

LLP searches at CMS: a snapshot

November 9th, 2021

Mario Masciovecchio

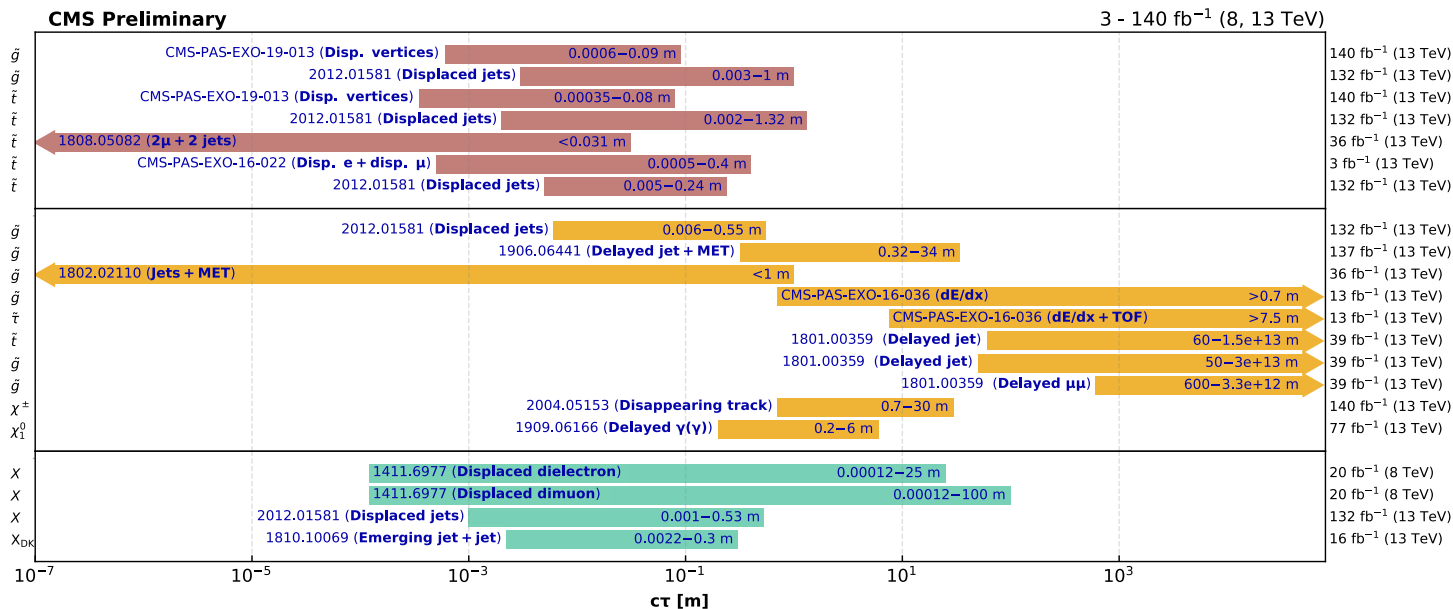
(University of California, San Diego)

- on behalf of the CMS collaboration -

LLPX (10th workshop of the LLP Community)

- CMS is actively searching for LLPs since LHC Run-1
 → Goal is to extend CMS reach and maximize accessible phase-space
- Long list of results, too long to be covered in 15'
 ➤ **Today** will only focus on **most recent CMS results**
 - Dedicated / detailed presentations [tomorrow](#)

Overview of CMS long-lived particle searches ([link](#))



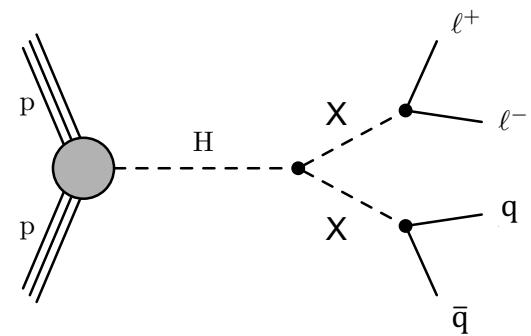
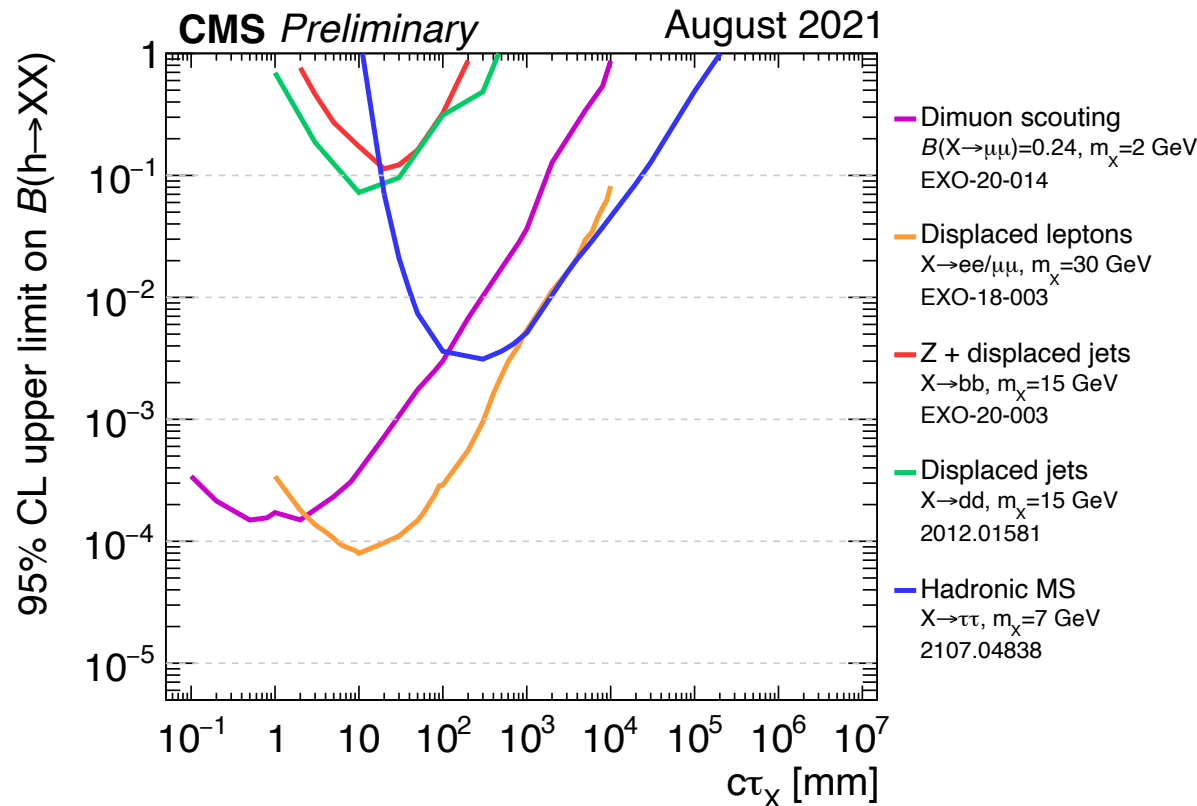
Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

