

A large group of people, including students and staff, are gathered in a massive industrial hall. In the background, the CMS detector structure is visible, a large, complex, circular structure with many layers of equipment. The hall has high ceilings and large windows. The text is overlaid on a semi-transparent grey circle.

CMS experiment in Belgium

Freya Blekman (VUB)

R-ECFA visit
Brussels
21 April 2017

Belgium at CERN

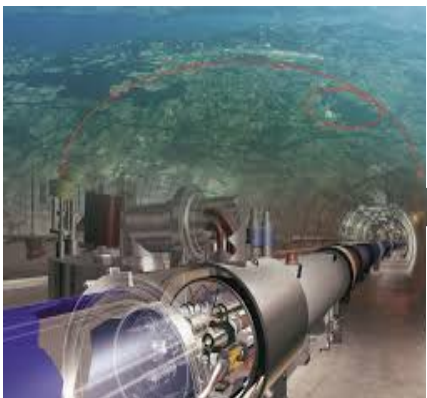
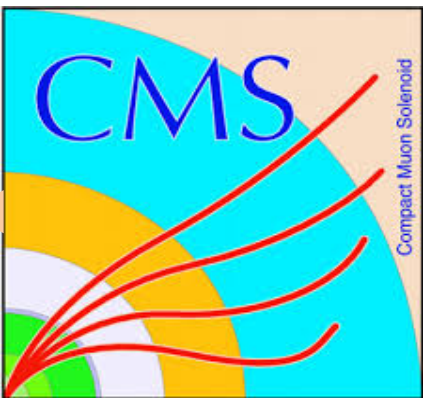
One of the twelve CERN founding member states

- Belgium nowadays one of the 22 CERN member states
- CERN membership of 27 M€/year funded by Belgian Federal Government (FOD Economie)
- CERN Mandate:
 - Fundamental scientific research
 - Technology transfer
 - Training and educating STEM professionals of the future
 - International collaboration

CMS experiment

Compact Muon Solenoid

Particle detector built around single solenoid magnet at 4 Tesla. The characteristic shape of the muon tracks in the tracker and muon system is also present in CMS logo.



General Purpose Detector

One of the general purpose detectors at the Large Hadron Collider, with a physics programme focusing on all aspects of LHC physics including heavy ion physics, Heavy flavour, SM and BSM measurement and searches

Project of a Generation

First designs in 1990s, construction in 2000s.

Operational since 2009
Run 1 2009-2012 at 7-8 TeV

Present:
Run 2 at 13 TeV collision energy.



High-Luminosity LHC

Next major upgrade to high-luminosity LHC with many detector changes in 2026 :
Phase II

CMS Collaboration

Statistics



Collaboration

4895 scientists,
incl. physicists with PhD, Engineers, PhD students

International

201 universities & scientific institutes, 46 countries

Spokesperson

Prof. Joel Butler (Fermilab)

Collaboration Board Chairperson

Jorgen D'Hondt (Vrije Universiteit Brussel)

Institutes in CMS

Belgian groups have been involved with CMS since the start of the experiment

Wallonia:

Université Catholique de Louvain
 Université Libre de Bruxelles
 Université Mons (until 2014)

Flanders:

Universiteit Antwerpen
 Universiteit Gent
 Vrije Universiteit Brussel

Currently 65 CMS members

(11 permanent researchers/
 faculty)

Currently 59 CMS members

(6 faculty)



+Associate institute: Katholieke Universiteit Leuven

Contribution to output, management and prizes: over-proportional

Collaboration between institutes

Collaboration in national context is essential to retain the leading role in CMS collaboration

- Up to 2017, all Belgian institutes were working together with theory in a program funded by the BELSPO (federal research agency) called Interuniversity Attraction Poles
 - This programme has ended in that form
 - This included common workshops ensure that Belgian expertise was retained
- In general, funding model in particle physics has evolved drastically over last years
- There is strong and consistent support from all groups to continue to closely collaborate
 - Also, ULB-VUB (+UA) have been very successfully collaborating since 1970s in Interuniversity Institute for High Energies (IIHE-ULB-VUB)
- **Lack of technicians limits ability to make impact detector at same level as physics/management**

Coordinating roles

- Important roles in collaboration that control how successful detector and collaboration is
- **Examples (not a complete list):**
 - UGent had multiple leadership roles in muon project, including upgrades
 - ULB has held leadership positions in CMS GEM upgrade (muons) and tracker
 - Various very visible roles in tracker by ULB, VUB, UCL
 - UA has had multiple leadership positions in CASTOR forward calorimeter
 - Deputy run coordinator UCL
 - Collaboration board chair VUB

Belgian detector contribution

STEEL RETURN YOKE
~500 tonnes

SILICON TRACKERS

Pixel ($100 \times 150 \mu\text{m}$) $\sim 16\text{m}^2 \sim 66\text{M}$ channels
Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2 \sim 9.6\text{M}$ channels



UA, UCL, ULB,
VUB, Umons
(incl. management)

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To Phase 1 CMS detector



Also: HPS

SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying $\sim 18,000\text{A}$

ULB,
VUB,
UGent

MUON CHAMBERS

Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

(incl. management)

PRESHOWER

Silicon strips $\sim 16\text{m}^2 \sim 137,000$ channels

FORWARD CALORIMETER

Steel + Quartz fibres $\sim 2,000$ Channels



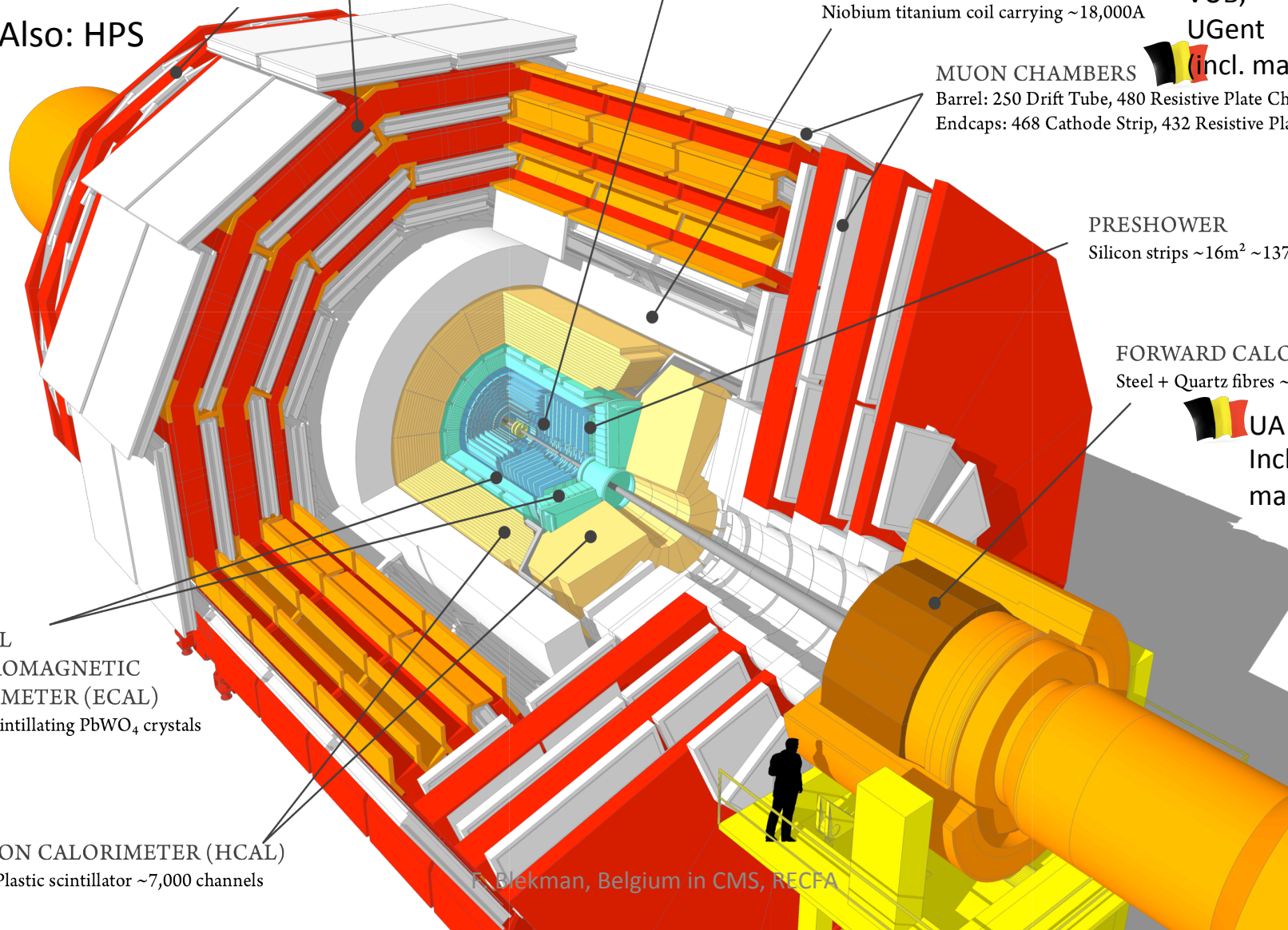
UA
Incl.
management

CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
 $\sim 76,000$ scintillating PbWO_4 crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator $\sim 7,000$ channels

