RWTH AACHEN
Phys. Inst. III A

SEARCH FOR NEW PHYSICS IN LEPTON + MET FINAL STATES

EXO-12-060

Bundesministerium
für Bildung
und Forschung

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on behalf of the CMS Collaboration

XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects

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OUTLINE

I. ANALYSIS

- Signal signature
- Standard model background processes
- Event reconstruction and selection
- Resulting distributions

II. PHYSICS INTERPRETATION

- Sequential standard model W’ without SM W – W’ interference
- Sequential standard model W’ with SM W – W’ interference
- Helicity-non-conserving contact interaction model
- Model independent cross section limit

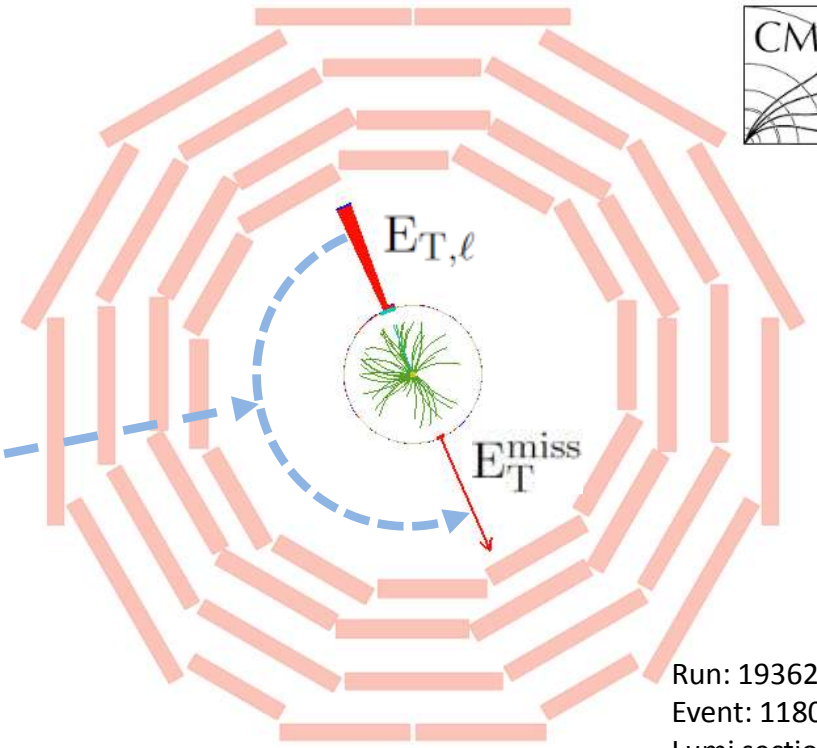
III. SUMMARY

I. ANALYSIS

SIGNAL SIGNATURE

- Signature: W-like decay to 1 lepton (ℓ) and 1 neutrino (ν)
- 2 search channels: ℓ = e,μ
- Characteristics:
  - Isolated high-energy ℓ
  - Missing transverse energy $\mathrm{E_T^{miss}}$ (from ν)
  - Transverse plane:
    - $\Delta\phi(\ell, \mathrm{E_T^{miss}}) \approx \pi$
    - $\frac{\mathrm{E_T}}{\mathrm{E_T^{miss}}} \approx 1$

transverse view of CMS



Run: 193621
Event: 1180868279
Lumi section: 1557

- Main discriminating variable: Transverse mass

$$\mathrm{M_T} = \sqrt{2 \cdot \mathrm{p_{T,\ell}} \cdot \mathrm{E_T^{miss}} \cdot (1 - \cos(\Delta\phi(\ell, \mathrm{E_T^{miss}})))}$$

- Signal models: W', Contact Interaction, … (details later!)

STANDARD MODEL(SM) BACKGROUND

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- SM background processes:

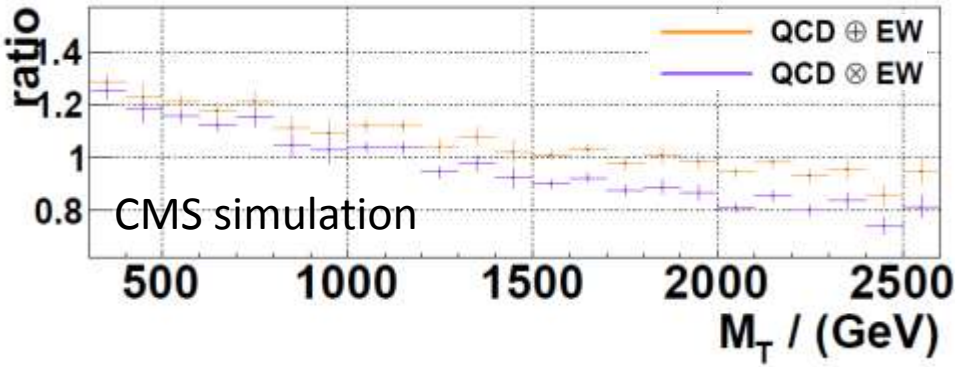
W → $\ell\,\nu$	QCD	ttbar & single top	W → $\tau\,\nu$
γ + Jets	Drell-Yan → $\ell\,\ell$	Drell-Yan → $\tau\,\tau$	WW, WZ, ZZ

- Background estimation:

– Based on MC simulation

– Parametrisation of MC prediction with empirical function $f(M_T) = \frac{a}{(M_T^3 + bM_T + c)^d}$

– SM W: NLO QCD and EW corrections applied using a mass dependent k-factor



MUON CHANNEL : EVENT SELECTION

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impact parameter

$d_{xy} < 0.2$ mm

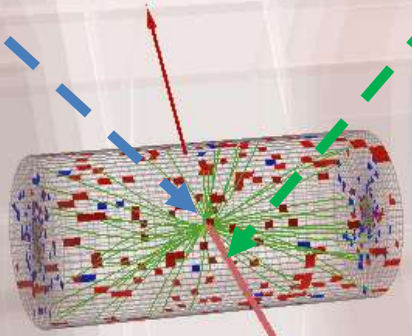
$d_z < 5$mm

tracker

≥ 1 pixel detector hit(s)

≥ 5 tracker layer hits

$\delta p_T / p_T < 0.3$



isolation

$$\frac{\sum_{\Delta R<0.3} p_T}{p_T^{\mu}} < 0.1$$

muon detector

≥ 2 μ-stations with segments

Run/Event: 208307 / 445184756
Lumi section: 287

- 1 μ with $p_T > 45$ GeV & $|\eta| < 2.1$
- veto if second μ with $p_T > 25$ GeV

kinematic selection:

- $|\Delta\phi(\ell, E_T^{miss})| > 2.5$
- $0.4 < \frac{E_T}{E_T^{miss}} < 1.5$

ELECTRON CHANNEL : EVENT SELECTION

isolation

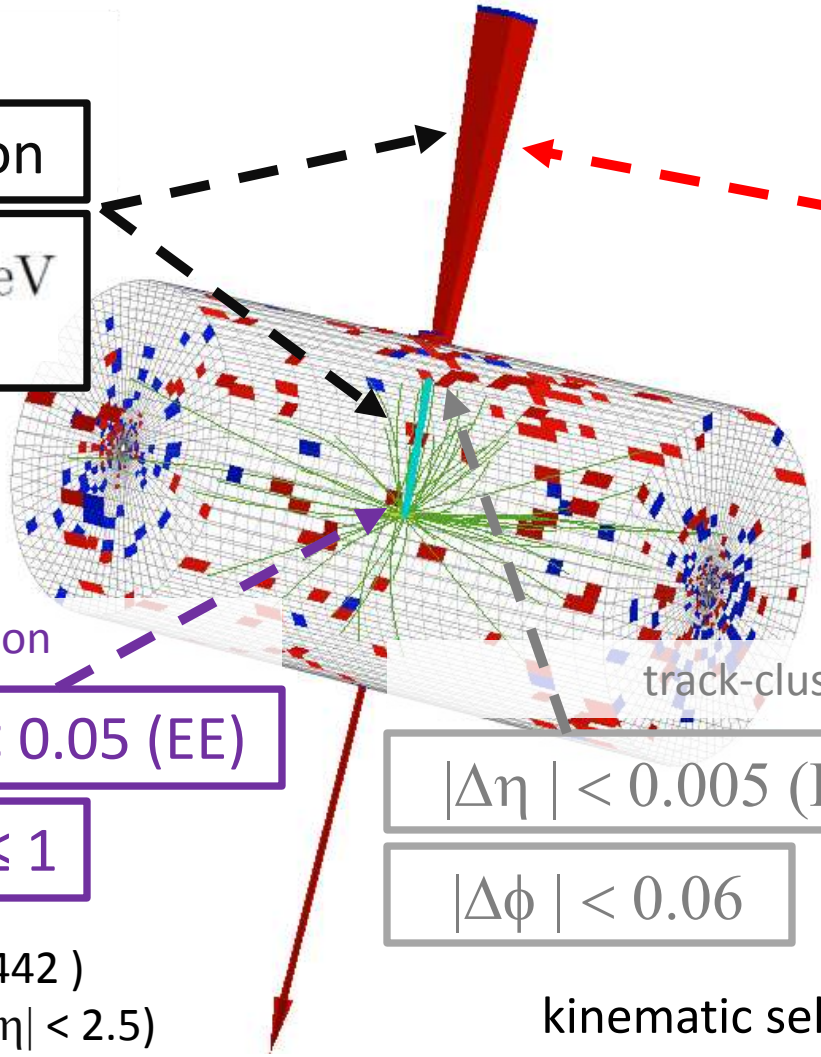
calorimetric isolation

$$\sum_{0.04<\Delta R<0.3} p_T < 5 \text{ GeV}$$

calorimeter

shower shape

H / E < 0.05



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Run/Event: 193621 / 1180868279
Lumi section: 1557

conversion rejection

d_{xy} < 0.02cm (EB) / < 0.05 (EE)

inner layer lost hits ≤ 1

track-cluster matching

$|\Delta\eta|$ < 0.005 (EB) / < 0.007 (EE)

$|\Delta\phi|$ < 0.06

EB = ECAL barrel ($|\eta|$ < 1.442)
EC = ECAL endcap (1.56 < $|\eta|$ < 2.5)

- 1 e with E_T > 100 GeV
- veto if second isolated e

kinematic selection:

- $|\Delta\phi(\ell, E_T^{miss})| > 2.5$
- $0.4 < \frac{E_T}{E_T^{miss}} < 1.5$

M_T DISTRIBUTIONS

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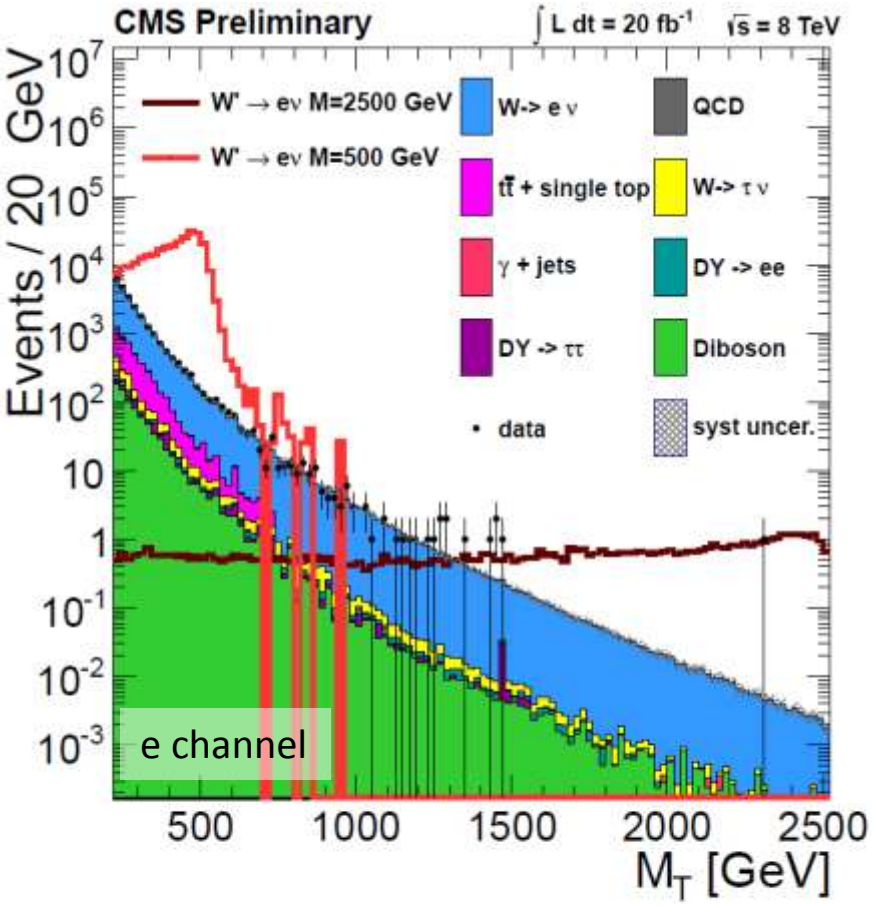

