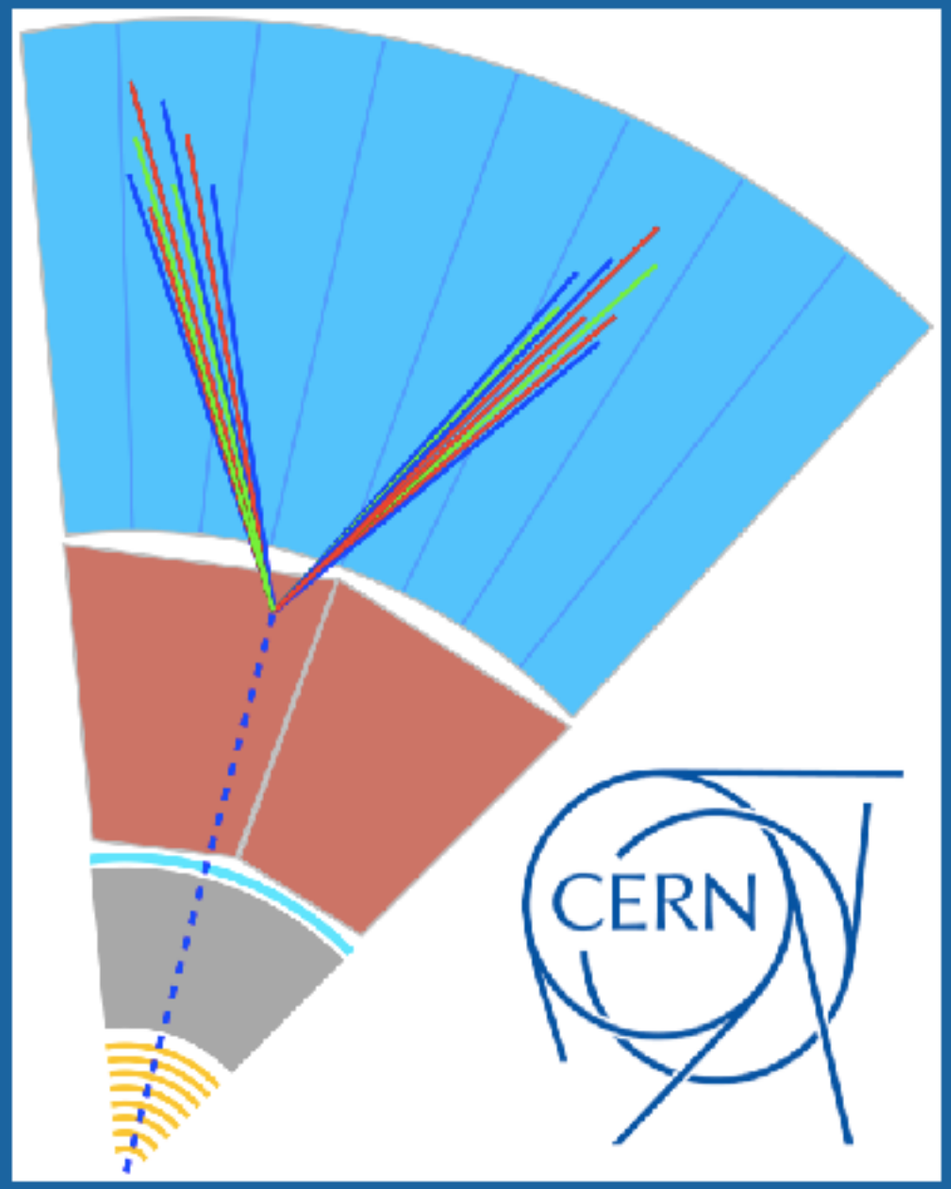
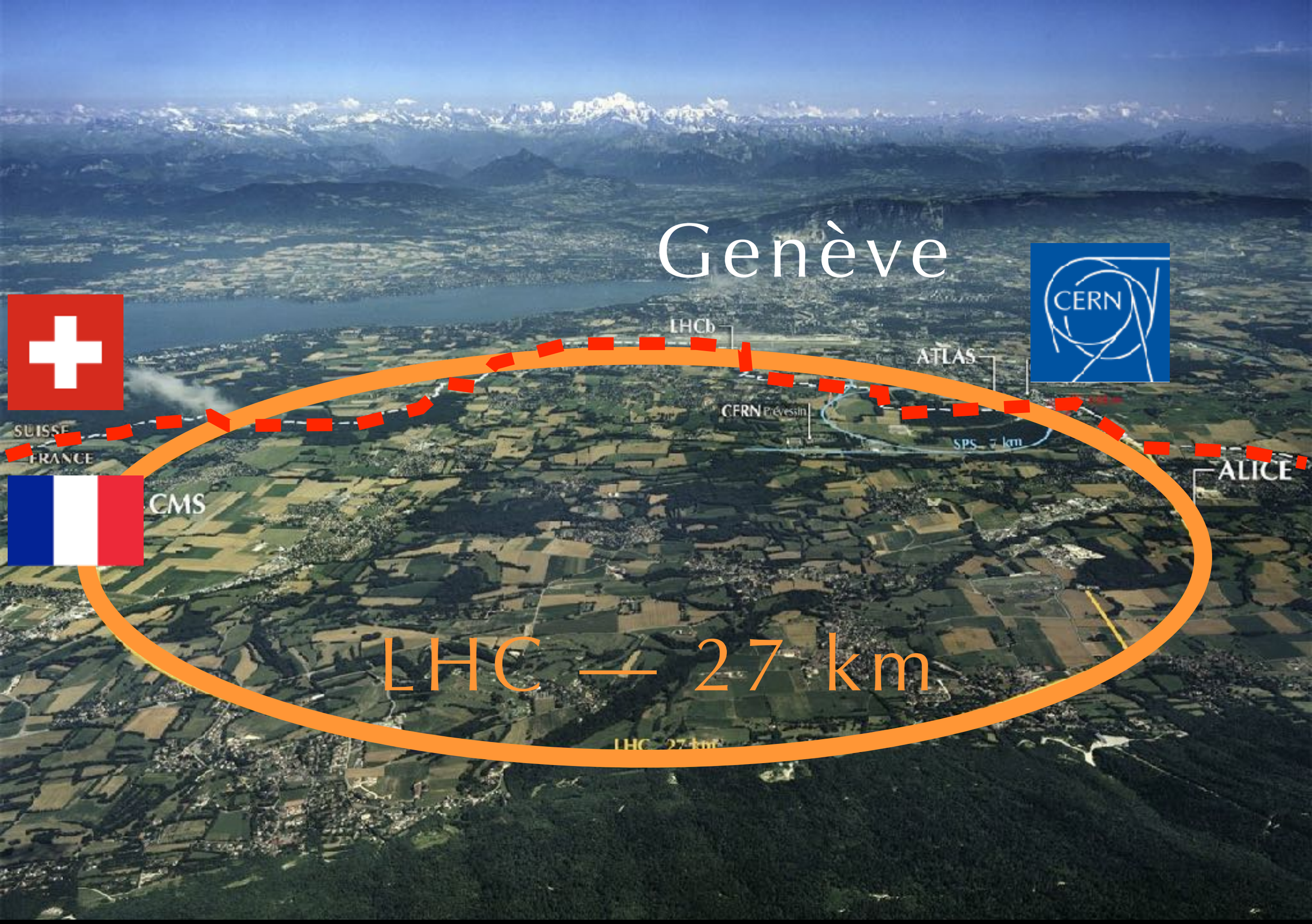


Searching for Long-Lived Particles at the LHC

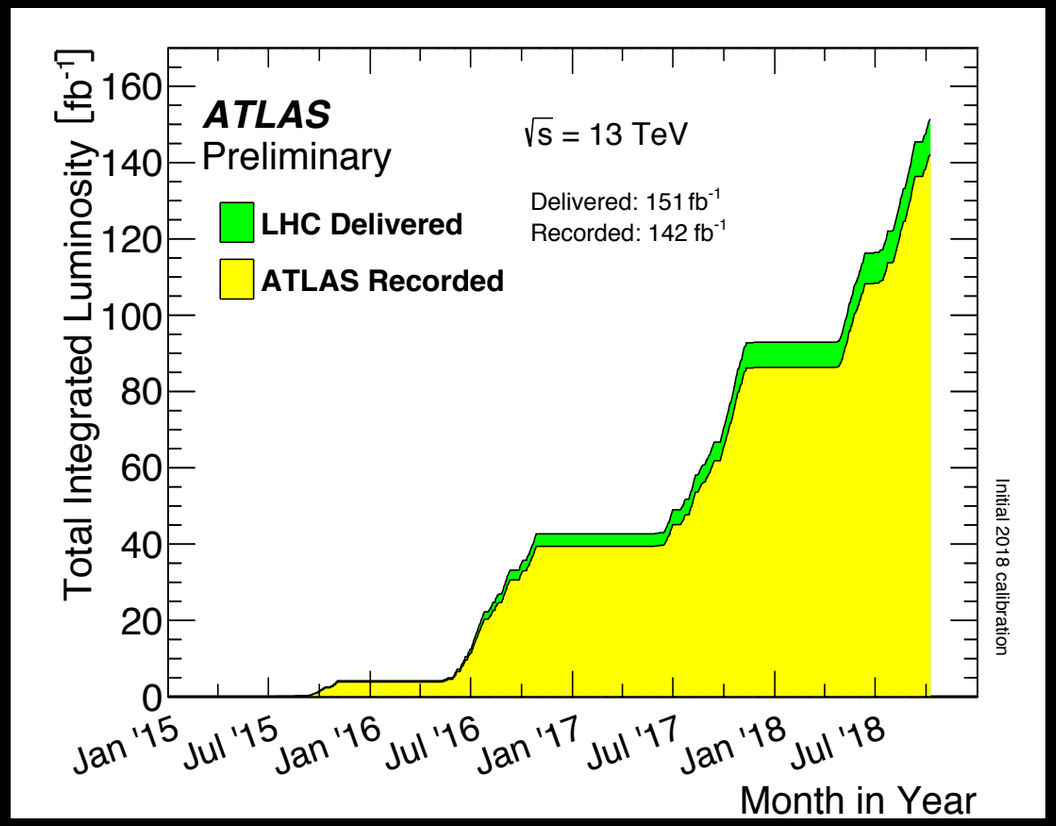
IPA 2018

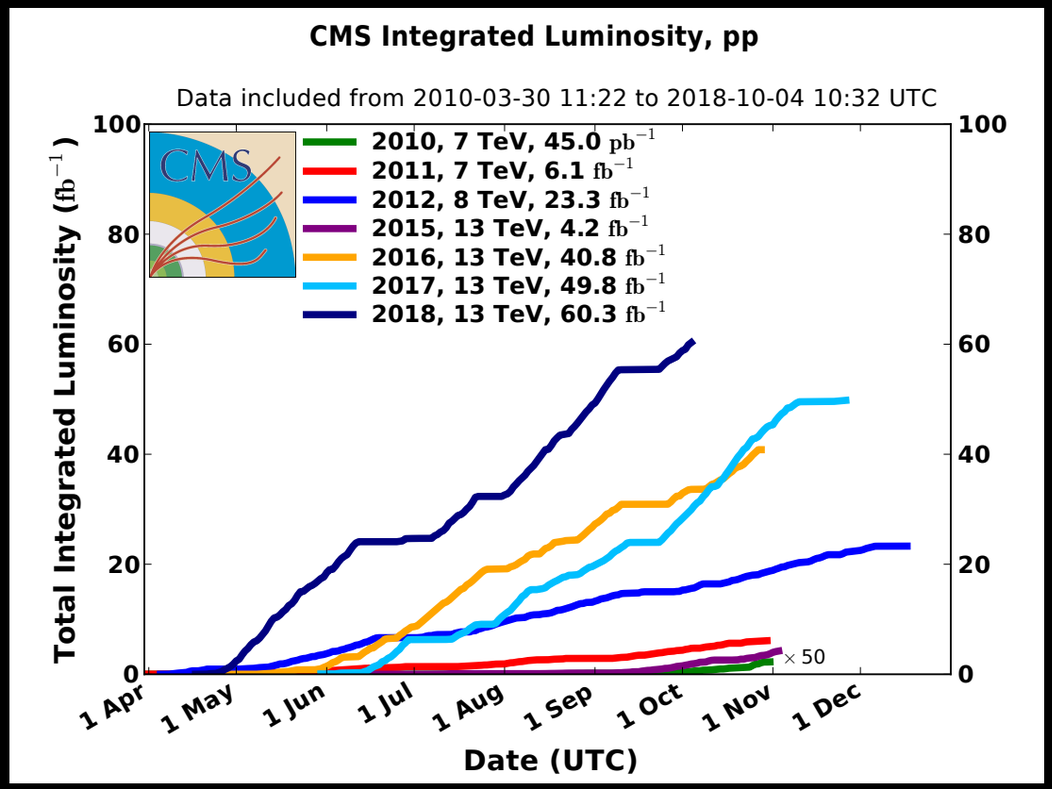
Cincinnati — 9 October 2018

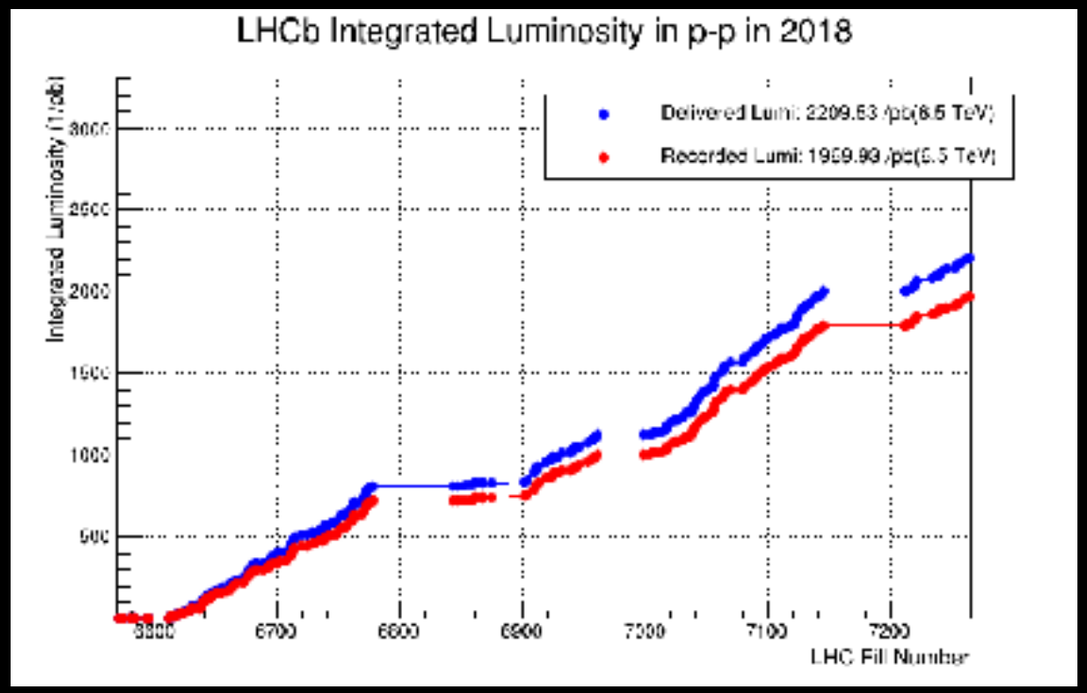
James Beacham [ATLAS/Duke University]


Genève
LHCb
ATLAS
CERN
CERN Prévessin
SPS
ALICE
SUISSE
FRANCE
CMS
LHC — 27 km

The Large Hadron Collider is a big-data discovery machine



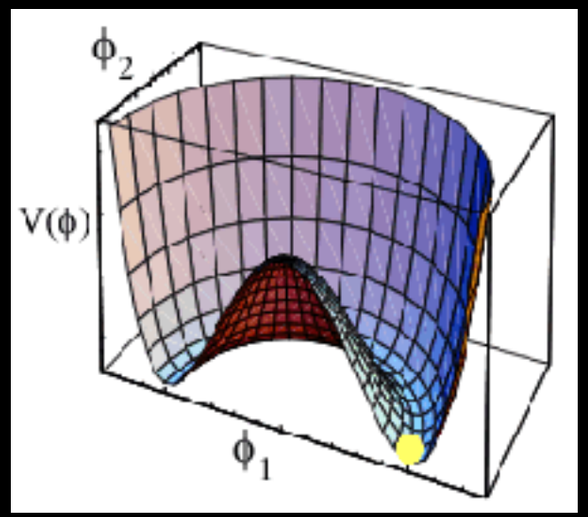




Run 2 has been a triumph

4 July 2012

4 July 2012



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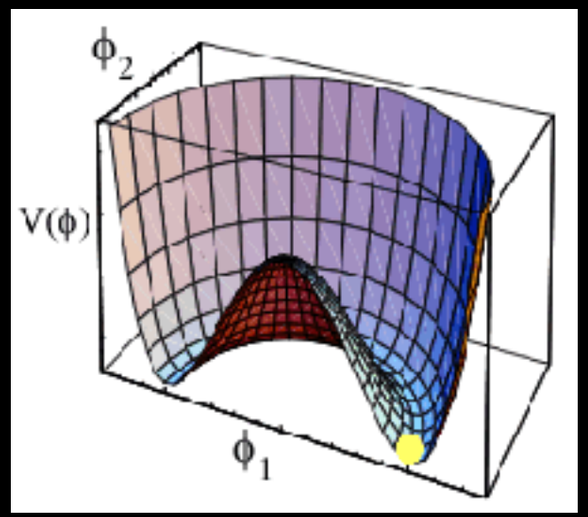

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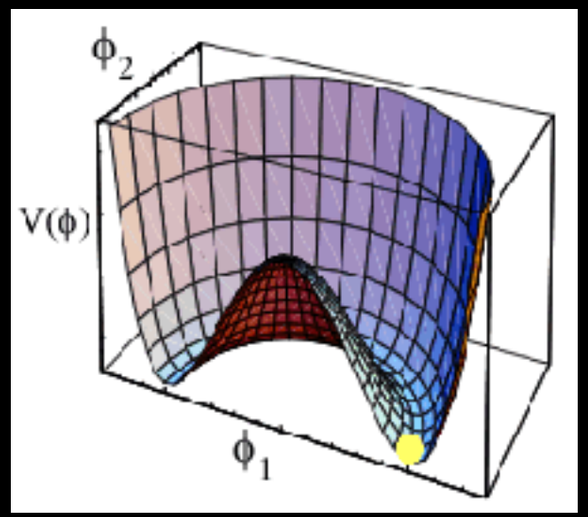

The day
everything
changed

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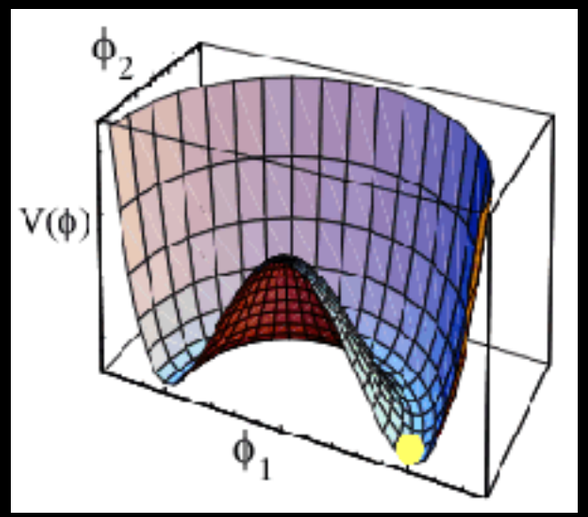

3 June 2015

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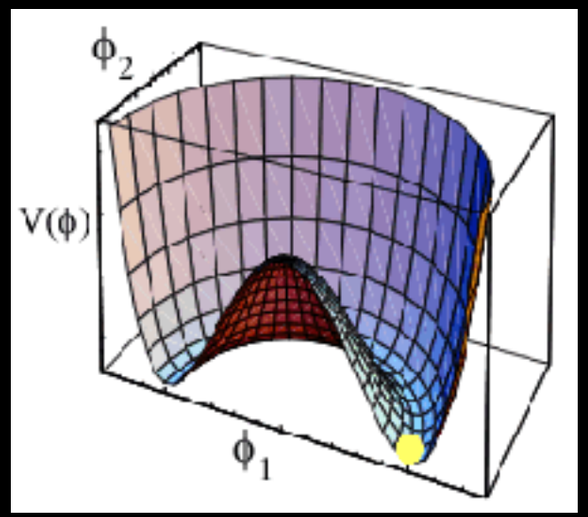

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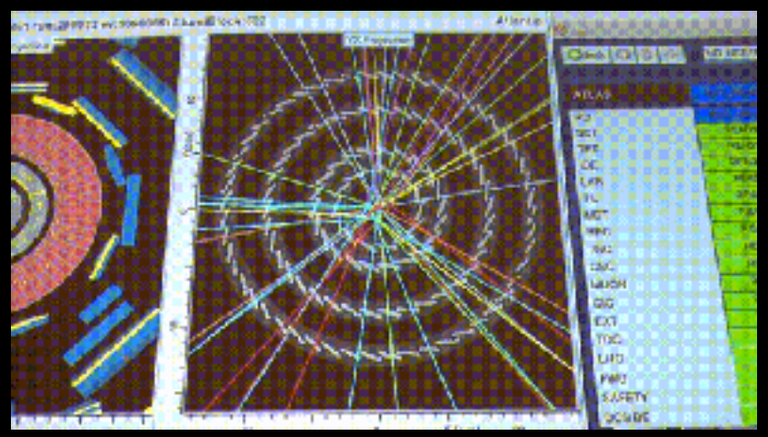

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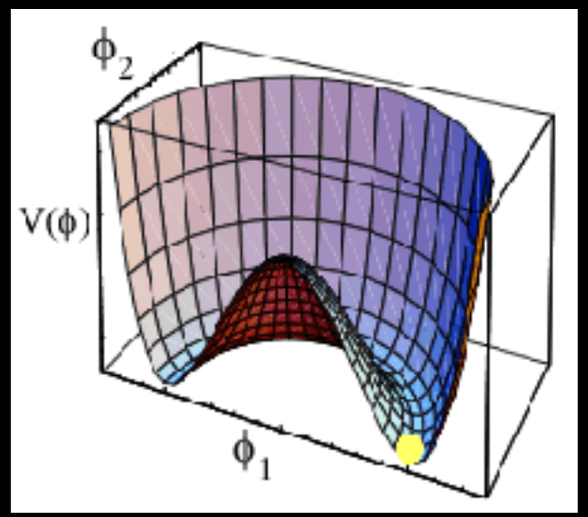

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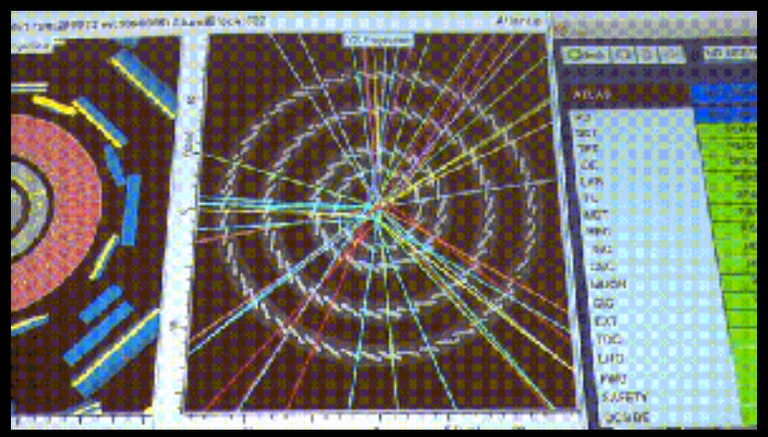

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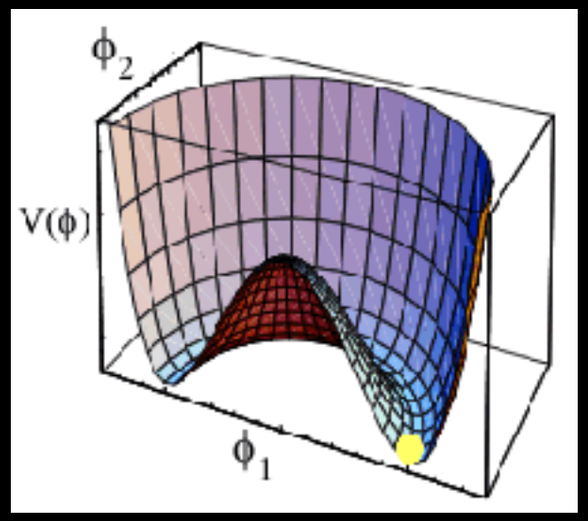

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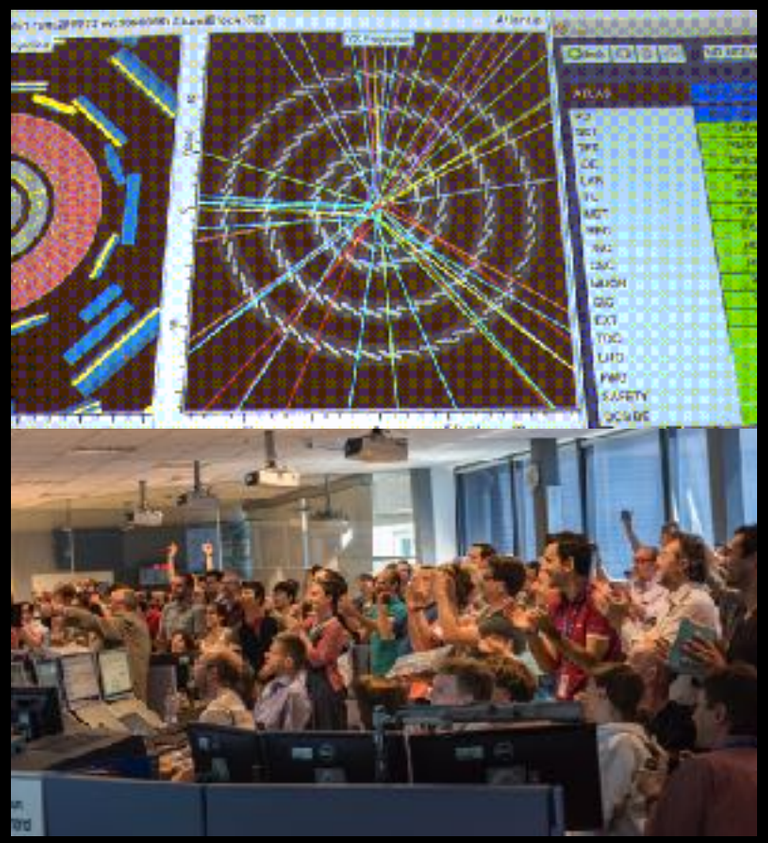
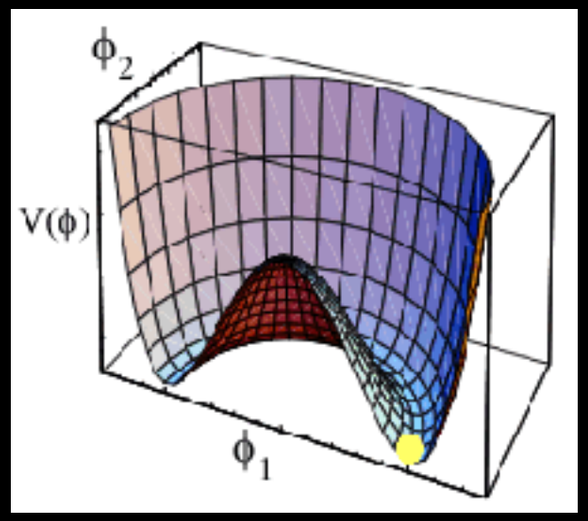


First proton-proton collisions at 13 TeV

4 July 2012



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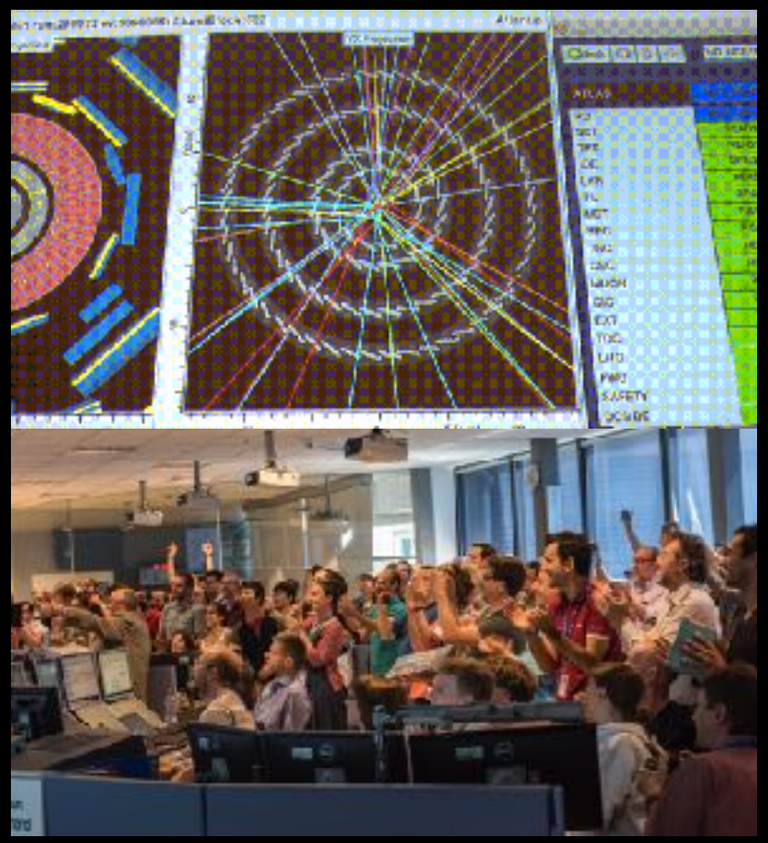

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2018

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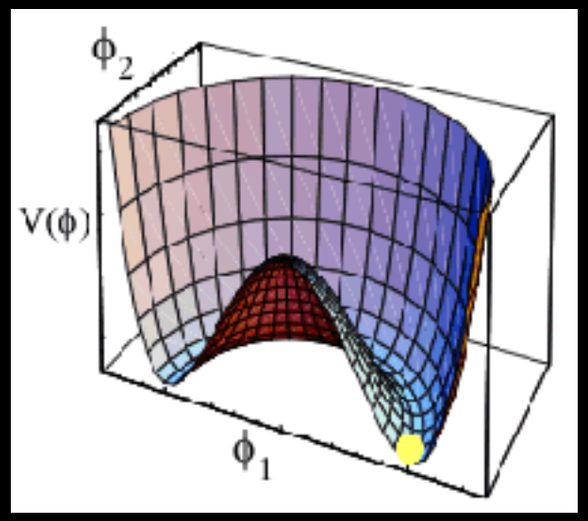

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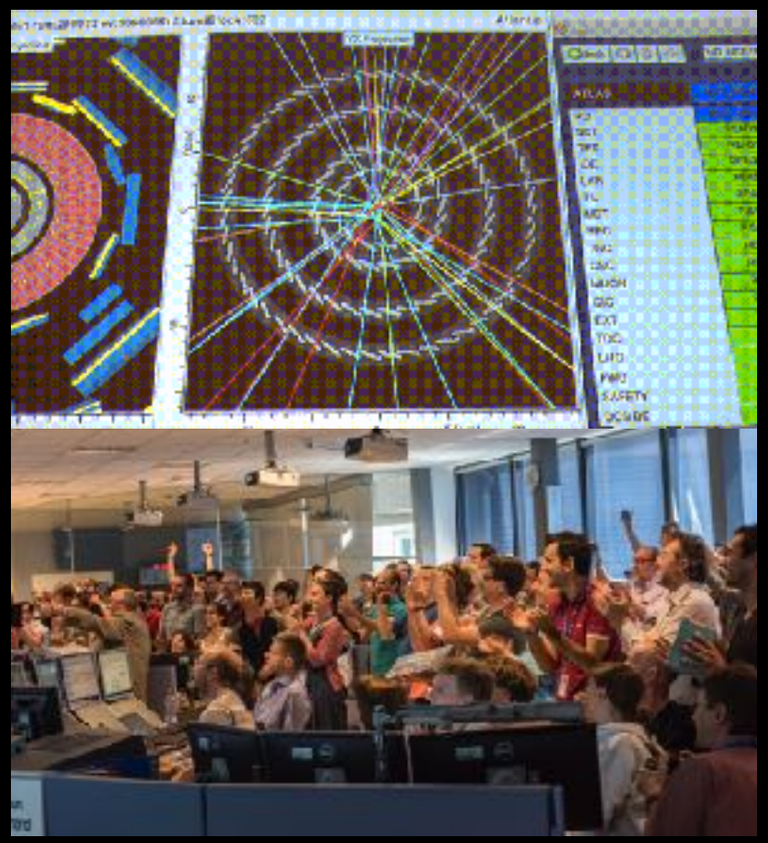

First proton-proton collisions at 13 TeV

2018

Thus far no new particle discoveries beyond the Higgs

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

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?

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?

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?

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

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 $m_{V_L V_L}$? 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?

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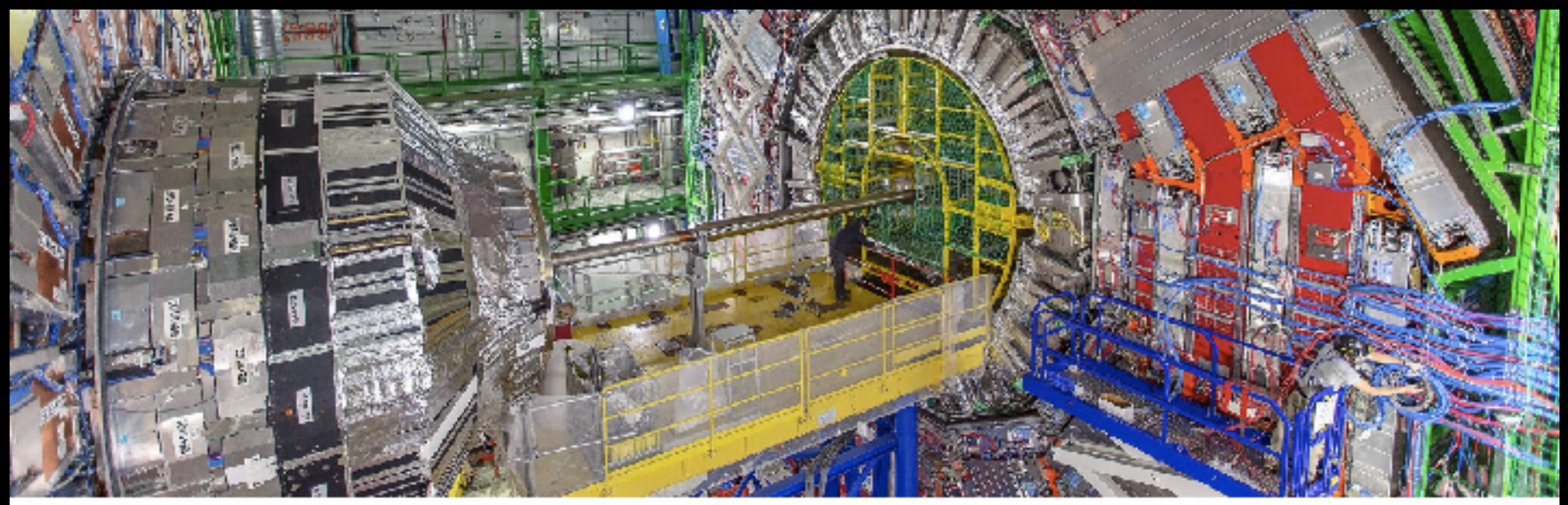
The paradigm is shifting — slowly



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. Lucy 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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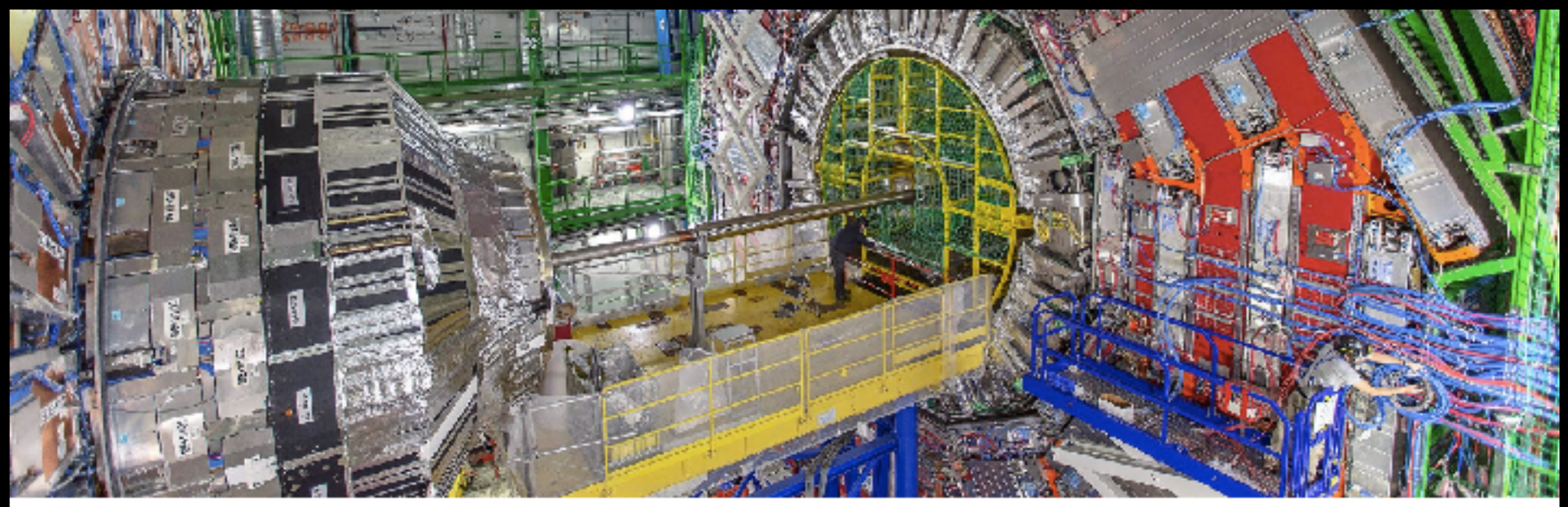

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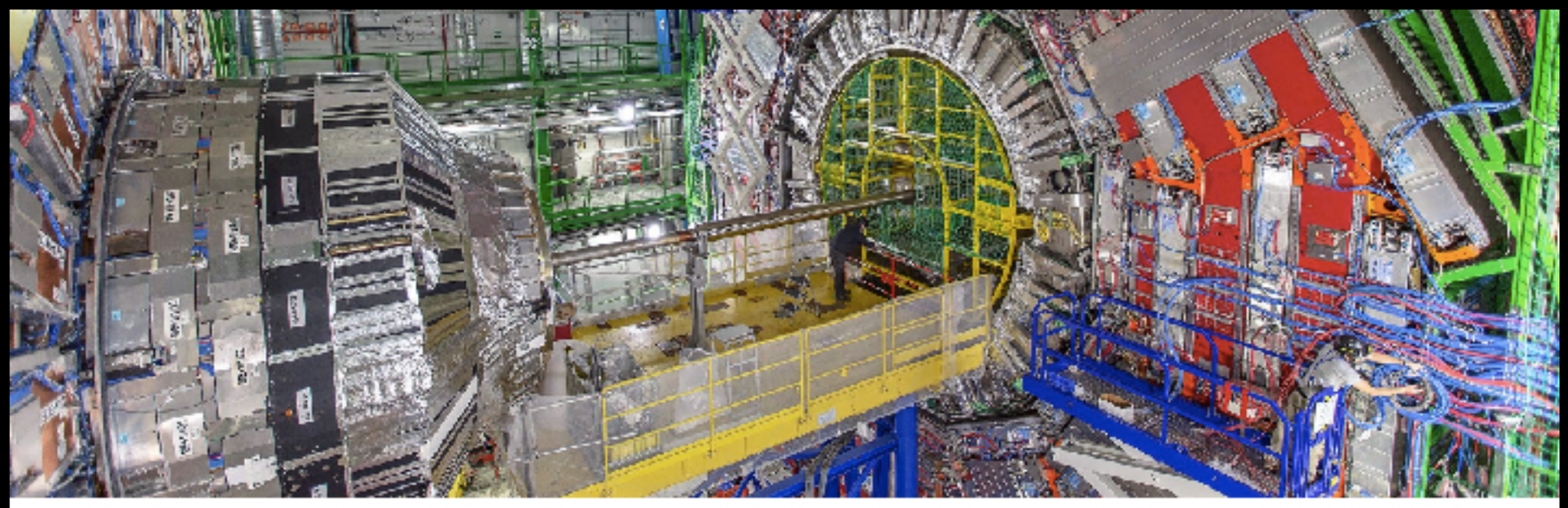
The paradigm is shifting — slowly



