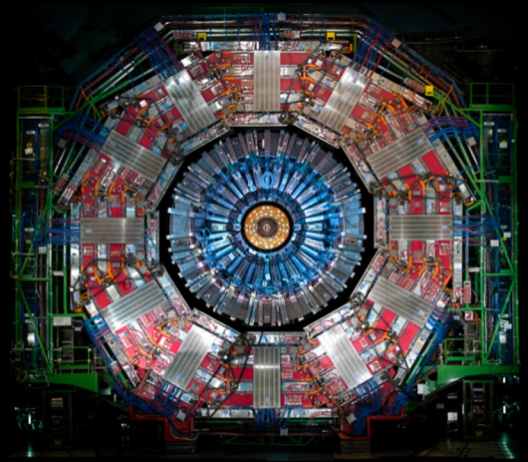
Belgium in CMS experiment

Didar Dobur
Ghent University

RECFA visit to Belgium
September 2025

Thanks to all my colleagues for their input:
B. Clerbaux, N. Van Remortel, P. Van Mechelen, S. Lowette, C. Delaere P. Vanlaer, A. Giammanco, G. De Lentdecker, A. Bethani, L. Thomas, L. Favart, M. Tytgat, A. Benecke, K. Skovpen, A. De Moor, J. Van der Linden, J. Knolle

Belgium in CMS experiment



1992

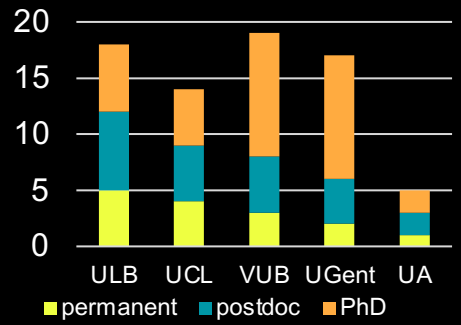
Letter of Intent
by the
CMS Collaboration

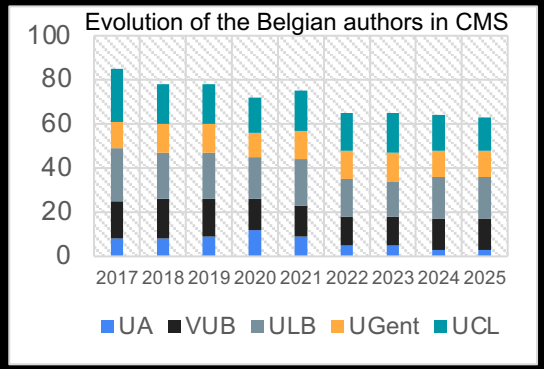
Université Libre, Bruxelles, BELGIUM
J. Sacton, C. Vander Velde, P. Vilain, G. Wilquet
Vrije Univ., Brussels, BELGIUM
J. Lemonne, S. Tavernier, W. Van Doninck, J. Wulleman
Université Catholique de Louvain, Louvain-la-Neuve, BELGIUM
D. Favart, G. Gregoire
Univ. Instelling Antwerpen, Wilrijk, BELGIUM
E. De Wolf, F. Veurbeure
Université de Mons Hainaut, Mons, BELGIUM
E. Daubie, F. Grard, O. Pingot, R. Windmolders

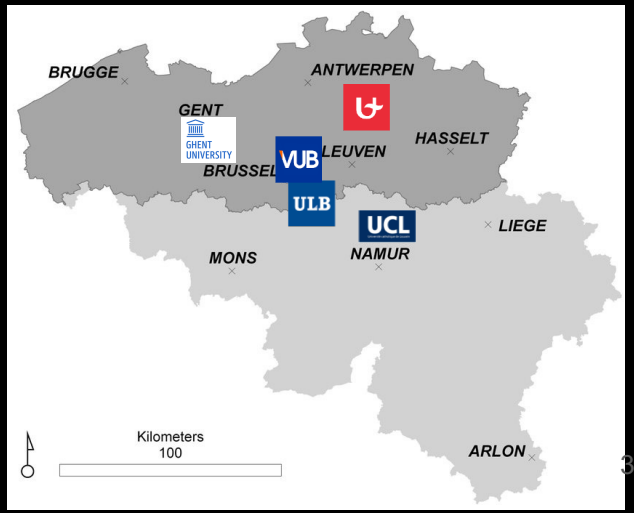
Five universities participate :

- **Université Libre De Bruxelles**
- **Université Catholique de Louvain**
- **Vrije Universiteit Brussel**
- **Universiteit Antwerpen**
- **Universiteit Gent**

In total 73 physicists corresponding to ~ 3%



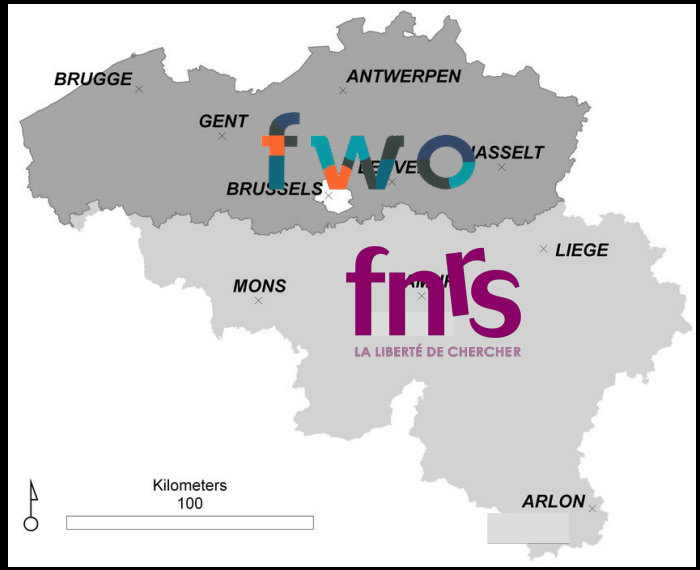




Funding (FWO & FNRS)

- Two regions - two funding agencies
  - Flanders: fwo →UA, UGent, VUB
  - Brussels-Walloon region: fnrs →UCL, ULB

“Base funding” to cover: M&O, Tier2, personnel for shifts/upgrade, EPR, technical personel, lab running:



- fwo
  - Special call: IRI (Int. Research Infrastructure)
  - VUB, UGent, UA apply together
  - ~ 6.2M € / 4y (‘23-’26)
  - Competitive, but so far stable

- fnrs
  - IISN handles conventions related to such large projects:
  - UCL/ULB application for 2/4y
  - Similar investment as FWO
  - Rather stable support

Funding (FWO & FNRS)

- Competitive funding for analysis
  - Smaller competitive projects with (very) low success rate → some attempts to increase it
  - Staring grants for new faculty/researchers
  - New: “WEAVE” across FWO-FNRS but also international

- Individual PhD and PD fellowships
  - Direct application with the funding agencies
  - Threshold is high, need access to excellent students
  - Data analysis better rewarded than instrumentation projects

- There exist funding at university level as well, but size differs across universities

- Global picture
  - sustained and rather stable HEP funding
  - strong support from our funding agencies

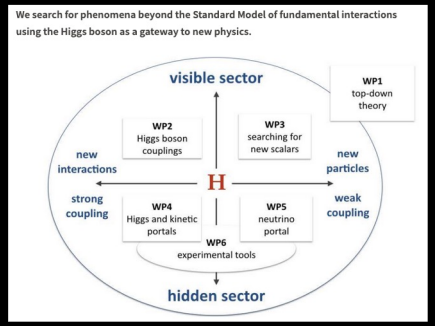
Funding (FWO & FNRS) → Inter-University Collaborations

- Competitive funding across FWO-FNRS: EoS (program discontinued)
  - Total budget: 3 772 000 € / 4 years (2018-2021)
  - Connecting experiment & theory ; connecting 6 groups in 5 universities north and south
  - Many workshops and events
  - 22 postdocs, >11 (including joint) PhDs

EOS
THE EXCELLENCE OF SCIENCE

be.h

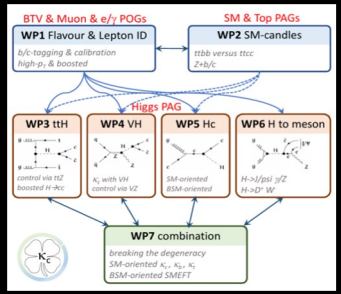
– The H boson gateway to physics beyond the Standard Model –



be.HEP EOS meeting 2018 @ Ghent

be.HEP EOS meeting 2022 @ Ghent

- FWO iBOF (Flanders only)
  - VUB + UA + UGent
  - Total budget: 2.4M € (2023-'2027)
  - Project focus: charm Yukawa coupling

