GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

III. Physikalisches
Institut A

RWTH AACHEN UNIVERSITY

CMS HIGHLIGHTS

Swagata Mukherjee, *on behalf of the CMS collaboration*

III. Physikalisches Institut A, RWTH Aachen University, Germany

ICNFP 2021 **24th August, 2021**

SETTING THE SCENE

The Lord of the Rings

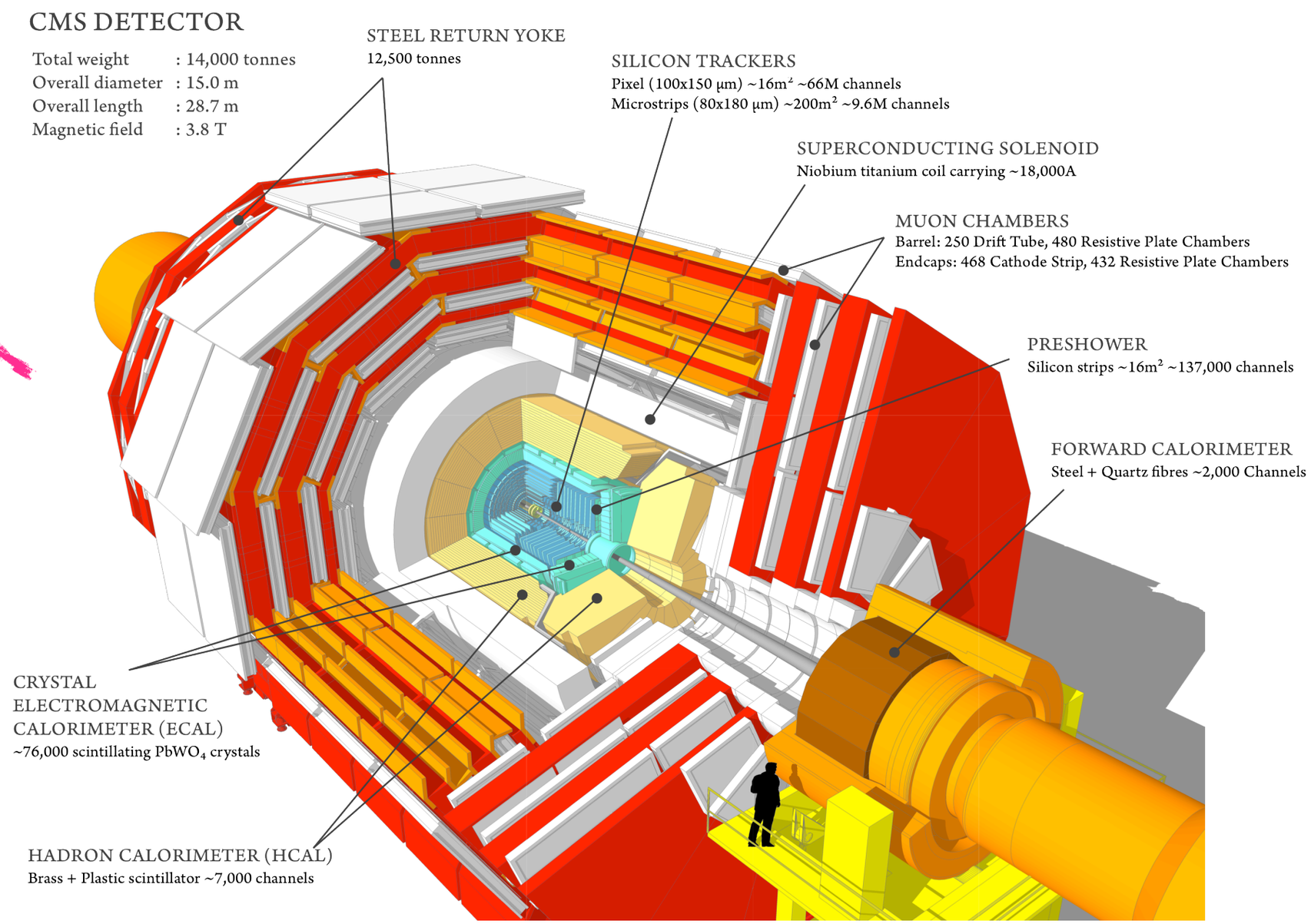
LHC

27 km long "ring", (mainly) pp collider

at the Swiss-French border

CMS: A general purpose detector

Co-axial layers of tracker, calorimeters, muon detectors.



CMS has a broad physics program

I'll try to give a glimpse of that in this talk

INTRODUCTION

- LHC started running in 2010 with two major focus
  - Find a Higgs boson, which was the last missing piece of **Standard Model (SM)**
  - Find new physics **beyond the Standard Model (BSM)**
- A Higgs boson was discovered in 2012. Its properties look SM-like.
- Next obvious question is: Where is new physics hiding?
  - **Two avenues to address the question**
    - Directly search for new particles in various final states
    - Measure known quantities precisely and look for deviation w.r.t SM prediction

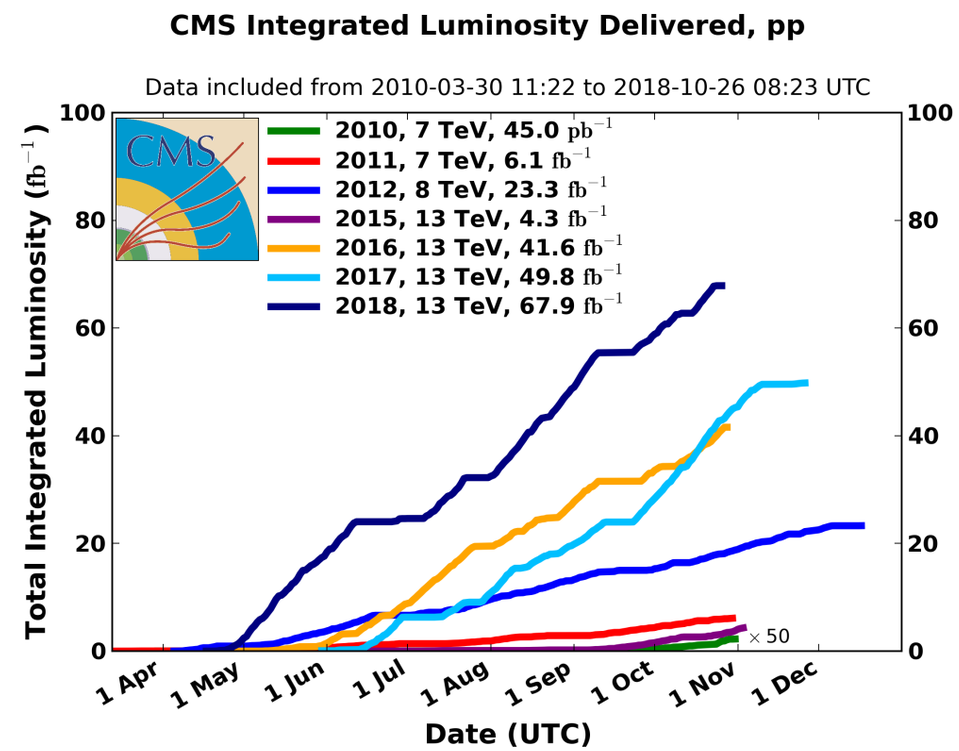
Run2 data taken during 2015-2018

We are here

CURRENT ACTIVITIES IN CMS

- Run2 data-taking ended in 2018.
- Long shutdown: 2019-2021.
- Run3 will start in 2022.
- Currently we are:
  - Making the most out of Run2 data
    - Continuing to produce Physics results from Run 2
  - Gearing up for near future (Run3)
    - Detector upgrade activities, planned for LS2, almost fully completed
  - Gearing up for far future (HL-LHC aka Phase2)
    - Finalizing the last two technical design reports (TDR)

Data collected until now



This talk will show highlights of just a few of a large number of CMS results, with personal bias

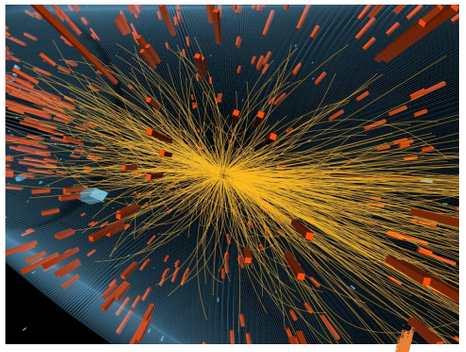
Link to all CMS results:

https://cms-results.web.cern.ch/cms-results/public-results/publications/

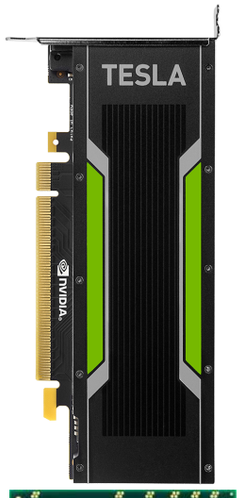
CMS TRIGGER SYSTEM

- **Two-level trigger system** to bring down huge rate to a manageable value.
  - **First level**: L1, hardware-based.
    - **Ongoing developments for Run3 to aid long-lived new particle searches**, which is a major focus for Run3 physics program.
      - Increase efficiency for displaced muons
      - Capability to trigger on hadronic particles in muon system
      - Exploit timing measurement of calorimeters
      - Usage of HCAL longitudinal depth information
  - **Second level**: High level trigger(HLT), software-based.
    - Transitioning to a **heterogeneous HLT farm** (deploy **CPU and GPU**)
      - Great to have it in Run3, critical requirement for HL-LHC. Impressive speed-up due to offloading of reconstruction code to GPUs.
      - Opens new possibilities for trigger algorithms leveraging on GPUs.

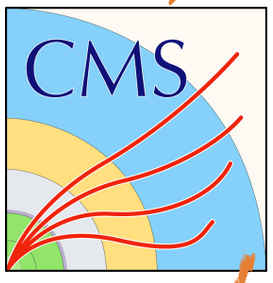
More in this talk
Trigger (CMS) by Pallabi Das



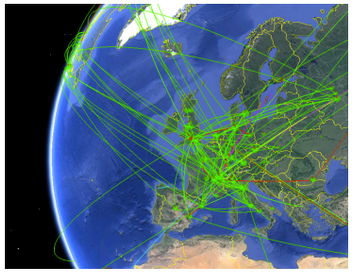
Up to 40 MHz



~100 kHz



~1 kHz



Promptly reconstructed.
RAW data saved.

RUN2 OBJECT / TRIGGER PERFORMANCE

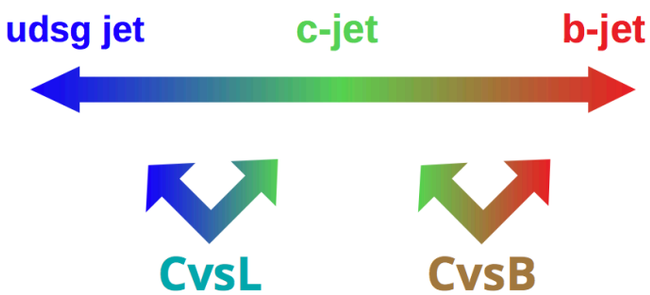
Impressive dielectron mass resolution during all years of Run2.

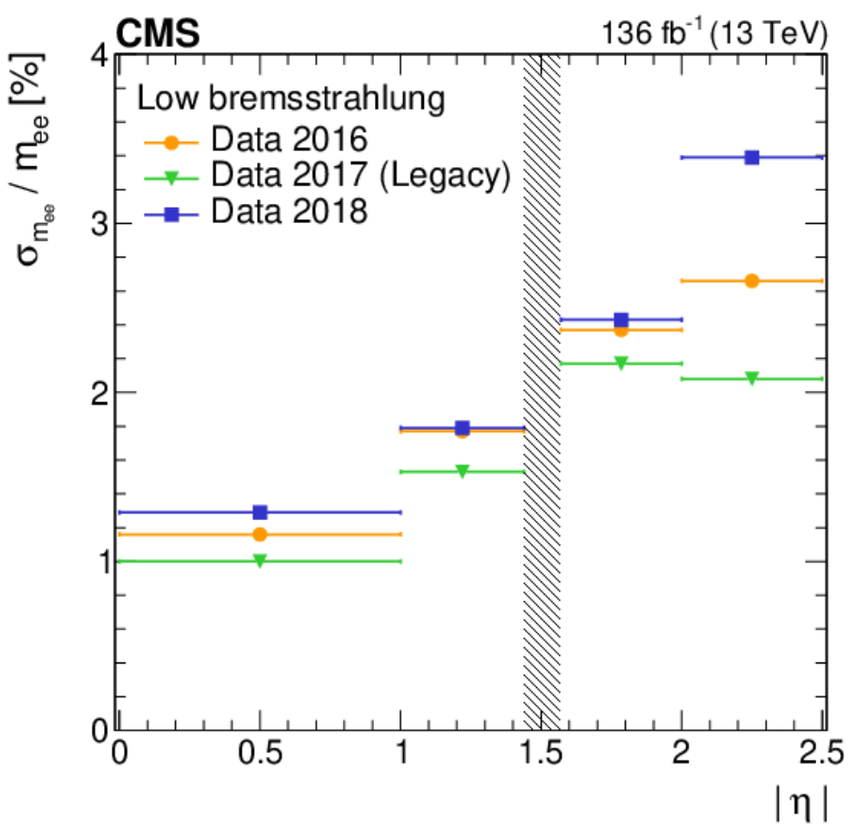
Most challenging part is far-endcap due to higher noise, more radiation damage.

