# SEARCHES FOR NEW PHYSICS WITH LOW MASS MEDIATORS AT THE LHC

Swagata Mukherjee, IIT Kanpur

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SINP, Kolkata, India

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# A BIG THANK YOU TO THE ORGANISERS

*Good to be back to SINP after many years!*


*CMS HCAL upgrade workshop, 2012*

*ICHEPAP 2023*

# SCOPE OF THE TALK



## IN THIS TALK I WILL FOCUS ON SEARCHES PERFORMED USING SCOUTING DATA

Will focus on Run2 physics results in this talk.

We are working on Run3 performance plots and physics results.

There are other ways to probe low mass (specially for dijet resonance),

*example: require a high-pT ISR jet/photon and focus primarily on merged regime. Pay the price in efficiency, but can probe very low dijet mass. Not discussed in this talk.*

# SCOPE OF THE TALK

IN THIS TALK I WILL FOCUS ON SEARCHES PERFORMED USING SCOUTING DATA

- **What is scouting data?**
  - **Its importance for low mass resonance searches**
- **Hadronic scouting data**
  - **Prompt dijet search, Prompt trijet search**
- **Non-hadronic scouting data**
  - **Prompt dimuon search, displaced dimuon search**

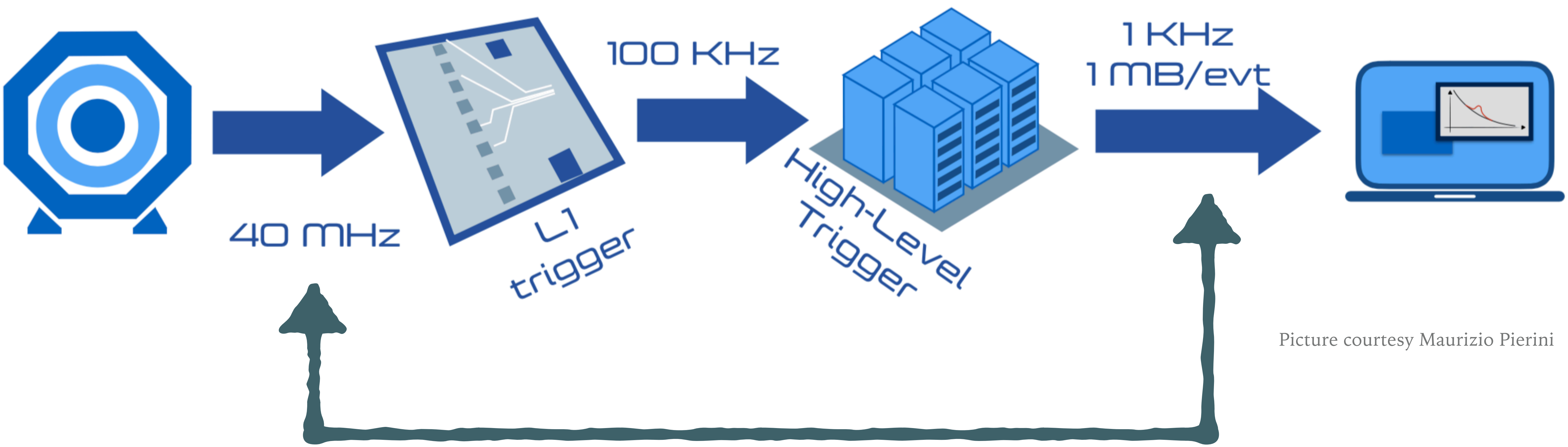
# TRIGGER STRATEGY AND SOME CONSEQUENCES

Huge amount of data coming in from LHC. Impossible to store all of them for a general purpose experiment.

Need to filter out events online

Filters are based on theory/pheno bias. Store events with high $p_T$ objects.

**Low** or **zero** sensitivity to new physics with low-mass.




Picture courtesy Maurizio Pierini

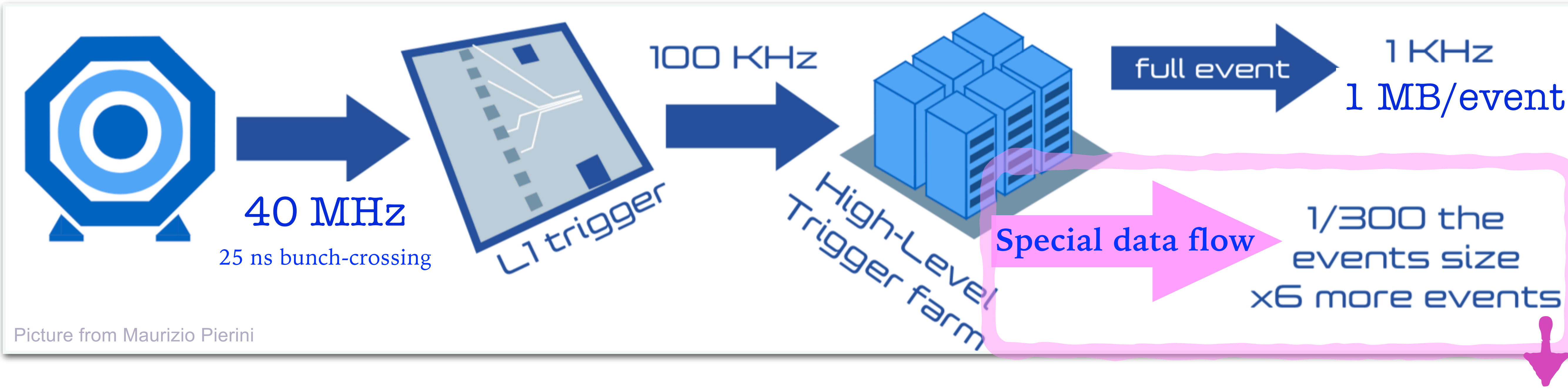
*Huge reduction in rate. Are we losing interesting (new physics)events?*

# MAKING THE MOST OUT OF SOFTWARE TRIGGERS

Objects are reconstructed at trigger level to take trigger decision.

Why throw away those trigger level objects?

Do analysis with them! **Helpful to explore low-mass region**!




Trigger Bandwidth = Event Rate × Event Size

~1 kHz × ~1 MB

**If we want to increase rate, then we need to decrease event size**

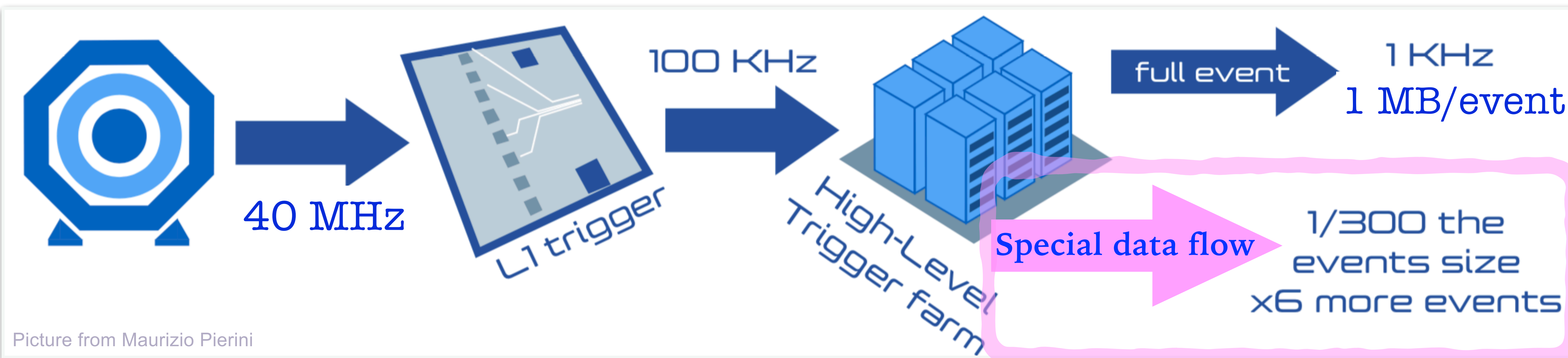
**So that the bandwidth stays within limits**

| | |
|---|---|
| No offline reconstruction | Save resources |
| No RAW data saved | Save storage |
| Minimalistic event content | Save storage |
| Looser trigger cuts | Explore low-mass phase space |

# MAKING THE MOST OUT OF SOFTWARE TRIGGERS

DO MORE DATA ANALYSIS

with less EVENT CONTENT




## DIFFERENT NAMES, SAME GAME 😎

This Special data flow is called

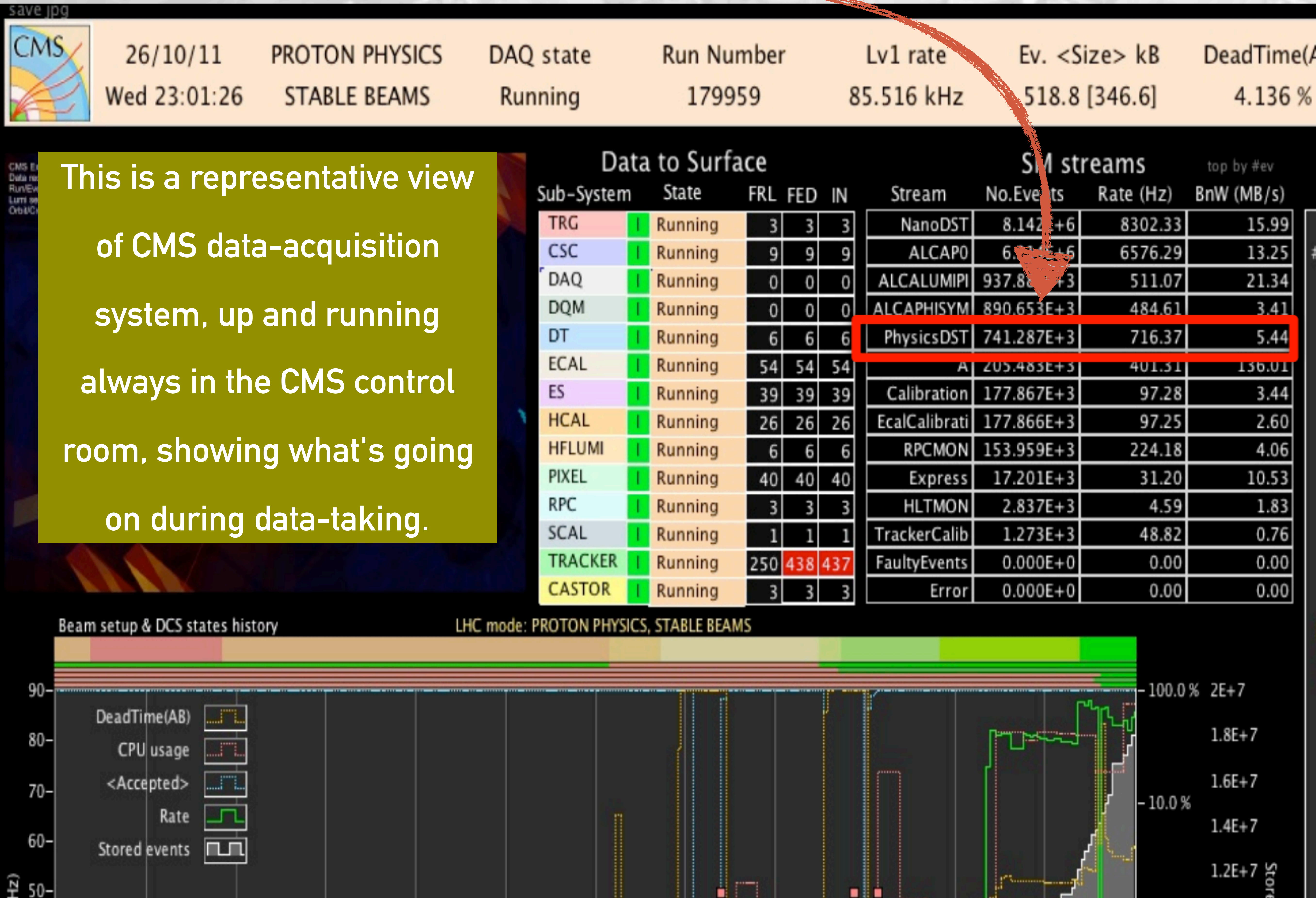
Data Scouting (**CMS**)
Trigger Level Analysis (**ATLAS**)
Turbo Stream (**LHCb**)

# A BIT OF HISTORY

The first ever scouting trigger was deployed during the last few hours of 2011 data taking

From Maurizio Pierini

This is a representative view of CMS data-acquisition system, up and running always in the CMS control room, showing what's going on during data-taking.



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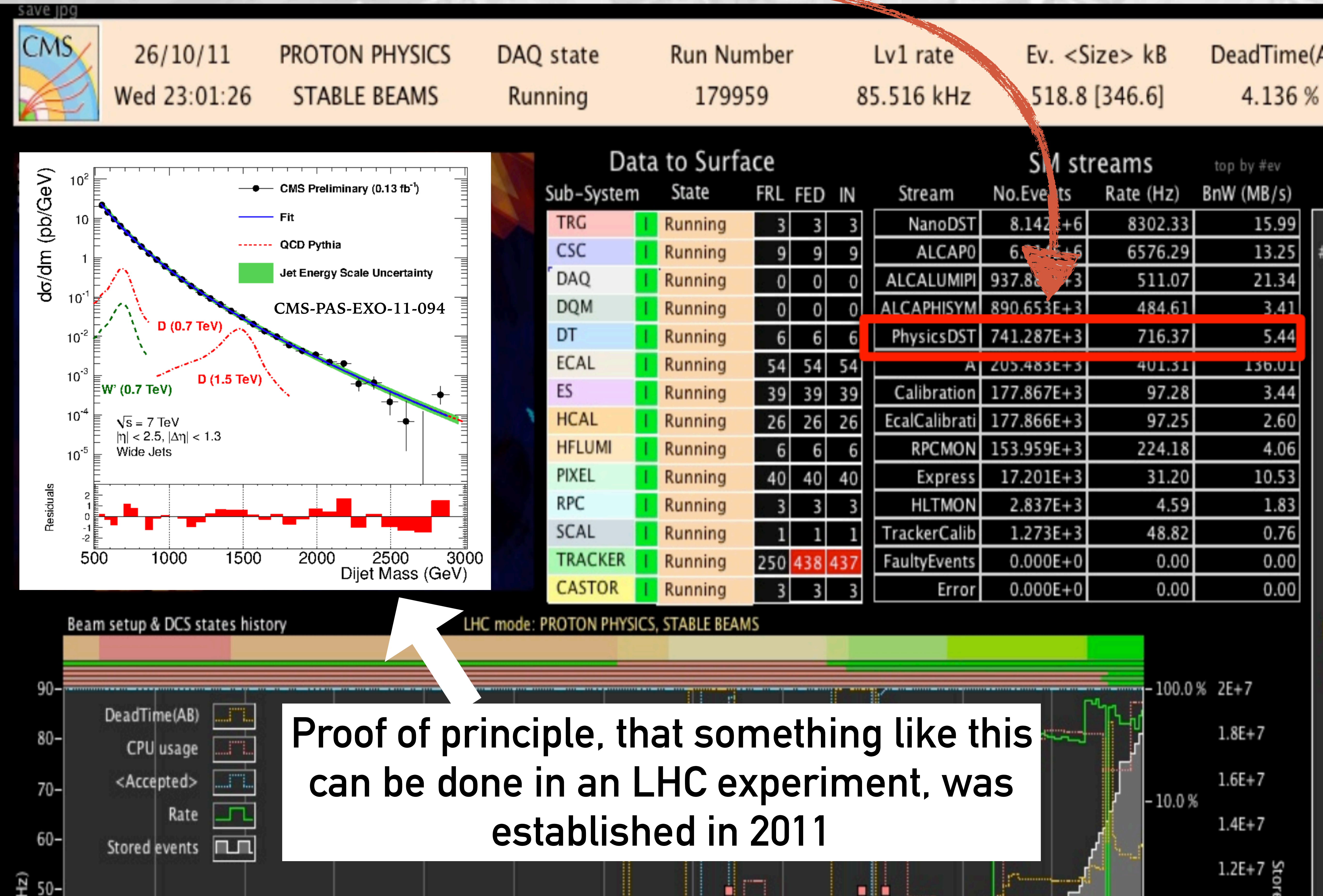



