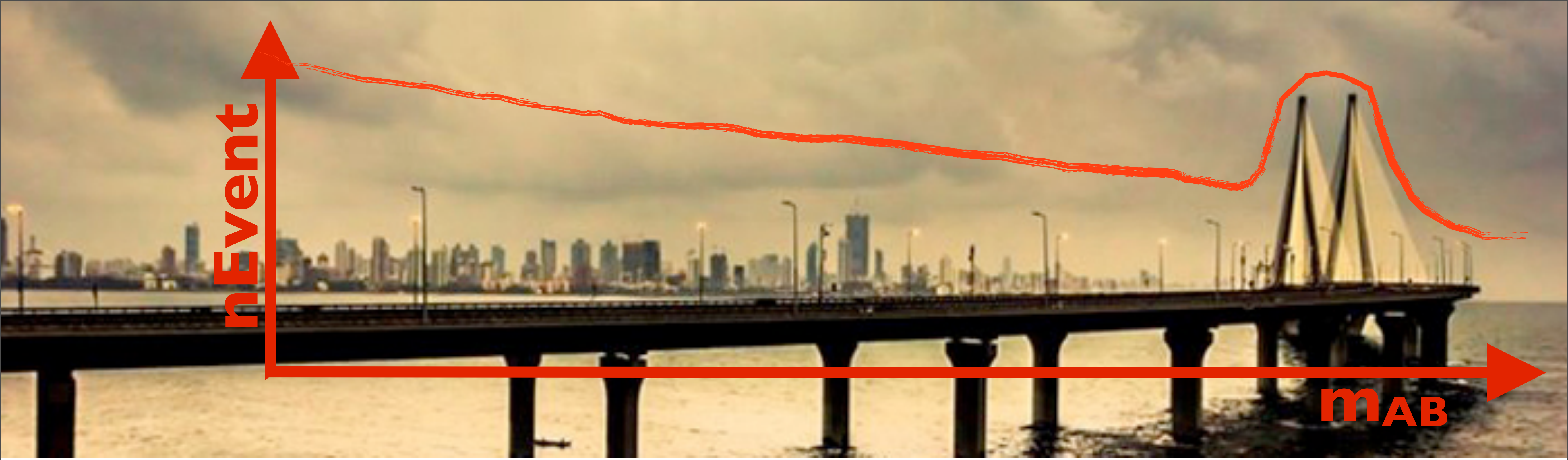

Search for new heavy resonances in final states with leptons and photons at CMS

Swagata Mukherjee *On behalf of the CMS Collaboration*

SUSY 2017,
TIFR, Mumbai, India

Physics Institute III A

RWTH AACHEN UNIVERSITY

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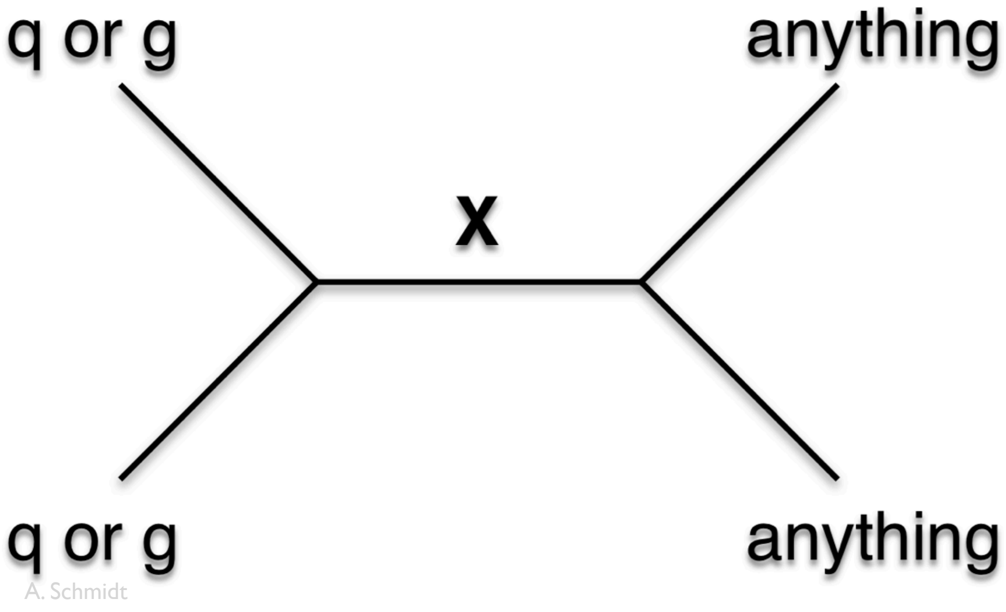
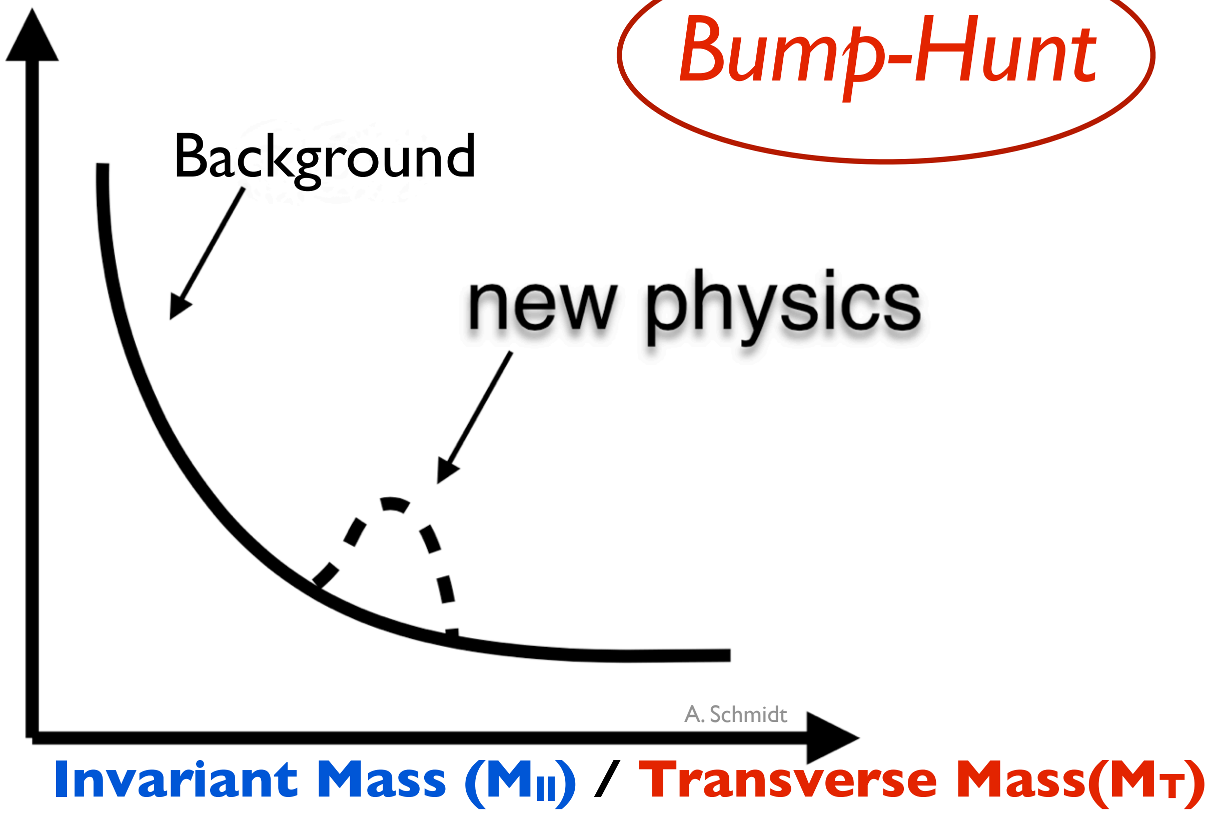
Introduction





Bump-Hunt

Broadly divided into 2 categories

Fully reconstructed final state

<u>This talk</u>

ee

μμ

eμ

γγ

Focus on lepton and photon.
Cleanest probe of new physics.

Final state not fully reconstructed

MET in the final state

<u>This talk</u>

ττ

e+MET

μ+MET

τ+MET

$\sim 13\ fb^{-1}$ 2016 data CMS-PAS-EXO-16-031

ee/μμ

Experimental Signature

- At least one pair of e or μ
  - Opposite sign μ-pair
- High p_T
  - $E_T(e) > 35$ GeV, $p_T(\mu) > 53$ GeV
- Isolated

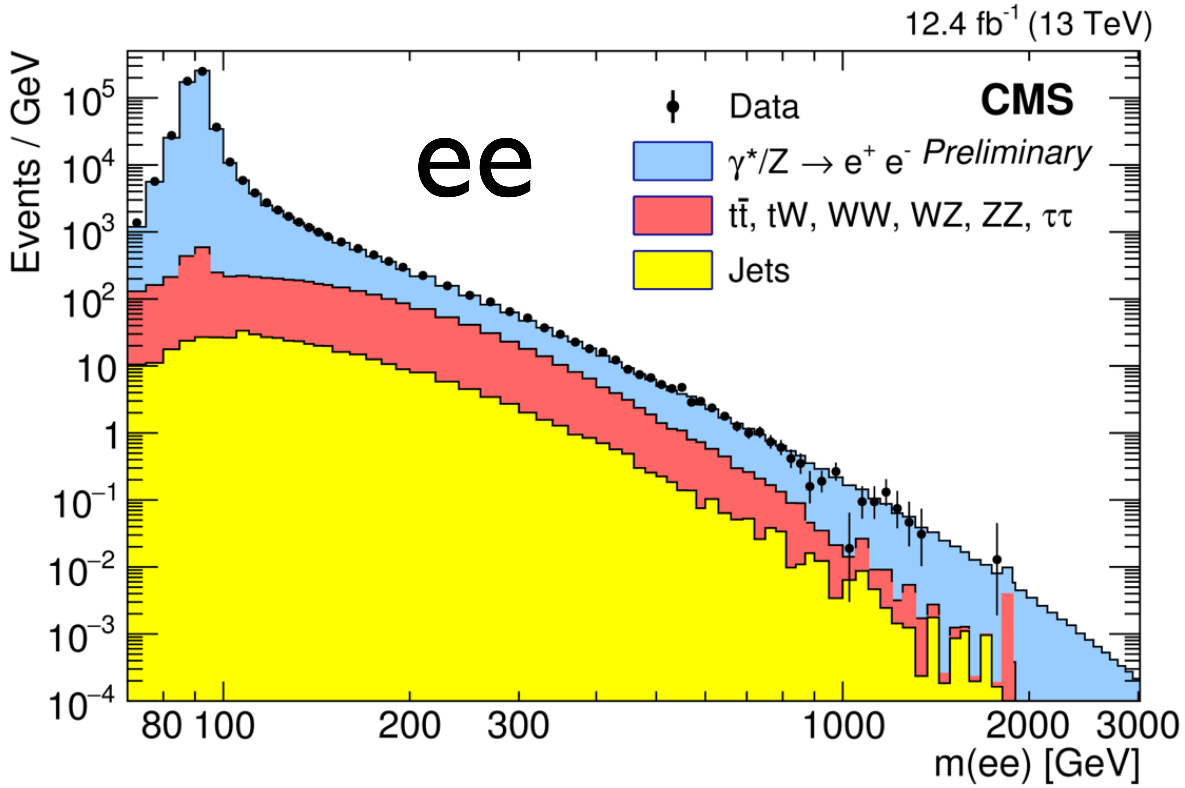
Background

Real Leptons

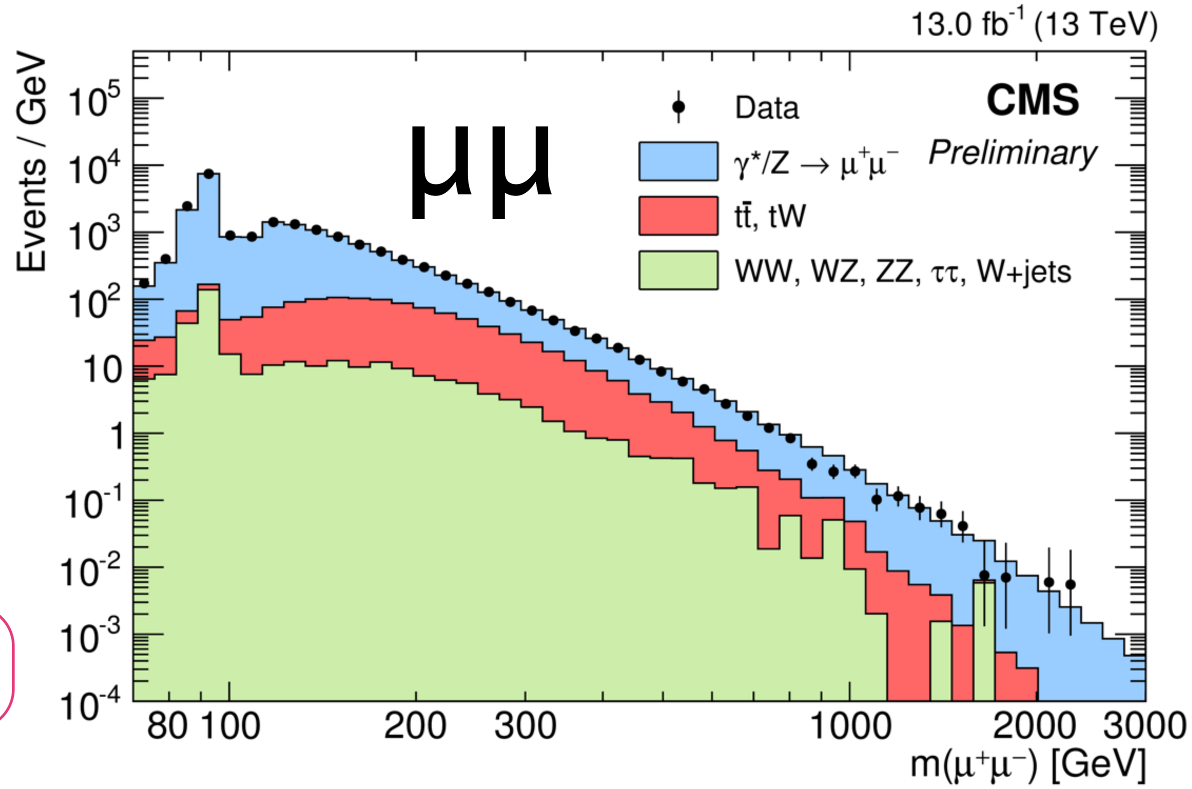
- **Dominant**
  - Drell-Yan (irreducible)
- **Other**
  - Top
  - Diboson

- W+Jets, QCD (e channel)

Jet faking electron. Data-driven.



No significant excess

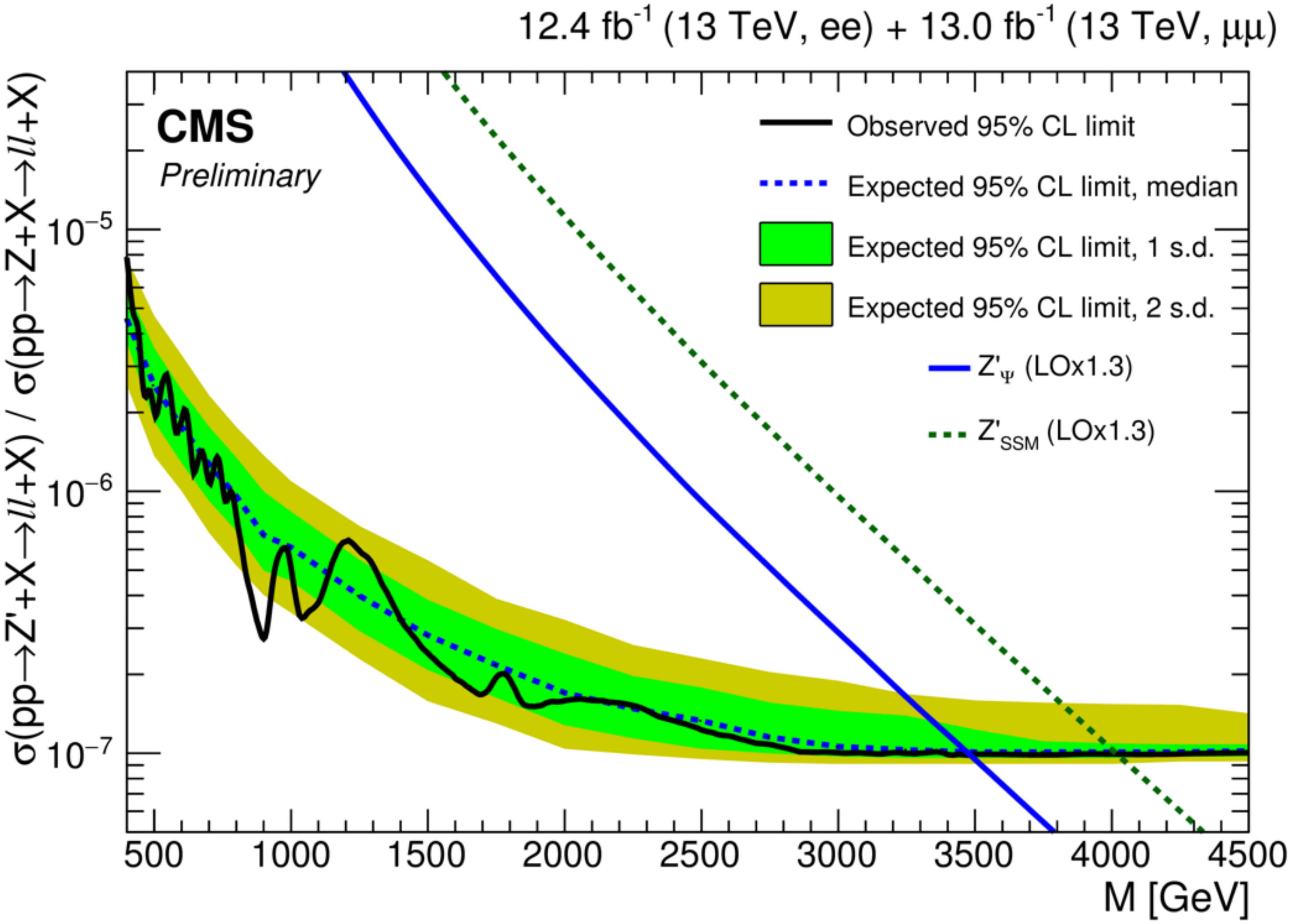


~13 fb^{-1} 2016 data CMS-PAS-EXO-16-031

ee/μμ

Theoretical Interpretation

- Sequential Standard Model (SSM)
  - Extended gauge group, additional U(1) symmetry
  - Predicts heavy Z'_{SSM} boson with SM-like couplings
  - Intrinsic width 3%
- GUT inspired model
  - E_6 gauge group
  - Predicts heavy Z'_{ψ}
  - Intrinsic width 0.6%



New particle	Mass Limit
Z'_{SSM}	4.0 TeV
Z'_{ψ}	3.5 TeV

eμ Lepton Flavor Violating (LFV) decay

CMS PAS EXO-16-058

HOT OFF THE PRESS

Experimental Signature

- e and μ → High p_T, isolated
- No other signal-specific cut in order to stay **model independent**

Background

- **Dominant**
  - TTbar, Diboson
- **Other**
  - Single Top
  - Drell-Yan

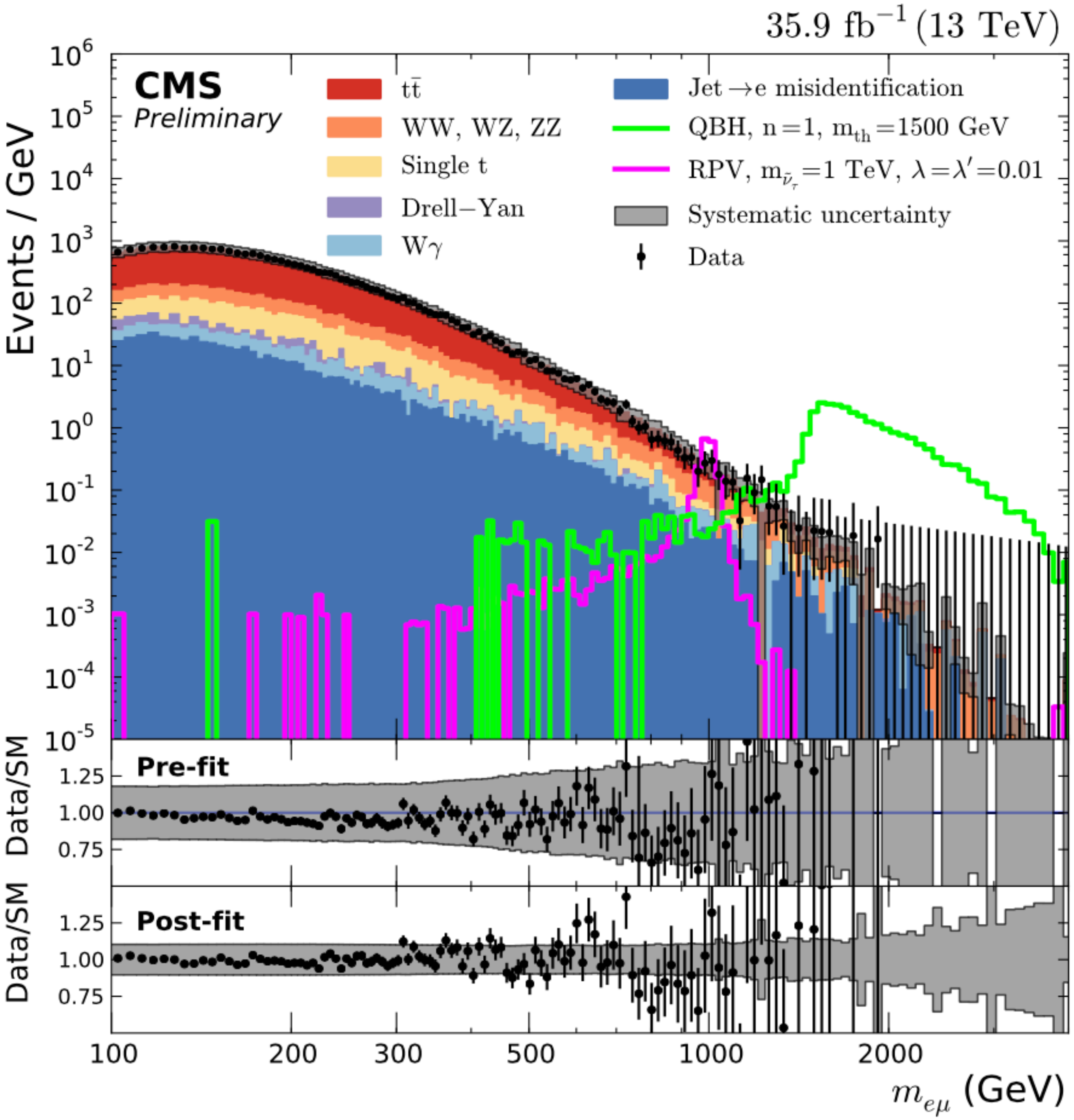
Real Leptons

- Wɣ

ɣ mis-identified as e

- W+Jets, QCD

Jet mis-identified as electron (Data-driven)



Limit extraction variable: Meμ

No significant excess

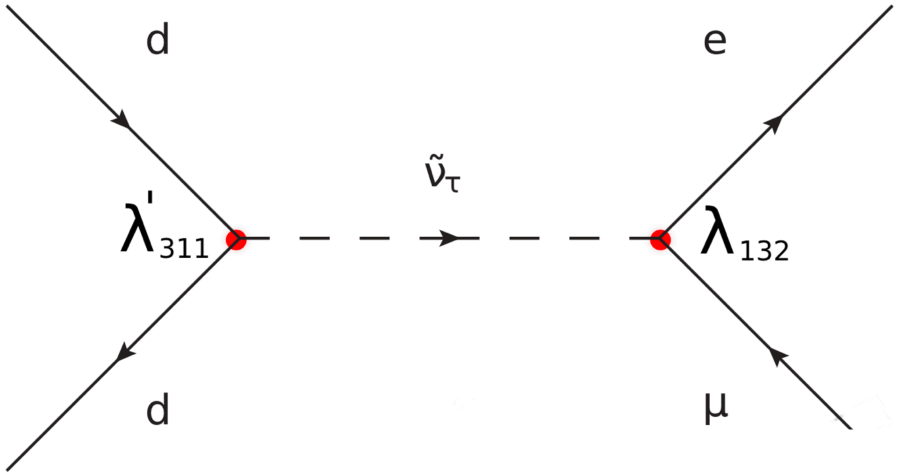
$\lambda_{132}\lambda'_{311} < 3.3 \times 10^{-7}\ (M_{\tilde{\nu}_\tau}/1\,\mathrm{TeV})^2$ at 90% CL

