Quasistable charginos
in ultraperipheral proton-proton collisions at the LHC

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Common situation in searching for SUSY particles

No events in the expected signal region

⇓

The limits are set on the fiducial cross section

⇓

These limits are reinterpreted in the framework of the particular SUSY model to get bounds on particle masses and other model parameters

⇓

Therefore most of the results are model dependent and sensitive to additional New Physics (extra Higgses, $Z'$, etc)

Ultraperipheral collisions (UPC) provide us with the model-independent method of searching for new particles in photon fusion.
Excluded in large parameters regions of many models. Searches for charged long-lived particles:

CMS, Eur.Phys.J. C75 (2015) no.7, 325, arXiv:1502.02522
ATLAS, Eur. Phys. J. C75, 407 (2015), arXiv:1506.05332
LHCb, Eur. Phys. J. C75, 595 (2015), arXiv:1506.09173
ATLAS, Phys. Rev. D93, 112015 (2016), arXiv:1604.04520
CMS, Phys. Rev. D94, 112004 (2016), arXiv:1609.08382
ATLAS, Phys. Lett. B788, 96 (2019), arXiv:1808.04095
ATLAS, Phys. Rev. D99, 092007 (2019), arXiv:1902.01636

Chargino production cross section depends on:
- squarks masses in case of production via strong interaction
- coupling to Z in case of Drell-Yan production
It is possible to detect protons in forward detectors to reconstruct full kinematics.

| Energy | $pp$ | $\sigma \sim Z^4$ | $\text{Pb Pb}$ |
|--------|------|-----------------|---------------|
| 13 TeV | 5.02 TeV/(nucleon pair) | 82 |
| $Z$ | 1 | 4.5 $\cdot 10^7$ |
| $Z^4$ | 1 | 6.6 $\cdot 10^7$ |
| Luminosity | 159 fb$^{-1}$ | 2.4 nb$^{-1}$ |
| ratio: | 21 months | 2 months |
| Duration | (Run 2) | (2015, 2018) |
Production of charged particles in photon fusion

Accessible analytically

\[ \sigma(NN \rightarrow NN\tilde{\chi}_1^+\tilde{\chi}_1^-) = \int_0^\infty \int_0^\infty \sigma(\gamma\gamma \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-) n_N(\omega_1) n_N(\omega_2) \, d\omega_1 \, d\omega_2. \]

Production of charginos in photon fusion is given by the Breit-Wheeler cross section,

\[ \sigma(\gamma\gamma \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-) = \frac{4\pi\alpha^2}{s} \left[ \left( 1 + \frac{4m^2_\chi}{s} - \frac{8m^4_\chi}{s^2} \right) \ln \frac{1 + \sqrt{1 - 4m^2_\chi/s}}{1 - \sqrt{1 - 4m^2_\chi/s}} - \left( 1 + \frac{4m^2_\chi}{s} \right) \sqrt{1 - \frac{4m^2_\chi}{s}} \right], \]

where \( \sqrt{s} \equiv \sqrt{4\omega_1\omega_2} \).

The equivalent photon approximation provides the momentum distribution of photons:

\[ n(\vec{q}) \, d^3q = \frac{Z^2\alpha}{\pi^2} \frac{\vec{q}^2_\perp}{\omega q^4} |F(\vec{q}^2)|^2 \, d^3q, \]

where \( q \) is the photon 4-momentum, \( -q^2 = \vec{q}^2_\perp + (\omega/\gamma)^2 \), form factor for proton is well approximated by

\[ F(\vec{q}^2) = G_D(\vec{q}^2) \left[ 1 + \frac{(\mu_p - 1)\tau}{1 + \tau} \right], \quad G_D(\vec{q}^2) \equiv \frac{1}{(1 + \vec{q}^2/\Lambda^2)^2}, \]

\( \mu_p = 2.79 \) is the proton magnetic moment, \( \tau = \vec{q}^2/4m_p^2 \), and \( \Lambda^2 = 0.71 \text{ GeV}^2 \). Form factors for heavy ions are measured experimentally.
Fiducial cross section

