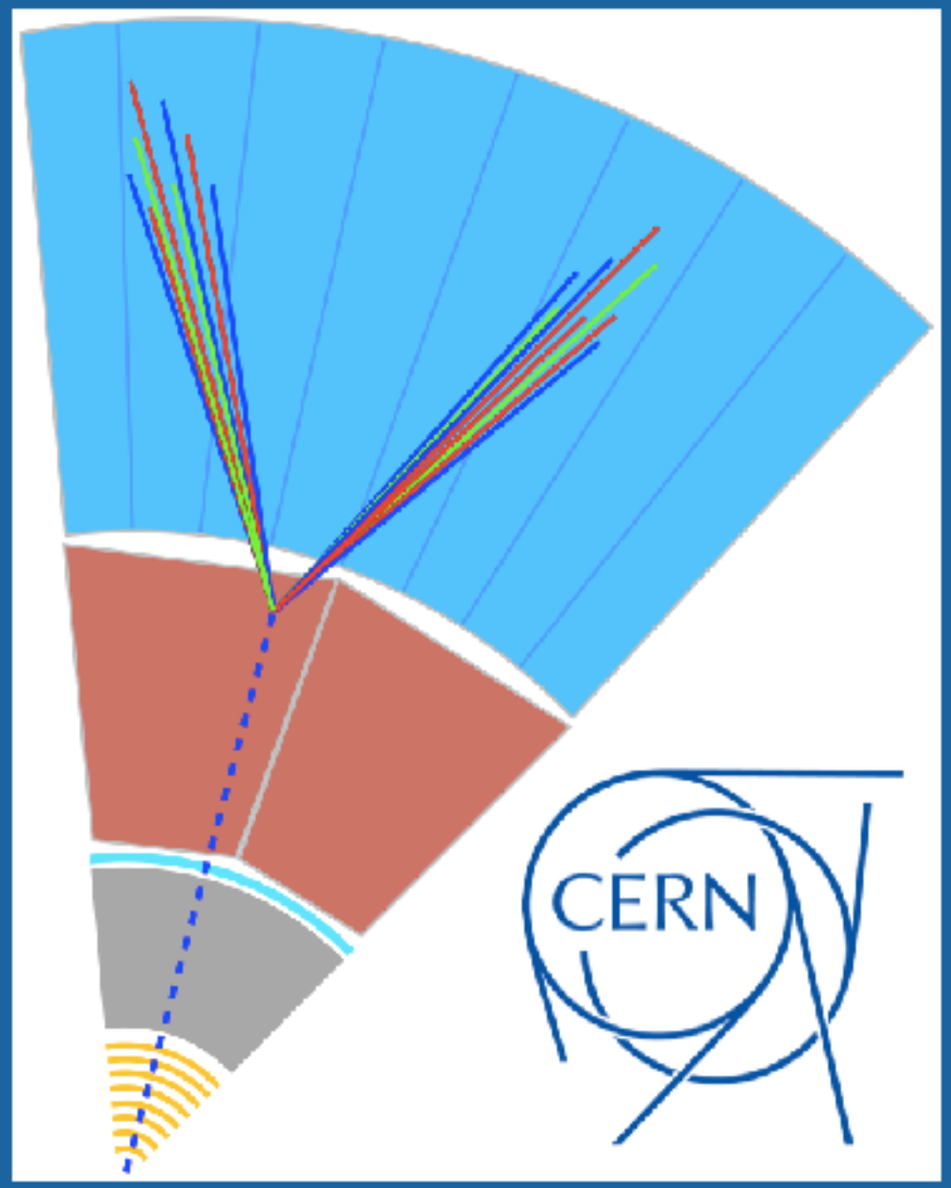


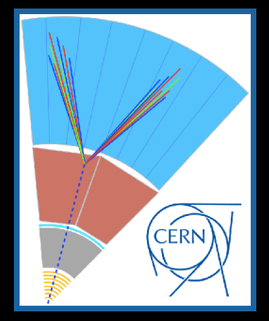
Mapping the Future: The LHC Long-Lived Particle Community

New Physics with Displaced Vertices

NCTS — Taiwan — 20 June 2018

James Beacham [ATLAS/Ohio State]
on behalf of the group

New physics X at the LHC



The overwhelming majority of the work of the LHC experiments

Stable

m_X

New physics could be hiding here

$\mathcal{O}(mm)$

$c\tau_X$

Outer edge of detector

Open questions before 4 July 2012

Electroweak symmetry breaking
- Does the Higgs boson exist?

Quarks and leptons
- Why three families?
- Why these masses and mixings?
- CP violation in the lepton sector
- Matter/anti-matter asymmetry
- Baryon and charged lepton number violation

Physics toward the Planck scale
- How does gravity play with the other forces?
- Are there more than three dimensions of space?
- Do all forces unify at high energy?
- Are there other forces?

Dark matter
- What is it? WIMP, sterile neutrino, axion, NLSP, other hidden sector particle?
- Only one type?
- Only gravitational or other interactions?
- Are we wrong about gravity? An emergent phenomenon?

Neutrinos
- Why do neutrinos have masses? And what are these masses?
- Majorana or Dirac?
- CP violation
- Are there more (sterile) neutrinos?

Two epochs of Universe's accelerated expansion
- Primordial: Is inflationary model correct? Which (scalar) field? Role of quantum gravity?
- Today: Dark energy (why is Λ so small?) or gravity modification?

Inspired by I. Shipsey

Open questions after 4 July 2012

Electroweak symmetry breaking
- ☑ Does the Higgs boson exist?
- ☐ Is m_h natural or fine-tuned?
- ☐ If natural, what new physics/symmetry governs this?
- ☐ Does it regularize divergent $V_L V_L$ cross-section at high m_{VLVL}? Or new dynamics?
- ☐ Elementary or composite Higgs?
- ☐ Is it alone or does the Higgs have siblings and cousins?
- ☐ Origin of couplings to fermions?
- ☐ Coupling to dark matter?
- ☐ Connection to hidden sectors?
- ☐ Does it violate CP?
- ☐ Cosmological EW phase transition?

Quarks and leptons
- ☐ Why three families?
- ☐ Why these masses and mixings?
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- ☐ Why do neutrinos have masses? And what are these masses?
- ☐ What's the role of h125?
- ☐ Majorana or Dirac?
- ☐ CP violation
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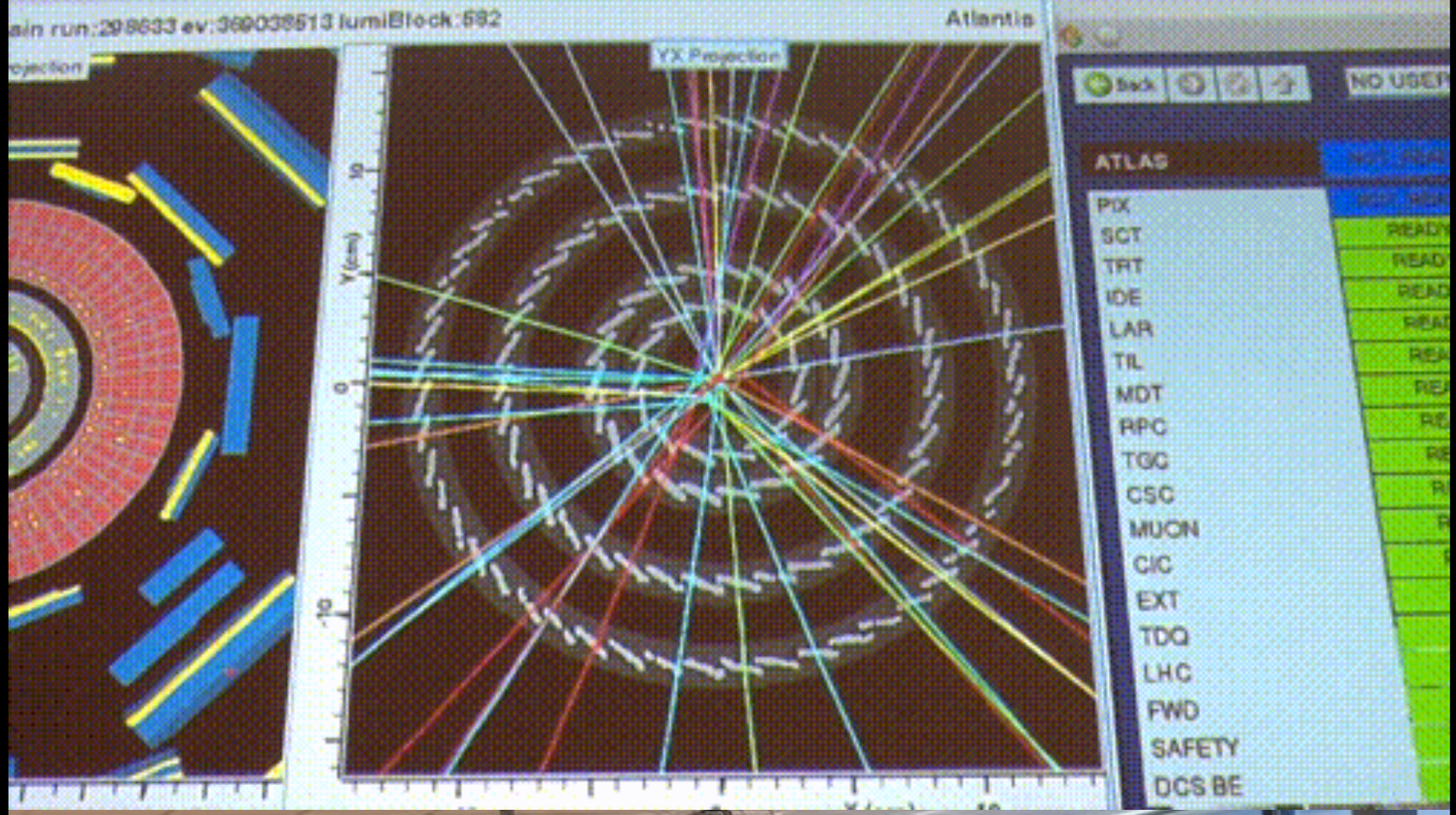
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YX Projection
ATLAS
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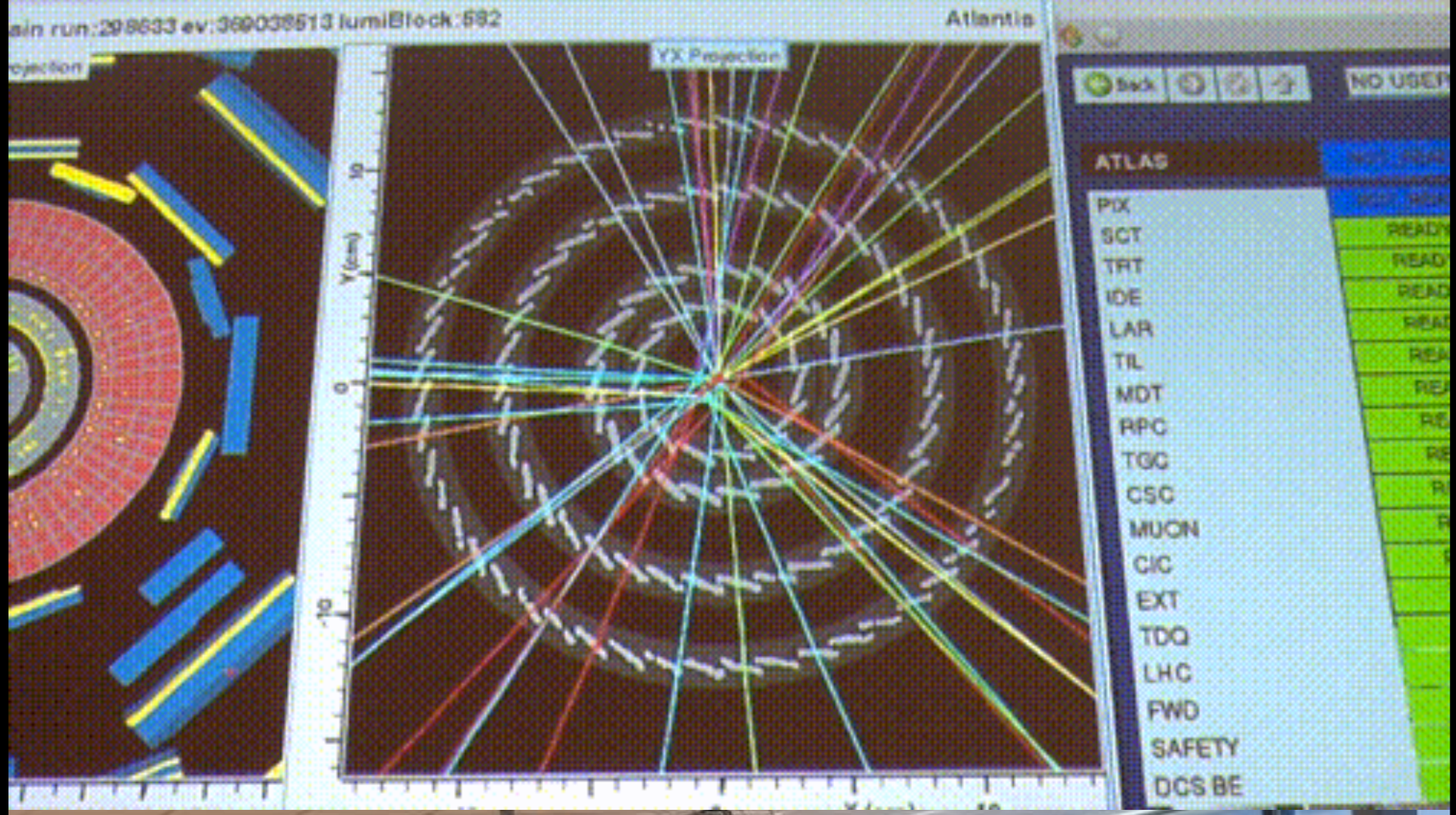
SAFETY
DCS BE

June 2015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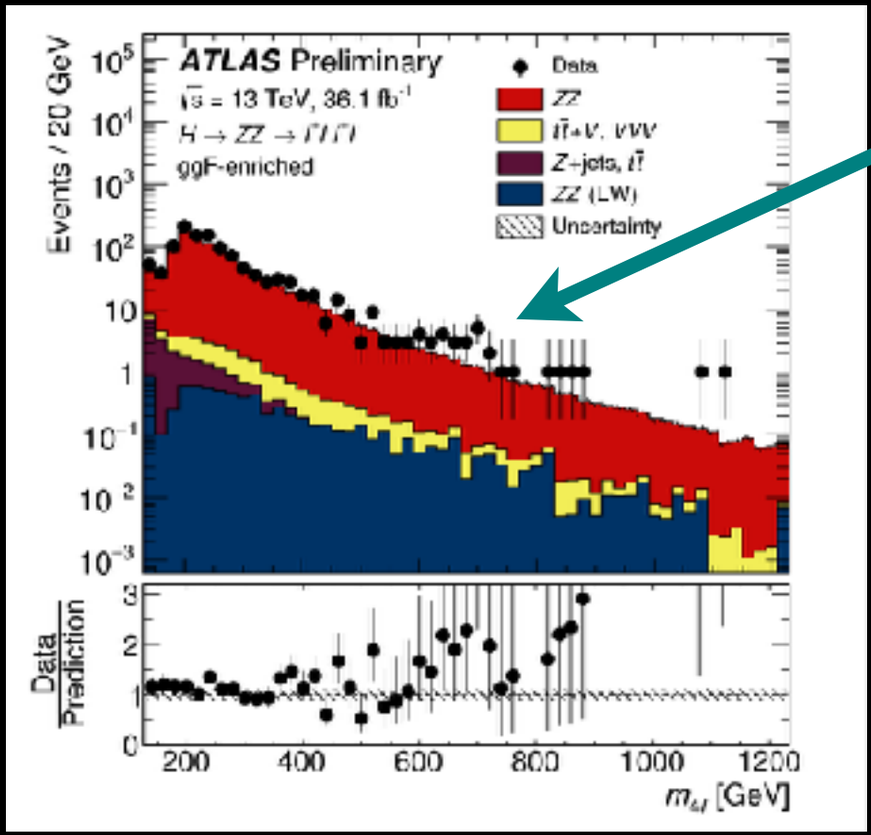
June 2015

New physics at the LHC in 2017

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



?

There are no more guarantees and no ace-in-the-hole motivations.

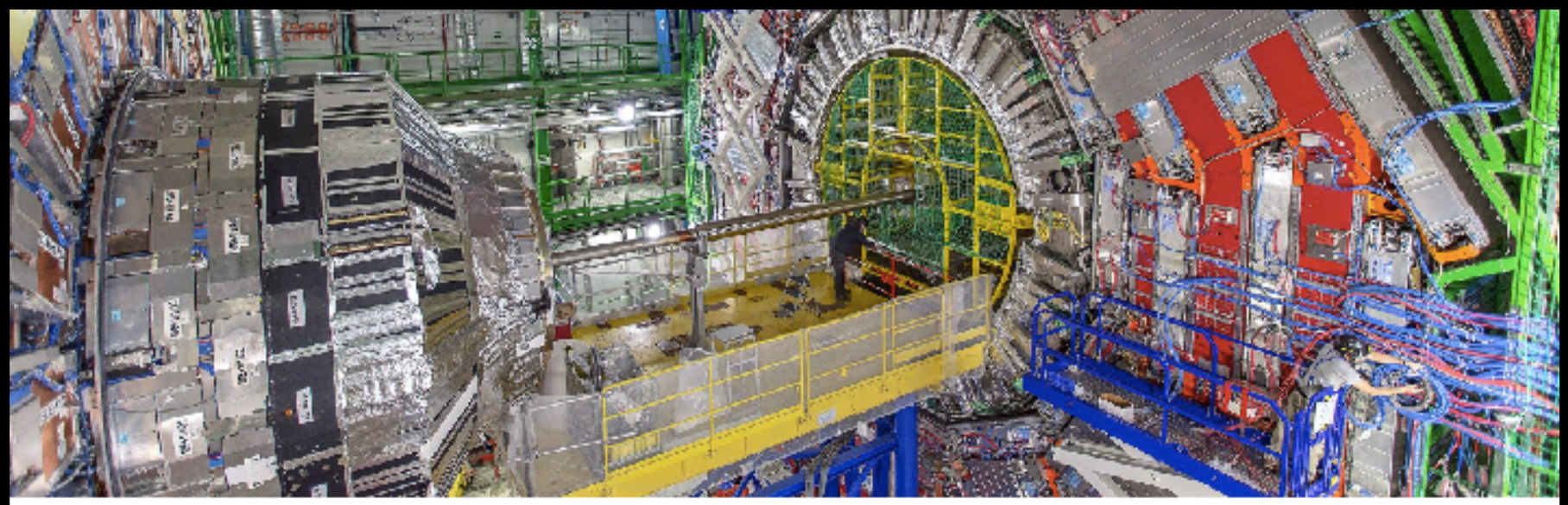
We must shift from theory-driven search strategies to signature-driven ones.

We would certainly love some old-school theoretical guidance, but we don't really have it (WIMP miracle in tension, lack of plain vanilla SUSY, lack of twenty-jet events filled with strong gravity, etc.)

What do we have? Some of the most sophisticated devices ever built.
How do we extend their reach into new physics parameter space?

