GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

III. Physikalisches Institut A | RWTH AACHEN UNIVERSITY

SEARCHES FOR NEW PHYSICS WITH LOW MASS MEDIATORS IN CMS

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On behalf of the CMS Collaboration

ICHEP 2022, Bologna

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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**

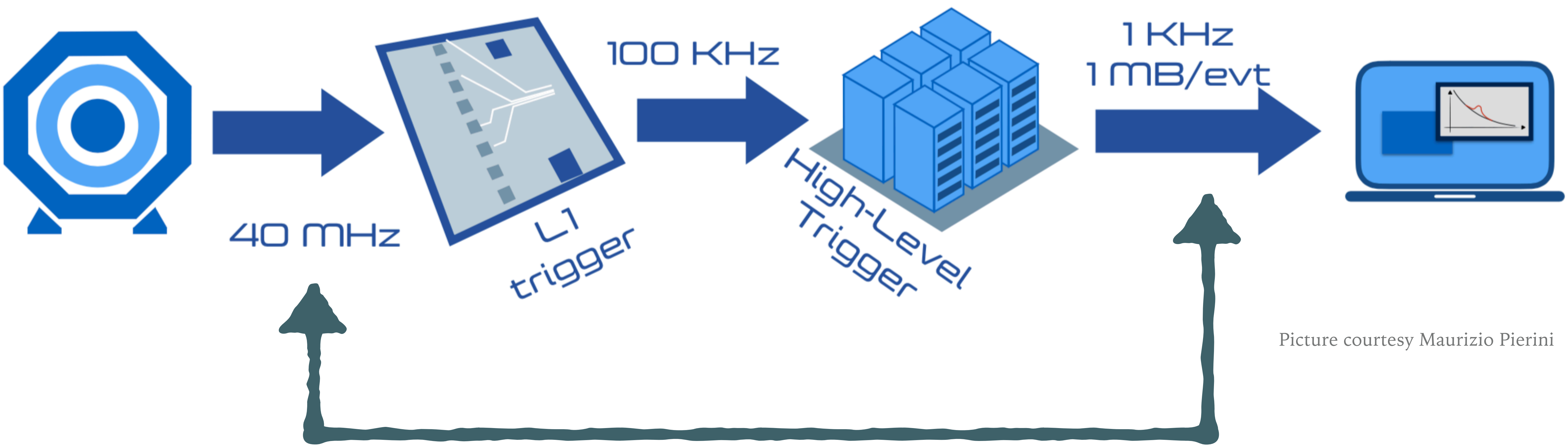
TRIGGER STRATEGY AND SOME CONSEQUENCES

Huge amount of data coming in from LHC. Impossible to store all of them.

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

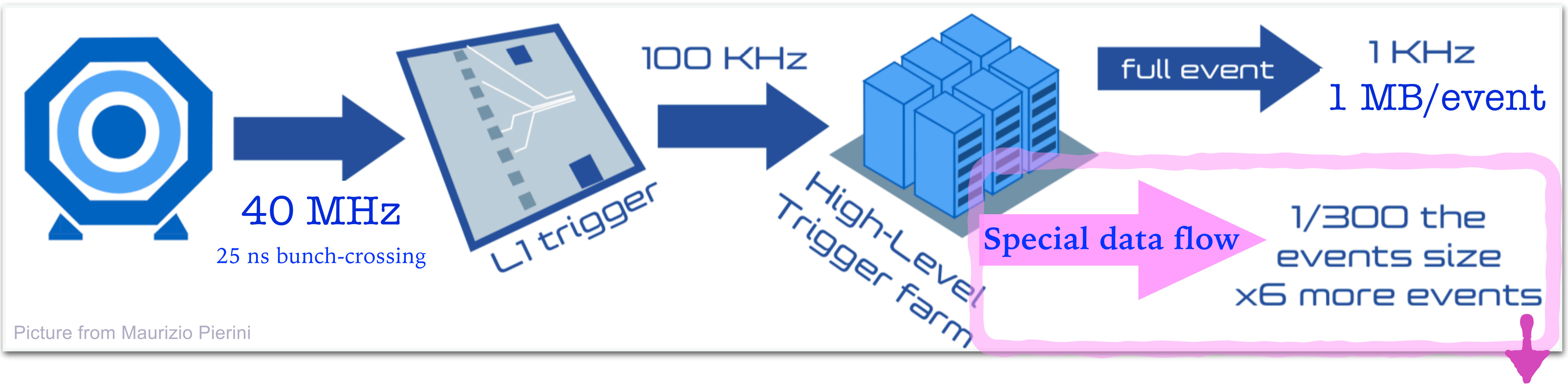
Huge reduction in rate. Are we losing interesting (new physics)events?

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**!



Picture from Maurizio Pierini

Trigger Bandwidth = Event Rate × Event Size

~1 kHz × ~1 MB

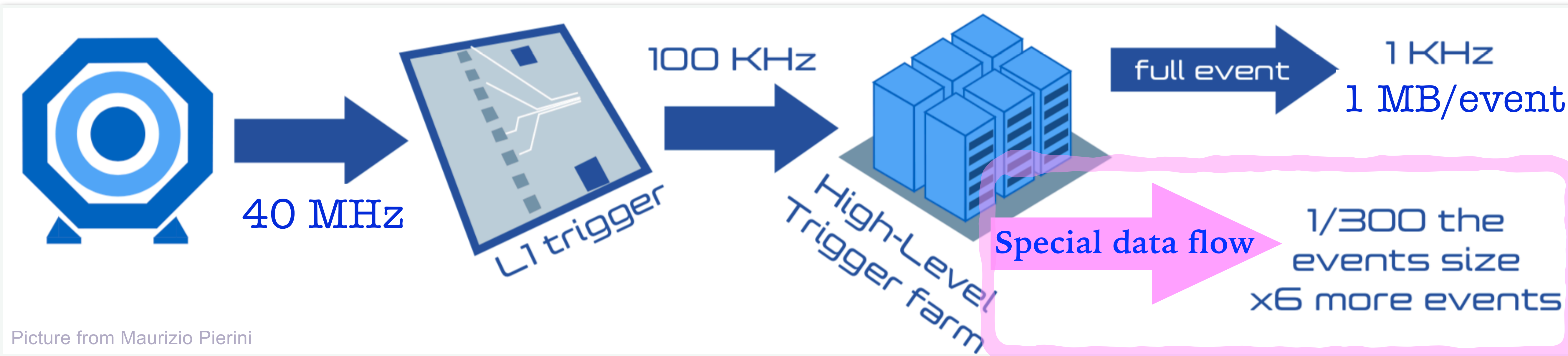
If we want to increase rate, then we need to decrease event size

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



Picture from Maurizio Pierini

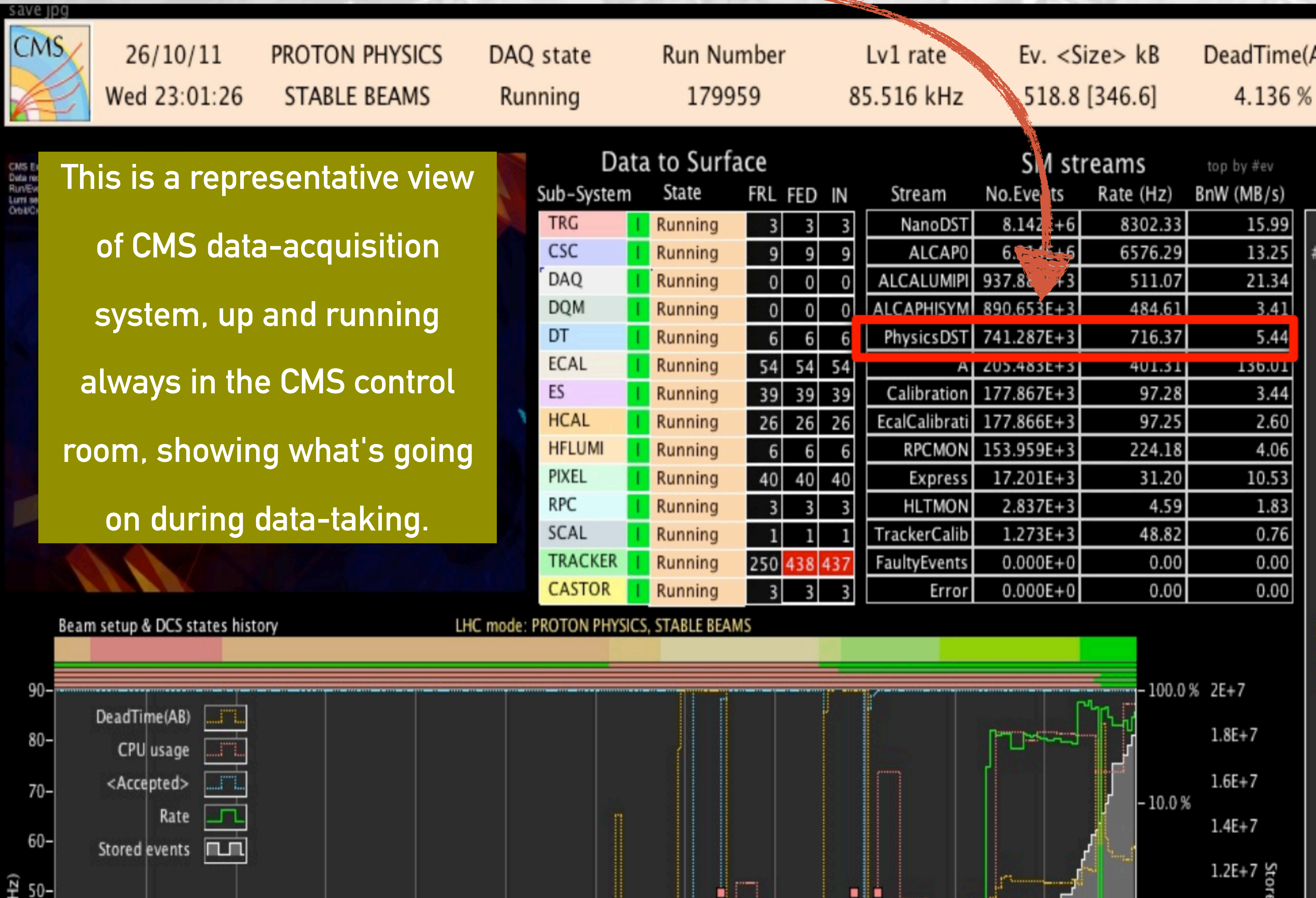
This Special data flow is called Data Scouting in **CMS**

This novel trigger strategy is being used in CMS since 2011

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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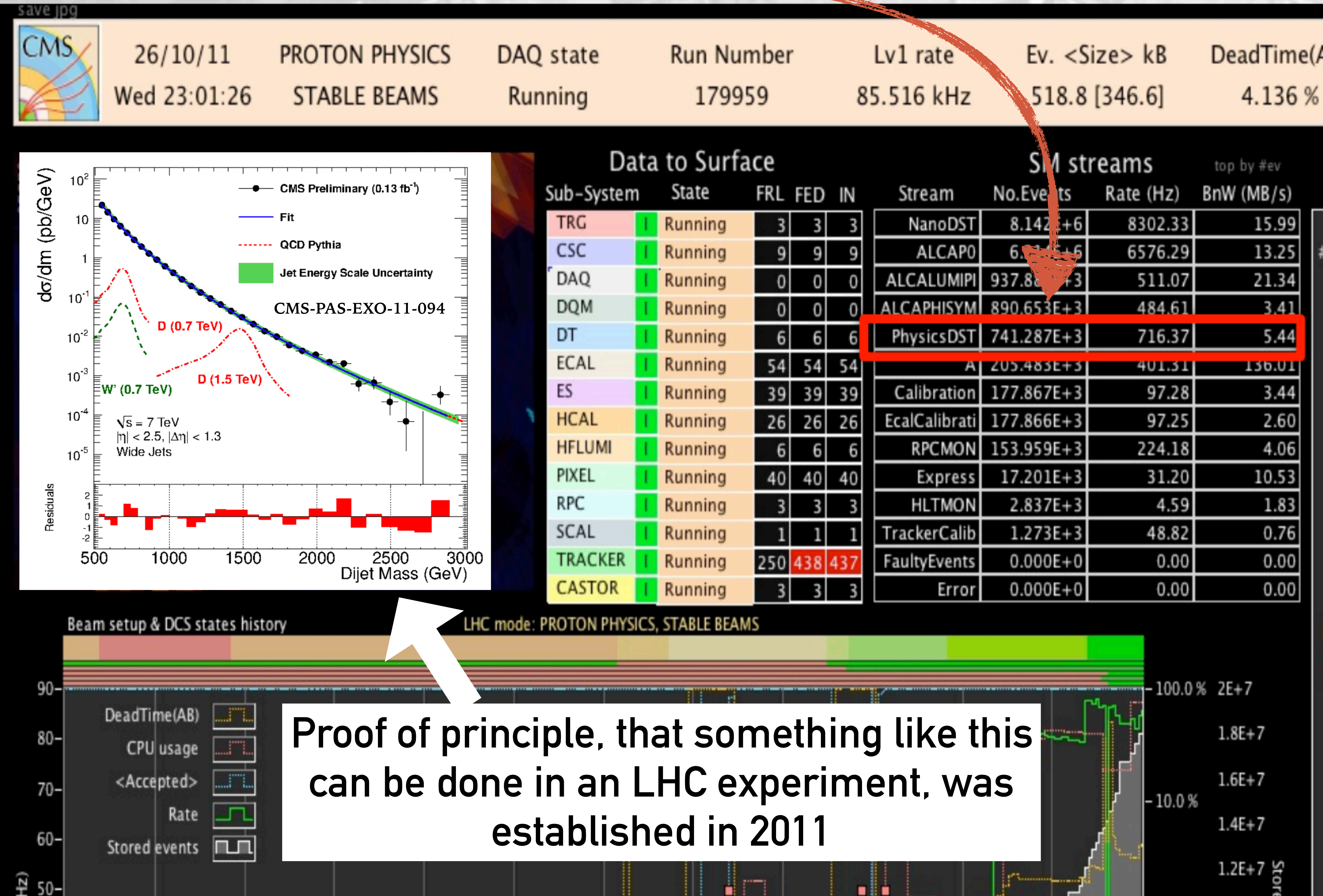