Strong indirect limits from low-energy muon conversion experiments

eμ

CMS PAS EXO-16-058

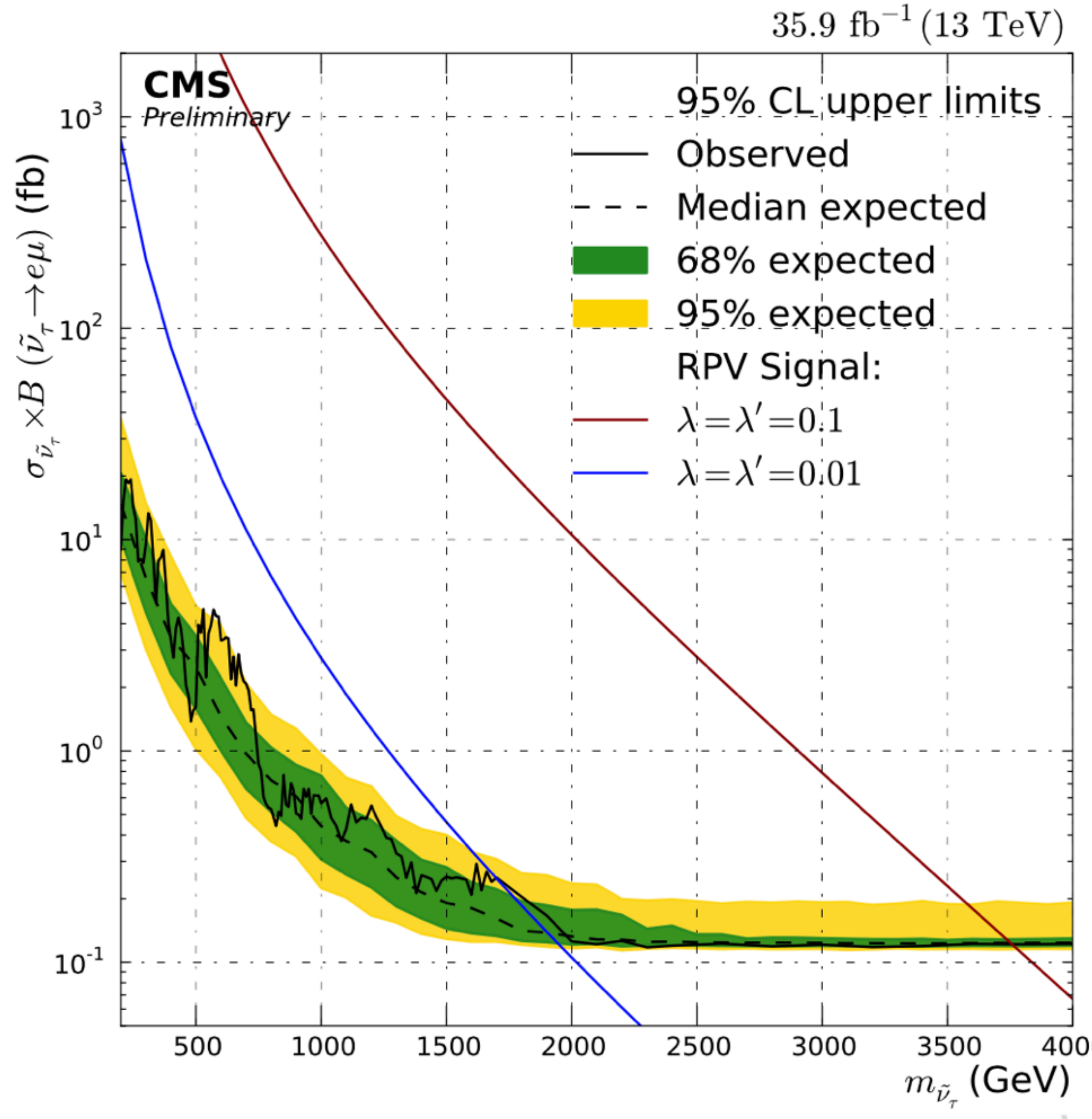
HOT OFF THE PRESS



Theoretical Interpretation

- R-Parity violating SUSY
  - Resonant production of τ sneutrino (LSP)
  - All RPV couplings vanish, except λ'_{311}, λ_{132}, λ_{231}

Coupling	mass limit
λ'= λ=0.01	1.7 TeV
λ'= λ=0.1	3.8 TeV



eμ

CMS PAS EXO-16-058

$$\mathcal{L}_{Z'\to l_1 l_2} \propto \frac{g_{EW}}{2\cos\theta_W}\kappa_{ij} Z'_\mu \left[\frac{1}{2}\bar{l}_1\gamma^\mu\gamma_5 l_2 - \left(\frac{1}{2} - 2\sin^2\theta_W\right)\bar{l}_1\gamma^\mu l_2\right]$$

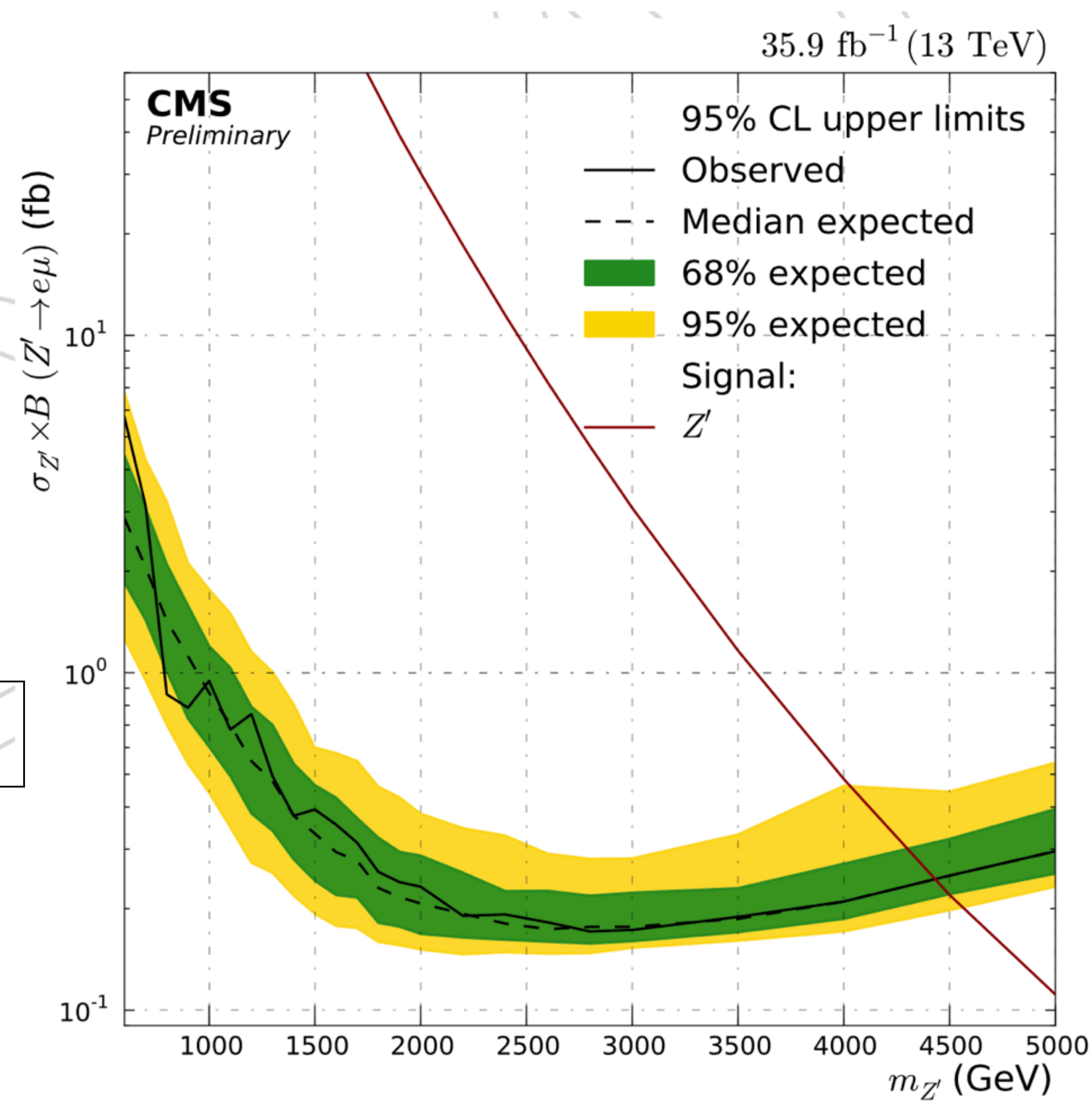
HOT OFF THE PRESS

Theoretical Interpretation

- ❖Z' in a LFV model
  - ❖SSM-like Z'
  - ❖Z'→eμ decay allowed
  - ❖Width 3%

Excluded upto 4.4 TeV

QBH interpretation in Shubhanshu's talk on Thursday @14.55



γγ

Phys. Lett. B 767 (2017) 147

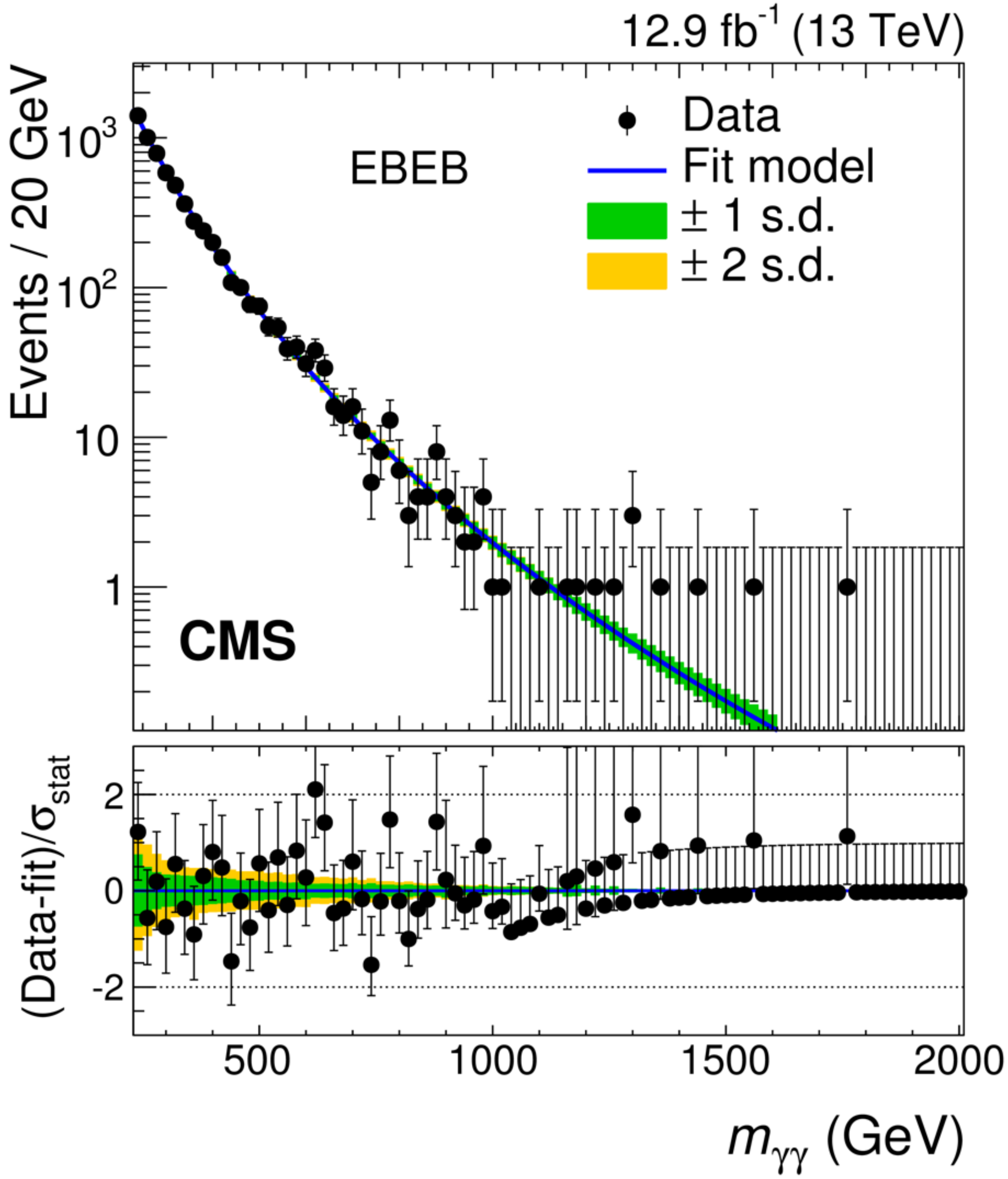
Experimental Signature

- Two high p_T(>75 GeV), isolated photons
- At-least one photon in barrel

Background

- Dominated by irreducible SM γγ production: ~90%
- Parametric fit to data with empirical function

$$f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\log(m_{\gamma\gamma})}$$



Possible Interpretations

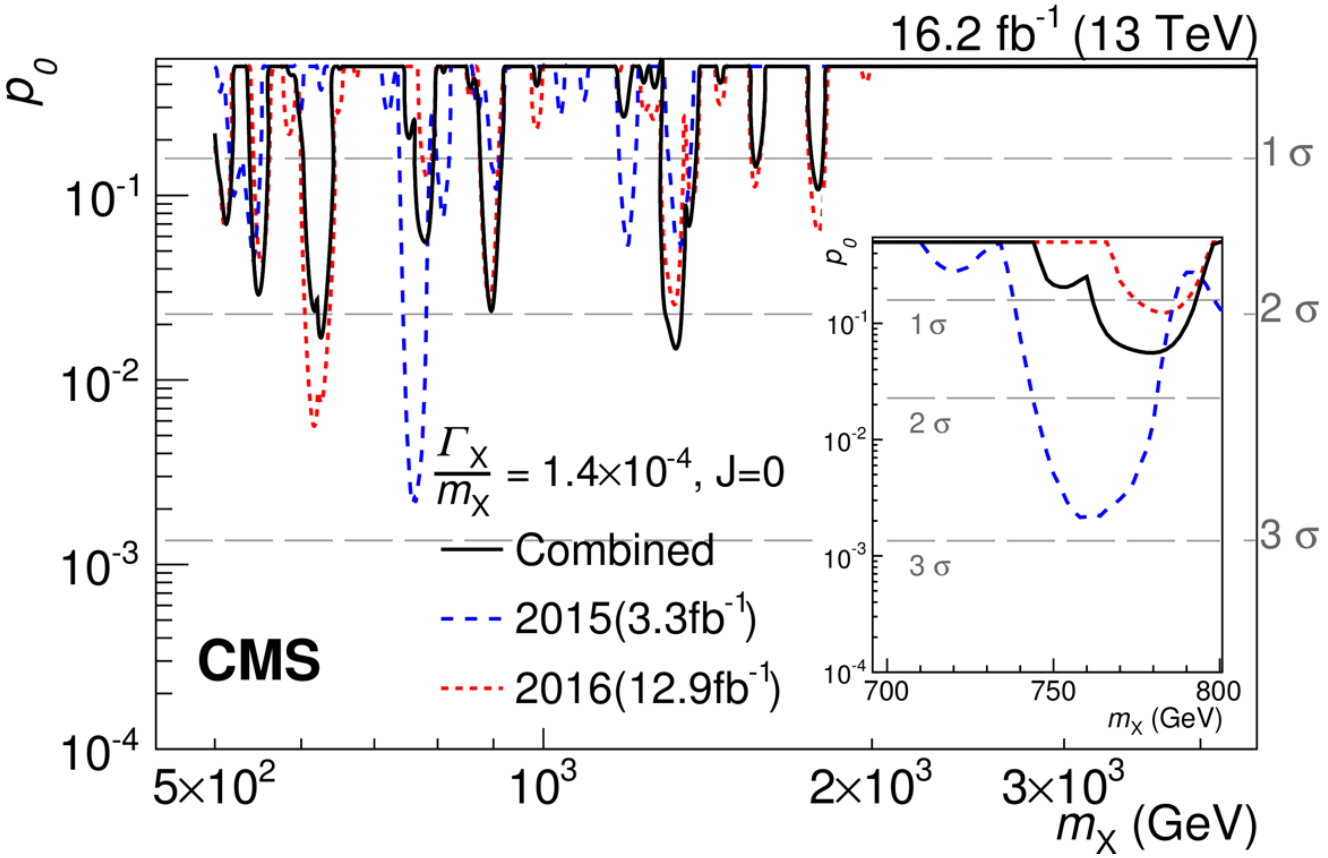
- Spin0: e.g. heavy scalar in non minimal Higgs sector
- Spin2: e.g. graviton, as predicted in several extra-dimensions model (RS model)

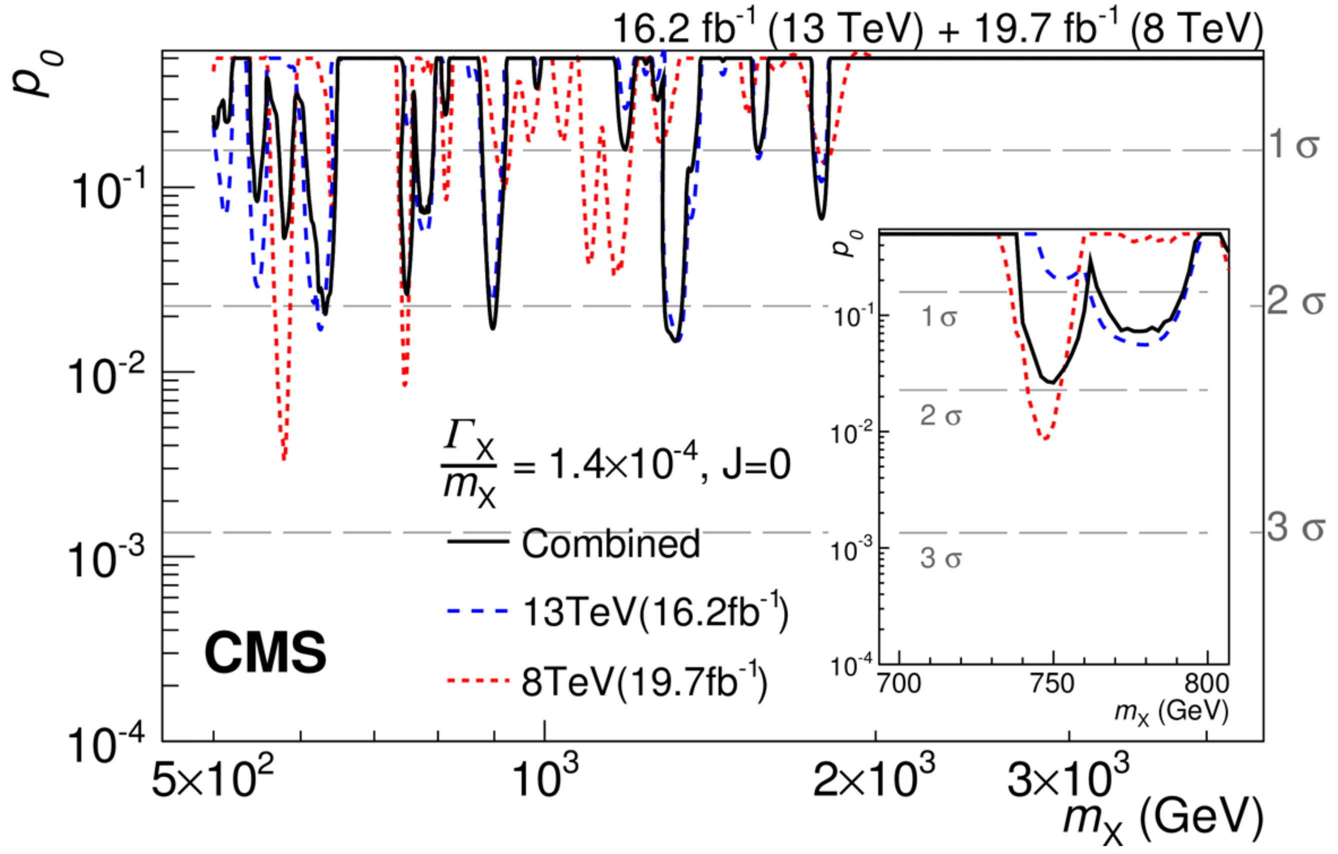
γγ

CMS : Phys. Lett. B 767 (2017) 147

Sizable excess observed by CMS and ATLAS at 750 GeV in 2015 data

Excess not confirmed with 4 times more data analyzed in 2016





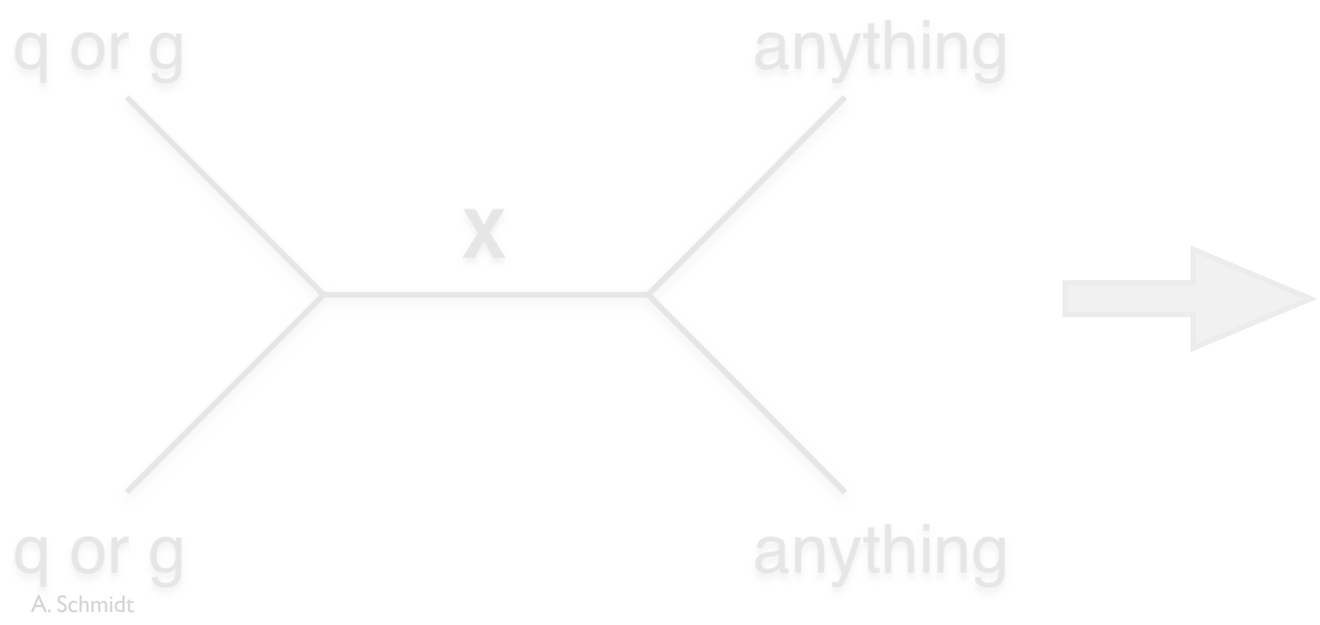
arxiv9909255

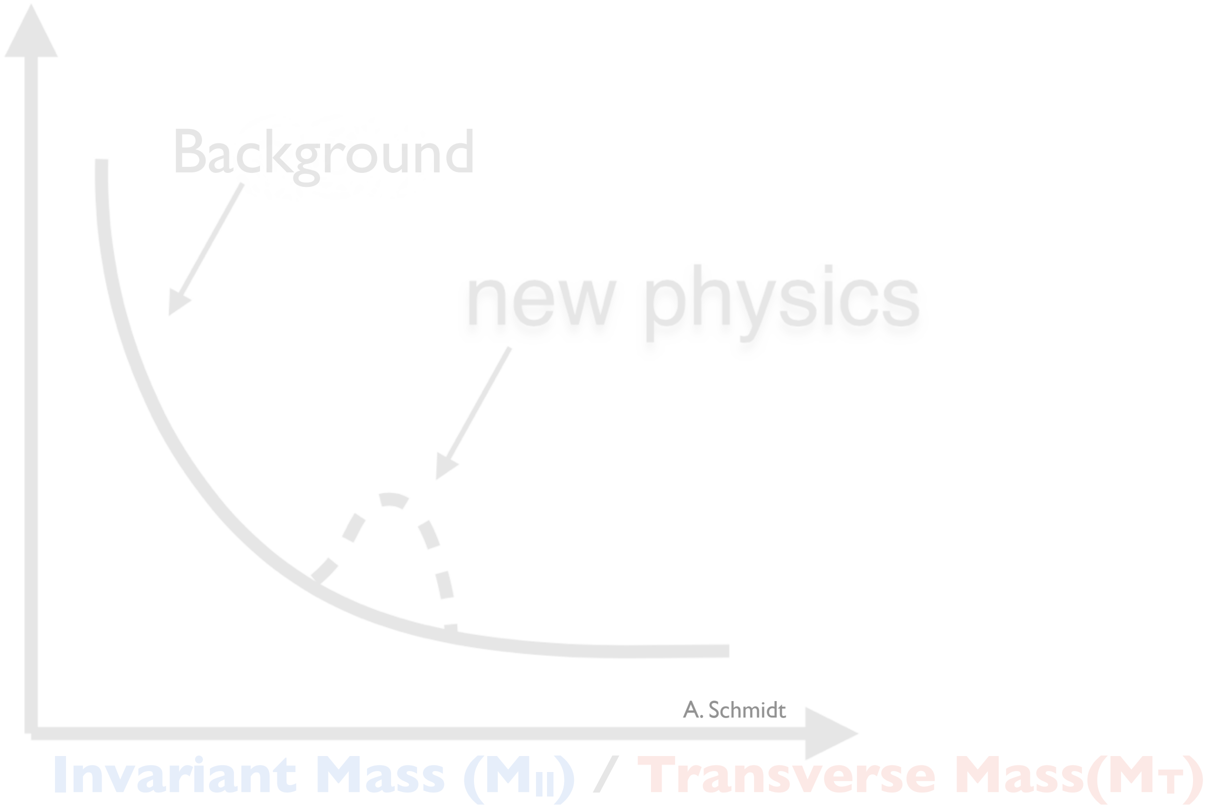
Width	Scenario	RS graviton coupling	RS graviton exclusion
Narrow (0.014%)	Detector resolution dominates	0.01	1.95 TeV (except 1.75-1.85 TeV)
Intermediate (1.4%)	Detector resolution and resonance width comparable	0.1	3.85 TeV
Broad (5.6%)	Resonance width dominates	0.2	4.45 TeV