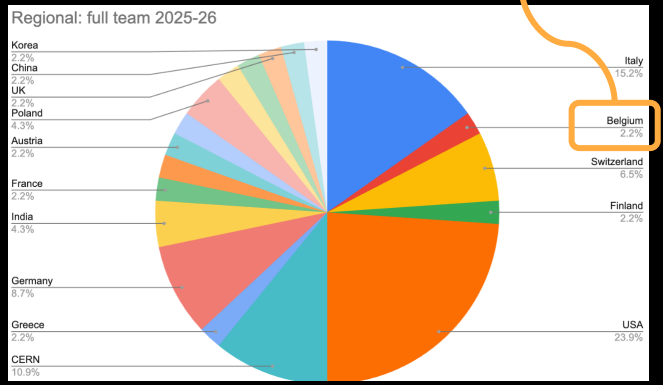


Visibility in CMS (last 5 years)

- Top management level
  - Gilles De Lentdecker: Muon Project Manager (‘25-’27)
  - Anna Benecke: Physics Performance and Datasets manager (‘25-’27)
  - Didar Dobur: Collaboration Board secretary (‘24-’25)
  - Pierre Van Mechelen: Publication committee deputy, Management Board (‘24-’26)

- Level-2 management
  - Gilles De Lentdecker: GEM system manager (‘22-’25)
  - Christophe Delaere: Outer Tracker project coordinator (‘21-now)
  - Michael Tytgat: Muon-RPC Institution Board Chair (‘22-’24)
  - Martin Delcourt: Tracker Data Performance Group (‘24-’26)
  - Laurent Thomas: L1 Trigger Data Performance Group (‘21-’23) and Jets and missing energy group (‘19-’21)
  - Steven Lowette: Exotica group (‘20-’22) and Physics officer ESPPU (‘24-’25)
  - Bugra Bilin: Generator group (‘23-’25)
  - Anna Benecke: Jets and missing energy group (‘23-’25)
  - Kirill Skovpen: Tracking group (‘23-’25) and Physics Data and MC Validation (‘21-’23)
  - Alexandre De Moor: Heavy flavour tagging group (‘25-’27)
  - Seth Moortgat: Heavy flavour tagging group (‘20-’21)
  - Joscha Knolle: Luminosity group (‘21-’23)
  - Sebastien Wertz: Cross-POG coordination (‘22-’23)
  - Claudio Caputo: Reconstruction (‘22-’23)
- And many Level-3 management positions

- CMS Awards: Inna Makarenko (2020), Pieter David (2021), Laurent Pétré (2022), Bugra Bilin (2022), Georgios Krintiras (2022), Sam Bein (2023), Anna Benecke (2024), Itana Bubanja (2024)
- CMS Thesis Award: Willem Verbeke (2022)



Belgium in CMS L2 physics coordination:

2025: 2.2%
2024: 4.4%
2022: 4.4%
2021: 6.8%
2020: 9%

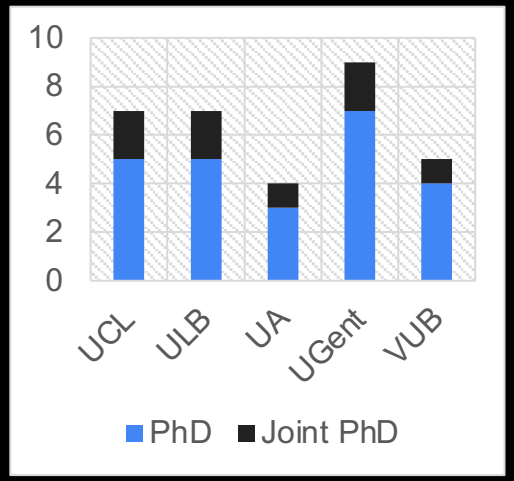
Decreese

CMS shifter mugs !!!

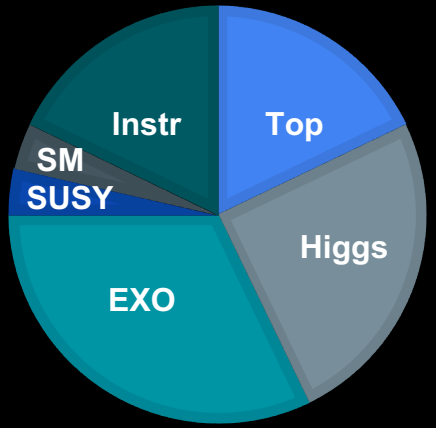
M. De Coen (UGent)
T. Jansens (UA)
T. Van Laer. (UA)
Oguz Guzel (UCLouvain)

Physics Output Highlights :PhD students

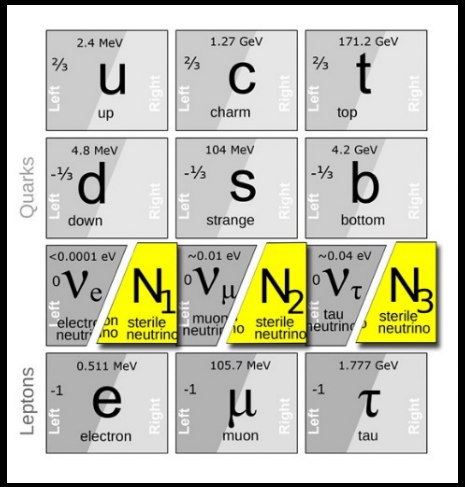
- 28 unique PhD theses in CMS completed in the last 5 years
- Assuming ~250 thesis/year in all CMS this corresponds to 2.2%
- Joint PhD → inter-university collaboration

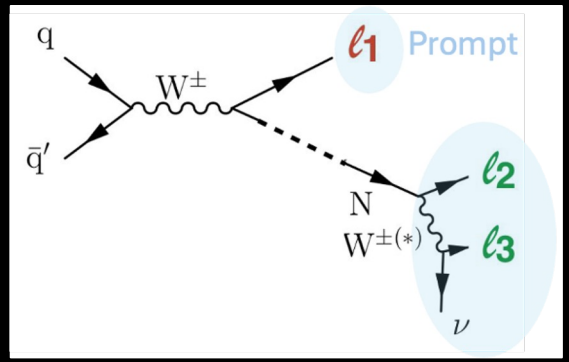


How they are distributed across CMS Physics groups

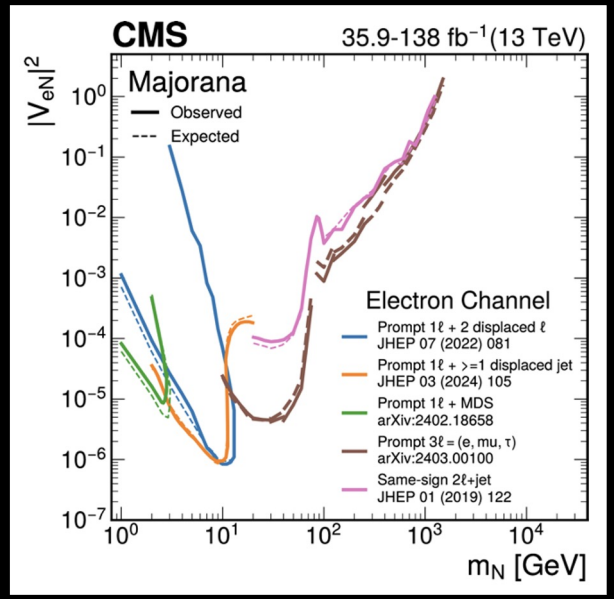


Search for Heavy Neutrinos





- Multiple experimental signature:
- Prompt or displaced vertices
- Best sensitivity
- Five PhD students graduated