Extending the CMS reach: few examples

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- Constant effort by CMS to extend accessible phase-space
- Use dedicated trigger strategy (e.g., high-rate *scouting* triggers)
- Explore leptonic + hadronic final states
- ➔ Extend reach across LLP mass & lifetime



For other CMS summary plots,
click [here](#)

Today



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- **Today** will only focus on **most recent CMS results**
 - Dedicated / detailed presentations [tomorrow](#)
 1. Search for LLPs in ee , $e\mu$ and $\mu\mu$ final states
 - ❖ [Submitted to EPJC \(CMS-EXO-18-003\)](#)
 2. Search for (LL) $\tilde{\tau}$ in all-hadronic final states
 - ❖ [CMS-PAS-SUS-21-001](#)
 3. Search for LL heavy neutral leptons in leptonic final states
 - ❖ [CMS-PAS-EXO-20-009](#)

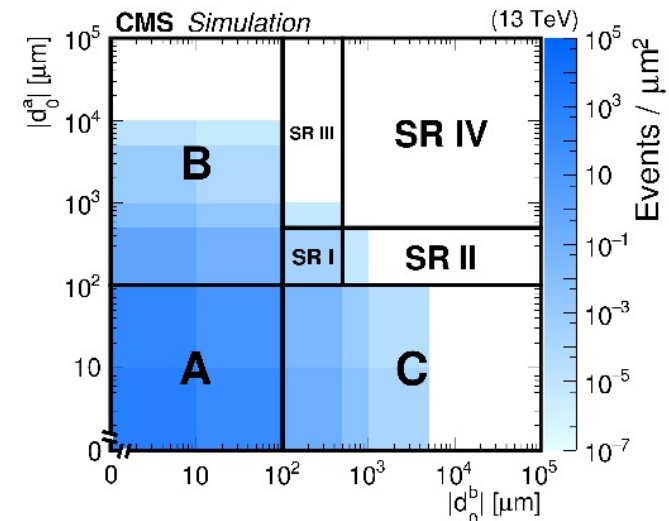
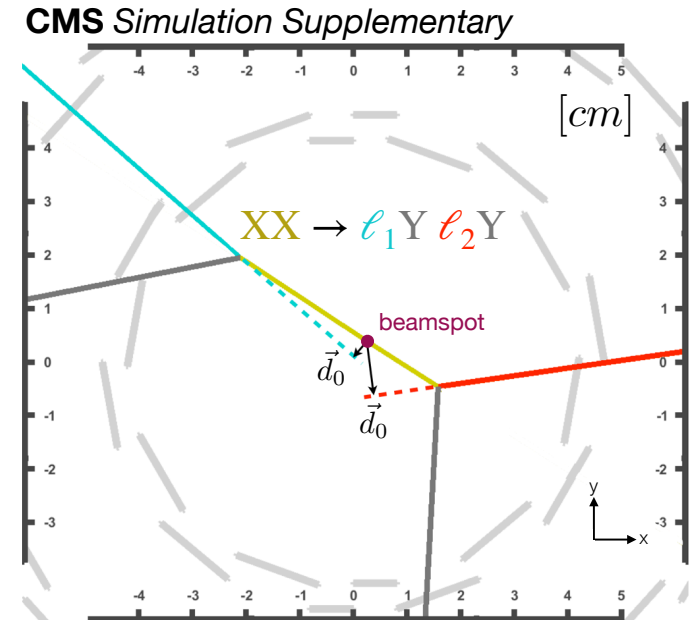
Search for LLPs in $ee, e\mu, \mu\mu$ final states [i]

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CMS-EXO-18-003

- Inclusive search for displaced leptons, as model-independent as possible
- NO requirement of common vertex
- Large transverse impact parameter, d_0
 - To largely suppress SM background
- Analysis strategy:
 - ❖ Select events with two displaced and isolated leptons ($ee, e\mu, \text{ or } \mu\mu$)
 - ❖ Categorize events in $|d_0^a| - |d_0^b|$
 - ❖ Estimate residual SM background via data-driven ABCD method
- ➔ Look for excess wrt. SM prediction