Proof of principle, that something like this can be done in an LHC experiment, was established in 2011

DIJET SEARCH WITH 2012 SCOUTING DATA

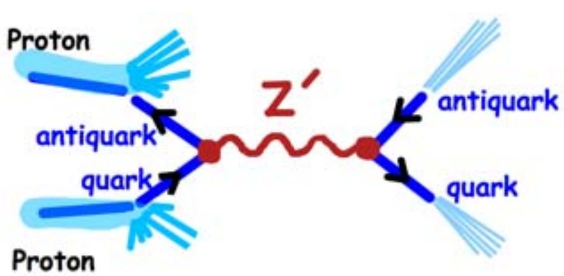
Phys. Rev. Lett. 117 (2016) 031802

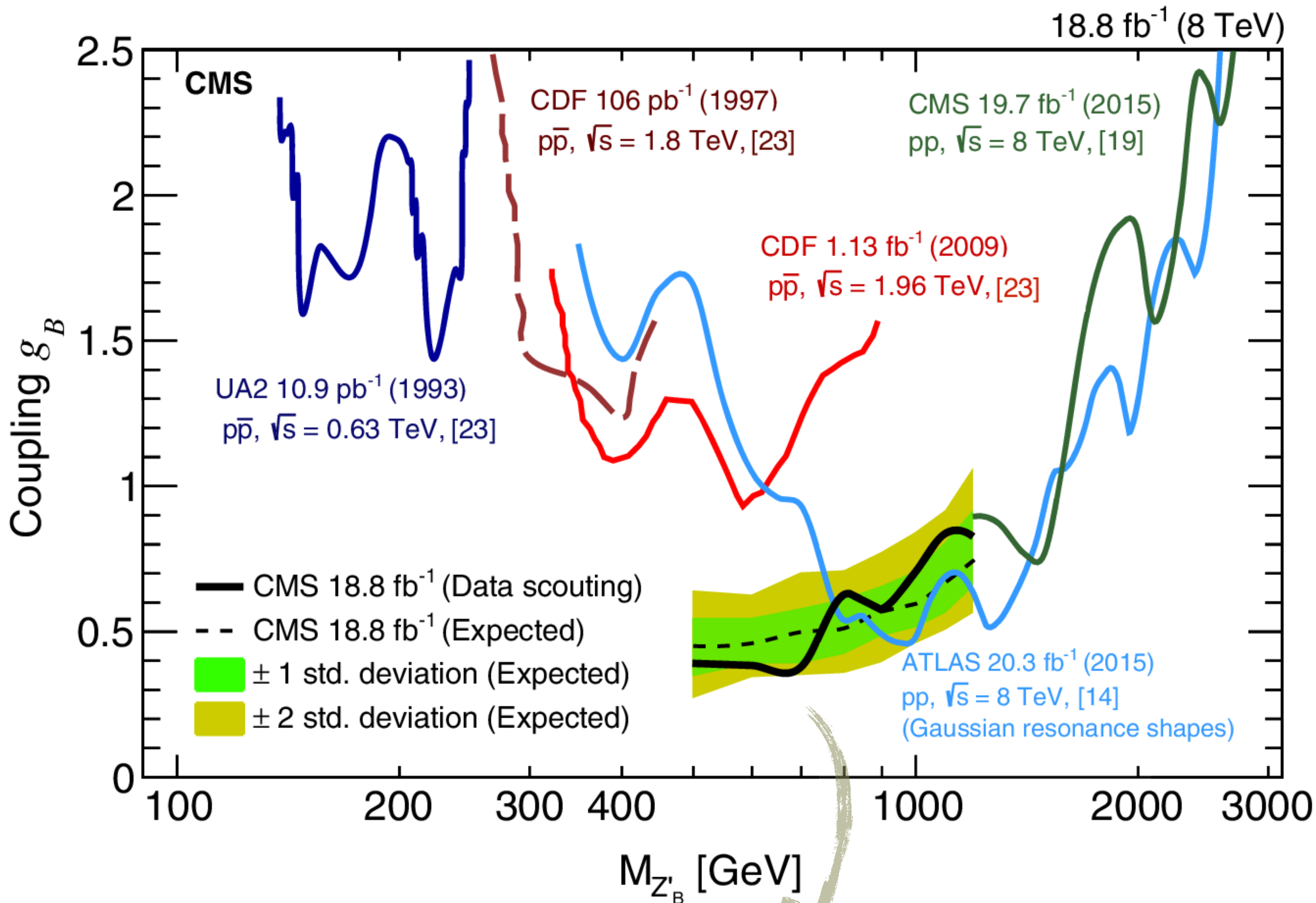
First "Trigger-Level Analysis" result published by an LHC experiment

- 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

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



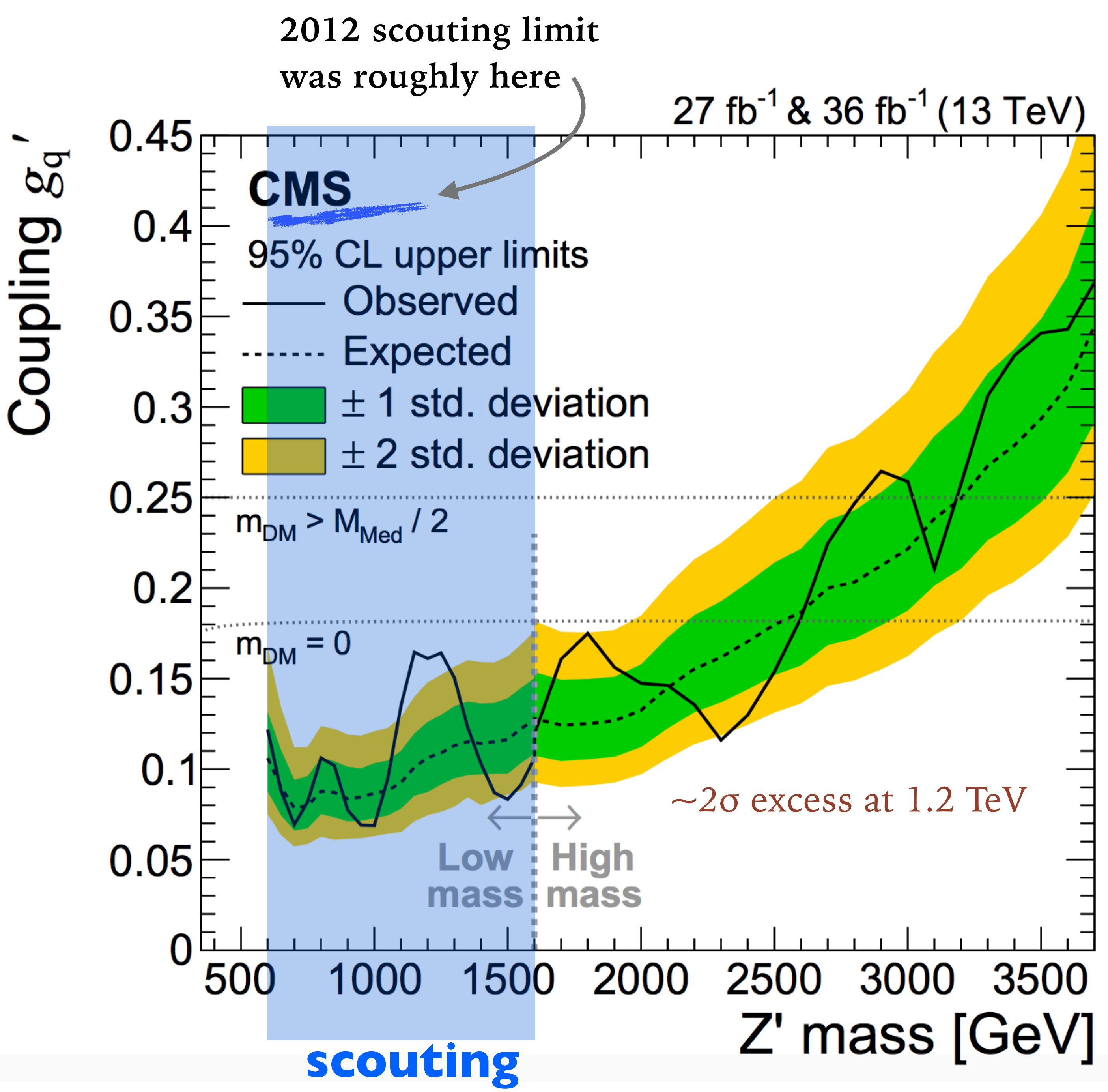


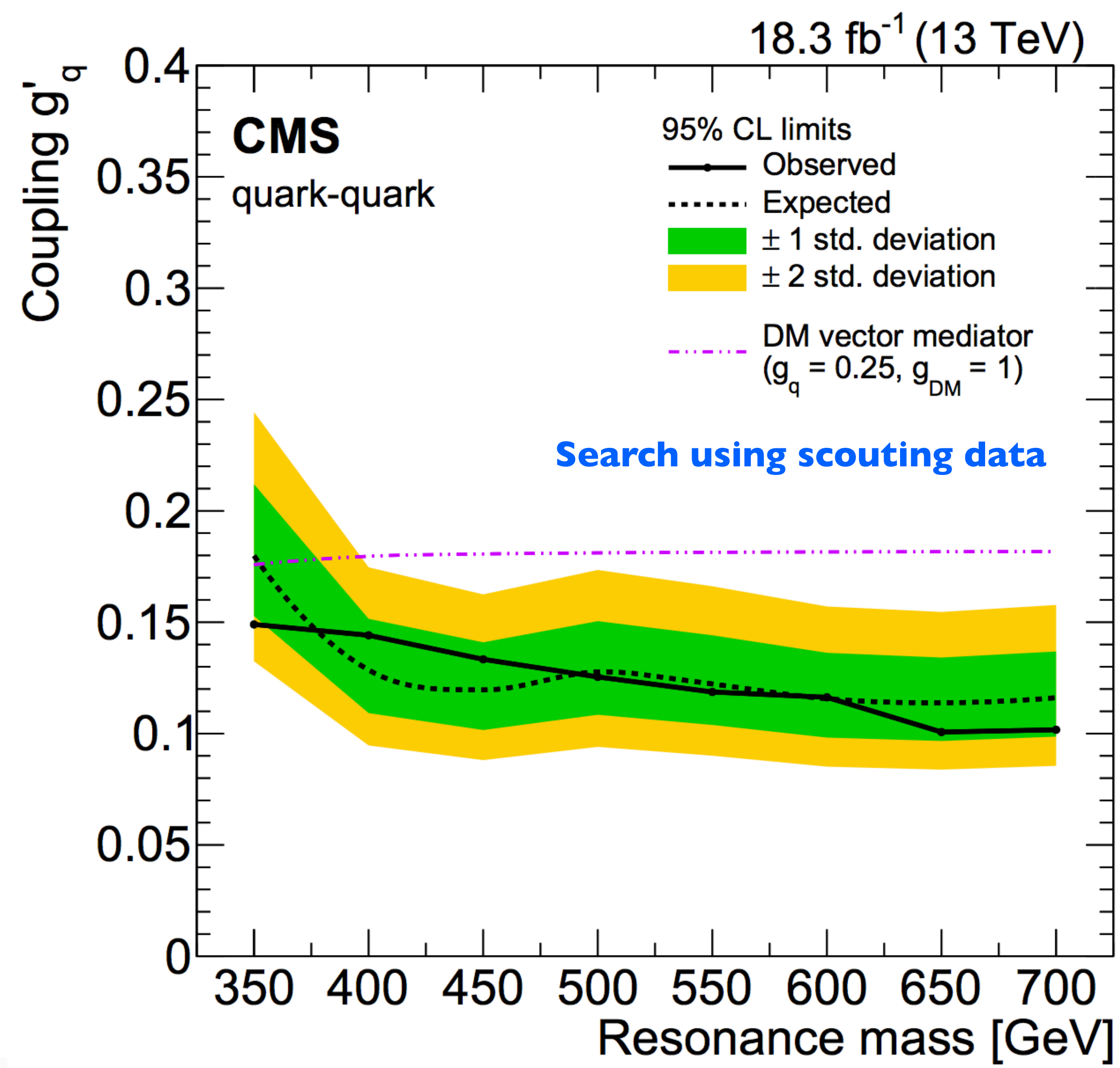
Using scouting, most stringent limits (at that time) in the range 500 - 800 GeV

