Search for new resonances decaying into diboson final states with large missing transverse momentum

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On behalf of the CMS Collaboration

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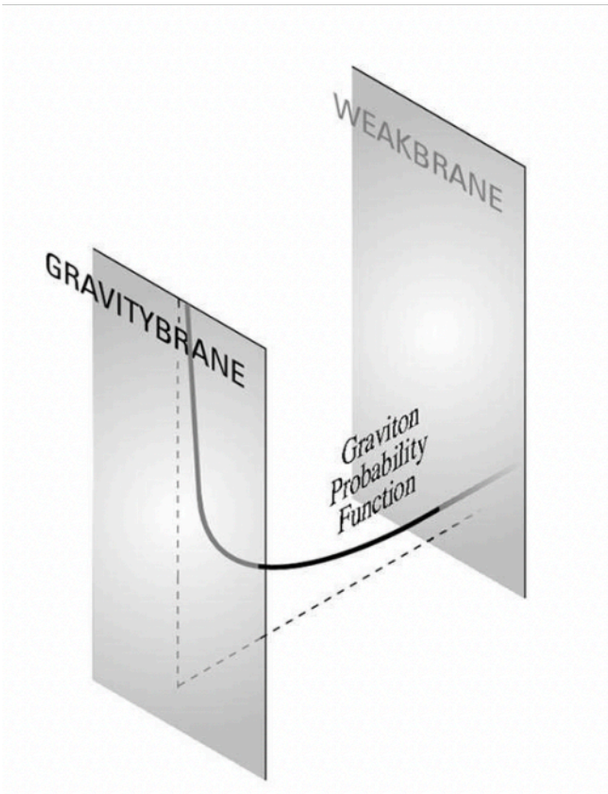
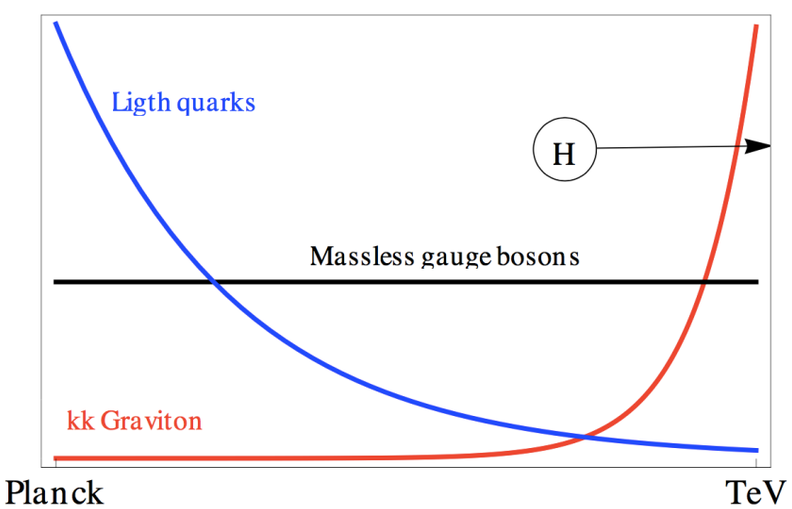
Motivation

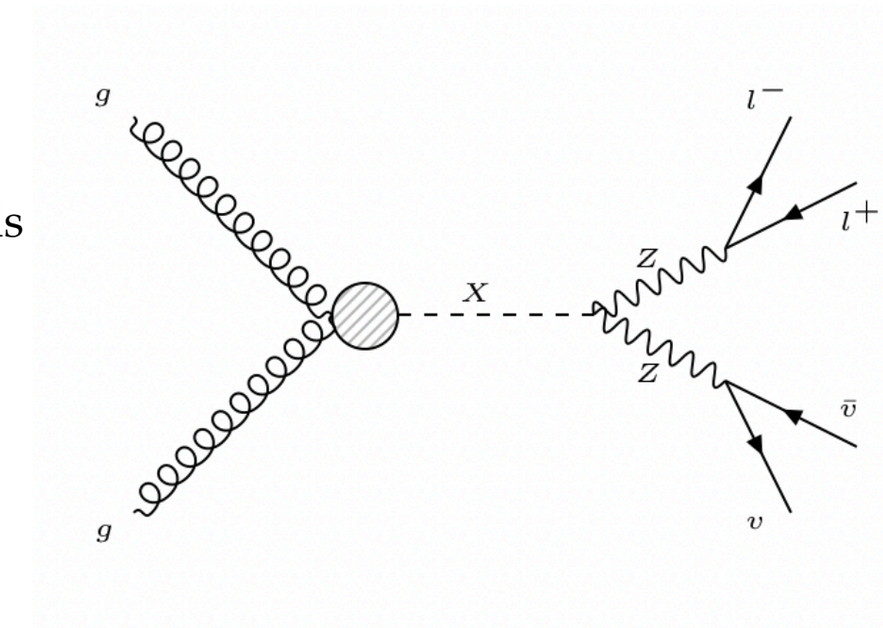




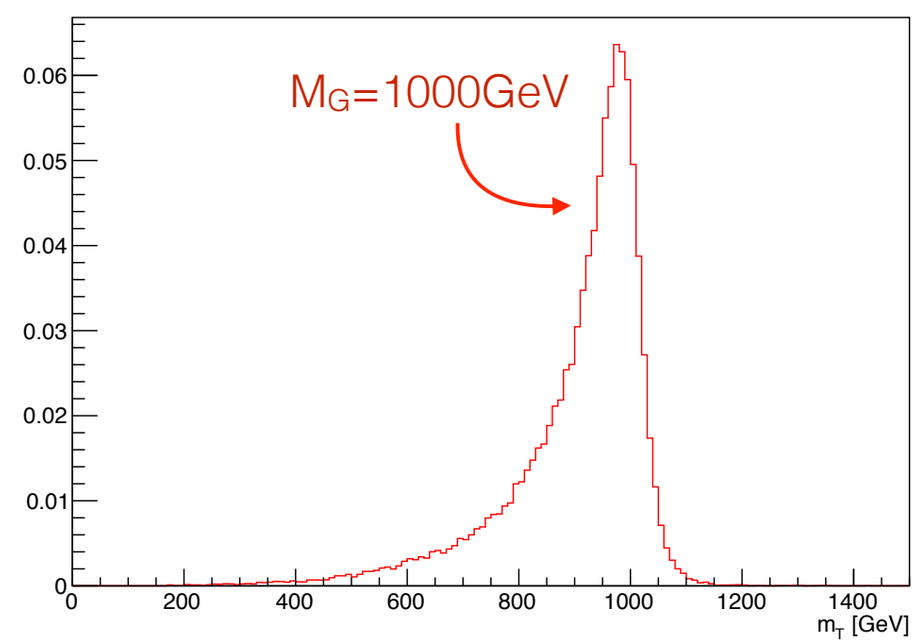
- ***Bulk Graviton Model***
  - **A possible solution to the hierarchy problem**
  - **Based on and extending the Randall-Sundrum (RS1) model**
    - Spin-2 Bulk Graviton in the extra dimension bulk
    - SM fields propagate in the bulk
    - couplings to light fermions and γ suppressed
  - **Warped extra dimensions, with 2 free parameters**
    - k(curvature constant) and R(extra dimension length)
    - Or equivalently $\tilde{k}\ (\equiv k/\overline{M_{PL}})$ and M_G (Graviton mass)

Analysis Introduction

- **The analysis aims at Search for heavy resonances decay into *ZZ→llνν* final states**
  - CMS-PAS-B2G-16-023
  - ~6 times larger cross-section compared with 4-leptonic channel
  - More controllable background compared with (semi)hadronic channels
- **Signal signatures**
  - A highly boosted Z decay to a pair of adjacent leptons
  - High p_T^{miss} from the other boosted Z decaying into neutrinos



- **Analysis strategy**
  - Use transverse mass m_T as the observable to separate signal over background
    - Signal mass cannot be fully reconstructed because the neutrinos are not detectable
  - p_T^{miss}, p_T^{Z} for background suppression
  - Major backgrounds: Z+Jets, ZZ/ZW, top pairs/WW



Data and MC Samples

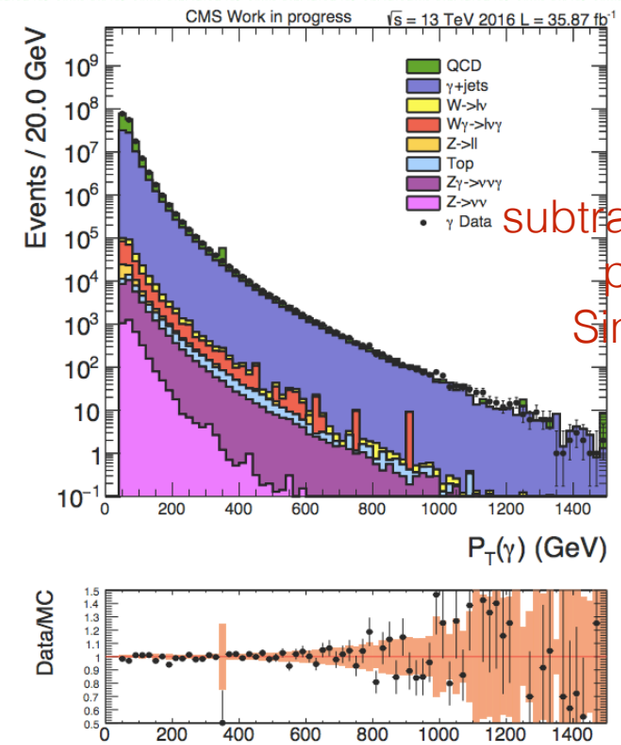
- **Data**:
  - ***35.9/fb LHC 2016 RunII 13TeV proton-proton collision data collected by CMS detector***
    - *Single-Lepton datasets* for signal region selection
    - *Single-Photon dataset* for Z+Jets background data-driven modeling
    - *Muon-EGamma dataset* for Non-resonant background (top pairs/WW) data-driven modeling
- **MC samples**:
  - Background
    - *ZZ/ZW di-boson samples*
  - Signal
    - *narrow width Spin-2 BulkGraviton→ZZ→2l2ν samples*
      - with mass points from 600 GeV to 2500 GeV

