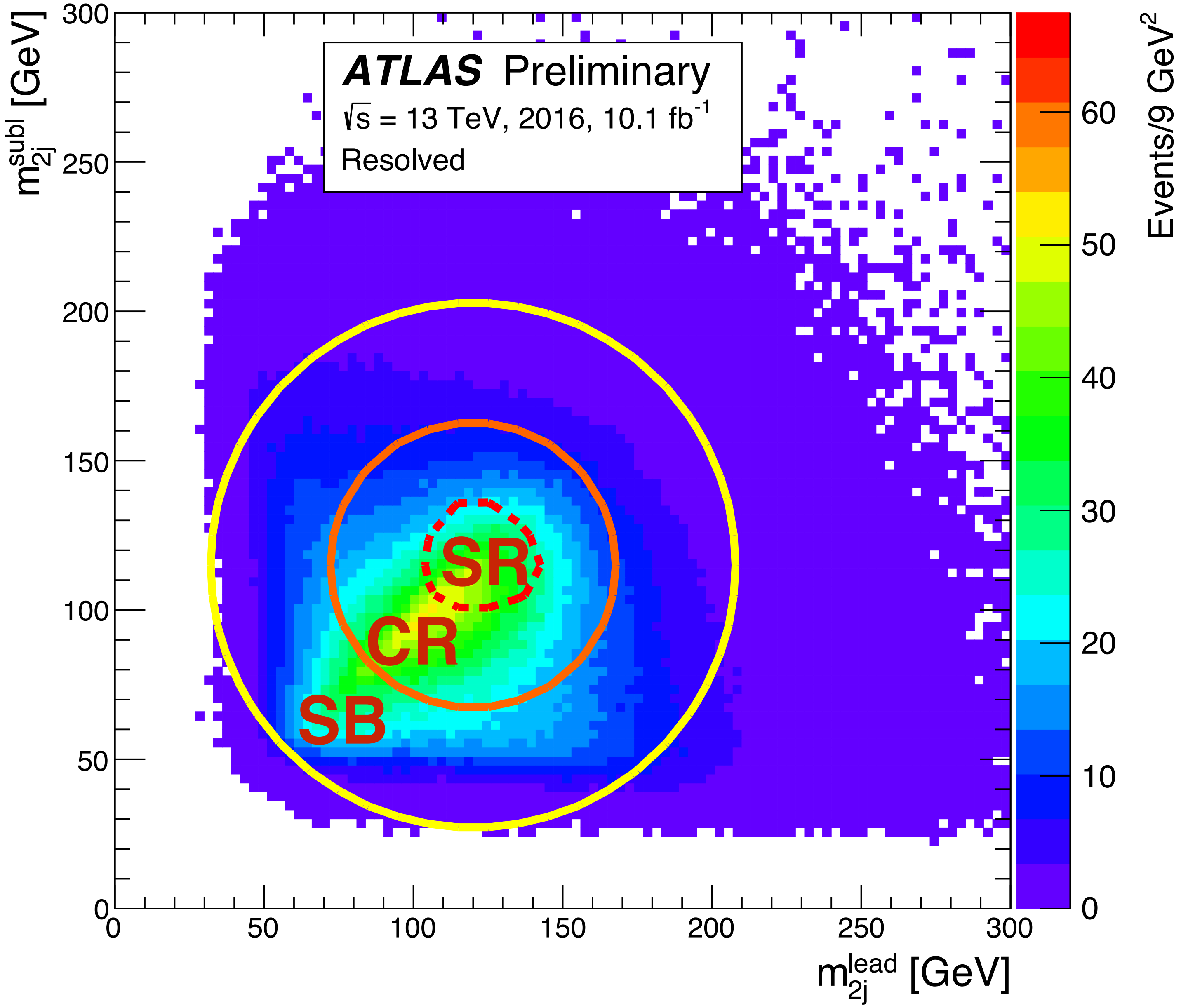




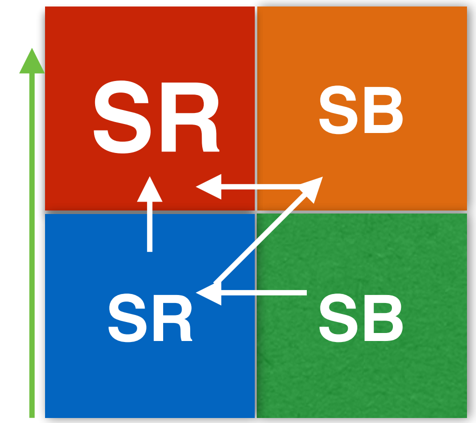
Estimate Background

- Background:
  - 93% qcd—data driven
  - 7% ttbar—MC
- 2b inclusive sample is used to derive the **normalization** estimation in 4b
- Background **shape** estimation comes from 2Tag SB/CR/SR regions;

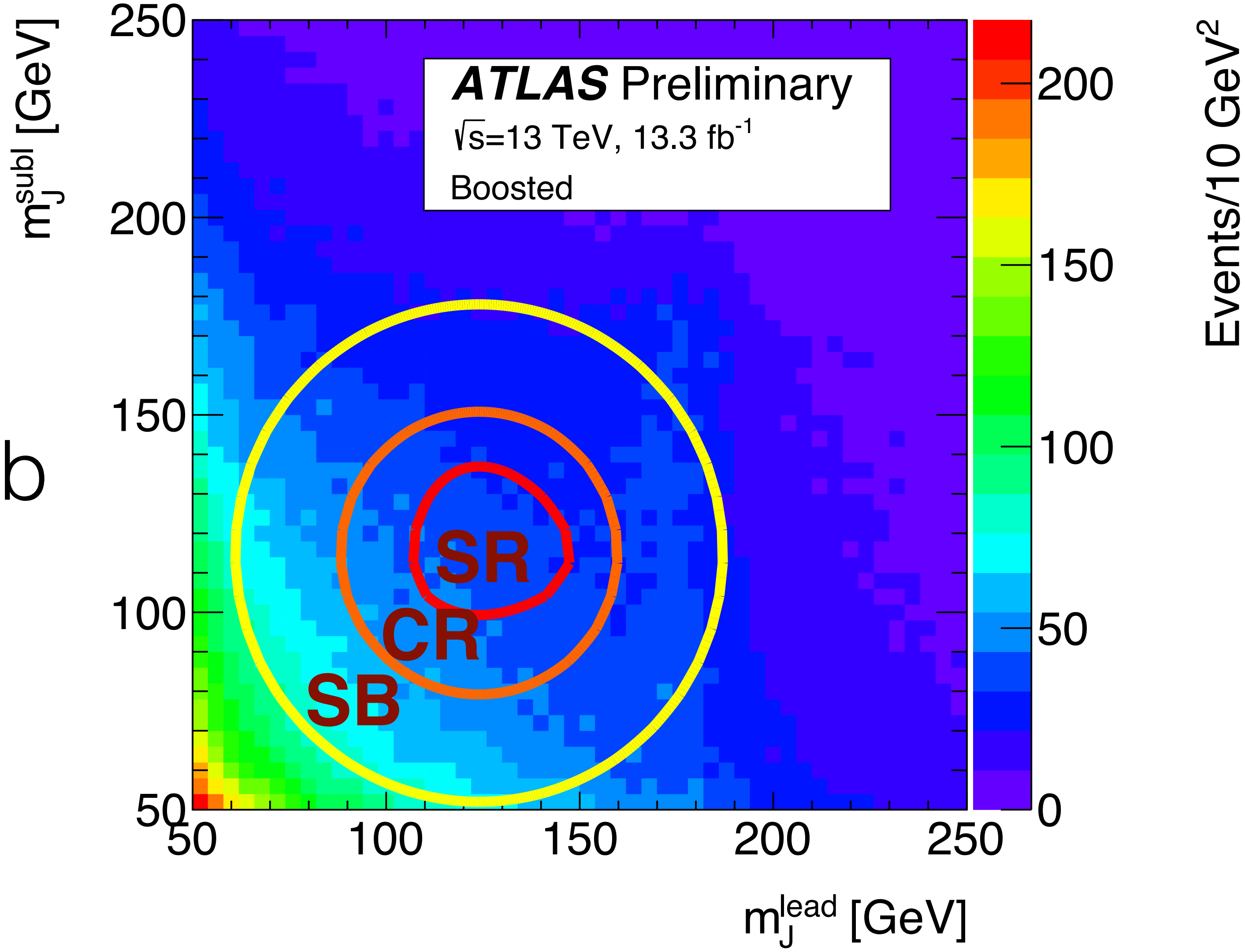




Estimate Background, Again



- Background:
    - 85% qcd—data driven
    - 15% ttbar—data driven
- Fit the leading jet mass to extract ttbar and qcd **normalization** estimation comes from 0b to N(2, 3, 4)b
- Background **shape** estimation comes from 0b SB/CR/SR regions;



