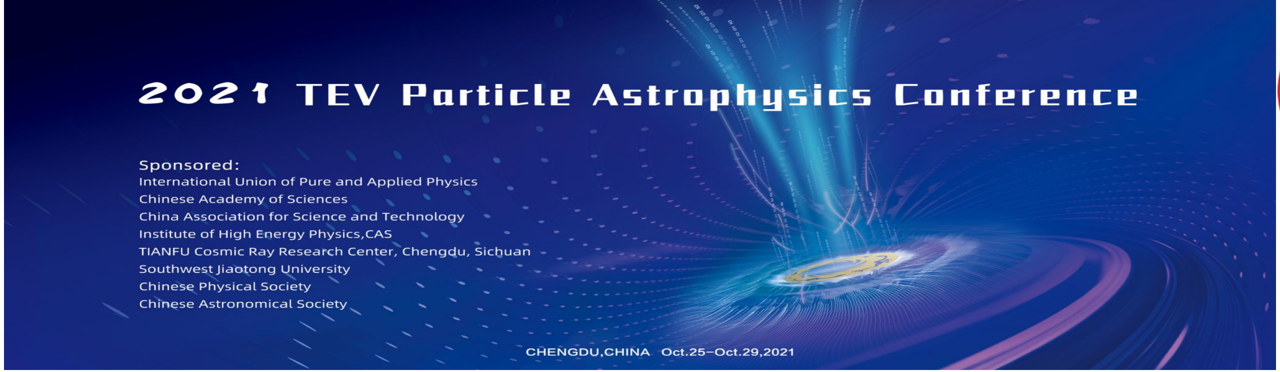


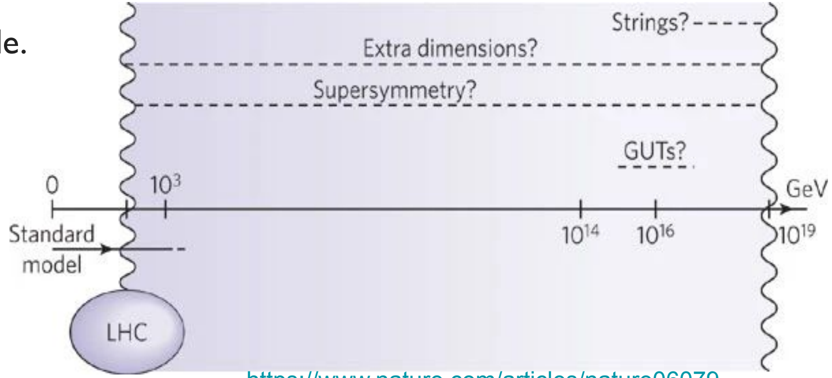
Searches for heavy resonances at CMS

JeongEun Lee
On behalf of the CMS Collaboration
SNU, Korea

24-29 October 2021
2021 TEV Particle Astrophysics Conference

Beyond the Standard Model with the LHC

- The standard model (SM) has been well tested up to ~100 GeV scale.
- But still, it is clear that the SM is not the final theory.
- There are many open questions:
  - Is the mass of Higgs natural or fine-tuned?
    If natural, what new physics (symmetry) governs this?
  - Why is there a hierarchy between weak scale vs. Planck scale?
  - How does gravity play with the other forces?
  - Are there more space dimensions than the familiar three?
  - Do all forces unify at high energy? Dark matter… etc



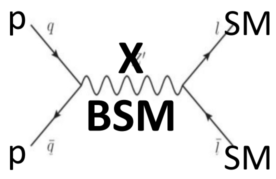
https://www.nature.com/articles/nature06079

- Many compelling theoretical ideas of BSM have been proposed to address them. Interestingly, these new theories have in common that they introduce new heavy resonances.
- The LHC is best positioned to test TeV energy scale, where potential hints of new physics may exist.

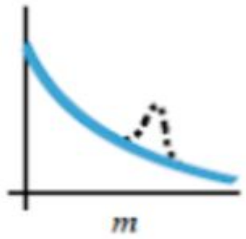
Extended Gauge Sector (New heavy Boson)	New heavy Fermions (Vector-Like-Quark)	Compositeness (Excited Fermion)
SSM, composite Higgs, Technicolor (W', Z') Kaluza-Klein excited SM (W_{KK}, G_{KK}) in Warped Extra dimension model Grand Unification Theory (leptoquark)	Vector-Like-Quark : Chiral structure important Mass dependent EWSB	Excited Fermion : New forces or New SM partners integrate out at low energies

Direct Search Strategy at the LHC

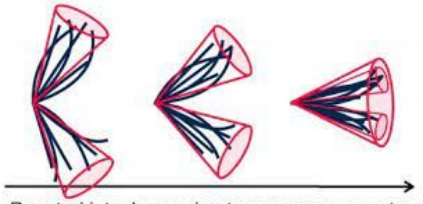
- Target BSM signatures :
  - New resonance will emerge at high mass spectra with various final states !
  - Single final state often can probes many BSM scenario, so analyses are mainly "**signature based**" :
    - Resonance search : dileptons, dijet, diboson (+lepton flavor violated, trijet, triboson .. etc)
  - Also, **Model-independent** result can be obtained and used to reinterpreted other various model



- Background Estimates :
  - SM Backgrounds are evaluated with **Simulation**
  - Define **Control Region (CR)** in the data to evaluate a given SM background in most searches.
  - **Validation Regions (VR)** is used to cross-check a background method.



- Advanced algorithm :
  - Exploiting the latest **jet substructure** and novel **Machine-learning algorithms**
  - Heavy resonances can produce **highly Lorentz boosted decay products** (W/Z/H-tagged jet, t/b/q-tagged jet), Deep Learning Based algorithm at CMS:
    DEEPJET, DEEPAK8, CNN (ImageTop) etc ..



JINST15(2020)P12012
JINST15(2020)P06005
PR(2020)841

Outline : Recent heavy resonances searches from CMS

(1) Recent results for **dilepton resonances**

$qq \to X^0 \to e^+e^-, \mu^+\mu^-$ JHEP07(2021)208 (EXO-19-019)

$qq \to X^{+-} \to e\nu, \mu\nu$ PAS EXO-19-017

$qq \to X^0 \to e^+\mu^-, e\tau, \mu\tau$ PAS EXO-19-014

(2) Recent results for **dijet (trijet) resonances**

$qq \to X^{0/+-} \to$ qq, qg, gg JHEP05(2020)033 (EXO-19-012)

$qq \to X^{0/+-} \to$ bb PAS EXO-20-008

$qq \to X^{+-} \to$ tb $\to$ Jb PLB820(2021)136535 (B2G-20-005)

$qq \to X_1^0 \to X_2^0$ g $\to$ ggg PAS EXO-20-007

New boson

SM particles

(3) Recent results for **diboson (triboson) resonances** *

$qq \to X^{+-} \to W\gamma \to jj\gamma$ arXiv:2106.10509 (EXO-20-001)

$qq \to X_1^0 \to X_2^0 W \to WWW \to jjjjjj$ PAS B2G-21-002

complete Run2 dataset (2016-2018, L = 137 fb^{-1})

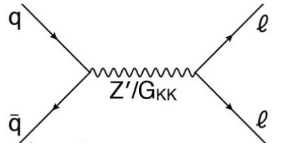
Small selection of **CMS heavy resonant searches** with **full Run-2 datasets** will be covered in this talk.

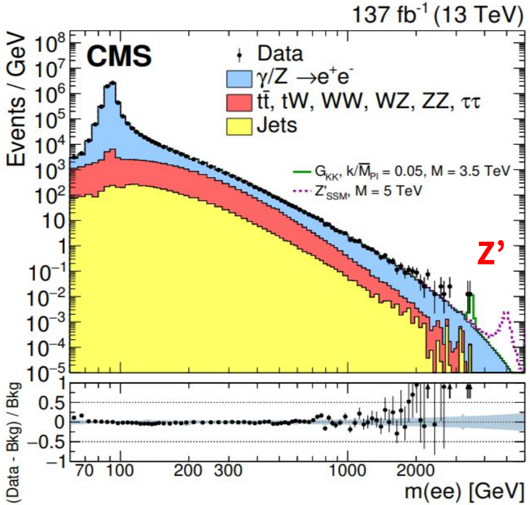
*dihiggs resonances, they may be covered in Sotiroulla and Vukasin's talk.