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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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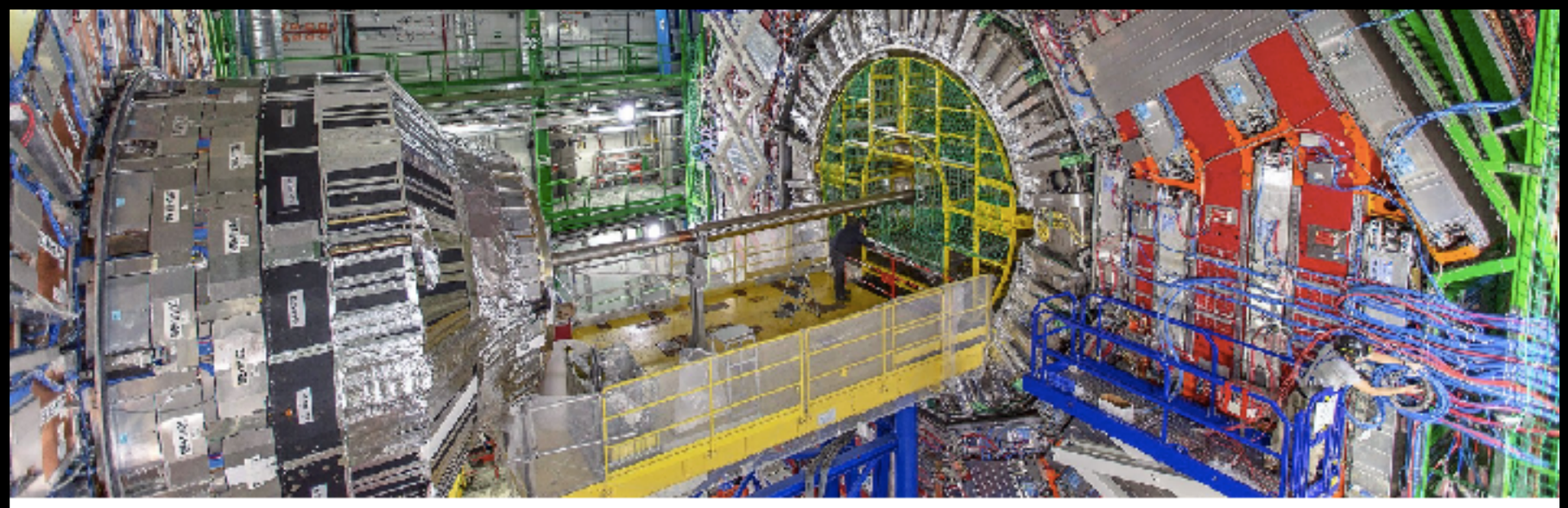

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Dennis Overbye [redacted] Michigan who…

Actions

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

To: James Beacham

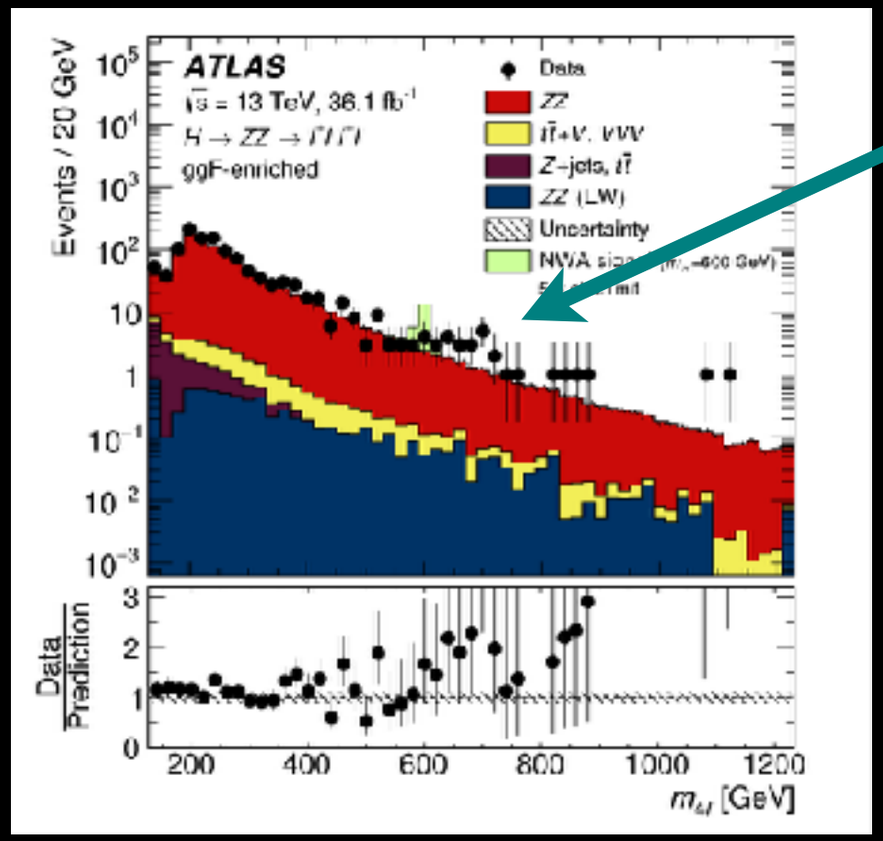
Inbox 22 June 2017 02:33

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

Sent from my iPhone

New physics at the LHC in 2018

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



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EPJC (2018) 78: 293

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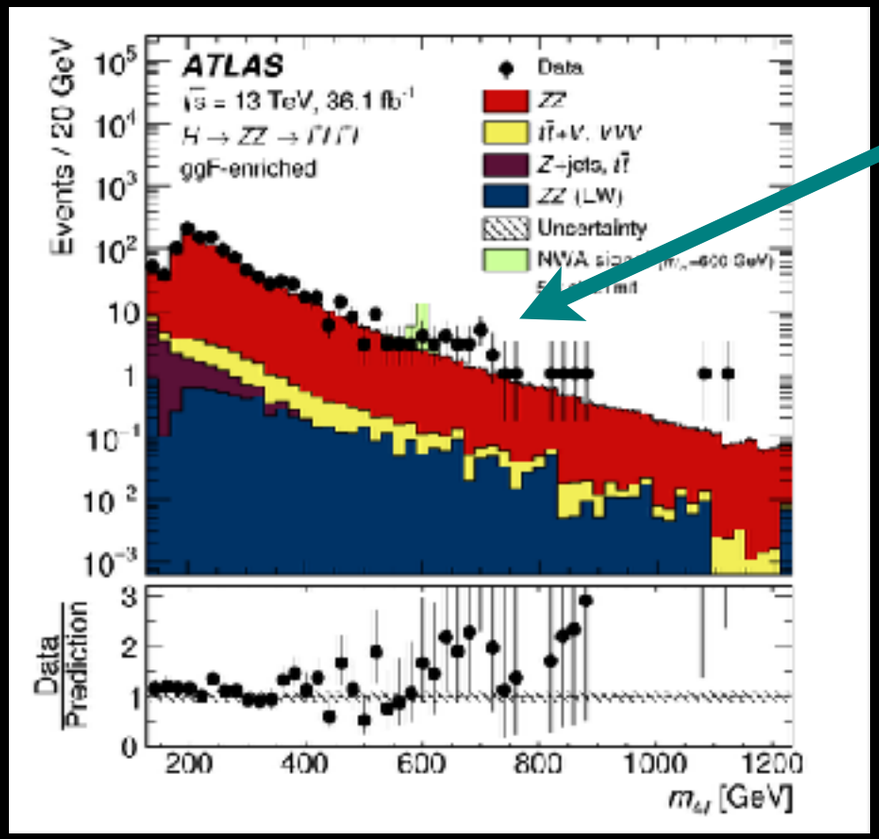

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Requires us to shift from theory-driven search strategies to signature-driven ones.

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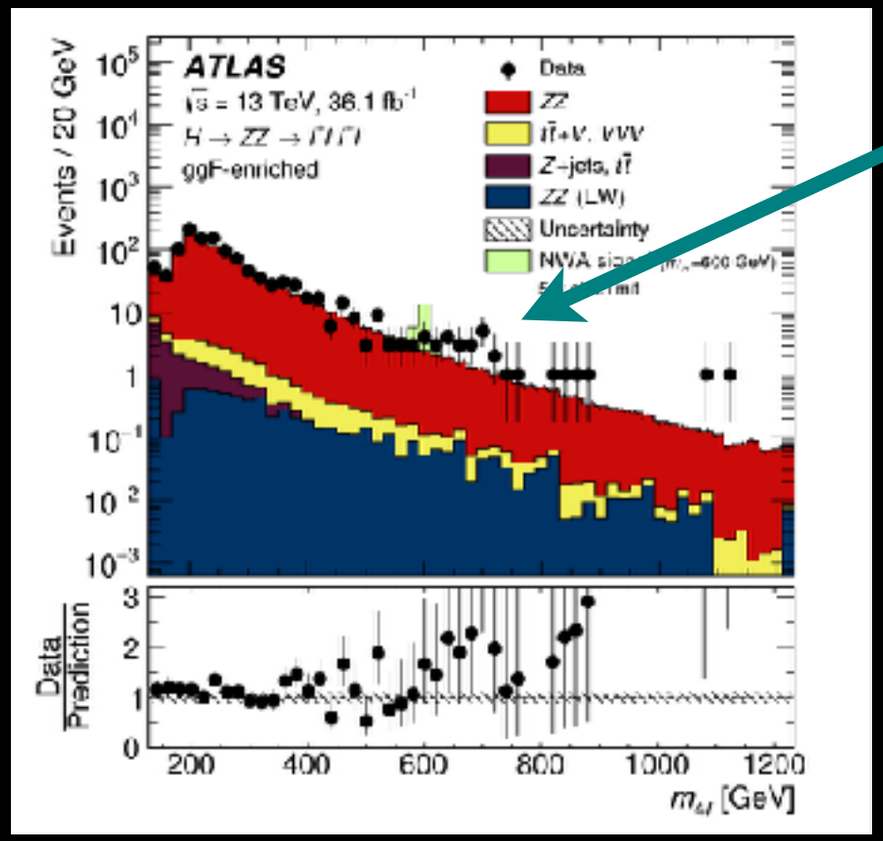

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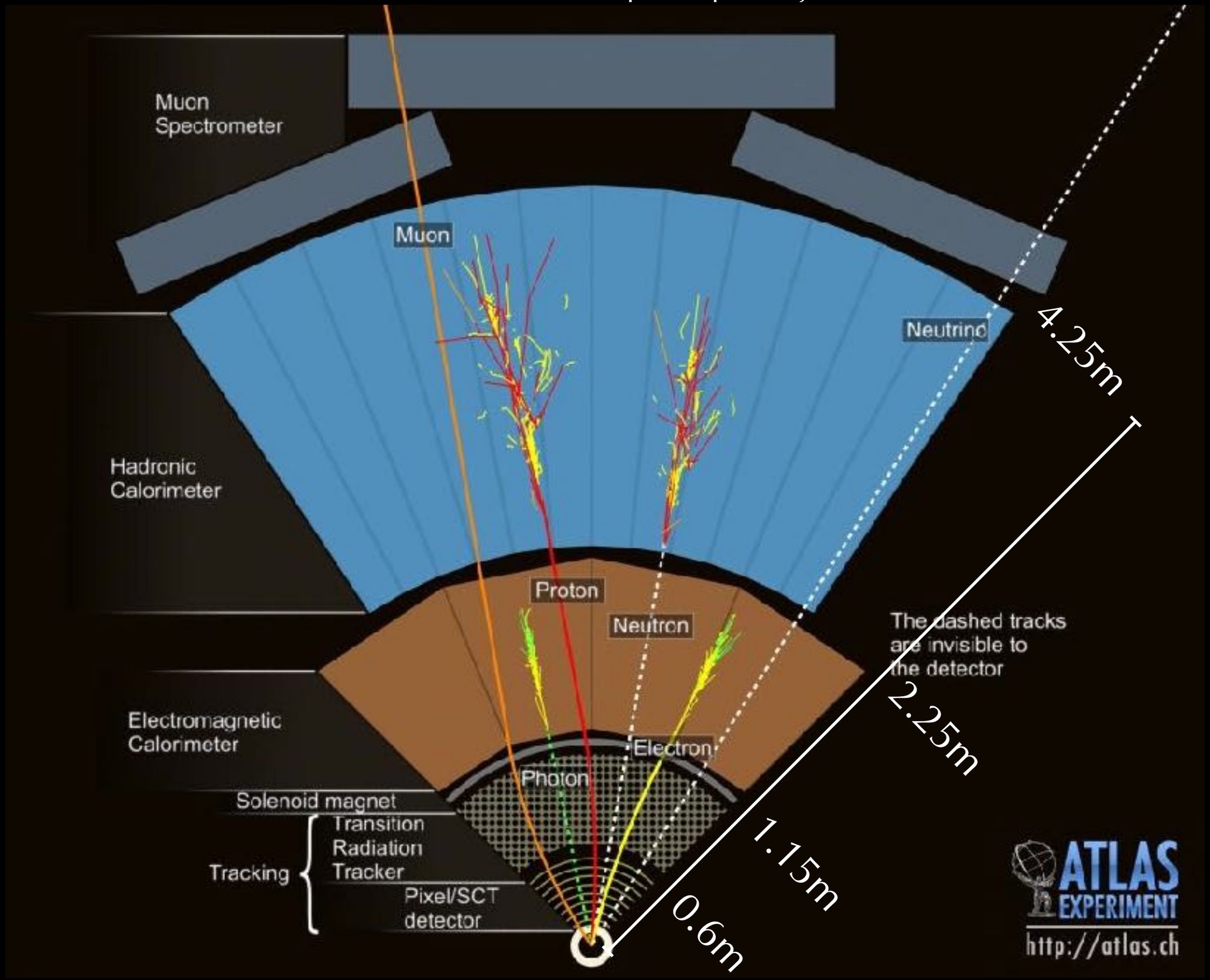
We would certainly love some old-school theoretical guidance, but we don't really have it (WIMP dark matter in tension, lack of plain vanilla SUSY, lack of twenty-jet events filled with strong gravity, etc.)

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

95% of our analysis effort at the LHC is dedicated to understanding five more-or-less prompt objects



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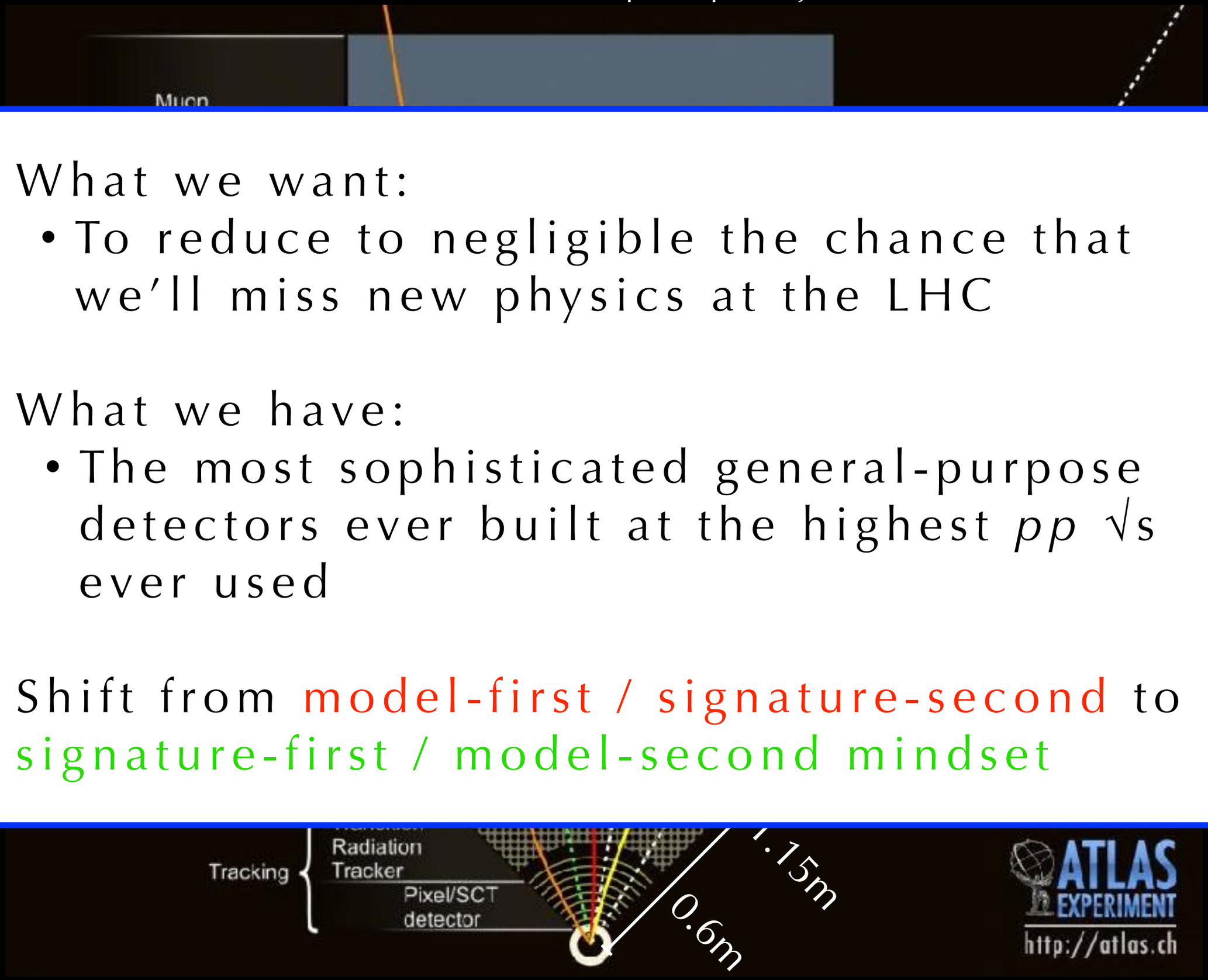


What we want:

- To reduce to negligible the 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

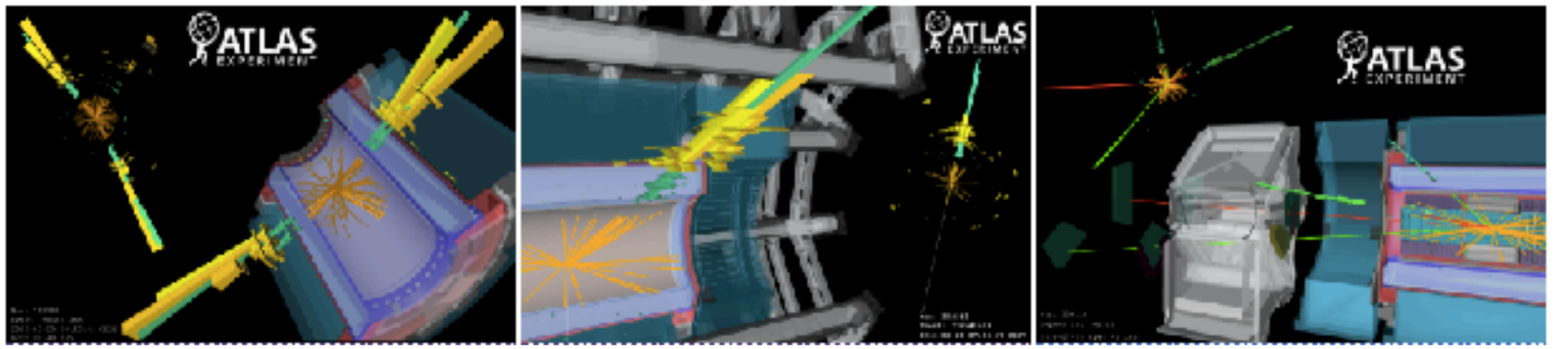
Where is new physics at the LHC?

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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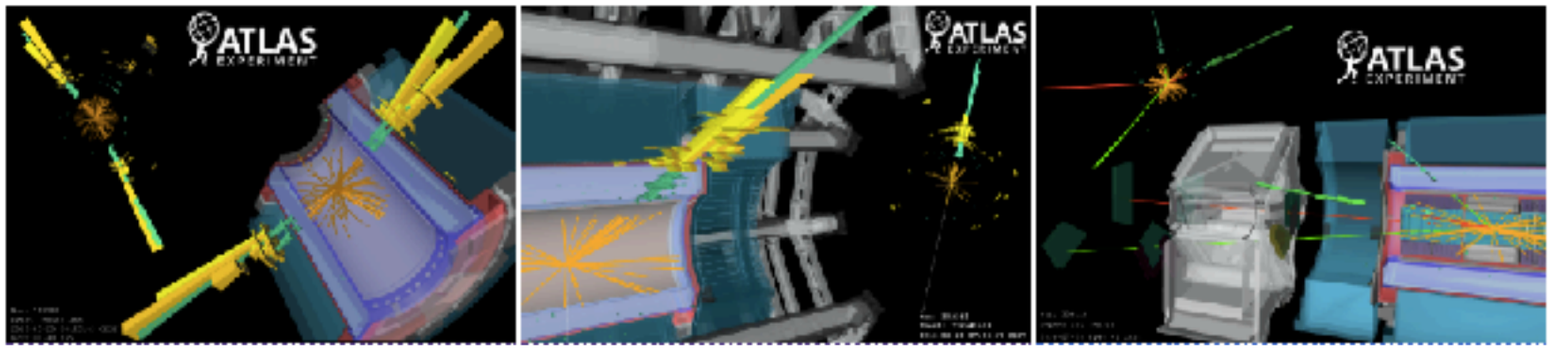

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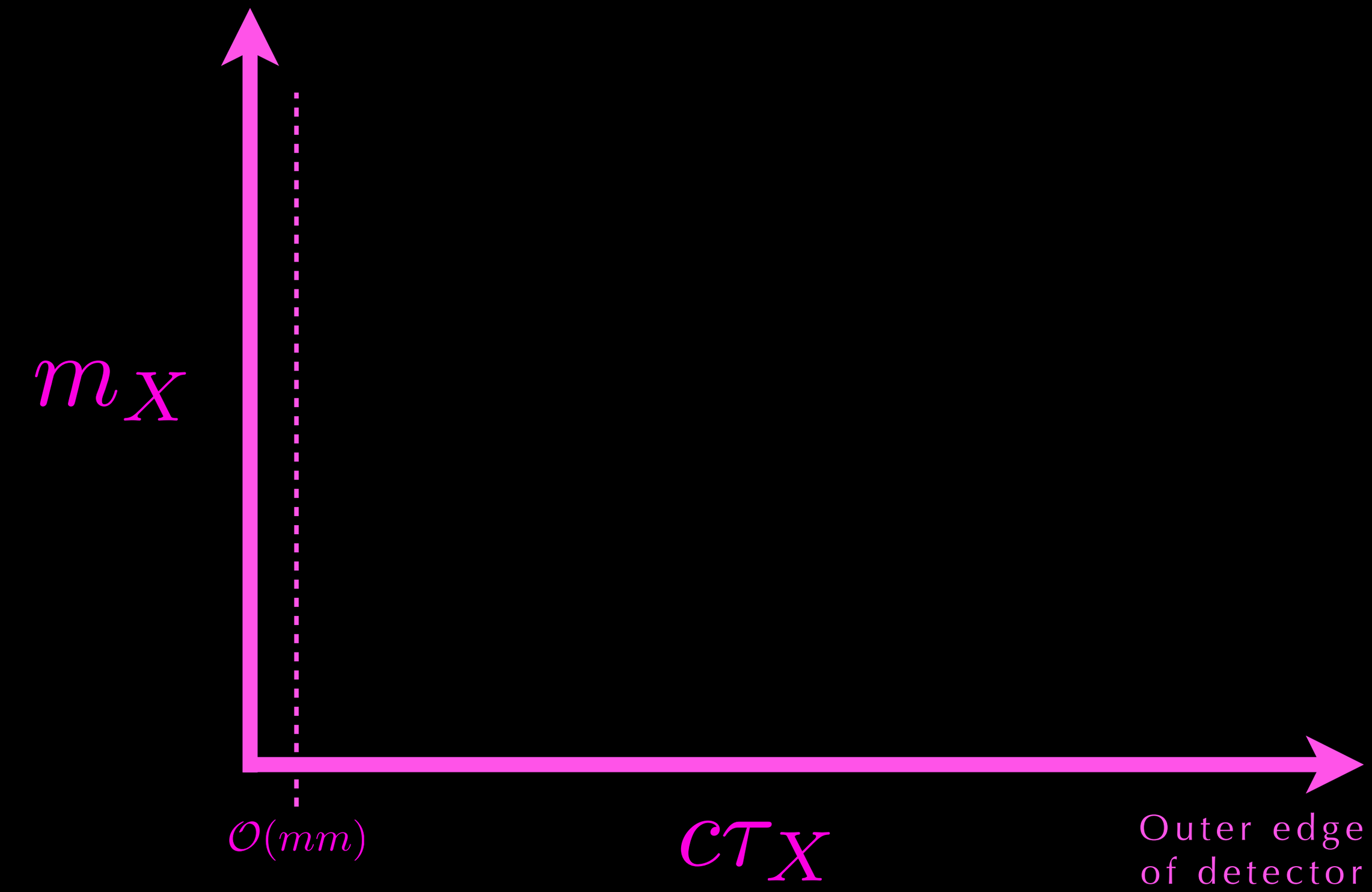
Date : YYYY-MM-DD Filter by date: ≥ ≤

Filtered results: [Papers Conference Publication]

Papers: (15)

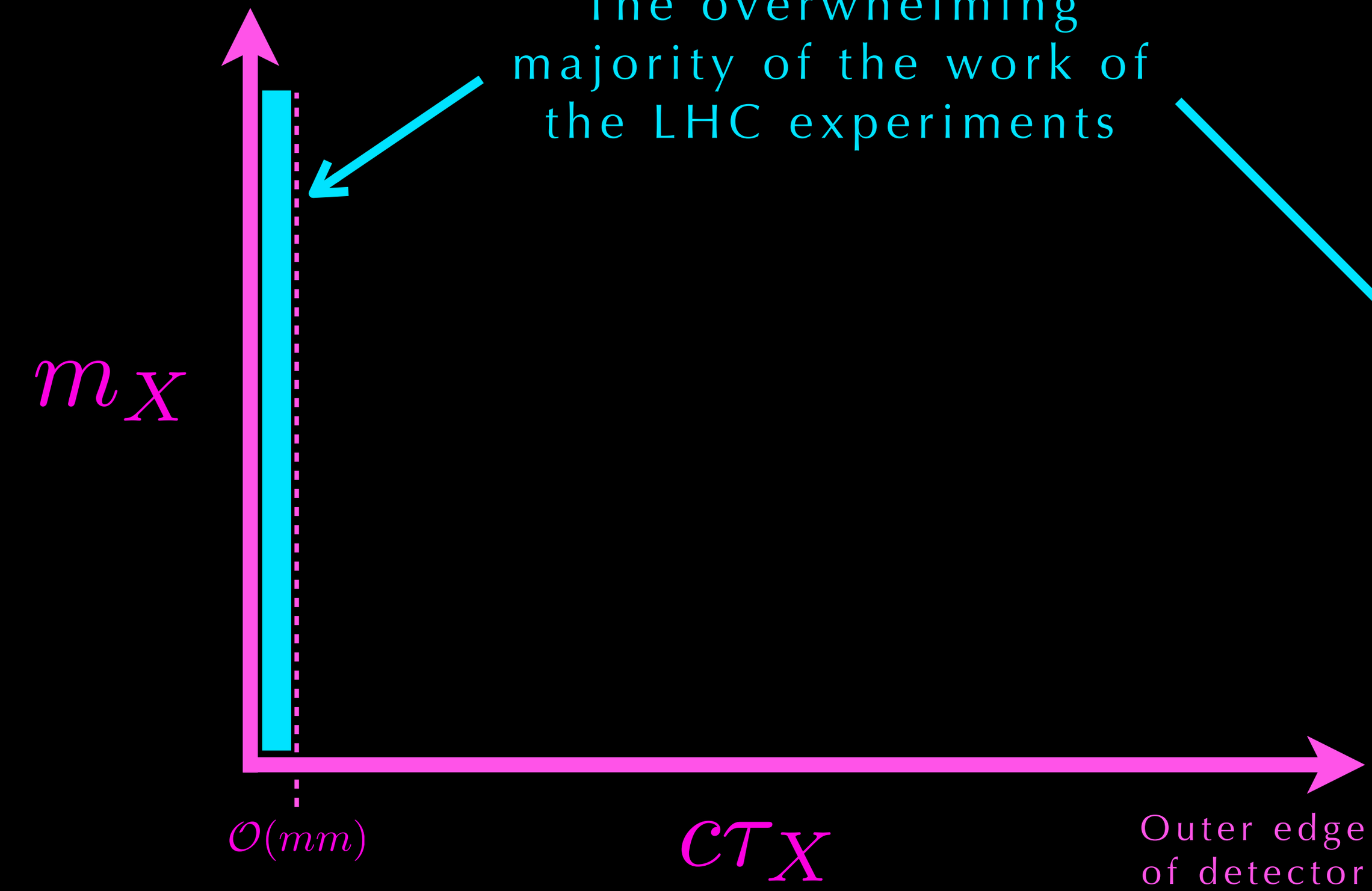
Short Title	Journal reference	Date	√s (TeV)	L	Links
Gaugino pair, gluino pair; disappearing track	Submitted to JHEP	06-DEC-17	13	36 fb^{-1}	Documents | 1712.02118 | Inspire HepData | Internal
Gluino pair, squark pair; displaced vertices	Phys. Rev. D 97	18-OCT-17	13	36 fb^{-1}	Documents | 1710.04901 |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

New physics X at the LHC



New physics X at the LHC

The overwhelming majority of the work of the LHC experiments



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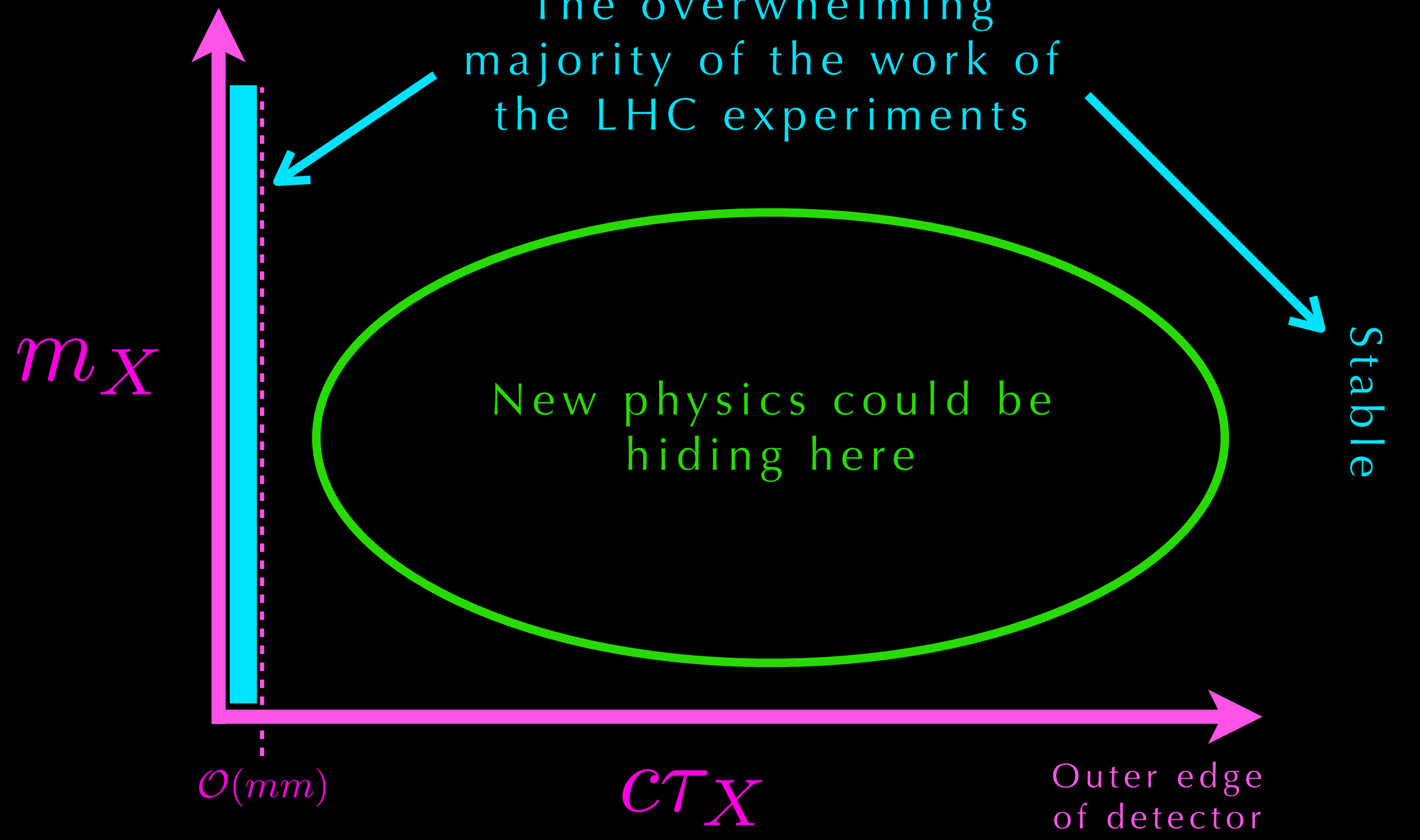
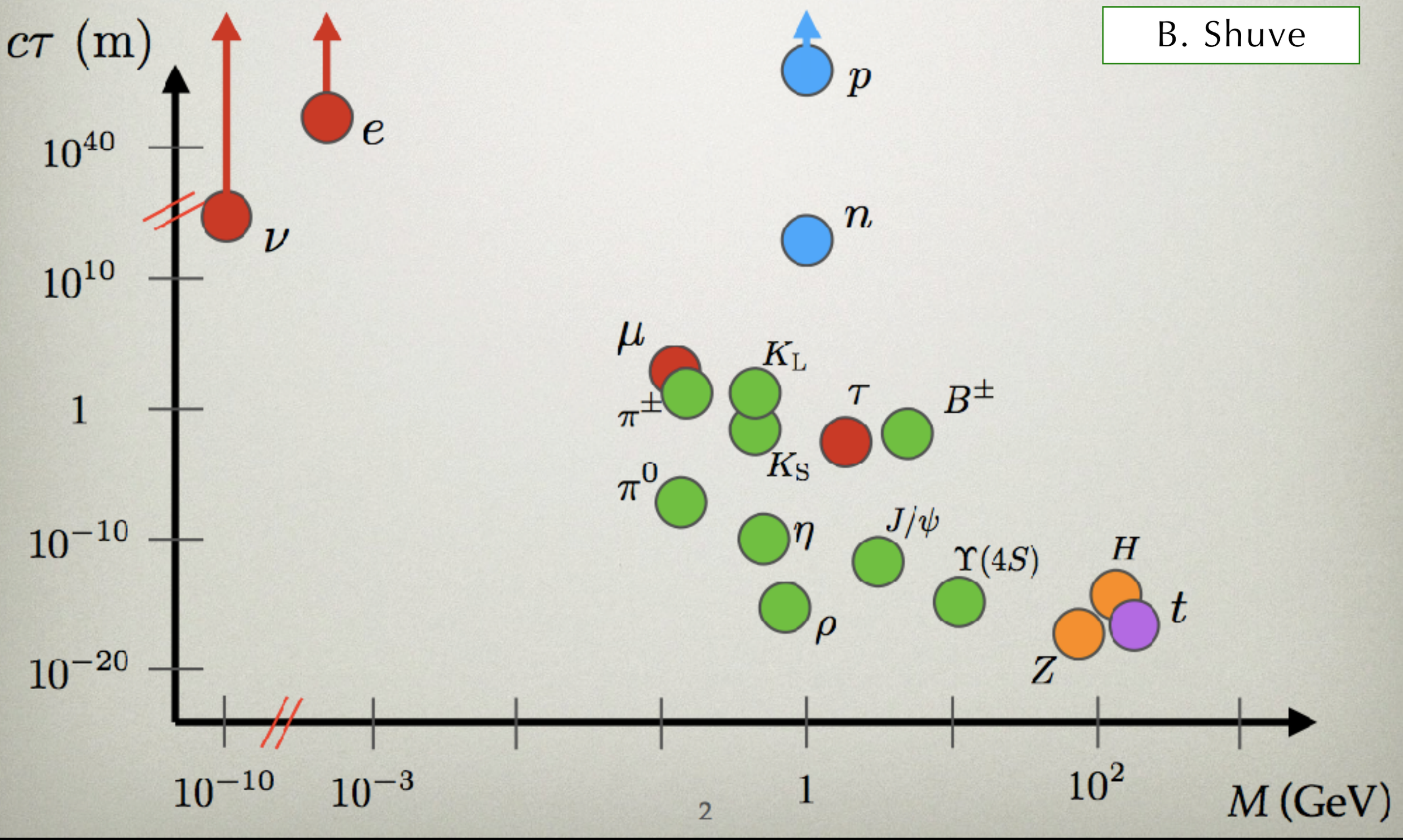


Long-lived particles at the LHC — Standard Model

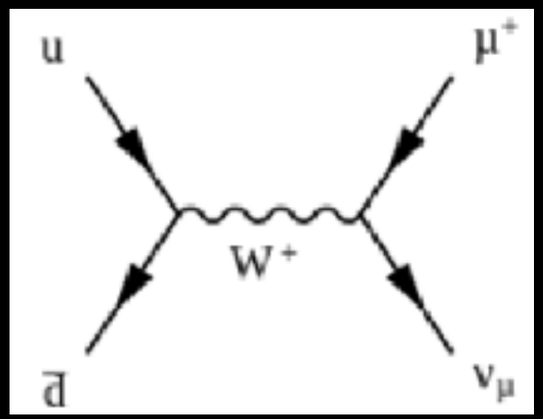
B. Shuve



LLPs — SM and beyond-the-SM

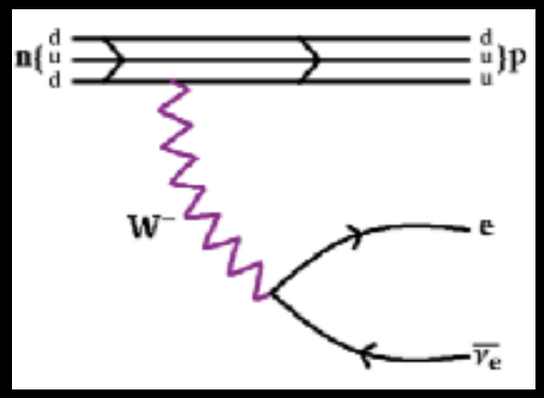
Long lifetimes typically arise in the SM when *approximate symmetries* make the particle stable

Small symmetry-breaking parameters can suppress the decay rate



Charged pion

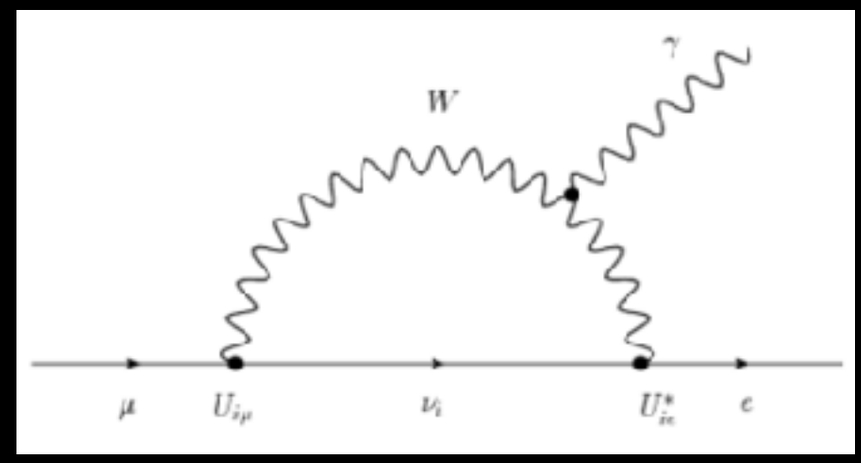
Decay highly off-shell



Neutron

Isospin: p and n nearly degenerate

Decay highly off-shell



FCNC

Lepton flavor violated only by extremely small neutrino Yukawas

BR(μ—>eγ)~10^{-54}

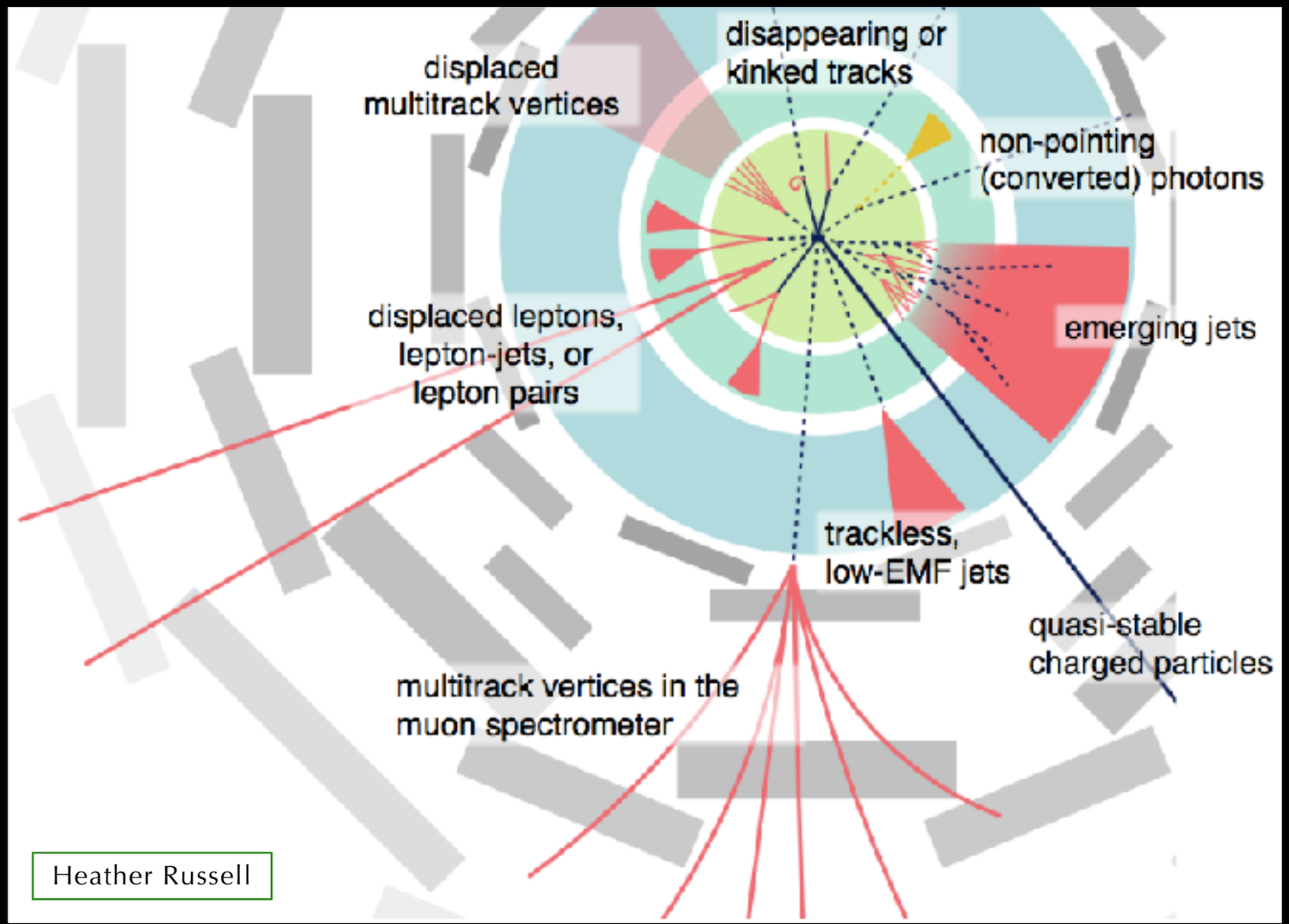
Same principles apply to BSM LLPs, which can generically appear

- Lifetime is best treated as a free parameter

Talks by Strassler, Knapen, Shuve, Ramsey-Mulsof, others

Long-Lived Particle Searches at the LHC

Mapping 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 most of its energy or decays to SM) somewhere in the detector acceptance of LHCb, CMS, ATLAS, MilliQan, MoEDAL, FASER, Codex-b, MATHUSLA, etc.

