

# CMS: Long-lived particles analysis

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# Prelude: Long-lived particles

Since the Higgs boson discovery, HEP experiments have been looking for new particles **beyond the Standard Model (BSM)**. However, no direct evidence of these particles has been found so far.

While **prompt signatures** have been largely exploited, **new physics could be hiding in particles with long lifetimes → long-lived particles (LLPs)**.

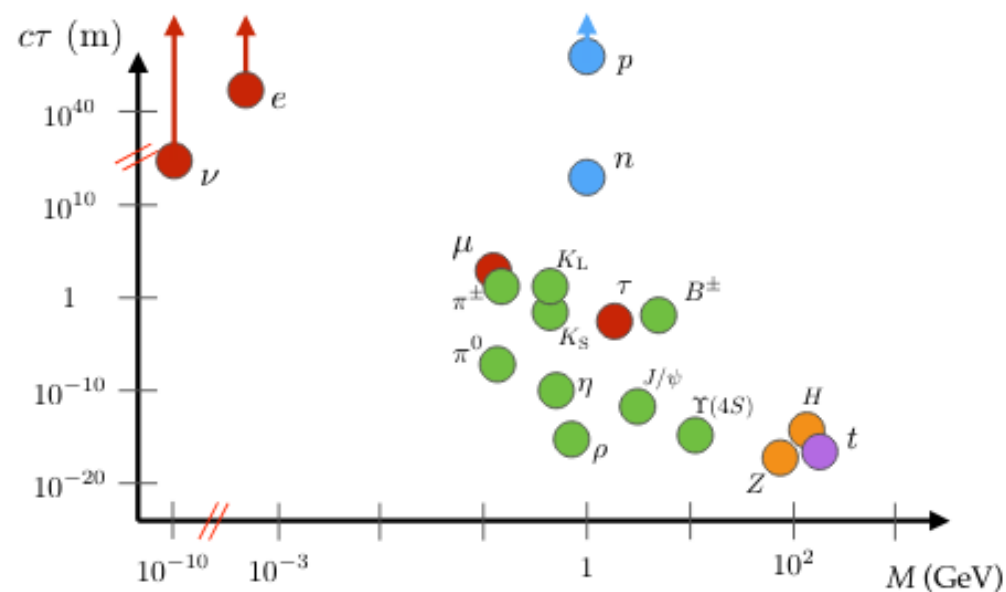
LLPs arise in a **wide variety of BSM models** and covering **different regions of the phase-space** (R-parity violating SUSY, gauge portal models, higgs portal models...)

Large lifetimes may be due to:

- Small couplings
- Very compressed spectra
- Heavy (off-shell) mediators



$$\frac{2\pi h}{\tau} = \frac{f_\pi^2}{256\pi m_\pi} \left[ \frac{G_F^2}{M_W^2} \frac{m_\mu}{m_\pi} (m_\pi^2 - m_\mu^2) \right]^2$$



# Long-lived particles at CMS

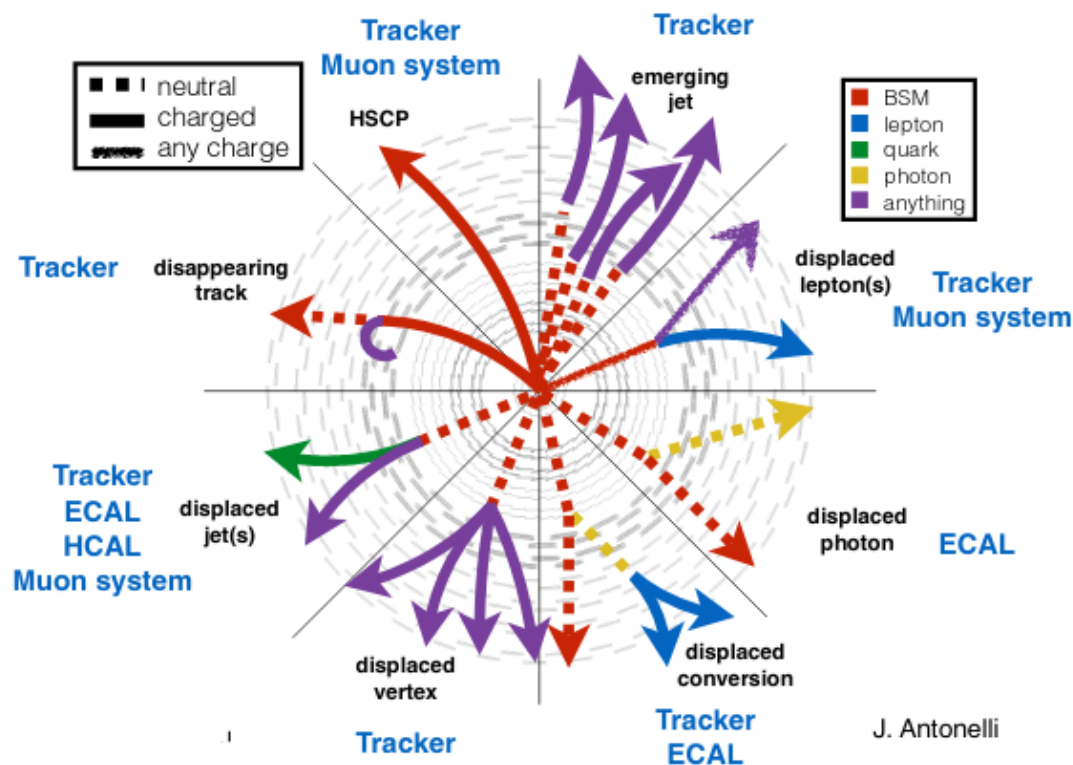
**Long-lived particles** are often challenging to detect and analyse:

- Standard reconstructions/triggers are optimized for prompt signatures
- Non-standard analysis methods
- Atypical backgrounds

But there are a lot of appealing searches, innovative techniques and possibilities to explore!

