Indirect Long Lived Particles searches at LHC

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On behalf of the ATLAS and CMS collaborations

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New physics, unconventional searches?

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While the SM is in excellent agreement with the LHC measurements, many problems should be still resolved ⇒ BSM (SM) scenarios exist to cover the limitations of it.

The new particles can either be:

- Prompt decaying —> standard SUSY-EXOTICA searches
- **Long-Lived Particles (LLPs), decay in the detector**
- Detector-stable (decay outside the detector) and stable

So we should be ready for **unconventional signature** searches even though ATLAS and CMS were initially designed to optimize object identification for prompt particles

Challenges:

- Trigger:
  - Suboptimal triggers
  - Timing information not always available
- Reconstruction
  - Secondary vertex finding algorithms
  - interaction point constraint in triggering/reconstruction
- Backgrounds:
  - instrumental background
  - Cosmic rays
  - In-time out-of-time pileup
  - Long-lived standard model hadrons

Unconventional signatures

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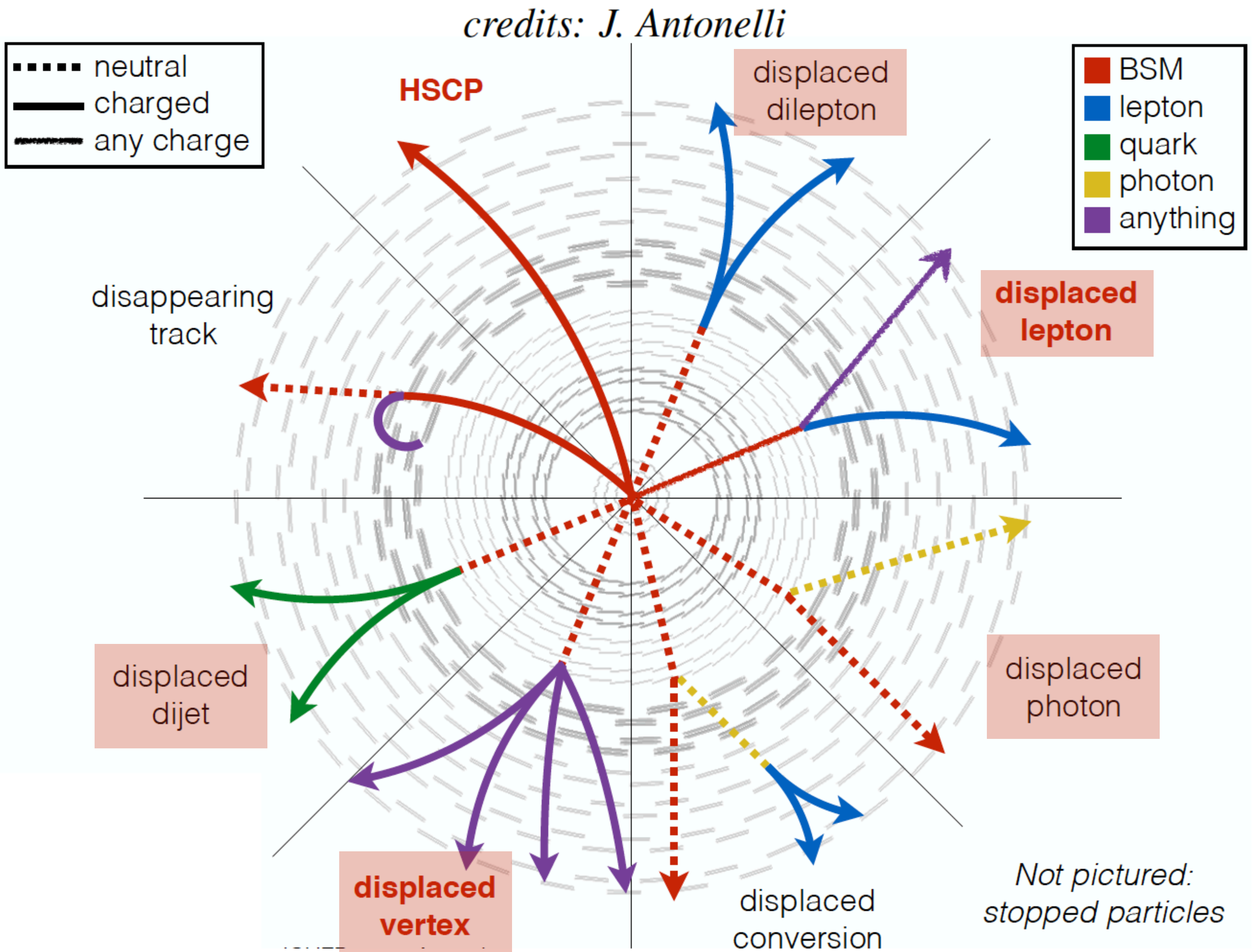
Long-lived particles (LLP) could be foreseen by several models due to:

- **Small coupling constants** --- e.g., RPV SUSY, HNL etc
- **Very off-shell intermediate decay products** --- e.g., split SUSY where heavy intermediate squarks enhance the gluino lifetime
- **Limited decay phase space** --- e.g., Anomaly mediated SUSY breaking model where the lightest neutralino and chargino are nearly degenerate



Covered in this talk

R-parity violating SUSY scenario

Displaced muons and vertices (DV)

ATLAS-CONF-2019-006

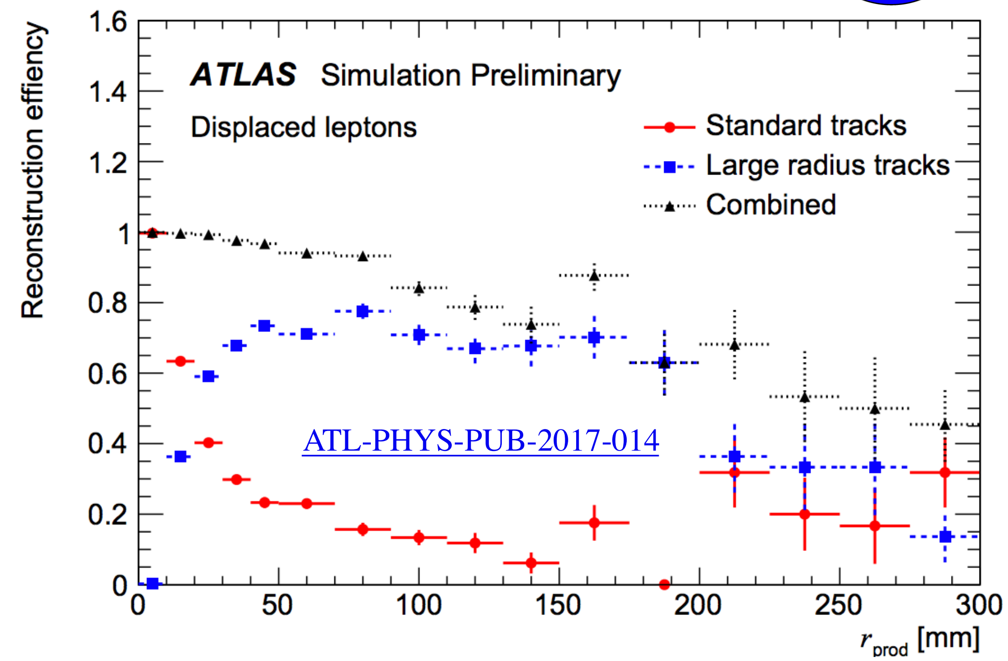
Run2 data

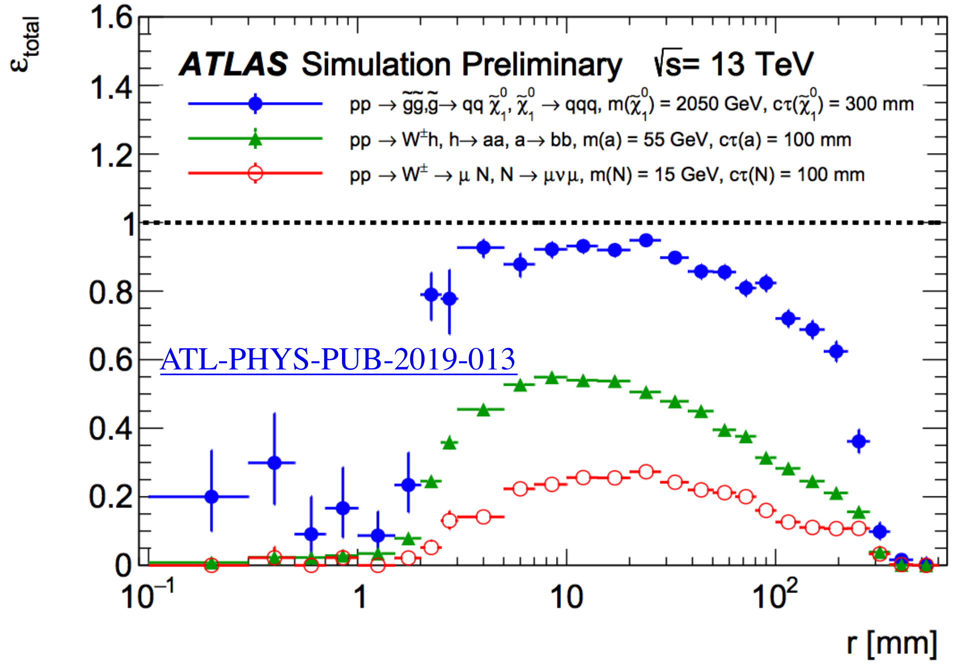
Search for long-lived particles decaying into at least one displaced muon and a displaced vertex with at least three tracks and a visible invariant vertex mass of at least 20 GeV.

