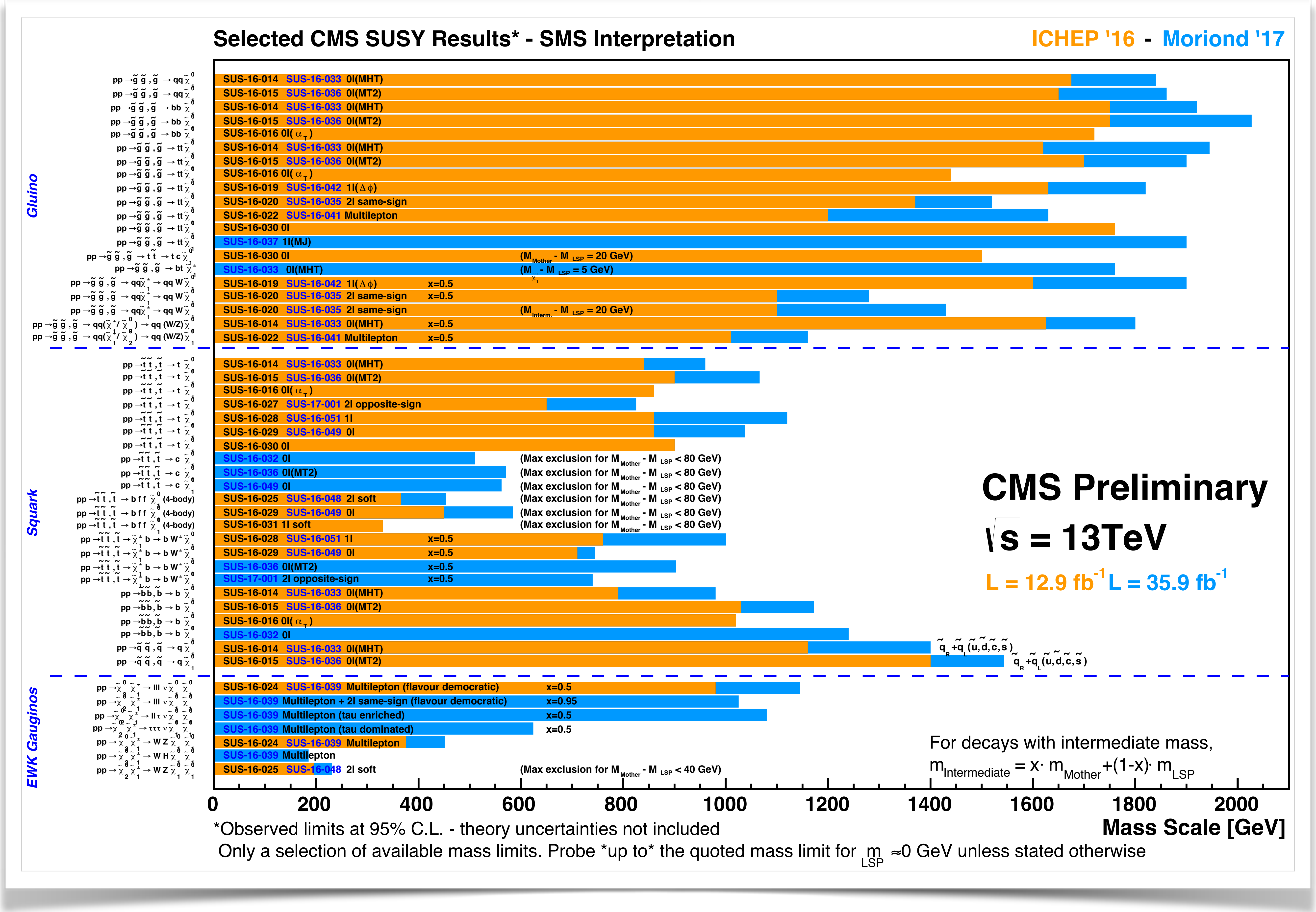
Search for R-Parity Violating (RPV) Supersymmetry at CMS

Jae Hyeok Yoo (UC Santa Barbara)
on behalf of the CMS Collaboration

12/11/2017

SUSY 17 in Mumbai, India

Why R-Parity Violating (RPV) SUSY?



- Recent searches at LHC set stringent limits on R-parity conserving (RPC) models
  - Tension in ability to explain hierarchy problem with little fine tuning
- A way to ease the tension: give up some assumptions, e.g., conservation of R-parity
- RPC searches require significant amount of MET due to undetected LSPs
- In RPV scenarios LSP can decay to SM particles → removes large MET signature
- This disfavors LSP as a DM candidate, but can weaken constraints from RPC searches

RPV SUSY in CMS

- RPV allows new interactions: lepton and baryon number violating interactions

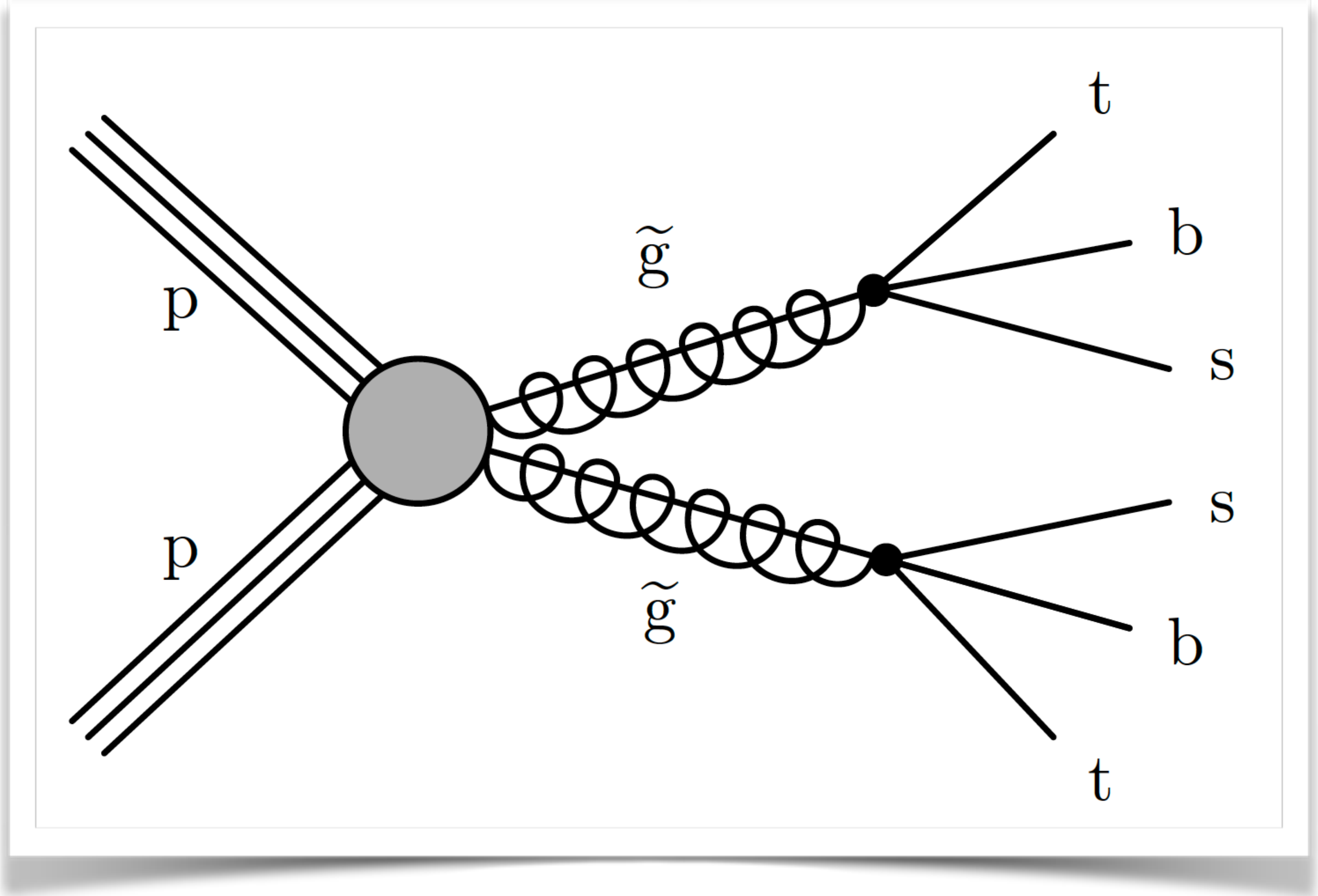
$$W_{RPV} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \epsilon_iL_iH_2 + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

~~Lepton number~~ (LLE, LQD) ~~Baryon number~~ (UDD)

- CMS has a preliminary result (CMS-PAS-SUS-16-040)
  - Will be submitted to arXiv soon
  - Similar search from ATLAS (JHEP09 (2017) 088)

RPV SUSY in CMS

- Target gluino pair production where gluino decays to tbs (via UDD)
  - Motivated by minimum flavor violating SUSY which makes 3rd generation couplings large
- **1-lepton** final state with **large jet and b jet multiplicities** and **no MET requirement**
  - Generic search sensitive to such high-mass signatures
- Backgrounds
  - $t\bar{t}$ (dominant), QCD, W+jets, and other (single top, Drell-Yan, di-boson, etc)
- Previous CMS result (CMS-PAS-SUS-16-013): $m_{\tilde{g}}$<1360 GeV
  - $m_{\tilde{g}}$ of interest ~1500 GeV → quarks from gluinos significantly boosted
  - Expect jets with a few hundred GeV of energy: allows to use fully efficient high H_T ($\Sigma p_{T,jet}$) trigger



Analysis strategy

Use three variables to distinguish signal from background: $\mathbf{M_J}$, $\mathbf{N_{jet}}$ and $\mathbf{N_b}$

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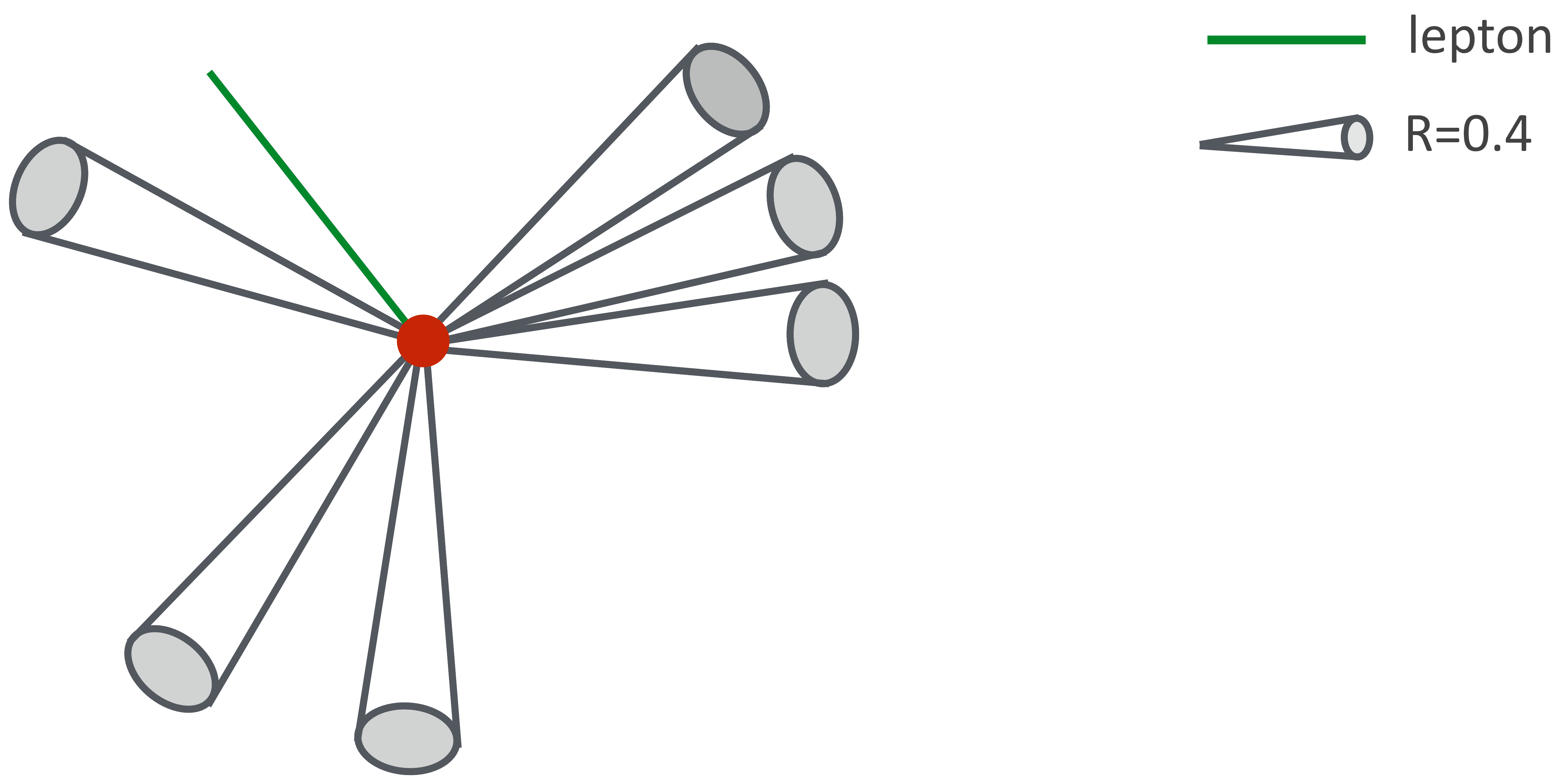
- To form a large-R jet, regular (R=0.4) jets and leptons are clustered together



