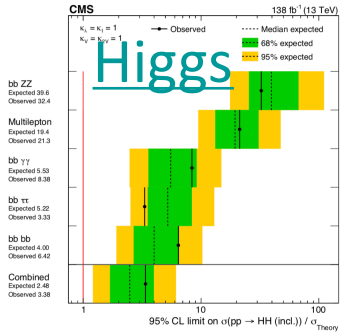
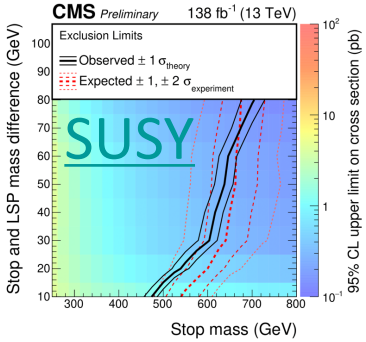
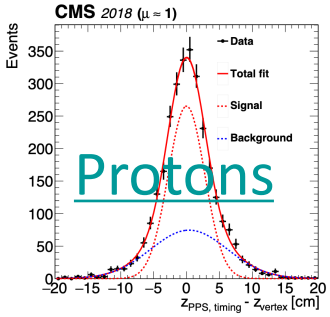
LIP-CMS group

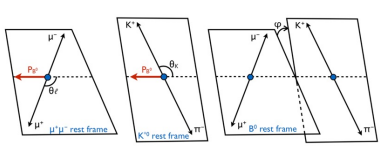
M. Araújo, D. Bastos, A. Boletti, R. Bugalho, T. Camporesi, D. Cardoso, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, L. Valla, J. Varela, J. Wulff

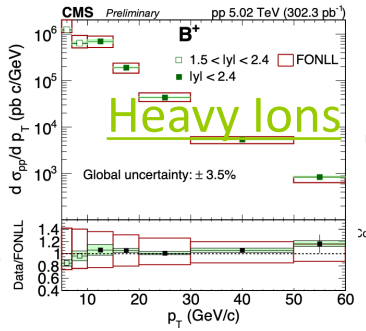
- Physics analyses
  - pp ($\gamma\gamma$) & HI collisions
  - precision measurements & searches (rare processes, BSM)
  - Top, Higgs, B, EWK, SUSY, Dark matter, Heavy Ions, Quarkonia
- Detector maintenance & operations
  - Precision Proton Spectrometer (PPS), ECAL, Computing
- Upgrades
  - PPS, Timing Detector (MTD), ECAL, HGCAL
- Training & Outreach
  - CERN, LIP, IST, Masterclasses, etc.

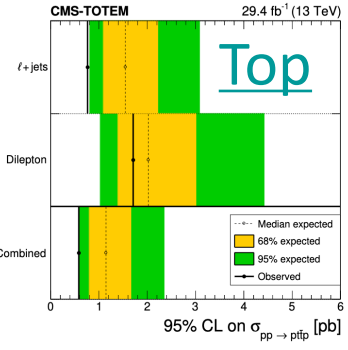


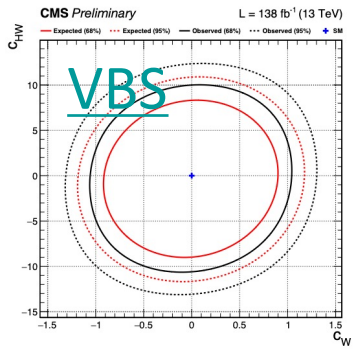


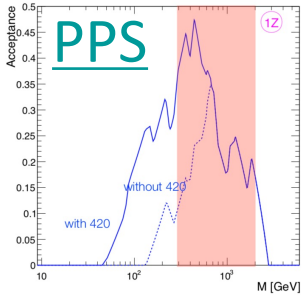


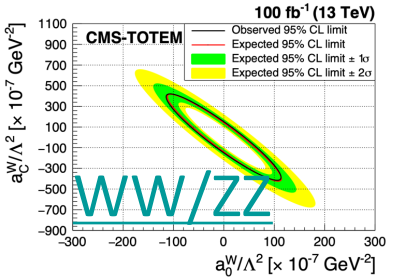












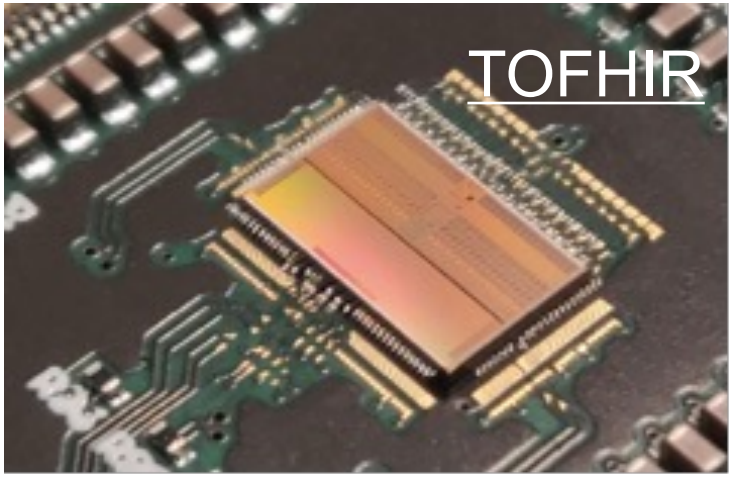
Fundação para a Ciência e a Tecnologia

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

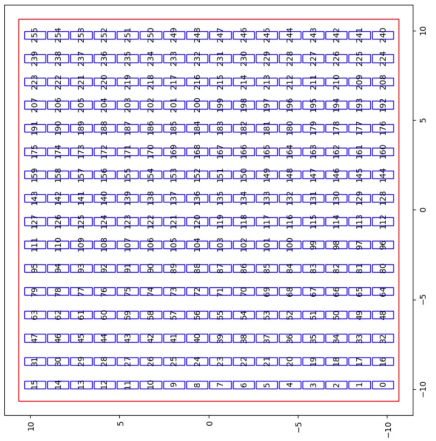
Detector Upgrades

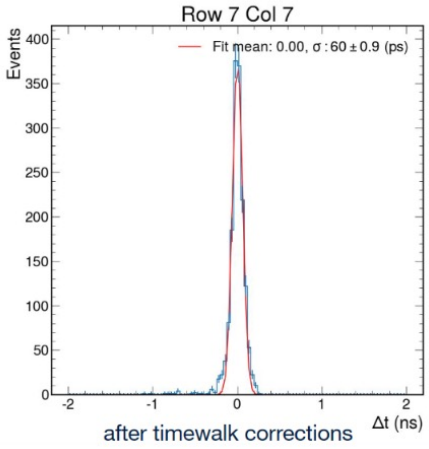
M. Araújo, D. Bastos, A. Boletti, R. Bugalho, T. Camporesi, D. Cardoso, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, L. Valla, J. Varela, J. Wulff

- Timing Detector MTD/BTL
  - Development of FE readout system of timing detector (LYSO crystals and SiPMs)
  - Based on fast timing TOF ASIC provided by Portuguese industry
  - 330k readout channels
  - Engineering run of final ASIC



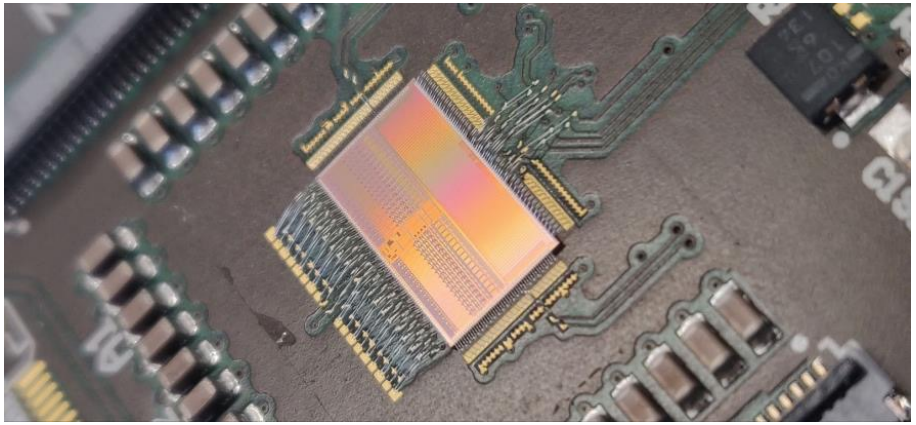
- PPS
  - Exploring LGAD sensors and associated electronics to use as timing detectors in the HL-LHC upgrade
  - challenging near beam non-uniform irradiation





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."*



Challenging years: 2024-2029

CMS will be facing an unprecedented situation in the next 5 years:

- 2024-25: Exploit the delivered luminosity for **physics** (Run 3)
- 2024-27: Complete the **upgrade** program construction, including detectors, software, all infrastructure and services needed
- 2025-26: **Decommission** the legacy systems that will not be part of the CMS upgrade detectors (services, infrastructure), ensure legacy systems are maintained and/or consolidated to guarantee full HL-LHC exploitation
- 2026-29: **Install and commission** the CMS Upgrade (infrastructure, services, detectors and software)

SWOT

M. Araújo, D. Bastos, A. Boletti, R. Bugalho, T. Camporesi, D. Cardoso, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, L. Valla, J. Varela, J. Wulff

Strengths

- Group well integrated in the Collaboration. Several senior physicists with long experience in HEP and strong impact. Several coordination positions, including leadership of the PPS sub-detector, convenership in physics groups, and leading role in several physics analyses. Leadership in areas of the Phase-2 Upgrades

Weaknesses

- Difficulty in attracting researchers to Portugal
- Funding insufficient to support young researchers. Lack of stable National funding at regular intervals. Funding not matched to increasing prices. EU funds are explored but cannot guarantee long-term goals of experiments

Opportunities

- Strong participation of Portuguese industry, world leader in segments of microelectronics IP market, in the CMS Phase-2 Upgrades for HL-LHC

Threats

- Unclear career prospects for senior physicists of the group with key responsibilities in the group and in the Collaboration

backup

Report 2023

The Compact Muon Solenoid (CMS) experiment at the LHC is a major scientific endeavor, and the research at the LHC is central to the quest for the fundamental physics laws of nature. LIP is a member of the CMS Collaboration at the LHC since its creation in 1992.

LIP had a leading role in the design and construction of important components of the CMS detector, namely the Data Acquisition System of the ECAL sub-detector used for the measurement of electrons and photons and the Trigger System that performs the online selection of the interesting collisions. Since the LHC start-up in 2010, LIP made major contributions to the CMS physics program in particular: the discovery and characterization of a Higgs boson; measurements of the top quark properties; the first observation of the B_s rare decay to dimuons; measurements and observations of B and Y mesons in pp and heavy ion collisions; measurements of the J/psi, Upsilon and χ_c polarizations; searches for a charged Higgs, a top squark, and for Dark Matter; search for exclusive processes. A group member served as Deputy Spokesperson of the Collaboration in 2012-13.

The group contributed to the Phase-1 Upgrade of the experiment by building and installing new High-Speed Optical Links (oSLB-oRM) that interface the ECAL electronics to the trigger system. The CMS experiment took data in Run2 (2015-2018) at an energy of 13TeV and, it started taking data again in Run3 (since 2022) after a period of maintenance and upgrades. During the long-shutdown (LS2) the group has been involved in the preparation of the PPS and the ECAL detectors.

The LIP group is leading the development of the new forward Precision Proton Spectrometer (PPS). PPS demonstrated -for the first time- the feasibility of operating a near-beam proton spectrometer at high luminosity on a regular basis. A member of the group is serving as PPS Project Coordinator.

Report 2023 - II

In the High-Luminosity phase of the LHC physics program starting in 2029, the accelerator will provide an additional integrated luminosity of 3000 fb^{-1} over 10 years of operation. The group participates in the construction of a new Timing Detector and in the upgrade of the Barrel and Endcap calorimeters. The group is responsible for the design and construction of the readout system of the Barrel Timing Layer (BTL), including a high-performance TOF ASIC for time measurement. The CMS collaboration attributed the CMS industry award to the LIP spin-off company PETsys Electronics for the challenging development of the TOFHIR2 front-end ASIC of the Barrel MTD detector. In collaboration with the Portuguese industry, LIP provided a high-performance ADC ASIC for the ECAL front-end electronics resistant to radiation. The CMS upgrade also includes the complete replacement of the Endcap calorimeters with a new high-granularity sampling calorimeter. LIP collaborated with Portuguese industry by supplying a high-current low voltage regulator (LVR) resistant to radiation for the High-Granularity Calorimeter (HGCAL) frontend system. The group is also involved in the upgrade of the PPS detector for HL-LHC, specifically in the area of precision timing detectors.