Event Selections

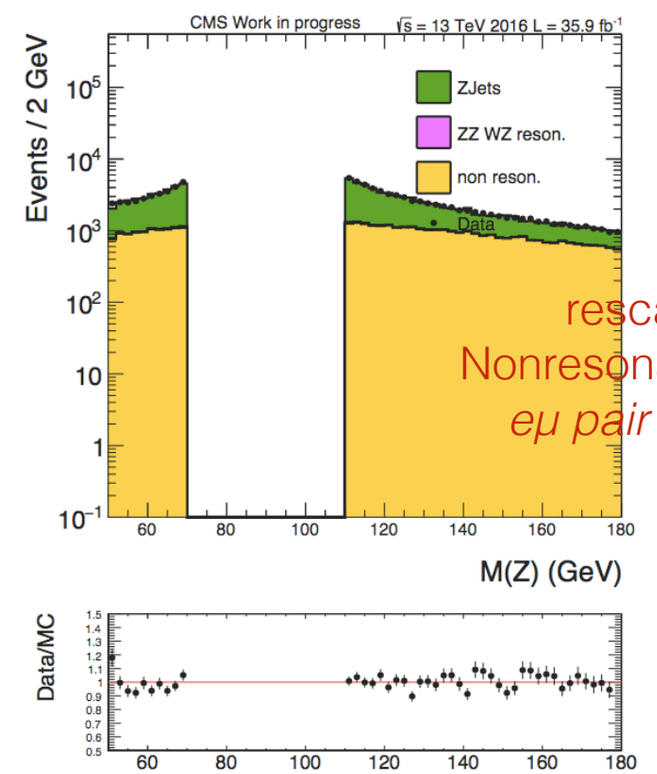
- **Electron Pair**
  - ***leading*: p_T>120 GeV, $|\eta|$<2.5**
    - The single electron trigger we use has p_T threshold at 115GeV
  - *sub-leading*: p_T>35 GeV, $|\eta|$<2.5
- **Muon Pair**
  - ***leading*: p_T>60 GeV, $|\eta|$<2.4**
    - The single muon trigger we use has p_T threshold at 55GeV
  - *sub-leading*: p_T>20 GeV, $|\eta|$<2.4
- **Leptonic Z Requirement**
  - same flavor opposite charge lepton-pair with invariant mass nearest to the 91.2GeV Z boson mass.
  - **70 GeV < M_{ll} < 110 GeV**
- **Signal Region** (SR)
  - Select events consistent with massive particle decaying to boosted Z boson and invisible recoil ($Z \rightarrow \nu\nu$)
    - $p_T^Z > 100$ GeV
    - $p_T^{miss} > 50$ GeV
    - $|\Delta\phi(p_T^{miss}, p_T^Z)| > 0.5$

Background Modeling

- **Z+Jets** (dominant background)
  - p_T^{miss} comes from mismeasurements of jet/lepton p_T
  - *Modeling method*: data-driven method using γ+jet events from Single-Photon dataset with physical p_T^{miss} backgrounds (non-γjet in dataset, eg. QCD, Wγ→lνγ) subtracted, reweighted to Z+Jets 2015 CMS data measurements
- **Non-resonance** (top pairs/WW)
  - *Modeling method*: data-driven method using *eμ* pairs from Muon-EGamma dataset, rescaled by event number outside Z mass window
- **Irreducible Resonance** (ZZ/ZW)
  - *Modeling method*: modeled using MC samples generated by *POWHEG*(ZZ) and *MadGraph5*(ZW). NNLO/NLO QCD correction and NLO/LO QED correction applied to ZZ sample.



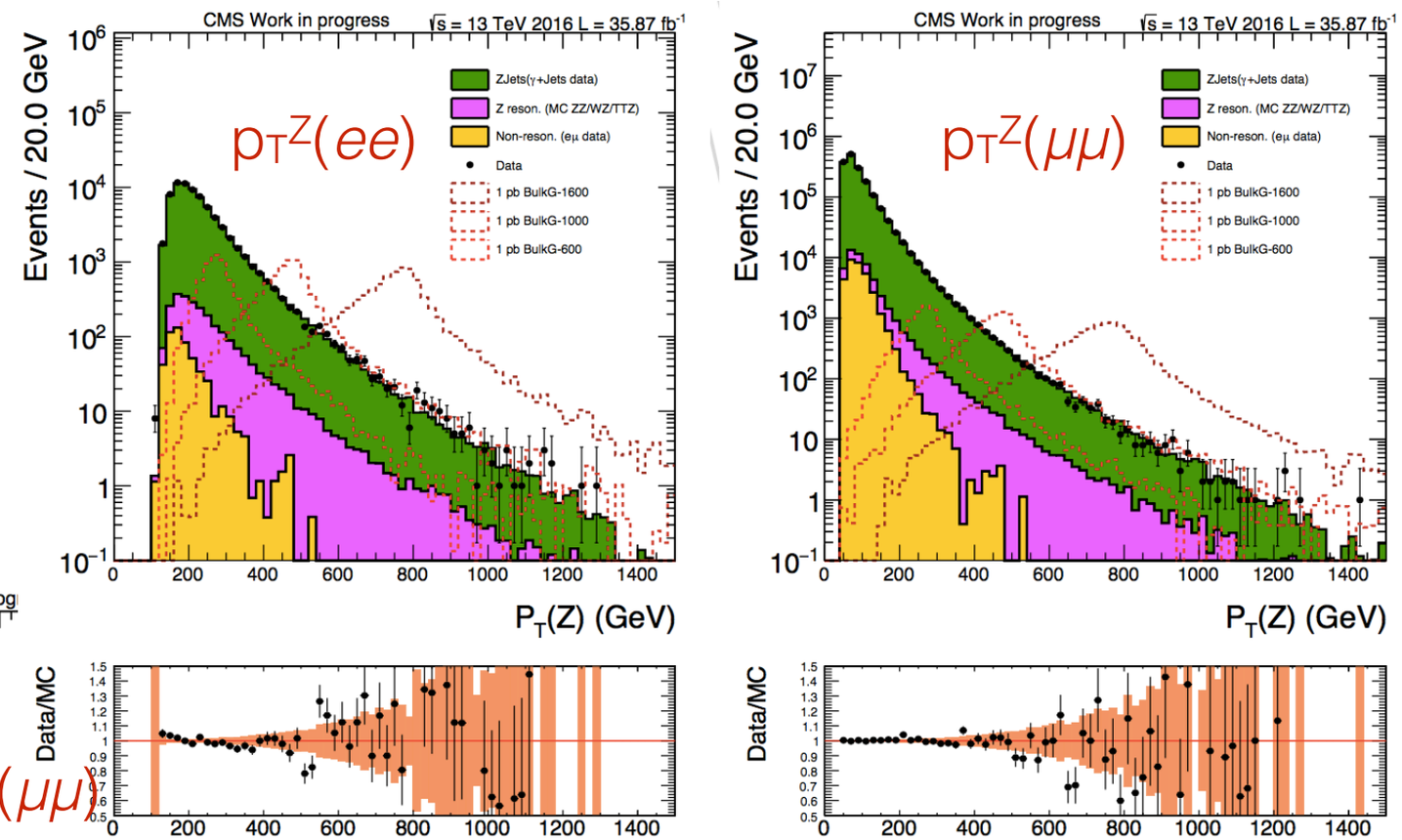
subtracting physical p_T^{miss} from SinglePhoton dataset

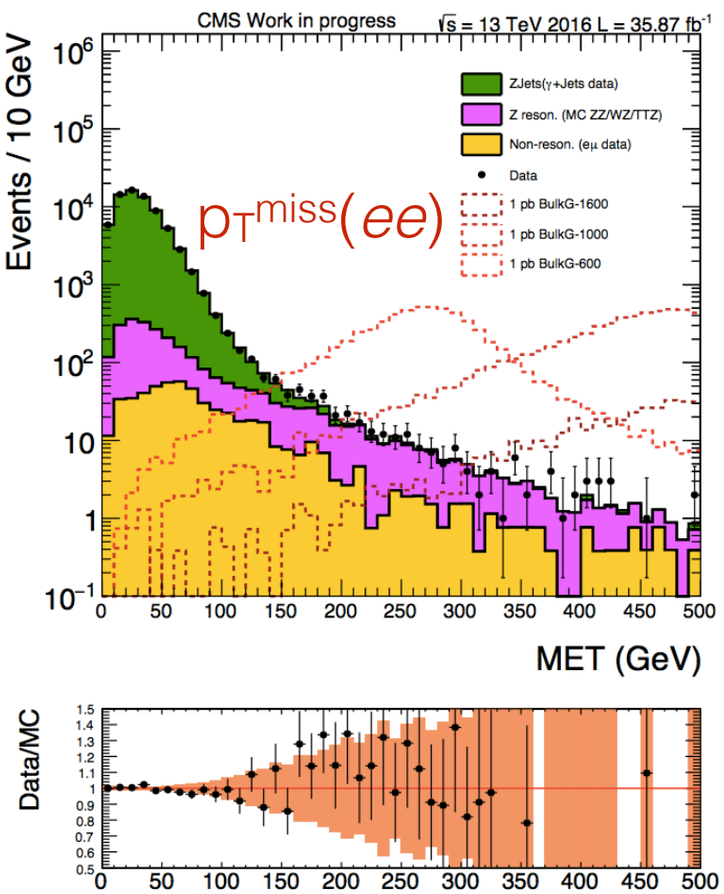


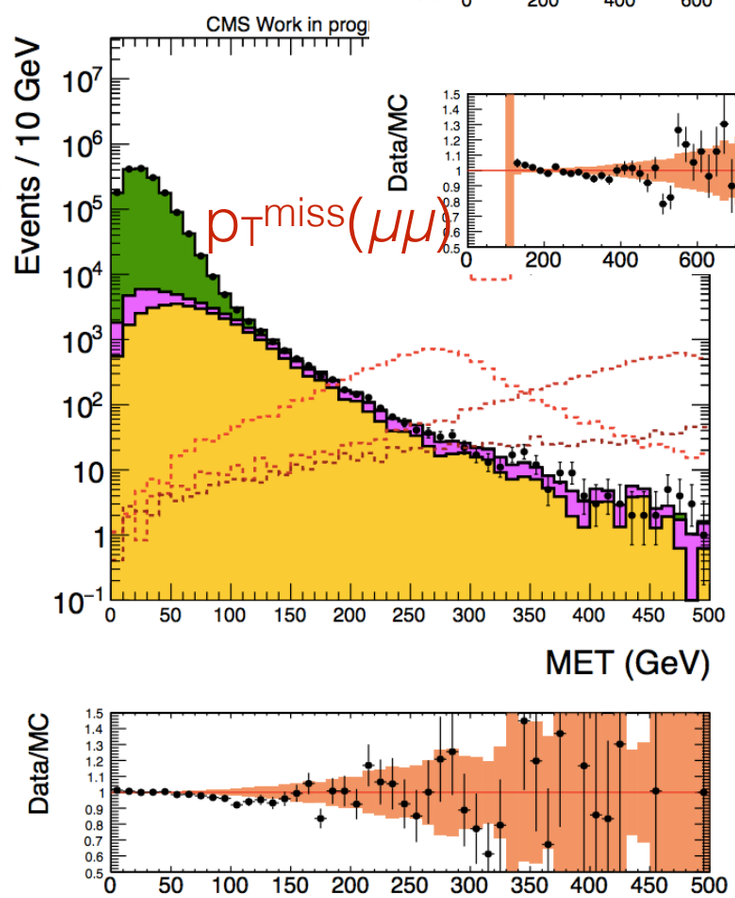
rescaling Nonresonance from *eμ pair sample*

Control Plots

- Data vs backgrounds for
  - Muon channel and electron channel
  - p_T^{miss} and p_T^{Z}





