Search for Long-Lived Particles, True Muonium and Exotic Hadrons with CMS Dimuon Scouting

September 30th, 2020

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CMS Scouting Dataset Exploration

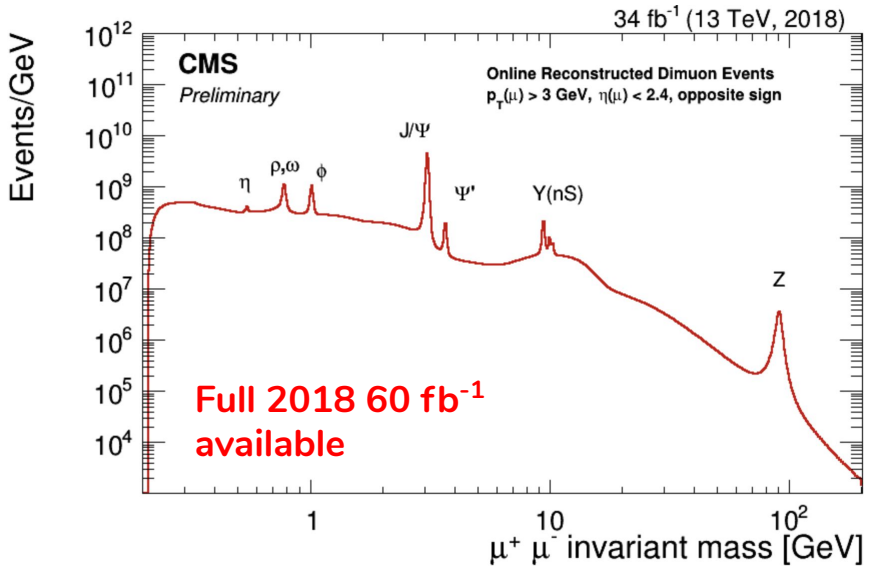
CMS recorded 19 Billion events with two muons in the final state using Scouting in 2018, compared to ~0.5 Billion in the 2018 (LowMass)DoubleMuon RECO dataset.

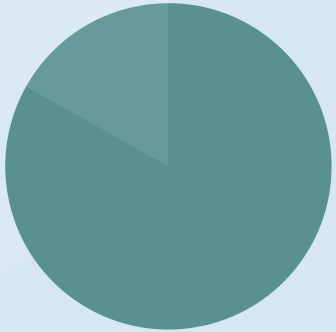
This CMS data is largely unexplored!

We perform:

1. First search of True Muonium
2. First low mass search for portals into the Dark Sector
3. Search for Exotic Hadrons and Quark bound states

We present the physics exploration of the scouting dataset. For an introduction into scouting, see e.g.: https://twiki.cern.ch/twiki/bin/view/CMS/TwikiUrl

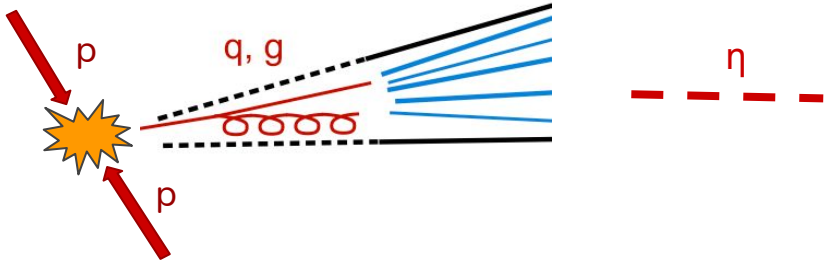


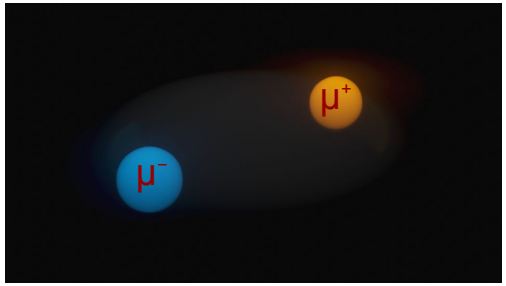


Search for True Muonium

Lars Noehte, Peter Meiring, Abanti Ranadhir Sahasransu

True Muonium - A SM prediction not yet seen





- Decays to muon pair largely through material interaction
  - In CMS look for dimuon vertex inside 1st Pixel Layer and Beam Pipe
- Fiducial cross section at LHCb 40 pb
  - Expect O(10k) True Muonia in CMS for 60 fb^{-1}
- Expected mass just above 0.21 GeV
- Mean free path of decay in silicon is 13 mm^{-1}

Good muon?

- nphits=0
- Ntklayers <= 5
- Chi2 > 10
- Pt > 3 GeV
- Eta < 1.2

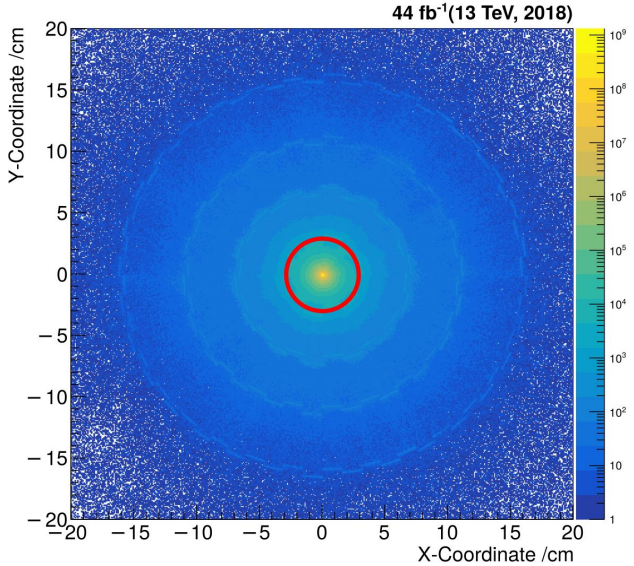
Event Selection?