Long-Lived Particle Searches at the LHC

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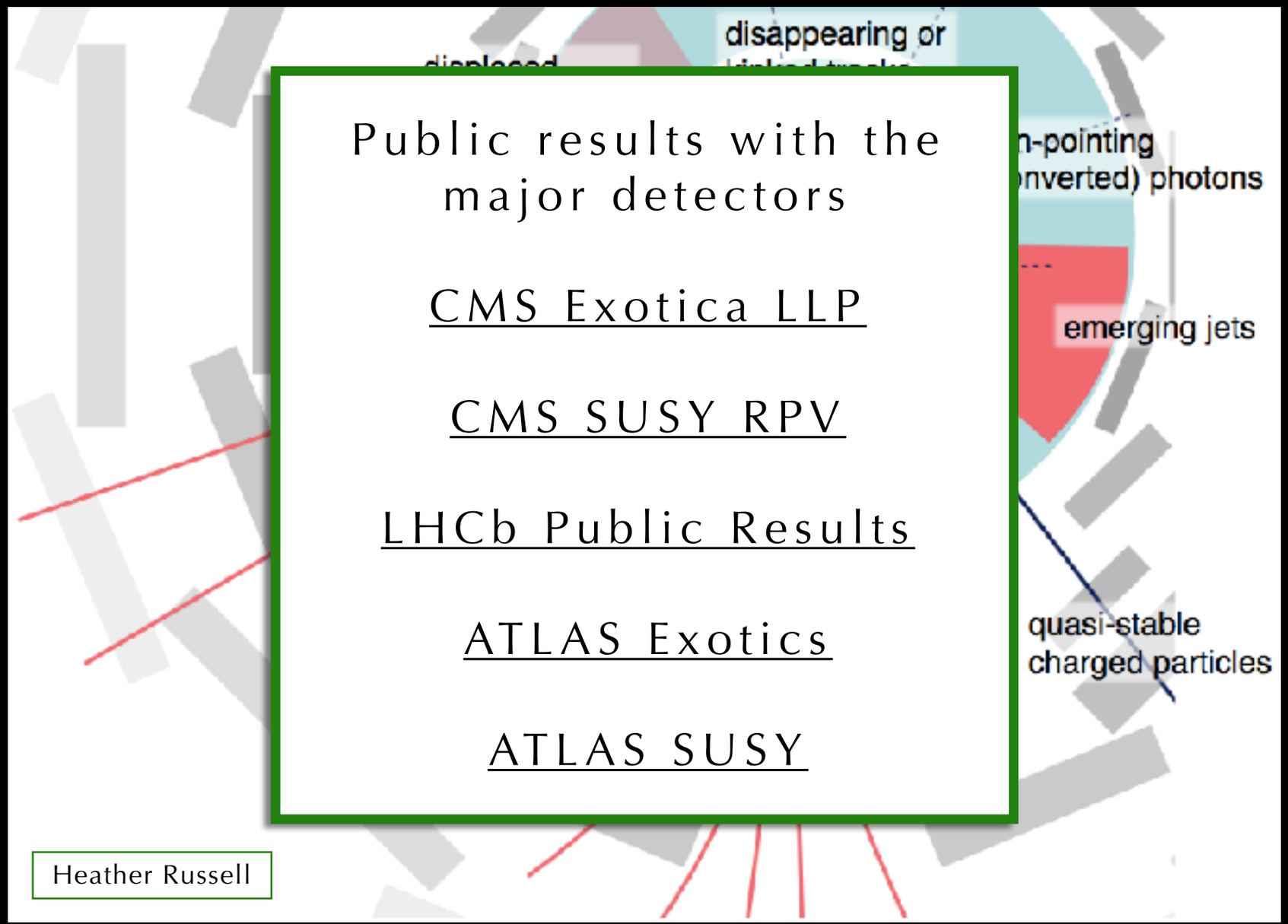

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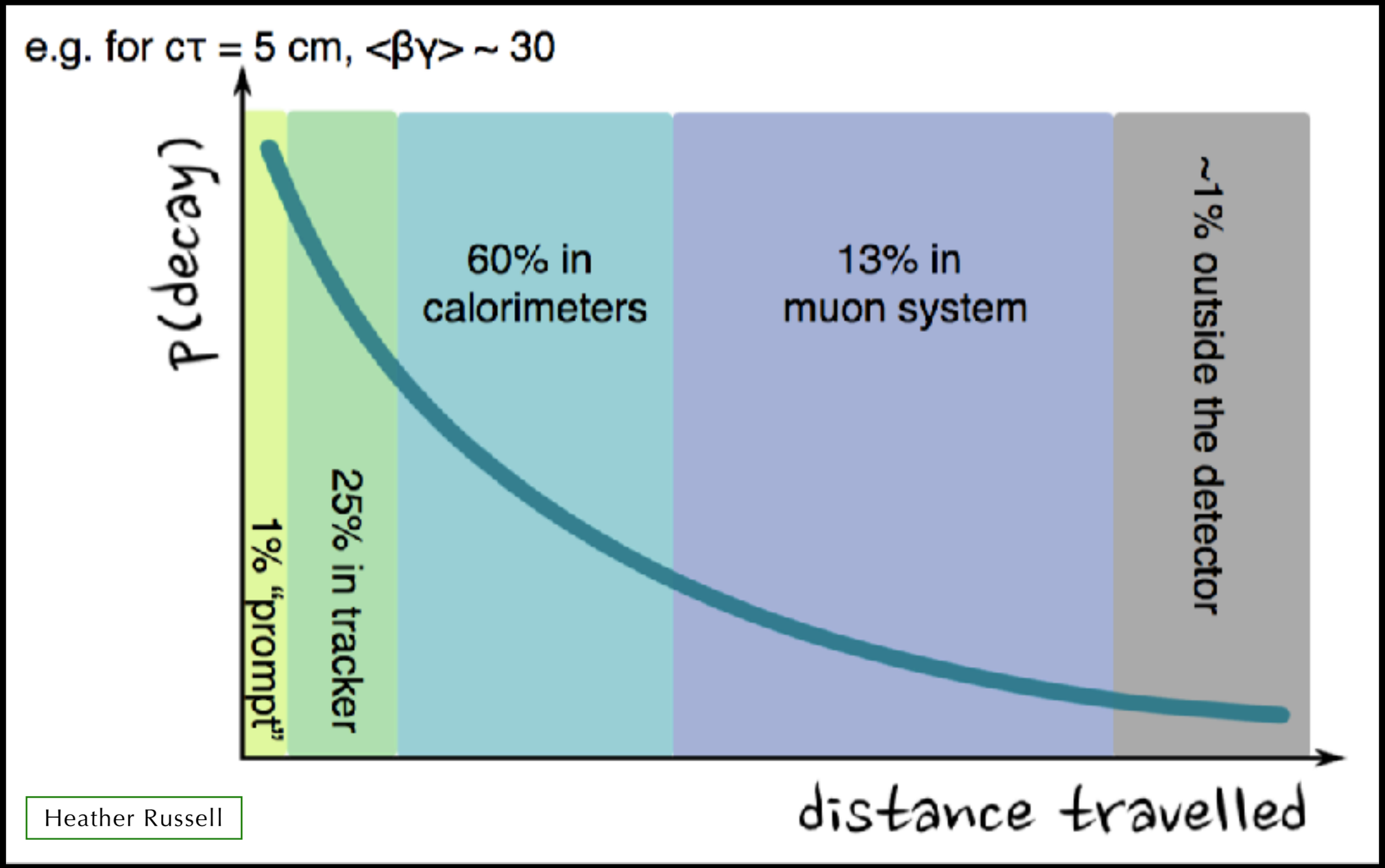
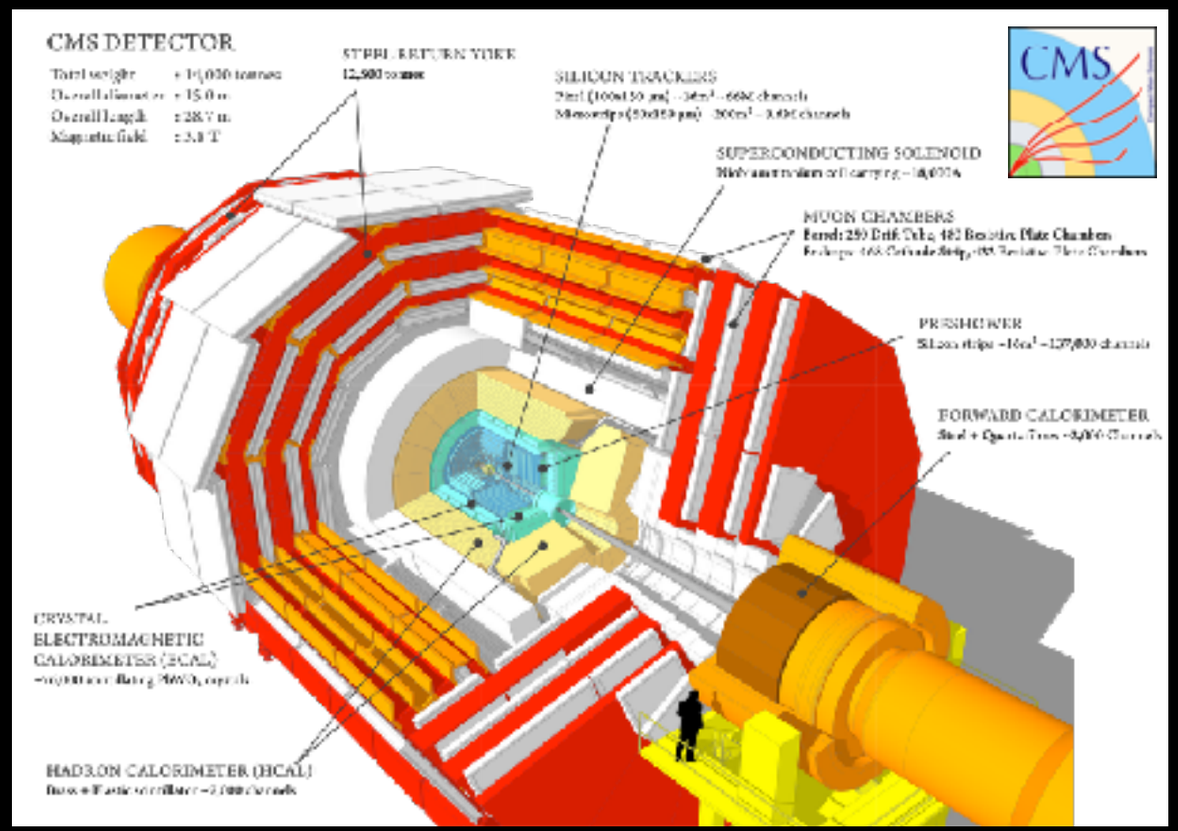
Long-Lived Particles at the LHC

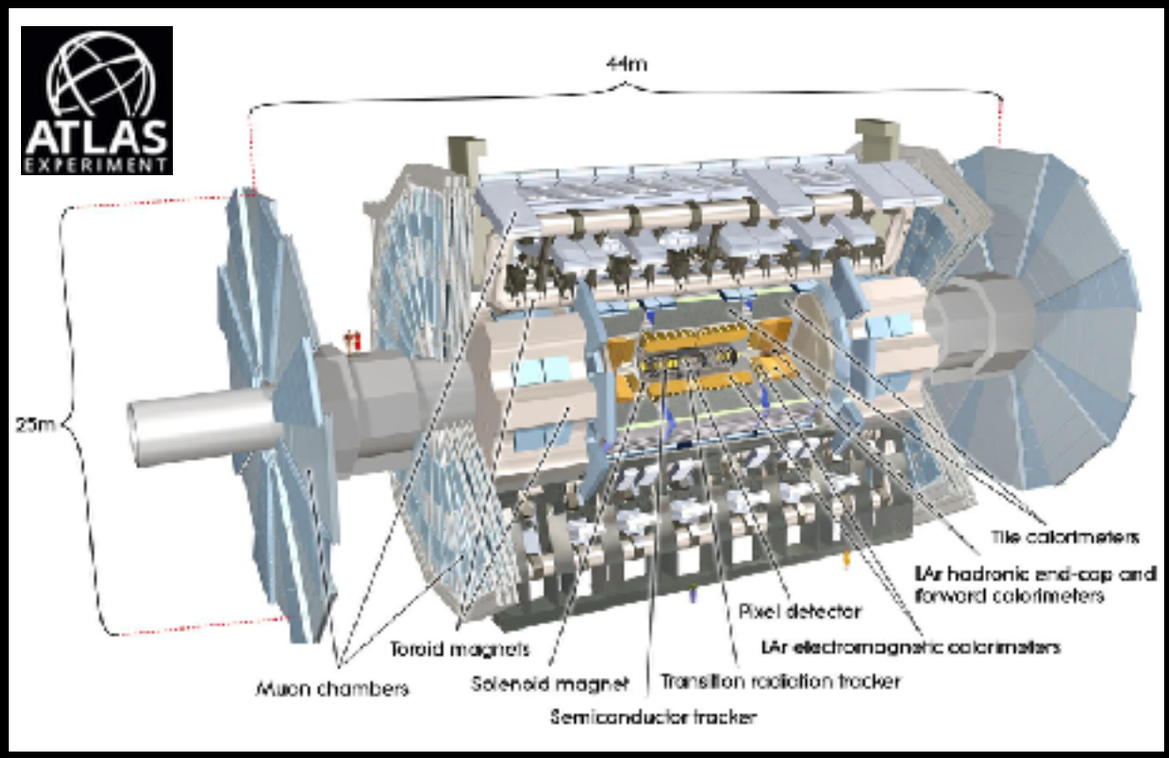
The observed lifetime of a particle is sampled from an exponential whose shape is set by its proper lifetime ctau

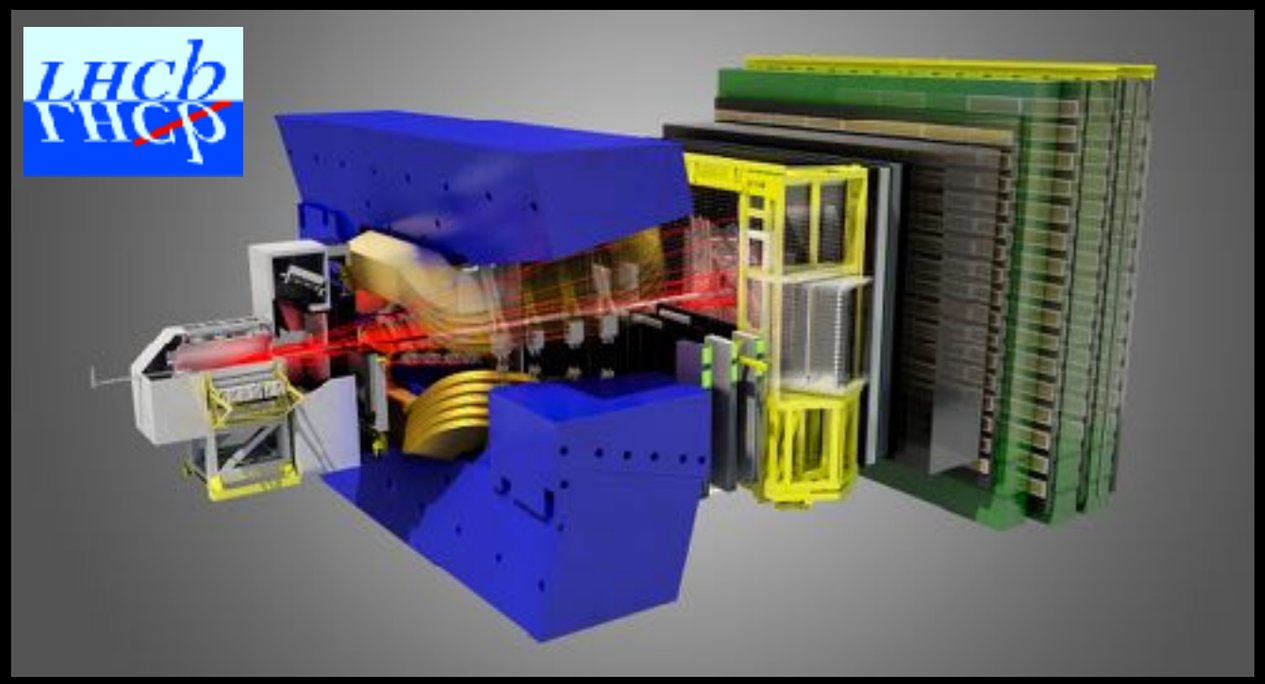


As a result, we can and must use multiple search strategies targeting all subdetectors of ATLAS, CMS, and LHCb — and beyond the detectors

Long-Lived Particles at three main experiments at the LHC





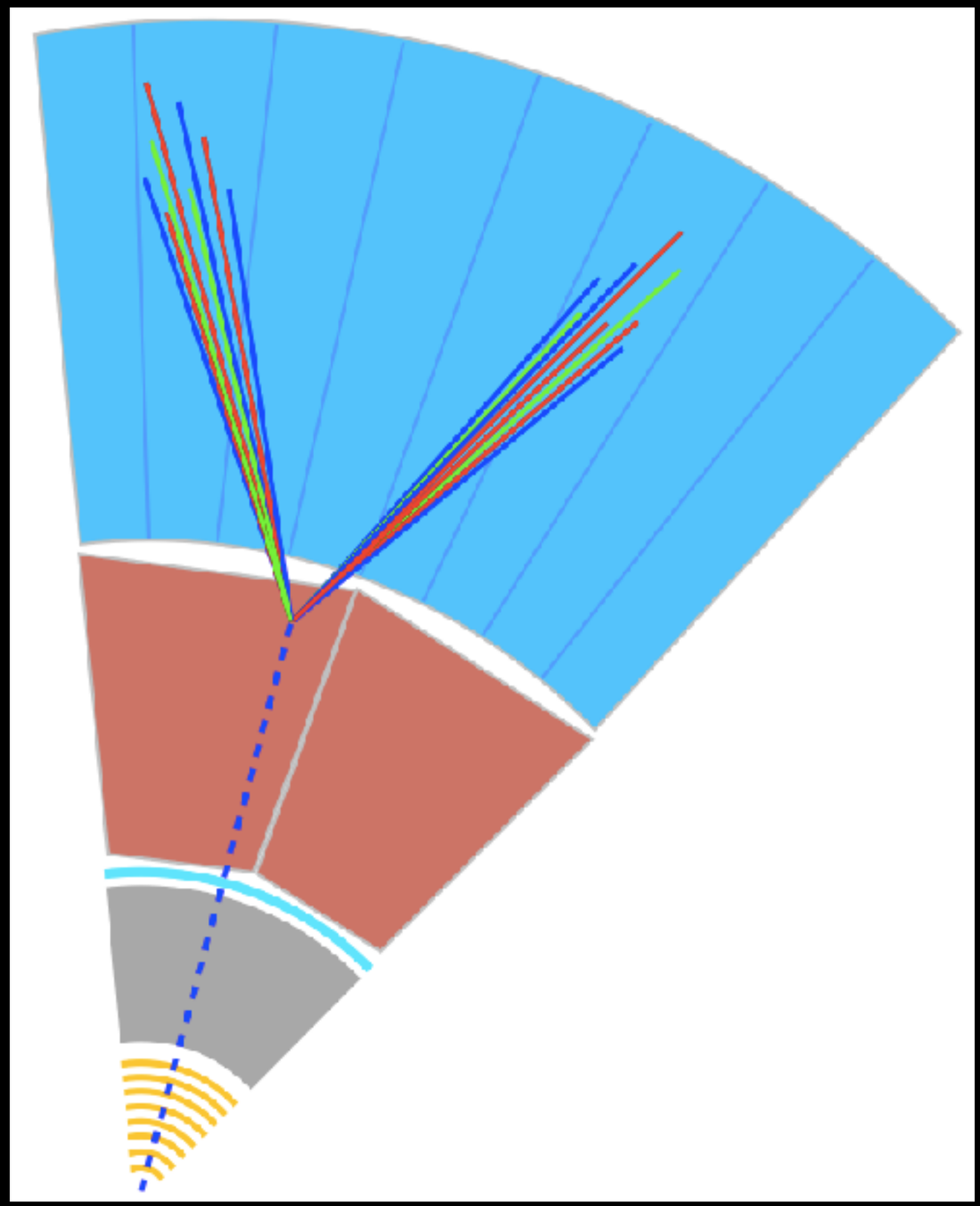


Searches are often SM-background-free but can be subject to very atypical background sources (like cosmic ray muons, beam halo, cavern backgrounds, etc.) that are challenging to estimate and irrelevant to most prompt searches

The lifetime frontier at the LHC

Long-lived particle searches are experimentally driven

Luckily it's easy to get LLPs in some usual BSM frameworks — a few examples here



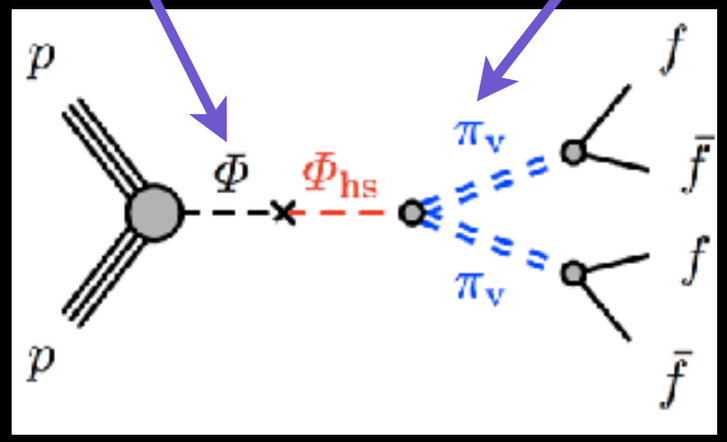
BSM example: Hidden sector portals

Higgs portal

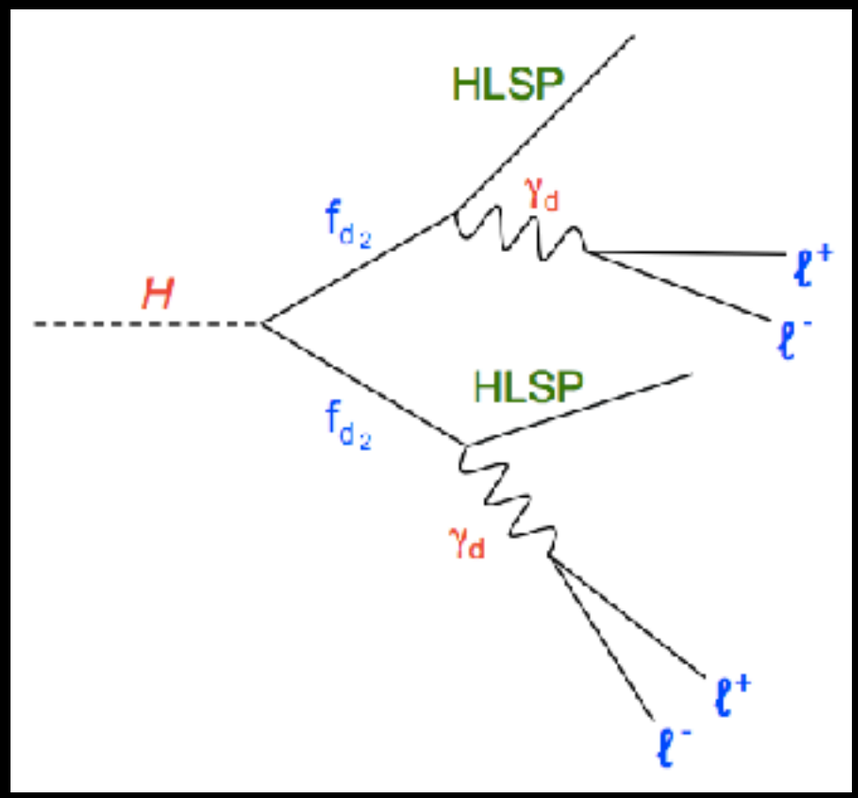
- Small width of SM Higgs —> easy to get BSM physics
- A wide range of LLP signatures can arise

SM Higgs-like scalar

Long-lived π_v



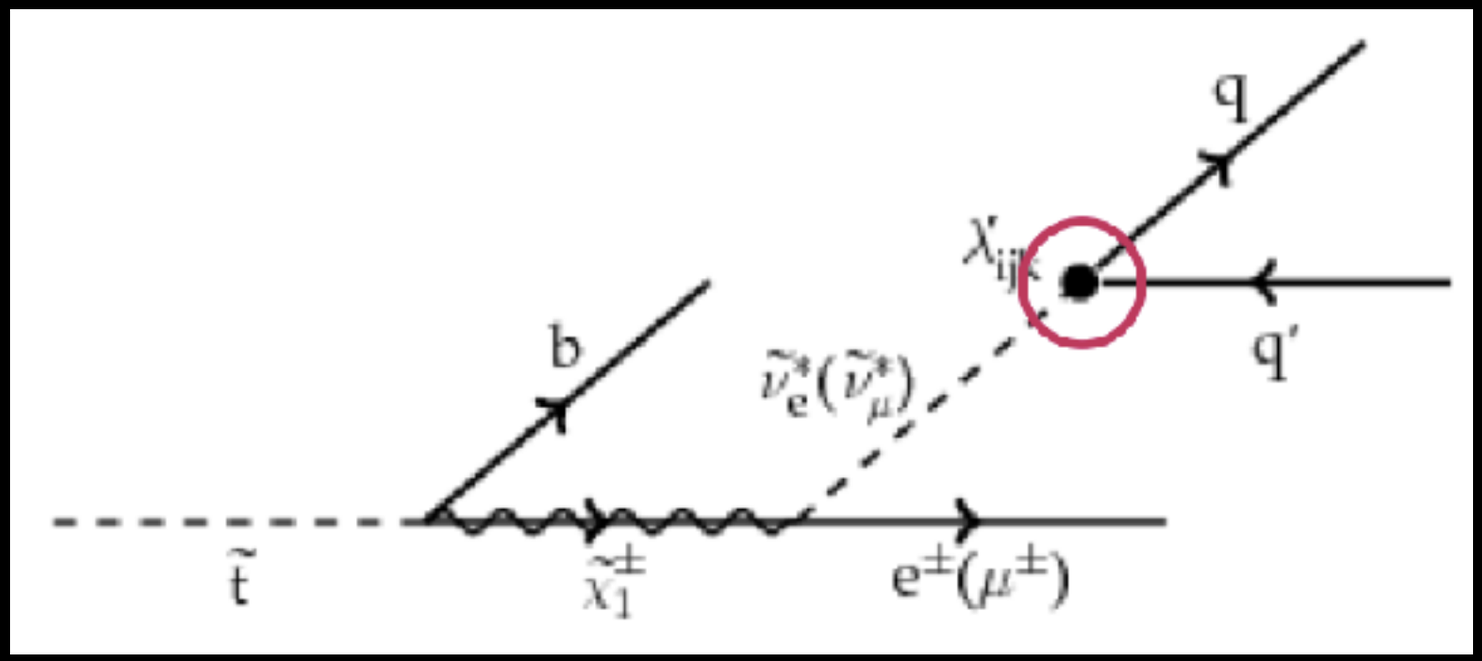
Higgs mixing with hidden sector scalar



Higgs decaying to dark sector fermions which decay to dark photons and lepton-jets

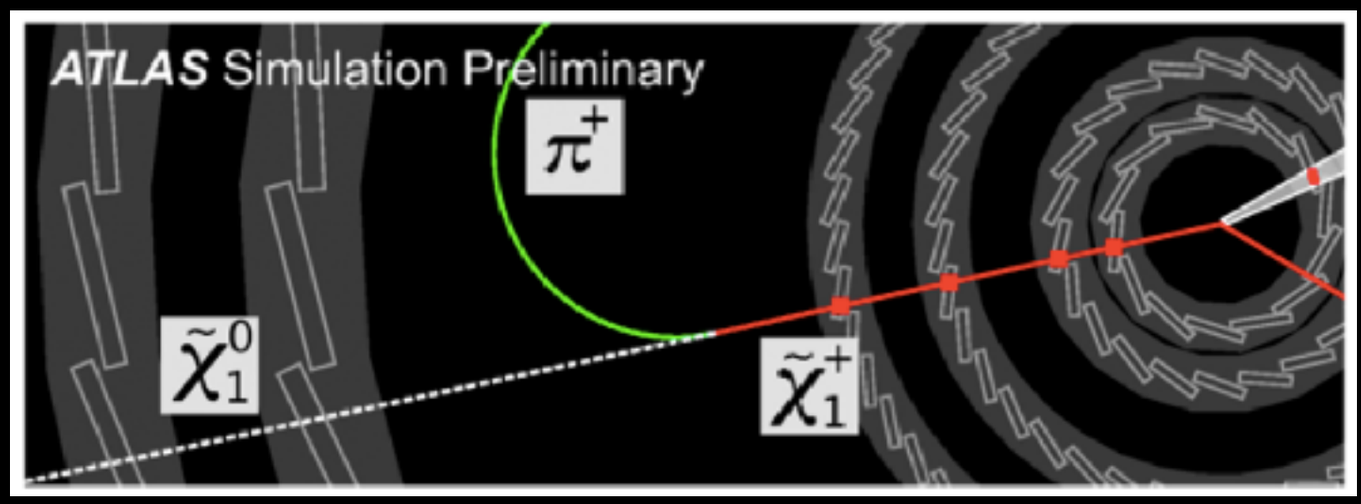
- Can use Higgs VBF and associated production modes for triggering on additional prompt objects

BSM example: RPV SUSY

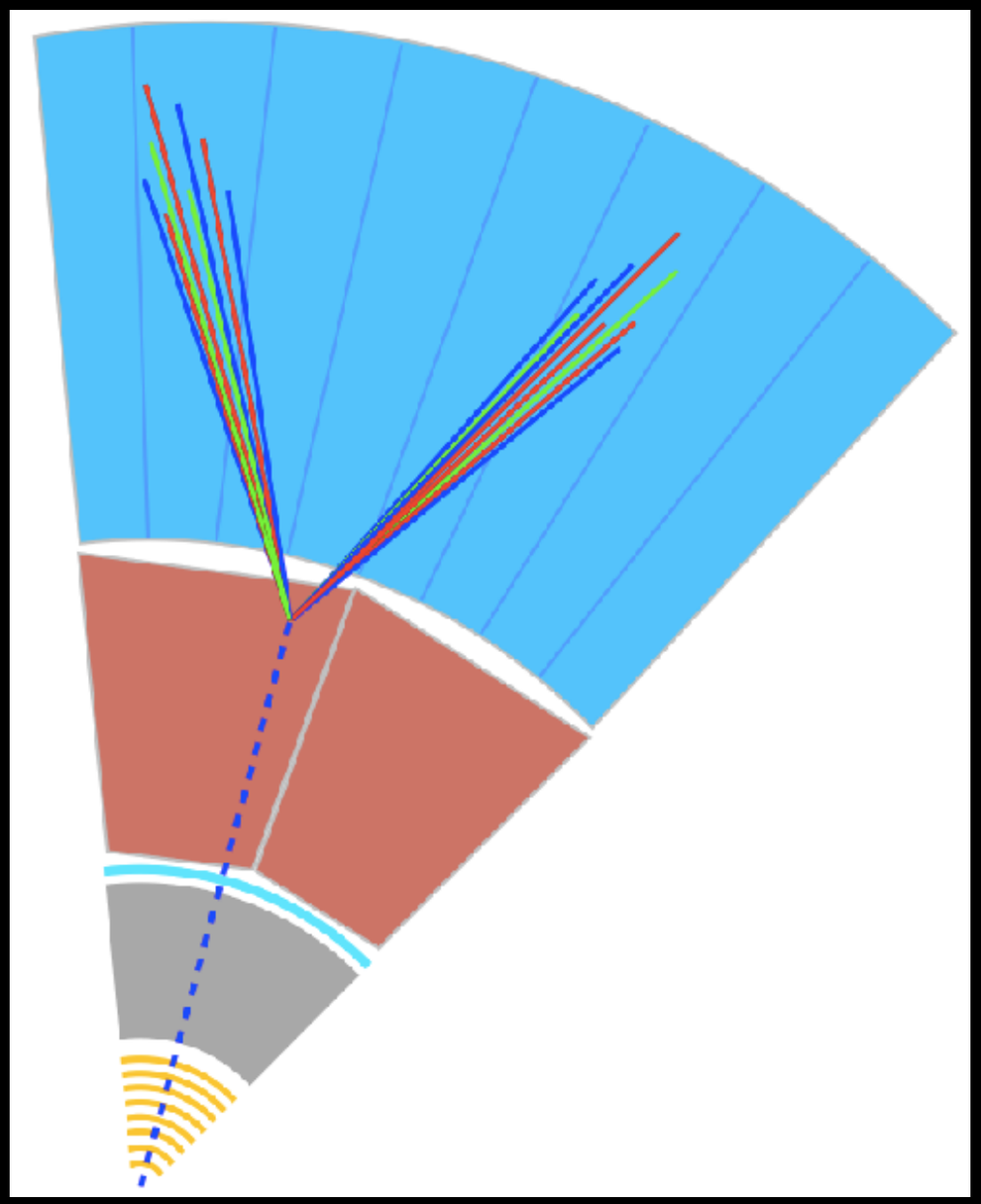


$|\lambda| < 10^{-8}$

Electroweak symmetry gives degeneracy of NLSP and LSP masses if little mixing between Higgsino / gauginos



Long-Lived Particle Basics



We have done LLP searches at the LHC since the beginning, but they've always been marginalized and usually performed by small groups of analyzers

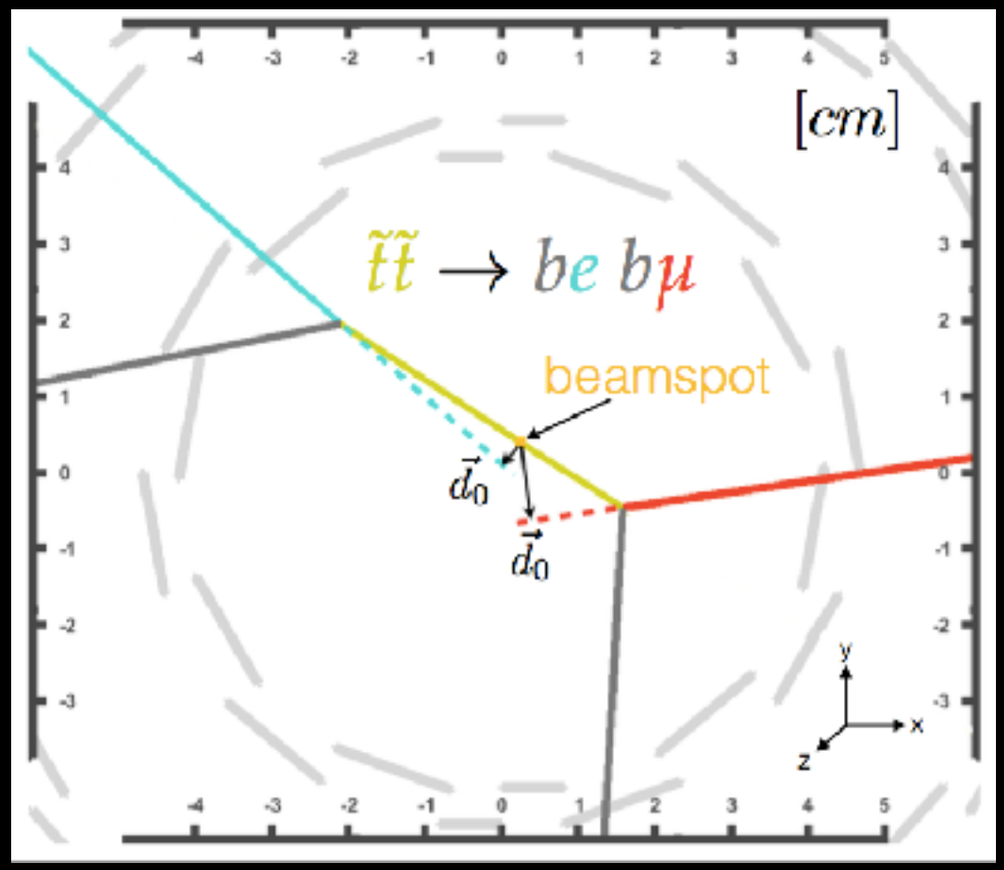
The following are some examples of the kinds of searches we do based on signature with an emphasis on what we're missing

