LHC 750 GeV Diphoton excess in a radiative seesaw model

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based on collaboration with

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talk @ Overview on the recent di-photon excess at the LHC Run 2,
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Intro: 750 GeV diphoton excess awakens!!

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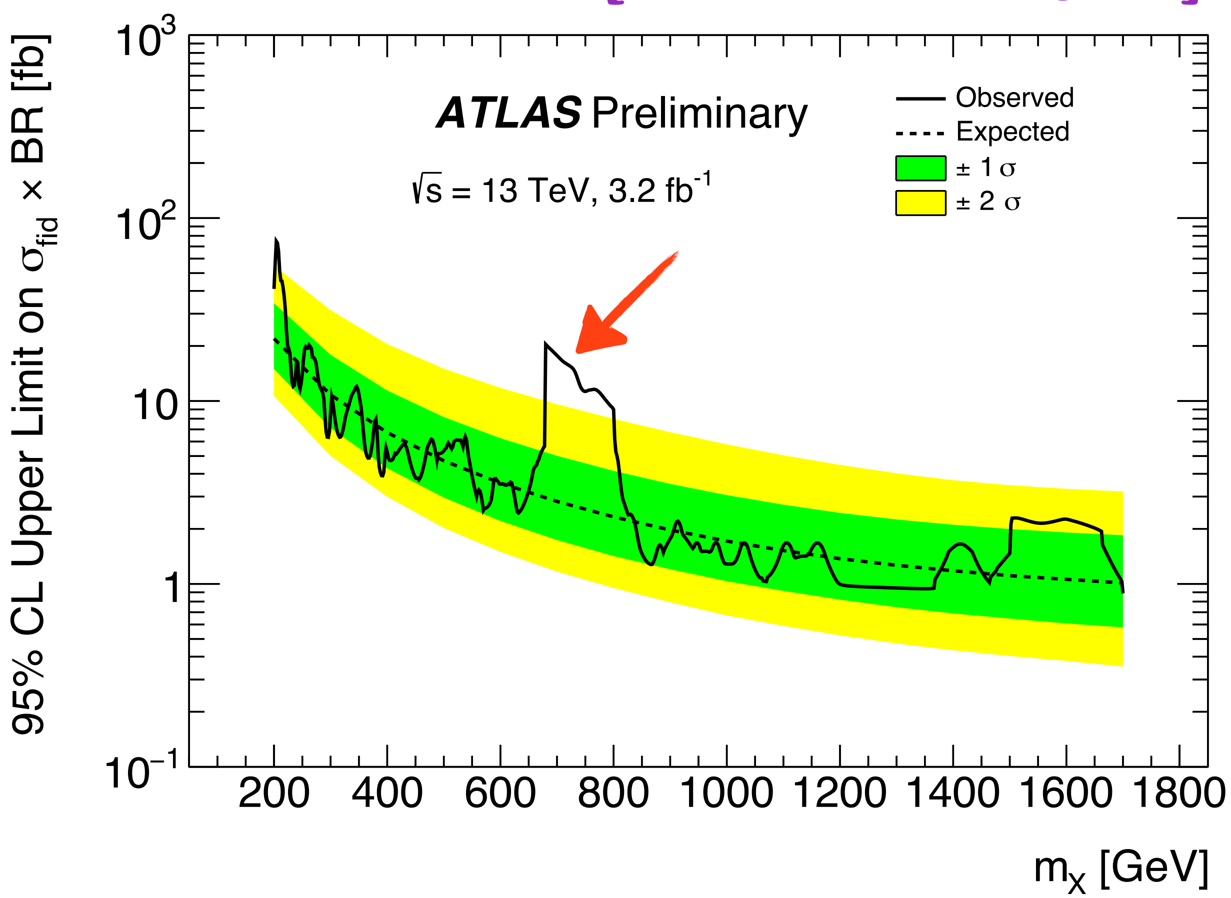
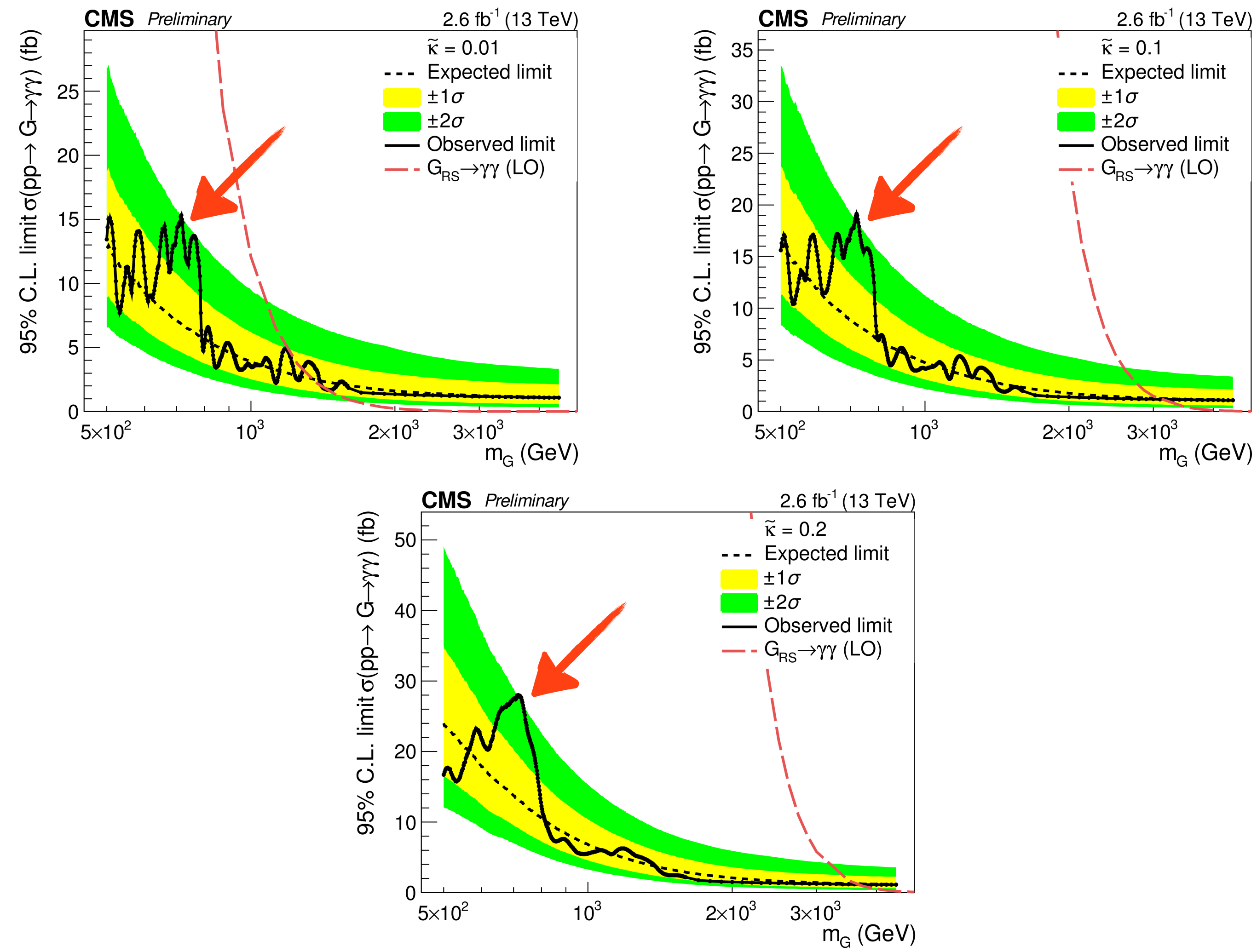


$$m_{\gamma\gamma} \simeq 750\,\mathrm{GeV}$$

[CMS-PAS-EXO-15-004]



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Intro: 750 GeV diphoton excess awakens!!