Excellent performance of muon triggers during Run2.

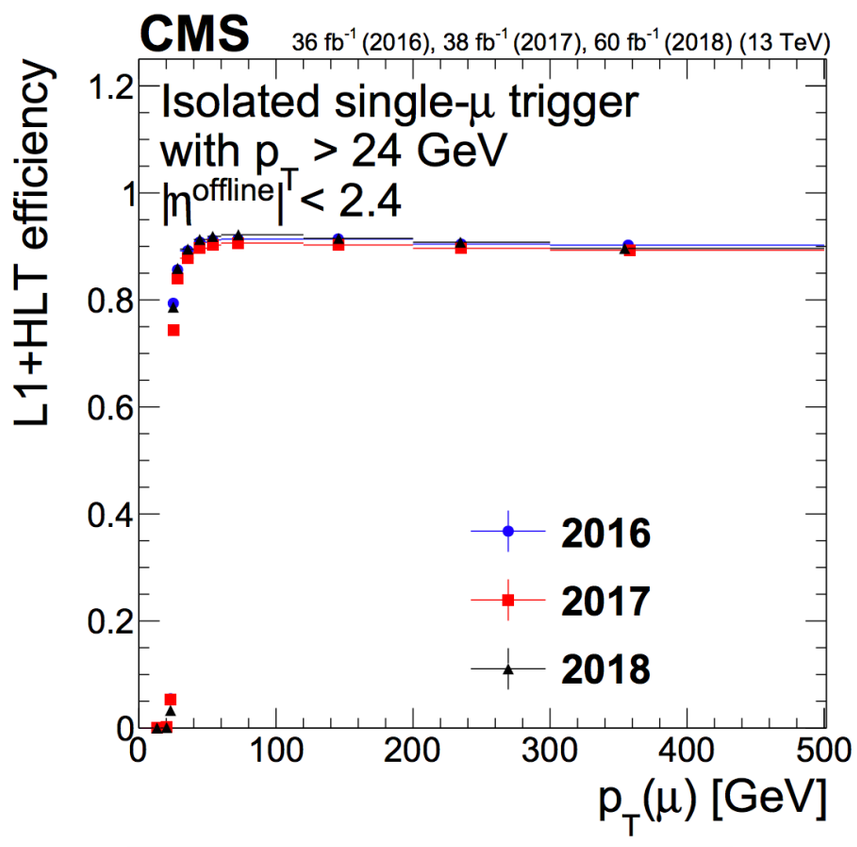
Used in many physics analyses.

Usage of advanced Machine-learning technique to identify jets initiated by charm quark.





JINST 16 (2021) P05014



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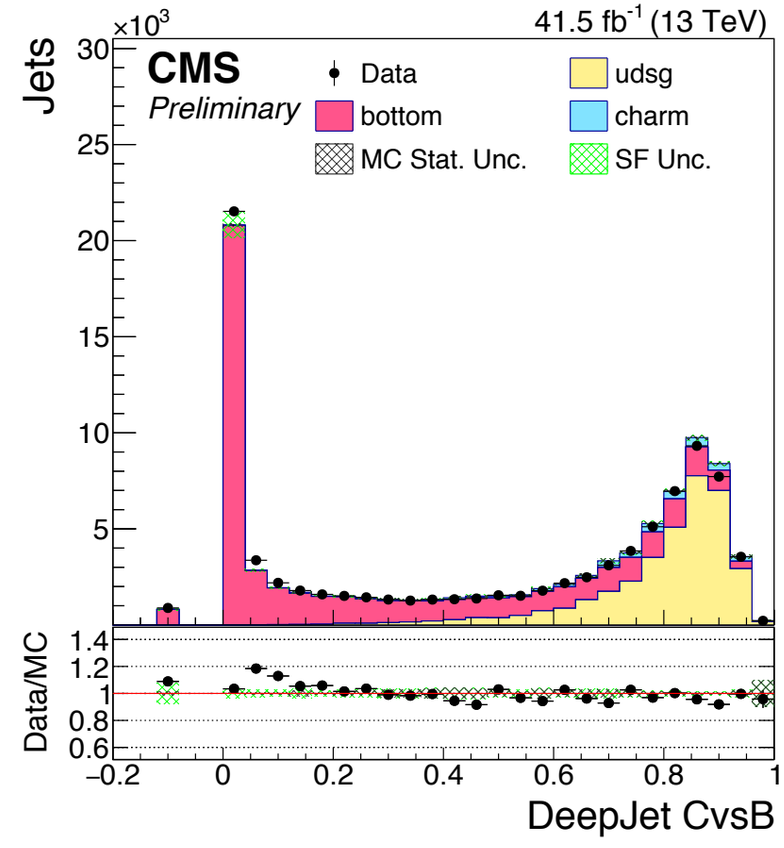


CMS-PAS-BTV-20-001

DATA SCOUTING @HLT

Relaxed trigger thresholds, and perform physics analysis with objects reconstructed @HLT.

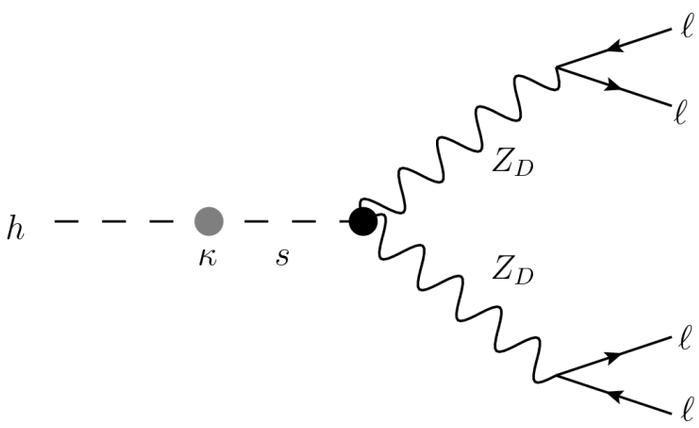
No RAW data saved. No offline reconstruction.

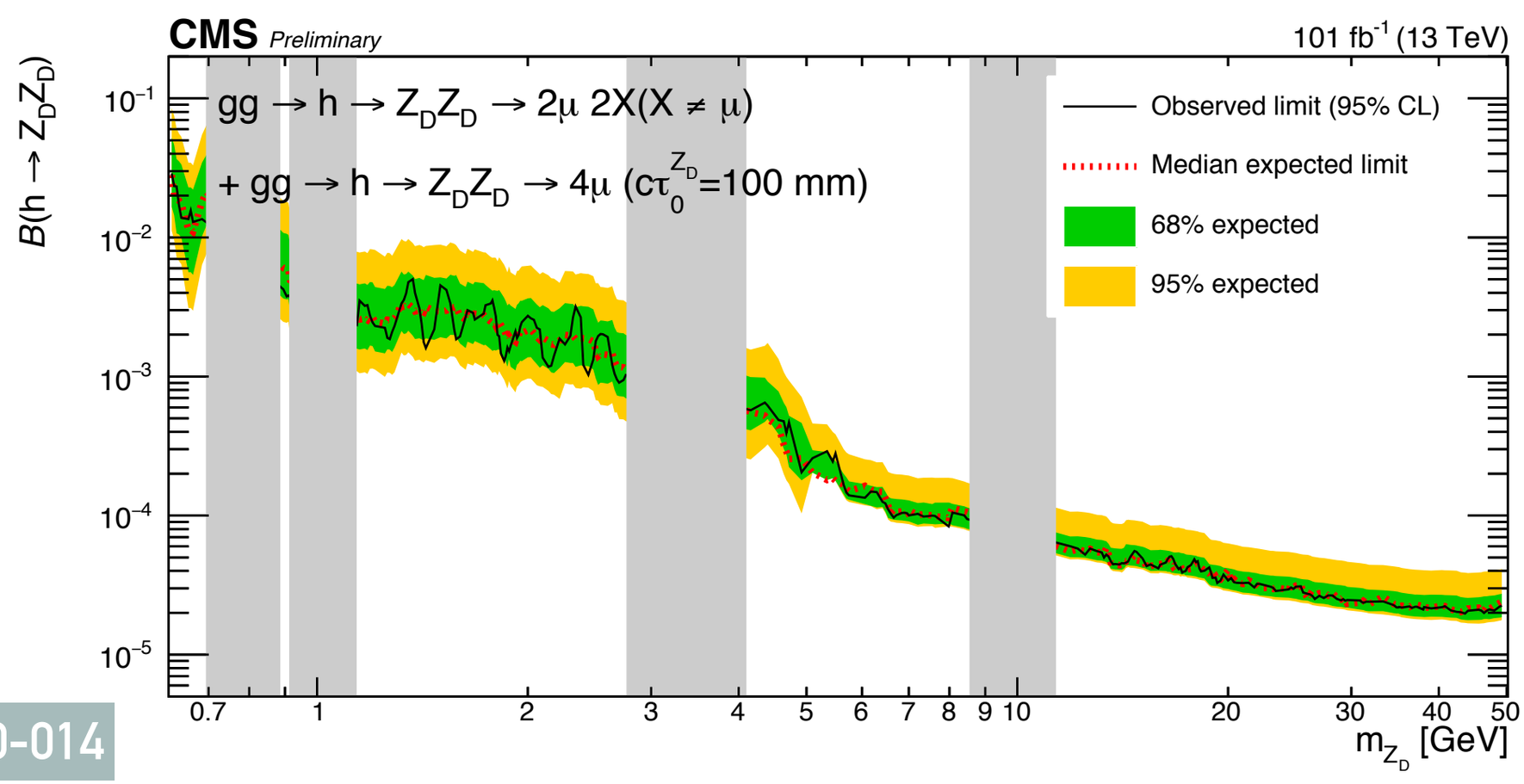
Save HLT objects in “scouting datasets”. Minimal event content.

High rate HLT paths, but very low bandwidth needed due to small event size.

Search for a narrow long-lived dimuon resonance

First search for long-lived BSM signatures using scouting data





Interaction with SM through Higgs (h) portal via Higgs mixing κ

CMS-PAS-EXO-20-014

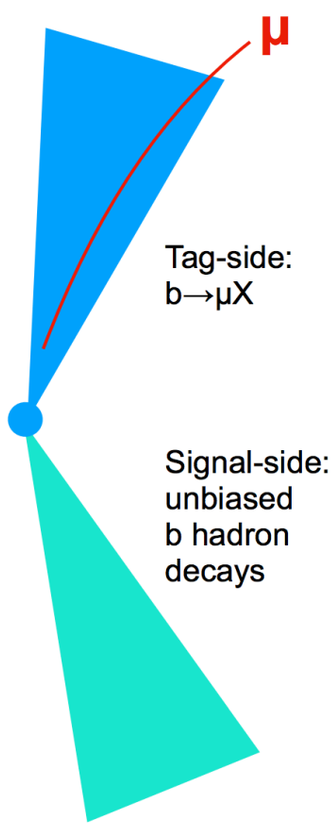
B-PARKING & LOW-PT ELECTRONS

Idea of data parking: collect data using a trigger, but do not reconstruct promptly. Reconstruct during technical-stop / shutdown.

