Leptoquark searches and high mass phenomena with taus at CMS

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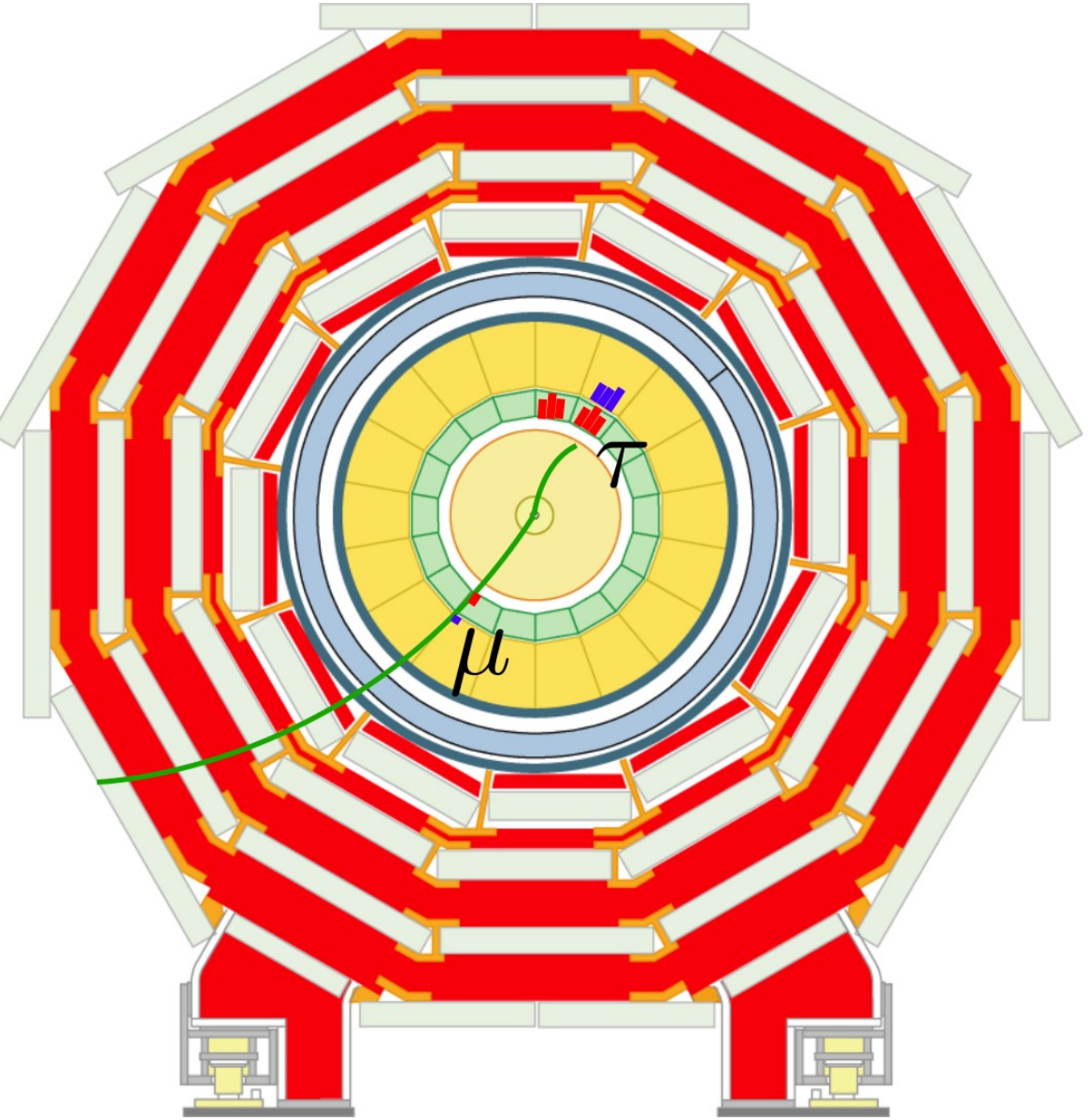
ON BEHALF OF
CMS COLLABORATION

VANDERBILT UNIVERSITY®

CMS Experiment



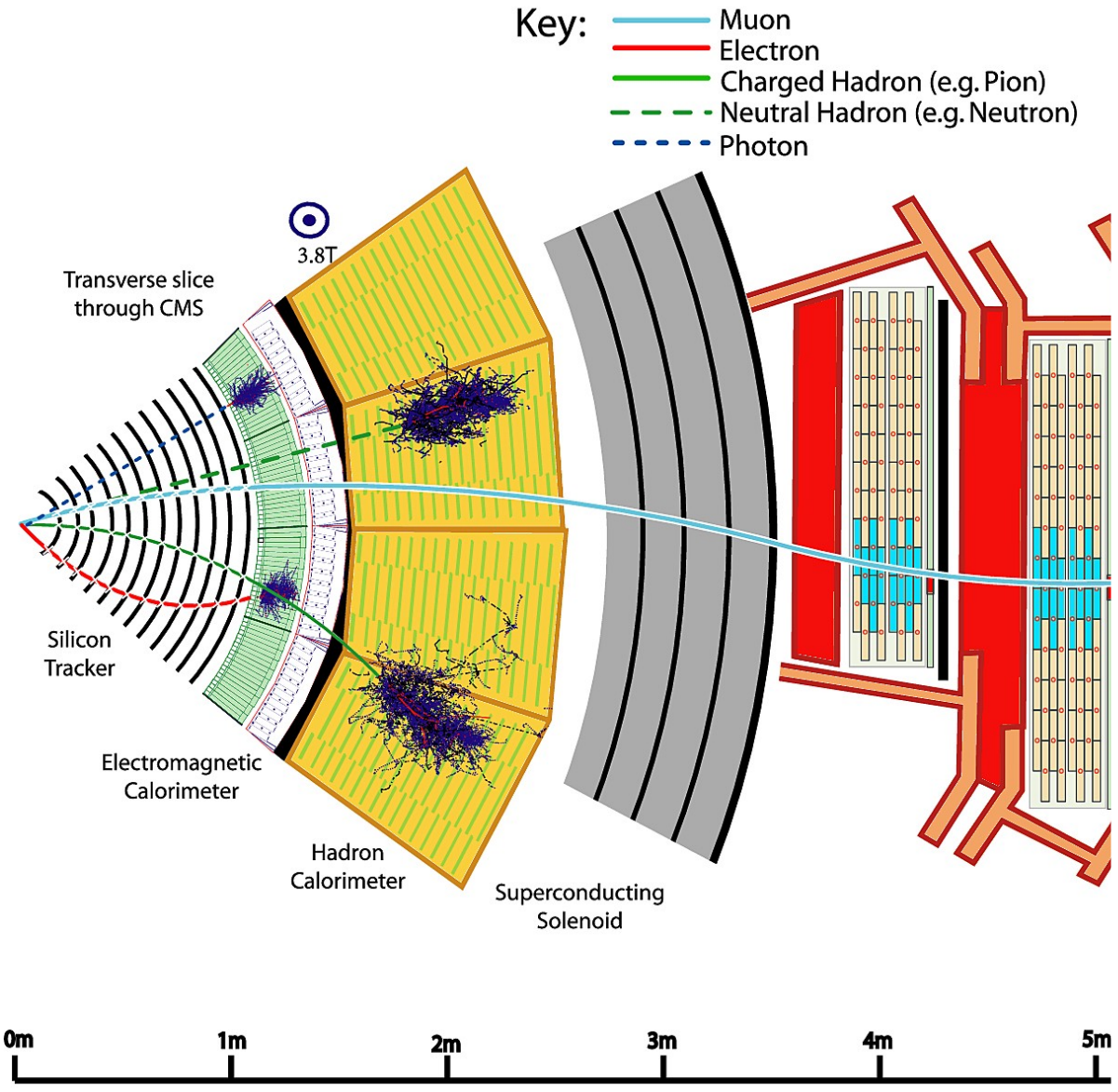
CMS has a great tau reconstruction:

High granularity **Pixel**
Full silicon **Strip**
Homogeneous **ECAL**
HCAL in the magnet
Muon system to veto

All subdetectors are combined to the best measurement of a single hadron

Most of the presented analysis use the data collected in 2016 corresponding to ~36 fb^{-1}

CMS Experiment



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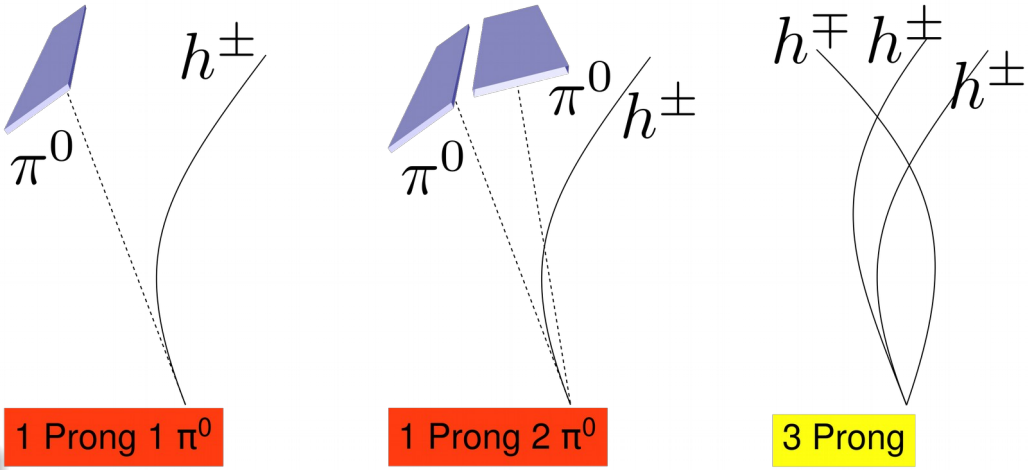
τ HPS: Hadron Plus Strips

