# The CMS group

Overview 2020-2021
LIP Jornadas, July 2022

M.Araújo, P.Bargassa, D.Bastos, A.Boletti, R.Bugalho, G.DaMolin, P.Faccioli, L.Ferramacho, M.Gallinaro, J.Hollar, N.Leonardo, H.Legoinha, T.Niknejad, M.Pisano, J.Seixas, P.Silva, J.C.Silva, C.Silva, R.Silva, M.Silveira, J.Varela, J.Wulff
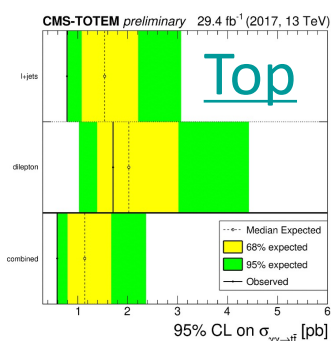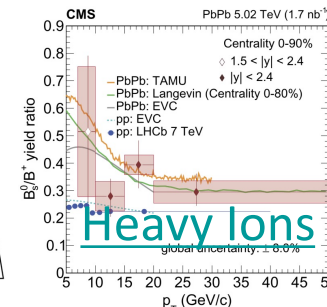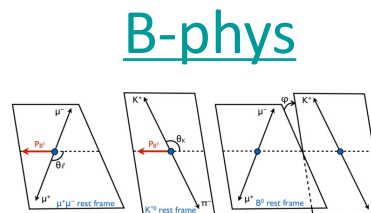
LIP-CMS group

- ## Physics analyses
  - Proton-proton & PbPb collisions
  - Precision measurements & searches (rare processes, BSM)
  - Top, Higgs, B, EWK, SUSY, Dark matter, Heavy Ions, Quarkonia
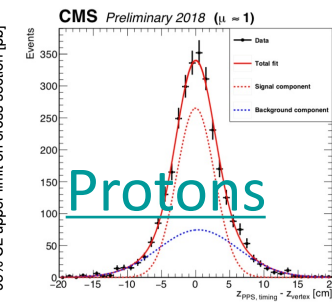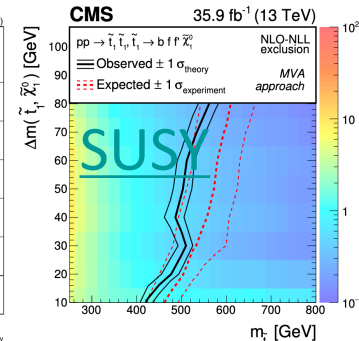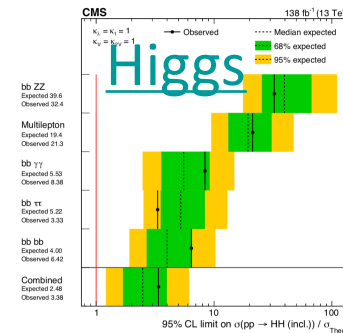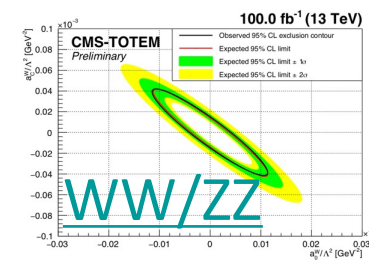
- ## Detector maintenance & operations
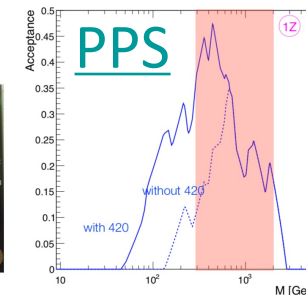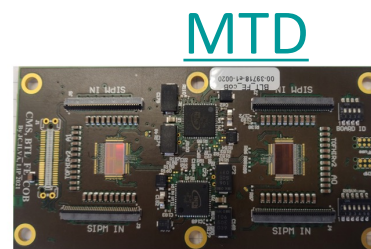 - Precision Proton Spectrometer (PPS), ECAL, Computing

- ## Upgrades
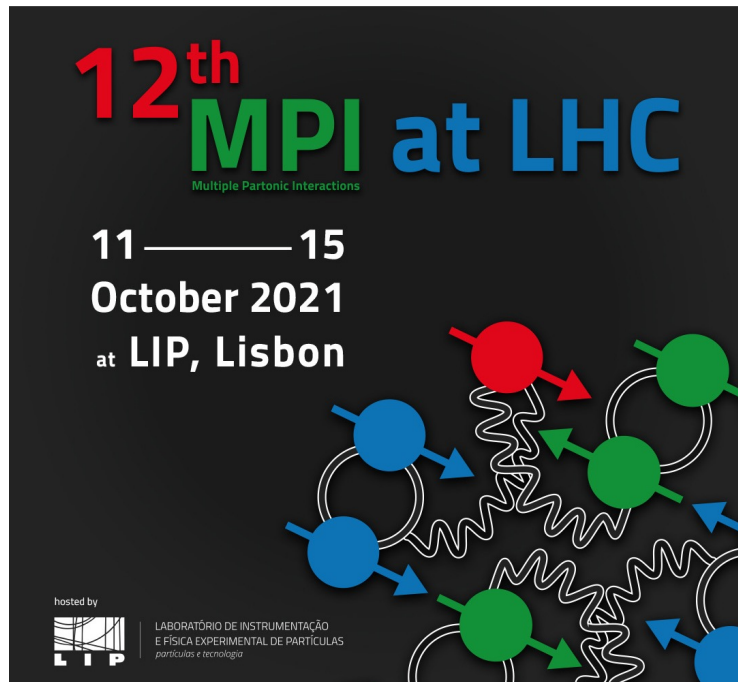 - PPS, Timing Detector (MTD), ECAL, HGCAL

- ## Training & Outreach
  - CERN, LIP, IST
  - LIP internship
  - MPI workshop

CERN/FIS-PAR/0005/2021, CERN/FIS-INS/0029/2021, PTDC/FIS-PAR/1214/2021
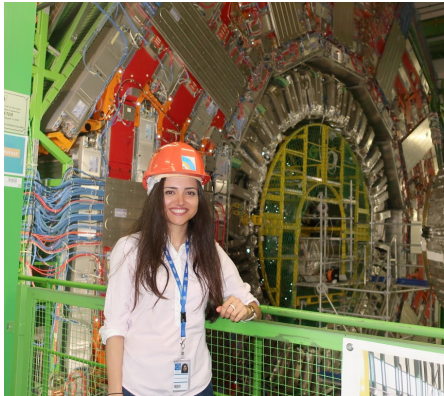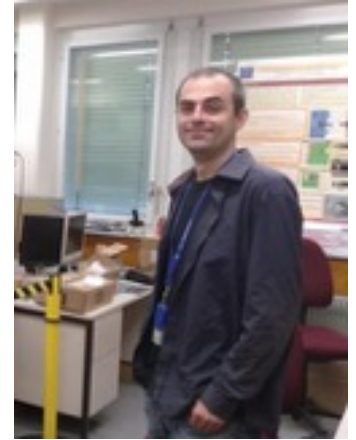
Other activities

- Coordination of LIP internship program
- Organization of 12th Multi-Parton Interaction (MPI) workshop

CMS Awards: 2021

- Jonathan Hollar received the CMS award for "his role as PPS Deputy Project Manager; he has followed the data-taking, the calibration, as well as the ongoing analyses with inexhaustible energy, competence, and tact"

- Tahereh Niknejad received the CMS award for "for important simulation work in the development of the front-end chip for the Barrel Timing Layer readout".