Blekman, Belgium in CMS, RECFA

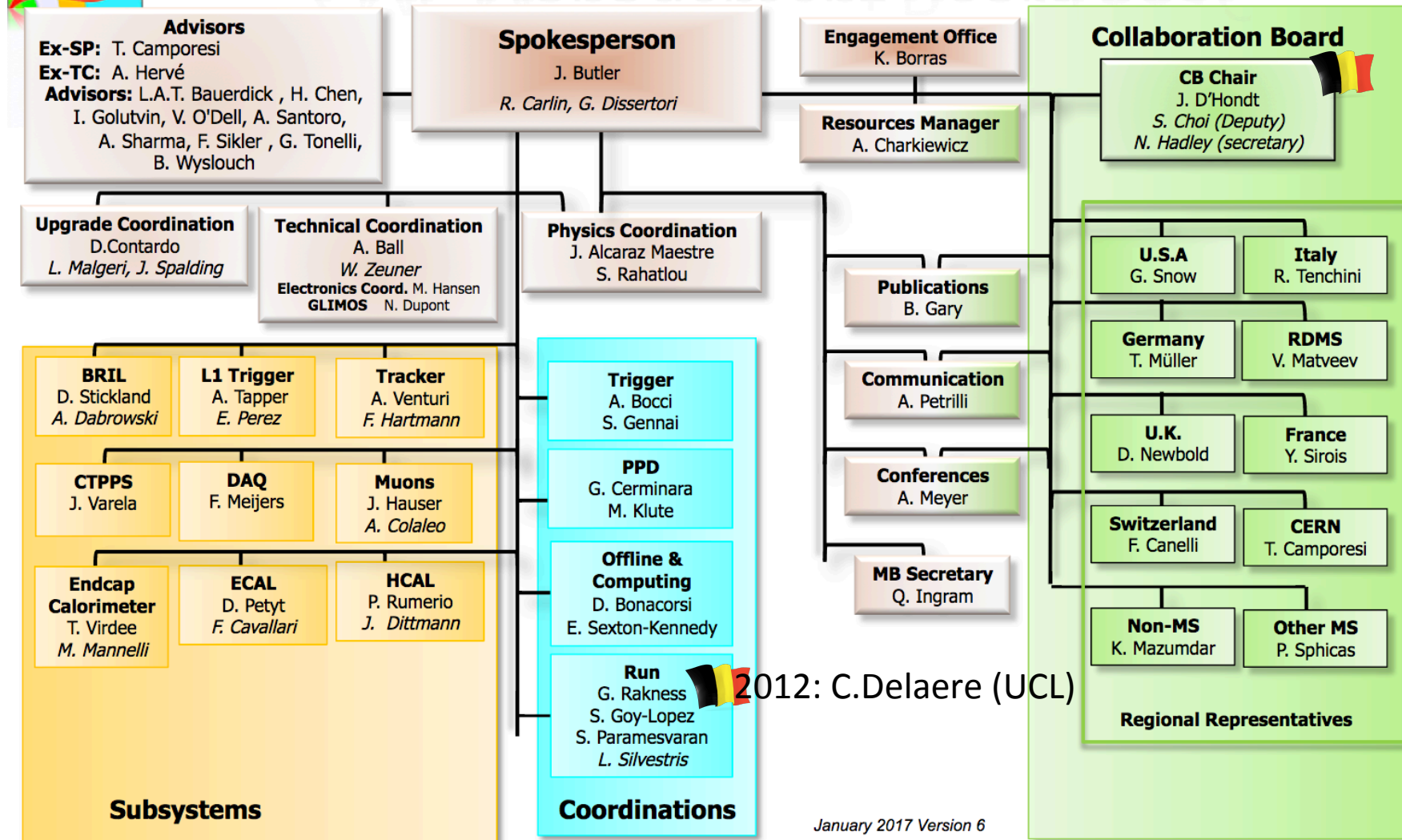
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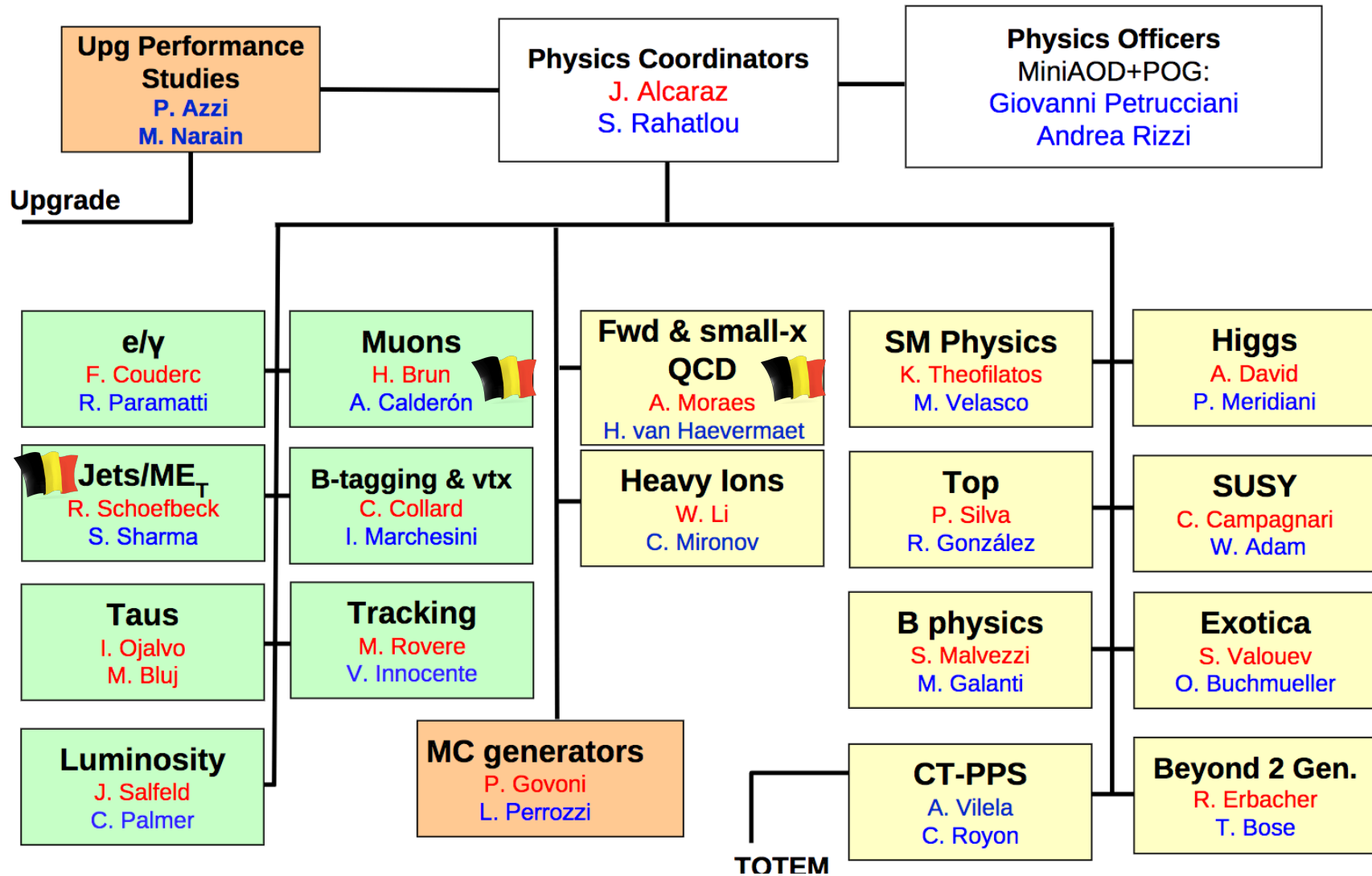
Coordination: Collaboration (2016)



CMS Management Board 2016



Coordination: Physics (example 2016)

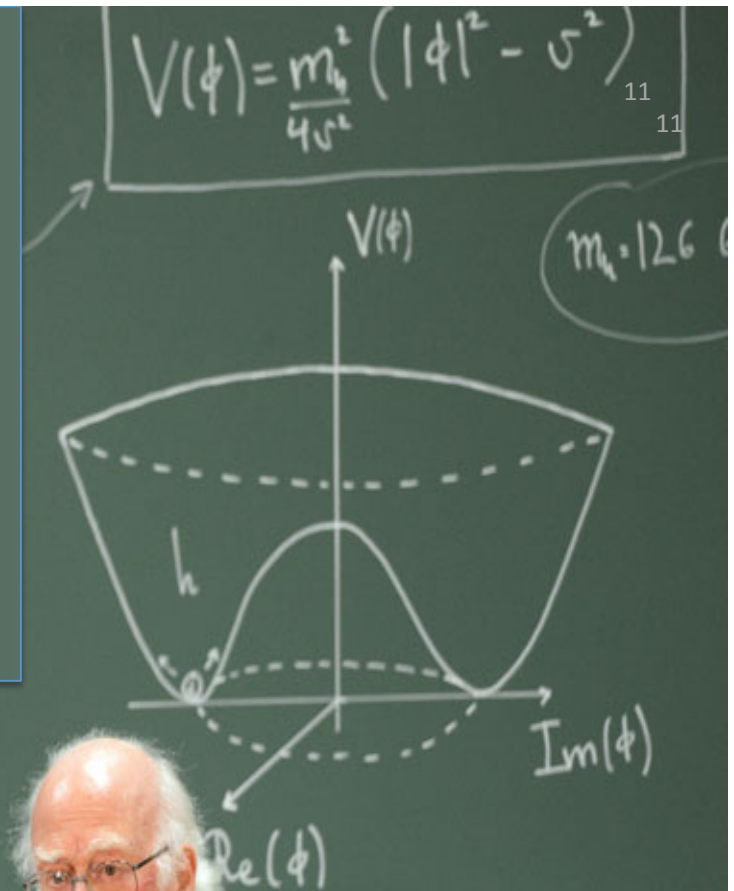


THE DISCOVERY OF THE STANDARD MODEL SCALAR

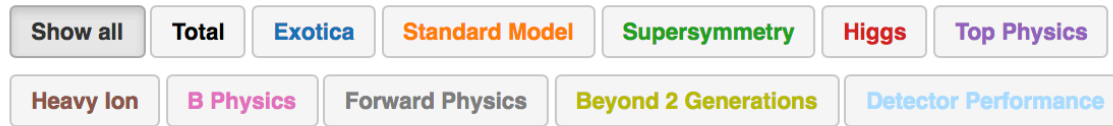
The genuine highlight of CMS for the LHC run 1 (2009-2012) is without doubt the Discovery of the Higgs boson in 2012

