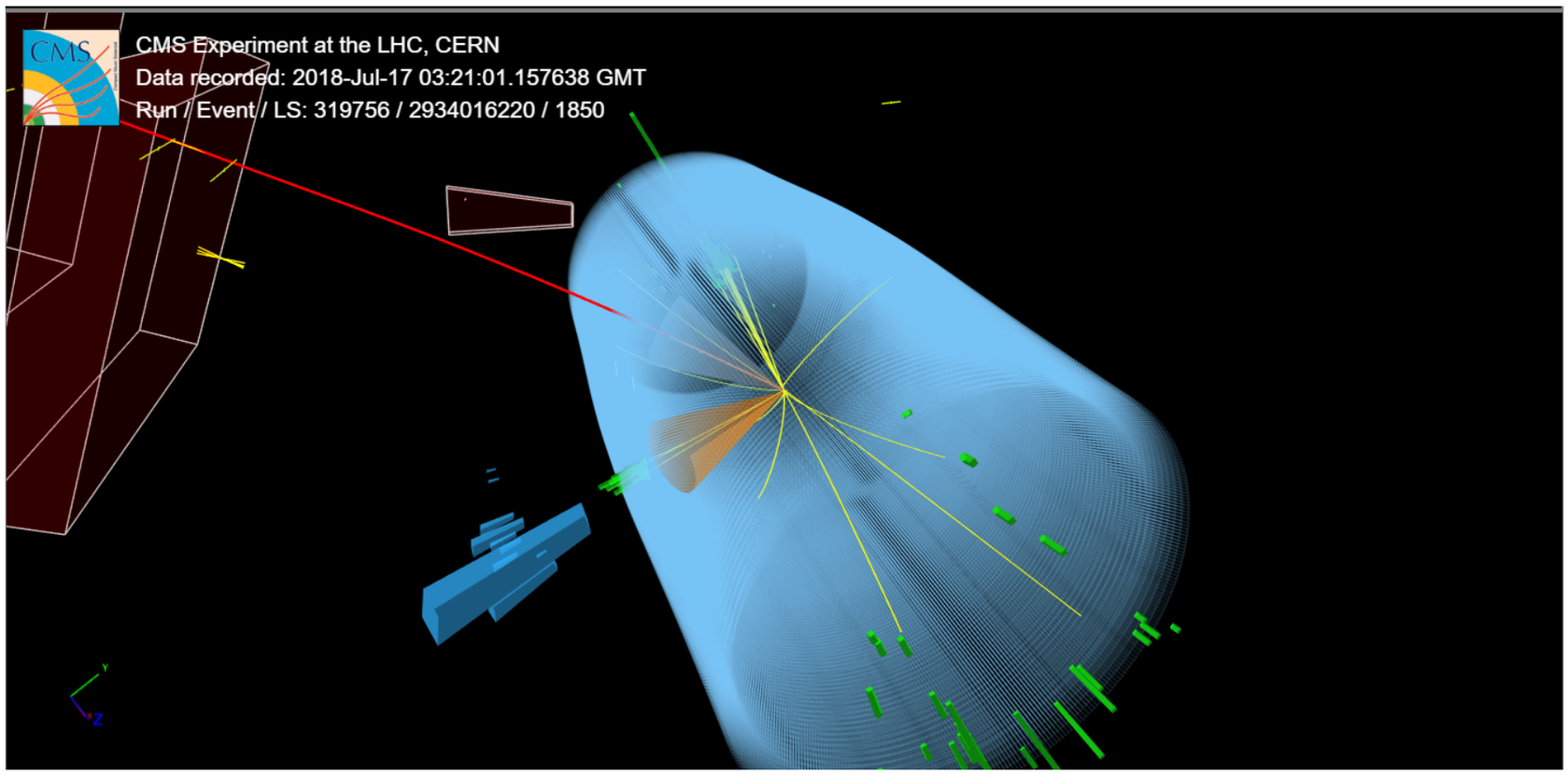
Imperial College London

Prospects for Run 3 at CMS

UK HEP Forum



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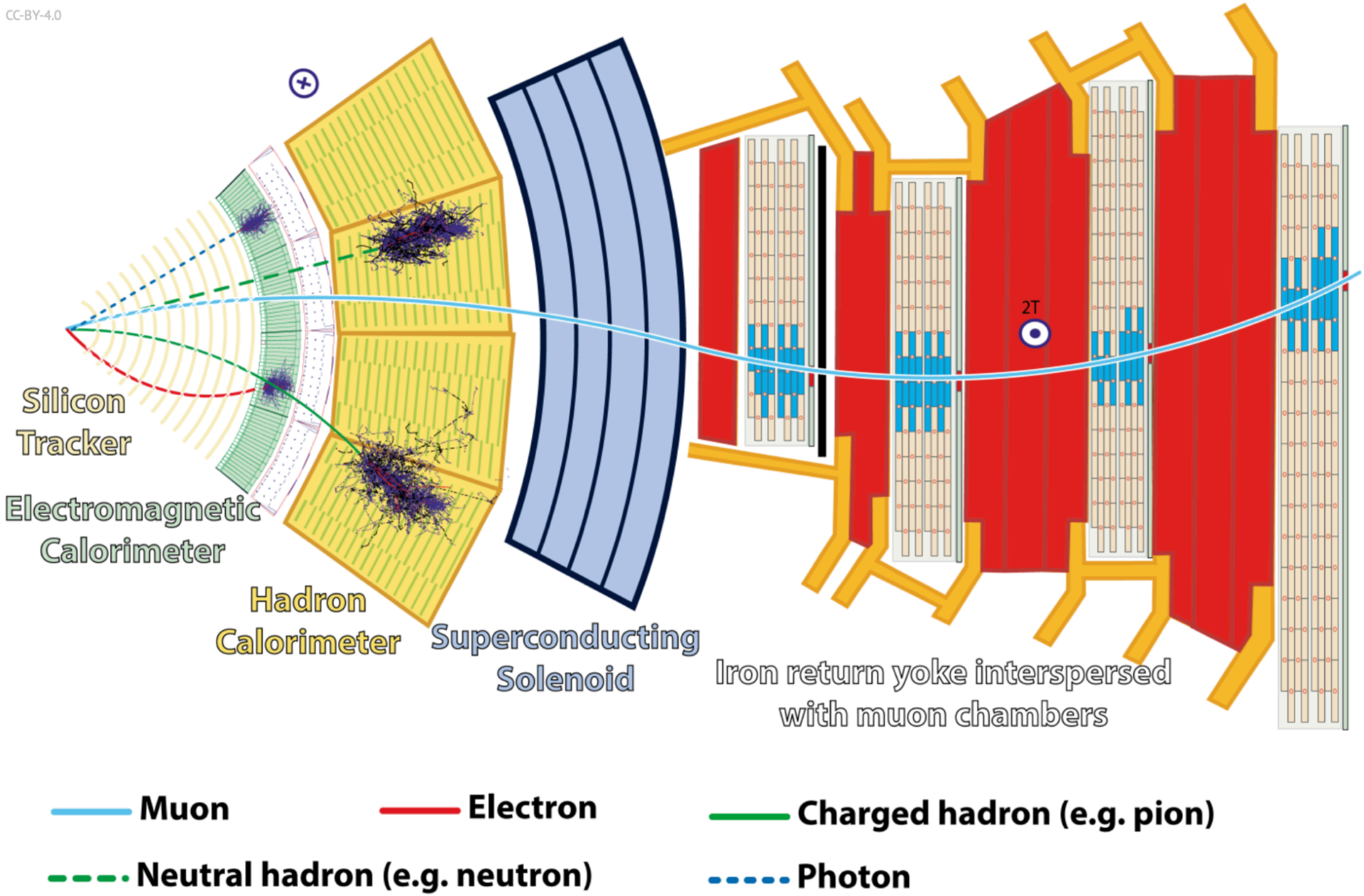
Overview

- I will discuss prospects for the CMS experiment in Run 3
- This is a very broad topic with many opportunities to explore new ideas / new models in Run 3
- The focus of today's talk will mainly be about analyses that can shed light on B-physics (muon g-2 anomalies discussed in backup)

The CMS detector



LHC Run 3 schedule

- Will take data until at least ~ end of 2024 (may be extended by 1 year)
- Will run p-p collisions at 13.6 TeV
- Total integrated luminosity ~ 160-200 fb^{-1} (compared to ~ 140 fb^{-1} in Run 2)

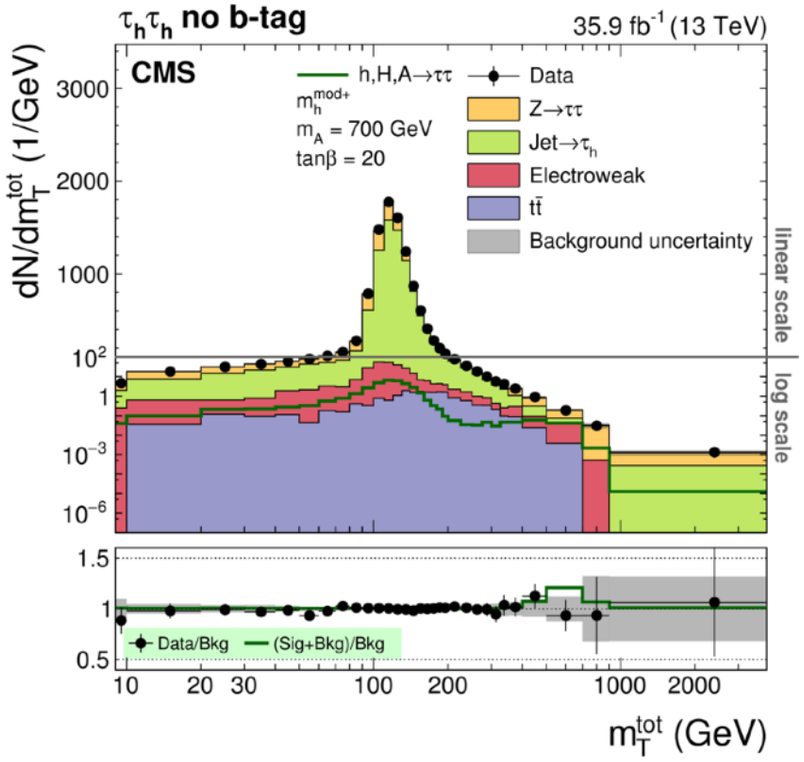
Run 3 prospects

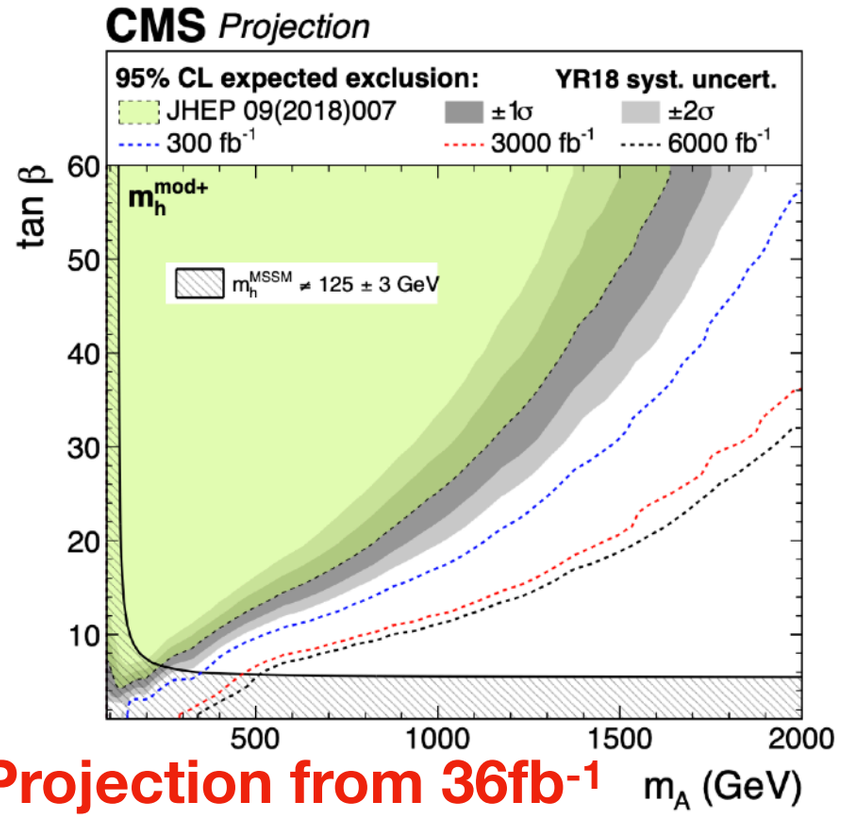
Many prospects for the Run 3 dataset, expected improvements due to, for example:

- Increased luminosity
- Unconventional trigger stratagies
- New ideas

Increased luminosity prospects

- Many CMS analyses are statistically limited
- We expect improvements in Run 3 from increased data sets
- A good example is search for heavy H/A→$\tau\tau$
- At high mass analysis is limited by statistics
- Gains can he even larger than projections!





Projection from 36fb^{-1}

Triggering at CMS

- CMS trigger has two levels:
  - Hardware based “L1”: 40 MHz → 100 kHz
  - Software based “HLT”: 100 kHz → 1 kHz
- “Conventional” triggers limited by the 1 kHz readout
- This 1 kHz limit comes mainly from limitations in how much data we can afford to **process**

Unconventional triggering

- **Data scouting** → save only objects reconstructed online
  - Write out only high-level objects reconstructed by the CMS trigger
  - Event size can be reduced from ~ 1 MB to ~ a few kB's
- **Data parking** → delay offline reconstruction
  - Store unprocessed events on tape
  - Event reconstruction performed later when resources are available e.g during shutdowns

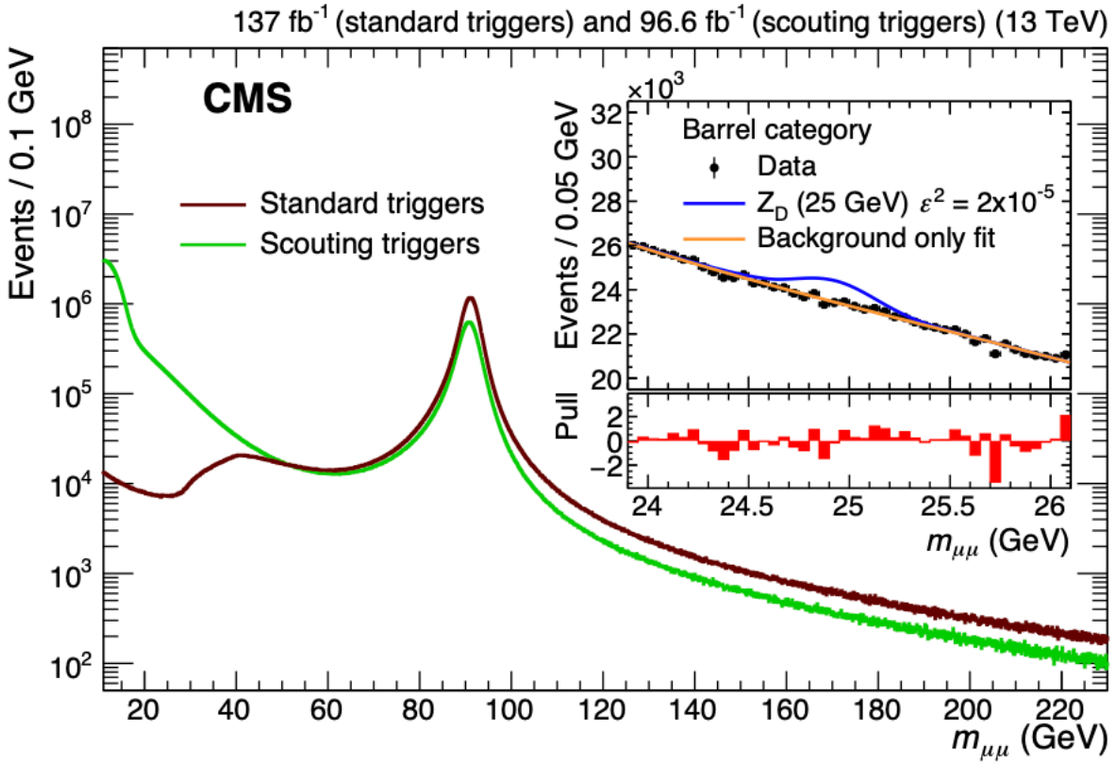
Data scouting

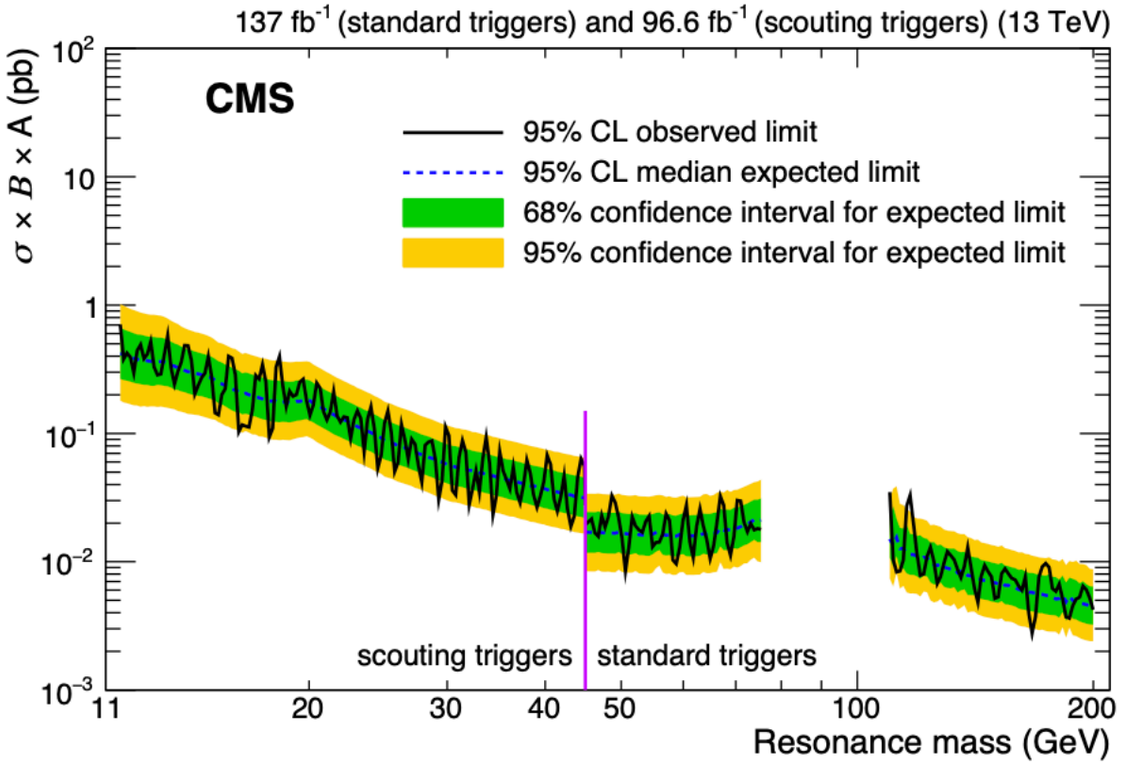
- The analyses that benefit the most from scouting are those that suffer from trigger thresholds e.g low p_T signatures

- An example Run 2 analysis is dark-photon search $Z_D \rightarrow \mu\mu$ [1912.04776]

  - Standard triggers require μμ p_T thresholds of (20,15) GeV compared to (4, 4) GeV for scouting

- Motivated by hidden, dark-sector models explaining dark matter



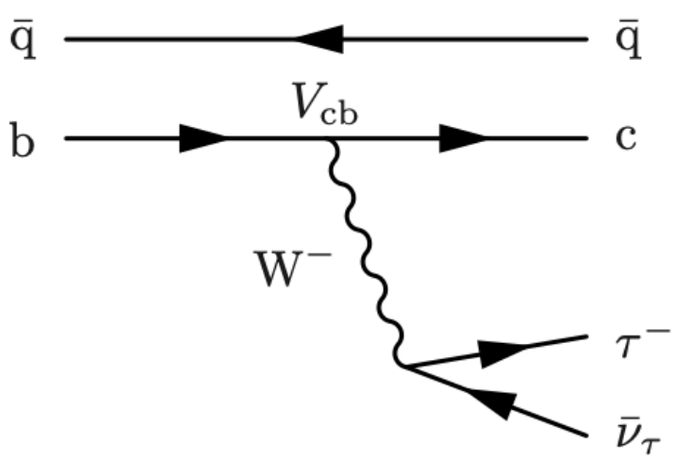


- In Run 3 we will use scouting to probe other "difficult" signatures

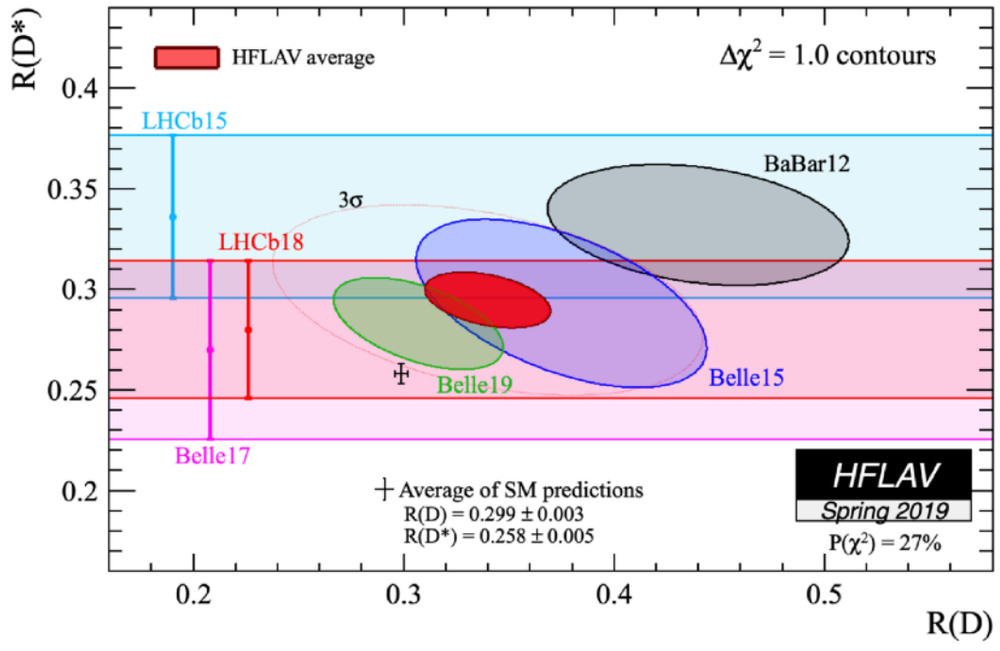
  - Extend scouting to store additional objects (currently only jets and muons stored)