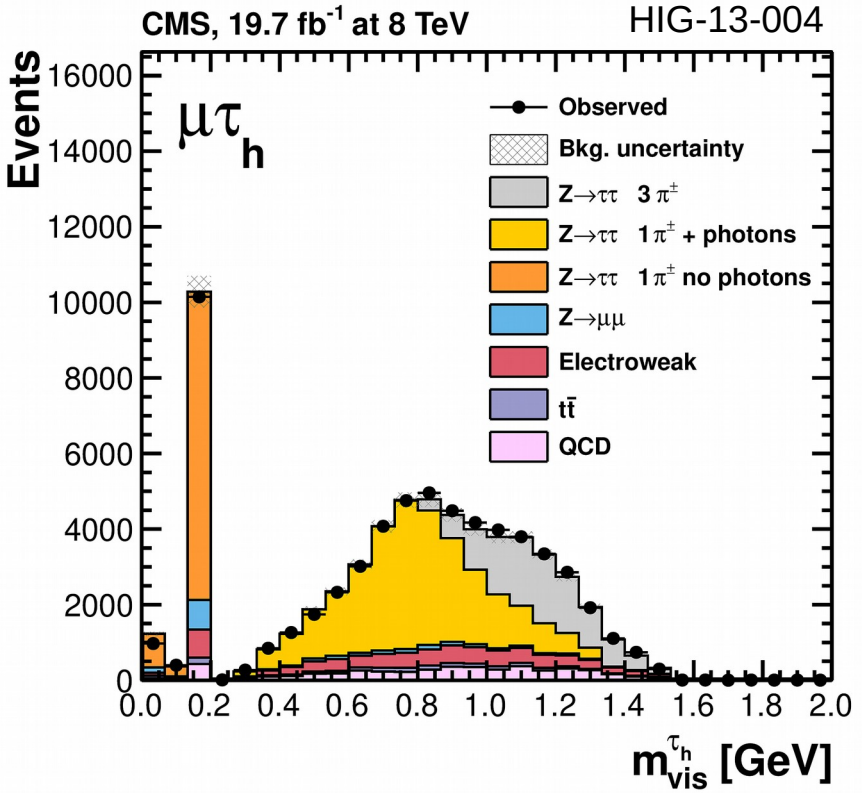
Combine (charged) Hadrons with the neutral π^0 which appear as a strip in the calorimeter



tau Mass 1.78 GeV

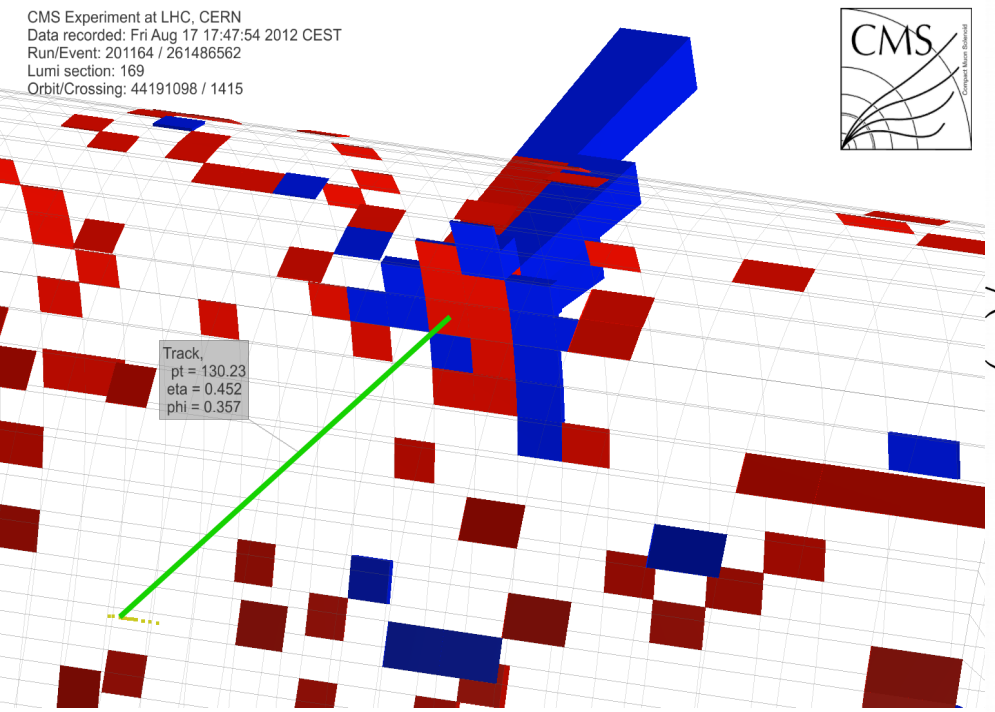
decay length $c \cdot \tau = 87.03\,\mu$m

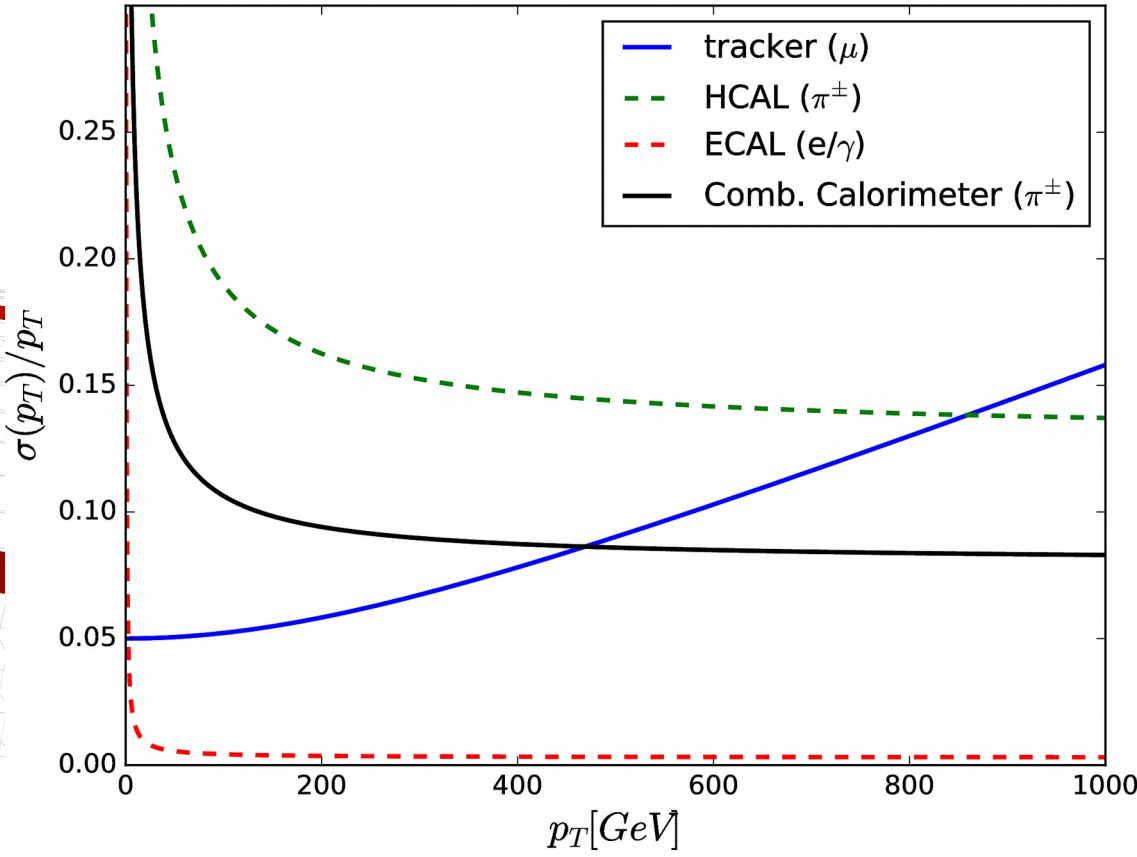
Decay Mode	Resonance	BR%
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$		17.4
$\tau^- \to \pi^- \nu_\tau$	$\pi(140\,\text{MeV})$	10.8
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770\,\text{MeV})$	26.0
$\tau^- \to h^- \pi^0 \pi^0 (\pi^0) \nu_\tau$	$a_1(1260\,\text{MeV})$	10.9
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260\,\text{MeV})$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		5.4
other had. decay modes		1.7
all had. decay modes		64.8