- Opp. charge
- Nvtx = 1

Analysis strategy

- Pixel tracker visible due to interactions with tracker material!

- Different processes take place in different (x,y)-regions:
  - **Signal region:**
    Layer 1, the only region where True Muonium will dissociate. BUT: rich in backgrounds!
  - **Background region 1:**
    Layers 2-3-4, which are enriched in photon conversions
  - **Background region 2:**
    Intermediate areas (i.e. NOT in tracker layers), composed of many physics objects (heavy flavor decays, fakes, ...)



Interaction vertices indicate tracker layers!

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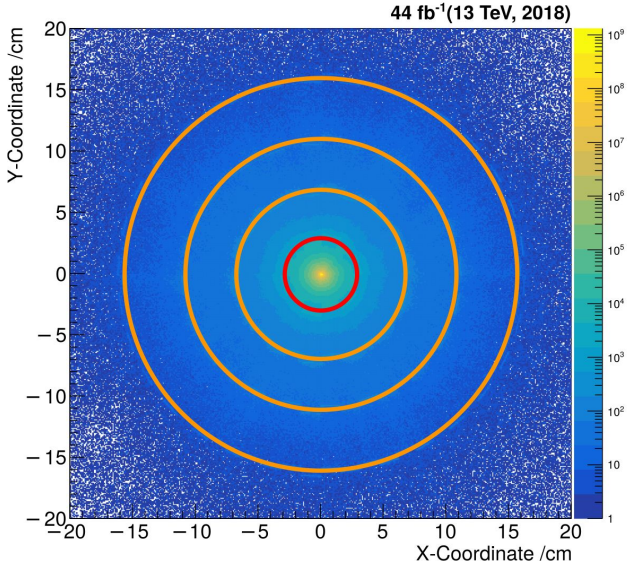

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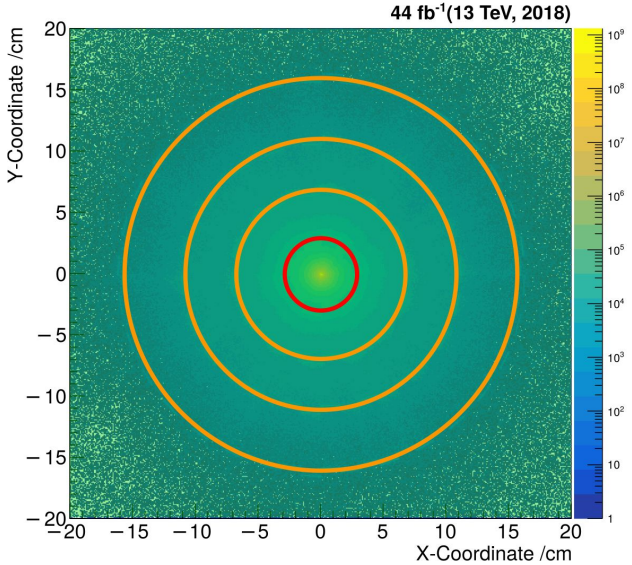