Cuts: \( \xi_{\text{min}} < \xi < \xi_{\text{max}} \), \( p_T > \hat{p}_T \), \( |\eta| < \hat{\eta} \).

\[
\sigma_{\text{fid.}}(pp \to pp \tilde{\chi}_1^+ \tilde{\chi}_1^-) = \frac{(4\xi_{\text{max}}E)^2}{(4\xi_{\text{min}}E)^2} \int_{\max(\hat{p}_T, \sqrt{s/4 - m_{\chi}^2}/\cosh \hat{\eta})}^{\sqrt{s/4 - m_{\chi}^2}} d\sigma \frac{d\sigma(\gamma\gamma \to \tilde{\chi}_1^+ \tilde{\chi}_1^-)}{dp_T} \frac{1}{\hat{x}} \int \frac{dx}{8x} n \left( \sqrt{\frac{sx}{4}} \right) n \left( \sqrt{\frac{s}{4x}} \right),
\]

where \( x = \omega_1/\omega_2 \), and

\[
\hat{x} = \left( \hat{X} + \sqrt{\hat{X}^2 + 1} \right)^2,
\]

\[
\hat{X} = \frac{\sqrt{s} p_T}{2(p_T^2 + m_{\chi}^2)} \left( \sinh \hat{\eta} - \sqrt{\cosh^2 \hat{\eta} + \frac{m_{\chi}^2}{p_T^2}} \cdot \sqrt{1 - \frac{4(p_T^2 + m_{\chi}^2)}{s}} \right).
\]

The differential with respect to \( p_T \) cross section is

\[
\frac{d\sigma(\gamma\gamma \to \tilde{\chi}_1^+ \tilde{\chi}_1^-)}{dp_T} = \frac{8\pi\alpha^2 p_T}{s(p_T^2 + m_{\chi}^2)} \cdot \frac{1 - \frac{2(p_T^4 + m_{\chi}^4)}{s(p_T^2 + m_{\chi}^2)}}{\sqrt{1 - \frac{4(p_T^2 + m_{\chi}^2)}{s}}}.\]
For $m_\chi = 100$ GeV, $pp$ collision energy 13 TeV, PbPb collision energy 5.02 TeV/(nucleon pair),

- $\sigma(pp \to pp \tilde{\chi}_1^+ \tilde{\chi}_1^-) = 2.84$ fb,
- $\sigma(Pb Pb \to Pb Pb \tilde{\chi}_1^+ \tilde{\chi}_1^-) = 21.2$ pb $\Rightarrow$ for 2.4 nb$^{-1}$ there are 0.053 events

Experimental cuts:
- Both protons hit the forward detectors.
- Transverse momentum of each chargino $> 20$ GeV.
- Pseudorapidity of each chargino $< 2.5$.

Fiducial cross section: $\sigma_{fid}(pp \to pp \tilde{\chi}_1^+ \tilde{\chi}_1^-) = 0.72$ fb.

For heavy ion to hit forward detector, its energy loss should be at least 7.8 TeV. Therefore fiducial cross section is suppressed by both the Breit–Wheeler cross section and nucleus form factor. But it is still possible to look for chargino in UPC with the help of Eloss and TOF methods if there will be enough statistics.
Mass reconstruction

With measured values:
- \( \mathbf{p}_1, \mathbf{p}_2 \) in main detector;
- \( \xi_1, \xi_2 \) in forward detectors (initial proton energy is \( E = 6.5 \text{ TeV} \)).

\[
m = \sqrt{\frac{1}{4} \left( E(\xi_1 + \xi_2) + \frac{\mathbf{p}_1^2 - \mathbf{p}_2^2}{E(\xi_1 + \xi_2)} \right)^2 - \mathbf{p}_1^2} = \frac{\sqrt{(E^2(\xi_1 + \xi_2)^2 - (\mathbf{p}_1^2 + \mathbf{p}_2^2))^2 - 4\mathbf{p}_1^2 \mathbf{p}_2^2}}{2E(\xi_1 + \xi_2)},
\]

\[
m = \sqrt{\frac{(2\xi_1 \xi_2 E^2 + \mathbf{p}_1 \mathbf{p}_2)^2 - \mathbf{p}_1^2 \mathbf{p}_2^2}{4\xi_1 \xi_2 E^2 + (\mathbf{p}_1 + \mathbf{p}_2)^2}}.
\]
Background: reactions producing a pair of muons.

