Bundesministerium für Bildung und Forschung

Universität Hamburg
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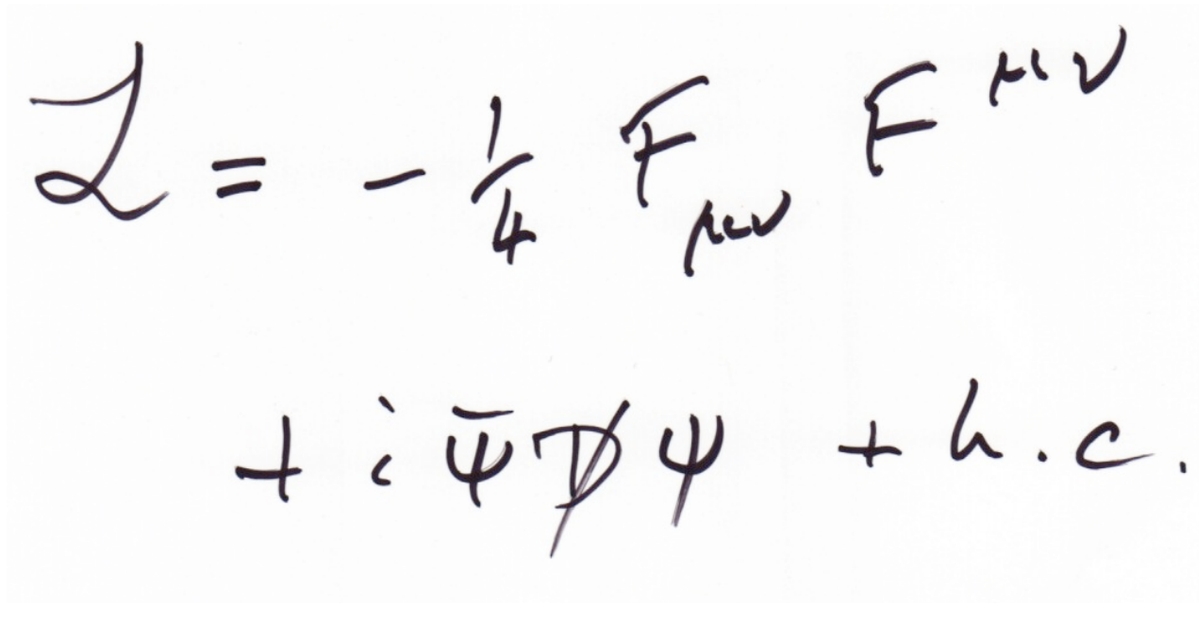
Boosting the sensitivity to new physical phenomena at the LHC

Roman Kogler
University of Hamburg

DESY Particle and Astroparticle Physics Colloquium
Feb 26, 2019

The Standard Model



- c (SLAC, Brookhaven '74)
- τ (SLAC '75)
- b (Fermilab '77)
- g (DESY, '78-79)
- W/Z (CERN '83)
- t (Fermilab '95)

… did not mention the ν sector

The Standard Model

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

$$+ i \bar{\Psi} \not{D} \Psi + h.c.$$

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$$+ |D_\mu \phi|^2 - V(\phi)$$

← H (CERN ’12)
and its gauge interactions

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$$+ |D_\mu \phi|^2 - V(\phi)$$

← H (CERN ’12) and its gauge interactions

$$+ \bar{\Psi}_i y_{ij} \Psi_j \phi + h.c.$$

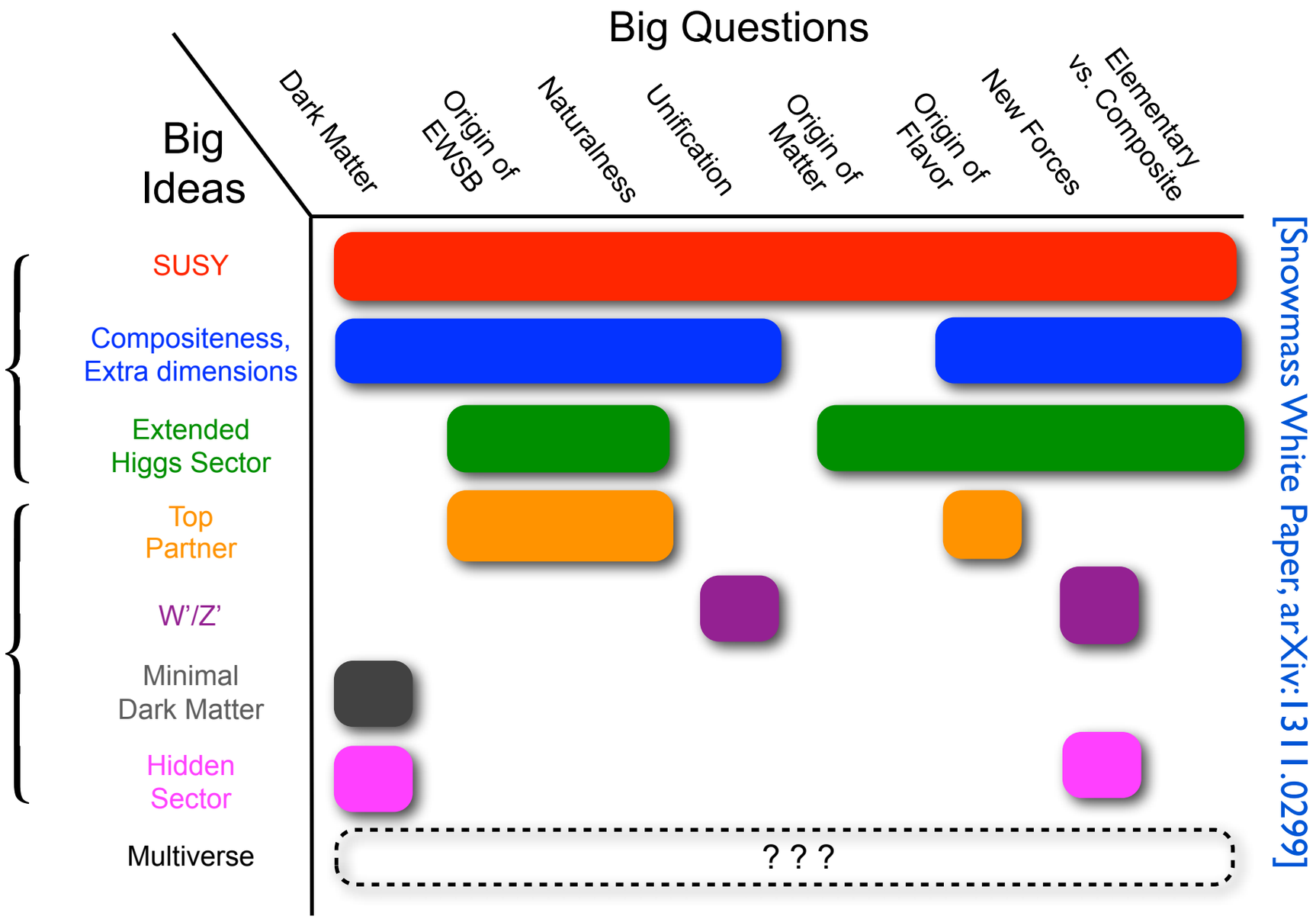
← Yukawa interactions (CERN ’16-18)

Beyond the Standard Model

Complete models

New matter fields / interactions

The unknown



- **Model-based searches**
- **Signature-based searches**

Searches?

Particle physics has coined the term

"Searches for New Physics"

but aren't these just measurements?

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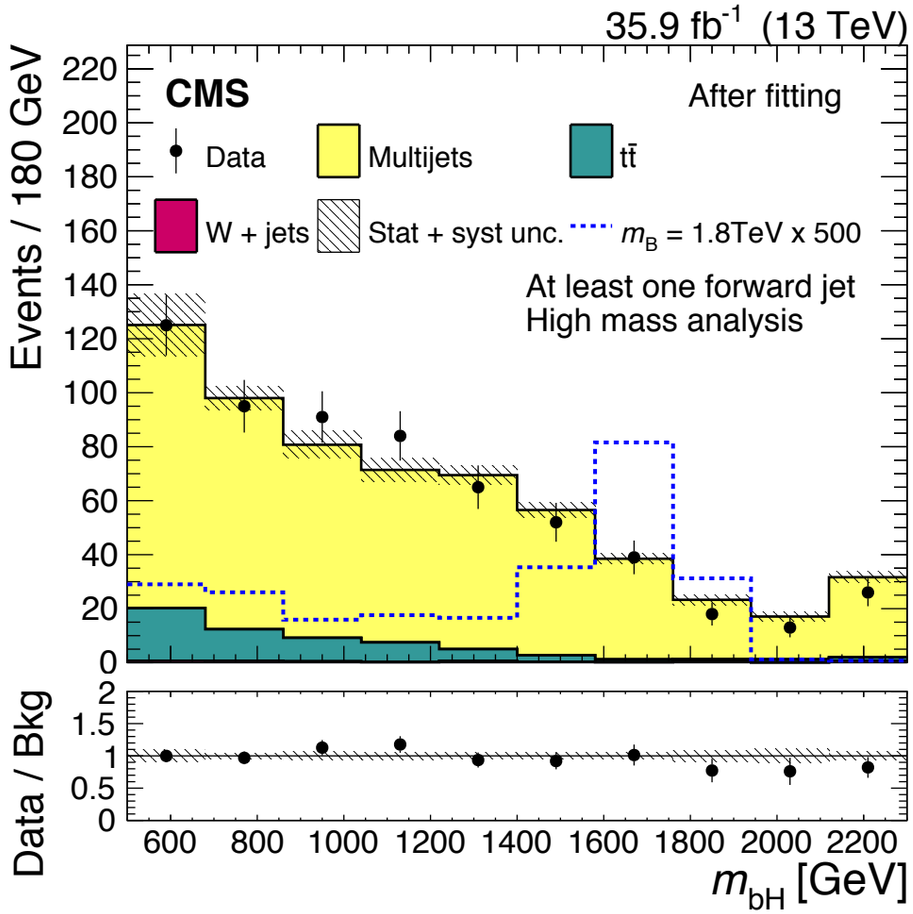
Search for b+H(bb) in EW production

[CMS, JHEP 06, 031 (2018)]



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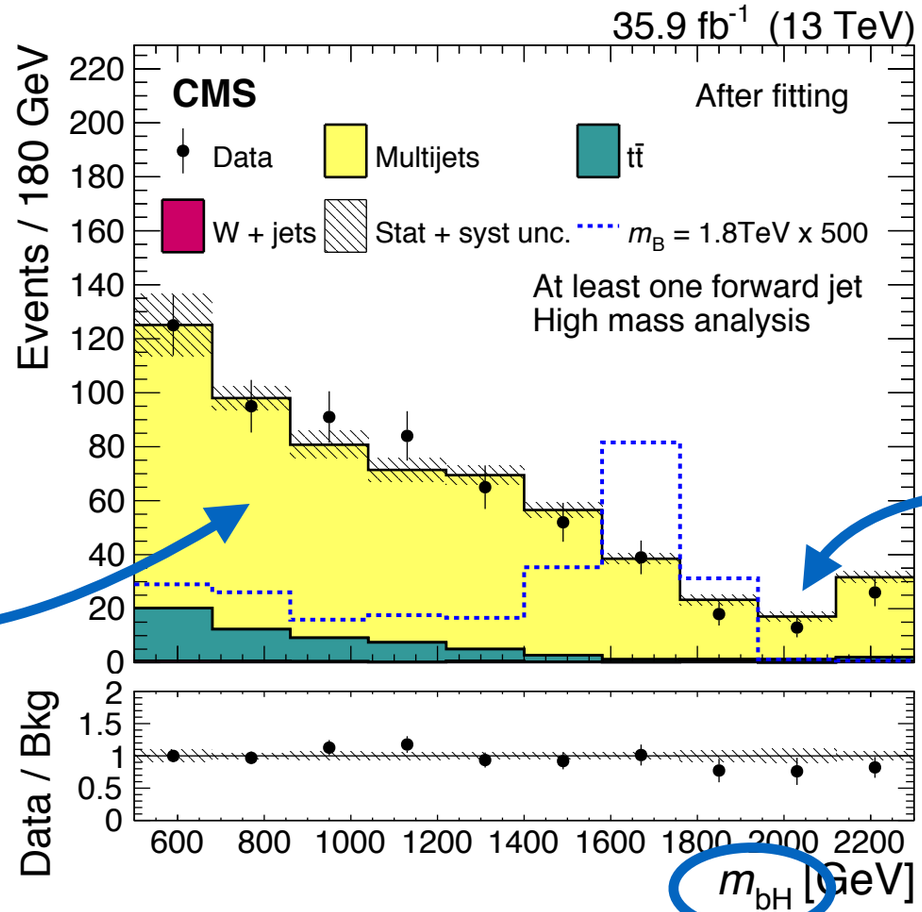

selected events: composted mostly of fakes

tails: small number of events

observable: useless in SM context

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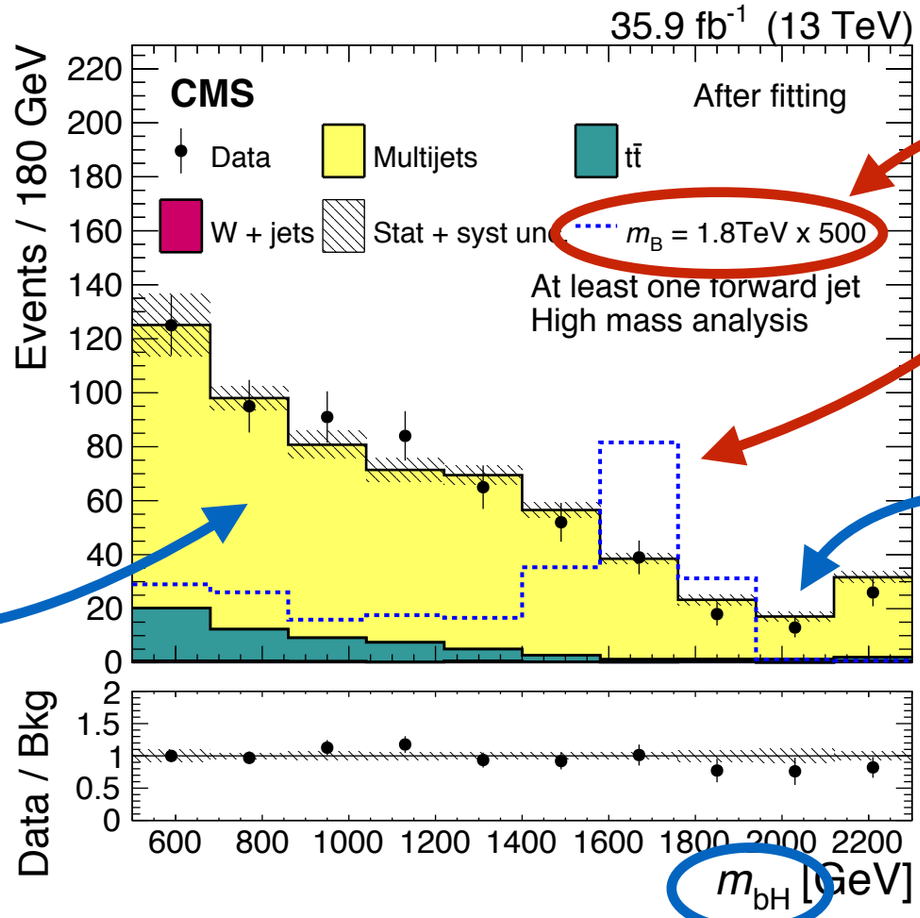


BUT: sensitivity to tiny signal!

selected events: composted mostly of fakes

tails: small number of events

observable: useless in SM context

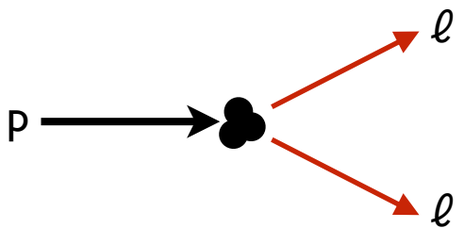
Overview

- Methodology
- Searches
  - Diboson resonances
  - tt resonances
  - Vector-like quarks
  - Leptoquarks
- Improving jet substructure methods
- Measurements

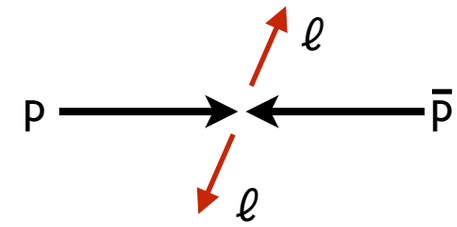
Emphasis on new results with personal involvement / interest not complete selection

Disclaimer: focus on simple interpretations in benchmark models, more complete interpretations possible and available

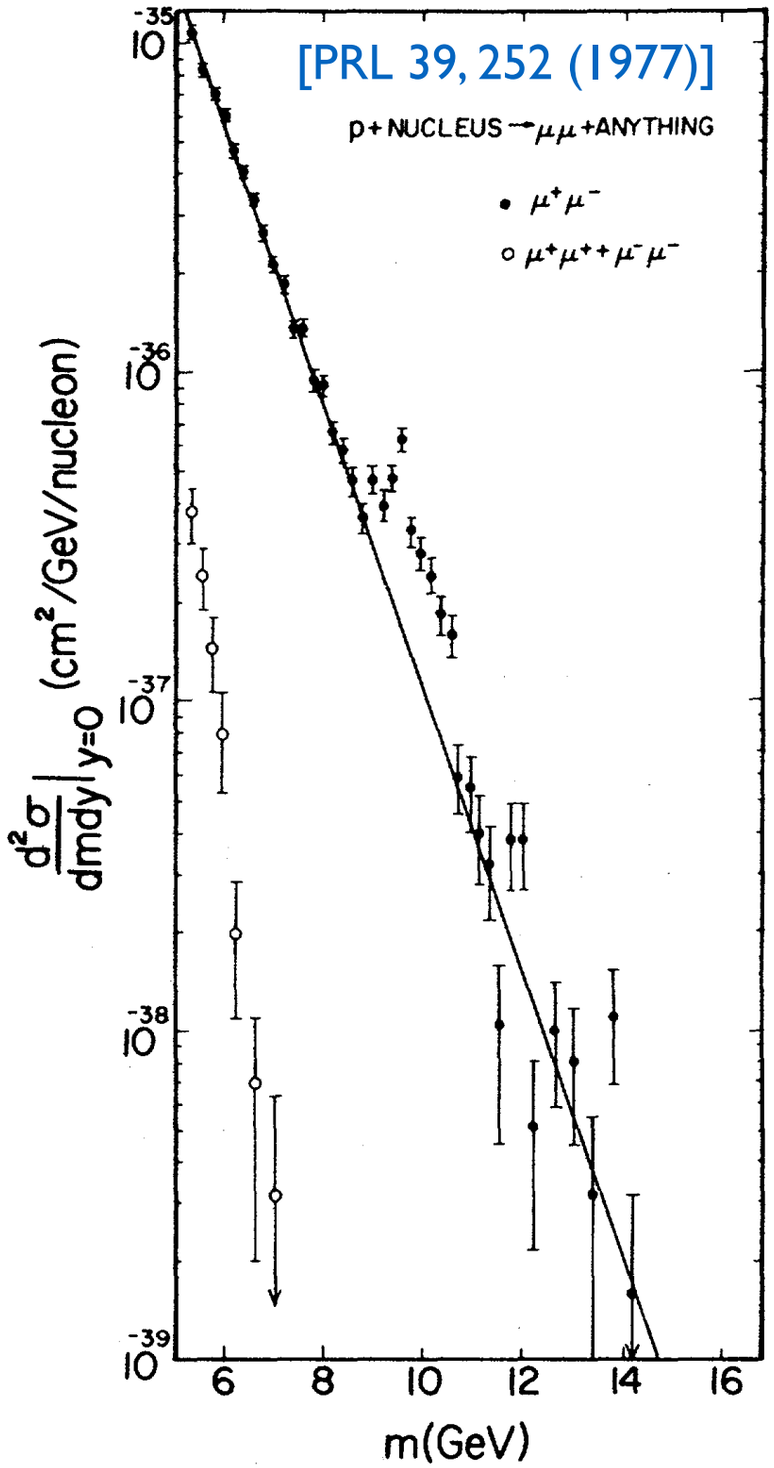
Methodology



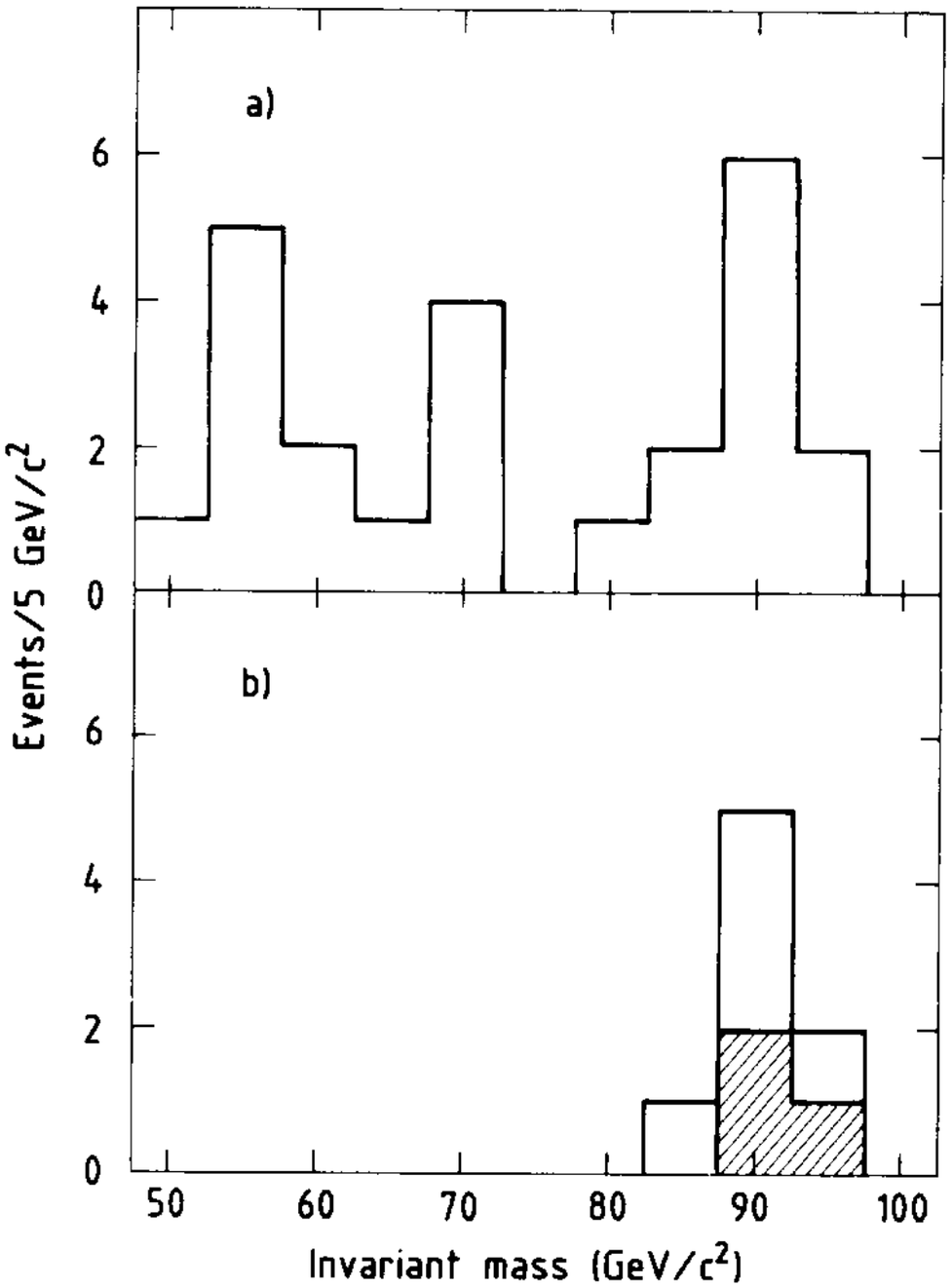
ℓℓ Resonances

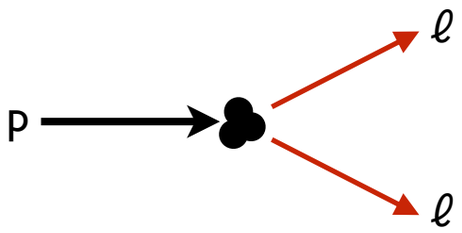


[PRL 39, 252 (1977)]



[UA1, PLB126, 398 (1983)
UA2, PLB129, 130 (1983)]





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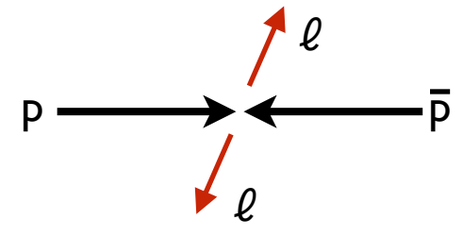

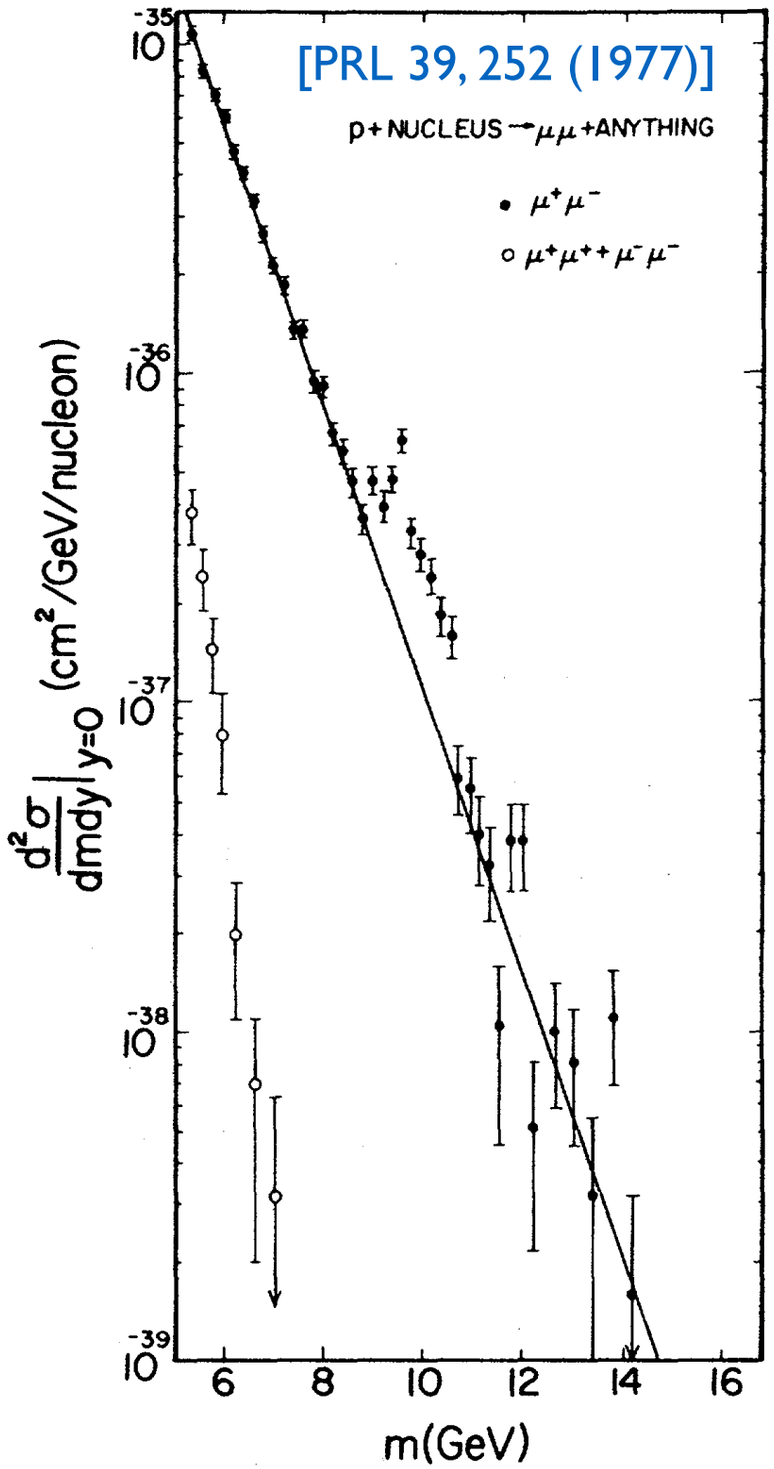

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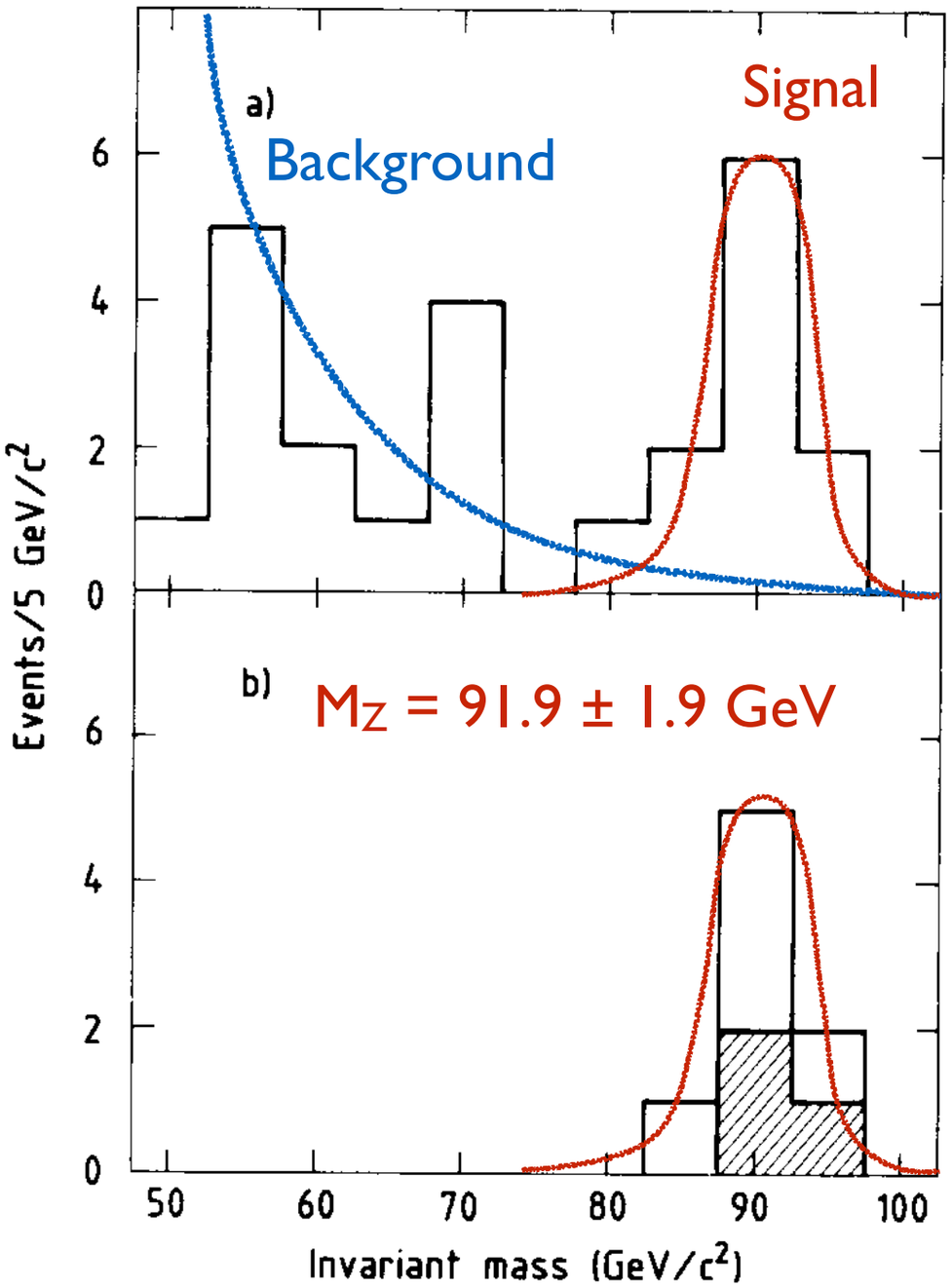
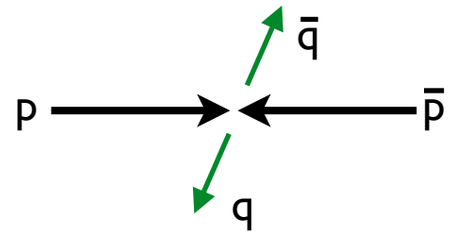


qq/gg Resonances



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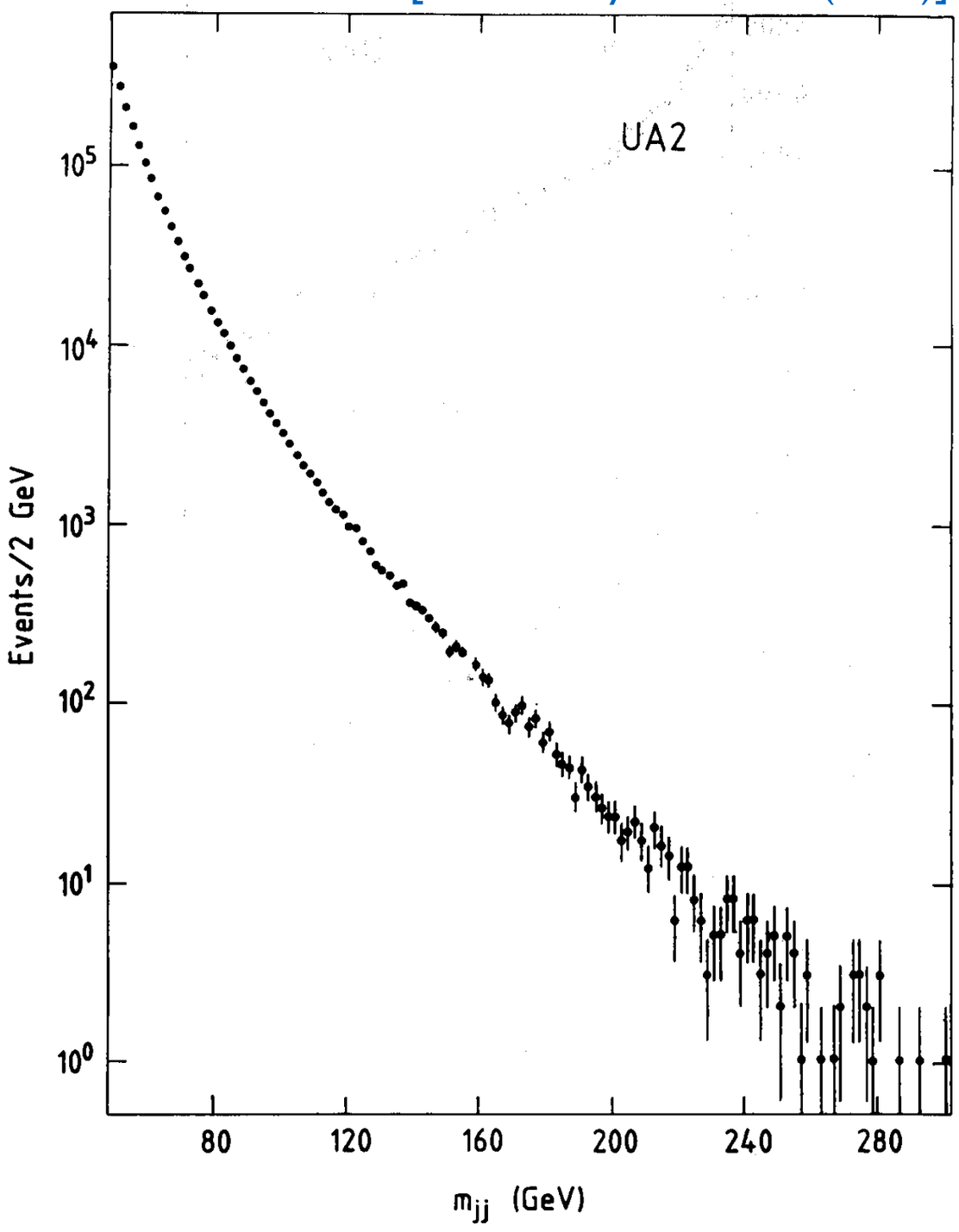

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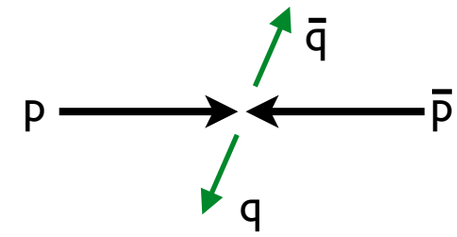

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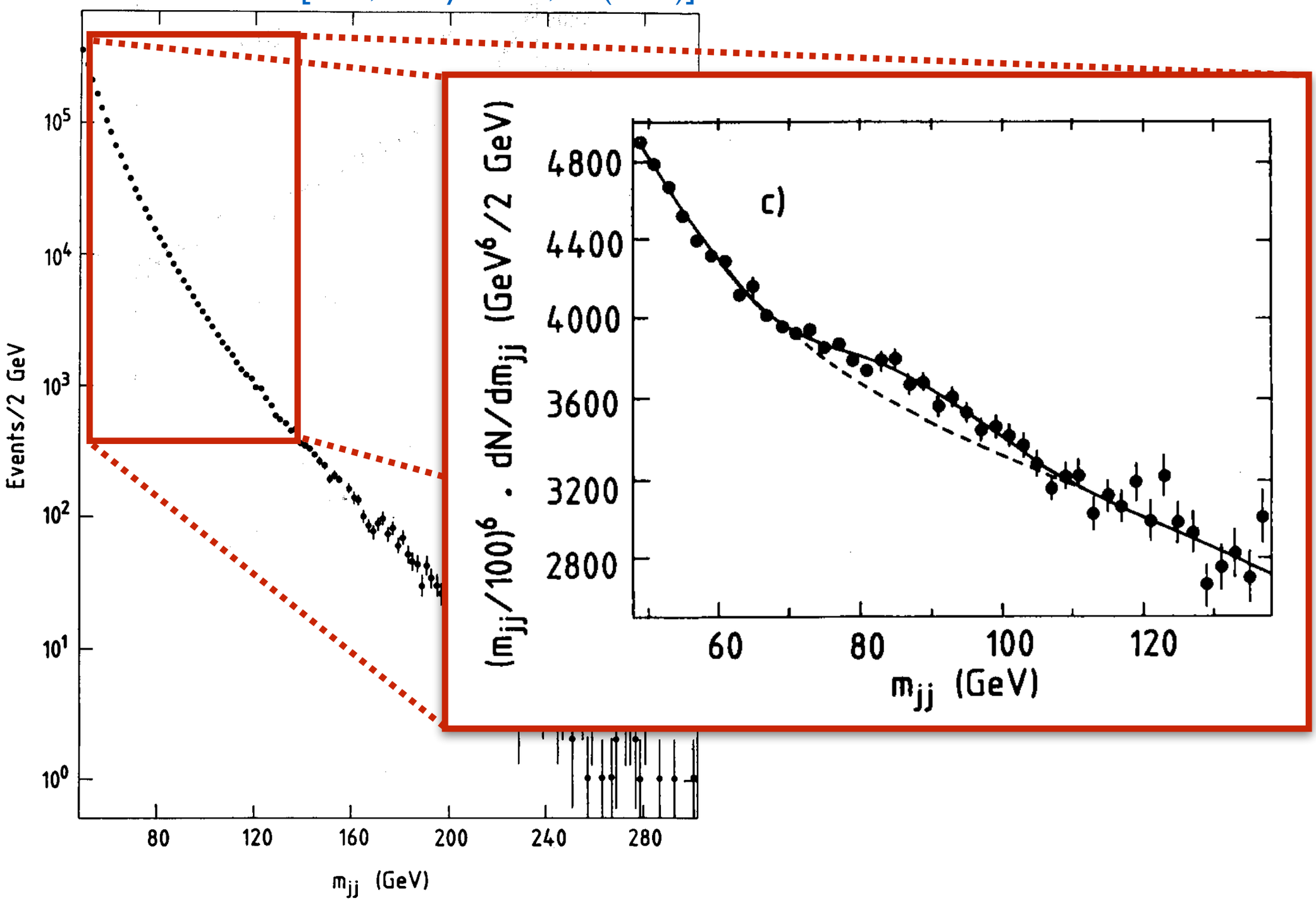

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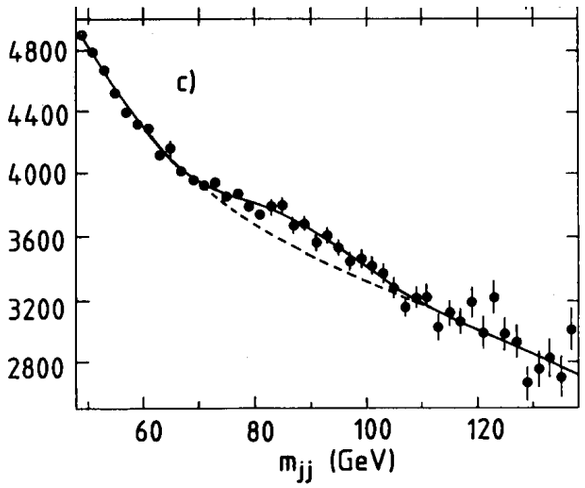
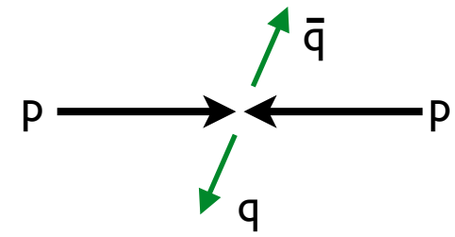
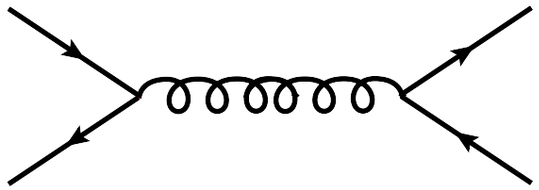


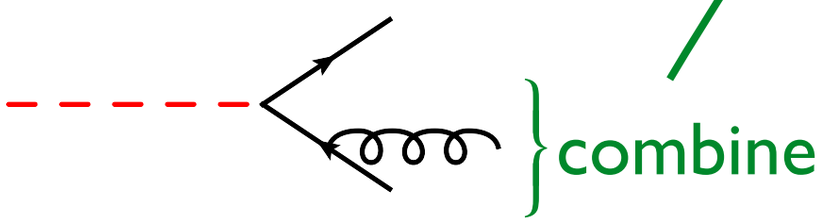


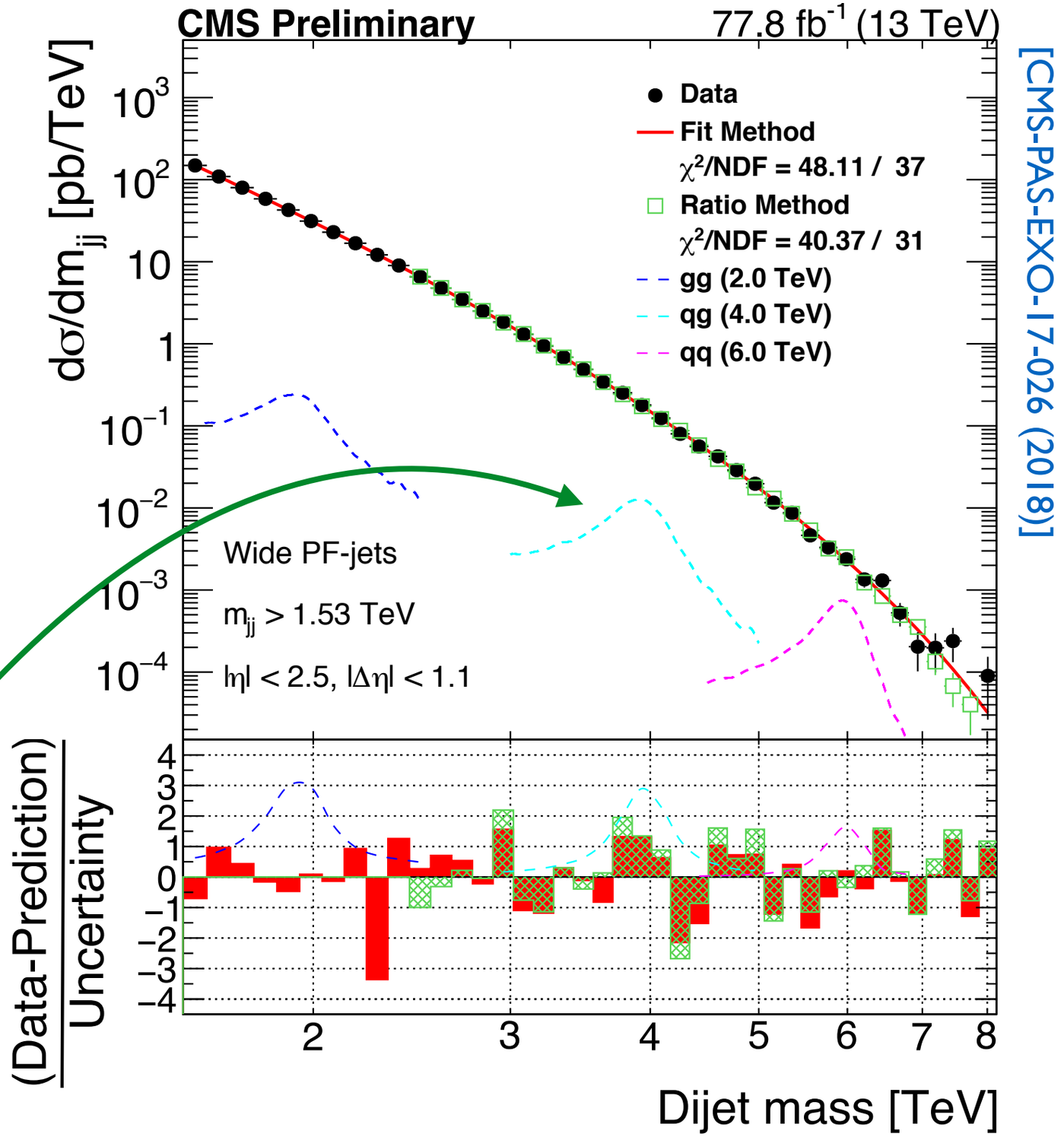
SM



BSM

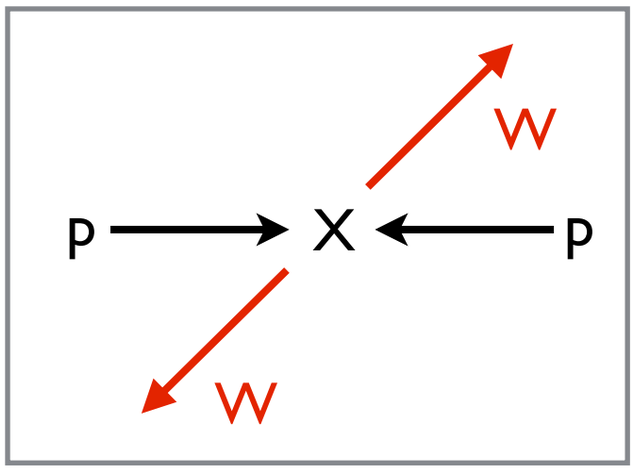
H.O.





