Searches for long-lived charged and neutral particles at CMS

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on behalf of the CMS Collaboration

Lake Louise Winter Institute

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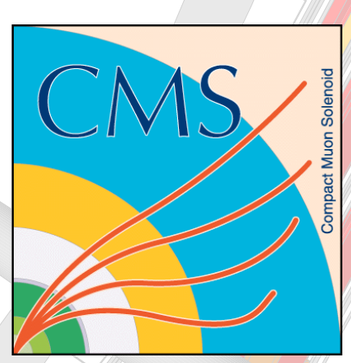
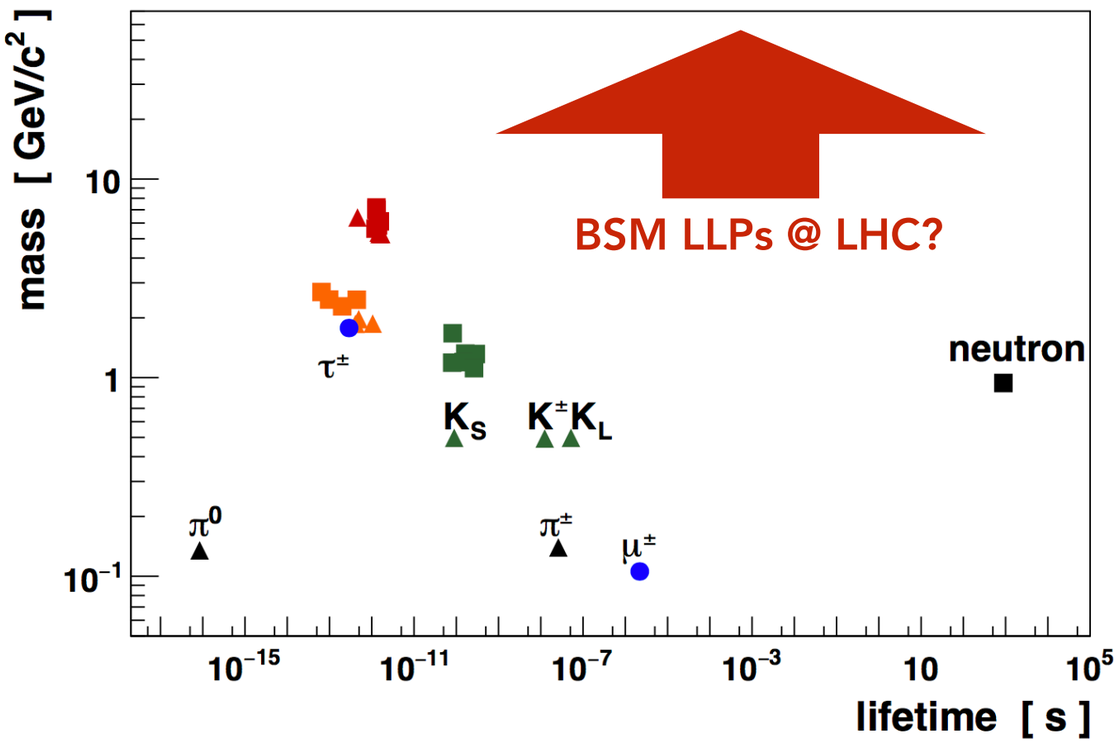
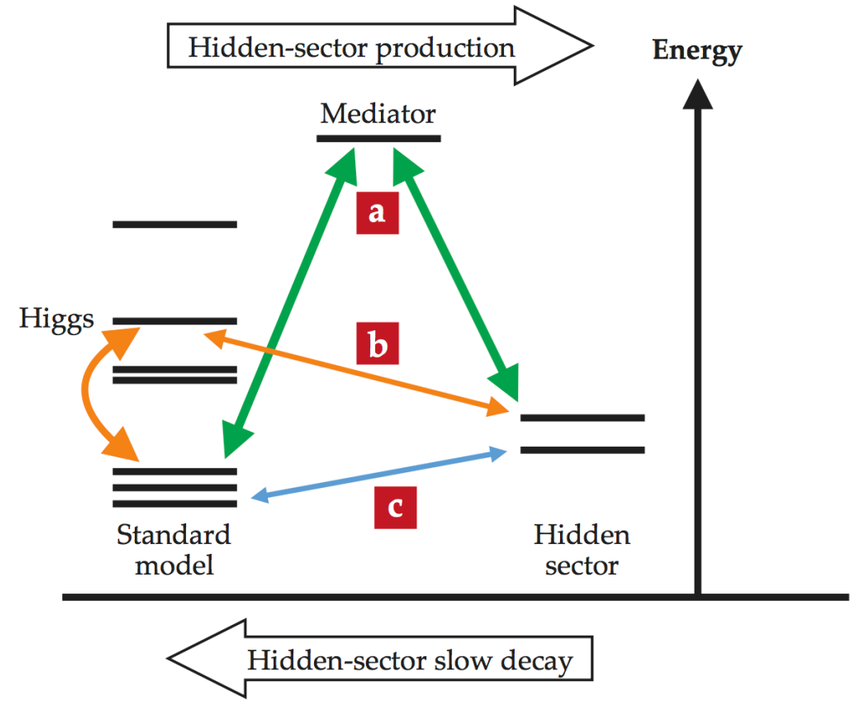
Imperial College London



Motivation for long-lived particle (LLP) searches

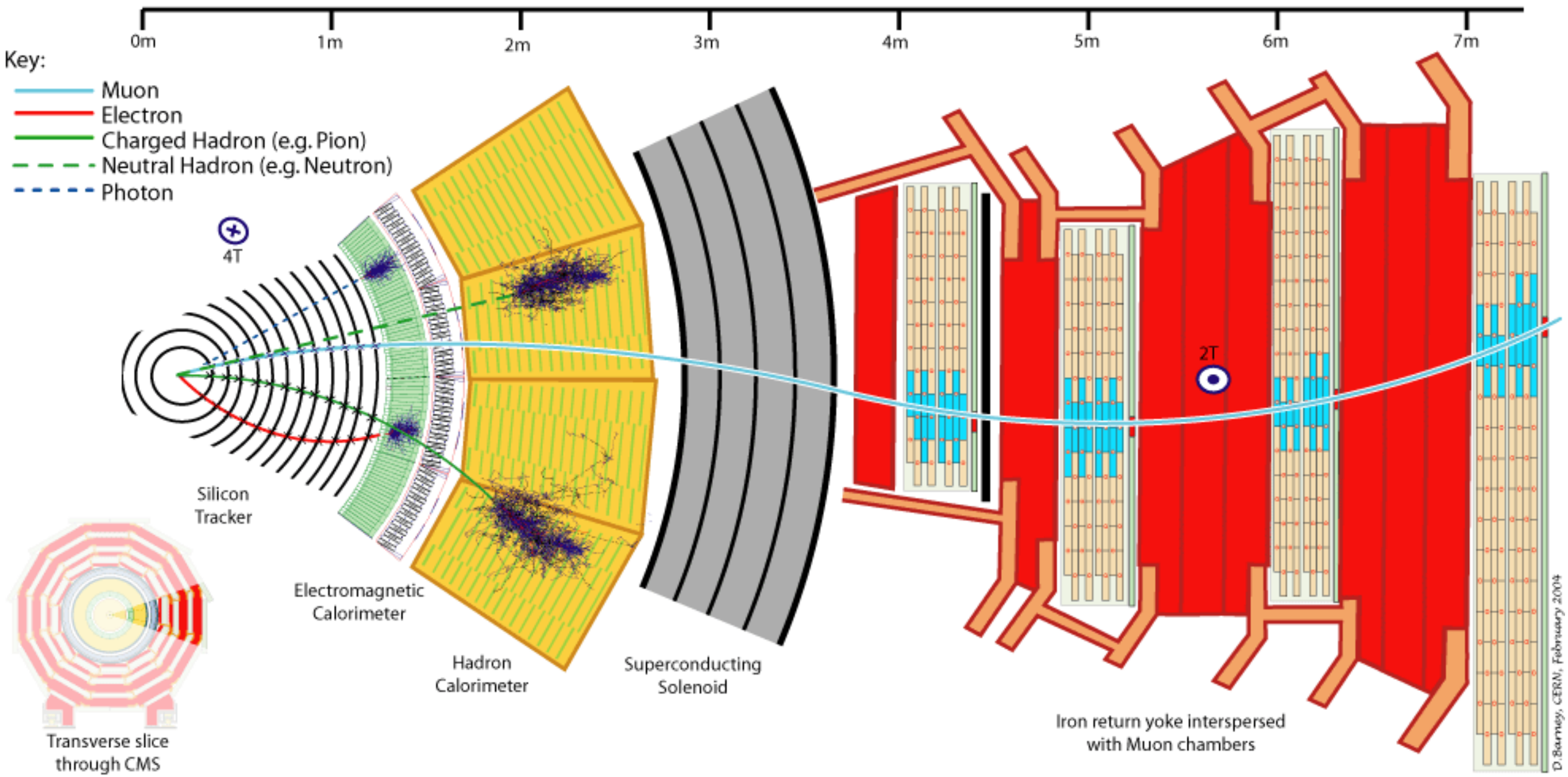
- SM particle zoo has many LLPs; same can be expected for BSM physics? Yes!
- SUSY, hidden valley, … small coupling constants, small mass splittings, heavy messengers, …