$$\Gamma_X/m_X = 1.4\,\tilde{k}^2$$

Most stringent limits on RS graviton

Search for New Physics *in Bump-Hunt technique*





Broadly divided into 2 categories

Fully reconstructed final state

This talk

ee

μμ

eμ

γγ

Final state not fully reconstructed

MET in the final state

This talk

ττ

e+MET

μ+MET

τ+MET

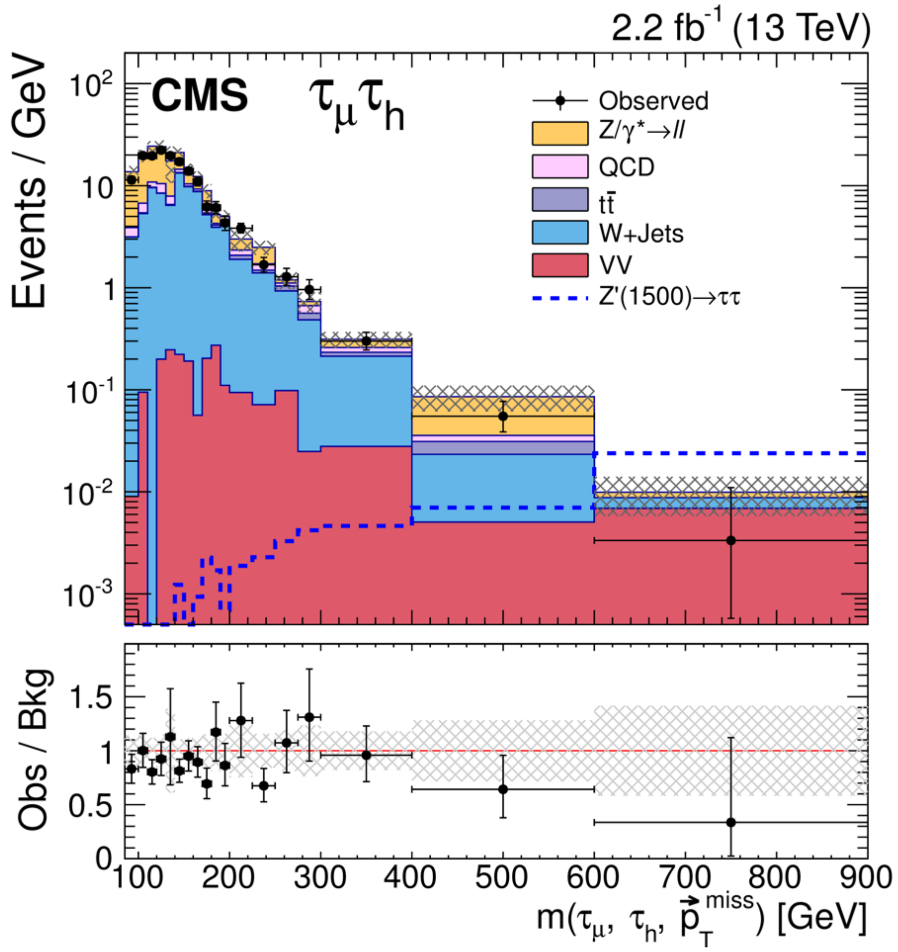
W' signature

2.2 fb^{-1} | 2015 data | JHEP 02 (2017) 048

$\tau\tau$

Experimental Signature

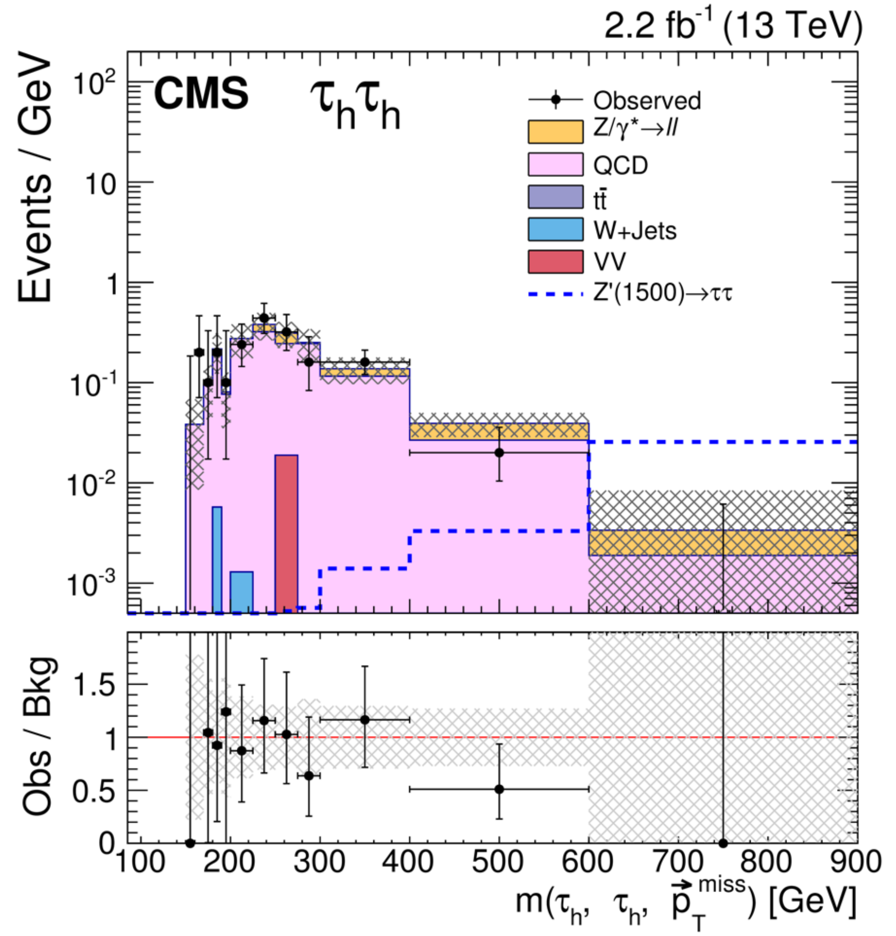
- $\tau_e\tau_\mu$, $\tau_e\tau_h$, $\tau_\mu\tau_h$, $\tau_h\tau_h$.
- Oppositely charged. Isolated. Intermediate to high p_T (20 to 60 GeV)
- Back-to-back tau-pair with MET aligned correspondingly
- MET>30 GeV. Veto b-jet.



Background

- Drell-Yan
- W+Jets (Substantial in $\tau_e\tau_h$, $\tau_\mu\tau_h$) Data-driven
- QCD multi-jet (Dominant in $\tau_h\tau_h$) Data-driven
- TTbar
- Diboson

No significant excess



Limit extraction variable:

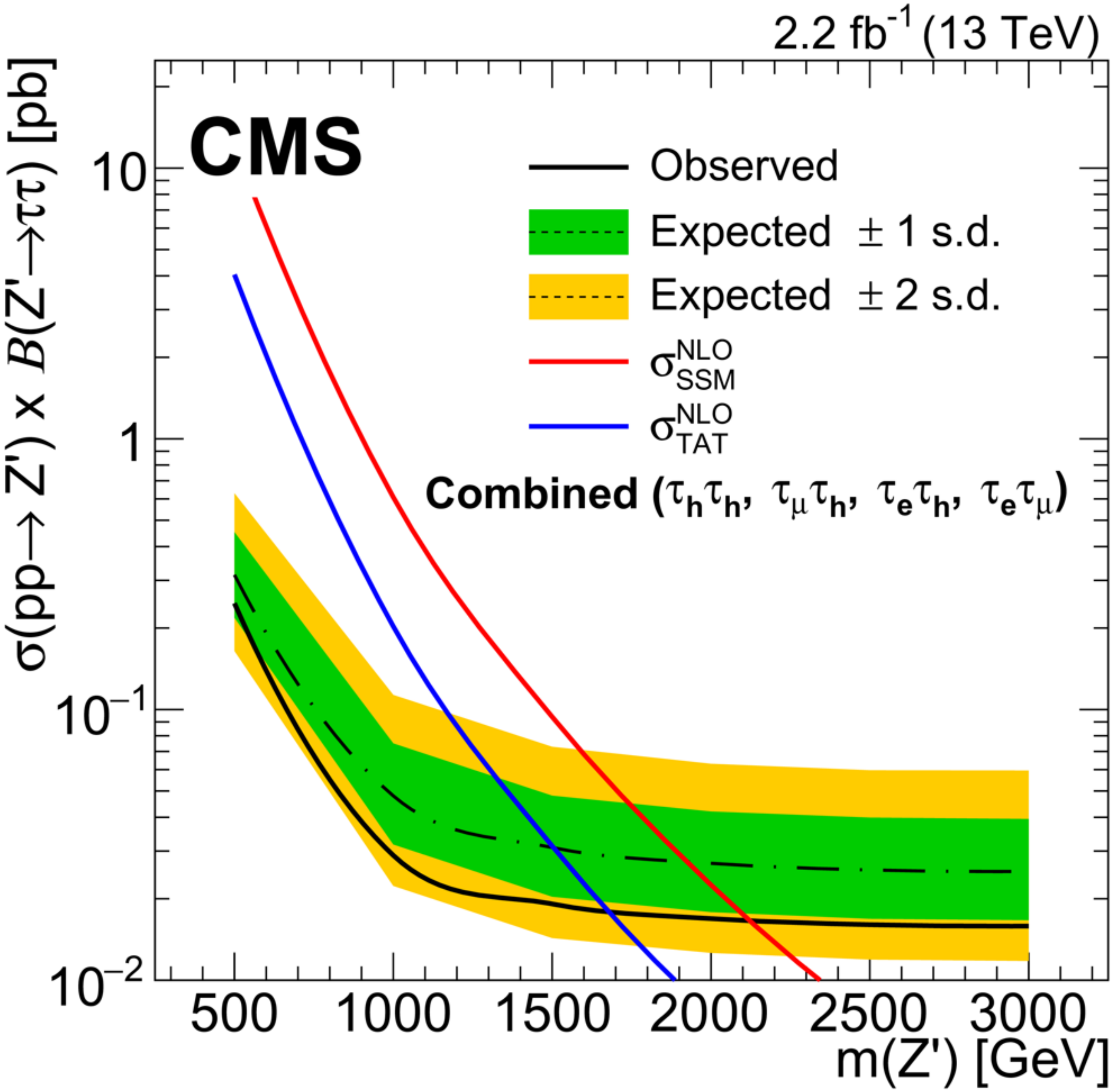
$$m(\tau_1, \tau_2, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{p}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

2.2 fb^{-1} 2015 data JHEP 02 (2017) 048

$\tau\tau$

Theoretical Interpretation

- ❖Sequential Standard Model (SSM)
  - ❖Benchmark model predicts neutral, spin-1 Z'_{SSM}
  - ❖Same couplings to quarks and leptons as the SM Z boson.
- ❖Topcolor-assisted technicolor (TAT)
  - ❖Z'_{TAT}: Enhanced coupling to 3rd generation fermion
  - ❖Suppression in production outweighs the increase of branching fraction
  - ❖$(\sigma\times B)_{TAT}$ ~ 1/3 of SSM



New particle	Mass Limit
Z'_{SSM}	2.1 TeV
Z'_{TAT}	1.7 TeV

10.1016/j.physletb.2017.04.043

2.3 fb^{-1} | 2015 data

$e/\mu/\tau_{\text{had}}$+MET

Experimental Signature

- High-p_T, isolated $e/\mu/\tau_{\text{had}}$ and MET
- Back-to-back → high $\Delta\Phi(\ell, \text{MET})$
- Balanced in p_T → $p_T(\ell)$/MET close to 1

Background

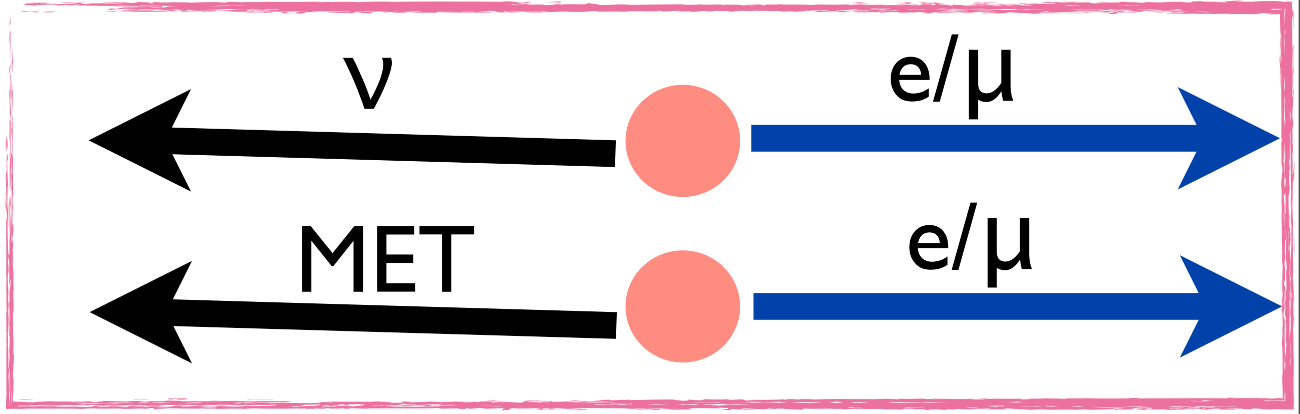
Real Leptons

- Dominant
  - W→ ℓ + ν (irreducible)
- Other
  - Top production
  - Drell-Yan
  - Diboson

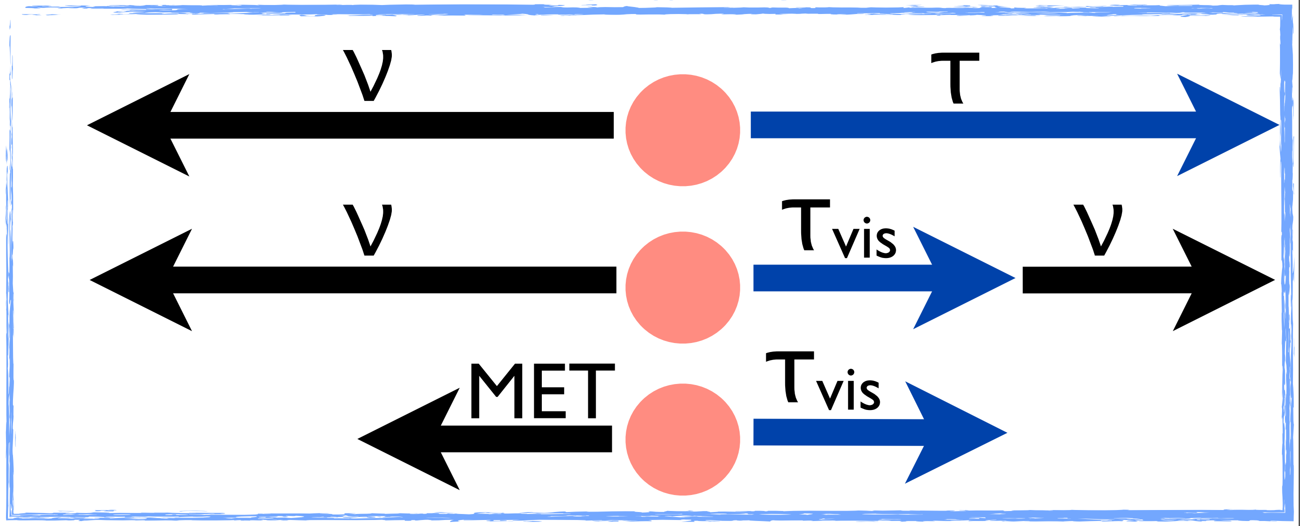
- QCD (e and τ channel)

Jet faking lepton Data-driven

e/μ channel



τ channel

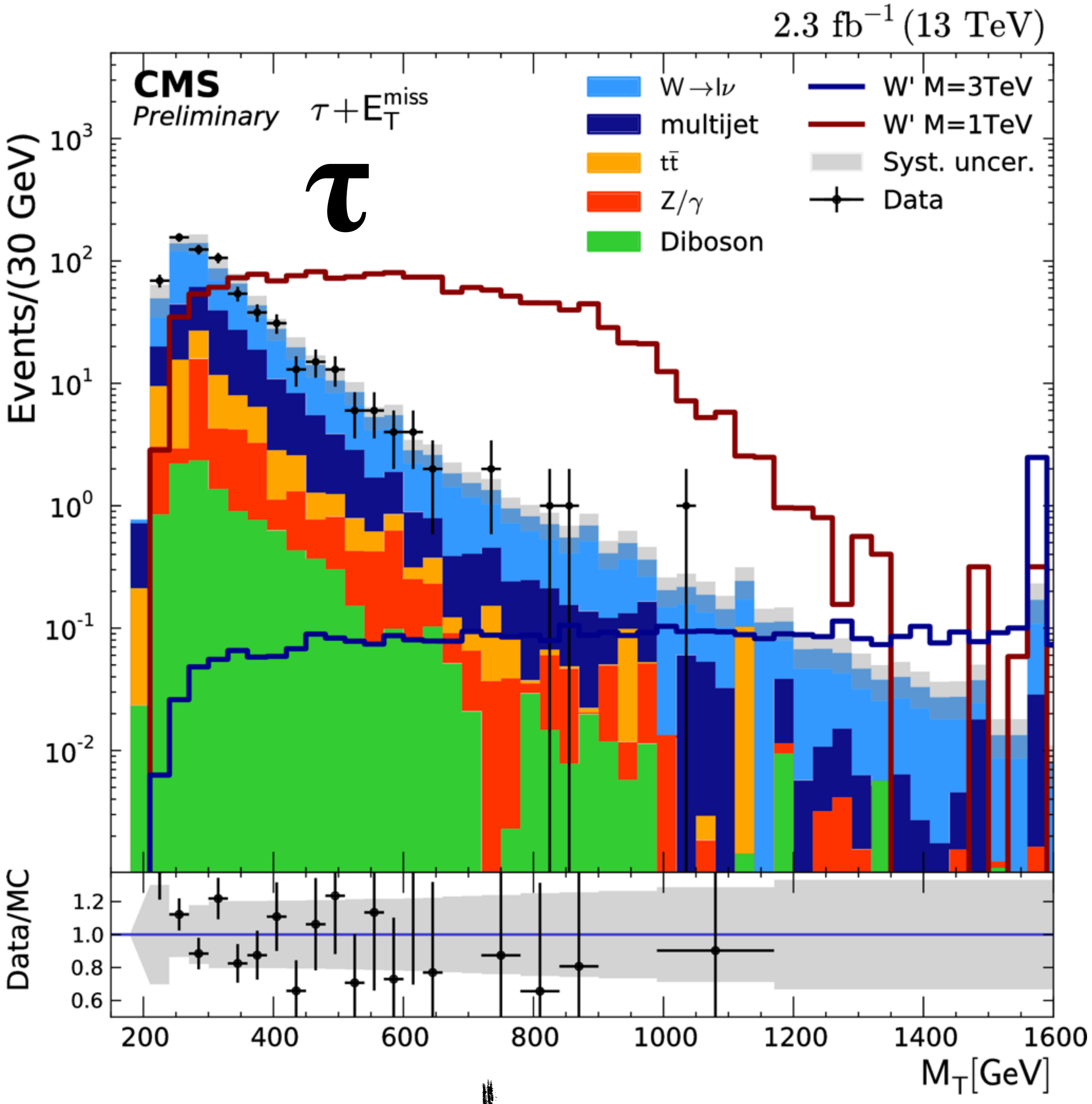


In spite of an extra neutrino, the back-to-back kinematics still hold for tau-channel

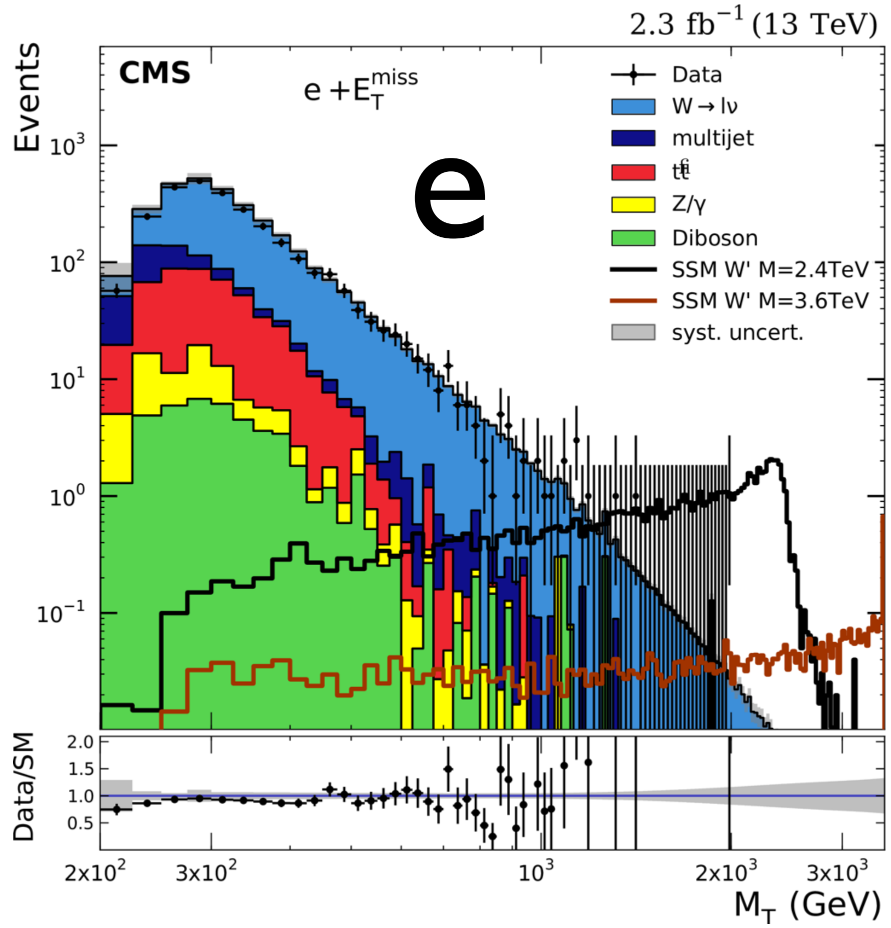
Limit extraction variable:

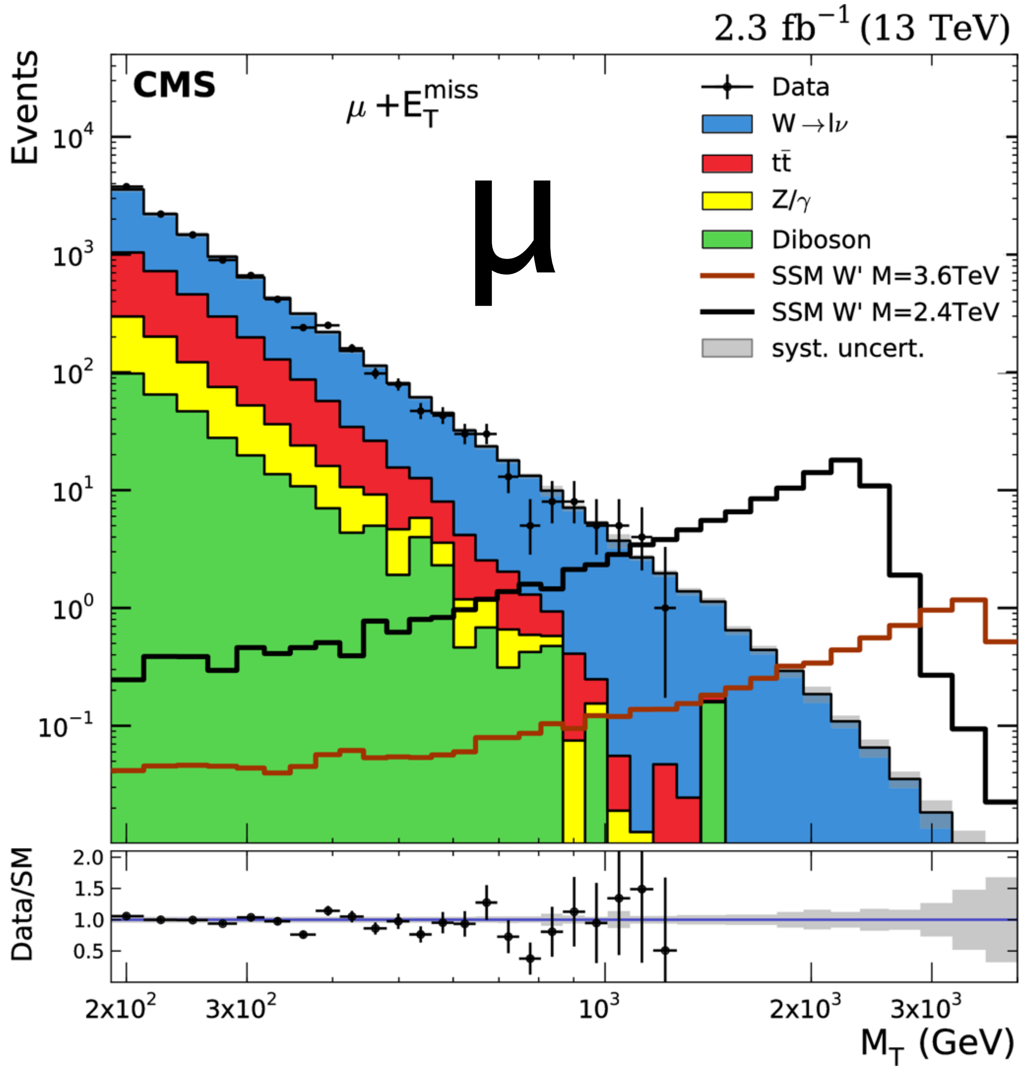
$$M_T = \sqrt{2 p_T^l E_T^{\text{miss}} (1 - \cos[\Delta\phi(\vec{p}_T^{\,l}, \vec{p}_T^{\,\text{miss}})])}$$

$e/\mu/\tau_{had}$+MET



No significant excess





No Jacobian peak in signal due to extra neutrino in τ channel

W’→e/μ/τ_{had}+MET

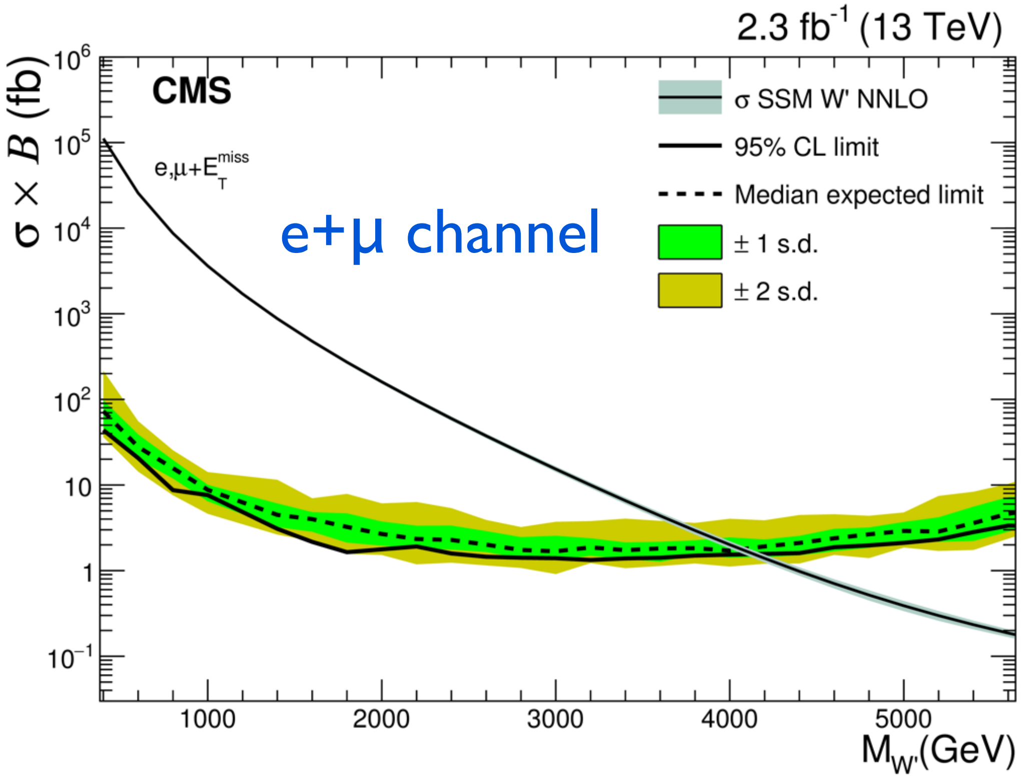
10.1016/j.physletb.2017.04.043

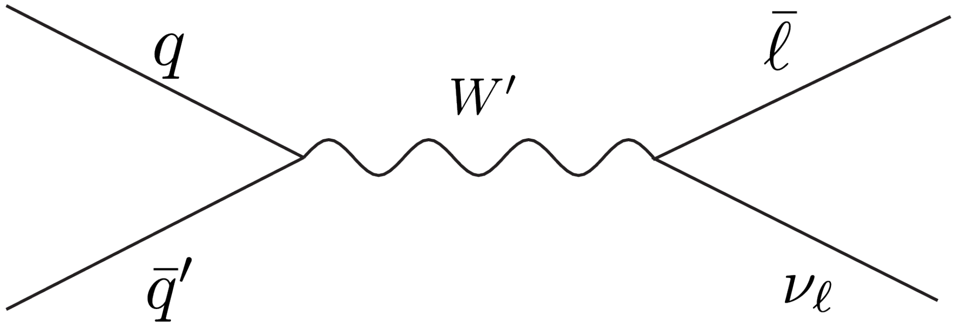
2.3 fb^{-1}

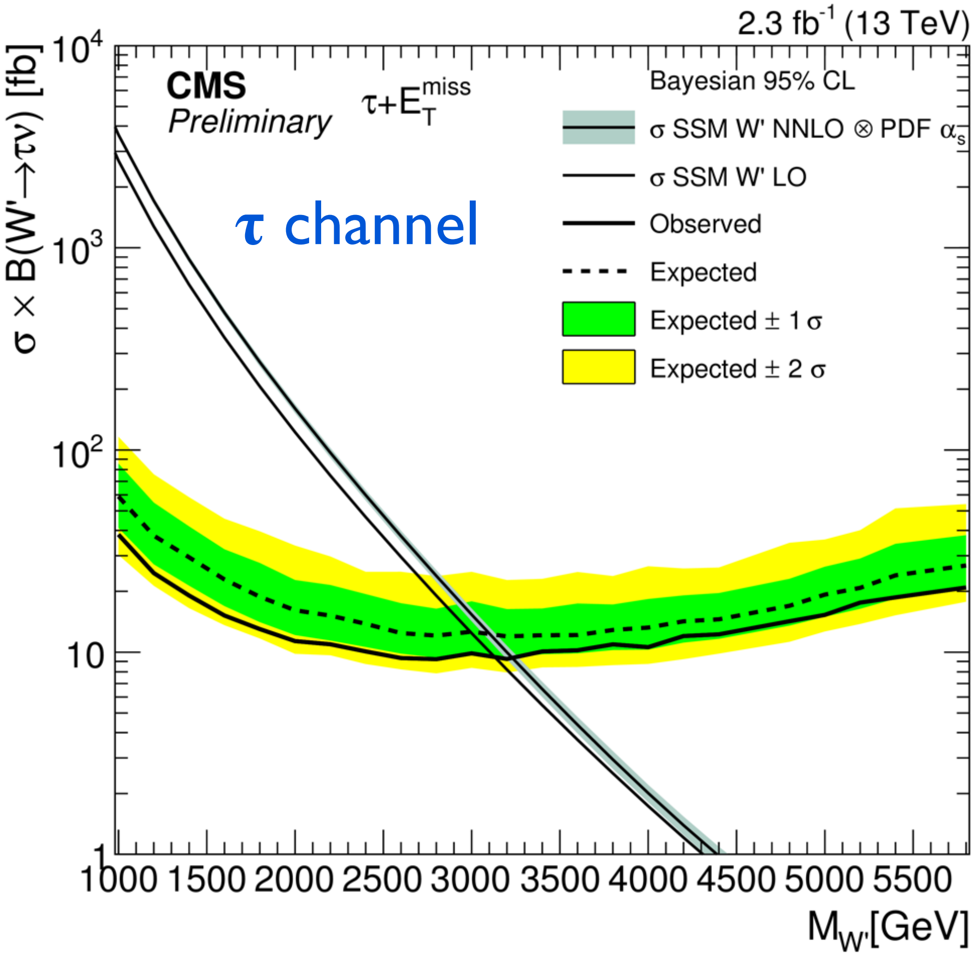
2015 data

Theoretical Interpretation

- Sequential Standard Model (SSM) predicts new massive boson W’
- Same couplings as SM W boson, but decays to bosons (W, Z, H) assumed to be suppressed
- W’→tb allowed if W’ sufficiently massive
- No interference with SM W boson



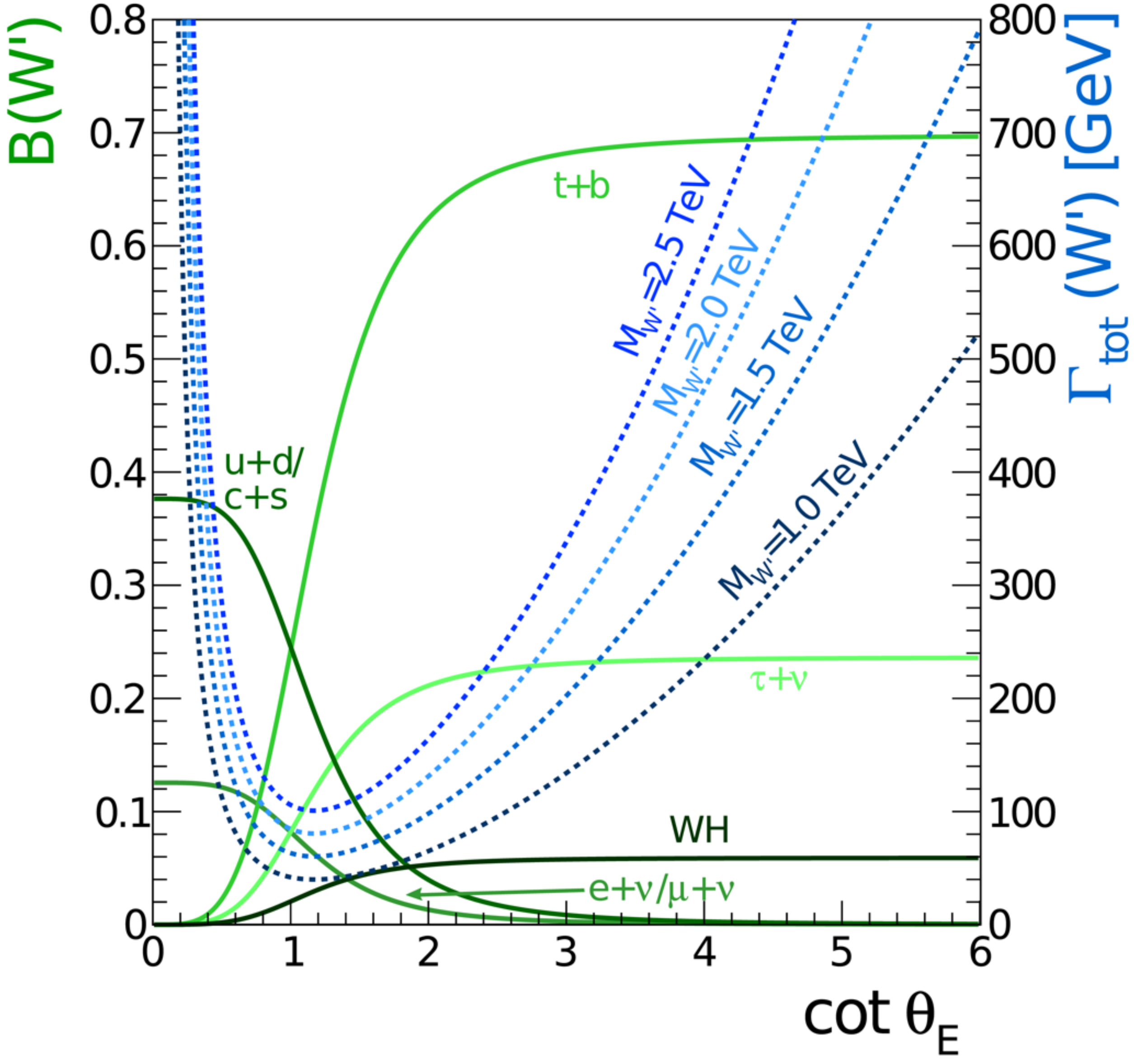


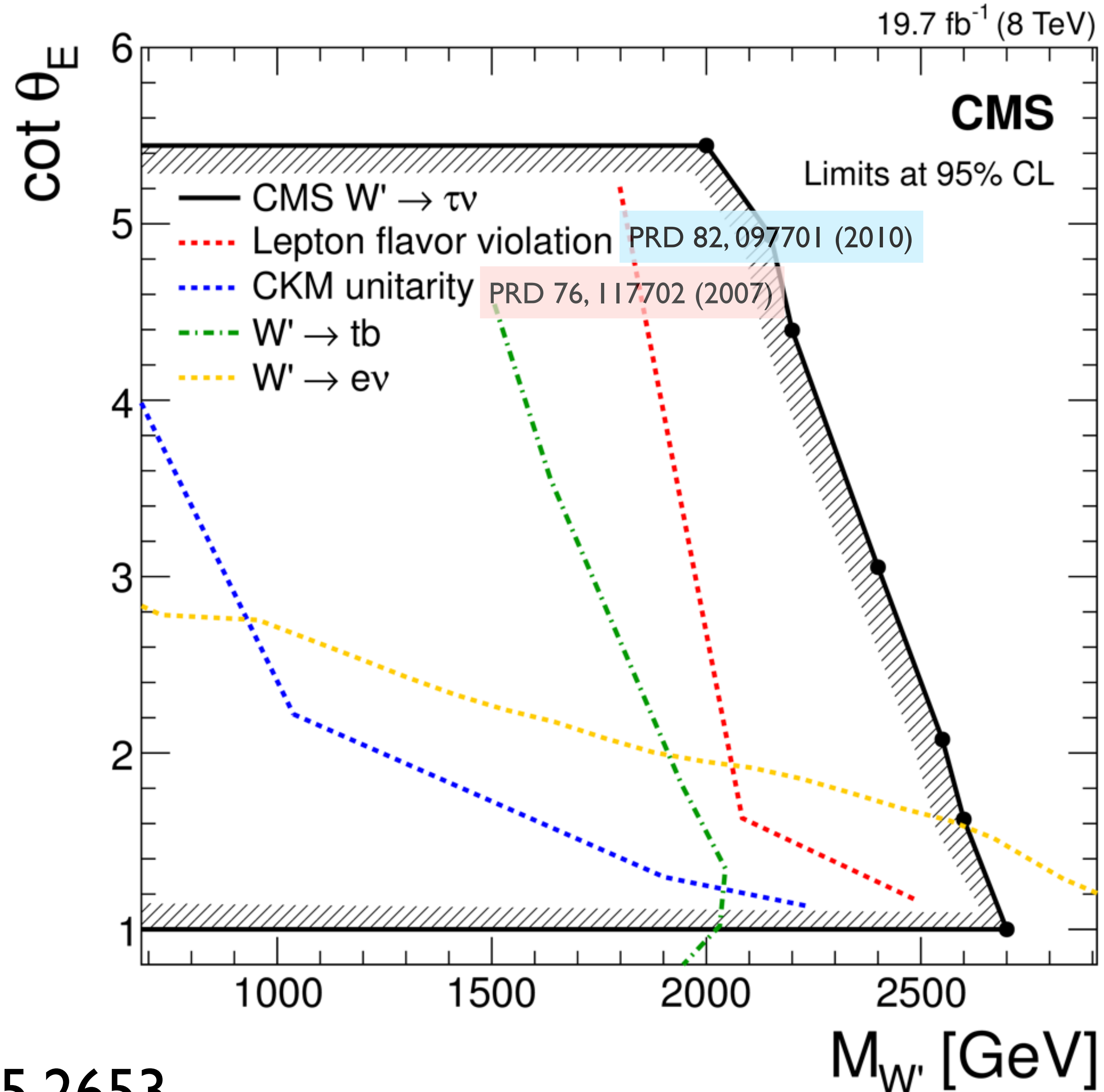


Final state	SSM W’ mass limit
e+μ channel	4.1 TeV
τ channel	3.3 TeV

Non-universal coupling

- τ_{had}+MET channel allows to test enhanced coupling to 3rd generation
- $SU(2)_{light}$ and $SU(2)_{heavy}$ → mixing angle θ_E
- After SSB, SM-like $SU(2)_{Weak}$ and $SU(2)_{Extended}$ exist
- $SU(2)_E$ gives rise to heavy W'





Theoretical Model by Kim & Lee, arxiv1105.2653

Conclusion & Outlook

- Wide program for high mass search.
  - No hint of New Physics so far.
  - Stringent limits on BSM scenarios.
- Surprises can come from low mass also !
  - Keep searching there. New efforts coming up.
- Current amount of data is only a small part of full LHC data expected
  - Expect ~3000 fb^{-1} in next 2 decades
- We are still at the beginning of a long journey

Conclusion & Outlook

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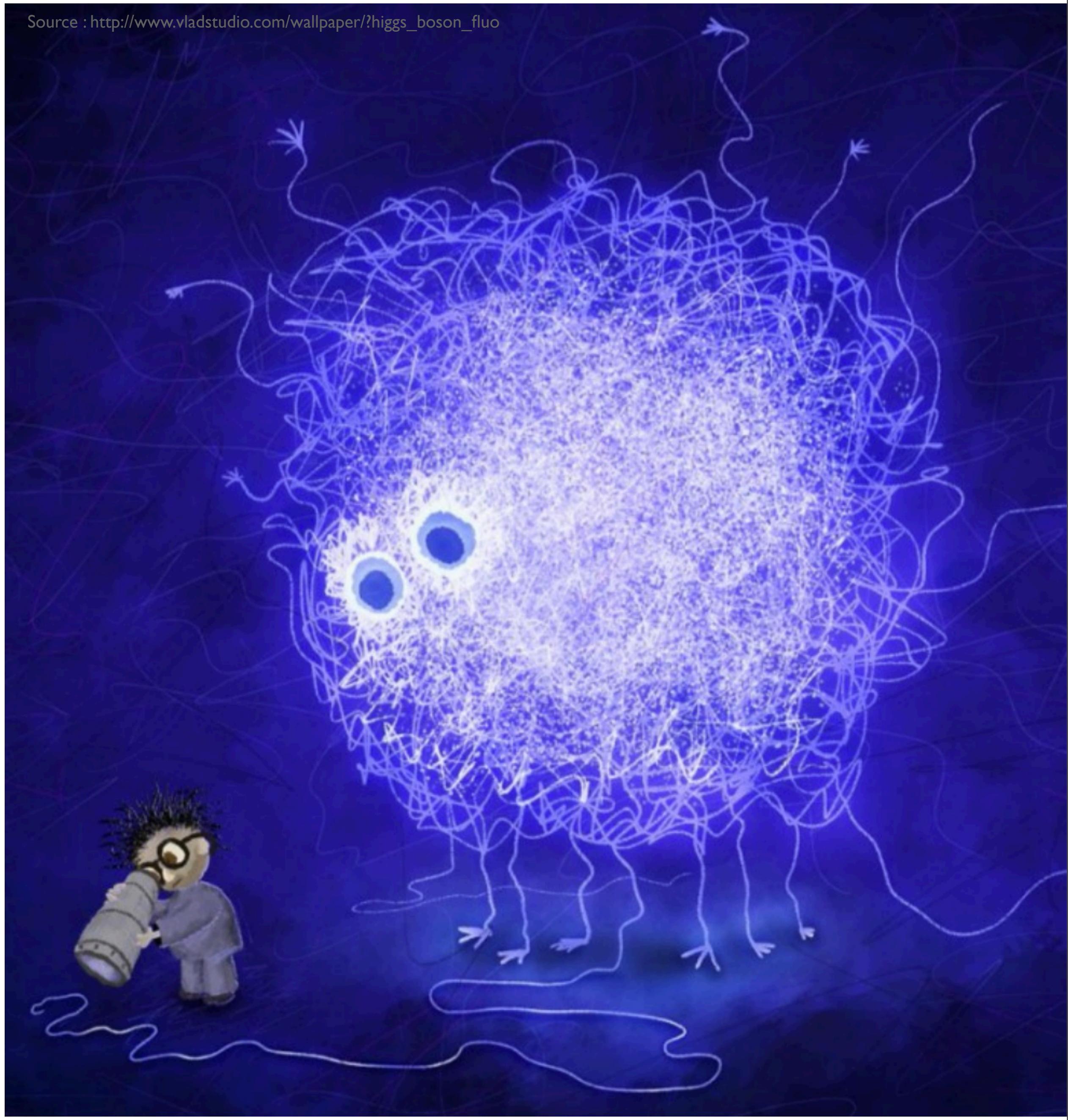
  - Expect ~3000 fb^{-1} in next 2 decades
- We are still at the beginning of a long journey, so ***stay tuned !***