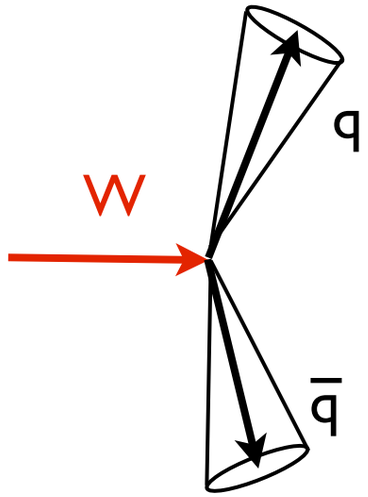
Boost!

pp→X→WW→Jets

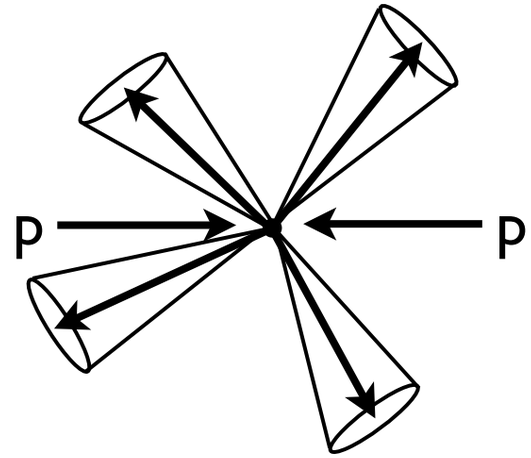


$M_X \sim 2\, M_W$

p_T^W small, $\gamma \lesssim 5$



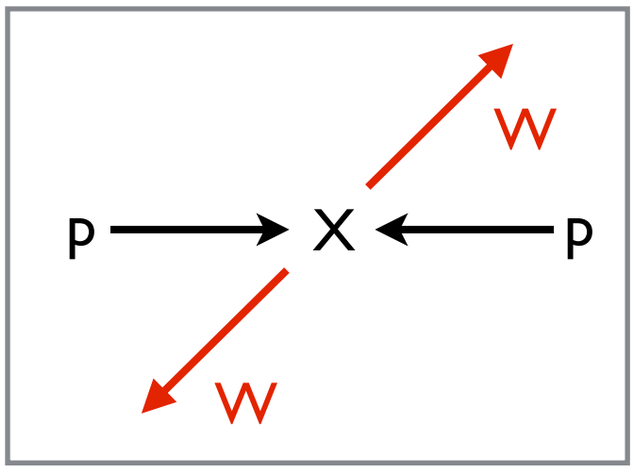
4 jet final state



combinatorics, background!

Boost!

pp→X→WW→Jets



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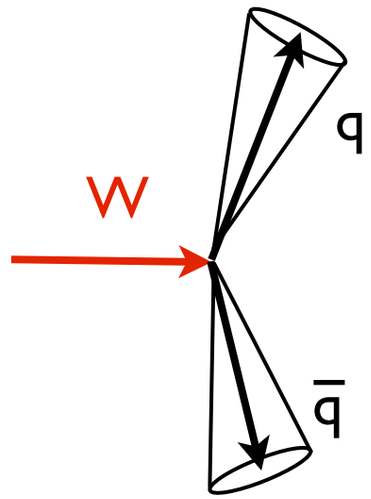

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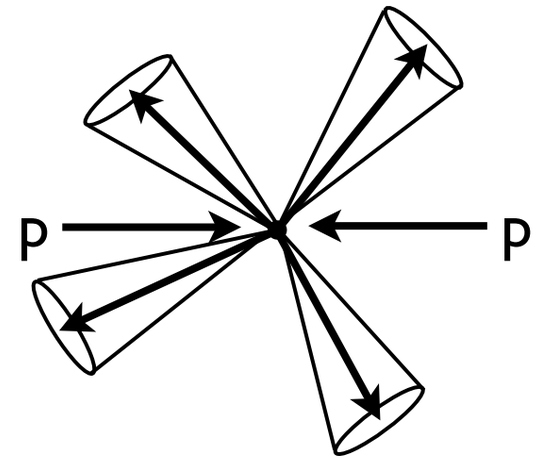
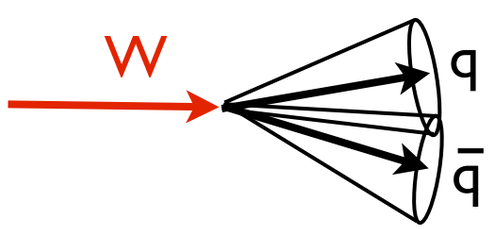


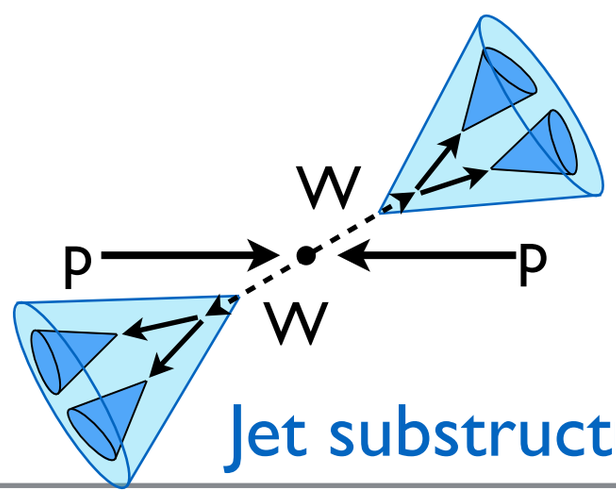
combinatorics, background!

$M_X \gg 2\ M_W$

p_T^W large, $\gamma \gg 5$



Dijet final state

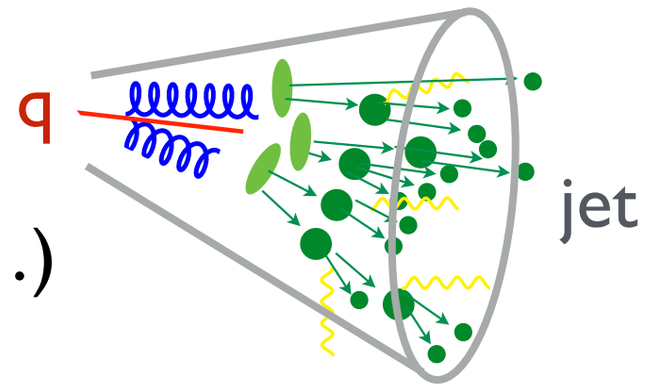


Jet substructure

W/Z/H Boson-Tagging I

Separation of QCD branching and 2-prong structure

1) Jetmass $M_{\text{jet}} = \left(\sum_i p_i \right)^2$



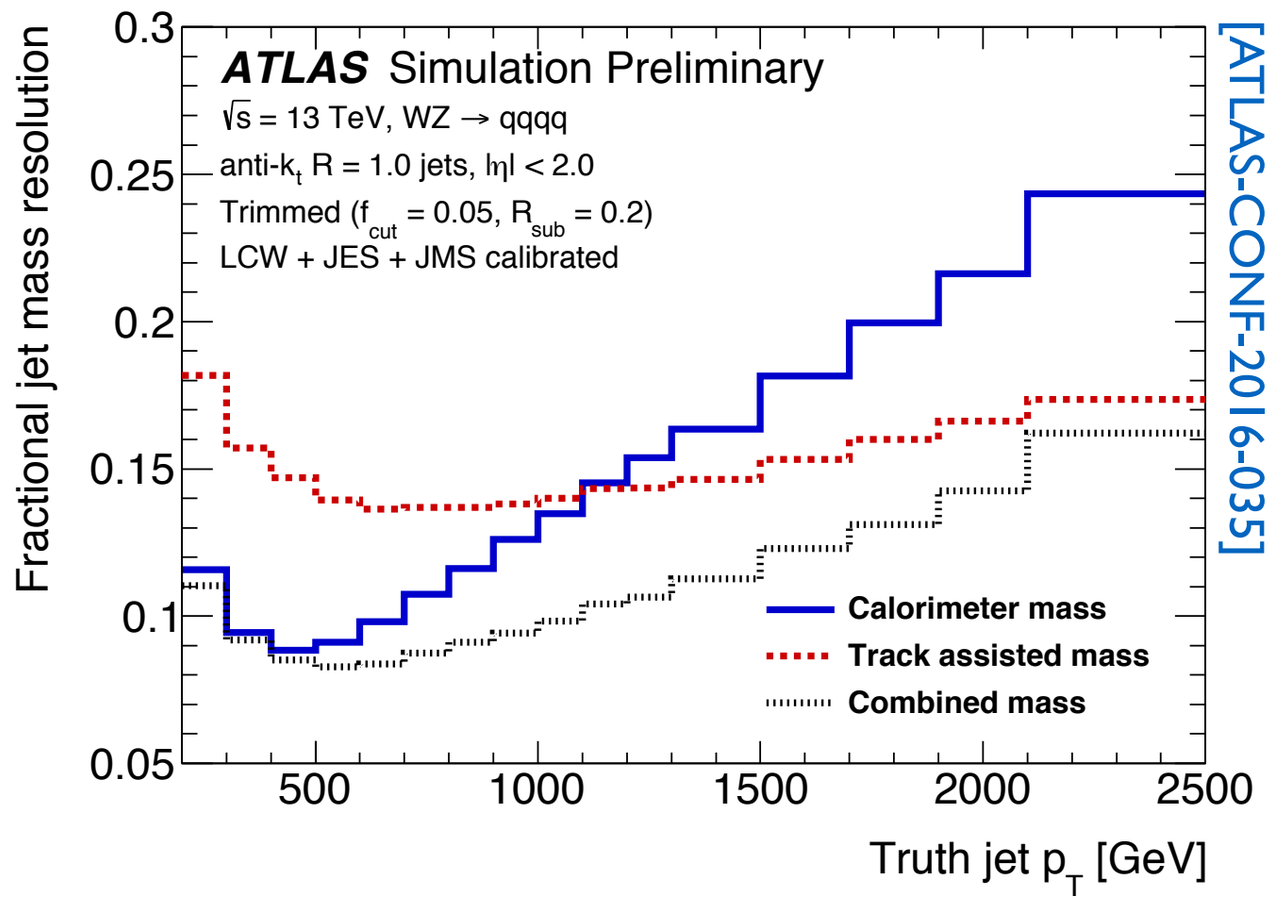
Subject to many systematic sources (rad, had, UE, PU…)

$$\delta M_{\text{UE/PU}} \propto p_T R^4$$

corrections through dedicated algorithms

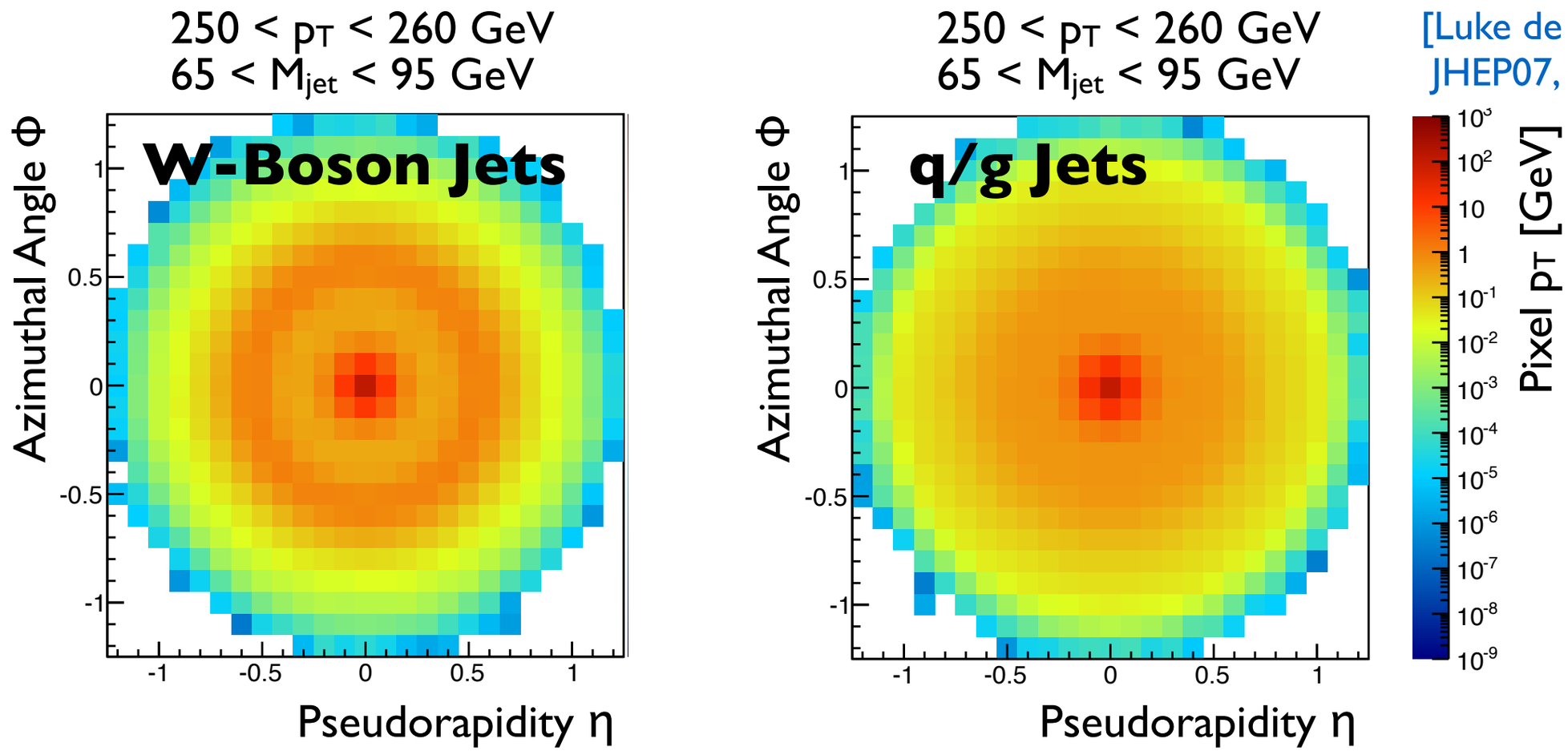
- PF+PUPPI (cal, PU, CMS)
- Track-assisted jet mass (cal, ATLAS)
- Soft-drop (UE/had, CMS)
- Trimming (PU/UE/had, ATLAS)

10-15% misidentification at 70-80% signal efficiency



W/Z/H Boson-Tagging 2

2) Substructure



[Luke de Oliveira et al., JHEP07, 069 (2016)]

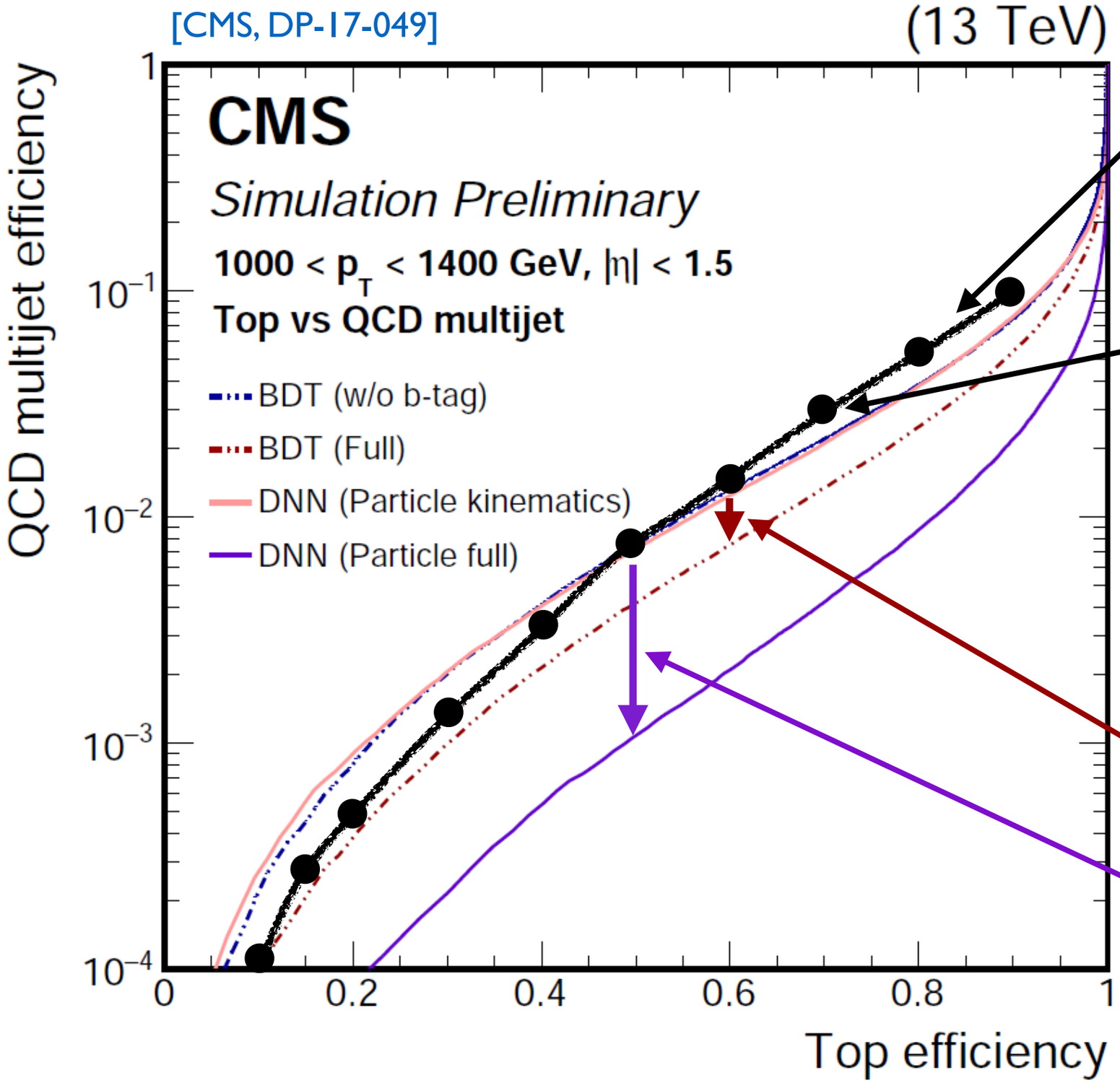
Exploit characteristic radiation pattern

- N-subjettiness ratios τ_2/τ_1 (CMS)
- Energy correlation ratios D_2 (ATLAS)
- Subjet b-tagging for H→bb (ATLAS/CMS)

1-5% misidentification at
50-60% signal efficiency

Top Quark Tagging

[CMS, DP-17-049]



soft drop mass,
$\tau_{3/2}$, subjet b
[CMS-PAS-JME-15-002]

today's standard
2-3% misidentification at
70% signal efficiency

A prime example for machine learning

gain from a BDT

gain from a deep neural network

[see also ATL-PHYS-PUB-2017-004]

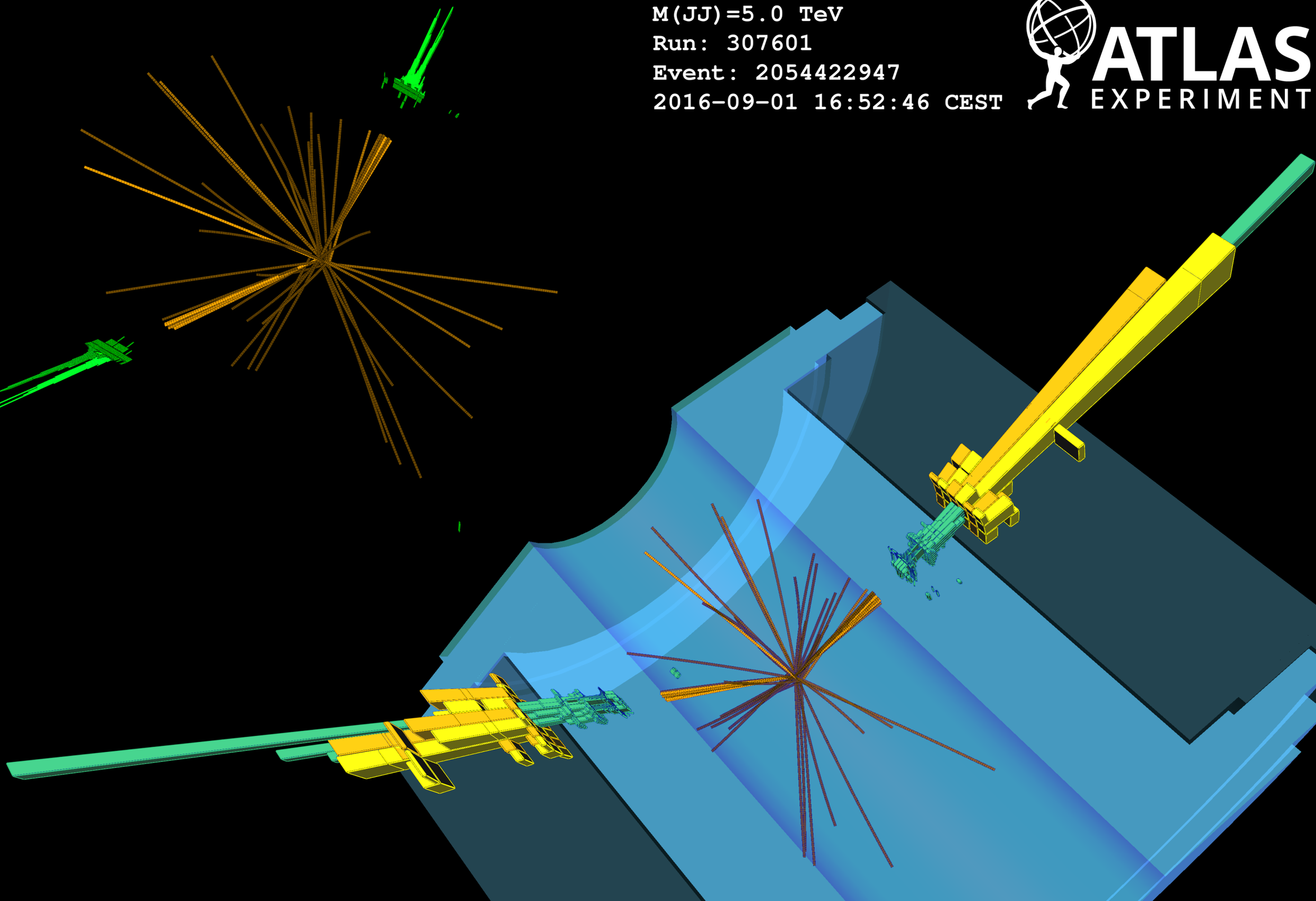
Searches

with heavy SM particles in the final state

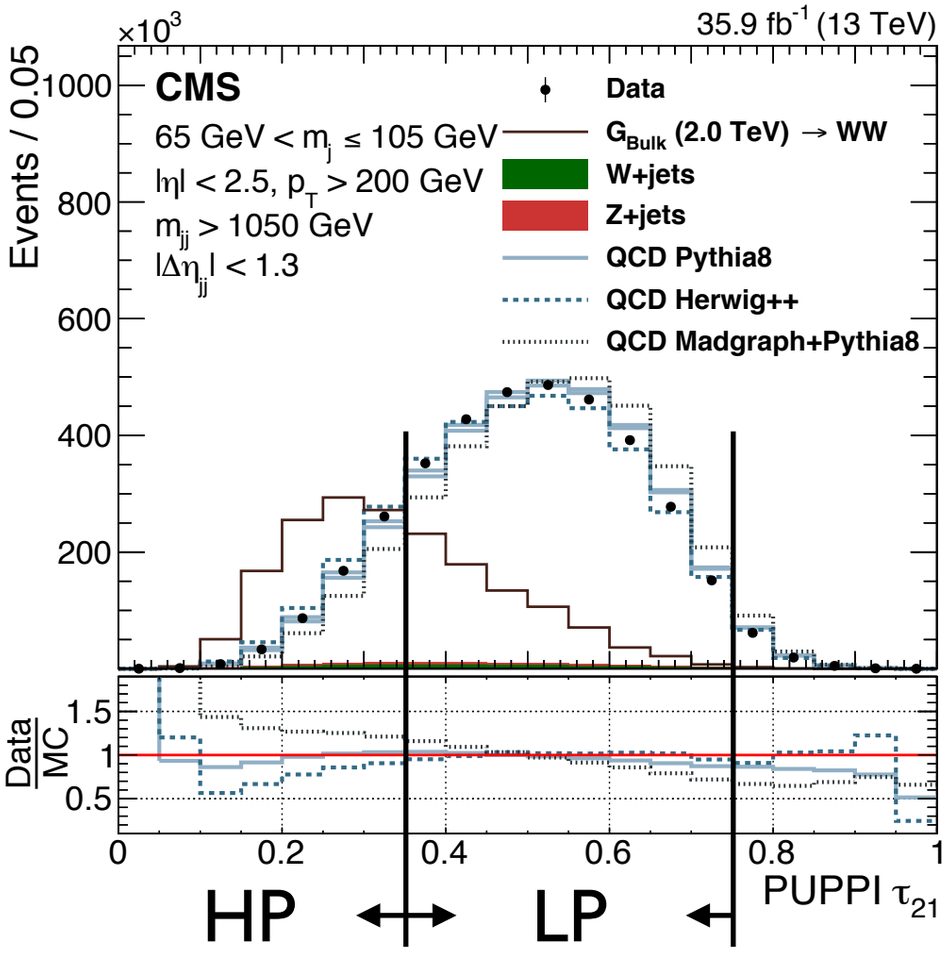
Diboson-tagged dijet event, M_{JJ} = 5.0 TeV

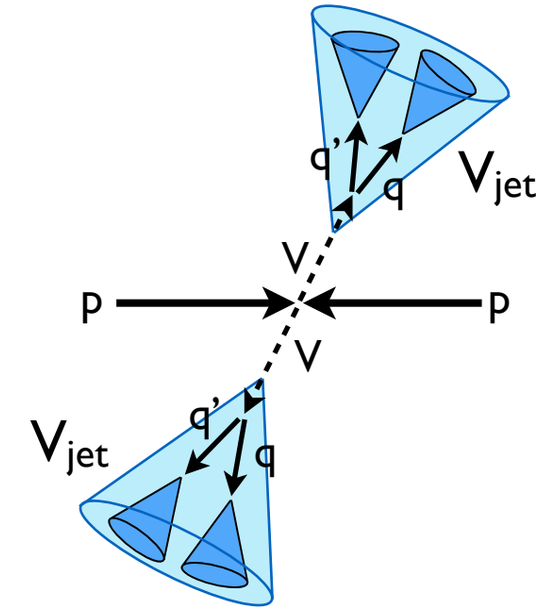
M(JJ)=5.0 TeV
Run: 307601
Event: 2054422947
2016-09-01 16:52:46 CEST

ATLAS EXPERIMENT

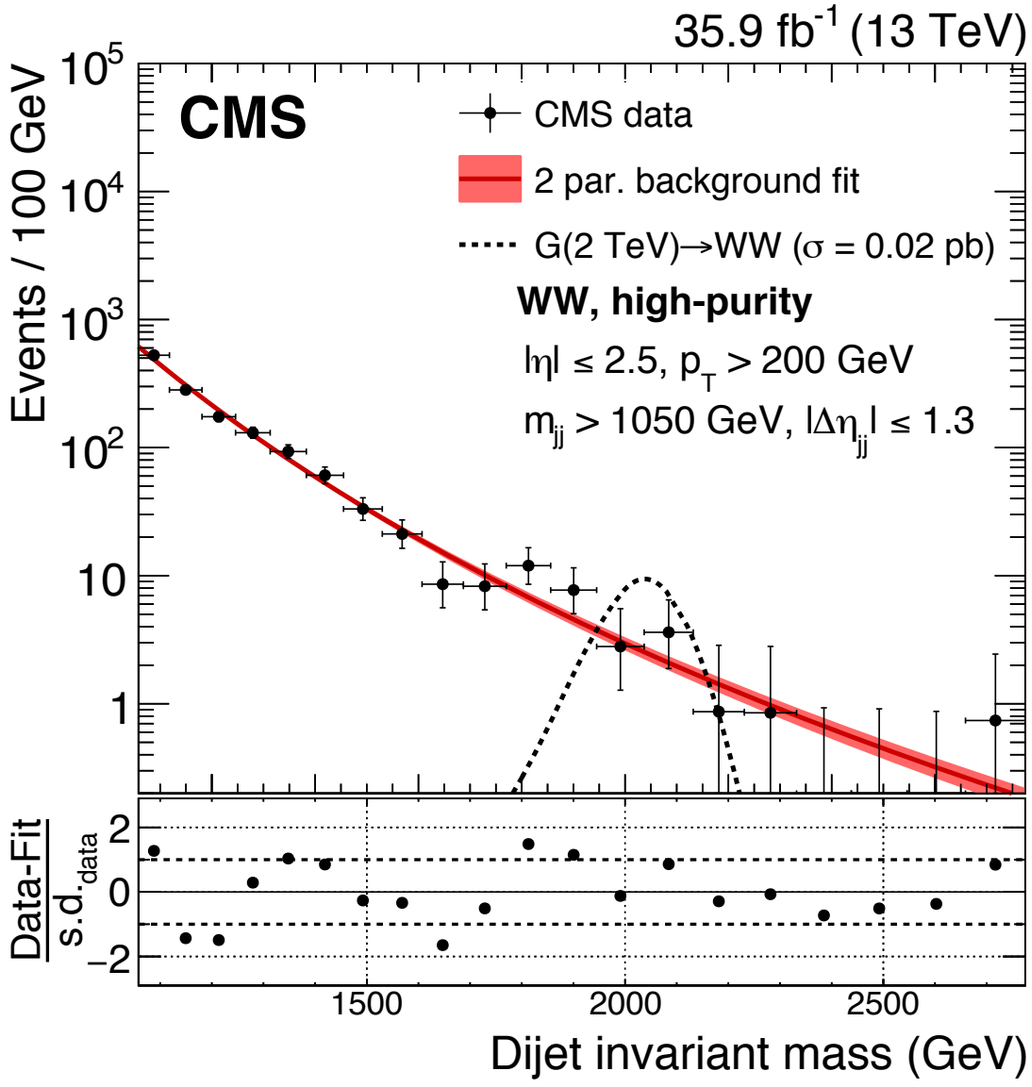


VV Resonances





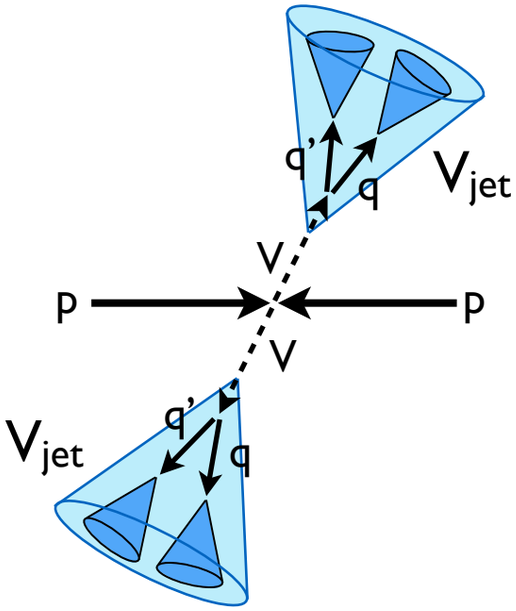
[CMS, PRD 97, 072006 (2018)]



Signal categories

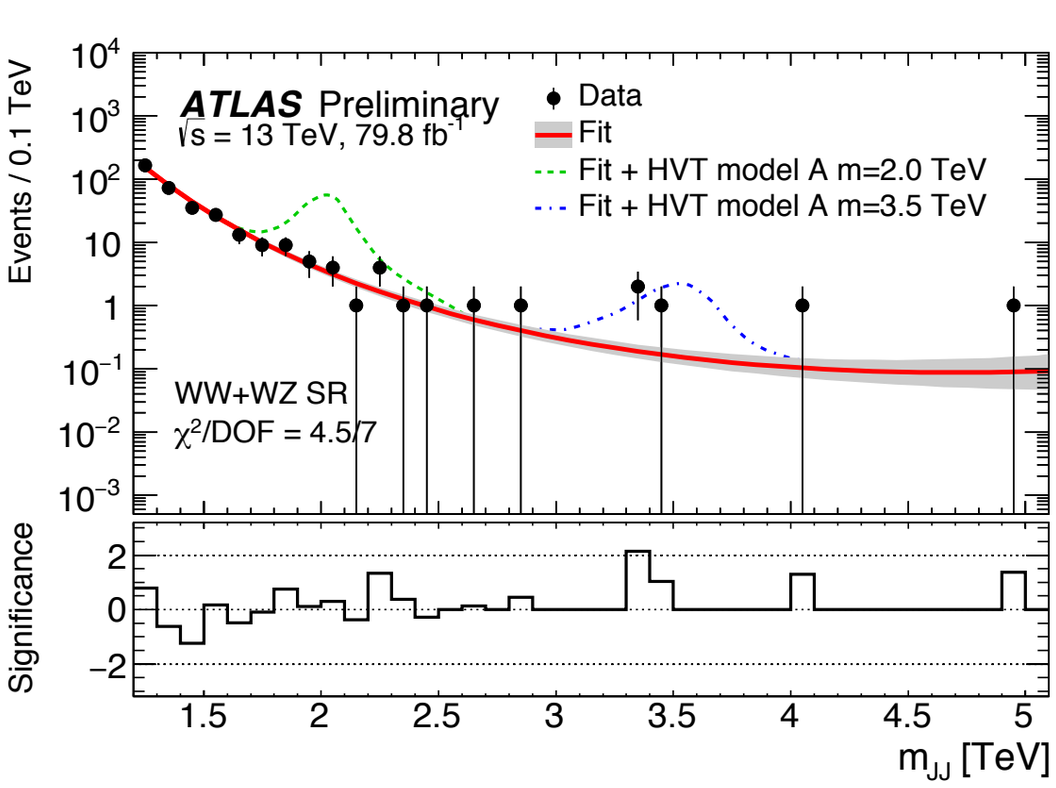
6 for VV: (WW, WZ, ZZ) x (HP, LP)
4 for qV: (W, Z) x (HP, LP)

VV Resonances

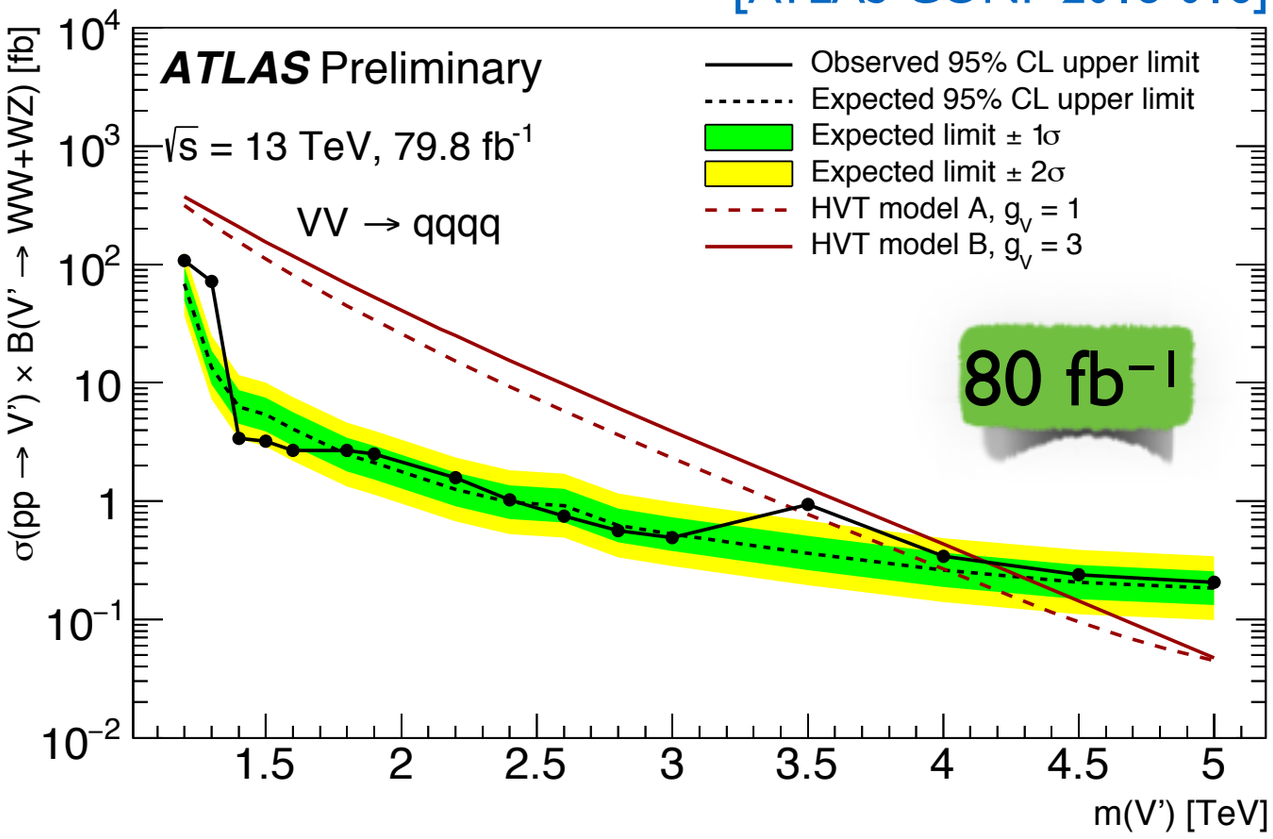


Improved jet substructure resolution with tracking information (TCCs):
50% improvement at high p_T

Optimal S/B with p_T dependent mass and D_2 selections



[ATLAS-CONF-2018-016]

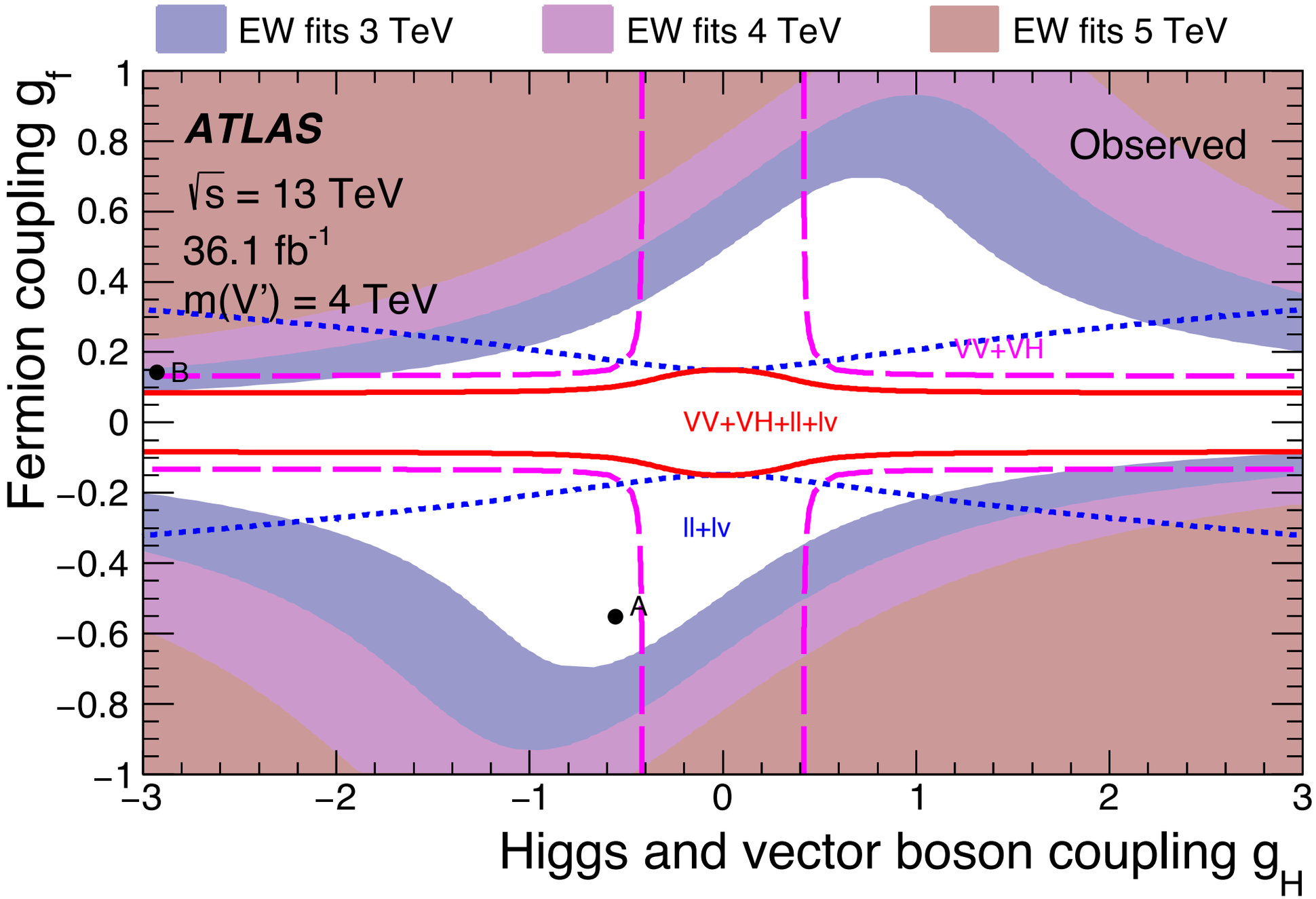


50% improvement w.r.t. expected sensitivity based on 2016 data!

Extension to 4- and 5-prongs: [CMS, arXiv:1806.01058]

VV, VH, ℓℓ, ℓν Combination

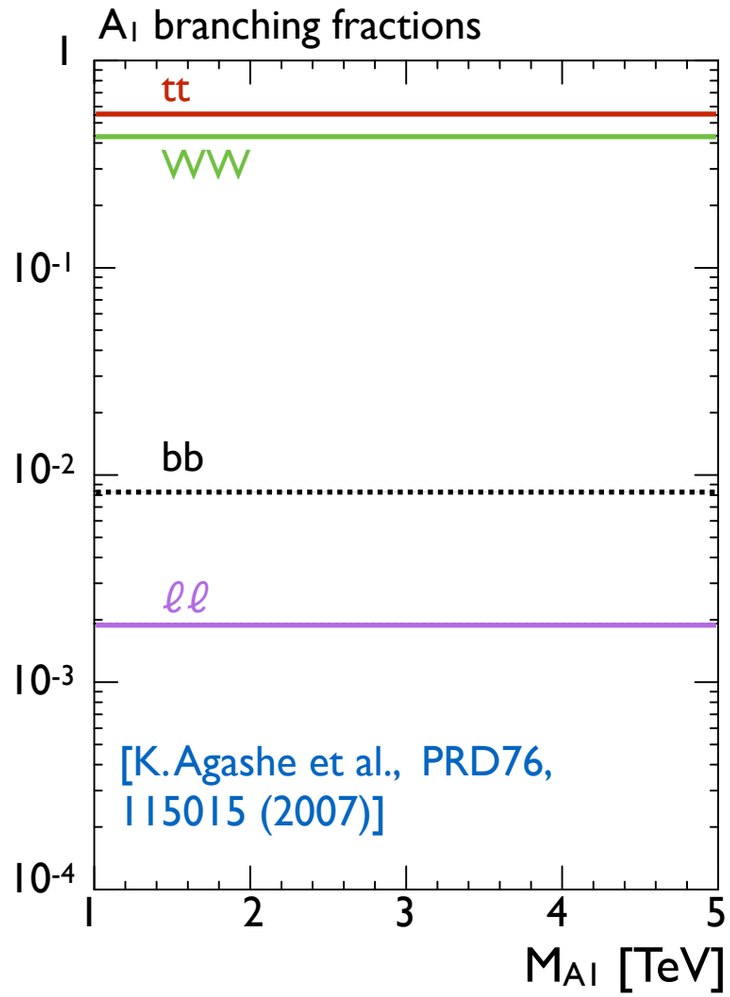
[ATLAS, PRD 98, 052008 (2018)]

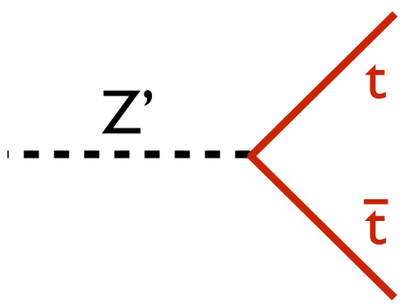


Other Possibilities?