Confirmation of the Standard Model as a exhaustive theory of fundamental particles and their interactions

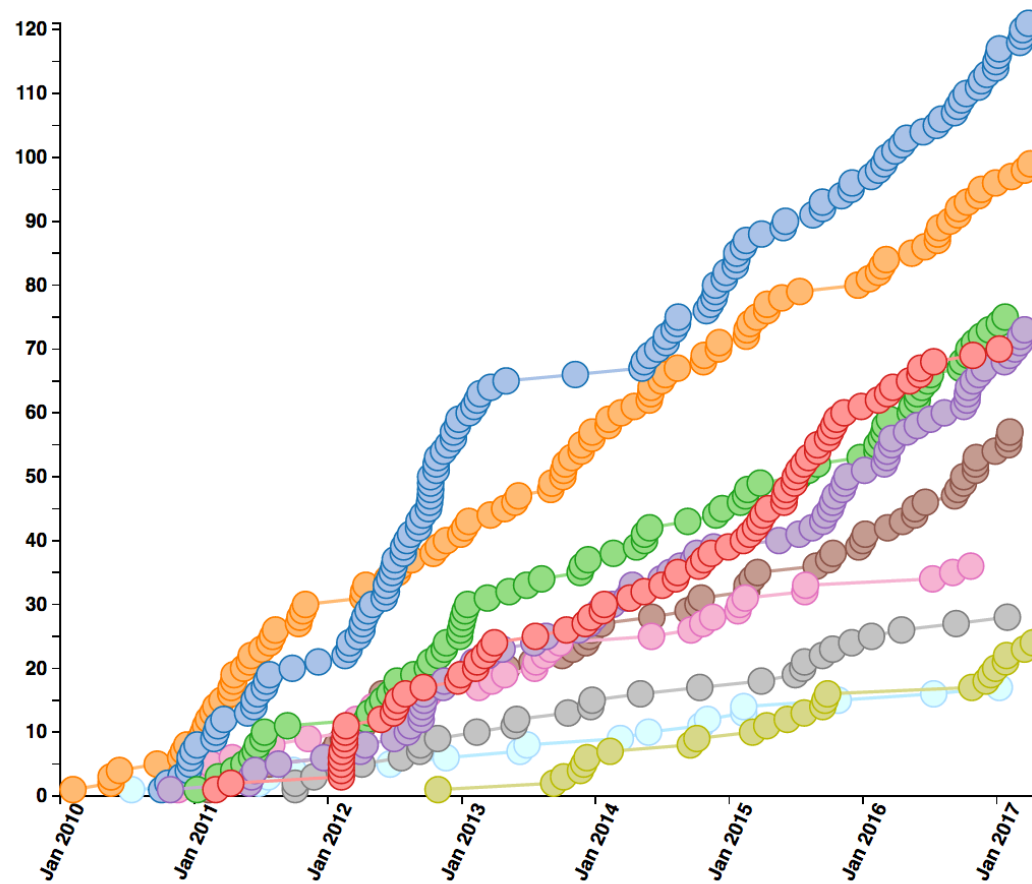
Belgian link to the 2013 Nobel prize-winning prediction of the Standard Model Scalar particle by Brout, Englert and Higgs in 1964



Coordination: Physics (timeline)



599 collider data papers submitted as of 2017-04-13



Coordination: Physics

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- The coordination of physics analysis is one of the main organisational challenges of large collaborations
 - Many small groups to work effectively, with 2 conveners coordinating, usually with 2-year staggered terms
- CMS has 9 dedicated physics analysis groups focusing on different physics topics, each containing 100s of analysts
 - Standard model physics: top, Higgs, small-x, heavy flavour and fQCD
 - Heavy Ion Physics
 - Searches: SUSY, Exotica, Beyond-2-generations
 - Each of these has numerous working-groups where analysis is reviewed (in charge of 5-10 ongoing papers)
- There are also 7 similar groups for the physics reconstruction:
 - Electrons/photons, muons, Jets/EtMiss, taus, b-tagging, tracking, luminosity

Coordination: Physics

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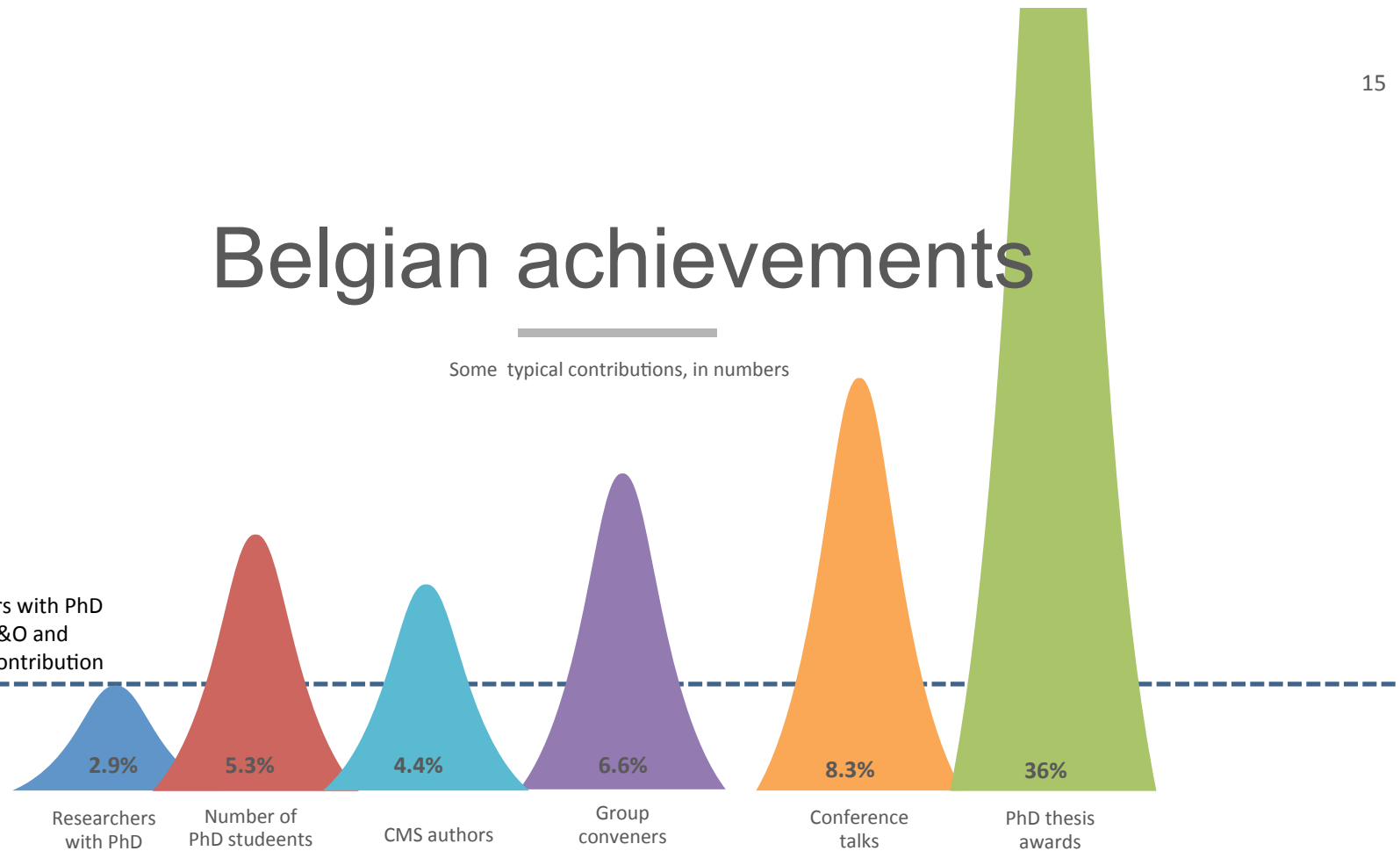
- The coordination of physics analysis is one of the main organisational challenges of large collaborations
 - Many small groups to work effectively, with 2 conveners coordinating, usually with 2-year staggered terms
 - Belgian contribution to physics groups
 - Organisation in place since
 - Convener roles: TOP (2x), fQCD (2x), B2G
 - Numerous (over 20) subgroup conveners from all current Be-CMS institutes and in most physics groups (excl. HI)
 - About 20 positions as physics object conveners
 - E/gamma, b-tagging, tau, tracking, jets/MET, Simulation
- 6.6% of CMS group conveners are Belgian**

In addition very visible roles in publication approval process (publication committee) incl. vice chair (UA) and many faculty structurally responsible for review papers in EXO, TOP, SUSY

Belgian achievements

Some typical contributions, in numbers

Number of researchers with PhD
Used to determine M&O and
'fair share' detector contribution



Belgian institutes have a huge impact in the CMS collaboration

Excellent example is the fact that 8 out of the 22 CMS thesis awards* have been awarded to Belgians, most recently in 2017 for Dr Cecile Caillol's thesis on $H \rightarrow \tau\tau$ (2016)