And how do we shape the attitude of the outside world, as well?

The paradigm is shifting — you are part of it



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. Lucien 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 18, 2017

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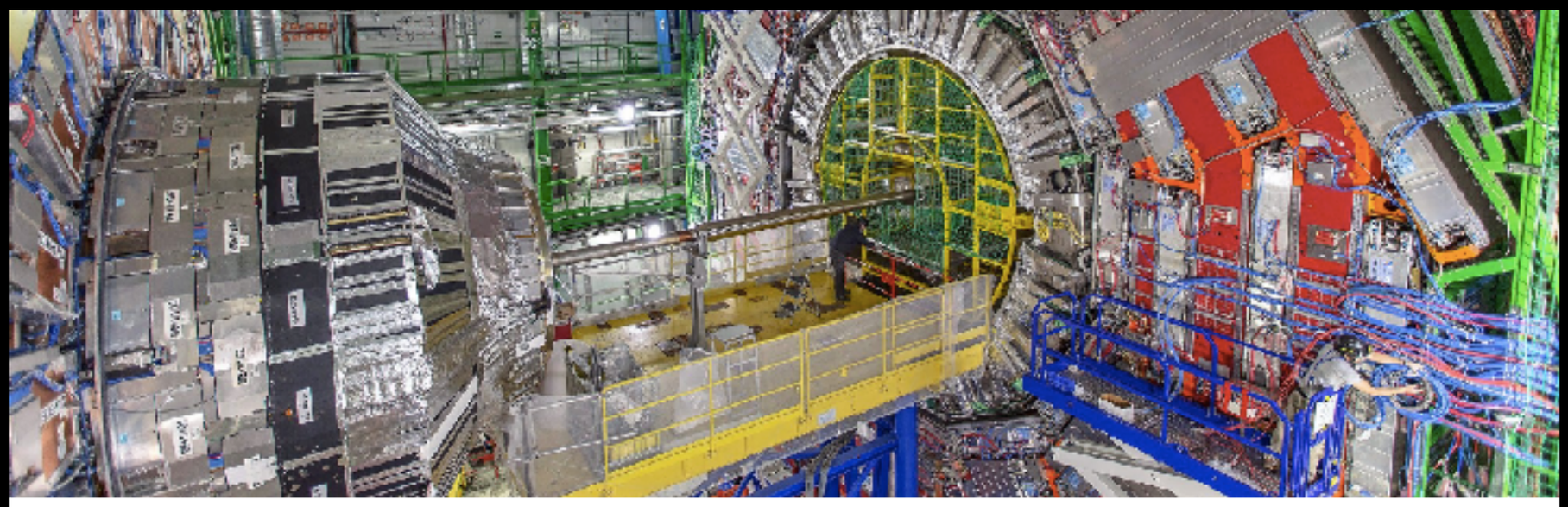

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Gordon Kane, a superstring theorist at the University of Michigan who is well known in the community for his optimism about supersymmetry, said his calculations predicted that the lightest superparticle should show up around about 1.6 trillion electron volts once enough data was properly analyzed. "Sadly," he wrote in an email, "the experimenters have not done realistic searches."

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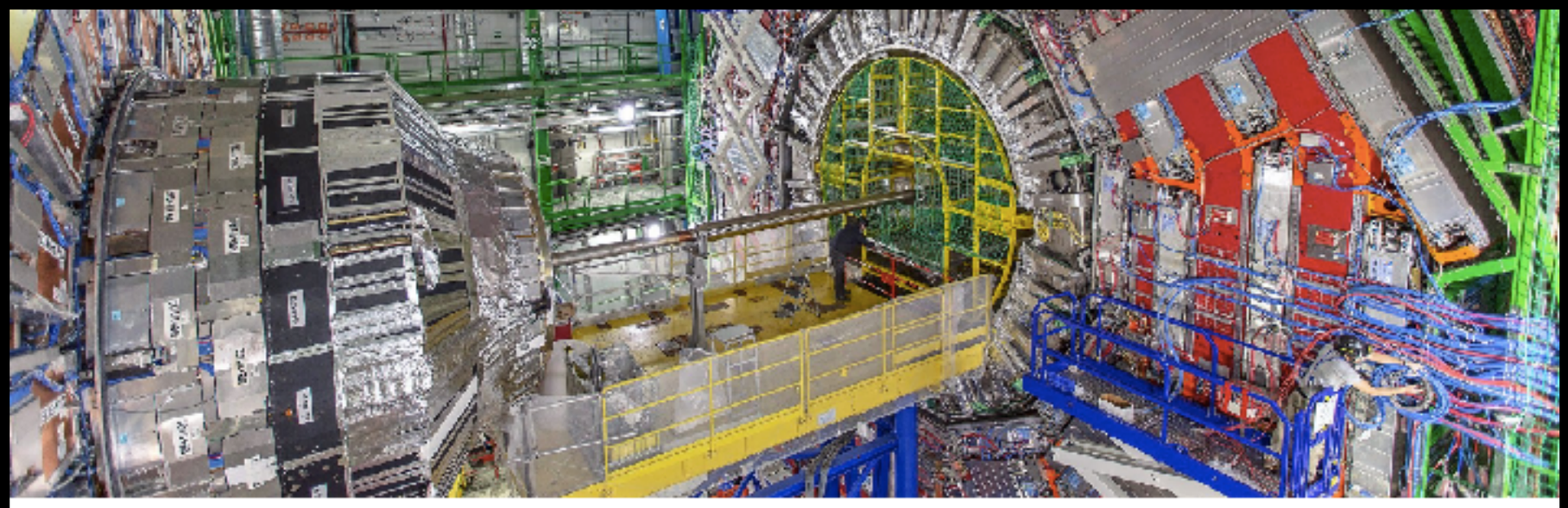

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Our job as physicists is to reduce, to negligible, the chance that we'll miss any possible new particles over the duration of the LHC's run. The first look at 13 TeV yielding a whole host of successful validations of the Standard Model prediction is *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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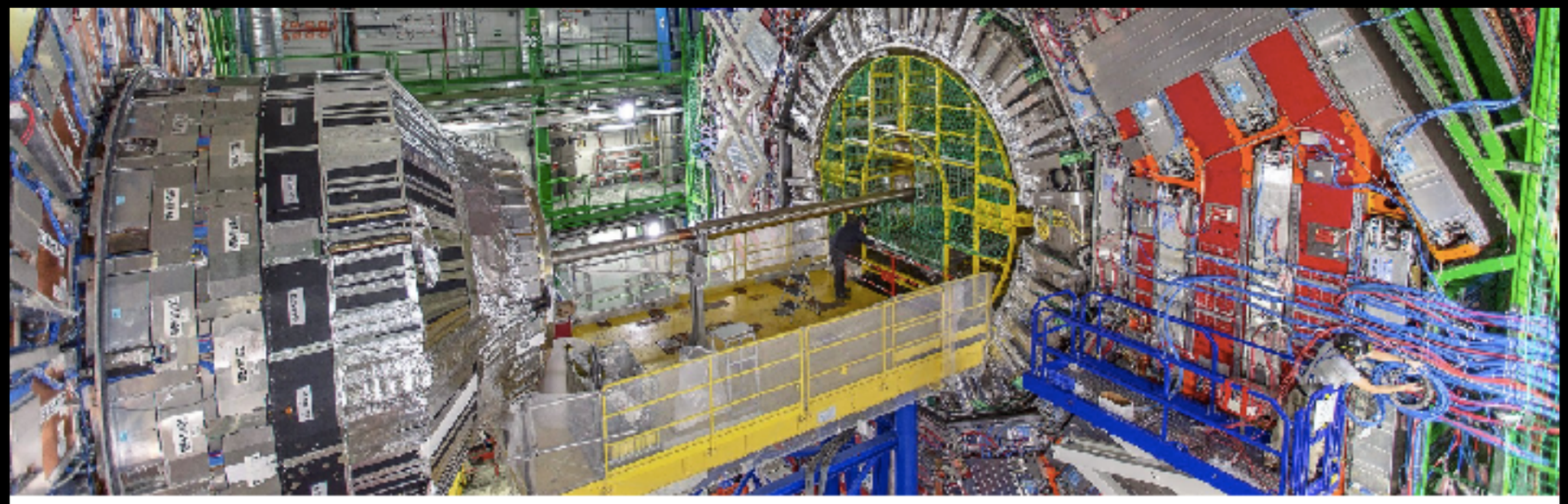

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Dennis Overbye [redacted] Michigan who

Actions

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

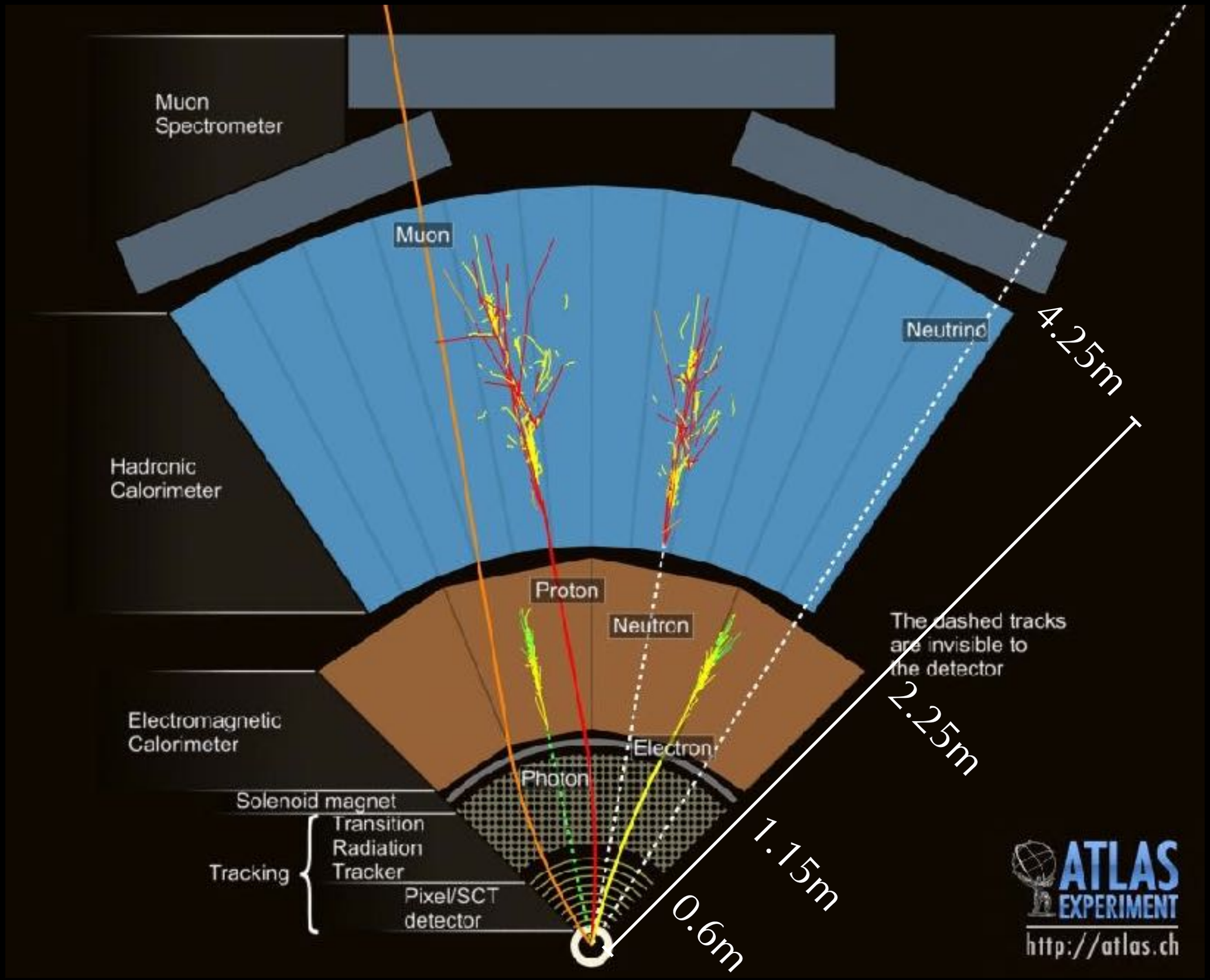
To: James Beacham

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

95% of our analysis effort is dedicated to understanding five prompt objects



What we want:

- To reduce to negligible to chance that we'll miss new physics at the LHC

What we have:

- The most sophisticated general-purpose detectors ever built at the highest *pp* √s ever used

Shift from model-first / signature-second to signature-first / model-second mindset

New Physics with Displaced Vertices
at NCTS?
I like the sound of that.

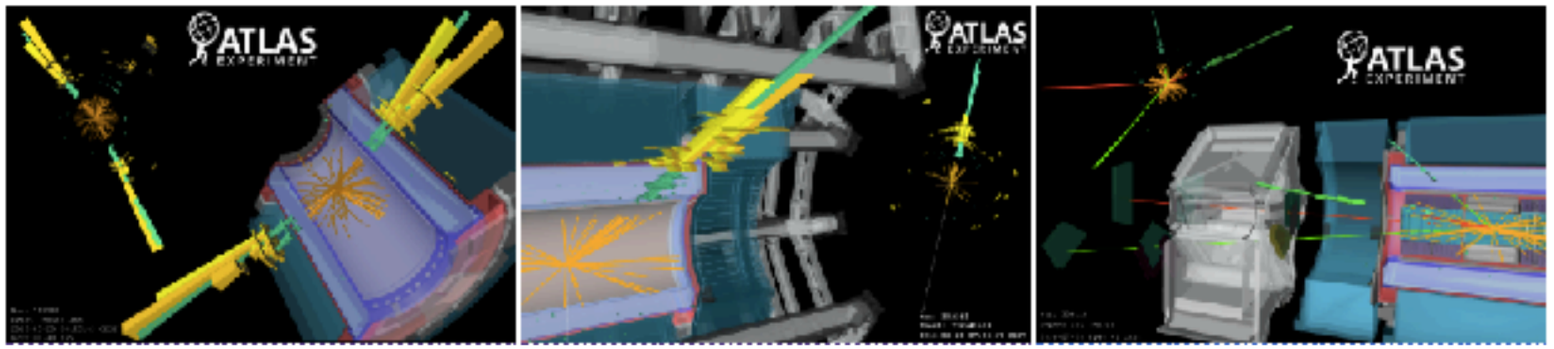
Where is new physics at the LHC?

ATLAS EXPERIMENT — PUBLIC RESULTS

Exotic Physics Searches

Contact: *ATLAS Exotics Working Group Conveners*

This page contains public results from the ATLAS Exotics Working Group, which is searching for physics beyond the Standard Model with a signature-based program. Our aim is to cover all experimentally viable signatures focusing on non-supersymmetric models from Extra Dimensions and mini Black Holes to Dark Matter, extended Higgs models, and Compositeness to name a few.



Filter Documents

Select the desired keywords to filter the results.

Selections within a section row are combined with a logical OR, while selections among different section rows are combined with a logical AND.

Global Selections: Show All | Deselect All | Show Latest 20

CM Energy: 7 TeV | 8 TeV | 13 TeV

Analysis characteristics: ISR | MVA / machine learning | EFT | High luminosity upgrade studies | Statistical combination | VBF | BSM reinterpretation | Long-lived massive particles | Trigger-level objects

Min luminosity : 0 fb^{-1} | Filter by minimum integrated luminosity

Date : YYYY-MM-DD | Filter by date: ≥ ≤

Filtered results: [Papers Currently Published]

Papers: (187)

Short Title	Journal reference	Date	√s (TeV)	L	Links
W/Z/Hgamma search 13 TeV 2016 NEW	Submitted to PRD	04-MAY-18	13	36 fb^{-1}	Documents | 1805.01908 | Inspire HepData | Briefing | Internal
Ubar resonances semileptonic 13 TeV 2016 NEW	Submitted to	28-APR-18	13	36 fb^{-1}	Documents | 1804.10823 | Inspire

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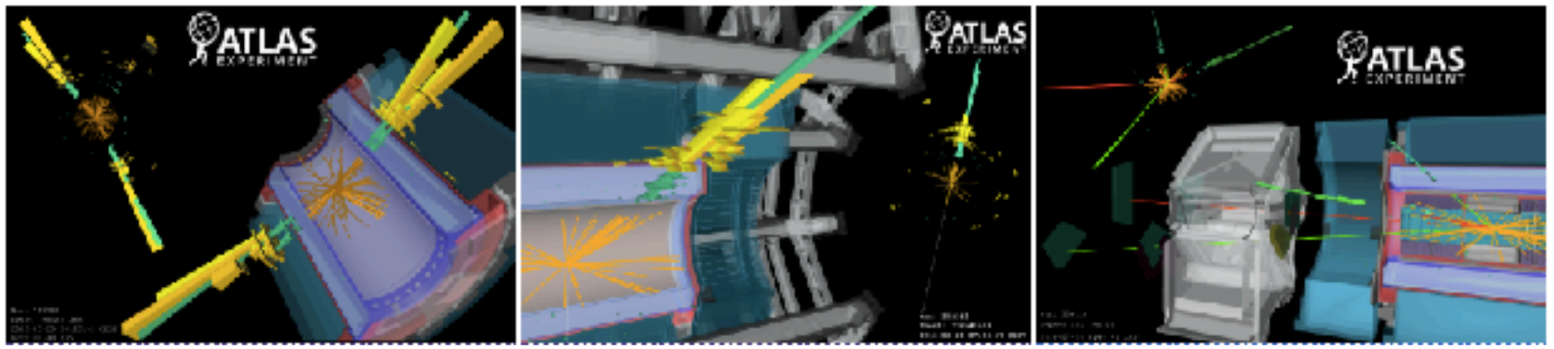