[13] J. Ellis, S. A. R. Ellis, J. Quevillon, V. Sanz, and T. You, "On the Interpretation of a Possible ∼ 750 GeV Particle Decaying into $\gamma\gamma$," arXiv:1512.05327 [hep-ph].
[14] M. Low, A. Tesi, and L.-T. Wang, "A pseudoscalar decaying to photon pairs in the early LHC run 2 data," arXiv:1512.05328 [hep-ph].
[15] B. Bellazzini, R. Franceschini, F. Sala, and J. Serra, "Goldstones in Diphotons," arXiv:1512.05330 [hep-ph].
[16] R. S. Gupta, S. Jager, Y. Kats, G. Perez, and E. Stamou, "Interpreting a 750 GeV Diphoton Resonance," arXiv:1512.05332 [hep-ph].
[17] C. Petersson and R. Torre, "The 750 GeV diphoton excess from the goldstino superpartner," arXiv:1512.05333 [hep-ph].
[18] E. Molinaro, F. Sannino, and N. Vignaroli, "Strong dynamics or axion origin of the diphoton excess," arXiv:1512.05334 [hep-ph].
[19] A. Falkowski, O. Slone, and T. Volansky, "Phenomenology of a 750 GeV Singlet," arXiv:1512.05777 [hep-ph].
[20] B. Dutta, Y. Gao, T. Ghosh, I. Gogoladze, and T. Li, "Interpretation of the diphoton excess at CMS and ATLAS," arXiv:1512.05439 [hep-ph].
[21] Q.-H. Cao, Y. Liu, K.-P. Xie, B. Yan, and D.-M. Zhang, "A Boost Test of Anomalous Diphoton Resonance at the LHC," arXiv:1512.05542 [hep-ph].
[22] S. Matsuzaki and K. Yamawaki, "750 GeV Diphoton Signal from One-Family Walking Technipion," arXiv:1512.05564 [hep-ph].
[23] A. Kobakhidze, F. Wang, L. Wu, J. M. Yang, and M. Zhang, "LHC diphoton excess explained as a heavy scalar in top-seesaw model," arXiv:1512.05585 [hep-ph].
[24] R. Martinez, F. Ochoa, and C. F. Sierra, "Diphoton decay for a 750 GeV scalar dark matter," arXiv:1512.05617 [hep-ph].
[25] P. Cox, A. D. Medina, T. S. Ray, and A. Spray, "Diphoton Excess at 750 GeV from a Radion in the Bulk-Higgs Scenario," arXiv:1512.05618 [hep-ph].
[26] D. Becirevic, E. Bertuzzo, O. Sumensari, and R. Z. Funchal, "Can the new resonance at LHC be a CP-Odd Higgs boson?," arXiv:1512.05623 [hep-ph].
[27] J. M. No, V. Sanz, and J. Setford, "See-Saw Composite Higgses at the LHC: Linking Naturalness to the 750 GeV Di-Photon Resonance," arXiv:1512.05700 [hep-ph].
[28] S. V. Demidov and D. S. Gorbunov, "On sgoldstino interpretation of the diphoton excess," arXiv:1512.05723 [hep-ph].
[29] W. Chao, R. Huo, and J.-H. Yu, "The Minimal Scalar-Stealth Top Interpretation of the Diphoton Excess," arXiv:1512.05738 [hep-ph].
[30] S. Fichet, G. von Gersdorff, and C. Royon, "Scattering Light by Light at 750 GeV at the LHC," arXiv:1512.05751 [hep-ph].
[31] D. Curtin and C. B. Verhaaren, "Quirky Explanations for the Diphoton Excess," arXiv:1512.05753 [hep-ph].
[32] L. Bian, N. Chen, D. Liu, and J. Shu, "A hidden confining world on the 750 GeV diphoton excess," arXiv:1512.05759 [hep-ph].
[33] J. Chakrabortty, A. Choudhury, P. Ghosh, S. Mondal, and T. Srivastava, "Di-photon resonance around 750 GeV: shedding light on the theory underneath," arXiv:1512.05767 [hep-ph].
[34] A. Ahmed, B. M. Dillon, B. Grzadkowski, J. F. Gunion, and Y. Jiang, "Higgs-radion interpretation of 750 GeV di-photon excess at the LHC," arXiv:1512.05771 [hep-ph].
[35] P. Agrawal, J. Fan, B. Heidenreich, M. Reece, and M. Strassler, "Experimental Considerations Motivated by the Diphoton Excess at the LHC," arXiv:1512.05775 [hep-ph].
[36] C. Csaki, J. Hubisz, and J. Terning, "The Minimal Model of a Diphoton Resonance: Production without Gluon Couplings," arXiv:1512.05776 [hep-ph].
[37] D. Aloni, K. Blum, A. Dery, A. Efrati, and Y. Nir, "On a possible large width 750 GeV diphoton resonance at ATLAS and CMS," arXiv:1512.05778 [hep-ph].
[38] Y. Bai, J. Berger, and R. Lu, "A 750 GeV Dark Pion: Cousin of a Dark G-parity-odd WIMP," arXiv:1512.05779 [hep-ph].
[39] E. Gabrielli, K. Kannike, B. Mele, M. Raidal, C. Spethmann, and H. Veermae, "A SUSY Inspired Simplified Model for the 750 GeV Diphoton Excess," arXiv:1512.05961 [hep-ph].
[40] R. Benbrik, C.-H. Chen, and T. Nomura, "Higgs singlet as a diphoton resonance in a vector-like quark model," arXiv:1512.06028 [hep-ph].
[41] J. S. Kim, J. Reuter, K. Rolbiecki, and R. R. de Austri, "A resonance without resonance: scrutinizing the diphoton excess at 750 GeV," arXiv:1512.06083 [hep-ph].
[42] A. Alves, A. G. Dias, and K. Sinha, "The 750 GeV S-cion: Where else should we look for it?," arXiv:1512.06091 [hep-ph].
[43] E. Megias, O. Pujolas, and M. Quiros, "On dilatons and the LHC diphoton excess," arXiv:1512.06106 [hep-ph].
[44] L. M. Carpenter, R. Colburn, and J. Goodman, "Supersoft SUSY Models and the 750 GeV Diphoton Excess, Beyond Effective Operators," arXiv:1512.06107 [hep-ph].
[45] J. Bernon and C. Smith, "Could the width of the diphoton anomaly signal a three-body decay ?," arXiv:1512.06113 [hep-ph].
[46] W. Chao, "Symmetries Behind the 750 GeV Diphoton Excess," arXiv:1512.06297 [hep-ph].
[47] M. T. Arun and P. Saha, "Gravitons in multiply warped scenarios - at 750 GeV and beyond," arXiv:1512.06335 [hep-ph].
[48] C. Han, H. M. Lee, M. Park, and V. Sanz, "The diphoton resonance as a gravity mediator of dark matter," arXiv:1512.06376 [hep-ph].
[49] S. Chang, "A Simple $U(1)$ Gauge Theory Explanation of the Diphoton Excess," arXiv:1512.06426 [hep-ph].
[50] I. Chakraborty and A. Kundu, "Diphoton excess at 750 GeV: Singlet scalars confront naturalness," arXiv:1512.06508 [hep-ph].
[51] R. Ding, L. Huang, T. Li, and B. Zhu, "Interpreting 750 GeV Diphoton Excess with R-parity Violation Supersymmetry," arXiv:1512.06560 [hep-ph].
[52] H. Han, S. Wang, and S. Zheng, "Scalar Dark Matter Explanation of Diphoton Excess at LHC," arXiv:1512.06562 [hep-ph].
[53] X.-F. Han and L. Wang, "Implication of the 750 GeV diphoton resonance on two-Higgs-doublet model and its extensions with Higgs field," arXiv:1512.06587 [hep-ph].
[54] M.-x. Luo, K. Wang, T. Xu, L. Zhang, and G. Zhu, "Squarkonium/Diquarkonium and the Di-photon Excess," arXiv:1512.06670 [hep-ph].
[55] J. Chang, K. Cheung, and C.-T. Lu, "Interpreting the 750 GeV Di-photon Resonance using photon-jets in Hidden-Valley-like models," arXiv:1512.06671 [hep-ph].
[56] D. Bardhan, D. Bhatia, A. Chakraborty, U. Maitra, S. Raychaudhuri, and T. Samui, "Radion Candidate for the LHC Diphoton Resonance," arXiv:1512.06674 [hep-ph].
[57] T.-F. Feng, X.-Q. Li, H.-B. Zhang, and S.-M. Zhao, "The LHC 750 GeV diphoton excess in supersymmetry with gauged baryon and lepton numbers," arXiv:1512.06696 [hep-ph].