- Ksenia Shchelina received the CMS award for "For her contribution to the exclusive di-lepton analysis which has allowed important improvements of the PPS calibration. In her role as Proton POG co-convenor, she is contributing in an essential way to making the proton information available to analyzers outside the PPS community."
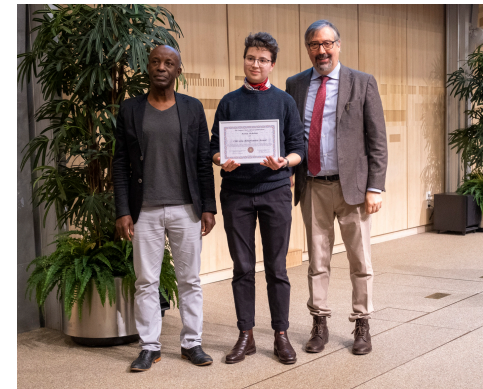
Coordination positions at CMS

Group members have presently the following coordination positions in the CMS collaboration

- PPS Deputy Coordinator (Level-1), since 2018 (J.Hollar)
- PPS Project Manager (Level-1), since 2022 (J.Hollar)
- ECAL Electronics Coordinator (Level-2), since 2011 (J.C.Silva)
- B-Physics Exotica and Rare Decays (ERD) coordinator (Level-3), since 2021 (A.Boletti)
- MTD/BTL electronics systems coordinator, since 2018 (J.Varela)
- MTD/BTL front-end electronics coordinator, since 2018 (J. C. Silva)
- MTD/BTL front-end ASIC coordinator, since 2020 (T. Niknejad)

LIP researcher appointed project manager at CERN

LIP-ECO/C.F. Gonçalves | 06 Julho, 2022

"Jonathan Hollar, researcher in the LIP-CM group, has been appointed coordinator of the PPS (Precison Proton Spectrometer) of the CMS experiment at the LHC."
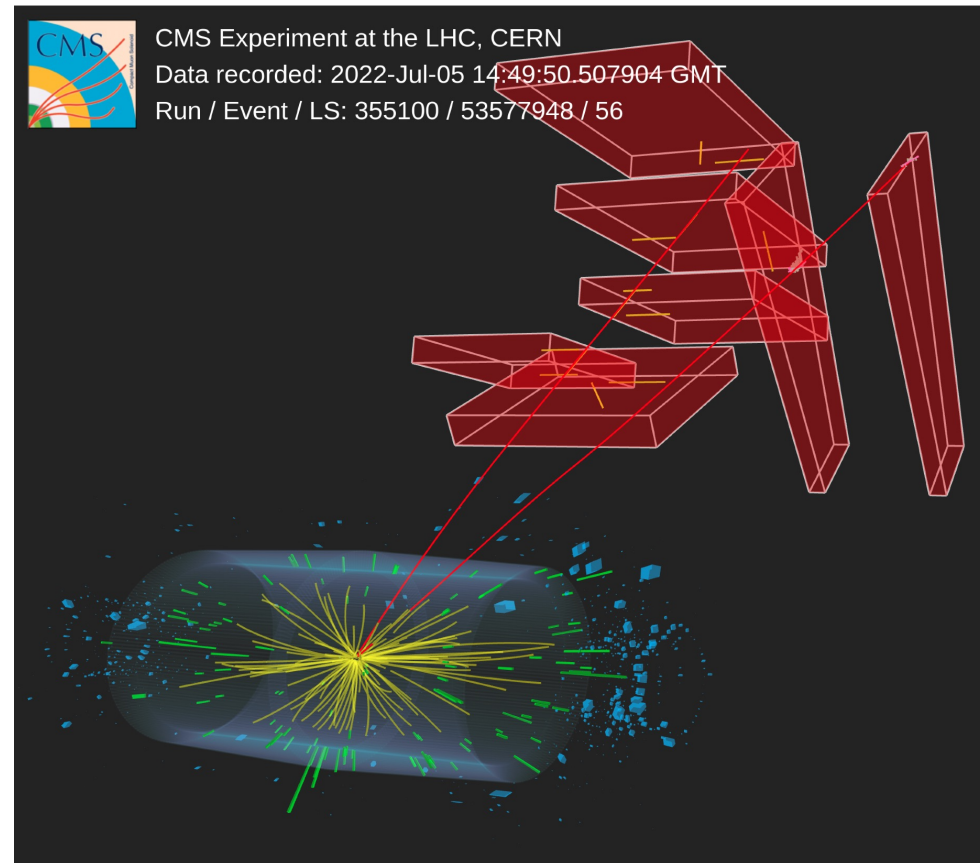
A special week

years HIGGS boson discovery

4 July 2022
CERN

July 4: Scientific Symposium to celebrate the 10th anniversary of the Higgs boson discovery - link to agenda

CMS Experiment at the LHC, CERN
Data recorded: 2022-Jul-05 14:49:50.507904 GMT
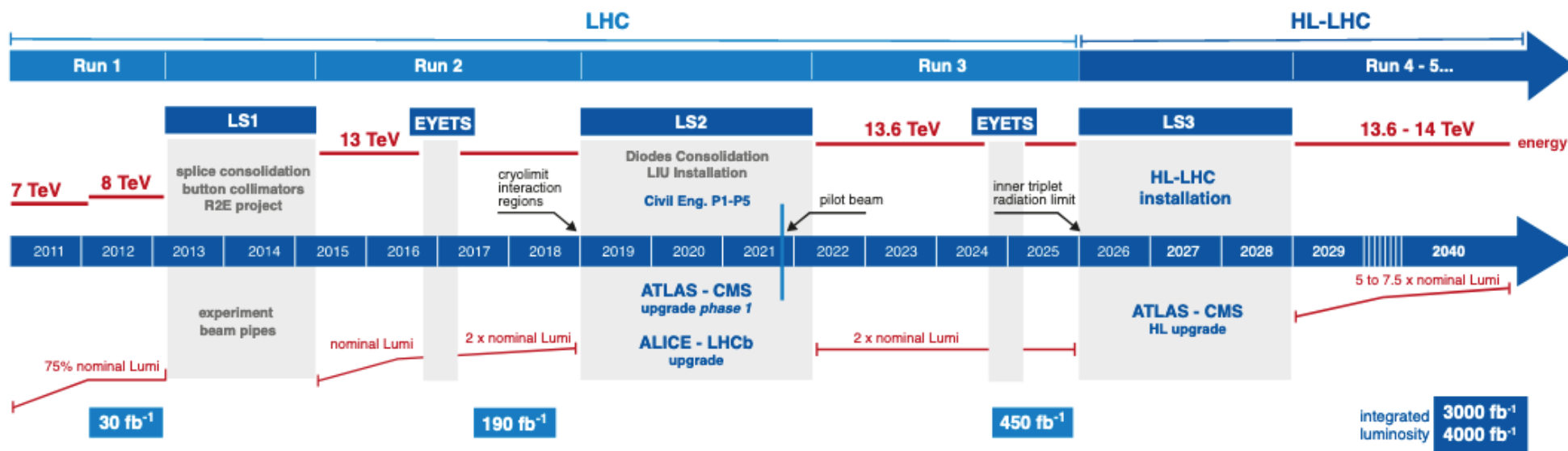Run / Event / LS: 355100 / 53577948 / 56

July 5: Run3 started!
First stable beams @13.6TeV: 3b (PU~20)

Updated schedule: Feb.2022

YETS 22/23   YETS 23/24   EYETS 24/25   LS3 (shifted by 1 year and extended to 3 years)

Detector Upgrades

The HL-LHC will provide an integrated luminosity of 3000 fb^{-1} over 10 years of operation. It will present many technological challenges. We are preparing by developing new detectors and by upgrading the current ones.