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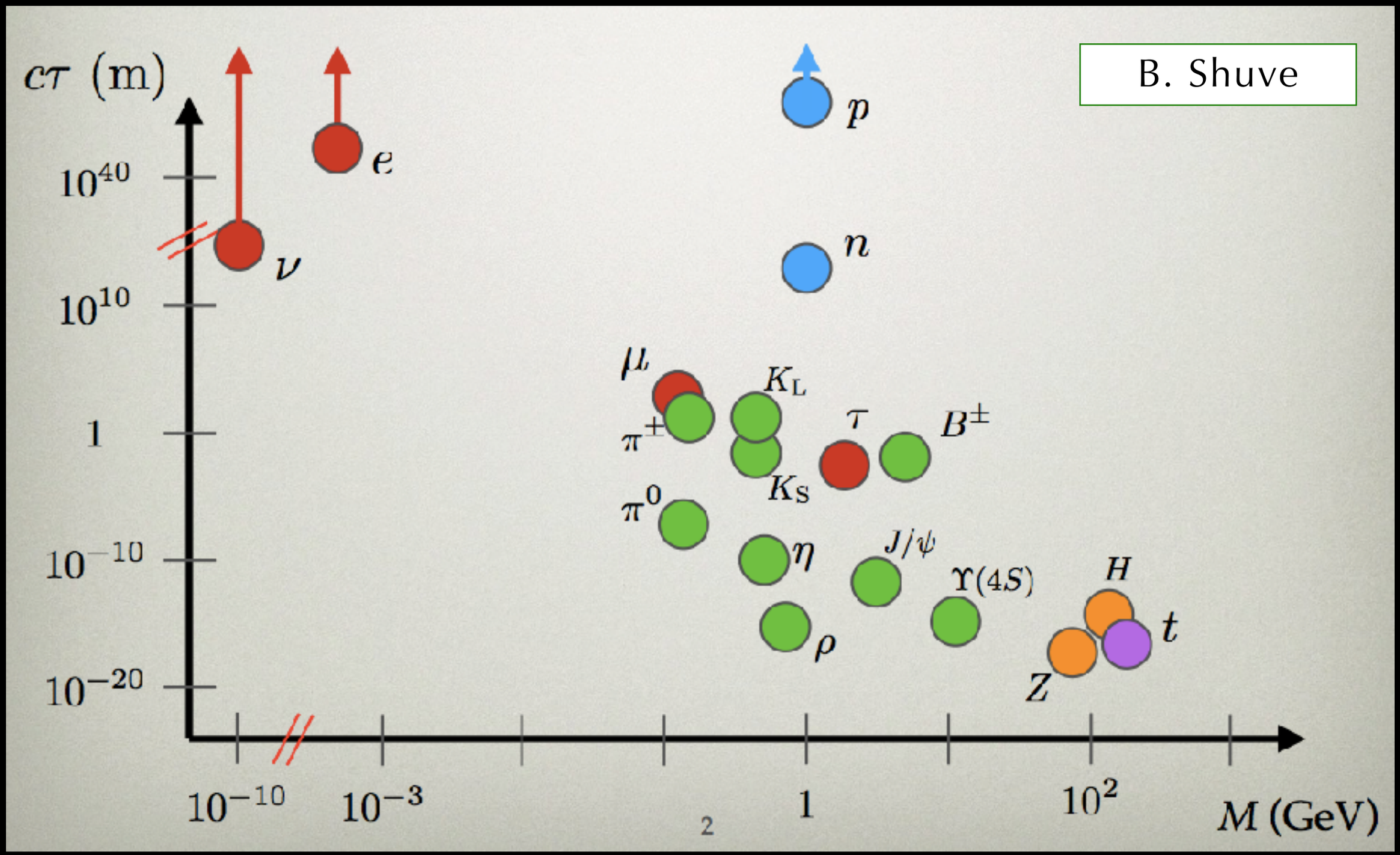
Date : YYYY-MM-DD Filter by date: ≥ ≤

Filtered results: [Papers Conference Publication]

Papers: (15)

Short Title	Journal reference	Date	√s (TeV)	L	Links
Gaugino pair, gluino pair; disappearing track	Submitted to JHEP	06-DEC-17	13	36 fb^{-1}	Documents | 1712.02118 | Inspire HepData | Internal
Gluino pair, squark pair; displaced vertices	Phys. Rev. D 97	18-OCT-17	13	36 fb^{-1}	Documents | 1710.04901 | Inspire

Long-lived particles at the LHC — SM & BSM

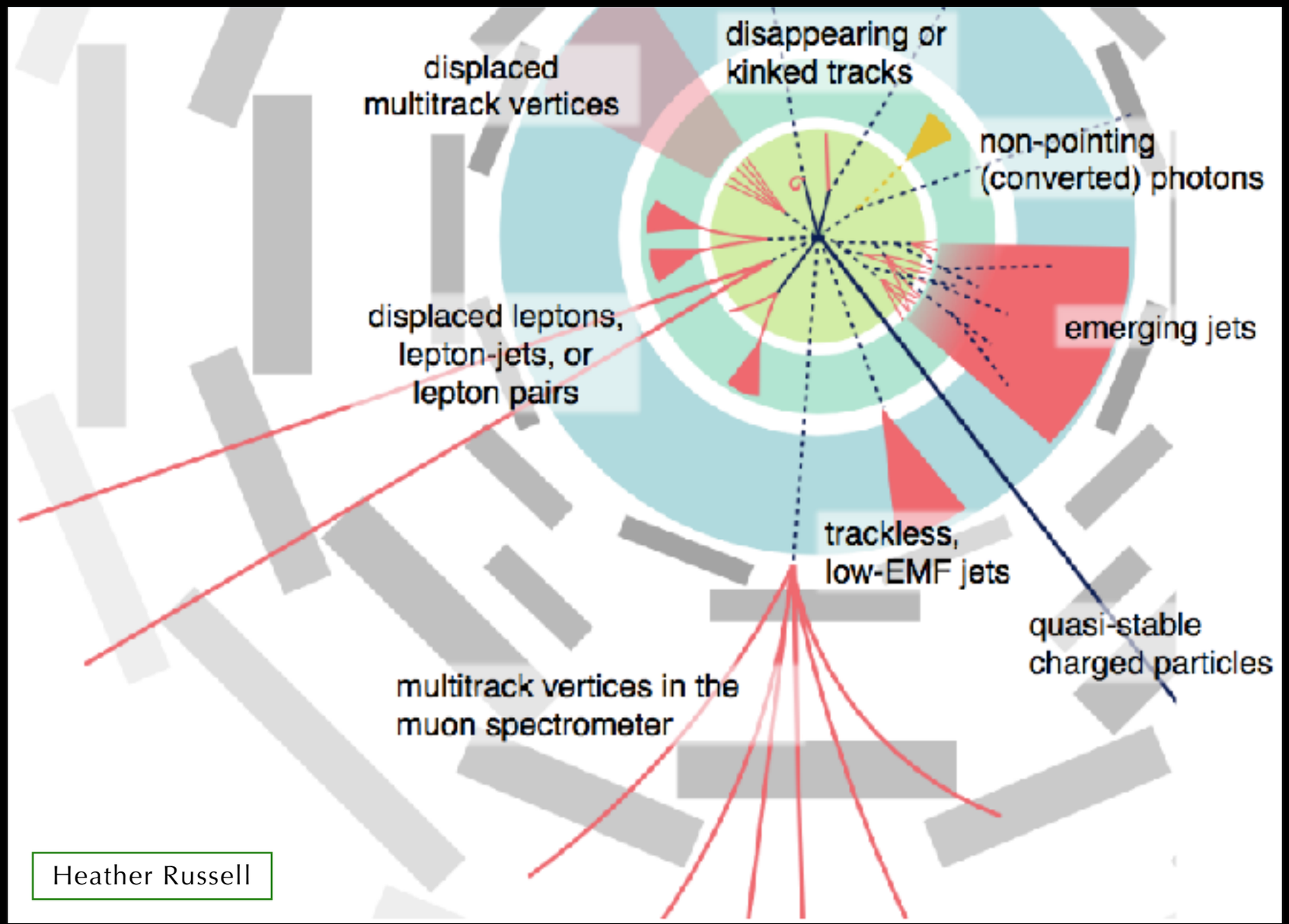


Same principles apply to BSM LLPs, which can generically appear

- Lifetime is usually best treated as a free parameter

The LHC LLP Community

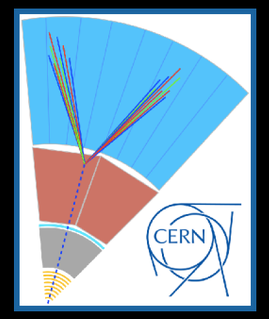
We map LLP signature space



What exactly do we mean by long-lived particle in the LHC context?

For our purposes, LLP = BSM particle with a non-negligible lifetime that dies (gives up all its energy or decays to SM) somewhere in the detector acceptance of LHCb, CMS, ATLAS, MilliQan, MoEDAL, FASER, Codex-b, MATHUSLA, etc.

The LHC LLP Community Initiative



Long-lived particle searches at ATLAS, CMS, LHCb are difficult

- Challenging triggering strategies
- Non-standard objects and reconstruction methods
- Baffling backgrounds irrelevant to standard searches for prompt or stable objects
- Difficult also means fun, but there's a danger we'll miss a possible discovery because of the atypical nature of these signatures

One question:

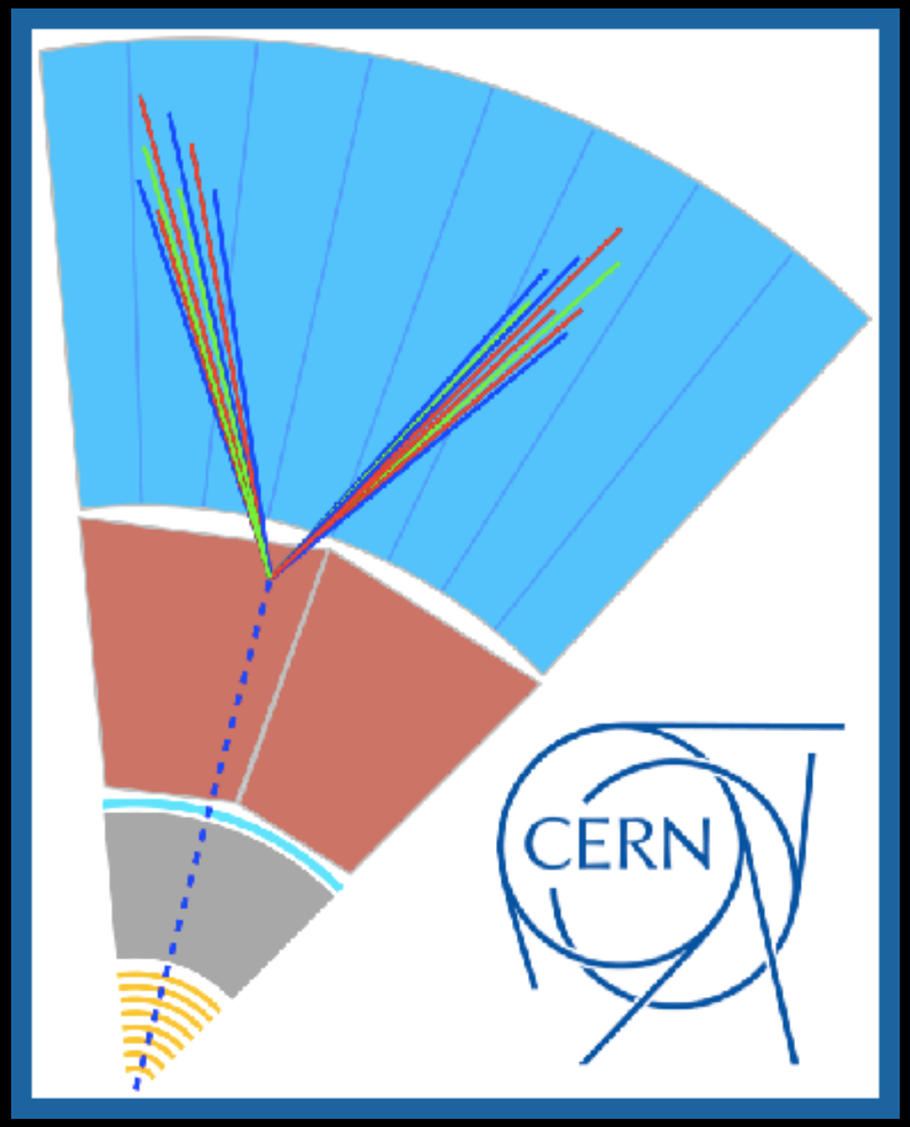
How do we best ensure that we don't miss BSM LLP signatures for the remainder of the LHC program and beyond?

Answer: Construct a *space* for the inter-experiment/theory community to discuss and collect the *results*

Space: Working-workshops

Results: White papers and website

LHC Long-Lived Particle Community



...building on the work of a few prior workshops

...in collaboration with the theory/pheno community and MoEDAL, milliQan, MATHUSLA, FASER, Codex-b, etc.

Workshops — two per year
Most recent last month:
LHC_LLP_May_2018

LHC LLP white paper in progress now
(likely public July)

Join the CERN egroup: lhc-llp

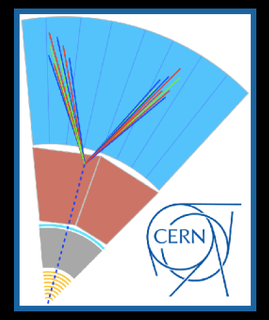
Website coming soon: cern.ch/longlivedparticles

The LHC LLP Community white paper

Many dozens of people working
for months with the consultation
of dozens more — a community

White paper: Experimental signature based focus

https://github.com/jbbeacham/LHCLLP



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

Version: 0.1.4

May 16, 2018

Abstract: Searches for long-lived particles (LLPs) beyond the Standard Model at the Large Hadron Collider — particles that can have non-negligible lifetimes and decay to SM particles within detectors but substantially displaced from the interaction vertex — constitute a rich, challenging, and increasingly fascinating avenue via which new physics may be discovered at the LHC. Members of the ATLAS, CMS, and LHCb experiments in conjunction with theorists, phenomenologists, and those working on dedicated experiments such as Moedal, MilliQan, MATHUSLA, CODEX-b, and FASER, here report upon the state of LLP searches at the LHC; propose a set of simplified models for LLP searches; survey the existing searches, the experimental coverage of LLP signatures, and enumerate gaps in this coverage; identify high-priority studies to be performed by the experimental collaborations to ensure that LLP signatures are not missed in detector upgrades planned for the upcoming high-luminosity era at the LHC; propose recommendations for new triggering strategies for LLPs in ATLAS, CMS, and LHCb; list ideas for new searches for LLPs; propose a set of recommendations for the presentation of search results to ensure future reinterpretation and recasting for LLP searches; discuss new frontiers for LLP searches such as those involving dark sector QCD-like theoretical ideas; and describe the often unexpected experimental challenges inherent in LLP searches, including atypical or non-standard background sources.

The LHC LLP Community *CERN, Geneva, Switzerland and worldwide*

Contact editors: lhc-llp-admin@cern.ch

White paper: Experimental signature based focus

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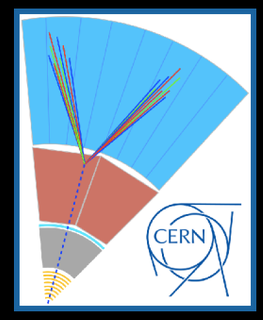

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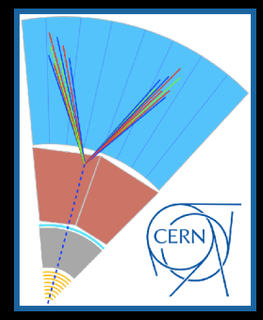

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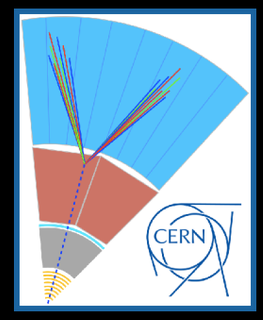

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Simplified model proposal organized around generic classes of LLP production and decay mode, always with an eye toward what the detectors might be able to do

White paper: Experimental signature based focus

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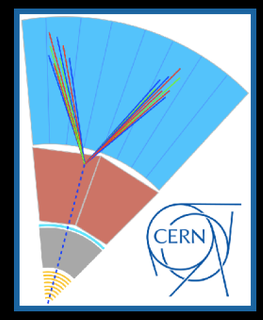

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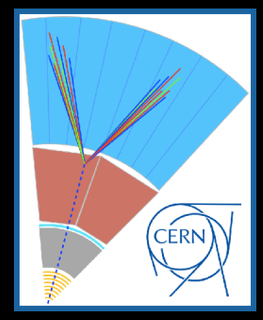
https://github.com/jbbeacham/LHCLLP



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

Version: 0.1.4

May 16, 2018

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Experimental coverage:
How well do the existing searches cover the parameter space?

White paper: Experimental signature based focus

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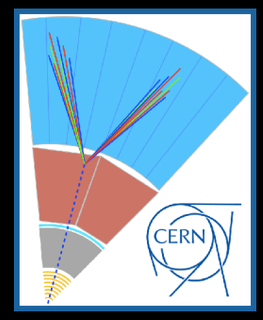

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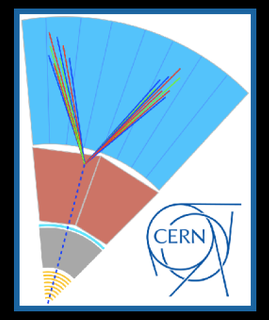

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Backgrounds to LLP searches can be small but unexpected. Collected wisdom and reference here.

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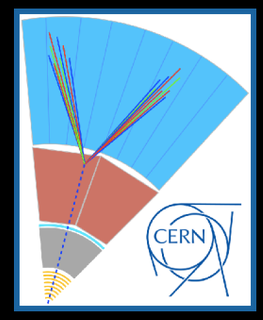

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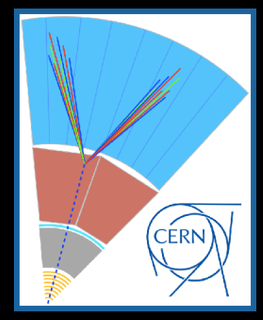

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What triggers are missing? What upgrade studies should be done to advocate for new detector components?

Long-term discussion, to be addressed here and in the future.

White paper: Experimental signature based focus

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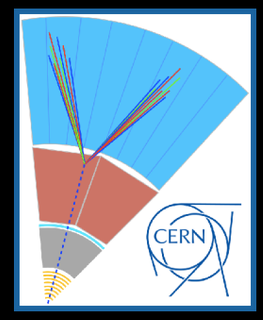

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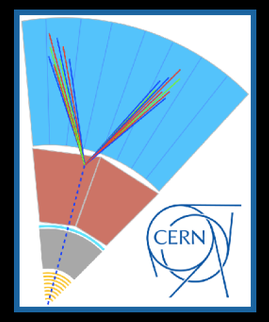

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How should we present our results to ensure optimal re-interpretation and re-cast-ability?

White paper: Experimental signature based focus

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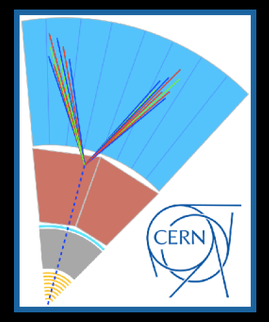

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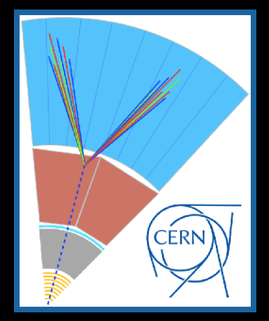

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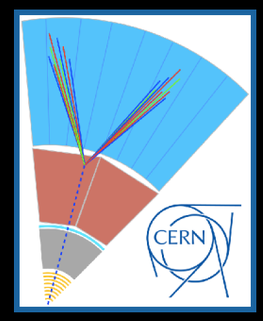
May 16, 2018

QCD-like (more or less) dark sectors: What kinds of experimental signatures are between emerging jets and SUEP?

Longer-term work on uncharted territory; still examining how we know what we don't know.

White paper: Simplified Models chapter



Signature first, model second

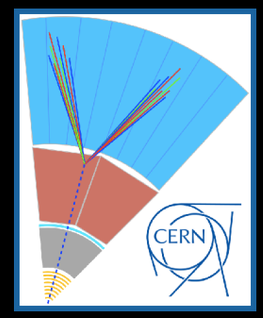
- General classes of motivations that can give rise to LLPs are many
  - Dark photons
  - Hidden valleys
  - R-parity violating supersymmetry
  - Dark QCD-like sectors
  - Heavy neutral leptons
  - Etc.