The group is actively involved and contributing to the physics analyses in the areas of Standard Model, Top quark, Higgs boson, Exotica, B mesons, SUSY, quarkonia, heavy ions, and PPS physics. A member of the LIP group has coordinated the CMS B Physics group in 2014-2016. Two former members of the group, now with CERN, have also coordinated in 2015-16 the CMS Higgs and Top physics groups.

In the recent (July 2019) institutional Evaluation Report performed by an international review panel under the initiative of FCT, LIP received the highest quality grade (EXCELLENT). The contribution of the CMS group to this evaluation was explicitly recognized. Quoting the report “The CMS group, while small in size, is really outstanding and world-class”.

Report 2023 - III

13 Articles in international journals (with direct contribution from team)

- *"Search for central exclusive production of top quark pairs in proton-proton collisions at 13 TeV with tagged protons"*, CMS Collaboration, arXiv:2310.112314, Submitted to the Journal of High Energy Physics
- *"Towards a muon collider"*, Carlotta Accettura et al, including G. Chachamis, G. Da Molin, M.Gallinaro, Eur.Phys.J.C 83 (2023) 9, 864
- *"Search for nonresonant Higgs boson pair production in final state with two bottom quarks and two tau leptons in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2373 authors), Phys. Lett. B 842 (2023) 137531
- *"Sub-25 ps timing measurements with 10 x 10 cm^2 PICOSEC Micromegas detectors"*, M. Gallinaro et al., Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip. 1046 (2023) 167687
- *"Towards robust PICOSEC Micromegas precise timing detectors"*, M.Gallinaro et al., JINST 18 (2023) 07, C07018
- *"A large area 100-channel PICOSEC Micromegas detector with time resolution at the 20 ps level"*, M.Gallinaro et al., JINST 18 (2023) 07, C0701
- *"Search for top squarks in the four-body decay mode with single lepton final states in proton-proton collisions at root s=13 TeV"*, CMS Collaboration (2373 authors), J. High Energy Phys. 6 (2023) 60
- *"Search for high-mass exclusive gammagamma->WW and gammagamma->ZZ production in proton-proton collisions at 13 TeV"*, CMS and TOTEM Collaborations, JHEP 07 (2023) 229
- *"Proton reconstruction with the CMS-TOTEM Precision Proton Spectrometer"*, CMS and TOTEM Collaborations, JINST 18 (2023) 09, P09009
- *"Development of the CMS detector for the CERN LHC Run 3"*, CMS Collaboration, arXiv:2309.05466
- *"Low-pT quarkonium polarization measurements: Challenges and opportunities"*, CMS Collaboration, Phys.Lett.B 840 (2023) 137871
- *"The EXTRA-BL4S experiment for the measurement of the energy and angular distributions of transition radiation X-rays"*, CMS Collaboration, JINST 18 P04017
- *"Cherenkov diffraction radiation emissions from single electrons and positrons on a fused silica radiator"*, CMS Collaboration, Nucl.Instrum.Meth.A 1052 (2023) 168287

7 PhD

- Diogo de Bastos: *"Search for the supersymmetric stop quark in the CMS experiment"*, 2017-11-19 / 2023-07-13 (finished), IST, Supervisor(s): Pedrame Bargassa, João Varela
- Mariana Araújo: *"Quarkonium production studies at LHC energies: towards the understanding of bound-state formation by the strong force"*, 2018-02-12 (ongoing), IST, Supervisor(s): Pietro Faccioli, Carlos Lourenço
- Matteo Pisano: *"Search for new physics in exclusive processes at the Large Hadron Collider"*, 2020-07-10 (ongoing), IST, Supervisor(s): Michele Gallinaro, Jonathan Hollar
- Johan Wulff: *"Timing Detectors and Measurements of Higgs Boson Properties"*, 2022-05-15 (ongoing), IST, Supervisor(s): Michele Gallinaro, Jonathan Hollar
- Giacomo Da Molin: *"Study of lepton universality in top quarks pairs events"*, 2022-09-01 (ongoing), IST, Supervisor(s): Michele Gallinaro
- Giovanni Marozzo: *"Search for New Physics in gauge boson scattering with the CMS experiment at the Large Hadron Collider"*, 2022-11-02 (ongoing), IST, Supervisor(s): Jonathan Hollar, Michele Gallinaro
- Henrique Legoinha: *"Probing the primordial quark gluon plasma with heavy flavour"*, 2023-09-20 (ongoing), IST, Supervisor(s): Nuno Leonardo

2 Master

- Henrique Legoinha: *"Probing the Quark Gluon Plasma with B0s and B+ Mesons: Cross Sections in pp and Nuclear Modification Factors in PbPb Collisions"*, 2021-10-01 / 2023-05-18 (finished), IST, Supervisor(s): Nuno Leonardo
- Simão Costa: *"Probing quark hadronization with B mesons at the LHC"*, 2022-09-15 / 2023-11-23 (finished), IST, Supervisor(s): Nuno Leonardo

Report 2023 - IV

Group members have the following coordination positions in the CMS collaboration structure:

- PPS Coordinator (Level-1), since 2021 (J.Hollar)
- ECAL Electronics Coordinator (Level-2), 2011-2023 (J.C.Silva)
- B-Physics Exotica and Rare Decays (ERD) coordinator (Level-3), 2021-2023 (A.Boletti)
- B-Physics Data Analysis Coordinator (Level-3), since 2023 (A.Boletti)
- Standard Model (SMP) PAG Monte-Carlo contact, since 2023 (G.B.Marozzo)
- MTD/BTL electronics systems coordinator, since 2018 (J.Varela)
- MTD/BTL front-end electronics coordinator, 2018-2023 (J.C.Silva)
- LHC HF WG co-Convener, since 2023 (N.Leonardo)

LIP group members participate in the following CMS structures:

- CMS Collaboration Board (M.Gallinaro, J.Varela)
- CMS Finance Board (J.Varela)
- CMS Management and Executive Boards (J.Hollar)
- CMS Publication Board (N.Leonardo)
- ECAL, MTD and HGCAL Institution Boards (J.Varela)
- PPS Institution Board (M.Gallinaro)
- MTD Steering Committee (J.Varela)

Organized Events

1 International Conferences or Workshops

- *"IDTM - Innovative Detector Technologies and Methods"*, [Conf-WS-Int] 2023-09-12 / 2023-09-14, Biblioteca Nacional, Lisbon

1 Advanced Training

- *"Course Physics at LHC 2023"*, 2023-03-06 / 2023-07-14, LIP, Lisbon

Report 2023 - IV

3) Experiment operation and maintenance

a) Physics objects development:

LIP members pursued participation in the activities of POGs (Physics Object Groups) in the validation of forward proton alignment and reconstruction efficiency (G.DaMolin, G.B.Marozzo, M.Pisano, J.Hollar), and PPS high-level trigger (M.Araujo). A member of the LIP/CMS group (J.Hollar) led the preparation of the reference paper describing key features of the proton reconstruction procedure, efficiency and reconstruction that was published (JINST 18 (2023) 09, P09009).

b) PPS commissioning and operation:

Under the leadership of a LIP member serving as PPS Project Manager (J.Varela), PPS collected over 100fb^{-1} of data in Run2. The group had leading roles in the PPS DAQ system (J.Hollar) and the Timing detectors (M.Gallinaro). LIP made major contributions to the timing detector electronics, online software, and detector operations. Since 2021, a LIP member serves as Project Manager (J.Hollar). Members of the group are actively involved in physics analyses using PPS data (M.Pisano, M.Gallinaro, J.Hollar), and had leading roles in the first PPS physics publications.

c) ECAL: A member of the group maintained the ECAL trigger and DAQ system.

d) Computing: A member of the group served as LIP/CMS interface with the LIP's Tier2 group.

e) General: The group provided central shifts and EPR work according to the rules of the CMS collaboration.

4) Phase 2 Upgrades (HL-LHC)

The R&D towards the Phase-2 upgrade carried by the group is organized in four areas:

a) R&D in the Barrel Timing Layer: Development of the frontend readout system of the timing detector (LYSO crystals and SiPMs) based on a fast-timing TOF ASIC provided by Portuguese industry (full LIP responsibility).

b) R&D for the PPS timing detectors: Develop LGAD sensors and associated electronics for use as timing detectors in the HL-LHC PPS upgrade, resistant to highly non-uniform radiation and with good (~40-50ps per plane) time resolution.

c) R&D in the ECAL frontend readout system: Development of the new ECAL readout system based on a new 160MS/s low power ADC ASIC provided by Portuguese industry (CEA Saclay, INFN-Torino and LIP responsibility).

d) R&D on the High Granularity Calorimeter: Support to the development of low voltage regulator (LVR) ASIC resistant to radiation provided by the Portuguese industry.

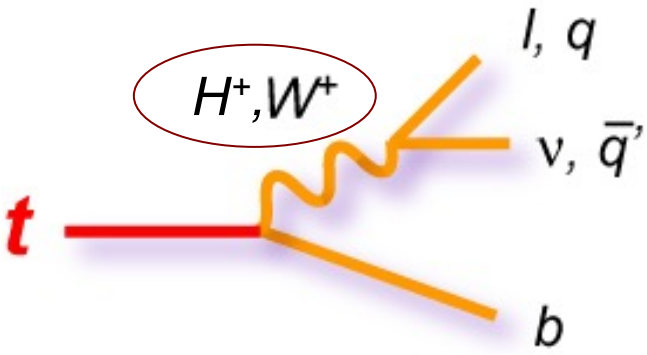
While a) and b) are the main focus of the current LIP/CMS group activities, c) and d) were developed in collaboration with the Portuguese industry and were successfully completed.

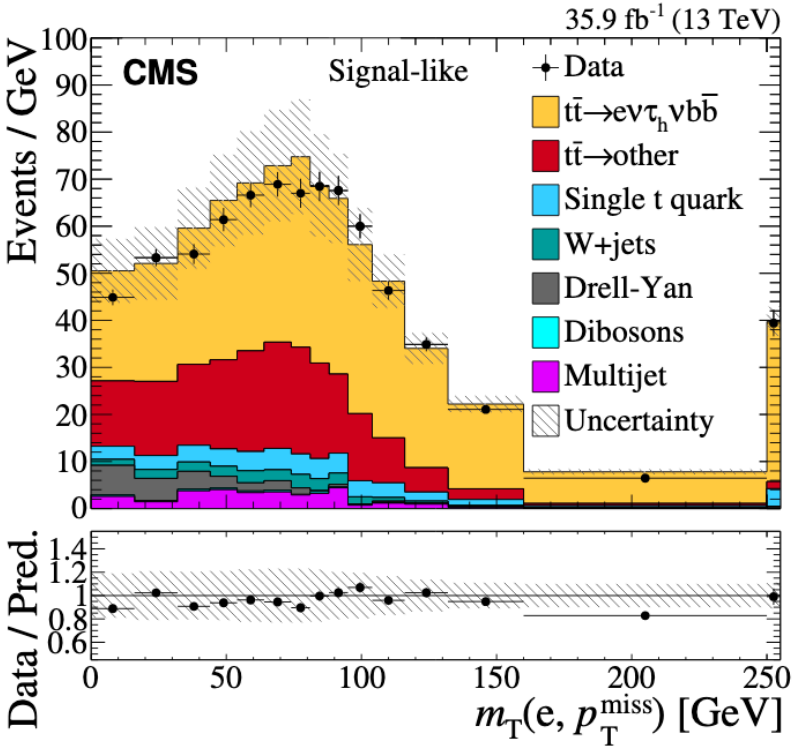
Top quarks and tau leptons

JHEP 02 (2020) 191

- Lepton flavor universality: check consistency with SM expectations

Work with full Run2 dataset ongoing
(PhD student: G. Da Molin)





- Study LFU in top quark decays
- t⟶(τν)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