Willem Verbeke (UGent)
CMS Best thesis award, 2022

PRL 120, 221801

JHEP 07 (2020) 081

JHEP 06 (2024) 123

JHEP 03 (2024) 105

JHEP 02 (2025) 036

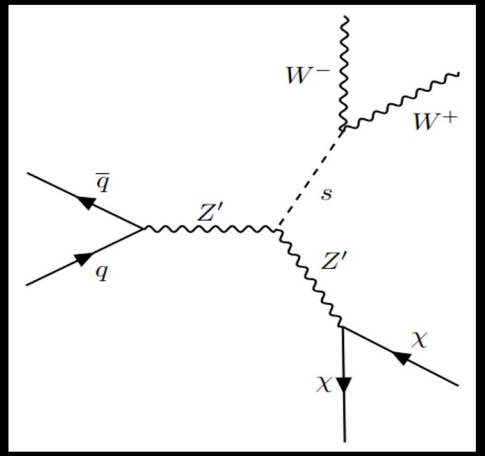
A nice example of inter-university collaboration

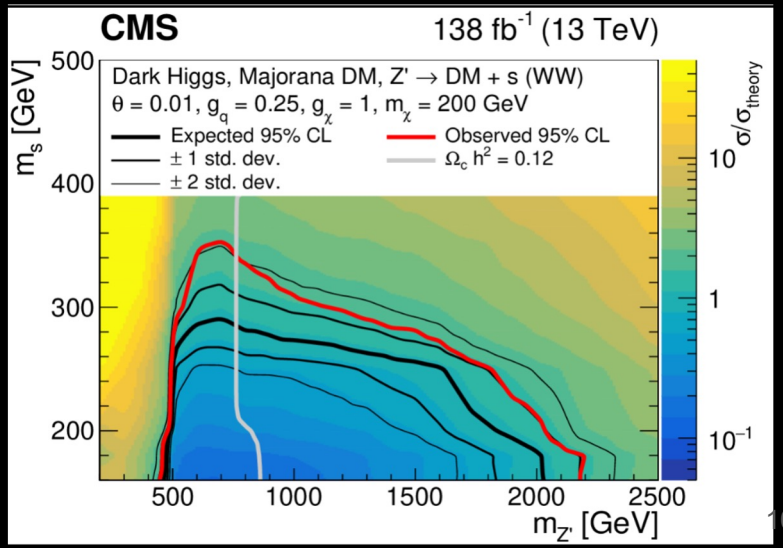
Search for dark matter

- UAantwerp historical in H→WW since early LHC. Nowadays perform several related new analysis:
  - Search for dark matter (χ) in association with a dark Higgs boson (s) decaying to a W^+W^- pair
  - Z' as a mediator to the dark sector
    - demonstrates the LHC's strength in searches where the mediator can be produced on-shell
  - Significantly improved exclusion regions in m_s-$m_{Z'}$ plane for different m_χ values

    JHEP 03 (2024) 134
  - Also study anomalous couplings of Higgs boson with vector bosons in H→WW

    EPJC 84 (2024) 779



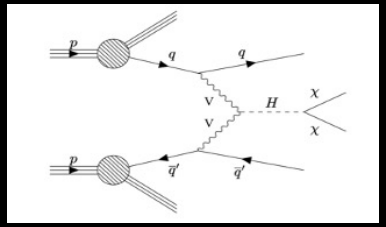


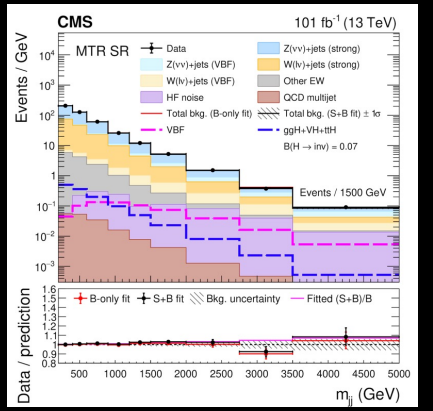
Search for BSM Higgs decays

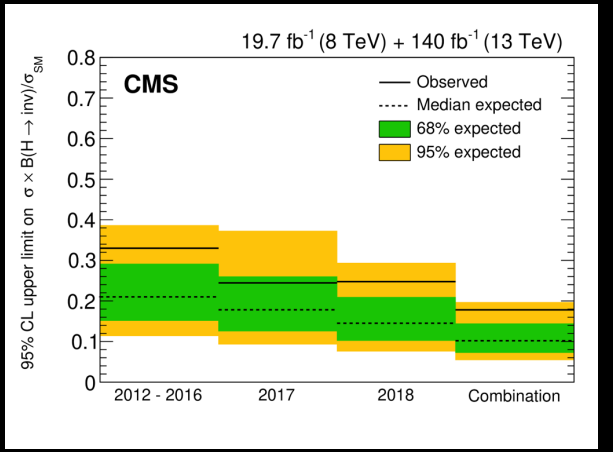
- Long-standing effort for H→invisible
- VBF signatures to search for Dark Matter

  Phys. Rev. D 105 (2022) 092007

- Run3 effort with ML to tag the production mode (1st time in CMS) → Strong synergy with VUB





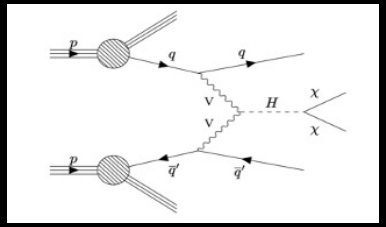


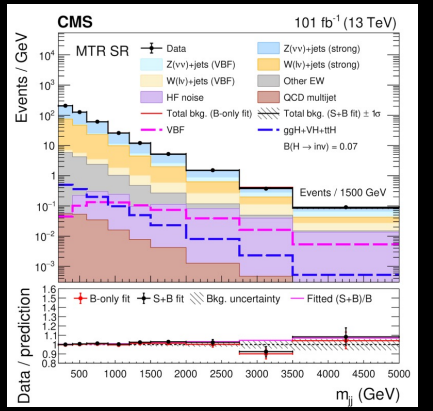
Search for BSM Higgs decays

- Long-standing effort for H→invisible
- VBF signatures to search for Dark Matter

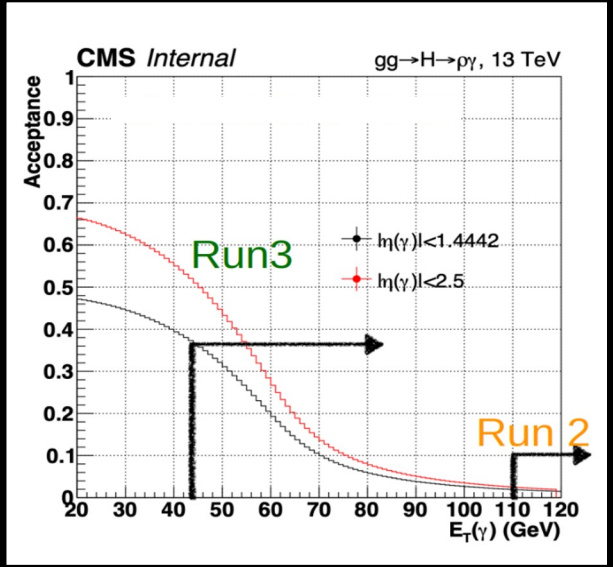
  Phys. Rev. D 105 (2022) 092007

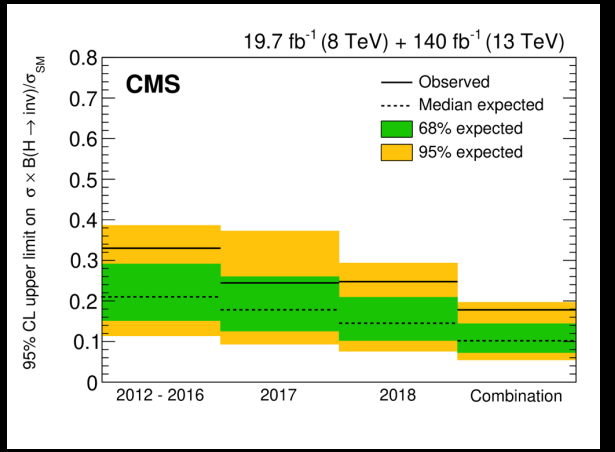
- Run3 effort with ML to tag the production mode (1st time in CMS) → Strong synergy with VUB





- ULB has a strong involvement in CMS trigger
- Developed a very interesting single-photon trigger with low p_T
- Opens Run3 data to many new analyses





Search for BSM Higgs decays

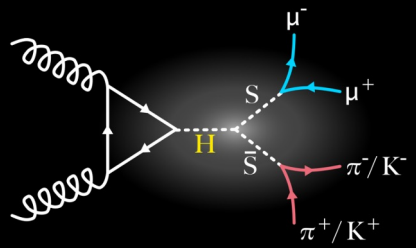
Upper bound on Higgs→new particles < ~10%