Uncertainties Countdown

- Signal uncertainty mainly comes from **b-tagging**
- Bkg uncertainty is dominated by **data driven** control region estimates
- Background/QCD **shape uncertainty** is also applied

Resolved

	2015			2016		
Source	Background	SM hh	G^*_{KK} (800 GeV)	Background	SM hh	G^*_{KK} (800 GeV)
Luminosity	–	2.1	2.1	–	3.7	3.7
JER	–	5.7	3.3	–	5.4	3.5
JES	–	6.4	1.3	–	6.6	1.3
b-tagging	–	23	35	–	23	35
Theoretical	–	9.7	4.2	–	9.7	4.2
Multijet	5	–	–	5	–	–
$t\bar{t}$	58	–	–	58	–	–
Total	5.5	26	35	5.5	27	36

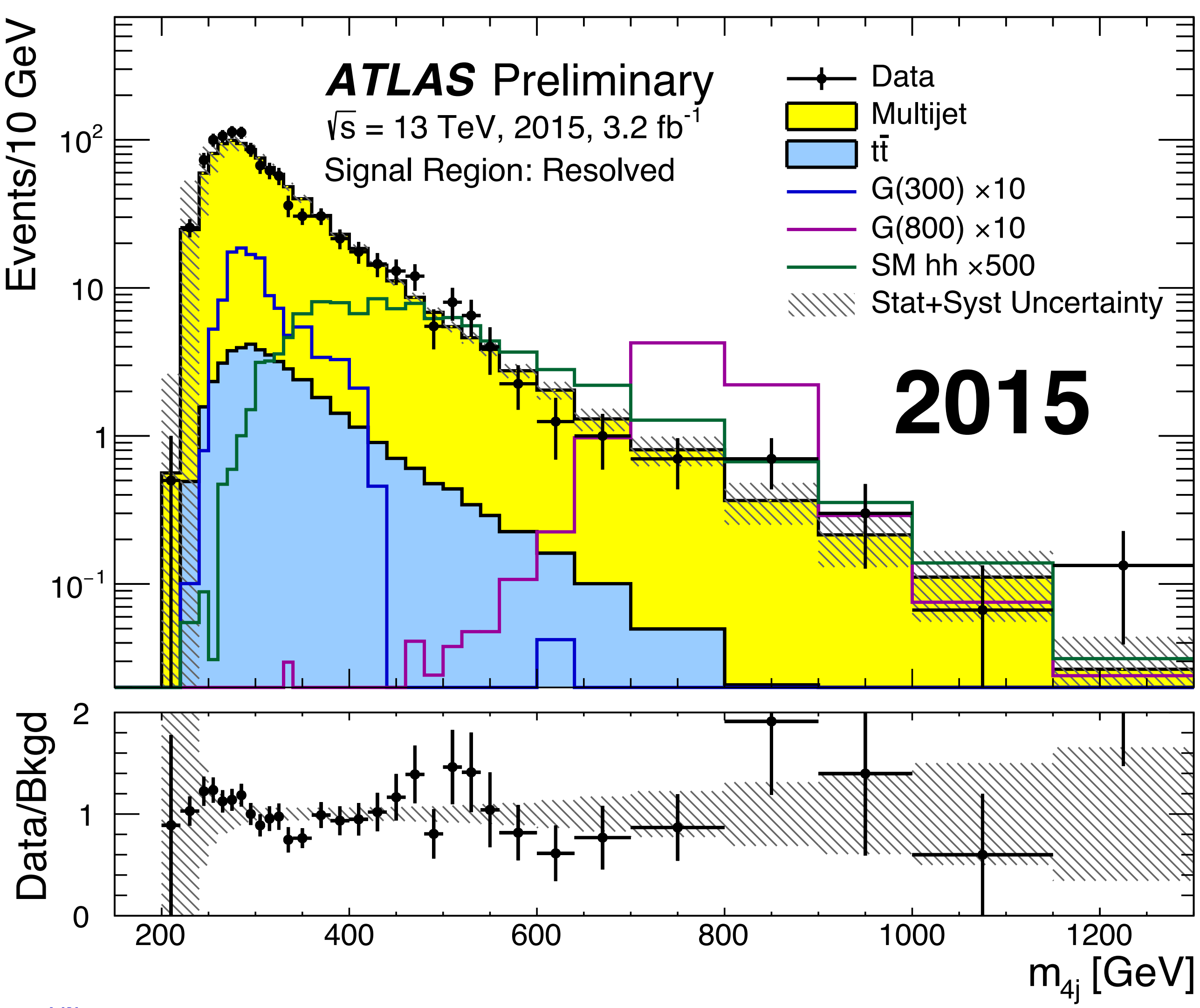
Boosted

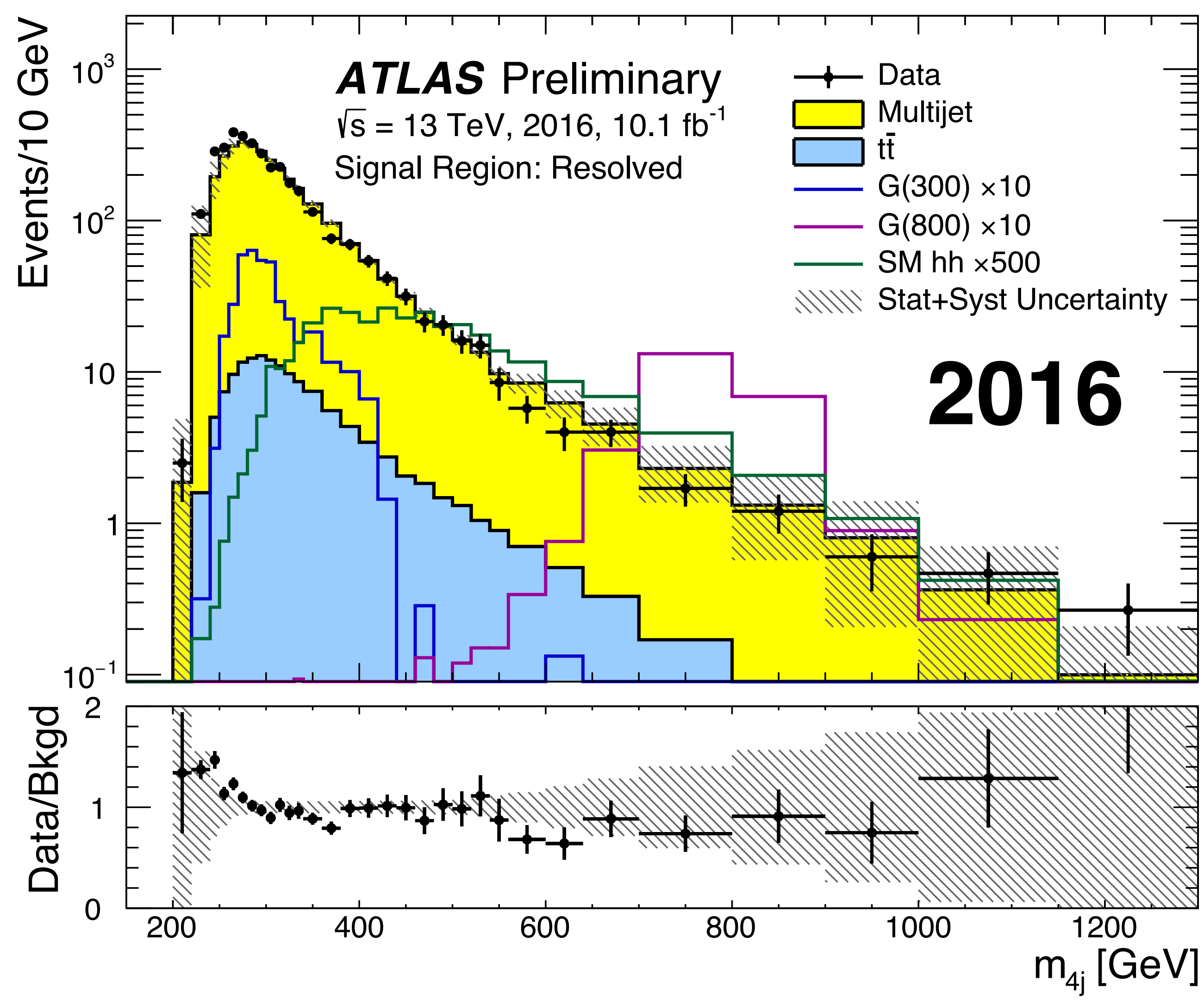
	2-tag-split		3-tag		4-tag	
Source	Background	G^*_{KK} (2 TeV)	Background	G^*_{KK} (2 TeV)	Background	G^*_{KK} (2 TeV)
Luminosity	-	2.9	-	2.9	-	2.9
JER	-	0.1	-	0.1	-	0.3
JMR	-	12	-	12	-	12
JES/JMS	-	4.5	-	4.2	-	3.3
b-tagging	-	58	-	15	-	38
Theoretical	-	2.7	-	2.3	-	2.4
Bkg Estimate	4.4	-	4.6	-	21	-
Statistical	0.5	1.4	1.1	1.0	1.2	1.3
$t\bar{t}$	1.6	-	4.7	-	10	-
Total Sys	4.7	59	6.6	20	24	40