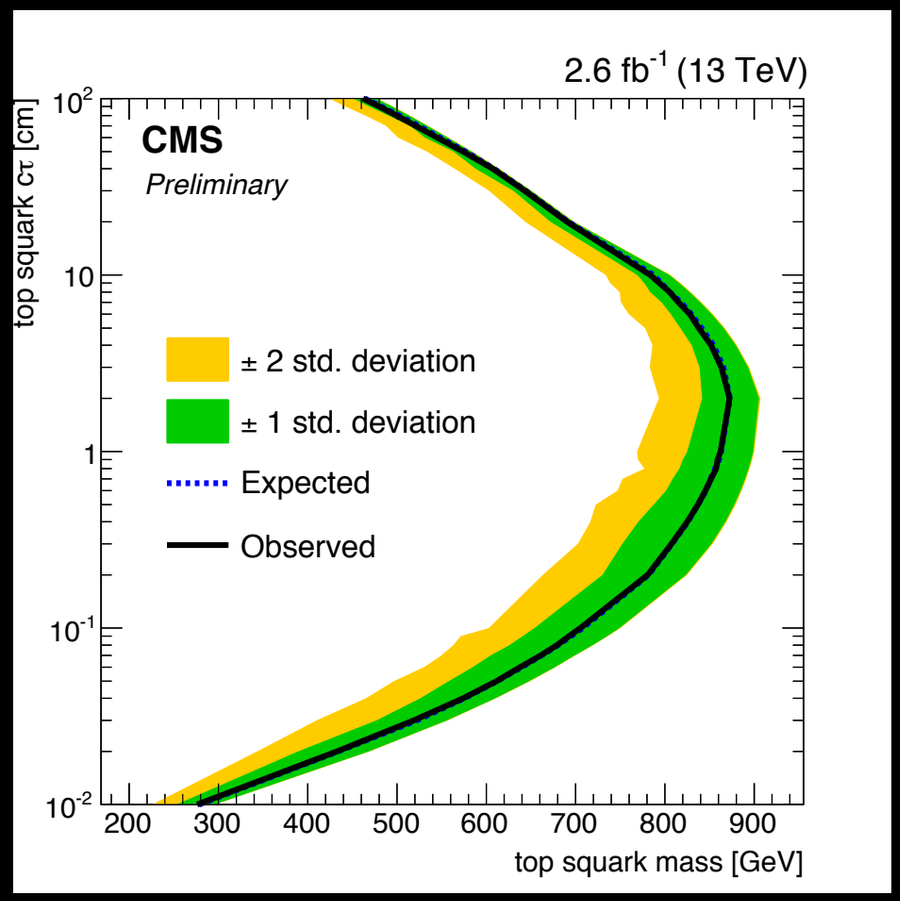
Full discussion requires examination of non-pointing/late photon searches, stopped particles, disappearing tracks, HSCPs — see slides in backup and forthcoming LHC LLP White Paper

Neutral or charged LLPs decaying to leptons

Identifying displaced leptons requires the capacity to find tracks with large impact parameters

- If LLP decay occurs in the inner tracker, can use large-d0 tracking
  - CMS has good tracking for such cases by default
  - ATLAS runs special re-tracking [ATLAS large radius tracking note] / re-vertexing on a subset of events
- Both approaches require customized triggering strategies

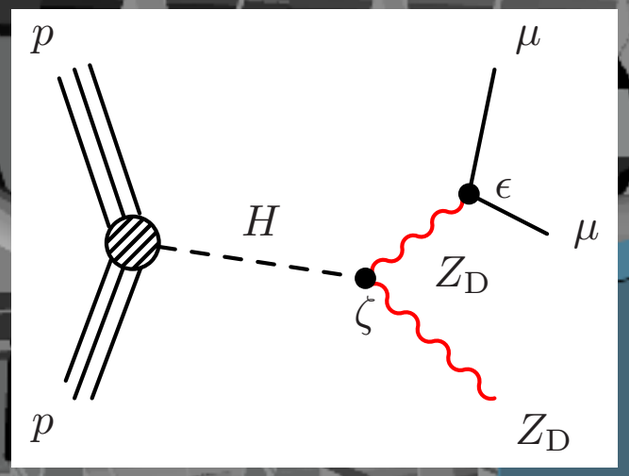


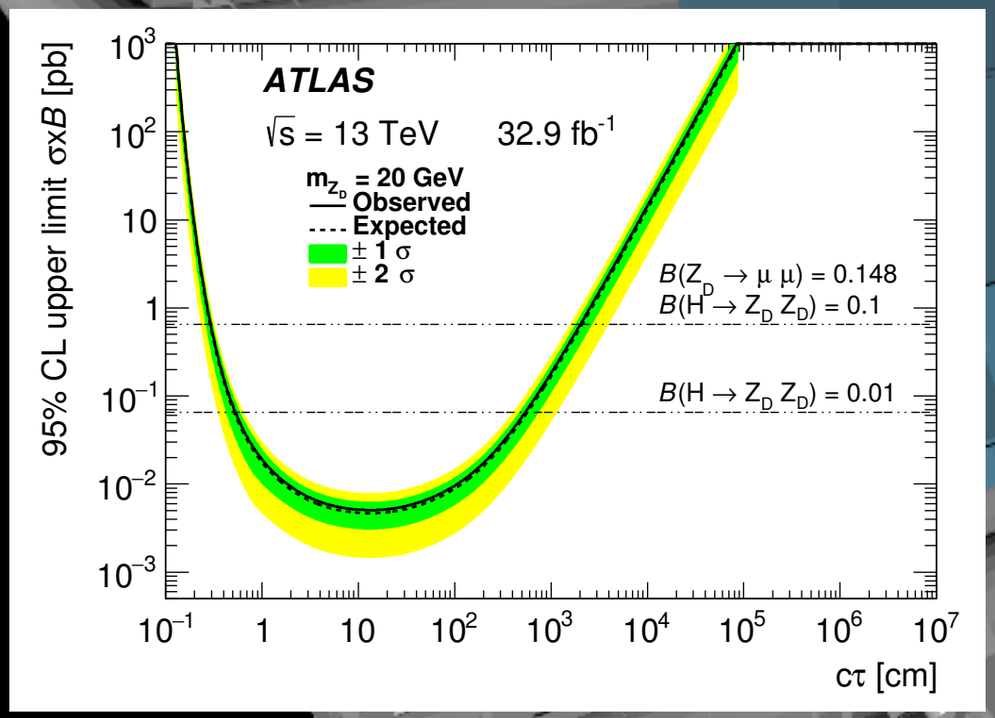


CMS-EXO-16-022

Neutral or charged LLPs decaying to leptons

Recent ATLAS result using tracks only in the muon system — can still point back toward the interaction point for small displacements of the potential LLP
arXiv:1808.03057 (submitted to PRD)





ATLAS EXPERIMENT

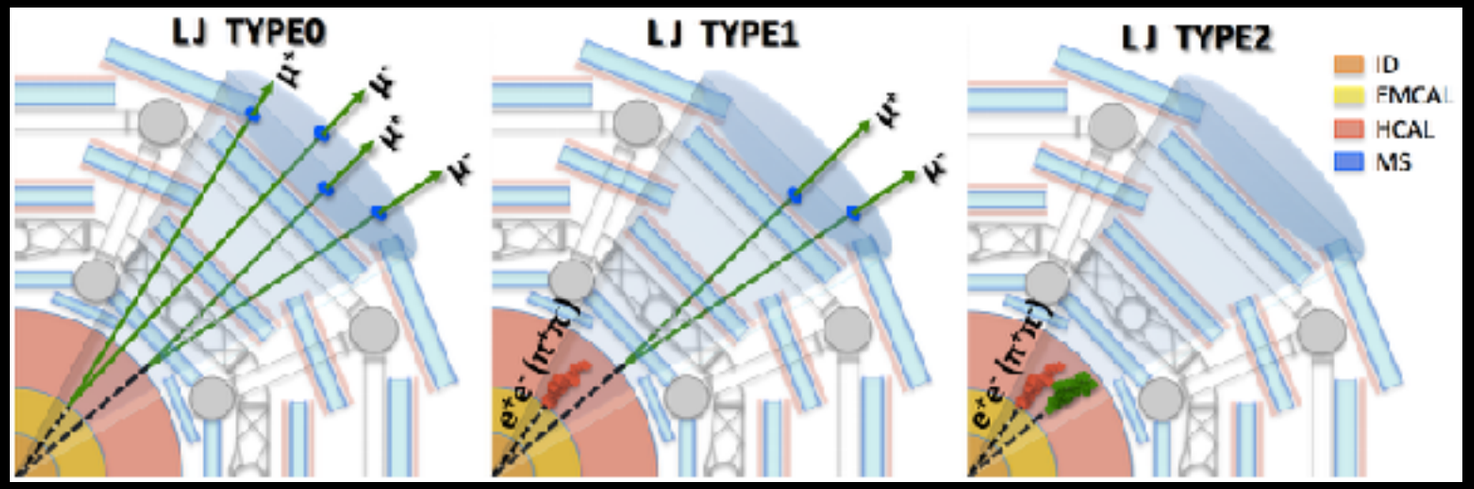
Run: 302265
Event: 18449422
2016-06-17 02:10:00 CEST

MS-only tracks extrapolated back to di-muon vertex at r_{vtx} = 2.2 cm

Neutral LLPs decaying to lepton-jets

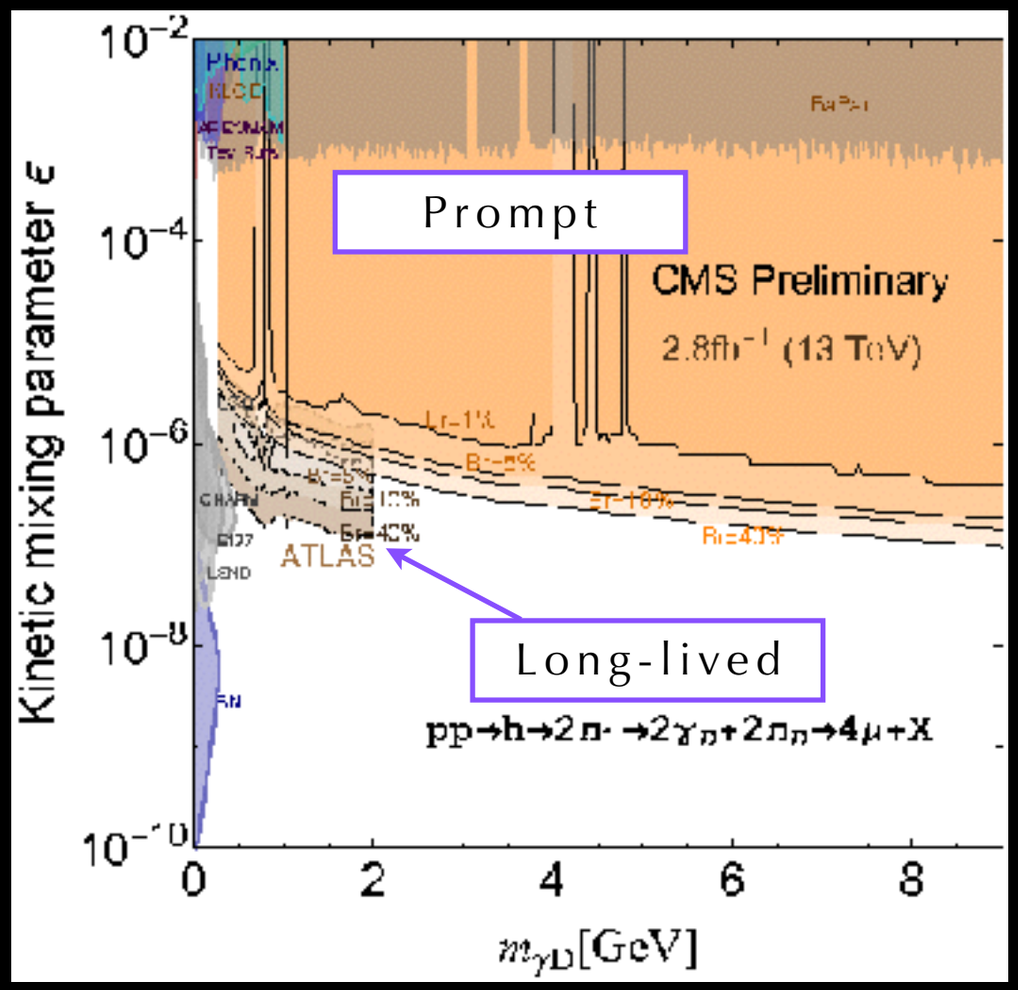
Lepton-jet = highly-collimated grouping of leptons from a low-mass, boosted BSM particle like a dark photon / Z_{dark}

- Confounds standard lepton isolation criteria



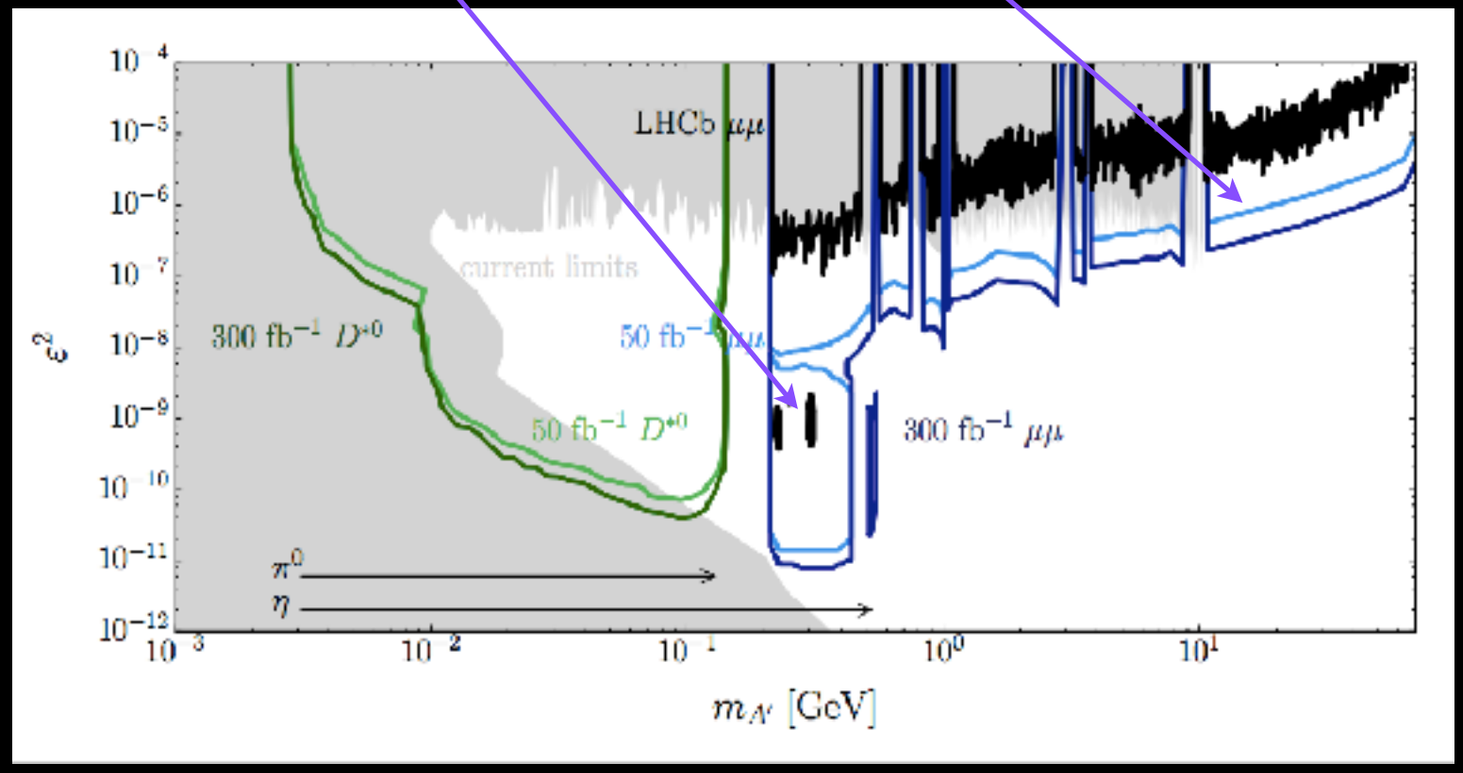
CMS-PAS-HIG-16-035

ATLAS-CONF-2016-042



LHCb exclusion in never-before-covered LLP space

Projections for LHCb upgrade — arXiv:1808.08865 — arXiv:1509.06765



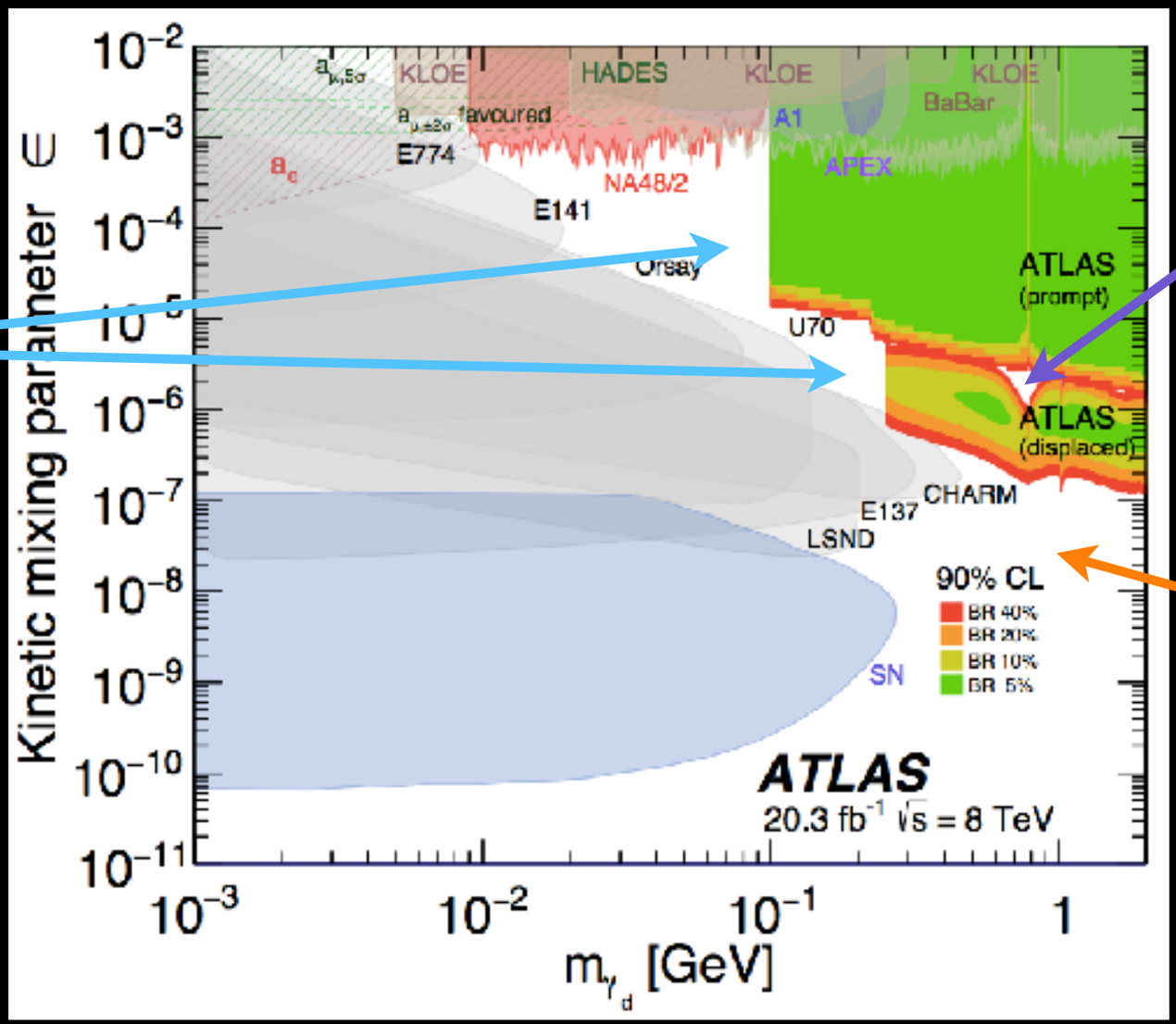
LHCb: PRL 120, 061801

Potential discoveries we're missing

Displaced lepton-jets

- Clearly apparent gaps where a discovery could be hiding
- Run 2 improvements already made (single LJ trigger, etc.)

JHEP 1602 (2016) 062



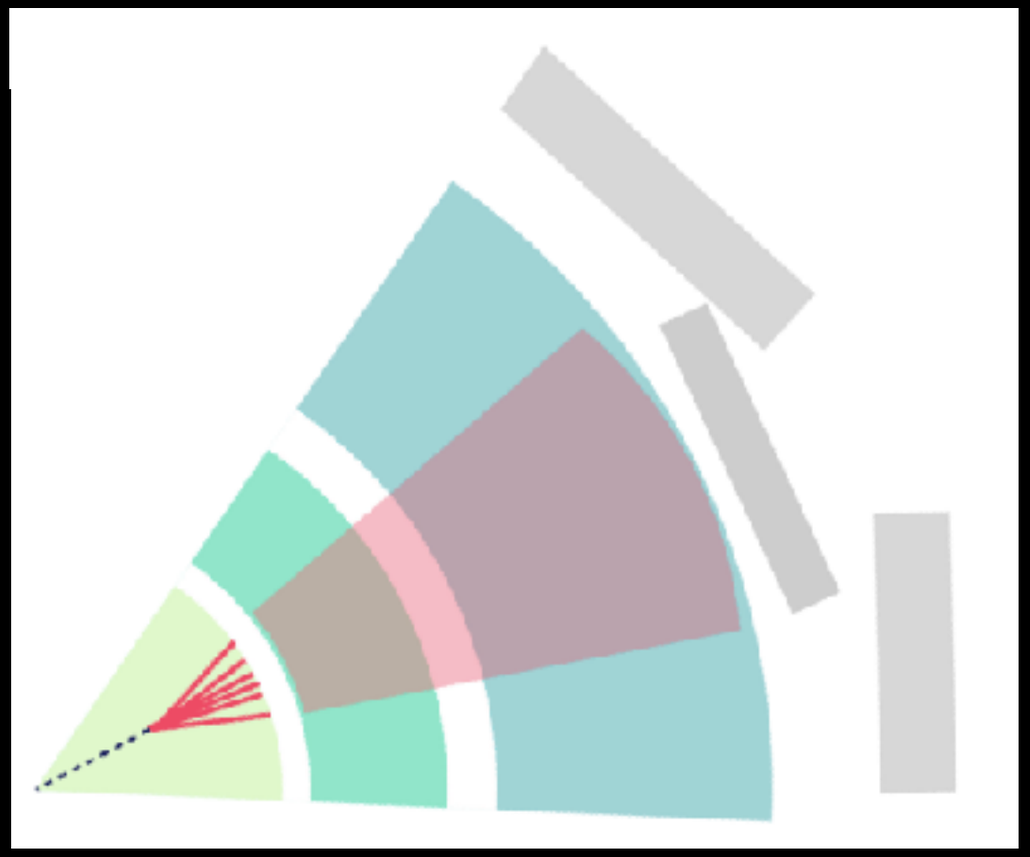
Low-mass: New triggers for non-standard LAr deposits

Mass-gap: Pion-jets

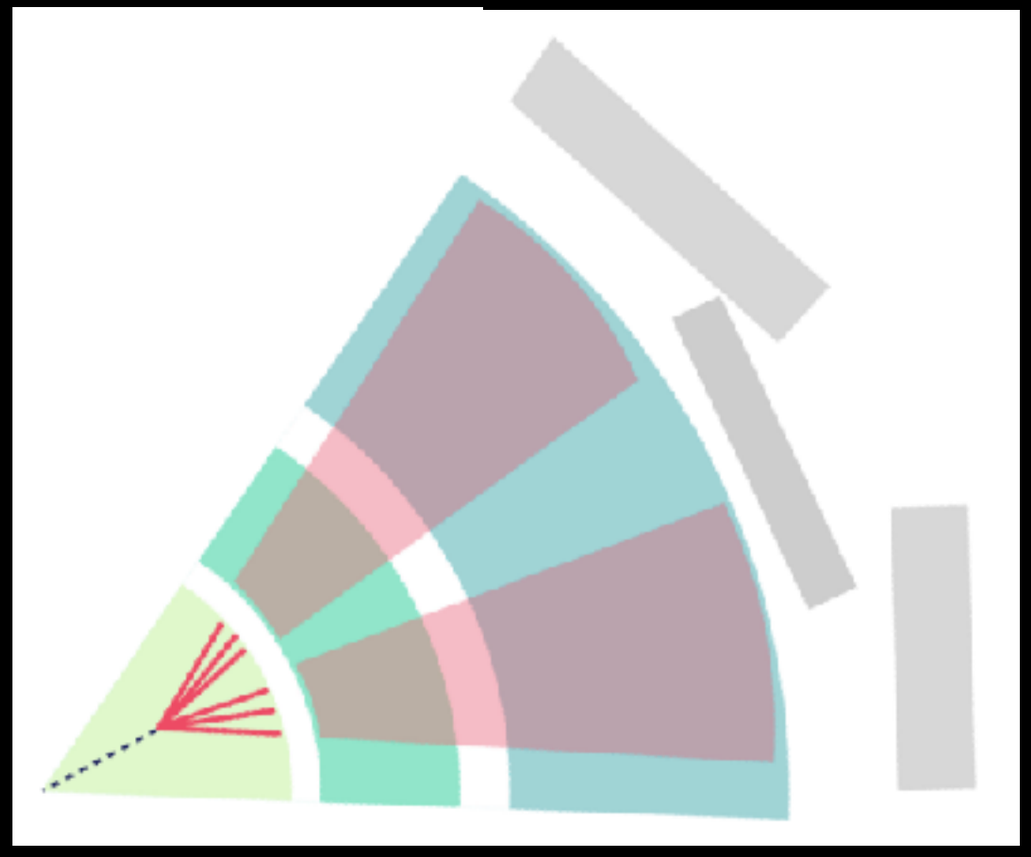
Very-displaced region: Need to trigger on single LLP decays

Neutral LLPs decaying to hadrons

The LLP can decay to jets in the inner tracker

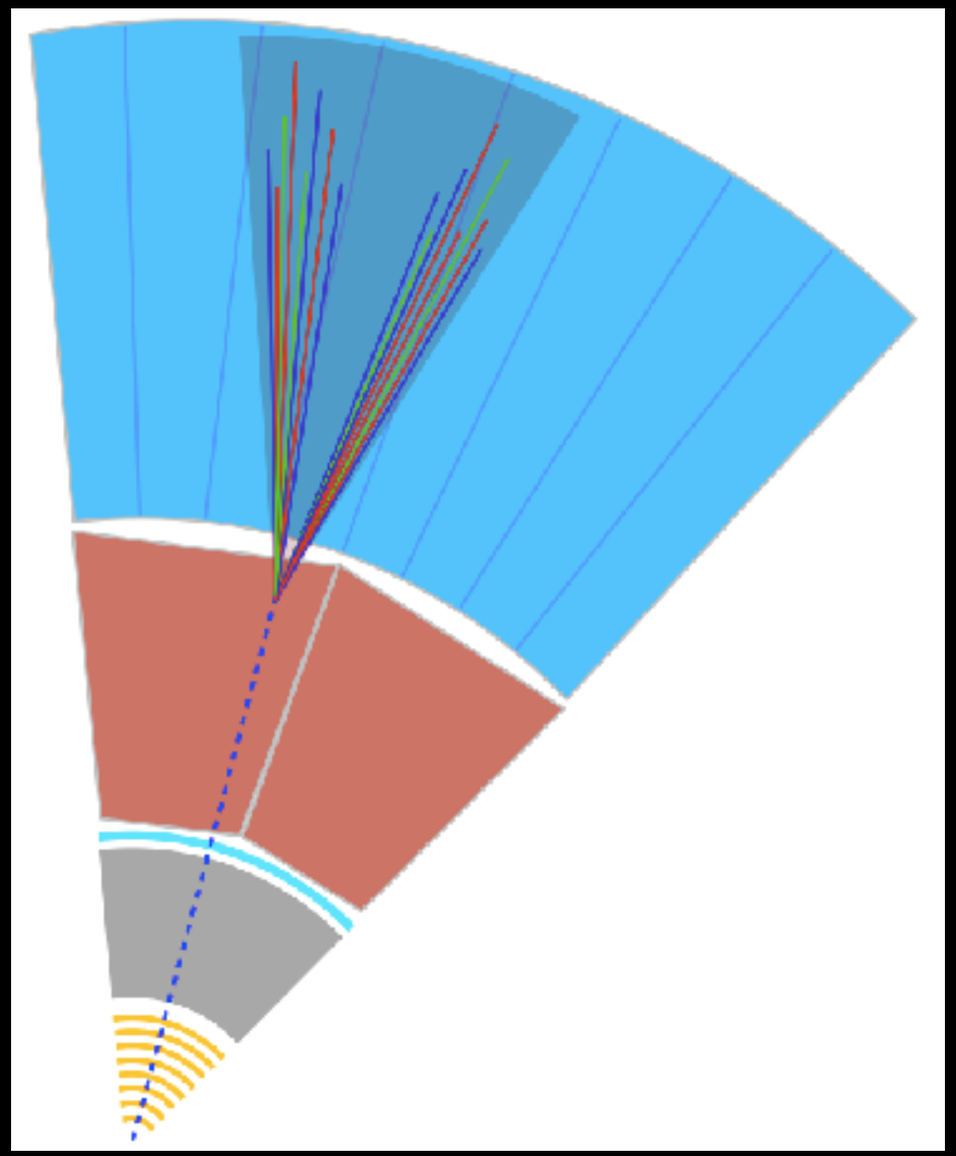


ATLAS approach — single multi-track vertex (see backup)

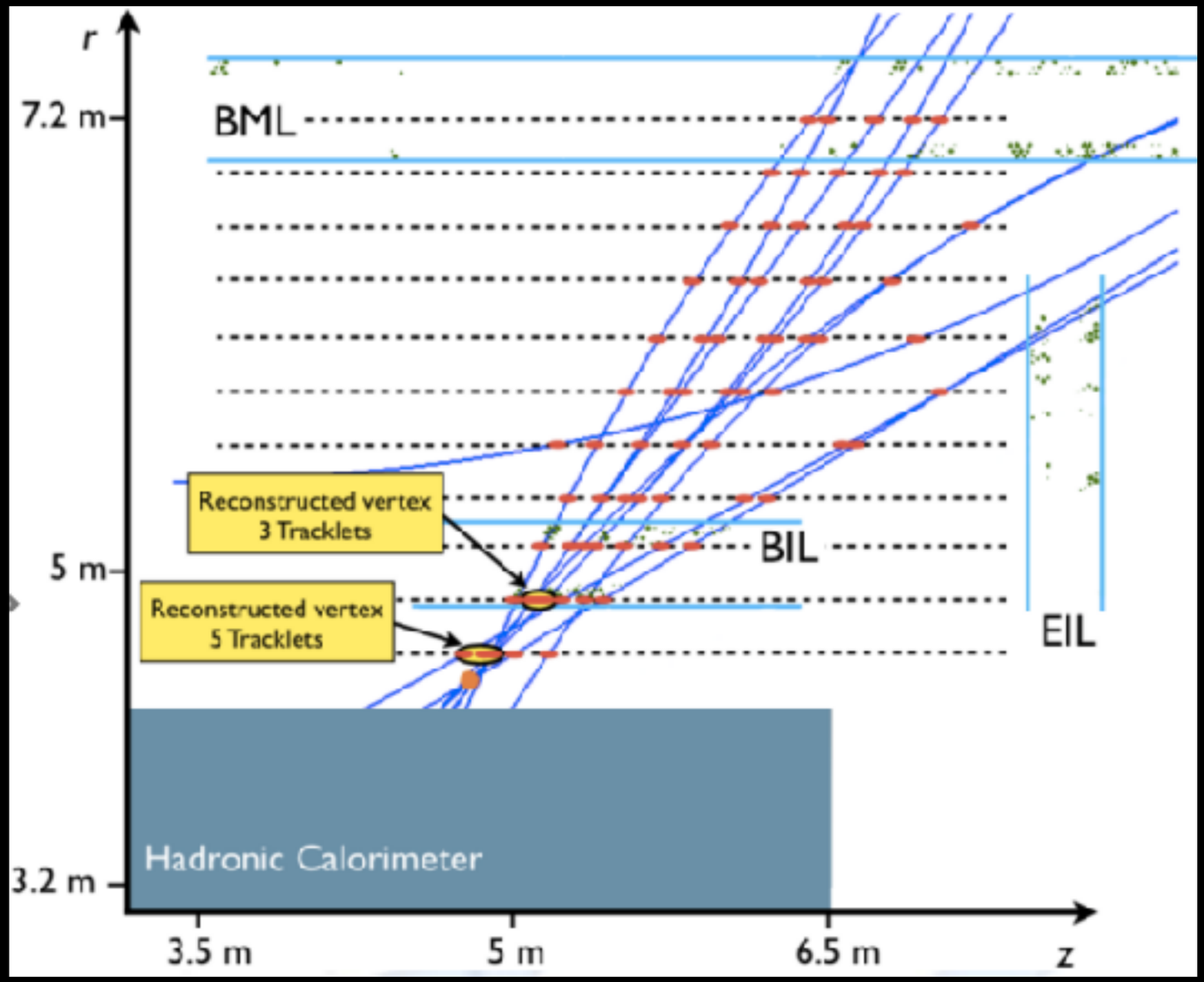


CMS and LHCb — displaced vertices with jet pairs downstream

Neutral LLPs decaying to hadrons



Or the LLP can decay in or just before the calorimeter...

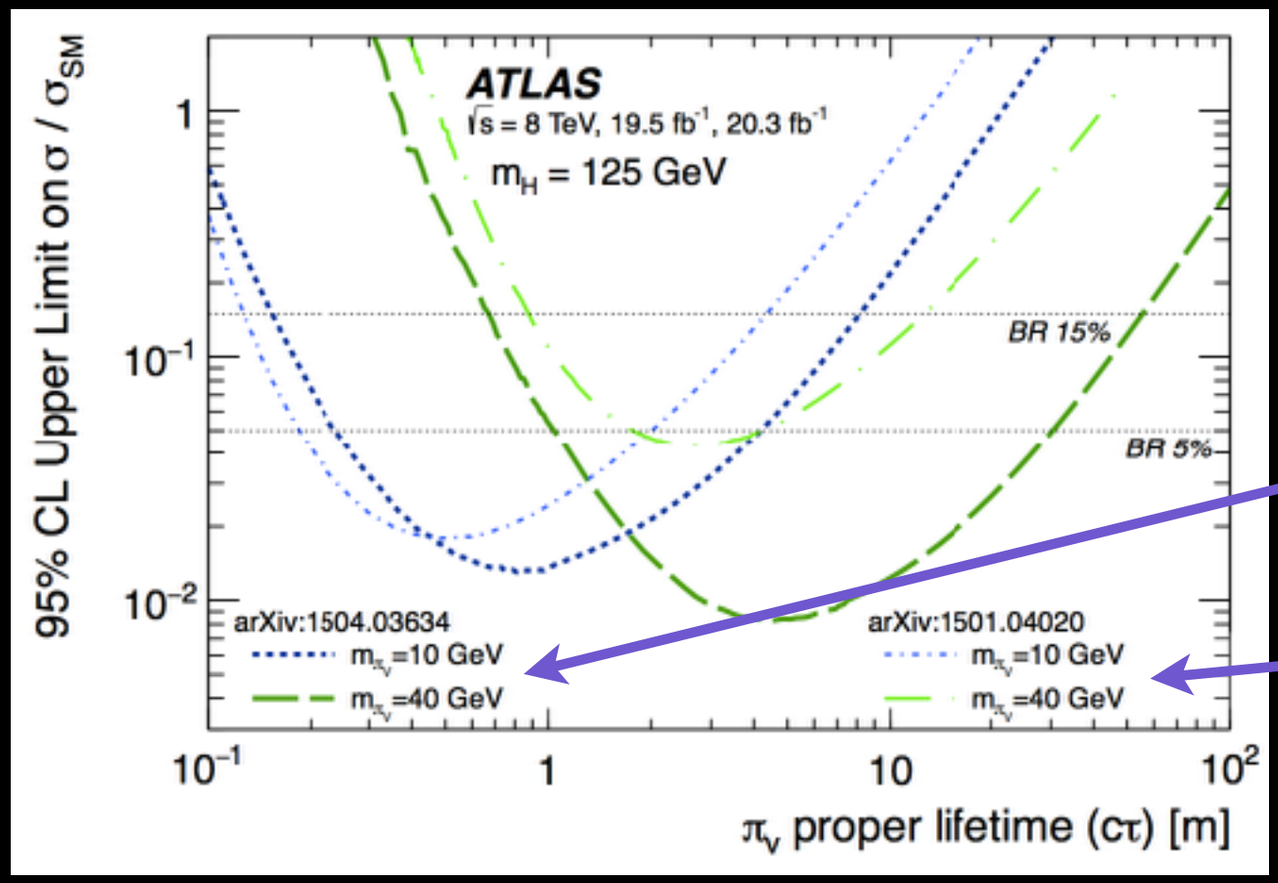


...or only in the MS

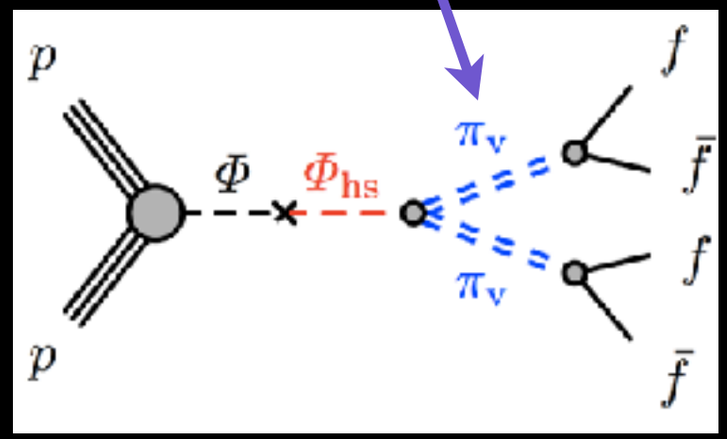
Neutral LLPs decaying to hadrons

SM-like Higgs —> LLPx2 —> hadronic jets

- Many searches for this already, but there are known limitations
  - What if m_{LLP} < 10-30 GeV?
  - What if ~mm < ctau < ~10 cm?
- Similar caveats for higher-mass H and LLP scenarios
  [see ATLAS-CONF-2016-103]



Long-lived π_v



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 edge or gap regimes?