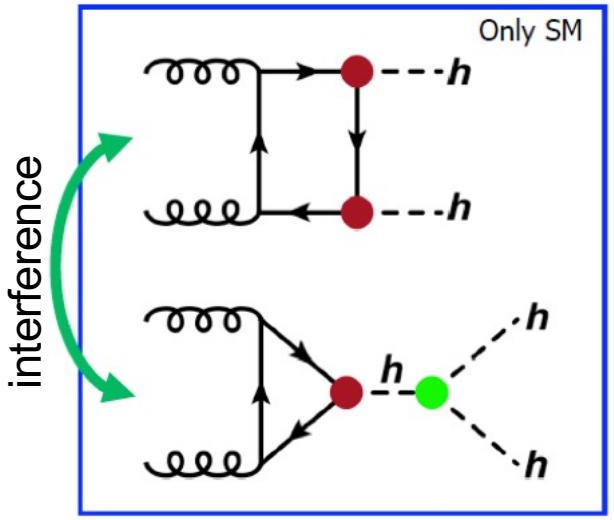
$$R_{\ell\tau_h/\ell\ell} = 0.973 \pm 0.009\,(\text{stat}) \pm 0.066\,(\text{syst})$$

$$\Gamma(t \to \tau\nu_\tau b)/\Gamma_{\text{total}} = 0.1050 \pm 0.0009\,(\text{stat}) \pm 0.0071\,(\text{syst})$$

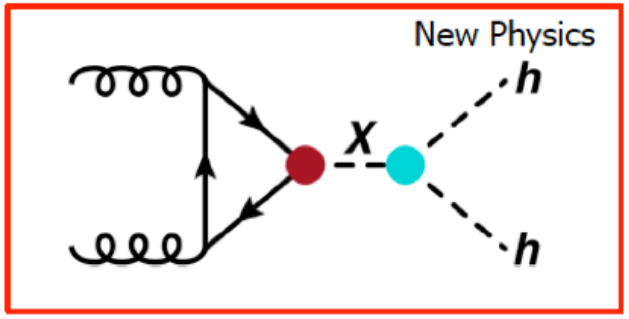
Double Higgs production

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

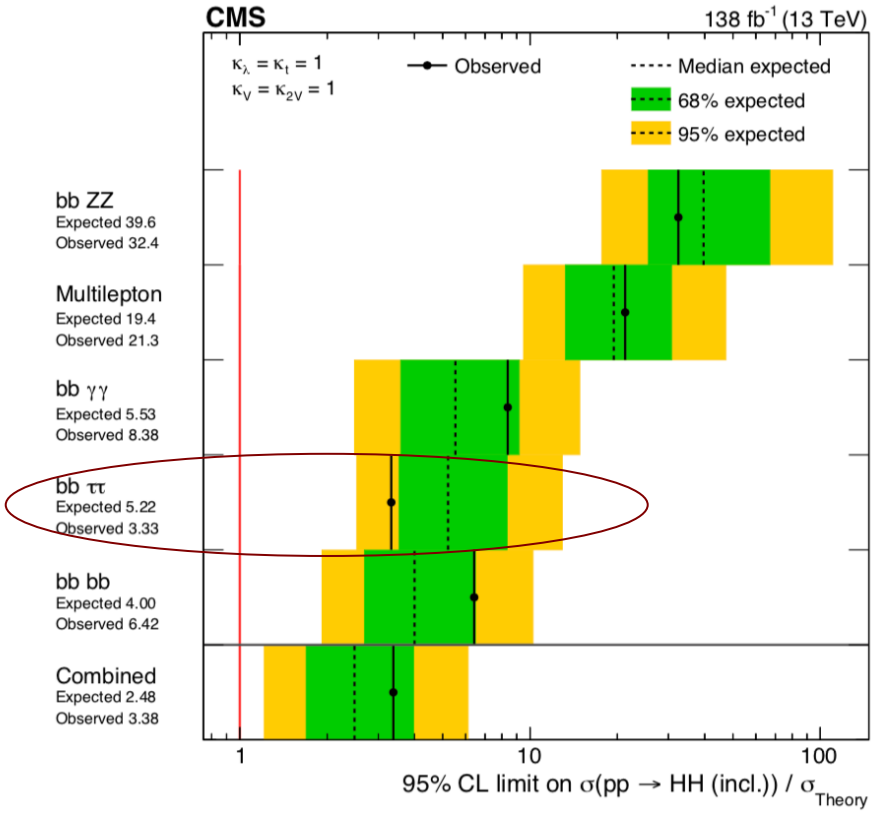
non-resonant production



resonant production



Resonant production search ongoing (PhD student: J. Wulff)

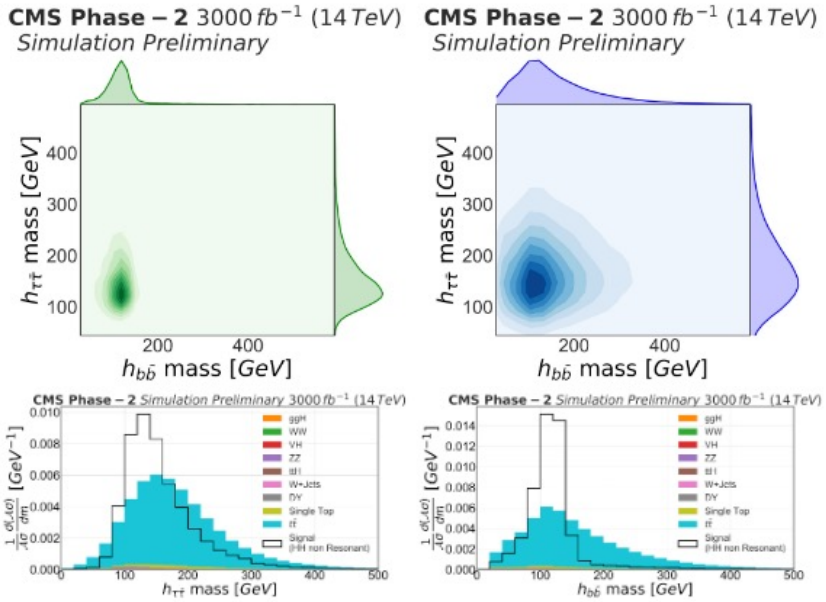


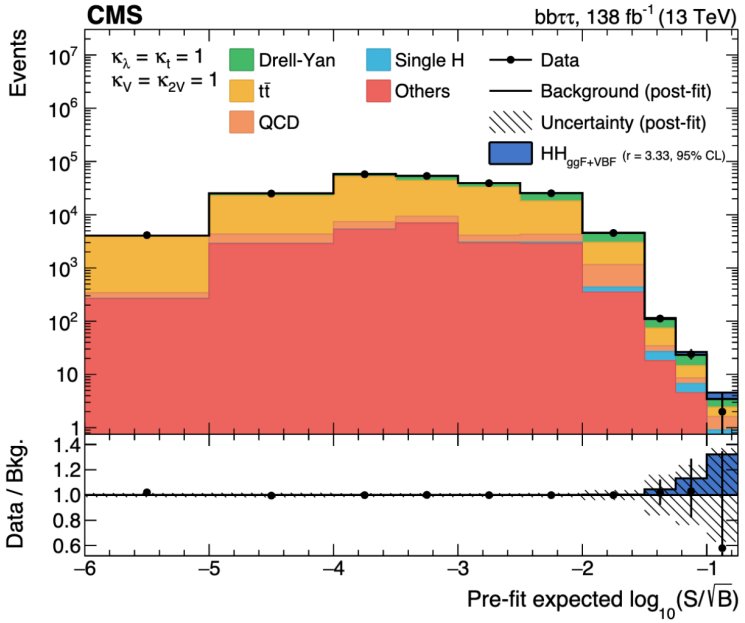
- Destructive interference in SM
- In SM, only σ=33fb at 13 TeV
- Not yet at the SM sensitivity

HH: Advanced Analysis Techniques

arXiv:1902.00134, arXiv:2105.07530, arXiv:2206.09401

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



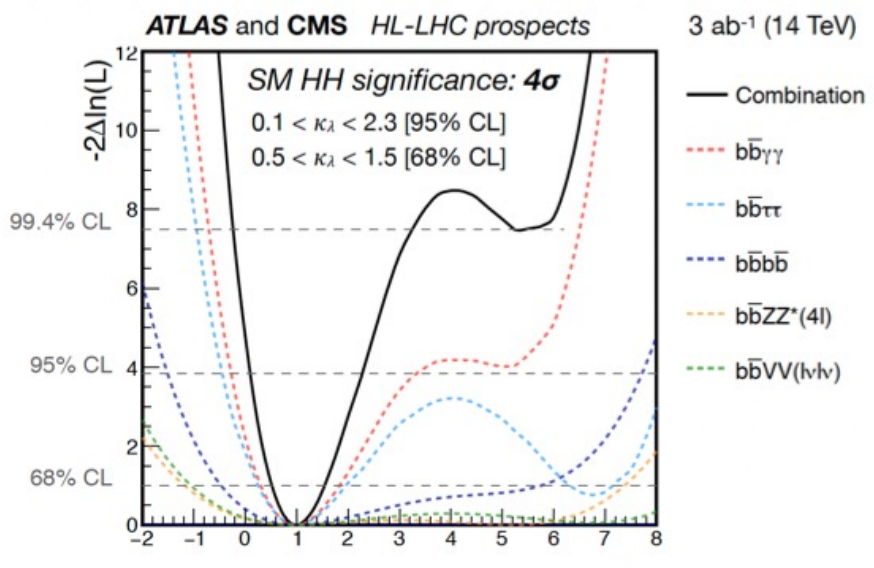


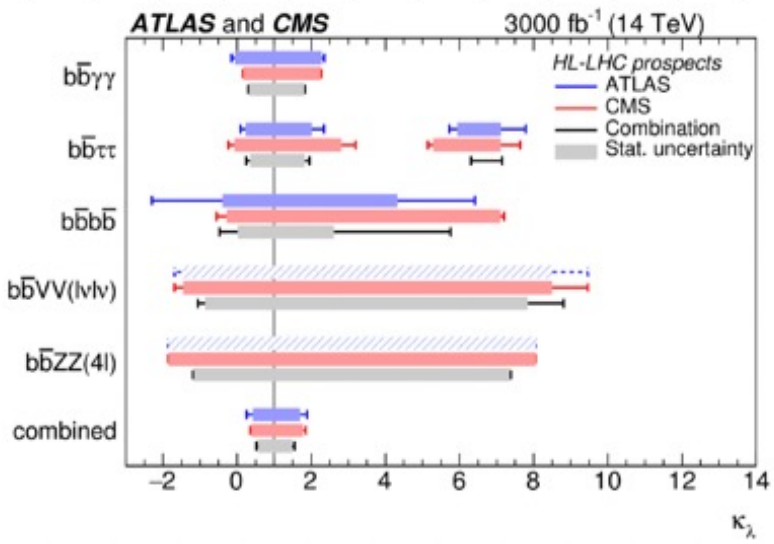
⇒ Results are better (x2-3) than 2016 results alone after scaling for luminosity

HL-LHC: Higgs self-coupling

arXiv:1902.00134

- 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	

MTD: Particle reconstruction

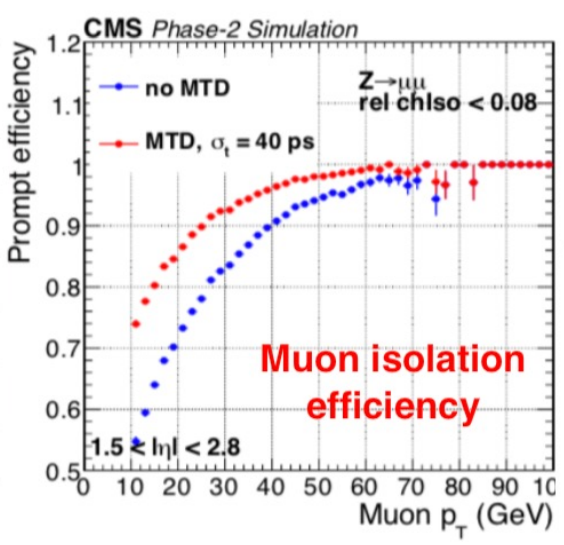
CERN-CMS-TDR-020

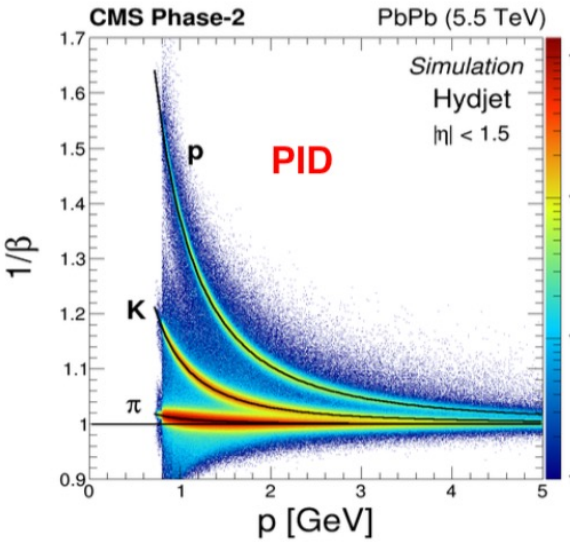
- Improve particle reconstruction/ID
  - Increase b-tagging efficiency
  - Increase photon and lepton Id, efficiency and isolation
  - Improve missing transverse momentum resolution
  - Reduce fake jet reconstruction
- 10%-20% gain in S/B in many Higgs decay channels