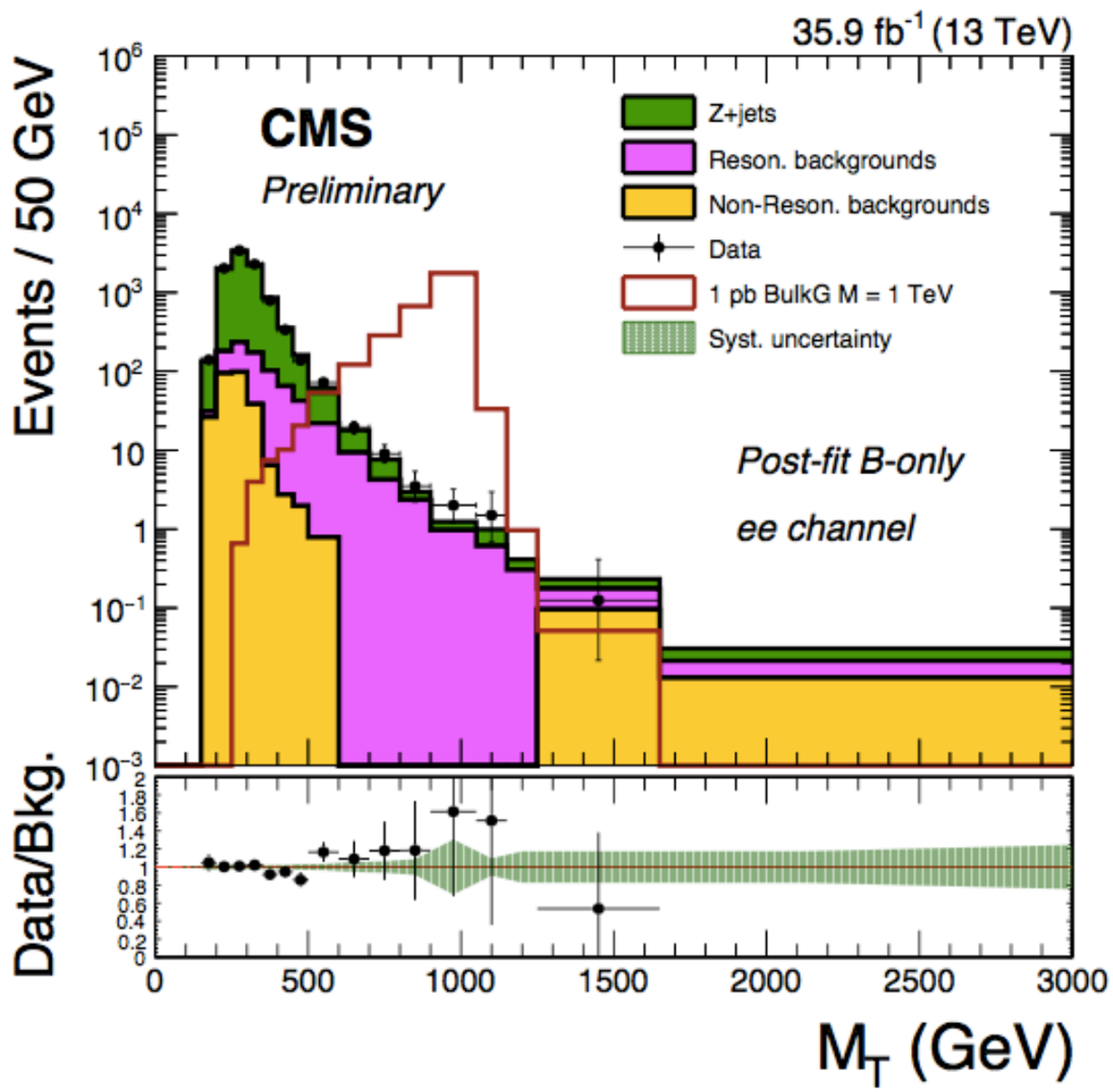


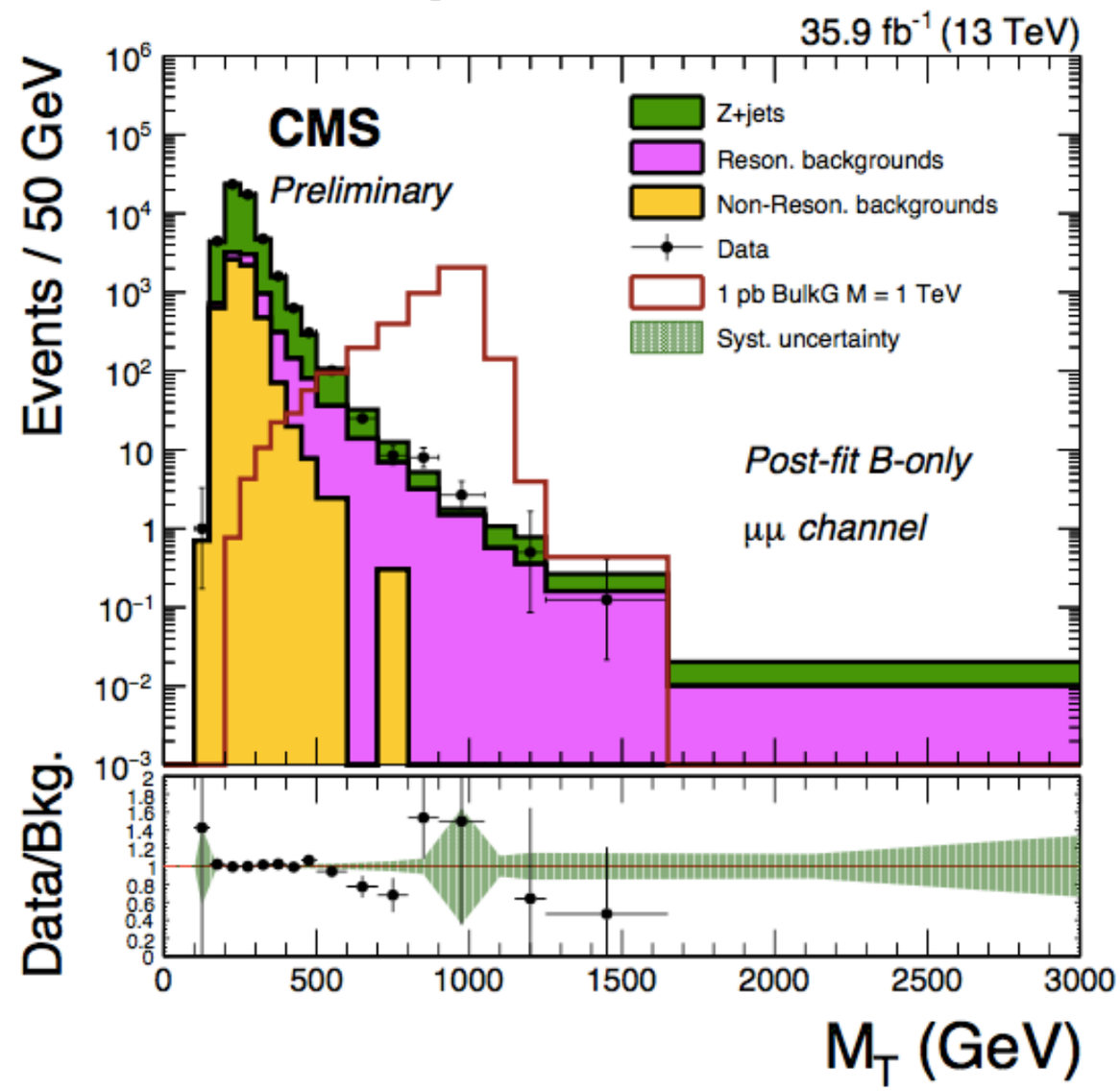
- Backgrounds are modeled well and agree with data
- Signal and backgrounds show different distributions

Discriminating Variable in SR

- **Discriminating variable**
  - *Transverse mass*

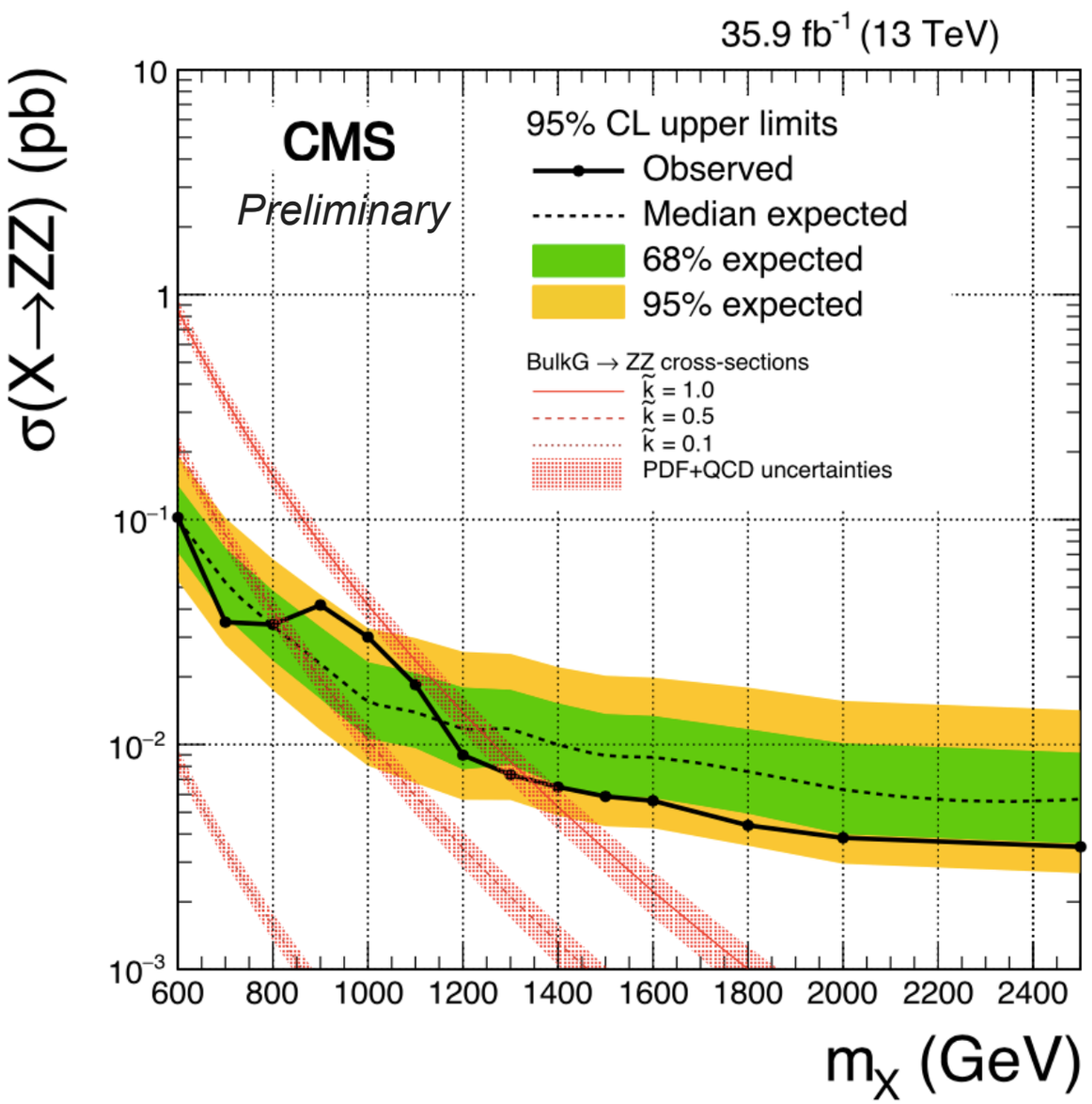
$$m_{\mathrm{T}}^2 = \left[\sqrt{p_{\mathrm{T}}^2, ll + m_{\ell\ell}^2} + \sqrt{(p_{\mathrm{T}}^{\mathrm{miss}})^2 + m_{\ell\ell}^2}\right]^2 - \left[\vec{p}_{\mathrm{T},\ell\ell} + \vec{p}_{\mathrm{T}}{}^2\right]^2$$





