Search for massive resonances decaying into pairs of boosted bosons in semi-leptonic final states at $\sqrt{s} = 8$ TeV

Course on Physics at the LHC

António Costa

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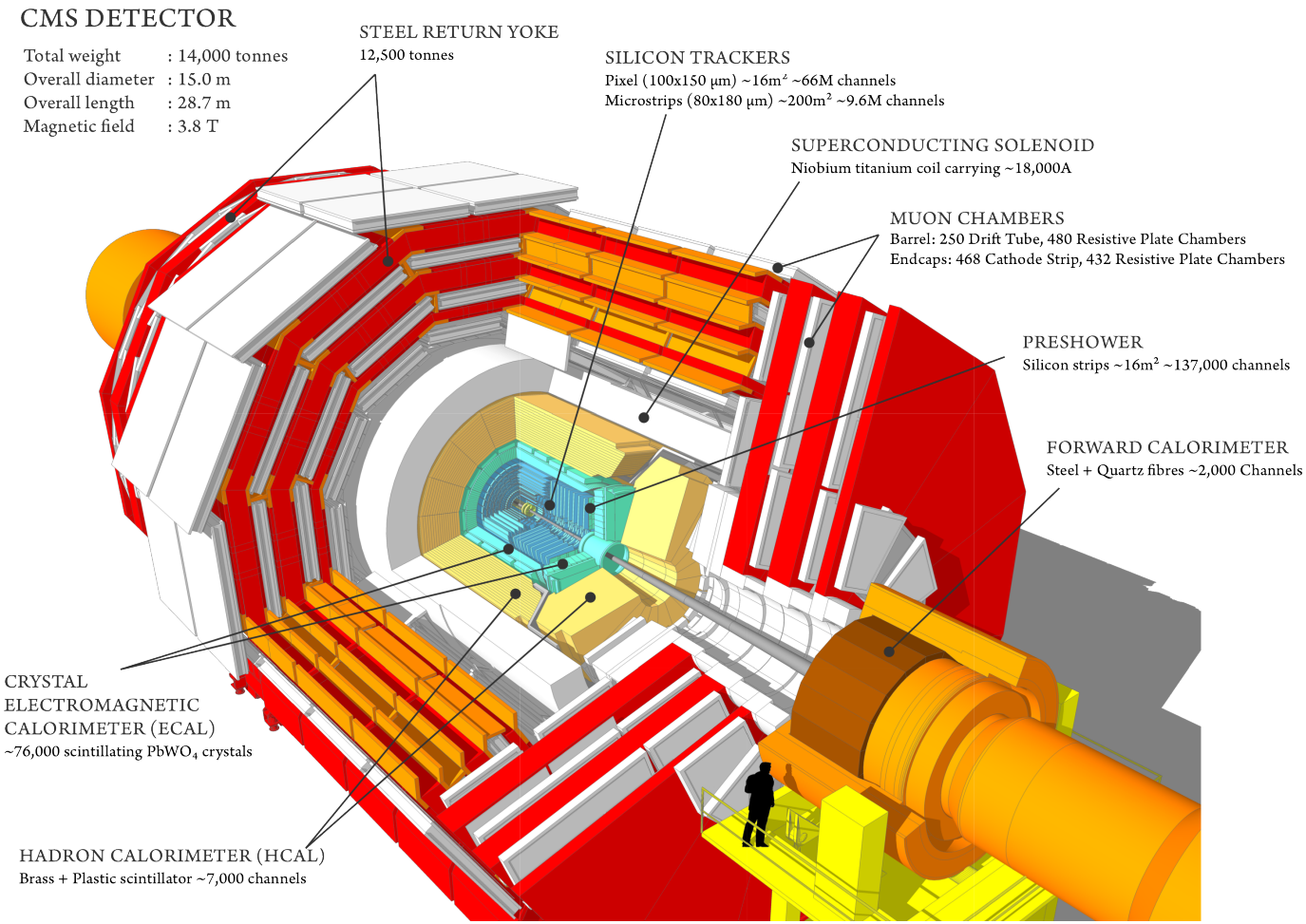
CMS Detector



Model

Large difference between mass of the Higgs boson and Planck scale $M_P l$, where the gravitational force is expected to have the same strength as the other fundamental forces.