*) Awards for best PhD thesis on a CMS related subject, awarded since 2000



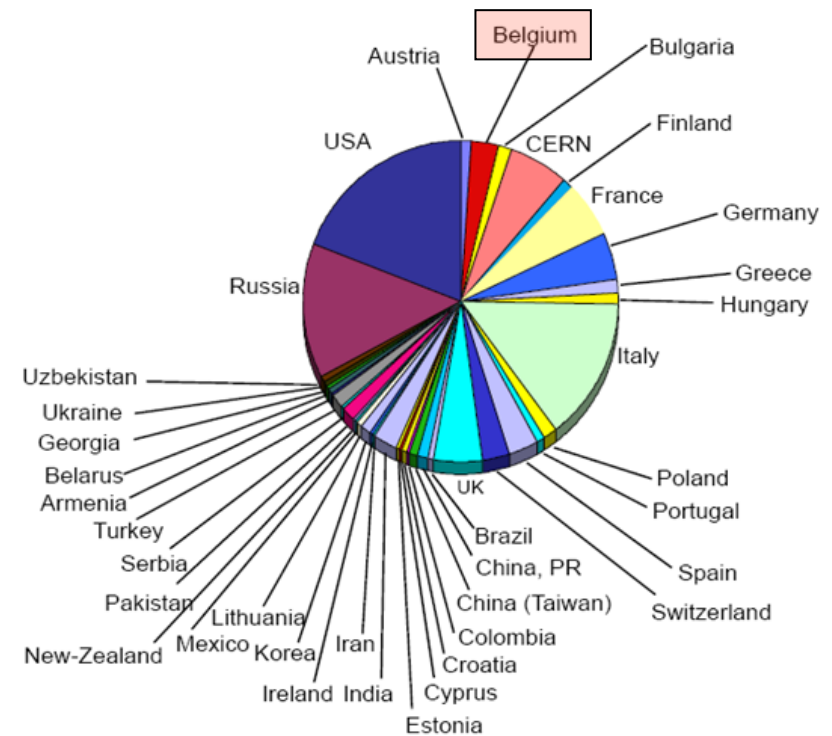
Dr Cecile Caillol

Conclusion and outlook

Much above proportional contribution
detector and operation physics papers
reflected in disproportional number management positions and prizes

More on the upgrades in the next talk – we are invested there too!

bodes very well for future!

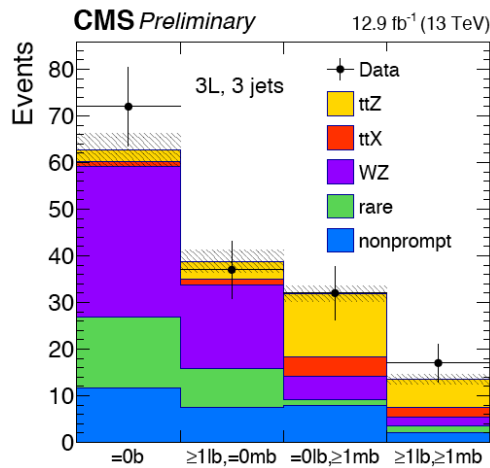
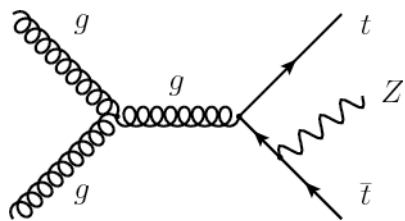


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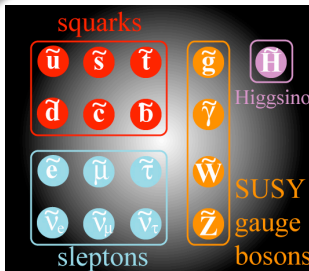
Physics Highlights: Gent

• Precision measurements in Top-quark sector

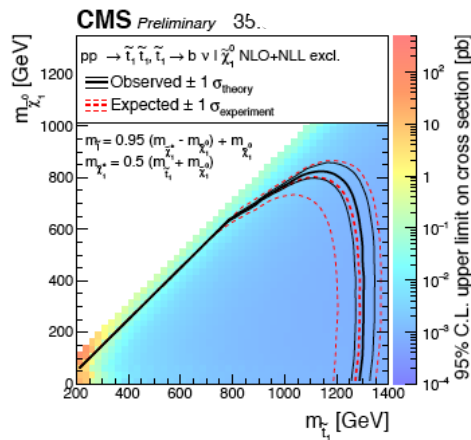
- Inclusive cross section
- Top-quark mass
- Spin correlation in to-pairs
- $tt+W/Z$ cross section & EFT interpretation



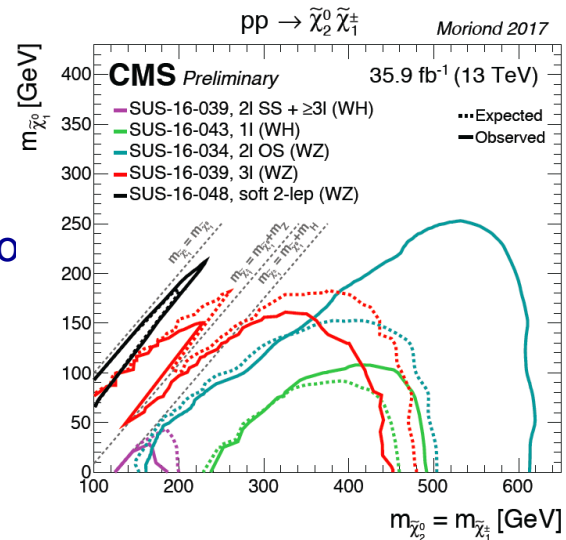
• Searches for Supersymmetry (SUSY)



- Electroweak production of chargino-neutralino pairs using multi-leptons
- Gluinos via strong production
- Search for stop-squarks

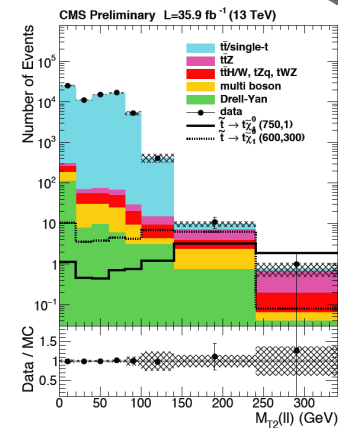
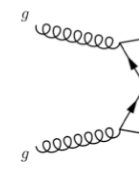


- Active in multiple analyses, leading roles
- JetMET Convenor: crucial for SUSY&beyond



• Search for Dark matter

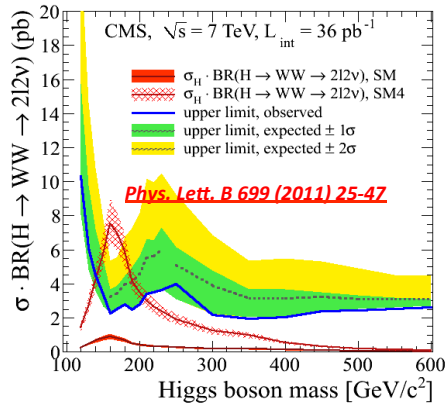
- top-pairs produced with DM



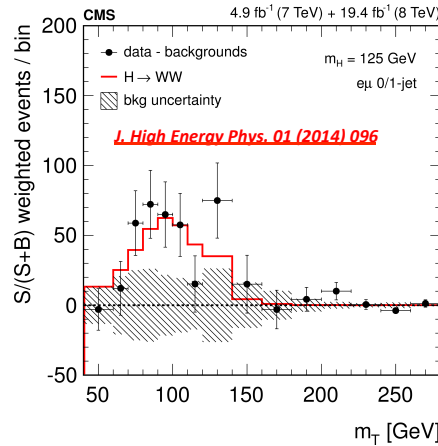
Physics Highlights: Antwerp

H(125 GeV) → WW: From early searches ... to discovery ... to measurements of properties

2010 data → First limit



Full Run I data → 4.3 sigma

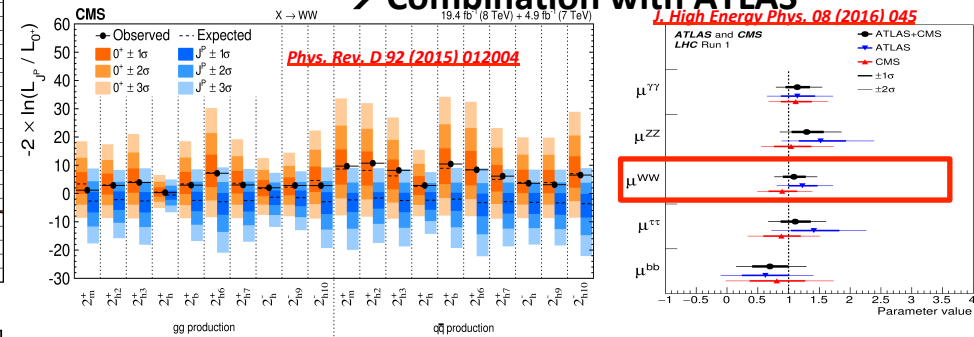


Full Run I data → Excluding spin 1 & 2

→ Constraining the H width

→ Differential x-section in p_{T,H}

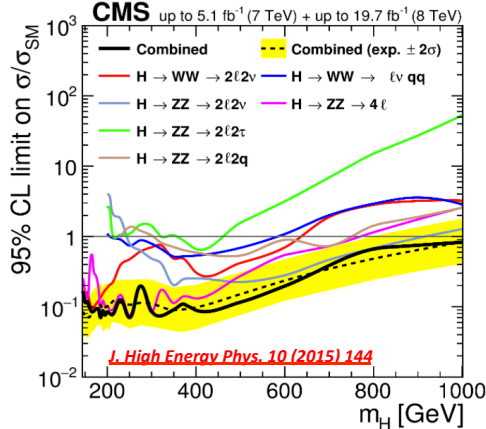
→ Combination with ATLAS



→ Run-I: Contributions to 13 papers
... including H discovery

→ Run-II: Contributions to first H → WW
Analysis @ 13 TeV ... more to come

Searches for 2nd high mass H → WW/ZZ

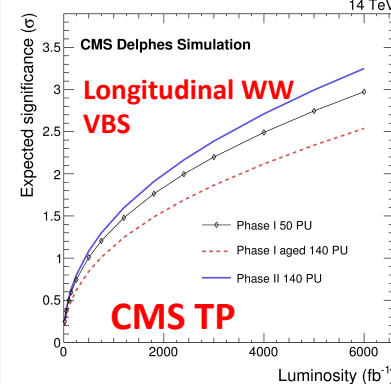


Full Run-I data:

- Limits up to 1 TeV for SM-like
- Parameter scan and limits for EWK singlet model
- Contribution to 1 paper

F. Blekman, Belgium in CMS, RECFA

WW Vector Boson Scattering

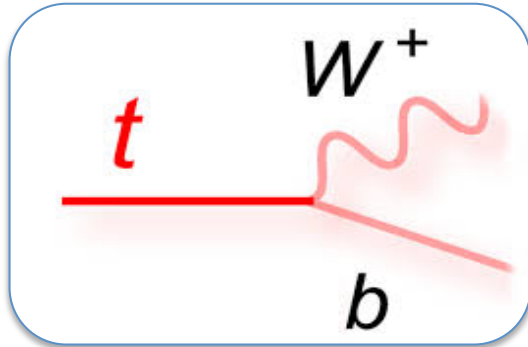


□ Prospects for WW VBS @ S-LHC = 3 ab⁻¹ (CMS Tech. Proposal)

□ Working on Run-II WW VBS measurements
→ First results with 2016 data expected soon

Physics Highlights: UCLouvain

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Standard model:

Diphoton production of $\mu\mu$ and quartic gauge boson couplings
(4 papers&preliminary results)
Also: link to TOTEM

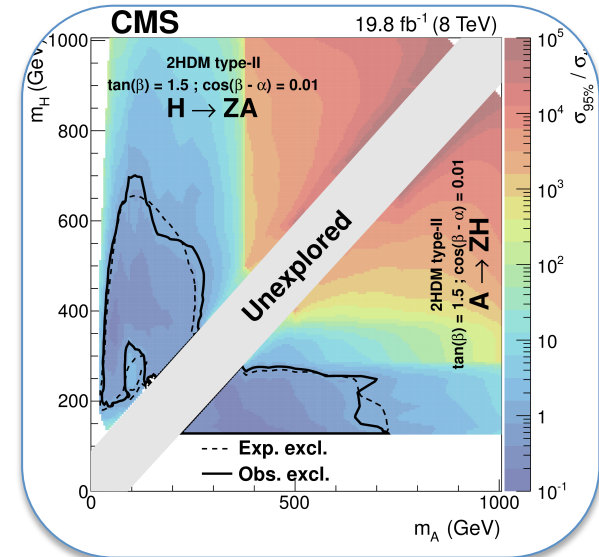
Top quarks:

Single top
t**t**bar in dileptons
tH production
Also: PDG and Reviews in Physics contributions
(11 papers&preliminary results)

Contributions to b-tagging, tau, tracking (incl. alignment), muons, datasets/performance

Searches:

Dimuon resonances
Massive long-lived particles
BNV top quarks
(8 papers&preliminary results)

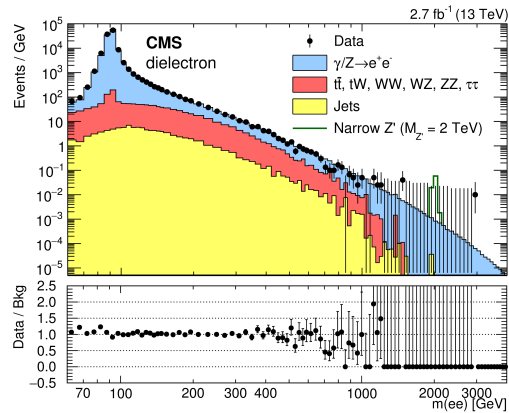


SM Scalar boson:

$H/A \rightarrow Z H/A \rightarrow \mu\mu$
 $H/A \rightarrow Z H/A \rightarrow \mu\tau$
 $h \rightarrow ZZ \rightarrow \mu\nu\nu$ ($\rightarrow h$ width)
(16 papers&preliminary results)

Plus: High-impact work & leadership CMS fast simulation
DELPHES parameterized detector simulation

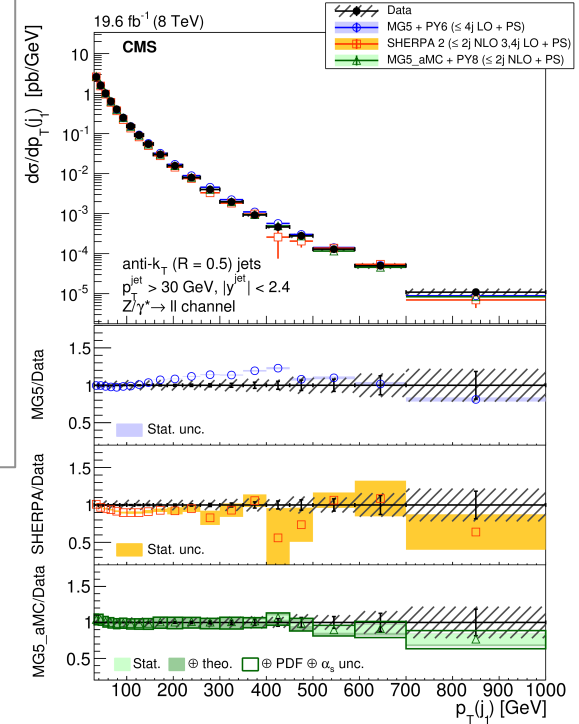
Physics Highlights: ULB



arXiv:1609.05391

Scalar sector:

Coupling to fermions ($ZH \rightarrow \ell\ell + \ell\ell \tau\tau$)
 Invisible decays incl off-shell tail and total decay width $H \rightarrow \ell\ell + \nu\nu$
 BSM $H \rightarrow \tau\tau$, $H \rightarrow \ell\ell + \nu\nu$
 SM cross section: $ZZ \rightarrow \ell\ell + \nu\nu$
 Strong expertise muon, tau leptons (incl convenerships)



Exotica:

High-mass resonances in $ee, \mu\mu, e\mu, \gamma\gamma$

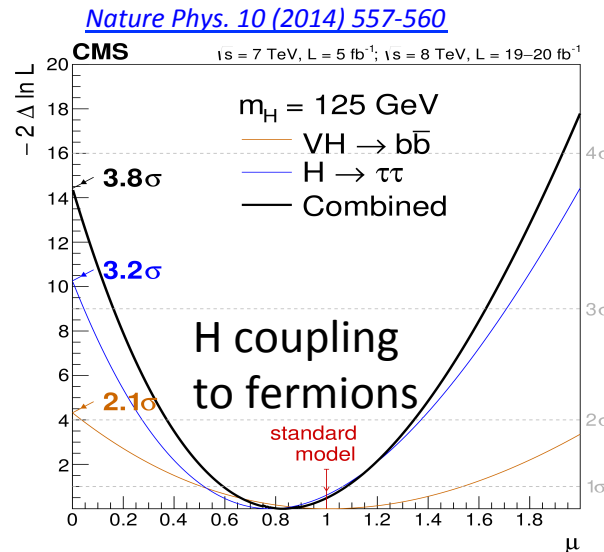
Initiated high-energy ee pair (HEEP) group

Top+Dark Matter (w ULB, UCL)

“Discovery alerts”

(task forces II 2011, $\gamma\gamma$ 2016)

Strong expertise electrons



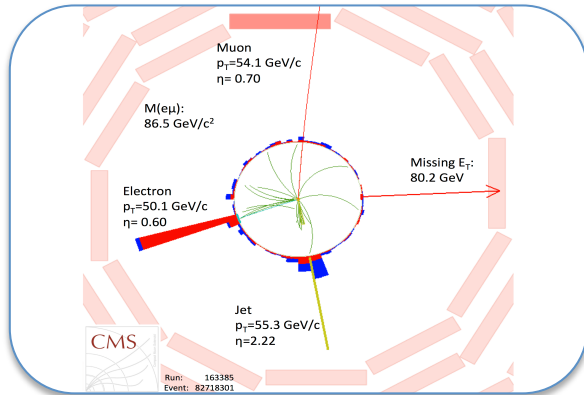
QCD studies:

Total and differential cross sections

Underlying events

Expertise in jet calibration

Physics Highlights: VUB



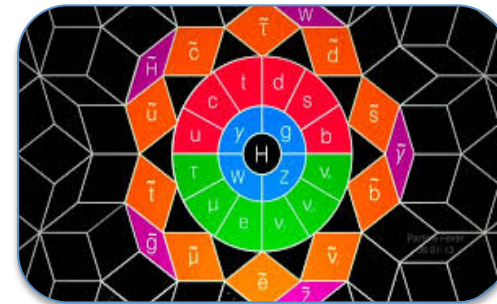
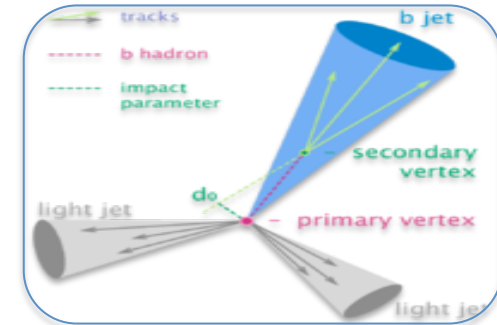
Searches for new Physics:

- SUSY top squarks
- SUSY jets+missing energy
- Dark matter including convenerships CMS and LHC working group
- Top+DM (with ULB, UCL)
- mono-jets

Exotica using top quarks including founding convenership B2G

- Vector-like quarks
- tW resonances
- Displaced new physics (DM, SUSY)
- Trackless jets (pheno)

