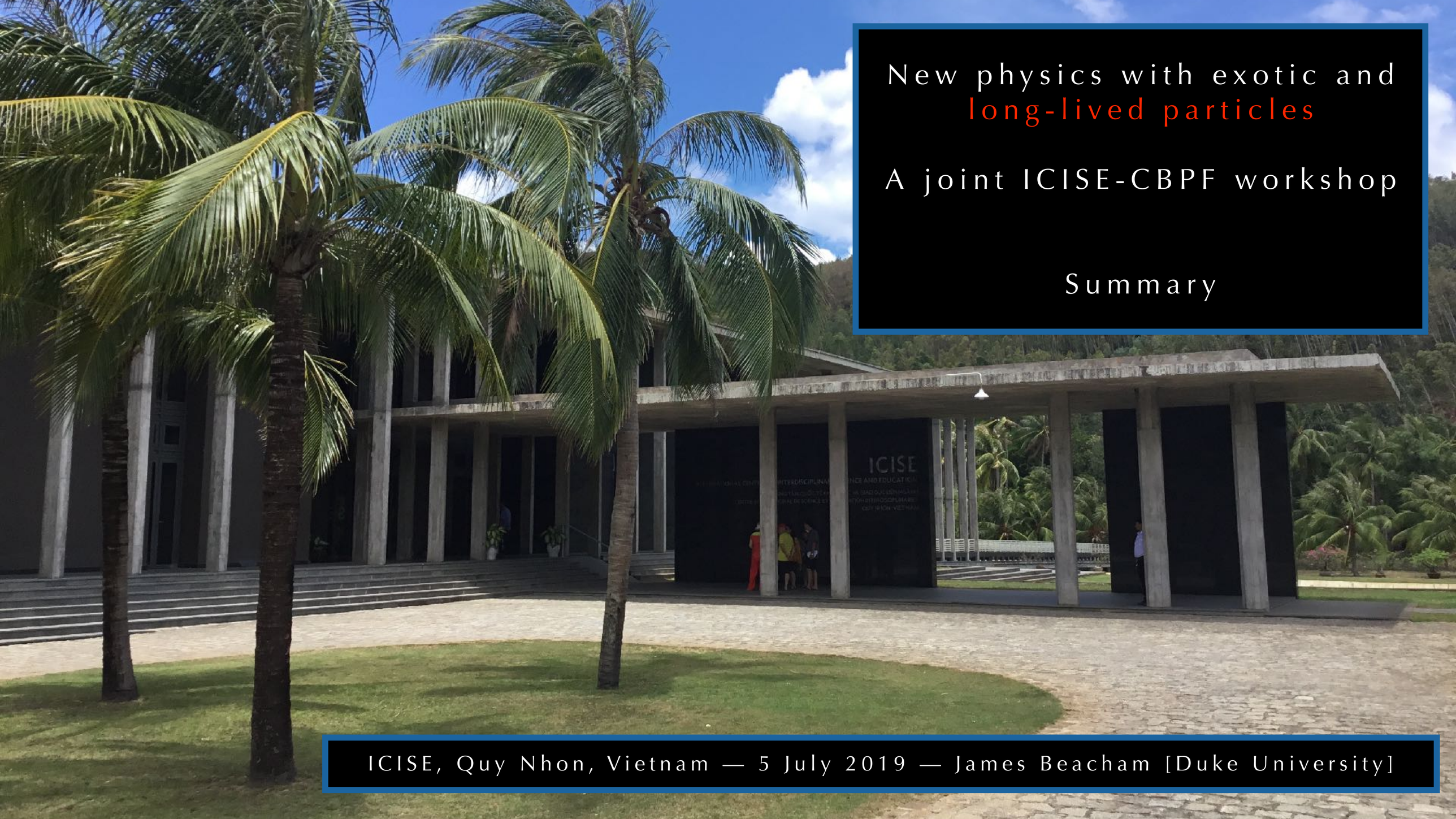


New physics with exotic and long-lived particles

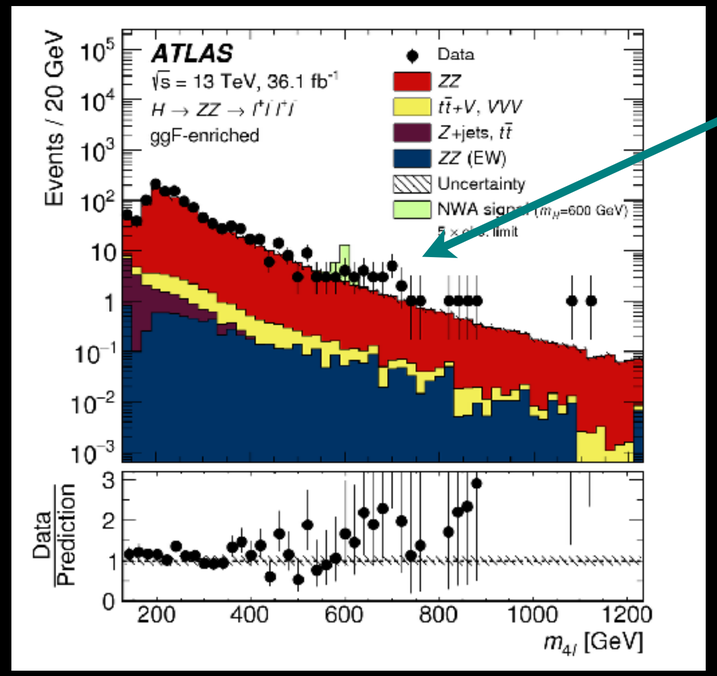
A joint ICISE-CBPF workshop

Summary

ICISE, Quy Nhon, Vietnam — 5 July 2019 — James Beacham [Duke University]

New physics in 2019

Our current extensive look at 13 TeV yields impressive agreement with Standard Model expectations and no unambiguous resonances or excesses



EPJC (2018) 78: 293

?

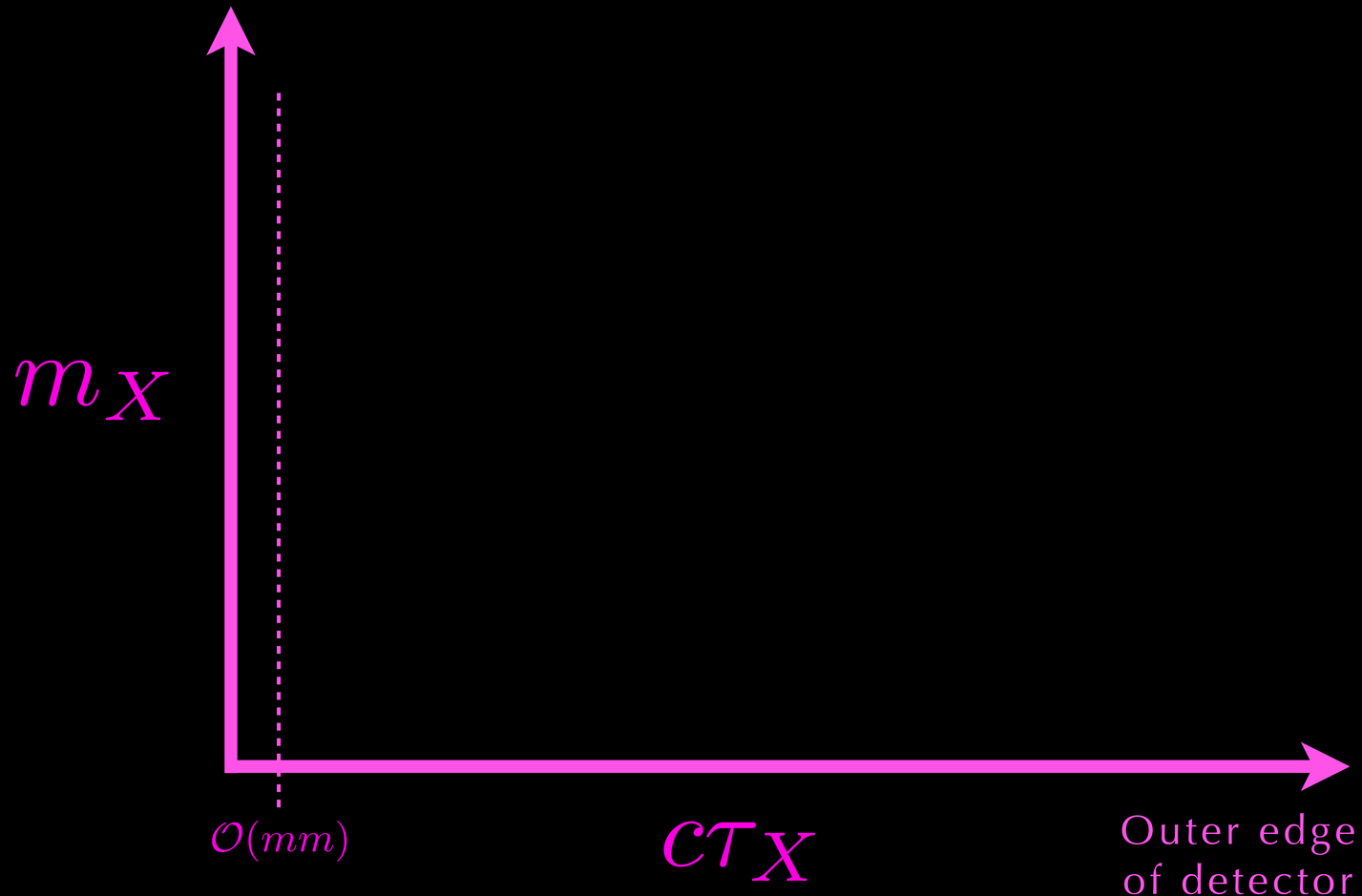
There are no more guarantees (like a source of electroweak symmetry breaking "just around the corner") and no ace-in-the-hole motivations for some specific search or experiment; just huge open questions, because we *know* the SM is incomplete.

Requires us to shift from theory-driven search strategies to signature-driven ones.

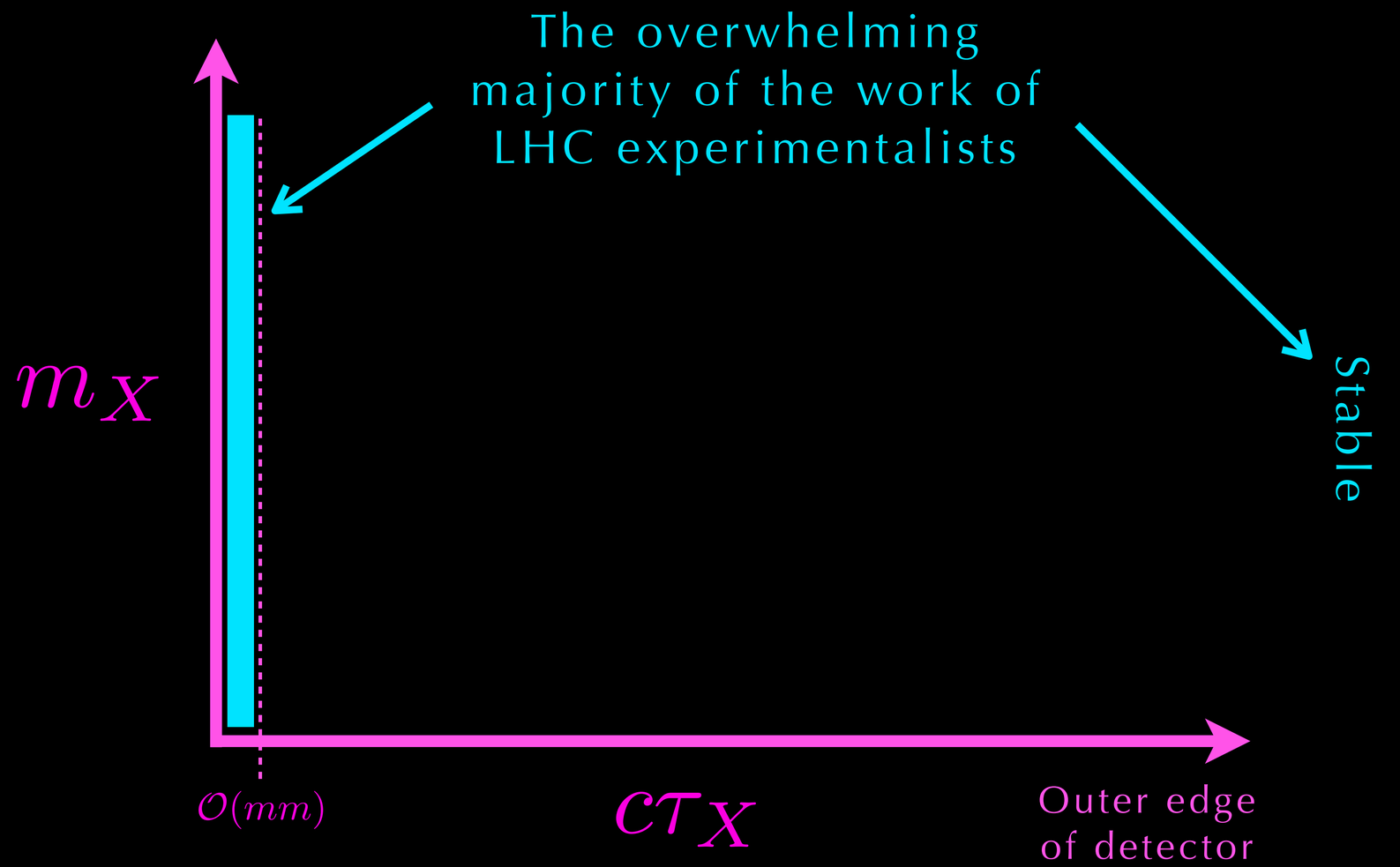
WIMP dark matter in tension, lack of evidence for minimal SUSY, lack of twenty-jet events filled with strong gravity, etc., compels us to switch from *particle-hunter* mindset to *cartographer* mindset

Where could the new physics be hiding? What are we overloooking or marginalizing?