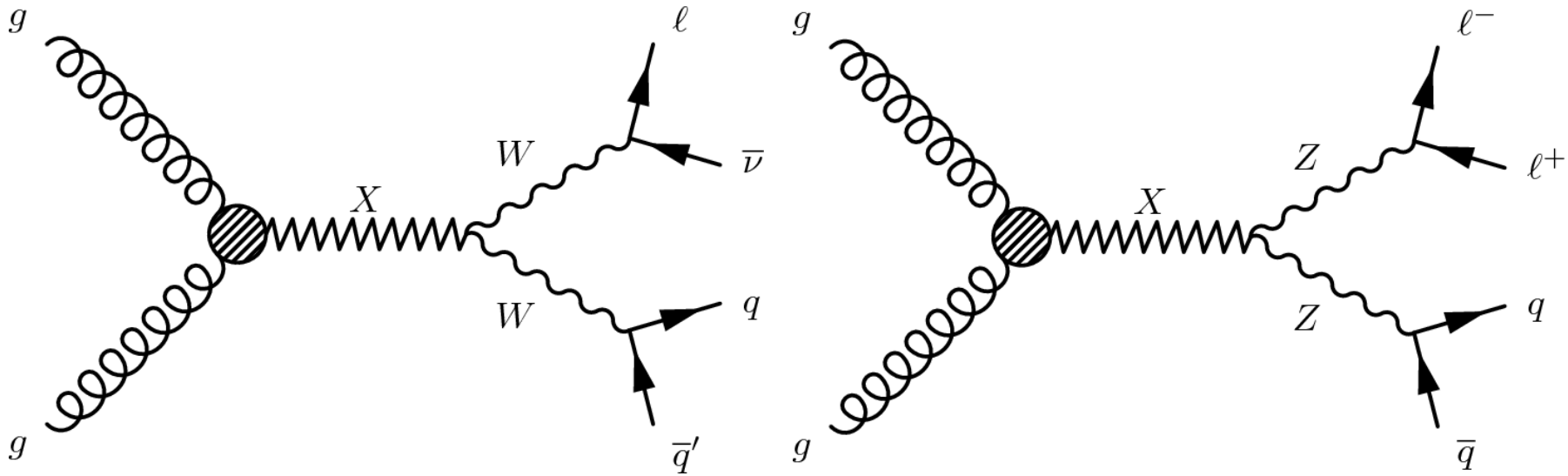
$$\Downarrow$$

Some models, such as the Randall–Sundrum, extend the number of spatial dimensions and predict the existence of new resonances coupling to pairs of massive vector bosons.

$$\Downarrow$$

Extension of this model to bulk graviton model, where only coupling to massive gauge bosons is relevant. It has two free parameters: the mass of the first mode of the KK bulk graviton, M_G, and the ratio $\frac{k}{\overline{M_{Pl}}}$, where k is the unknown curvature scale of the extra dimension, and $\overline{M_{Pl}}$ is the reduced Planck mass.

Decay Channels



Two Feynman diagrams for the production of a generic resonance X decaying to some of the final states considered in this study.

Simulation

- Bulk graviton is forced to decay to the WW and ZZ final states.
- Vector gauge bosons are predominately produced with a longitudinal polarization.
- Graviton masses considered lie in the range 600 to 2500 GeV.
- The total cross section of the process $pp \rightarrow G_{bulk}$ at $\sqrt{s} = 8$ TeV is 15.1 fb, for a graviton mass of 1 TeV and $\frac{k}{M_{Pl}} = 0.5$.
- At the same resonance mass, the Branching Fraction of $G_{bulk} \rightarrow WW$ is 18.7% and of $G_{bulk} \rightarrow ZZ$ is 9.5%.

Online Trigger

$l\nu + V - jet$ **channel**:

- Trigger requiring either one muon or one electron, no isolation requirements and loose identification criteria.
- $p_T > 40$ GeV for the muons and $p_T > 80$ GeV for the electrons.

$ll + V - jet$ **channel**:

- Trigger requiring either two muons or two electromagnetic energy deposits, with loose identification criteria.
- No lepton isolation requirements.
- $p_T > 22$ GeV for the highest-p_T muon and $p_T > 8$ GeV for the second highest-pT muon.
- $E_T > 33$ GeV for the electrons.