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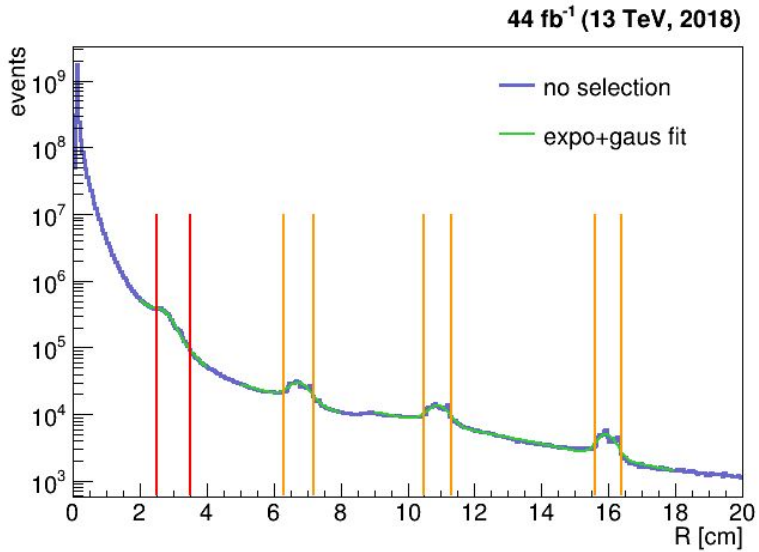
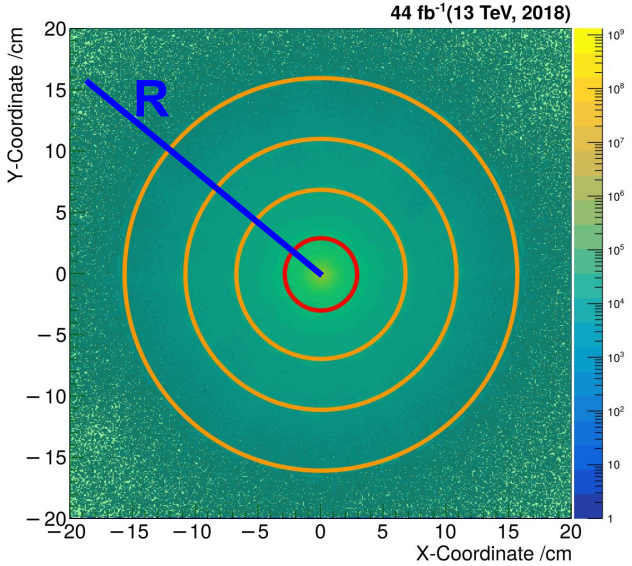
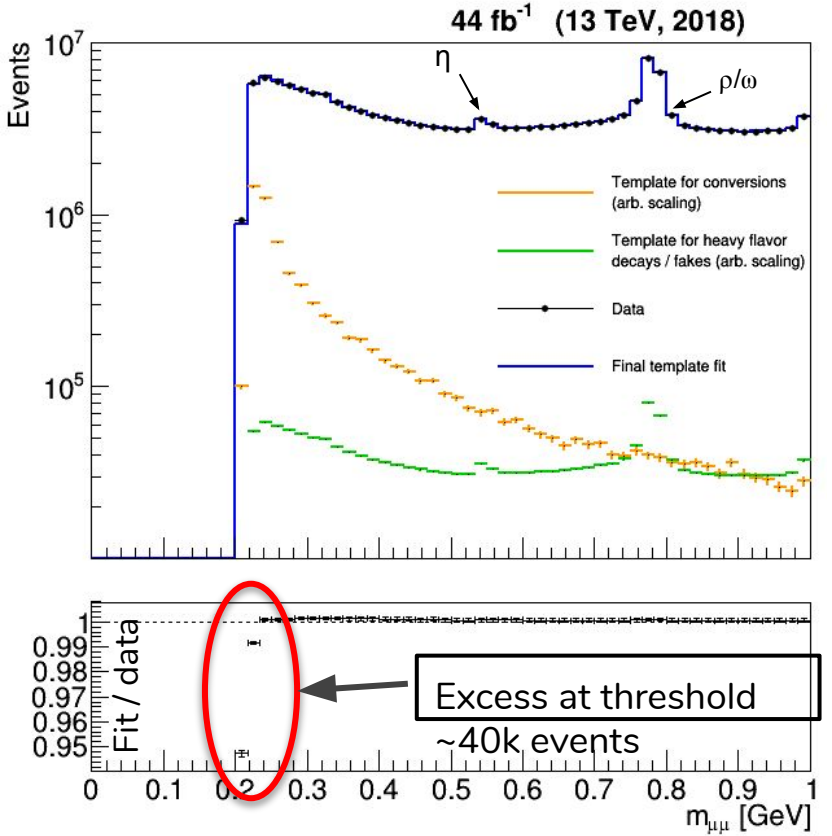




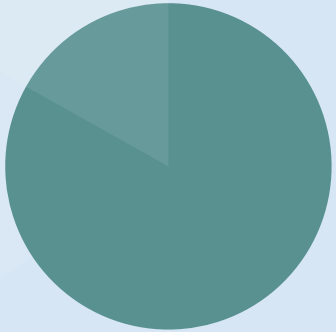
Interaction vertices indicate tracker layers!

Result

- Fully data-driven template fit performed
- **True Muonium** expected just above **0.2 GeV**
  - **Excess observed!**
    - **Compatible with True Muonium?**
  - Also a deficit at 0.25 GeV
- **Not conclusive, extra studies needed:**
  - Account for muon reconstruction efficiency
  - Improving object/event selection
  - Use dedicated MC simulations to estimate the backgrounds and effects from PU
  - Account for systematics
- **Already started studying:**
  - Photon conversion spectrum dependence on tracker layer
  - Impact of muon isolation criteria