B-physics anomalies

b→clν

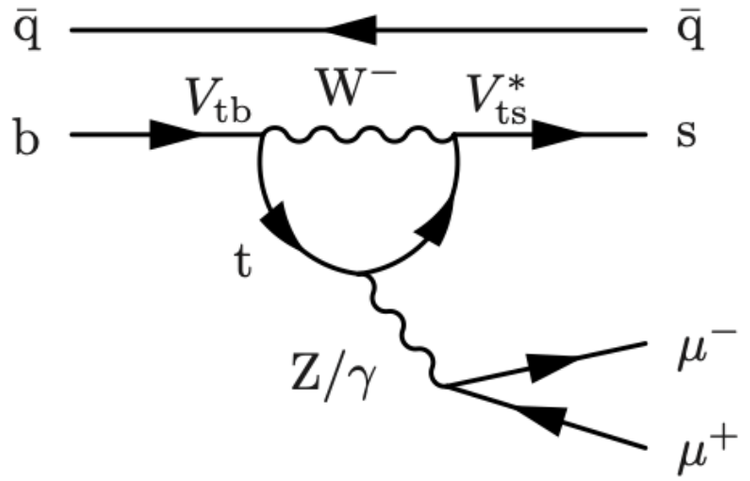


[HFLAV]

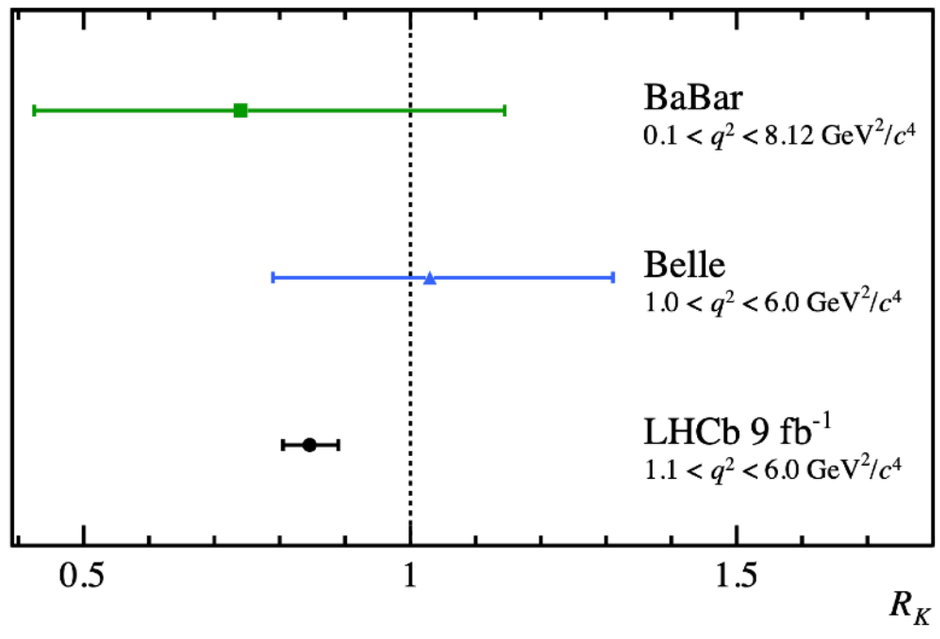


$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}l\nu)}$$

b→sll



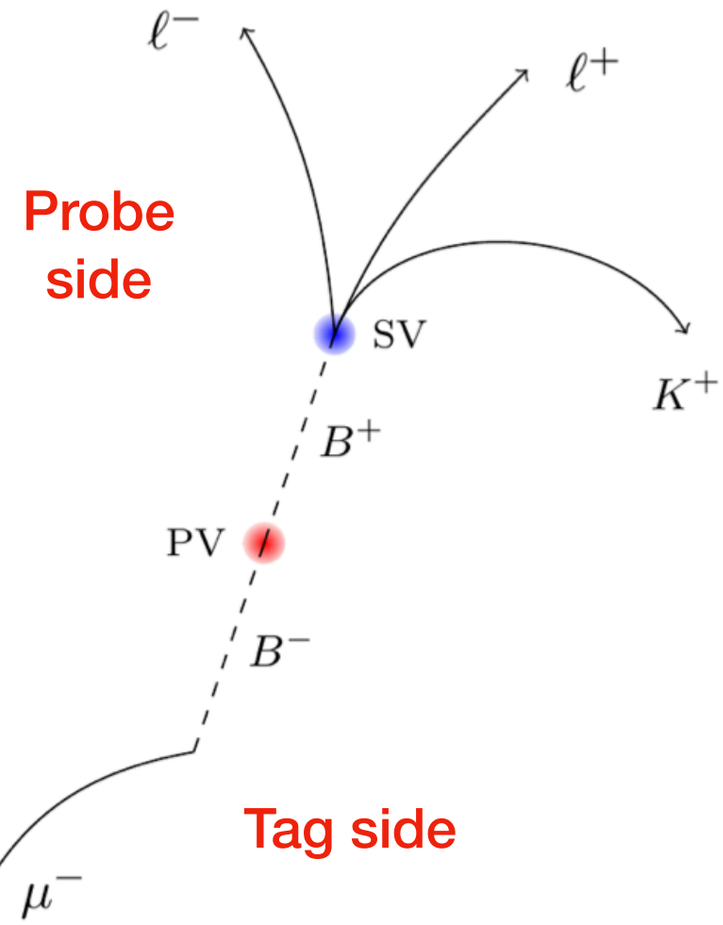
[2103.11769]

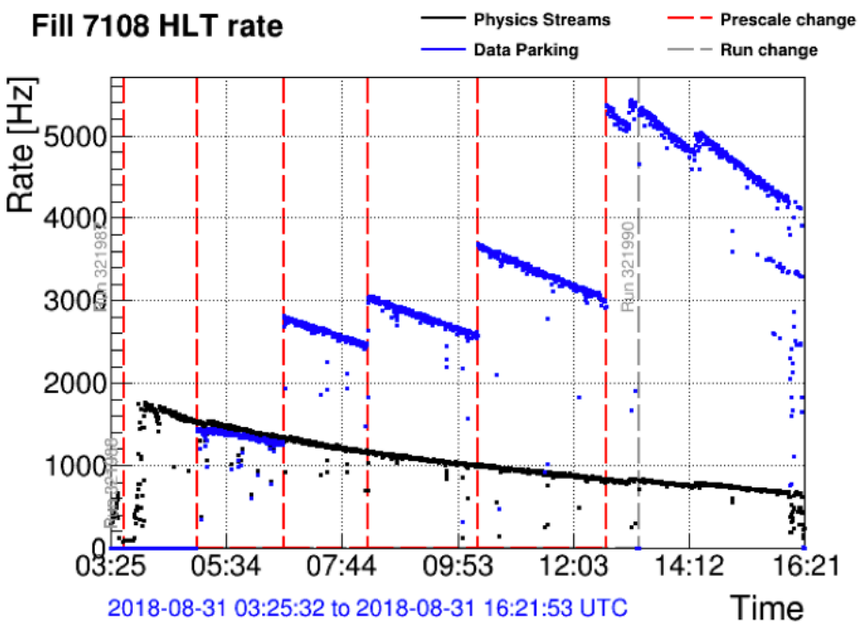


$$R(K^{(*)}) = \frac{\mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(B \to K^{(*)}ee)}$$

Data parking

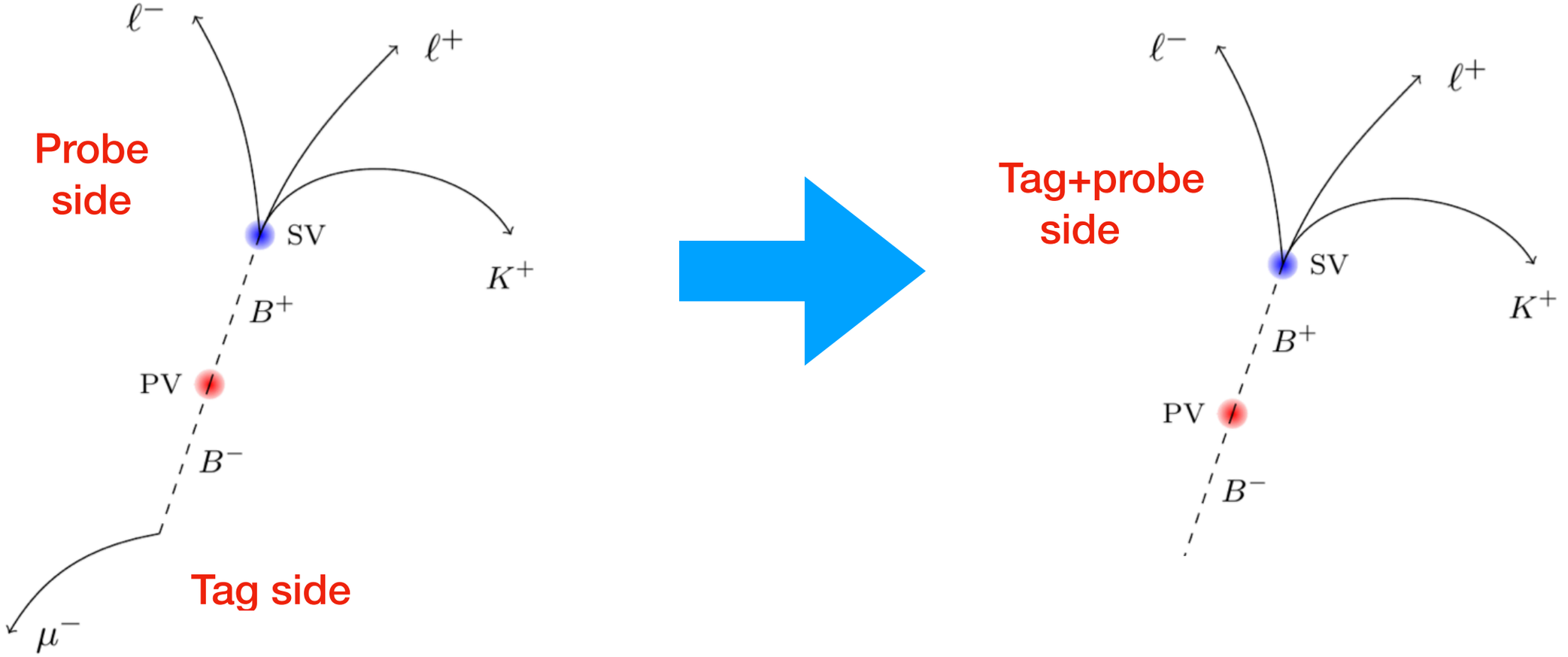
- In 2018 CMS collected 10 billion unbiased B hadron decays
  - Trigger strategy involves triggering on displaced muon from “other” B hadron decay
  - $B \rightarrow K^{(*)} l^+ l^-$ branching ratio ~ 10^{-7}
  - Need ~ 10^{10} events to get ~ 100 events assuming reconstruction efficiency ~ 10%
- Dataset readout is up to ~ 5 kHz
  - Too large to reconstruct promptly → “park” dataset
- Data analyses of this dataset are ongoing