The lifetime frontier



The lifetime frontier



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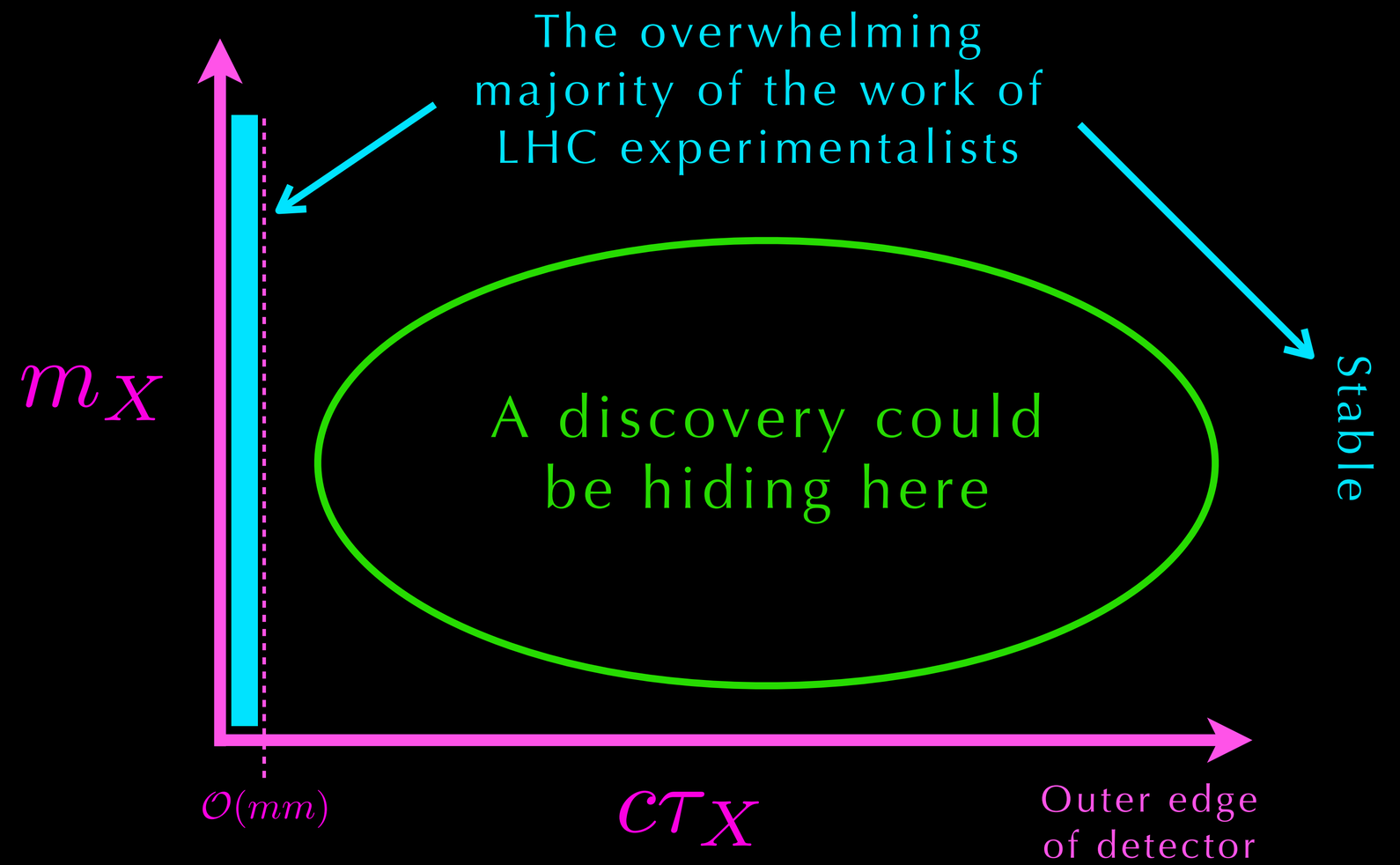
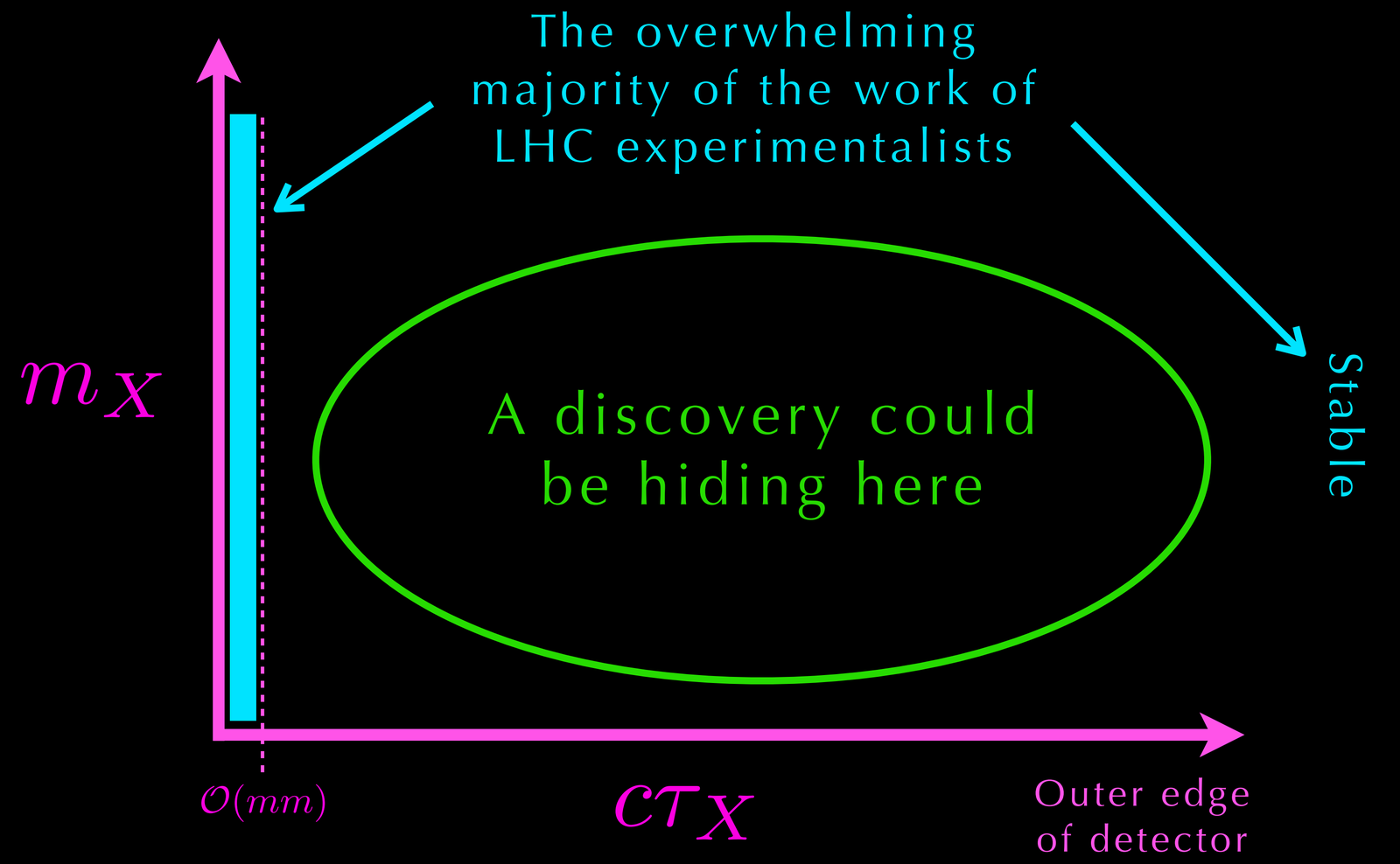


The lifetime frontier

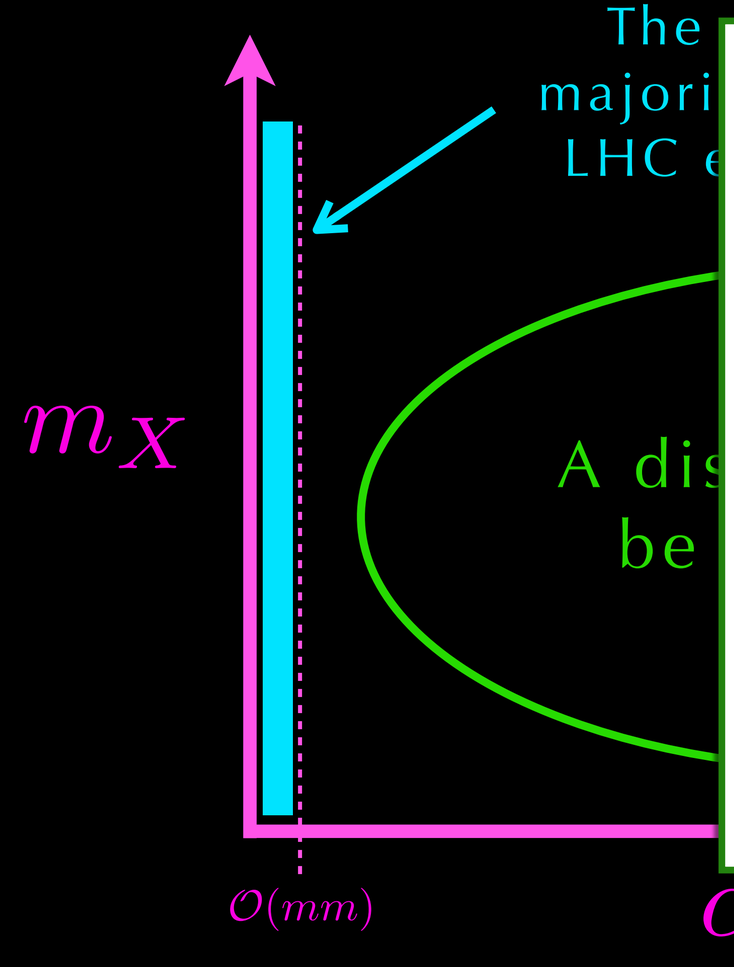


Large majority of our searches and analysis strategies at the LHC and beyond assume the new particle decays promptly

Particle lifetimes in the SM span a very wide range and long lifetimes can generically appear in BSM theories

Obliges us to perform dedicated searches for long-lived BSM particles

The lifetime frontier



We've been doing LLP searches since day one of the LHC (and at LEP, & Tevatron), but until ~2016, they were always considered fringe, and they still make up less than 10% of our "exotic" searches at ATLAS/CMS/LHCb.

But the paradigm is indeed shifting, and you are a part of it!

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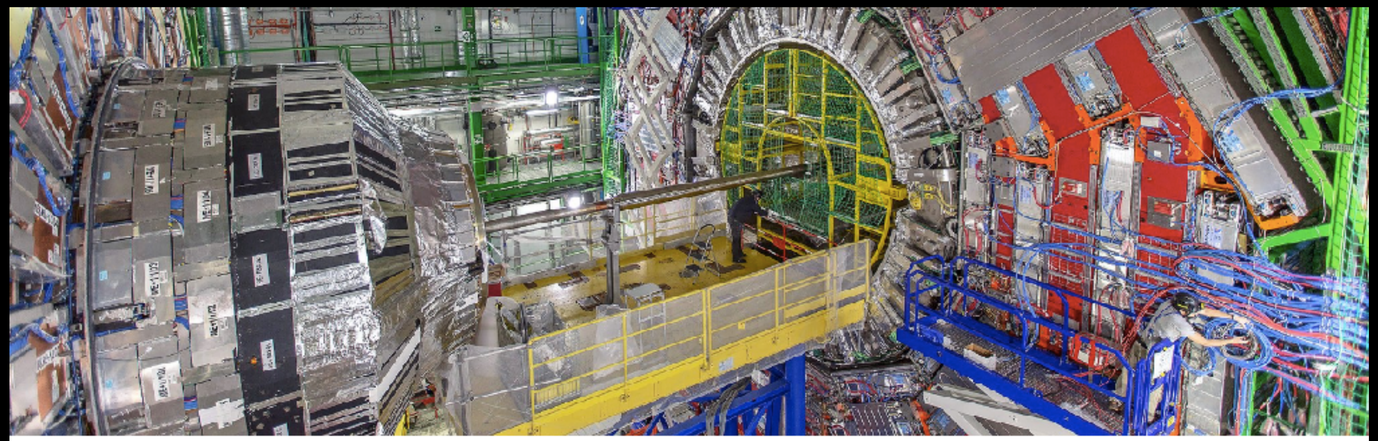
Shifting paradigms is an uphill battle



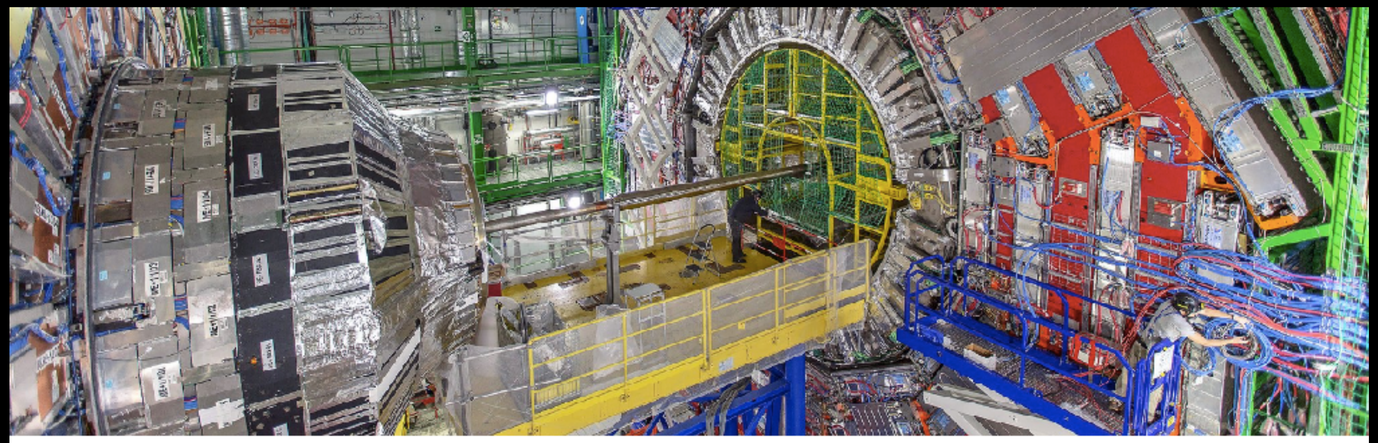
CERN hosts thousands of scientists, representing 22 member countries, all working to understand how the universe was created. CMS is one of seven detectors on site. Lesiye Davis/The New York Times

Yearning for New Physics at CERN, in a Post-Higgs Way

Physicists monitoring the Large Hadron Collider are seeking clues to a theory that will answer deeper questions about the cosmos. But the silence from the frontier has been ominous.

By DENNIS OVERBYE JUNE 19, 2017

Shifting paradigms is an uphill battle



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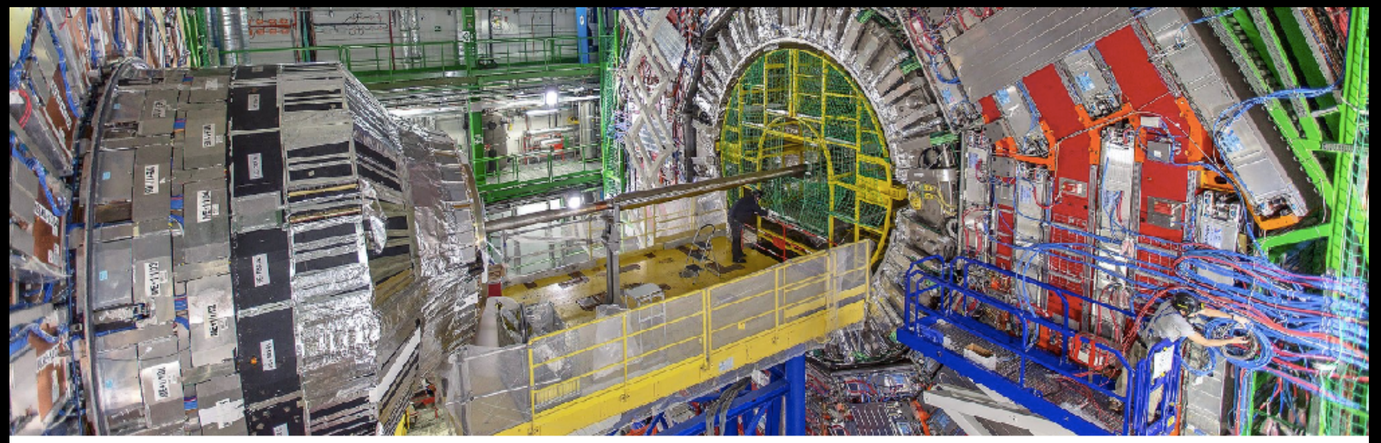
Shifting paradigms is an uphill battle



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Me:

LHC, ATLAS, CMS, LHCb, and ALICE) and that our job as physicists is not "to find the Higgs" or "to find SUSY".

Our job as physicists is to reduce, to negligible, the chance that we'll miss any possible new particles over the duration of the LHC's run. The first look at 13 TeV yielding a whole host of successful validations of the Standard Model prediction is *not* a bad thing at all. It's freedom. And for those of us who like to think in wild new ways, this is exciting.