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

Channel	No MTD	<σ_t> 35 ps	<σ_t> 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



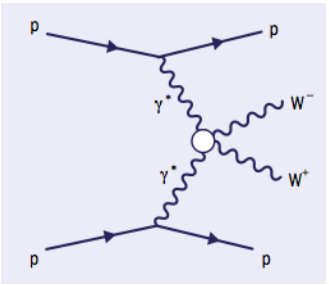


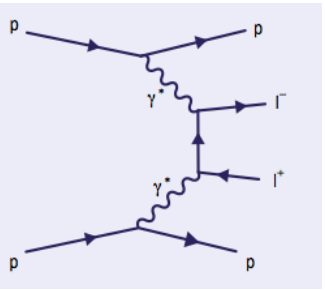
Exclusive production

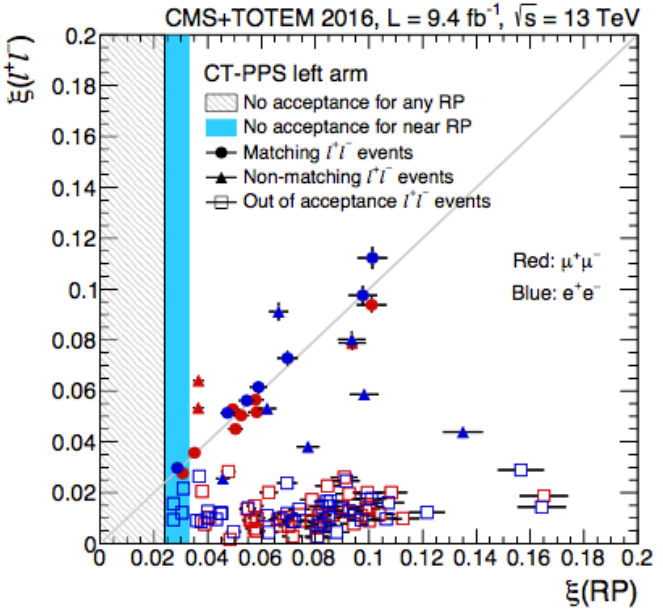
JHEP 07(2018)153

- 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

Exclusive top/tau pair production search ongoing (PhD student: M. Pisano)

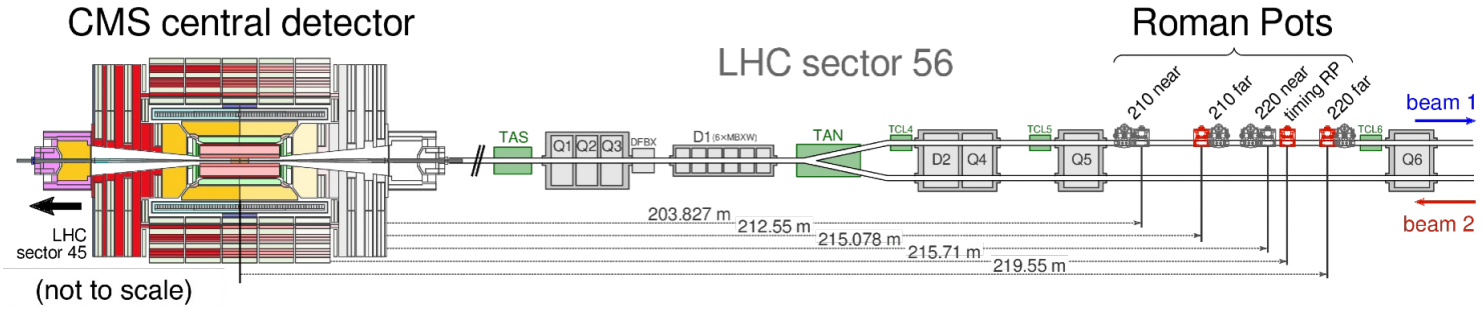






Physics w/ forward protons

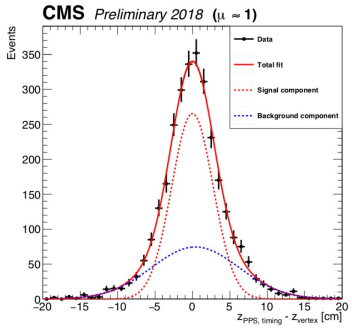
JHEP 07(2018)153, arXiv:2210.05854, arXiv:2211.16320, arXiv:2310.11231



Proton reconstruction

arXiv:2210.05854

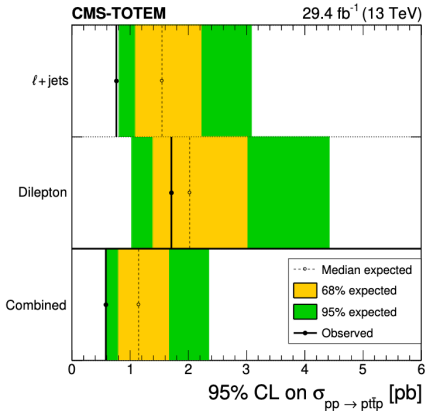
PPS collected more than 100/fb of data in Run2



Exclusive top quark pairs

arXiv:2310.11231

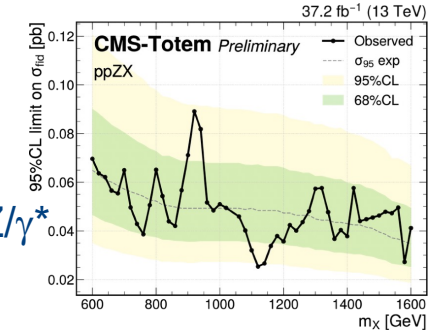
Search for central exclusive production of ttbar pairs in pp interactions with tagged protons



Zγ+X production

arXiv:2303.04596

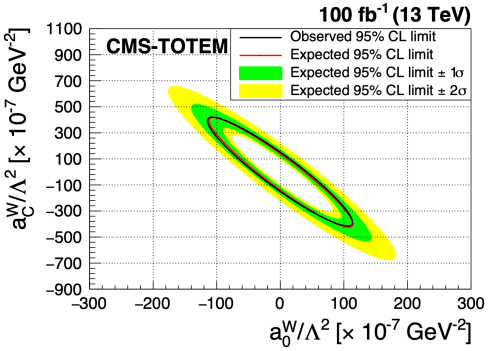
Search for anomalous Z/γ* central production with 2017 data



Exclusive WW/ZZ

arXiv:2211.16320

Search for γγ⟶WW/ZZ with forward protons



Vector Boson Scattering

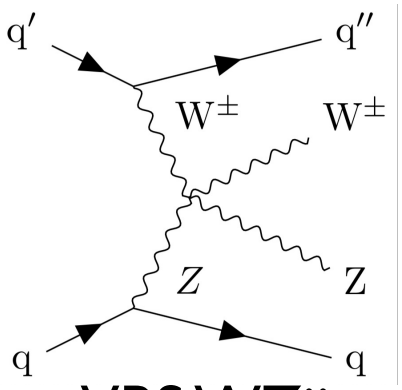
arXiv:2005.09889, arXiv:2106.01393

- 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

Ongoing with full Run2 dataset (PhD student: G.B. Marozzo and U.Perugia)

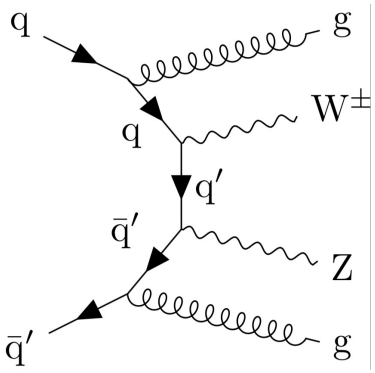
Also: WW incl. taus (Run3)

ssWW EW signal: σ=27 fb

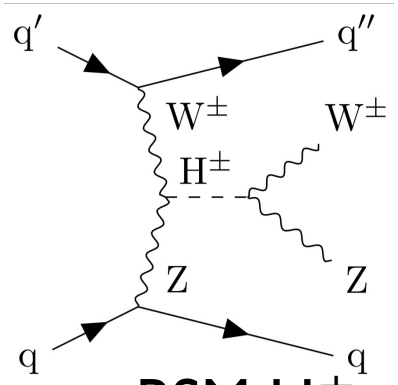


VBS WZjj

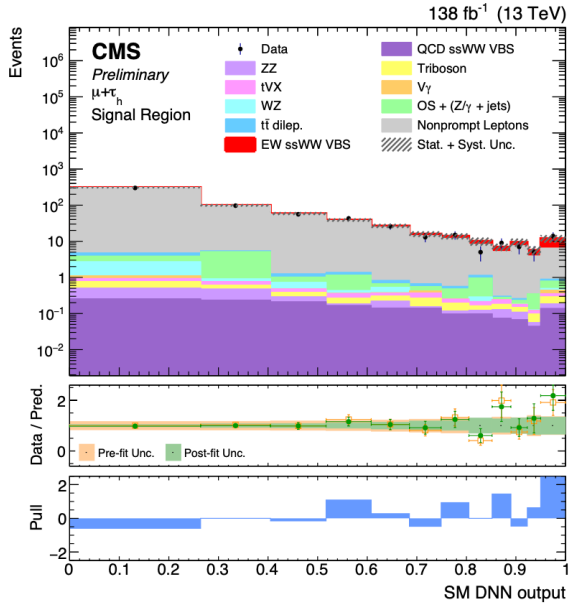
QCD bkg: σ=26 fb



Non-VBS WZjj



BSM H$^{\pm}$

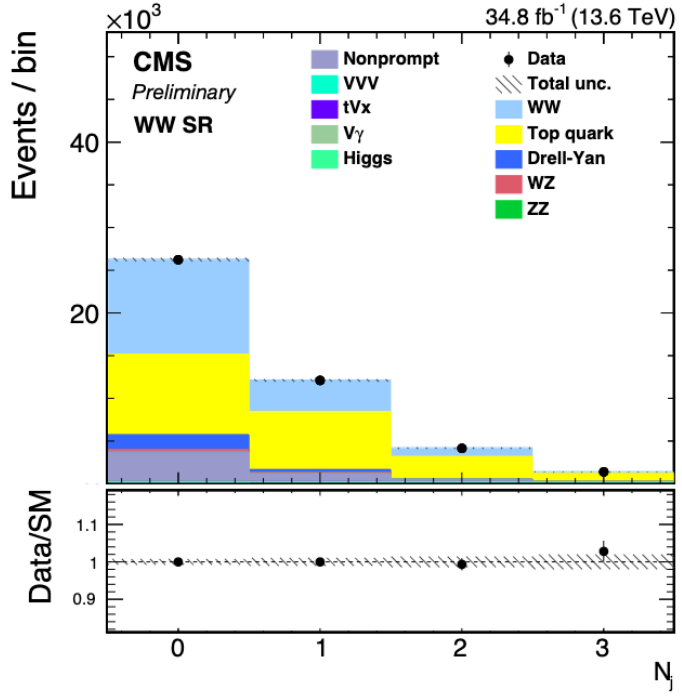


WW ($e/\mu,\tau_h$)

- WW production at 13.6 TeV
- Include tau leptons
- Define CRs and SR
- Combine and fit

Ongoing with Run3 dataset (PhD student: G.B.Marozzo)

- Study WW production, where one W decays to a light **lepton** (e, μ) and the other to a hadronic **tau** (τ_h). **New measurement** at the LHC and possible test of LFU



Current status:

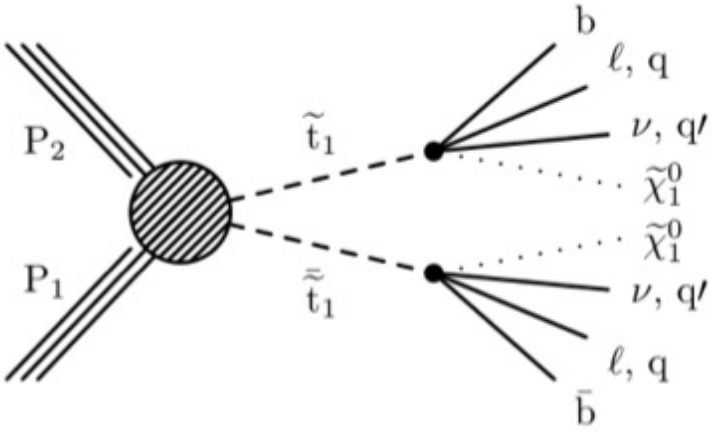
- Analysis workflow for **full 2022** dataset
- Refined background estimation for **tau Fake Rates**
- Finalized **systematics** estimation

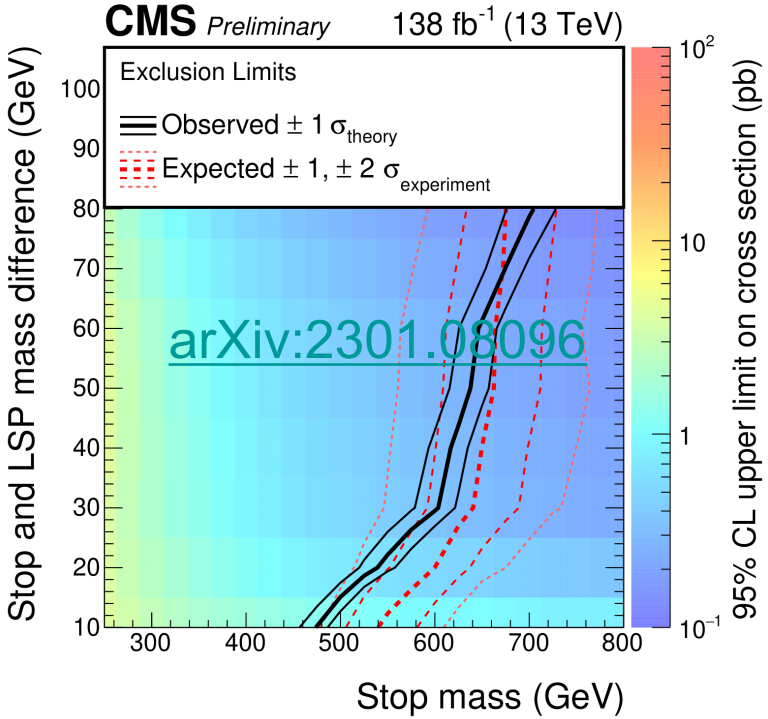
SUSY

JHEP 09(2018)065, arXiv:2301.08096

- 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
- Results with full Run2 data (to be published in JHEP)

Search with full Run2 dataset
(PhD student: D. Bastos)

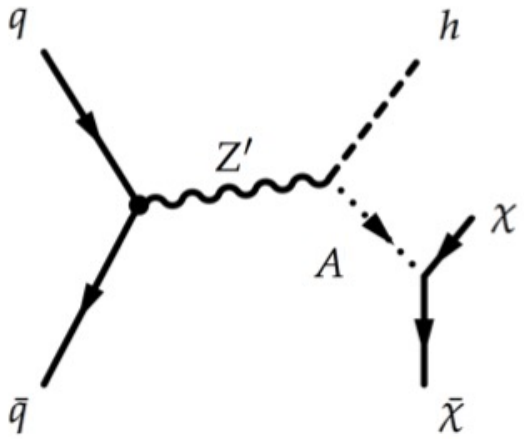




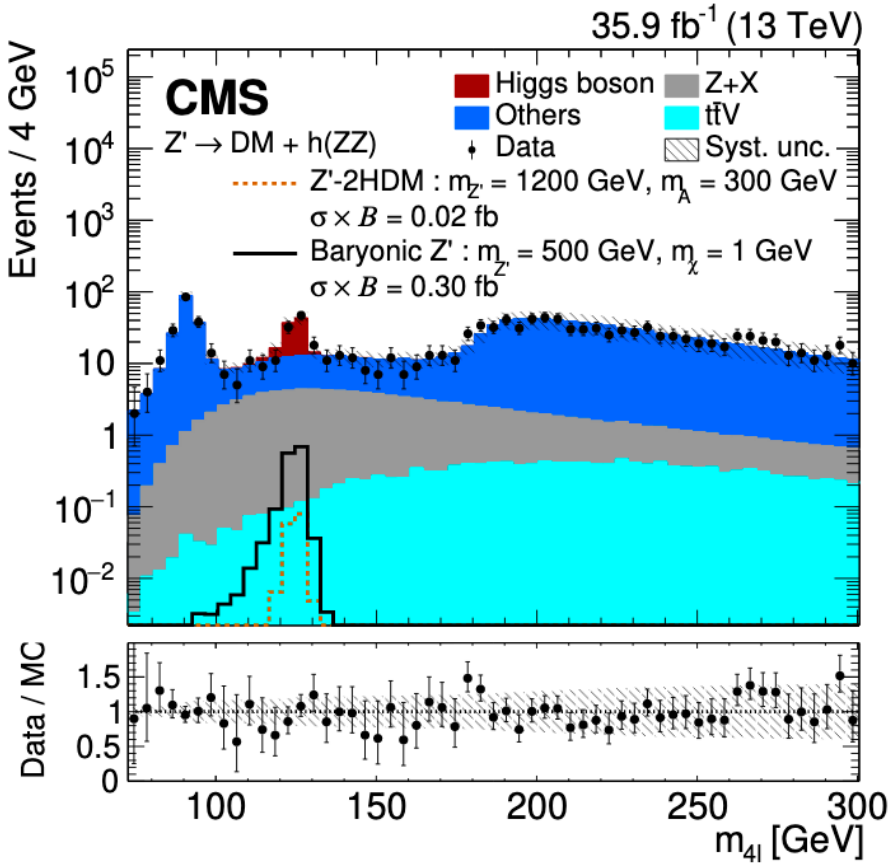
Higgs + Dark Matter

JHEP 03 (2020) 025, EXO-23-005

- DM search with H(→ZZ)
- Generic search: pp→X+MET
- Model independent search
  - –Signature: h(→ZZ/bb/γγ)+MET



Search with full Run2 dataset ongoing (w/Politecnico Bari)



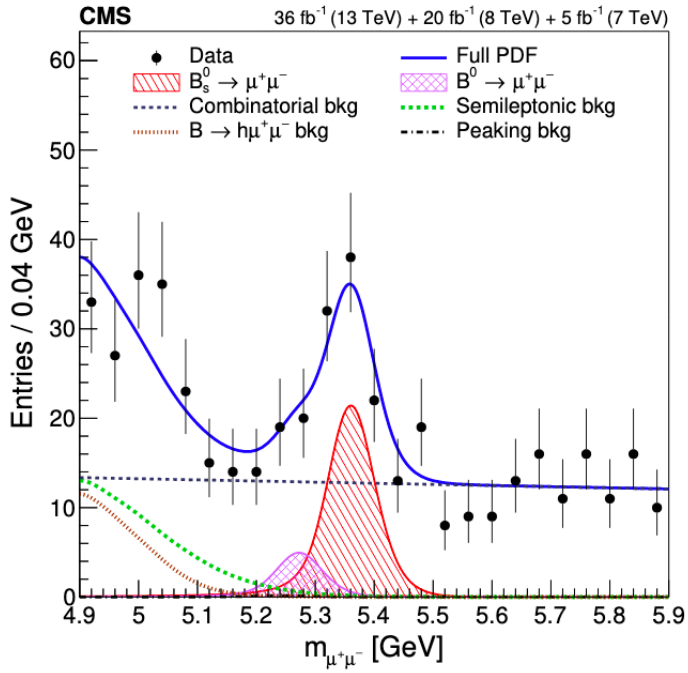
- Signal events at large MET

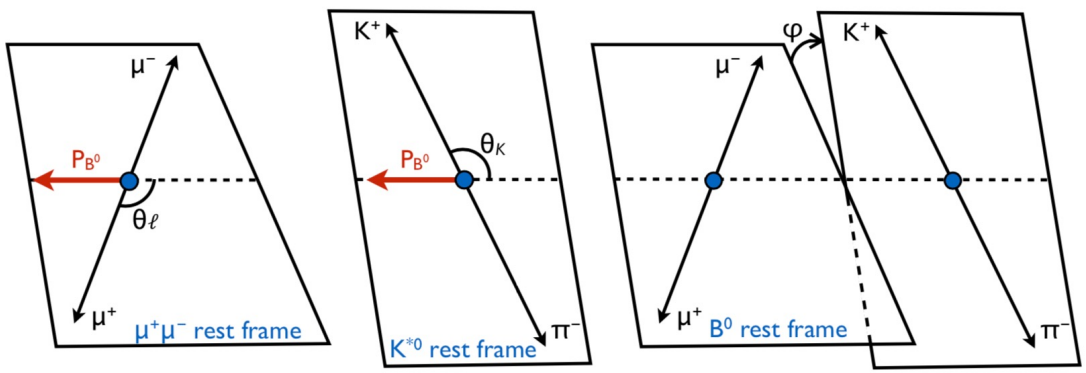
B-physics

JHEP 4(2020)188, arXiv:2007.02434

- Indirect search for NP
  - May provide sensitivity beyond collision energy
  - Test Lepton Flavour Universality
- Precise measurements and rare decays
  - NP through virtual contributions
- Explore b⟶sμμ transitions
  - B⟶μμ, B⟶K*μμ
- Study decay rates and angular variables
  - Measure BRs and lifetime
  - B⟶K*(K⁺π⁻)μμ
  - B⟶J/ψ(μμ)ϕ(KK)
- Goldmine in “parked” dataset

Ongoing (A. Boletti)



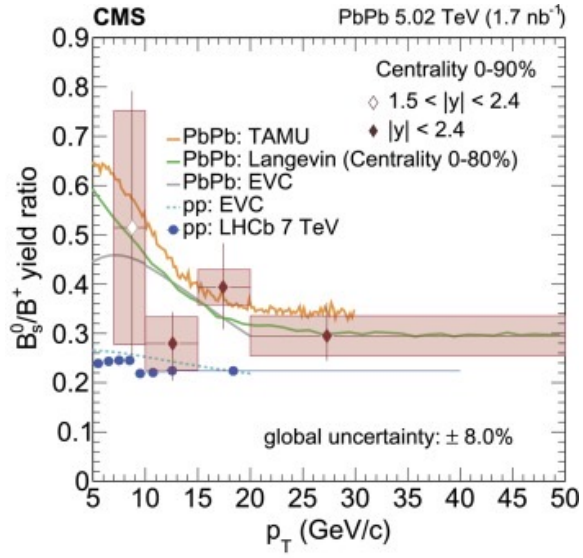


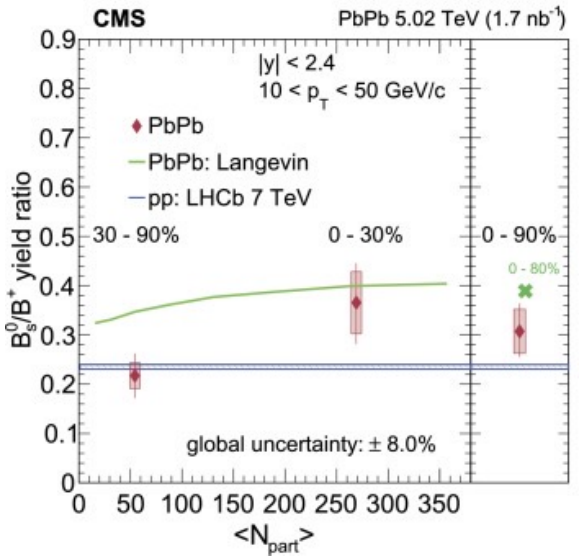
Heavy Ions

PLB 829(2022)137062, HIN-21-014

- Explore heavy ion collisions at highest energies
- CMS has excellent capability to study low p_T probes in HI
- Explore heavy flavour as novel probe of QGP
- Detected B mesons in ion collisions
- Probe mass and energy dependence

