Experimental Coverage: Overview

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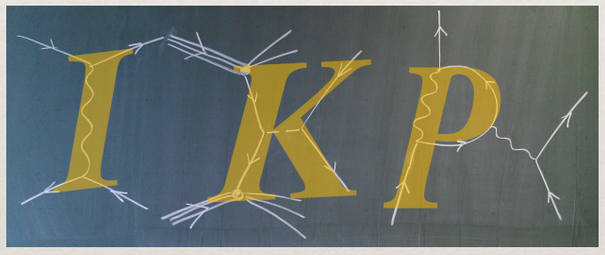

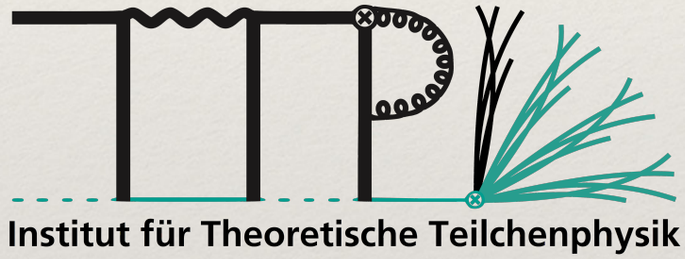

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Contributors : Juliette Alimena, Alberto Escalante del Valle, Philippe Mermod, Antonio Policchio.
Avid readers: Giovanna Cottin, Sascha Mehlhase, <your name> (still time to criticize!)

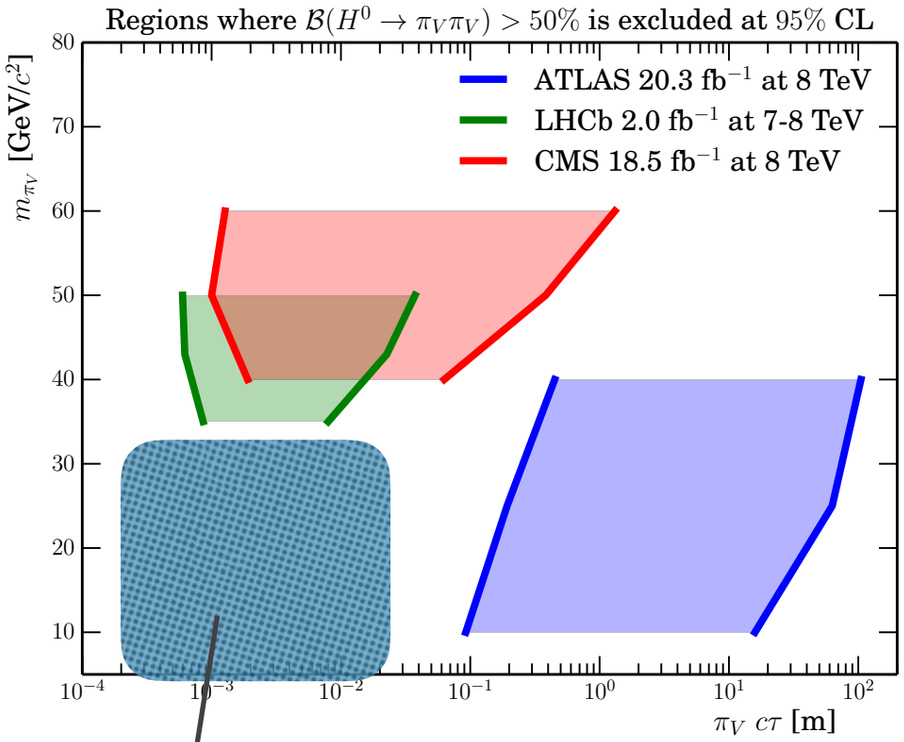
Searches for long-lived particles at the LHC, CERN, 17.05.2018