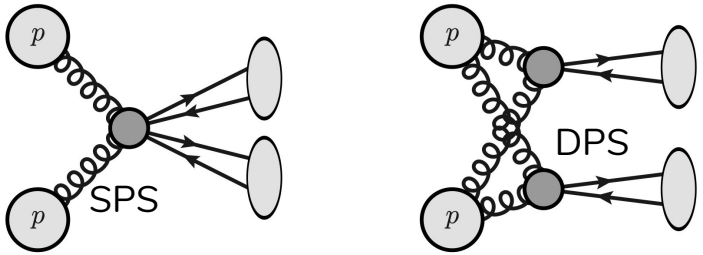
JPsi-JPsi Bump Hunt

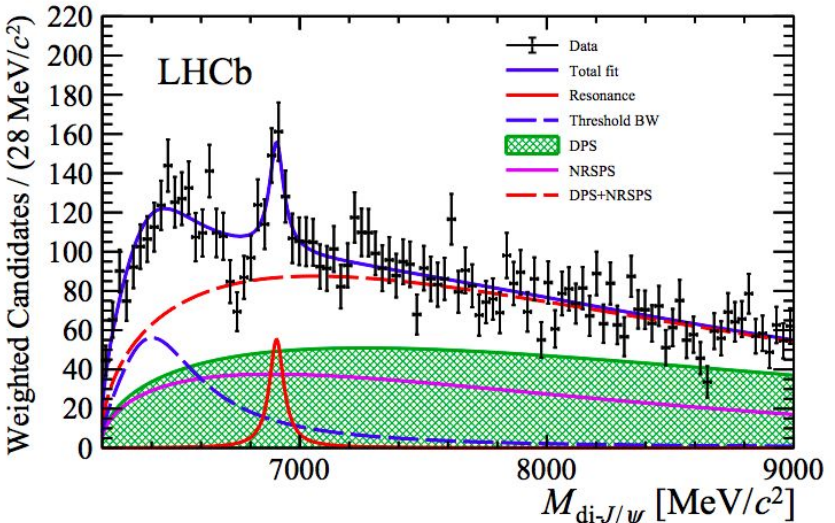


Chiara Aimè, Robert Lee

Di J/Psi mass spectrum

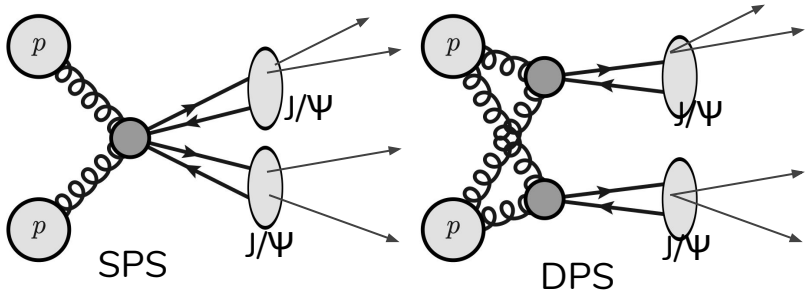
- Standard Model predicts tetraquarks (e.g cccc) that may decay in 4 muons
- LHCb has investigated the J/Psi - J/Psi mass spectrum → evidence of a resonance around 6.9 GeV/ $\mathbf{c^2}$
- CMS does so too using Scouting (we have 10 times more data!)





Our analysis - from West to East

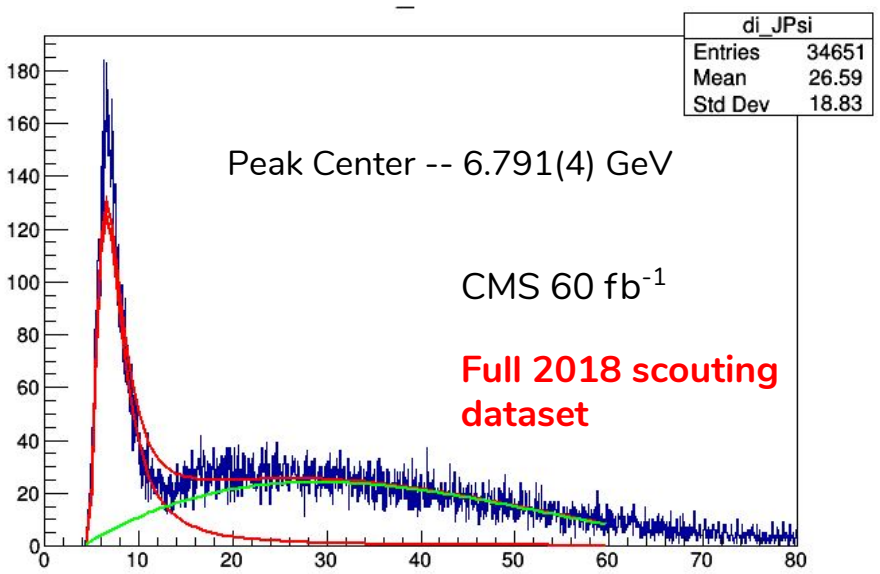
- Our team is from three completely different time zones. **This analysis has been performed worldwide!**
- **DATA**: full 2018 run scouting data (61.3 fb^{-1})
- **GOOD EVENT?**
  - 4 muons
  - Total charge = 0
  - Invariant mass of each muon pair compatible with J/Psi mass <u>within 3%</u>



- The hardest task was to **select all the possible combinations among the 4 muons**

Observation of di-J/Ψ Resonance with CMS at 13 TeV

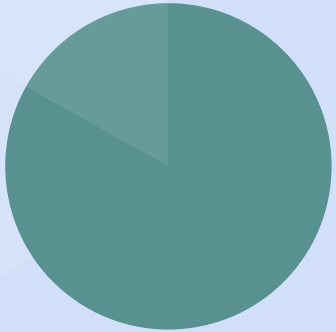
- Broad (and very big) resonant feature near threshold observed in di-J/Ψ invariant mass spectrum
- Compatible with X(6900) observation by LHCb?
- Double peak structure observed by LHCb not yet resolved
- Detailed analysis of decay kinematics and simulation of production modes to be done



