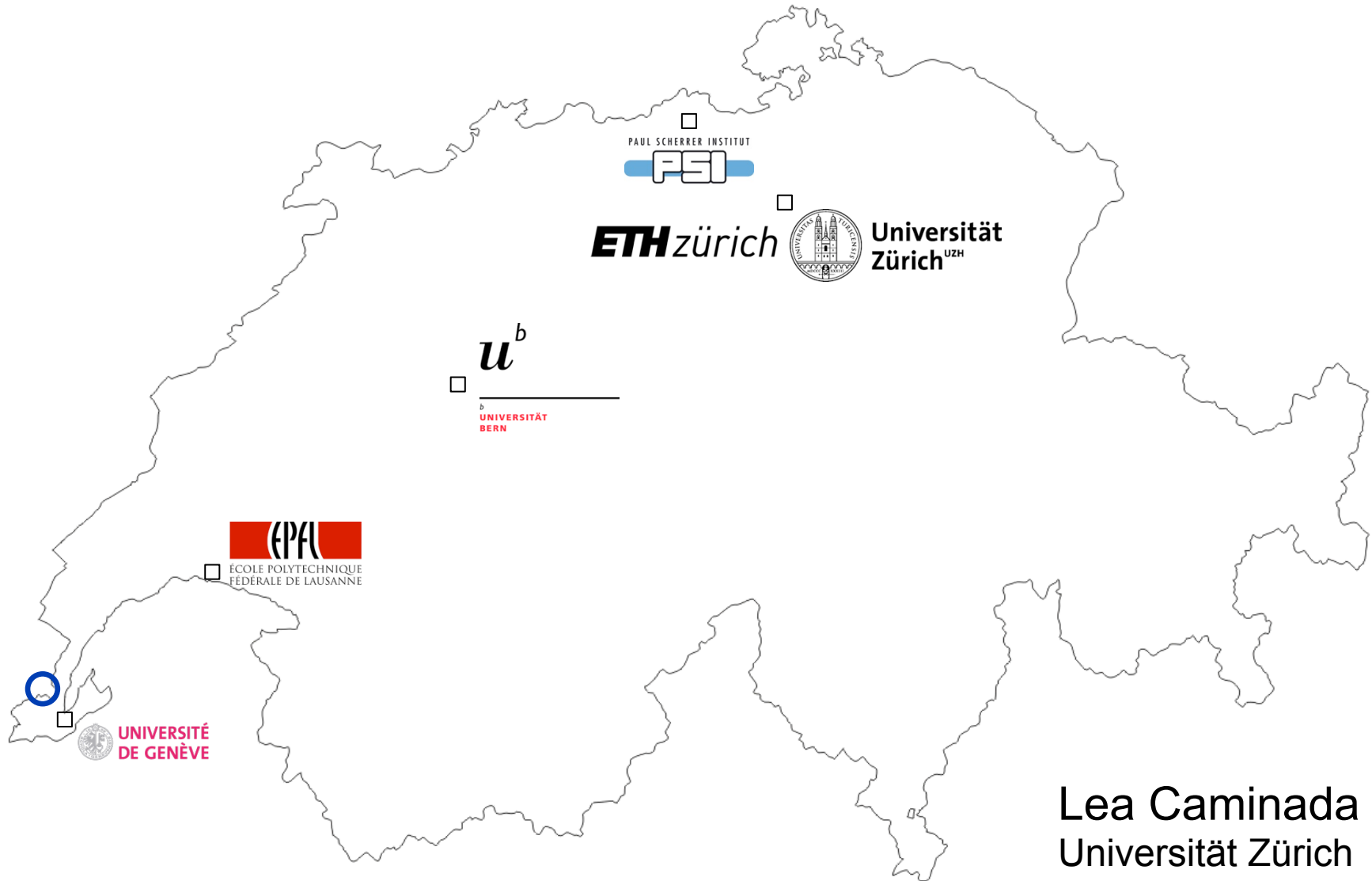
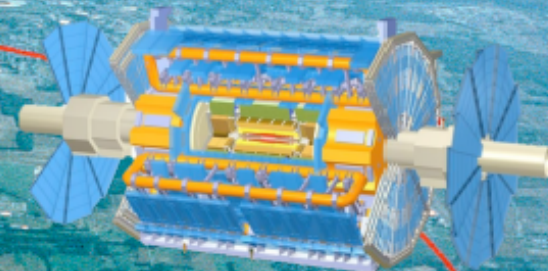
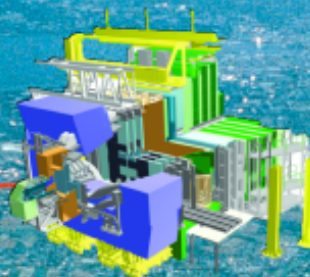
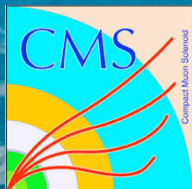


# Swiss Participation in LHC Experiments



Lea Caminada  
Universität Zürich  
RECFA Visit  
April 1, 2016



## CMS

**ETHZ:** G. Dissertori, C. Grab, F. Pauss, R. Wallny, L. Bianchini, B. Casal Larana, M. Dittmar, M. Donega, D. Hits, M. Ito, G. Kasieczka, W. Lustermann, B. Mangano, M. Marionneau, P. Martinez Ruiz Del Arbol, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, L. Perrozzi, A. Starodumov, K. Theofilatos, *F. Bachmair, P. Berger, C. Dorfer, C. Heidegger, J. Hoss, T. Klijnsma, M. Masciovecchio, M. Meinhard, J. Pata, G. Perrin, M. Quittnat, D. Sanz Becerra, M. Schönenberger, V. Tavolaro, M. Vesterbacka Olsson, D. Zhu, R. Jimenez Estupinan, R. Becker, D. da Silva, M. Dröge, C. Haller, U. Röser*

**UZH:** F. Canelli, B. Kilminster, L. Caminada, A. de Cosa, T. Hreus, A. Hinzmann, C. Lange, P. Robmann, T. Aarrestad, R. del Burgo, C. Galloni, J. Ngadiuba, D. Pinna, G. Rauco, D. Salerno, K. Bösiger, R. Maier

**PSI:** R. Horisberger, D. Kotlinski, Q. Ingram, W. Bertl, W. Erdmann, H.C. Kästli, U. Langenegger, T. Rohe, S. Wiederkehr, B. Meier, S. Streuli

## LHCb

**EPFL:** A. Bay, T. Nakada, O. Schneider, F. Blanc, G. Haefeli, M. Dorigo, C. Fitzpatrick, T. Head, P. Hopchev, M. Martinelli, P. Pais, A. Puig, M. Tobin, G. Andreassi, V. Battista, V. Bellee, S. Giani, O. Girard, C. Khurewathanakul, I. Komarov, A. Kuonen, M. Marinangeli, B. Maurin, M. Schubiger, P. Stefko, Z. Xu, N. Auberson, F. Bernard, J. Dervey, R. Frei, R. Gonzalez, G. Masson

**UZH:** N. Serra, U. Straumann, R. Bernet, C. Betancourt, M. Chrzaszcz, N. Chiapolini, R. Coutiho, K. Müller, P. Owen, O. Steinkamp, B. Storaci, A. Vollhardt, I. Bezshyiko, E. Bowen, E. Graverini, F. Lionetto, A. Mauri, M. Tresch, A. Weiden, C. Abellan, S. Steiner

## ATLAS

**UniBE:** A. Ereditato, M. Weber, H. P. Beck, S. Braccini, A. Cervelli, S. Haug, F. Meloni, A. Miucci, G. Sciaccia, Y. Bandi, M. Hostettler, C. Merlassino, G. Mullier, M. Rimoldi, M. Stramaglia, S. Stucci, R. Haenni, P. Lutz, J. Singh

**UniGE:** G. Iacobucci, A. Clark, M. Nessi, X. Wu, T. Golling, A. Sfyrla, P. Mermod, L. S. Ancu, M. Benoit, D. Ferrere, S. Gonzalez-Sevilla, L. March Ruiz, A. Coccaro, L. Paolozzi, S. Schramm, T. J. Khoo, F. Guescini, J. Gramling, A. Katre, C. Delitzsch, N. Calace, A. Lioni, A. Dubreuil, M. Lanfermann, L. Meng, E. Akilli, F. Di Bello, M. Valente, I. Ortega Ruiz, B. Ristic, C. Cuccagna, M. Vicente, F. Cadoux, S. Débieux, Y. Favre, F. Guezzi Messaoud, D. La Marra, S. Michal

**CMS:** 7 professors + 30 scientists + 24 PhD students

**LHCb:** 5 professors + 20 scientists + 20 PhD students

**ATLAS:** 9 professors + 16 scientists + 23 PhD students

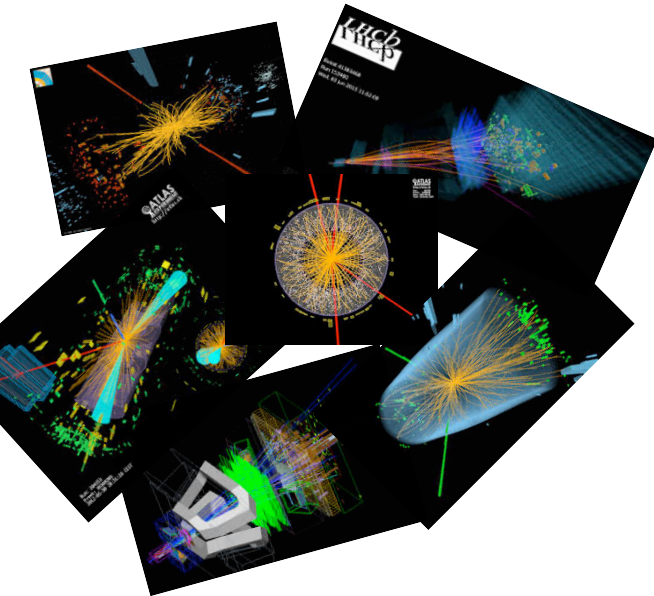
Professor Scientist PhD student Technical personnel