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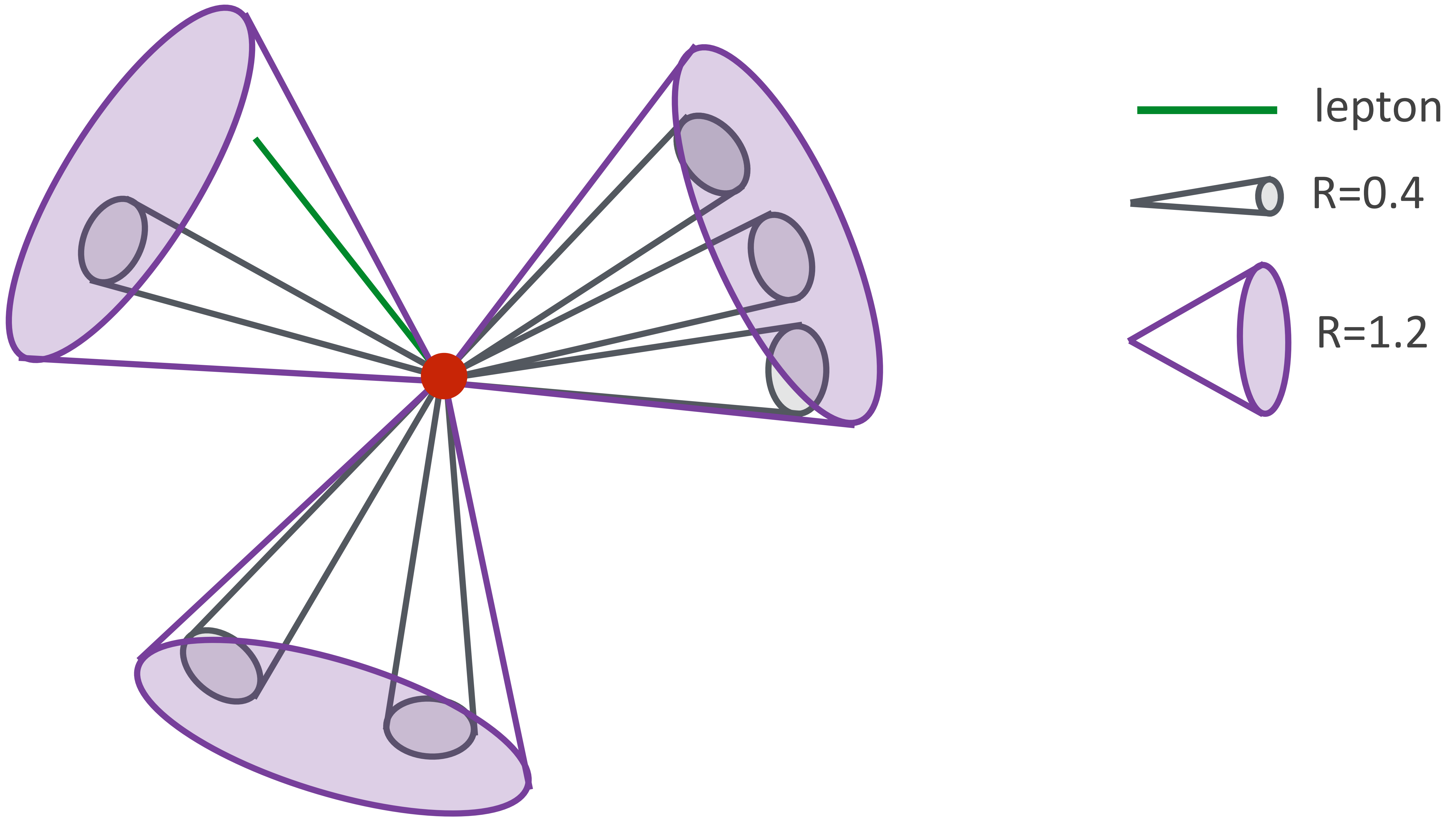

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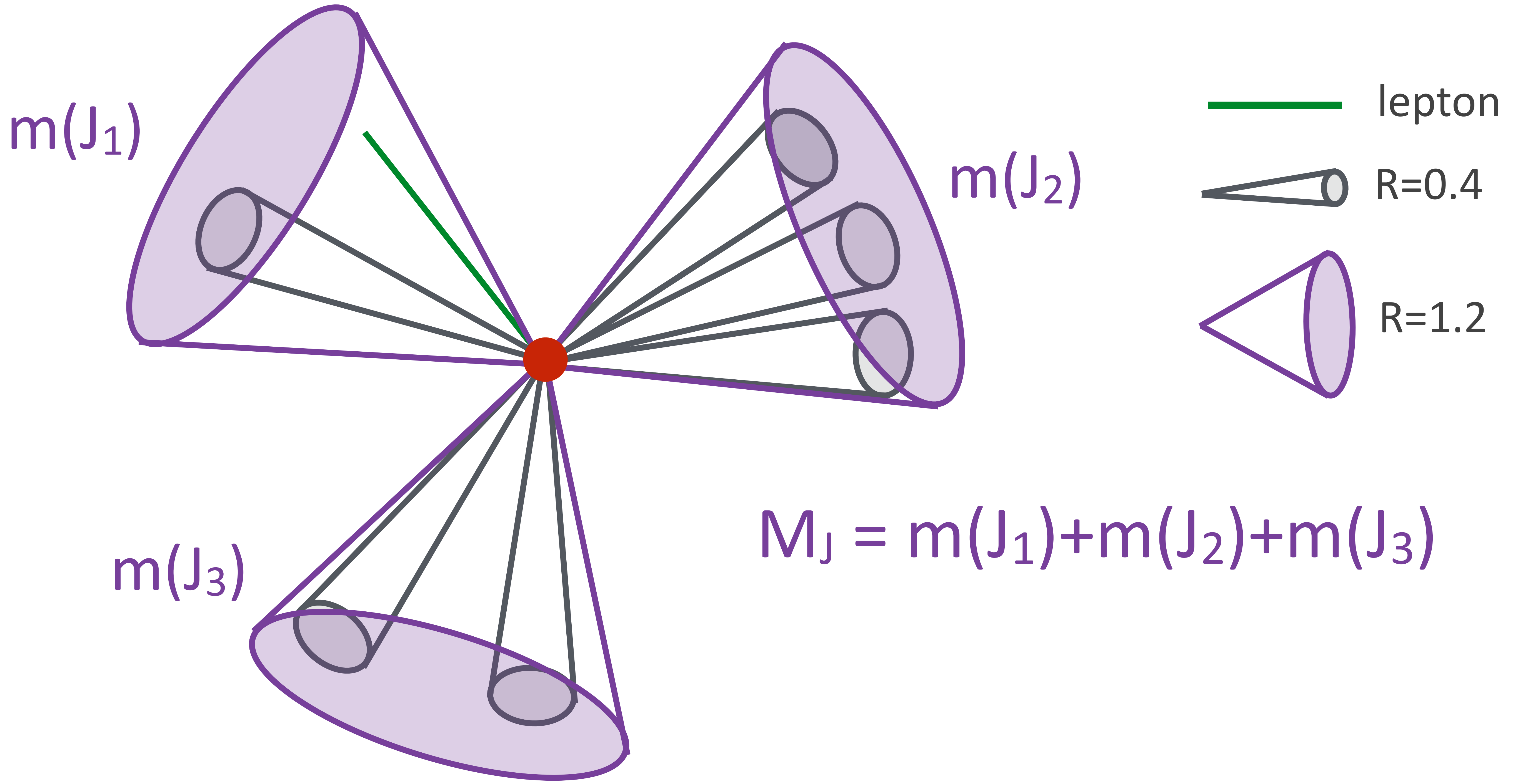

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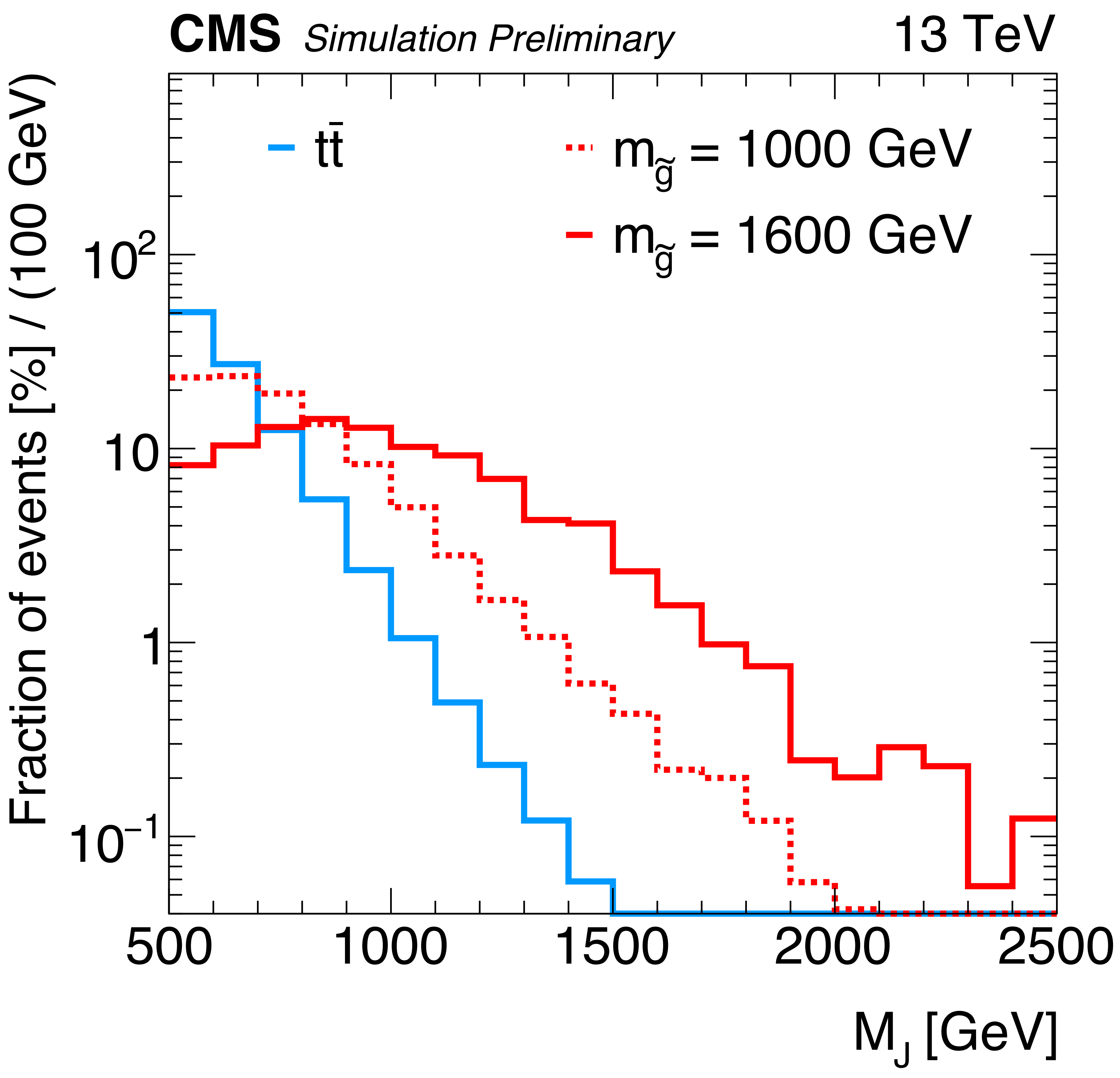

$$M_J = \sum_{J_i \in \text{large-}R \text{ jets}} m(J_i)$$

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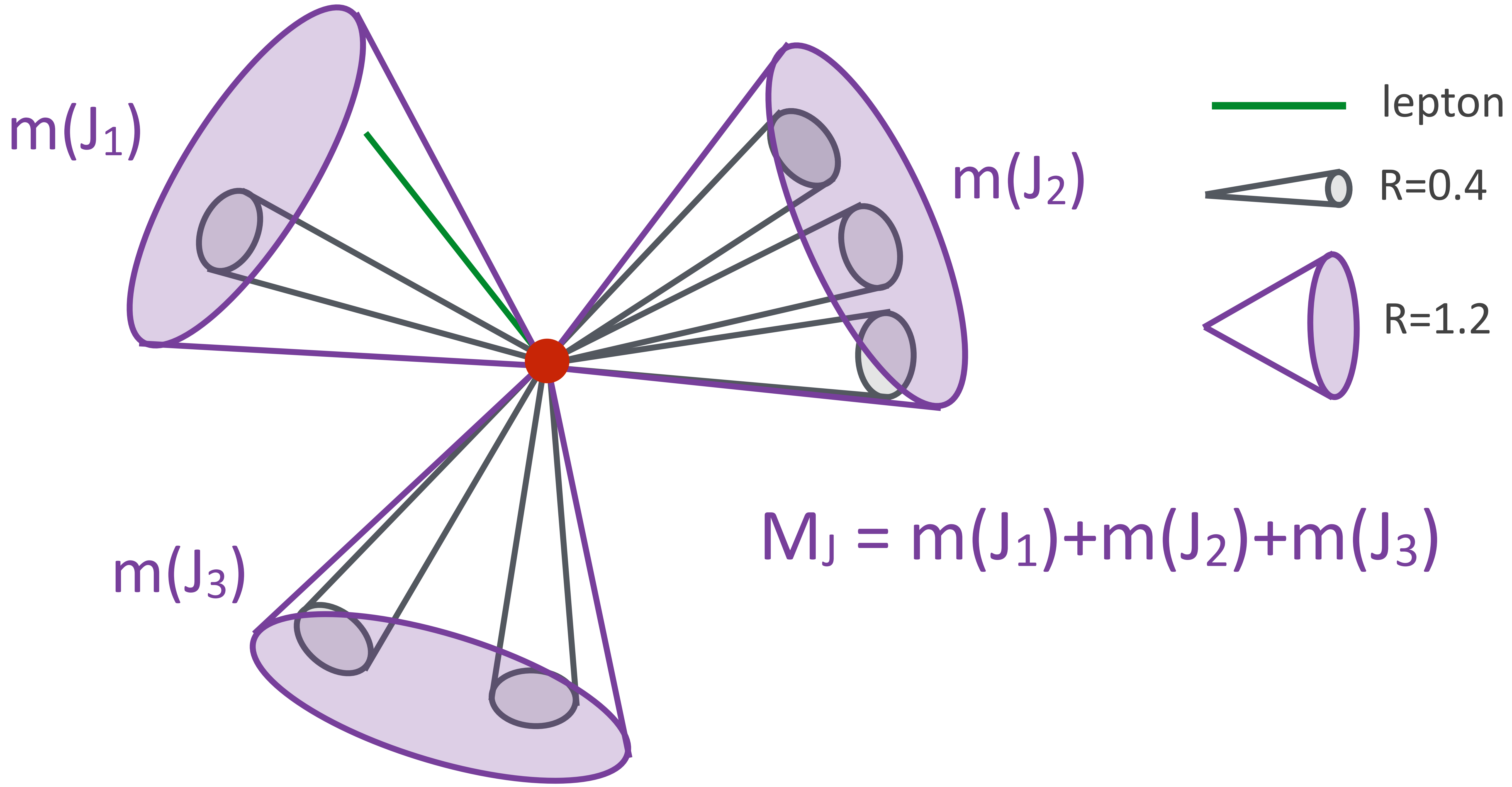