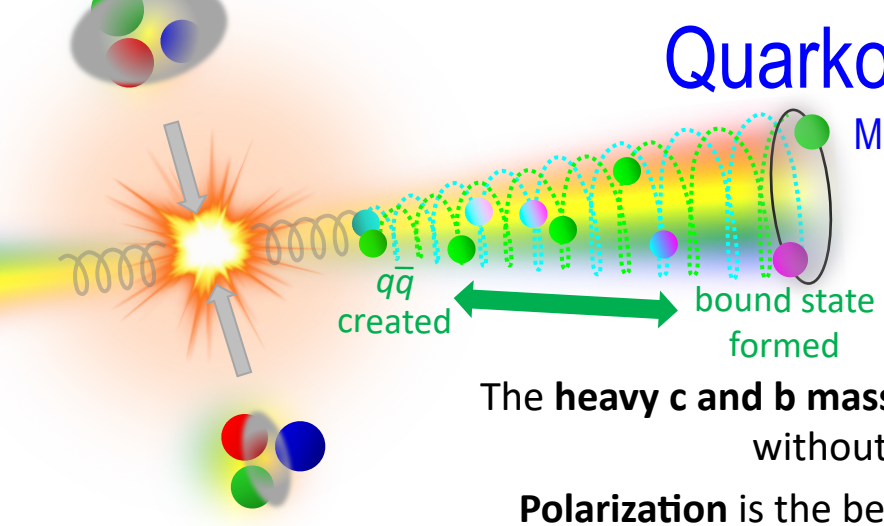
Work ongoing (Master students:
H. Legoinha, S. Costa)



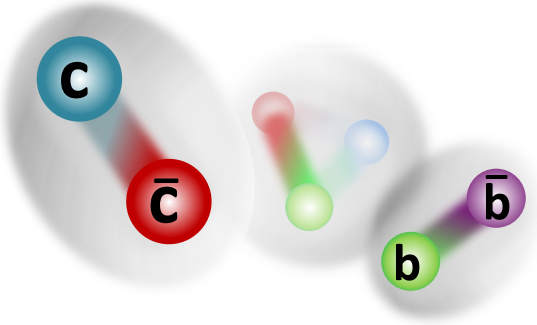


Quarkonium production

M. Araújo, P. Faccioli, C. Lourenço

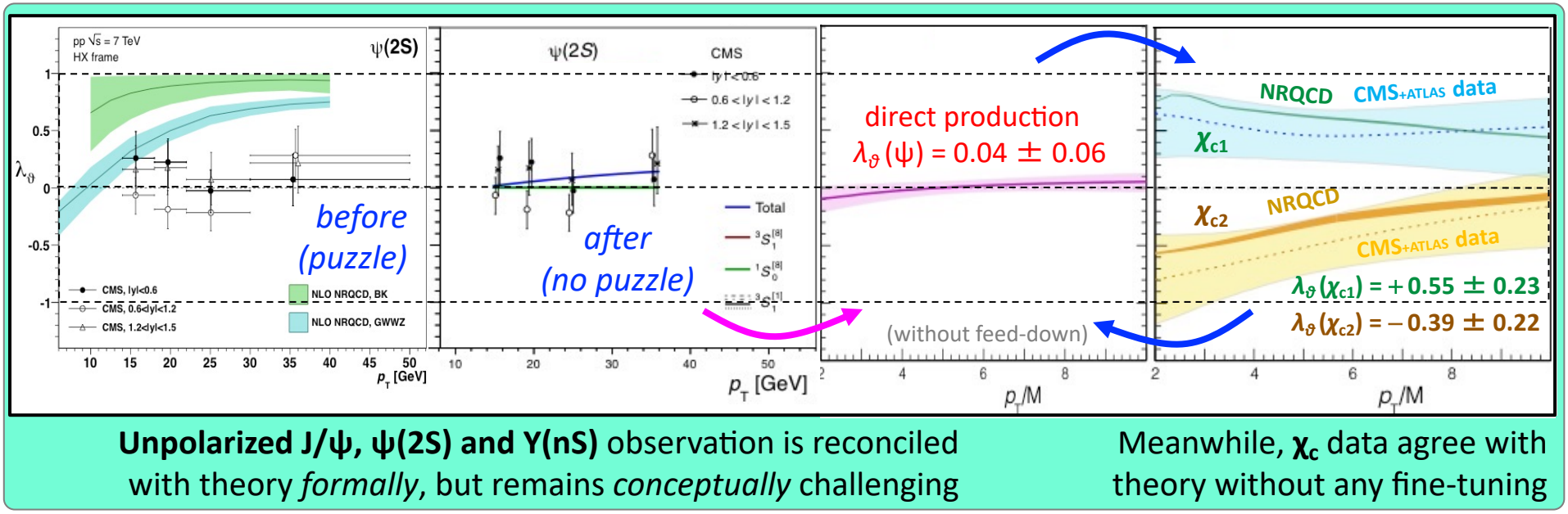


An ideal probe to study **hadron formation**



The **heavy c and b masses** allow us to study the (long-distance) bound state formation without complications caused by the (short-distance) $q\bar{q}$ creation step.

Polarization is the best observable to understand how the bound states are formed. CMS measurements (with LIP leadership) highlighted and solved **long-term puzzles.**



Unpolarized J/ψ, ψ(2S) and Υ(nS) observation is reconciled with theory *formally*, but remains *conceptually* challenging

Meanwhile, **χ_c** data agree with theory without any fine-tuning

Ongoing (Mariana's thesis): much improved S-wave polarization measurements using Run 2 data
Will we see deviations from zero and flat? Synergy with Pheno activity: new global data analyses

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.

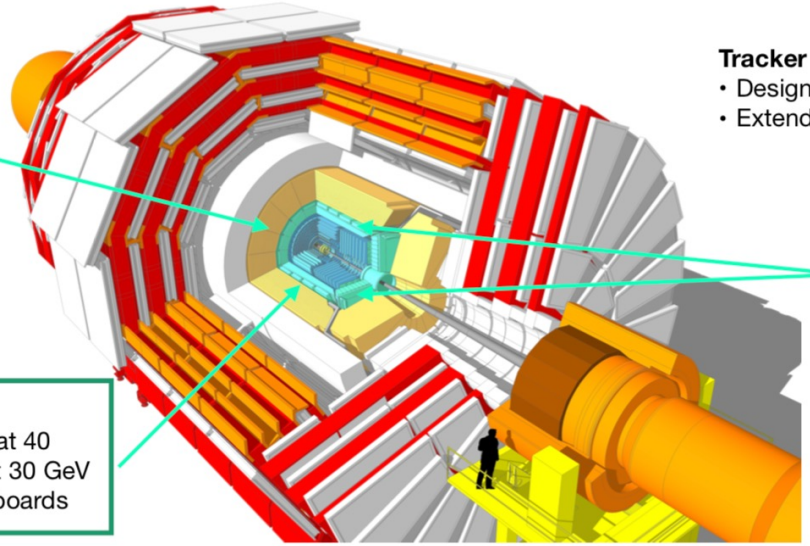
LIP Contributes to

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

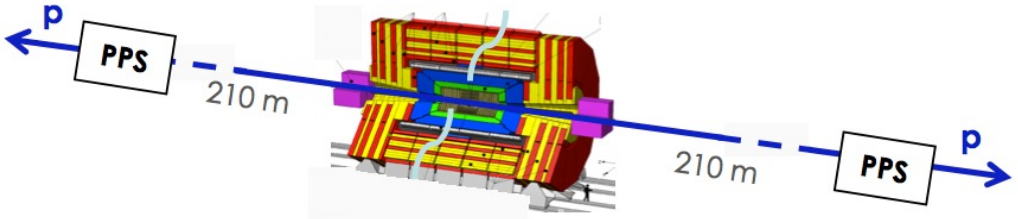


Tracker Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

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

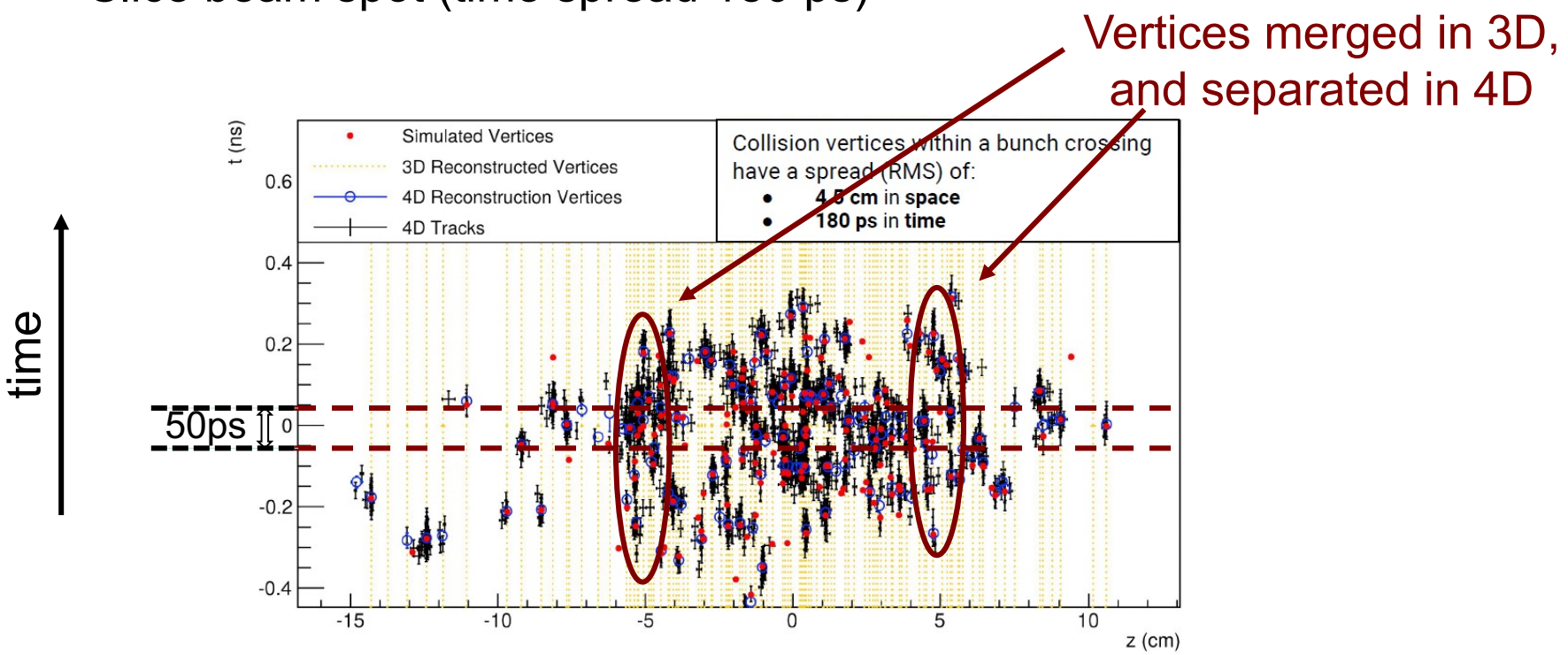


LIP contributes to

Precision Proton Spectrometer
Detector design and physics prospects

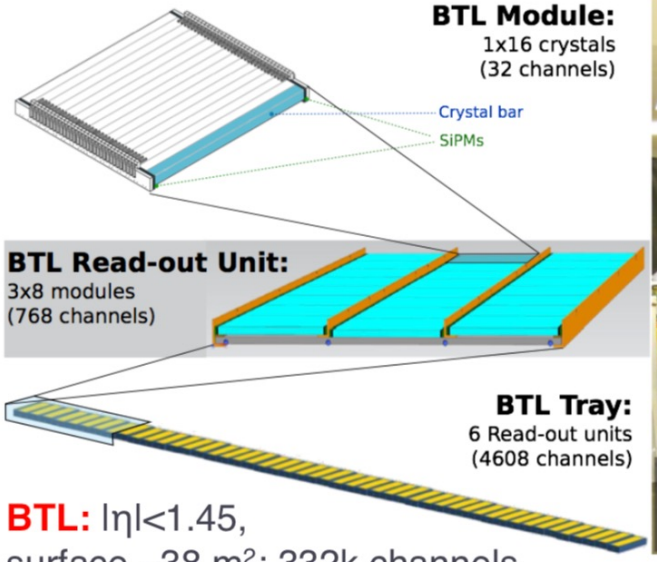
MIP Timing Detector

- Time-tagging tracks with a resolution of ~30-40 ps
  - 4D vertex reconstruction
  - Track-vertex association
- Reduce effective PU to the LHC Run2 level
  - Slice beam spot (time spread 180 ps)

