LHC Searches for Neutrino Physics in τ Channel

Heavy Neutrino, Z′ and W′

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Workshop on "Neutrinos at the High Energy Frontier"

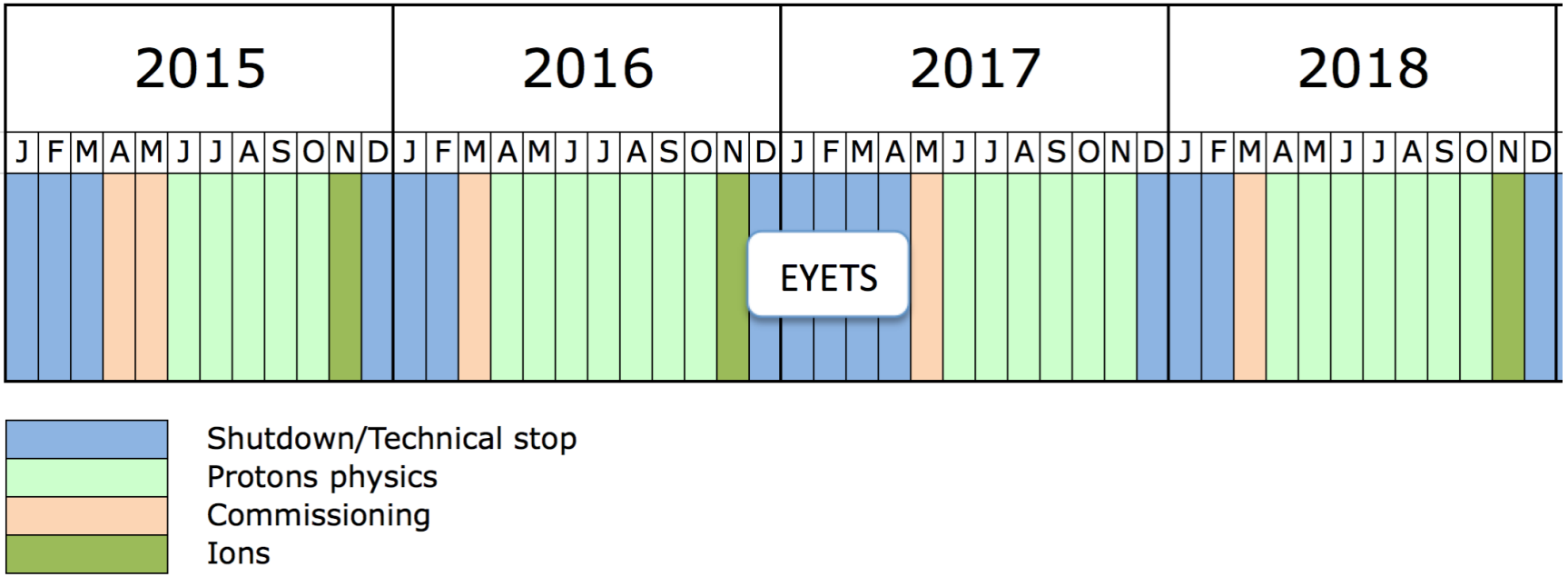
Amherst Center for Fundamental Interactions (ACFI)
University of Massachusetts
Amherst MA

July 18-20, 2017

http://www.physics.umass.edu/acfi/seminars-and-workshops/neutrinos-at-the-high-energy-frontier

Introduction

- 13 TeV data – 2.2 fb-1 in 2015, 36 fb-1 in 2016 and data in 2017/2018



2016 maximum peak lumi was 1.5×10^{34} cm^{-2} s^{-1} with <pileup> ~50 with 2208 colliding bunches

Peak luminosity "soft" limit is ~1.7×10^{34} from inner triplets

- "ultimate" filling scheme with 25ns and 2556b
- 40-50 fb-1/year in 2017/18 so >100 fb-1 in Run 2

Introduction

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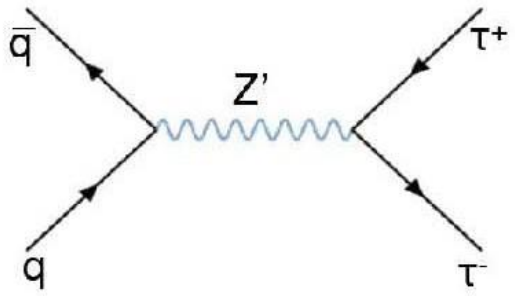
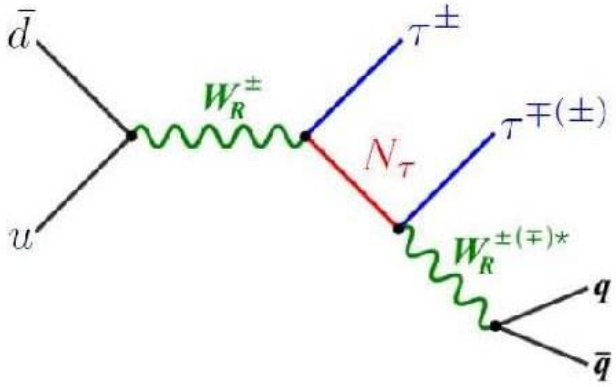
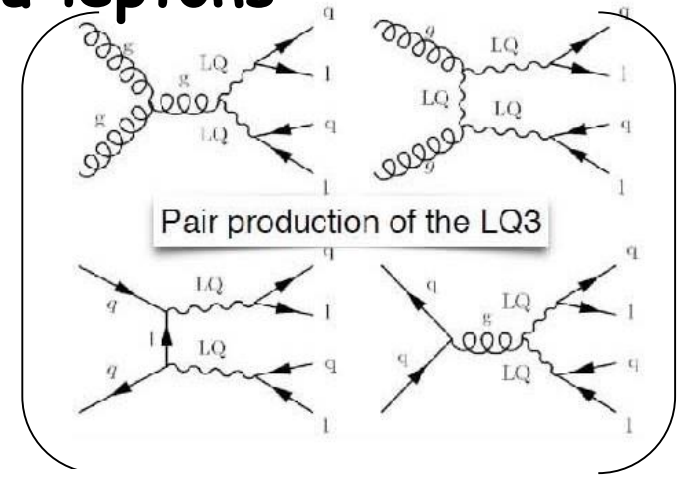
links

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

- Selected topics - Search for heavy gauge bosons (W' and Z') and heavy neutrinos with tau leptons



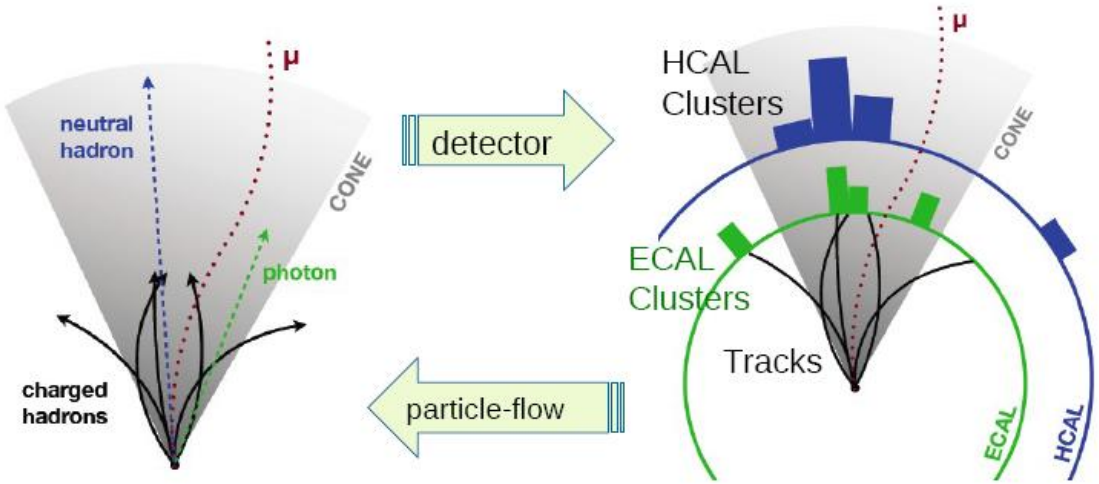




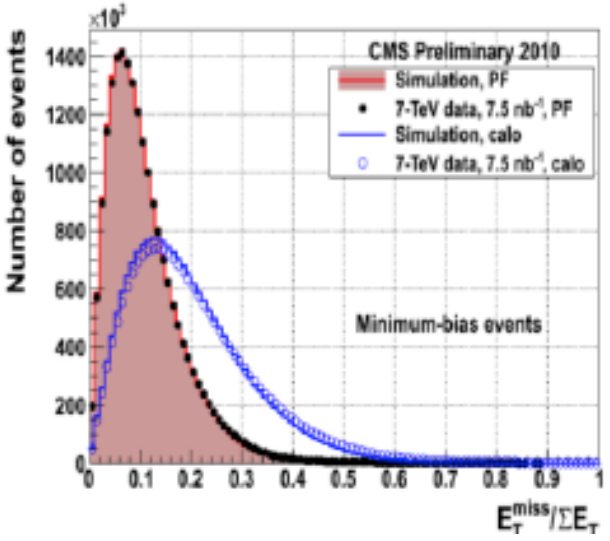
- Tau leptons: $\tau\tau \rightarrow \tau_h\tau_h\ ,\ \tau_e\tau_h\ ,\ \tau_\mu\tau_h\ \ ,\ \tau_e\tau_\mu$

Particle Flow (PF) Algorithm

- All physics objects (charged hadrons, neutral hadrons, γ, e, μ, $\tau \rightarrow$ jets, MET) are reconstructed with the PF algorithm (with corresponding calibrations).
- The list of "particles" is given to the jet clustering and missing E_T (MET) reconstruction algorithm