# What happened since the last RECFA visit in 2009...

First collisions at LHC seen by ATLAS, CMS and LHCb



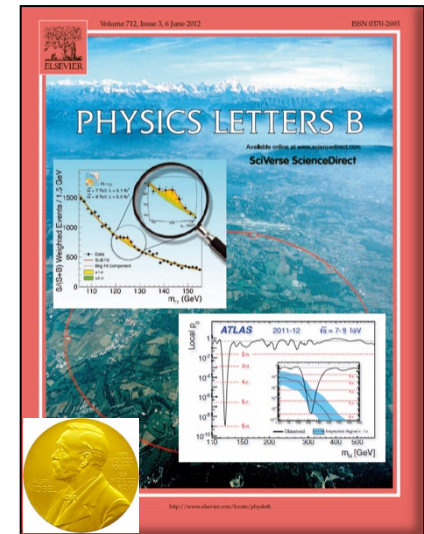
Many more collisions



Lots of physics results in all areas



A prize-winning discovery



# What do we hope to find next at the LHC?

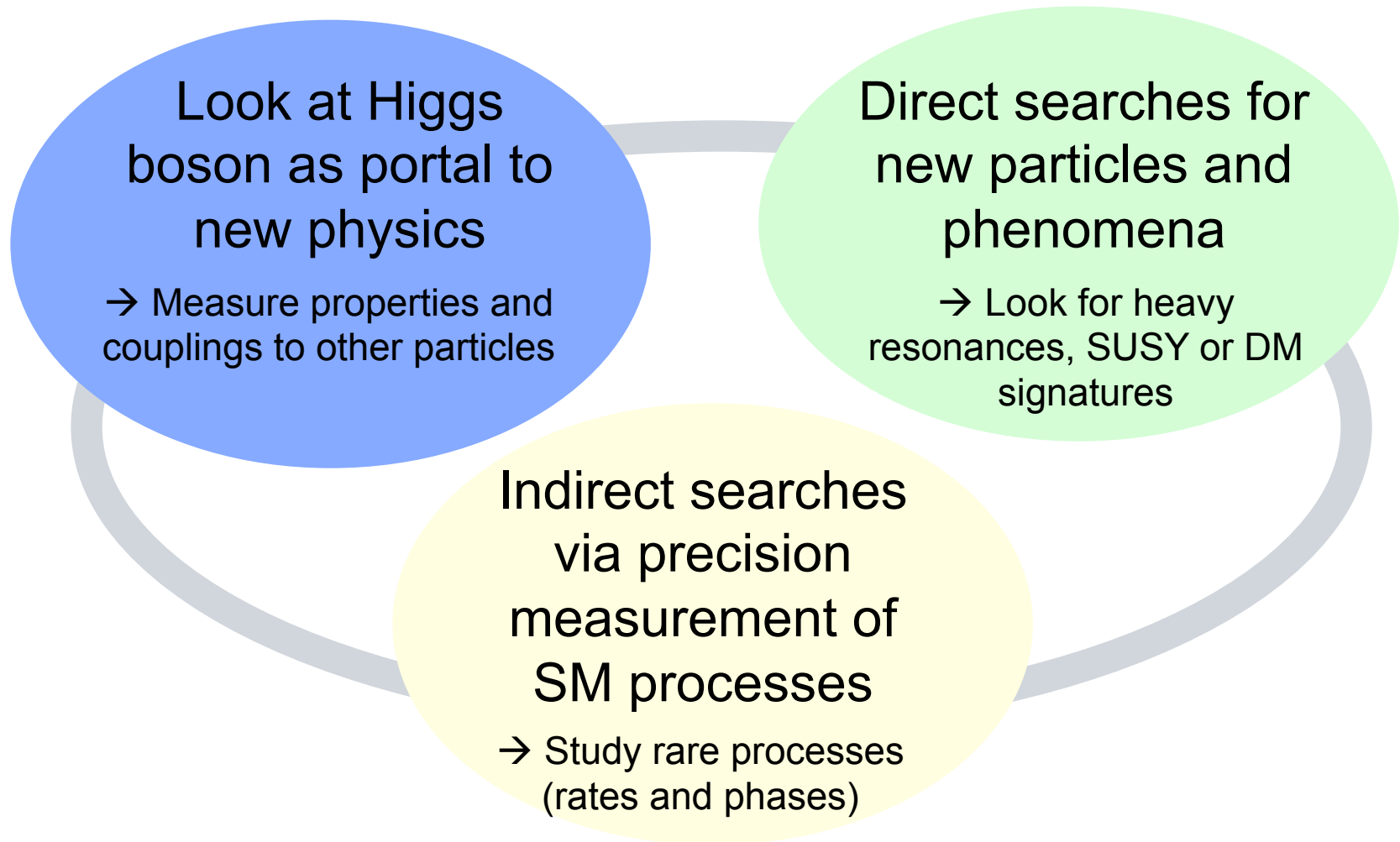
- With the discovery of the Higgs boson we have completed the Standard Model
- However, SM cannot be a complete theory of particle physics as it leaves open many fundamental questions:

- > Why is the Higgs boson so light?
- > What is the origin of the matter/antimatter asymmetry in the universe?
- > Why are there 3 families of fermions?
- > What is Dark Matter?
- > ...

- These questions requires New Physics which potentially manifests itself at the LHC

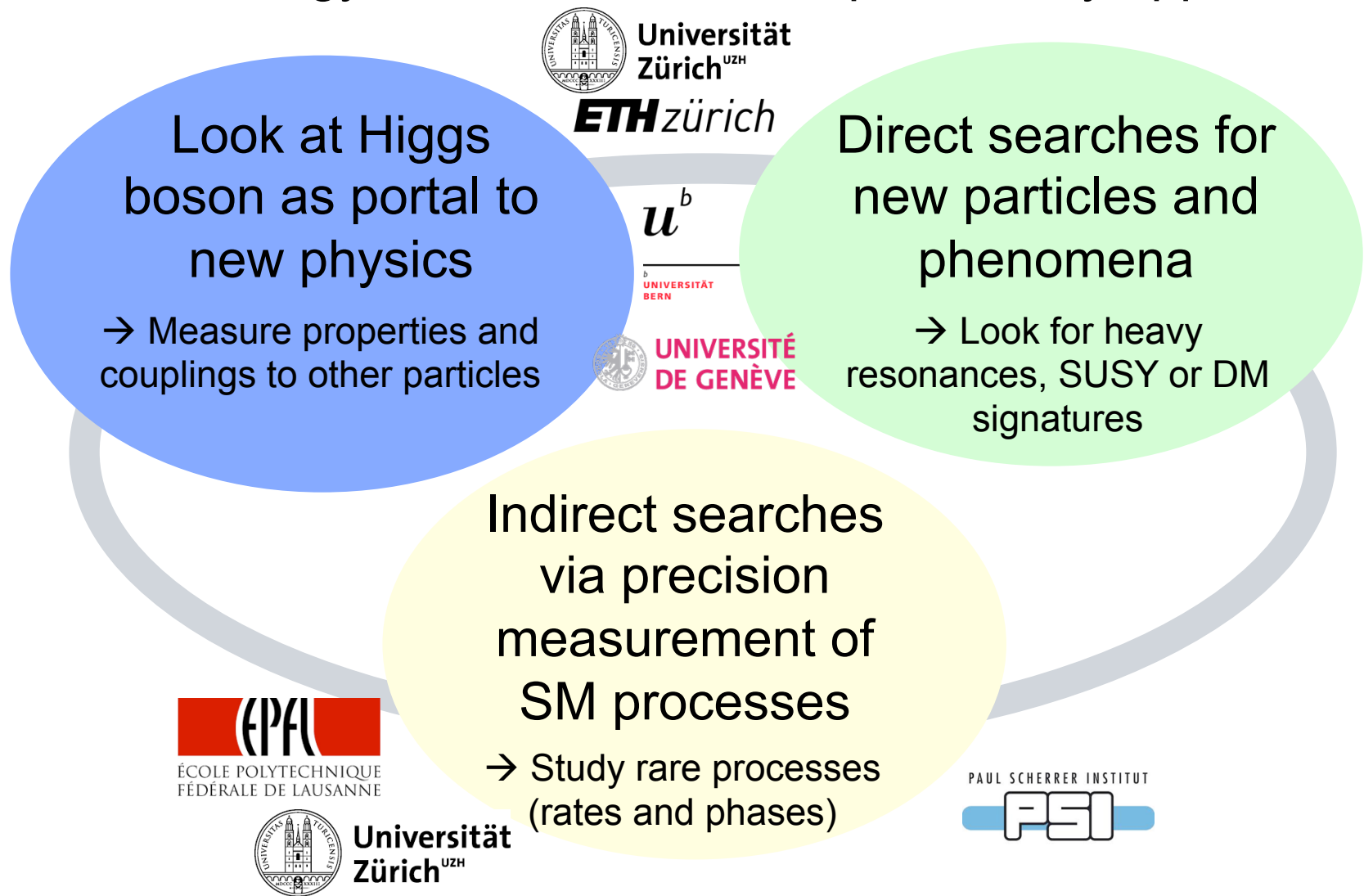
# How to find New Physics?

- Search strategy makes use of 3 complementary approaches



# How to find New Physics?

- Search strategy makes use of 3 complementary approaches



→ Broadly covered by Swiss physics analysis program

# CH Scientific Strategy

- CH is a key player in 3 LHC experiments and involved in all aspects of the experiments:
  - Original detector design, construction and commissioning
  - Detector performance, operation and maintenance
  - Physics analyses
- Leadership roles by members of CH groups at all levels
- CH committed to next phases in LHC physics program
  - Detector upgrades
  - Physics analysis in Run 2 and thereafter

## ATLAS

Collaboration Board Chair **K. Pretzl** (UniBE) 1994-1996  
Technical Coordinator **M. Nessi** (UniGE) 2000-2012  
Trigger Coordinator **A. Sfyrla** (UniGE) since 2014  
Pixel Project Leader **D. Ferrere** (UniGE) 2014-2015  
IBL Project Leader **D. Ferrere** (UniGE) 2014-2015  
Trigger and DAQ IB Chair **H. P. Beck** (UniBE) 2009-2011  
FTK Run Coordinator **L. Ancu** (UniGE) since 2014  
IBL Mechanical WG Convener **F. Cadoux** (UniGE) 2011-2013  
Pixel Readout Upgrade Convener **F. Meloni** (UniBE) since 2014  
Physics Performance WG Convener **A. Coccaro** (UniGE), **S. Schramm** (UniGE),  
**T. Khoo** (UniGE), **F. Meloni** (UniBE)  
Physics Analysis WG Convener **T. Golling** (UniGE), **F. Meloni** (UniBE)  
Publication Committee Chair: **G. Iacobucci** (UniGE)