Source : http://www.vladstudio.com/wallpaper/?higgs_boson_fluo

Extra Slides

CMS PAS EXO-16-001

eμ Lepton Flavor Violating (LFV) decay

Experimental Signature

- e and μ → High p_T, isolated
- No other signal-specific cut in order to stay **model independent**

Background

- **Dominant**
  - TTbar, Diboson
- **Other**
  - Single Top
  - Drell-Yan

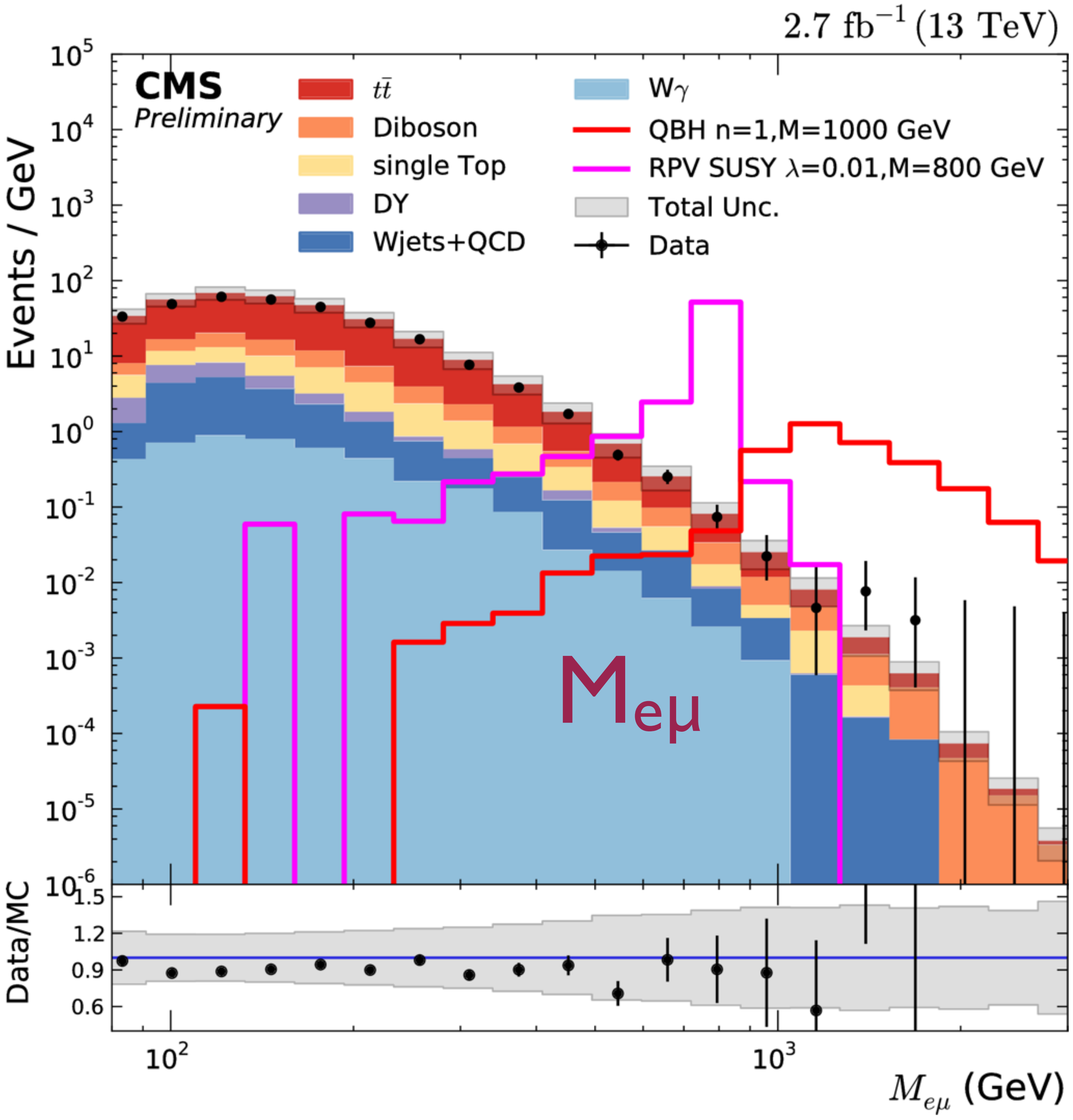
Real Leptons

- Wɣ

ɣ mis-identified as e

- W+Jets, QCD

Jet mis-identified as electron (Data-driven)



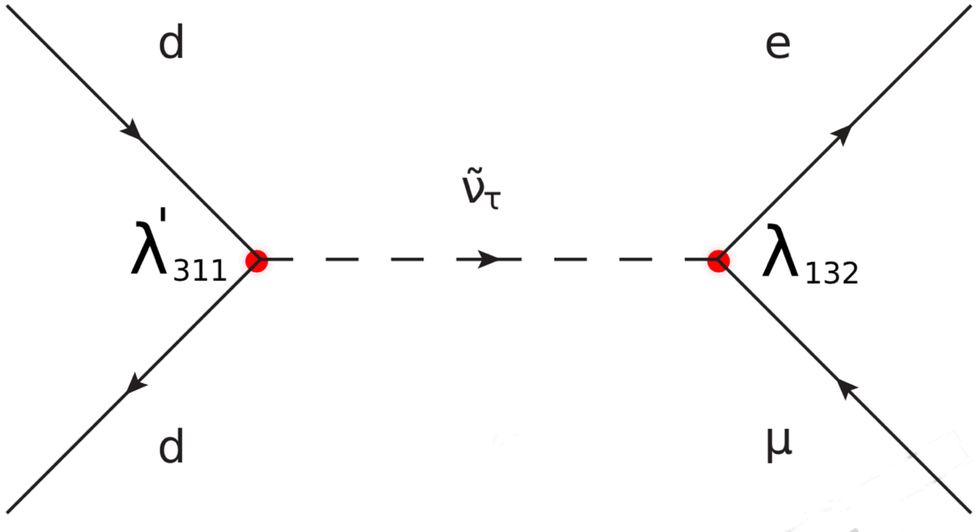
Limit extraction variable: Meμ

No significant excess

eμ

$\lambda_{132}\lambda'_{311} < 3.3 \times 10^{-7}\ (M_{\tilde{\nu}_\tau}/1\,\mathrm{TeV})^2$ at 90% CL

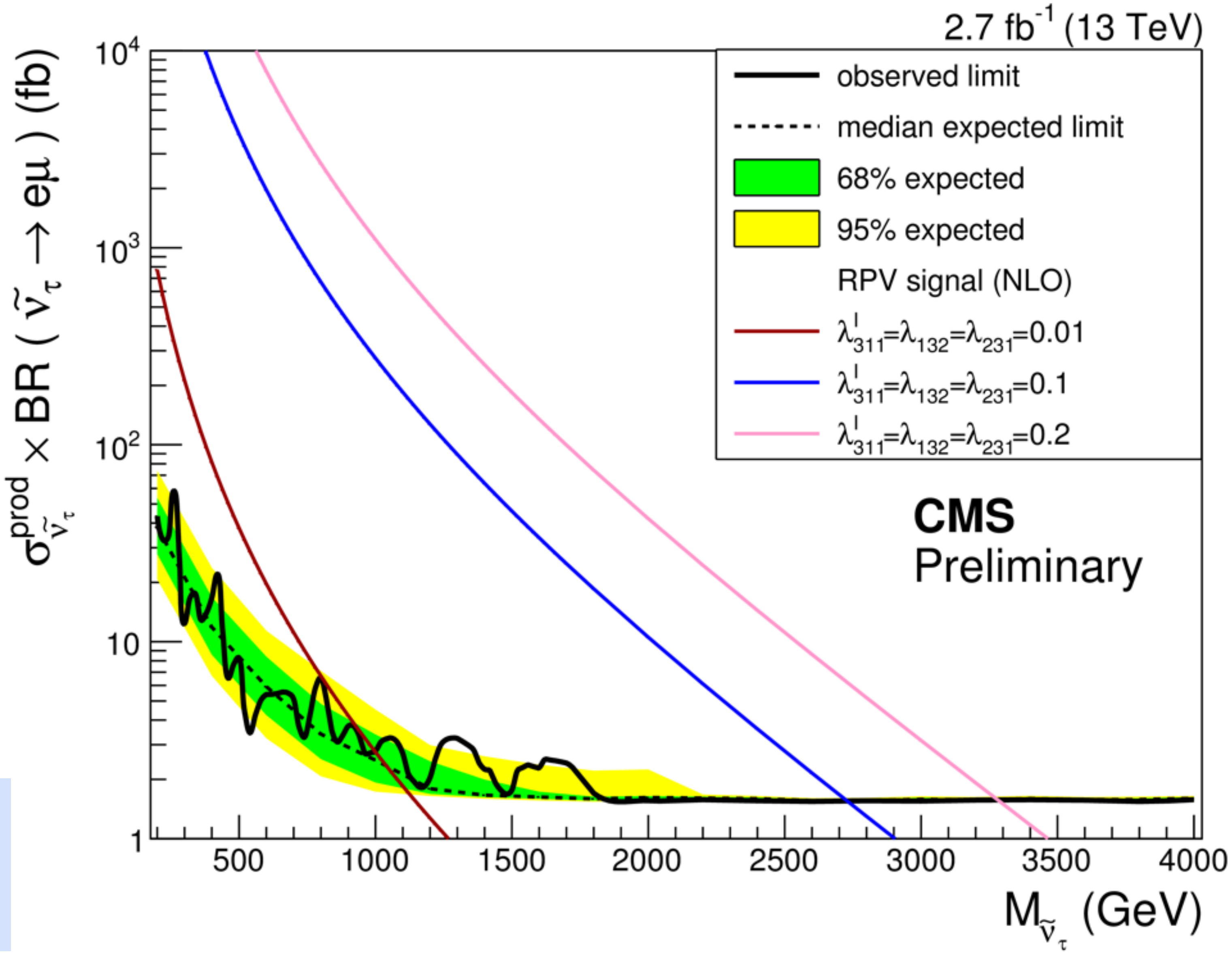
Strong indirect limits from low-energy muon conversion experiments



Theoretical Interpretation

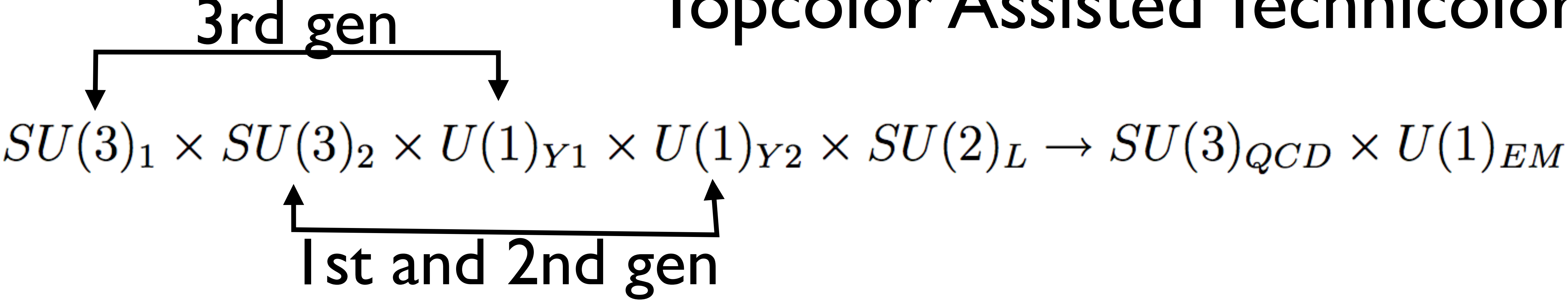
- R-Parity violating SUSY
  - Resonant production of **τ** sneutrino (LSP)
  - All RPV couplings vanish, except λ'_{311}, λ_{132}, λ_{231}

Coupling	mass limit
λ’= λ=0.01	1.0 TeV
λ’= λ=0.1	2.7 TeV
λ’= λ=0.1	3.3 TeV



QBH interpretation in Shubhanshu’s talk on Thursday @14.55

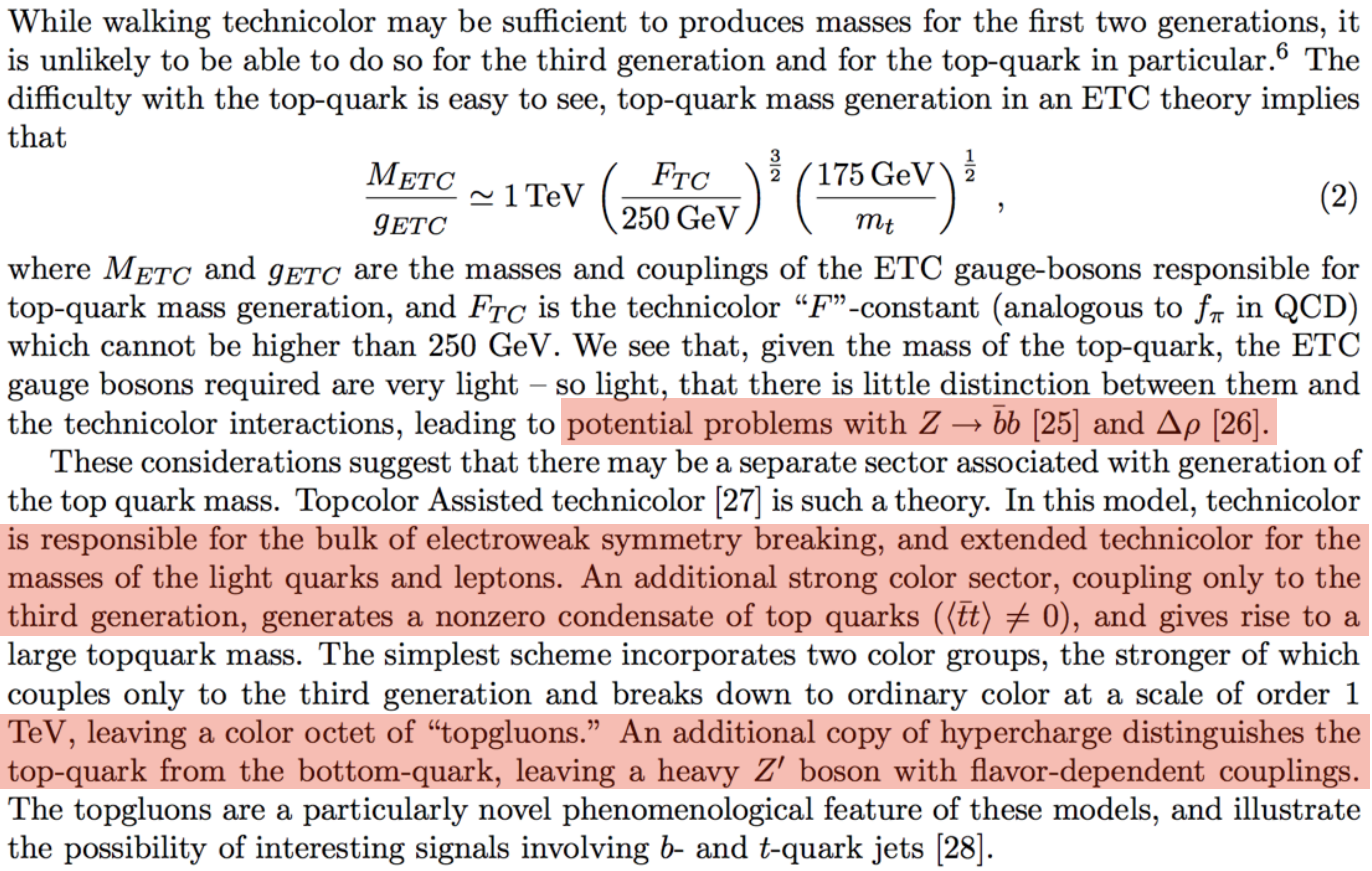
Topcolor Assisted Technicolor



3rd gen

$$SU(3)_1 \times SU(3)_2 \times U(1)_{Y1} \times U(1)_{Y2} \times SU(2)_L \rightarrow SU(3)_{QCD} \times U(1)_{EM}$$

1st and 2nd gen



While walking technicolor may be sufficient to produces masses for the first two generations, it is unlikely to be able to do so for the third generation and for the top-quark in particular.[6] The difficulty with the top-quark is easy to see, top-quark mass generation in an ETC theory implies that

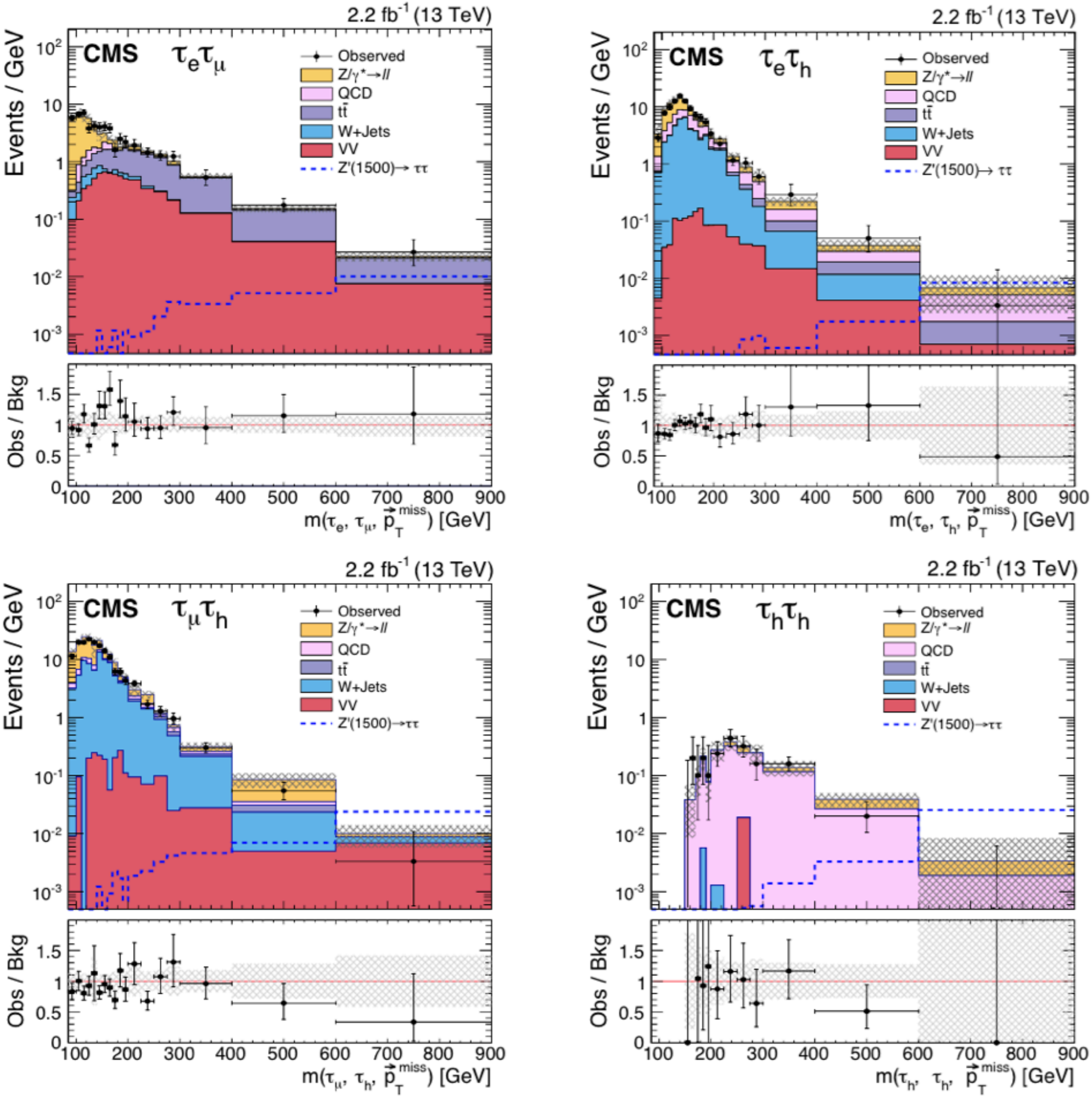
$$\frac{M_{ETC}}{g_{ETC}} \simeq 1\,\mathrm{TeV}\left(\frac{F_{TC}}{250\,\mathrm{GeV}}\right)^{\frac{3}{2}}\left(\frac{175\,\mathrm{GeV}}{m_t}\right)^{\frac{1}{2}}, \qquad (2)$$

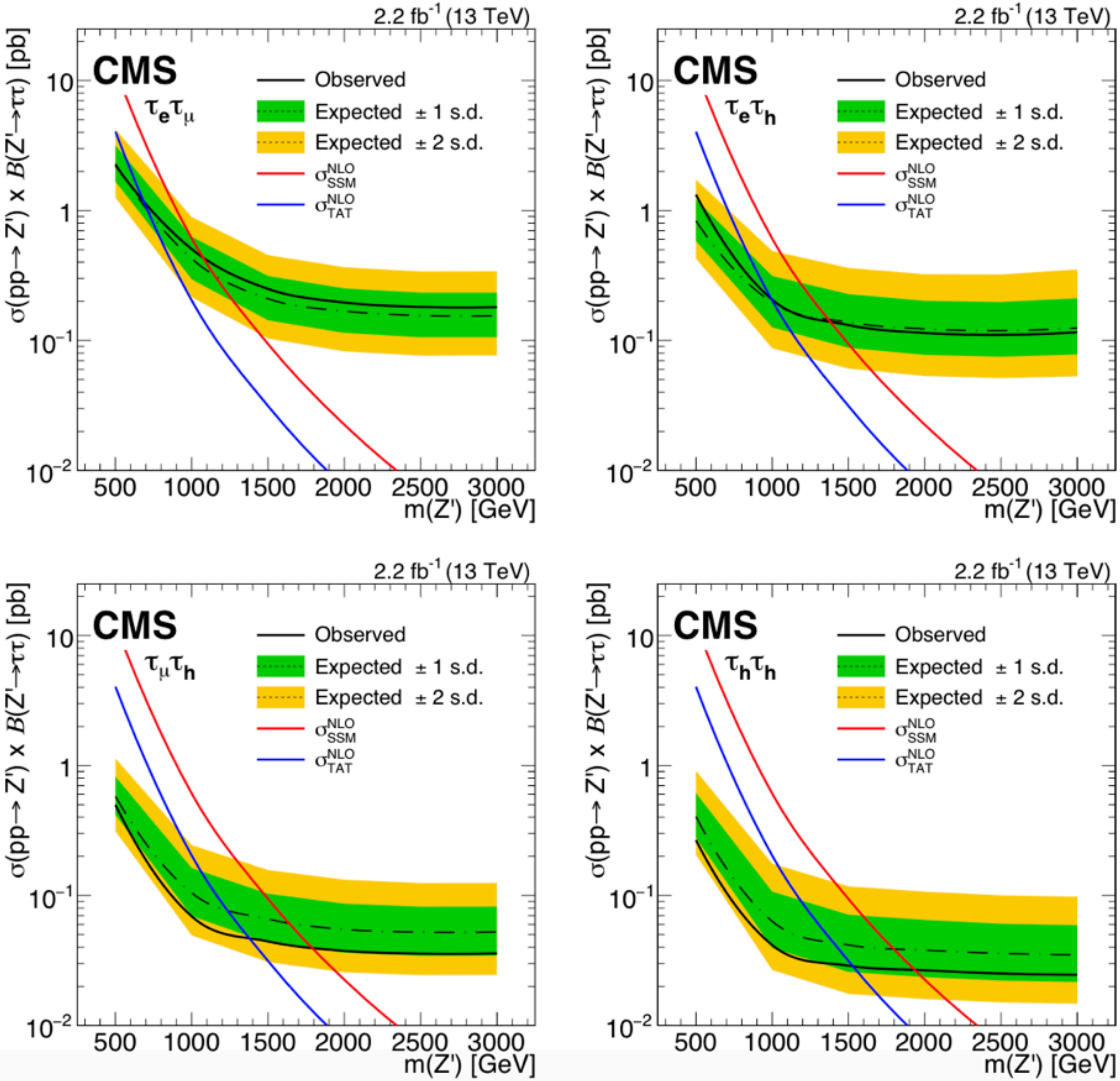
where M_{ETC} and g_{ETC} are the masses and couplings of the ETC gauge-bosons responsible for top-quark mass generation, and F_{TC} is the technicolor "F"-constant (analogous to f_π in QCD) which cannot be higher than 250 GeV. We see that, given the mass of the top-quark, the ETC gauge bosons required are very light – so light, that there is little distinction between them and the technicolor interactions, leading to potential problems with $Z \to \bar{b}b$ [25] and $\Delta\rho$ [26].