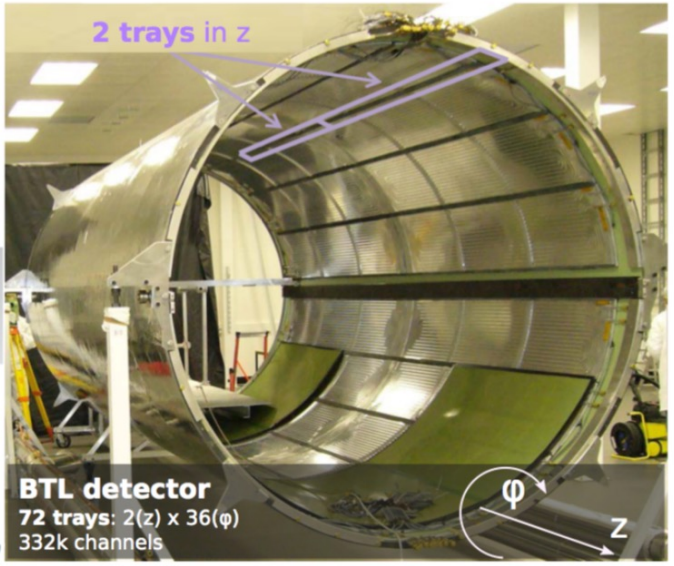


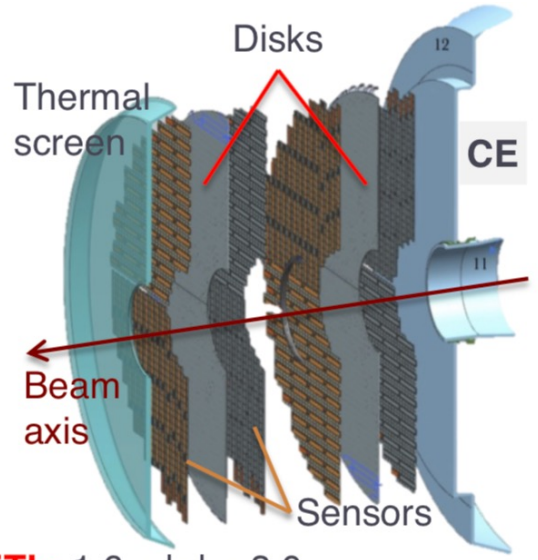
MIP Timing Detector

- Barrel Timing Layer (BTL):
  - Arrays of LYSO crystal bars with dual-end SiPM readout
  - Two meaurements per hit (improves resolution)
  - Mounted inside the Tracker Support Tube (independent cooling)
- Endcap Timing Layer (ETL):
  - LGAD modules bump-bonded to ASIC
  - Two layers (improves resolution and redundancy)



BTL: $|\eta|<1.45$,
surface ~38 m^2; 332k channels



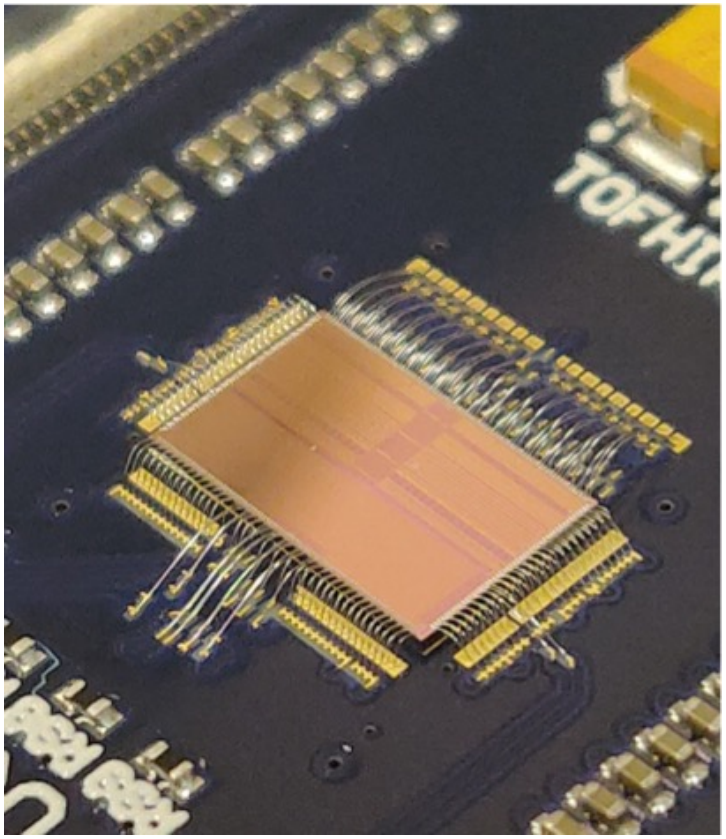


ETL: $1.6 < |\eta| < 3.0$,
surface ~14 m^2; ~8.5 M channels

MTD/BTL electronics

JINST 16(2021)P07023, doi:10.1109/NSS/MIC44867.2021.9875751, arXiv:2404.01208

- LIP is responsible for the MTD barrel readout electronics
- Major effort on development of new TOFHIR (Time Of Flight at High Rate) ASIC with associated FE boards
  - maintain 20ps jitter with 2.5MHz MIP rates and large dark count rate from irradiated SiPMs
- Completed system tests with prototype
  - Results in-line with expectations
  - Further refinements implemented (DCR cancellation, SEU, etc)
- Received final ASIC
  - Characterization tests ongoing
- FE boards with TOFHIR received
  - Tests ongoing

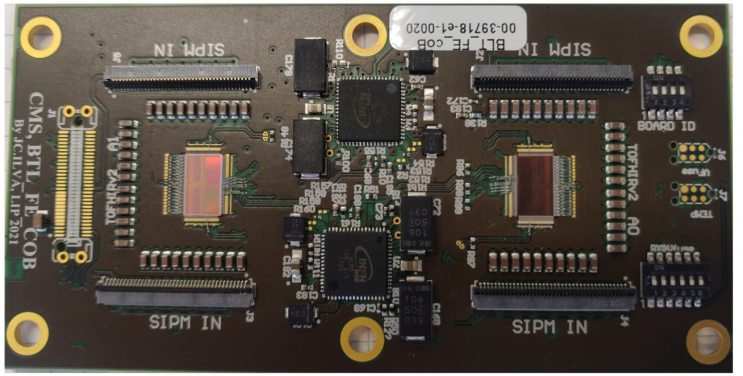


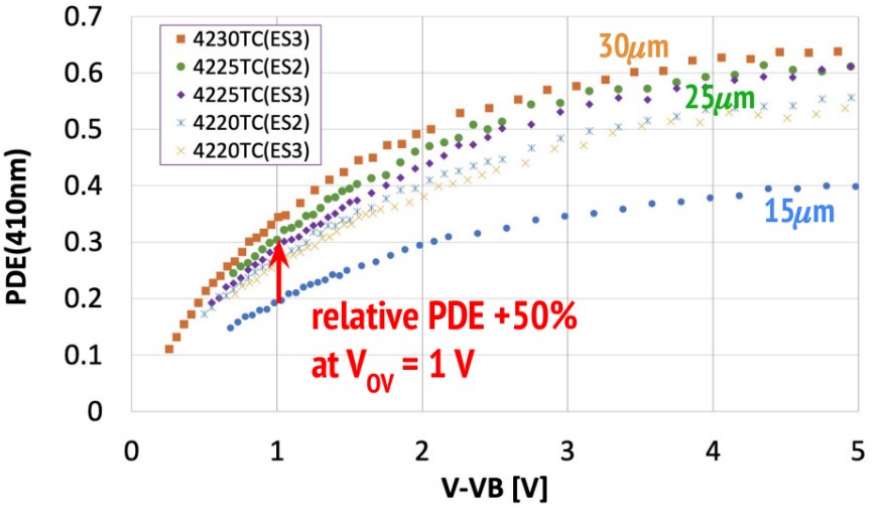
MTD/BTL performance optimization

Extensive performance optimisation campaign launched in 2022

- recover performance from multiple factors without major BTL design/cost changes

- **LYSO arrays**
  - Package optimisation: studied modules with minimal amount of glue between LYSO and reflector (ESR)
  - Studied impact of SiPM optical window thickness (FBK vs HPK) and crystals/SiPM aspect ratio
- **Electronics**
  - TOFHIR2B/X/C: noise reduction by gain tuning, to cope with smaller signals
- **SIPM arrays**
  - Cell size optimisation: developed a full response model varying SiPM cell electrical parameters/size

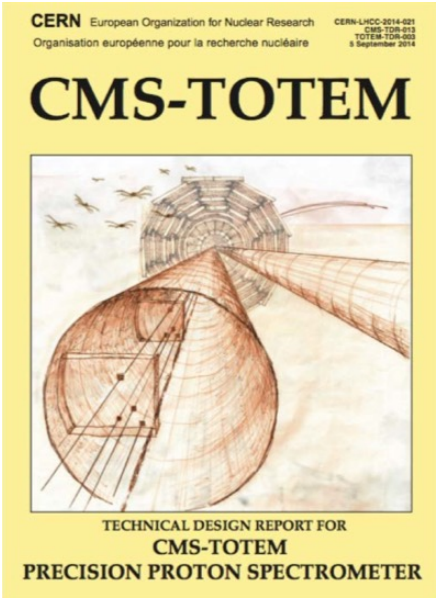


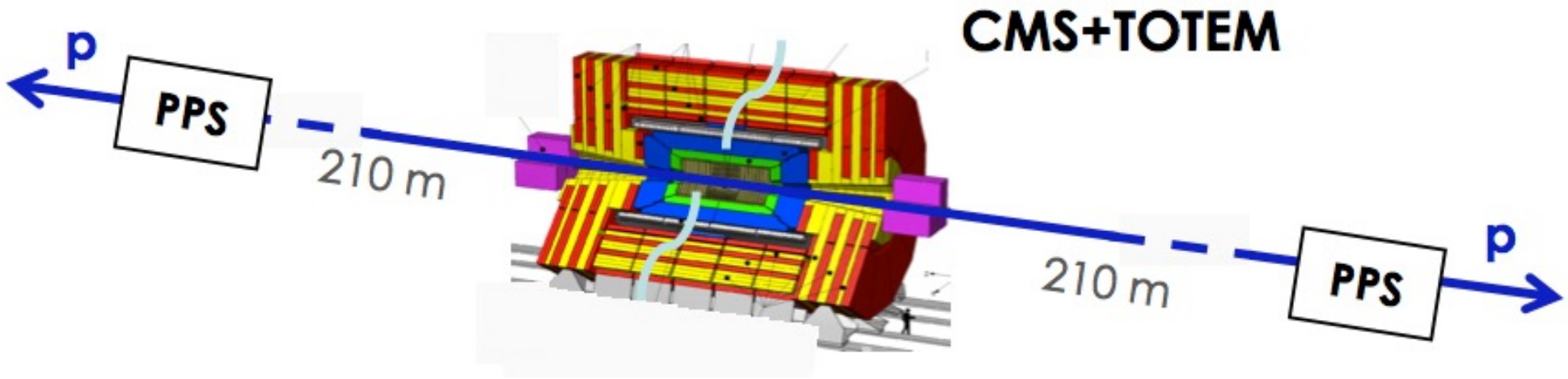


Precision Proton Spectrometer

CERN-LHC-2014-021

- Precision Proton Spectrometer (PPS) aims at measuring the surviving scattered protons on both sides of CMS in standard running conditions
- Precise timing and tracking detectors
- PPS data combined with those of central detector
- Collected ~100/fb of data in Run2



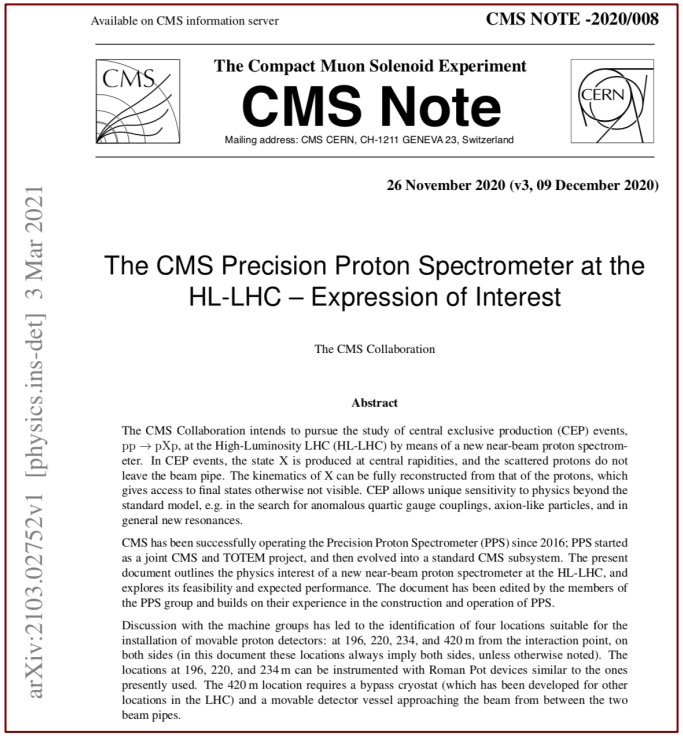


PPS: Run3 and beyond

arXiv:2103.02752

- Timing and tracking detectors being improved for Run3
  - 2 tracking+2 timing RPs per side
- LIP involvement in timing/DAQ electronics from the beginning
  - HPTDC boards designed by LIP, contributions to DAQ/readout chain integration, timing firmware, etc.
- HL-LHC: Expression of interest for new PPS system approved by CMS
  - Expanded physics program
  - 4 locations identified: near 200m (current location) and 420m (new technology)
  - New technologies required for HL-LHC
  - Exploring synergies with MTD/ETL upgrade