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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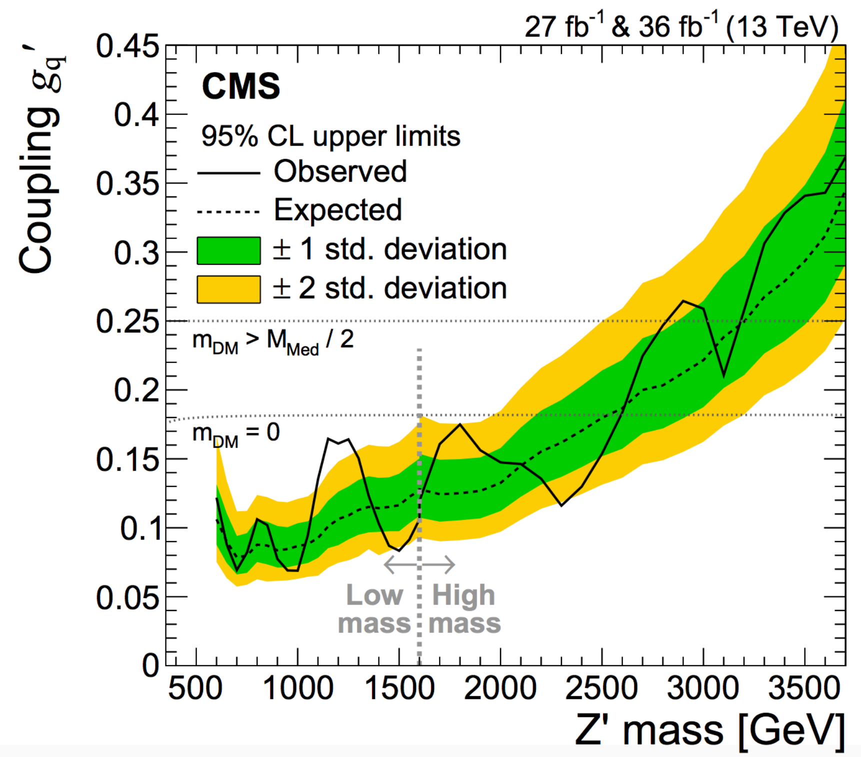
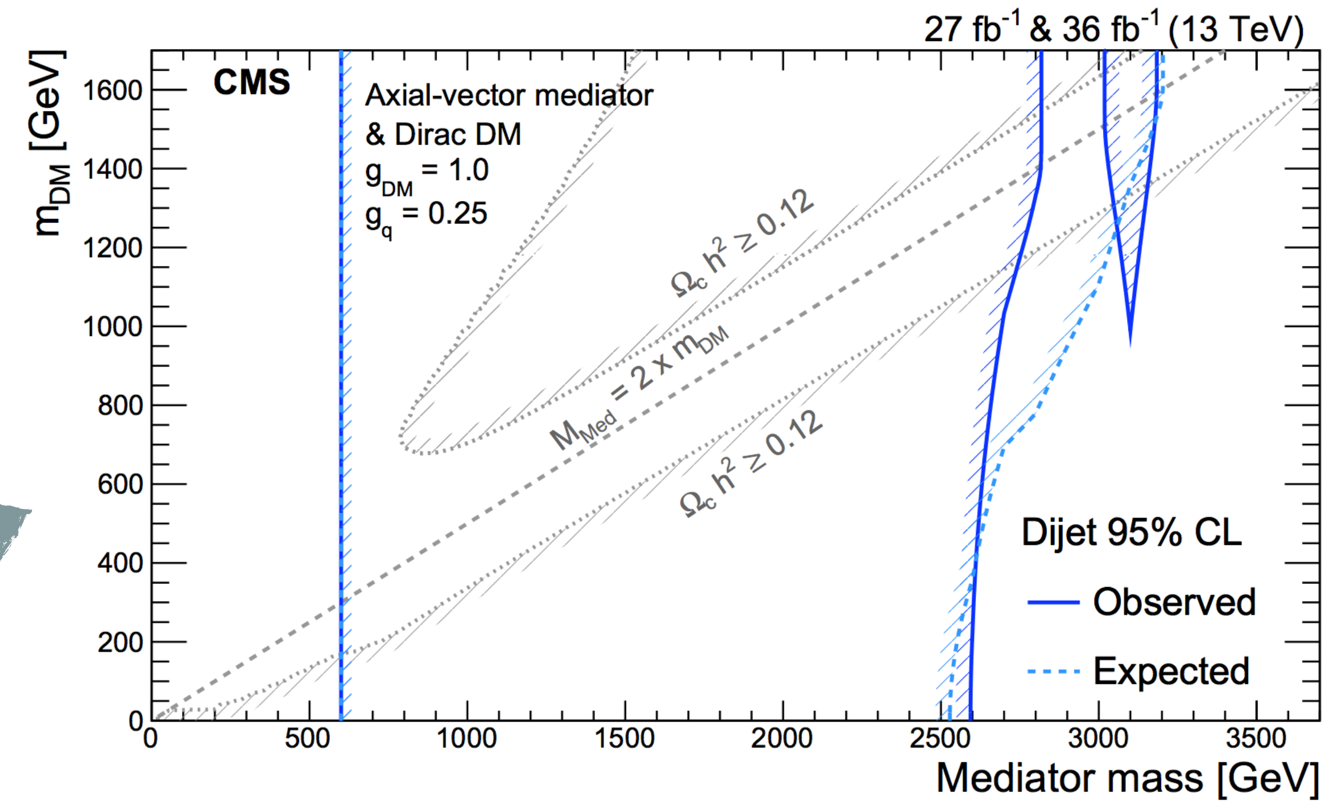
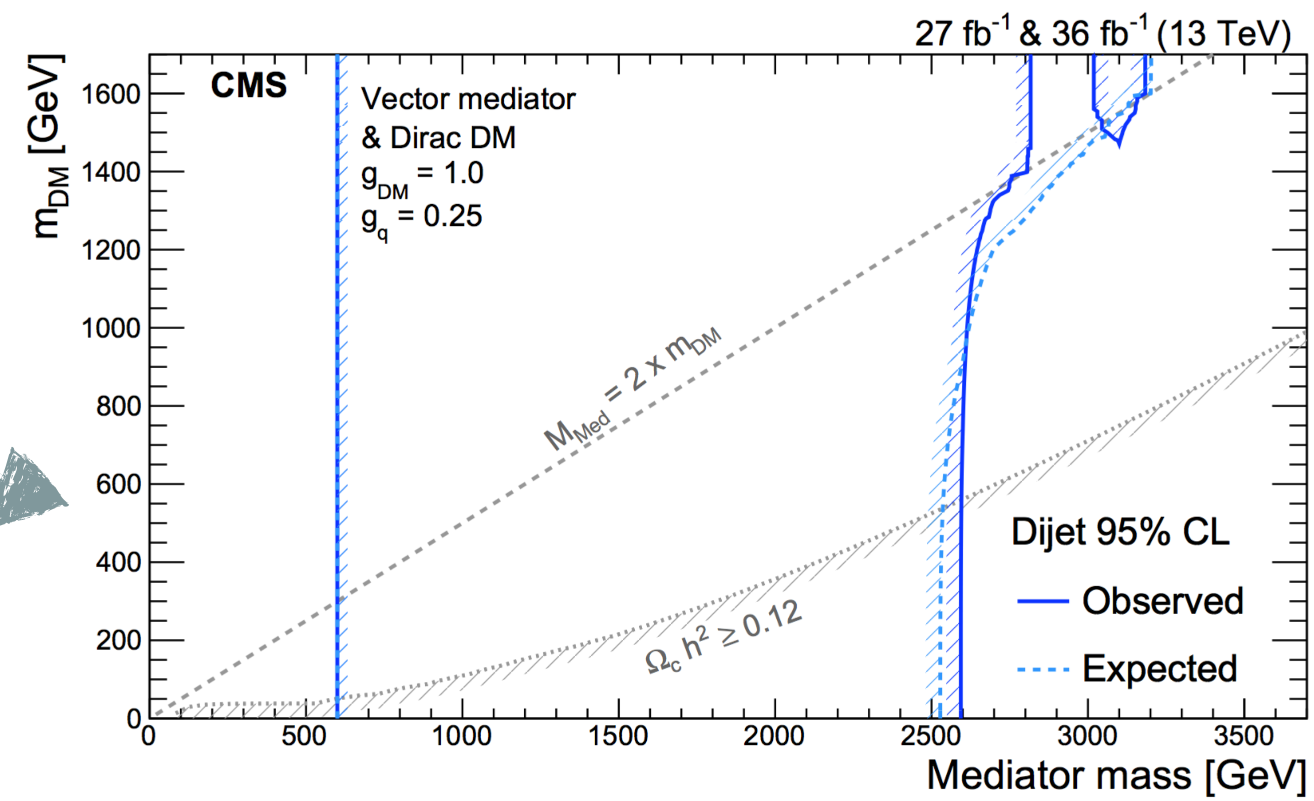