Dilepton Resonances

Dilepton Resonances (Z',W')

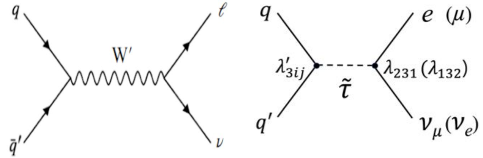
$qq \rightarrow X^0 \rightarrow e^+e^-, \mu^+\mu^-$

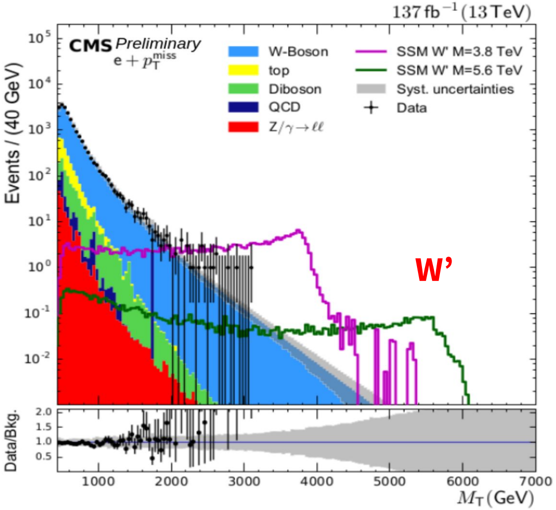




JHEP07(2021)208

$qq \rightarrow X^{+-} \rightarrow e\nu, \mu\nu$





PAS EXO-19-017

$$M_T = \sqrt{2p_T^{\ell}\ p_T^{\text{miss}}(1-\cos[\Delta\phi(\ell,\vec{p}_T^{\,\text{miss}})])}$$

Probing new gauge boson masses up to about 7 TeV

$qq \rightarrow Z'/G_{KK} \rightarrow e^+e^-, \mu^+\mu^-$

- Search for bump in high invariant mass spectrum.
- **X^0** : Z' in SSM/GUT and G_{KK} in RS model of WED
- SM background DY(main), Jets (data-driven)
  - j misidentified as l estimated from data.
  - Combined background shape normalized to data around m_Z
- Highest m_{inv} observed in Run2: 3.47(e), 3.34(μ)TeV

$qq \rightarrow W'/W_{KK}/\text{RPV stau} \rightarrow e\nu, \mu\nu$

- Search for signal in high transverse mass spectrum.
- **X^{+-}**: W'/W_{KK} in SSM/ED and RPV SUSY stau
- ν can be determined $p_T^{miss} = -\Sigma p_T$ in an event
- Kinematic Selection:
  - $\Delta\phi(\ell, p_T^{miss}) > 2.5$ (back-to-back decay)
  - $0.4 < p_T^{\ell}/p_T^{miss} < 1.5$ (energy balanced)
- Highest M_T observed in Run2: 3.1(e), 2.9(μ)TeV

Dilepton Resonances (Z')

$qq \rightarrow Z'/G_{KK} \rightarrow e^+e^-, \mu^+\mu^-$

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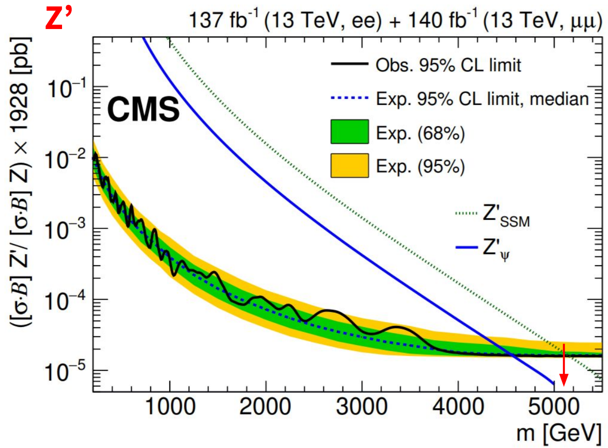
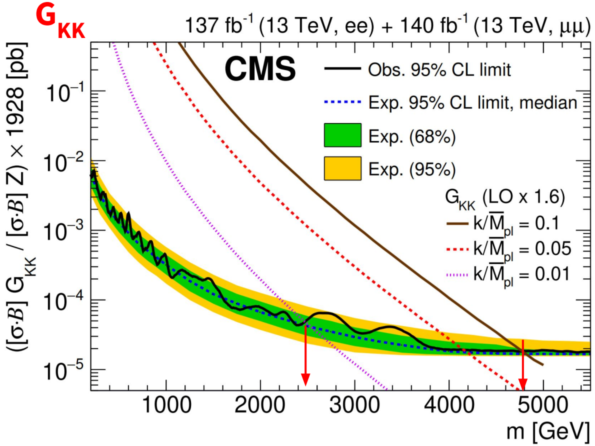
$$R_\sigma = \frac{\sigma(\mathrm{pp} \rightarrow \mathrm{Z}' + X \rightarrow \ell\ell + X)}{\sigma(\mathrm{pp} \rightarrow \mathrm{Z} + X \rightarrow \ell\ell + X)}$$

Upper limits are set on the ratio of the σB of a new narrow dilepton resonance to that of the SM Z in data region [60-120] GeV





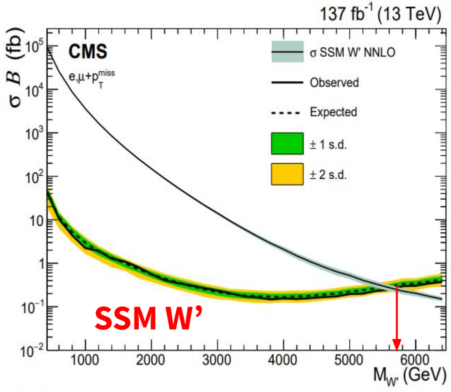
m(Z')<5.15 TeV excluded at 95%CL for e, μ comb. channel with an intrinsic width of 0.6%

$m(G_{KK})$< 2.47~4.78 TeV excluded at k/M_{Pl}=0.01~0.1

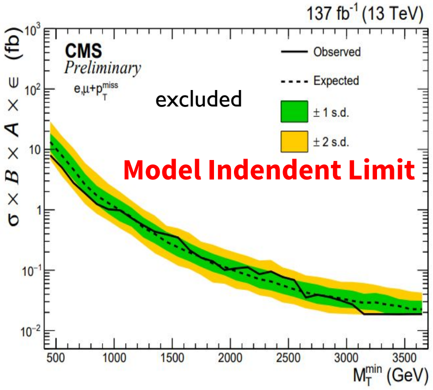
Dilepton Resonances (W')

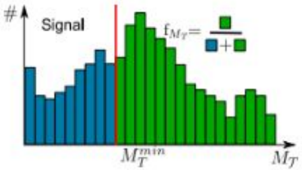
qq→W'/W_{KK}/RPV stau→ $e\nu, \mu\nu$

PAS EXO-19-017



m(W')<5.7 TeV excluded for e, μ comb.





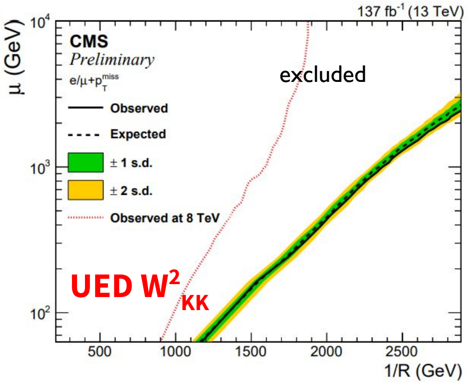
single bin (M_T^{min} ~∞) approach used.

Model-Independent limit = $(\sigma BA\varepsilon)_{excl}$ ~0.02-10 fb for M_T^{min} =0.5~3.6TeV

This MI Limit can be used to test BSM with same final states!

$$\boxed{[\sigma\mathcal{B}\mathcal{A}\epsilon]_{\mathrm{excl}}(M_{\mathrm{T}}^{\mathrm{min}}) = \frac{[\sigma\mathcal{B}\mathcal{A}\epsilon]_{\mathrm{MI}}(M_{\mathrm{T}}^{\mathrm{min}})}{f_{M_{\mathrm{T}}}(M_{\mathrm{T}}^{\mathrm{min}})}}$$

if $[\sigma BA\varepsilon]_{excl} < [\sigma BA\varepsilon]_{theory=RPV}$ ⇒ theory exclude!



W^2_{KK} has W'-like kinematics and decay

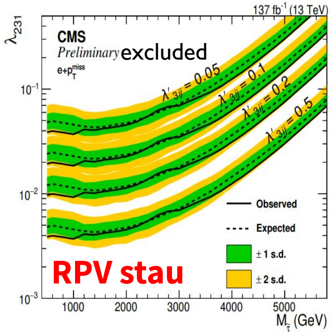
Bounds in plane of 2 parameters :

R : Radius of extra dimension (M∝1/R)

μ : a bulk mass parameter (0.05-10 TeV)

$$M(W_{KK}^{(n)}) = \sqrt{M_W^2 + (n/R)^2}$$

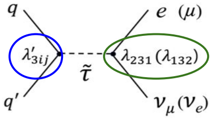
1/R<2.8 TeV excluded at μ=2 TeV



MI is applied to RPV SUSY model

Bounds in $\mathbf{m_{stau}}$-**λ** parameters

- production: λ'_{3ij} ,
- e (μ)decay : $\lambda_{231}(\lambda_{132})$



$\lambda_{231}(\lambda_{132})$ > 0.004 (0.005) excluded at m_{stau}=1 TeV, λ'_{3ij}=0.5

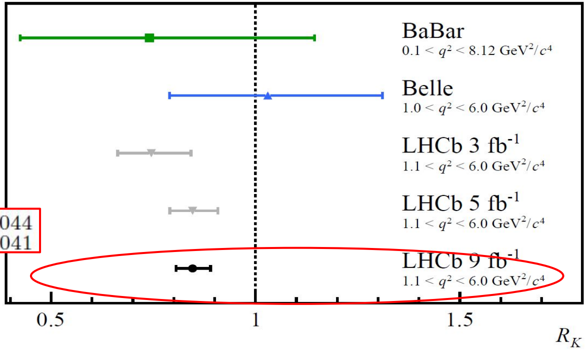
Lepton Flavor Violation Test at the TeV scale

New measurement from LHCb of R_K with full Run-1 and 2 data sets.