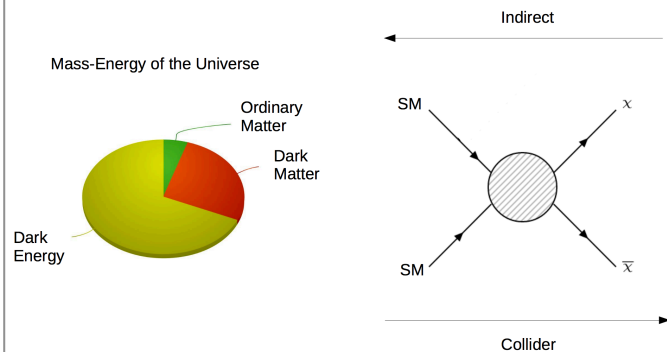
At least one paper/preliminary result on each topic



Top quarks:

- Cross section (early, differential, top-as-a-tool)
- Top mass (& mass difference)
- Anomalous couplings
- FCNC (also tH)
- Discovery tW production
- Rare decays (ttt)

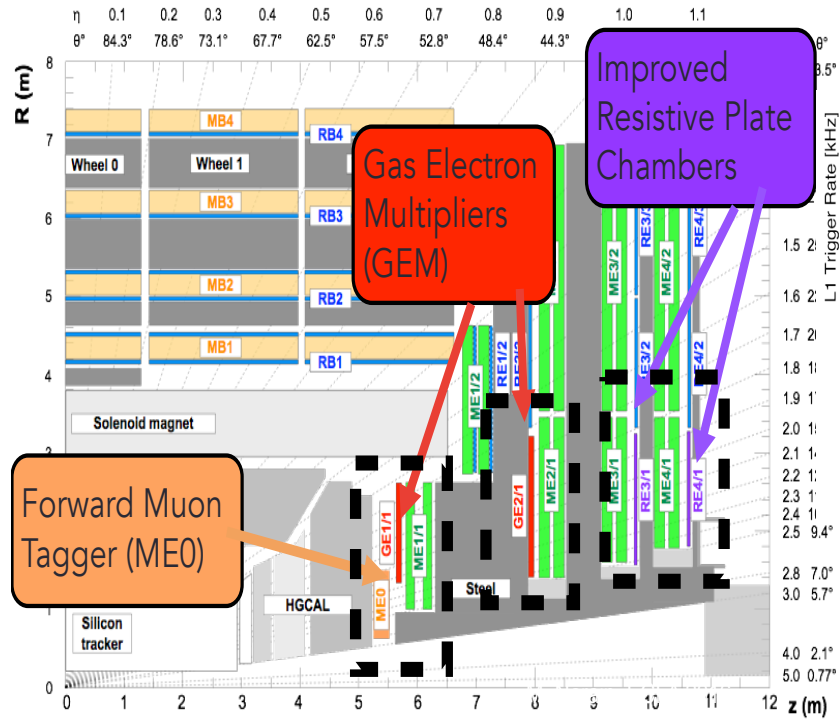
Convenerships incl. founding convener, two other conveners ex-VUB, many sub-conveners
 Multiple papers on each topic



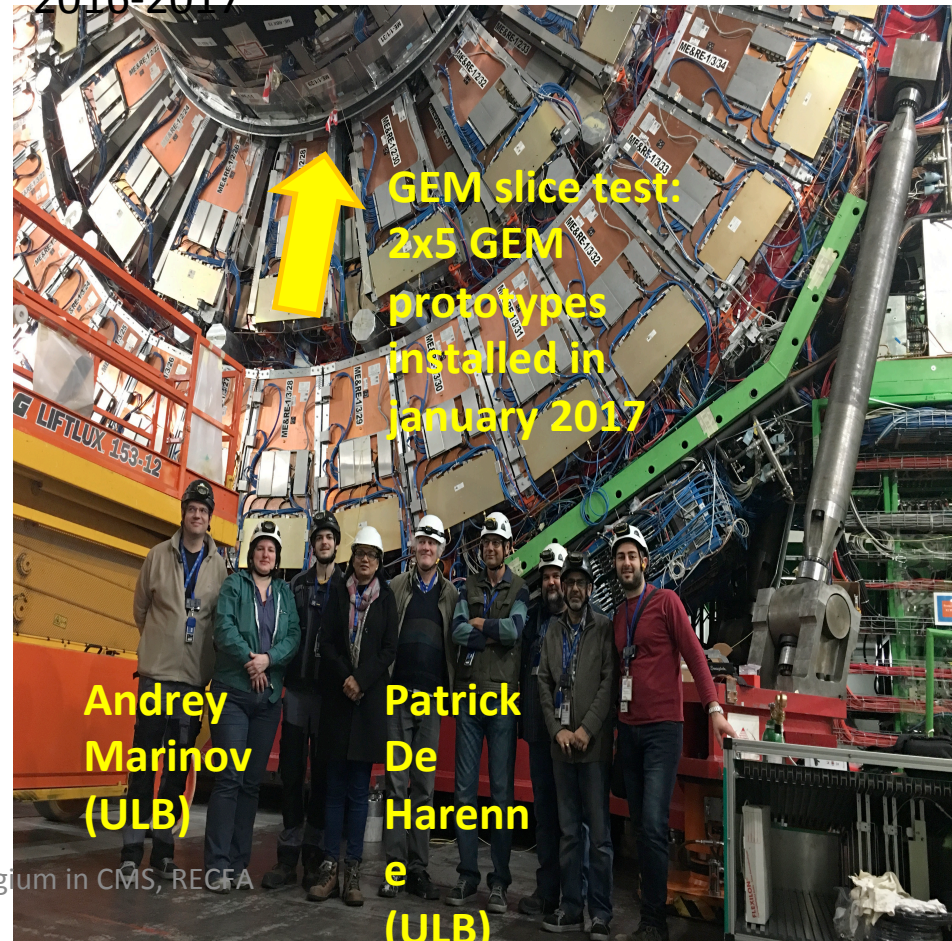
B-tagging:

Visible leadership (2 conveners in 4 years)
 Charm tagging
 Calibration/new algorithms/simulation
 High-multiplicity, future studies

Phase-1 upgrade: Muon endcap extension in η



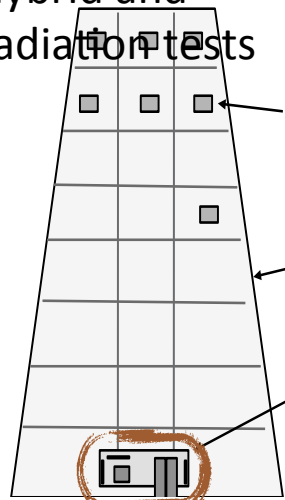
GEM slice test (GE1/1 station): installation and commissioning during extended technical stop 2016-2017



GEM DAQ system: opto-hybrid and DAQ architecture; FPGA radiation tests

Opto-hybrid:

- board which transmits the GEM trigger data through existing optical fibres
- designed at IIHE



Completed PhD theses since 2010: ULB

- Detection of high energy electrons in the CMS detector at the LHC – O. Charaf – octobre 2010 – ULB - IISN
- Data-driven multi-jet and V+jets background estimation techniques for top quark pair production at CMS – G. Hammad – août 2011 – ULB – FRIA, boursier de la fondation Van Buuren.
- Search for new physics at the LHC through the study of the lepton pairs mass spectrum at 7 TeV in CMS – V. Dero – décembre 2011 – ULB – IISN
- Search for new heavy narrow resonances decaying into a dielectron pair with the CMS detector – L. Thomas – septembre 2014 – ULB – assistant ULB – FRIA
- Search for new massive resonances decaying to dielectrons or electron-muon pairs with the CMS detector – Th. Reis – février 2015 – ULB – IISN
- Development of the new trigger and data acquisition system for the CMS forward muon spectrometer upgrade – E. Verhagen – mars 2015 – ULB – ARC/AIDA/PAI
- Measurement of Z boson production in association with jets at the LHC and study of a DAQ system for the Triple-GEM detector in view of the CMS upgrade – A.Léonard – juin 2015 – ULB, FNRS
- Measurement of the Z boson pair-production cross section in pp collisions at 7 and 8 TeV, and ECAL timing studies for the phase-2 upgrade of the CMS experiment - L. Pernié – septembre 2015 – ULB - IISN
- Scalar boson decays to tau leptons: In the standard model and beyond – C. Caillol – avril 2016 – ULB
- Study of Triple-GEM detectors for the CMS muon spectrometer upgrade at LHC and study of the forward-backward charge asymmetry for the search of extra neutral gauge bosons – F. Zenoni – avril 2016 – ULB
- Study of Triple-GEM detector for the upgrade of the CMS muon spectrometer at LHC – Th. Maerschalk – juillet 2016 – ULB
- Development of the DAQ System of Triple-GEM Detectors for the CMS Muon Spectrometer Upgrade at LHC – Thomas Lenzi – décembre 2016 – ULB

Completed PhD theses since 2010: VUB

- Joris Maes – Estimation of b-tag efficiency using top quarks (2010)
- Petra Van Mulders – Calibration of the jet energy scale using top quarks (2010)
- Maryam Zeinali – Measurement of the jet energy scale using top quarks (2011)
- Nadjieh Jafari – Measurement of the b-tagging efficiency using top quarks (2011)
- Michael Maes – Measurement of the top quark production cross section (2013)
- Stijn Blyweert – Measurement of the top quark mass and the mass difference top quark and antiquark (2013)
- Alexis Kalogeropoulos – Search for direct stop quark production (2014)
- Gerrit Van Onsem – Search for new heavy quarks (2014)
- Annik Olbrechts – Measuring the anomalous couplings of the Wtb vertex (2016)
- Lana Beck – The search for Standard Model production of four top quarks (2017)