LIP Contributes to

Calorimeter Endcap
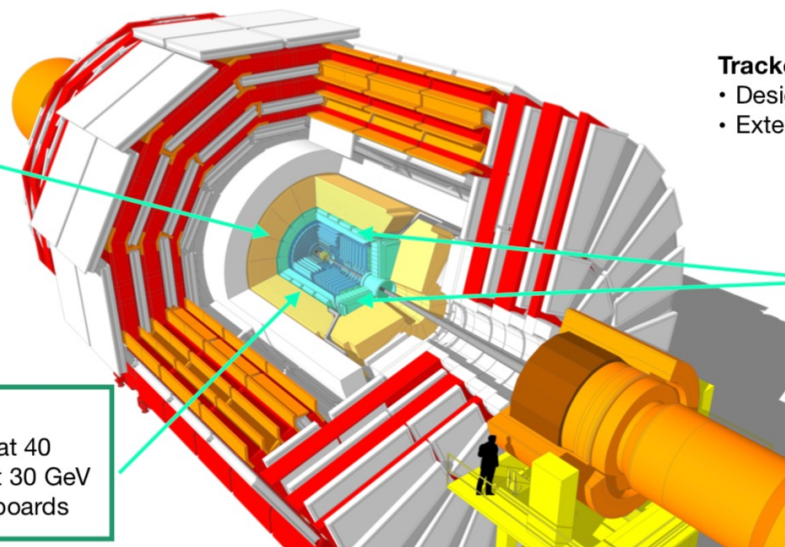- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

Muon systems
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

LIP Contributes to

Barrel Calorimeters
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Tracker Si-Strip and Pixels increased granularity
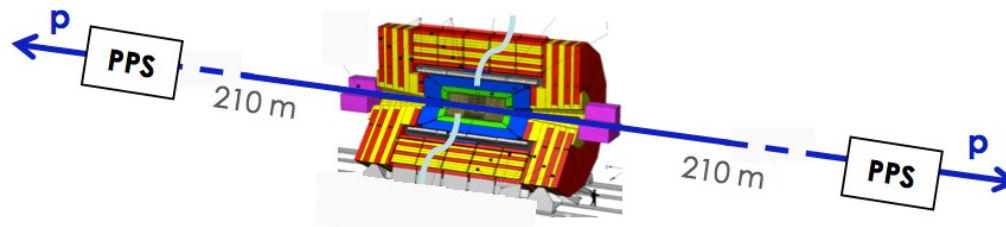- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

LIP Contributes to

MIP Timing Detector - MTD
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

L1-Trigger/HLT/DAQ
- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
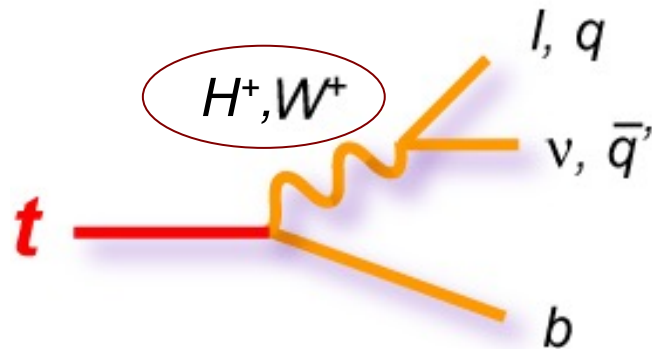- HLT output 7.5 kHz

LIP contributes to

Precision Proton Spectrometer
Detector design and physics prospects

p — PPS — 210 m — 210 m — PPS — p

See presentation by J. Hollar

Top quarks and tau leptons

- Lepton flavor universality (LFU): check consistency with SM expectations
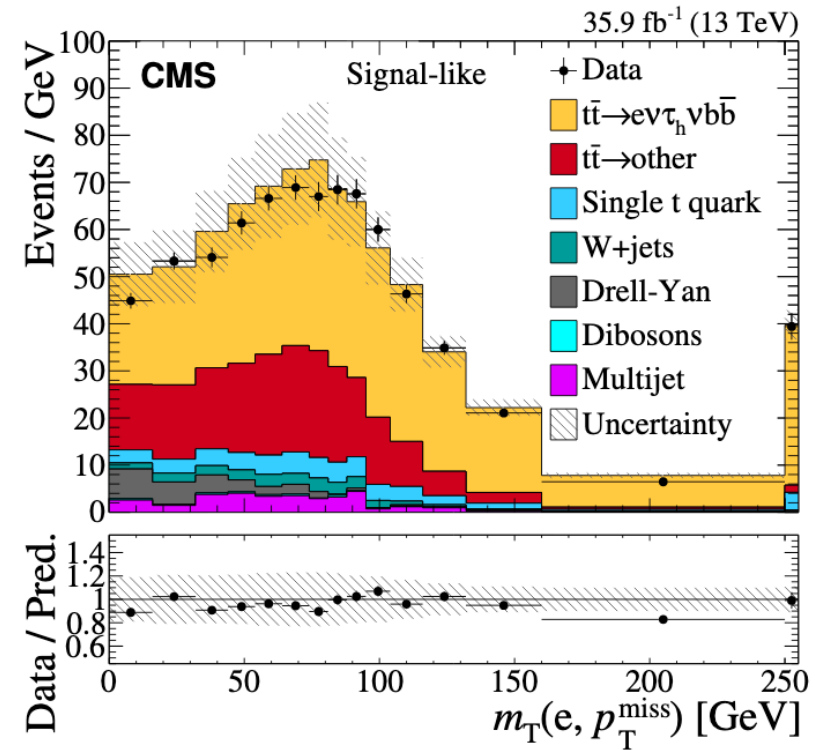
G. Da Molin, A. Toldaiev, M. Gallinaro

- Test of LFU in top quark decays

- $t \rightarrow (\tau\nu)b$ decay exclusively involves 3rd gen. leptons/quarks

- Measure cross section, ratio of cross section to light (e/μ) dileptons, ratio of partial to total width

$$R_{\ell\tau_h/\ell\ell} = 0.973 \pm 0.009\,(\text{stat}) \pm 0.066\,(\text{syst})$$

$$\Gamma(t \rightarrow \tau\nu_\tau b)/\Gamma_{\text{total}} = 0.1050 \pm 0.0009\,(\text{stat}) \pm 0.0071\,(\text{syst})$$
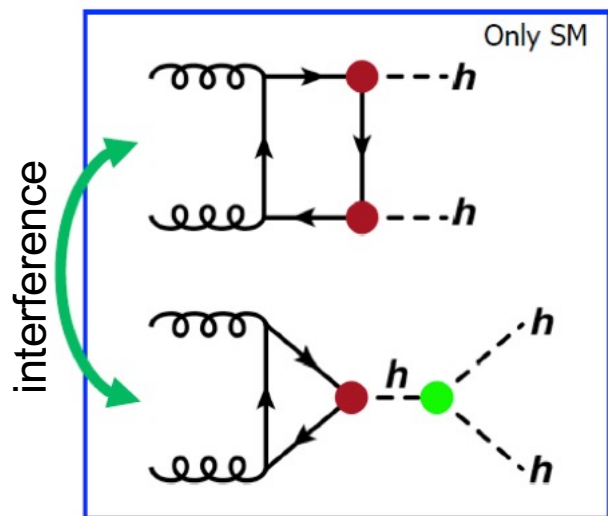
See presentation by G. Da Molin
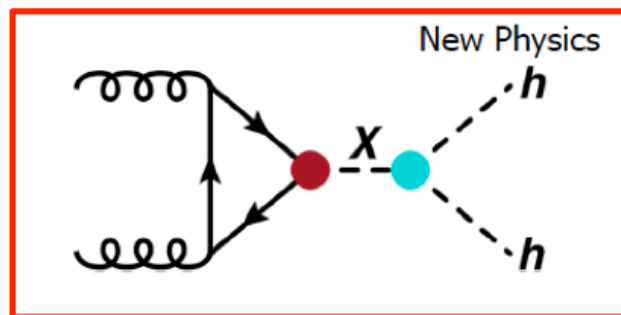
Double Higgs production

arXiv:1902.00134, Mach.Learn.Sci.Tech.1(2020)045006, Rev.Phys.5(2020)100045, arXiv:2105.07530, arXiv:2206.09401