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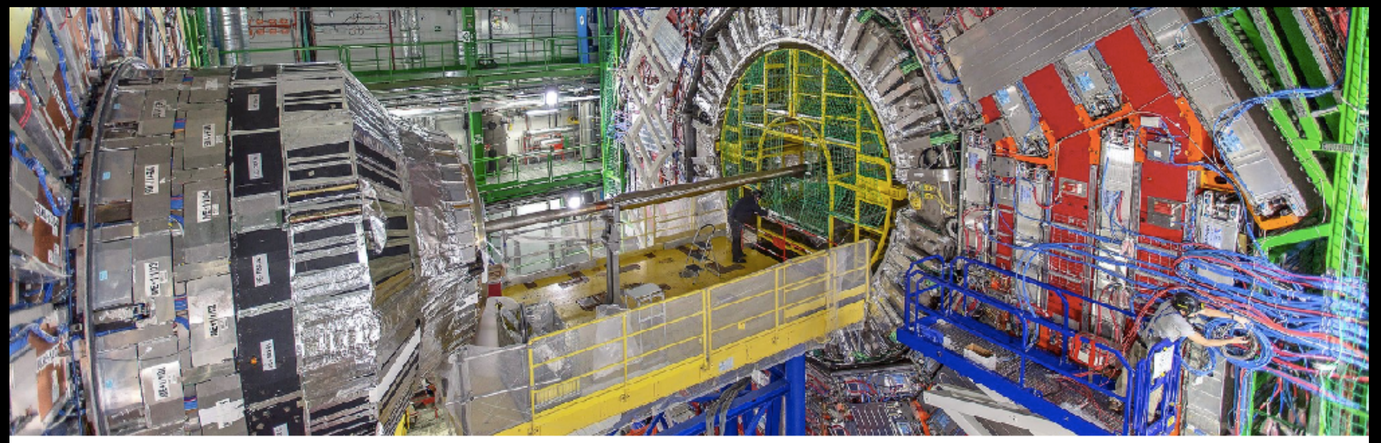

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Dennis Overbye

Actions

In response to the message from James Beacham, 21/06/2017

To: James Beacham

Inbox 22 June 2017 02:33

Well said
Lots of good ideas there but I have to get off my airplane now
Dennis

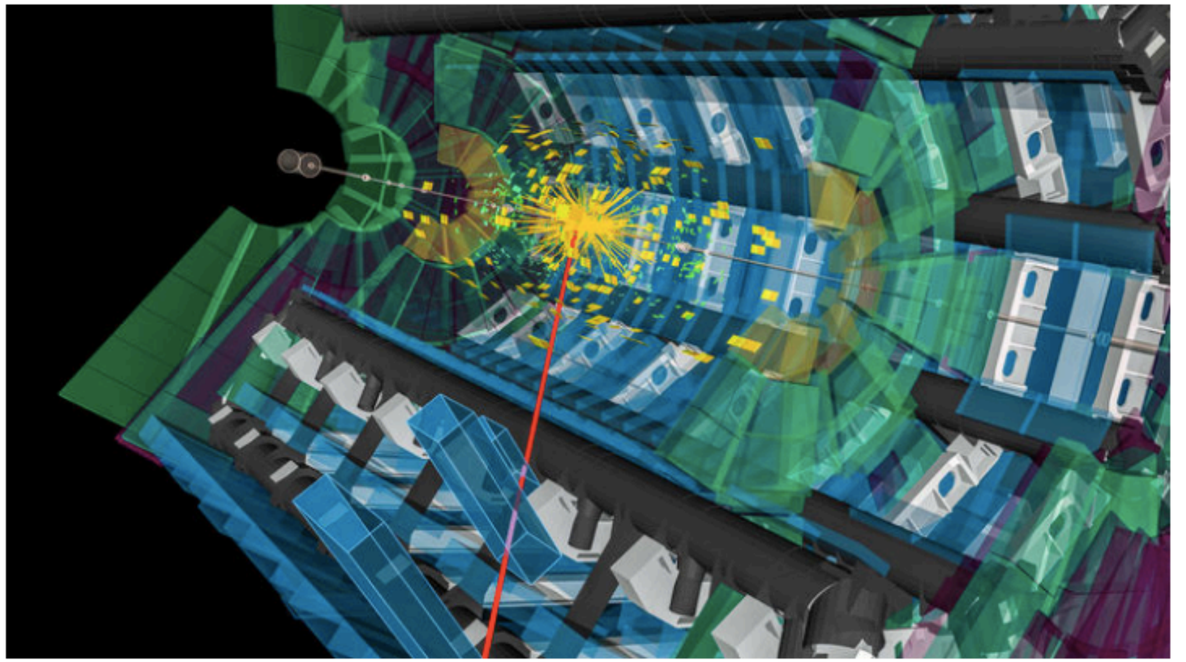
Sent from my iPhone

The world is watching

Article in Science News about our May LLP workshop at CERN

22 May 2019

Science



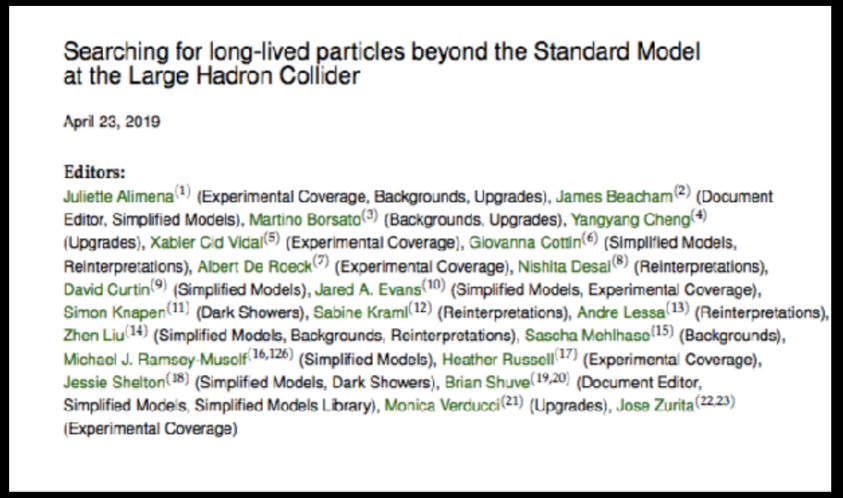
In a simulated event, the track of a decay particle called a muon (red), displaced slightly from the center of particle collisions, could be a sign of new physics. ATLAS EXPERIMENT © 2019 CERN

Atom smasher could be making new particles that are hiding in plain sight

By **Adrian Cho** | May. 22, 2019 , 12:20 PM

Are new particles materializing right under physicists' noses and going unnoticed? The world's great atom smasher, the Large Hadron Collider (LHC), could be making long-lived particles that slip through its detectors, some researchers say. Next week, they will gather at the LHC's home, CERN, the European particle physics laboratory near Geneva, Switzerland, to discuss how to capture them. They argue the LHC's next run should emphasize such searches, and some are calling for new detectors that could sniff out the fugitive particles.

Background reading



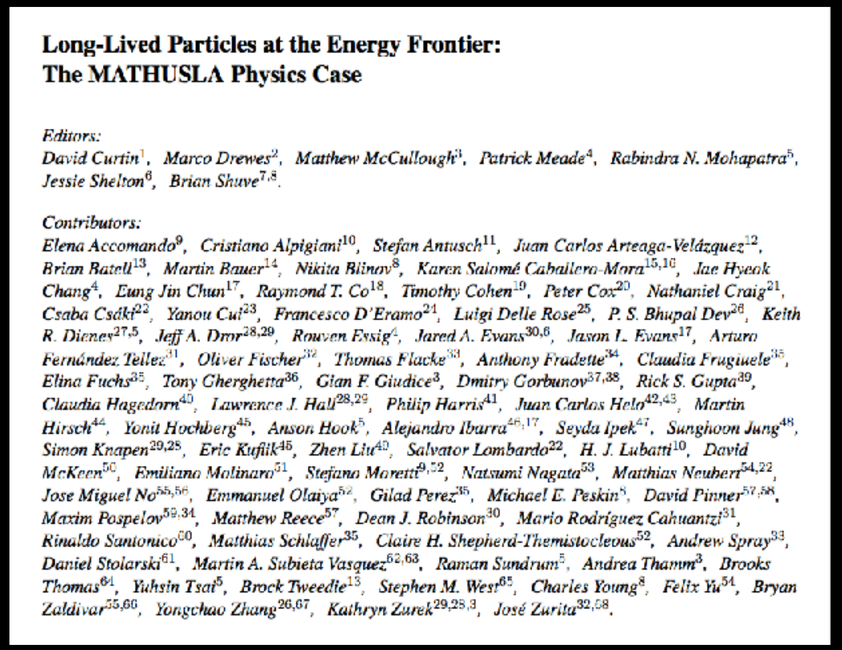
Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Editors:

Juliette Alimena[1] (Experimental Coverage, Backgrounds, Upgrades), James Beacham[2] (Document Editor, Simplified Models), Martino Borsato[3] (Backgrounds, Upgrades), Yangyang Cheng[4] (Upgrades), Xabier Cid Vidal[5] (Experimental Coverage), Giovanna Cottin[6] (Simplified Models, Reinterpretations), Albert De Roeck[7] (Experimental Coverage), Nishita Desai[8] (Reinterpretations), David Curtin[9] (Simplified Models), Jared A. Evans[10] (Simplified Models, Experimental Coverage), Simon Knapen[11] (Dark Showers), Sabine Kraml[12] (Reinterpretations), Andre Lessa[13] (Reinterpretations), Zhen Liu[14] (Simplified Models, Backgrounds, Reinterpretations), Sascha Mehlhase[15] (Backgrounds), Michael J. Ramsey-Musolf[16,126] (Simplified Models), Heather Russell[17] (Experimental Coverage), Jessie Shelton[18] (Simplified Models, Dark Showers), Brian Shuve[19,20] (Document Editor, Simplified Models, Simplified Models Library), Monica Verducci[21] (Upgrades), Jose Zurita[22,23] (Experimental Coverage)

LHC LLP Community white paper arXiv:1903.04497 (provisionally accepted for publication in J. Phys. G)



Long-Lived Particles at the Energy Frontier: The MATHUSLA Physics Case

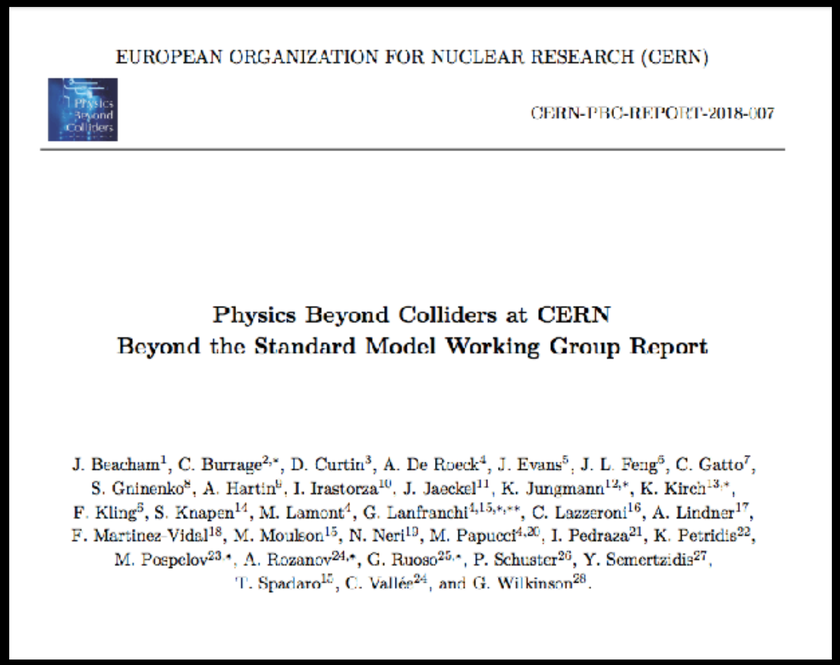
Editors:

David Curtin[1], Marco Drewes[2], Matthew McCullough[3], Patrick Meade[4], Rabindra N. Mohapatra[5], Jessie Shelton[6], Brian Shuve[7,8].

Contributors:

Elena Accomando[9], Cristiano Alpigiani[10], Stefan Antusch[11], Juan Carlos Arteaga-Velázquez[12], Brian Batell[13], Martin Bauer[14], Nikita Blinov[8], Karen Salomé Caballero-Mora[15,16], Jae Hyeok Chang[4], Eung Jin Chun[17], Raymond T. Co[18], Timothy Cohen[19], Peter Cox[20], Nathaniel Craig[21], Csaba Csáki[22], Yanou Cui[23], Francesco D'Eramo[24], Luigi Delle Rose[25], P. S. Bhupal Dev[26], Keith R. Dienes[27,5], Jeff A. Dror[28,29], Rouven Essig[4], Jared A. Evans[30,6], Jason L. Evans[17], Arturo Fernández Tellez[31], Oliver Fischer[32], Thomas Flacke[33], Anthony Fradette[34], Claudia Frugiuele[35], Elina Fuchs[35], Tony Gherghetta[36], Gian F. Giudice[3], Dmitry Gorbunov[37,38], Rick S. Gupta[39], Claudia Hagedorn[40], Lawrence J. Hall[28,29], Philip Harris[41], Juan Carlos Helo[42,43], Martin Hirsch[44], Yonit Hochberg[45], Anson Hook[5], Alejandro Ibarra[46,17], Seyda Ipek[47], Sunghoon Jung[48], Simon Knapen[29,28], Eric Kuflik[45], Zhen Liu[49], Salvator Lombardo[22], H. J. Lubatti[10], David McKeen[50], Emiliano Molinaro[51], Stefano Moretti[9,52], Natsumi Nagata[53], Matthias Neubert[54,22], Jose Miguel No[55,56], Emmanuel Olaiya[57], Gilad Perez[35], Michael E. Peskin[5], David Pinner[57,58], Maxim Pospelov[59,34], Matthew Reece[57], Dean J. Robinson[30], Mario Rodríguez Cahuantzi[31], Rinaldo Santonico[60], Matthias Schlaffer[35], Claire H. Shepherd-Themistocleous[52], Andrew Spray[33], Daniel Stolarski[61], Martin A. Subieta Vasquez[62,63], Raman Sundrum[5], Andrea Thamm[3], Brooks Thomas[64], Yuhsin Tsai[5], Brock Tweedie[13], Stephen M. West[65], Charles Young[8], Felix Yu[54], Bryan Zaldivar[55,66], Yongchao Zhang[26,67], Kathryn Zurek[29,28,3], José Zurita[32,68].

MATHUSLA physics case document arXiv:1806.07396 (accepted for publication in Reports on Progress in Physics)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PBC-REPORT-2018-007

Physics Beyond Colliders at CERN
Beyond the Standard Model Working Group Report

J. Beacham[1], C. Burrage[2,*], D. Curtin[3], A. De Roeck[4], J. Evans[5], J. L. Feng[6], C. Gatto[7], S. Gninenko[8], A. Hartin[9], I. Irastorza[10], J. Jaeckel[11], K. Jungmann[12,*], K. Kirch[13,*], F. Kling[5], S. Knapen[14], M. Lamont[4], G. Lanfranchi[4,15,*,**], C. Lazzeroni[16], A. Lindner[17], F. Martinez-Vidal[18], M. Moulson[15], N. Neri[19], M. Papucci[4,20], I. Pedraza[21], K. Petridis[22], M. Pospelov[23,*], A. Rozanov[24,*], G. Ruoso[25,*], P. Schuster[26], Y. Semertzidis[27], T. Spadaro[15], C. Vallée[24], and G. Wilkinson[28].

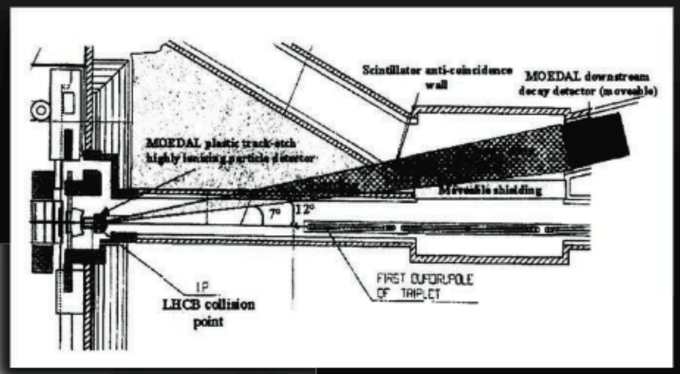
PBC BSM WG report arXiv:1901.09966 (to be submitted for publication in J. Phys. G)

The LHC LLP white paper was designed to be a comprehensive document — a combination review paper, set of recommendations, accounting of open discovery possibilities, record of accumulated knowledge, and speculation for the future — that, combined with the MATHUSLA physics case document and the PBC BSM WG report, serves as the definitive guide to LLP searches at the LHC and beyond

The future is now

MoEDAL's 1st LoI to the LHCC in 1999

*Originally, MoEDAL was proposed to search for Highly Ionizing Particles **and** new long-lived particles*



ELSEVIER

Nuclear Physics B (Proc. Suppl.) 78 (1999) 52–57

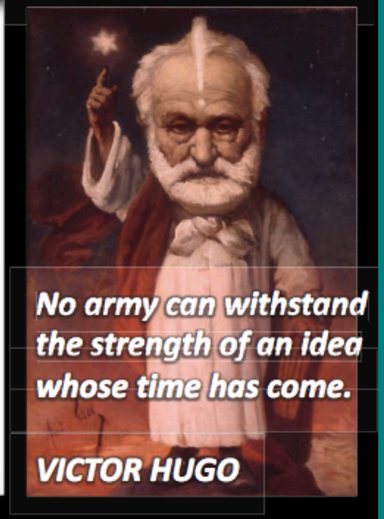
www.elsevier.nl/locate/npe

Searching for Exotic Particles at the LHC with Dedicated Detectors.