In 2018, CMS used low pT muon triggers to save a sample of unbiased B hadron decays recoiling against the triggering muon

Studying how to further optimize the trigger for Run 3

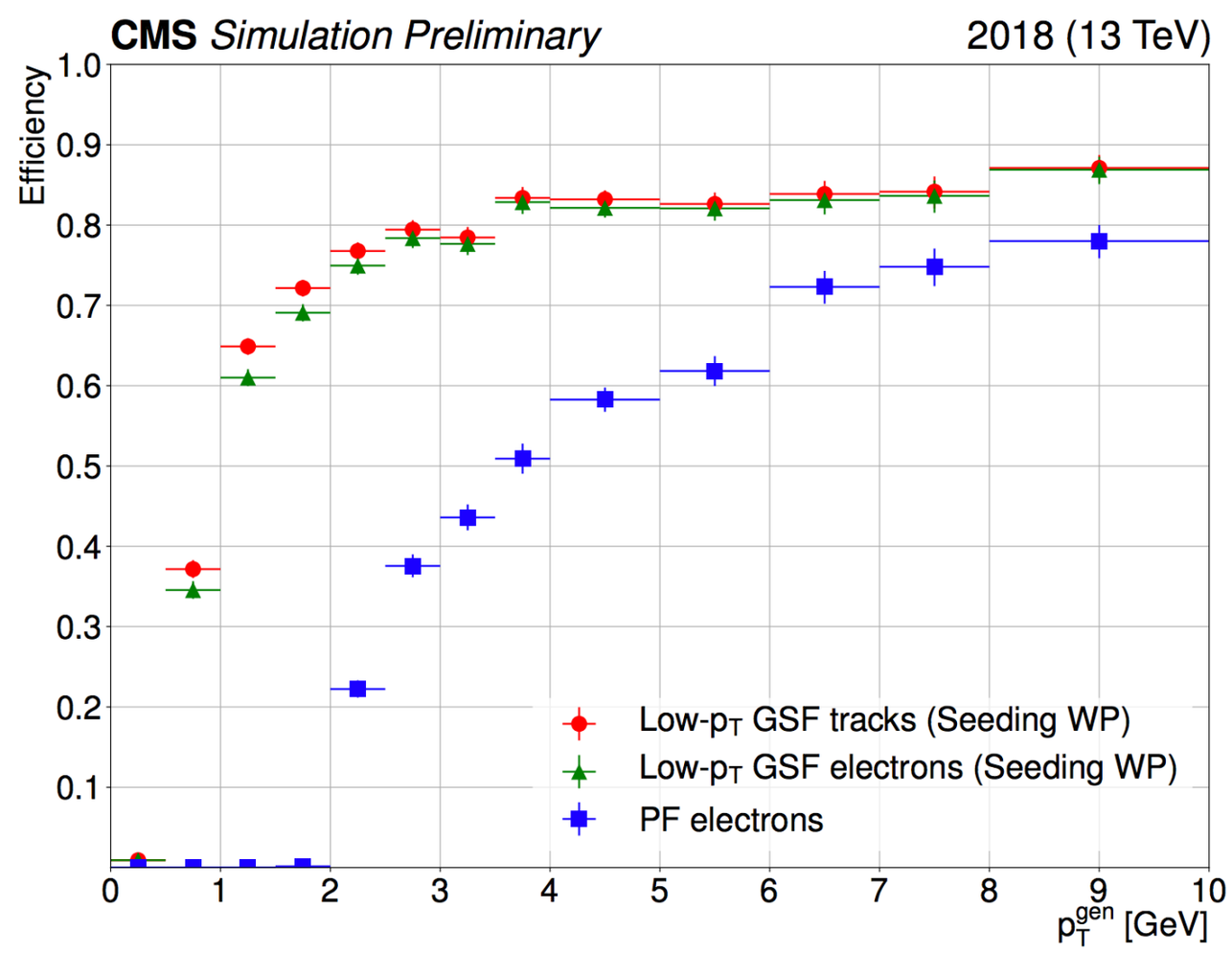
Main goal of B-parking is to make CMS competitive with LHCb in the R(K)/R(K*) measurements.



Several ongoing analysis on lepton flavour universality violation(LFUV).

Developed dedicated low-pT electron reconstruction for such analyses.

https://cds.cern.ch/record/2704495/



B-physics results in this talk
Latest B-physics results from the CMS experiment by Caterina Aruta

HUNTING THE HIGGSINOS

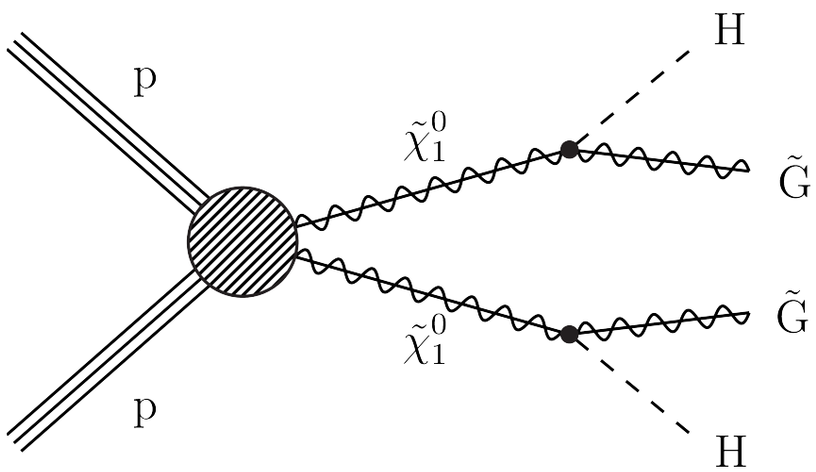
More on SUSY in this talk
SUSY (CMS) by Koushik Mandal

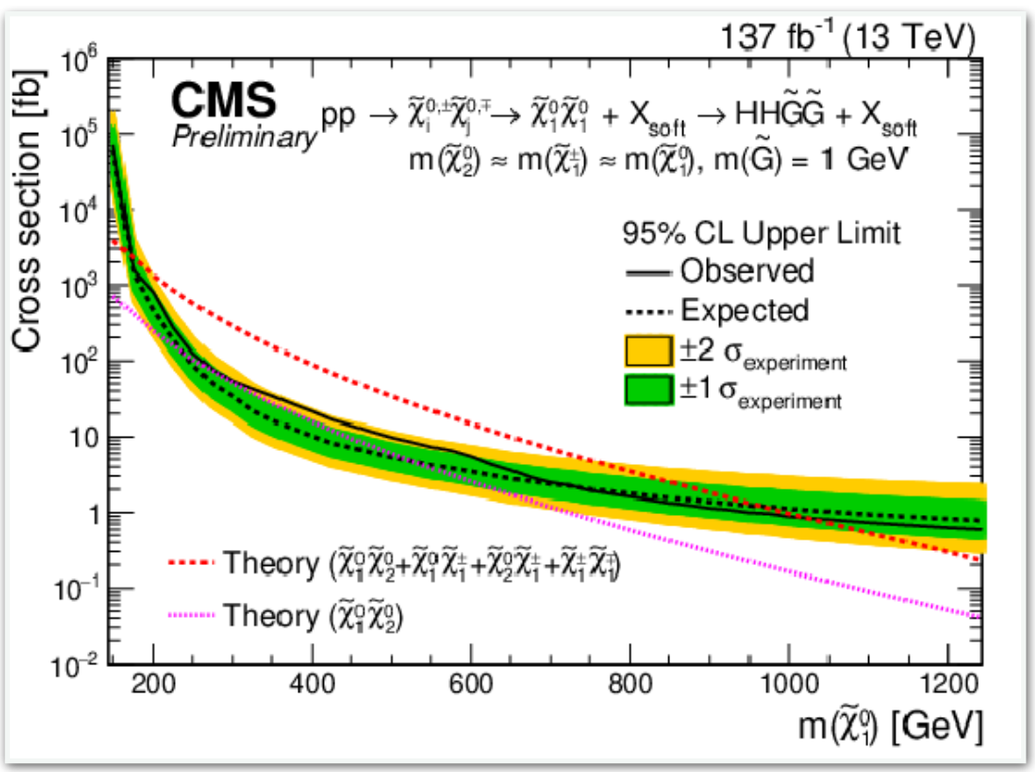
Signature: HH(4b)+MET

Search performed in 2 scenarios: resolved and boosted

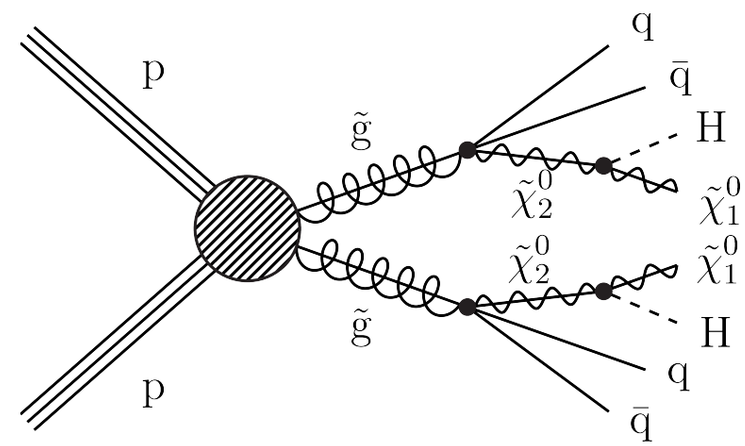
CMS-PAS-SUS-20-004

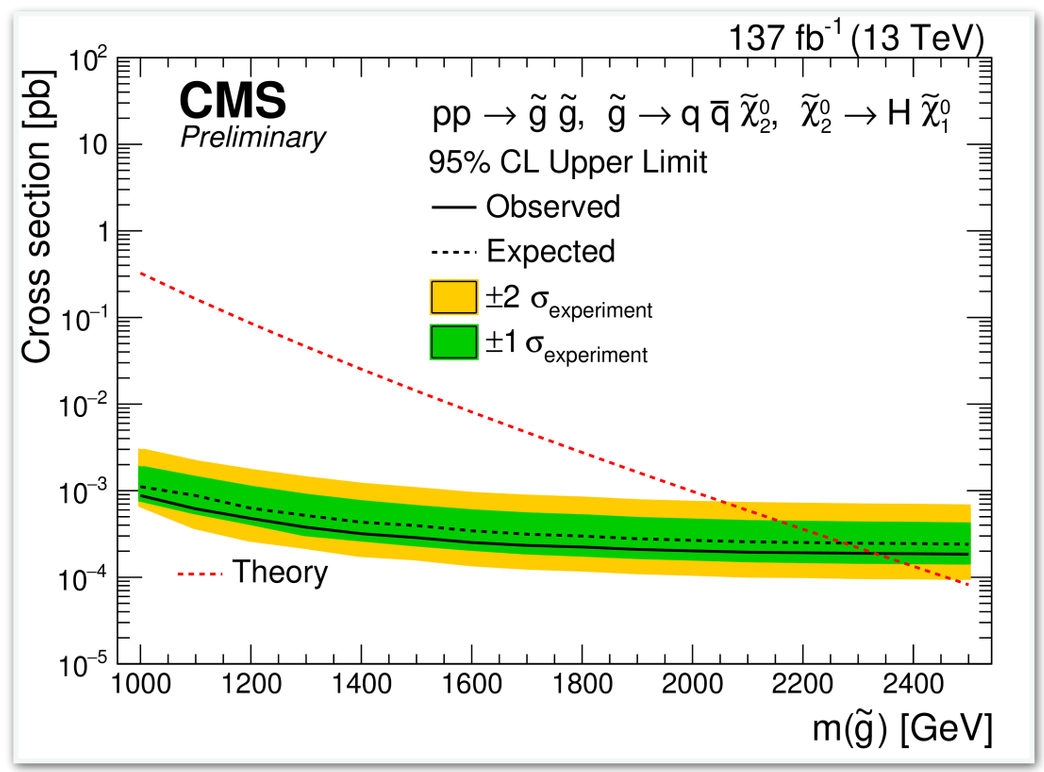
Gauge mediated SUSY breaking
Boost to cross section from different production channels
Parameter of interest: NLSP mass





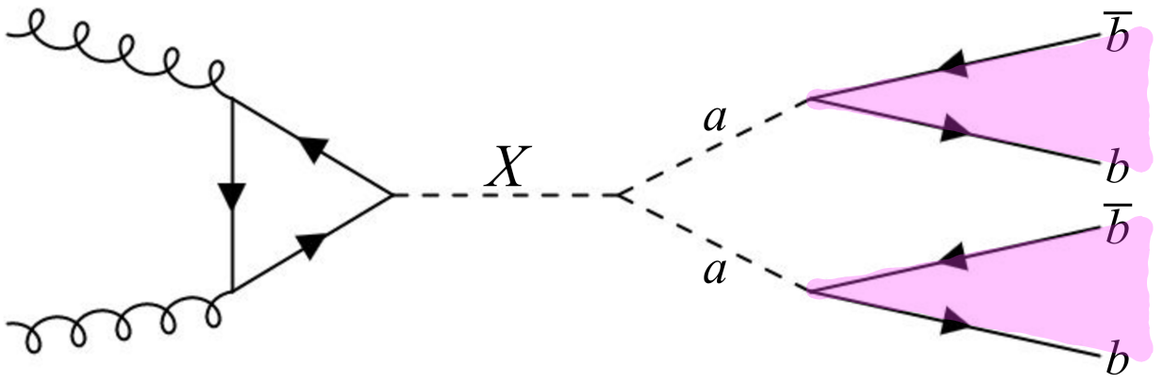
Simplified SUSY model
Mass degenerate NLSP, bino LSP
Parameters of interest: LSP and NLSP masses





