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MSSM30 long-lived particle benchmarks

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Content

(1) Introduction

(2) MSSM30 and sample with LLPs

(3) Conclusion and Outlook

References:

(1) LLP White paper, `arxiv.org/abs/1903.04497`

(2) Jonathan Lee Feng, “Long-Lived Particles and the Future of Particle Physics” talk, CERN 2023-06-19 `https://cds.cern.ch/record/2862921`

(3) Soumyananda Goswami, “Status and Prospect of Search for Long-Lived Particles” talk, CERN 2023-05-22 `https://cds.cern.ch/record/2859396`

(4) Shehu AbdusSalam and students, ... Work in progress

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(1) Introduction

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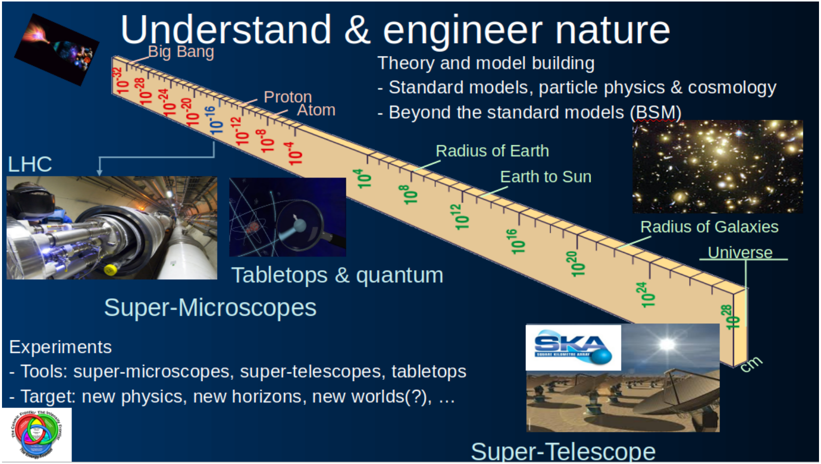
Introduction



Understand & engineer nature

Theory and model building
- Standard models, particle physics & cosmology
- Beyond the standard models (BSM)

Tabletops & quantum

Super-Microscopes

Experiments
- Tools: super-microscopes, super-telescopes, tabletops
- Target: new physics, new horizons, new worlds(?), …

Super-Telescope

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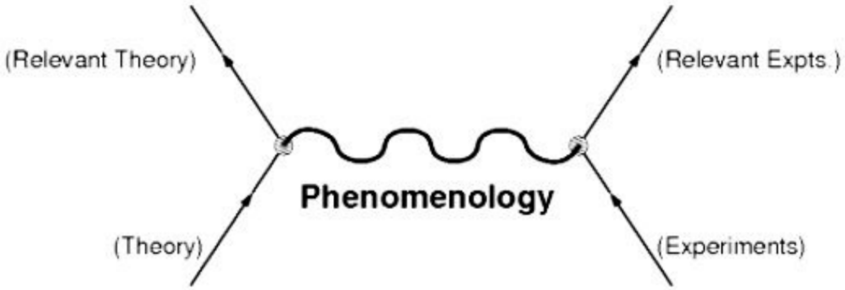
Theory + Experiment



www.phenomen.physik.uni-freiburg.de

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Long-lived particles, cf. $c\tau \gtrsim 10\mu m$ [1]

Particles in the Standard Model (SM) have lifetimes spanning an enormous range of magnitudes, from the Z boson ($\tau \sim 2 \times 10^{-25}$ s) through to the proton ($\tau \gtrsim 10^{34}$ years) and electron (stable).

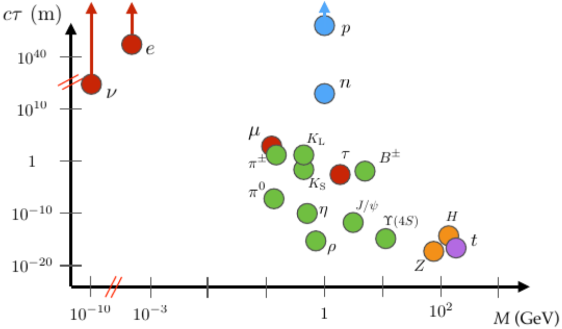

Figure 1.1: Particle lifetime $c\tau$, expressed in meters, as a function of particle mass, expressed in GeV, for a variety of particles in the Standard Model [1].

