

# Exotics at the LHC

Status and prospects

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EOS be.h Equinox Meeting

# Ok, the Higgs – now what?



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## Possibility landscape

- that's it!  
the SM is all there is!



source: undisclosed

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the SM all there is!




*“The reports of my death have been  
greatly exaggerated”*

Dr. B.S.M. Physics

# Ok, the Higgs – now what?

## Possibility landscape

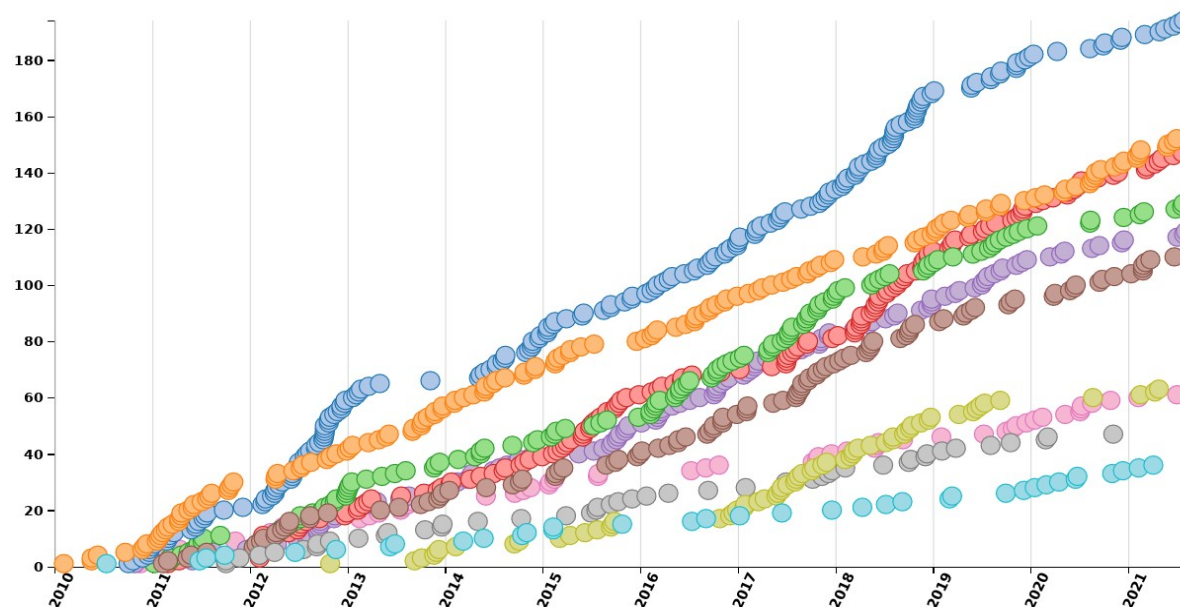
- 
- that's all there is!  
the SM all there is!
  - NP exists, but a very high mass scale
    - EFTs? deviations in decay rates?
  - NP exists at our mass scale, but too low cross section
    - smarter triggers? high lumi?
  - NP is already in our data!
    - swamped in similar background?
    - “cleaned” in standard reconstruction? not reconstructed? forgot to trigger?
    - ...

# Exotics searches with CMS

- very large scope of new physics topics
  - dark matter, long-lived particles, leptoquarks, dijet/lepton/photon resonances, heavy neutrinos, extra dimensions, etc etc
  - (more or less) all “searches” except most SUSY, exotic Higgs, heavy resonances in top/H/W/Z final states, and SM EFT analyses