Dedicated event reconstruction

→ **Large-radius** tracking (**LRT**) algorithm

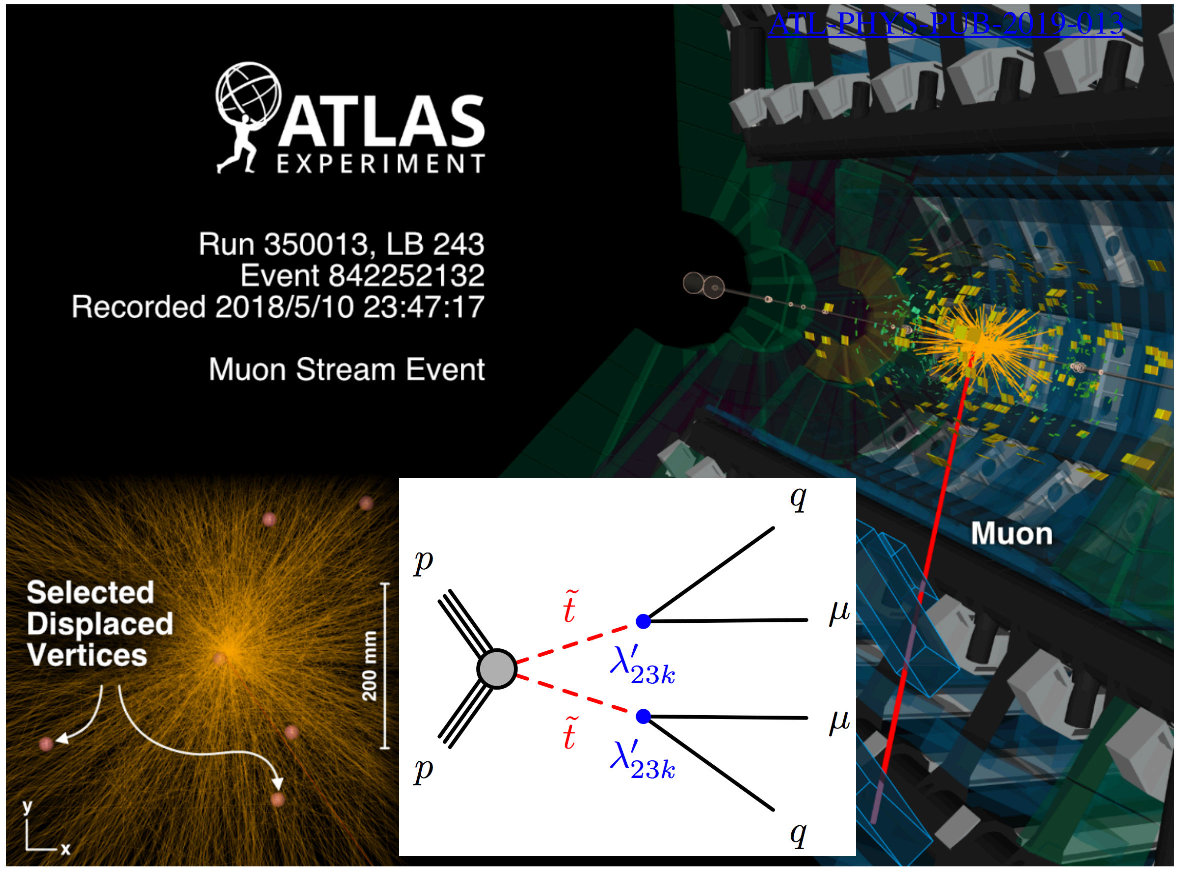
- Larger d_0 ~300 mm (wrt standard reconstruction)
- computer-intensive, can be run only on a limited fraction of the RAW data → "filter" selection





Event selection

- either E_T^{miss} trigger (> 180 GeV offline) or μ-trigger (pT > 60 GeV)
- Cosmic muon veto to eliminate high-mass vertices from a single cosmic-ray muon which is reconstructed as two back-to-back muons
- Fake-muon veto to remove accidental reconstruction μ
- Heavy-flavor veto



Displaced muons and vertices (DV)

ATLAS-CONF-2019-006

ATLAS EXPERIMENT

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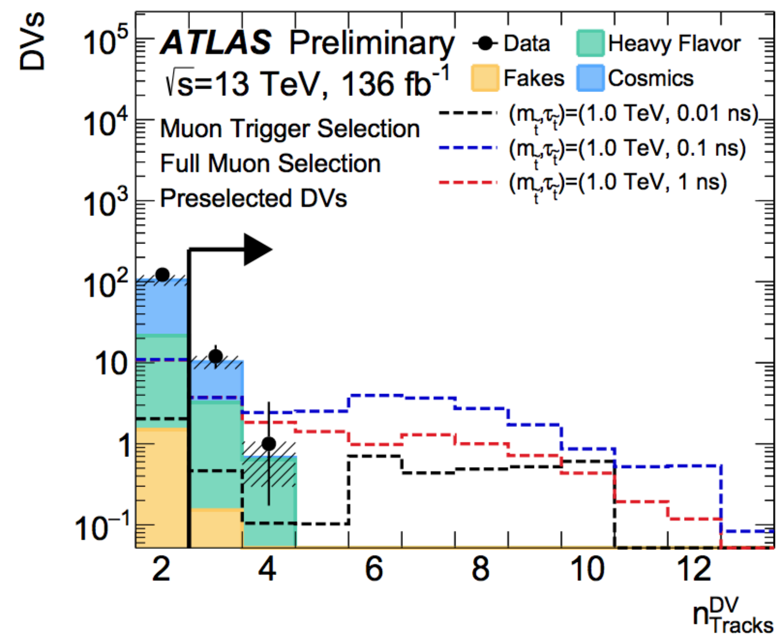
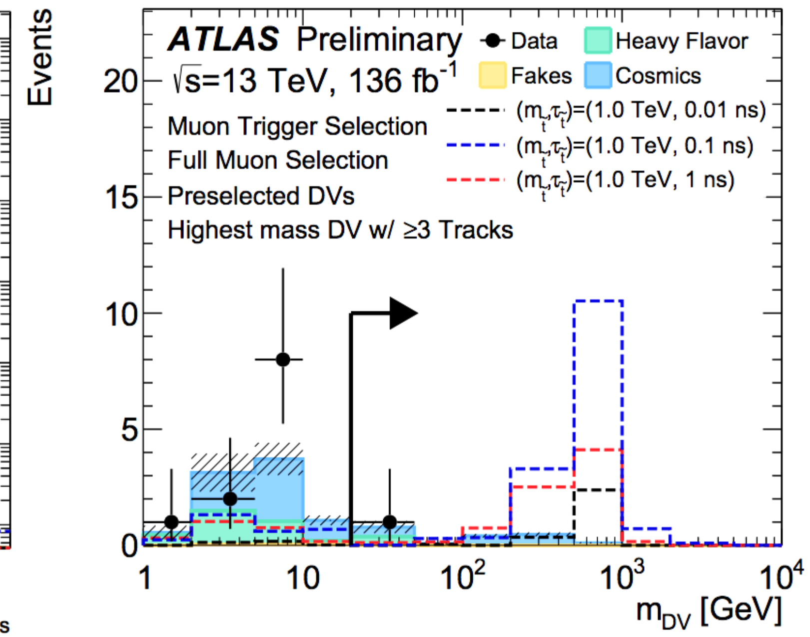
Run2 data

Background estimation

Sources of background for DVs include material interactions and randomly intersecting tracks, suppressed by requiring