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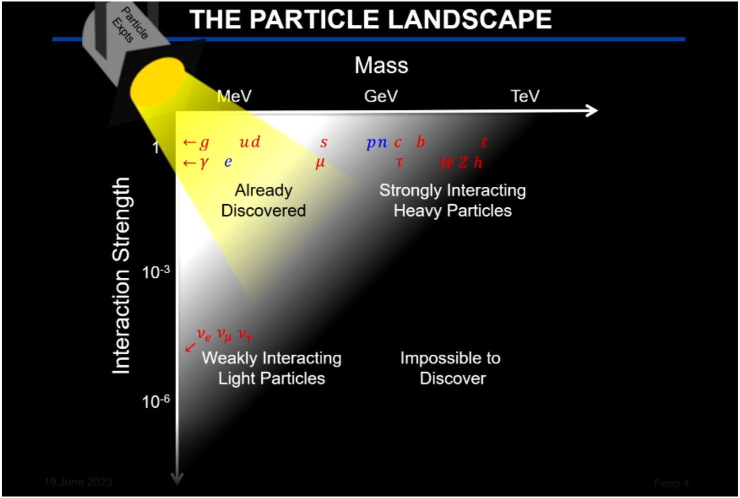
An experiment perspective particles landscape



From Feng’s talk, CERN 2023-06-19 [2]

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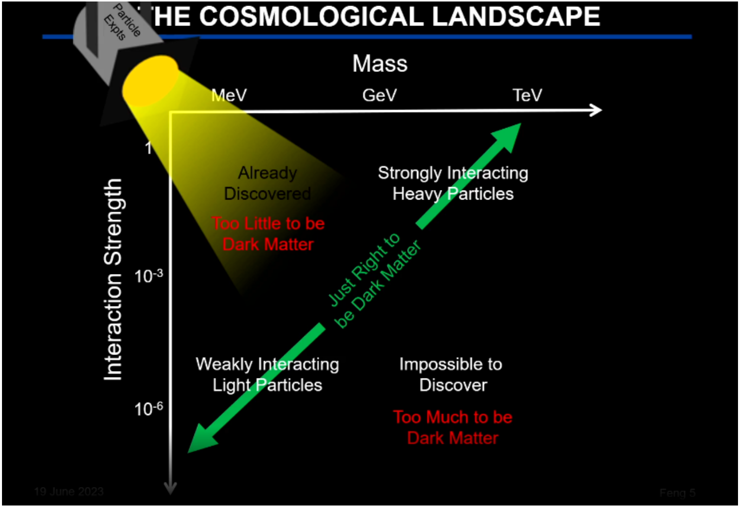
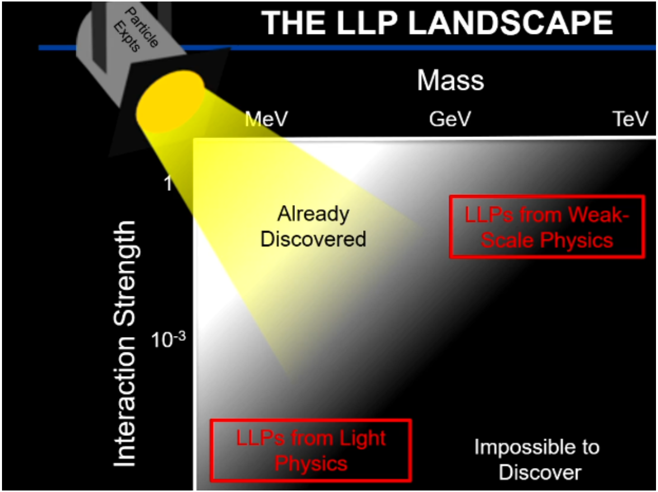
Connection to dark matter



From Feng’s talk, CERN 2023-06-19 [2]

Heavy and light long-lived particles



From Feng's talk, CERN 2023-06-19 [2]

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Beyond the standard model long-lived particles

(1) Hierarchy problem vs LEP limits conflict

(2) Solution:
Symmetry such that interactions involve new particle pairs;
E.g. R-parity for SUSY, Extended Higgs sector Z_2-symmetry

(3) Lightest or next-to lightest new particle = long-lived particle (LLP) and dark matter candidate

(4) Particle physics scenarios with and without gravito as lightest new particle

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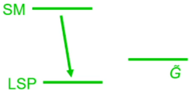
Beyond the standard model long-lived particles

