Displaced Dark Photon Searches at CMS

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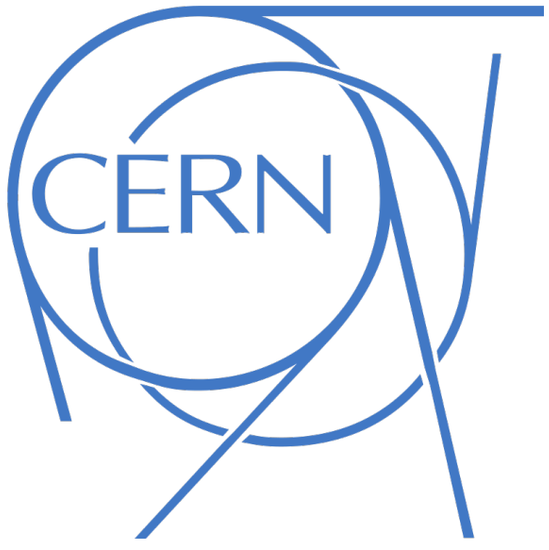
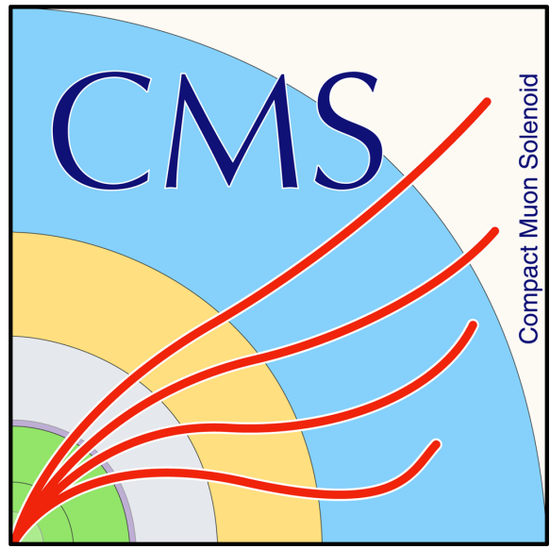
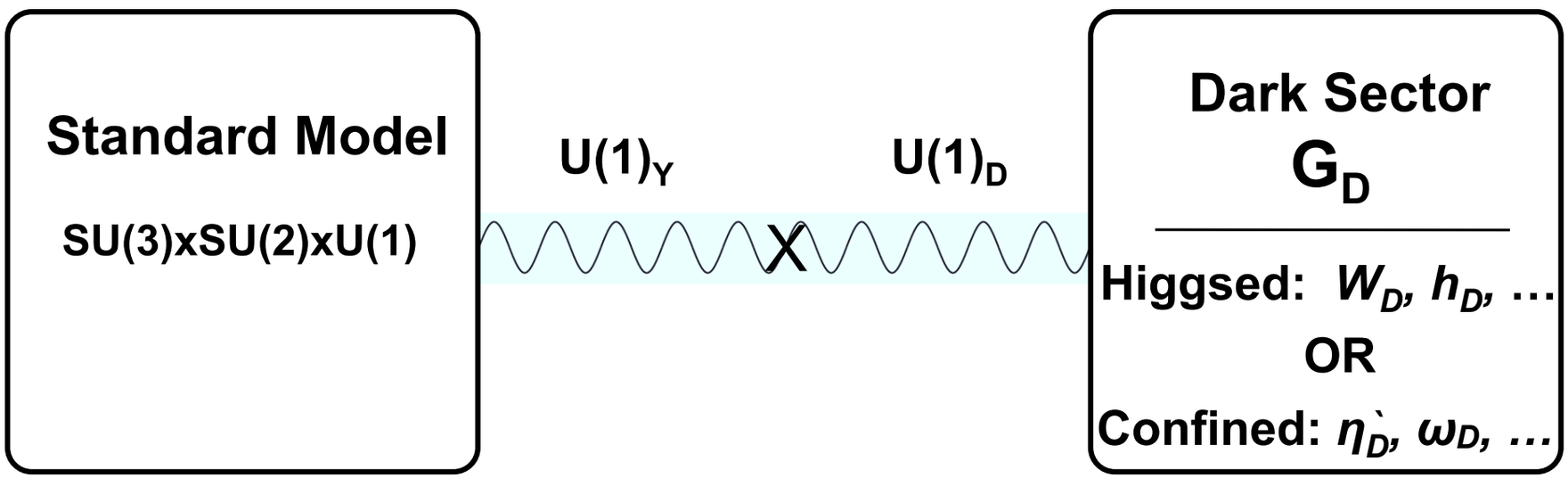




Dark Photons



- Dark photon (Z_D) → **new $U(1)_D$ gauge symmetry**
- Can serve as a connection between the SM and a dark sector
- Z_D can talk to the SM particles through **kinetic mixing**

$$\mathcal{L} \subset -\frac{1}{4}\,\hat{B}_{\mu\nu}\,\hat{B}^{\mu\nu} - \frac{1}{4}\,\hat{Z}_{D\mu\nu}\,\hat{Z}_D^{\mu\nu} + \frac{1}{2}\frac{\epsilon}{\cos\theta}\,\hat{Z}_{D\mu\nu}\,\hat{B}^{\mu\nu} + \frac{1}{2}\,m_{D,0}^2\,\hat{Z}_D^{\mu}\,\hat{Z}_{D\mu}$$

ϵ : Kinetic mixing coefficient

Dark Photon Interactions

- Assuming Z_D only decays on-shell to SM particles
  - Z_D width (and hence its lifetime) only depends on ϵ, M_{ZD} and known SM parameters
  - We can map the displacement regime we are probing to ϵ for a given M_{ZD}
- Interactions of Z_D with SM fermions are similar to that of Z, ɣ
  - Drell-Yan-like production of Z_D possible
  - But the cross section is suppressed by ϵ^2

