CMS Recent BSM Highlights

Andrés Flórez

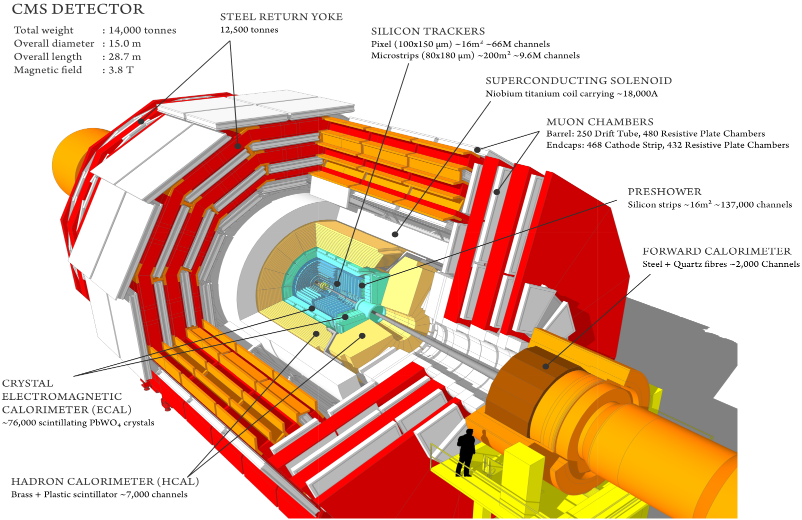
Universidad de los Andes (Colombia)
On behalf of the CMS Collaboration

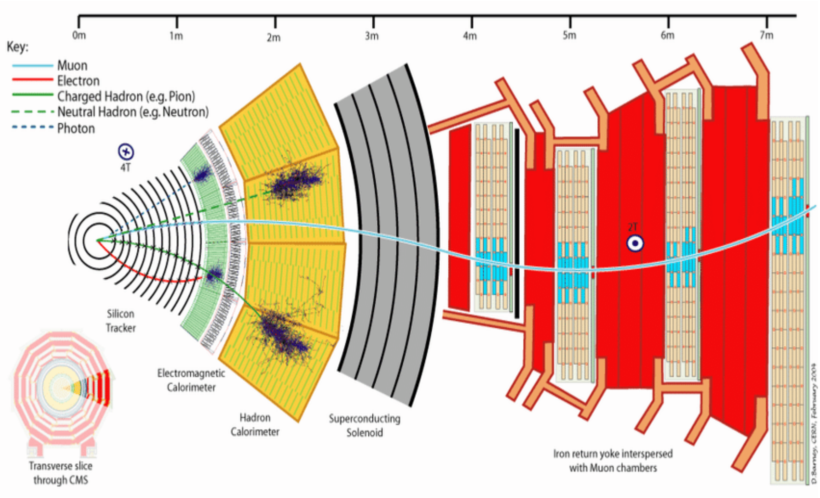
December 5^{th}, 2018

Overview

- CMS has a very broad physics program to search for physics beyond the standard model (SM).
- I will focus on some of the recent results from CMS, related with Exotic models and Supersymmetry.
- I hope to give you an overview of the interesting physics being conducted by CMS.
- I have tried to put enough details in the slides so you can comprehend the overall concept of each analysis.
- The title of each slide has a hyperlink to the CMS site, where you can find the documentation.

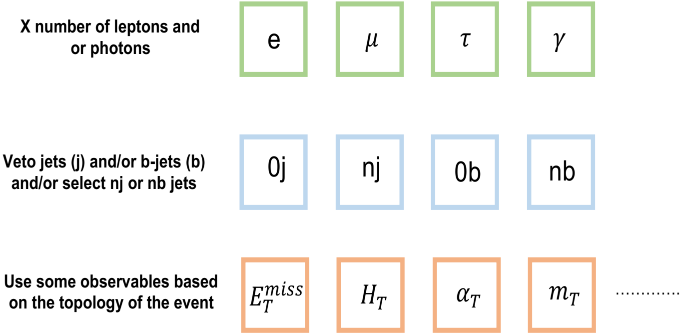
The CMS Detector




0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

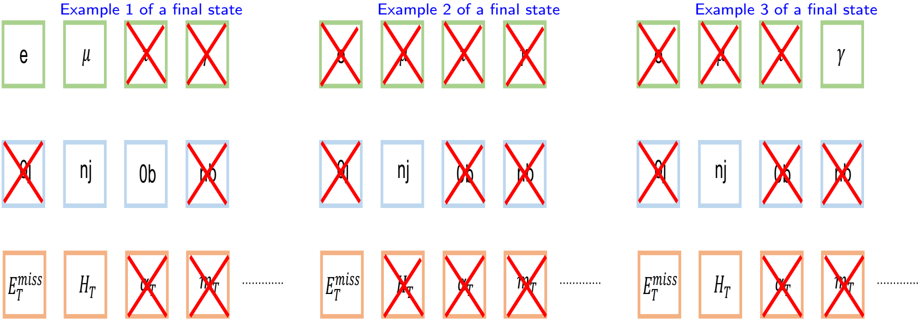
What do we search for?

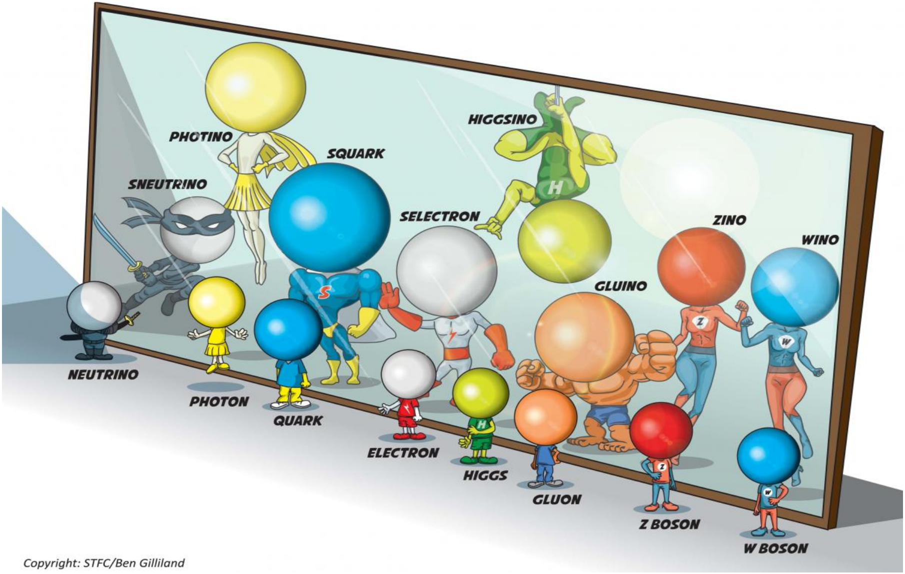
- Depending on the signal model, we search for different combinations of leptons, photons, jets and, b-jets.
- We also use characteristics of each event to discriminate possible signals from SM processes: displaced vertices, missing transverse momentum (energy) E_T^{miss}, etc.
- In addition, we reconstruct observables based on the topology of the signal process under study: H_T, m_T. α_T etc.



What do we search for?

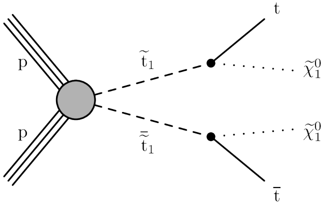
- As a general rule of thumb, we search for an enhancement of events with respect to the expected background processes from the SM.
- If there is agreement between the background expectation and the observed data, limits are set at 95% CL on the production cross section of such models.





taken from: http://united-states.cern/physics/supersymmetry

$\tilde{t}\bar{\tilde{t}} \to e\mu$ (35.9 fb^{-1}) - CMS PAS SUS-18-003

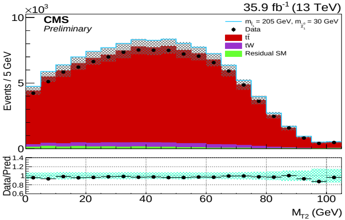


- The analysis searches for the production of a pair of $\tilde{t}$ quarks, in leptonic final states to an electron and a muon.
- The analysis is optimised to be sensitive to the so called compressed mass spectra scenario:

$$m(\tilde{t}_1) - m(\tilde{\chi}_0^1) \approx m(top)$$

- The analyses requires exactly one $e\mu$ pair with opposite charge and $m(e,\mu) > 20$ GeV, and two jets with at least one b-tagged jet.
- The M_{T2} distribution is used as fitting variable to search for signal.