J. L. Pinfold, [a*]

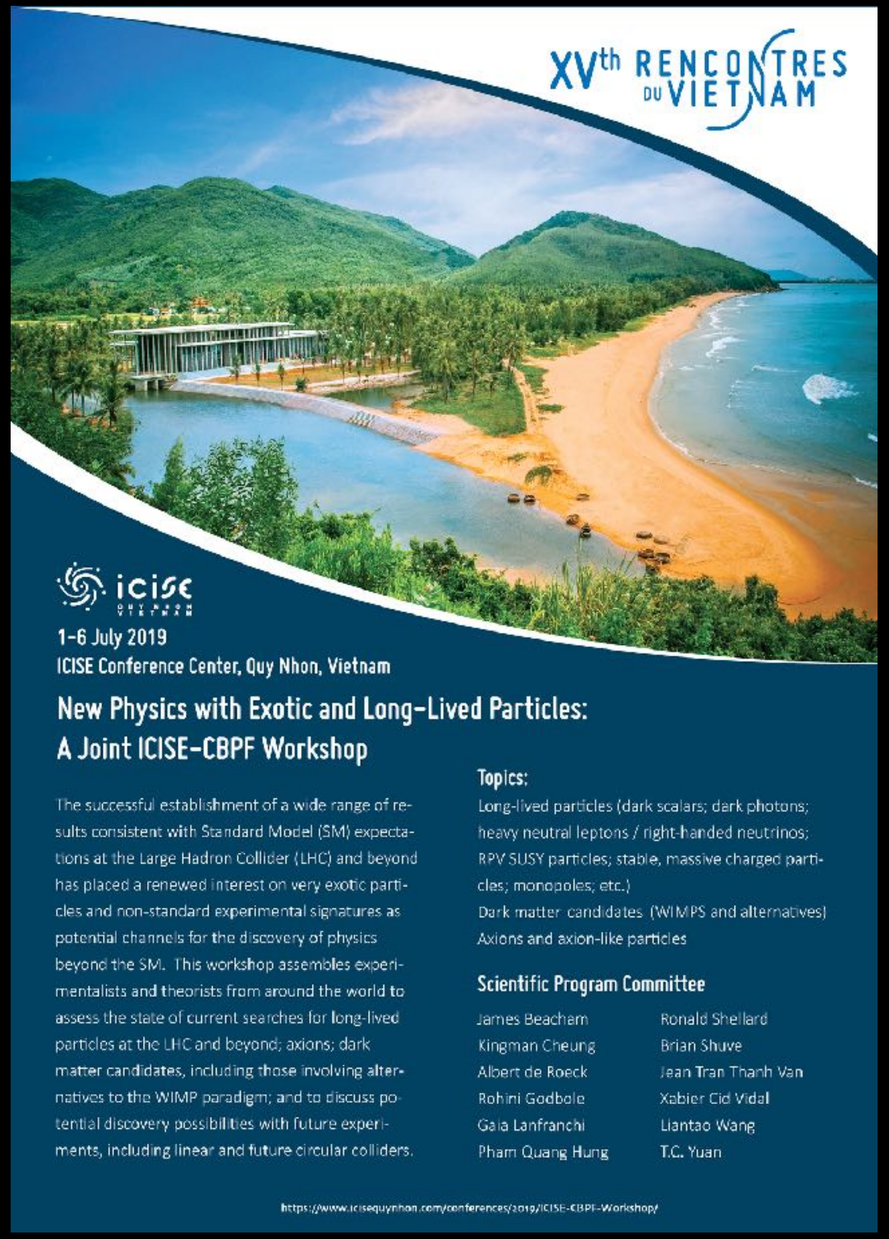
[a]Centre for Subatomic Research, University of Alberta,
Edmonton, Alberta T6G 2N4,Canada

The LHC will open up a new energy regime where it may be possible to observe physics beyond the Standard Model. Therefore the search for exotic phenomena, such as: magnetic monopoles, massive stable particles; slowly decaying exotic particles; highly penetrating particles; and, free quarks and gluons, will be an important part of the LHC physics program. We propose that the search strategy for exotics planned for the main LHC detectors be extended with modest dedicated experiments designed to enhance the physics reach of the LHC. We shall use two examples to illustrate this thesis. First, a passive, plastic track-etch detector "ball" designed to detect highly ionizing particles and measure their Z/β. Such a detector is currently the subject of a Letter of Intent to the LHCC from the MOEDAL collaboration. Another (active) small acceptance detector – protected by shielding and monitoring an extended decay zone – specifically designed to detect massive stable particles and detect slowly decaying particles, is described. The use of such a detector at the LHC, has recently been proposed.



J. Pinfold talk

Leveraging the global community

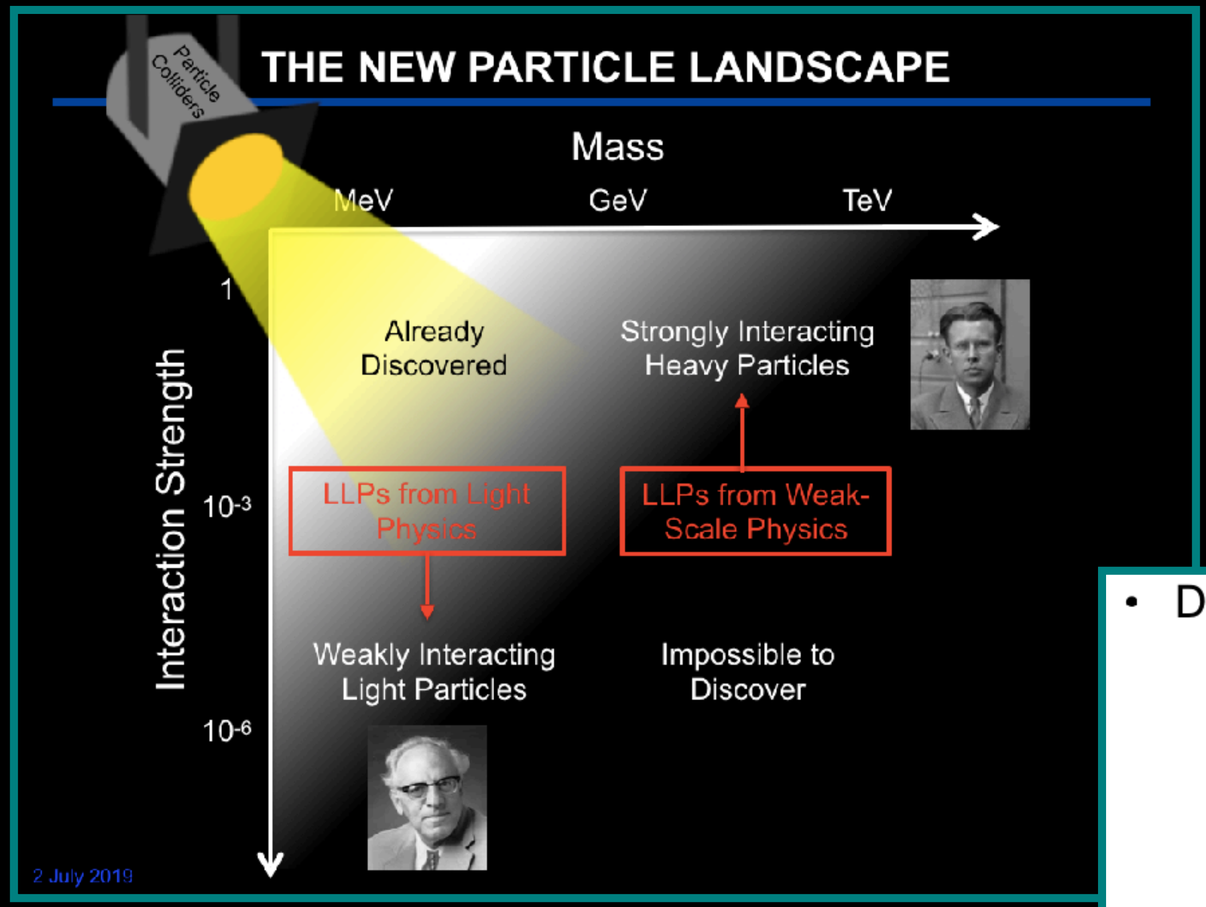


Workshops like this are a vital component of the global effort toward ensuring that "exotic" shifts from meaning "weird" to meaning "mapping the unknown, as is our duty as physicists"

This particular workshop has the unique function of highlighting the research programs of southeast Asia and Latin America, as a joint workshop of ICISE and CBPF, and we're fortunate to be able to do so with many of the pioneers of these searches here in person

We learned (or were reminded of) many lessons throughout the last four days

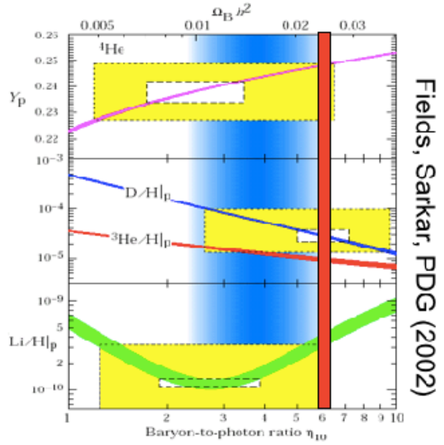
Lesson #1: LLPs are generic and ubiquitous

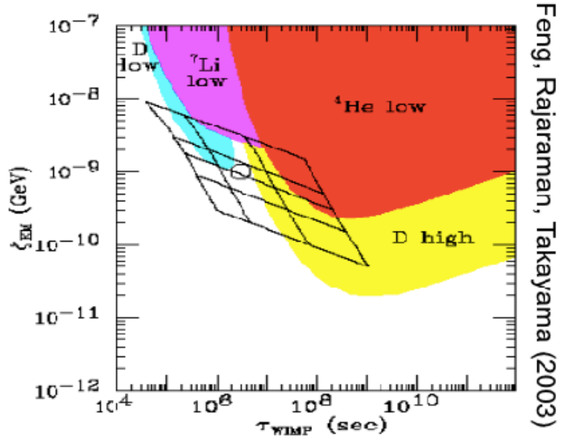


J. Feng reminded us that LLPs — BSM particles with lifetimes longer than what we'd consider "prompt" at, e.g., the central detectors of the LHC — arise very naturally from basic theoretical considerations...

...especially those with cosmological signficance

- Decays to superWIMPs can impact light element abundances





- BBN excludes $\chi \rightarrow Z\tilde{G}$, but $\tilde{l} \rightarrow l\tilde{G}$ may be ok and may even fix the longstanding lithium anomaly! It is not true that BBN categorically excludes LLP lifetimes > 1s.

LLPs feature naturally in ideas connecting particle physics and cosmology — and sometimes our "standard" assumptions are misguided!

Lesson #2: LLP searches at ATLAS/CMS/LHCb are on fire...

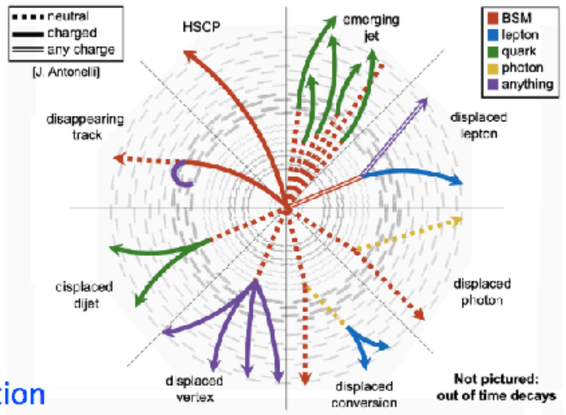
Long-Lived Particle Searches

Different LLP varieties:

- Charges
- Final states
- Decay locations
- Lifetimes

Some challenges:

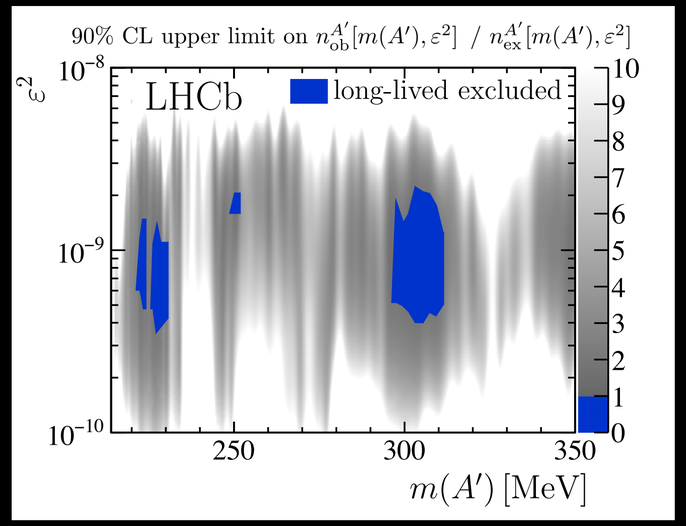
- Dedicated triggers
- Unique object reconstruction
- Atypical backgrounds
- Unusual discriminating variables



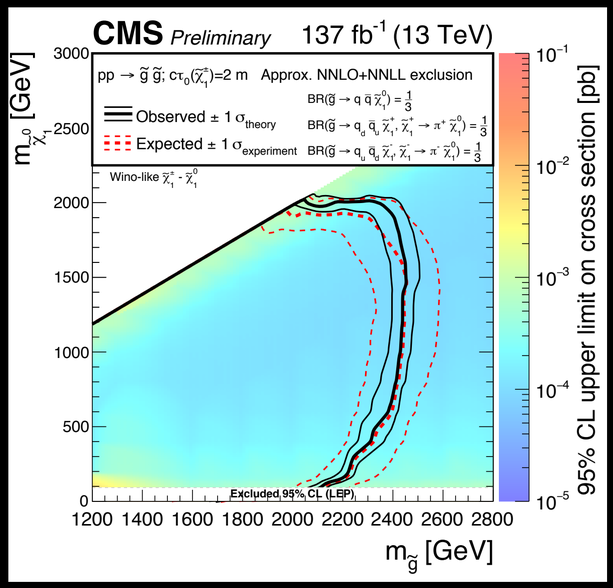
This talk will showcase a few recent example LLP searches to illustrate the variety of signatures and ~~challenges~~ opportunities for innovation

July 2, 2019 Juliette Alimena 18

J. Alimena talk

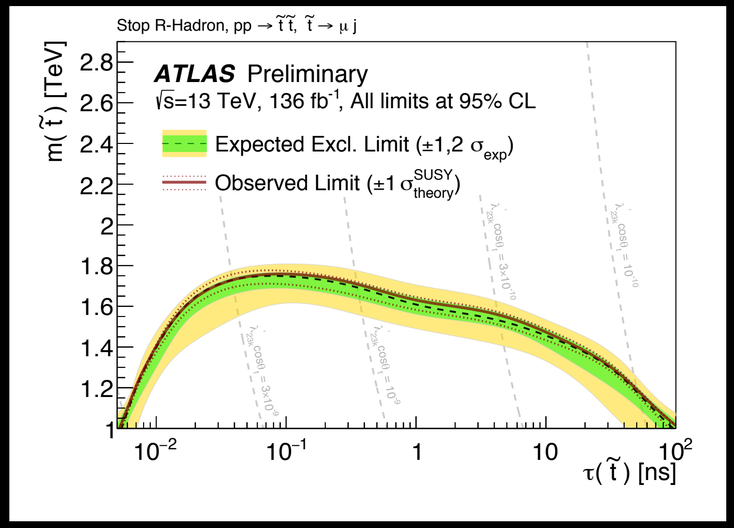


L. de Paula talk



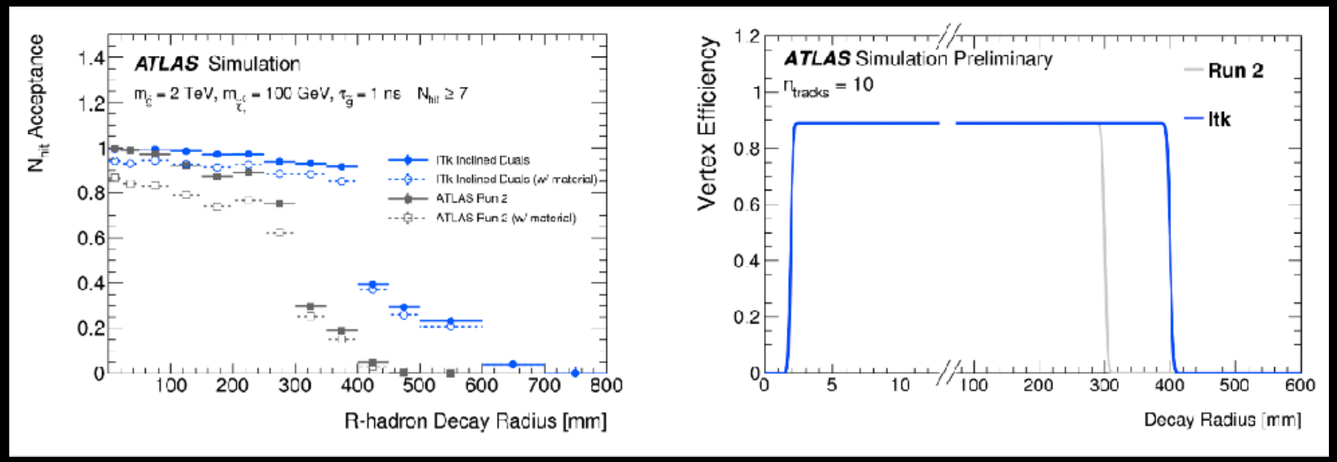
H. Rejeb Sfar talk

Despite challenges inherent to these searches, many dedicated, inventive people and teams continue to make great progress, including several searches already using the full Run 2 dataset