And now it would be interesting to look for other mesons

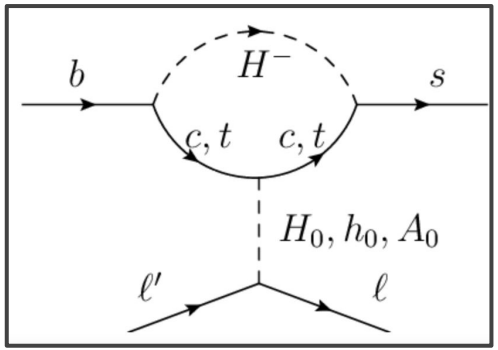
Search for Displaced μμ

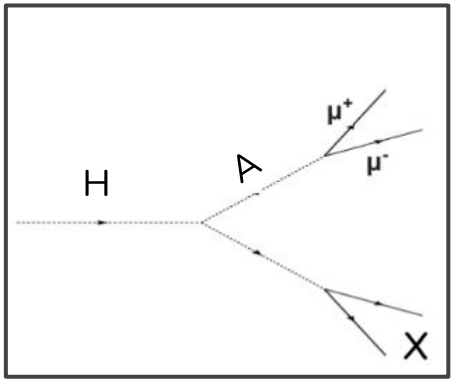
Gaia Grosso, Farouk Mokhtar

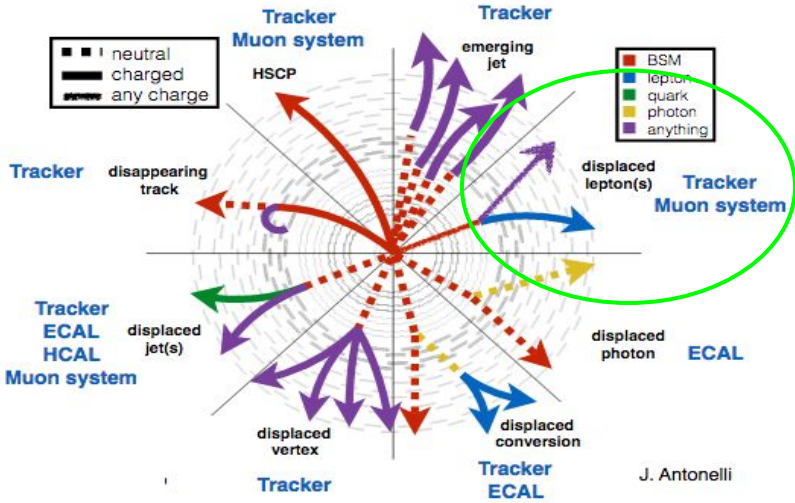


Displaced Signatures?

- **Ex**: long-lived neutral particles decaying to pairs of muons







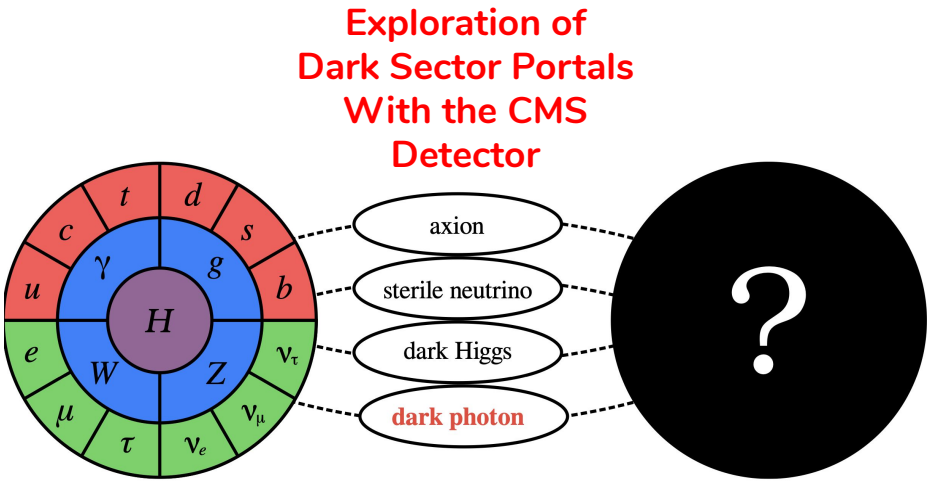
- Why we look at Run-2 dimuon **scouting** data:

  ~ muon triggers in CMS often have cuts that associate the muon track to the beam spot or vertex. In dimuon scouting, you have in principle access to muons that are displaced by up to **15 cm in the barrel**

  ~ allows probing small masses

Our Target

- Perform the **dimuon bump-hunt search** for **displaced signatures** in scouting datasets (0.2-10 GeV)
- Perform the signal extraction asking for the dimuon vertex to be displaced from the beam spot (**L > 0**)
- Extract model-independent **cross-section exclusion limits** as a function of **mass** and **lifetime** hypothesis



Search for low mass mediators with small couplings to Standard Model ⇒ displaced signatures

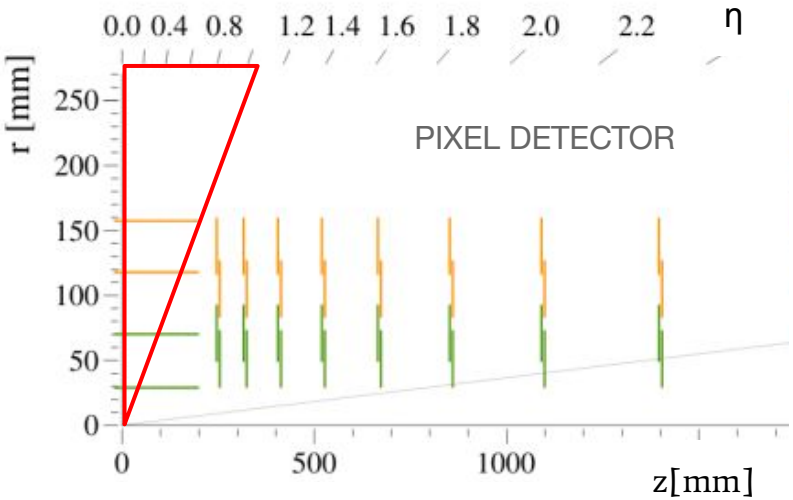
Our basis code: https://github.com/jsalfeld/DarkPhotonAnalysisV2 (which is used for ongoing scouting searches for Dark Photons and other mediators)