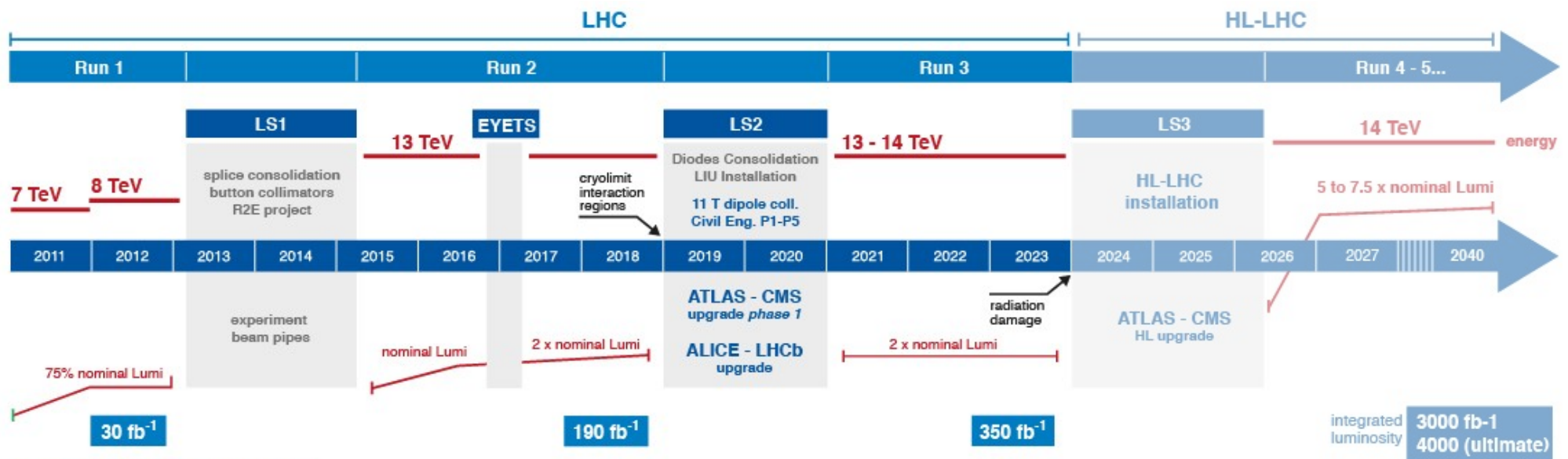


1061 collider data papers submitted as of 2021-09-05



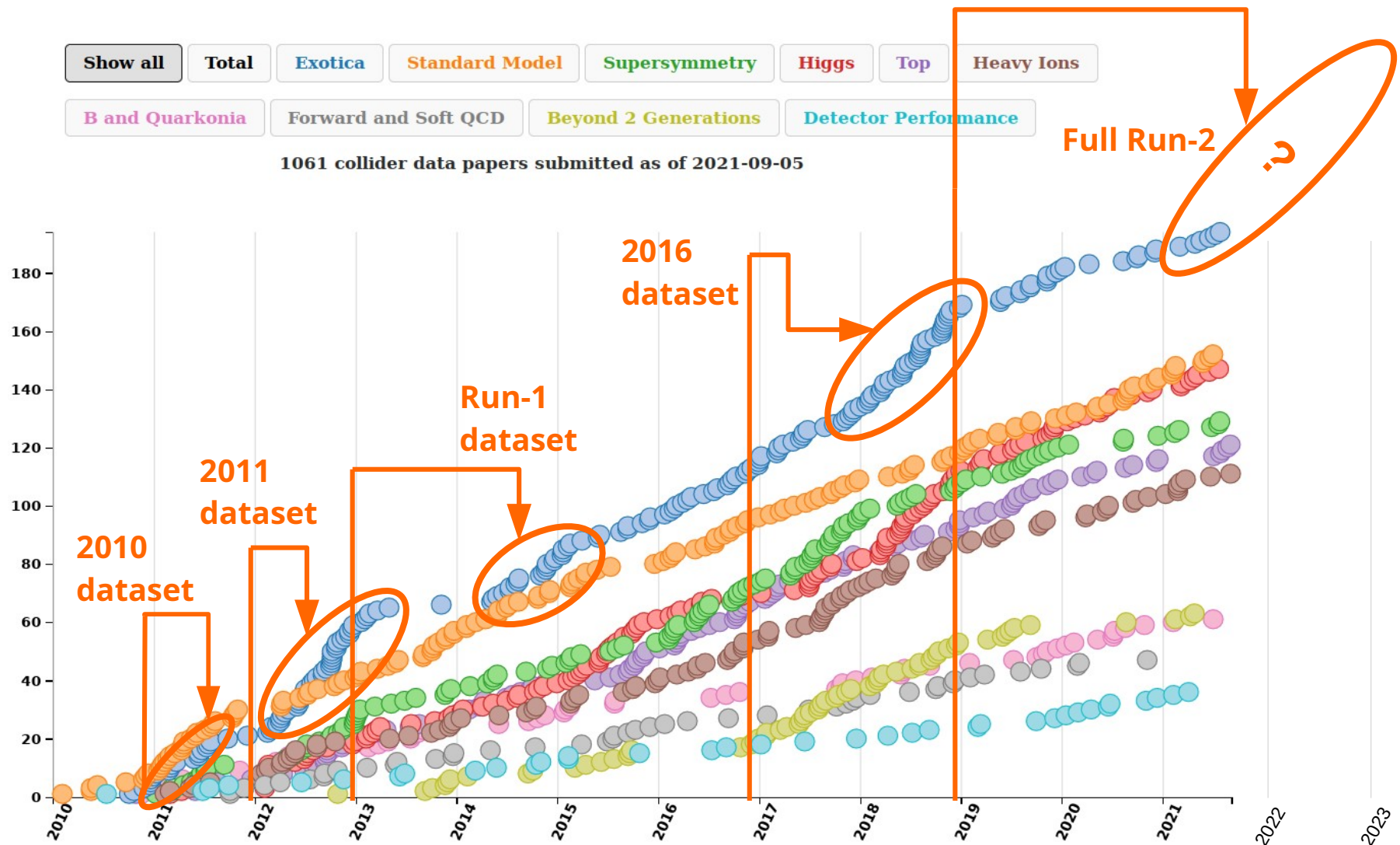
# LHC Timeline

- the **Run-2** dataset is our current workhorse
  - mainly  $136\text{fb}^{-1}$  of **13TeV** c.o.m. **pp** collisions
  - huge physics output
- **Run-3** is our next big thing
  - large sample at higher energy, but deteriorating detectors
  - note: 2021 was canceled, LS3 shifted



# CMS exotica publications

- first we have to finish Run-2!



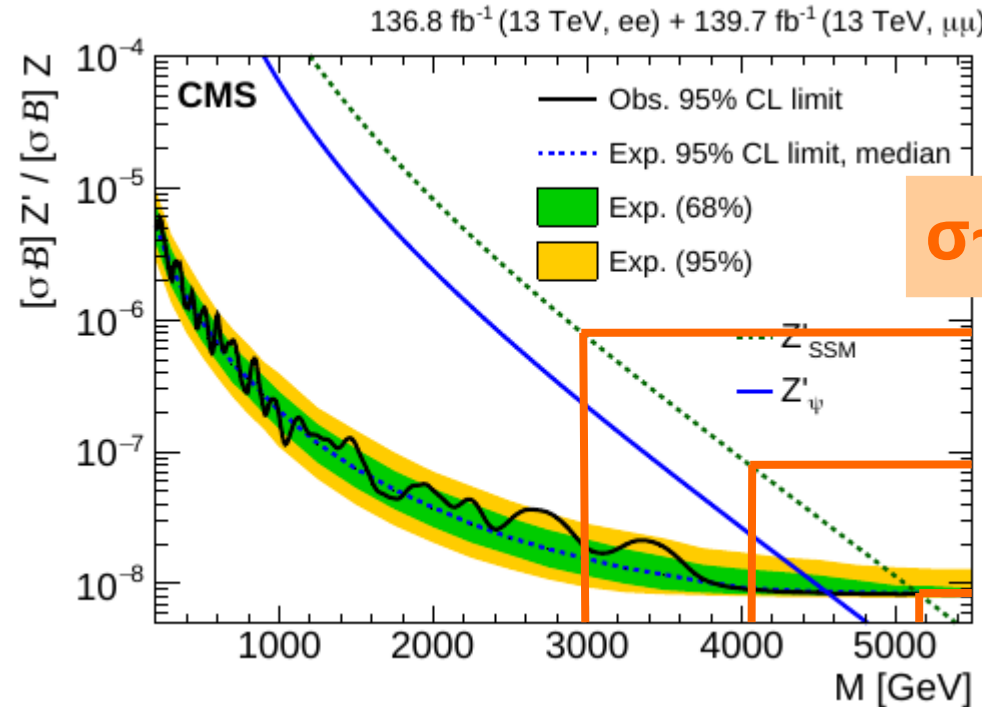


- first we have to finish Run-2!
- data taking stopped 2.5y ago
  - but we're still far from done
  - “only” ~20 Exotica papers on full Run-2 dataset submitted or published
- this summer: 13 (!) new preliminary results were made public in conferences
  - in principle we still expect many more to come
- in the following, I will cherry-pick some Run-2 results to demonstrate the challenges for Run-3

# Run-3: LHC context

- collect  $\sim 190/\text{fb}$  in 2022-2024
  - luminosity will double  
>3 years from now
- many new physics scenarios have rapidly falling cross sections
  - physics stays compelling but no more easy doubling  
→ strategy shift
- c.o.m. energy will increase, probably to 13.6 TeV
  - high-mass EXO searches get an extra boost
  - $\sigma_{14\text{TeV}} / \sigma_{13\text{TeV}} \sim 1.5 @ 3\text{TeV}$  ;  $\sim 2.6 @ 6\text{TeV}$