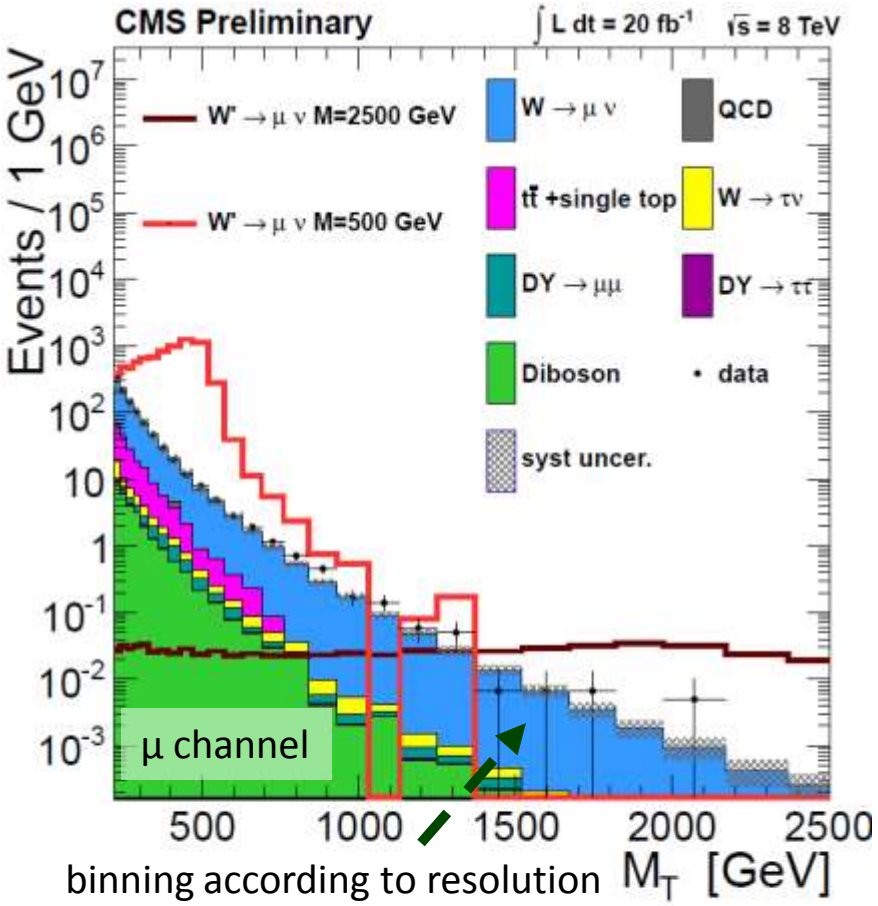

- Full 2012 CMS dataset
- Highest M_T Event at :

  2.3 TeV (e) / 2.1 TeV (μ)
- No strong indications for new physics

e channel	M_T > 1.5 TeV
Data	1
SM	$1.99^{+0.27}_{-0.24}$

μ channel	M_T > 1.5 TeV
Data	3
SM	$2.27^{+0.62}_{-0.49}$

II. PHYSICS INTERPRETATION

SEQUENTIAL STANDARD MODEL (SSM)

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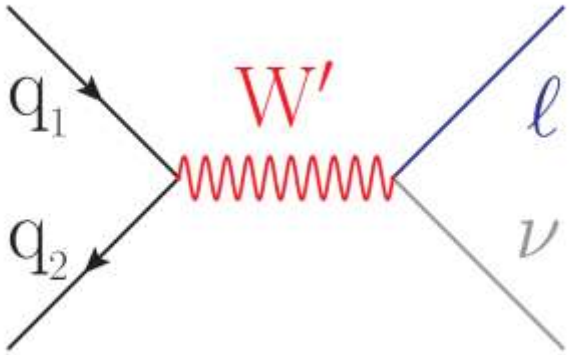
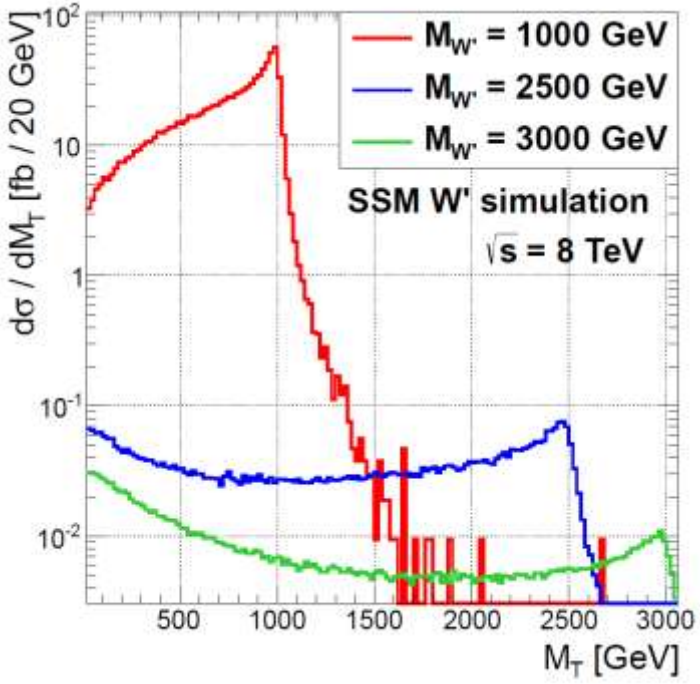
- Simple benchmark model for searches
- Predicts heavy charged boson called W'
- Model assumptions:
  - W' = carbon copy of standard model W
  - Decay to tb possible if $m_{W'}$ large enough
  - Decay to WZ is suppressed

  → 8% BR per ℓ channel
- Model without SM W – SSM W' interference:
  - Probed W' mass range: 300 GeV – 4000 GeV
  - W' leads to Jacobian Peak in M_T spectrum
  - For large $m_{W'}$: off-shell part dominates





LIMITS : SSM WITHOUT INTERFERENCE

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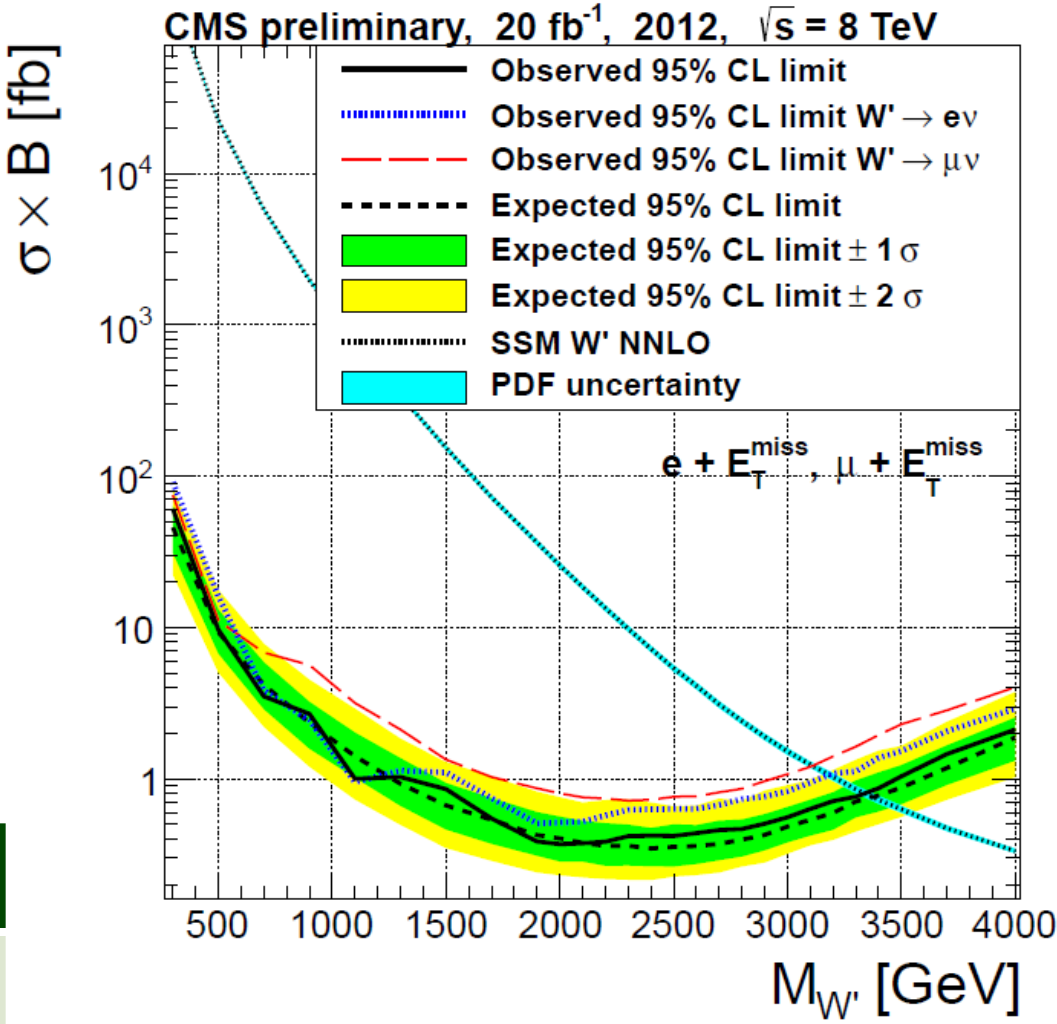
- No strong indication for new physics
- Set 95% CL exclusion limits
- Bayesian approach
- Use M_T spectrum in range:

  240 GeV - 4000 GeV

- Use multiple bins

→ account for shape and total variation



combined 95% CL limits :