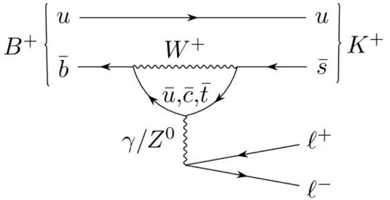
The most precise measurement to date! R_K = BF (B+ → K+ μ+ μ-) / BF (B+ → K+ e+ e-)

3.1σ away from the SM expectation! "Evidence for LF Violation in b decays"

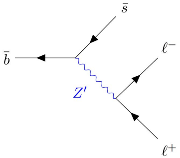
→ Strong hints for BSM physics

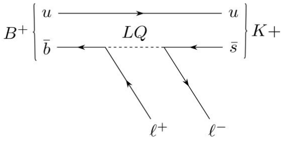


SM contribution



BSM contributions could explain these effects !

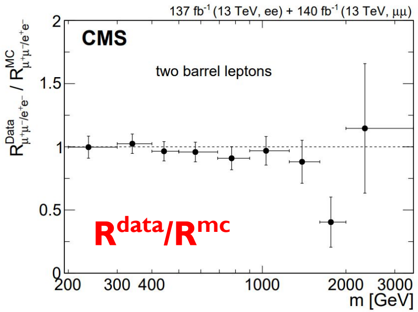




LHCb 2021.03 result(9 fb^{-1}) :

CMS Submitted to Nature, arXiv:2103.11769

qq→Z'→ $e^+e^-, \mu^+\mu^-$ (LFV)



JHEP07(2021)208

Search for signs of the LUV at TeV-scale by comparing the m(ee) vs. m(μμ) spectra.

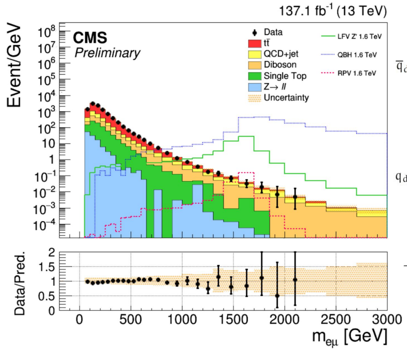
$$R_{\mu^+\mu^-/e^+e^-} = \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)/dm_{\ell\ell}}{d\sigma(q\bar{q} \to e^+e^-)/dm_{\ell\ell}}$$

If R is not unity, LFU is violated.

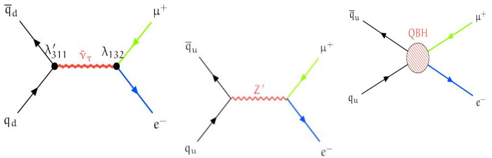
This is the first result to test LFV at TeV scale using LHC data in dilepton decays.

Good Agreement up to $m_{\ell\ell}$ = 1.5 TeV.

qq→RPV $\tilde{\nu}_\tau$ /Z'/QBH→$e\mu$, $e\tau$, $\mu\tau$ (LFV)



PAS EXO-19-014

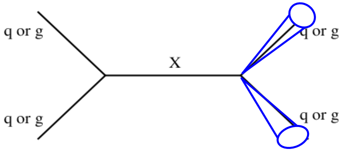


Channel	RPV (TeV) $\lambda = \lambda' = 0.01$	RPV (TeV) $\lambda = \lambda' = 0.1$	Z' (TeV)	QBH (TeV)
$e\mu$	2.2 (2.2)	4.2 (4.2)	5.0 (4.9)	5.6 (5.6)
$e\tau$	1.6 (1.6)	3.7 (3.7)	4.3 (4.3)	5.2 (5.2)
$\mu\tau$	1.6 (1.6)	3.6 (3.7)	4.1 (4.2)	5.0 (5.0)

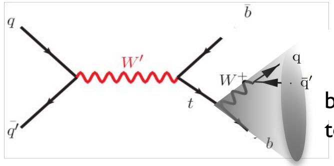
Dijet (trijet) Resonances

Dijet Resonances

qq→X(V'/G_{KK}/q*/C ...)→ qq, qg, gg

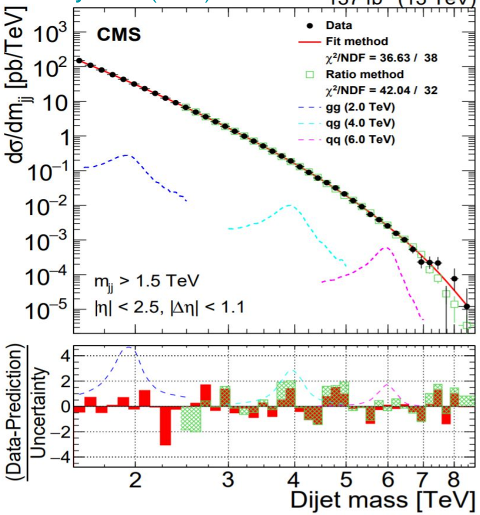


3rd generation:qq→W'→ tb→ Jb



boosted top-jet

JHEP05(2020)033



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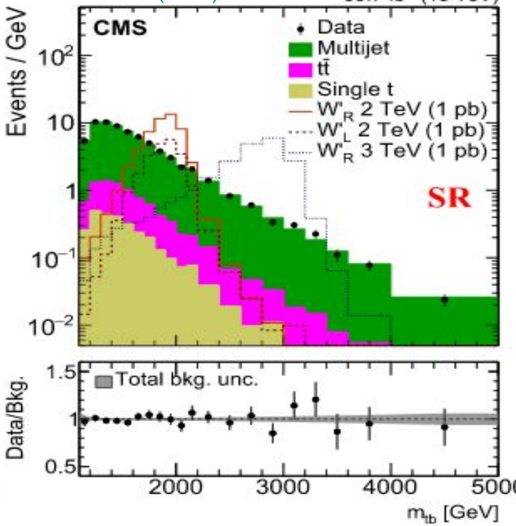
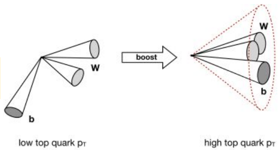


qq→X→ qq, qg, gg

- Various BSMs predict dijet resonance in TeV scale.
- Dijet ($|\eta|$ < 2.5) with highest p_T used. (2 wide-jets ΔR<1.1)
- No significant SM Background.
- Steeply falling dijet mass spectrum from QCD.
- Dijet angular cut : SR (m_{jj} > 1.5 TeV)
  - $|\Delta\eta|$ < 1.1 to reject large QCD rate (t-channel)
- QCD in SR estimated with 2 methods :
  - background-fit method (m_{jj} > 1.5 TeV)
  - Ratio method (m_{jj} > 2.4 TeV) reduced syst. unc

qq→W'→ tb→ Jb



- $W'_{R/L}$ in Left-Right model, W'_L interfere with SM
- Search for W' decays into a Lorentz-boosted top and b
- Use large area R jets and exploits jet substructure
- b-tag for AK4 j: DEEPJET tagger algorithm
- t-tag for AK8 j: m_{SD}, m decorr. DEEPAK8 tagger (t vs. QCD)

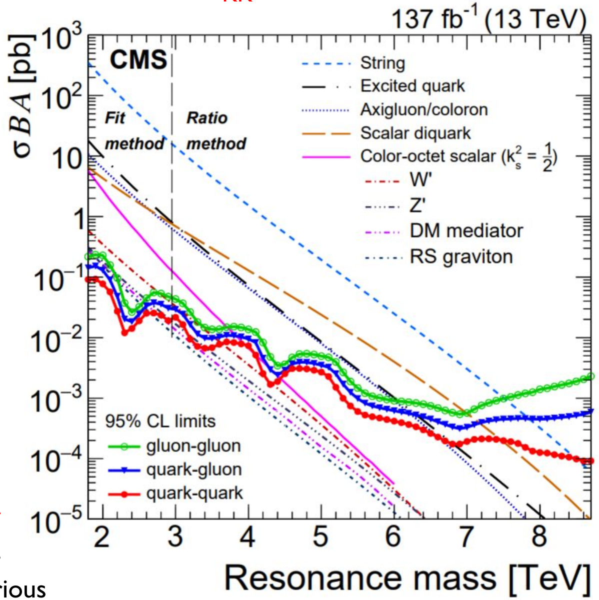
3rd generation: qq→Z'→ b$\bar{b}$, bg→b*→ bg , qq→$\bar{b}$*b→ $\bar{b}$gb

PAS EXO-20-008

Dijet Resonances (X⟶ qq,qg,gg, Z'/b*⟶bb,bg)

JHEP05(2020)033

qq⟶X(V'/G_{KK}/q*/C ...)⟶ qq, qg, gg

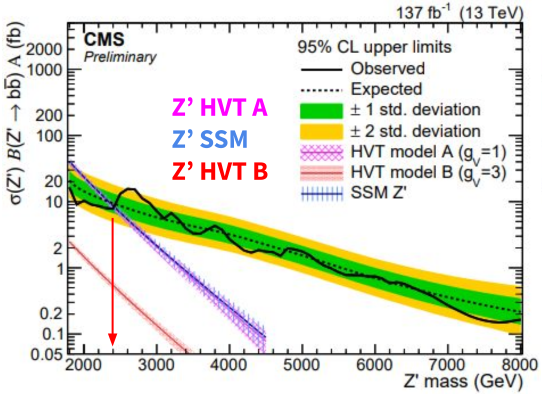


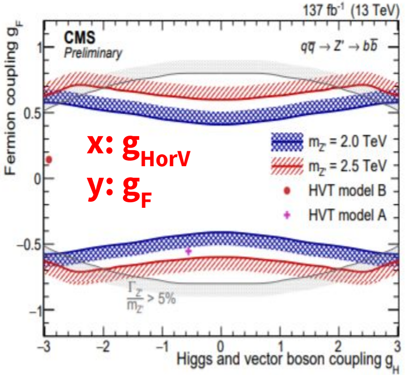
95% CL limits for gg qg qq channels are applied to various models of new resonances.