$M_J = m(J_1)+m(J_2)+m(J_3)$

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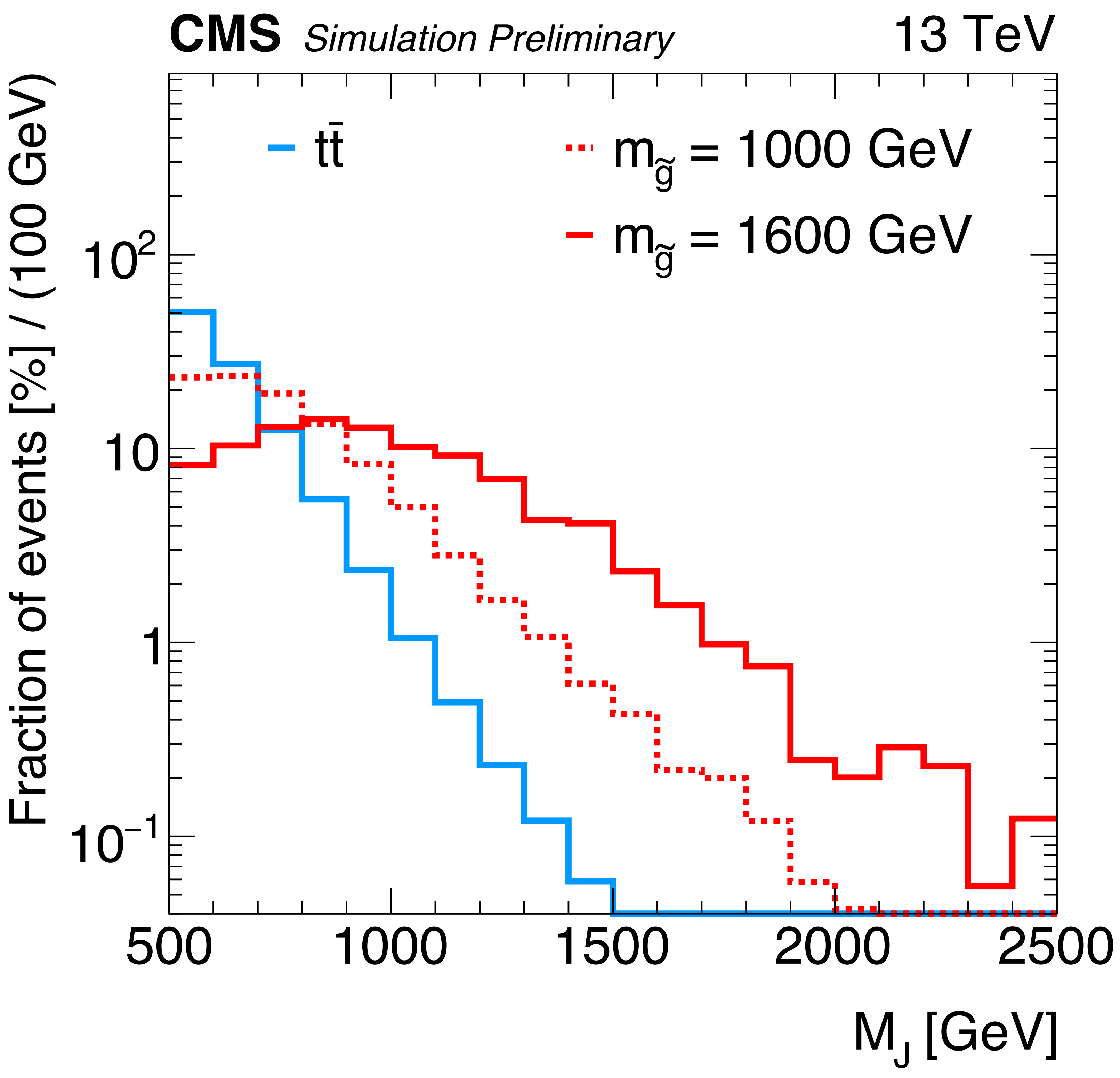

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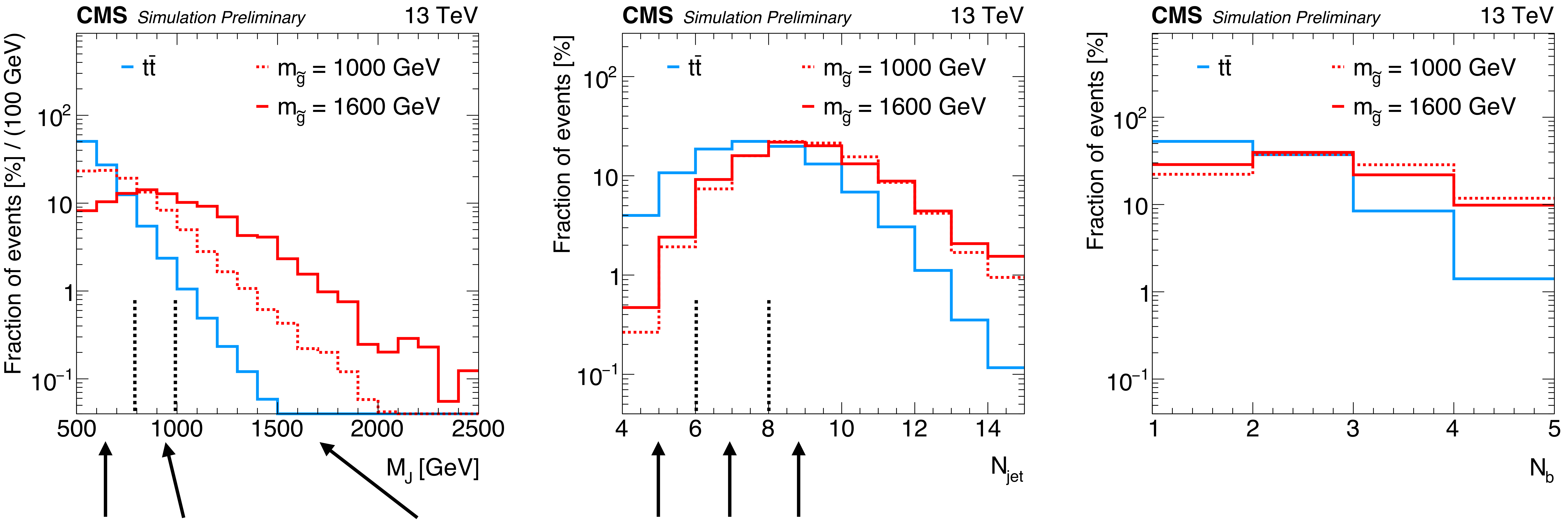

Make bins of (N_{jet}, M_J) and use N_b distribution in each bin

* Baseline selection: N_{lep}=1, H_T>1200 GeV, M_J>500 GeV, N_{jet}≥4 and N_b≥1

Analysis regions

N_{jet} / M_J	4-5	6-7	≥8
500-800 GeV			
800-1000 GeV			
>1000 GeV			

3 N_{jet} and 3 M_J bins with two high M_J bins merged for N_{jet}=4-5 due to limited size of data sample in the M_J>1000 GeV bin

Analysis regions

<table>
<tr><th>N_{jet} / M_J</th><th>4-5</th><th>6-7</th><th>≥8</th></tr>
<tr><td>500-800 GeV</td><td>CR</td><td>CR</td><td>SR</td></tr>
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<tr><td>>1000 GeV</td><td>SR</td><td>SR
most sensitive</td></tr>
</table>

Low N_{jet}, low M_J region used to validate the analysis procedure

Sensitivity driven by N_{jet}≥8 and M_J>1000 GeV bin

Analysis regions

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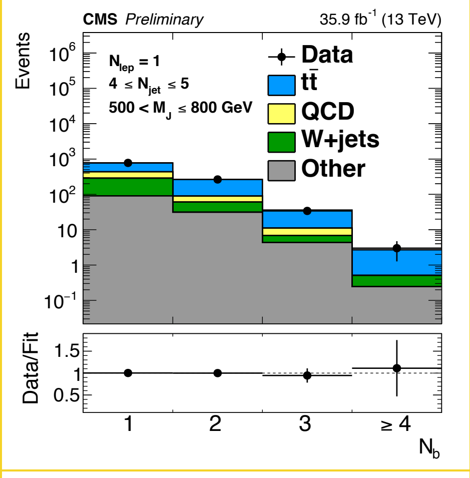
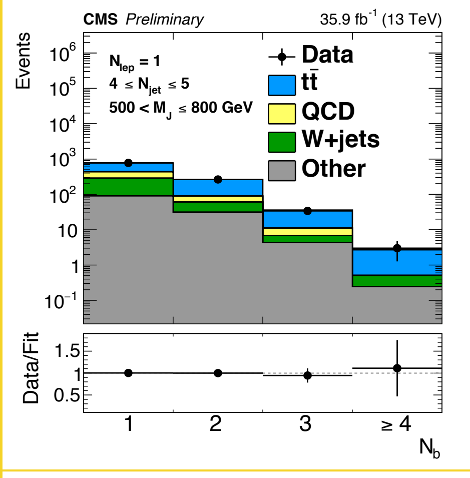
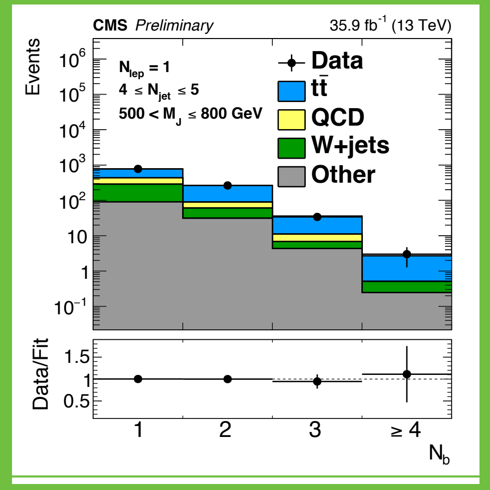
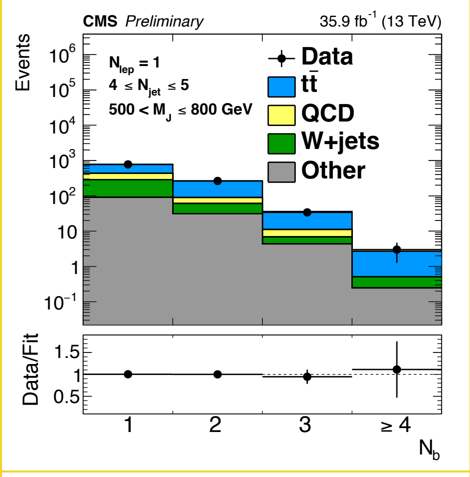
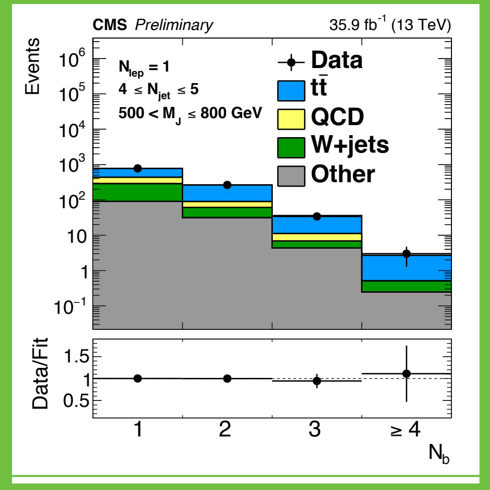
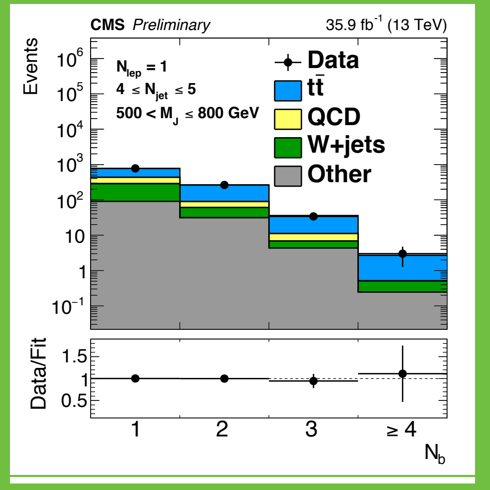
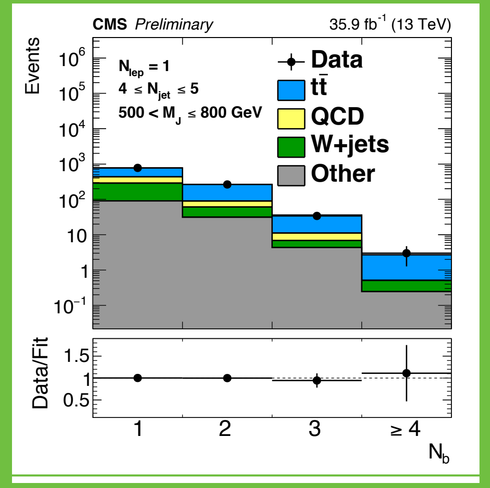
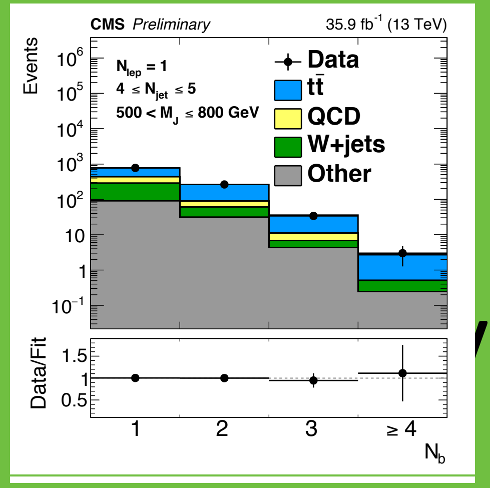
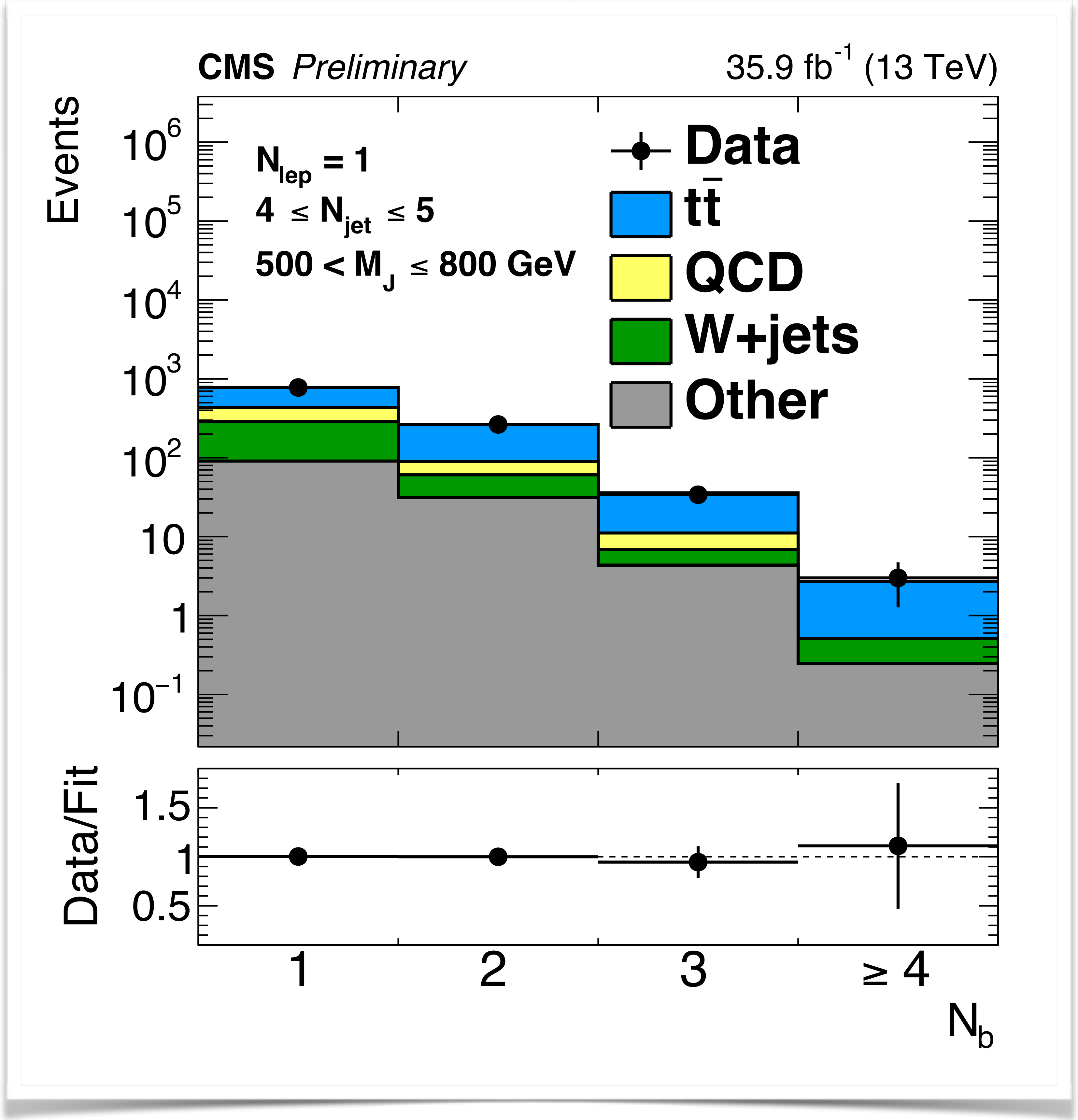
500-800 GeV			
800-1000 GeV			
>1000 GeV			