- Still lots of room for BSM Higgs decays

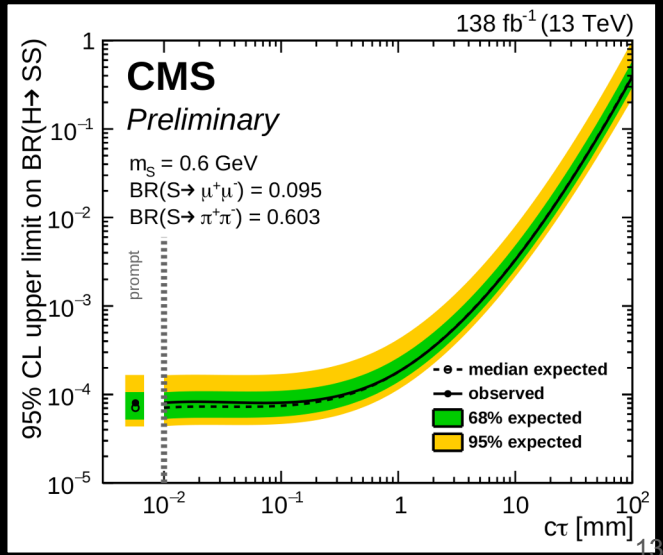
Search for H→SS at very low mass

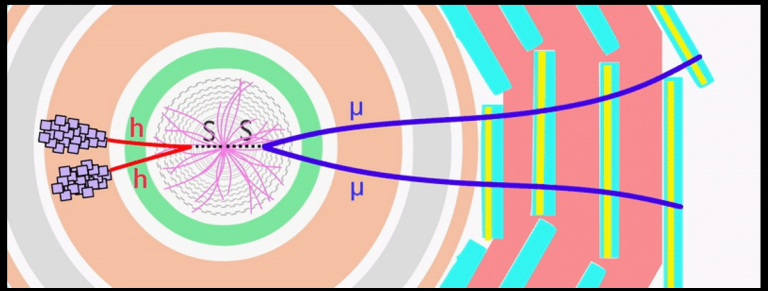
- Exclusive decay to collimated pairs of muons and hadrons
- Excellent mass resolution, nearly background free
- Considered prompt decay as well as displaced

Sensitivity BR(H→SS) below 10^{-4} over wide mass range m(S)<2GeV



CMS-PAS-EXO-24-034





Search for fractionally charged particles

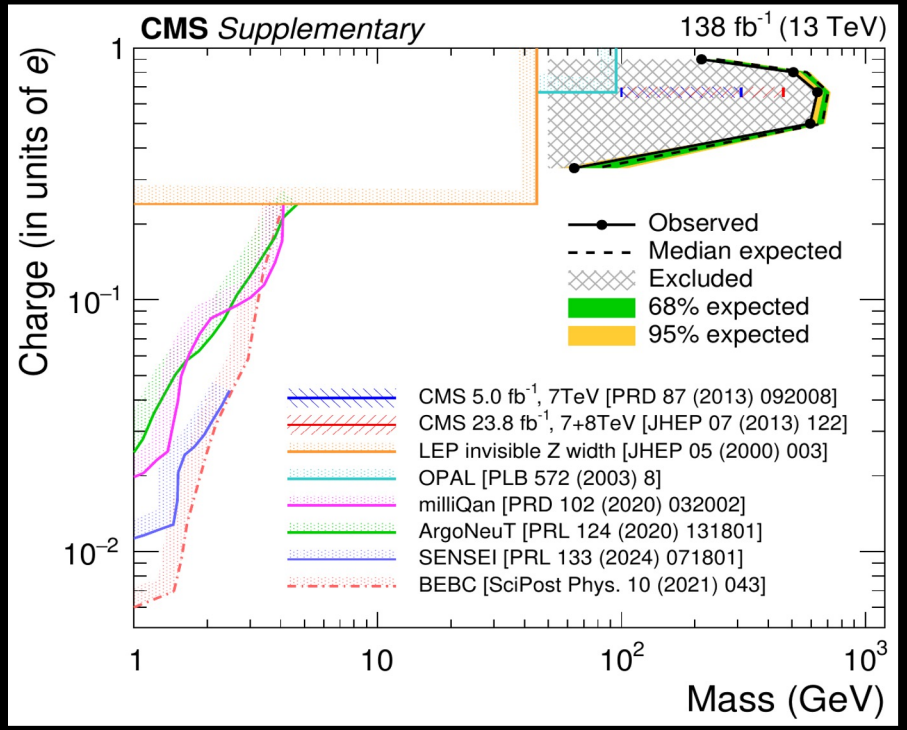
CMS drives searches for high-mass fractionally charged particles

- CMS Si tracker is unparallelled
- Use tracker dE/dx measurements
  - Search for muon-like particle with low ionization
- Unique leading sensitivity for ⅓ < Q < 1e

- Run-3 analysis in the works
  - Combine tracker dE/dx with muon beta
  - Invert Bethe-Bloch to estimate both particle charge and mass
  - Aiming also at lower mass and charge

Synergy with milliQan experiment

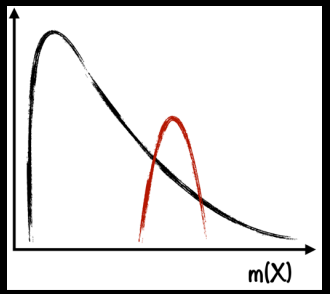
PRL 134 (2025) 131802

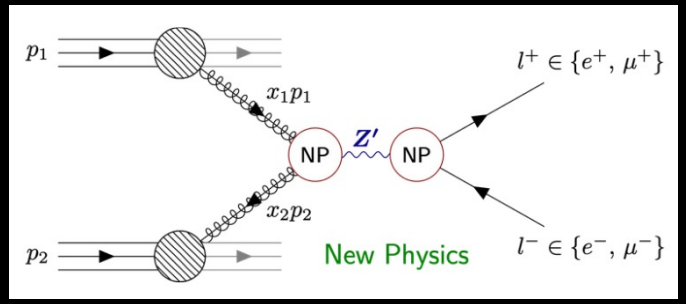


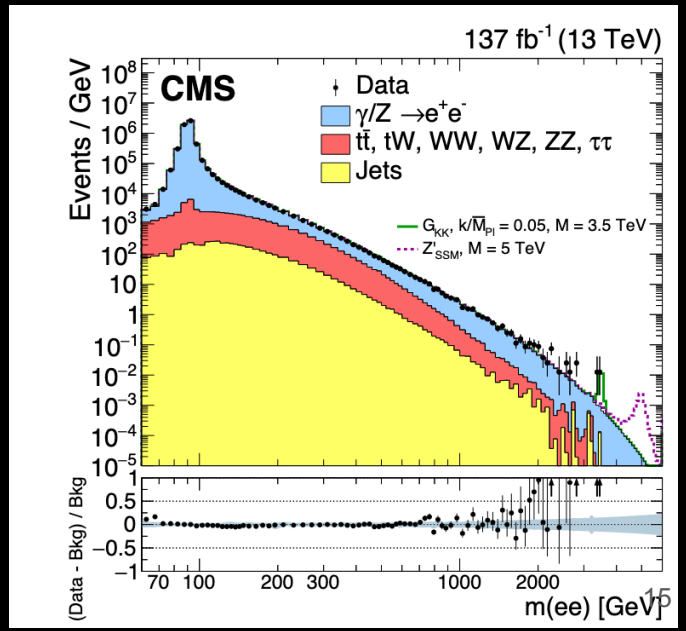
Search for Heavy resonances

- ULB leadership since early LHC
- Looking for new particles in the tail of DY process
- Impact on high pT electron and tau reconstruction & ID
- Bump hunt in $m(ee)$ $m(\mu\mu)$ tails *JHEP 07 (2021) 208*
- Bur also LFV resonances and QBHs in eμ, eτ and μτ final states. JHEP 05 (2023) 227

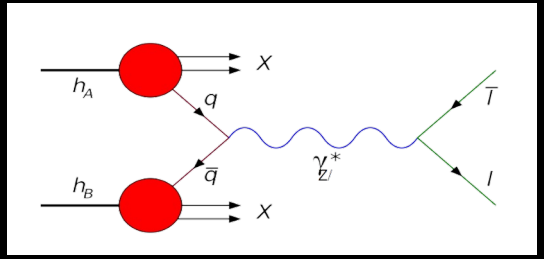
- Run3 effort with improved techniques is ongoing