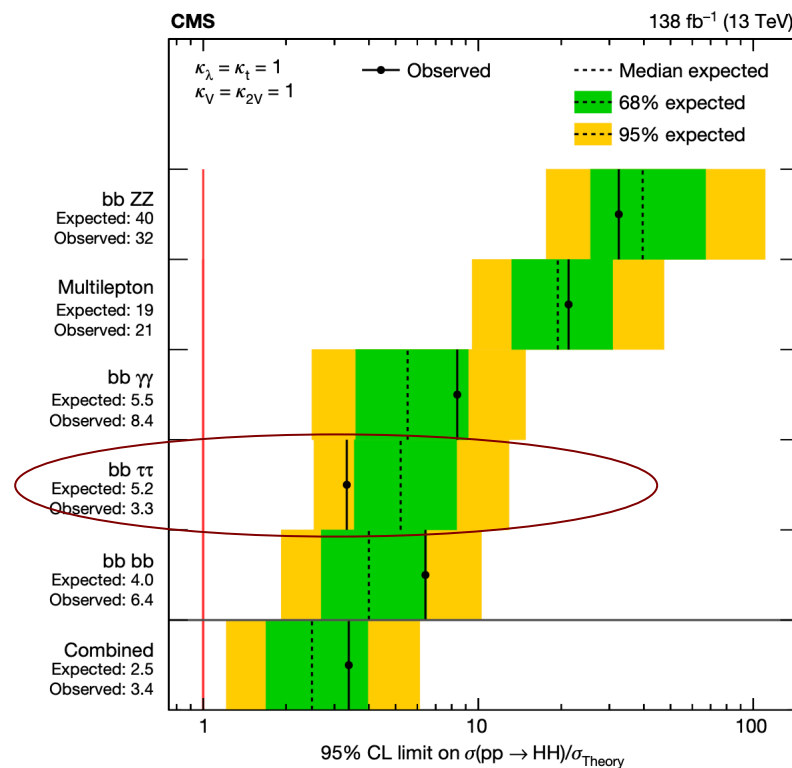J. Wulff, G. Strong, M. Gallinaro

non-resonant production

resonant production

[See presentation by J. Wulff](#)

- Measure Higgs self-coupling
  - BSM could give large enhancement
- In SM, only σ=33fb at 13 TeV

$\Rightarrow$ better (x2-3) than 2016 results alone after scaling for luminosity

Exclusive production

M. Pisano, J. Hollar, M. Gallinaro

- LHC as photon collider
- EWK processes with small cross sections
- Study $\gamma\gamma$ interactions at high energies in exclusive processes with leading protons
- High-mass system in central detector, together with very forward protons in PPS
  - momentum balance between central system and forward protons, provides strong kinematical constraints
  - central system mass measured by momentum loss of two leading protons
- Couplings in SM are small and deviations from predictions may hint for NP
- Sensitive anomalous couplings ($\gamma\gamma VV$, $\gamma\gamma tt$)
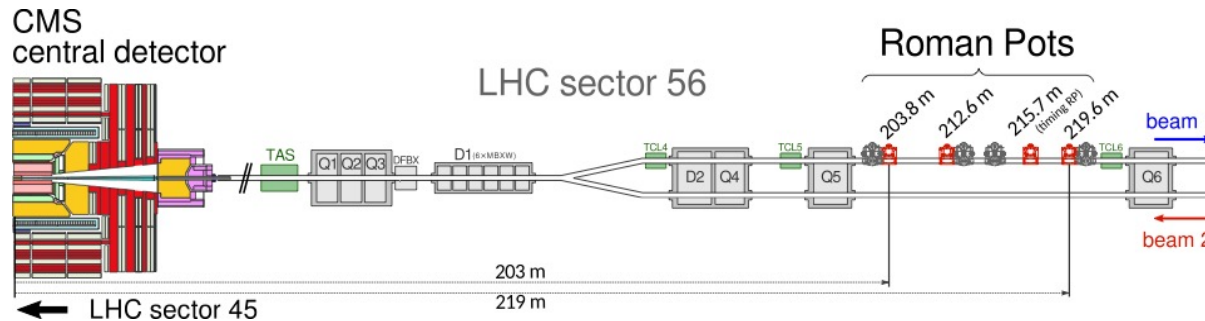- Search for new BSM resonances

See presentation by M. Pisano

CMS+TOTEM 2016, L = 9.4 fb⁻¹, √s = 13 TeV

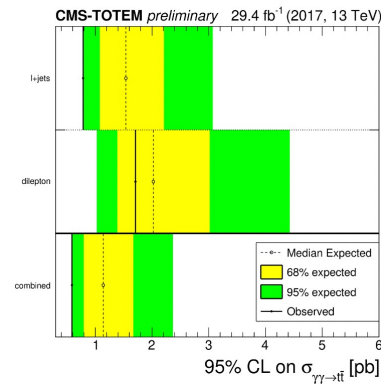# Physics w/ forward protons

Proton reconstruction
CMS-PRO-21-001

PPS collected more than 100/fb of data in Run2
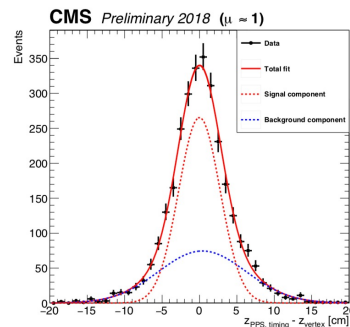
Exclusive top quark pairs
CMS-TOP-21-007
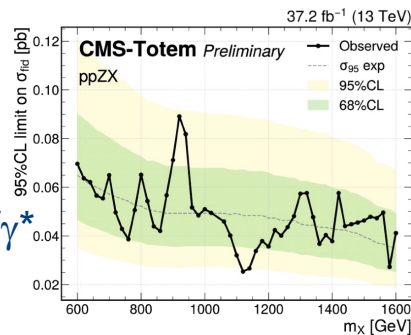
Search for central exclusive production of ttbar pairs in pp interactions with tagged protons

Zγ+X production
CMS-PAS-EXO-19-009

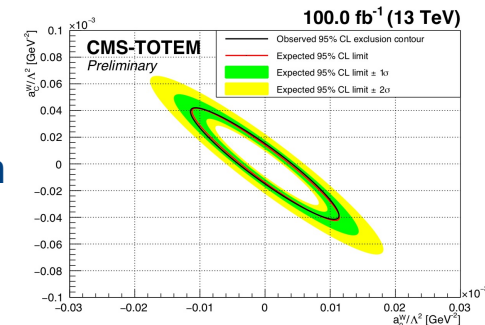Search for anomalous Z/γ* central production with 2017 data