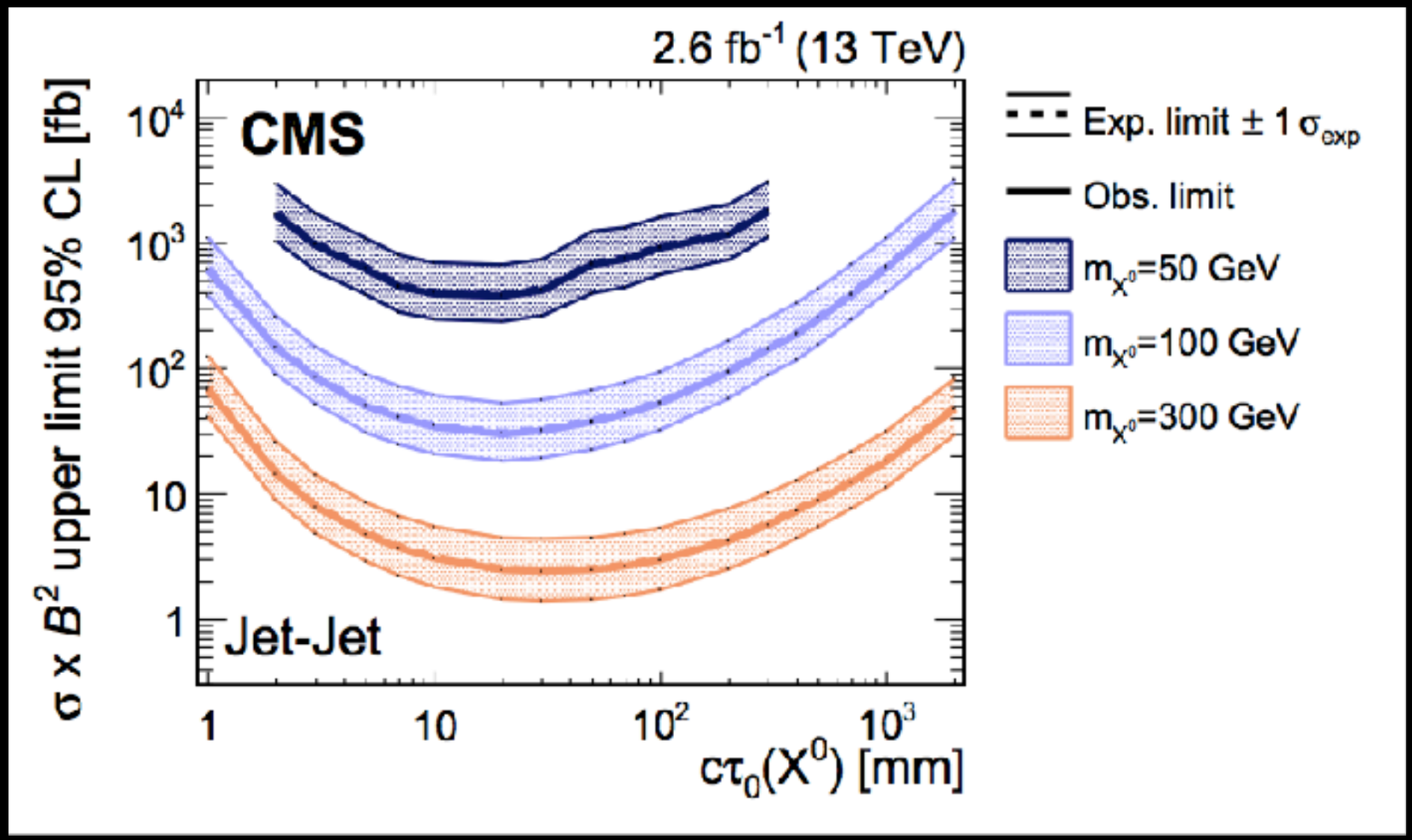
ATLAS: PRD 92 (2015) 012010

PLB 743 (2015) 15-34

Uncovered LLP realms

Low-mass, low-p_T everything

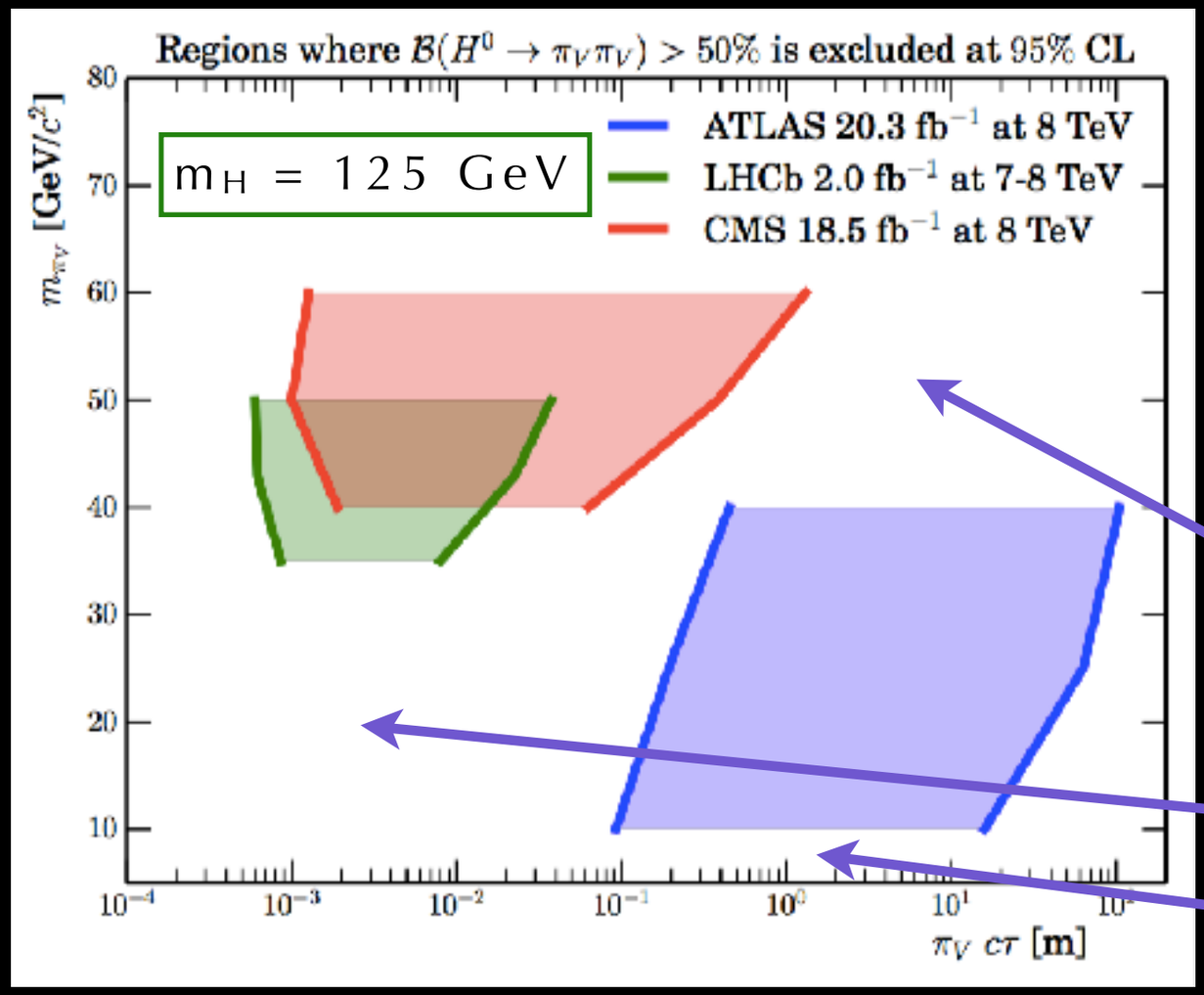
- For pair-produced, long-lived scalars decaying to jets, CMS has an inclusive search: PLB 780 (2018) 432-454
  - Same caveat here: What about for smaller masses and lifetimes?



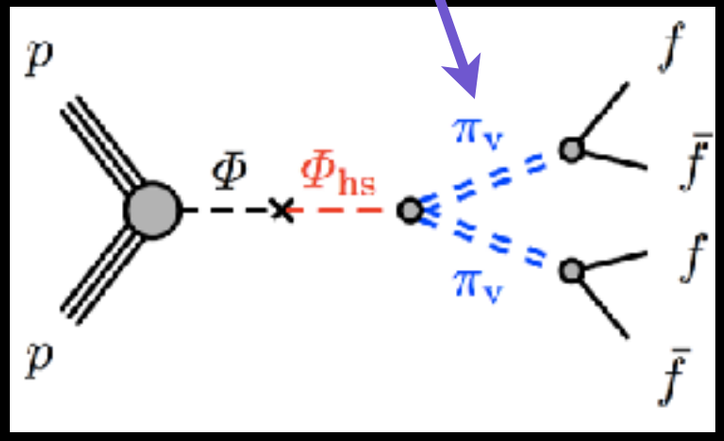
Uncovered LLP realms

Comparing searches

- SM-like Higgs —> LLPx2 —> jets
- Big open areas should inspire new triggers, methods to lower thresholds, new ID methods, etc.



Long-lived π_v



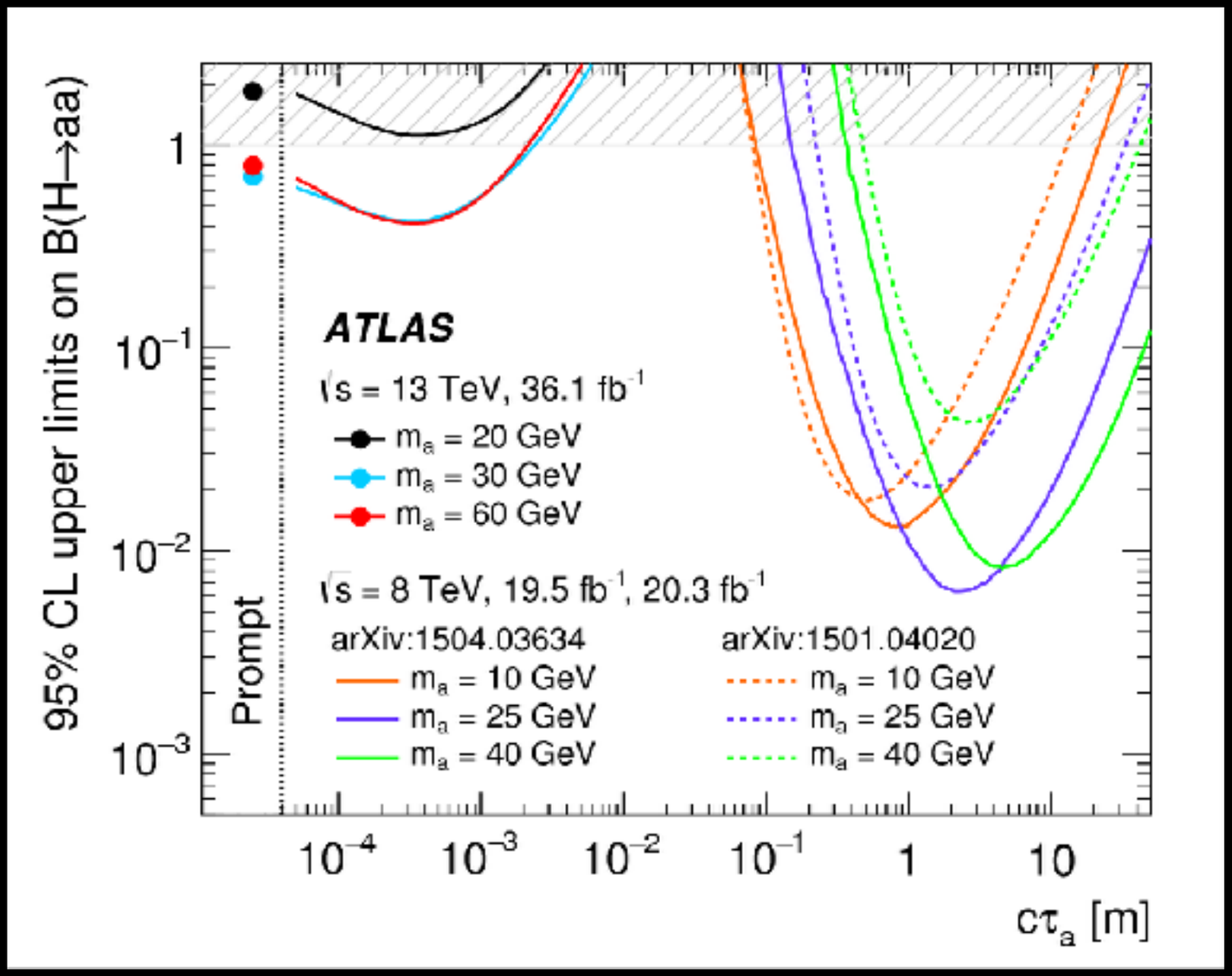
A discovery could be hiding here! (Model-dependent plot, but illustrative)

LHCb: EPJC 77 (2017) 812

Getting-close-to-covered LLP realms

Very short-lived LLPs decaying to jets

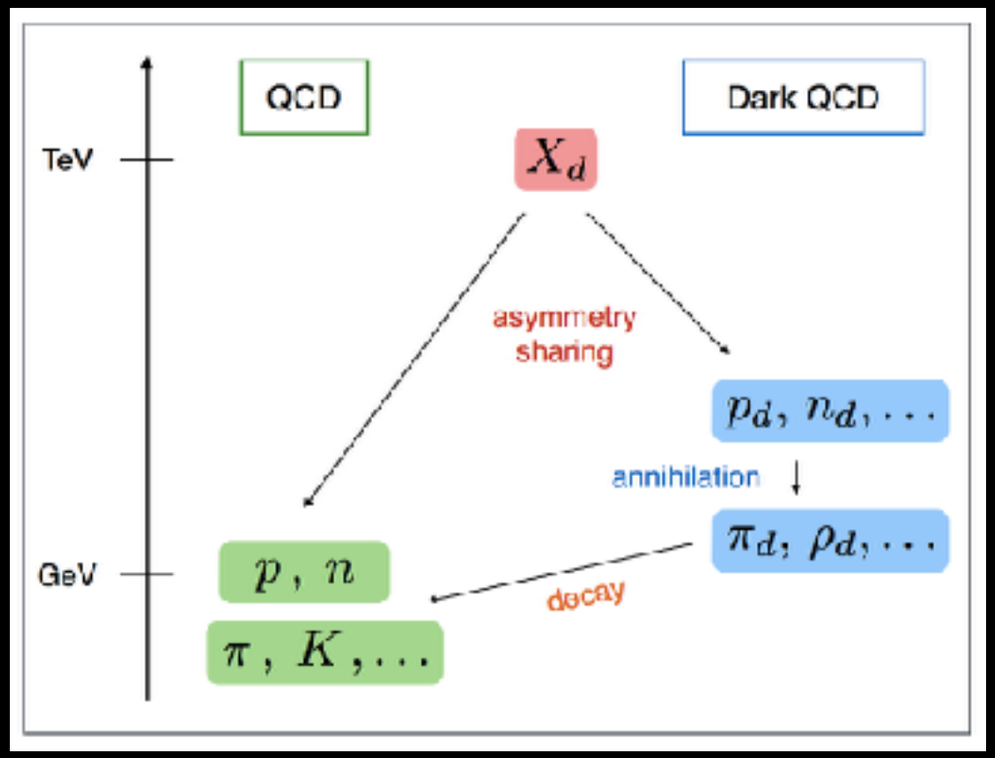
- Recent ATLAS search for W/Z/h125 —> *aa* —> 4b for a promptly decaying *a*, where an additional limit was set on a scenario with an *a* with a non-zero lifetime [arXiv:1806.07355]



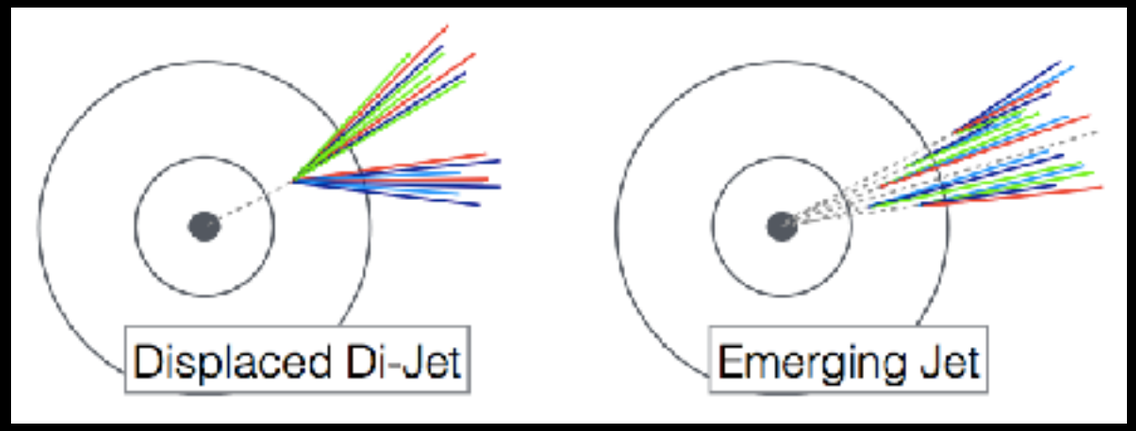
- Essentially required generating some additional simulated samples and calculating a limit, an excellent gain for just a little extra work

- We should encourage all experimentalists doing any search for promptly decaying particles to produce similar plots!

LLPs from dark QCD-like sectors — emerging jets

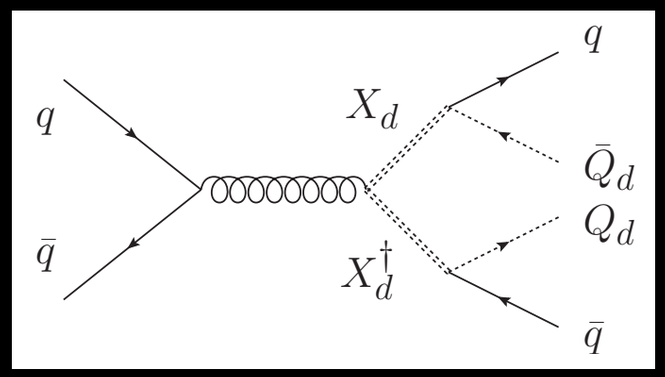


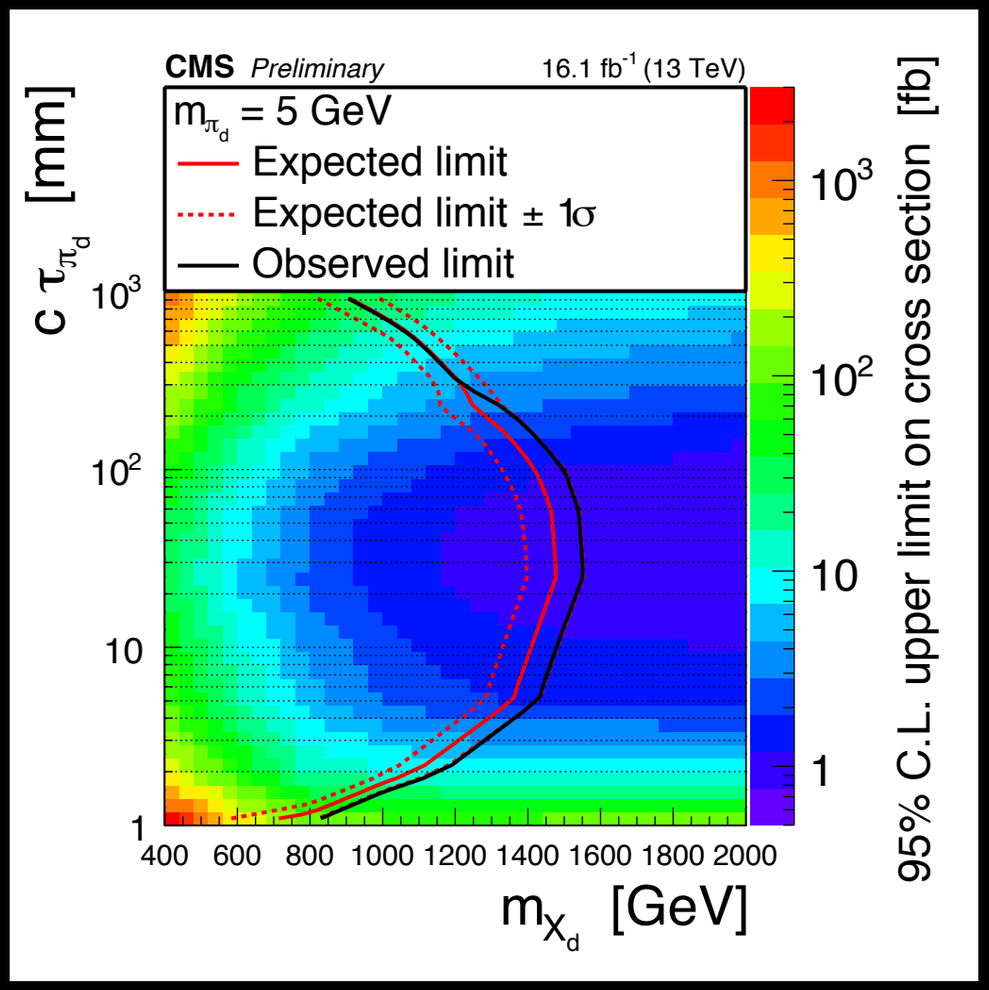
JHEP (2015) 2015: 59



Dark quarks hadronize first in the hidden sector and, e.g., dark pions then decay to the visible sector via multiple displaced vertices of varying displacements within the same jet object

Thus, this is **neither prompt jets nor a pair of displaced jets** pointing to the same displaced vertex, but to **emerging jets**.





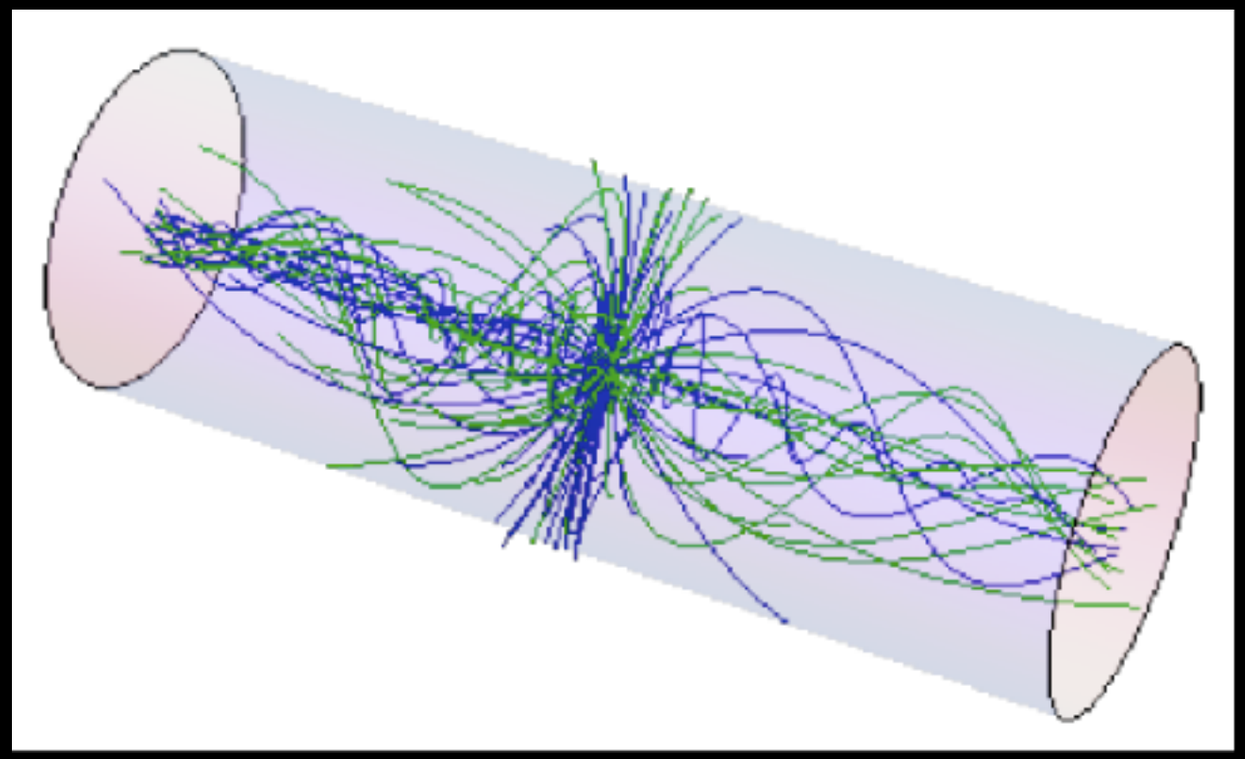
CMS-PAS-EXO-18-001

First results for this dark-QCD model at the LHC — ATLAS search in progress

Uncovered LLP realms

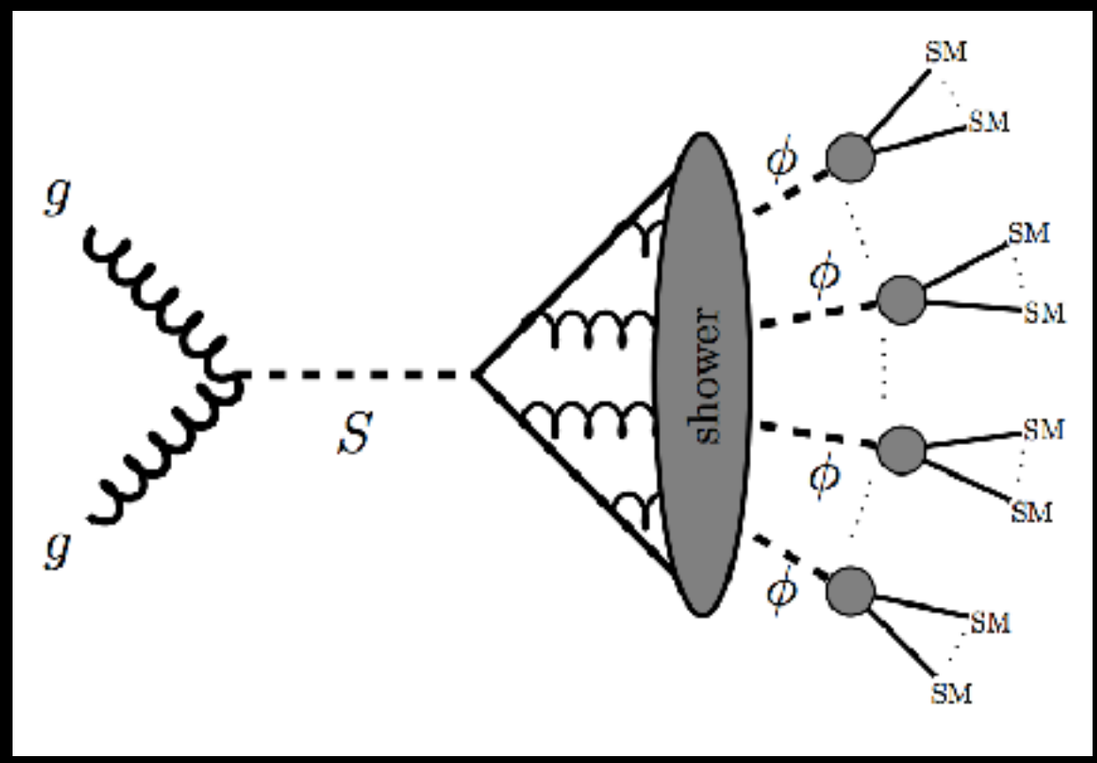
What about the other end of the dark QCD spectrum?

- Very strongly coupled hidden sector yielding a soft radiation pattern in the detector
  - Soft, unclustered energy patterns, or SUEPs: JHEP (2017) 2017: 76



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

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

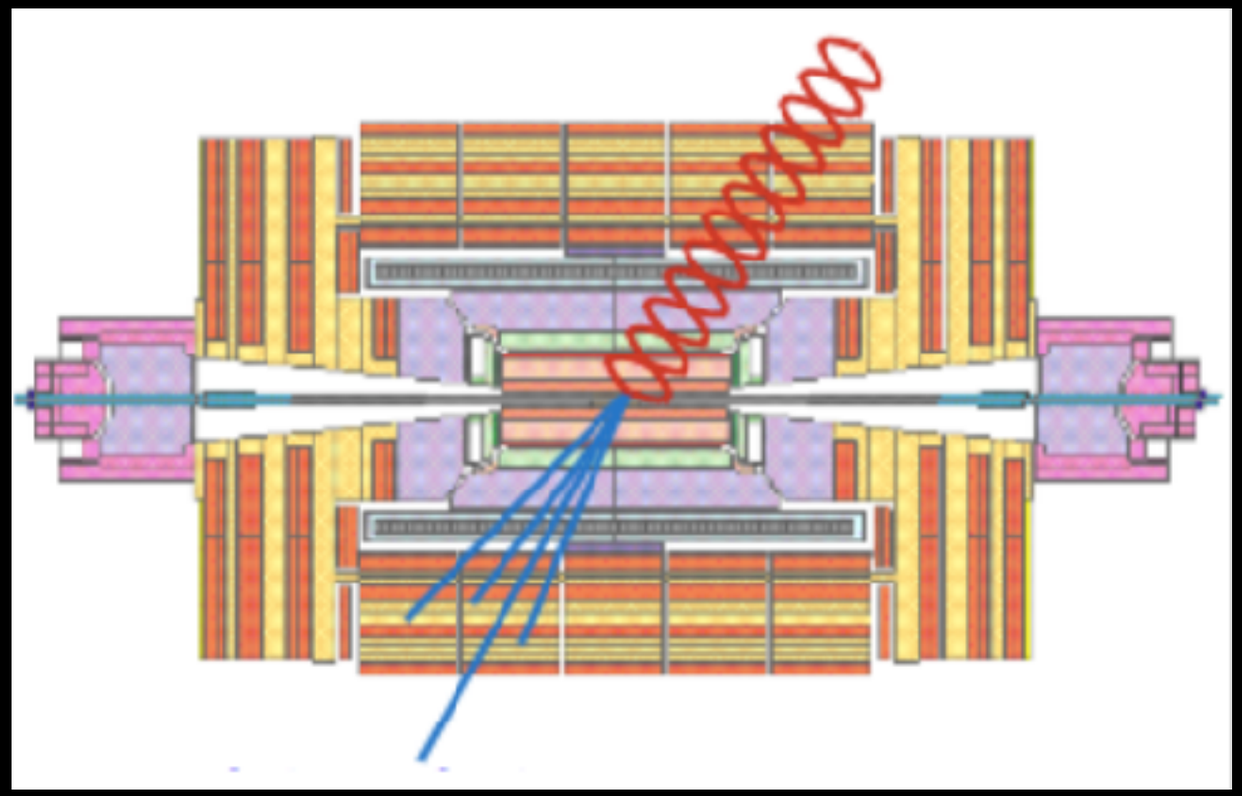


Could a high multiplicity soft muon trigger be useful here?

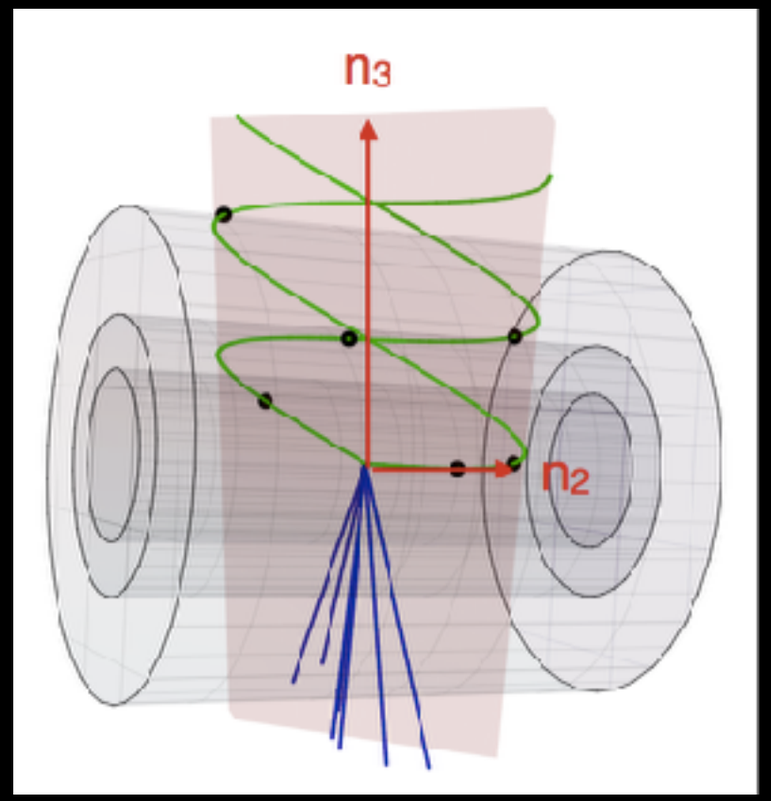
Uncovered LLP realms

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

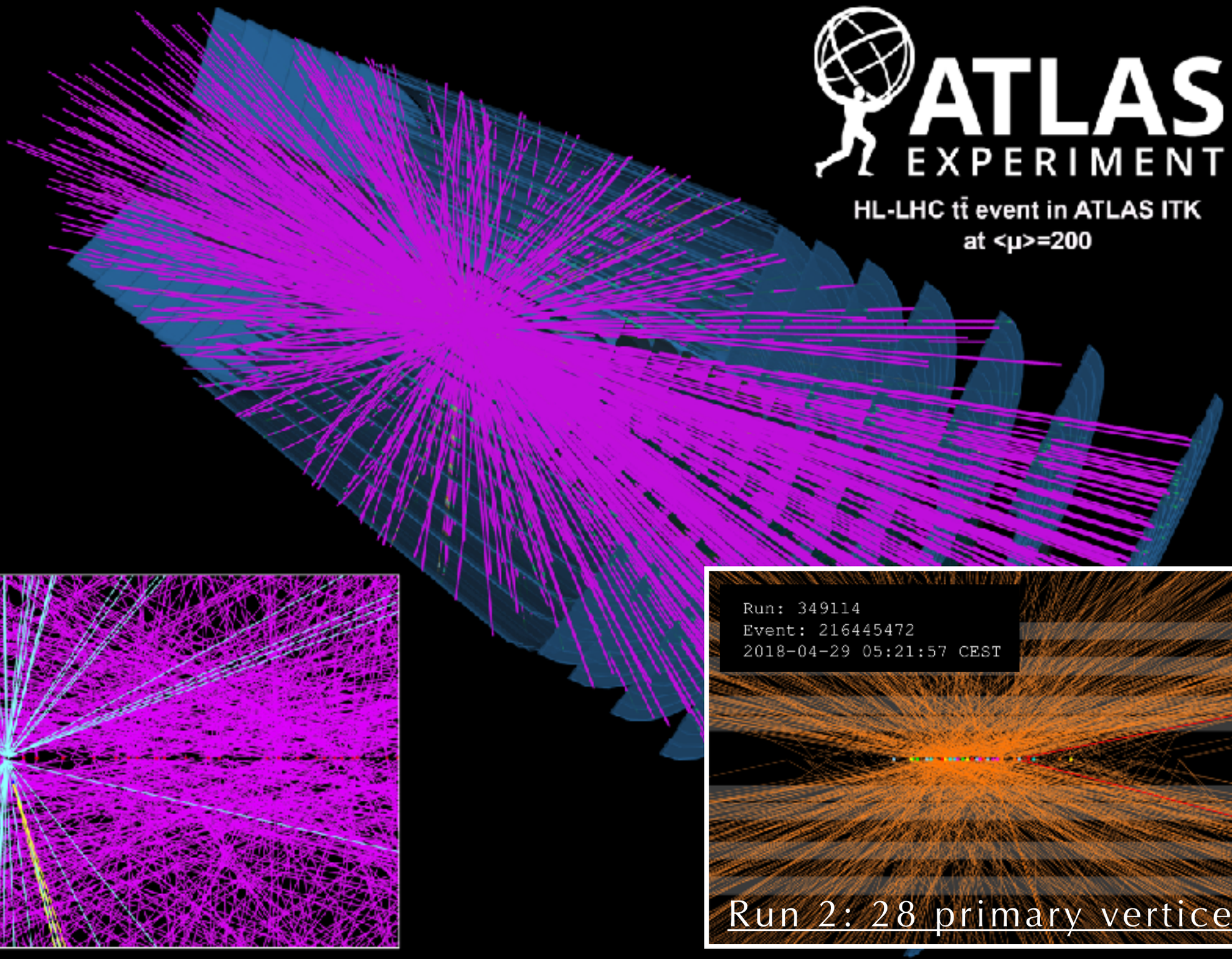


Talk by Knapen at Trieste LHC LLP Workshop

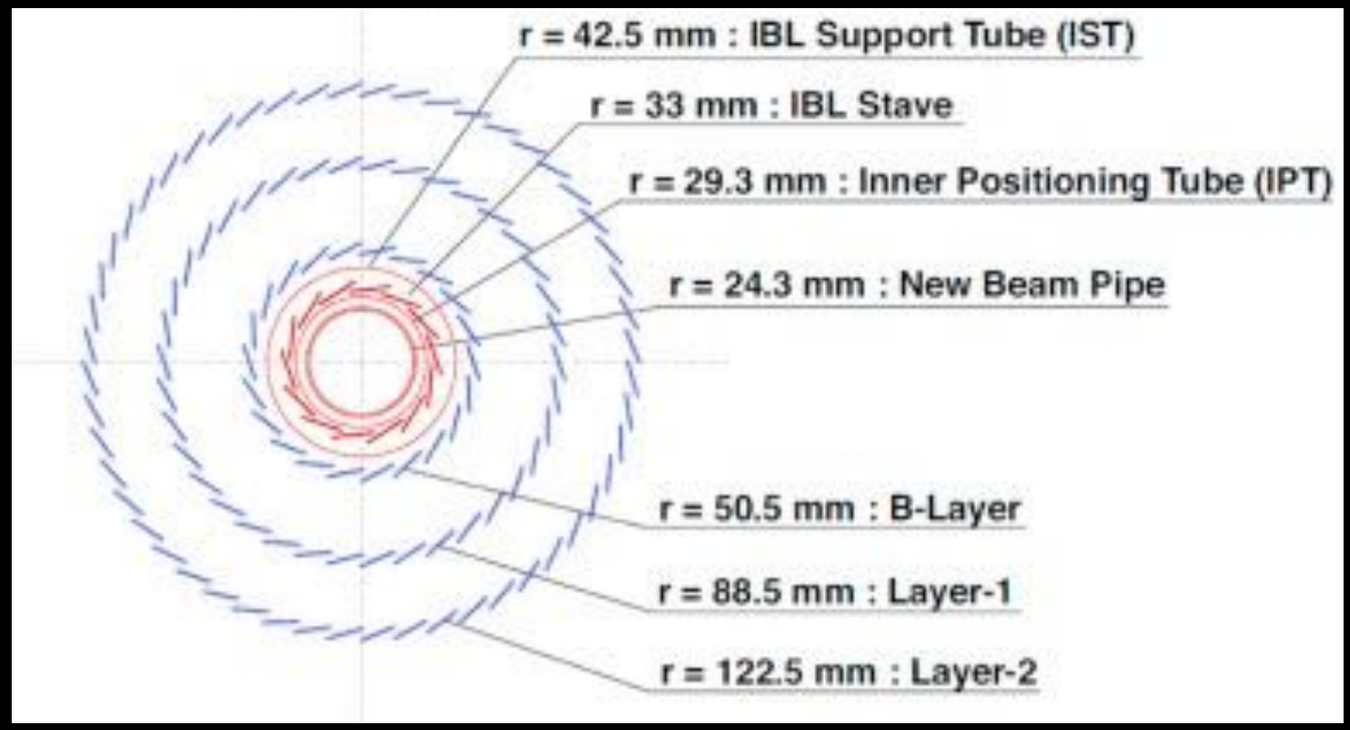


- This is hard, both because standard tracking isn't useful here and because it's difficult to model in Geant4 — only existing search is at D0
- S. Knapen, et al, proposed a model-independent method of looking for patterns of hits that lay in a plane in the detectors — promising avenue for discovery

High-luminosity LHC will be a game-changer



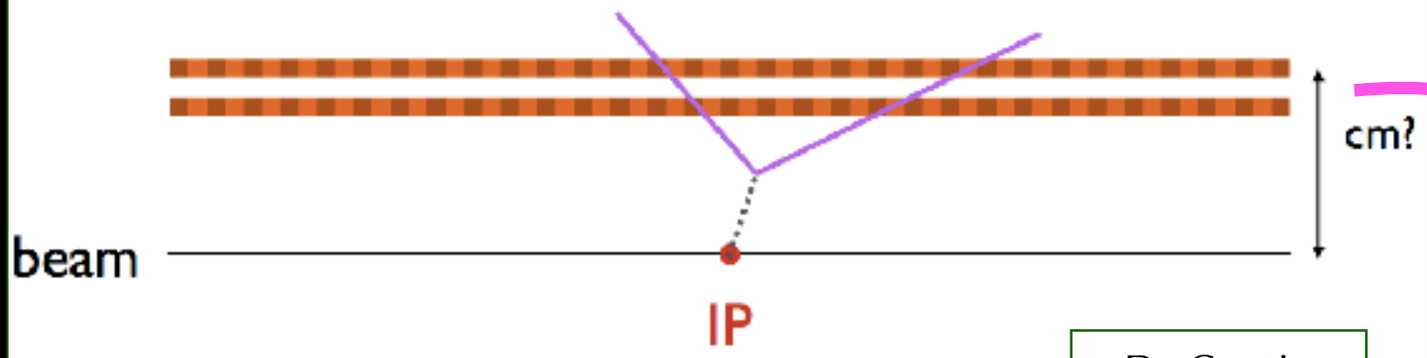
Possible detector upgrades



NIMA 831 (2016) 65-70

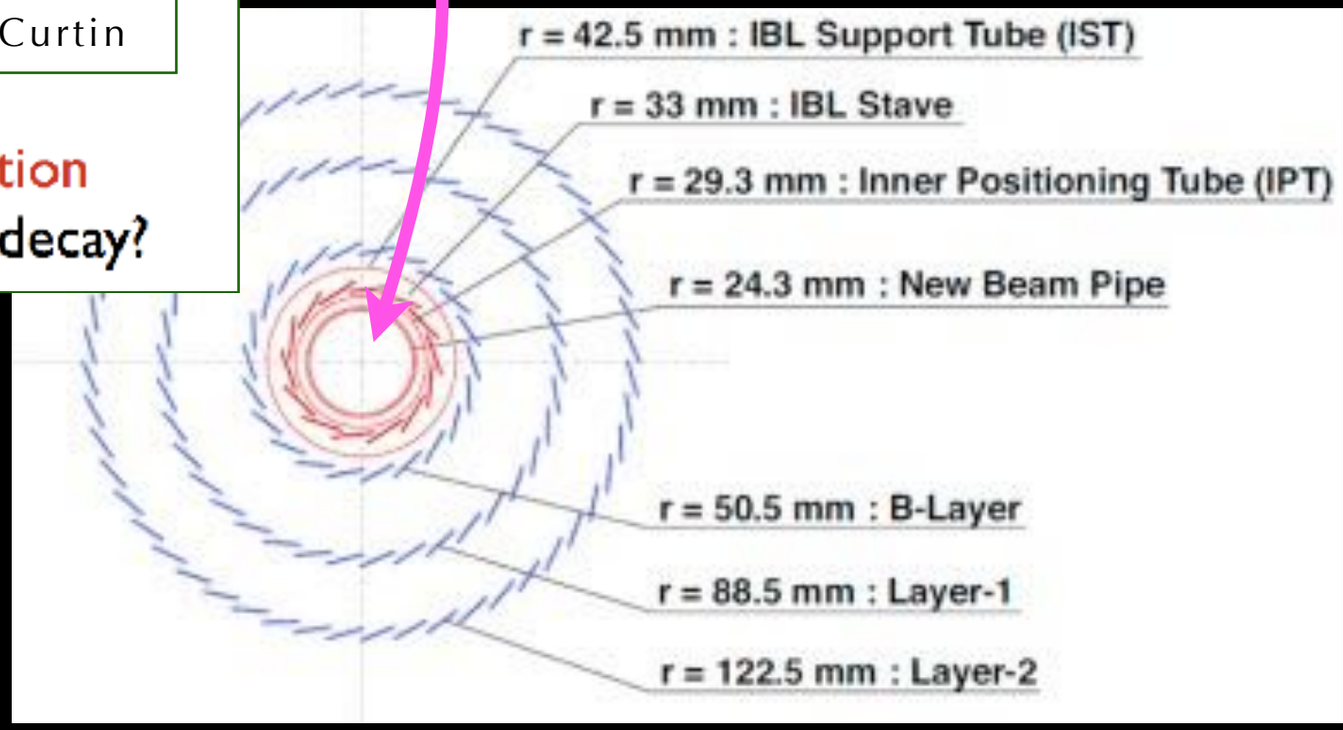
Possible detector upgrades

What about triggering on very short decay lengths in tracker?