Model	SSM
Observed Limit	$m_{W'} < 3.35$ TeV
Expected Limit	$m_{W'} < 3.40$ TeV

SEQUENTIAL STANDARD MODEL W' WITH INTERFERENCE

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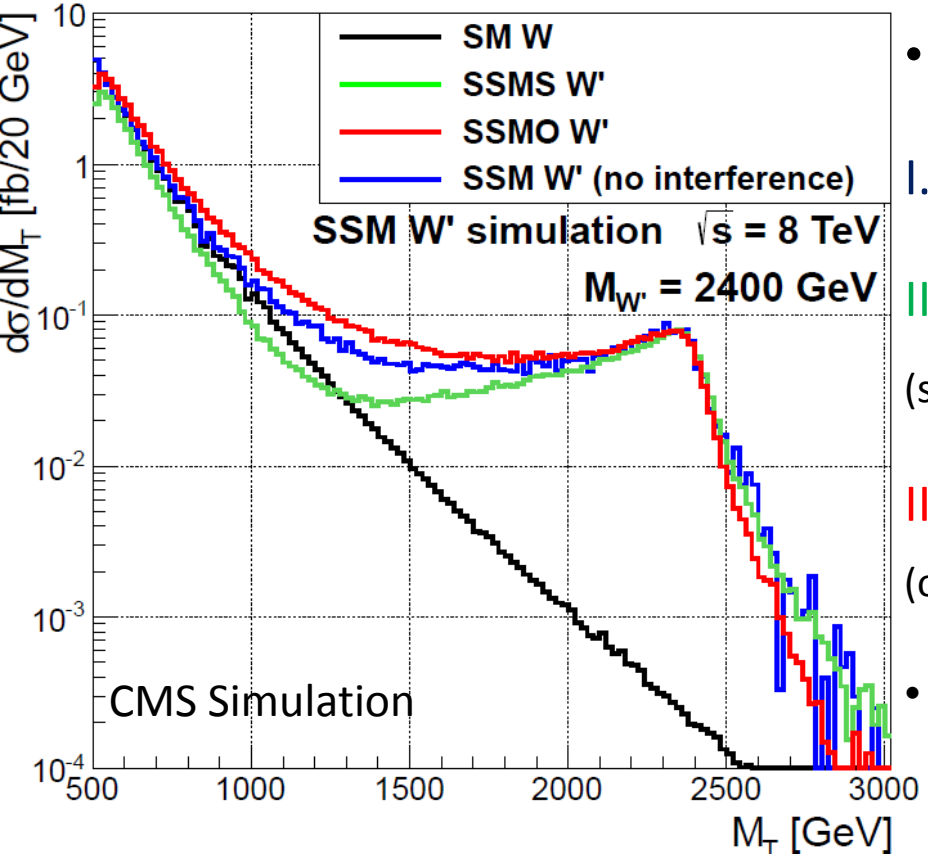
- Previous slides: SSM W' without SM W and SSM W' interference



- In general: 3 scenarios

I. No SM W – SSM W' interference (SSM)

II. Destructive interference ($M_W < M < M_{W'}$)

(same sign of coupling for leptons and quarks (SSMS))

III. Constructive interference ($M_W < M < M_{W'}$)

(opposite sign of coupling for leptons and quarks (SSMO))

- Basic model assumptions stay the same

combined 95% CL limits :

Model	SSMO	SSMS
Observed Limit	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.10$ TeV
Expected Limit	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.20$ TeV

CONTACT INTERACTION MODEL

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• Basic idea :

– Quarks and Leptons = composite objects of fundamental subparticles

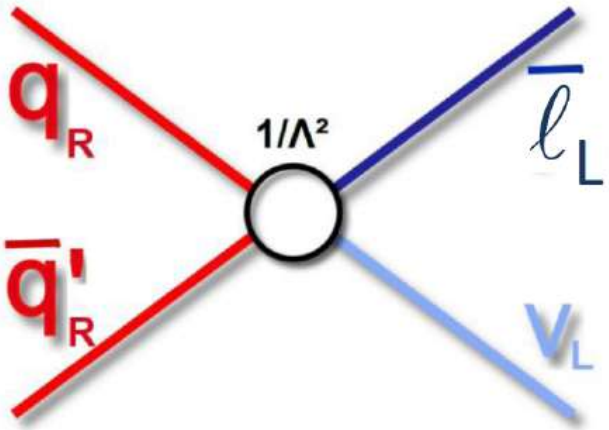
– At energies << binding energy Λ: substructure manifests as 4 fermion contact interaction

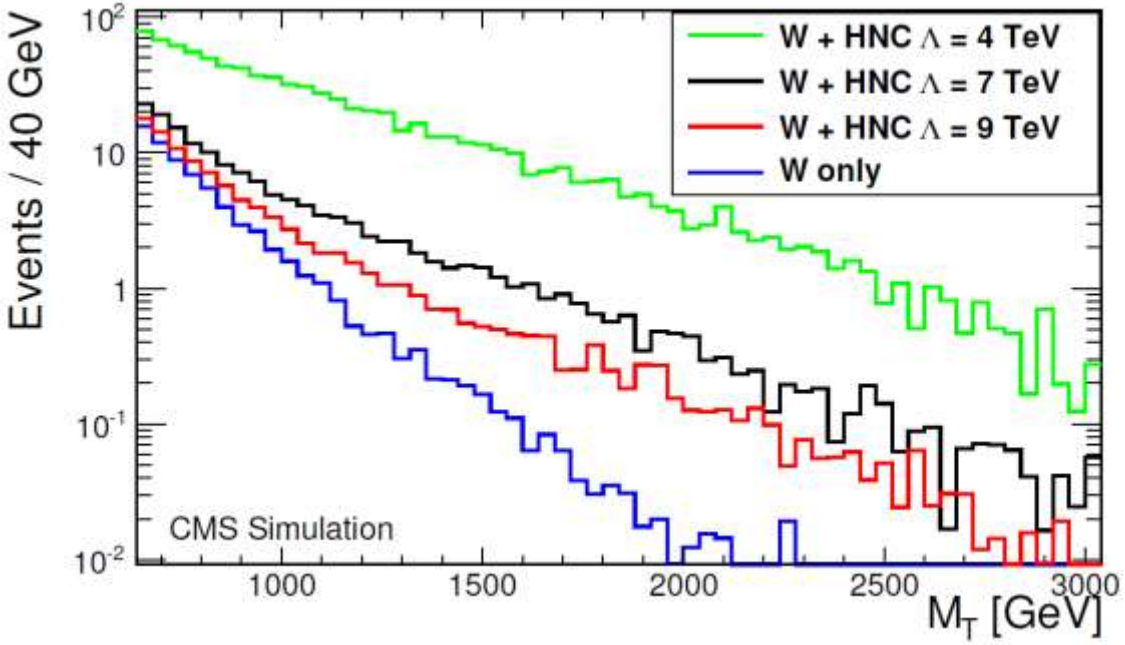
• Helicity-non-conserving contact interaction model:

– Event signature like SSM W'

– No interference with SM W

– Cross section $\sigma \propto \Lambda^{-4}$



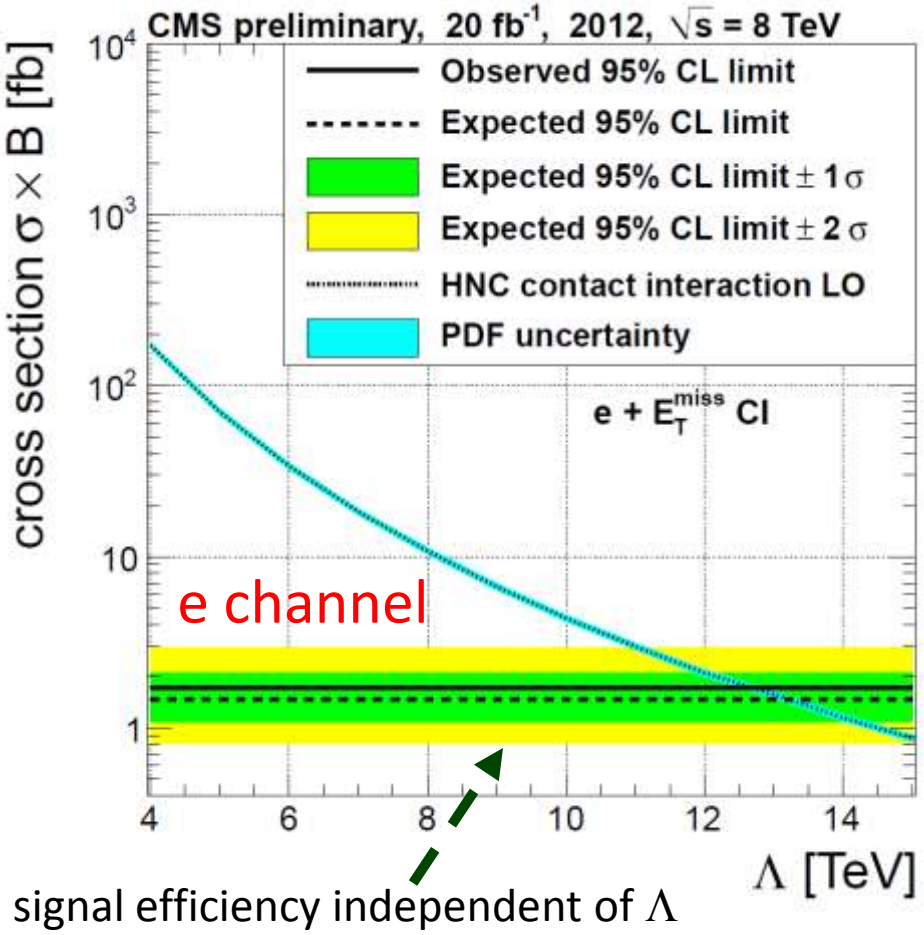


signal shape & efficiencies:

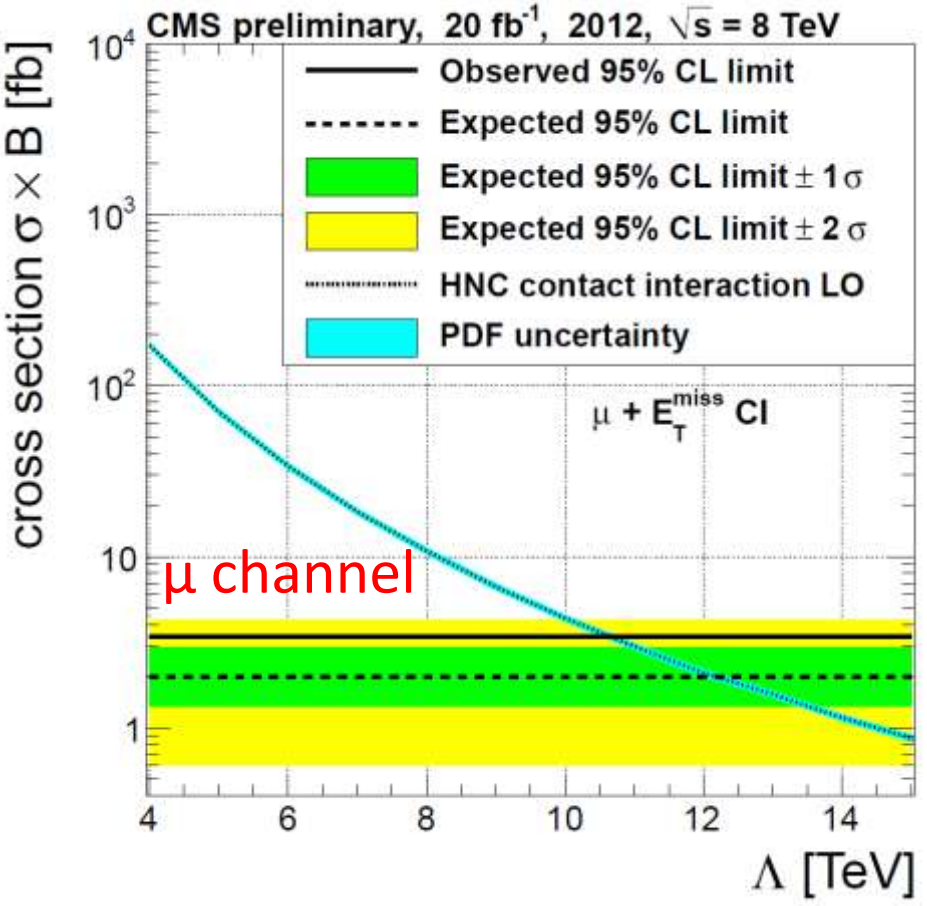
→ independent of Λ

→ flat excess instead of jacobian peak

CONTACT INTERACTION LIMIT



signal efficiency independent of Λ



combined 95% CL Limits : EXO-12-060

Model	e channel	μ channel
Observed Limit	$\Lambda < 13.0$ TeV	$\Lambda < 10.9$ TeV
Expected Limit	$\Lambda < 13.3$ TeV	$\Lambda < 12.2$ TeV