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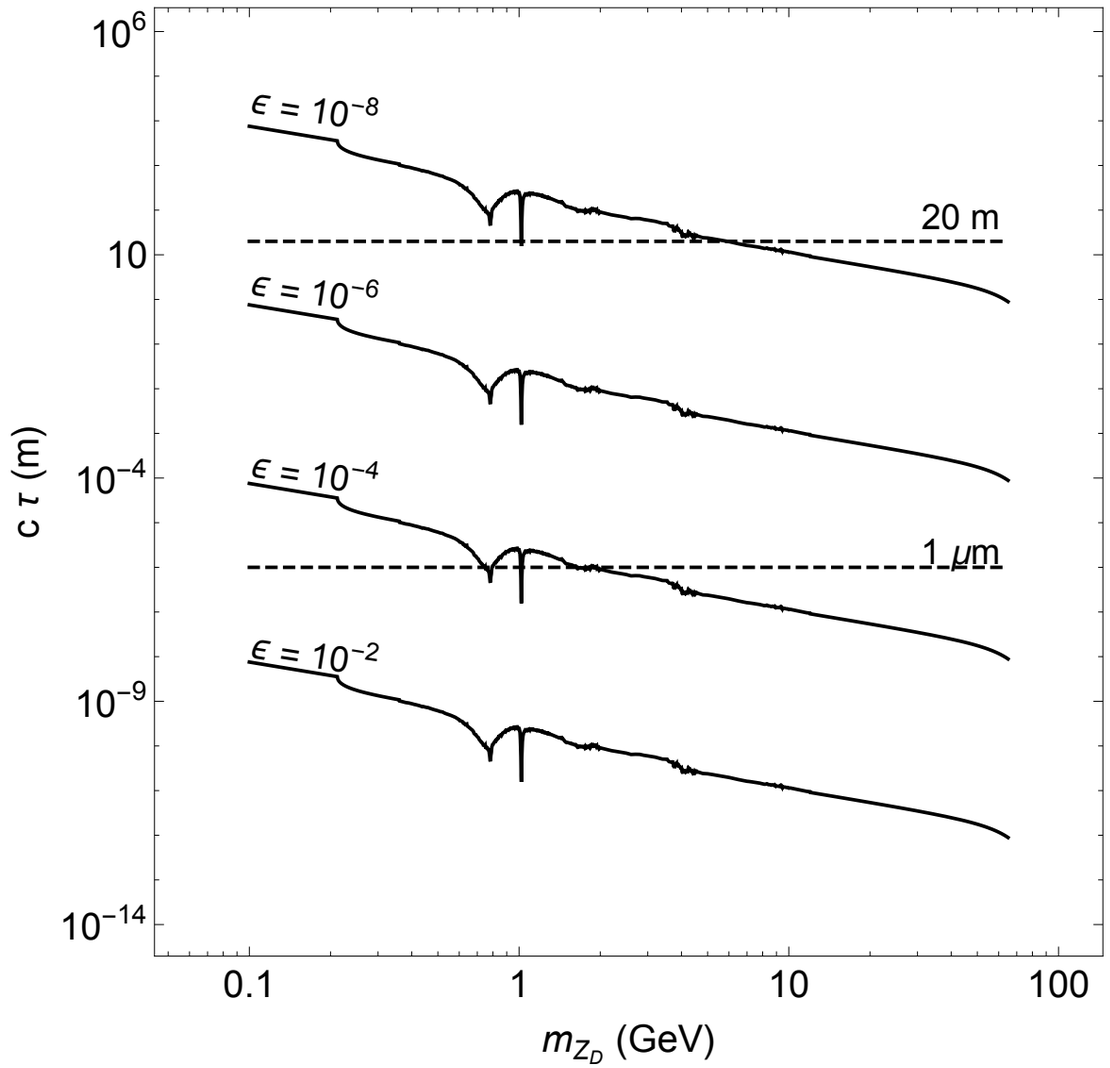
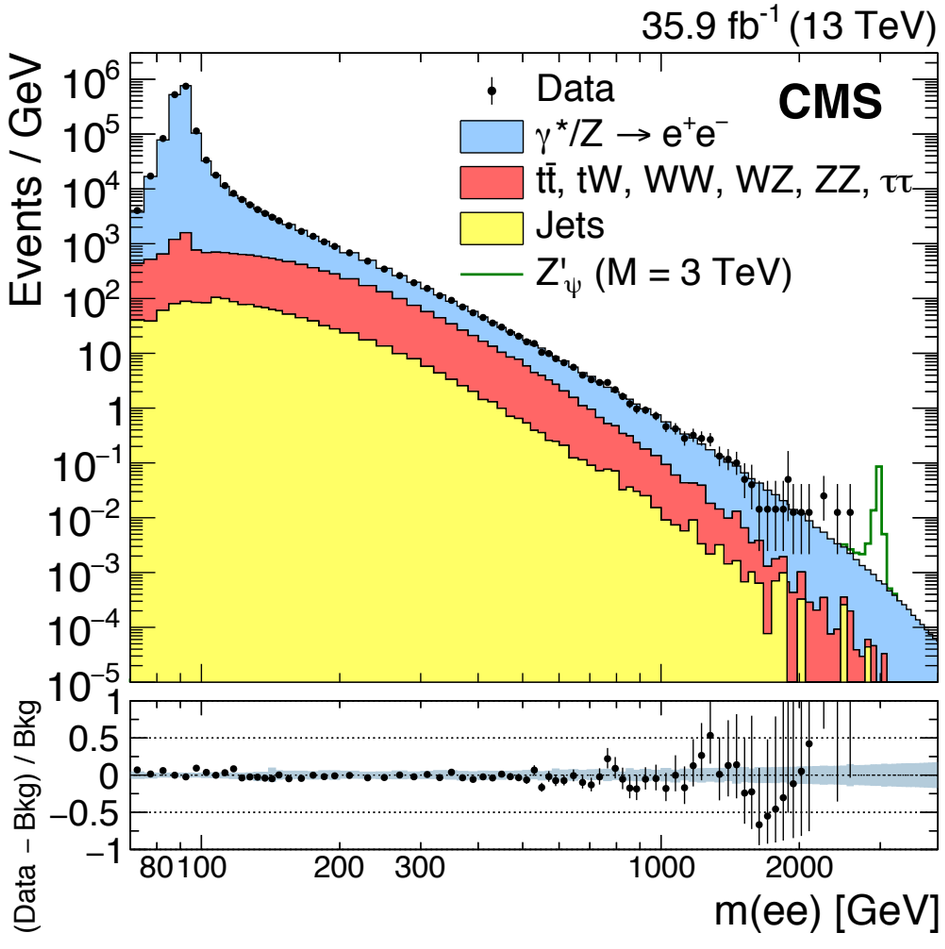


