Search for Supersymmetry in events with opposite-sign same-flavour dileptons, jets and E_T^{miss} with the CMS detector

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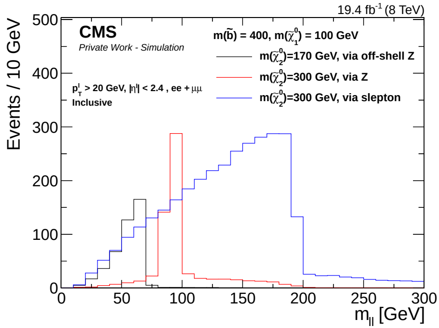
Outline

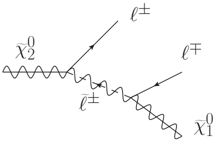
Dilepton mass edges

Dilepton production

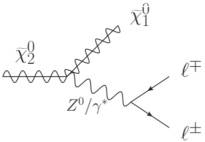
- Two same-flavour, opposite-sign leptons (e^+e^-,$\mu^+\mu^-$, SF)
- Special emphasis on decay $\tilde{\chi}_2^0 \rightarrow l^- l^+ \tilde{\chi}_1^0$
- Mass difference between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$
  $\rightarrow$ edge in the distribution of the invariant mass of the dilepton system m_{ll}



Sequential 2-body decays

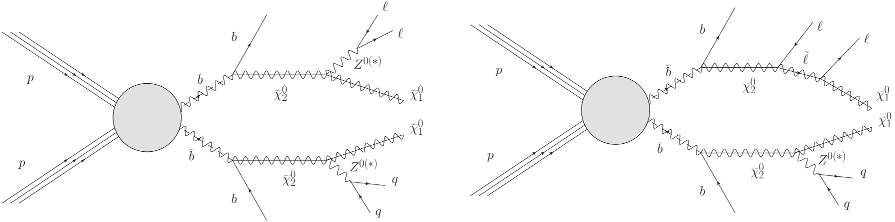


2-body decay with on-Shell or off-Shell Z



Signature of the full event

- Dilepton signature is part of larger decay chain
- in R-parity conserving models there are two decay chains
- Expect large missing transverse energy (E_T^{miss}) from the undetected LSPs and several jets
- Example model: Production of sbottom squarks decaying to b quarks and $\tilde{\chi}_0^2$



Analysis Overview

- Events are collected with Dilepton triggers (ee,$\mu\mu$,$e\mu$, τ not considered)
- 2012 dataset collected by CMS, $\sqrt{s} = 8$ TeV, $19.4 fb^{-1}$
- Results public in CMS PAS-SUS-12-019
- Two analysis strategies

Cut & Count at low invariant mass

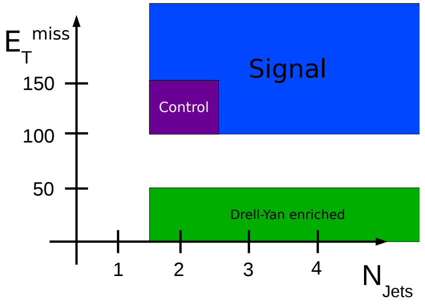
- Search for an excess of events at low invariant dilepton mass m_{ll}
- "Simple" cut & count approach: Count number of events passing event selection & compare to background prediction

Search for kinematic edge

- Search for edge in dilepton invariant mass distribution
- Perform unbinned Maximum-Likelihood-Fit to exploit shape information
- Not restricted to low invariant mass range

Event Selection

- 2 leptons ($p_T > 20$ GeV, $|\eta| < 2.4$)
  - $e^\pm e^\mp$, $\mu^\pm \mu^\mp$ } signal
  - $e^\pm \mu^\mp$ } control
- 2 regions in lepton-η:
  - Central: $|\eta| < 1.4$
  - Forward: at least one $|\eta| > 1.6$
- 2 regions m_{ll}:
  - Cut & Count experiment: 20 GeV $< m_{ll} <$ 70 GeV
  - Edge search: $m_{ll} > 20$ GeV
- N_{jets}: Number of jets with $p_T > 40$ GeV and $|\eta| < 3.0$
- Spatial separation of objects:
  - ΔR(leptons) > 0.3
  - ΔR(lepton, jets) > 0.4



Regions

- Signal region:
  $E_T^{miss} > 100$ GeV & $N_{jets} >= 3$ **or**
  $E_T^{miss} > 150$ GeV & $N_{jets} >= 2$
- Control region:
  100 GeV $< E_T^{miss} <$ 150 GeV & $N_{jets} = 2$
- Drell-Yan control region:
  $E_T^{miss} < 50$ GeV & $N_{jets} >= 2$