## CMS

Deputy Collaboration Board chair **F. Pauss** (ETH), **G. Dissertori** (ETH)  
Deputy Physics Coordinator **G. Dissertori** (ETH)  
Pixel Project Leader **R. Horisberger** (PSI)  
Pixel Upgrade Coordinator **R. Horisberger** (PSI), **W. Erdmann** (PSI)  
Pixel Upgrade MB Chair **R. Horisberger** (PSI)  
ECAL IB Chair **G. Dissertori** (ETH), **Q. Ingram** (PSI)  
ECAL DCS Project Leader **G. Dissertori** (ETH)  
Tracking WG Convener: **A. De Cosa** (UZH), **C. Lange** (UZH), **T. Hreus** (UZH),  
Physics Performance WG Convener **F. Moortgat** (ETH), **G. Dissertori** (ETH),  
**P. Meridiani** (ETH), **A. Rizzi** (ETH), **A. Schmidt** (UZH), **A. Hinzmann** (UZH)  
Physics Analysis WG Convener **V. Chiochia** (UZH), **W. Erdmann** (PSI),  
**U. Langenegger** (PSI), **F. Ronga** (ETH), **F. Moortgat** (ETH), **P. Musella** (ETH),  
**P. Martinez** (ETH), **N. Chanon** (ETH), **K. Theofilatos** (ETH), **L. Bianchini** (ETH),  
**M. Donega** (ETH), **B. Mangano** (ETH), **A. Hinzmann** (UZH), **B. Kilminster** (UZH),  
**F. Canelli** (UZH), **A. De Cosa** (UZH)

## LHCb

Spokesperson **T. Nakada** (EPFL) 1995-2008  
Collaboration chair **U. Straumann** (UZH) 2008-2012  
Physics Coordinator **O. Schneider** (EPFL) 2000-2008, **T. Nakada** (EPFL) 2008-2009  
Trigger Coordinator **U. Straumann** (UZH) 1996-1997  
Operation Coordinator **B. Storaci** (UZH) since 2015  
ST Project leader **U. Straumann** (UZH) 1998-2005, **O. Steinkamp** (UZH) 2005-2008,  
**M. Needham** (EPFL) 2008-2010, **M. Tobin** (EPFL) since 2015  
TELL1 Coordinator **G. Haefeli** (EPFL) since 2007  
Tracking Upgrade Leaders **F. Blanc** (EPFL) since 2011, **O. Steinkamp** (UZH) since 2014  
Tracking Upgrade WG Coordinators **C. Abellan Beteta** (UZH),  
**G. Haefeli** (EPFL), **T. Head** (EPFL), **F. Blanc** (EPFL), **M. Martinelli** (EPFL)  
Physics Performance WG Convener **M. Dorigo** (EPFL), **M. Martinelli** (EPFL)  
Physics Analysis WG Convener **J. Van Hunen** (EPFL), **A. Bay** (EPFL),  
**O. Schneider** (EPFL), **R. Muresan** (EPFL), **G. Cowan** (EPFL),  
**K. Müller** (UZH), **C. Fitzpatrick** (EPFL), **A. Puig** (EPFL), **Y. Amhis** (EPFL),  
**J. Anderson** (UZH), **N. Serra** (UZH), **S. Tournear** (EPFL), **M. Martinelli** (EPFL)  
Speakers Bureau Chair **O. Steinkamp** (UZH) 2012-2013



# ATLAS

Superconductor  
and casing for  
barrel toroid coil  
**UniBE + UniGE**

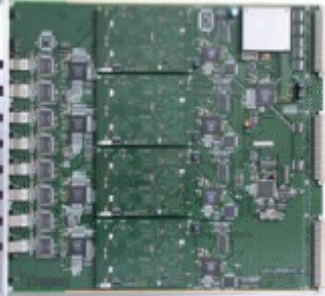


$u^b$

b  
UNIVERSITÄT  
BERN



Si Strip Tracker (SCT)  
electronics design,  
readout prototyping  
and construction  
**UniGE**

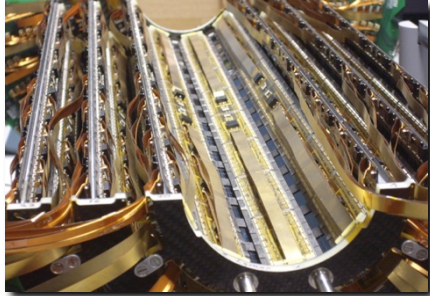


Readout  
electronics and  
trigger for LAr  
calorimeter  
**UniGE**

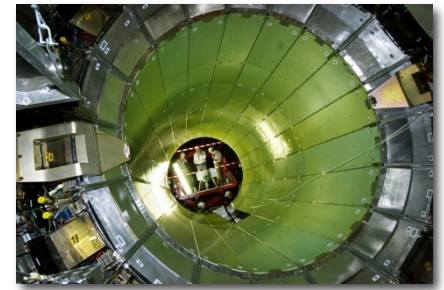


TDAQ  
Trigger and  
data flow  
**UniBE + UniGE**

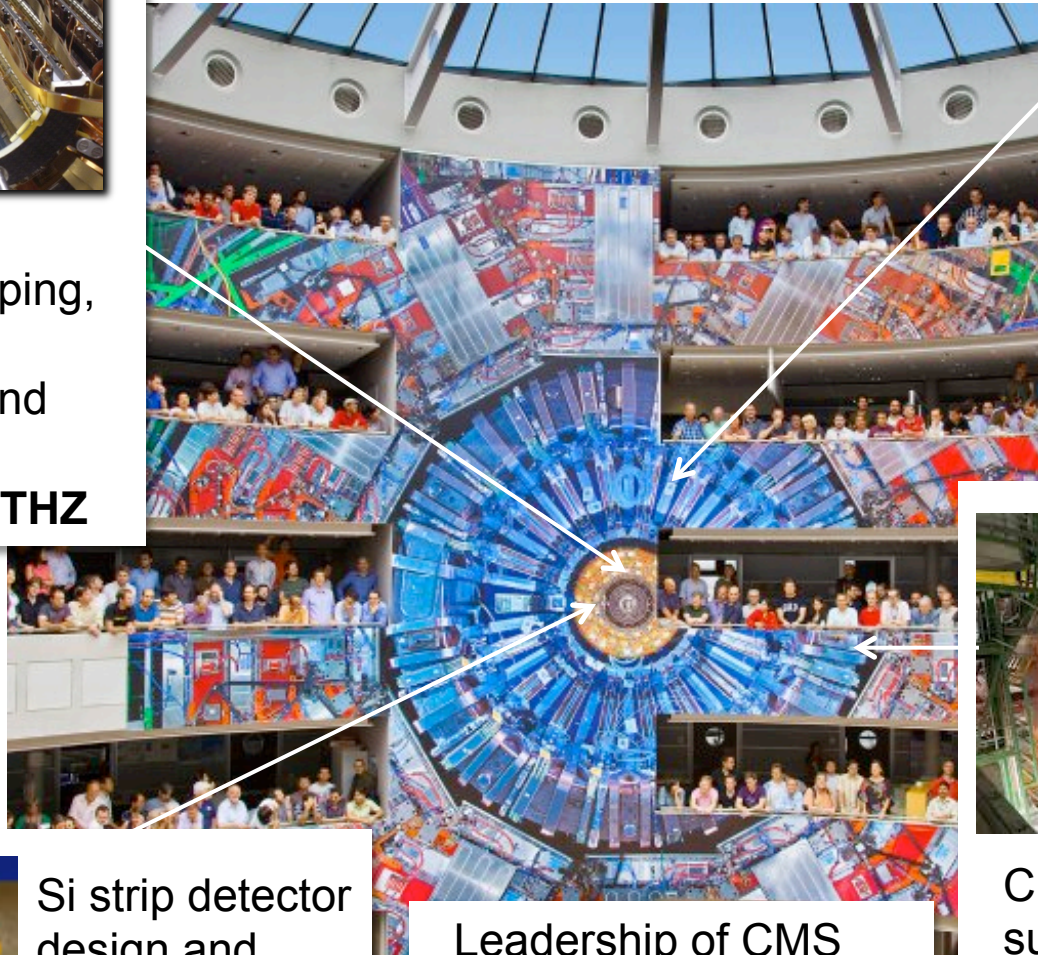
# CMS



Pixel detector  
design, prototyping,  
construction,  
maintenance and  
operation  
**PSI + UZH + ETHZ**



ECAL crystal and  
photosensors R&D,  
electronics design  
and integration, DCS  
system development,  
operation  
**ETHZ + PSI**

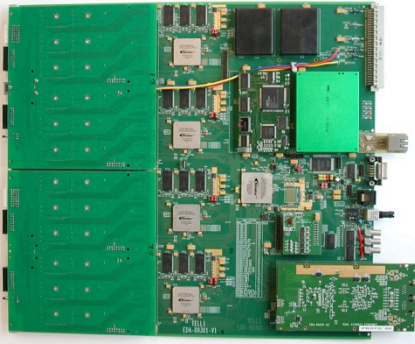


Si strip detector  
design and  
electronics  
**ETHZ**

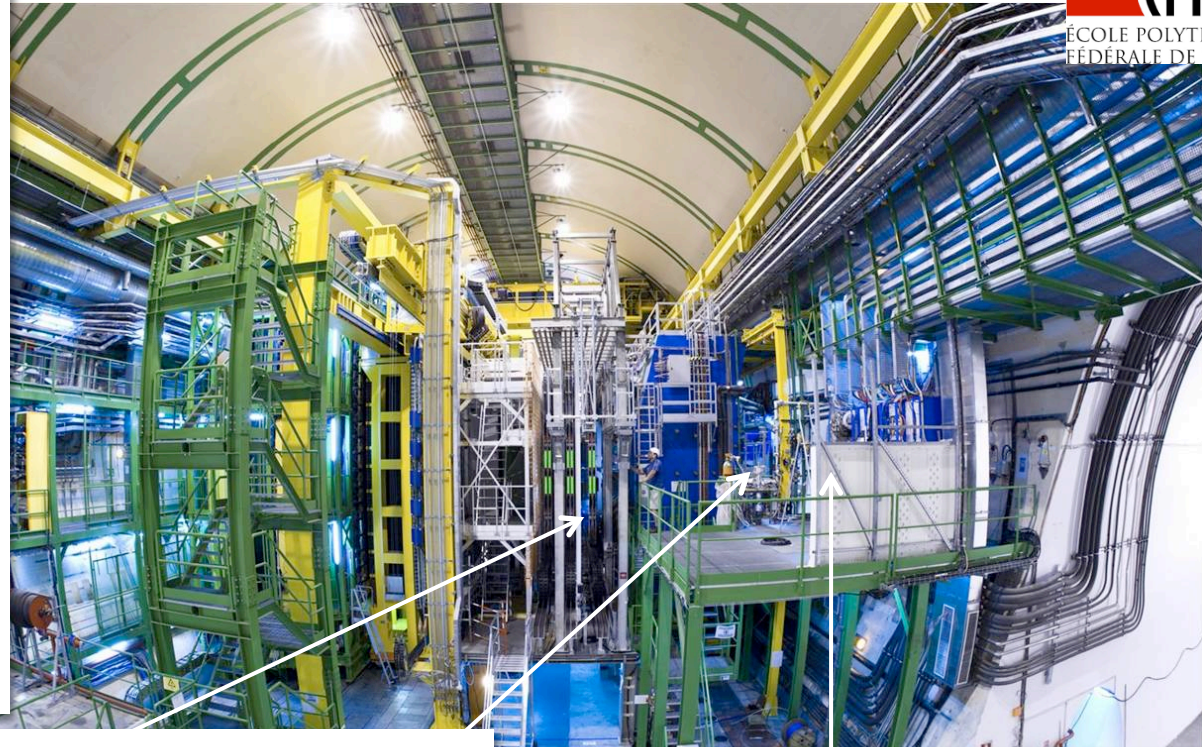
Leadership of CMS  
integration and  
engineering center  
**ETHZ**