EXTENDED HIGGS SECTOR

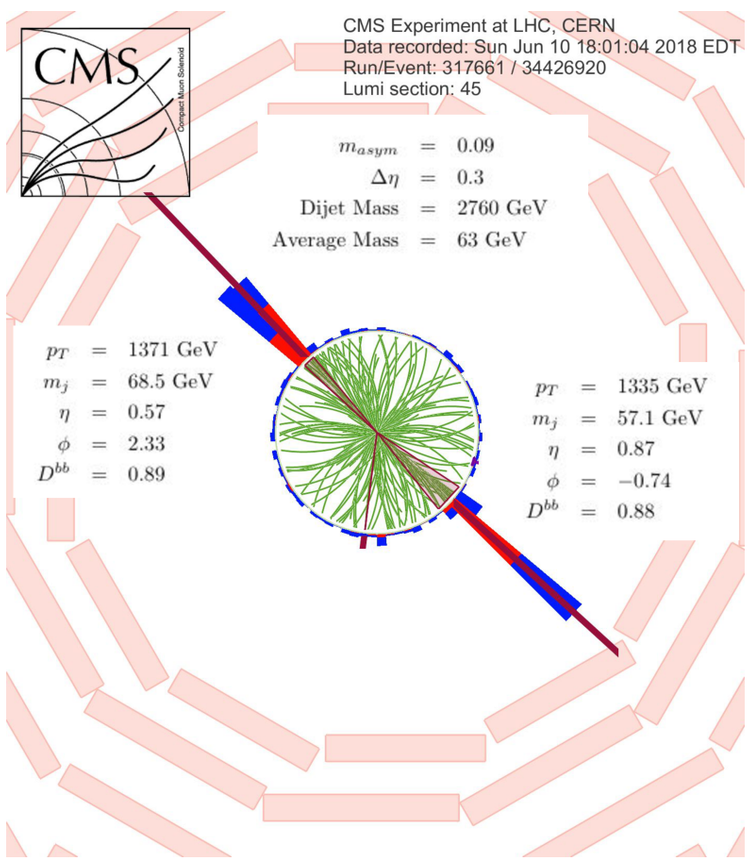
CMS-PAS-B2G-20-003

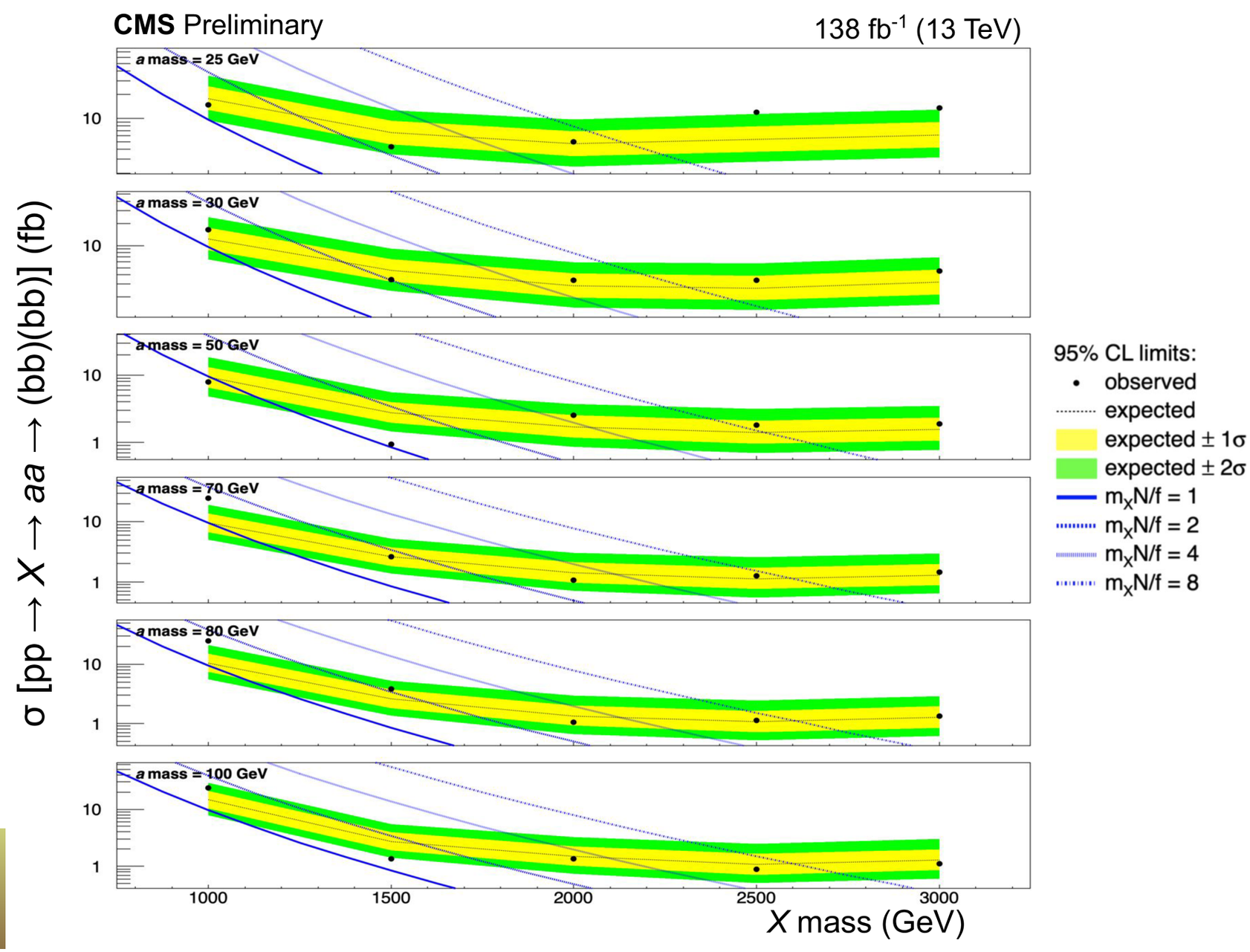


2 large radius jets in final state

Jet substructure and flavor identification techniques are used

X→aa and a→bb branching fractions are assumed to be 100%

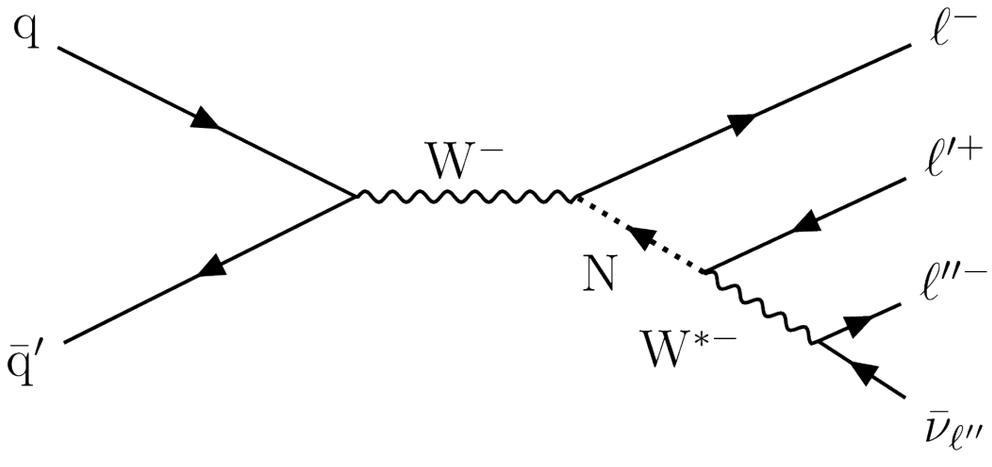


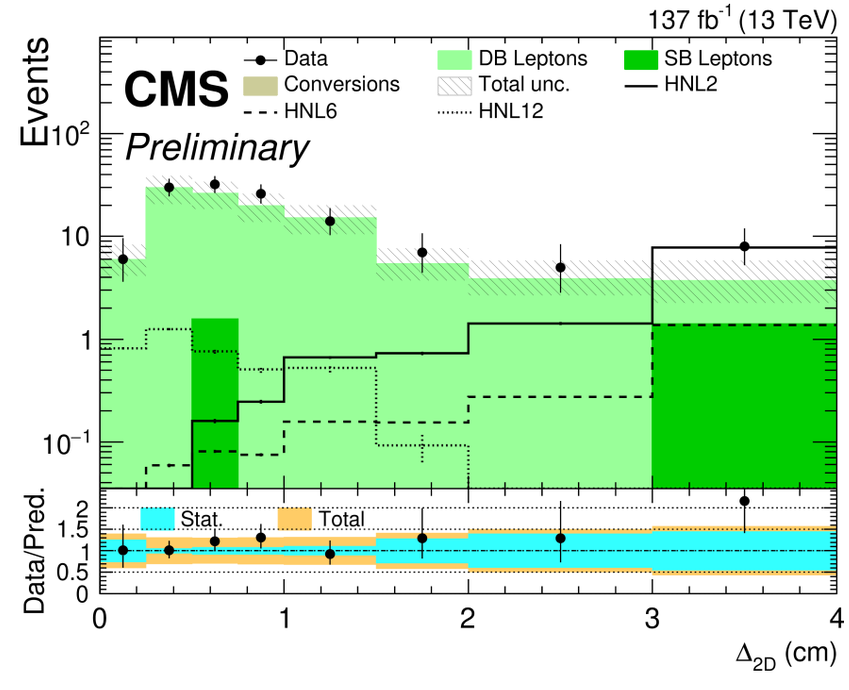


More on BSM in this talk
Dark Matter (CMS) by Siqi Yuan

LONG LIVED HEAVY NEUTRAL LEPTON

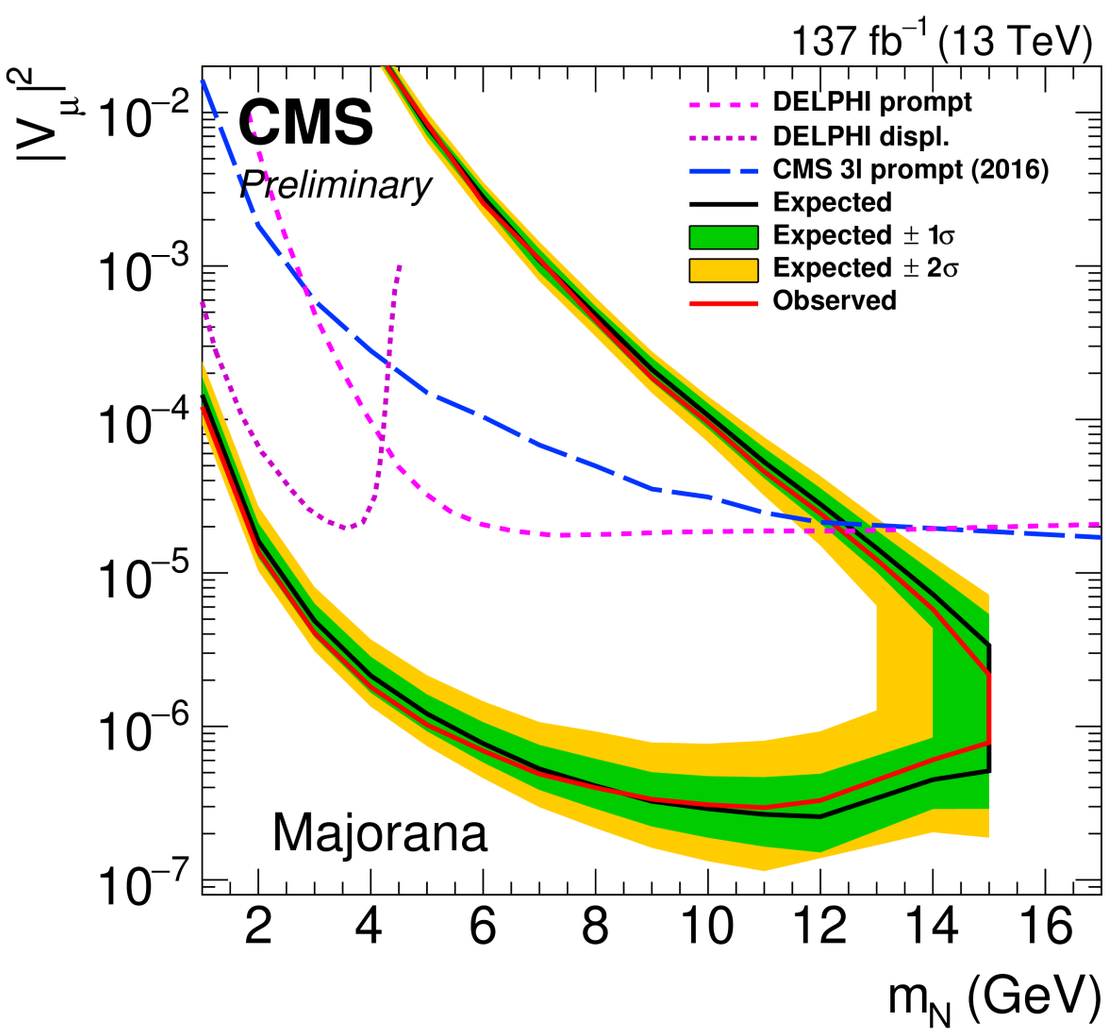
CMS-PAS-EXO-20-009

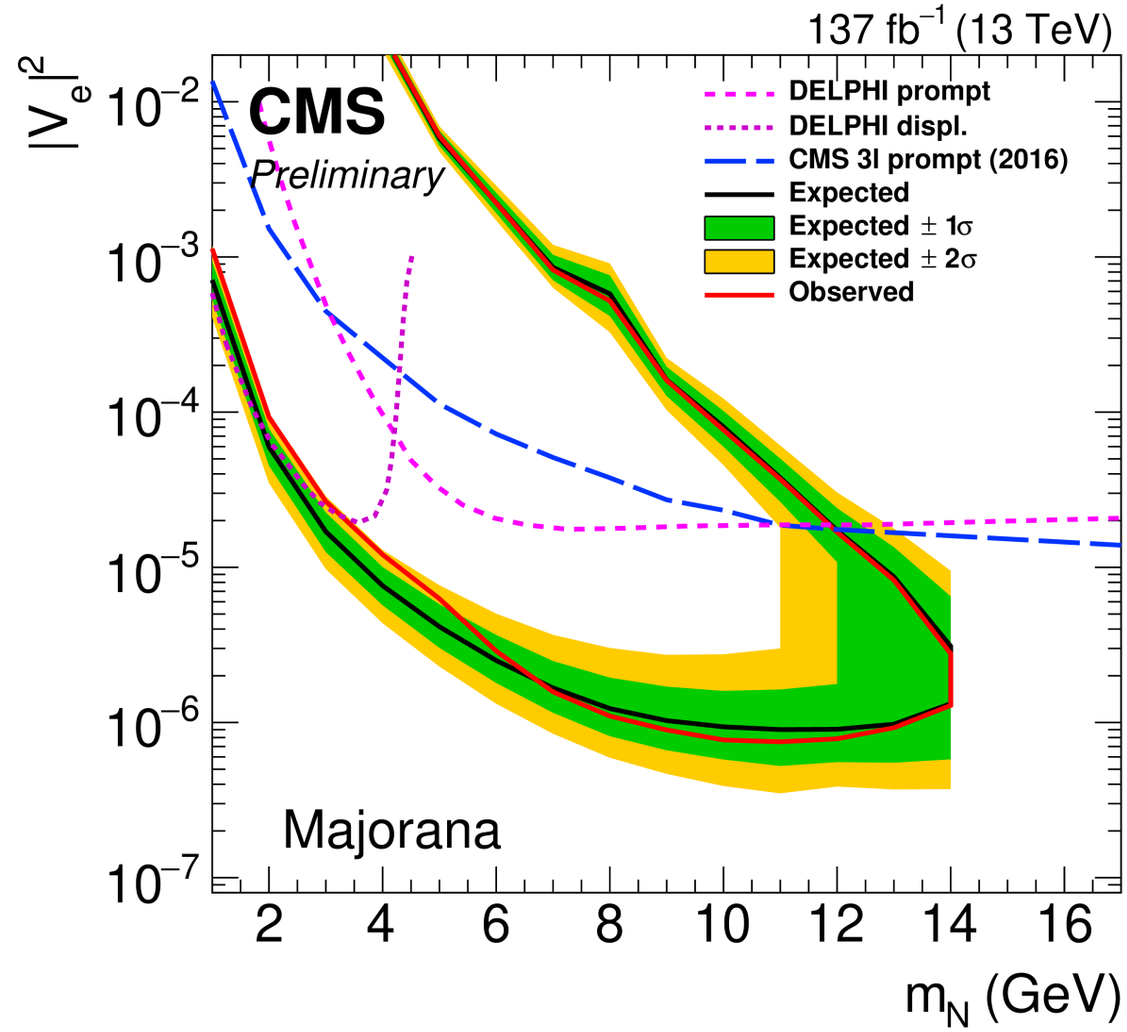




No excess was found in data

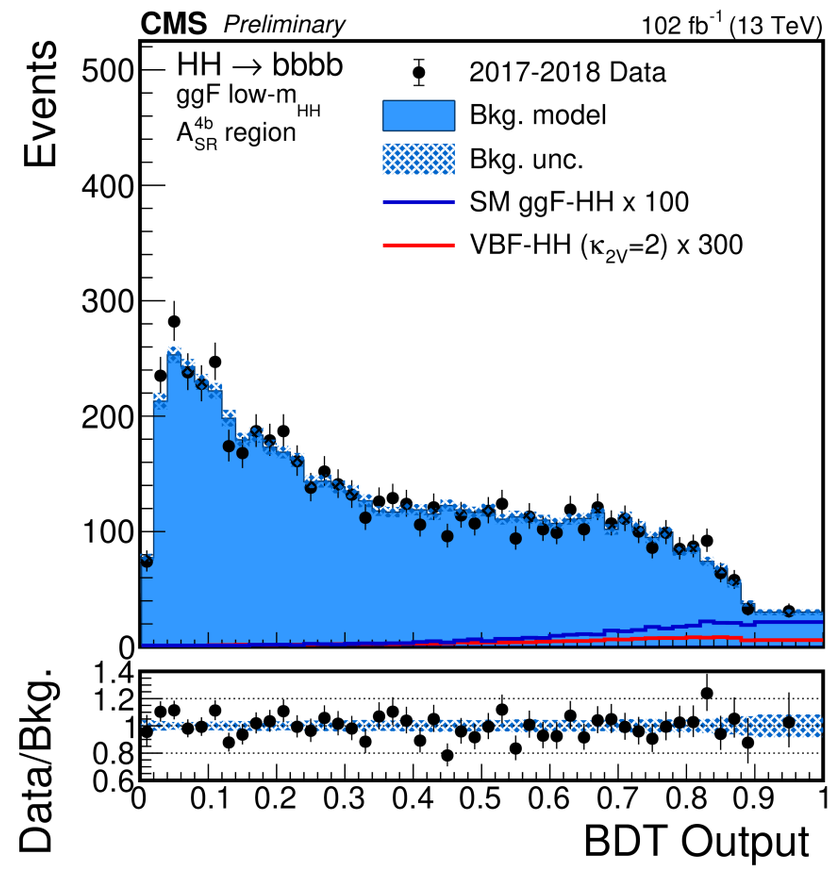