[58] O. Antipin, M. Mojaza, and F. Sannino, "A natural Coleman-Weinberg theory explains the diphoton excess," arXiv:1512.06708 [hep-ph].
[59] F. Wang, L. Wu, J. M. Yang, and M. Zhang, "750 GeV Diphoton Resonance, 125 GeV Higgs and Muon g-2 Anomaly in Deflected Anomaly Mediation SUSY Breaking Scenario," arXiv:1512.06715 [hep-ph].
[60] J. Cao, C. Han, L. Shang, W. Su, J. M. Yang, and Y. Zhang, "Interpreting the 750 GeV diphoton excess by the singlet extension of the Manohar-Wise Model," arXiv:1512.06728 [hep-ph].
[61] F. P. Huang, C. S. Li, Z. L. Liu, and Y. Wang, "750 GeV Diphoton Excess from Cascade Decay," arXiv:1512.06732 [hep-ph].
[62] W. Liao and H.-q. Zheng, "Scalar resonance at 750 GeV as composite of heavy vector-like fermions," arXiv:1512.06741 [hep-ph].
[63] J. J. Heckman, "750 GeV Diphotons from a D3-brane," arXiv:1512.06773 [hep-ph].
[64] M. Dhuria and G. Goswami, "Perturbativity, vacuum stability and inflation in the light of 750 GeV diphoton excess," arXiv:1512.06782 [hep-ph].
[65] X.-J. Bi, Q.-F. Xiang, P.-F. Yin, and Z.-H. Yu, "The 750 GeV diphoton excess at the LHC and dark matter constraints," arXiv:1512.06787 [hep-ph].
[66] J. S. Kim, K. Rolbiecki, and R. R. de Austri, "Model-independent combination of diphoton constraints at 750 GeV," arXiv:1512.06797 [hep-ph].
[67] L. Berthier, J. M. Cline, W. Shepherd, and M. Trott, "Effective interpretations of a diphoton excess," arXiv:1512.06799 [hep-ph].
[68] W. S. Cho, D. Kim, K. Kong, S. H. Lim, K. T. Matchev, J.-C. Park, and M. Park, "The 750 GeV Diphoton Excess May Not Imply a 750 GeV Resonance," arXiv:1512.06824 [hep-ph].
[69] J. M. Cline and Z. Liu, "LHC diphotons from electroweakly pair-produced composite pseudoscalars," arXiv:1512.06827 [hep-ph].
[70] M. Bauer and M. Neubert, "Flavor Anomalies, the Diphoton Excess and a Dark Matter Candidate," arXiv:1512.06828 [hep-ph].
[71] M. Chala, M. Duerr, F. Kahlhoefer, and K. Schmidt-Hoberg, "Tricking Landau-Yang: How to obtain the diphoton excess from a vector resonance," arXiv:1512.06833 [hep-ph].
[72] D. Barducci, A. Goudelis, S. Kulkarni, and D. Sengupta, "One jet to rule them all: monojet constraints and invisible decays of a 750 GeV diphoton resonance," arXiv:1512.06842 [hep-ph].
[73] G. M. Pelaggi, A. Strumia, and E. Vigiani, "Trinification can explain the di-photon and di-boson LHC anomalies," arXiv:1512.07225 [hep-ph].
[74] S. M. Boucenna, S. Morisi, and A. Vicente, "The LHC diphoton resonance from gauge symmetry," arXiv:1512.06878 [hep-ph].
[75] C. W. Murphy, "Vector Leptoquarks and the 750 GeV Diphoton Resonance at the LHC," arXiv:1512.06976 [hep-ph].
[76] A. E. C. Hernández and I. Nisandzic, "LHC diphoton 750 GeV resonance as an indication of $SU(3)_c \times SU(3)_L \times U(1)_X$ gauge symmetry," arXiv:1512.07165 [hep-ph].
[77] U. K. Dey, S. Mohanty, and G. Tomar, "750 GeV resonance in the Dark Left-Right Model," arXiv:1512.07212 [hep-ph].
[78] J. de Blas, J. Santiago, and R. Vega-Morales, "New vector bosons and the diphoton excess," arXiv:1512.07229 [hep-ph].
[79] A. Belyaev, G. Cacciapaglia, H. Cai, T. Flacke, A. Parolini, and H. Serôdio, "Singlets in Composite Higgs Models in light of the LHC di-photon searches," arXiv:1512.07242 [hep-ph].
[80] P. S. B. Dev and D. Teresi, "Asymmetric Dark Matter in the Sun and the Diphoton Excess at the LHC," arXiv:1512.07243 [hep-ph].
[81] W.-C. Huang, Y.-L. S. Tsai, and T.-C. Yuan, "Gauged Two Higgs Doublet Model confronts the LHC 750 GeV di-photon anomaly," arXiv:1512.07268 [hep-ph].
[82] S. Moretti and K. Yagyu, "The 750 GeV diphoton excess and its explanation in 2-Higgs Doublet Models with a real inert scalar multiplet," arXiv:1512.07462 [hep-ph].
[83] K. M. Patel and P. Sharma, "Interpreting 750 GeV diphoton excess in SU(5) grand unified theory," arXiv:1512.07468 [hep-ph].
[84] M. Badziak, "Interpreting the 750 GeV diphoton excess in minimal extensions of Two-Higgs-Doublet models," arXiv:1512.07497 [hep-ph].
[85] S. Chakraborty, A. Chakraborty, and S. Raychaudhuri, "Diphoton resonance at 750 GeV in the broken MRSSM," arXiv:1512.07527 [hep-ph].
[86] Q.-H. Cao, S.-L. Chen, and P.-H. Gu, "Strong CP Problem, Neutrino Masses and the 750 GeV Diphoton Resonance," arXiv:1512.07541 [hep-ph].
[87] W. Altmannshofer, J. Galloway, S. Gori, A. L. Kagan, A. Martin, and J. Zupan, "On the 750 GeV di-photon excess," arXiv:1512.07616 [hep-ph].
[88] M. Cvetič, J. Halverson, and P. Langacker, "String Consistency, Heavy Exotics, and the 750 GeV Diphoton Excess at the LHC," arXiv:1512.07622 [hep-ph].
[89] J. Gu and Z. Liu, "Running after Diphoton," arXiv:1512.07624 [hep-ph].
[90] B. C. Allanach, P. S. B. Dev, S. A. Renner, and K. Sakurai, "Di-photon Excess Explained by a Resonant Sneutrino in R-parity Violating Supersymmetry," arXiv:1512.07645 [hep-ph].
[91] H. Davoudiasl and C. Zhang, "A 750 GeV Messenger of Dark Conformal Symmetry Breaking," arXiv:1512.07672 [hep-ph].
[92] N. Craig, P. Draper, C. Kilic, and S. Thomas, "How the $\gamma\gamma$ Resonance Stole Christmas," arXiv:1512.07733 [hep-ph].
[93] K. Das and S. K. Rai, "The 750 GeV Diphoton excess in a $U(1)$ hidden symmetry model," arXiv:1512.07789 [hep-ph].
[94] K. Cheung, P. Ko, J. S. Lee, J. Park, and P.-Y. Tseng, "A Higgcision study on the 750 GeV Di-photon Resonance and 125 GeV SM Higgs boson with the Higgs-Singlet Mixing," arXiv:1512.07853 [hep-ph].
[95] J. Liu, X.-P. Wang, and W. Xue, "LHC diphoton excess from colorful resonances," arXiv:1512.07885 [hep-ph].
[96] J. Zhang and S. Zhou, "Electroweak Vacuum Stability and Diphoton Excess at 750 GeV," arXiv:1512.07889 [hep-ph].
[97] J. A. Casas, J. R. Espinosa, and J. M. Moreno, "The 750 GeV Diphoton Excess as a First Light on Supersymmetry Breaking," arXiv:1512.07895 [hep-ph].
[98] L. J. Hall, K. Harigaya, and Y. Nomura, "750 GeV Diphotons: Implications for Supersymmetric Unification," arXiv:1512.07904 [hep-ph].
[99] H. Han, S. Wang, and S. Zheng, "Dark Matter Theories in the Light of Diphoton Excess," arXiv:1512.07992 [hep-ph].
[100] J.-C. Park and S. C. Park, "Indirect signature of dark matter with the diphoton resonance at 750 GeV," arXiv:1512.08117 [hep-ph].
[101] A. Salvio and A. Mazumdar, "Higgs Stability and the 750 GeV Diphoton Excess," arXiv:1512.08184 [hep-ph].
[102] D. Chway, R. Dermíšek, T. H. Jung, and H. D. Kim, "Glue to light signal of a new particle," arXiv:1512.08221 [hep-ph].
[103] G. Li, Y.-n. Mao, Y.-L. Tang, C. Zhang, Y. Zhou, and S.-h. Zhu, "A Loop-philic Pseudoscalar," arXiv:1512.08255 [hep-ph].