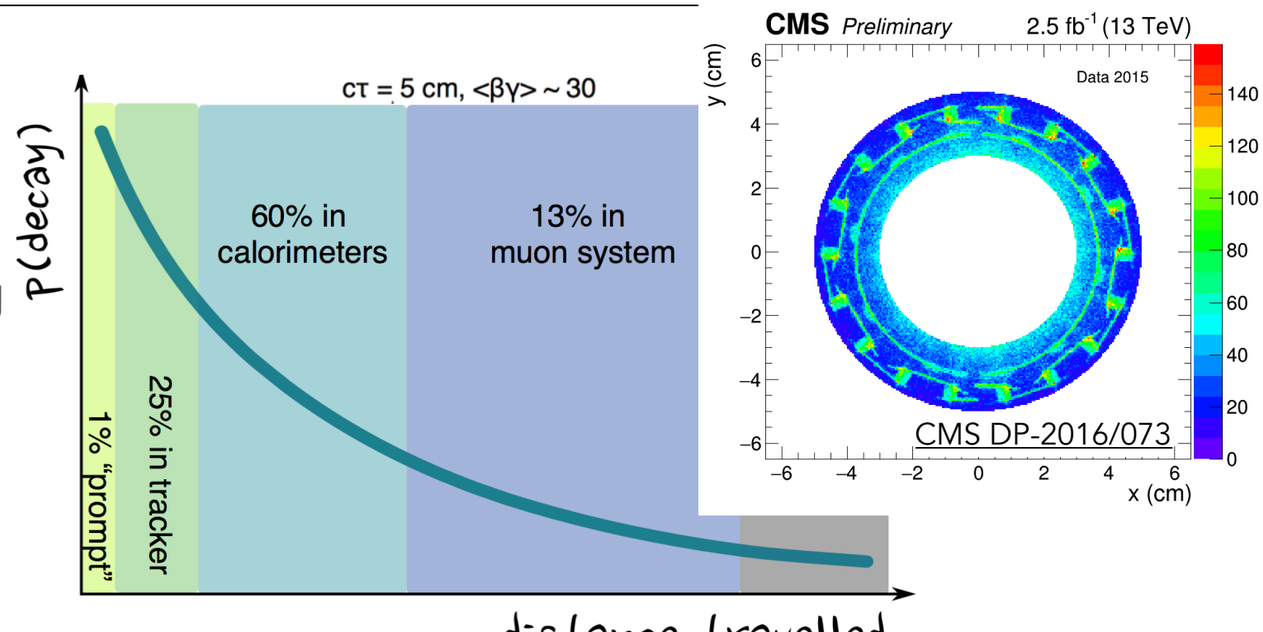
- Now entering LHC luminosity-scaling era
- Imperative that we maximally exploit the LHC detectors using **new ideas/techniques**

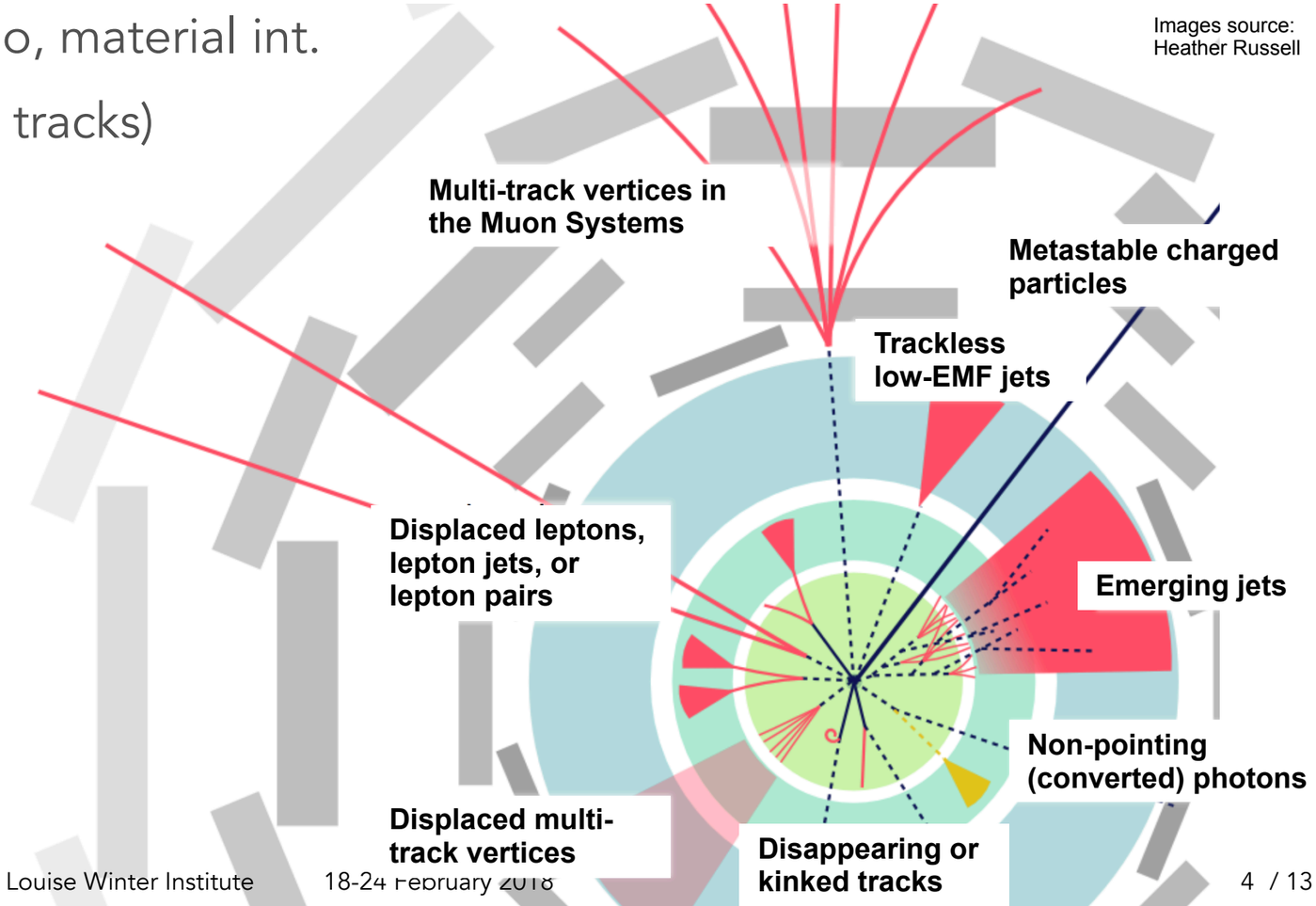
The CMS detector



Detecting LLPs within CMS: signatures and challenges

- **Wide variety of "unusual" detector signatures**
- **Requires non-standard and novel techniques**
  - Charged LLPs: dE/dx, TOF, non-standard tracking
  - Neutral LLPs: vertexing @ large displacements
  - Stopped LLPs: out-of-collision events
- **Other non-standard aspects:**
  - **Bkgds**: SM weak decays, cosmics, beam halo, material int.
  - **Trigger** (e.g. out-of-collision, "non-prompt" tracks)
  - **Simulation** (e.g. R-hadron cloud model)
- In these slides
  - Example techniques/searches
  - Summary and future





Charged LLPs: track-based signatures

12.9 fb^{-1} @ 13 TeV

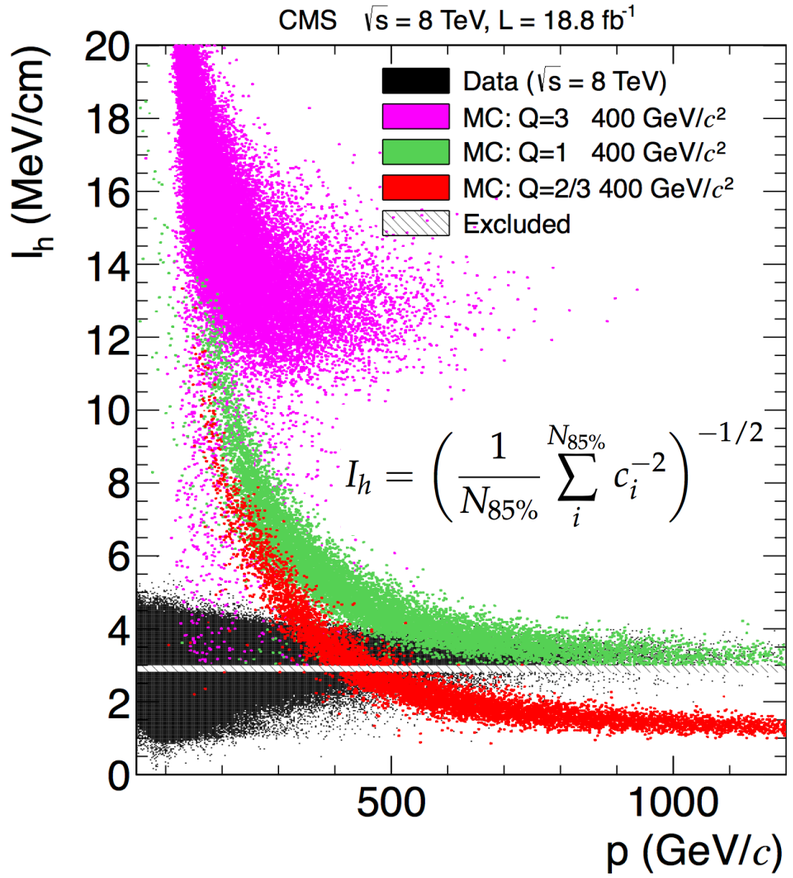
CMS-PAS-EXO-16-036

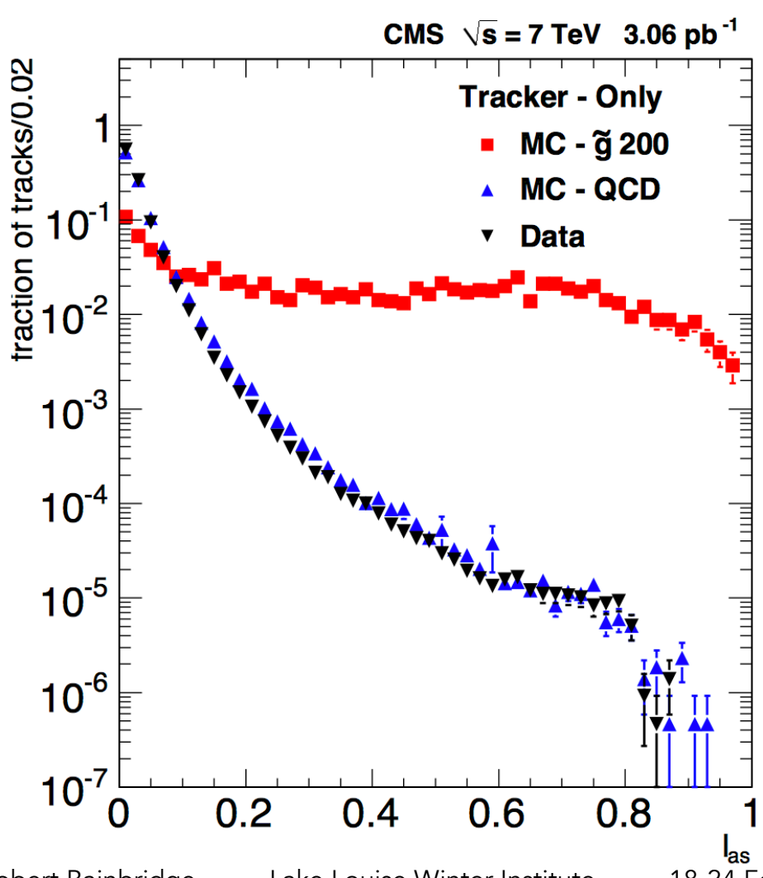
- Charged LLPs can be: **heavy & slow**, **quasi-stable on detector-scale**, **multiple/fractional charge**