D. Curtin

Some sort of tracklet-based DV reconstruction in the double-layer to trigger on possible LLP decay?



NIMA 831 (2016) 65-70

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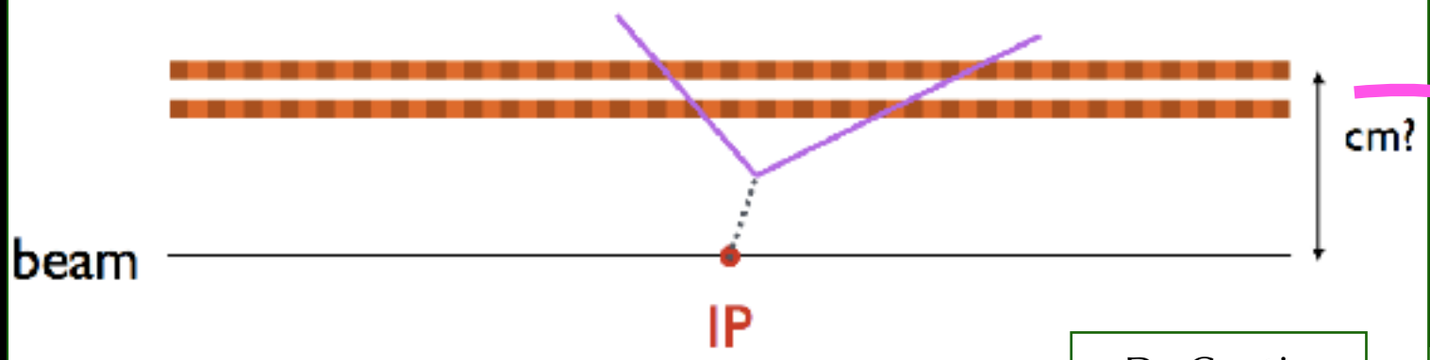
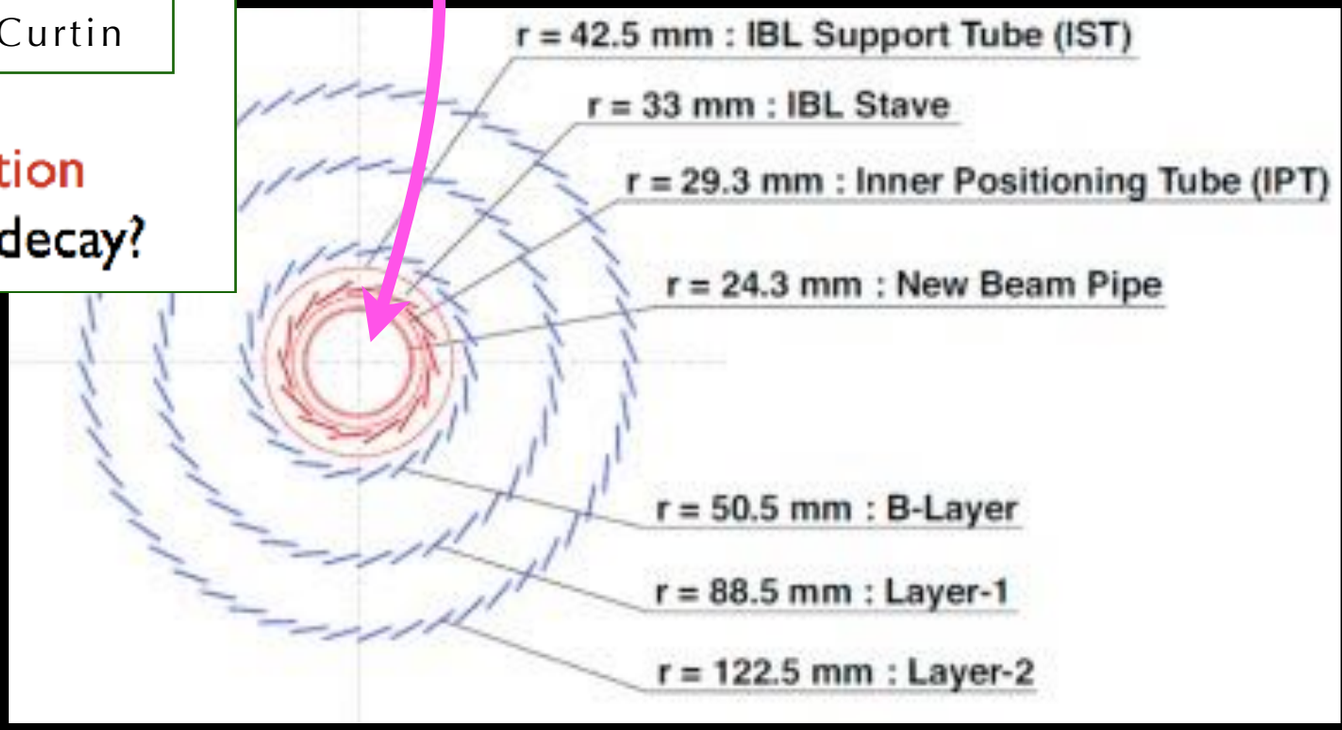


D. Curtin

Some sort of tracklet-based DV reconstruction in the double-layer to trigger on possible LLP decay?

Blue sky idea for ATLAS:

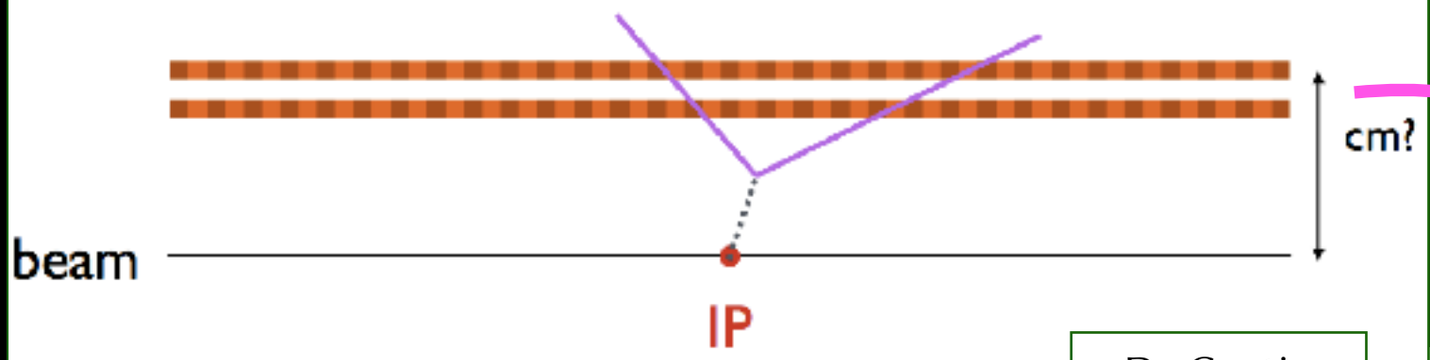
Simple high-resolution double-tracking layer inside the IBL



NIMA 831 (2016) 65-70

Possible detector upgrades

What about triggering on very short decay lengths in tracker?



D. Curtin

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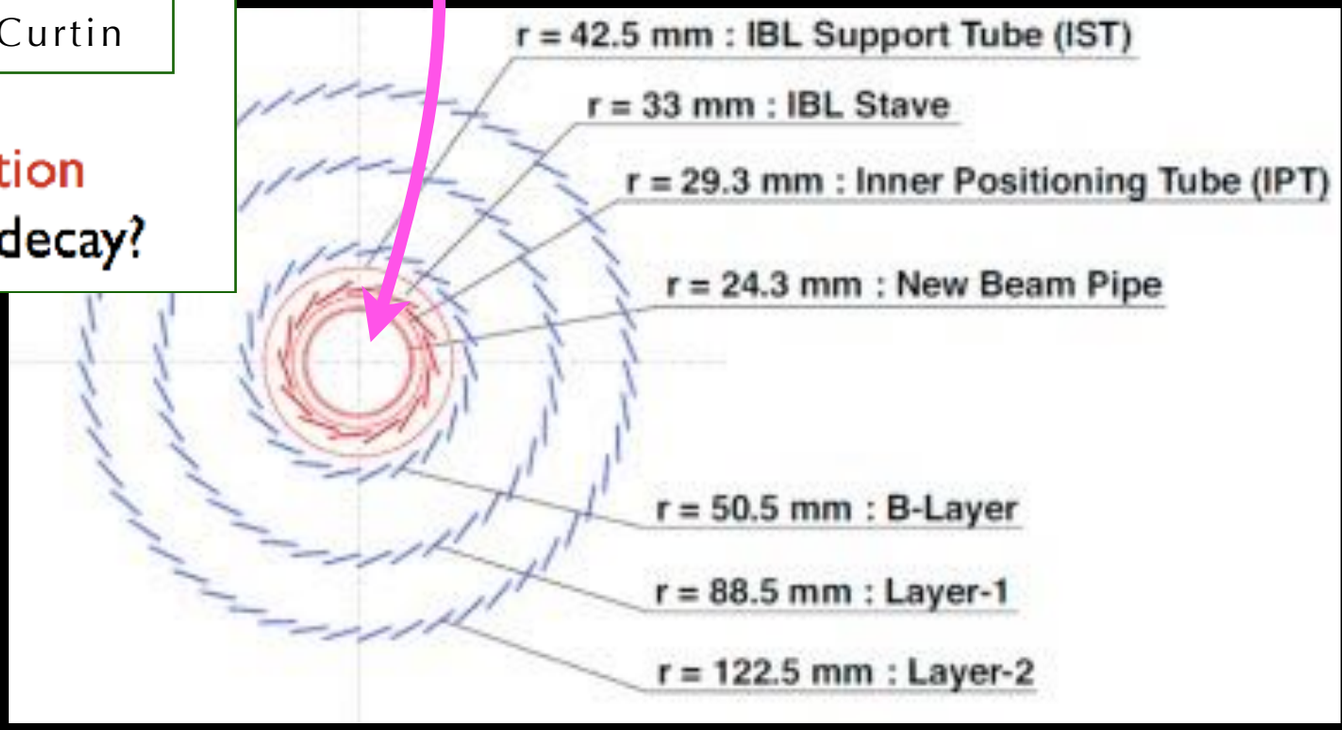

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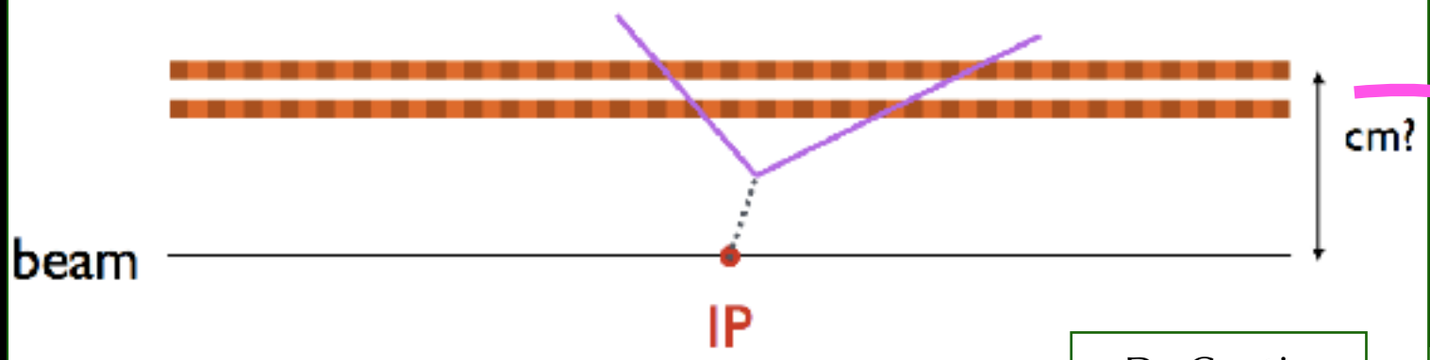

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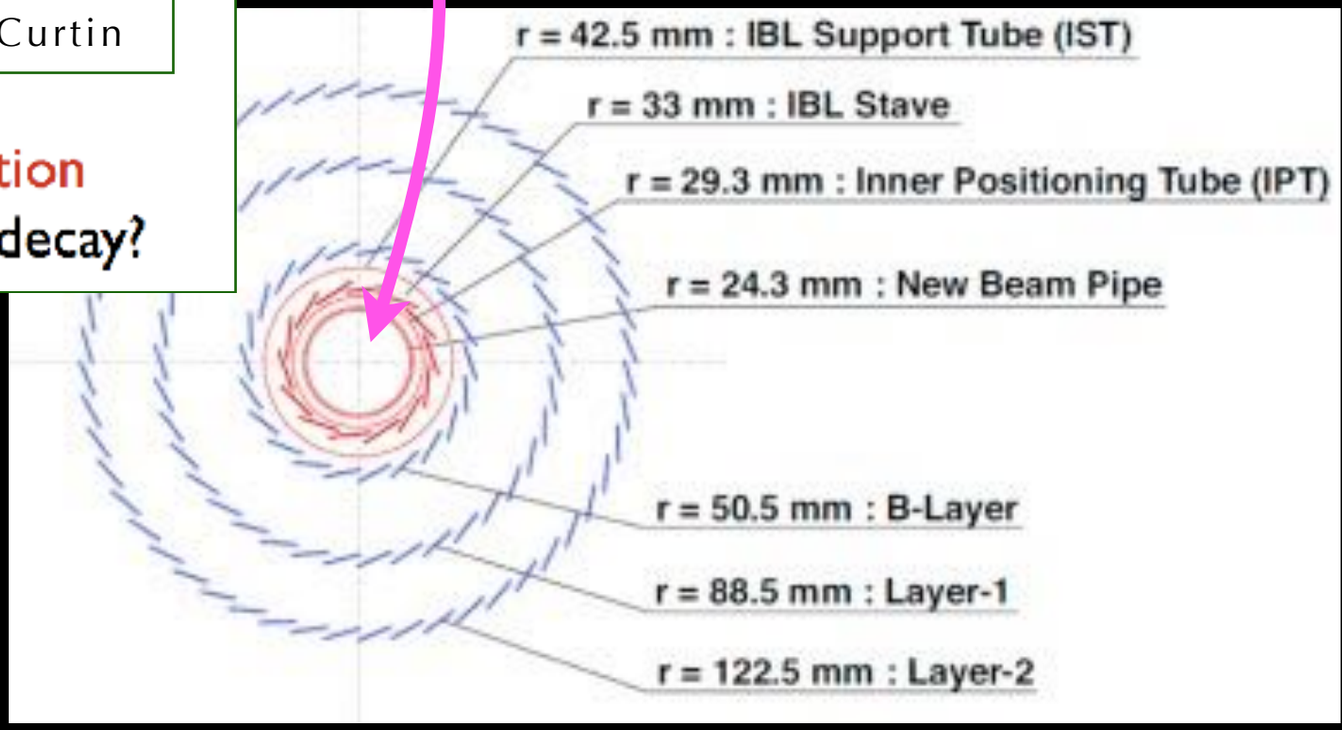
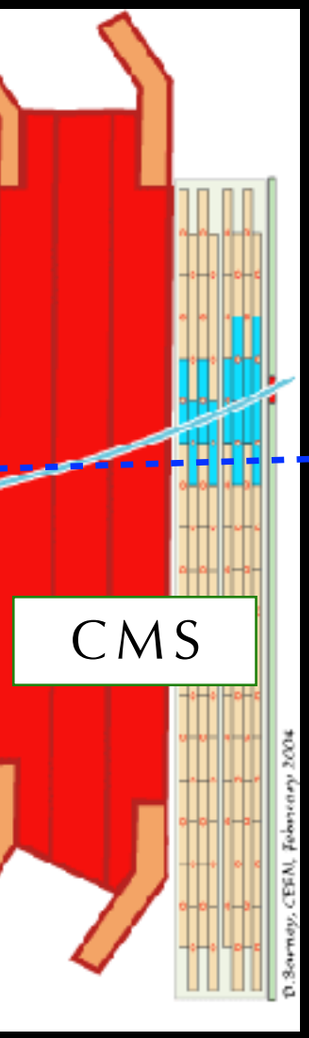


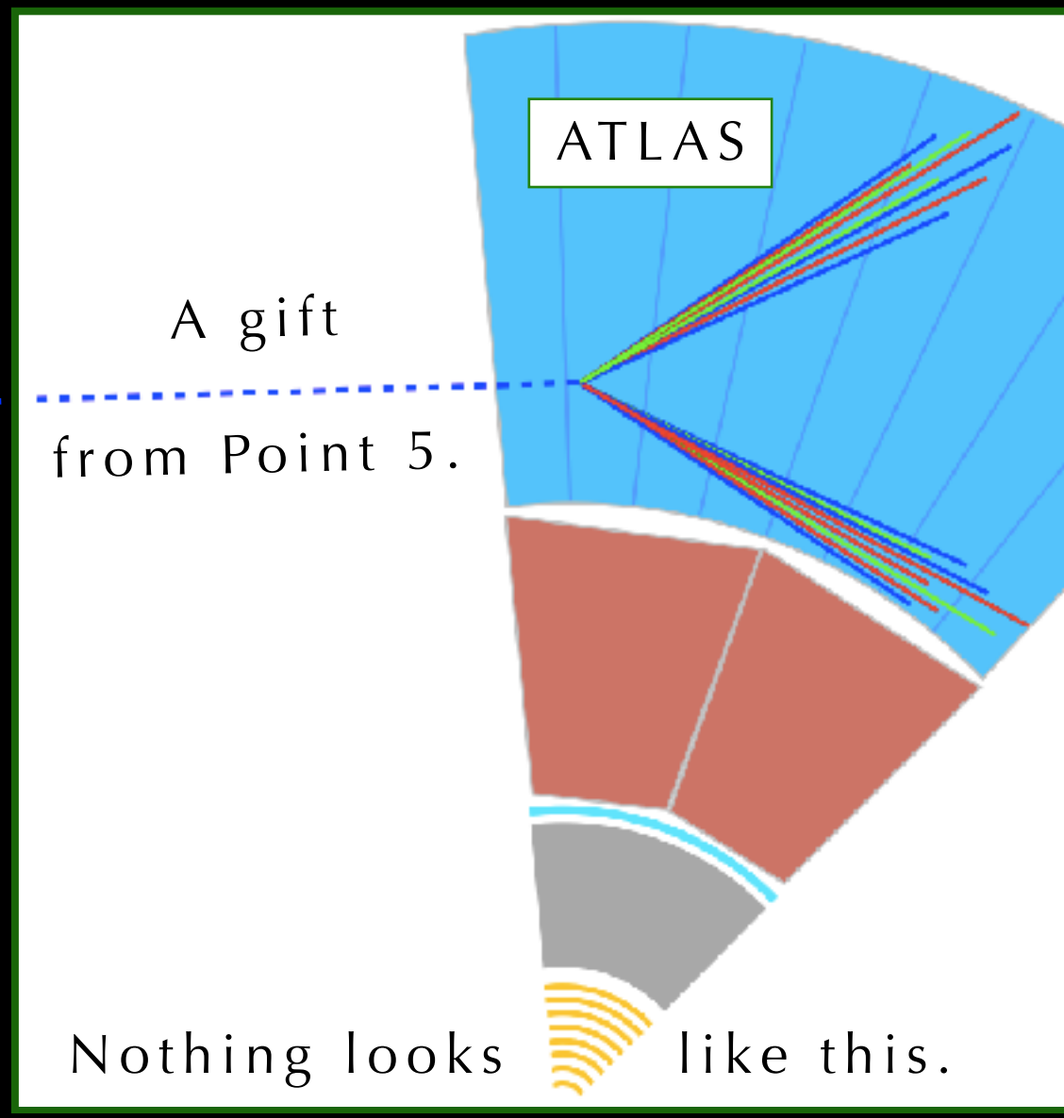
NIMA 831 (2016) 65-70

- Pileup would likely make it useless!
- What about a purposely temporary next-to-beam tracking layer that would only survive a certain integrated luminosity and die?

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

What are we missing?





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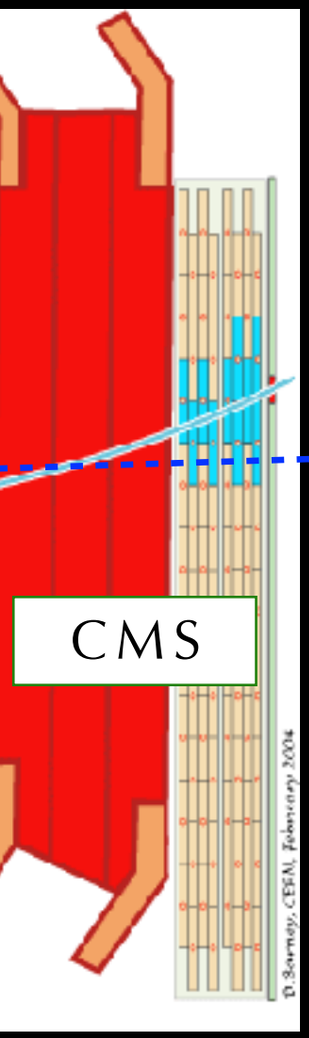

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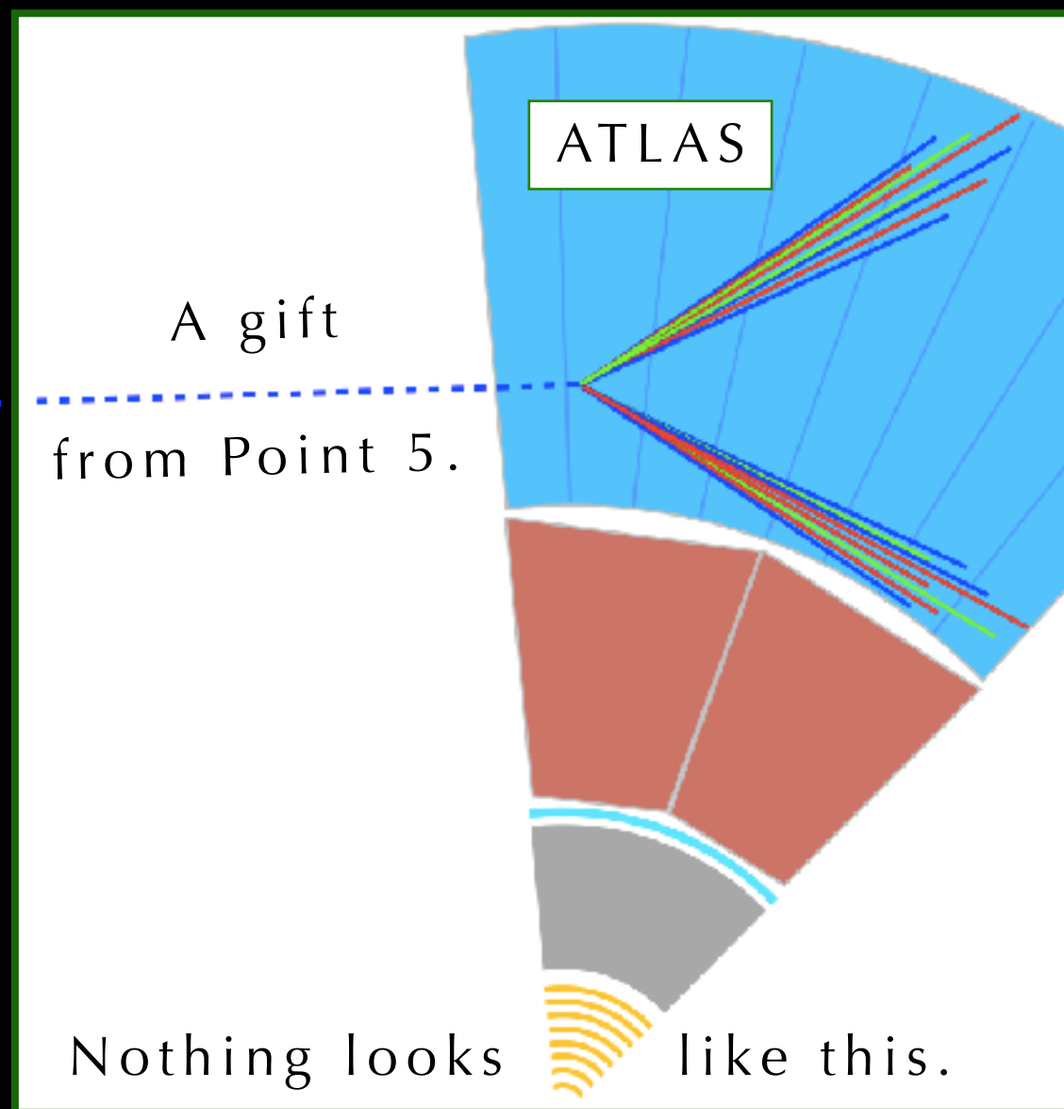
- Solid angle coverage is vanishingly small, ~10^{-7}... <— absurd



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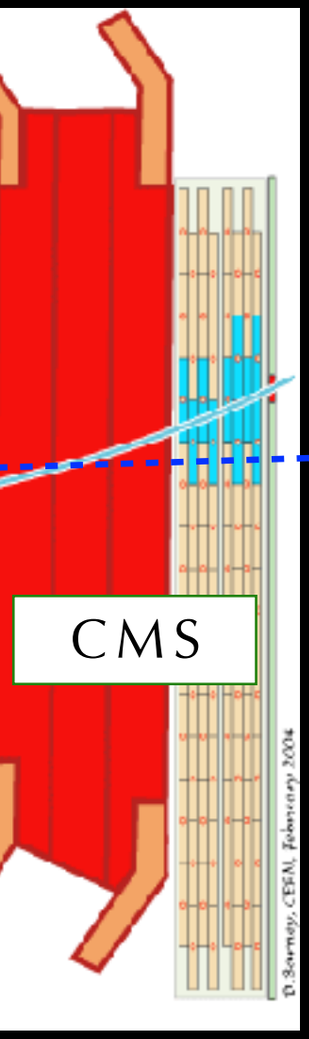

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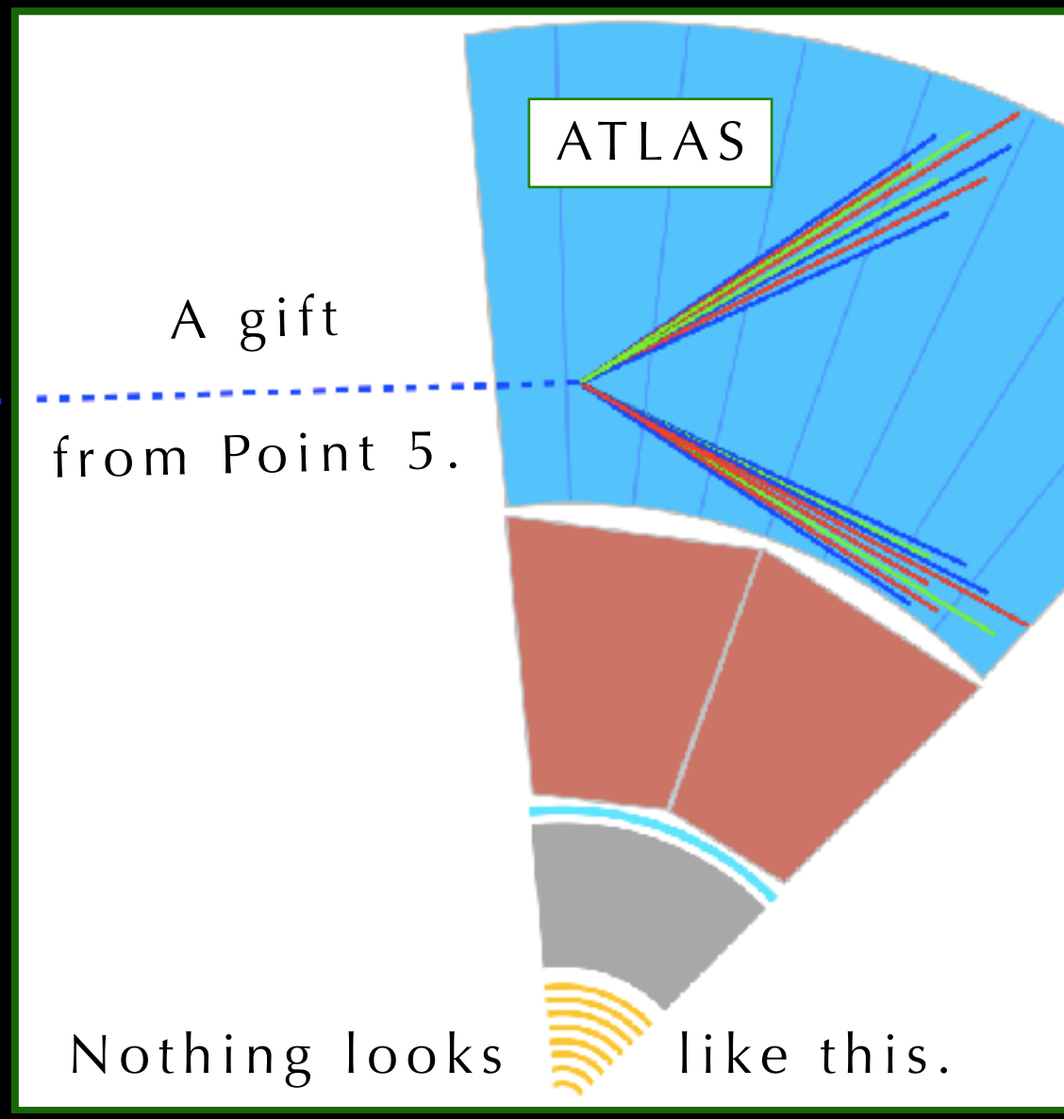
    - Remember that the LHC is our only good source of Higgses, Ws, etc., for a very long time.



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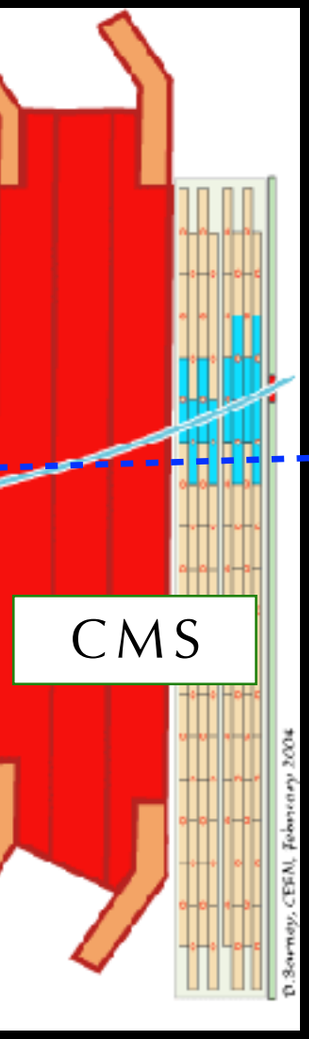

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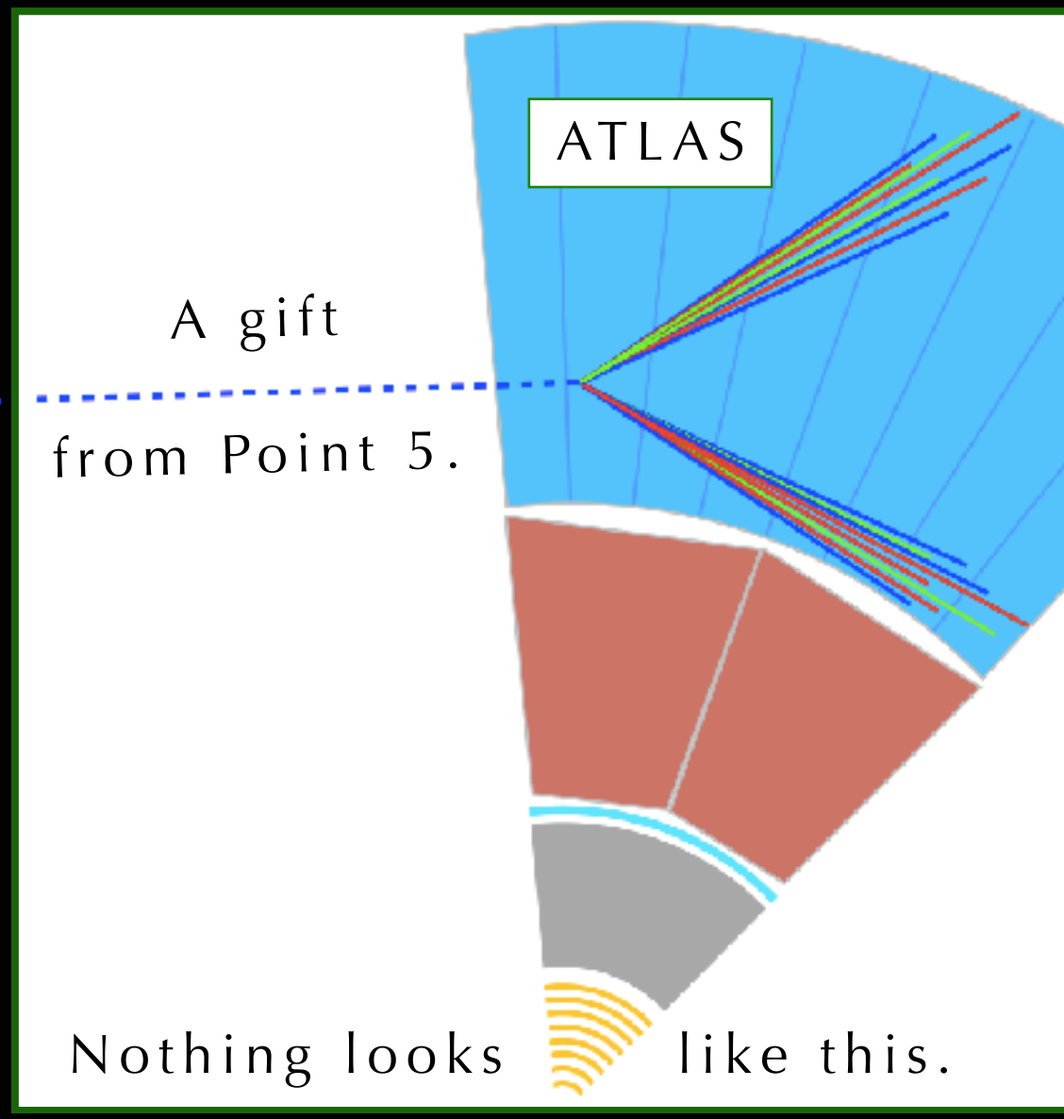

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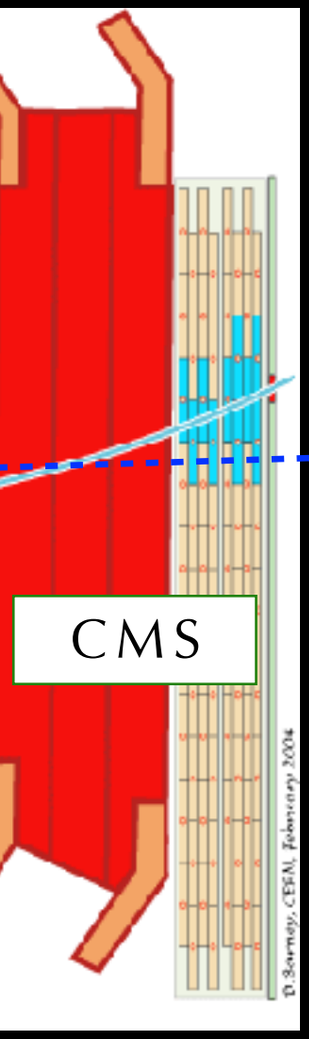

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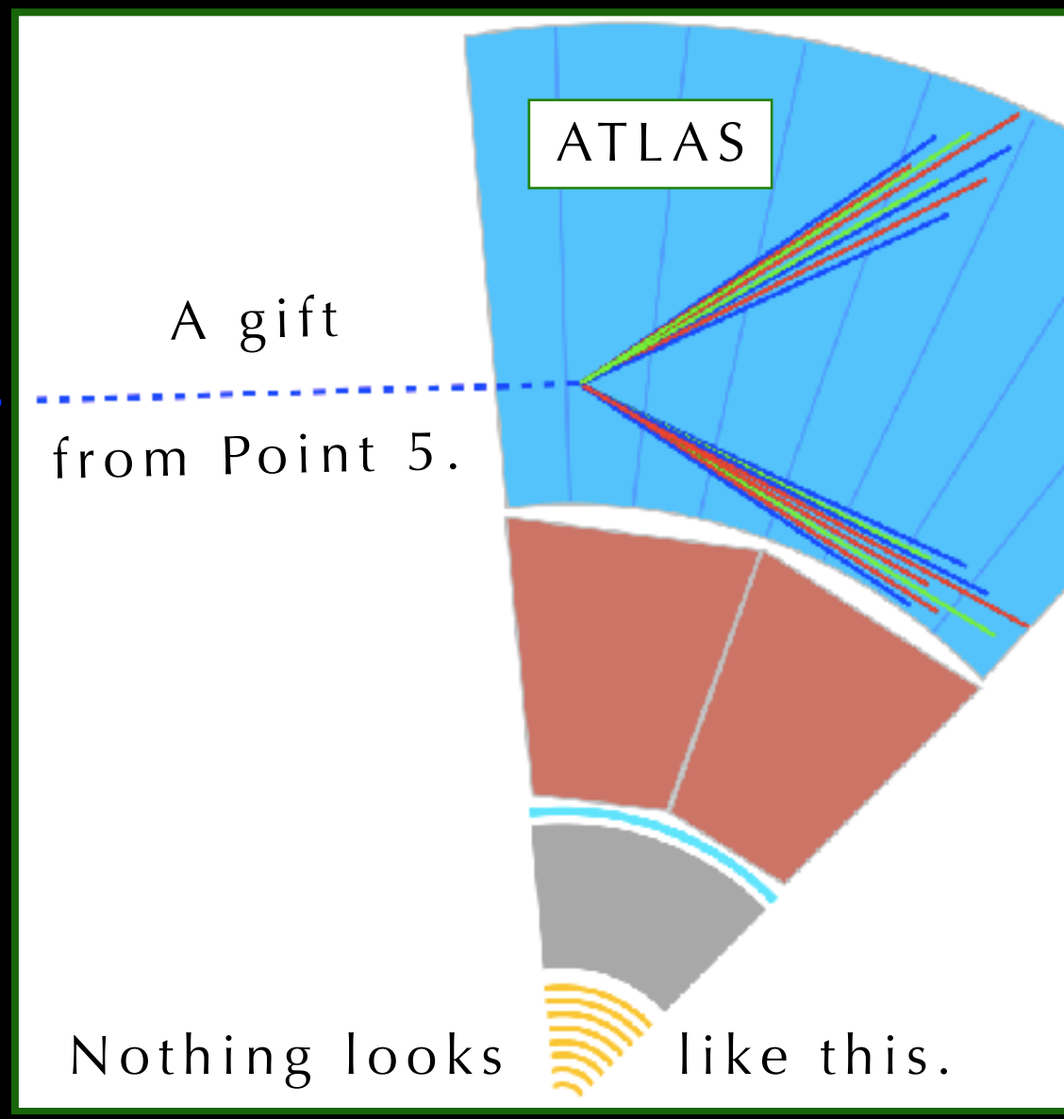