B-physics in Run 3

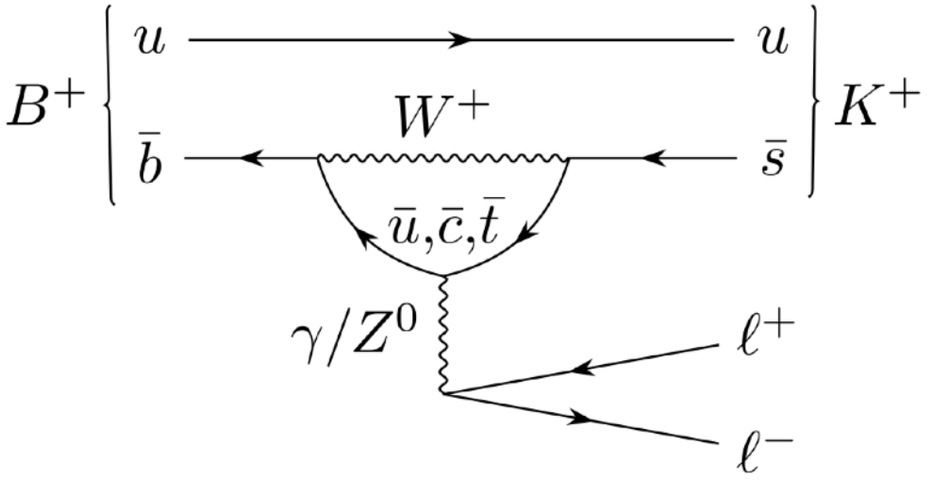
- Plan to produce a similar B-physics dataset in Run 3
  - We have learned a lot from Run 2 parked dataset
  - Different LHC conditions/schedule in Run 3 - change in strategy to account for this
  - Run 3 dataset will likely not follow the same strategy as Run 2
  - E.g we can increase our acceptance for $B \to K^{(*)} e^+ e^-$ by triggering on electrons directly

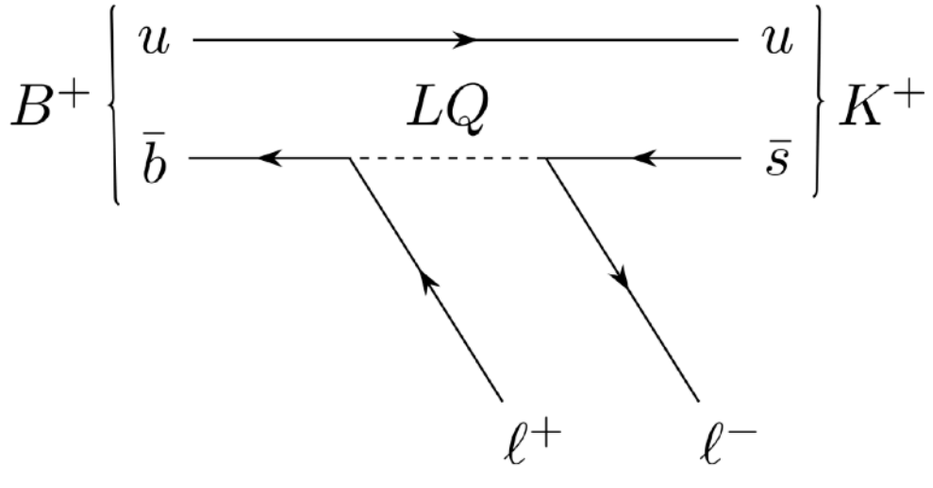


Leptoquark models

- The various B-physics anomalies can be explain by leptoquarks
- Various types of models depending on spin / quantum numbers: **[2103.12504]**
  - Scalar leptoquarks (LQ$_S$)
  - Vector leptoquarks (LQ$_V$)
- Combination of 2 LQ$_S$ required to explain both b→clν and b→sll
- But a single LQ$_V$ can explain both (U_1)
- In next slides we will look at LQ$_V$ as an example

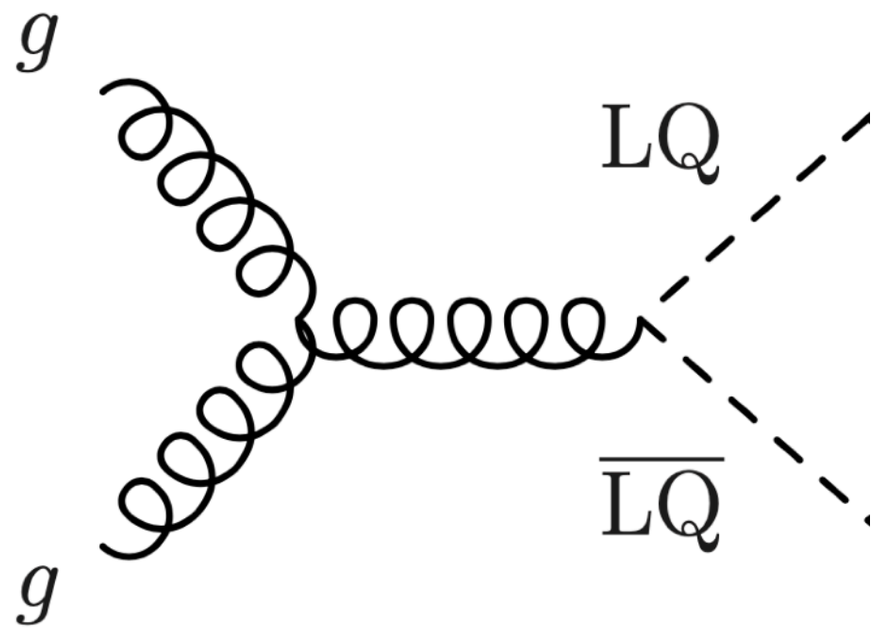
	Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
LQ$_S$	S_3 $(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	✓	✗	✗
	S_1 $(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	✗	✓	✗
	R_2 $(\mathbf{3}, \mathbf{2}, 7/6)$	✗	✓	✗
LQ$_V$	U_1 $(\mathbf{3}, \mathbf{1}, 2/3)$	✓	✓	✓
	U_3 $(\mathbf{3}, \mathbf{3}, 2/3)$	✓	✗	✗