MODEL INDEPENDENT CROSS SECTION LIMIT

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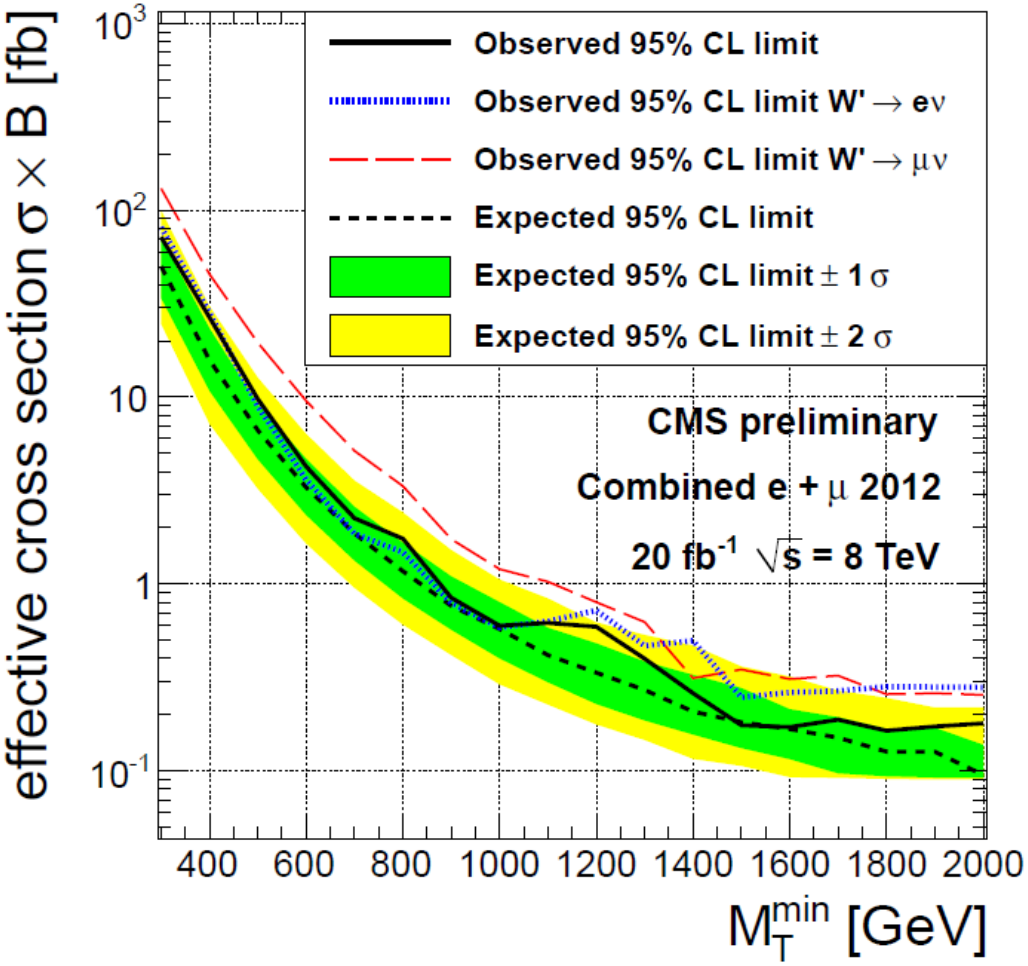

- Select events above M_T threshold M_T^{min} (singlebin limit)
- Apply acceptance and detector efficiency on possible signal cross section

86% electron-channel / 83% muon-channel

III. SUMMARY

SUMMARY

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- Presented CMS search for new physics in lepton + MET final states
- Results use 20 fb^{-1} of 2012 pp collision data
- No signs for physics beyond the standard model

Model	SSM	SSMO	SSMS	CI e-channel	CI-μ channel
Obs. Limit	$m_{W'} < 3.35$ TeV	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.10$ TeV	$\Lambda < 13.3$ TeV	$\Lambda < 10.9$ TeV
Exp. Limit	$m_{W'} < 3.40$ TeV	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.20$ TeV	$\Lambda < 13.0$ TeV	$\Lambda < 12.2$ TeV

- For plots, notes and additional information about this analysis see

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO12060

- For information about other CMS EXO results see

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

THANK YOU

BACKUP

HIGHEST M_T EVENT : ELECTRON CHANNEL

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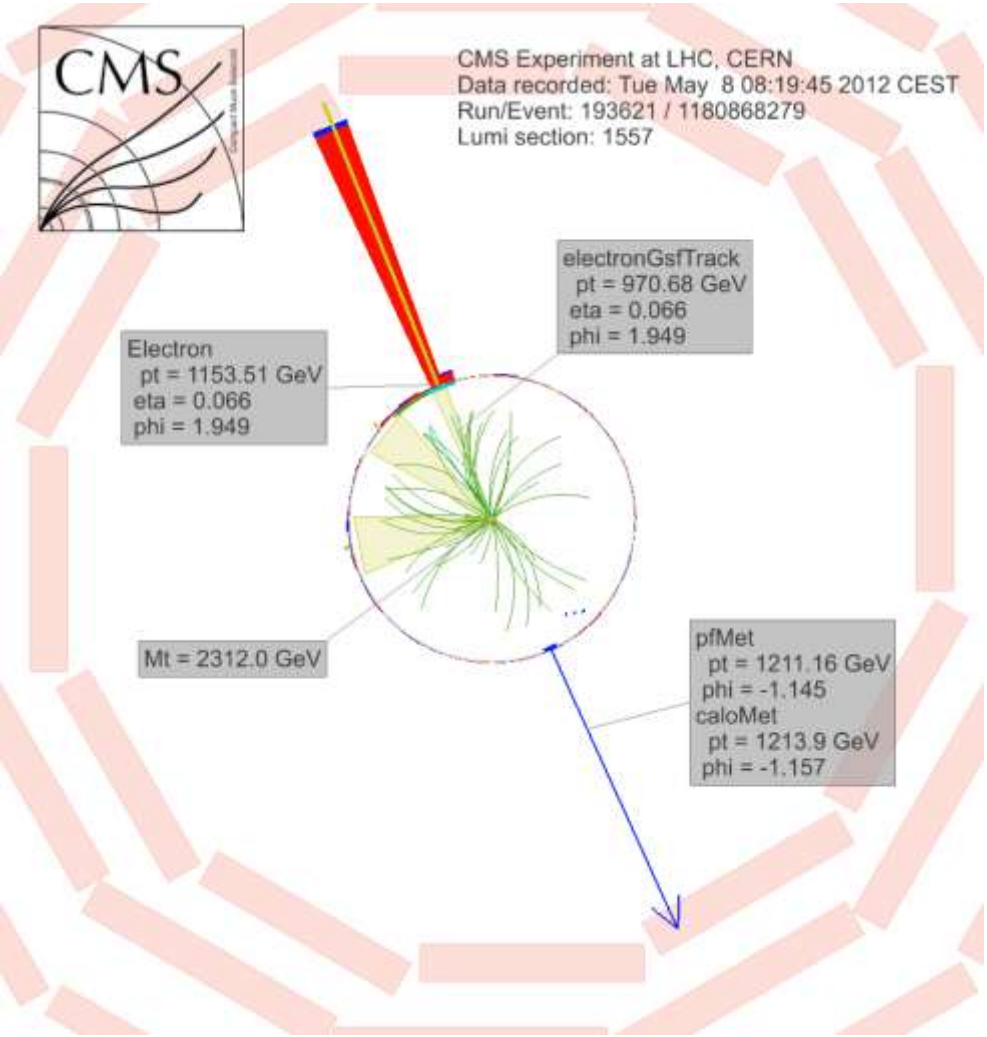
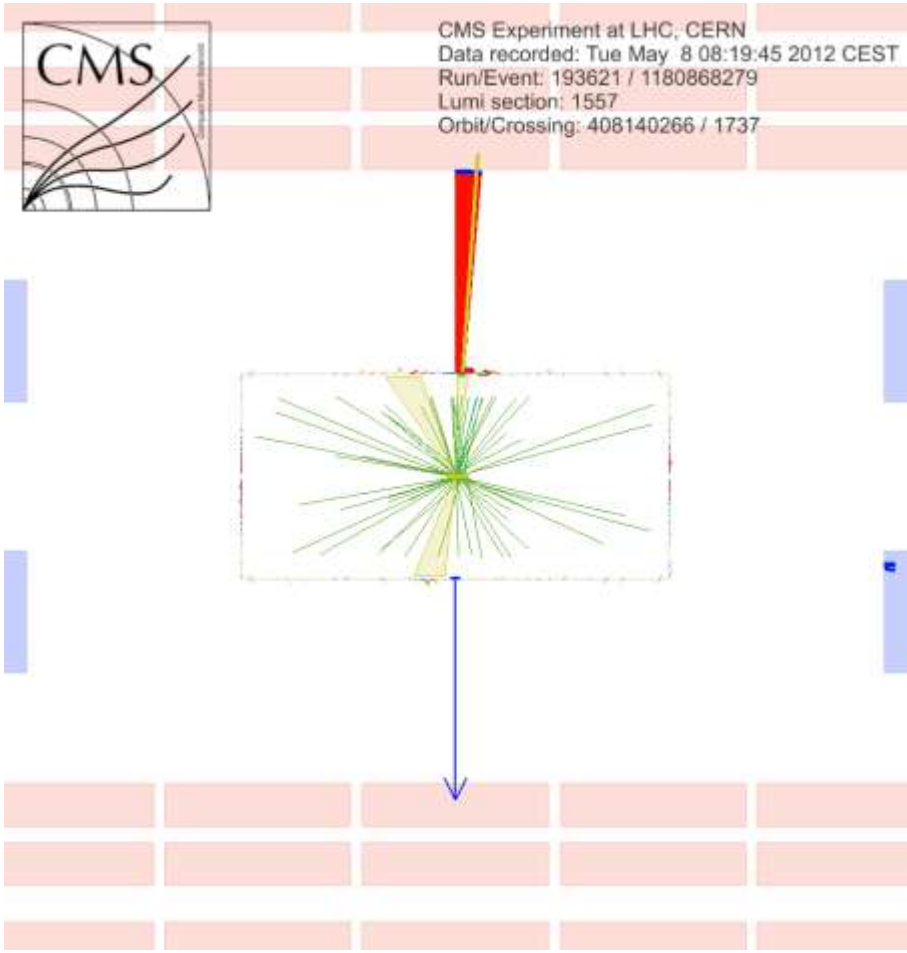
ρ - ϕ view