2 leptons from a displaced vertex, and a 3rd lepton from the primary vertex.

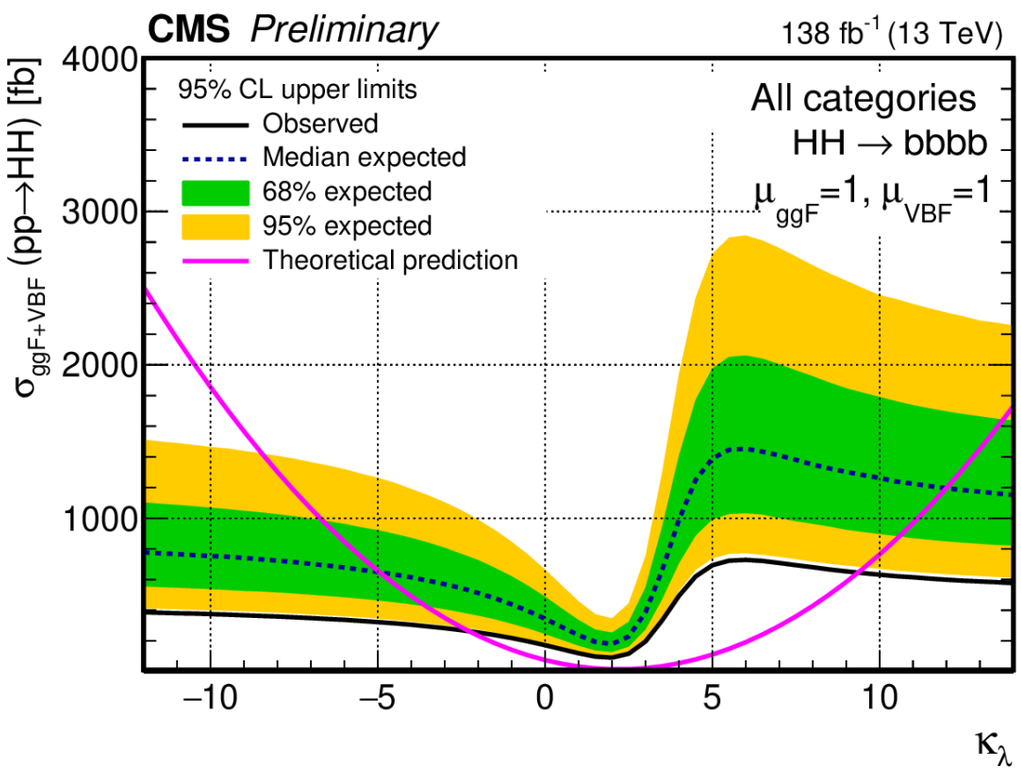


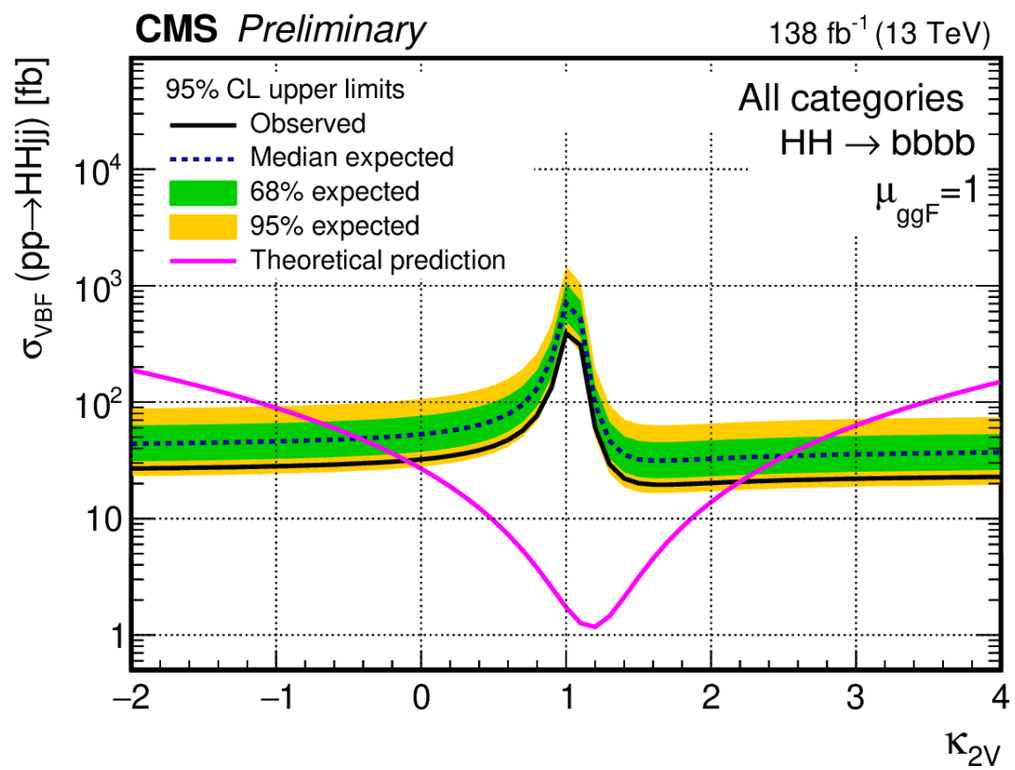


DI HIGGS

- Search for HH(4b)
- Gluon fusion and vector boson fusion production modes investigated.
- DNN-based b-jet tagger used in this analysis
- Observed upper limit on the HH production cross section: 3.6 times the SM prediction





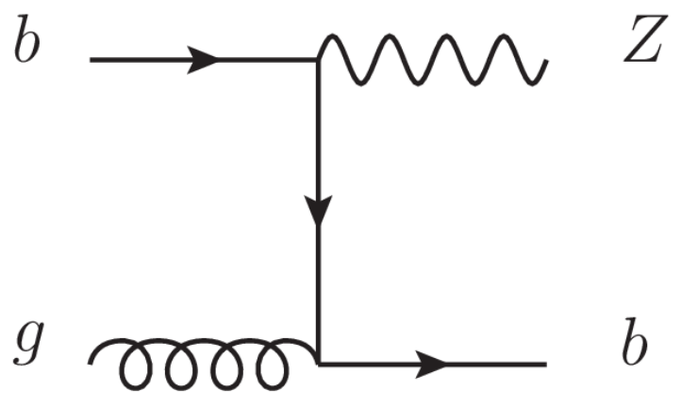


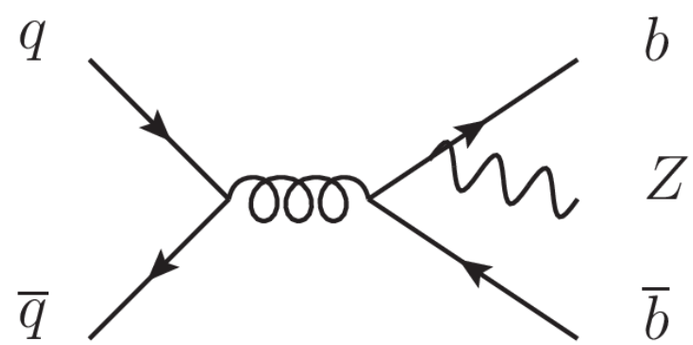
Latest Higgs results in this talk

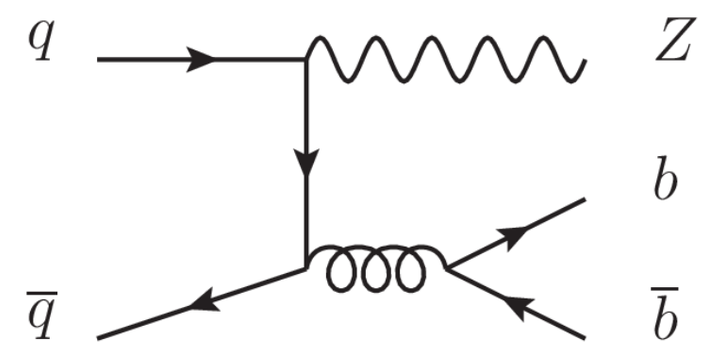
Overview of the latest Higgs physics results from the CMS experiment by Angela Taliercio