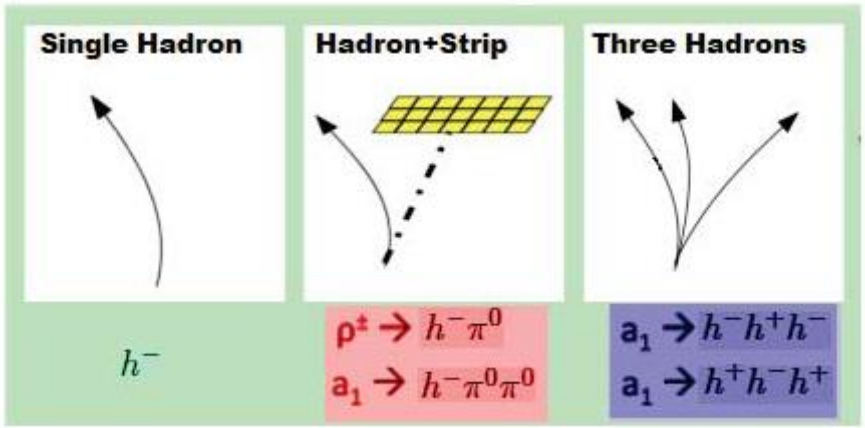
- ✓ Improvements in all the reconstructed objects
  - ❑ Jets and MET: resolution and energy scale improved w.r.t. calorimeter based reconstruction
  - ❑ Lepton isolation: background rejection improved
  - ❑ **Excellent reconstruction** and identification for τ_h



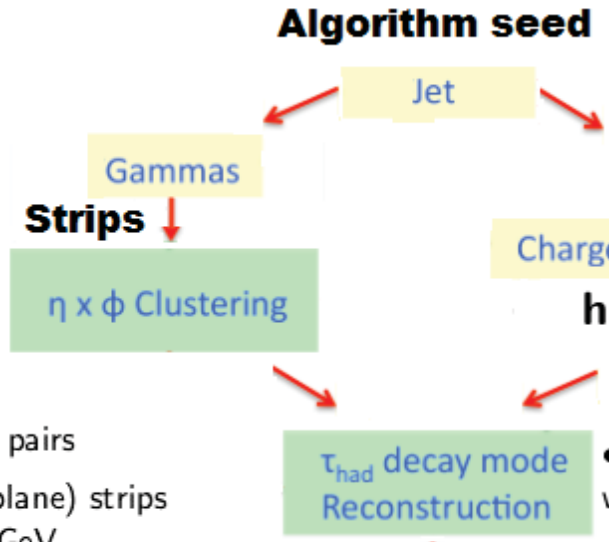
Hadronically Decaying Tau

Hadron-plus-Strips (HPS) Algorithm

Decay channel	BR (%)
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	17.36
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	17.85
$\tau^- \to h^- \nu_\tau$	11.6
$\tau^- \to h^- \pi^0 \nu_\tau$	26.0
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$	4.8
others	3.1



- Reconstruction of the decay modes:
  - ✓ 1 prong, 1 prong + π^0's, 3 prongs
- Various working points for the isolation
- Veto for electrons and muons



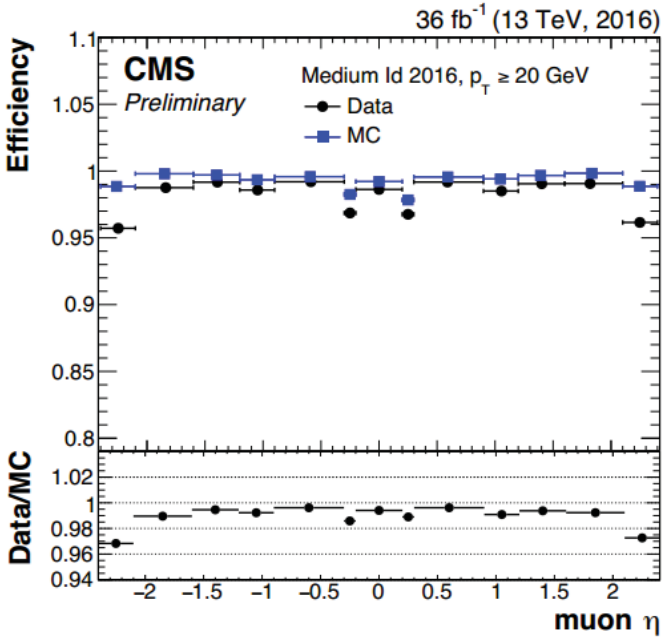
- pT > 0.5 GeV
- distance between trk and τ_h production vertex
  < 0.4 cm in the direction of the beamline
  < 0.03 cm in the transverse plane

- Photons from $\pi^0 \to \gamma\gamma$ decays may convert to e^+e^- pairs
- Define 0.05 - 0.20 ($\eta - \phi$ plane) strips to look for e, γ of pT > 0.5 GeV
- π^0: strips with ≥ 1 e, γ candidates with overall pT > 2.5 GeV

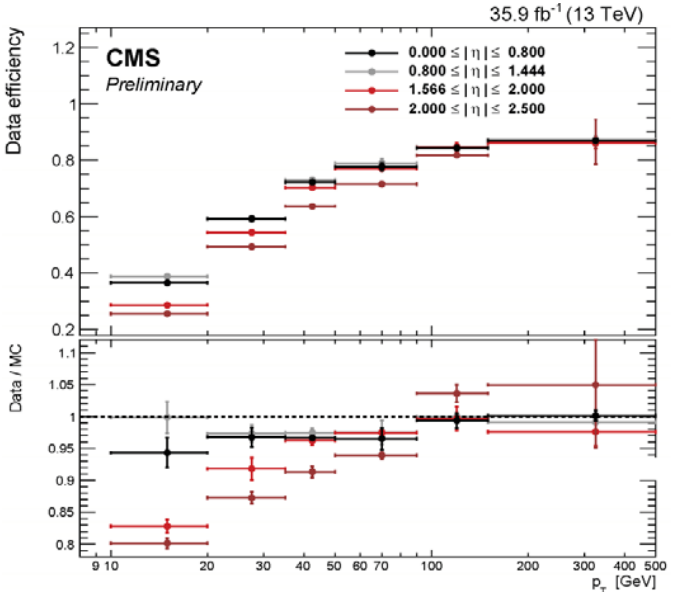
- Mass window cut to ensure consistency with ρ, a_1, π decay

Examples of Particle ID Performance

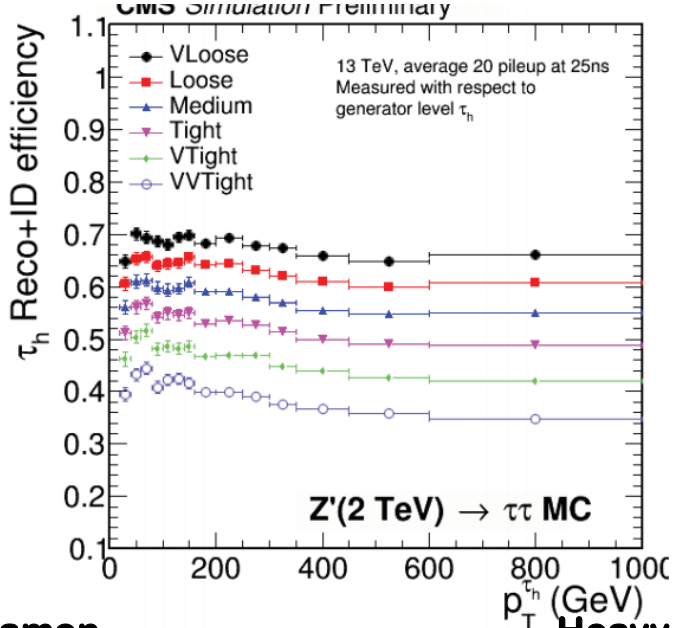
μ



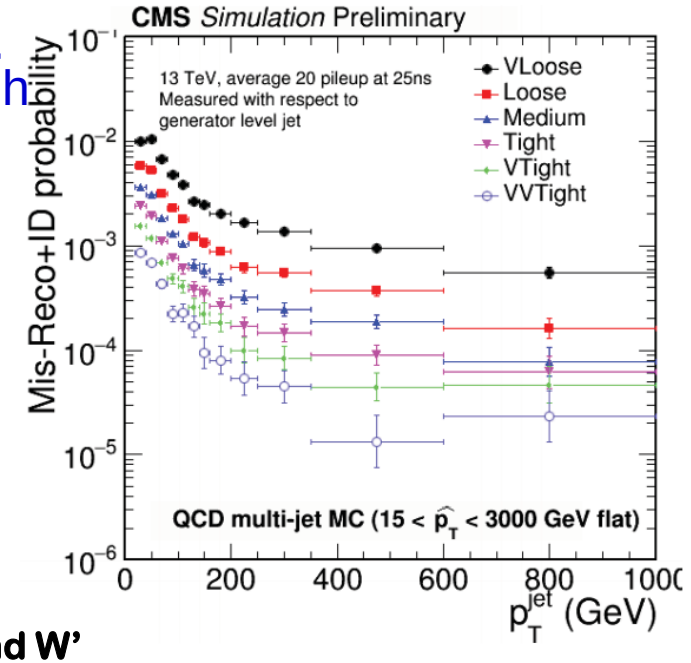
e



τ_h



$j \rightarrow \tau_h$



Publications

JHEP

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JHEP 02 (2017) 048
EXO-16-008 (2.2 fb-1)

Search for heavy resonances decaying to tau lepton pairs in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS collaboration

E-mail: cms-publication-committee-chair@cern.ch

Abstract: A search for heavy resonances that decay to tau lepton pairs is performed using proton-proton collisions at $\sqrt{s} = 13$ TeV. The data were collected with the CMS detector at the CERN LHC and correspond to an integrated luminosity of 2.2 fb^{-1}. The observations are in agreement with standard model predictions. An upper limit at 95% confidence level on the product of the production cross section and branching fraction into tau lepton pairs is calculated as a function of the resonance mass. For the sequential standard model, the presence of Z′ bosons decaying into tau lepton pairs is excluded for Z′ masses below 2.1 TeV, extending previous limits for this final state. For the topcolor-assisted technicolor model, which predicts Z′ bosons that preferentially couple to third-generation fermions, Z′ masses below 1.7 TeV are excluded, representing the most stringent limit to date.