Fit N_b distributions simultaneously across (N_{jet},M_J) bins

Low N_{jet}, low M_J region constrain systematic uncertainties

How the fit works

- N_b shapes for each process taken from simulation, but varied to assess potential mis-modeling
- Appropriate range measured in dedicated control samples



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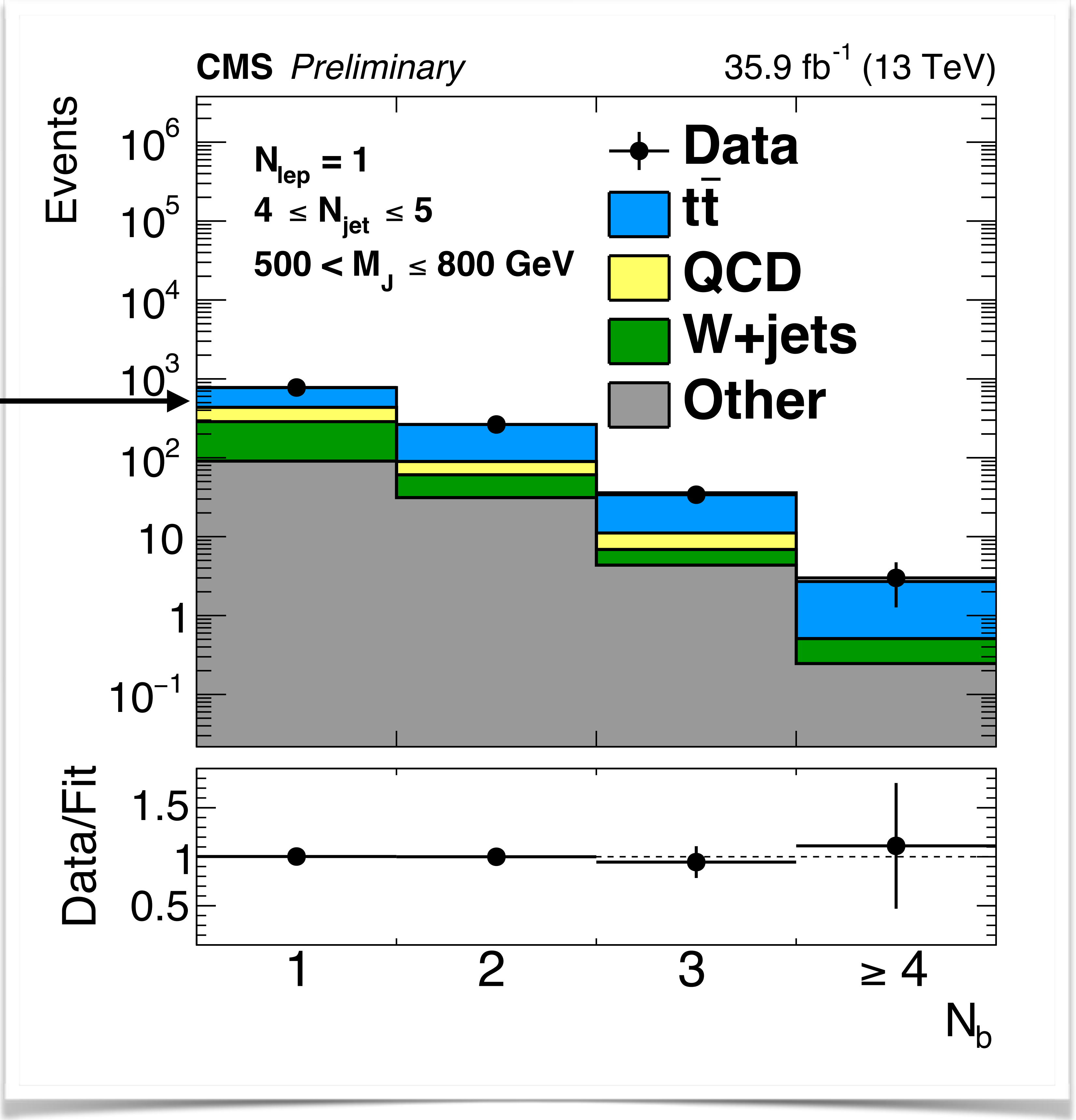

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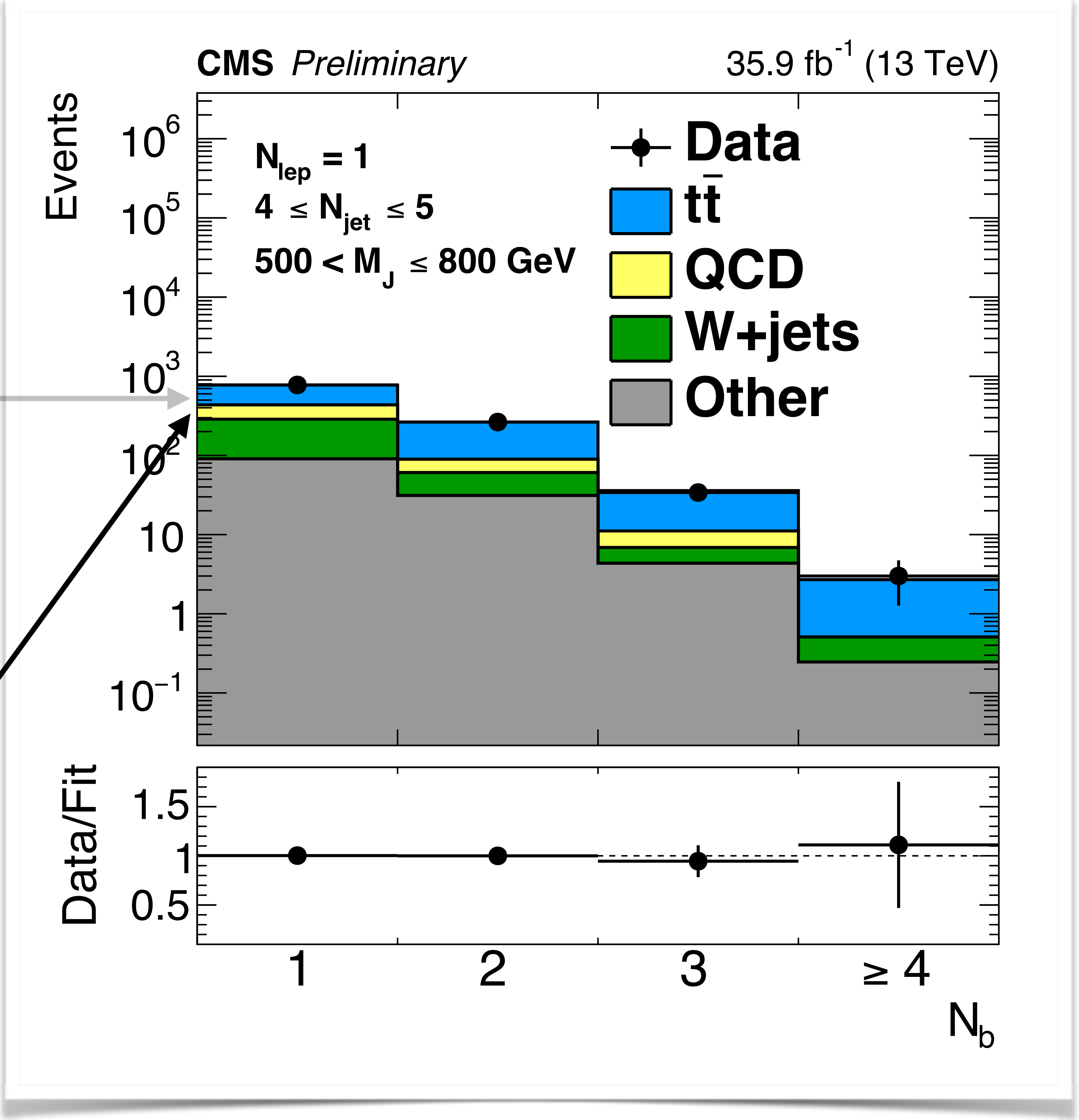
- 0-lepton region included in the simultaneous fit



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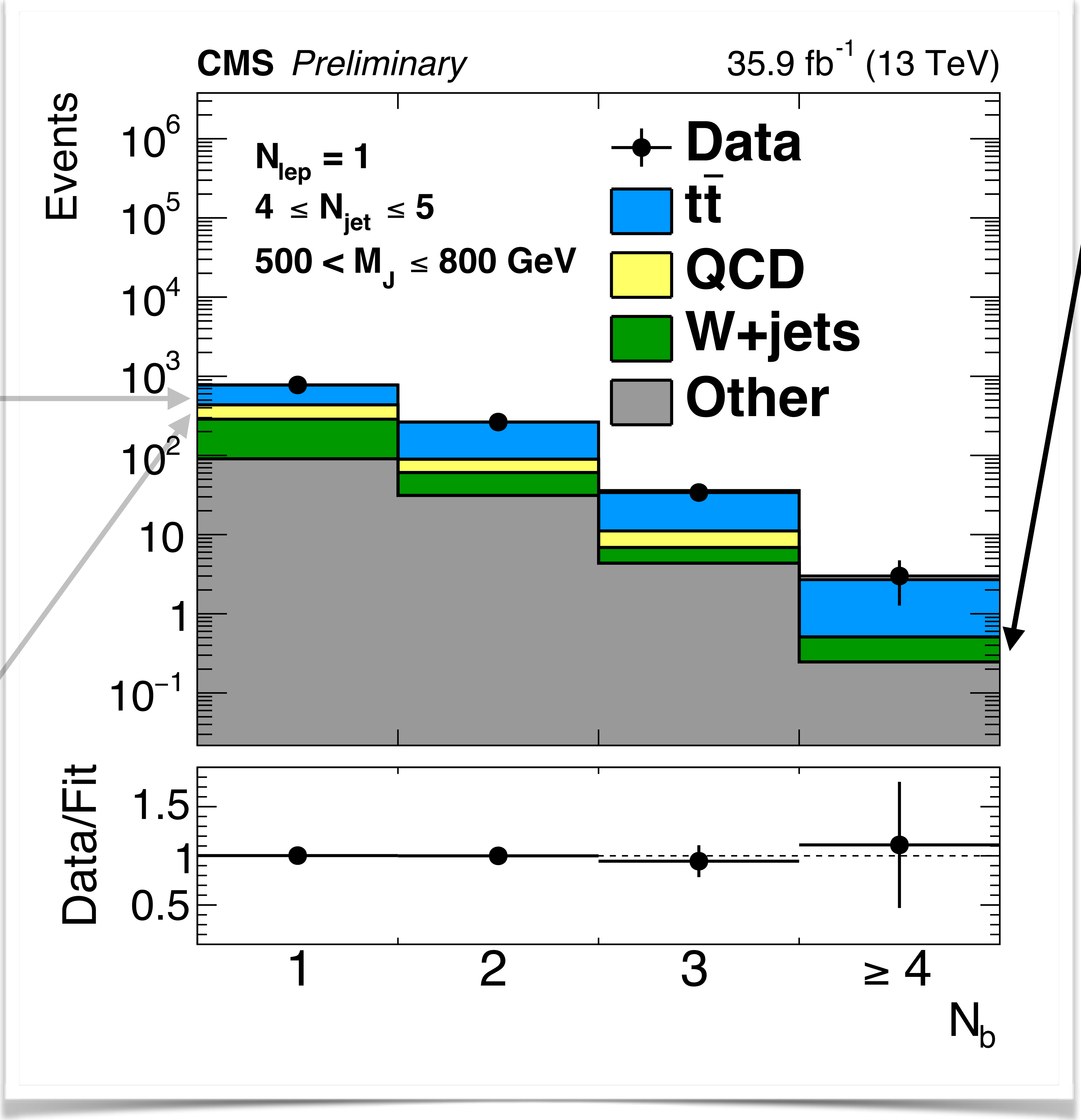
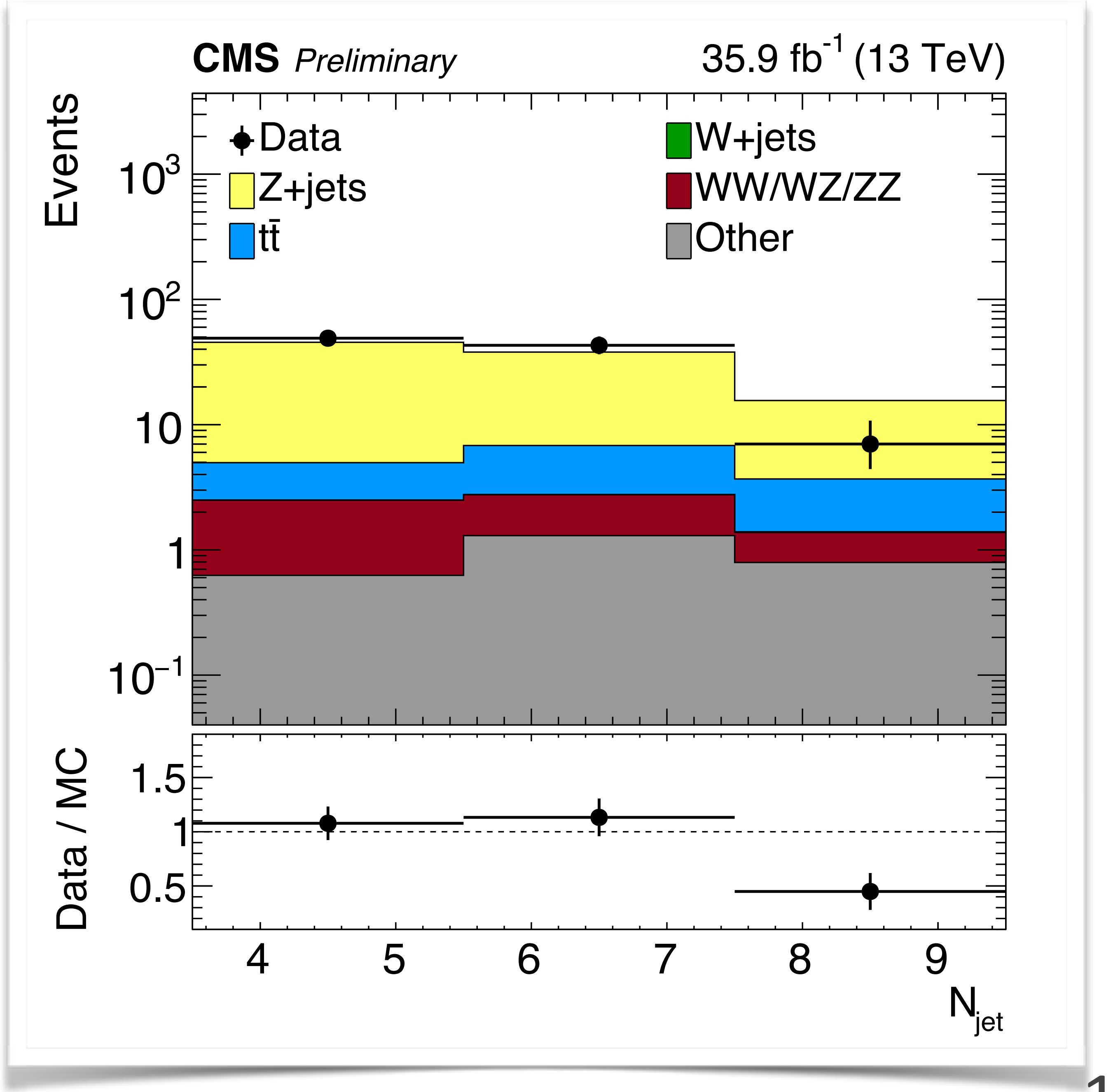