High p_T Taus

CMS TDR

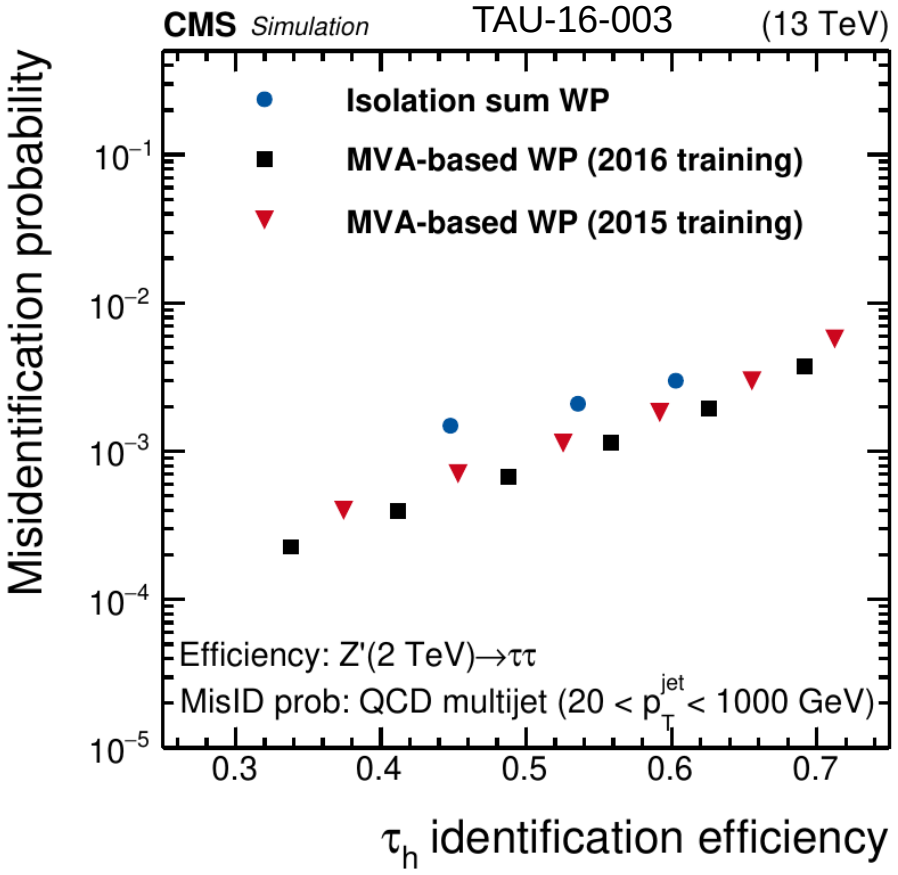


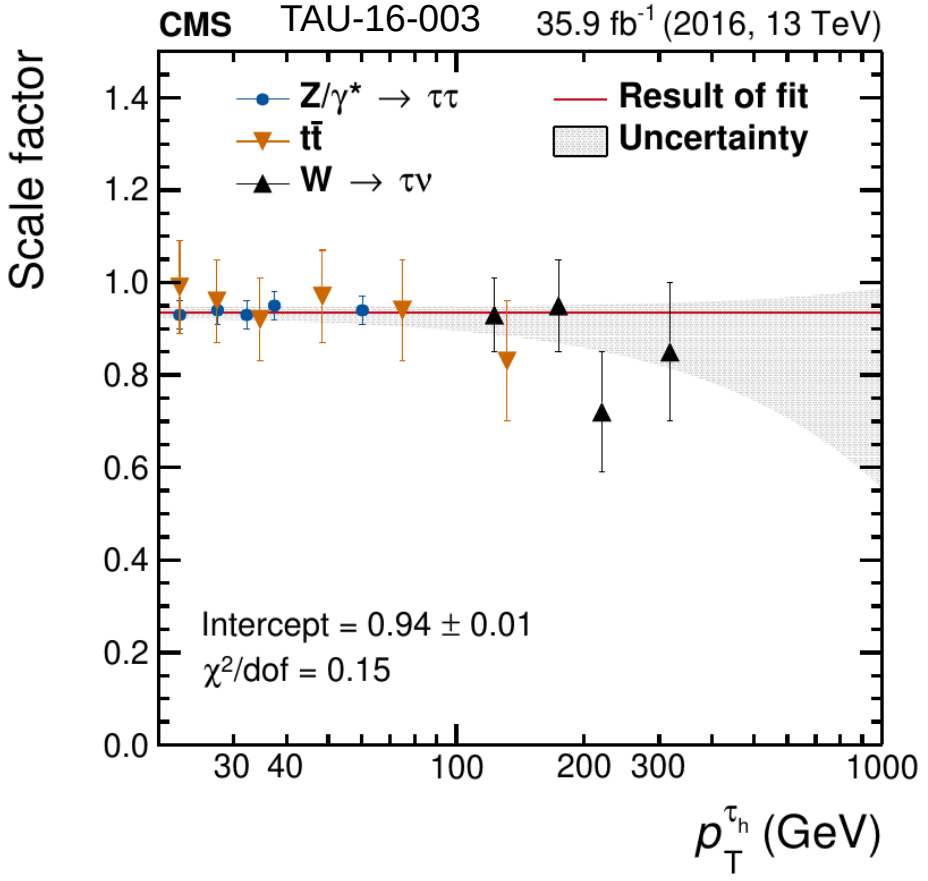


For high p_T taus calorimeters are better than tracks

→ A good combination of subdetectors is important

Tau Isolation

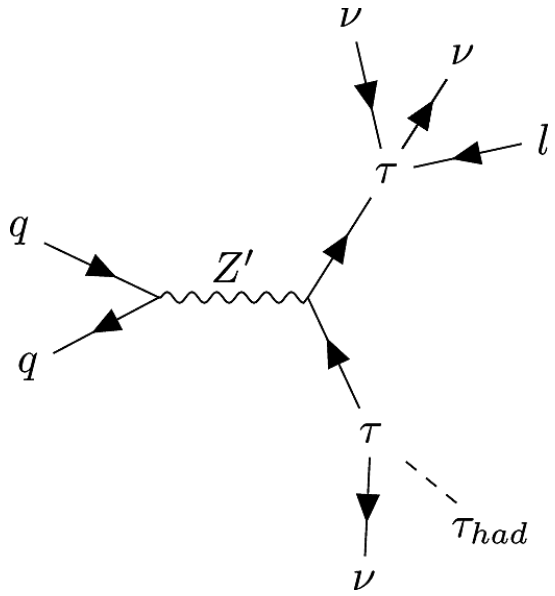


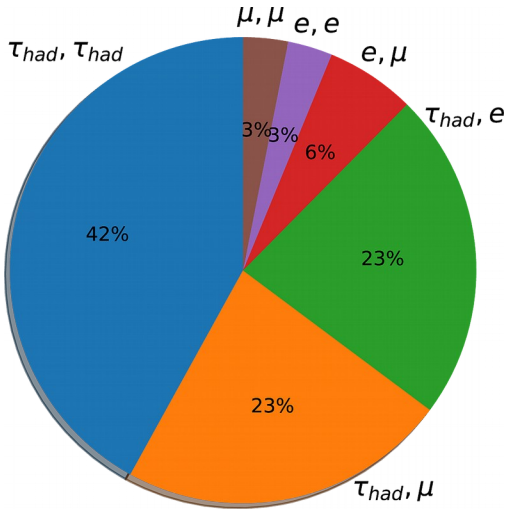


- Good tau identification allows separation of particles belonging to the tau and others.
- The MVA training is p_T aware and allows several working points
- The high p_T evolution is open for improvement