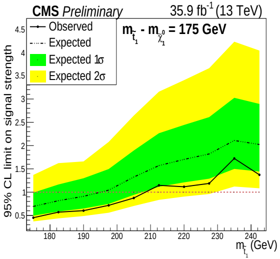
$$M_{T2}^2 = \min_{\vec{p}_{T1}^{miss} + \vec{p}_{T2}^{miss} = \vec{E}_T^{miss}} \left(\max \left[m_T^2(\vec{p}_T^{\ell 1}, \vec{p}_{T1}^{miss}), m_T^2(\vec{p}_T^{\ell 2}, \vec{p}_{T2}^{miss}) \right] \right)$$



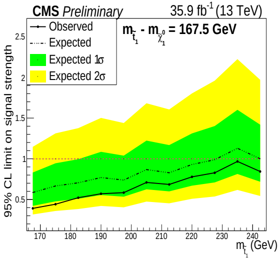
$\tilde{t}\bar{\tilde{t}} \rightarrow e\mu$ (35.9 fb^{-1})- **CMS PAS SUS-18-003**

- Since no excess above the SM BKG expectation is observed, upper limits at 95% CL on the signal strength are set as function of the $\tilde{t}$ mass.
- The analysis considers scenarios where R-parity is conserved ($P_R = (-1)^{3B-L+2s}$)

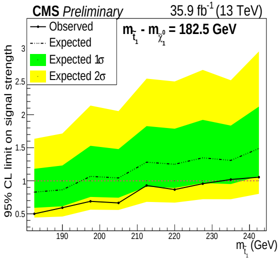
$m(\tilde{t}_1) - m(\tilde{\chi}_0^1) \approx m(top)$

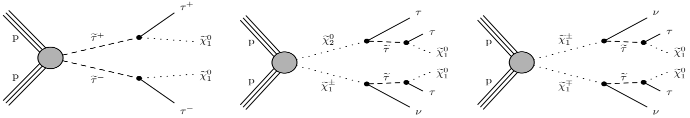


$m(\tilde{t}_1) - m(\tilde{\chi}_0^1) \approx m(top) - 7.5GeV$



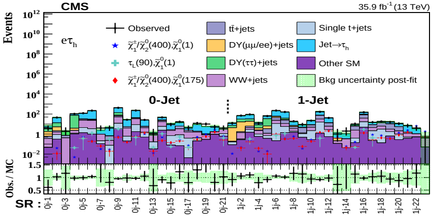
$m(\tilde{t}_1) - m(\tilde{\chi}_0^1) \approx m(top) + 7.5GeV$





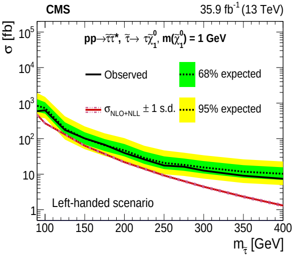
- Scenarios where the $\tilde{\tau}$ and the $\tilde{\chi}_1^0$ are nearly mass degenerate (compressed-mass-spectra) allow to obtain a relic DM density consistent with cosmological observations.
- The analysis consideres three scenarios for that $\tilde{\tau}$ pair production: (i) $\tilde{\tau}_L$, (ii) $\tilde{\tau}_R$, and (iii) maximal mixing between the right- and left-handed eigenstates.
- The following final states are considered: $e\mu$, $e\tau_h$, $\mu\tau_h$ and $\tau_h\tau_h$.

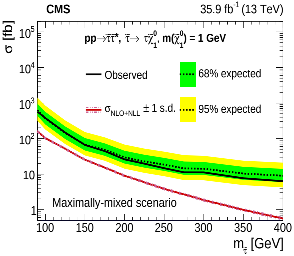
Selection requirement	$e\mu$	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$
$\lvert\Delta\phi(\ell_1,\ell_2)\rvert$	<1.5	<1.5	<1.5	<1.5
$\lvert\Delta\eta(\ell_1,\ell_2)\rvert$	<2	<2	<2	—
$\Delta R(\ell_1,\ell_2)$	<3.5	<3.5	<3.5	—
b-tagged jet veto	$p_T > 20$ GeV, medium CSV	$p_T > 20$ GeV, medium CSV	$p_T > 20$ GeV, medium CSV	$p_T > 30$ GeV, loose CSV
Additional jet veto	>1 jet, $p_T > 20$ GeV	>1 jet, $p_T > 20$ GeV	>1 jet, $p_T > 20$ GeV	—
$\lvert\Delta\eta(\text{jet},\ell_i)\rvert$ (1–jet events)	<3	<3	<3	—
$\Delta R(\text{jet},\tau_h)$ (1–jet events)	—	<4	<4	—
$m(\ell_1,\ell_2)$ [GeV]	90–250	>50	>50	—
e/μ p_T upper bound [GeV]	<200	—	—	—
$m_T(e/\mu,\vec{p}_T^{miss})$ [GeV]	—	20–60 or >120	20–60 or >120	—
Σm_T [GeV]	—	>50	>50	—

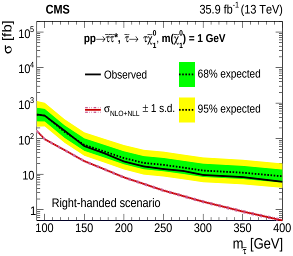


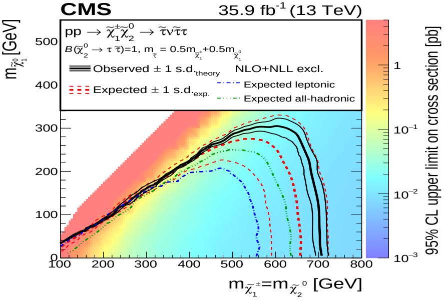
$\tilde{\tau}\bar{\tilde{\tau}}$ $(35.9\ fb^{-1})$- arXiv:1807.02048

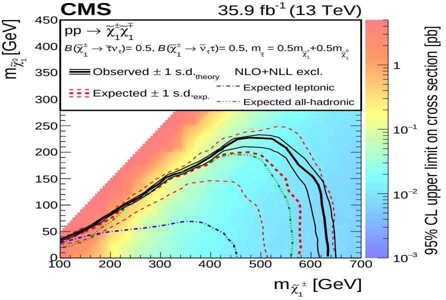
$\tilde{\tau}_L$ | maximally-mixed $\tilde{\tau}$ | $\tilde{\tau}_R$





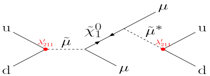




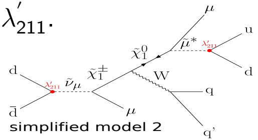


$\tilde{\mu}$ or $\tilde{\nu}_\mu$ (35.9 fb^{-1})- arXiv:1811.09760

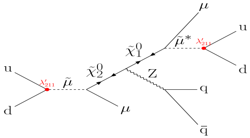
- The search focuses on the production of $\tilde{\mu}$ and $\tilde{\nu}_\mu$ candidates, in the context of RPV scenarios, via λ'_{211}.



simplified model 1

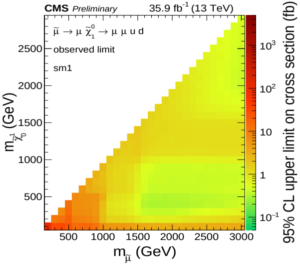


simplified model 2

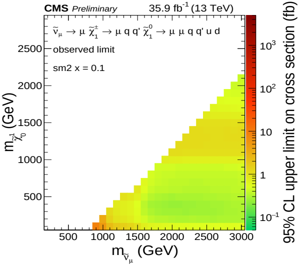


- The analysis requires a well identified muon pair with same electric charge, and at least two jets with $p_T > 40$ GeV and $|\eta| < 2.4$.

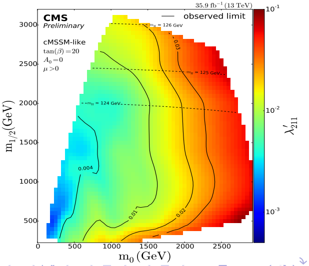
Upper cross section limit at 95% CL in the $m_{\tilde{\chi}_1^0}$ vs $m_{\tilde{\mu}}$ plane.



Upper cross section limit at 95% CL in the $m_{\tilde{\chi}_1^0}$ vs $m_{\tilde{\nu}_\mu}$ plane.

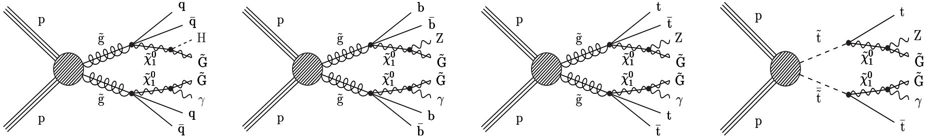


Upper coupling limits as a function of m_0 and $m_{1/2}$ for a modified cMSSM

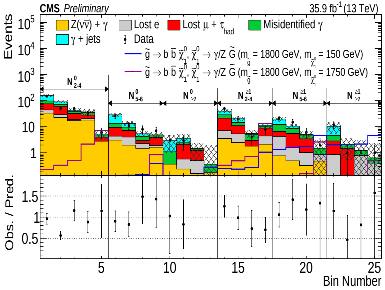


$\gamma + jets + E_T^{miss}$- CMS PAS SUS-18-002

- The search focuses in final states with at least one γ, multiple jets and large E_T^{miss}, motivated by gauge-mediated supersymmetry breaking (GMSB).
- In GMSB scenarios, assuming R-parity conservation, the gravitino is the DM candidate.