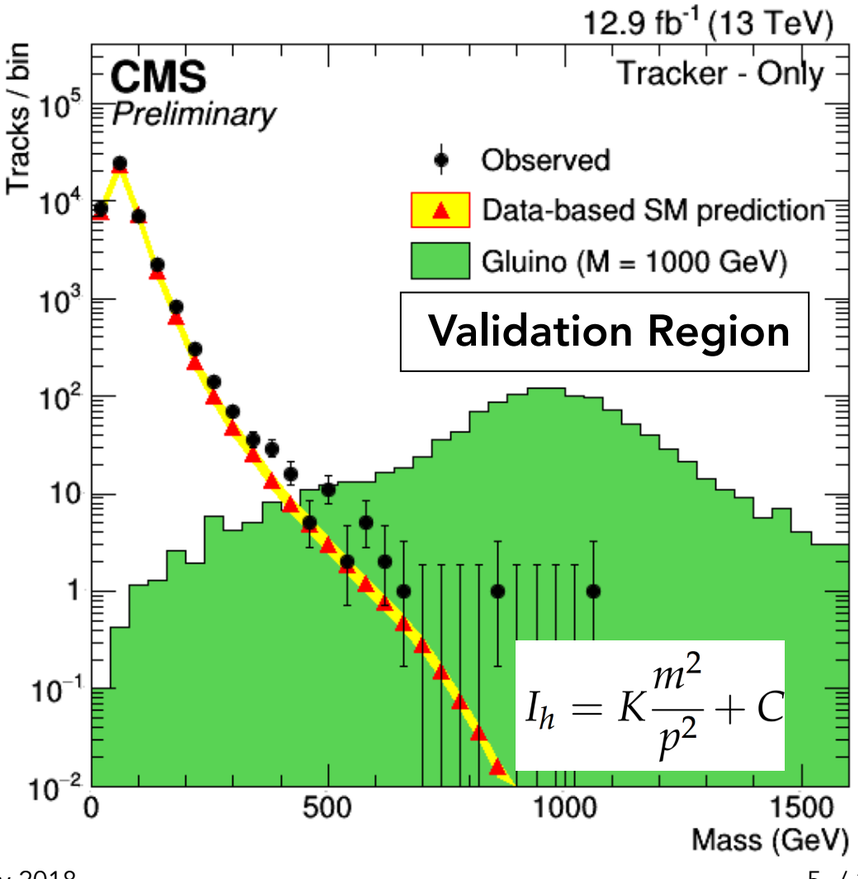
- **Tracker "anomalous" dE/dX measurements** for $\beta < 0.9$ and/or |Q| != 1e (c.f. ~3 MeV/cm for SM MIPs)
- I_h is dE/dx estimator, I_{as} indicates MIP-compatibility, mass: $I_h = K\,(m/p)^2 + C$ (|Q| = 1e)

- **TOF measurements** δt from DTs (residuals from "zigzag" track) and CSCs (sampling time)
- Track β estimated from weighted average of δt measurements using $1/\beta = 1 + c\delta t / L$

- Requirements on track p_T, I_{as}, $(1/\beta)$, and **M**; data sidebands used to estimate background