**For Run 2:** The long-lived group is covering a wide variety of signatures using all tools available at the moment

**Future:** New triggers, new displaced reconstructions, MTD, and more



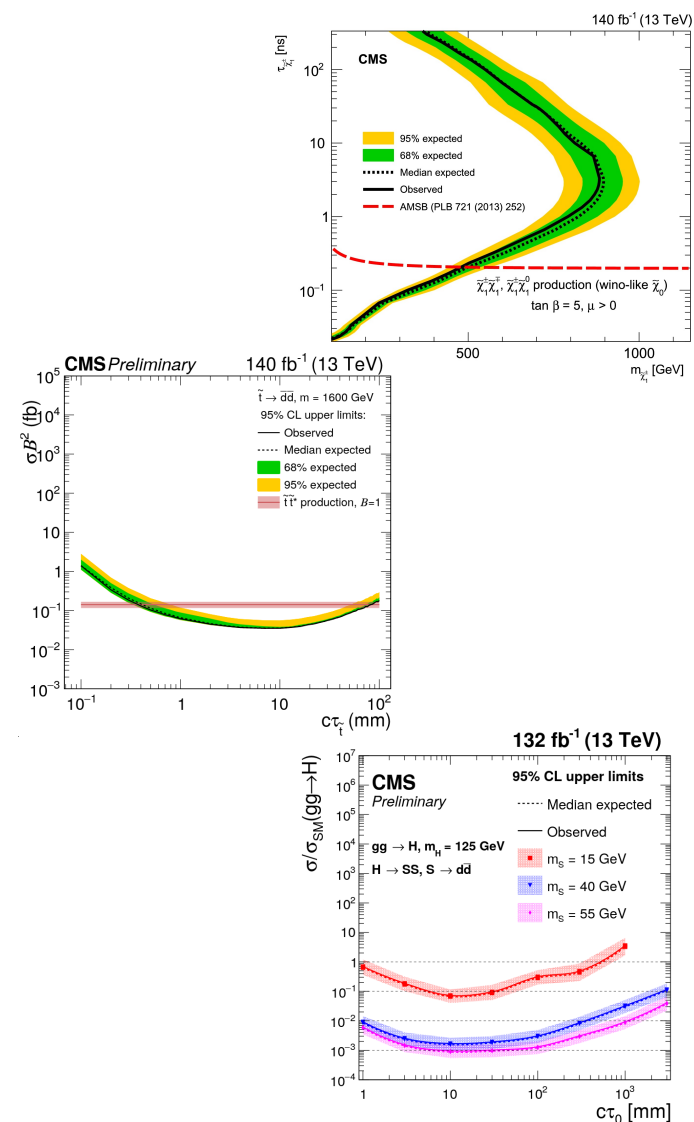
# Long-lived CMS searches: Some examples

Some examples with public results:

- The CMS Collaboration, Search for disappearing tracks in proton-proton collisions at  $\sqrt{s} = 13$  TeV  
[10.1016/j.physletb.2020.135502](https://arxiv.org/abs/10.1016/j.physletb.2020.135502)
- The CMS Collaboration, Search for long-lived particles decaying to jets with displaced vertices  
<http://cds.cern.ch/record/2734120>
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<http://cds.cern.ch/record/2734120>

A lot of searches coming soon, and among these...

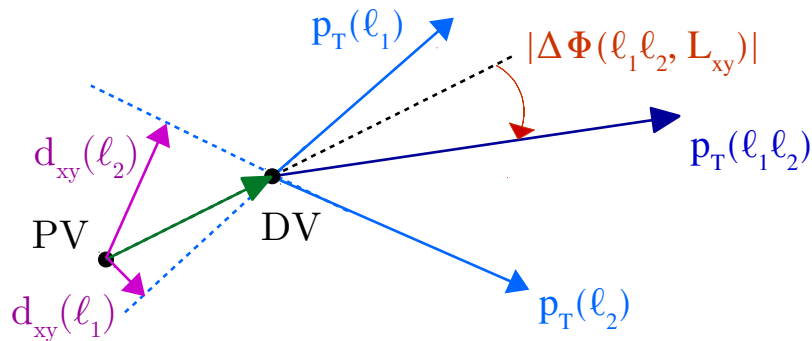
Search for long-lived particles decaying into dilepton pair produced in a displaced vertex in proton-proton collisions at 13 TeV



## Search for long-lived particles decaying into dilepton pair produced in a displaced vertex (2016+2017+2018).

### Signature

2 opposite charged same flavour leptons associated to a common displaced vertex (DV) within tracker:



### Key variables

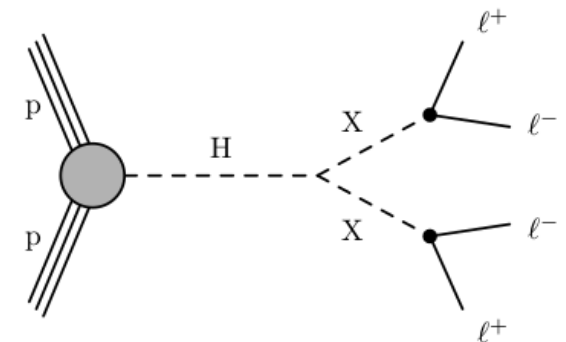
- $\min. d_{xy}/\sigma_{dxy}$ : Discriminant, large in displaced decays
- $L_{xy}/\sigma_{Lxy}$ : Discriminant, large in displaced decays
- $|\Delta\Phi(\ell_1, \ell_2, L_{xy})|$ : Collinearity, small for displaced decays

### Background

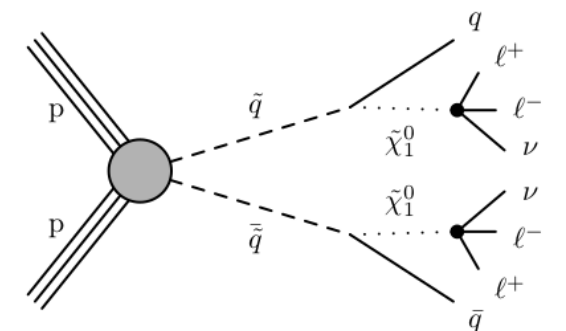
Mainly instrumental, estimated from data in control regions

## Benchmark models

**BSM Higgs model**  
 $H \rightarrow XX \rightarrow 4\ell$



**RPV SUSY model**  
 $2\tilde{q}, \tilde{q} \rightarrow \tilde{\chi}_1^0 q, \tilde{\chi}_1^0 \rightarrow \ell\ell\nu$



## Trigger

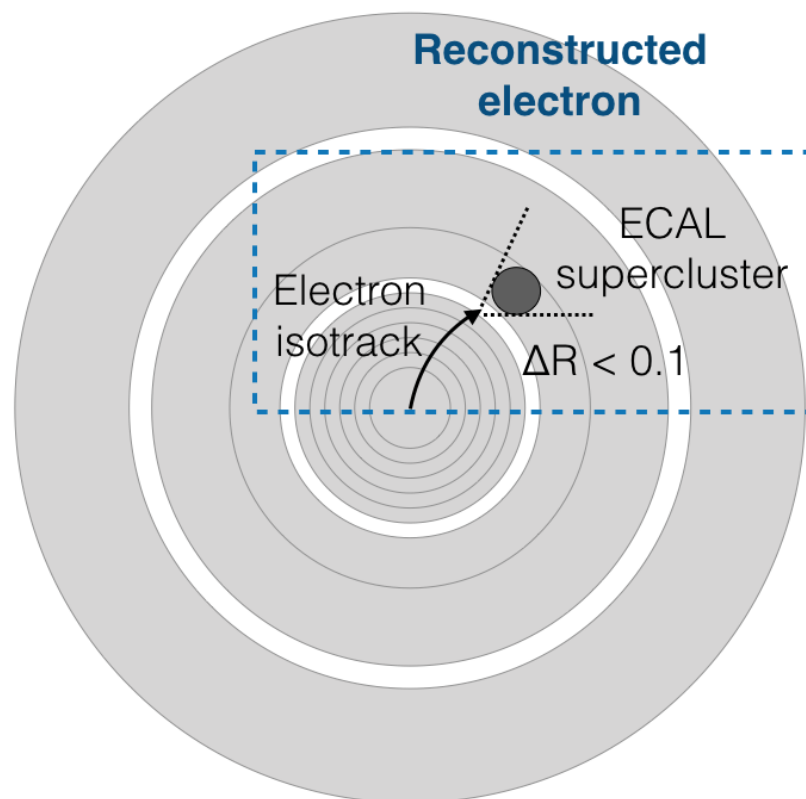
**Use of photon triggers:** Clusters trigger as long as the electrons hit the ECAL

## Electron reconstruction

**Goal:** Identify displaced reconstructed tracks that could belong to electrons.

**Electron = displaced track + ECAL cluster**

- ✓ Displaced tracks do not depend so much on the IP
- ✓ Clusters are detected in the ECAL



## Trigger

**Use of displaced muon triggers:** That use the information of the muon chambers and do not have strong constraints on the IP.

## Muon reconstruction

**Use of displaced muon reconstruction:** **Displaced global muons**

→ Targets in-line muons produced within the inner-tracker volume, with the muon leaving hits in both the inner tracker and the muon chambers.

- Seeded by “Displaced Standalone muons” (cosmic-like seeding)
- Uses a displaced-muon tracking

## Muon ID

A lot of work has been dedicated to design a dedicated **working ID for displaced global muons**.