Charting the Drell-Yan process



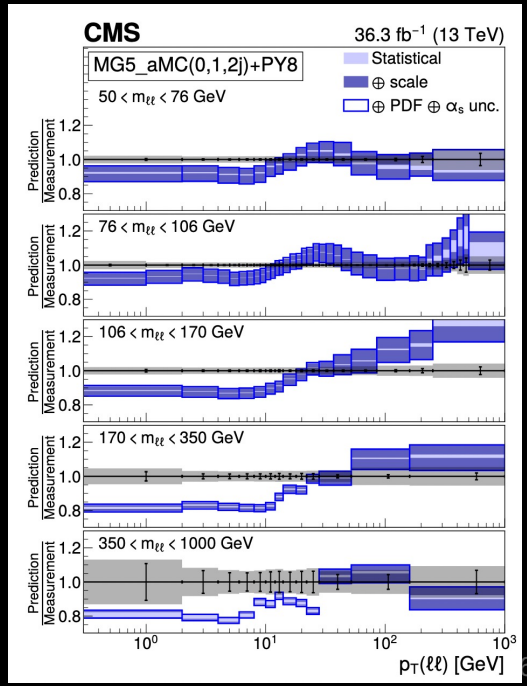
Differential cross section measurement

- Precise test of the standard model
  - Important input to parton distribution functions and gluon resummation

EPJC 83, 628 (2023)

- Ongoing efforts with full Run2 data
  - Scouting data (Run2 + Run3)
  - Single -> multi-dimensional fit

Standard data stream: ~ 1 kHz, ~ 1000 MB/s	Prompt offline reconstruction
Scouting data stream: ~ 5 kHz, ~ 40 MB/s	No offline reconstruction

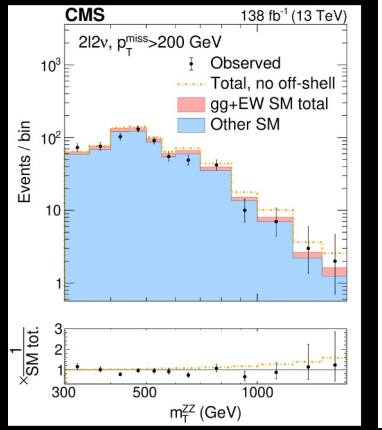


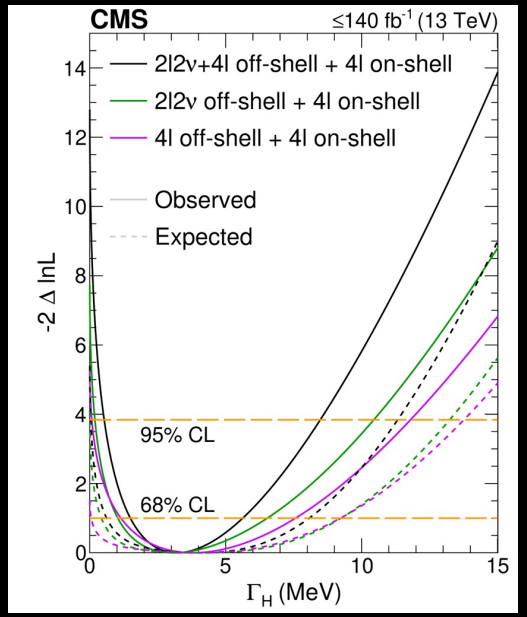
Measuring the Higgs decay width

Nat. Phys. 18 (2022) 1329

- Accessing the H decay width through off-shell region

$$\sigma^{\text{on-shell}} \propto \frac{g_p^2 g_d^2}{\Gamma_H} \propto \mu_p \Rightarrow \sigma^{\text{off-shell}} \propto g_p^2 g_d^2 \propto \mu_p \Gamma_H,$$





- ULB contribution in decay mode **H → ZZ → 2l2ν**

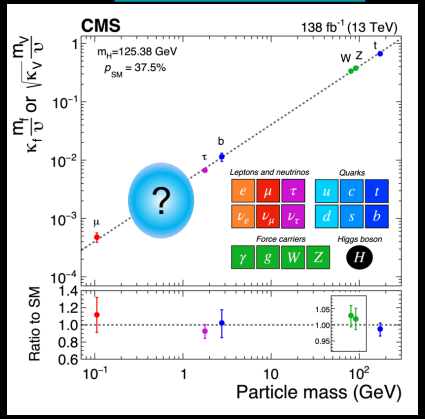
  $\Gamma_H = 4.1$ MeV ;

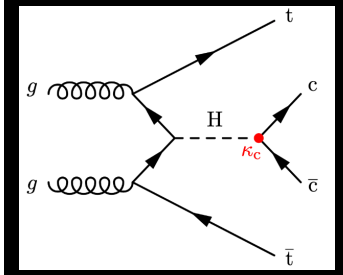
  measurement: $\Gamma_H = 3.2^{+2.4}_{-1.7}$ MeV

- Various side projects in the ZZ final state:
  - Study of constraints on the trilinear coupling from off-shell H decays HIG-25-003
  - Study of Vector-Boson Scattering and EFT interpretation SMP-23-001

Higgs-charm coupling

Nat. Phys. 18 (2022) 1329





- Simultaneous b and c jet identification with *ParticleNet* tagger
- All decay modes of $t\bar{t}$
- Collaborative effort

First ever limit on ttH(H→cc) production!

μ ≲ 8 x SM observed

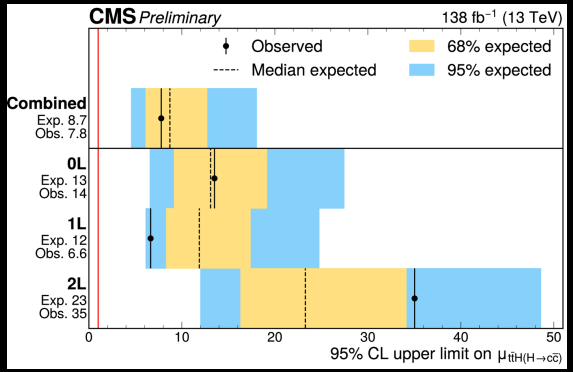
Most stringent individual limits on Higgs-charm coupling and surpasses the HL-LHC projections from 2022

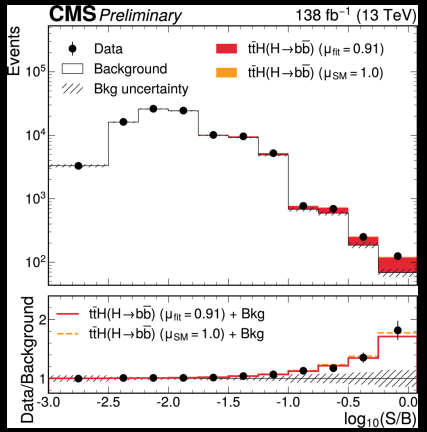
κ_c ≲ 3 x SM observed

Side products:

Highest sensitivity to $ttH(H \to b\bar{b})$ 4.4 σ observed

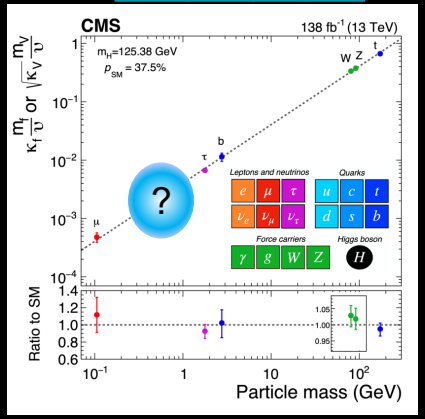
PAS-HIG-24-018 (2025)

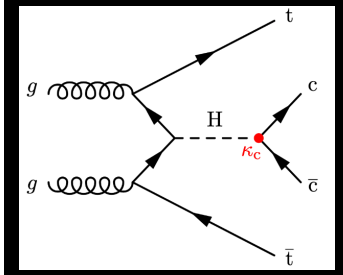




Higgs-charm coupling

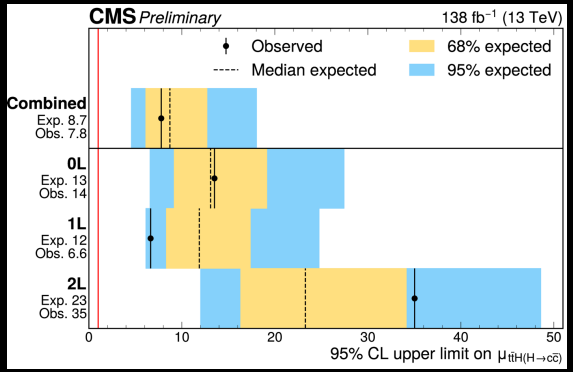
Nat. Phys. 18 (2022) 1329





- Simultaneous b and c jet identification with *ParticleNet* tagger
- All decay modes of $t\bar{t}$
- Collaborative effort

PAS-HIG-24-018 (2025)



First ever limit on ttH(H→cc) production!