Axial vector

Limits translated to dark matter mass vs mediator mass plane

Vector





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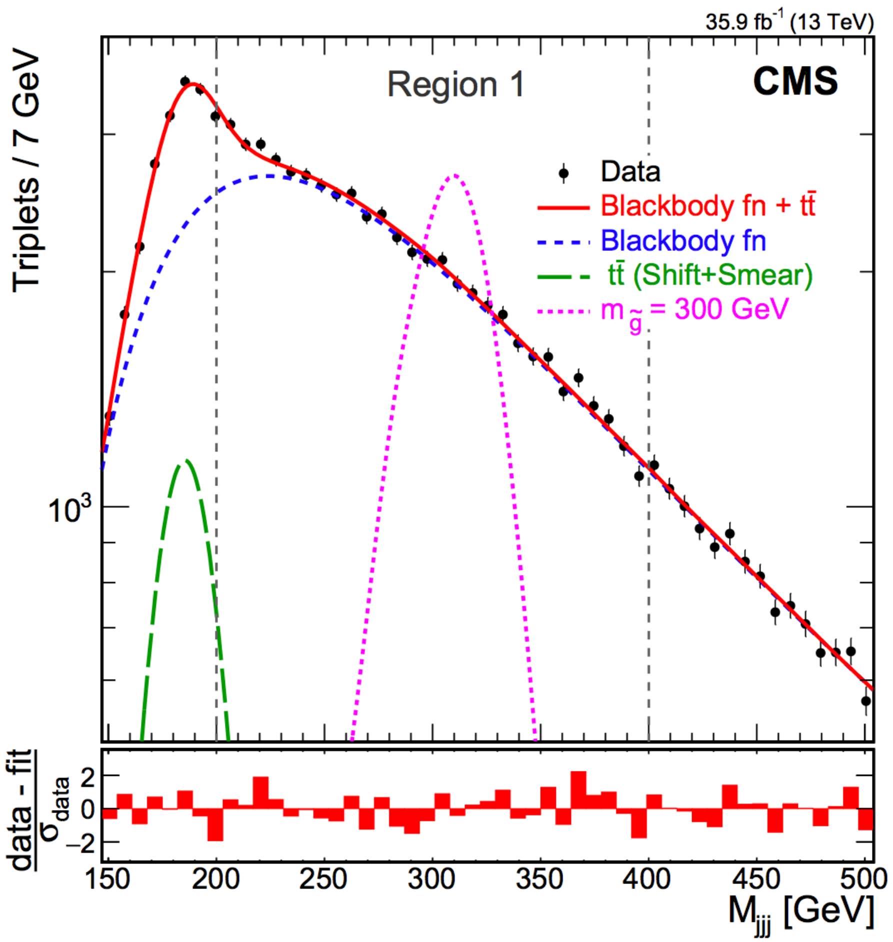
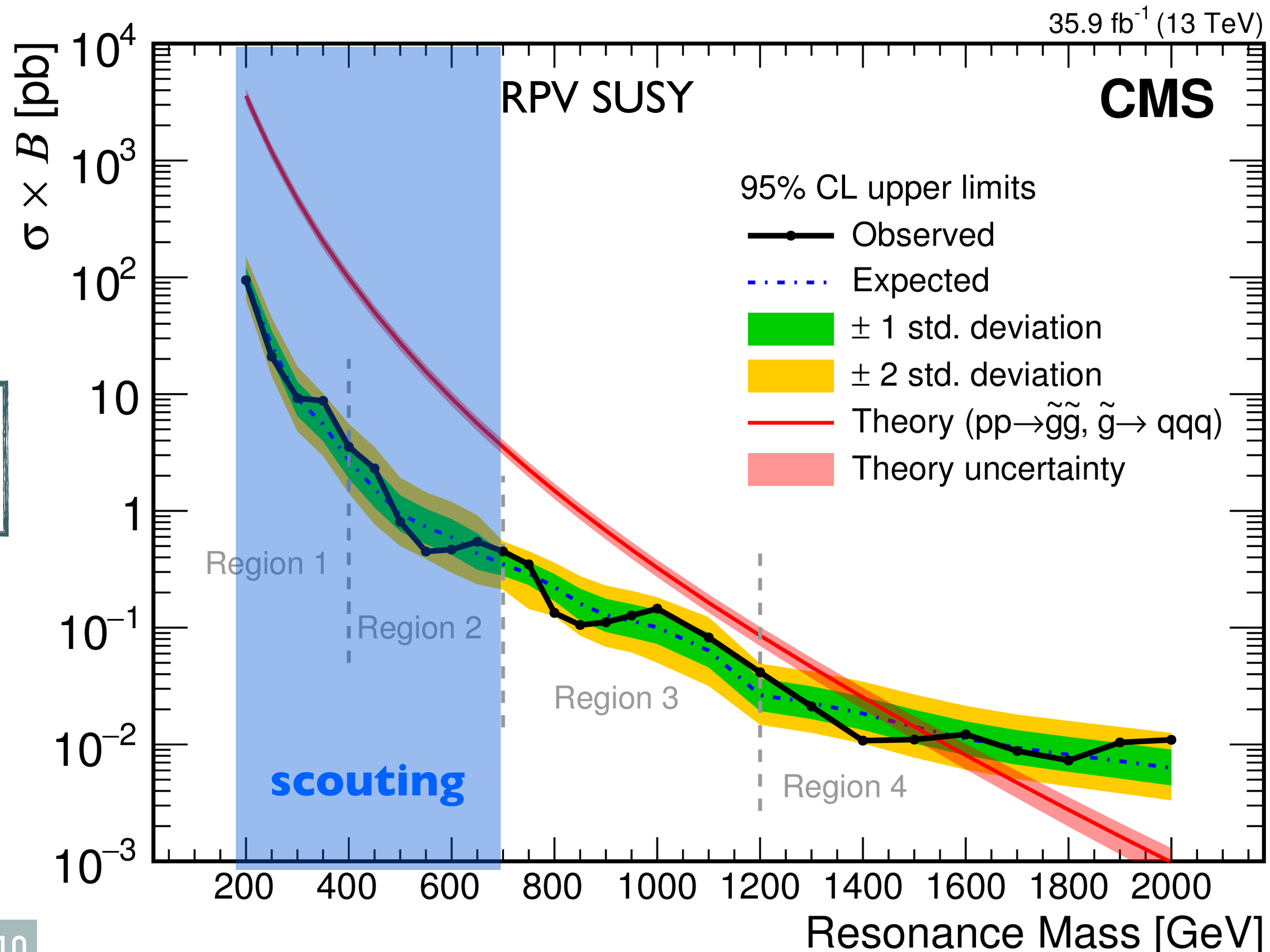
SEARCH FOR PAIR-PRODUCED 3-JET RESONANCE



Top quark reconstructed in scouting data, in region 1

Particle flow (PF) scouting

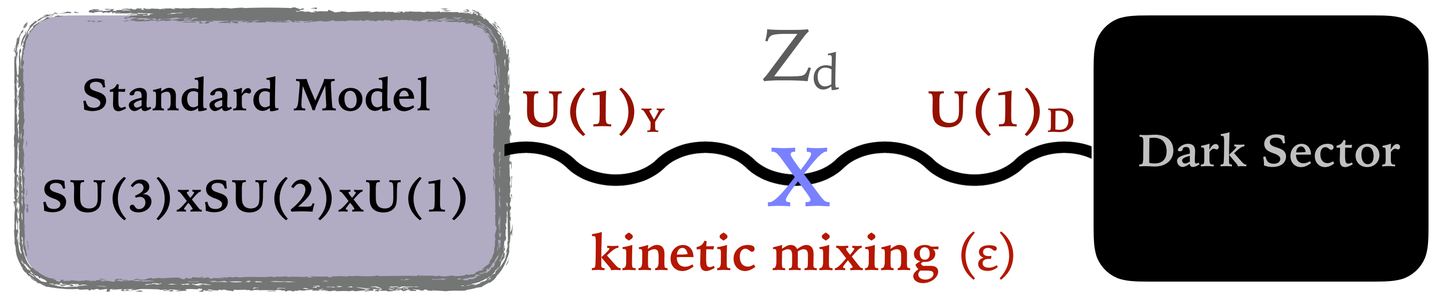
- Higher quality objects (example: **PF Jet** vs **Calo Jet**)
- All PF candidates saved in PF scouting, which leads to bigger event size
  - More information allows to do more complicated searches
- Lower rate is allowed to compensate for higher event-size



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

NON HADRONIC SCOUTING CHASING THE LOW P_T MUONS

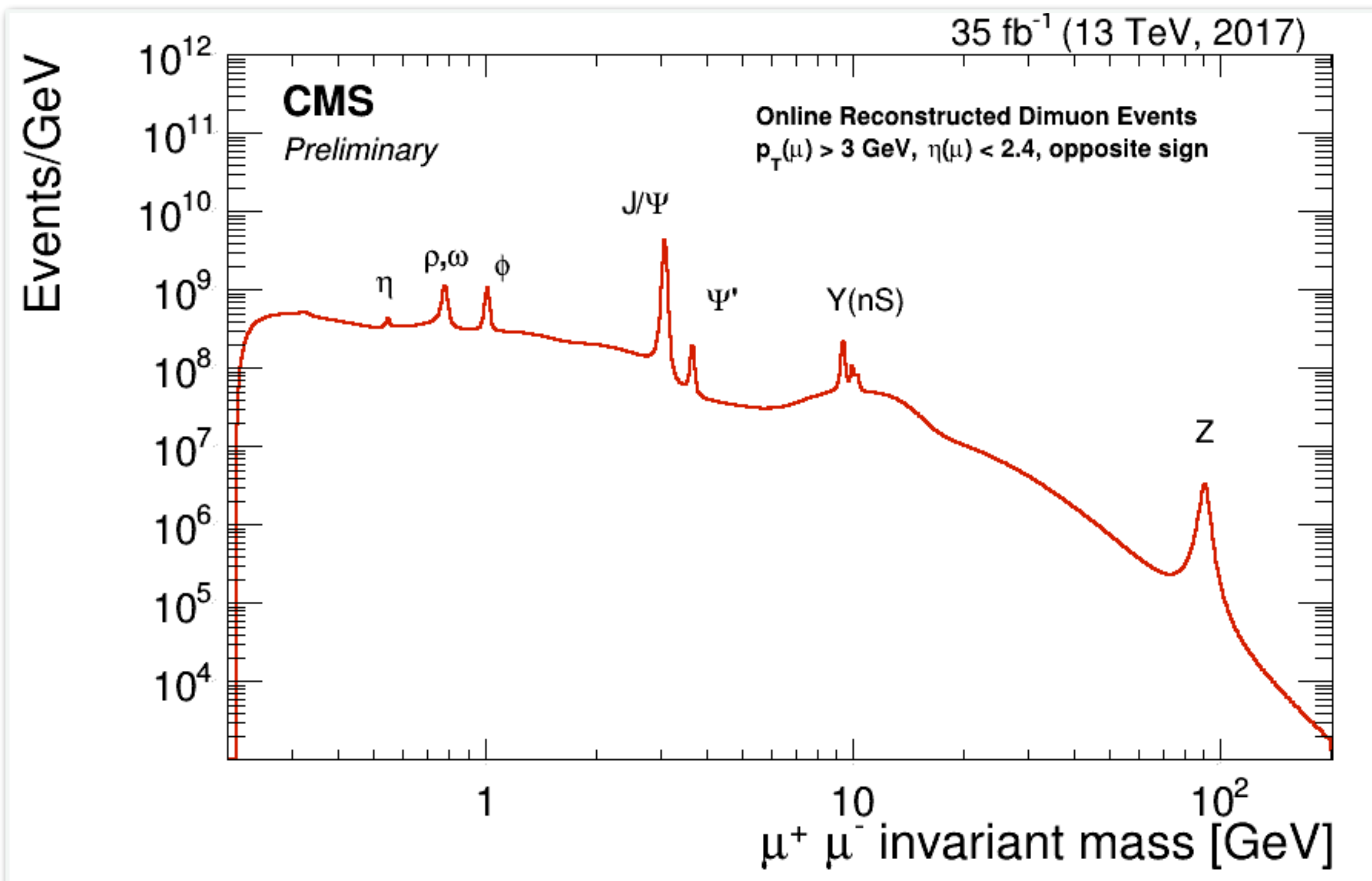
In 2017, CMS deployed a new, improved, dedicated dimuon scouting trigger for dark-photon searches.



Dark photon in Hidden sector model

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

No additional offline identification cuts on muon



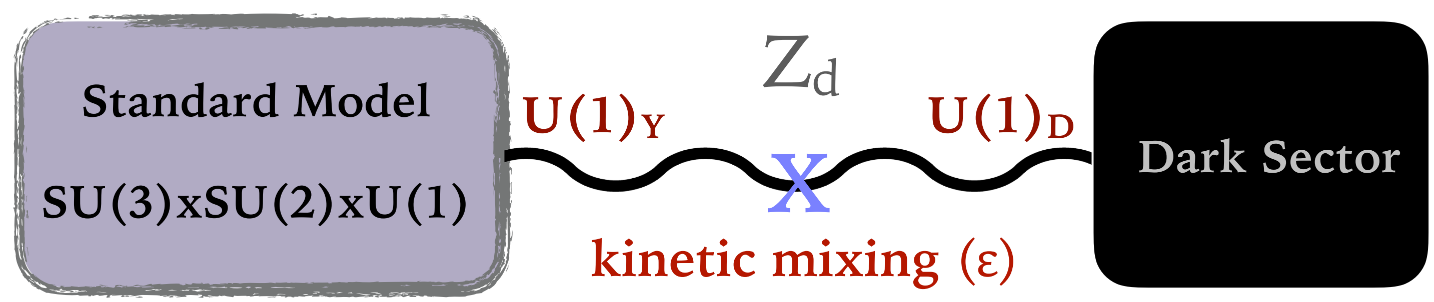
https://twiki.cern.ch/twiki/bin/view/CMSPublic/HLTDiMuon2017and2018