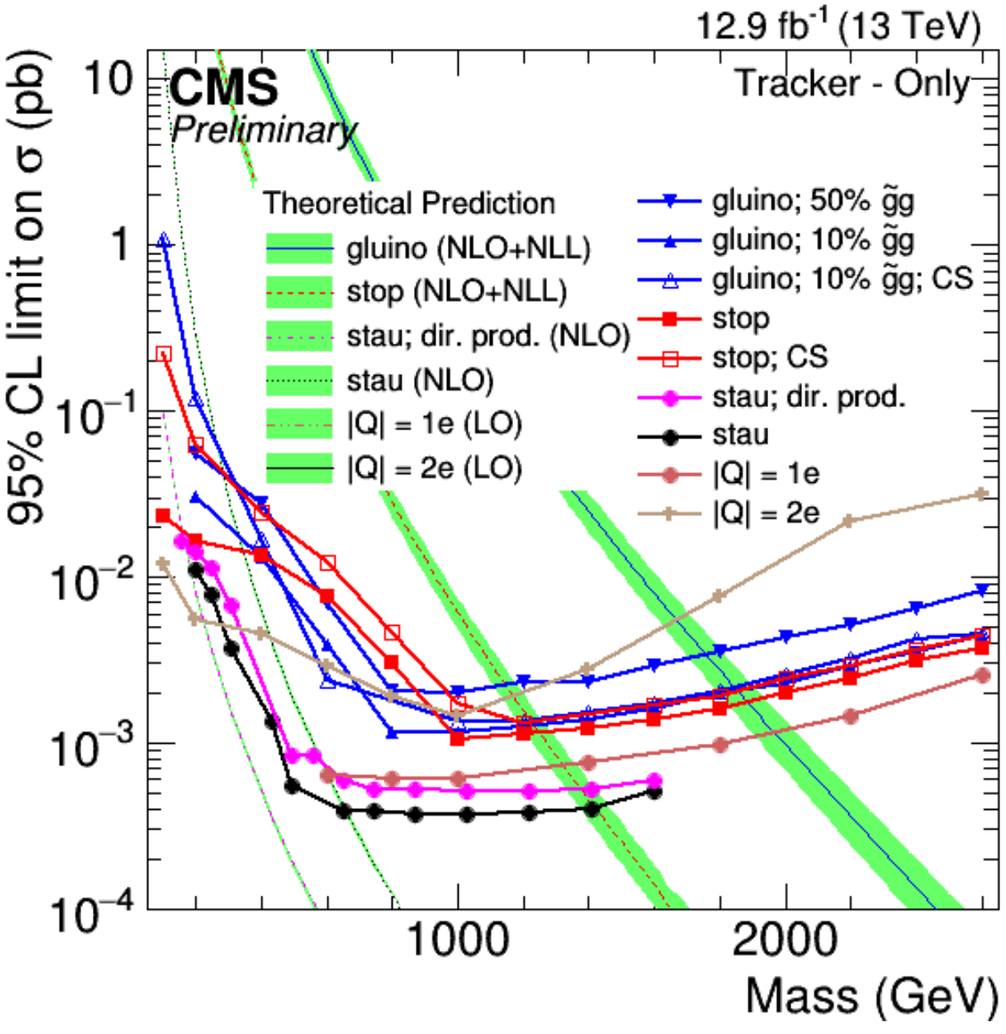


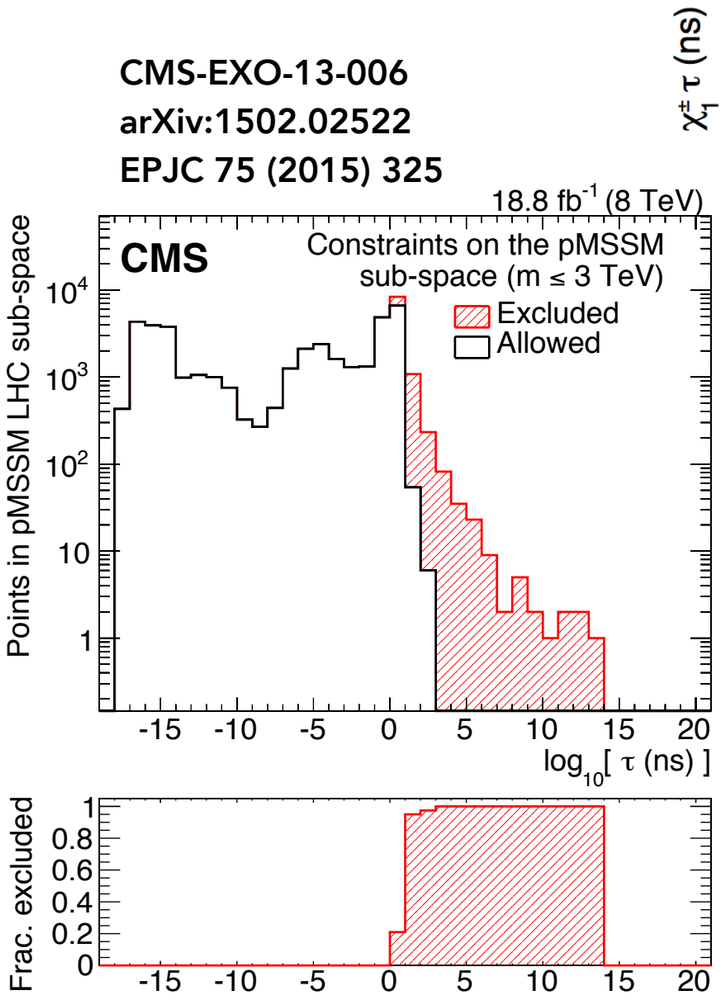
Charged LLPs: track-based signatures

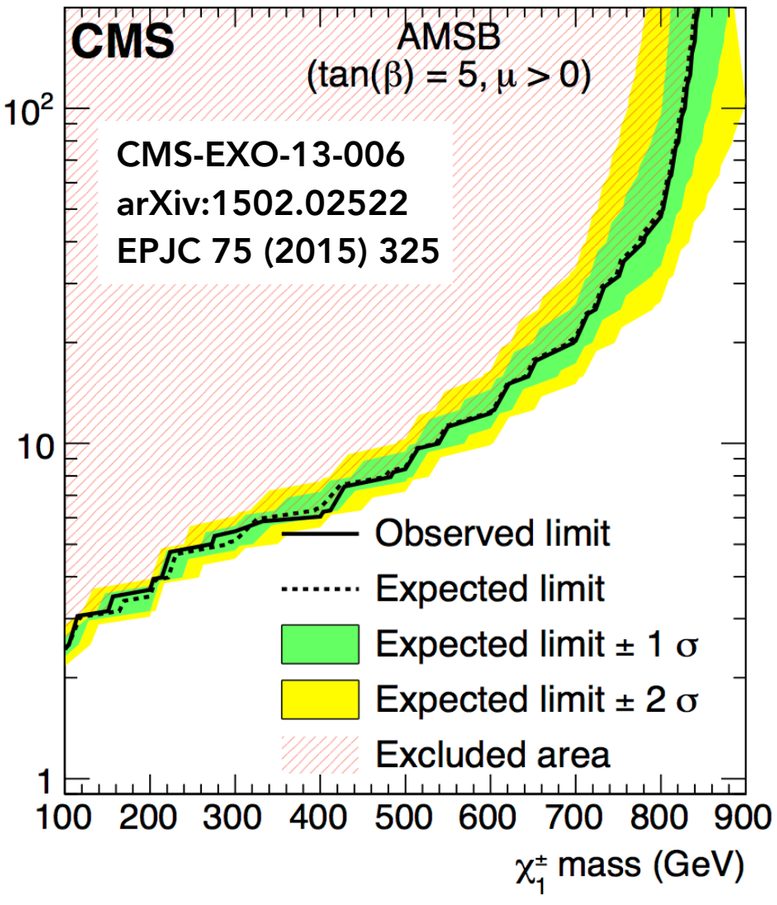
12.9 fb^{-1} @ 13 TeV

CMS-PAS-EXO-16-036

- **Broad utility for many models with hadron- or lepton-like quasi-stable charged LLPs**
- Split-SUSY scenario ⟹ quasi-stable $\tilde{g}$ that forms an R-hadron: **exclude $\tilde{g}$ up to 1850 GeV**
- Advertisement: update with full 2016 data set soon …





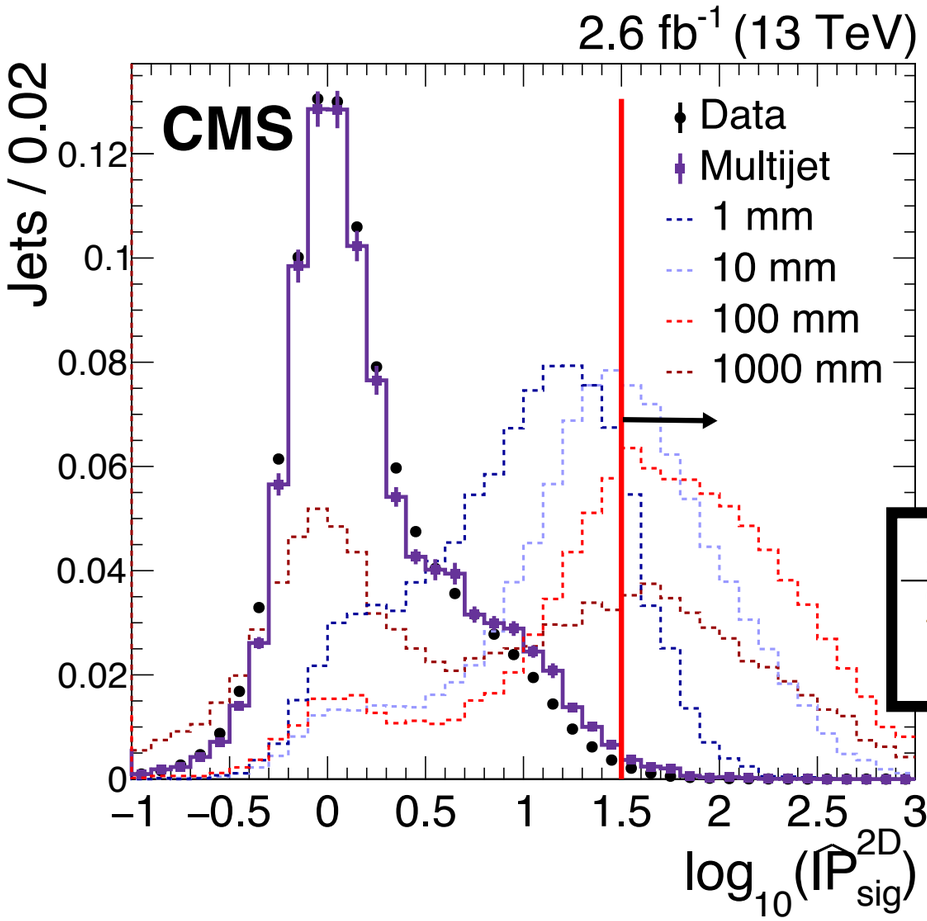


Displaced "tagged" jets

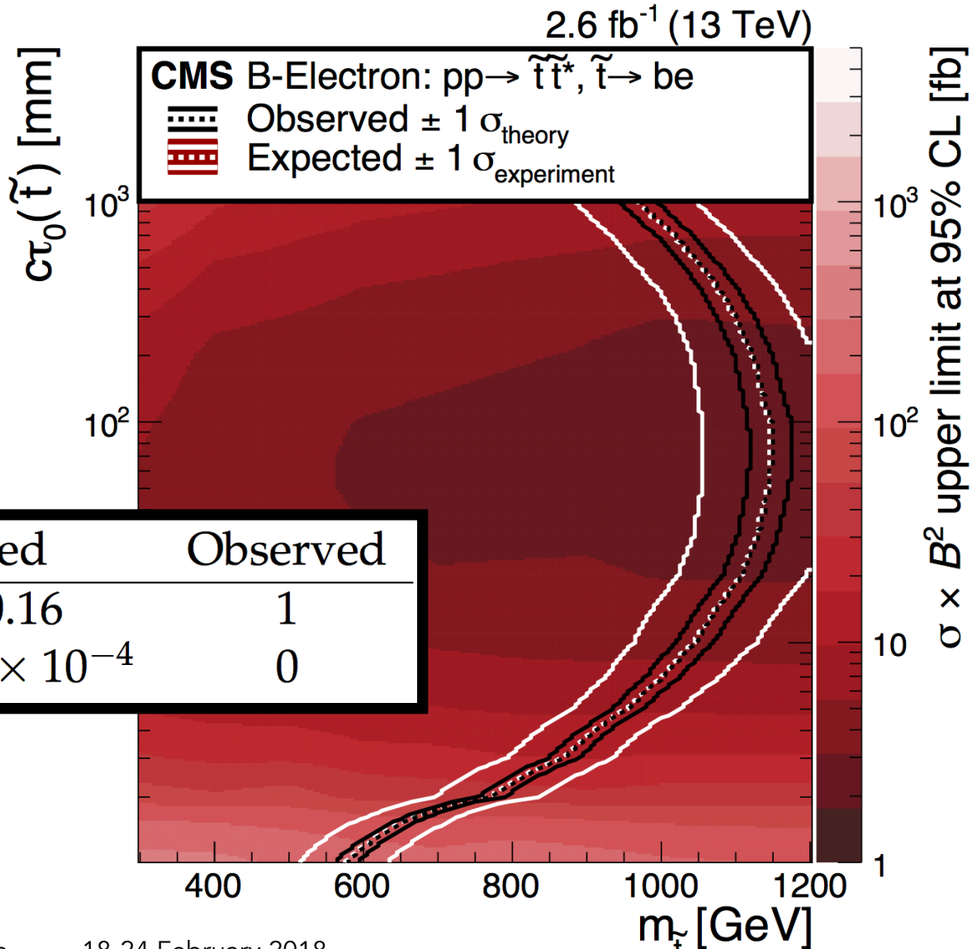
2.6 fb^{-1} @ 13 TeV (NEW)

CMS-EXO-16-003
arXiv:1711.09120
Submitted to PLB

- Search for **LLP pair production in final states with at least two displaced jets**
- Multiple interpretations: e.g. **SUSY RPV** model with top-squark pair production, with decay $\tilde{t} \to b\ell$
- **Triggers**: HT > 500 (350), ≥2 jets, ≤2 "prompt" tracks w/ IP^{2D} < 1mm, (≥1 track w/ IP^{2D}_{sig} > 5)
- Several variables: e.g. median **transverse impact parameter significance** of tracks associated to jet
- Dominant background is QCD multijet, estimated using data-driven fake rate measurement