Analysis Result

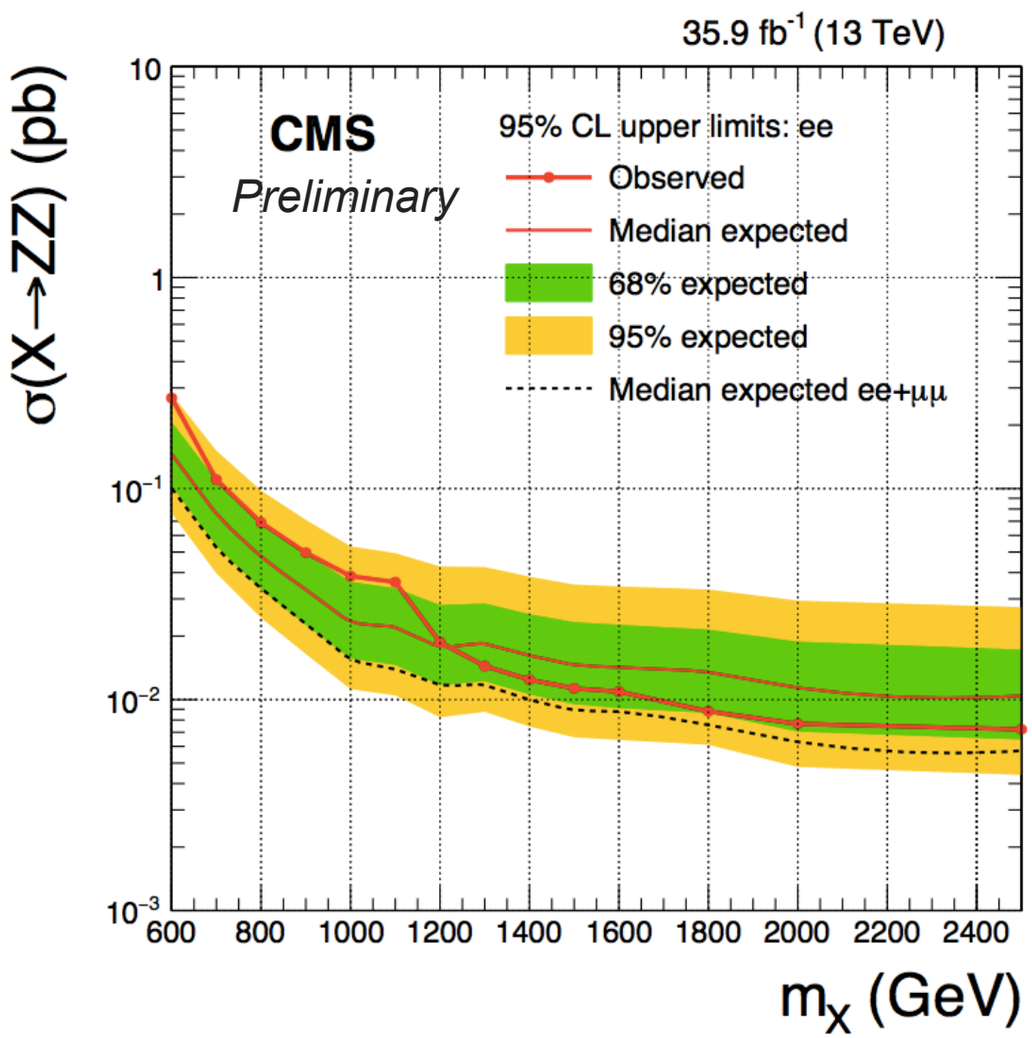
- **Limit plot for 2e2ν and 2μ2ν channels combined**

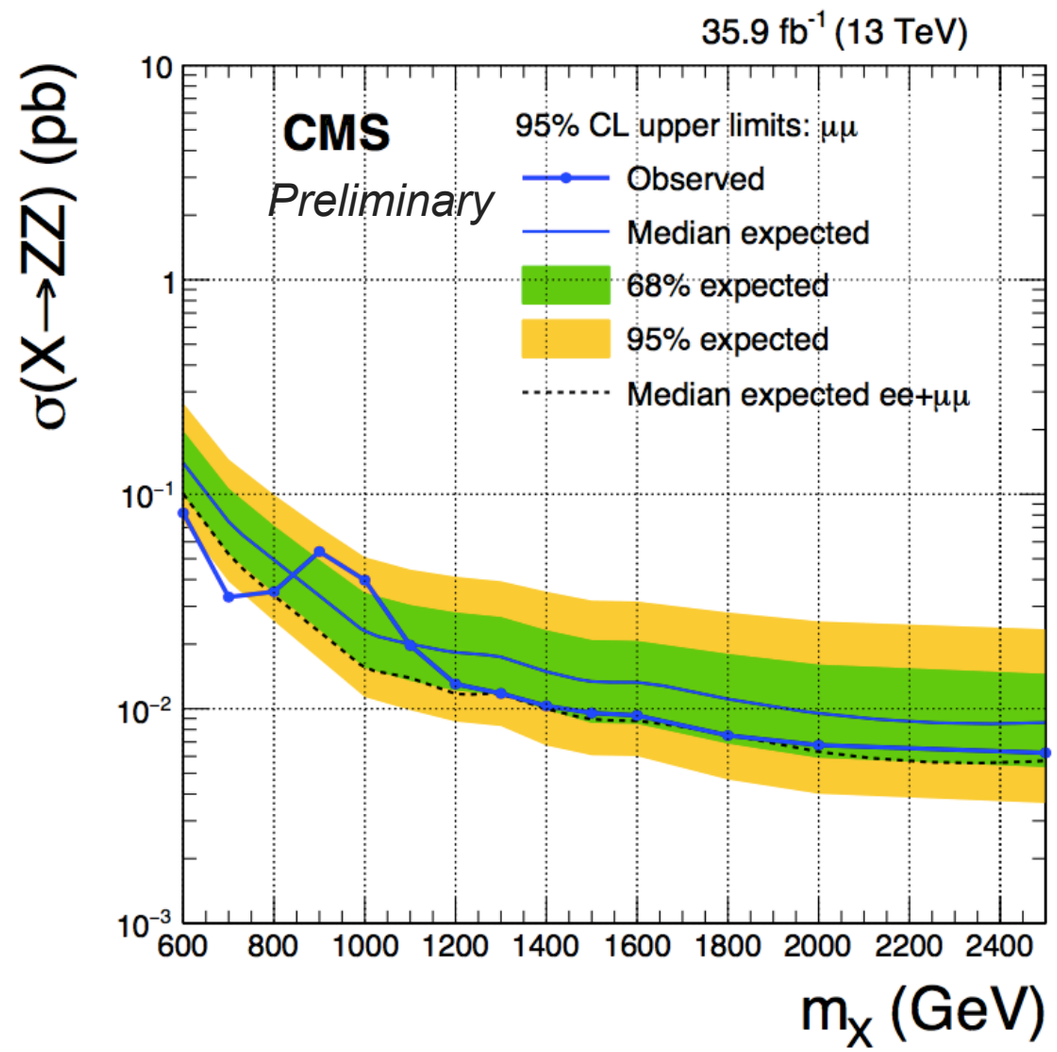


- **No observed data excess beyond 2 standard deviations**
- **The Spin-2 Bulk Graviton is excluded at 95% confidence level**
  - *below 800 GeV* with $\tilde{k} = 0.5$
    - previously published result
      - *below 610 GeV* [arXiv:1209.3807]
  - *below 1350 GeV* with $\tilde{k} = 1.0$
    - previously published result
      - *below 1100 GeV* [arXiv:1606.04833]

Analysis Result

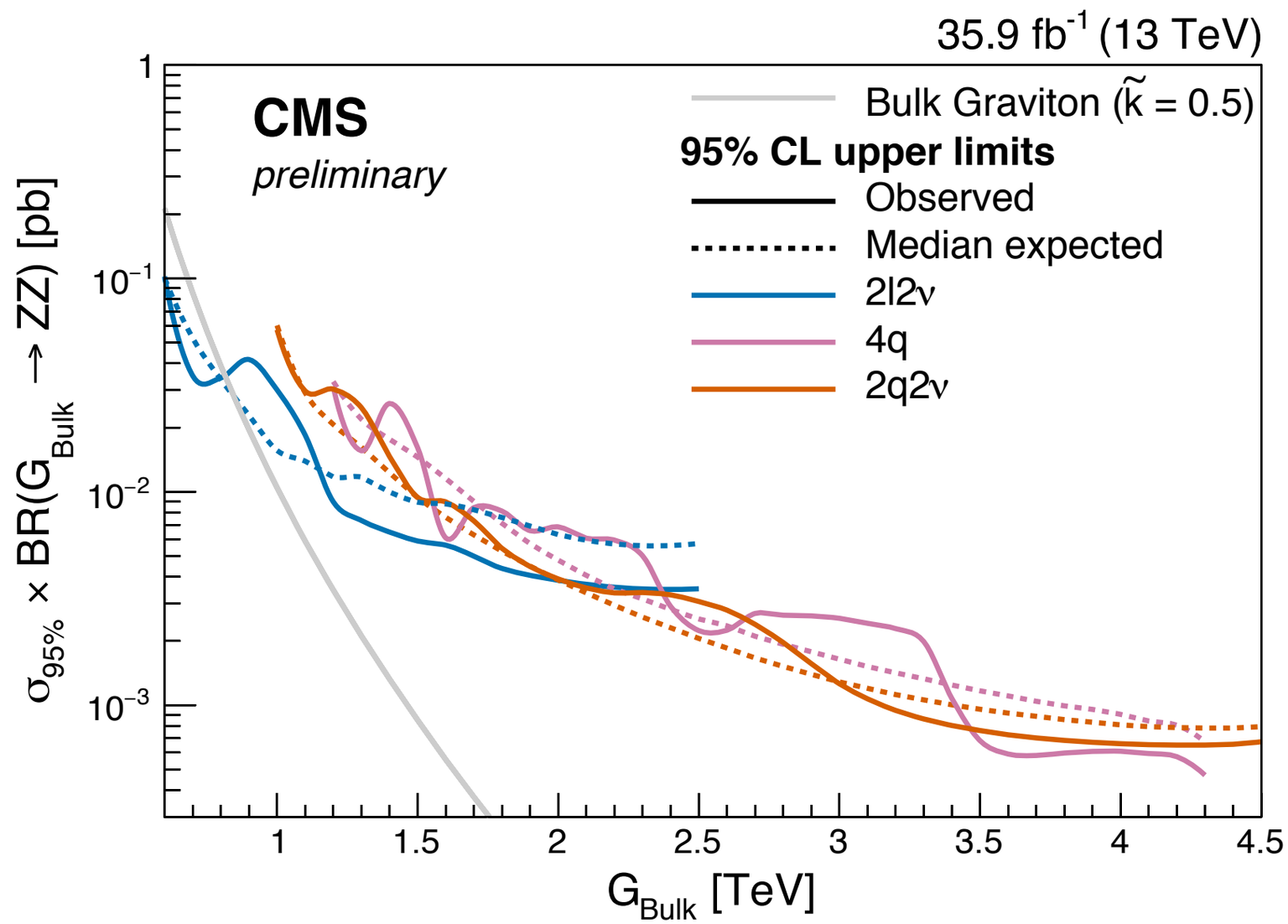
- **Limit plots for *2e2ν channel*(*left*) and *2μ2ν channel*(*right*)**





Result Comparison

- **A limit plot comparison** among
  - Other existing public CMS RunII searches with 2016 full data (***ZZ channel, different final states***)
    - CMS-PAS-B2G-17-005 (2q2ν)
    - CMS-PAS-B2G-17-001 (4q)
  - The *llνν* search
    - CMS-PAS-B2G-16-023 (2l2ν)
- Comparing to these searches (with partial/full hadronic final states), the *llνν* search
  - **has better sensitivity in the low mass region**
  - is more limited by statistics in higher mass region
    - Very limited data for signal region data selection or background modeling beyond 1000GeV m_T
    - Less capable of exploring M_G region beyond 2000GeV for now



- With more data collected, better result in the higher mass region can be expected.