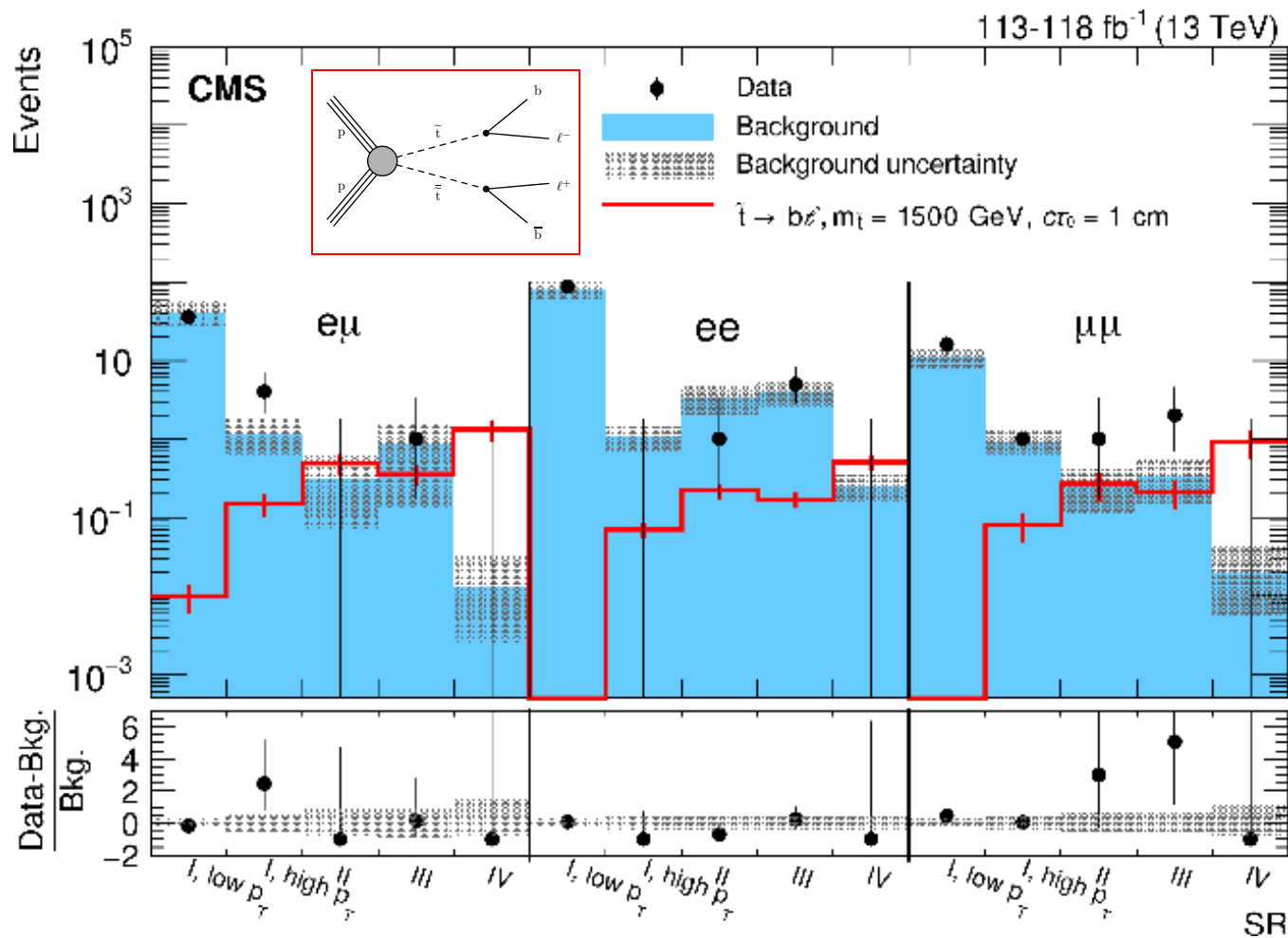


Search for LLPs in $ee, e\mu, \mu\mu$ final states [ii]

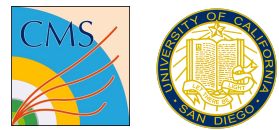
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CMS-EXO-18-003

- NO significant excess in data
- Results are used to constrain models of BSM physics with LLPs



Search for LLPs in $ee, e\mu, \mu\mu$ final states [iii]

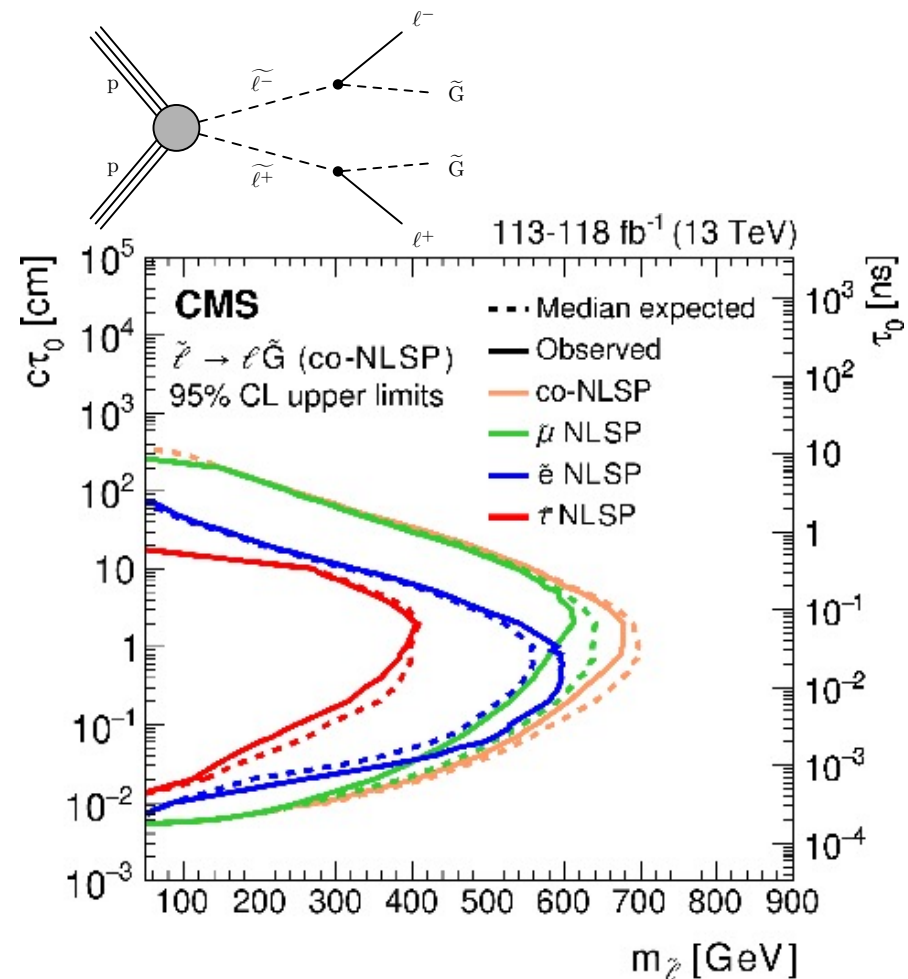
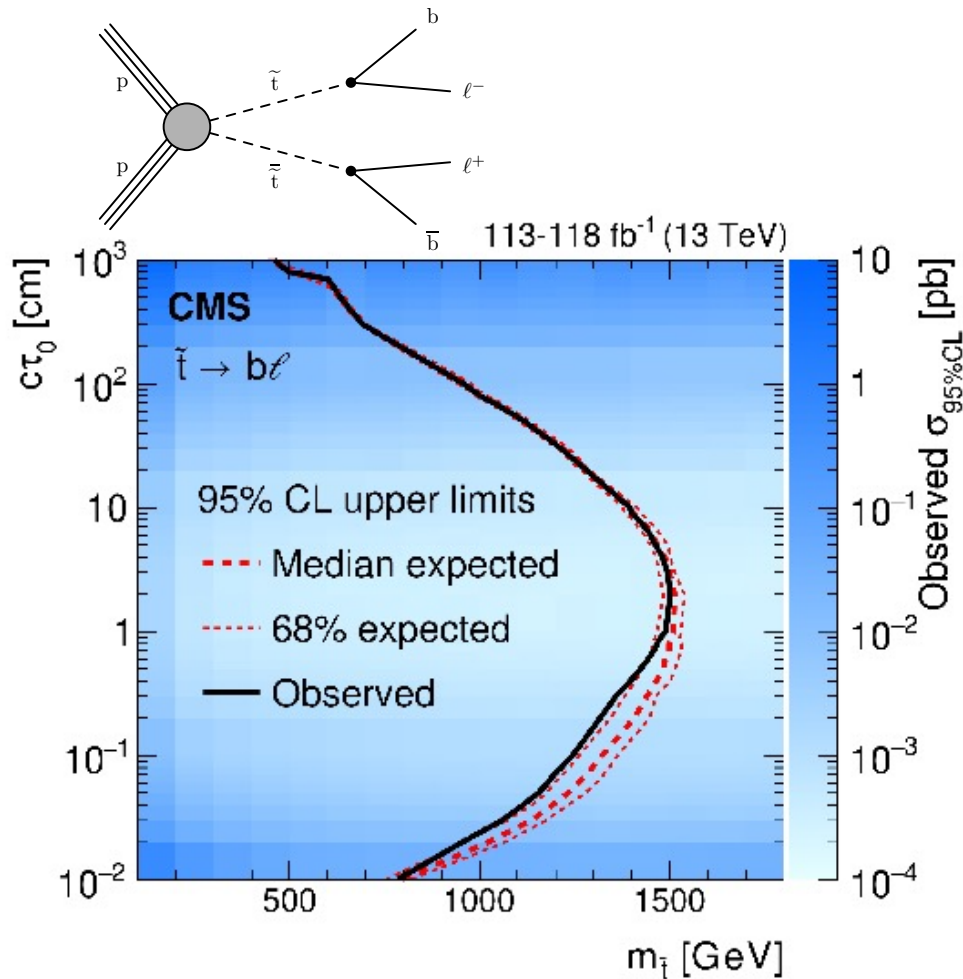