Keywords: Beyond Standard Model, Hadron-Hadron scattering (experiments), Particle and resonance production

ArXiv ePrint: 1611.06594

doi:10.1007/JHEP02(2017)048

JHEP02(2017)048

JHEP

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Published: March 14, 2017

JHEP 02 (2017) 077
EXO-16-016 (2.2 fb-1)

Search for heavy neutrinos or third-generation leptoquarks in final states with two hadronically decaying τ leptons and two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS collaboration

E-mail: cms-publication-committee-chair@cern.ch

Abstract: A search for new particles has been conducted using events with two high transverse momentum (p_T) τ leptons that decay hadronically, at least two high-p_T jets, and missing transverse energy from the τ lepton decays. The analysis is performed using data from proton-proton collisions, collected by the CMS experiment in 2015 at $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 2.1 fb^{-1}. The results are interpreted in two physics models. The first model involves heavy right-handed neutrinos, N_ℓ ($\ell = e, \mu, \tau$), and right-handed charged bosons, W_R, arising in a left-right symmetric extension of the standard model. Masses of the W_R boson below 2.35 (1.63) TeV are excluded at 95% confidence level, assuming the N_τ mass is 0.8 (0.2) times the mass of the W_R boson and that only the N_τ flavor contributes to the W_R decay width. In the second model, pair production of third-generation scalar leptoquarks that decay into $\tau\tau$bb is considered. Third-generation scalar leptoquarks with masses below 740 GeV are excluded, assuming a 100% branching fraction for the leptoquark decay to a τ lepton and a bottom quark. This is the first search at hadron colliders for the third-generation Majorana neutrino, as well as the first search for third-generation leptoquarks in the final state with a pair of hadronically decaying τ leptons and jets.

Keywords: Beyond Standard Model, Hadron-Hadron scattering (experiments), proton-proton scattering

ArXiv ePrint: 1612.01190

doi:10.1007/JHEP03(2017)077

JHEP03(2017)077

Publications

Acepted in JHEP, July 13, 2017

EXO-16-023 (12.9 fb-1)

EXO-17-??? (36 fb-1)

And 2017 data …

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP/2017-025
2017/03/14

CMS-EXO-16-023

Search for third-generation scalar leptoquarks and heavy right-handed neutrinos in final states with two tau leptons and two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

Abstract

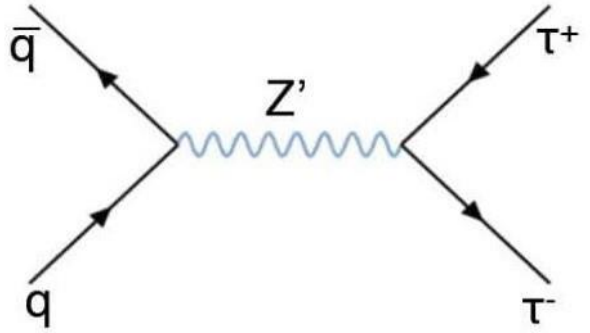
A search is performed for third-generation scalar leptoquarks and heavy right-handed neutrinos in events containing one electron or muon, one hadronically decaying τ lepton, and at least two jets, using a $\sqrt{s} = 13$ TeV pp collision data sample corresponding to an integrated luminosity of 12.9 fb^{-1} collected with the CMS detector at the LHC in 2016. The number of observed events is found to be in agreement with the standard model prediction. A limit is set at 95% confidence level on the product of the leptoquark pair production cross section and β^2, where β is the branching fraction of leptoquark decay to a τ lepton and a bottom quark. Assuming $\beta = 1$, third-generation leptoquarks with masses below 850 GeV are excluded at 95% confidence level. An additional search based on the same event topology involves heavy right-handed neutrinos, N_R, and right-handed W bosons, W_R, arising in a left-right symmetric extension of the standard model. In this search, W_R bosons are assumed to decay to a tau lepton and N_R followed by the decay of the N_R to a tau lepton and an off-shell W_R boson. Assuming the mass of the right-handed neutrino to be half of the mass of the right-handed W boson, W_R boson masses below 2.9 TeV are excluded at 95% confidence level. These results improve on the limits from previous searches for third-generation leptoquarks and heavy right-handed neutrinos with τ leptons in the final state.

Submitted to the Journal of High Energy Physics

*See Appendix B for the list of collaboration members

$Z' \rightarrow \tau\,\tau$

- **Additional gauge bosons emerge in varioys extended gauge models.**
  - LR Model, extending the standard model gauge group with right-handed charged boson as well as an additional neutral current
  - Sequential standard model (SSM), having heavy gauge bosons with the SM coupling strengths.
  - Models with preferred couplings to 3rd generation fermions (e.g., Topcolor-assisted technicolor (TAT) model)



$Z' \to \tau\,\tau$

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EXO-16-008 (2.2 fb-1)

Final states:

- $\tau_h\tau_h$, $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_e\tau_\mu$

Selections:

- *opposite electric charge*
- *back-to-back*
- *missing E_T > 30 GeV*

QCD & DY are dominant.

Process	$\tau_e\tau_\mu$	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_h\tau_h$
Drell-Yan	321 ± 37	375 ± 40	882 ± 130	8 ± 3
W+jets	19 ± 6	456 ± 35	916 ± 96	0.1 ± 0.1
Diboson	108 ± 11	18 ± 4	29 ± 7	0.5 ± 0.5
tt	223 ± 20	26 ± 6	26 ± 7	—
QCD multijet	36 ± 16	250 ± 50	122 ± 84	49 ± 13
Total	707 ± 47	1125 ± 73	1976 ± 180	58 ± 13
Observed	728	1113	1807	55
Z'_{SSM} (1.0 TeV)	$24.7 + 1.9$	$19.1 + 1.4$	$53 + 4$	$45 + 3$
Z'_{SSM} (1.5 TeV)	4.7 ± 0.3	3.0 ± 0.1	9.4 ± 0.4	8.6 ± 0.4
Z'_{SSM} (2.0 TeV)	1.2 ± 0.1	0.77 ± 0.04	2.3 ± 0.1	2.1 ± 0.1

$\tau_h\tau_h$ - the best sensitivity

Limit extraction variable:

$$m(\tau_1, \tau_2, \not{E}_T) = \sqrt{(E_{\tau_1} + E_{\tau_2} + \not{E}_T)^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{\not{E}}_T)^2}.$$

$Z' \to \tau\,\tau$

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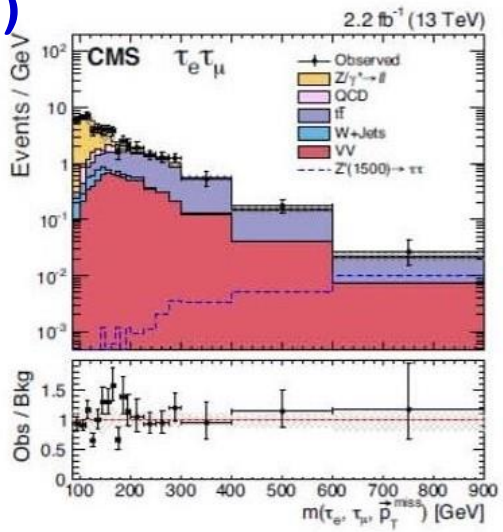
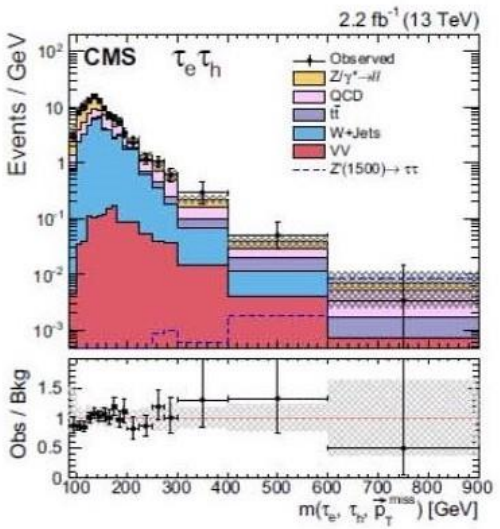
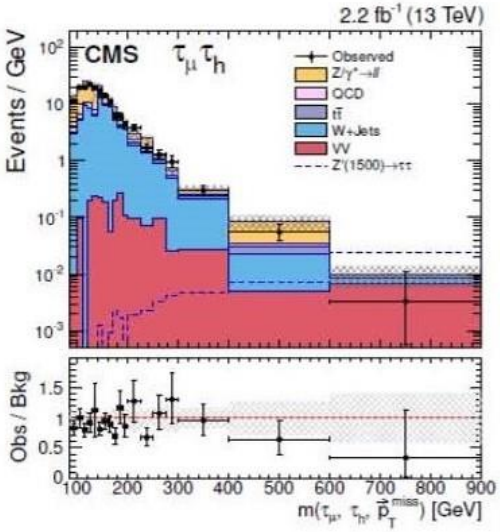
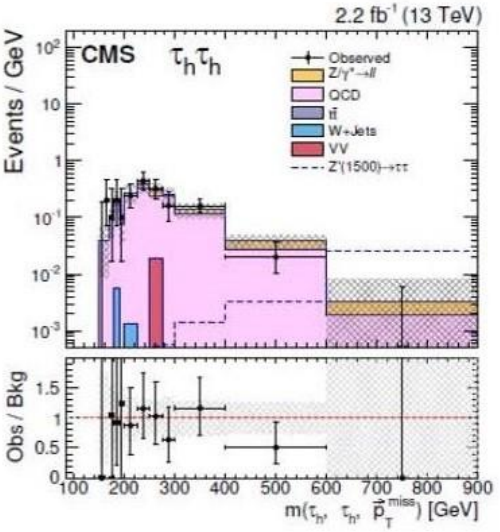
EXO-16-008 (2.2 fb-1)









QCD & DY are dominant.