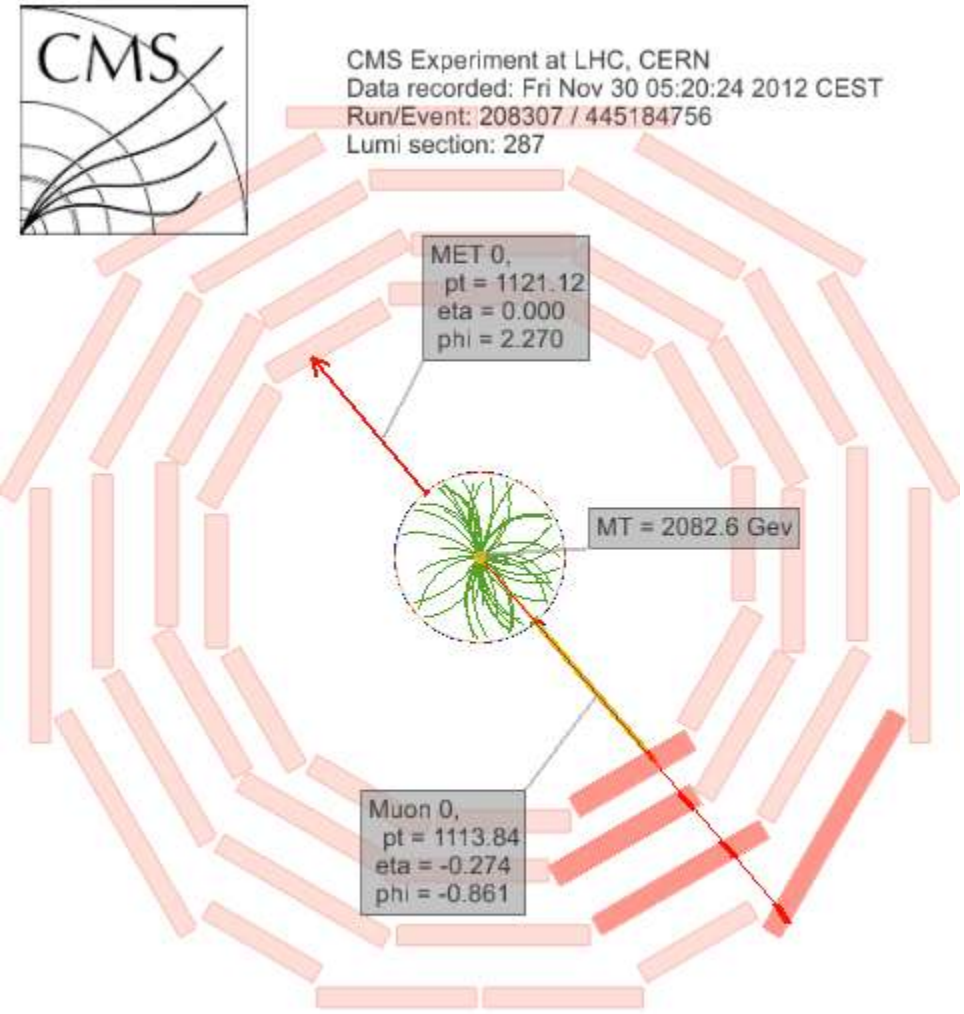


ρ - z view



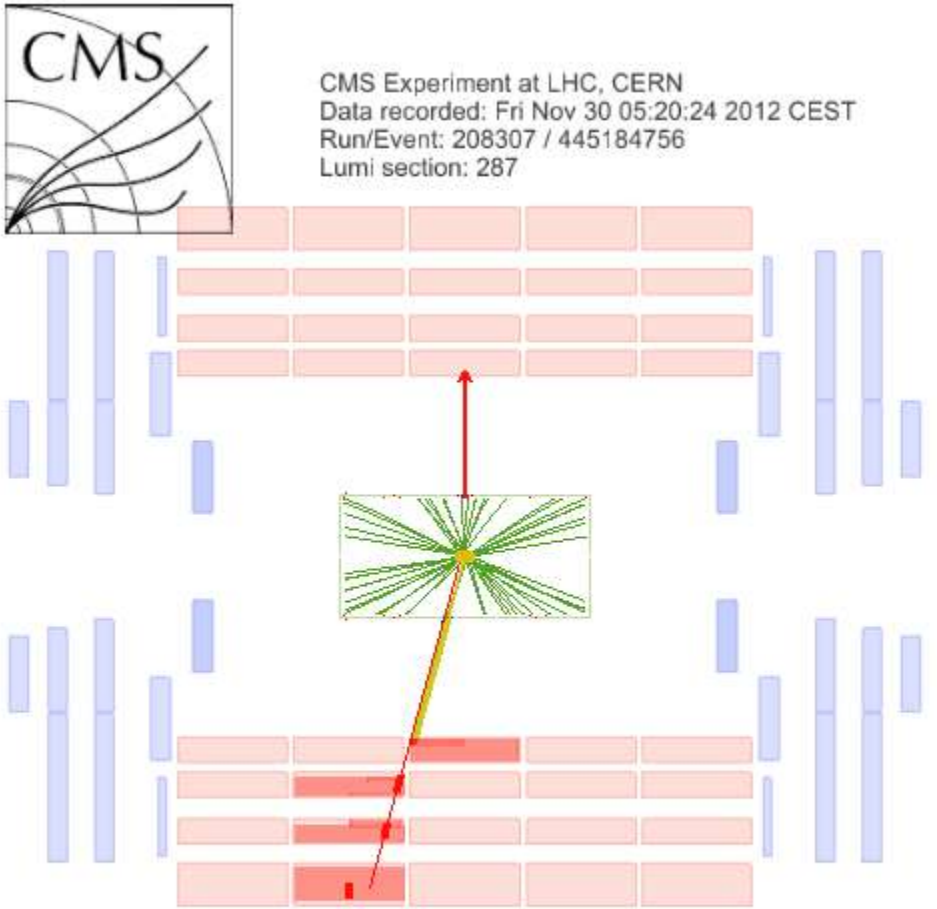
HIGHEST M_T EVENT : MUON CHANNEL

ρ - ϕ view

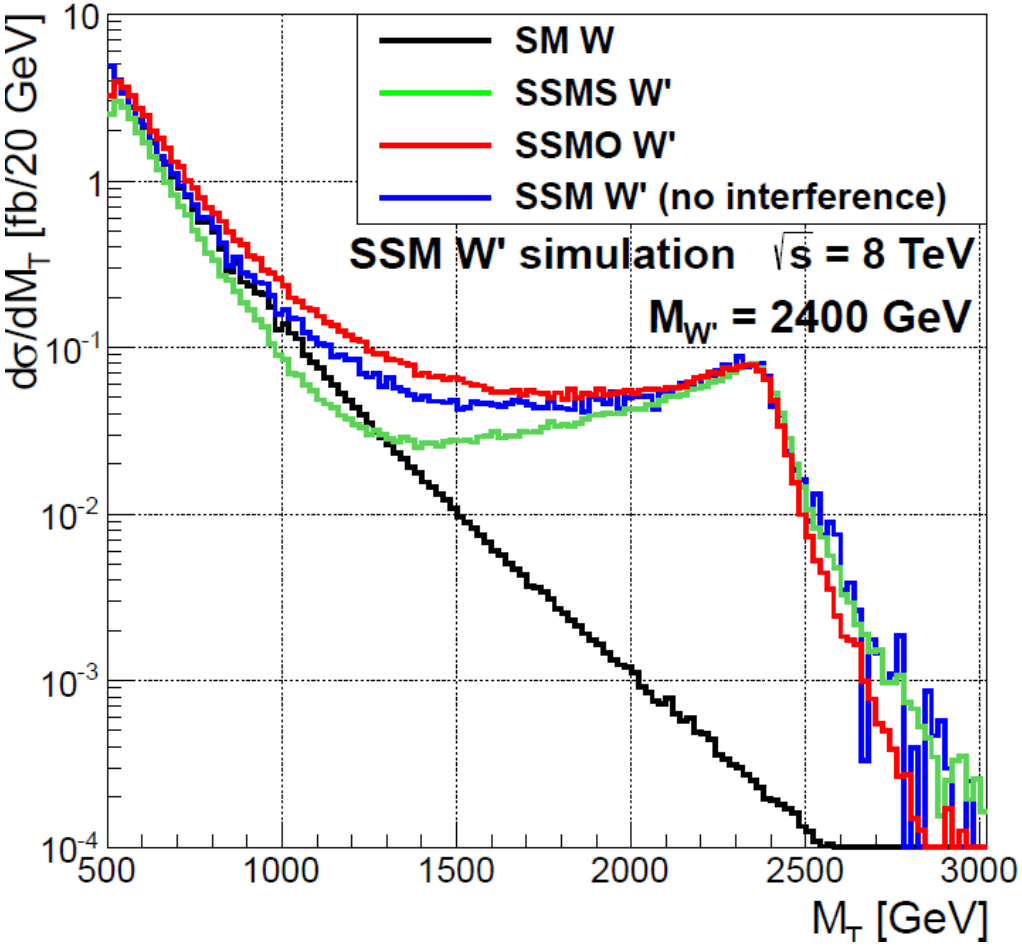


ρ - z view

EXO-12-060



SSM WITH SM W - SSM W' INTERFERENCE



- Same sign scenario (SSMS)
  - $a_{ij}^{L} = 1$
  - destructive interference for :

    $M_W < M < M_{W'}$

- Opposite sign scenario (SSMO)
  - leptons: $a_{ij}^{L} = 1$
  - quarks: $a_{ij}^{L} = -1$
  - constructive interference for :

    $M_W < M < M_{W'}$

$$\mathcal{L} = \frac{V_{ij}}{2\sqrt{2}} g_w \bar{f}_i \gamma^\mu a_{ij}^L (1-\gamma^5) W'_\mu f_j + \text{h.c.}$$