N_{tags}	Expected	Observed
2	1.09 ± 0.16	1
≥3	$(4.9 \pm 1.0) \times 10^{-4}$	0

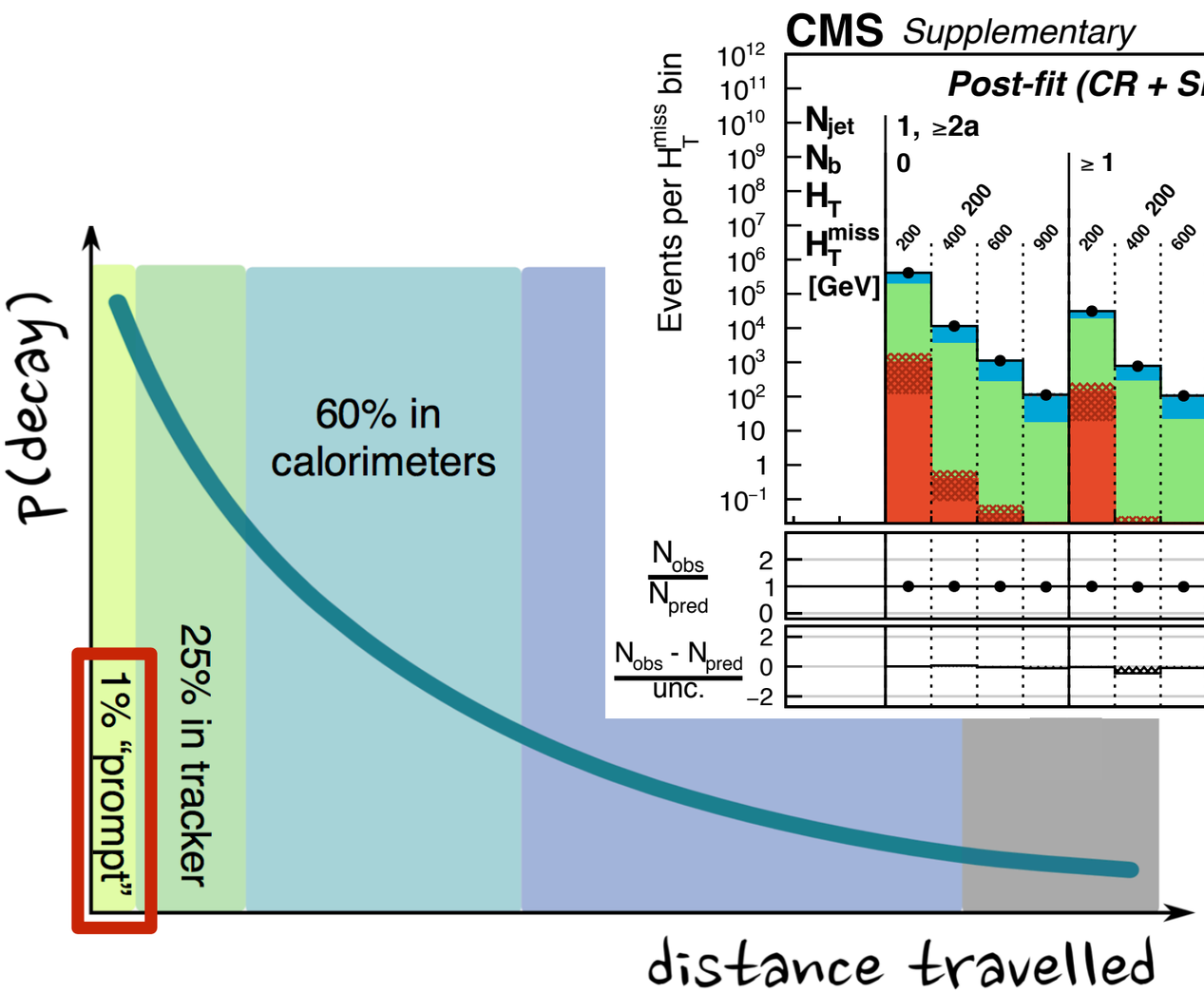


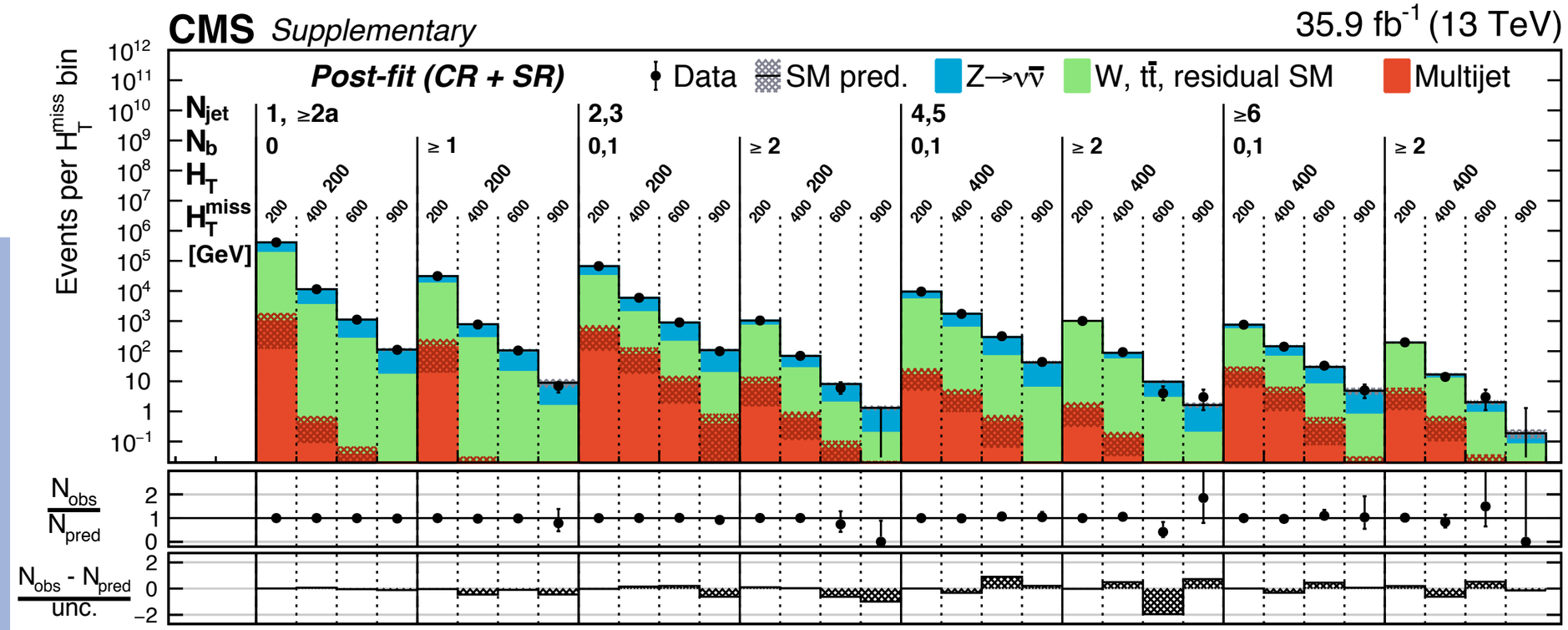
(Prompt) jets + p_T^{miss} search

35.9 fb^{-1} @ 13 TeV (NEW)

CMS-SUS-16-038
arXiv:1802.02110
Submitted to JHEP

- **Inclusive jets + p_T^{miss} search** for RP-conserving SUSY using N_{jet}, N_b, H_T, H_T^{miss} with **low thresholds**
- Reinterpretation: split-SUSY inspired $\tilde{g}$ (R-hadron) $\rightarrow q\bar{q}\tilde{\chi}_1^0$ with $10^{-6} < c\tau < 10^2$ m, and stable $\tilde{g}$
- Acceptance comes from "prompt" jets, of which number decreases with increasing $c\tau$



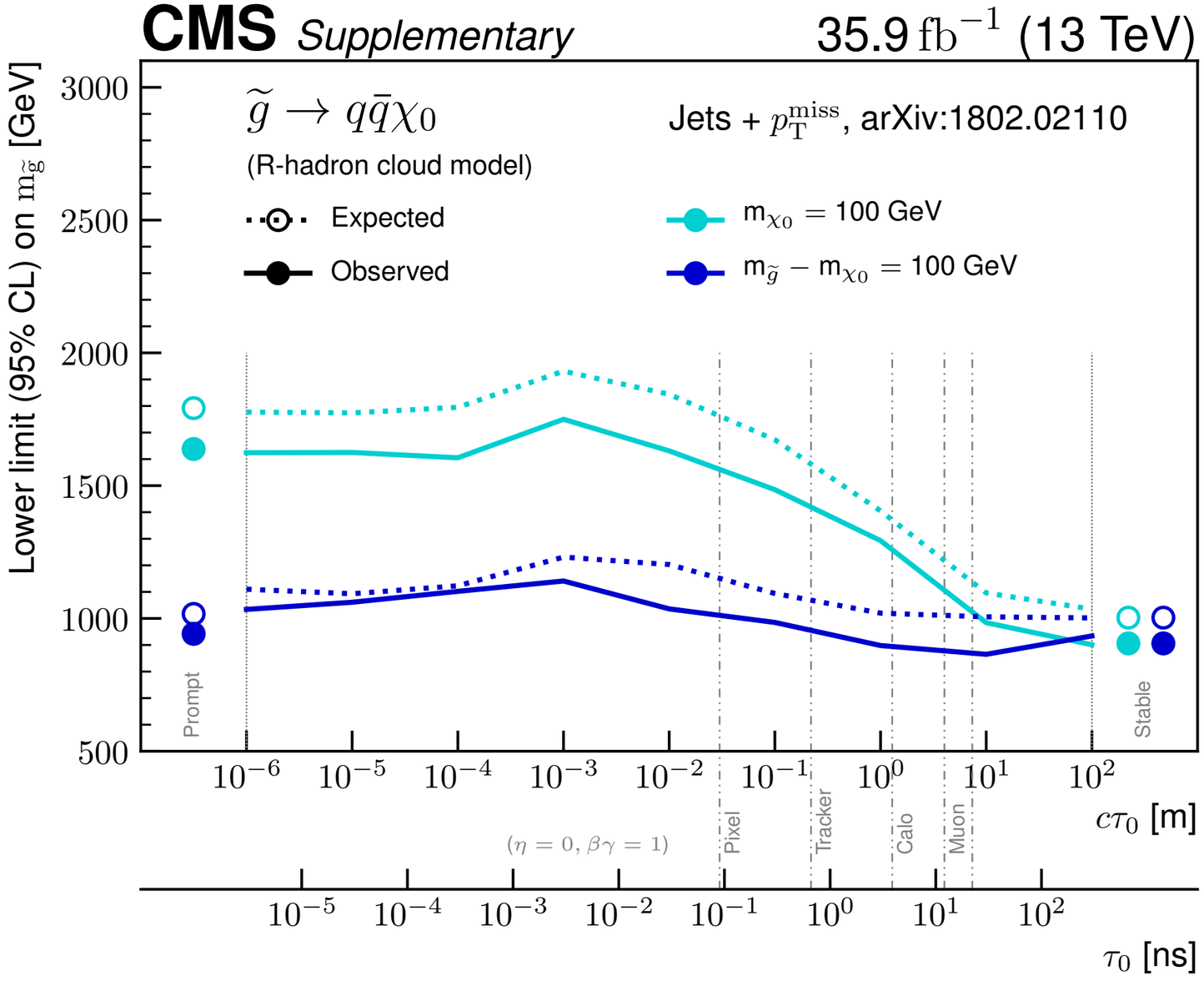


(Prompt) jets + p_T^{miss} search

35.9 fb^{-1} @ 13 TeV (NEW)

CMS-SUS-16-038
arXiv:1802.02110
Submitted to JHEP

- Large Δm: limits weaken vs $c\tau$ (fraction of "prompt" jets falls), rely on monojet @ 1 m, b-tagging @ 1 mm
- Small Δm: soft (displaced) jets ⟹ rely on ISR, limits are ~independent of $c\tau$
- Continuous coverage for **small and large lifetimes** ⟹ utility in repurposing inclusive "prompt" searches