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CMS-EXO-18-003

→ Obtain constraints among most stringent to date for a range of BSM physics models involving new LLPs that decay to displaced leptons



Search for (LL) $\tilde{\tau}$ in all-hadronic final states [i]

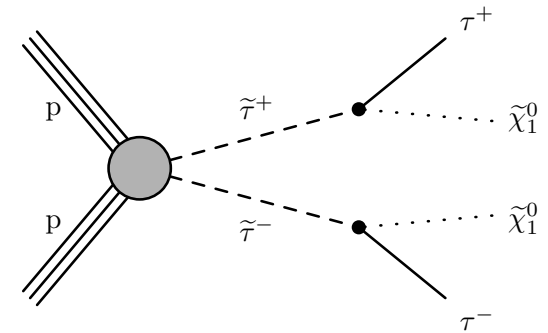


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[CMS-PAS-SUS-21-001](#)

- Search for $\tilde{\tau}$ in all-hadronic final states
 - $\tilde{\tau}$'s are produced in pairs
 - $\tilde{\tau}$ can be prompt, or **long-lived** (LL)
 - Each $\tilde{\tau}$ decays to $\tau + \tilde{\chi}_1^0$, or $\tau + \tilde{G}$
 - $\tilde{\chi}_1^0 / \tilde{G}$ is the lightest SUSY particle (LSP)
 - $\tilde{\tau}$ is the next-to-LSP (NLSP)
 - **Final states:** two hadronic τ 's + \vec{p}_T^{miss}



- Analysis strategy:
 - ❖ Select events with two isolated hadronic τ leptons + p_T^{miss}
 - ❖ For prompt $\tilde{\tau}$'s, categorize events in M_{T2} , N_{jets} , $\sum_i M_T(\tau_i)$, $p_T(\tau_1)$
 - ❖ For **LL** $\tilde{\tau}$'s, require large impact parameter and categorize in $p_T(\tau_2)$
 - ❖ Estimate SM background via data-driven techniques
- Look for excess wrt. SM prediction

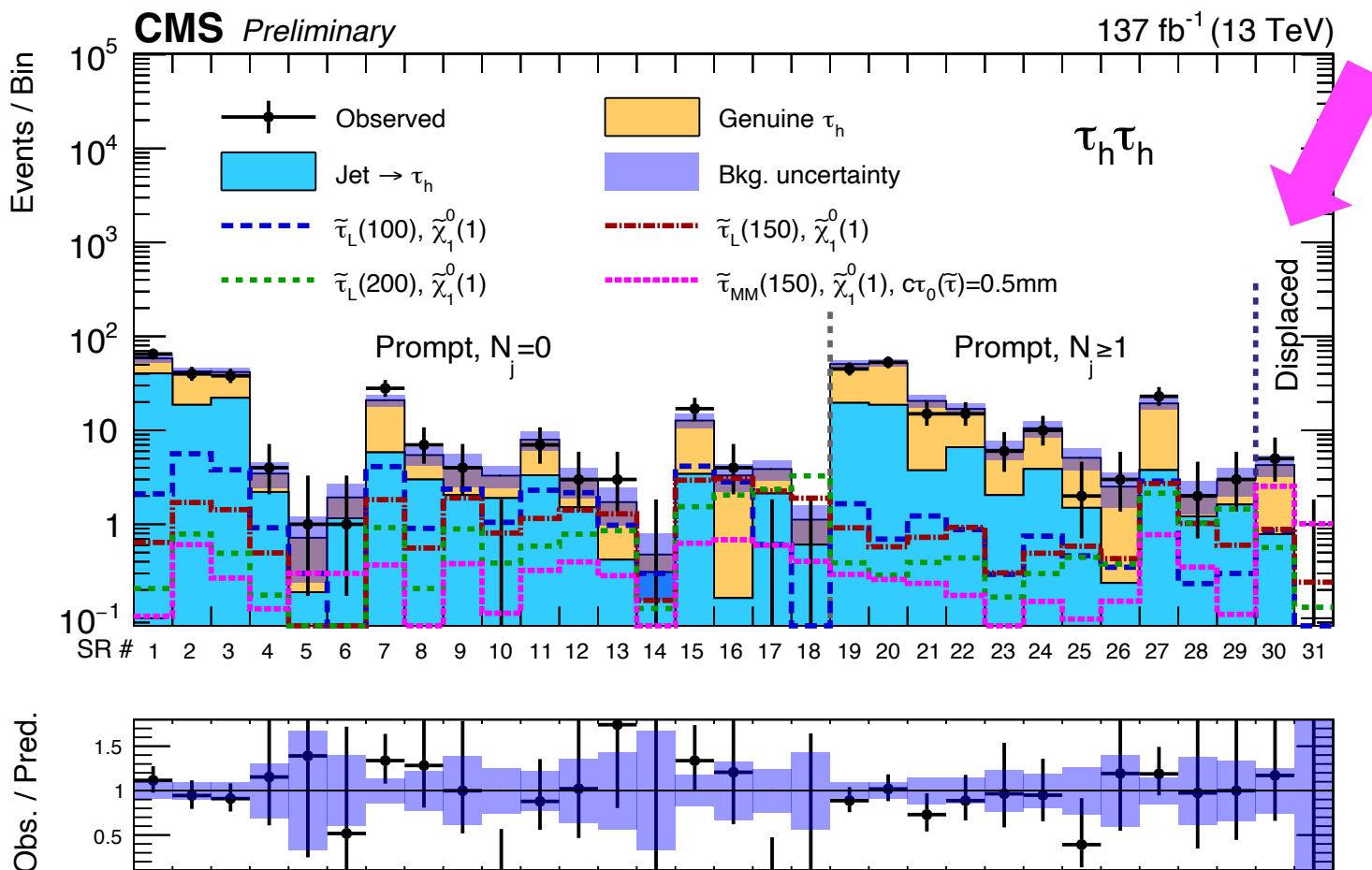
Search for (LL) $\tilde{\tau}$ in all-hadronic final states [ii]

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CMS-PAS-SUS-21-001

- NO significant excess in data
- Results are used to constrain models of BSM physics



Search for (LL) $\tilde{\tau}$ in all-hadronic final states [iii]