- W+jets normalization determined by a global normalization parameter largely constrained by low N_{jet} bins
- Relative normalizations between N_{jet} bins allowed to change based on the constraints measured in Drell-Yan sample



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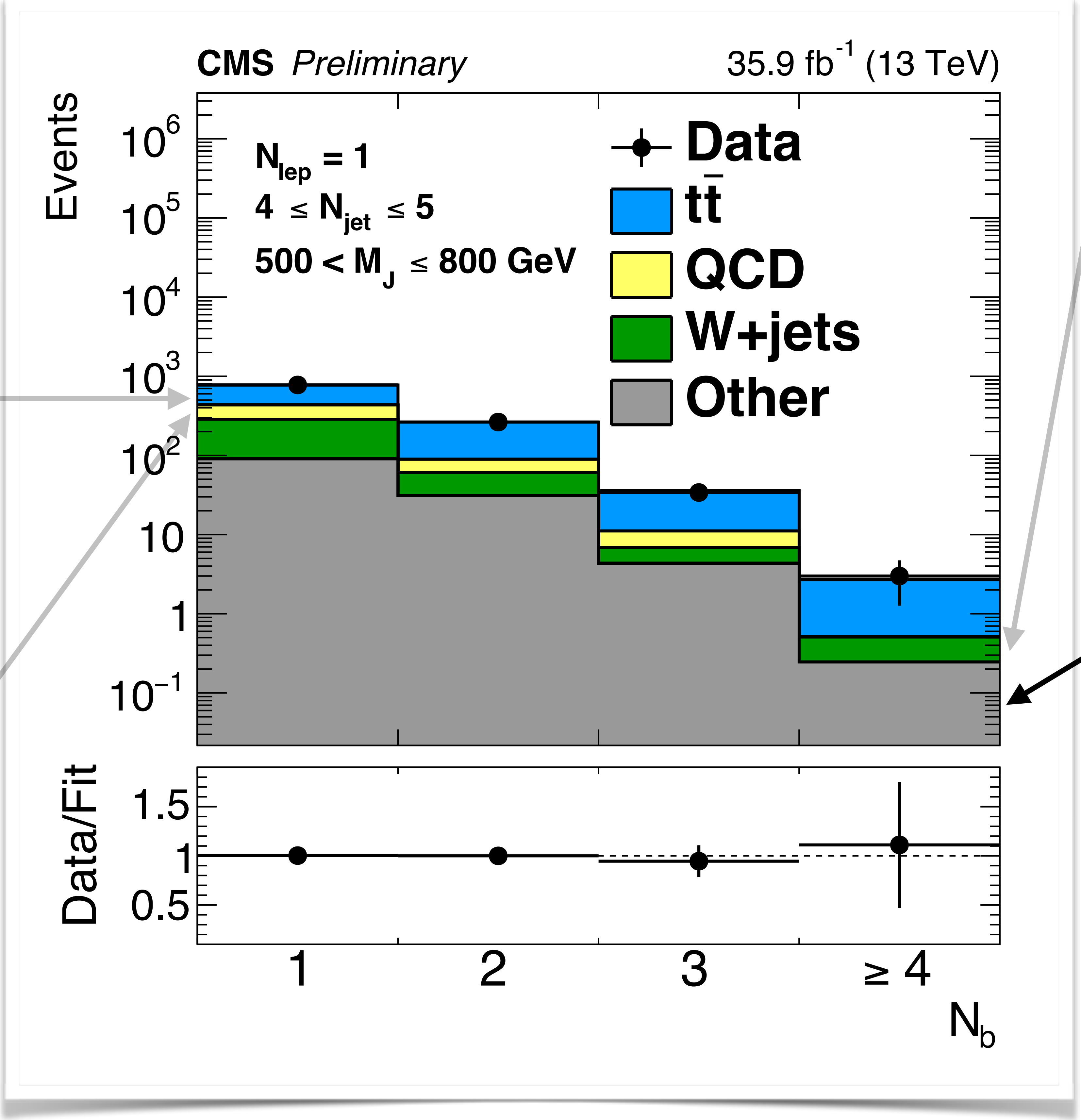

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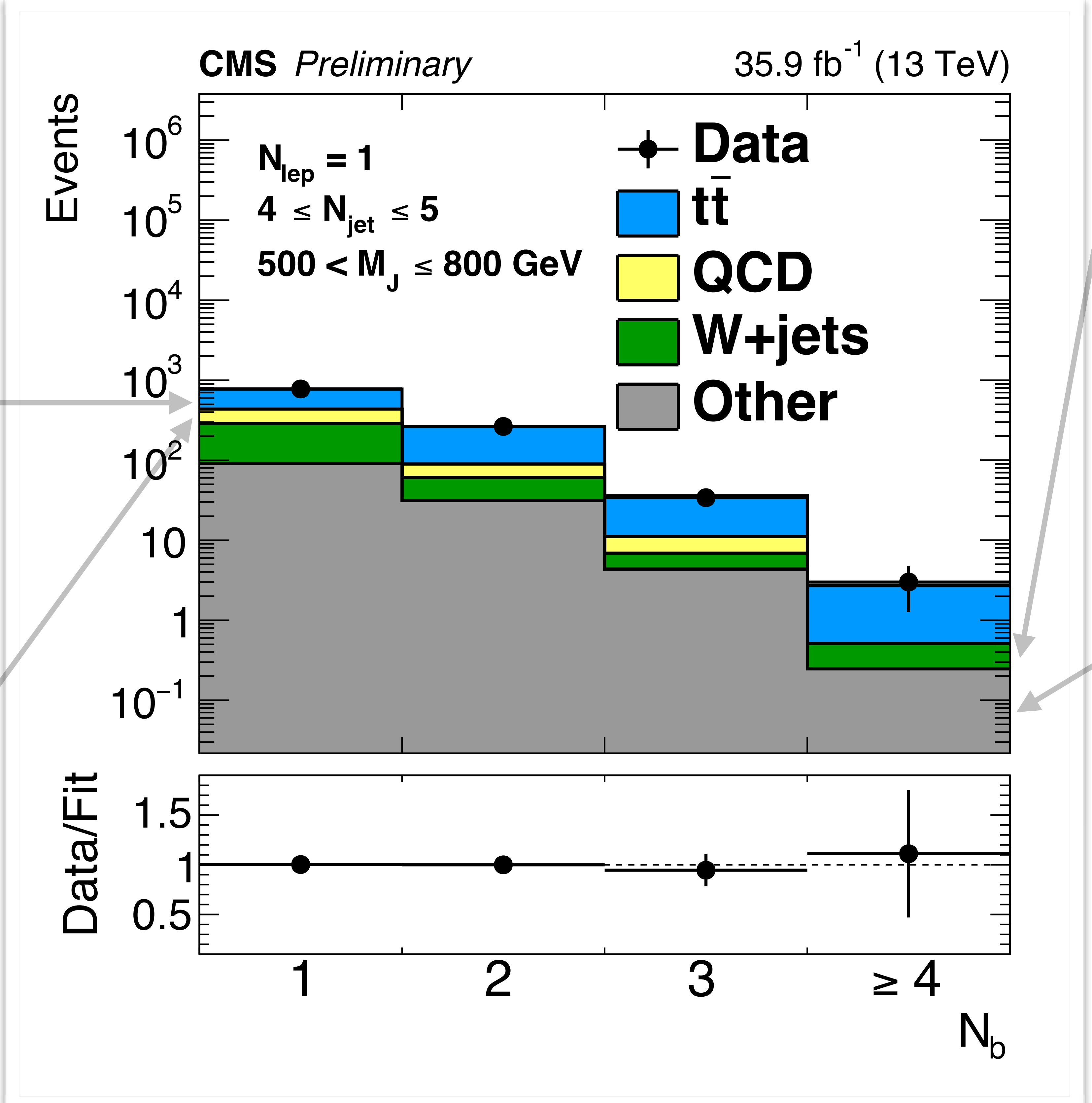

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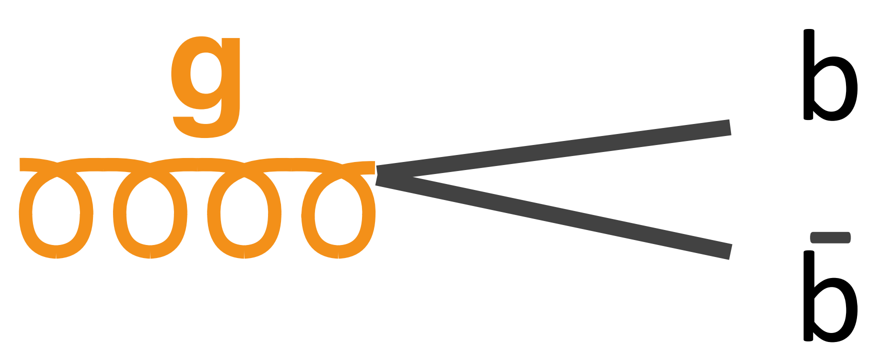
Challenge:
to understand potential mis-modeling of N_b shape

Modeling of gluon splitting

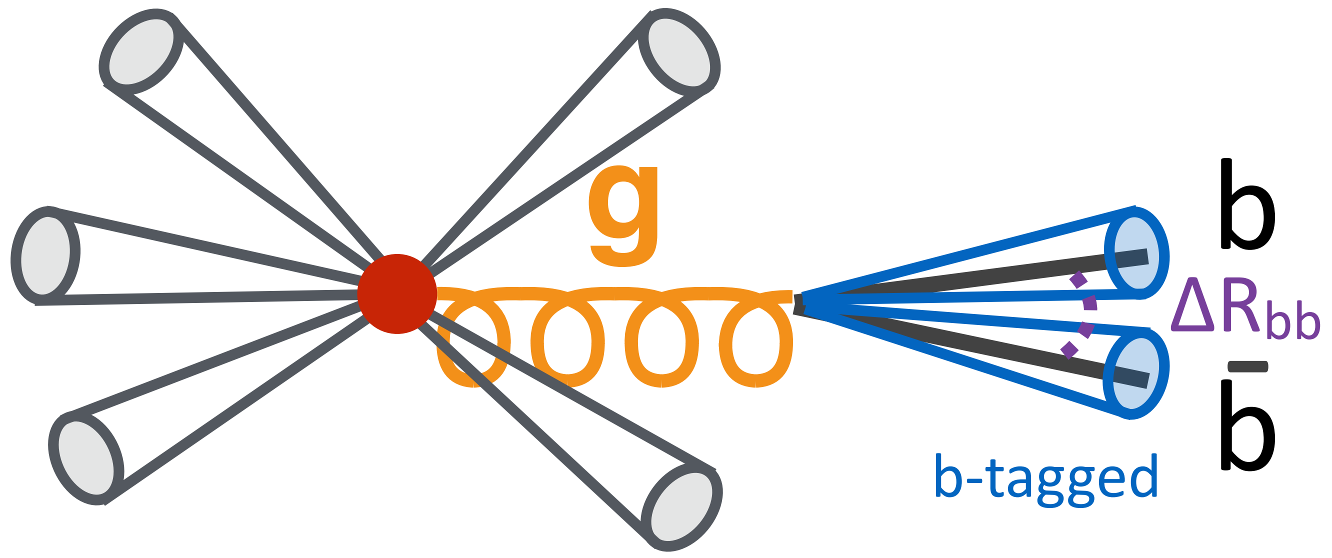
GS



- Dominant background systematic uncertainty: modeling of gluon splitting (GS)
  - GS can produce additional b quarks, for example, $t\bar{t}+b\bar{b}$
- Sample
  - N_{lep}=0, H_T>1500 GeV, N_b=2, N_{jet}≥4, M_J>500 GeV
- Use ΔR_{bb} as a proxy of GS
  - ΔR_{bb}: ΔR between two b-tagged jets

Modeling of gluon splitting

GSbb



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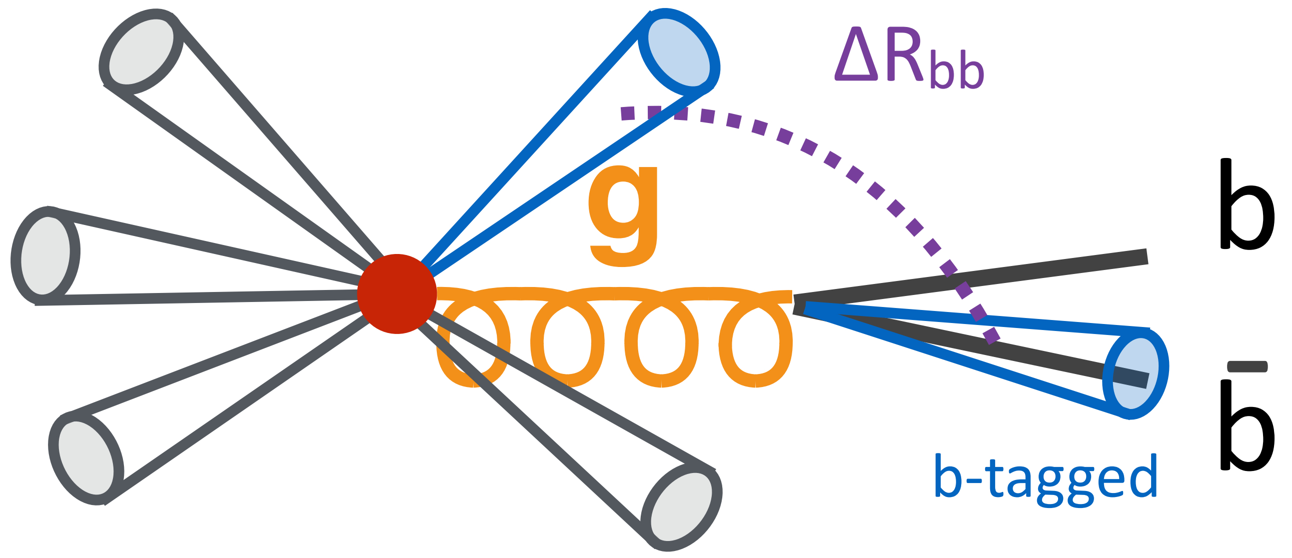
Modeling of gluon splitting

