Quasistable charginos in ultraperipheral proton-proton collisions at the LHC

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based on
arXiv:1906.08568

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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

One has to know the production cross section to compare with experimental limit!

⇓

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!

Quasistable chargino

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

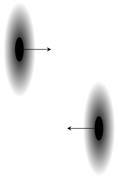
ATLAS, Phys. Rev. D99, 092007 (2019), arXiv:1902.01636

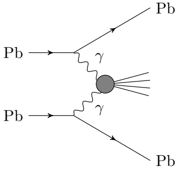
. . .

For chargino production cross section depends on:

- squarks masses in case of production via strong interaction
- coupling to Z in case of Drell-Yan production

Ultraperipheral collisions at the LHC





$$\sigma \sim Z^4$$

	pp	Pb Pb
Energy	13 TeV	5.02 TeV/(nucleon pair)
Z	1	82
Z^4	1	$4.5 \cdot 10^7$
Luminosity	159 fb^{-1}	2.4 nb^{-1}
	ratio:	$6.6 \cdot 10^7$
Duration	21 months (Run 2)	2 months (2015, 2018)

It is possible to detect protons in forward detectors to reconstruct full kinematics!

Distance from the IP, m	200	420
ξ range	0.015–0.15	0.002–0.02
6.5 TeV p energy loss, GeV	97.5–975	13–130
0.5 PeV ^{208}Pb energy loss, TeV	7.8–78	1.0–10

Production of charged particles in photon fusion

Accessible analytically!

$$\sigma(NN \to NN\tilde{\chi}_1^+\tilde{\chi}_1^-) = \int\limits_0^\infty \int\limits_0^\infty \sigma(\gamma\gamma \to \tilde{\chi}_1^+\tilde{\chi}_1^-)\, n_N(\omega_1)\, n_N(\omega_2)\, \mathrm{d}\omega_1\, \mathrm{d}\omega_2.$$

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

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

where $\sqrt{s} \equiv \sqrt{4\omega_1\omega_2}$.

The equivalent photon approximation provides the momentum distribution of photons:

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

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

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

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

Fiducial cross section

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

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

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

$$\frac{\mathrm{d}\sigma(\gamma\gamma\to\tilde{\chi}_1^+\tilde{\chi}_1^-)}{\mathrm{d}p_T} = \frac{8\pi\alpha^2 p_T}{s(p_T^2+m_\chi^2)}\cdot\frac{1-\dfrac{2(p_T^4+m_\chi^4)}{s(p_T^2+m_\chi^2)}}{\sqrt{1-\dfrac{4(p_T^2+m_\chi^2)}{s}}}.$$

Charginos in ultraperipheral collisions

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,
- $\sigma(\text{Pb Pb} \to \text{Pb Pb}\,\tilde{\chi}_1^+\tilde{\chi}_1^-) = 21.2$ 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: $\sigma_{\text{fid}}(pp \to pp\tilde{\chi}_1^+\tilde{\chi}_1^-) = 0.72$ 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.

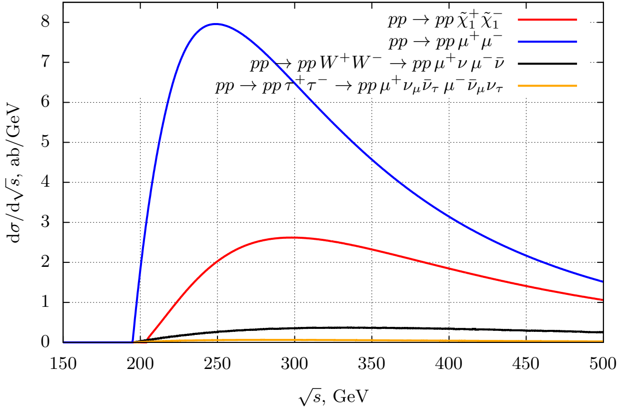
With measured values:

- $\vec{p}_1$, $\vec{p}_2$ in main detector;
- ξ_1, ξ_2 in forward detectors (initial proton energy is $E = 6.5$ TeV).