**Proof of principle, that something like this can be done in an LHC experiment, was established in 2011**

# DIJET SEARCH WITH 2012 SCOUTING DATA

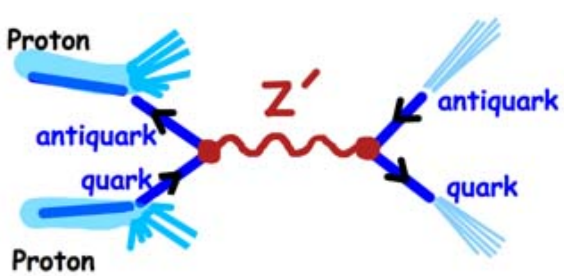
Phys. Rev. Lett. 117 (2016) 031802

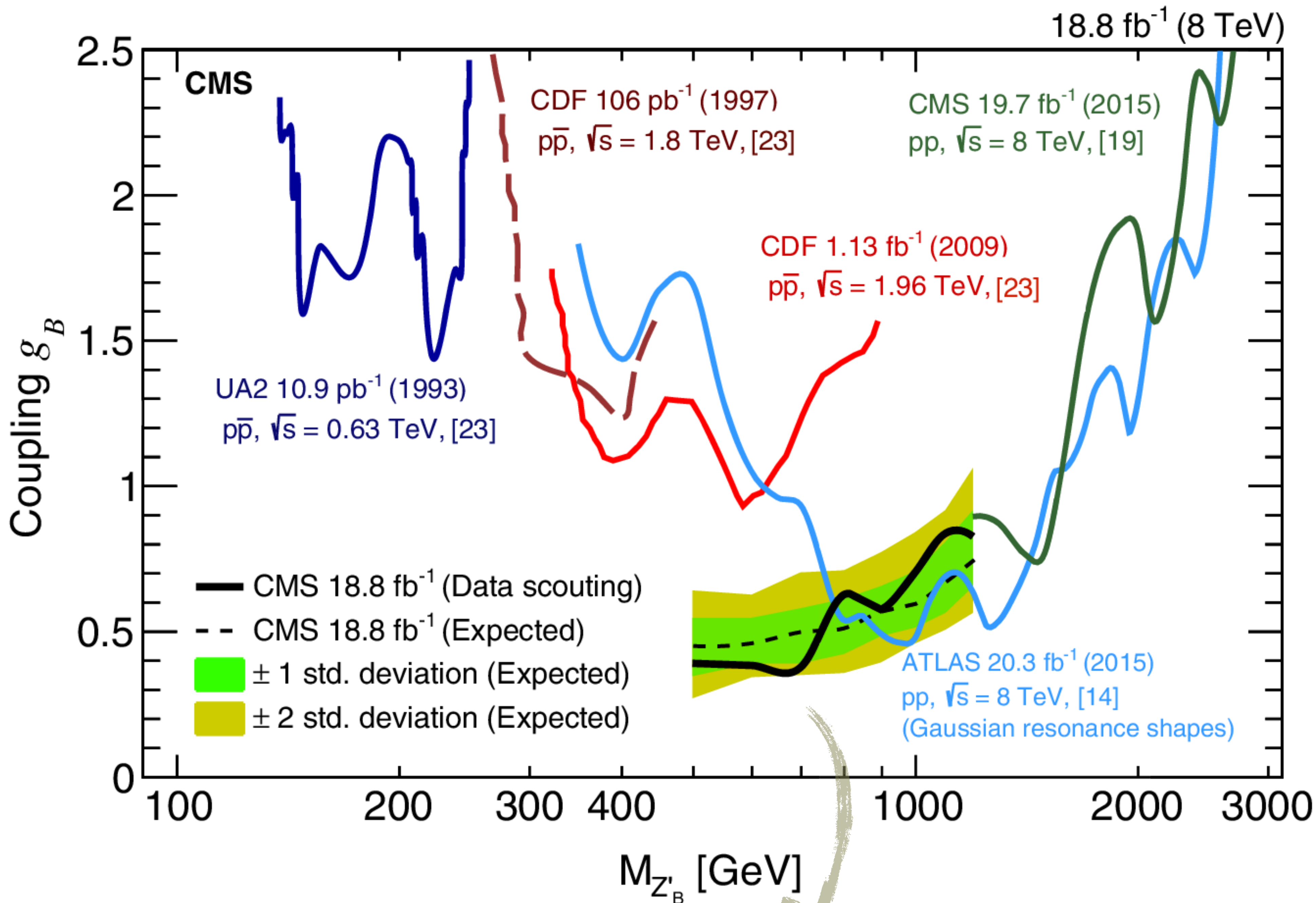
## First "Trigger-Level Analysis" result published by an LHC experiment

- Jets@HLT have worse energy resolution.
- Derive jet energy correction factors for HLT jets by comparing them with offline jets.
  - A special trigger stream is used which saves offline jet and HLT jets to enable HLT vs offline comparison.

Coupling of leptophobic $Z'_B$ to SM quarks

$$\frac{g_B}{6} Z'_{B\mu} \bar{q} \gamma^{\mu} q,$$

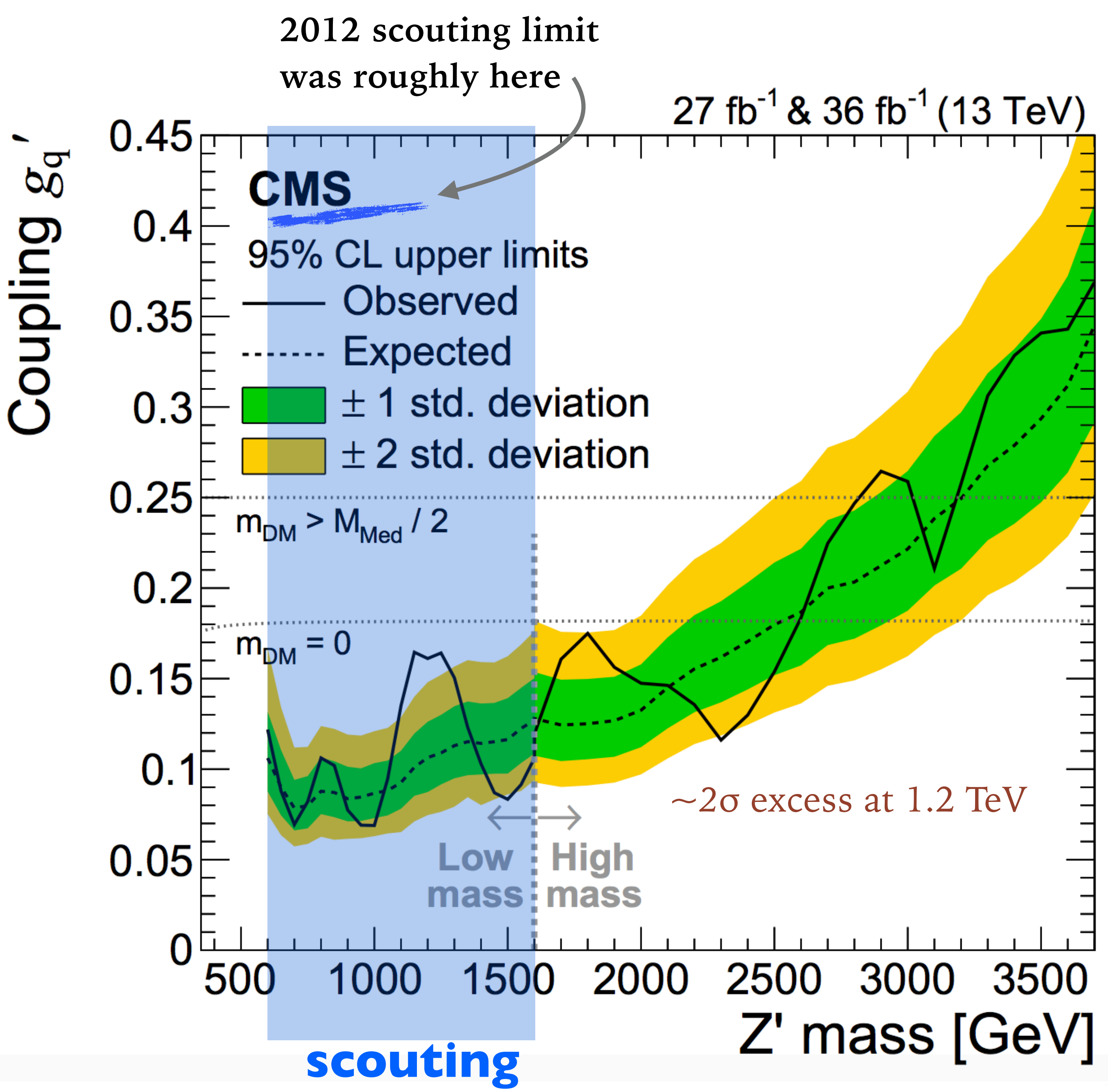


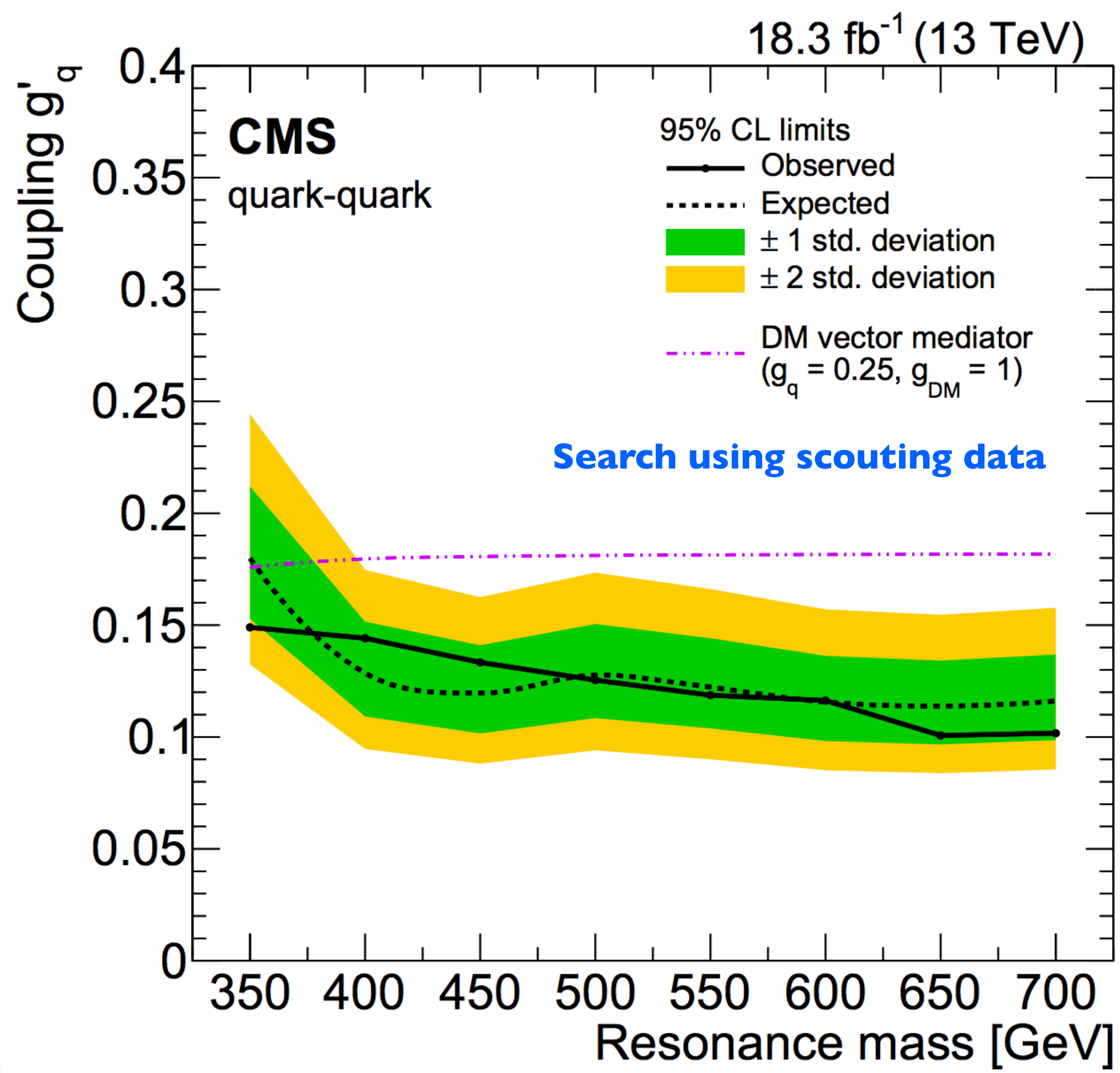

**Using scouting, most stringent limits (at that time) in the range 500 - 800 GeV**

# DIJET SEARCH WITH RUN2 DATA

Dijet search was repeated with 13 TeV data (Run2), improving the limits by an impressive amount.




A new dijet search was performed on Run2 scouting data, by selecting events with 3 jets, which allows to probe even lower masses.