Signal Region: Resolved

- Final discriminant, **M4J**; no significant excess observed

Obs	**1231**	**3990**
Exp	1189 ± 76	3860 ± 230



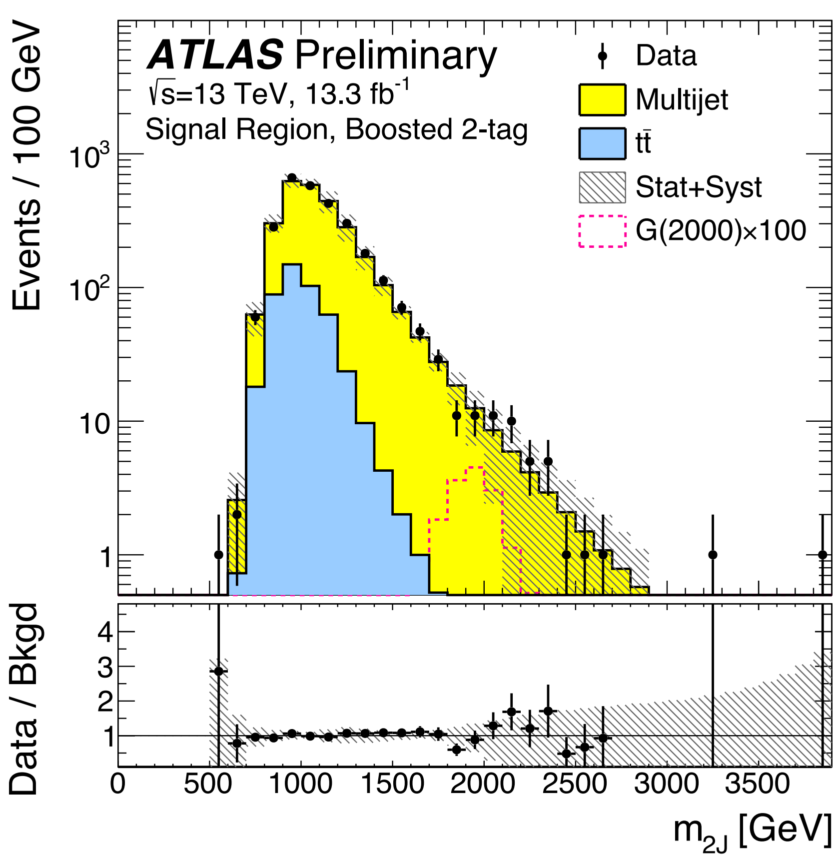


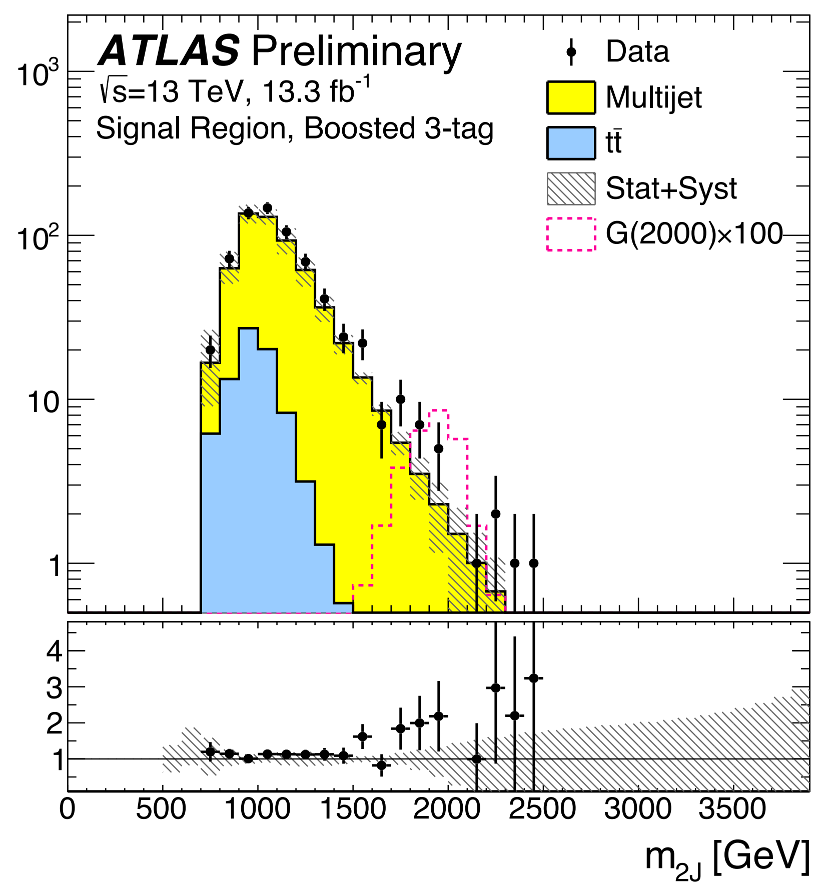
Signal Region: Boosted

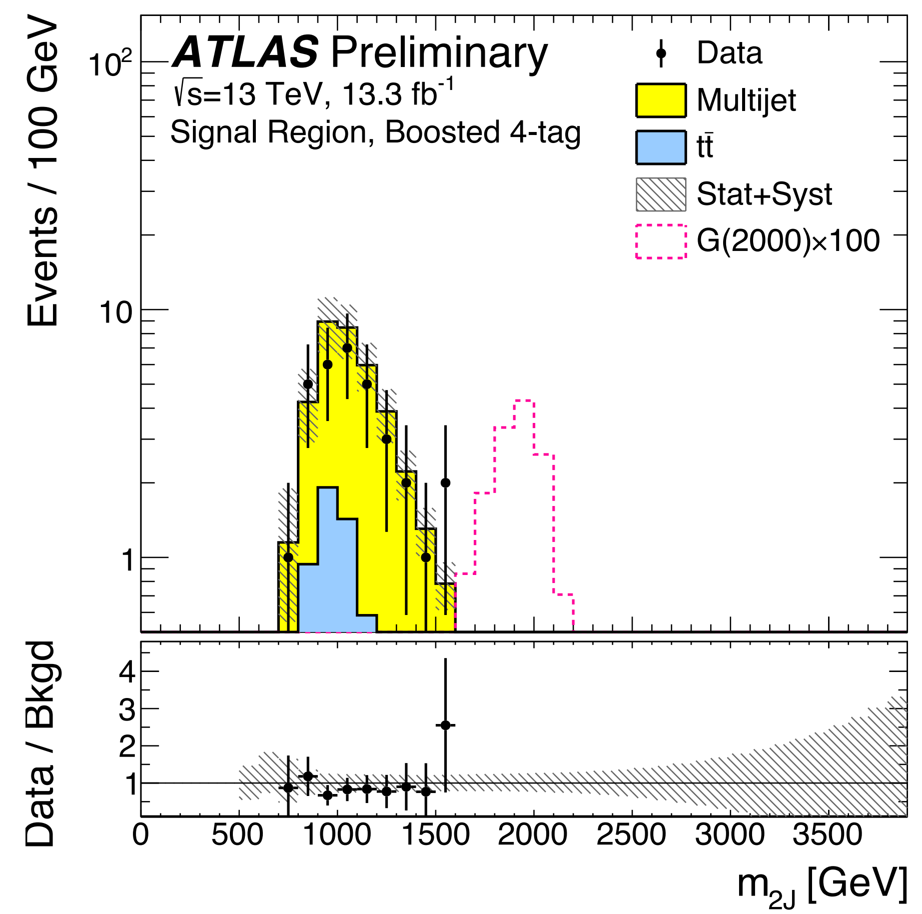
- Final discriminant, **M2J**; no significant excess observed