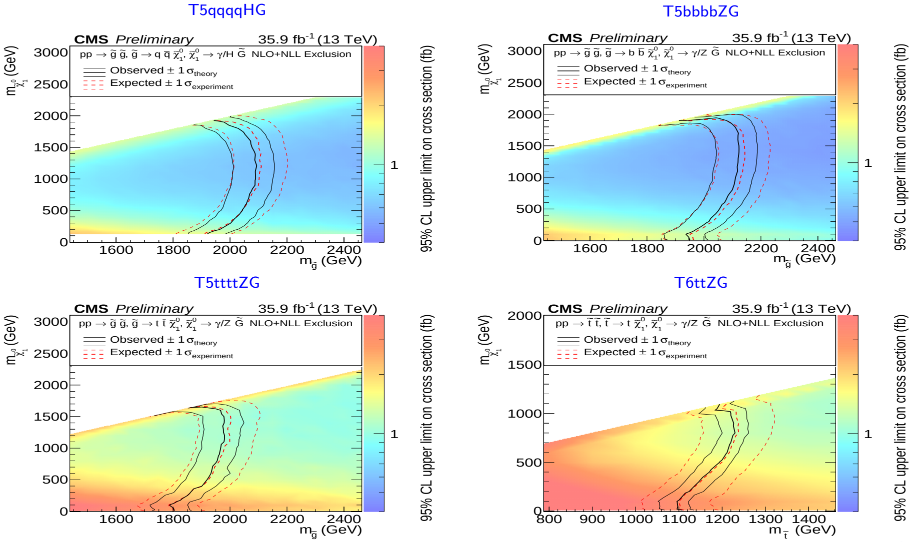


- Depending on the scenario, signal events were required to pass: ($p_T^{\gamma} > 100$ GeV & $H_T^{\gamma} > 800$ GeV) or ($p_T^{\gamma} > 190$ GeV & $H_T^{\gamma} > 500$ GeV)
- The selected events are divided into 25 independent signal regions based on E_T^{miss}, number of jets, and number of b-tagged-jets.



$\gamma + jets + E_T^{miss}$- CMS PAS SUS-18-002

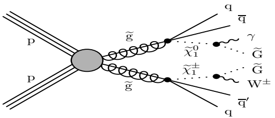
- 95% CL upper limits for $\tilde{g}$ or $\tilde{t}$ pair production cross sections.



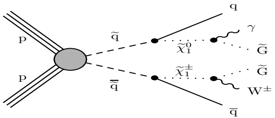
$\gamma + \ell + E_T^{miss}$- CMS PAS SUS-17-012

- Events with at least one γ, one lepton (e or μ), and large E_T^{miss} are studied.
- The analysis consideres general gauge-mediated (GGM) supersymmetry breaking models.
- m_T is used as the main discrimination variable ($m_T = \sqrt{2p_T^{\ell}E_T^{miss}(1 - cos\Delta\phi(\ell, E_T^{miss}))}$). Signal is defined as events passing $E_T^{miss} > 120$ GeV and $m_T > 100$ GeV.

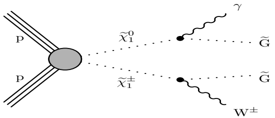
T5Wg

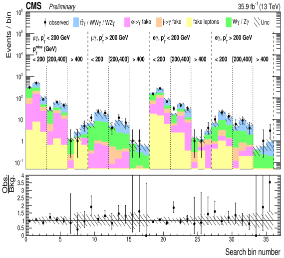


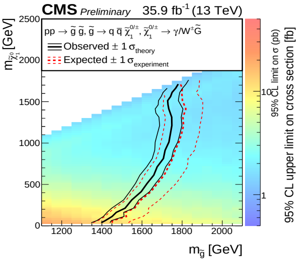
T6Wg

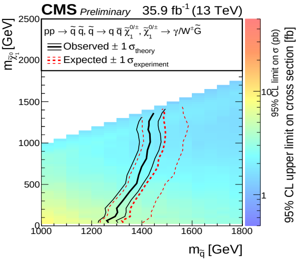


TChiWg





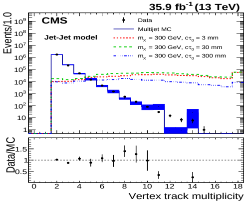


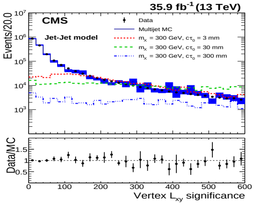


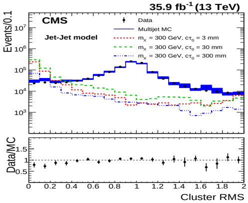
Exotic models

Long-lived-particles - **CMS-PAS-EXO-18-007**

- This analysis focuses in the production of long-lived particles decaying into jets.
- The search considers that each long-lived particle has a desplaced decay vertex up to 55 cm, in the transverse plane, from the main production vertex.
- Several models predict long-lived particles decaying into displaced jets, such as: SUSY GMSB or RPV models.
- Events with at least one dijet pair, $H_T > 400$ GeV, where each jets must have at least a $p_T > 50$ GeV and $|\eta| < 2.0$ are selected.
- For secondary vertices, displaced tracks associated with each dijet candidate are selected by requiring transverse impact parameters larger than 0.5 mm and transverse impact parameter significances larger than 5.



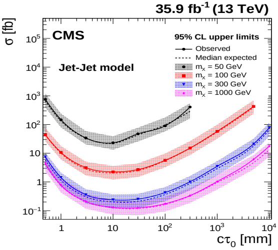




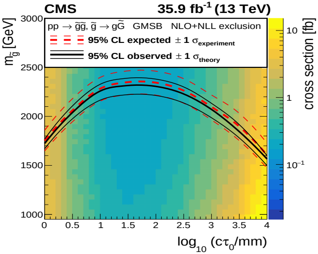
Long-lived-particles - **CMS-PAS-EXO-18-007**

- Limits are set for different models: Jet-Jet model, and SUSY models.
- The Jet-Jet model considers the pair-production of long-lived scalar neutral particles X particles. The pairs are produced through a $2 \to 2$ scattering process, mediated by an off-shell Z boson propagator.

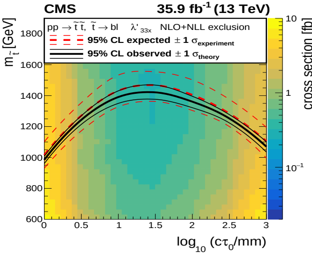
95% CL upper limits on the pair production cross section of the long-lived particle X, using the Jet-Jet model.



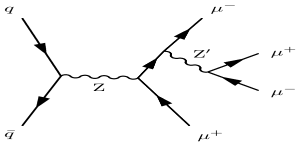
95% CL limits for the long-lived gluino model in the mass-lifetime plane, assuming a 100% branching fraction for $\tilde{g} \to g\tilde{G}$



95% limits for the long-lived top squark model in the mass-lifetime plane, assuming a 100% branching fraction for $\tilde{t} \to b\ell$

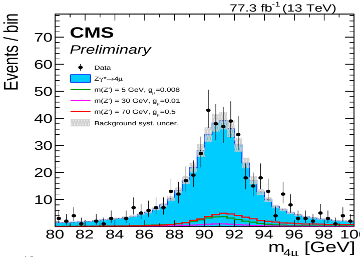


$Z \to 4\mu$ ($77.3\ fb^{-1}$) - CMS-PAS-EXO-18-008



- The inclusion of an additional $U(1)'$ symmetry in the SM, is one of the simplest extensions.
- Such an extension, gives rise to the well known Z' boson.
- "To make the extension anomaly-free, only some generation-dependent couplings are allowed"..
- The analysis uses the $L_\mu - L_\tau$ gauge symmetry: assumes couplings to the 2nd and 3rd generations only.

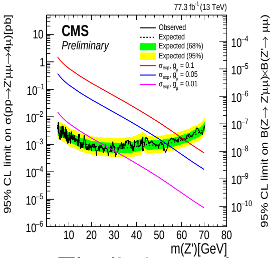
- Event selection criteria:
  1. $n_\mu \geq 4$
  2. $4 < m_{\mu^+\mu^-} < 120$ GeV
  3. $m(Z_1) > 12$ GeV
  4. $80 < m_{4\mu} < 100$ GeV
- Z_1: dimuon pair closest to Z mass.



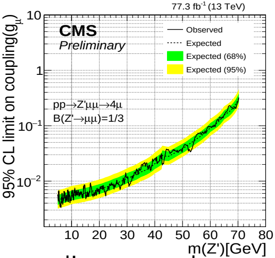
	Background	$m(Z') = 5$ GeV g_μ=0.008	$m(Z') = 15$ GeV g_μ=0.01	$m(Z') = 70$ GeV g_μ=0.5	Observed Data
$80 < m_{4\mu} < 100$ GeV	423.0±39.2	37.1±3.7	31.4±3.1	53.8±5.4	441
$4.9 < m(Z_2) < 5.1$ GeV	9.2±3.1	23.3±2.3	-	-	13
$14.7 < m(Z_2) < 15.3$ GeV	7.7±2.8	-	18.9±1.9	-	6
$68.6 < m(Z_1) < 71.4$ GeV	34.9±6.5	-	-	36.0±3.6	35

$Z \to 4\mu$ ($77.3\ fb^{-1}$) - CMS-PAS-EXO-18-008

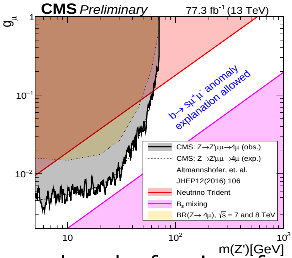
95% CL upper limits on $\sigma(Z'\mu\mu)$ production cross section and branching fraction vs $m(Z')$



95% CL upper limits on the gauge coupling strength as function of $m(Z')$

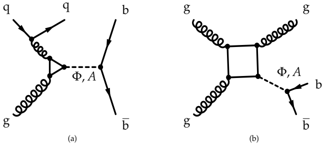


Comparison with other experiments sensitive to the same parameter space



- The limits on the gauge coupling strength, g_μ, assume that the fraction of $B(Z' \to \mu\mu)$ is equal to $1/3$.
- The shaded yellow region shows constraints derived from the ATLAS measurements at 7 and 8 TeV of $Z \to 4\mu$.
- Shaded red: trident cross section by the CCFR Collaboration and magenta from global analysis of B_s mixing.
- **The region in between the red and magenta constrains ,and for $m(Z') > 10$ GeV, is a candidate region to explain the LHCb B-decay anomalies.**

$b\bar{b}$ pairs ($35.9\ fb^{-1}$) - CMS-PAS-EXO-17-024



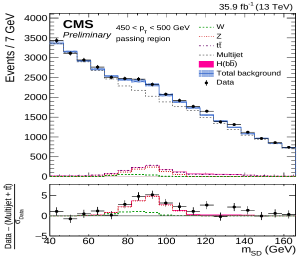
One-loop diagrams of processes exchanging a scalar (Φ) or pseudoscalar (A) mediator, leading to a boosted double b-jet signature.