[104] M. Son and A. Urbano, "A new scalar resonance at 750 GeV: Towards a proof of concept in favor of strongly interacting theories," arXiv:1512.08307 [hep-ph].
[105] Y.-L. Tang and S.-h. Zhu, "NMSSM extended with vector-like particles and the diphoton excess on the LHC," arXiv:1512.08323 [hep-ph].
[106] H. An, C. Cheung, and Y. Zhang, "Broad Diphotons from Narrow States," arXiv:1512.08378 [hep-ph].
[107] J. Cao, F. Wang, and Y. Zhang, "Interpreting The 750 GeV Diphton Excess Within TopFlavor Seesaw Model," arXiv:1512.08392 [hep-ph].
[108] F. Wang, W. Wang, L. Wu, J. M. Yang, and M. Zhang, "Interpreting 750 GeV Diphoton Resonance in the NMSSM with Vector-like Particles," arXiv:1512.08434 [hep-ph].
[109] C. Cai, Z.-H. Yu, and H.-H. Zhang, "The 750 GeV diphoton resonance as a singlet scalar in an extra dimensional model," arXiv:1512.08440 [hep-ph].
[110] Q.-H. Cao, Y. Liu, K.-P. Xie, B. Yan, and D.-M. Zhang, "The Diphoton Excess, Low Energy Theorem and the 331 Model," arXiv:1512.08441 [hep-ph].
[111] J. E. Kim, "Is an axizilla possible for di-photon resonance?," arXiv:1512.08467 [hep-ph].
[112] J. Gao, H. Zhang, and H. X. Zhu, "Diphoton excess at 750 GeV: gluon-gluon fusion or quark-antiquark annihilation?," arXiv:1512.08478 [hep-ph].
[113] W. Chao, "Neutrino Catalyzed Diphoton Excess," arXiv:1512.08484 [hep-ph].
[114] X.-J. Bi, R. Ding, Y. Fan, L. Huang, C. Li, T. Li, S. Raza, X.-C. Wang, and B. Zhu, "A Promising Interpretation of Diphoton Resonance at 750 GeV," arXiv:1512.08497 [hep-ph].
[115] F. Goertz, J. F. Kamenik, A. Katz, and M. Nardecchia, "Indirect Constraints on the Scalar Di-Photon Resonance at the LHC," arXiv:1512.08500 [hep-ph].
[116] L. A. Anchordoqui, I. Antoniadis, H. Goldberg, X. Huang, D. Lust, and T. R. Taylor, "750 GeV diphotons from closed string states," arXiv:1512.08502 [hep-ph].
[117] P. S. B. Dev, R. N. Mohapatra, and Y. Zhang, "Quark Seesaw Vectorlike Fermions and Diphoton Excess," arXiv:1512.08507 [hep-ph].
[118] N. Bizot, S. Davidson, M. Frigerio, and J. L. Kneur, "Two Higgs doublets to explain the excesses $pp \to \gamma\gamma(750\ \mathrm{GeV})$ and $h \to \tau^{\pm}\mu^{\mp}$," arXiv:1512.08508 [hep-ph].
[119] L. E. Ibanez and V. Martin-Lozano, "A Megaxion at 750 GeV as a First Hint of Low Scale String Theory," arXiv:1512.08777 [hep-ph].
[120] C.-W. Chiang, M. Ibe, and T. T. Yanagida, "Revisiting Scalar Quark Hidden Sector in Light of 750-GeV Diphoton Resonance," arXiv:1512.08895 [hep-ph].
[121] S. K. Kang and J. Song, "Top-phobic heavy Higgs boson as the 750 GeV diphoton resonance," arXiv:1512.08963 [hep-ph].
[122] Y. Hamada, T. Noumi, S. Sun, and G. Shiu, "An O(750) GeV Resonance and Inflation," arXiv:1512.08984 [hep-ph].
[123] X.-J. Huang, W.-H. Zhang, and Y.-F. Zhou, "A 750 GeV dark matter messenger at the Galactic Center," arXiv:1512.08992 [hep-ph].
[124] S. Kanemura, K. Nishiwaki, H. Okada, Y. Orikasa, S. C. Park, and R. Watanabe, "LHC 750 GeV Diphoton excess in a radiative seesaw model," arXiv:1512.09048 [hep-ph].
[125] S. Kanemura, N. Machida, S. Odori, and T. Shindou, "Diphoton excess at 750 GeV in an extended scalar sector," arXiv:1512.09053 [hep-ph].
[126] A. E. C. Hernández, "The 750 GeV diphoton resonance can cause the SM fermion mass and mixing pattern," arXiv:1512.09092 [hep-ph].
[127] Y. Jiang, Y.-Y. Li, and T. Liu, "750 GeV Resonance in the Gauged $U(1)'$-Extended MSSM," arXiv:1512.09127 [hep-ph].
[128] K. Kaneta, S. Kang, and H.-S. Lee, "Diphoton excess at the LHC Run 2 and its implications for a new heavy gauge boson," arXiv:1512.09129 [hep-ph].
[129] E. Ma, "Diphoton Revelation of the Utilitarian Supersymmetric Standard Model," arXiv:1512.09159 [hep-ph].
[130] A. Dasgupta, M. Mitra, and D. Borah, "Minimal Left-Right Symmetry Confronted with the 750 GeV Di-photon Excess at LHC," arXiv:1512.09202 [hep-ph].
[131] D. Palle, "On the possible new 750 GeV heavy boson resonance at the LHC," arXiv:1601.00618 [physics.gen-ph].
[132] S. Jung, J. Song, and Y. W. Yoon, "How Resonance-Continuum Interference Changes 750 GeV Diphoton Excess: Signal Enhancement and Peak Shift," arXiv:1601.00006 [hep-ph].
[133] C. T. Potter, "Pseudoscalar Gluinonia to Diphotons at the LHC," arXiv:1601.00240 [hep-ph].
[134] E. Palti, "Vector-Like Exotics in F-Theory and 750 GeV Diphotons," arXiv:1601.00285 [hep-ph].
[135] T. Nomura and H. Okada, "Four-loop Neutrino Model Inspired by Diphoton Excess at 750 GeV," arXiv:1601.00386 [hep-ph].
[136] X.-F. Han, L. Wang, L. Wu, J. M. Yang, and M. Zhang, "Explaining 750 GeV diphoton excess from top/bottom partner cascade decay in two-Higgs-doublet model extension," arXiv:1601.00534 [hep-ph].
[137] P. Ko, Y. Omura, and C. Yu, "Diphoton Excess at 750 GeV in leptophobic U(1)′ model inspired by E_6 GUT," arXiv:1601.00586 [hep-ph].
[138] K. Ghorbani and H. Ghorbani, "The 750 GeV Diphoton Excess from a Pseudoscalar in Fermionic Dark Matter Scenario," arXiv:1601.00602 [hep-ph].
[139] U. Danielsson, R. Enberg, G. Ingelman, and T. Mandal, "The force awakens - the 750 GeV diphoton excess at the LHC from a varying electromagnetic coupling," arXiv:1601.00624 [hep-ph].
[140] W. Chao, "The Diphoton Excess from an Exceptional Supersymmetric Standard Model," arXiv:1601.00633 [hep-ph].
[141] C. Csaki, J. Hubisz, S. Lombardo, and J. Terning, "Gluon vs. Photon Production of a 750 GeV Diphoton Resonance," arXiv:1601.00638 [hep-ph].
[142] T. Modak, S. Sadhukhan, and R. Srivastava, "750 GeV Diphoton excess from Gauged $B-L$ Symmetry," arXiv:1601.00836 [hep-ph].
[143] B. Dutta, Y. Gao, T. Ghosh, I. Gogoladze, T. Li, Q. Shafi, and J. W. Walker, "Diphoton Excess in Consistent Supersymmetric SU(5) Models with Vector-like Particles," arXiv:1601.00866 [hep-ph].
[144] A. Karozas, S. F. King, G. K. Leontaris, and A. K. Meadowcroft, "Diphoton excess from E_6 in F-theory GUTs," arXiv:1601.00640 [hep-ph].
[145] A. E. C. Hernández, I. d. M. Varzielas, and E. Schumacher, "The 750 GeV diphoton resonance in the light of a 2HDM with S_3 flavour symmetry," arXiv:1601.00661 [hep-ph].
[146] F. F. Deppisch, C. Hati, S. Patra, P. Pritimita, and U. Sarkar, "Implications of the diphoton excess on Left-Right models and gauge unification," arXiv:1601.00952 [hep-ph].
[147] H. Ito, T. Moroi, and Y. Takaesu, "Studying 750 GeV Di-photon Resonance at Photon-Photon Collider," arXiv:1601.01144 [hep-ph].