CMS magnet  
superconducting  
coil design and  
engineering  
**ETHZ**



TELL1 common  
readout board (~300  
in LHCb): Design,  
production,  
maintenance and  
operation  
**EPFL**



Si Tracker design, construction, operation and  
maintenance



Inner Tracker (IT)  
**EPFL**



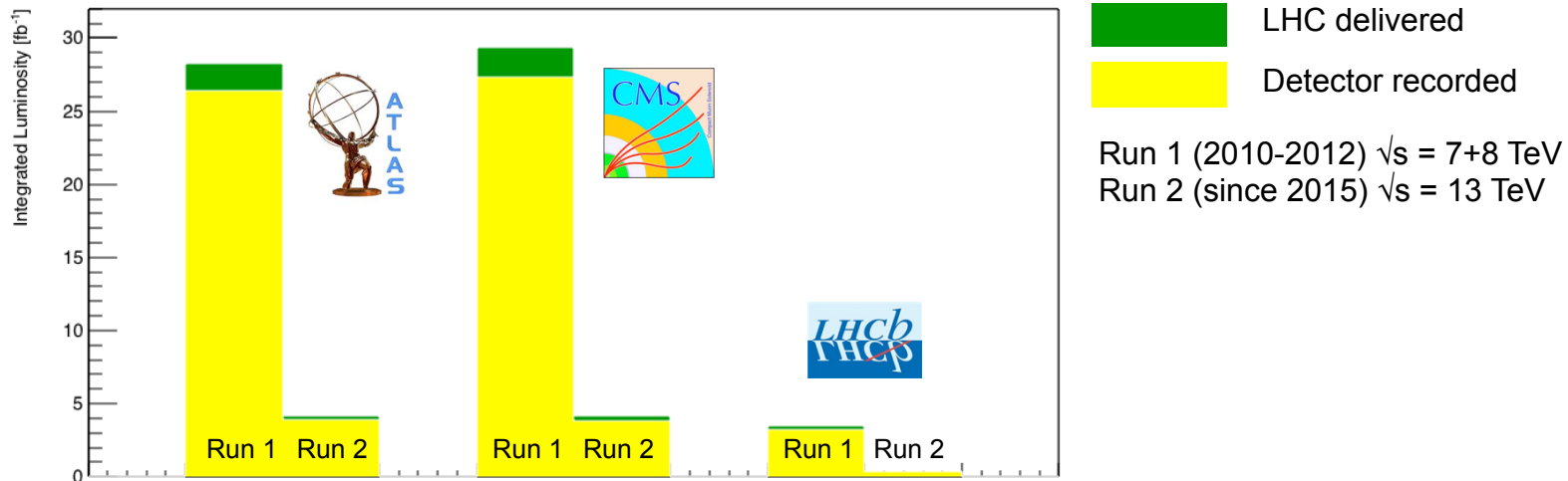
Tracker Turicensis (TT)  
**UZH**



Vertex locator (VELO)  
analog transmission  
lines, power distribution  
**EPFL**

# LHC and detector performance

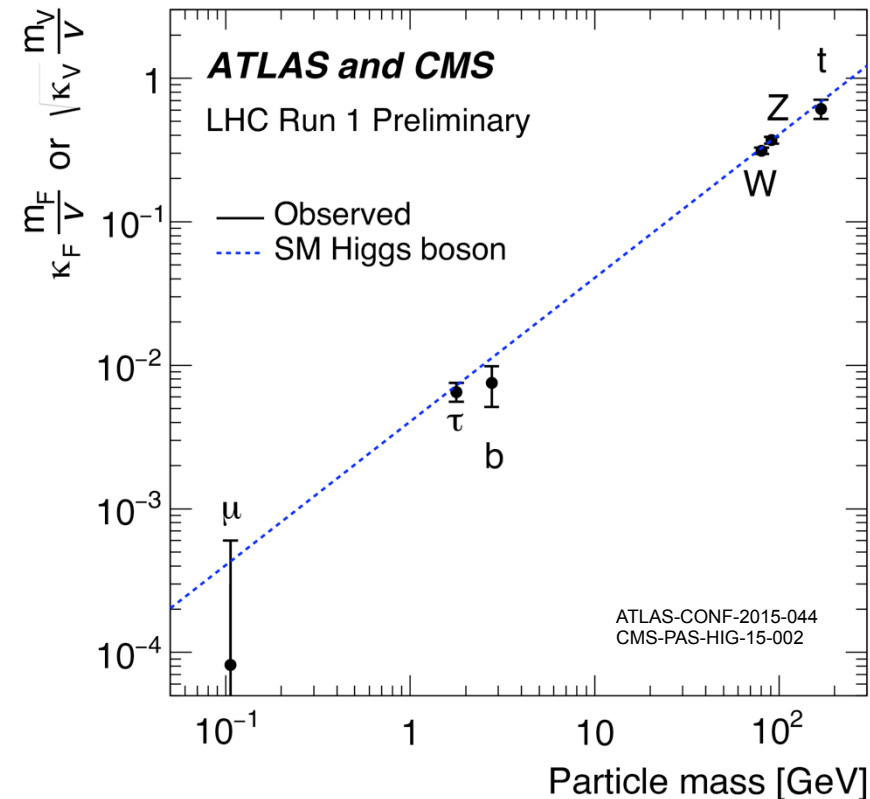
- LHC delivered p-p collisions at  $\sqrt{s} = 7, 8$  and 13 TeV
- Detectors showed excellent performance
  - Data-taking efficiency  $> 90\%$  and  $> 95\%$  channels working
  - Significant effort of CH institutes targeted at detector operation and maintenance proves to be crucial
- This allowed to produce wealth of physics results
  - More than 1400 papers published by CMS, ATLAS and LHCb
  - Will present a selection of results with major contributions from the CH institutes



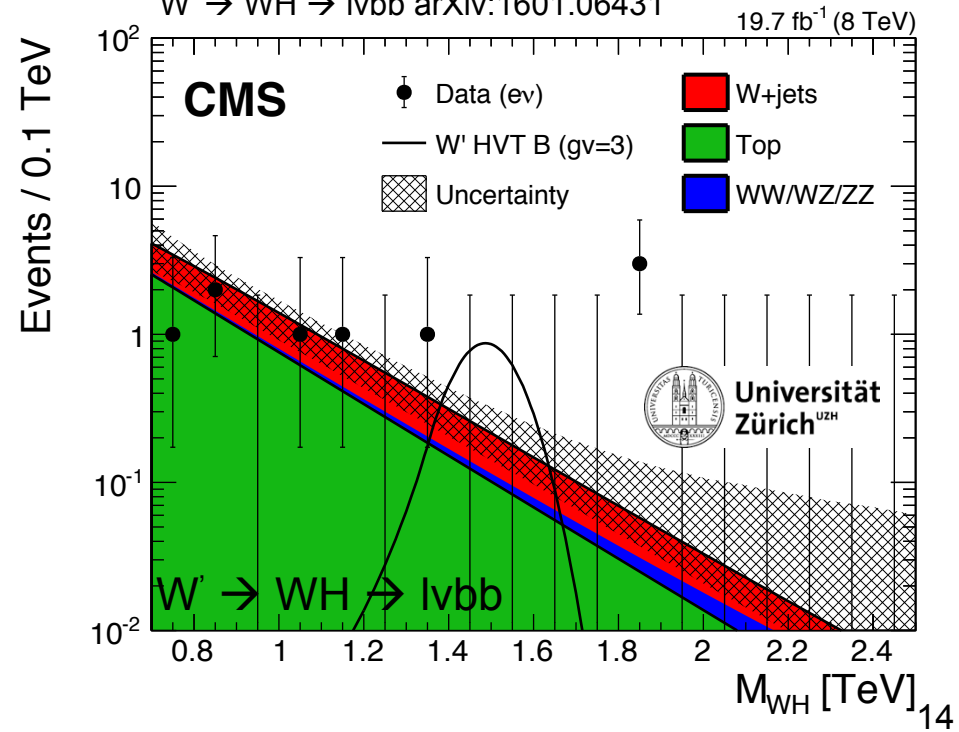


# The Higgs boson

- So far, our Higgs boson has properties very much like the SM Higgs boson
- But we still don't know if indeed there is only this one Higgs boson nor if it couples to New Physics → look at final states with Higgs boson(s) as probe for New Physics