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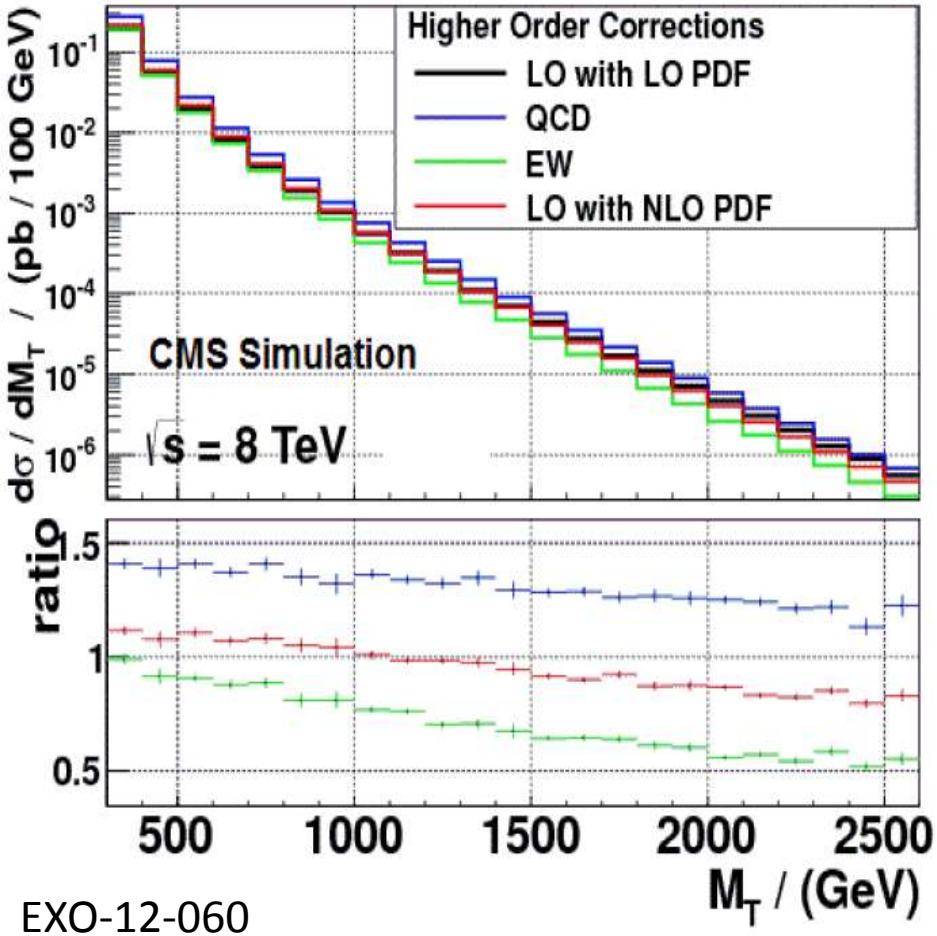
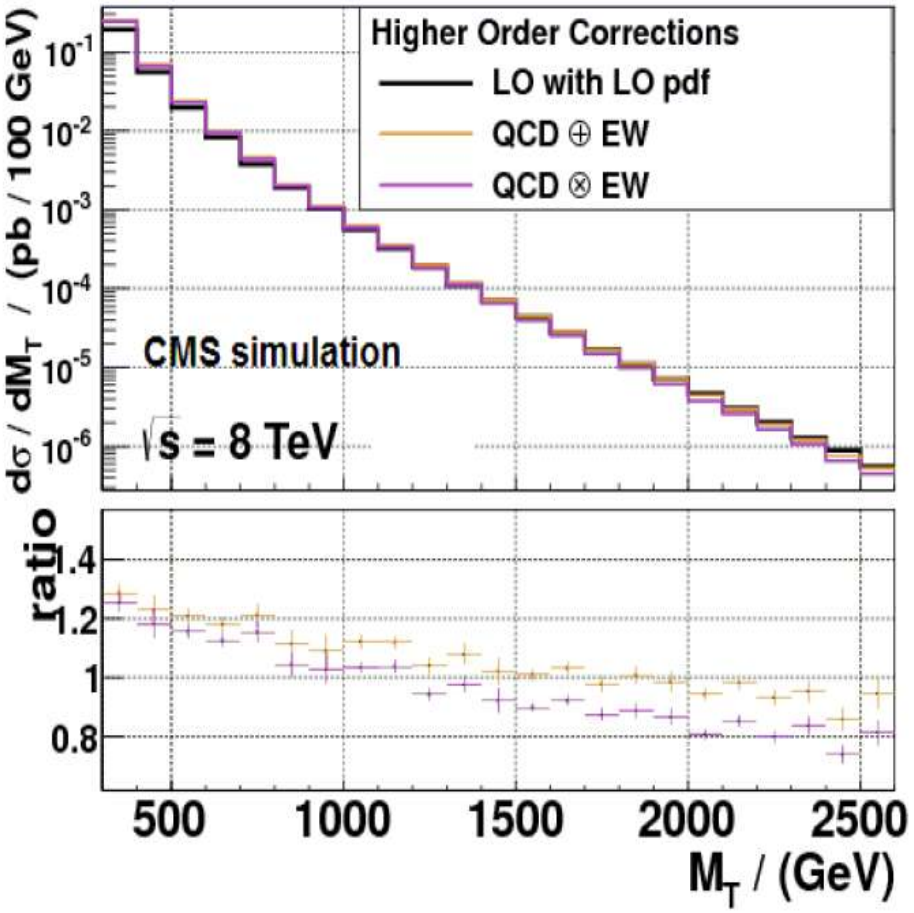
COMBINING NLO QCD AND EW CORRECTIONS FOR W





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- Using Horace (EW) and MC@NLO (QCD) to determine higher order corrections
- Apply corrections using a M_T dependent k-factor for W
- EW corrections important for high M_T
- Two different combination schemes

for details on the method see:
arXiv: 0907.0276

SYSTEMATIC UNCERTAINTIES

- Luminosity
- Lepton energy scale
- Lepton resolution
- MET
  - composite object
  - split MET into components
  - shift components by their uncertainty
  - recalculate MET
- W-kfactor
  - difference between two combination schemes
- Data/MC scalefactor
- Pileup correction

systematic uncertainty	value
luminosity	4.4 %
μ energy scale	5% / (p_T / [TeV])
μ resolution	3.2%
e energy scale	0.6% (EB) / 1.5% (EC)
e resolution	1.3% (EB) / 2.8% (EC)
W-kfactor	≈ 10 %
scalefactor	≈ 3 % (e) / ≈ 6 % (μ)

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SSM SIGNAL EFFICIENCIES

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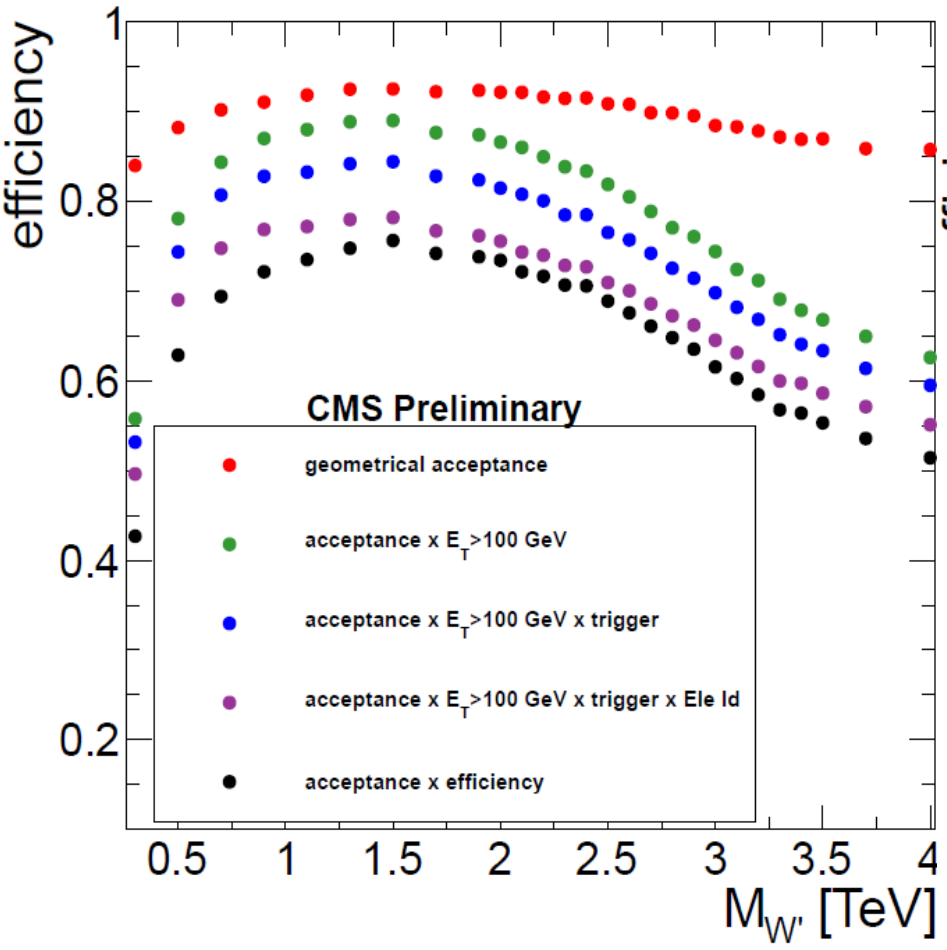
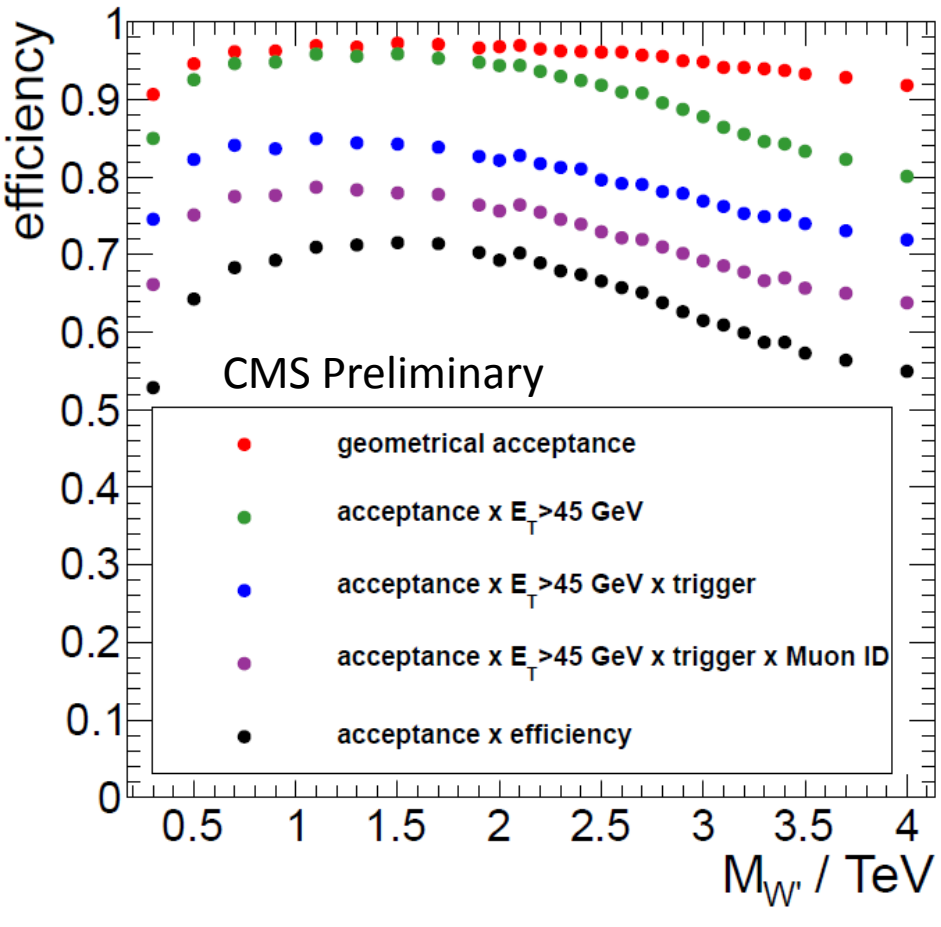




LIMIT SETTING

- Found no strong indication for physics beyond the standard model
- Set 95% CL exclusion limits in terms of bayesian statistics
- Using multiple bins to account for total and shape variation
- Use M_T spectrum in range from 240 GeV to 4000 GeV
- 20 GeV binwidth in electron channel
- Variable binning in muon channel