Obs	**2813**	**671**	**32**
Exp	2770 ± 130	596 ± 39	38 ± 9

2bs **3b** **4b**



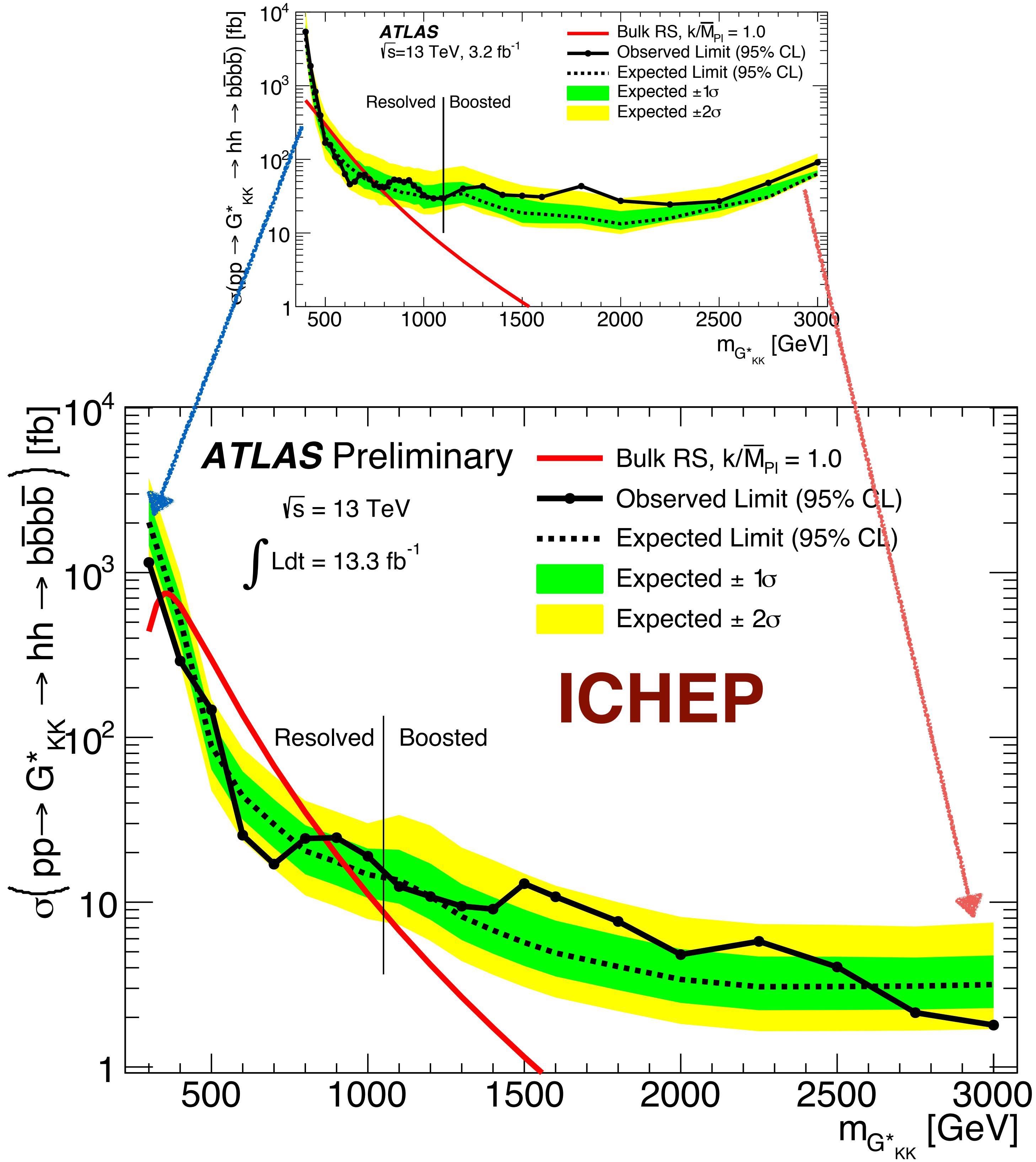




Combined Limits

- Resolved + Boosted Combined Asymptotic Limits
- Non-Resonance limit: **μ=29 (330 fb)**
- Significant **improvements in low mass and high mass**