$Z' \to \tau\,\tau$

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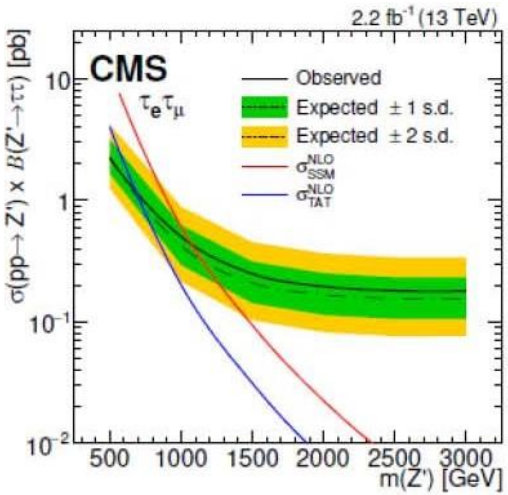
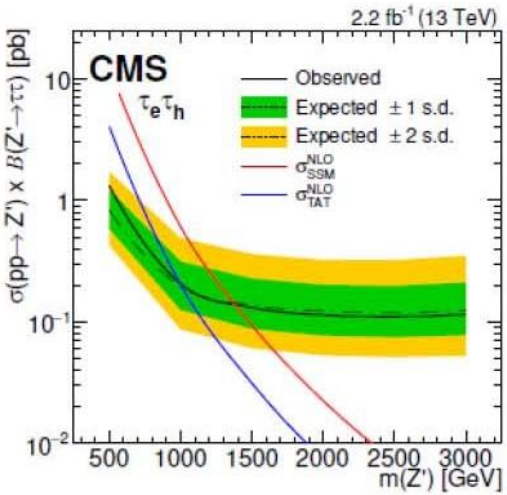
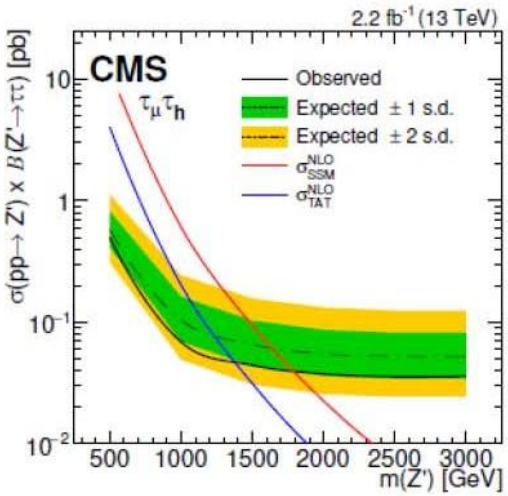
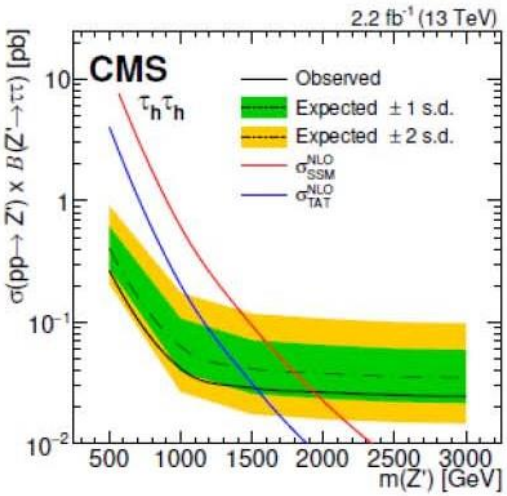
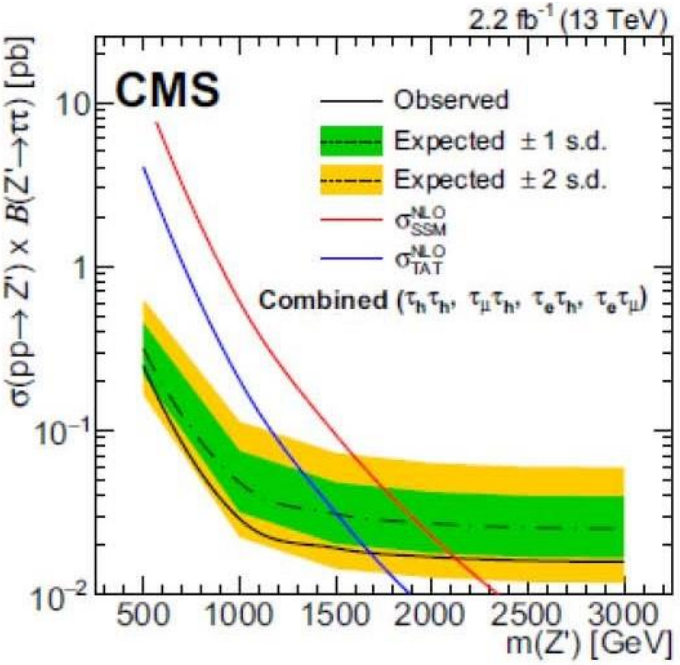
EXO-16-008 (2.2 fb-1)









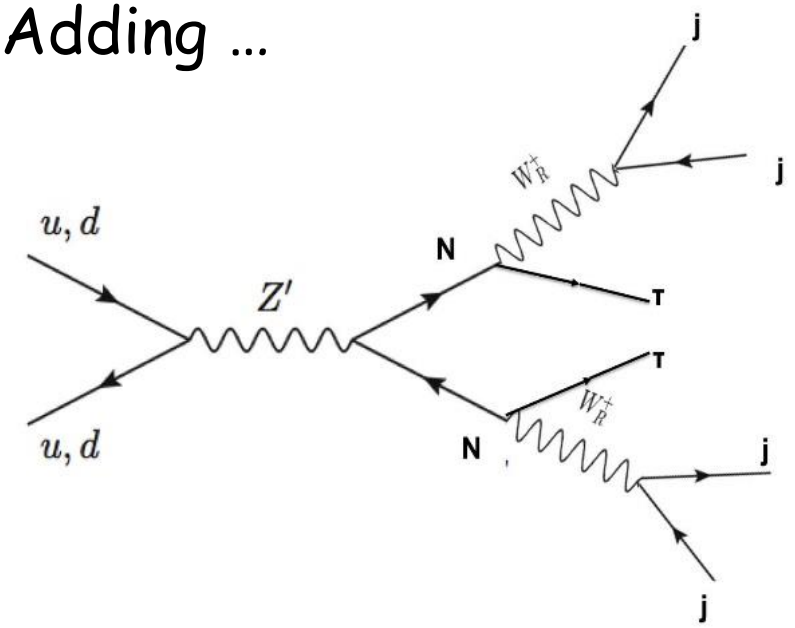


The presence of Z'_{SSM} bosons decaying into τ lepton pairs is excluded for masses below 2.1 TeV

$\tau_h\tau_h$ - the best limit

2016 Data

- EXO-17-007 (36 fb-1) in progress
- Challenge is to understand the uncertainty of scale factor of the tau ID in p_T > 300 GeV
- Adding …



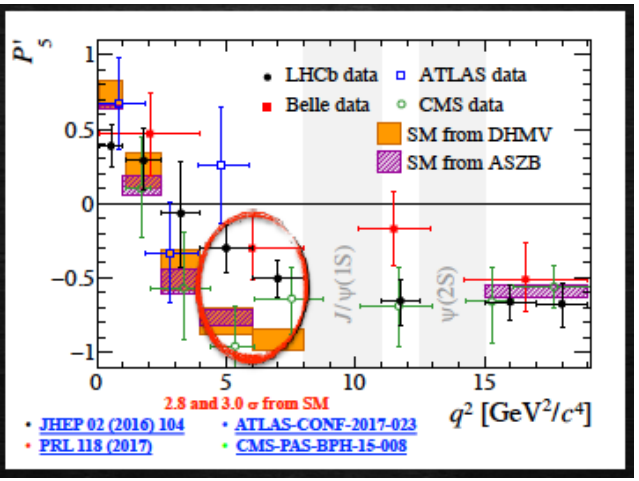
EXO-17-016 (36 fb-1)

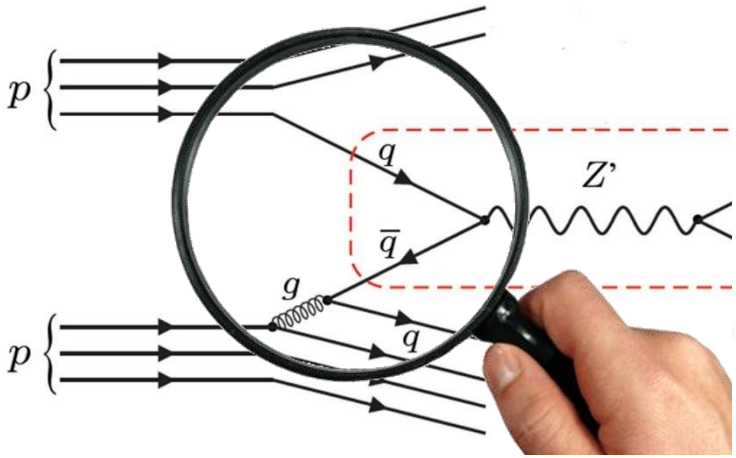
in progress

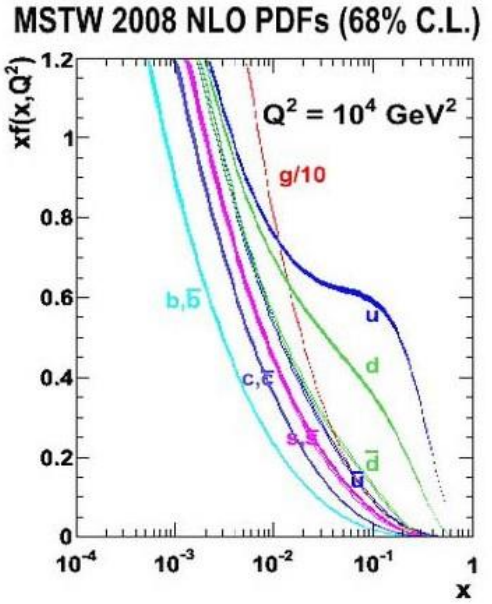
- What else?