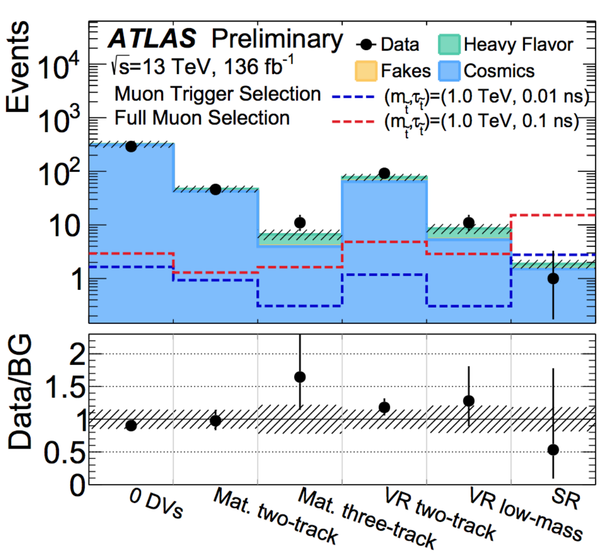
- m_{DV} > 20 GeV and #tracks in DV ≥ 3

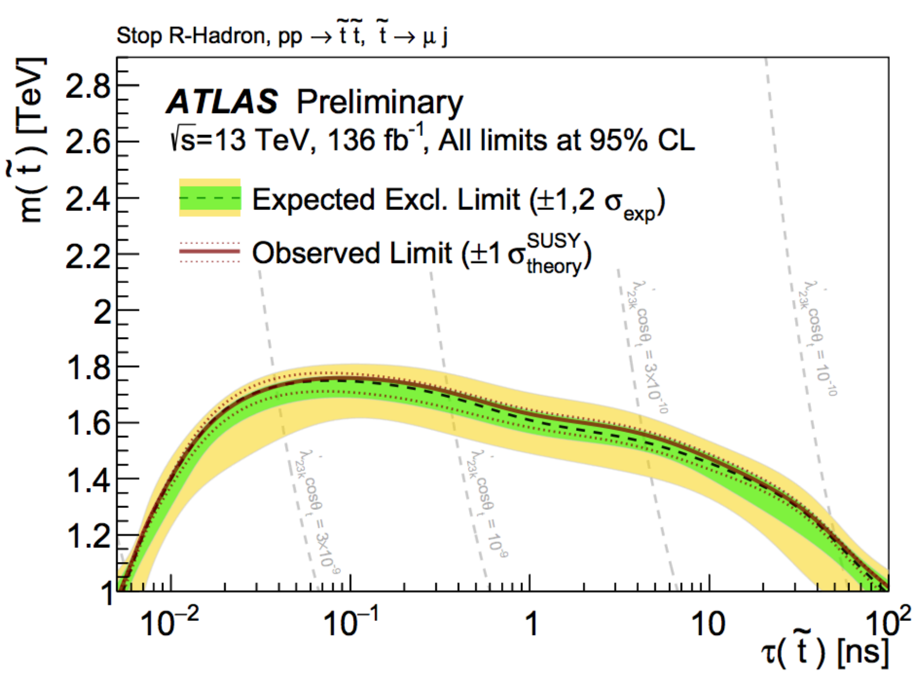


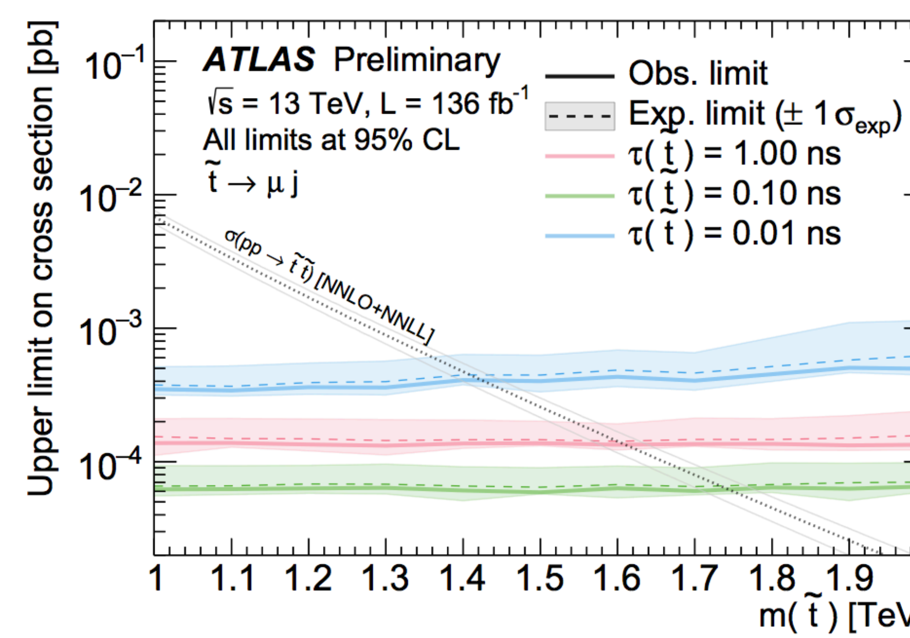


Results and interpretation

- $E_{\mathrm{T}}^{\mathrm{miss}}$ SR: $0.43 \pm 0.16 \pm 0.16$ exp, 0 obs
- μ SR: $1.88 \pm 0.20 \pm 0.28$ exp, 1 obs
- results are interpreted in **top-squark RPV scenario**
- **top-squark masses are excluded up to 1.7 TeV for a wide range of lifetimes**
- prompt searches are able to probe up to 1.2 TeV





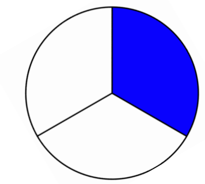


Search with displaced di-leptons

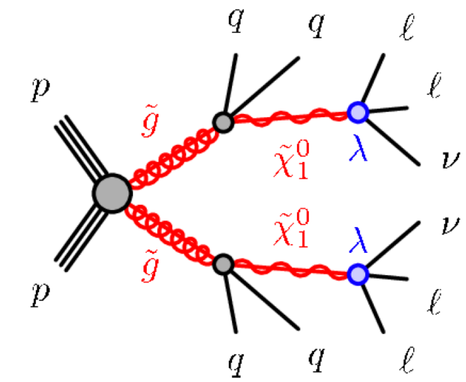
ATLAS-SUSY-2017-04

New

Run2 data

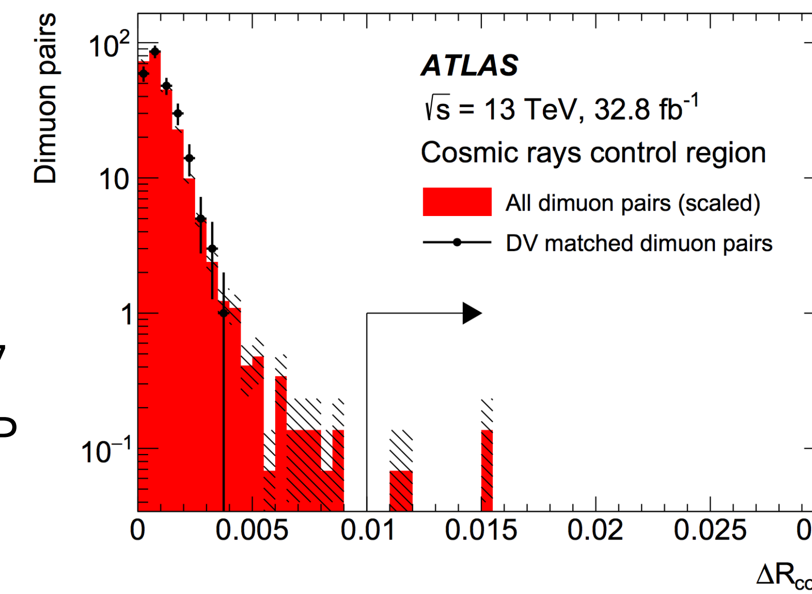


Search for long-lived particles decaying into an oppositely charged lepton pair, μμ, ee, or eμ, which are required to form a vertex, within the inner tracking volume of ATLAS.



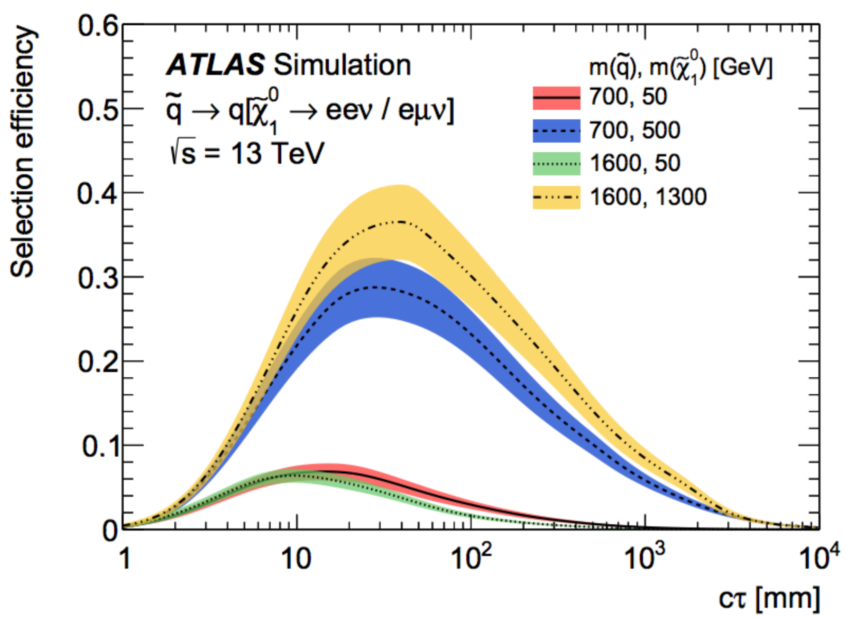
Main features

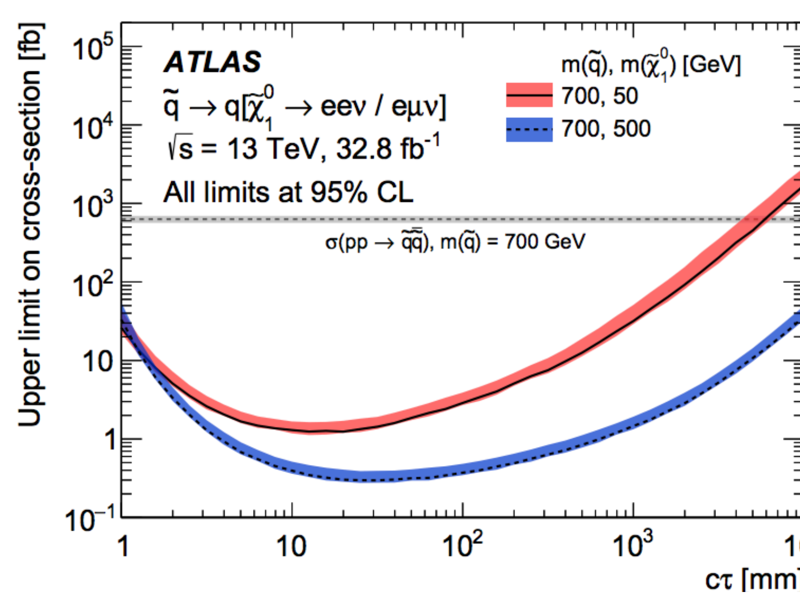
- Dedicated event reconstruction → LRT algorithm
- Either μ trigger (pT > 60 GeV) or γ trigger (pT > 140 GeV single, pT > 50 GeV double γ)
- Main background:
  - Cosmic μ → cosmic muon veto
  - Random crossing of two uncorrelated leptons