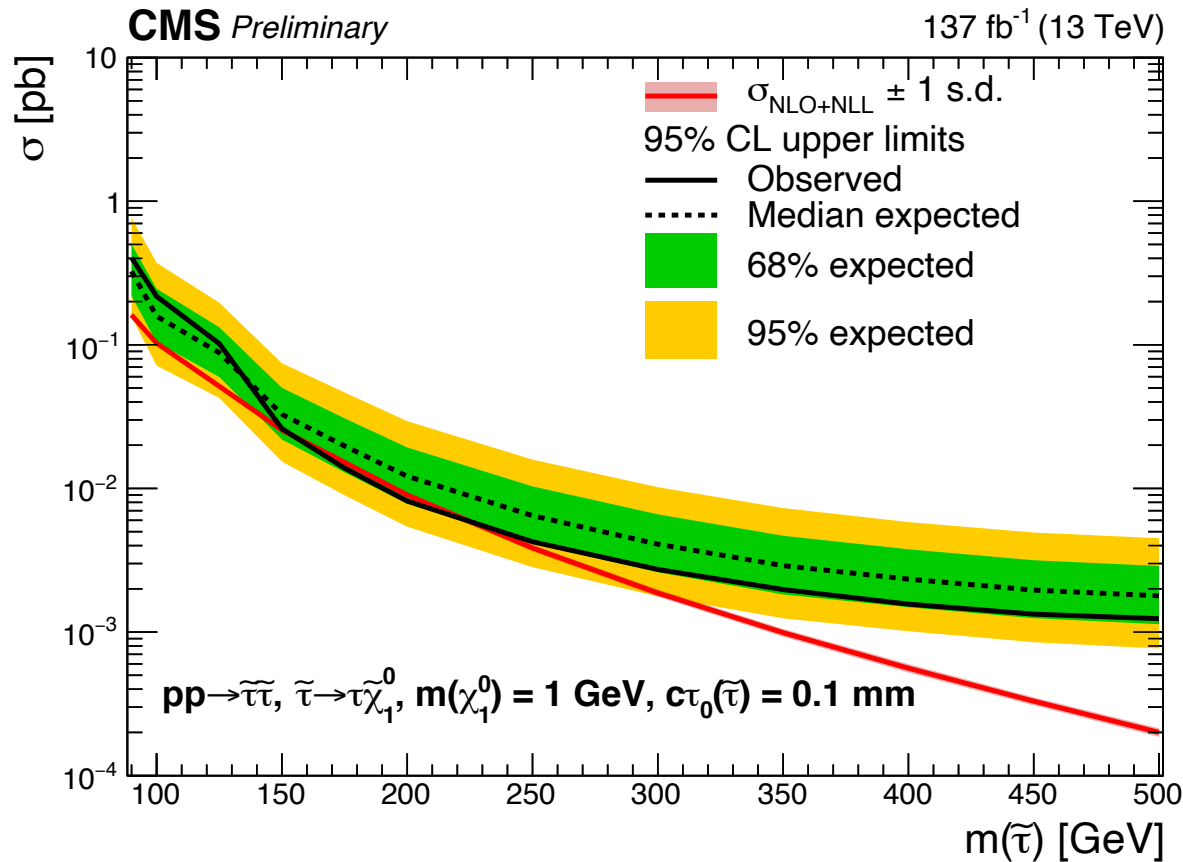


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[CMS-PAS-SUS-21-001](#)

→ In a scenario with $c\tau_0(\tilde{\tau})=0.1$ mm and a nearly massless LSP, exclude at 95% C.L. $\tilde{\tau}$ mass range [150, 220] GeV

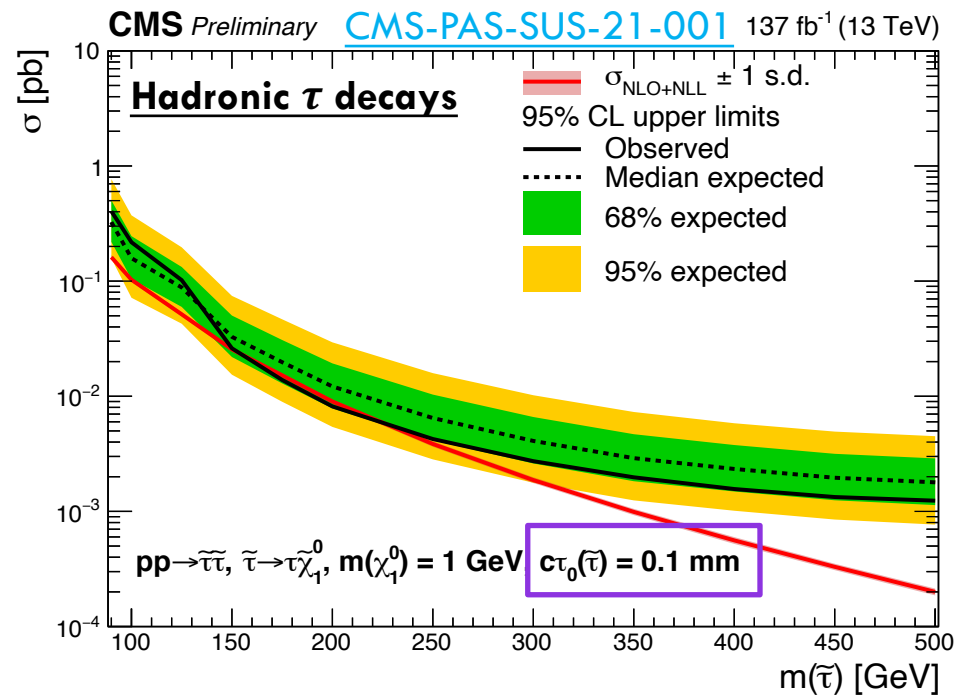
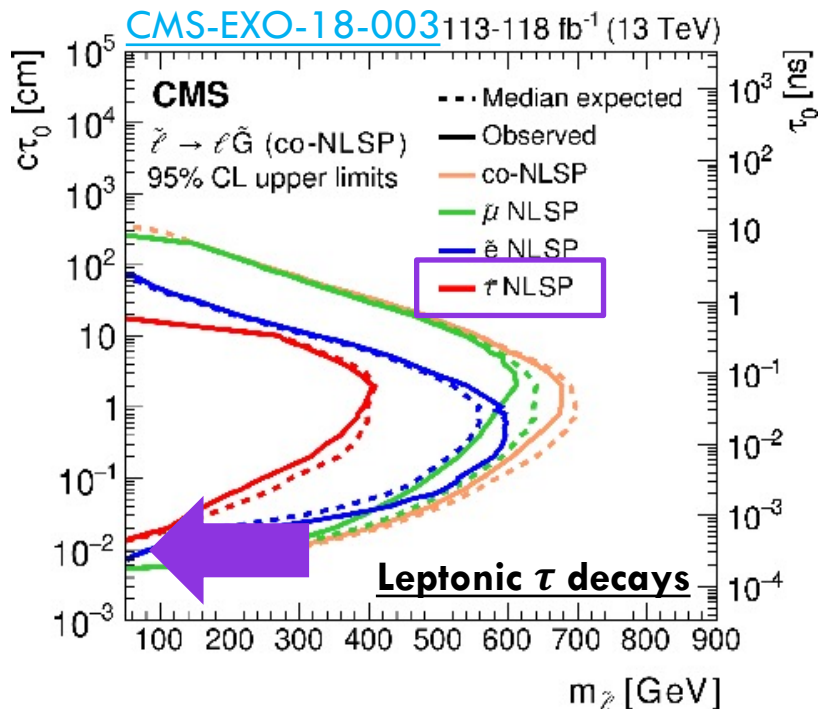