Puzzle with Anomalies in B decays

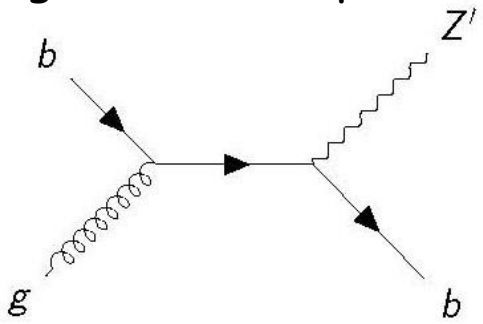
CERN Seminar by Simone Bifani (LHCb), April 18, 2017



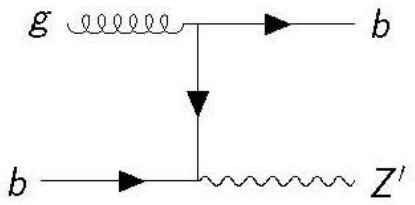




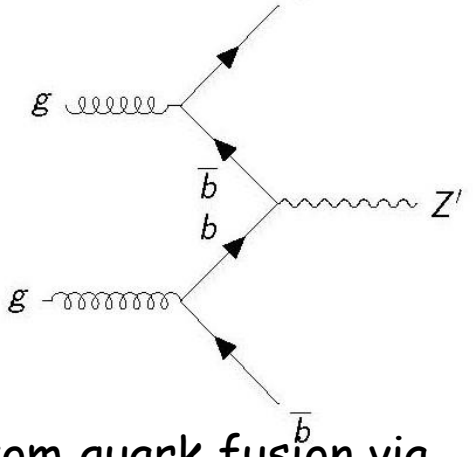
Gauge bosons couple to 3rd generation fermions



Z' is suppressed by a facor of $1/M(Z')^2$ in addition to the bottom PDF



The radiative suppression is solved with $g \rightarrow bb$, but adding a gluon splitting fraction in addition to the bottom PDF



Bottom quark fusion via gluon splitting to bb -- Z' production associated with b jets

In Progress at Mitchell Institute

Bottom-quark Fusion Processes at the LHC Probing Z' Models and B-meson Decay Anomalies

M. Dalchenko, B. Dutta, R. Eusebi, P. Huang, T. Kamon, and D. Rathjens

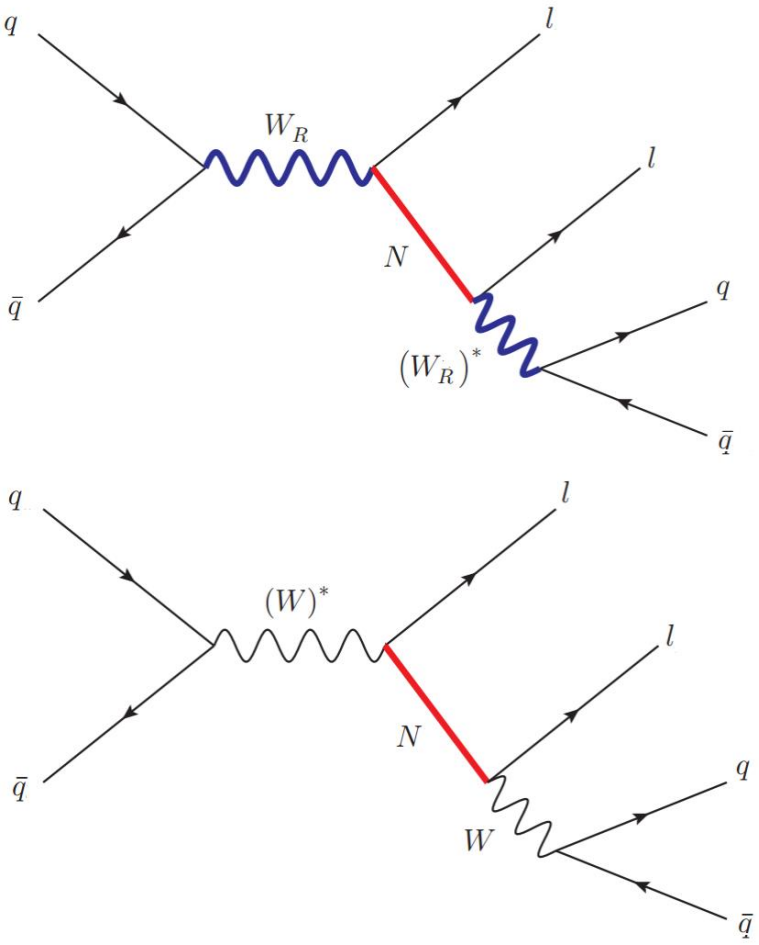
- We study a generic framework (δ_{bs}, g_b, g_μ) of models of a heavy neutral gauge boson (Z') to explain anomalies in B meson decays reported by the LHCb experiment: the Z' boson couples mostly to third generation fermions.
- Bottom-quark fusion arising from gluon splitting is an essential production mechanism at the LHC for probing such a Z' boson.
- $Z' \to \mu\mu$ decays with at least one bottom-tagged jet in its final state would allow for eploring a larger region of the parameter space of the models at the ongoing LHC run and HL-LHC.

WR $\rightarrow \tau_h$ + N

- Small but non-zero SM neutrinos from neutrino oscillation experiments.

  - Left-right symmetry extension (LRSM) with $SU(2)_R$, predicting three additional gauge bosons, $WR^{\pm}$ and Z', and naturally connecting with neavy neutrino states: N_l (l = e, μ, τ)

  - "Seesaw" mechanism … V_{lN}, m_N



- LRSM in this talk

WR in $\tau_h + \tau_h$

JHEP 02 (2017) 077
EXO-16-016 (2.2 fb-1)

Final states:

- $\tau_h\tau_h qq$

Selections:

- *2 τ_h with high p_T*
- *2 jets with high p_T*
- *missing E_T > 50 GeV*
- *invariant mass of $\tau_h\tau_h$ > 100 GeV*

QCD is dominant.

Process	Prediction
DY+jets	1.3 ± 0.5
W+jets	0.9 ± 0.4
$t\bar{t}$	2.5 ± 0.9
Multijet	15.1 ± 4.1
Total	19.8 ± 4.2
Observed	14
$m(W_R) = 1.0$ TeV	61.1 ± 1.5
$m(W_R) = 2.7$ TeV	1.60 ± 0.02

Limit extraction variable:

$$m(\tau_{h,1}, \tau_{h,2}, j, j, E_T^{miss}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{j_1} + E_{j_2} + E_T^{miss})^2 - (\vec{p_{\tau_1}} + \vec{p_{\tau_2}} + \vec{p_{j_1}} + \vec{p_{j_2}} + \vec{E_T})^2}.$$

WR in $\tau_h + \tau_h$

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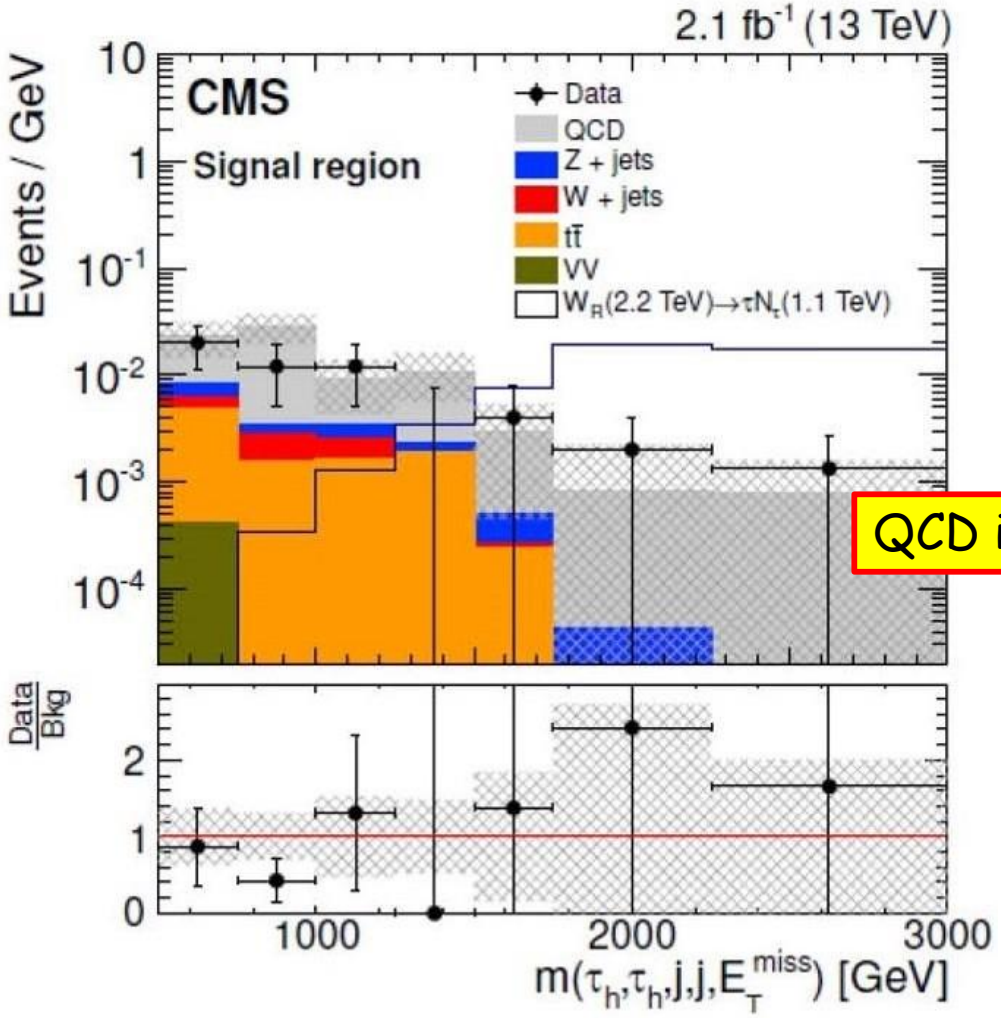
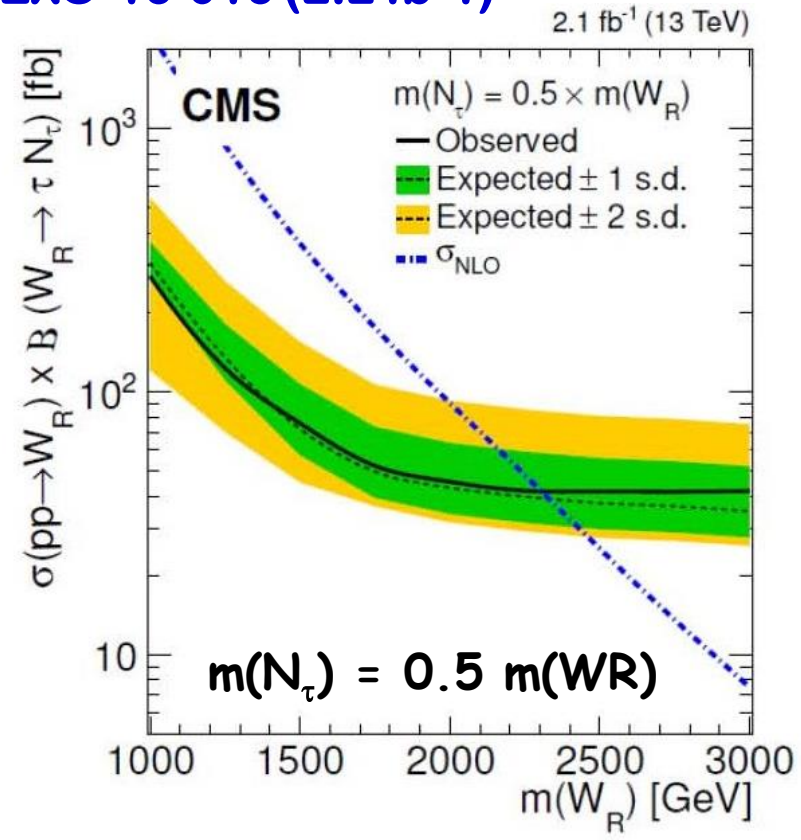
EXO-16-016 (2.2 fb-1)