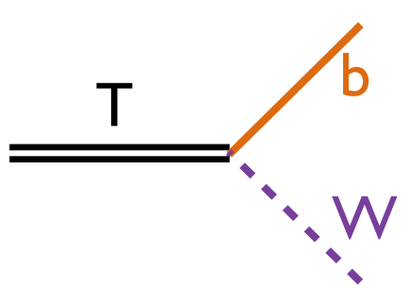
The 3rd Generation

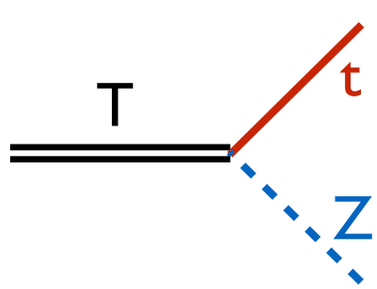
- Focus on t and b quarks in model building
  - Addresses a number of questions (Naturalness, mass hierarchies…)
  - Couplings to t and b dominant
- Weak constraints from EWPO and low energy measurements
- Many incarnations: new gauge groups, extended scalar sectors, extra dimensions…

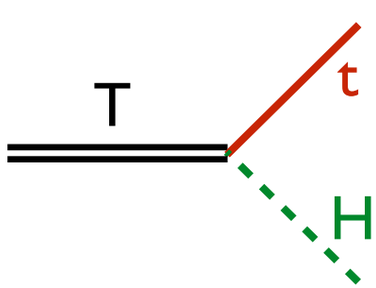




Resonances

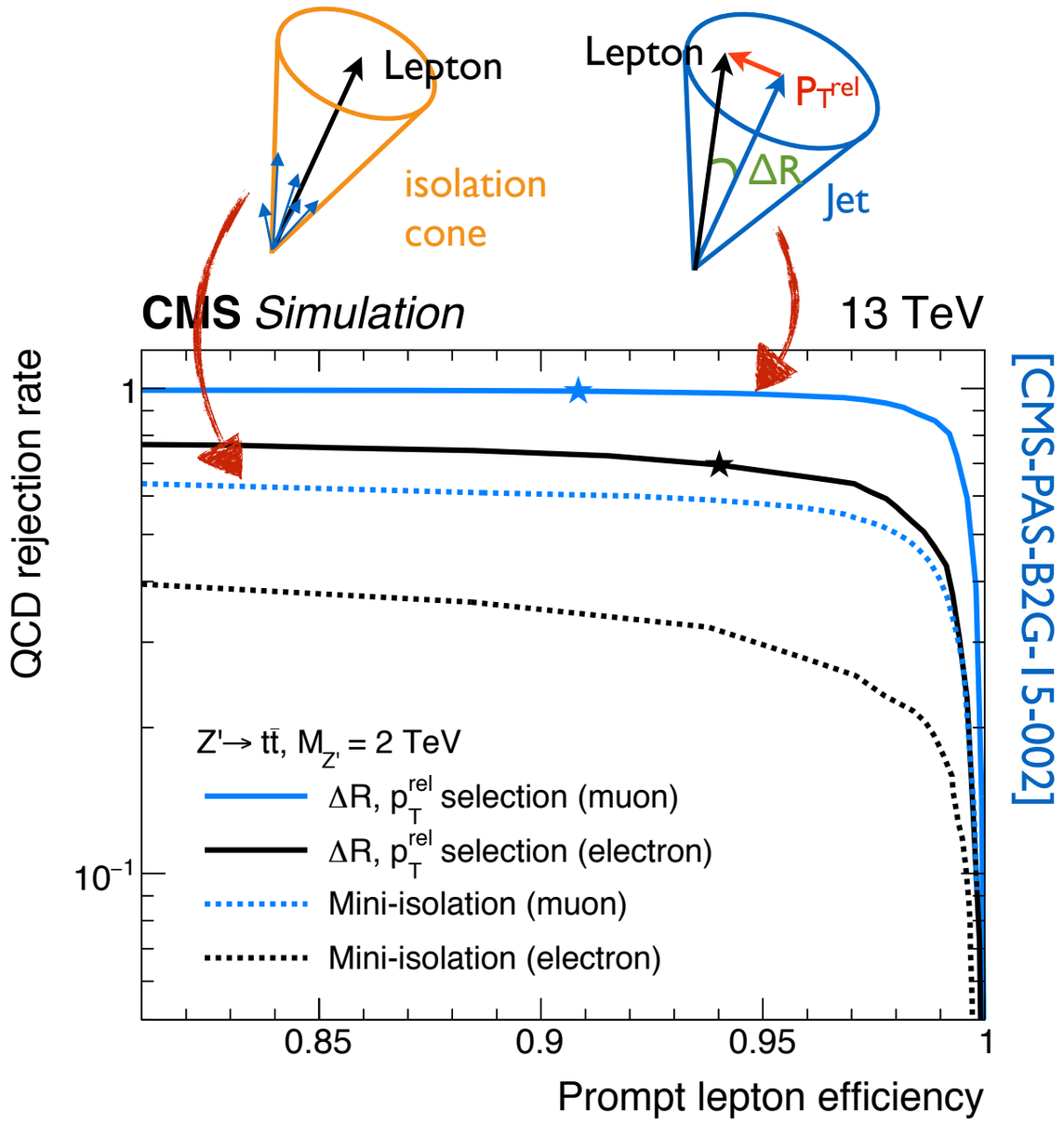


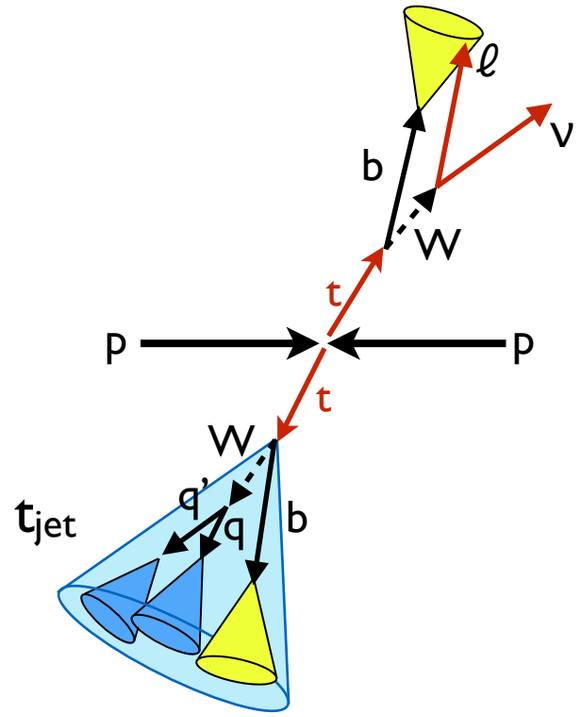


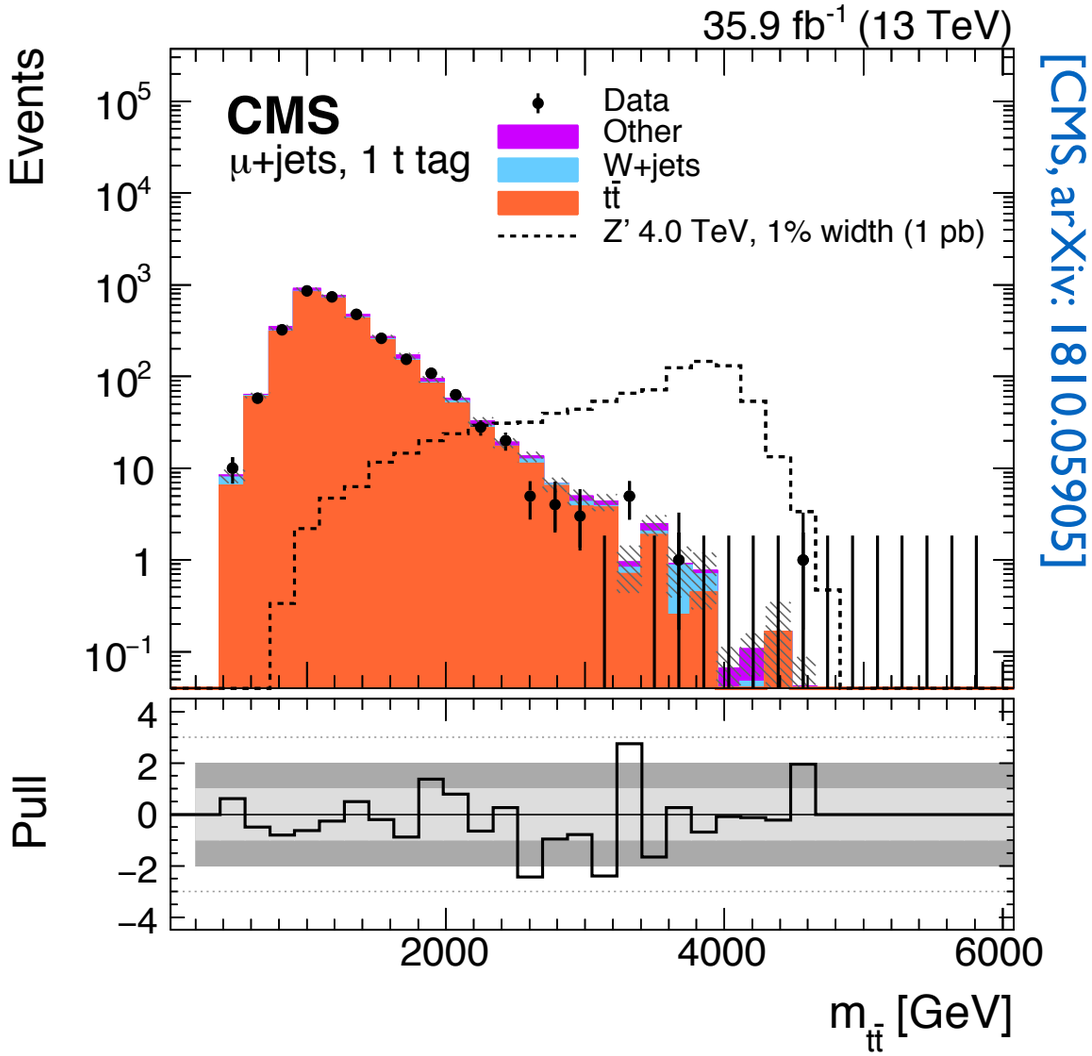


Vector-like quarks (VLQs)

$t\bar{t}$ Resonances

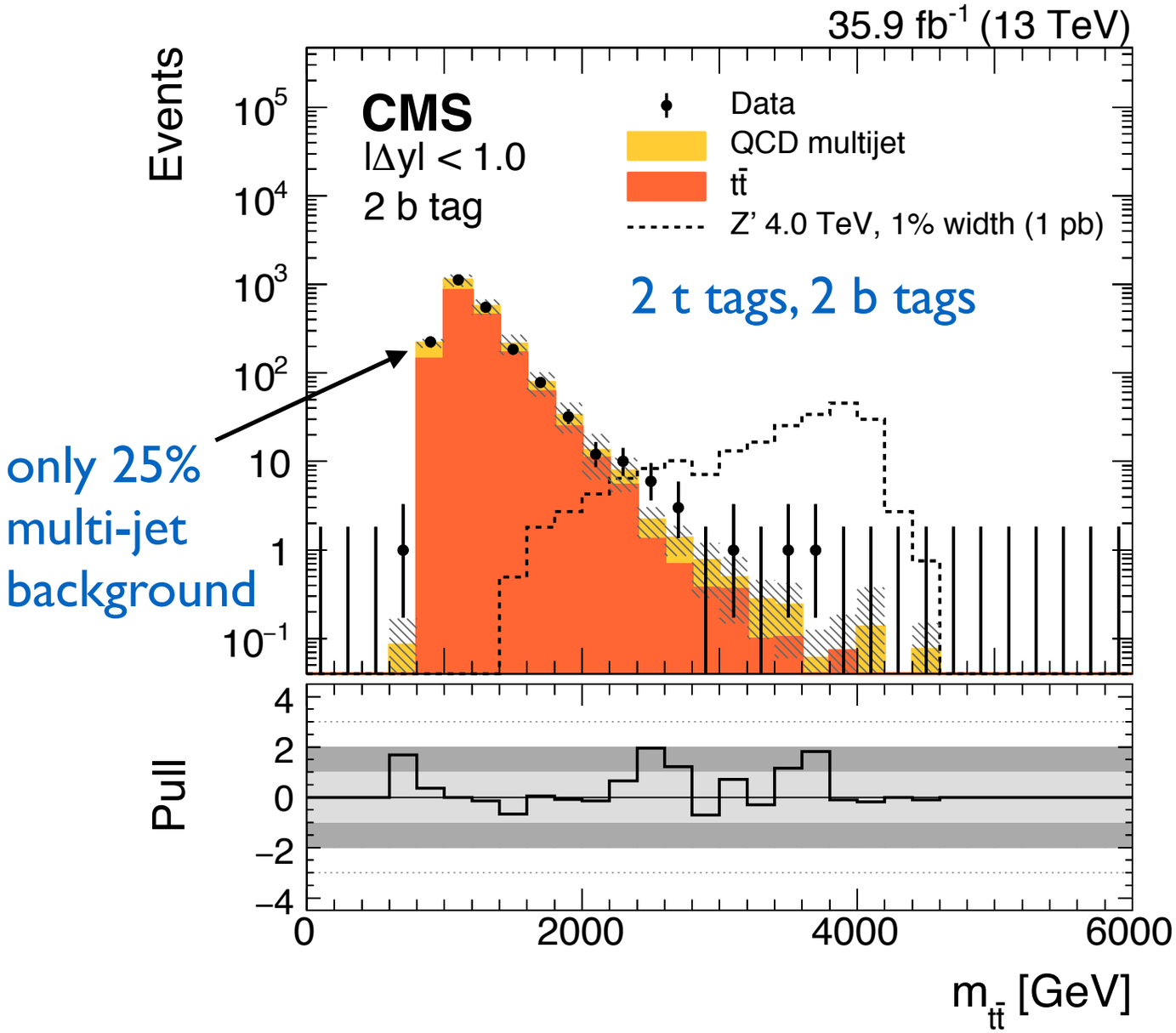




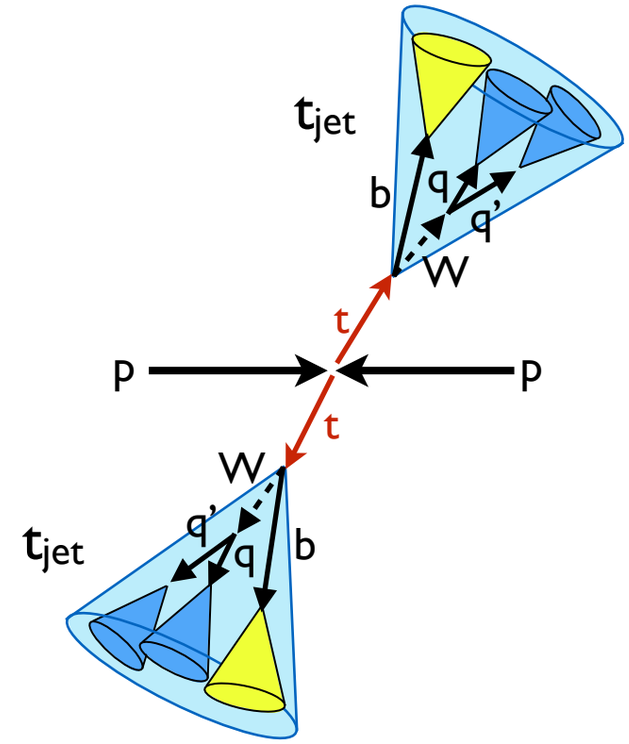


- improved PU mitigation, b-tagging
- BDT for W+jet suppression
- CRs to constrain backgrounds

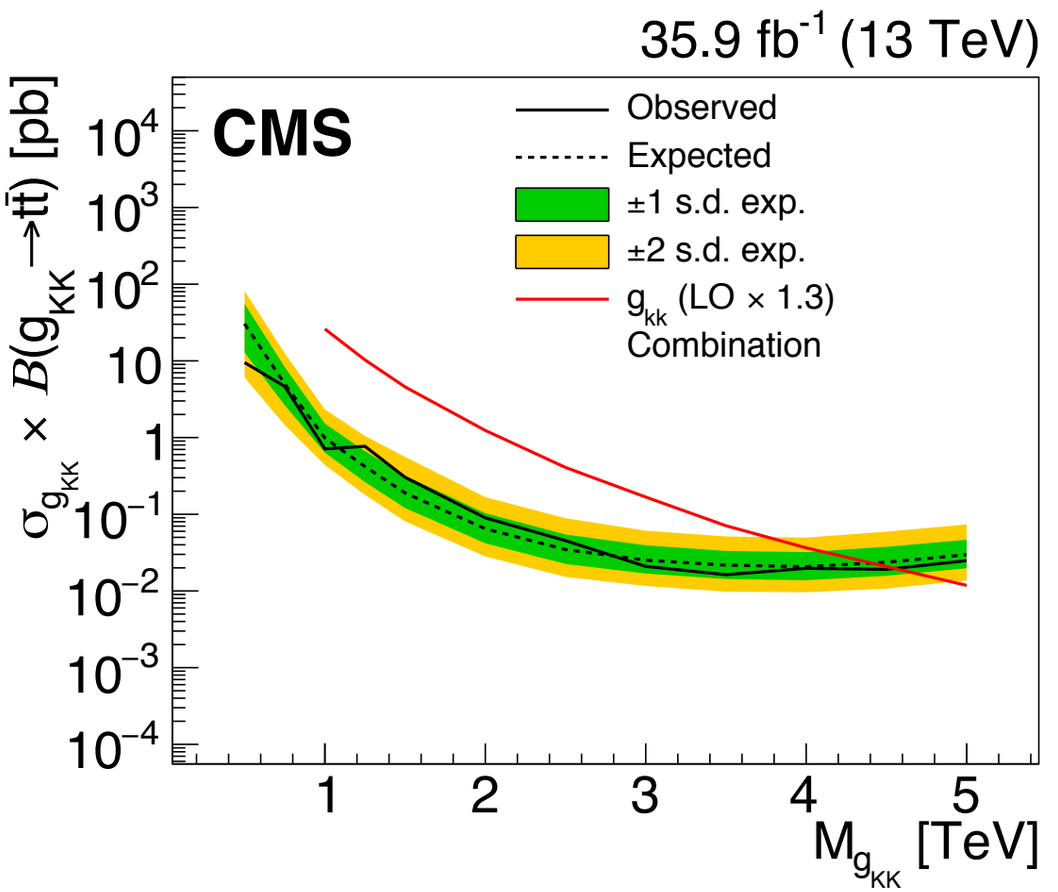
$t\bar{t}$ Resonances



only 25% multi-jet background



[CMS, arXiv: 1810.05905]

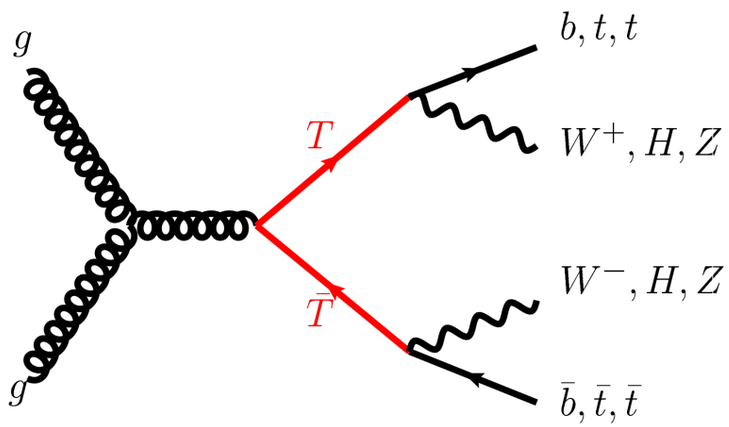


Combination of $\ell\ell$, ℓ+jets and all-hadronic channels:
Kaluza-Klein gluons excluded below **4.6 TeV**

VLQ Pair Production

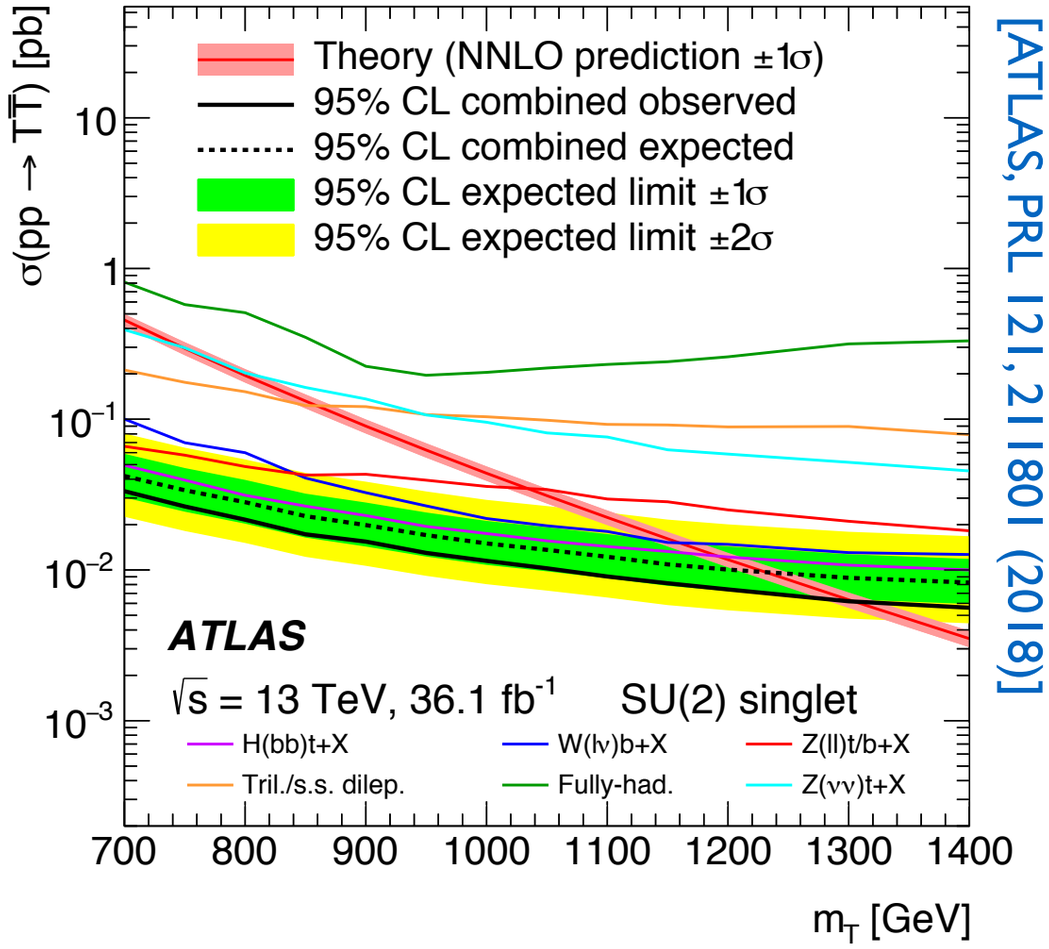
$T\bar{T}$ and $B\bar{B}$ pair production

- Rich phenomenology
  - T → bW, tZ, tH
  - B → tW, bZ, bH



- Numerous searches profit from jet substructure tagging
  - orthogonality: leptonic and hadronic channels (tags)

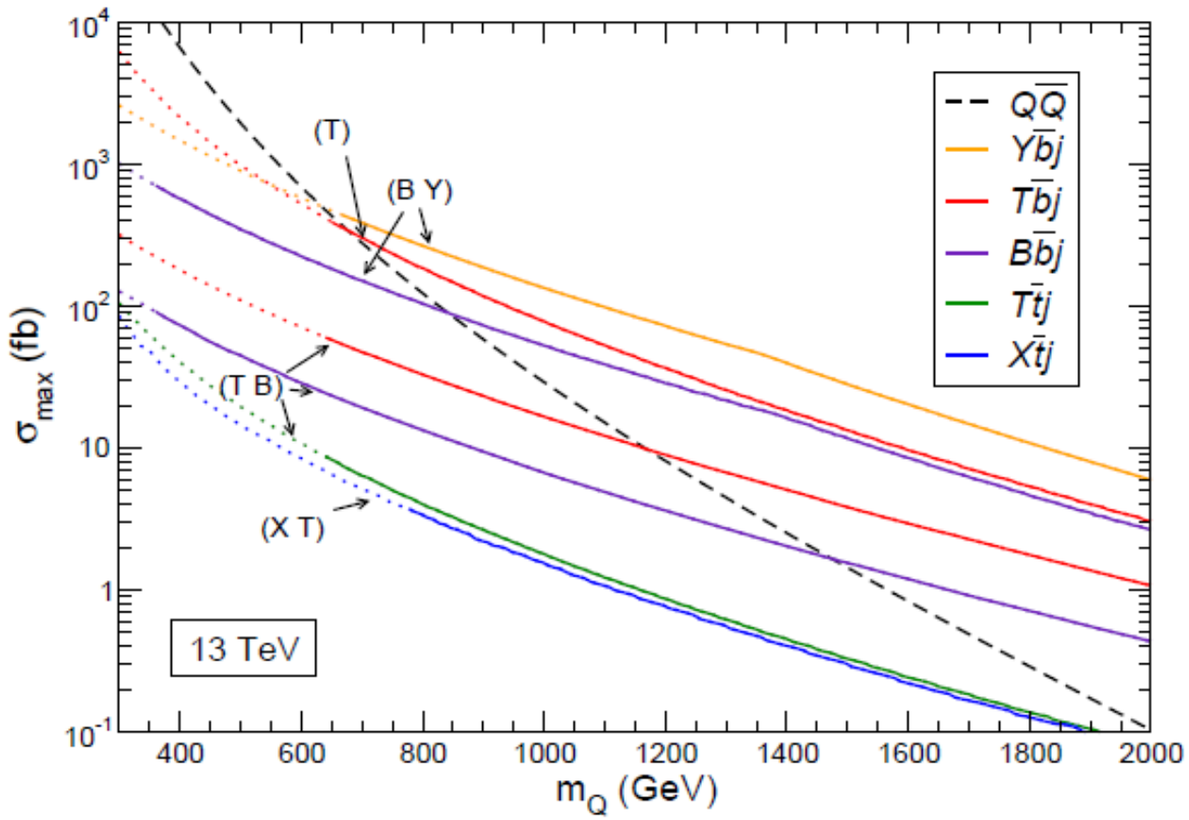
- Grand combination:
  Exclusion of T / B below
  1.3 / 1.2 TeV

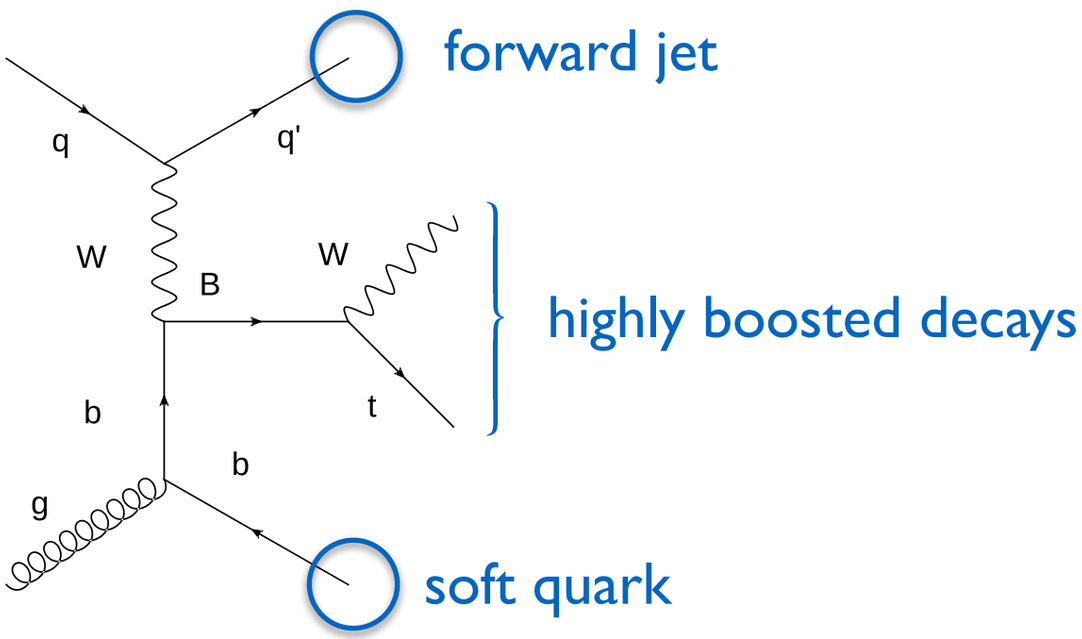


VLQ Single Production

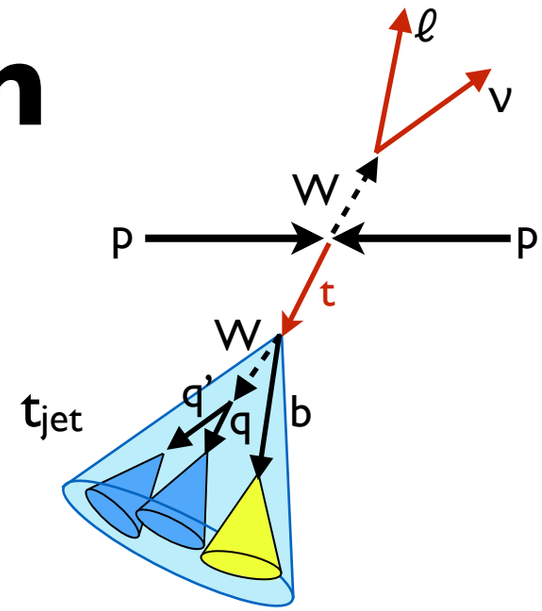
- Electroweak production can dominate for heavy VLQs
- Model dependent cross section:
  - Couplings (mixing parameters)
  - Weak quantum numbers
- Signature: one forward jet and associated production with a heavy quark

[J.A. Aguilar-Saavedra et al., PRD 88, 094010 (2013)]



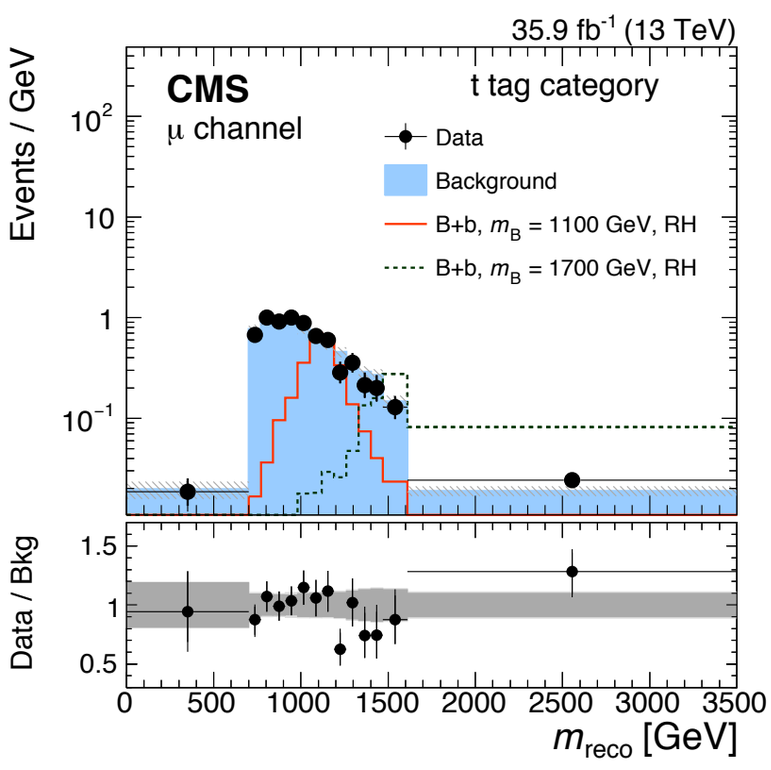


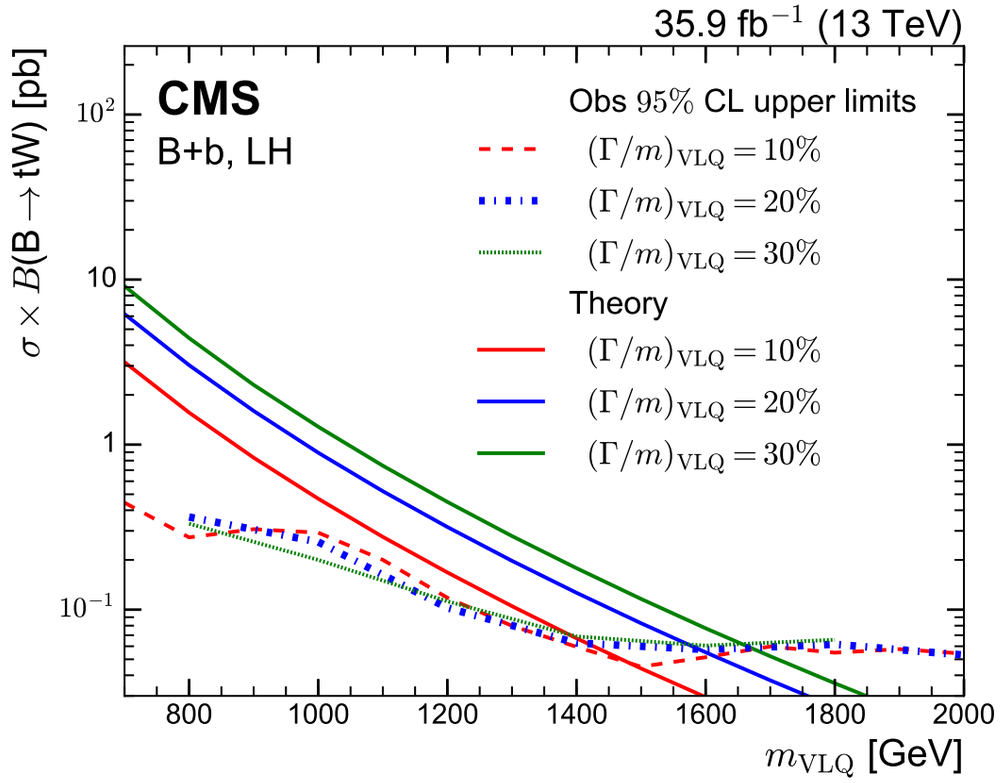
VLQ Single Production



Single B→tW (ℓ+jets)

- Various decay possibilities
  - Jet assignment through t tag or χ^2 probabilities
  - VLQ mass reconstruction with ~10% resolution
- SM backgrounds from control region without forward jet
  - Validation region: small χ^2 values

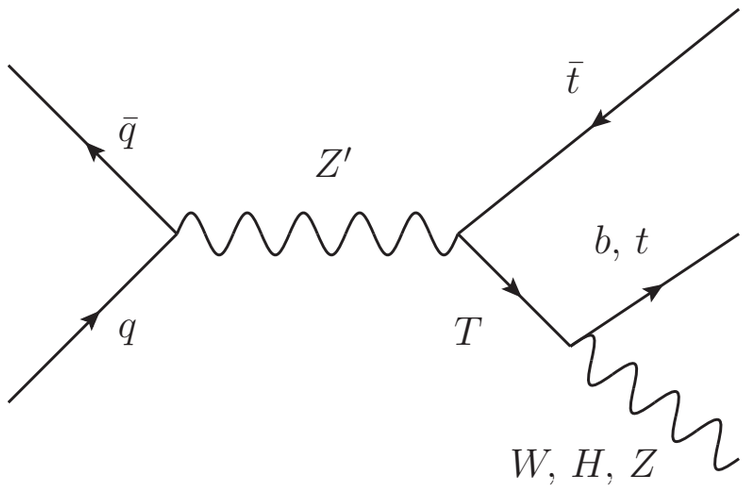




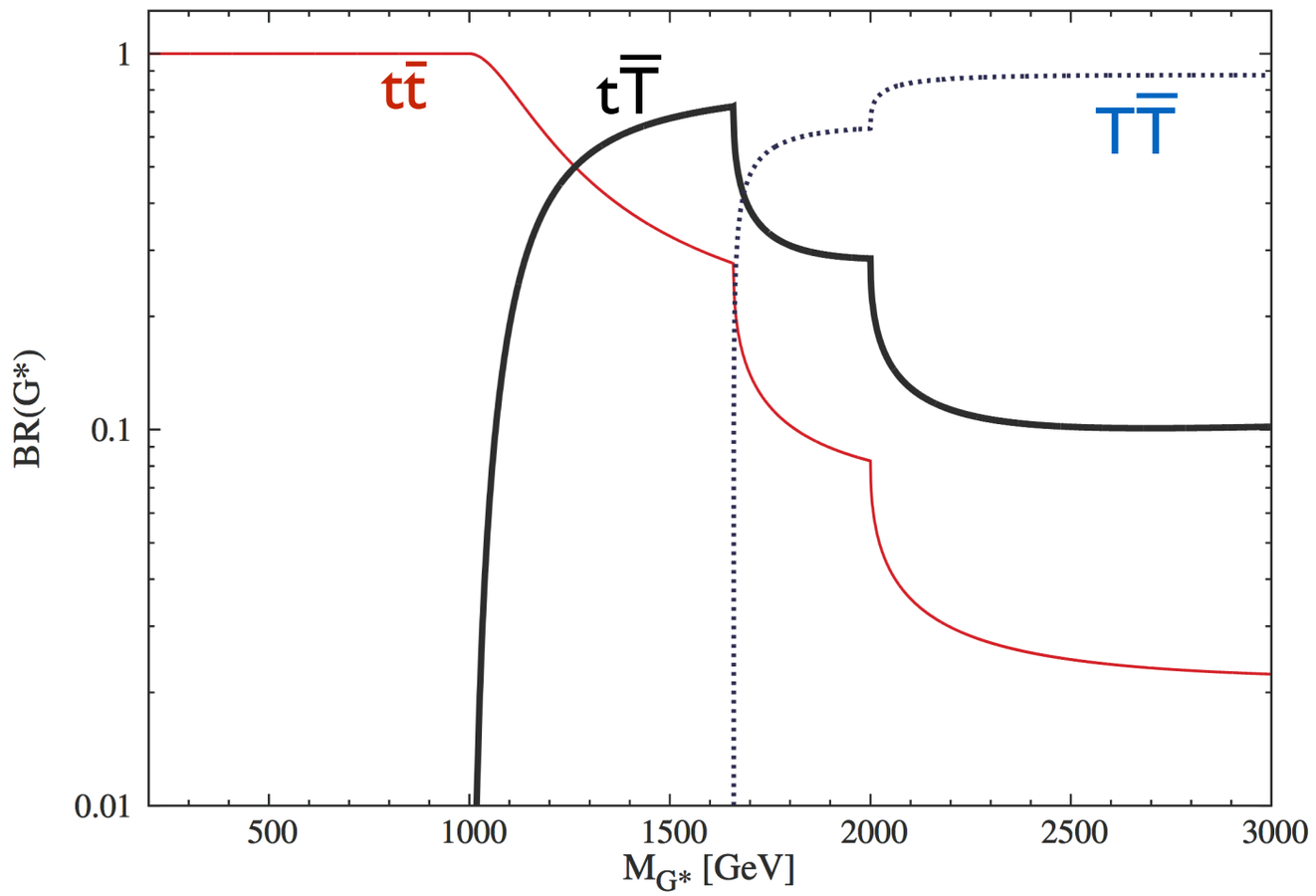
Resonant VLQ Production

No signals in $t\bar{t}$ or $T\bar{T}$ production

- Traditional searches: hole in sensitivity in $t\bar{T}$



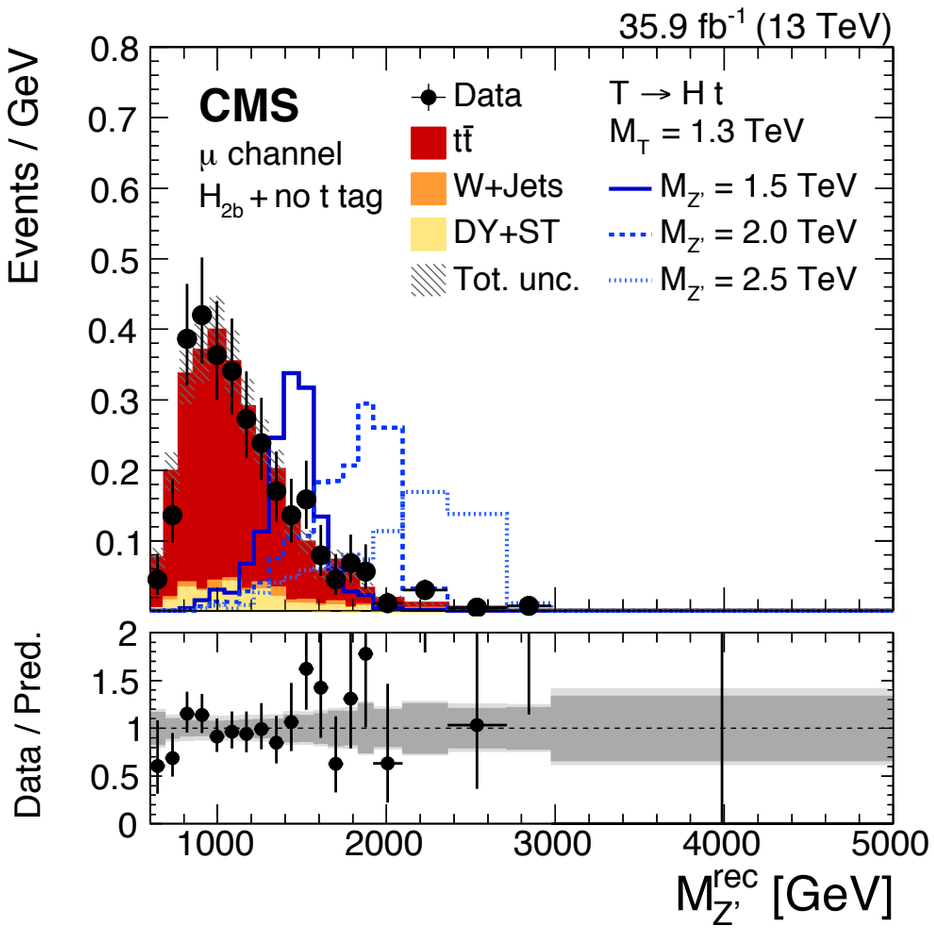
[C. Bini et al., JHEP 1201, 157 (2012)]

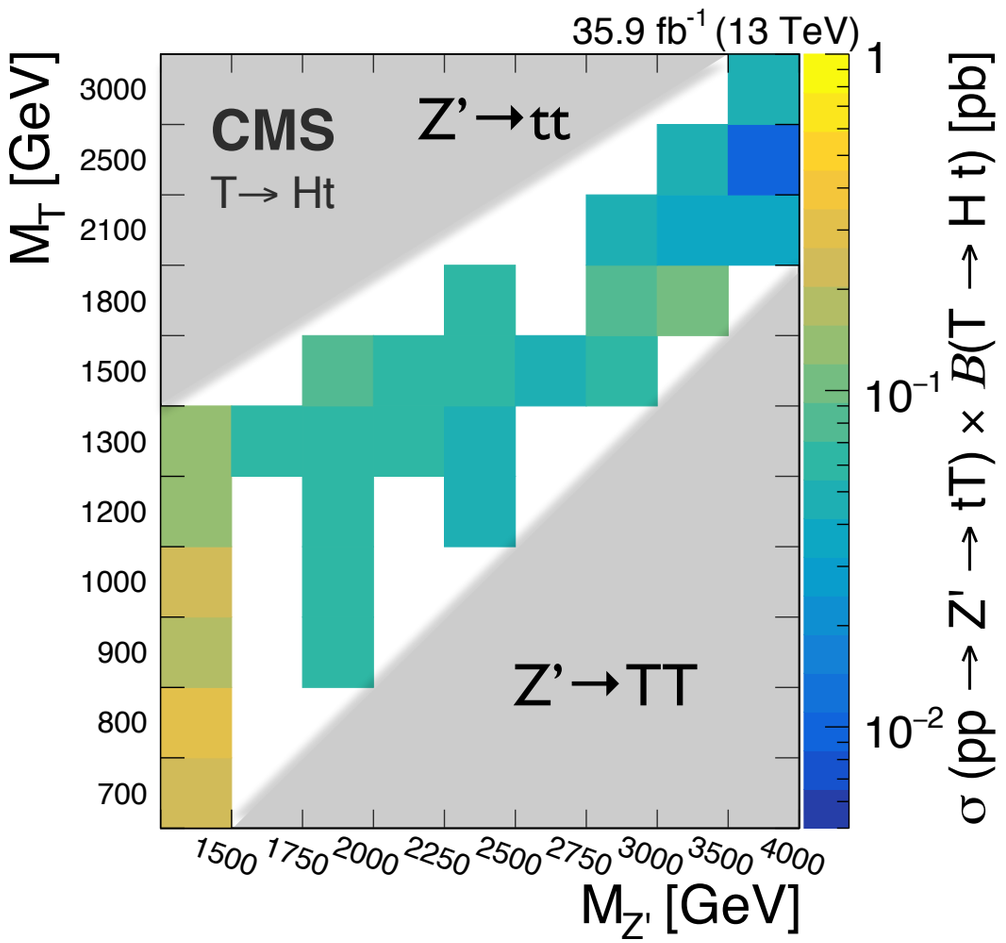


- Final state: resonant $t\bar{t}Z$ and $t\bar{t}H$ production
  - Collimation depends on ratio of Z' and T masses

Resonant VLQ Production

- Search with Z/W/H/t tags
  - Validation of efficiency and mis-identification rates
- Z' reconstruction through minimum of χ^2 term
- Constrain dominant backgrounds from control regions (W+jets, $t\bar{t}$)





The Intriguing Flavour Story

- No hints for BSM effects from direct searches so far
  - Never stop looking for all (im)possible signatures

The Intriguing Flavour Story

- No hints for BSM effects from direct searches so far
  - Never stop looking for all (im)possible signatures
- We can get inspired by existing riddles
  - Anomalies in flavour data:

$$R_{D^{(*)}} = \left. \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}l\bar{\nu})} \right|_{l\in\{e,\mu\}}$$ BaBar, Belle, LHCb **3.8 σ**

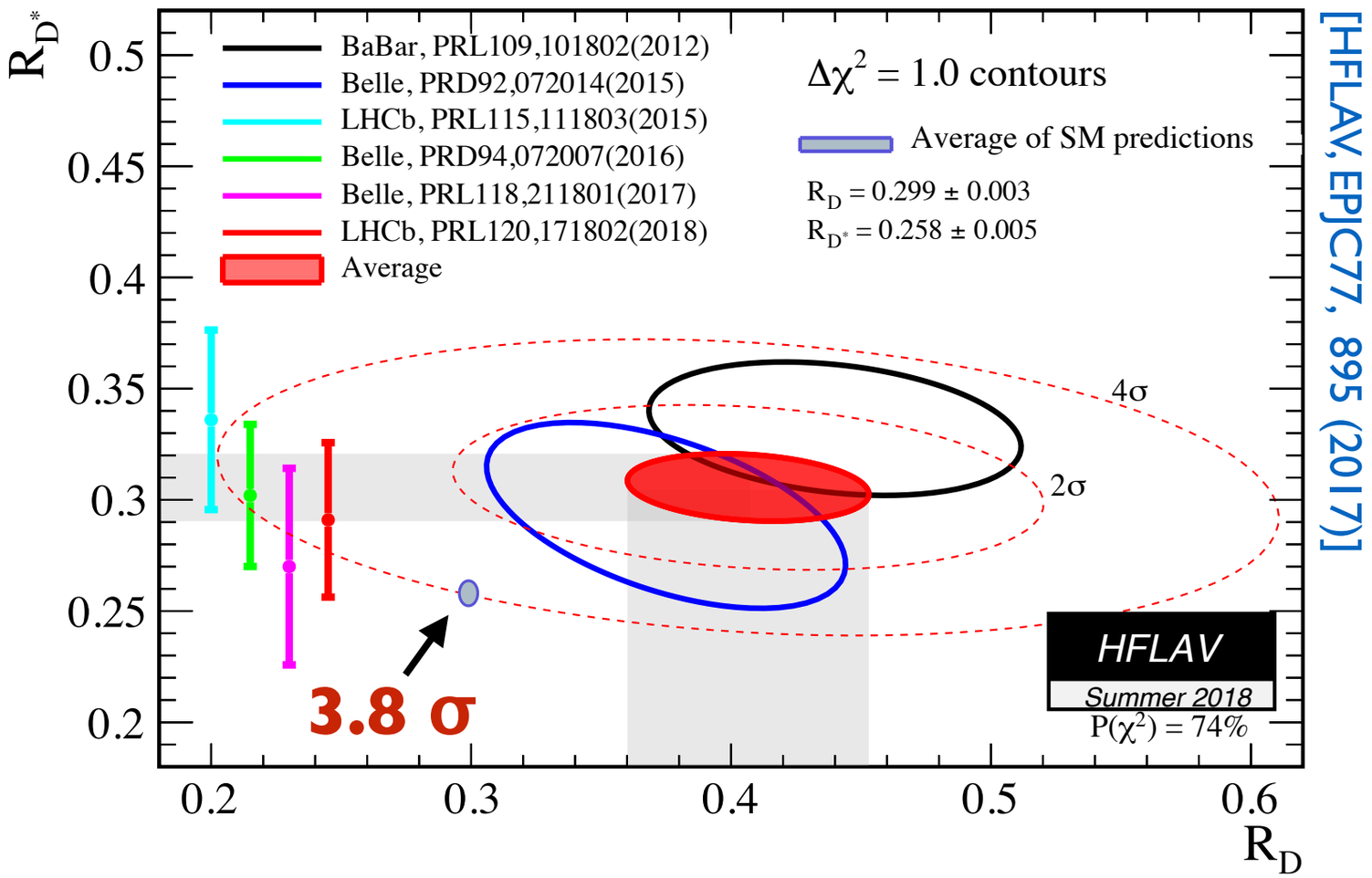
$$R_{J/\psi} = \frac{\mathcal{B}(B_c \to J/\psi\tau\bar{\nu})}{\mathcal{B}(B_c \to J/\psi\mu\bar{\nu})}$$ LHCb **2.0 σ**

$$R^{[q_1^2,q_2^2]}_{K^{(*)}} = \frac{\mathcal{B}'(B \to K^{(*)}\mu\mu)}{\mathcal{B}'(B \to K^{(*)}ee)}$$ LHCb **−2.5 σ**

$(g-2)_\mu$ E821, BNL **3.5 σ**

Consequences at high p_T?

