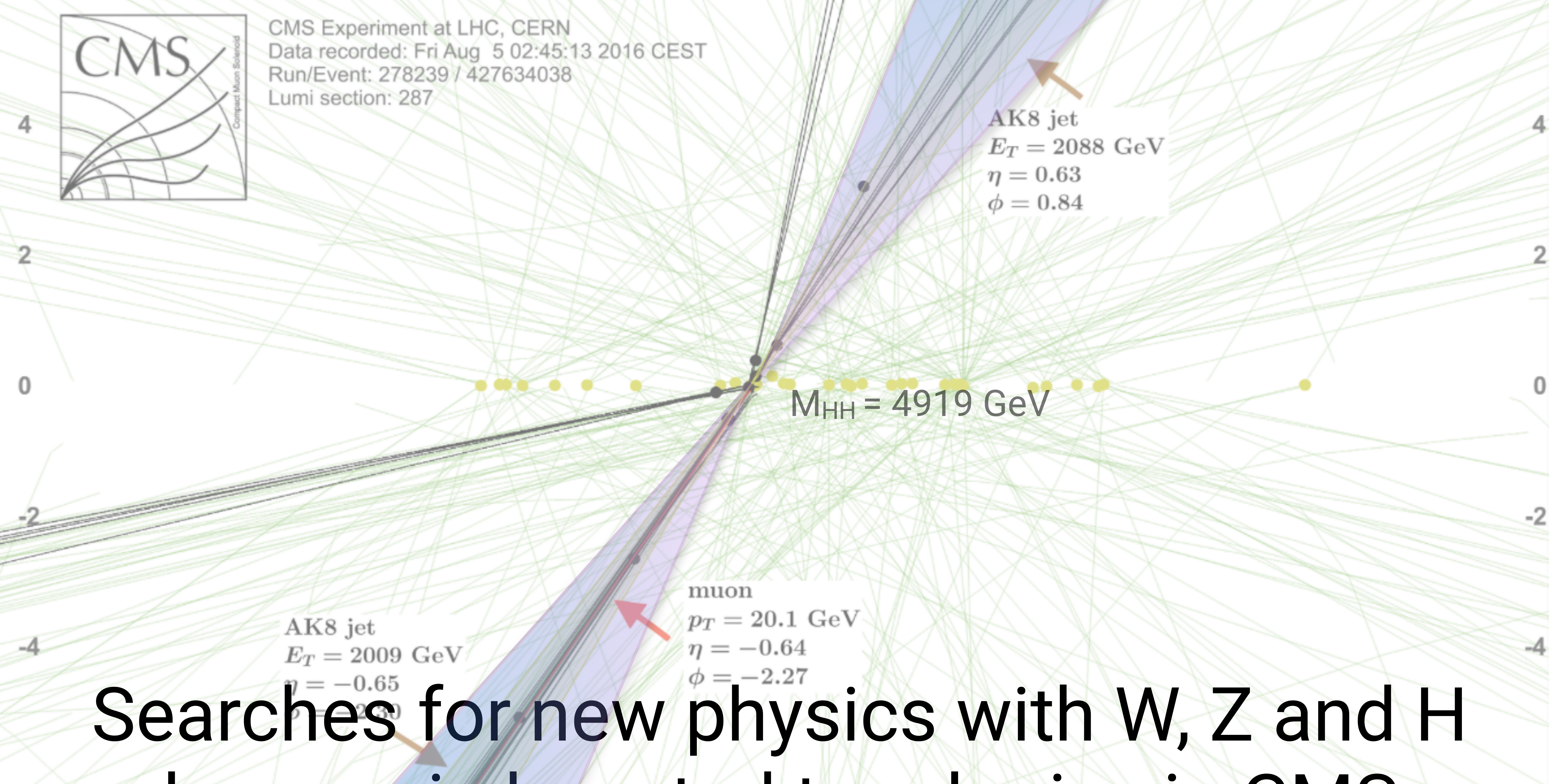


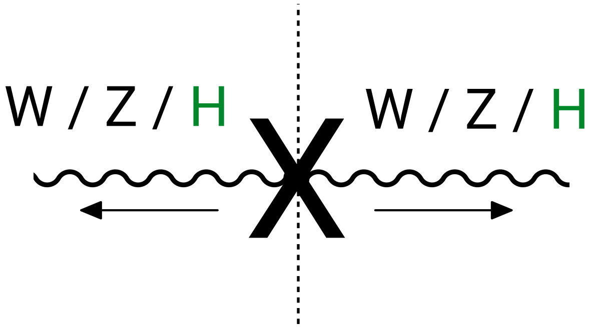
Searches for new physics with W, Z and H bosons in boosted topologies in CMS

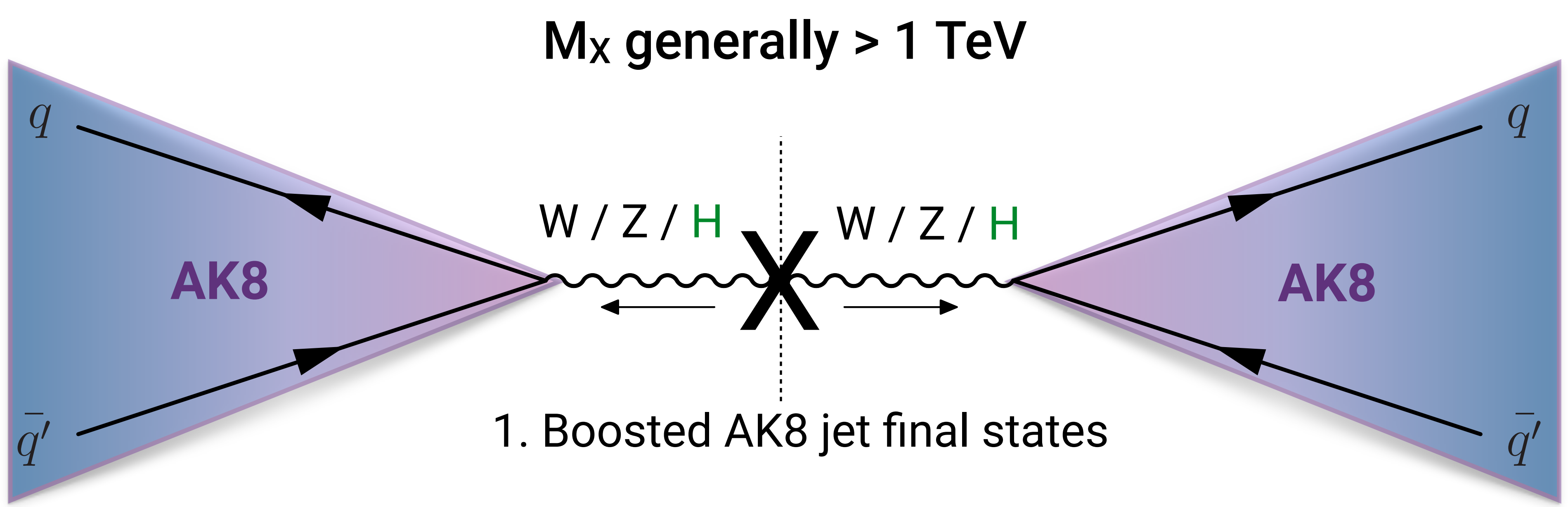
Thea Klæboe Årrestad
On behalf of the CMS Collaboration

Universität Zürich UZH

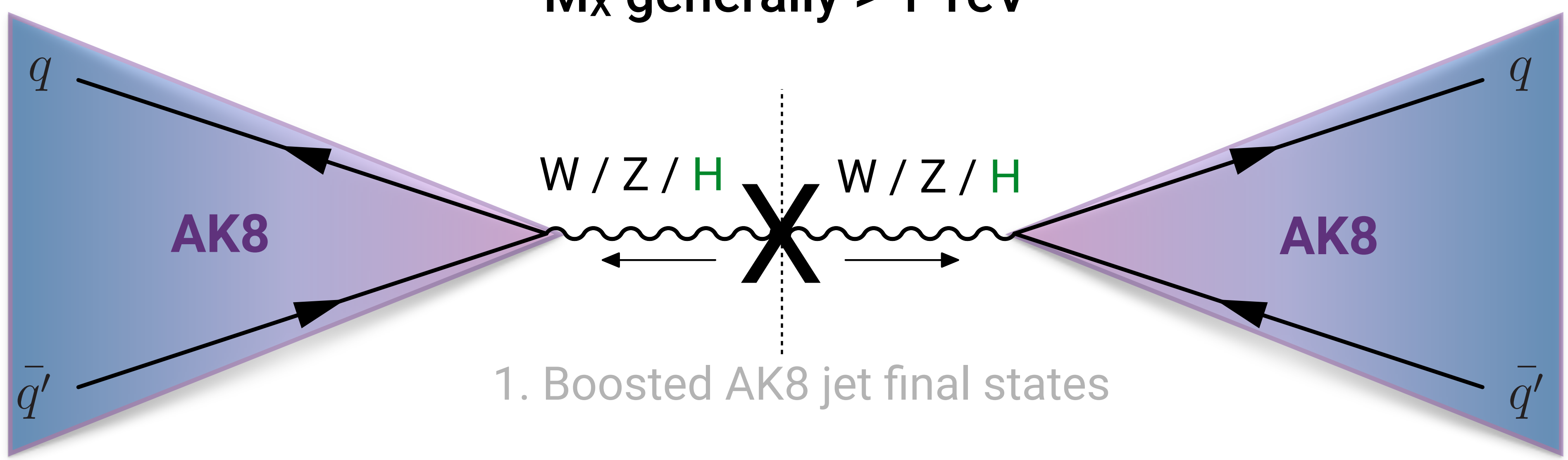
BOOST 2018
July 18th
Sorbonne Université, Paris

M_X generally > 1 TeV



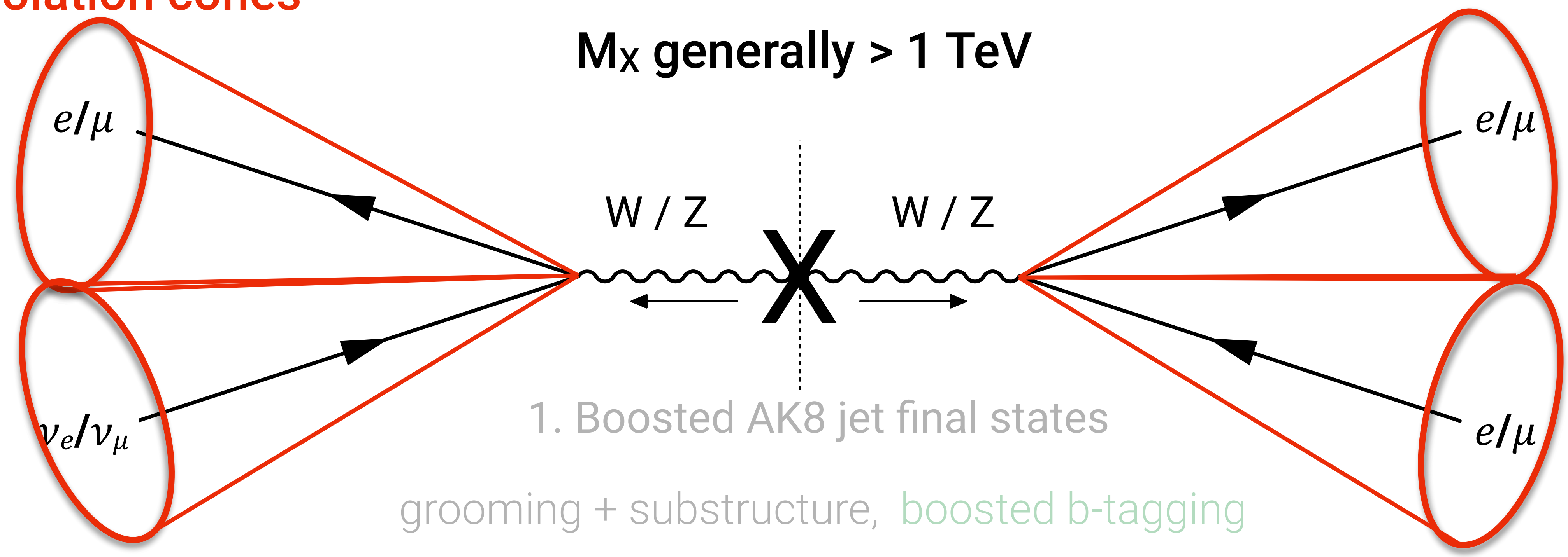

Mx generally > 1 TeV
q
q̄′
AK8
W / Z / H
X
W / Z / H
AK8
q
q̄′
1. Boosted AK8 jet final states

M_X generally > 1 TeV

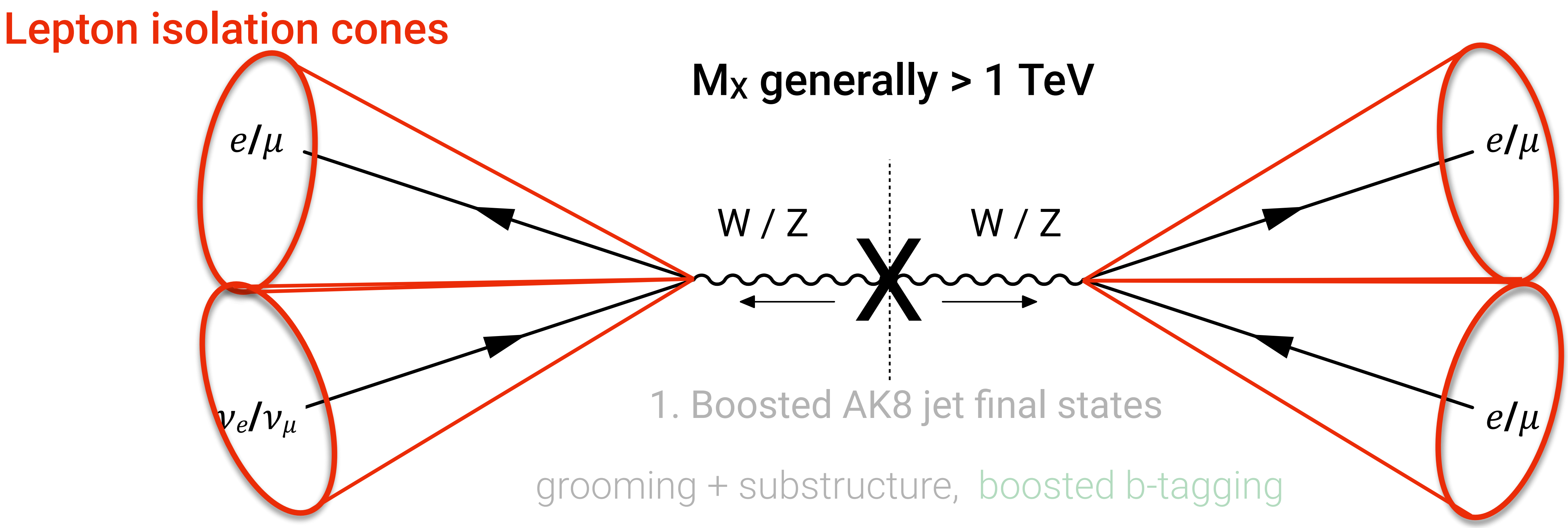


grooming + substructure, boosted b-tagging

Lepton isolation cones



2. Boosted leptonic final states

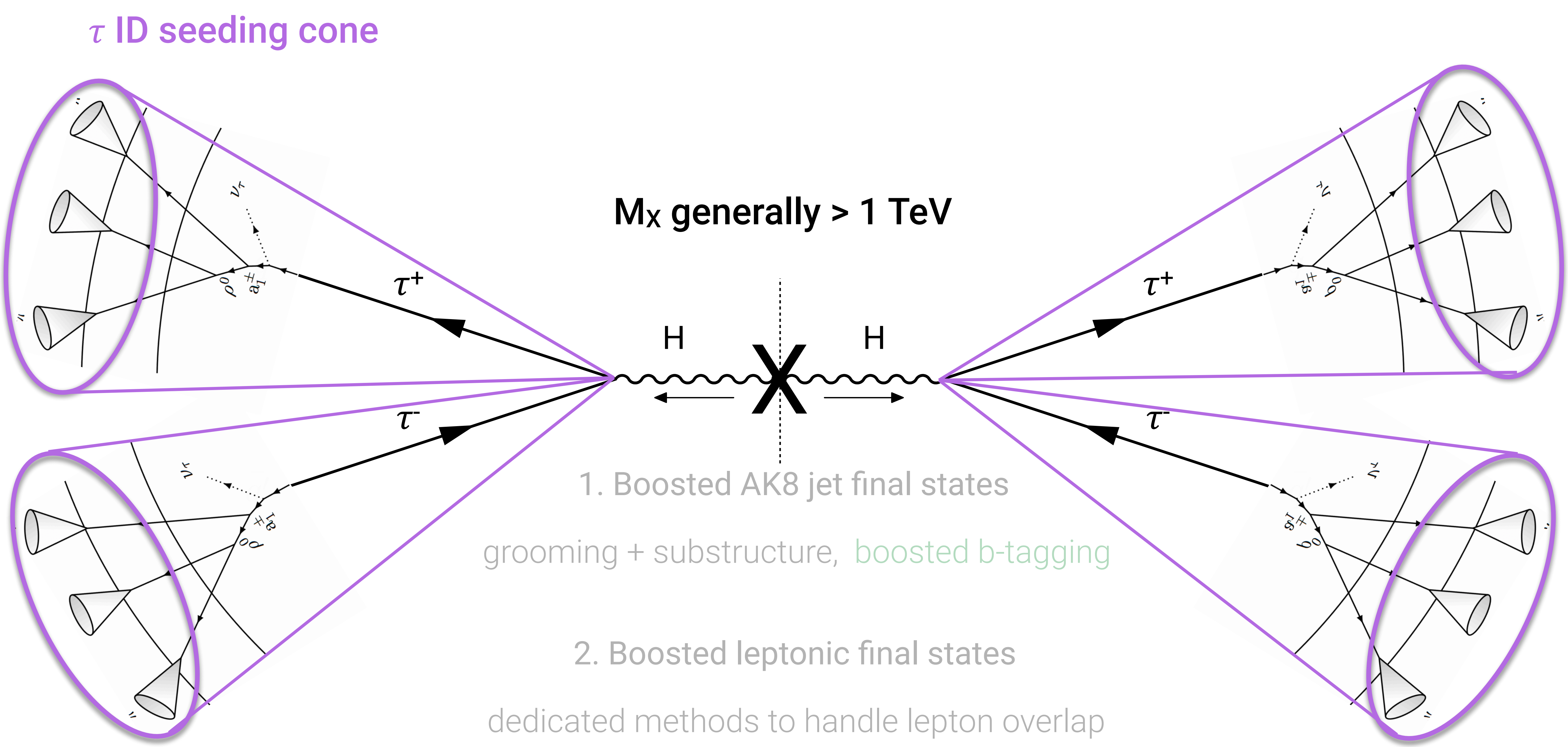


1. Boosted AK8 jet final states

grooming + substructure, boosted b-tagging

2. Boosted leptonic final states

dedicated methods to handle lepton overlap



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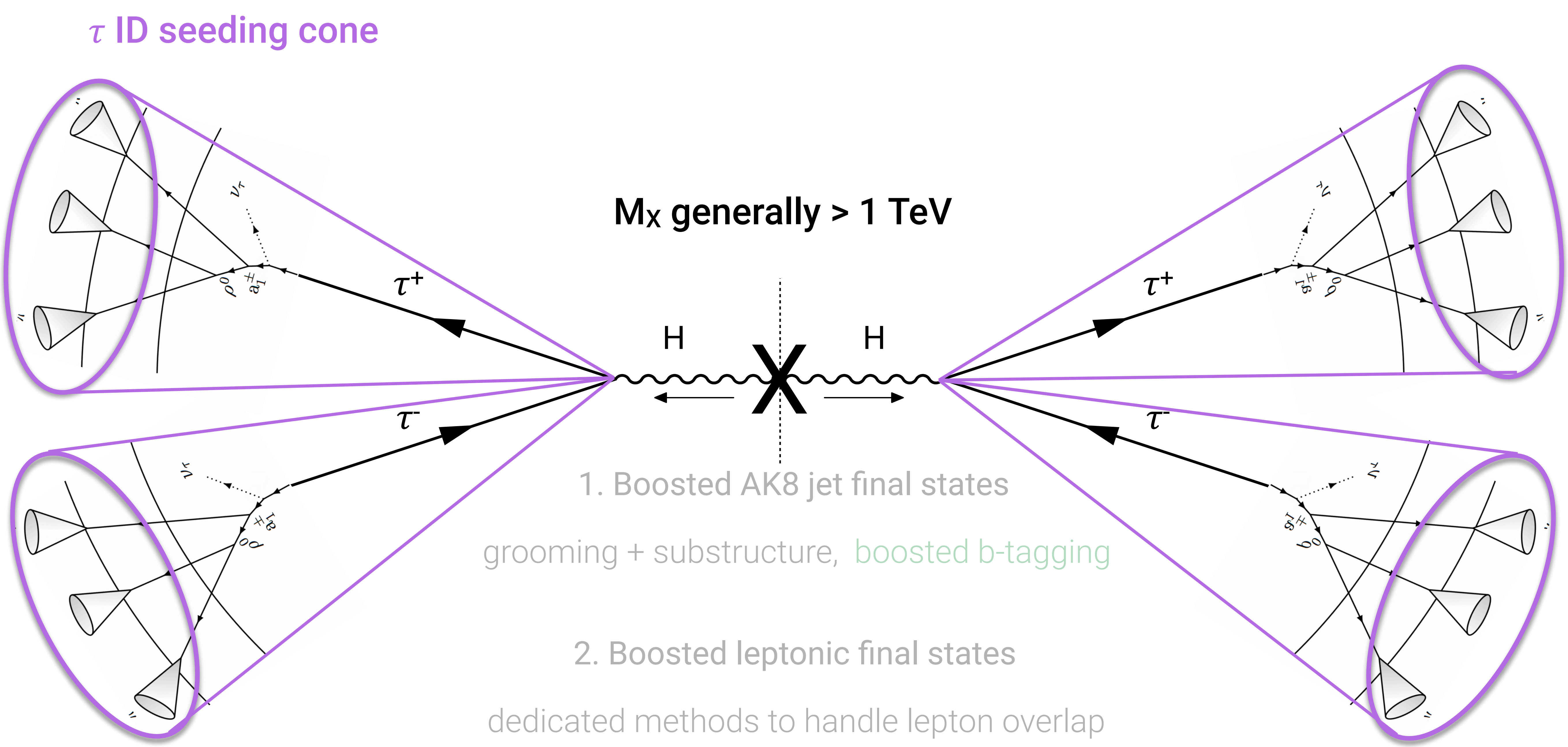
3. Boosted tau final states



1. Boosted AK8 jet final states

grooming + substructure, boosted b-tagging

2. Boosted leptonic final states

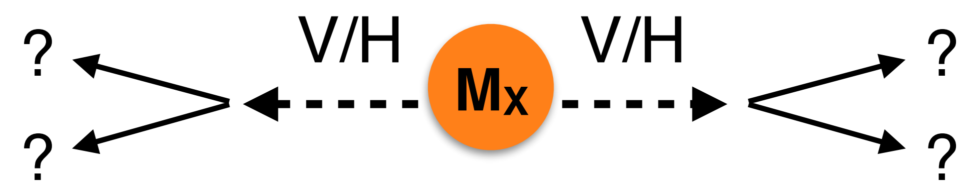
dedicated methods to handle lepton overlap

3. Boosted tau final states

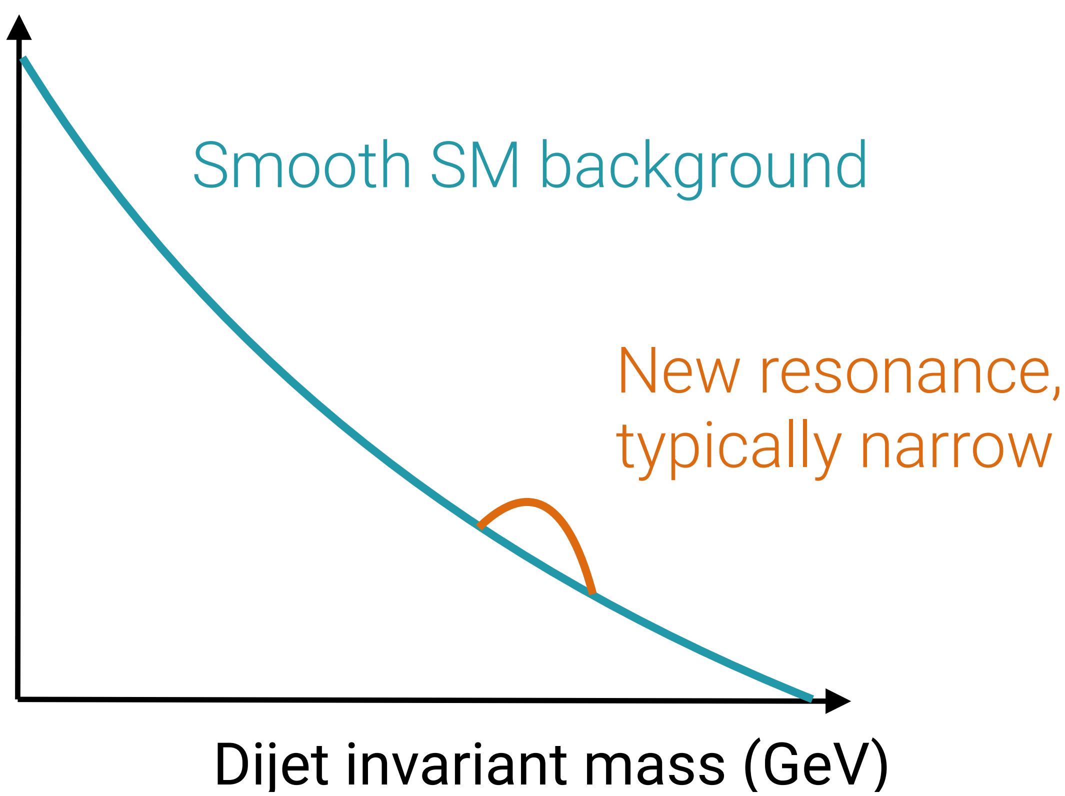
~all of the above!

General search strategy

1. Reconstruct hadronically/leptonically decaying bosons
   - **Diboson:** hadronic, leptonic and semi-leptonic VV, VH and HH (V= W/Z)
   - **Single boson:** qV, AV



2. Bump hunt in invariant mass spectrum



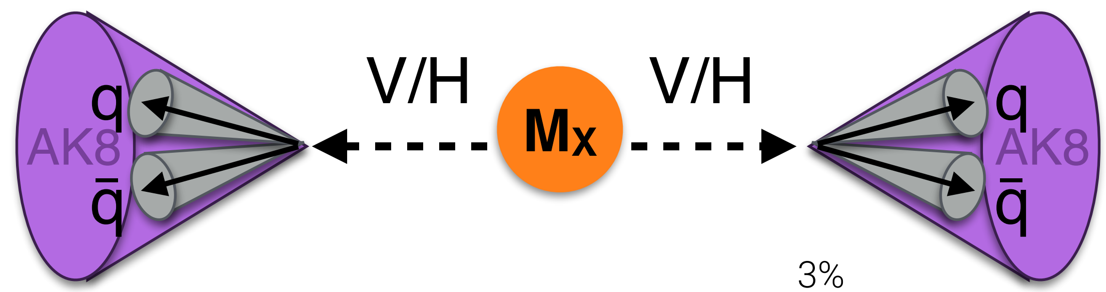
<u>Disclaimer:</u>
Many more interesting CMS analyses with boosted bosons than shown here, selected a few which highlight boosted reconstruction

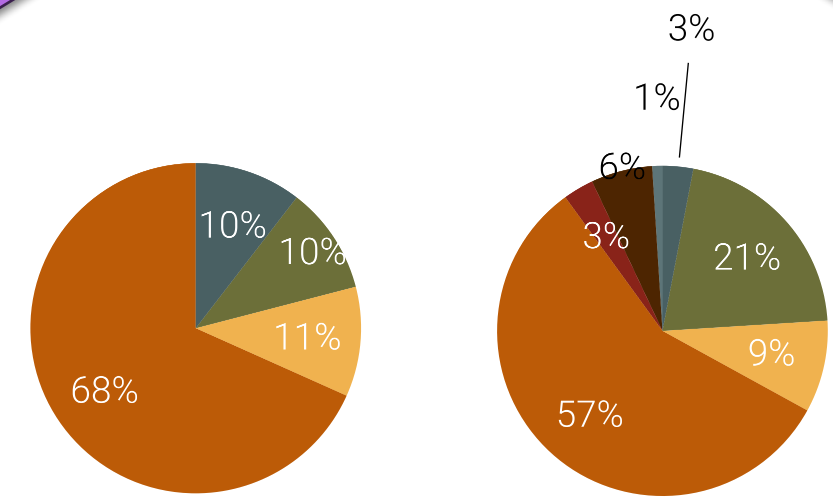
All hadronic final states

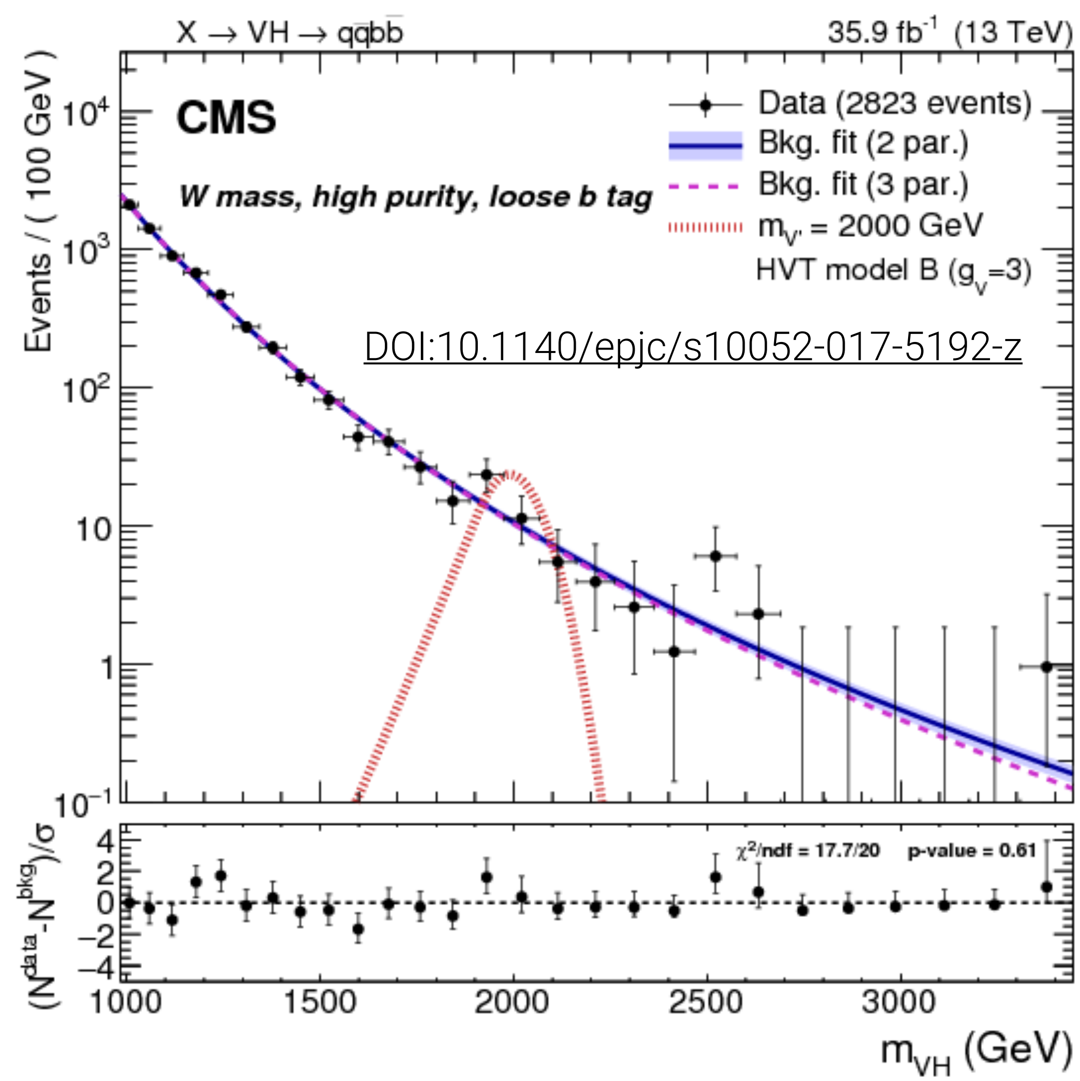
X→VV, VH or HH decaying hadronically

The pros:

- Largest branching fraction (good at high m_X where background is low)
- simple and robust: background (QCD) estimated from fit to data with smoothly falling function







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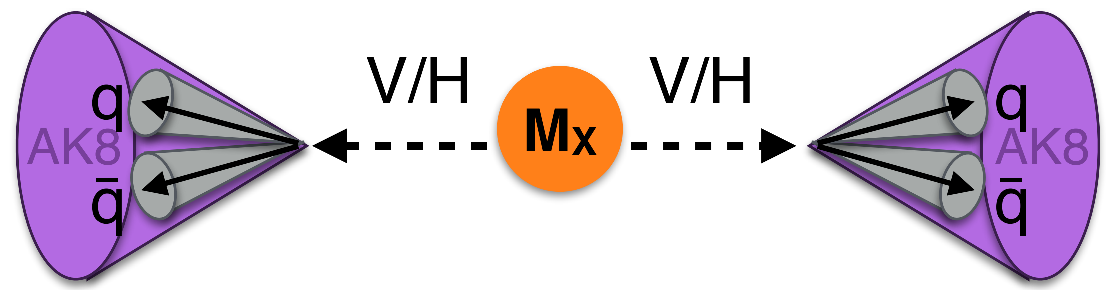