Summary

- A search for a heavy resonance decaying to ZZ with final state *llνν* is performed using 35.9 fb^{-1} of 13 TeV data from the CMS experiment
- A narrow width spin-2 Bulk Graviton hypothesis is examined
  - No significant data excess is observed
  - Exclusions are reported for:
    - graviton mass below 800 GeV with $\tilde{k} = 0.5$
    - graviton mass below 1350 GeV with $\tilde{k} = 1.0$
- The analysis result is compared with similar CMS searches with different final states.

Thank
You
köszönöm
Asante
Shukria
Dhanyavadagalu
Vinaka
Kiitos
Maake
شكرا
Manana
Dankon
감사합니다
Dankscheen
спасибо
Kam Sah Hammida
Mauruuru
Biyan
Diolch i Chi
Terima Kasih
Matondo
Taiku
Dank Je
Tack
Blagodaram
Ngiyabonga
Dziekuje
Chokrane
Grazie
Juspaxar
Arigato
Mochchakkeram
Gracias
Khap
Paldies
Tingki
நன்றி
धन्यवाद
cảm ơn bạn
Gratias Tibi
Ua Tsaug Rau Koj
Bedankt
Dakujem
Grazas
Di Ou Mèsi
Kia Ora
Kop Khun Khap
Obrigado
Děkuji
Nuwun
Nirringrazzjak
ありがとう
Suksama
Hvala
Rahmat
Matur Nuwun
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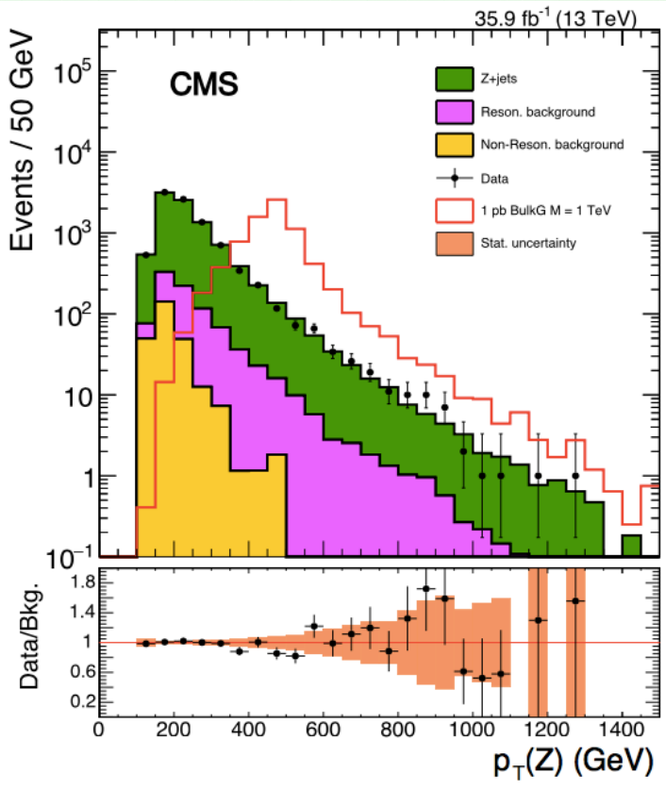
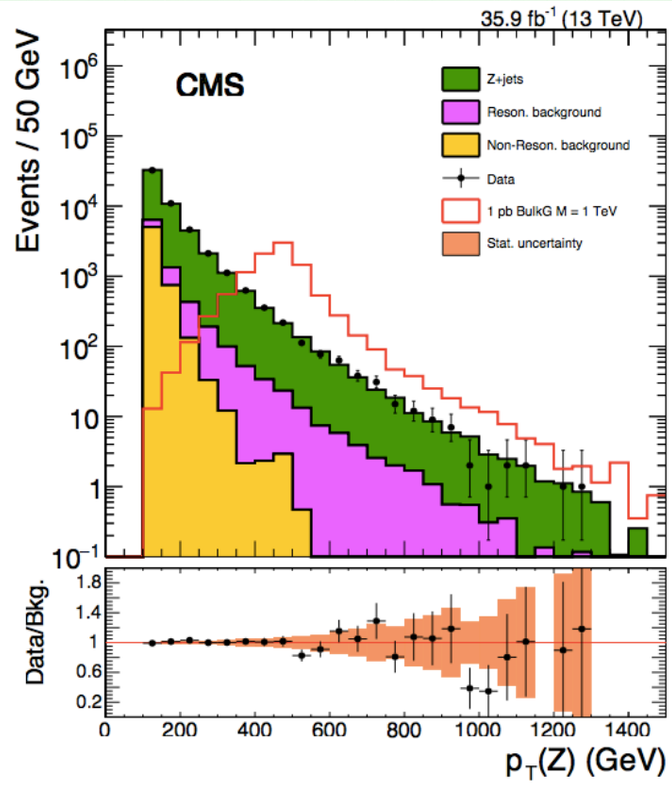
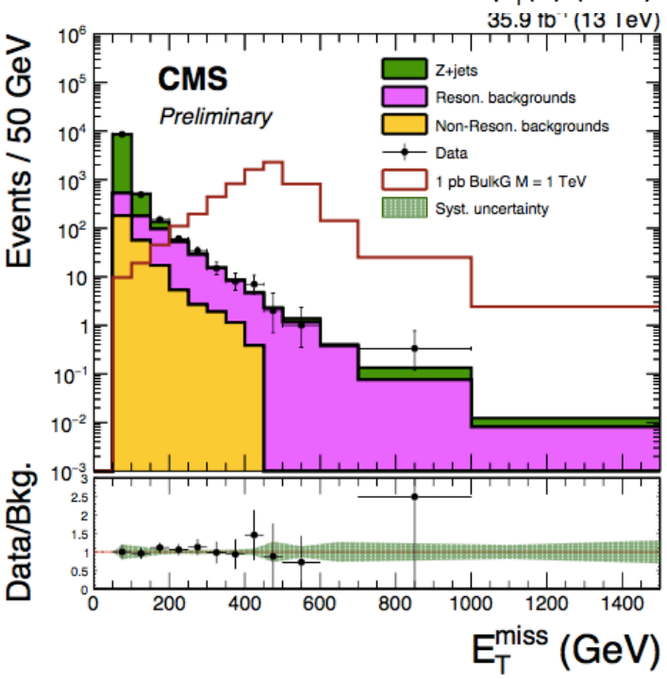
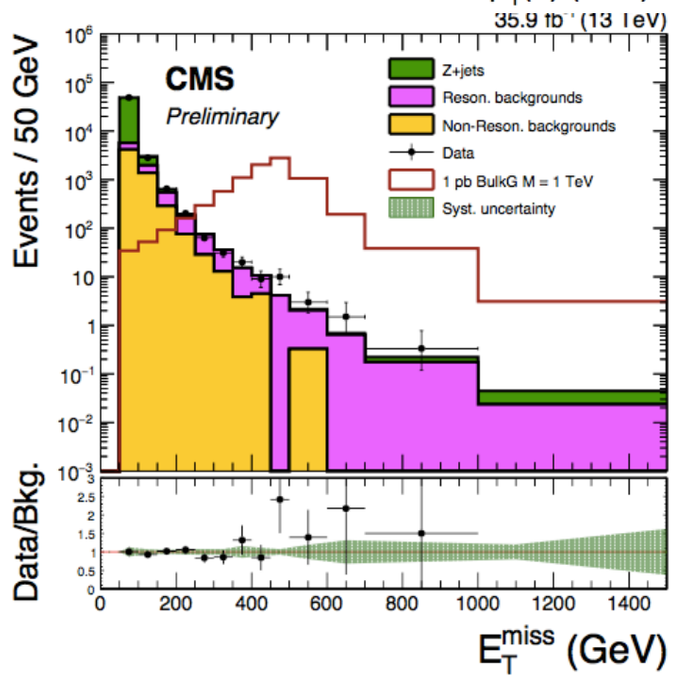
Salamat
ขอบคุณ
Najis Tuke