Muon Reconstruction and Selection

Large values of the mass of a ZZ resonance

$\Downarrow$

Leptons originating from the high-p_T Z boson are highly collimated because of the large Lorentz boost

$\Downarrow$

Small values of angular separation $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

Global muon reconstruction, which uses both the inner tracking system and the muon spectrometer, fails to very closed muons, causing the loss of one of them

$\Downarrow$

In the di-lepton final state, selection requires two tracker muons (less precise reconstructed muons) of which at least one should be reconstructed and identified as a global muon.

Muon Reconstruction and Selection

An isolation requirement is applied in order to suppress the background from multi-jet events.

$l\nu + V - jet$ **channel**:

- One global muon with $p_T > 50$ GeV and $|\eta| < 2.1$.

$ll + V - jet$ **channel**:

- Two muons, one with $p_T > 40$ GeV and the other with $p_T > 20$ GeV, and $|\eta| < 2.4$.

Electron Reconstruction and Selection

Electron candidates are reconstructed by matching energy deposits in the ECAL with reconstructed tracks and obey precise isolation criteria.

$l\nu + V - jet$ **channel**:

- One global muon with $p_T > 90$ GeV and $|\eta| < 2.51$.

$ll + V - jet$ **channel**:

- Two electrons with $p_T > 40$ GeV and $|\eta| < 2.5$.

Jets Reconstruction and Missing E_T

- Jets are reconstructed using the Particle-Flow (PF) algorithm, which combines information from all sub-detector systems.
- Particles not associated with the primary-event vertex are rejected
- Criteria regarding isolation and tagging is applied to the jets, that must also have $p_T > 30$ GeV and $|\eta| < 2.4$.
- In the $l\nu + V - jet$ channel it is required an $E_T^{miss} > 40$ GeV for muons and $E_T^{miss} > 80$ GeV for electrons.