Prompt Dark Photon Decays

- Here we are probing **$\epsilon \sim 10^{-3}$**
- Look for a bump in the dilepton mass spectrum
- Main background is Drell-Yan
- Signal cross section ~ ϵ^2 x Drell-Yan cross section
- Search sensitivity depends on how many Drell-Yan events in a given mass range we can save to tape

- Standard lepton triggers in CMS have a **threshold of ~10-20 GeV on lepton p_T**
- Very high acceptance for dilepton masses around and above the Z peak
- **Our Z' searches are able to probe masses up to a few TeV**



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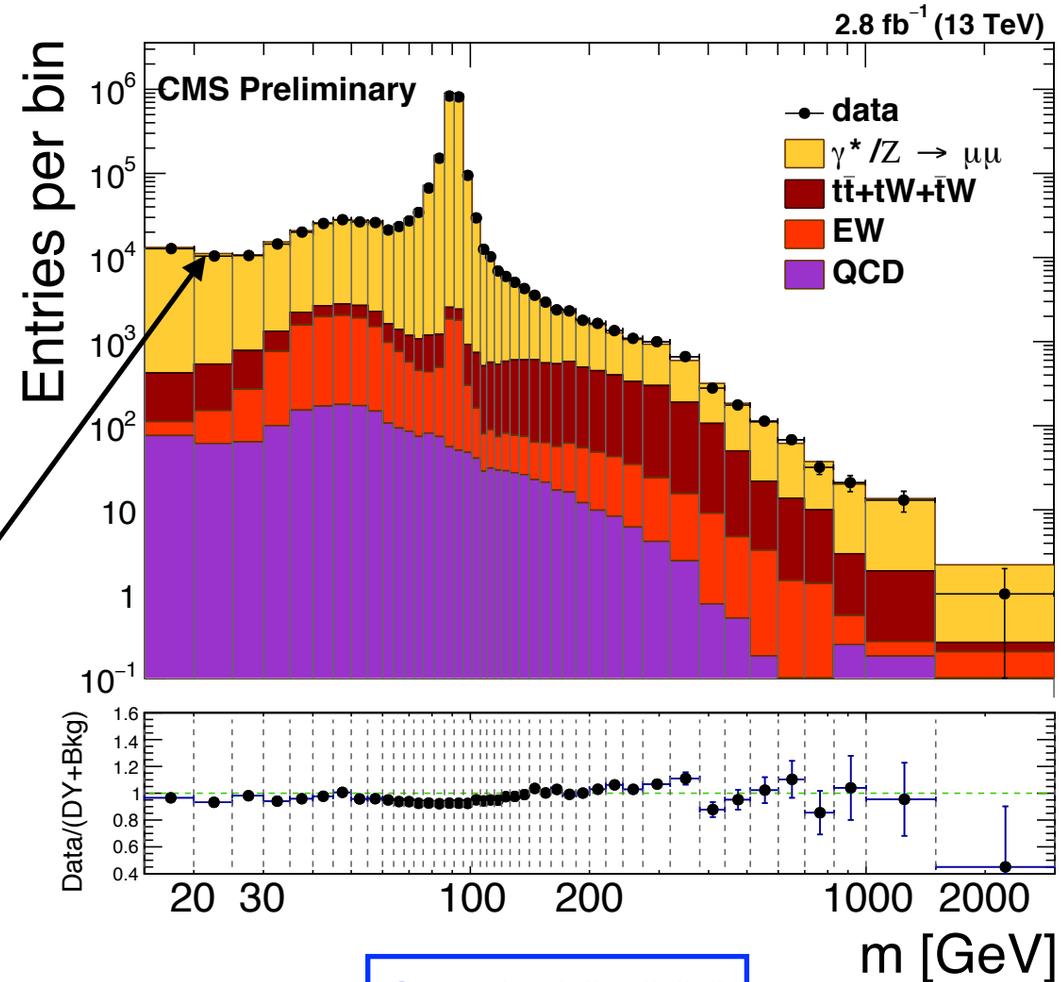
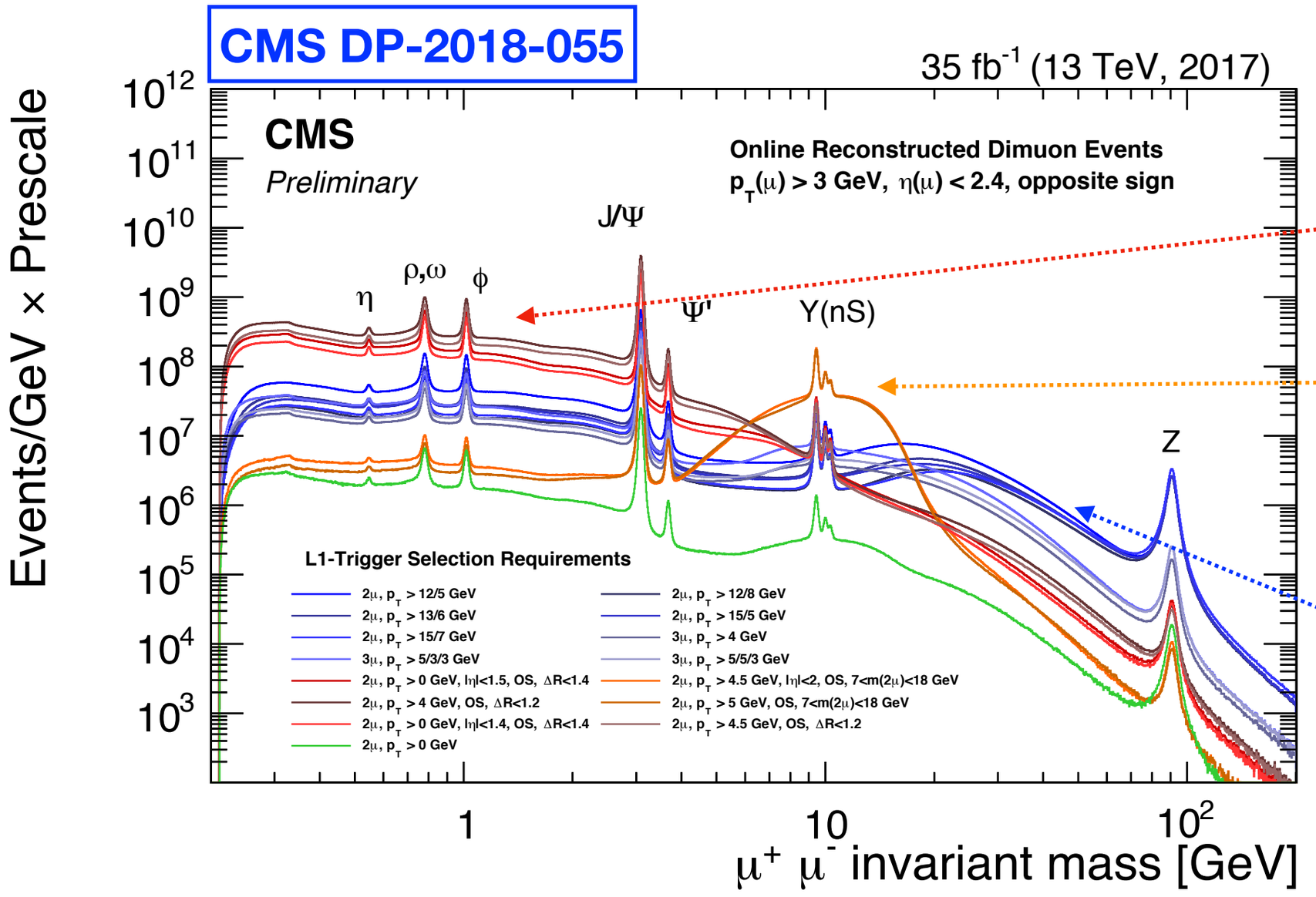
- **But we suffer large acceptance loss for low dilepton masses**