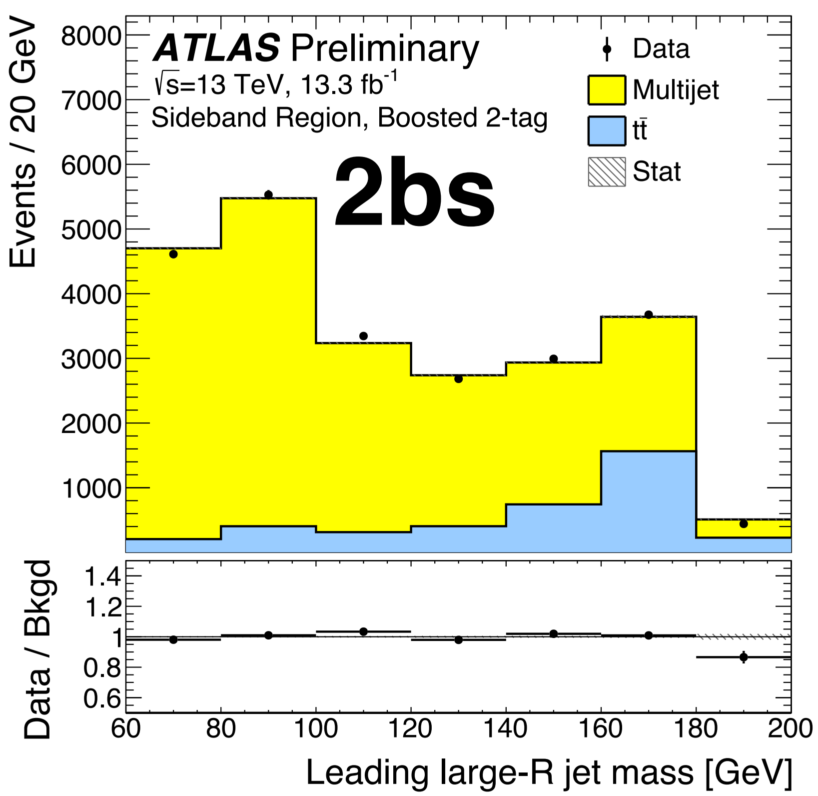
Moriond

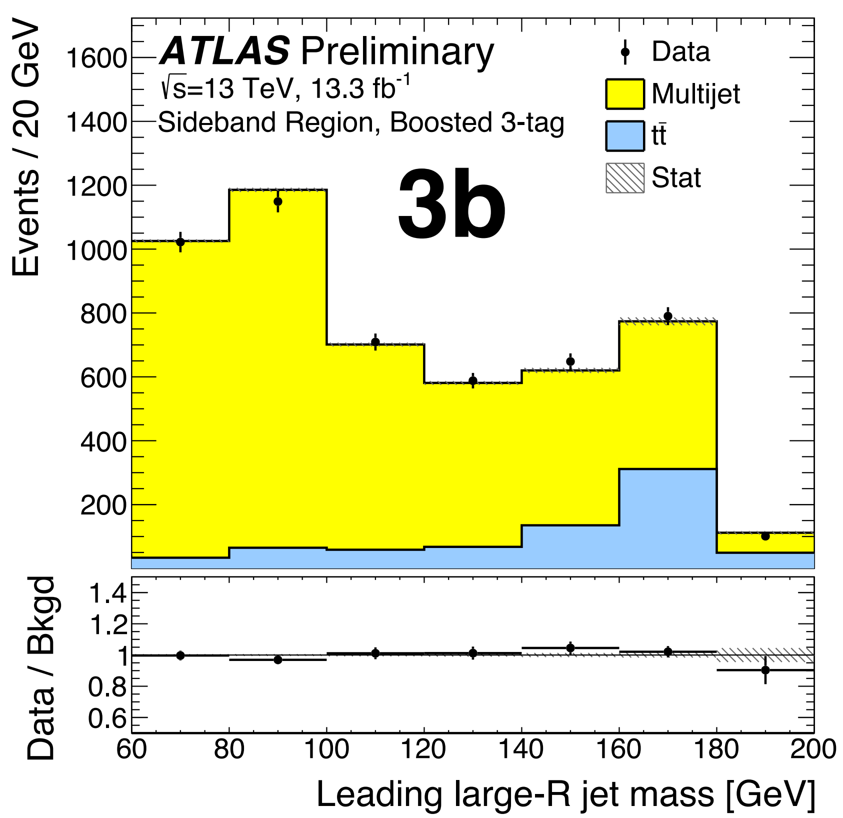


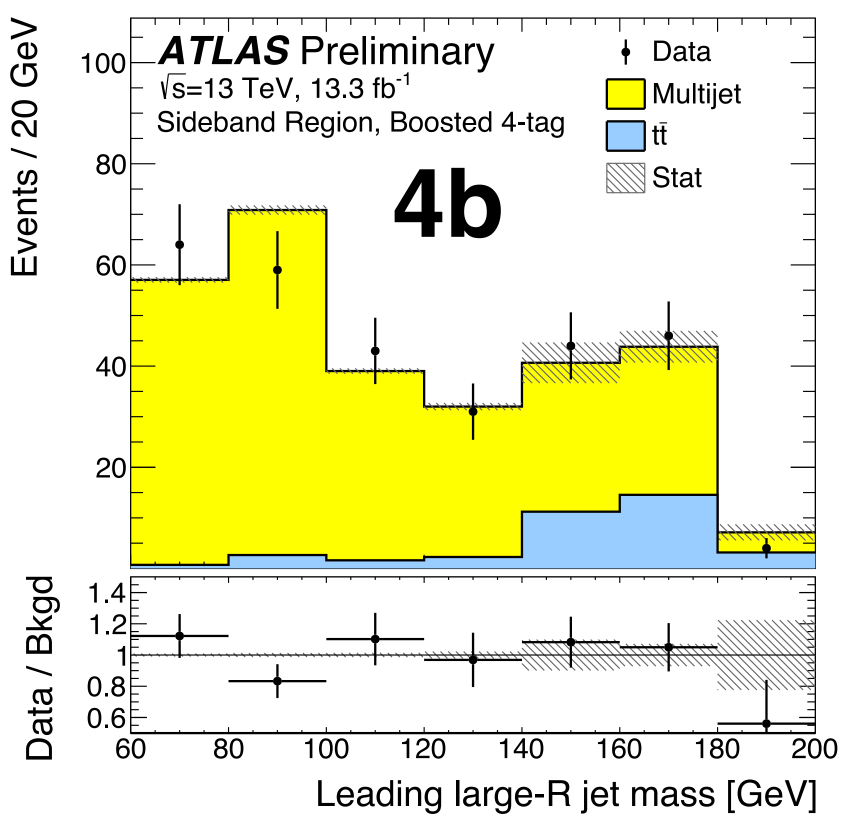
Back up Slides

Fit on Leading Jet Mass Distribution

- Given: $N^{\nu_b}_{data} = \mu^{\nu_b}_{qcd} N^{0b}_{qcd} + \alpha^{\nu_b}_{t\bar{t}} N^{\nu_b}_{t\bar{t}}$
- Simultaneous **fit** of μ_{qcd}, a_{tt} to extract the normalization factors
- All fits are independent