Exclusive WW/ZZ
CMS-SMP-21-004

Search for γγ→WW/ZZ with forward protons

SUSY

D. Bastos, P. Bargassa
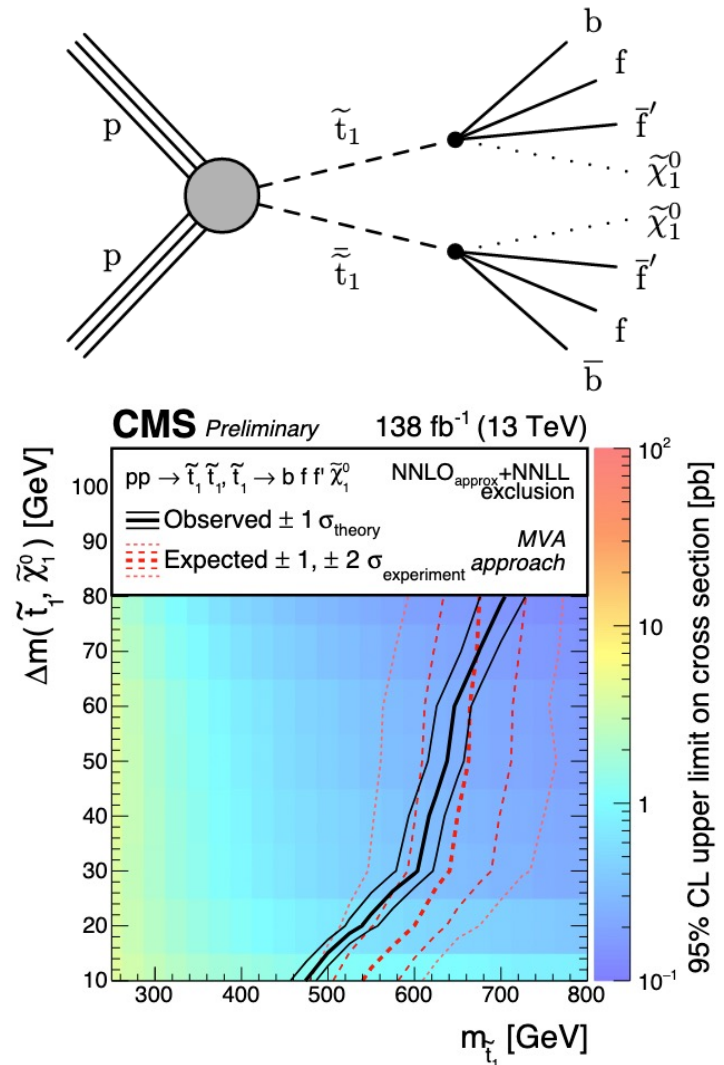
- **Search for stop through 4-body decay**
  - May be lightest squark produced
  - Neutralino (LSP) may be DM candidate

- **Probe compressed scenario:**
  - m(stop)-m(neutralino)<m_W

- **Use ML/MVA**

- **Legacy results with Run2 data**

- **First presented at SUSY2022**

See presentation by Diogo Bastos @SUSY2022

B-physics

A. Boletti, M. Faria, N. Leonardo

- **Indirect search for NP**
  - Provides sensitivity beyond collision energy
  - Precision measurements and rare decays

- **Exploring Flavour Anomalies**
  - NP through virtual contributions
  - study b→sμμ transitions (FCNC)
  - rare decays B→μμ, B→K*μμ

- **Study decay rates and angular variables**

- **Goldmine in "parked" dataset**
  - Test lepton flavour universality
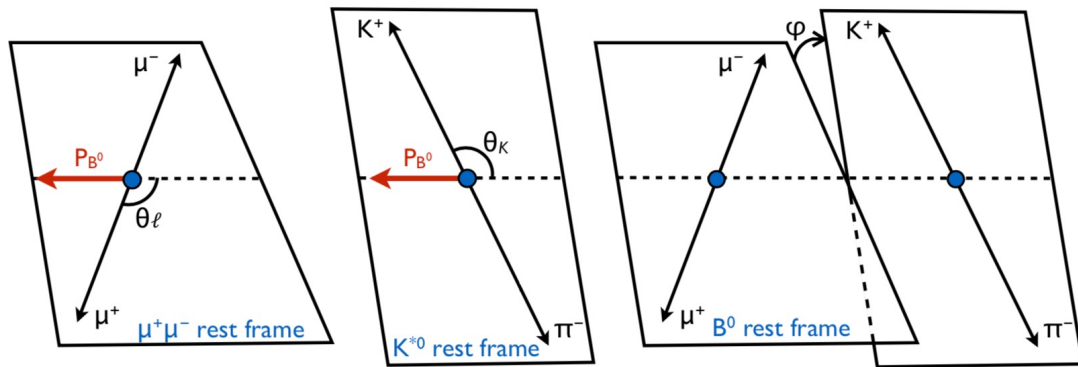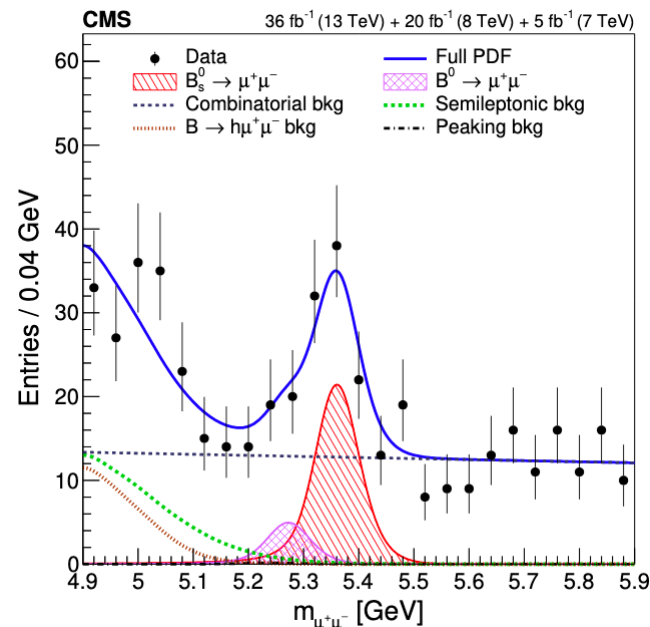
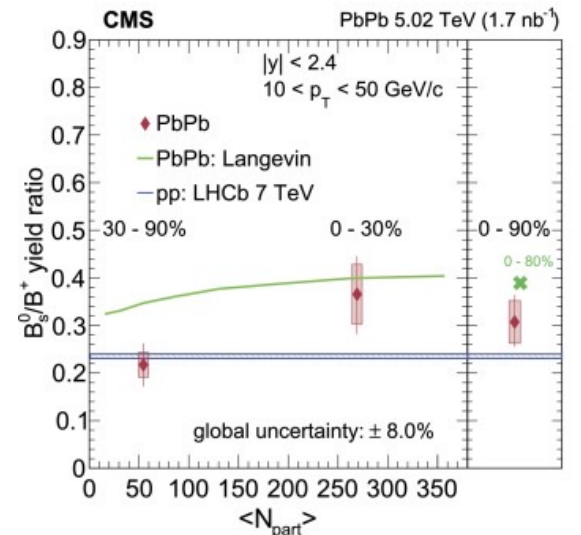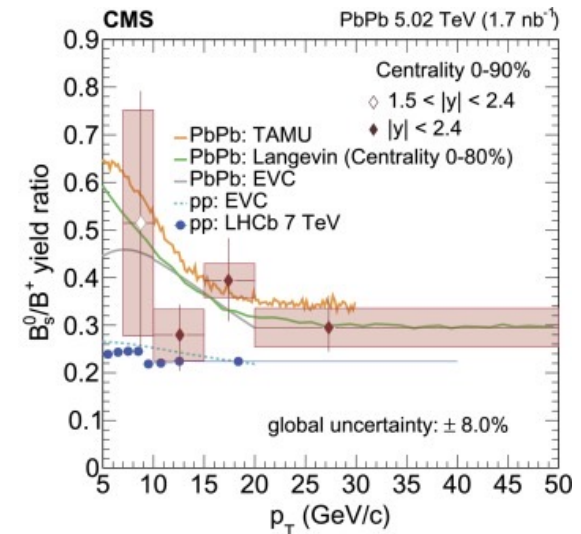# Heavy Ions