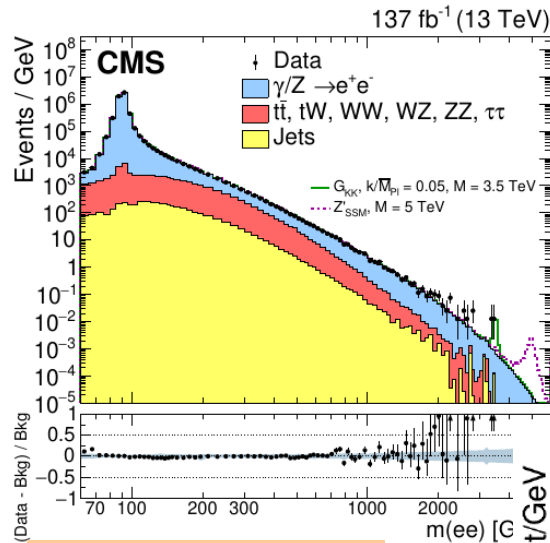
arXiv:2103.02708



$$\sigma \sim M^{-8.5}$$

# Run-3: the physics challenge

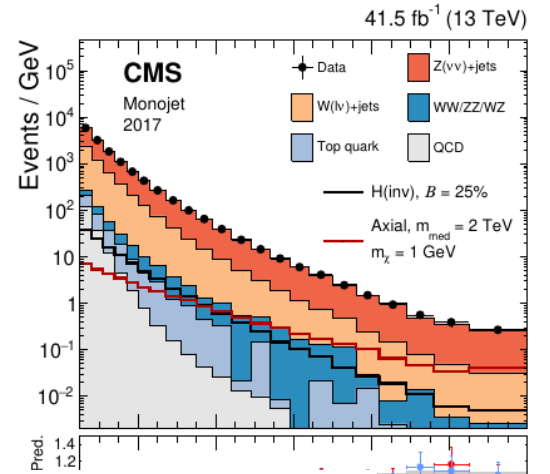
- Run-3's challenge is to push the limits of our physics coverage
  - ultimate high-mass LHC reach from increase in c.o.m. energy



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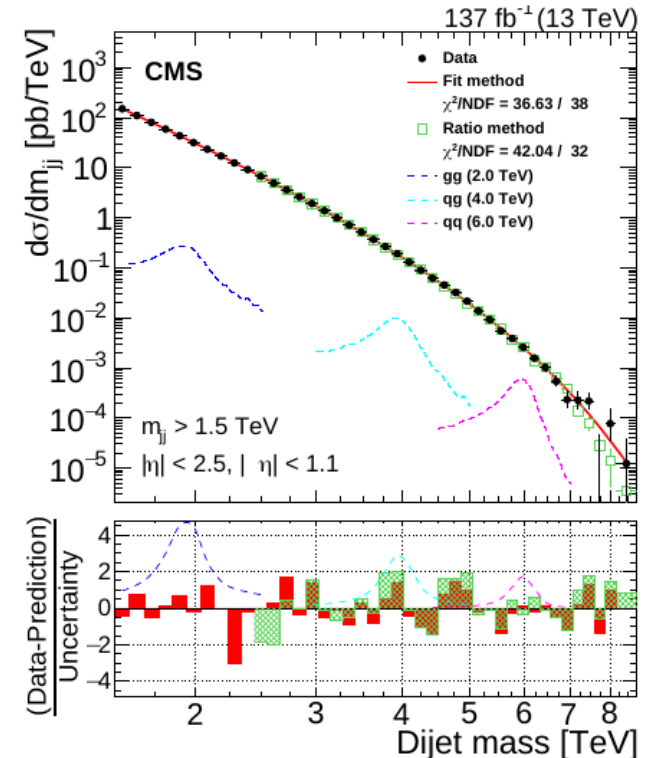
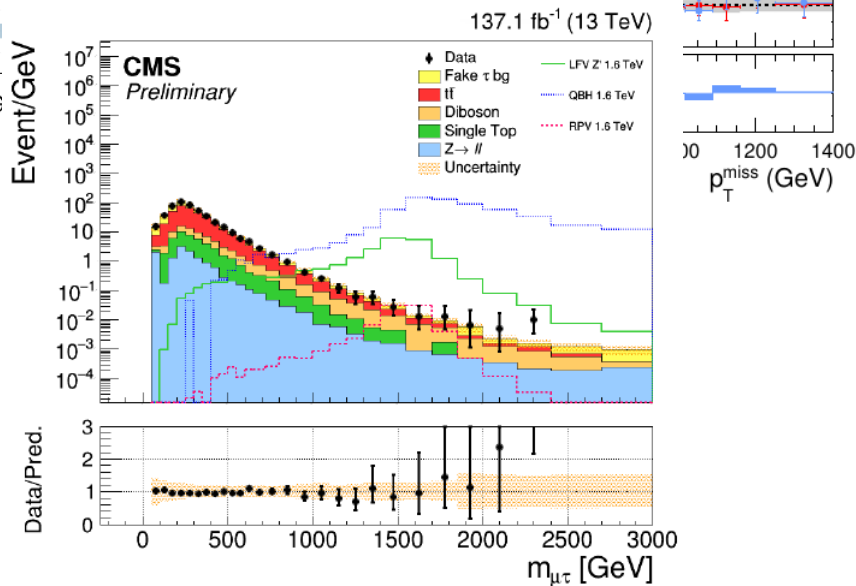


EXO-19-014  
Amandeep's talk!