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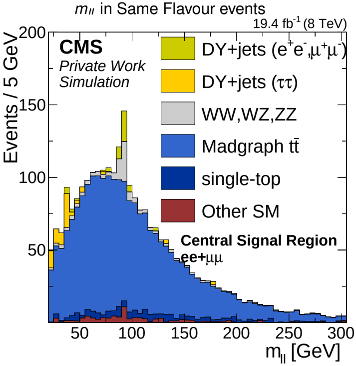
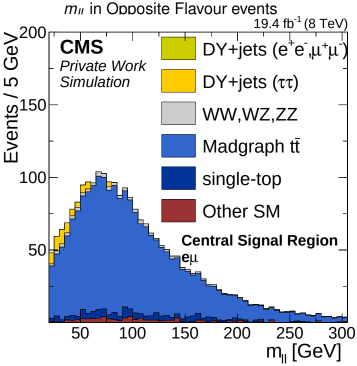
Background processes

Several SM processes contribute to event selection:

- Flavour-symmetric backgrounds (98%), e.g. $t\bar{t}$, Drell-Yan$\rightarrow \tau\tau$, fake leptons $\rightarrow$ estimated from eμ-events
- Backgrounds with Z bosons, e.g. Drell-Yan$\rightarrow$ ee, $\mu\mu$. Both Z-Peak and continuum estimated from data
- Rare processes like $t\bar{t}V$, Diboson covered by the estimates for the other two





Background predictions

Flavour symmetric backgrounds

- $e^+e^- + \mu^+\mu^-$ estimated from $e^\pm\mu^\mp$
- Reco/Id and trigger efficiencies cancel to first order when comparing SF and OF
- Two independent methods to determine correction for remaining differences ($R_{SF/OF}$): Direct measurement in control region and from measurement of efficiencies

$R_{\mathrm{SF/OF}}$	Central	Forward
from efficiencies	1.03±0.01±0.06	1.11±0.04±0.08
from Control Region	0.99±0.05±0.02	1.11±0.11±0.03
Weighted Average	1.00±0.04	1.11±0.07

- 4% syst. uncertainty on dominant background in central region

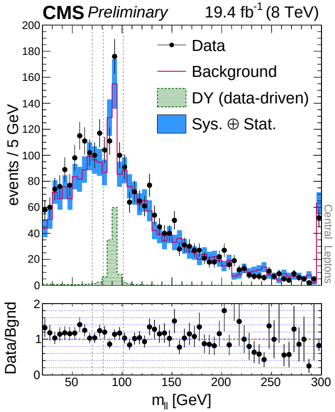
Drell-Yan background

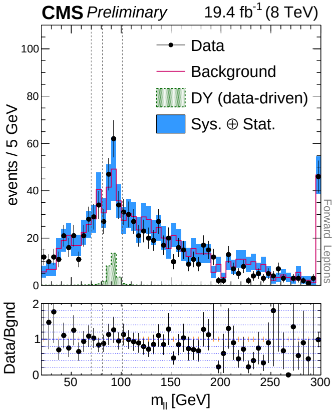
- Contribution on the Z peak estimated with two independent methods from data (Z-Jets-Balance and from $\gamma + E_T^{miss}$ events)
- Prediction at low masses derived by multiplying with $r_{out,in}$, the ratio of peak and low mass in the Drell-Yan control region ($\approx 7\%$)

Results of Cut & Count at low mass

	central	forward
Observed [SF]	860	163
Flav. Sym. [OF]	$722 \pm 27 \pm 29$	$155 \pm 13 \pm 10$
Drell-Yan	8.2 ± 2.6	1.7 ± 1.4
Total Estimates	730 ± 40	157 ± 16
Observed – Estimated	130^{+48}_{-49}	6^{+20}_{-21}
Significance [σ]	2.6	0.3

- Achieved 5%(10%) background uncertainty in central (forward) region
- Good agreement between prediction and observation in forward region
- Slight excess seen for central leptons





Search for a kinematic edge

- Perform simultaneous, unbinned Maximum-Likelihood-Fit to m_{ll} distribution in ee, $\mu\mu$ and $e\mu$ events in central & forward
- Model consists of three parts:

Flavor-symmetric backgrounds

$$\mathcal{P}_{FSE}(m_{ll}) = \begin{cases} \mathcal{P}_{FSE,1}(m_{ll}) = c_1 \cdot m_{ll}^{\alpha} & \text{if } 20 < m_{ll} < m_{ll}^{(1)} \\ \mathcal{P}_{FSE,2}(m_{ll}) = \sum_{i=0}^{3} c_{2,i} \cdot m_{ll}^{i} & \text{if } m_{ll}^{(1)} < m_{ll} < m_{ll}^{(2)} \\ \mathcal{P}_{FSE,3}(m_{ll}) = c_3 \cdot e^{-\beta m_{ll}} & \text{if } m_{ll}^{(2)} < m_{ll} < 300 \end{cases}$$

Requesting 0^{th} and 1^{st} derivative to be continuous reduces number of free parameters to 6.