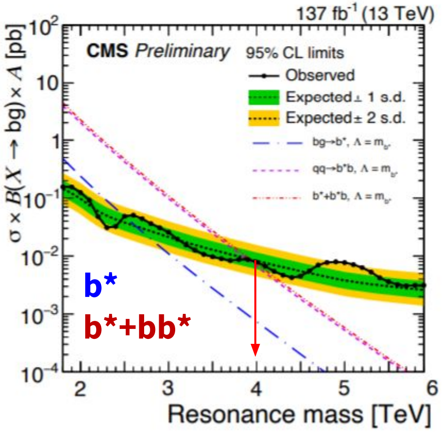
Model	Final state	obs(exp)TeV
String	qg	7.9 (8.1)
Scalar diquark	qq	7.5 (7.9)
Axigluon/coloron	$q\bar{q}$	6.6 (6.4)
Excited quark	qg	6.3 (6.2)
Color-octet scalar ($k_s^2 = 1/2$)	gg	3.7 (3.9)
W' SM-like	$q\bar{q}$	3.6 (3.9)
Z' SM-like	$q\bar{q}$	2.9 (3.4)
RS graviton ($k/\overline{M}_{Pl} = 0.1$)	$q\bar{q}$, gg	2.6 (2.6)
DM mediator ($m_{DM} = 1$ GeV)	$q\bar{q}$	2.8 (3.2)

qq⟶Z'⟶ bb, bg⟶b*⟶ bg, qq⟶b*b⟶ bgb

PAS EXO-20-008







Heavy Vector Triplet Model Z'

HVT A (SSM-like) g_V=1

HVT B (Compositeness) g_V=3

m($Z'_{A=SSM}$)< 2.4 TeV excluded and get constraint in g_H-g_F HVT coupling

Compositeness b*

m(b*)<4.0 TeV excluded using combined channel (single b* + bb* signals(x10))

Dijet Resonances($W'_{LR}\rightarrow tb$)

$qq\rightarrow W'\rightarrow \underline{t}b\rightarrow Jb$

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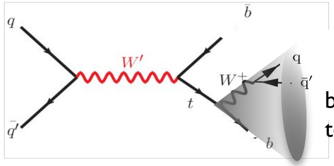
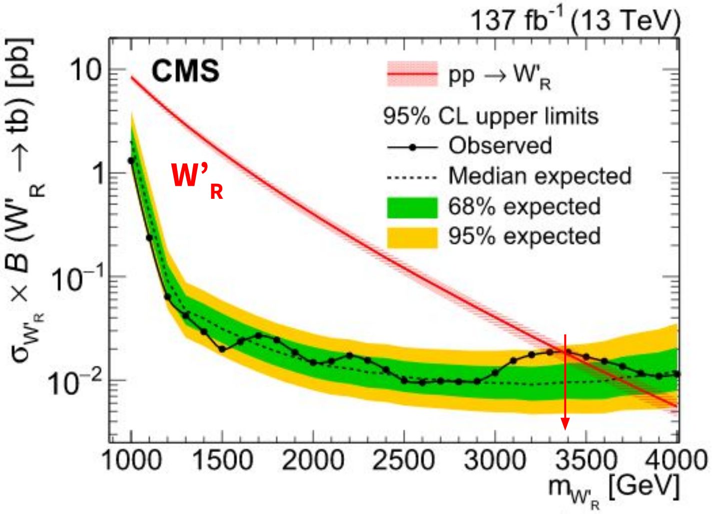
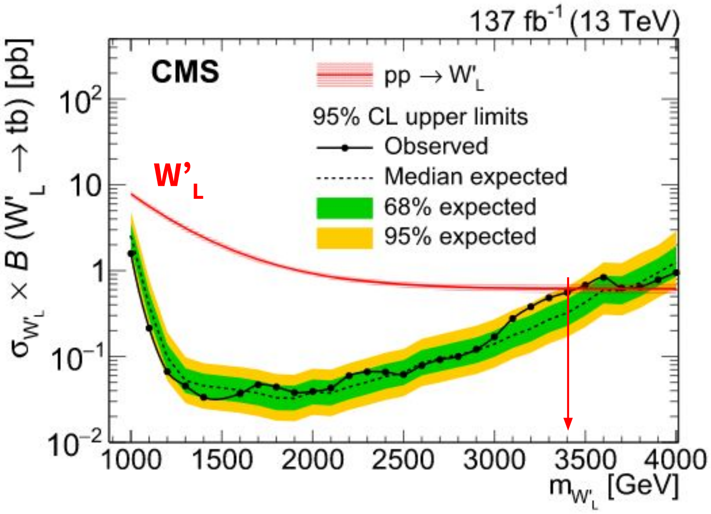


boosted
top-jet



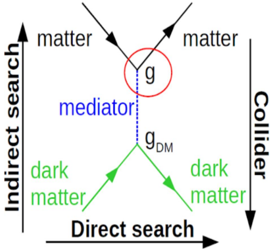


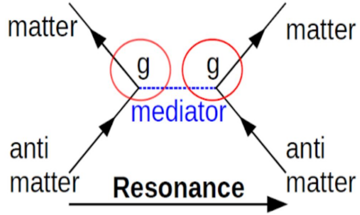
$m(W'_{RL})<3.4$ TeV excluded at 95% CL

Theoretical **σ** for W'_L saturates at high m because of the interference with SM (single top production)

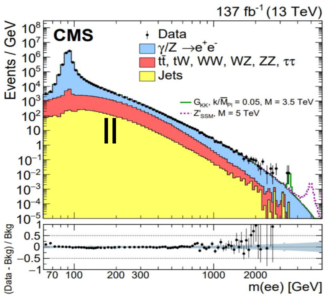
Interplay between DM Mediator - di-fermion Search

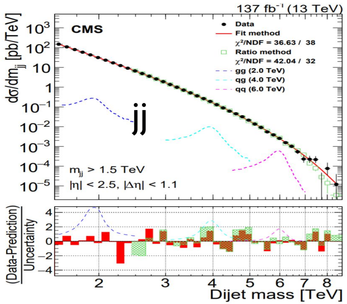
If DM was produced by matter annihilation (s-channel) in collider, the Mediator can be observed also in the decay to matter particles (di-fermion searches) ⇒





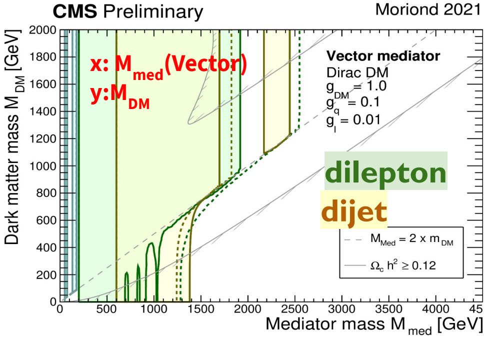
Interplay between DM - di fermion Resonances

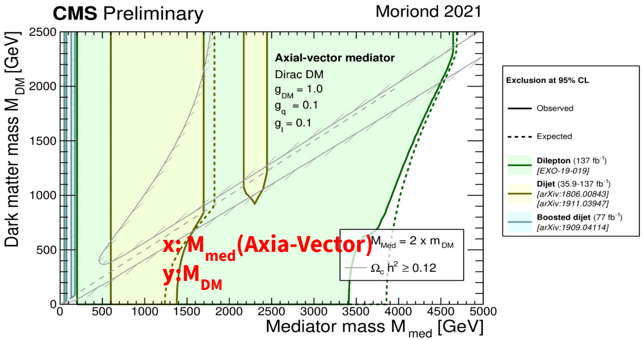


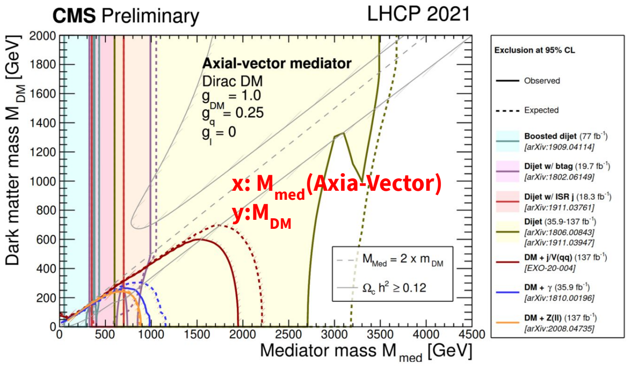


Difermion Searches provide Strong constraints for dark matter mass : $M_{DM} > M_{med}/2$