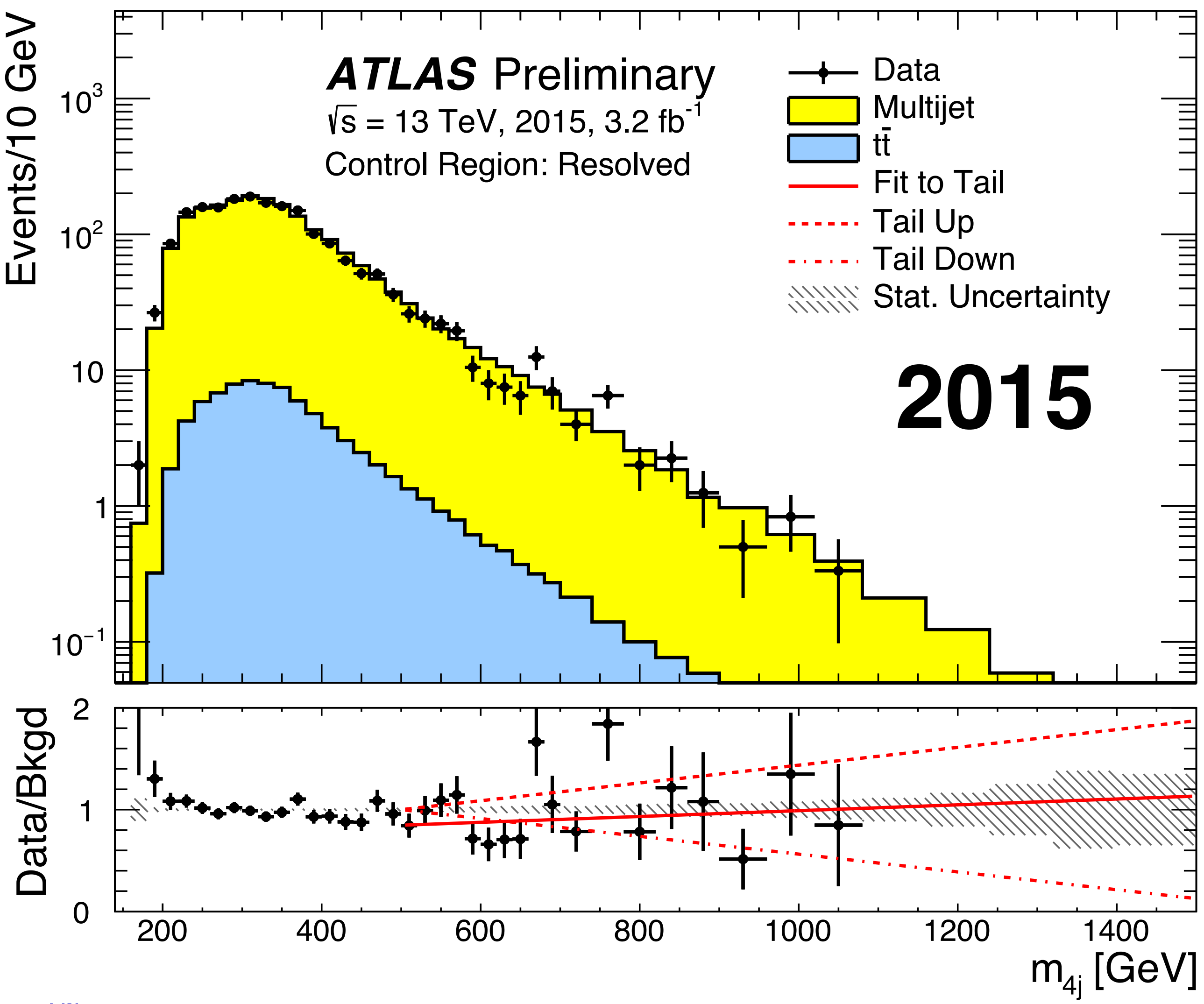
Reweighting Details

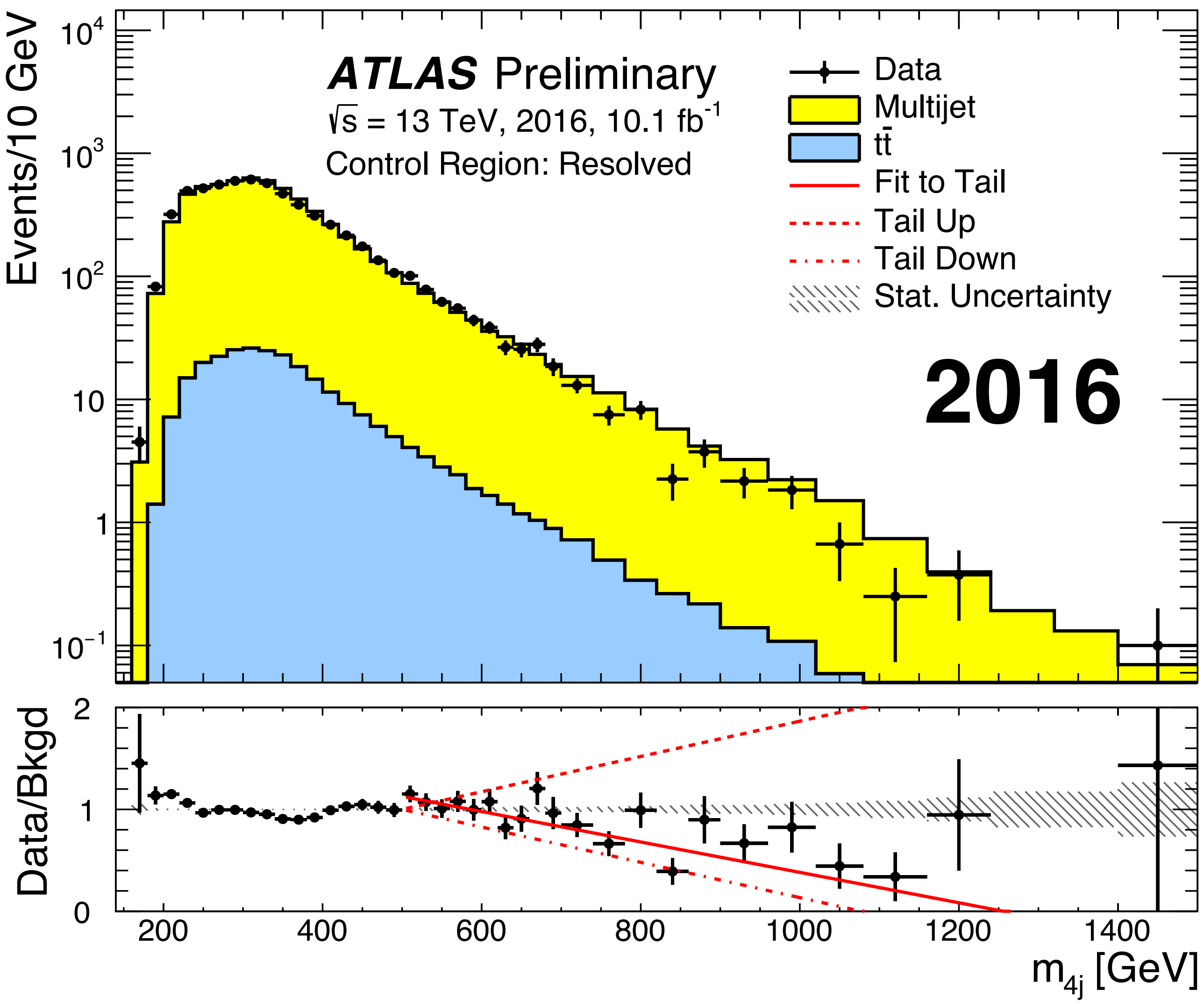
- Kinematics dependence of μ_{qcd} is corrected by reweighting
- Resolved: Njet distribution, leading Higgs candidate pT, subleading Higgs candidate E
- Boosted; leading Higgs candidate pT, leading track jet pT of the leading Higgs candidate, leading track jet pT of the subleading Higgs candidate
- Iterated reweighting is used such that the correlations are taken into account.