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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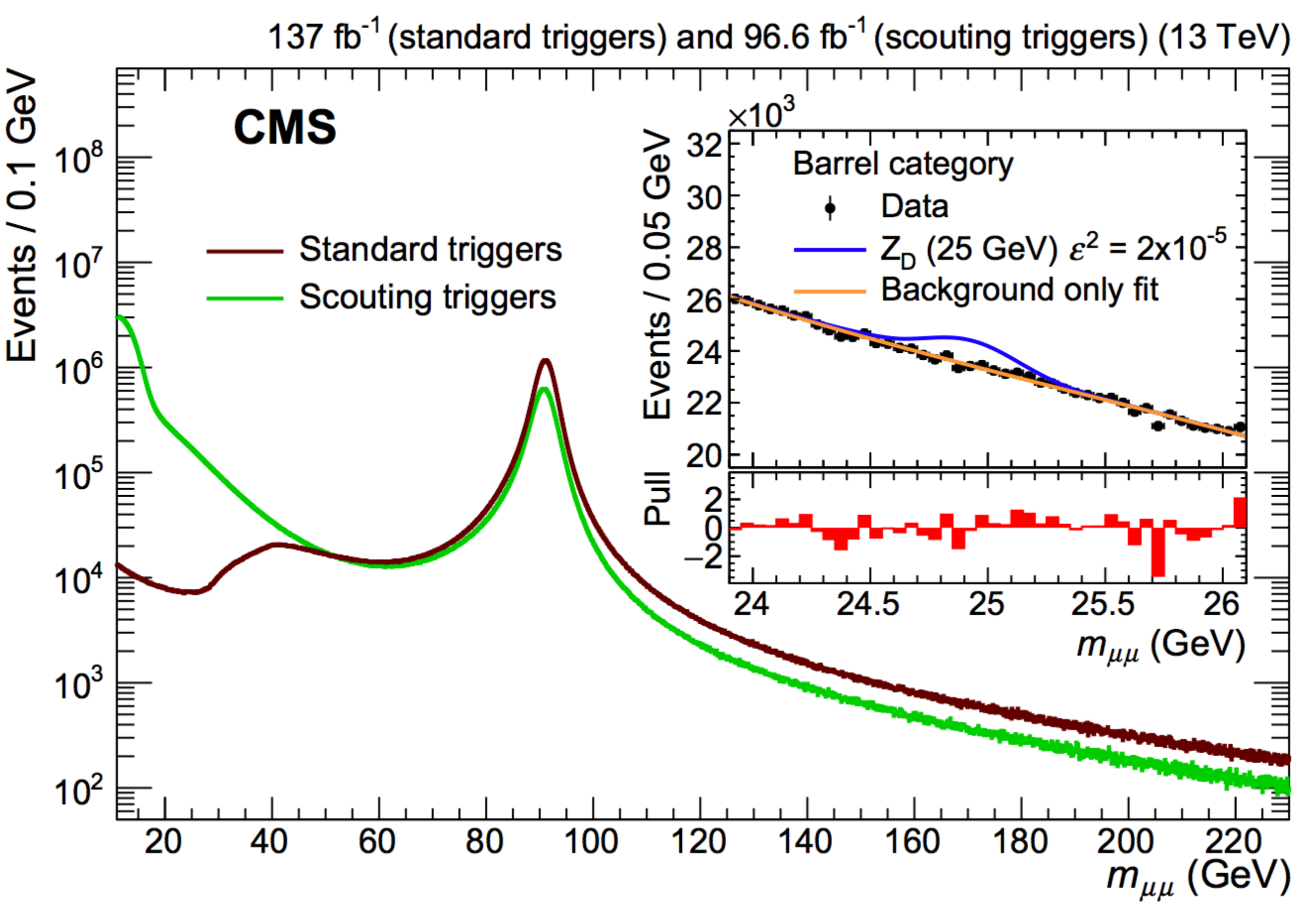
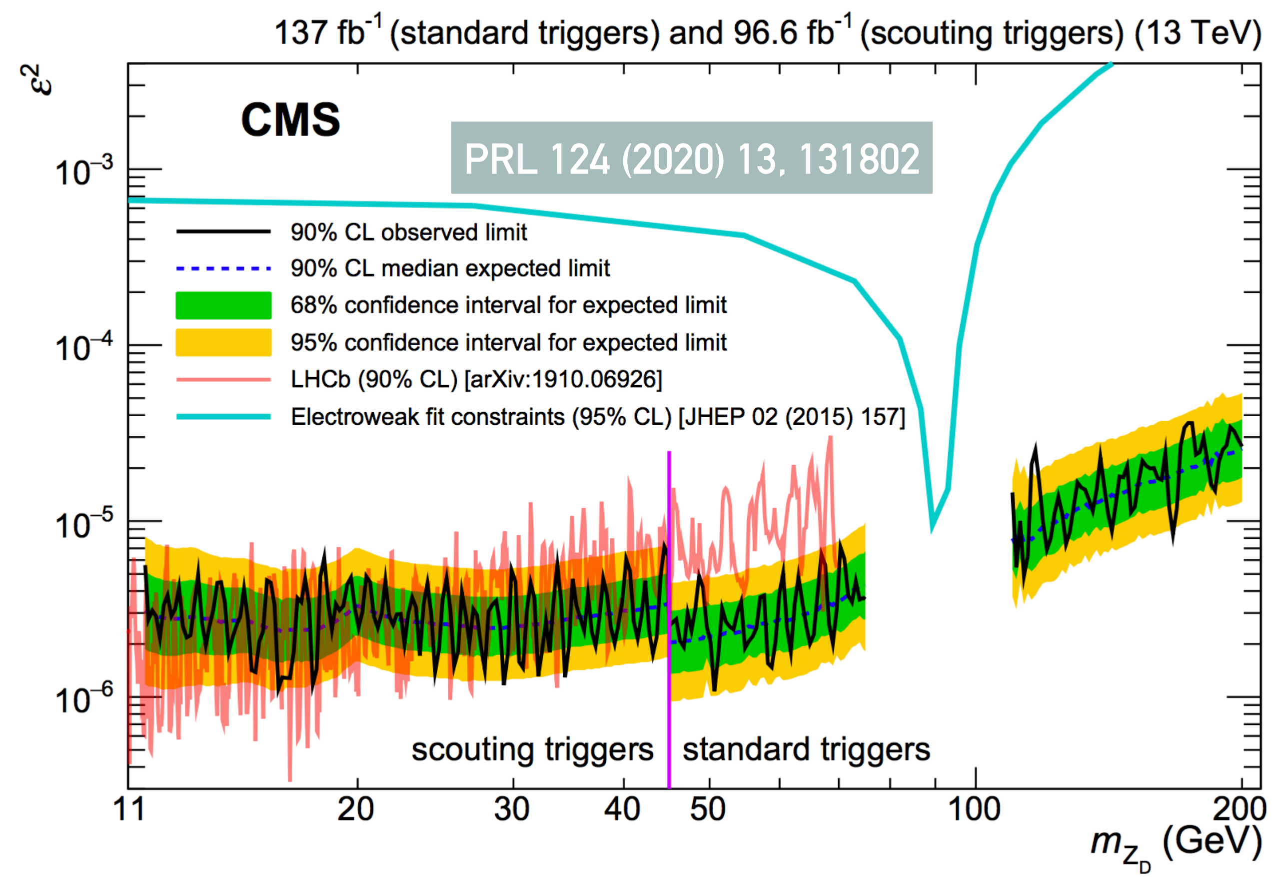




PRL 124 (2020) 13, 131802

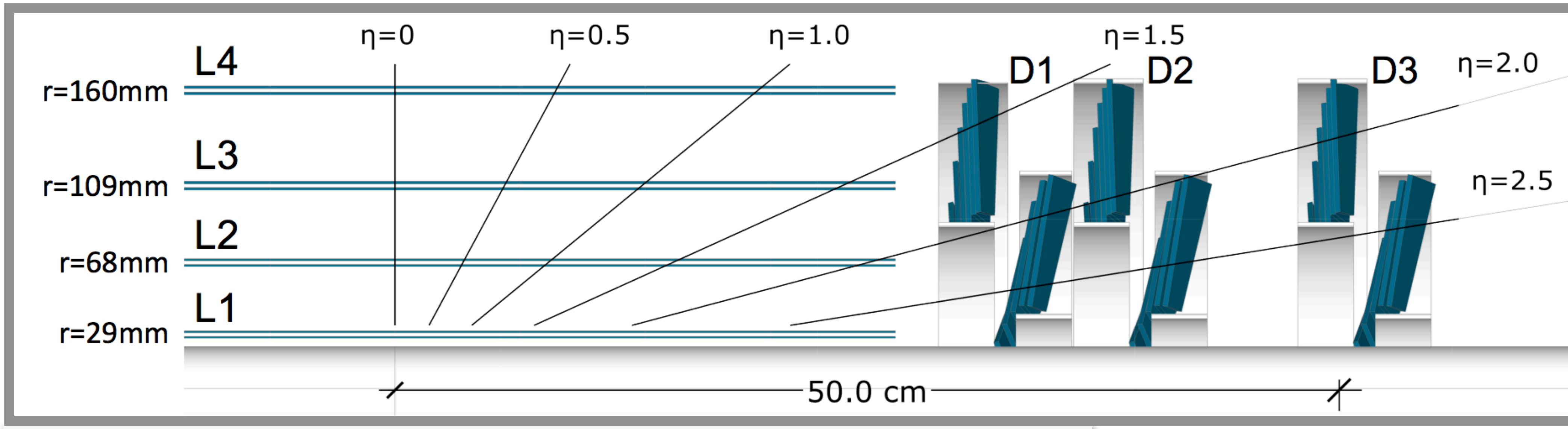
NON HADRONIC SCOUTING DISPLACED DIMUON SEARCH

JHEP 04 (2022) 062

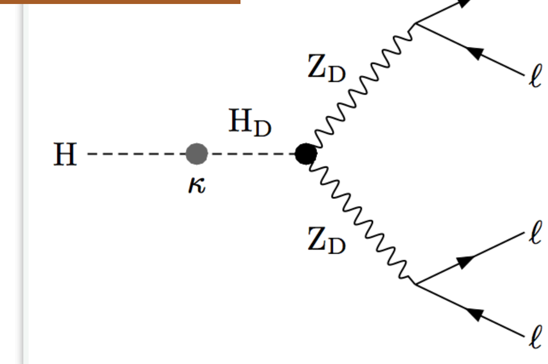
First CMS search for long-lived BSM signatures using scouting data

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

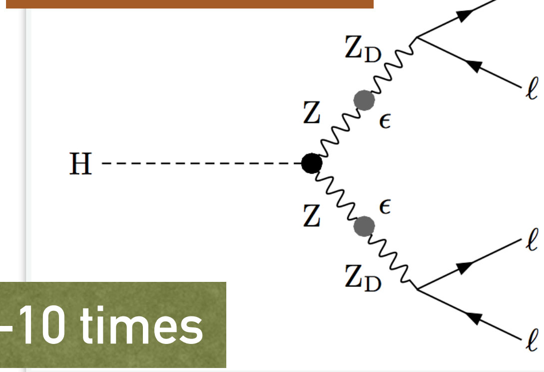
Range of accessible transverse displacement: $0 \leq l_{xy} < 109$ mm