H. Legoinha, J. Silva, M. Faria, N. Leonardo

- **Study properties of quark gluon plasma (QGP)**
  - Ion collisions at the highest energies

- **Explore heavy flavour as novel probe of QGP**
  - Exclusive reconstruction of b hadrons (first time in HI @ CMS)

- **First observation of B_s mesons in nuclear collisions**

- **Study effect of QGP on hadronization**

Quarkonia

M. Araujo, P. Faccioli, J. Seixas

- The heavy c and b masses allow to study the (long-distance) bound state formation without complications caused by the (short-distance) qq creation step

- Polarization is the best observable to understand how the bound states are formed
  - First measurements of P-wave quarkonium polarization: χ_{c1}/χ_{c2} ratios
  - First significant deviation from unpolarized production scenario
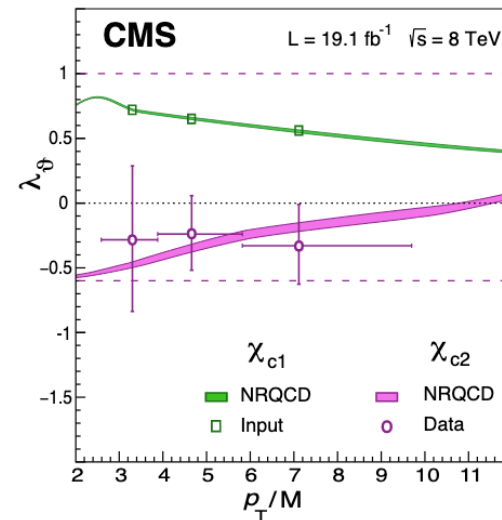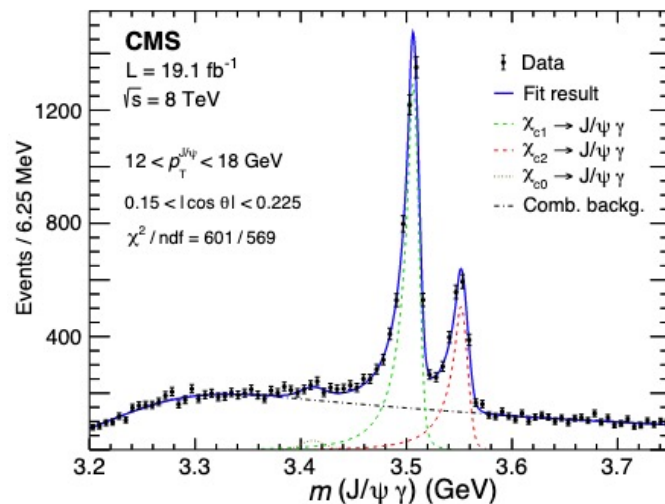
- Ongoing (Mariana's thesis): improved S-wave polarization measurements using Run2 data. Deviations from zero and flat? Synergy with Pheno activity: new global data analyses.
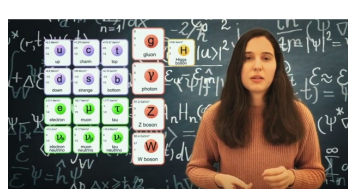
Recent MSc and PhD theses

Measurement of b-quark fragmentation fraction ratios at the CMS experiment: a key ingredient for the $B_s^0 \to \mu^+\mu^-$ rare decay analysis

CERN-THESIS-2018-274, May 2018
Now at LLR, Paris

Bruno Afonso Fontana Santos Alves

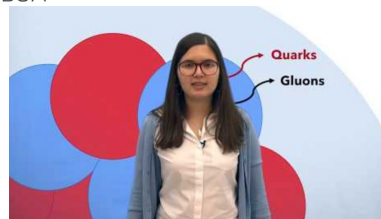

Probing the quark gluon plasma medium through B meson production measurements in PbPb collisions at the LHC

Júlia Manuela Cardoso Silva

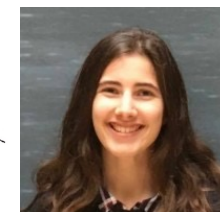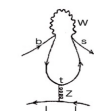CERN-THESIS-2019-256, Oct. 2019
Now at U. Manchester, UK

Search for exclusively produced top quark pairs at the LHC

CERN-THESIS-2019-280, Dec. 2020
Now at DESY, Hamburg

Beatriz Ribeiro Lopes

Investigating the flavour anomalies through the rare beauty decay $B^0 \to K^{*0}\mu^+\mu^-$

Maria Carolina Feliciano Faria

CERN-THESIS-2021-220, Oct. 2021
Now at EPFL, Lausanne

TÉCNICO LISBOA
UNIVERSIDADE DE LISBOA
INSTITUTO SUPERIOR TÉCNICO

DEEP LEARNING METHODS
APPLIED TO HIGGS PHYSICS AT THE LHC

Giles Chatham Strong

CERN-THESIS-2021-211

arXiv:1902.00134, Mach. Learn. Sci. Techn.1 045006, Dec. 2020
Now at U. Padova, Italy

TÉCNICO LISBOA
Universidade de Lisboa
Instituto Superior Técnico

Top quark physics and search for physics beyond the Standard Model at the Large Hadron Collider

Author: Oleksii Toldaiev

CERN-THESIS-2020-203

JHEP 02 (2020) 191, Oct. 2020
Now at Cern with U. Indiana, USA

Summary

- LIP/CMS group actively involved with leading roles in data analysis and detector upgrades
  - *LIP/CMS group with major responsibilities in MTD and PPS*
- Run3 started and will allow us to further probe the SM
  - *Unique measurements in uncharted territory*
- Integrated luminosity will double Run1+Run2 datasets
- Plans for HL-LHC well defined and already in progress
- Planning of next endeavors is underway (FCC, Muon collider, etc.)