WG goals

- Original aim: identify the most obvious gaps in coverage of the current studies.
- Byproduct: provide a concise summary of searches, inviting to challenge the shortcomings and caveats.
- Last report: https://indico.cern.ch/event/649760/contributions/2689329/
- Since then: Lot of feedback from Trieste's workshop and additional contributions gave a mature document: many pairs of eyes on it, new plots, nice text, omissions corrected, etc.
- Also, now the backgrounds have their own chapter (thanks to Juliette, Martino and Sascha!).
- Better connection with simplified model chapter.
- Chapter is technically "ready to go", but is always nice to improve things.
- Today: due to time limitations, I will not cover the searches in detail (see yesterday's talks by Jennifer, Steven and Elena) but rather discuss the three open questions:
  - 1) How to better convey the information about a gap in coverage?
  - 2) Can we summarise the search information in table format (with minimal info loss)?
    Helps to connect to simplified models!
  - 3) How to classify the *exotic* signatures (disappearing tracks, emerging jets, out-of-time decays, etc)?

1) Gap information

a) Plot (visual, but model dependent)



Not covered!

Which is the better way to convey the concrete information about the gap in low masses and low lifetimes for displaced jet searches?

b) Bulleted list (concise, but can cause confusion)

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?

c) Short paragraph

1. All-hadronic

The obvious disadvantage of the all-hadronic decay modes is the *lack of sensitivity for low LLP masses* ($m_{LLP} \lesssim 30$ GeV) *and low lifetimes*: ($c\tau < 10$ cm) is hard since the decays in the tracker (and calorimeter) are highly suppressed. This is due to the inclusive jet triggers p_T thresholds. One way out is to *trigger on associated objects* in the events, which is theoretically motivated from Higgs production via VBF and VH, and from mono-X searches for dark matter mediators. Another option is to have either a *quick online reconstruction of hadronic DVs* or *low p_T track identification* that would allow to save the events for offline analysis. Last but not least, *hadronically decaying τ* could profit from the *CMS displaced jet trigger*. Such an option is currently under scrutiny by the CMS collaboration.

2) Summarising the searches

Tables? Any useful?

directly links to WP bibliography

DISPLACED HADRONIC OBJECTS

EXP.	ADD. INFO	TRIGGER	REF	SIMPL. MODEL	COMMENTS
	HCAL	*Cal Ratio*	[182,183]	HAHM / HV	2 DV req.
	MS	*Muon RoI*	[184]	HAHM / HV	2 DV req.
ATLAS	ID	ET > 250 + 5 tracks	[185]	RPV squarks split SUSY GGM (MSSM variants)	
	ID + X	VBF, …	[137]		
					Offline displaced jet tagging
CMS	INCL 8 TEV	HT > 350	[193]	Z'	Reconstructs DV
	INCL 13 TEV	HT > 500	[186]	Z’	No DV requested
LHCB	1 DV	DV	[188]	HV	
	2 DV	DV	[189]	HV	

Can we learn something from this table without specifying the the trigger and event selection strategy?

Should we add / remove columns?

3) Classification

- We started with *standard* final states from prompt searches (hadronic, leptonic, semi-leptonic, photonic) but considering the displaced (not coming from PV) versions.
- Whatever does not fit above : *Other long-lived* signatures (/dev/null).
- The current classification is based on existing searches:
  - Heavy Stable Charged Particles (HSCP)
  - Disappearing Tracks (DT)
  - Stopped Particles (SP)
  - Magnetic Monopoles (HIP)
  - Quirks* (not public search yet)
  - Stable Interacting Massive Particles (SIMPS) [these share phenomenological features with emerging jets]
- Fine, this is a way to classify,…but some of these entries are models, theories or particles, NOT signatures. Also inconsistent with the displaced objets taxonomy.
- Example: A Heavy Stable Charged Particle could decay in the inner detector/tracker (disappearing/kinked track), in the calorimeter and muon chambers (HSCP) or nest in the detector for a while (SP search). One example, 3 names, a signature being confused with the name of a particle.