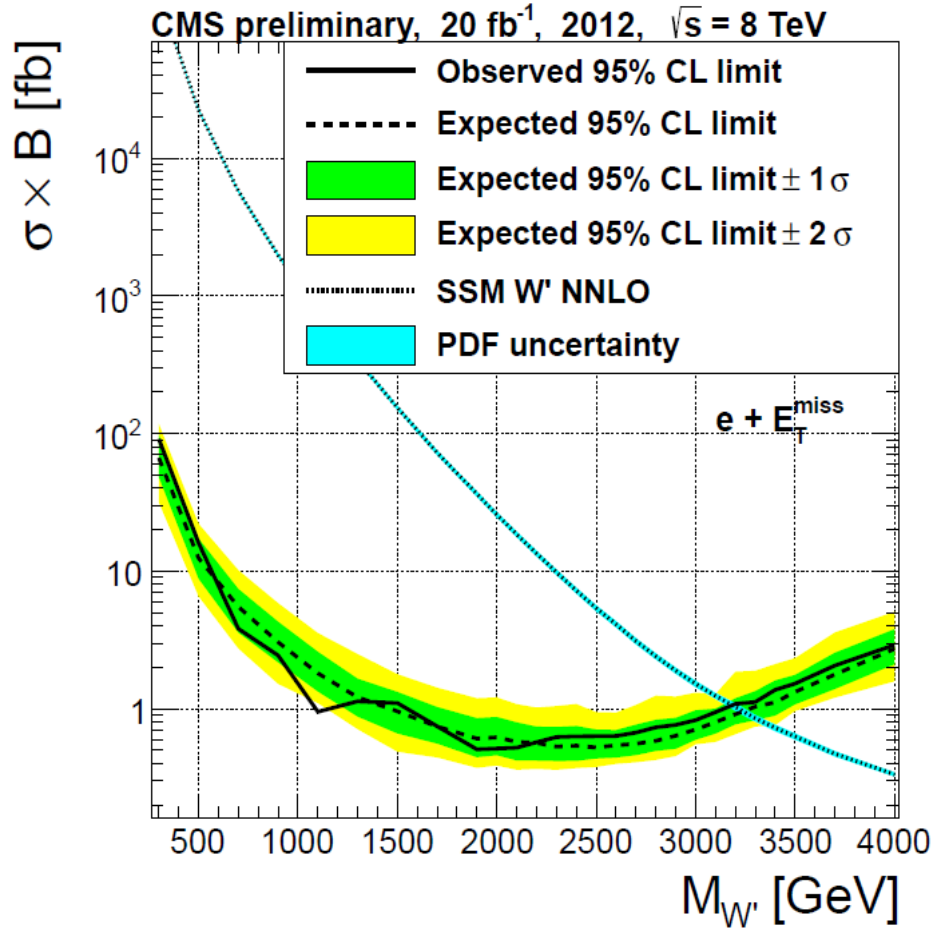
$$0.95 = p(\theta_{0.95}) = \int_0^{\theta_{0.95}} d\theta\ \pi(\theta) \cdot \prod_{\text{channels}} L'(\text{data}|\theta)$$

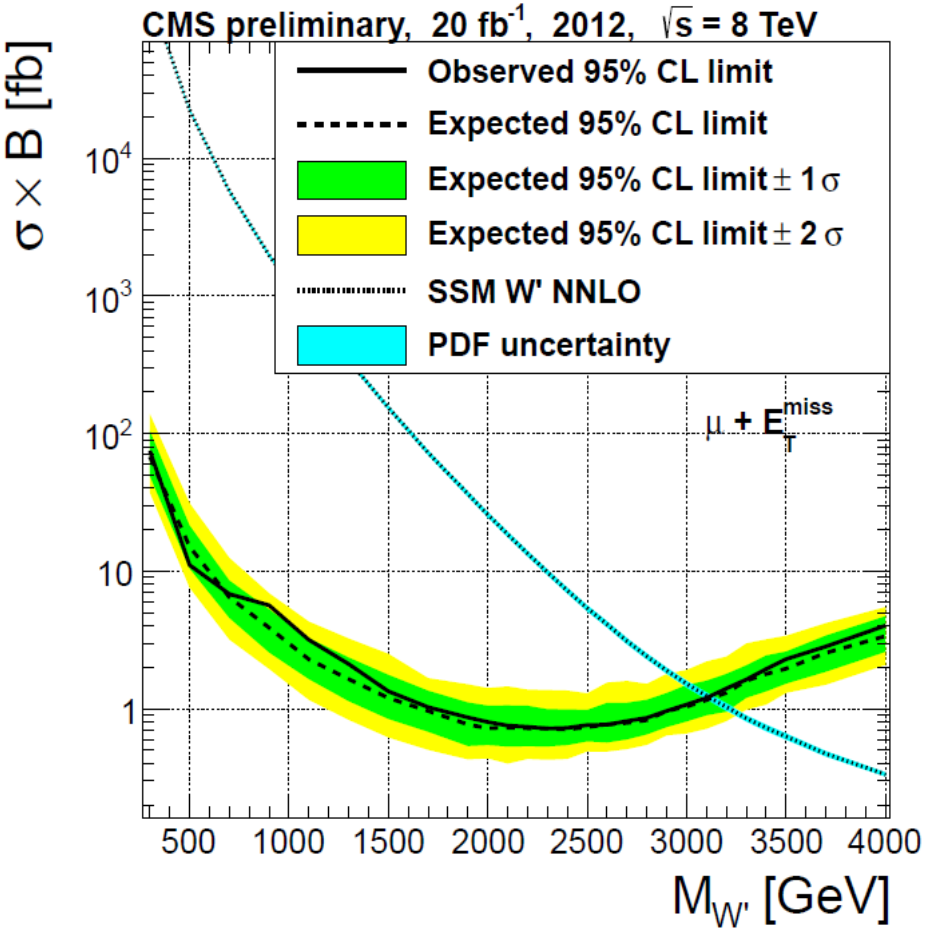
$$L'(\text{data}|\theta) = \int d\vec{\nu}\ L_{\text{Poisson}}(\text{data}|\theta, \vec{\nu}) \cdot \pi(\vec{\nu})$$

$\vec{\nu}$ nuisance parameters

θ parameter of interest

SSM SINGLE CHANNEL LIMITS





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SSM LIMITS

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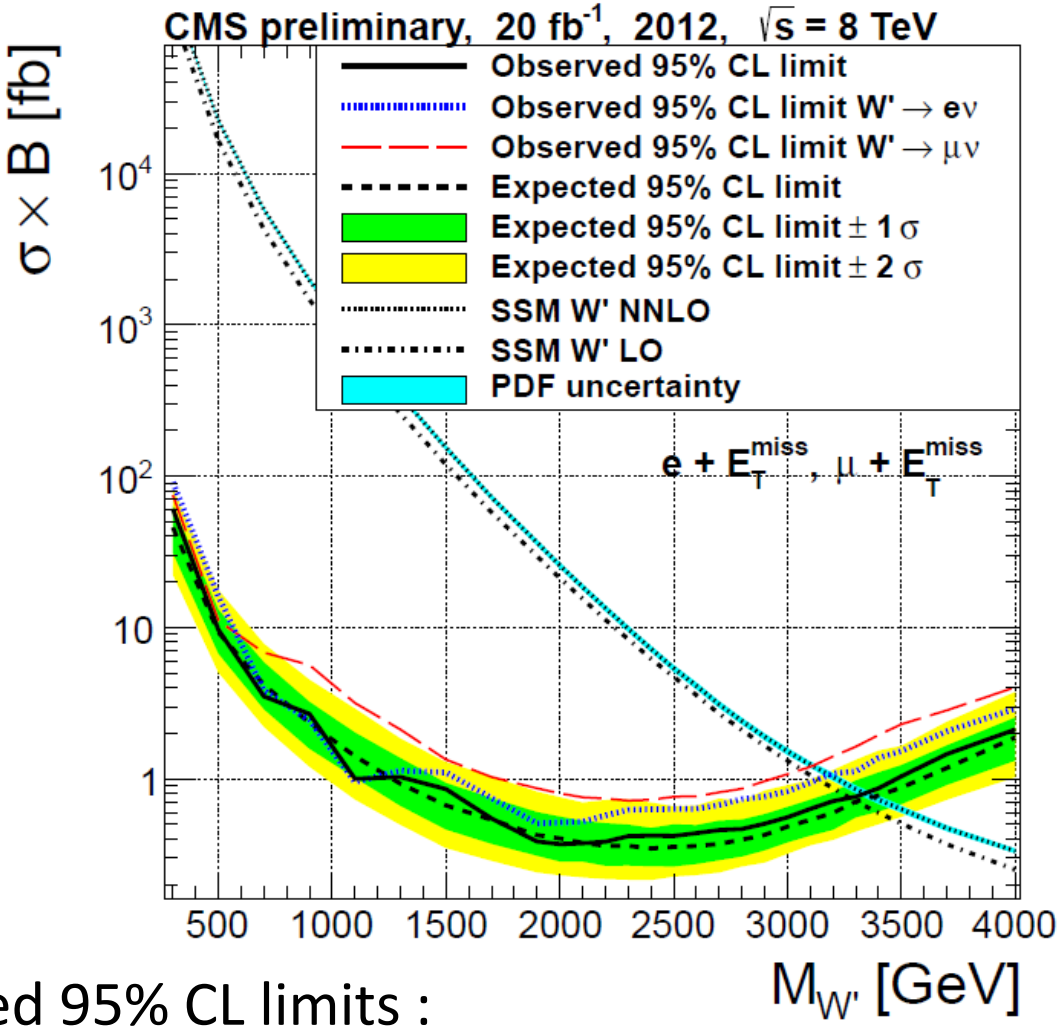
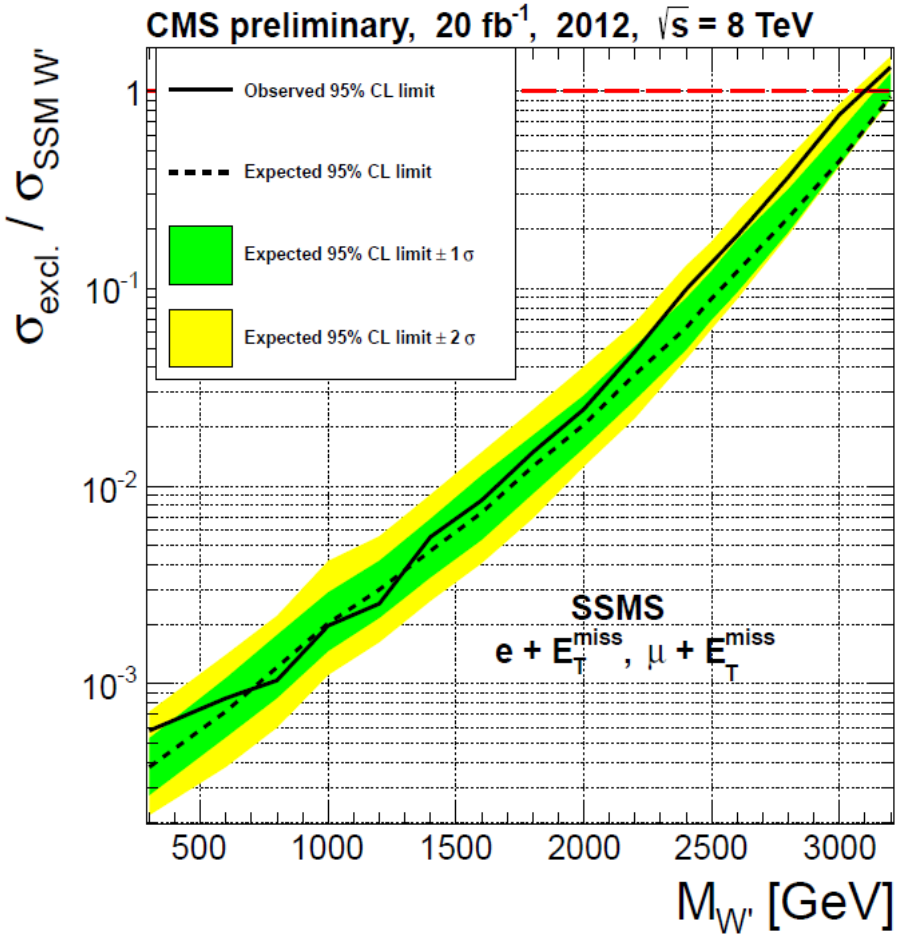
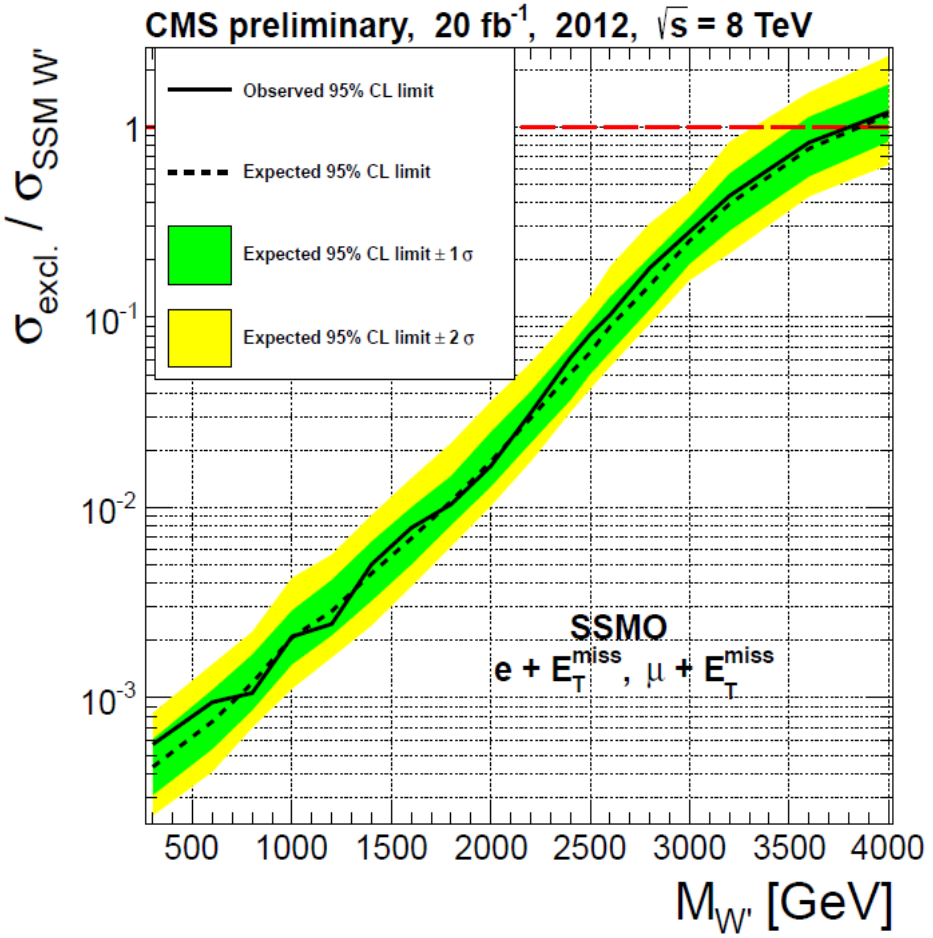