TeV-range constraints (M_{med}-M_{DM}) from mediator searches







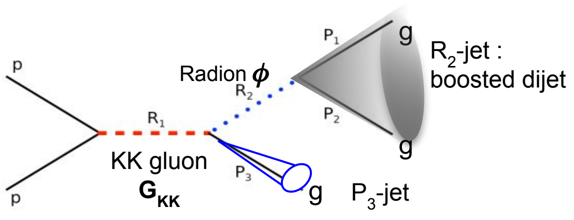
Vector M_{med} < 1.92 TeV (g_{med-l}= 0.01)

Axial-Vector M_{med} < 4.64 TeV (g_{med-l}= 0.1)

(dijet) benchmark coupling g_{med-l}= 0, g_{med-q}= 0.25

Trijet Resonances

$qq \rightarrow G_{KK} \rightarrow \phi\ g \rightarrow ggg$

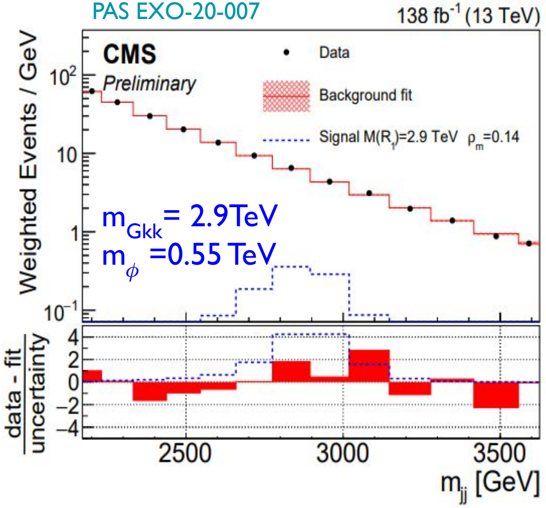


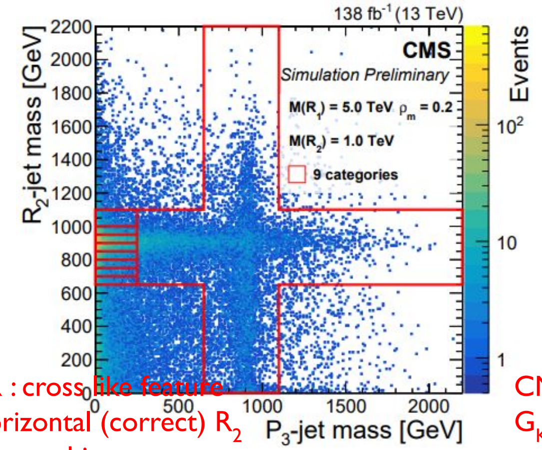
$\rho_m = M_{R_2}/M_{R_1} < 0.2$ (m_G>2TeV)

- It is crucial to extend searches in unexplored final state the 'Cascade resonance decay'
- This is the first LHC search for a trijet resonance with a boosted dijet

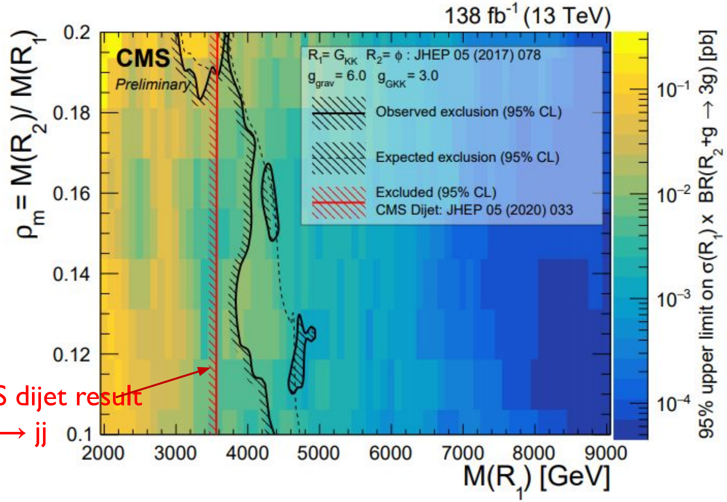
- $R_1(G_{KK})$ decays into 3 gluon jets via a R_2(scalar ϕ), Only consider $M(R_1) >> M(R_2)$
- Kinematic of trijet decays only depends on the resonance masses: R_1=2-9TeV, R_2=0.4~1.4TeV
- The boosted R_2-jets = single jet containing jet substructure with 2 prong jets
- Empirical 3-parameter fit to data in up to various CRs.
- R_2 jet substructure significantly improves sensitivity(~0.5TeV) compared to dijet result. The largest local significance ~3.2σ

PAS EXO-20-007





SR : cross like feature horizontal (correct) R_2 jet matching



CMS dijet result
$G_{KK} \rightarrow jj$

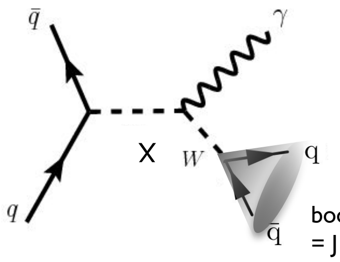
Diboson (triboson) Resonances

Wγ Resonances (all hadronic)

qq→X→ Wγ→ jjγ

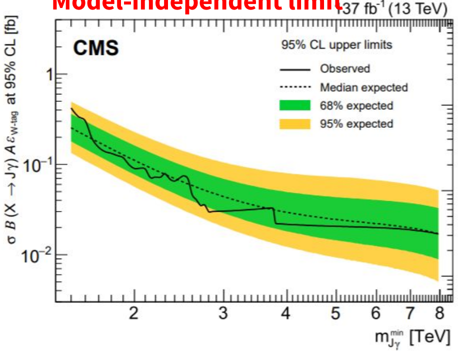
arXiv:2106.10509

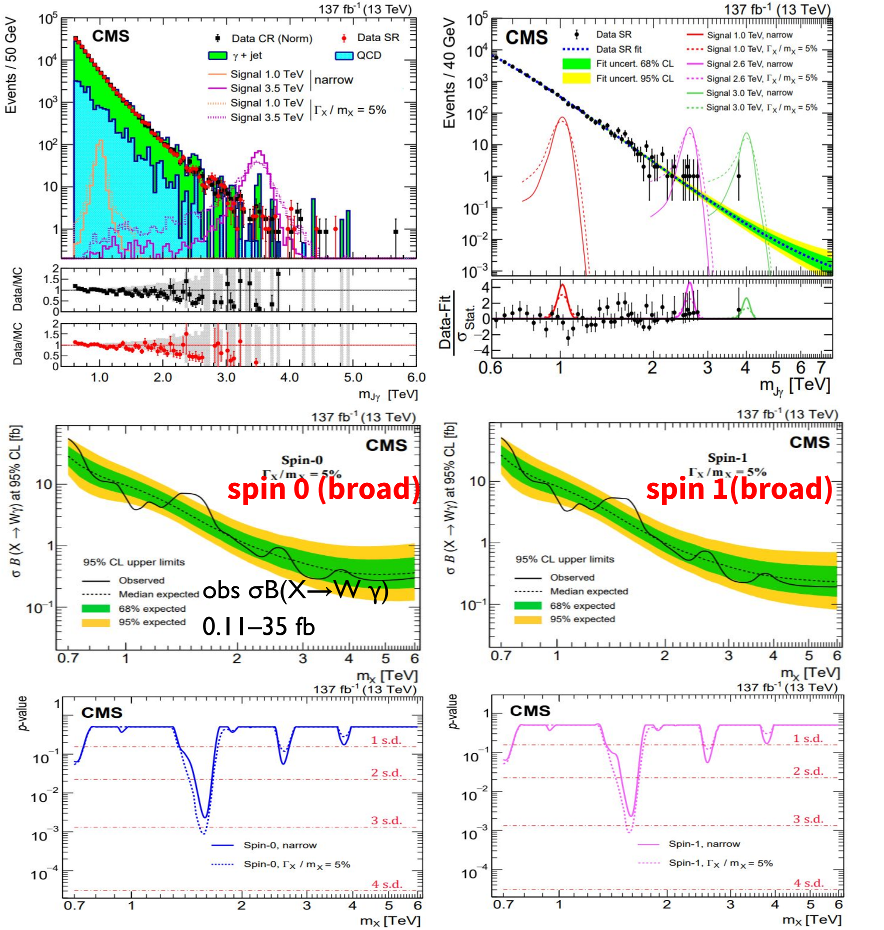
- Targeting heavy (0.7–6.0 GeV) resonances X
  - Spin 0 or 1; narrow or 5% broad resonances
- Lorenz-boosted W boson decaying hadronically reconstructed as a large-R jet (AK8) with 2-prong jet substructure
- $m_{J\gamma}$ distribution fitted by the parametric function
- Largest excess for spin 0 or 1 X resonances is 3.1(2.8)σ for broad (narrow) signals at 1.58 TeV
- The results reported are the most restrictive limits to date.
- Model-independent limits set on $\sigma B(X \rightarrow W\gamma)A\varepsilon$ for various $m^{min}_{J\gamma}$



boosted W-jet = J

Model-independent limit

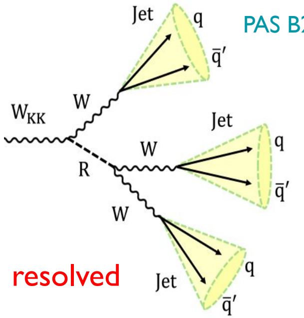




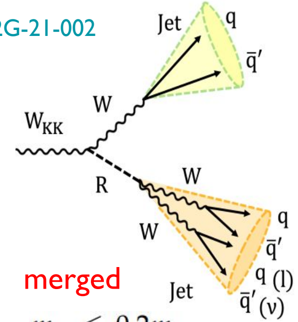
Triboson Resonance (all hadronic+semileptonic)