GSb



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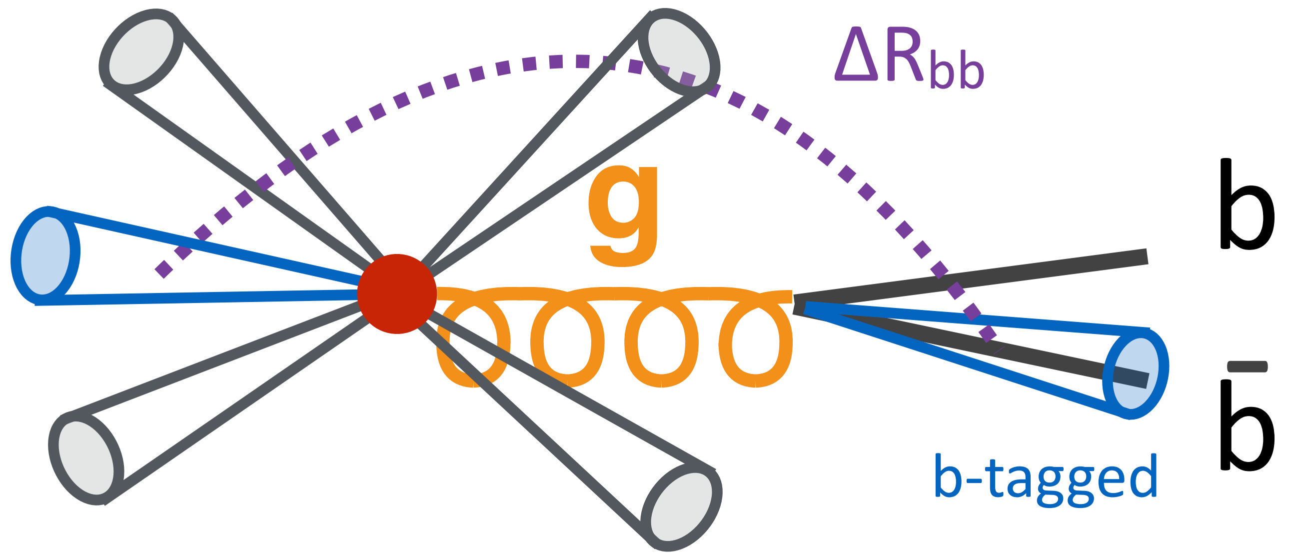

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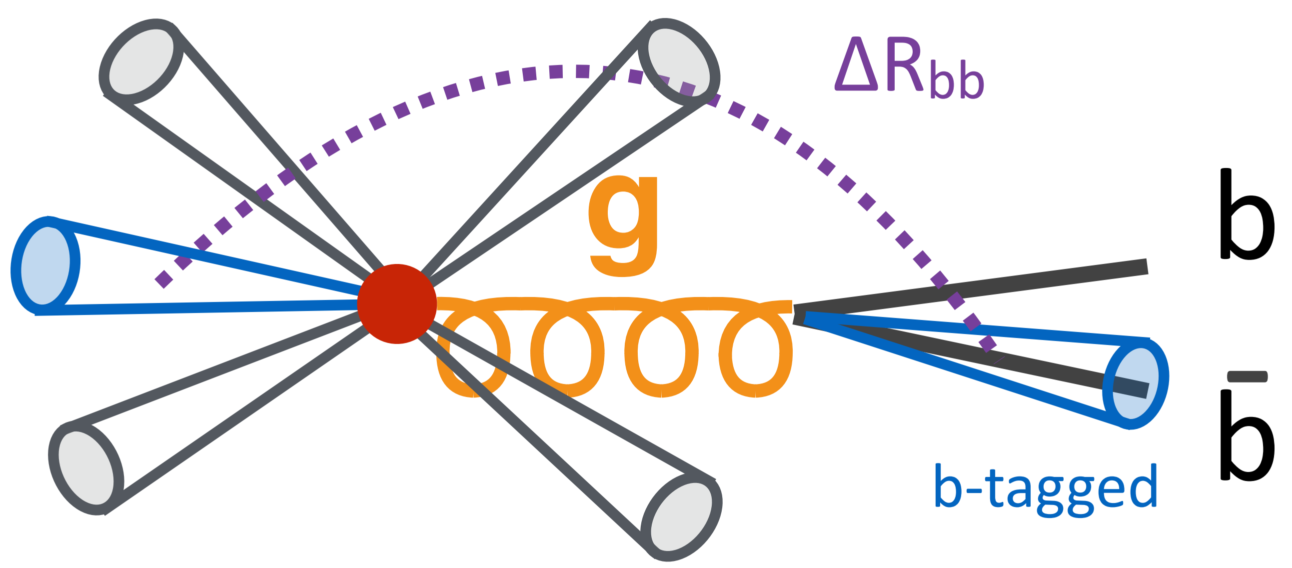
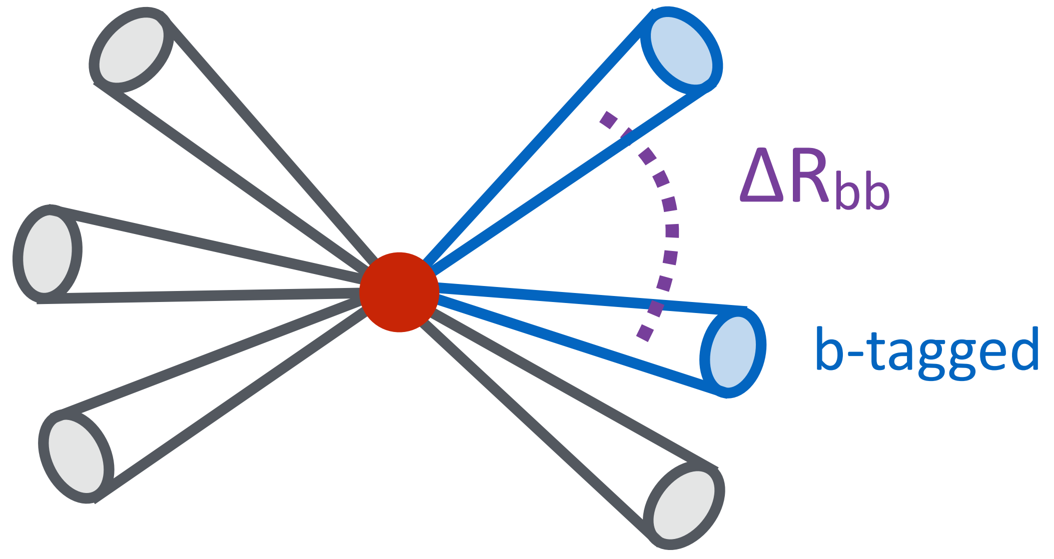


no GS



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Modeling of gluon splitting

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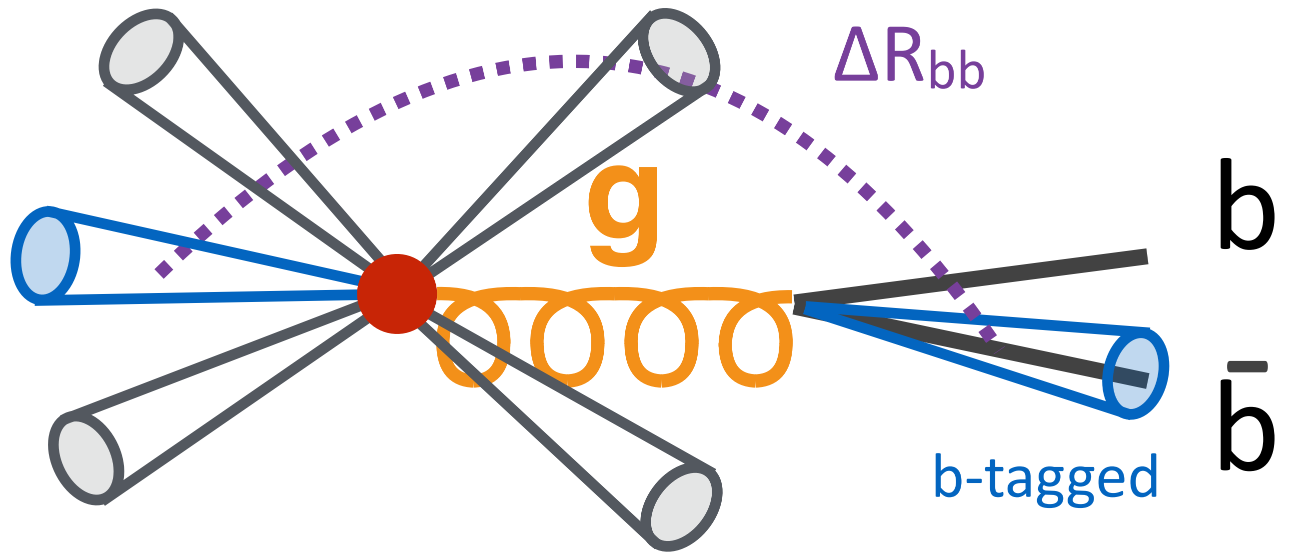

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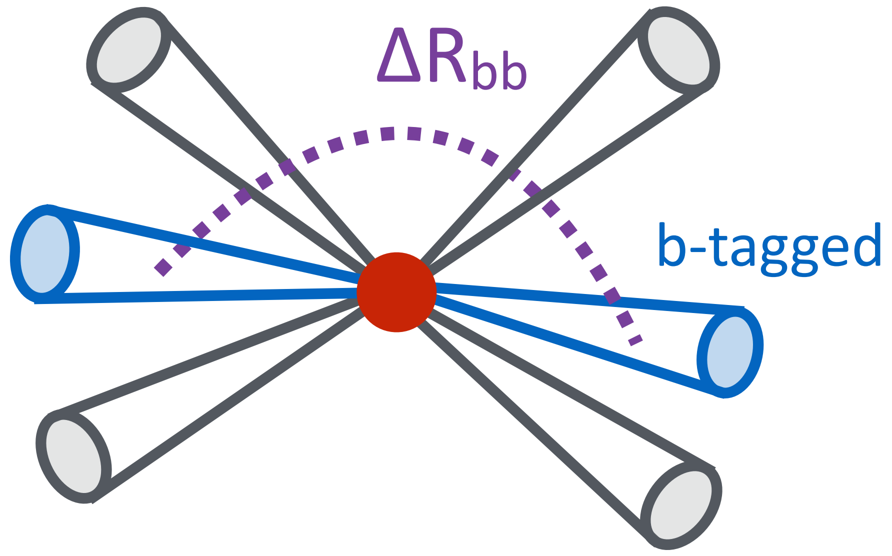

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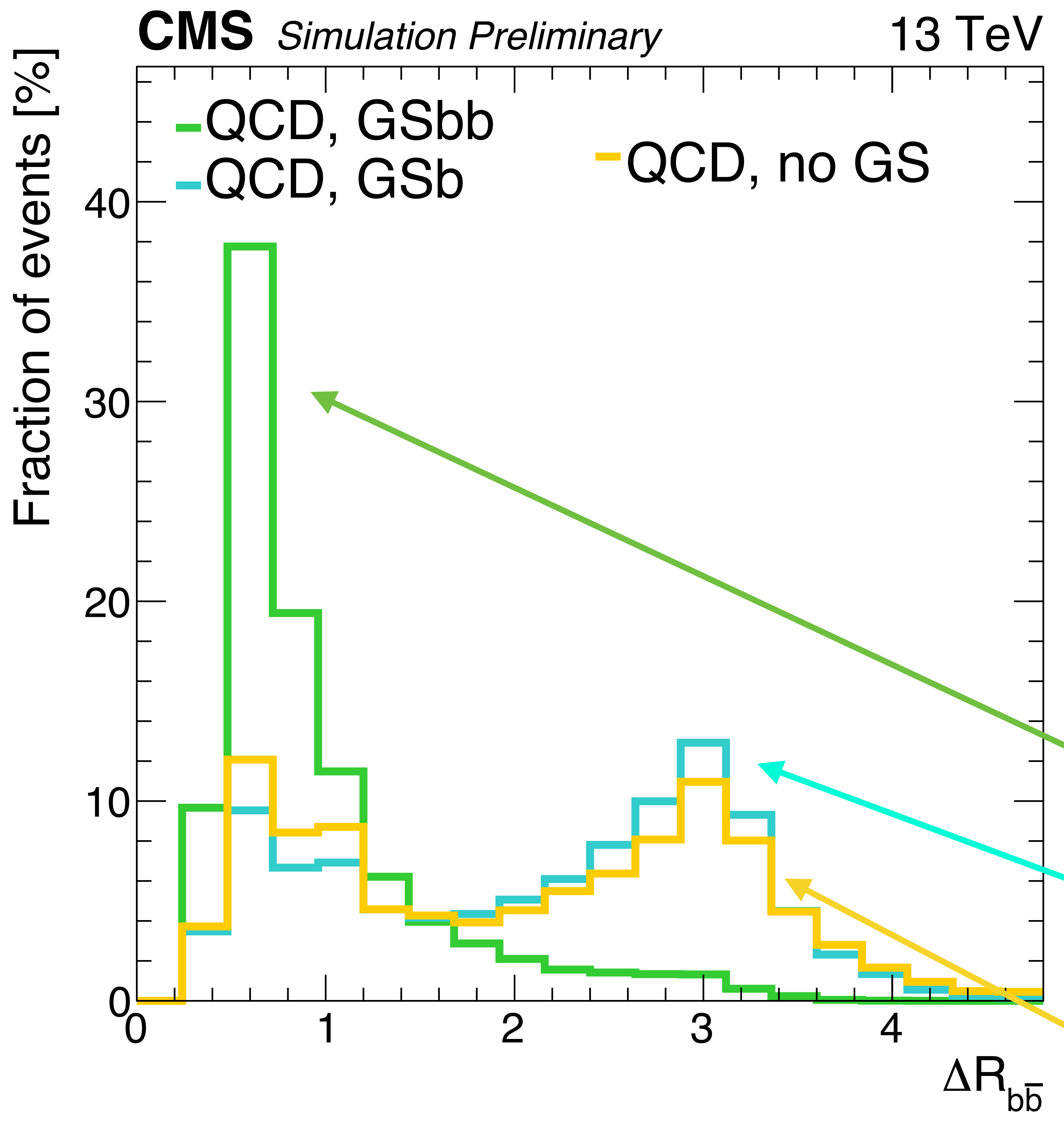