EXO-16-056 JHEP doi:10.1007/JHEP08(2018)130

EXO-19-004 PLB doi:10.1016/j.physletb.2020.135448

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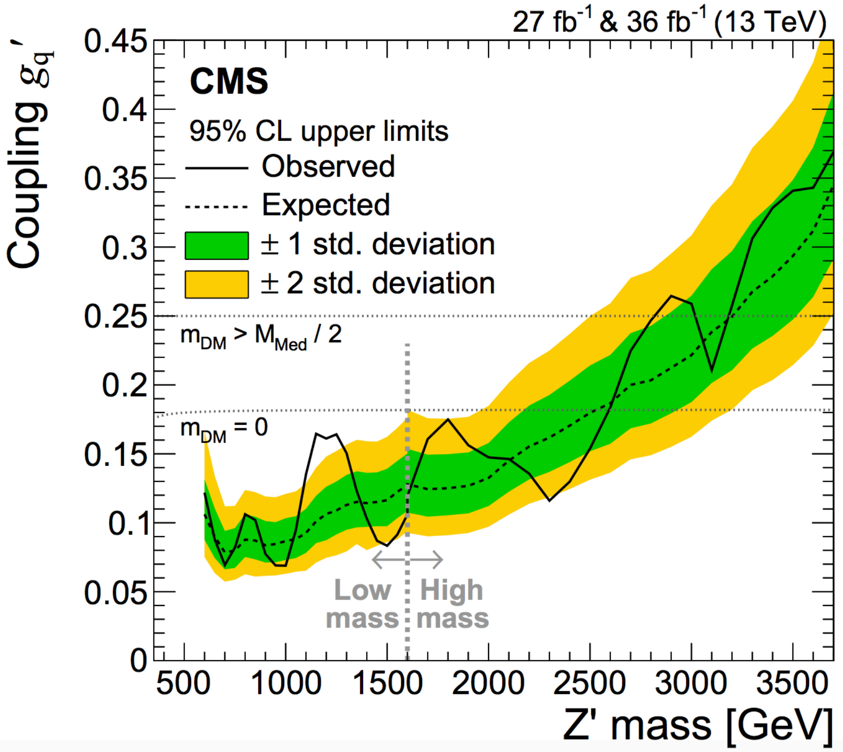
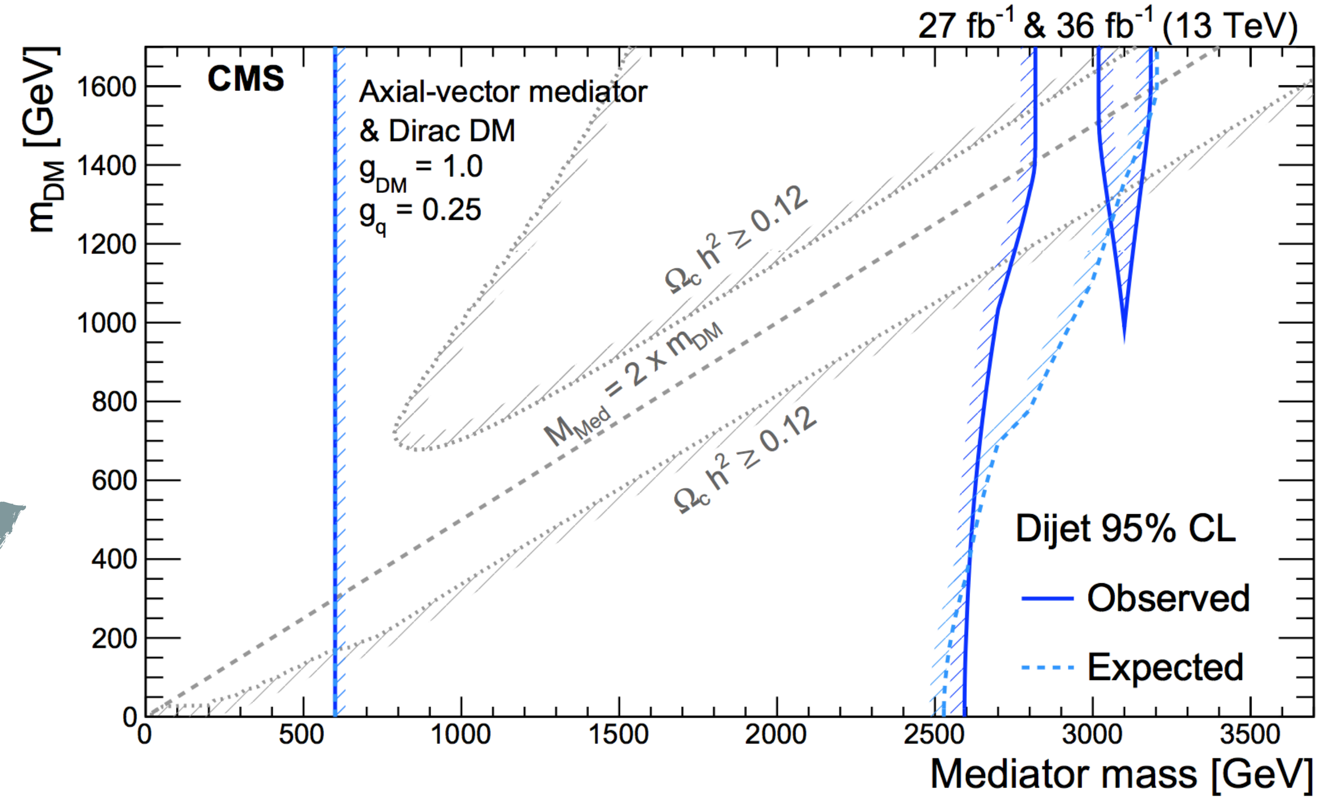
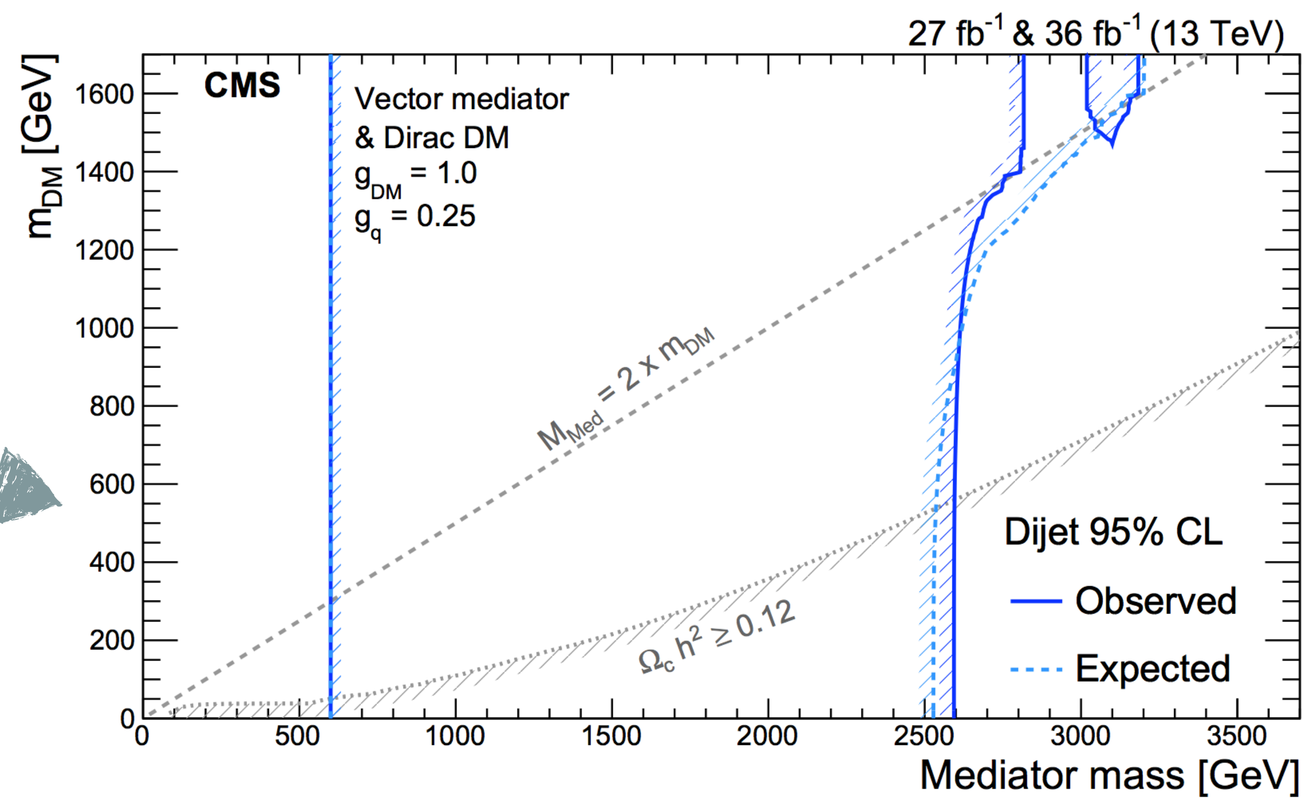



Axial vector

Vector

Limits translated to dark matter mass vs mediator mass plane




EXO-16-056

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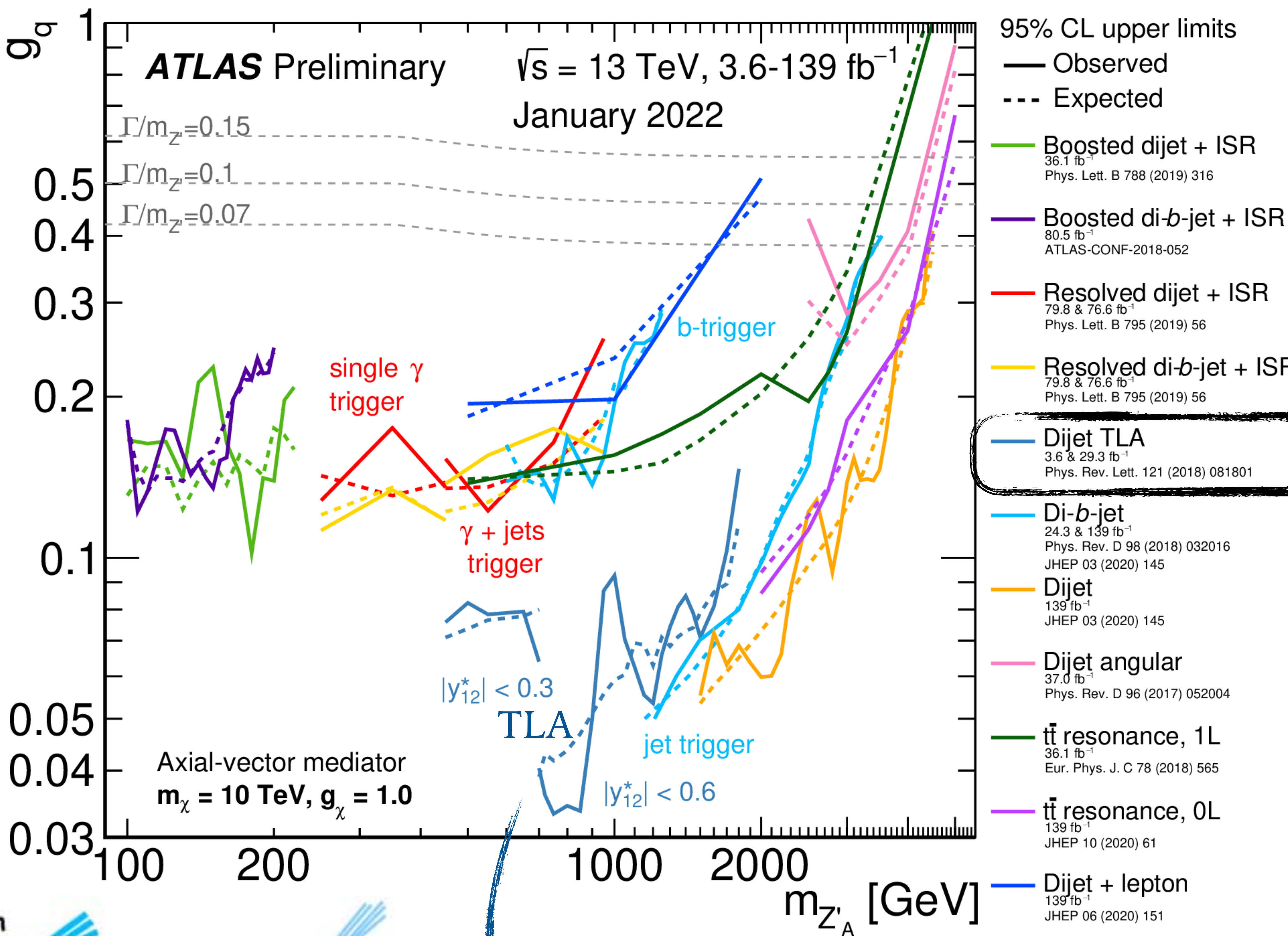
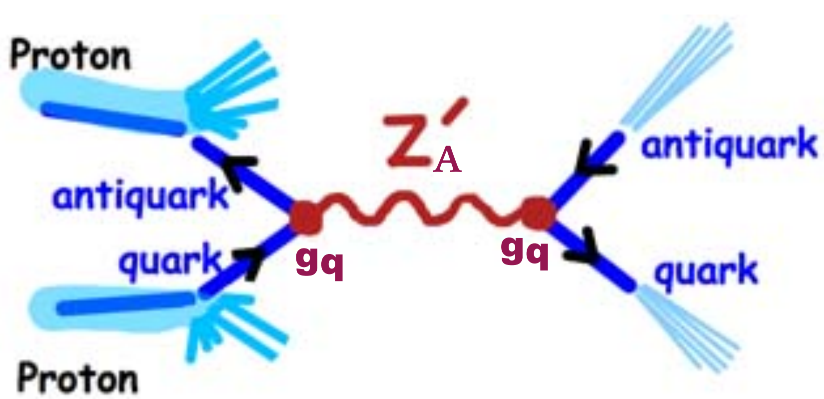
# SEARCHES WITH SPECIAL DATA FLOW IN ATLAS



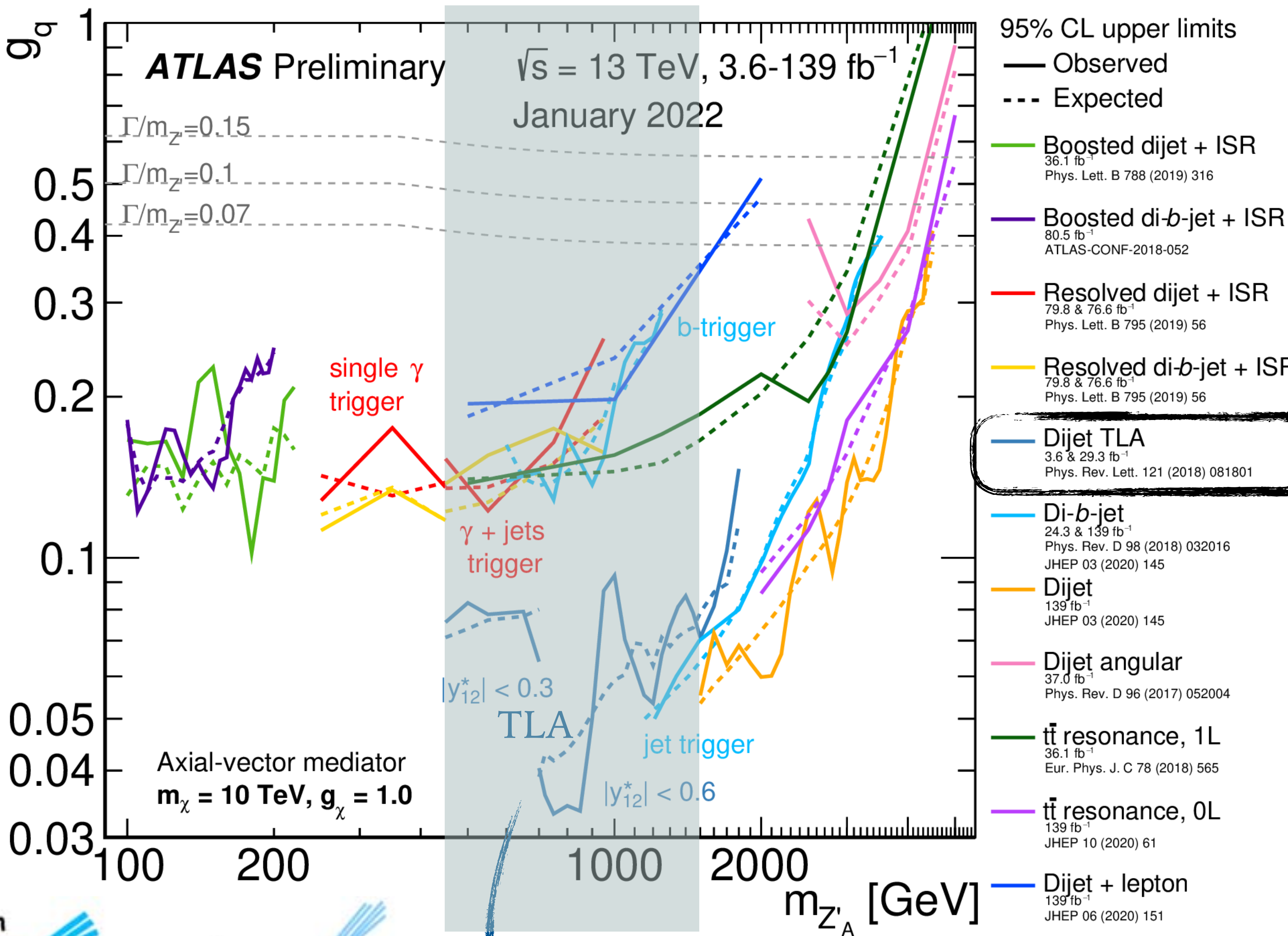

Jet final state

**TLA = Trigger Level Analysis**



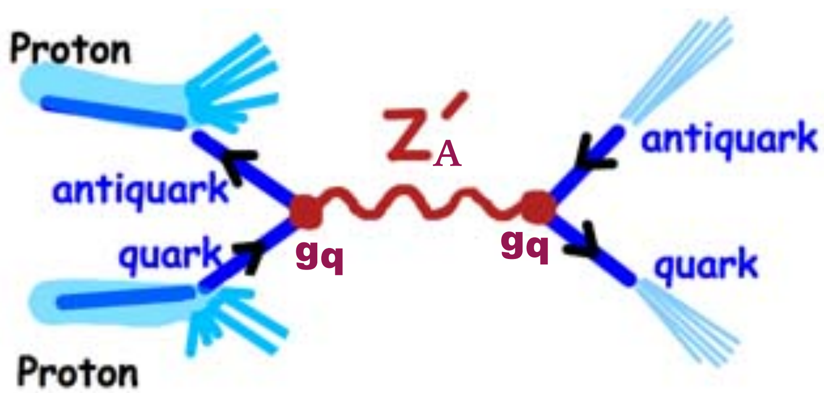

TLA provides the strongest limits in medium mass range

# SEARCHES WITH SPECIAL DATA FLOW IN ATLAS




**Jet final state**

**TLA = Trigger Level Analysis**




**TLA provides the strongest limits in medium mass range**

# MULTI-JET RESONANCE SEARCH

CMS-PAS-EXO-21-004

Search for pair-produced multijet signals: merged & resolved tri-jets, merged di-jets using PF scouting data