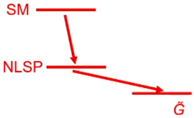
(4) Particle physics scenarios with and without gravito as lightest new particle

- $\tilde{G}$ not LSP

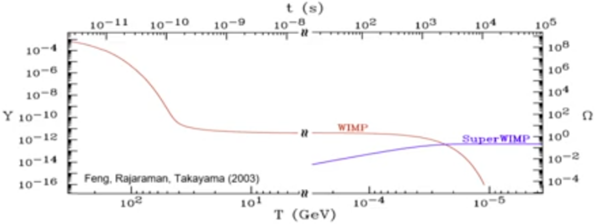


- Assumption of most of literature

- $\tilde{G}$ LSP



- Completely different cosmology and particle physics



Feng, Rajaraman, Takayama (2003)

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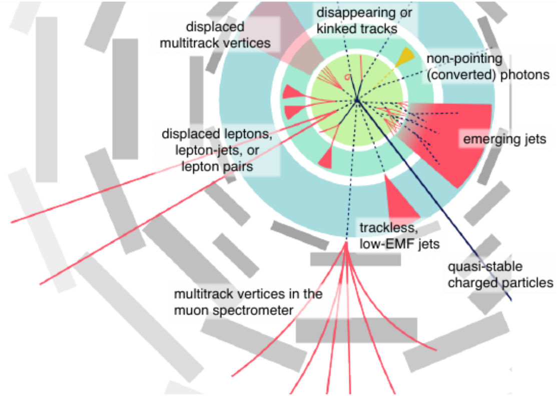
Collider signatures of long-lived particles



From LLP white paper [1].

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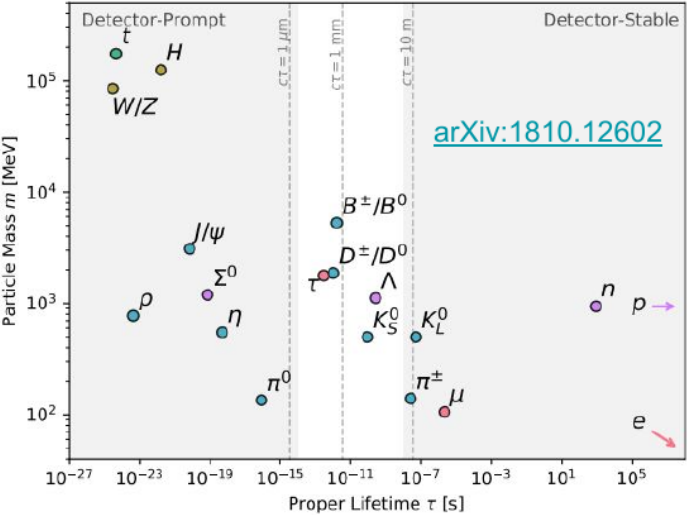
Collider signatures of long-lived particles



LLP searches sensitive to the white band region

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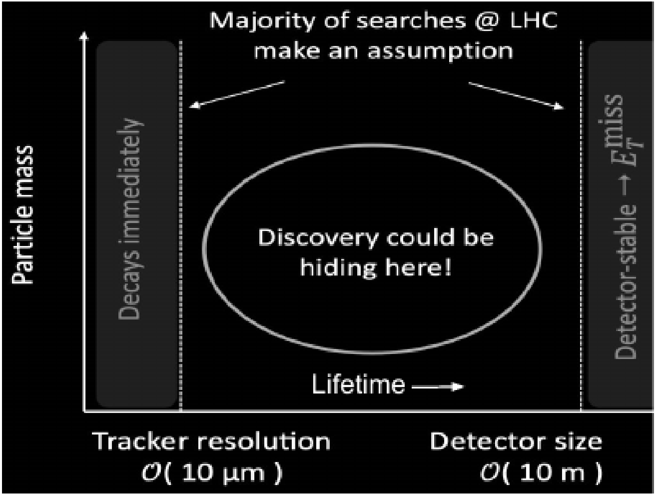
Collider signatures of long-lived particles



From Goswami's talk, CERN 2023-05-22 [3]