Backup





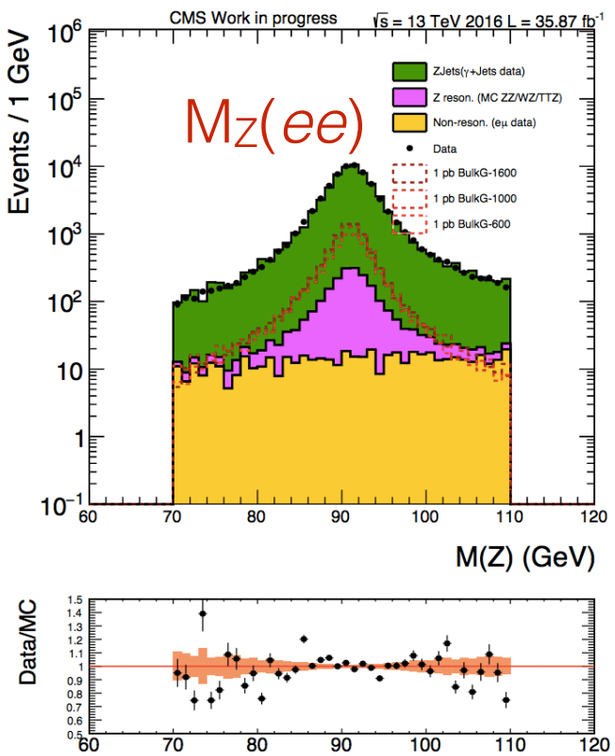


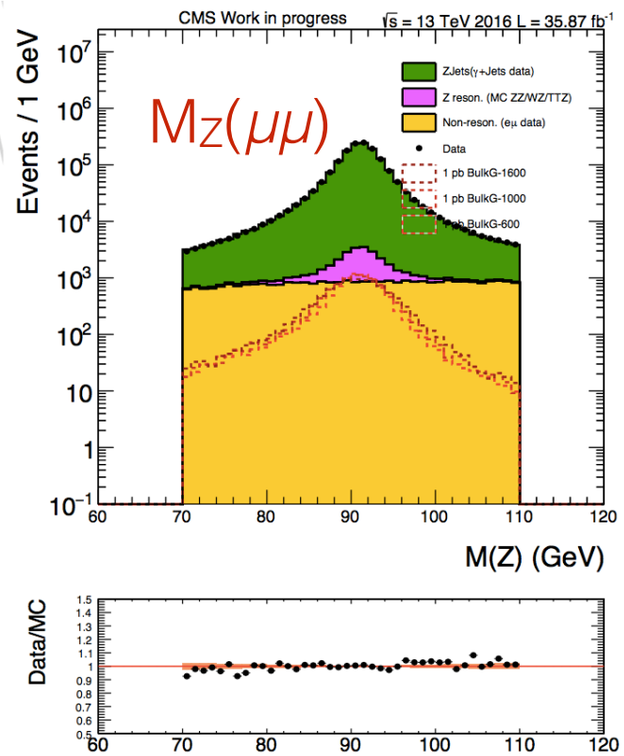


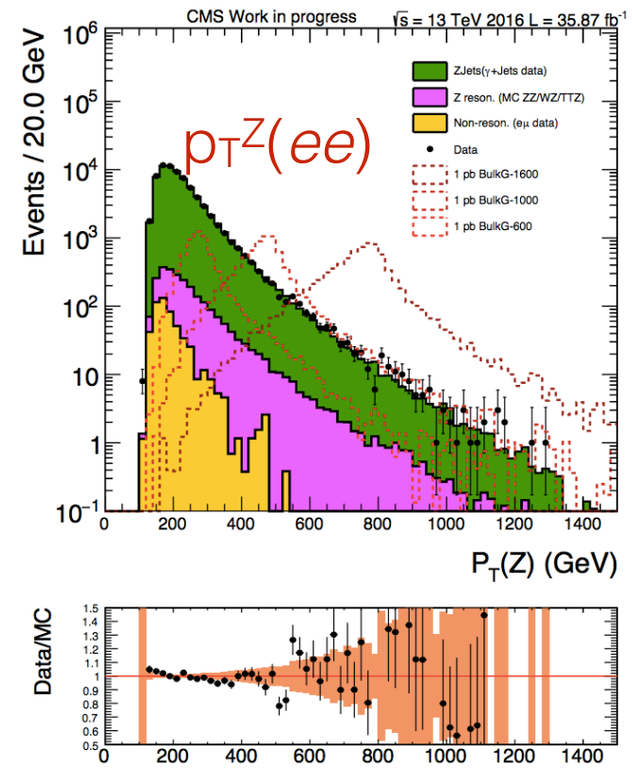
	Source	Signal	Z+jets	Reson	Non-Reso
	Luminosity	2.5%	2.5%	2.5%	2.5%
	PDF on cross-section	-	1.7%	1.7%	-
	QCD on cross-section	-	2.3%	3.0%	-
	EW NLO correction	-	-	3.0%	-
Electron channel	PDF on acceptance	1.0%	3.4%	1.0%	-
	QCD on acceptance	(-)	22.7%	2.9%	-
	Trigger eff.	0.1%	-	(-)	-
	Lepton ID eff.	0.5%	-	(-)	-
	Z p_T reweighting	-	2.1%	-	-
	Non-reson. scale fact.	-	-	-	10.0%
E_T^{miss} modeling uncertainties	Muon scale	0.1%	-	10.1%	-
	Elec. scale	1.8%	-	0.4%	-
	Photon scale	2.9%	-	0.5%	-
	Jet energy scale	1.5%	-	0.4%	-
	Jet energy resolution	1.5%	-	0.5%	-
	Unclustered E	2.3%	-	0.5%	-
	Hadronic recoil	-	0.1%	-	-
Muon channel	PDF on acceptance	1.0%	3.4%	1.0%	-
	QCD on acceptance	(-)	13.1%	2.9%	-
	Trigger eff.	0.2%	-	(-)	-
	Lepton ID eff.	0.9%	-	(-)	-
	Tracking eff.	1.0%	1.0%	1.0%	1.0%
	Z p_T reweighting	-	0.5%	-	-
	Non-reson. scale fact.	-	-	-	2.4%
E_T^{miss} modeling uncertainties	Muon scale	10.9%	-	1.8%	-
	Elec. scale	(-)	-	(-)	-
	Photon scale	0.1%	-	(-)	-
	Jet energy scale	1.2%	-	0.1%	-
	Jet energy resolution	1.9%	-	0.2%	-
	Unclustered E	1.8%	-	0.3%	-
	Hadronic recoil	-	0.1%	-	-

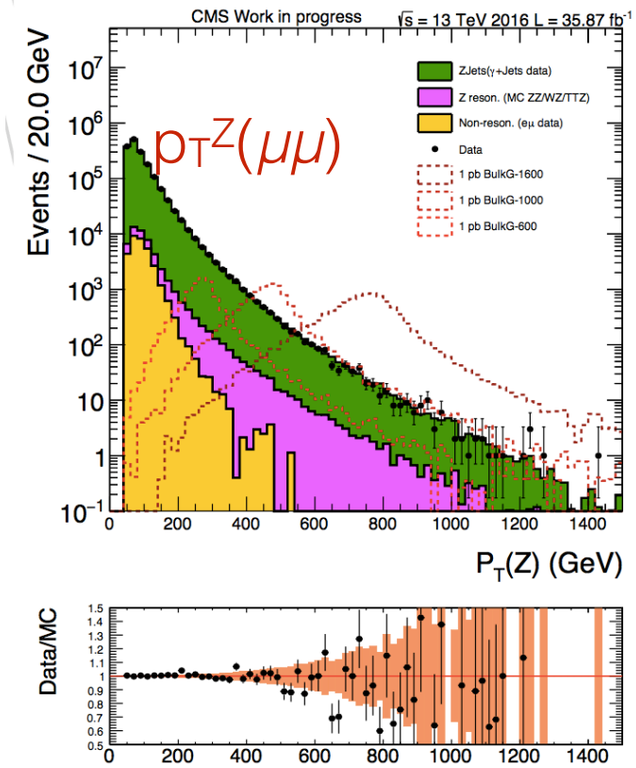
DRAFT

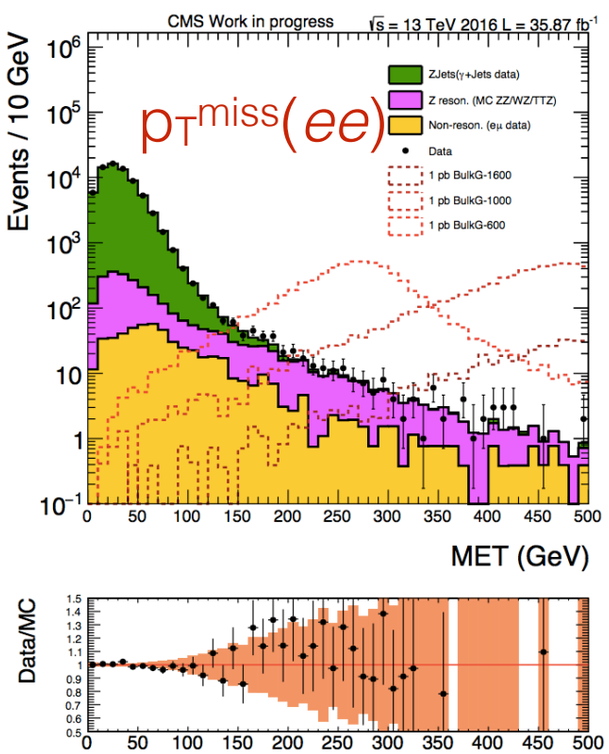
Backup

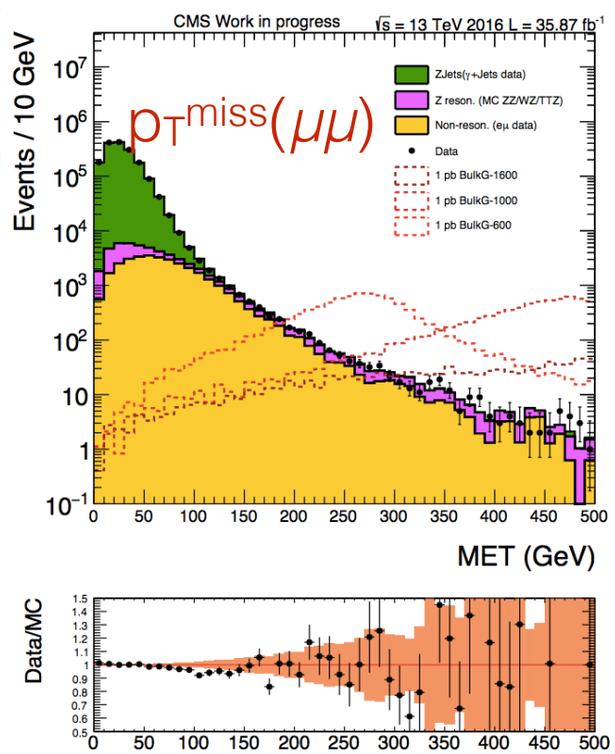

CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
Mz(ee)
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events / 1 GeV
M(Z) (GeV)
Data/MC

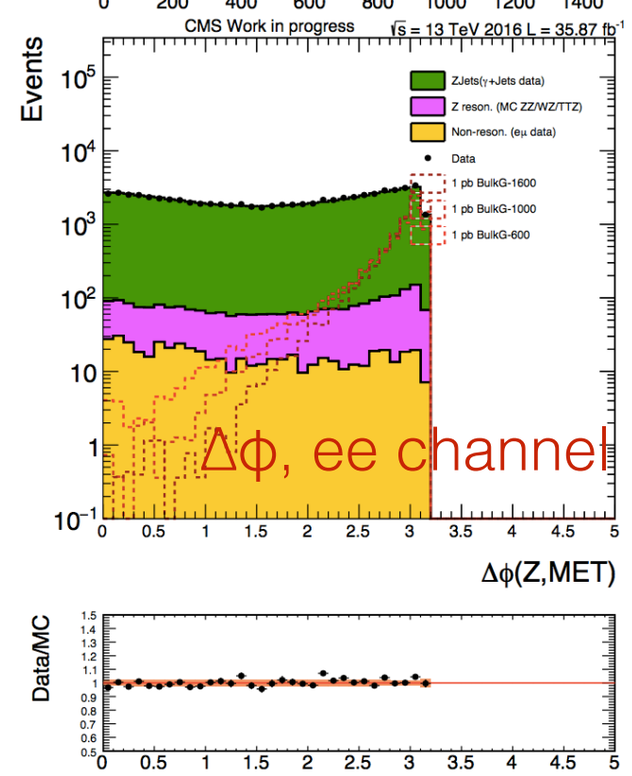

CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
Mz(μμ)
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events / 1 GeV
M(Z) (GeV)
Data/MC