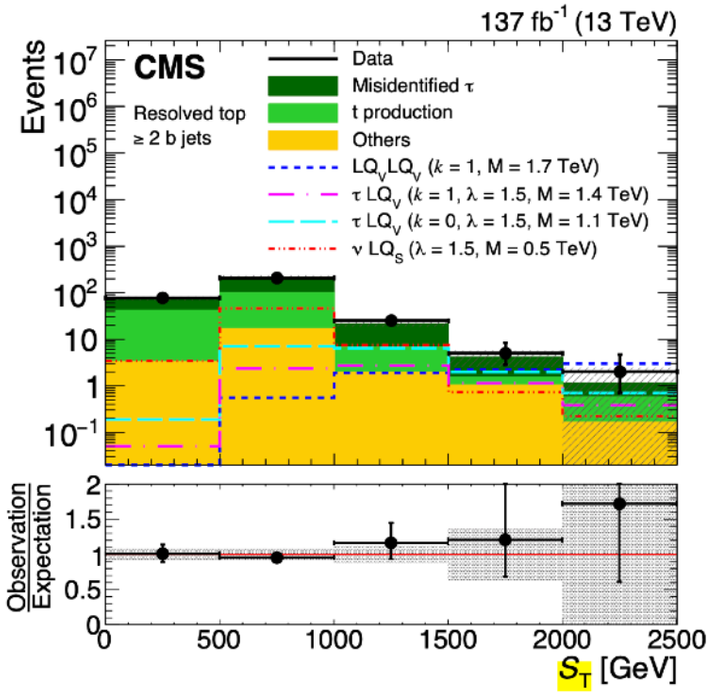


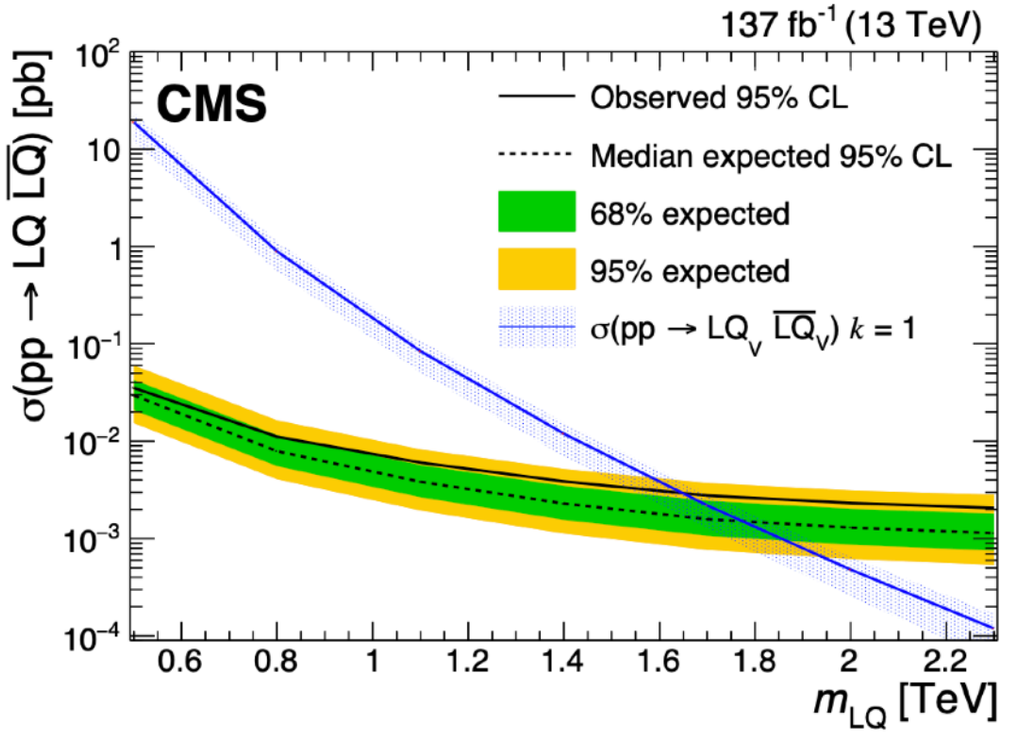
Leptoquark signatures: resonant

- Largest LQ_V production cross sections for pair production



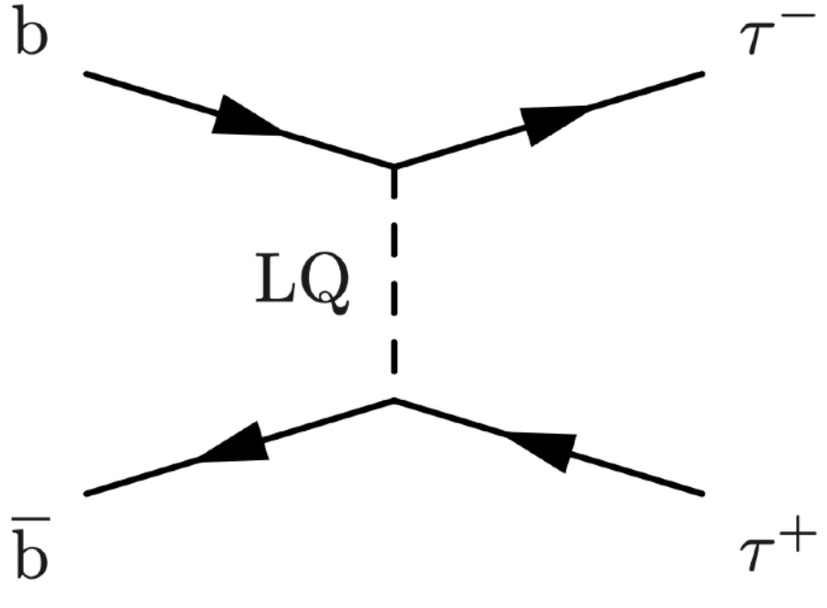
- Several combination of LQ_V decays possible
- In a recent analysis by CMS we consider the $LQ_V\ LQ_V \rightarrow b\tau + tv$ [2012.04178]
- Signature:
  - b-tagged jet
  - hadronic τ
  - hadronic t (resolved or merged)
  - Missing p_T



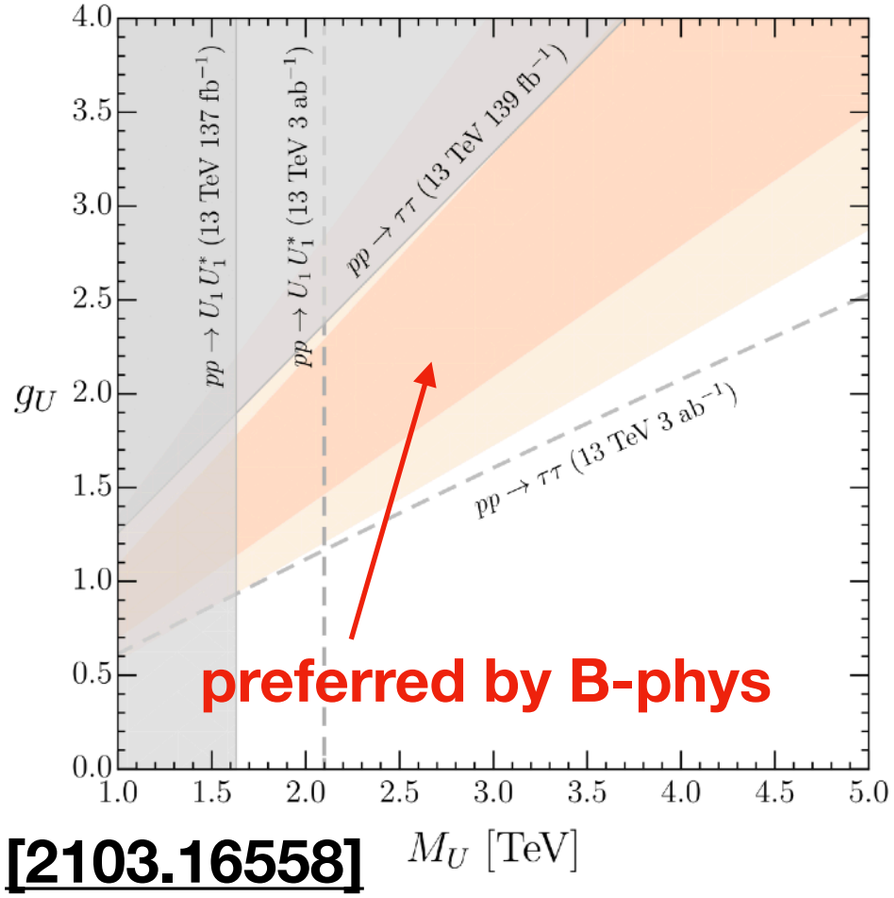


Leptoquark signatures: t-channel

- Ideal scenario: LQ_V not far above current the bound (~ 2 TeV)
- But mass could be beyond LHC reach
- In this scenario we can still obtain a bound from high-p_T if we consider t-channel



- Starting to become sensitive to B-physics best fit regions with Run 2 data
- Will get even better with Run 3
  - Current expectation based on reinterpretations
  - A dedicated search should do even better



[2103.16558]

Summary

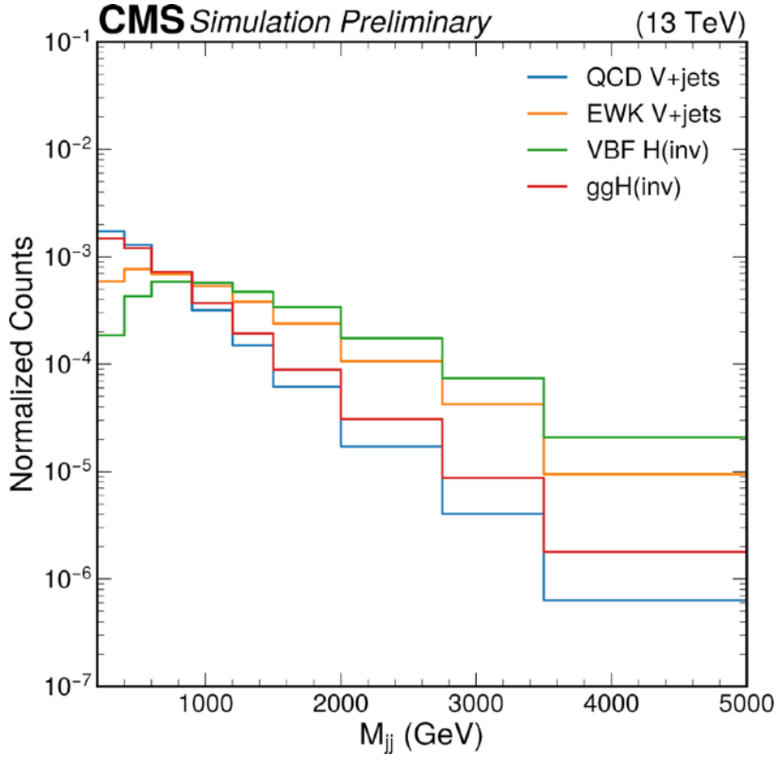
- Presented a few examples of prospects for CMS experiment in Run 3
- Benefits from increased luminosity, dedicated trigger strategies, and new ideas
- Many other interesting analyses to be explored in Run 3 and beyond
- Stay tuned for more CMS results in future!

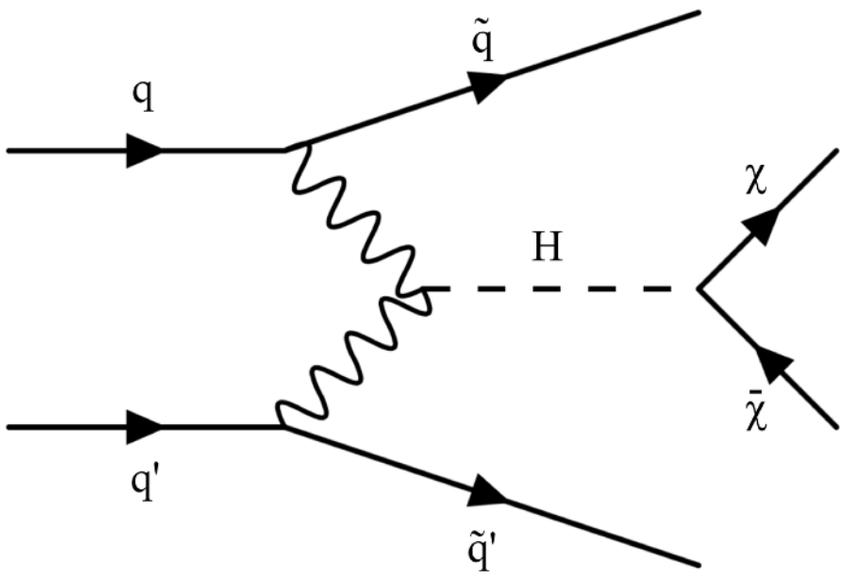
Thanks for your attention!