Instead of probing the parameter space of your favorite model, think about the more generic kinds of ways an LLP could be produced at the LHC interaction points and then how it could appear in the detector

- Much clearer way of comparing searches and noting whether and to what extent certain signatures have been covered
- Creates a useful grammar of LLP signatures/searches across experiment

This kind of focus also makes it easier to point out where experimentalists have opportunities for new searches or to significantly extend the reach of existing searches — new projects with discovery potential!

Experimental coverage chapter



Excellent work done by the experimental coverage group, spearheaded and edited by José Zurita; for the rest of this talk, a few thoughts about uncovered realms in LLP/DV searches

Chapter functions as both a review of existing LLP-related searches at ATLAS, CMS, and LHCb and a clear enumeration of gaps in coverage, a.k.a., open opportunities for discovery-oriented projects for experimentalists to take on

3.2 Overview of Gaps

1. All-hadronic
   - Use associated object triggers (especially motivated by Higgs like VBF and VH)
   - Try to push to lower masses & lifetimes
   - Online reconstruction of hadronic displaced objects
   - Exclusion limits for displaced hadronic taus. Opportunity for CMS displaced triggers?
2. Leptonic
   - Intermediate region between low-mass (lepton-jets) and high-mass (resolved ATLAS/CMS searches)
   - Continue to push to go to lower masses, p_T thresholds
   - Tau leptons in LLP decay, in particular if they come from ID. Opportunity for CMS displaced triggers?
3. Semi-Leptonic
   - Low masses (like Majorana neutrino)
   - Making sure to cover all flavor combinations (for example, one CMS search only covers $e^{\pm}\mu^{\mp}$), as well as same-sign vs. opposite sign leptons
   - Trigger on associated objects or use dilepton trigger if there are two LLPs?
4. Photonic
   - No coverage for LLPs decaying into $l\gamma$, $j\gamma$ or without E_T^{miss}.
   - Poor coverage (non-dedicated search) for single γ, only if two jets are present, needs recasting of CMS delayed photon study [186].
   - Prompt photons searches useless, as they veto "non-standard" photons.
   - No coverage for softer photons.
5. Other exotic long-lived signatures
   - DTs: $c\tau \sim$ mm are very hard to probe. Unclear if ATLAS IBL will be present in HL-LHC run. What is the lowest distance new layers (or double layers) can be inserted at?

Experimental coverage chapter

Excellent work done by the experimental coverage group, spearheaded and edited by José Zurita; for the rest of this talk, a few thoughts about uncovered realms in LLP/DV searches

Chapter
searches
gaps in
oriented

Not covered in this talk

- Semi-leptonic decays (ask Giovanna about her excellent new work on how to improve sensitivity to heavy neutral lepton-like signatures in a model-indepdent way)
- SIMPs, particles with anomalous ionization (monopoles, HECOs, millicharged particles), stopped particles, heavy stable charged particles, disappearing tracks, etc.

3.2 Over

1. All-hadr
   - Use as
     like V
   - Try to
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   - Exclus
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2. Leptonic
   - Interm
     mass
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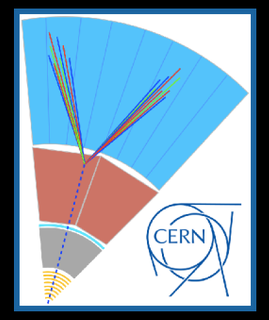
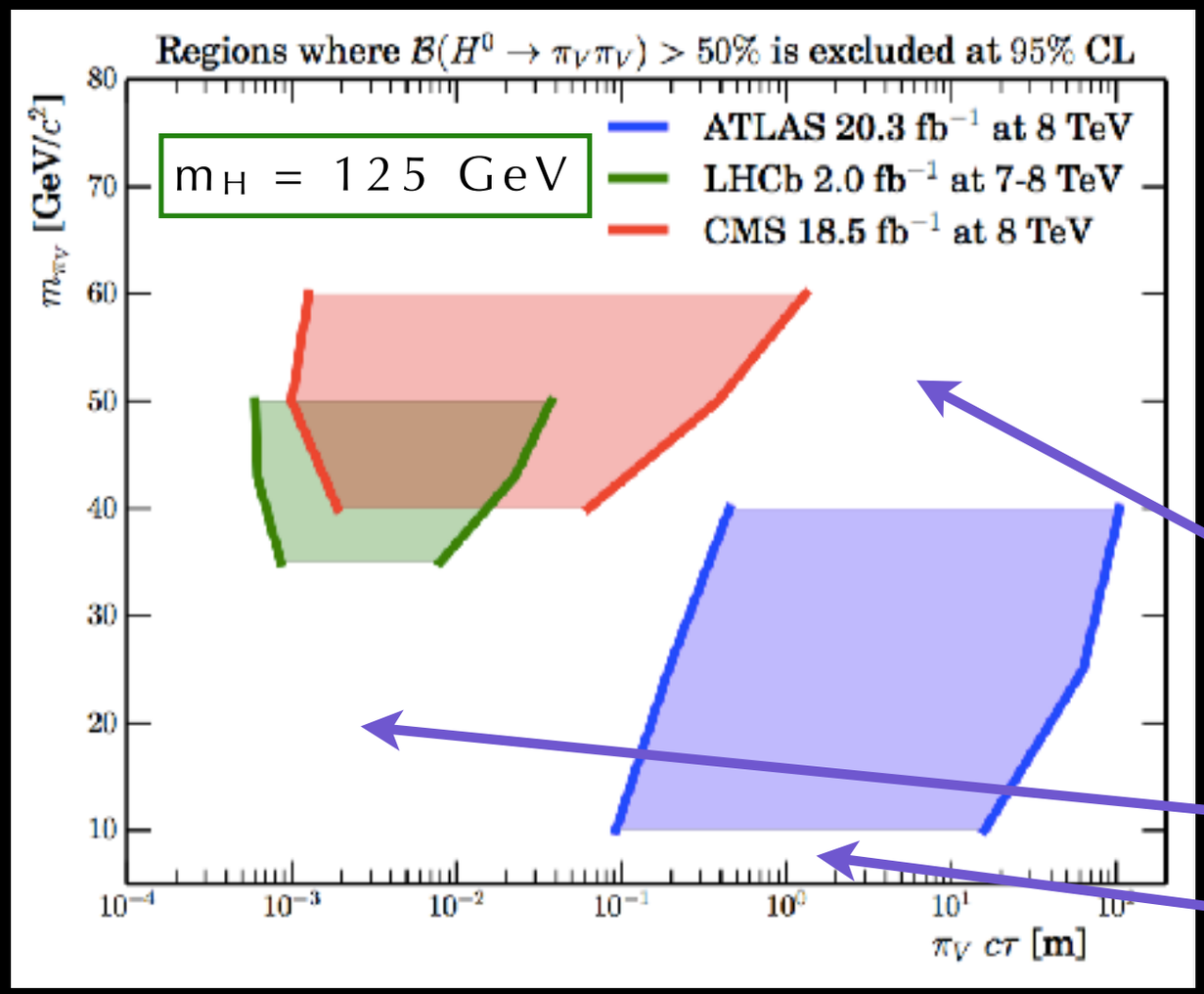
Uncovered LLP/DV realms

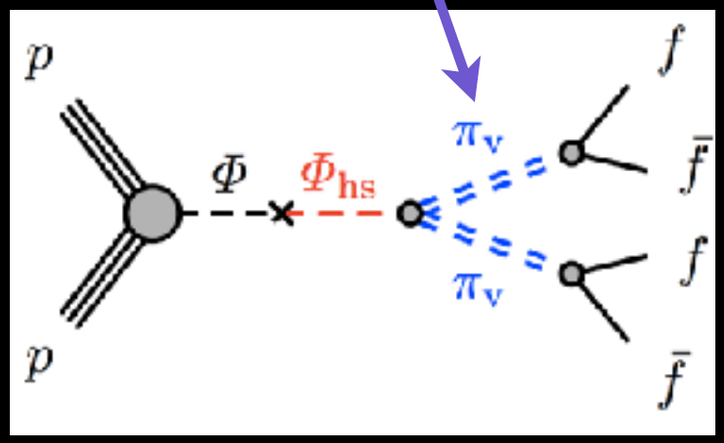


Low-mass, low-pT everything

- Start with a simple example everyone loves:
  h125 —> LLPx2 —> jets
- Many searches for this already, but there are known limitations
  - What if m_{LLP} < 10-30 GeV?
  - What if ~mm < ctau < ~10 cm?



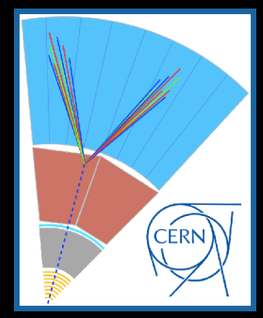
Long-lived π_v



A discovery could be hiding here! (Model-dependent plot, but illustrative)

LHCb: arXiv:1705.07332

Uncovered LLP/DV realms



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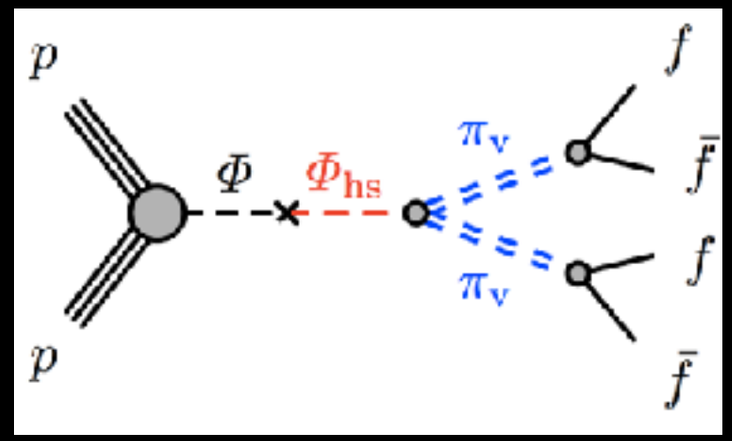
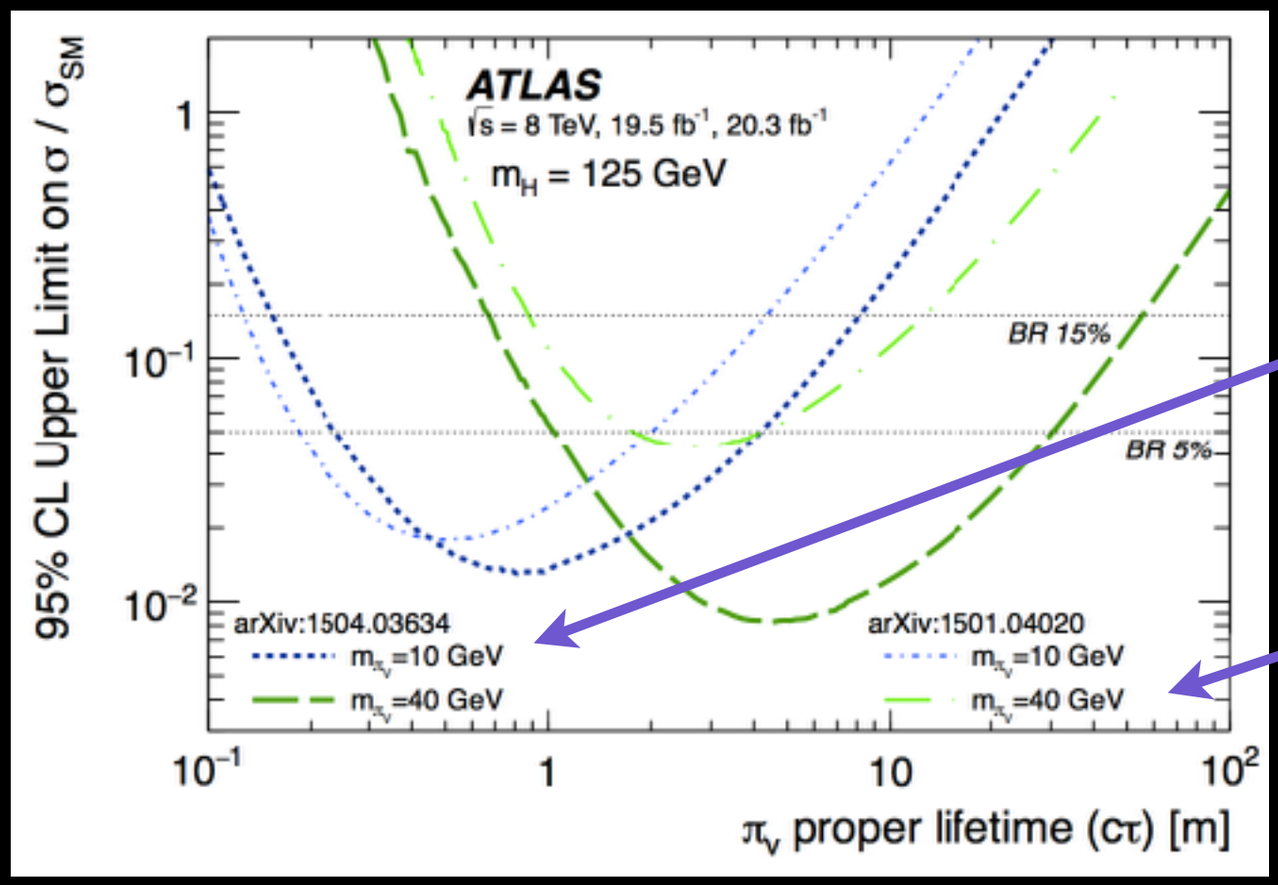




Decay in either inner detector or muon spectrometer

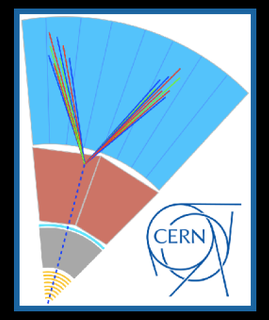
Decay in or just before the HCal with a special trigger (CalRatio)

- How to trigger on these regimes?

ATLAS: arXiv:1504.03634

arXiv:1501.04020

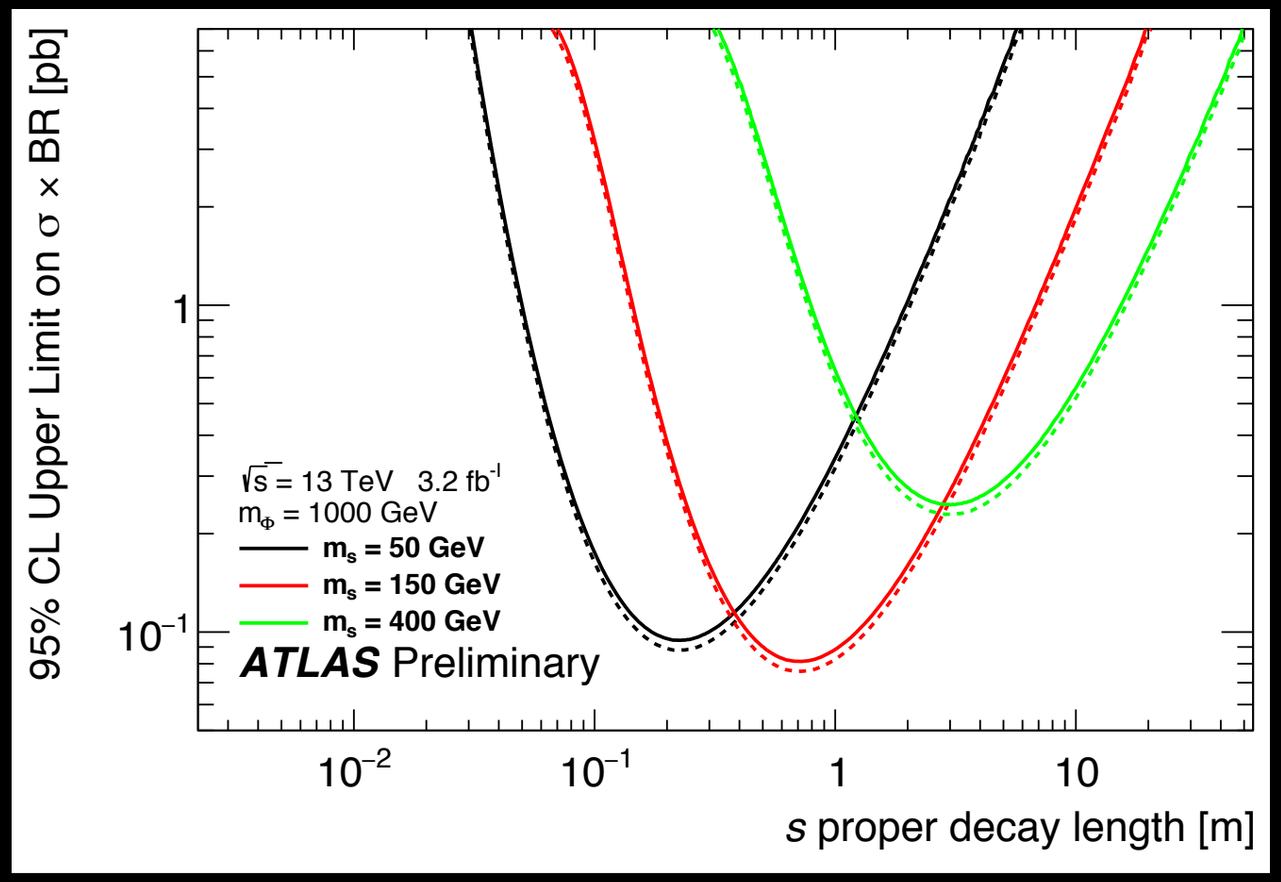
Uncovered LLP/DV realms



Low-mass, low-pT everything

- Same limitations hold for H —> LLPx2 —> jets, m_H > 125 GeV
  - What if m_{LLP} / m_X < 5%?
  - What if ~mm < ctau < a few cm?

ATLAS CalRatio for higher-mass scalars

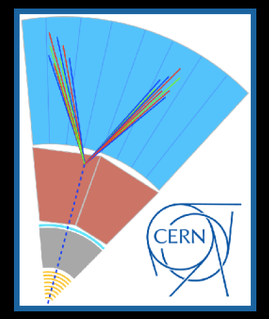


ATLAS-CONF-2016-103

What about for m_H < 125 GeV?