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[1] K. Harigaya and Y. Nomura, “Composite Models for the 750 GeV Diphoton Excess,” `arXiv:1512.04850 [hep-ph]`.

[2] Y. Mambrini, G. Arcadi, and A. Djouadi, “The LHC diphoton resonance and dark matter,” `arXiv:1512.04913 [hep-ph]`.

[3] M. Backovic, A. Mariotti, and D. Redigolo, “Di-photon excess illuminates Dark Matter,” `arXiv:1512.04917 [hep-ph]`.

[4] A. Angelescu, A. Djouadi, and G. Moreau, “Scenarii for interpretations of the LHC diphoton excess: two Higgs doublets and vector-like quarks and leptons,” `arXiv:1512.04921 [hep-ph]`.

[5] Y. Nakai, R. Sato, and K. Tobioka, “Footprints of New Strong Dynamics via Anomaly,” `arXiv:1512.04924 [hep-ph]`.

[6] S. Knapen, T. Melia, M. Papucci, and K. Zurek, “Rays of light from the LHC,” `arXiv:1512.04928 [hep-ph]`.

[7] D. Buttazzo, A. Greljo, and D. Marzocca, “Knocking on New Physics’ door with a Scalar Resonance,” `arXiv:1512.04929 [hep-ph]`.

[8] A. Pilaftsis, “Diphoton Signatures from Heavy Axion Decays at LHC,” `arXiv:1512.04931 [hep-ph]`.

[9] R. Franceschini, G. F. Giudice, J. F. Kamenik, M. McCullough, A. Pomarol, R. Rattazzi, M. Redi, F. Riva, A. Strumia, and R. Torre, “What is the gamma gamma resonance at 750 GeV?,” `arXiv:1512.04933 [hep-ph]`.

[10] S. Di Chiara, L. Marzola, and M. Raidal, “First interpretation of the 750 GeV di-photon resonance at the LHC,” `arXiv:1512.04939 [hep-ph]`.

[11] T. Higaki, K. S. Jeong, N. Kitajima, and F. Takahashi, “The QCD Axion from Aligned Axions and Diphoton Excess,” `arXiv:1512.05295 [hep-ph]`.

[12] S. D. McDermott, P. Meade, and H. Ramani, “Singlet Scalar Resonances and the Diphoton Excess,” `arXiv:1512.05326 [hep-ph]`.

~150 papers already arose.

Intro: misc. on the excess

- ***In terms of signal strength:*** **[Buttazzo,Greljo,Marzocca, arXiv:1512.04929]**

[ATLAS-CONF-2015-081, CMS-PAS-EXO-15-004]

$$\mu^{\rm ATLAS}_{\rm 13TeV} = \sigma(pp \to S + X)_{\rm 13TeV} \times \mathcal{B}(S \to \gamma\gamma) = (6.2^{+2.4}_{-2.0})\,{\rm fb},$$
$$\mu^{\rm CMS}_{\rm 13TeV} = \sigma(pp \to S + X)_{\rm 13TeV} \times \mathcal{B}(S \to \gamma\gamma) = (5.6 \pm 2.4)\,{\rm fb},$$

[CERN-PH-EP-2015-043, CMS-PAS-HIG-14-006]

$$\mu^{\rm ATLAS}_{\rm 8TeV} = \sigma(pp \to S + X)_{\rm 8TeV} \times \mathcal{B}(S \to \gamma\gamma) = (0.46 \pm 0.85)\,{\rm fb},$$
$$\mu^{\rm CMS}_{\rm 8TeV} = \sigma(pp \to S + X)_{\rm 8TeV} \times \mathcal{B}(S \to \gamma\gamma) = (0.63 \pm 0.25)\,{\rm fb}.$$

looks compatible at around 2σ

- ***Both of ATLAS and CMS reported the bump around 750GeV.***
- ***The diphoton channel would look clean, then reliable(!?).***

Intro: misc. on the excess

- ***In terms of signal strength:*** **[Buttazzo,Greljo,Marzo**

[ATLAS-CONF-2015-081, CMS-PAS-EXO-15-0

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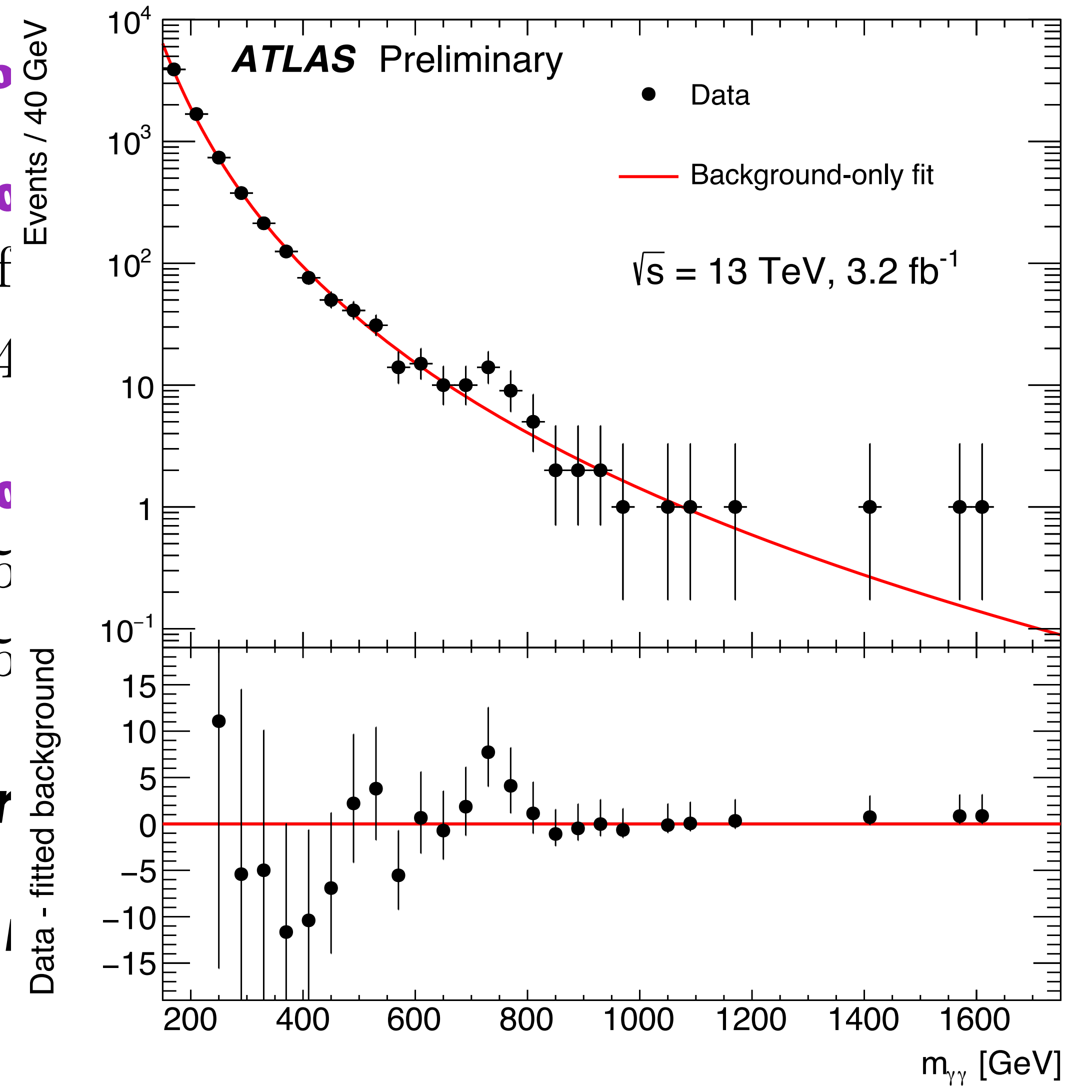