SMP-16-009

Muon Scouting

- In Run-2 CMS has introduced a muon scouting stream
- Records data using muon triggers with much lower thresholds
- But only a very limited amount of event information is recorded
- **Has the potential to improve our reach for low mass dimuon resonances**



For masses < 10 GeV

Scouting trigger :
ΔR(μμ) < 1.4 +
pT(μ)> 4 GeV or |ημ| < 1.5

For masses ~ 10-20 GeV

Scouting trigger :
7 < m(μμ) < 18 GeV +
pT(μ) > 4.5 GeV

For masses above 20 GeV

Standard dimuon triggers

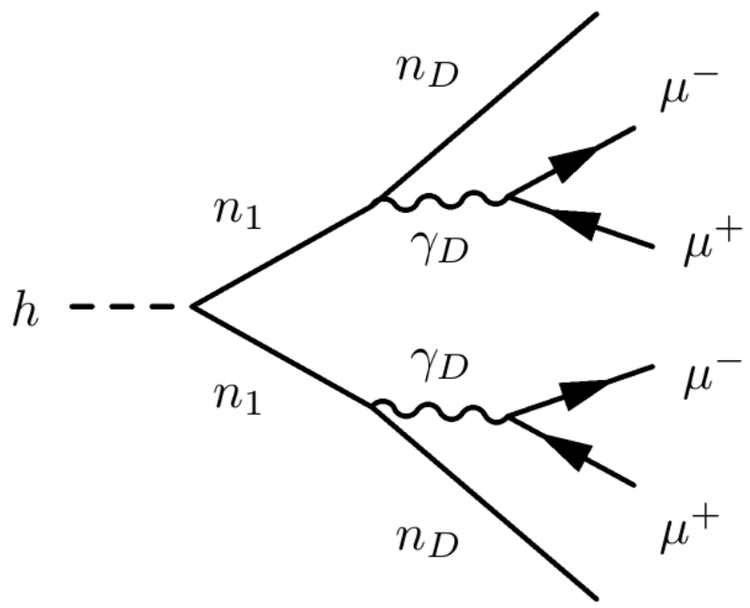
Displaced Dark Photons

- Searching for **dimuon pairs with displacements up to ~10 cm** — within the pixel detector
- Here we are probing **$\epsilon \sim 10^{-6}$**
- Cross section of Drell -Yan like production of Z_D is too small
- Assume some BSM interaction enhances the production cross section
- Dark photons typically produced in pairs in such scenarios

Dark SUSY

Dark photons produced in cascade decay of the Higgs

Lightest neutralino decays to Z_D and dark neutralino



Displaced Z_D Search

- Search for **long-lived Z_D in the mass range 0.25 - 8.5 GeV**
- Events selected using a trimuon trigger :
  - Online thresholds of 15,5,5 GeV on μ p_T
  - Muons reconstructed online **without a vertex constraint**