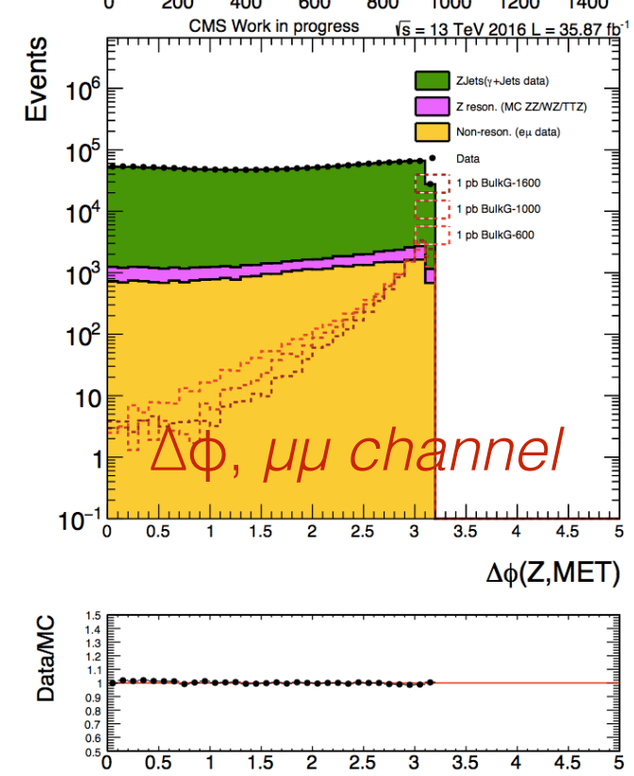

CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
pTZ(ee)
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events / 20.0 GeV
PT(Z) (GeV)
Data/MC


CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
pTZ(μμ)
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events / 20.0 GeV
PT(Z) (GeV)
Data/MC


CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
pTmiss(ee)
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events / 10 GeV
MET (GeV)
Data/MC


CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
pTmiss(μμ)
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events / 10 GeV
MET (GeV)
Data/MC


CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
Δϕ, ee channel
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events
Δϕ(Z,MET)
Data/MC

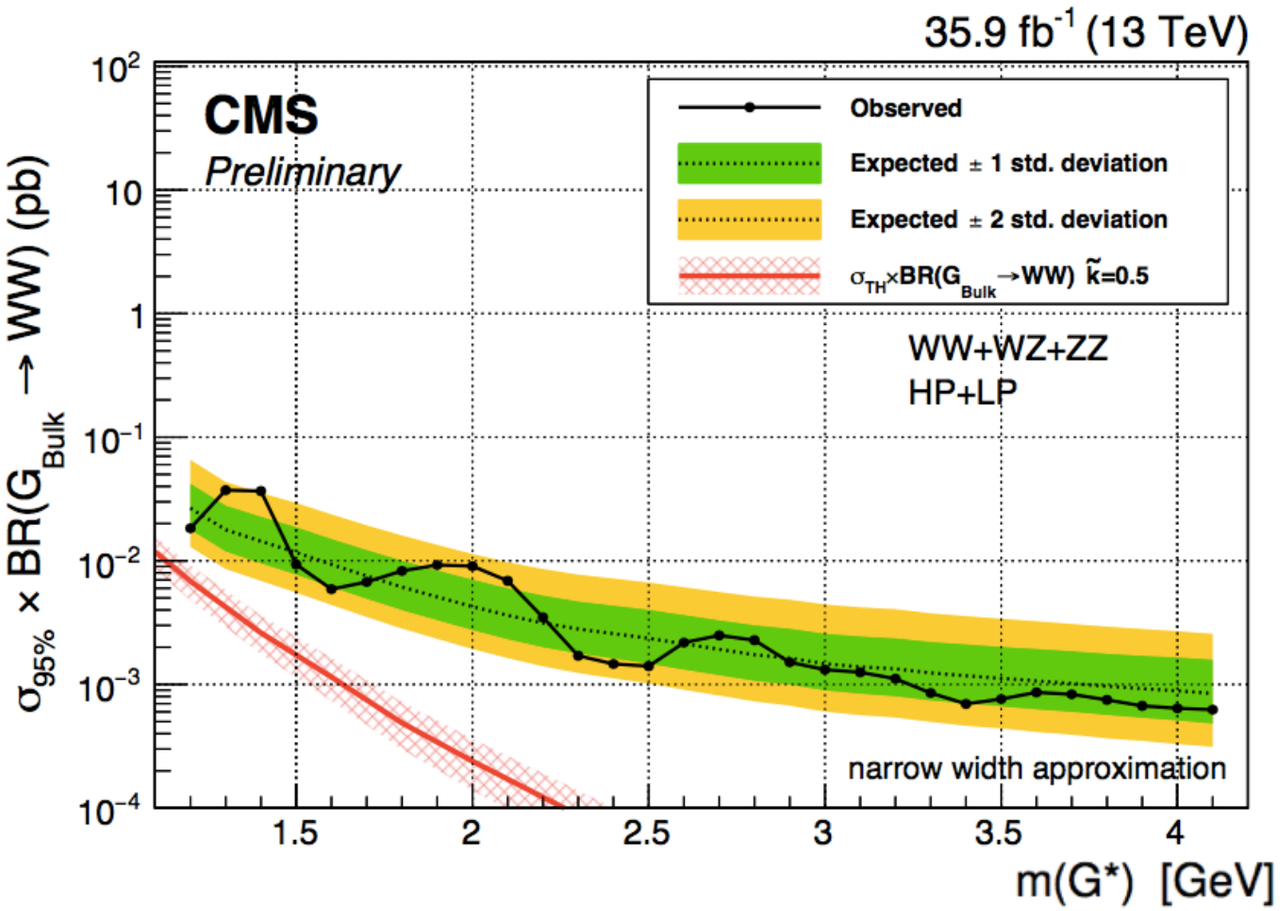

CMS Work in progress
√s = 13 TeV 2016 L = 35.87 fb-1
Δϕ, μμ channel
ZJets(γ+Jets data)
Z reson. (MC ZZ/WZ/TTZ)
Non-reson. (eμ data)
Data
1 pb BulkG-1600
1 pb BulkG-1000
1 pb BulkG-600
Events
Δϕ(Z,MET)
Data/MC

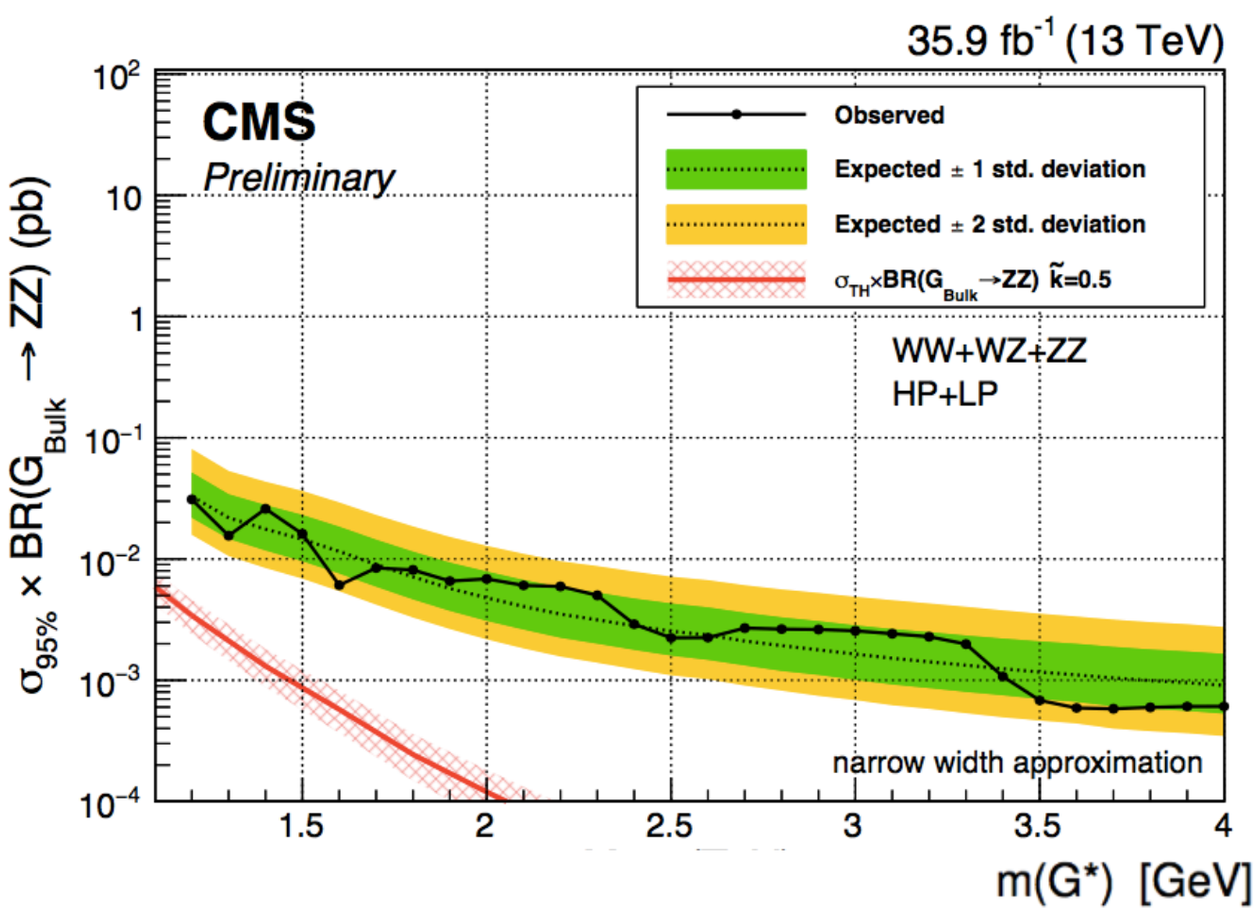
Backup

	electron channel	muon channel
data	9336	52806
Z+jets	8421 ± 203	44253 ± 336
Reson.	637 ± 38	2599 ± 164
Non-Reson.	271 ± 28	5961 ± 211
Total background	9329 ± 269	52813 ± 711

	muon channel		electron channel	
Mass points	$p_T > 50$ GeV	$p_T > 60$ GeV	$p_T > 115$ GeV	$p_T > 120$ GeV
600	77.01%	76.99%	53.82%	53.27%
800	81.91%	81.91%	63.2%	63.09%
1000	83.58%	83.58%	65.95%	65.92%
1200	84.22%	84.22%	69.16%	69.15%
1400	84.75%	84.75%	70.2%	70.2%
1600	84.93%	84.93%	70.16%	70.16%
1800	84.5%	84.5%	70.4%	70.4%
2000	83.06%	83.06%	71.87%	71.87%