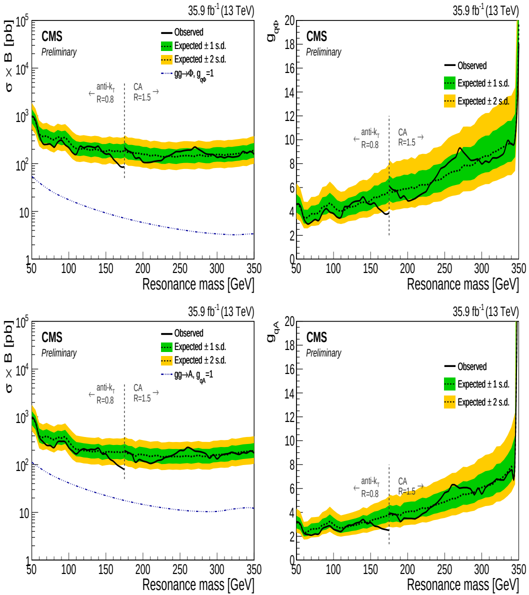
- Depending on the signal hypothesis, the analysis uses two different jet-recon. algorithms (anti-$k_t - AK8$) or Cambridge-Aachen (CA15)).
- The event selection requires a hard ISR jet with $p_T > 450 GeV$ (500 GeV) and $|\eta| < 2.5$ for AK8 (CA15) jets.
- $n_\ell = 0$ and $p_T^{miss} > 140$ GeV.
- The soft-drop algorithm is used to reduce QCD contamination: $\frac{min(p_{T1}, p_{T2})}{p_{T1}+p_{T2}} > z_{cut}(\frac{\Delta R_{1,2}}{R_0})^\beta$
- A dimensionless mass scale variable for QCD multijet jets, $\rho = log(m_{SD}^2/p_T^2)$ is used to characterize the correlation between the jet b tagging discriminator, jet mass, and jet p_T.
- **Events with $\Phi(b\bar{b})$-tag are defined as passing.**

			AK8 jets				
m_Φ [GeV]	$p_T > 450$ GeV	$m_{SD} > 40$ GeV	Lepton veto	$p_T^{miss} < 140$ GeV	$N_2^{1,DDT} < 0$	$-6.0 < \rho < 2.1$	double-b tag
50	75.0 ± 0.1	37.5 ± 0.2	36.2 ± 0.2	32.9 ± 0.2	14.7 ± 0.1	14.3 ± 0.1	7.3 ± 0.1
100	75.4 ± 0.1	42.2 ± 0.2	40.6 ± 0.2	37.5 ± 0.2	18.0 ± 0.1	17.5 ± 0.1	7.1 ± 0.1
125	75.5 ± 0.2	42.3 ± 0.2	40.6 ± 0.2	37.5 ± 0.2	18.1 ± 0.1	17.5 ± 0.1	6.1 ± 0.1
			CA15 jets				
m_Φ [GeV]	$p_T > 500$ GeV	$m_{SD} > 82$ GeV	Lepton veto	$p_T^{miss} < 140$ GeV	$N_2^{1,DDT} < 0$	$-4.7 < \rho < -1.0$	double-b tag
200	61.0 ± 0.1	35.6 ± 0.1	33.9 ± 0.1	31.1 ± 0.1	13.9 ± 0.1	13.0 ± 0.1	3.3 ± 0.0
300	63.4 ± 0.1	35.7 ± 0.1	34.0 ± 0.1	31.1 ± 0.1	13.2 ± 0.1	11.1 ± 0.1	1.9 ± 0.0
350	64.3 ± 0.1	35.8 ± 0.1	33.9 ± 0.1	31.1 ± 0.1	13.0 ± 0.1	8.6 ± 0.1	1.1 ± 0.0

$b\bar{b}$ pairs (35.9 fb^{-1}) - **CMS-PAS-EXO-17-024**

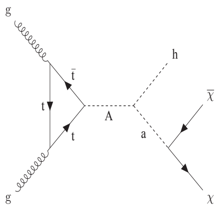
- QCD-multi-jet is the dominant BG (estimated from data).
- The figure below shows the observed and fitted background in one of the p_T categories for the AK8 selection.
- The QCD-multijet BG in the passing region is predicted using the failing region and the pass-fail ratio $R_{p/f}$.

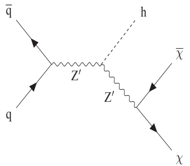


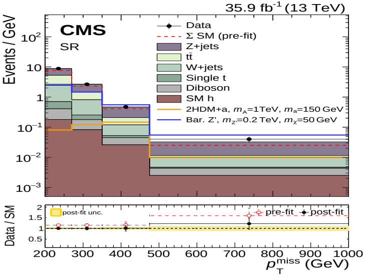


$\chi\tilde{\chi} + h$ - CMS-EXO-16-50

- The analysis explores the production of DM in association to a scalar Higgs boson h, with a mass of 125 GeV that decays to a $b\bar{b}$ pair.
- Results are interpreted in terms of two simplified models:
  1. A type-2 two-Higgs doublet model extended by an additional light pseudoscalar boson a ($2HDM + a$).
  2. A baryonic Z' model, in which a "baryonic Higgs" boson mixes with the SM Higgs boson.
- Events with large E_T^{miss}, no isolated leptons or photons, and a a CA15 jet identified as a Higgs boson candidate, are selected.



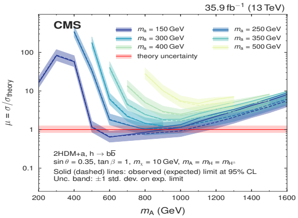




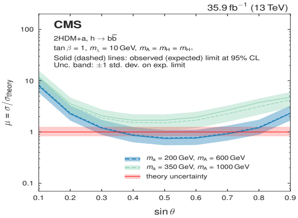
$\chi\tilde{\chi} + h$ - CMS-EXO-16-50

Upper limits at 95% CL on the signal strength modifier, defined as $\mu = \sigma/\sigma_{theory}$.

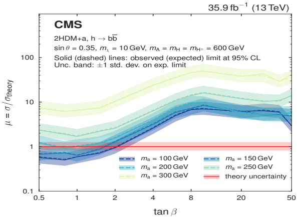
m_A = mass of the pseudoscalar



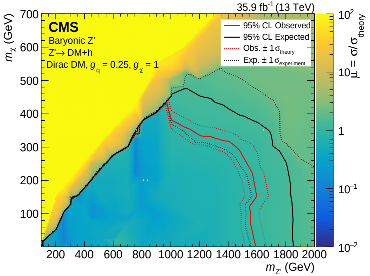
θ = mixing between "a" and "A"



$tan\beta$ = ratio of the VEV between h and H



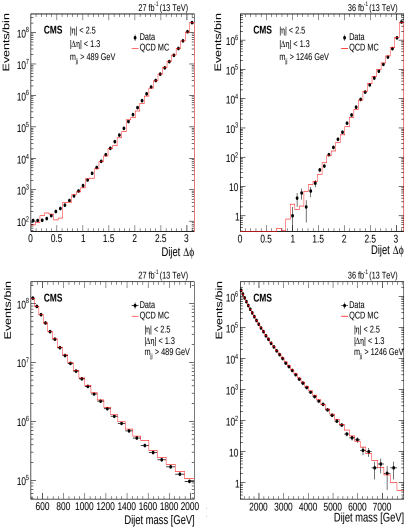
- The baryonic Z' model considers an additional $U(1)_B$ Z' gauge boson that couples to the baryon number B.
- The model predicts the existence of a new Dirac fermion, that is neutral under SM gauge symmetries, has non-zero B, and is stable.



Dijet Resonances (36 fb^{-1}) - **CMS-EXO-16-056**

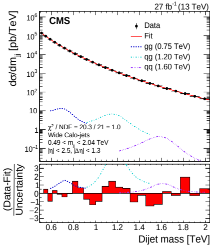
- CMS divides the search into narrow and broad resonance spectrums,using wide jets: $p_T > 30$ GeV, $|\eta| < 2.5$.
- The narrow resonance search, separates events into two m_{jj} regions:
  1. $0.6 < m_{jj} < 1.6$ TeV (27 fb^{-1})
  2. $m_{jj} > 1.6$ TeV (36 fb^{-1})
- The broad resonance search, uses the same events as the high-mass narrow resonance scenario.
- Several benchmark models used: **String resonances, Scalar diquarks, Mass-degenerate excited quarks, Axigluons and colorons, W', Z', Randall-Sundrum, Dark matter mediators**, etc.