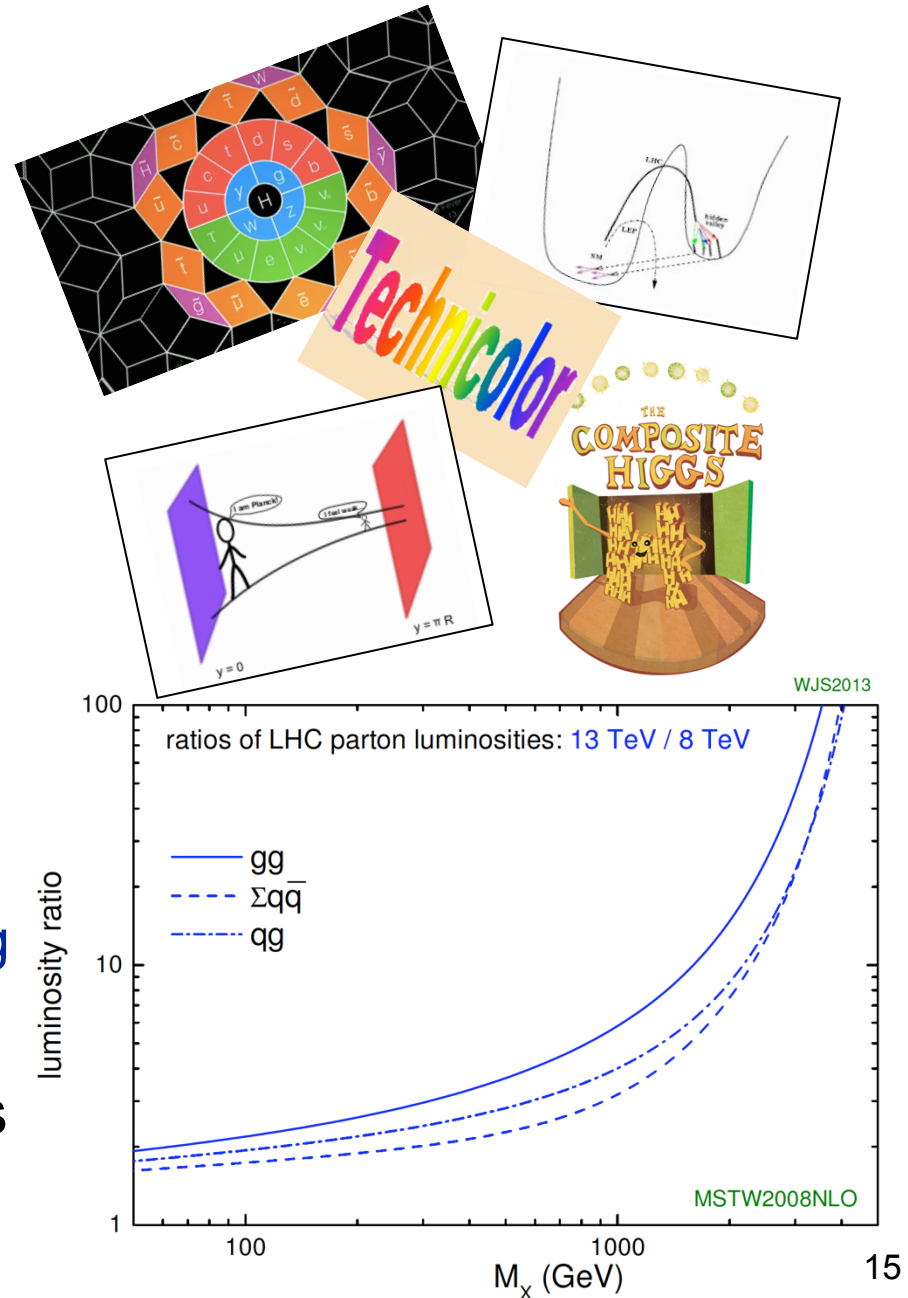


MSSM  $H \rightarrow bb$  JHEP 11 (2015) 071  
 $Z' \rightarrow ZH \rightarrow \tau\tau qq$  arXiv:1502.04994  
 $G \rightarrow HH \rightarrow \tau\tau bb$  CMS-PAS-EXO-15-008  
 $W' \rightarrow WH \rightarrow l\nu bb$  arXiv:1601.06431



# Searches for new phenomena

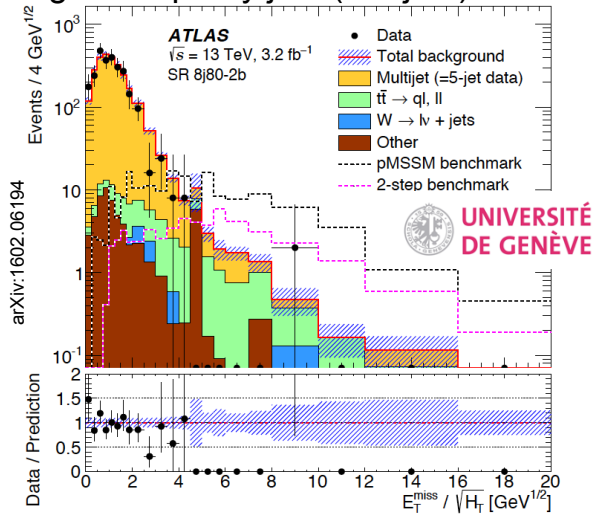
- Beyond-SM theories predict new phenomena within reach of the LHC
  - SUSY, extra-dimensions, composite Higgs, hidden sectors...
- Great potential for direct searches in early 13 TeV data
  - 13 TeV data provides significantly higher mass reach for gg induced processes
  - Allows to follow up on tantalizing excesses observed in Run 1
- Variety of models and channels studied by CH institutes



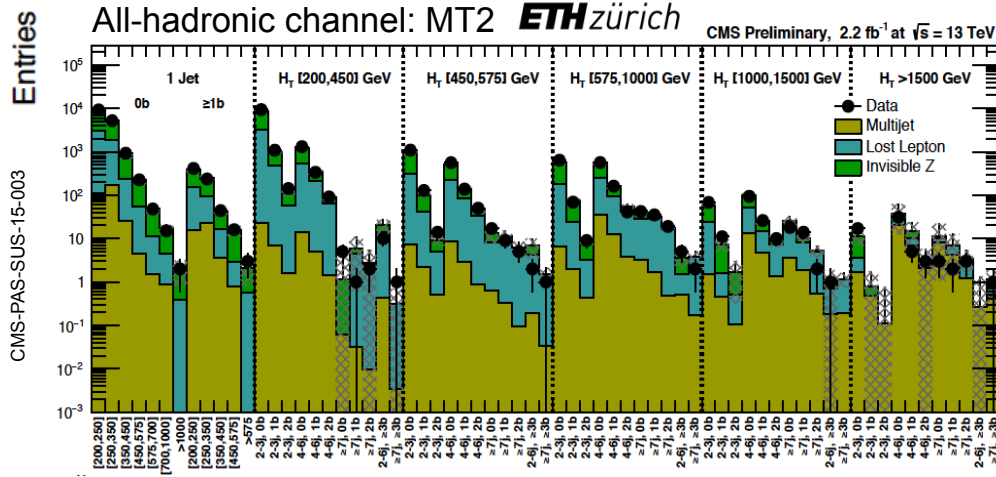
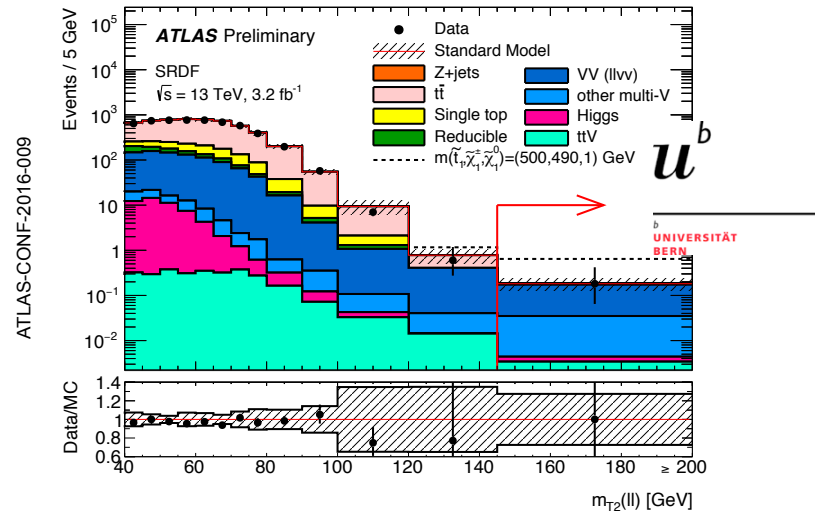
# Direct searches for SUSY

- Focus on event topologies to cover large set of models
  - No significant excesses observed so far, limits are getting more and more stringent...but SUSY has many ways to hide

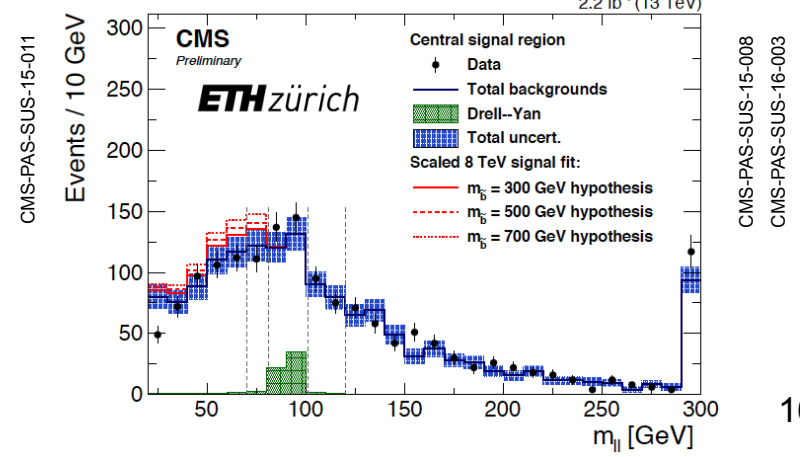
High-multiplicity jets (+ b-jets) + MET



Stop production in final state with leptons and b-jets



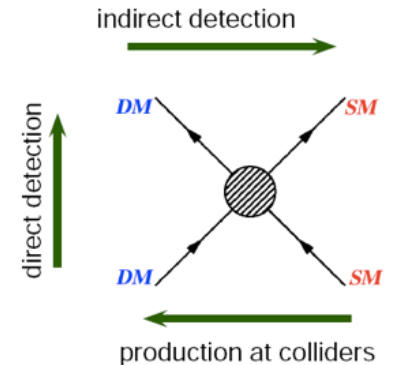
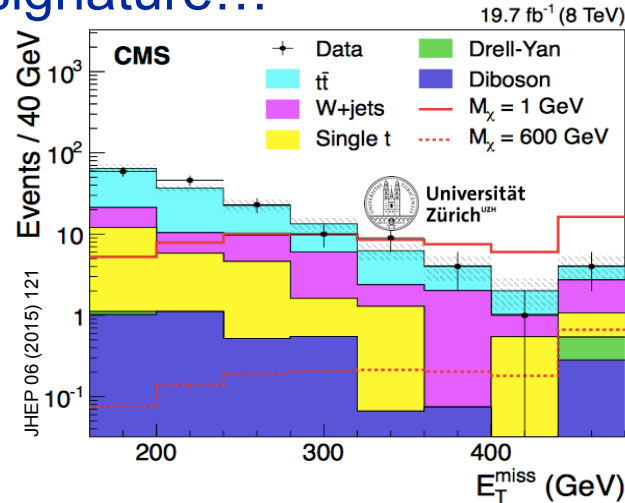
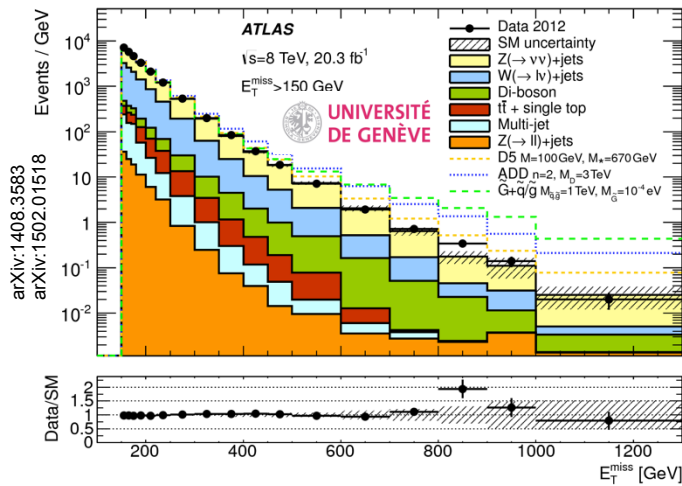
OS leptons + jets + MET (also SS-, tri-lepton)