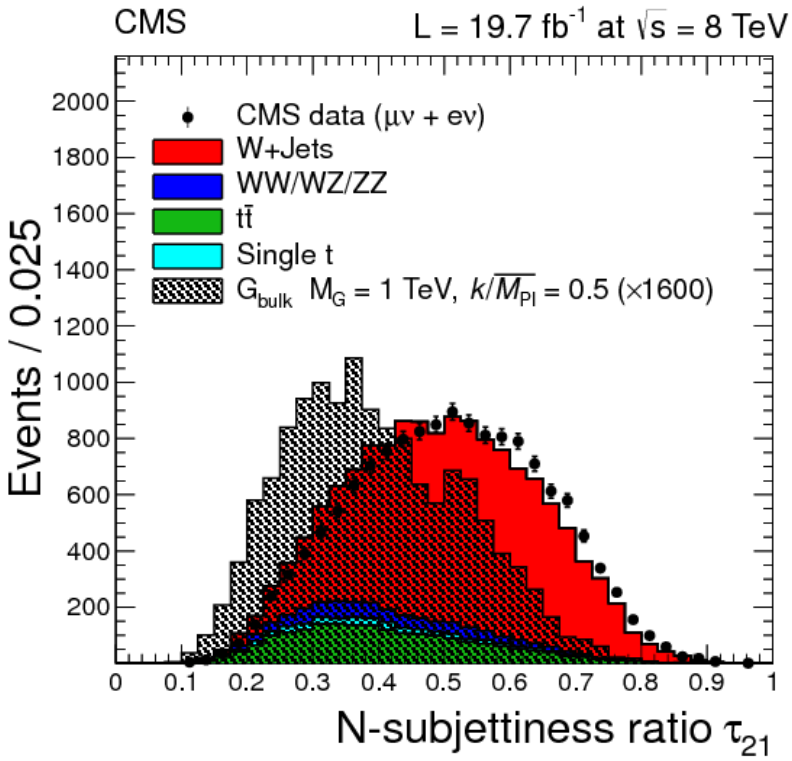
Bosons Reconstruction

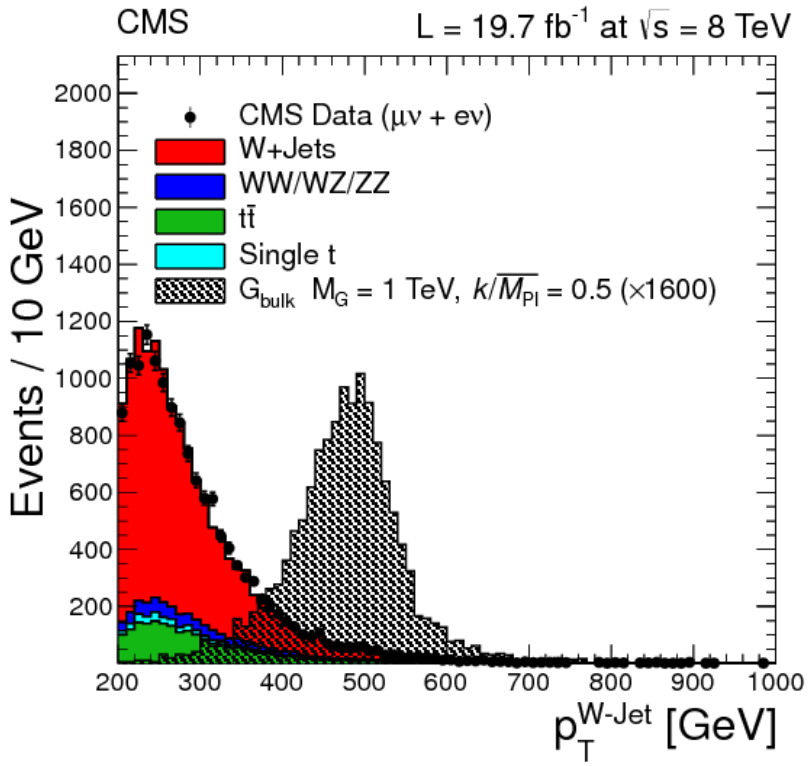
- In the leptonic channels where there are neutrinos the missing transverse energy is associated to the system of neutrinos (one or three, depending on the lepton decay).
- The invariant masses of ll and $l\nu$ have to be consistent with the boson masses associated.
- In the hadronic channels the reconstructed jet mass also has to be close to the boson masses and jet substructure analysis is performed in order to reduce background.

Final event selection and categorisation

- In the $ll + V - jet$ channel both the leptonic and the hadronic V-boson candidates must have a p_T greater than 80 GeV, while for the $l\nu + V - jet$ channel this minimum threshold is set at 200 GeV, due to higher trigger thresholds and larger multijet background.
- Applied criteria regarding that the two W bosons from the decay of a massive resonance are approximately back-to-back in the $l\nu + V - jet$ channel.
- The minimum value of m_{VV} is 700 GeV for the $l\nu + V - jet$ channel and 500 Gev for the $ll + V - jet$ channel.
- Categorisation having in mind lepton flavour (muon or electron) and V-jet purity (one or two subjets)

Final event selection and categorisation





Hadronic W p_T and N-subjettiness ratio τ_{21} distributions for the combined muon and electron channels and with $65 < m_{jet} < 105$ GeV. The VV, $t\bar{t}$, and single-t backgrounds are taken from simulation and are normalized to the integrated luminosity of the data sample. The W+jets background is rescaled such that the total number of background events matches the number of events in data. The signal is scaled by a factor of 1600 for better visualization.