→ Only tuned with **H→XX Monte Carlo simulation** (for the moment)

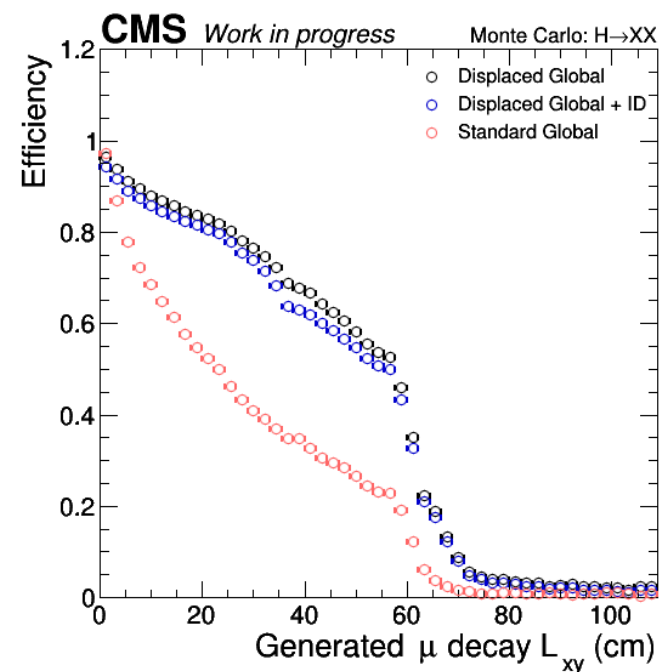
→ Retains **~96%** of signal displaced muons

→ **Assure quality** of displaced muon objects

→ **Cuts being optimized**, now using:

- $\sigma_{p_T}/p_T < 0.3$  (Good  $p_T$  resolution)
- $\chi^2/\text{ndof} < 10$  (Good muon hit fit)
- $N_{\text{hits}} > 22$  (Good muon quality)

### Displaced global muon reconstruction efficiency



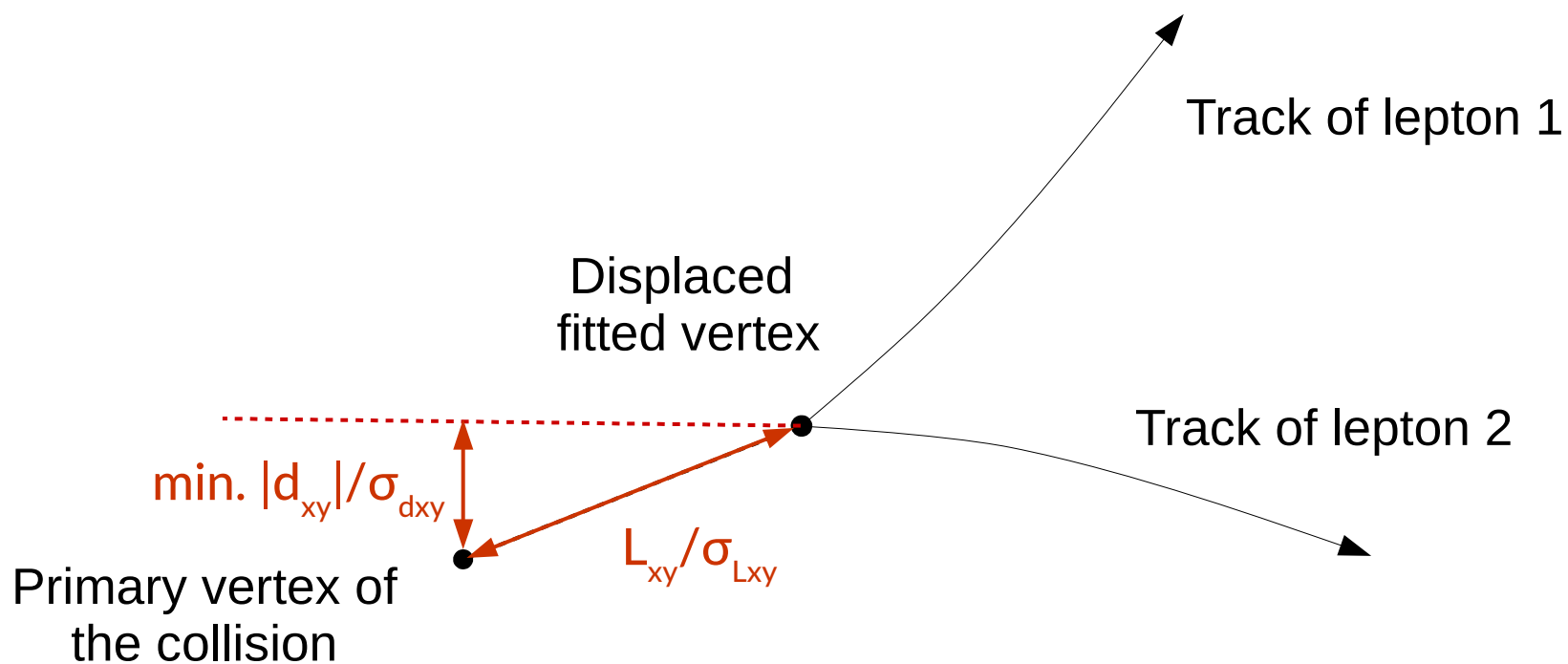


# Long-lived candidates reconstruction

Reconstructed tracks are paired and fitted to common vertices:

**Displaced dilepton vertex  $\equiv$  Long-lived candidate**

*(Keeping at least 1 DV per event)*



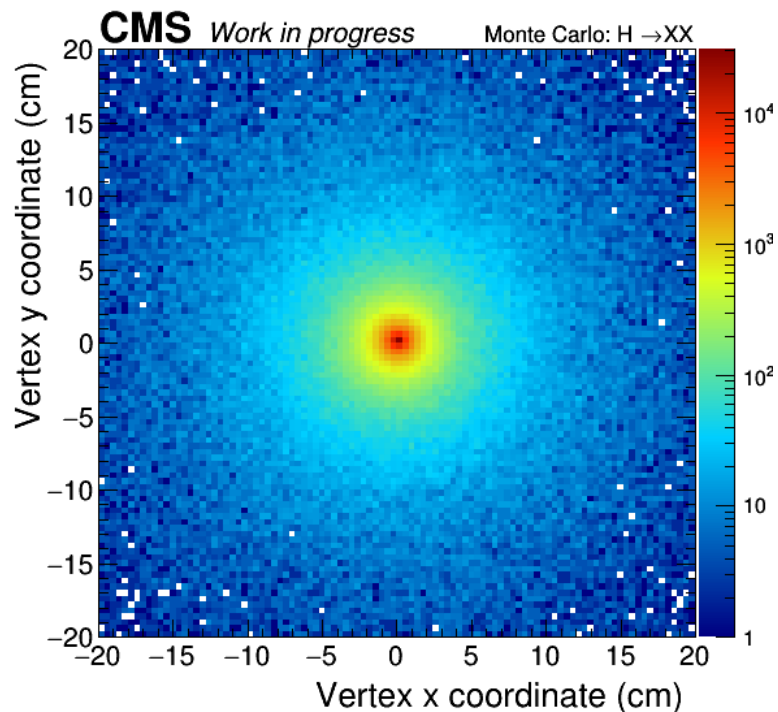
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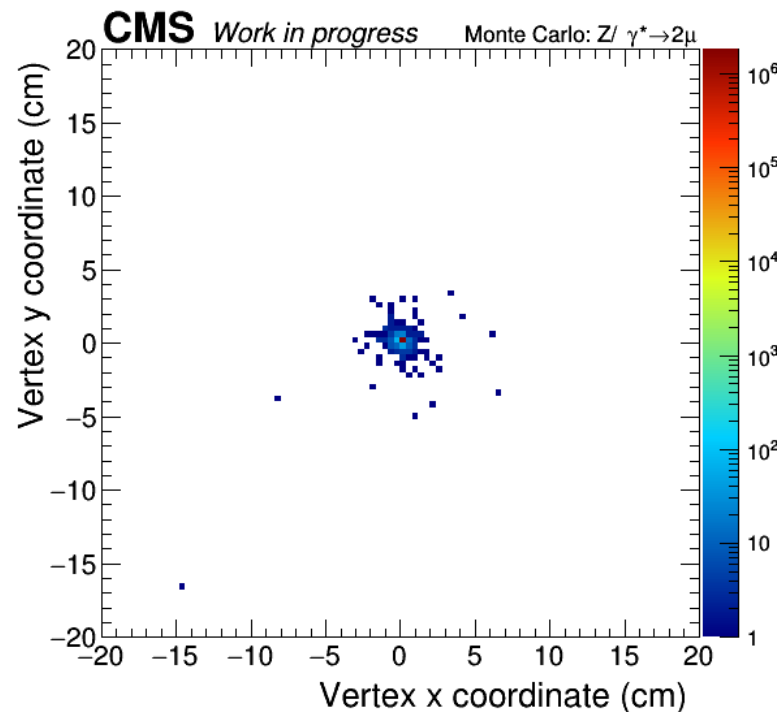
(Keeping at least 1 DV per event)

Dimuon fitted vertices  
H  $\rightarrow$  XX Monte Carlo (signal)



VS

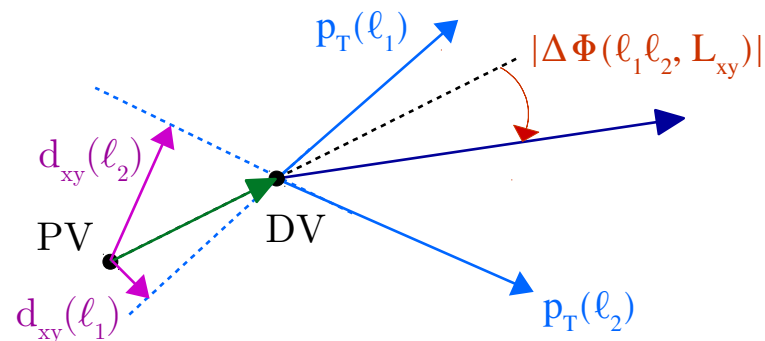
Dimuon fitted vertices  
Drell-Yan Monte Carlo (bkg)



# Long-lived candidates selection

The fitted displaced vertices must fulfill a set of requirements to discriminate between signal and background:

- ✓ Both electrons and muons passing ID cuts (quality)
- ✓  $p_T$  and  $\eta$  cuts consistent with trigger thresholds
- ✓ Min.  $\Delta R$   $\rightarrow$  Assure good trigger efficiency
- ✓ Min. Dilepton  $m_{ll}$   $\rightarrow$  Reject low mass resonances
- ✓ Max. Relative isolation  $\rightarrow$  Reject leptons from jets
- ✓ Max. Vertex  $\chi^2/\text{ndof}$   $\rightarrow$  Assure good vertex quality
- ✓ Minimum  $\cos(\alpha_{\mu\mu})$   $\rightarrow$  Only for muons to reject cosmics
- ✓ Opposite charge (Signature)
- ✓ Collinearity  $|\Delta\Phi| < \pi/2$   $\rightarrow$  Only forward candidates ( $\sim 0$  in signal)

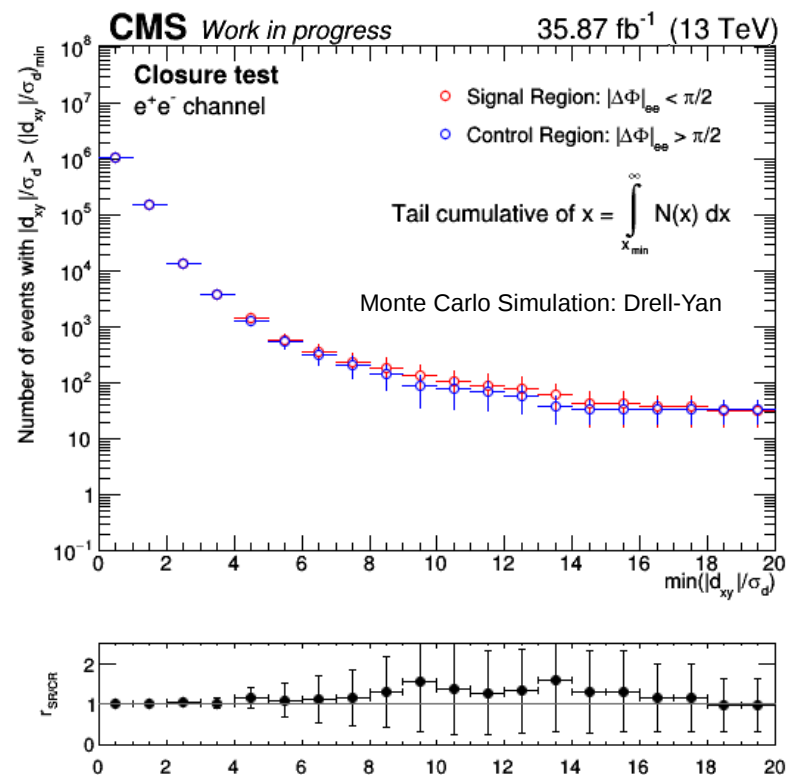
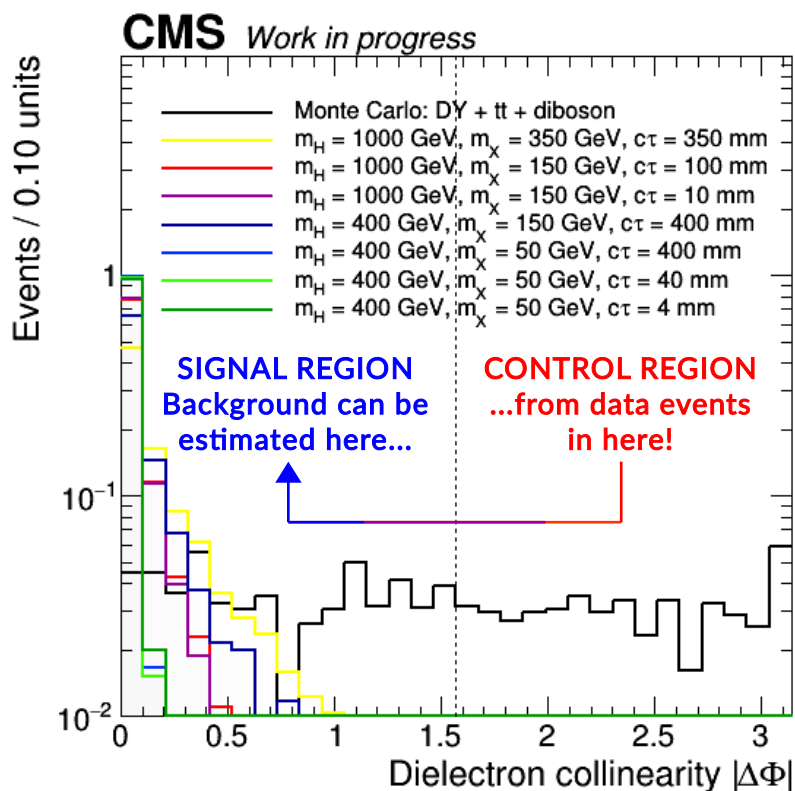


# Background estimation from data

**SM background is prompt:** Instrumental effects, resolution, PU, could cause displacement → Usually hard to be emulated by simulation.