Z-backgrounds

Convolution of Breit-Wigner $\otimes$ Double-Sided Crystal Ball, parameters fixed in Drell-Yan control region, normalization free parameter in signal region.

Signal Model

Triangle $\otimes$ Gaussian to model the edge

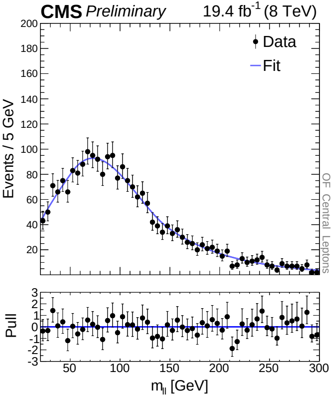
$$\mathcal{P}_S(m_{ll}) = \frac{1}{\sqrt{2\pi\sigma_{ll}}} \int_0^{m_{ll}^{edge}} y \cdot \exp\left(-\frac{(m_{ll}-y)^2}{2\sigma_{ll}^2}\right) dy$$

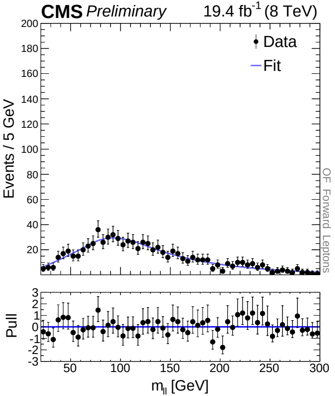
$R(SF/OF)$ is nuisance parameter, parametrized with Gaussian

Result

	Central	Forward
Drell–Yan	158 ± 23	71 ± 15
Flav. Sym. [OF]	2270 ± 44	745 ± 25
$R_{SF/OF}$	1.03	1.02
Signal events	126 ± 41	22 ± 20
$m_{\ell\ell}^{edge}$ [GeV]	78.7 ± 1.4	
Local Significance [σ]	2.4	

- Results comparable to counting experiment
- No excess seen in forward region
- 126(22) signal events in central(forward) region at and edge position of $\approx$79 GeV





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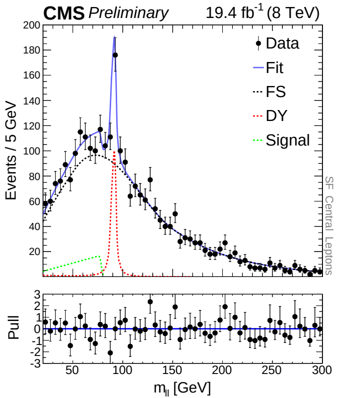
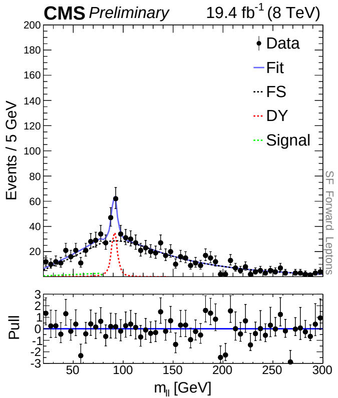




Summary

- Performed search for Supersymmetry in events with two SFOS leptons, jets und E_T^{miss}
- Background prediction from data with high precision
- Results public since August (CMS-PAS-SUS-12-019)
- 2.6(0.3)σ deviation from expectation in central (forward) signal region
- Performed shape analysis with unbinnend maximum likelihood fit in search for an edge
- Best edge position fitted to be at $\approx$79 GeV, local 2.4σ
- Conclude that we do not observe evidence for a significant signal
- Paper extending the counting experiment to on Z and high masses, including interpretation coming soon
- We are eager to study this again next year at $\sqrt{s} = 13$ TeV and studies are ongoing to test our methods under the new conditions

Thank you for your attention

Search for a kinematic edge

- Perform simultaneous, unbinned Maximum-Likelihood-Fit to m_{ll} distribution in ee, $\mu\mu$ and $e\mu$ events in central & forward
- Likelihood defined as product of probability density functions (PDFs) of the model for all events in a dataset
- Simultaneous fit: Multiply likelihoods for the six datasets
- Use RooFit-packet to minimize $-log\mathcal{L}$