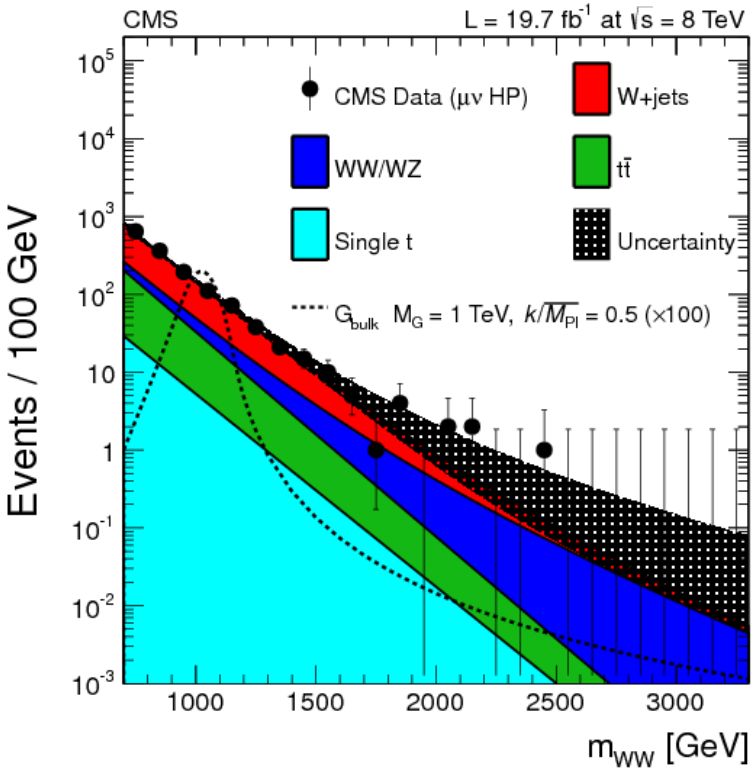
Background Modeling

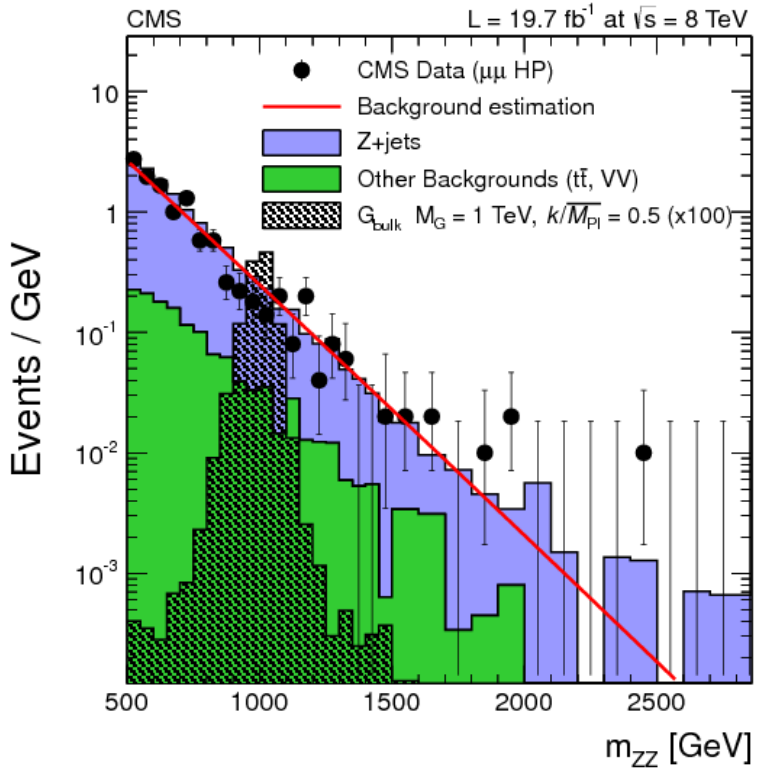
Dominant background comes from SM V+jets events and its estimation in the signal region is derived from a fit excluding this same region, while the predictions for the other minor backgrounds come from the simulation.

	$\mu\mu$ + V-jet HP	$\mu\mu$ + V-jet LP	ee + V-jet HP	ee + V-jet LP
Observed yield	575	338	360	233
Expected background	622 ± 29	338 ± 22	370 ± 22	207 ± 17
Bulk graviton ($k/\overline{M}_{\mathrm{Pl}} = 0.5$)		Signal expectation (MC)		
$m_{\mathrm{G}} = 800\,\mathrm{GeV}$	2.4	0.5	2.0	0.4
$m_{\mathrm{G}} = 1200\,\mathrm{GeV}$	0.16	0.04	0.14	0.035

	$\mu\nu$ + V-jet HP	$\mu\nu$ + V-jet LP	eν + V-jet HP	eν + V-jet LP
Observed yield	1483	1546	892	988
Expected background	1434 ± 38	1644 ± 41	878 ± 30	978 ± 31
Bulk graviton ($k/\overline{M}_{\mathrm{Pl}} = 0.5$)		Signal expectation (MC)		
$m_{\mathrm{G}} = 800\,\mathrm{GeV}$	12.8	5.1	10.1	3.9
$m_{\mathrm{G}} = 1200\,\mathrm{GeV}$	0.92	0.43	0.79	0.37