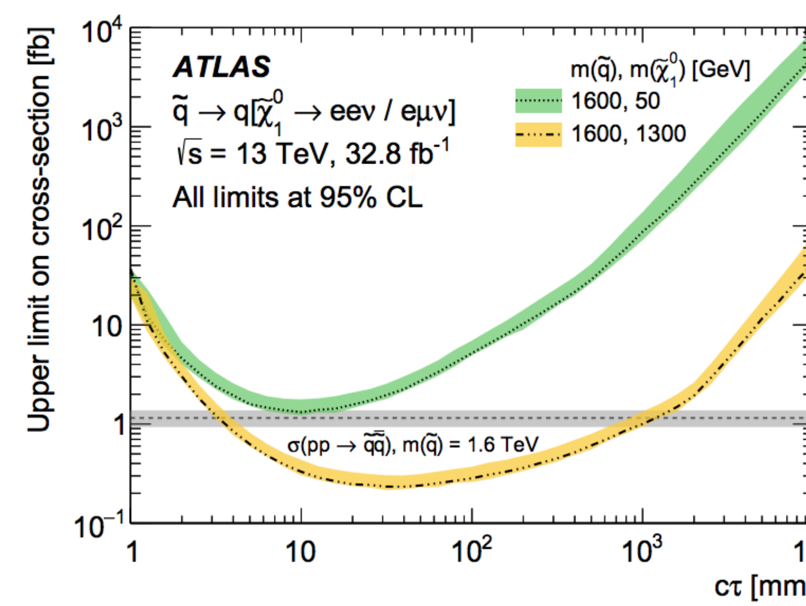


Results and interpretation

- No events are observed, consistent with the estimated bkg of 0.27 ± 0.17
- Two independent scenarios are considered, each corresponding to an LSP decay that is mediated by a single dominant RPV coupling, λ_{121} or λ_{122}







Gauge-mediated supersymmetry breaking scenario

Search with nonprompt jets and MET

Submitted to PLB **arXiv:1906.06441**

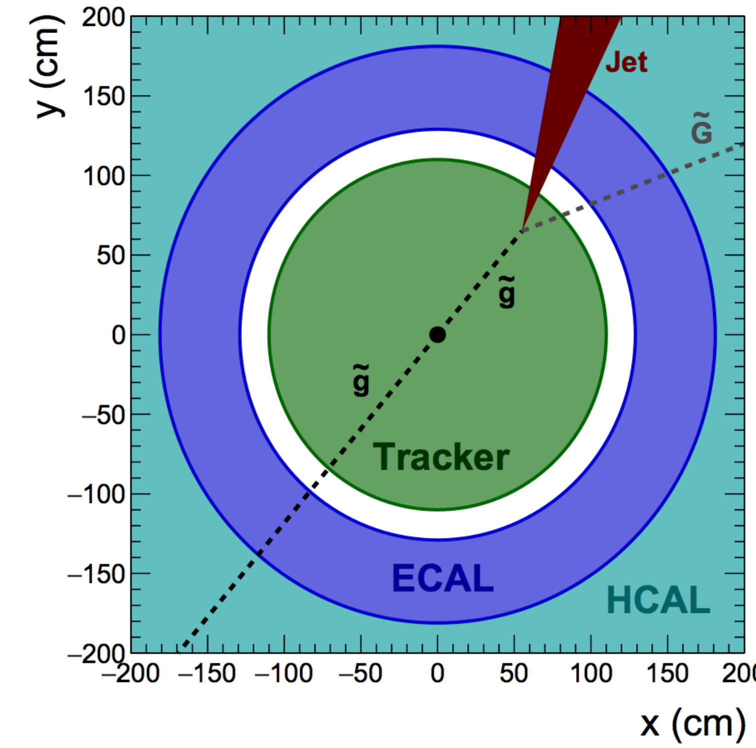
CMS GHENT UNIVERSITY

Run2 data

Search for long-lived particles leading to missing transverse momentum and displaced, nonprompt jets which are identified using the timing capabilities of the CMS electromagnetic calorimeter.

Reconstruction and identification

- Shower would arrive late at the ECAL → use **ECAL timing** (σ ~ 100ps)
- Targeting decays **beyond the acceptance of the tracker → (0.5-1.5 m)**
- Events collected with a trigger requiring E_T^{miss} > 120 GeV

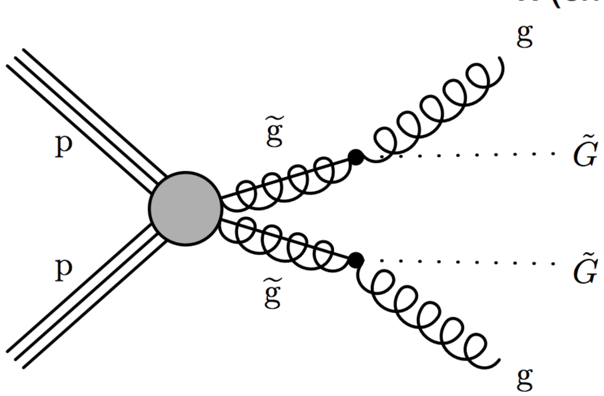


Selection and backgrounds

The selection criteria are optimized taking into account the principal background sources that produce delayed timing signals, which are:

- Direct interactions with ECAL front-end
- Satellite bunches
- Beam halo deposits in ECAL
- Cosmic muon deposits in ECAL → Dominant
- Noise deposits

→ predicted from data with independent ABCD methods



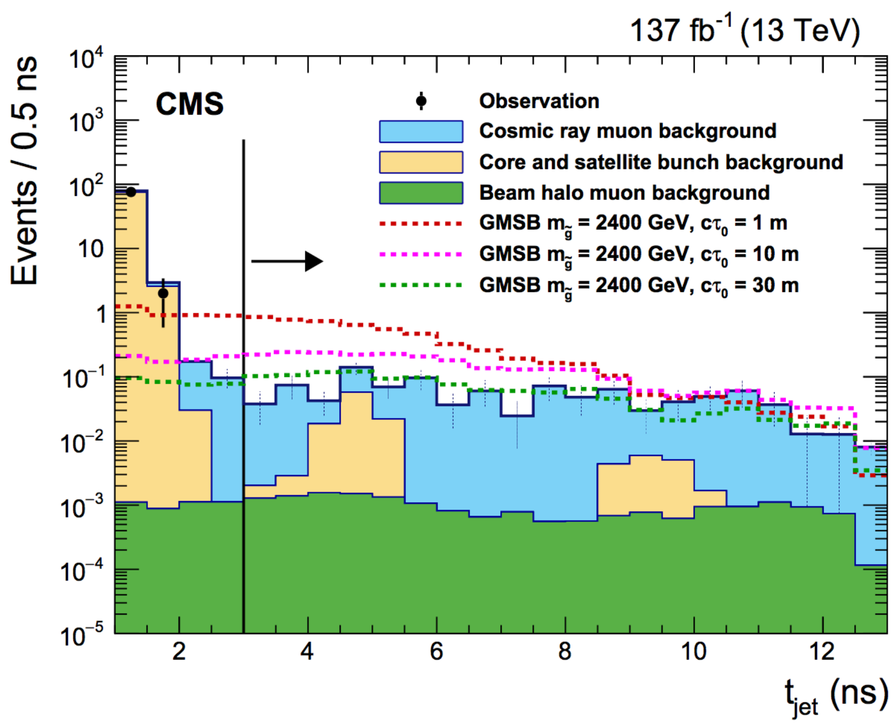
- Offline E_T^{miss} > 300 GeV → to reject multijet production from core and satellite bunch collisions;
- The timing and position informations of the DT and RPC muon systems → background cosmic ray muons