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

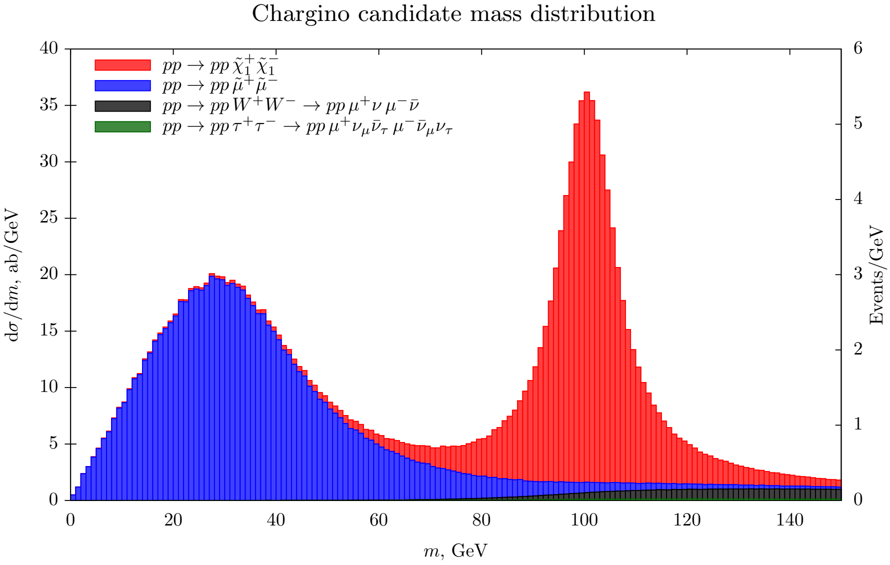
$$m = \sqrt{\frac{(2\xi_1\xi_2E^2 + \vec{p}_1\vec{p}_2)^2 - \vec{p}_1^{\,2}\vec{p}_2^{\,2}}{4\xi_1\xi_2E^2 + (\vec{p}_1+\vec{p}_2)^2}}.$$

Background: reactions producing a pair of muons.



Reaction	Cross section, fb
$pp \to pp\,\tilde{\chi}_1^+\tilde{\chi}_1^-$	0.72
$pp \to pp\,\mu^+\mu^-$	1.60
$pp \to pp\,W^+W^- \to pp\,\mu^+\mu^-\,\nu_\mu\bar{\nu}_\mu$	0.15
$pp \to pp\,\tau^+\tau^- \to pp\,\mu^+\nu_\mu\bar{\nu}_\tau\,\mu^-\bar{\nu}_\mu\nu_\tau$	0.02

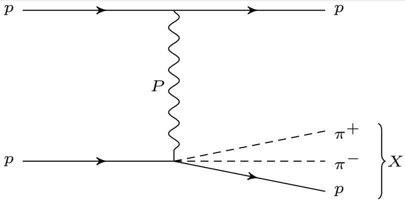
Signal



Integrated luminosity: 150 fb^{-1}

Pile-up

The combination of low energy muons with protons from low mass diffractive dissociation is mimicking the chargino production in UPC.



L. A. Harland-Lang *et al.*, JHEP 1904 (2019) 010, arXiv:1812.04886, Appendix B

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

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

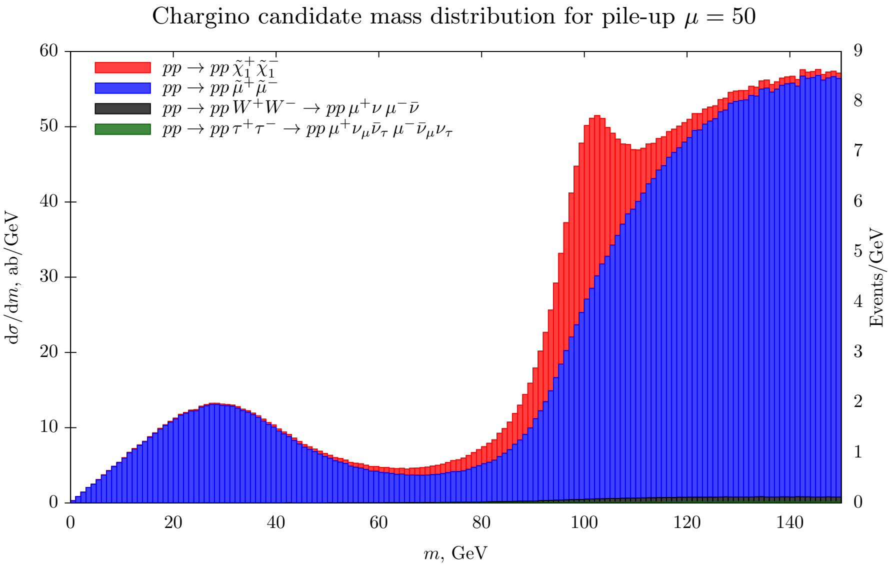
A.B.Kaidalov *et al.*, Phys.Lett.B45 (1973) 493