combined 95% CL limits :

Model	SSM	SSMO	SSMS
Observed Limit	$m_{W'} < 3.35$ TeV	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.10$ TeV
Expected Limit	$m_{W'} < 3.40$ TeV	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.20$ TeV

LIMITS : SSM WITH INTERFERENCE





combined 95% CL limits :

Model	SSMO	SSMS
Observed Limit	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.10$ TeV
Expected Limit	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.20$ TeV

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SSM LIMIT SUMMARY

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Model	Channel	Obs. Limit	Exp. Limit
SSM	e	$m_{W'} < 3.20$ TeV	$m_{W'} < 3.25$ TeV
SSM	μ	$m_{W'} < 3.15$ TeV	$m_{W'} < 3.10$ TeV
SSM	Combined	$m_{W'} < 3.35$ TeV	$m_{W'} < 3.40$ TeV
SSMO	e	$m_{W'} < 3.60$ TeV	$m_{W'} < 3.60$ TeV
SSMO	μ	$m_{W'} < 3.05$ TeV	$m_{W'} < 3.30$ TeV
SSMO	Combined	$m_{W'} < 3.80$ TeV	$m_{W'} < 3.80$ TeV
SSMS	e	$m_{W'} < 3.00$ TeV	$m_{W'} < 3.10$ TeV
SSMS	μ	$m_{W'} < 2.80$ TeV	$m_{W'} < 2.90$ TeV
SSMS	Combined	$m_{W'} < 3.10$ TeV	$m_{W'} < 3.20$ TeV

MISSING TRANSVERSE ENERGY

- Use particle-flow MET: EXO-12-060

$$\vec{\not{E}}_{\mathrm{T}}^{\,\mathrm{uncorr.}} = -\sum_{i} \vec{p}_{\mathrm{T,\,i}}$$

sum over pf objects

$$\vec{\not{E}}_{\mathrm{T}}^{\,\mathrm{uncorr.}} = -\sum_{\substack{\mathrm{jet} \\ \vec{p}_{\mathrm{T,\,jet}}^{\,\mathrm{L123}} > 10\mathrm{GeV}}} \vec{p}_{\mathrm{T,\,jet}}^{\,\mathrm{uncorr.}} - \sum_{\substack{\mathrm{jet} \\ \vec{p}_{\mathrm{T,\,jet}}^{\,\mathrm{L123}} < 10\mathrm{GeV}}} \vec{p}_{\mathrm{T,\,jet}}^{\,\mathrm{uncorr.}} - \sum_{i \notin \mathrm{jets}} \vec{p}_{\mathrm{T,\,i}}$$

- Type I corrections → propagate JEC corrections to MET

Levels of jet energy corrections:

L1 = energy offset due to pile-up

L2 = correct jet response in η

L3 = correct jet response in p_T

- Systematic uncertainties:
  - MET = composite object
  - split MET into components
  - shift components by their uncertainty
  - recalculate MET

SPLIT UED

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- Model assuming one additional compact space dimension with Radius R
- SM particles are lowest excitation modes of Kaluza-Klein particles

  → W' = W_n = excitation mode of SM W boson

- Parameters of the model
  - Radius of extra dimension R
  - Bulk mass μ
- Coupling and mass:
  - Only even states couple to SM particles

$$m^2_{W_n} \equiv m^2_n = m^2_W + \left(\frac{n}{R}\right)^2 .$$

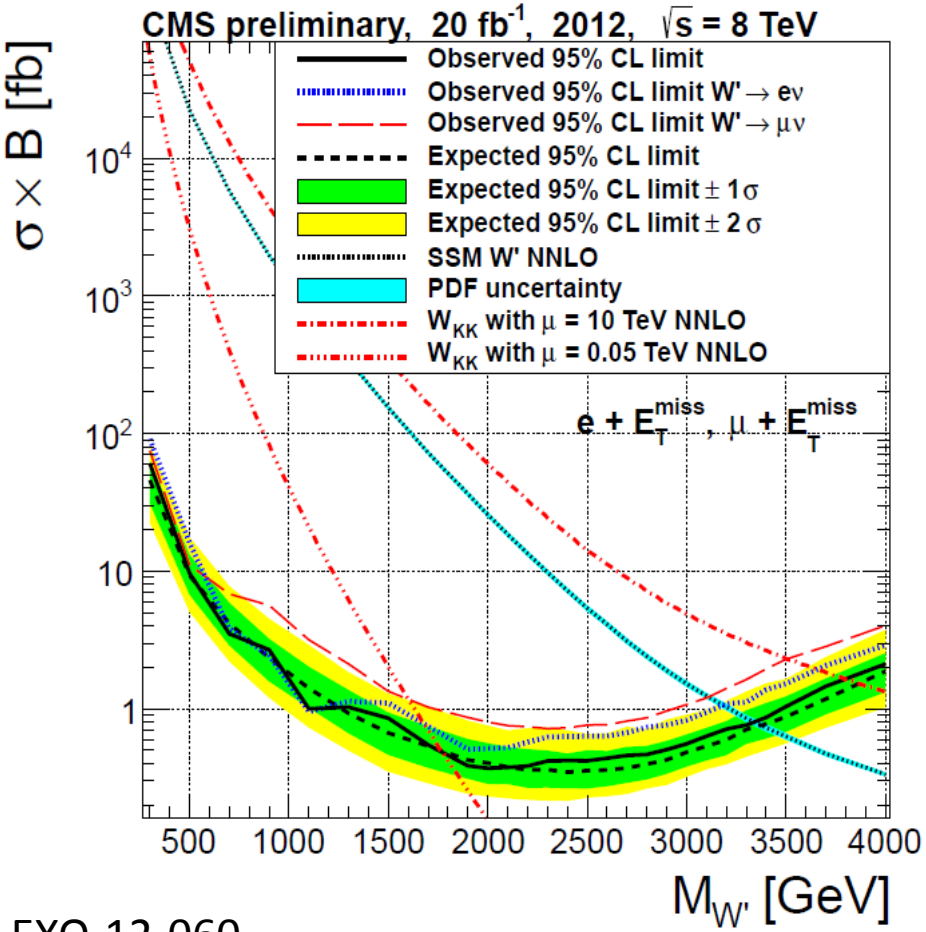
$$g_n = g^{\mathrm{SM}} \mathcal{F}_n ,$$

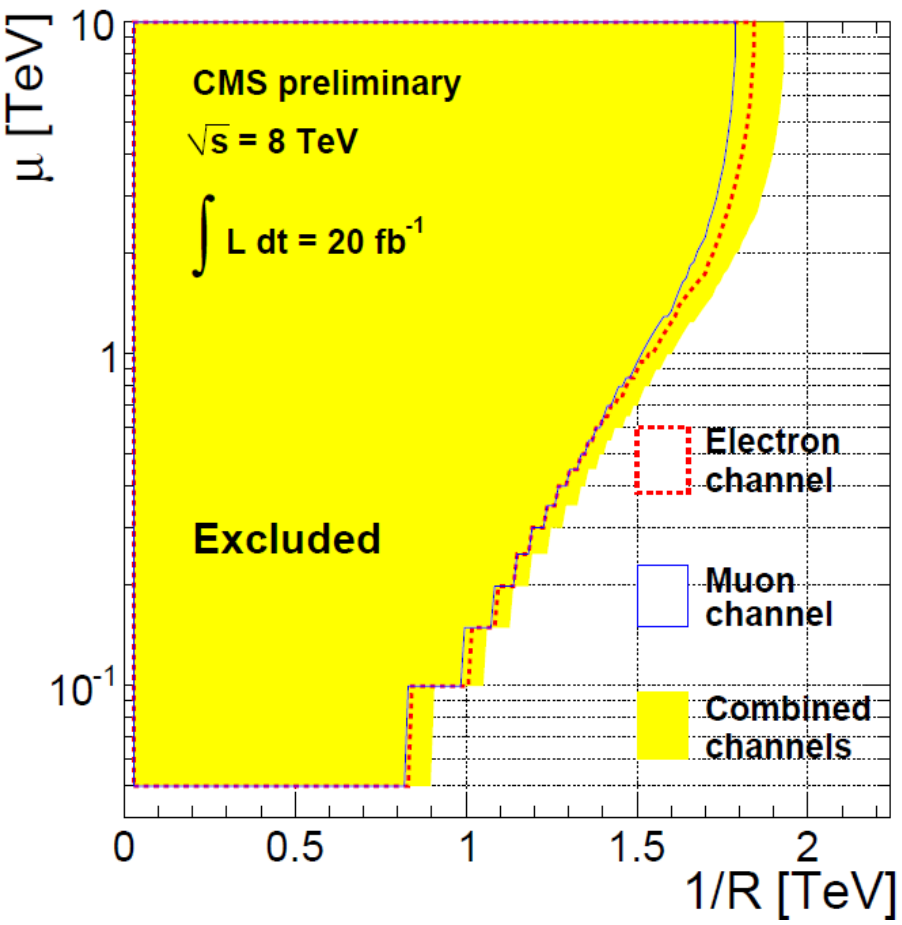
$$\mathcal{F}_n(x) = \begin{cases} 0 & \text{if } n = 2m+1 \\ = \frac{x^2(-1+(-1)^m e^{2x})(\coth x - 1)}{\sqrt{2(1+\delta_{m0})(x^2+m^2\pi^2/4)}} & \text{if } n = 2m \end{cases}$$

(x = π μ R)

- LHC only sensitive to n = 2
- Same decay modes and kinematics as SSM W'

SPLIT-UED EXCLUSION LIMITS





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