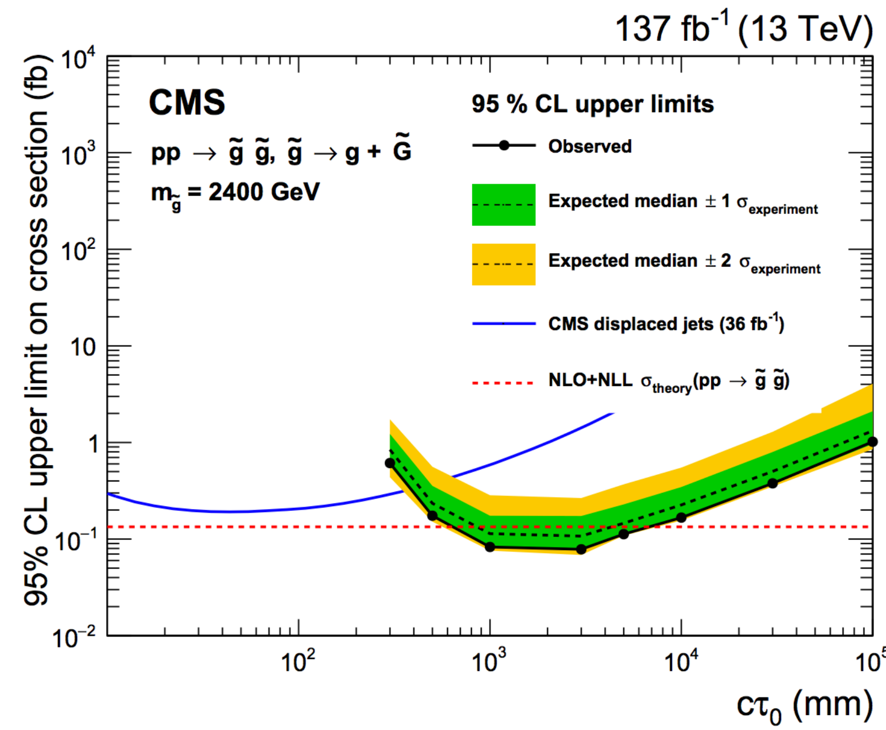
Search with nonprompt jets and MET

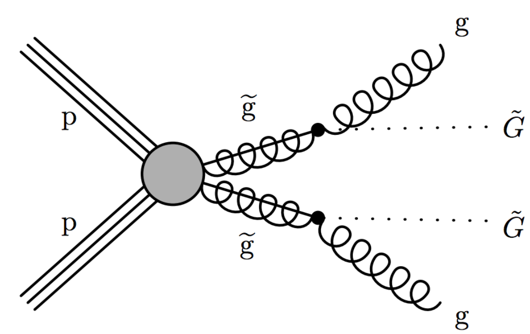
Submitted to PLB **arXiv:1906.06441**

Run2 data

HEP DATA entry

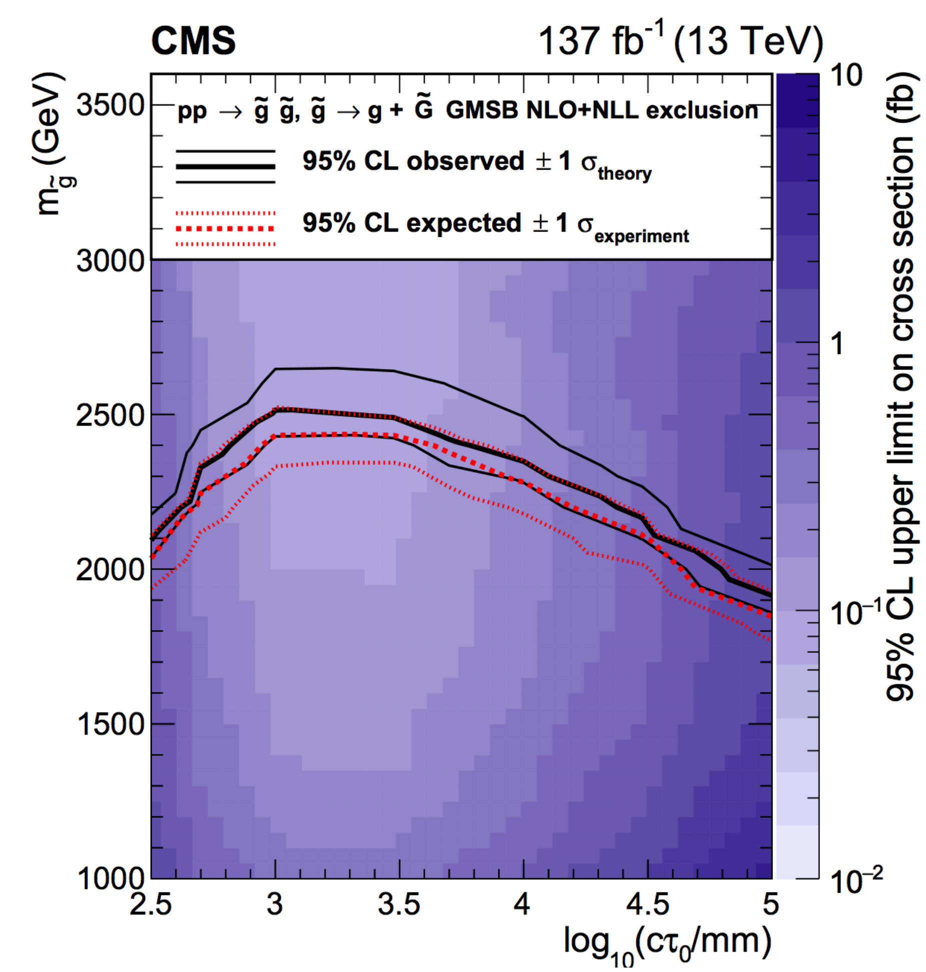






Results and interpretation

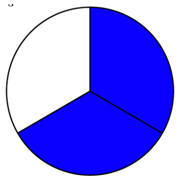
- Jet time — median time of all matched ECAL cells satisfying quality criteria, for SR > 3ns
- The overall background prediction for the SR is $1.1^{+2.5}_{-1.1}$ events, which is consistent with the observation of 0 events
- results are interpreted in **GMSB SUSY model in which gluinos are pair produced and form R-hadrons**
- **gluinos masses excluded up to 2.5 TeV**
- prompt searches are able to probe up to 2.2 TeV



Search with delayed photons

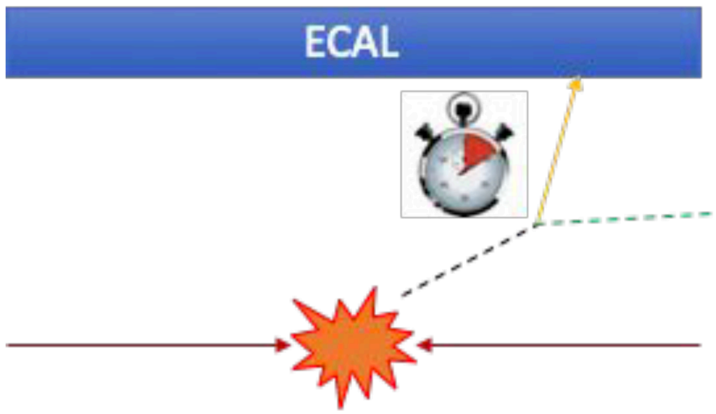
New

Run2 data

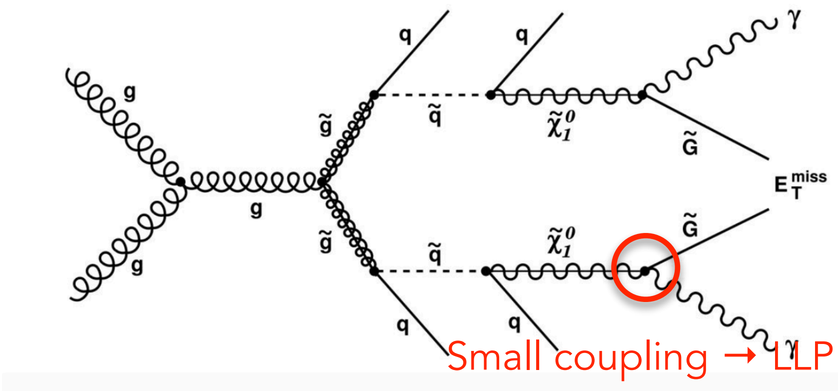


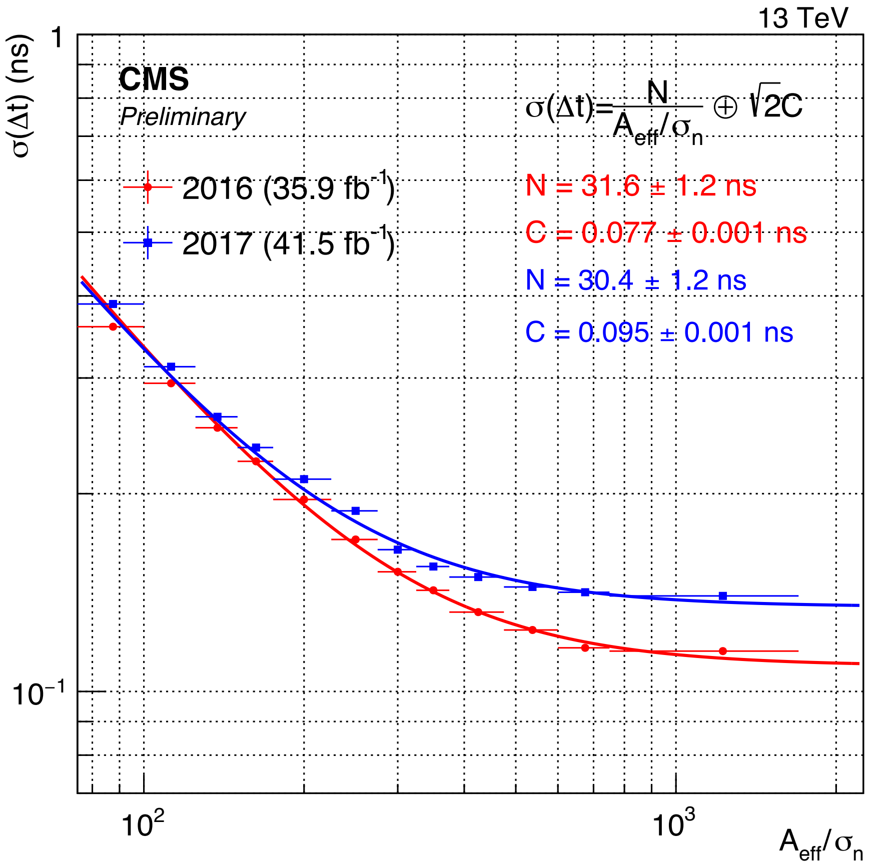
Search for long-lived particles decaying to photons. The study exploits the capability of the CMS ECAL to measure photon arrival times with high precision to detect signatures of late-arriving photons produced at displaced vertices.