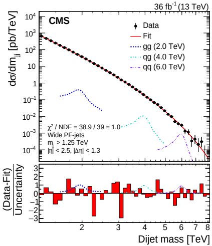
- QCD-multijet events are the dominant source BG.



Narrow dijet

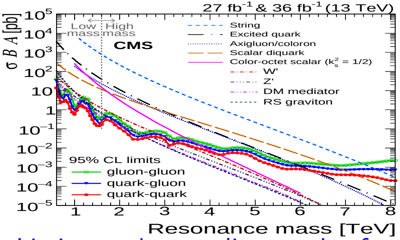
- m_{jj} for the observed number of events in each bin divided by the integrated luminosity and the bin width, with bins of width corresponding to the dijet mass resolution.



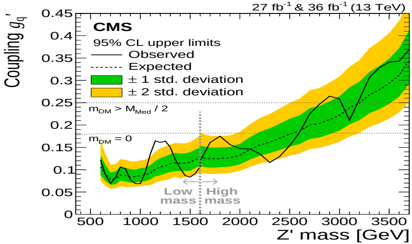


$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\, ln(x)}} \quad , \quad \frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\, ln(x)+P_4\, ln^2(x)}}$$

Limits on the resonance mass

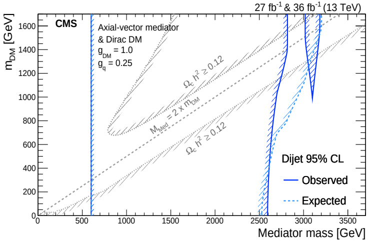


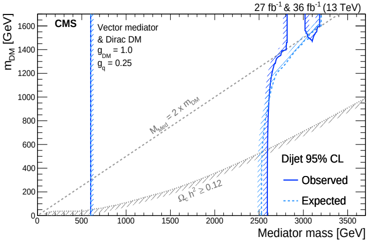
Limits on the coupling to q's of a leptophobic Z'

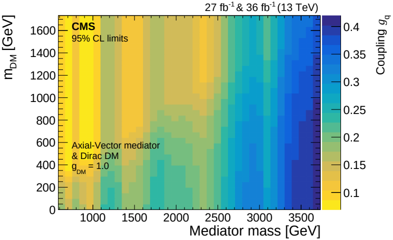


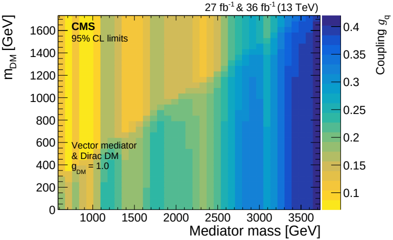
Narrow dijet: Limits on a dark matter mediator

Limits are set to constrain simplified models of DM, with leptophobic vector and axial-vector mediators that couple only to quarks and DM particles.





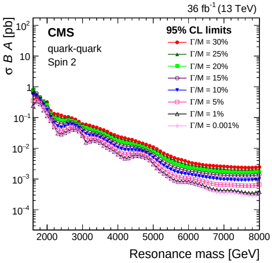




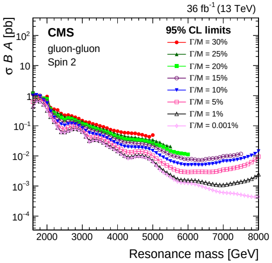
Dijet Resonances (36 fb^{-1}) - **CMS-EXO-16-056**

- The search for narrow resonances assumes the resonance width, Γ, is negligible compared to the experimental dijet mass resolution.
- The broad resonance search, constrains the width up to 30% of the resonance mass (M). Limits are given as function of Γ/M.
- The shape of a broad resonance depends on the relationship between the width and the resonance mass. The cross section is described by Breit-Wigner:

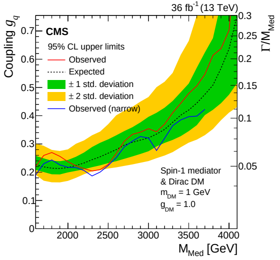
$$\hat{\sigma} \propto \frac{\pi}{m^2}\frac{[\Gamma^i M][\Gamma^f M]}{(m^2-M^2)^2+[\Gamma M]^2}, \text{ Spin1: } \Gamma M \rightarrow (\frac{m^2}{M^2})\Gamma M, \text{ Spin2: } \Gamma M \rightarrow (\frac{m^4}{M^4})\Gamma M$$



95% CL upper limits for spin-2 resonances produced and decaying in the qq channel.



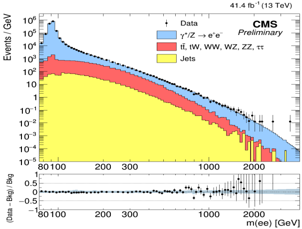
95% CL upper limits for spin-2 resonances produced and decaying in the gg channel.



95% CL upper limits on g_q vs resonance mass for a vector mediator.

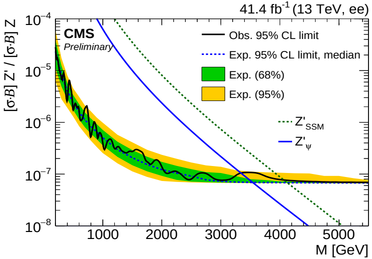
$Z' \to ee$ ($77.3\ fb^{-1}$) - CMS-PAS-EXO-18-006

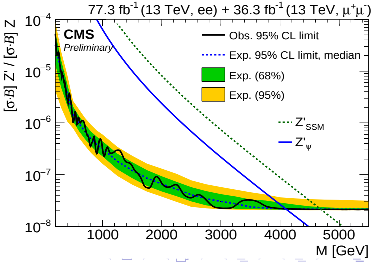
- The analysis selects two well reconstructed and isolated electrons, with $E_T > 35$ GeV.
- Electrons are selected in the barrel region using $|\eta| < 1.4442$ or in the endcap region $1.566 < |\eta| < 2.5$.
- The dielectron pair is formed with the highest p_T electrons.



Channel	Model	Obs. limit [TeV]	Exp. limit [TeV]
ee (2017)	Z'_{SSM}	4.10	4.15
	Z'_{ψ}	3.35	3.55
ee (2016 and 2017) + $\mu\mu$ (2016)	Z'_{SSM}	4.7	4.7
	Z'_{ψ}	4.1	4.1

The 95% CL upper limits on $\sigma \times B$ for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the $\sigma \times B$ fraction for a Z boson.



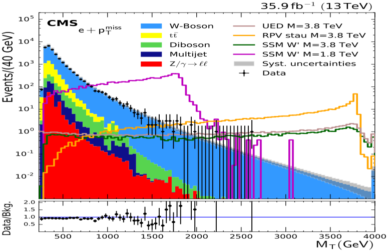


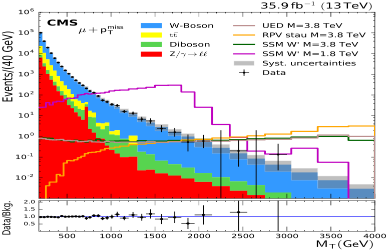
$W' \to \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-16-033

- The search for $W' \to \ell + E_T^{miss}$, focuses in final states where $\ell \to \mathrm{e}$ or $\ell \to \mu$.
- m_T is used to search for signal events:

$$m_T = \sqrt{2p_T^{\ell} E_T^{miss}(1 - cos\Delta\phi(\ell, E_T^{miss}))}$$

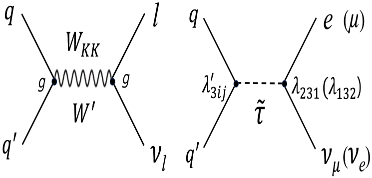
- The main source of BG events come from W+jets, $\mathrm{t\bar{t}}$, single-t, and DY+jets.
- Event selection criteria was used:
  1. $N_{\mathrm{e}/\mu} = 1$
  2. ℓ identification: Tight
  3. $p_T^{\mathrm{e}}(p_T^{\mu}) > 130(53)$ GeV
  4. $E_T^{miss}(\mathrm{e}) > 150$ GeV
  5. $0.4 < p_T/E_T^{miss}(\mu) < 0.15$
  6. $\Delta\phi(\ell, E_T^{miss}) > 2.5$
  7. $m_T(\mathrm{e}, E_T^{miss}) > 250$ GeV
  8. $m_T(\mu, E_T^{miss}) > 100$ GeV
- multijet, estimated from data using isolation templates.



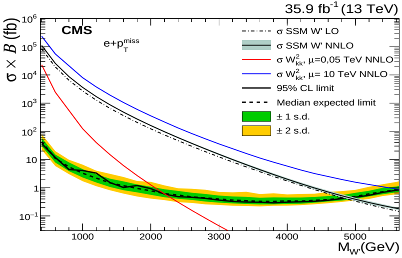


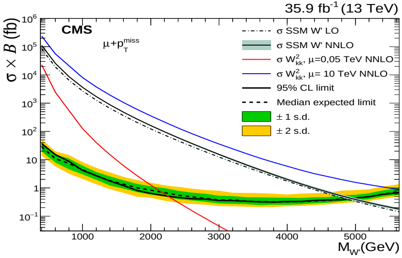
$W' \to \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-16-033

- The analysis sets limits for different models:
  1. **SSM**
  2. **Split-UED:** universal extra dimensions with fermions propagating in the bulk. In this model all SM particles have corresponding Kaluza-Klein (KK) partners.
  3. **RPV SUSY:** The analysis studies the cases where a tau slepton decays to $\mathrm{e} + \nu_\mu$ or $\mu + \nu_\mathrm{e}$.