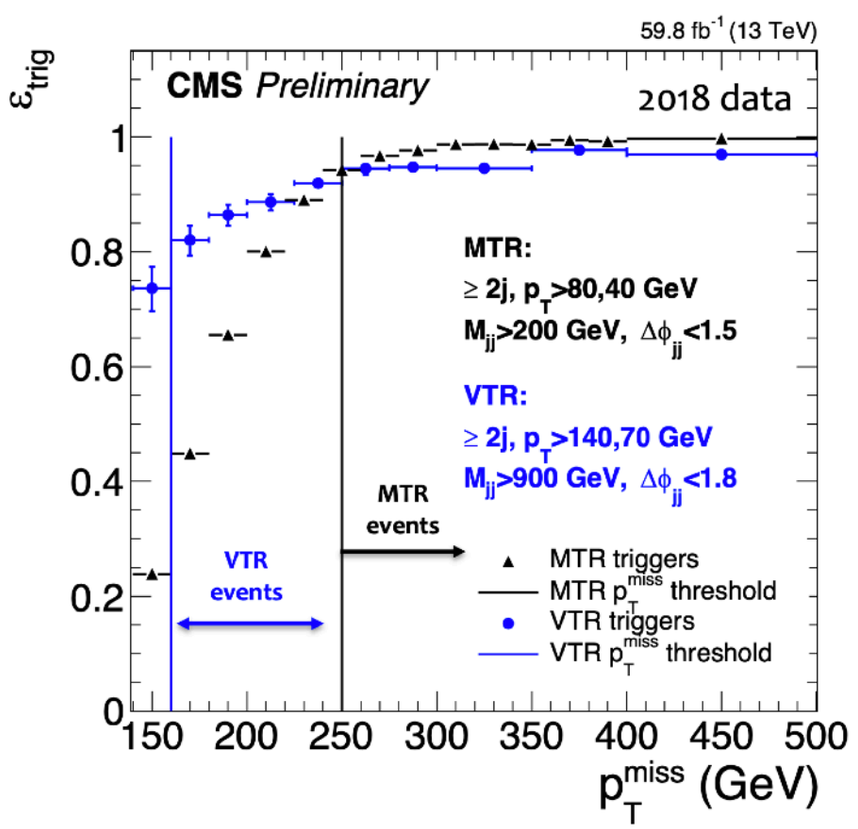
Backup

New trigger ideas at CMS

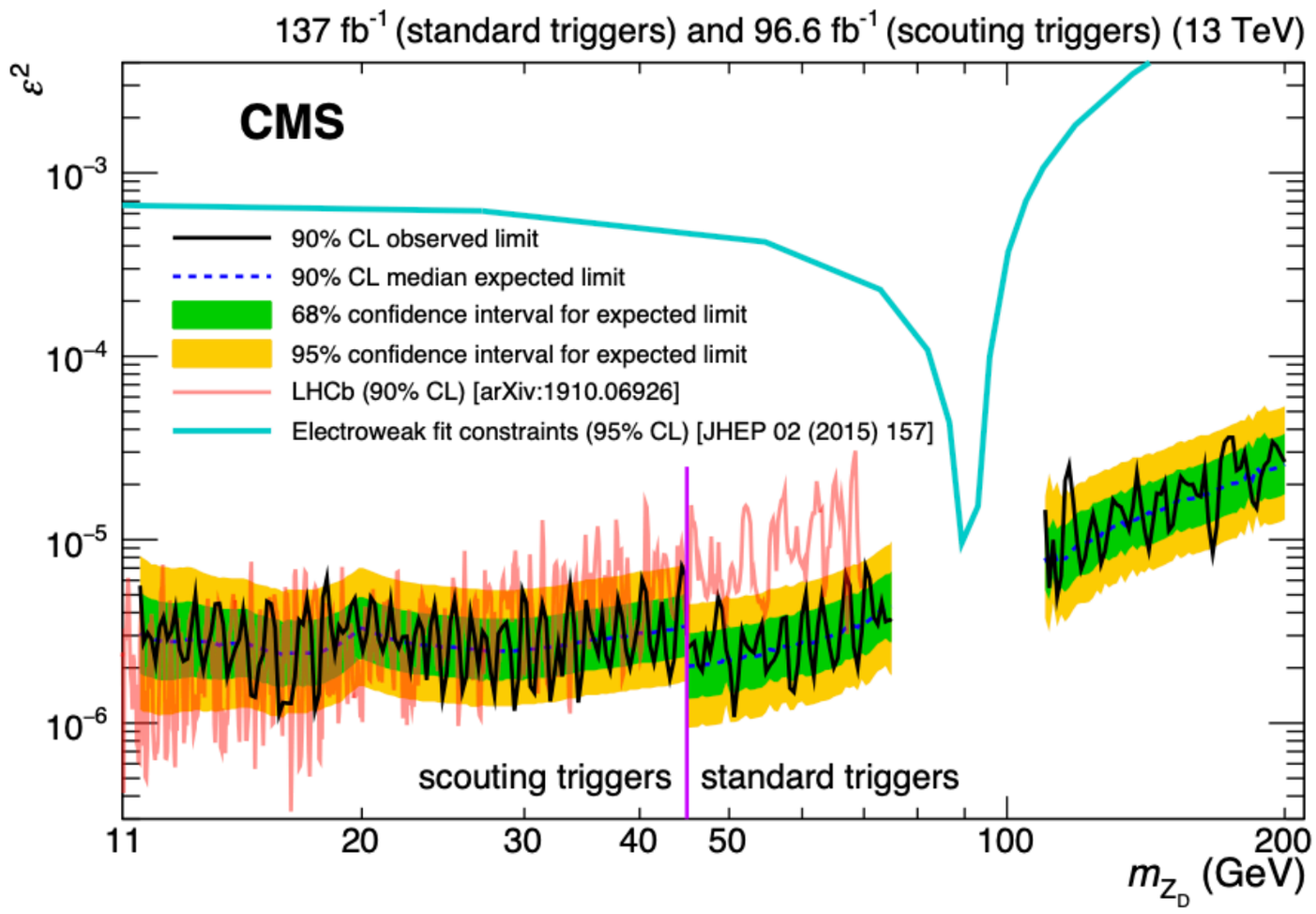
- Can reduce trigger rates by exploiting more features of the signal processes
- E.g VBF H→invisible trigger used in 2018
  - Exploit kinematics of jets at L1 and HLT to reduce MET thresholds