It is observed that backgrounds shows a very characteristic behavior with  $|\Delta\Phi|$  that we could take advantage of:

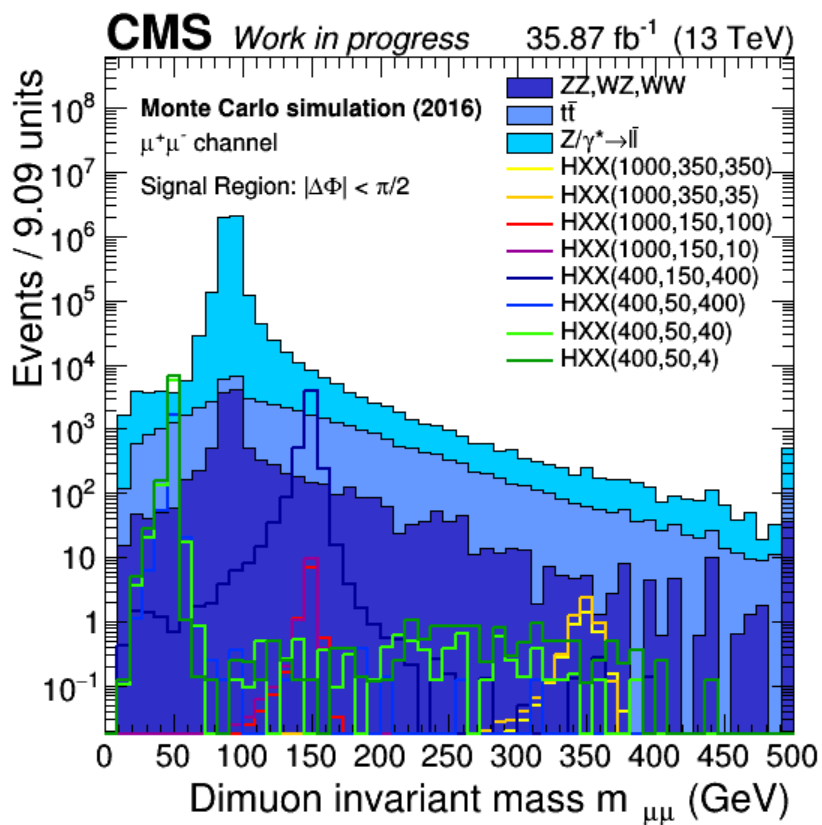
- ✓ Signal  $|\Delta\Phi| \sim 0$ : Mostly contained in  $|\Delta\Phi| < \pi/2$
- ✓ Background shows a forward-backward symmetric behavior:



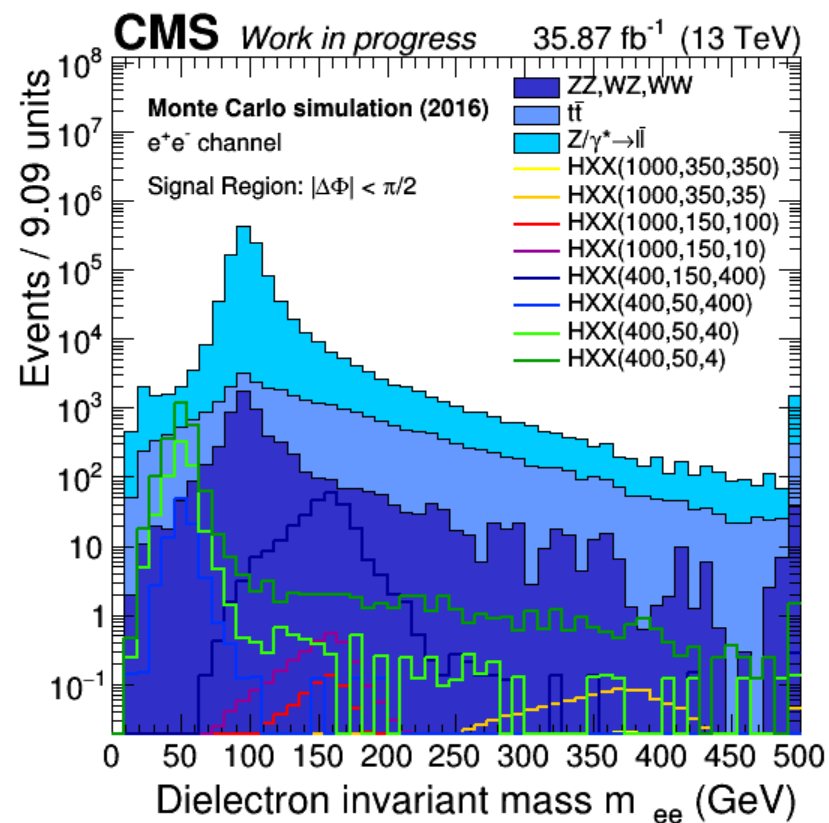
# Signal region: Invariant mass (Monte Carlo)

Monte Carlo simulation shows that the invariant mass of each decaying particle is reconstructed:

Signal Region ( $|\Delta\Phi| < \pi/2$ )  
Dimuon mass  $m_{\mu\mu}$  (GeV)



Signal Region ( $|\Delta\Phi| < \pi/2$ )  
Dielectron mass  $m_{ee}$  (GeV)