arXiv:2107.13021

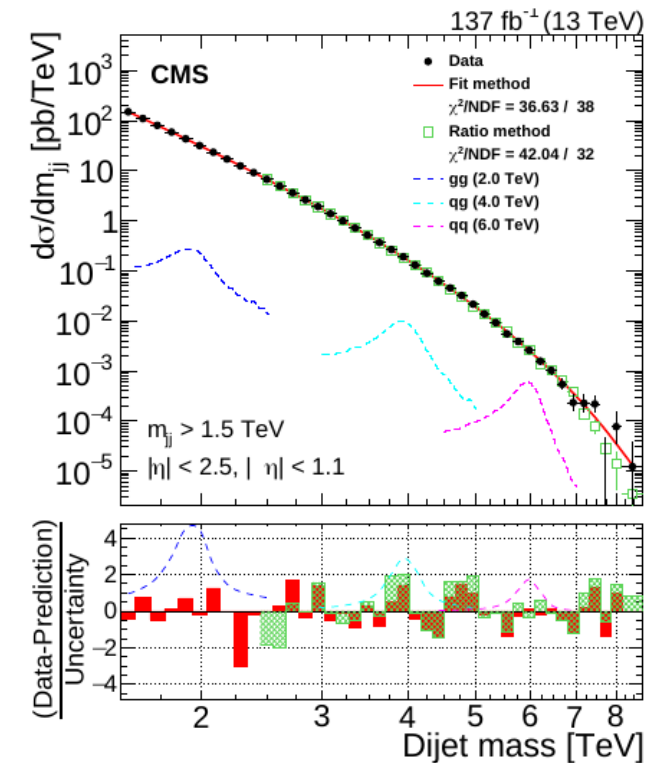
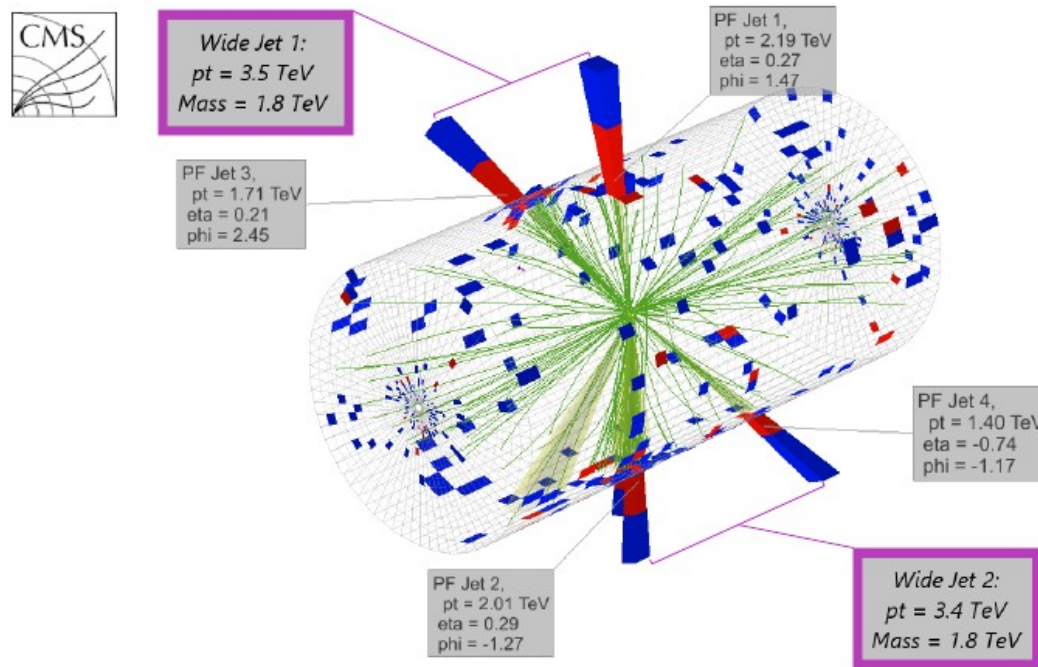
arXiv:1911.03947



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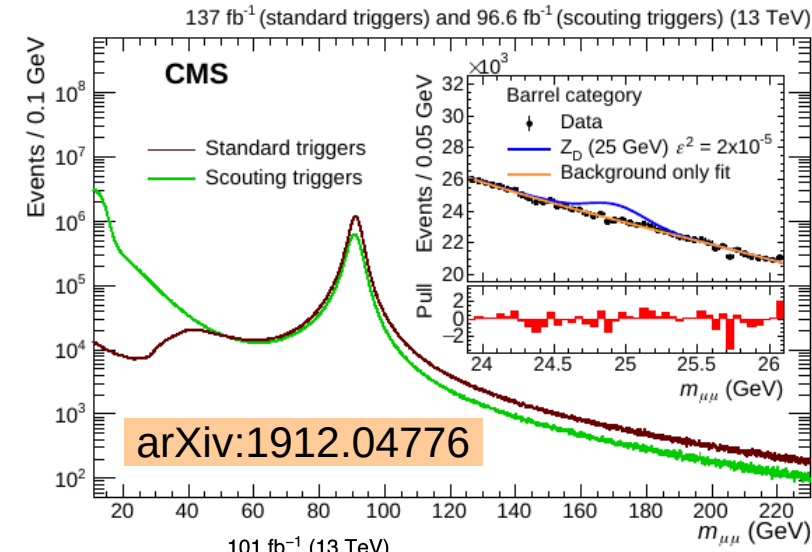
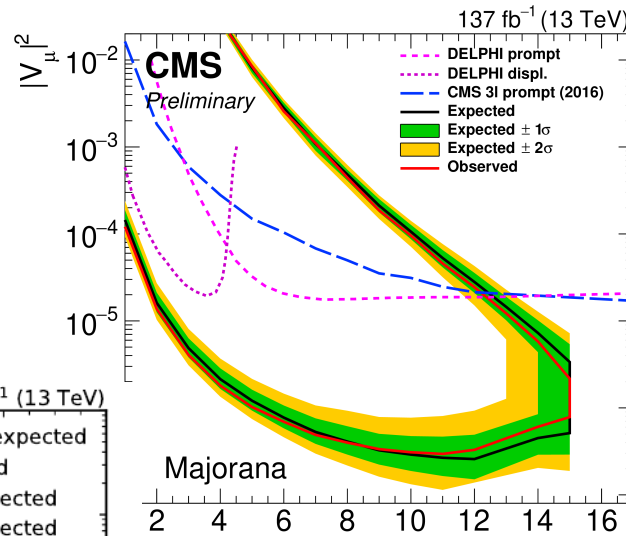
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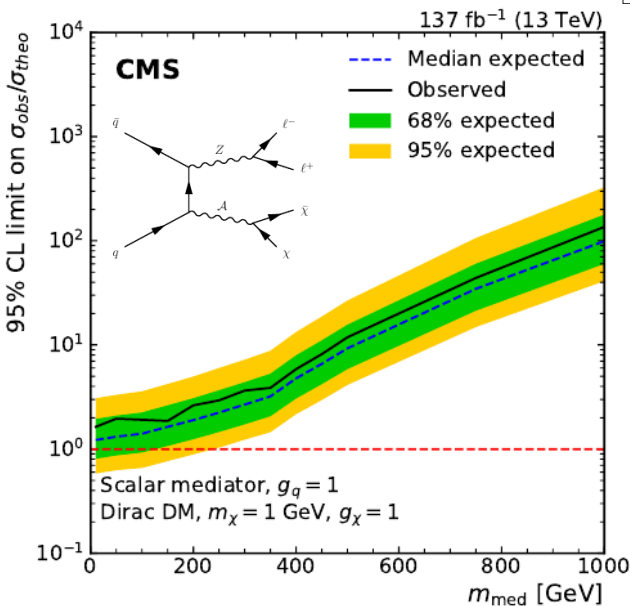