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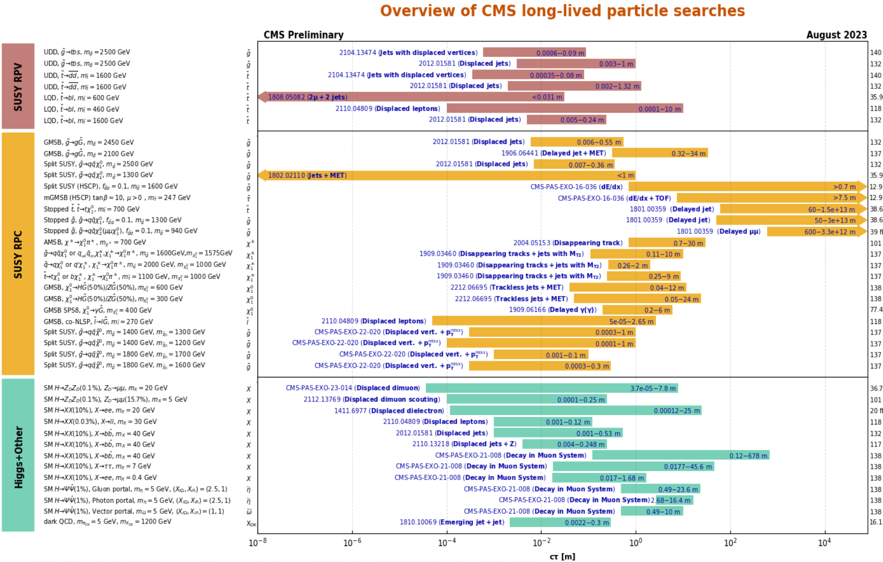
Collider limits for long-lived particles



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

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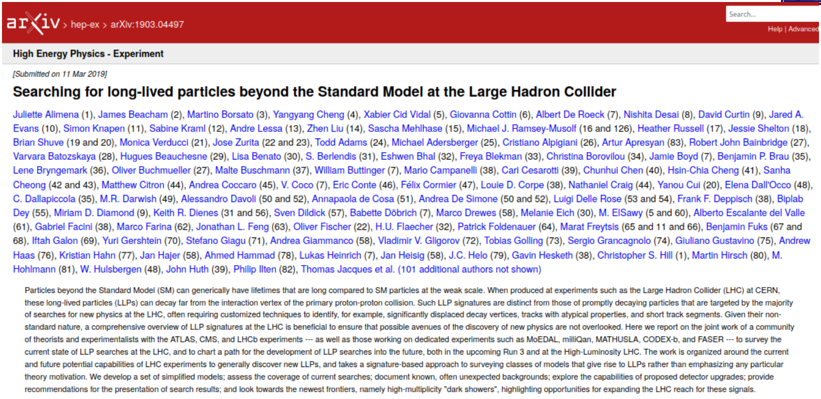
LLP colliders limits and white paper ...



High Energy Physics - Experiment

[Submitted on 11 Mar 2019]

Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

Juliette Alimena (1), James Beacham (2), Martino Borsato (3), Yangyang Cheng (4), Xabier Cid Vidal (5), Giovanna Cottin (6), Albert De Roeck (7), Nishita Desai (8), David Curtin (9), Jared A. Evans (10), Simon Knapen (11), Sabine Kraml (12), Andre Lessa (13), Zhen Liu (14), Sascha Mehlhase (15), Michael J. Ramsey-Musolf (16 and 126), Heather Russell (17), Jessie Shelton (18), Brian Shuve (19 and 20), Monica Verducci (21), Jose Zurita (22 and 23), Todd Adams (24), Michael Adersberger (25), Cristiano Alpigiani (26), Artur Apresyan (83), Robert John Bainbridge (27), Varvara Batozskaya (28), Hugues Beauchesne (29), Lisa Benato (30), S. Berlendis (31), Eshwen Bhal (32), Freya Blekman (33), Christina Borovilou (34), Jamie Boyd (7), Benjamin P. Brau (35), Lene Bryngemark (36), Oliver Buchmueller (27), Malte Buschmann (37), William Buttinger (7), Mario Campanelli (38), Cari Cesarotti (39), Chunhui Chen (40), Hsin-Chia Cheng (41), Sanha Cheong (42 and 43), Matthew Citron (44), Andrea Coccaro (45), V. Coco (7), Eric Conte (46), Félix Cormier (47), Louie D. Corpe (38), Nathaniel Craig (44), Yanou Cui (20), Elena Dall'Occo (48), C. Dallapiccola (35), M.R. Darwish (49), Alessandro Davoli (50 and 52), Annapaola de Cosa (51), Andrea De Simone (50 and 52), Luigi Delle Rose (53 and 54), Frank F. Deppisch (38), Biplab Dey (55), Miriam D. Diamond (9), Keith R. Dienes (31 and 56), Sven Dildick (57), Babette Döbrich (7), Marco Drewes (58), Melanie Eich (30), M. ElSawy (5 and 60), Alberto Escalante del Valle (61), Gabriel Facini (38), Marco Farina (62), Jonathan L. Feng (63), Oliver Fischer (22), H.U. Flaecher (32), Patrick Foldenauer (64), Marat Freytsis (65 and 11 and 66), Benjamin Fuks (67 and 68), Iftah Galon (69), Yuri Gershtein (70), Stefano Giagu (71), Andrea Giammanco (58), Vladimir V. Gligorov (72), Tobias Golling (73), Sergio Grancagnolo (74), Giuliano Gustavino (75), Andrew Haas (76), Kristian Hahn (77), Jan Hajer (58), Ahmed Hammad (78), Lukas Heinrich (7), Jan Heisig (58), J.C. Helo (79), Gavin Hesketh (38), Christopher S. Hill (1), Martin Hirsch (80), M. Hohlmann (81), W. Hulsbergen (48), John Huth (39), Philip Ilten (82), Thomas Jacques et al. (101 additional authors not shown)