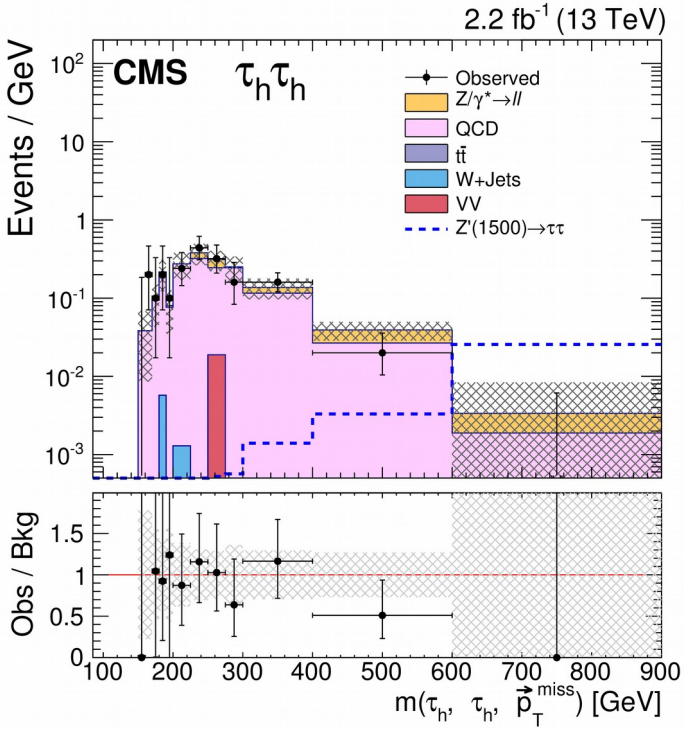
CMS-EXO-16-008

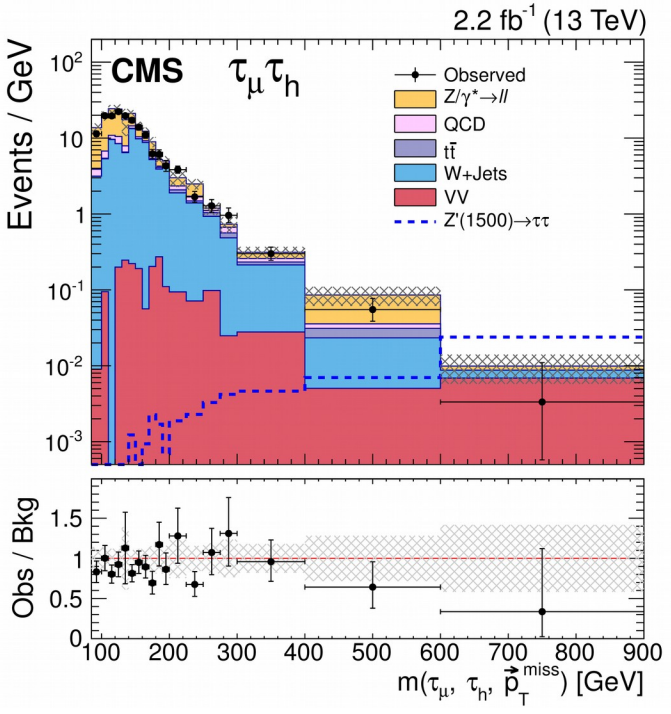
Z’ → ττ





Z’ → ττ final states

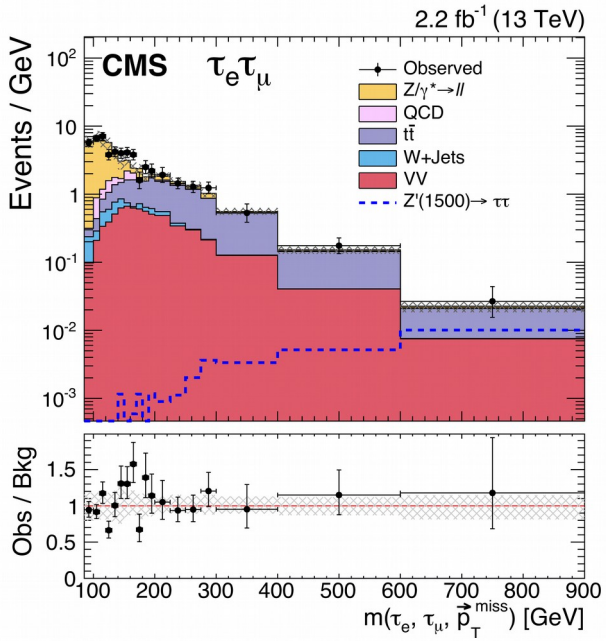


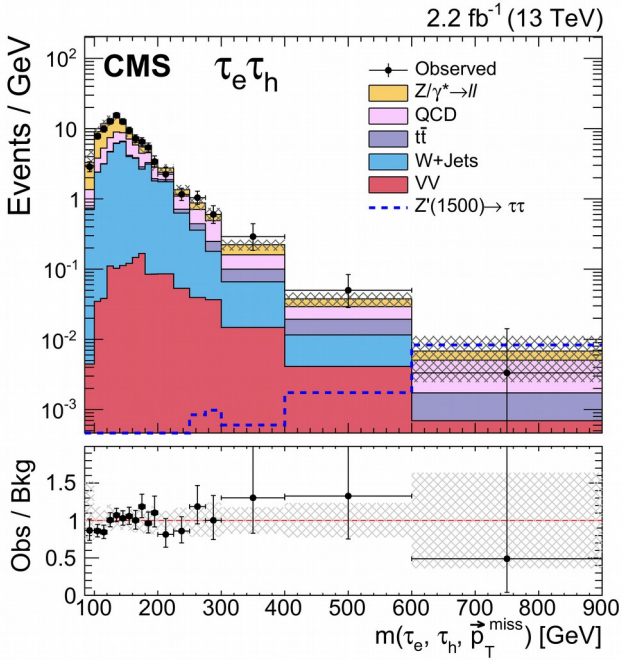


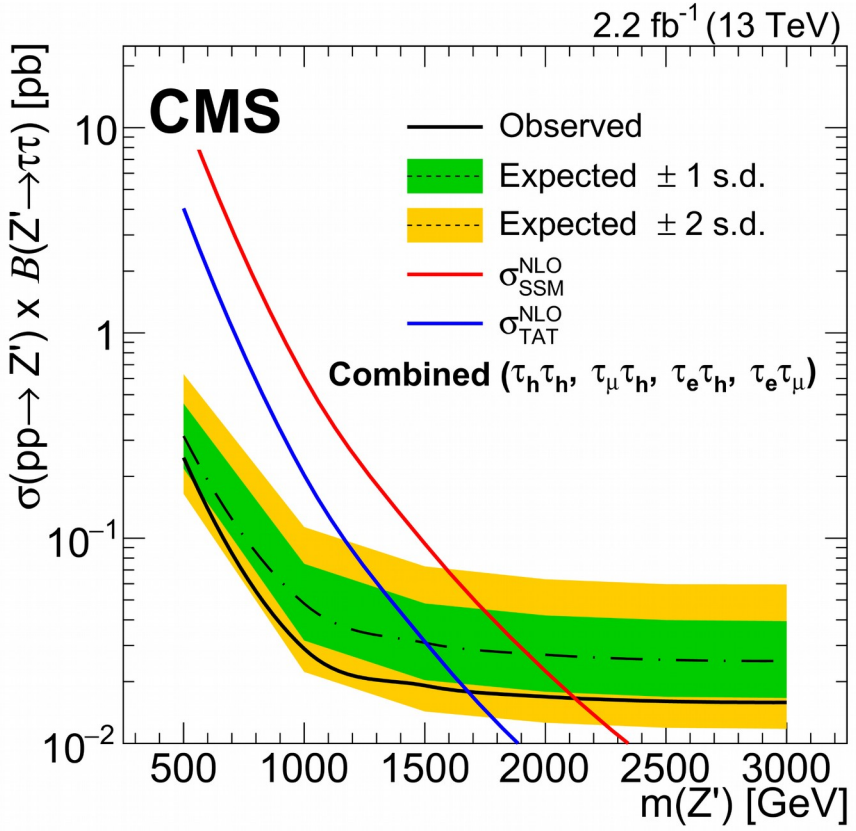
$$m(\tau_1, \tau_2, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})^2}$$

- Many final states
- Use event kinematics to distinguish from QCD di-jet events
- Various backgrounds dominant for the different final states
- Data driven approach to validate all background predictions

Z’ → ττ





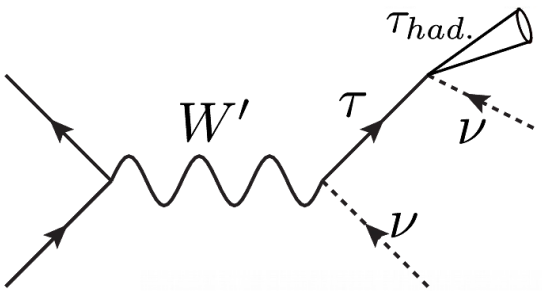


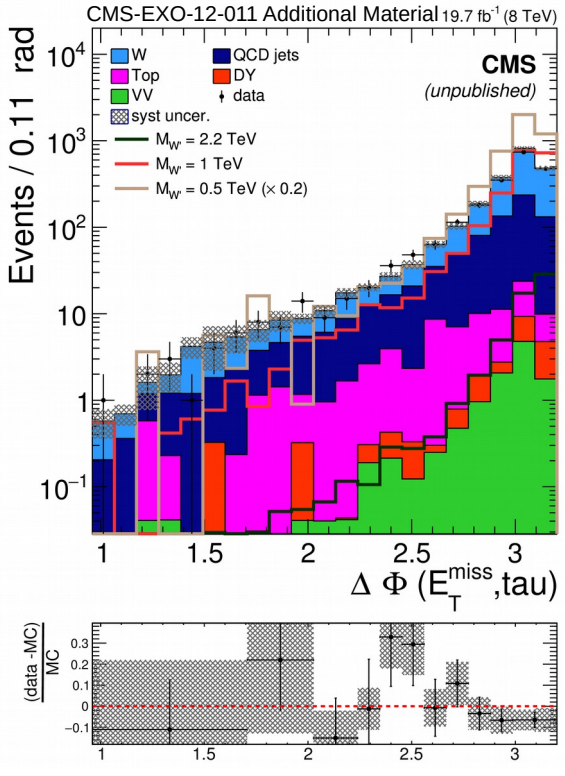
Sequential Standard Model (SSM)
- Carbon copy of the SM Z
- Allow for tt decay (changes branching fraction)

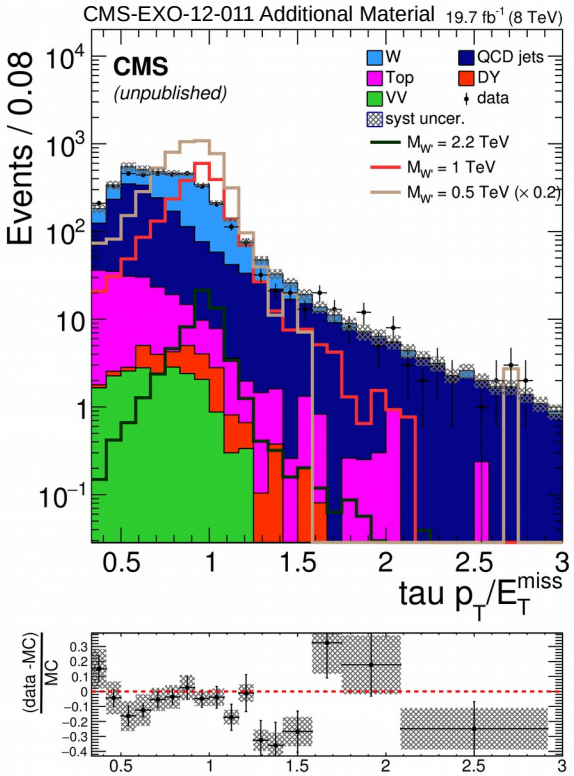
Topcolor-Assisted Technicolor (TAT)
- Higher coupling to third Gen. fermions
- 2HDM which would explain a heavy top

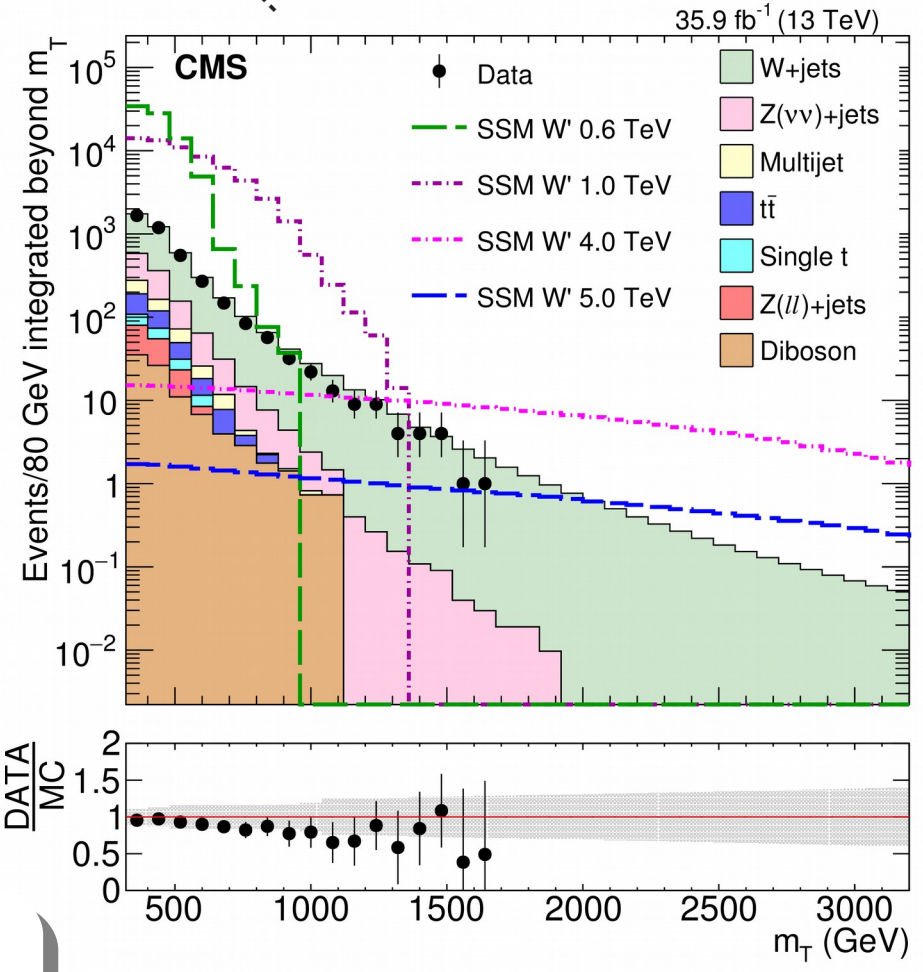
- pp data from 2015
- SSM exclusion $M_{Z'} < 2.1$ TeV