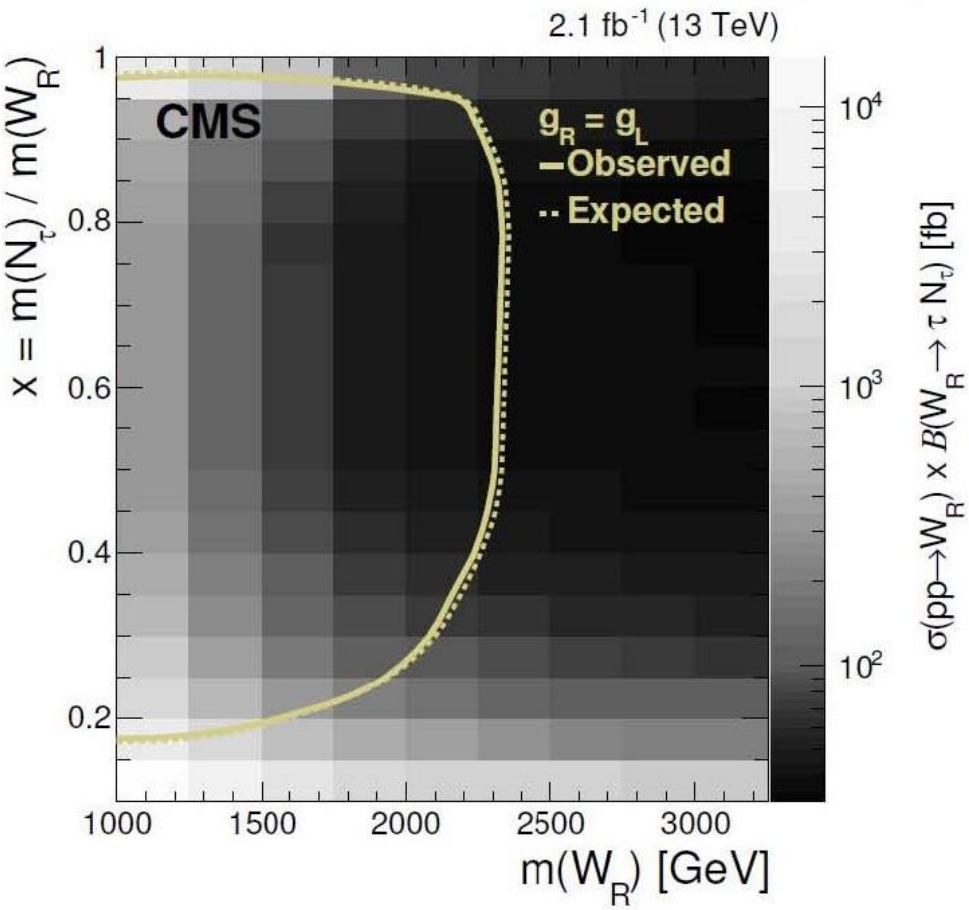


QCD is dominant.

WR in $\tau_h + \tau_h$

JHEP 02 (2017) 077
EXO-16-016 (2.2 fb-1)