Muon selection

- At least 4 isolated muons with $p_T > 8$ GeV, $|\eta| < 2.4$
- At least one muon with $p_T > 17$ GeV, $|\eta| < 0.9$
- Ensures trigger efficiency of 96-97%

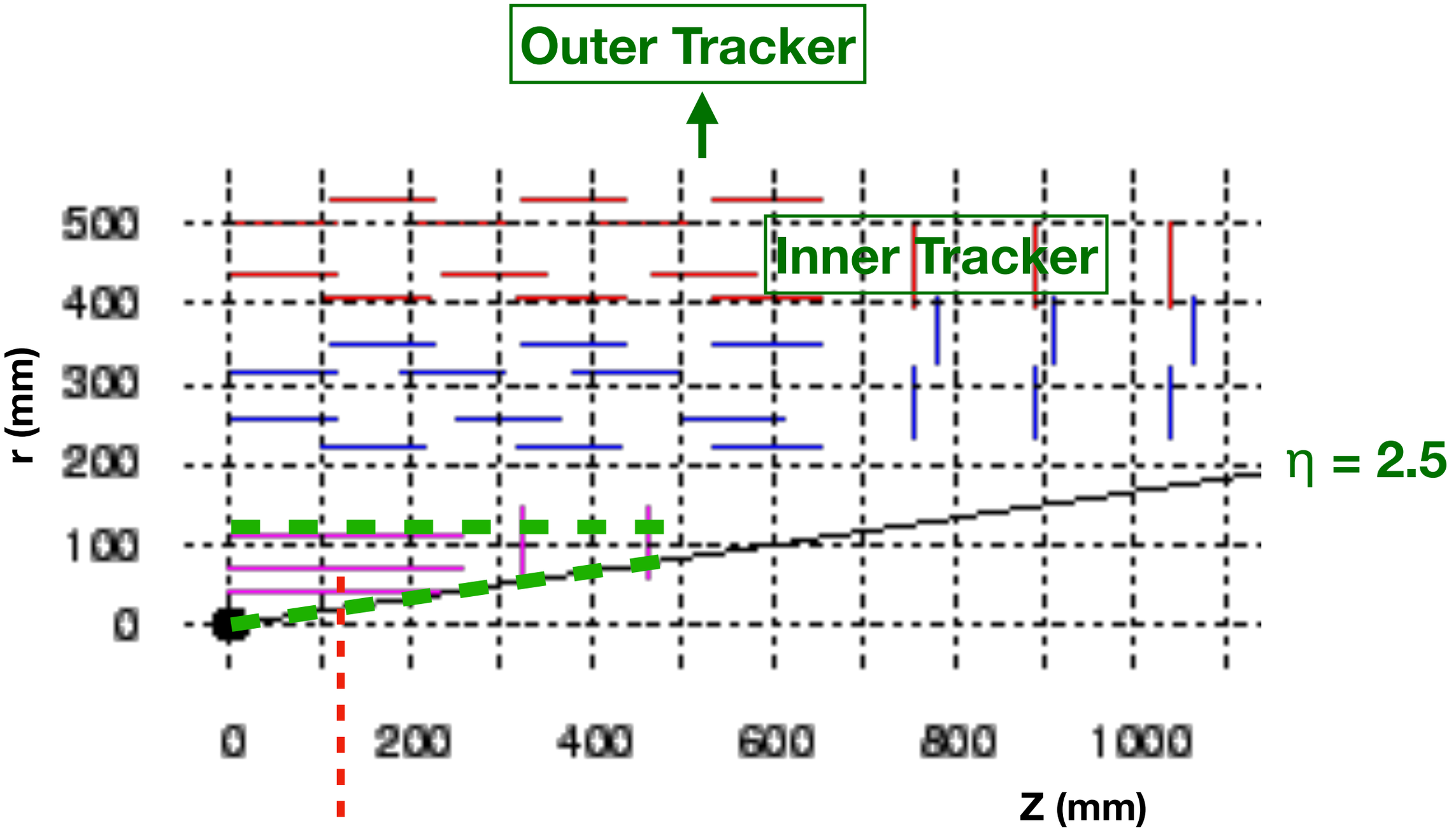
Displaced dimuon selection

- $m(\mu^+\mu^-) < 9$ GeV
- Dimuon vertex fit probability > 1% OR $\Delta R(\mu^+\mu^-) < 0.01$
- At least 1 hit in pixel barrel OR 2 hits in pixel endcap
- Defines a fiducial region within which selection efficiency is uniform and high