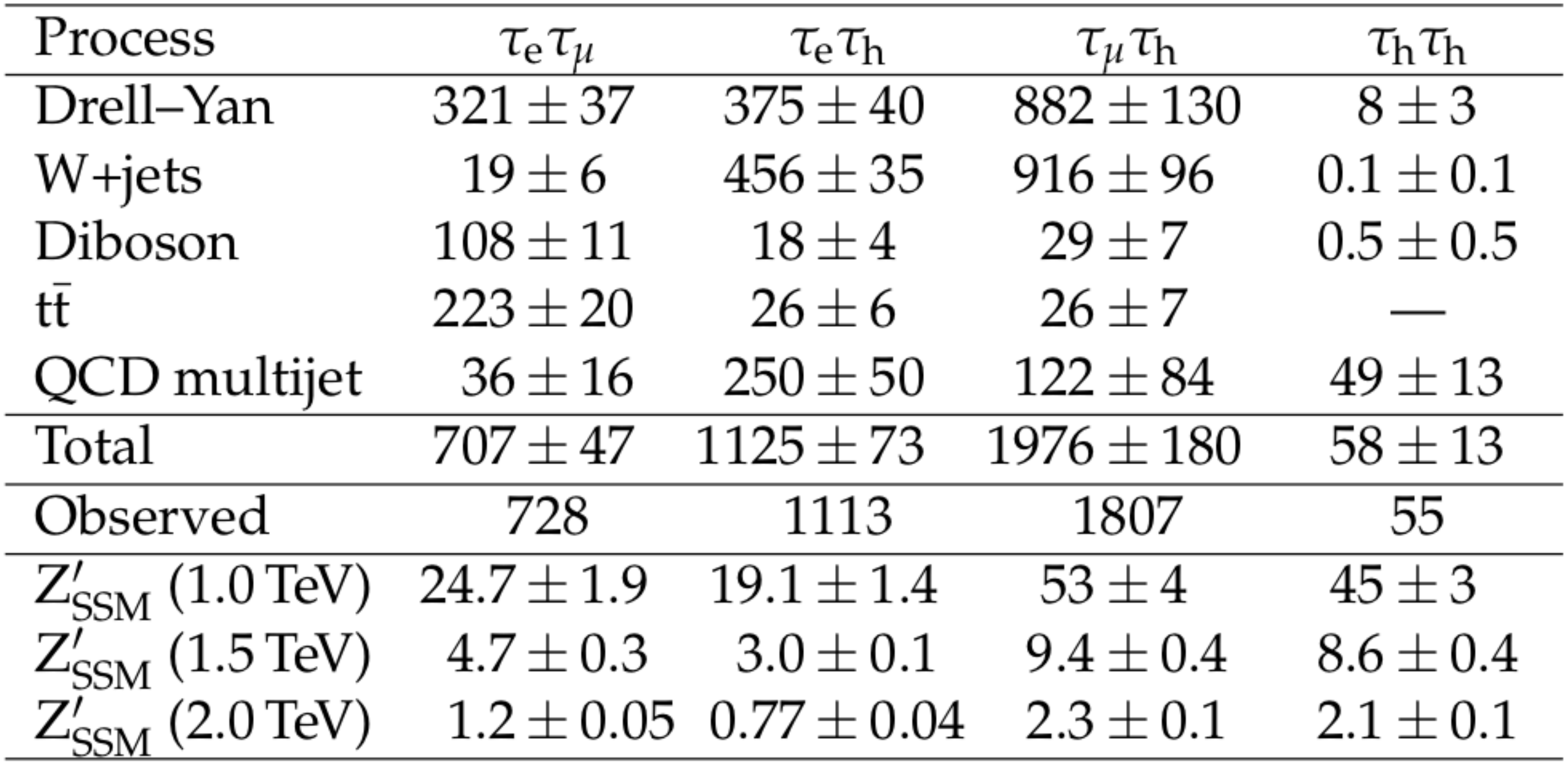
These considerations suggest that there may be a separate sector associated with generation of the top quark mass. Topcolor Assisted technicolor [27] is such a theory. In this model, technicolor is responsible for the bulk of electroweak symmetry breaking, and extended technicolor for the masses of the light quarks and leptons. An additional strong color sector, coupling only to the third generation, generates a nonzero condensate of top quarks ($\langle\bar{t}t\rangle \neq 0$), and gives rise to a large topquark mass. The simplest scheme incorporates two color groups, the stronger of which couples only to the third generation and breaks down to ordinary color at a scale of order 1 TeV, leaving a color octet of "topgluons." An additional copy of hypercharge distinguishes the top-quark from the bottom-quark, leaving a heavy Z' boson with flavor-dependent couplings. The topgluons are a particularly novel phenomenological feature of these models, and illustrate the possibility of interesting signals involving b- and t-quark jets [28].

Topcolor Assisted Technicolor

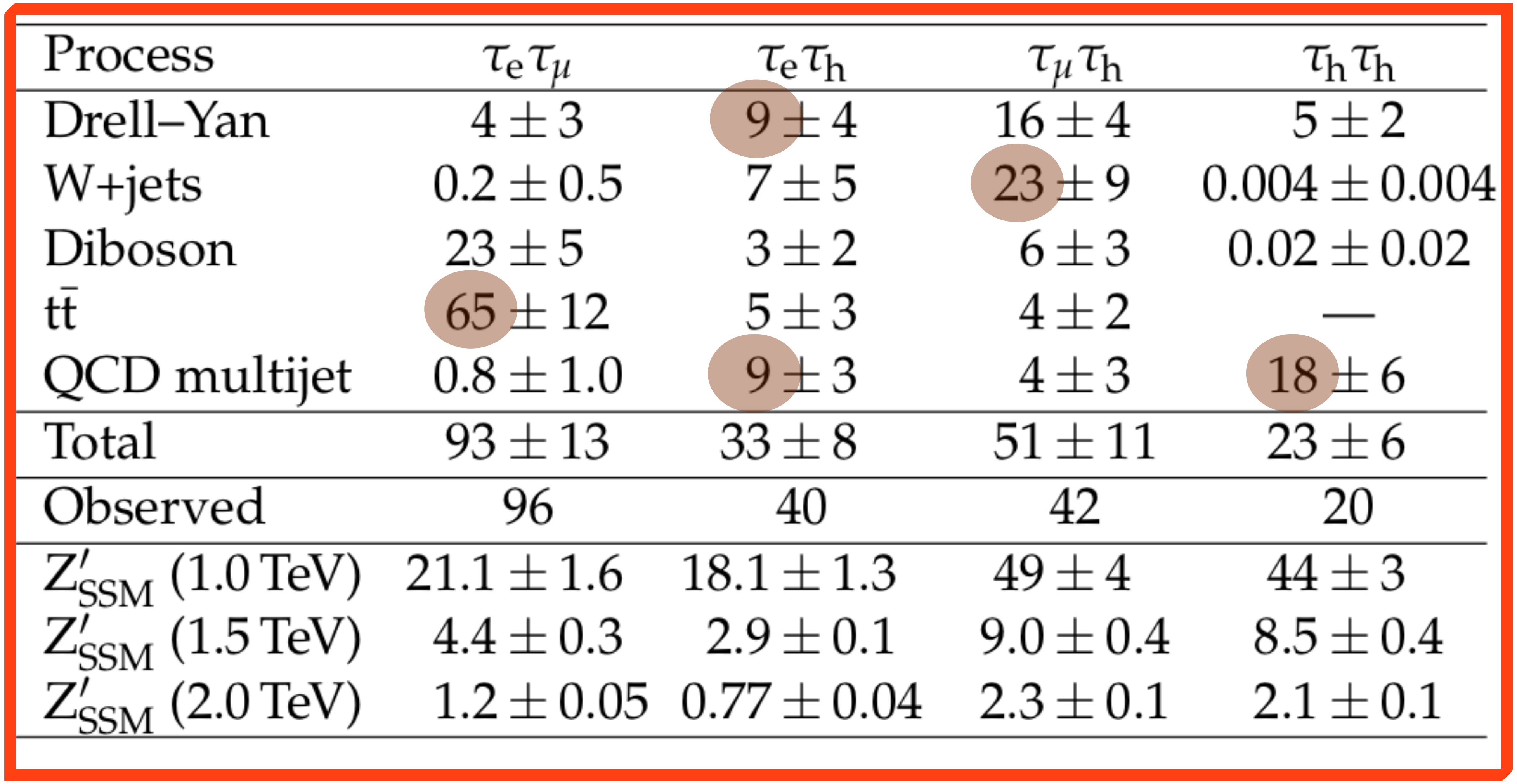
doi:10.1088/1742-6596/37/1/007


2.2 fb^{-1} (13 TeV)
CMS
$\tau_e\tau_\mu$
$\tau_e\tau_h$
$\tau_\mu\tau_h$
$\tau_h\tau_h$
Observed
$Z/\gamma^*\rightarrow ll$
QCD
$t\bar{t}$
W+Jets
VV
$Z'(1500)\rightarrow\tau\tau$
Events / GeV
Obs / Bkg
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
0
0.5
1
1.5
100
200
300
400
500
600
700
800
900
$m(\tau_e, \tau_\mu, \vec{p}_T^{miss})$ [GeV]
$m(\tau_e, \tau_h, \vec{p}_T^{miss})$ [GeV]
$m(\tau_\mu, \tau_h, \vec{p}_T^{miss})$ [GeV]
$m(\tau_h, \tau_h, \vec{p}_T^{miss})$ [GeV]


2.2 fb^{-1} (13 TeV)
CMS
$\tau_e\tau_\mu$
$\tau_e\tau_h$
$\tau_\mu\tau_h$
$\tau_h\tau_h$
Observed
Expected ± 1 s.d.
Expected ± 2 s.d.
σ^{NLO}_{SSM}
σ^{NLO}_{TAT}
$\sigma(pp\to Z') \times B(Z'\to\tau\tau)$ [pb]
10^{-2}
10^{-1}
1
10
500
1000
1500
2000
2500
3000
m(Z') [GeV]



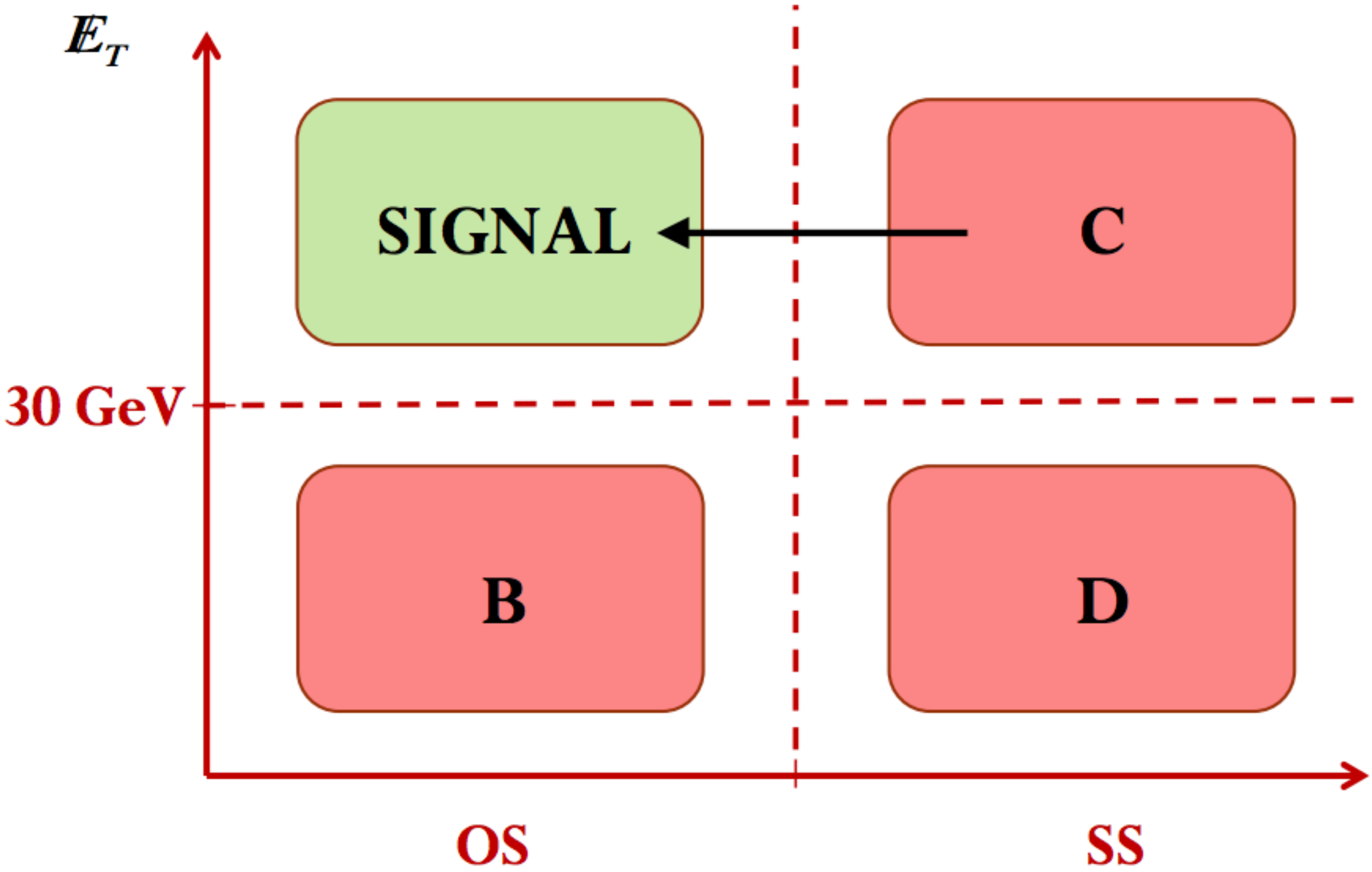
Process	$\tau_e\tau_\mu$	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_h\tau_h$
Drell–Yan	321 ± 37	375 ± 40	882 ± 130	8 ± 3
W+jets	19 ± 6	456 ± 35	916 ± 96	0.1 ± 0.1
Diboson	108 ± 11	18 ± 4	29 ± 7	0.5 ± 0.5
$t\bar{t}$	223 ± 20	26 ± 6	26 ± 7	—
QCD multijet	36 ± 16	250 ± 50	122 ± 84	49 ± 13
Total	707 ± 47	1125 ± 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 ± 0.05	0.77 ± 0.04	2.3 ± 0.1	2.1 ± 0.1



Process	$\tau_e\tau_\mu$	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_h\tau_h$
Drell–Yan	4 ± 3	9 ± 4	16 ± 4	5 ± 2
W+jets	0.2 ± 0.5	7 ± 5	23 ± 9	0.004 ± 0.004
Diboson	23 ± 5	3 ± 2	6 ± 3	0.02 ± 0.02
$t\bar{t}$	65 ± 12	5 ± 3	4 ± 2	—
QCD multijet	0.8 ± 1.0	9 ± 3	4 ± 3	18 ± 6
Total	93 ± 13	33 ± 8	51 ± 11	23 ± 6
Observed	96	40	42	20
Z'_{SSM} (1.0 TeV)	21.1 ± 1.6	18.1 ± 1.3	49 ± 4	44 ± 3
Z'_{SSM} (1.5 TeV)	4.4 ± 0.3	2.9 ± 0.1	9.0 ± 0.4	8.5 ± 0.4
Z'_{SSM} (2.0 TeV)	1.2 ± 0.05	0.77 ± 0.04	2.3 ± 0.1	2.1 ± 0.1

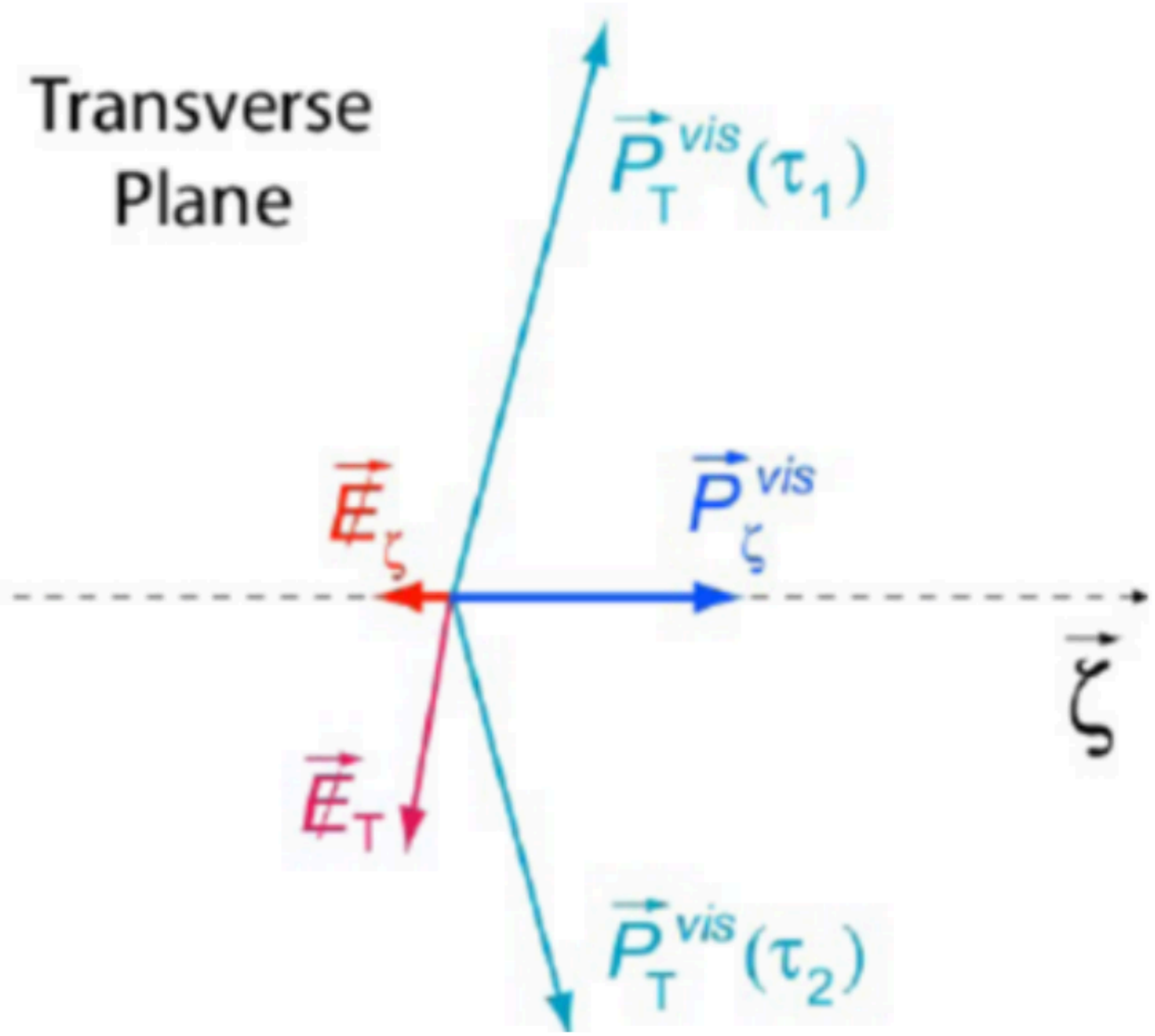
$m(\tau 1,\tau 2,pT^{miss}) >$ 300 GeV

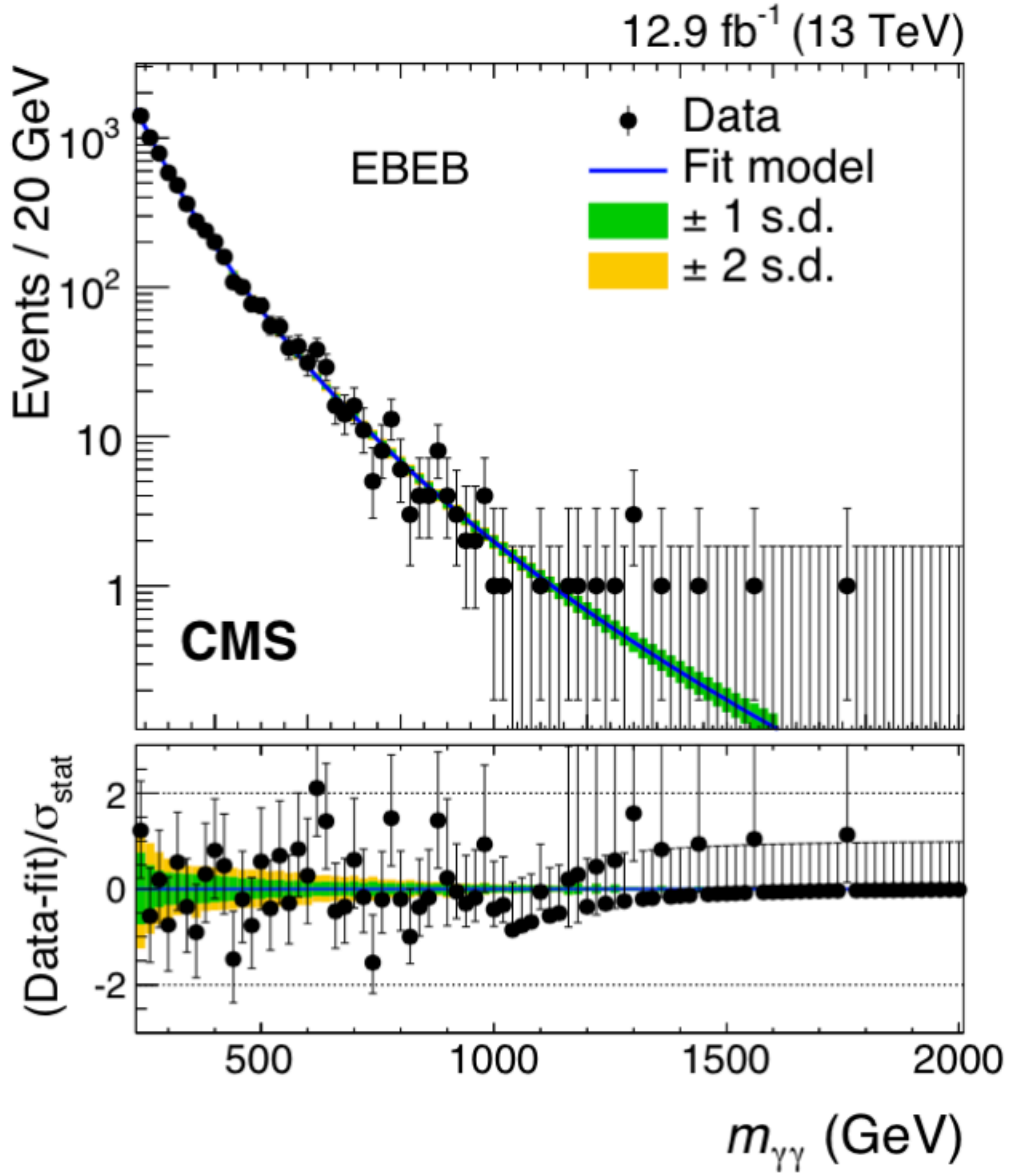
QCD Estimation in τhτh

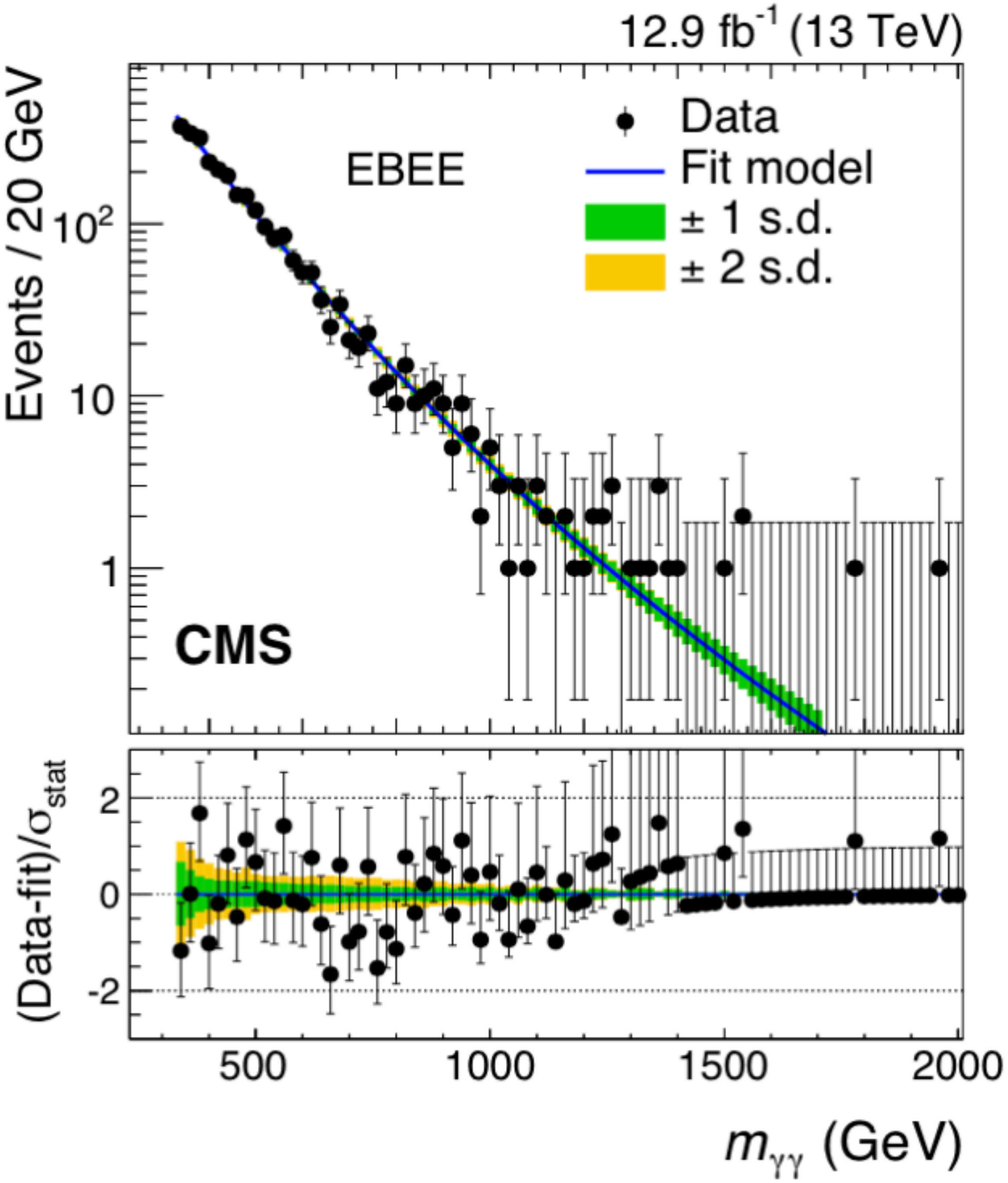


Derive OS/SS SF using low-MET CRs (B/D)