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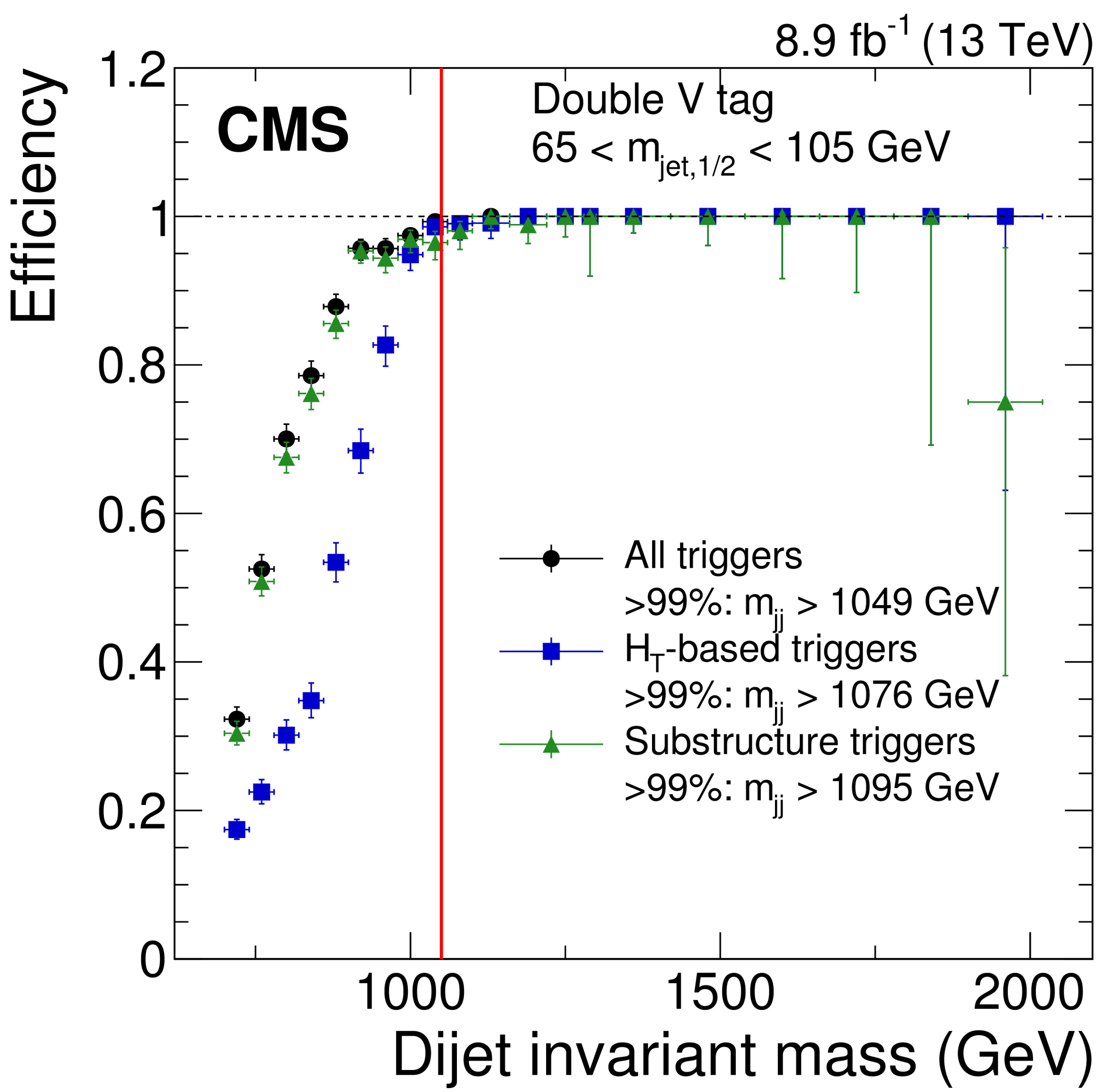

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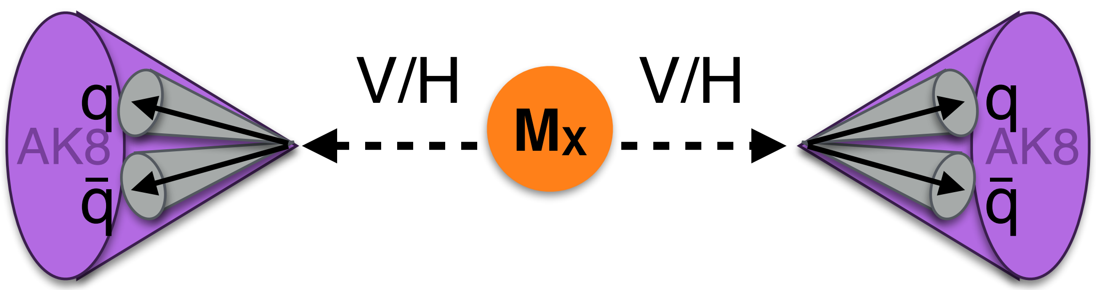

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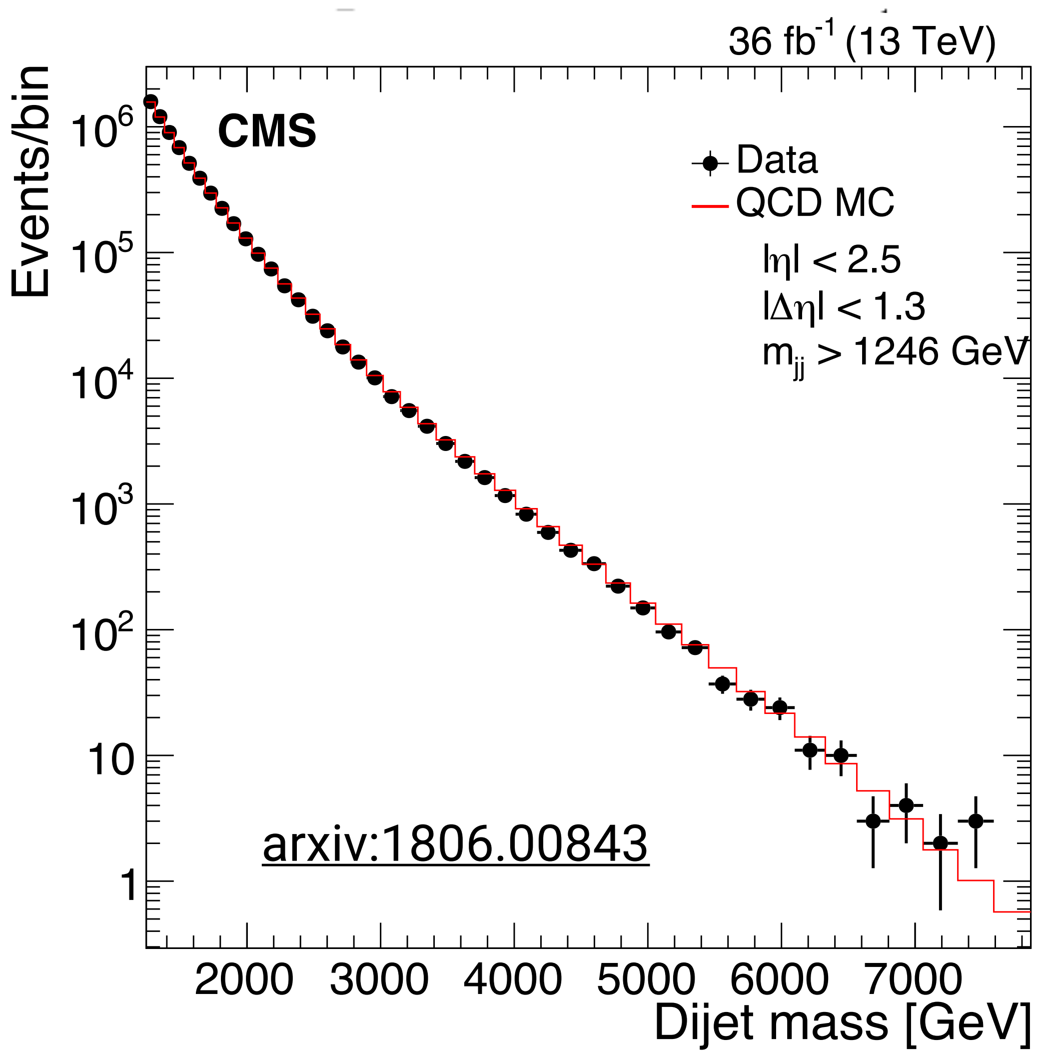
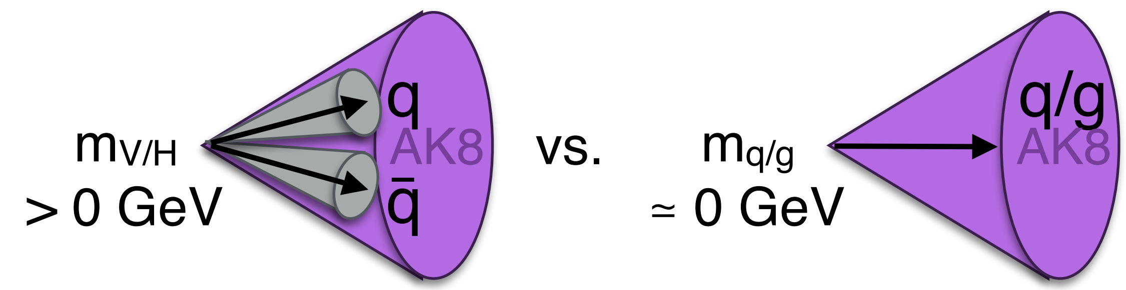
- Largest branching fraction (good at high m_X where background is low)
- simple and robust: background (QCD) estimated from fit to data with smoothly falling function

The cons:

- trigger limited (need smoothly falling m_{jj})
- less sensitive in high-mass tail due to parametric fit
- overwhelming multijet background

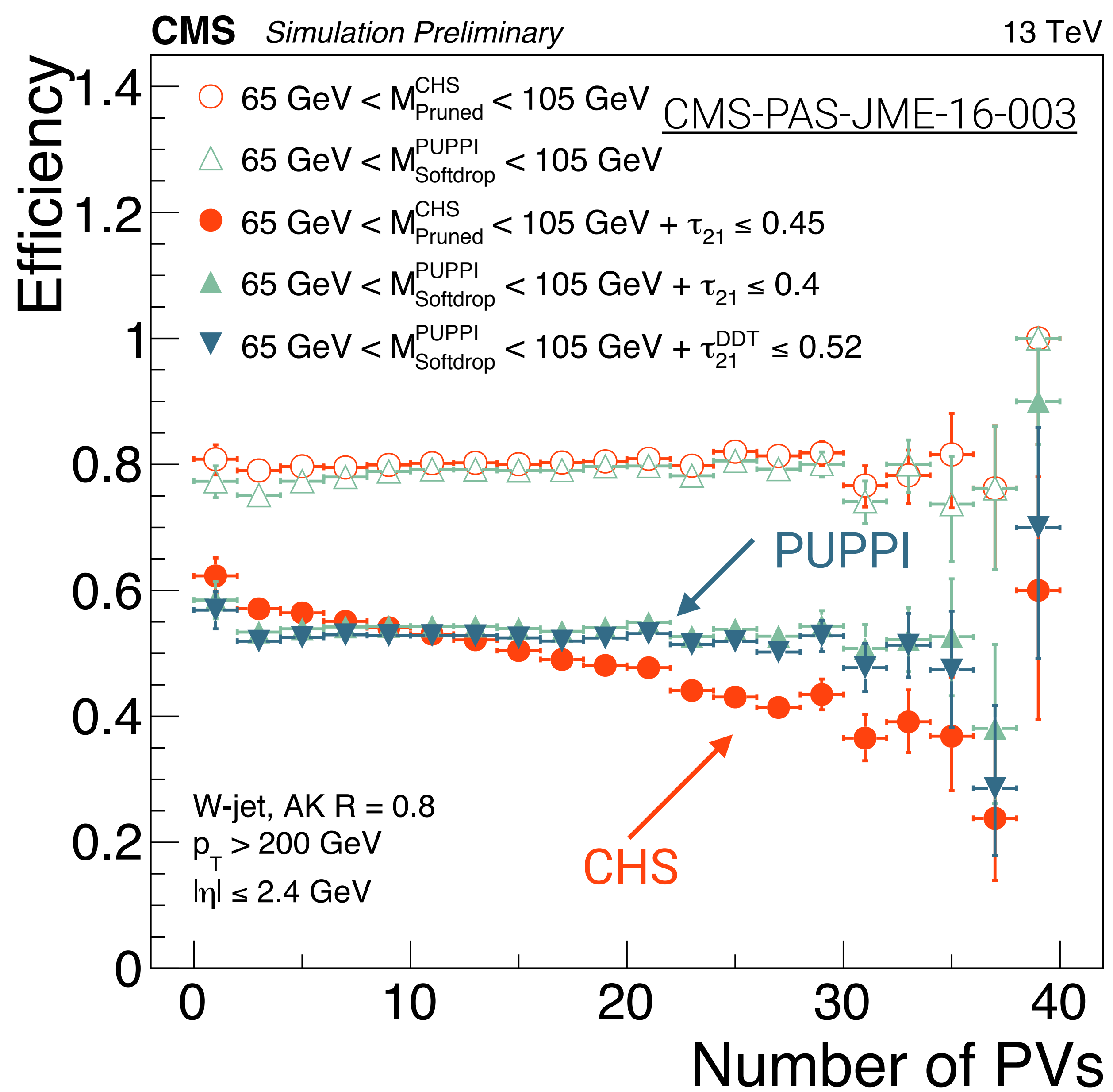


Boson reconstruction



1. Get rid of pile-up

 - PileUp Per Particle Identification (PUPPI) (CMS “default” for AK8 (A. Beneckes talk)



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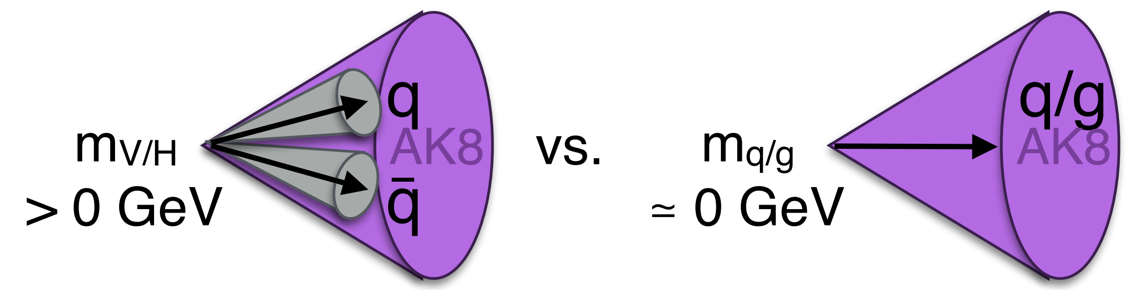

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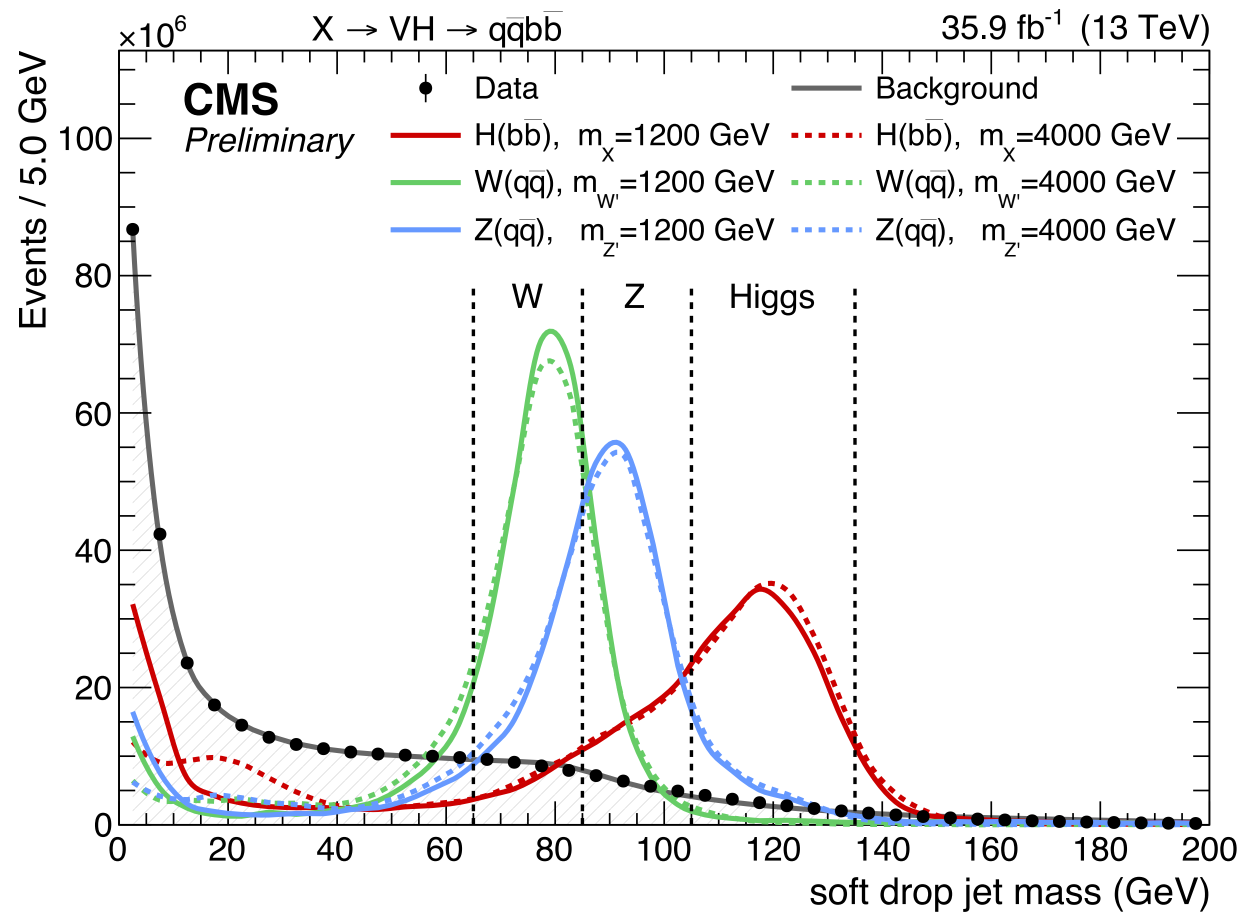
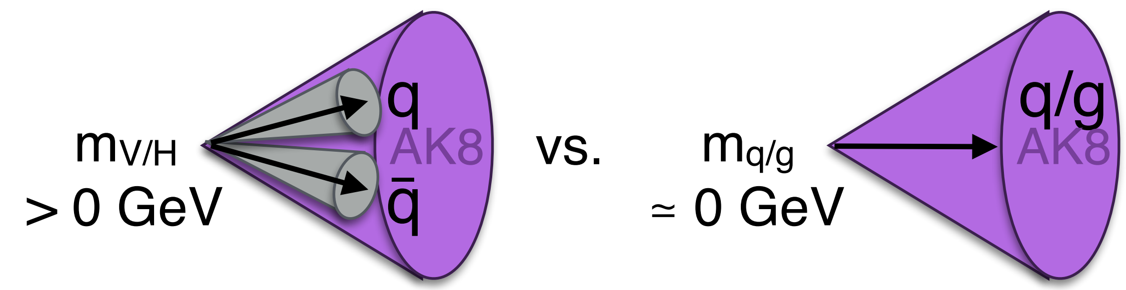


! Orthogonal mass windows
Important for combining results, mass resolution is key for choice of groomer

Boson reconstruction



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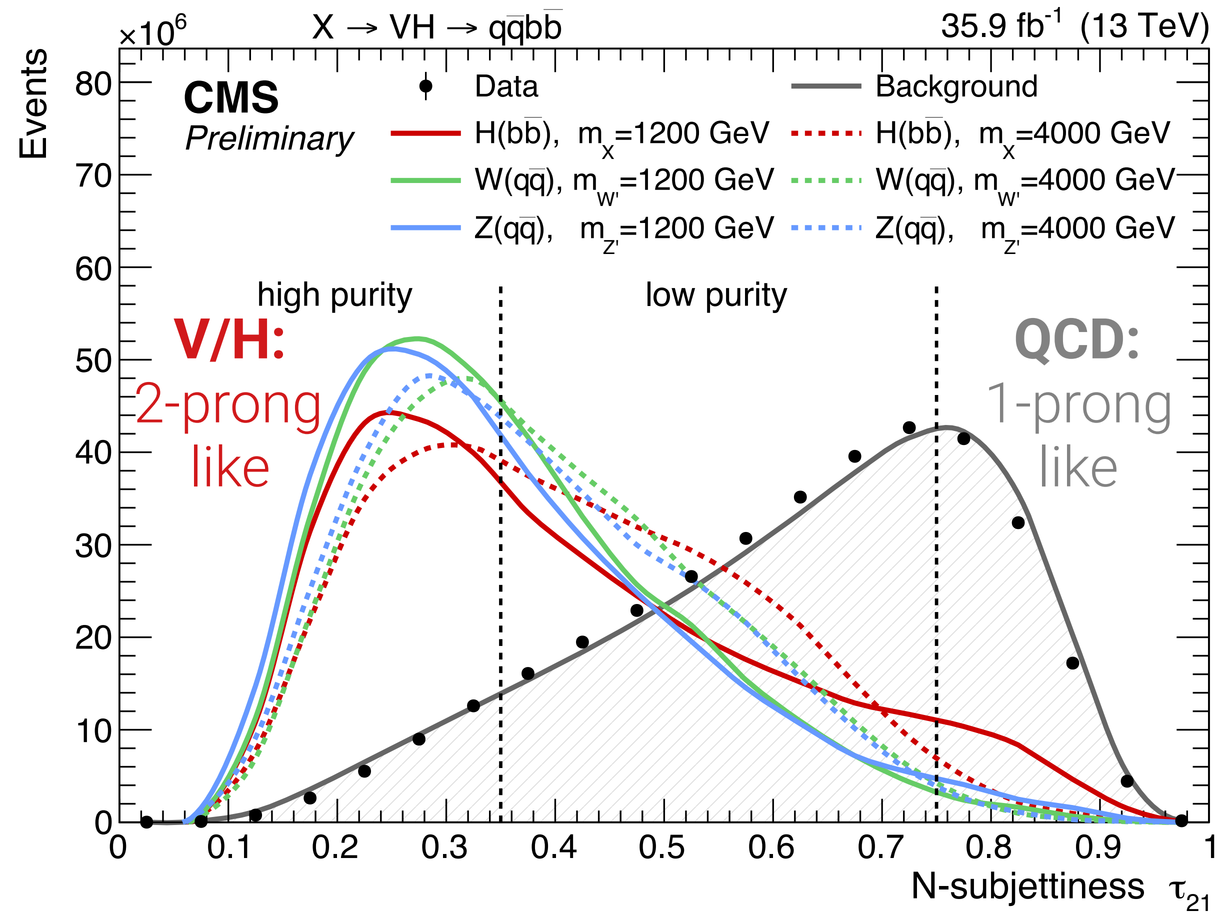
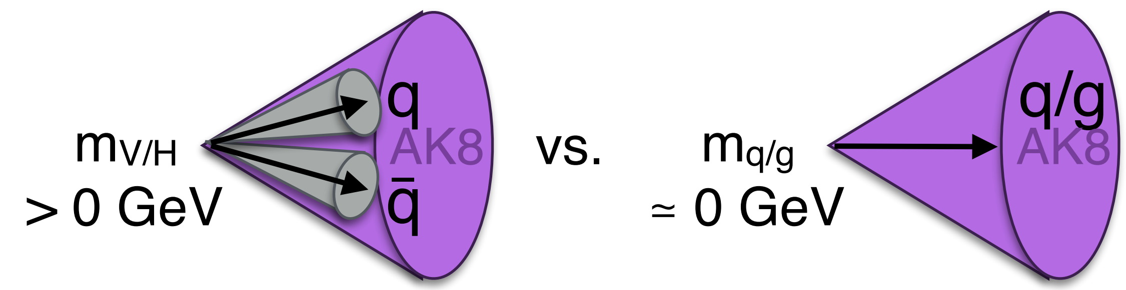
3. Tag by resolving jet substructure

   - n-subjetiness ratio τ_{21} (C. Suarez talk)



! Two τ_{21} categories:
high-purity: best S/B
low-purity: high efficiency

Boson reconstruction



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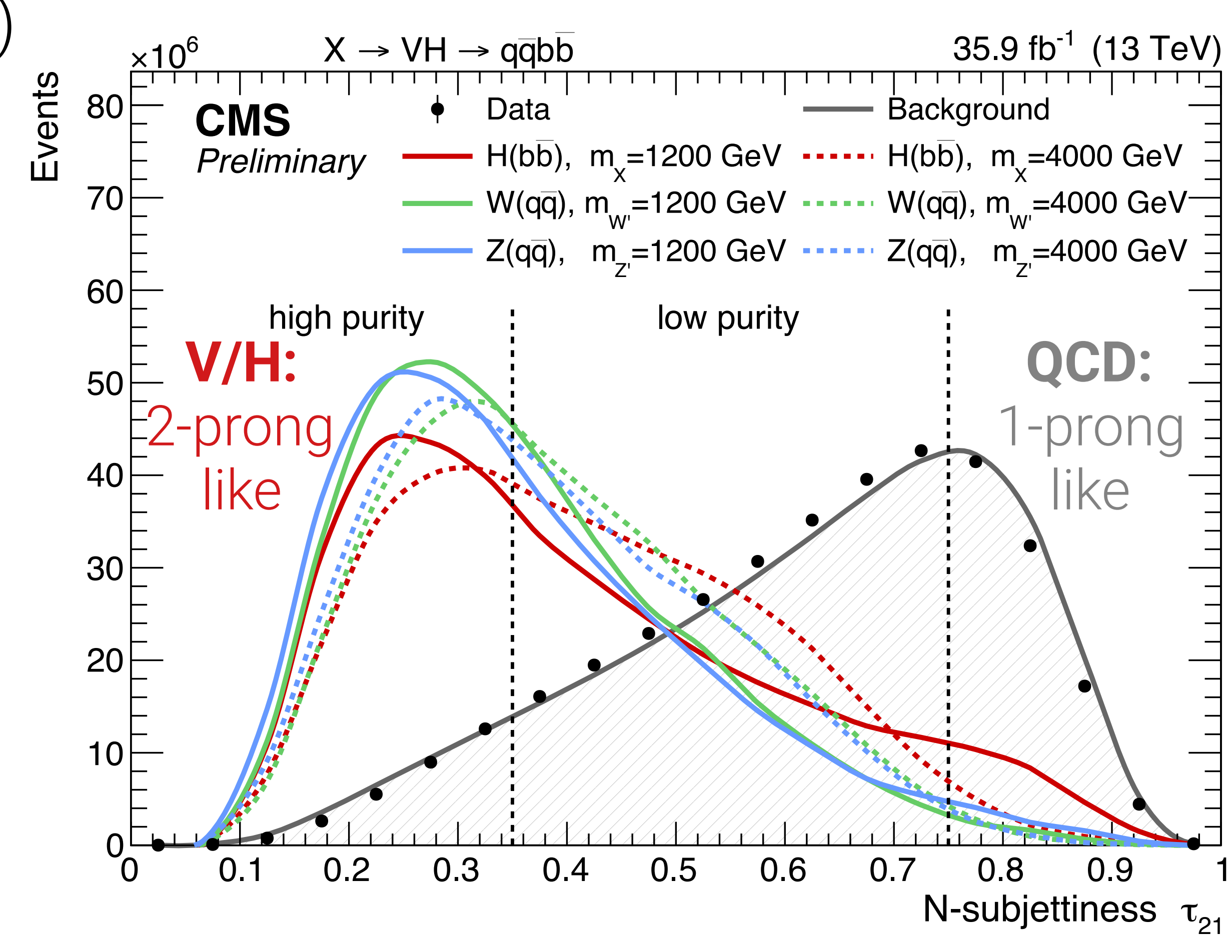
   - n-subjetiness ratio τ_{21} (C. Suarez talk)

3. After PUPPI + softdrop + τ_{21}

   - at p_T~500 GeV: ~55% e_S at ~2% e_B



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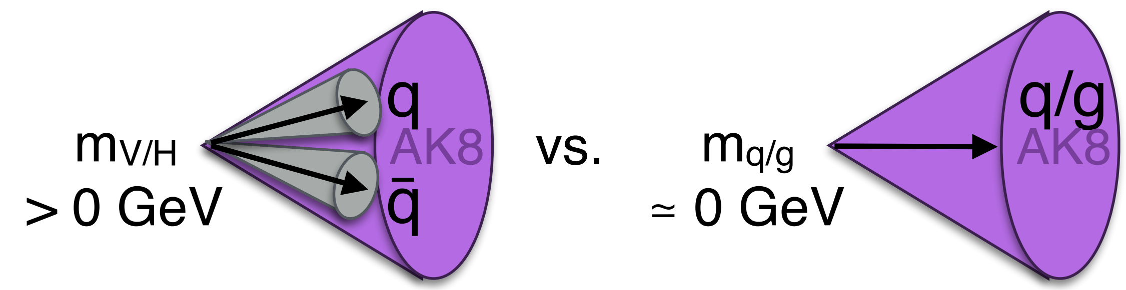

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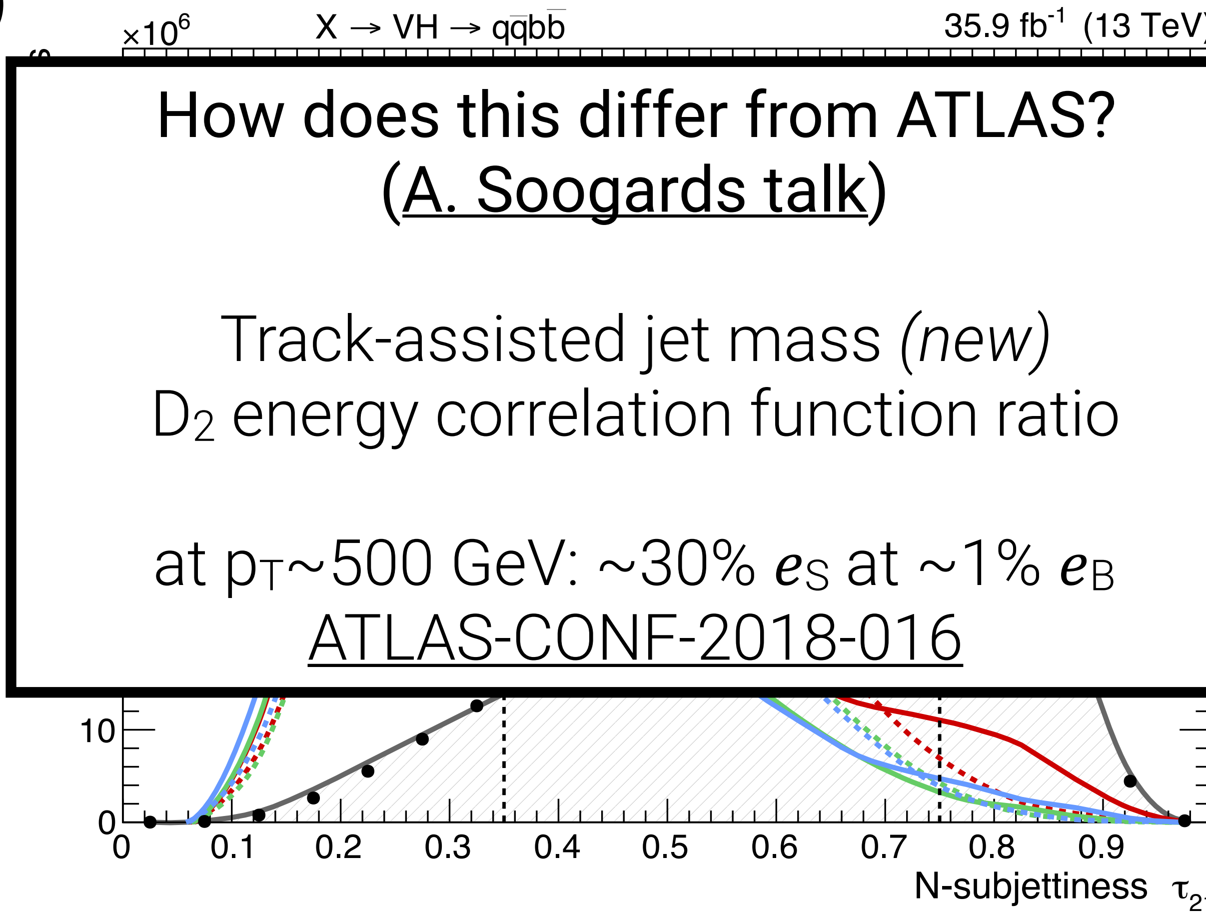

How does this differ from ATLAS?
(A. Soogards talk)

Track-assisted jet mass *(new)*
D_2 energy correlation function ratio

at p_T~500 GeV: ~30% e_S at ~1% e_B
ATLAS-CONF-2018-016

! Two τ_{21} categories:
high-purity: best S/B
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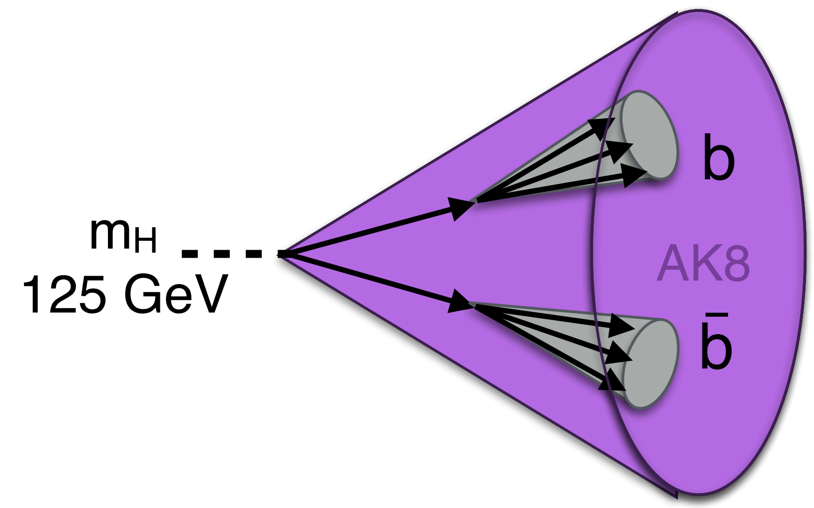
Higgs reconstruction