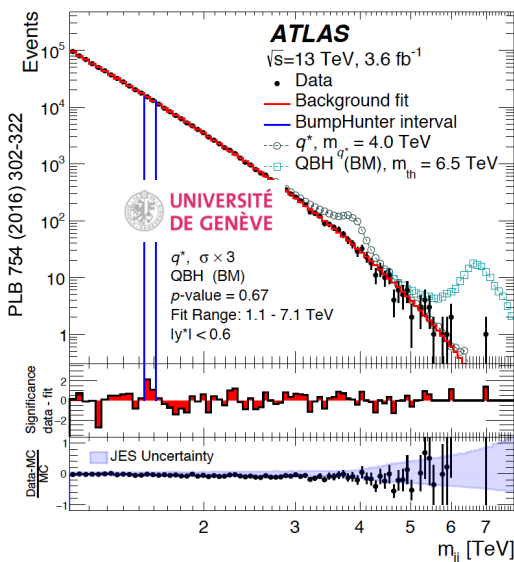


# Direct searches for exotic particles

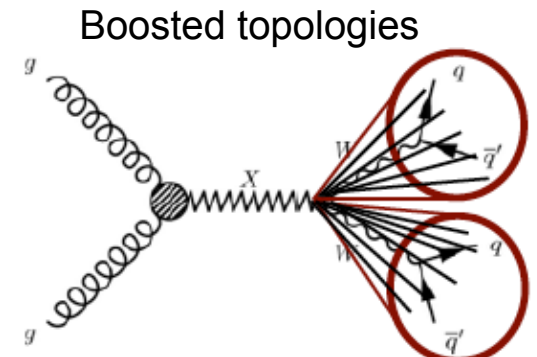
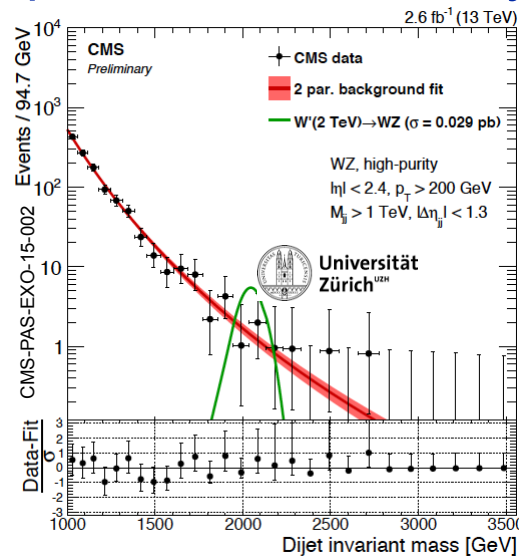
- Looking for bumps and excesses in 13 TeV data:  
MET + recoiling jets as DM signature...



## ... di-jets/di-boson as decay products from heavy resonances ...

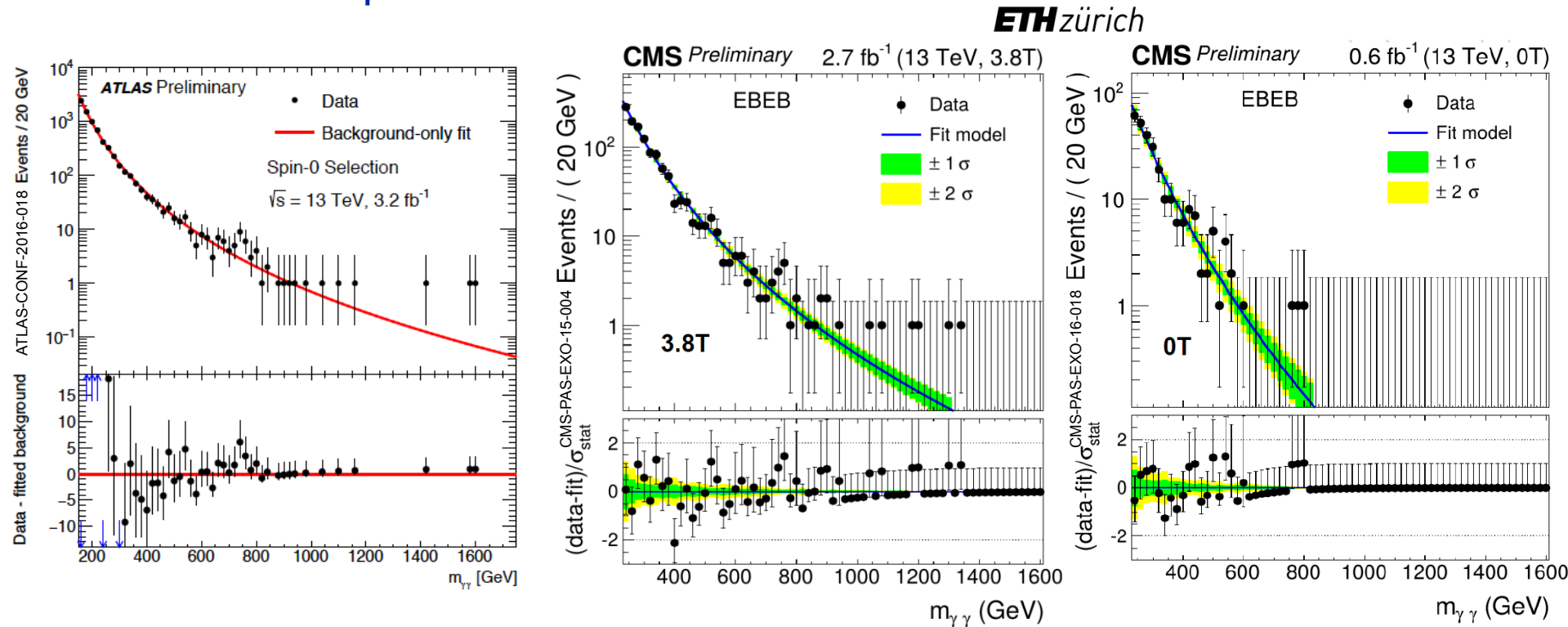


arXiv:1603.08791  
ATLAS-CONF-2015-073



# Direct searches for exotic particles

- Looking for bumps and excesses in 13 TeV data:  
... and also di-photons ...



- > Excess of events observed at  $m_{\gamma\gamma} \sim 750$  GeV in both, ATLAS and CMS...
- > Eagerly awaiting this year's data to see if excess grows into a new signal!

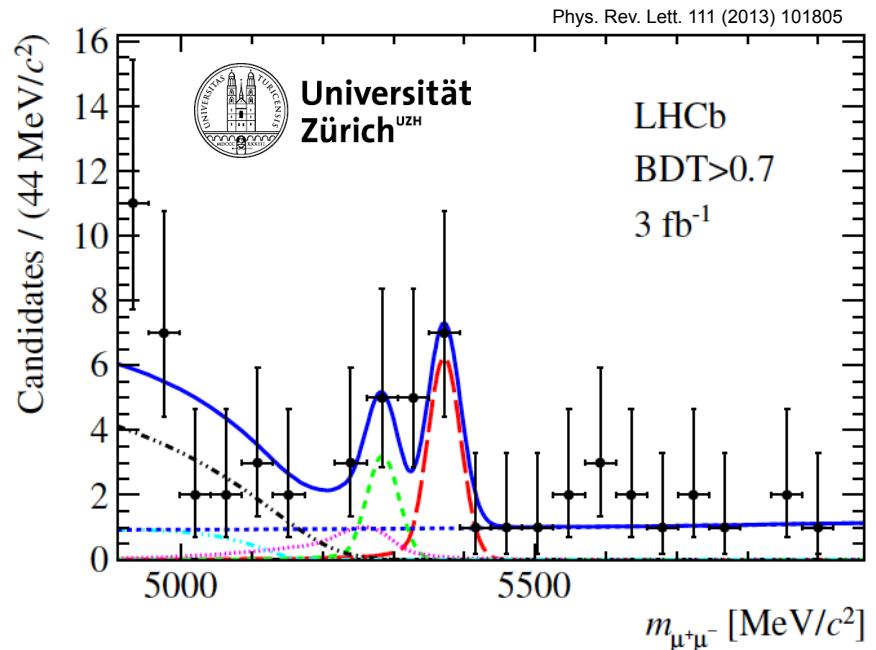
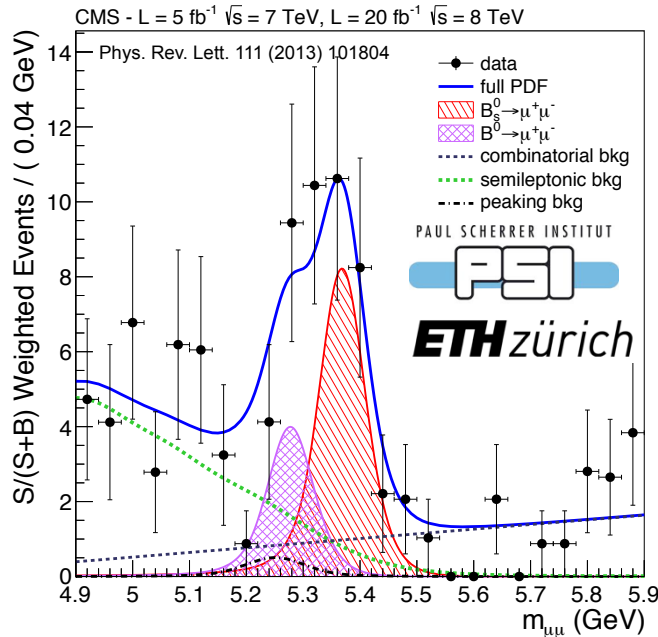
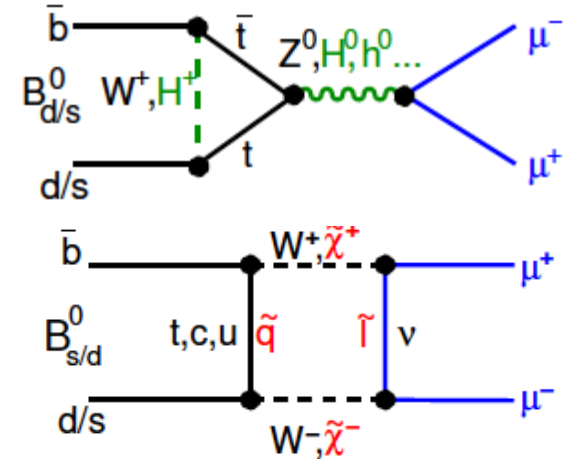
# Indirect searches with B decays