Heavy Stable Charged Particles (HSCP)

CMS-EXO-12-026, CMS PAS EXO-16-036, CERN-PH-EP-2014-252, CERN-EP-2016-131

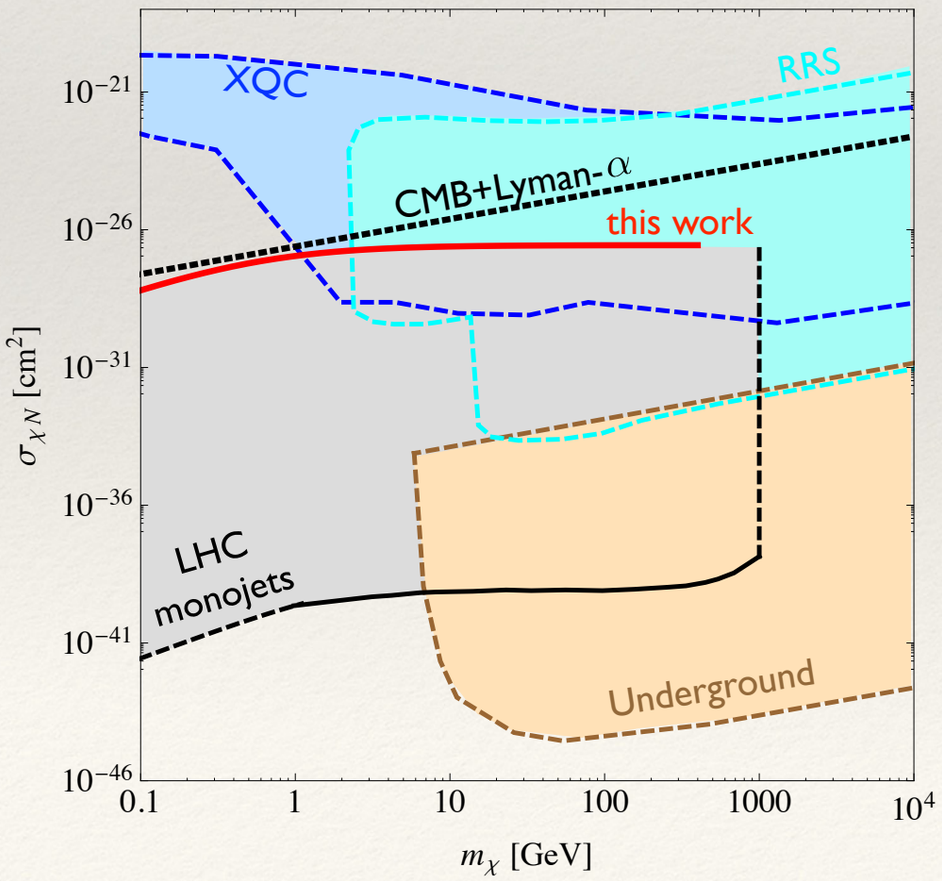
- HSCP searches @ ATLAS, CMS rely on two key properties:
  - $|q| \neq e$: ionization loss (dE/dx) different than SM particles.
  - Large mass -> $\beta = v/c < 1$: longer time-of-flight (TOF) to calorimeters.
    TOF information used optionally (partonic exchange can change q).
- Trigger on single muon or MET + offline "good track" selection.
- Common benchmarks: colored (weak) HSCPs: R-hadrons (sleptons)
- LHCb: no radiation in the ring imaging Cherenkov detector (RICH).
  Requests two OS μ with $m(\mu\mu) > 100$ GeV, $\beta > 0.8$ (muon chamber rec.) + ANN.

Stopped particles (SP)

- HSCP with very low kinetic energy gets stopped (most likely in the dense calorimeters) and decays when no collisions take place (out-of-time decays).
- Refs: CERN-PH-EP-2013-061, CMS PAS EXO-16-004, CMS PAS EXO-17-004.
- Dedicated trigger selecting crossings without nearby bunches + hard jet. ATLAS also requests $|h|<1.3$ and MET > 50 GeV.
- The action happens in the muon systems, as the Stopped Particles make themselves cozy in the calorimeter.
- Main bgds: cosmic muons, beam halos (protons interacting with beampipe).