W'→ τν





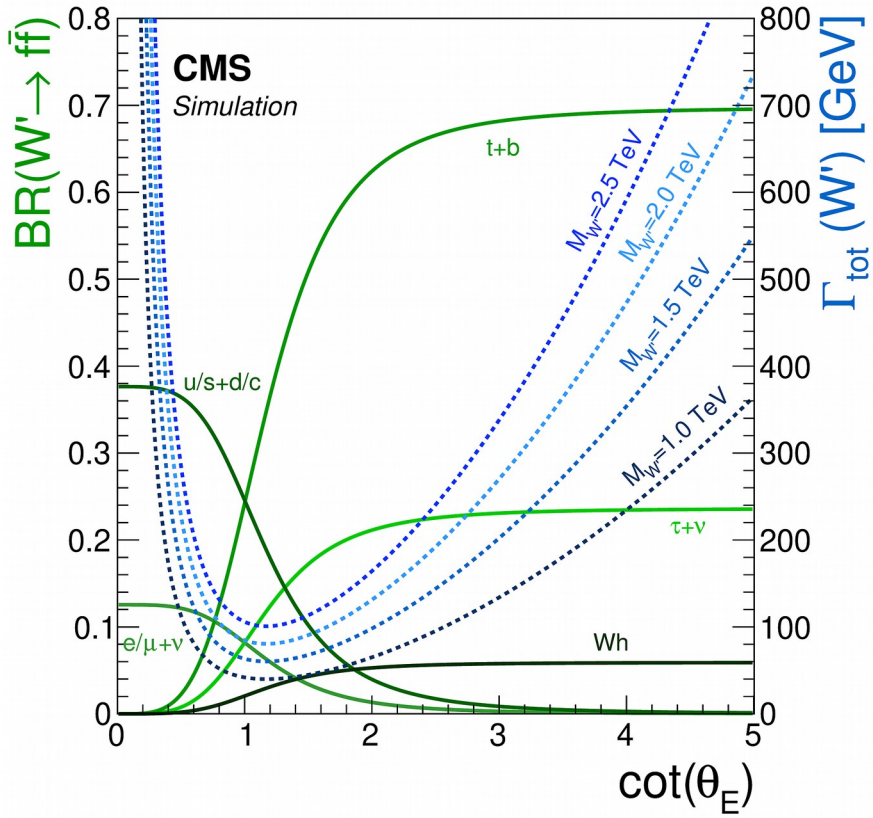


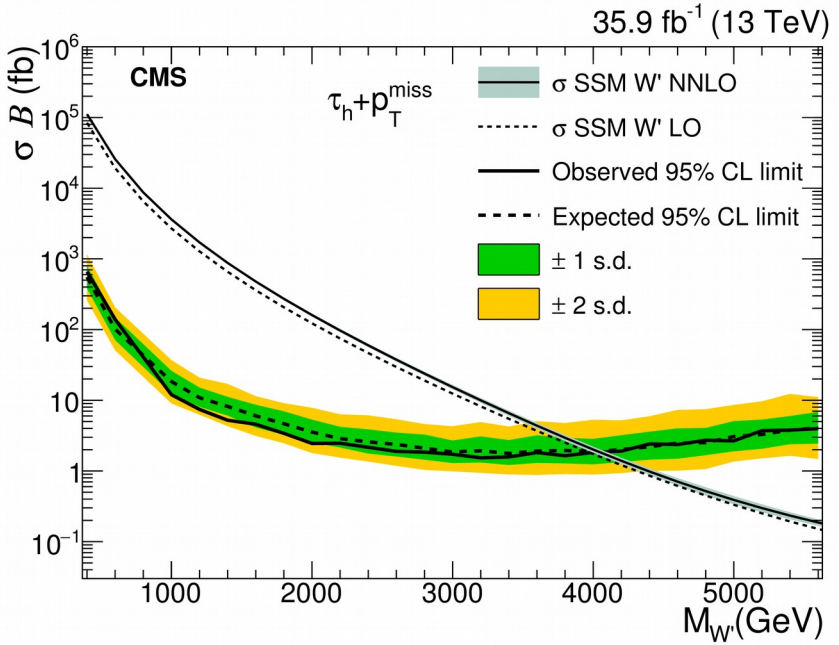


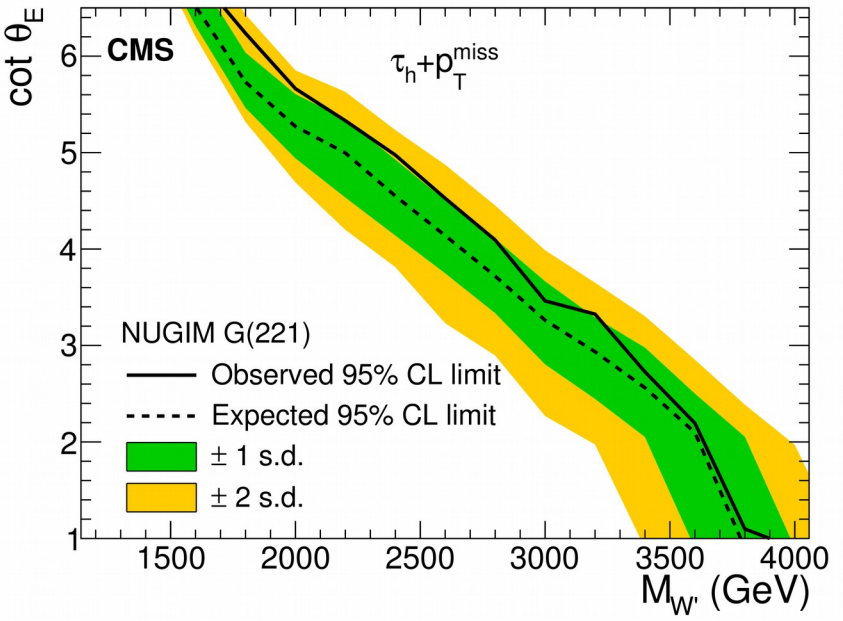
- Final state with only one tau in the event
- Properties are washed out but one can sill look for an access of events
- Can use kinematics to reduce QCD significantly

W'→ τν

- NUGIM G(221) same as TAT
- Search performs a scan of the mixing parameter
- Full 2016 pp data
- SSM exclusion $M_{w'}$< 4 TeV
- Event with the highest (published) tau p_T at the LHC