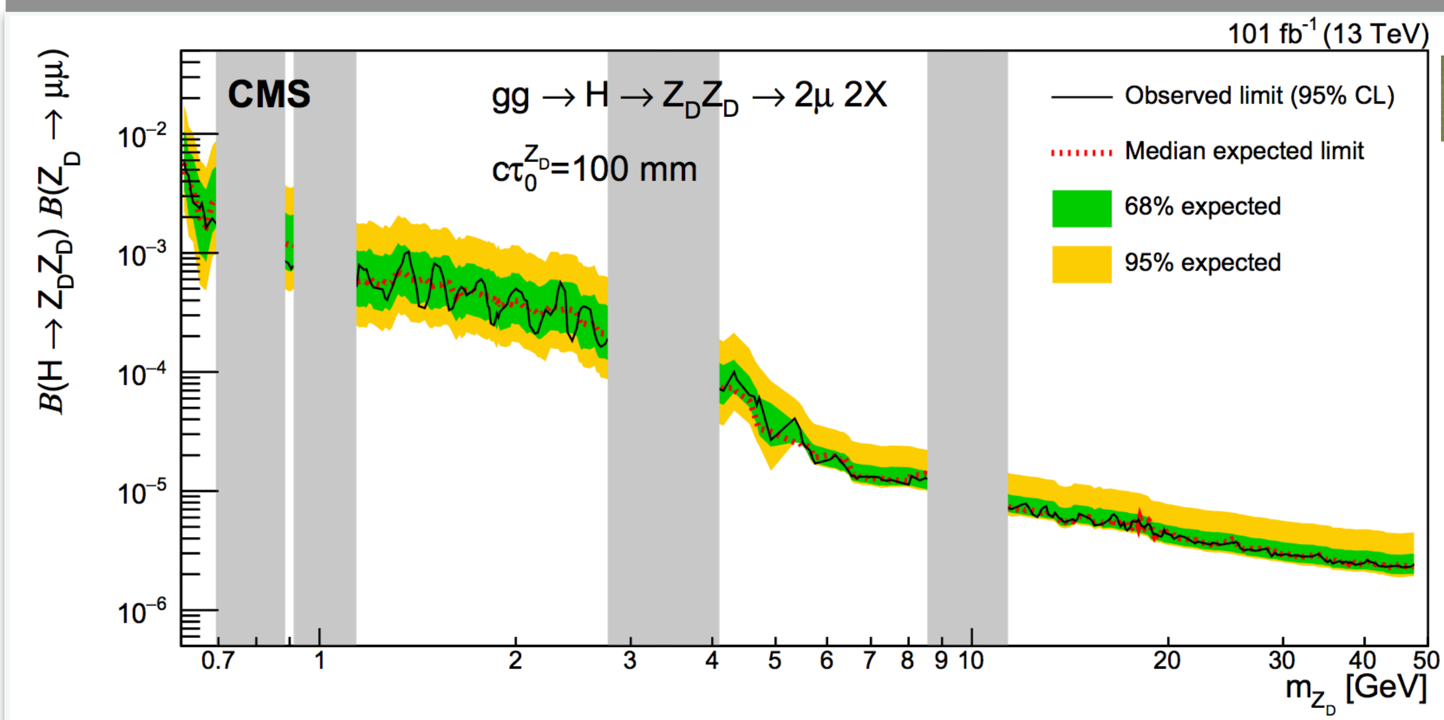


Higgs portal

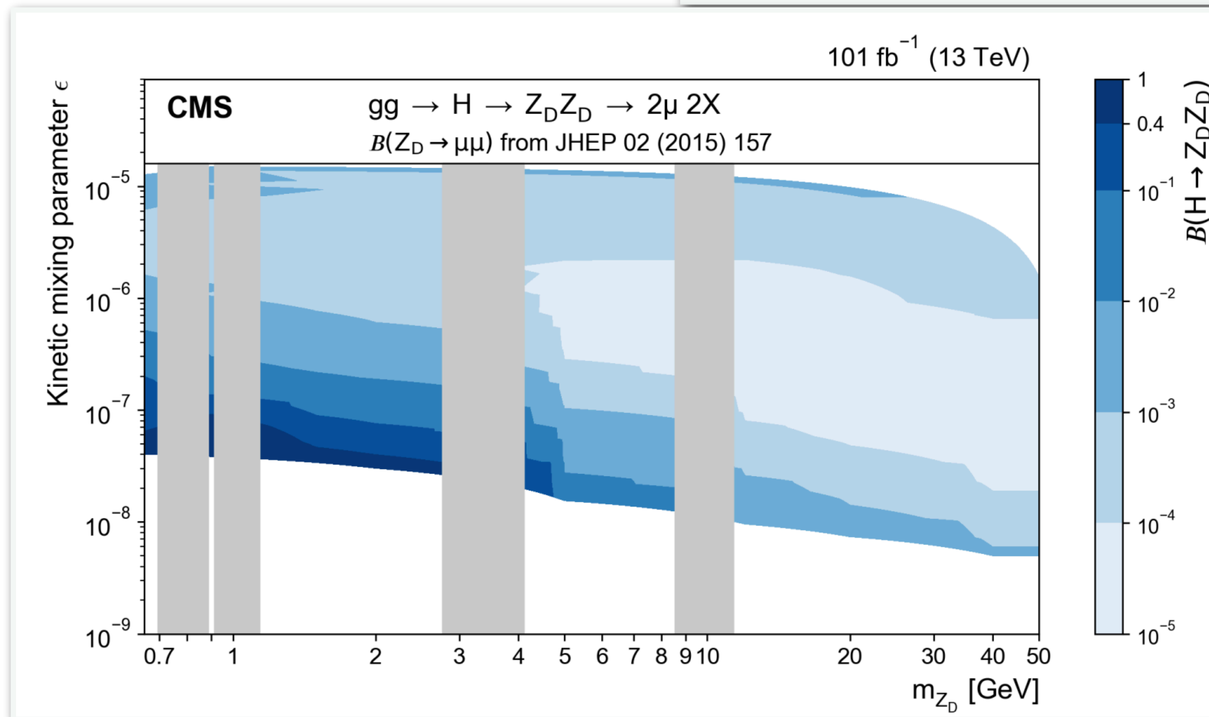


Hypercharge portal





Improved previous limits by 2-10 times



Probed very low masses, thanks to scouting triggers!

Bonus: Exclusion limits on the branching fraction $B(B \to \varphi X) * B(\varphi \to \mu\mu)$ as a function of the signal mass hypothesis for a given lifetime. Stringent limits at low mass. Competitive with LHCb. (Plot in backup)

SUMMARY AND OUTLOOK

SCOUTING STRATEGIES FOR RUN3 IS BEING FURTHER IMPROVED

- More rate budget allocated to scouting (30 kHz in Run3, compared to ~5 kHz in 2018).
  - Taking advantage of heterogeneous computing farm (speedup due to GPUs).
- Electron scouting newly added.
- Event content revisited and improved.

LEAVE NO STONE UNTURNED. DO THE BEST THAT CAN BE DONE WITH CMS.

AN EXCITING FUTURE AWAITS...

MORE SEARCHES WITH SCOUTING DATA TO COME.

Link to CMS EXO public results

EXTRA SLIDES

Figure 1: Calo Scouting. Event size ≈1.5 kB

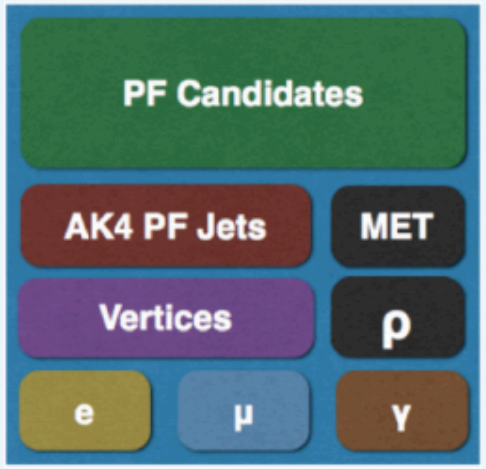
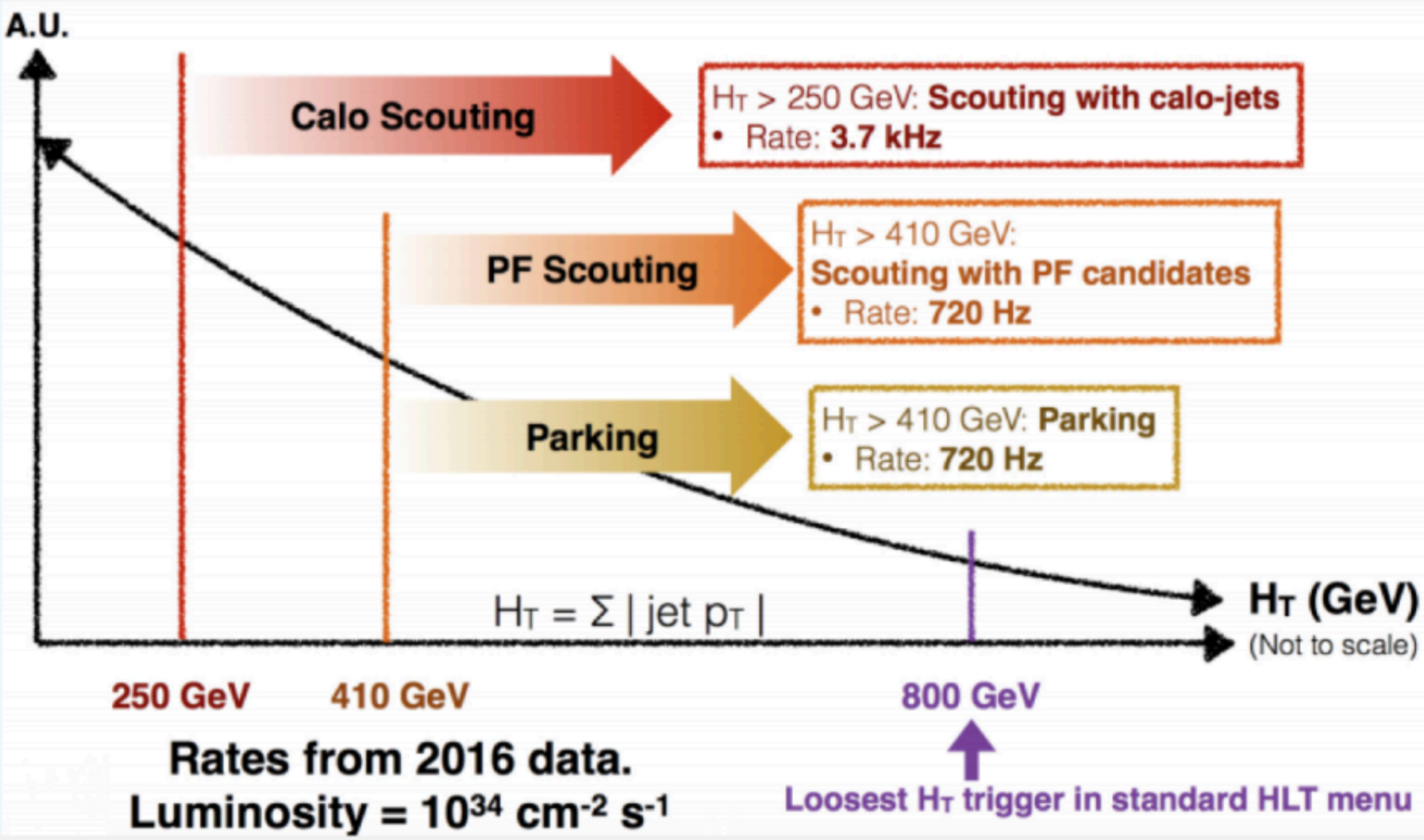
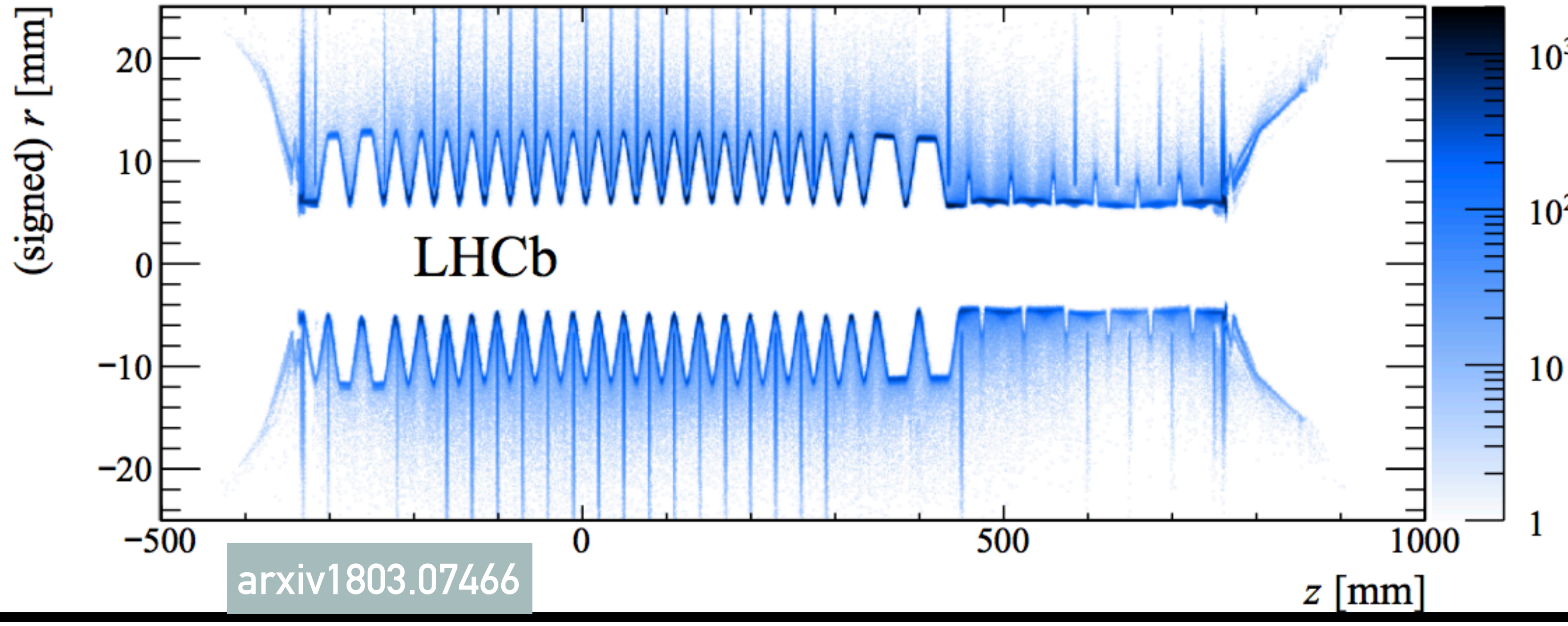


Figure 2: PF Scouting. Event size ≈10 kB



LONG-LIVED DARK PHOTON SEARCH (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