Particles beyond the Standard Model (SM) can generically have lifetimes that are long compared to SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction vertex of the primary proton-proton collision. Such LLP signatures are distinct from those of promptly decaying particles that are targeted by the majority of searches for new physics at the LHC, often requiring customized techniques to identify, for example, significantly displaced decay vertices, tracks with atypical properties, and short track segments. Given their non-standard nature, a comprehensive overview of LLP signatures at the LHC is beneficial to ensure that possible avenues of the discovery of new physics are not overlooked. Here we report on the joint work of a community of theorists and experimentalists with the ATLAS, CMS, and LHCb experiments --- as well as those working on dedicated experiments such as MoEDAL, milliQan, MATHUSLA, CODEX-b, and FASER --- to survey the current state of LLP searches at the LHC, and to chart a path for the development of LLP searches into the future, both in the upcoming Run 3 and at the High-Luminosity LHC. The work is organized around the current and future potential capabilities of LHC experiments to generally discover new LLPs, and takes a signature-based approach to surveying classes of models that give rise to LLPs rather than emphasizing any particular theory motivation. We develop a set of simplified models; assess the coverage of current searches; document known, often unexpected backgrounds; explore the capabilities of proposed detector upgrades; provide recommendations for the presentation of search results; and look towards the newest frontiers, namely high-multiplicity "dark showers", highlighting opportunities for expanding the LHC reach for these signals.

... are mostly simplified models based.

We propose new, complementary, approach: use other collider, dark matter, eEDM, etc limits when benchmarking or interpreting results.

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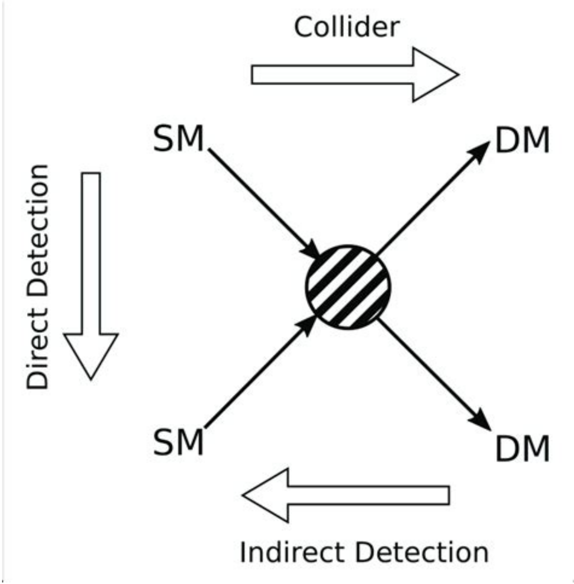
Searches for dark matter particle