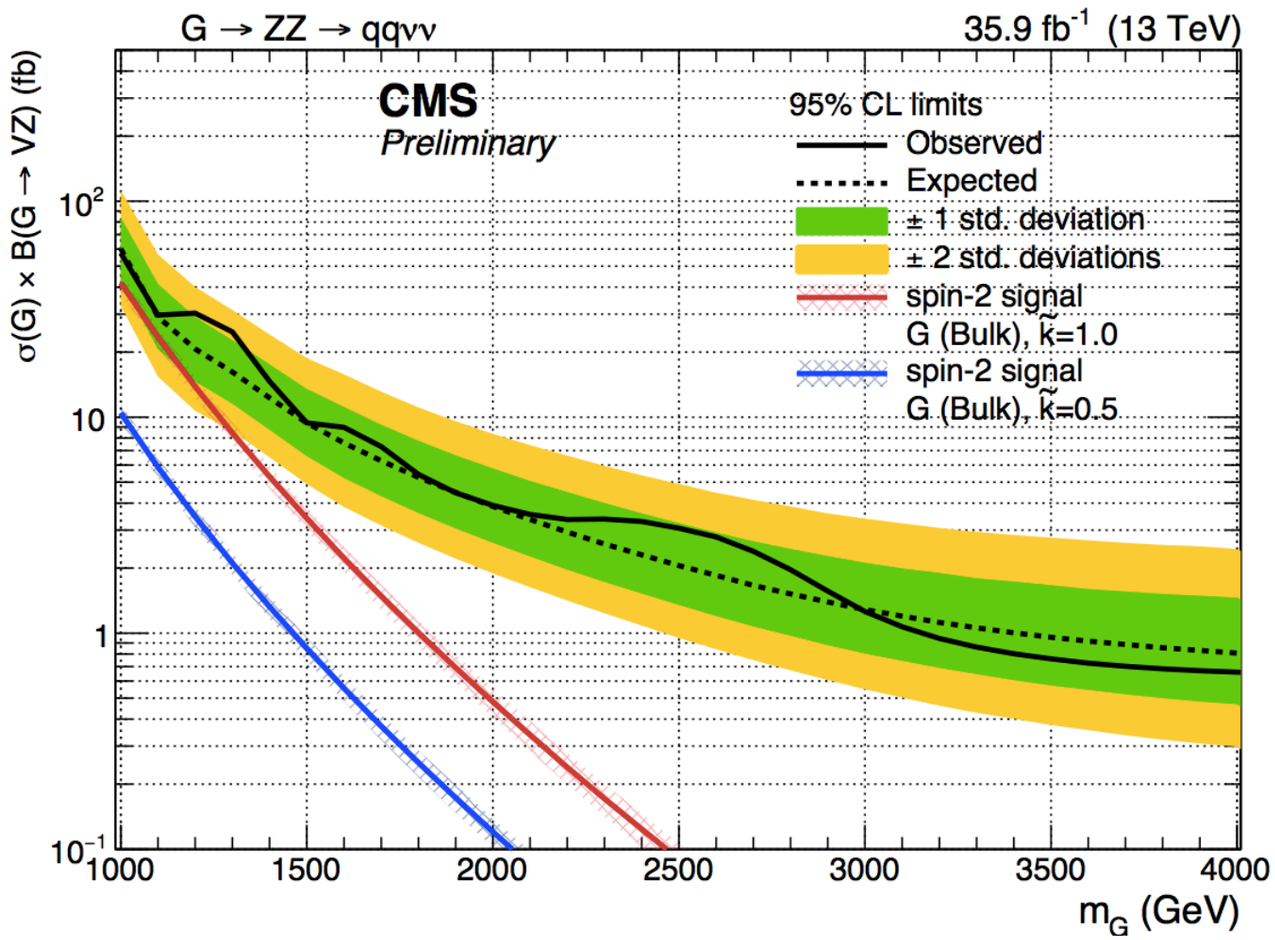
Backup

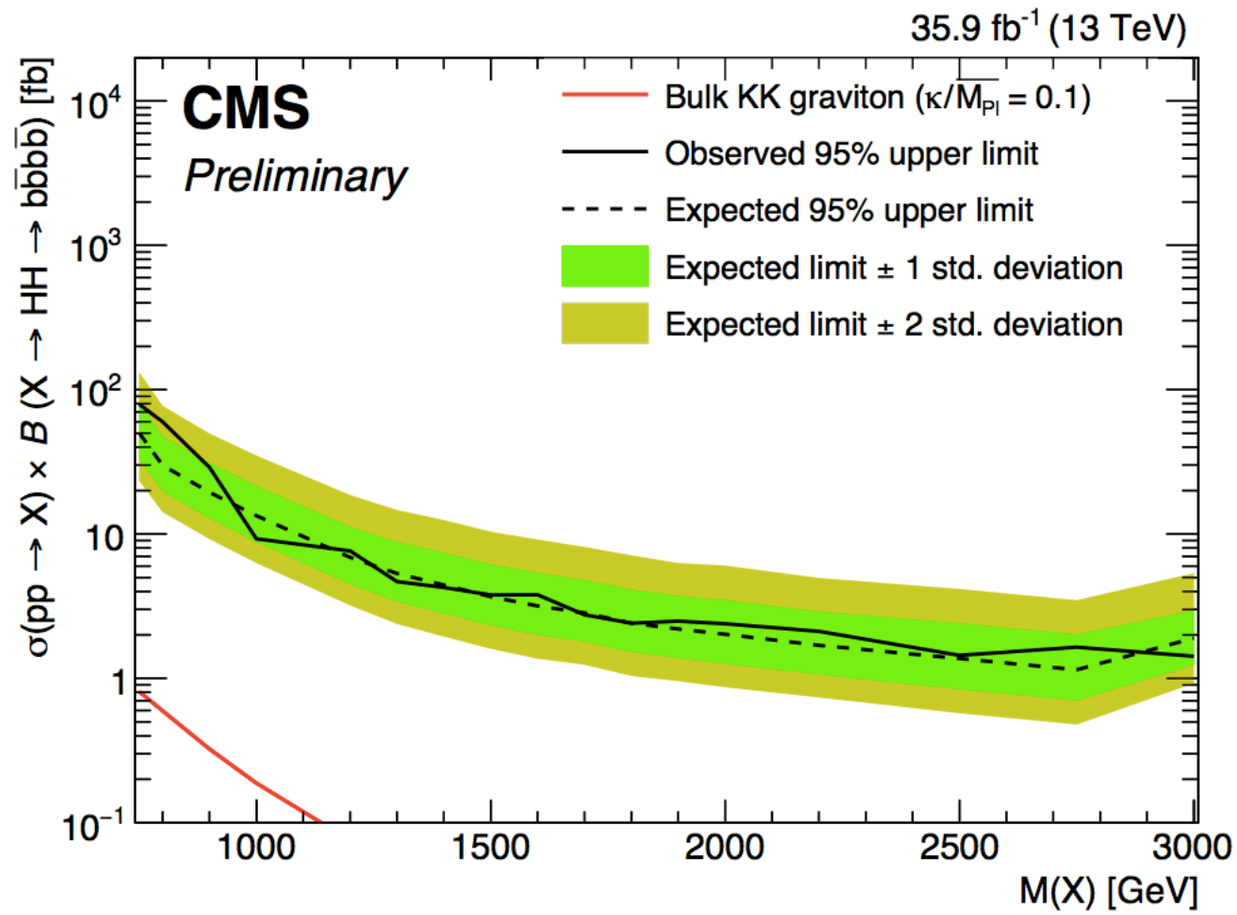




- [CMS PAS B2G-17-001]

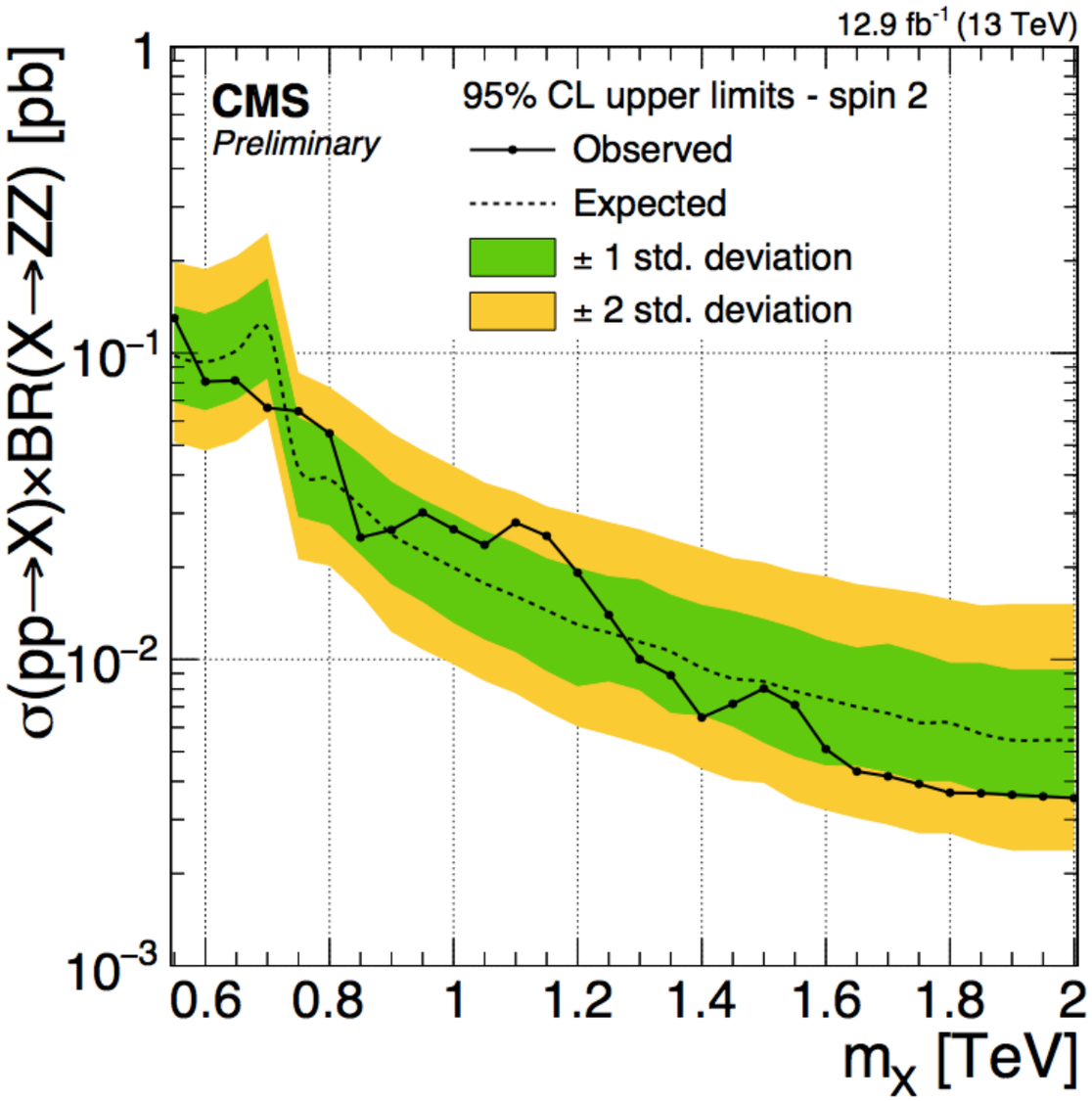
Backup





- [CMS PAS B2G-17-005]
- [CMS PAS B2G-16-026]

Backup



- [CMS PAS HIG-16-034]