- ***Both of ATLAS and CMS reported the bump ar***
- ***The diphoton channel would look clean, then***

- ***No excess is found in the other channels (ZZ, Zγ, ll, jj, ...)***

!?!?!?
looks very exotic...

Via 8TeV LHC bounds, they should not be so large

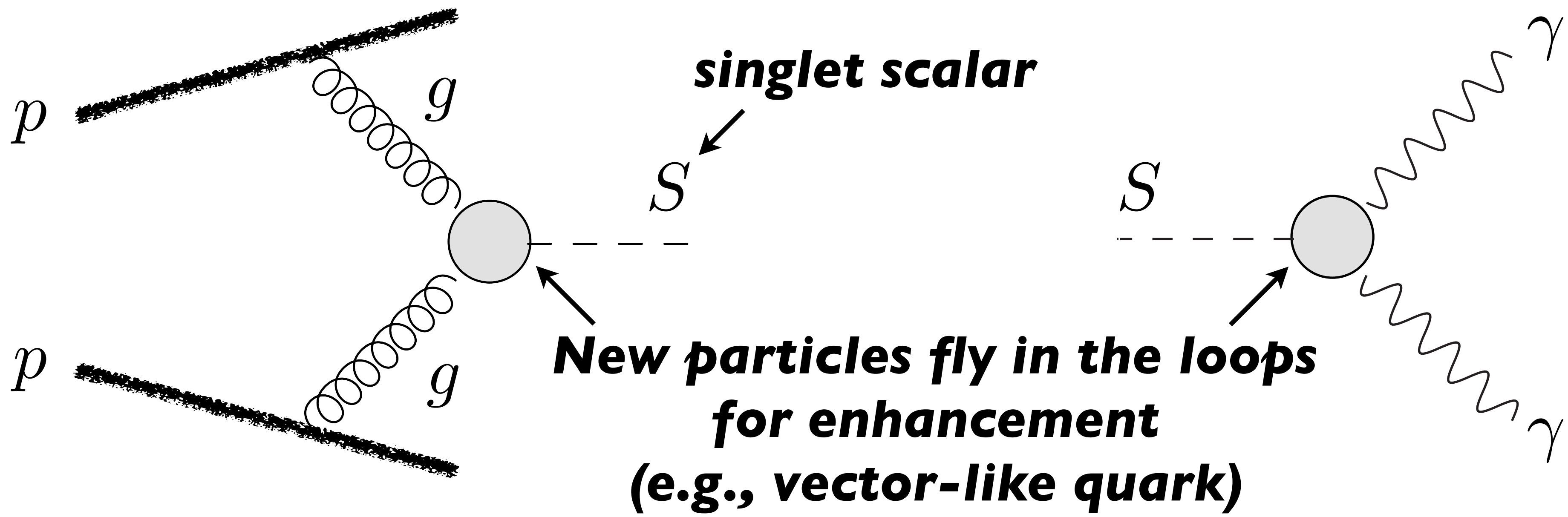
- ***ATLAS best-fit value of Γ_S = 45GeV ($\Gamma_S/m_S \approx$ 6%)***

sizable

Small Γ_S would be OK at the current stage.

[an ordinary type] [McDermott,Meade,Ramani, arXiv:1512.05326], many others

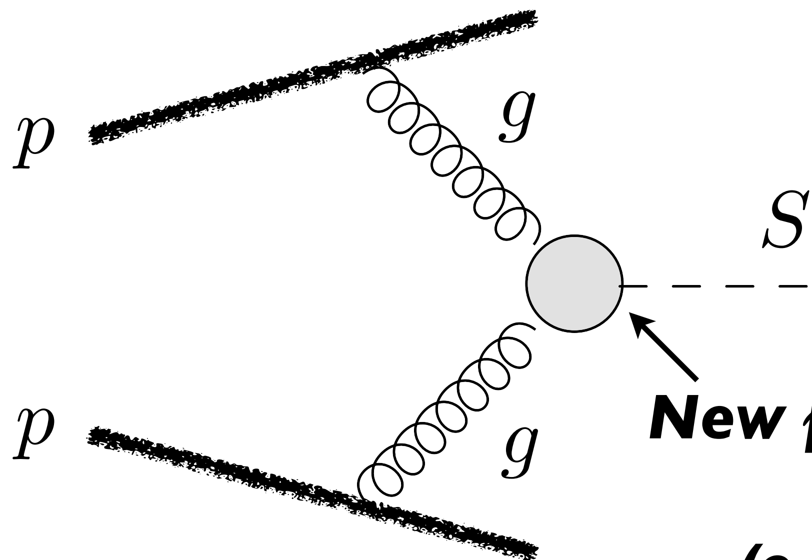
production: gluon fusion ***(decay: photon fusion)***