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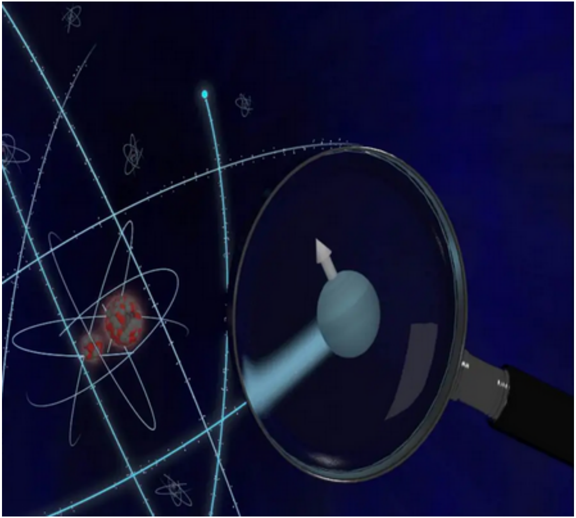
Electric Dipole Moment (EDM) of e^-



`https://sitn.hms.harvard.edu/flash/2014/`

`looking-closer-the-search-for-the-electron-electric-dipole-moment/`

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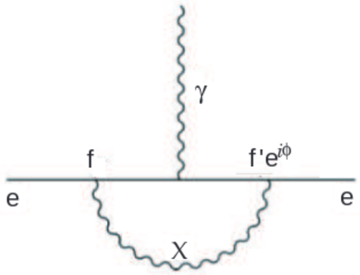
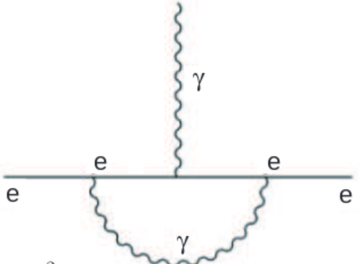
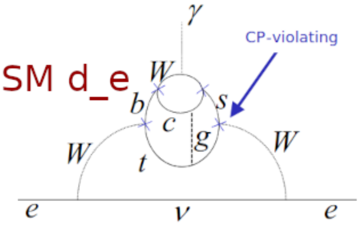
e^- Electric Dipole Moment

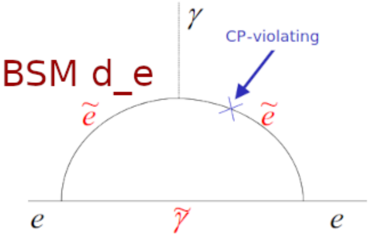


EDM



g-2





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Long-lived particle benchmarks based on the 30-parameters MSSM

AbdusSalam, Shehu[1]

[1] *Department of Physics, Shahid Beheshti University, Tehran*

Abstract

Benchmarks for new physics searches at the large hadron collider (LHC) are sometimes constructed around specific features of interest without incorporating duly deserved results from other experiments. In this seminar, the complementary approach, whereby new physics model points that passed non-collider and dark matter limits are used, is going to be presented. This will be within the context of an R-parity-conserving minimal supersymmetric standard model with thirty free supersymmetry-breaking parameters (MSSM30). A selection of MSSM30 spectra, featuring long-lived particles, that survive the current electron electric dipole moment limits from ACME and JILA experiments, and the supersymmetry and Higgs bounds from the LHC will be extracted from a sample as benchmarks for further collider phenomenology studies.

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ذرات معیار با عمر طولانی از مدل حداقلی ابرتقارن با ۳۰ پارامتر

عبدالسلام، شهو ۱
[1]دانشکده فیزیك دانشگاه شهید بهشتی ، تهران

چکیده

جستجوهای فیزیک جدید در برخورددهنده بزرگ هادرونی ال‌اچ‌سی[1] مبتنی بر معیارهایی حول ویژگی‌های خاص هستند، و گاهی اوقات این معیارها بدون در نظر گرفتن قیدها و نتایج آزمایشگاهی مرتبط دیگر ساخته می‌شوند. در این سمینار، روشی متفاوت و تکمیلی ارائه می شود و در آن ذرات معیاری معرفی می‌گردد که با محدودیت‌های به دست آمده از آزمایشهای غیر برخورددهنده ها و ماده تاریک هم‌خوانی دارند. این معیارها در چارچوب مدل استاندارد حداقلی ابرتقارن تعریف شده‌اند که حافظ پاریته آر[2] بوده و دارای سی پارامتر آزاد برای شکست ابرتقارن (MSSM30[3])می‌باشد. با توجه به اینکه ذرات غیراستاندارد با نیمه عمر طولانی(LLP[4])در حال حاضر نقطه تمرکز جستجوی فیزیک جدید در ال‌اچ‌سی هستند، مجموعه‌ای از طیف‌های پارامتری MSSM30 برای جستجوی LLP ها در شتابگرهای نسل آینده ارائه خواهد شد. این طیف ها با محدودیت‌های گشتاور دوقطبی الکتریکی الکترون، حاصل از آزمایش‌های اکمه[5] و جیلا[6]، سازگار هستند و ناقض نتایج ال‌اچ‌سی درباری ابرتقارن و بوزون هیگز نمی‌باشند.