Displaced τ leptons: a comparison

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- Results from [CMS-EXO-18-003](#) and [CMS-PAS-SUS-21-001](#) are used to constrain a GMSB model of $\tilde{\tau} \rightarrow \tau + \text{LSP}$, where $\tilde{\tau}$ is long-lived
- The two results are found to be \sim **complementary**
 - [CMS-EXO-18-003](#): **inclusive** selection, using **specialized displaced lepton ID**
 - [CMS-PAS-SUS-21-001](#): **specific** target benchmark, with **NO** specialized ID for displaced (hadronic) τ leptons and with **modest displacement requirement**





Displaced τ leptons: a brief outlook

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- Work is on-going in order to improve sensitivity/reach of searches for displaced τ leptons across parent LLP mass and lifetime
- Few R&D directions towards the LHC Run-3:
- Improvement of displaced (τ) lepton **triggers**
 - Improvement of displaced (τ) lepton **identification**
 - Access/usage of **semi-leptonic final states**
 - ❖ As opposed to all-hadronic and/or all-leptonic

Search for LL HNLs in leptonic final states [i]

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CMS-PAS-EXO-20-009

- Search for **right-handed sterile HNLs**:

- Can be a Majorana or Dirac particle
 - ❖ If Dirac, lepton number (LN) is conserved
 - ❖ If Majorana, LN can be violated

- Interact with ν_{SM} via $\nu_{SM} \rightarrow N$ mixing

- Is produced in W -boson decays

- Decays only to $W\ell$ or $Z\nu$

- ❖ With $Z \rightarrow \ell\ell$ and $W \rightarrow \ell\nu$

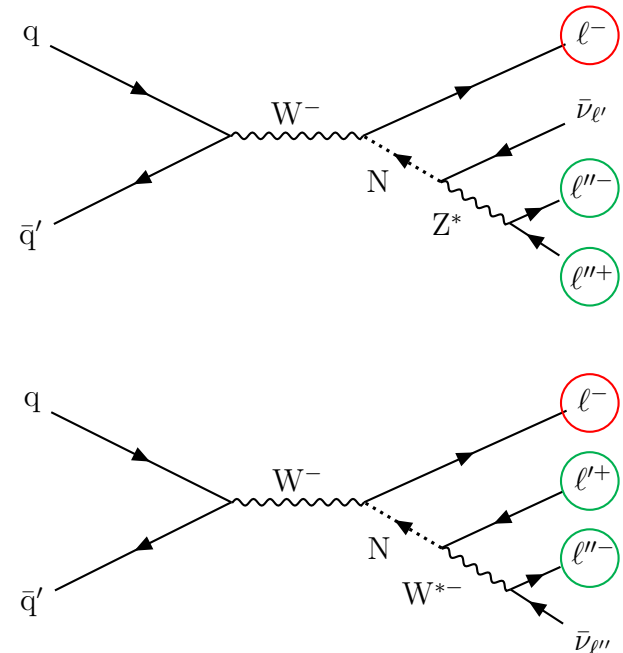
- **Final states with 3 ℓ** :

$$eee, e^\pm e^\mp \mu, e^\pm e^\pm \mu / \mu\mu\mu, \mu^\pm \mu^\mp e, \mu^\pm \mu^\pm e$$

- **Lifetime:** $\tau_N \propto \sum_i |V_{iN}|^{-2} m_N^{-5}$

- ❖ Lifetime is large at low mass and/or at low coupling

- One **prompt** + two **displaced** charged leptons



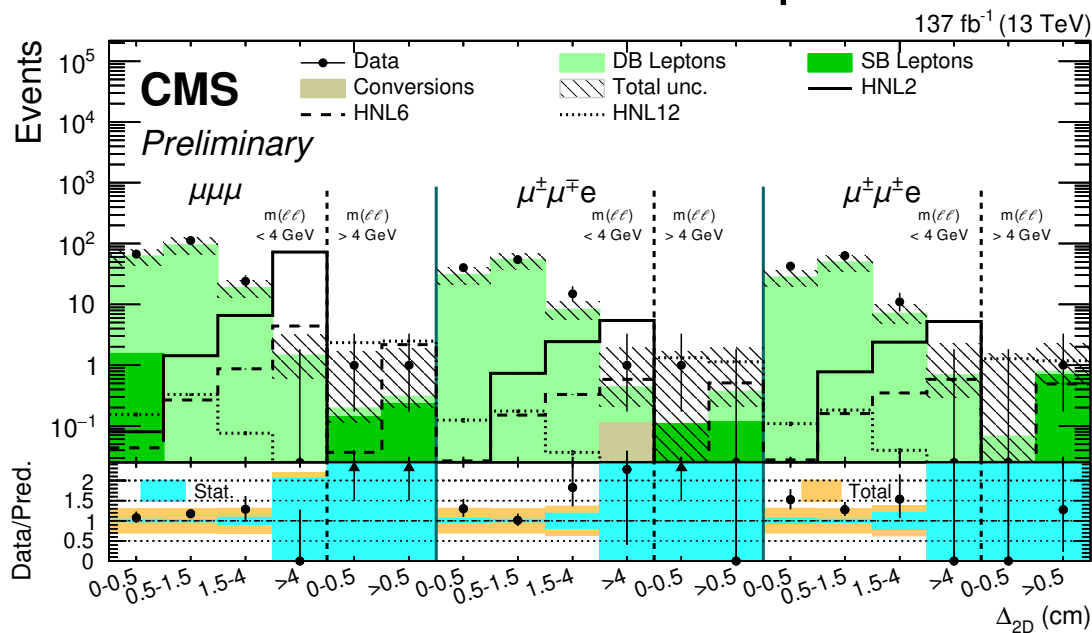
Search for LL HNLs in leptonic final states [ii]

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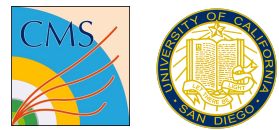
[CMS-PAS-EXO-20-009](#)

- Analysis strategy:
- ❖ Select events with one prompt + two displaced leptons
- ❖ In each three-lepton final state, categorize selected events
 - Transverse displacement of displaced lepton pair, Δ_{2D}
 - Dilepton invariant mass of displaced lepton pair, $m_{\ell\ell}$
- ❖ Estimate SM background using data control samples
- ➔ Look for an excess wrt. SM prediction



- NO significant excess
- ➔ Use results to constrain models of BSM physics

Search for LL HNLs in leptonic final states [iii]