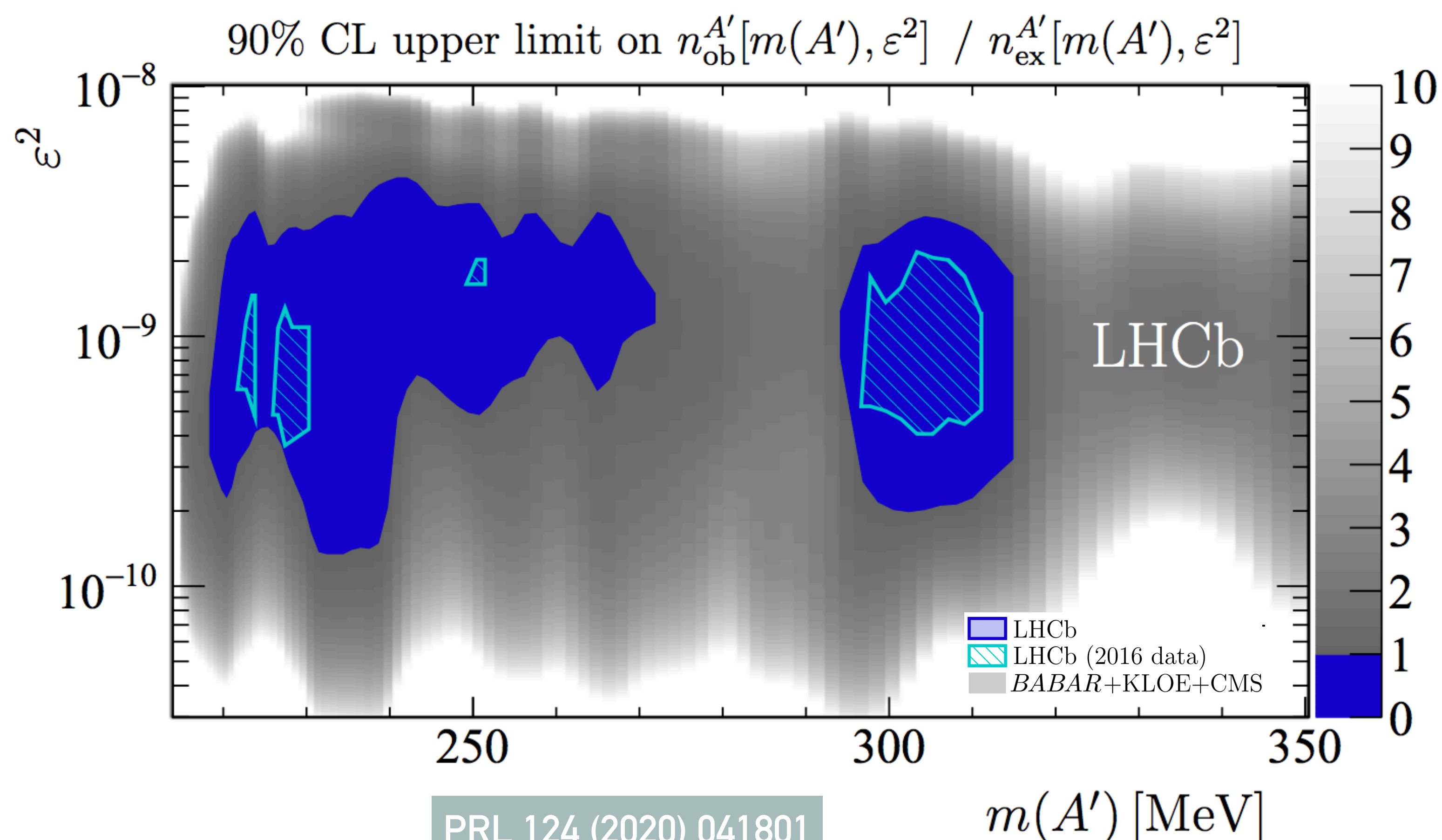


arxiv1803.07466

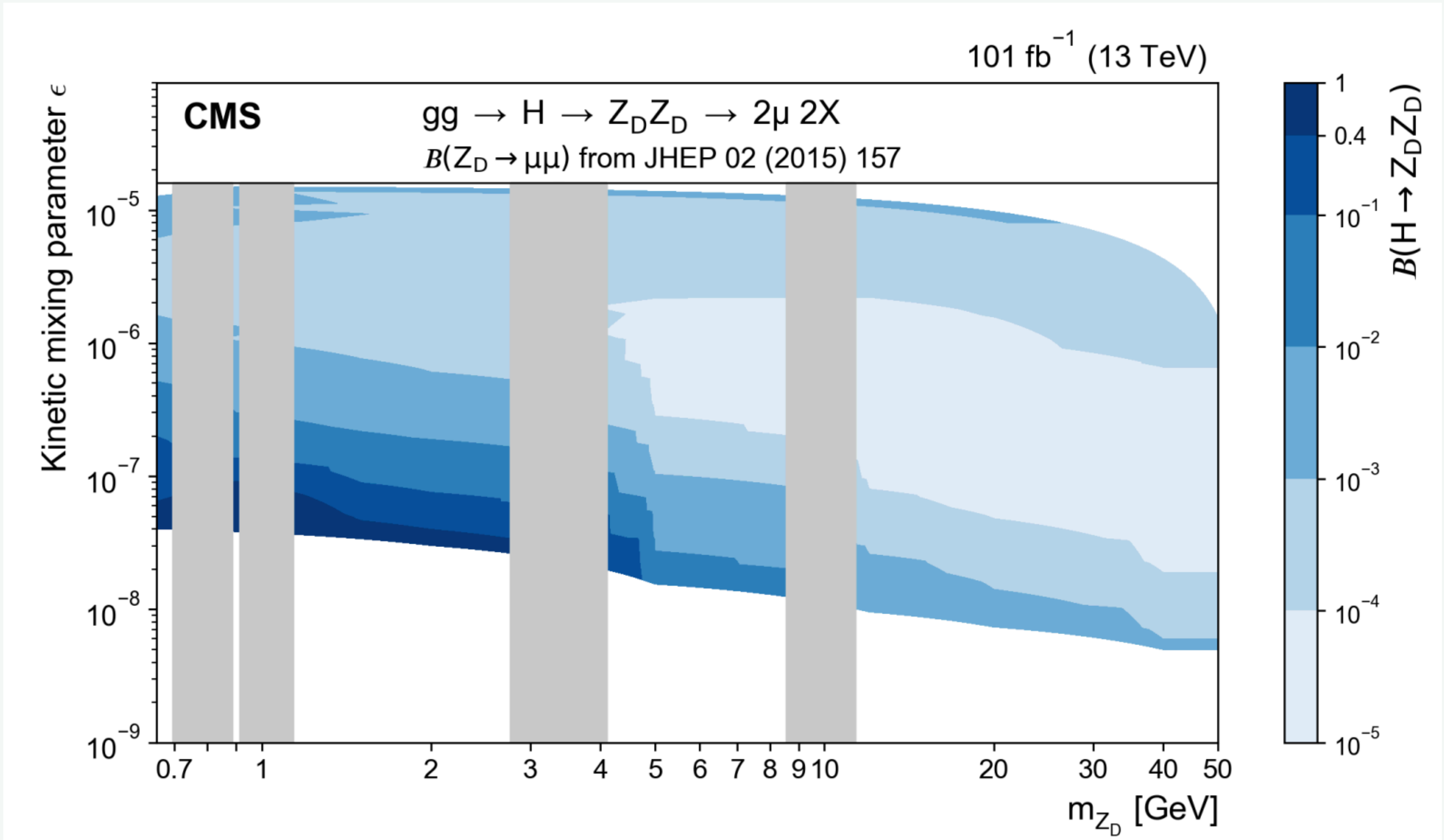
Material background mainly from photon conversions

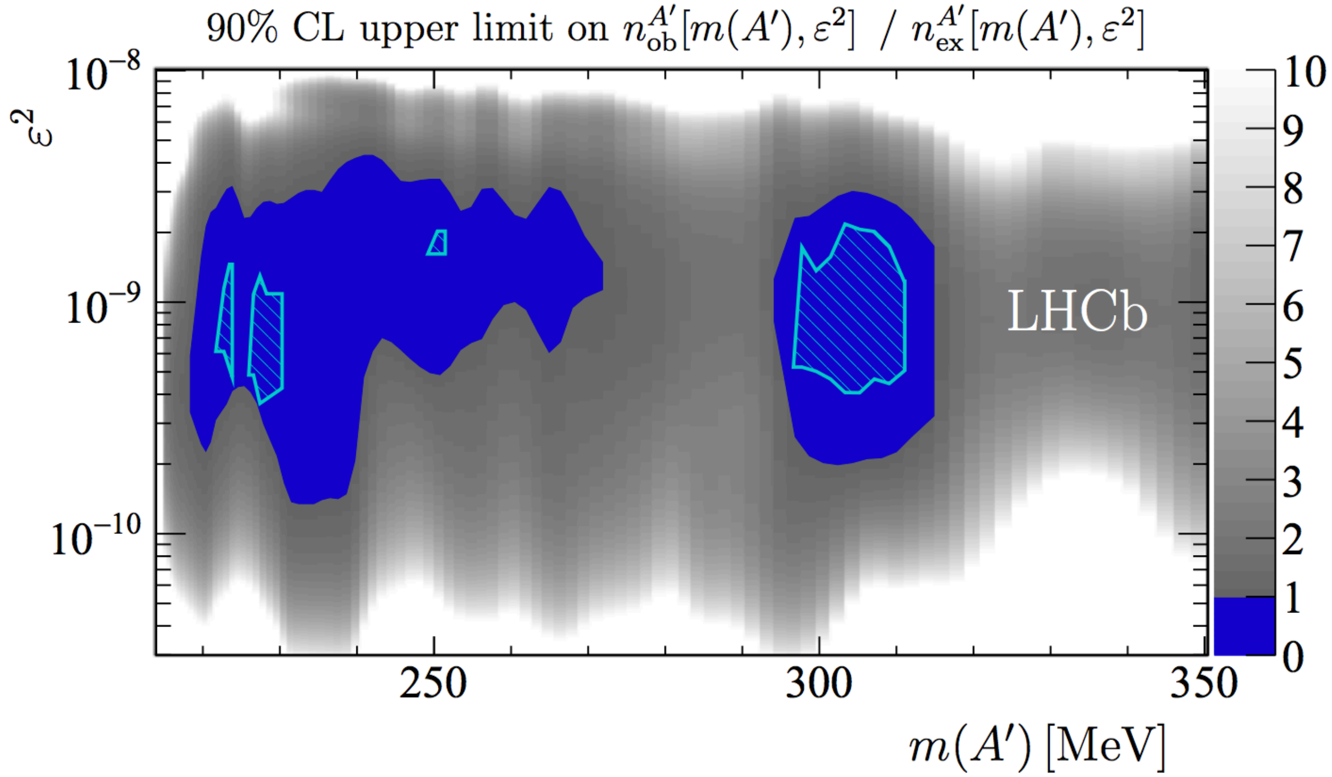
Displaced search probes the very low mass region (214-350 MeV)

A region generally accessible only by beam-dump experiments!



PRL 124 (2020) 041801





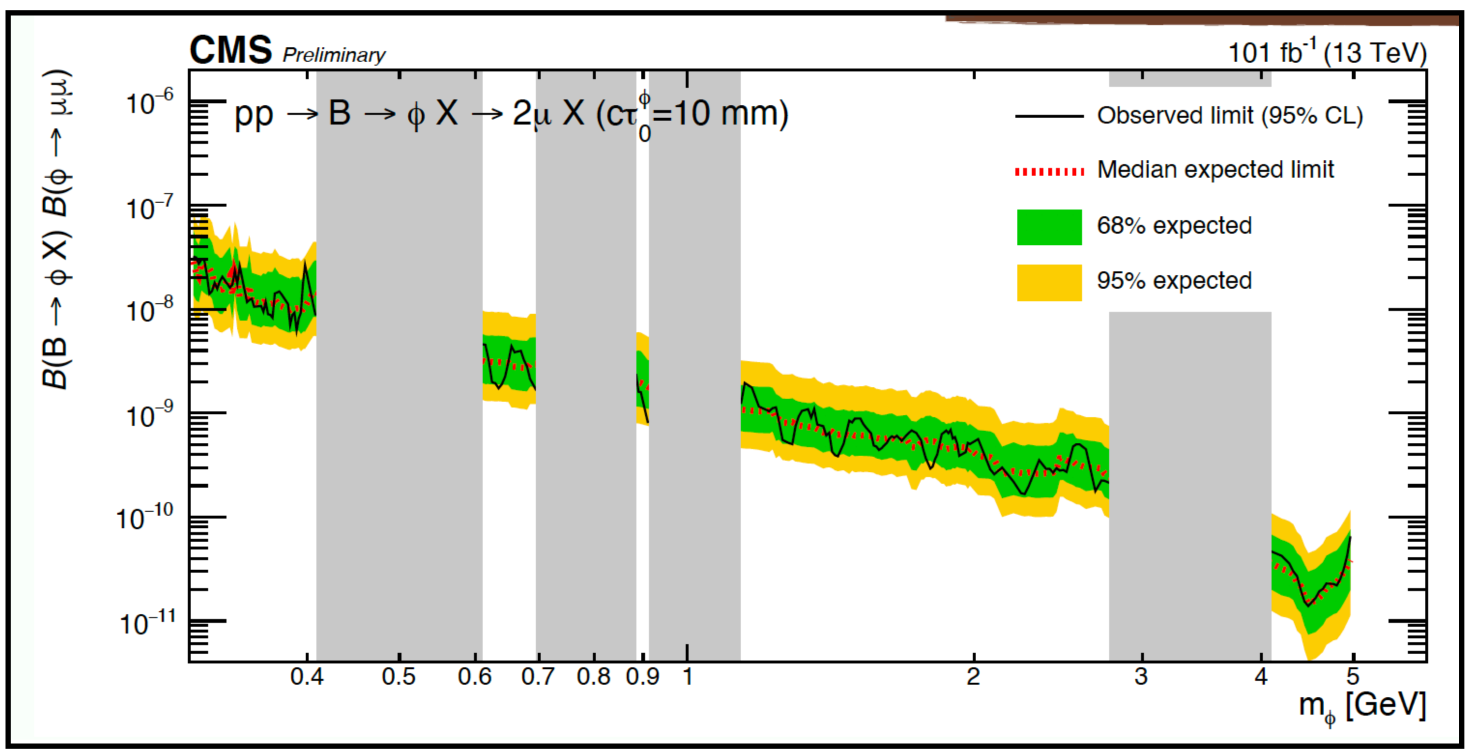
PRL 124 (2020) 041801

LHCb
LHCb (2016 data)
BABAR+KLOE+CMS

Scouting trigger in CMS

- Very competitive constraints on models of BSM physics
  - Theorists will have access to a state-of-the-art dataset for reinterpretation
- **Bonus**: Exclusion limits at 95% CL on the branching fraction B(B → ϕX) * B(ϕ → μμ) as a function of the signal mass (m_ϕ) hypothesis for a given lifetime: **LHCb, careful!**
  - Not easy to compare since CMS limits are on the inclusive B → ϕX branching ratio, while the LHCb limits are on the exclusive B0 → ϕK* and B^+ → ϕK^+ branching ratios
- Exclusion limits at 95% CL on the branching fractions for h → $Z_D Z_D$
- **B(h → $Z_D Z_D$) and as B(h → $Z_D Z_D$) × B(Z_D → μμ)**