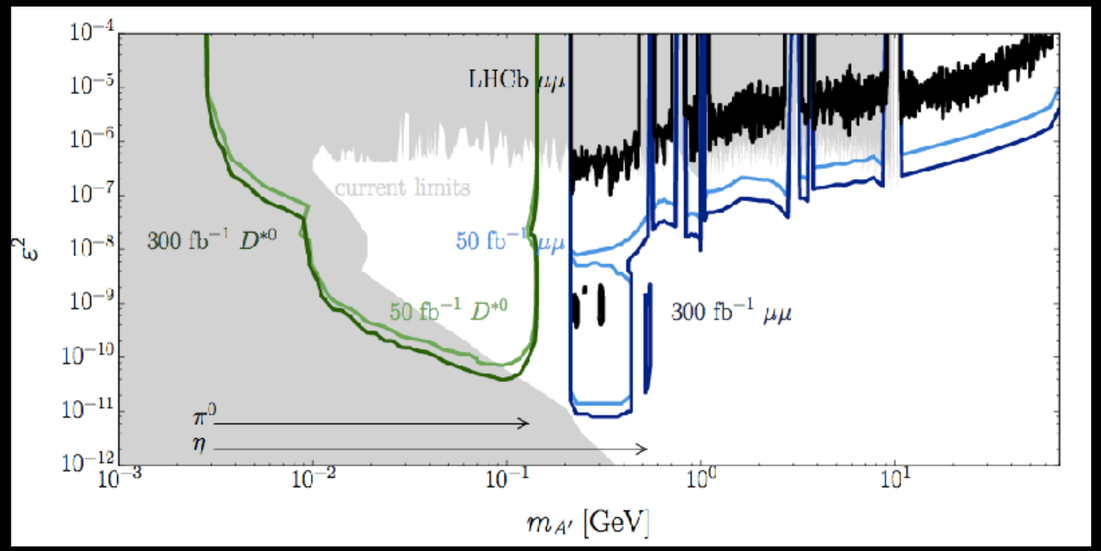


A. Morris talk

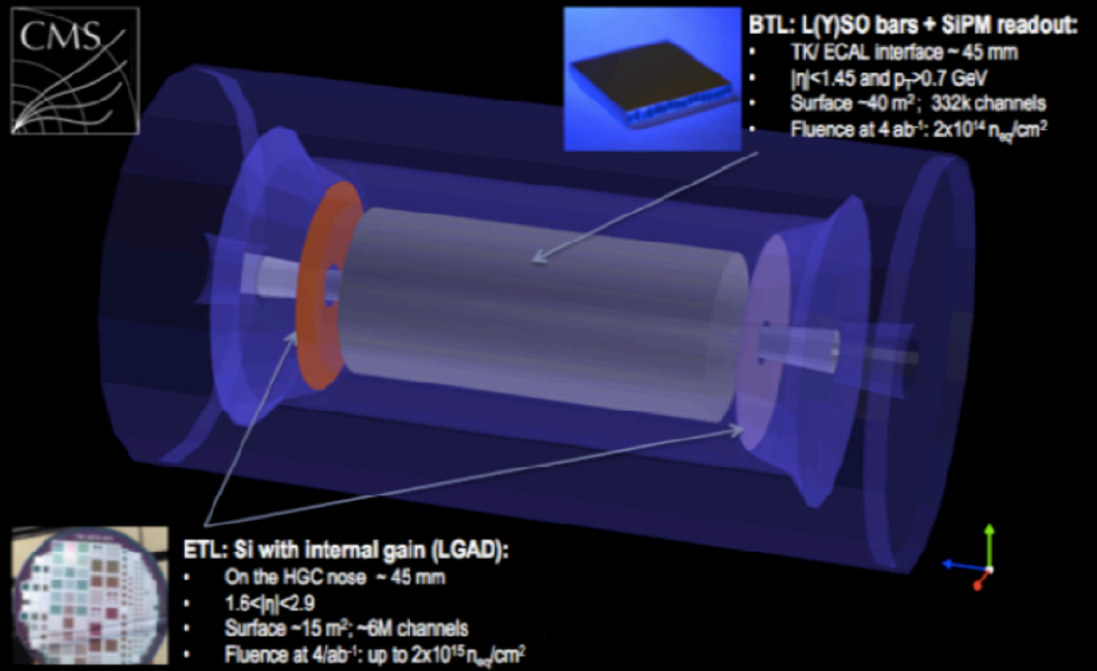
Lesson #3: …and they're just going to get hotter



A. Morris talk



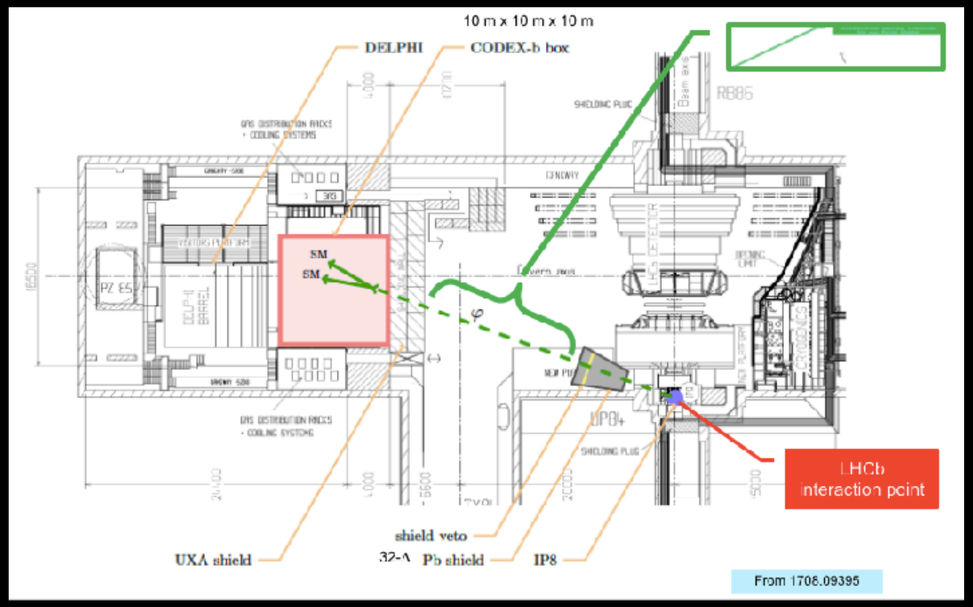
L. de Paula talk



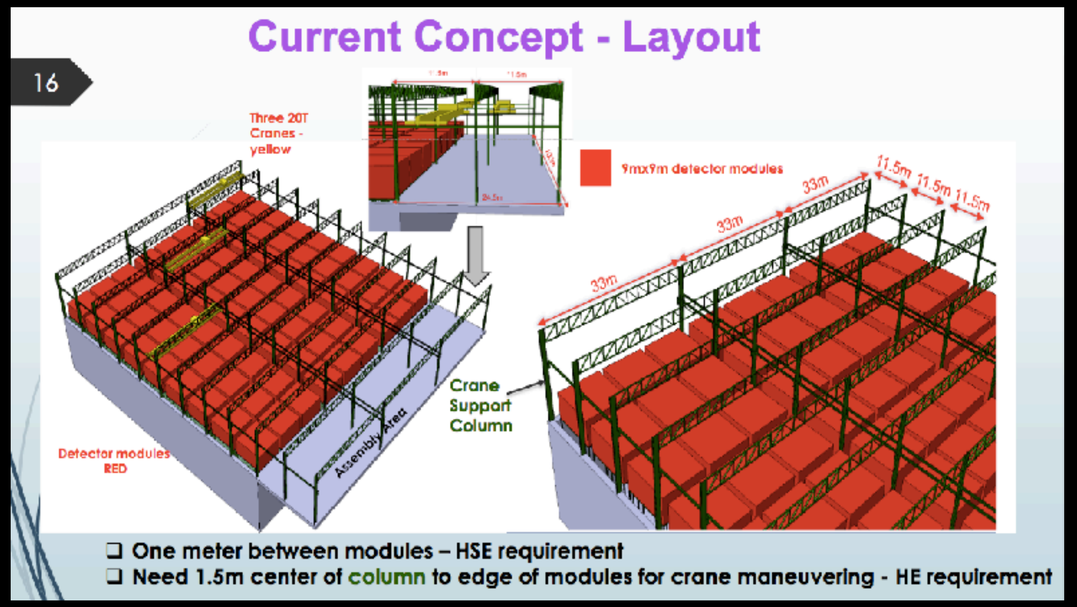
J. Alimena talk

Plans for Run 3 and HL-LHC upgrades promise to greatly improve our ability to detect LLPs

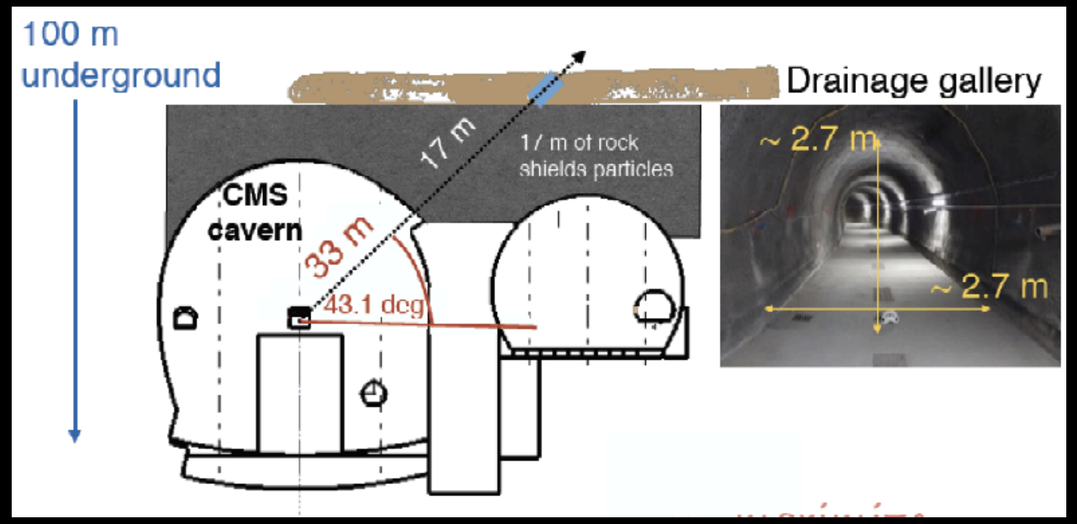
Lesson #4: LLP searches don't end at the outer edges of ATLAS/CMS/LHCb



CODEX-b: C. Young talk

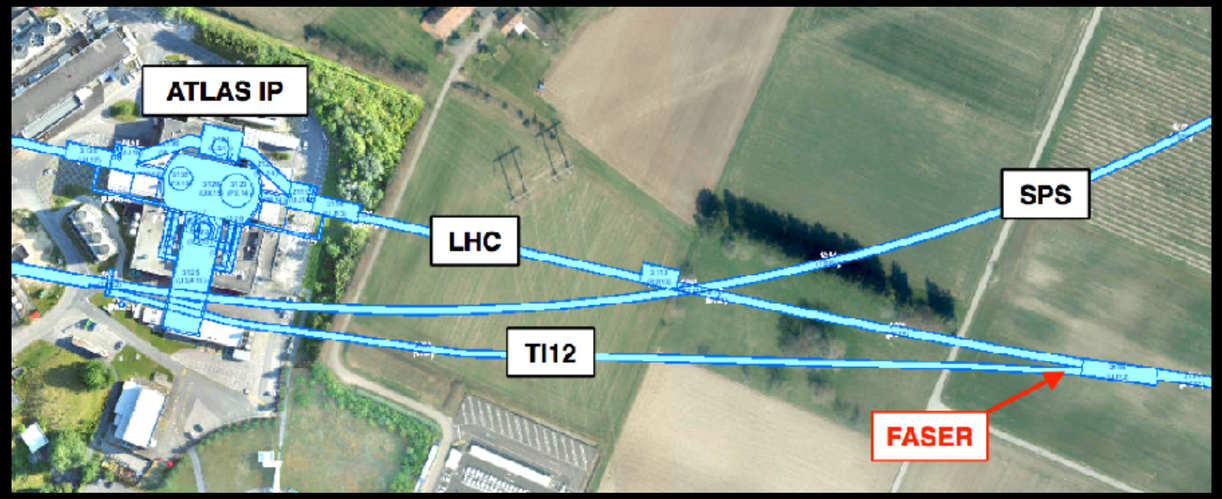


MATHUSLA: H. Lubatti talk

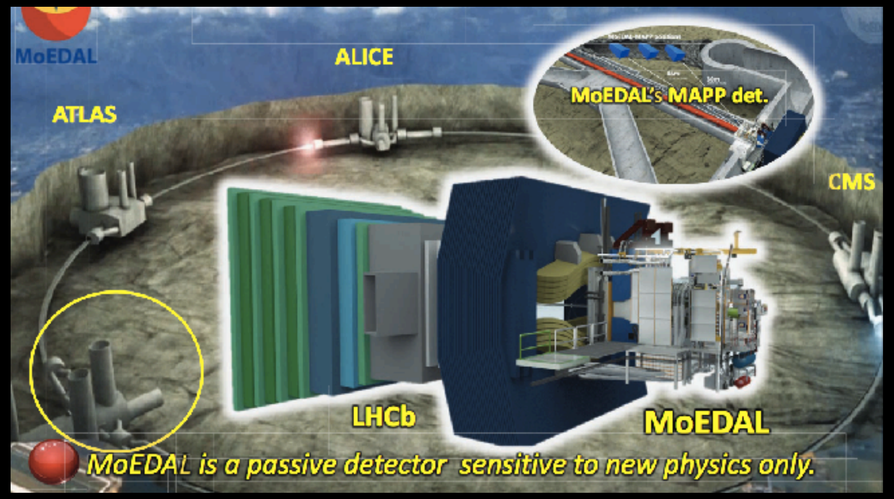


MilliQan: A. de Roeck talk

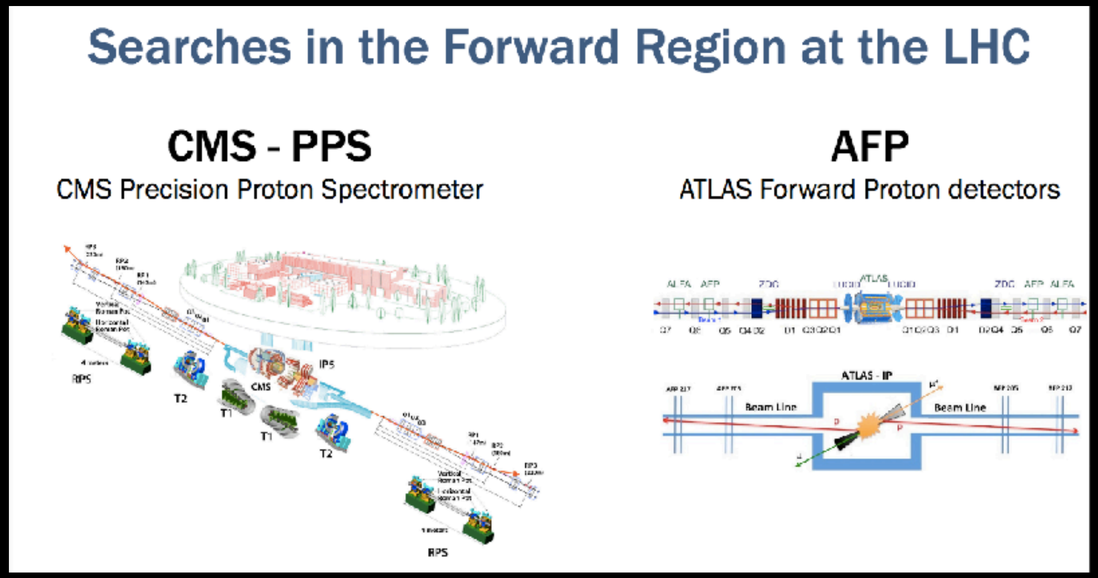
Lesson #4: LLP searches don't end at the outer edges of ATLAS/CMS/LHCb