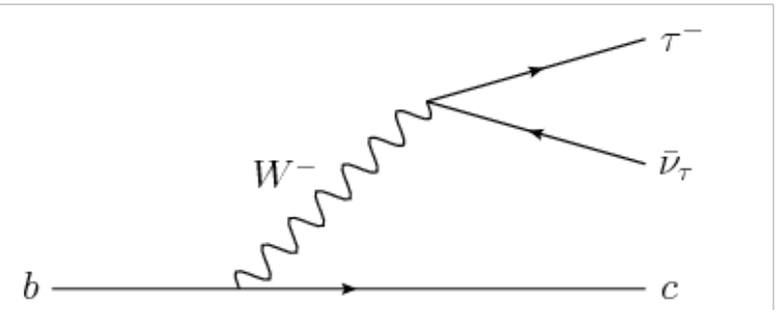
$R_{D(*)}$ and $R_{J/\psi}$



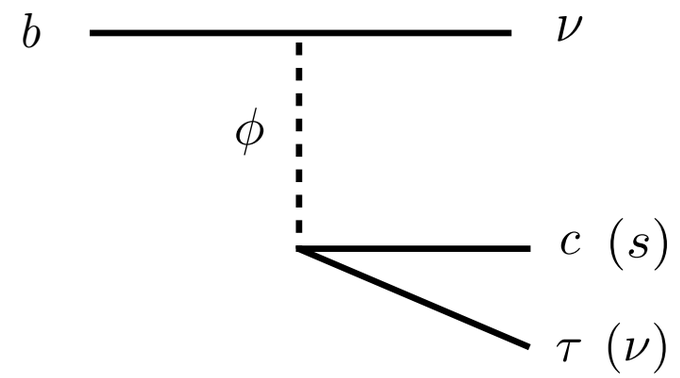
[HFLAV, EPJC77, 895 (2017)]

- Uncertainties in SM prediction
  - form factors for τ vs ℓ decay ~ m_τ
  - strong decay of D*
  - soft photon corrections
  - **total: ~4-5%**

SM weak decay



Possible BSM contribution from LQs

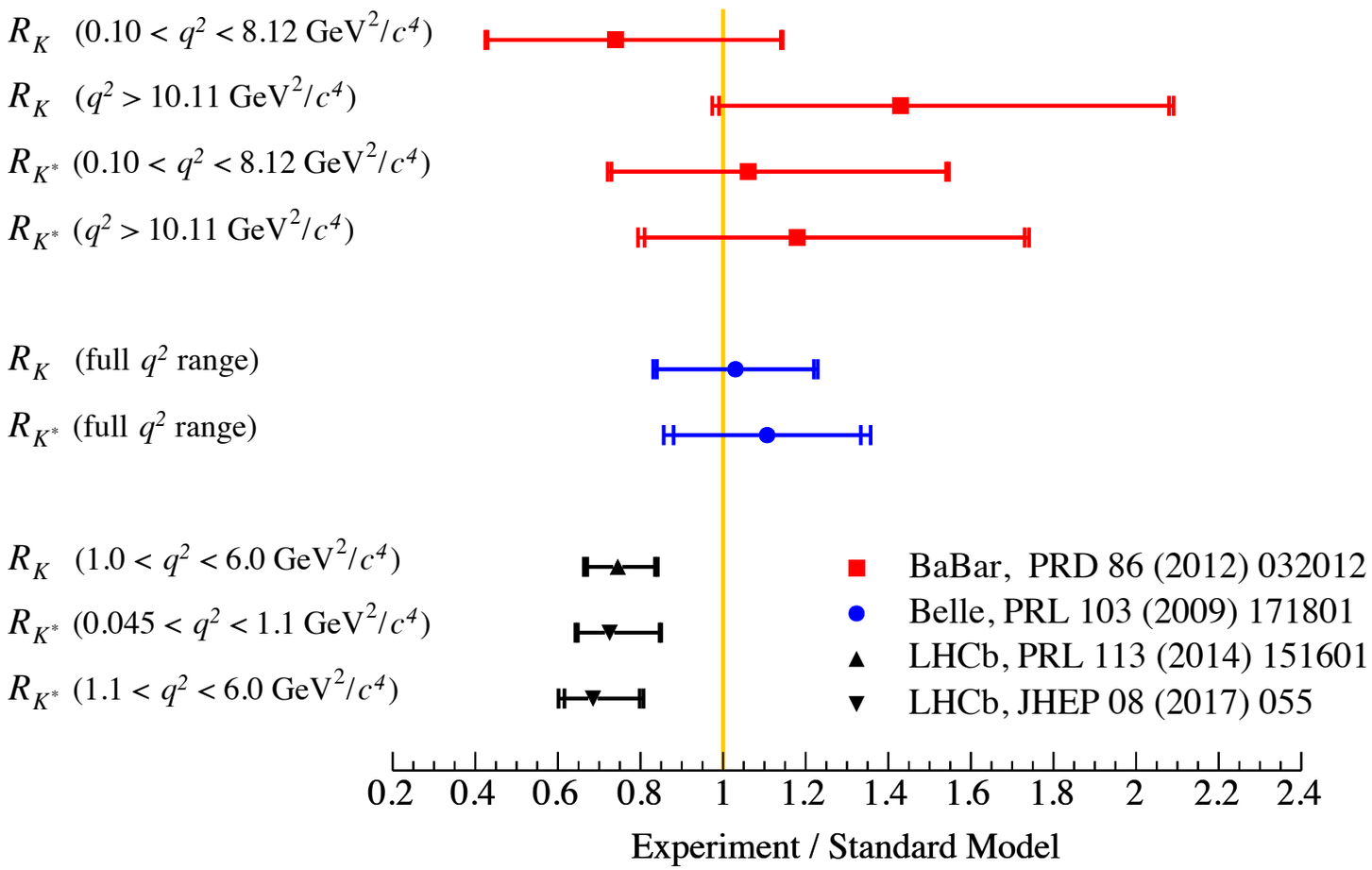


[Bauer, Neubert, PRL 116, 141802 (2016)]

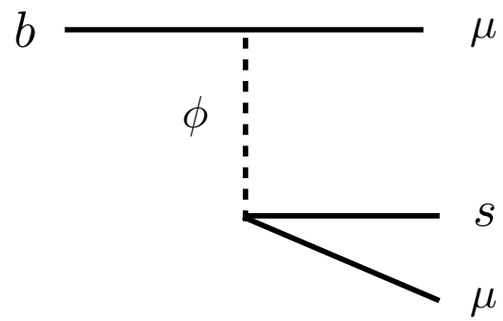
LQ couplings
tree-level: **bτ, cν, cτ, bν**
loop: **tτ, sν, sτ, tν**

$R_{K(*)}^{[q_1^2,q_2^2]}$

[Bifani et al.,arXiv:1809.06229]

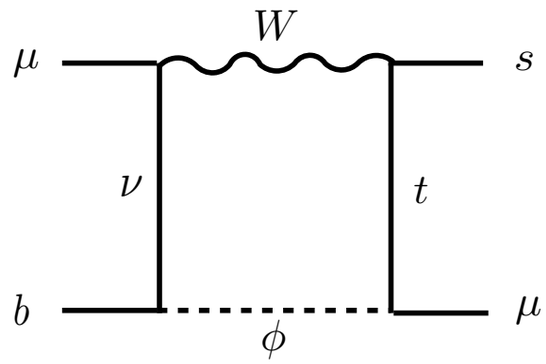


- Hadronic effects negligible
  - except with LFUV, then could have an effect
- LHCb measurements below SM by 2.1 - 2.6σ



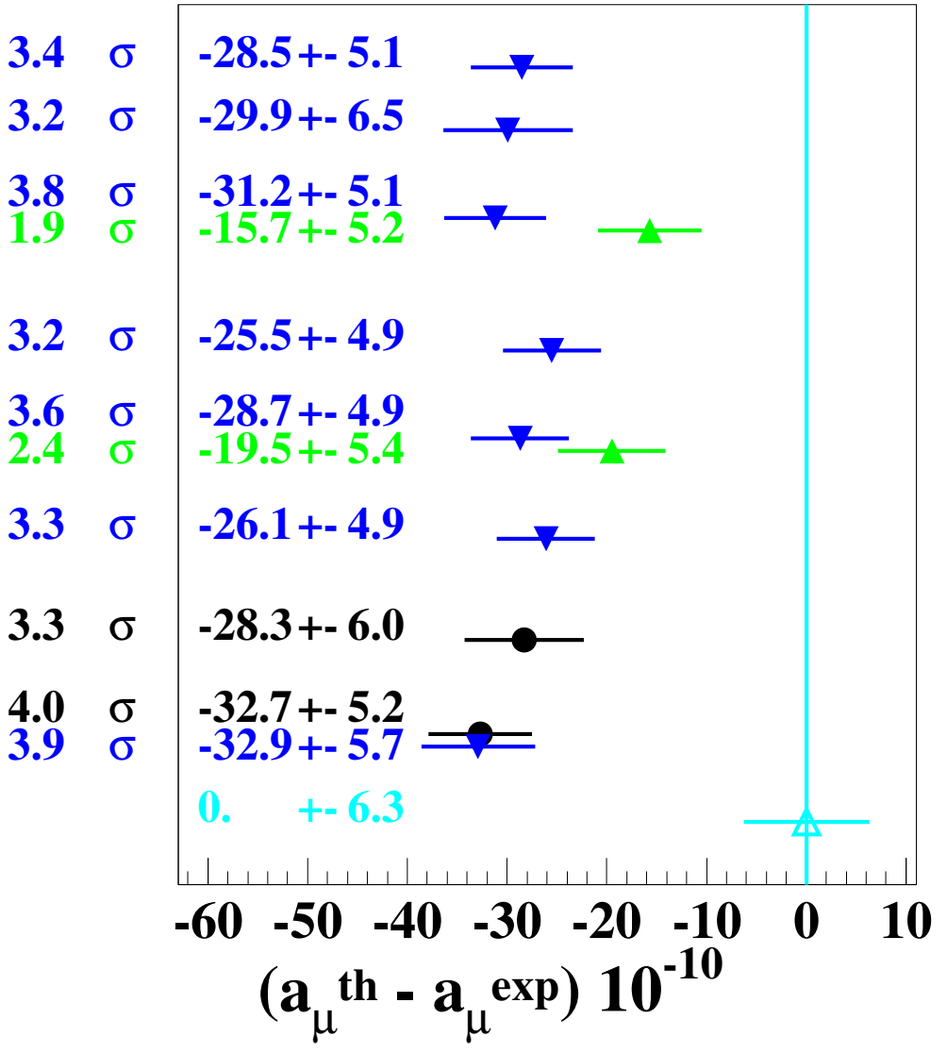
LQ couplings at tree-level: **sμ, bμ**

Can lead to enhancement of SM prediction



LQ couplings loop-induced: **tμ, cμ**

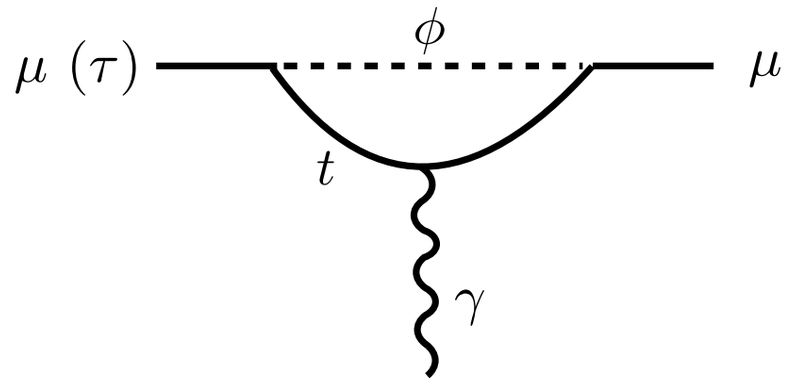
$(g-2)_\mu$



e^+e^-	Hagiwara+ Phys. Lett. B 649 (2007) 173
e^+e^-	Jegerlehner+ Phys. Rep. 477 (2009) 1
e^+e^- / τ	Davier+ Eur.Phys.J. C 66 (2010) 127
e^+e^-	Davier+ Eur.Phys.J. C66 (2010) 1
e^+e^- / τ	Davier+ Eur.Phys.J. C71 (2011) 1515
e^+e^-	Hagiwara+ J.Phys. G38 (2011) 085003
$e^+e^- + \tau$	Jegerlehner+ Eur.Phys.J. C71 (2011) 1632
$e^+e^- + \tau$ / e^+e^-	Jegerlehner arXiv:1511.04473
BNL-E821	Bennett+ Phys. Rev. D73 (2006) 072003

[D. Bernard, arXiv: 1607.07181]

- About 3σ deviation, depending on $\Delta\alpha_{had}$ (e^+e^- or τ decays)
- LQ couplings loop-induced: **tμ**



LQ Phenomenology

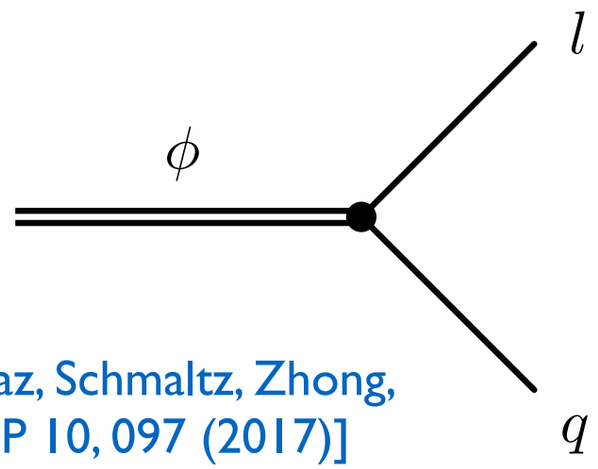
- Nature of possible LQs
  - Model dependent
  - Additional constraints from B(B→Kνν), Δm_{Bs}, $D_{(s)}$→μν…
  - Global fits to flavour data: suggest at least one LQ state with mass O(1-3) TeV

	Y	Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
scalar	1/3	S_1	✗*	✓	✗*
	7/6	R_2	✗*	✓	✗
	1/6	$\widetilde{R_2}$	✗	✗	✗
	1/3	S_3	✓	✗	✗
vector	2/3	U_1	✓	✓	✓
	2/3	U_3	✓	✗	✗

Combinations of scalar LQs can explain $R_{K^{(*)}}$ and $R_{D^{(*)}}$, e.g. S_1 and S_3 [79]

[Angelescu et al., arXiv:1808.081

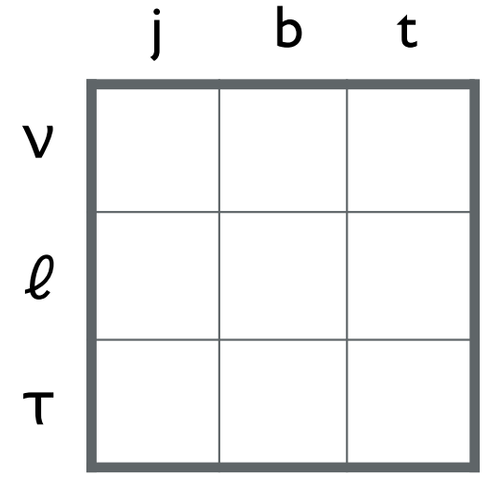
- Probe the full flavour matrix!



[Diaz, Schmaltz, Zhong, JHEP 10, 097 (2017)]

$$Y_{L,R} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & Y_{L,R}^{c\mu} & Y_{L,R}^{c\tau} \\ 0 & Y_{L,R}^{t\mu} & Y_{L,R}^{t\tau} \end{pmatrix}$$

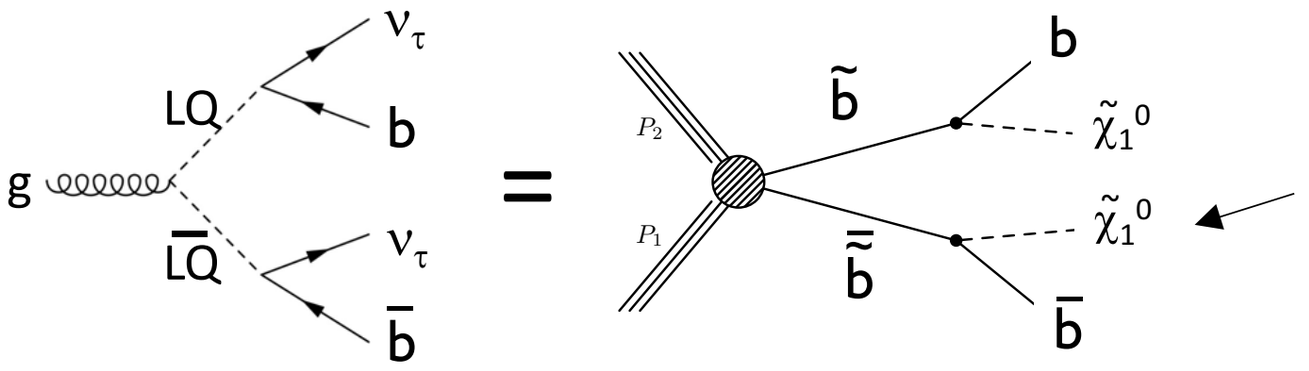
and $\ell_i \to \nu_i$



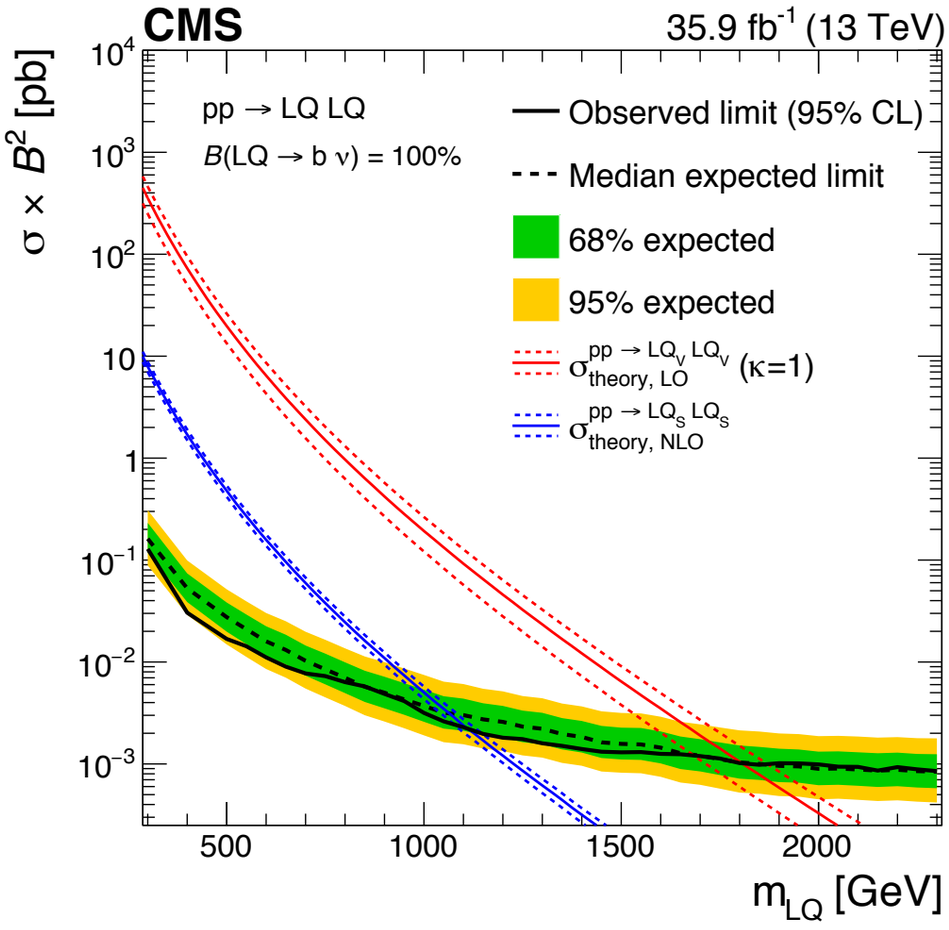
LQ Pair → νν+bb̄(qq̄)

[CMS, PRD 98, 032005 (2018)]

- Reinterpretation of SUSY M_{T2} sbottom search



Both $\tilde{b}$ and LQ are scalar
→ Equivalent under
$m(\chi_1^0) = m(LSP) = 0$



Mass exclusions

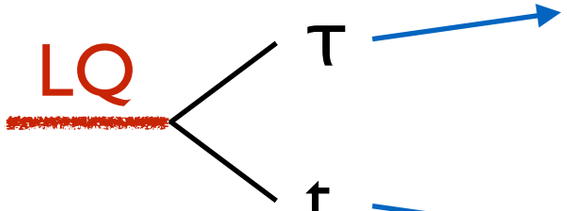
scalar LQs → bν: 1.1 TeV
vector LQs → bν: 1.8 TeV

scalar LQs → tν: 1.0 TeV
vector LQs → tν: 1.8 TeV

Relevant for $R_{D(*)}$ and $R_{K(*)}$

LQ Pair → $\tau\bar{\tau}+t\bar{t}$

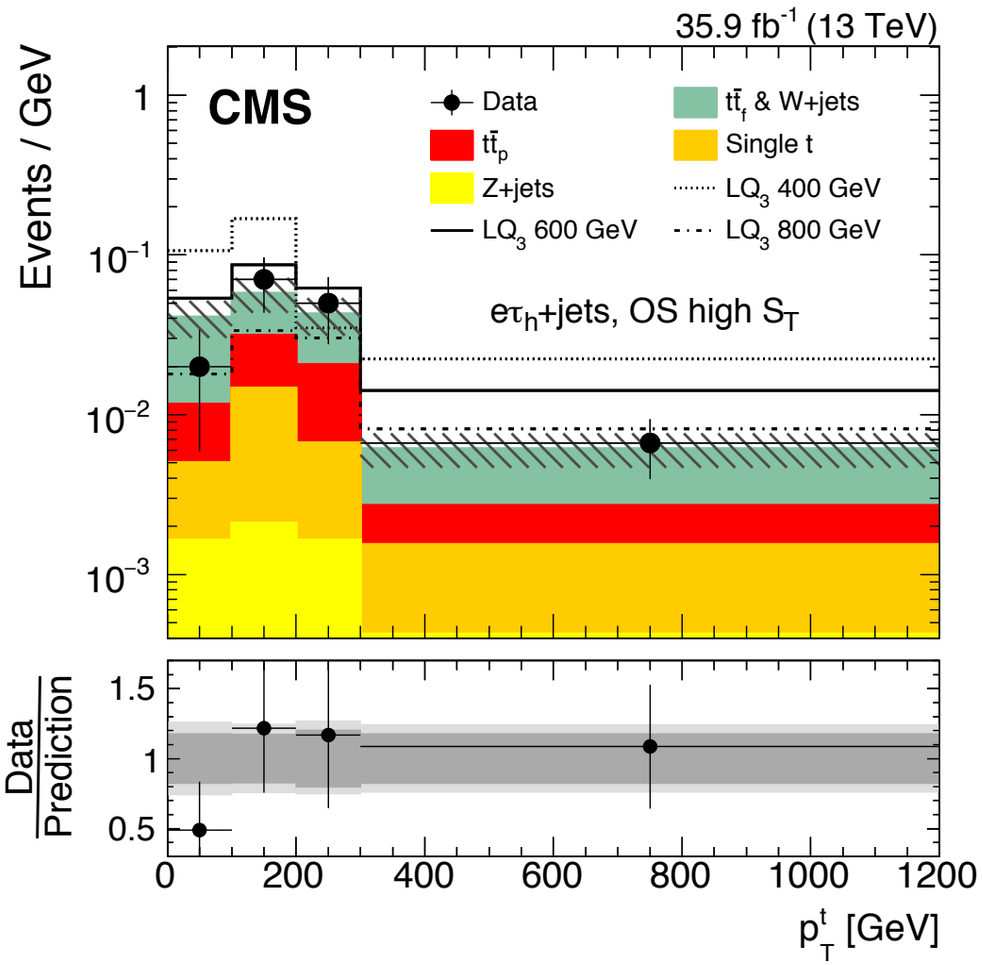
[CMS, EPJC 78, 707 (2018)]

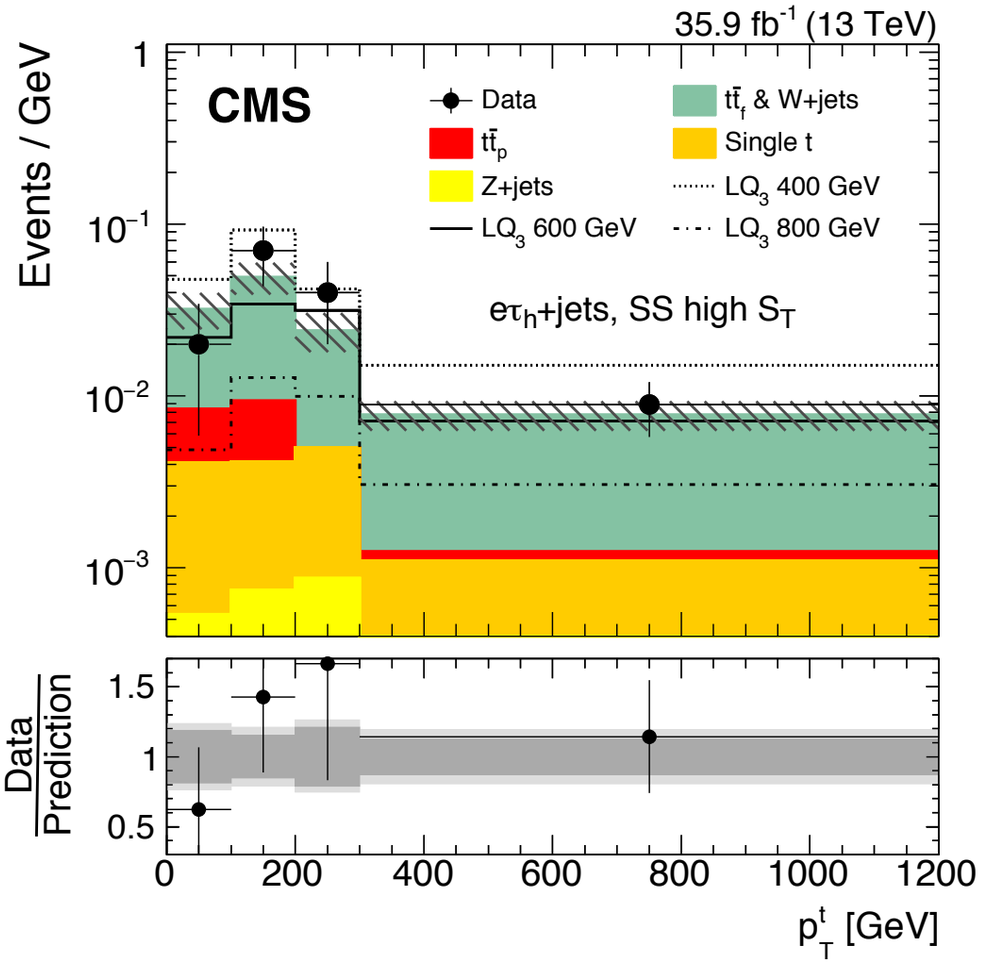


Background estimation through ID inversion

Reconstruct top decay: p^t_T sensitive to m_{LQ}

- Cat A: ℓ + 2τ_h + jets
  Sensitivity for low m_{LQ}
- Cat B: ℓ + τ_h + jets
  Sensitivity for high m_{LQ}



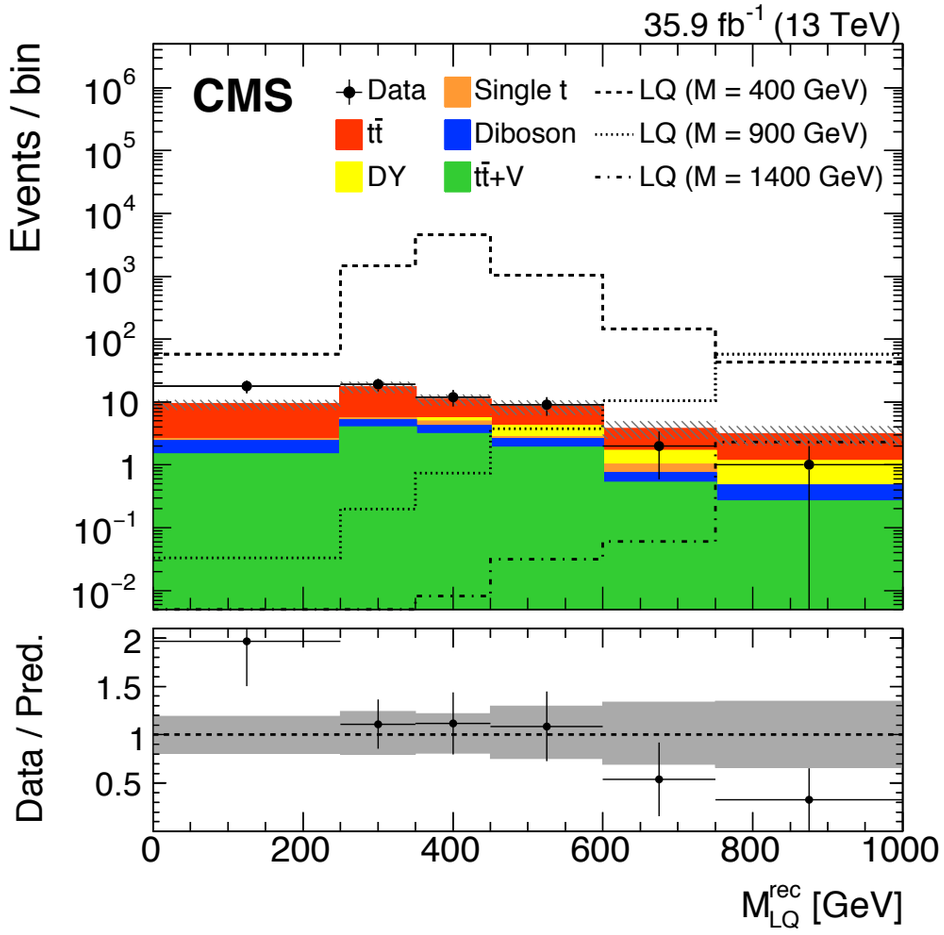


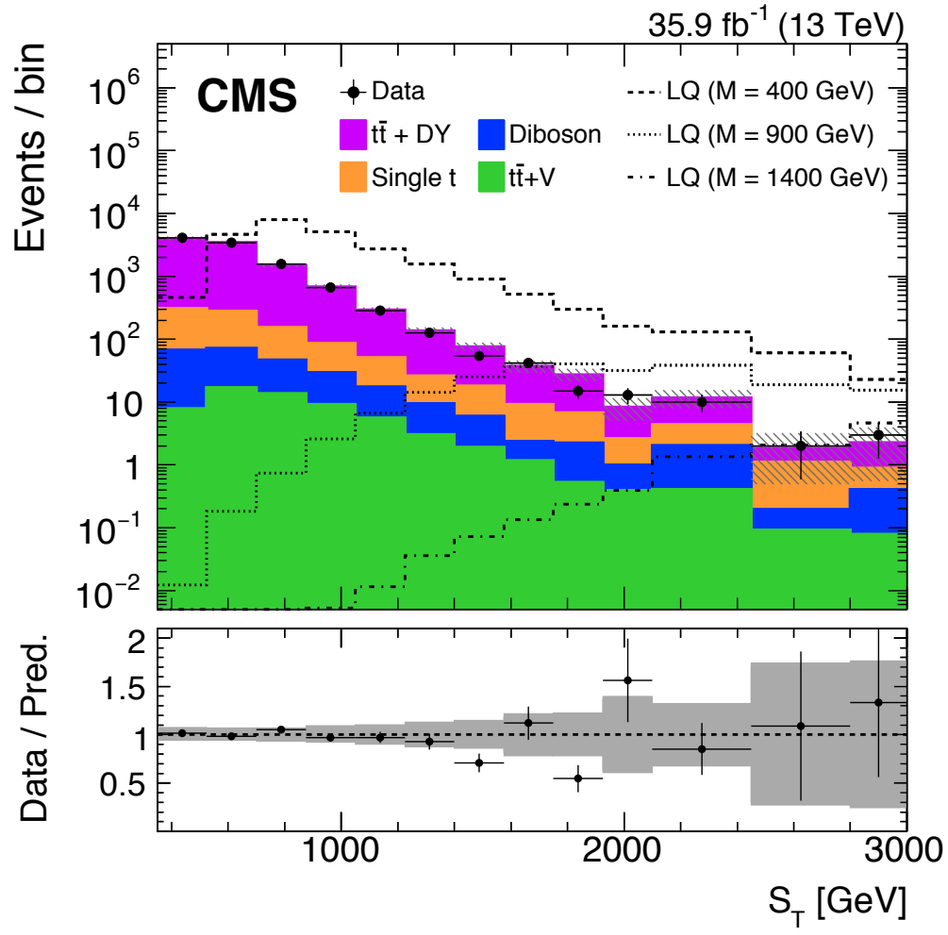
LQ Pair → μμ̄+tt̄ [CMS, PRL 121, 241802 (2018)]

- Up to 4 leptons in final state
  - two signal regions: 2μ+ℓ+jets and 2μ+jets

reconstruct M_{LQ} → measured e and μ misID

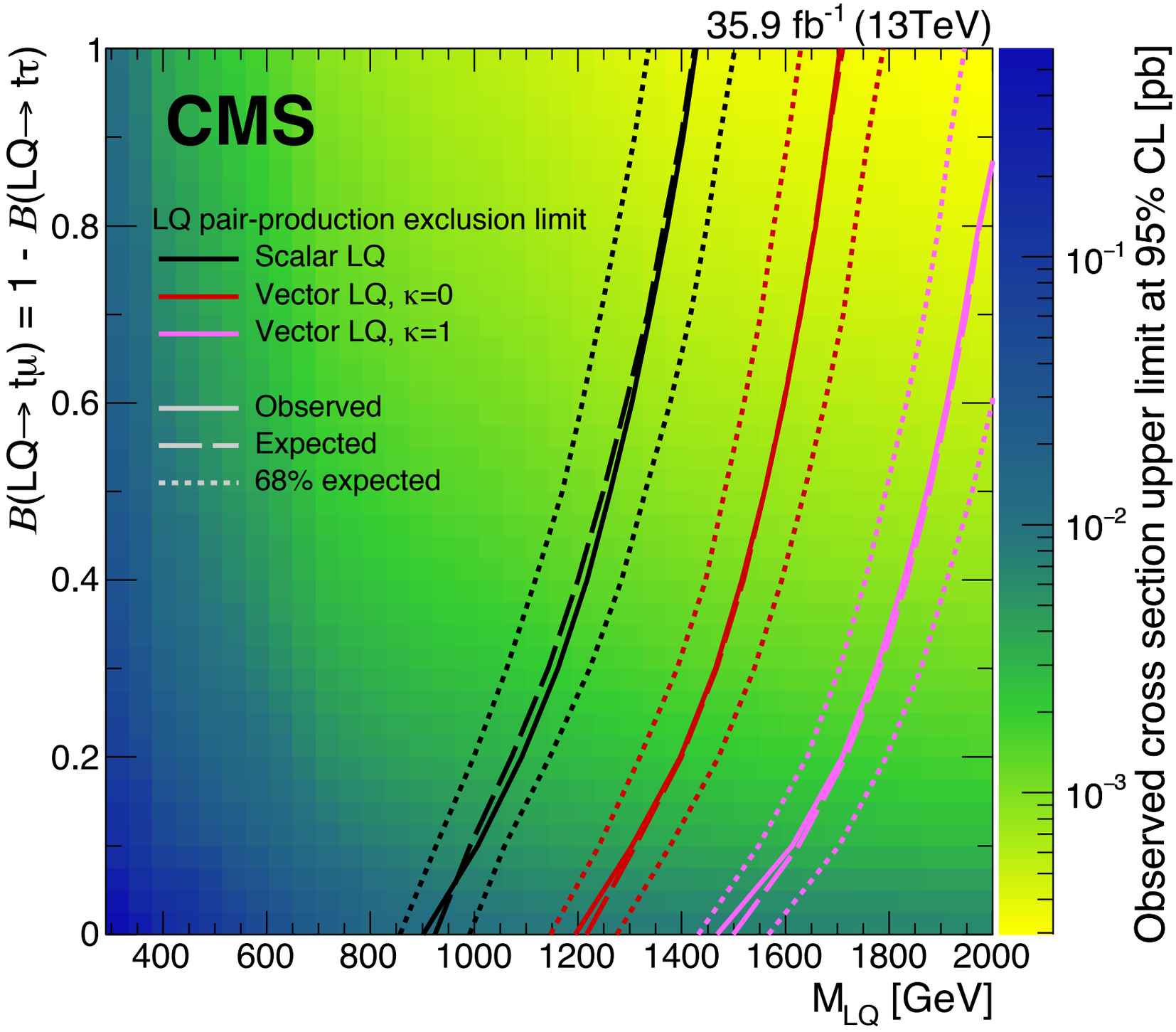
measure S_T → tt̄+DY obtained from 2e+jets CR





Combination

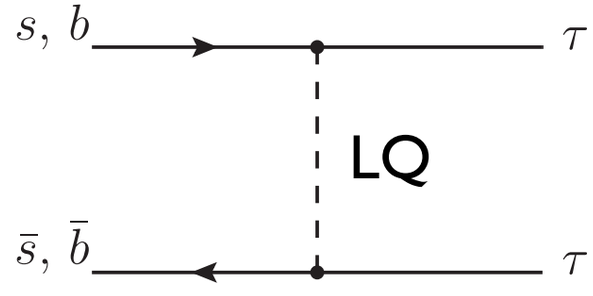
[CMS, PRL 121, 241802 (2018)]



Exclusion between **0.9** and **1.4 TeV** for tτ and tμ (scalar LQs)

Relevant for $R_{D^{(*)}}$, $R_{K^{(*)}}$ and $(g-2)_\mu$

Numerous other interesting channels to explore…



Improving Jet Substructure

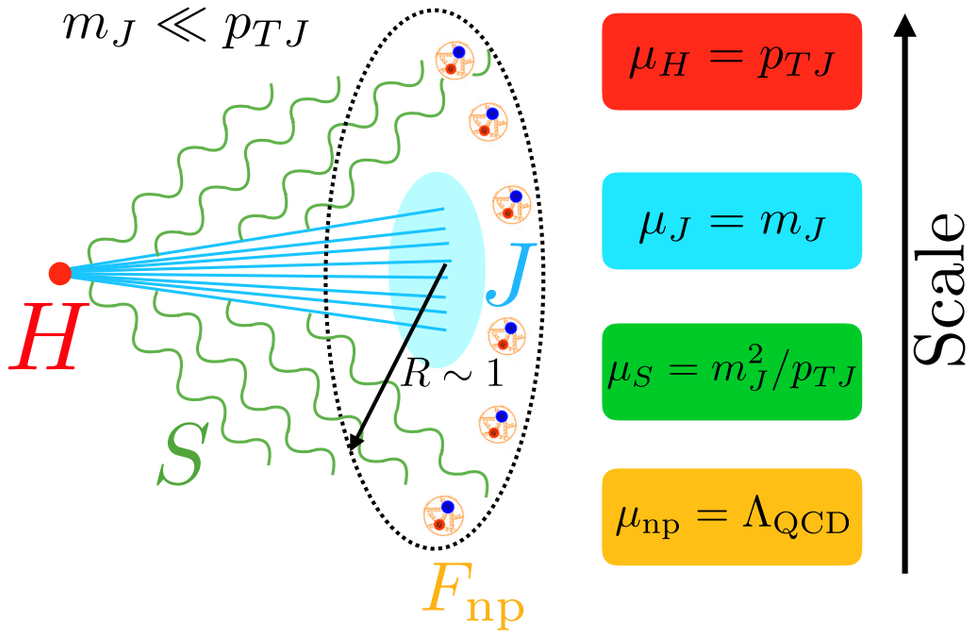
Substructure Taggers

- Groomer (trimming, pruning, mMDT, soft drop…)
- Selection on substructure variables (mass, τ_N, D_N, N_N…)
- Dedicated algorithms (Johns Hopkins, HEP, HOTVR…)
- Machine learning taggers

Impossible to name them all…

Analytical calculations

- Complicated: different scales involved
- Many calculations completed recently
- Knowledge not fully exploited



[Larkoski, Moult, Nachmann, arXiv:1709.04464]

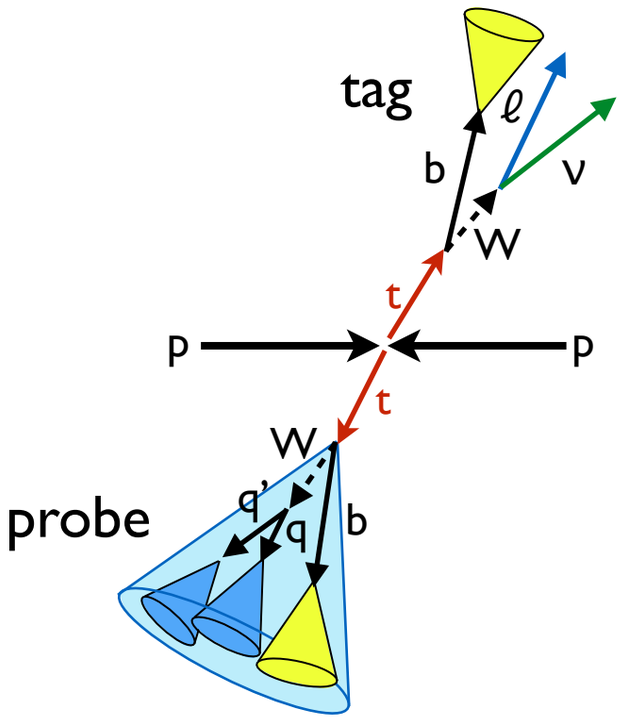
Application in analyses

- Commissioning: dedicated measurements!
- Systematic uncertainties important for performance