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A Question: What are the ways of getting LLP from BSMs ?

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(2) MSSM30 and sample with LLPs

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The MSSM

MSSM-105: $(M_Q^2)_{ij}, \quad (M_U^2)_{ij}, \quad (M_D^2)_{ij}, \quad (M_L^2)_{ij}, \quad (M_E^2)_{ij},$
$e^{\phi_1} M_1, \quad e^{\phi_2} M_2, \quad M_3, \quad M_{H_1}^2, \quad M_{H_2}^2, \quad \tan\beta, \quad e^{\phi_\mu},$
$(A_U)_{ij} = (a_U Y_U)_{ij}, \quad (A_D)_{ij} = (a_D Y_D)_{ij}, \quad (A_E)_{ij} = (a_E Y_E)_{ij}$

Constrained MSSMs:
mSUGRA/CMSSM, mGMSB, mAMSB, LVS, G2-MSSM,
CMSSM: $m_{1/2}, m_0, A_0, \tan\beta, \mathrm{sign}(\mu)$; GUT-scale

pMSSM: MSSM-105 minus “extra” {CP-violating, FCNC}
$\tan\beta, \; m_{H_1}^2, \; m_{H_2}^2; \; M_{1,2,3}; \; m_{\tilde{f}_{1,2,3,4,5}}^{3rdgen}, \; m_{\tilde{f}_{1,2,3,4,5}}^{1/2ndgen}; A_{t,b,\tau}$

MSSM30: systematic reduction of parameters, 1411.1663

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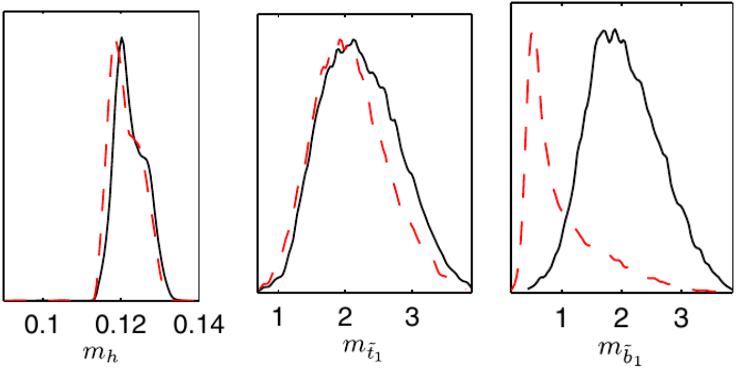
Motivation: pMSSM global fit

(1) $m_h \sim 117$ to 129 GeV @ 95% CR,

(2) $m_{\tilde{t}_1} \sim 2$ to 3 TeV, undetermined $m_{\tilde{b}_1}, m_{\tilde{g}}, \ldots$



Y-axis: probability density See 0809.0284, 0904.2548

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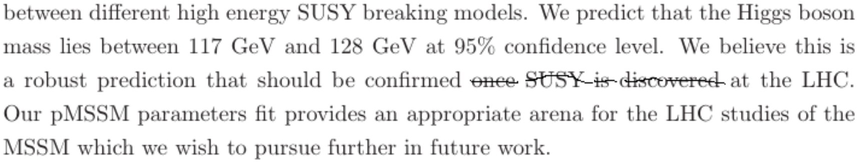
Motivation: BSMs explorations proposal

Shehu S. AbdusSalam PhD Thesis, 2009



between different high energy SUSY breaking models. We predict that the Higgs boson mass lies between 117 GeV and 128 GeV at 95% confidence level. We believe this is a robust prediction that should be confirmed ~~once SUSY is discovered~~ at the LHC. Our pMSSM parameters fit provides an appropriate arena for the LHC studies of the MSSM which we wish to pursue further in future work.