Reconstruction and identification



- **Out-of-Time (OOT) photons**: dedicated photon collection built from ECAL rechit seeds explicitly flagged out-of-time (more than 3ns)
- Triggers:
  - 2016: at least two γ passing custom out-of-time γ identification, 95% efficient in signal after offline selection
  - 2017: customized displaced photon + H_T trigger, 99.9% efficient in signal after offline selection





Selection variables

- **Photon time reconstruction**: time of arrival of the photon at the ECAL
  - calculated on a weighted sum of the timestamps of each ECAL crystal in the photon cluster
  - Weighted by ECAL time resolutions obtained from dedicated measurement as a function of effective crystal amplitude

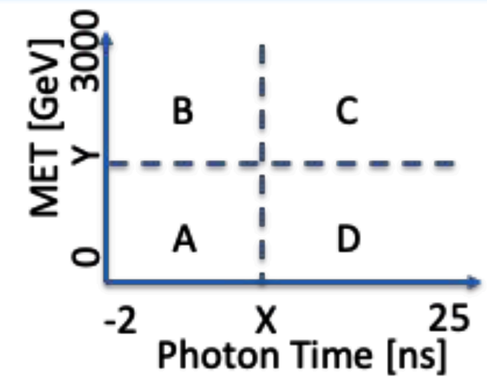
Search with delayed photons

CMS-EXO-19-005

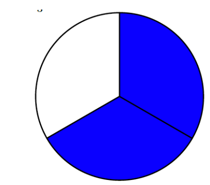
New

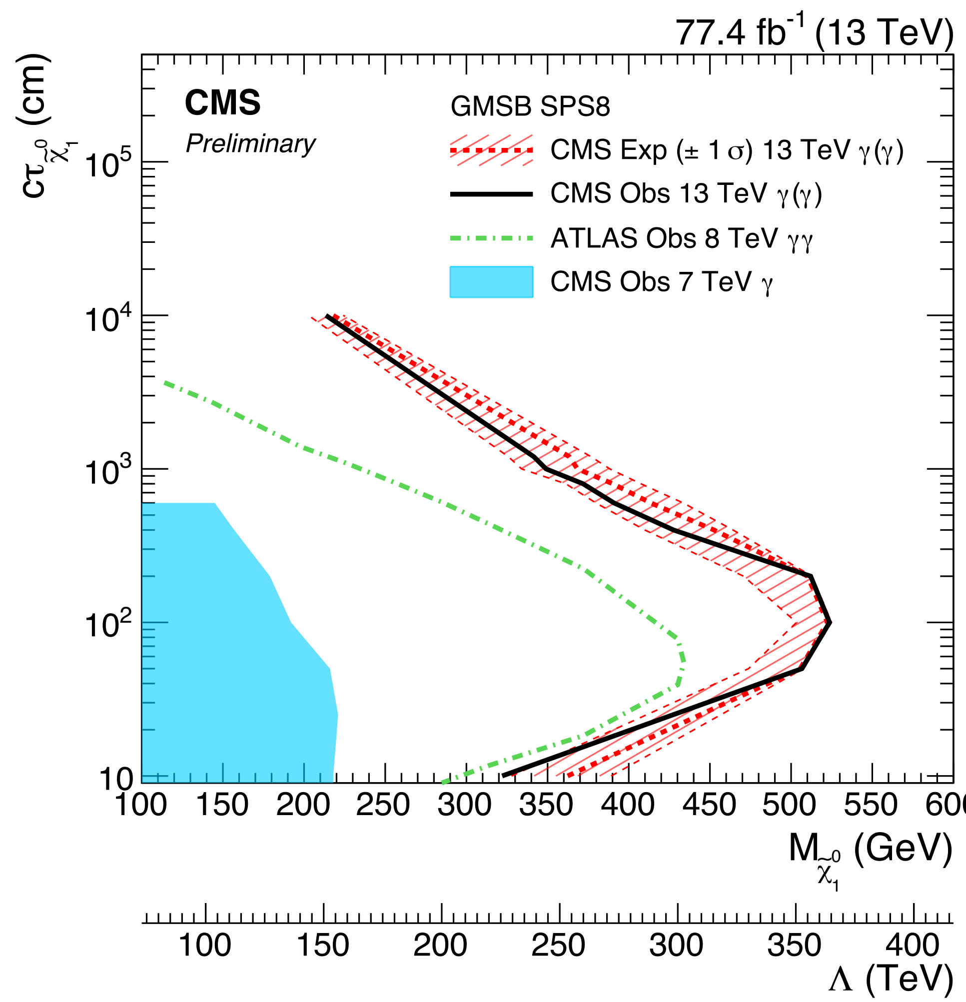
Background estimation

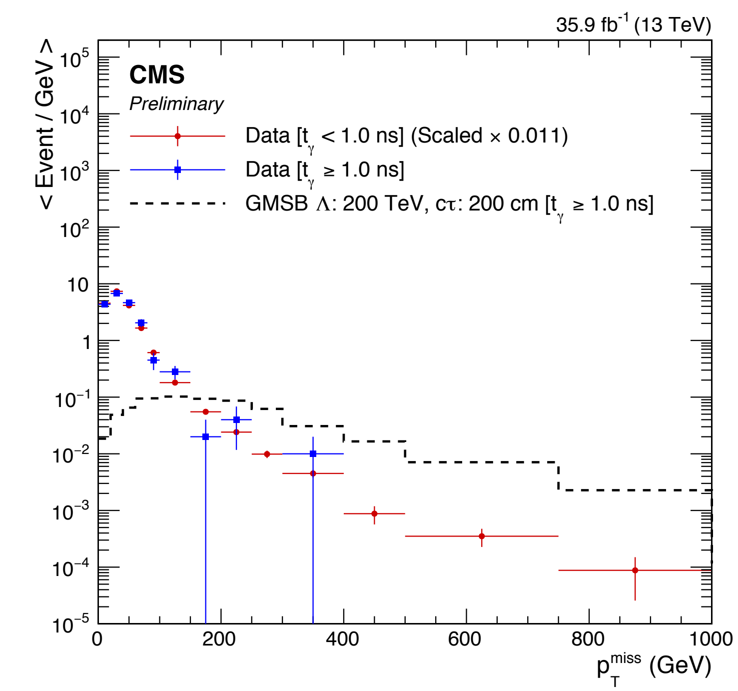
- Derived from data using *ABCD* method. The background components are obtained performing a simultaneous fit that is constrained to obey the standard ABCD relationship, within the bounds of a small systematic uncertainty derived from a validation check of the method in a control region.

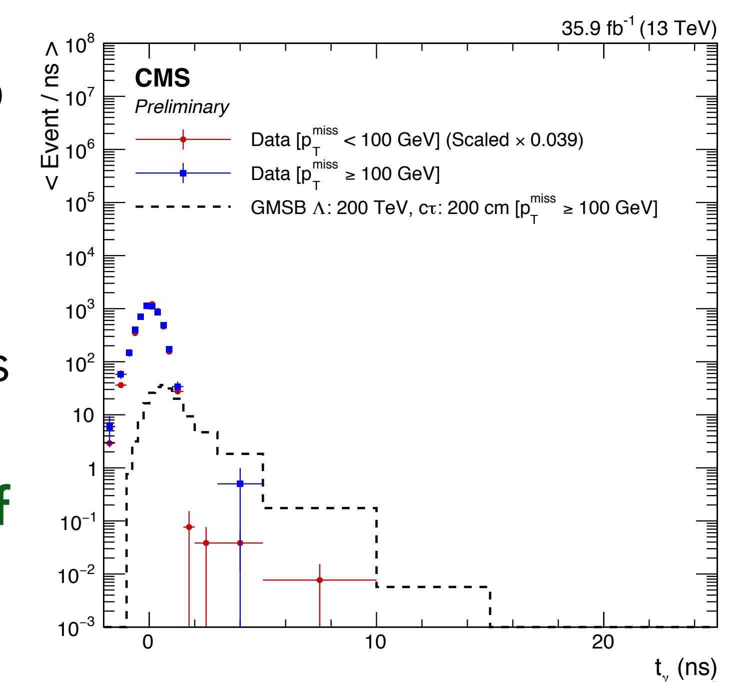


Run2 data









Results and interpretation

- The observation in each region is consistent with the expected background from the fit
- Results are interpreted in the context of GMSB, where long-lived neutralinos are produced as secondaries and decay to a photon and a gravitino
- **GMSB as benchmark model: upper limits on cross-section as a function of breaking scale (Λ) and proper lifetime (cτ).**