On top of mass and substructure, take advantage of b-tagging. Two methods:



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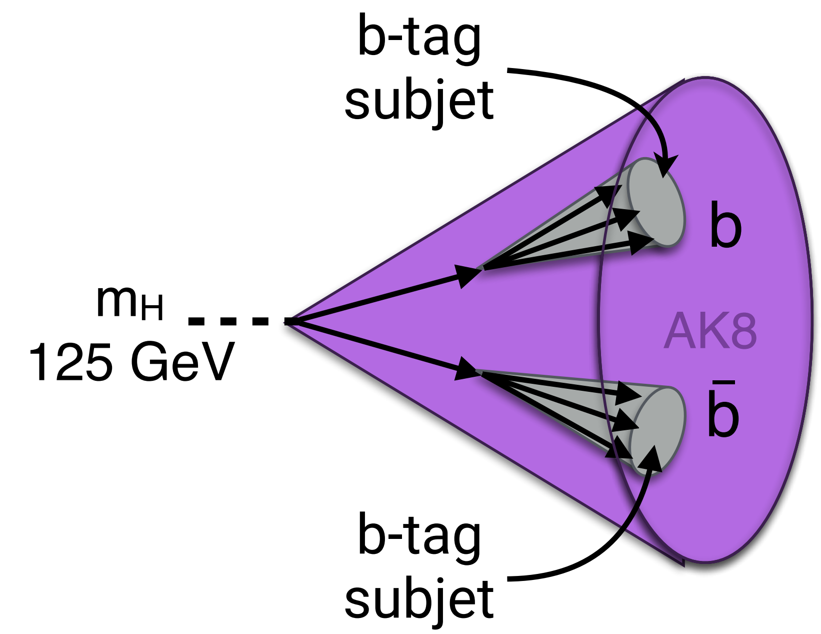

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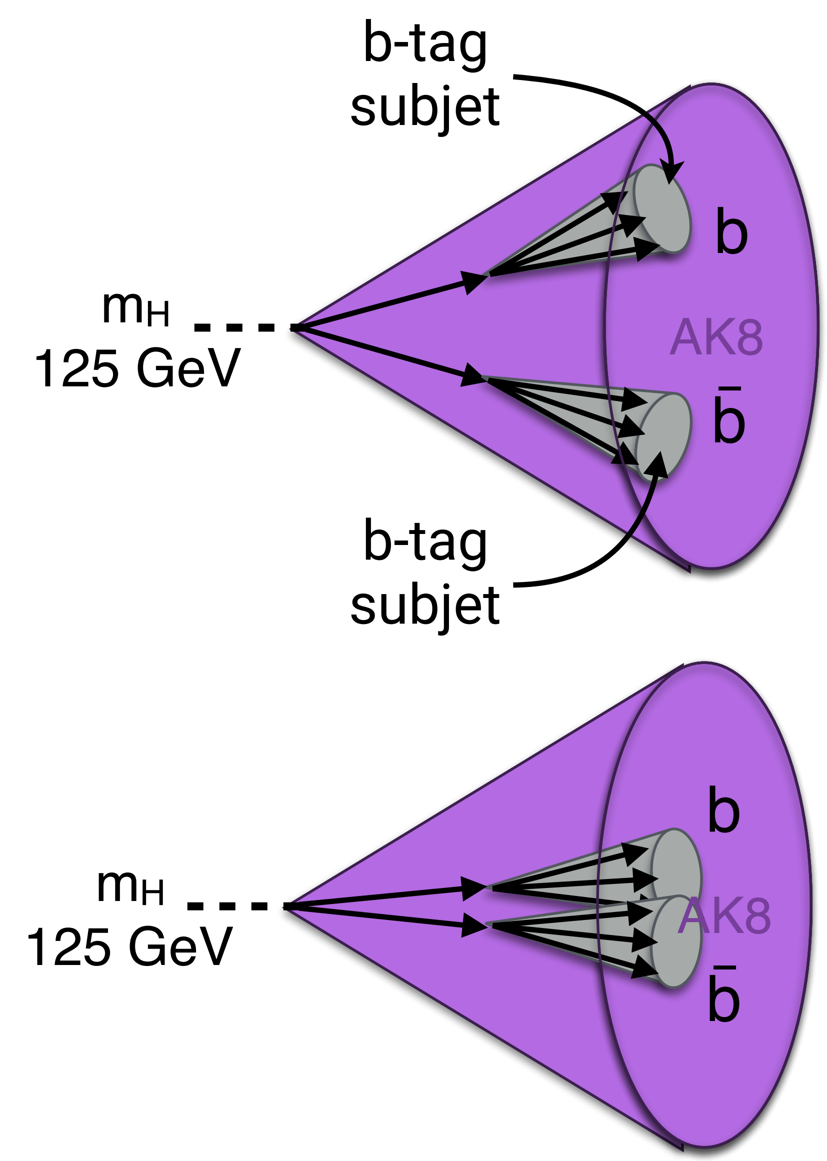
- If boost is high, subjets overlap. Track-sharing leads to performance drop



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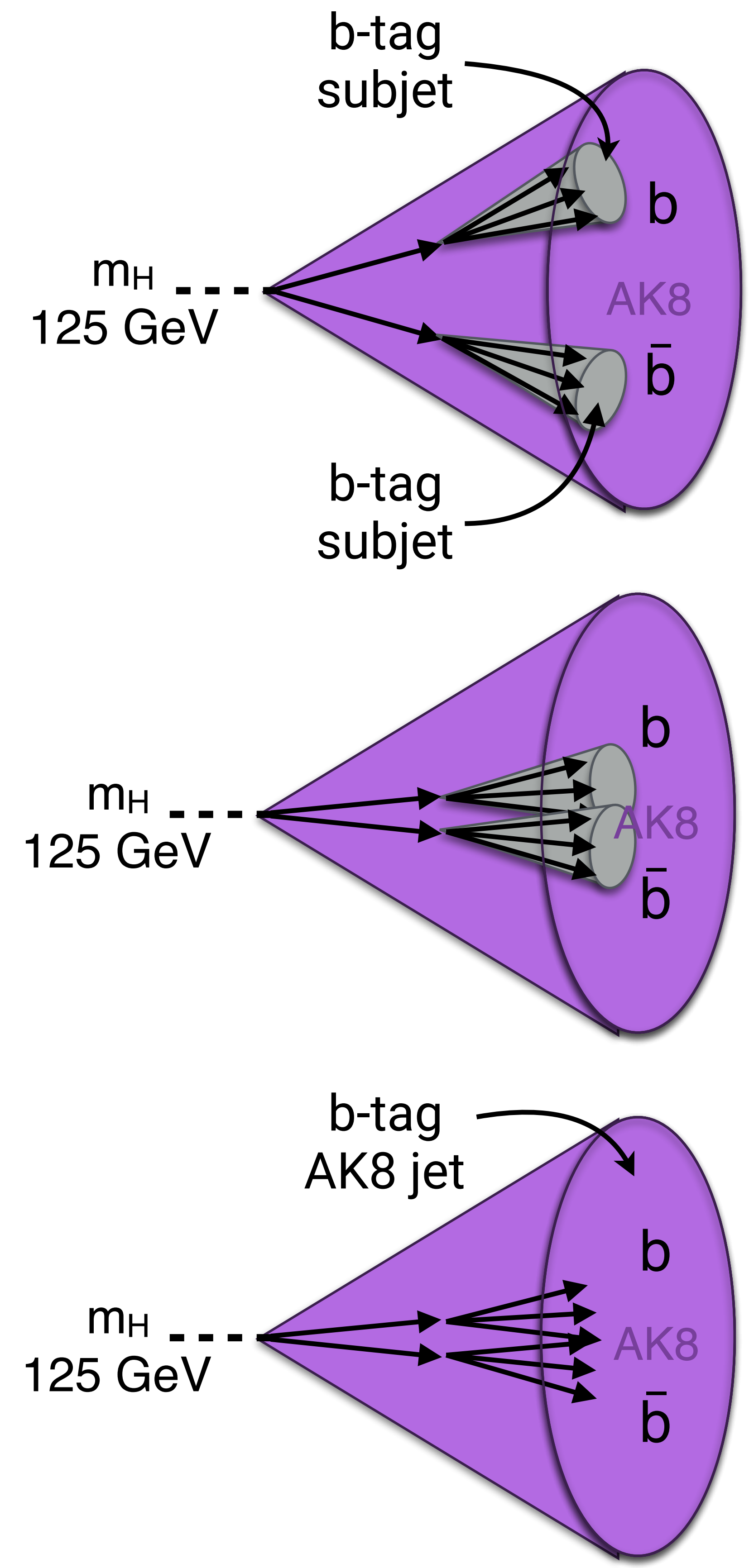
- Enter: double-b MVA tagger not relying on subjets



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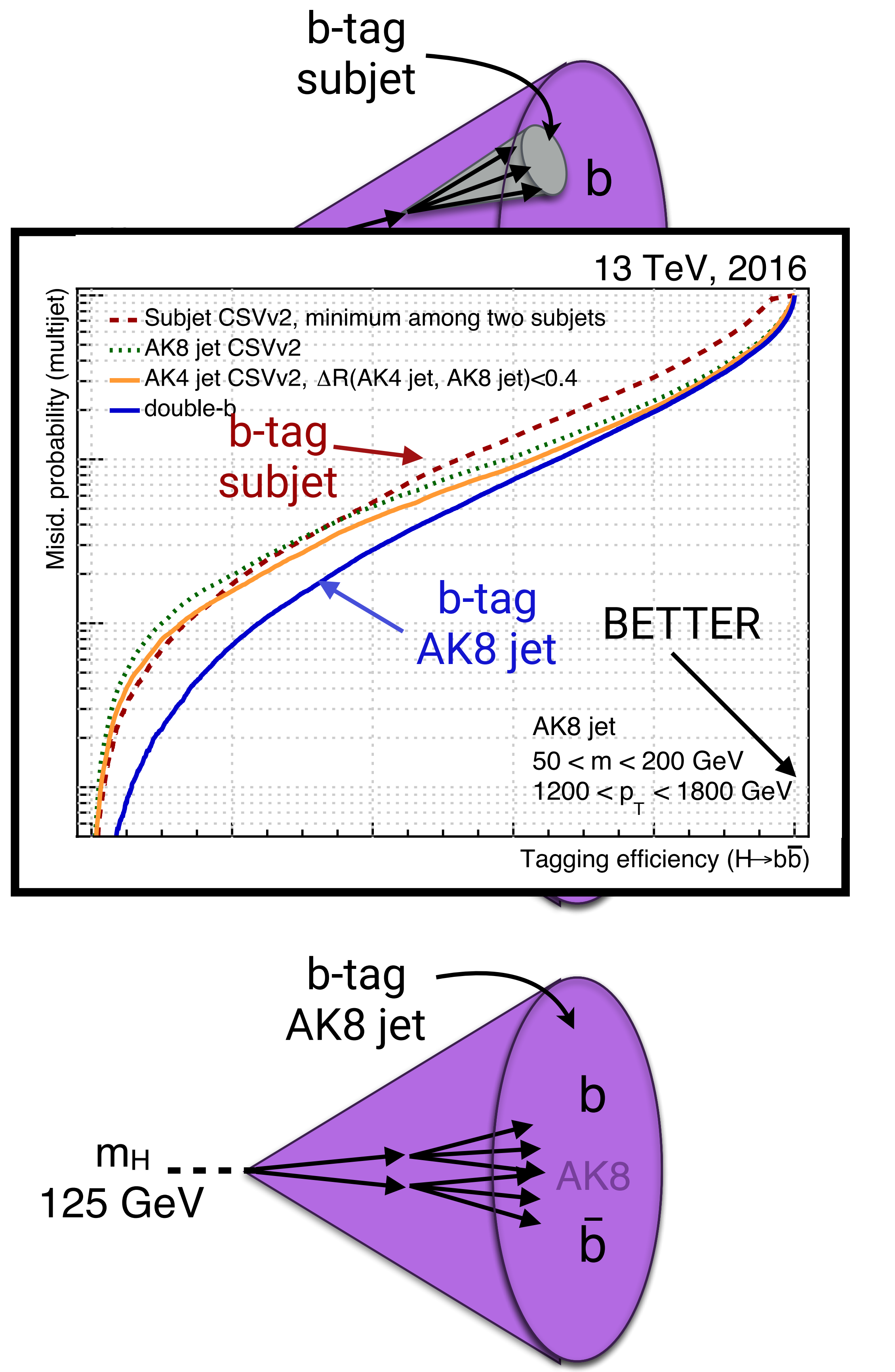

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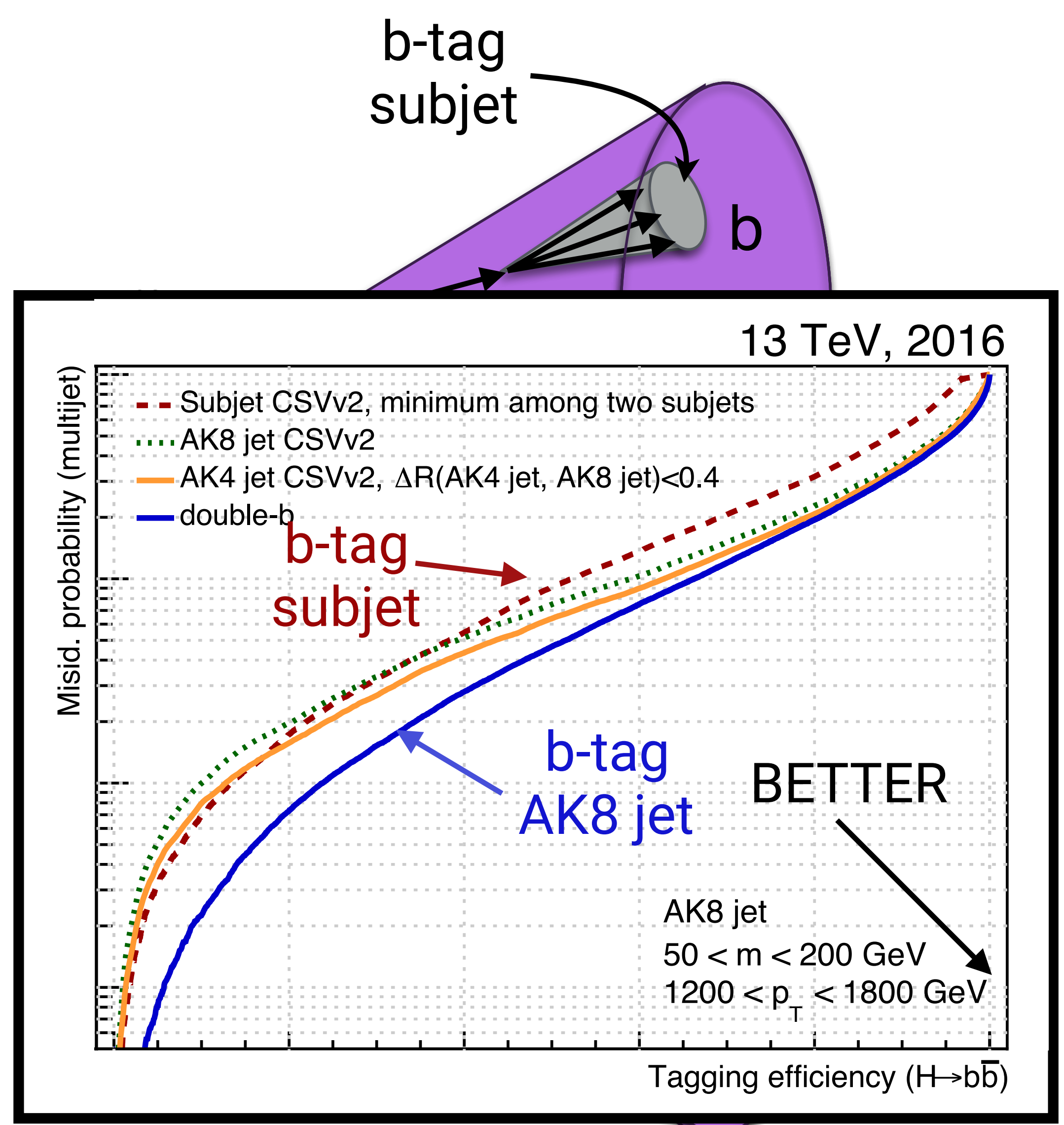
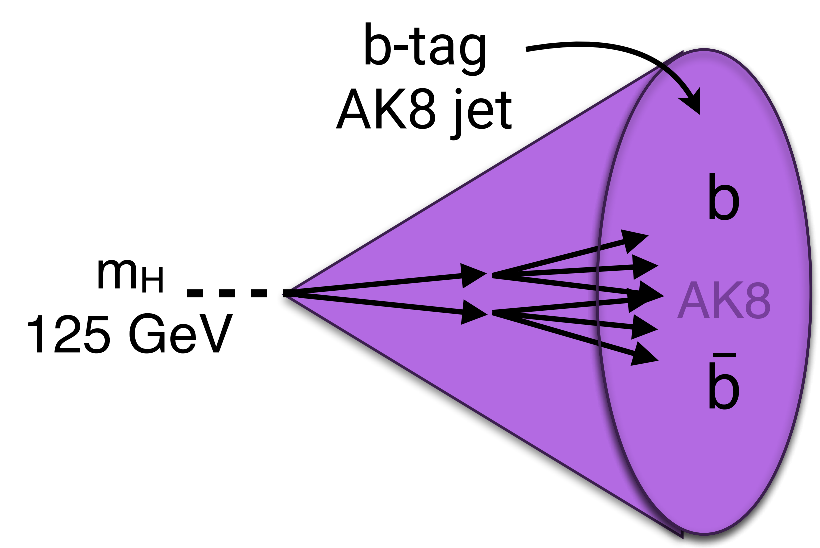
Additional difference: background!

- if QCD dominant, double-b best performance
- if $t\bar{t}$ dominant, subjet b-tagging slightly better performance (double-b tagger not trained agains $t\bar{t}$)





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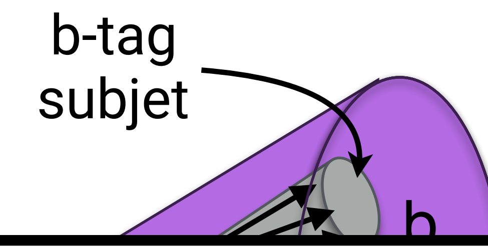
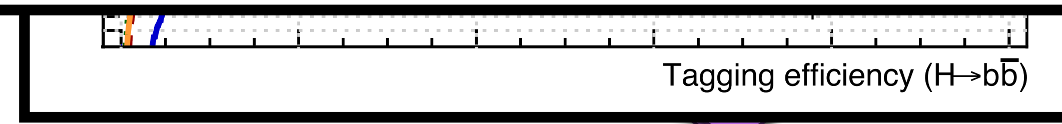
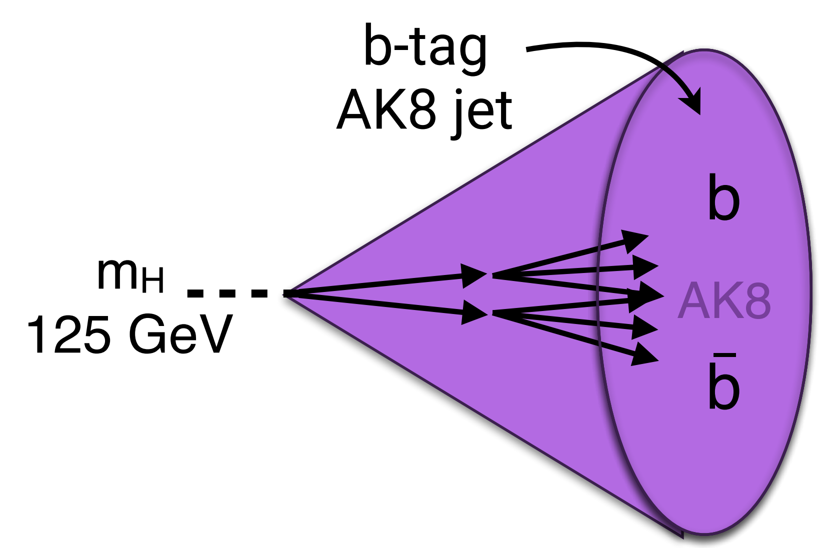


How does this differ from ATLAS?
(A. Soogards talk)

Subjet b-tagging on trimmed subjets (leading track jets) of size R=0.2 within R=1.0 jet. New: switch to variable R tagging and dedicated double-b tagger (S. Gangulys talk)

ATLAS-CONF-2016-039



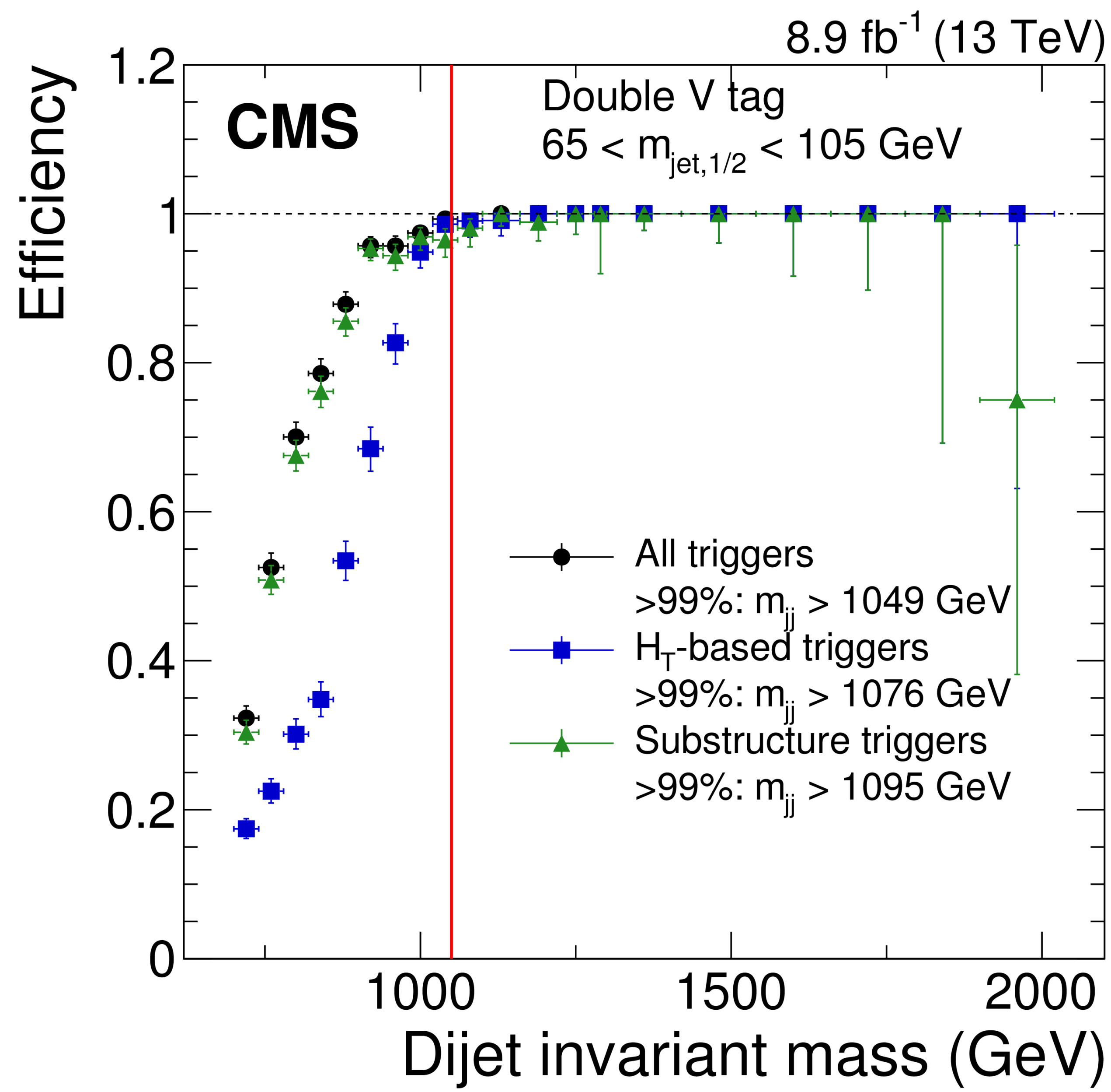


All-hadronic triggers

Grooming algorithms at HLT lowers m_{jj} trigger thresholds

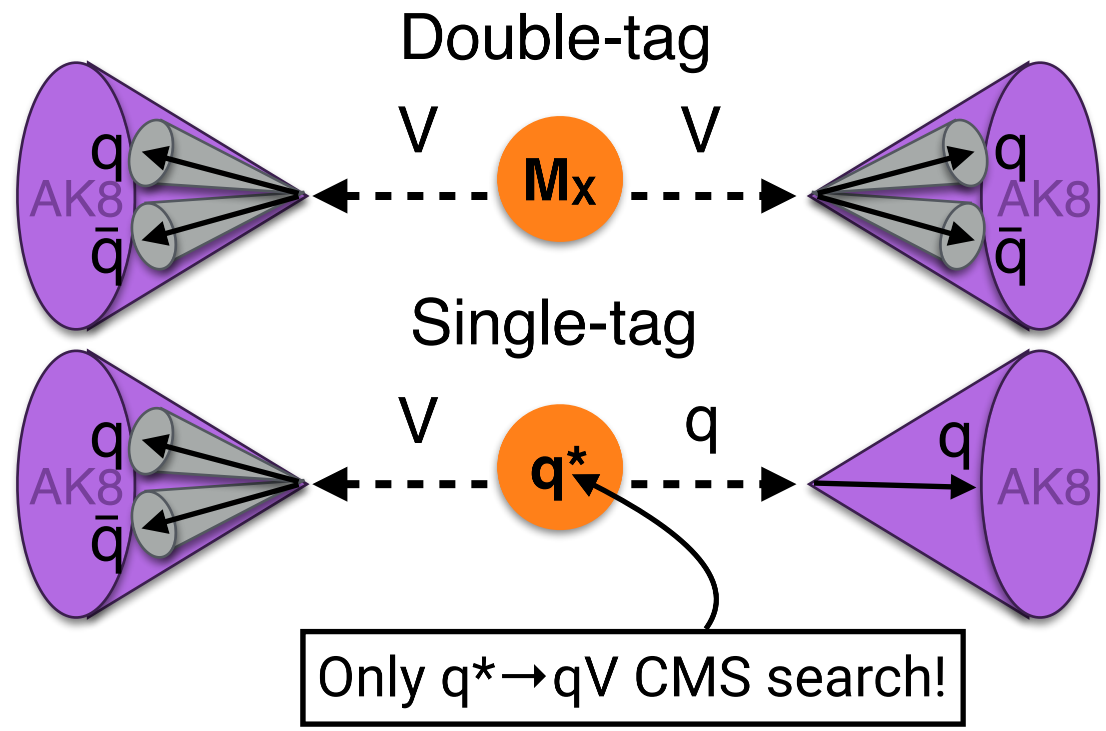
- cut on jet trimmed mass (slightly less aggressive than mMDT used offline) of 30/50 GeV
- fully efficient at offline softdrop mass of ~50 GeV

As of 2018, new double-b tag + trimmed mass trigger further lowering thresholds!



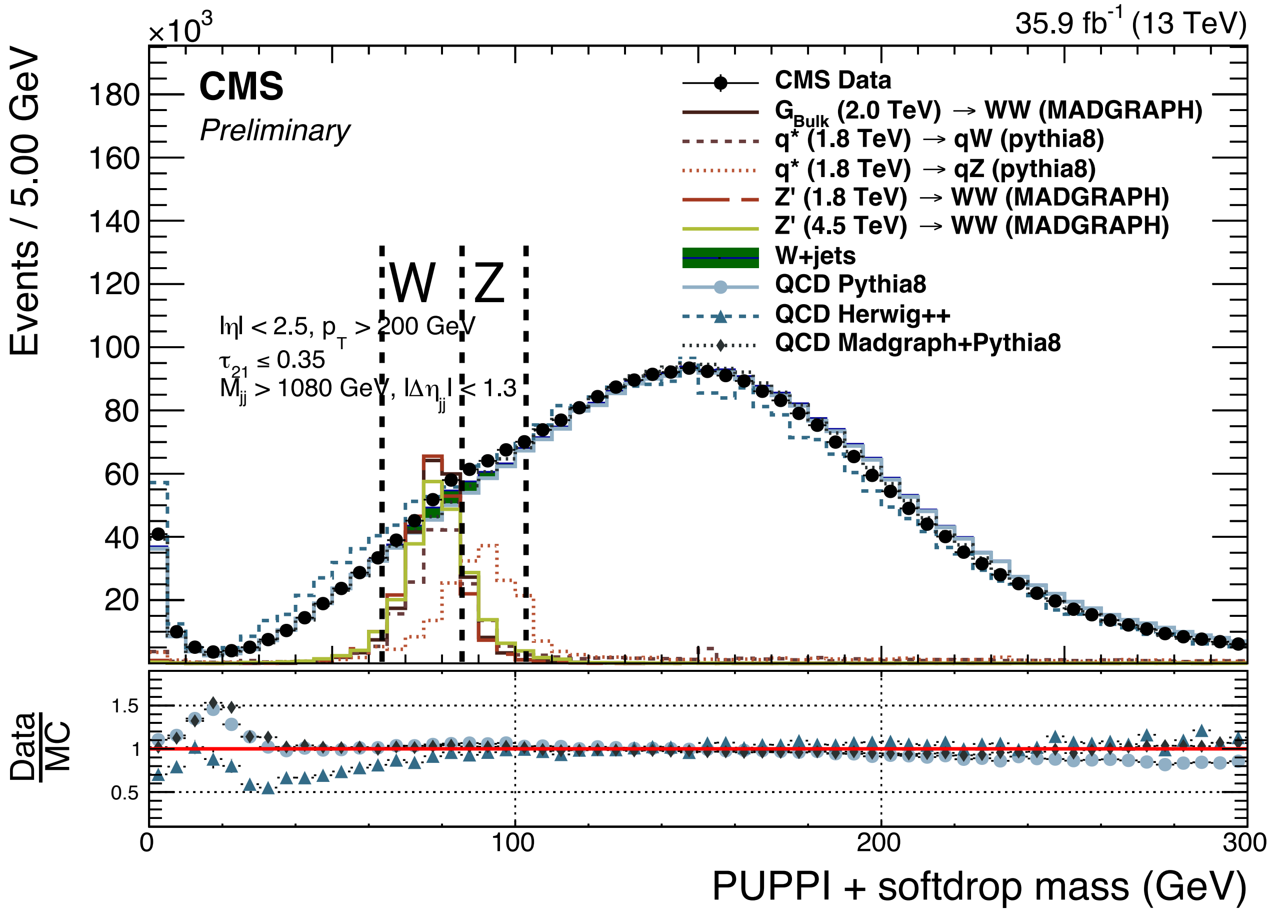
VV/qV fully-hadronic

B2G-17-001



Categorisation (10 in total)

- WW/WZ/ZZ and qW/qZ
- τ_{21} high-purity / low-purity (LP 20% improvement at high m_X)



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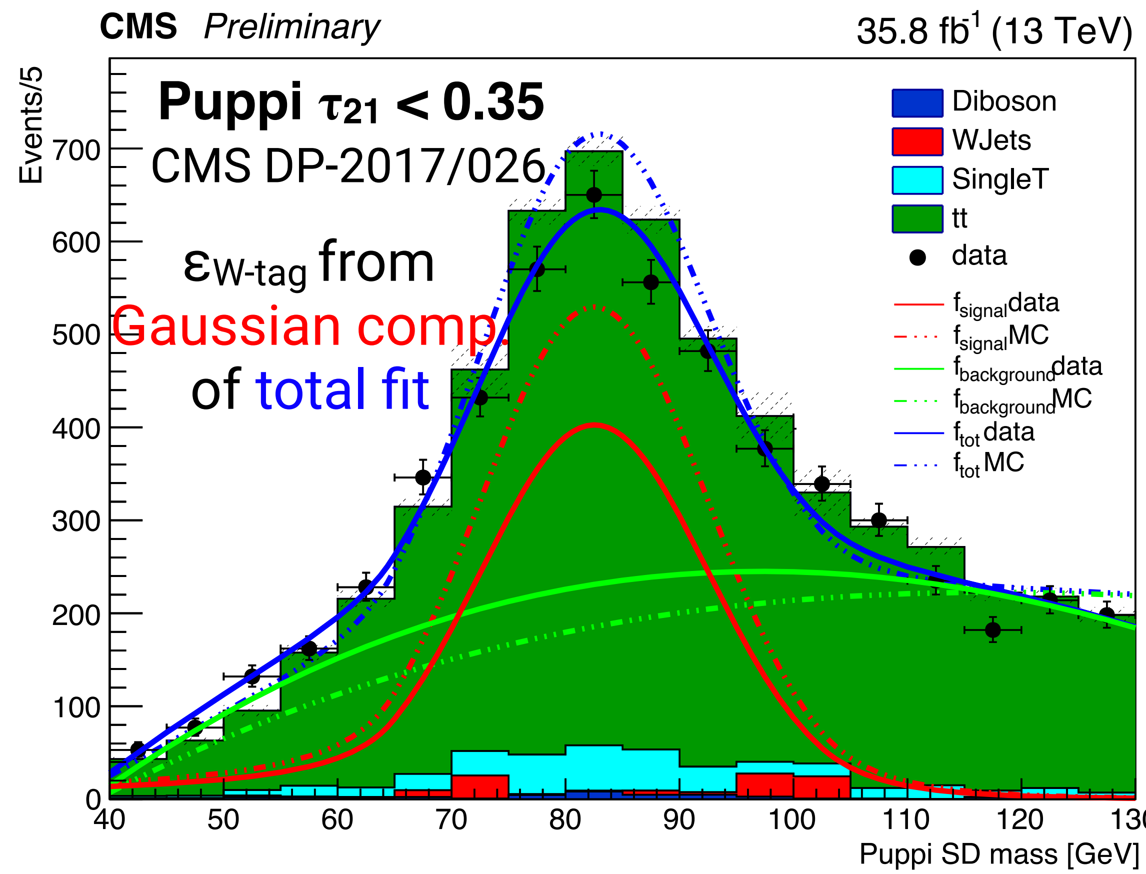