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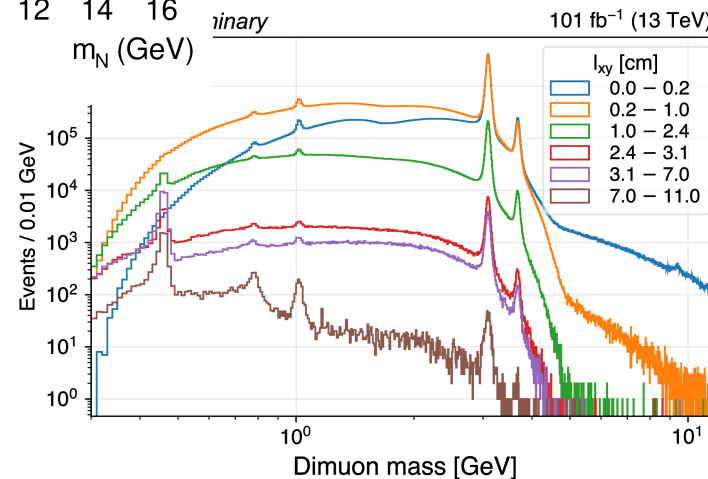
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  - ultimate high-mass LHC reach from increase in c.o.m. energy
  - intense hunt for low-mass and low-coupling new physics



arXiv:2008.04735



EXO-20-009  
 Liam's talk!

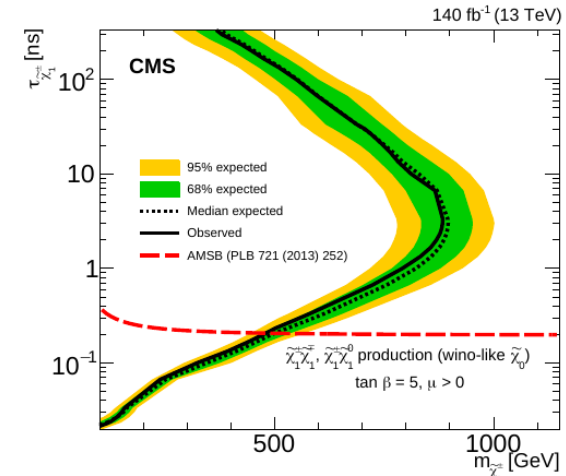


EXO-20-014

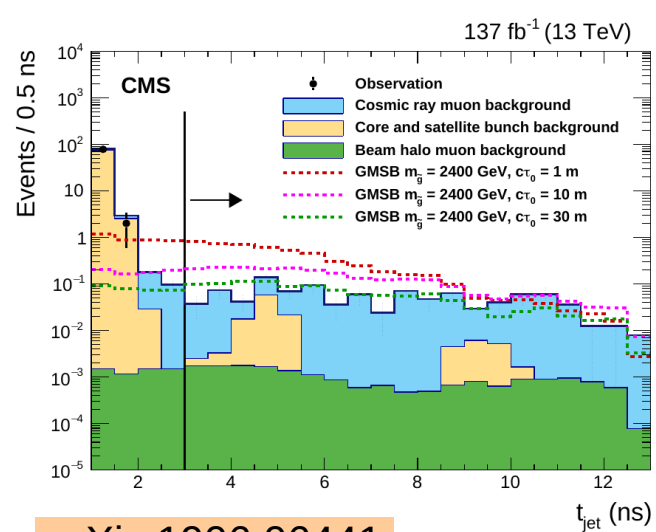
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  - maximal use of the detector for unconventional searches

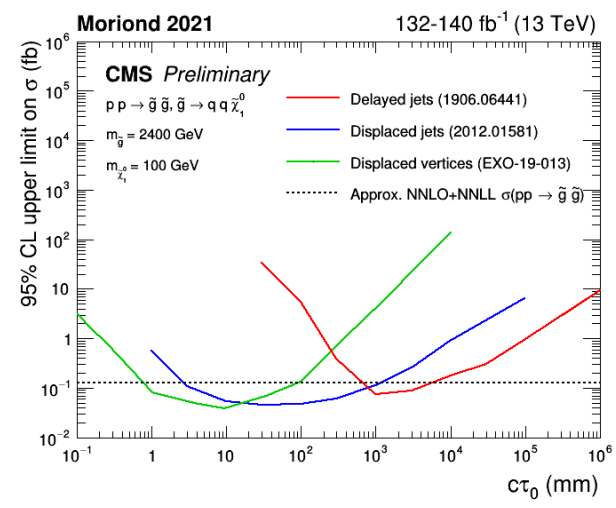
also Sam's talk!