Require dimuon masses to be compatible within 5 times the core mass resolution

$$|m_1 - m_2| < 0.13\,\mathrm{GeV}/c^2 + 0.065 \times (m_1 + m_2)/2$$

Search Region



Fiducial Search Region
L_{xy} < 9.8 cm ; L_z < 46.5 cm

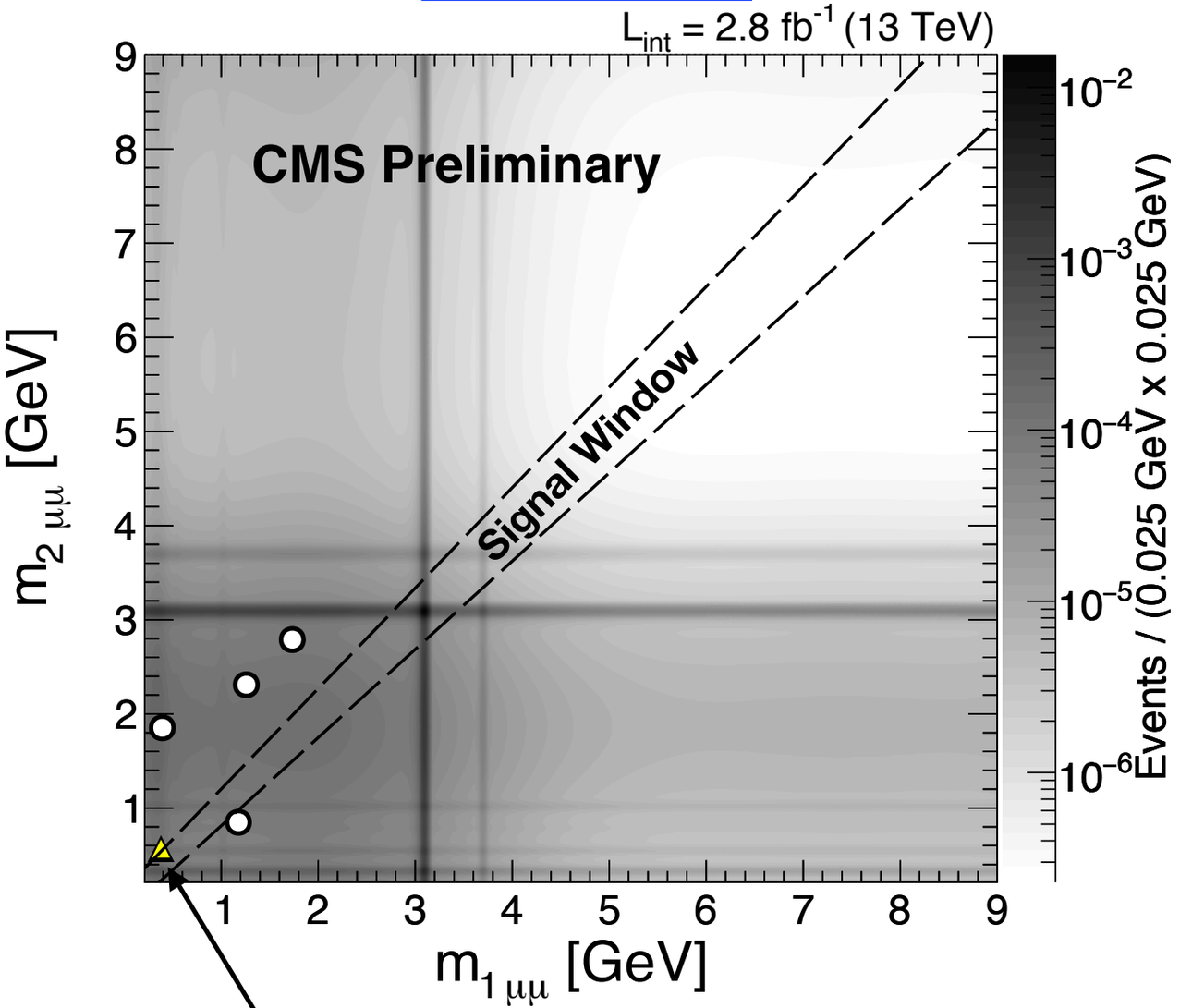
Selection eff. / acceptance
= 0.63 ± 0.13

Signal Extraction

Background Prediction

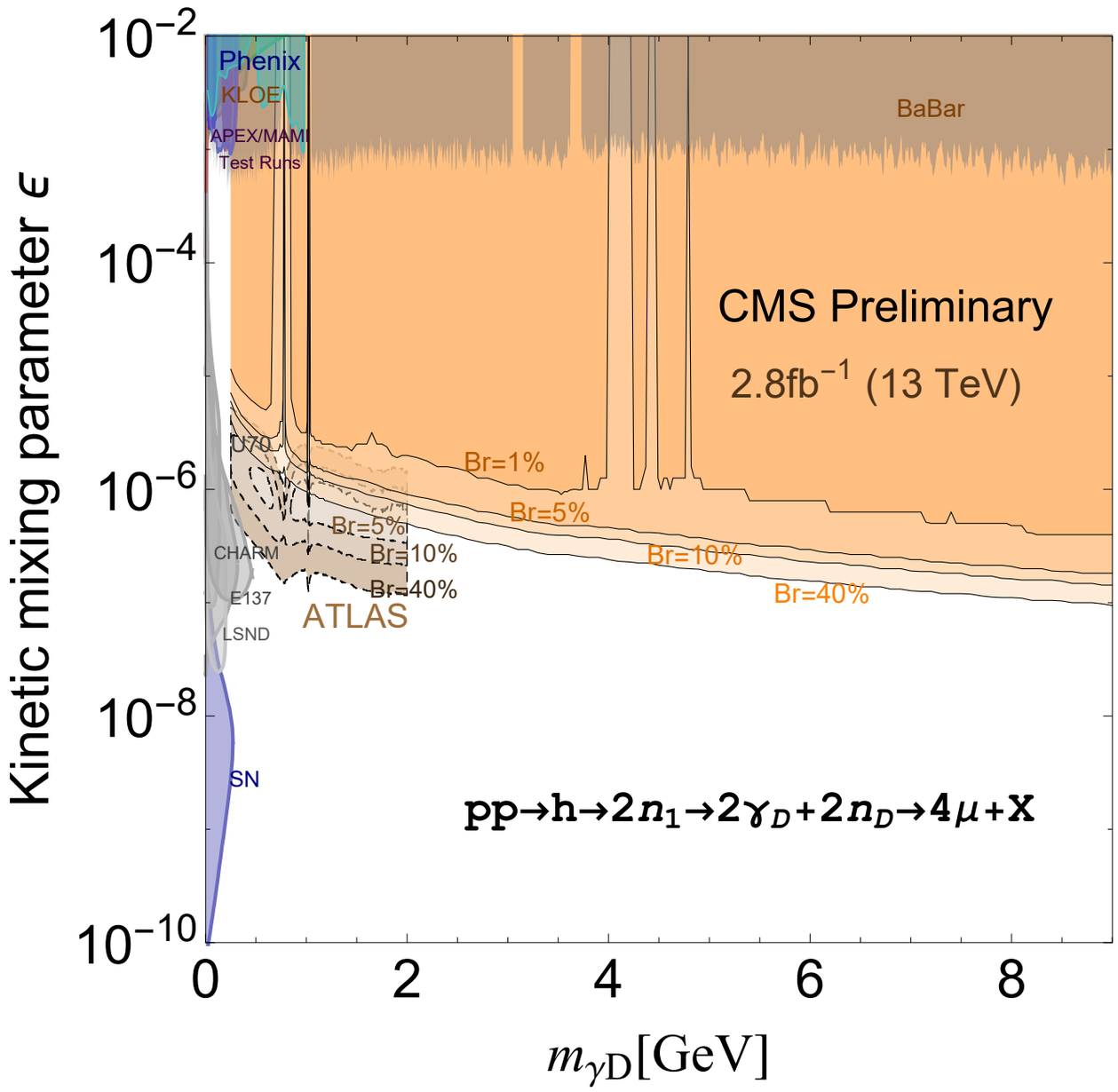
- **Low background search**
- **bb events with b decays to muon pairs (~90%)**
  - Data driven templates used to estimate the probability of a b quark decay to a dimuon pair
  - Normalization from off-diagonal sidebands
- **Direct J/ψ production (~10%)**
  - Estimated from simulation
- Contribution from other sources found to be negligible
- **Estimated background in the signal window : 0.74 ± 0.34(stat) ± 0.15(syst)**
- **1 event observed**