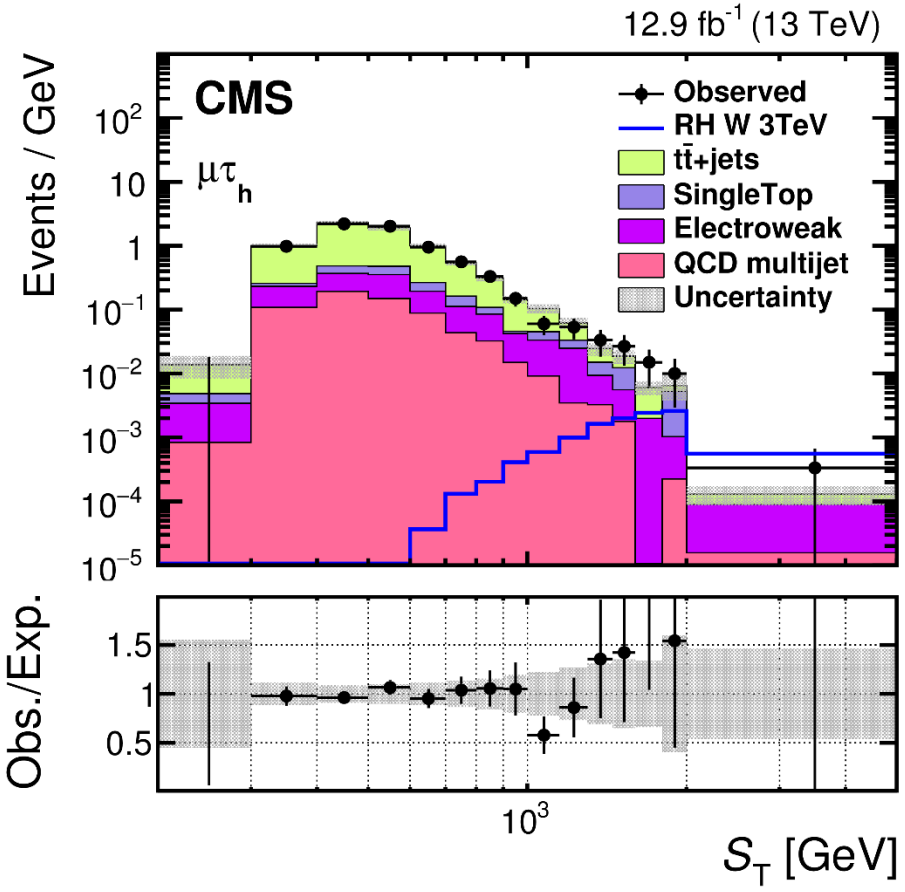


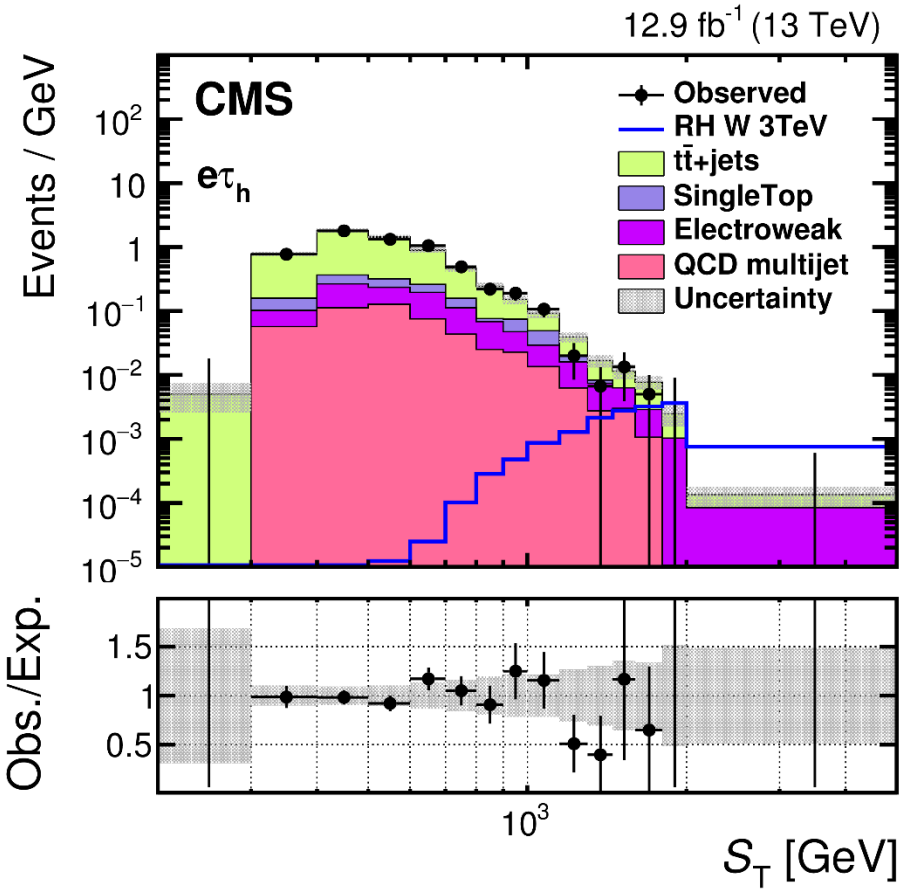


$m(WR^{\pm}) > 2.35\ (1.63)$ TeV for $m(N_\tau) = 0.8\ (0.2)\ m(WR)$

WR in lepton + τ_h

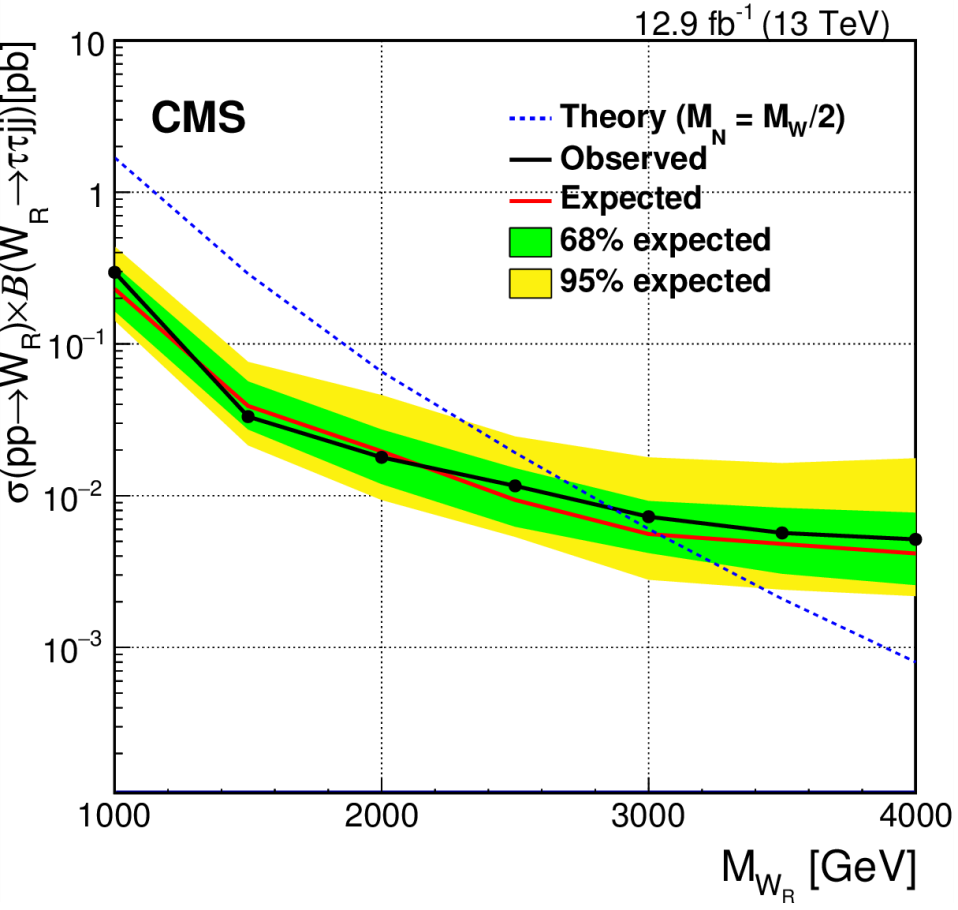
Acepted in JHEP, July 13, 2017
EXO-16-023 (12.9 fb-1)

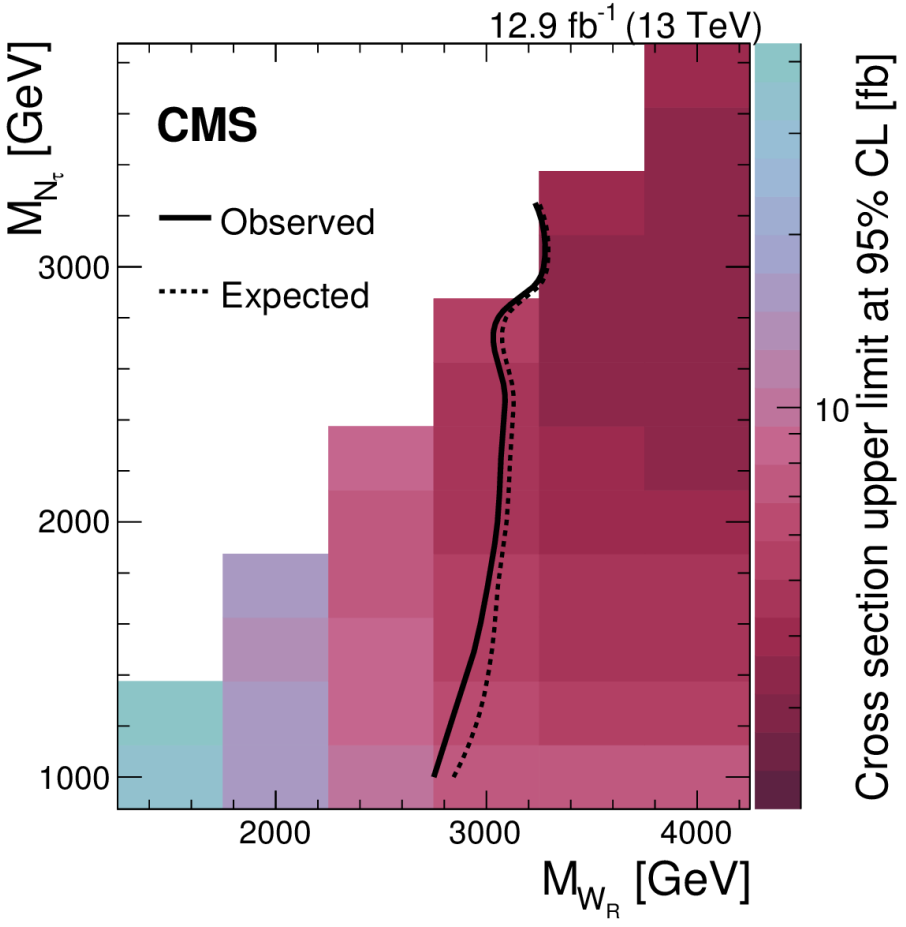




WR in lepton + τ_h

Acepted in JHEP, July 13, 2017
EXO-16-023 (12.9 fb-1)

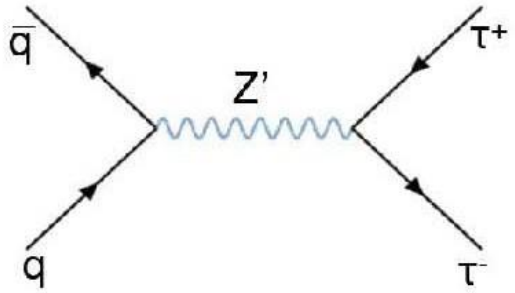


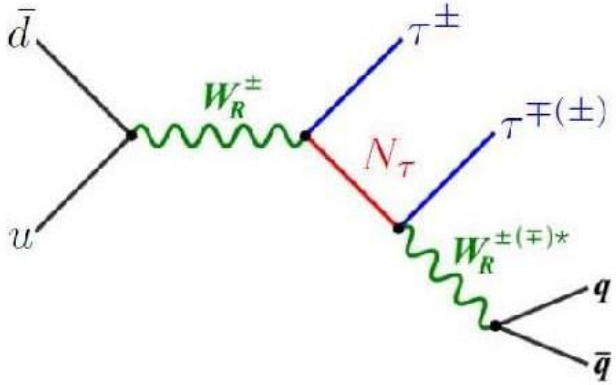


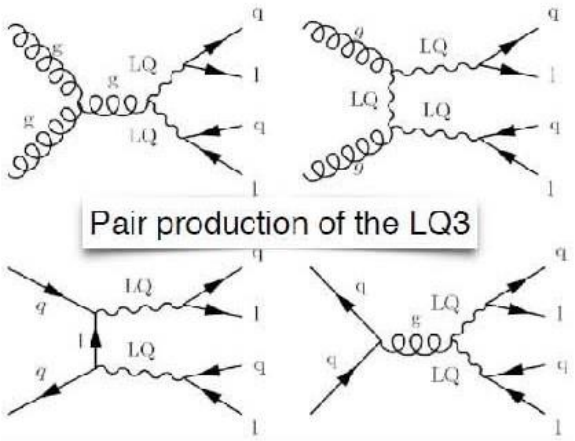
$m(WR^{\pm}) > 2.9$ TeV for $m(N_\tau) = 0.5\ m(WR)$

Summary

- Heavy neutrino/gauge bosons couple to third-generation fermions.
- Selected topics from 13 TeV data: Z' > 2.1 TeV (2.2 fb-1), $WR^{\pm}$ > 2.9 TeV for N_{τ} = 0.5 WR (12.9 fb-1)
- Understanding tau ID scale in high pT
- Finishing up with the entire 2016 data (36 fb-1) .. Targeting at $WR^{\pm}$ > 3.** TeV
- Z' ($\rightarrow \mu\mu$) + b jets ?
- Preparing with 2017 data