$qq \rightarrow W_{KK} \rightarrow WR \rightarrow WWW \rightarrow jjjjjj\ (jjJ)$

PAS B2G-21-002



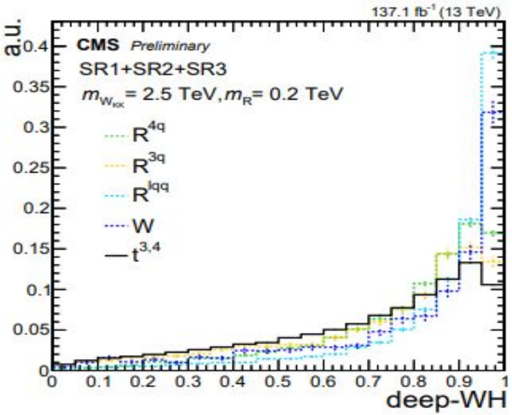
resolved

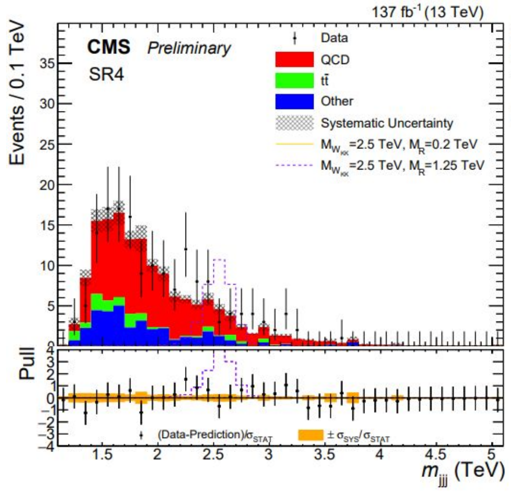


merged

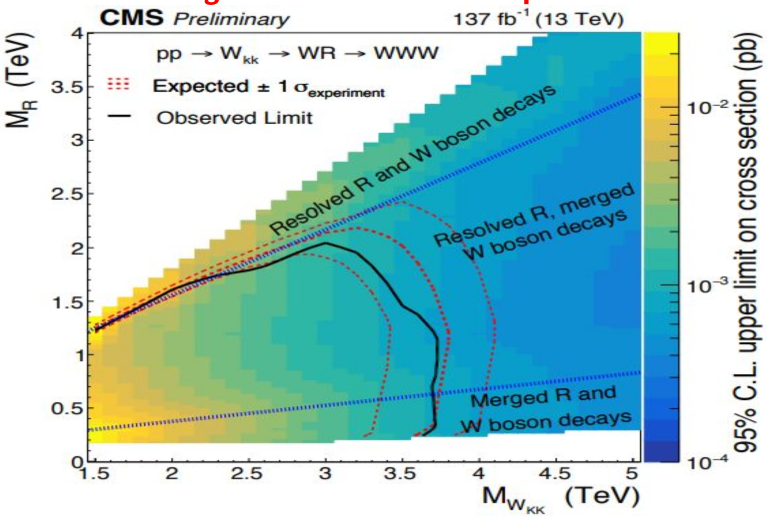
$m_R \leq 0.2 m_{W_{KK}}$

- Recently, triboson resonance in all hadronic channel is also updated at CMS
- Target events either two or three massive large-R AK8 jets and without any leptons
- 2 final states are simultaneously probed : R^{4q}, R^{3q} (1 quark leaks out of the cone), R^{lqq}
- Event categorization based on
  - number of merged jets, jet masses, and the NN tagger score (jet substructure)
- Two discriminators : SM W vs. q/g (deep-W), W and Higgs vs. q/g (deep-WH)
- Finally, the full hadronic analysis combined with the semileptonic analysis. PAS B2G-20-001
- $m(W_{KK})$ < 3.0 - 3.7 TeV excluded at m_R = 1.1 - 2 TeV (the most stringent limits to date)





Combining the all-hadronic semilepton searches



Summary and Outlook

- A wide variety of heavy resonance searches have been performed at CMS
  - Broad experimental signatures and theoretical models now considered.
- Still no evidence of new physics yet.
- The high energy/luminosity of LHC pushed the exclusion limits towards multi TeV scale.

All CMS Results (link1,link2)

- Upcoming Run-3, expect to include newer approaches to search for interesting BSM signatures
- In the future, more data (×20!) to be collected by the end of the HL-LHC.

→ So, this is just the beginning, STAY TUNED for new results !!

Thank you very much.