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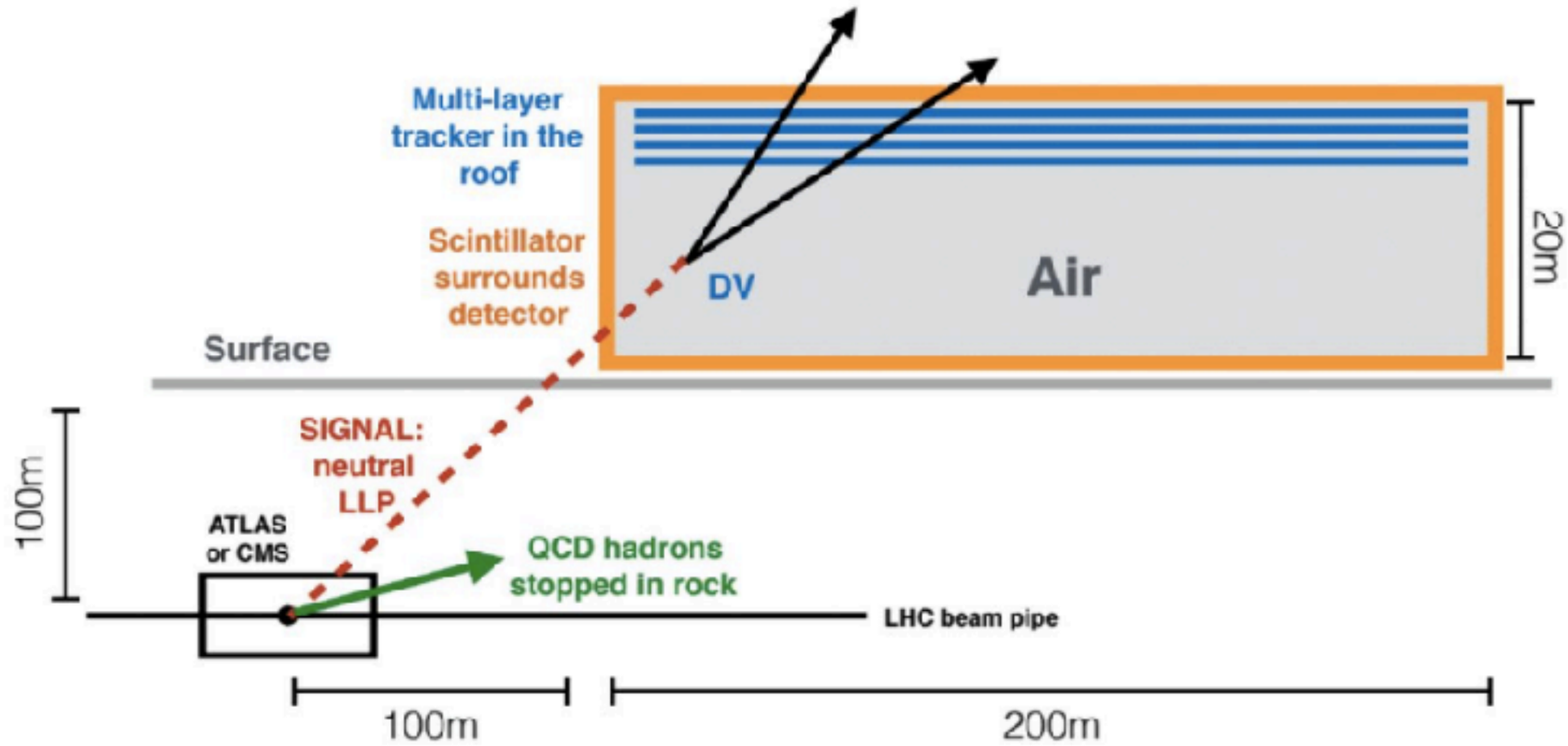
Meade, Nussinov, Papucci, Volansky mentioned this in passing in 2009

MATHUSLA: Ultra-long-lived particles

Letter of Intent (July 2018): https://inspirehep.net/record/1685035

Detector design

Simple concept: effectively just a large (mostly empty) box to enclose displaced vertices



Talk by Mason Proffitt from May 2018

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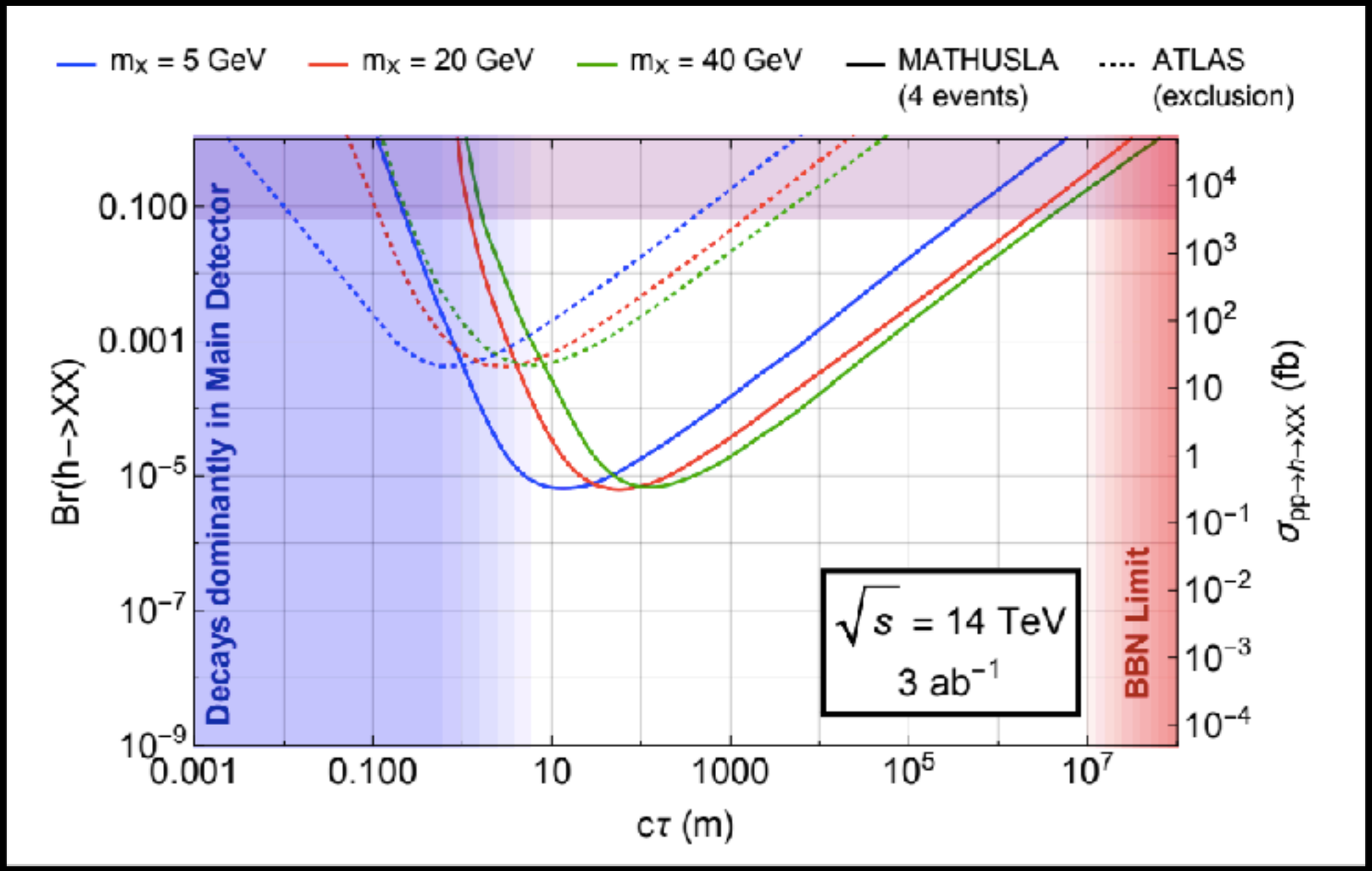
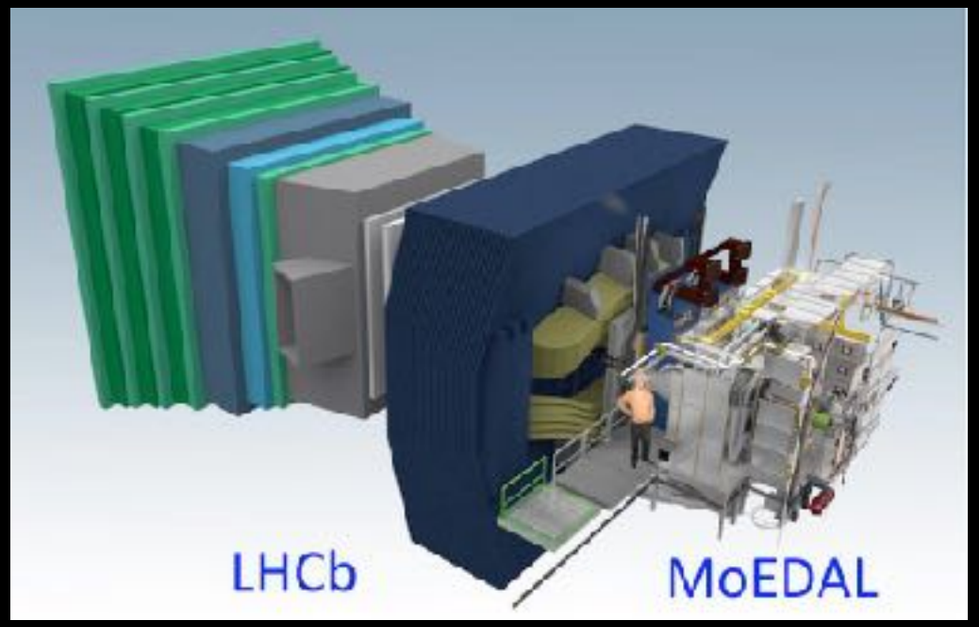
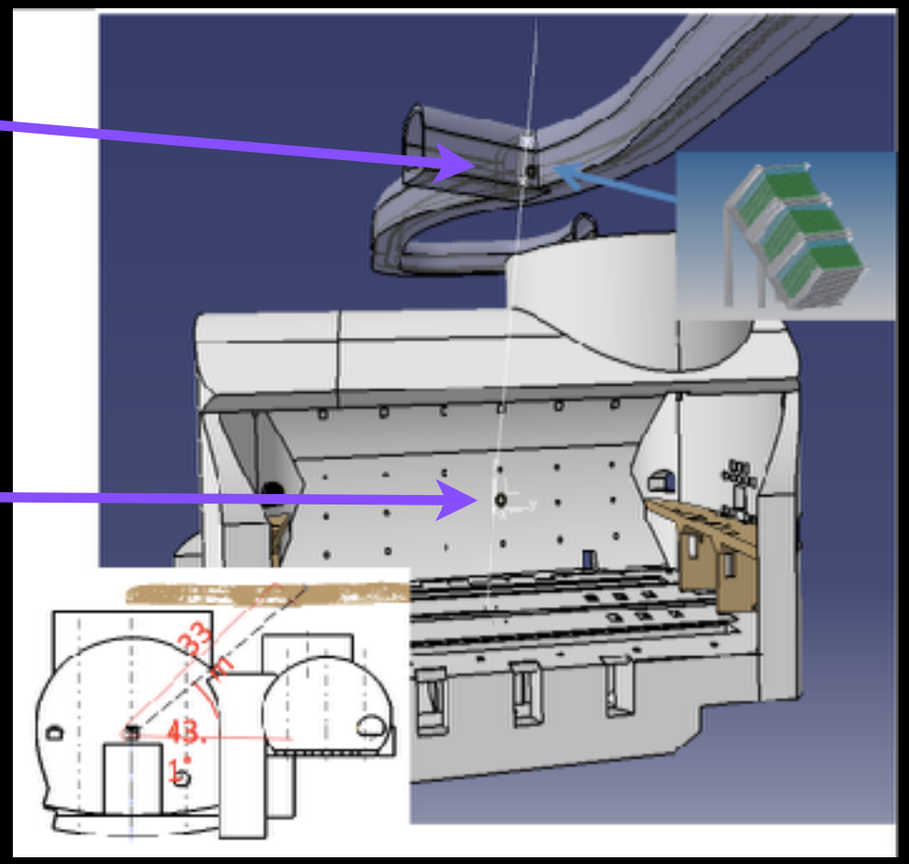


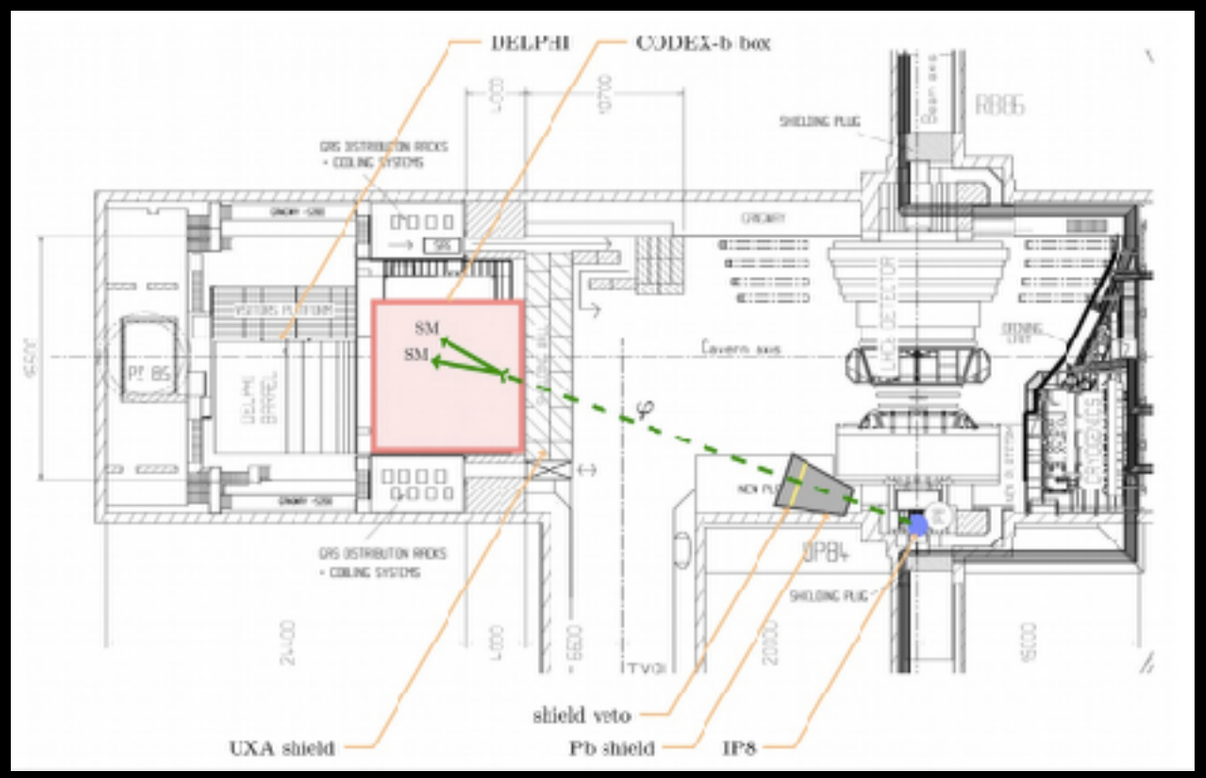
MATHUSLA physics case: arXiv:1806.07396

Additionally a whole host of other dedicated detectors for LLPs either existing or proposed — MoEDAL, MilliQan, FASER, Codex-b — and existing or planned experiments that are sensitive to similar long-lived physics — NA62, SeaQuest, SHiP, others



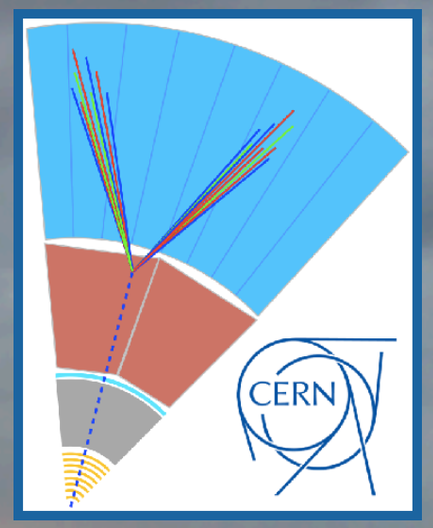
CODEX-b: 20m from LHCb IP
behind 3m of concrete





FASER: Service tunnel TI18,
~400m away from ATLAS IP

LHC Long-Lived Particle Community



Upcoming workshop

Searching for long-lived particles at the LHC:
Fourth workshop of the LHC LLP Community

23-25 October 2018 — Nikhef — Amsterdam

https://indico.cern.ch/e/LHC_LLP_October_2018

Join the CERN egroup: lhc-llp

photo by M.Borsato

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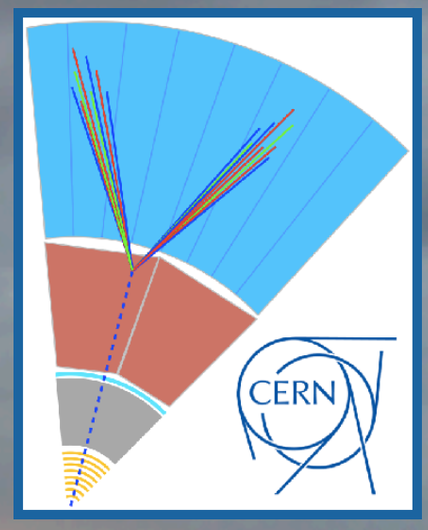

Everything in this talk — and more — is discussed at length at the LHC LLP Community workshops and in the forthcoming white paper (public in November)

The only thing we're missing is *your* voice and ideas; join us!

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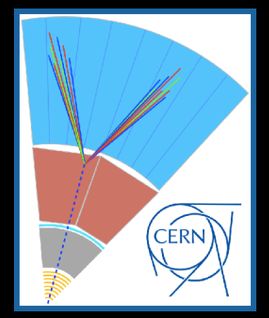
Conclusions



Discoveries could be just around the corner

- LLP signatures are moving from the edges of our research programs in ATLAS, CMS, and LHCb — as well as inspiring dedicated detectors near the main LHC interaction points — to benefit from a more coordinated effort to identify uncovered realms of potential discovery

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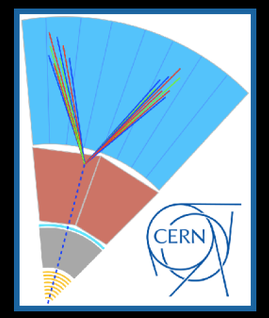

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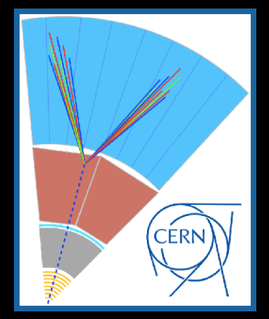

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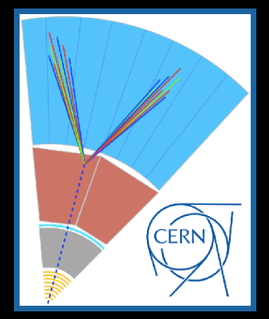

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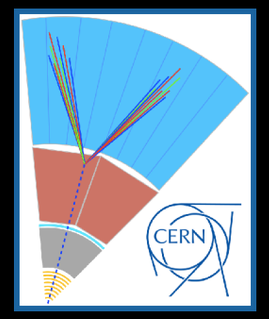

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  - We endeavor to reduce this chance to as small as possible

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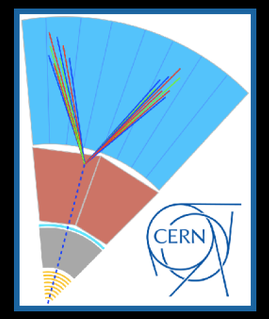

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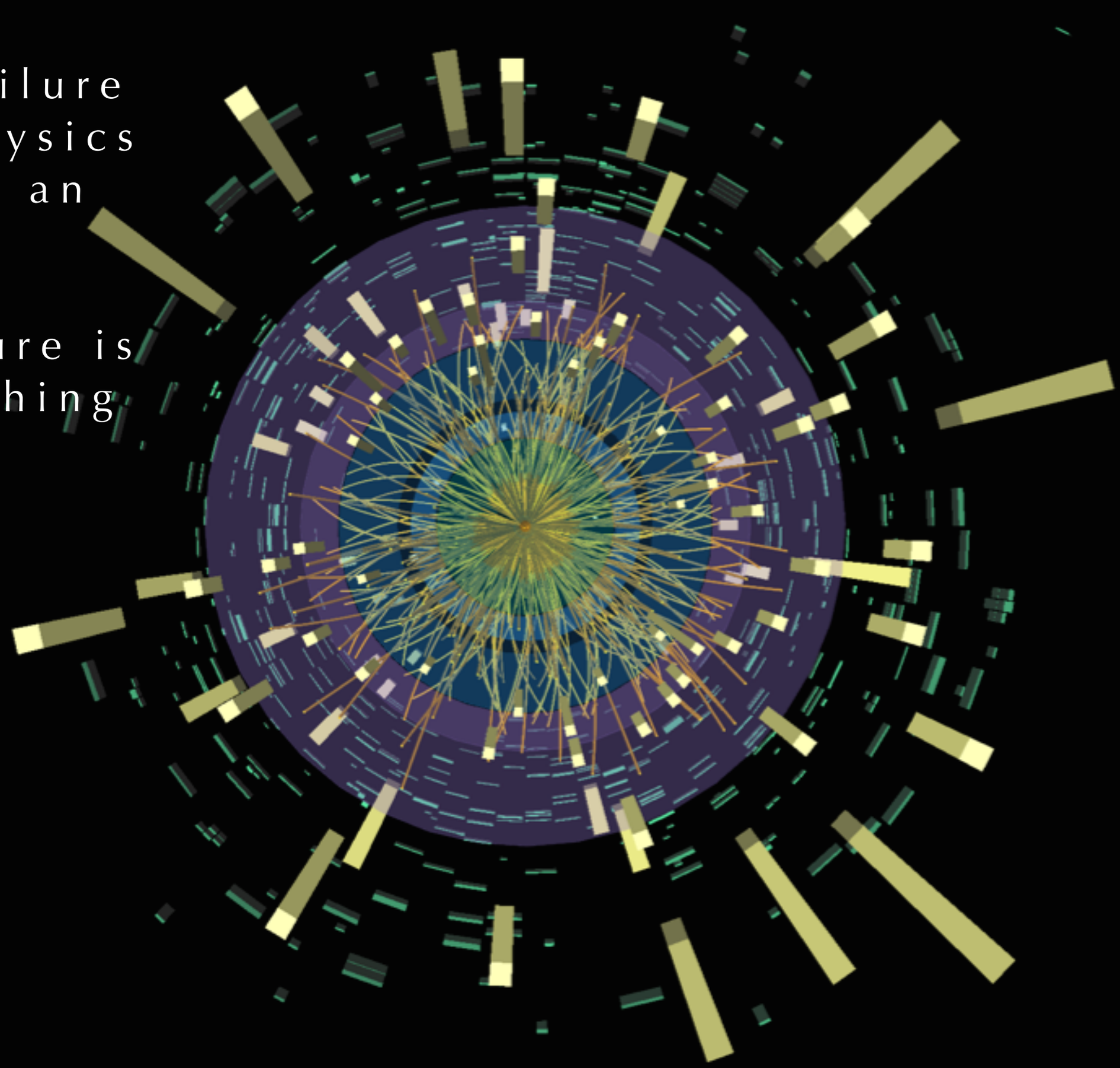
A critical examination of LLP searches is *vital* to map the future of the LHC's research program!

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

The only failure is to stop searching

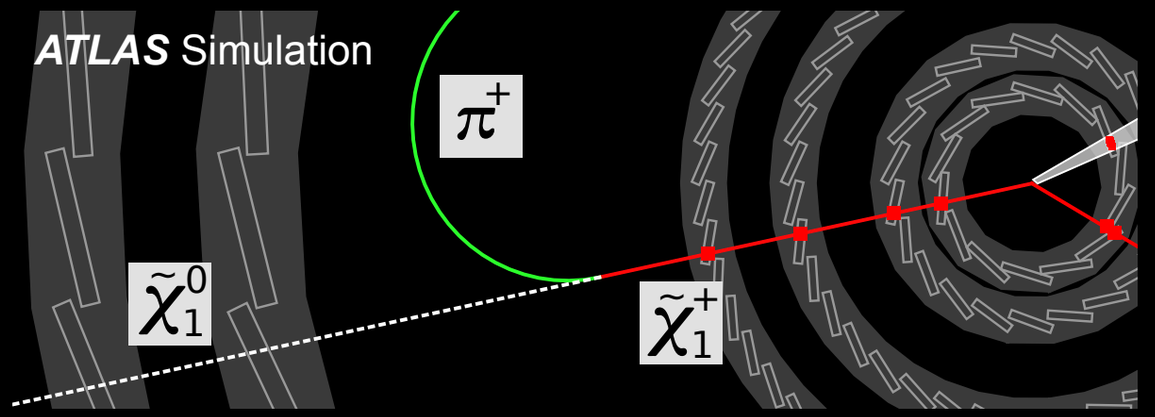


James Beacham
@jbbeacham

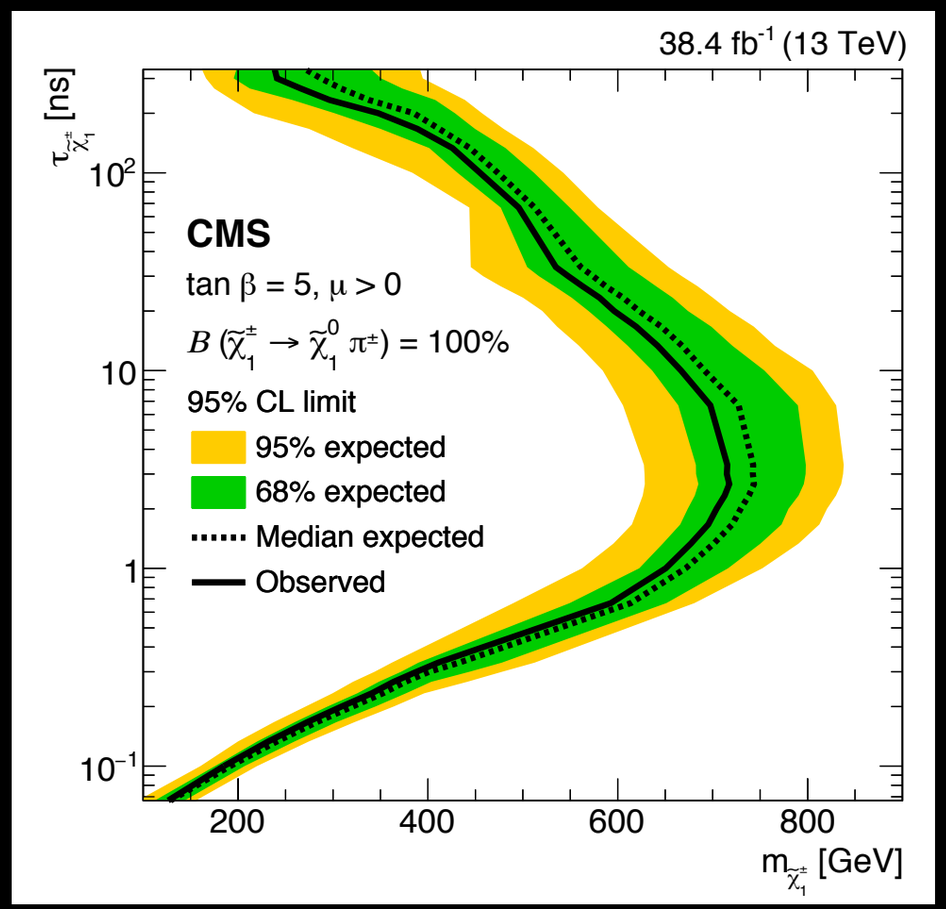
Charged LLPs in the inner detector

Disappearing tracks

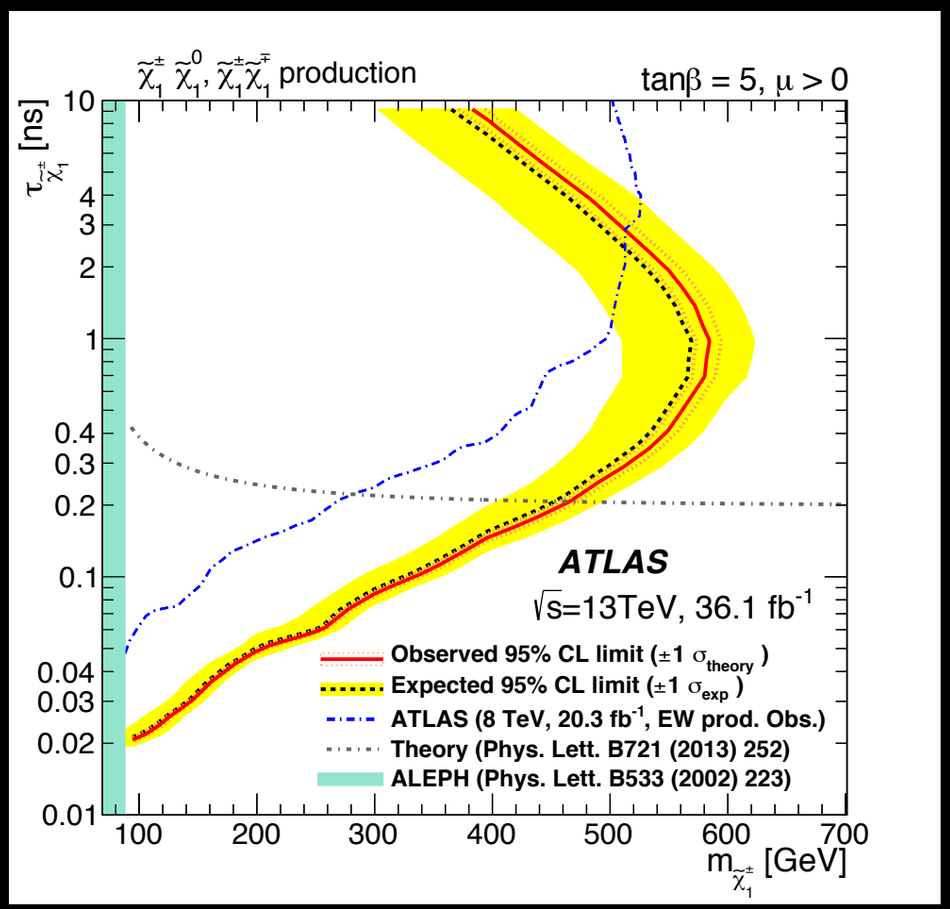
- BSM LLP is a charged particle that decays to a very soft SM particle and a neutral particle that escapes the detector
- Signature is a track with too few hits to be considered a standard track — a tracklet



CMS: JHEP 08 (2018) 016



ATLAS: JHEP 06 (2018) 022



Proposed tracking upgrades for the HL-LHC era will likely improve sensitivity to lower lifetimes

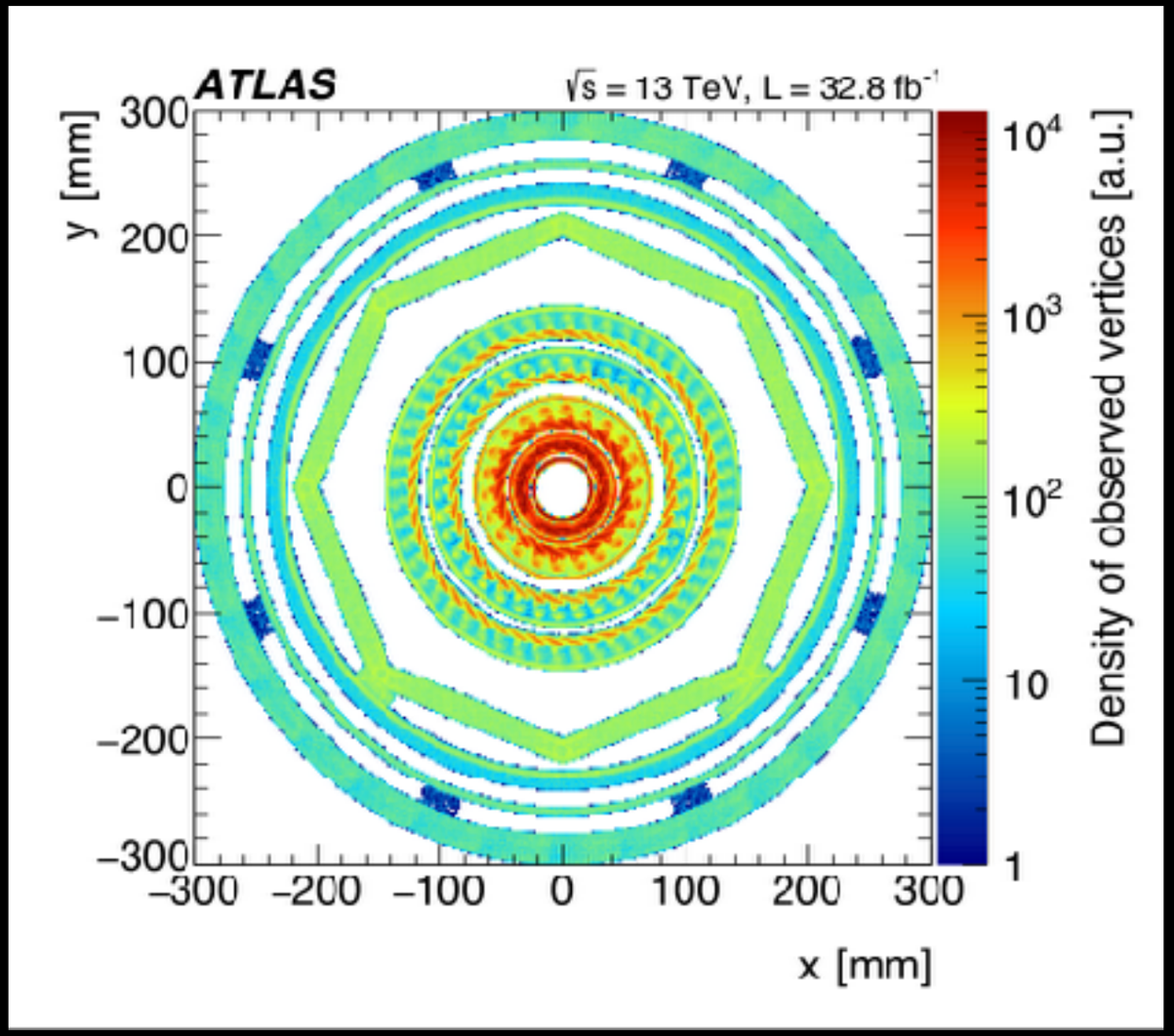
Single displaced vertex in the inner detector

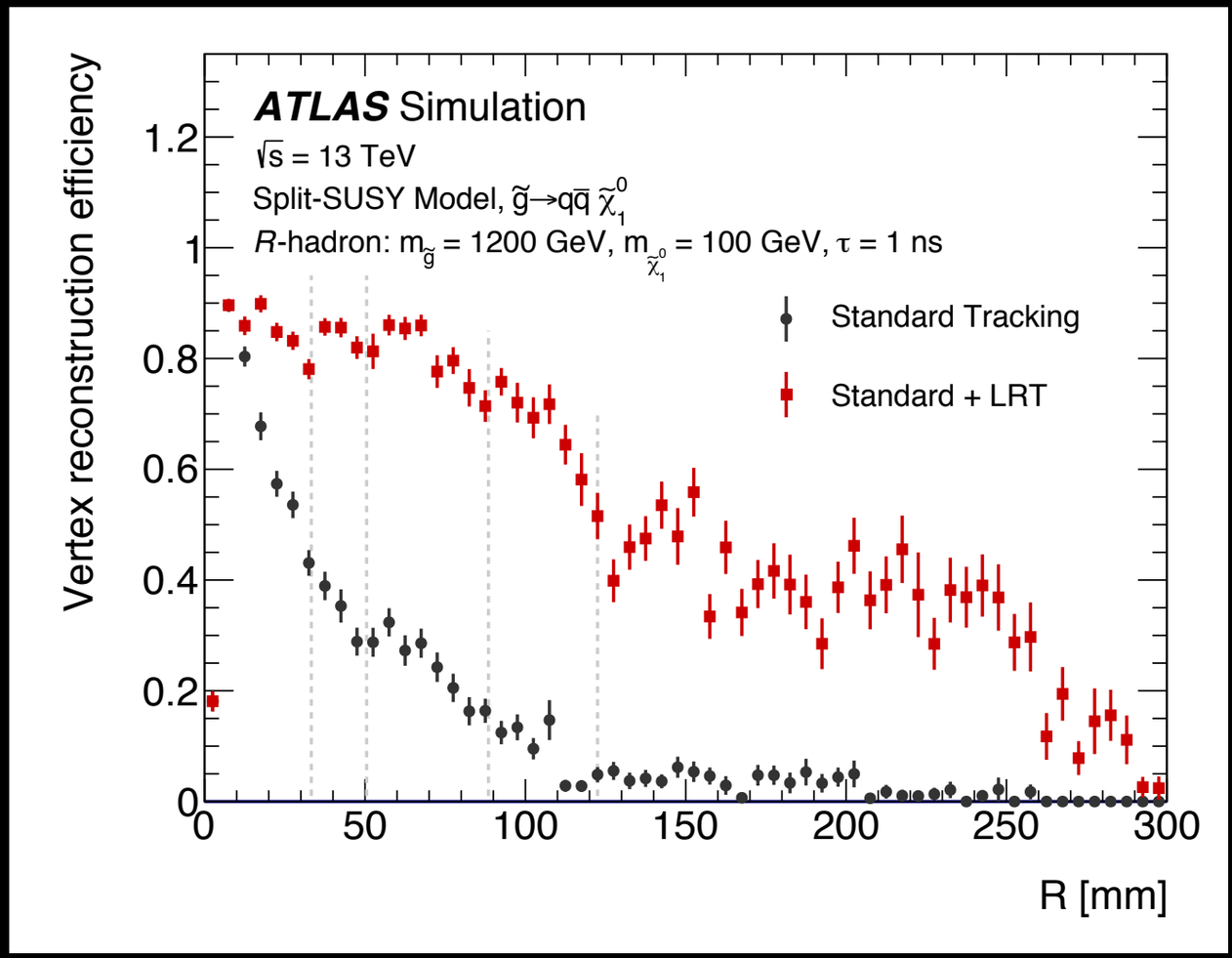
ATLAS search targeting events with one displaced vertex in the inner detector with five tracks plus a large amount of missing energy

- Uses ATLAS large-radius tracking (LRT)
- Many supplementary efficiency plots provided as auxiliary material