Efficiency Measurements

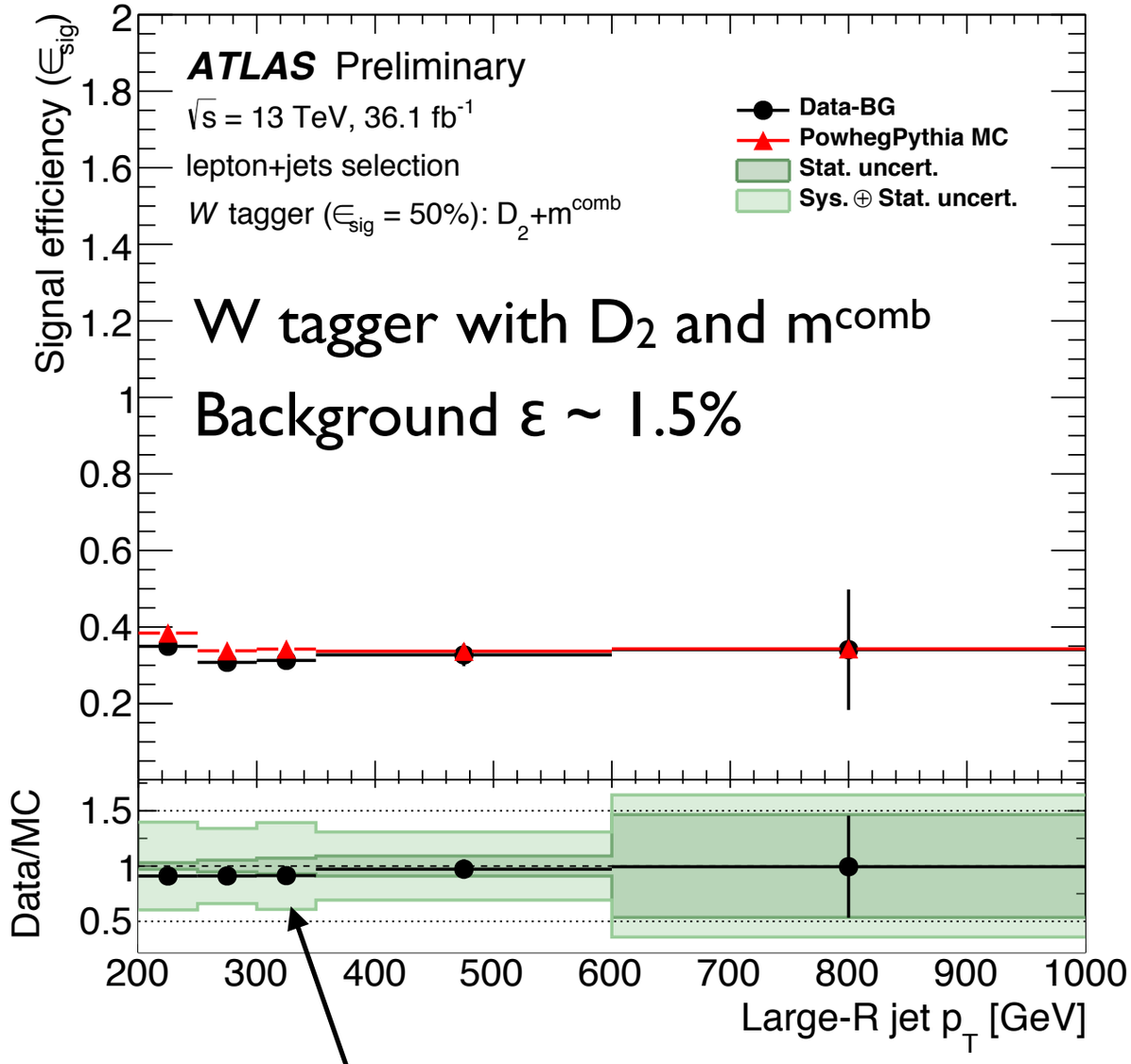
Tag-and-probe measurements

- $t\bar{t}$ production for W and t



- extrapolations to Z and H from simulation

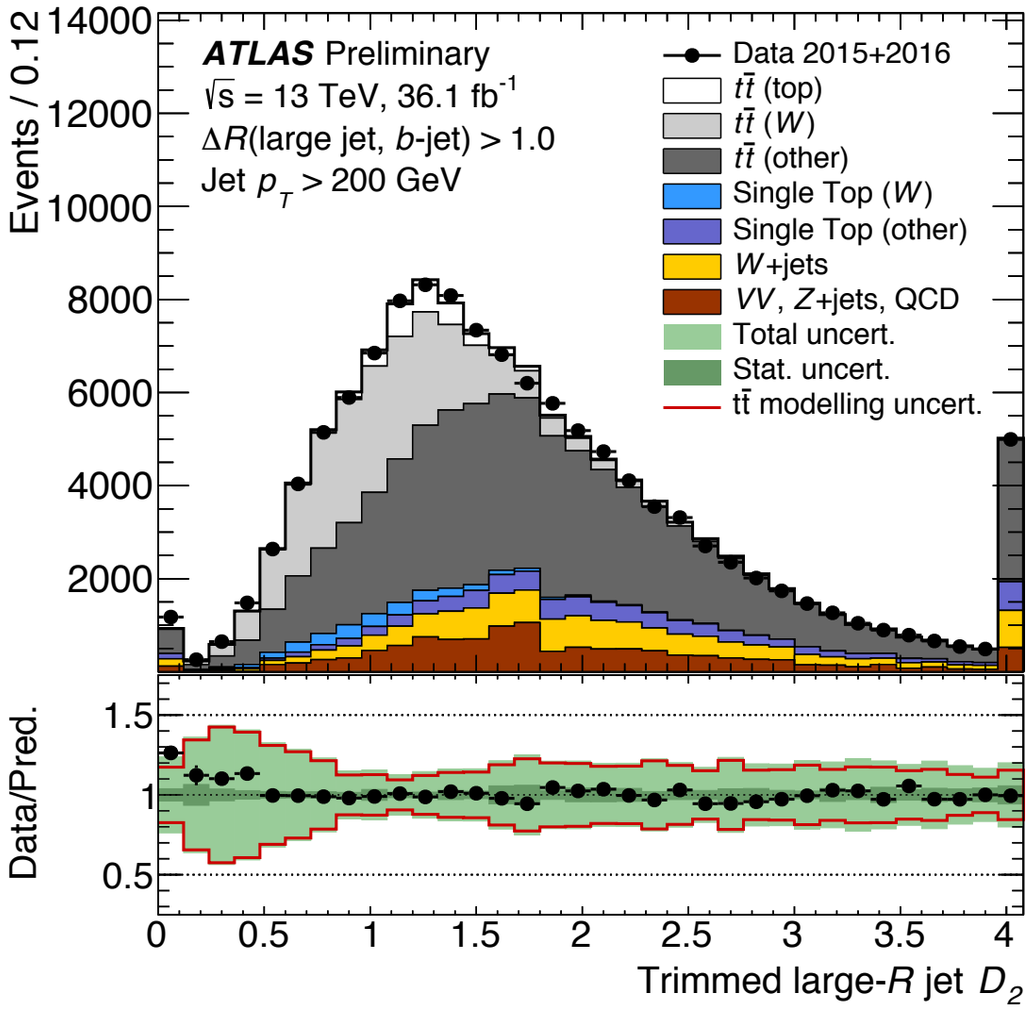
[ATLAS-CONF-17-064]



systematic uncertainty by factor ~5 larger than statistical uncertainty

Modelling of D_2

[ATLAS-CONF-17-064]

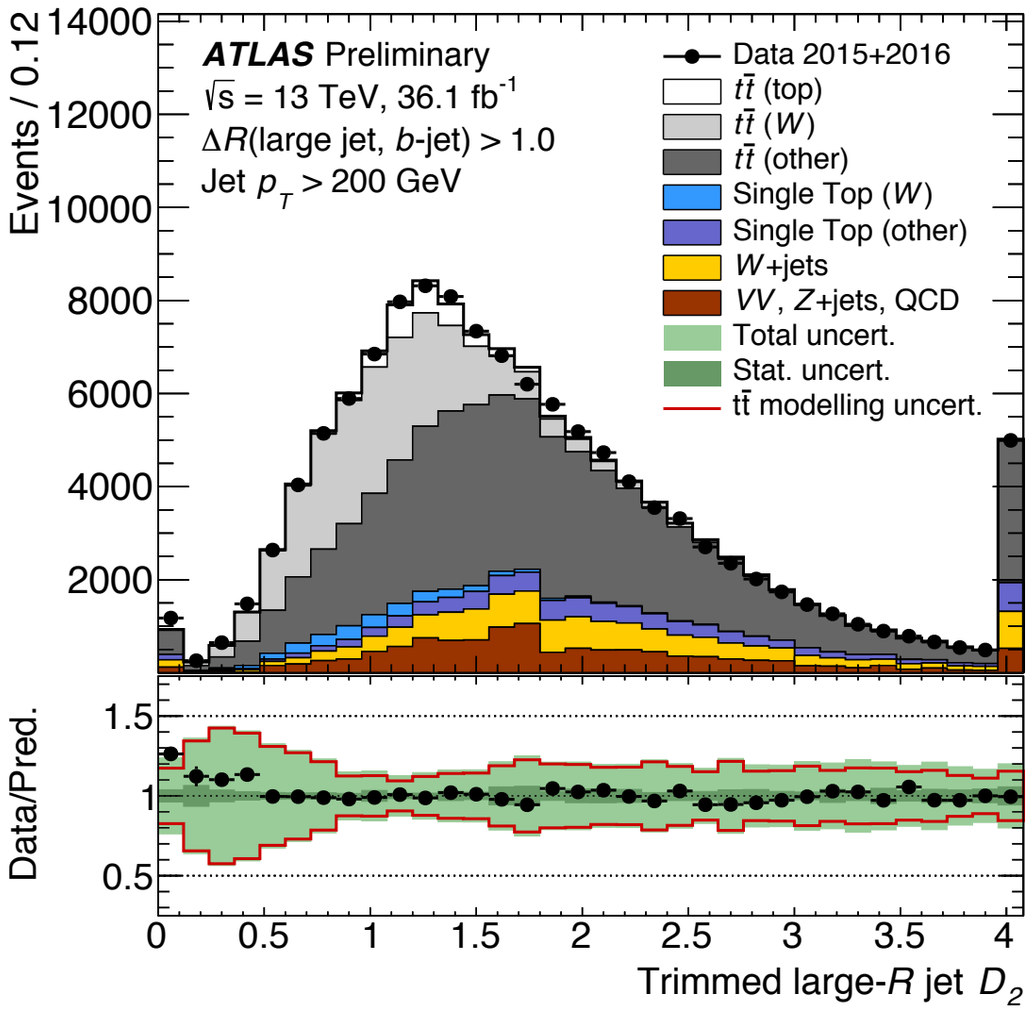


Large modelling uncertainties (radiation, hadronization)

Expected?

Modelling of D_2

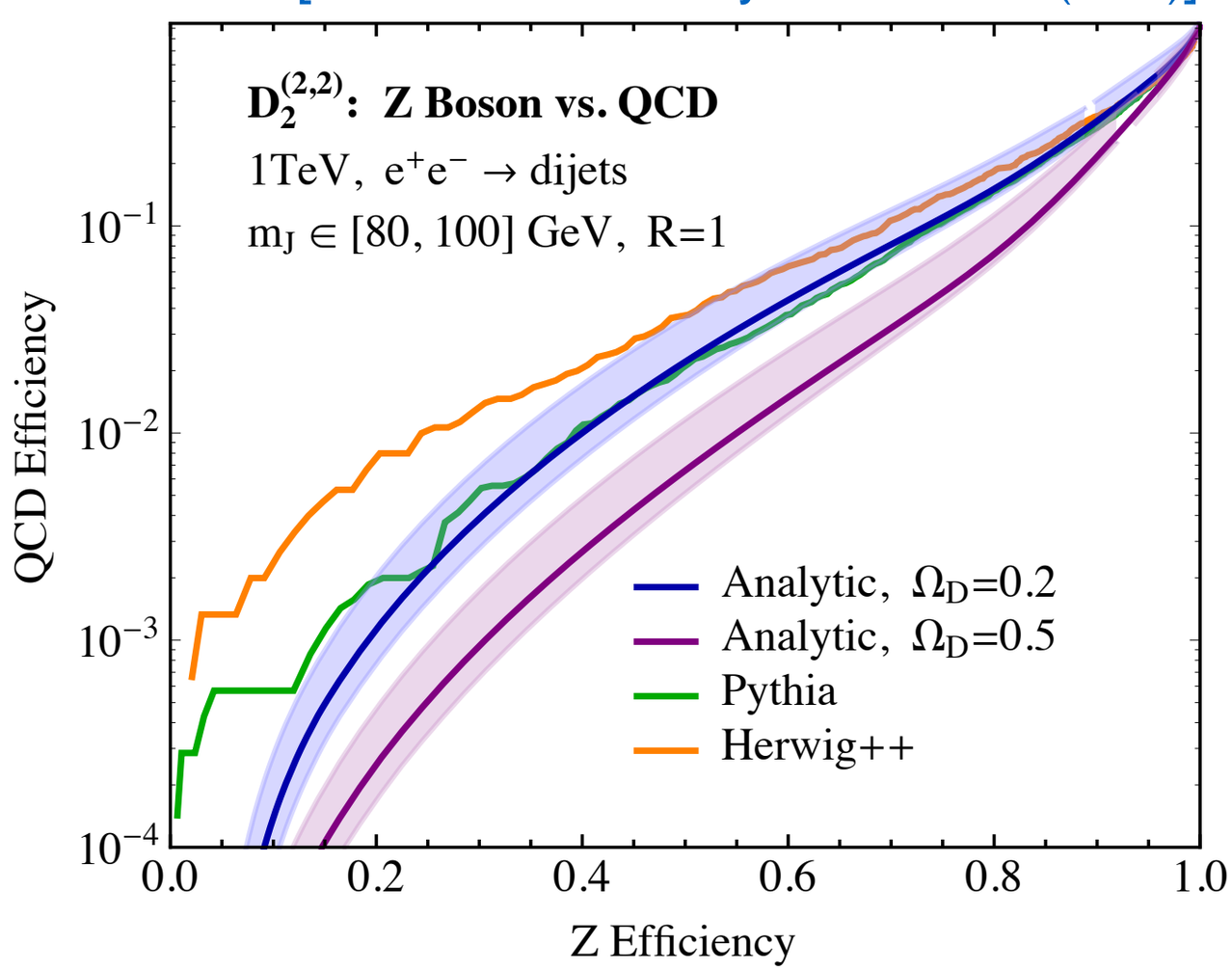
[ATLAS-CONF-17-064]



Large modelling uncertainties (radiation, hadronization)

Expected?

[Larkoski, Moult, Neill, JHEP 1605, 117 (2016)]

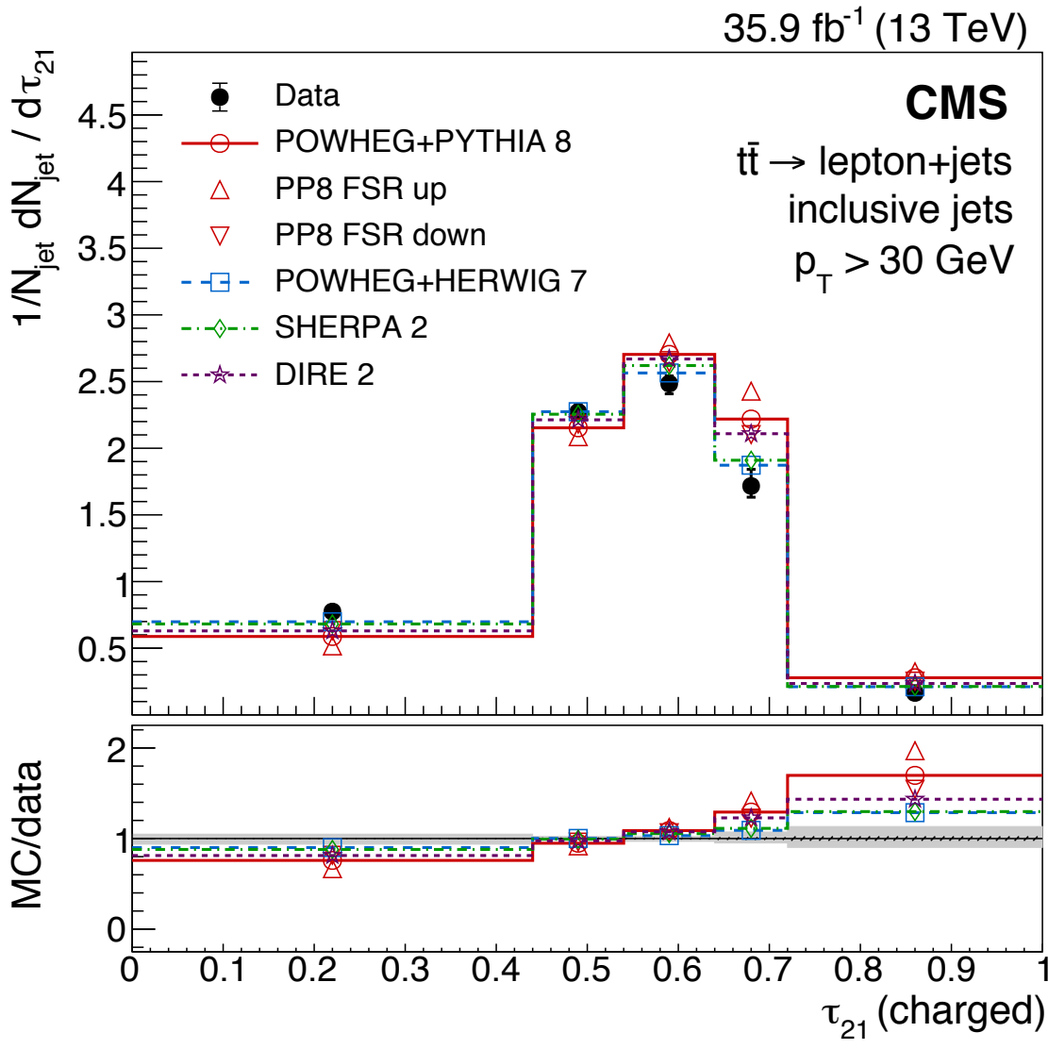


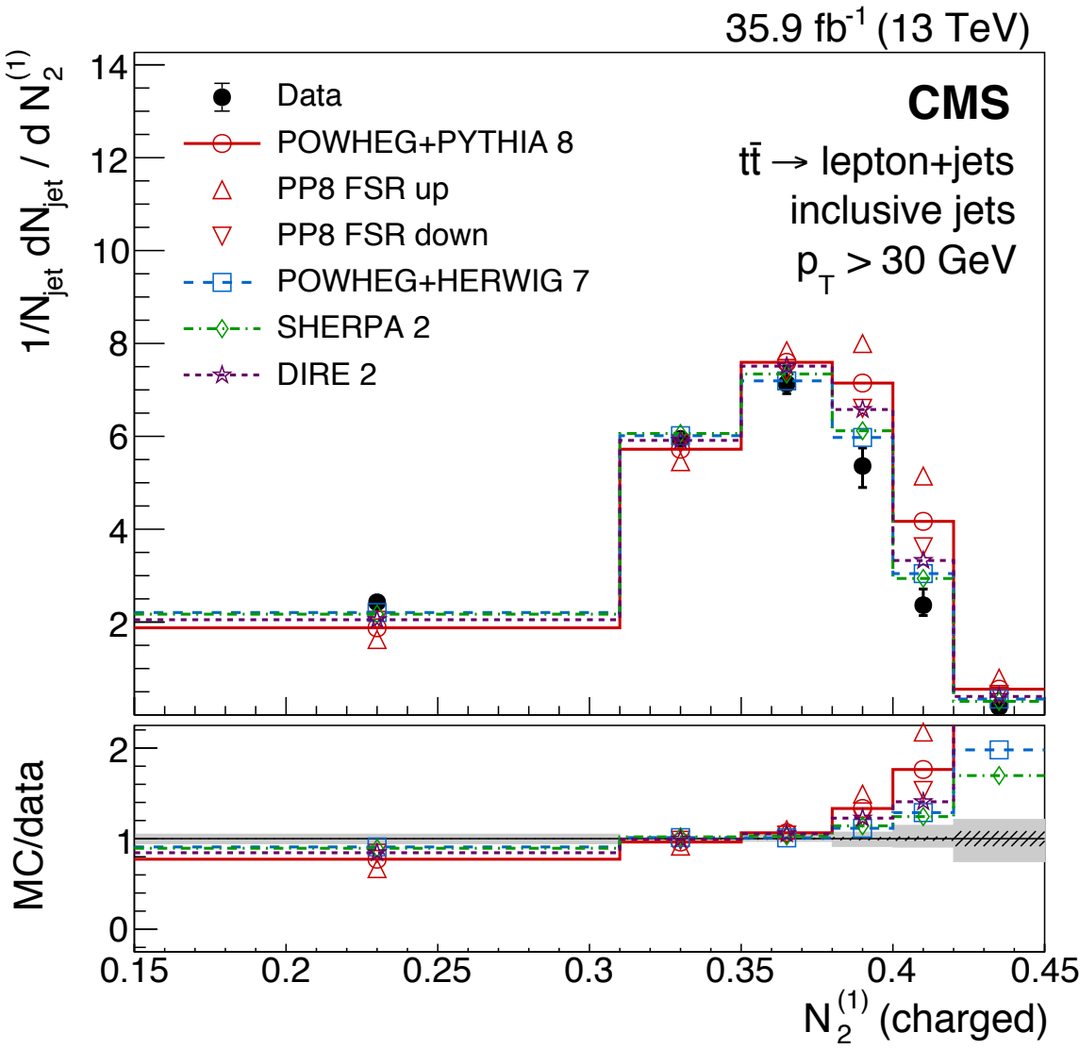
Two-prong structure: smaller phase space for perturbative radiation

→ larger sensitivity to NP effects

Power to the Data: 1. Measurements

[CMS, PRD 98, 092014 (2018)]

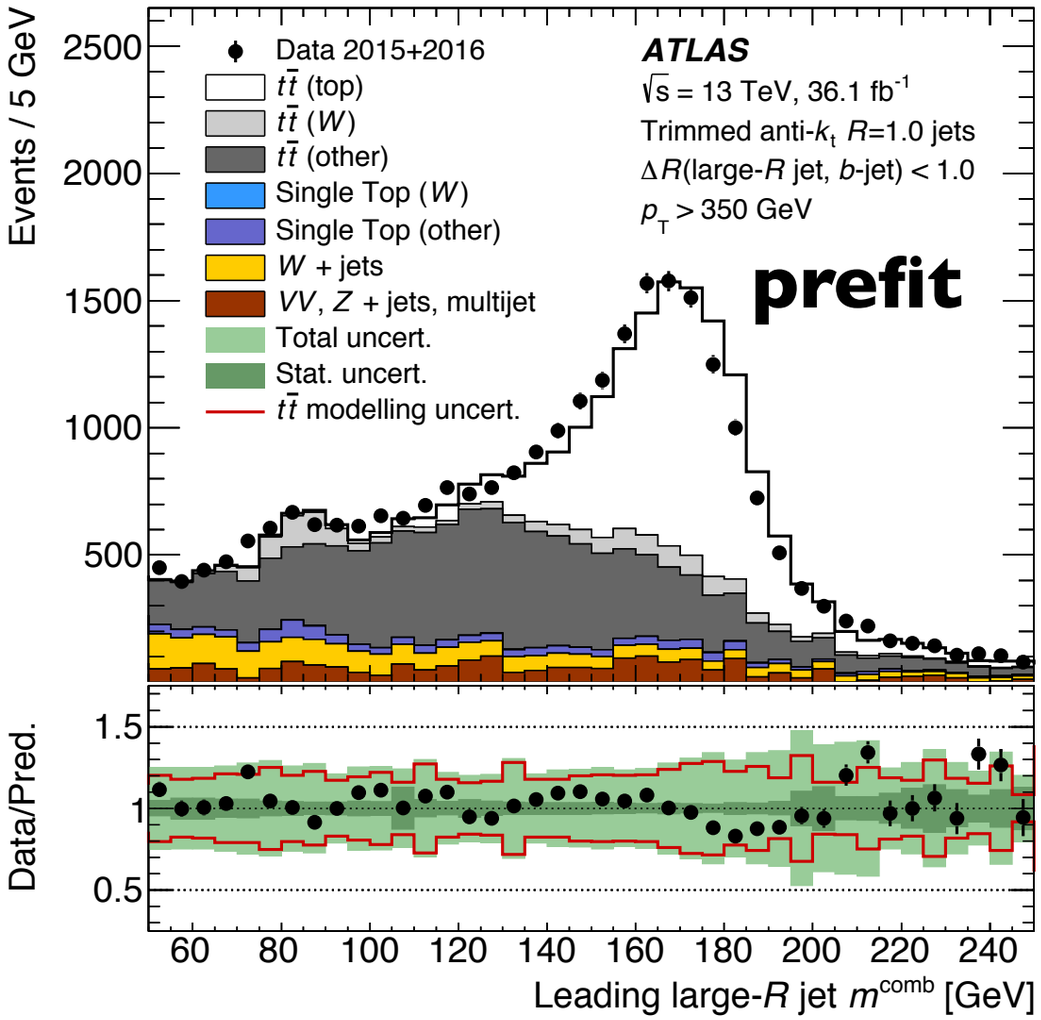




- Unfolded distributions in tt̄ production: great!
- Measurement on inclusive small-R jets: 1-prong
- Two- and three-prong measurements not available yet

Power to the Data: 2. In-Situ-Det.

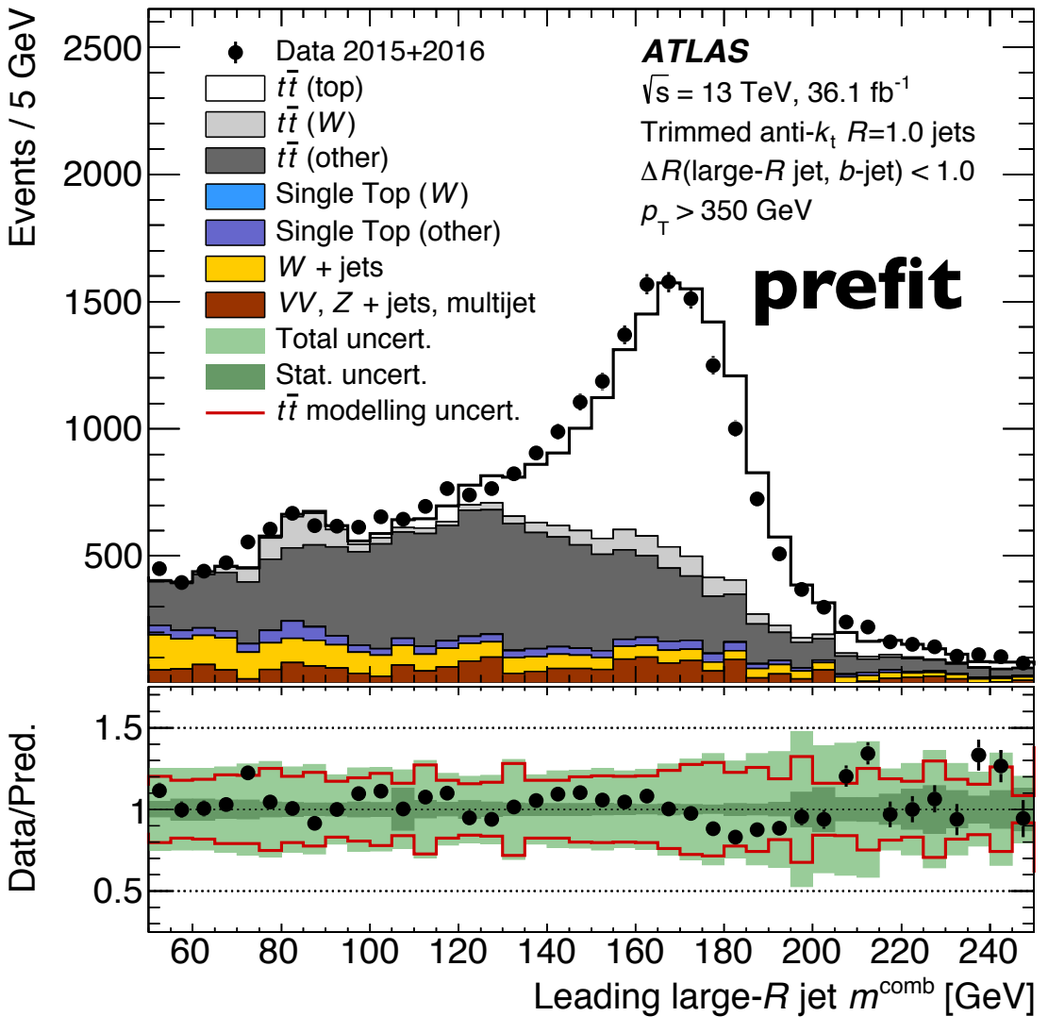
[ATLAS, arXiv:1808.07858]



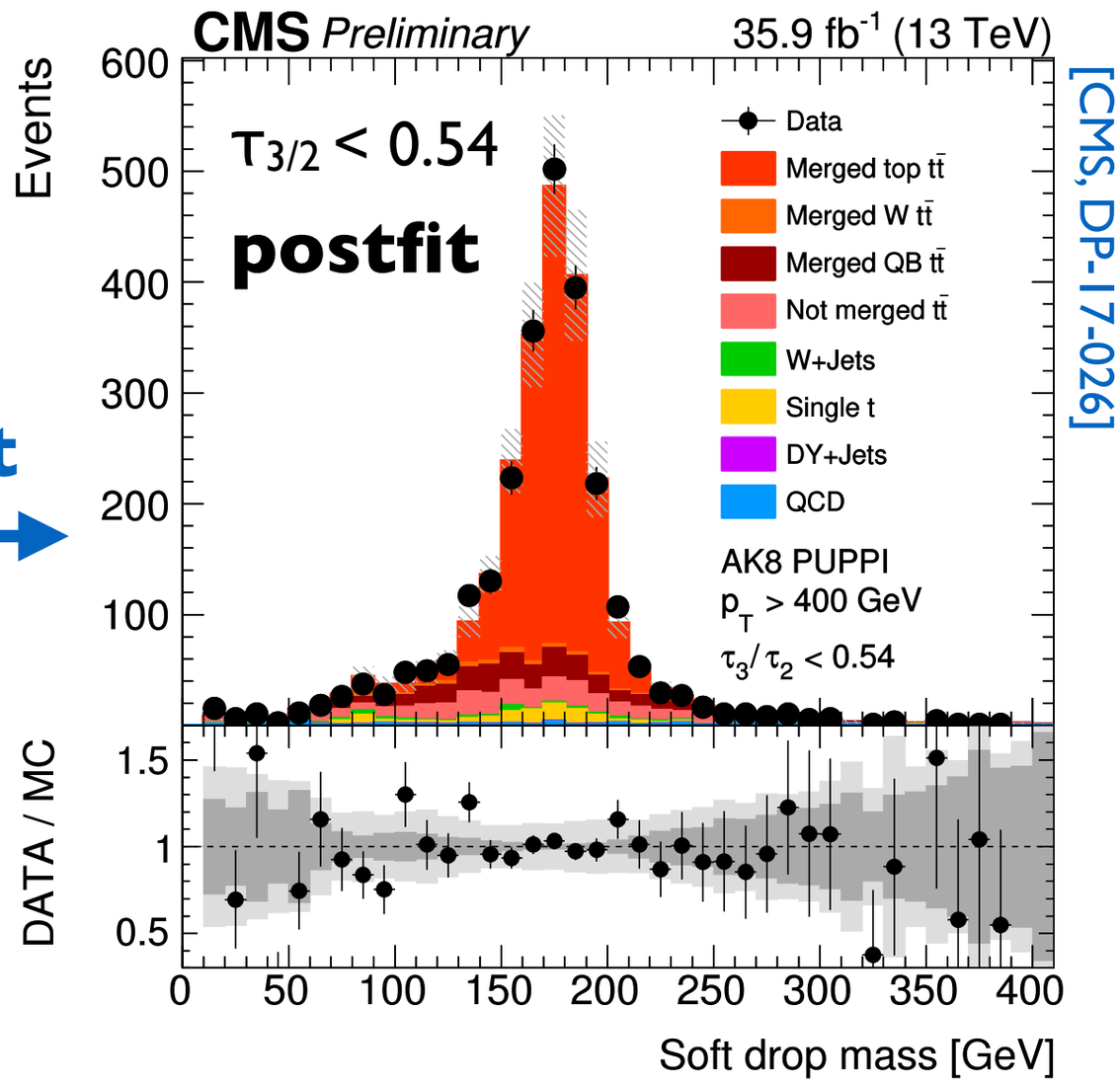
- Fit tagging efficiency and systematic uncertainties simultaneously
- Statistical precision sufficient to constrain modelling uncertainties!
- Can we learn from this for modelling NP effects?

Power to the Data: 2. In-Situ-Det.

[ATLAS, arXiv:1808.07858]

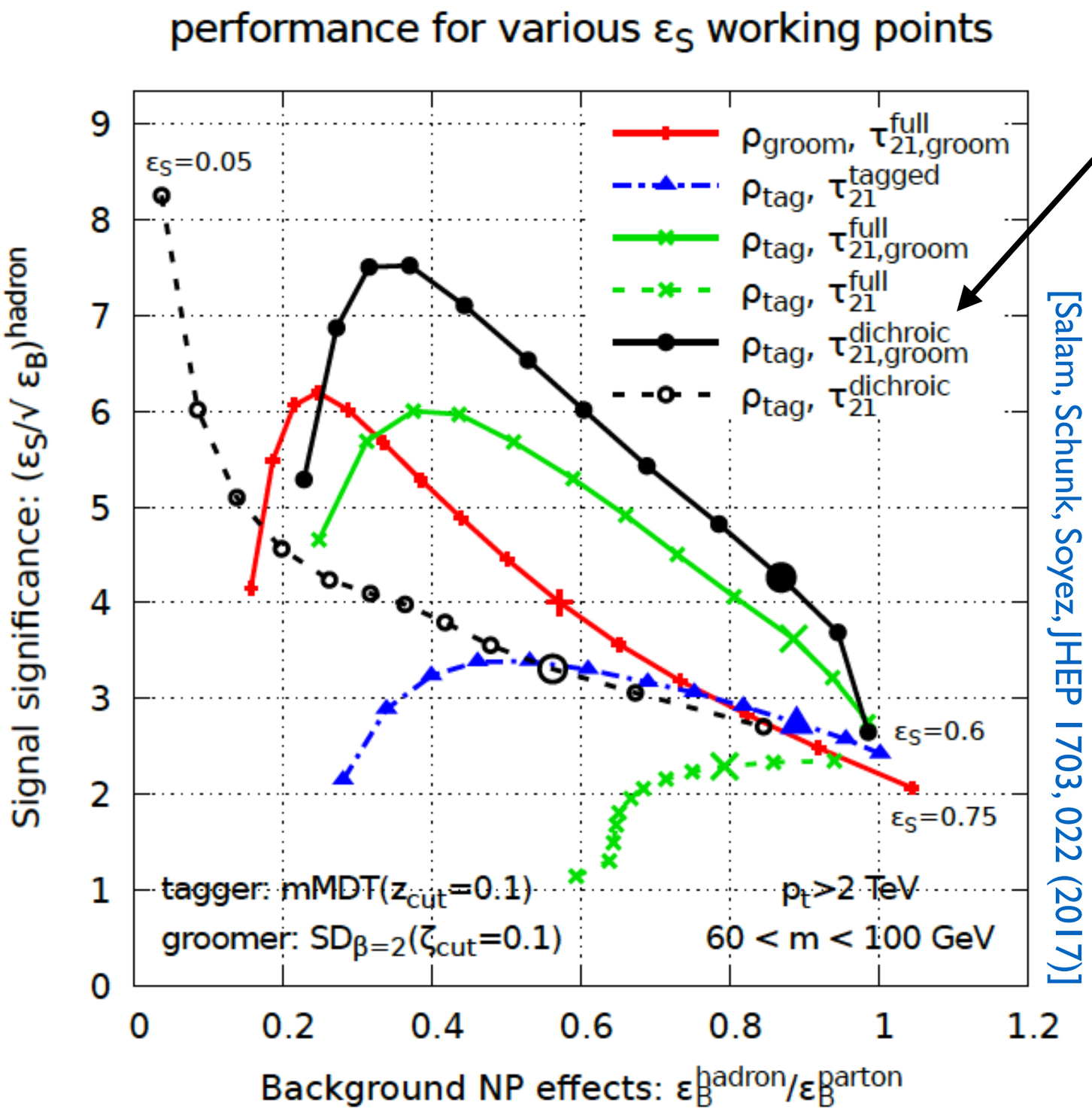


fit



- Fit tagging efficiency and systematic uncertainties simultaneously
- Statistical precision sufficient to constrain modelling uncertainties!
- Can we learn from this for modelling NP effects?

3. Get Help



[Salam, Schunk, Soyez, JHEP 1703, 022 (2017)]

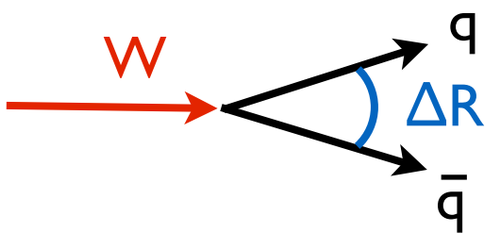
Dichroic τ_{21} ratios

- less sensitive to non-perturbative effects at similar or better signal significance
- could reduce dominant uncertainties considerably
- experimental studies needed
  - full analysis with all systematics included

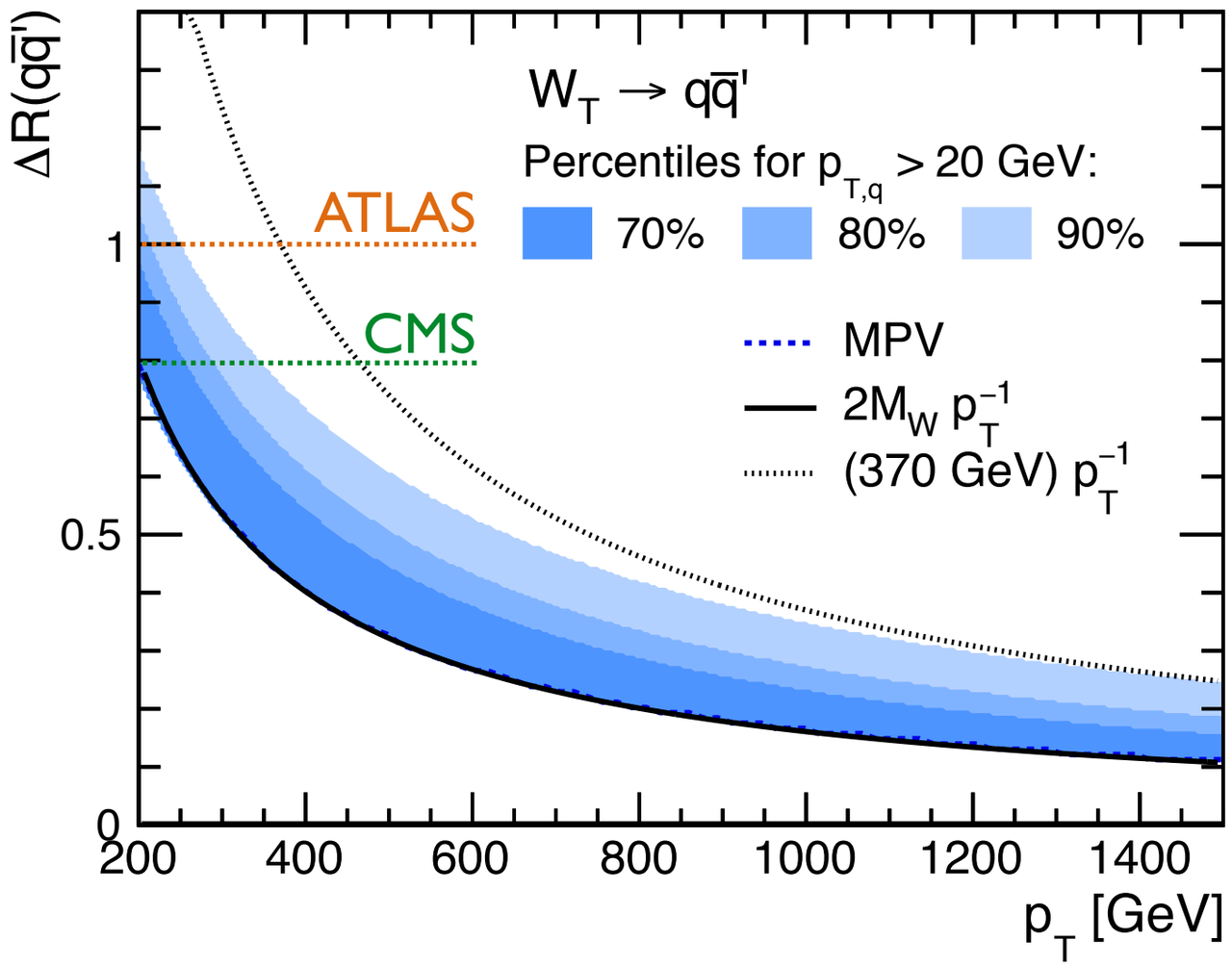
Collimation

- Collimation depends on p_T

$$\Delta R \approx \frac{2M}{p_T}$$ (rule of thumb)



- Ensure high signal efficiency: Jet distance parameter of
  - R = 1.0 (ATLAS)
  - R = 0.8 (CMS)



R~1 optimal for $p_T \lesssim 600$ GeV, catchment area too large at very high p_T

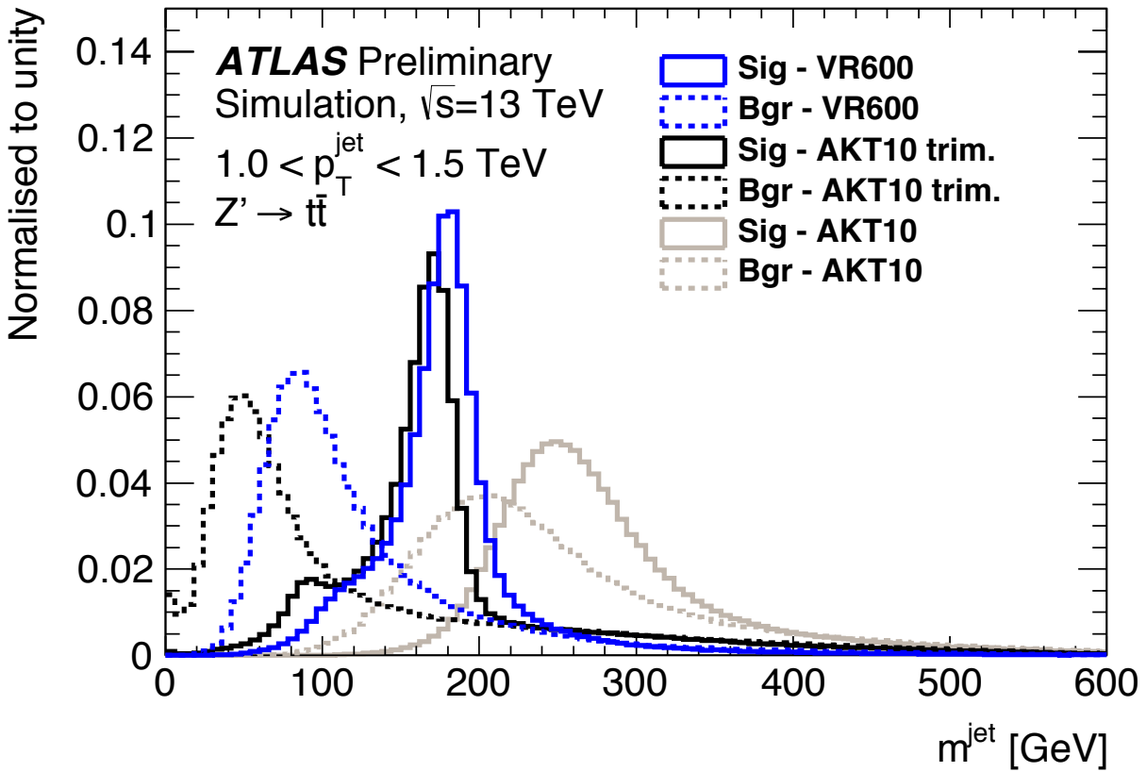
Possible to compensate for $\delta M \sim p_T R^4$ with shrinking R

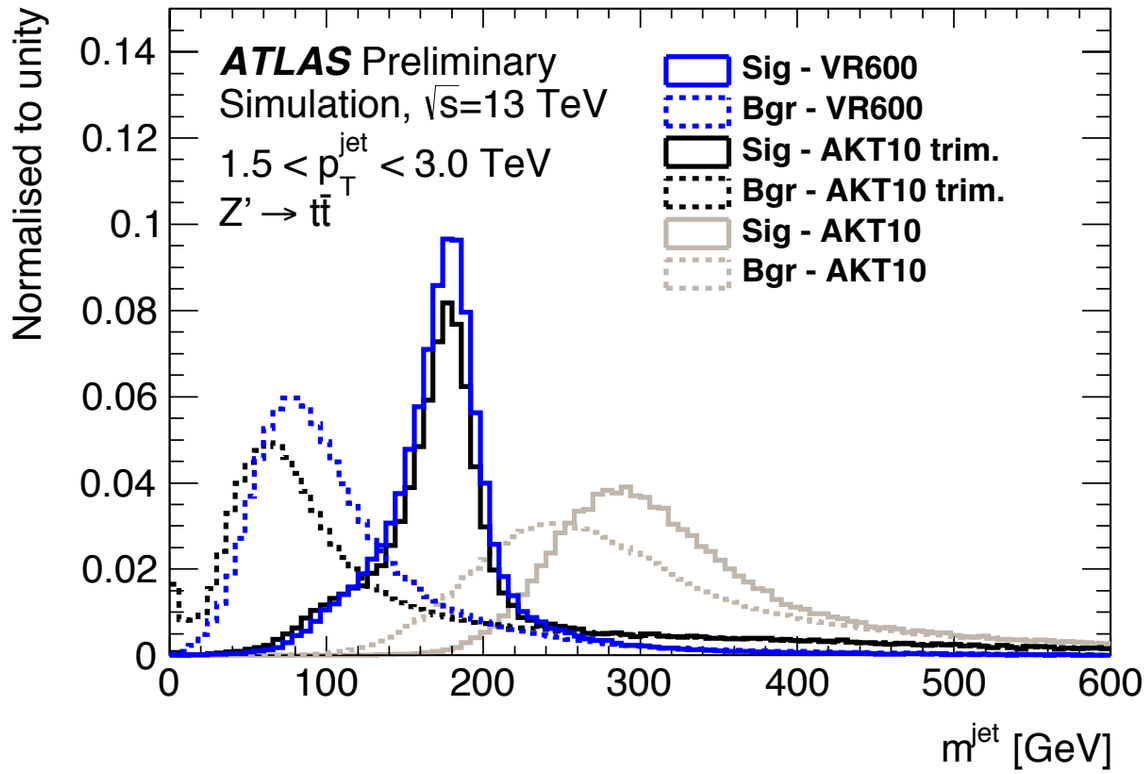
Variable R for W Tagging

Variable R jet clustering [Krohn, Thaler, Wang, JHEP 0906, 059 (2009)]

- IRC safe and computationally not more expensive than other algorithms

[ATLAS, PHYS-PUB-2016-013]

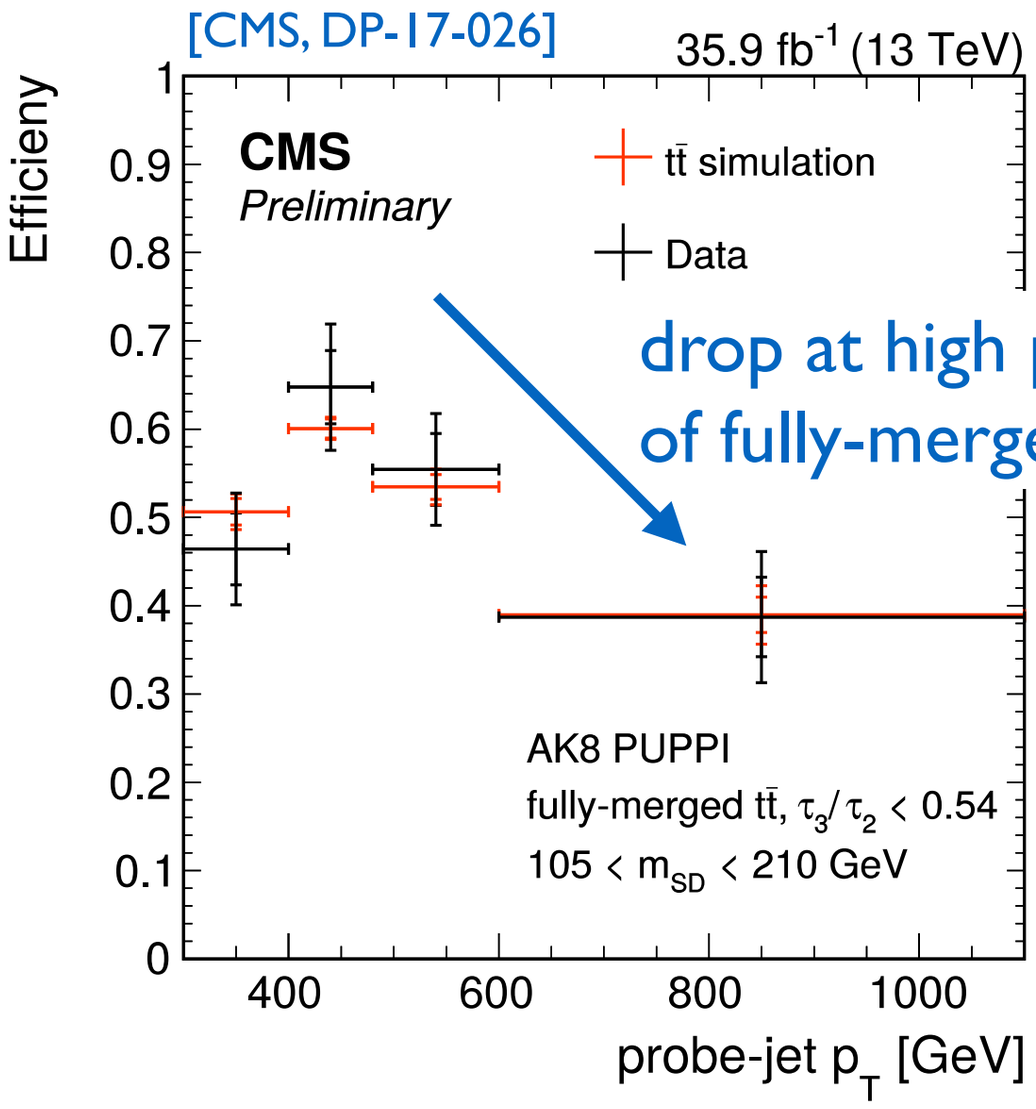




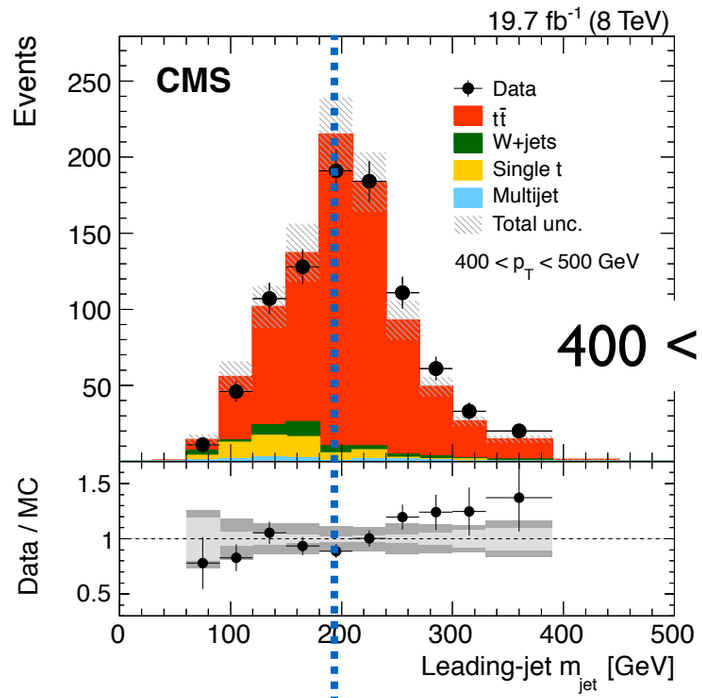
- Signal: similar effect as trimming, background less effected
- Performance studies promising, none with full systematics
- Reduction of modelling uncertainties (esp. NP)?