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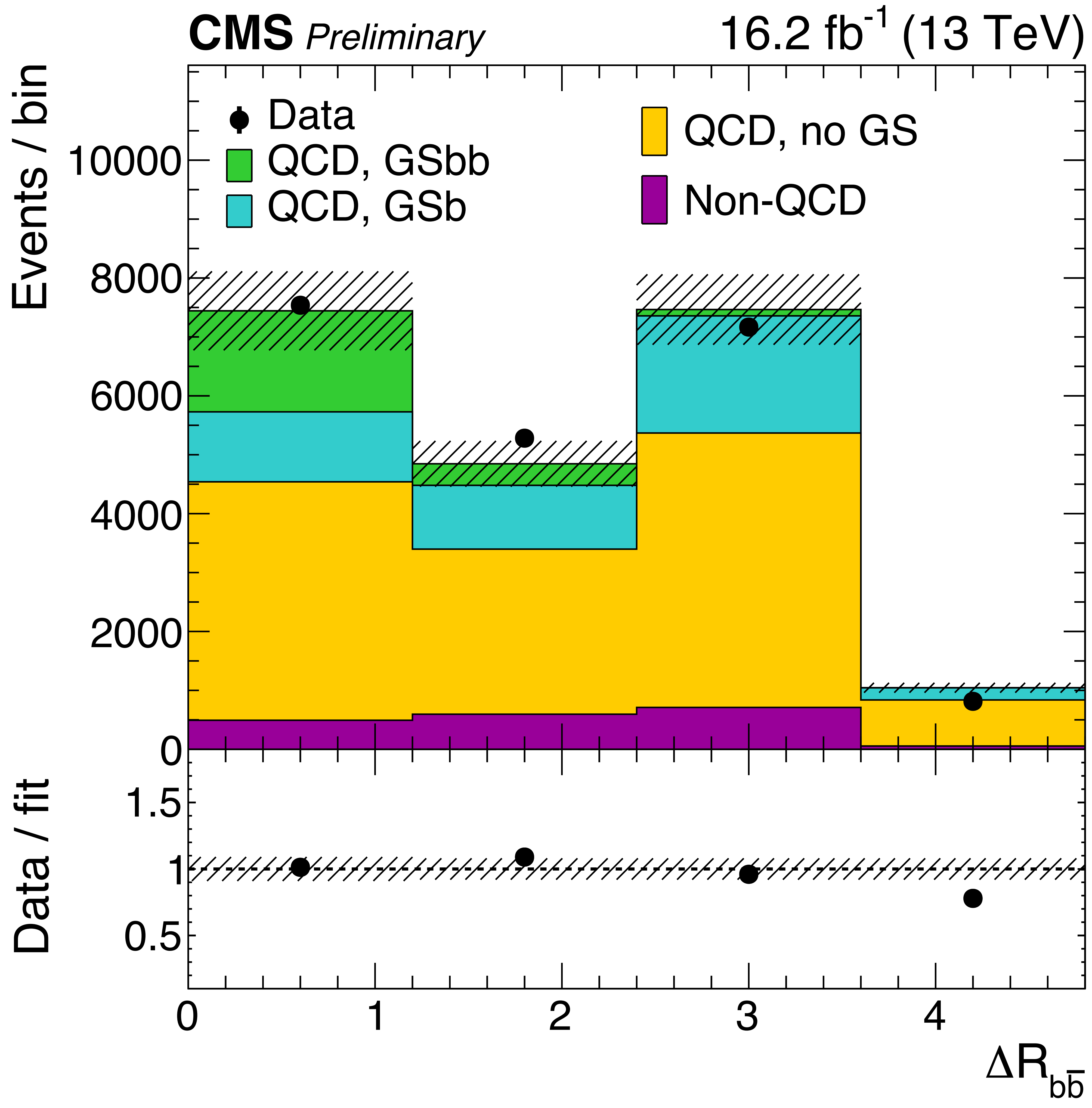
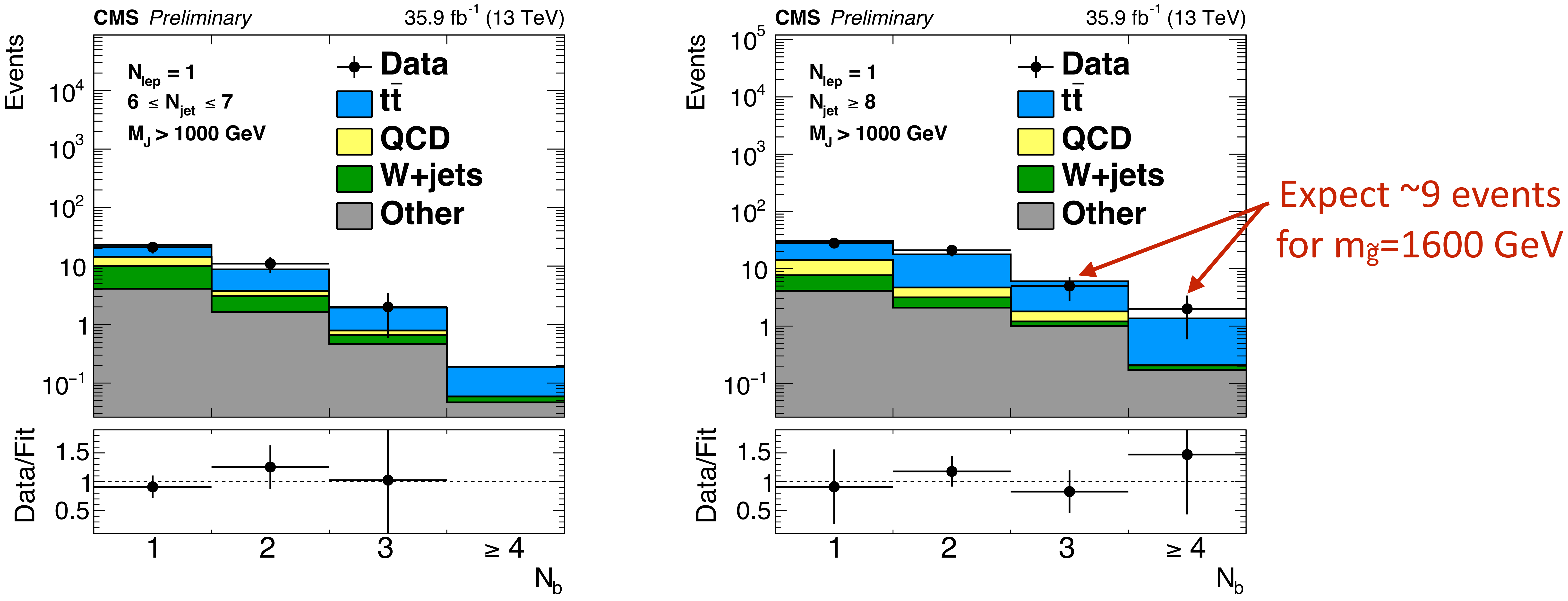


- Fit coarsely binned ΔR_{bb} distributions to get relative contributions of GS and no GS
  - Not rely on the details of ΔR_{bb} modeling
  - GSbb and GSb are combined in the fit because both are GS events
- Extracted weights
  - Fit extracted 25% less GS and 22% more non-GS components than simulation
  - Systematic uncertainty for GS modeling

Results: post-fit N_b distributions and exclusion limit

- Post-fit N_b distributions in two most sensitive bins
  - M_J>1000 GeV, N_{jet}=6-7 (left) and ≥8 (right)



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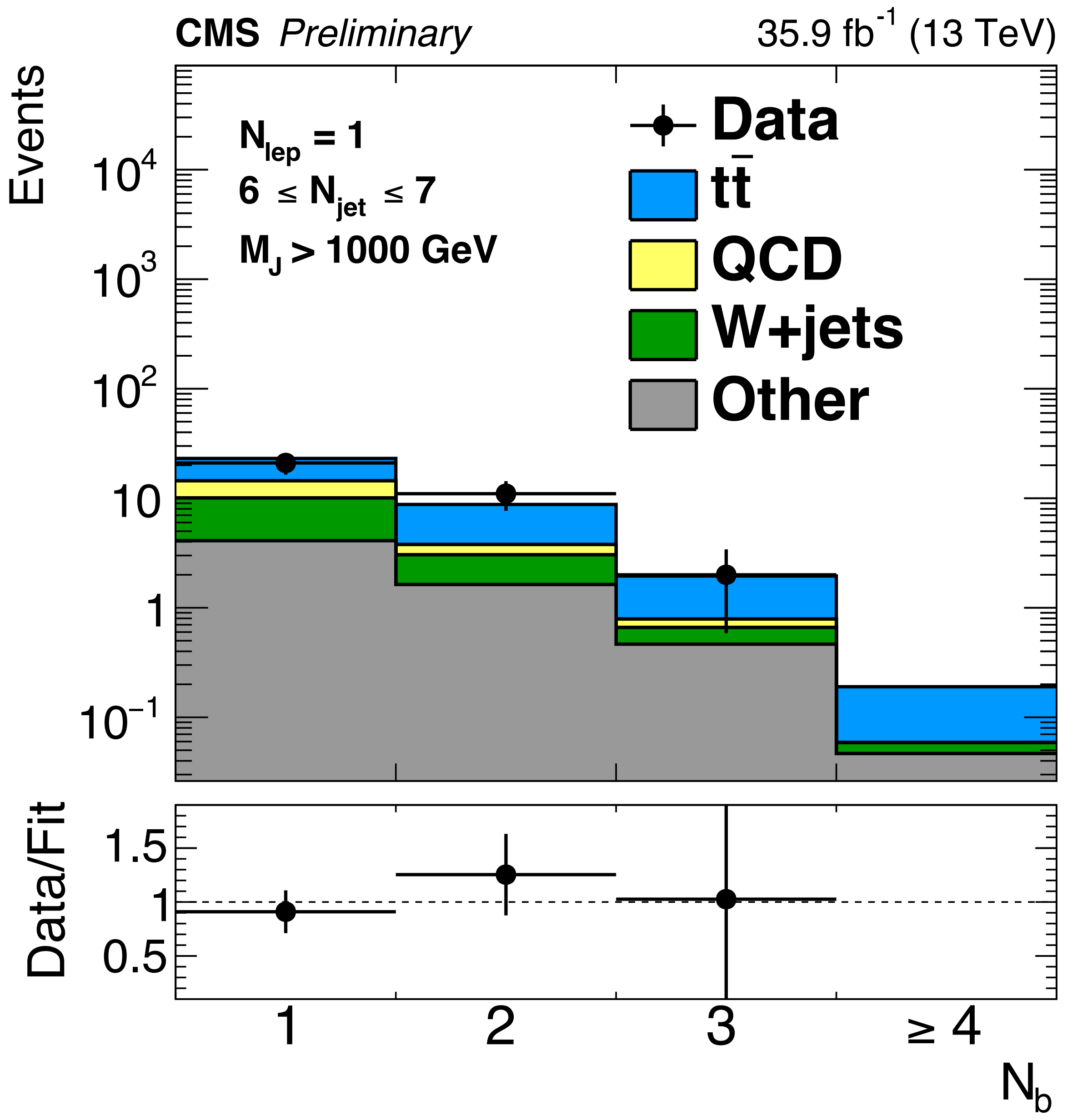