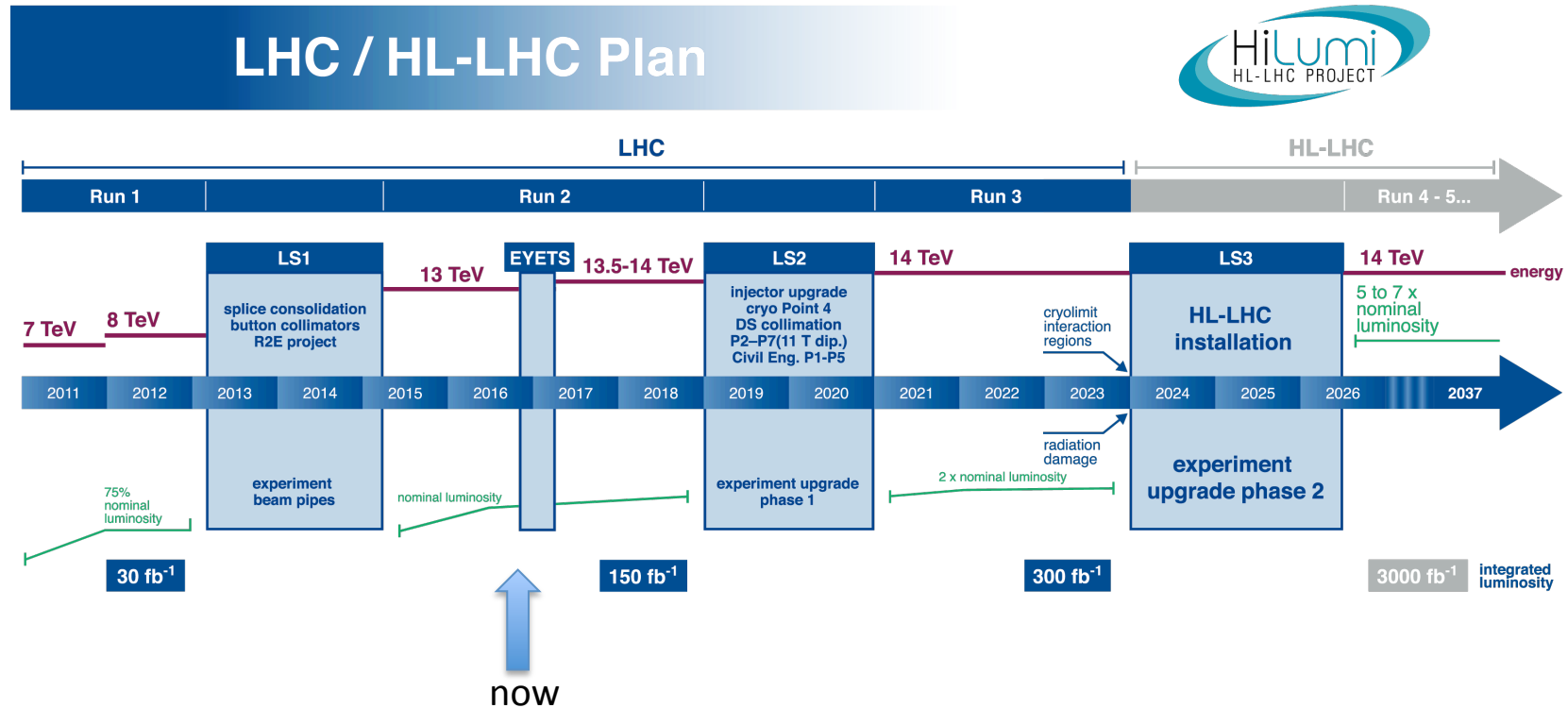
Completed PhD theses since 2010: UGent

- - 2011: Lukas Vaneldereren
- - 2012: Piet Verwilligen
- - 2012: Benjamin Klein
- - 2012: Sinéad Walsh
- - 2012: Andrey Marinov
- - 2014: Filip Thyssen
- - 2015: Joseph McCartin
- - 2015: Guillaume Garcia
- - 2015: Nadja Strobbe
- - 2015: Kelly Beernaert

Completed PhD theses since 2010: UCLouvain

- 1) 2017-24-03 Alexandre Mertens Search for 2HDM extensions of the scalar sector close to the alignment limit with the CMS detector (Ch. Delaere)
- 2) 2016-10-20 [Adrien Caudron](#)
[The final state with two b jets and two leptons at the LHC as a probe of the scalar sector](#) (Christophe Delaere)
- 3) 2016-04-25 [Laurent Forthomme](#)
[Measurement of exclusive two-photon processes with dilepton final states in pp collisions at the LHC](#)
[Krzysztof Piotrzkowski](#)
- 4) 2015-10-16 [Andrey Popov](#)
[Search for anomalous Higgs boson production in association with single top quarks using the CMS detector](#)
[Andrea Giammanco](#)
- 5) 2015-10-14 [Camille Beluffi](#)
[Search for rare processes with a Z+bb signature with the CMS detector, using the Matrix Element Method](#)
[Vincent Lemaître](#)
- 6) 2015-10-09 [Lucia Perrini](#)
[Search for higgs bosons decaying to tau leptons with the CMS experiment at the LHC](#) Giacomo Bruno
- 7) 2015-09-25
[Suzan Basegmez](#) [A new method for mapping detector material in situ and a matrix element approach to the search for heavy di-muon resonance at the LHC.](#) Giacomo Bruno
- 8) 2015-06-08 [Ludivine Céard](#) [First measurement of the associated production of a Z boson with b jets at the LHC](#) [Christophe Delaere](#)
- 9) 2014-02-12 [Michele Gabusi](#) [Search for baryon number violation in top-quark decays with the CMS experiment](#) [Giacomo Bruno](#) and [Paolo Vitulo](#)
- 10) 2013-10-07 [Arnaud Pin](#) [The Matrix Element Method at the LHC: A Search for the Associated Production of Higgs and Z bosons](#) [Vincent Lemaître](#)
- 11) 2011-09-16 [Julien Caudron](#) [First observation of the Top Quark at the Large Hadron Collider](#) [Vincent Lemaître](#)
- 12) 2011-07-12 [Nicolas Schul](#) [Measurements of two-photon interactions at the LHC](#) [Krzysztof Piotrzkowski](#)
- 13) 2010-10-14 [Loïc Quertenmont](#) [Search for Heavy Stable Charged Particles](#) [Giacomo Bruno](#)
- 14) 2010-04-30 [Séverine Oryn](#) [Photoproduction of top and Higgs particles at the LHC](#) [Vincent Lemaître](#)

Long-term plan



- LHC planned to run at least until 2037
- Total dataset two orders of magnitude larger than data currently on disk

CMS LHC Hi Lumi Upgrades (>2023)

New Tracker



- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to $\eta \sim 4$

Muons



- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to $\eta \sim 4$

New Endcap Calorimeters

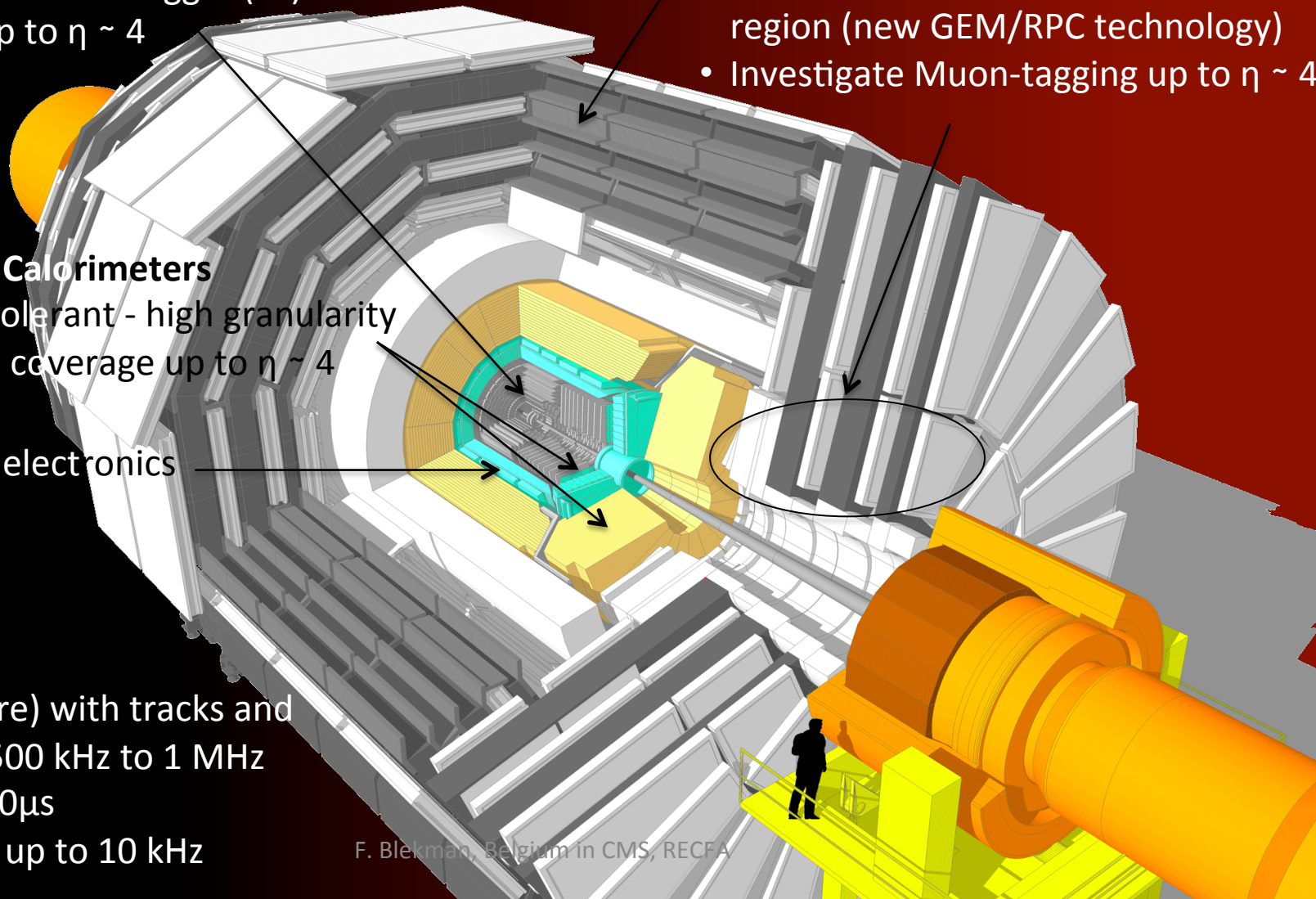
- Radiation tolerant - high granularity
- Investigate coverage up to $\eta \sim 4$

Barrel ECAL

- Replace FE electronics

Trigger/DAQ

- L1 (hardware) with tracks and rate up ~ 500 kHz to 1 MHz
- Latency $\geq 10\mu$ s
- HLT output up to 10 kHz



Belgium and the CMS tracker

Belgian institutes are contributing to the tracker construction (and R&D) since 1993!