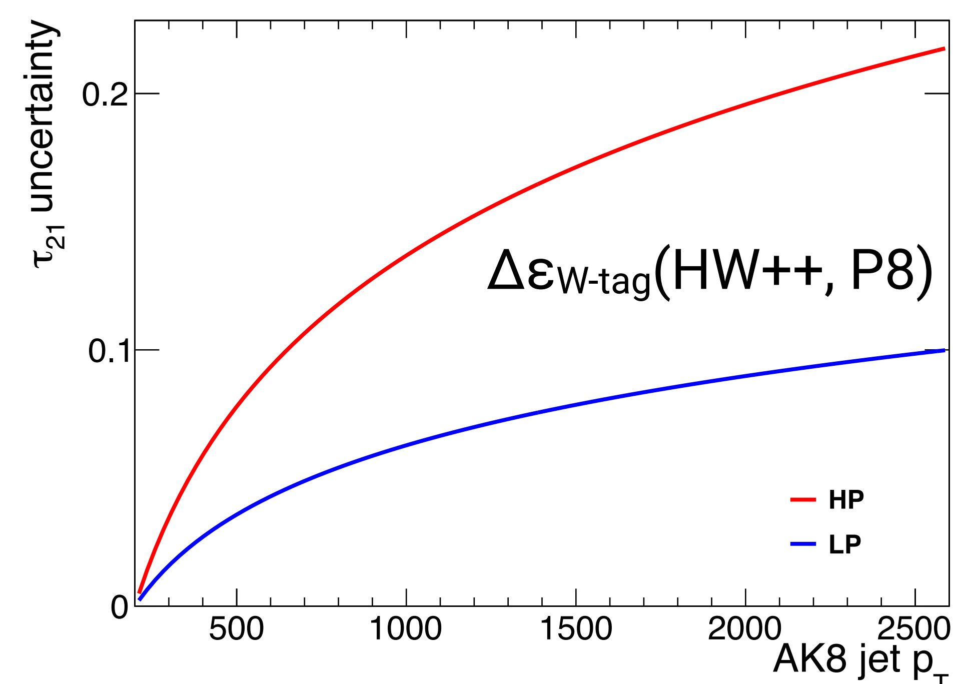

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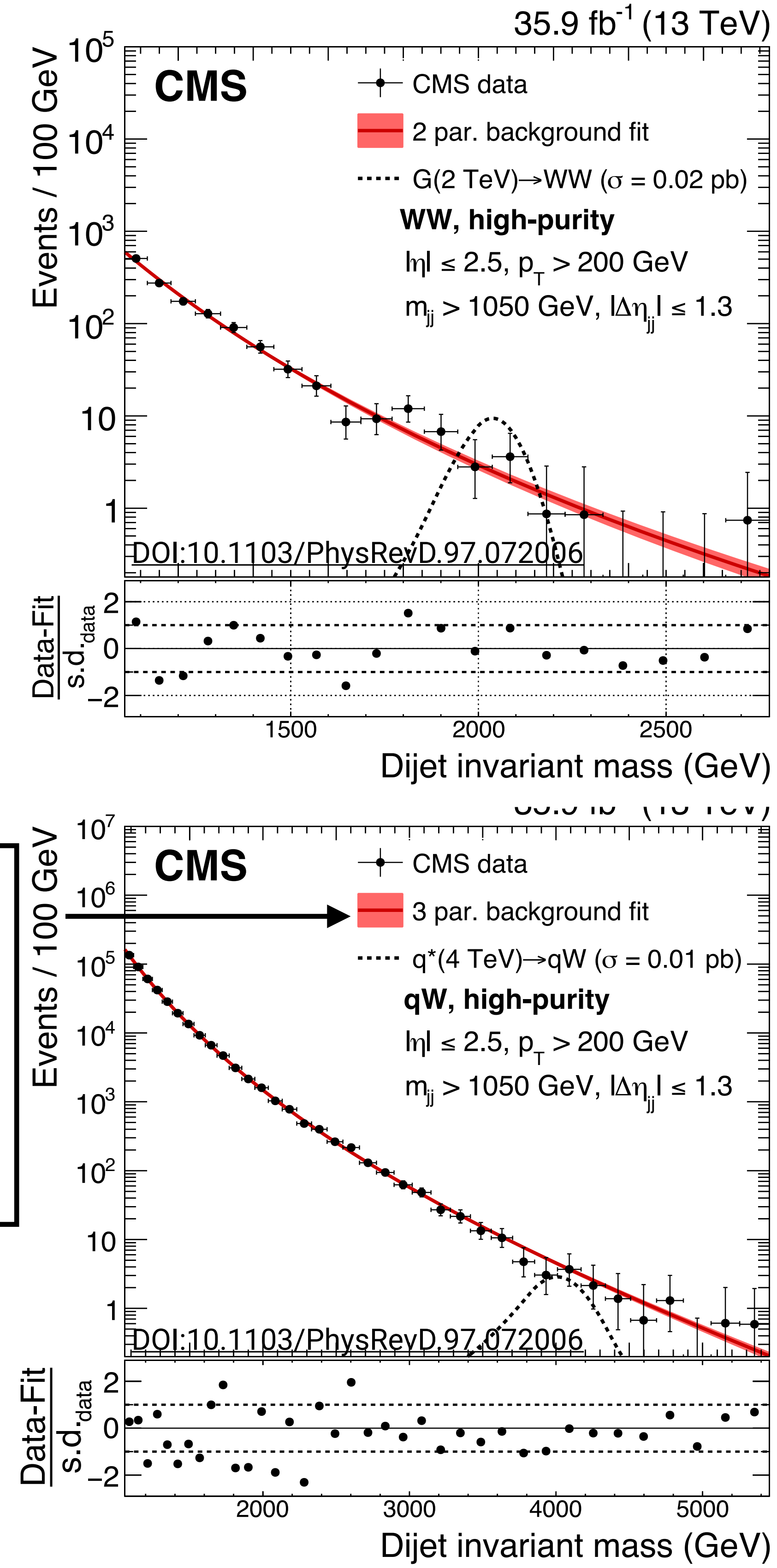
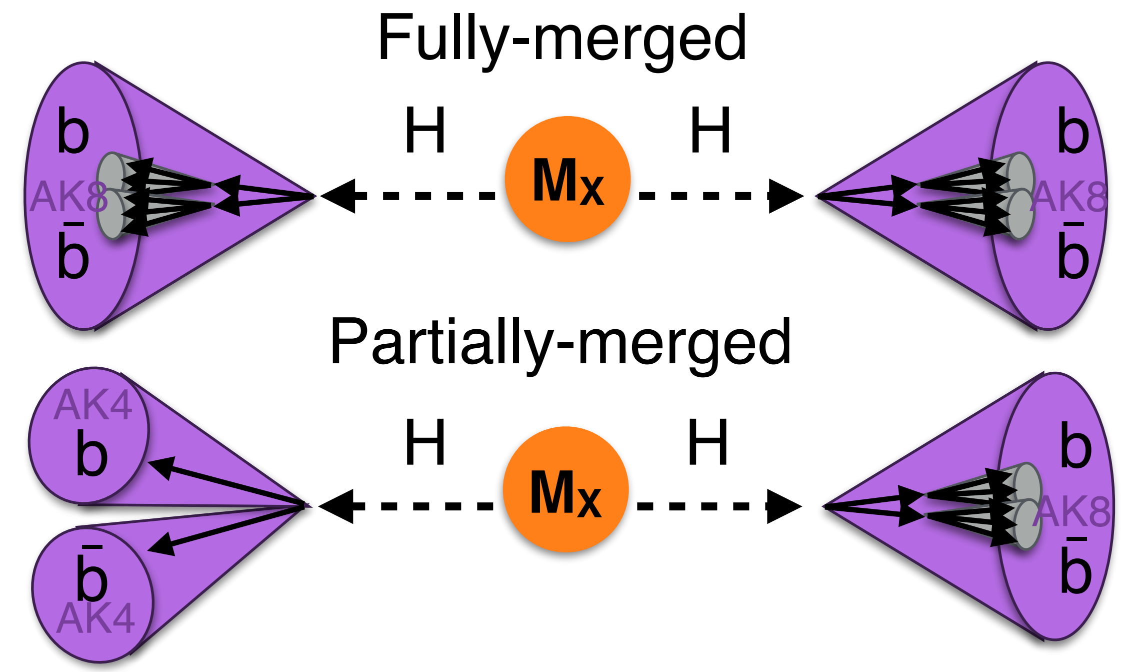
Background fit with parametric function in signal region (weakness: large uncertainty in tail of spectrum)

More parameters needed when statistics increase



HH fully hadronic

B2G-17-019, B2G-16-026

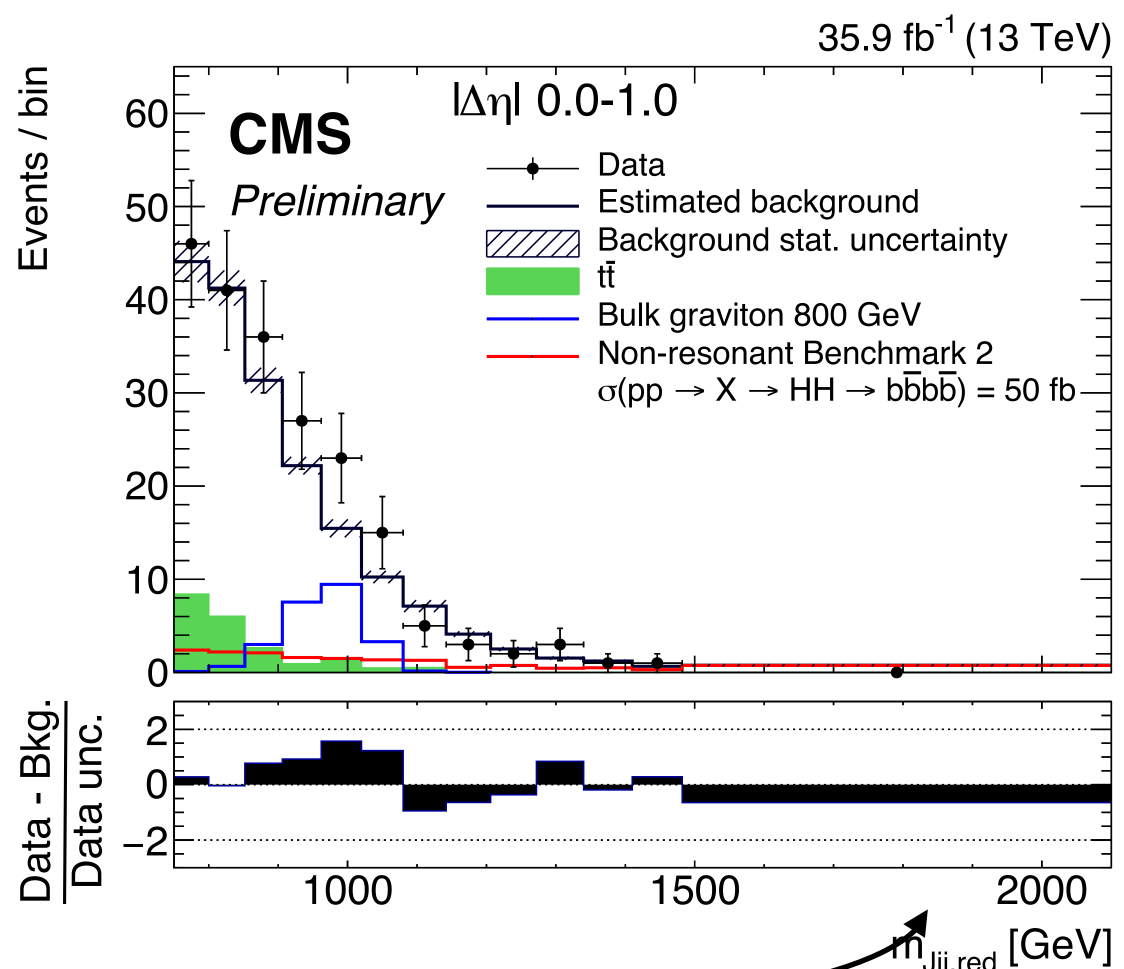


Two complementary searches

- fully-merged: tag two AK8 with double-b
- partially-merged: tag one AK8 with double-b, tag two AK4 with CSV

Background shape: anti b-tag region
Background normalisation: mass sidebands

Adding partially-merged result improves limits by up to 55% !



Fit reduced mass $m_{Jjj,red} \equiv m_{Jjj} - (m_J - m_H) - (m_{jj}(j_1, j_2) - m_H)$
8-10% improvement on HH mass resolution

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B2G-17-019, B2G-16-026

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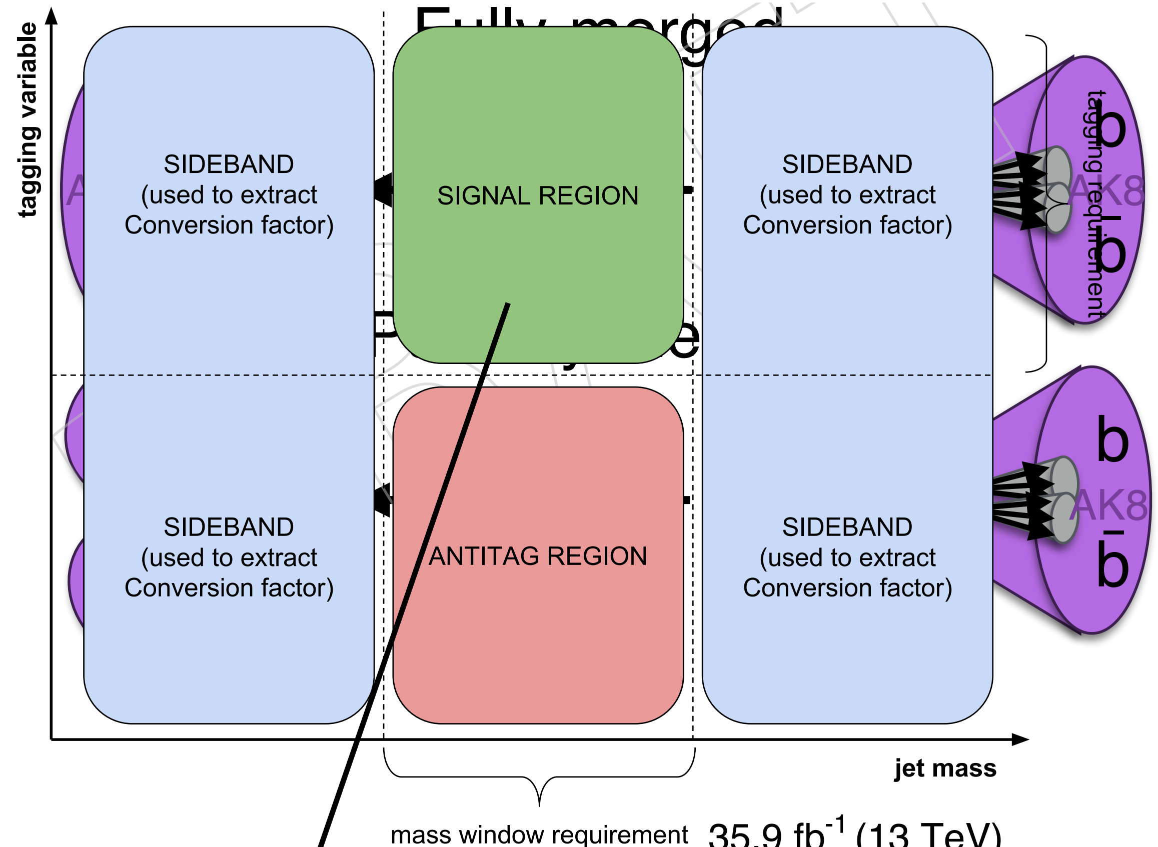

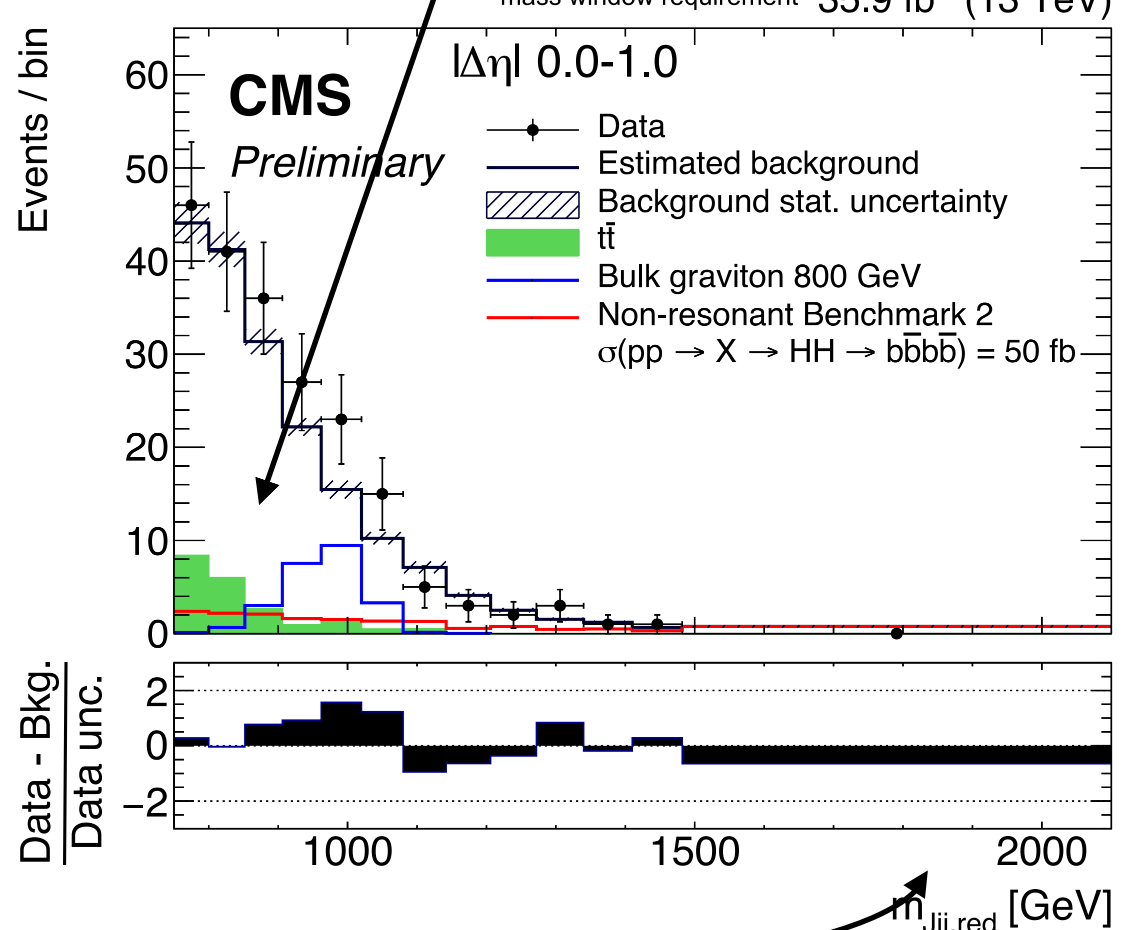

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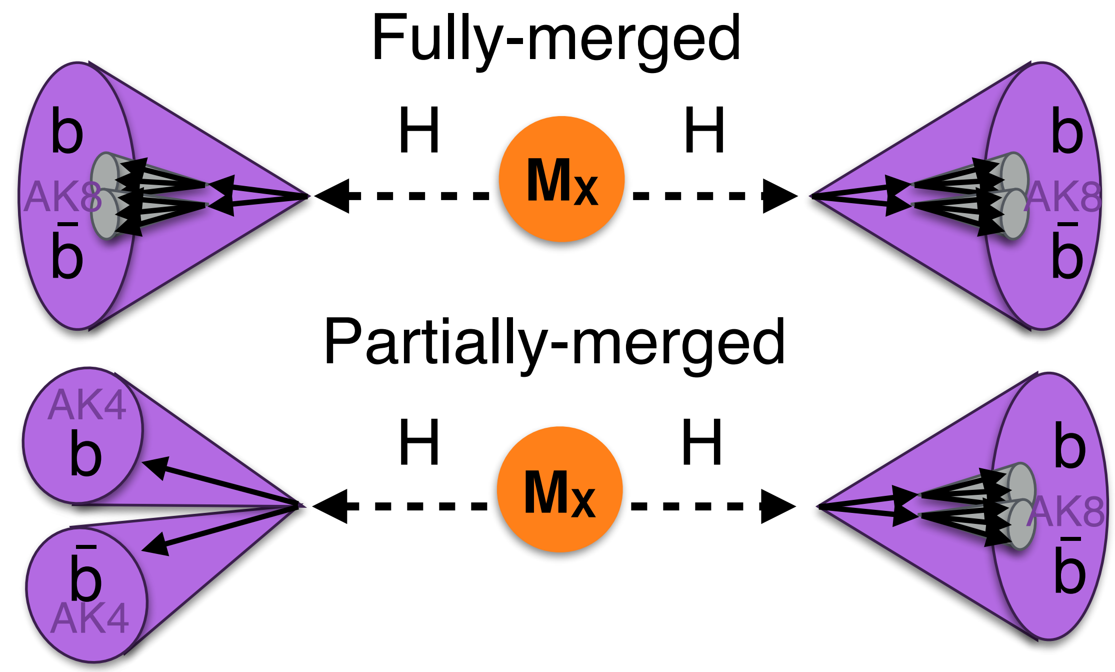

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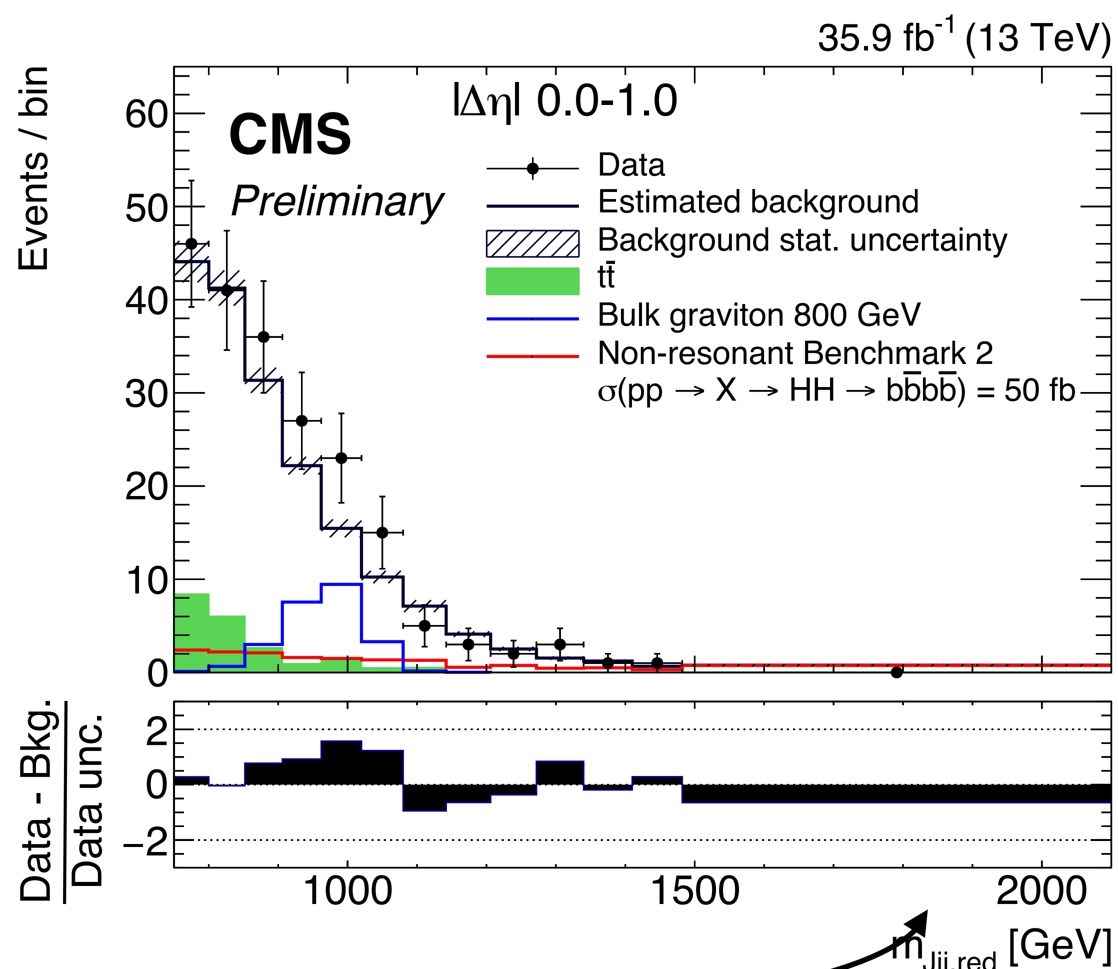
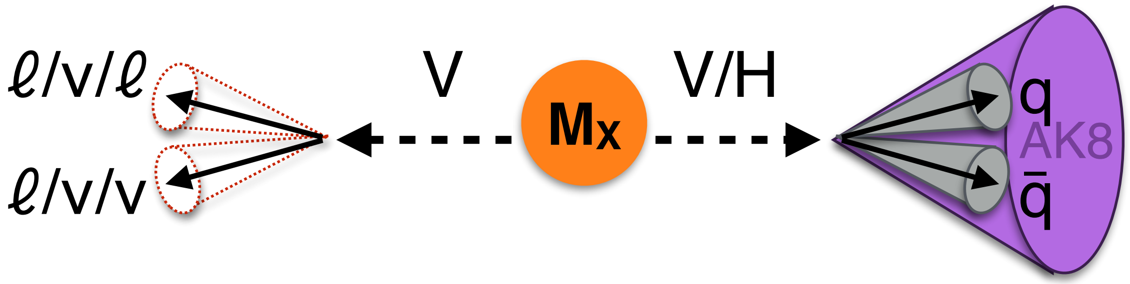


Fit reduced mass $m_{Jjj,red} \equiv m_{Jjj} - (m_J - m_H) - (m_{jj}(j_1, j_2) - m_H)$
8-10% improvement on HH mass resolution

Semi-leptonic final states



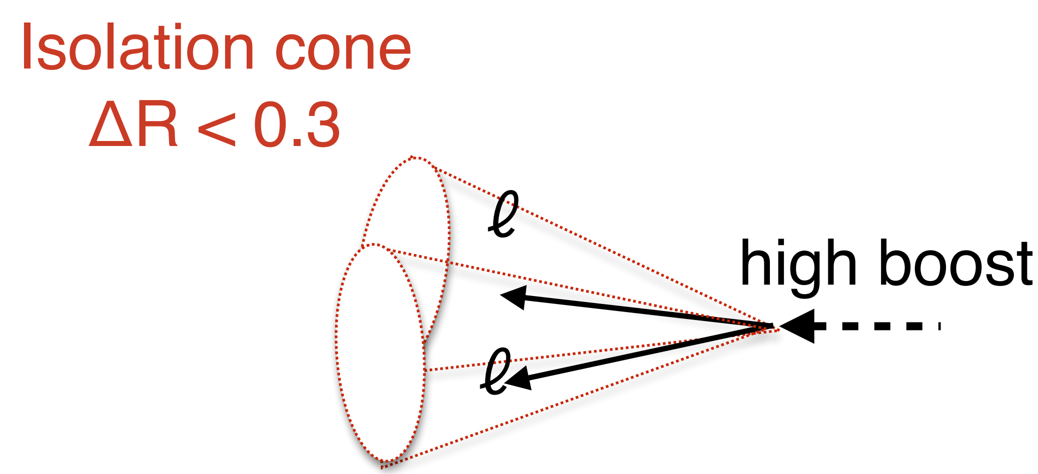
X→VV or VH where one V decays leptonically (ℓℓ/ℓν/νν)

The pros:

- can trigger on lepton, lower thresholds, while retaining good signal efficiency through hadronic leg
- less background (most sensitive at low m_X) and background well-modelled in simulation (unlike QCD)

The cons:

- leptons can overlap, hard to reconstruct
- leptons required to be isolated from hadronic activity within isolation cone. Need to avoid overlap



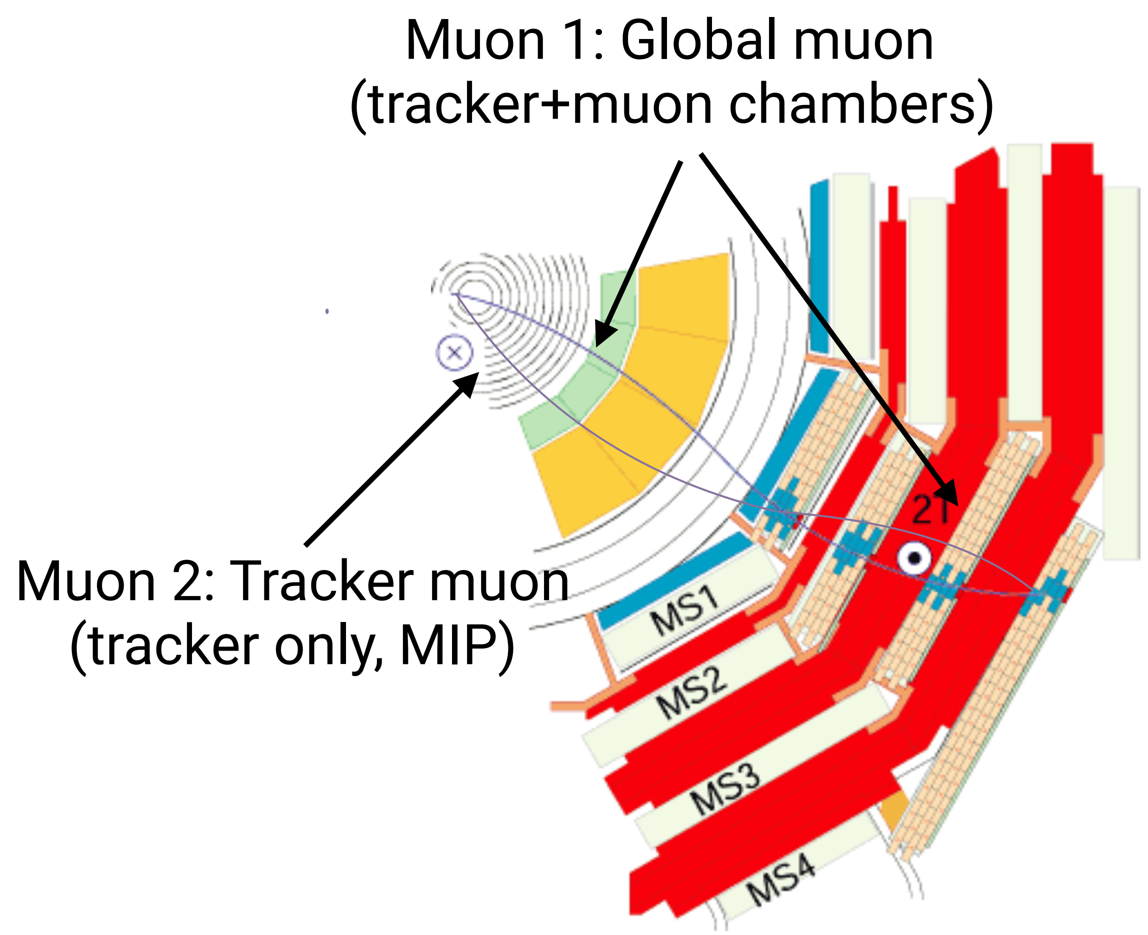
With standard reconstruction, leptons would be rejected due to non-isolation

Boosted lepton reconstruction

For muons close in ΔR, “global muon” efficiency drops when same muon track segments are used to seed algorithm, only one muon left after cleaning

- allow one muon to be identified in tracker only. Efficiency increase of 4-18%

Leptons required to be isolated from other hadronic activity in event



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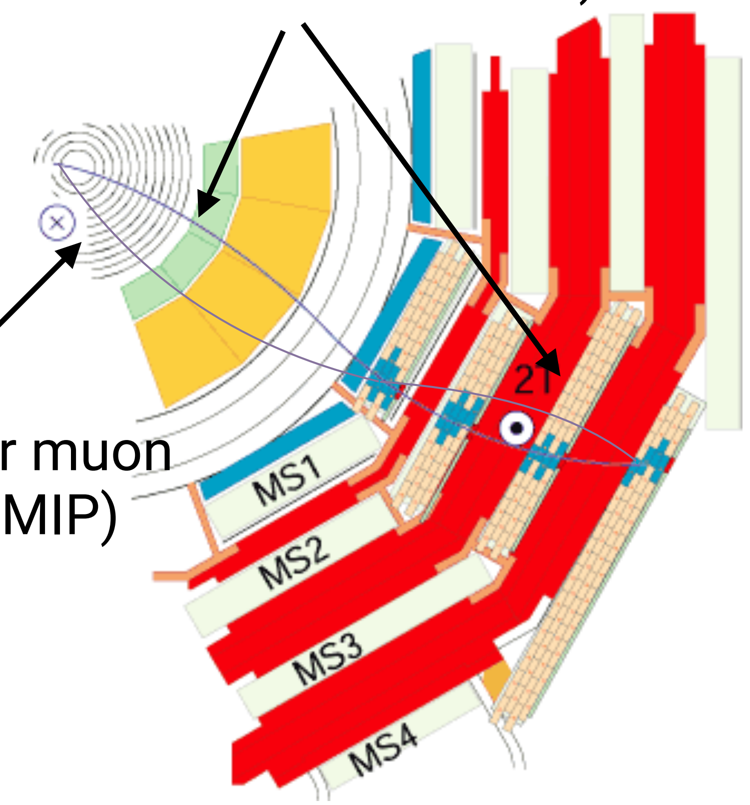
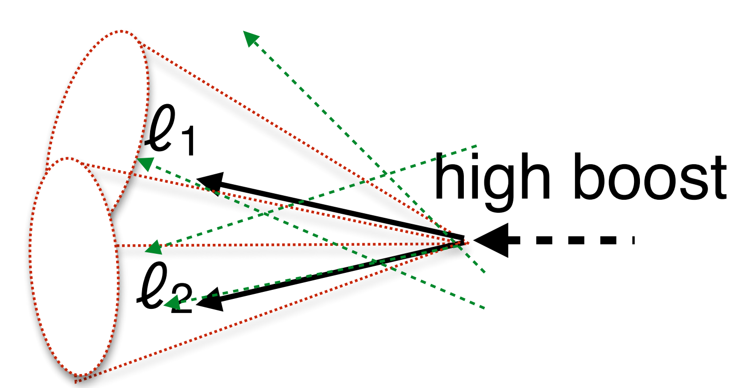