HIG-16-035



1 event in signal window
Dimuon masses : 0.56, 0.40 GeV

Results



HIG-16-035

Results shown for the Dark SUSY model assuming n_1 mass = 10 GeV, n_D mass = 1 GeV

Limits shown for different values of BR(h→2γ_D+X)

Very Displaced Dileptons

- **What about dilepton decays outside the pixel detector ?**
  - No 13 TeV results *yet* … but a search was performed using 8 TeV data **PRD 91, 052012(2015)**
  - Targeting dilepton (both dielectron and dimuon) decays with transverse displacement up to 50 cm
- **Triggers**
  - Need triggers which do not rely on tracking information
  - Use diphoton triggers ; dimuon triggers relying solely on standalone tracks in the muon system
- **Tracking**
  - Search still does rely on tracks in the silicon tracker
  - Need to match tracks to ECAL clusters to disambiguate photons from electrons
  - Need to match tracker tracks to standalone muons for a more precise measurement of p_T and displacement
  - This restricts the search to displacements up to 50 cm, beyond which tracking becomes extremely inefficient

Analysis Details

PRD 91, 052012 (2015)

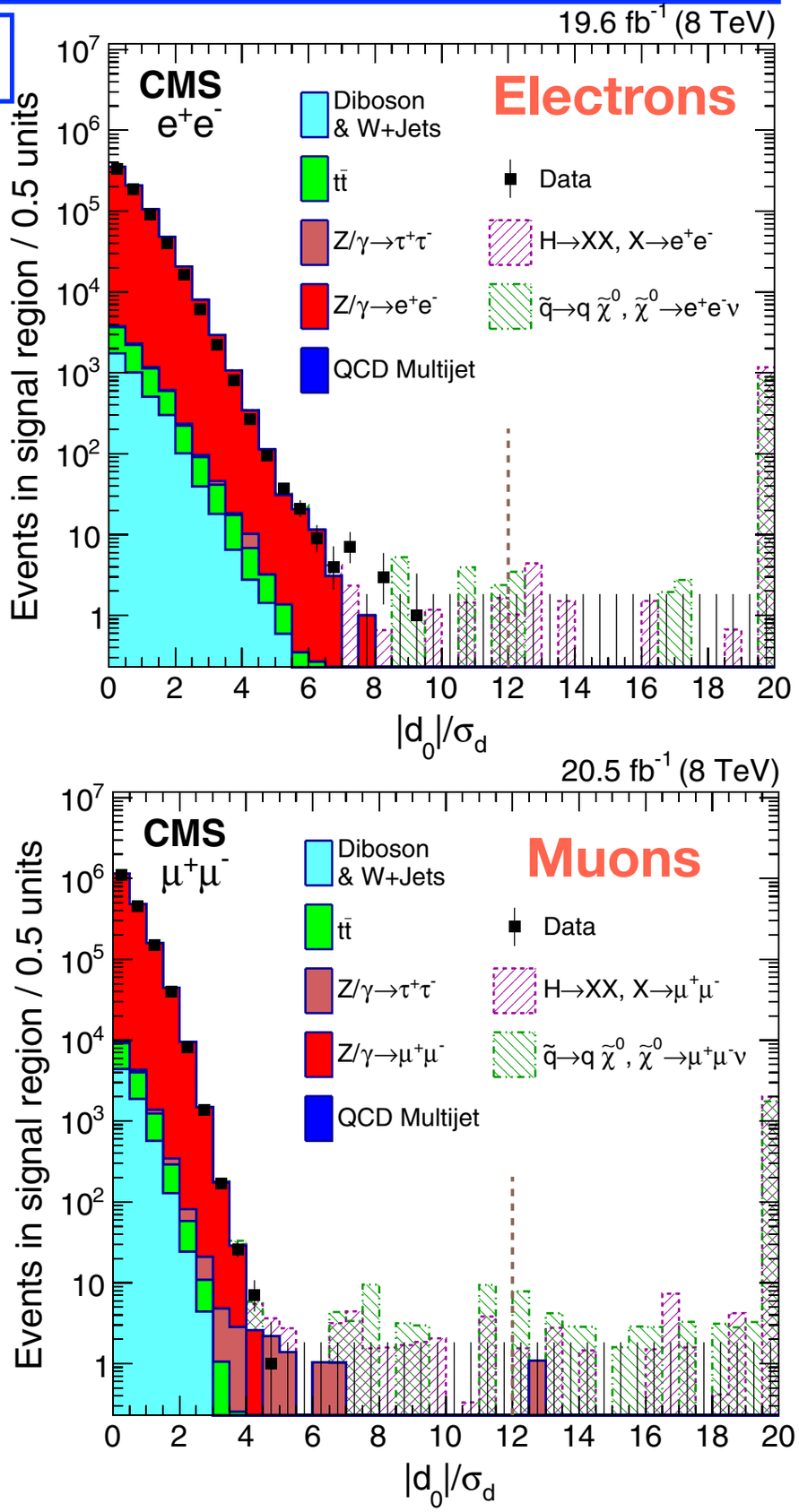
Lepton selections

- Pair of isolated muons or electrons