FASER: J. Feng talk



MoEDAL/MAPP: J. Pinfold talk

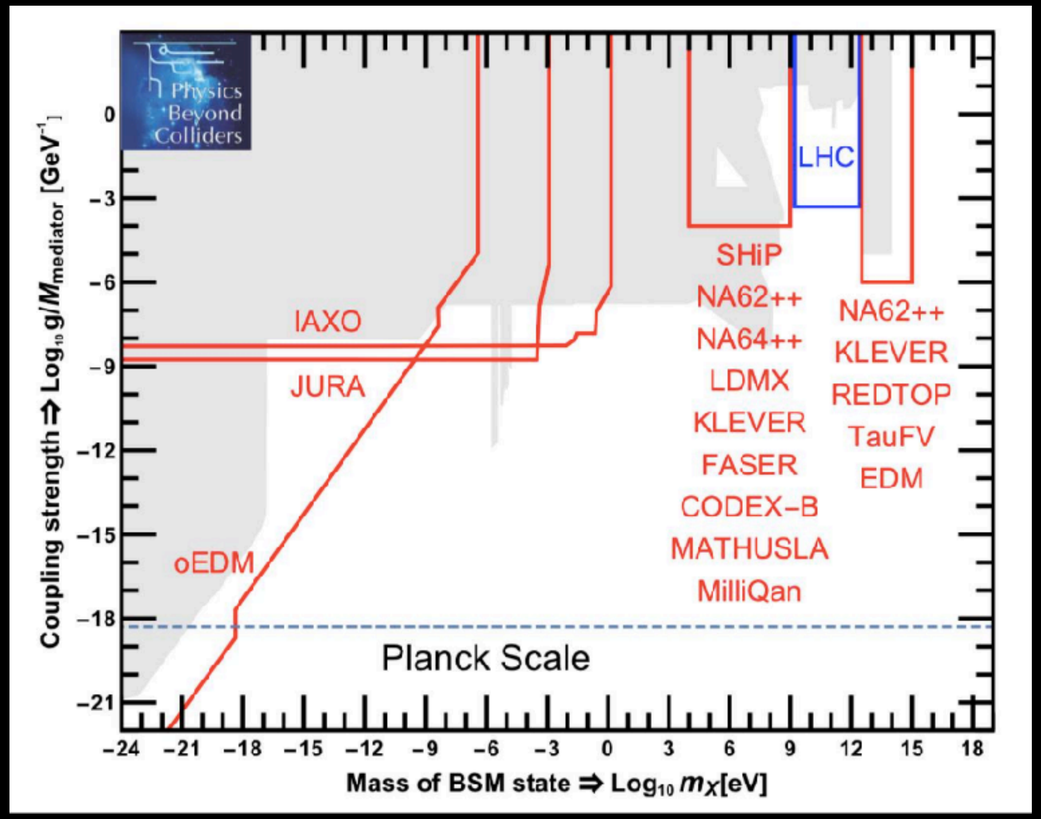


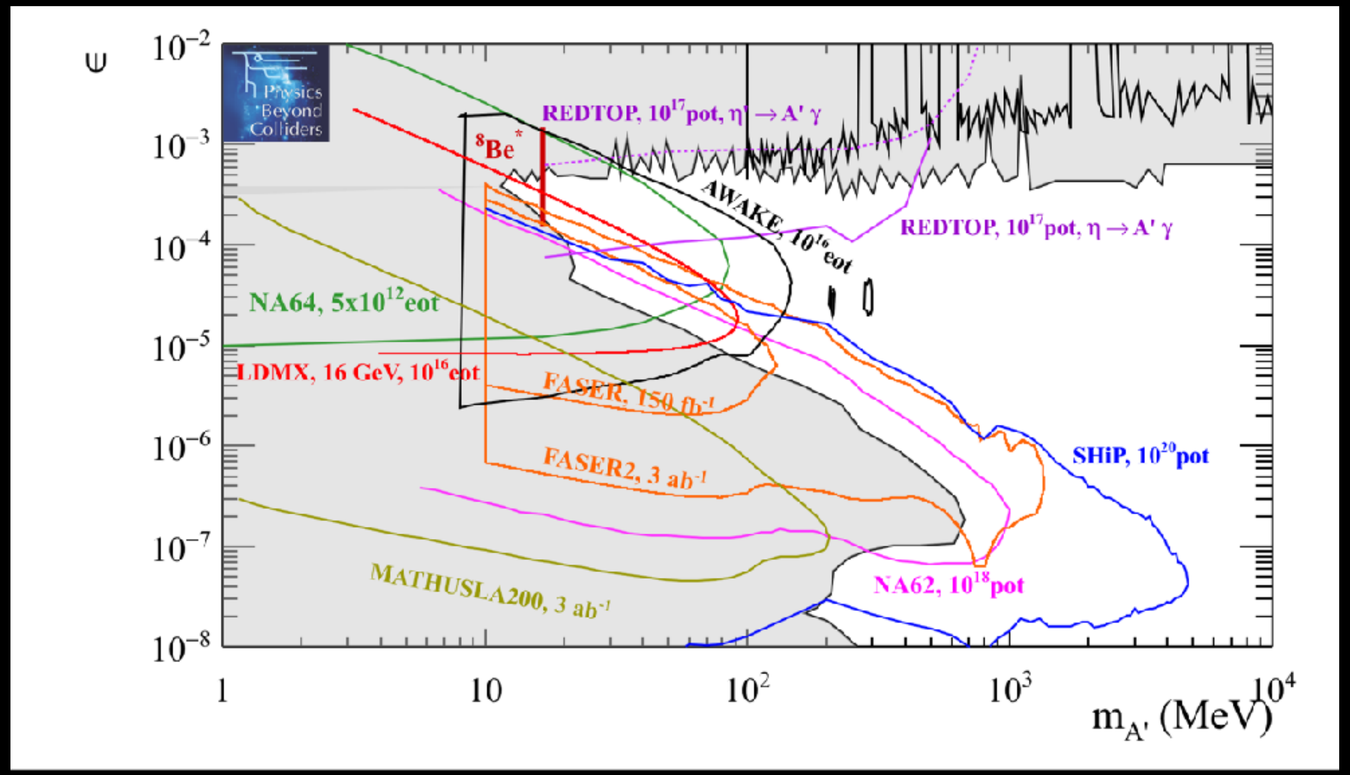
Forward experiments: A. Moraes talk

- We should pursue the search for long-lived particles at the LHC vigorously and collaboratively!

C. Young talk

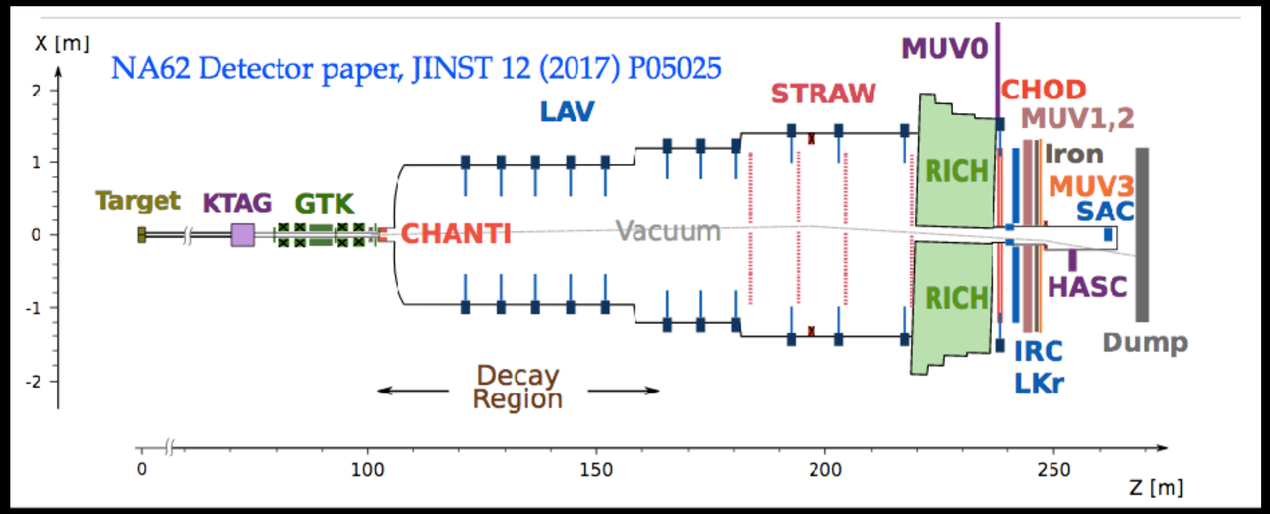
Lesson #5: Experiments beyond colliders are necessary for a comprehensive LLP research program



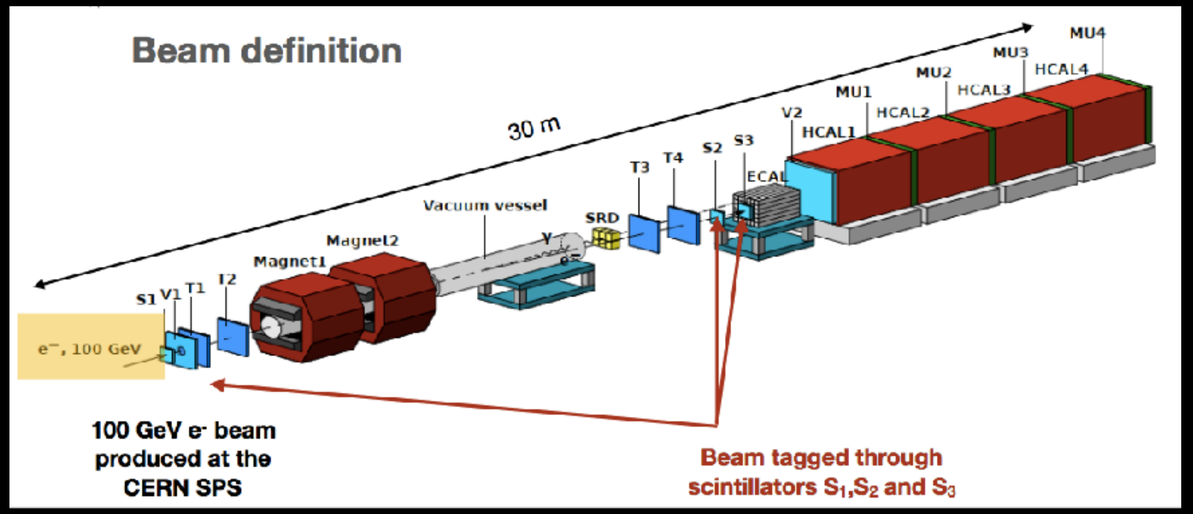


A. de Roeck talk

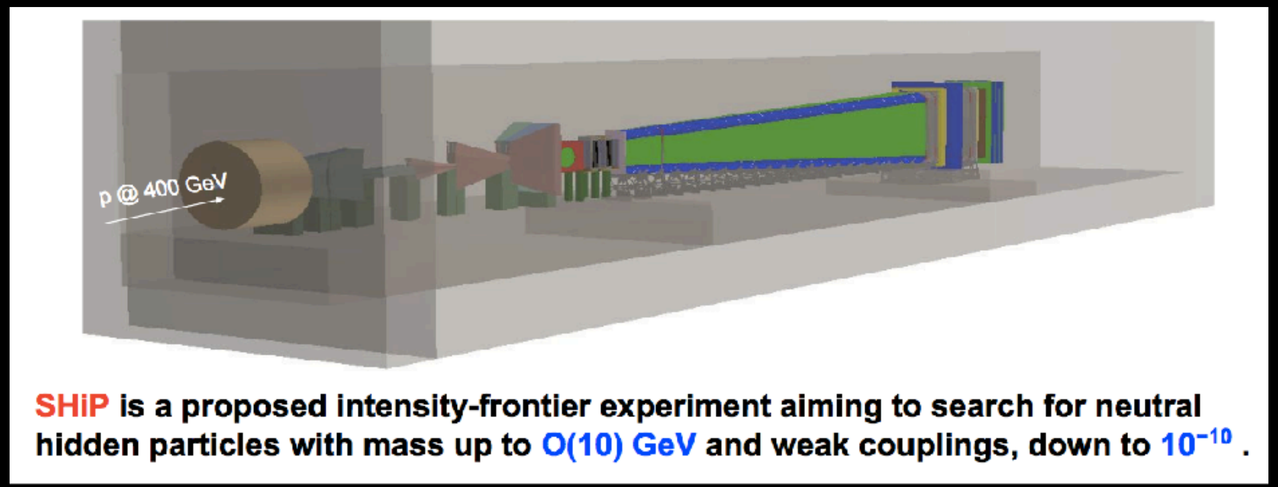
Lesson #5: Experiments beyond colliders are necessary for a comprehensive LLP research program



NA62: A. Shaikhiev talk

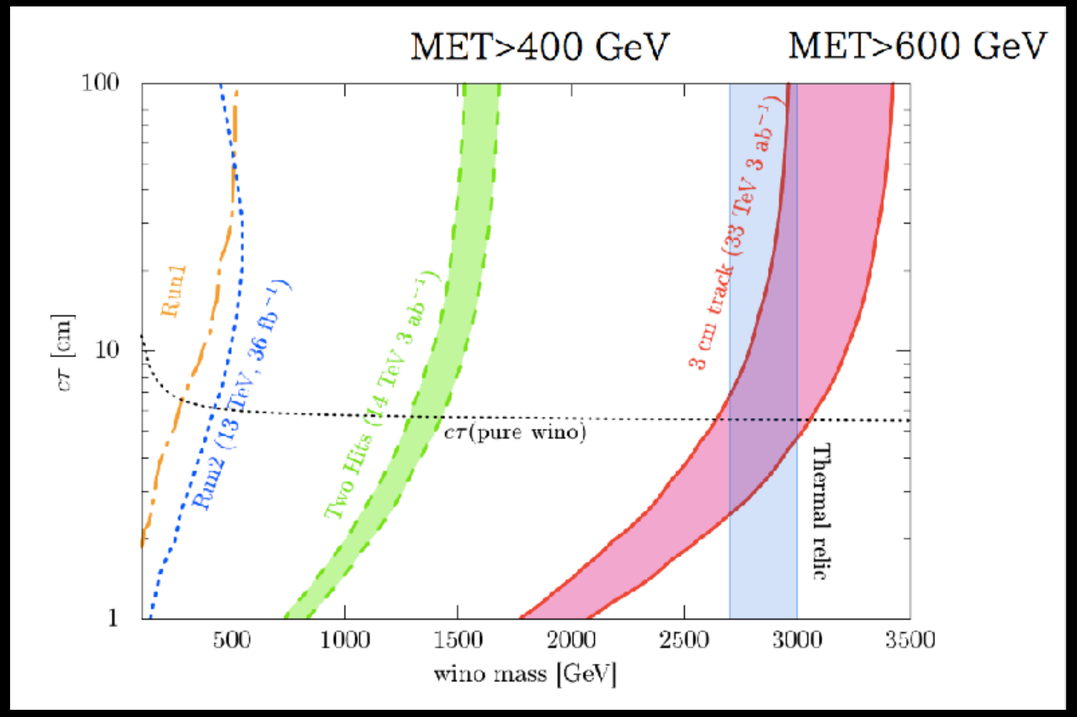


NA64: L. Molina Bueno talk

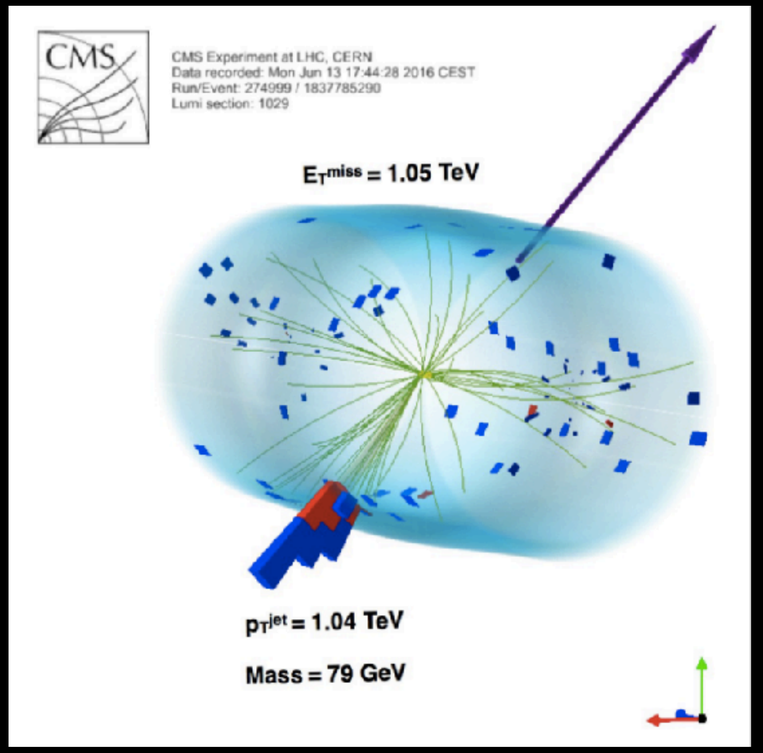


SHiP: Ia. Bezshyiko talk

Lesson #6: The quest for dark matter (DM) is leading in a multiplicity of directions



Wino DM: S. Shirai talk

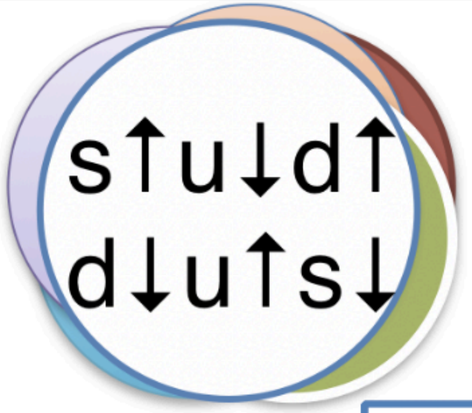


J. Rani Komaragiri talk

- Heavy neutrinos with masses below the electroweak scale can simultaneously generate the **light neutrinos masses** (seesaw mechanism) and **baryon asymmetry of the universe** (leptogenesis)… and possibly even the **Dark Matter**.