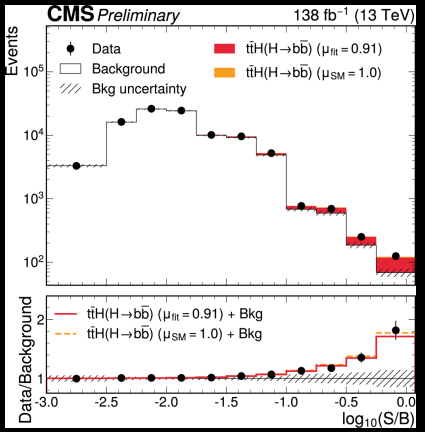
μ ≲ 8 x SM observed

Most stringent individual limits on Higgs-charm coupling and surpasses the HL-LHC projections from 2022

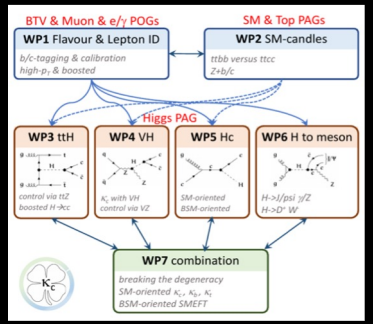
κ_c ≲ 3 x SM observed

Side products:

Highest sensitivity to $ttH(H \to b\bar{b})$ 4.4 σ observed



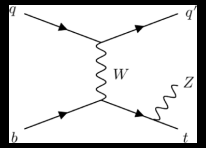
iBOF project



Many more results on Higgs-charm coupling are ongoing → High impact in the coming years

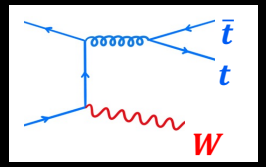
Top quark measurements ($t\bar{t} + V$)

- Leadership in several $t\bar{t} + V$ measurements
  - Observation of tZq, Inclusive and differential measurements

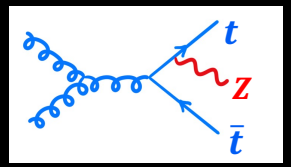


PRL. 122 (2019) 132003
JHEP 02 (2025) 177

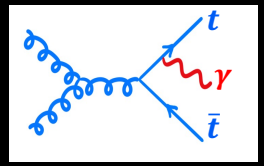
  - Inclusive and differential measurements of $t\bar{t}W$, $t\bar{t}Z$ and $t\bar{t}\gamma$