V.A. Khoze, A.D. Martin, M.G. Ryskin, J.Phys. G44 (2017) no.5, 055002, arXiv:1702.05023

Low mass approximation:

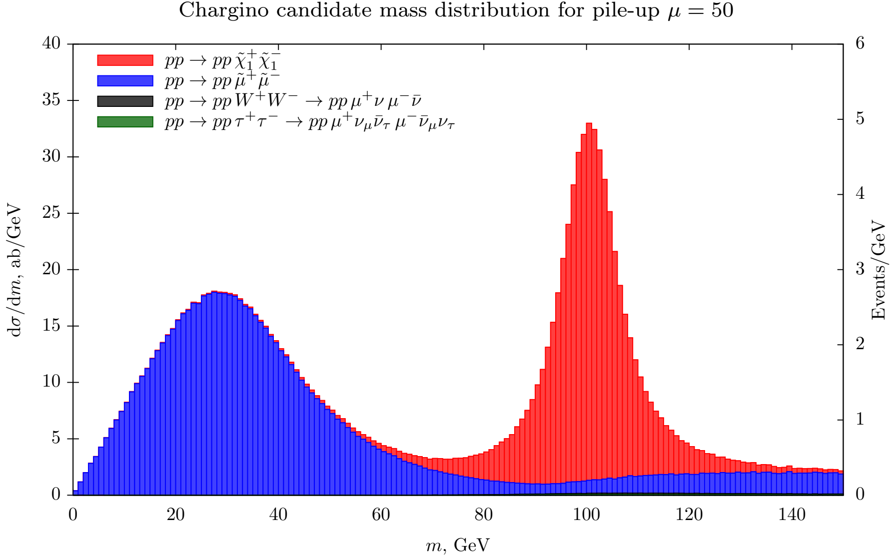
$$M_X^2 \frac{\mathrm{d}\sigma}{\mathrm{d}M_X^2} \propto 1 + \frac{2\ \mathrm{GeV}}{M_X}.$$

Pile-up



Integrated luminosity: 150 fb^{-1}

Pile-up

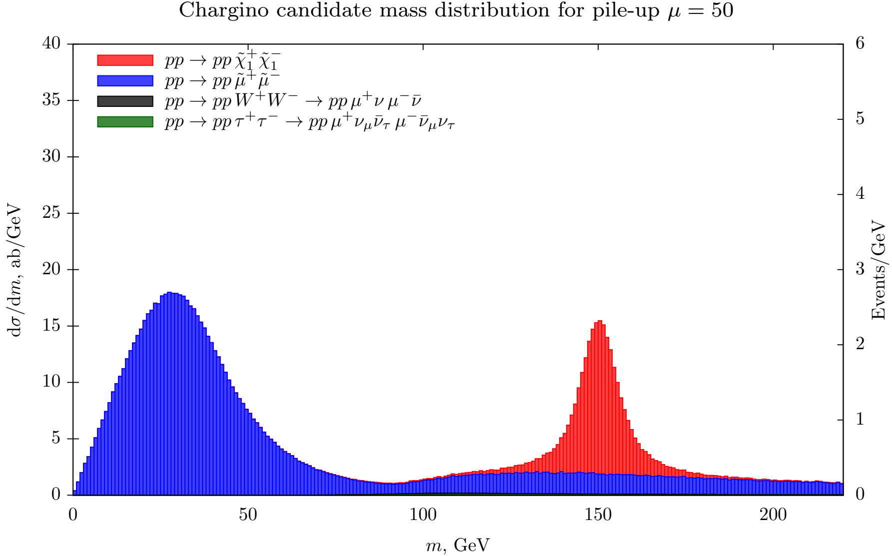


with the cut on total longitudinal momentum:

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

Integrated luminosity: 150 fb^{-1}

Results with $m_\chi = 150$ GeV



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

- Ultraperiferal 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.