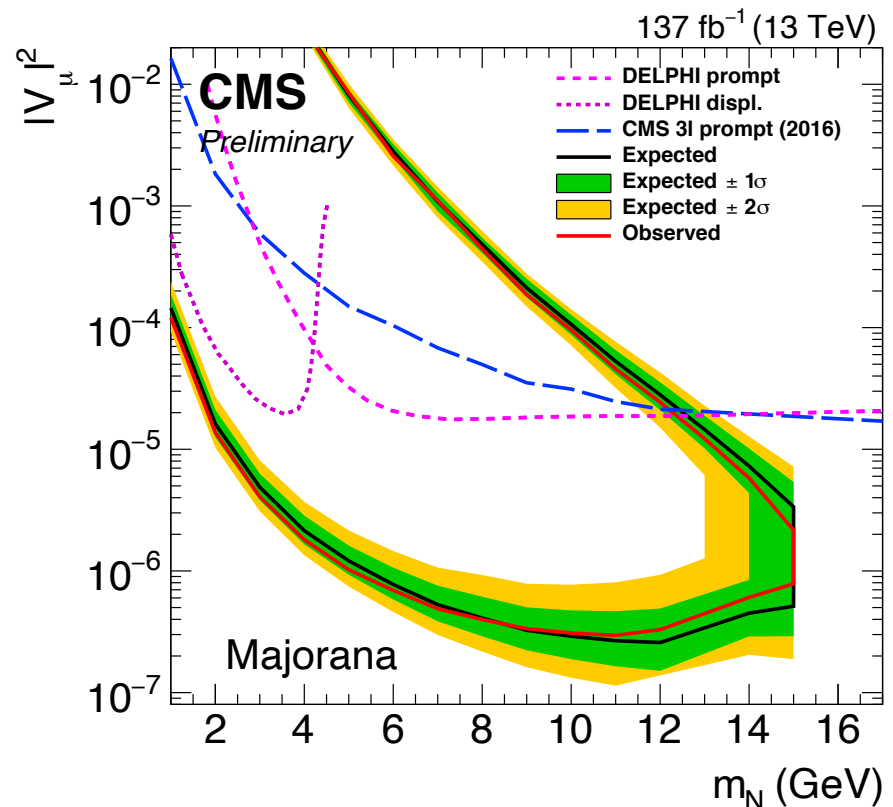
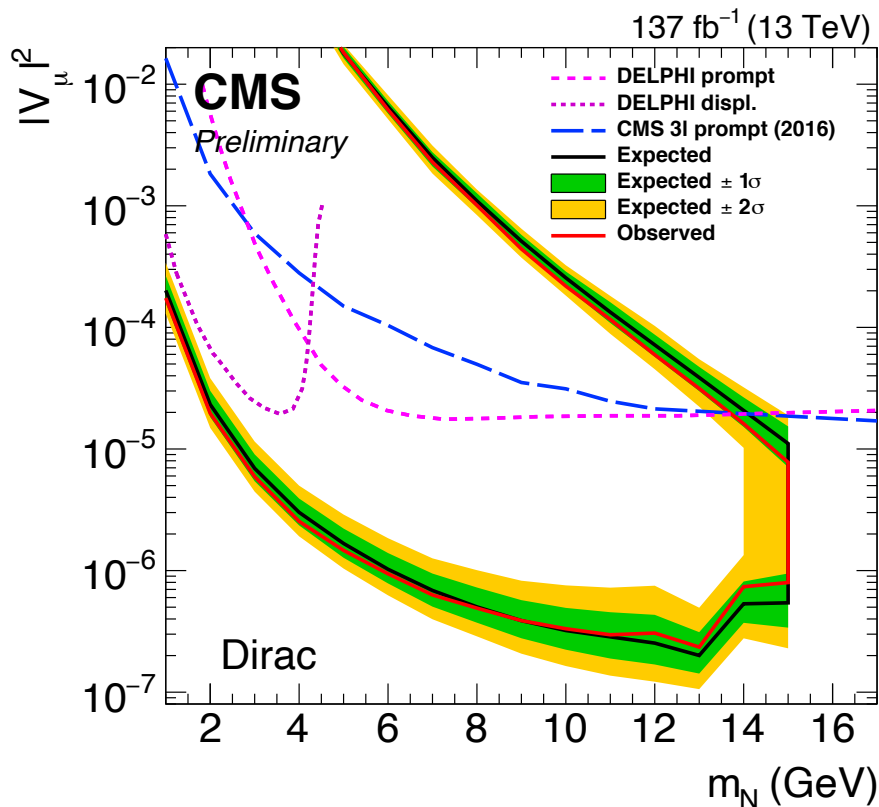
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[CMS-PAS-EXO-20-009](#)

→ Obtain constraints among most stringent to date

- Significant extension wrt. DELPHI and previous CMS results



Search for LL HNLs: a brief outlook

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- Work is on-going in order to improve sensitivity/reach of searches for LL HNLs across mass and lifetime

- **Lifetime:** $\tau_N \propto \sum_i |V_{iN}|^{-2} m_N^{-5}$

➤ Lifetime is large:

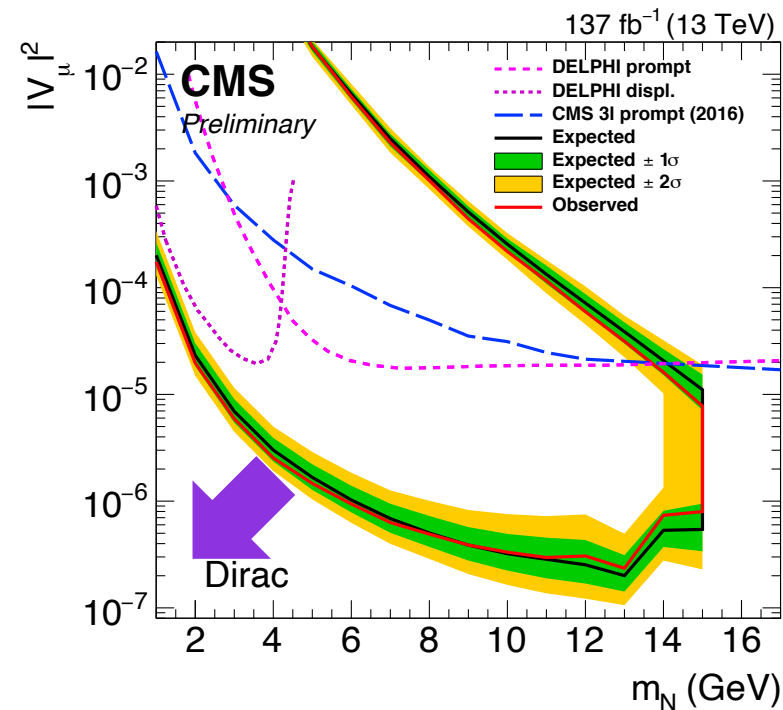
1. At low mass
2. At low coupling

→ Target **semi-leptonic final states**, too

- Larger branching fraction
- Larger (challenging) backgrounds
- ❖ In addition to 3-lepton channel

→ Use **B parking data** ([backup](#)) and/or **decays in the muon system**

- To improve sensitivity towards lower mass range





Summary & outlook

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- The CMS LLP search program using Run-2 data is progressing well
 - Today, a snapshot of three new results since last LLP workshop:
 - Search for LLPs in ee , $e\mu$ and $\mu\mu$ final states
 - Search for (LL) $\tilde{\tau}$ in all-hadronic final states
 - Search for LL heavy neutral leptons in leptonic final states
 - ❖ Dedicatated / detailed presentations [tomorrow](#)
 - More Run-2 results are in the pipeline!
- **Outlook**, towards the LHC **Run-3** (and beyond):
 - LLPs will be at the center of the Run-3 CMS search program
 - CMS trigger strategy will be extensively developed in Run-3
 - ❖ In terms of trigger selection and object reconstruction
 - ❖ Including high-rate scouting ([backup](#)) & B parking triggers ([backup](#))
 - Unprecedented chance to search so far unexplored phase-space!