TOP-24-003
JHEP 07 (2023) 219

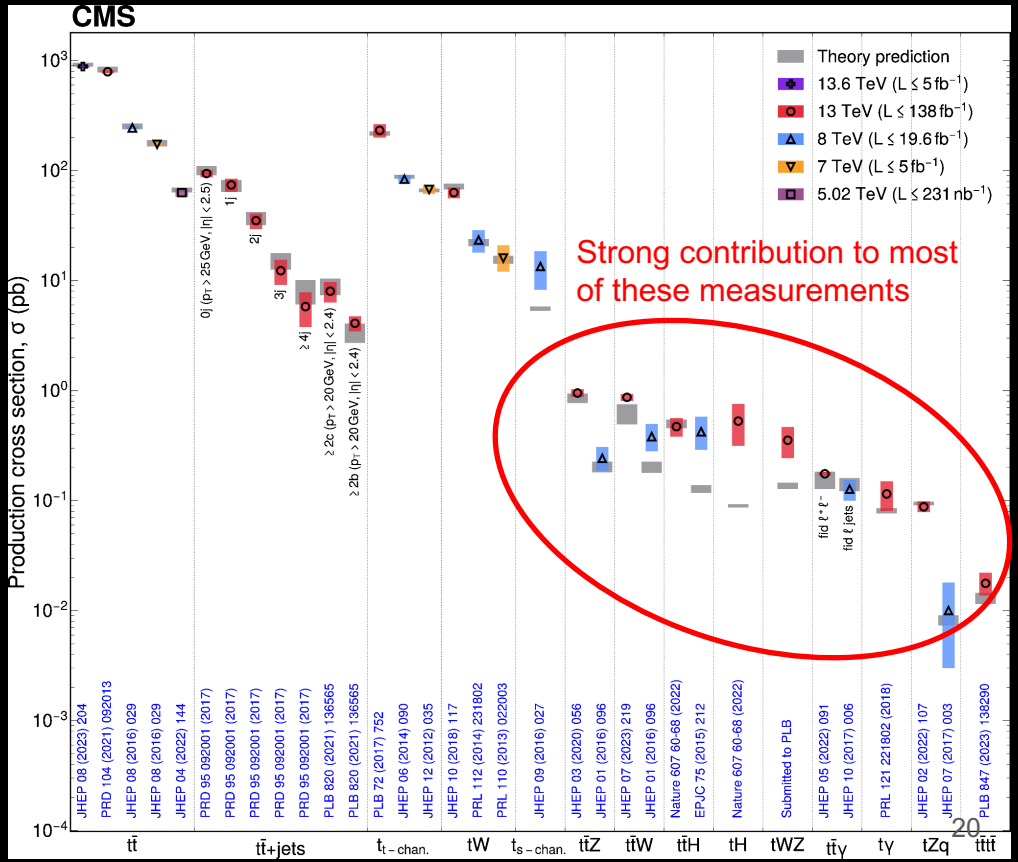


JHEP 03 (2020) 056



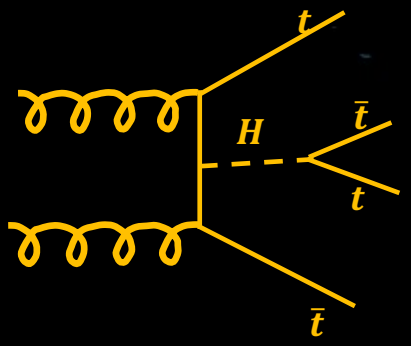
JHEP 05 (2022) 091

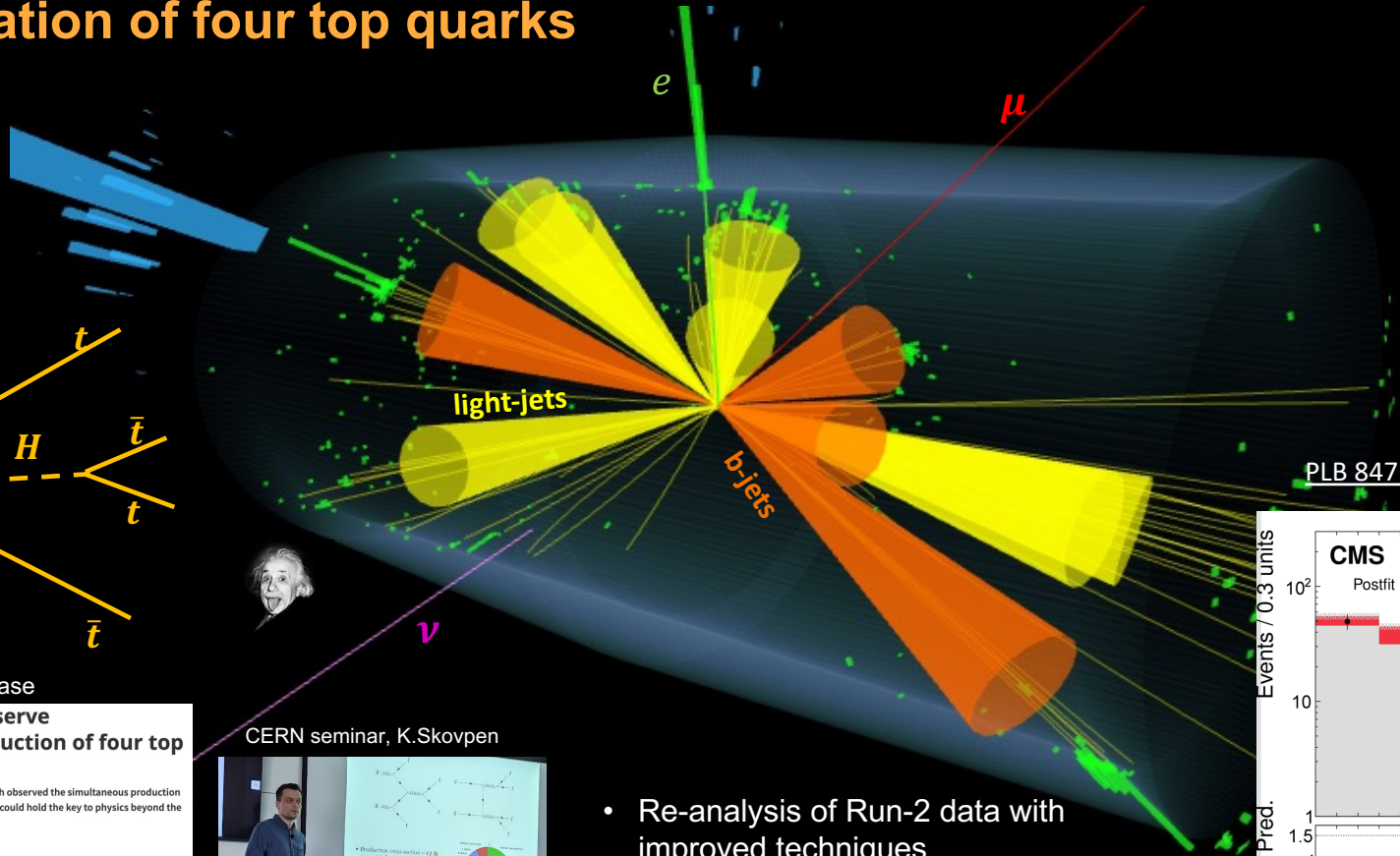
Strong synergy with the theory colleagues at UCLouvain (F. Maltoni, G.Durieux, C. Degrande)



Observation of four top quarks

GHENT UNIVERSITY



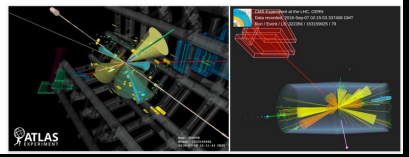


CRN Press-release

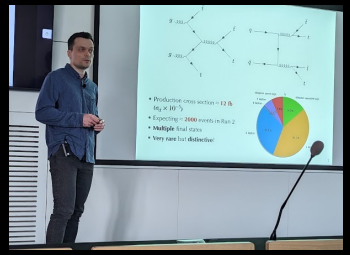
ATLAS and CMS observe simultaneous production of four top quarks

The ATLAS and CMS collaborations have both observed the simultaneous production of four top quarks, a rare phenomenon that could hold the key to physics beyond the Standard Model

24 MARCH, 2023 | By Naomi Dinmore

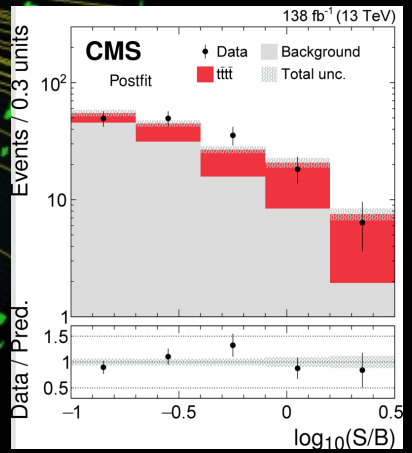


CERN seminar, K.Skovpen



- Re-analysis of Run-2 data with improved techniques
- Observation with $> 5\sigma$
- Important milestone at LHC
- Ongoing Run3 analysis

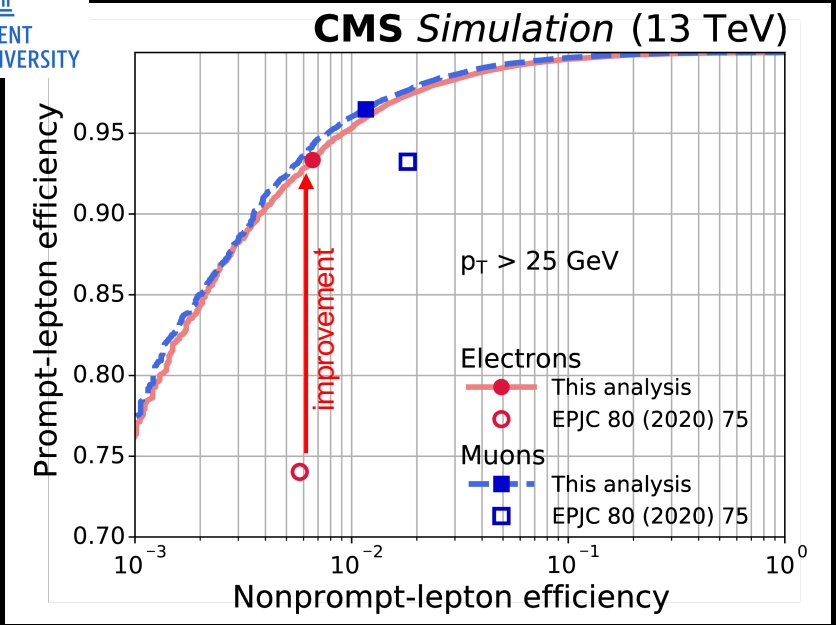
PLB 847 (2023) 138290



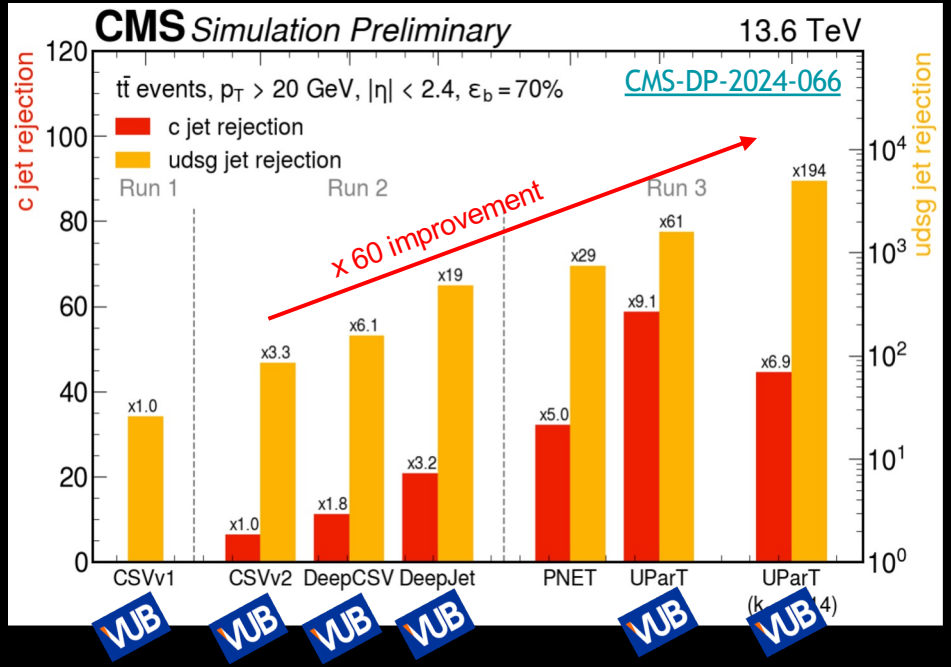
Jet-tagging and lepton identification with ML