## Particle flow (PF) scouting

- Higher quality objects (example: **PF Jet** vs **Calo Jet**)
- All PF candidates saved in PF scouting, which leads to bigger event size
  - More information allows to do more complicated searches
- Lower rate is allowed to compensate for higher event-size

Trigger Bandwidth = Event Rate × Event Size
~1 kHz × ~1 MB

**If we want to increase rate, then we need to decrease event size**

**So that the bandwidth stays within limits**

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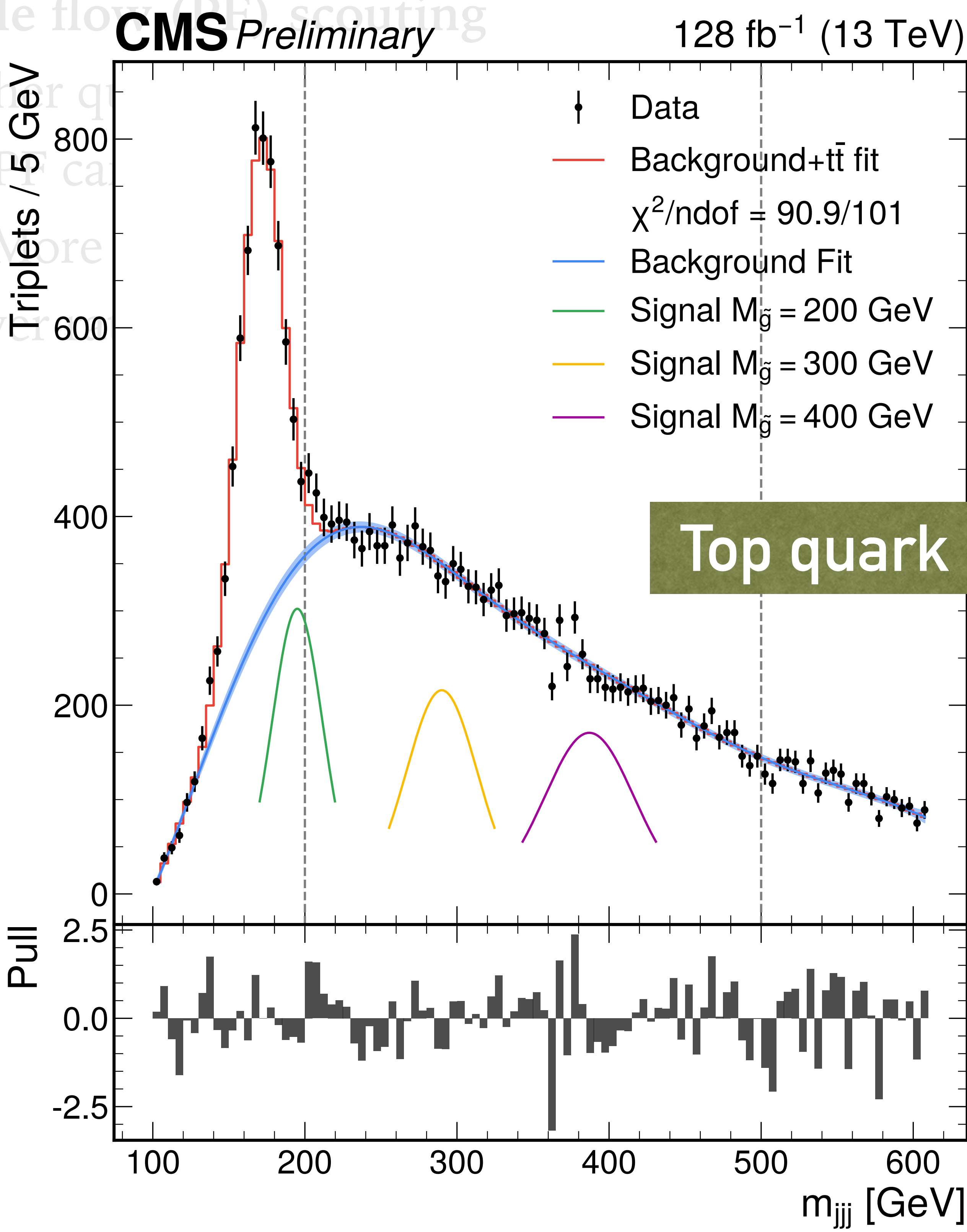


Top quark reconstructed in scouting data

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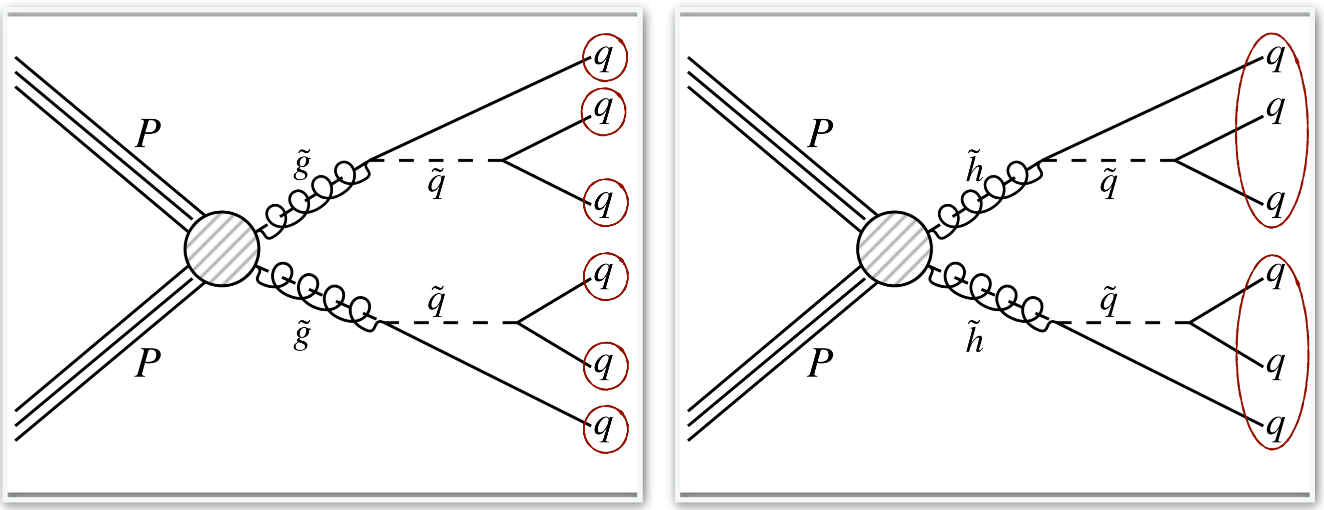
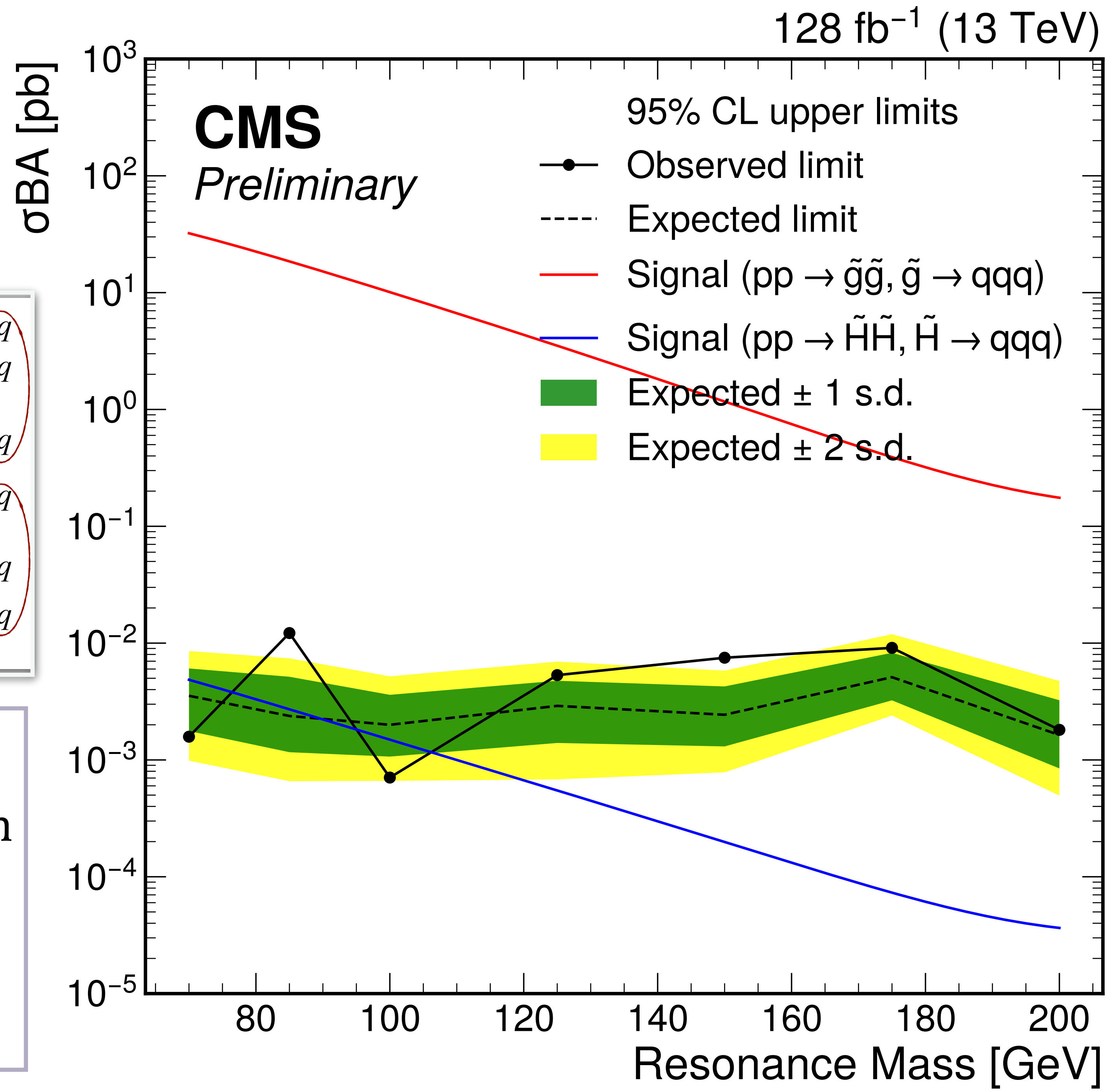
**Extended prior exclusions on resonance masses to even lower masses of ~70-200 GeV.**




For the first time:

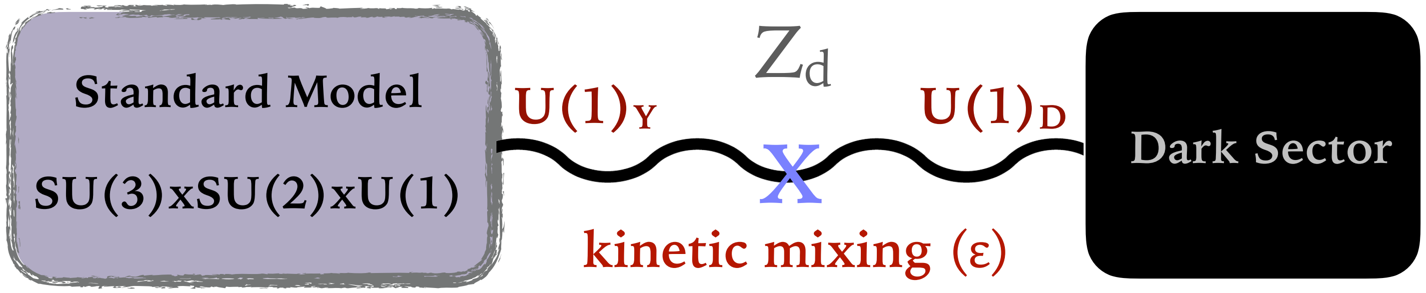
- Probed EW production of RPV SUSY in fully hadronic final states.
- Exclusions on prompt hadronically decaying mass-degenerate higgsinos.