Data distribution & the different cuts

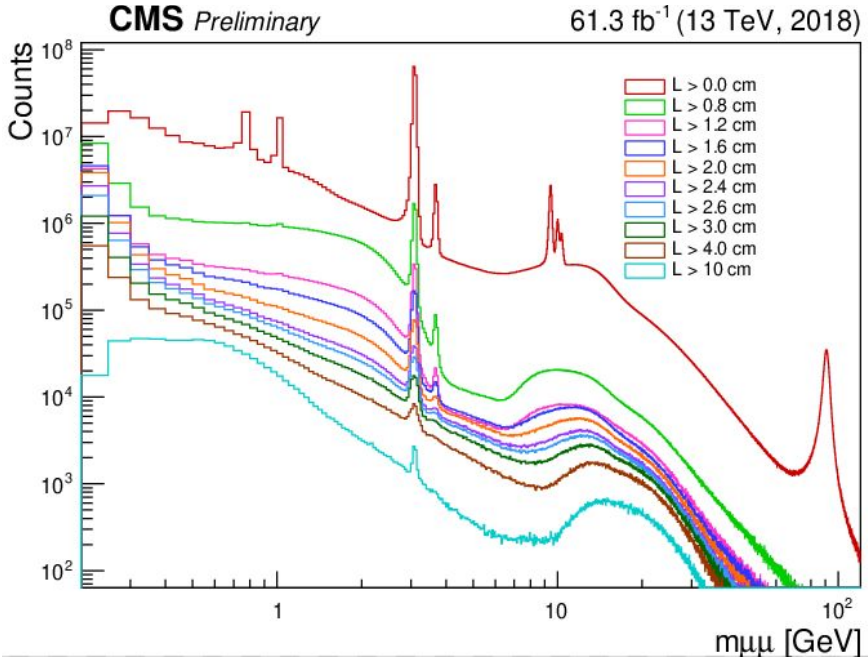
we explored the full Run of 2018 scouting data (61.3 fb^{-1})

Requirements:

- Common reconstructed vertex
- Both μ with:
  - $|\eta| < 0.9 \quad \rightarrow$ Lmax =15cm
  - PT > 3 GeV



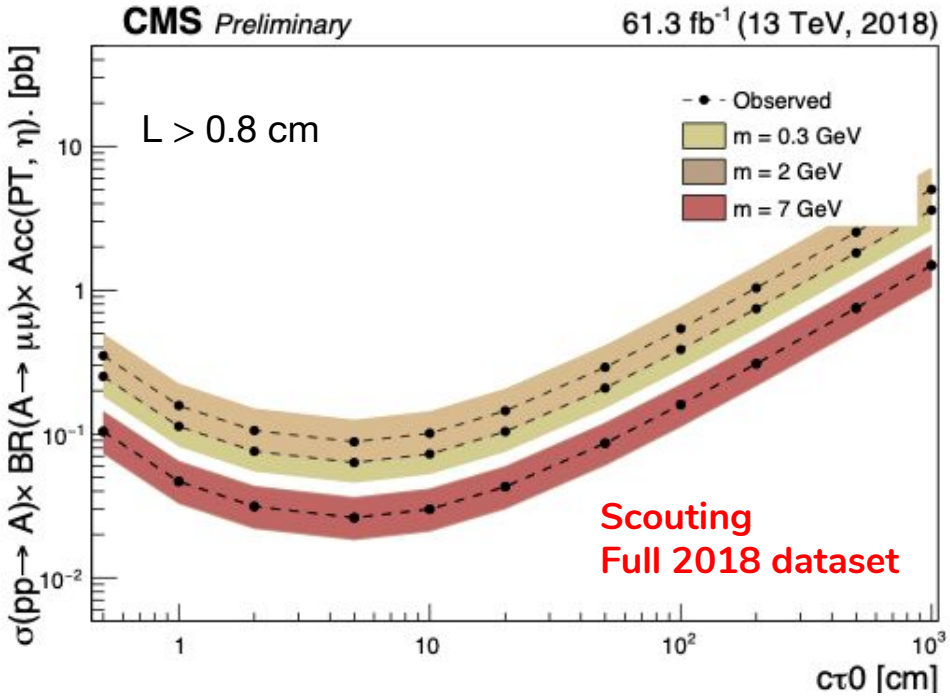
Selections on the absolute distance of the μμ vertex from the beam line (L)



Exclusion limits plots

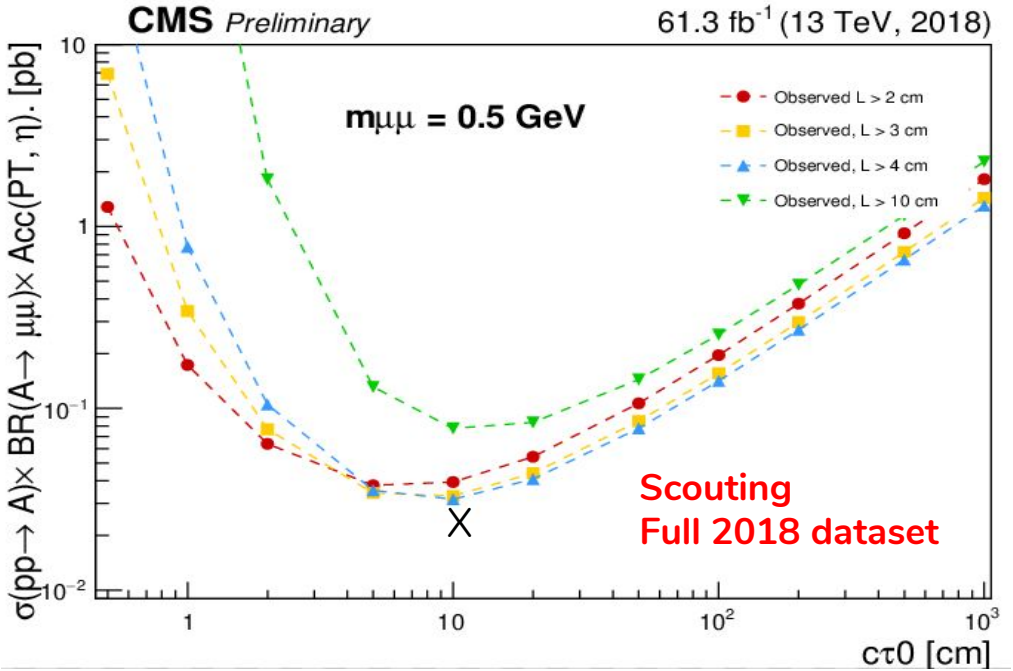
m ∈ [0.2, …, 10] GeV
L ∈ [0.8, 1.2, 2, 3, 4, 10] cm
cτ0 ∈ [0.5, …, 1000] cm