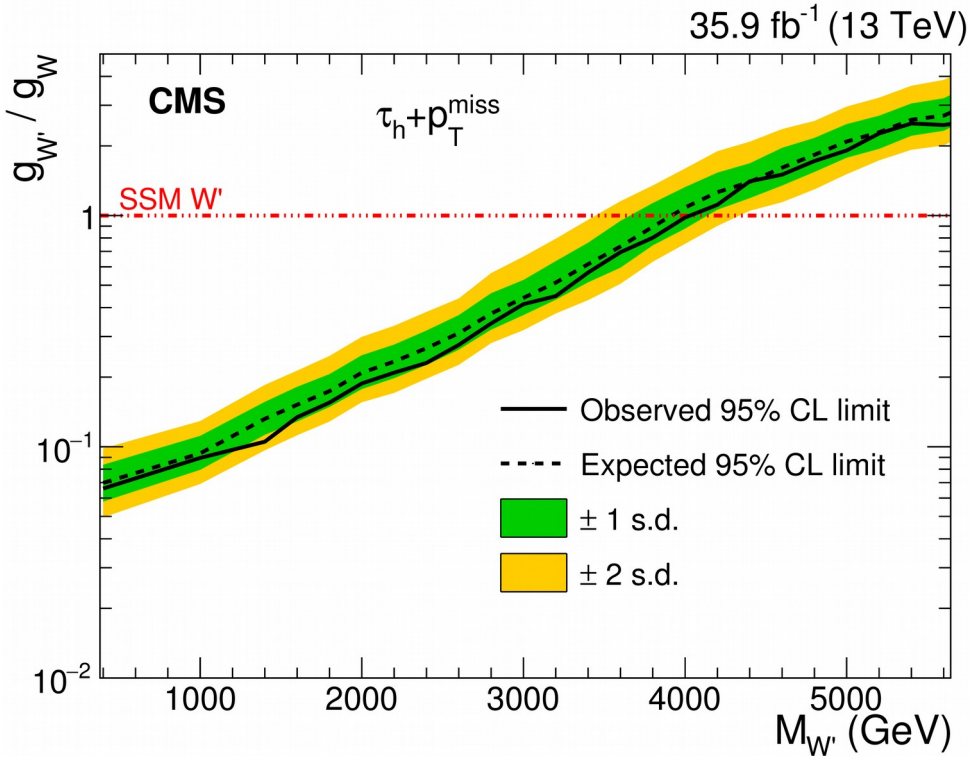


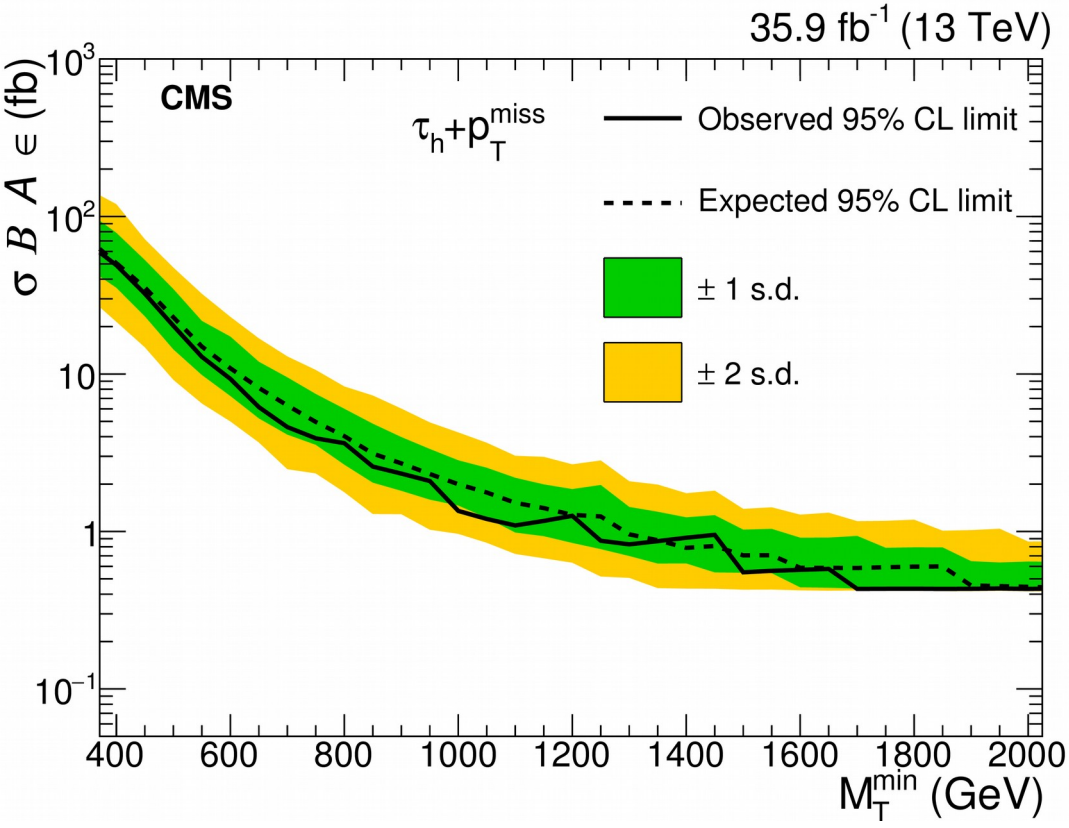




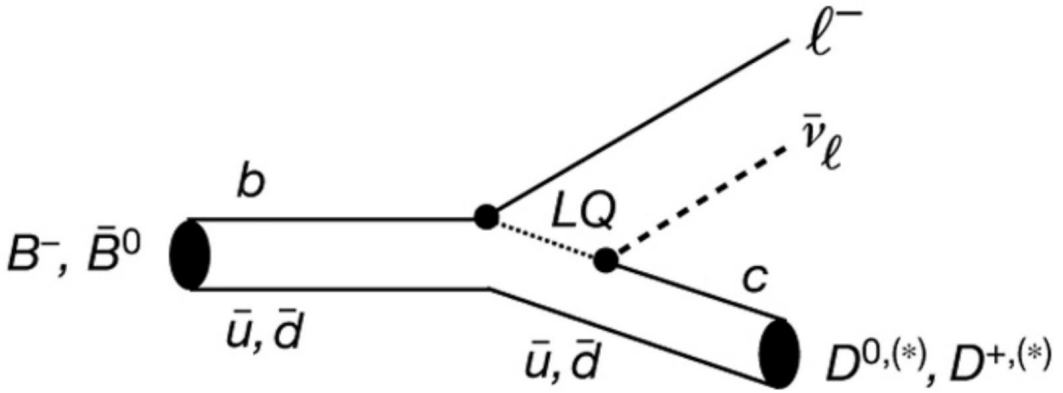
W'→ τν Comment

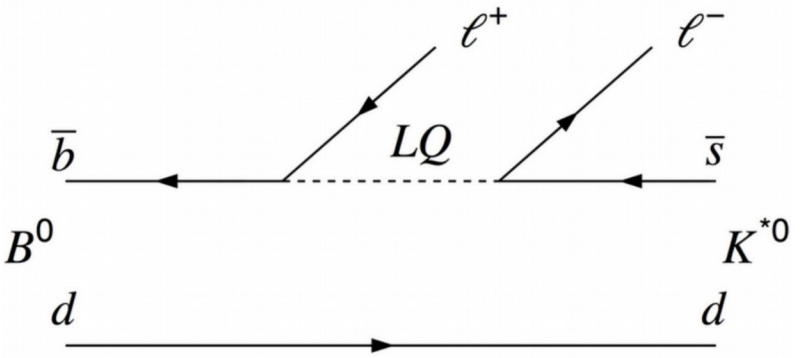
- Multiple model independent limits published
- Varying coupling strength
- Cross section exclusion as a function of M_T





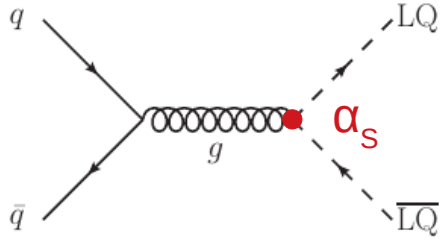
Leptoquarks with taus



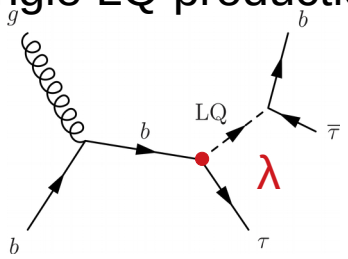


- Leptoquarks (LQ) predicted by several BSM theories
- Third generation of increased interest since they could explain the observed b-anomalies
- Several dedicated searches at CMS focus on three:
  - LQ pair production (CMS-EXO-16-023,CMS-PAS-EXO-17-016 **ττ+jj**,CMS-B2G-16-028 **t+τ**)
  - Single LQ production (CMS-EXO-17-029 **ττ+b**)

LQ pair production



Single LQ production



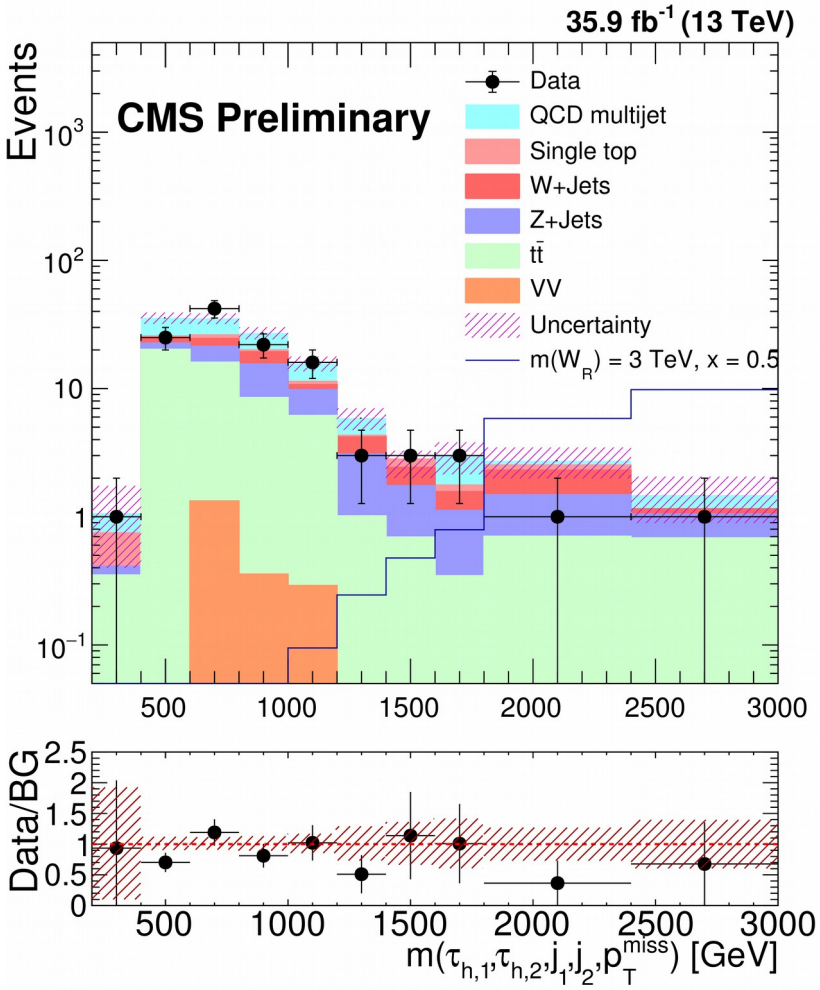
Single LQ production in **ττ+b**

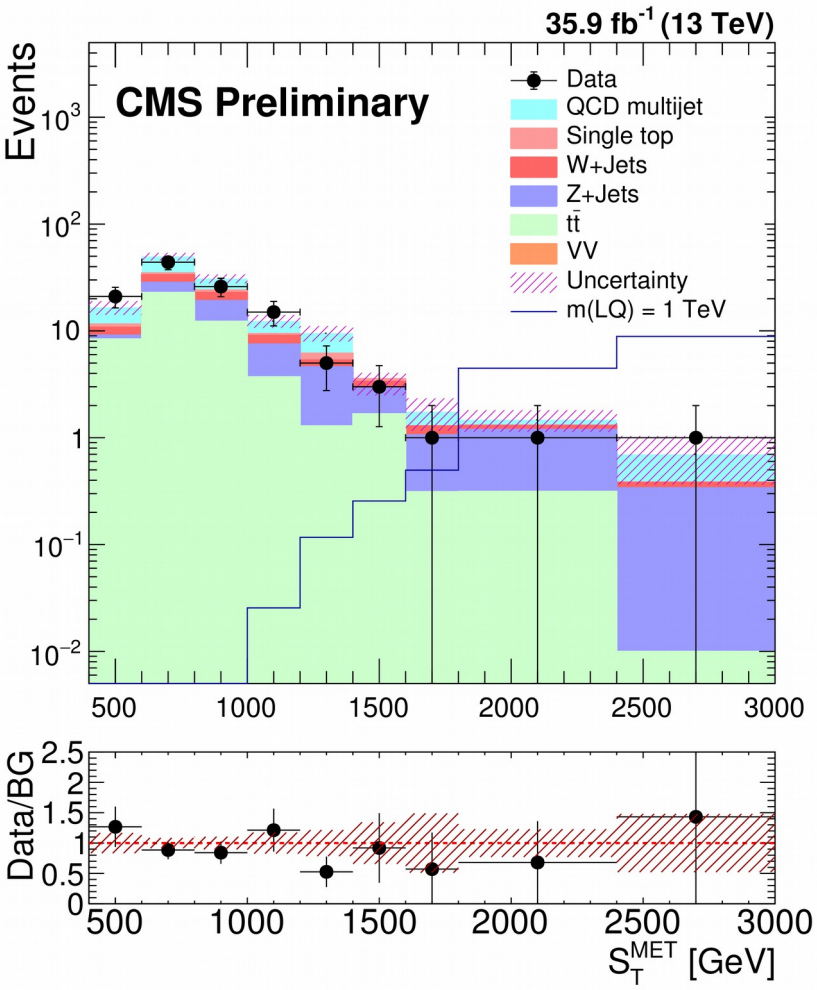
Pair production	β2	2β(1-β)	(1-β)2
1st gen	eejj	evjj	νvjj
2nd gen	μμjj	μvjj	
3rd gen	**ττ bb** **ττ tt** μμ tt	τv bt μv bt	νν bb νν tt