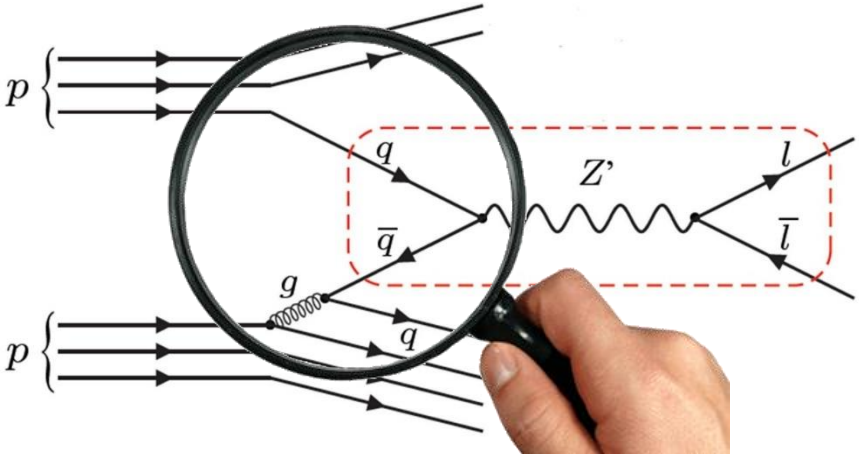


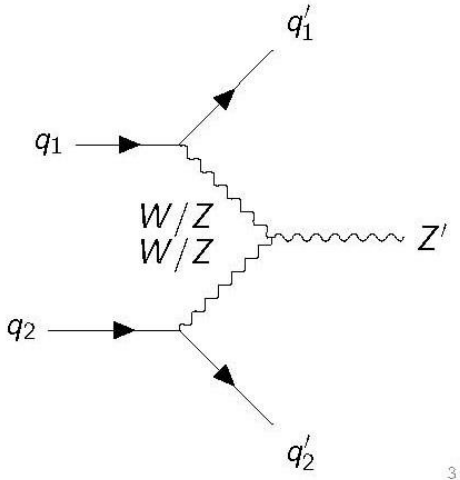


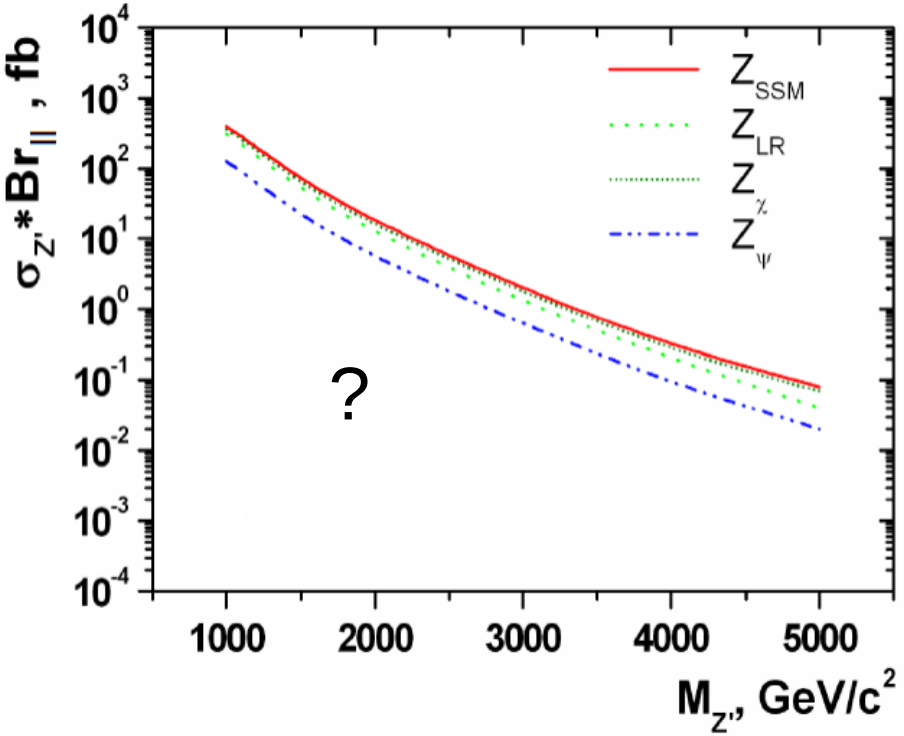
Backups

Z′ in VBF

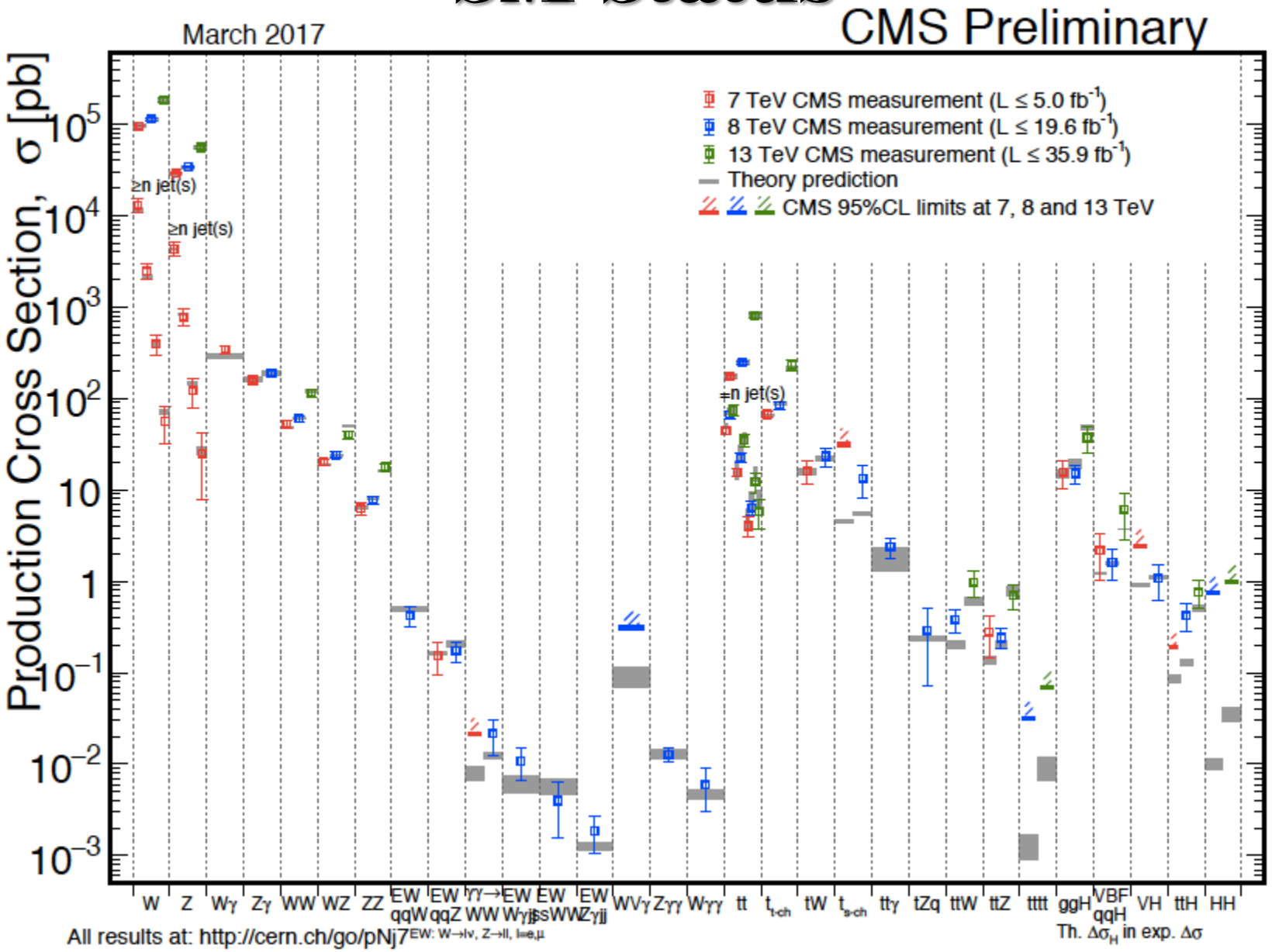
- Fermiophobic gauge bosons?







SM Status


March 2017
CMS Preliminary
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb-1)
8 TeV CMS measurement (L ≤ 19.6 fb-1)
13 TeV CMS measurement (L ≤ 35.9 fb-1)
Theory prediction
CMS 95%CL limits at 7, 8 and 13 TeV
≥n jet(s)
≥n jet(s)
≥n jet(s)
W Z Wγ Zγ WW WZ ZZ EW qqW EW qqZ γγ→WW EW Wγjj EW ssWW EW Zγjj WVγ Zγγ Wγγ tt t t-ch tW t s-ch ttγ tZq ttW ttZ tttt ggH VBF qqH VH ttH HH
All results at: http://cern.ch/go/pNj7
EW: W→lν, Z→ll, l=e,μ
Th. Δσ_H in exp. Δσ

New CMS Searches: Moriond/Aspen

SUSY

Description	CADI Line
Jets+MET with MHT	SUS-16-033
Jets+MET with MT2	SUS-16-036
Jets+MET bb/cc	SUS-16-032
Jets+MET stop	SUS-16-049
1L MJ	SUS-16-037
SS 2L	SUS-16-035
Stop 2L	SUS-17-001
Strong multilep	SUS-16-041
photon+HT	SUS-16-047
H(gg)+jets	SUS-16-045
Ewk multilep	SUS-16-039
Ewk soft 2L OS	SUS-16-048
Ewk HH->4b	SUS-16-044

Exotica / B2G

Description	CADI Line
Dijet resonance	EXO-16-056
Type III seesaw	EXO-17-006
MUSiC generic	EXO-14-016
X5/3 SS 2L	B2G-16-019
W' → tb → 1L	B2G-17-010
VLQs to Z → ll	B2G-17-007
VH had resonance	B2G-17-002
VV had resonance	B2G-17-001

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

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