Leptons required to be isolated from other hadronic activity in event

- require lepton energy >> surrounding hadronic activity (∑p_T of charged particles within cone)

ℓ_1 iso: $p_{T,had}$/ $p_{T\ell_1} < 10\%$

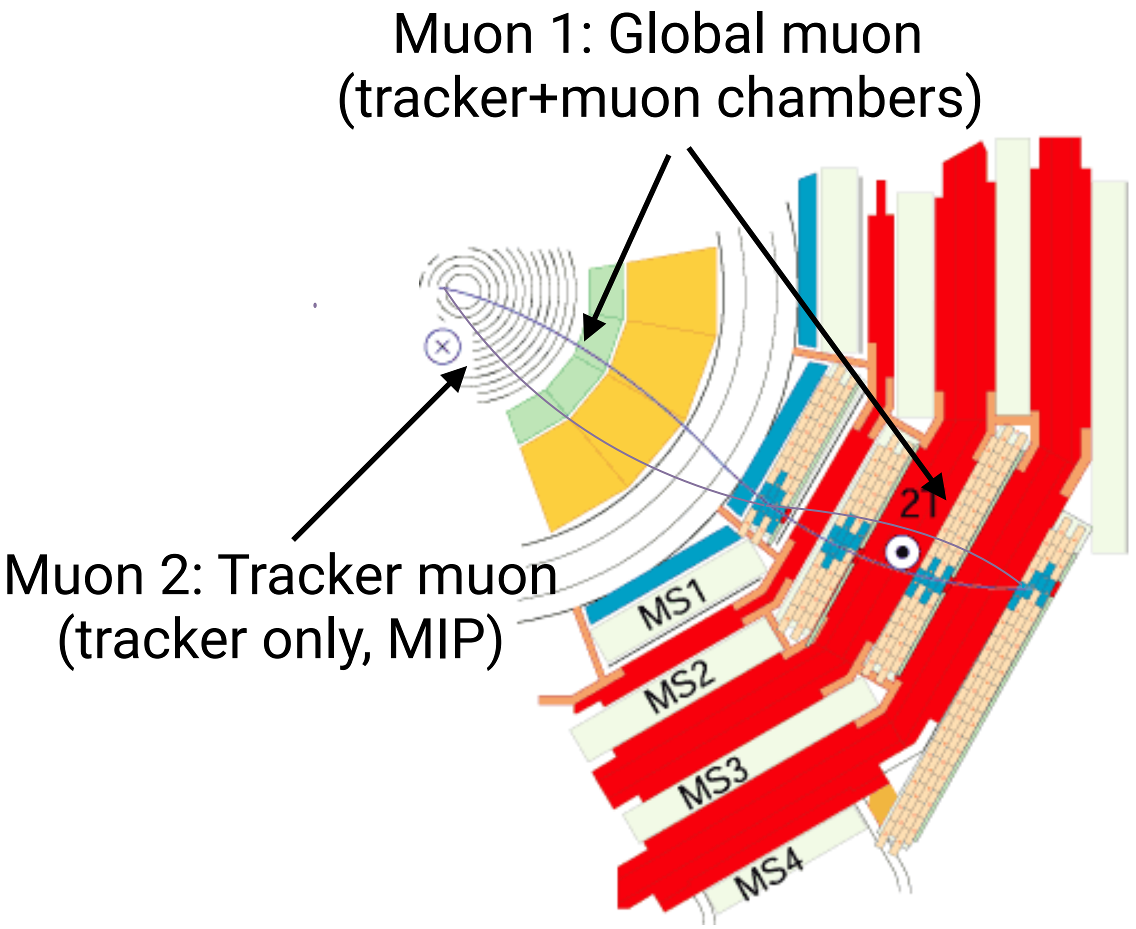


Requirement fails if second high-p_T lepton enters cone!

Boosted lepton reconstruction

For muons close in ΔR, "global muon" efficiency drops when same muon track segments are used to seed algorithm, only one muon left after cleaning

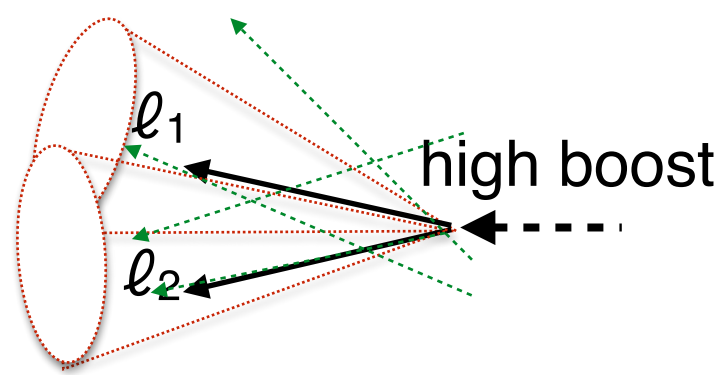
- allow one muon to be identified in tracker only. Efficiency increase of 4-18%



Leptons required to be isolated from other hadronic activity in event

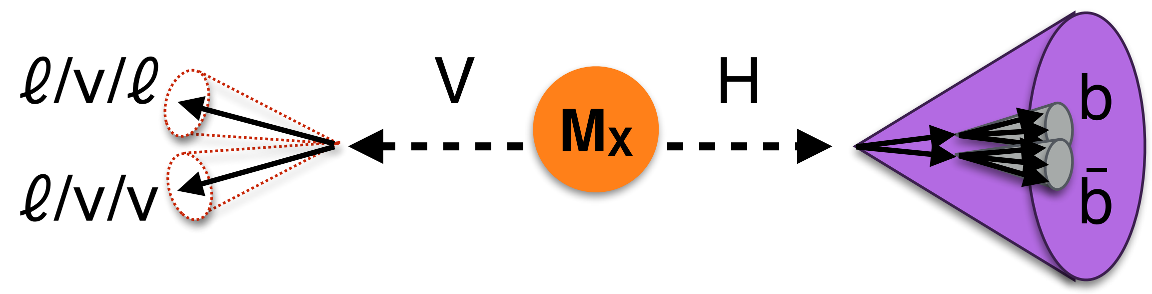
- require lepton energy >> surrounding hadronic activity ($\sum p_T$ of charged particles within cone)
- to retain efficiency at high boost, remove all other PF electrons and muons before computing isolation

ℓ_1 iso: $(p_{T,had} - p_{T,\ell 2}) / p_{T\ell 1} < 10\%$



VH semi-leptonic

B2G-17-004

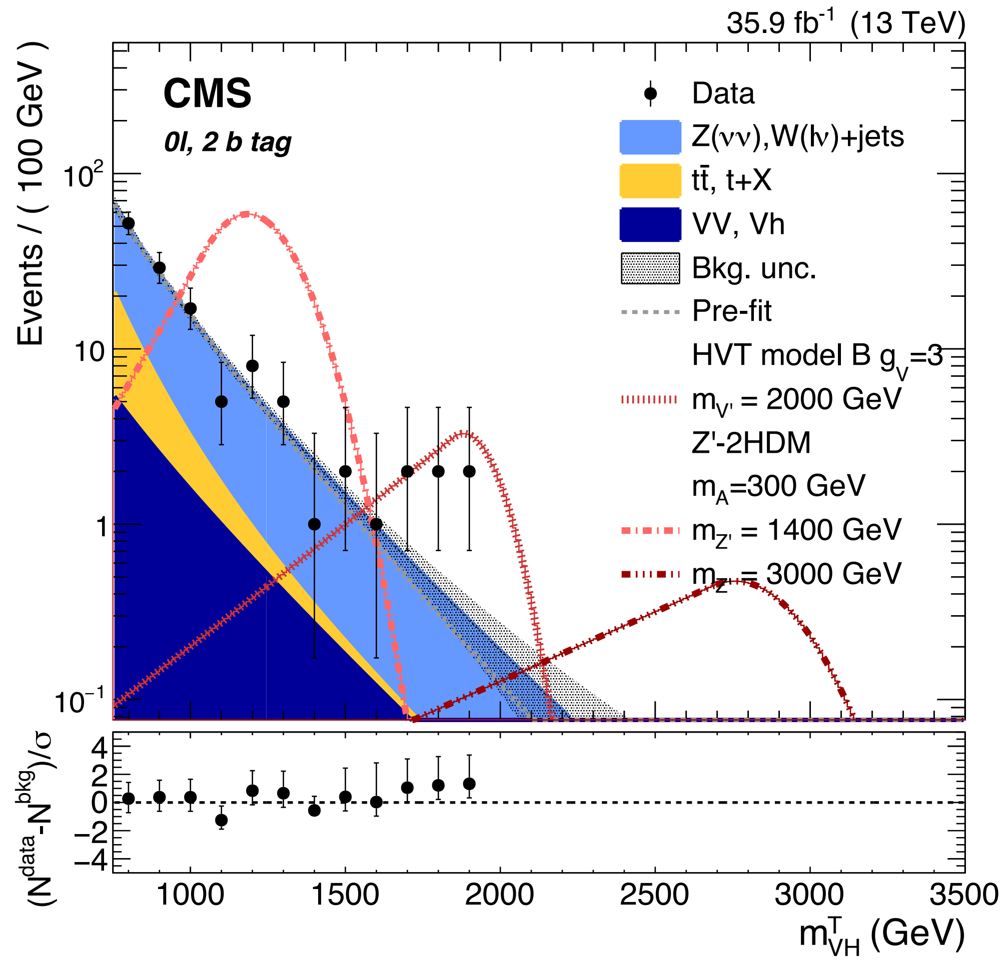


3 final states: $H \rightarrow b\bar{b}$ with $V \rightarrow \ell\ell/\ell\nu/\nu\nu$ (orthogonal 0,1,2 lepton categories)

R.o.I: m_{VH}^{T} for νν, m_{VH} for ℓℓ/ℓν

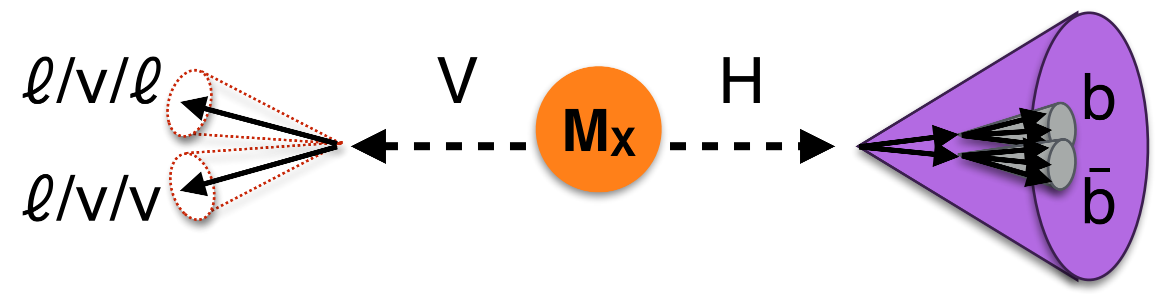
2 b-tag categories based on number of subjet b-tags:

- 2 b-tagged subjets: dominate at low m_X
  → ε_S 29-19% (degrade with m_X)
  → ε_B ~0.5%
- 1 b-tagged subjet: dominate at high m_X
  → ε_S 13-24% → ε_B ~3%



VH semi-leptonic

[B2G-17-004](B2G-17-004)



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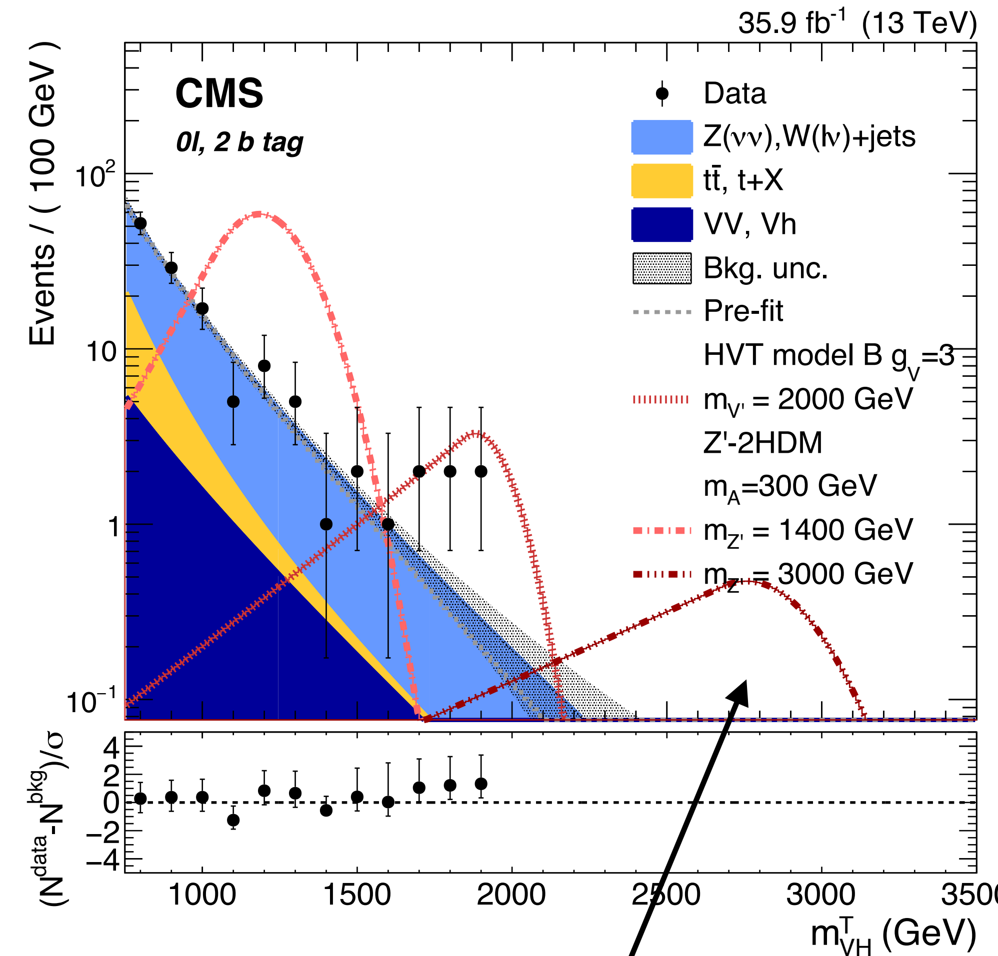
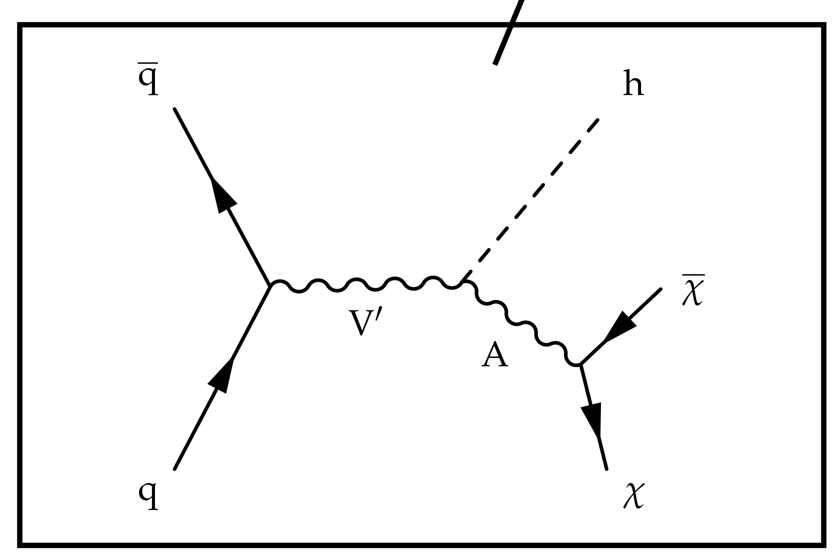
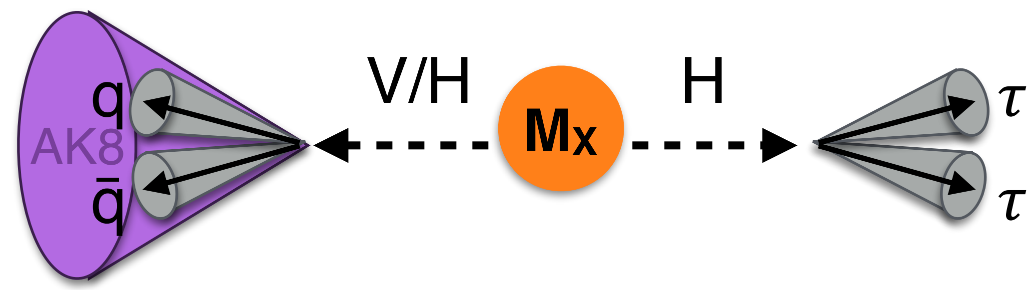




For the first time, also set limits on dark matter where $\nu\nu \to \chi\chi$

- most stringent limits on model to date!

Boosted τ final states

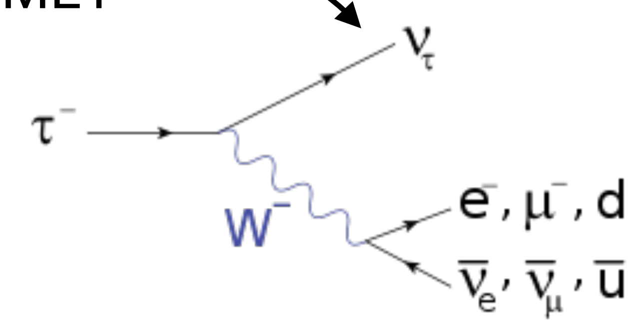


$X \to VH \to q\bar{q}\tau\tau$ or $X \to HH \to b\bar{b}\tau\tau$

The pros:

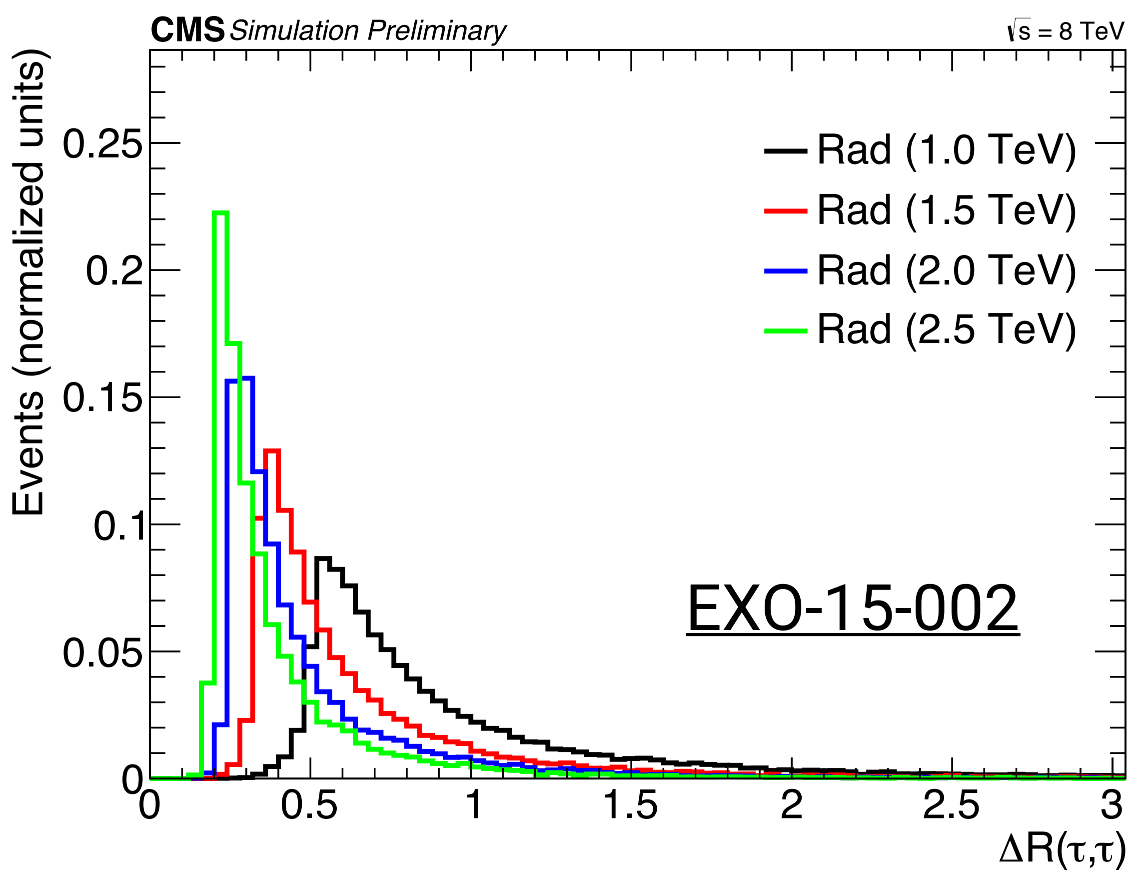
- high branching fraction
- with one τ decaying leptonically, low background and possibility to trigger on lepton+MET

Trigger and tag using lepton and MET



The cons:

- extremely challenging to reconstruct $H \to \tau\tau$ as τ decay products overlap



Boosted τ reconstruction

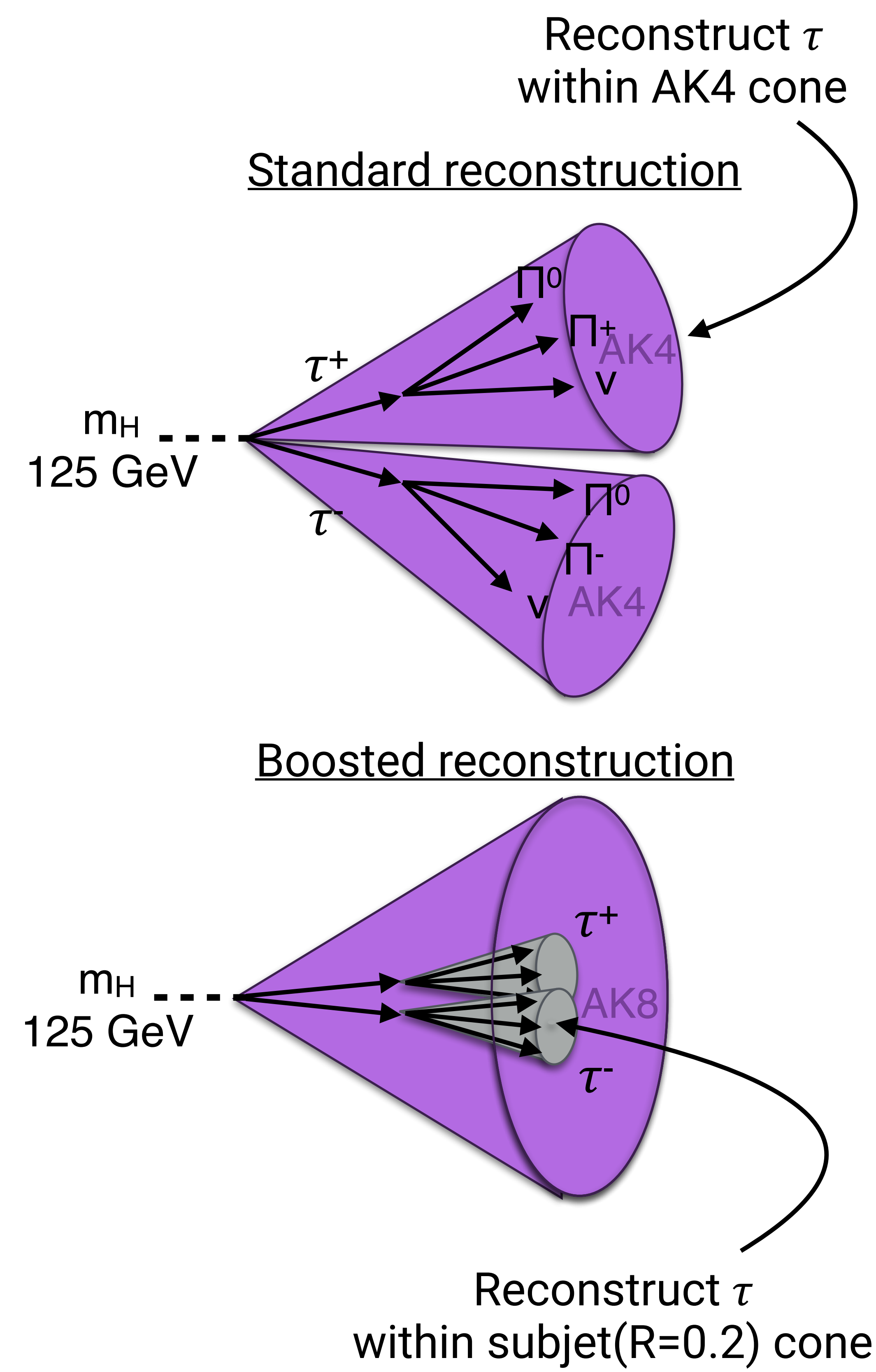
Standard τ reconstruction algorithms attempt to identify τ by reconstructing τ decay products (Π^0,$\Pi^{+/-}$)

- look within AK4 jet cone

For boosted $\tau\tau$ final states, AK4 cones overlap and efficiency drops

- Rather "seed" reconstruction using AK8 softdrop subjets R=0.2 → subjet τ-tagging

Huge gain in efficiency using dedicated reconstruction!



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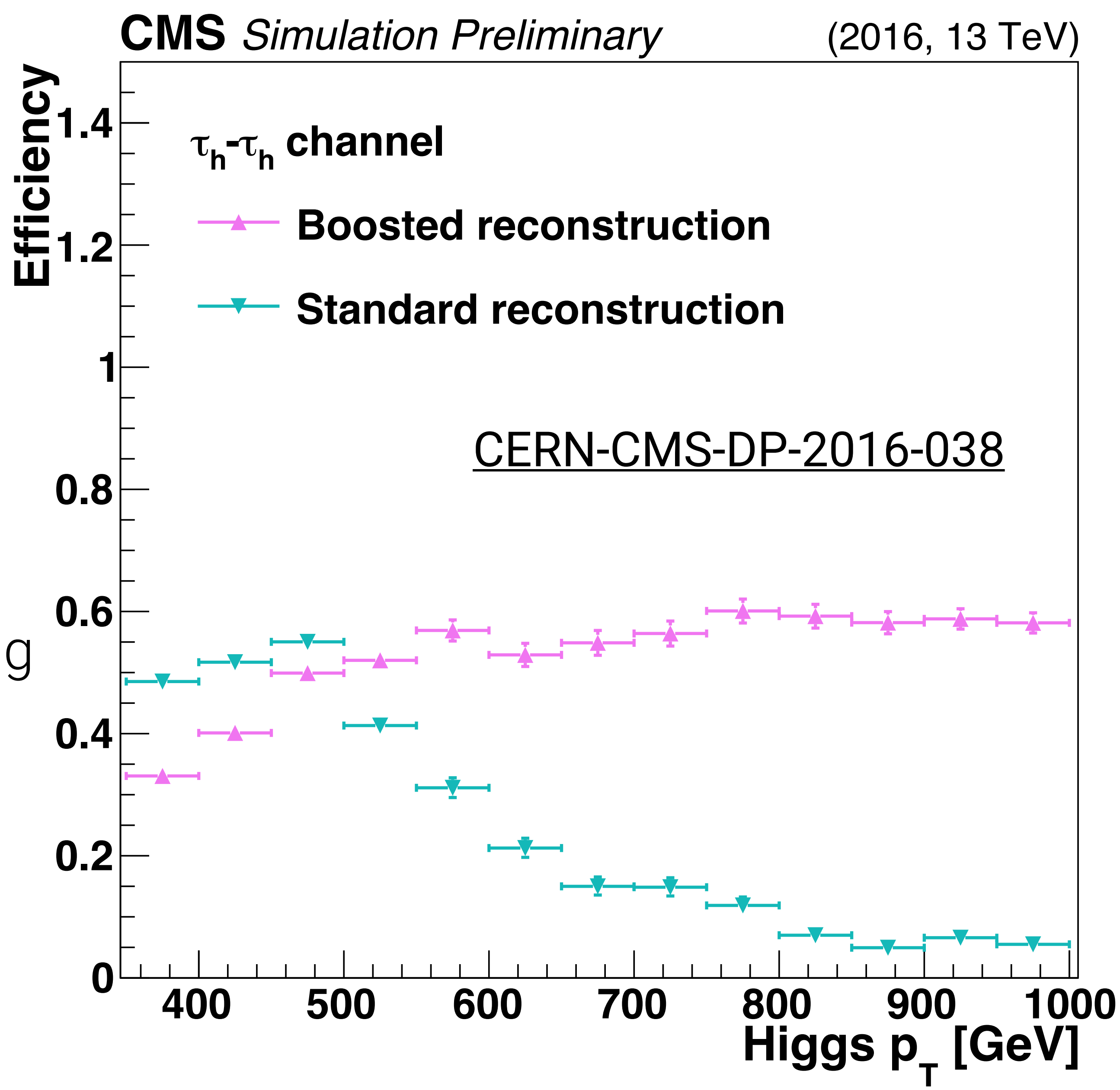
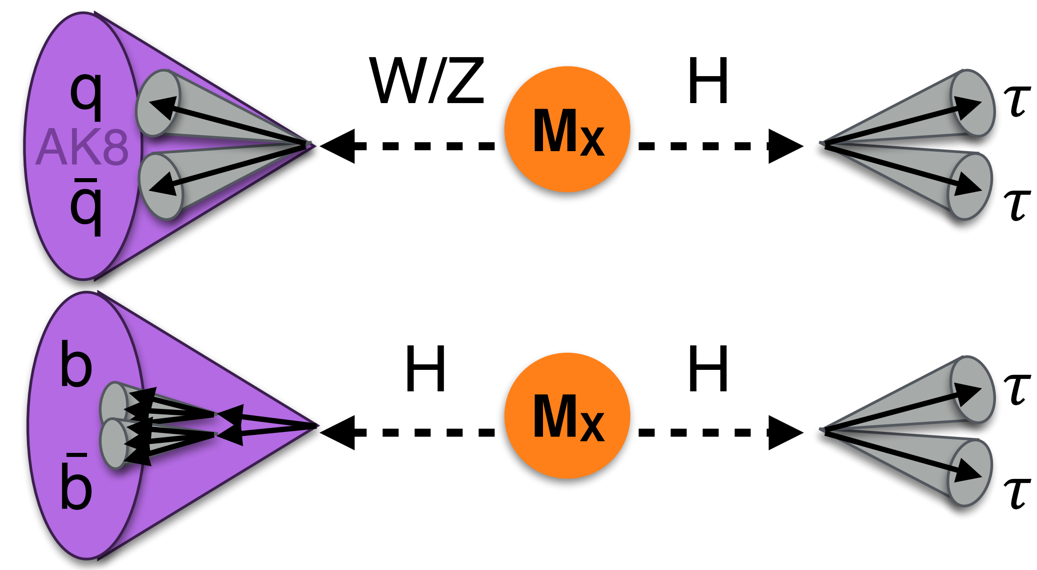