arXiv:2004.05153

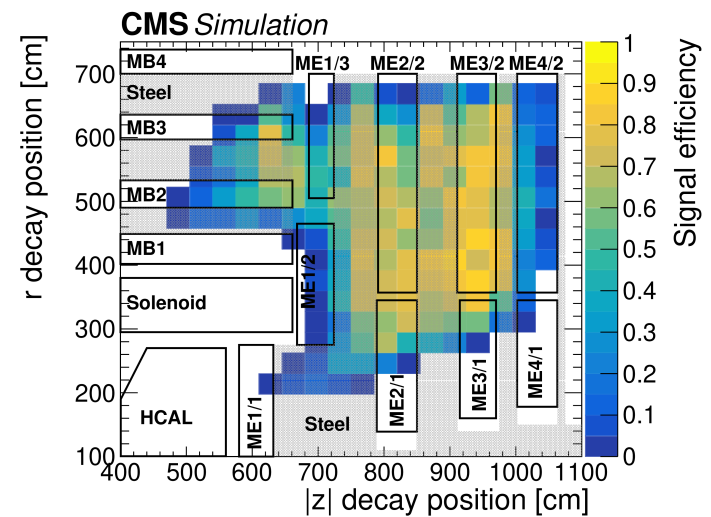


arXiv:1906.06441



arXiv:2104.13474

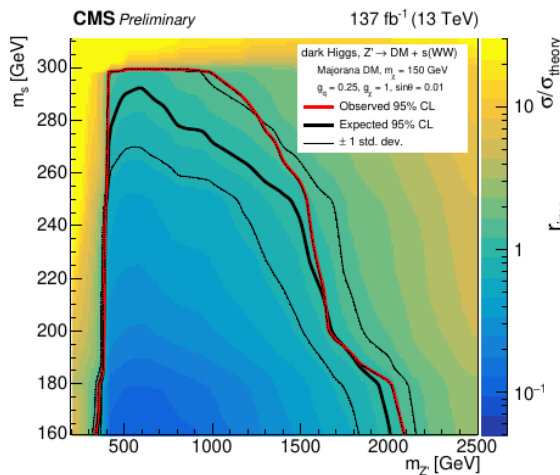
arXiv:2012.01581



arXiv:2107.04838

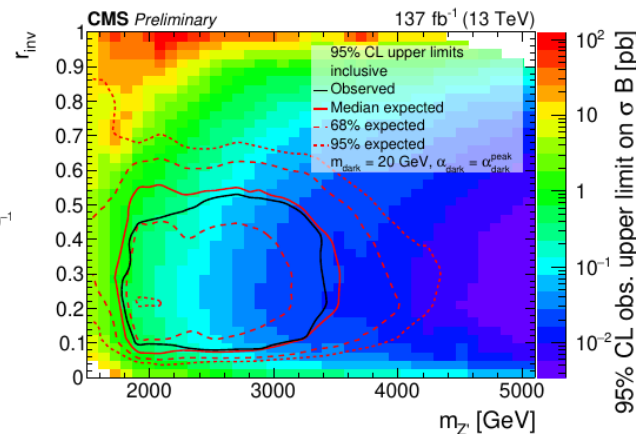
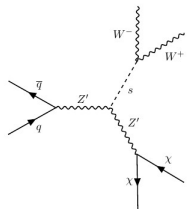
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  - explore new phenomenologies



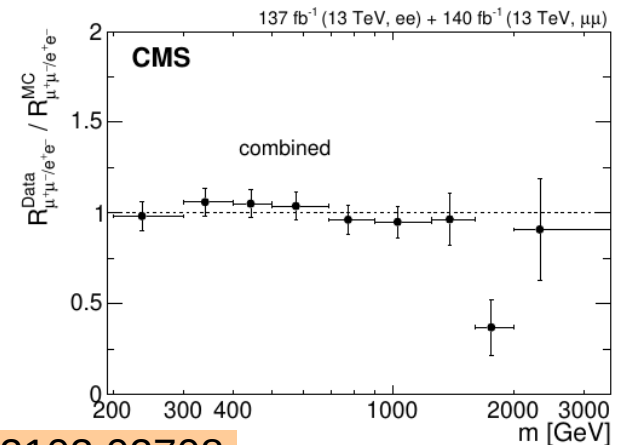
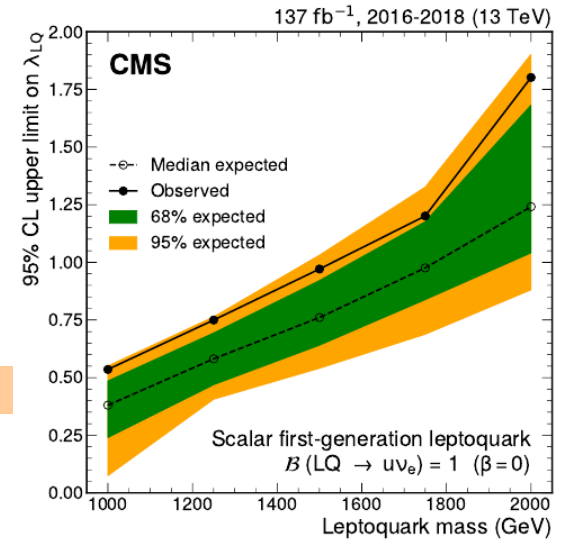
EXO-20-013

be.h



EXO-19-020

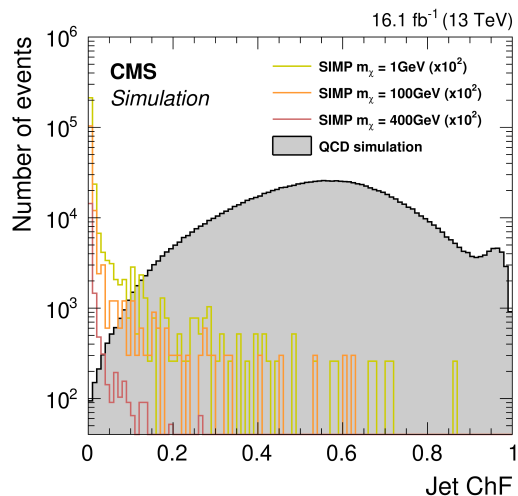
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  - intense hunt for low-mass and low-coupling new physics
  - maximal use of the detector for unconventional searches
  - explore new phenomenologies
  - attempt the exotic exotics



arXiv:2105.09187



arXiv.org > hep-ph > arXiv:1612.00850

High Energy Physics - Phenomenology

[Submitted on 2 Dec 2016]

Triggering Soft Bombs at the LHC

Simon Knapen, Simone Pagan Griso, Michele Papucci, Dean J. Robinson

arXiv.org > hep-ph > arXiv:1112.2999

High Energy Physics - Phenomenology

[Submitted on 13 Dec 2011 (v1), last revised 3 May 2012 (this version, v4)]

Sensitivity of LHC experiments to exotic highly ionising particles

A. De Roeck, A. Katre, P. Mermod, D. Milstead, T. Sloan

arXiv.org > hep-ph > arXiv:1708.02243

High Energy Physics - Phenomenology

[Submitted on 7 Aug 2017 (v1), last revised 13 Nov 2017 (this version, v2)]

Tracking down Quirks at the Large Hadron

Simon Knapen, Hou Keong Lou, Michele Papucci, Jack Setford

arXiv.org > hep-ph > arXiv:1708.08951

High Energy Physics - Phenomenology

[Submitted on 29 Aug 2017 (v1), last revised 9 May 2018 (this version, v2)]

Stable Sexaquark

Glennys R. Farrar

arXiv.org > hep-ph > arXiv:1904.08458

High Energy Physics - Phenomenology

[Submitted on 17 Apr 2019 (v1), last revised 13 Sep 2019 (this version, v2)]

Discovering True Muonium at LHCb

Xabier Cid Vidal, Philip Ilten, Jonathan Plews, Brian Shuve, Yotam Soreq

arXiv.org > hep-ph > arXiv:1812.07688

High Energy Physics - Phenomenology

[Submitted on 18 Dec 2018 (v1), last revised 16 Jun 2020 (this version, v2)]

New physics searches with heavy-ion collisions at the LHC

Roderik Bruce, David d'Enterria, Albert de Roeck, Marco Drewes, Glennys R. Farrar, Andrea C