Assembly of current strip tracker was done in Belgium (1800 silicon detectors)

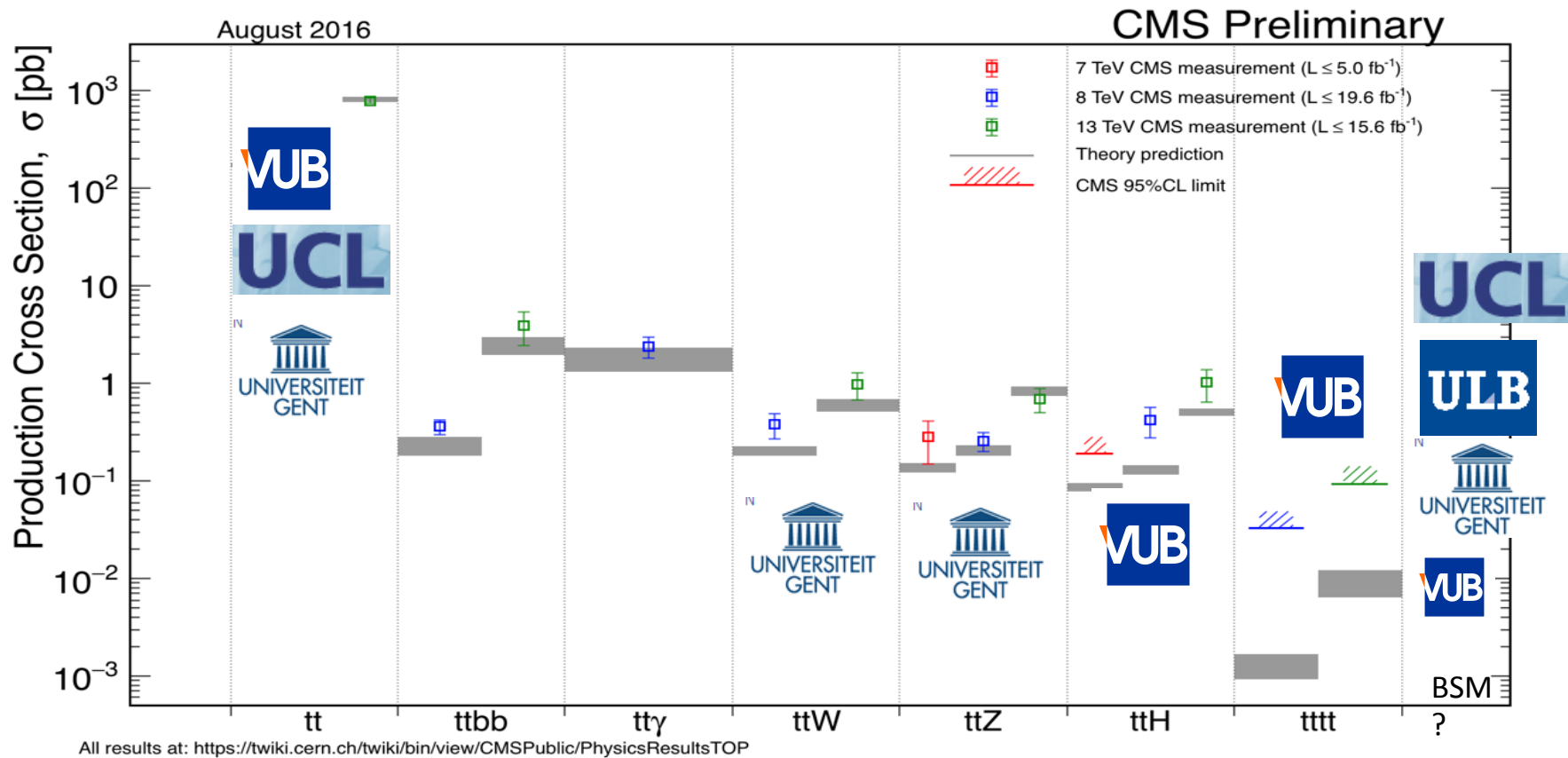
Design&construction of supports, cooling, quality controls, slow control

Belgian scientists involved with installation in 2008

Still heavily involved in operations, shifts

Belgium is committed to also contributing to the Phase-2 strip tracker for HL-LHC

Ex: Top quark physics in Belgium

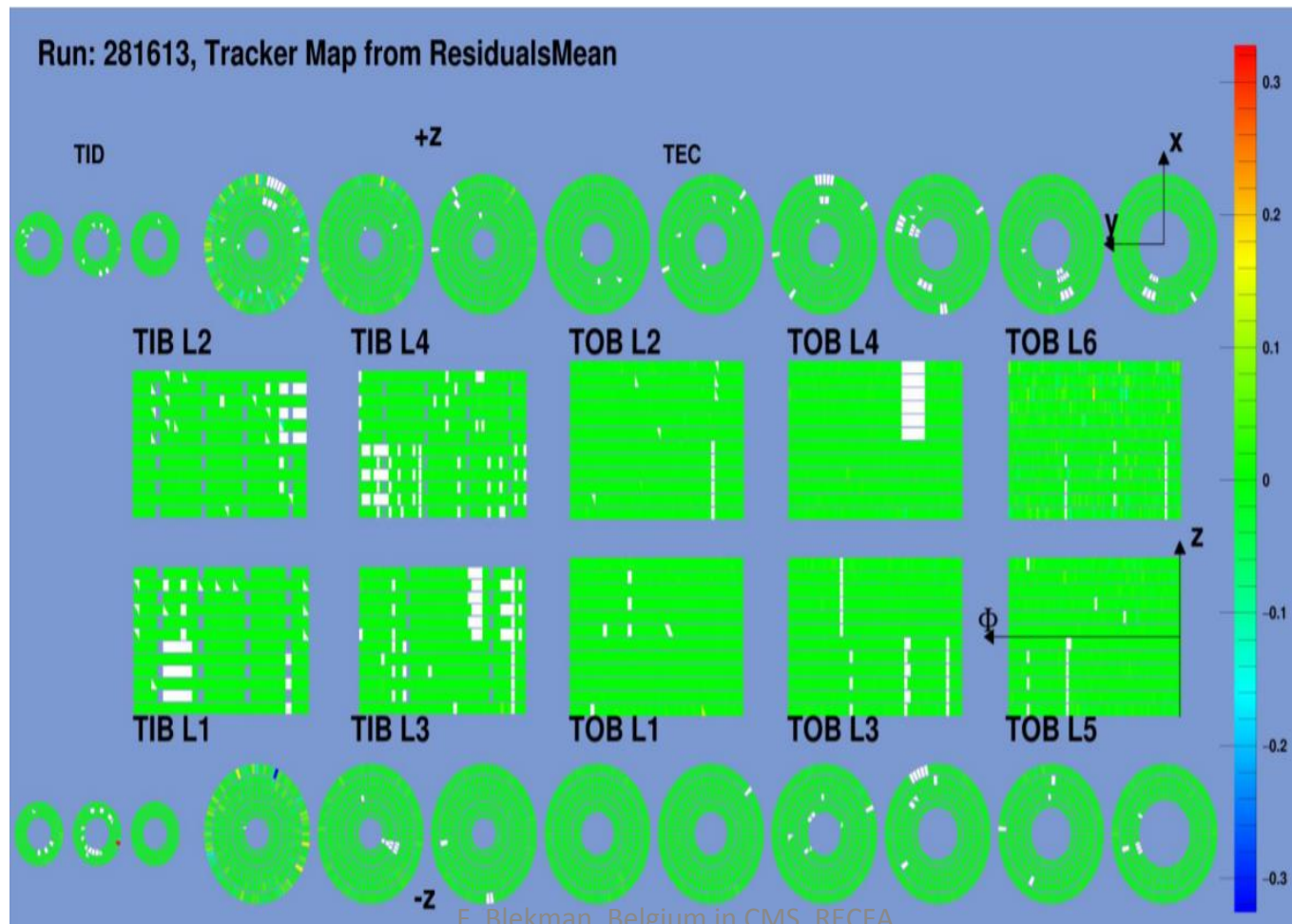


Silicon strip tracker data quality monitoring

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Combined Brussels effort from IIHE

- **Conveners:** Thomas Hreus, Tomislav Seva (ULB); Hugo Delannoy (ULB) with Isabelle De Bruyn (VUB)
- **Contributions:** validation tools; historic DQM; shifter training



F. Blekman, Belgium in CMS, RECFA

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CASTOR forward calorimeter

- Design
 - forward em/had calorimeter
 - tungsten/quartz sampling with Cherenkov radiation
 - acceptance in rapidity $-6.6 < \eta < -5.2$
 - 16-fold segmentation in azimuth

Physics objects

- energy flow
- rapidity gaps
- forward jets

Large UAntwerp involvement in

- construction
- maintenance & operation
- alignment & calibration
- commissioning of physics objects
- physics analysis