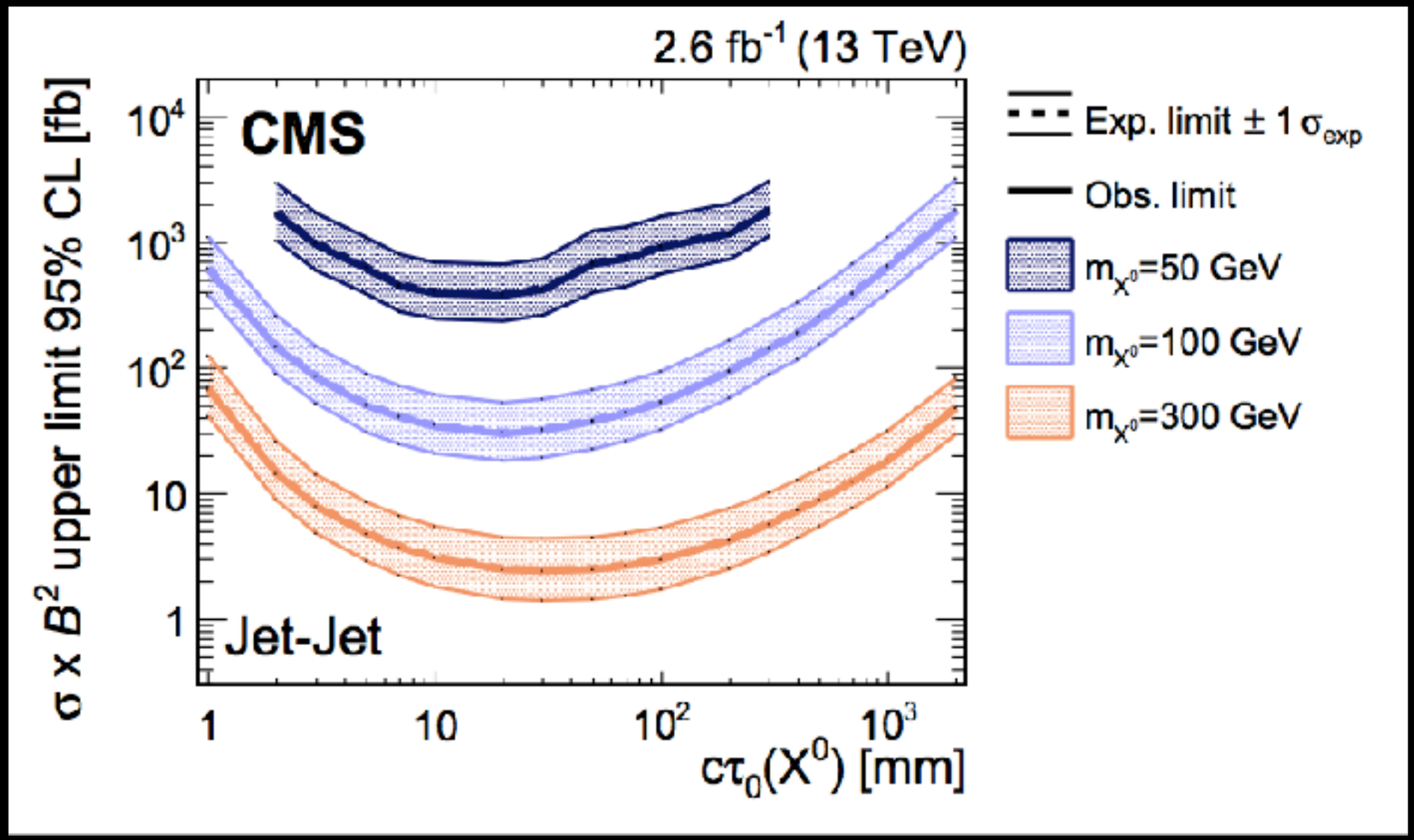
- Low mass H decaying to low mass LLP decaying to soft hadrons — buried signal
- Thresholds on, e.g., ATLAS CalRatio trigger too high?
- Will ATLAS photon-jets triggers be sensitive to this?
- Could new ideas for inner-detector triggers (e.g., hit multiplicity) catch these events?

Uncovered LLP/DV realms



Low-mass, low-pT everything

- What about pair-produced, long-lived scalars decaying to jets?
  - CMS has a good inclusive search: PLB 780 (2018) 432-454
  - What about for smaller masses and lifetimes?



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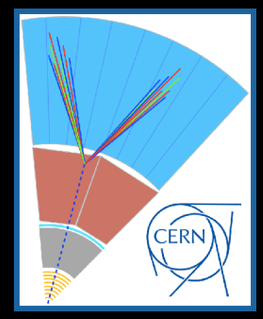
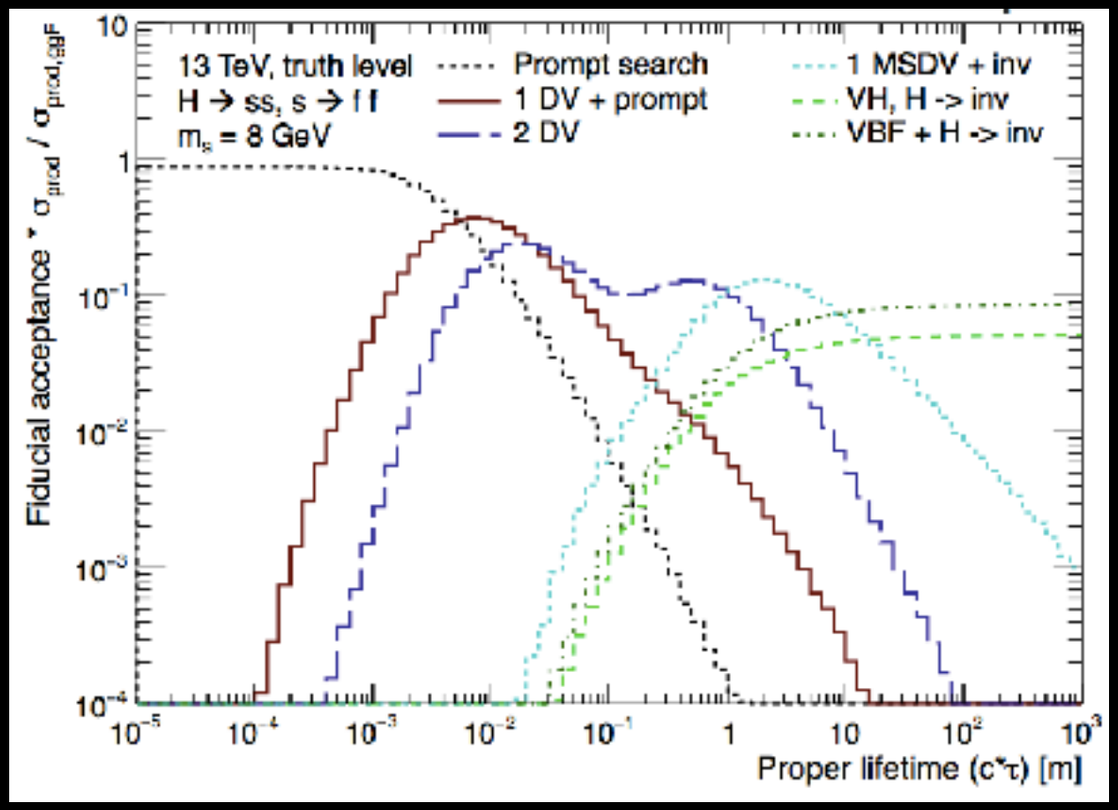


Very short-lived LLPs decaying to jets

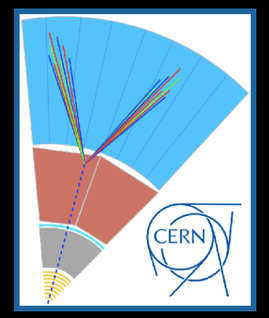
- Still unclear how some of our searches match together
  - E.g., h125 —> xx —> 4b, for x either prompt, for which searches exist (for associated production), or fairly long-lived (ctau > a few mm), for which searches also exist (for primarily ggH)



H.Russell truth study

- How big is the gap between these two? ATLAS central recasting of prompt to non-negligible but still small lifetime version public very soon

Uncovered LLP/DV realms



Very short-lived LLPs decaying to jets

- Still unclear how some of our searches match together
  - Related question: Exactly how well do our existing b-methods (b-tagging and triggers) provide sensitivity to the very short (just past the optimal b-thresholds) lifetime regime? What about alternate b-tagging methods using RNNs, etc., that we don't use for actual b-tagging because they don't provide a sizable enough gain in efficiency compared to the effort or complication?

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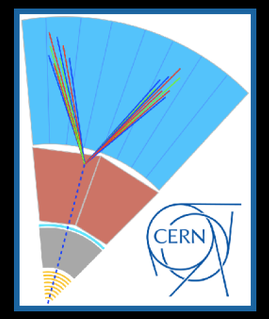

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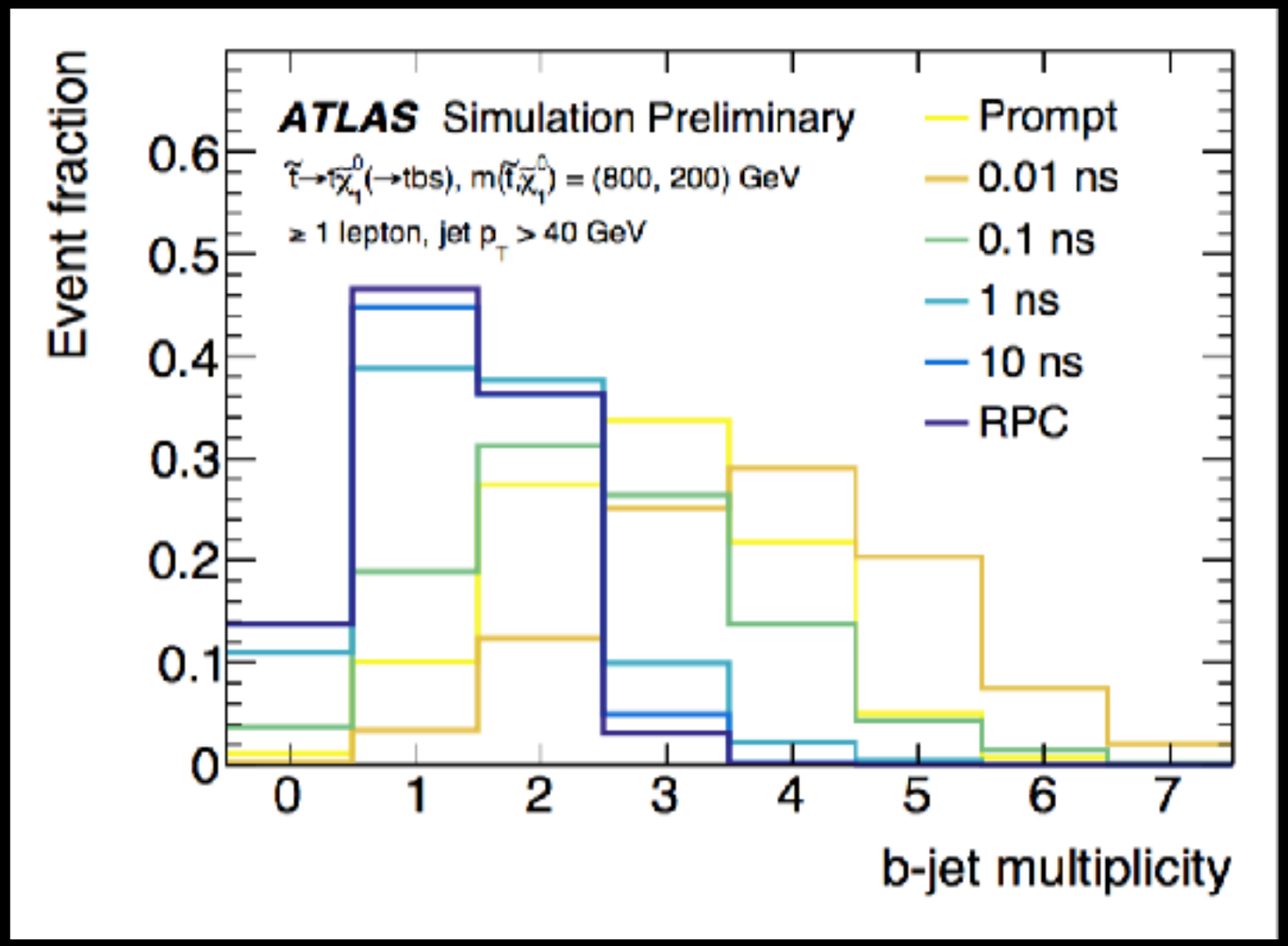
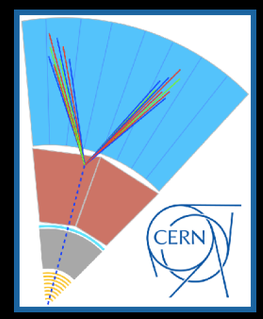
- Still unclear how some of our searches match together
  - Related question: Exactly how well do our existing b-methods (b-tagging and triggers) provide sensitivity to the very short (just past the optimal b-thresholds) lifetime regime? What about alternate b-tagging methods using RNNs, etc., that we don't use for actual b-tagging because they don't provide a sizable enough gain in efficiency compared to the effort or complication?



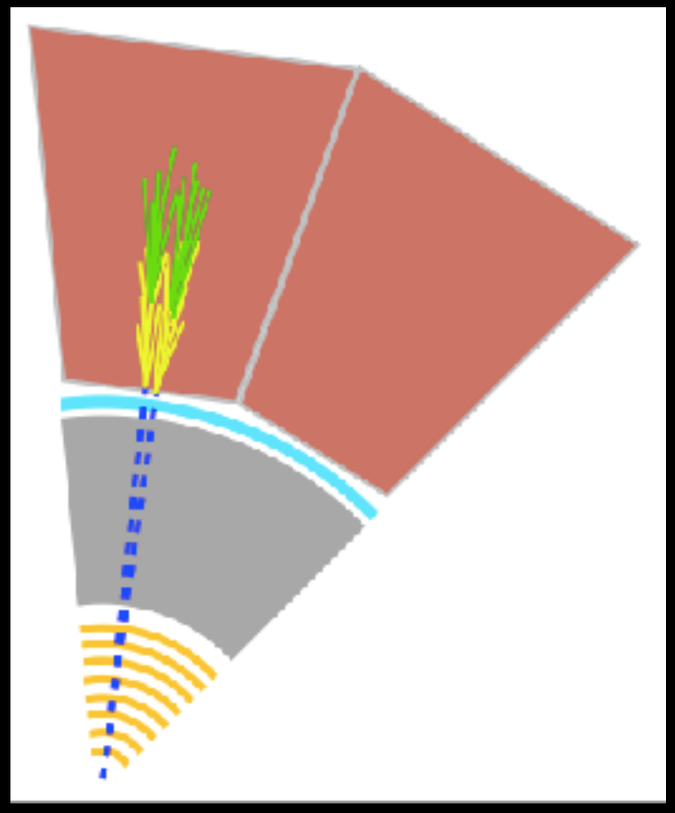
- Experimental collaborations need to do these studies centrally
- ATLAS SUSY group recently did this for a few RPV-meets-RPC searches: ATLAS-CONF-2018-003 [Karri Folan DiPetrillo talk]
- Need to do the same in a comprehensive way for h125

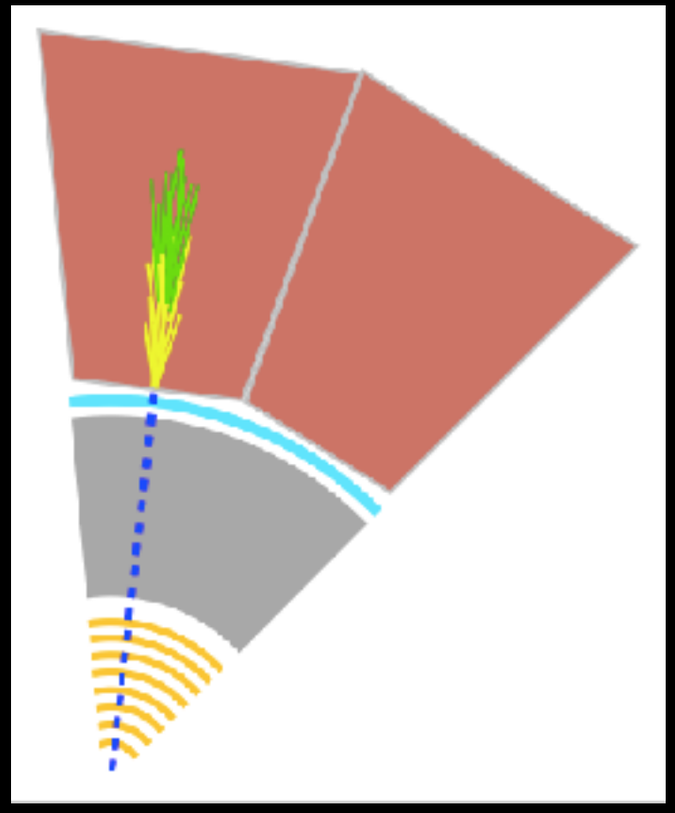
Uncovered LLP/DV realms



Photon-related signatures

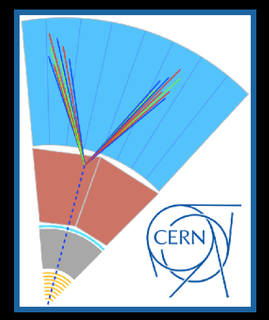
- From, e.g., axions / ALPs, or h125 —> LLPx2 —> {photons or electrons}
- Most existing LLP-related photon searches are for non-pointing or late photons in a rather model-dependent context: GMSB with a neutralino decaying to a gravitino and a photon
  - Searches require a large amount of MET





- How do we target different kinds of non-standard photon (or electron) signatures that could be evidence of LLPs?
  - Essentially looking for atypical blobs of energy in the ECal with little to no energy in the HCal — photon-jets triggers could help here

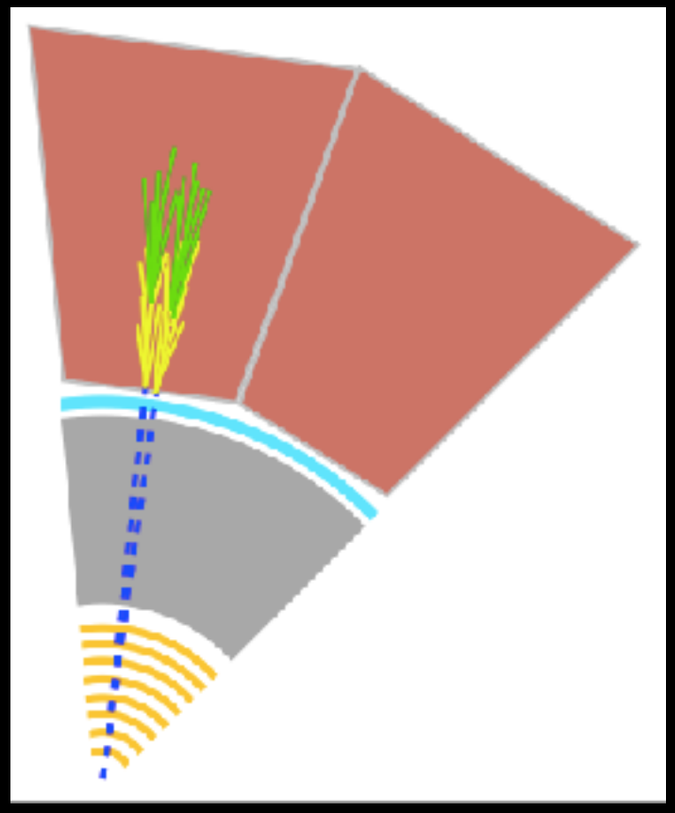
Uncovered LLP/DV realms

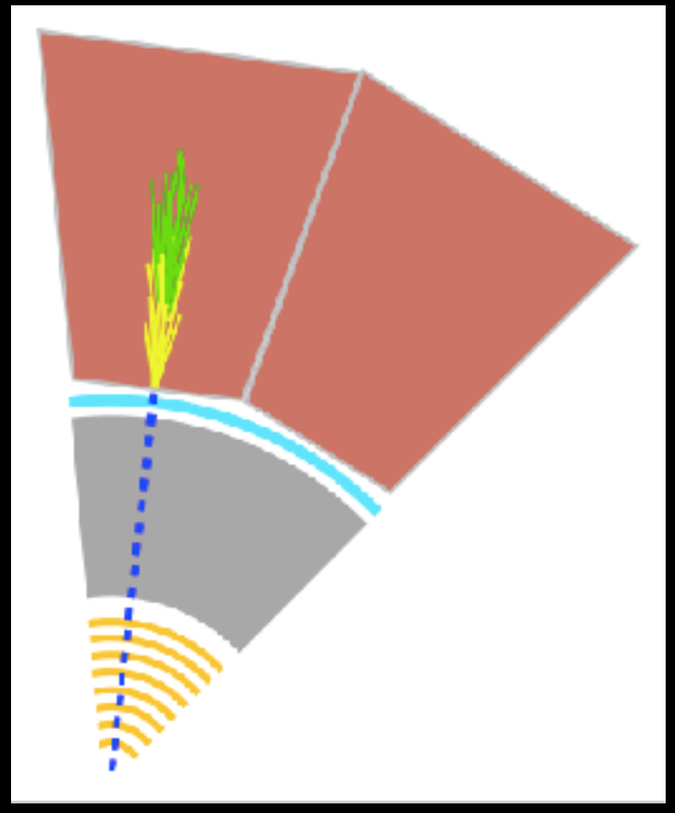


Photon-related signatures

Challenge is extending to lower mass LLPs, softer deposits

- Trigger rate limited by energy of two deposits (~20 GeV)
- Typically mitigated for individual photons with hadronic isolation (also good here) or ring isolation (not good here)