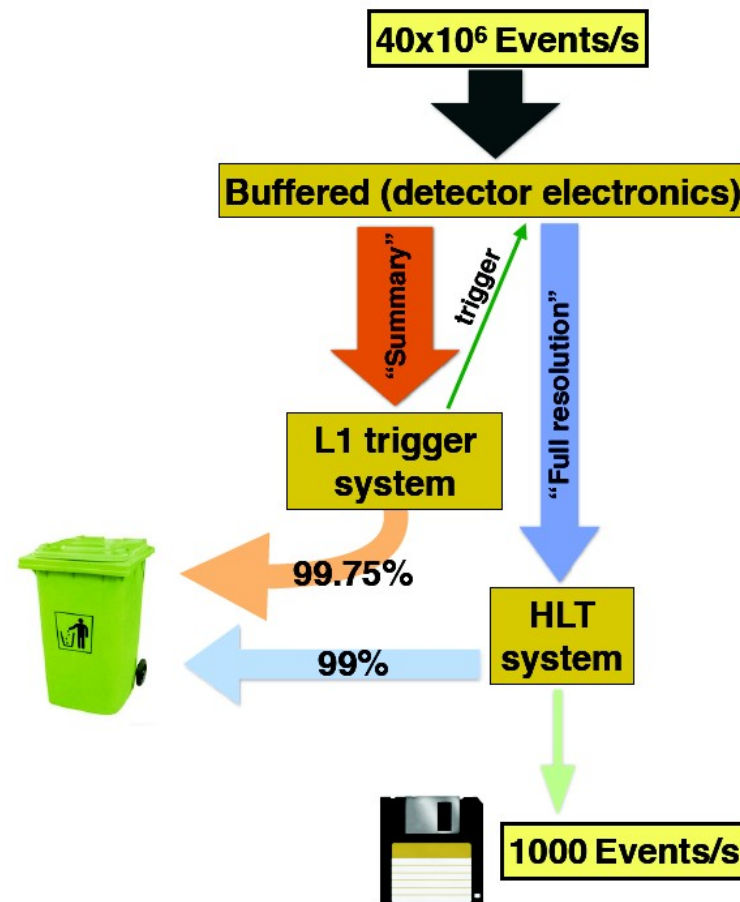




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  - **ultimate high-mass LHC reach** from increase in c.o.m. energy
  - intense hunt for **low-mass and low-coupling** new physics
  - maximal use of the detector for **unconventional searches**
  - explore **new phenomenologies**
  - attempt the **exotic exotics**
  - provide **re-interpretation tools** to the pheno community
- how? any challenge brings **opportunities for innovation**
  - **trigger** at lower thresholds or higher rates; roll out cross triggers
  - deploy **next-gen reconstruction and computing** techniques
  - work **towards ultimate precision** where relevant
  - push our **detector beyond its design** capabilities
  - **publicly share** our results, likelihoods, and efficiencies

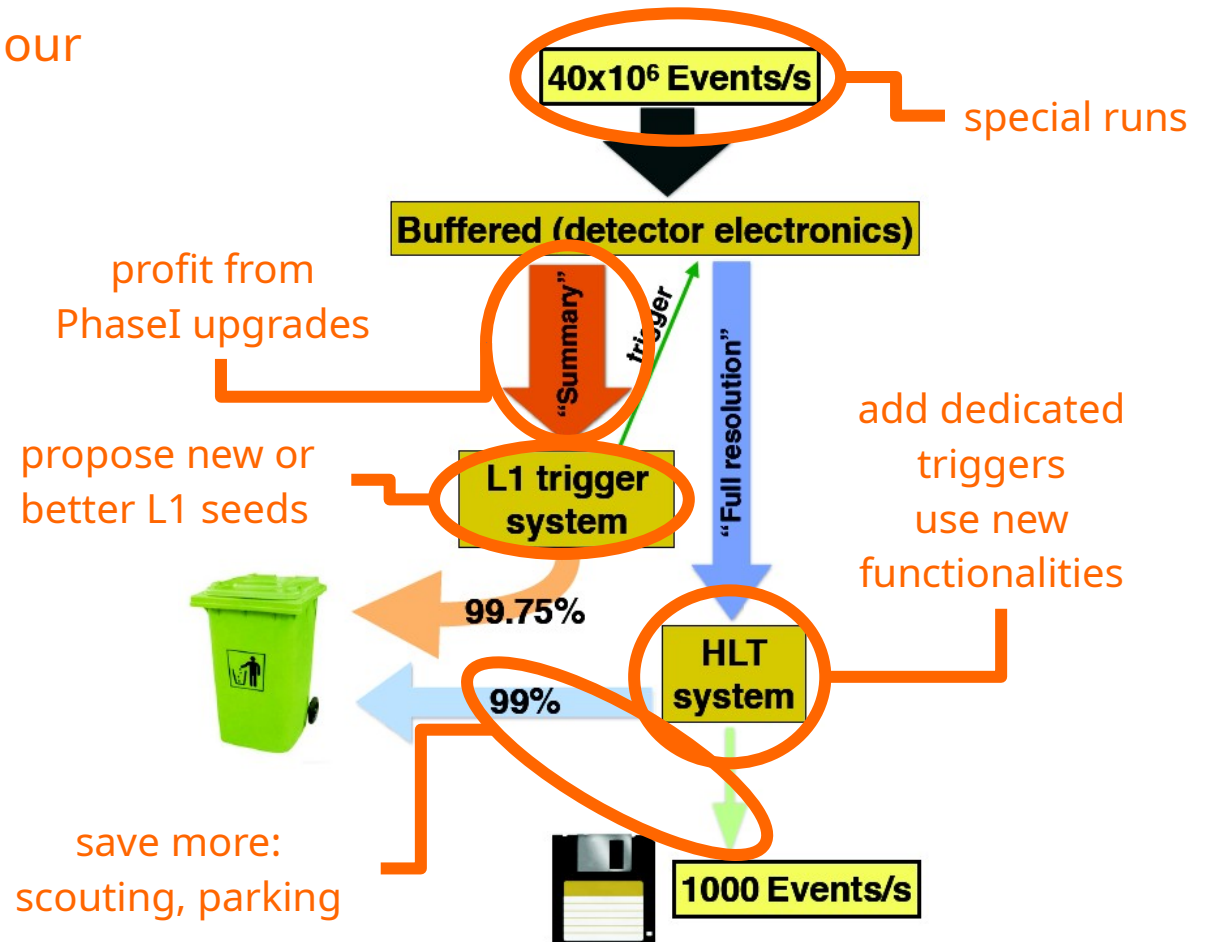
# Run-3: an extra word on trigger

- the trigger in Run-3 defines our physics program until 2028
- 2021 is the year we build the menu
- investment now to make Run-3 a success