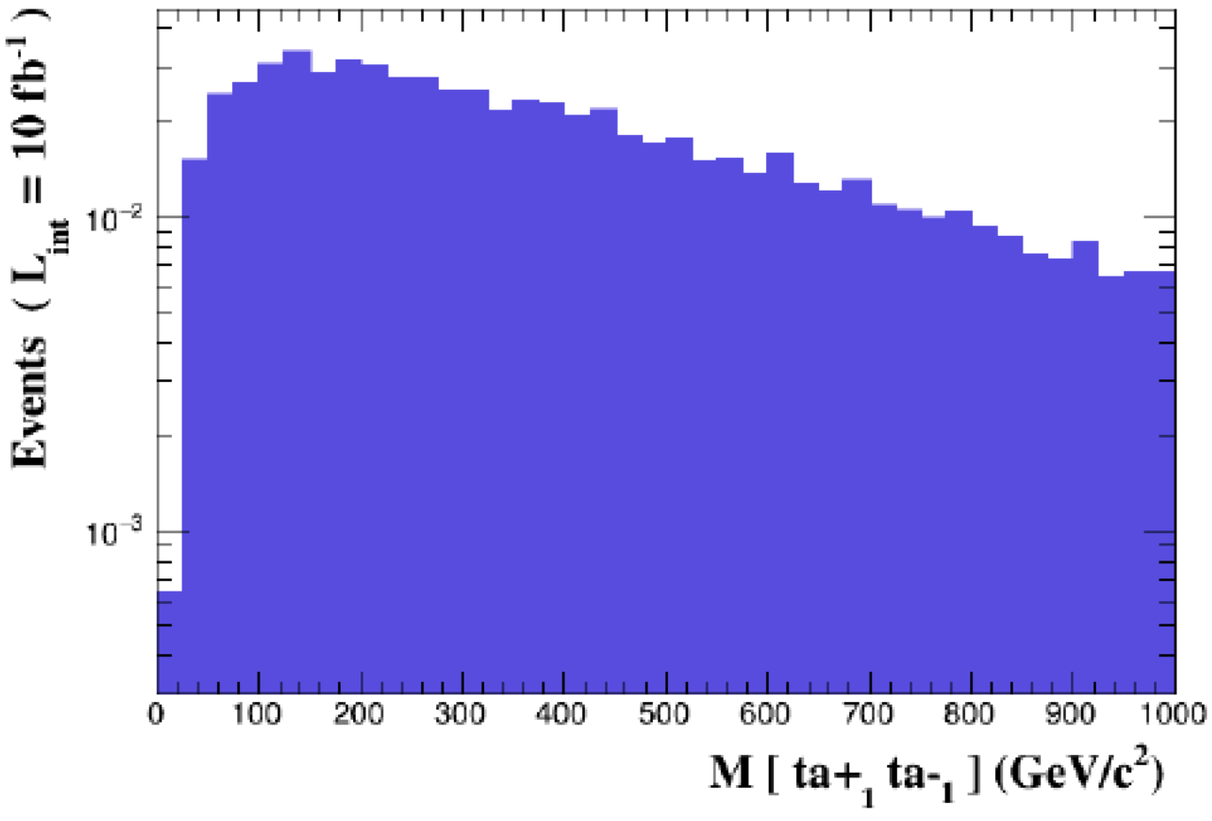




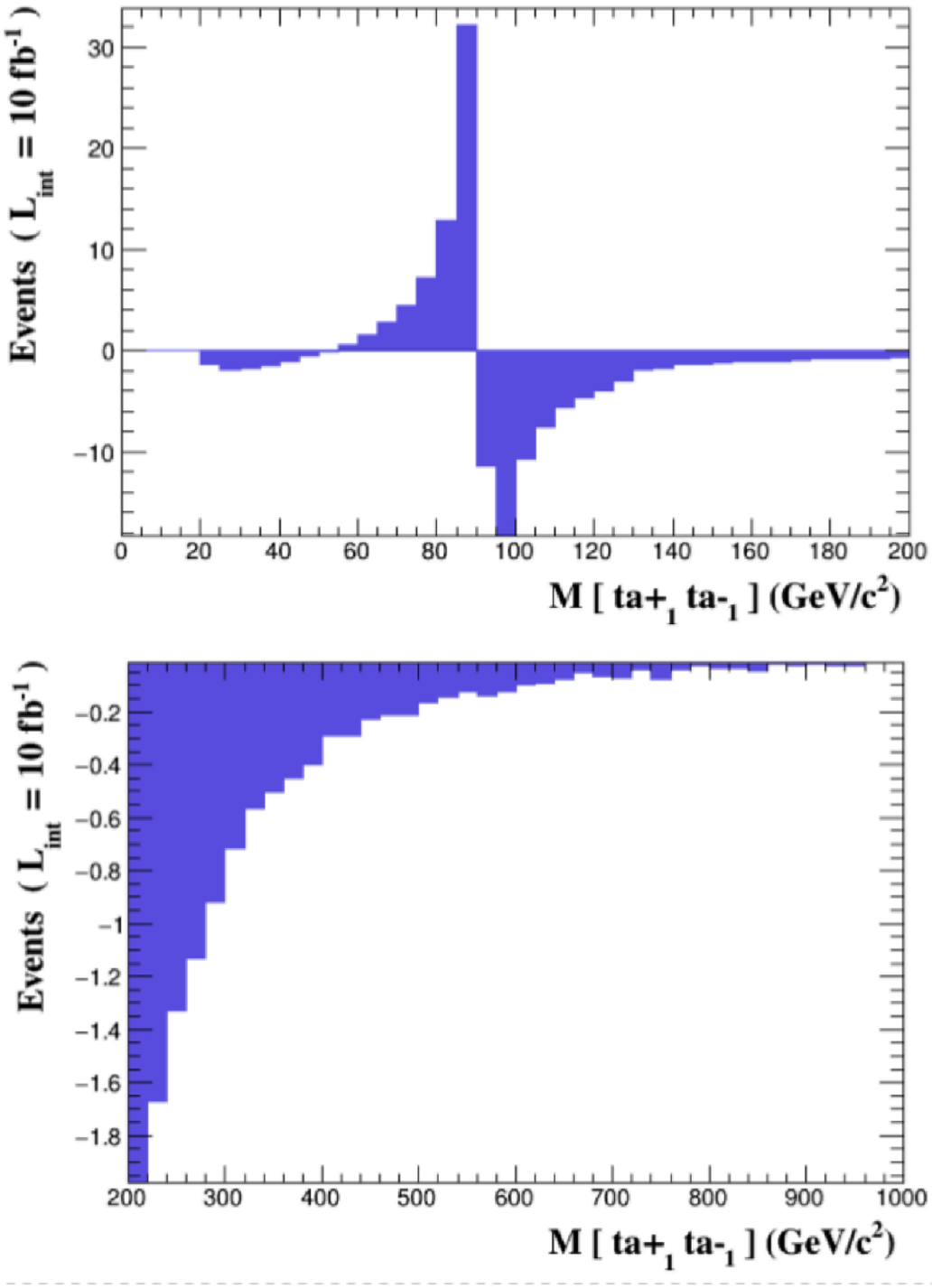
Dark photon comparison to other results



LQ_V t-channel mass distribution



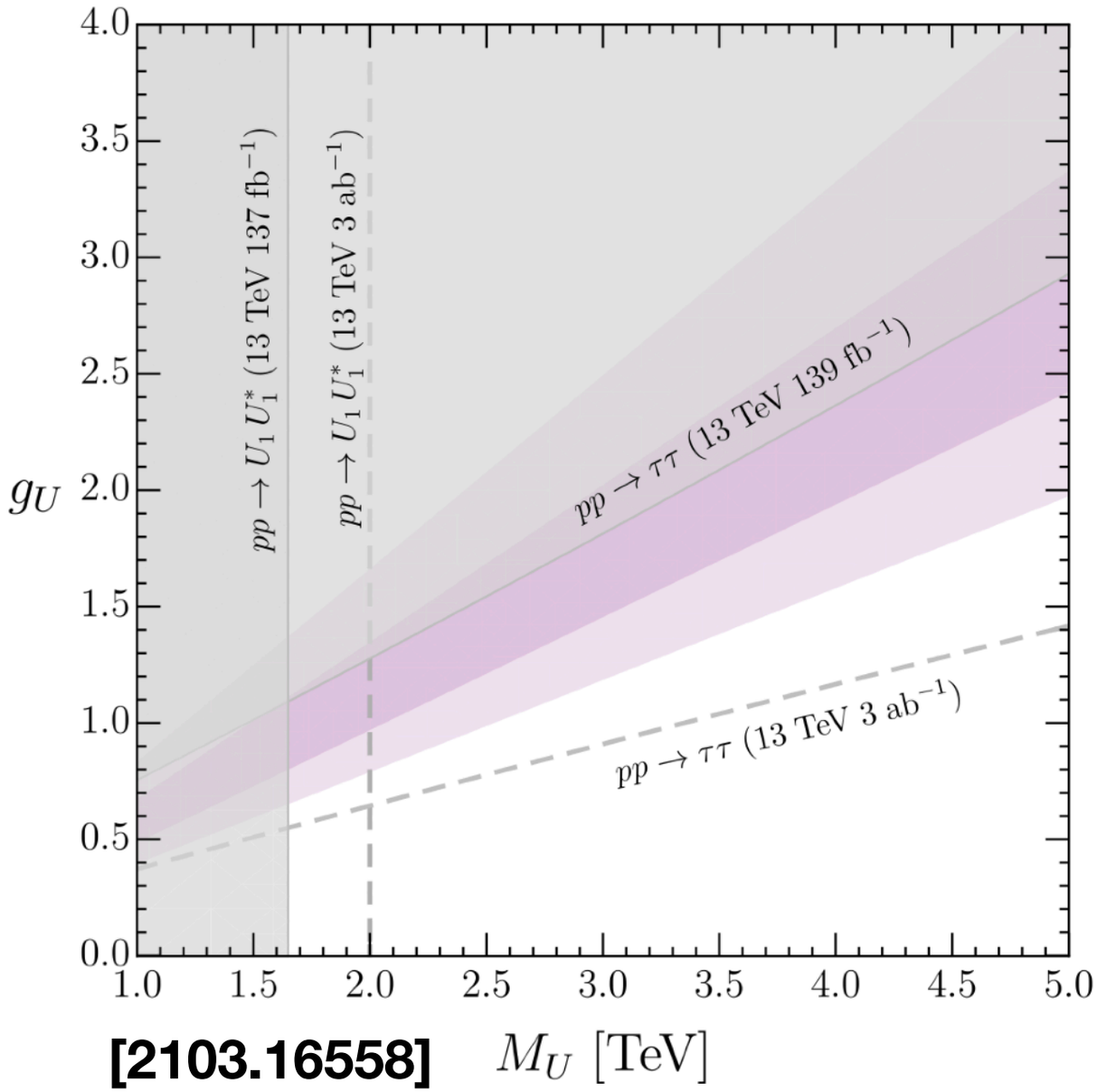
No interference



Interference with Drell-Yan

Alternative benchmark model for LQ_V

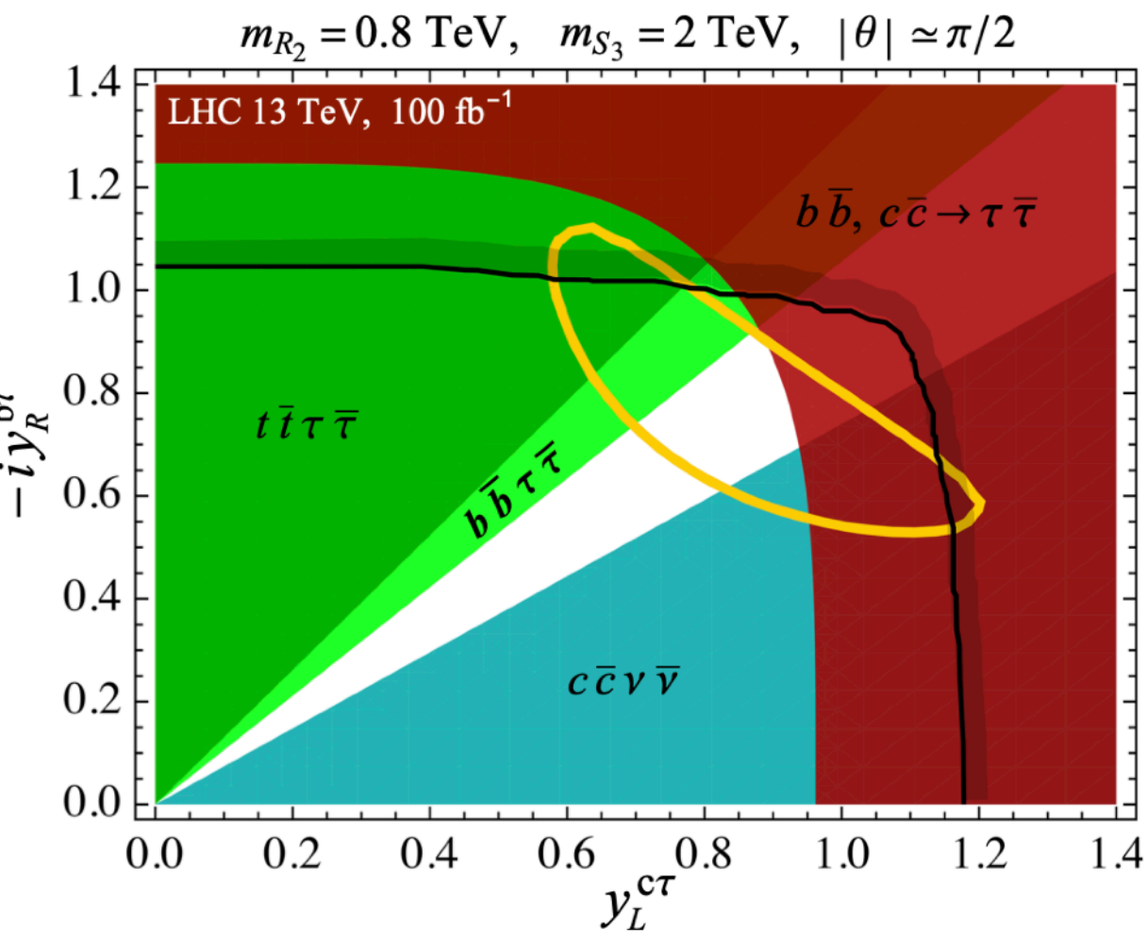
- Benchmark model which includes right-handed couplings



[2103.16558]

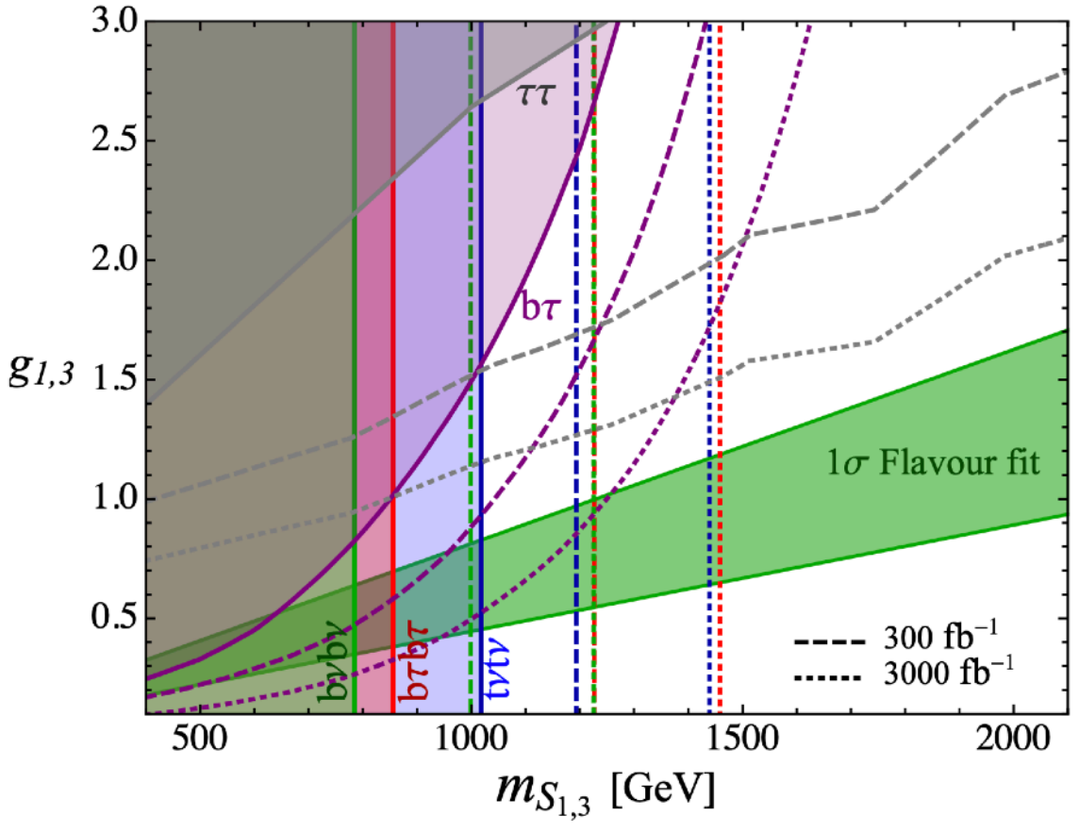
Scalar LQ_S examples

$R_2 + S_3$



[1806.05689]