Using jet substructure tools in scouting, for the first time

NN-based quark/gluon discriminator for resolved analysis

# NON HADRONIC SCOUTING CHASING THE LOW $P_T$ MUONS

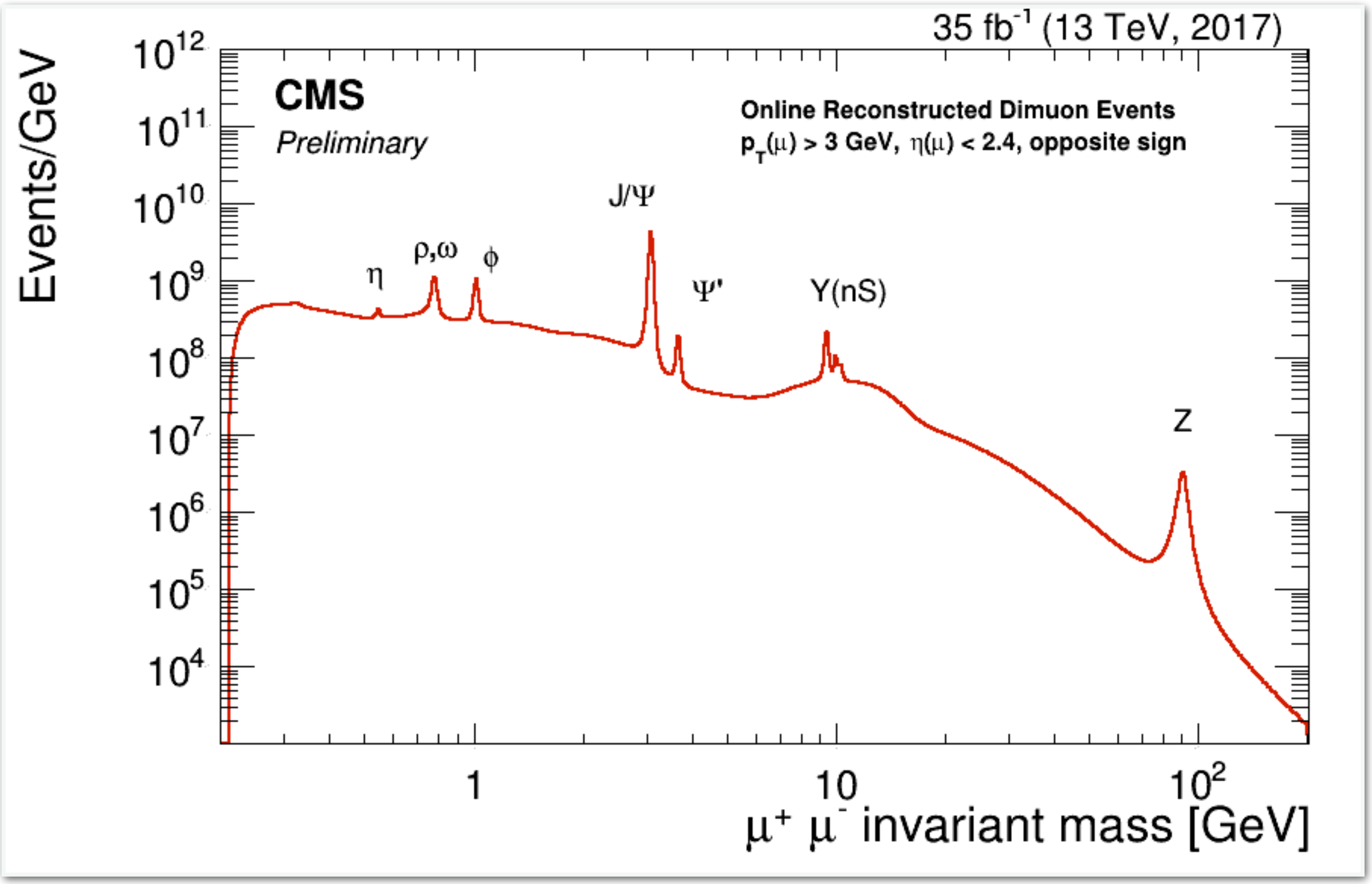
**In 2017, CMS deployed a new, improved, dedicated dimuon scouting trigger for dark-photon searches.**




Dark photon in Hidden sector model

Di-muon mass distribution at trigger level (muon scouting)

No additional offline identification cuts on muon



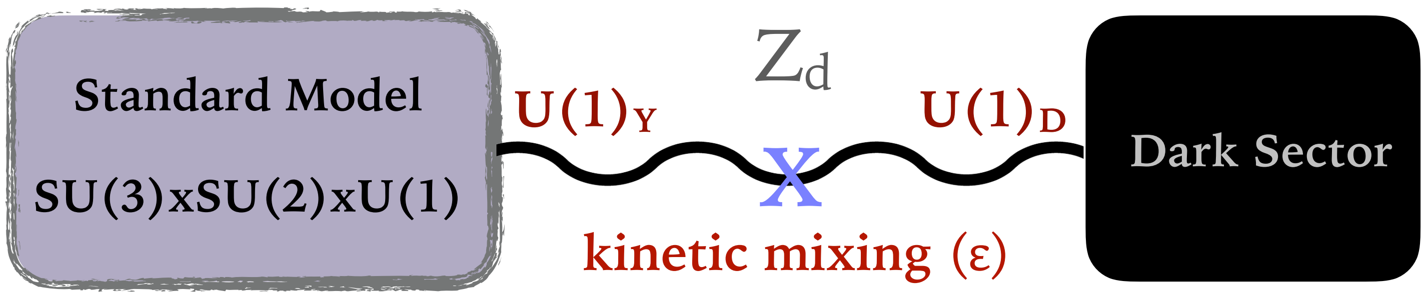

https://twiki.cern.ch/twiki/bin/view/CMSPublic/HLTDiMuon2017and2018

# NON HADRONIC SCOUTING CHASING THE LOW $P_T$ MUONS

Prompt dimuon search

First CMS analysis using non-hadronic scouting

Best limits in most of the phase space probed. Even at low masses (11.5-45 GeV), limits competitive to LHCb

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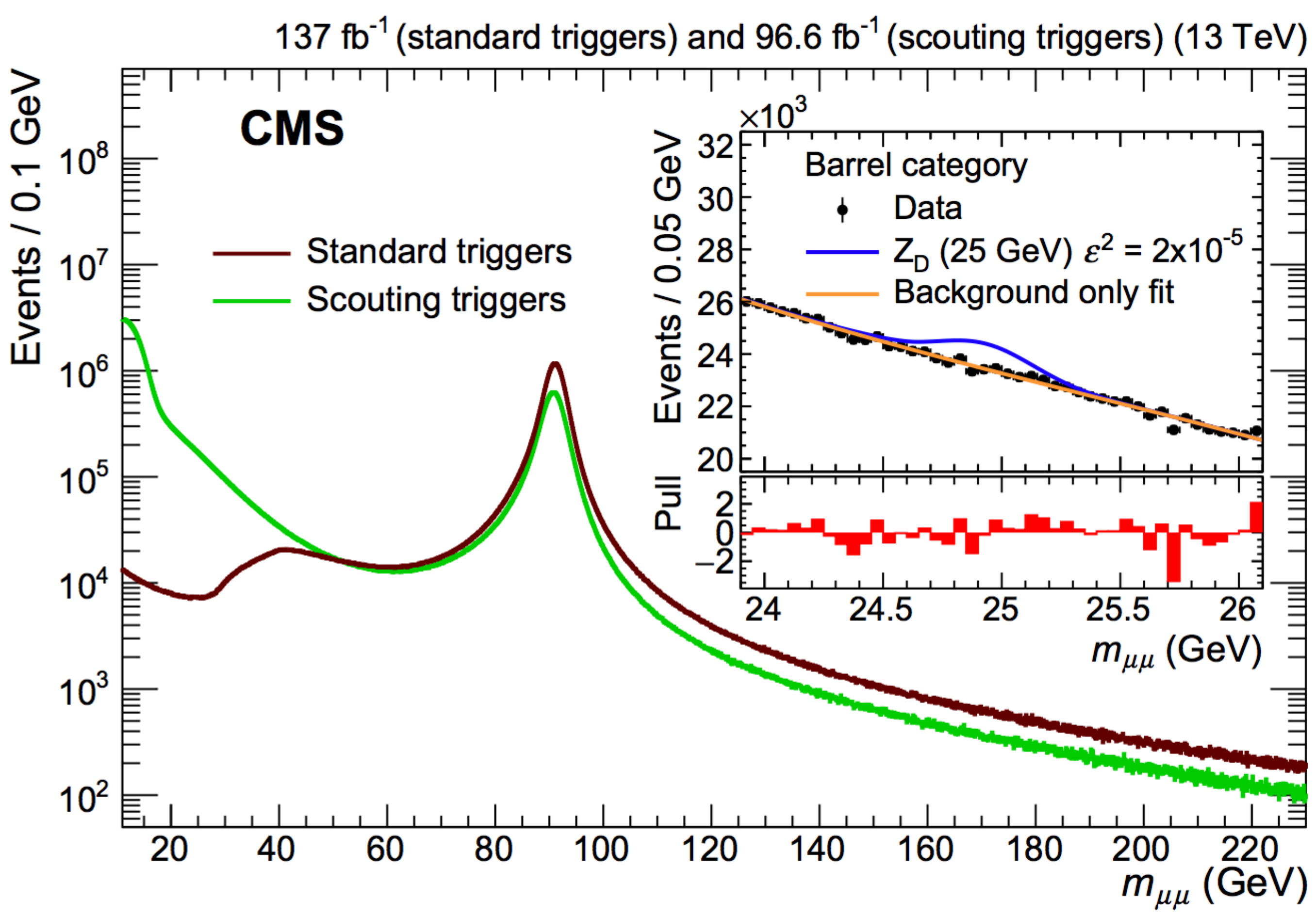
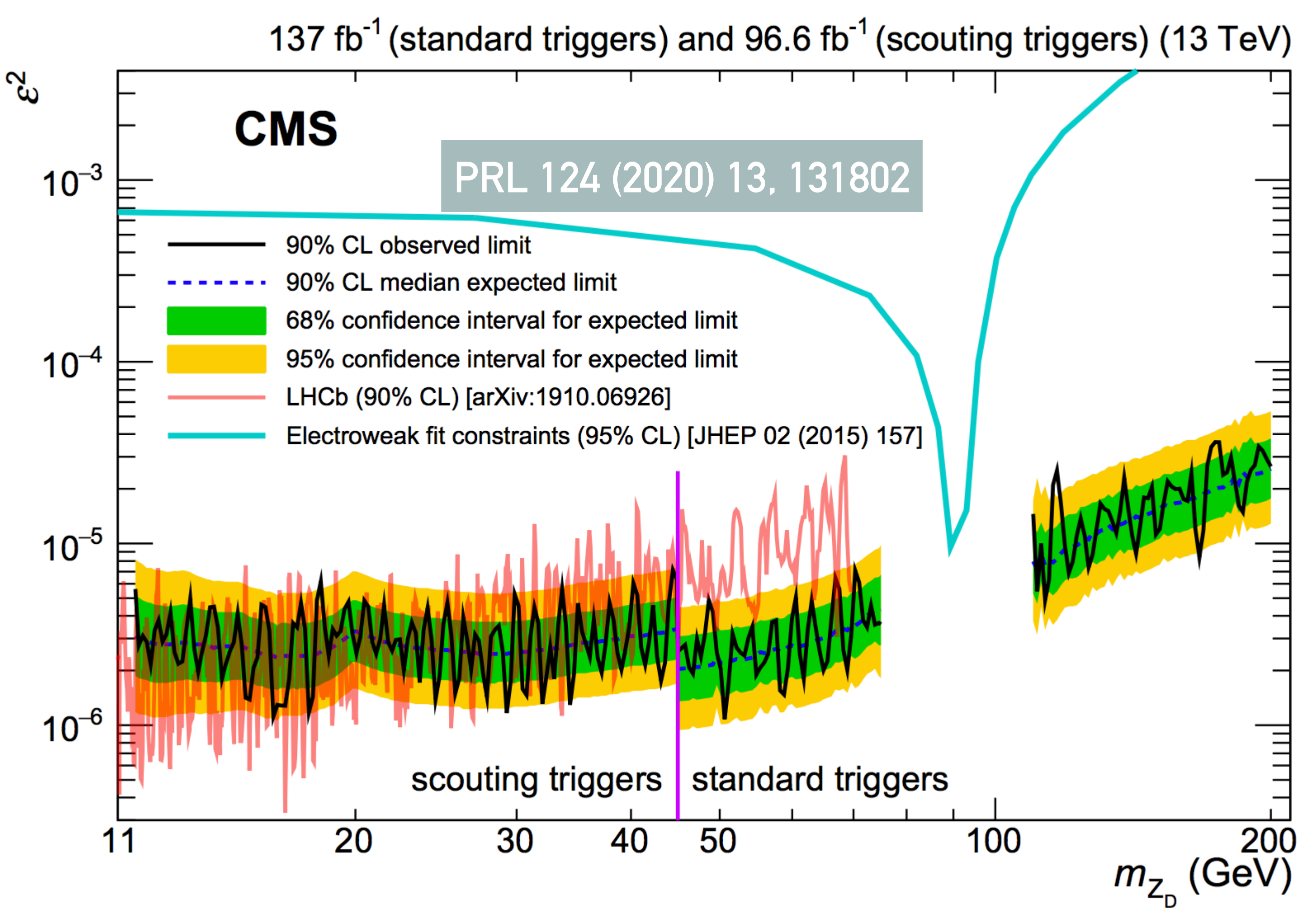


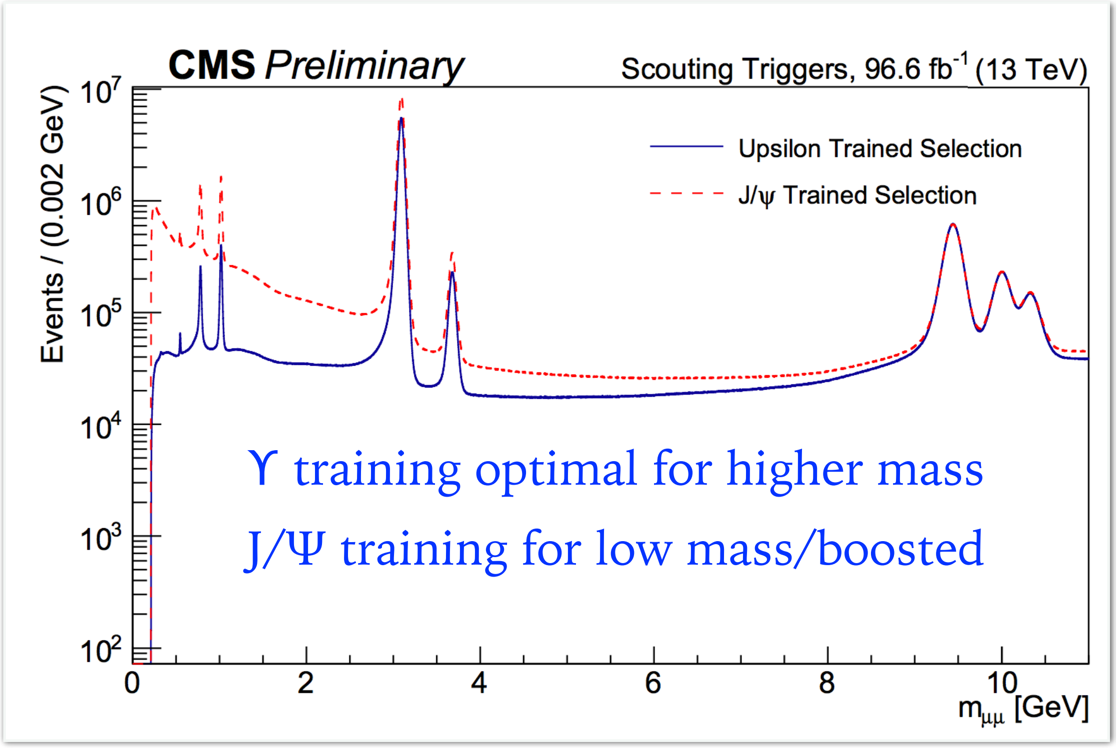



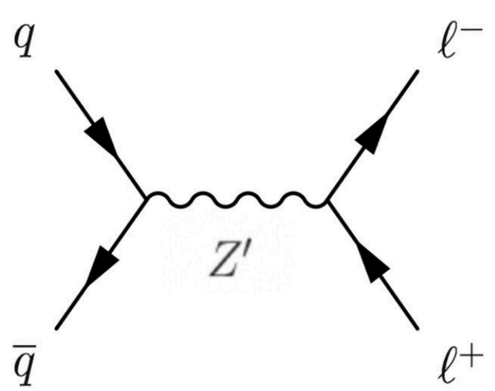

PRL 124 (2020) 13, 131802

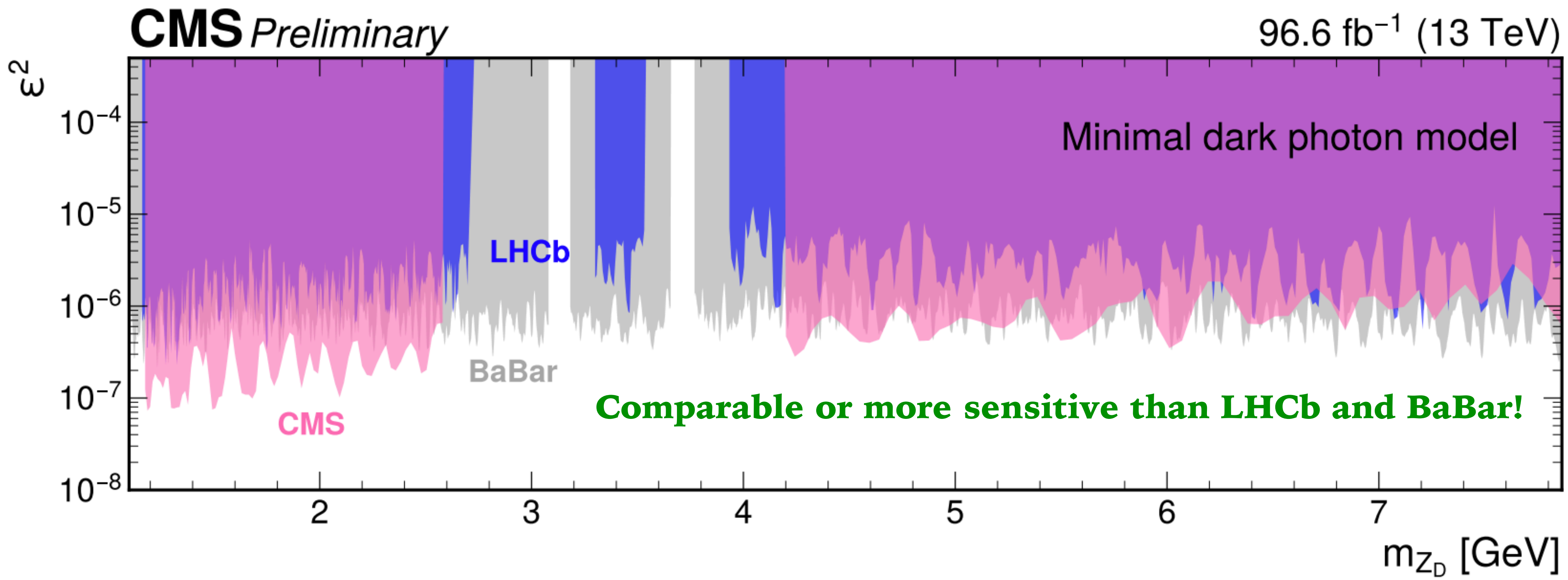
# GEV SCALE RESONANCE DECAYING TO MUONS

EXO-21-005

- Search for ultra low mass dimuon resonances
  - Mass range: 1.1-2.6 GeV and 4.2-7.9 GeV
- Data collected by dedicated **scouting** muon trigger.
  - Muons reconstructed at high-level trigger used in analysis.
- Muons required to pass a MVA discriminant
  - Two MVAs based on J/ψ and ϒ(1S)
- Results interpreted in context of dark photon and pseudoscalar (2HDM+S)