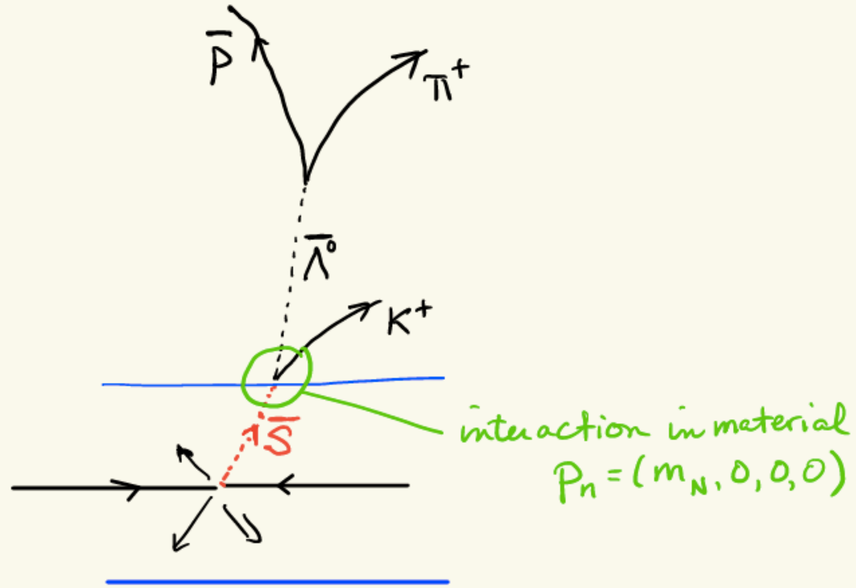
M. Drewes talk

Lesson #6: The quest for dark matter (DM) is leading in a multiplicity of directions



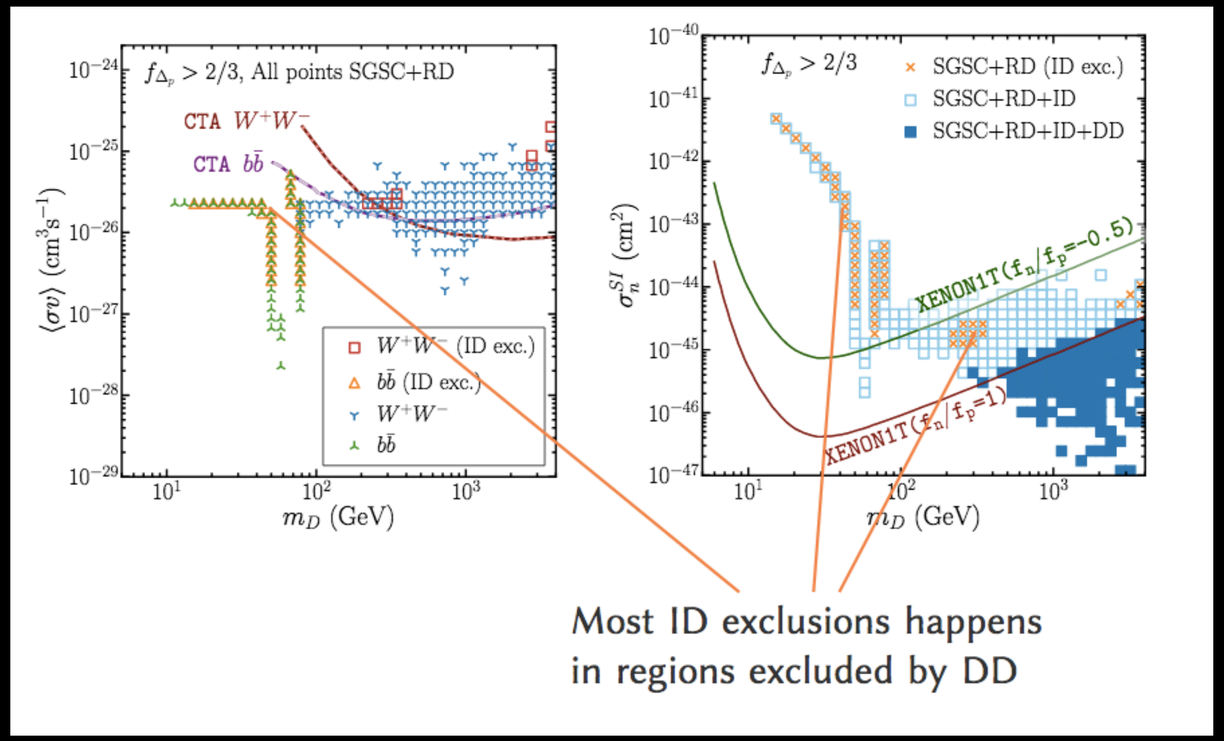
Q=0, B=2
Spin-0, scalar
m ~ 1.7-2 GeV

Crucial fact: *S does not couple to pions*
➜ radius of S much smaller than usual hadrons
➜ hard to produce S with hadrons

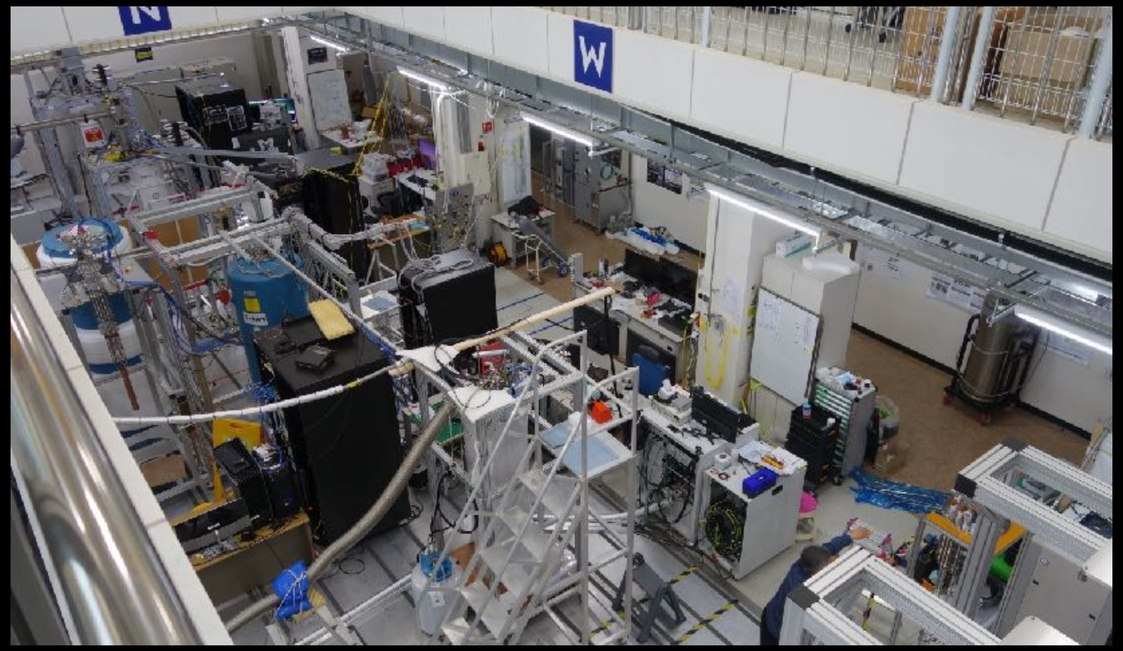


A stable sexaquark as DM: G. Farrar talk

Lesson #6: The quest for dark matter (DM) is leading in a multiplicity of directions

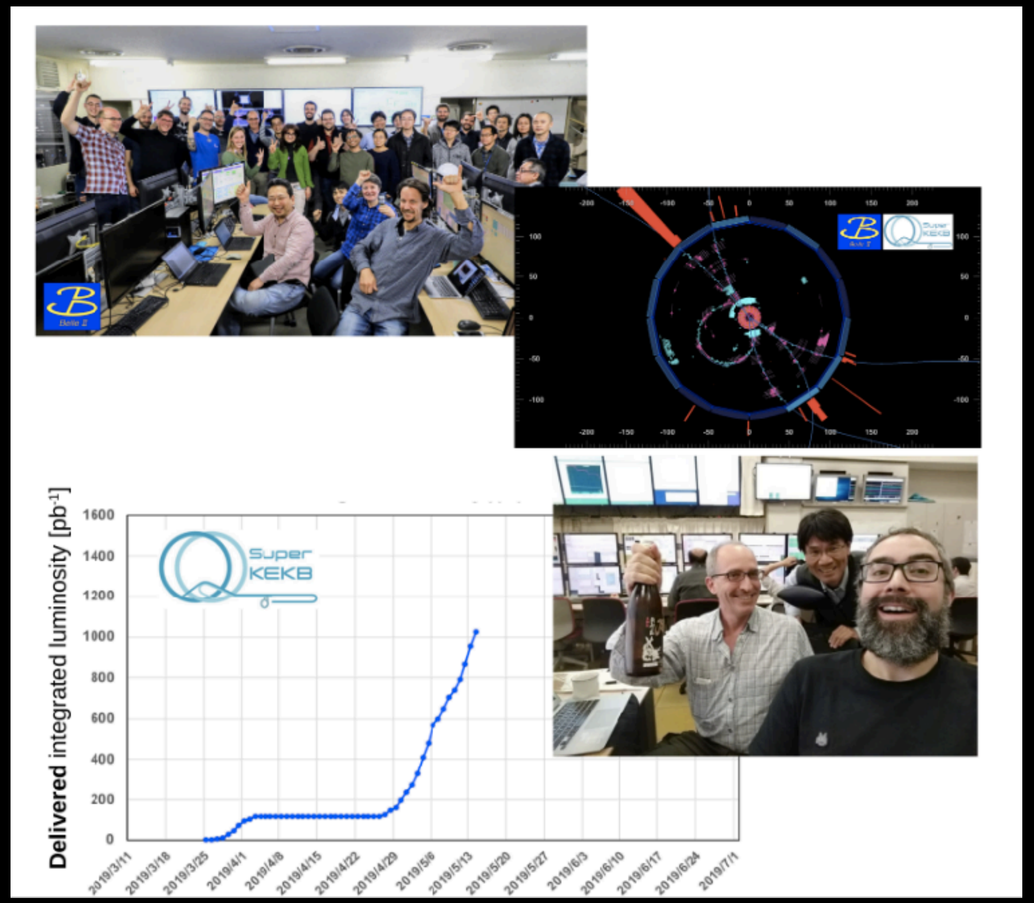


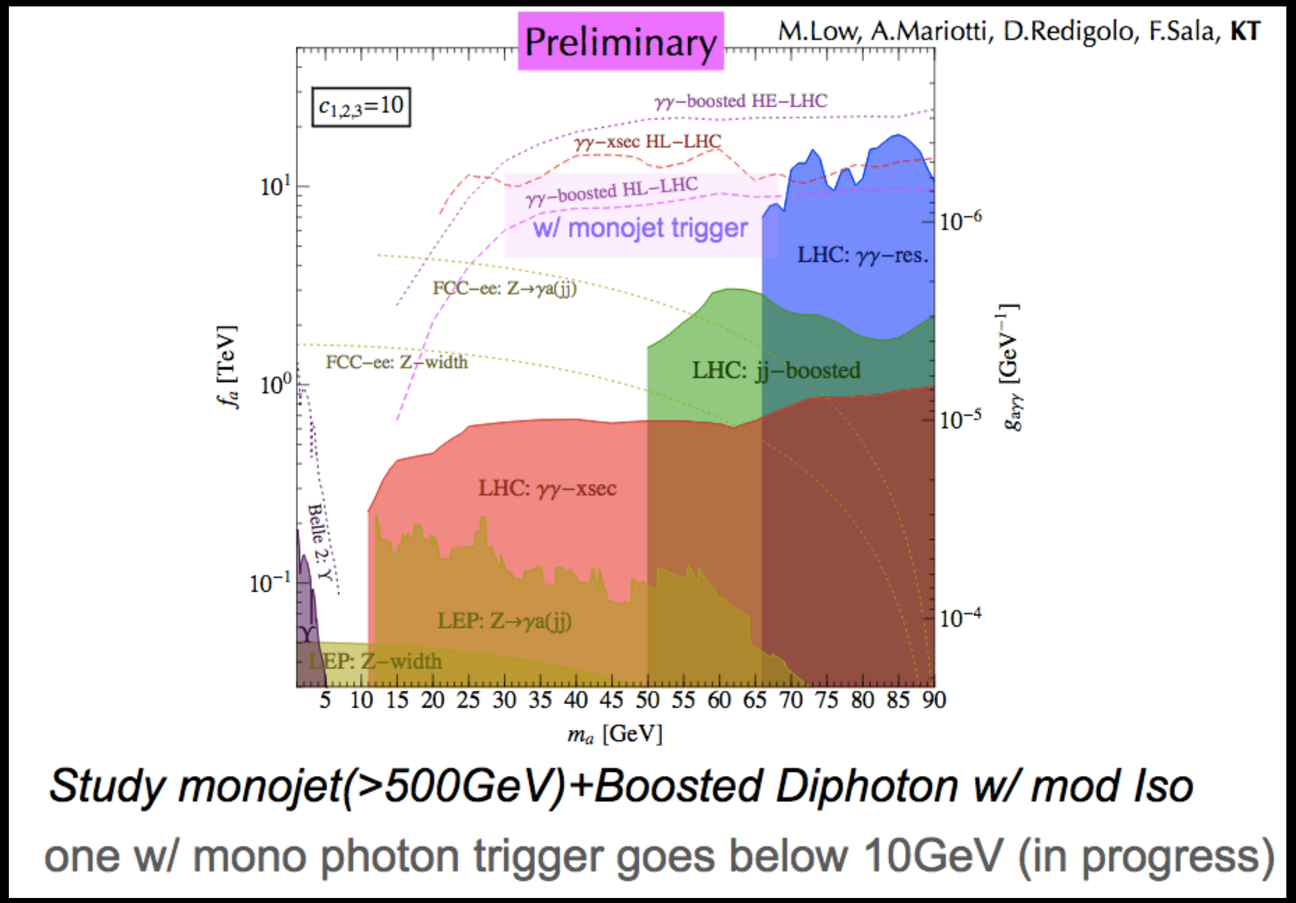
Triple DM from a gauged 2HDM:
R. Ramos talk



Axion DM search at CAPP:
S. Youn talk

Lesson #7: Dark photons; axions; ALPs; light, invsible particles are being pursued with vigor