$B_{s,d}^0 \rightarrow \mu^+ \mu^-$  as golden channel:

- Very sensitive to loop contributions of new heavy states
- Very small theoretical uncertainties

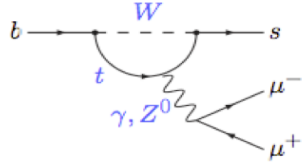
→  $B_s^0$  decay observed in both, CMS and LHCb, with BR consistent with SM

→ Combined analysis published in Nature 522, 68-72 (04 June 2015)

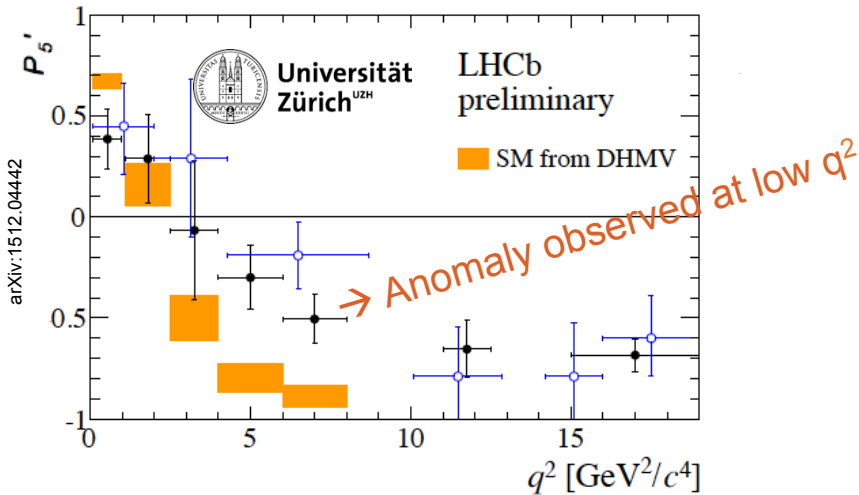


# Indirect searches with B decays

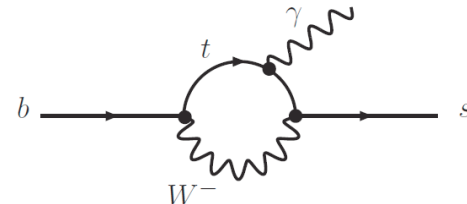
$$B^0 \rightarrow K^* \mu^+ \mu^-$$



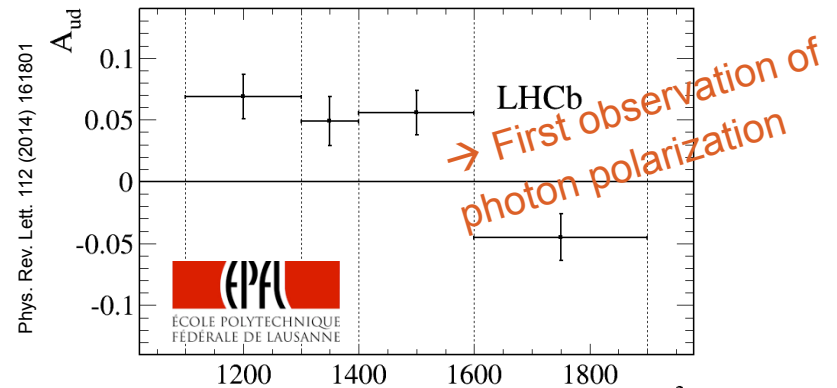
Angular analysis allows to classify NP contributions



$$B^+ \rightarrow K^+ \pi^+ \pi^- \gamma$$

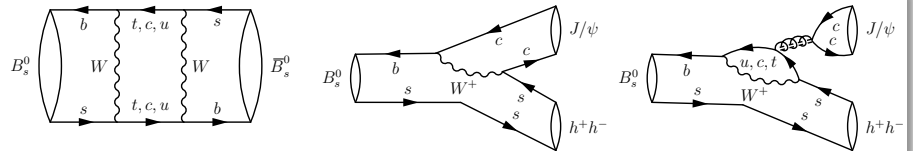


Polarization of photon is sensitive to NP contributions → can be observed through interference of intermediate hadronic states

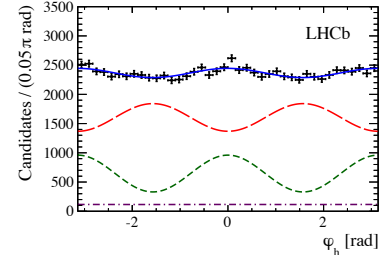
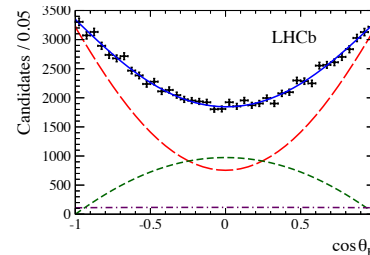
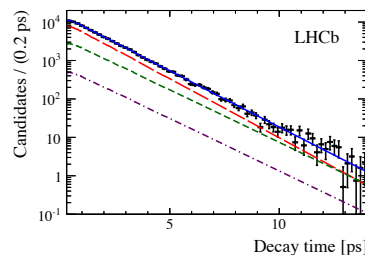


## CP violation in $B_s \rightarrow J/\psi K^+ K^-$

Time-dependent angular analysis to measure CP sensitive phase



Phys. Rev. Lett. 114 (2015) 041801

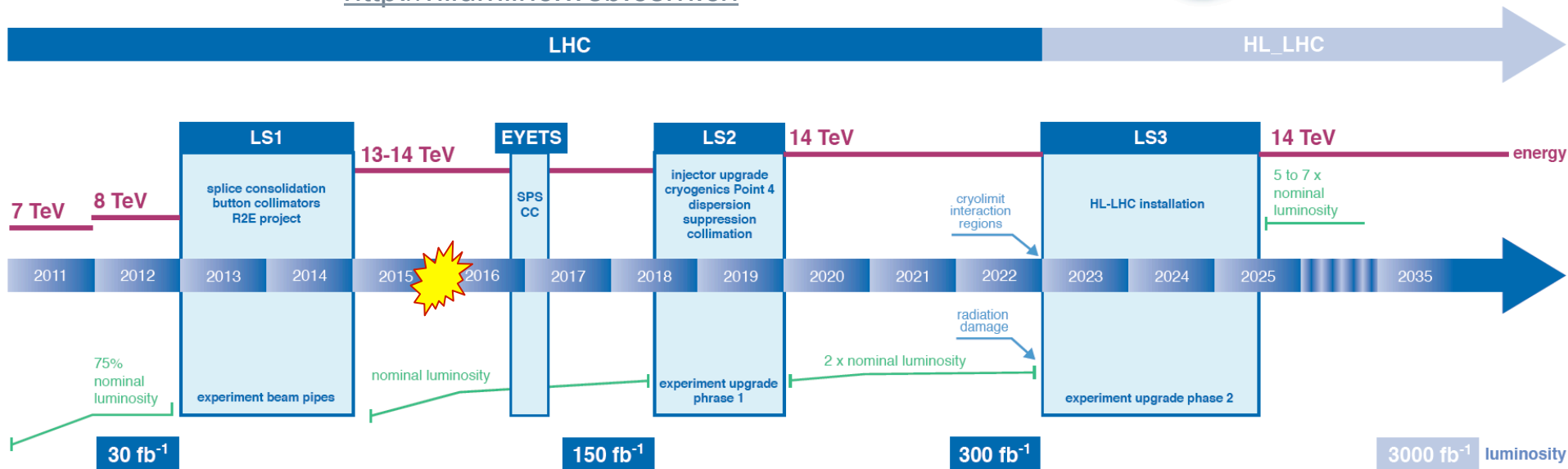


# What's next?

- We are still at the beginning of a long and rich LHC physics program

## LHC / HL-LHC Plan

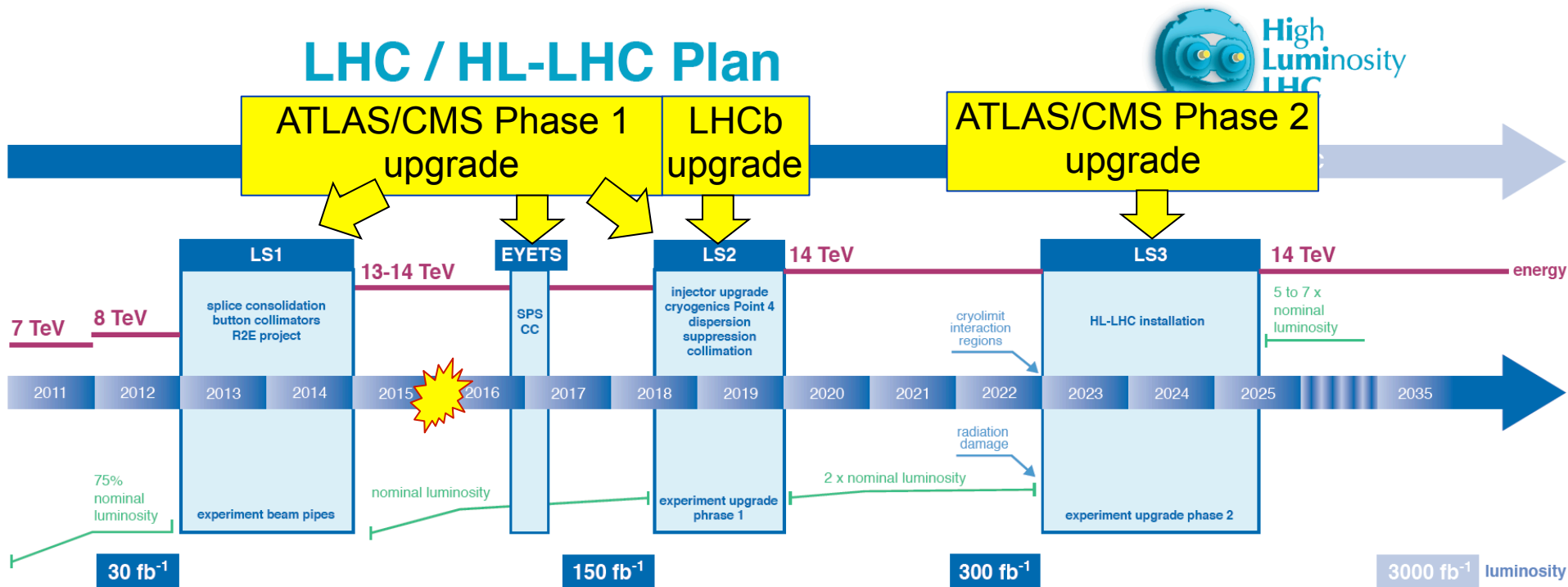
<http://hilumilhc.web.cern.ch>



- Need to invest in accelerator and detector technologies to achieve an optimal performance and best physics reach