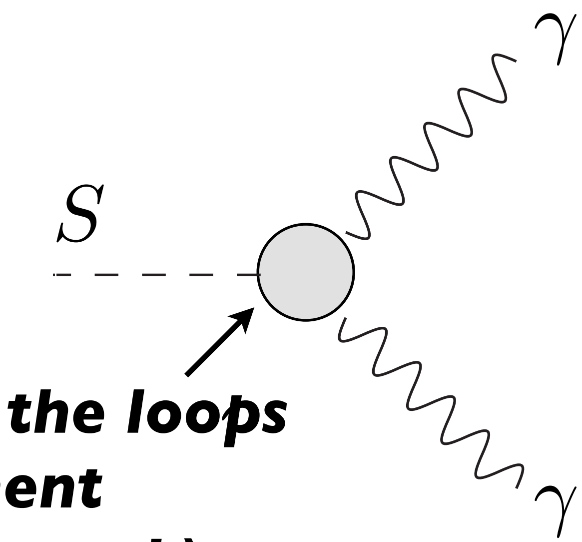
Intro: basic setups for explanation

[an ordinary type] [McDermott,Meade,Ramani, arXiv:1512.05326], many others

production: gluon fusion ***(decay: photon fusion)***



singlet scalar

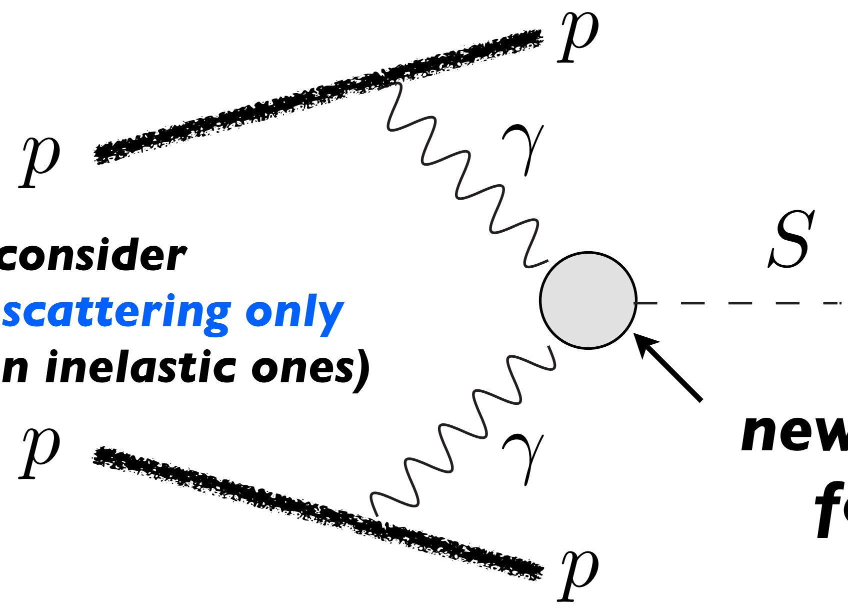


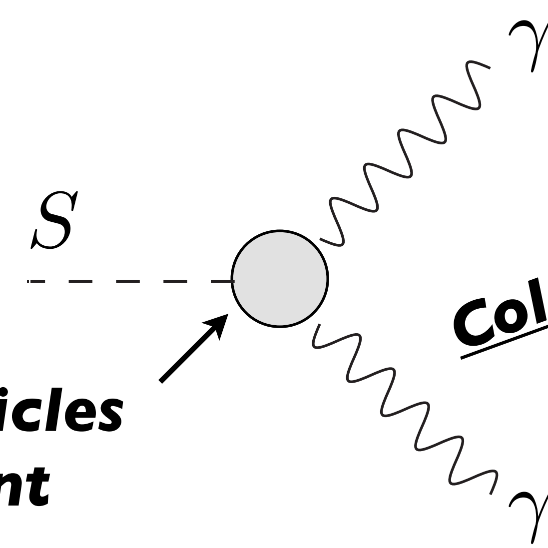
New particles fly in the loops
for enhancement
(e.g., vector-like quark)

[another type: (when B(S→γγ) = O(10)%)] [Fichet,von Gersdorff,Royon, arXiv:1512.05751] [Csaki,Hubisz,Terning, arXiv:1512.05776] [Csaki,Hubisz,Lombardo,Terning, arXiv:1601.00638]

production: photon fusion ***(decay: photon fusion)***

We consider
*the **elastic scattering only***
(cleaner than inelastic ones)





new charged particles
for enhancement

Colored new particle
is not required.

Statement: radiative seesaw model is
a reasonable setup to realize this scenario.

Contents

Model Setup

[Kanemura,KN,Okada,Orikasa,Park,Watanabe, arXiv:1512.09048], [KN,Okada,Orikasa, arXiv:1507.02412]

	Lepton Fields			Scalar Fields					New Scalar Fields	
Characters	L_{L_i}	e_{R_i}	N_{R_i}	Φ	Σ_0	h_1^+	h_2^+	k^{++}	j_a^{++}	S
$SU(3)_C$	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
$SU(2)_L$	**2**	**1**	**1**	**2**	**1**	**1**	**1**	**1**	**1**	**1**
$U(1)_Y$	$-1/2$	-1	0	$1/2$	0	1	1	2	2	0
$U(1)$	0	0	$-x$	0	$2x$	0	x	$2x$	$2x$	0

SM leptons

DM

SM Higgs

global U(1) flavor sym.

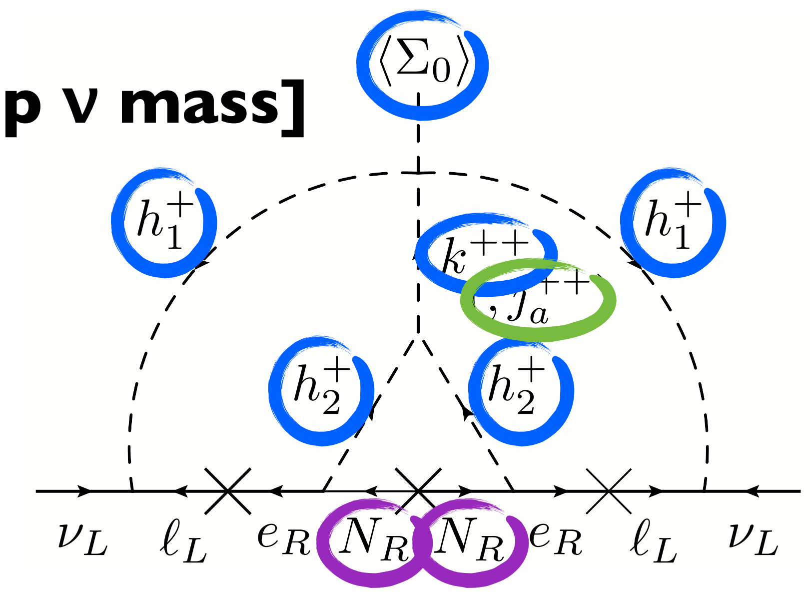
negative parity remains after U(1) breaking (lightest one → DM)

origin of breakdown of global U(1) (including pseudo NG boson)

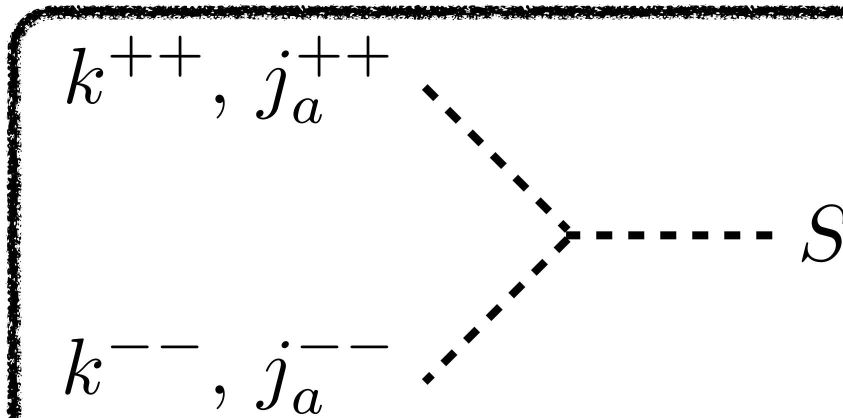
doubly-charged scalars for enhancing loop effect

candidate for 750GeV excess

[3-loop ν mass]



- ☑ ν mass: naturally explained
- ☑ DM is found. Relic is explained.
- ☑ $k^{\pm\pm}$ has no direct coupling to leptons:
  - less lepton flavor violation,
  - can be light as ~300GeV



These trilinear couplings contribute to S ⇔ γγ.

[note: a huge trilinear coupling leads to violation of tree-level unitarity.]

S Production through Photon Fusion

[Csaki,Hubisz,Terning, arXiv:1512.05776]

[general formula]

(minimum) impact parameter (uncertainty contained) proton mass

$$\sigma(p(\gamma)p(\gamma) \to S + X \to \gamma\gamma + X) = \frac{128\alpha_{\rm EW}^2 \Gamma_S}{3m_S^3} \mathcal{B}^2(S \to \gamma\gamma)(2J_S + 1)\log^3\left[\frac{r_*}{r_m}\right]$$

$r_* \equiv q_*/m_p$, $r_m \equiv m_S/\sqrt{s}$

spin of S

$q_* = (130 - 170)\,\text{MeV}$

$$\sigma(pp \to S + X \to \gamma\gamma + X) = \left(\frac{\Gamma_S}{45\,\text{GeV}}\right) \times \mathcal{B}^2(S \to \gamma\gamma) \times \begin{cases} (6.5 - 31)\text{fb} & , \sqrt{s} = 8\ \text{TeV}, \\ (73 - 162)\text{fb} & , \sqrt{s} = 13\ \text{TeV}. \end{cases}$$

sizable σ when B(S→γγ), Γ_S are reasonably large.