Top Tagging at High p_T

[CMS, DP-17-026]

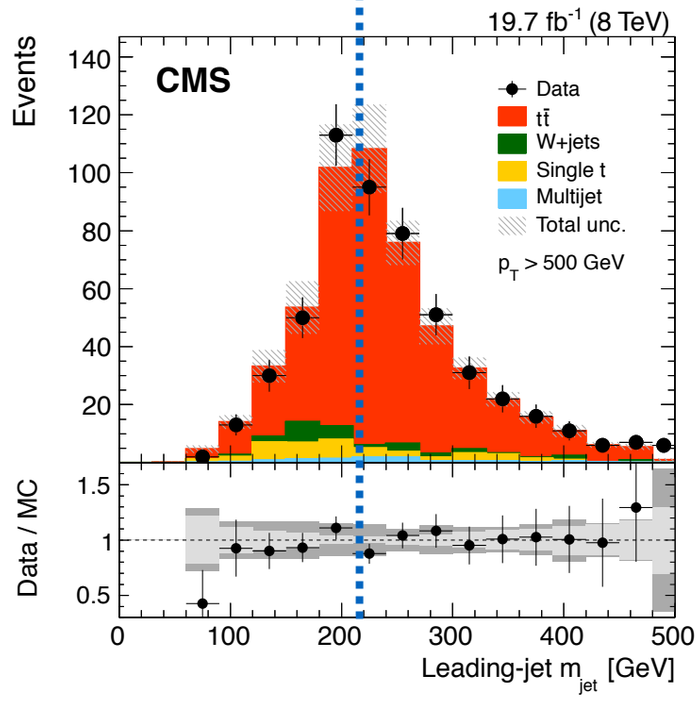


drop at high p_T of fully-merged ε



400 < p_T < 500 GeV

→ peak shifts by ~ 20 GeV



p_T > 500 GeV

Drop at high p_T usually not seen as merged Ws get tagged

[CMS, EPJC 77, 467 (2017)]

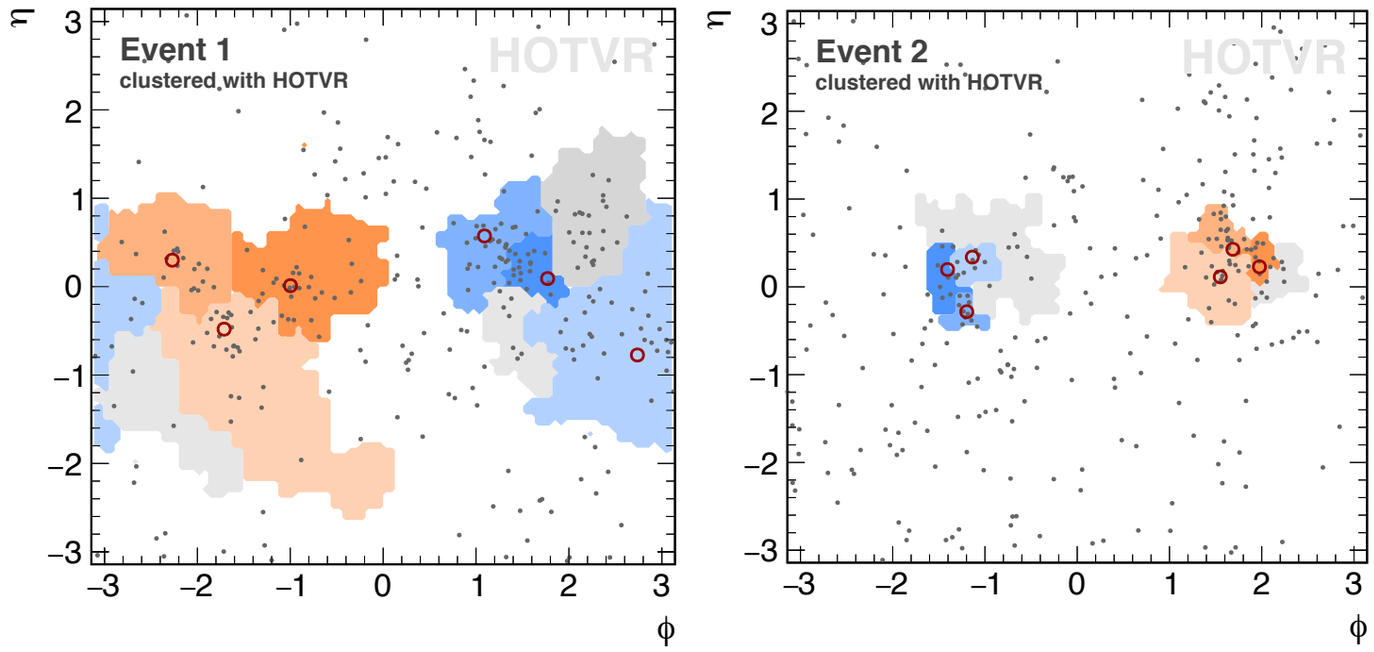
HOTVR

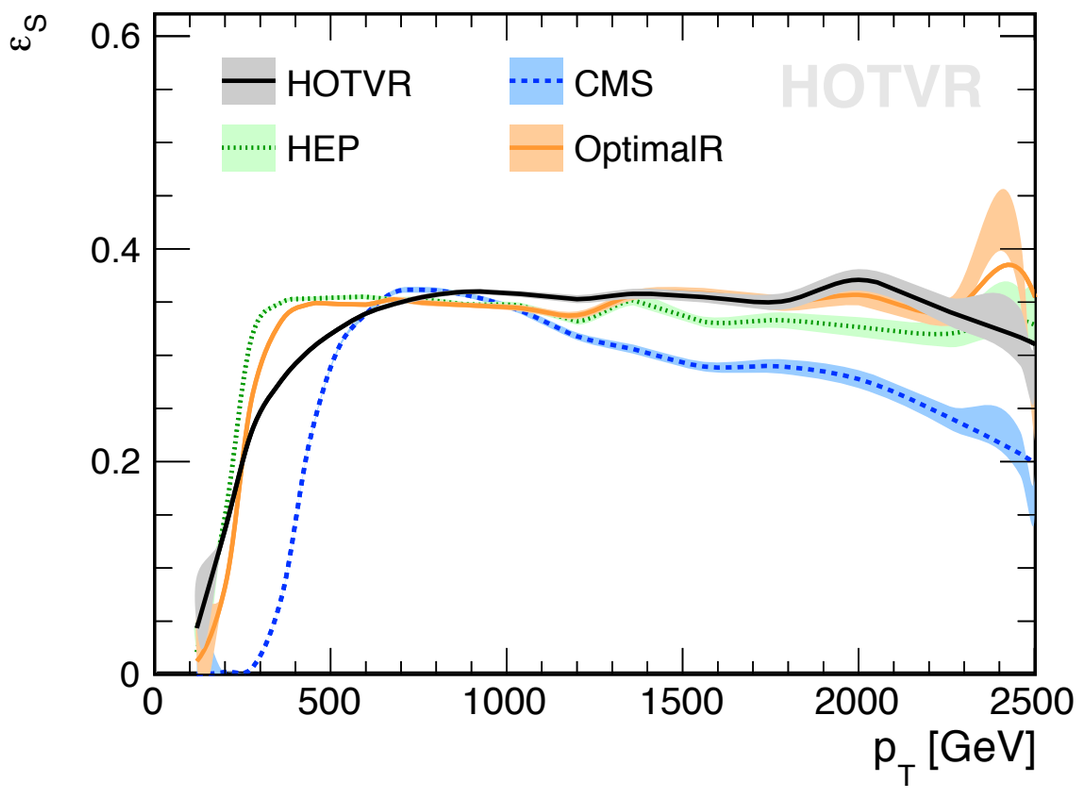
Heavy Object Tagger with Variable R

- Adaptive jet radius with VR
  - drawback: large catchment area at low p_T
- Solution: vetoed jet clustering
  - mass jump condition
  - remove soft/wide angle rad.

  [Stoll, JHEP 04, 111 (2015)]
- Proof of principle:
  Stable performance with little algorithmic complexity
- Interesting in combination with advanced methods?

[Lapsien, RK, Haller, EPJ C 76, 600 (2016)]

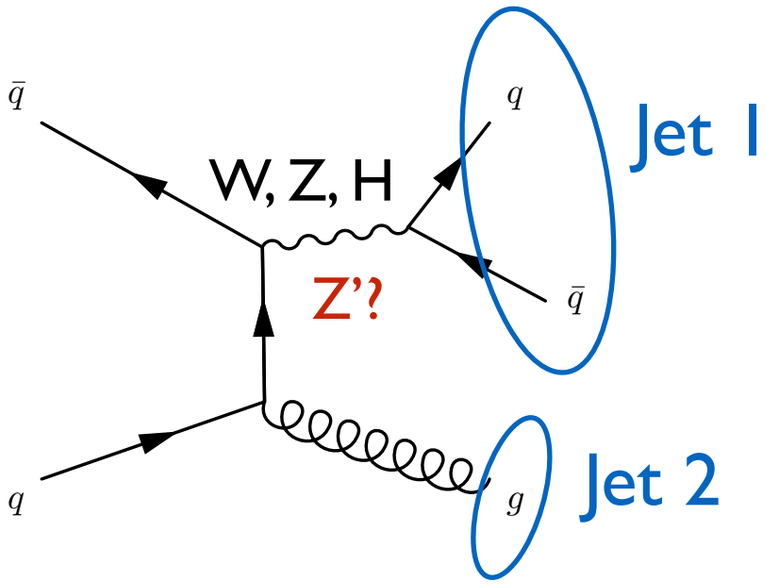




Measurements

with highly-boosted final states

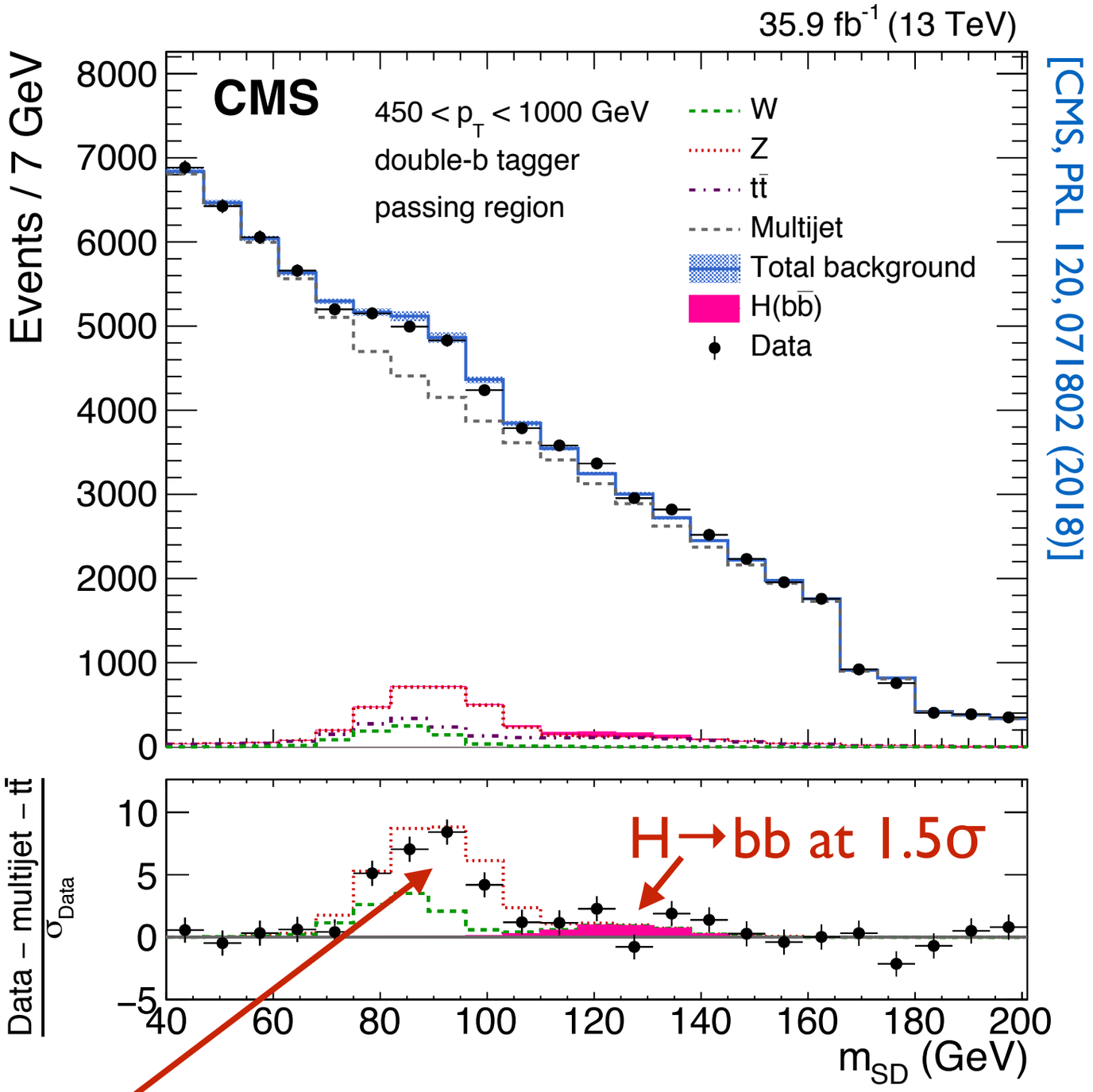
H→bb̄ in H+Jet



First observation of Z→bb̄ in a single jet at an hadron collider

Promising channel for Higgs p_T measurements

Result obtained with $N_2^{1,DDT}$: constant background efficiency!



Z+jet with 5.1σ

Signal resolution of ~10 GeV

$t\bar{t}$ Cross Sections

All-hadronic channel

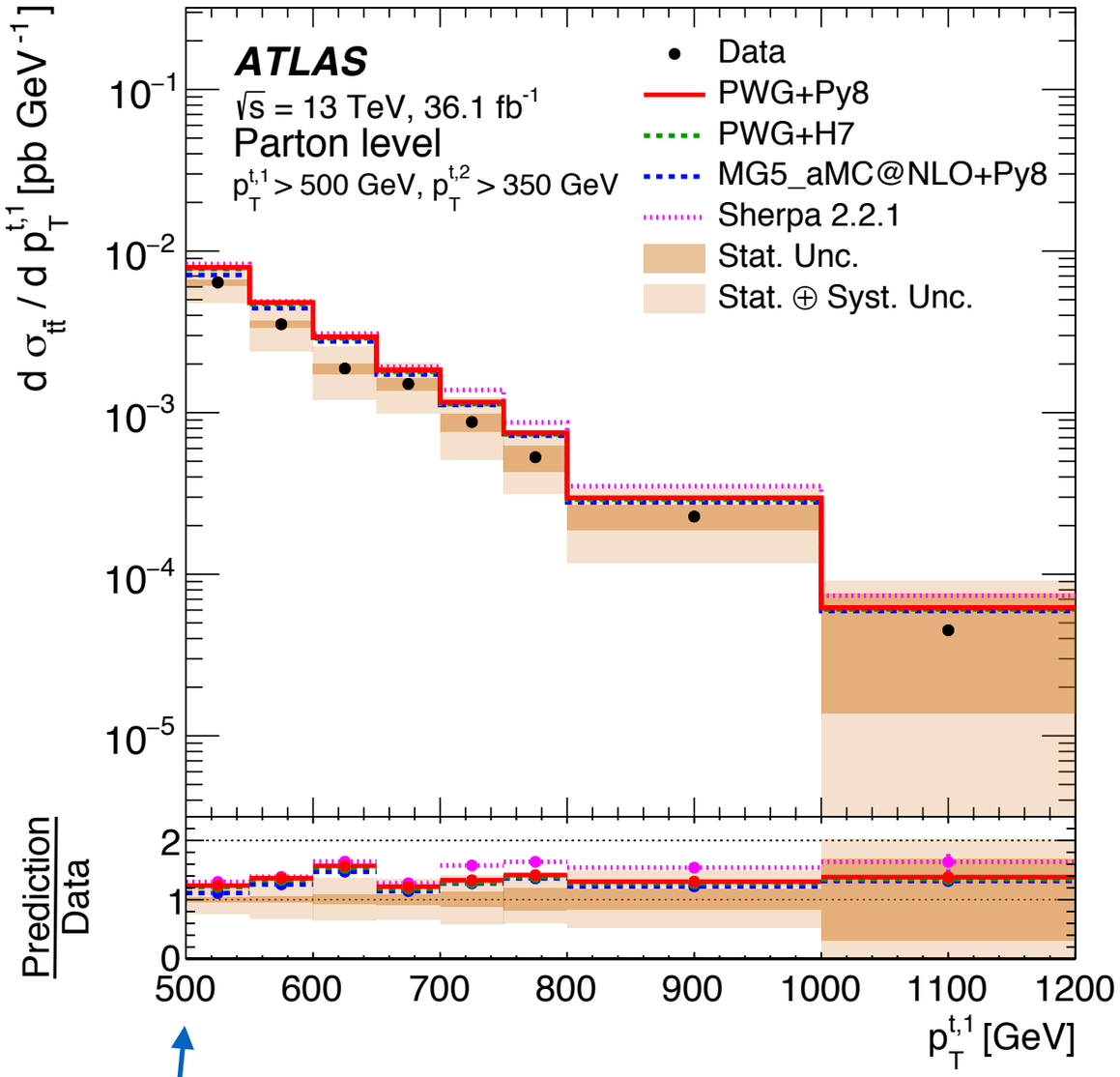
- t tag: jet mass and τ_{32} (p_T dependent cuts)
- t and b tagging offer unique opportunity to constrain backgrounds

2nd large-R jet				
1t1b	J (7.6%)	K (21%)	L (42%)	S
0t1b	B (2.2%)	D (5.8%)	H (13%)	N (47%)
1t0b	E (0.7%)	F (2.4%)	G (6.4%)	M (30%)
0t0b	A (0.2%)	C (0.8%)	I (2.2%)	O (11%)
	0t0b	1t0b	0t1b	1t1b

Leading large-R jet

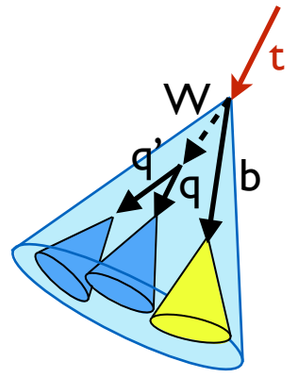
- Leading uncertainties:
  - t and b tagging (12 / 8%)
  - Jet energy scale (6%)
  - Modelling (18%)
  - Statistics: 2%

[ATLAS, PRD 98, 012003 (2018)]



Measurement starts where others stop!

Top Quark Jet Mass

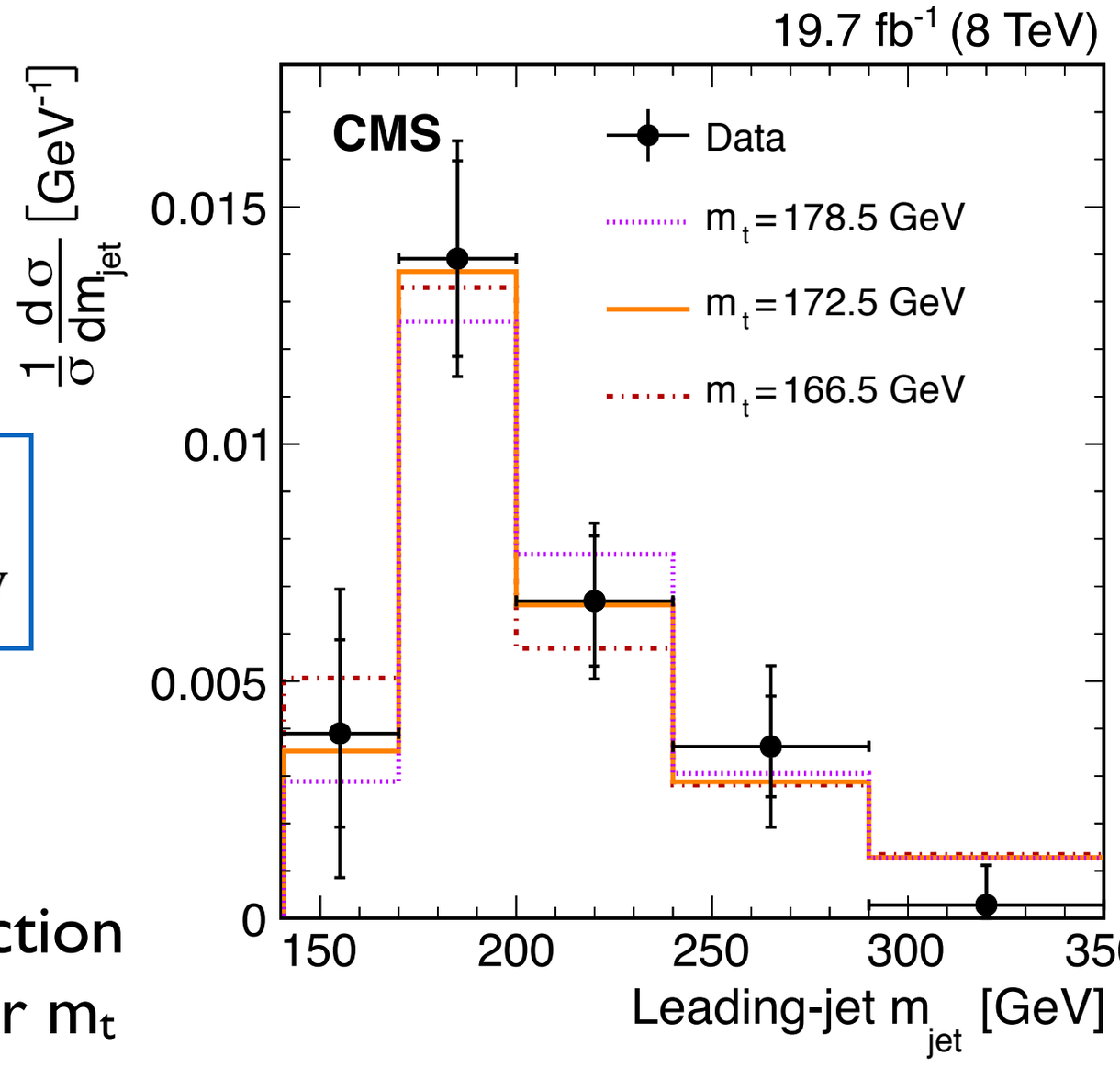


First unfolded measurement: fully-merged top quark decays

- Large CA jets, R = 1.2
  - ✓ sufficient statistics at 8 TeV
  - ✗ susceptibility to PU and UE
- Sensitivity to top quark mass:

$$m_t = 170.8 \pm 6.0\,(\text{stat}) \pm 2.8\,(\text{syst}) \pm 4.6\,(\text{model}) \pm 4.0\,(\text{theo})\,\text{GeV}$$

- Large improvements with 13 TeV data possible
- Will help to establish a firm connection between theory and experiment for m_t

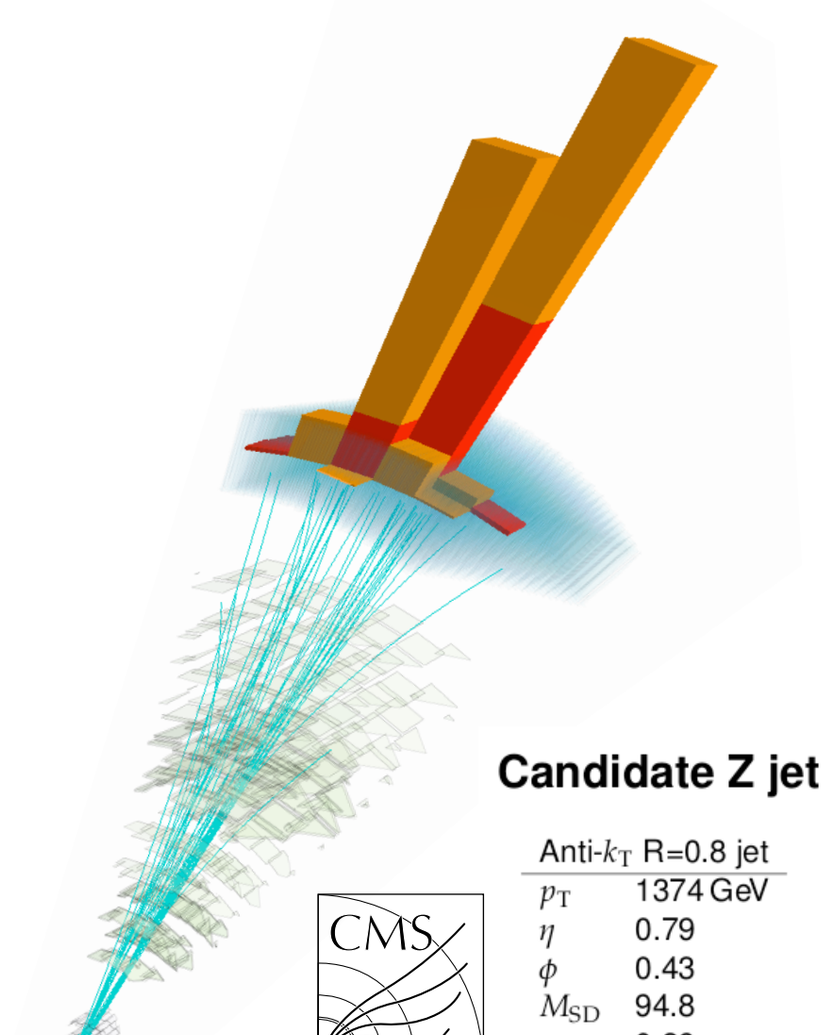


[CMS, EPJC 77, 467 (2017)]

Outlook

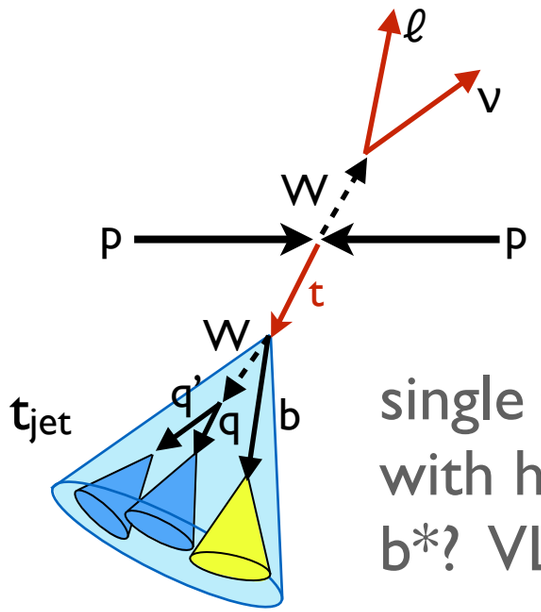
Searches

- Huge gain from jet substructure techniques
- Exciting interplay between:
  - model building
  - tools development
  - commissioning
  - application



Measurements

- Jet substructure goes precision
- Coming years will bring a number of novel measurements using jet substructure
  - $t\bar{t}$, single top, differential H production, jet mass of top, W and Z…



single top (tW) with high p_T? b*? VLQ?

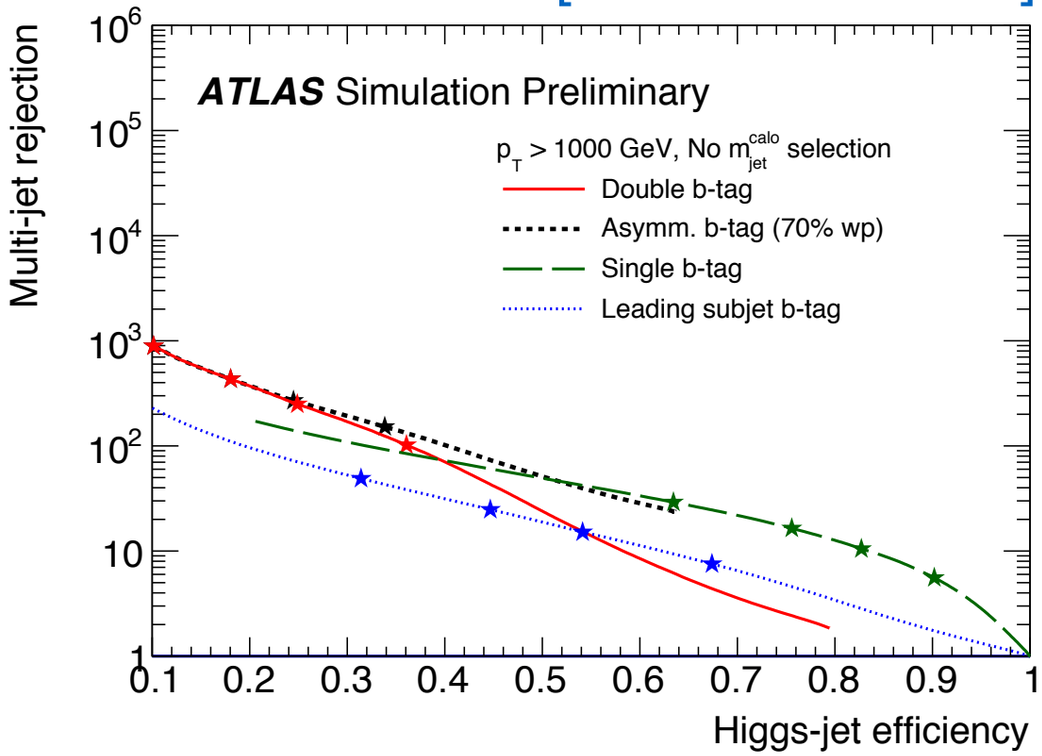
Additional Material

Identifying Boosted H→bb

Subjet b tagging (ATLAS)

Leading track jets with R=0.2 inside a large jet with R=1.0

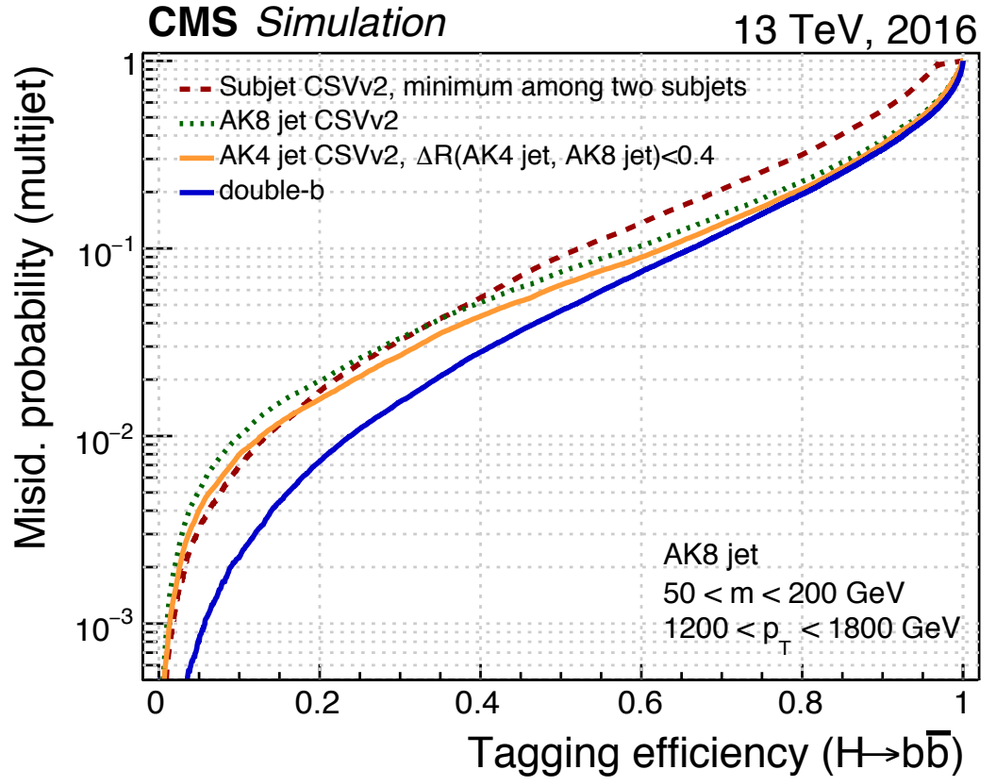
[ATL-CONF-2016-039]



Discrimination against boosted t→bW with double b-tag

Double-b tagger (CMS)

BDT based on track, SV, substructure inputs

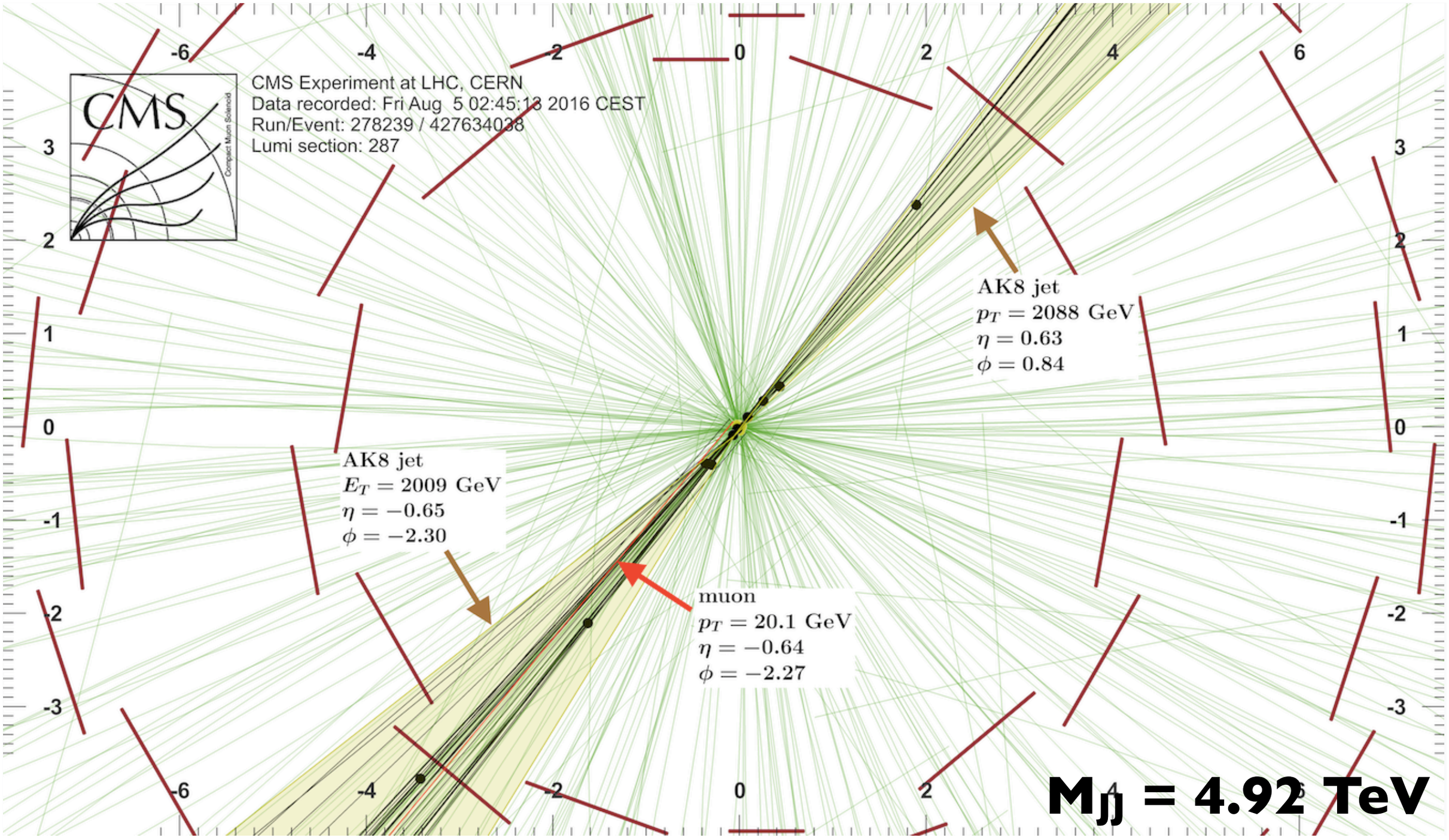


[CMS, JINST 13 (2018) P05011]

Improvement at high p_T, discrimination against g→bb

Boosted H→bb Candidate

[CMS, DP-17-032]



Background Estimates

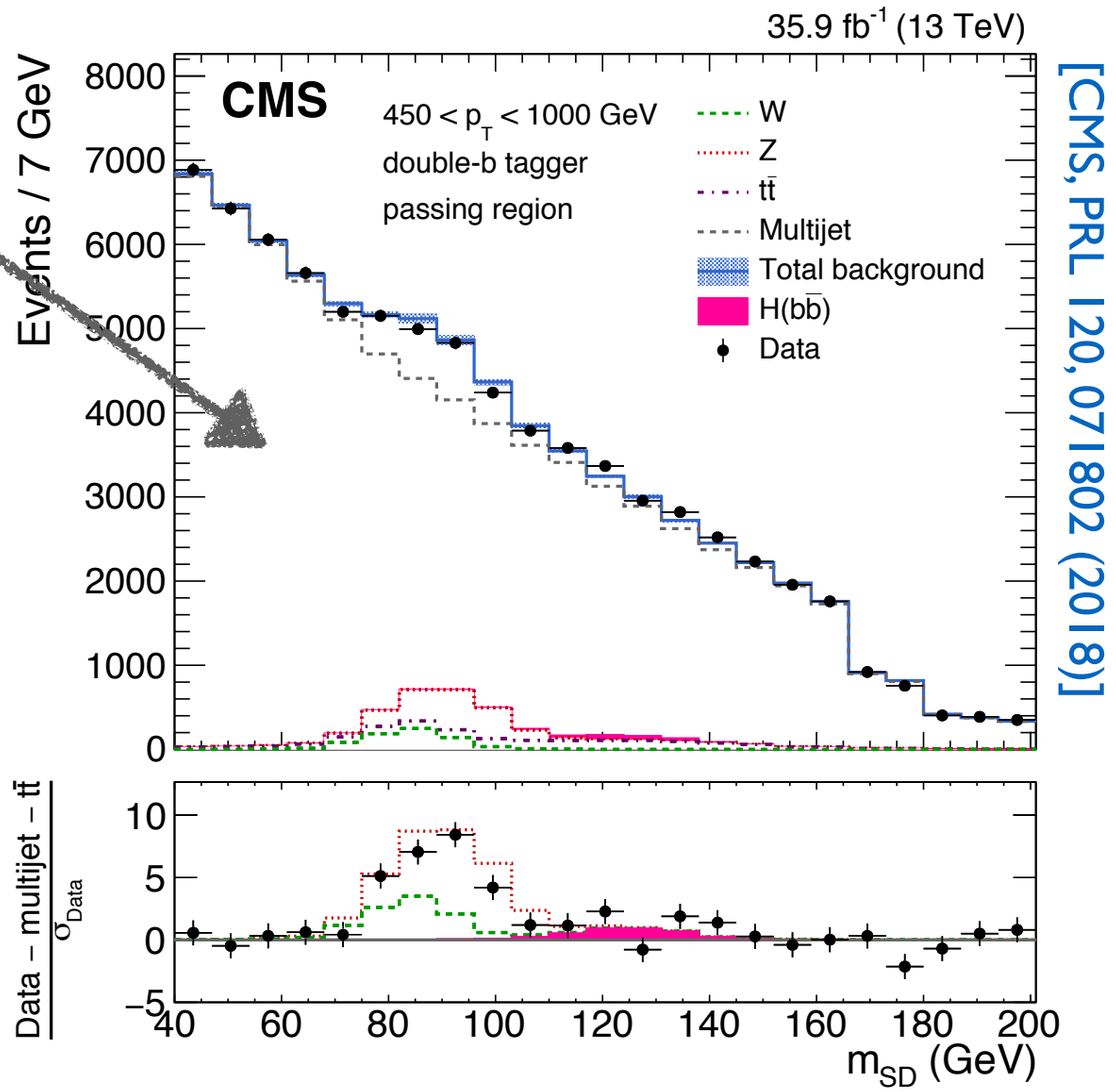
Multi-jet background

A curse

- many orders of magnitude larger than any signal
- modelling very difficult, large uncertainties

and a blessing

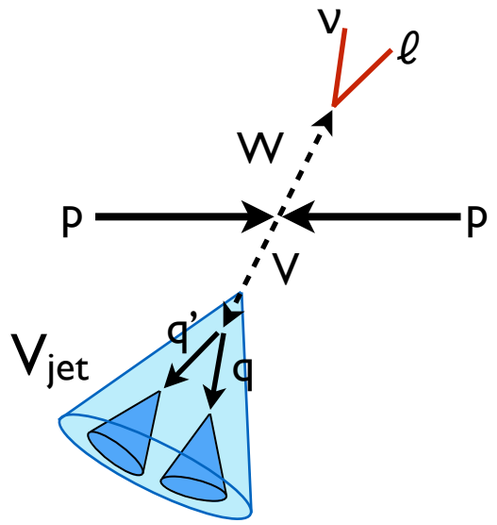
- jet mass: opportunity for dedicated control and validation regions
- precise predictions from data possible with in-situ validations



Numerous methods

- ABCD extrapolations, $R_{p/f}$, decorrelated taggers, transfer factors…

VW Resonances (LJ)



Simultaneous fit to jet mass and resonance mass spectra:

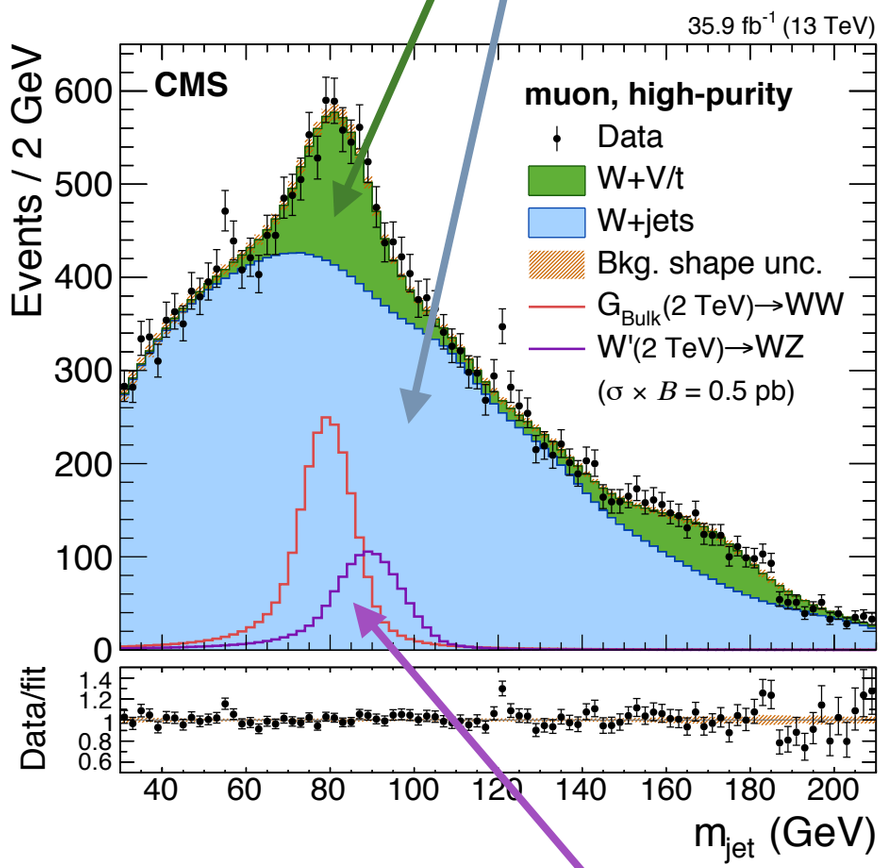
$$P(X \to WV) = P(m_{\text{jet}}, m_{WV} | m_X, \vec{\theta})$$

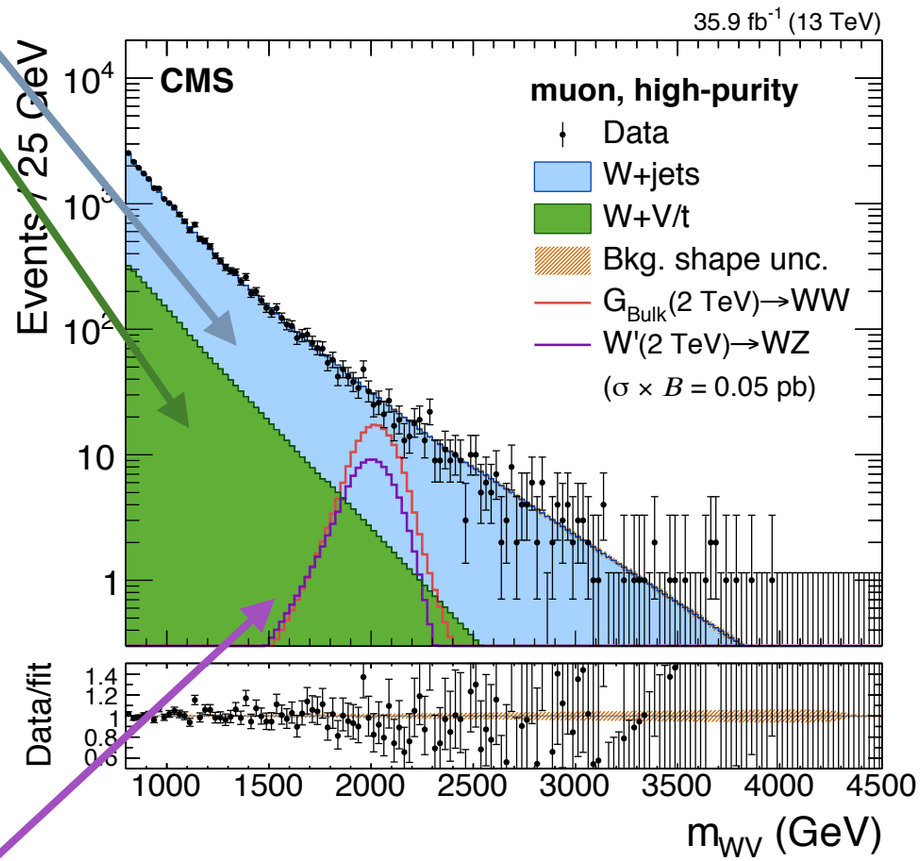
SM bkgd: resonant

non-resonant

non-resonant

[CMS, JHEP 05, 088 (2018)]

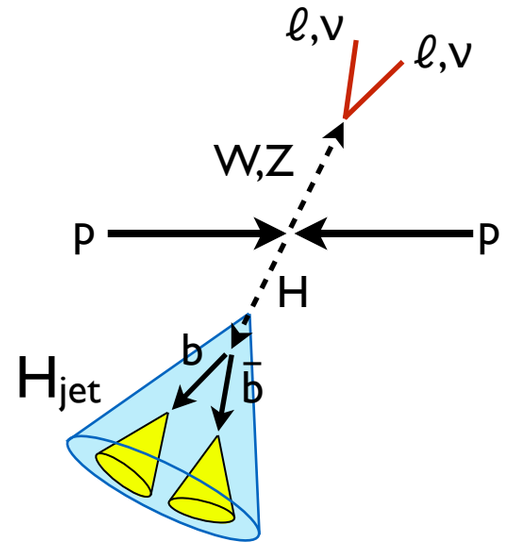




Signal: resonant in m_{jet} and m_{WV}

[see also ATLAS, JHEP 03, 042 (2018)]

VH Resonances

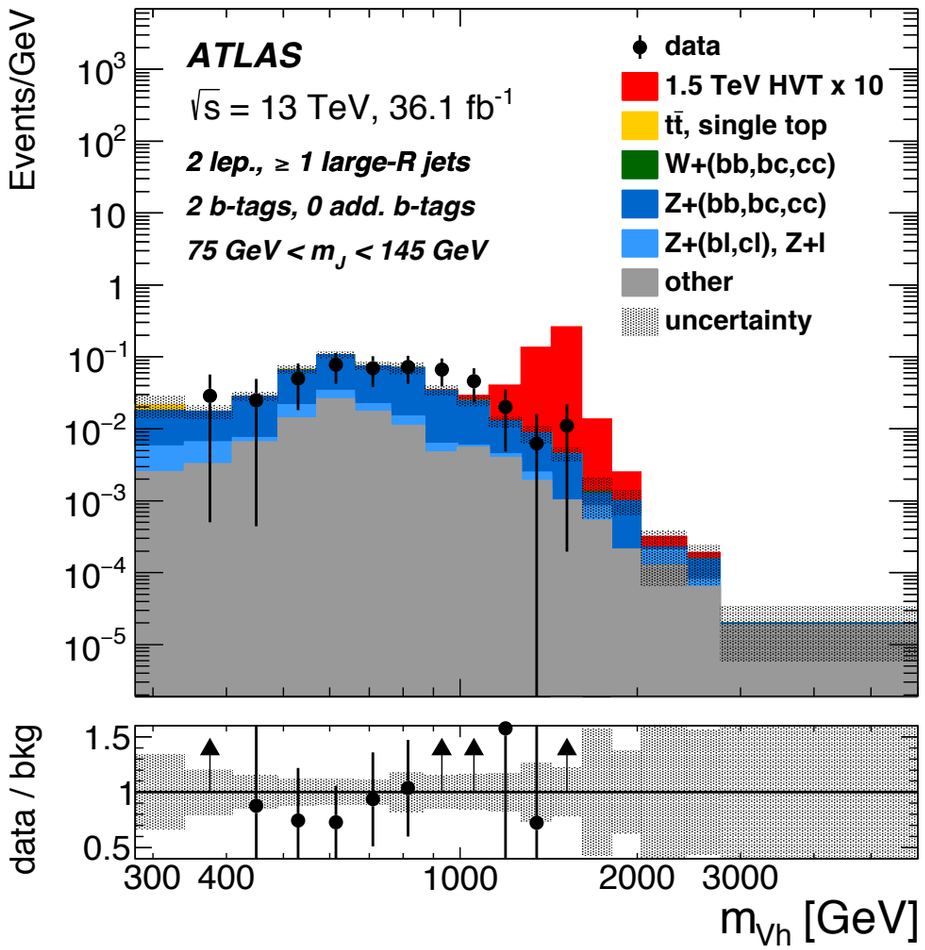


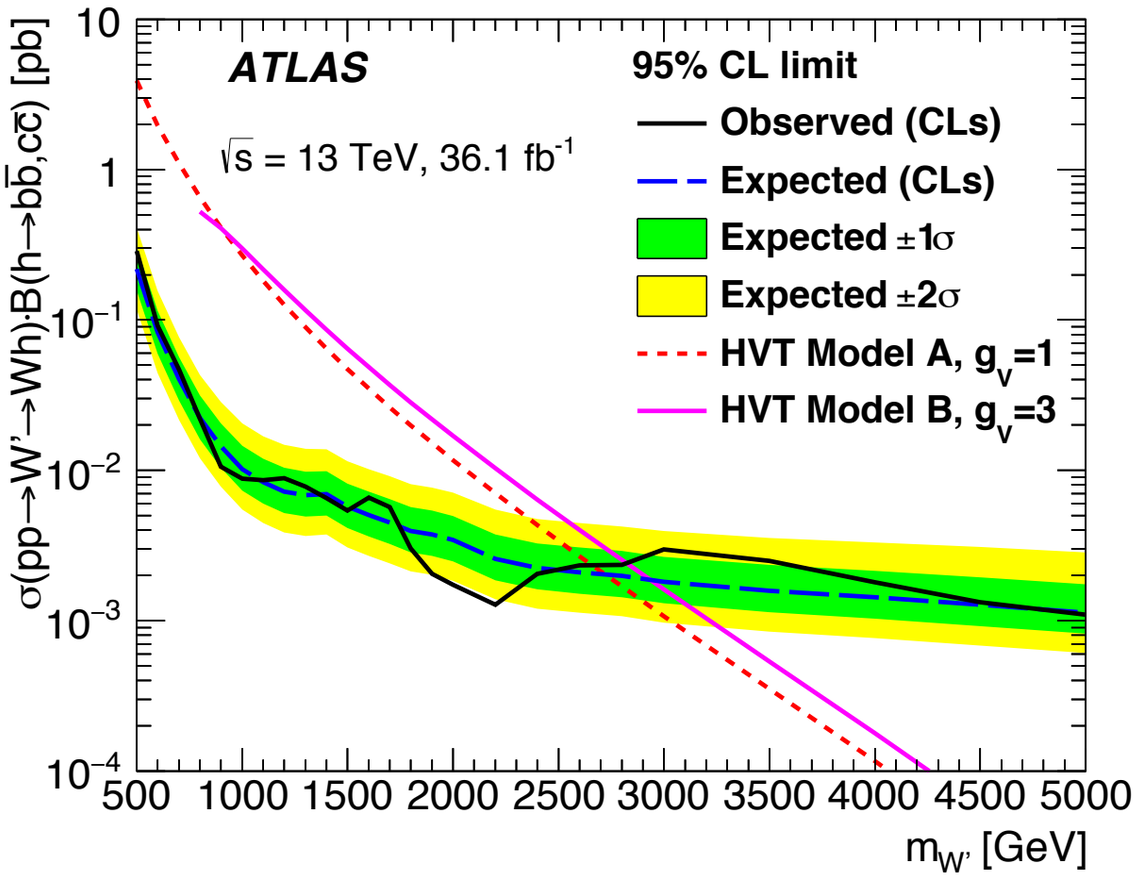
Analysis in 6 categories:

(νν$b\bar{b}$, ℓν$b\bar{b}$, ℓℓ$b\bar{b}$) x (resolved H, merged H)

Very different background compositions in each category, relies on modelling of SM backgrounds

[ATLAS, JHEP 03, 174 (2018)]

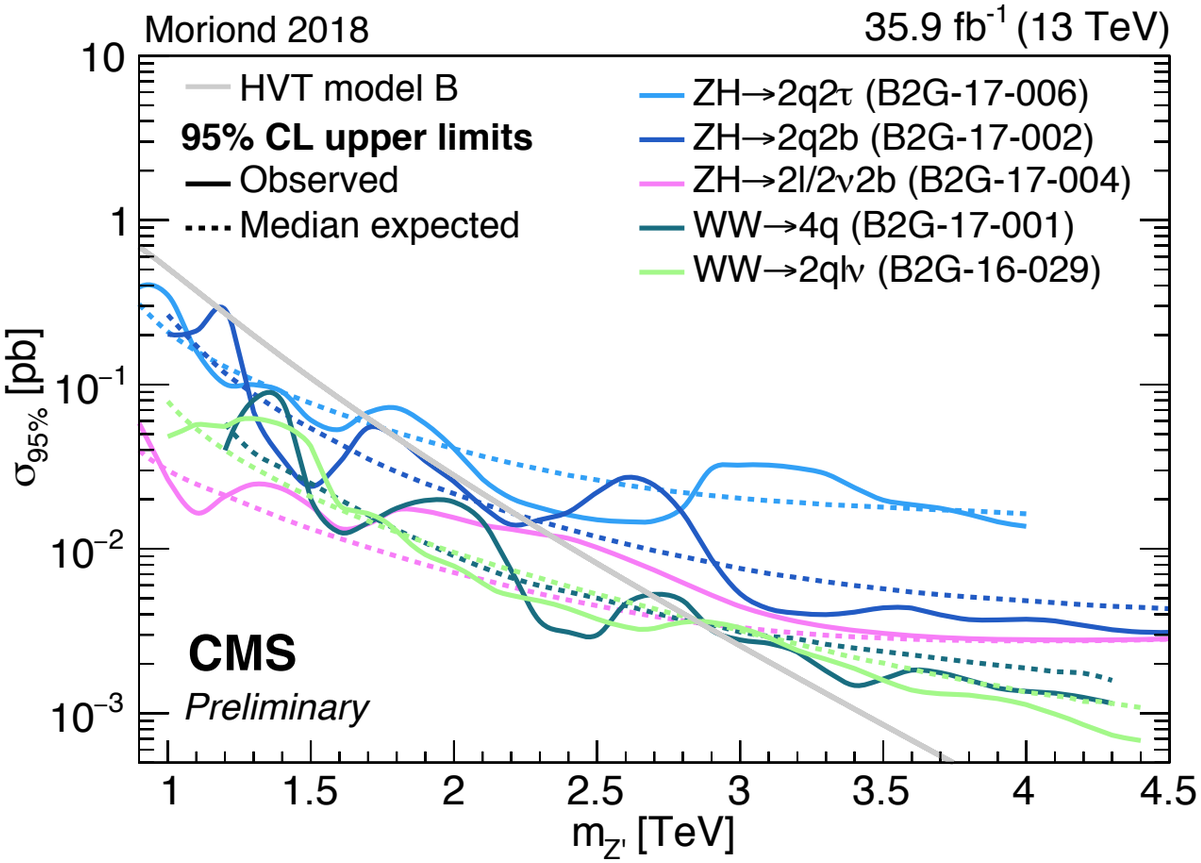




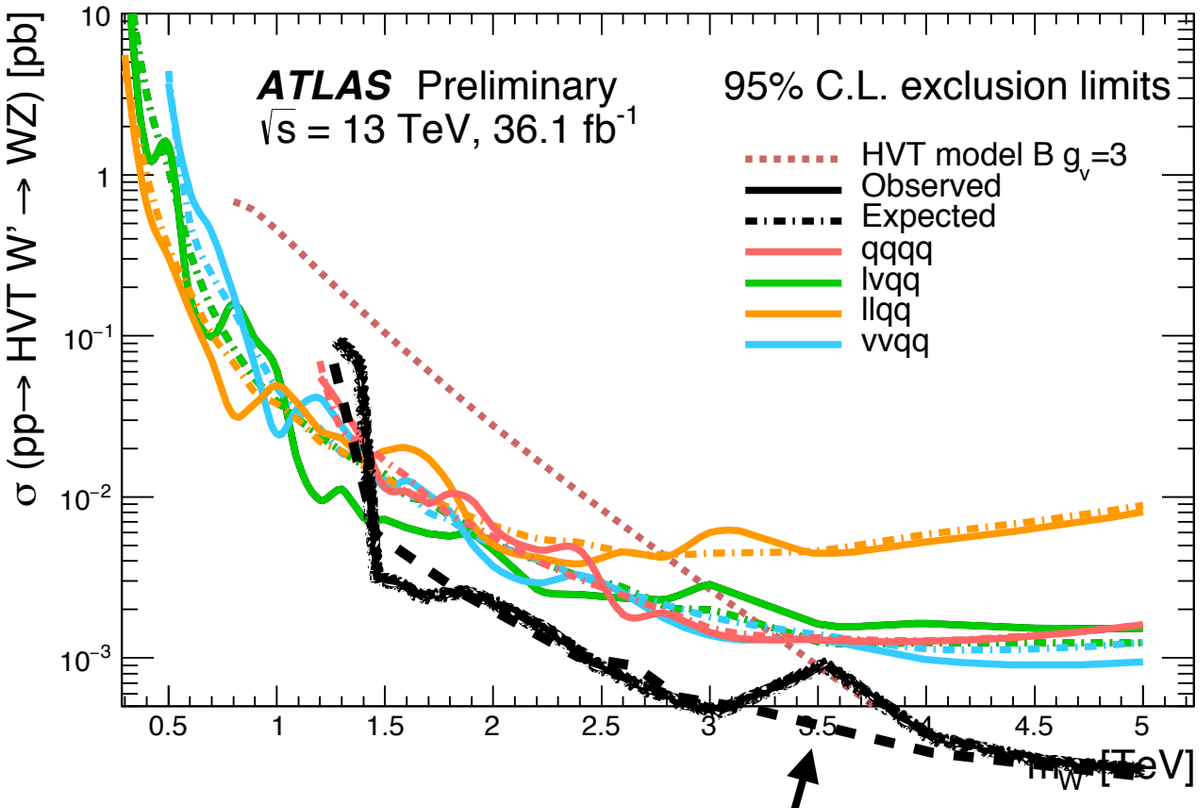
[see also CMS-PAS-17-004]

Diboson Summary

Z’



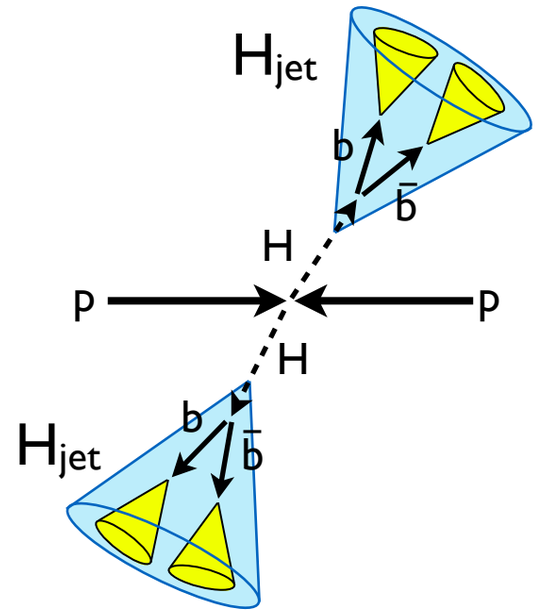
W’



Complementary search channels, important to look at all of them!

new 80 fb⁻¹ result

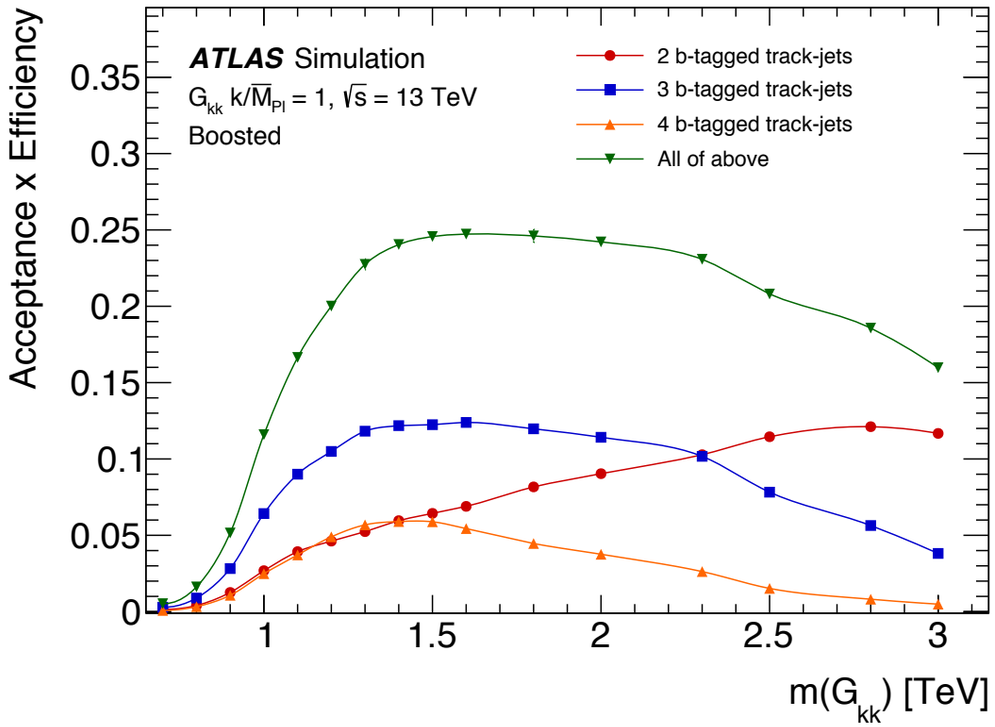
HH → 4b



[ATLAS, arXiv:1804.06174]

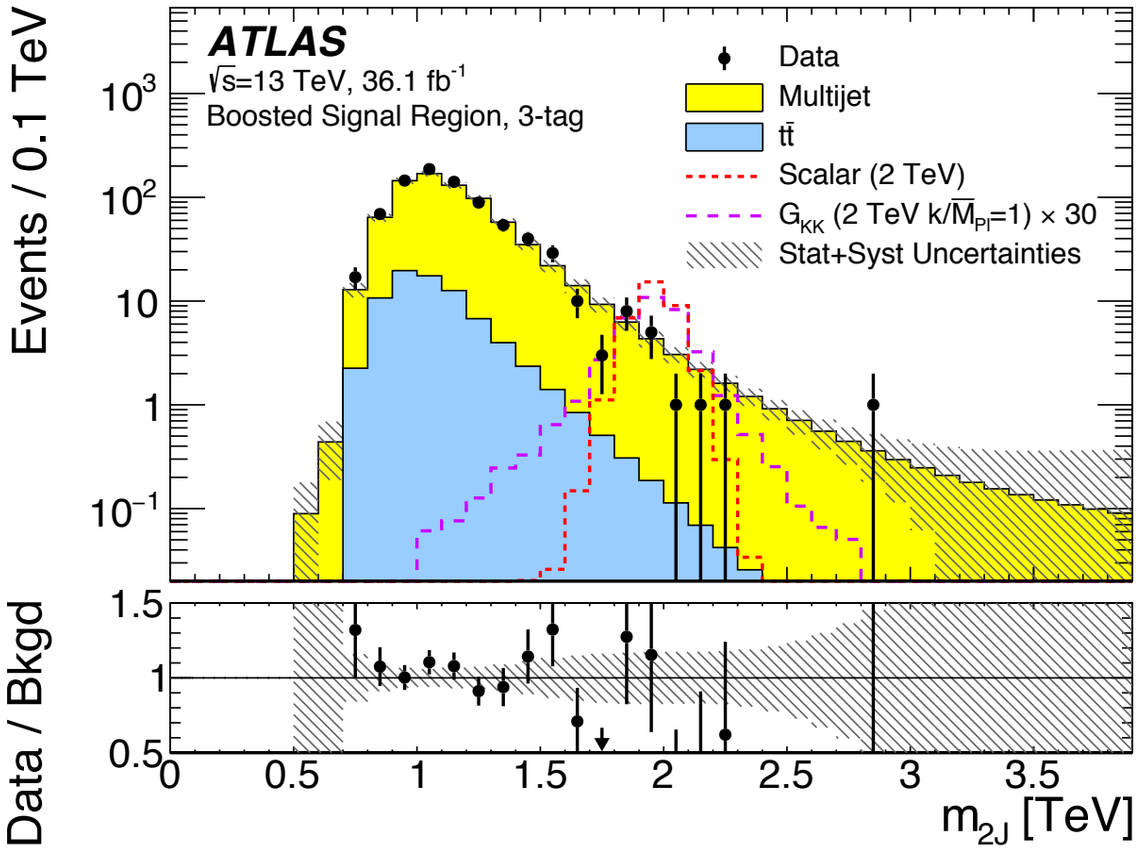
Resonant (BSM) and non-resonant (SM and BSM)

- combination of resolved and fully-merged
- 3 orthogonal signal categories, based on N(b-jets)



Non-resonant production larger than 13 x SM excluded @ 95% CL

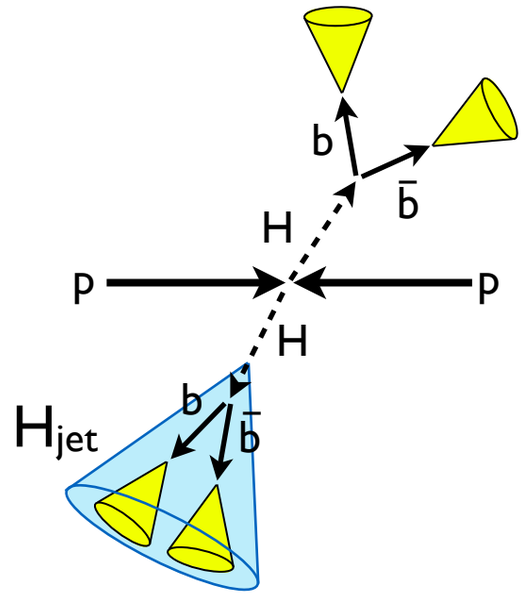
[see also CMS, PLB 781, 244 (2018), CMS-PAS-HIG-17-009]



Boosted analysis extends mass range

NEW

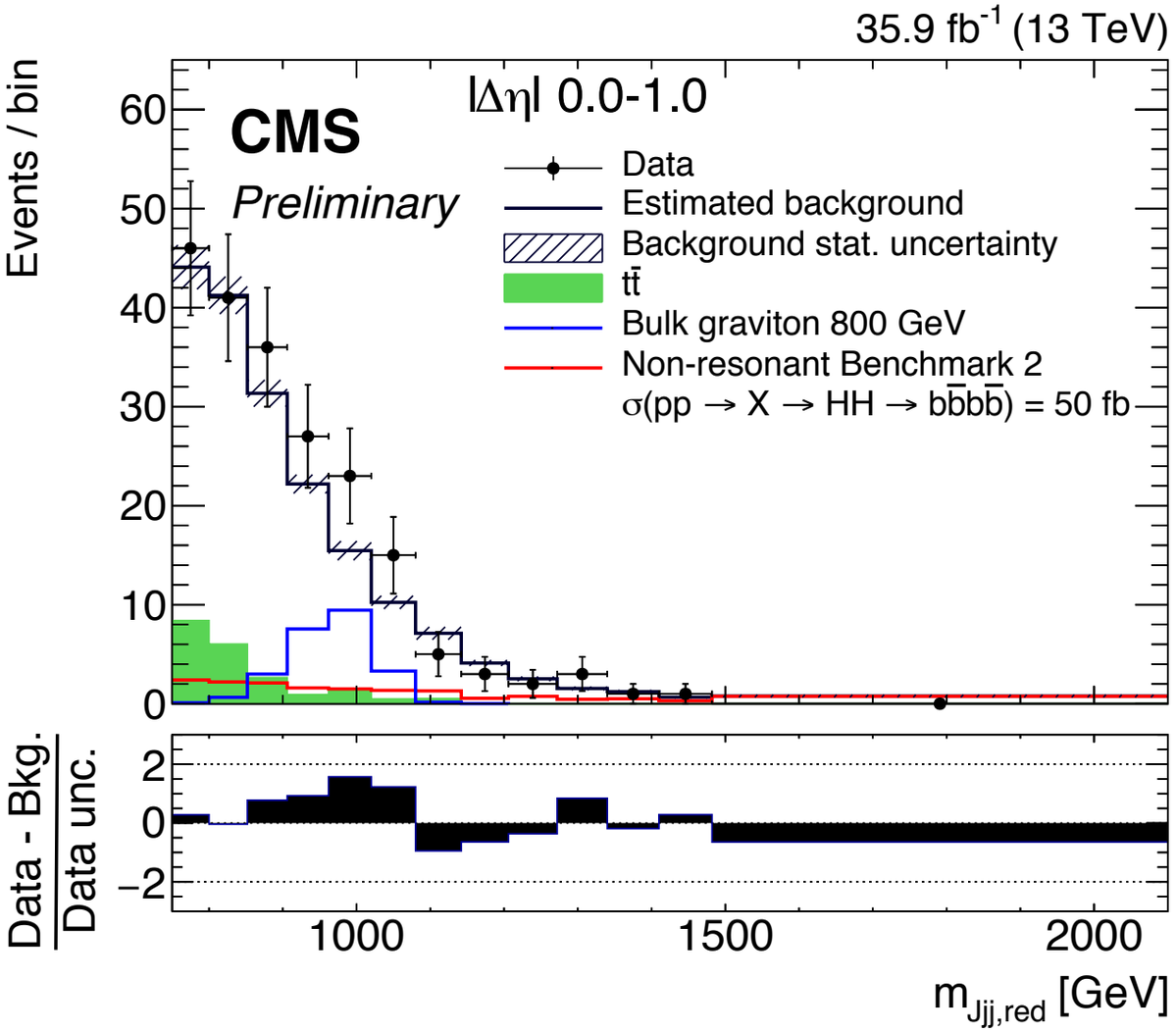
HH → 4b



[CMS-PAS-B2G-17-019]

So far uncovered: semi-resolved

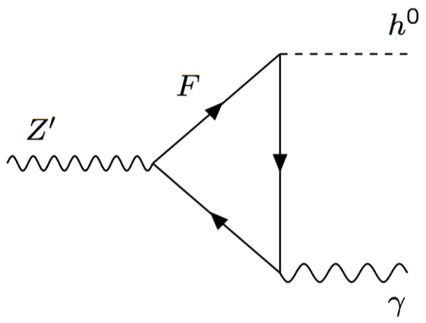
- resolved + merged final state
- orthogonal to fully-merged analysis [CMS, PLB 781, 244 (2018)]



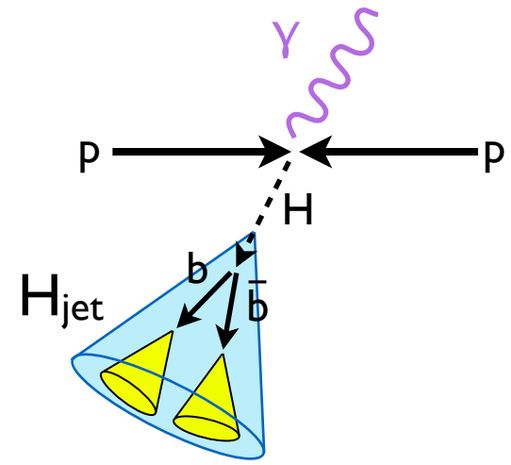
- improves limits on resonant production up to 55%
  - for radion with m = 0.75 - 1.6 TeV
  - above 1.6 - 2 TeV: sensitivity from fully merged analysis
- non-resonant production: better by factors of 2-3 for some benchmarks

NEW

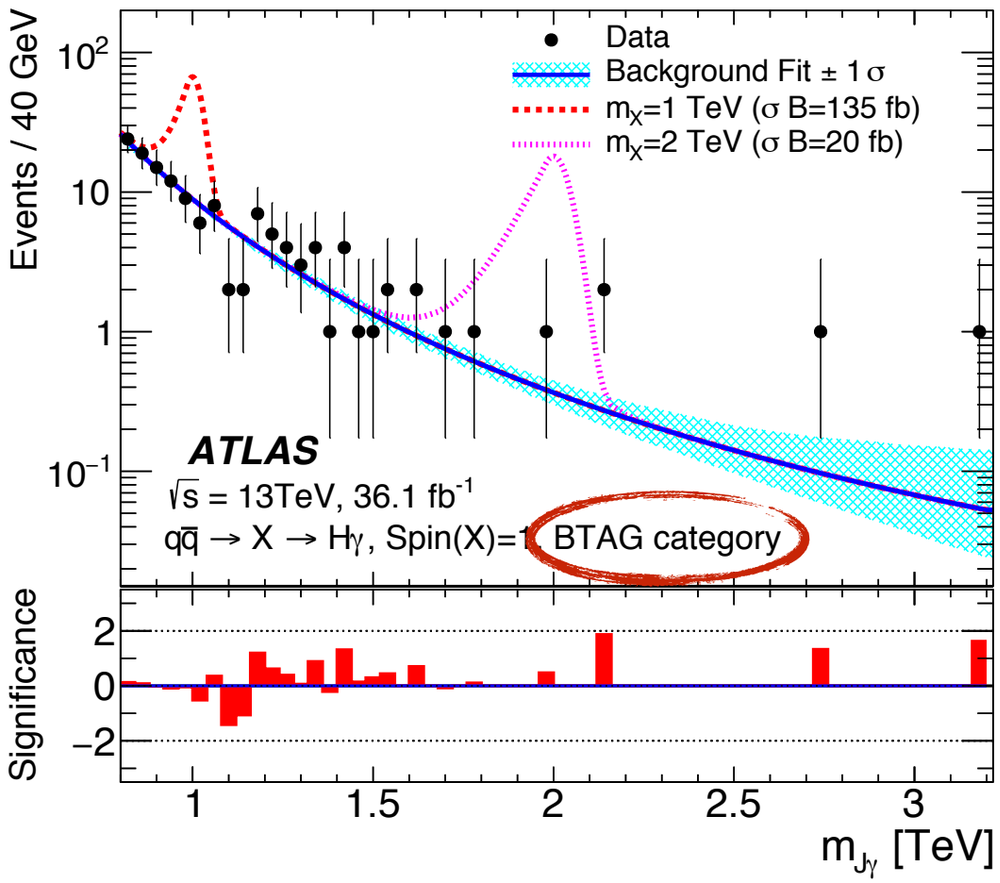
γH Resonances



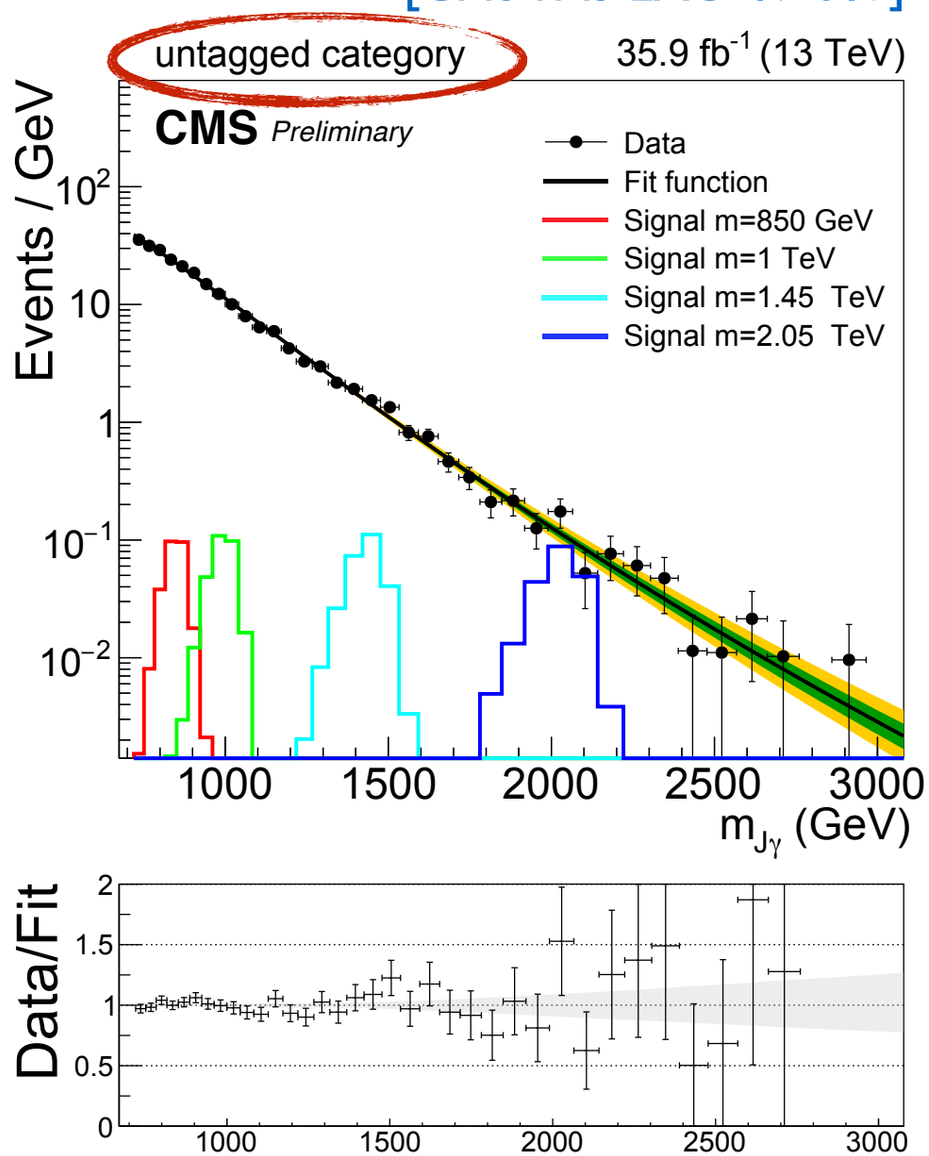
[BA Dobrescu, PJ Fox, J Kearney
EPJC77, 704 (2017)]



[ATLAS, arXiv:1805.01908]

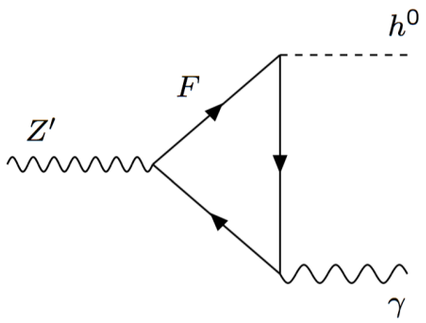


[CMS-PAS-EXO-17-019]



NEW

γH Resonances



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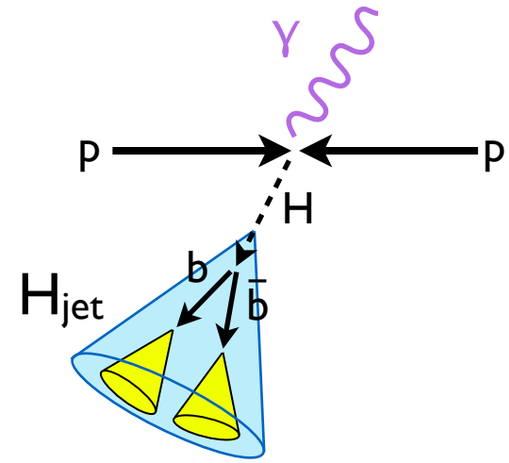
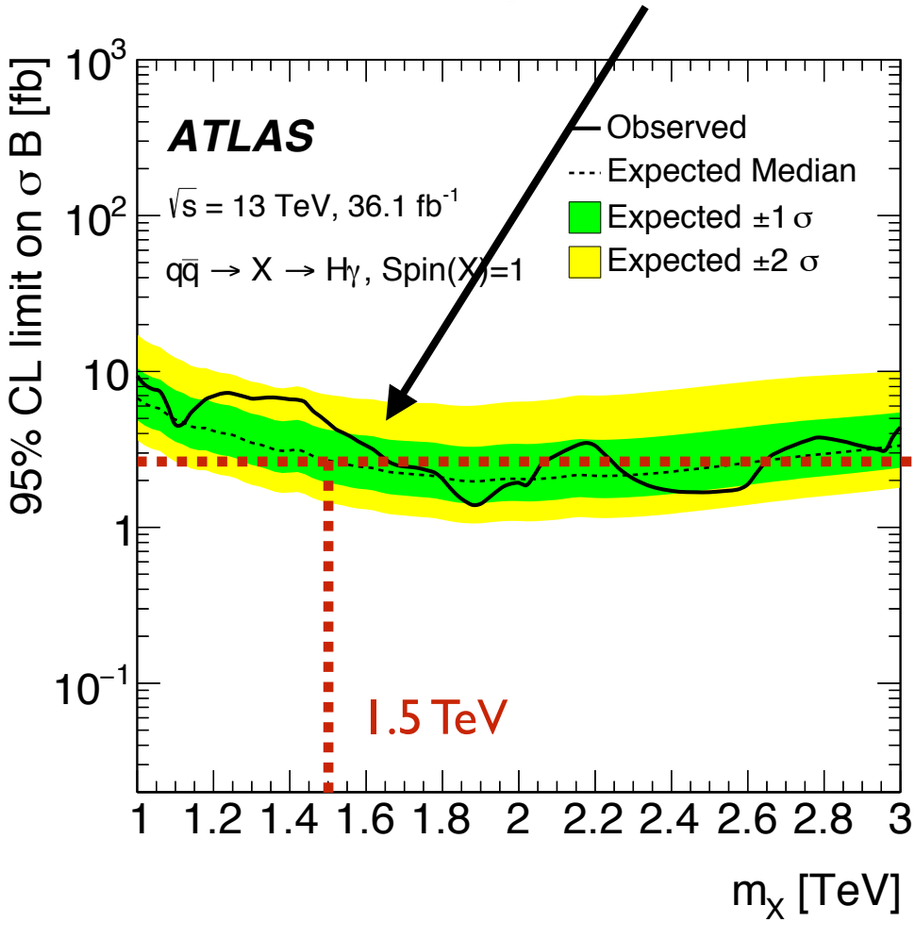
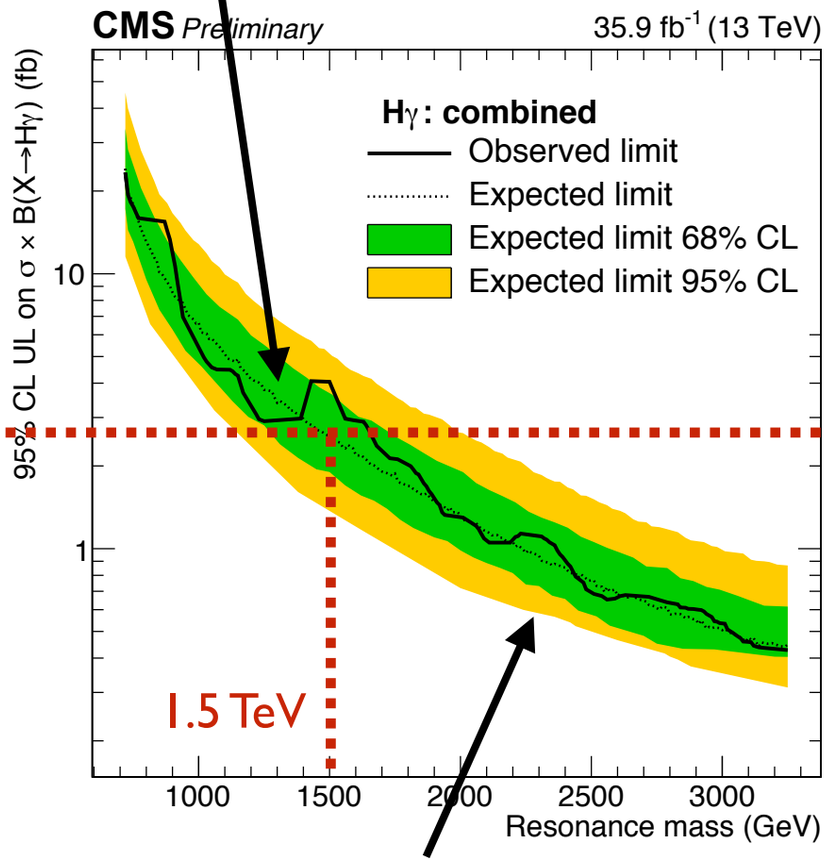


[CMS-PAS-EXO-17-019]
[ATLAS, arXiv:1805.01908]

Very similar sensitivity up to 1.5 TeV





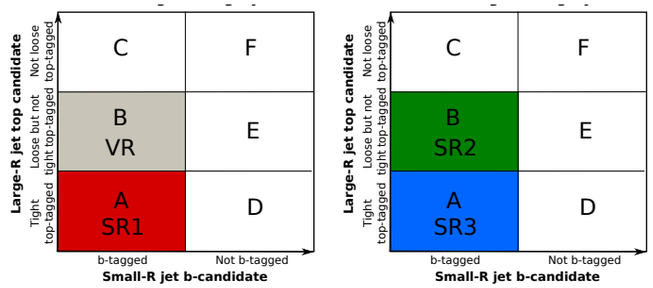
better sensitivity
due to untagged category

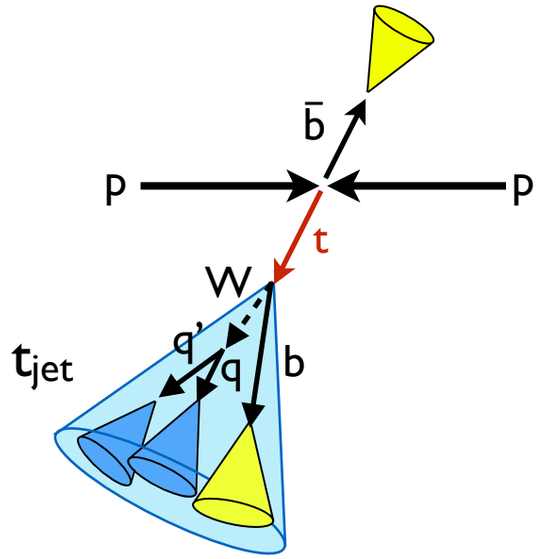
tb and tt Resonances

W' → tb (JJ)