Model independent limits on σ×B×Acceptance also provided for the inclusive and boosted selections.

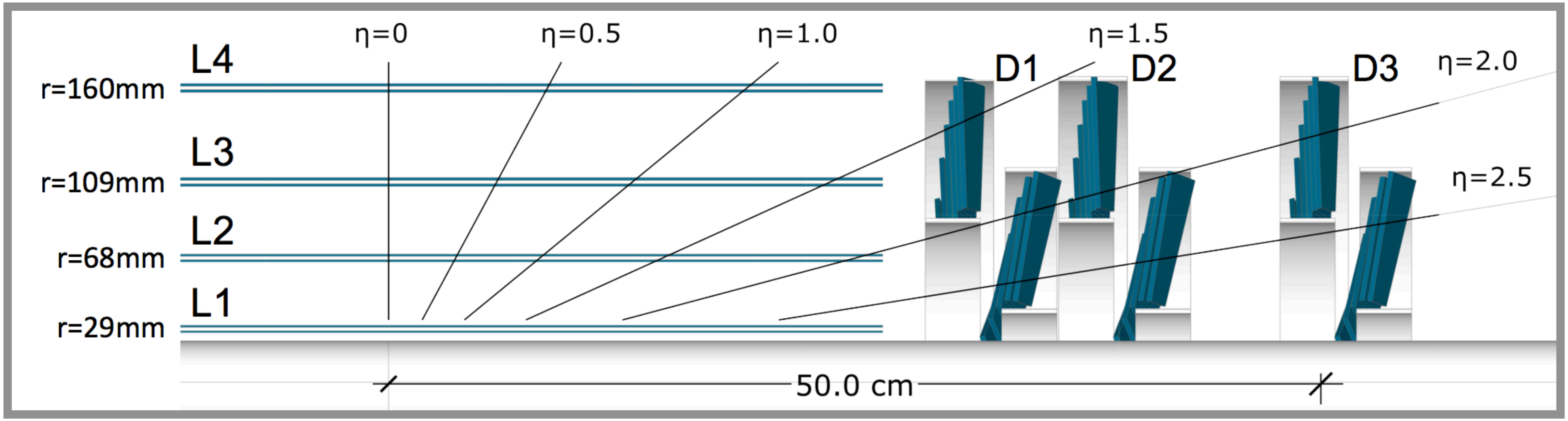
# NON HADRONIC SCOUTING DISPLACED DIMUON SEARCH

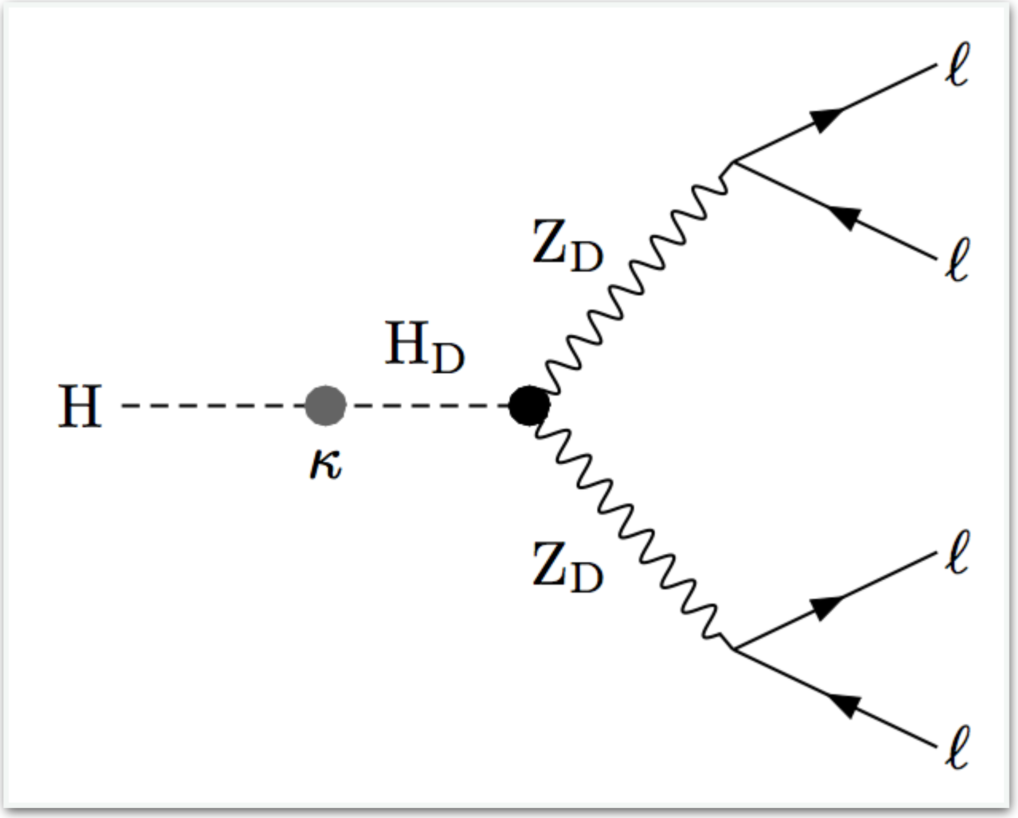
JHEP 04 (2022) 062

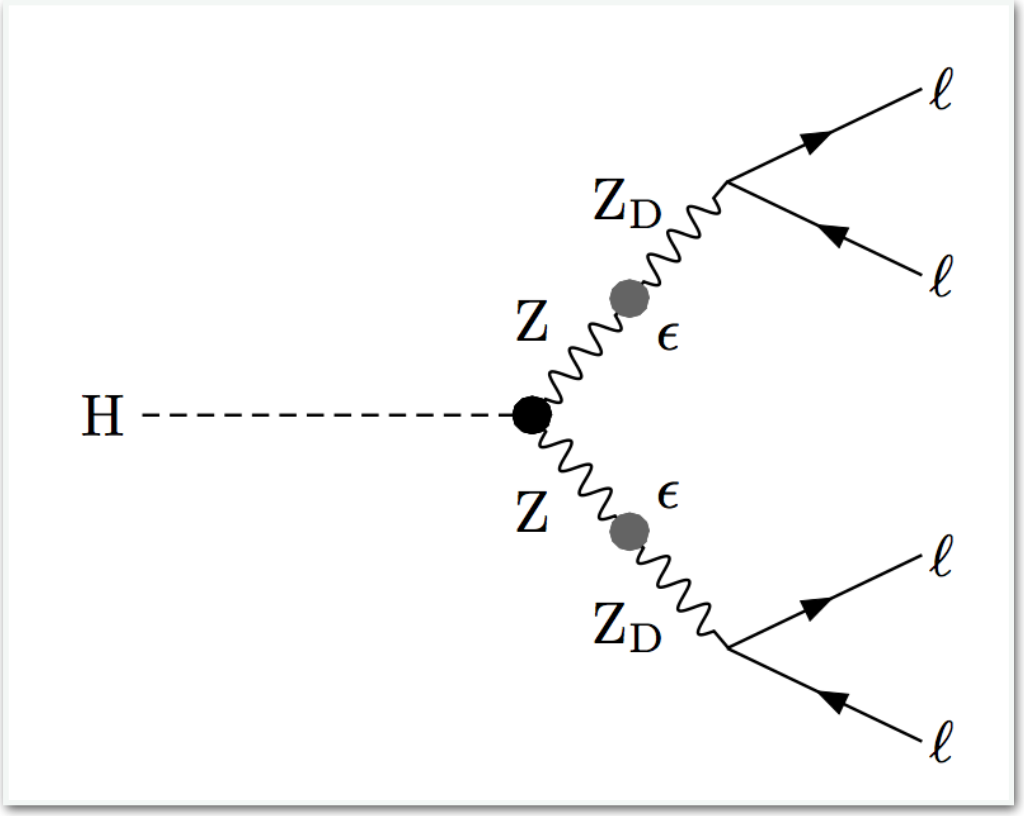
## First CMS search for long-lived BSM signatures using scouting data

Presence of ≥2 hits in inner tracker required in scouting dimuon trigger

Range of accessible transverse displacement: $0 \leq l_{xy} < 109$ mm



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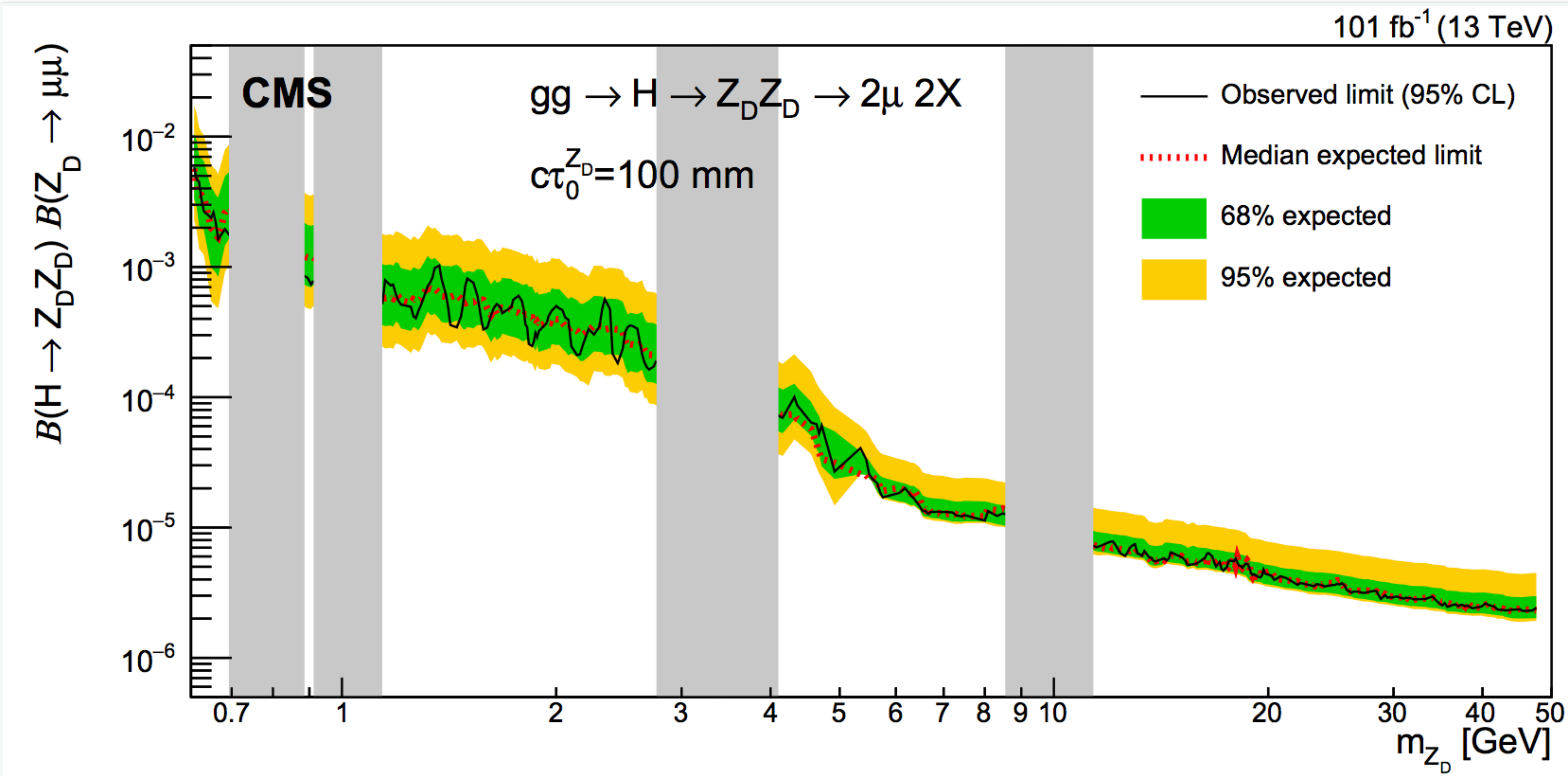
JHEP 04 (2022) 062




Probed very low masses, thanks to scouting triggers!