Strongly Interacting Massive Particles (SIMPs)

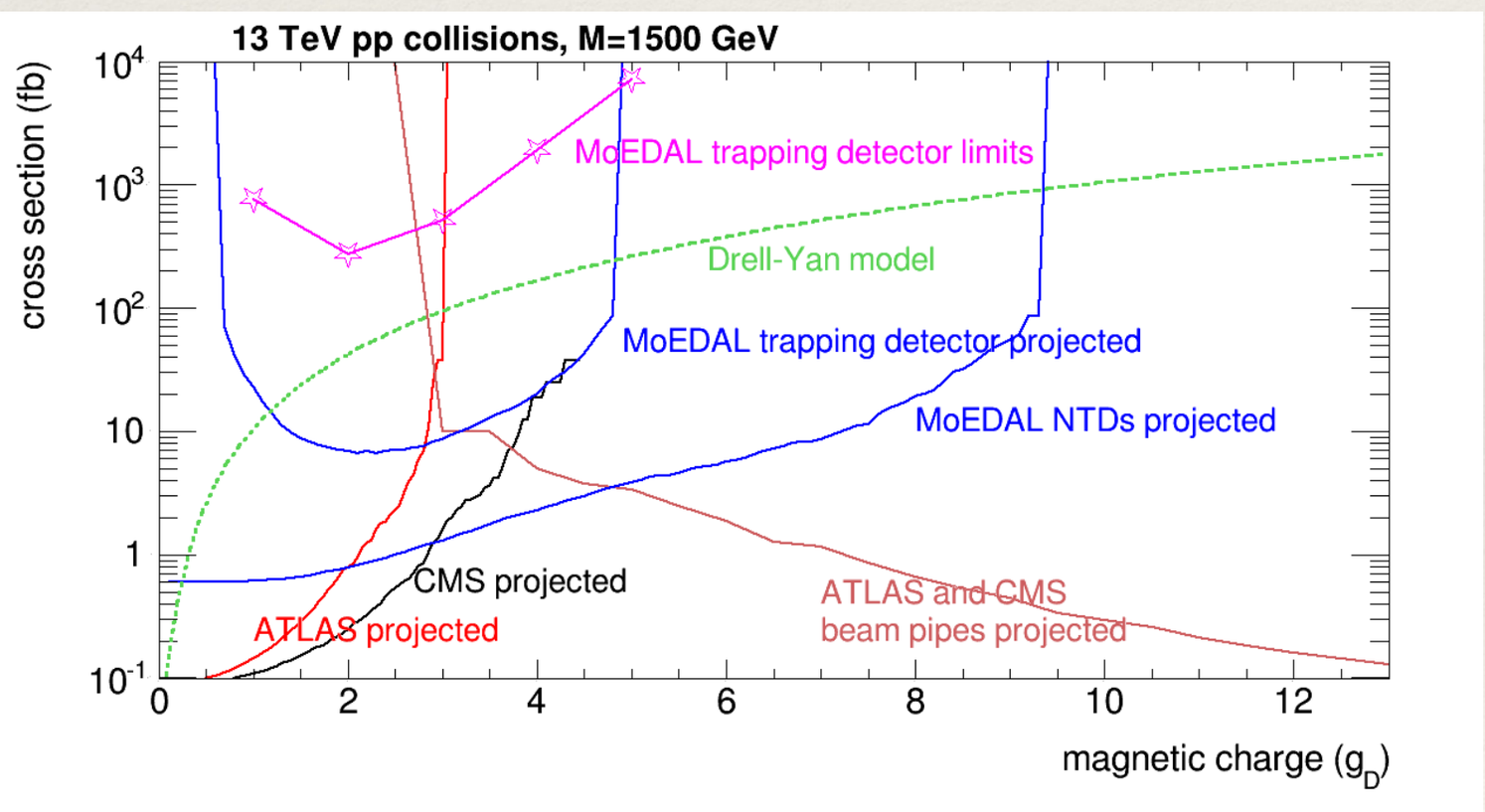
- Based on: Daci, de Bruyn, Lowette, Tytgat, Zaldivar, 1503.05505.
- Motivated by self-interacting DM (missing satellites, core-cusp).
- χ colored, simplified model with qq -> M -> χ $\bar{\chi}$, M ~ 1 GeV.



- Signature: HCAL deposit without associated track (2 trackless jets!). Pheno similar to emerging jets.
- Trick: small charged energy fraction.
- Analysis underway by CMS! (see talks by S. Lowette @ April 2017 workshop and A. de Roeck@Trieste.)