Exciting years ahead!

spares

CMS "Gold" Award

- PETSys: awarded the CMS gold award for *"the challenging development of the TOFHIR2 front-end ASIC of the barrel MTD detector. The circuit performs precise time measurement of ionizing particles detected by LYSO scintillating crystals associated with silicon photomultipliers (SiPM) at high rate and in the presence of an overwhelmingly large SiPM dark noise (DCR) due to radiation damage. TOFHIR2 implements an innovative DCR cancellation circuit which significantly improves the time resolution of the detector."*
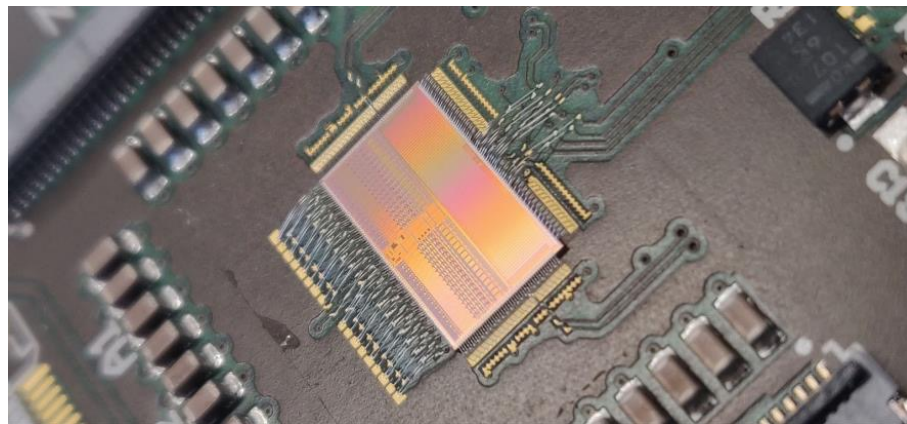
HH: Advanced Analysis Techniques

1) Select HH events in different categories: $\mu\tau_h bb$, $e\tau_h bb$, and $\tau_h\tau_h bb$

2) Train classifier consisting of an ensemble of deep neural networks (DNN) on half of MC data to classify signal and background events using final-state features

3) Apply classifier to other half of MC data

4) Treat the classifier prediction as a summary statistic of the data and infer the signal strength via a combined hypothesis test for each decay-channel category
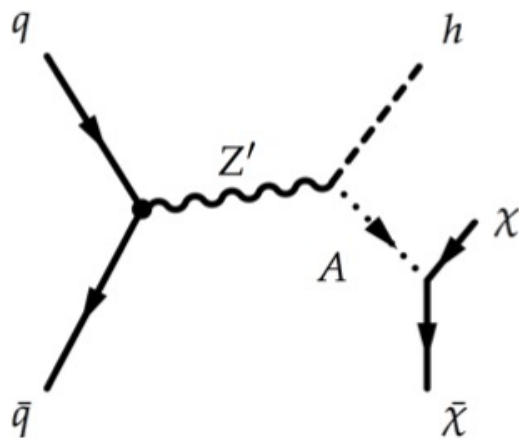
5) 52 pre-processed features are used to define each event
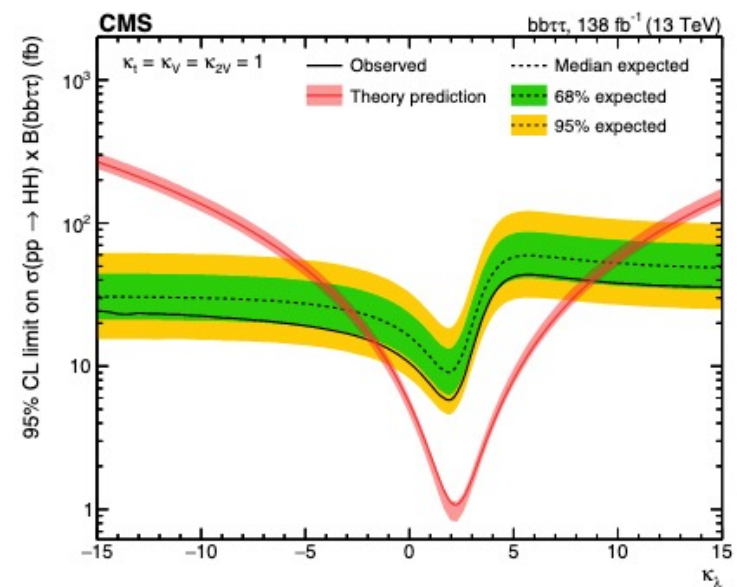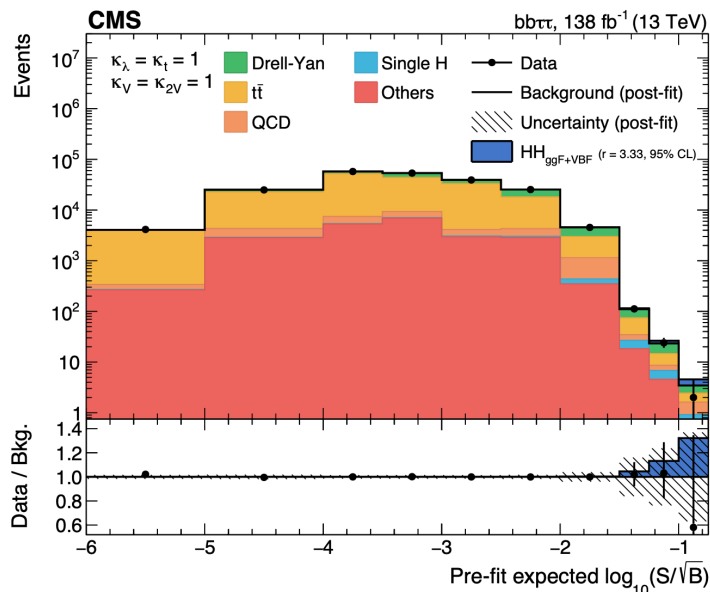
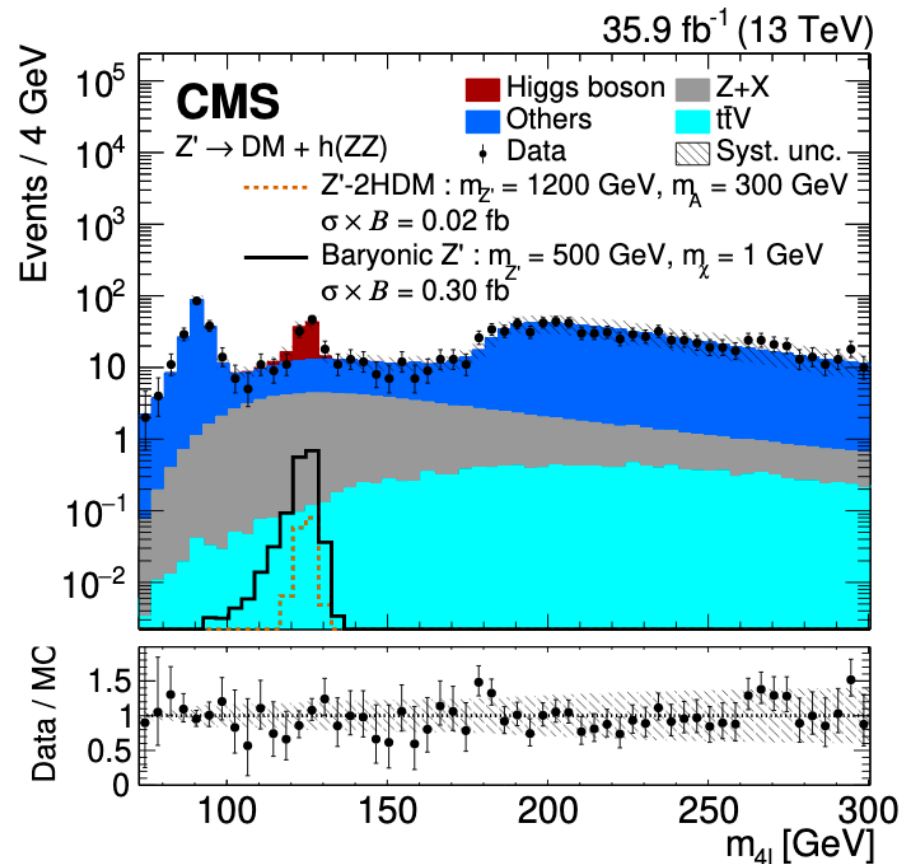⇒ Results are better (x2-3) than 2016 results alone after scaling for luminosity