Backup

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Other

CI

Dark Matter

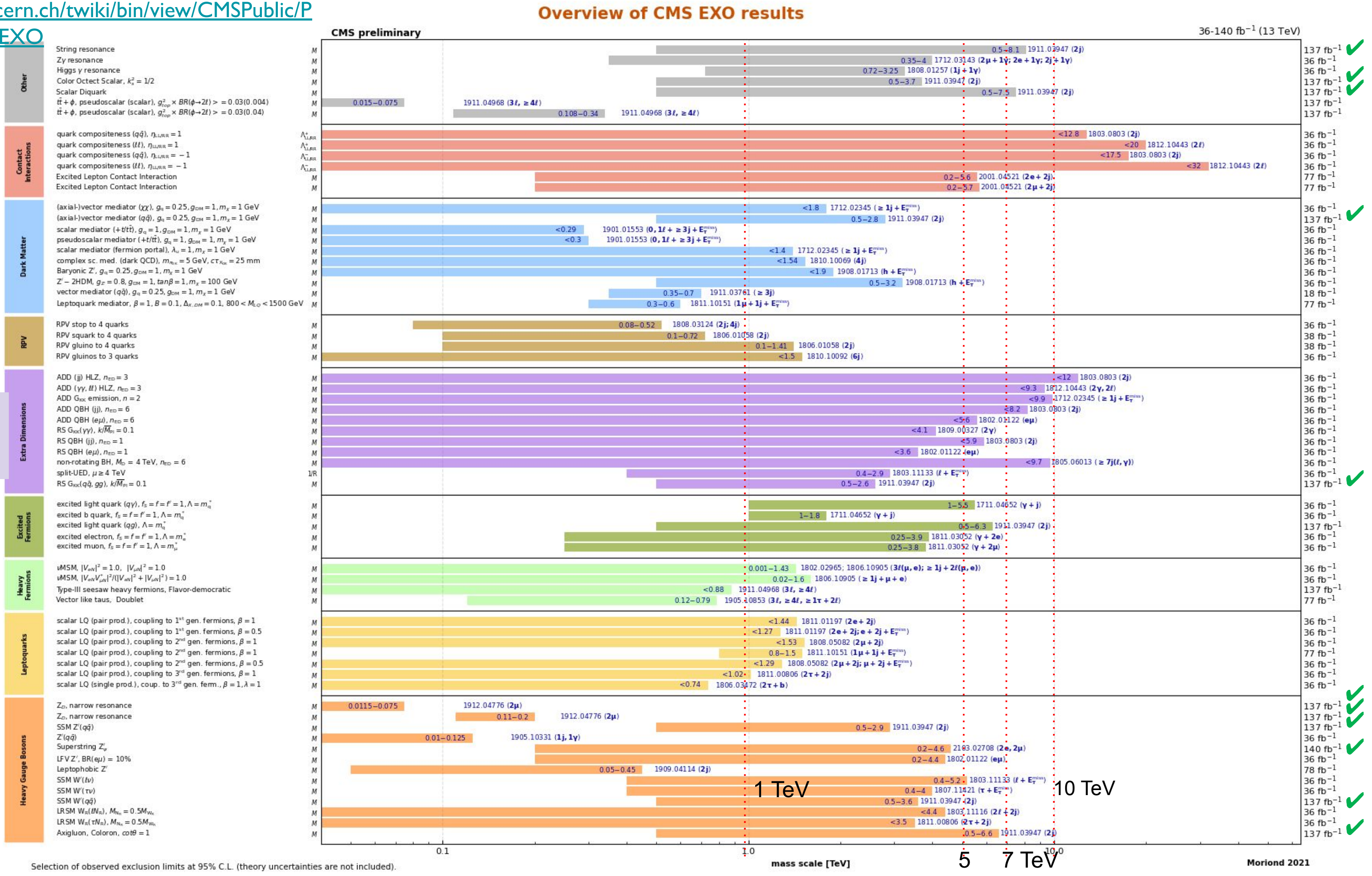
RPV

Extra Dimension

Excited/ Heavy Fermion

Lepto quark

Heavy Gauge Bosons

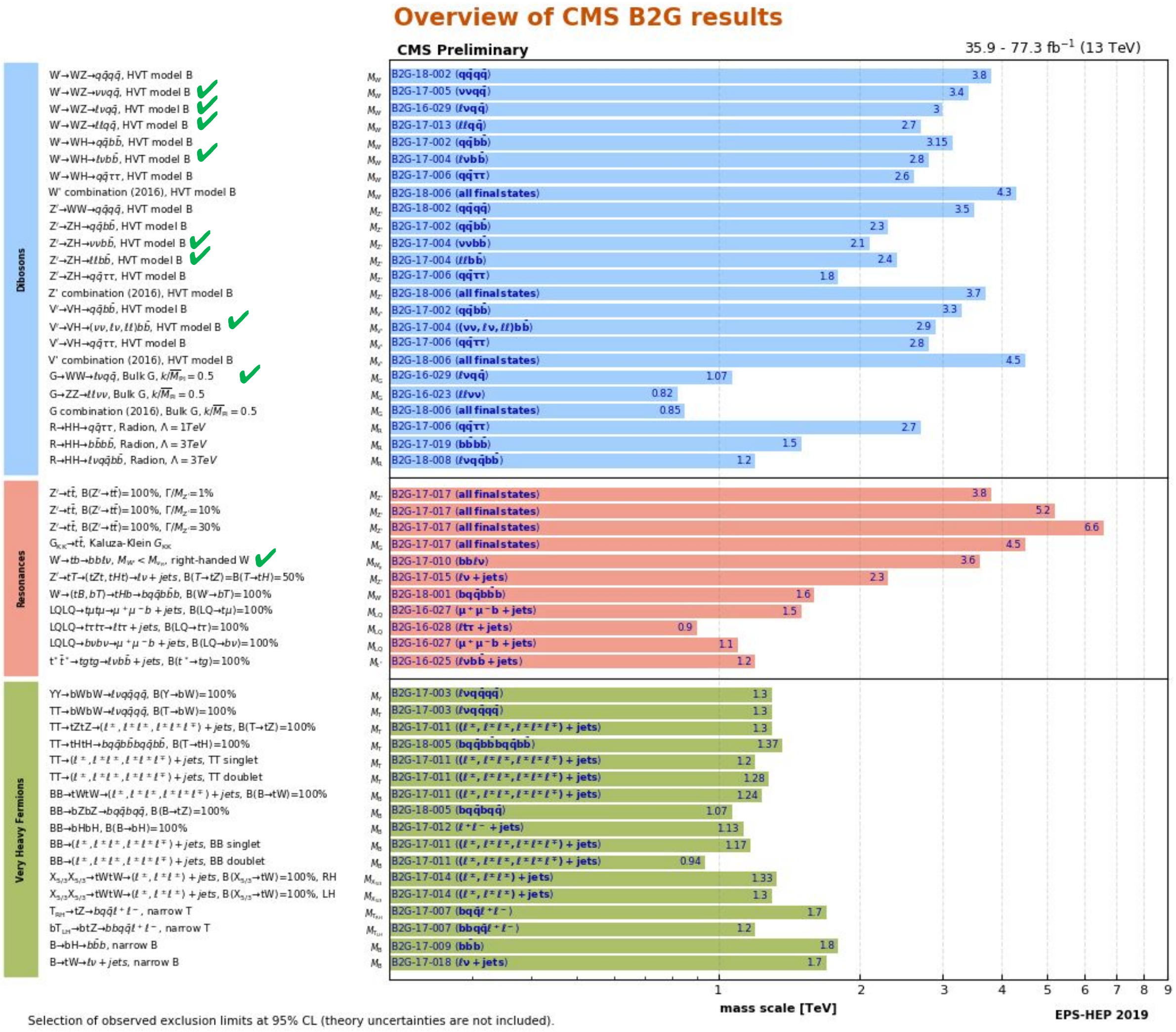


http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G/index.html

Dibosons

Resonances

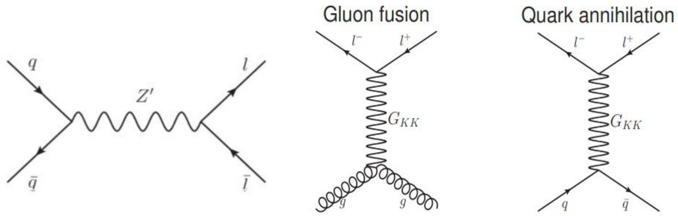
Heavy Fermion



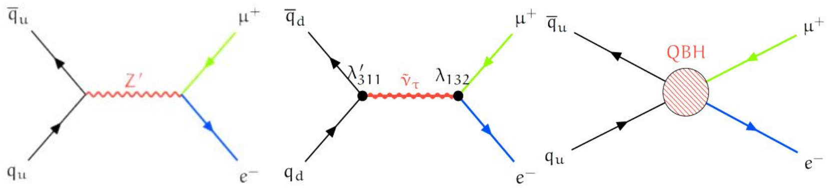
References of Dilepton resonances

- Recent results for dilepton resonances with full (2016-2018) Run-2 datasets

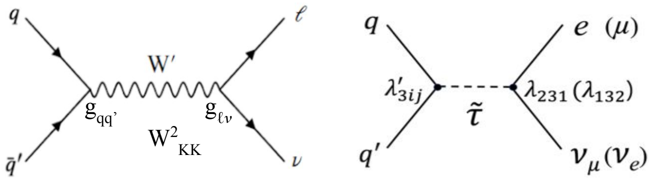
(1) JHEP07(2021)208(EXO-19-019) Published 27 Jul 2021 [$\mathscr{L}$ = 140 fb^{-1}]
"Search for resonant and nonresonant new phenomena in high-mass dilepton (ee, μμ) final states at $\sqrt{s}$ =13TeV"



(2) PAS EXO-19-014 Published 23 Aug 2021 [$\mathscr{L}$ = 137 fb^{-1}]
"Search for heavy resonances and quantum black holes in eμ, eτ, and μτ final states in pp collisions at $\sqrt{s}$=13TeV"



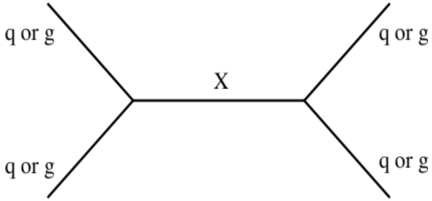
(3) PAS EXO-19-017 Published 22 Mar 2021 [$\mathscr{L}$ = 137 fb^{-1}]
"Search for new physics in the lepton (e, μ) + missing transverse momentum final states in pp collisions at $\sqrt{s}$=13TeV"



References of Di(tri)jet resonances

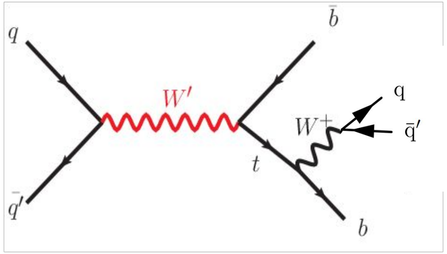
- Recent results for dijet (trijet) resonances with full (2016-2018) Run-2 datasets

(1) JHEP05(2020)033 (EXO-19-012) Published 8 May 2020 [$\mathscr{L}$ = 137 fb^{-1}]
"Search for high mass dijet resonances with
a new background prediction method in pp collisions at √s=13 TeV"

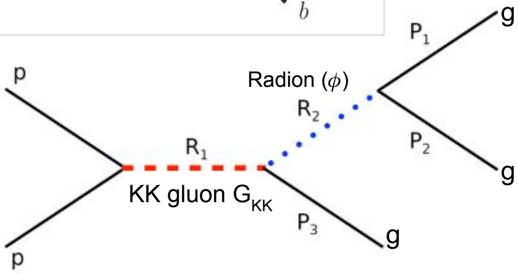


(2) PAS EXO-20-008 Published 26 Jul 2021 [$\mathscr{L}$ = 137 fb^{-1}]
"Search for heavy resonances decaying to b quarks
in pp collisions at √s=13 TeV"

(3) PLB820(2021)136535 (B2G-20-005) Published 10 Sep 2021 [$\mathscr{L}$ = 137 fb^{-1}]
"Search for W′ bosons decaying to a top and a bottom quark
at √s=13TeV in the hadronic final state"

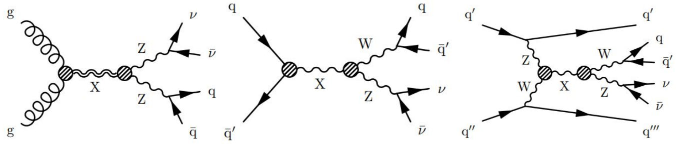


(4) PAS EXO-20-007 Published 5 Jun 2021 [$\mathscr{L}$ = 138 fb^{-1}]
"Search for high mass trijet resonances using final states
with boosted dijet resonances in pp collisions at √s=13 TeV