Control Region: Resolved

- **Good** agreement in shape and normalization

Obs	**3995**	**12752**
Exp	4021 ± 88	12970 ± 110



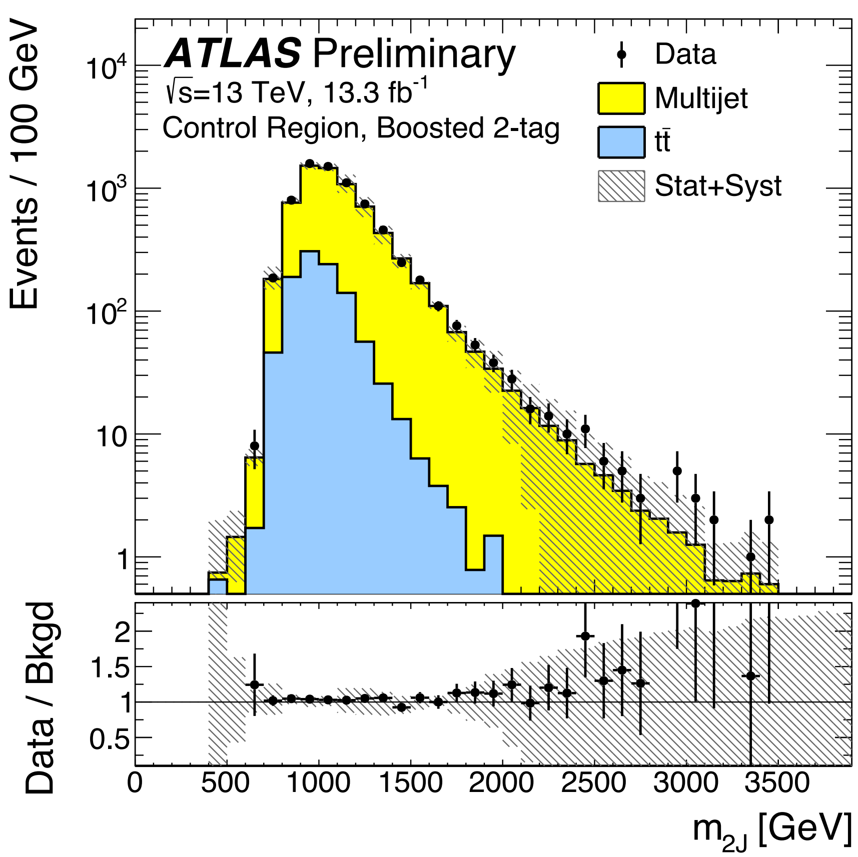


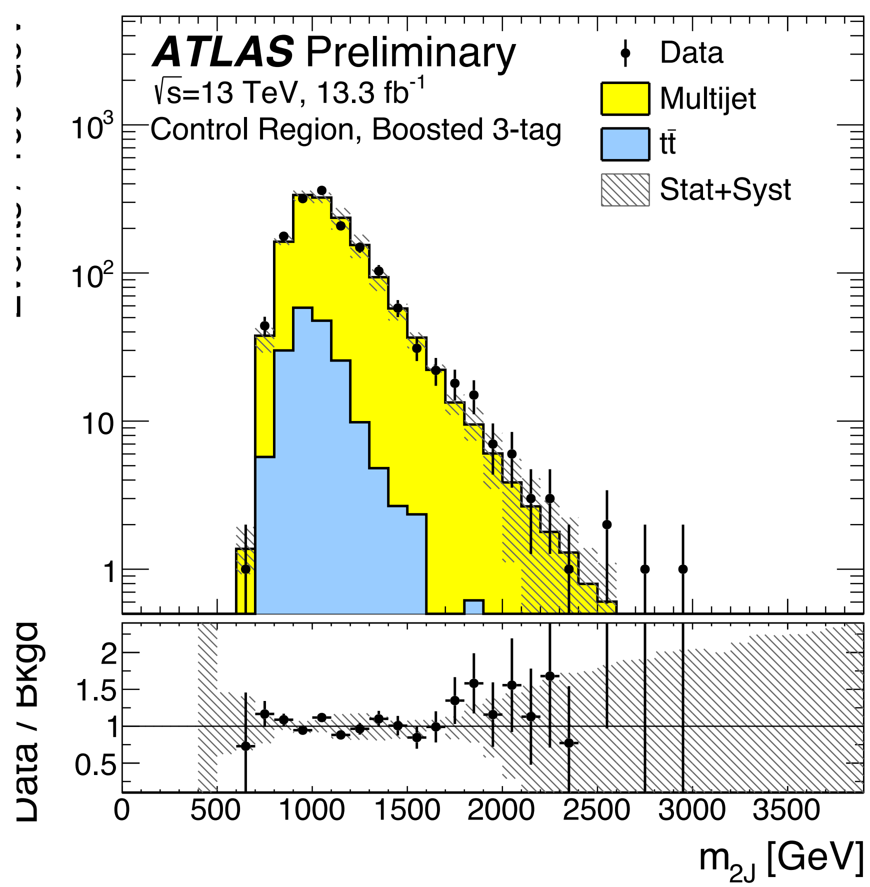
Control Region: Boosted

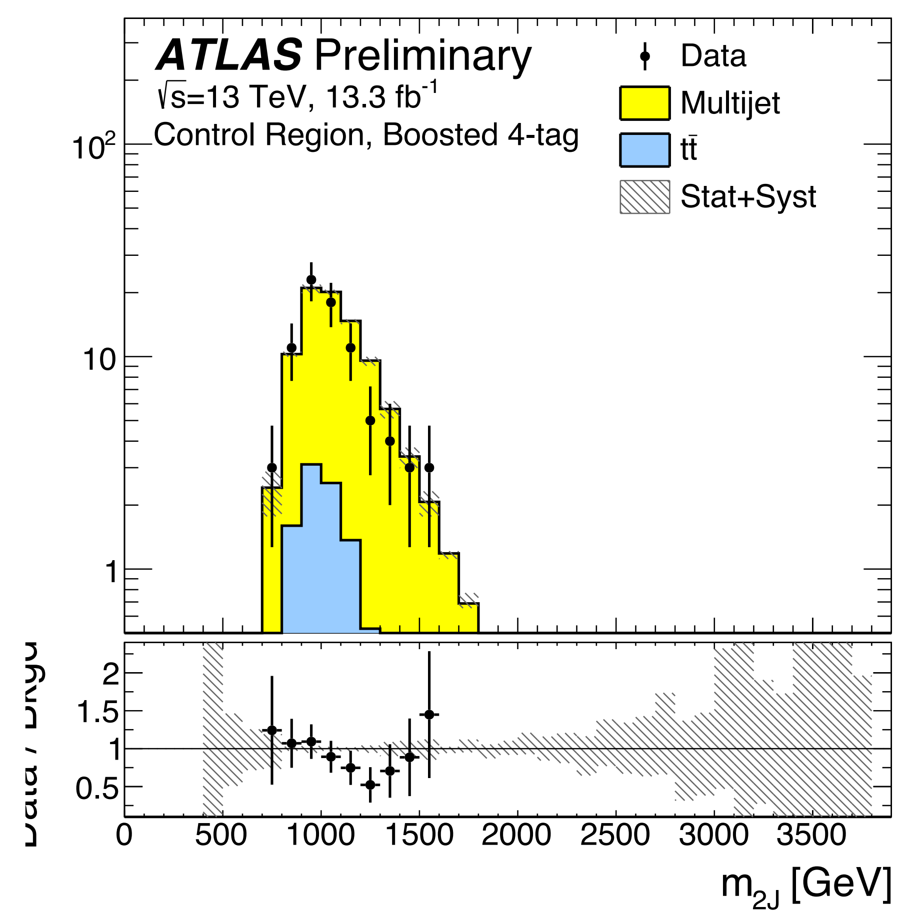
- **Good** agreement in shape and normalization