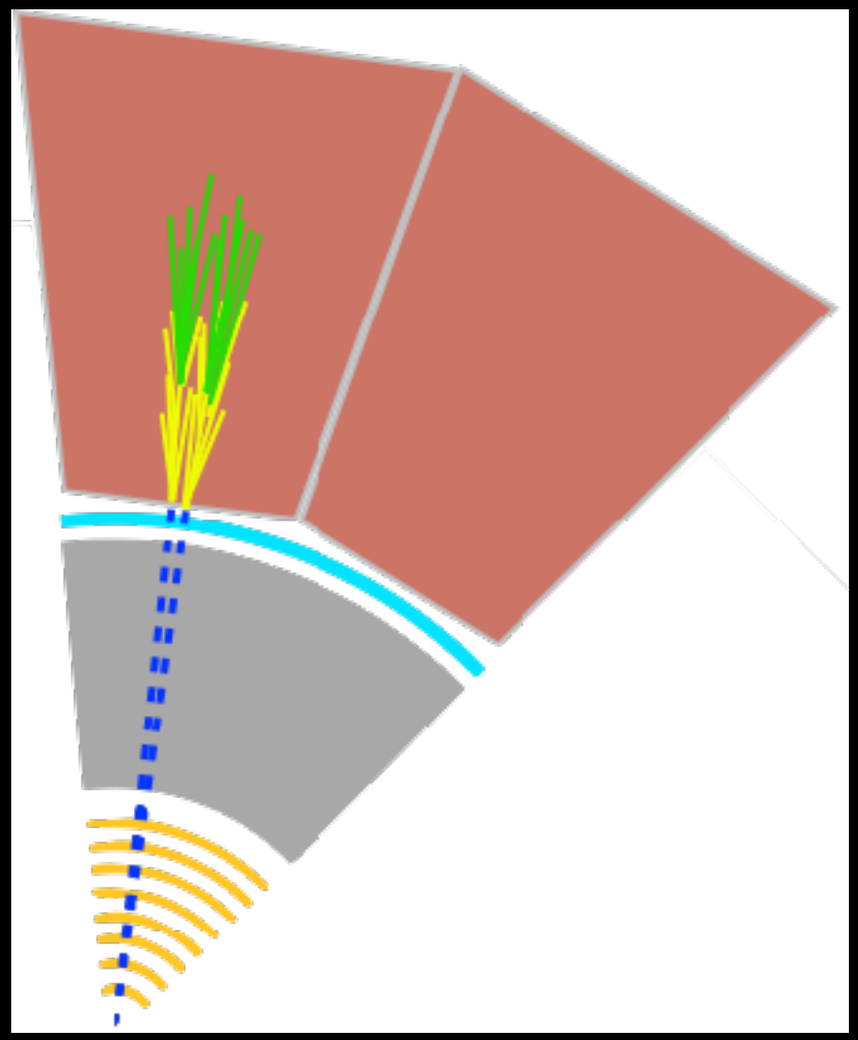
- Can use substructure at HLT in ATLAS — this could help lower ECal deposit thresholds
- What are the CMS capabilities here?

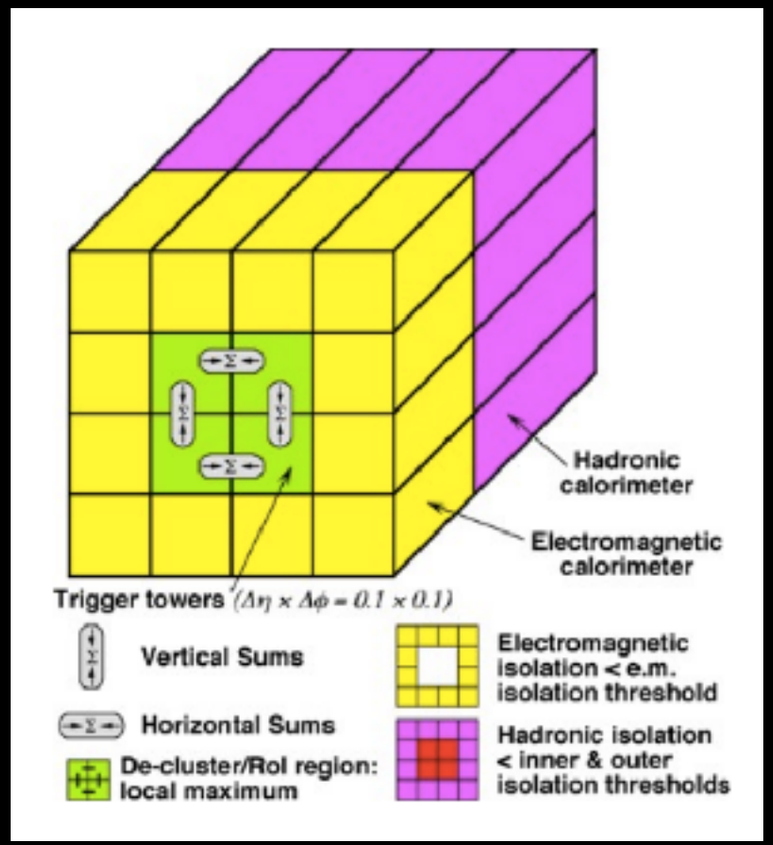
Uncovered LLP/DV realms

How to trigger on photon-jets?

Signature:

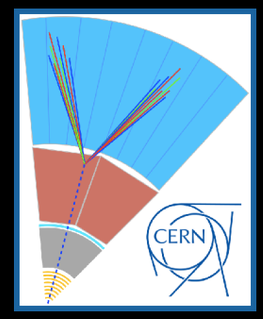
- An ugly blob of energy in the electromagnetic calorimeter
- Little-to-no energy in the hadronic calorimeter





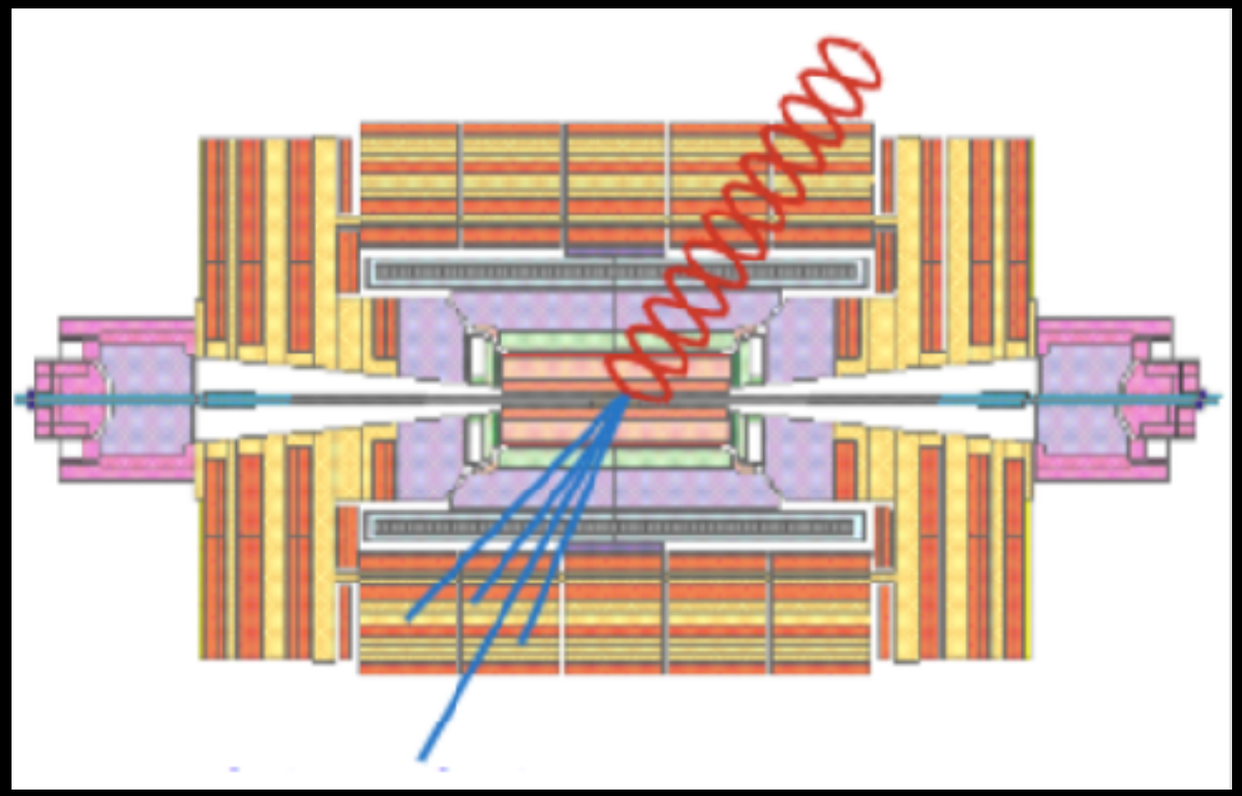
- Too wide to be an isolated photon and be caught by standard high-level photon triggers
- Use hard veto on HCal activity and possibly jet substructure variables applied to ECal-only objects
- Some combination of extra techniques are necessary to ensure the trigger rate doesn't get too high — still to be determined what this would do for LLP signatures for, e.g., soft electron or photon decays from low-mass LLPs

Uncovered LLP/DV realms

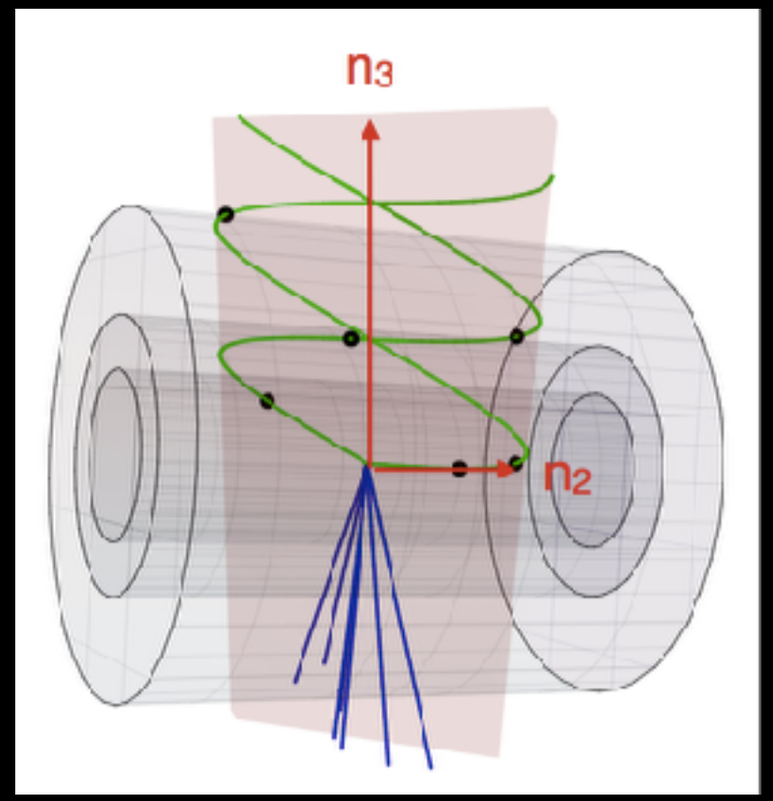


Non-standard tracks from quirks

- Quirks: Particles charged under new confining gauge group but with masses much greater than the confinement scale —> distinct quirk/antiquirk pairs never form —> they oscillate until they annihilate
- As such, they leave a wild, oscillating-pair signature in the detector

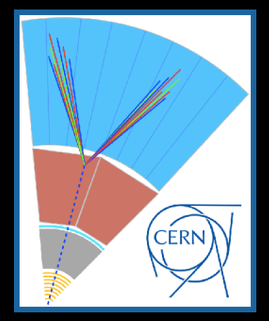


Talk by Knapen at Trieste LHC LLP Workshop

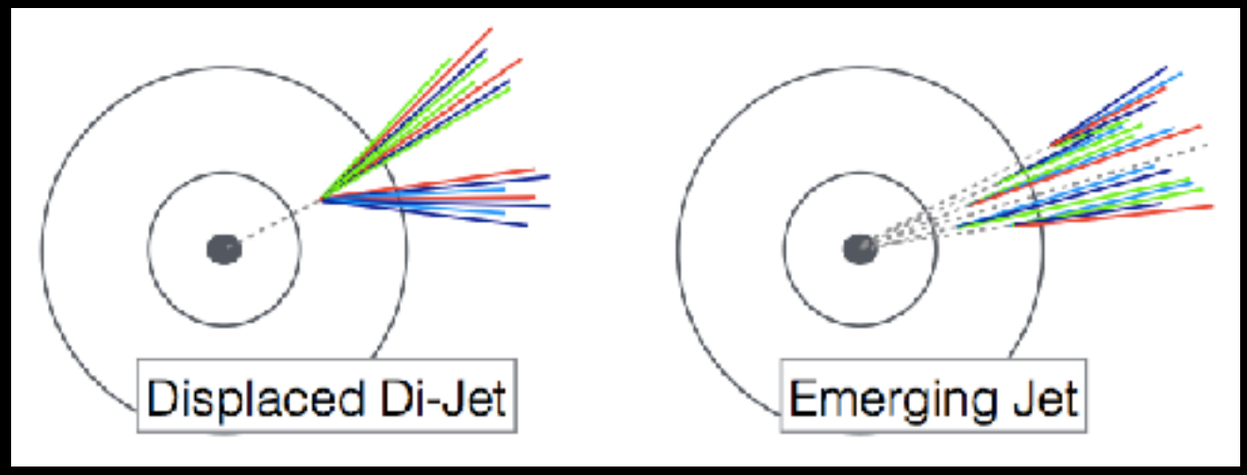


- This is hard, both because standard tracking isn't useful here and because it's difficult to model in Geant4 — only existing search is at D0
- S. Knapen, et al, proposed a model-independent method of looking for patterns of hits that lay in a plane in the detectors — promising avenue for discovery

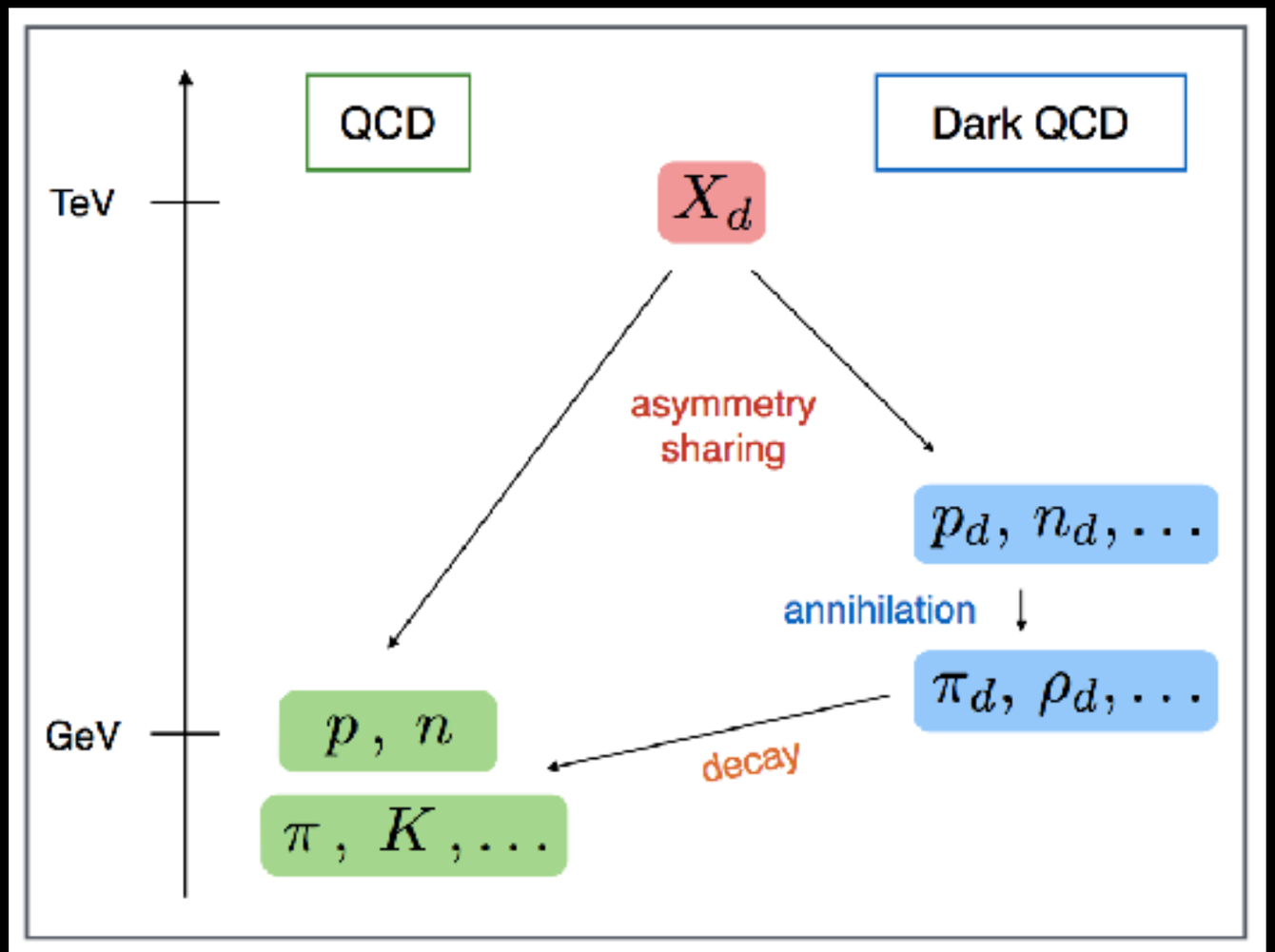
Uncovered LLP/DV realms



Why should beyond-the-Standard Model physics be simple, like a U(1) symmetry? What about dark QCD?