Improved previous limits by 2-10 times

# DARK PHOTON SEARCH IN LHCb

Search for dark photons decaying into a pair of muons

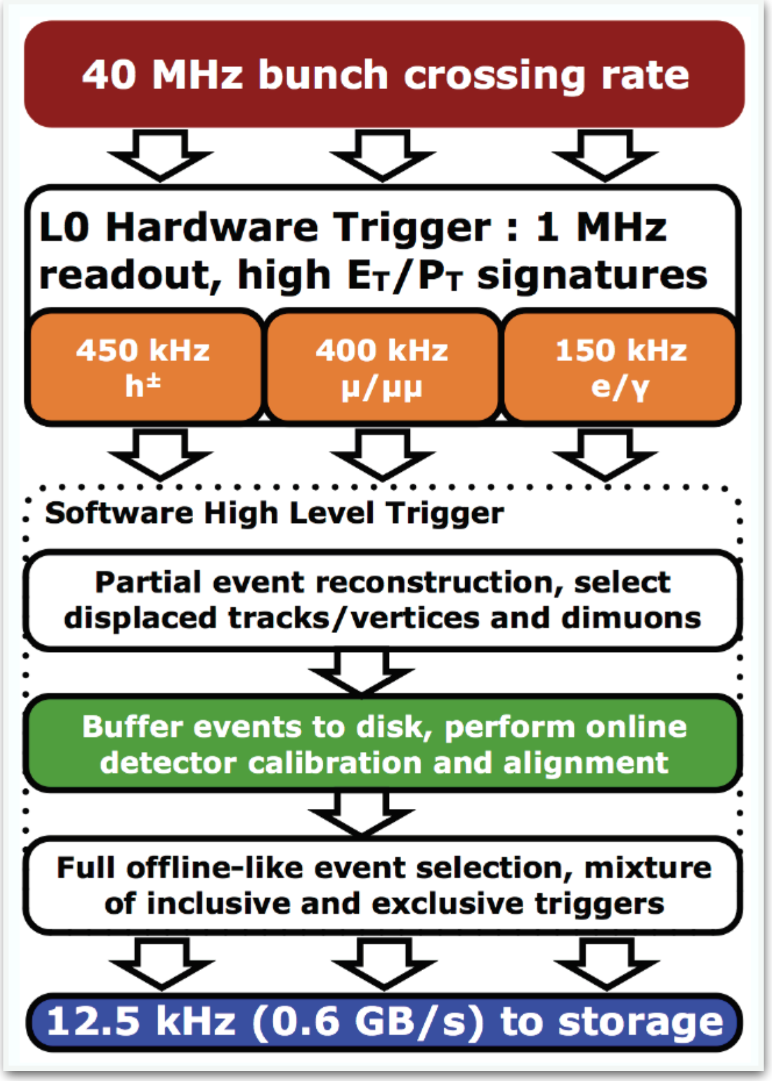
**Real-time** reconstruction and calibration (**Turbo stream**)

- Reduced event content, but fine for bump-hunt
- **Very low-$p_T$ trigger** allows to probe very low masses

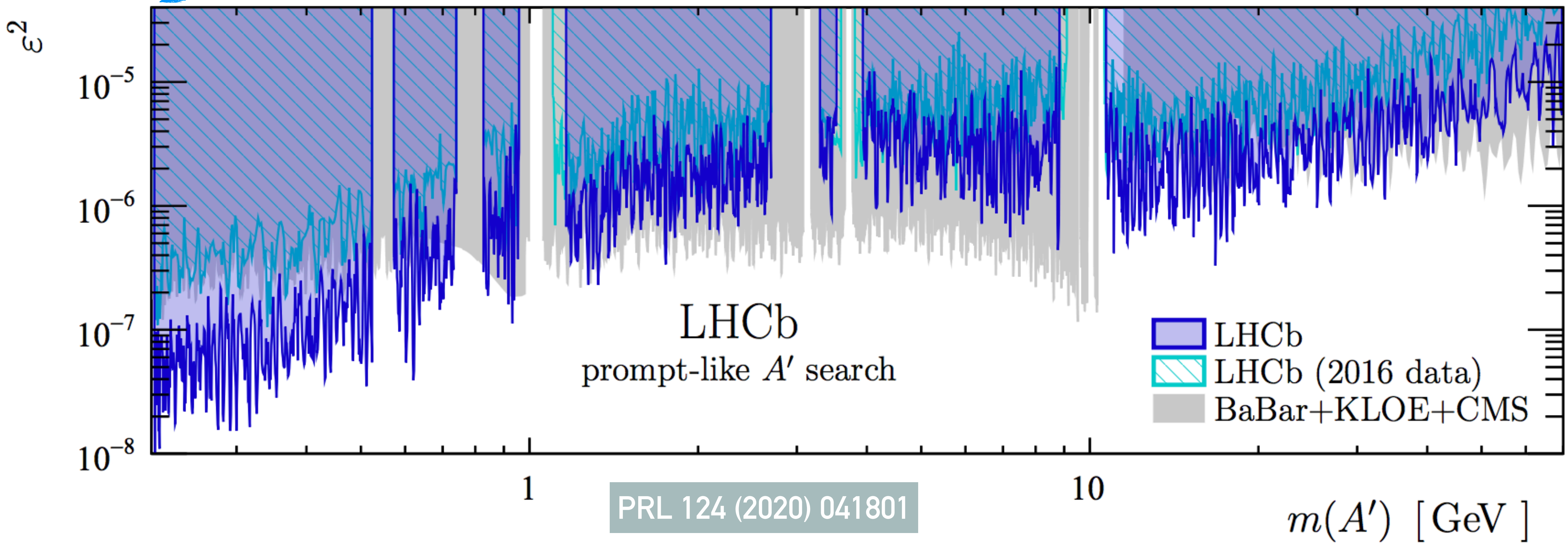
Prompt search up to 70 GeV

Used 5.5 fb$^{-1}$ of Run2 LHCb data (13 TeV)

Fully data-driven analysis



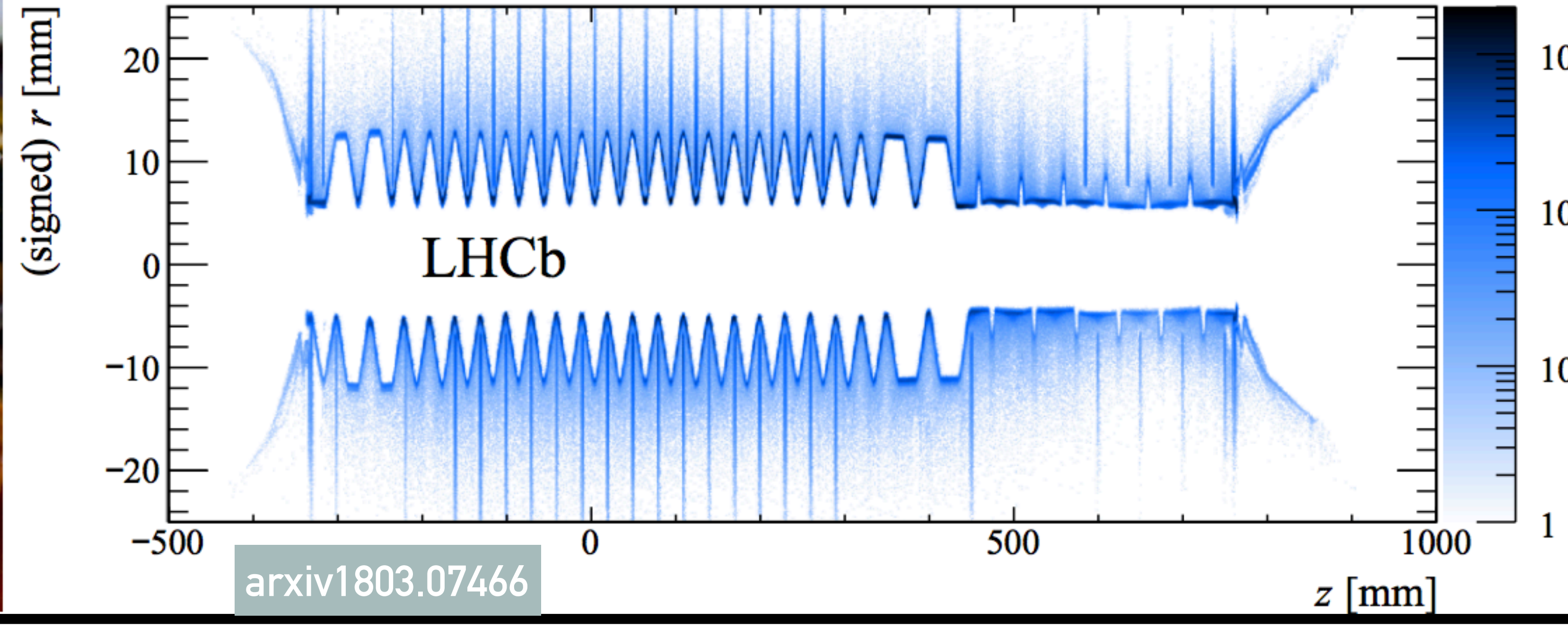

LHCb put the most stringent limit in the 214-740 MeV mass region




PRL 124 (2020) 041801

# LONG-LIVED DARK PHOTON SEARCH IN LHCb

Background dominated by material interactions for displaced dimuon search @LHCb.
Precise knowledge of location of material in LHCb VELO is essential to reduce the background

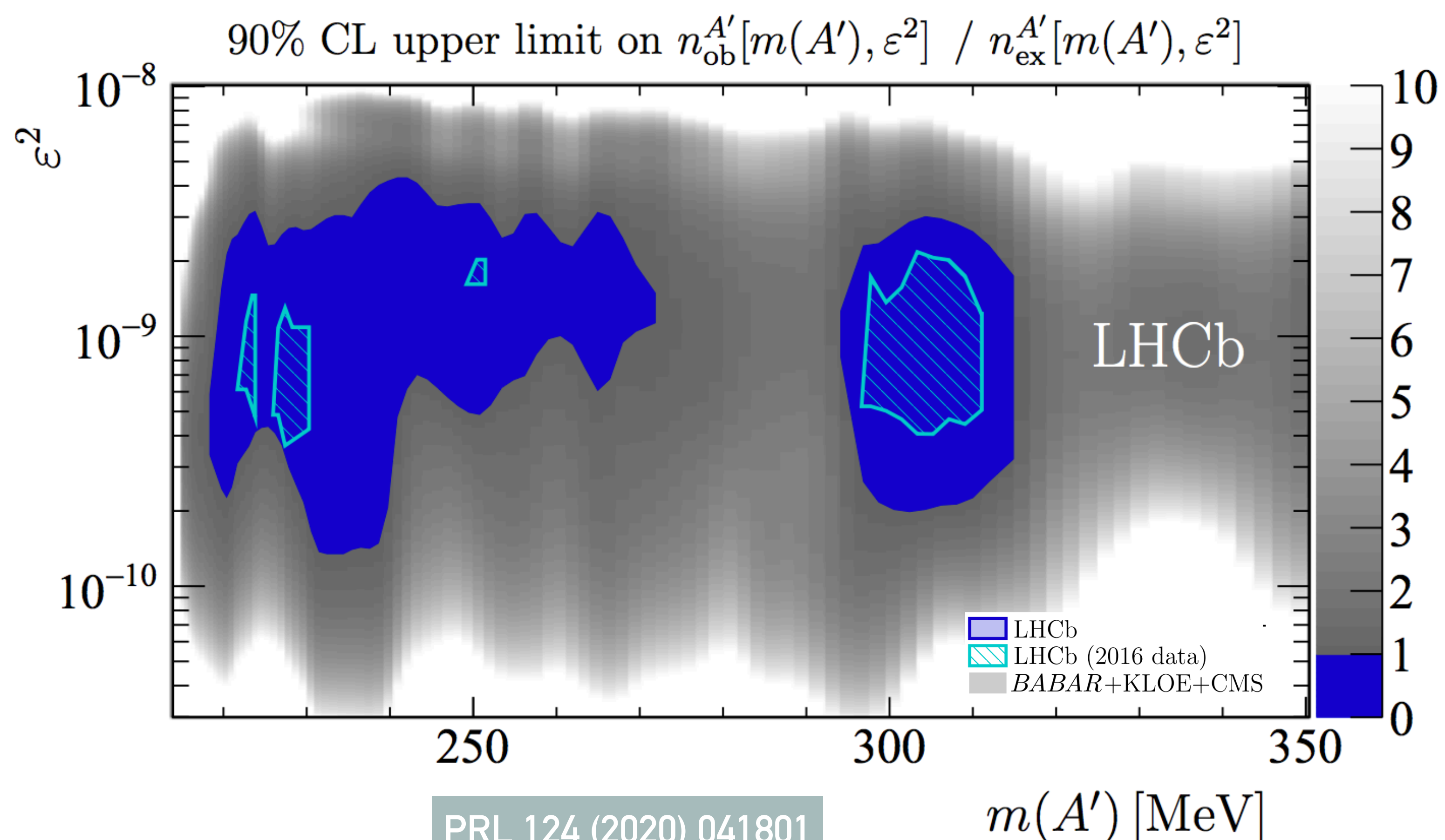



arxiv1803.07466

Material background mainly from photon conversions

Displaced search probes the very low mass region (214-350 MeV)

A region generally accessible only by beam-dump experiments!




PRL 124 (2020) 041801

# SUMMARY AND OUTLOOK

LHC experiments have used **novel trigger strategies** to look for new physics in challenging areas of the phase space.

Searches have **null results** so far. But **strong limits** given on various models.

"If we ever do find the elusive material, the scientists who get the glory will have built their success on the foundations laid by all those who found nothing."

*Taken from this interesting article*

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LHC experiments have used **novel trigger strategies** to look for new physics in challenging areas of the phase space.

Searches have null results so far. But strong limits given on various models.

## Run3

**For ongoing Run3: we have various improvements**

- Better triggers strategies, more final states are covered. Will perform searches in **new final states** that were never searched before
- **Better event-content** of scouting data
- Usage of **heterogeneous HLT** farm, offload parts of reconstruction to GPUs
- Collecting significantly **more scouting events** in Run3 than Run2
- Planning to use **innovative analysis techniques** that can boost the reach of an analysis significantly

# SUMMARY AND OUTLOOK

LHC experiments have used novel trigger strategies to look for new physics in challenging areas of the phase space.

Searches have null results so far. But strong limits given on various models.

LHC data is valuable and finite.

Our main aim is to make the most of it.

Leave no stone unturned.

in **new final states** that were never searched before

Better event-content of scouting data

Usage of heterogeneous HLT farm, offload parts of reconstruction to GPUs

Collecting significantly more scouting events in Run3 than Run2

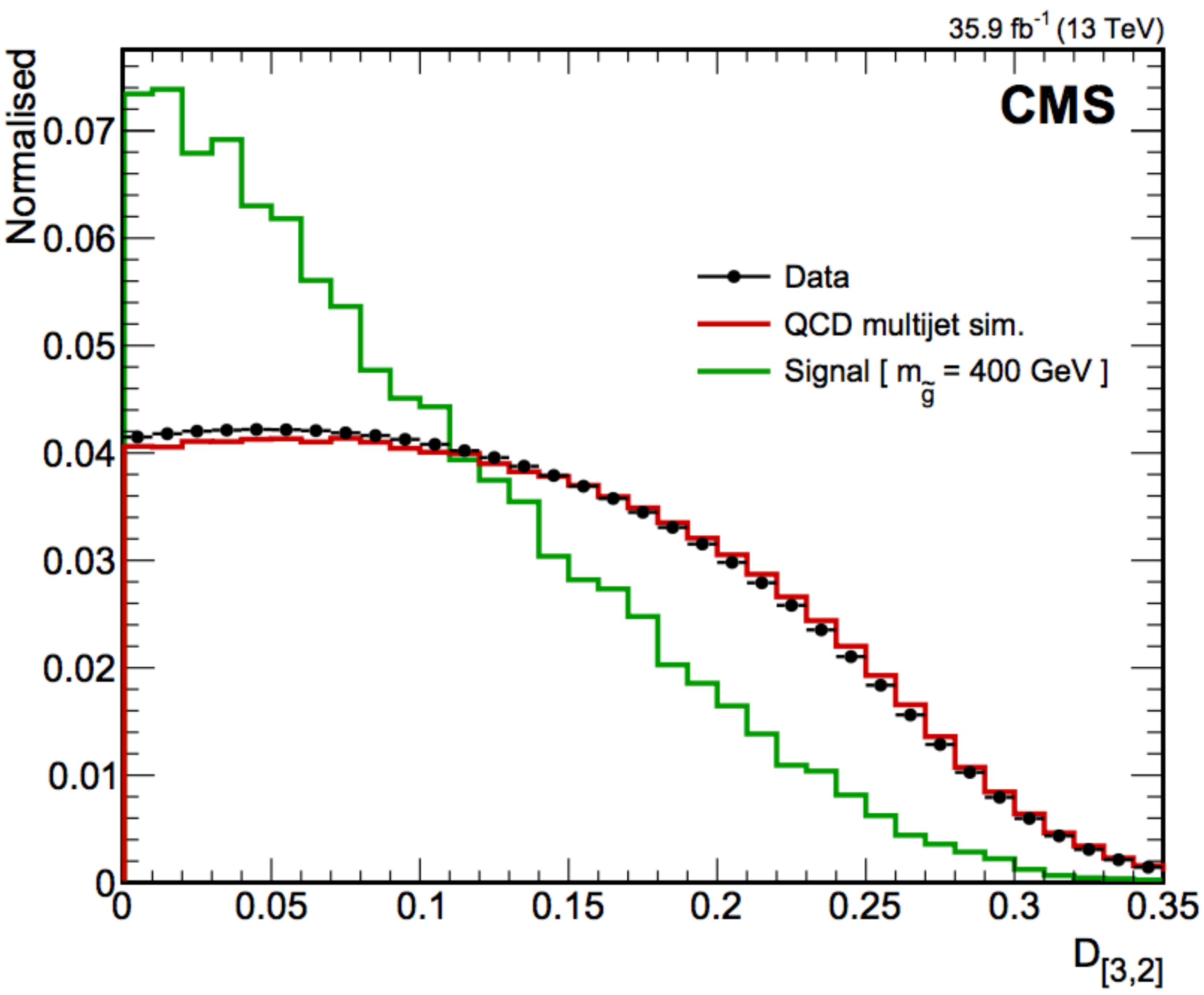
Planning to use **innovative analysis techniques** that can boost the reach of an analysis significantly