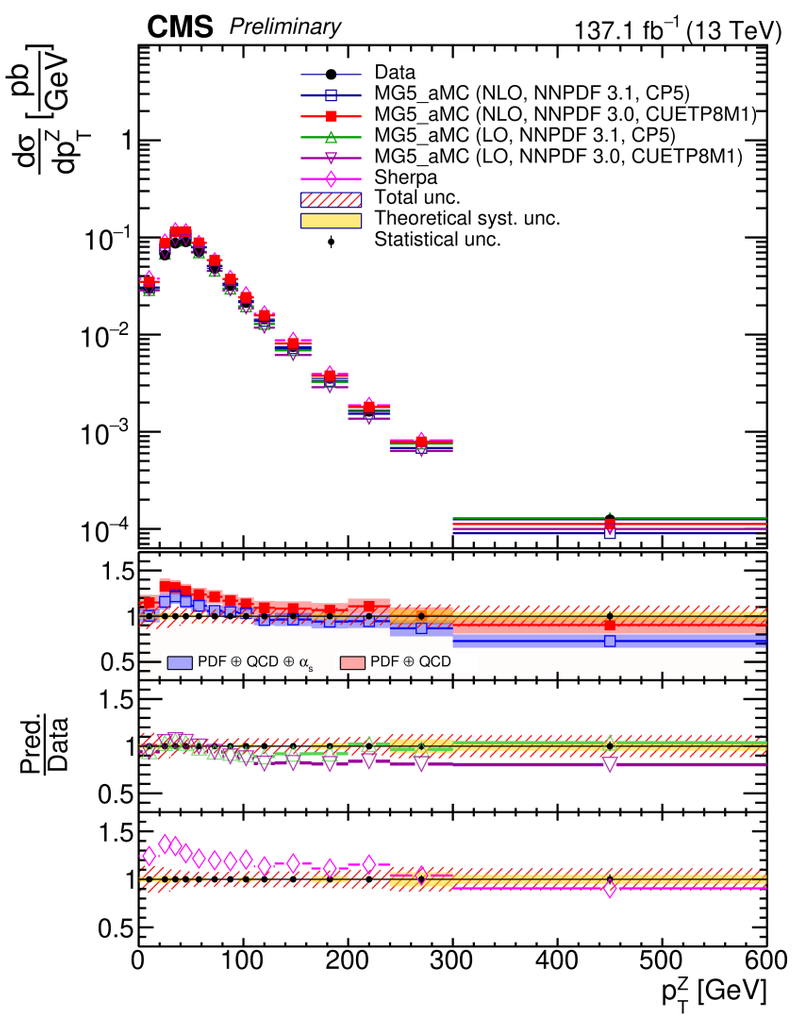
Z+B JETS CROSS SECTION MEASUREMENT

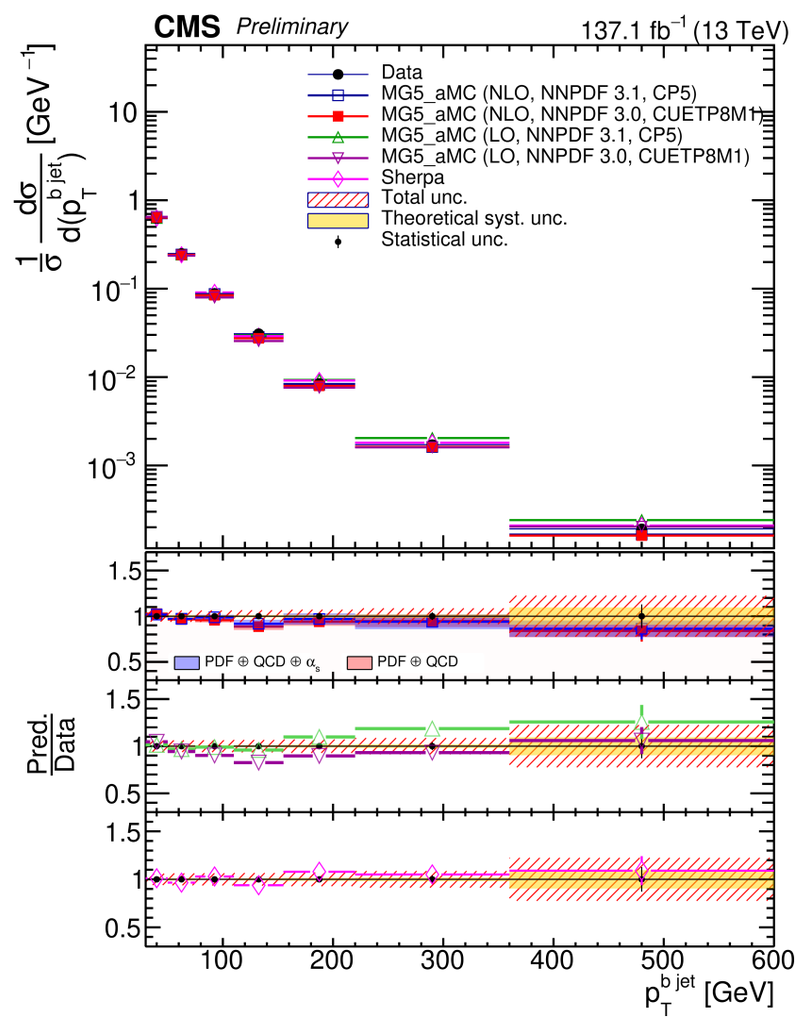
CMS-PAS-SMP-20-015











The differential cross section distributions are measured as a function of various kinematic observables

Present measurements can be used as an input for the further optimization of the simulation parameters.

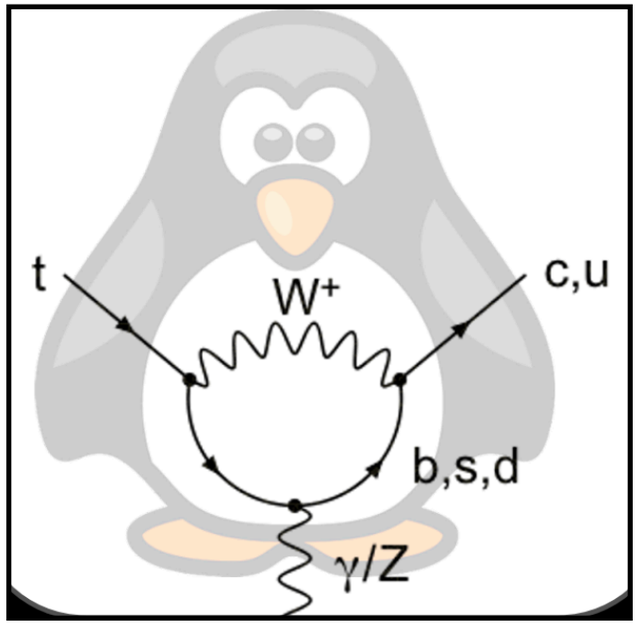
Important precision tests of the perturbative QCD predictions

More in this talk
Standard Model (CMS) by Patrick Connor

SEARCH FOR FCNC IN TOP SECTOR

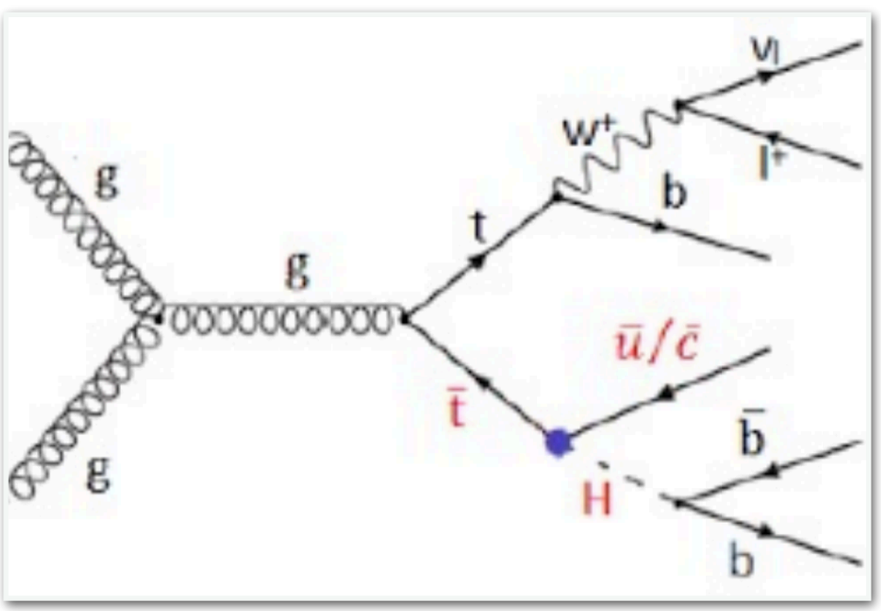
CMS-PAS-TOP-19-002

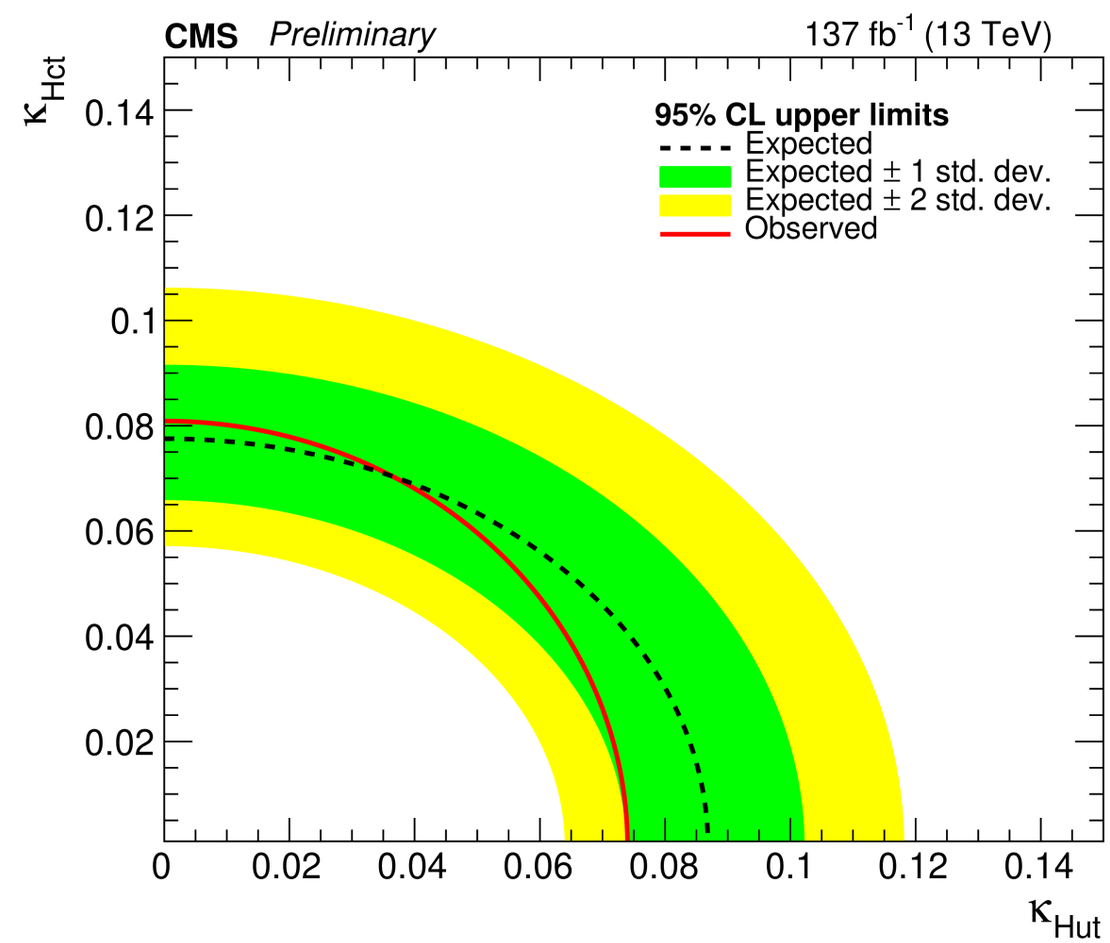
- Flavor changing neutral currents (FCNC) allow for transitions between quarks of different flavor but same electric charge
- Highly suppressed in the SM due to the GIM mechanism
- Only small contributions appear at one loop level
- Many extensions of the SM predict the presence of FCNC and give rise to detectable FCNC amplitude



Any evidence of FCNC will indicate the existence of new physics

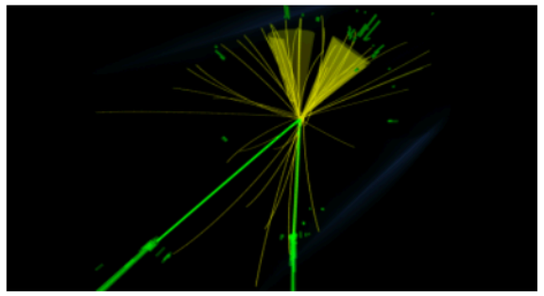
Search for tHq (q = u,c), H→bb, usage of DNN to associate the reconstructed objects to the matrix-element partonic final state





PHYSICS BRIEFINGS

https://cms.cern/tags/physics-briefing



LIVE LONG AND PROSPER: SEARCHING FOR THE LONG-LIVED RELATIVES OF THE HIGGS BOSON

16 AUG 2021

Live long and prosper: Searching for the long-lived relatives of the Higgs boson A recent result from CMS searches for long-lived particles through the so-called "Higgs portal" in ways never done before. For about a decade now the CMS experiment at...