SSM interpretation

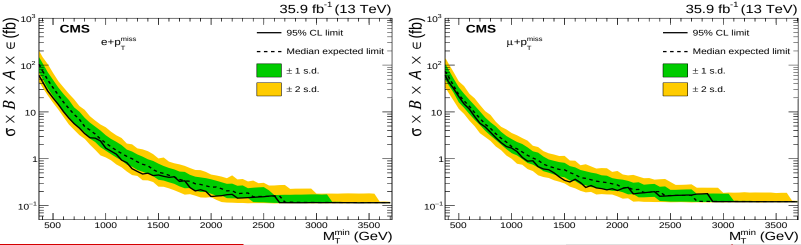




$W' \rightarrow \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - **CMS-EXO-16-033**

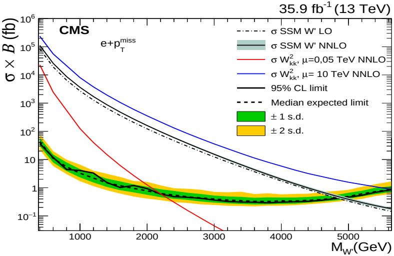
Model-independent cross section limit

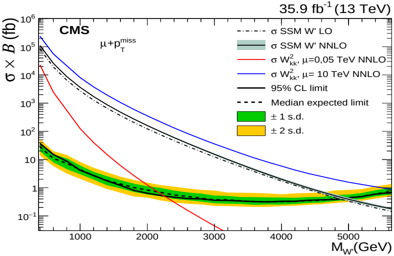
- The limit is set using a single bin ranging from a lower threshold on M_T to infinity. For each M_T point, the analysis provides the acceptance A and efficiency ϵ. No other assumptions are made.
- "In order to determine any limit for a specific model from the model-independent limit shown here, only the model-dependent part of the efficiency needs to be applied."
- A factor f_{M_T} that reflects the effect of the threshold M_{min} on the signal is determined by counting the events with $M_T > M_{min}$ and dividing it by the number of generated events.



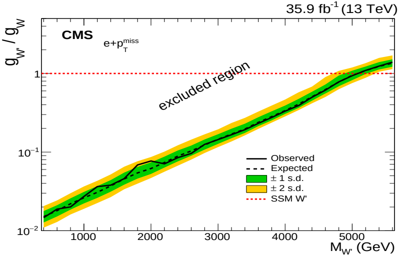
$W' \to \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-16-033

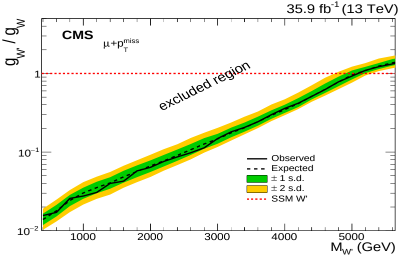
Limits on an SSM W' boson (Combined limit 5.2 TeV)





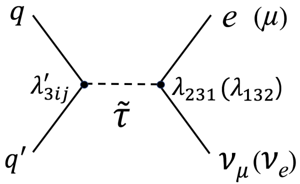
Limits on the coupling strength

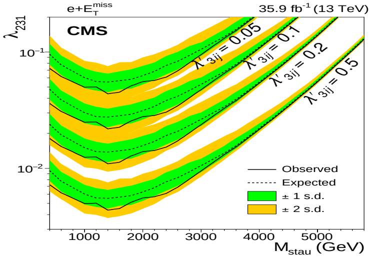


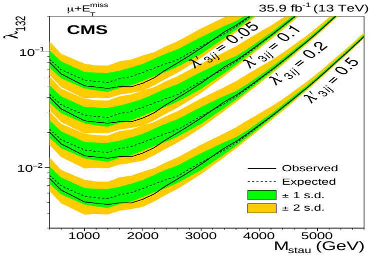


$W' \rightarrow \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-16-033

Limits on RPV SUSY





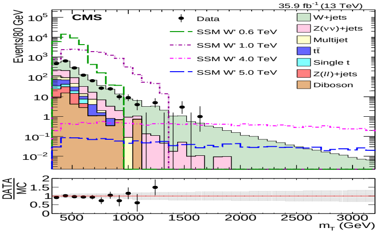


- λ_{231} is used for $\mathrm{e} + \nu_\mu$ and λ_{132} for $\mu + \nu_\mathrm{e}$
- At low masses, the $\tilde{\tau}$ signal has higher efficiency w.r.t the SSM W' scenario.
- The fraction f_{M_T} is determined at generator level and a correction is applied w.r.t the SSM W' model.

$W' \to \tau_h + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-17-008

- The analysis searches for the production of $W' \to \tau_h \nu$.
- Two benchmark models are considered: SSM and nonuniversal gauge interaction (NUGIM).
- NUGIM models predict larger BF for third generation fermions and explain the large mass of the top quark.
- **The NUGIM models propose a** $SU(2)_{light} \times SU(2)_{heavy} \times U(1)$ **symmetry. Through mixing we get the SM** $SU(2)_W$ **and an extended group,** $SU(2)_E$**, from which the** W' **emerge.**
- There is a mixing angle, θ_E, which allows to modify the couplings to the heavy boson.

- $m_T(\tau_h, p_T^{miss})$ is used as the main discrimination variable.
- Main event selection criteria:
  1. $p_T(\tau_h) > 80$ GeV
  2. $p_T^{miss} > 200$ GeV
  3. $0.7 < p_T(\tau_h)/p_T^{miss} < 1.3$
  4. $\Delta\phi > 2.4$
  5. $m_T(\tau_h, p_T^{miss}) > 300$ GeV



$W' \to \tau_h + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-17-008

SSM

95% CL upper limits on the cross section, considering same couplings as the SM W-boson.

Coupling strength

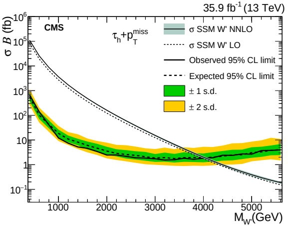
95% CL upper limits on the ratio of couplings. The values above the observed limit contour are excluded.

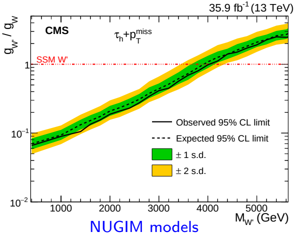
$$\Gamma_{W'} = \Gamma_W (g'_W / g_W)$$

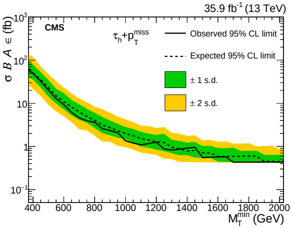
Model-Independent

95% CL upper limits on the product of cross section, branching fraction, and acceptance.

$$(\sigma B \epsilon)_{excl} = ((\sigma B \epsilon)_{MI}\, m_T^{mis})/f_{m_T}$$



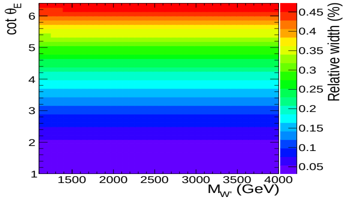


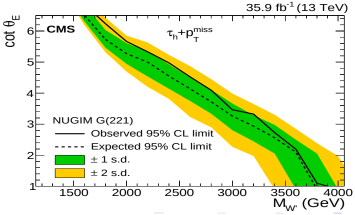


NUGIM models

Width of the W′ boson as a function of $M_{W'}$ and mixing

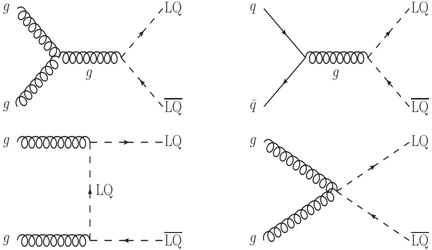
95% CL upper limits on the mixing angle $cot\theta_E$ as a function





LQ_3 ($35.9\ fb^{-1}$) - CMS-B2G-16-028

- Leptoquarks (LQ*s*) are hypothetical particles that carry both baryon and lepton quantum numbers.
- Third generation LQ*s* ($\mathrm{LQ}_3 s$) have currently become of great interest since they can explain the anomaly observed in the $\bar{\mathrm{B}} \to \mathrm{D}\tau\bar{\nu}$ and $\bar{\mathrm{B}} \to \mathrm{D}^*\tau\bar{\nu}$ decay rates, announced by the BaBar, LHCb and Belle collaborations.
- **There is a 4σ deviation of these decay rated w.r.t the SM prediction. The difference can be explained assuming large couplings of LQ*s* to third generation particles.**



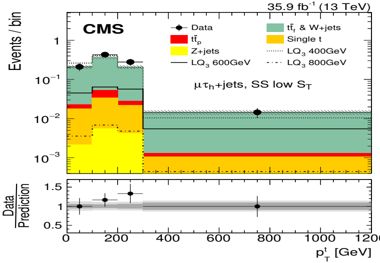
LQ_3 ($35.9\ fb^{-1}$) - CMS-B2G-16-028

- **Two search regions are considered: (1) $\ell\tau_h\tau_h$+jets, which has good sensitivity for LQ_3s masses below 500 GeV, and (2) $\ell\tau_h$+jets, where ℓ is an e or μ.**
- The dominant sources of BGs come from $\mathrm{t\bar{t}}$ and W+jets.
- The event selection criteria is shown in the table below. In addition $p_T^{\ell} > 30$ GeV, and at least two jets with $p_T > 50$ GeV and $|\eta| < 2.4$.