- μ p_T > 26 GeV; e p_T > 36, 21 GeV; Lepton |η| < 2
  - *Driven by trigger thresholds*
- Dilepton mass > 15 GeV
  - *Suppress J/ψ, Υ decays and γ* conversions*

Displaced selection

- Lxy < 50 cm for each lepton : *Fiducial selection*
- μμ(ee) fit to a common vertex : χ^2/dof < 5(10)
- d_{xy}/σ_d > 12 for each track
- Opening angle between leptons < 2.48 rad
  - *Suppress cosmics*
- |Δφ| < π/2
  - *angle between dilepton momentum, vector from primary vertex to the dilepton vertex*
  - *Suppress combinatoric background*

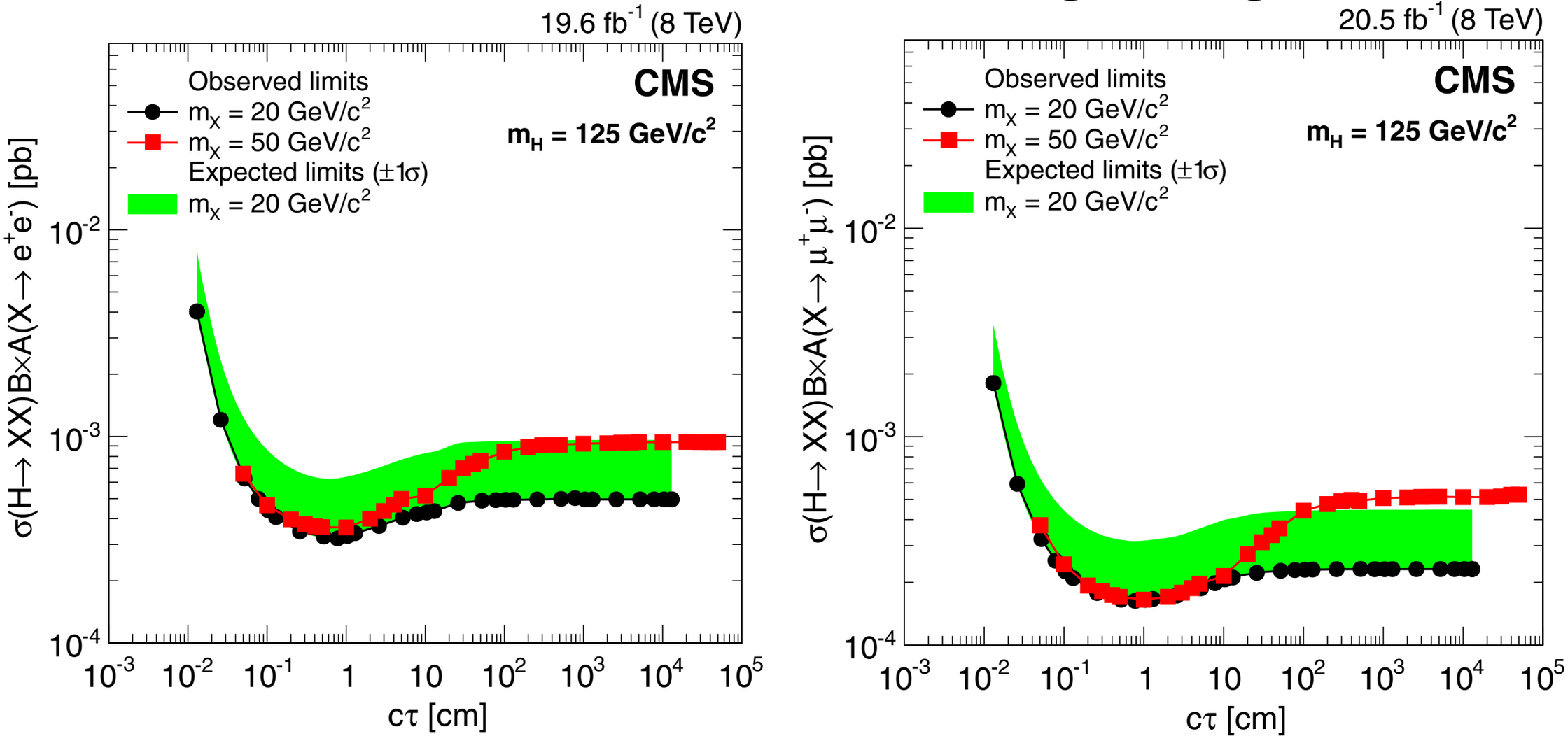
Background estimated from |Δφ| > π/2 control region



Results

PRD 91, 052012 (2015)

No events observed in the signal region



Results are shown here for H decay to a pair of spin-0 bosons but expect similar results for the spin-1 case

Event selection efficiency relative to the kinematic, geometrical acceptance ranges between ~ 30-60%

Summary

- Searches for dark photons being pursued by CMS exploring a wide range of lifetimes
- Involve non-trivial challenges involving the design of triggers and reconstruction of displaced candidates
- Treasure trove of 13 TeV data waiting to be explored
- Hope to update these searches with the full LHC Run-2 data set soon … so stay tuned