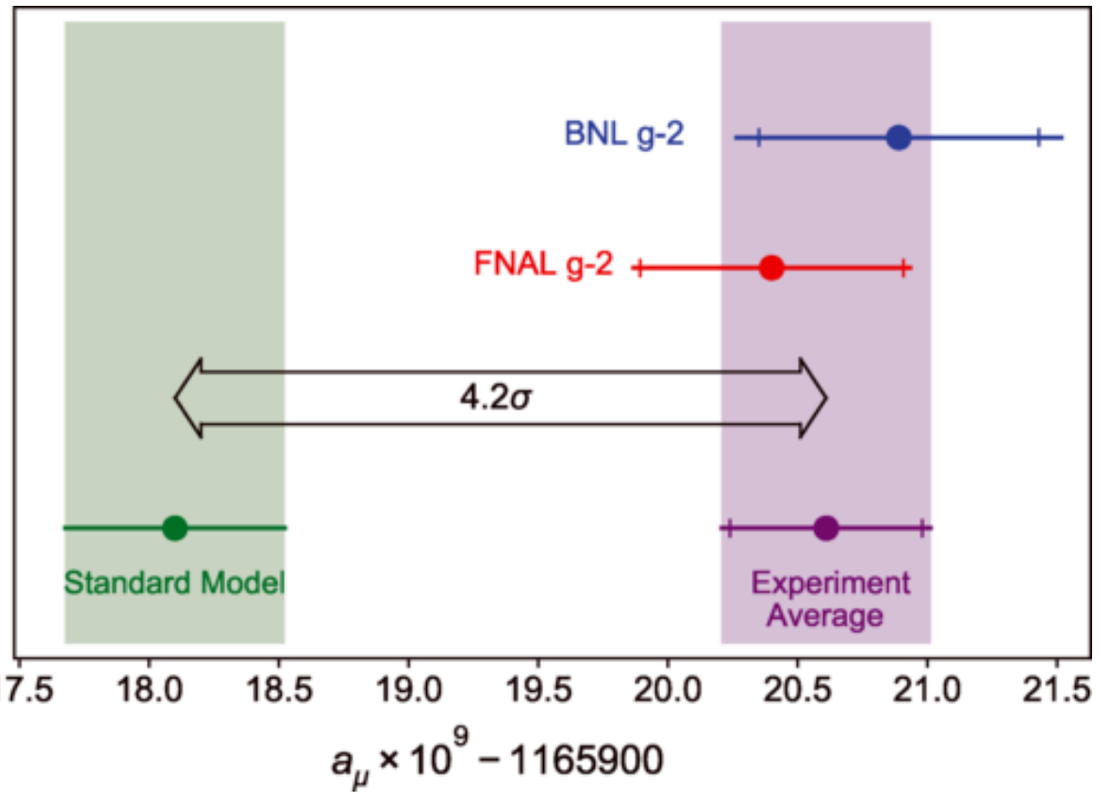
$S_1 + S_3$



[1803.10972]

Muon g-2

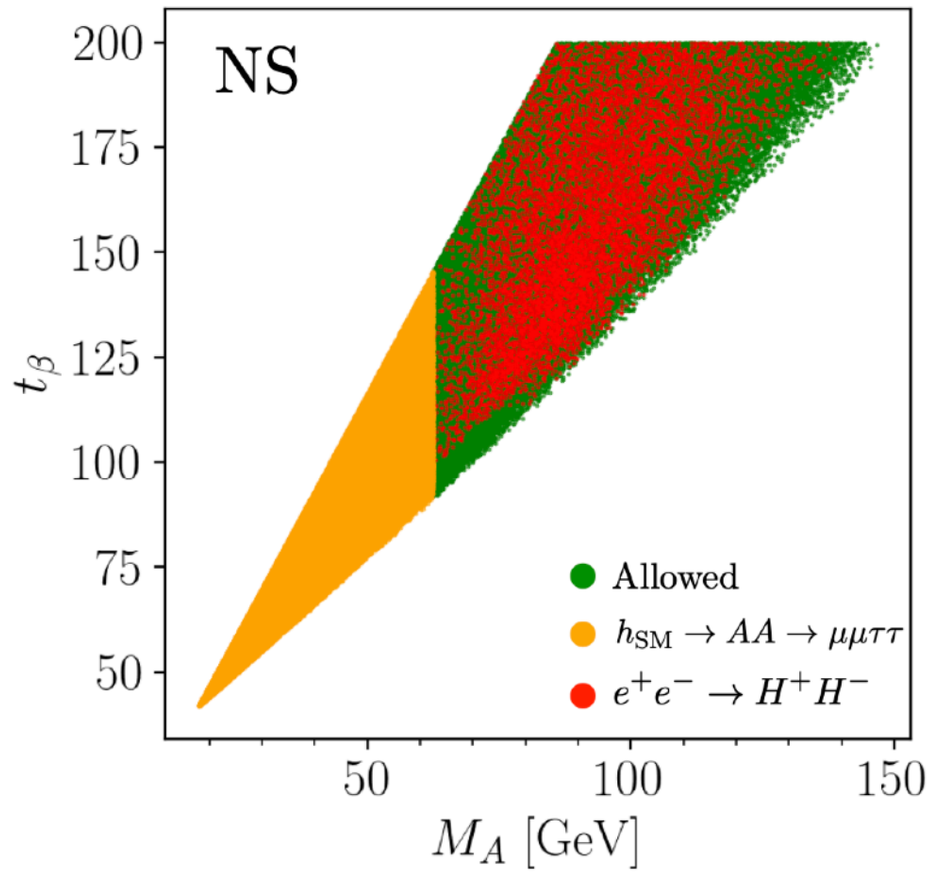
- Tension between muon g-2 SM prediction and measurements ~ 4.2σ
- Various models explaining this deviation
- Several explanations involve additional pseudoscalars, A
- Natural candidates are two-Higgs-doublet models (2HDM)
  - 5 Higgs bosons: h, H, A, $H^{\pm}$
- Several searches by CMS for 2HDMs but in next slide I will discuss a signature currently not directly targeted



Lepton specific 2HDM

- Lepton-specific 2HDM
  - tanβ = v_2/v_1 (v_i= vacuum expectation value)
  - For large tanβ coupling to leptons are enhances, while couplings to quarks are suppressed
- Usual production modes are suppressed but can pair produce
  - e.g pp→Z*→HA
- Final states with τ leptons
  - HA→4τ
  - HA→ZAA→2l + 4τ
- Signal cross sections can be large compared to backgroun
  - e.g σ(pp→HA→4τ) = 15—260 fb, σ(pp→ZZ →4τ) = 17 fb
- These signatures are currently unexplored at the LHC
  → can be probed with Run 2 + Run 3 data

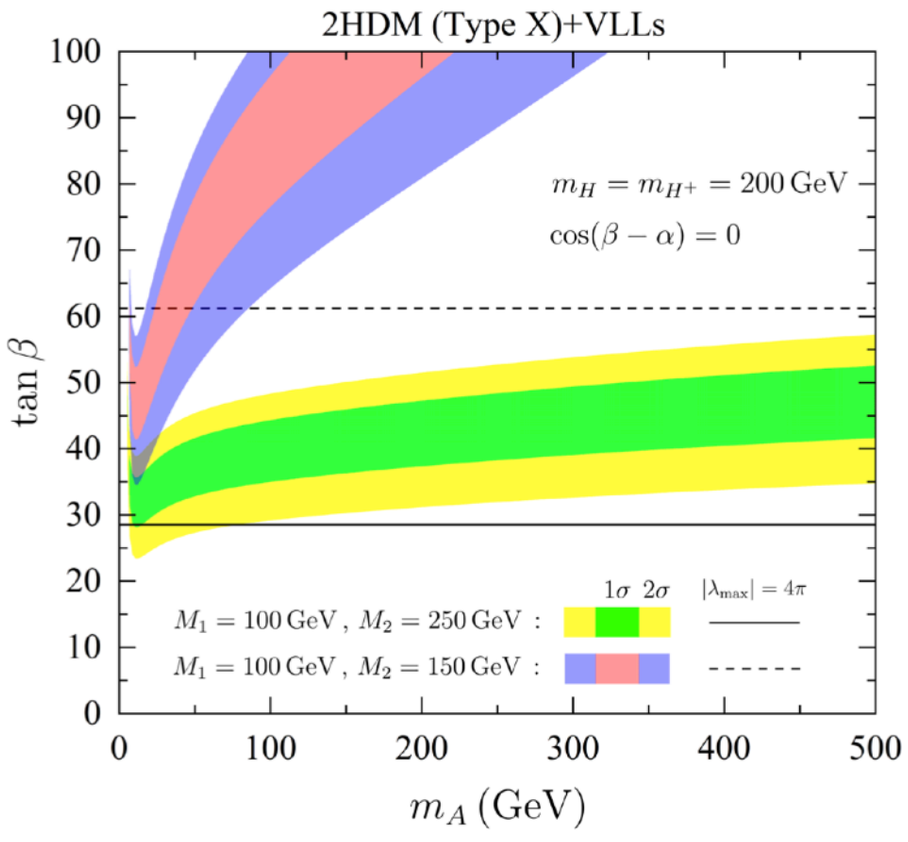
[2104.10175]



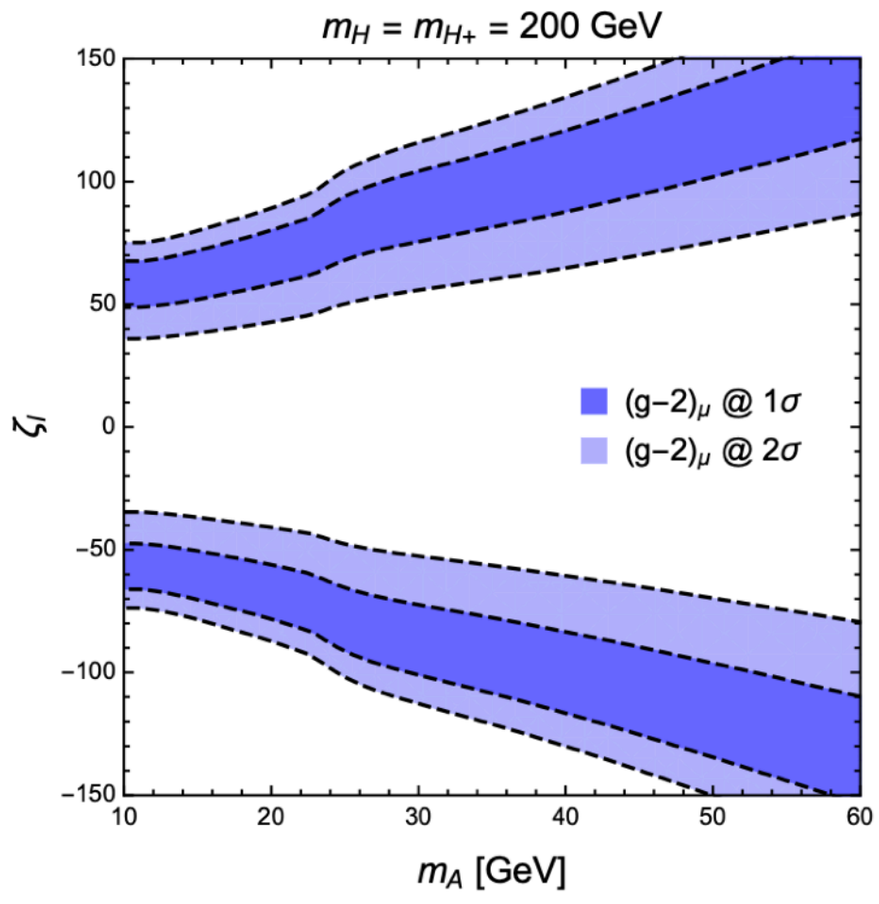
Non-minimal muon g-2 models

- Minimal 2HDM models require large tan

- Non-minimal models can relax constraints by introducing additional particle content e.g vector-like leptons, right-handed neutrinos



Vector-like leptons [2104.03367]



RH neutrinos [2012.06911]