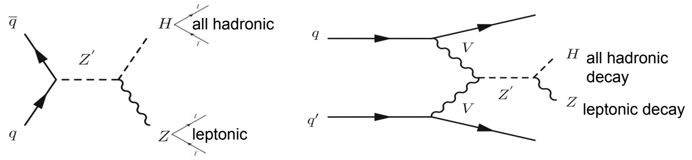
References of Di(tri)boson resonances

- Selected results for diboson resonances with full Run-2 datasets

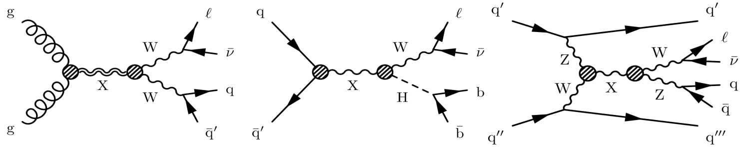


Semi-leptonic decays :

(1) arXiv:2109.08268 (B2G-20-008) Submitted PRD 17 Sep 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for heavy resonances decaying to $Z(\nu\bar{\nu})V(q\bar{q}')$ in pp collisions at $\sqrt{s}$=13TeV"

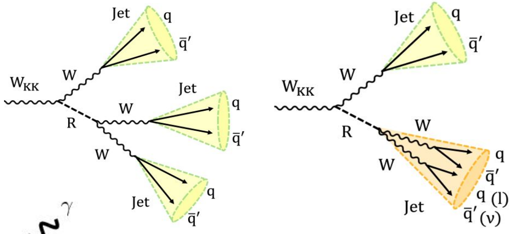


(2) EPJC81(2021)688 (B2G-19-006) Published 3 Aug 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for a heavy vector resonance decaying to a Z boson and a Higgs boson in pp collisions at $\sqrt{s}$=13TeV"

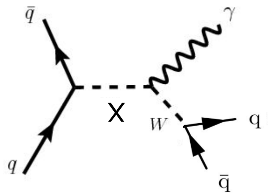


(3) arXiv:2109.06055 (B2G-19-002) Submitted PRD 13 Sep 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for heavy resonances decaying to WW, WZ, or WH boson pairs in the lepton plus merged jet final state in pp collisions at $\sqrt{s}$=13TeV"

All-hadronic decays :



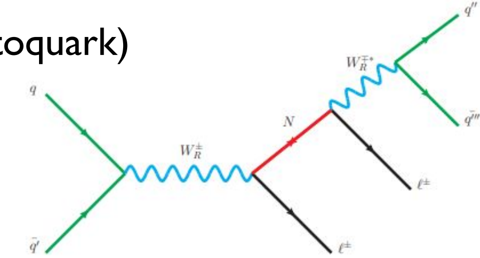
(1) PAS B2G-21-002 Published 26 Jul 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for resonances decaying to three W bosons in the hadronic final state at $\sqrt{s}$=13TeV"



(2) arXiv:2106.10509 (EXO-20-001) Submitted PLB 19 Jun 2021
"Search for Wγ resonances in pp collisions at $\sqrt{s}$=13 TeV using hadronic decays of Lorentz-boosted W bosons"

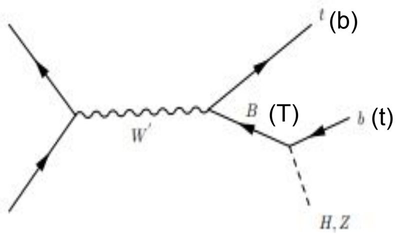
Recent results of Other heavy resonances

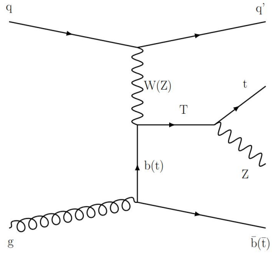
- Recent results for **other** (heavy neutrino, vector-like quark, excited quark, leptoquark)



(1) PAS EXO-20-002 Published 23 Mar 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for a right-handed W boson and heavy neutrino in pp collisions at √s=13TeV"

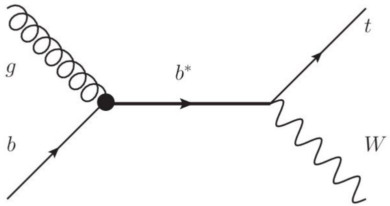
(2) PAS B2G-20-002 Published 16 Mar 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for W′ decaying to a vector-like quark and a top or bottom quark in the all-jets final state"



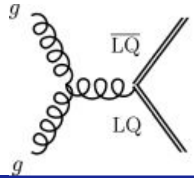


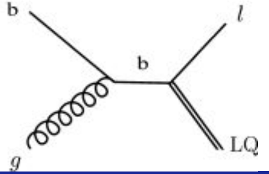
(3) PAS B2G-19-004 Published 16 Mar 2021 [$\mathcal{L}$ = 136 fb^{-1}]
"Search for single production of a vector-like quark T decaying to a top quark and a Z boson with the Z boson decaying to neutrinos"

(4) PAS B2G-20-010 Published 23 Mar 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for a heavy resonance decaying into a top and a W boson in the lepton+jets final state at 13 TeV"



(5) arXiv:2104.12853v1 (B2G-19-003) Published 26 Apr 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for a heavy resonance decaying to a top and a W boson at √s=13 TeV in the fully hadronic final state"





(6) PLB819(2021)136446 (EXO-19-015) 10 Aug 2021 [$\mathcal{L}$ = 137 fb^{-1}]
"Search for singly and pair-produced leptoquarks coupling to third-generation fermions in proton-proton collisions at √s=13TeV"

Machine Learning Algorithm in CMS

JINST15(2020)P12012

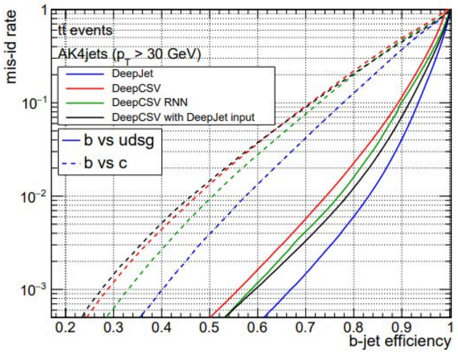


Figure 8. An interpolation between the DeepCSV tagger [19] and DeepJet.

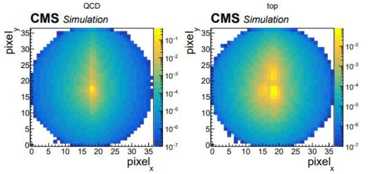
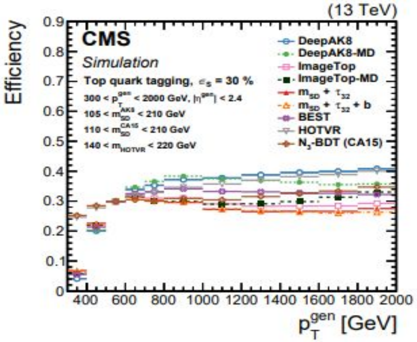
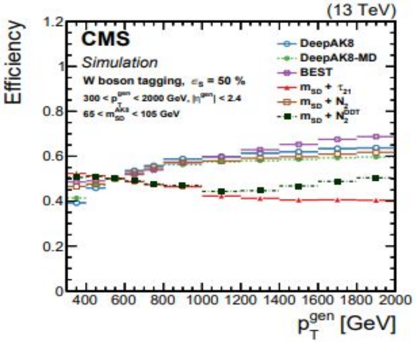


Table 1. Summary of the CMS algorithms for the identification of hadronically decaying t quarks and W, Z and H bosons. See text for explanation of the algorithm names. The column "Subsection" indicates the subsection where the algorithm is described, and the column "jet p_T [GeV]" indicates the jet p_T threshold to be used in each algorithm. The * in DeepAK8 and DeepAK8-MD algorithms indicates the ability of these algorithm to also identify the decay modes of each particle.

Algorithm	Subsection	jet p_T [GeV]	t quark	W boson	Z boson	H boson
$m_{SD} + \tau_{32}$	6.1	400	✓			
$m_{SD} + \tau_{32}$ + b	6.1	400	✓			
$m_{SD} + \tau_{21}$	6.1	200	✓	✓		
HOTVR	6.2	200	✓			
N_3-BDT (CA15)	6.3	200	✓			
$m_{SD} + N_2$	6.3	200		✓	✓	✓
BEST	6.5	500	✓	✓	✓	✓
ImageTop	6.6	600	✓			
DeepAK8$^{(*)}$	6.7	200	✓	✓	✓	✓
Jet mass decorrelated algorithms						
$m_{SD} + N_2^{DDT}$	6.3	200		✓	✓	✓
double-b	6.4	300			✓	✓
ImageTop-MD	6.6	600	✓			
DeepAK8-MD$^{(*)}$	6.7	200	✓	✓	✓	✓





JINST15(2020)P06005

Time schedule

https://project-hl-lhc-industry.web.cern.ch/content/project-schedule

Nominal luminosity $1.0 \times 10^{34} cm^{-2}s^{-1}$

X2 Run 2

X10 Run 3

LHC will Restart in 2022