At smaller masses, larger background



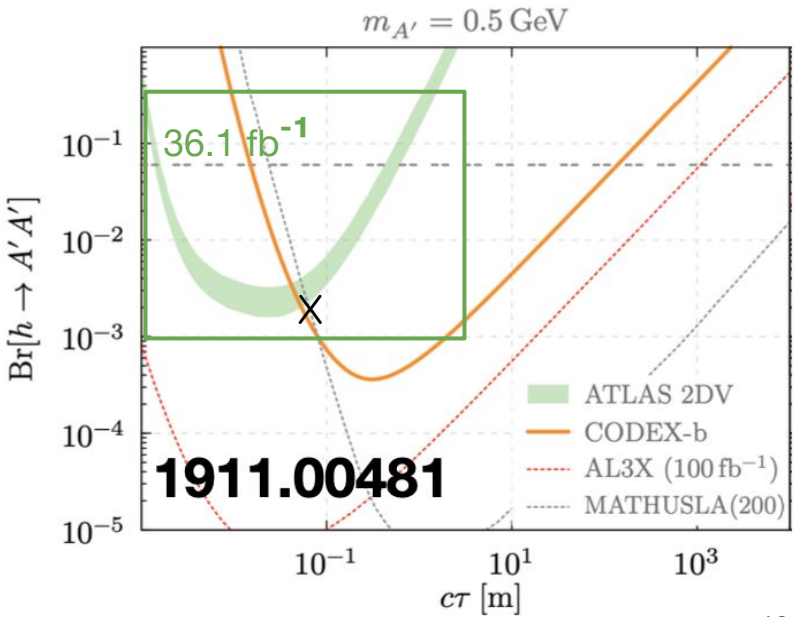
Exclusion limits plots

Optimization of the exclusion reach over a set of L choices for a given mass hypothesis



Comparable to ATLAS results

xsec(pp→ H @13TeV) ≈ 30 pb



Conclusions

First CMS inclusive model independent LLP dimuon limit at 13 TeV below 10 GeV

First search for True Muonium at High-Energy Collider

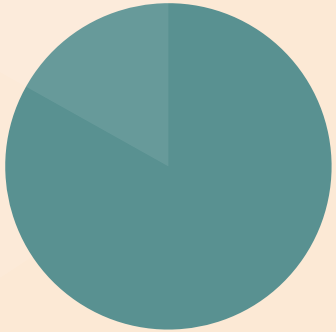
Observation of di-J/Ψ bump at threshold in pp collisions at 13 TeV

All analyses have been performed with 20 billion Dimuon events, heavy usage of computing Resources, equivalent to HL-LHC era in 2038

Our sincere gratitude to Jakob for these innovative analyses ideas and guidance.

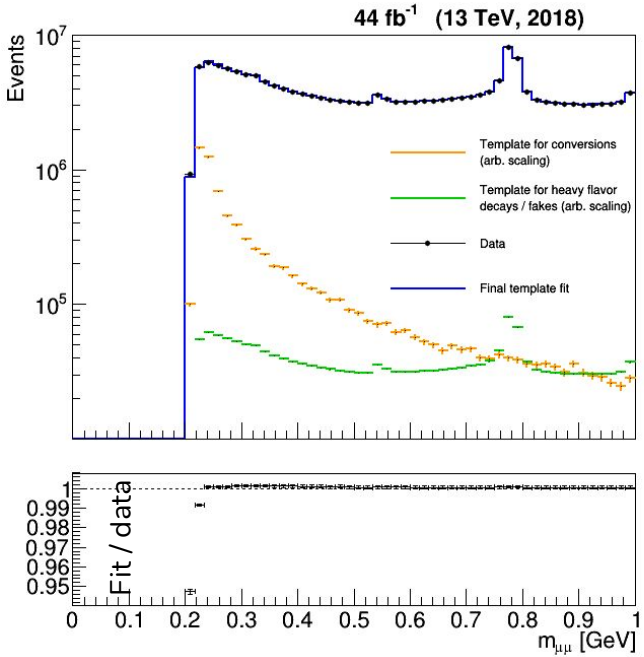
Research Team (a 4-continent collaboration :)