Table 1: Summary of selection criteria in event categories A ($\ell\tau_\mathrm{h}$ + jets) and B ($\ell\tau_\mathrm{h}\tau_\mathrm{h}$ + jets), where $\ell = \mu, \mathrm{e}$. In category A, the two subcategories, OS and SS, are defined by the charge of the $\ell\tau_h$ pair. The fit variable used in each category is also shown.

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

- The p_T of top-quarks (p_T^t) from LQ_3s decays, is expected to be larger w.r.t to the BG process. Therefore, p_T^t, from a t decaying to jets, is used as discrimination variable for events in category A.
- "A kinematic reconstruction of the top quark candidate is performed by building top quark hypotheses using between one and five jets."



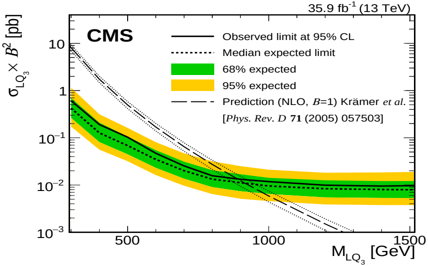
LQ_3 ($35.9\ fb^{-1}$) - **CMS-B2G-16-028**

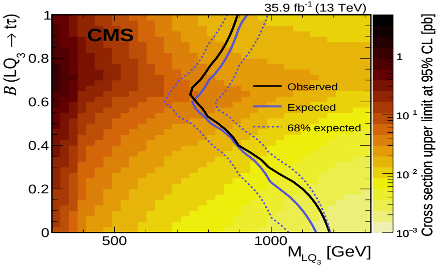
A counting experiment is conducted for events falling in category B

Process	$e\tau_h\tau_h$ + jets	$\mu\tau_h\tau_h$ + jets
LQ_3 (300 GeV)	97^{+25}_{-24}	167^{+36}_{-37}
LQ_3 (400 GeV)	73^{+14}_{-13}	98^{+19}_{-17}
LQ_3 (500 GeV)	$34.1^{+6.6}_{-6.2}$	$44.9^{+8.5}_{-7.9}$
LQ_3 (600 GeV)	$14.1^{+2.8}_{-2.7}$	$21.1^{+4.1}_{-3.8}$
LQ_3 (700 GeV)	$7.3^{+1.5}_{-1.4}$	$7.1^{+1.5}_{-1.4}$
LQ_3 (800 GeV)	$3.2^{+0.7}_{-0.7}$	$4.4^{+1.0}_{-0.9}$
LQ_3 (900 GeV)	$1.5^{+0.4}_{-0.3}$	$1.9^{+0.4}_{-0.4}$
LQ_3 (1000 GeV)	$0.8^{+0.2}_{-0.2}$	$0.9^{+0.2}_{-0.2}$
$t\bar{t}_f$	$2.5^{+0.8}_{-1.2}$	$3.2^{+1.5}_{-1.2}$
$t\bar{t}_{p+f}$	$1.5^{+0.8}_{-0.8}$	$2.0^{+0.8}_{-0.9}$
Single t	$0.3^{+0.3}_{-0.3}$	$0.0^{+0.2}_{-0.0}$
W+jets	$0.5^{+1.2}_{-0.5}$	$0.4^{+0.7}_{-0.4}$
Z+jets	$1.4^{+0.5}_{-0.5}$	$1.0^{+0.4}_{-0.4}$
Diboson	$1.6^{+1.7}_{-1.6}$	$1.7^{+1.8}_{-1.7}$
Total background	$7.9^{+2.4}_{-2.5}$	$8.4^{+2.6}_{-2.3}$
Data	9	11

- No excess above the SM expectation is observed in either category.
- Upper limits at 95% CL are set on $\sigma \times B^2$ of LQ_3 pairs.

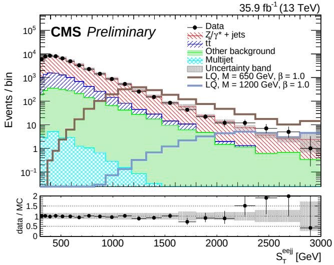
The theoretical curve corresponds to the NLO cross section with uncertainties from PDF and scale variations.

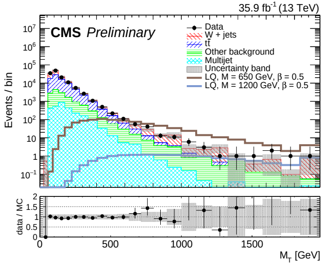




- Two final states are considered: (1) eejj and (2) $e\nu jj$.
- eejj selection criteria:
  1. $N_j = 2$ (w/ highest p_T).
  2. $N_e = 2$ (w/ highest p_T).
  3. $p_T(e_1 + e_2) > 70$ GeV.
  4. $S_T > 300$ GeV.
- $e\nu jj$ selection criteria:
  1. e and jj same as eejj.
  2. $p_T^{miss} > 70$ GeV.
  3. $\Delta\phi(p_T^{miss}, j_1) > 0.5$, $\Delta\phi(p_T^{miss}, e) > 0.8$.
  4. $S_T > 300$ GeV.
  5. $m_T(p_T^{miss}, e) > 50$ GeV.
- BG from $W + jets$ and $t\bar{t}$ estimated from MC, but the normalisation corrected using data and MC in dedicated CRs.

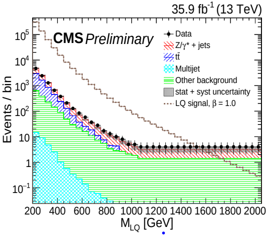
- QCD estimated from data.



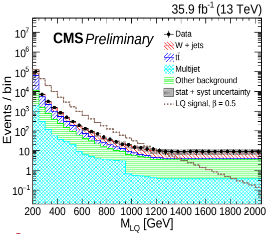


LQ_e $(35.9\ fb^{-1})$ - CMS-PAS-EXO-17-009

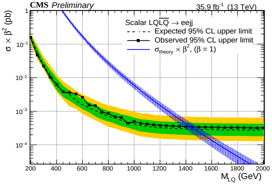
eejj

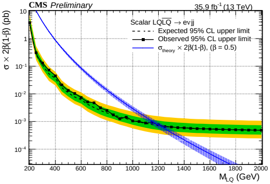


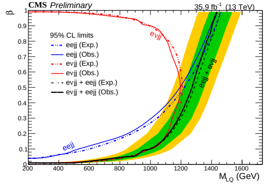
eeνj



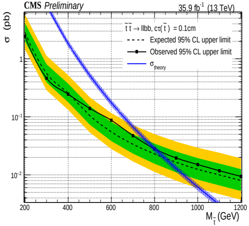
- No excess above the SM. Therefore, 95% CL limits are set.
- β corresponds to $LQLQ \to$ eejj BF.

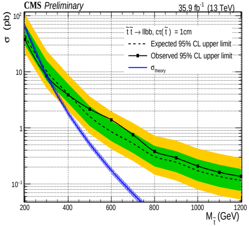






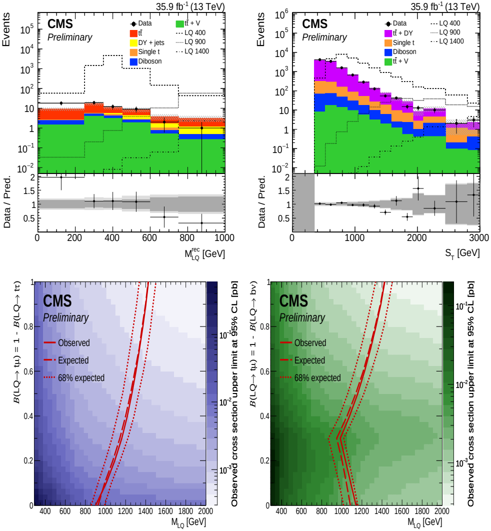
95% CL on the long-lived RPV SUSY $\tilde{t}$ pair production cross section as a function of $\tilde{t}$ mass for $c\tau = 0.1$ cm (top) and 1 cm (bottom).





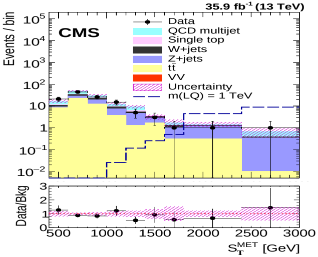
$LQ_{t\mu}$ $(35.9\ fb^{-1})$ - CMS-PAS-B2G-16-027

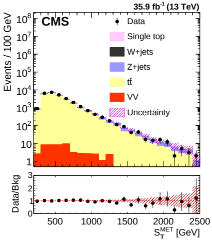
- Search for $LQLQ \rightarrow \mathrm{tt}\mu\mu$
- The analysis required at least two well isolated muons, with $p_T > 30$ GeV, and two jets (at least 1 $\mathrm{b-}$tagged).
- In addition $S_T^{lep} > 200$ GeV and $S_T^{lep} > 350$ GeV is required.
- The analysis is slitted in two categories:
  1. Additional: μ or e, and $Q(\mu_1) \times Q(\mu_2) < 0$.
  2. No additional μ or e is required.