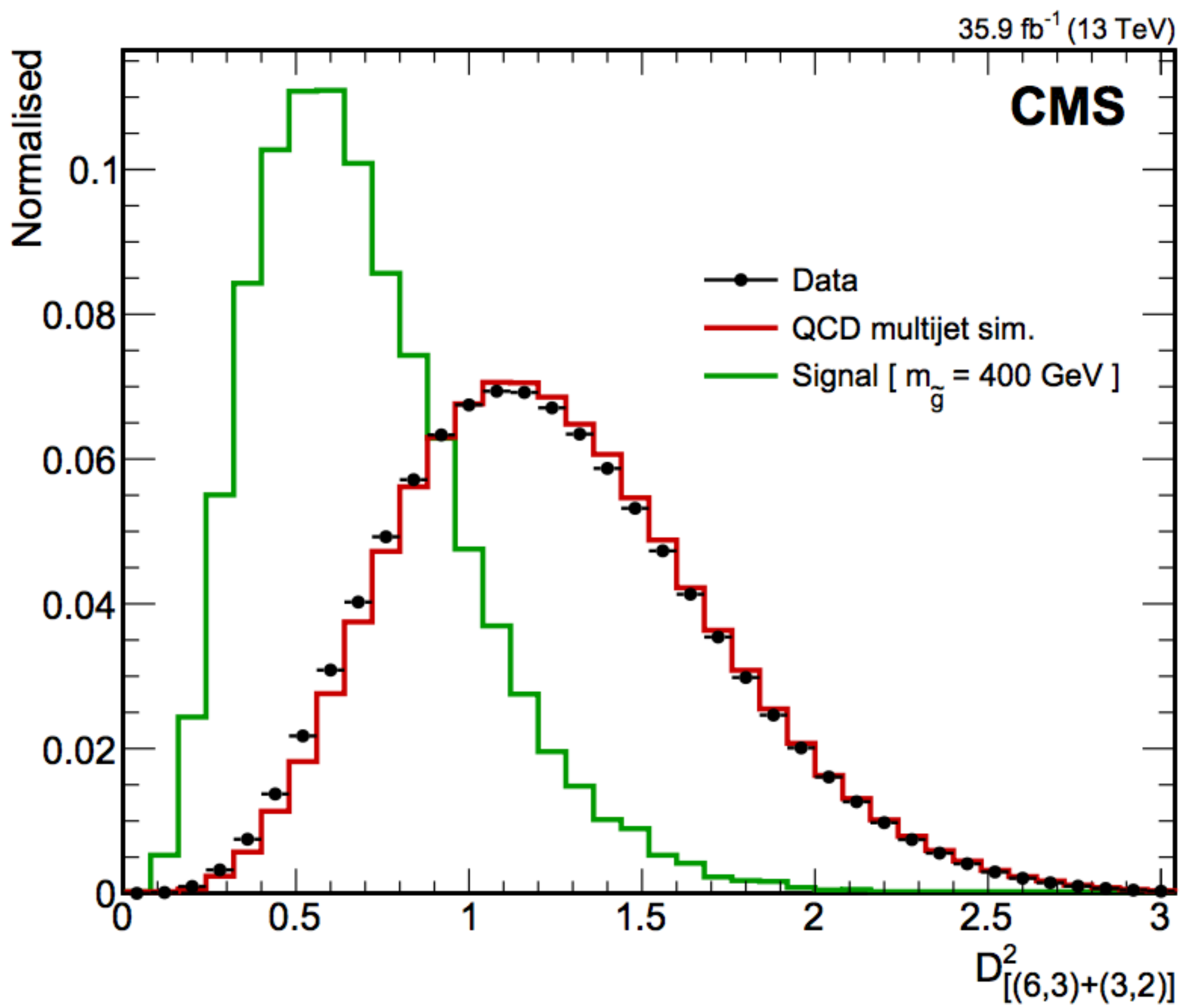
# EXTRA SLIDES

# Dalitz Variables

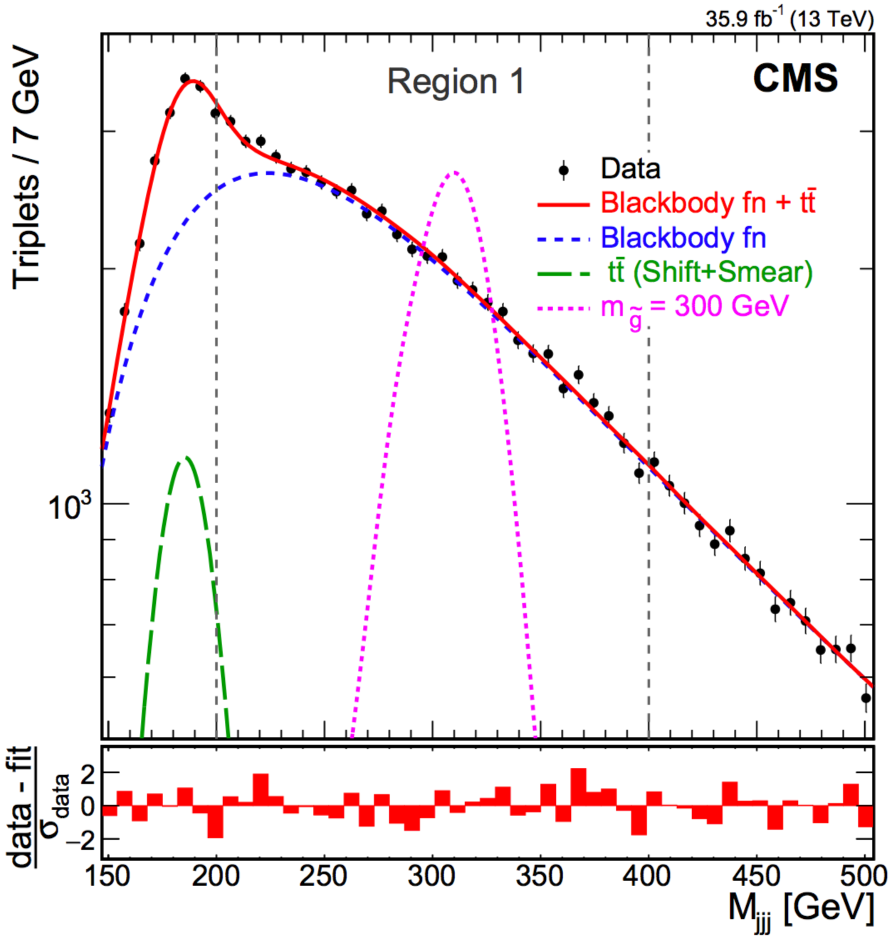
$$\hat{m}(3,2)^2_{ij} = \frac{m^2_{ij}}{m^2_{ijk} + m^2_i + m^2_j + m^2_k}.$$

$$D^2_{[3,2]} = \sum_{i>j} \left( \hat{m}(3,2)_{ij} - \frac{1}{\sqrt{3}} \right)^2.$$

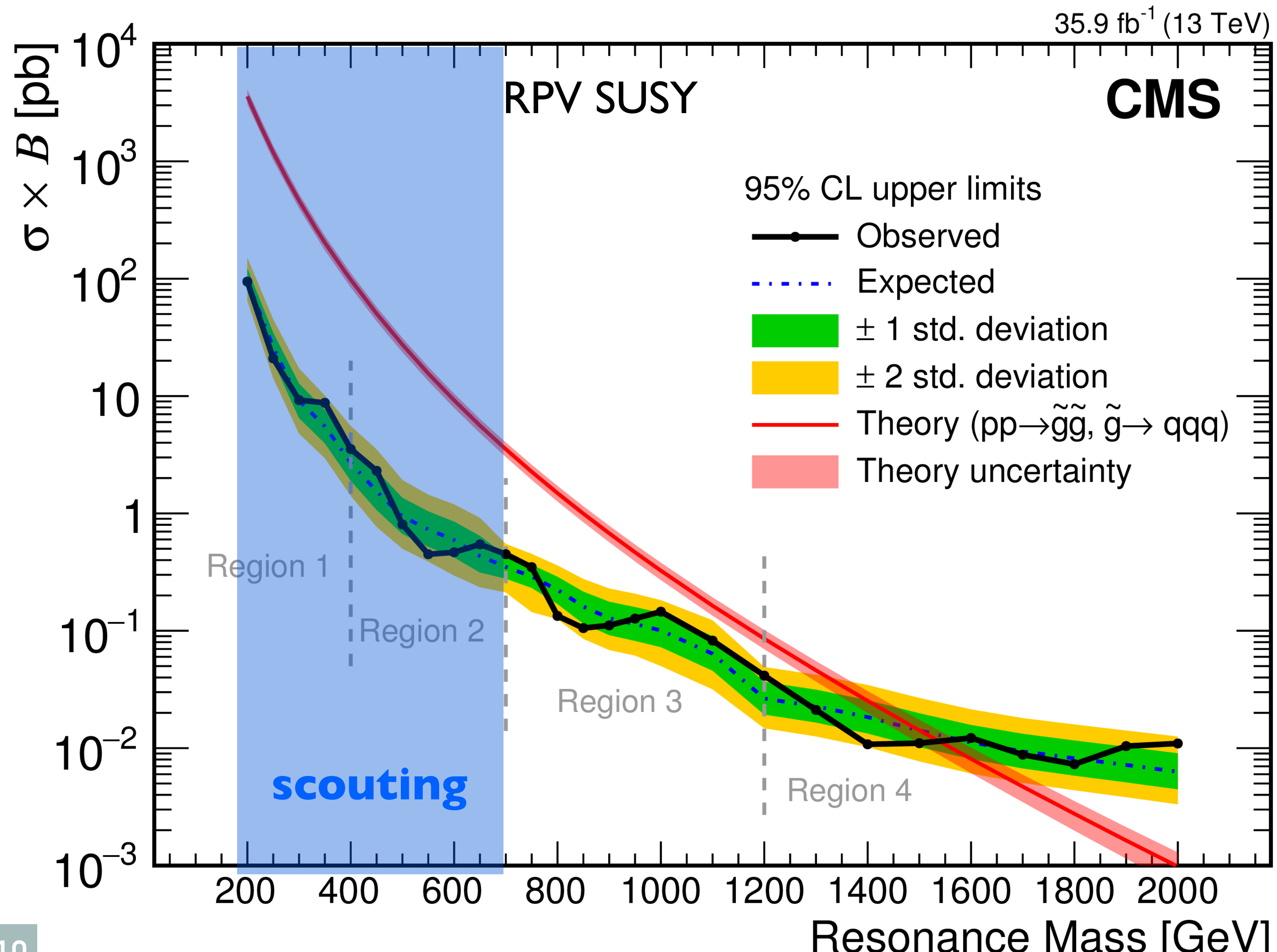


# OLD RESULT OF MULTIJET RESONANCE

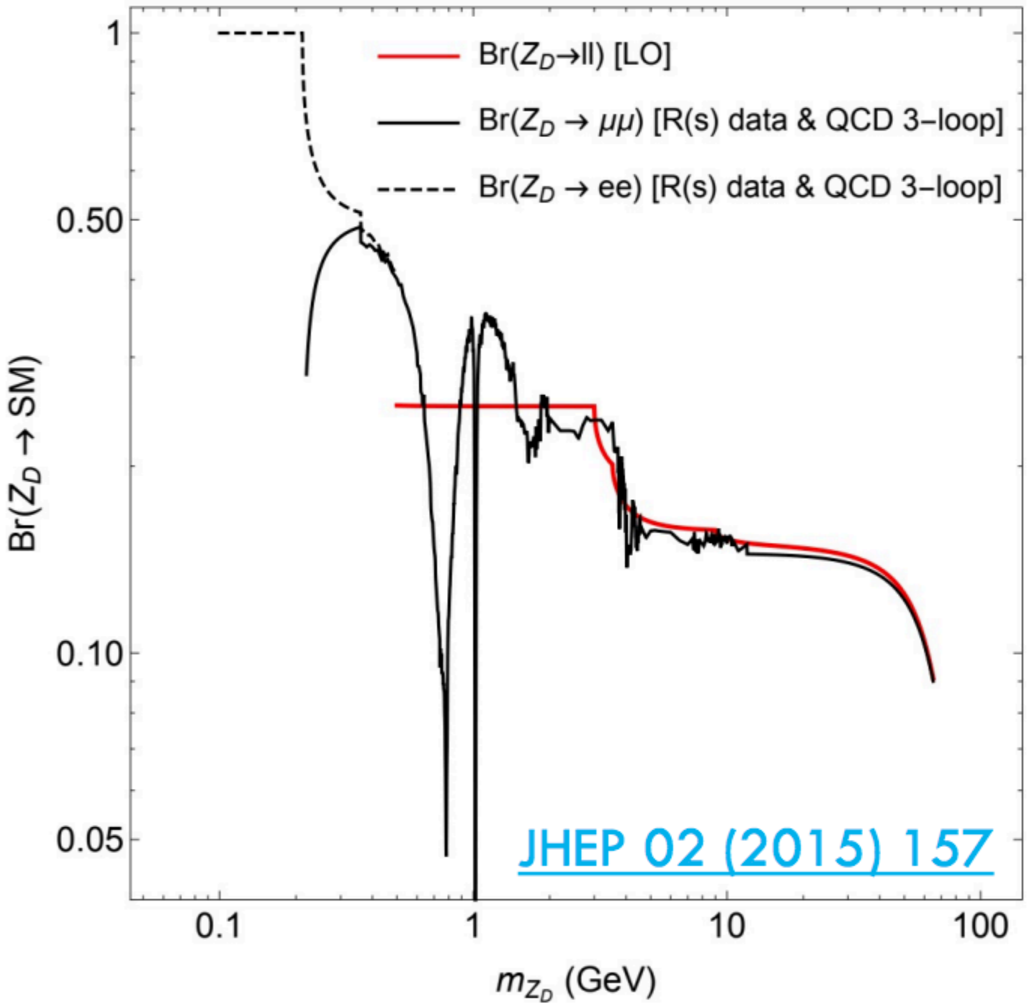



Top quark reconstructed in scouting data, in region 1




particle flow scouting used in the mass range $200 < M_{jjj} < 700$ GeV

❖ Sizeable **decay branching fraction of $Z_D \rightarrow \mu\mu$**




❖ If $\varepsilon \lesssim 10^{-4}$, then $Z_D$ will be **long-lived**