Proposal:
extensive, robust explorations of BSMs to pass on/from

(o) HiggsBound, SModelS, SUSY-AI, dark matter, & eEDM

(o) Then: HPC, statistical/ data analyses

(o) Today: Deep-learning and advanced HPC should be used

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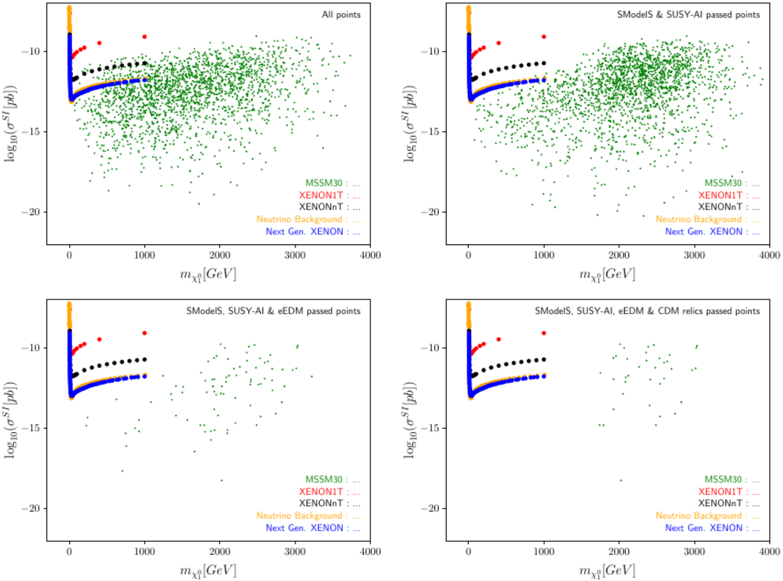
MSSM30 sample with LLPs



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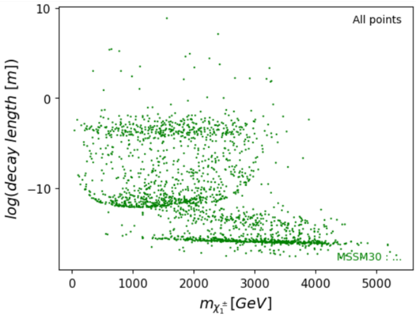
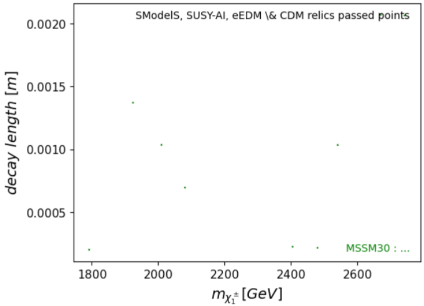
MSSM30 sample with LLPs





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(3) Summary, conclusion/outlook

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Conclusion and outlook

- Use mode-independent results (fiducial cross sections)
- Machine-learning leveraged global fits
- Reinterpret using published likelihoods
- Prospects w.r.t future facilities
- SuperWIMP scenarios

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Thanks for Listening!

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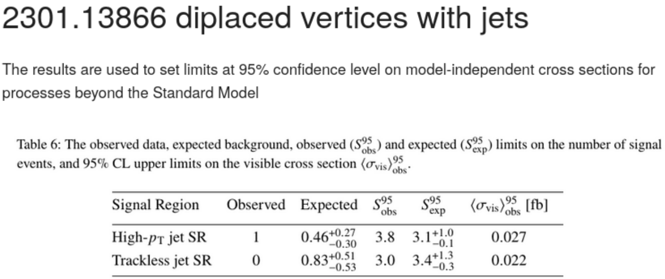
ATLAS LLP fiducial cross sections



2301.13866 diplaced vertices with jets

The results are used to set limits at 95% confidence level on model-independent cross sections for processes beyond the Standard Model

Table 6: The observed data, expected background, observed (S^{95}_{obs}) and expected (S^{95}_{exp}) limits on the number of signal events, and 95% CL upper limits on the visible cross section $\langle\sigma_{\text{vis}}\rangle^{95}_{\text{obs}}$.

Signal Region	Observed	Expected	S^{95}_{obs}	S^{95}_{exp}	$\langle\sigma_{\text{vis}}\rangle^{95}_{\text{obs}}$ [fb]
High-p_{T} jet SR	1	$0.46^{+0.27}_{-0.30}$	3.8	$3.1^{+1.0}_{-0.1}$	0.027
Trackless jet SR	0	$0.83^{+0.51}_{-0.53}$	3.0	$3.4^{+1.3}_{-0.3}$	0.022

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