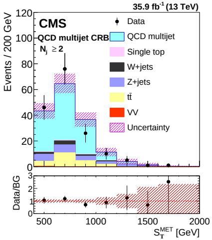


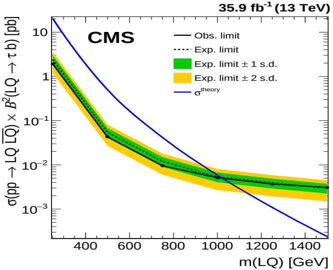
$LQ_{b\tau_h}$ (35.9 fb^{-1}) - CMS-PAS-B2G-16-027

- Search for $LQLQ \to \mathrm{bb}\tau_h\tau_h$
- The analysis selects two hadronic τ leptons, with $p_T > 70$ GeV, and two jets with $p_T > 50$ GeV and $|\eta| < 2.4$.
- In addition, $p_T^{miss} > 50$ GeV, and $m(\tau_h, \tau_h) > 100$ GeV, was requested.
- S_T^{miss} is the main discrimination variable.
- $\mathrm{t\bar{t}}$ and QCD multijet are the main BGs.



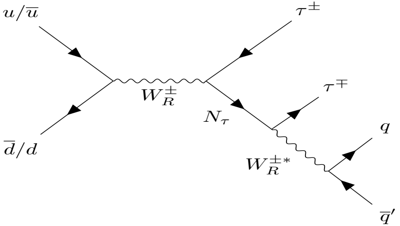


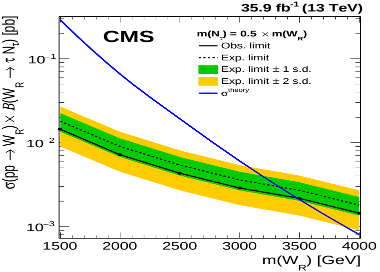


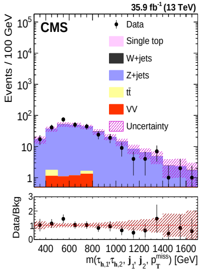


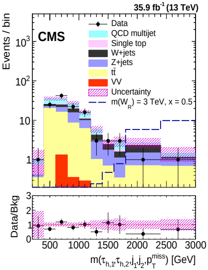
HN_{τ_h} ($35.9\ fb^{-1}$) - CMS-PAS-B2G-16-027

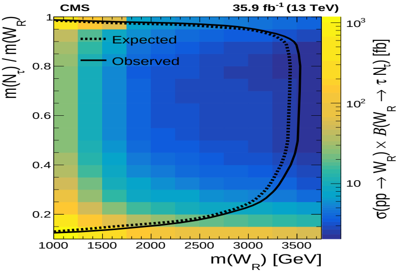
Third Generation Heavy Neutrino









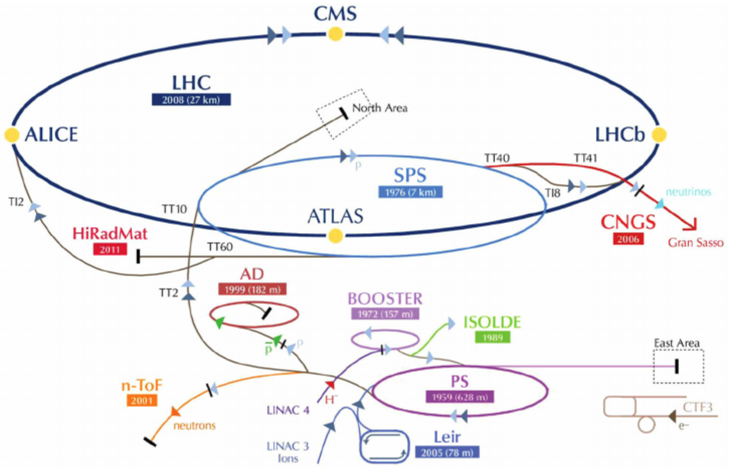


Summary

- The physics program to search for physics beyond the SM at CMS is quite broad and robust.
- **Unfortunately, no signs of new physics have been found until now.**
- CMS have reported some results using combined data from the 2015 up to 2017.
- CMS has gathered about $140 fb^{-1}$ of data and important results with this full luminosity sample are expected soon.
- Only 5% of the LHC expected luminosity has been recorded up to know, the room for possible discoveries is still quite open.
- More analyses are expected to be released soon, so keep your eyes open for more interesting physics to come!

BACKUP

The Large Hadron Collider (LHC)



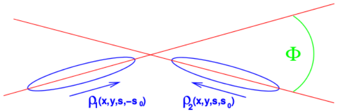
Some important concepts

1. Cross Section

In particle physics, a cross section (σ) represents the *probability of production* of a specific process. This quantity is related with the level of the interaction between the beam and the target, or between two beams, and it depends on the energy of collisions.

Some important concepts

1. Cross Section
2. Luminosity



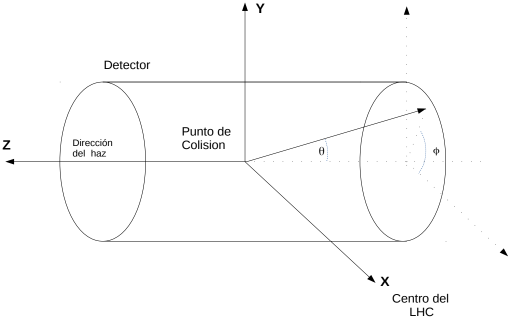
$$\mathcal{L} \sim \frac{N_A \times N_B \times f \times F}{4\pi(\sigma_A \times \sigma_B)} \quad (1)$$

$$L = \int \mathcal{L} dt \quad (2)$$

$$N_i = \sigma_i \times L \quad (3)$$

Some important concepts

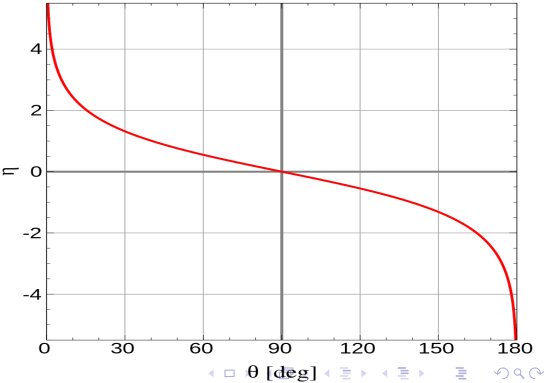
1. Cross Section
2. Luminosity
3. Coordinate systems



Some important concepts

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right].$$

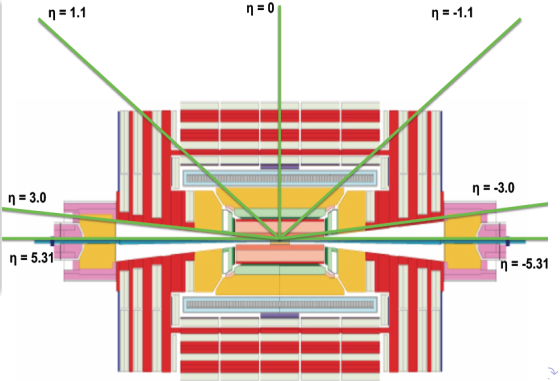
1. Cross Section
2. Luminosity
3. Coordinate systems
4. Pseudorapidity



Some important concepts

$$\eta \equiv -ln\left[tan\left(\frac{\theta}{2}\right)\right].$$

1. Cross Section
2. Luminosity
3. Coordinate systems
4. Pseudorapidity
5. η-gaps.



Some important concepts

1. Cross Section
2. Luminosity
3. Coordinate systems
4. Pseudorapidity
5. η-gaps.
6. Missing transverse momentum $\not{p}_T$

$$\sum_i \vec{p}_i^{\,T} = 0,$$

$$= \sum_j \vec{p}_j^{\,T}(visible) + \sum_k \vec{p}_k^{\,T}(invisible)$$

$$\sum_k \vec{p}_k^{\,T}(invisible) = -\sum_j \vec{p}_j^{\,T}(visible)$$

$$\not{p}_T = -\sum_j \vec{p}_j^{\,T}(visible) \qquad (1)$$

Particle Flow Algorithm - CMS

Particle Flow Algorithm - CMS

- The Particle Flow (PF) algorithm used by the CMS collaboration, has no precedent in the history of HEP.

Particle Flow Algorithm - CMS

- The Particle Flow (PF) algorithm used by the CMS collaboration, has no precedent in the history of HEP.
- The algorithm uses the information from the different sub-detectors to reconstruct individual particle candidates: Muons, electrons, photons, charged and neutral hadrons.

Particle Flow Algorithm - CMS

- The Particle Flow (PF) algorithm used by the CMS collaboration, has no precedent in the history of HEP.
- The algorithm uses the information from the different sub-detectors to reconstruct individual particle candidates: Muons, electrons, photons, charged and neutral hadrons.
- The reconstructed particles are then used to reconstruct more complicated objets such as jets (see next) and hadronic taus (τ_h), and to also to measure the $\not{p}_T$ in the event.

Particle Flow Algorithm - CMS

- The Particle Flow (PF) algorithm used by the CMS collaboration, has no precedent in the history of HEP.
- The algorithm uses the information from the different sub-detectors to reconstruct individual particle candidates: Muons, electrons, photons, charged and neutral hadrons.
- The reconstructed particles are then used to reconstruct more complicated objets such as jets (see next) and hadronic taus (τ_h), and to also to measure the $\not{p}_T$ in the event.