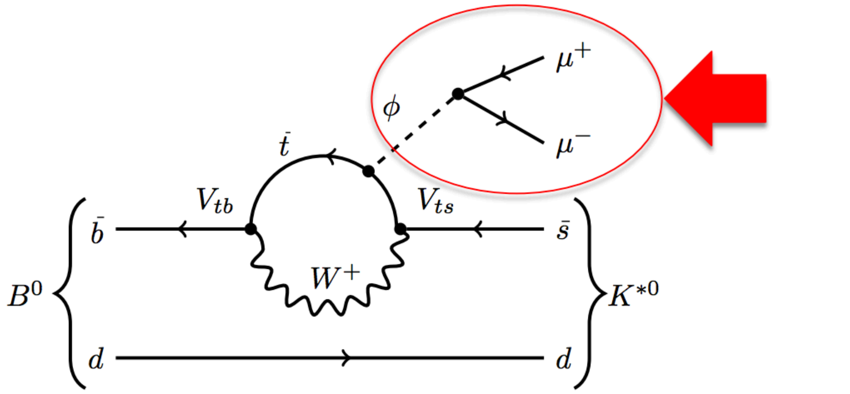
- **Efficiency of such triggers measured as a function of the dimuon** transverse displacement l_{xy} from the interaction point and of the minimum p_T^μ of the pair, using events with at least two muons selected with orthogonal standard triggers
- **CMS pixel tracker geometry** used for an l_{xy} categorisation plus bins of dimuon transverse momentum brings maximisation of the sensitivity to different signal topologies
- A search for a resonant dimuon peak in each mass window is performed



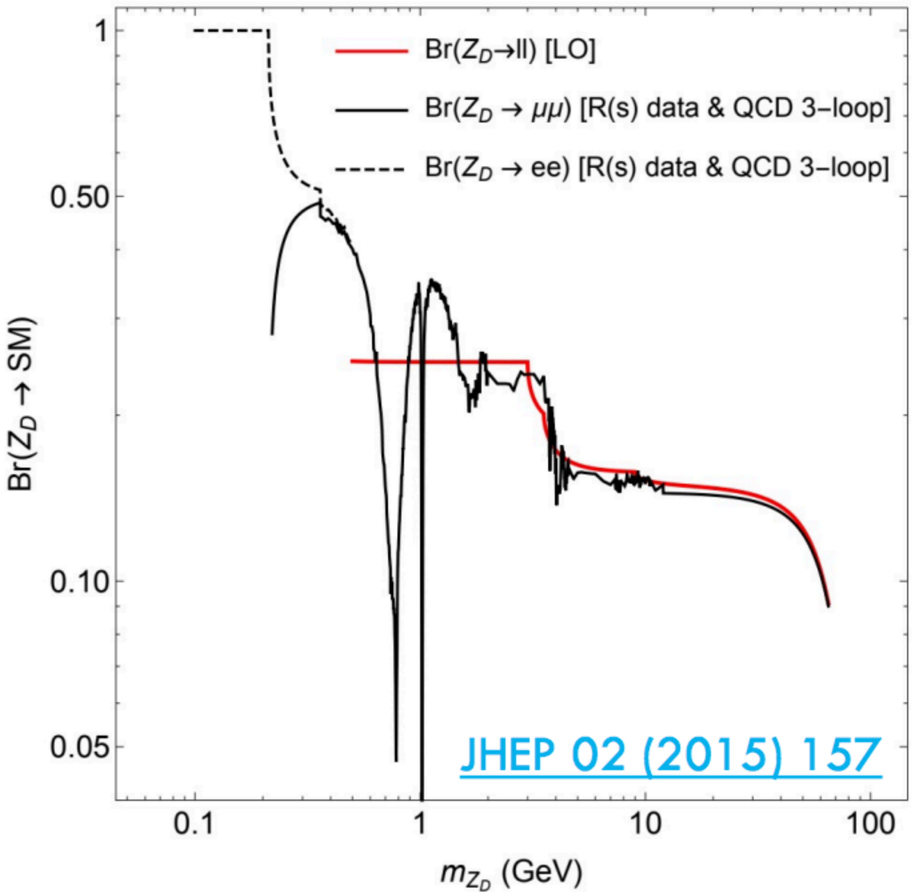
2. Singlet scalar field (ϕ):

- Minimal extension to the SM adds a singlet scalar field (ϕ) [3, 4]
  - ϕ is mixing with the SM-like Higgs boson
  - Coupling of SM fermions to ϕ is proportional to mixing angle (s_θ)
  - ϕ is likely long-lived (LL)

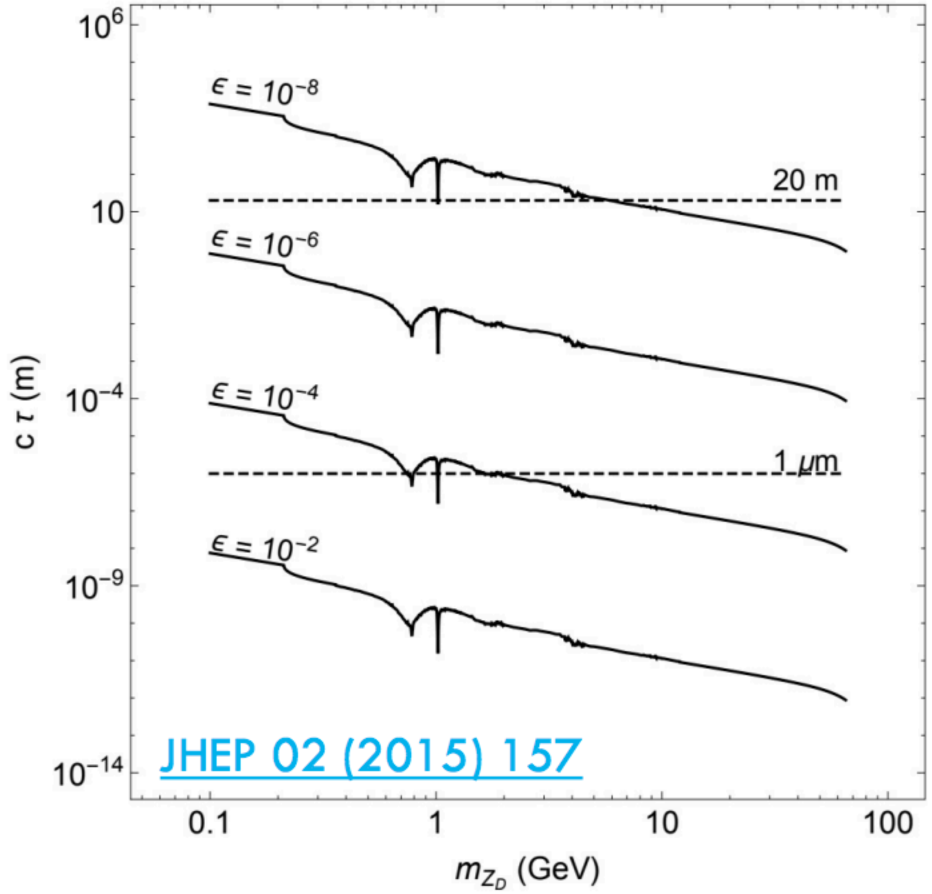
→ **Scalar resonance** produced in B hadron decay: **B→ϕX**
- With sizeable **decay** branching fraction of **ϕ→μμ**

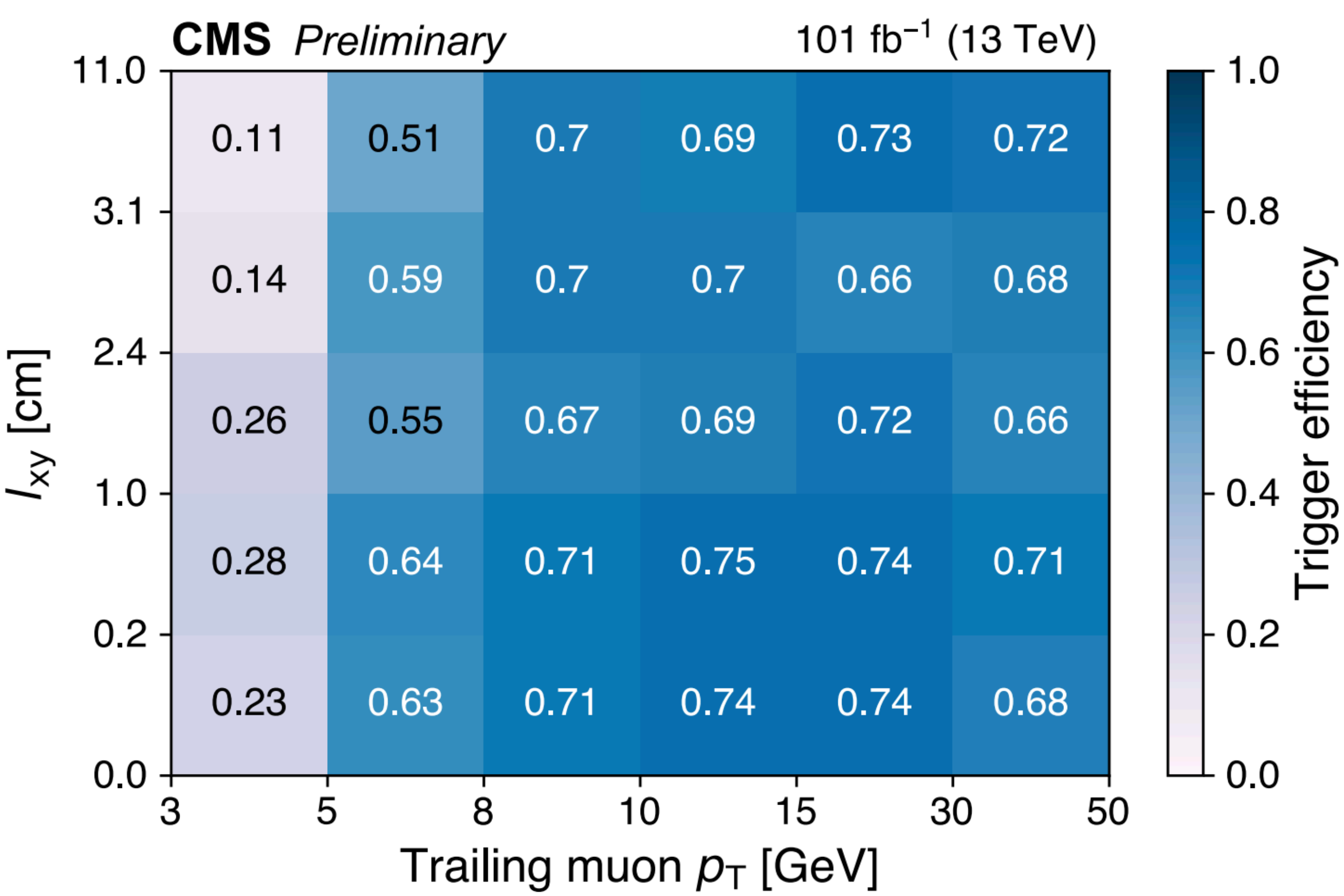


❖ Sizeable **decay branching fraction of $Z_D \rightarrow \mu\mu$**



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





- For BSM signal, expect dimuon system vector to be collinear with DV vector

→ Require **$\Delta\phi(\mu\mu, \overrightarrow{DV}) < 0.02$ (0.1)**
  - To suppress backgrounds with DV formed from accidental crossing of μ-trajectories
  - ❖ Relaxed for 2nd μ-pair

- To further suppress backgrounds with fake DVs from cosmic μ's, μ's from PU, or μ's from QCD, also require **$\Delta\phi(\mu_1, \mu_2) < 2.8$**