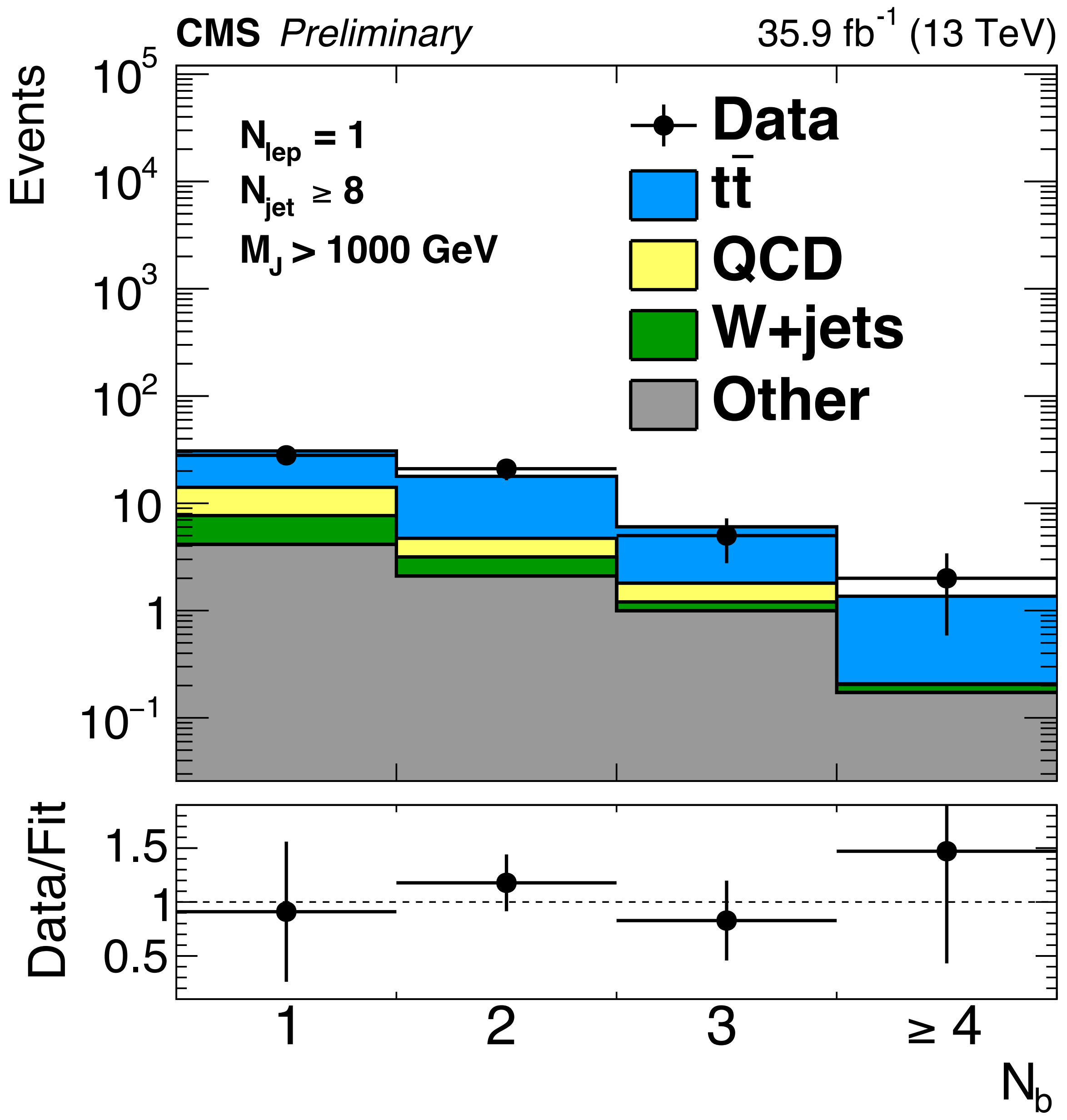

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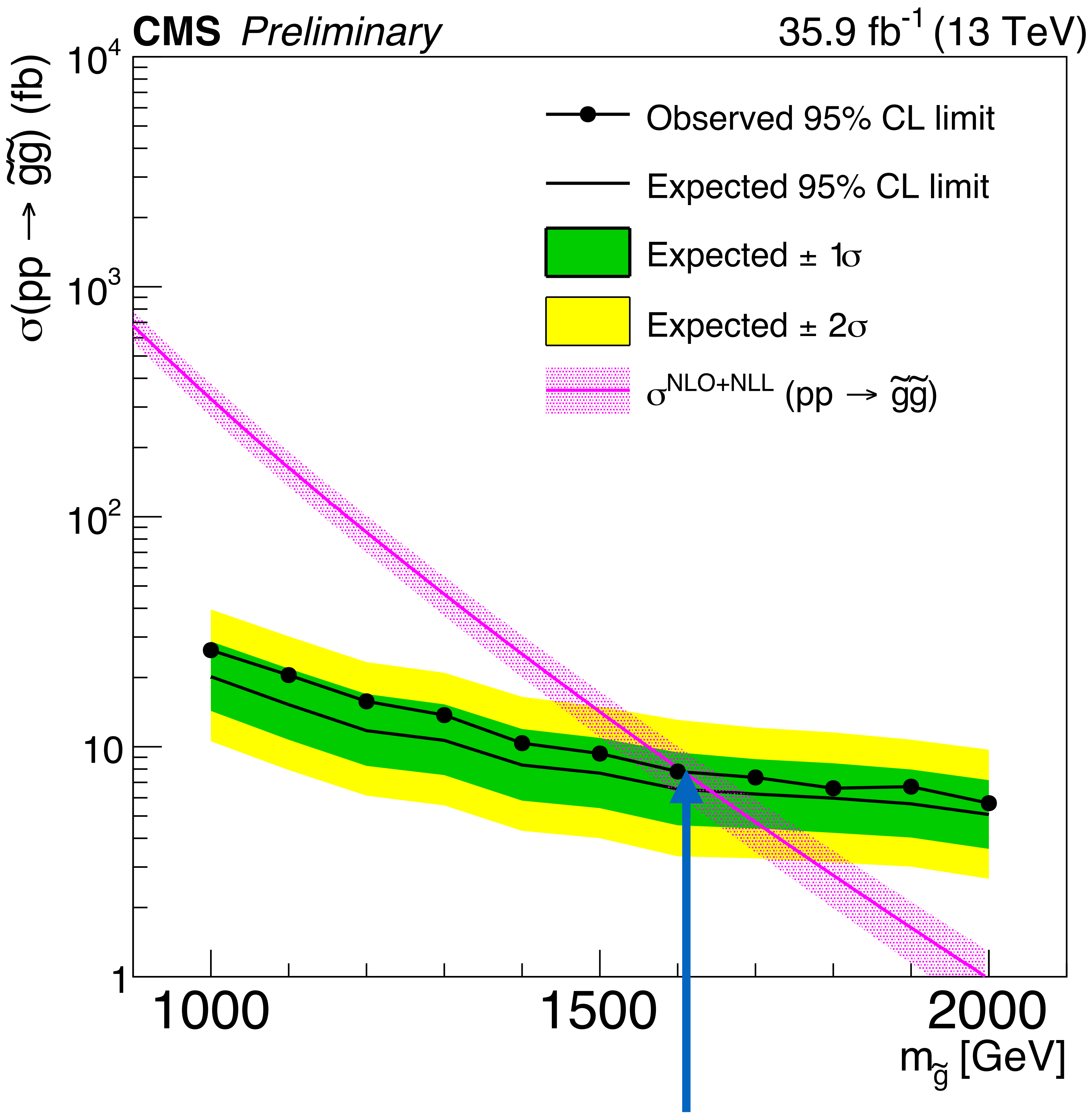


Excluded $m_{\tilde{g}}$ up to 1610 GeV

~250 GeV stretch wrt previous CMS preliminary result (CMS-PAS-SUS-16-013)

Summary

- RPV SUSY can evade the constraints from RPC SUSY searches by allowing LSP to decay to SM particles resulting in signatures without MET
- CMS performed a search in the single-lepton final state targeting gluino pair production where gluino decays to tbs
- No significant excess was observed and set **the limit of 1610 GeV** at 95% CL for gluino mass in this scenario

backup

0-lepton region used to constrain QCD in 1-lepton region

1-lepton

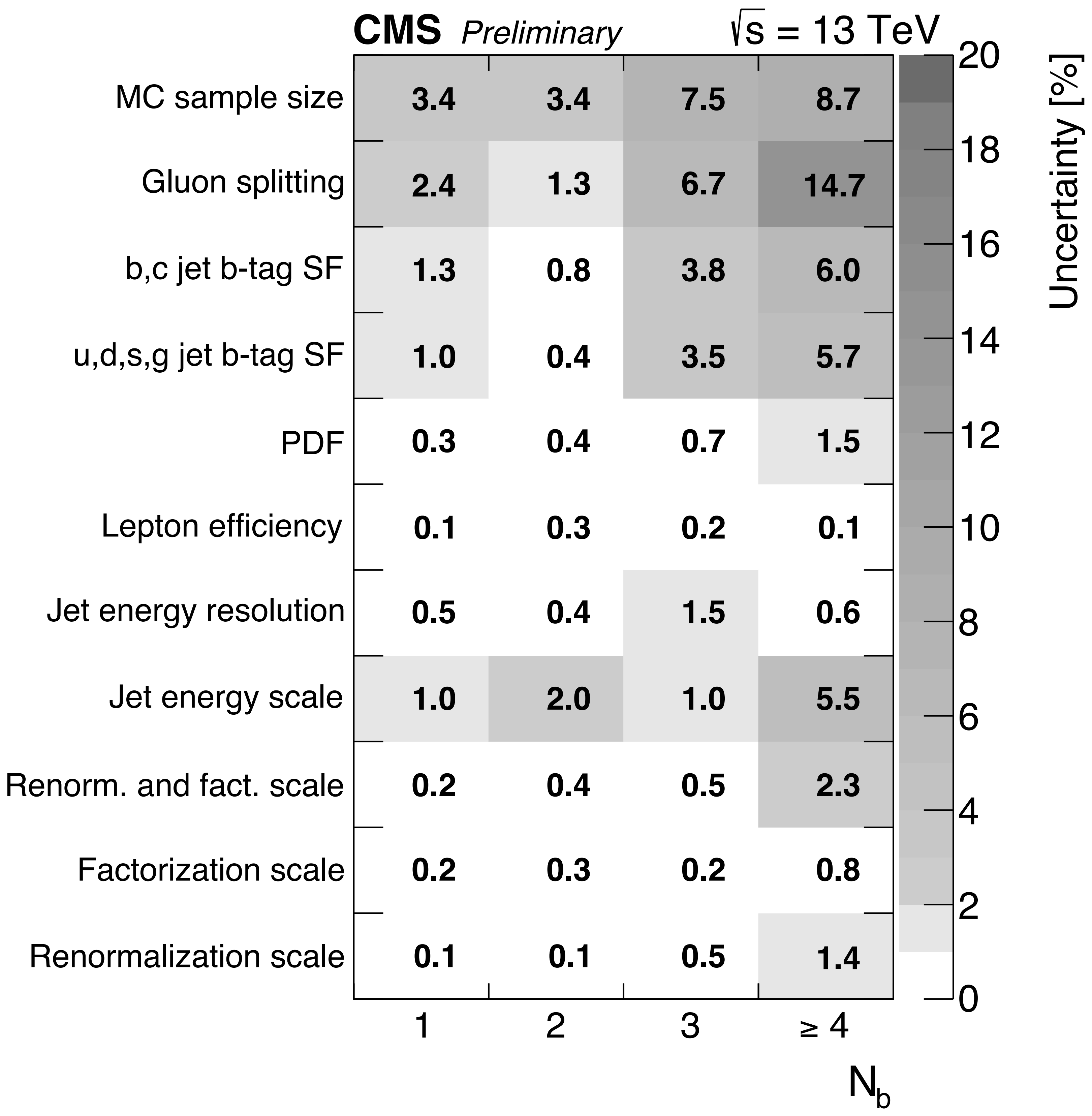
M_J \ N_{jet}	4-5	6-7	>=8
500-800 GeV	CR	CR	SR
800-1000 GeV	CR	SR	SR
>1000 GeV		SR	SR most sensitive

0-lepton

M_J \ N_{jet}	6-7	8-9	>=10
500-800 GeV	CR	CR	SR
800-1000 GeV	CR	SR	SR
>1000 GeV		SR	SR most sensitive

Only normalization is used: N_b shape is not used

Systematic uncertainties



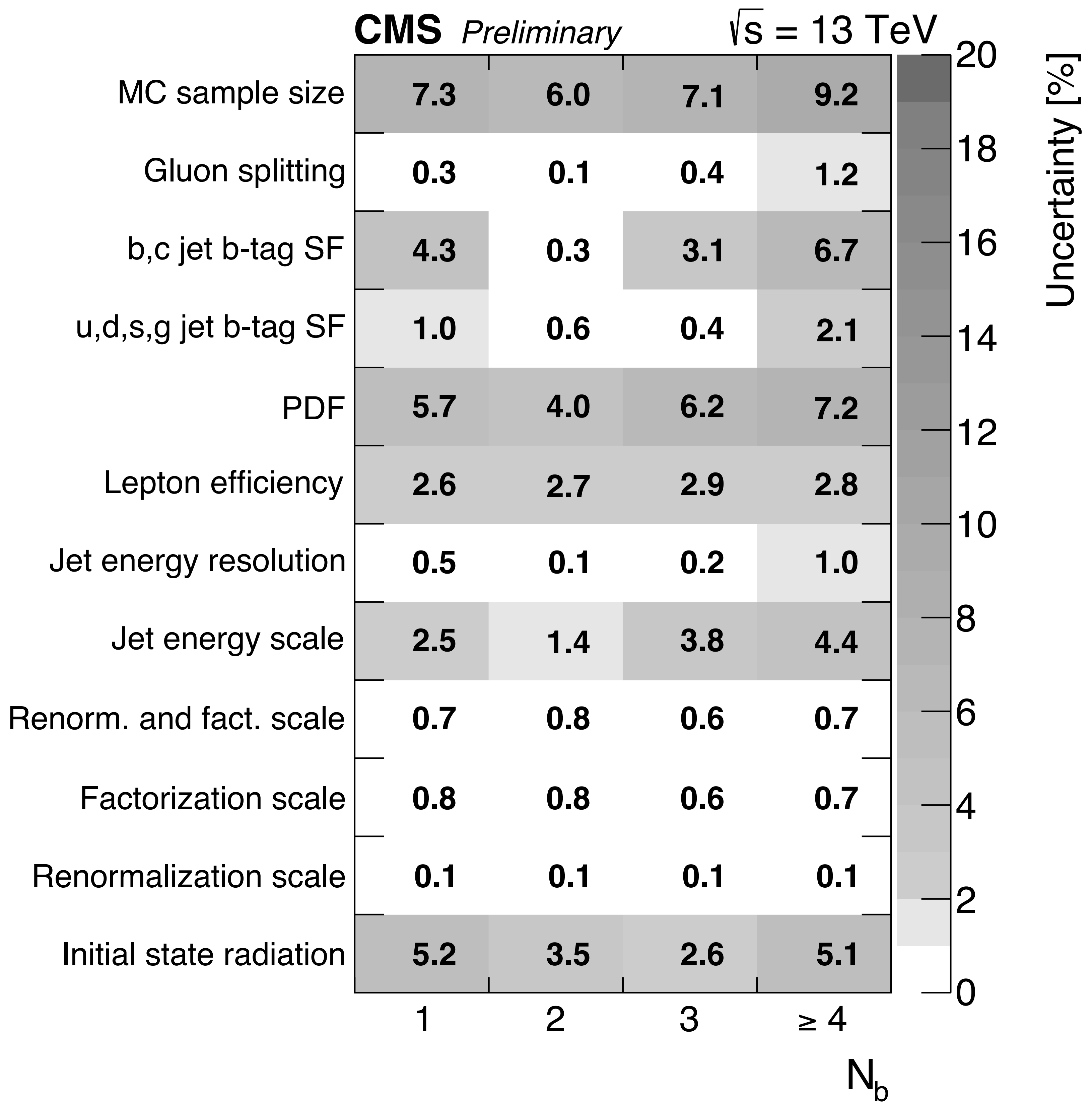


Figure 3: Background (left) and $m_{\tilde{g}} = 1600\,\text{GeV}$ signal (right) systematic uncertainties on the $N_{\text{jet}} \geq 8$ and $M_J \geq 1000\,\text{GeV}$ bin. SF in the label means scale factor.

Post-fit yields

Table 1: Table of the post-fit yields for the background-only fit, observed data, and expected yields for $m_{\tilde{g}} = 1600$ GeV in each search bin.

N_b	QCD	$t\bar{t}$	W+jets	Other	All bkg.	Data	Expected $m_{\tilde{g}} = 1600$ GeV
$4 \leq N_{jet} \leq 5,\ 500 < M_J < 800$ GeV							
1	148	340	196	91	775 ± 43	777	0.50 ± 0.13
2	29	175	30	31	264 ± 17	264	0.39 ± 0.11
3	4.3	24.8	2.5	4.4	36 ± 4	34	0.18 ± 0.08
≥ 4	0.0	2.2	0.3	0.2	2.7 ± 0.4	3	0.04 ± 0.04
$4 \leq N_{jet} \leq 5,\ M_J > 800$ GeV							
1	16.5	26.3	22.5	11.0	76 ± 6	77	0.32 ± 0.11
2	1.1	10.6	3.4	3.8	19 ± 2	18	0.40 ± 0.12
3	0.7	1.3	0.3	0.3	2.7 ± 0.5	3	0.13 ± 0.06
≥ 4	0.00	0.09	0.03	0.01	0.13 ± 0.03	0	0.03 ± 0.03
$6 \leq N_{jet} \leq 7,\ 500 < M_J < 800$ GeV							
1	197	620	169	120	1106 ± 48	1105	2.5 ± 0.3
2	49	440	36	66	591 ± 21	588	3.1 ± 0.3
3	6.4	89.2	4.6	13.4	114 ± 8	112	1.4 ± 0.2
≥ 4	1.9	11.4	0.6	2.1	16 ± 2	21	0.25 ± 0.09
$N_{jet} \geq 8,\ 500 < M_J < 800$ GeV							
1	130	574	53	68	825 ± 38	821	3.5 ± 0.3
2	45	478	14	49	586 ± 20	603	5.4 ± 0.4
3	6.3	138.1	2.5	16.7	164 ± 9	148	3.0 ± 0.3
≥ 4	2.8	29.8	0.4	4.8	38 ± 4	40	1.4 ± 0.2
$6 \leq N_{jet} \leq 7,\ 800 < M_J < 1000$ GeV							
1	17.3	48.4	19.2	12.3	97 ± 8	105	1.2 ± 0.2
2	6.6	30.1	4.3	7.3	48 ± 4	37	2.0 ± 0.3
3	0.8	6.6	0.5	1.3	9.3 ± 1.0	12	1.0 ± 0.2
≥ 4	0.0	0.9	0.1	0.2	1.1 ± 0.2	2	0.31 ± 0.09
$N_{jet} \geq 8,\ 800 < M_J < 1000$ GeV							
1	17.0	58.7	10.3	10.2	96 ± 8	90	4.2 ± 0.4
2	5.8	47.5	2.5	6.8	63 ± 5	65	5.3 ± 0.4
3	1.1	15.0	0.4	2.0	19 ± 2	22	2.6 ± 0.3
≥ 4	0.2	3.4	0.1	0.9	4.6 ± 0.6	5	1.3 ± 0.2
$6 \leq N_{jet} \leq 7,\ M_J > 1000$ GeV							
1	4.4	8.7	6.0	4.1	23 ± 2	21	2.0 ± 0.3
2	0.7	5.0	1.4	1.6	8.8 ± 1.2	11	2.3 ± 0.3
3	0.1	1.2	0.2	0.5	1.9 ± 0.3	2	1.0 ± 0.2
≥ 4	0.00	0.13	0.01	0.05	0.19 ± 0.04	0	0.23 ± 0.08
$N_{jet} \geq 8,\ M_J > 1000$ GeV							
1	6.4	16.7	3.5	4.1	31 ± 3	28	5.4 ± 0.4
2	1.6	13.1	1.1	2.1	18 ± 2	21	8.2 ± 0.5
3	0.6	4.2	0.2	1.0	6.0 ± 0.8	5	5.7 ± 0.4
≥ 4	0.0	1.2	0.0	0.2	1.4 ± 0.3	2	3.2 ± 0.3