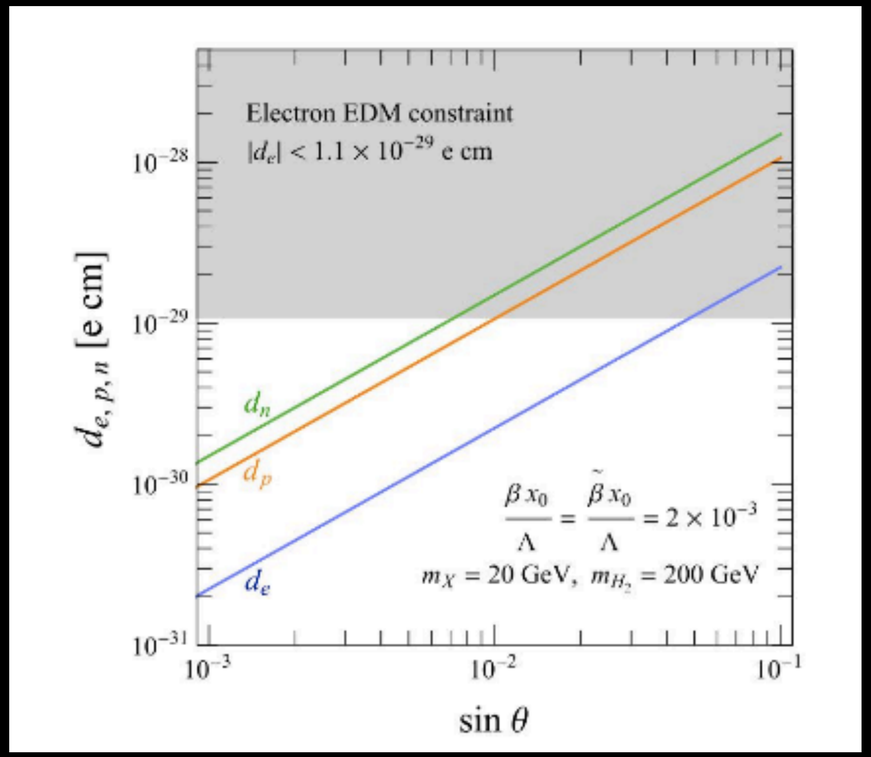




Belle II: I. Jaeglé talk

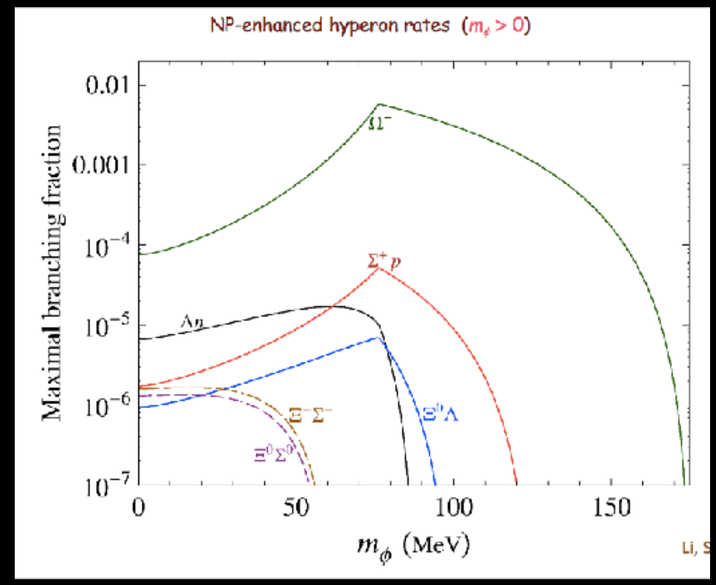
ALPs at the LHC: K. Tobioka talk

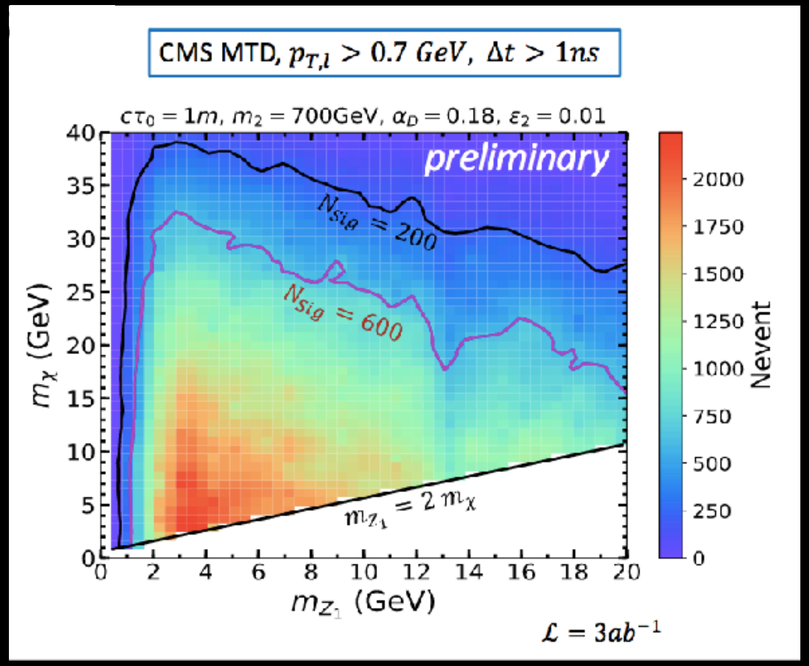
Lesson #7: Dark photons; axions; ALPs; light, invsible particles are being pursued with vigor



CP-violating dark photon tests: G. Li talk

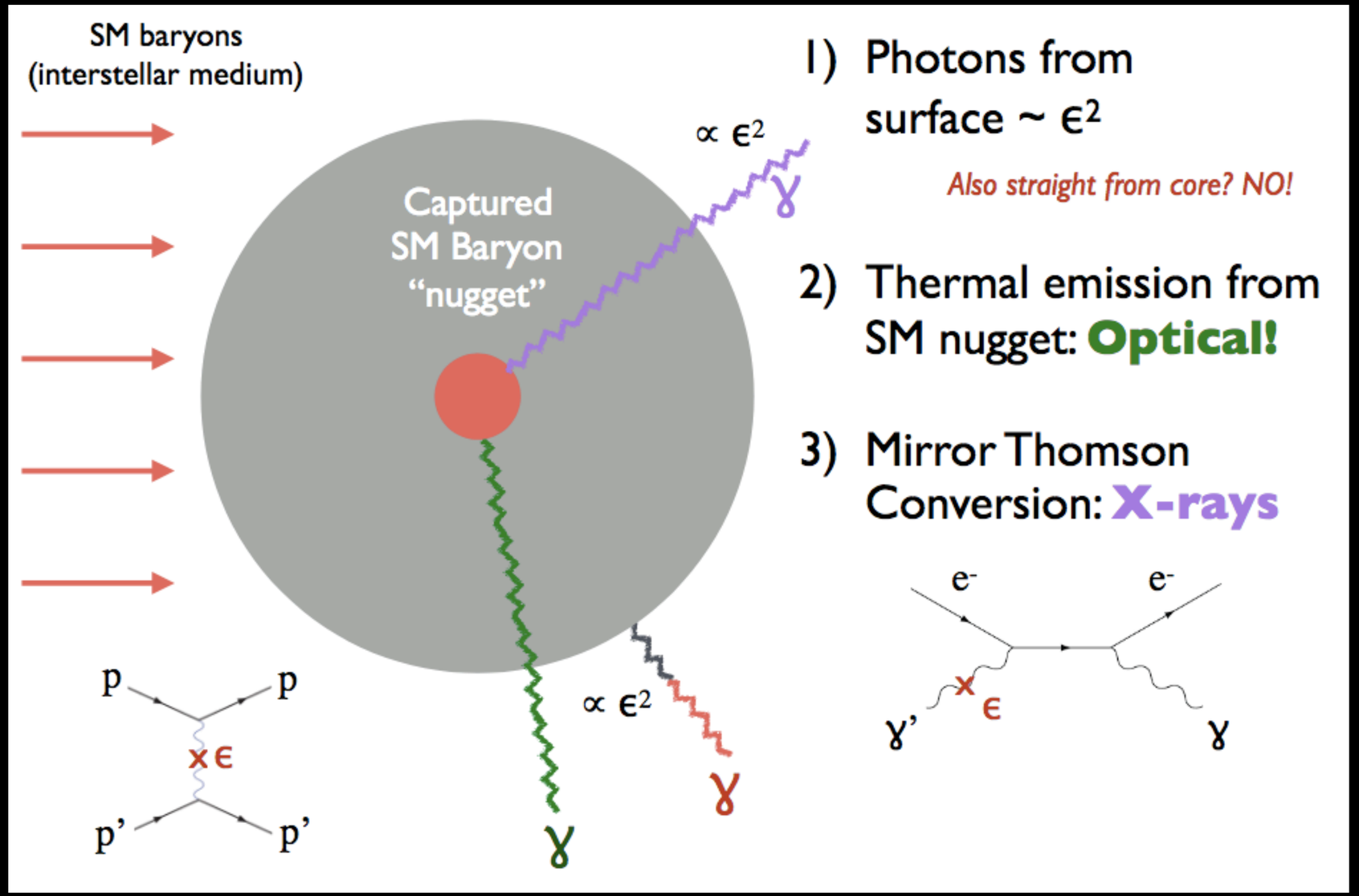
Plans to search for deviations from expected BRs in hyperon decay modes at BESIII: J. Tandean talk



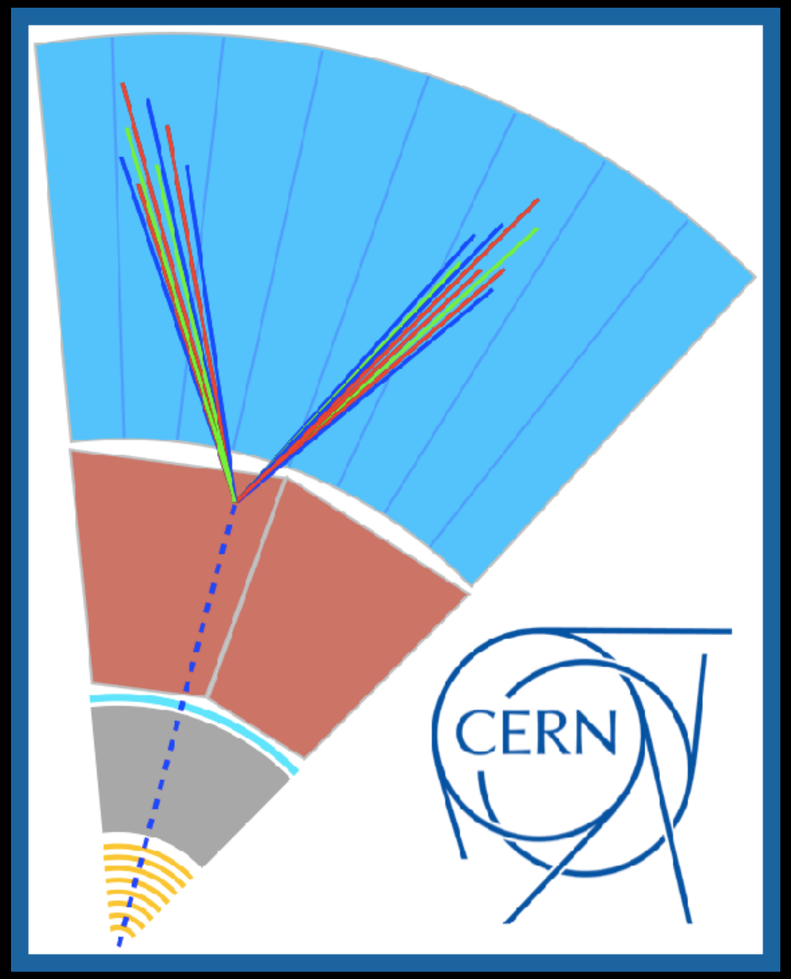


Time-delayed LLP signals from dark photos with the planned CMS timing layer: V.Q. Tran talk

Lesson #8: Nearly-dark mirror stars? Possibly!



D. Curtin talk



LHC Long-Lived Particle Community

...in collaboration with the theory/pheno community and MoEDAL, MilliQan, MATHUSLA, FASER, CODEX-b, AL3X, etc.

Formed to address one question:
How do we best ensure that we don't miss BSM LLP signatures for the remainder of the LHC program?

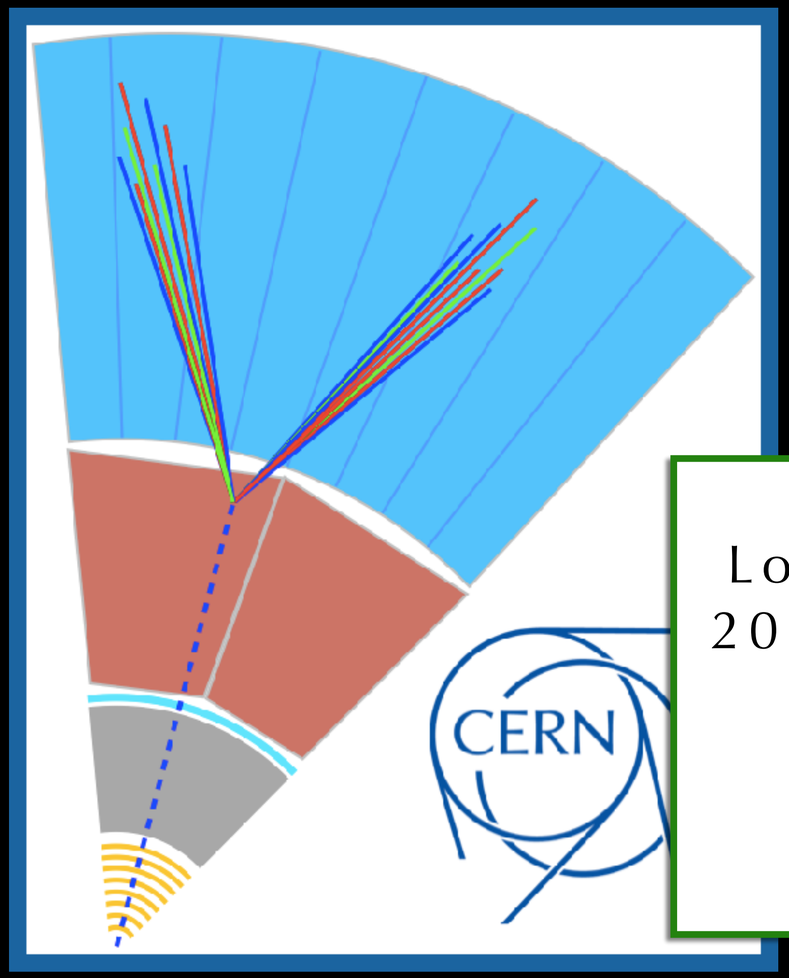
Workshops — two per year

LHC LLP white paper:
11 March 2019 — arXiv:1903.04497
Accepted for publication in J. Phys. G

Join the CERN egroup: lhc-llp

cern.ch/longlivedparticles

LHC Long-Lived Particle Community



Location of workshop for fall of 2019 to be determined very soon

If you're not on the lhc-llp egroup, please join!

...v/pheno community and ...SER, CODEX-b, AL3X, etc.

...he question:
...e don't miss BSM LLP ...of the LHC program?

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cern.ch/longlivedparticles

James Beacham [Duke]

Conclusions

The future of particle physics is long-lived!

Successful establishment of a wide range of results consistent with SM expectations requires us to shift from theory-driven to signature-driven search strategies

Our duty is to explore the unknown; this means stretching our current detectors at the LHC to the limits of their discovery potential at 13/14 TeV, with a renewed focus on LLP signatures, irrespective of theory model or motivation, as well as fully exploring the lifetime frontier with dedicated detectors using particles produced at the main LHC interaction points and experiments beyond colliders — *and* keeping a close connection to astrophysics and cosmology

Long-lived particle signatures, previously regarded as fringe efforts, are taking their place within the central set of BSM searches at the LHC and beyond

Items for discussion

1) This was a joint ICISE-CBPF workshop, intended to both build bridges among the physics communities of southeast Asia and Latin American and to provide an interface with the global community of those interested in very forward-thinking exotic BSM physics, particularly involving long-lived particle signatures at colliders and beyond. The response and participation at this workshop has been very positive, so it would be wonderful to follow up with a second version in Brazil. When and where?

Items for discussion

2) What are we missing?

- A broader discussion of the general classes of models that yield dark showers at colliders, and their phenomenology, would be very welcome (see Ch. 7 of the LHC LLP Community white paper)

- Very different alternatives to dark matter paradigms — i.e., not even particle dark matter — could provide valuable counterpoints

- Substantial (but incomplete) work and thought has gone toward very exotic and LLP searches at future colliders (FCC-xx, CEPC, CLIC/ILC); including this community ensures a coherent approach toward shifting the attitude of HEP in general

James Beacham [Duke]

Items for discussion

3) What questions have we raised at this workshop that need to be followed up on or focused on for the near future?

Items for discussion

4) As we've seen repeatedly this week — and as you know — the connections between HEP and astrophysics and cosmology are more important than ever. Would this ICISE-CBPF Exotic/LLP initiative benefit from the inclusion of people from, e.g., the dark matter direct detection, gravitational wave, multi-messenger astronomy, etc., communities?

Items for discussion

5) What new project — paper, model, game-changing LHC upgrade idea, new dedicated LLP detector using an LHC IP, novel way of probing BSM physics with existing facilities — will you have completed or originated by the time of the next ICISE-CBPF Exotic/LLP conference?

Join us on the terrace to discuss these things and more over rice wine at the round table this afternoon, and thank you for making this an excellent workshop!