PRD 97, 052012

Auxiliary: SUSY-2016-08

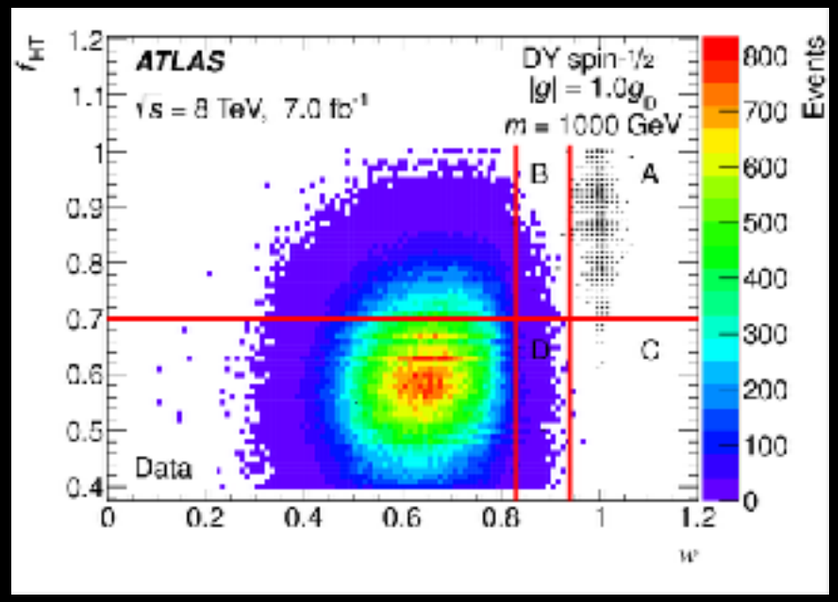




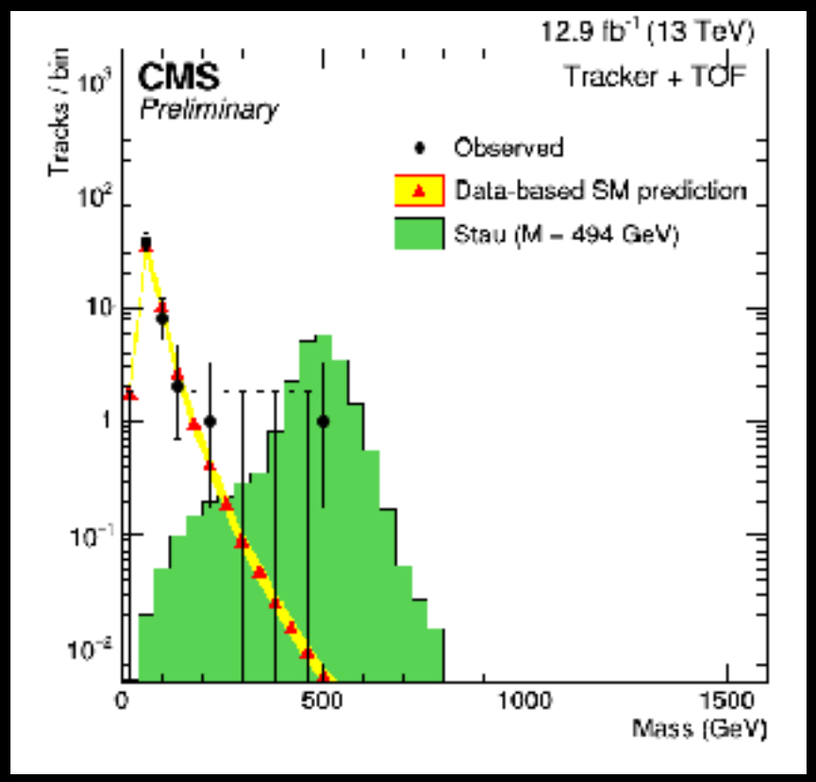
Charged LLPs throughout the detector

Heavy, stable charged particles

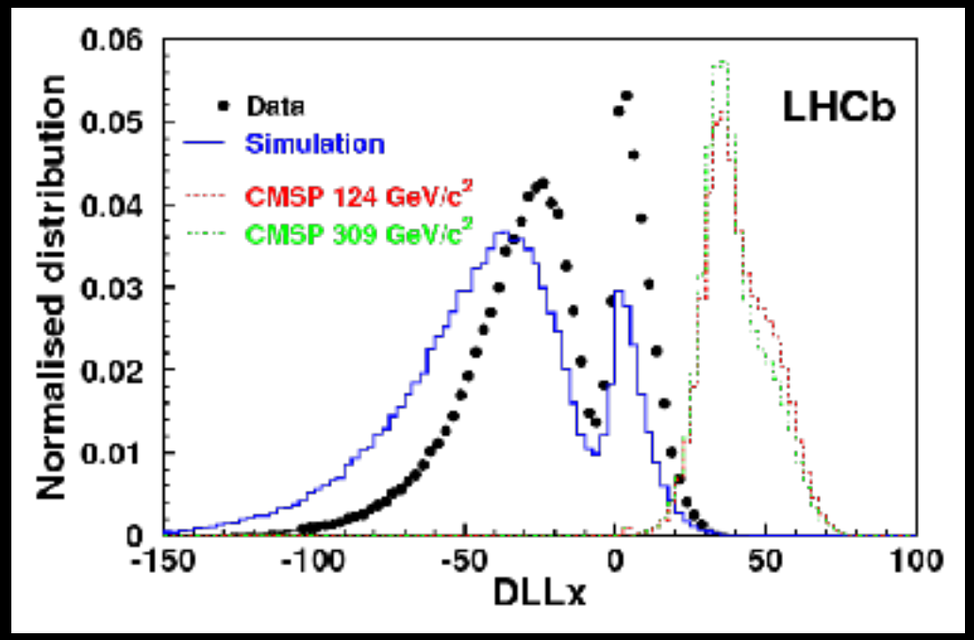
- They propagate through the detector like muons, but leave behind a very non-muon-like signature
- Can move much at speeds much slower than the speed of light or leave high ionization
- ID them via atypical ways that the charged particle interacts with the detector material



ATLAS [PRD 93, 052009 (2016)] search for high electric charge objects such as monopoles



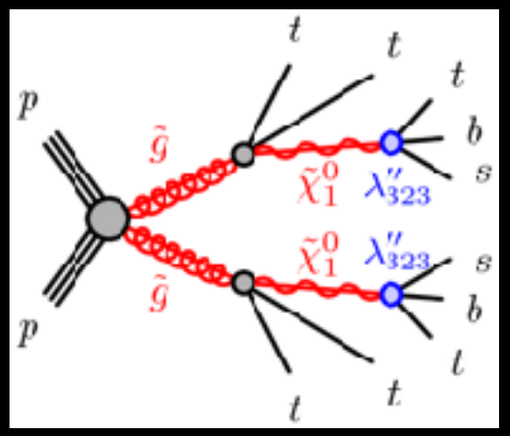
CMS [CMS-EXO-16-036] — exploiting time of flight discrimination using muon system and increased energy loss in silicon tracker



LHCb [EPJC (2015) 75: 595] — utilizing an estimator of the absence of Cherenkov radiation in RICH detectors

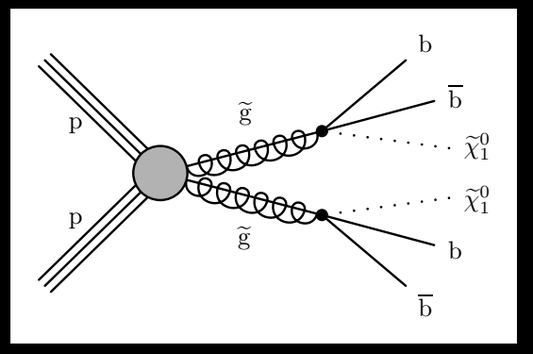
Getting-close-to-covered LLP realms

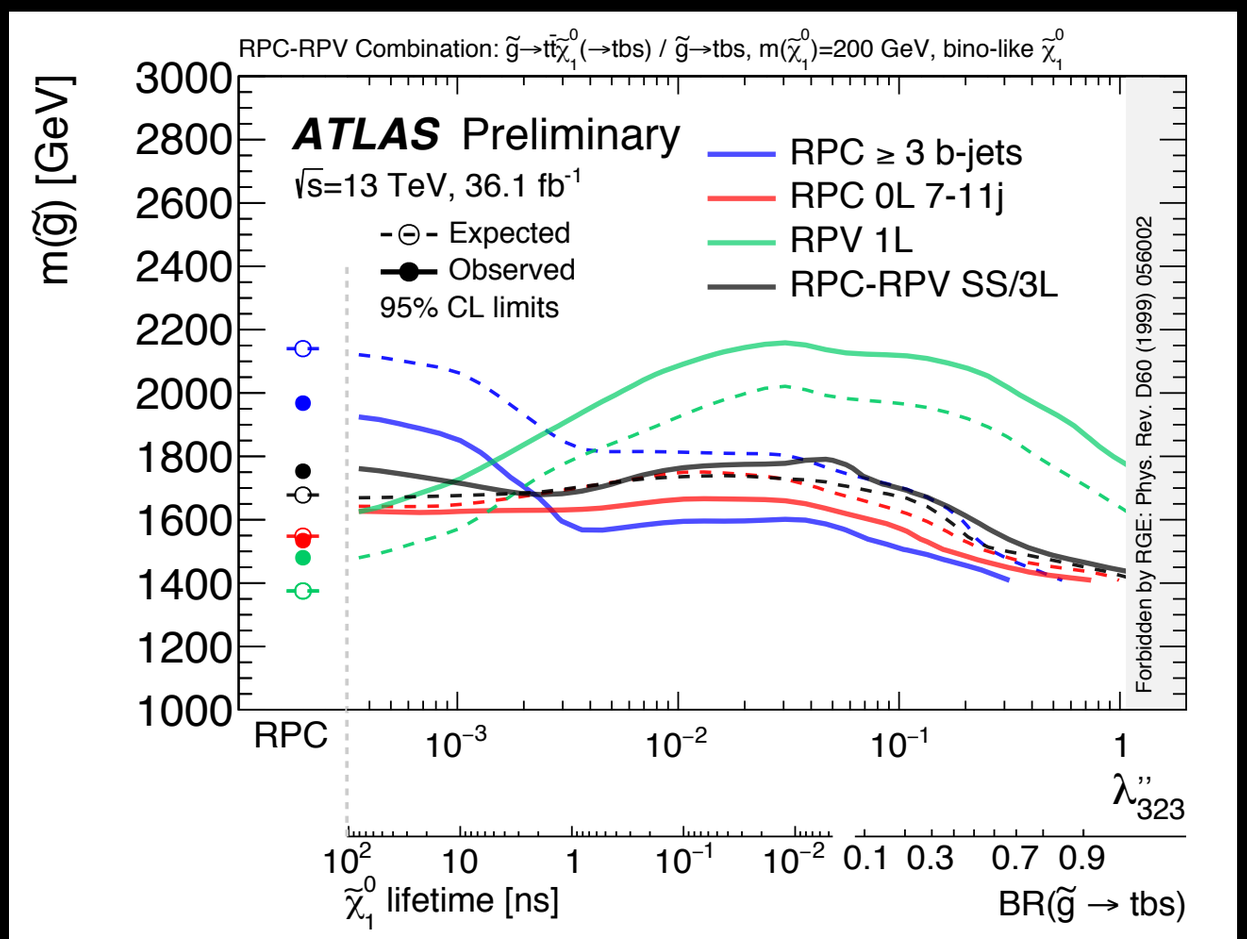
Connecting results of searches for promptly-decaying new particles and LLPs

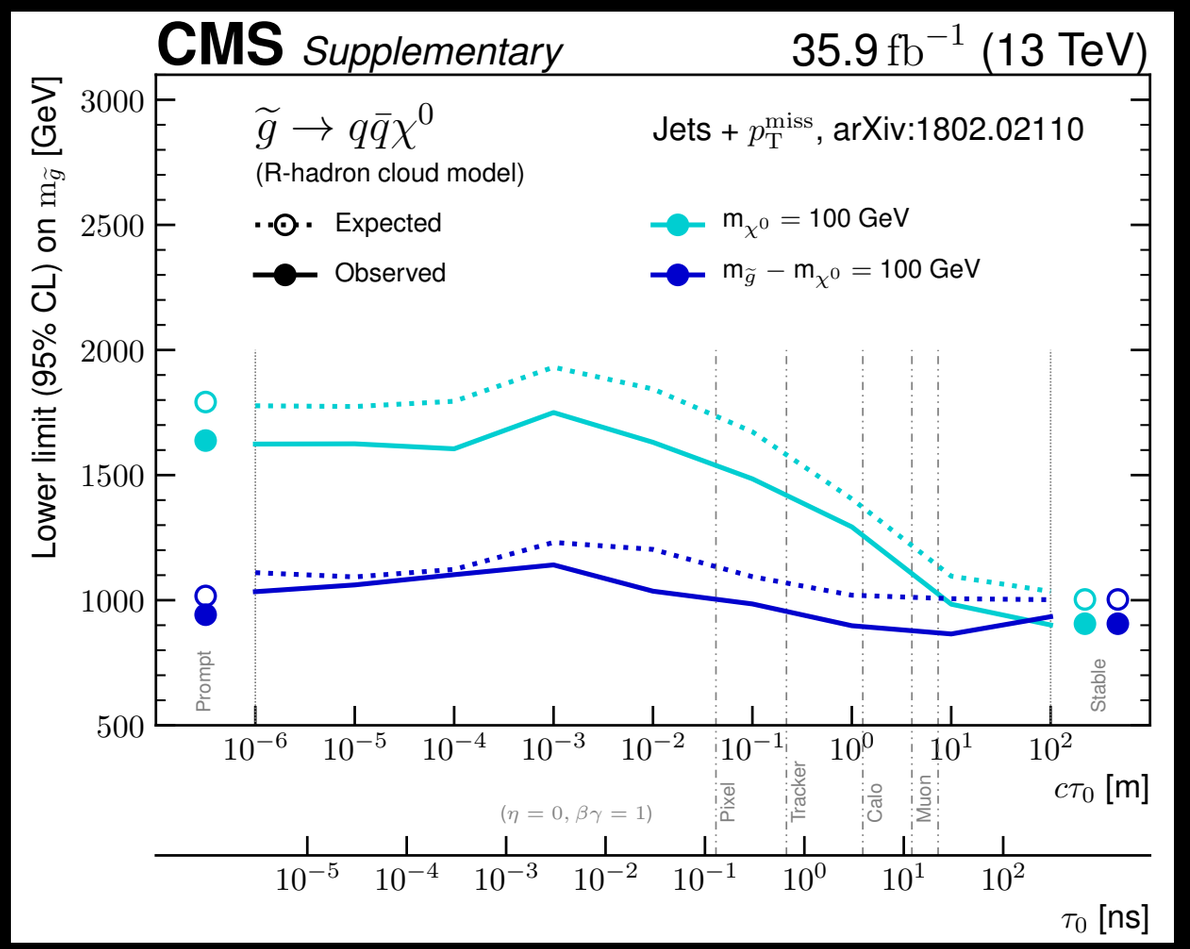


ATLAS recently did a dedicated re-interpretation for a few RPV-meets-RPC searches:
ATLAS-CONF-2018-003
[Karri Folan DiPetrillo talk]

CMS also did something similar in the context of a SUSY search for jets + missing energy:
JHEP 05 (2018) 025



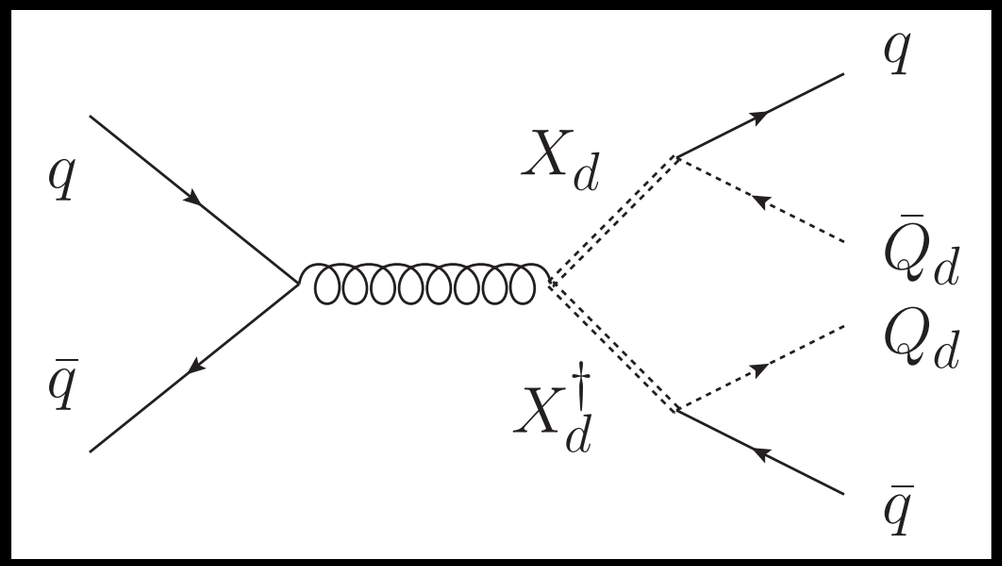


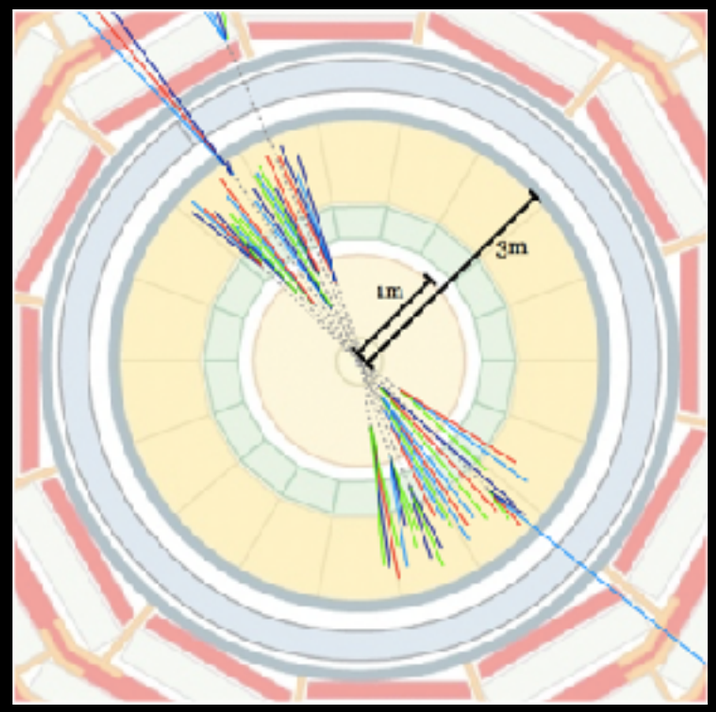


Starting-to-be-addressed LLP realms

Atypical jets and jets with non-standard tracks

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





JHEP (2015) 2015: 59

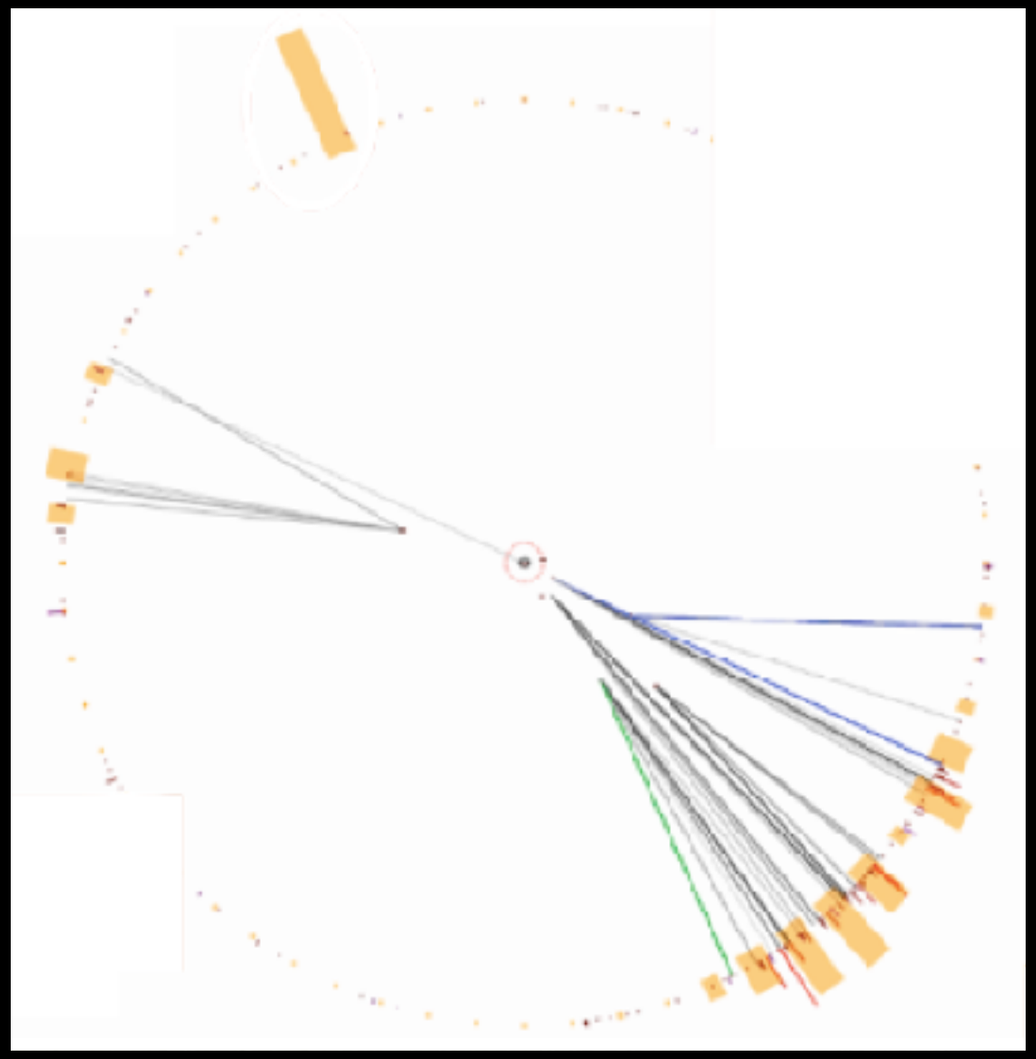
Dark QCD
—> dark quarks
—> hadronization into dark mesons in the hidden sector, some of which eventually decay to the SM
—> dark pions w/variable lifetimes
—> jets w/multiple displaced vertices / tracks in a single jet or event

Uncovered LLP realms

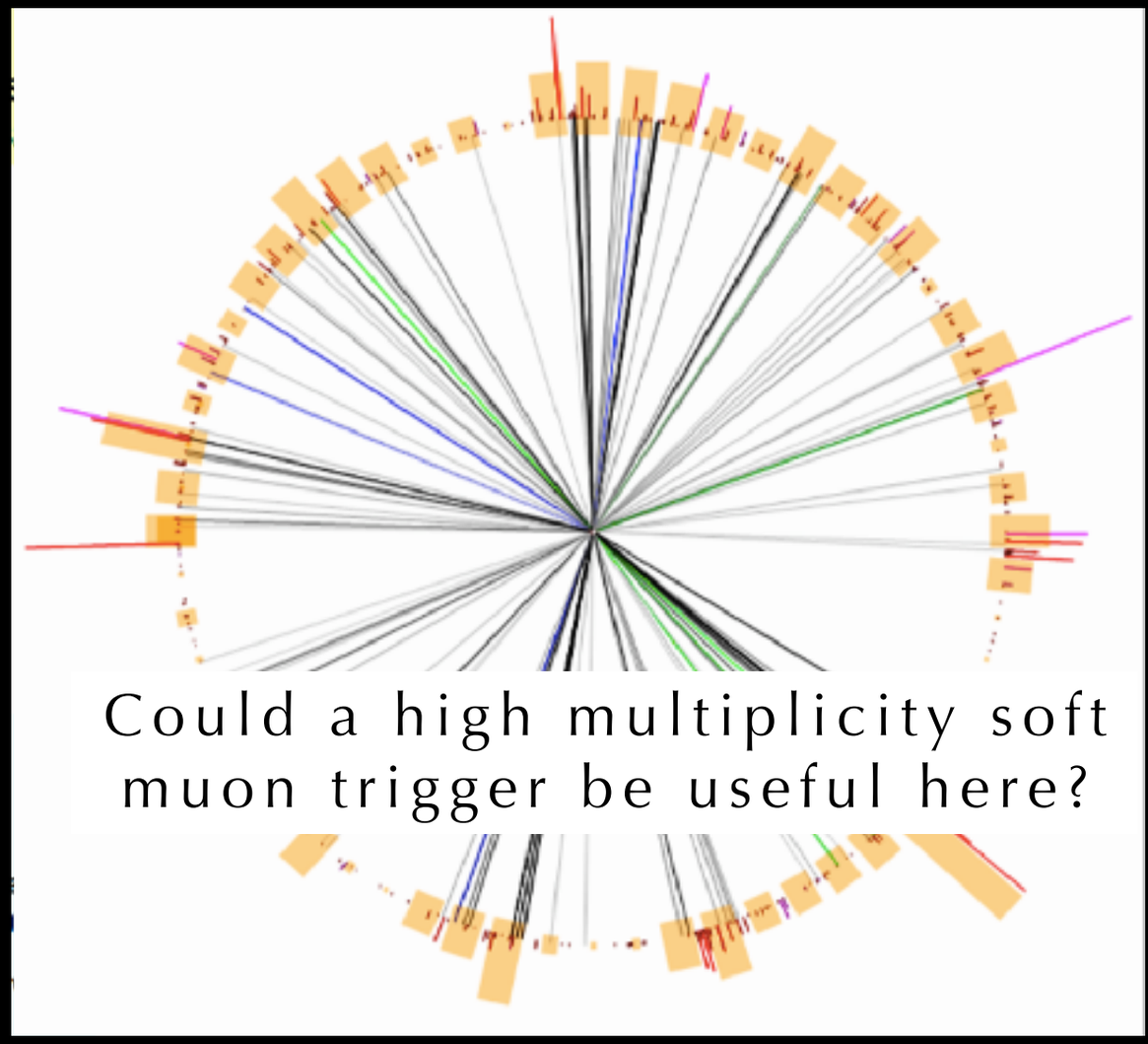
How to interpolate between these two regimes?

- What's the phenomenology?

Emerging jets —
JHEP (2015) 2015: 59



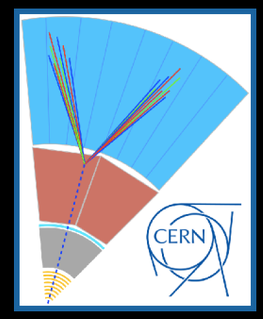
SUEP —
JHEP (2017) 2017: 76



Could a high multiplicity soft muon trigger be useful here?

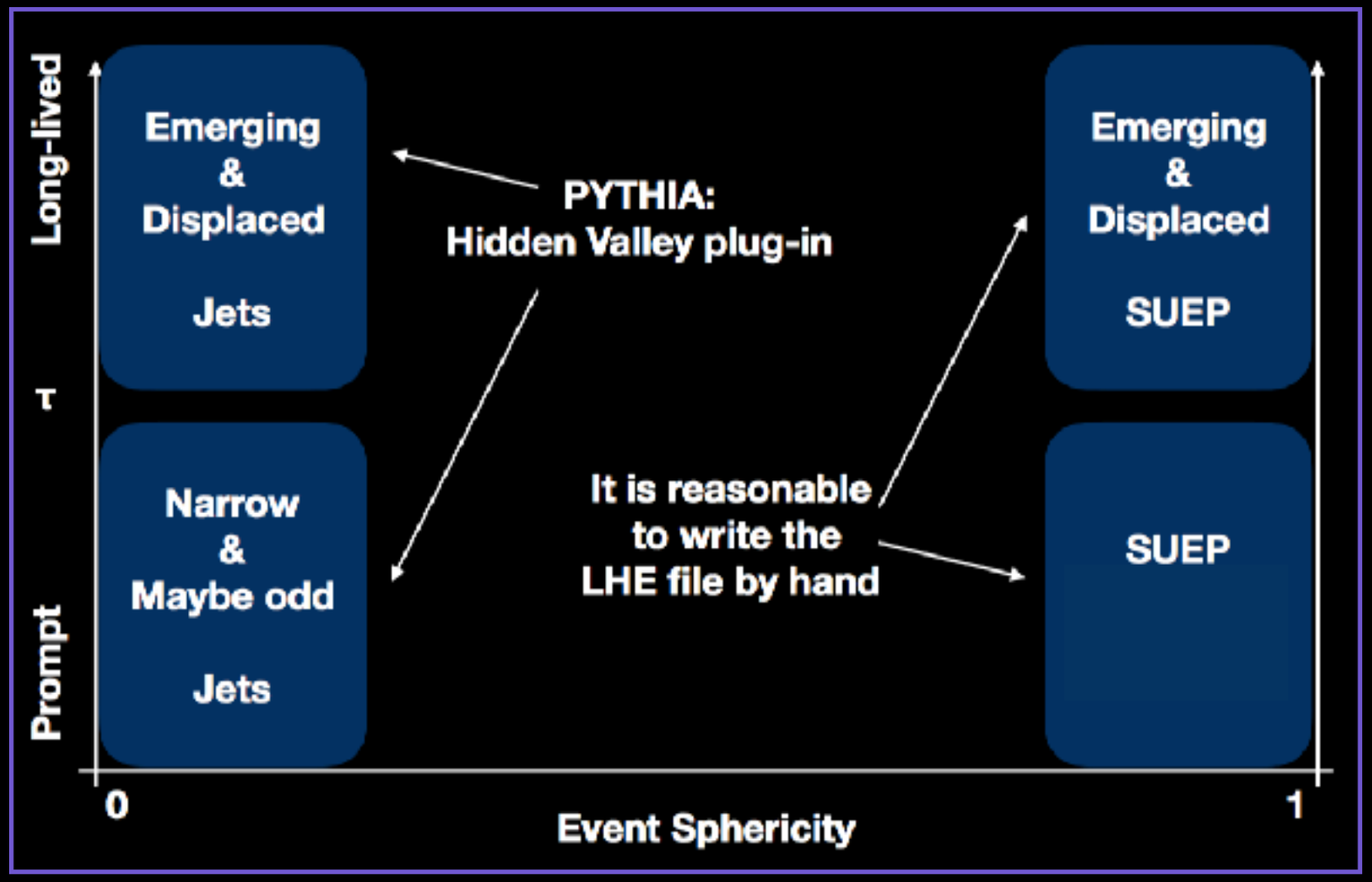
Images by M. Strassler [e.g., a talk from 2007]

Uncovered LLP 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*

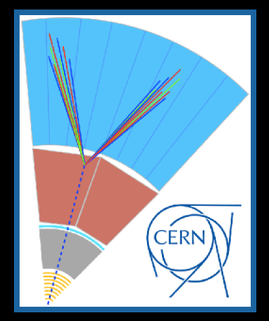


Dark showers working group (Knapen, Shelton, Scholtz, Stolarski, Linthorne, Freytsis, Reece, Cesarotti, et al) began investigating this in earnest last year — many unknowns w.r.t. phenomenology resulting from any of the methods used for any of these regimes!
[Summary from Trieste]

- How do we model these?

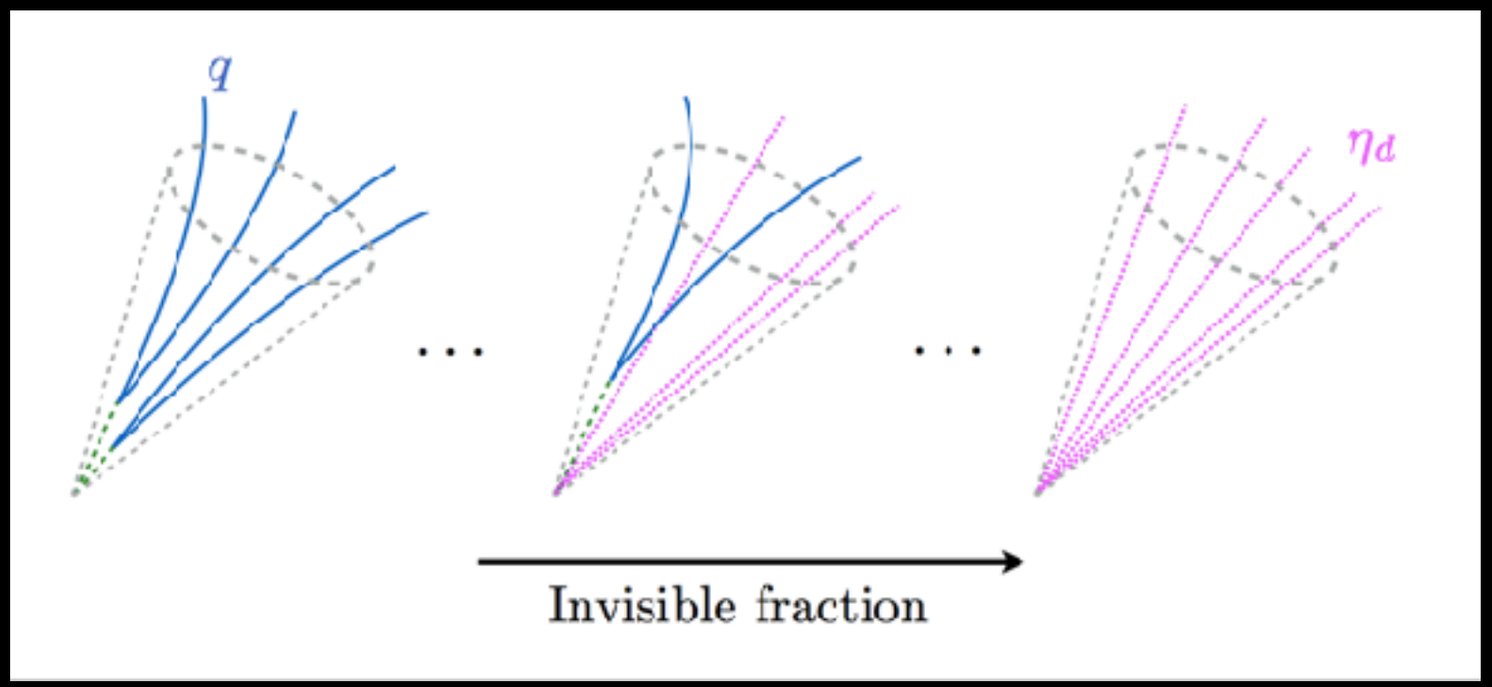
- Does it make sense to interpolate some key distributions between the edge cases and generate events based upon these?
- Strassler: "Has anyone even tried to validate the Pythia Hidden Valley module?" [Talk at our CERN workshop in May 2018]
- Perhaps displaced-vertex gun approach would simply work best

Uncovered LLP 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

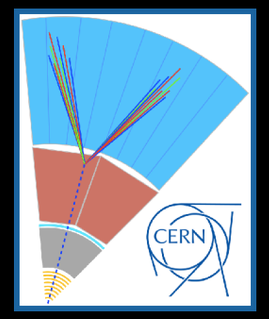


Talk by Mishra-Sharma at Trieste LHC LLP Workshop

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 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

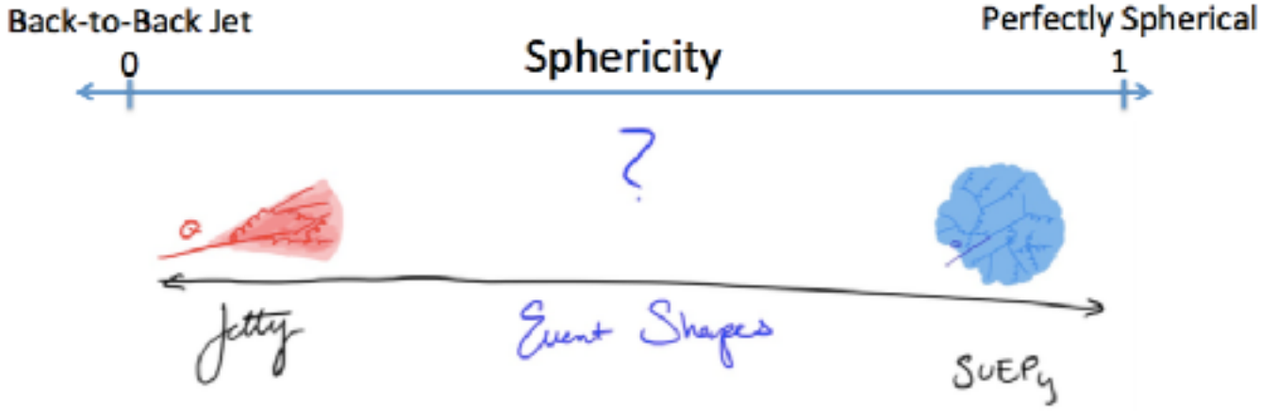
- Toy to build intuition for SUEP-to-Jet problem
- Extra finite 5th dimension (x^μ, z)
- Warp space with $\Lambda_5 < 0 \rightarrow$ AdS (RS1)
- Boundary on interval: UV, IR cutoffs
- AdS/CFT to calculate hidden sector dynamics

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

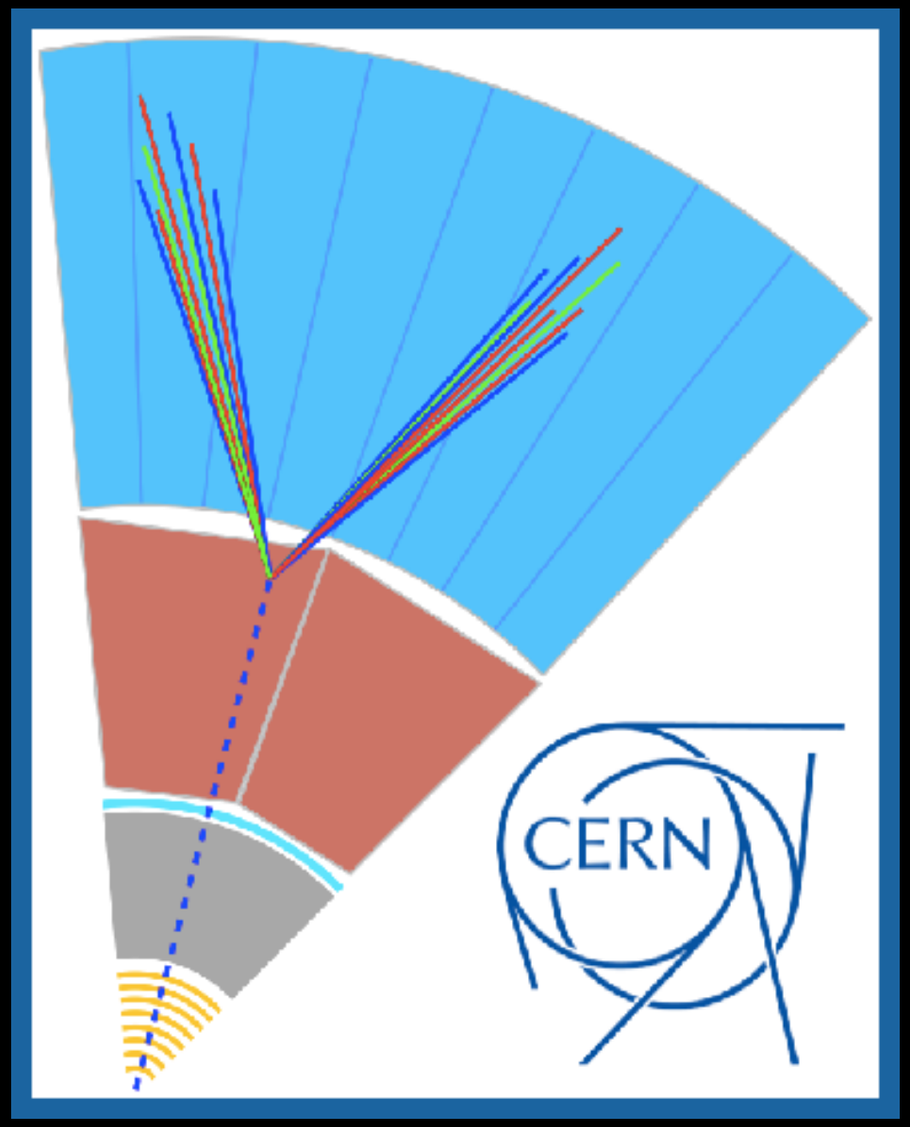
C. Cesarotti talk in Trieste

Promising way to interpolate pheno between the two regimes

Sphericity of KK Modes



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:
LHC_LLP_May_2018

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

Join the CERN egroup: lhc-llp

Website coming soon: cern.ch/longlivedparticles