[branching ratio of S]

$$\Gamma_{S\to\gamma\gamma} : \Gamma_{S\to Z\gamma} : \Gamma_{S\to ZZ} : \Gamma_{S\to W^+W^-} \approx 1 : 2\left(\frac{s_W^2}{c_W^2}\right) : \left(\frac{s_W^4}{c_W^4}\right) : 0$$

$$\to \mathcal{B}(S \to \gamma\gamma) \simeq 0.591, \quad \mathcal{B}(S \to \gamma Z) \simeq 0.355, \quad \mathcal{B}(S \to ZZ) \simeq 0.0535$$

dominant!

subdominant.
8TeV LHC constraint is no problem.

[ATLAS, arXiv:1407.8150]

Quantum numbers determine the ratios.

(They are universal, not sensitive to number of $J_a^{\pm\pm}$, S ⇔ $J_a^{\pm\pm}$ trilinear couplings)

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[branching ratio of S]

fixed

Cross section and Γ_S are directly correlated.

$$\Gamma_{S\to\gamma\gamma} : \Gamma_{S\to Z\gamma} : \Gamma_{S\to ZZ} : \Gamma_{S\to W^+W^-} \approx 1 : 2\left(\frac{s_W^2}{c_W^2}\right) : \left(\frac{s_W^4}{c_W^4}\right) : 0$$

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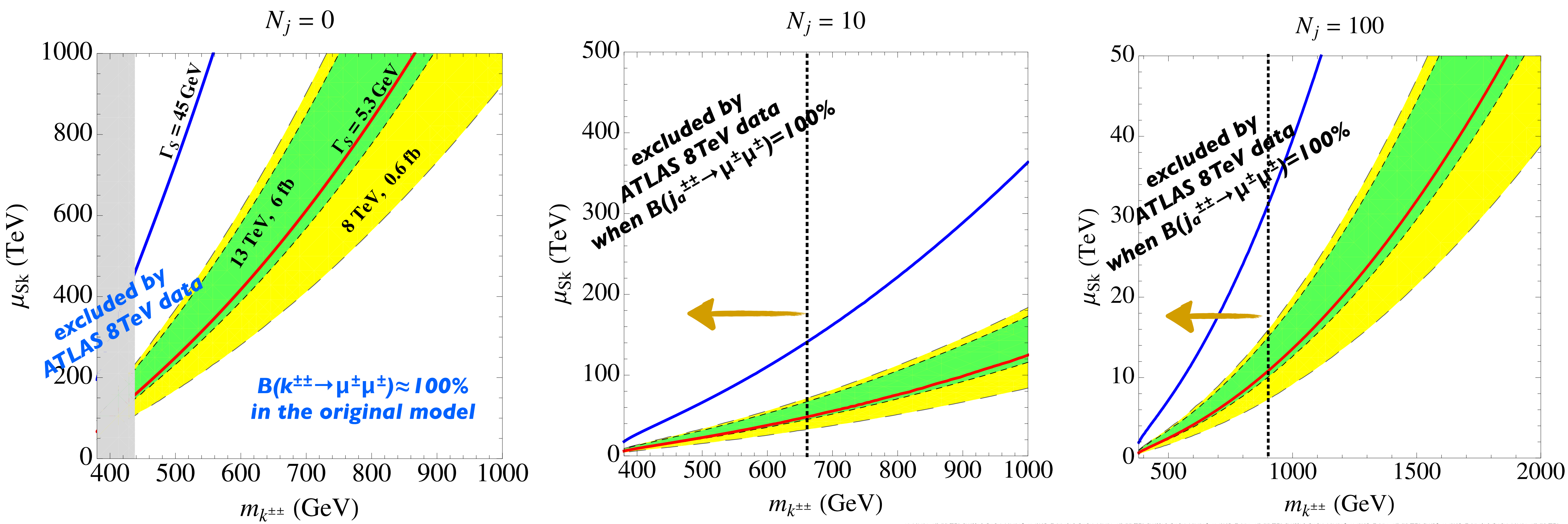
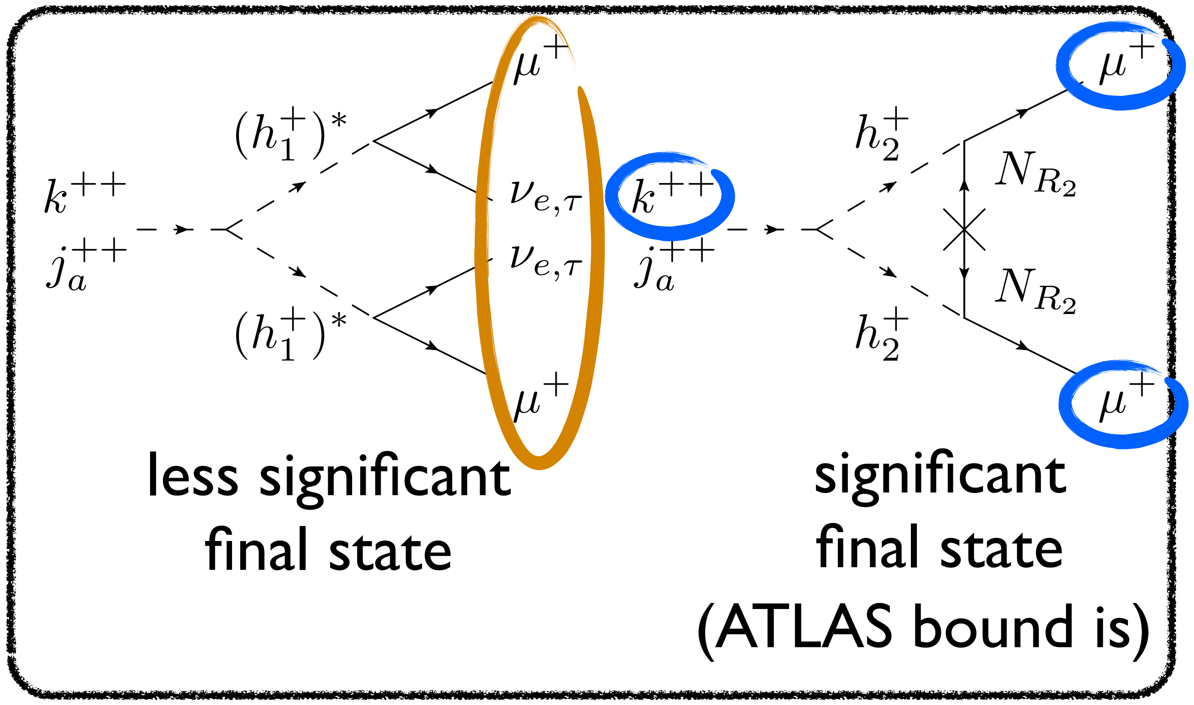
Result



- ☑ Γ_S=45GeV is not achievable in this scenario.
- ☑ Γ_S=5.3GeV (experimental resolution) is OK.
- ☑ After considering
  - (i) tree-level unitarity: $\mu_{Sk} \leq$ 1~10 TeV,
  - (ii) ATLAS 8TeV bound, **[ATLAS, arXiv:1412.0237]**



~100 additional $j_a^{\pm\pm}$ are required.

(N^2 enhancement in $\Gamma_{S\to\gamma\gamma}$, only N enhancement in signal of pp→doubly charged scalars)

Kenji Nishiwaki (KIAS)

Summary & Discussion

- ***Radiative seesaw model <u>with various doubly-charged scalars</u> is interesting:***
  - ☑ ν mass: naturally explained
  - ☑ DM is found. Relic is OK.

    Other motivations are there.

    +

  - ☑ <u>LHC 750 diphoton excess is also explained through photon fusion.</u>
  - ☑ collider-rich in doubly-charged scalar pair productions

    less ambiguous than gluon fusion

  - ✱ 4-loop extension: multiple $k^{\pm\pm}$s also help ν physics. **[Nomura,Okada, arXiv:1601.00386]**

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  - ☑ detailed collider analysis
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