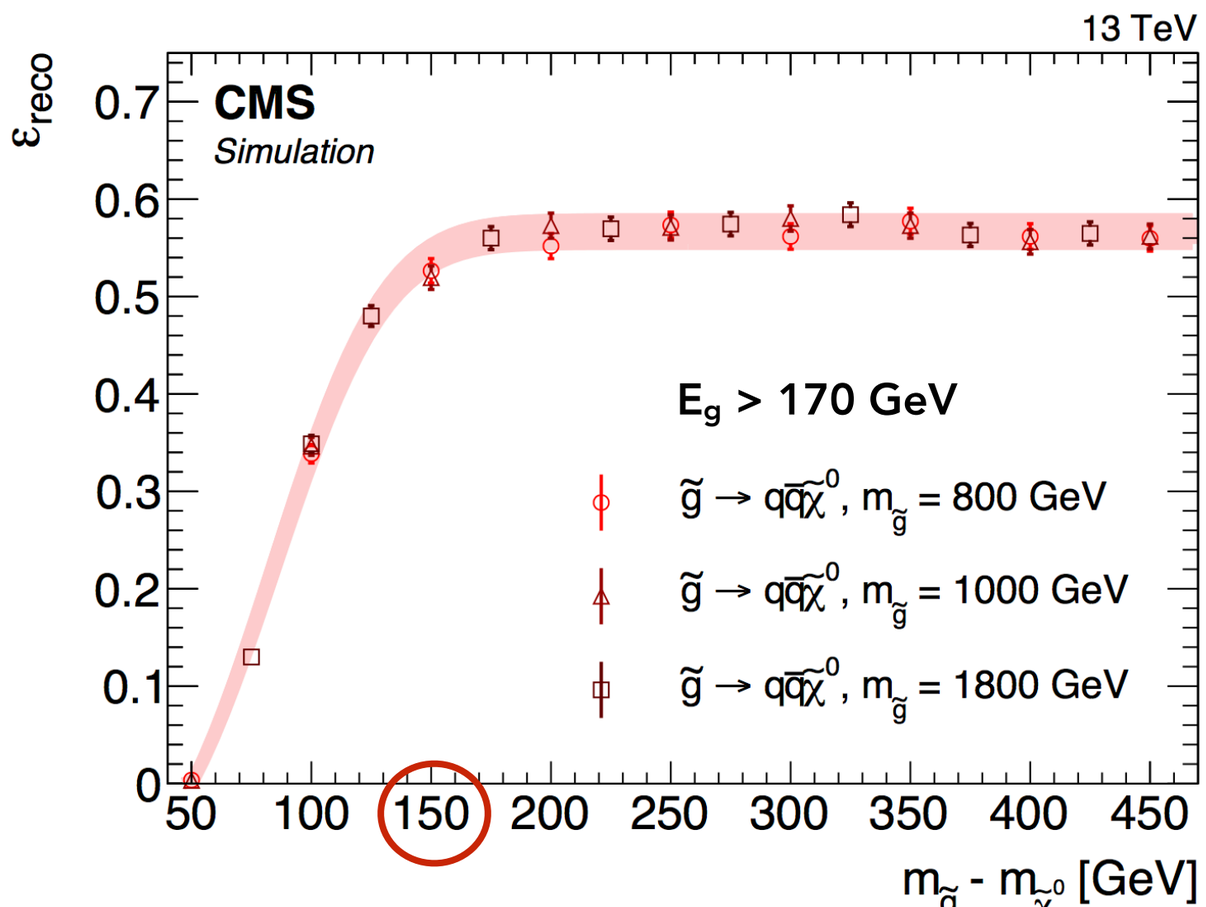


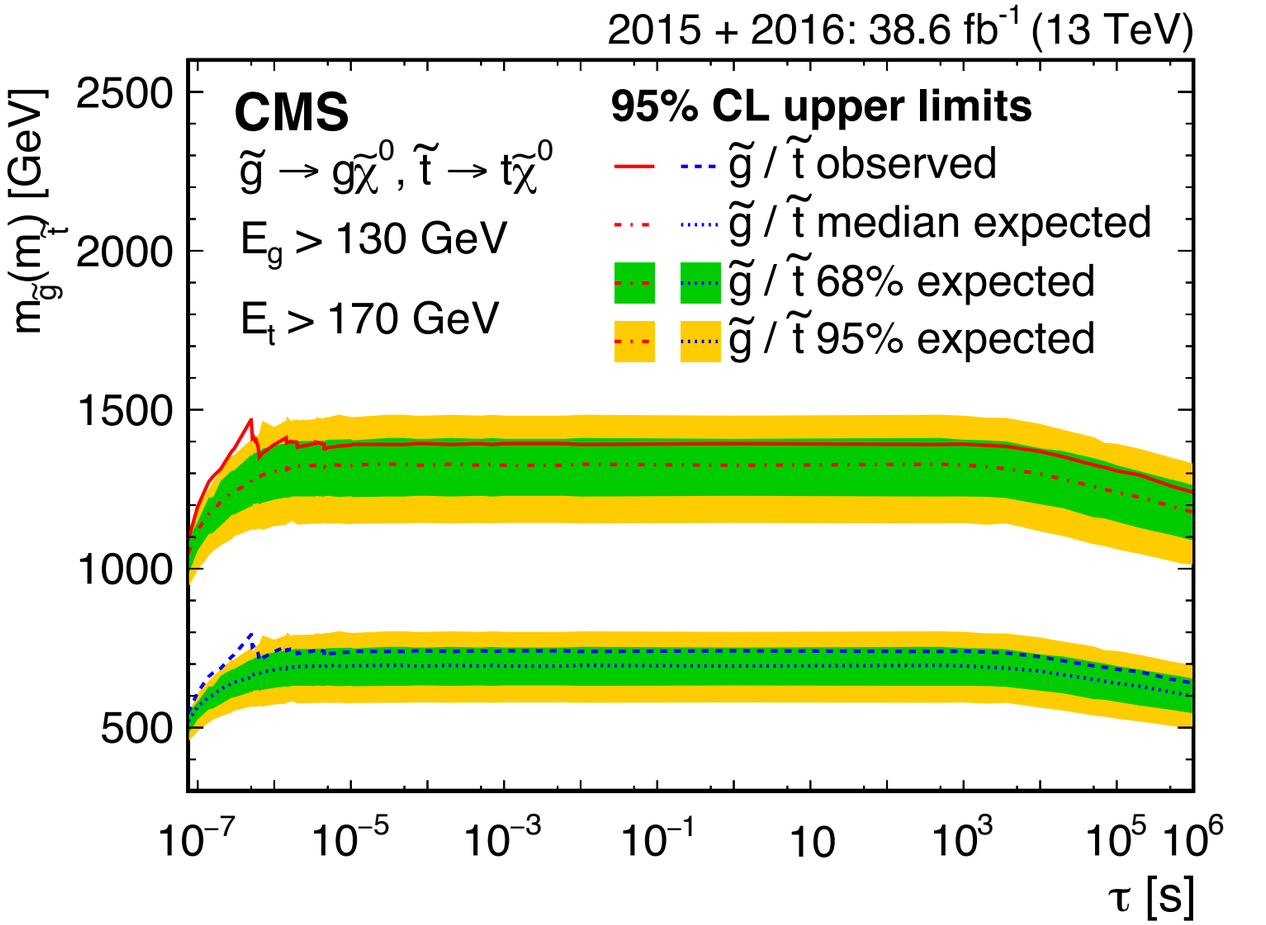
"Stopped" LLPs: hadronic decays

38.6 fb^{-1} @ 13 TeV

CMS-EXO-16-004
arXiv:1801.00359
Submitted to JHEP

- Search for **out-of-collisions decays of "stopped" LLPs** that come to rest in calorimeters / muon system
- R-hadrons with low β can lose all K.E. through ionisation / nuclear int.
- $\tilde{g}$ (R-hadron) → $q\bar{q}\tilde{\chi}_1^0$ and $\tilde{g}$ (R-hadron) → $g\tilde{\chi}_1^0$ and $\tilde{t}$ (R-hadron) → $t\tilde{\chi}_1^0$
- **Dedicated trigger**: 721-hour live-time in 2015 + 2016; observed 4 + 13 events (consistent with bkgd)
- Exclude m_{gluino} < 1385 GeV over **large lifetime range**: 1 μs < τ < 10^5 s
- **Complementary information** w.r.t. dE/dx analysis: study decays vs particle propagation





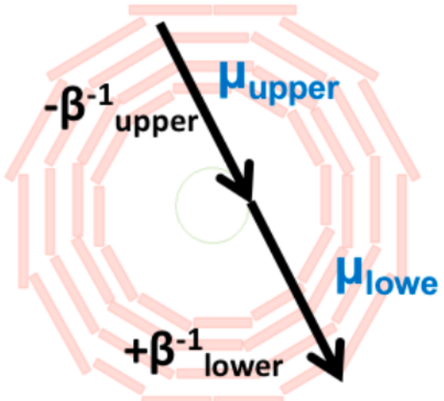
"Stopped" LLPs: muonic decays

38.6 fb^{-1} @ 13 TeV (NEW)

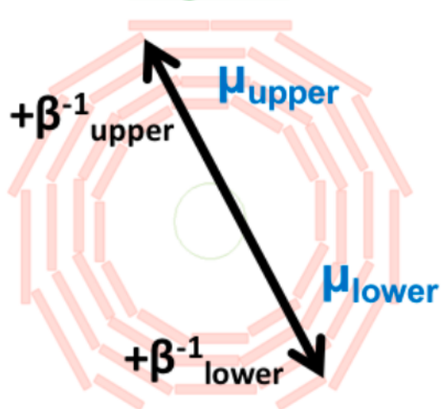
CMS-EXO-16-004
arXiv:1801.00359
Submitted to JHEP