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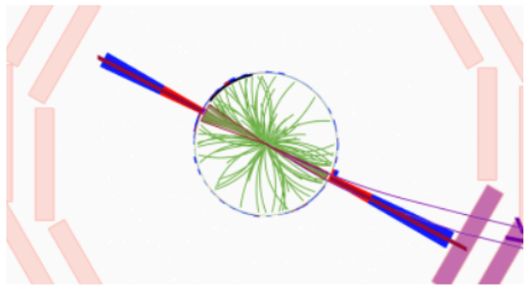

ANY MORE HIGGSES WE SHOULD KNOW ABOUT?

04 AUG 2021

This year marked the ninth anniversary of the discovery of the Higgs boson; the Standard Model particle linked to the mystery of creating the mass of all the other fundamental particles through the so-called Higgs mechanism. While a single Higgs...

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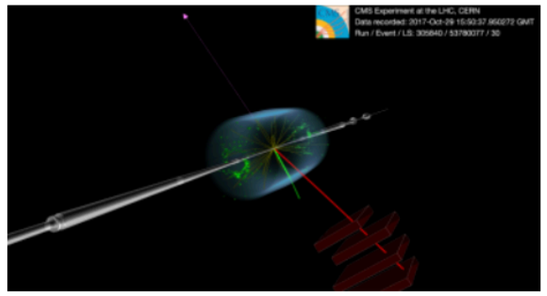

SEARCHING FOR THE DARK SIDE OF THE UNIVERSE

02 AUG 2021

Could you imagine what the dark part of the universe is like? The Standard Model of Particle Physics explains matter at the subatomic level and the related phenomena such as interactions and forces between the subatomic particles. Still, we already...

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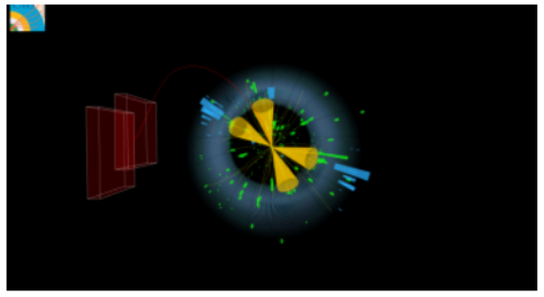

THE FOUR BEAUTIES IN THE TALE OF TWO HIGGSES

30 JUL 2021

The interaction of the Higgs boson with its own field leads to its mass generation. Since the Higgs boson mass has already been measured, the study of the Higgs pair production at the LHC reveals directly the strength of the Higgs self coupling λHHH...

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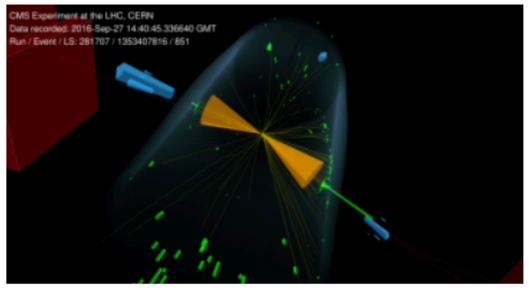

JETS-OF-ALL-TRADES: CONSTRAINING STANDARD MODEL AND BEYOND

25 JUL 2021

For the first time, CMS physicists extract the fundamental parameters of QCD together with constraints on the New Physics. Any tiny failure of the Standard Model to explain data behaviour is a possible window for the New Physics. An example is...

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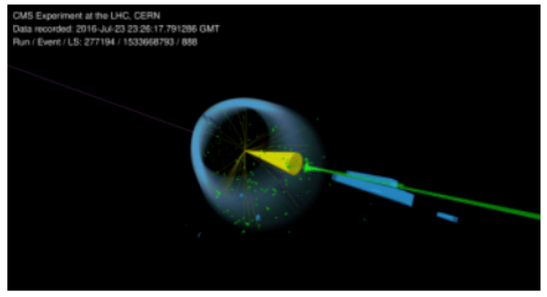

A TALE OF TWO COLLIDERS AND THE UNRIVALLED PRECISION ON THE Z INVISIBLE WIDTH

19 JUL 2021

The most powerful particle collider in the world, the Large Hadron Collider (LHC), was built in the 27 km tunnel originally excavated for the highest energy electron-positron collider ever built, LEP. As an extraordinarily sensitive machine, LEP was...

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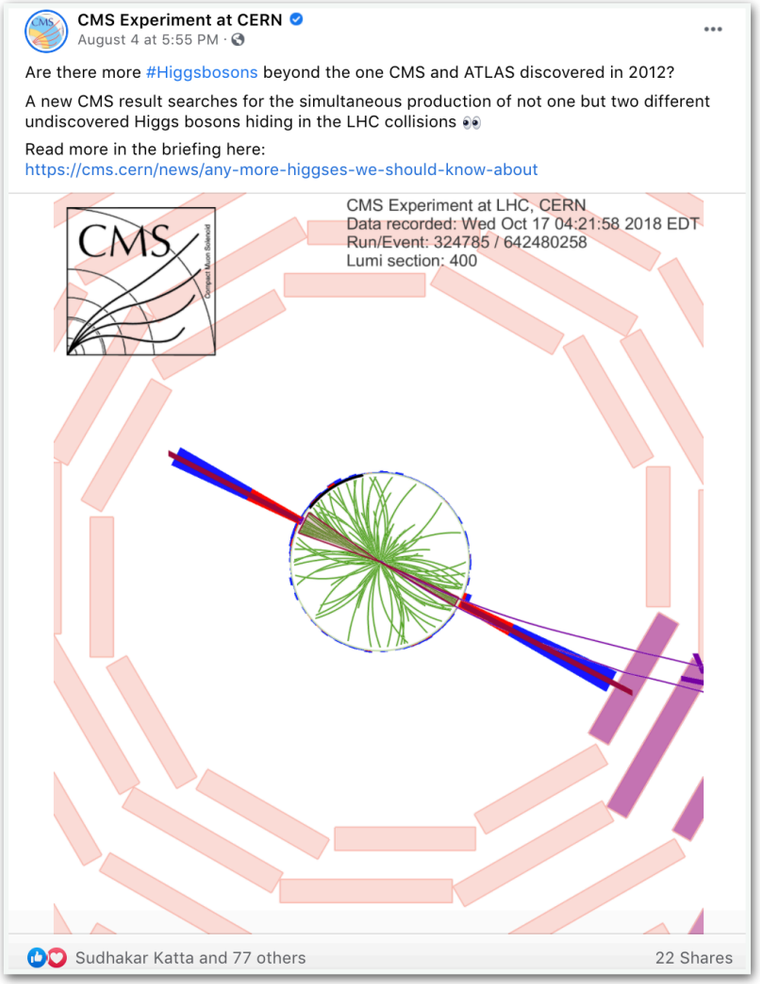
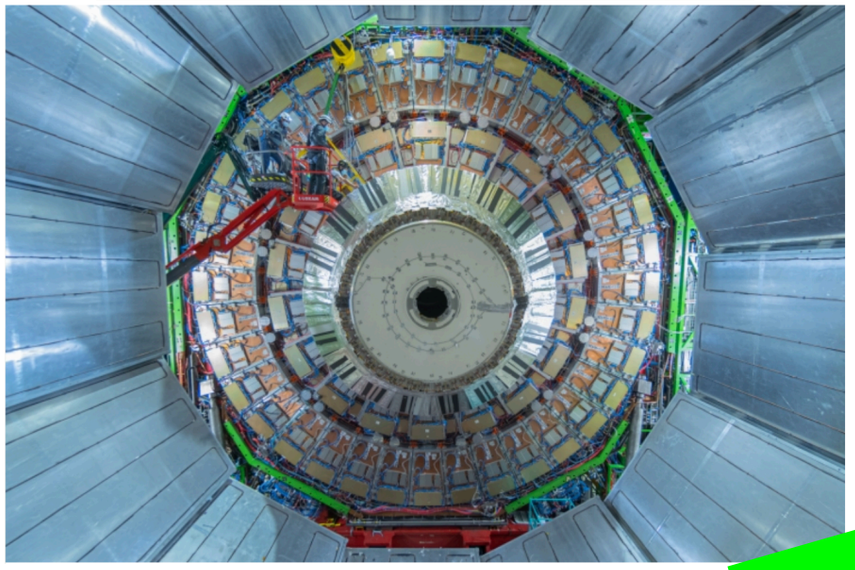


Physics briefings generally shared in social media to reach a broader audience.

Telling the world what we do, in easy & understandable language.
Mostly aimed at non-expert and young people.

DETECTOR ACTIVITIES DURING LS2

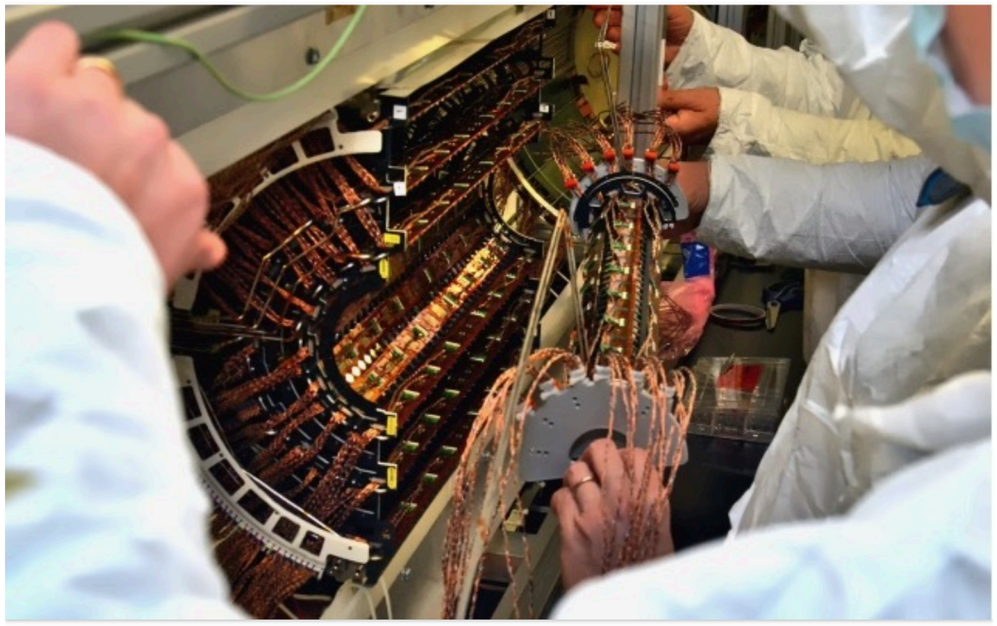
New GEM detector GE1/1 integrated in CMS



New CMS beam pipe installed, fully aligned and leak tested

LS2 milestones

CMS pixel tracker reinstallation after extensive repair and upgrade



CMS on track for the Pilot Beam Test (Oct 2021) and for the start of Run3 (Feb 2022)

HL-LHC UPGRADE

CMS detector upgrade in HL-LHC is a critical necessity, ensuring:
- Radiation hardness
- Mitigation of physics impact of high pileup

L1-Trigger

L1 tracks at 40 MHz
Regional ParticleFlow
750 kHz output

Barrel Calorimeters

ECAL+HCAL: New electronics
ECAL: Lower operating temperature to mitigate radiation-induced noise

HLT/DAQ

Heterogeneous (CPU+GPU)
7.5 kHz output

Tracker

Increased granularity
Extended coverage in η

Endcap Calorimeter (HGCAL)

Radiation tolerant
High granularity
5D (x,y,z,Energy,time) measurement

Muon systems

DT, CSC: new FE/BE readout
New GEM and RPC chambers
Extended coverage in η

MIP Timing Detector

Precision timing
Barrel: Crystals + SiPMs
Endcap: Low Gain Avalanche Diodes

Beam Radiation Instrumentation and Luminosity (BRIL)

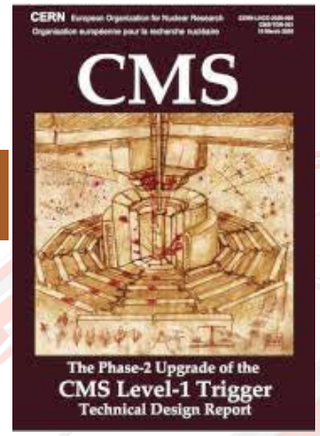
Improved precision of luminosity measurement

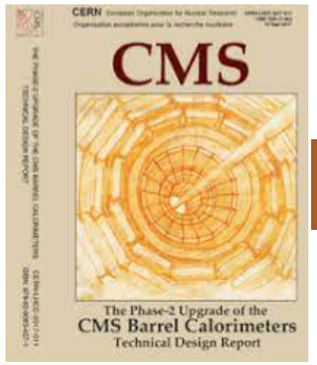
HL-LHC UPGRADE

More in this talk
The Phase-2 upgrade of the CMS experiment at LHC
by Davide Zuolo

The TDRs!