Heavy neutral leptons

Search with dilepton displaced vertex

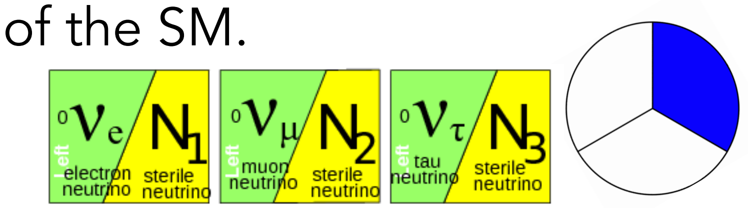
New

ATLAS-EXOT-2017-26

arXiv:hep-ph/0503065

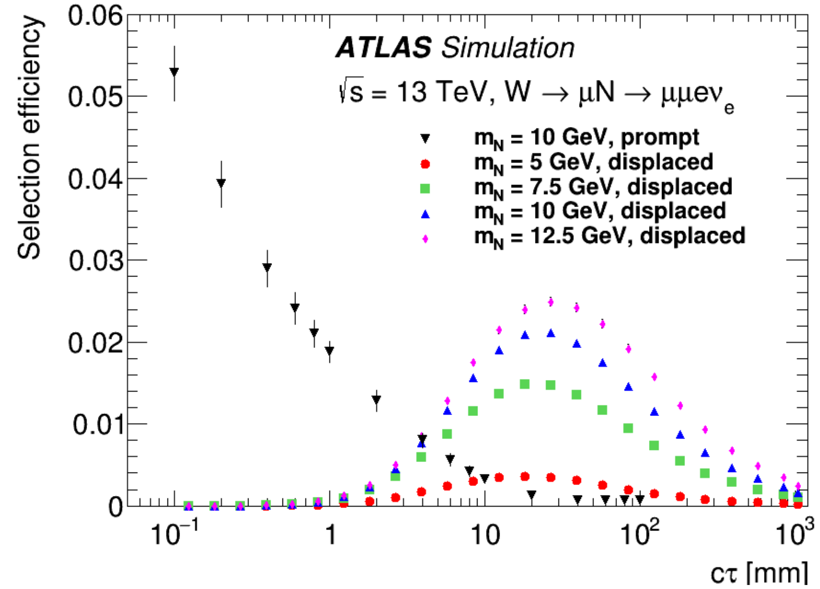
Run2 data

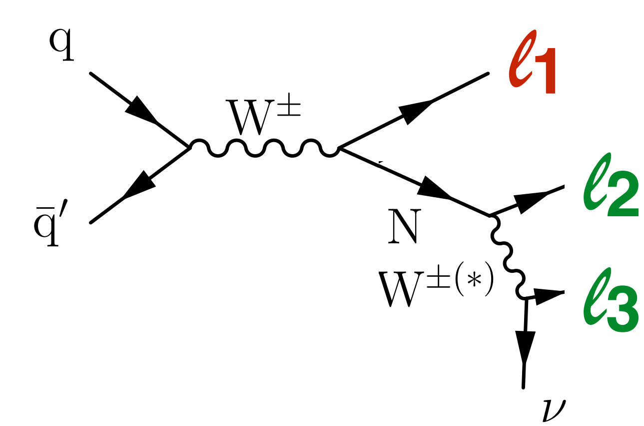
Right-handed **HNL** as potential solution for some of the outstanding problems of the SM.



Main features

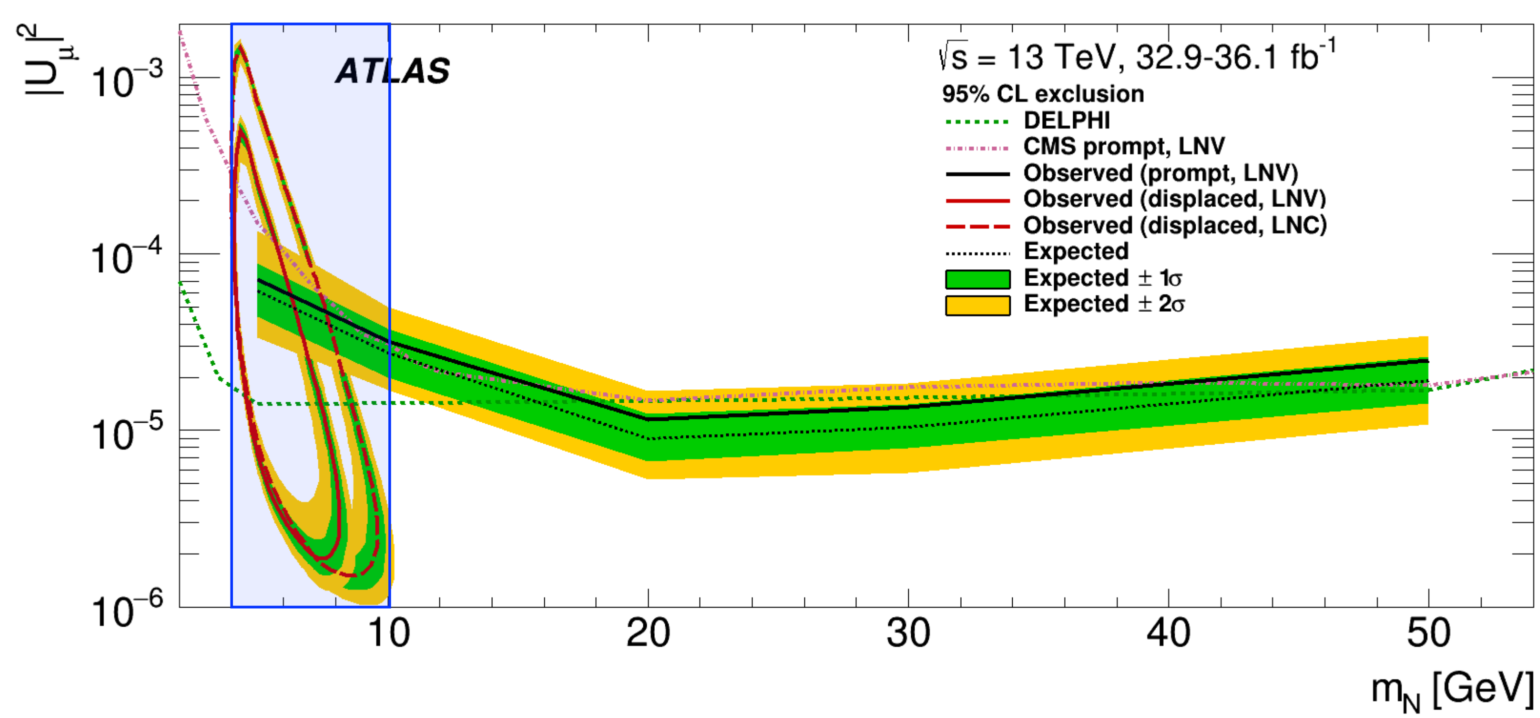
- Dedicated event reconstruction → LRT algorithm
- Main backgrounds:
  - Cosmic μ → cosmic muon veto
  - Hadronic interaction with the material, decays of metastable particle (M_{DV} > 4 GeV is applied in the SR)
  - accidental crossing





Results

- Results on $|V_{\mu N}|$ ($|V_{eN}|$ for the prompt case);
- HNL mass range: [4.5,10] GeV;
- Results presented with LNC and LNV separately;
- Search regions in bins of m_{DV}
- Excluded coupling strength down to $|V_{\mu N}|^2$ ~ $2*10^{-6}$ ($1.5*10^{-6}$) assuming LNV (LNC);



- The shape of an oblique ellipse approximately corresponds to HNL proper decay lengths in the range 1–30 mm. It is also limited from below by the product of integrated luminosity and efficiency.

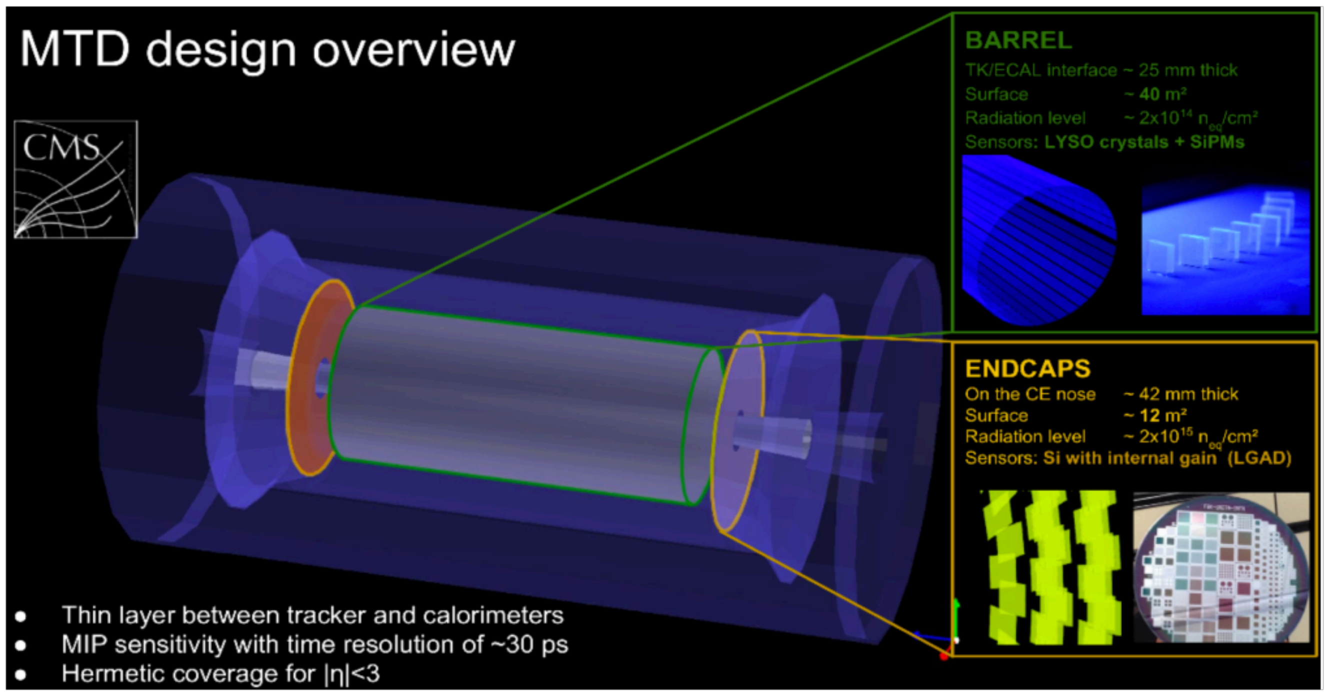
Future steps

MIP timing detector, delayed γ case

CERN-LHCC-2017-027

Calorimeters upgrade

- **HL-LHC** conditions pose significant **challenges** for the experiments
- **Precision timing** can be used to significantly mitigate the effect of pileup and provide additional physics capabilities
- MIP Timing Detector for CMS ensures **maximal coverage in η and pT for charged particles**