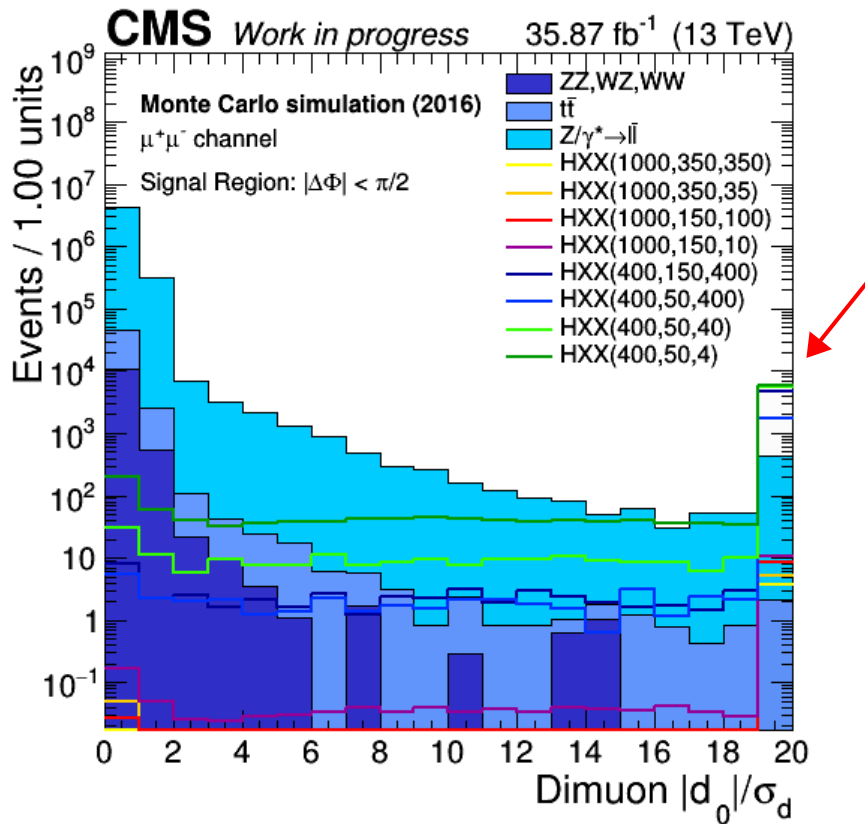


# Signal region: Displacement (Monte Carlo)

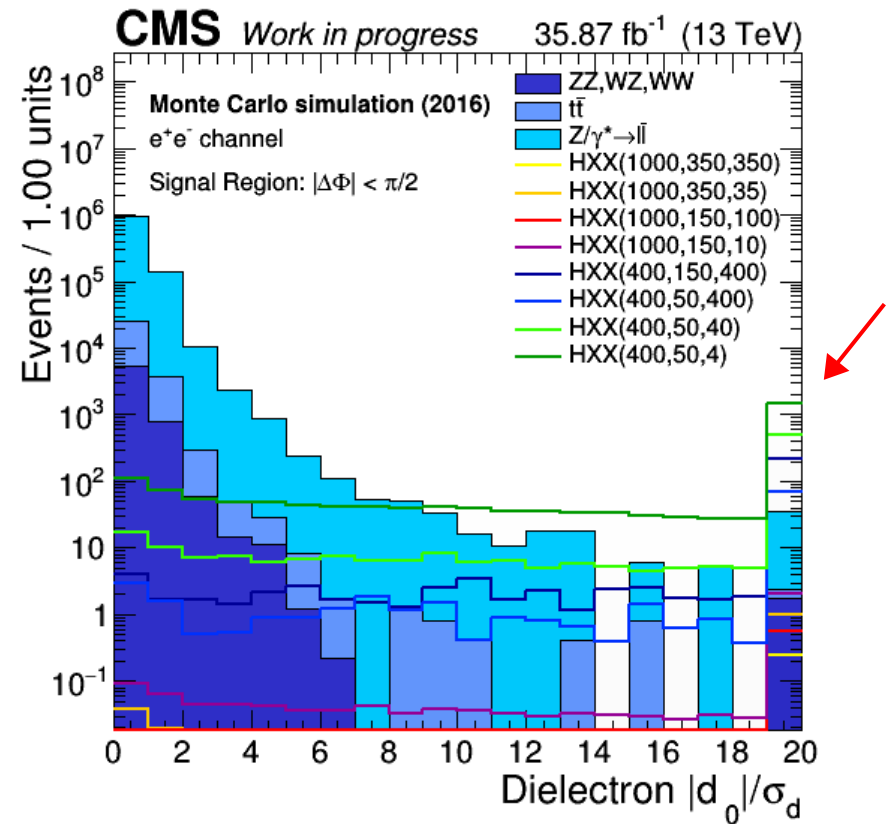
Monte Carlo simulation shows that most of the signal is contained at the overflow bin (large displacement) while background is left at lower values: **Good discrimination**

(We should note that QCD is not shown here and have a non-negligible contribution at high  $|d_0|/\sigma_d$  values)

Signal Region ( $|\Delta\Phi| < \pi/2$ )  
Dimuon min.  $|d_0|/\sigma$



Signal Region ( $|\Delta\Phi| < \pi/2$ )  
Dielectron min.  $|d_0|/\sigma$





# Summary, conclusions and prospects

- Exciting time ahead us for long-lived searches! LLPs could offer a chance to discover new and exotic physics!
- A wide variety of signatures is being explored at this moment!
- IFCA focusing on a search for long-lived particles decaying to displaced dileptons
  - A lot of progress in the last months → Targeting Moriond 2021
  - Public results will be coming soon