VH/HH to $\tau\tau qq$ / $\tau\tau bb$ B2G-17-006

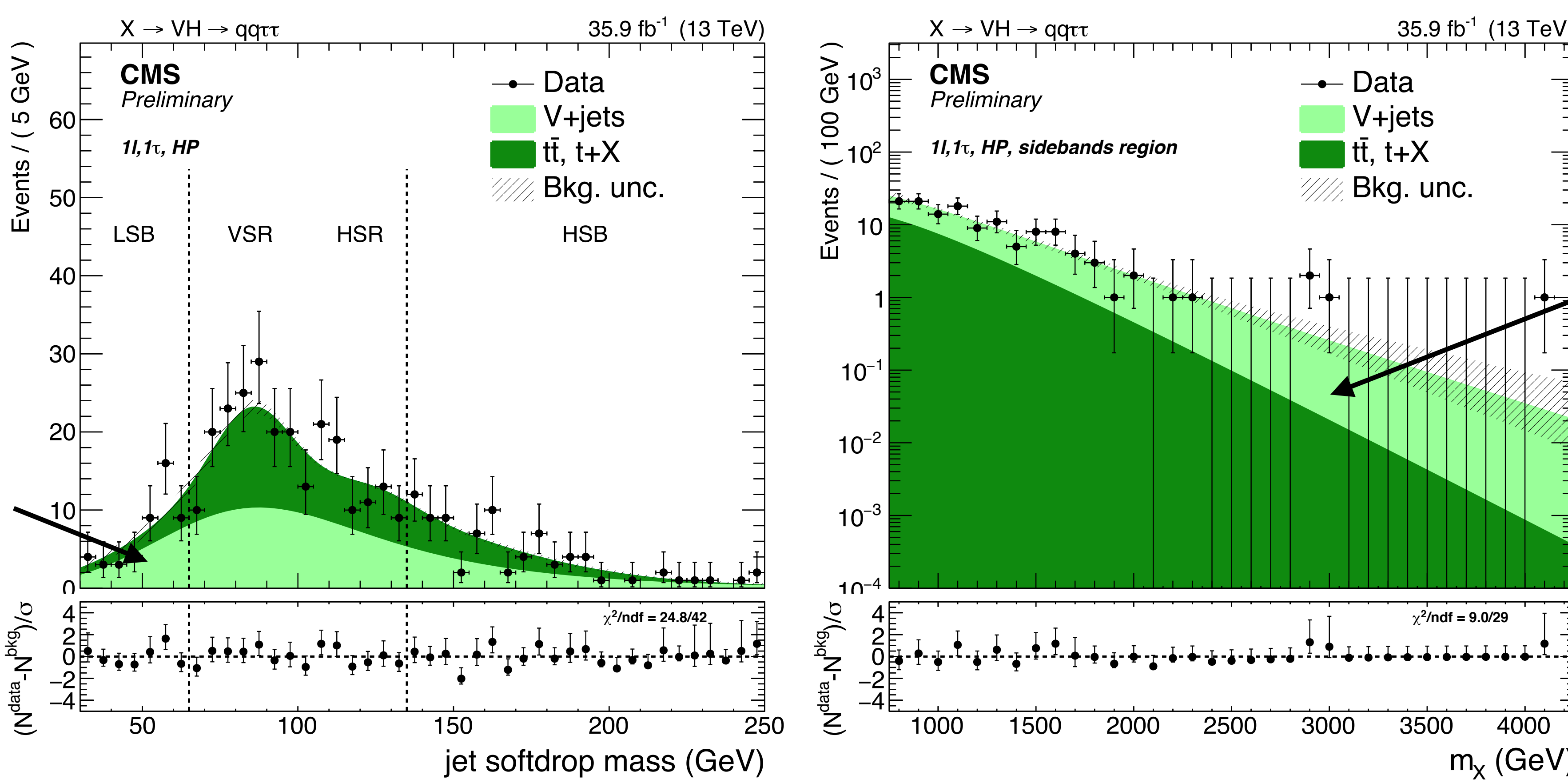


3 orthogonal searches: WH/ZH/HH

Combine subjet b-tagging, boosted V reconstruction and boosted τ tagging

- both fully-hadronic and semi-leptonic $\tau\tau$ final states using boosted reconstruction

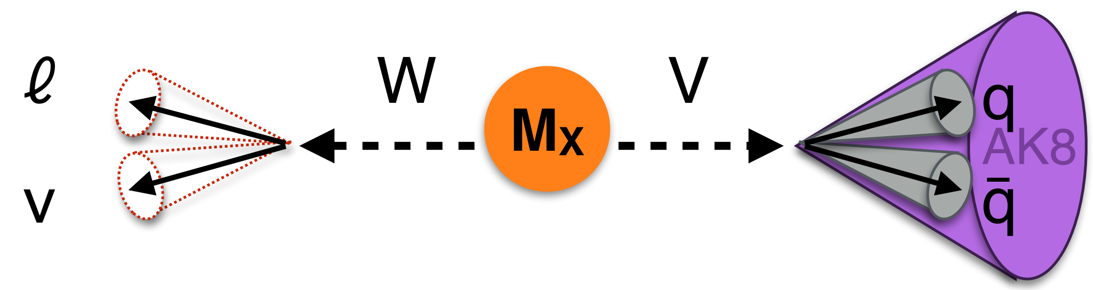
normalisation from mass sidebands



shape from m_X sideband, extrapolated to signal region via transfer function

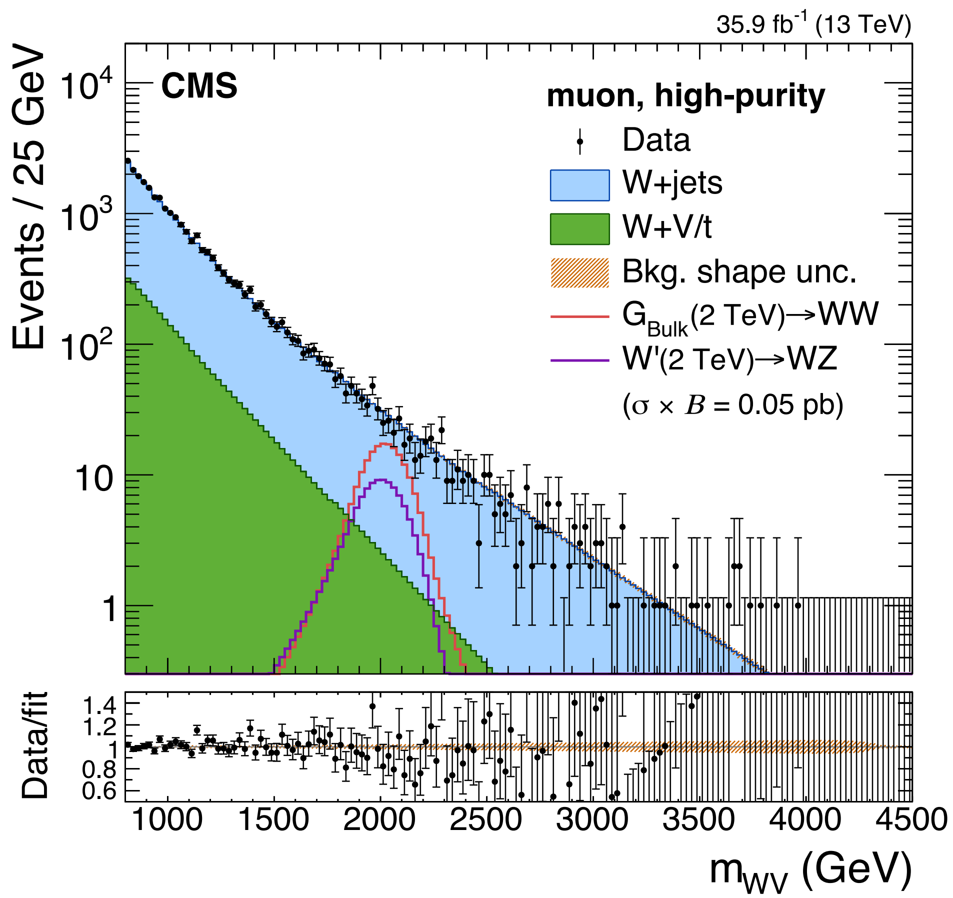
Going multidimensional

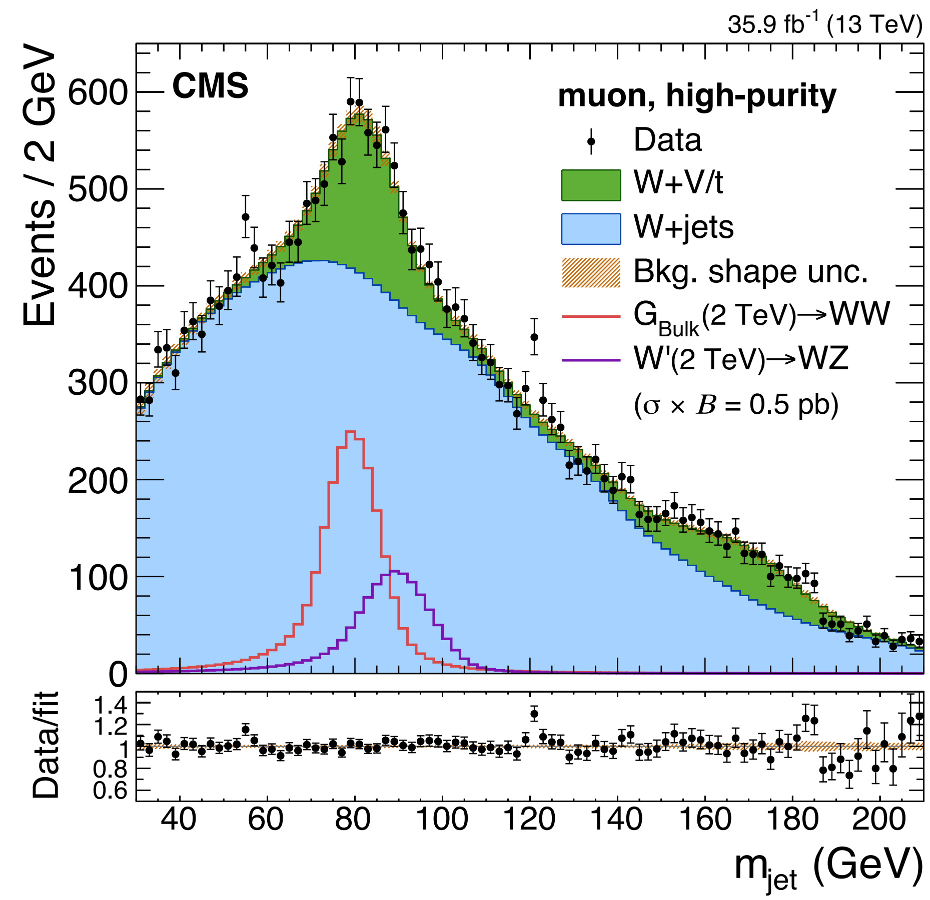
JHEP 05 (2018) 088

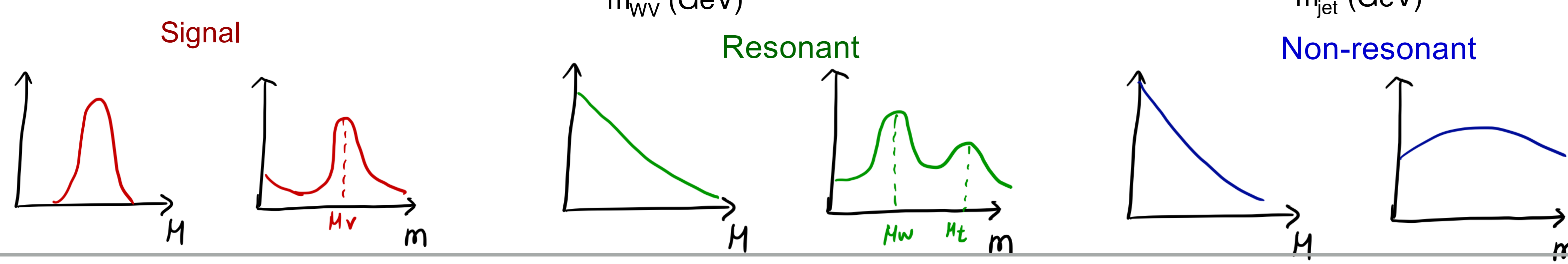


Take advantage of signal peaking in both jet mass and invariant mass and search for $X \rightarrow VW$ in $M_{\ell\nu,AK8}$-m_{AK8} plane

$$P_{\mathrm{W+jets}}(m_{\mathrm{WV}}, m_{\mathrm{jet}}) = P_{\mathrm{WV}}(m_{\mathrm{WV}}|m_{\mathrm{jet}}, \theta_1)\, P_j(m_{\mathrm{jet}}|\theta_2)$$







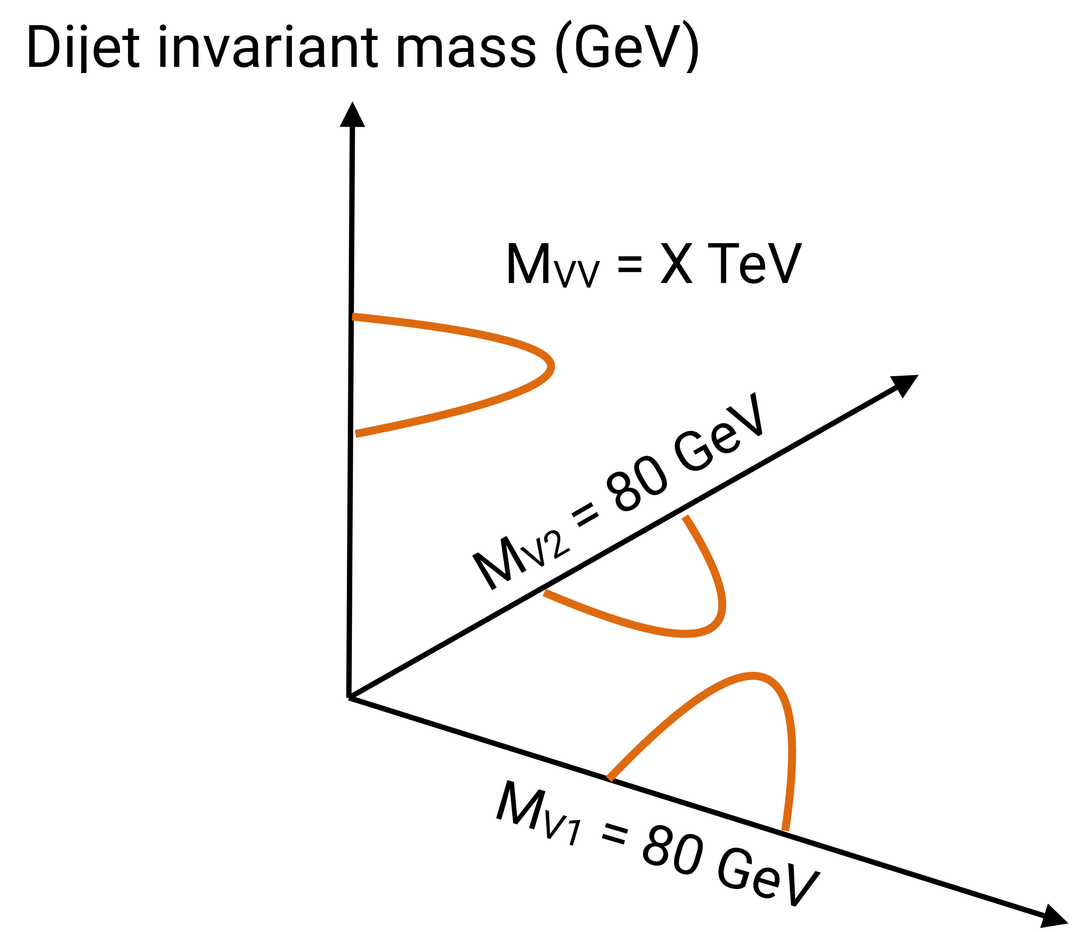
Outlook: 2D→3D

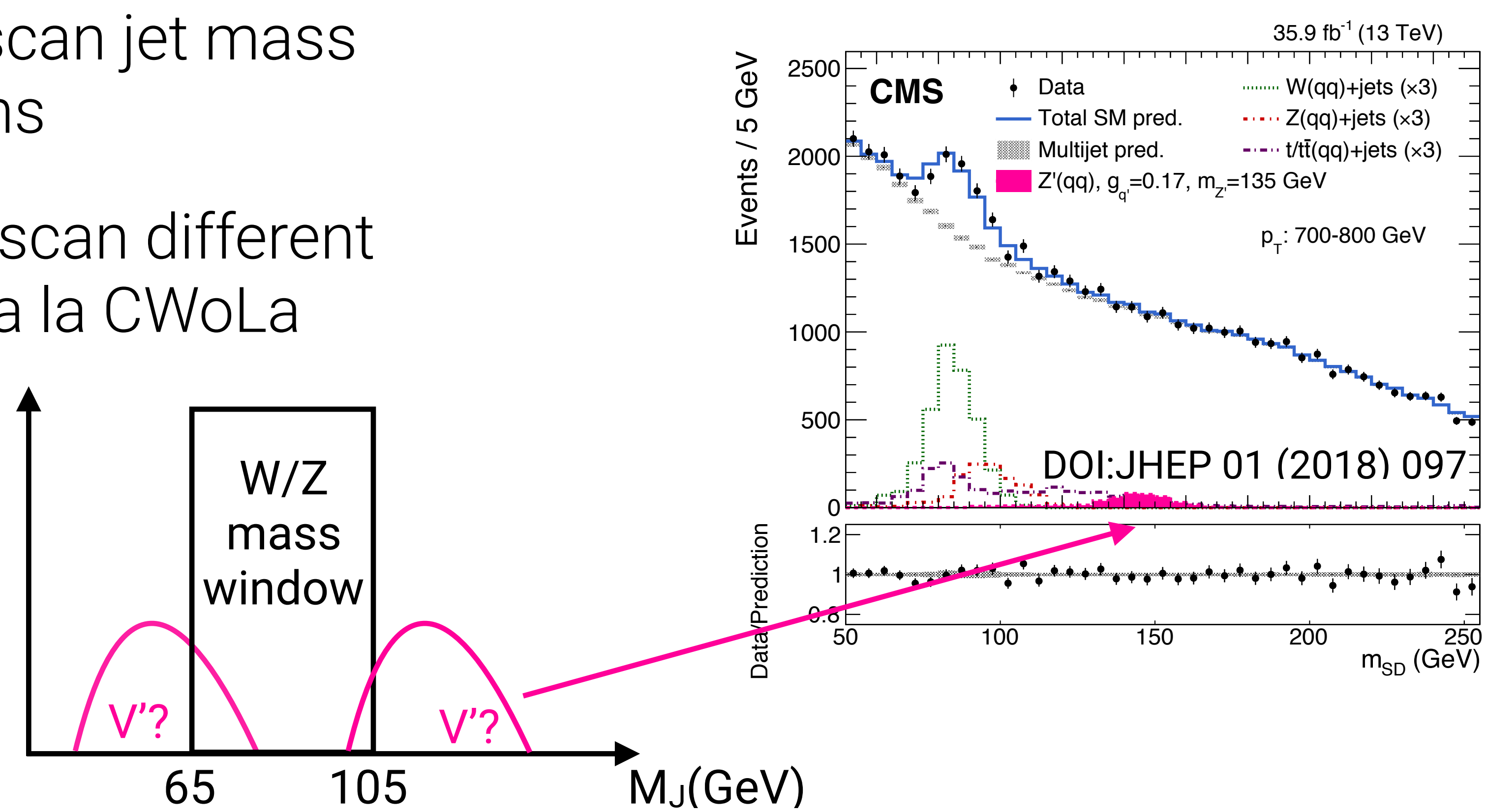
For all-hadronic, extend this to 3D scan of M_{V1}-M_{V2} - M_{VV}

- use full jet mass line shape, can incorporate all VV searches in one common framework

No signs of new physics in diboson searches

- 3D fit easily extendable to scan jet mass in search for non-SM bosons
- cascade decay signatures, scan different τ ratios. Ideal for searches a la CWoLa (no signal prior)





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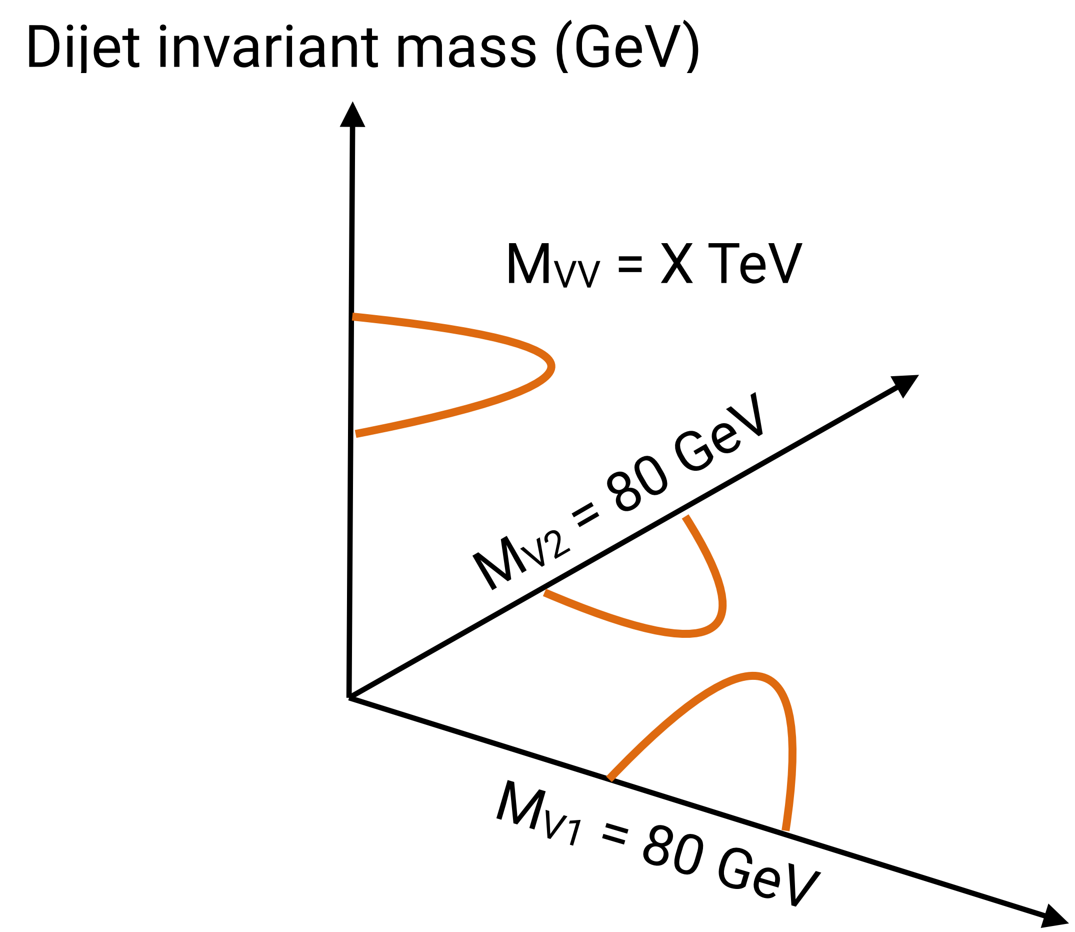
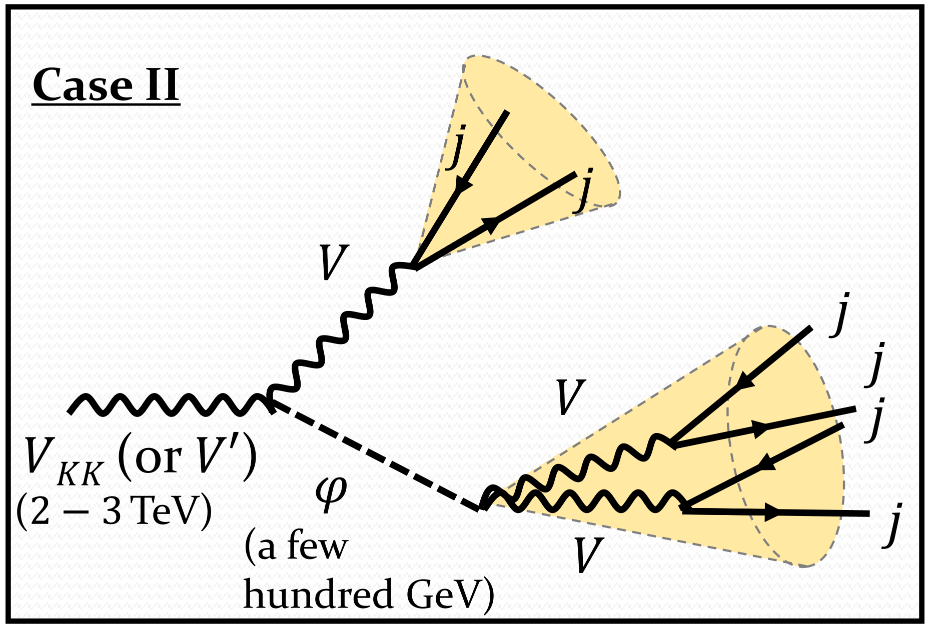
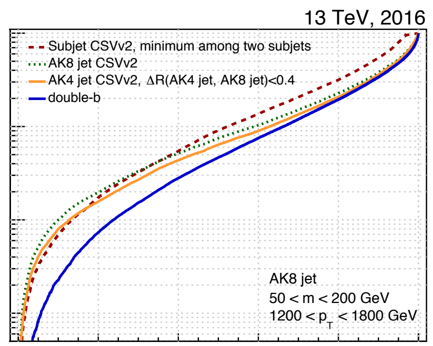
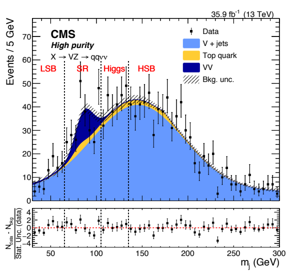
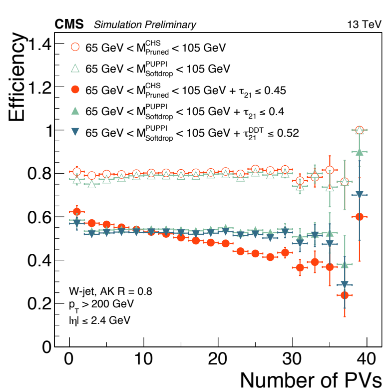


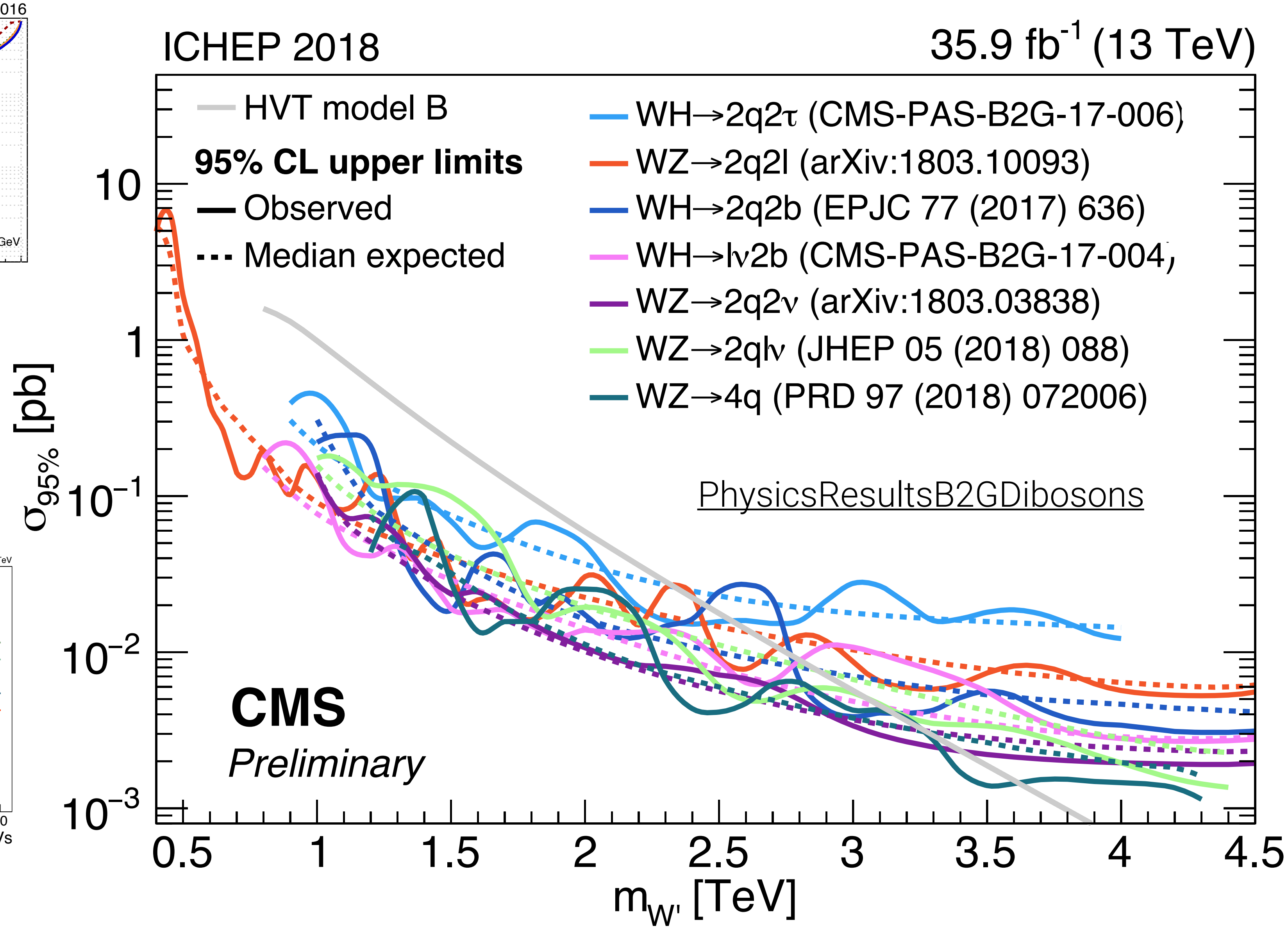


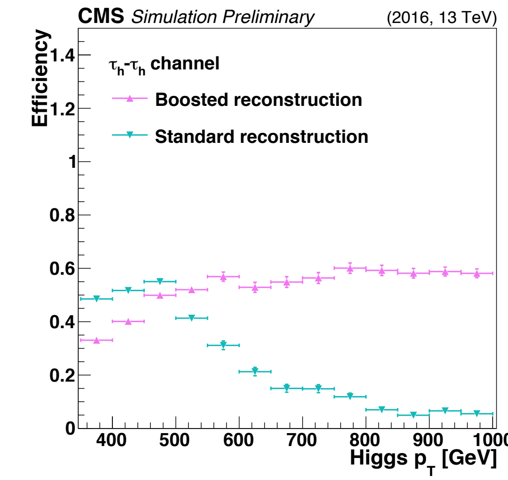
Summary

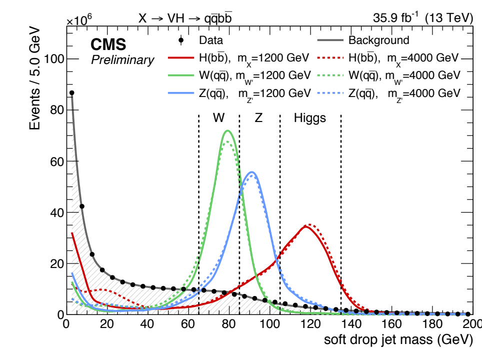

13 TeV, 2016
Subject CSVv2, minimum among two subjets
AK8 jet CSVv2
AK4 jet CSVv2, ΔR(AK4 jet, AK8 jet)<0.4
double-b
AK8 jet
50 < m < 200 GeV
1200 < p_T < 1800 GeV

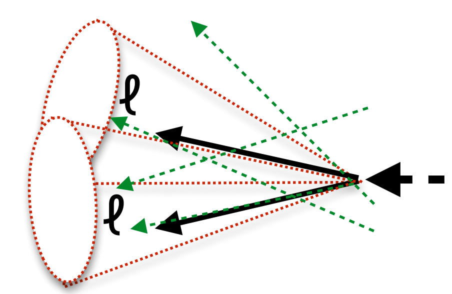



CMS Simulation Preliminary
13 TeV
Efficiency
W-jet, AK R = 0.8
Number of PVs


ICHEP 2018
35.9 fb^{-1} (13 TeV)
HVT model B
95% CL upper limits
Observed
Median expected
WH→2q2τ (CMS-PAS-B2G-17-006)
WZ→2q2l (arXiv:1803.10093)
WH→2q2b (EPJC 77 (2017) 636)
WH→lν2b (CMS-PAS-B2G-17-004)
WZ→2q2ν (arXiv:1803.03838)
WZ→2qlν (JHEP 05 (2018) 088)
WZ→4q (PRD 97 (2018) 072006)
PhysicsResultsB2GDibosons
CMS
Preliminary
$\sigma_{95\%}$ [pb]
$m_{W'}$ [TeV]


CMS Simulation Preliminary
(2016, 13 TeV)
τ_h-τ_h channel
Boosted reconstruction
Standard reconstruction
Efficiency
Higgs p_T [GeV]


X → VH → qqbb
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
Events / 5.0 GeV
soft drop jet mass (GeV)