BACKUP

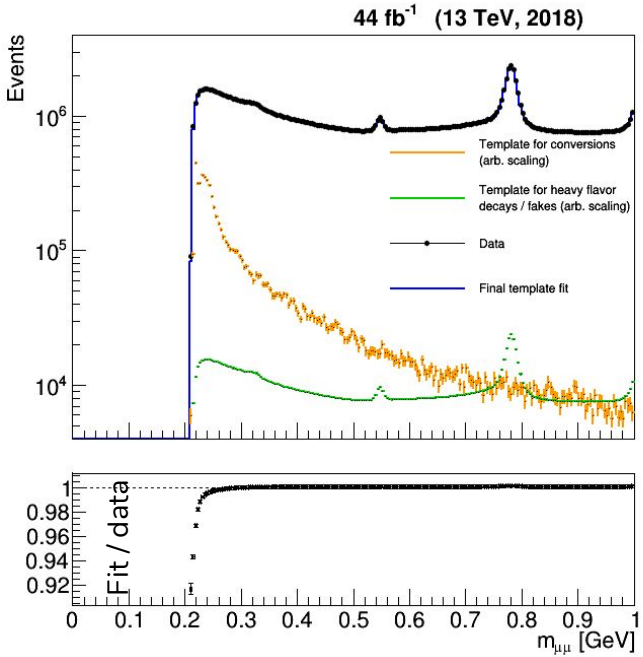


True muonium: Template fit to all data

Default binning

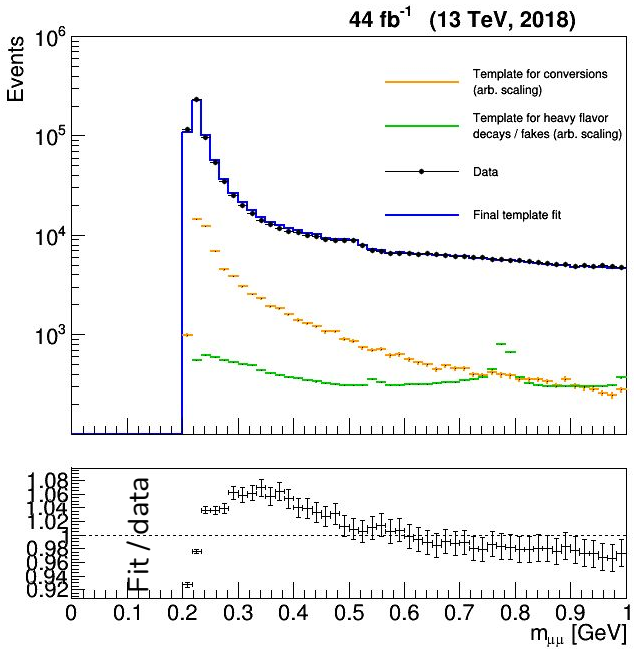


Finer binning



True muonium: Template fit to Tracker L1

Default binning



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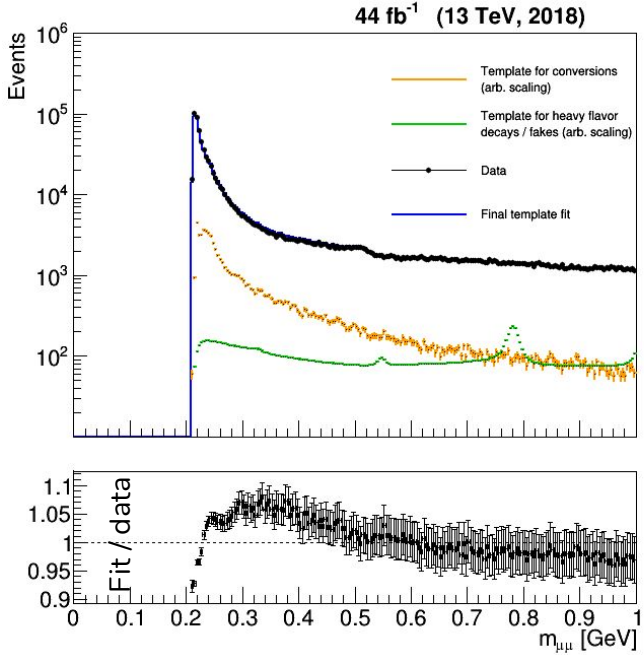
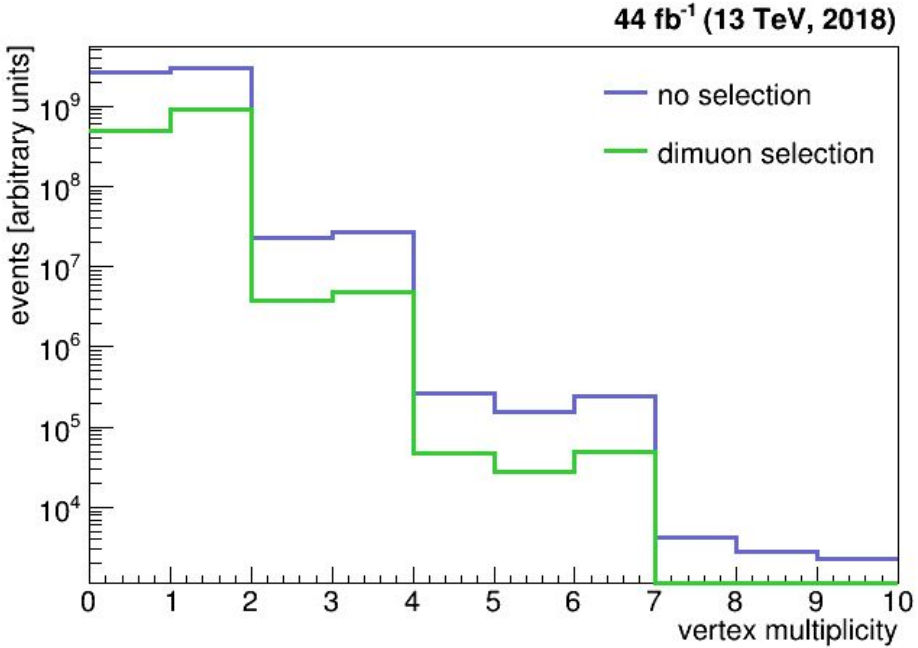


True muonium: vertex == 1 chosen



True Muonium: Iso selection not productive