Magnetic Monopoles (MM)

- ATLAS [CERN-PH-EP-2015-174] looks for highly-ionising particles (HIPs).
  HIPs encompass a variety of BSM scenarios: magnetic monopoles, stable microscopic black holes, dyons, etc.
  Focus on MM for the sake of the argument, results are recastable.



Contributed by P. Mermod.

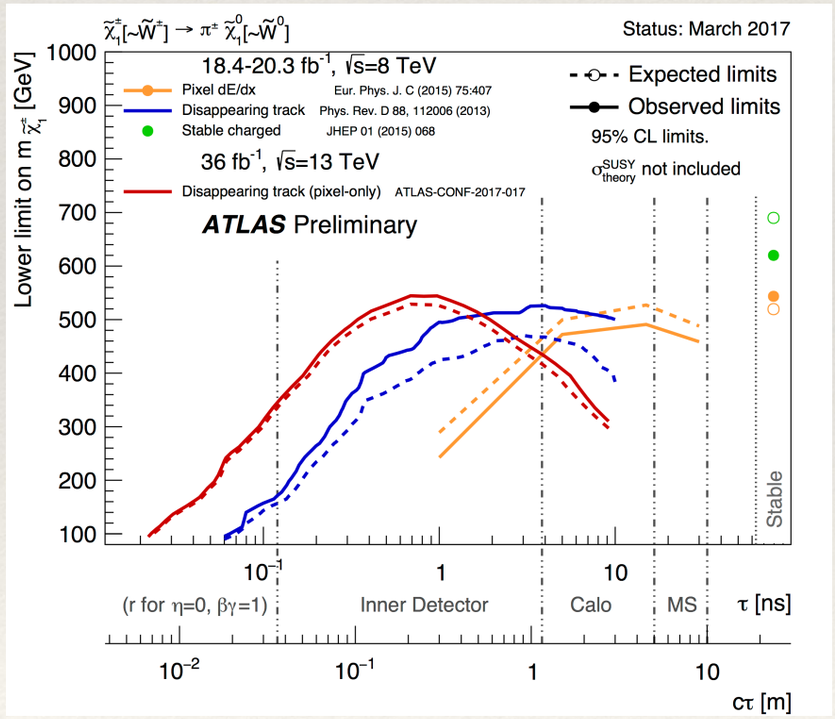
- Magnetic charge quantized in units of $g_D \approx 68.5$.
  - Behaves as a particle with $q/e = n\ 68.5$, ionisation power 4700 n^2 times the electron.
  - HUGE coupling constant, forbids any reasonable/possible perturbative calculation beyond LO.

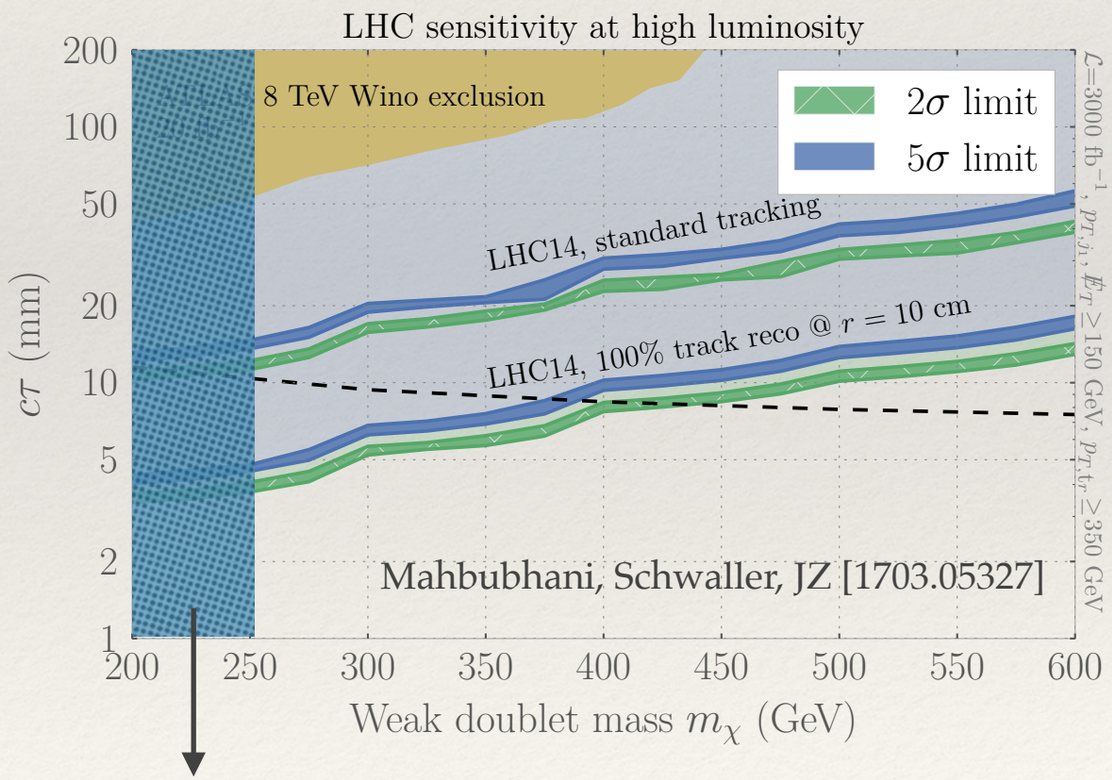
Quirks (Q)