ℓ
ℓ

Backup

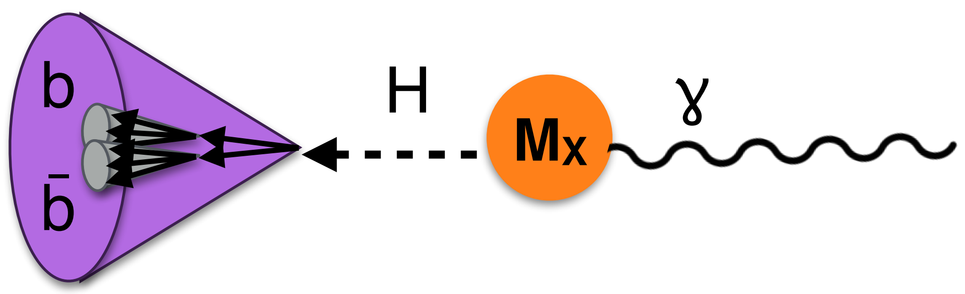
γ+W/Z/H resonance search
EXO-17-019

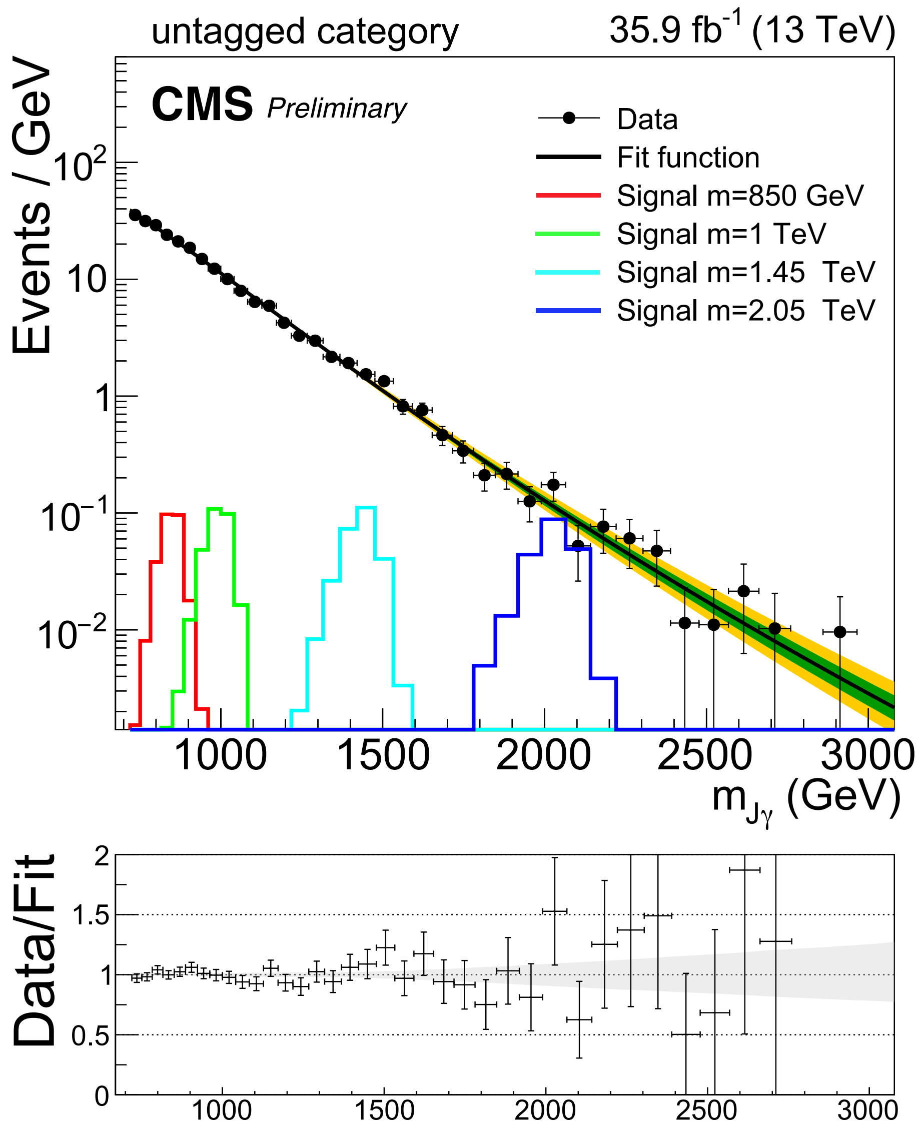
CMS first search in γ+W/Z/H final state

Two categories

- b-tagged Higgs jet (double-b tagger)
- non b-tagged (gain at low background)

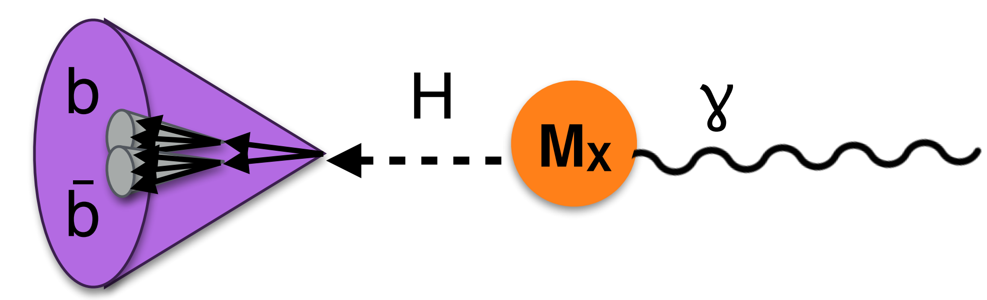
Background estimate from fit to data (similar to VV and VH all-hadronic)





γ+W/Z/H resonance search

EXO-17-019



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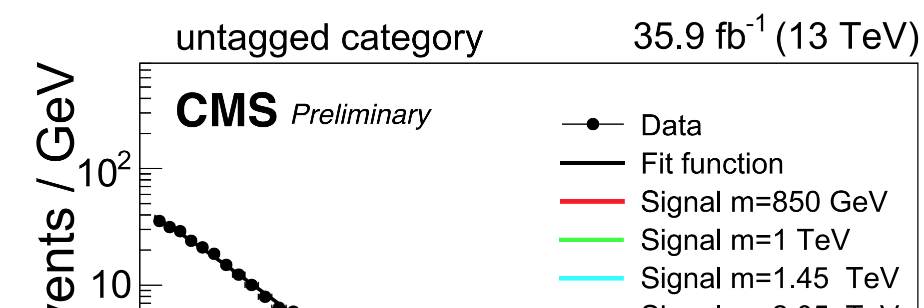
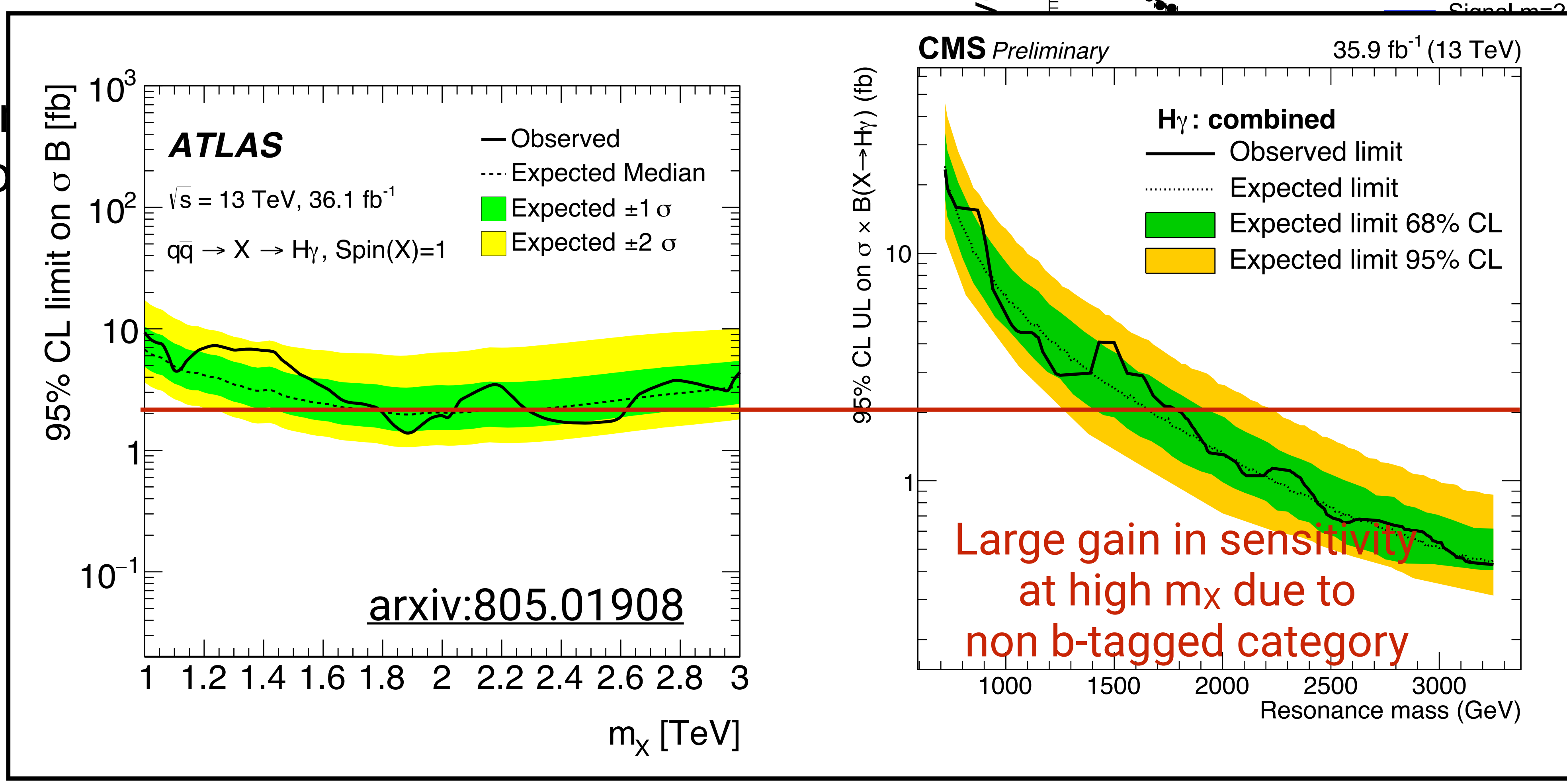
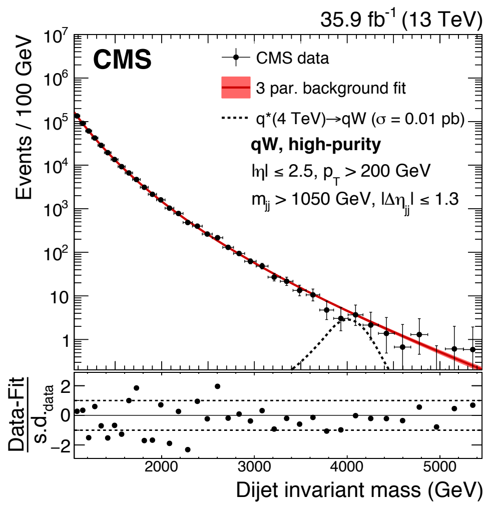
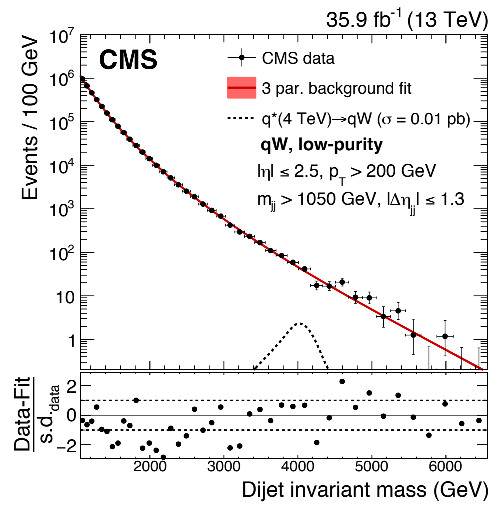


Backgrou
(similar to



B2G-17-001


35.9 fb^{-1} (13 TeV)
CMS
CMS data
3 par. background fit
q*(4 TeV)→qW (σ = 0.01 pb)
qW, high-purity
|η| ≤ 2.5, p_T > 200 GeV
m_{jj} > 1050 GeV, |Δ$η_{jj}$| ≤ 1.3
Events / 100 GeV
Data-Fit / s.d.$_{data}$
Dijet invariant mass (GeV)


35.9 fb^{-1} (13 TeV)
CMS
CMS data
3 par. background fit
q*(4 TeV)→qW (σ = 0.01 pb)
qW, low-purity
|η| ≤ 2.5, p_T > 200 GeV
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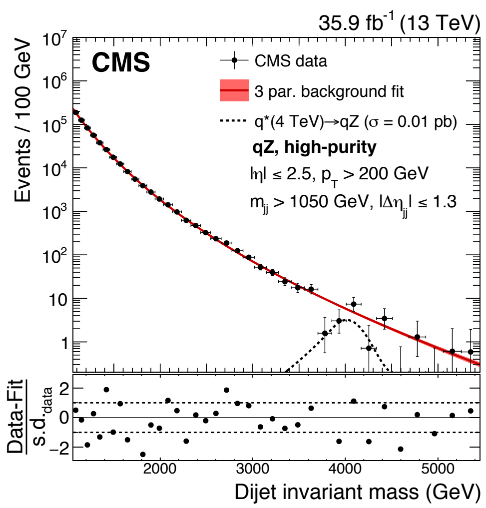
35.9 fb^{-1} (13 TeV)
CMS
CMS data
3 par. background fit
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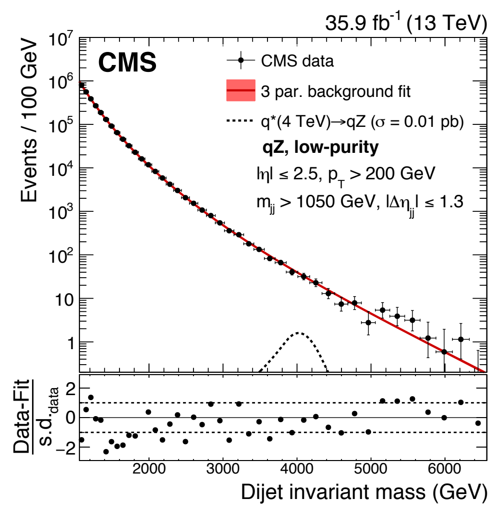
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CMS data
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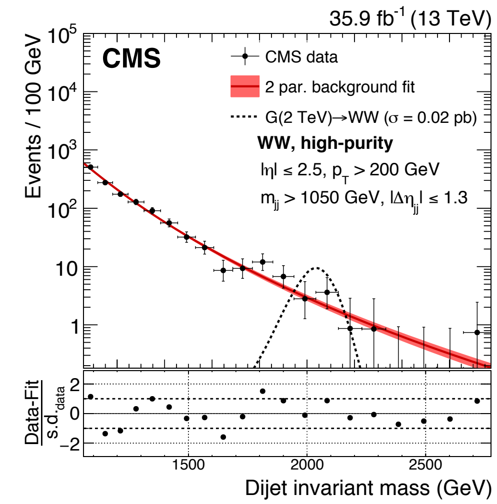
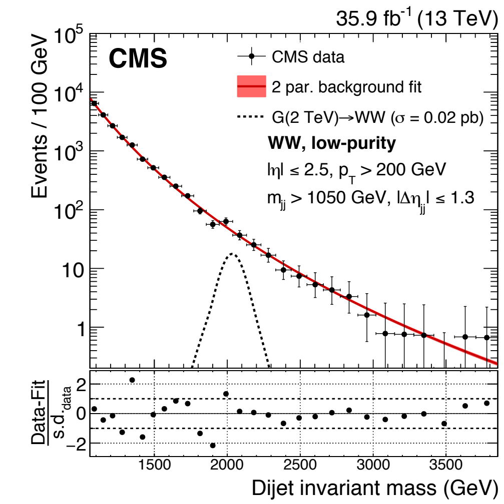
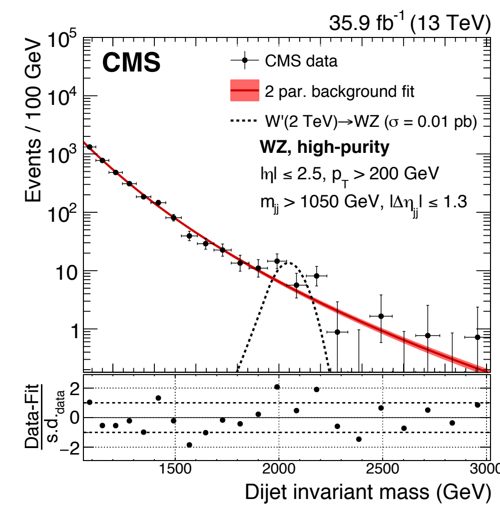
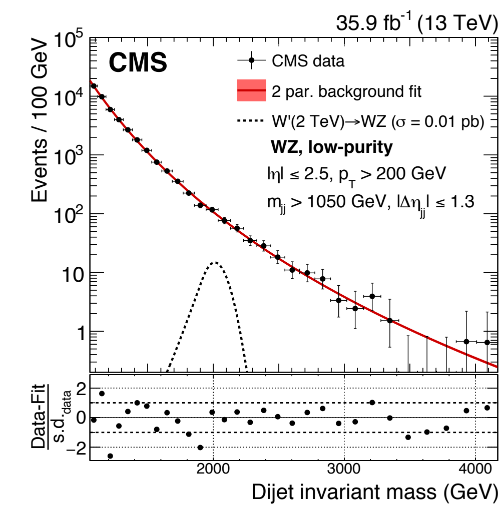
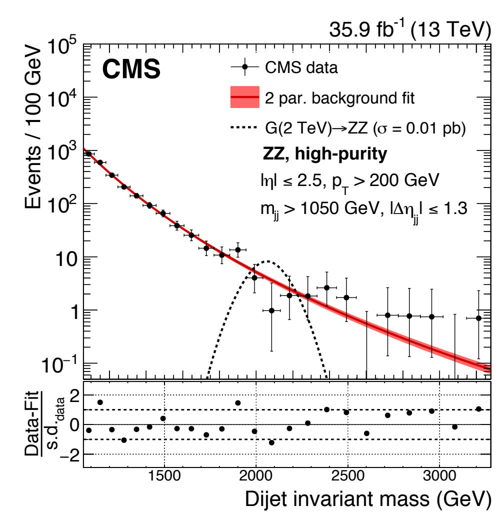
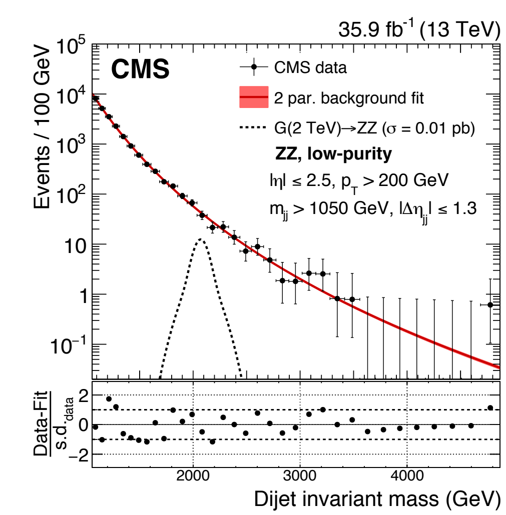

35.9 fb^{-1} (13 TeV)
CMS
CMS data
2 par. background fit
G(2 TeV)→WW (σ = 0.02 pb)
WW, high-purity
|η| ≤ 2.5, p_T > 200 GeV
m_{jj} > 1050 GeV, |Δ$η_{jj}$| ≤ 1.3
Events / 100 GeV
Data-Fit / s.d.$_{data}$
Dijet invariant mass (GeV)


35.9 fb^{-1} (13 TeV)
CMS
CMS data
2 par. background fit
G(2 TeV)→WW (σ = 0.02 pb)
WW, low-purity
|η| ≤ 2.5, p_T > 200 GeV
m_{jj} > 1050 GeV, |Δ$η_{jj}$| ≤ 1.3
Events / 100 GeV
Data-Fit / s.d.$_{data}$
Dijet invariant mass (GeV)


35.9 fb^{-1} (13 TeV)
CMS
CMS data
2 par. background fit
W'(2 TeV)→WZ (σ = 0.01 pb)
WZ, high-purity
|η| ≤ 2.5, p_T > 200 GeV
m_{jj} > 1050 GeV, |Δ$η_{jj}$| ≤ 1.3
Events / 100 GeV
Data-Fit / s.d.$_{data}$
Dijet invariant mass (GeV)

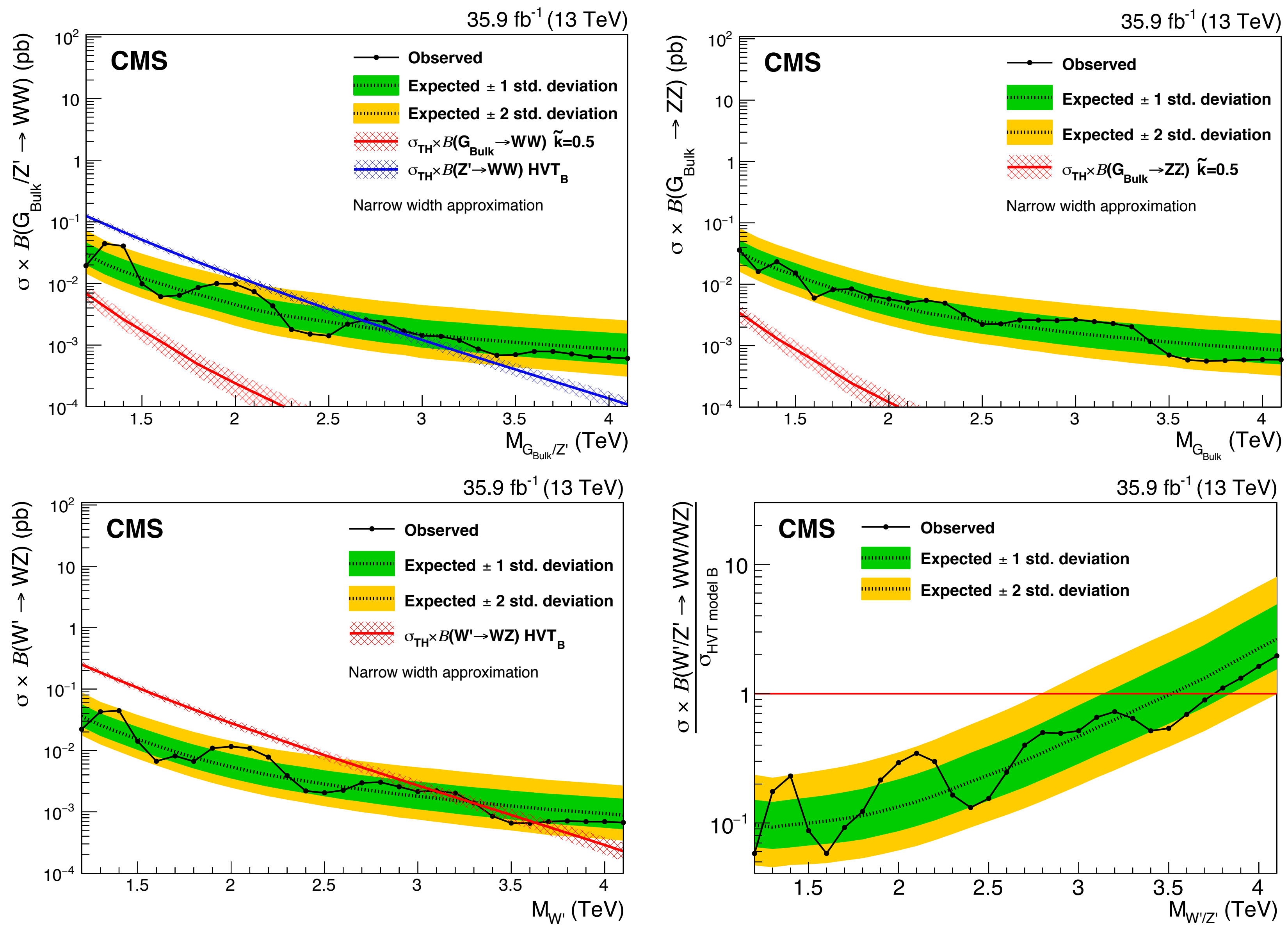

35.9 fb^{-1} (13 TeV)
CMS
CMS data
2 par. background fit
W'(2 TeV)→WZ (σ = 0.01 pb)
WZ, low-purity
|η| ≤ 2.5, p_T > 200 GeV
m_{jj} > 1050 GeV, |Δ$η_{jj}$| ≤ 1.3
Events / 100 GeV
Data-Fit / s.d.$_{data}$
Dijet invariant mass (GeV)


35.9 fb^{-1} (13 TeV)
CMS
CMS data
2 par. background fit
G(2 TeV)→ZZ (σ = 0.01 pb)
ZZ, high-purity
|η| ≤ 2.5, p_T > 200 GeV
m_{jj} > 1050 GeV, |Δ$η_{jj}$| ≤ 1.3
Events / 100 GeV
Data-Fit / s.d.$_{data}$
Dijet invariant mass (GeV)

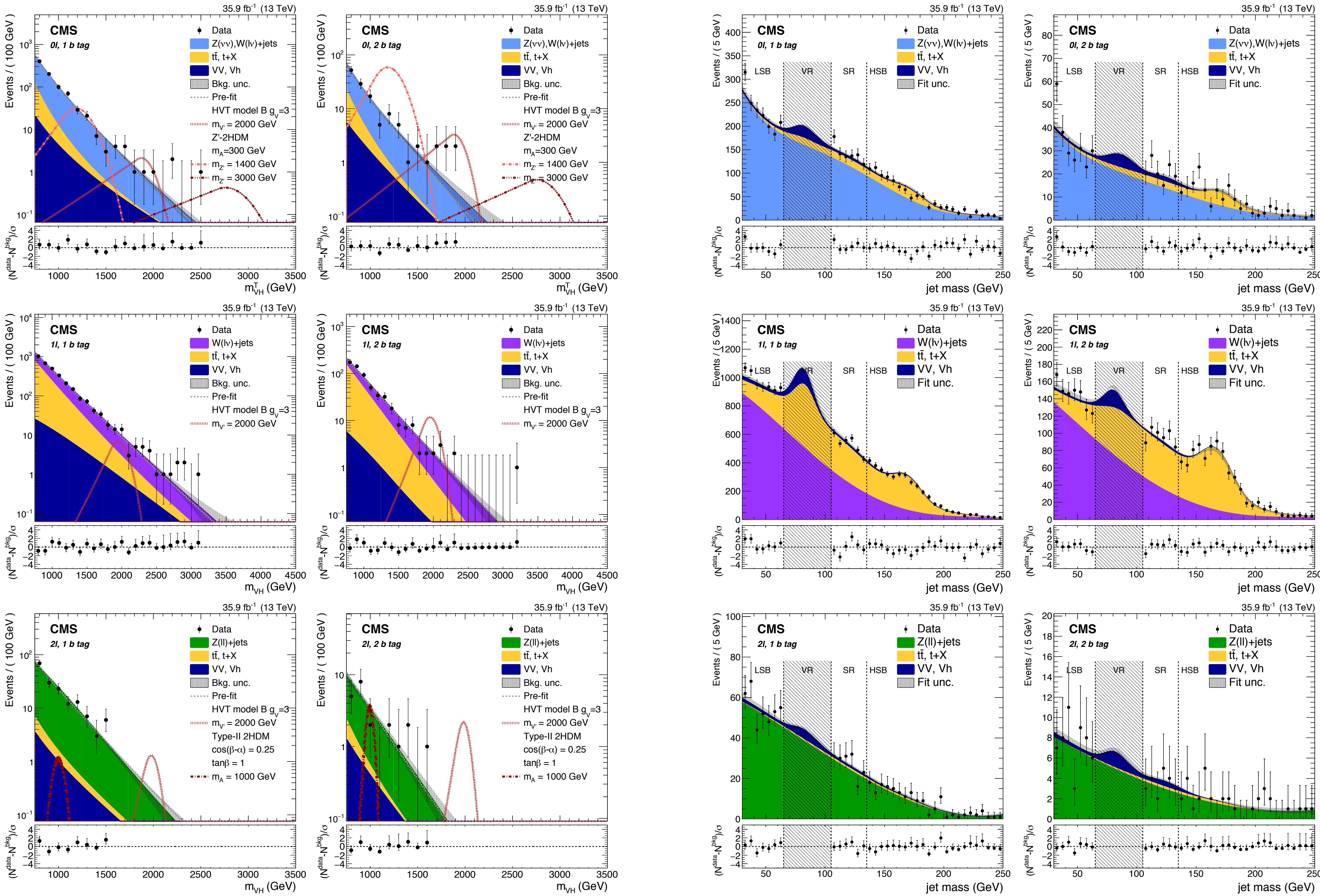

35.9 fb^{-1} (13 TeV)
CMS
CMS data
2 par. background fit
G(2 TeV)→ZZ (σ = 0.01 pb)
ZZ, low-purity
|η| ≤ 2.5, p_T > 200 GeV
m_{jj} > 1050 GeV, |Δ$η_{jj}$| ≤ 1.3
Events / 100 GeV
Data-Fit / s.d.$_{data}$
Dijet invariant mass (GeV)

B2G-17-001

Source	Relevant quantity	Uncertainty (%) Double-tag HP+HP	Double-tag HP+LP	Single-tag HP+j	Single-tag LP+j
Jet energy scale	Resonance shape	2	2	2	2
Jet energy resolution	Resonance shape	6	7	4	3
PDF	Resonance shape	5	7	13	8
Jet energy scale	Signal yield	<1		<1	
Jet energy resolution	Signal yield	<1		<1	
Jet mass scale	Signal yield	<2		<1	
Jet mass resolution	Signal yield	<6		<8	
Pileup	Signal yield	2			
PDF (acceptance)	Signal yield	2			
Integrated luminosity	Signal yield	2.5			
Jet mass scale	Migration	<36		<10	
Jet mass resolution	Migration	<25		<7	
V tagging τ_{21}	Migration	22	33	11	22
V tagging p_T-dependence	Migration	19–40	14–29	9–23	4–11
PDF and scales (W′ and Z′)	Theory	2–18			
PDF and scales (G_{bulk})	Theory	8–78			
PDF and scales (q*)	Theory			1–61	

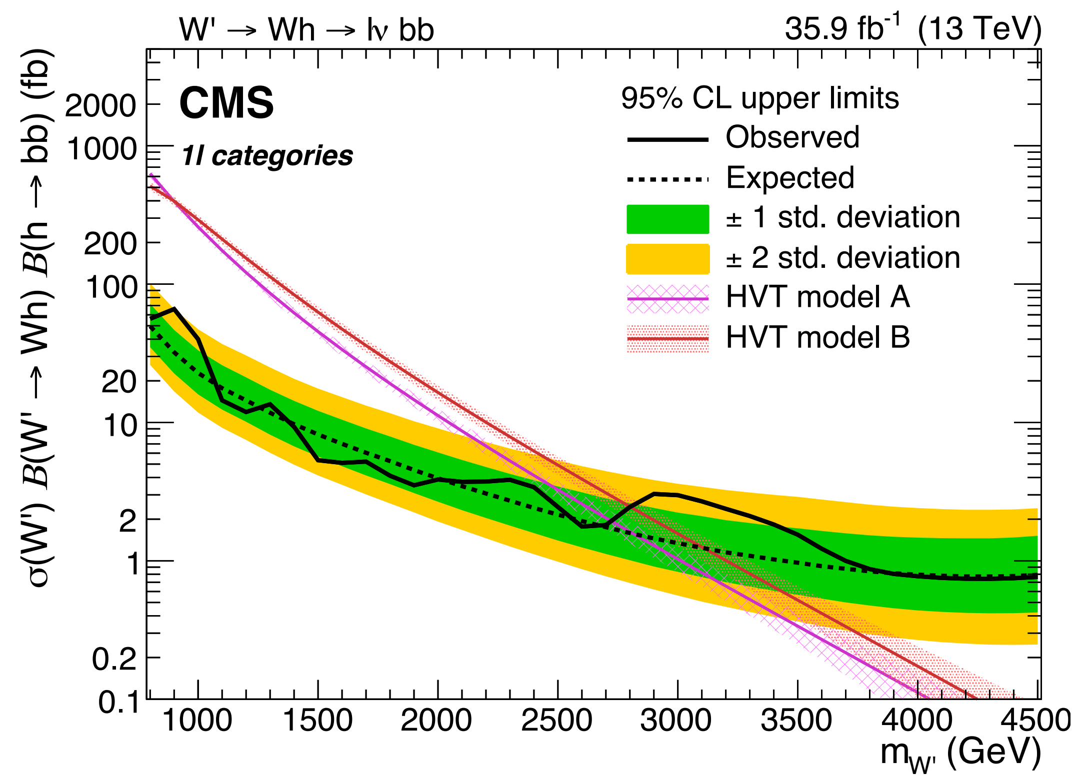


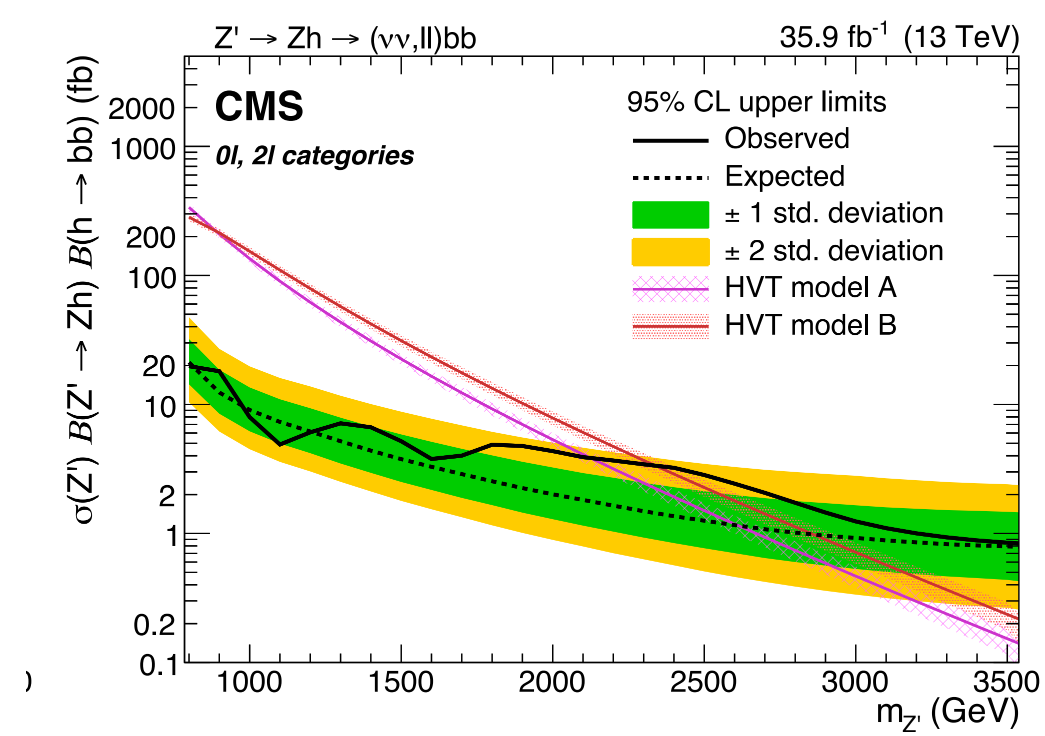
B2G-17-004


CMS
35.9 fb^{-1} (13 TeV)
0l, 1 b tag
0l, 2 b tag
1l, 1 b tag
1l, 2 b tag
2l, 1 b tag
2l, 2 b tag
Data
Z(νν),W(lν)+jets
W(lν)+jets
Z(ll)+jets
tt̄, t+X
VV, Vh
Bkg. unc.
Fit unc.
Pre-fit
HVT model B g_V=3
$m_{V'}$ = 2000 GeV
Z'-2HDM
m_A=300 GeV
$m_{Z'}$ = 1400 GeV
$m_{Z'}$ = 3000 GeV
Type-II 2HDM
cos(β-α) = 0.25
tanβ = 1
m_A = 1000 GeV
LSB
VR
SR
HSB
Events / (100 GeV)
Events / (5 GeV)
$(N^{data}-N^{bkg})/\sigma$
m^T_{VH} (GeV)
m_{VH} (GeV)
jet mass (GeV)