$$\begin{aligned}
\mathcal{L}(m_{ll};\mathbf{p}) = \; & \text{Poisson Factors(measured number of events,fitted number of events)} \\
\times \; & \prod_{central,forward} \\
\times \; & \prod_{e^+e^-} \left[n_{B,ee}\cdot\mathcal{P}_{FS}(m_{ll};\mathbf{p}_{FS}) + n_{Z,ee}\cdot\mathcal{P}_Z(m_{ll};\mathbf{p}_Z^e) + n_{S,ee}\cdot\mathcal{P}_S(m_{ll};\mathbf{p}_S^e)\right] \\
\times \; & \prod_{\mu^+\mu^-} \left[n_{B,\mu\mu}\cdot\mathcal{P}_{FS}(m_{ll};\mathbf{p}_{FS}) + n_{Z,\mu\mu}\cdot\mathcal{P}_Z(m_{ll};\mathbf{p}_Z^\mu) + n_{S,\mu\mu}\cdot\mathcal{P}_S(m_{ll};\mathbf{p}_S^\mu)\right] \\
\times \; & \prod_{e^\pm\mu^\mp} \left[n_{B,e\mu}\cdot\mathcal{P}_{FS}(m_{ll};\mathbf{p}_{FS})\right] \\
\times \; & \text{Gaussian Constraints}(R_{SF/OF}).
\end{aligned}$$

Background Model

- Perform simultaneous, unbinned Maximum-Likelihood-Fit to m_{ll} distribution in ee, $\mu\mu$ and $e\mu$ events in central & forward
- Opposite Flavour: fit only model for flavour-symmetric backgrounds:

kinematic turnon for $f(m_{ll}) < m_1$:

$$\mathcal{P}_{FS,1}(m_{ll}) = a \cdot m_{ll}^b \quad (1)$$

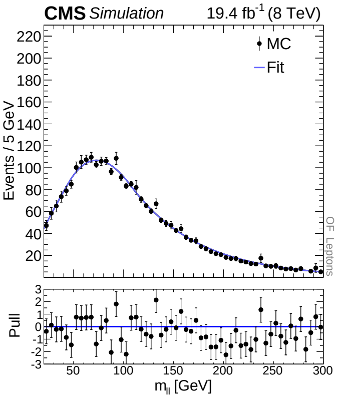
polynomial for $m_1 < f(m_{ll}) < m_2$:

$$\mathcal{P}_{FS,2}(m_{ll}) = c + d \cdot m_{ll} + e \cdot m_{ll}^2 + f \cdot m_{ll}^3 \quad (2)$$

exponential for $f(m_{ll}) > m_2$:

$$\mathcal{P}_{FS,3}(m_{ll}) = g \cdot e^{(-h \cdot m_{ll})} \quad (3)$$

Require function to be continuously differentiable in m_1 und m_2



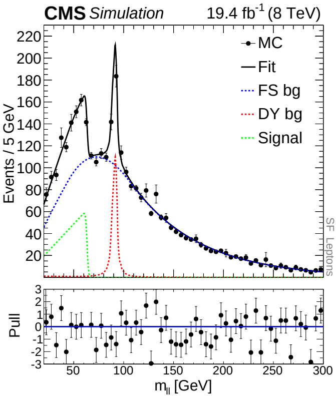
Signal Model

- Perform simultaneous, unbinned Maximum-Likelihood-Fit to m_{ll} distribution in ee, $\mu\mu$ and $e\mu$ events in central & forward
- Same Flavour: fit additionally model for Z-Peak and signal:

- Signal model: Triangular shape with endpoint at kinematic mass edge, smeared by resolution:

$$\mathcal{P}_S(m_{ll}) = \frac{1}{\sqrt{2\pi}\sigma} \int_0^{m_{\max}} dy \cdot y \cdot e^{\frac{-(m_{ll}-y)^2}{2\sigma^2}} . \qquad (4)$$

- Endpoint m_{max} common parameter between Central and Forward region



Application of $R_{SF/OF}$

- Correction factor $R_{SF/OF}$ has to be considered in the fit
- Connection of yields in *ee* and $\mu\mu$ datasets reduces number of free parameters:

$$n_{Sig,ee} = f_{ee} \cdot n_{Sig}, \qquad n_{Sig,\mu\mu} = (1 - f_{ee}) \cdot n_{Sig}, \tag{5}$$

$$n_{Z,ee} = f_{ee} \cdot n_Z, \qquad n_{Z,\mu\mu} = (1 - f_{ee}) \cdot n_Z. \tag{6}$$

- The background in the simultaneous fit is further constraint by $R_{SF/OF}$:

$$n_{B,ee} = f_{ee} \cdot R_{SF/OF} \cdot n_{B,e\mu}, \qquad n_{B,\mu\mu} = (1 - f_{ee}) \cdot R_{SF/OF} \cdot n_{B,e\mu}. \tag{7}$$

- $R_{SF/OF}$ free parameter, constraint by Gaussian with mean and width set to measured values