Background Modeling



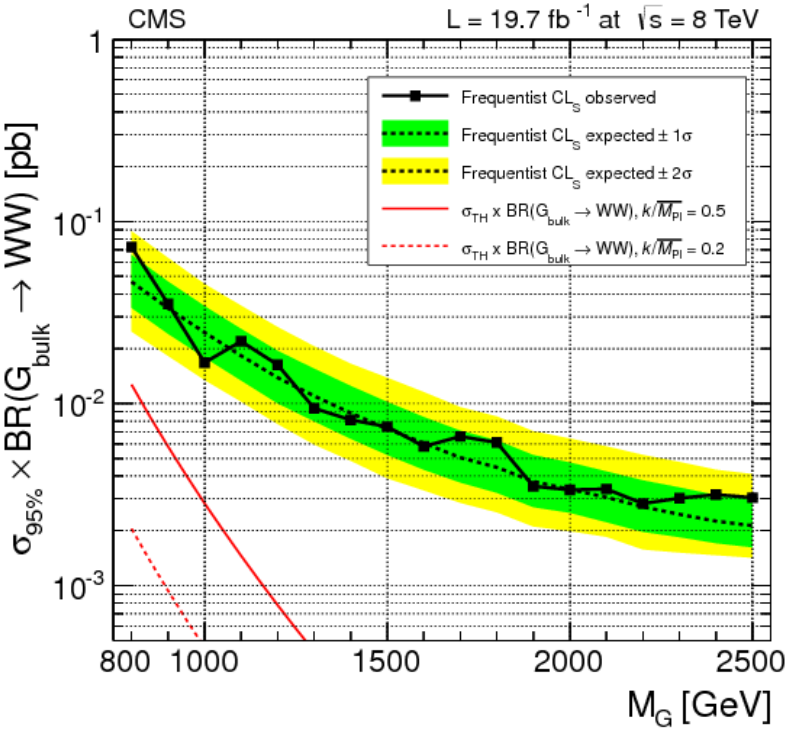


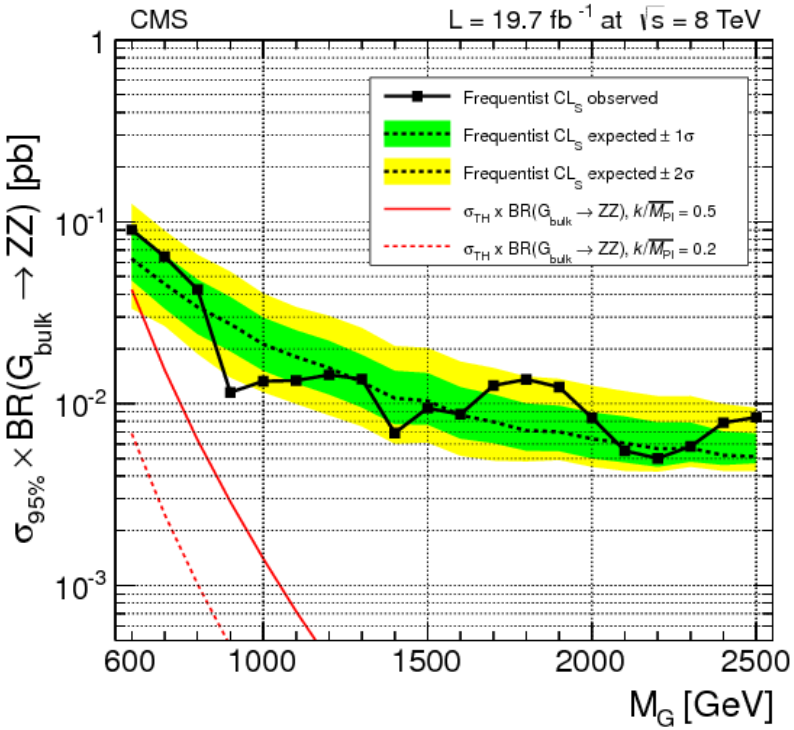
Final distributions in m_{WW} for data and expected backgrounds. Also shown is a hypothetical bulk graviton signal with mass of 1000 GeV and $\frac{k}{M_{Pl}} = 0.5$. The normalization of the signal distribution is scaled up by a factor of 100 for a better visualization.

Signal Modeling

- The shape of the reconstructed signal mass distribution is extracted from the bulk graviton Monte Carlo samples generated with the coupling $\frac{k}{M_{Pl}} = 0.2$.
- The natural width of the resonance is sufficiently small to be neglected when compared to the detector resolution, making the modeling of the detector effects on the signal shape independent of the model used for generating the events.
- The signal mass distribution is parametrized separately for events with electrons and muons.