The direction of $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ is required to be consistent with the expectation for a pair of high-p_{T} τ lepton decays, to reduce the background from events with W bosons (primarily W+jets and $\mathrm{t\bar{t}}$ events). This requirement is implemented through a variable known as "CDF-ζ" [41], referred to below as the ζ variable. This variable is defined by considering a unit vector, denoted the $\hat{\zeta}$ axis, along the bisector between the p_{T} directions of the two τ lepton candidates. Two projection variables for the visible τ lepton decay products and $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ are then constructed: $p_{\zeta}^{\mathrm{vis.}} = (\vec{p}_{\mathrm{T}}^{\tau_1} + \vec{p}_{\mathrm{T}}^{\tau_2}) \cdot \hat{\zeta}$ and $p_{\zeta} = (\vec{p}_{\mathrm{T}}^{\tau_1} + \vec{p}_{\mathrm{T}}^{\tau_2} + \vec{p}_{\mathrm{T}}^{\mathrm{miss}}) \cdot \hat{\zeta}$. In contrast to signal events in which $p_{\zeta}^{\mathrm{vis.}}$ and p_{ζ} are strongly correlated, these two variables are nearly independent in events with a W boson because in this case the direction and magnitude of $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ are correlated with those of the lepton, but not with those of the jet. Events are selected by requiring $\zeta = p_{\zeta} - 3.1p_{\zeta}^{\mathrm{vis.}} > -50\,\mathrm{GeV}$.







$$\boxed{q(\mu) = -2\log\frac{L(\mu S + B|\hat{\hat{\vec{\theta}}}_{\mu})}{L(\hat{\mu}S + B|\hat{\vec{\theta}})},}$$

$$ds^2 = e^{-2\sigma(\phi)}\eta_{\mu\nu}dx^{\mu}dx^{\nu} + r_c^2 d\phi^2$$

$$\overline{M}_{Pl}^2 = \frac{M^3}{k}(1 - e^{-2kr_c\pi})$$

rc -> compactification radius of extra dim.

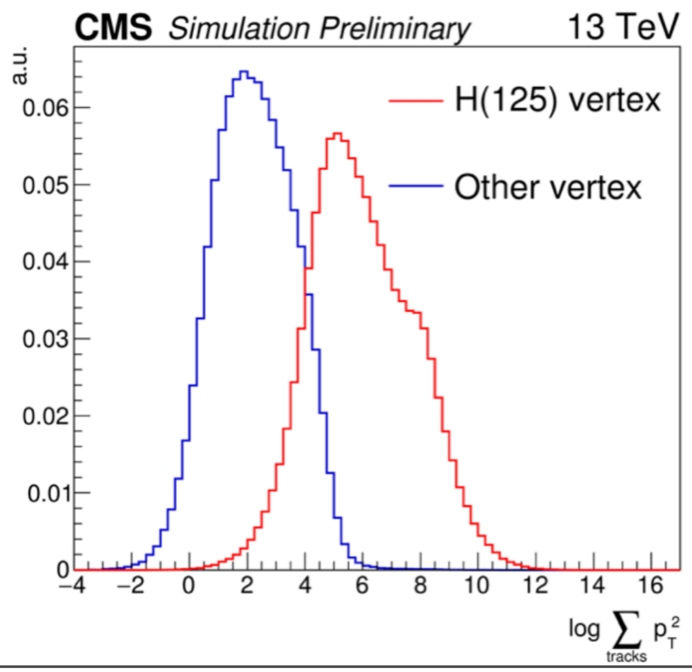
diphoton vertex

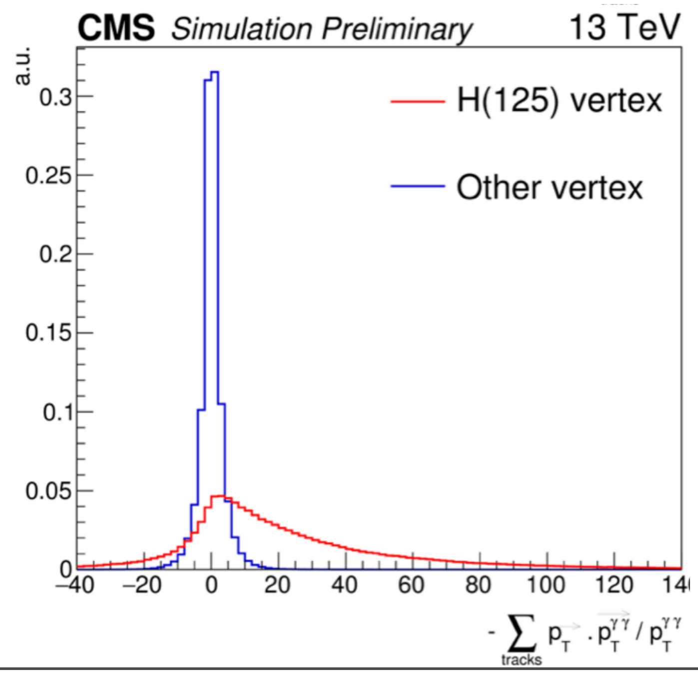
- $\sum \vec{p_T}^2$. It is the sum of the squared transverse momenta of the charged particle tracks associated with the vertex. This variable is sensitive to the production hard objects and is used in the official vertex-finding algorithm of CMS.

- $-\sum\left(\vec{p_T} \cdot \frac{\vec{p_T}^{\gamma\gamma}}{|\vec{p_T}^{\gamma\gamma}|}\right)$, commonly known as p_T-balance. This is the sum of the transverse momentum of all the charged tracks associated to the vertex, projected onto the axis of the di-photon momentum in the transverse plane. This is a measure of the degree to which the charged hadronic activity balances the transverse momentum of the di-photon system.

- $\frac{(|\sum \vec{p_T}|-|\vec{p_T}^{\gamma\gamma}|)}{(|\sum \vec{p_T}|+|\vec{p_T}^{\gamma\gamma}|)}$, commonly known as p_T-asymmetry. This is an asymmetry quantity formed from the total transverse momentum of all the charged tracks associated to the vertex and the transverse momentum of the di-photon system. This is a further measure of the balancing between the charged hadronic activity and the di-photon system

$$\boxed{pull_{conv} \;=\; |z_{conv} - z_{vtx}|/\sigma}$$

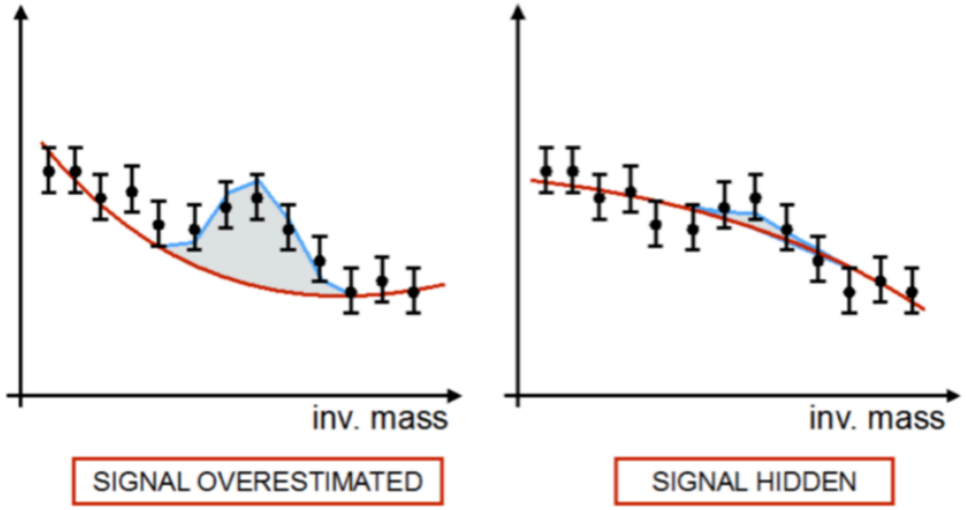




diphoton mass fit

Background model: parametric fit to the data with empirical function $f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot\log(m_{\gamma\gamma})}$

possible mis-modelling assessed with MC and included as a "bias-term"



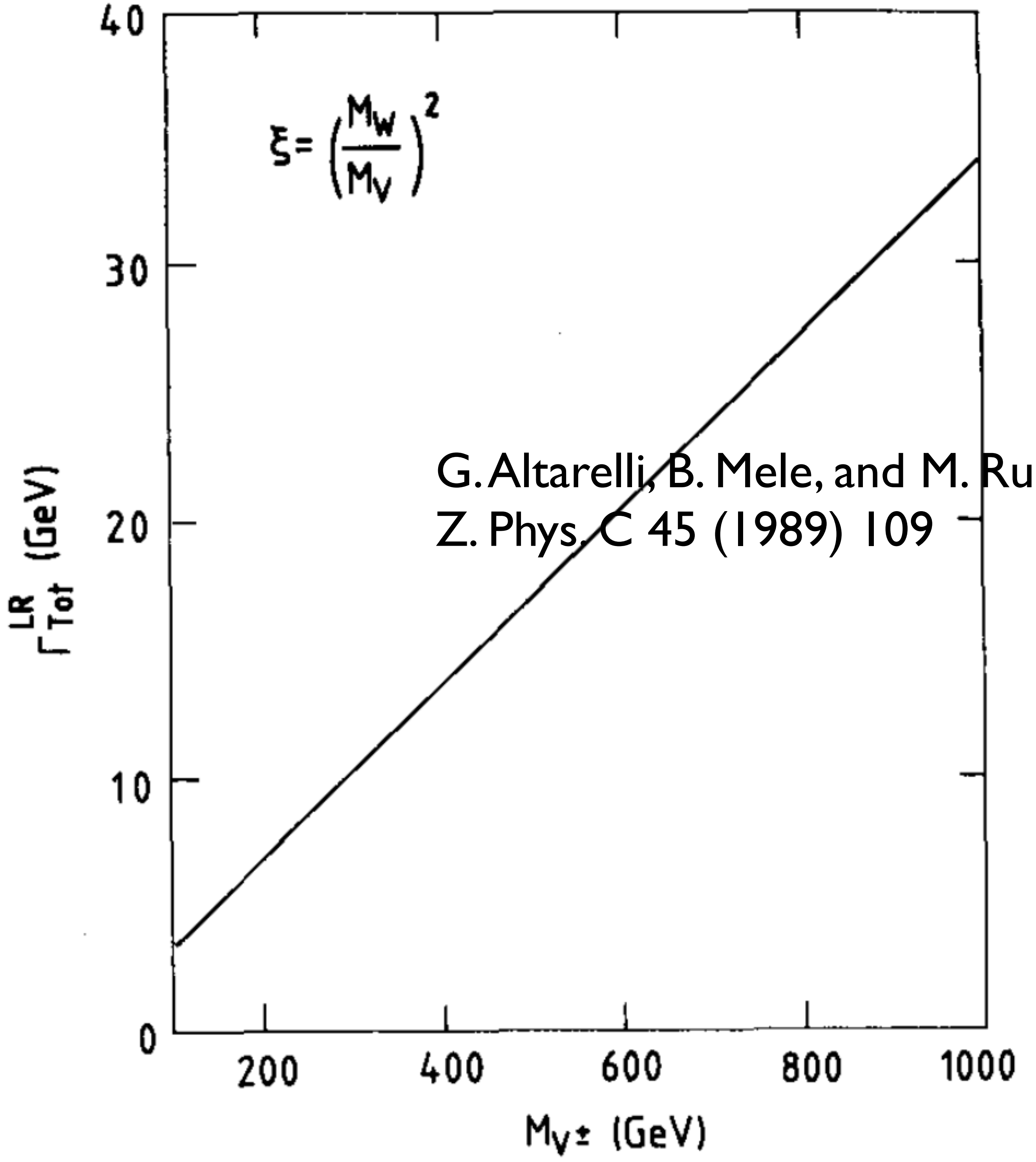
diphoton mass fit

The accuracy of the background parameterization is assessed using simulation and is quantified by studying the difference between the true and predicted numbers of background events in several $m_{\gamma\gamma}$ intervals in the search region. The relative widths of the intervals, defined by $2(x_1 - x_2)/(x_1 + x_2)$ with x_1 and x_2 the lower and upper bin edges, range between 2% and 15%. Pseudo-experiments are drawn from the mass spectrum predicted by the simulation and are fit with the chosen background model. The total number of events in each pseudo-experiment is taken from a Poisson distribution whose mean is set equal to the observation in data. For each interval, the distribution of the pull variable, defined as the difference between the true and predicted numbers of events divided by the estimated statistical uncertainty, is constructed. If the absolute value of the median of this distribution is found to be above 0.5 in an interval,

an additional uncertainty is assigned to the background parametrization. A modified pull distribution is then constructed, increasing the statistical uncertainty in the fit by an extra term, denoted the "bias term". The bias term is parametrized as a smooth function of $m_{\gamma\gamma}$, which is tuned in such a manner that the absolute value of the median of the modified pull distribution is less than 0.5 in all intervals. The amplitude of the bias term function is comparable to that of the 1 standard deviation bands in Fig. 1. This additional uncertainty is included in the likelihood function by adding to the background model a component having the same shape as the signal. The normalization coefficient of this component is constrained to have a Gaussian distribution of mean zero, with a width equal to the integral of the bias term function over the full width at half maximum of the tested signal shape. The inclusion of this additional component has the effect of avoiding falsely positive or falsely negative tests that could be induced by a mismodeling of the background shape, and it reduces the sensitivity of the analysis by at most 10%.

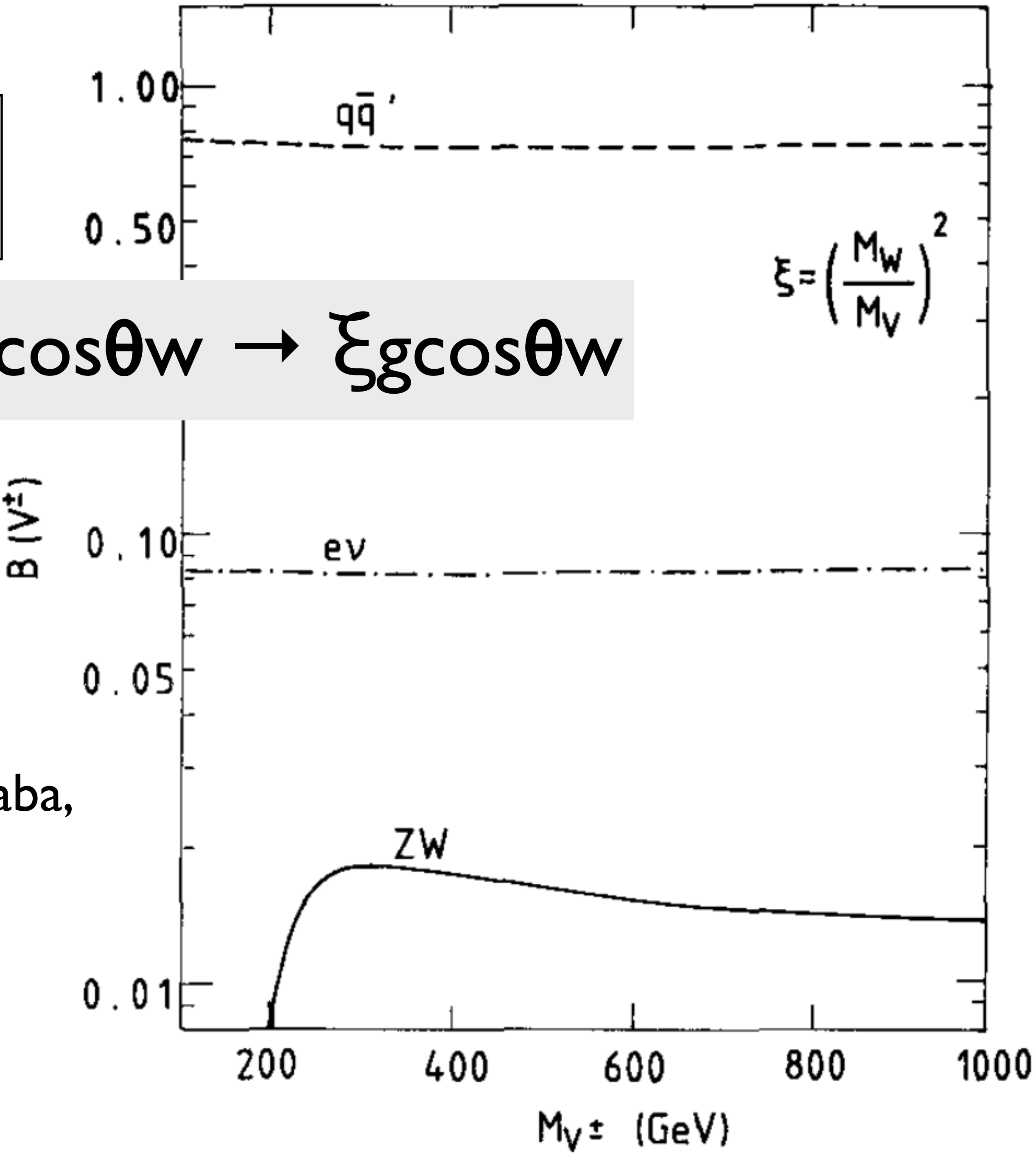
W’ssm

$$V_{W^-W^+V^0} = V_{W^\mp V^\pm Z} = ie\,\mathrm{cotg}\,\theta_w \cdot [g_{\mu\nu}(q-p)_\lambda + g_{\mu\lambda}(p-r)_\nu + g_{\nu\lambda}(r-q)_\mu]$$