# What's next?

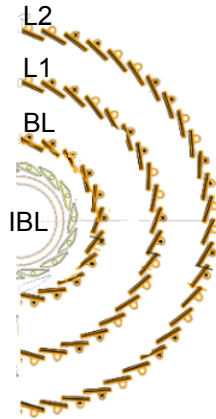
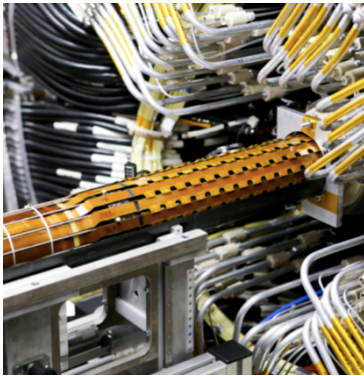
- We are still at the beginning of a long and rich LHC physics program



- Need to invest in accelerator and detector technologies to achieve an optimal performance and best physics reach

# ATLAS upgrade activities

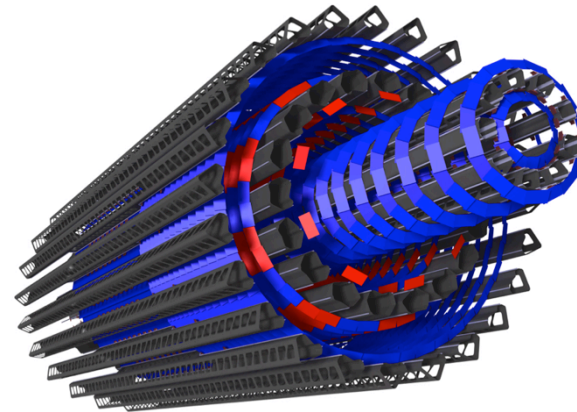
## Phase 1 Pixels



- Insettable B-layer (IBL):
  - Additional innermost tracking layer installed in LS1
  - Major involvement in design, prototyping and construction
  - Loaded and tested in **UniGE** cleanroom
- Upgrade of electronics of outer pixel layers in LS1:
  - Development of optical links and installation lead by **UniBE**

## Phase 2 Pixels

- Proponents for 5-layer pixel system
- R&D on innovative Si pixel technology: HV-CMOS, monolithic CMOS
- Design of mechanical support structure featuring tilted sensors at intermediate  $\eta$



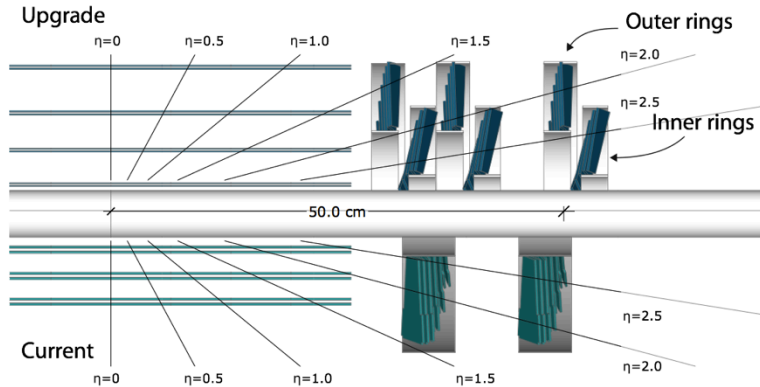
## Trigger and Offline

- Design, production, testing and integration of Fast Track Trigger (FTK) during LS1
- Physics simulation to motivate detector choices for Phase 2

# CMS upgrade activities

## Phase 1 Pixels

- New 4-layer pixel system

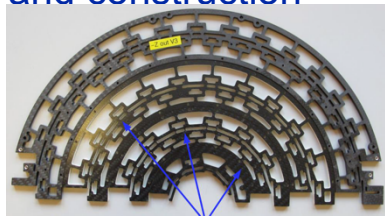


## Phase 2 Pixels

- CH groups focus on conception after Phase 1 installation
- System design, performance and envelop definition
- Development of ROC based on Phase 1 experience **PSI**
- Sensor R&D (eg diamond **ETH**)
- Physics simulation to select best detector configuration **UZH**

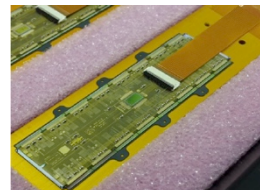
### PSI

- Readout Chip (ROC), sensor and module design
- Module production for L1&2
- Mechanics design and construction



### ETH

- L1&2 module qualification and L1-4 reception test
- Testbeam and irradiations



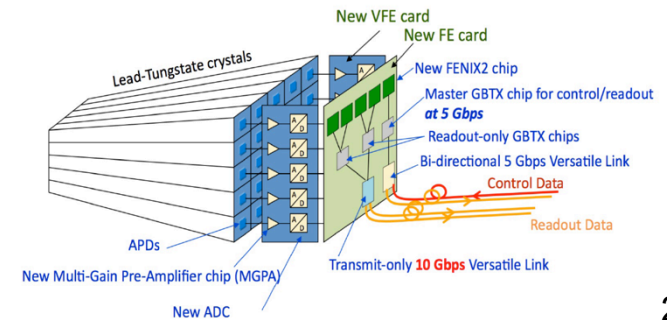
### UZH

- Cooling system and Supply Tube
- Assembly of readout electronics and power system



## Phase 2 ECAL

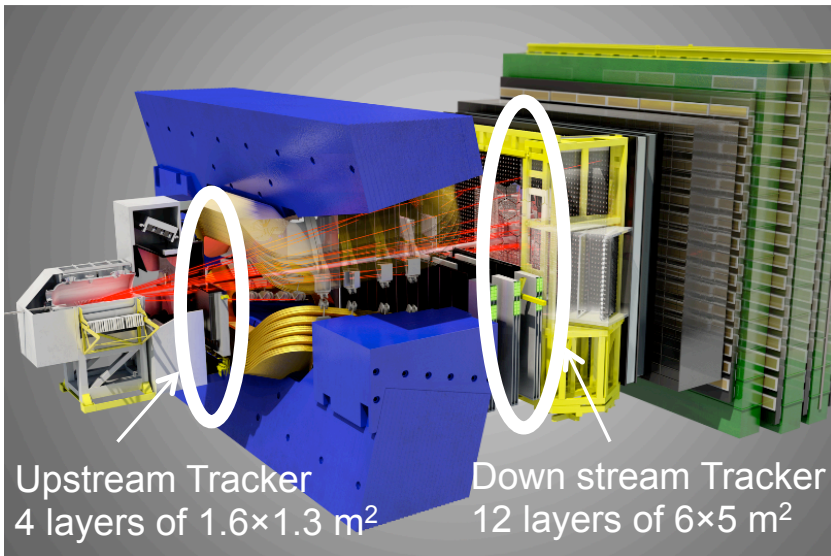
- ETH: Design and prototyping of electronics for ECAL barrel



Joint effort for detector integration & testing at PSI



# LHCb upgrade activities



Go to 40 MHz readout and full software trigger  
→ need to replace all readout electronics and tracking devices

## Downstream Tracker

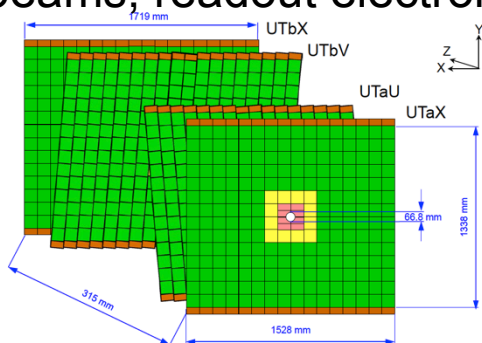
### EPFL

- Proponents of new technology: Scintillating Fibers (SciFi) read out with Silicon Photo-Multipliers

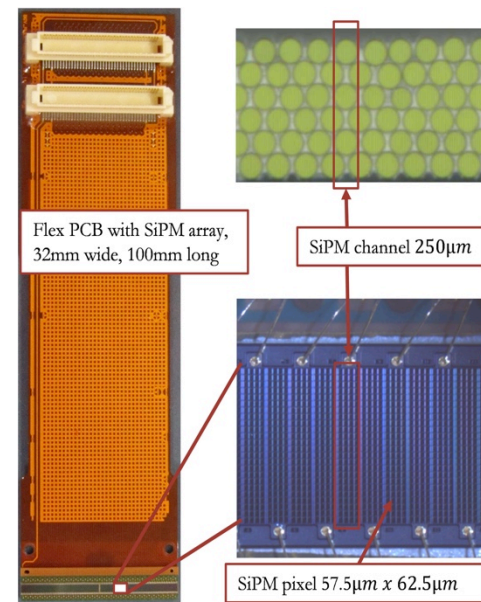
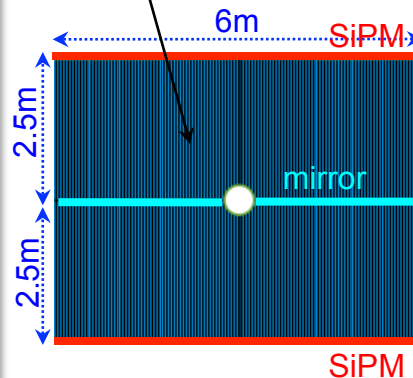
## Upstream Tracker (UT)

### UZH

- Large surface Si strip detector
- Sensor testing, characterization in test beams, readout electronics



Vertical fibers (x) + stereo (uv)  
3 stations x 4 layers (xuvx)



# Summary and Outlook

- CH has been a key player in 3 LHC experiments since the very beginning
  - Strongly involved in detector construction, operation and maintenance as well as physics analysis
- Wealth of physics results came out of this effort
- CH committed to next phases of LHC scientific program
  
- Strategy Workshop on High-Energy Particle Physics in Switzerland (SWHEPPS 2016) in June:
  - Kick-off to prepare Pillar 1 white paper
  - More information at [www.ethz.ch/swhepps2016](http://www.ethz.ch/swhepps2016)



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