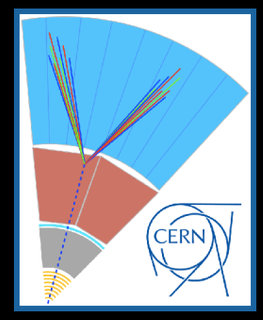


Ex: arXiv:1502.05409



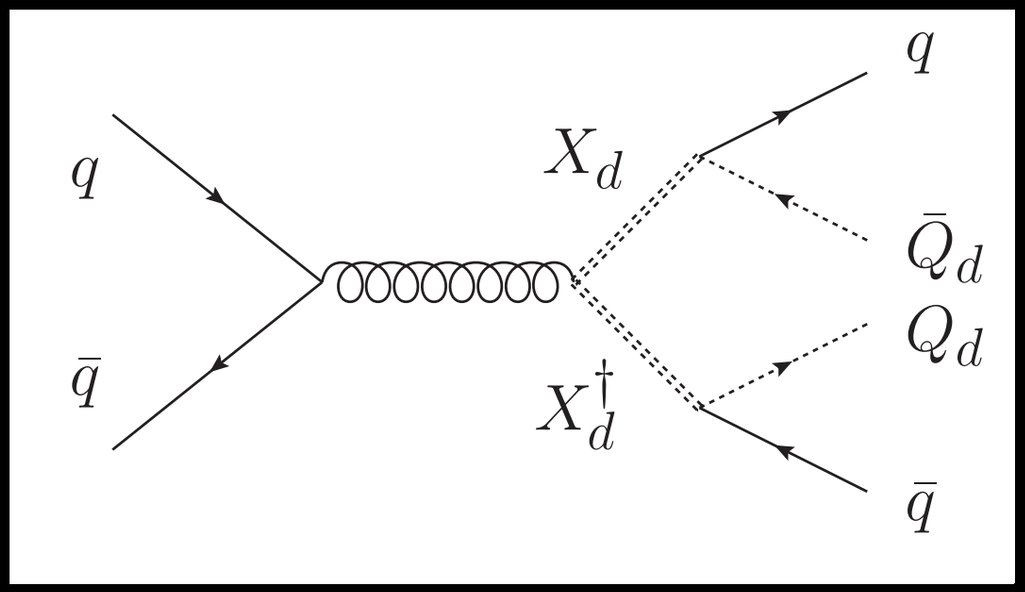
One corner of dark-QCD-like models: **A novel LHC signature** where dark or hidden sector quarks decay to the visible sector via multiple displaced vertices of varying displacements within the same jet object. Pair-produced dark quarks then give rise to **neither prompt jets nor a pair of displaced jets** pointing to the same displaced vertex, but to **emerging jets**.

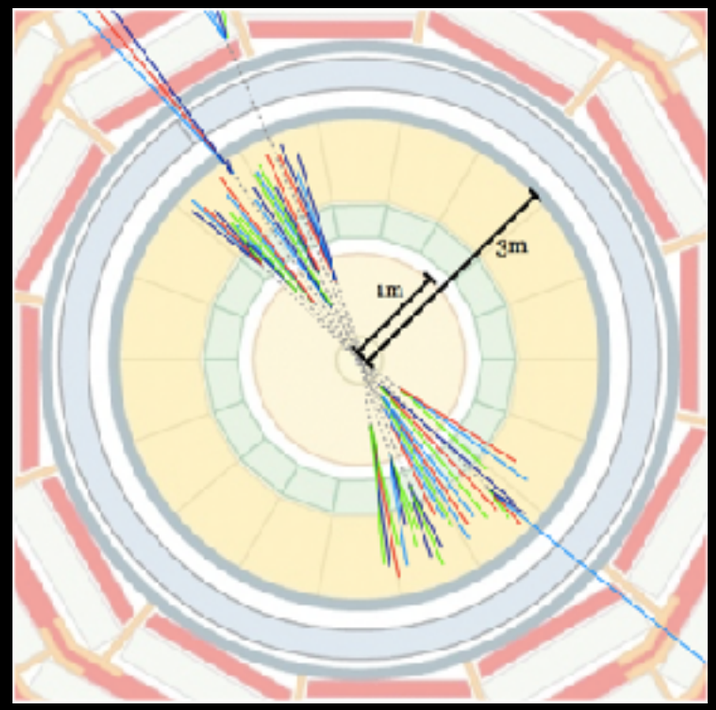
Uncovered LLP/DV realms



Atypical jets and jets with non-standard tracks

- Hidden sectors with strongly coupled dynamics — dark QCD
  - Pencil-like jet regime — emerging jets





arXiv:1502.05409

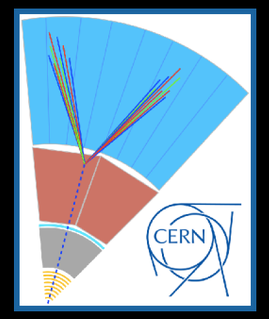
Dark QCD —> dark quarks —> dark pions w/variable lifetimes —> jets w/ multiple displaced vertices / tracks in a single jet or event

Analysis strategy could target 4-jet signal:
2 QCD jets + 2 dark-QCD / emerging jets

Emergingness defined per jet or per event? Count number of displaced vertices per event? What if generators don't yield jets with DVs clustered near a jet? How do we trust existing generators to give us reliable pheno?

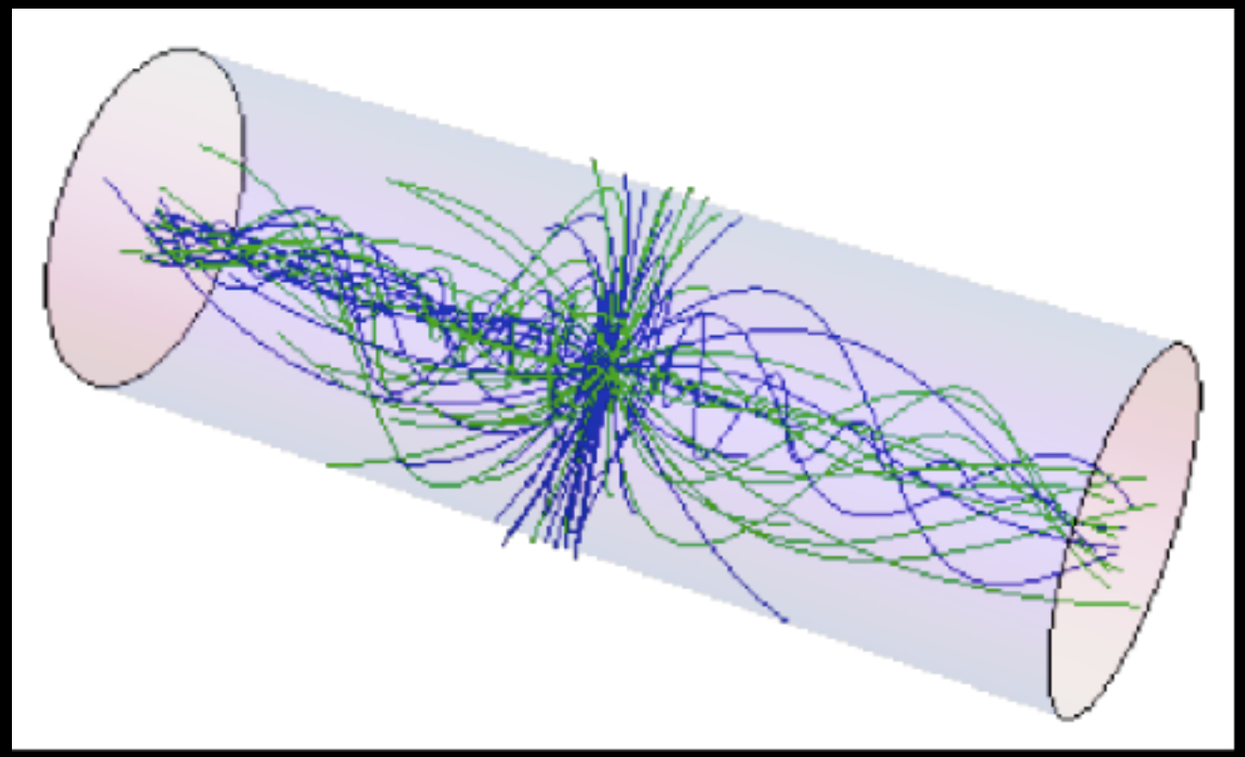
Searches underway in ATLAS & CMS (see A. Belloni talk on Friday)

Uncovered LLP/DV realms

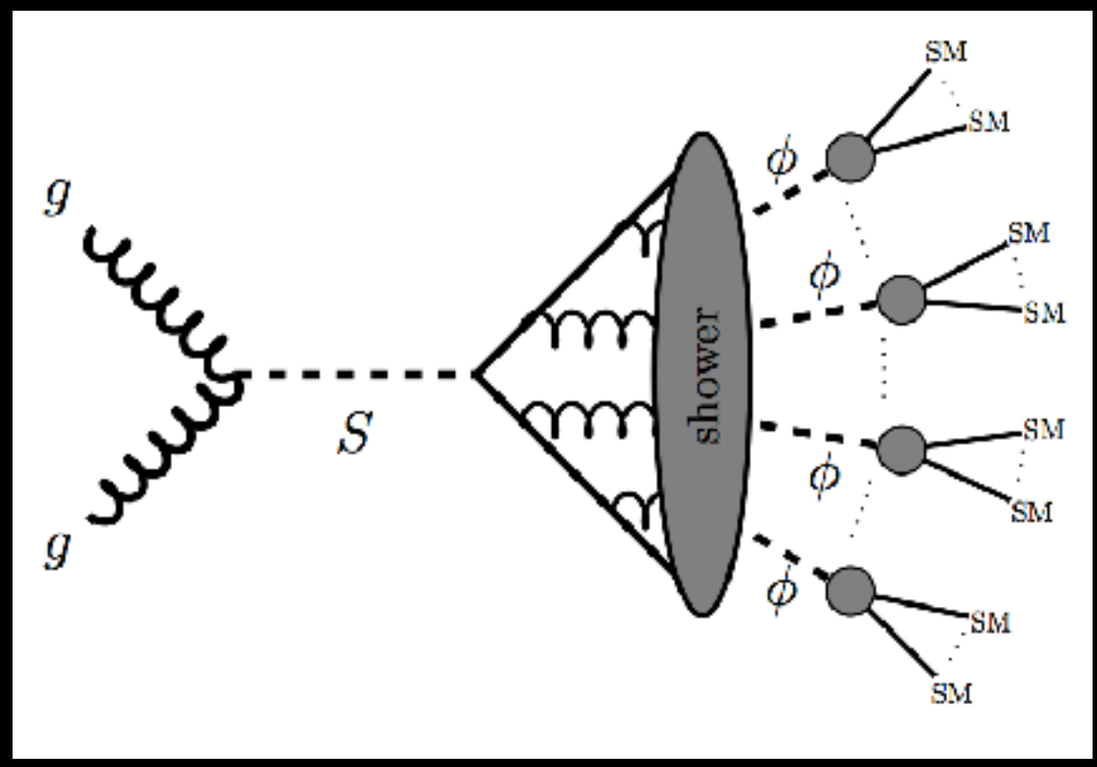


Atypical jets and jets with non-standard tracks

- Hidden sectors with strongly coupled dynamics — dark QCD
  - Soft, unclustered energy patterns, or SUEPs: arXiv:1612.00850

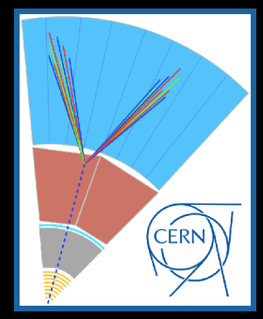


Cylinder is edge of ECal, with ~100 very soft electrons and muons swarming around



Hidden valley scenario with confining dynamics — here a strongly coupled regime with a high-mass mediator decaying eventually to a large multiplicity of low-energy SM states

Uncovered LLP/DV realms

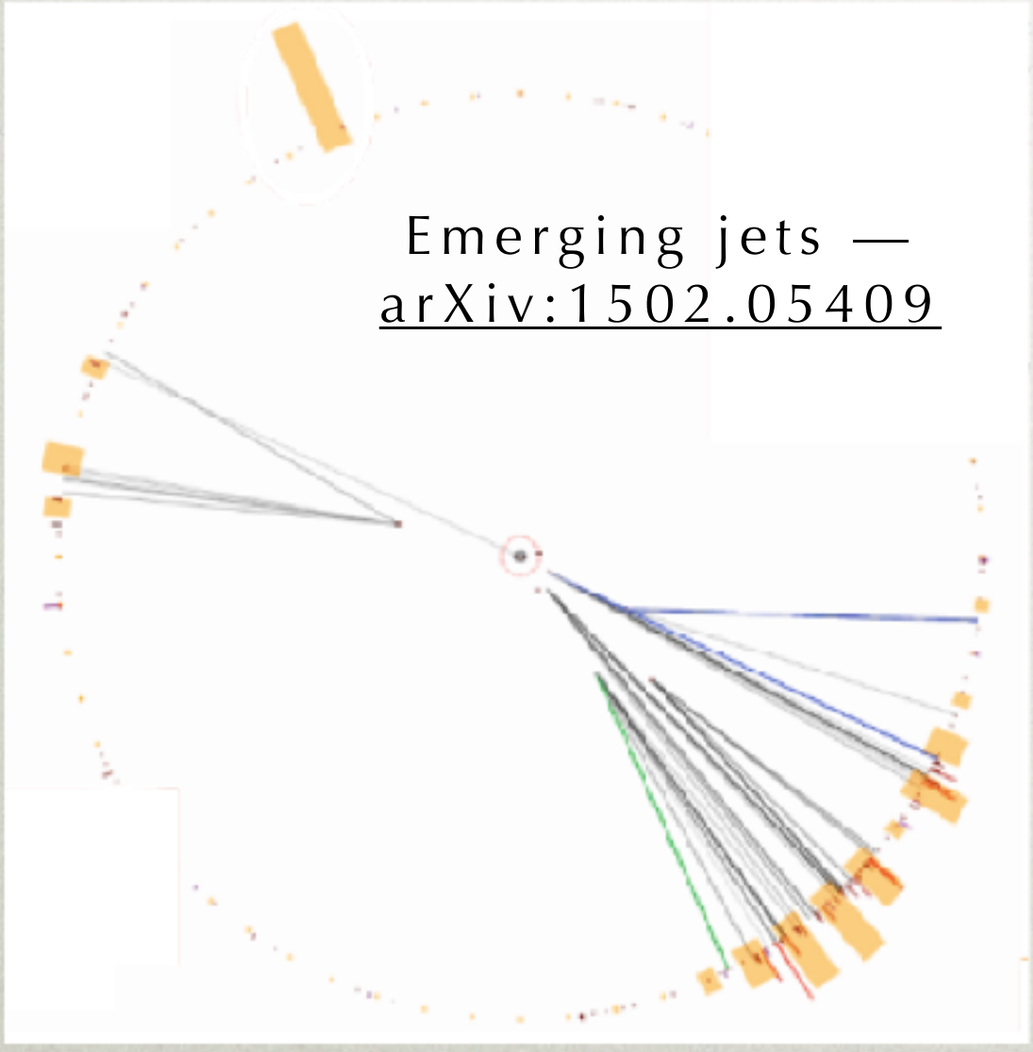


Atypical jets and jets with non-standard tracks

- Hidden sectors with strongly coupled dynamics — dark QCD
  - Soft, unclustered energy patterns, or SUEPs: arXiv:1612.00850

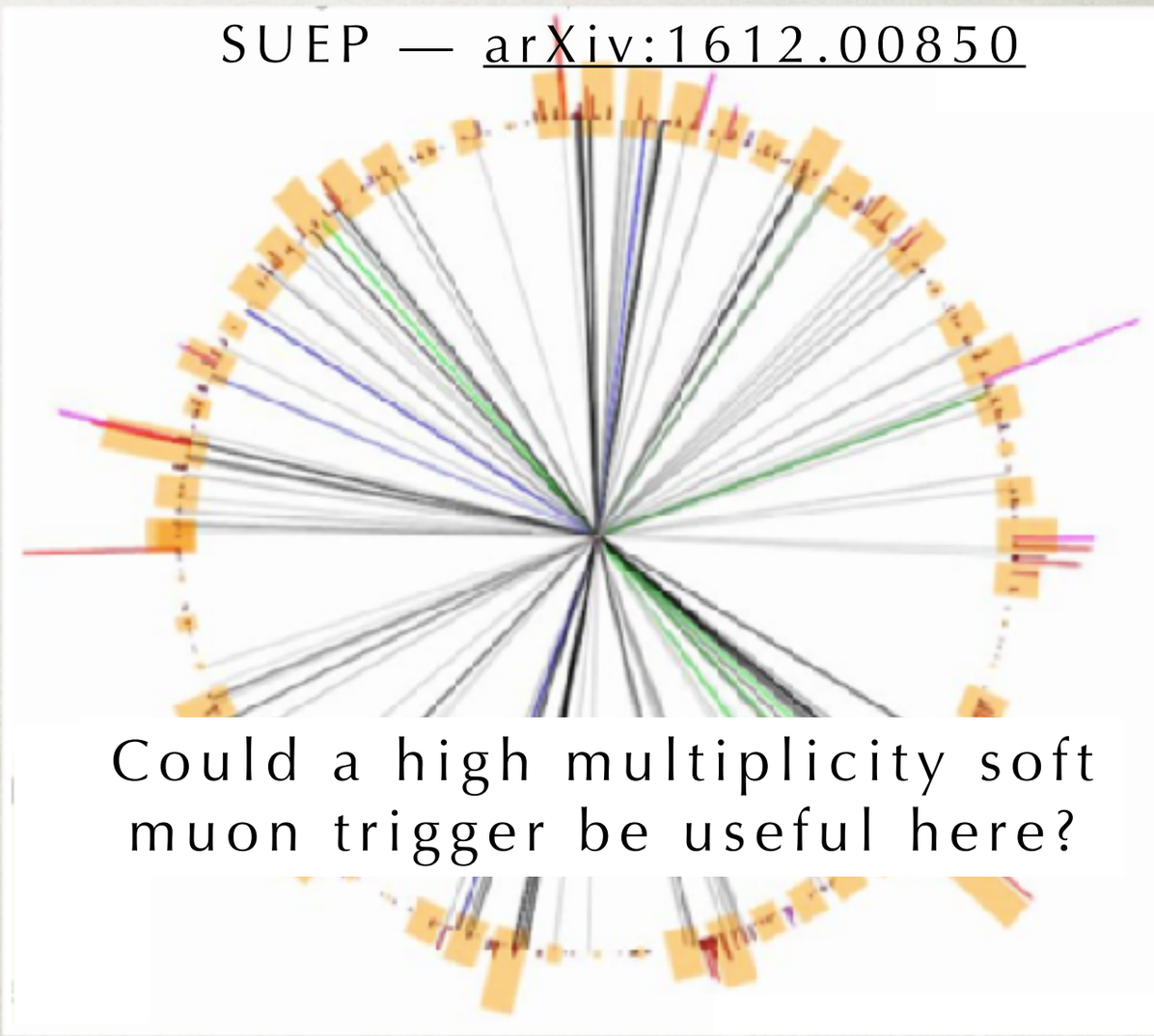
Schwaller, Stolarski, Weiler 2015

Emerging jets — arXiv:1502.05409



Knapen *et al.*, 2016

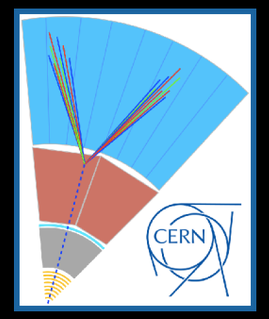
SUEP — arXiv:1612.00850



Could a high multiplicity soft muon trigger be useful here?