G. Altarelli, B. Mele, and M. Ruiz-Altaba, Z. Phys. C 45 (1989) 109

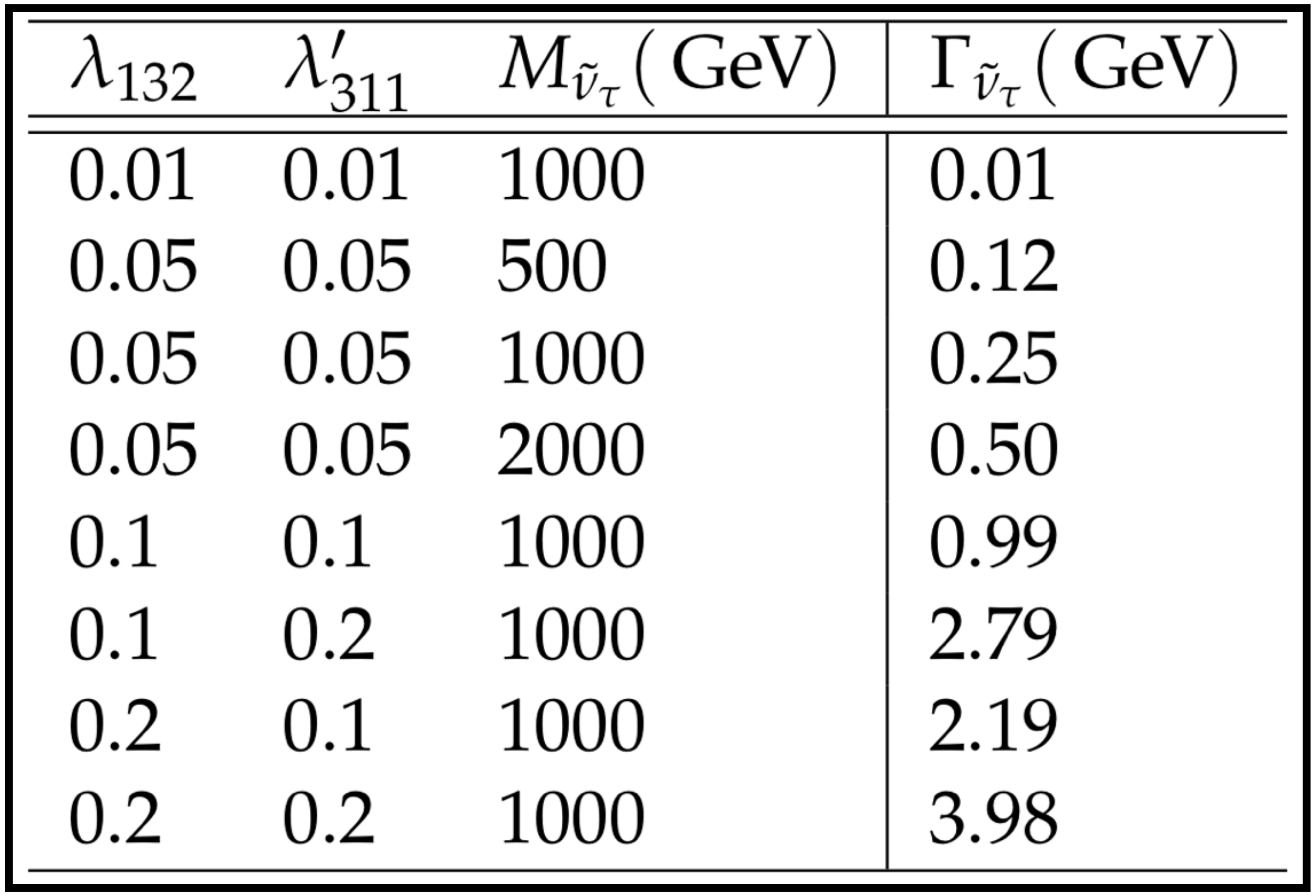
gcosθw → ξgcosθw



$$\Gamma_{W'} = \frac{4}{3}\frac{m_{W'}}{m_W}\Gamma_W$$

Mass m	Width Γ
1 TeV	33 GeV
5 TeV	170 GeV
6 TeV	200 GeV

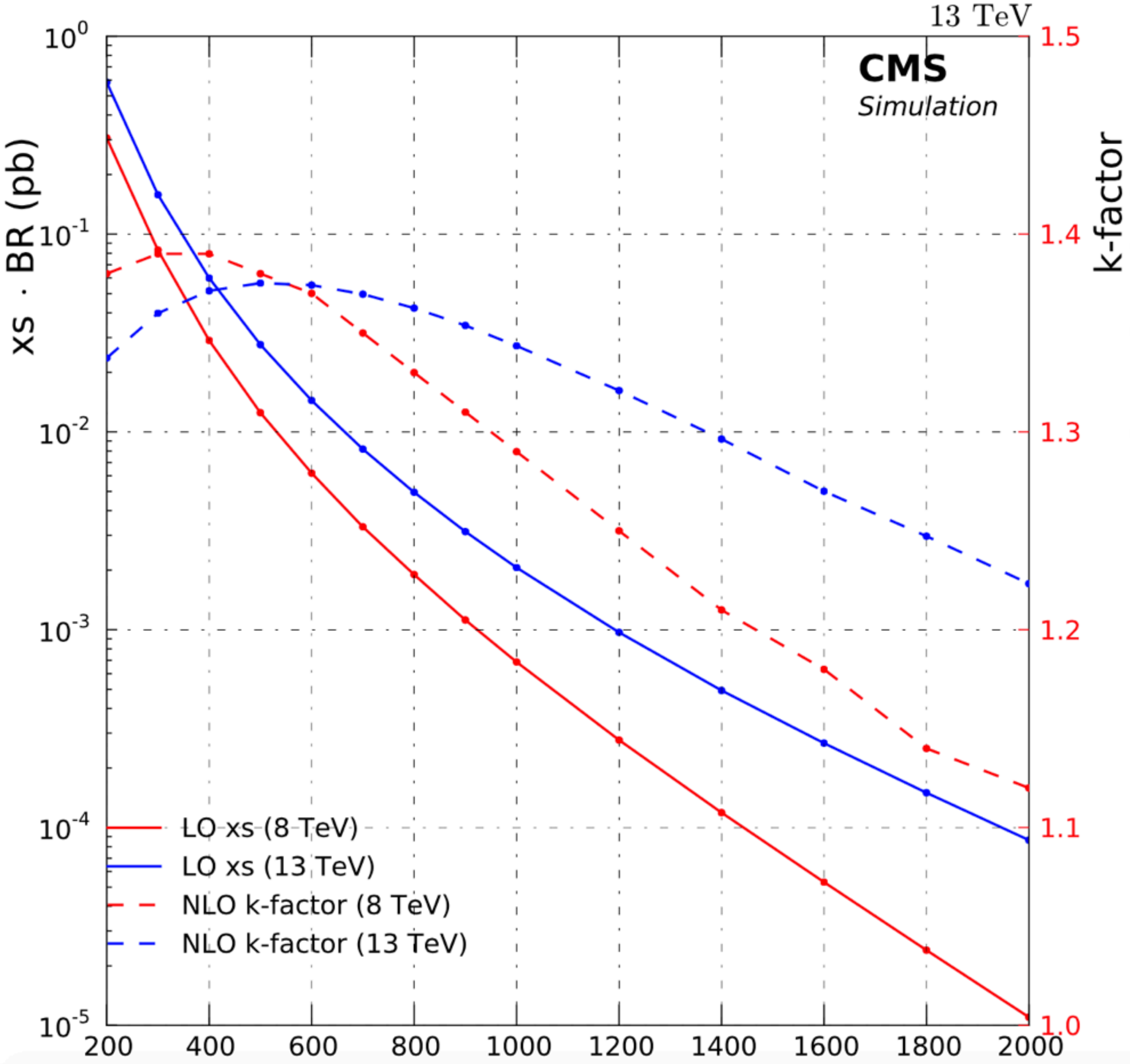
RPV tau sneutrino



λ_{132}	λ'_{311}	$M_{\tilde{\nu}_\tau}$ (GeV)	$\Gamma_{\tilde{\nu}_\tau}$ (GeV)
0.01	0.01	1000	0.01
0.05	0.05	500	0.12
0.05	0.05	1000	0.25
0.05	0.05	2000	0.50
0.1	0.1	1000	0.99
0.1	0.2	1000	2.79
0.2	0.1	1000	2.19
0.2	0.2	1000	3.98

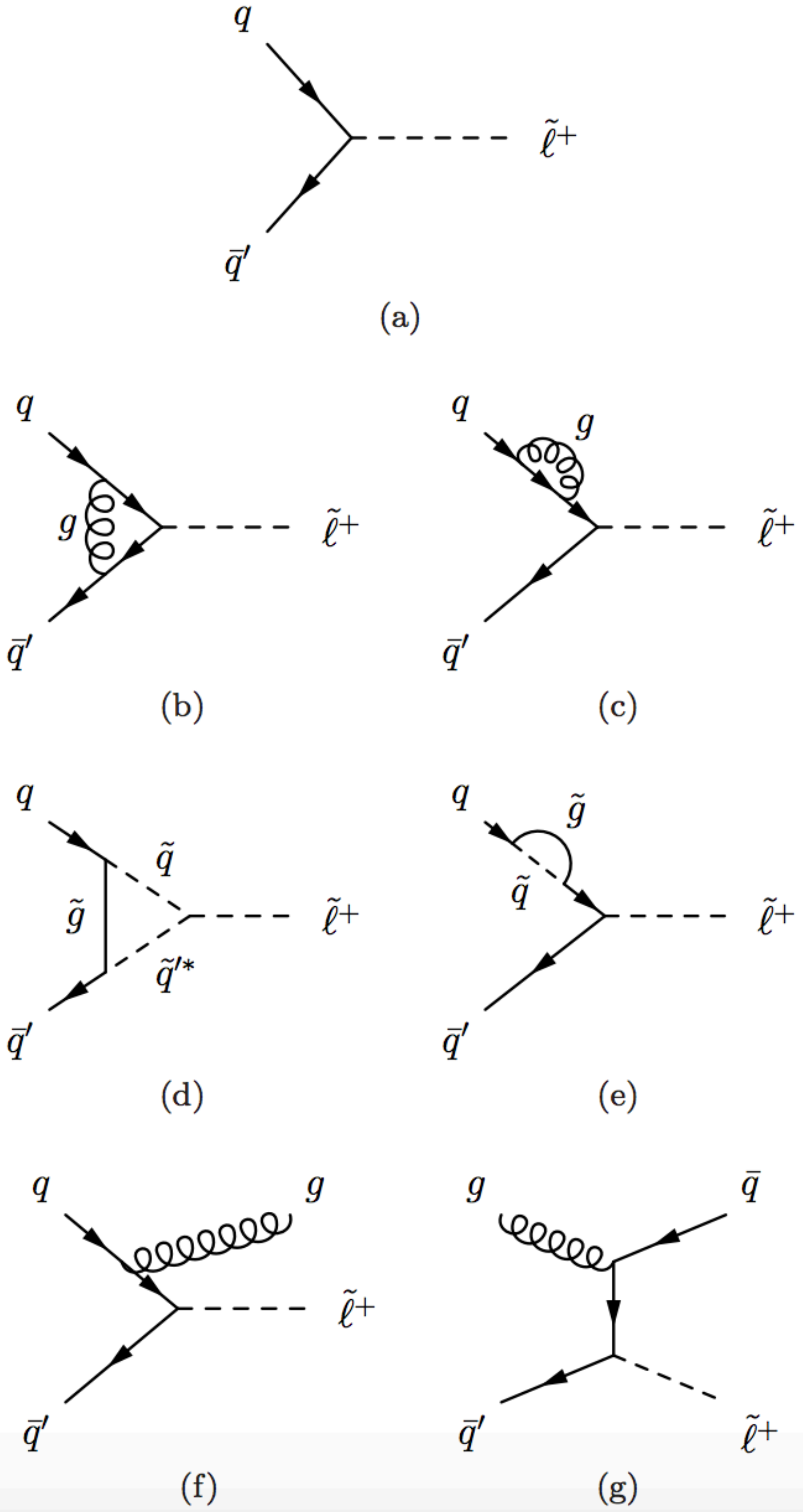
Width of tau sneutrino at LO with CALCHEP generator

$$\frac{\Gamma_{\tilde{\nu}_\tau}}{M_{\tilde{\nu}_\tau}} \approx 0.02 \cdot \left(3(\lambda'_{311})^2 + 2(\lambda_{132})^2\right)$$



RPV tau sneutrino NLO k-factor

arxiv0611195



(a) LO;
(b) QCD vertex corrections;
(c) QCD self energy;
(d) SUSY-QCD vertex correction;
(e) SUSY-QCD self energy;
(f) QCD real gluon radiation;
(g) QCD Compton process.

	CTEQ 6				MRST 04			
	LO	QCD	SUSY-QCD $A = 0\,\text{TeV}$	SUSY-QCD $A = 1\,\text{TeV}$	LO	QCD	SUSY-QCD $A = 0\,\text{TeV}$	SUSY-QCD $A = 1\,\text{TeV}$
σ [fb] Tevatron	25.72	38.43	39.23	40.22	25.55	37.73	38.52	39.50
σ [fb] LHC	358.7	467.0	478.0	491.6	347.4	471.2	482.4	496.2

$$\underbrace{P(B|A)}_{\text{Posterior}} = \frac{\overbrace{P(A|B)}^{\text{Likelihood}}\,\overbrace{P(B)}^{\text{Prior}}}{P(A)}$$

B is the theory

A is the measurement

$$P(n|s+b) = \frac{e^{-(s+b)}(s+b)^n}{n!}$$

$$p(\mathcal{H}|x) = \frac{\mathcal{L}(x|\mathcal{H}) \times \pi(\mathcal{H})}{\int \mathcal{L}(x|\mathcal{H}')\pi(\mathcal{H}')d\mathcal{H}'},$$

$$p(\theta,\nu|x) = \frac{\mathcal{L}(x|\theta) \times \pi(\theta) \times \pi(\nu)}{\int \mathcal{L}(x|\theta')\pi(\theta') \times \pi(\nu')d\theta'}.$$

$$p(\theta|x) = \frac{\int \mathcal{L}(x|\theta) \times \pi(\theta) \times \pi(\nu)d\nu}{\int\int \mathcal{L}(x|\theta')\pi(\theta') \times \pi(\nu')d\theta' d\nu'}.$$

$$1-\alpha = \int_{\theta_{\mathrm{down}}}^{\theta_{\mathrm{up}}} p(\theta|x)d\theta$$

LFV in R-Parity Violating (RPV) SUSY

super-potential allows terms like this

$$W_{\Delta L=1} = \frac{1}{2}\lambda_{ijk}\underset{\substack{\longleftrightarrow \\ \text{LLE}}}{L_i L_j \bar{e}_k} + \lambda'_{ijk}\underset{\substack{\longleftrightarrow \\ \text{LQD}}}{L_i Q_j \bar{d}_k} + \mu'_i L_i H_u$$

λ and λ’ terms violate lepton number (and also lepton flavor)

They also violate R-parity.

R-parity (R) = $(-1)^{3B+L+2s}$

R=(+1) for SM, R=(-1) for SUSY particles

R-Parity Conserving SUSY: Proton always stable

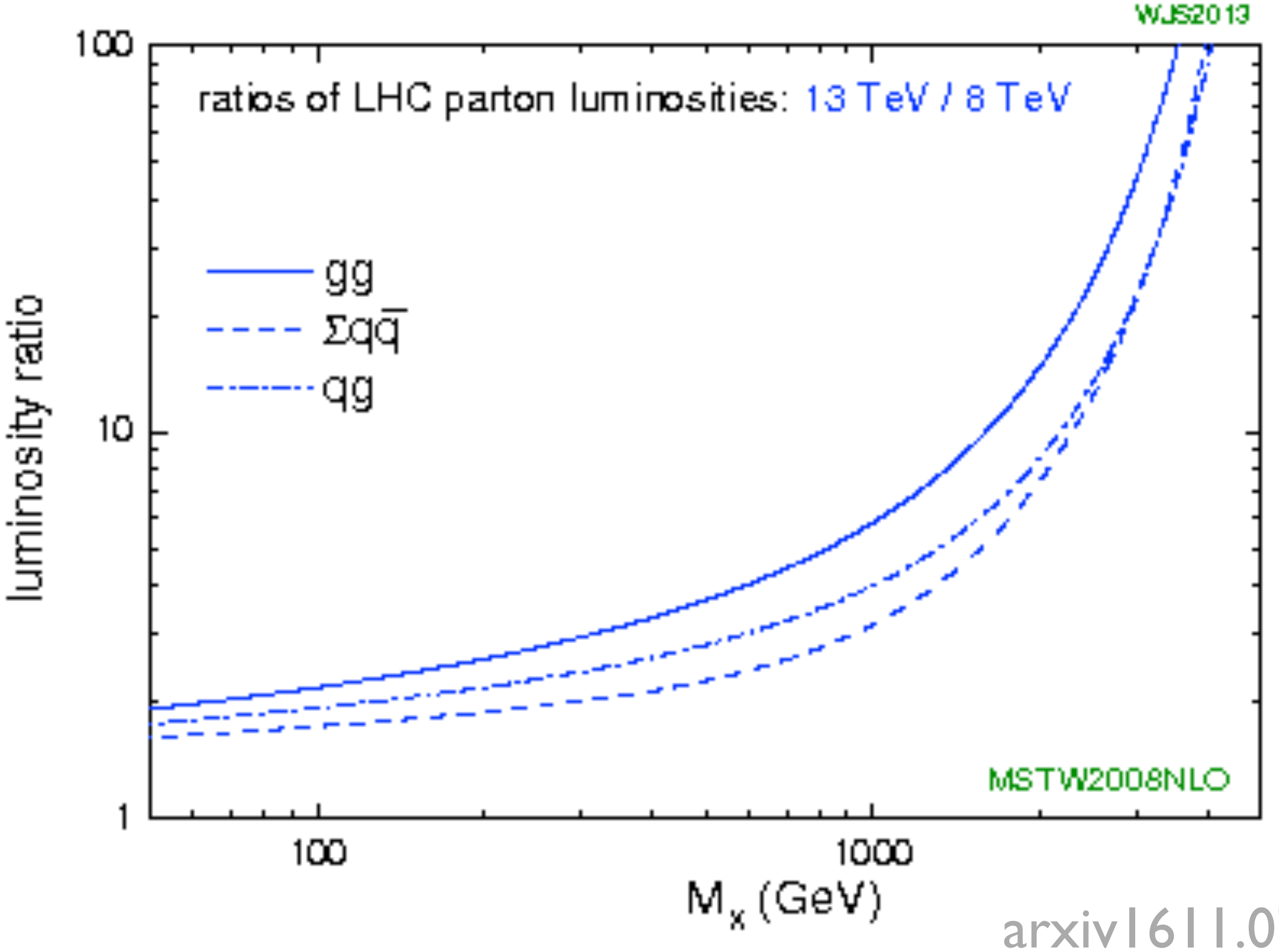
B → baryon num.
L → lepton num.
s → particle spin

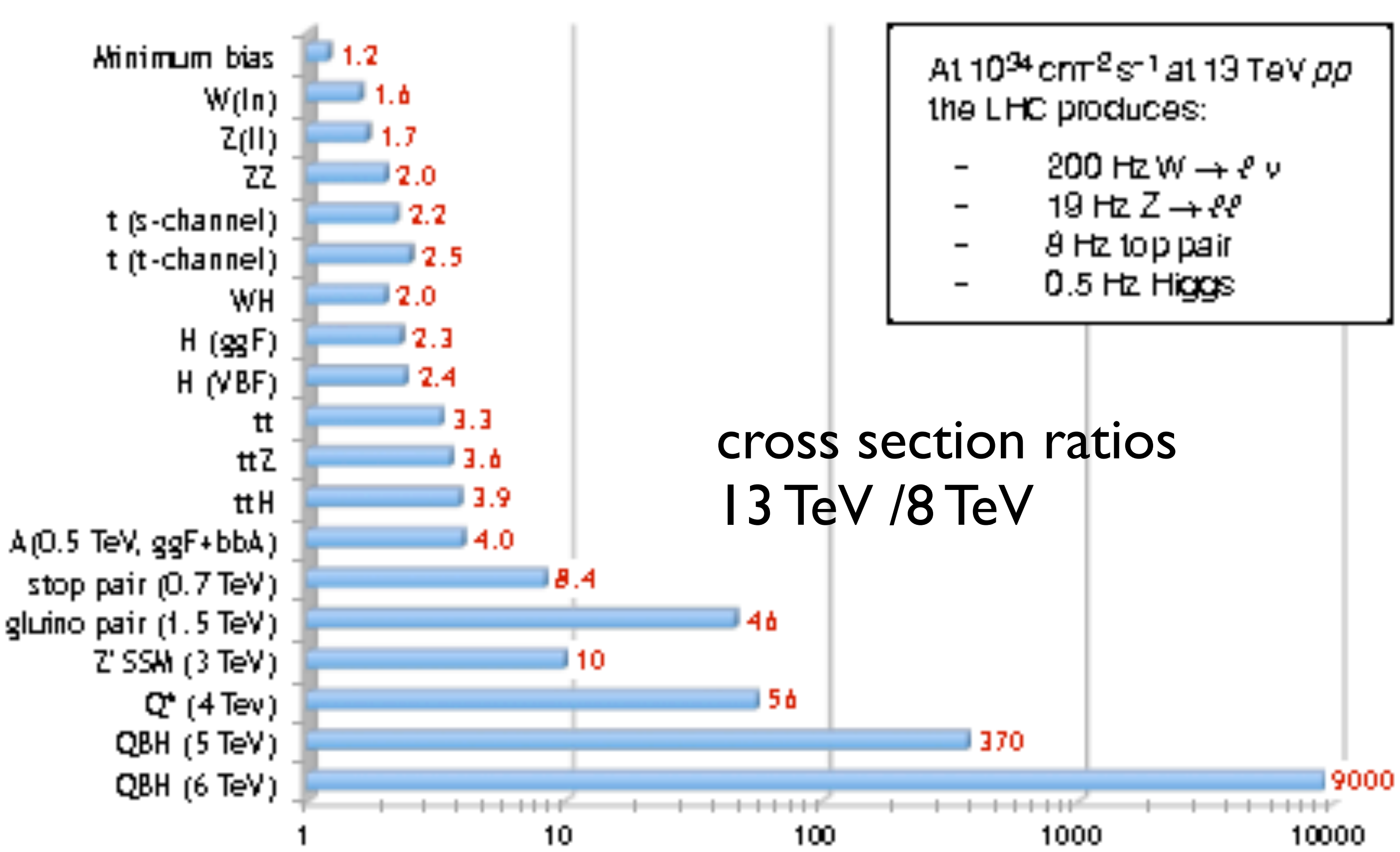
If only L (or B) is violated, then the proton would be still stable!

In RPV SUSY, the Lightest SUSY Particle (LSP) is unstable → low MET in event

From Run I to Run II

- 7/8 TeV ➡ 13 TeV
  - Increase in center-of-mass energy in run-II significantly extends reach of run-I





cross section ratios
13 TeV /8 TeV

arxiv1611.07864

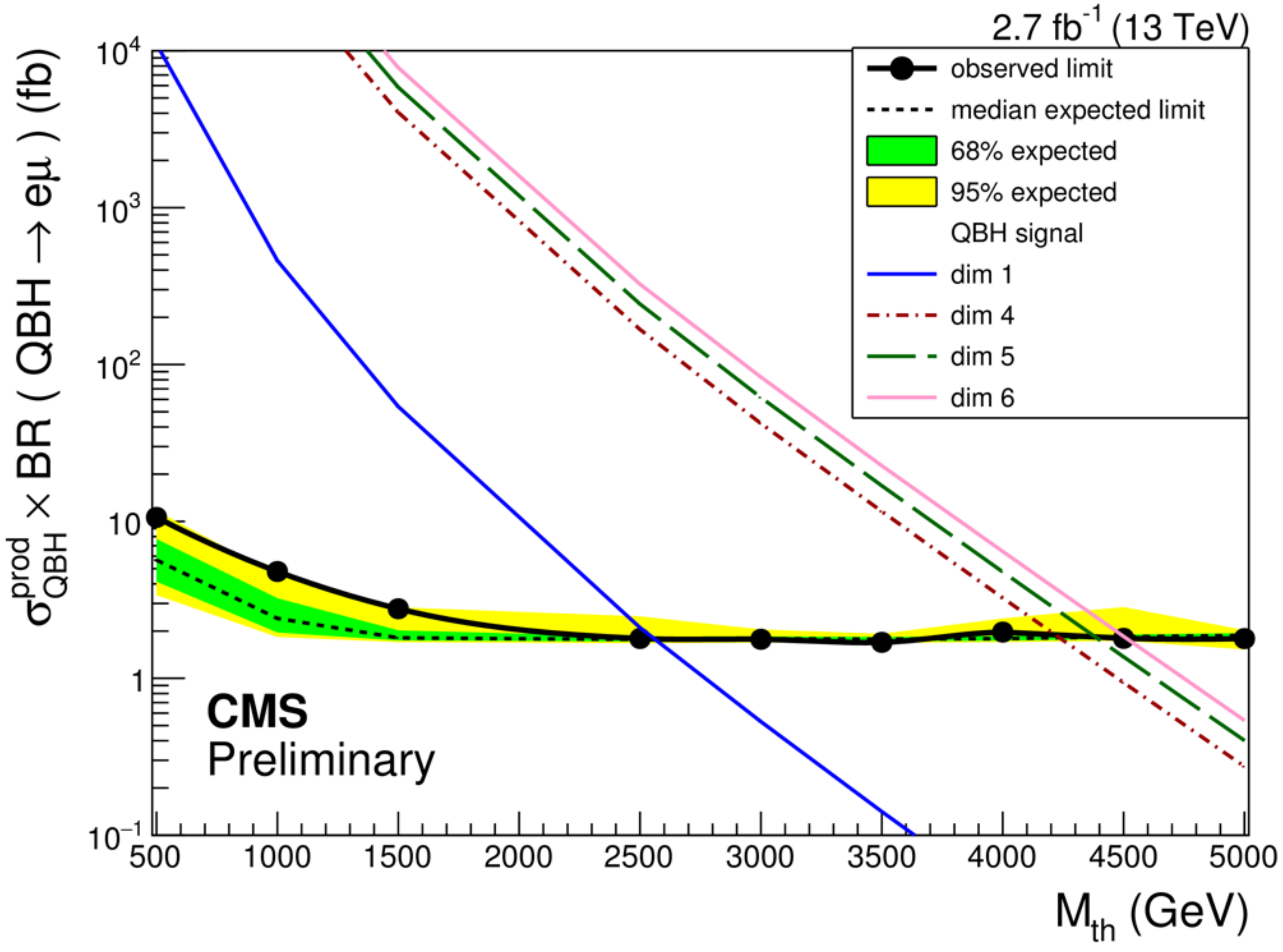
- Increased instantaneous luminosity
  - Increased pile-up
    - mean value **27** (in2016) vs **21** (in 2012)
  - Increased event rate, challenge for trigger

Experimentally
more difficult

eμ - QBH interpretation

Theoretical Interpretation

- **Quantum Blackhole (QBH)**
  - Extra dimension(s) → Fundamental Planck scale lowered to TeV region
  - QBH produced if $\sqrt{s}>M_P$
  - Spin-0, colorless, charge-neutral QBH
  - n=1 (RS), n=4,5,6 (ADD)
  - Signal generated by QBH generator (Douglas M. Gingrich arxiv 0911.5370)



Electric charge, QCD color, spin conserved