Higgs + Dark Matter

- DM search with H($\rightarrow$ZZ)

- Generic search: pp$\rightarrow$X+MET

- Model independent search
  - Signature: h($\rightarrow$ZZ/bb/$\gamma\gamma$)+MET

- Signal events at large MET

# Vector Boson Scattering

- VV production via VBS (V=W,Z,γ)
  - Purely EW process (QCD treated as bkg)
  - V self-interactions precisely predicted
- Small cross section: similar for EWK and QCD processes
- Study same-sign WW production
- Include tau leptons in final state
  - τ leptons could enhance sensitivity to BSM wrt light leptons
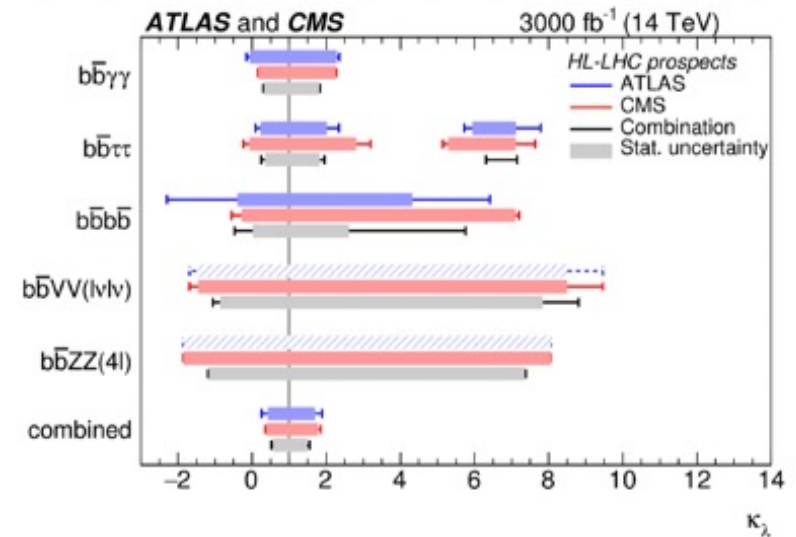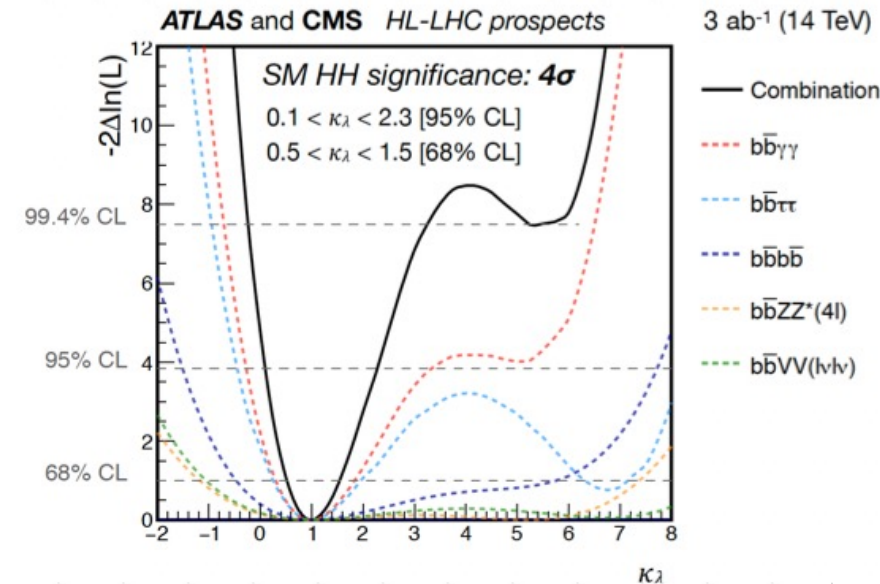
ssWW EW signal: σ=27 fb

QCD bkg: σ=26 fb

VBS WZjj

Non-VBS WZjj

BSM H$^{\pm}$
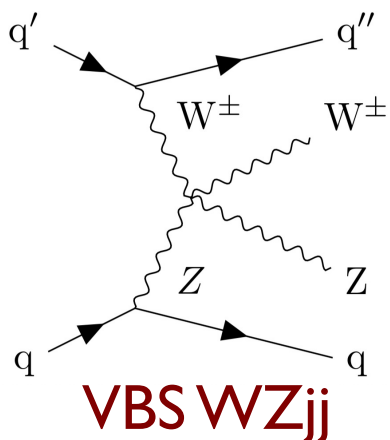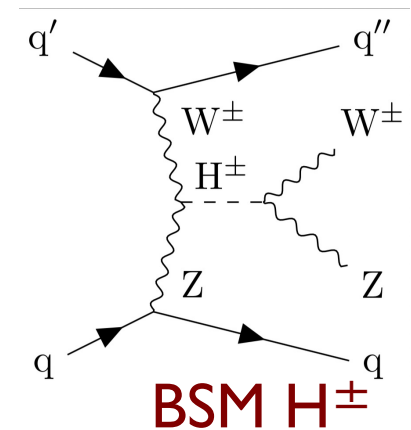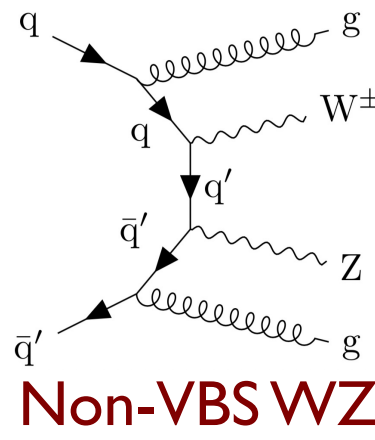
HL-LHC: Higgs self-coupling

- Significance of HH at 4σ level (both expts.)
- Uncertainty on k_λ of 50%

	Statistical-only		Statistical + Systematic	
	ATLAS	CMS	ATLAS	CMS
$HH \to b\bar{b}b\bar{b}$	1.4	1.2	0.61	0.95
$HH \to b\bar{b}\tau\tau$	2.5	1.6	2.1	1.4
$HH \to b\bar{b}\gamma\gamma$	2.1	1.8	2.0	1.8
$HH \to b\bar{b}VV\,(ll\nu\nu)$	-	0.59	-	0.56
$HH \to b\bar{b}ZZ\,(4l)$	-	0.37	-	0.37
combined	3.5	2.8	3.0	2.6
	Combined		Combined	
	4.5		4.0	

- Improve particle reconstruction/ID
  - Increase b-tagging efficiency
  - Increase photon and lepton Id, efficiency and isolation
  - Improve missing transverse momentum resolution
  - Reduce fake jet reconstruction

- 10%-20% gain in S/B in many Higgs decay channels

HH production sensitivity (sigmas) at 3 ab^{-1}

Channel	No MTD	$\langle\sigma_t\rangle$ 35 ps	$\langle\sigma_t\rangle$ 50 ps
bbbb	0.89	0.95	0.94
bbττ	1.3	1.58	1.48
bbγγ	1.7	1.85	1.83
bbWW	0.53	0.579	0.576
bbZZ	0.38	0.423	0.418
Combined	2.4	2.71	2.63
Luminosity gain	-	+26%	+20%

HL-LHC@140PU