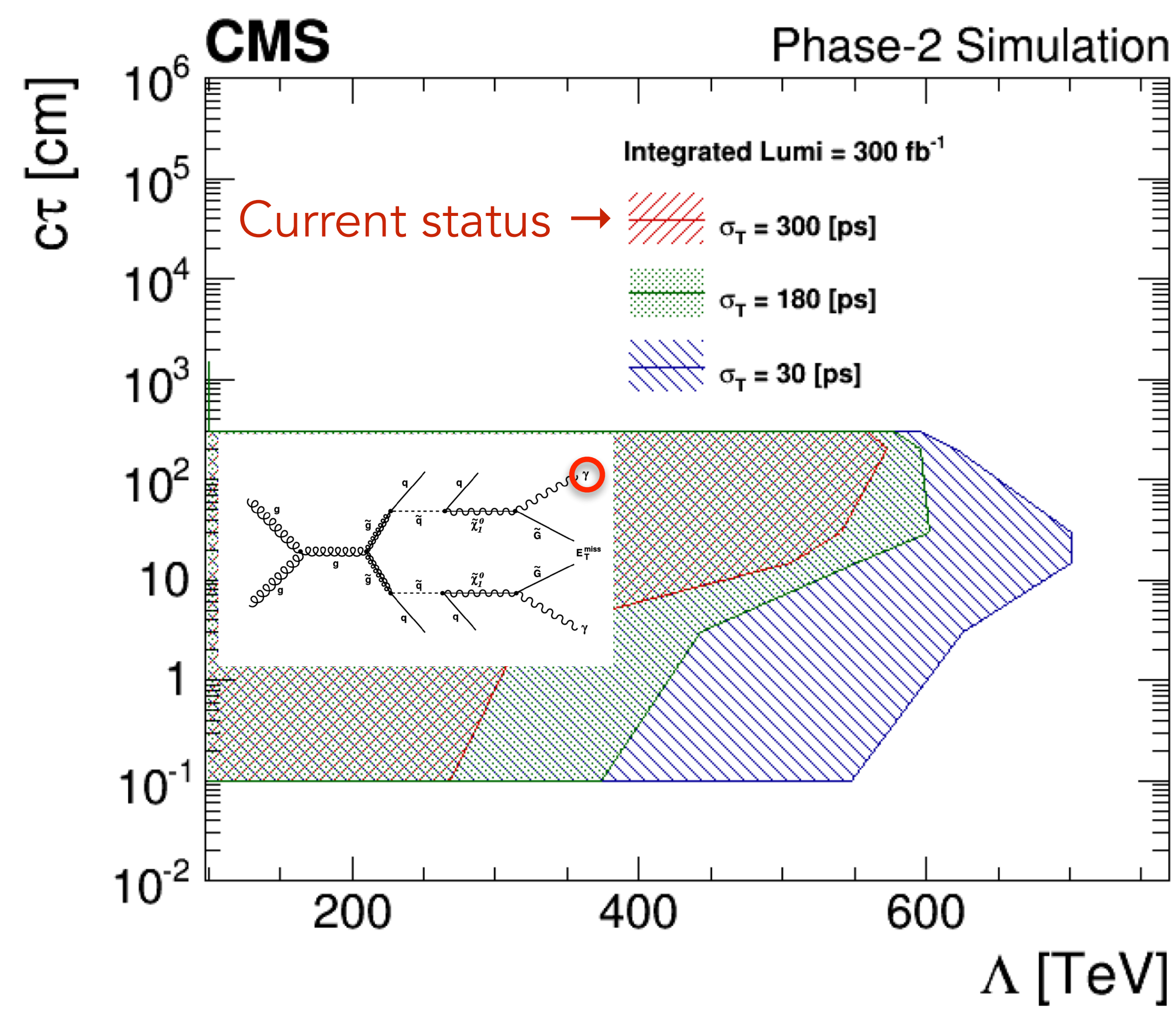
- With sufficient time resolution (30ps) and coverage for charged particles, traditional 3D vertex fit can be upgraded to a 4D fit

Physics case

The excellent resolution of the MTD apparatus can be exploited to determine with high accuracy the time of flight of the neutralino, and similarly the photon

The **vertex timing provided by the MTD** detector will bring the **TOF resolution to about 30 ps.**

→ dramatic increase in sensitivity at short lifetimes.



Summary and outlook

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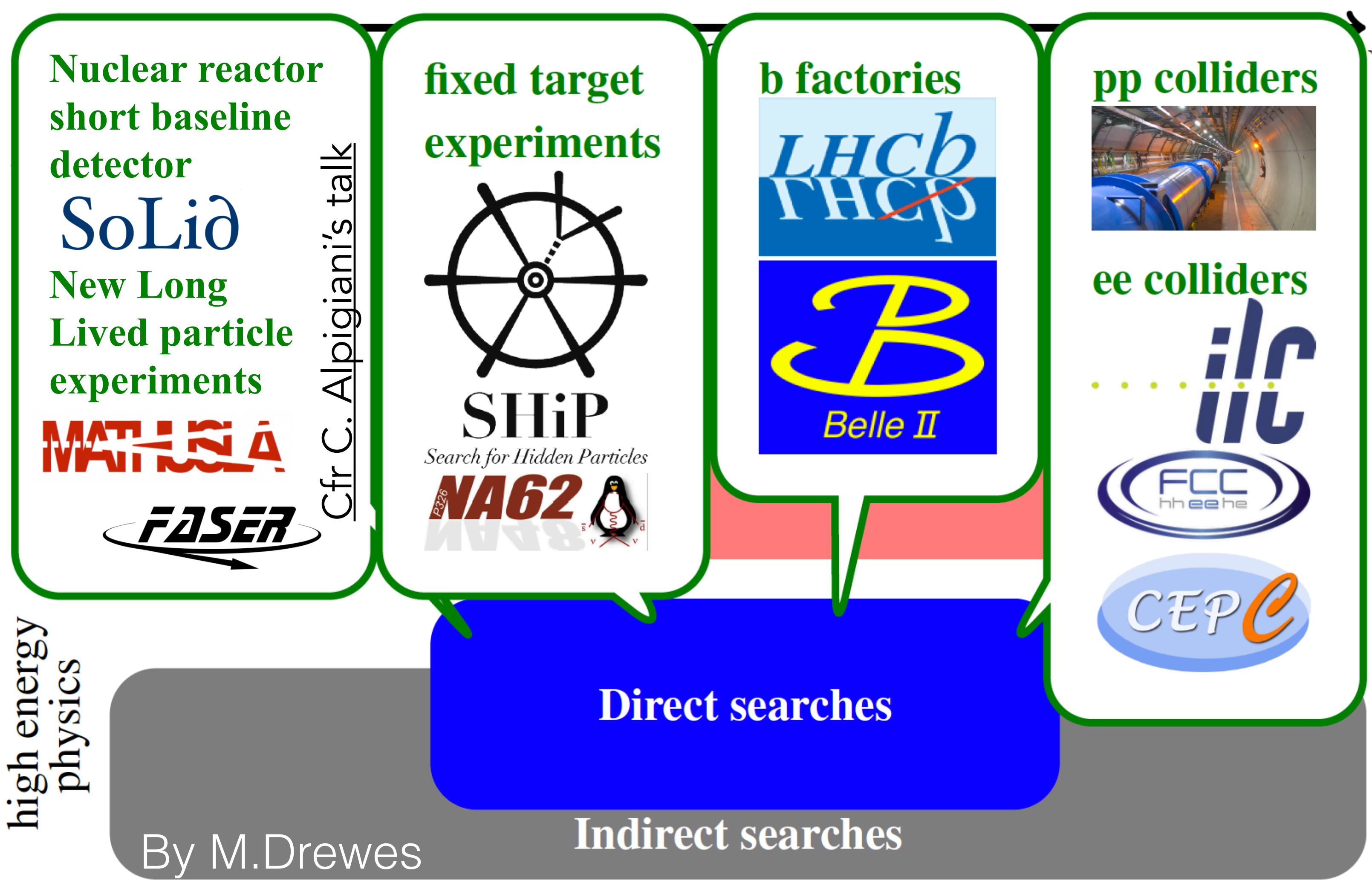
This was only a tiny selection of all the many analysis looking at LLP signature!

- Full Run 2 analyses will be published soon
- New triggers, reconstruction algorithms and analysis strategies and techniques are being further developed
- Detector hardware and trigger upgrades will come to play in the HL-LHC phase



The very wide range of masses, energies and models necessitates to explore the complementary reach of our experiments. Collaborations among the LHC and the rest could really lead to comprehensive understanding of this new challenging frontier!!!

LLPs hunting is open!

Backup slides