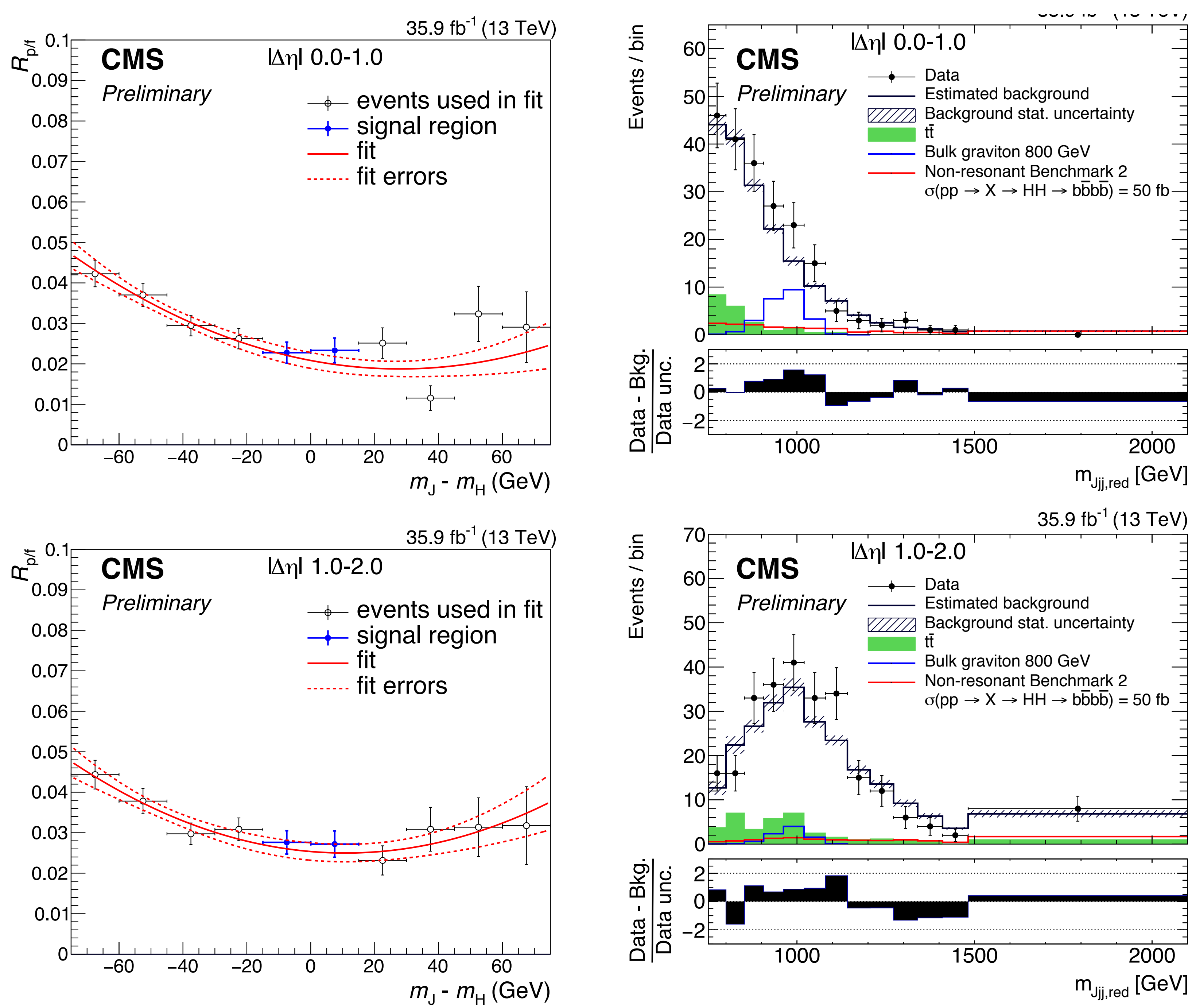
B2G-17-004

	shape	V+jets	$t\bar{t}$, t+X	VV, Vh	Signal
Bkg. normalization	—	2–15%	—	—	—
Top quark bkg. scale factors	—	—	2–17%	—	—
Jet energy scale	✓	—	—	3%	1%
Jet energy resolution	✓	—	—	<1%	<1%
Jet mass scale	—	—	—	6%	1%
Jet mass resolution	—	—	—	6%	11%
Electron identification, isolation	—	—	1–3%	1–4%	
Muon identification, isolation	—	—	1–3%	1–5%	
Lepton scale and resolution	✓	—	—	—	1–5%
Hadronic τ veto	—	—	—	3% (0ℓ)	
p_T^{miss} scale and resolution	—	—	—	1%	1%
Electron, muon, p_T^{miss} trigger	—	—	—	3–4%	
b tagging	—	—	3% (0ℓ, 1ℓ) 2–5% ‡	4% (1b) 5% (2b)	2–5% (1b) 3–7% (2b)
Higgs boson jet	—	—	—	—	6%
Top quark p_T	—	—	6–14% ‡	—	—
Pileup	—	—	<1%	<1%	<1%
Factorization and renormalization scales	—	—	21% ‡	19%	3–28% †
PDF normalization	—	—	5% ‡	5%	8–36% †
PDF acceptance	—	—	2% ‡	<2%	<1%
Luminosity	—	—	—	2.5%	2.5%



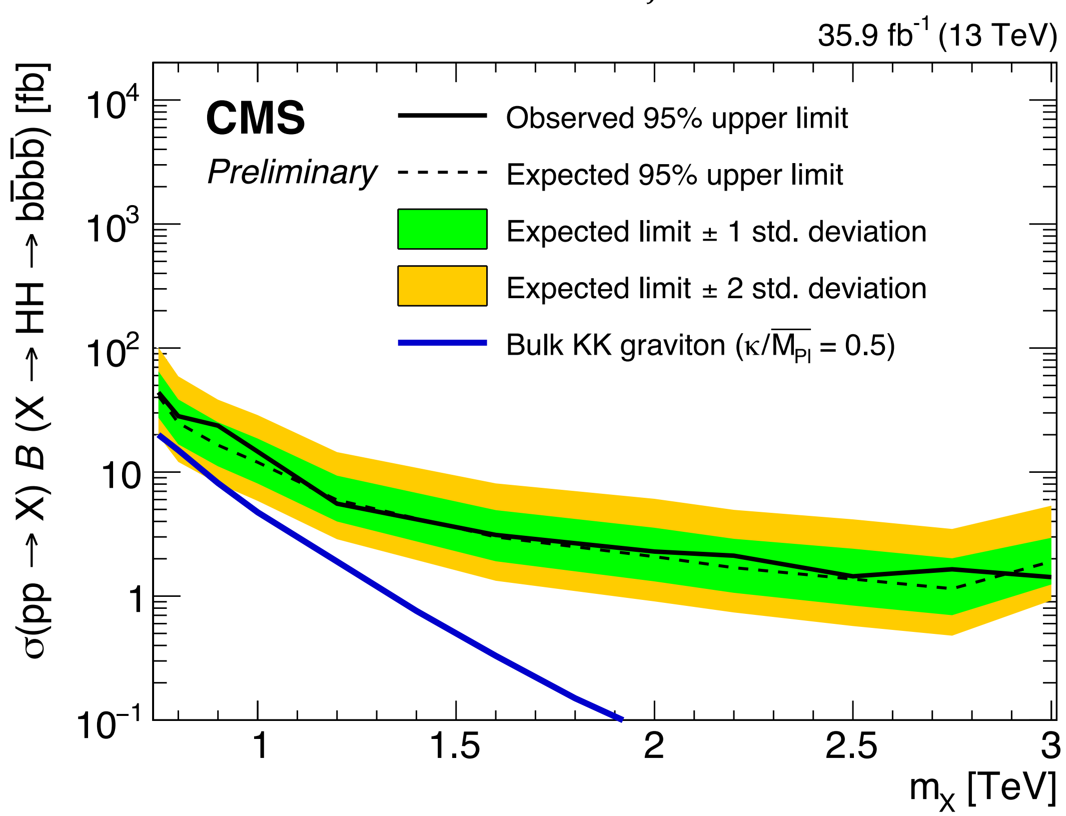


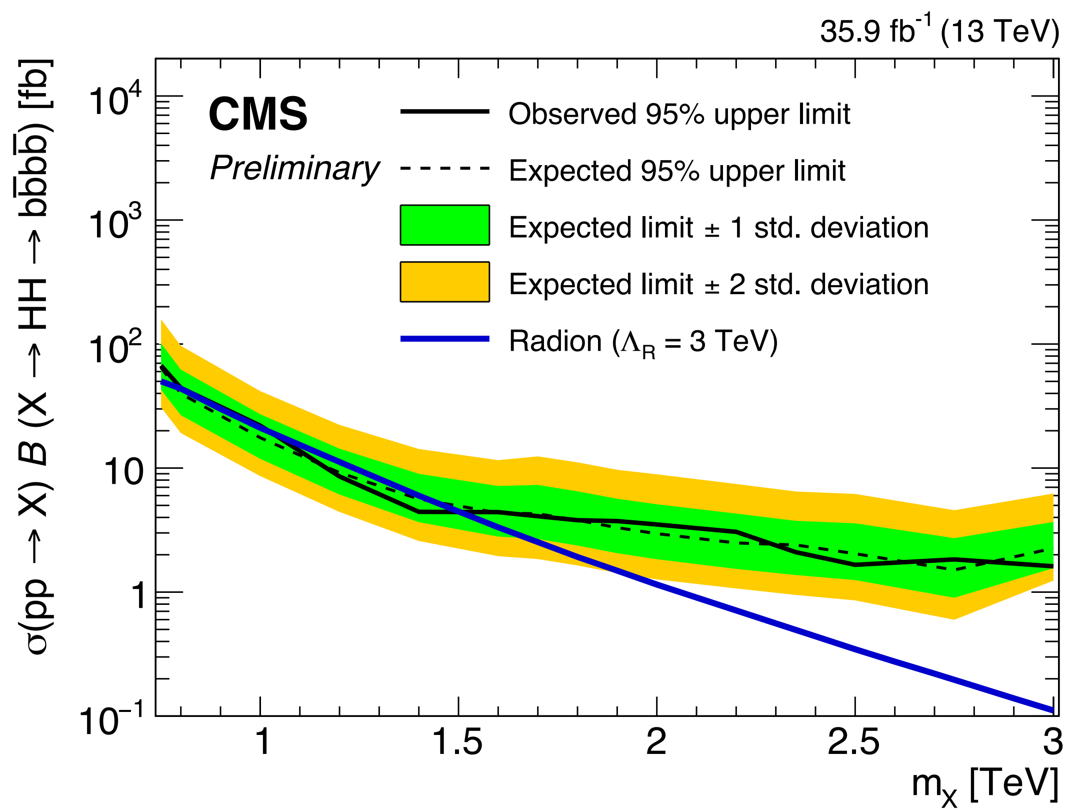
B2G-17-019


35.9 fb-1 (13 TeV)
CMS
Preliminary
|Δη| 0.0-1.0
|Δη| 1.0-2.0
events used in fit
signal region
fit
fit errors
R p/f
mJ - mH (GeV)
Data
Estimated background
Background stat. uncertainty
tt̄
Bulk graviton 800 GeV
Non-resonant Benchmark 2
σ(pp → X → HH → bb̄bb̄) = 50 fb
Events / bin
Data - Bkg.
Data unc.
mJjj,red [GeV]

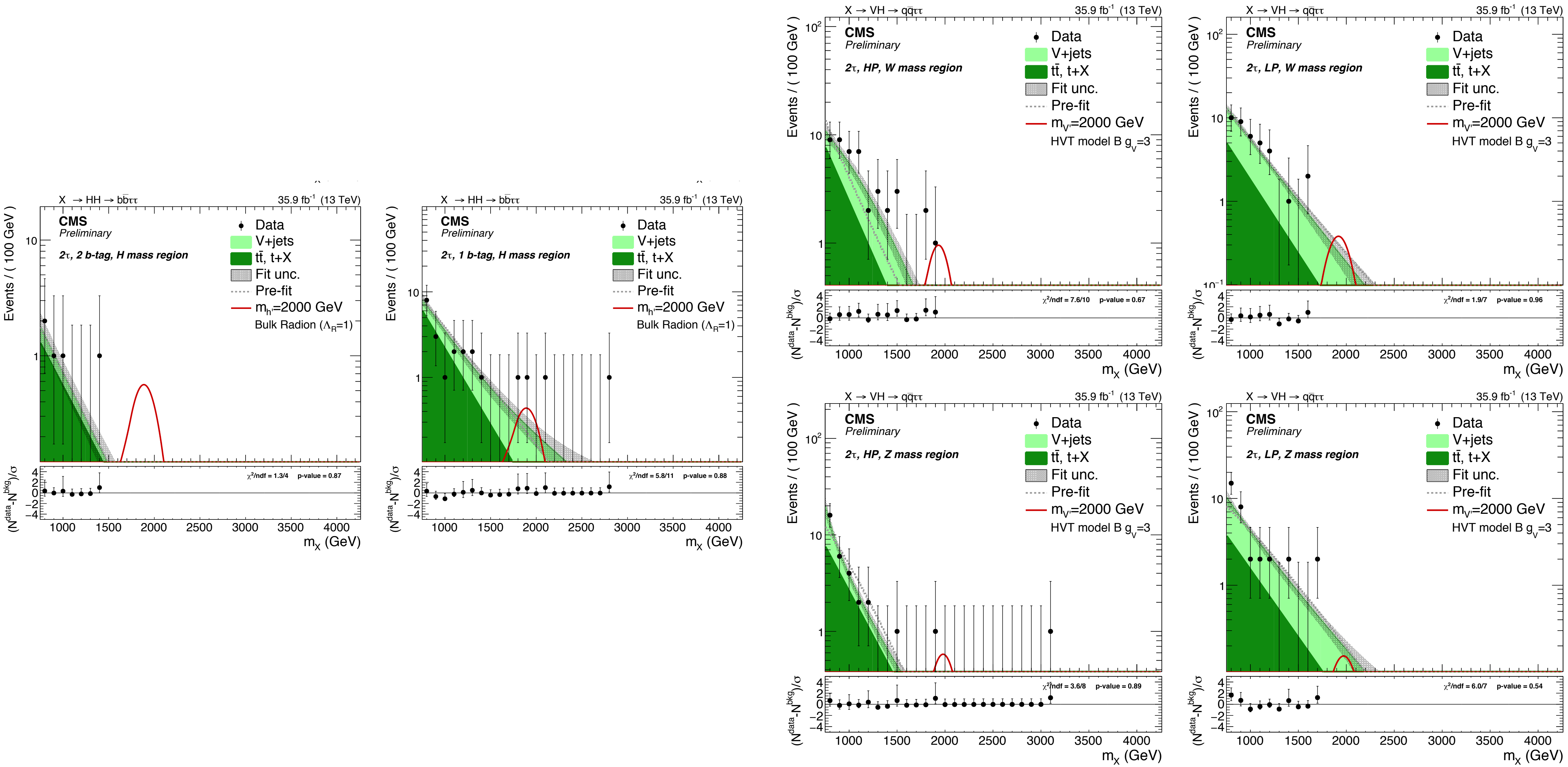
B2G-17-019

Source	Uncertainty (%)
Signal yield	
Trigger efficiency	1–15
H jet energy scale and resolution	1–3
H jet mass scale and resolution	2
H jet τ_{21} selection	14–30
H tagging correction factor	5–20
b tagging selection	2–9
Pileup modelling	1–2
PDF and scales	0.1–3
Luminosity	2.5
Background yield	
QCD background $R_{p/f}$ fit	2–10
$t\bar{t}$ +jets cross section	5



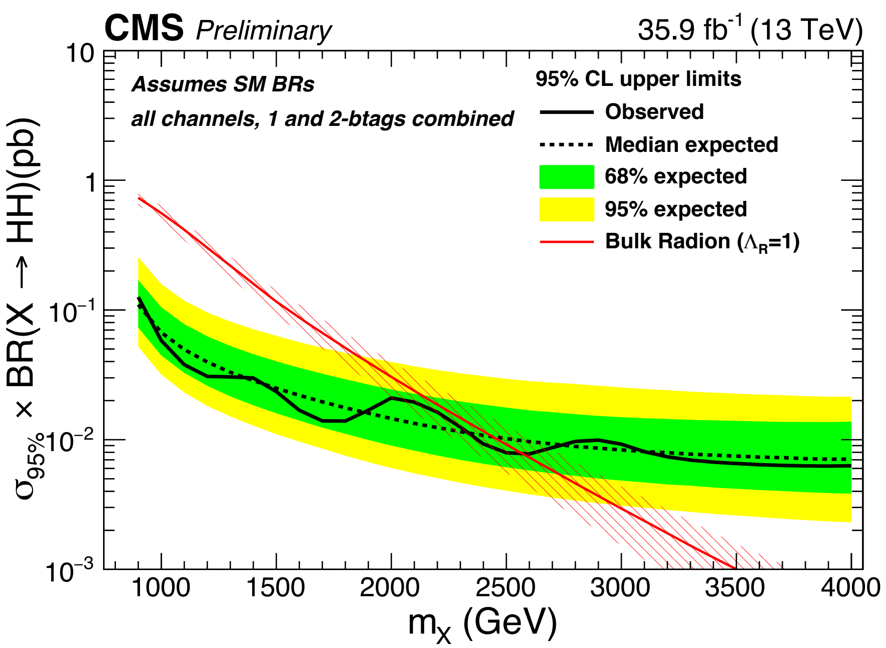


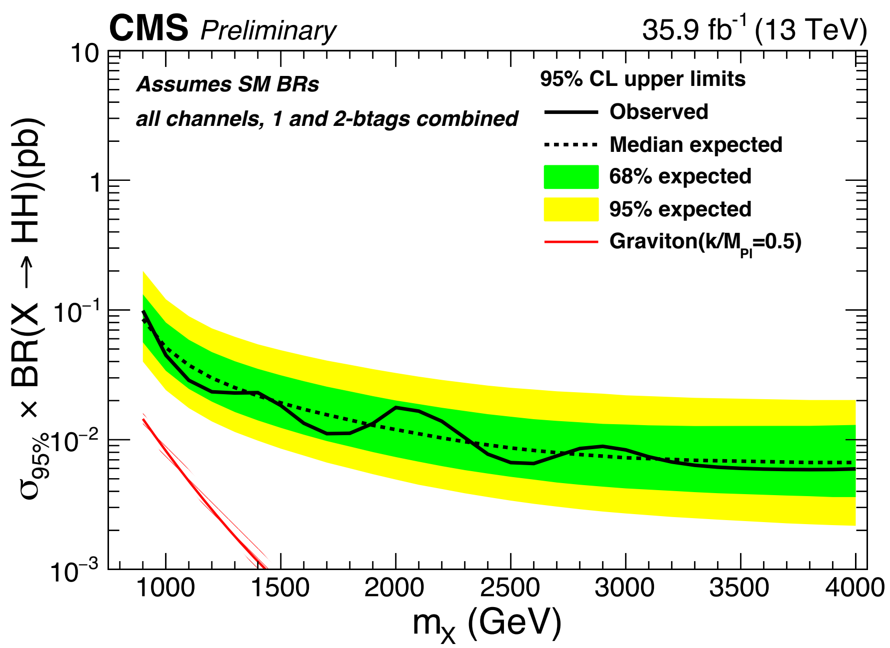
B2G-17-006


X → HH → bb̄ττ
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
2τ, 2 b-tag, H mass region
Data
V+jets
tt̄, t+X
Fit unc.
Pre-fit
m_h=2000 GeV
Bulk Radion (Λ_R=1)
Events / (100 GeV)
χ^2/ndf = 1.3/4 p-value = 0.87
$(N^{data}-N^{bkg})/\sigma$
m_X (GeV)
X → HH → bb̄ττ
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
2τ, 1 b-tag, H mass region
Data
V+jets
tt̄, t+X
Fit unc.
Pre-fit
m_h=2000 GeV
Bulk Radion (Λ_R=1)
Events / (100 GeV)
χ^2/ndf = 5.8/11 p-value = 0.88
$(N^{data}-N^{bkg})/\sigma$
m_X (GeV)
X → VH → qq̄ττ
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
2τ, HP, W mass region
Data
V+jets
tt̄, t+X
Fit unc.
Pre-fit
$m_{V'}$=2000 GeV
HVT model B g_V=3
Events / (100 GeV)
χ^2/ndf = 7.6/10 p-value = 0.67
$(N^{data}-N^{bkg})/\sigma$
m_X (GeV)
X → VH → qq̄ττ
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
2τ, LP, W mass region
Data
V+jets
tt̄, t+X
Fit unc.
Pre-fit
$m_{V'}$=2000 GeV
HVT model B g_V=3
Events / (100 GeV)
χ^2/ndf = 1.9/7 p-value = 0.96
$(N^{data}-N^{bkg})/\sigma$
m_X (GeV)
X → VH → qq̄ττ
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
2τ, HP, Z mass region
Data
V+jets
tt̄, t+X
Fit unc.
Pre-fit
$m_{V'}$=2000 GeV
HVT model B g_V=3
Events / (100 GeV)
χ^2/ndf = 3.6/8 p-value = 0.89
$(N^{data}-N^{bkg})/\sigma$
m_X (GeV)
X → VH → qq̄ττ
35.9 fb^{-1} (13 TeV)
CMS
Preliminary
2τ, LP, Z mass region
Data
V+jets
tt̄, t+X
Fit unc.
Pre-fit
$m_{V'}$=2000 GeV
HVT model B g_V=3
Events / (100 GeV)
χ^2/ndf = 6.0/7 p-value = 0.54
$(N^{data}-N^{bkg})/\sigma$
m_X (GeV)

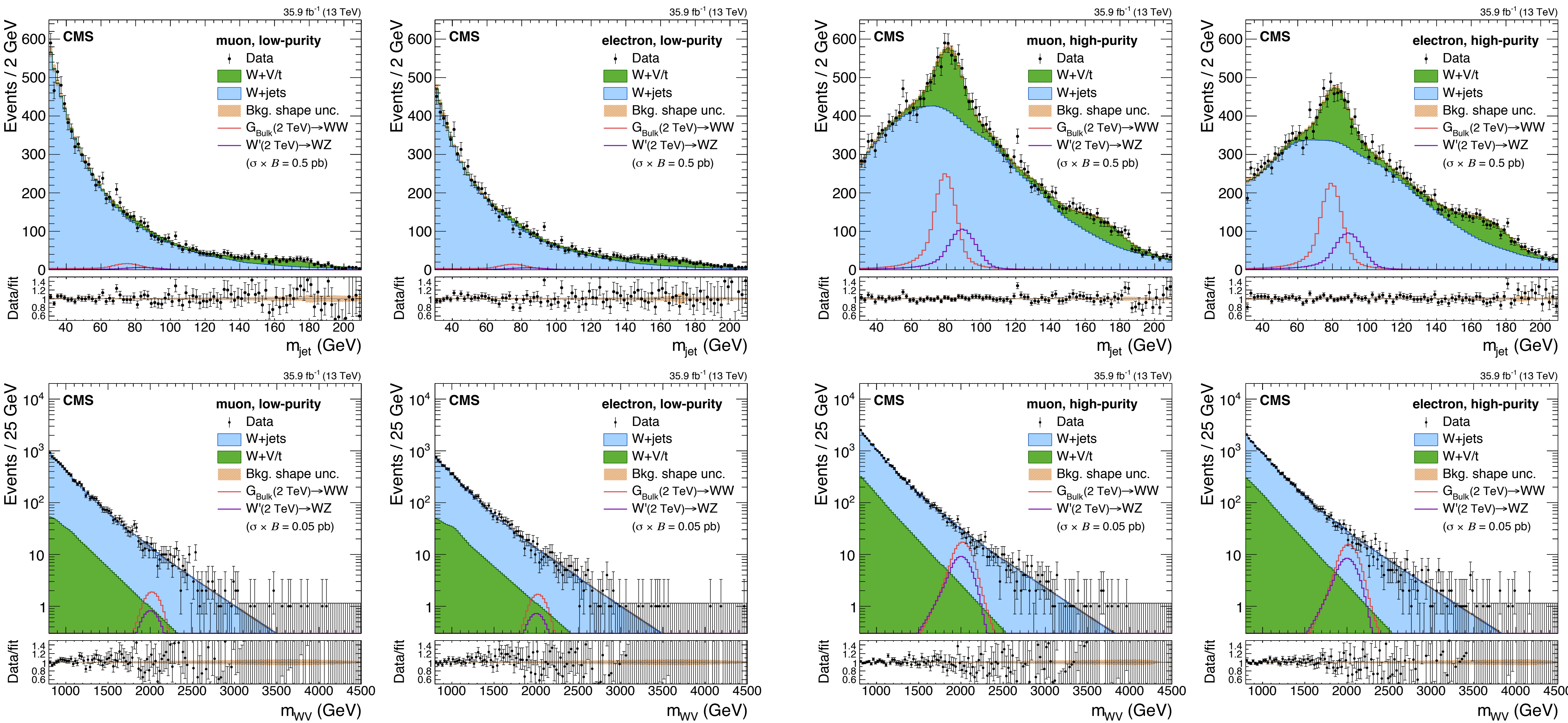
B2G-17-006

	shape	V+jets	$t\bar{t}$, t+X	Signal
α-function	✓	✓	-	-
Bkg. normalization		11–60%	2–38%	-
Top scale factors		-	5–14%	-
jet energy scale	✓	-	-	✓
jet energy resolution	✓	-	-	✓
jet mass scale		-	-	1%
jet mass resolution		-	-	8%
V tagging		-	-	6%(HP)–11%(LP)
V tagging extr.		-	-	8%–18%(HP), 2%–8%(LP)
b-tagging		-	-	3–7% (1b), 3.7–5.4% (2b)
b-tagged jet veto		-	3%	1%
trigger		-	-	2%
leptons Id, Iso		-	-	2%
τ Id		-	-	6–8% ($\ell\tau_h$), 10–13% ($\tau_h\tau_h$)
τ Id pt extr.	✓	-	-	0.5–18% ($\ell\tau_h$), 0.2–30% ($\tau_h\tau_h$)
τ energy scale	✓	-	-	1% ($\ell\tau_h$), $5-3\%$ (τ_h)
pile-up		-	-	0.5%
QCD scales†		-	-	2.5%–12.5%, 10%–19%
PDF scale†		-	-	6%–37% ,10%–64%
PDF acceptance		-	-	0.5%–2%
luminosity		-	-	2.6%

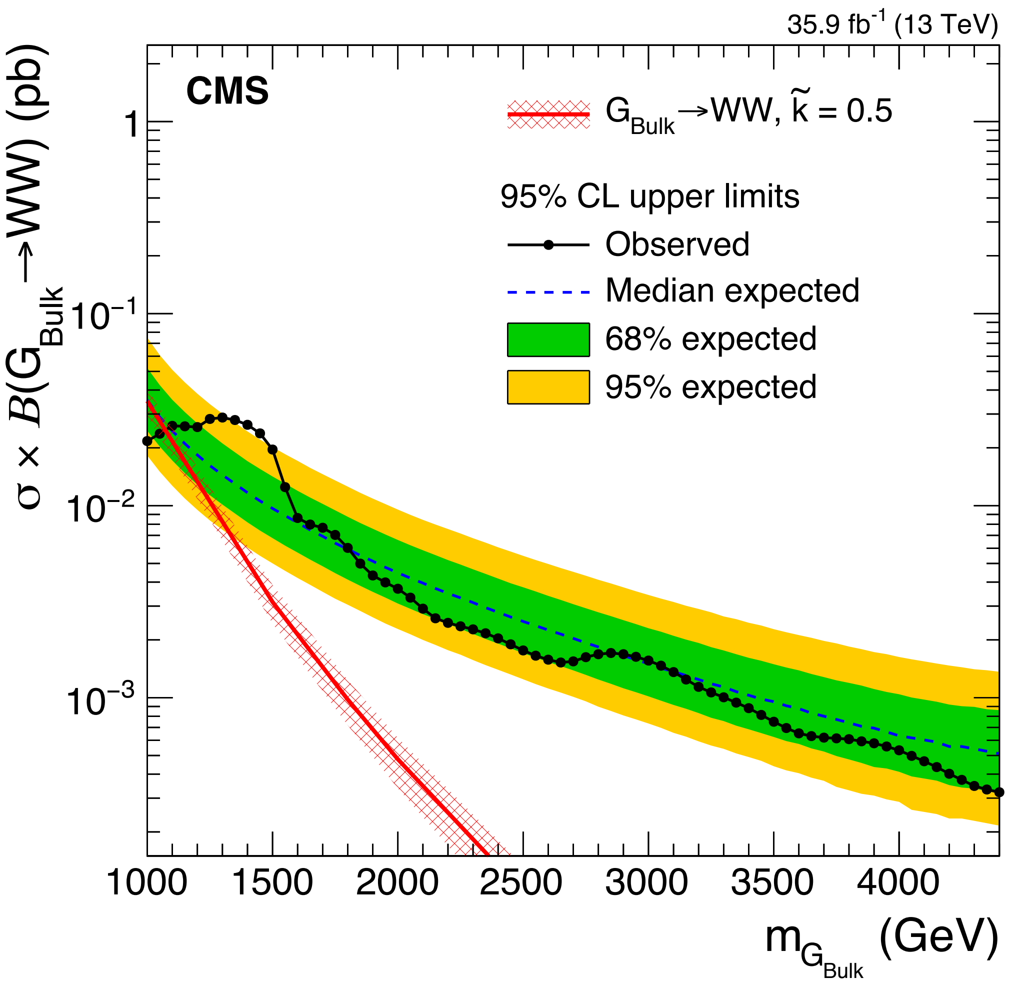


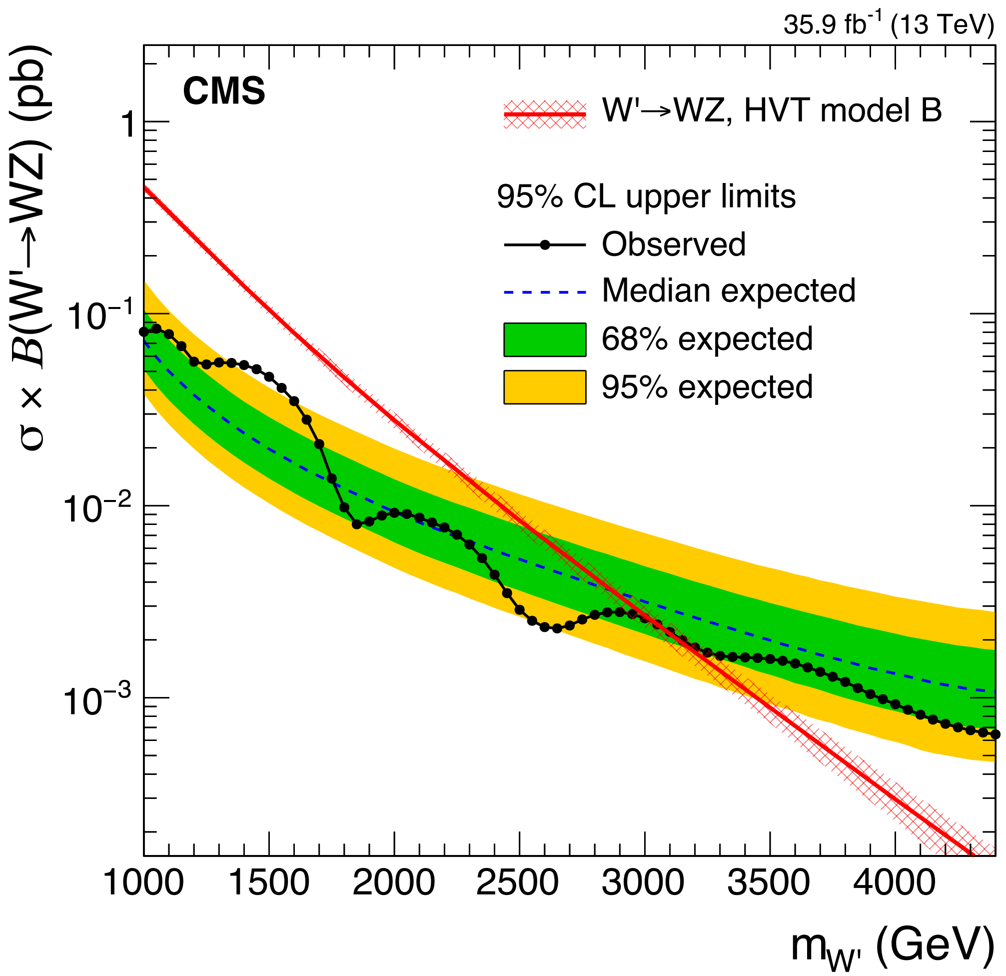


B2G-16-29


35.9 fb^{-1} (13 TeV)
CMS
muon, low-purity
electron, low-purity
muon, high-purity
electron, high-purity
Data
W+V/t
W+jets
Bkg. shape unc.
G_{Bulk}(2 TeV)→WW
W'(2 TeV)→WZ
(σ × B = 0.5 pb)
(σ × B = 0.05 pb)
Events / 2 GeV
Events / 25 GeV
Data/fit
m_{jet} (GeV)
m_{WV} (GeV)

B2G-16-029


35.9 fb-1 (13 TeV)
CMS
GBulk→WW, k̃ = 0.5
95% CL upper limits
Observed
Median expected
68% expected
95% expected
σ × B(GBulk→WW) (pb)
mGBulk (GeV)


35.9 fb-1 (13 TeV)
CMS
W'→WZ, HVT model B
95% CL upper limits
Observed
Median expected
68% expected
95% expected
σ × B(W'→WZ) (pb)
mW' (GeV)