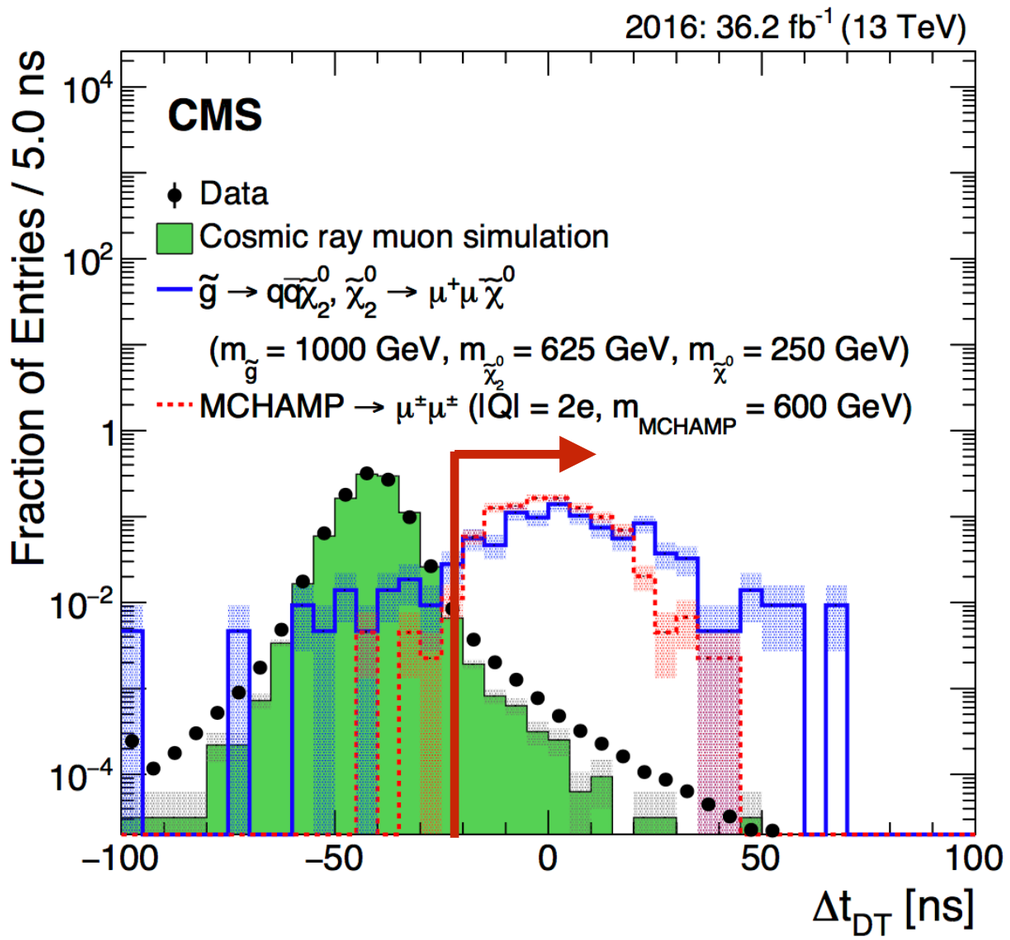
- **New: also consider muonic decays of "stopped" LLPs in Muon Systems**
- g (R-hadron) → $qq\chi_2^0$, $\chi_2^0 \rightarrow \mu\mu\chi_1^0$ and MCHAMP ($|Q| = 2e$) → $\mu^{\pm}\mu^{\pm}$
- Dedicated trigger**:** require an out-of-collisions high-p_T muon
- **Dedicated reconstruction**: require two non-pointing standalone muons
- **Use timing info to suppress cosmic rays**, e.g: $\delta t_{DT} = t_{DT}(\text{upper}) - t_{DT}(\text{lower}) > -20$ ns

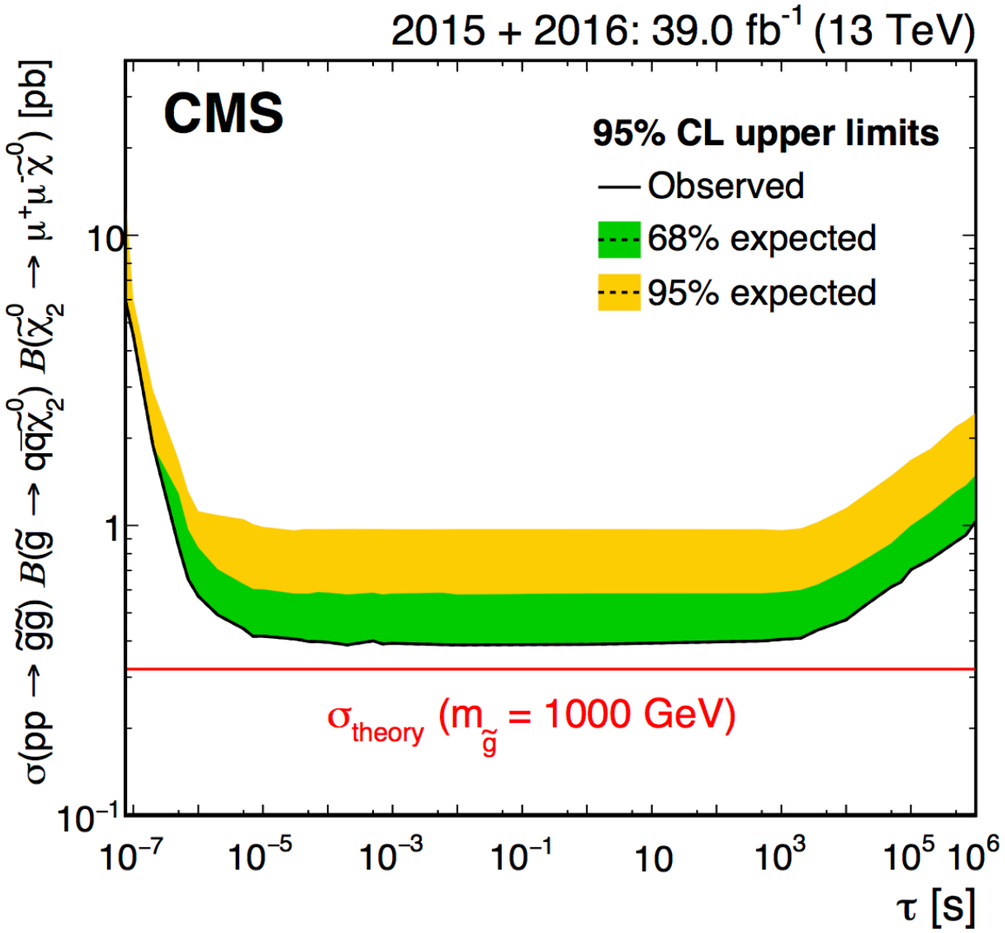
Cosmics



Signal

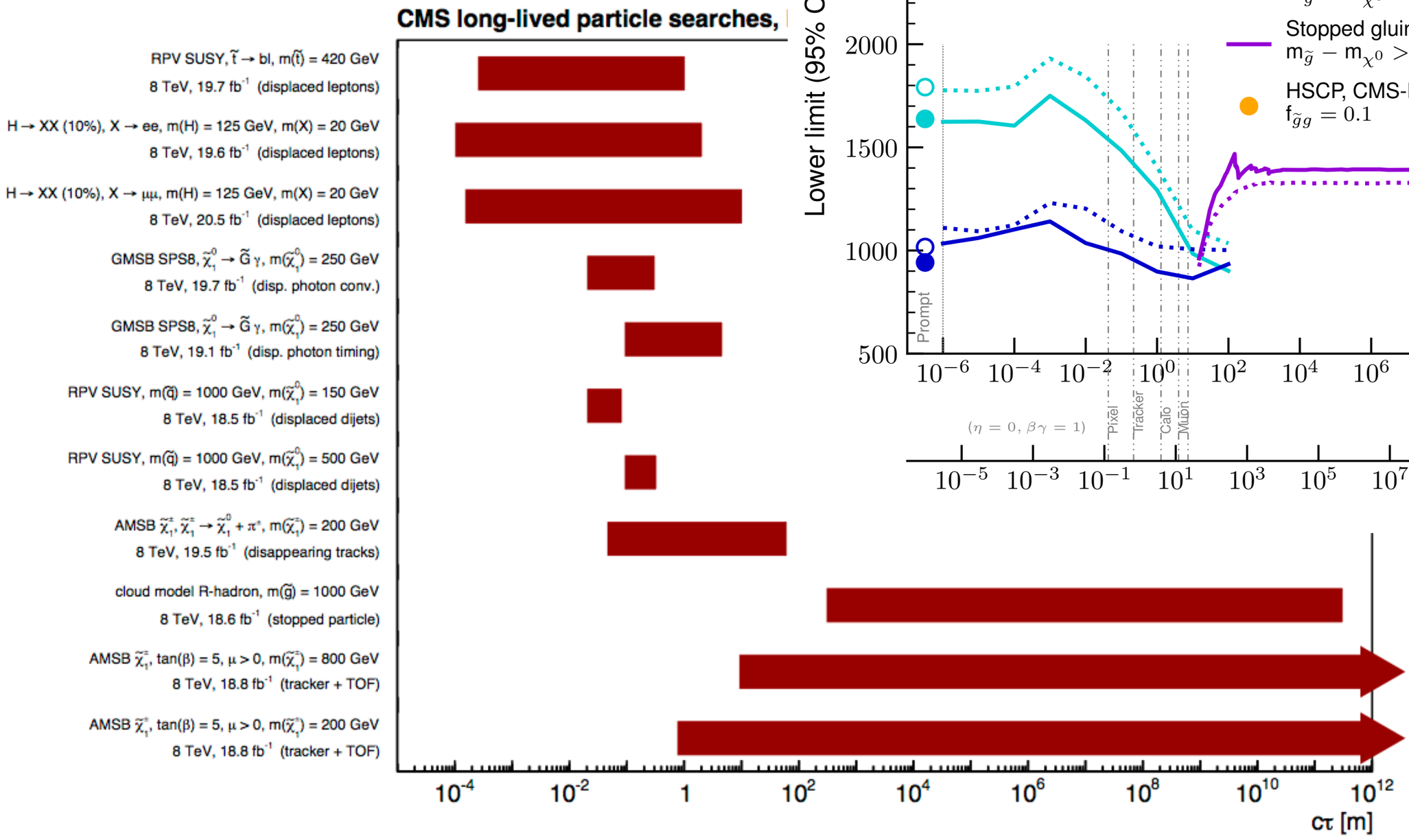






Overview of coverage

- Many searches and models
- Cover many orders of magnitude in $c\tau$



Summary

- **LLP search programme is still a rich and developing area of research at the LHC**