Will concentrate on **tau** final states

Run 2 CMS results available

LQ pair production ττ+jj

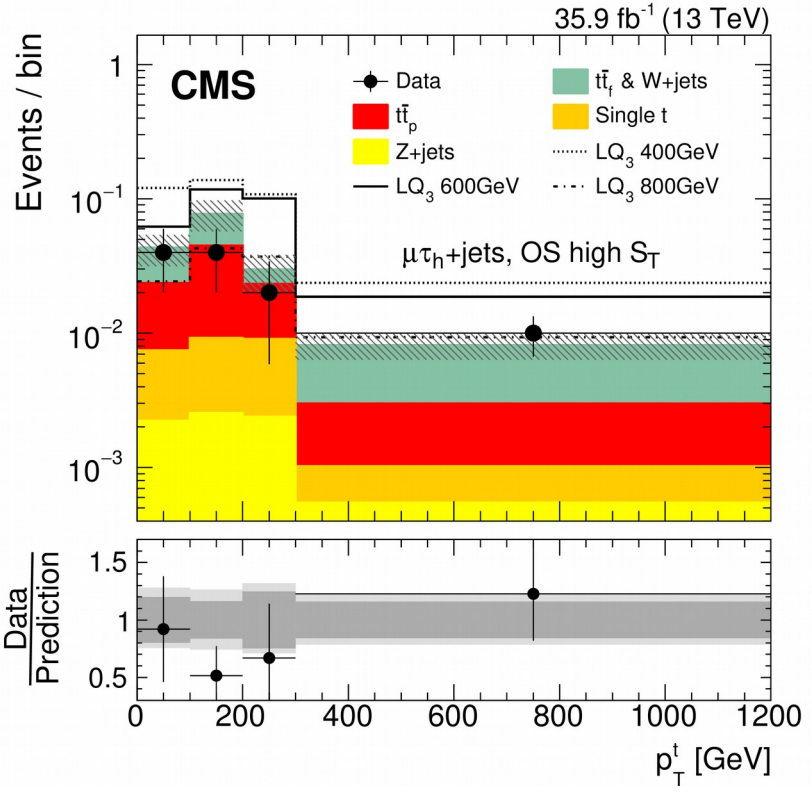




- Use $\tau_h\tau_h$ final state
- No B-tagging
- Full 2016 pp data
- No deviation observed

LQ pair production ttτ+Xj

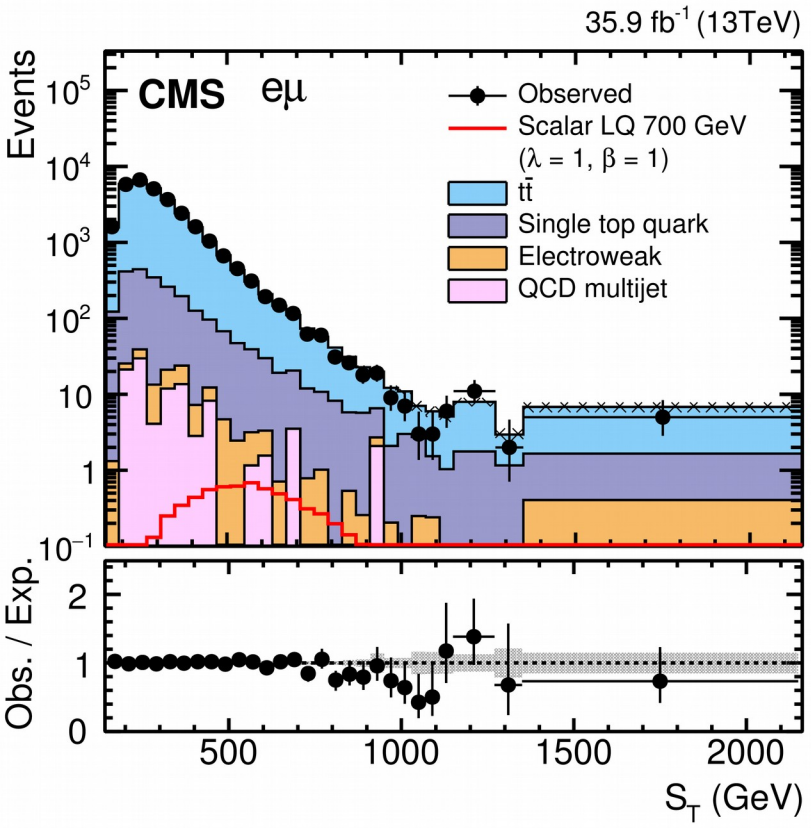
	Category A		Category B
	OS $\ell\tau_h$ + jets	SS $\ell\tau_h$ + jets	OS $\ell\tau_h\tau_h$ + jets
Jet selection	$\geq$4 jets	$\geq$3 jets	$\geq$3 jets
p_T^{miss} selection	$p_T^{miss} > 100$ GeV	$p_T^{miss} > 50$ GeV	$p_T^{miss} > 50$ GeV
τ_h selection	$p_T > 100$ GeV		$p_T^{\tau 1} > 65$ GeV, $p_T^{\tau 2} > 35$ GeV
b tagging	$\geq$1 b tag		—
S_T selection	—		$S_T > 350$ GeV
Fit variable	p_T^t in two S_T bins		number of events

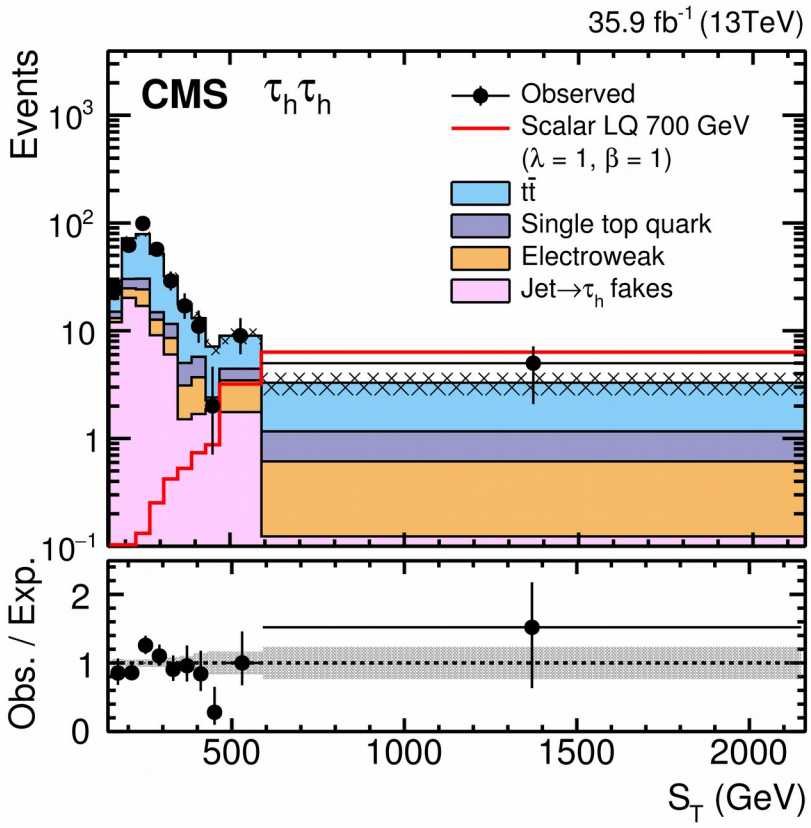


Search in e/μ+τ(τ) with jets

- tt dominant background estimated from data with normalization factors from simulation
- 9 signal regions combined
  - ➔ Enhancing sensitivity in various signal regions