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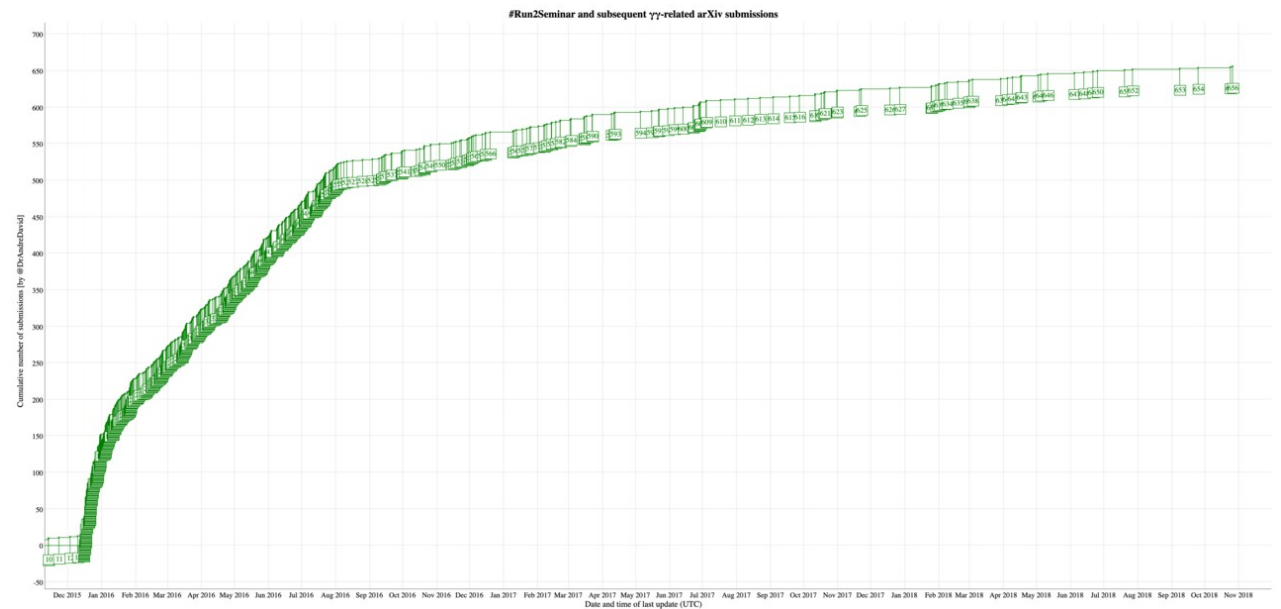
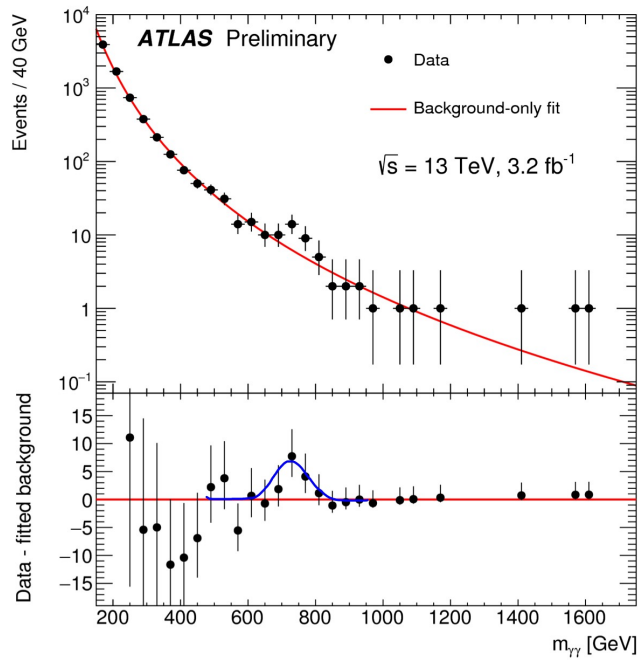


# Wrapping up

- 10 years of exotics searches with enormous impact
  - no discoveries so far...
- the exotica physics outlook for LHC Run-3 is exciting!
  - slight energy increase, significantly larger dataset
  - plenty of room for innovation, in particular for triggers
- LHC Run-2 is not over!
  - majority of publications still to come
  - it will remain a reference dataset and sandbox for years to come
- beyond: HL-LHC era will bring us a new detector
  - many enhanced capabilities for exotic final states

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- 10 years of exotics searches with enormous impact
  - no discoveries so far... but remember this?



# Wrapping up

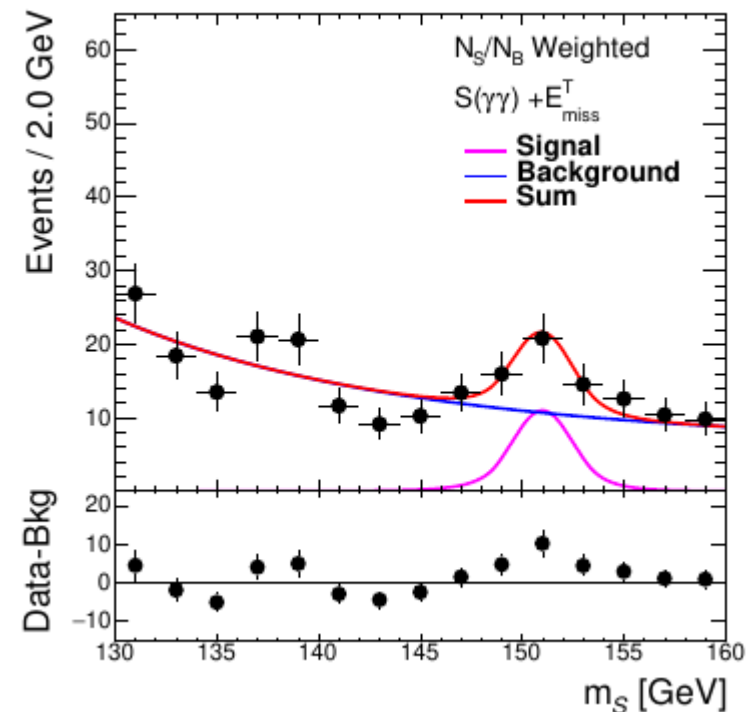
- 10 years of exotics searches with enormous impact
  - no discoveries so far... until yesterday!

Combining the  $\gamma\gamma$  and  $Z\gamma$  channels, with associated leptons, di-jets, bottom quarks and missing energy, we obtain a local (global) significance of  $5.1\sigma$  ( $4.8\sigma$ ) for a mass of  $m_S = 151.5$  GeV and

arXiv:2109.02650

## V. CONCLUSIONS AND OUTLOOK

In this article we accumulated evidence :



# Exotics at the LHC