Limits on a narrow-width bulk graviton model

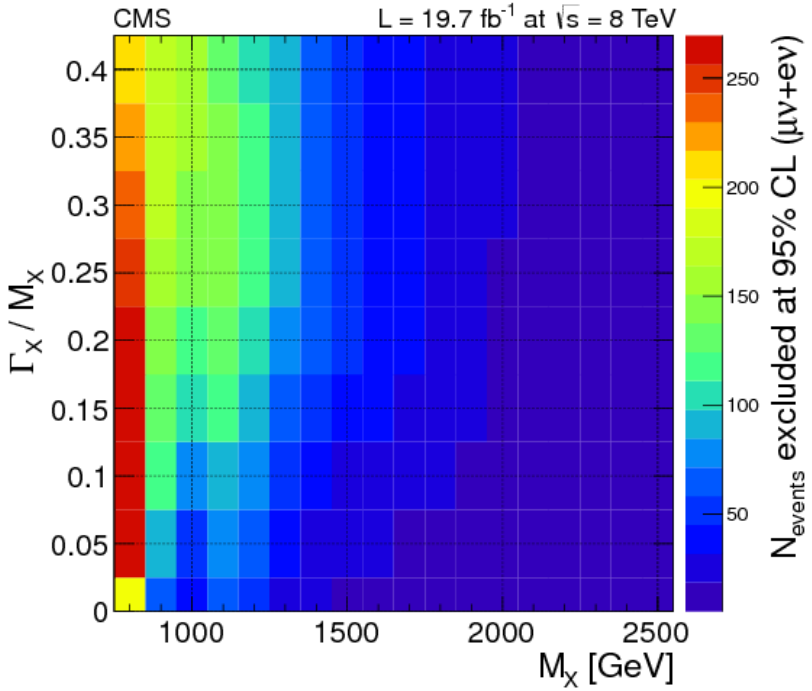


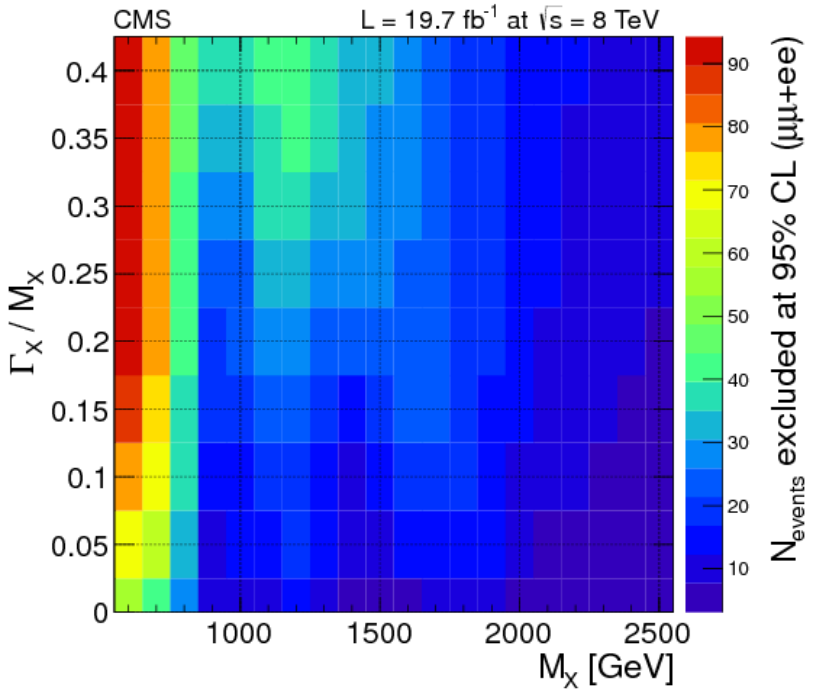


Observed (solid) and expected (dashed) 95% CL upper limits on the product of the graviton production cross section and the branching fraction of $G_{bulk} \to WW$ and $G_{bulk} \to ZZ$

BACKUP

Observed exclusion limits at 95% CL





Observed exclusion limits at 95% CL on the number of events for a $WV \rightarrow l\nu + V - jet$ and $ZV \rightarrow ll + V - jet$