Shower deconstruction used for the first time in an analysis

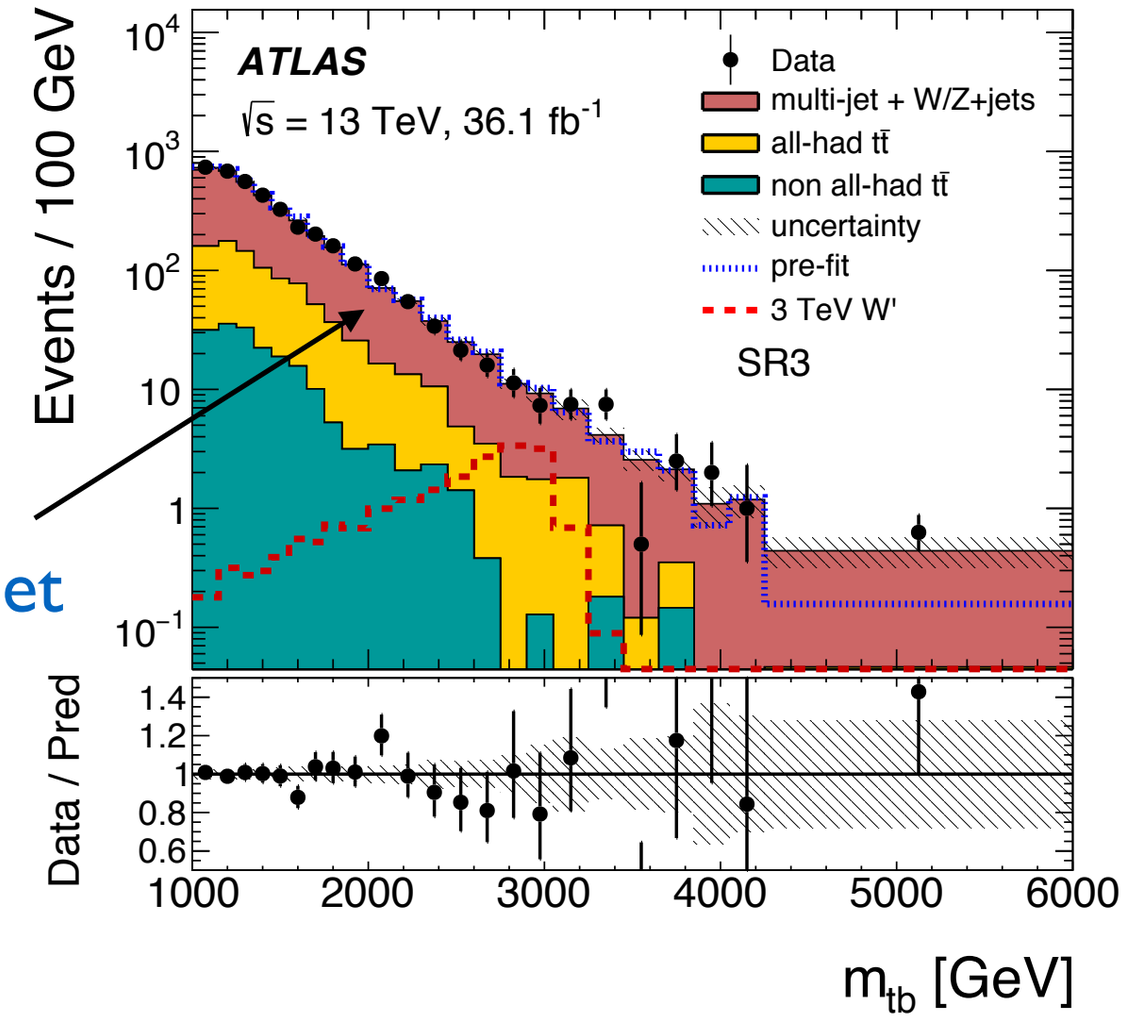
Multi-jet backgrounds: sidebands



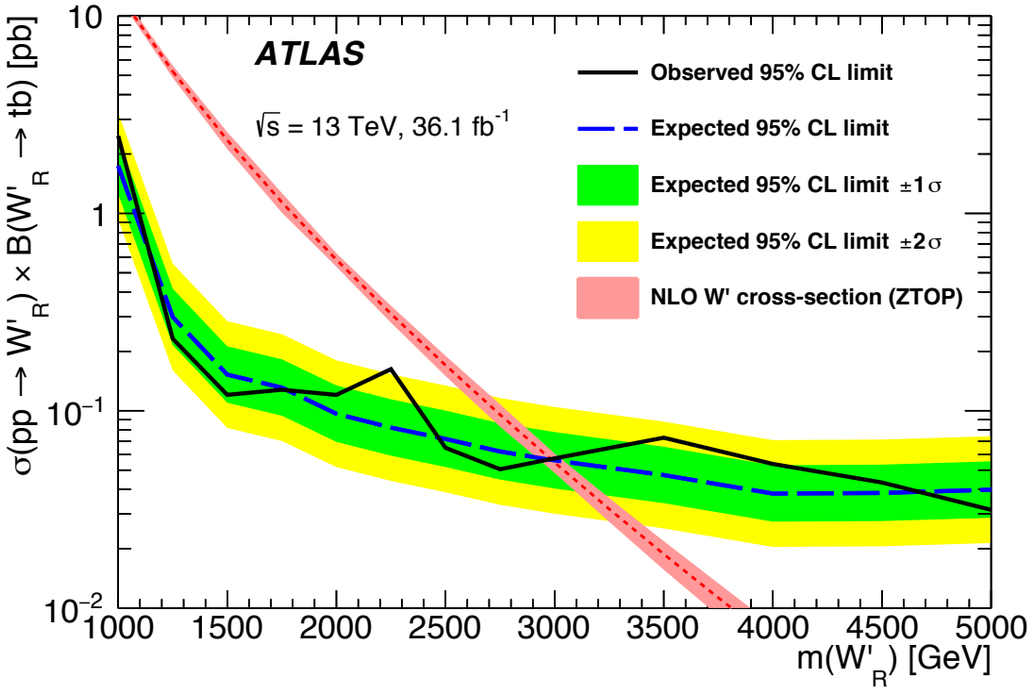


[ATLAS, PLB 781, 327 (2018)]

tight t tag, 2b tags



75% multi-jet bkgd



W_R' exclusion: 3.0 TeV

LJ (CMS): 3.6 TeV

[see also CMS, PLB 777, 39 (2018)]

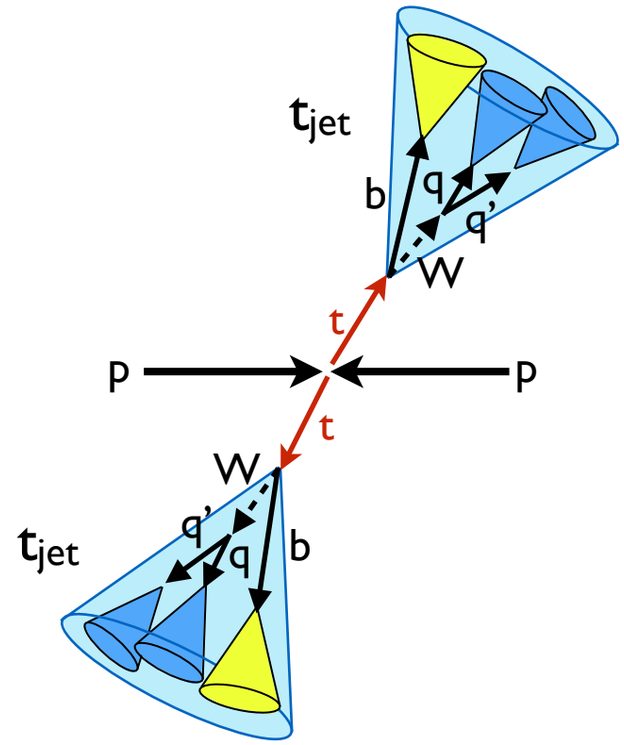
Z' → tt (LL,LJ,JJ)

NEW

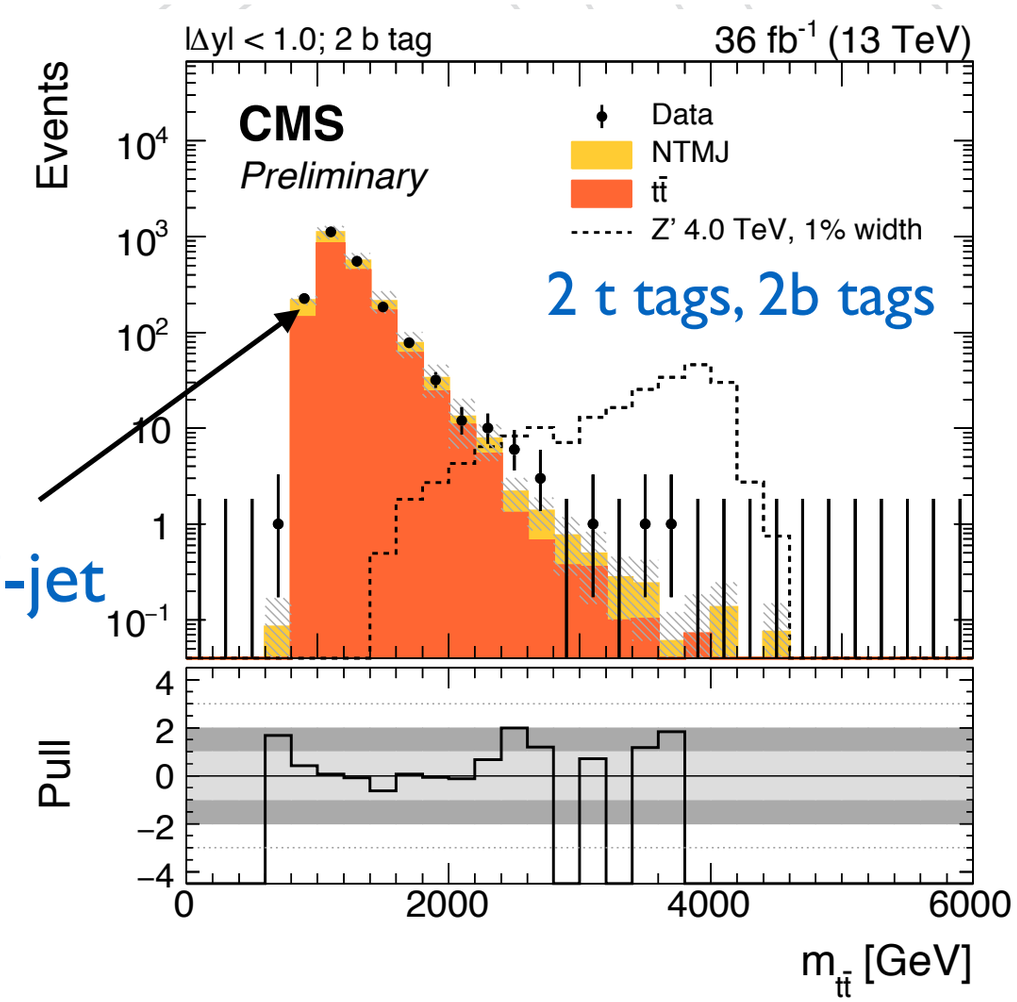
Many improvements since last result

- improved PU mitigation, b-tagging
- BDT for W+jet suppression
- CRs to constrain backgrounds

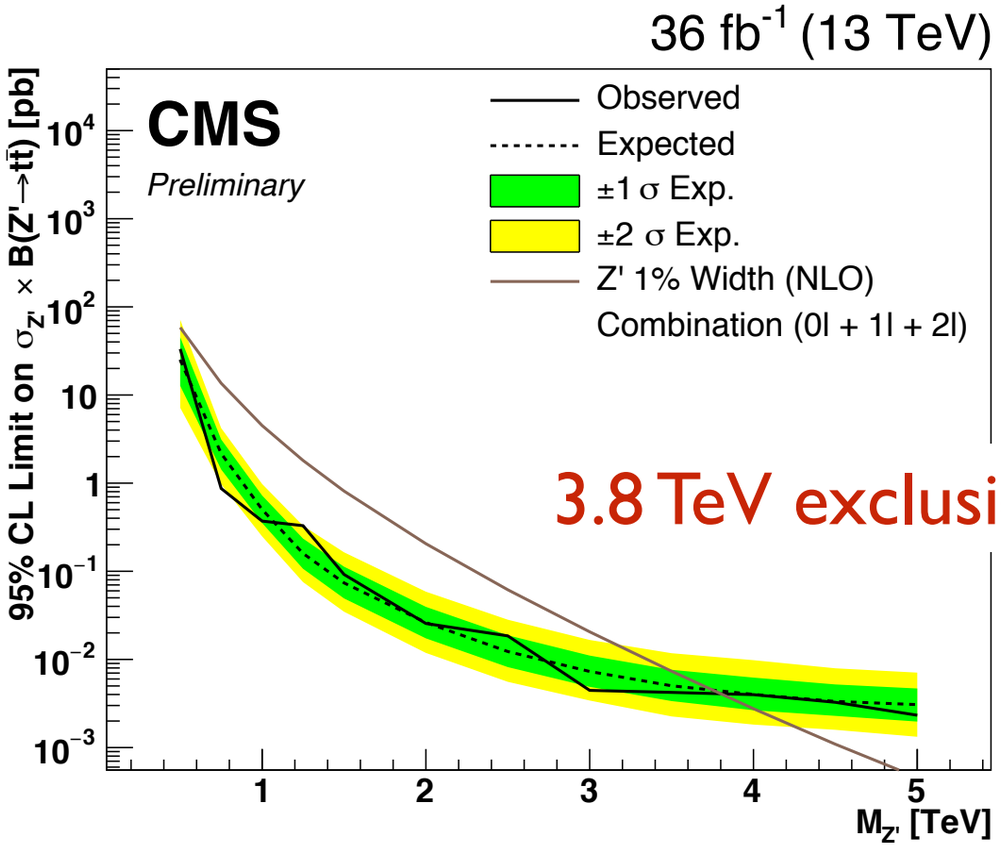
} 10-40% improvement



[CMS-PAS-17-017]

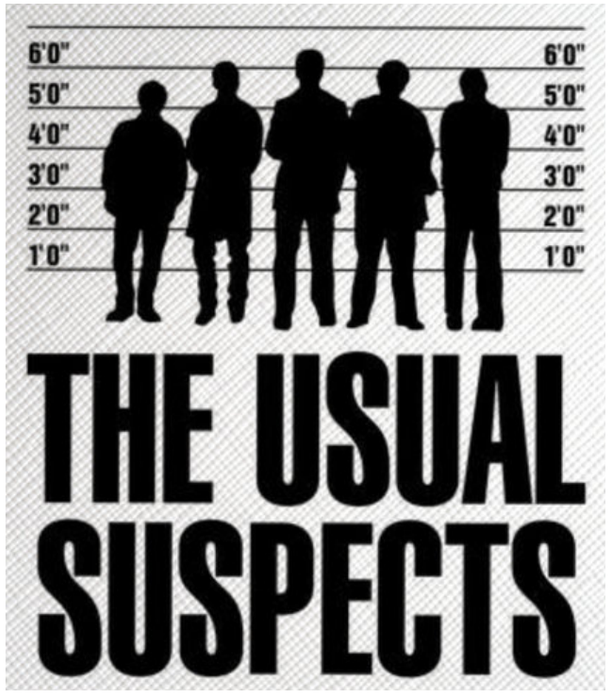


25% multi-jet bkgd



3.8 TeV exclusion

[see also ATLAS, arXiv:1804.10823]



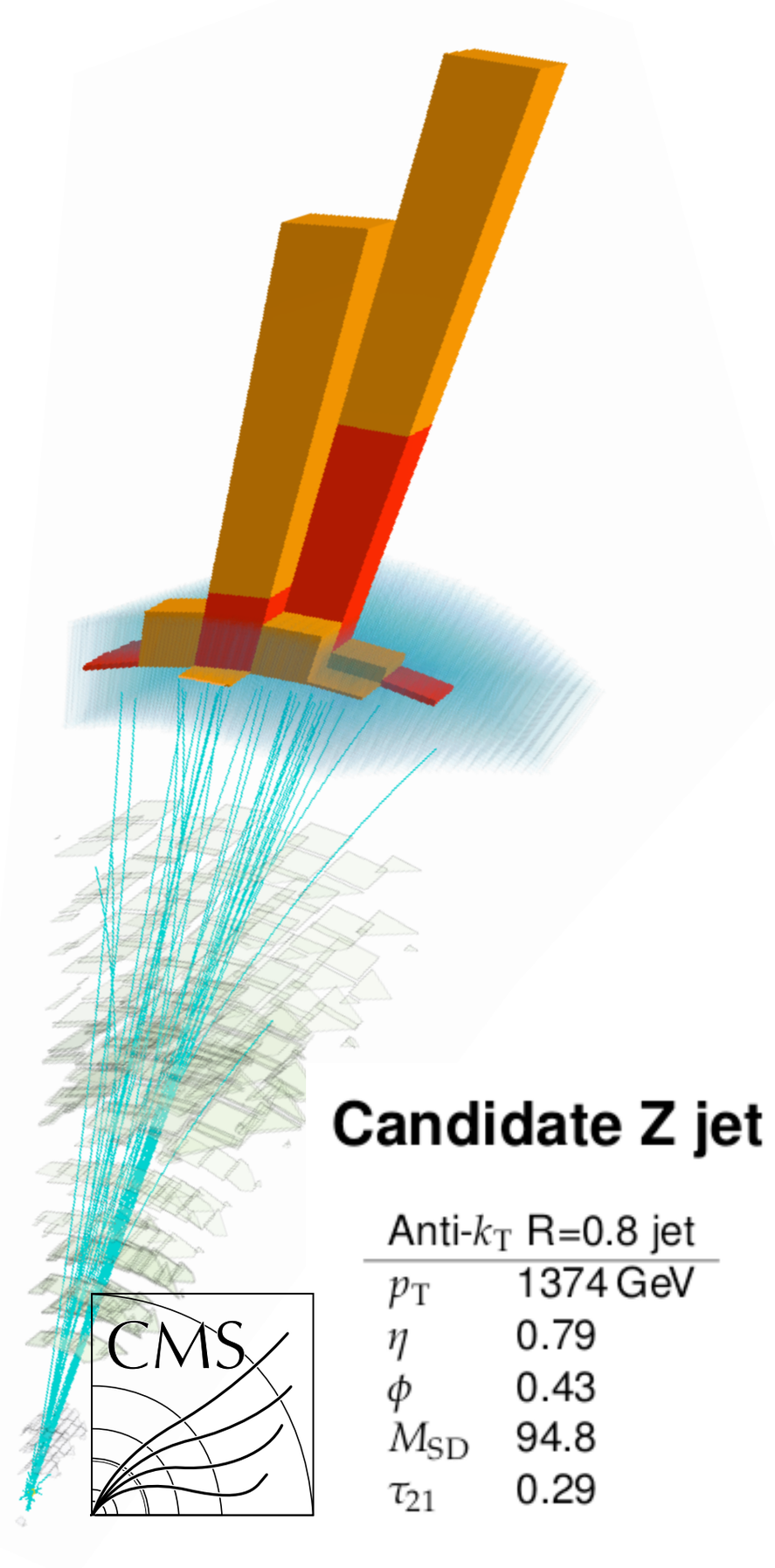
(narrow resonances)

Dijet bump hunts with jet tagging

Improvements on methods and reconstruction essential to achieve ultimate sensitivity

Phase transition in searches: target large widths, contact interactions, cascade decays

Exciting times ahead!

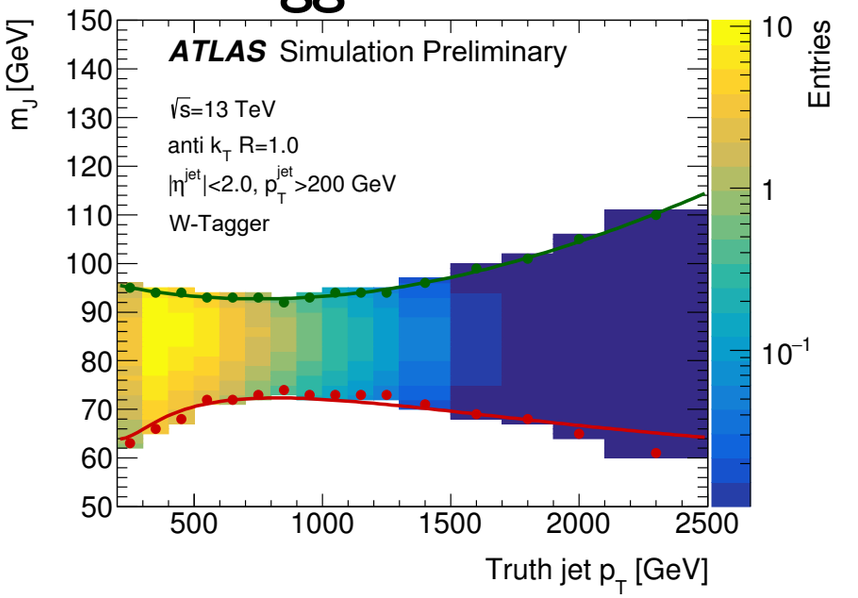


NEW

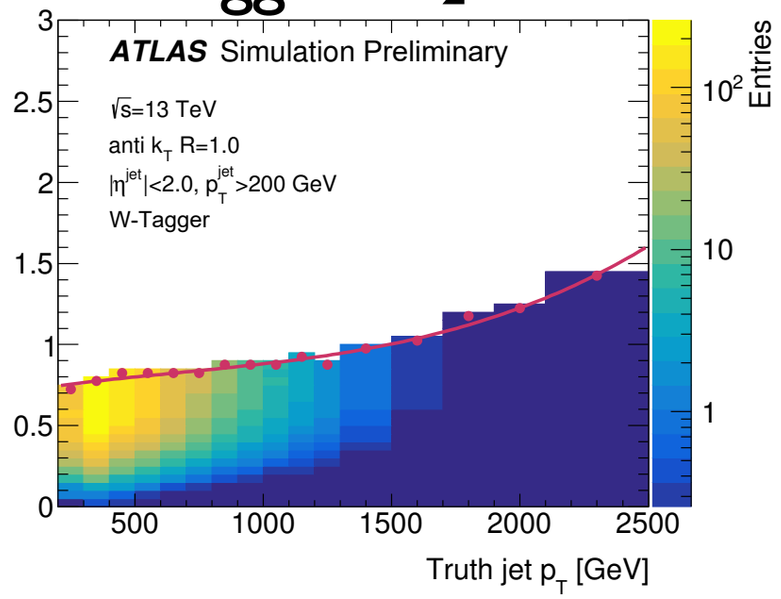
80 fb^{-1}

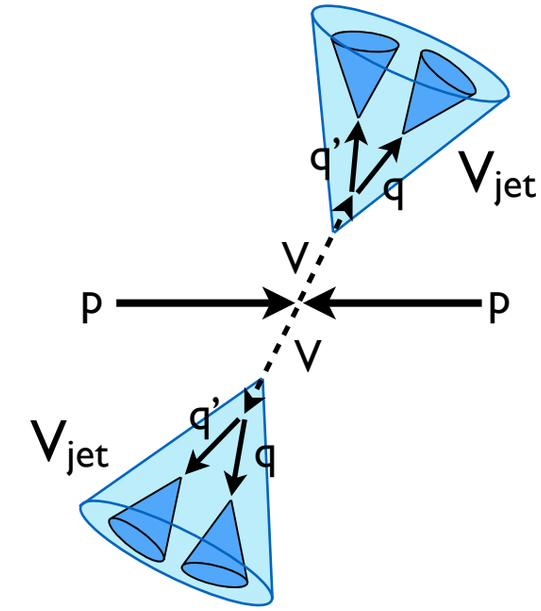
VV Resonances (JJ)

W tagger: mass cuts



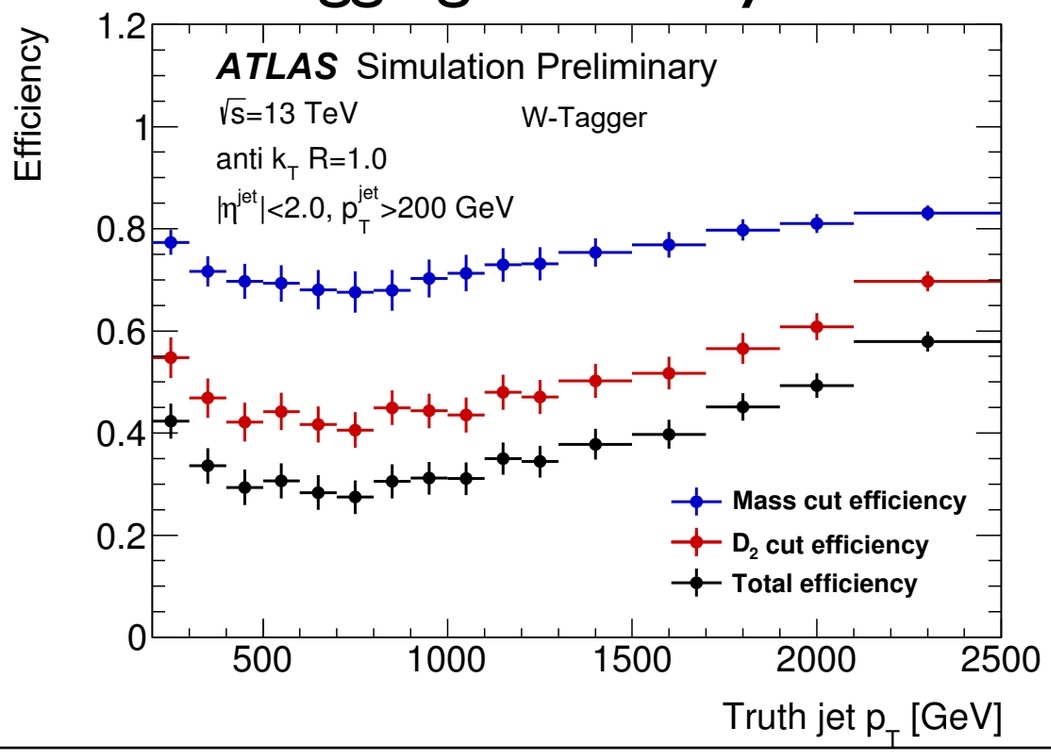
W tagger: D_2 cuts



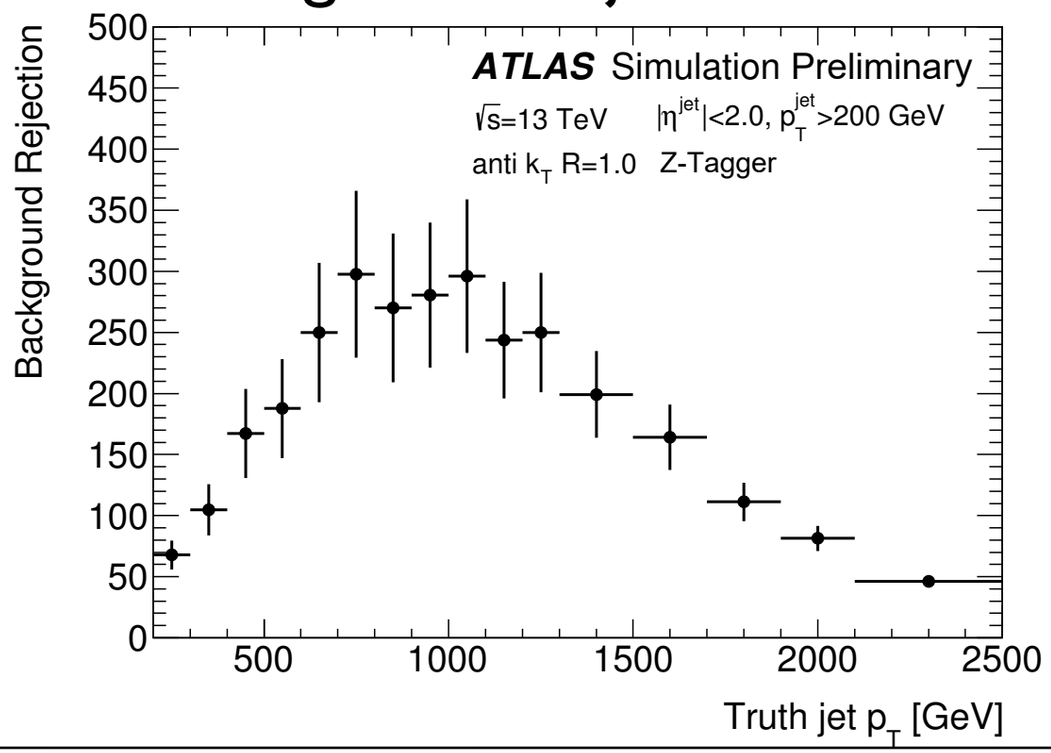


[ATLAS-CONF-2018-016]

W tagging efficiency



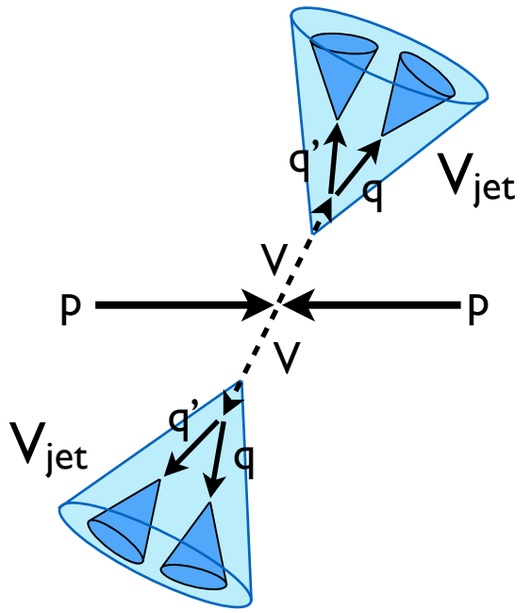
background rejection



NEW

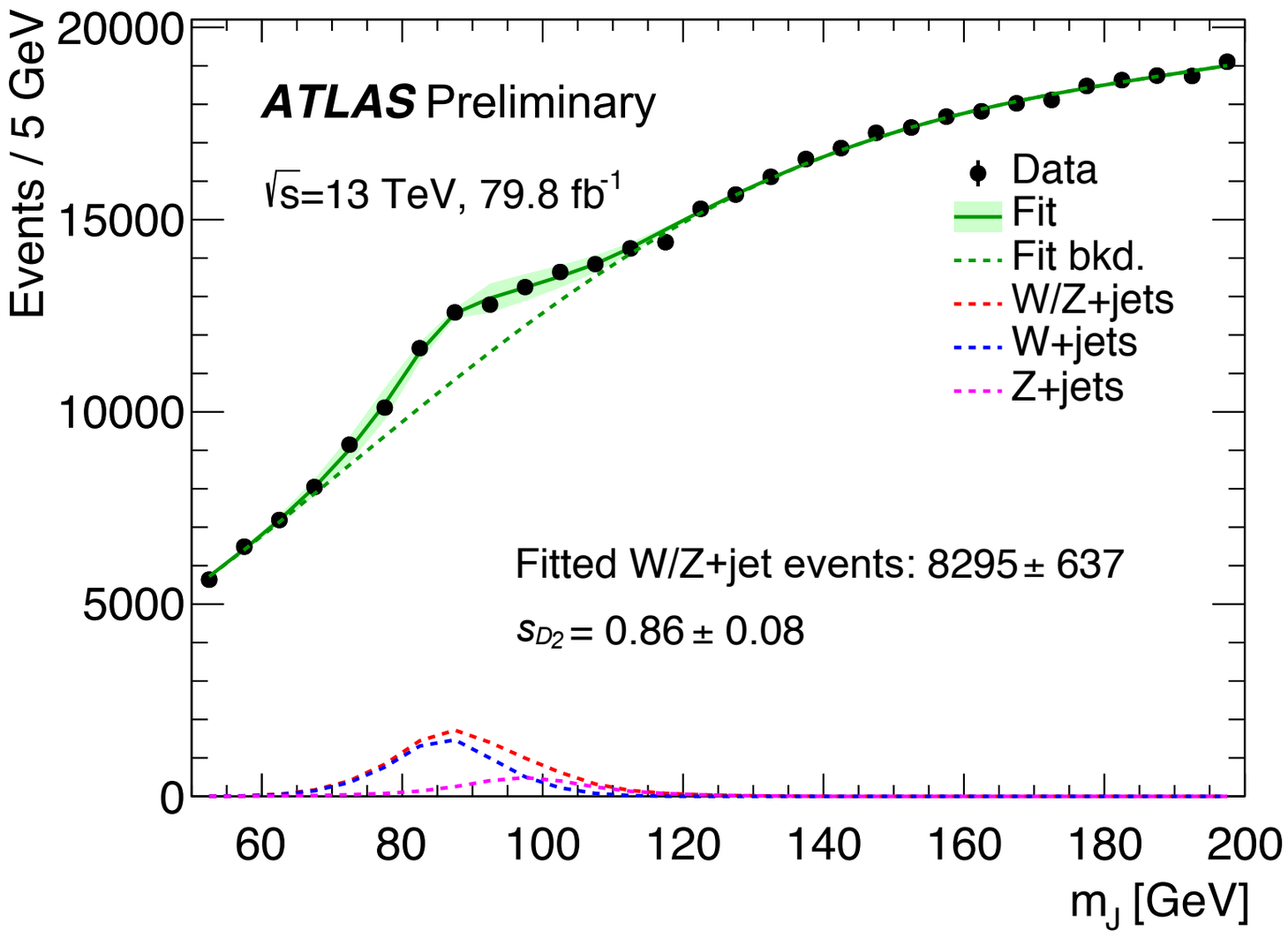
80 fb⁻¹

VV Resonances (JJ)



[ATLAS-CONF-2018-016]

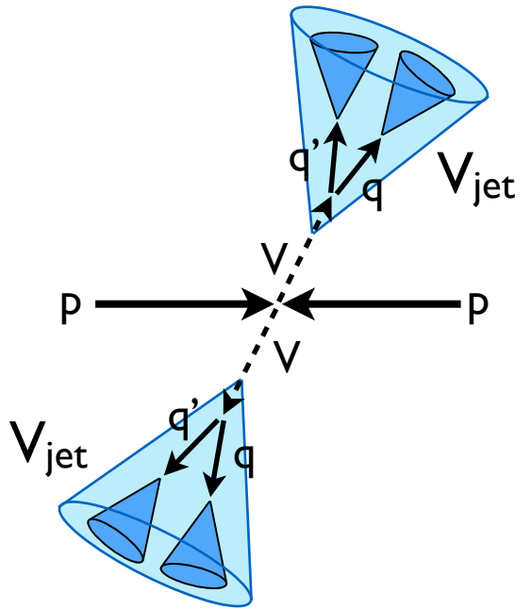
W tagger: signal efficiency measurement of D_2 cut



NEW

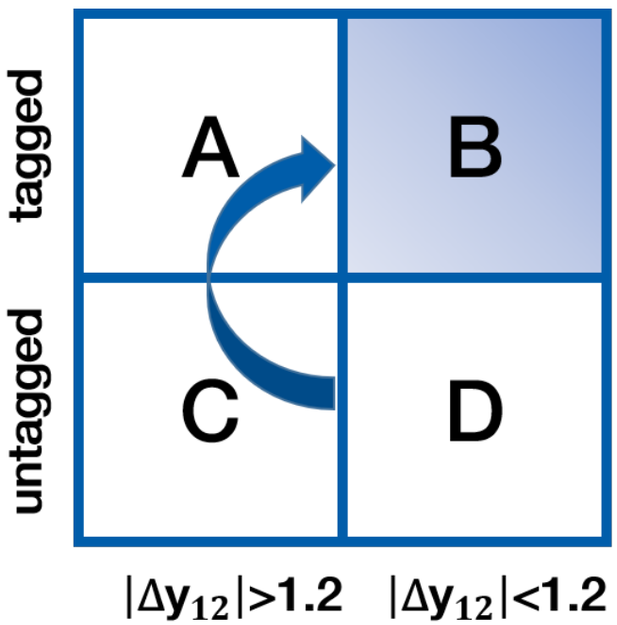
80 fb^{-1}

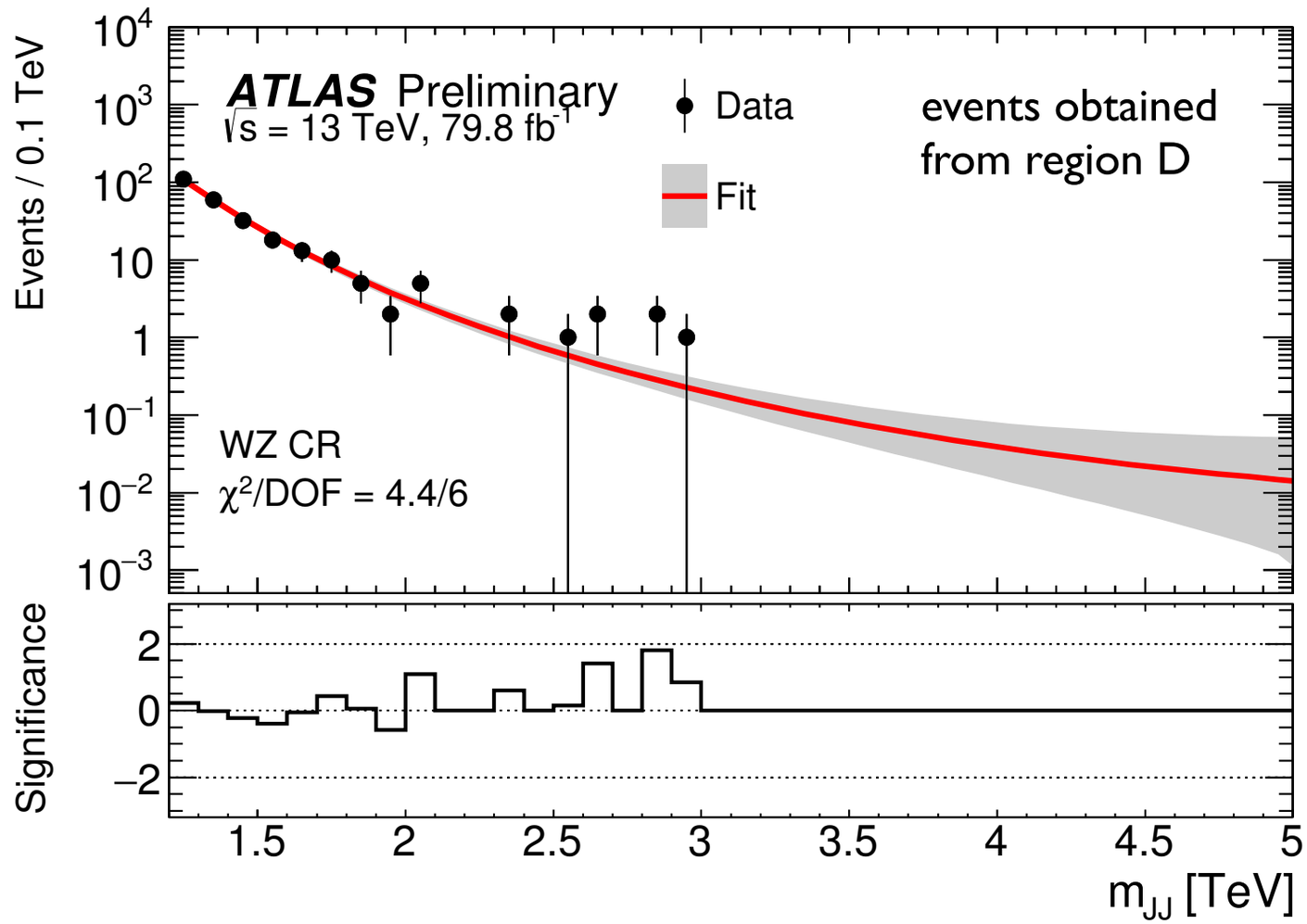
VV Resonances (JJ)



[ATLAS-CONF-2018-016]

Validating the background model

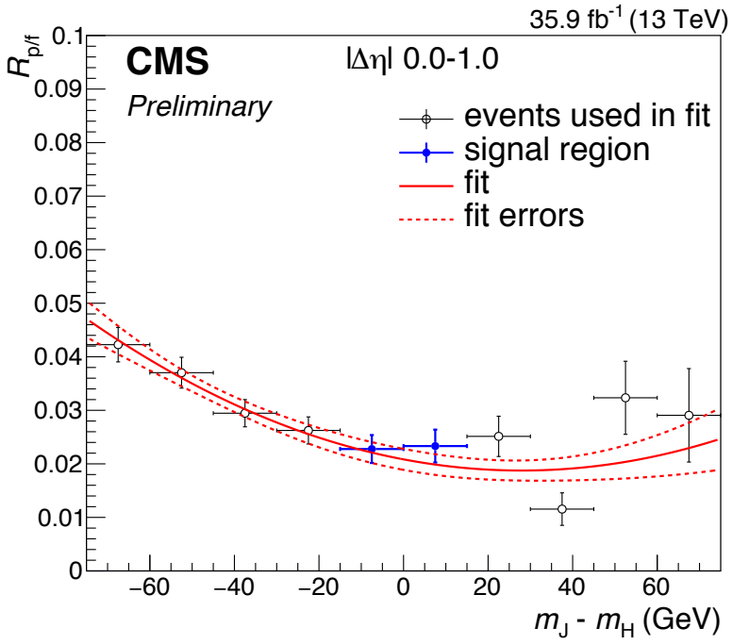


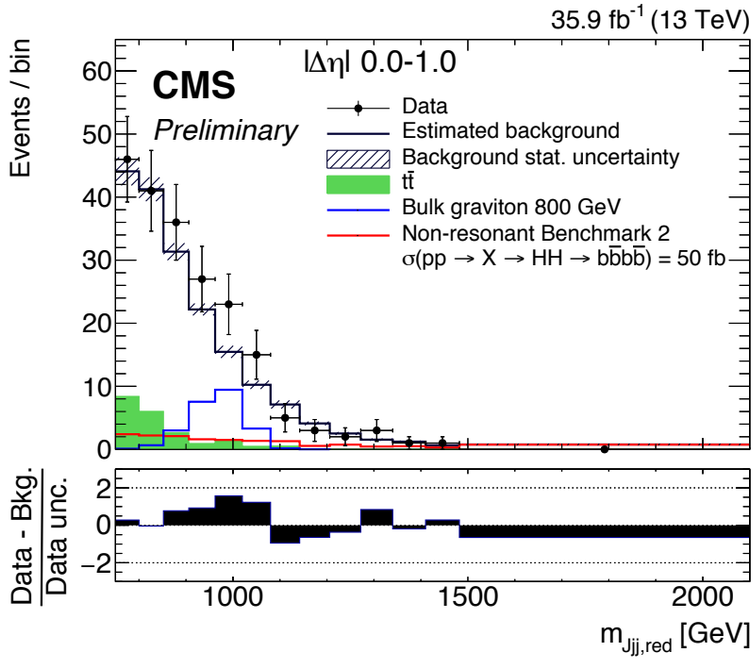


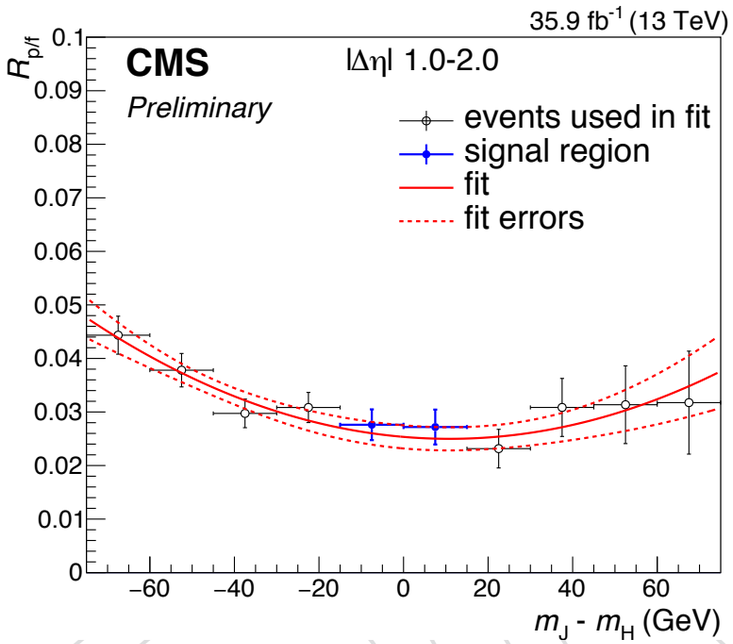
NEW

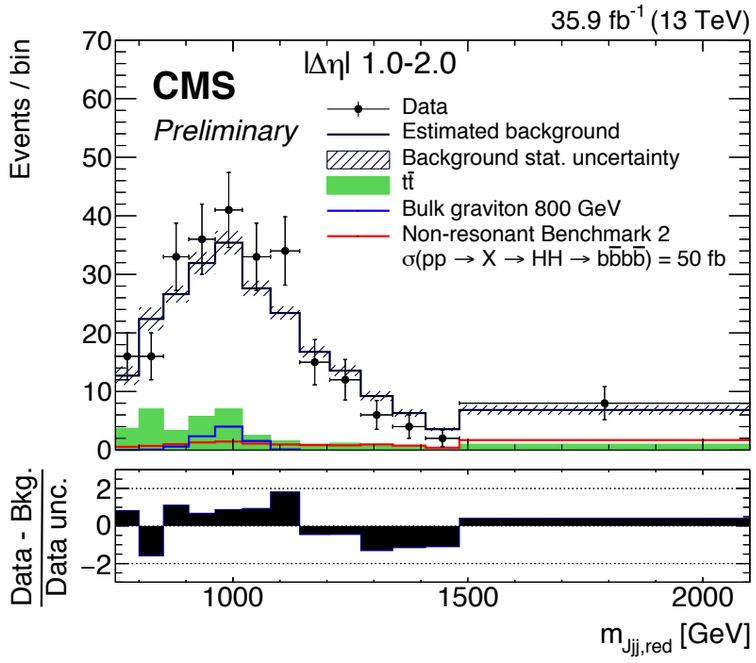
HH → 4b

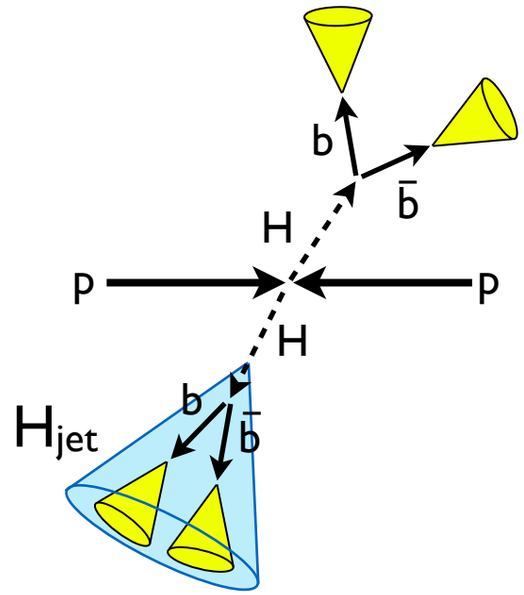
Background estimation through $R_{p/f}$











[CMS-PAS-B2G-17-019]