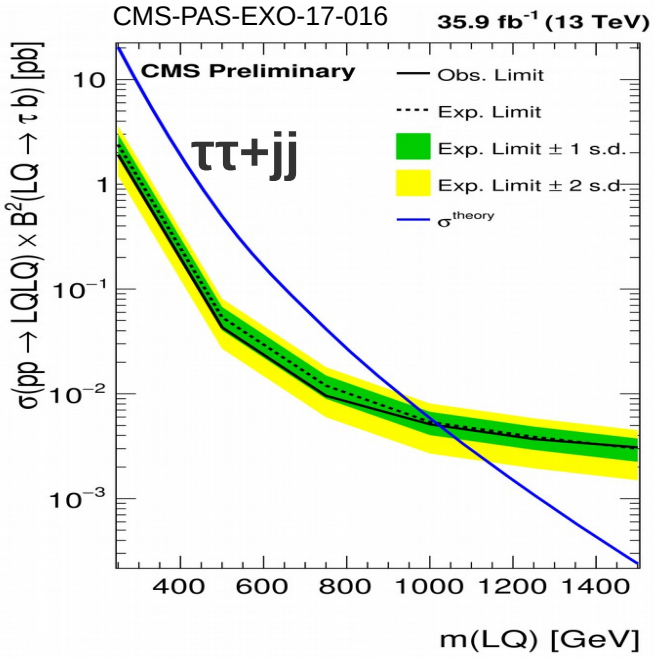
Single LQ production ττ+b

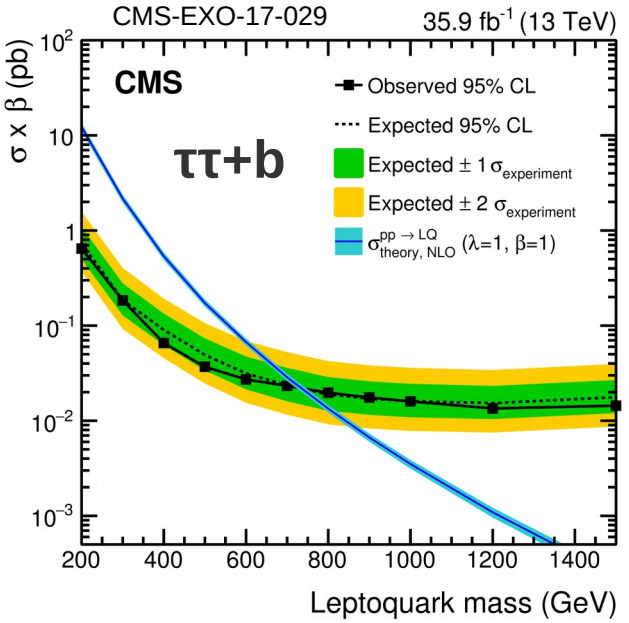


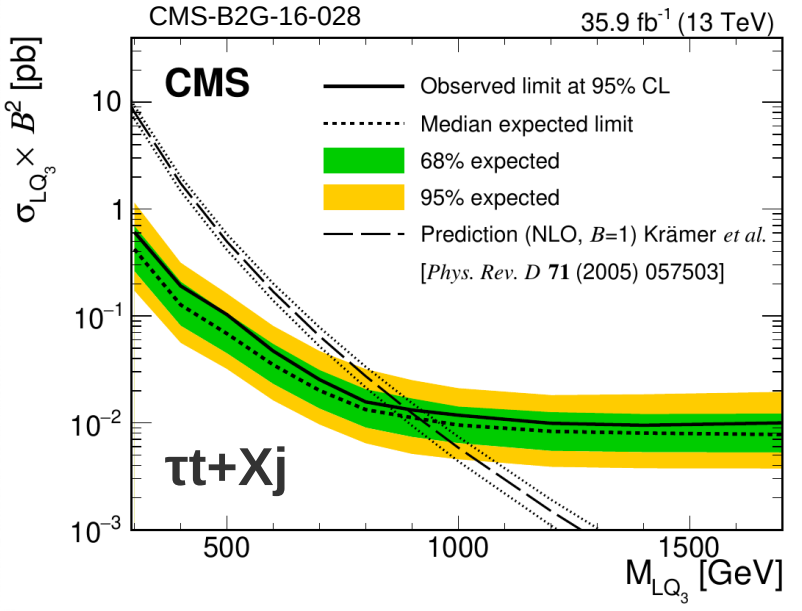


- Use μτ, eτ and $\tau_h\tau_h$ final state
- Full 2016 pp data
- No strong deviations observed

LQ results

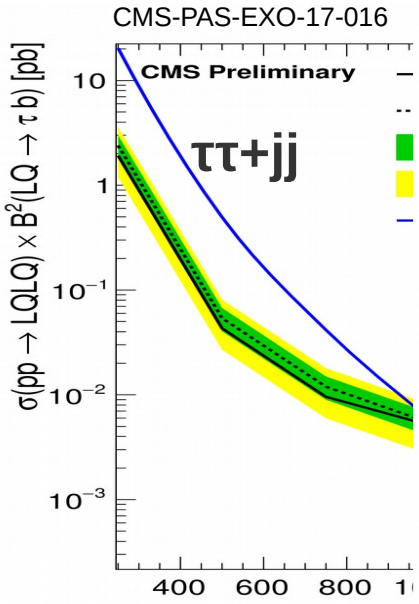


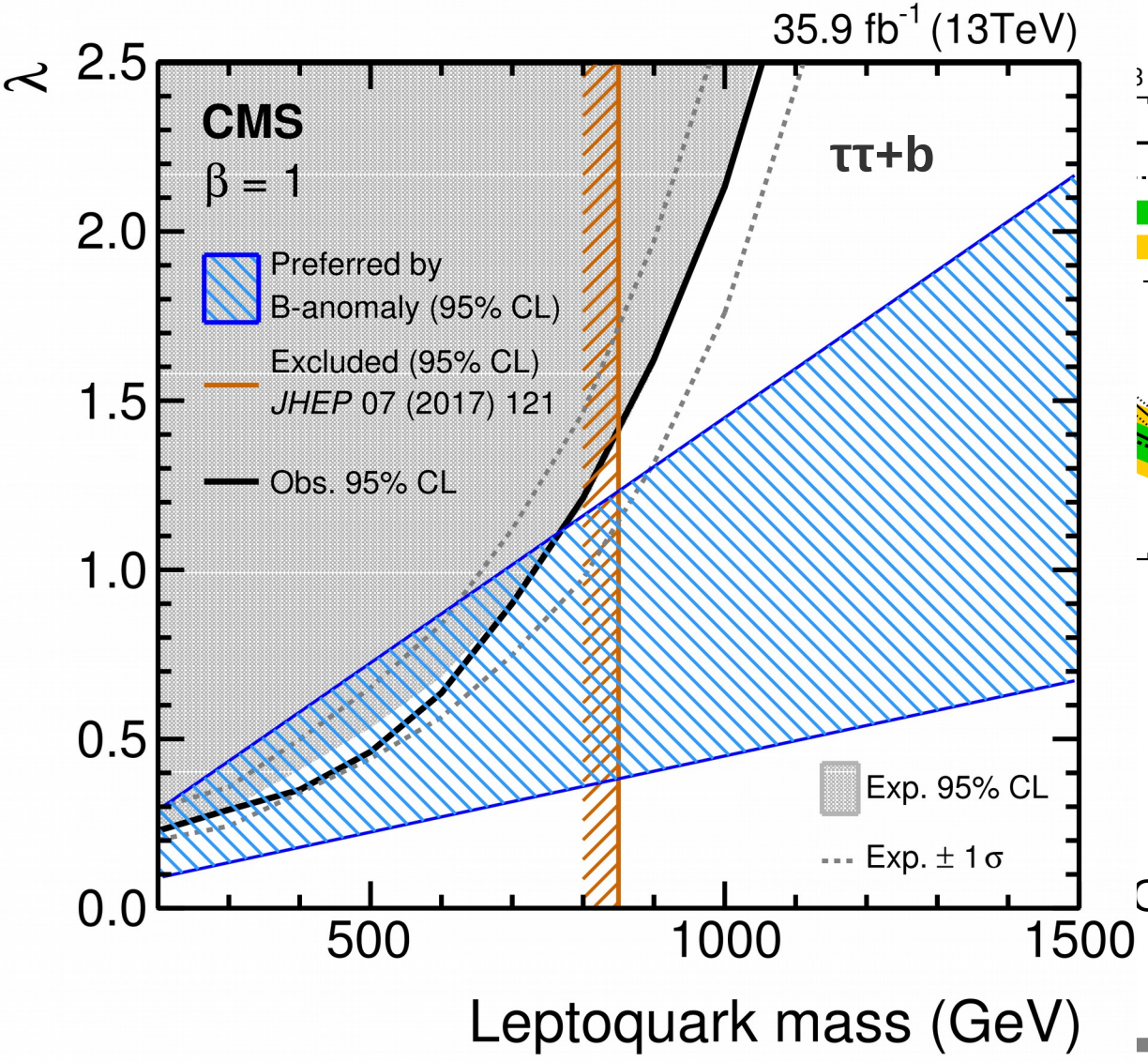


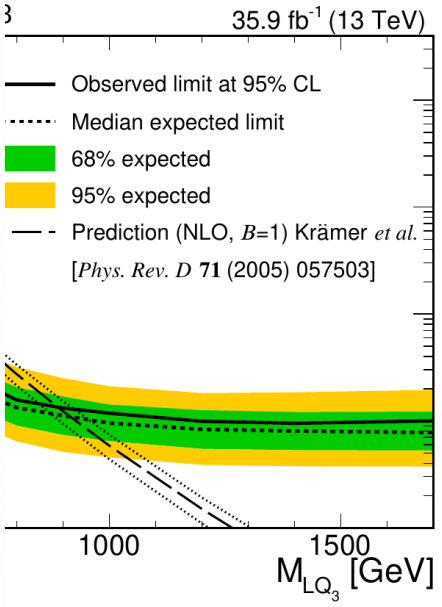


- LQ with tau final states are of huge interest
- No deviation from the standard model seen for $M_{LQ} < 1020GeV$
- Strongest deviation in ττ+b ~500GeV within 1σ

LQ results







- L
- N
- S

LQ results

CMS searches in:

- τb τb, νt νt, νb νb, τt τt, and μt μt for LQ pair productions
- νj νj, νb νb, and νt νt as reinterpretation of SUSY M_{T2} search
- ττb for single LQ production

τb

- Scalar LQ: $M_{LQ} < 1020$GeV
- Vector LQ: $M_{LQ} < 950$GeV

CMS-PAS-EXO-17-016
CMS-EXO-17-029

τt

- Scalar LQ: $M_{LQ} < 900$GeV

CMS-EXO-17-029

μt

- Scalar LQ: $M_{LQ} < 900$GeV

CMS-B2G-16-027

νq/νb/νt

- Scalar LQ: $M_{LQ} < 1790/1810/1780$ GeV
- Vector LQ: $M_{LQ} < 980/1100/1020$ GeV

CMS-SUS-18-001

Summary

- Taus become more relevant as third generation fermions
- Good tau identification for the full tau p_T range.
- No new physics observed yet
- No signs for LQ for $M_{LQ} < 1TeV$

  ➔ **Room left for LQ discovery**

  ➔ **LS2 will be the time to improve the anlysis further**