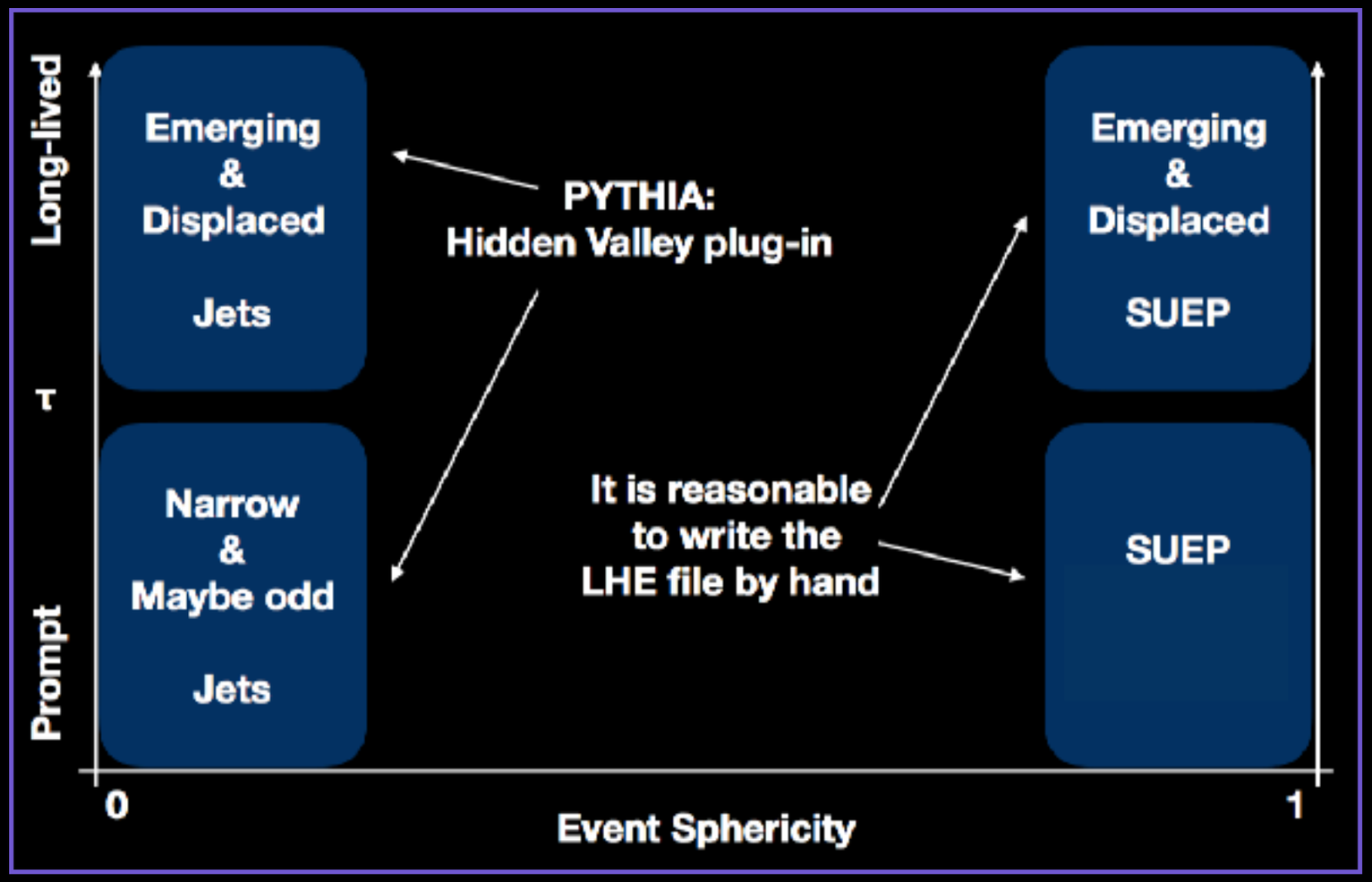
Images by M. Strassler

Uncovered LLP/DV realms



Atypical jets and jets with non-standard tracks

- Hidden sectors with strongly coupled dynamics — dark QCD
  - Between jets and SUEPs — this is where *we really don't know what we don't know*

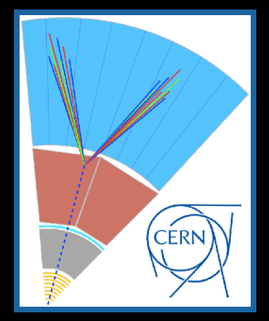


Dark showers working group (Knapen, Shelton, Scholtz, Stolarski, Linthorne, Freytsis, Reece, Cesarotti, et al) began investigating this in earnest last year — many unknowns w.r.t. phenomenology resulting from any of the methods used for any of these regimes!
[Summary from Trieste]

- How do we model these?

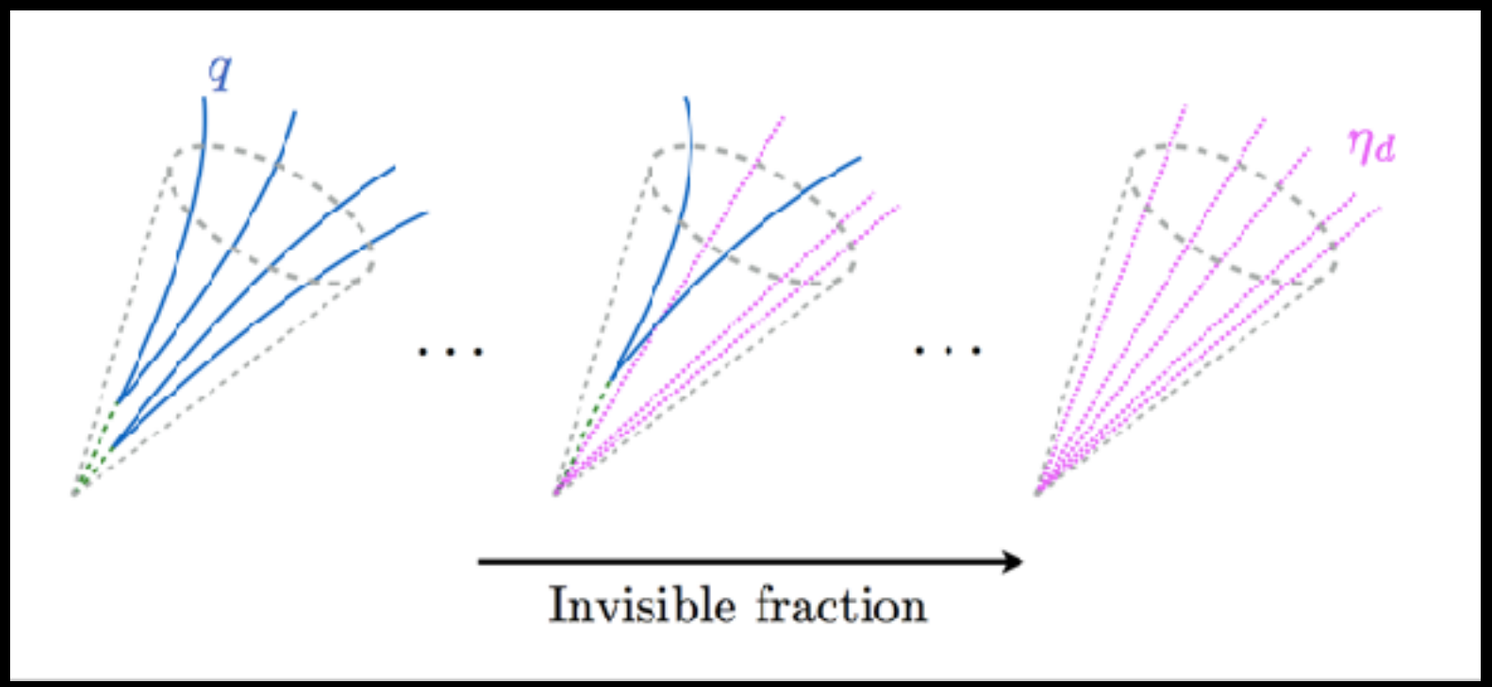
- Does it make sense to interpolate some key distributions between the edge cases and generate events based upon these?
- Strassler: "Has anyone even tried to validate the Pythia Hidden Valley module?" [Talk last month at our CERN workshop]
- Perhaps displaced-vertex gun approach would simply work best

Uncovered LLP/DV realms



Atypical jets and jets with non-standard tracks

- Hidden sectors with strongly coupled dynamics — dark QCD
  - One version of in-between — semi-visible jets
  - Jet of visible matter + dark matter from, e.g., hidden valleys

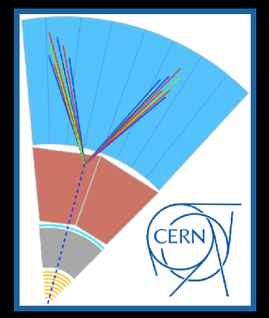


Talk by Mishra-Sharma at Trieste LHC LLP Workshop

Neither an emerging jet (where there's no sizable MET) nor a completely detector-invisible object

- Looking for a di-jet-like resonance with jets wider than QCD and non-zero MET
  - Cohen, Lisanti, Lou, Mishra-Sharma pointed out this discovery avenue we may be overlooking: arXiv:1707.05326

Uncovered LLP/DV realms



Between jets and SUEPs

- Intriguing approach by C. Cesarotti and M. Reece: Abandon the SU(N) scheme, use a model for dark shower with more control using AdS/CFT correspondence where they look at KK modes to understand hidden sector hadrons

Extra Dimensions

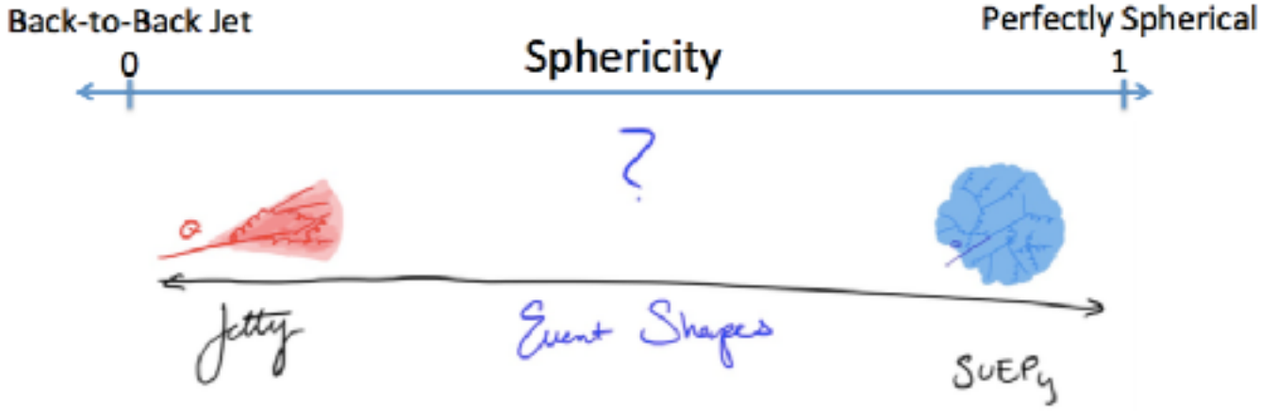
- Toy to build intuition for SUEP-to-Jet problem
- Extra finite 5th dimension (x^μ, z)
- Warp space with $\Lambda_5 < 0 \rightarrow$ AdS (RS1)
- Boundary on interval: UV, IR cutoffs
- AdS/CFT to calculate hidden sector dynamics

$$ds^2 = \left(\frac{R}{z}\right)^2 \left(\eta^{\mu\nu} dx_\mu dx_\nu + dz^2\right)$$

C. Cesarotti talk in Trieste

Promising way to interpolate pheno between the two regimes

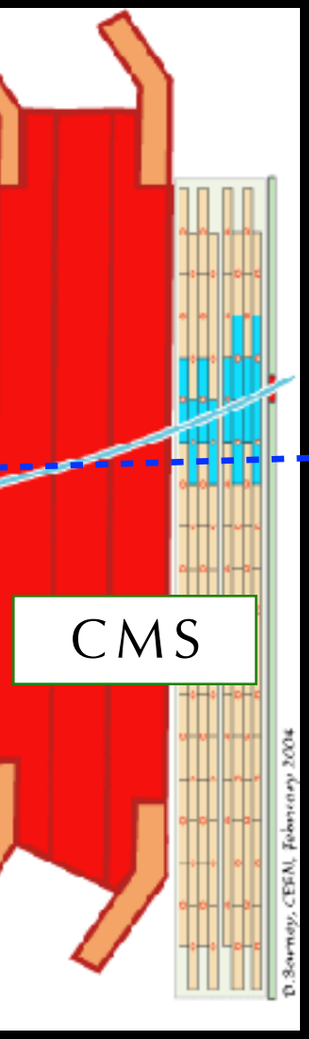
Sphericity of KK Modes



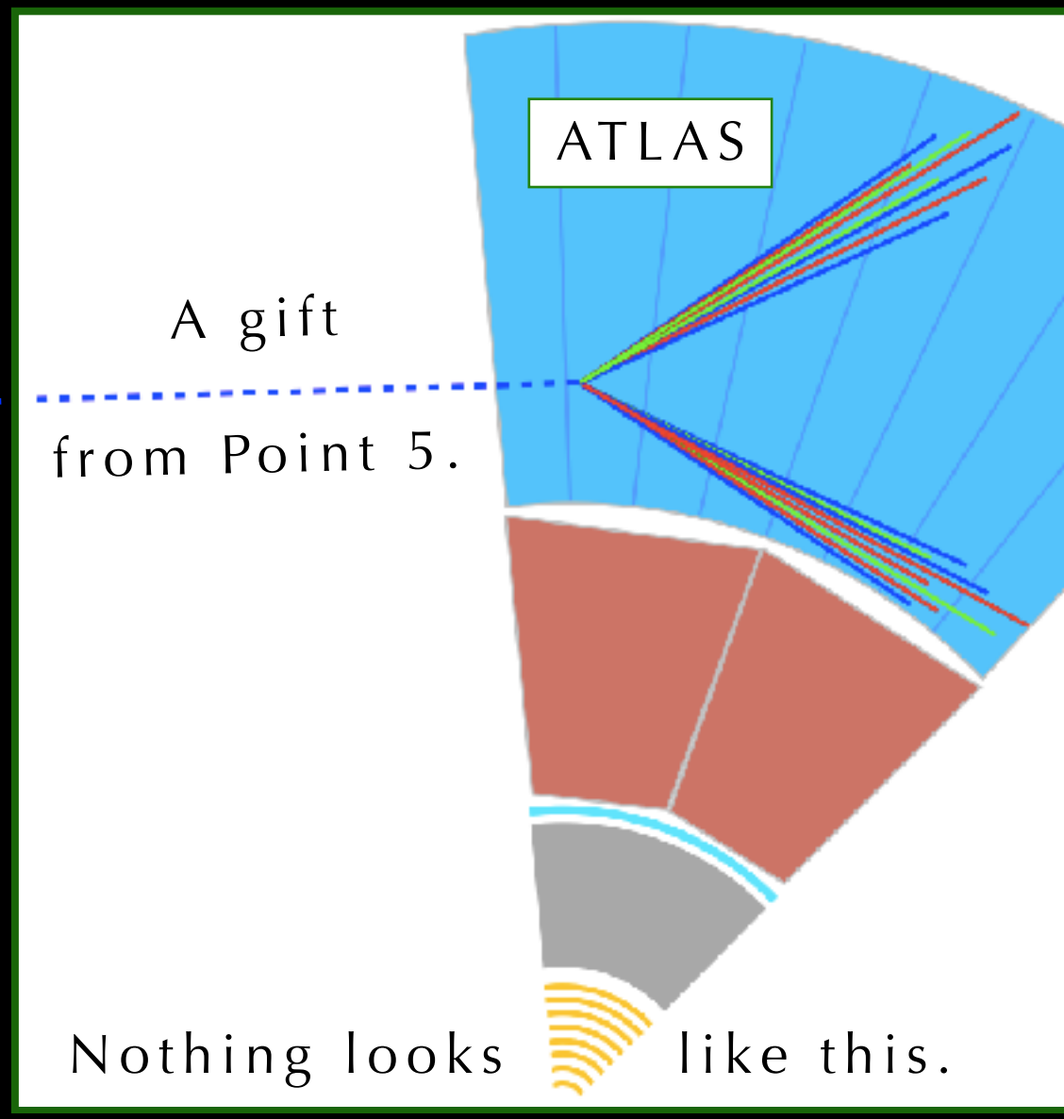
Bonus (and ad for MATHUSLA): How do we break things?

What are we missing?

- What about nearly-trivial insanities?



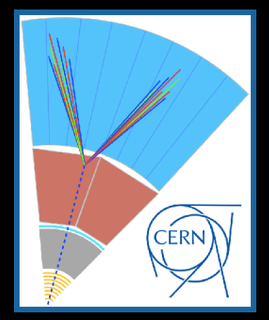
- ATLAS and CMS can each be used as a detector for LLPs produced in the other
- Solid angle coverage is vanishingly small, ~10^{-7}... <— insane
- ...but non-zero. And the signature is so rare that it would immediately show up in unfilled bunch crossings <— trivial
- A quizzical use of time? Why not spend a month looking for this and getting a limit, as a proof of concept?
  - Remember that the LHC is our only good source of Higgses, Ws, etc., for a very long time.



- Side benefit, speaking of trivial: The result would trivially be featured in the popular science press (cf. MATHUSLA, MilliQan, etc.); reaching the public in novel ways is of utmost importance in 2018

Meade, Nussinov, Papucci, Volansky mentioned this in passing in 2009

Conclusions



Discoveries could be just around the corner

- LLP and displaced vertex signatures are moving from the edges of our research programs in ATLAS, CMS, and LHCb to benefit from a more coordinated effort to identify uncovered realms
- LHC LLP Community focuses on signature-first / model-second
- Upcoming white paper includes entire chapter on Experimental Coverage, functioning as both a review of the existing searches and an enumeration of gaps in coverage and opportunities for extensions
- Plenty of work to be done — if you're in ATLAS / CMS / LHCb and looking for a novel search or technique to make a large difference in discovery physics, dive in!
- We don't choose where the new physics may be hiding — we only choose to keep exploring
- The nightmare scenario at the LHC is not no-new-physics; it's, "You didn't keep the right events and didn't do the right searches."
  - The LHC LLP Community endeavors to reduce this chance to as small as possible

Workshops like this one right here are *vital* to map the future of the LHC's research program!

There's no failure in particle physics when you're an explorer

The only failure is to stop searching

Here's to a productive and invigorating workshop!

James Beacham
@jbbeacham