The end... till the LHC Run-3



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THANK YOU

Backup



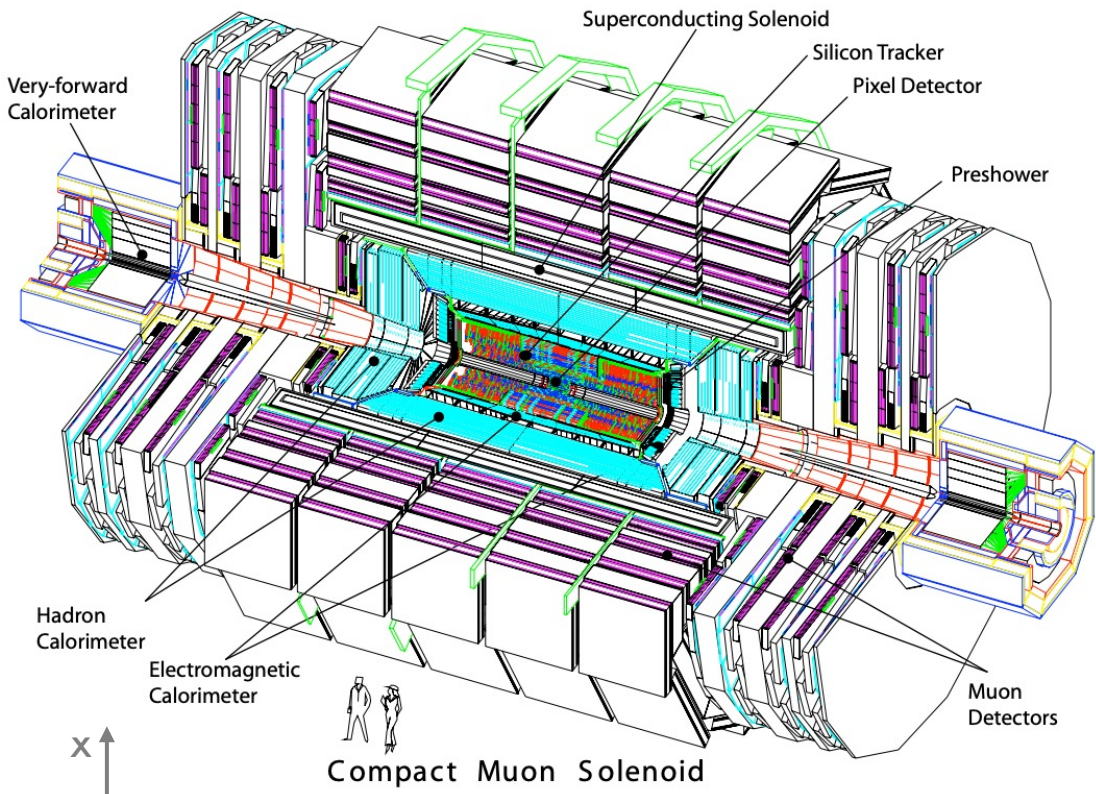
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The CMS detector

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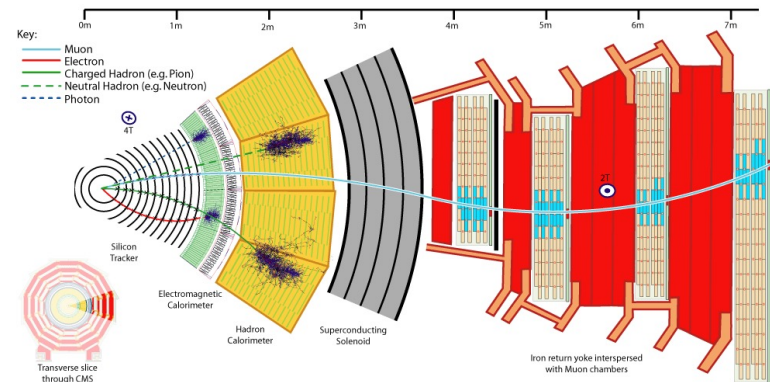
- The CMS detector at the LHC:



From: [CERN-LHCC-2006-001](https://cds.cern.ch/record/2006001)

→ Main features:

- Highly granular tracking system
- Electromagnetic+hadron calorimeter
- Superconducting solenoid ($B = 3.8 \text{ T}$)
- Robust and redundant muon system



From: [CMS-OUTREACH-2016-027](https://cds.cern.ch/record/2016027)

The CMS trigger system

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- Collision data delivered by LHC and collected by the CMS detector are filtered by a two-level trigger system:
 1. Level-1 Trigger (L1T)
 2. High Level Trigger (HLT)

} ⇒ Total rate reduction by $\sim 10^6$
- Only events selected at HLT are then fully reconstructed offline, due to constraints on computing and storage resources



The CMS scouting triggers

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- **Data scouting**, used in CMS since 2011:
 - **Idea:** “Do more, with less”
 1. **Increase of trigger acceptance rate**
 - ❖ Looser (more inclusive) selections
 2. **Decrease of event size**, to compensate
 - ❖ Keep only HLT-level information
 - Similar streams were used by ATLAS and LHCb during LHC Run-2
- **Unprecedented potential for LLP searches at CMS**
- ❖ The **CMS scouting triggers** will be in use during the LHC **Run-3**
 - With significant improvement/extension wrt. Run-2

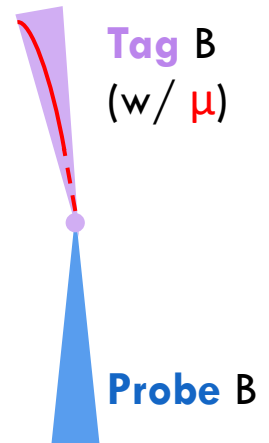
The CMS B physics parking program



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- Alternative/complementary approach to scouting data to cope with limited trigger acceptance, with focus on **B physics anomalies**
- **Unbiased** sample of $O(10^{10})$ B's was collected during LHC Run-2
 1. Trigger on **muon** from “tag” B
 2. Collect unbiased sample of “probe” B's
 - Collected data are “**parked**”
 - Undergo full offline reconstruction at later stage, to deal with limited computing resources



→ **Unprecedented potential for B physics in CMS**

- Including searches for BSM (LLP) signatures

❖ The **CMS B parking triggers** will be in use during the **LHC Run-3**