- Quirks are particles charged under both SM and a new confining gauge group SU(N), such that the quirk masses are above the confinement scale Λ (no hadronization).
- Quirk-antiquirk pair can form a bound state while being separated by a distance *l* (string scale). This generates a tension in the pair, leading to a trajectory different from the SM helix.
- Only existing search… D0! (FERMILAB-PUB-10-324-E)
- See talks by M. Farina and S. Knapen at Trieste's workshop

Disappearing track (DT)

- Charged particle decays into neutral particle plus a soft charged one (e.g: $X^+ \to X^0 + \pi^+, \mu^+$). Track vanishes in thin air. Trigger on hard jet + MET.
- $c\tau$: ATLAS went from 30 to 12 cm with 4th layer. CMS pixel detector upgrade?
- Wino (Higgsino) $c\tau$ = 55 (6.6) mm. Scalar models have no preferred value!





- How low can we go in $c\tau$?

Mono jet + soft-leptons:
Schwaller, JZ [1312.7350], Low and L.-T. Wang,[1404.0682],
Barducci, Belyaev, Bharucha, Porod, Sanz [1504.02472].

Proposals for exotics taxonomy

Proposal I

2) Highly ionizing tracks:
- a- calo decays: HSCP
- b- HIPS: monopoles
- c-quirks

3) anomalous tracks:
- b1-disappearing/kinked tracks
- b2-emerging tracks: SIMPS, emerging jets

4) Out of time decays: SP

Proposal II

2) Highly Ionizing/Calorimeter Signatures:
- a- Large dE/dx: HSCP
- b- Out-of time decays: SP
- c- Trackless signatures: SIMPS, emerging jets

3) Unconventional Track Signatures :
- a- Highly-Ionizing tracks: monopoles and quirks models
- b- disappearing/kinked tracks

Proposal III

2) In-time exotic long-lived signatures:
- a- Slow and/or anomalously ionizing tracks (HSCPs, fractionally charged, quirks, monopoles)
- b- disappearing/kinked tracks
- c- Trackless jets
- d- Emerging jets

3) Out-of-time long-lived signatures:
- a) OoT calo
- b) OoT muons

2a) could be broken into a bunch of options:
- a- Slow & highly ionizing tracks (HSCP & quirks)
- b- Low dE/dx (fractional)
- c- Extremely high ionization (Monopoles)

Conclusions

- We've come a long way, the chapter is ready for shipping, but there is always room for improvements.
- The goal was to provide all essential information for the non-expert reader, and refer the avid one to the original publications. ✓
- Still to see:
  - Best way to report the gap (plots and/or bulleted list and/or short paragraph?)
  - Can the search info be summarised in tables? Maybe for the webpage only?
  - How to best classify the "weird tracks and friends" signatures.