Obs	**7200**	**1529**	**81**
Exp	6954 ± 52	1507 ± 24	94.4 ± 5.8

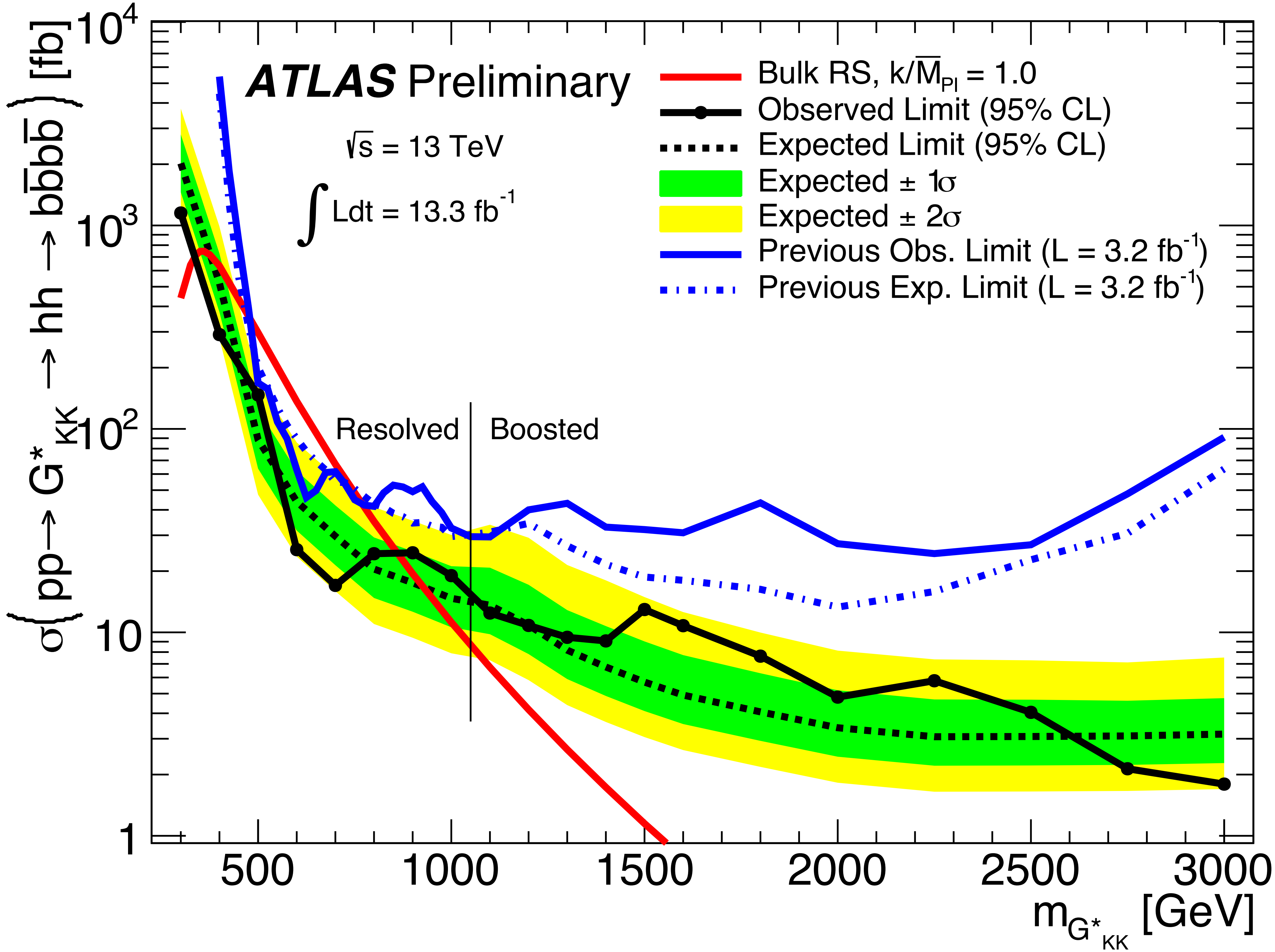
2bs **3b** **4b**



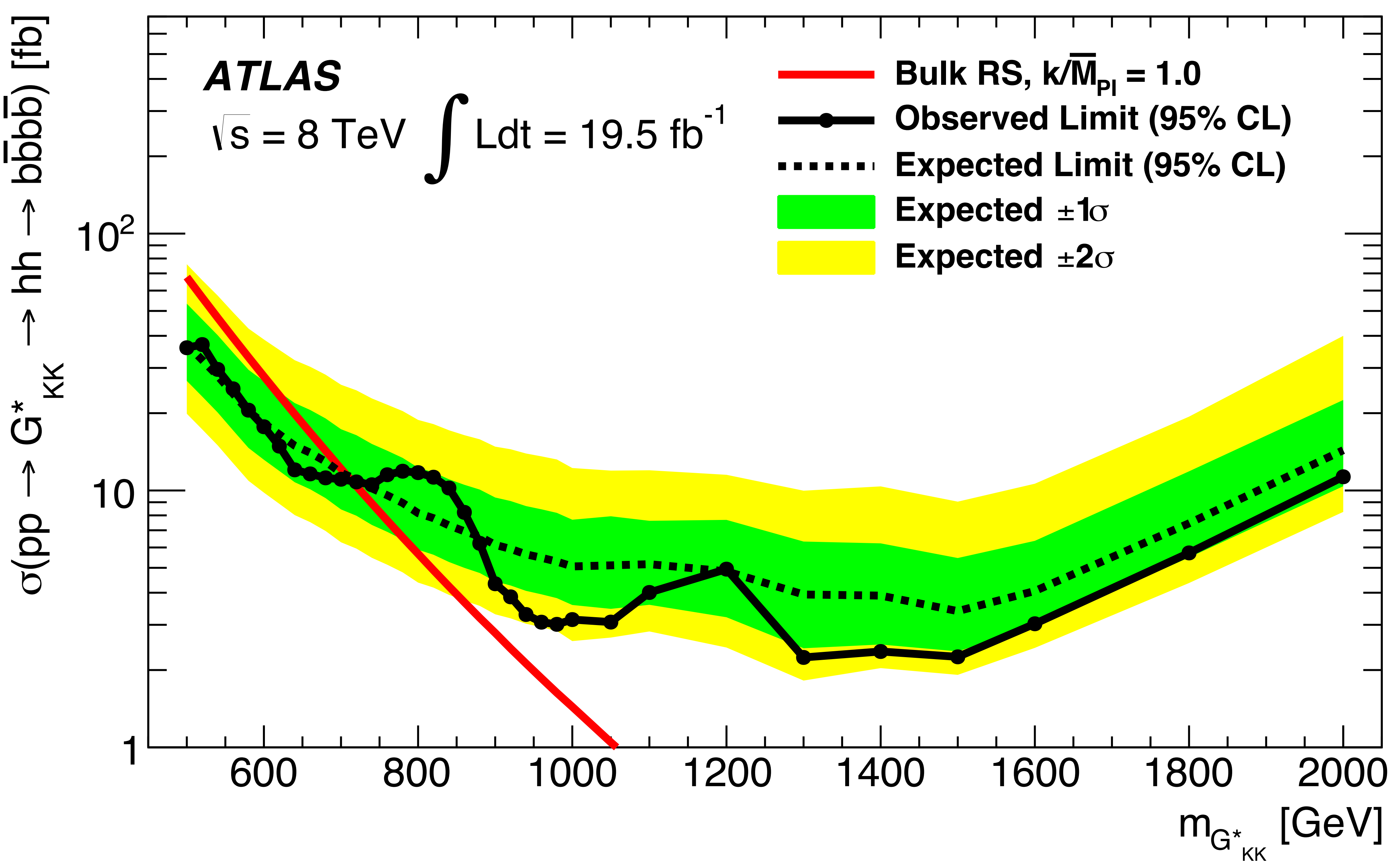




Limit Comparison



Run I Combined Limit



Run I Resolved and Boosted

Resolved

Sample	Signal Region Yield
Multijet	81.4 ± 4.9
$t\bar{t}$	5.2 ± 2.6
Z+jets	0.4 ± 0.2
Total	87.0 ± 5.6
Data	87
SM hh	0.34 ± 0.05
G^*_{KK} (500 GeV), $k/\bar{M}_{\mathrm{Pl}} = 1$	27 ± 5.9

Boosted

Sample	Signal Region Yield
Multijet	23.5 ± 4.1
$t\bar{t}$	2.2 ± 0.9
Z+jets	0.14 ± 0.06
Total	25.7 ± 4.2
Data	34
G^*_{KK} (1000 GeV), $k/\bar{M}_{\mathrm{Pl}} = 1$	2.1 ± 0.6