GHENT UNIVERSITY

Electron and muon identification efficiency



c-, udsg-jet rejection with 70% b-jet tagging efficiency

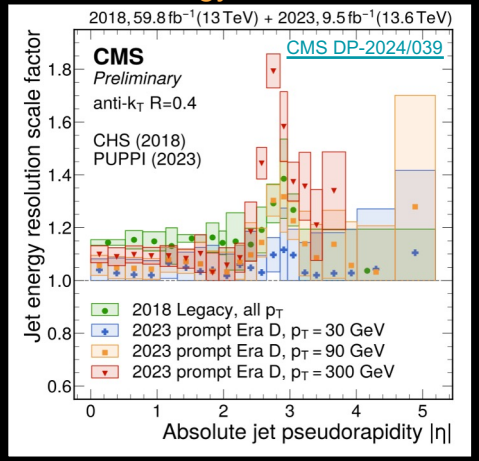


ML based lepton ID and accurate calibrations, were key in several first observation of top-Higgs processes (tZq, ttH, tWZ, tttt)

Evolution of the light- (yellow bars) and c-jet (red bars) rejection for a fixed b-jet identification efficiency of 70% for taggers from Run 1 to Run 3. Belgium contributed directly in the development of several of these taggers across the years

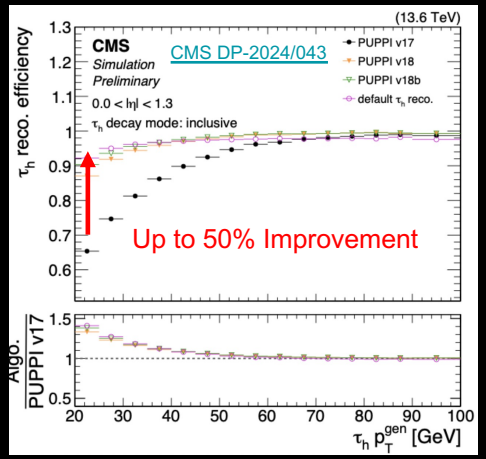
Improved data quality and objects

Jet energy resolution



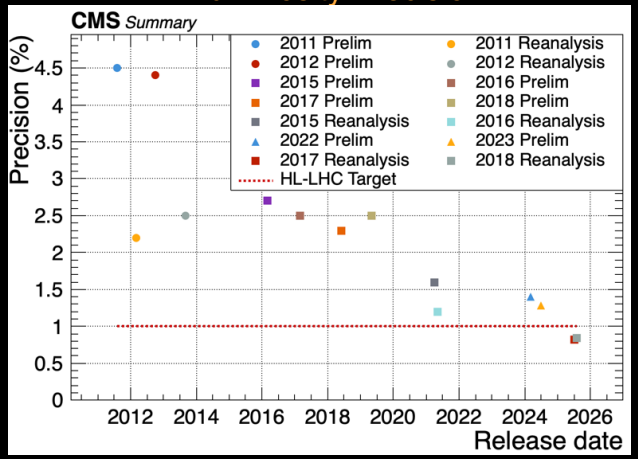
Improved jet energy calibrations in prompt reconstruction, outperforming legacy Run2

Hadronic tau identification



Improved hadronic tau identification making it robust against PU → important for HL-LHC

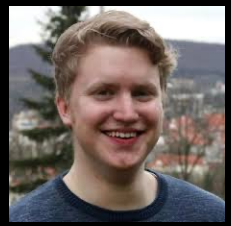
Luminosity Precision



- Significant contribution to luminosity calibrations: Beam position and shape studies
- New era of precision cross section measurements!

Anna Benecke (UCL)
JetMet POG convenor,
2024 CMS award

L. Thomas (ULB),
JetMET POG convenor,
L1 Trigger DPG convener,
2017 CMS award



J. Knolle (UGent),
Lumi POG convenor
2020 CMS award

Top physics workshop in Ghent

https://indico.cern.ch/event/1473617/

JetMET workshop in Brussels

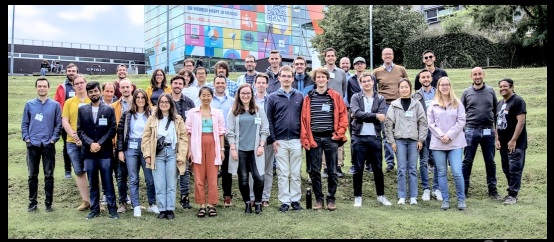
https://indico.cern.ch/event/1230157/

NPS workshop in Louvain-la-Neuve

https://indico.cern.ch/event/1484533/

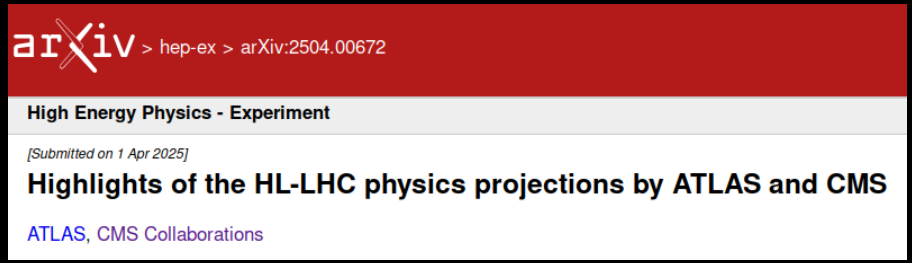
BTV workshop in Brussels

https://indico.cern.ch/event/1274182/



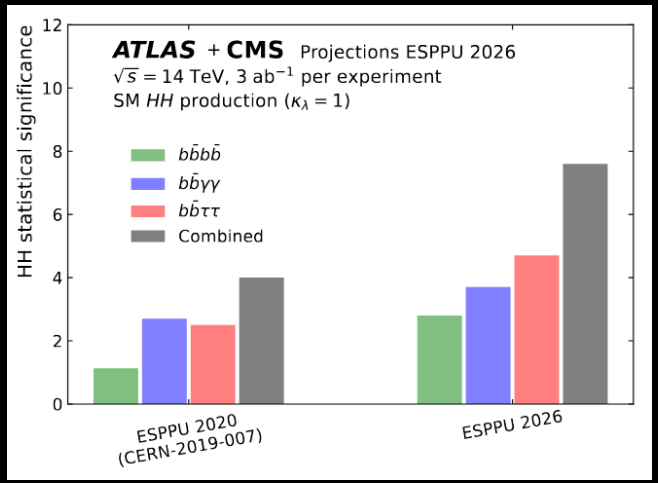
HL-LHC input to European Strategy

- ATLAS + CMS inputs to the European Strategy on Particle Physics Update 2026
- Much improved estimate of key goals at HL-LHC: Higgs self-coupling, rare Higgs decays, top physics,...
- Impact assessment of HL-LHC knowledge of scalar potential on viable BSM models



Belgian contribution

- Co-coordination of the overall effort, S. Lowette (VUB)
- Theoretical studies underpinning the BSM interpretations F. Maltoni and S. Tentori (UCLouvain)



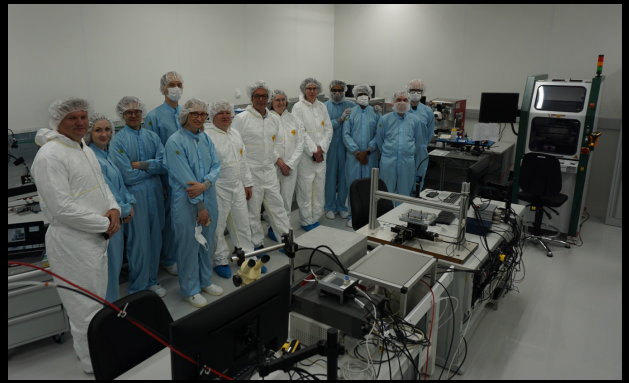
Visit of the CMS management

The program in Ghent
> https://indico.ugent.be/event/199/

April 2025

Visit in Brussels and UCL:
https://indico.cern.ch/event/1534412/

Fruitful event where young people could get a chance to interact with the SP-team and we could show our labs/activities



Celebrations

A Decade of Discoveries in High-Energy Physics

https://agenda.irmp.ucl.ac.be/event/4816/

- Symposium to celebrate the discoveries of the past decade
- ~200 participants at Brussels Town Hall
- Invited inspirational speakers, panel discussion and an outreach event

Summary

The Belgian participation in CMS
- is strong in all areas from detector to high-quality data
- is leading in physics analyses
- is impactful in the management

More than the sum of the individual parts
- continued tradition of collaboration between institutes
- strong sense of community
- also with pheno, theory, neutrino, astroparticle

Funding situation is good and stable
- Always felt support by our funding agencies
- EOS program unfortunately discontinued

The future is exciting
- Run-3 in full swing: large datasets and many novelties
- HL-LHC will bring another decade of new opportunities