- **Still a significant headroom of unexplored techniques and parameter space**
- New reconstruction techniques, pixel detector, Level-1 topological triggers, …
- Several updates and new dedicated searches coming soon …

- **Still a large discovery potential with Run 2 data set! A very interesting area to follow!**

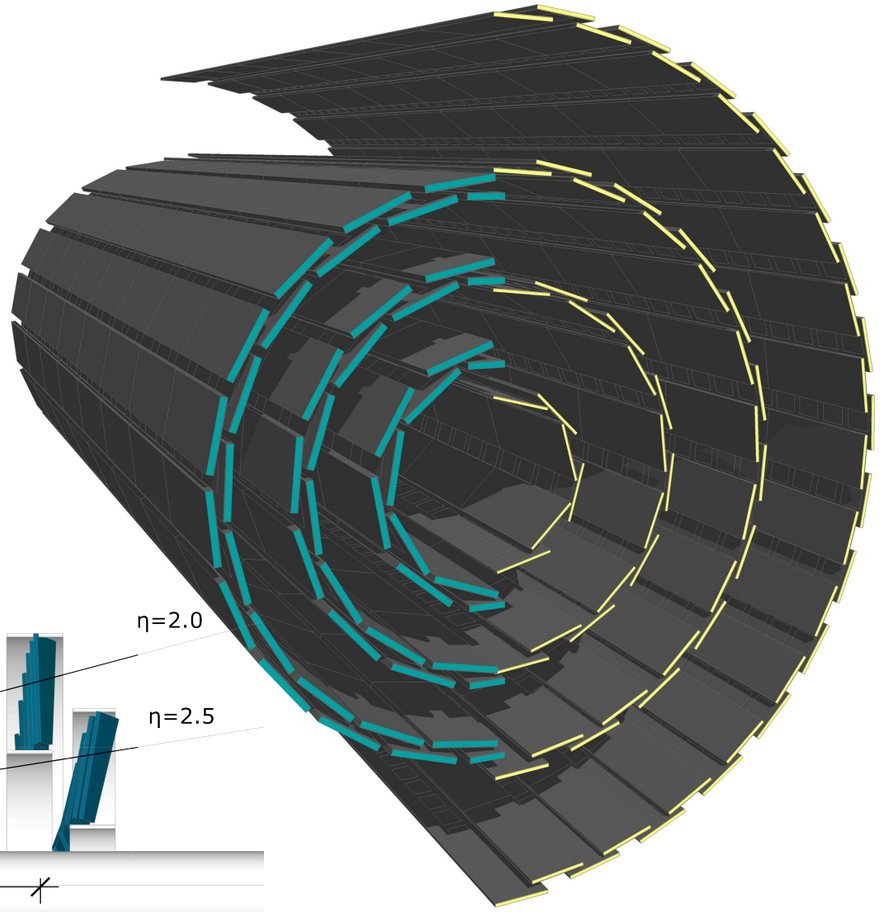
I'd like to thank the LLWI for this opportunity, Imperial College London for its support …

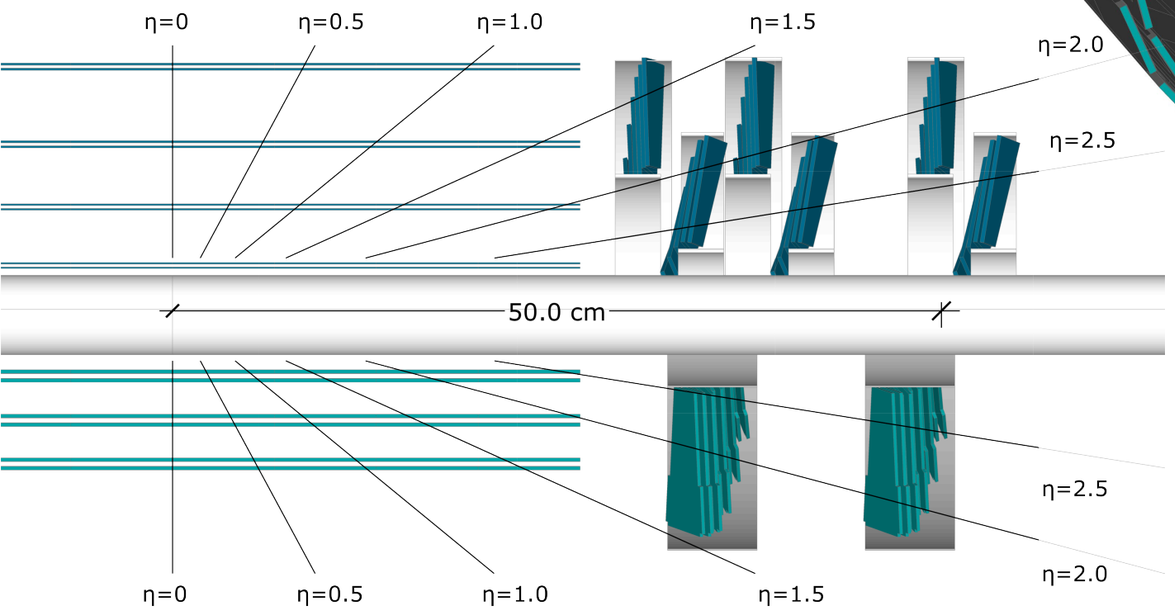
… and the audience for your attention!

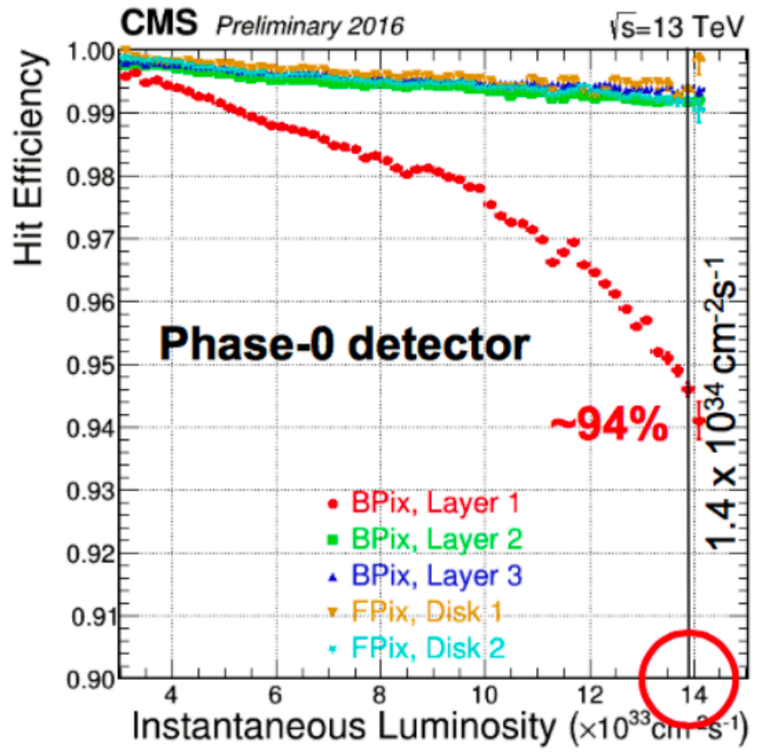
Bonus ...

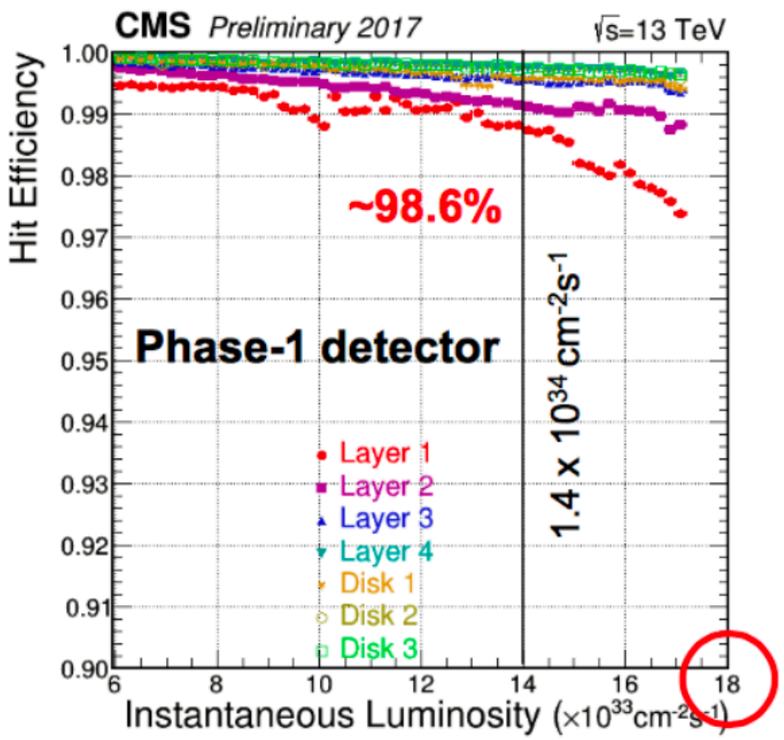
Pixel upgrade

- 4 layers, 3 disks, smaller radius inner layer (3 cm)
- New readout chip, significantly improved performance
- Higher redundancy, efficiency @ high rate and pileup









Charged LLPs: disappearing tracks

19.5 fb^{-1} @ 8 TeV

CMS-EXO-12-034
arXiv:1411.6006
JHEP 01 (2015) 096

- **Charged LLPs decaying within detector to undetected daughters** ⟹ "disappearing tracks"
- AMSB scenarios favour nearly mass-degenerate pure wino $\chi_1^{\pm}$ and χ_1^0 ($\Delta m \lesssim 200$ MeV)
- Probe direct production of long-lived charginos: $\tilde{\chi}_1^{\pm} \rightarrow \pi + \tilde{\chi}_1^0$
- Require: ISR jet + p_T^{miss} (trigger), $p_T^{track} > 50$ GeV, $E_{calo} < 10$ GeV, ≥3 missing outer-tracker hits
- Technique is a useful probe in a difficult region of phase space
- Advertisement: 13 TeV update coming very soon …