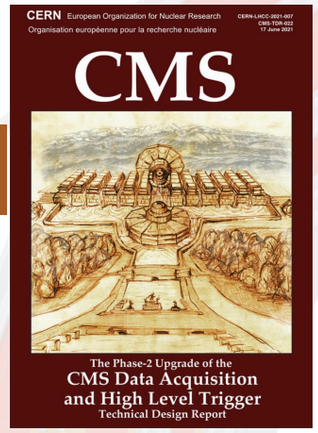
L1-Trigger



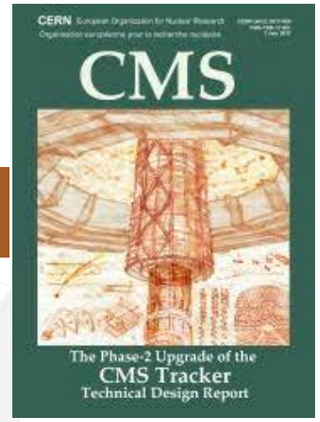


Barrel Calorimeters

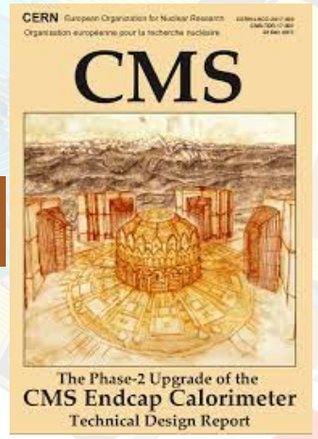
HLT/DAQ

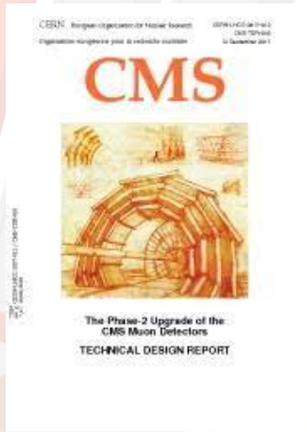


Tracker



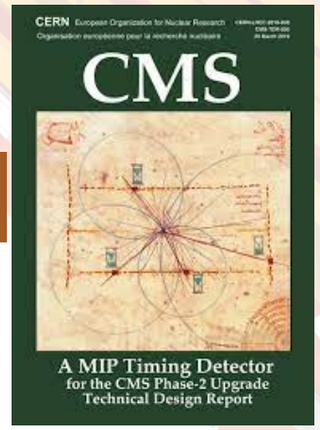
Endcap Calorimeter (HGCAL)

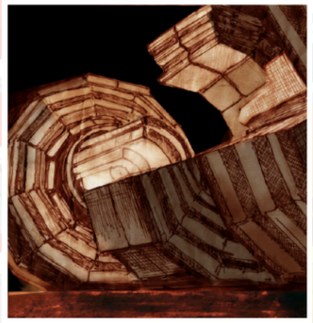




Muon systems

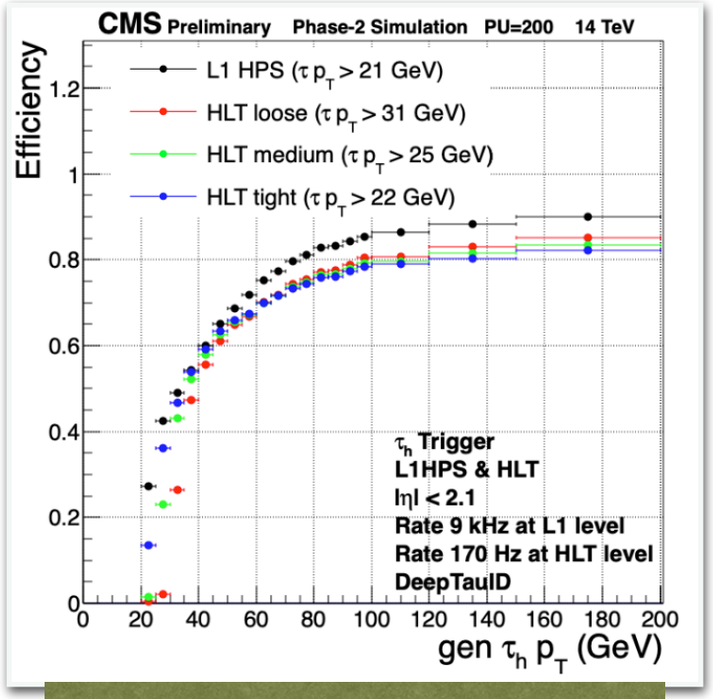
MIP Timing Detector



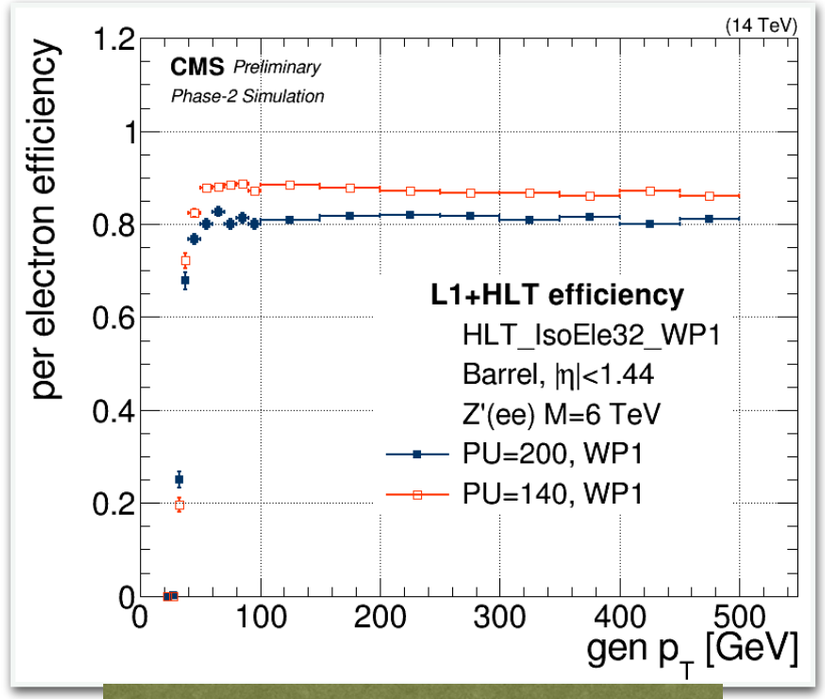


Beam Radiation Instrumentation and Luminosity (BRIL)

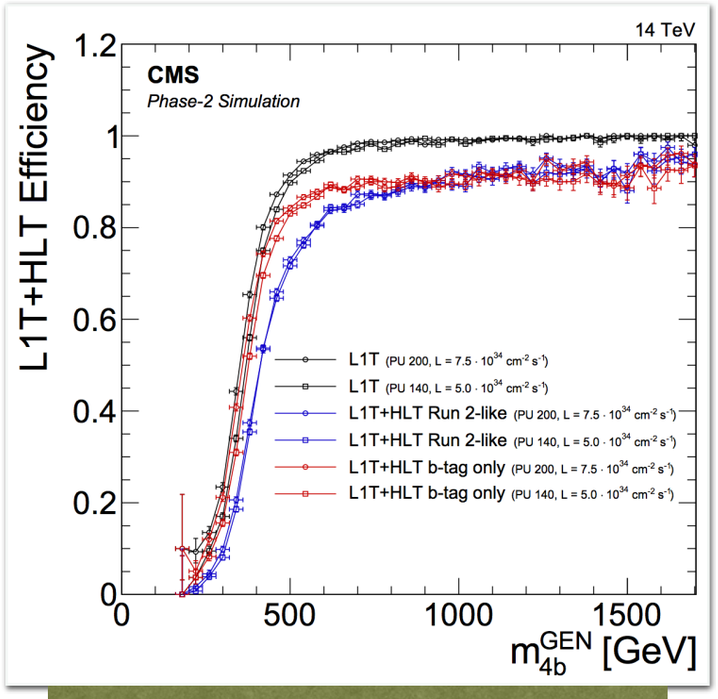
PHASE2 HLT TDR: SOME HIGHLIGHTS



Taus@HLT
CNN-based tau identification



Workhorse single electron HLT
(~1 kHz rate)

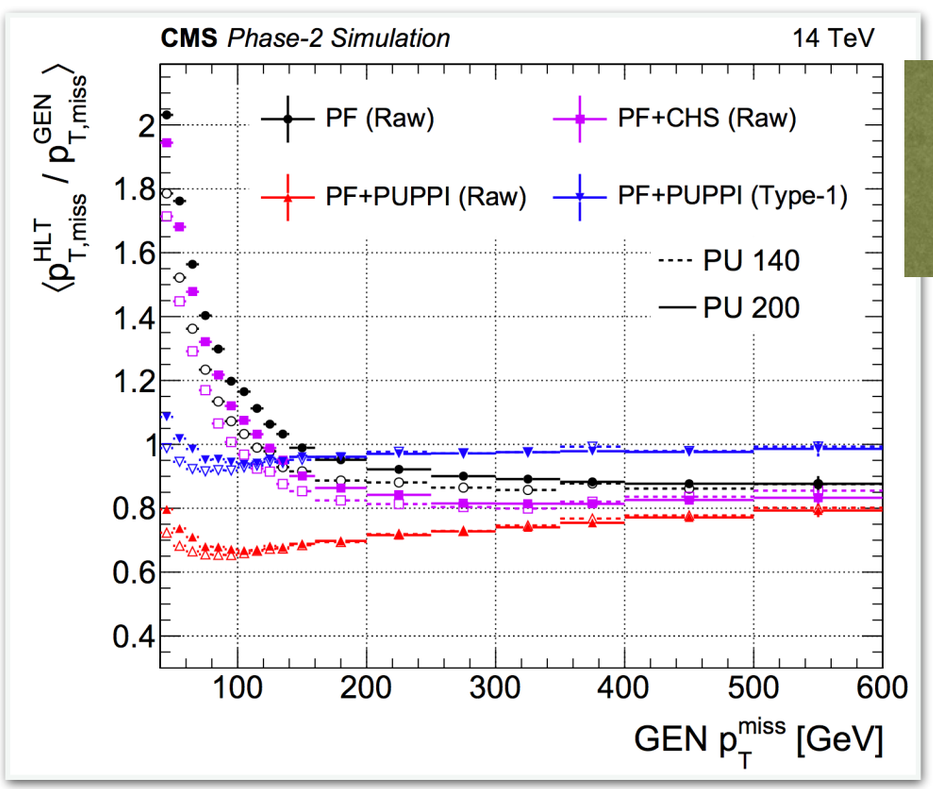


DeepCSV b-jet tagging @HLT

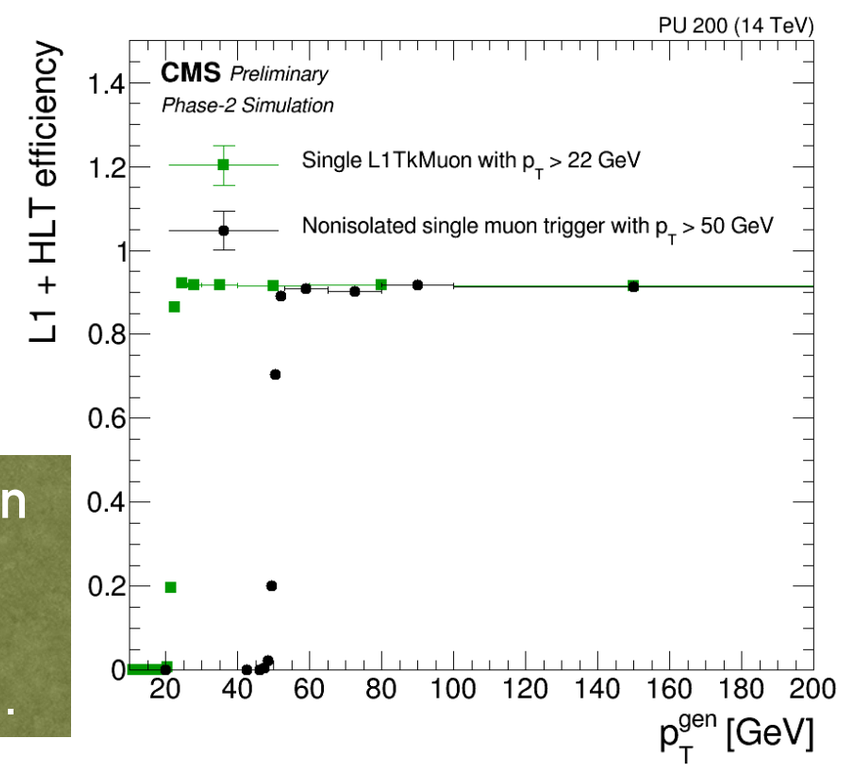
Run2-like efficiency & thresholds

Rate and timing under control

Prepared simplified but realistic HLT menu for HL-LHC



PF+PUPPI MET
Stable MET response
after corrections



Sharp turn-on
for muons.
Thanks to
tracking@L1.

SUMMARY

Wealth of new results analysing Run 2 data.

Several new models/signatures explored for the first time.

We still have many years and luminosity in front of us…

Up to now, LHC delivered ~5% of the total expected

CMS activities span in several different areas:

- Physics analysis
- Development of new techniques which are needed to exploit the huge amount of data
- Preparation and upgrades for the coming Run3 & HL-LHC

Stay tuned!

EXTRA SLIDES