\[
\begin{align*}
\text{Reaction} & \quad \text{Cross section, fb} \\
pp \to pp \tilde{\chi}_1^+ \tilde{\chi}_1^- & \quad 0.72 \\
pp \to pp \mu^+ \mu^- & \quad 1.60 \\
pp \to pp W^+ W^- \to pp \mu^+ \nu \mu^- \bar{\nu} & \quad 0.15 \\
pp \to pp \tau^+ \tau^- \to pp \mu^+ \nu \mu^- \nu \bar{\nu} & \quad 0.02
\end{align*}
\]
Signal

Chargino candidate mass distribution

$pp \rightarrow pp \tilde{\chi}_1^+ \tilde{\chi}_1^-$

$pp \rightarrow pp \tilde{\mu}^+ \tilde{\mu}^-$

$pp \rightarrow pp W^+ W^- \rightarrow pp \mu^+ \nu \mu^- \bar{\nu}$

$pp \rightarrow pp \tau^+ \tau^- \rightarrow pp \mu^+ \bar{\nu}_\tau \mu^- \bar{\nu}_\tau \nu_{\tau}$

Integrated luminosity: 150 fb$^{-1}$
The combination of low energy muons with protons from low mass diffractive dissociation is mimicking the chargino production in UPC.

\[ p + p \rightarrow \pi^+ + \pi^- + p + X \]

Probability for a proton to hit the forward detector after dissociation \( P_{SD} \approx 0.01 \).

About 40% of bunch crossings with 50 collisions at once will produce at least one proton hitting one of the forward detectors!

Low mass approximation:

\[ M_X^2 \frac{d\sigma}{dM_X^2} \propto 1 + \frac{2 \text{ GeV}}{M_X}. \]
Chargino candidate mass distribution for pile-up $\mu = 50$

- $pp \to pp \tilde{\chi}^+_1 \tilde{\chi}^-_1$
- $pp \to pp \tilde{\mu}^+ \tilde{\mu}^-$
- $pp \to pp W^+ W^- \to pp \mu^+ \nu \mu^- \bar{\nu}$
- $pp \to pp \tau^+ \tau^- \to pp \mu^+ \nu \bar{\nu} \tau^+ \mu^- \bar{\nu}$

Integrated luminosity: 150 fb$^{-1}$
Pile-up

Chargino candidate mass distribution for pile-up $\mu = 50$

$pp \rightarrow pp \tilde{\chi}^+_1 \tilde{\chi}^-_1$

$pp \rightarrow pp \tilde{\mu}^+ \tilde{\mu}^-$

$pp \rightarrow pp W^+ W^- \rightarrow pp \mu^+ \nu \mu^- \bar{\nu}$

$pp \rightarrow pp \tau^+ \tau^- \rightarrow pp \mu^+ \nu \tau^- \bar{\nu} \mu^- \bar{\nu} \nu \tau$

with the cut on total longitudinal momentum:

$|p_{\parallel,1} + p_{\parallel,2} - (\xi_1 - \xi_2) E| < 20 \text{ GeV}$

Integrated luminosity: 150 fb$^{-1}$
Results with $m_\chi = 150$ GeV

Chargino candidate mass distribution for pile-up $\mu = 50$

with the cut on total longitudinal momentum:

$$|p_{\parallel,1} + p_{\parallel,2} - (\xi_1 - \xi_2)E| < 20 \text{ GeV}$$

Integrated luminosity: 150 fb$^{-1}$
Conclusions

- Ultraperipheral collisions provide us with the model-independent method for New Physics searches in photon-photon fusion.
- Detection of both protons in forward detectors allows for full kinematics reconstruction.
- Quasistable chargino with the mass up to 150 GeV can be found in \( pp \) collisions with already available LHC data.
- To find chargino in heavy ions much more statistics required.