HPTDC board



Available on CMS information server

CMS NOTE -2020/008

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

26 November 2020 (v3, 09 December 2020)

The CMS Precision Proton Spectrometer at the HL-LHC – Expression of Interest

The CMS Collaboration

Abstract

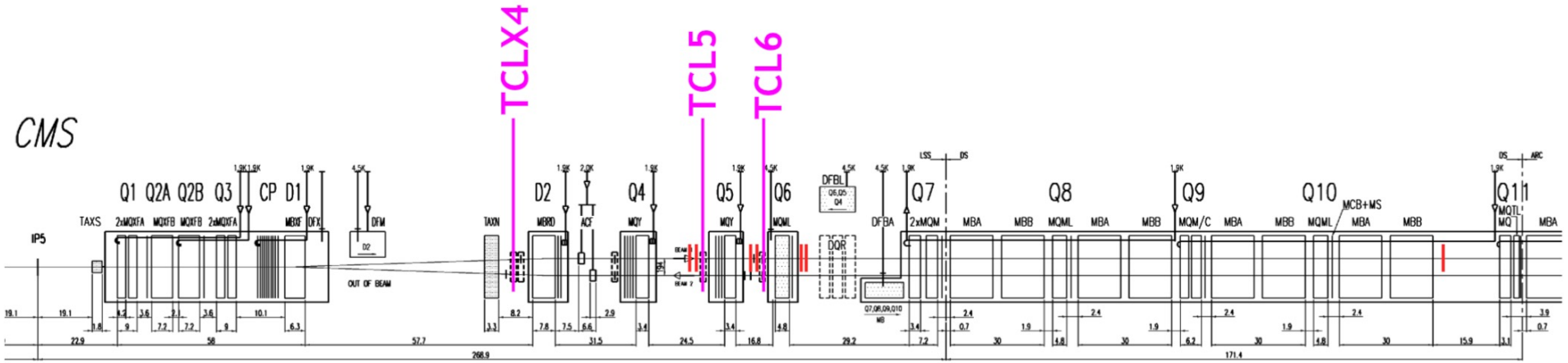
The CMS Collaboration intends to pursue the study of central exclusive production (CEP) events, $pp \to pXp$, at the High-Luminosity LHC (HL-LHC) by means of a new near-beam proton spectrometer. In CEP events, the state X is produced at central rapidities, and the scattered protons do not leave the beam pipe. The kinematics of X can be fully reconstructed from that of the protons, which gives access to final states otherwise not visible. CEP allows unique sensitivity to physics beyond the standard model, e.g. in the search for anomalous quartic gauge couplings, axion-like particles, and in general new resonances.

CMS has been successfully operating the Precision Proton Spectrometer (PPS) since 2016; PPS started as a joint CMS and TOTEM project, and then evolved into a standard CMS subsystem. The present document outlines the physics interest of a new near-beam proton spectrometer at the HL-LHC, and explores its feasibility and expected performance. The document has been edited by the members of the PPS group and builds on their experience in the construction and operation of PPS.

Discussion with the machine groups has led to the identification of four locations suitable for the installation of movable proton detectors: at 196, 220, 234, and 420 m from the interaction point, on both sides (in this document these locations always imply both sides, unless otherwise noted). The locations at 196, 220, and 234 m can be instrumented with Roman Pot devices similar to the ones presently used. The 420 m location requires a bypass cryostat (which has been developed for other locations in the LHC) and a movable detector vessel approaching the beam from between the two beam pipes.

PPS@HL-LHC: Run4 and beyond

- After Run3 all RPs must be removed to allow for reconfiguration of HL-LHC
- Layout of proposed RP stations



suitable for standard Roman Pot technology
in each location 2 units
with a few metres lever arm
(→track angles)

- needs cryogenic bypass
- signal protons between beam pipes
  →limited space

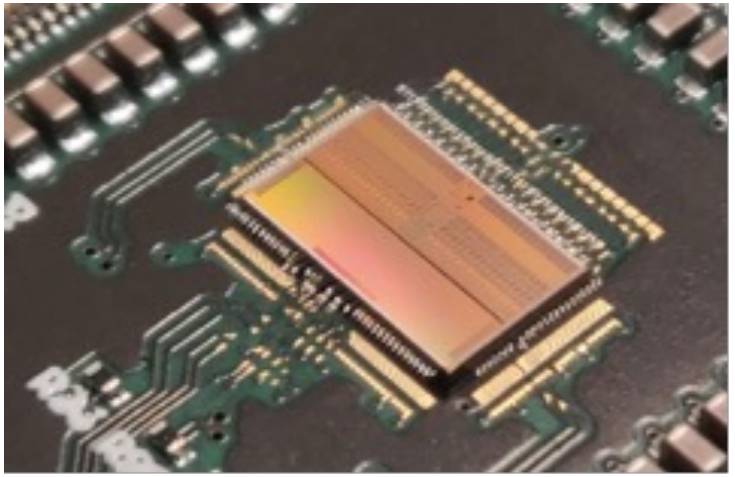
→new developments needed

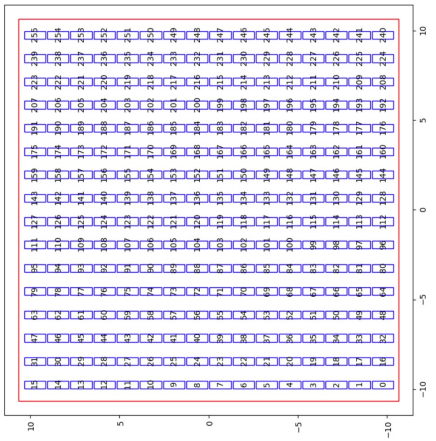
Detector Upgrades

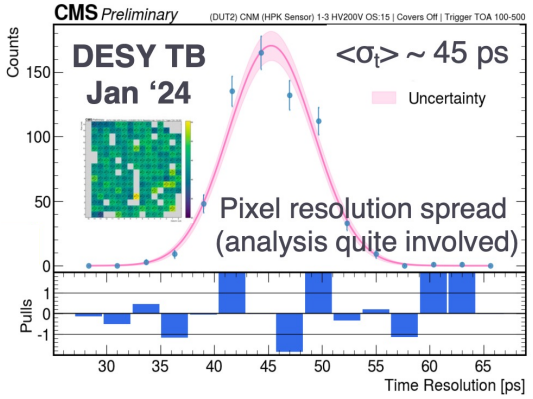
M. Araújo, D. Bastos, A. Boletti, R. Bugalho, T. Camporesi, D. Cardoso, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, J. Varela, J. Wulff

- Timing Detector MTD/BTL
  - Development of FE readout system of timing detector (LYSO crystals and SiPMs)
  - Based on fast timing TOF ASIC provided by Portuguese industry
  - 330k readout channels
  - Engineering run of final ASIC
- PPS
  - Exploring LGAD sensors and associated electronics to use as timing detectors in the HL-LHC upgrade
  - challenging near beam non-uniform irradiation

arXiv:2404.01208

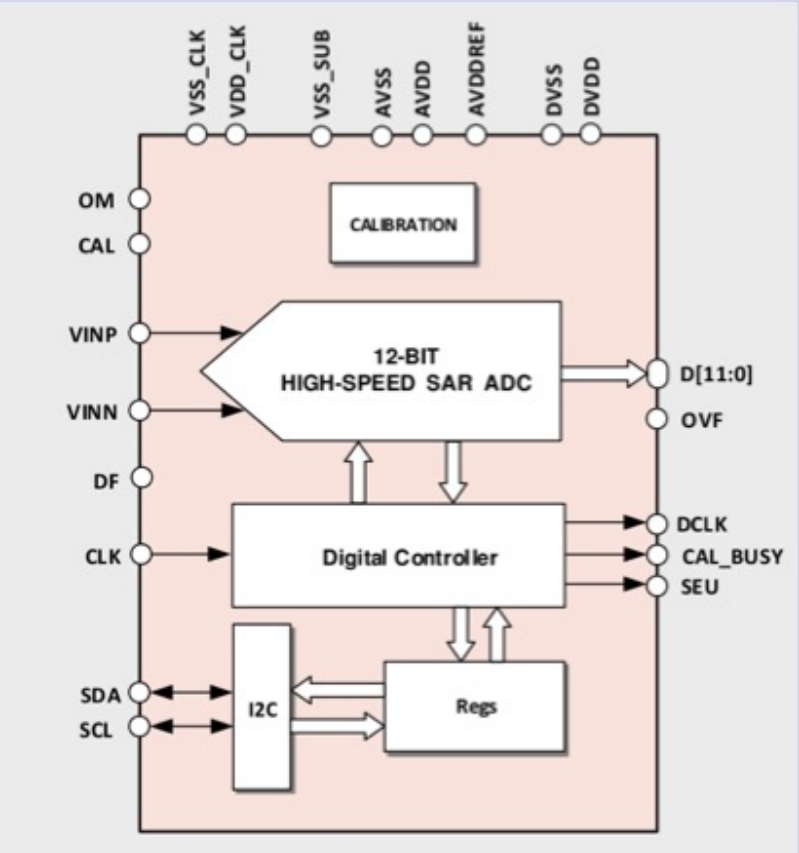






ECAL

- Long term LIP responsibility for ECAL electronics/DAQ
- HL-LHC: full replacement of electronics to meet new trigger/pileup requirements
- Collaboration with Portuguese industry developing new low-power ADC IP block
- 12 bit resolution with sampling rate of 160MS/s
- First design provided and integrated in LITE-DTU chip for evaluation since 2020



HGCAL: new rad-hard ASIC

New rad-hard ASIC developed by Portuguese industry performs well

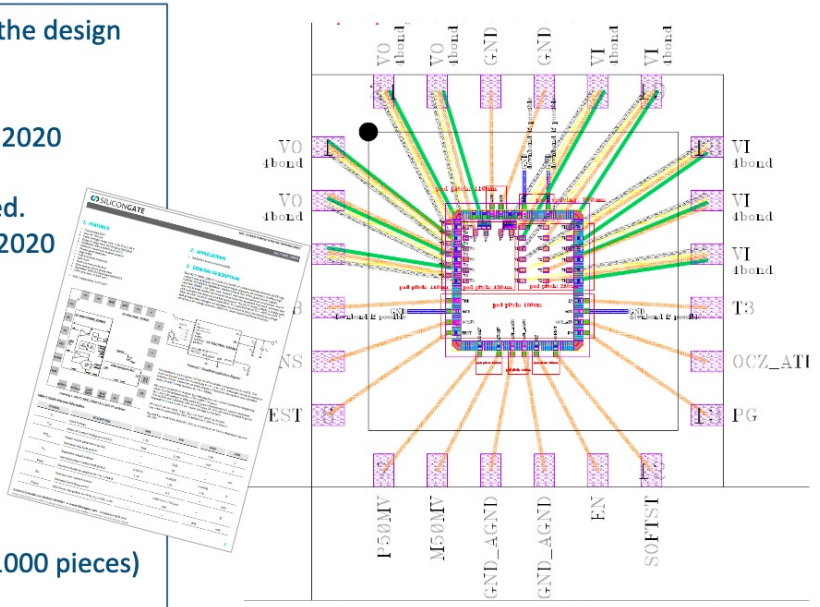
Slide from presentation at CMS week (April 2021)

CERN contract placed with SiGate in Portugal for the design and electrical characterization.

- TSMC 130nm, CRN01 LDO submission March 2020
- Electrical characterization done at SiGate
- Very detailed characterization report delivered.
- Excellent results shown by Sandro at TWEPP 2020
- Also presented to ESE
- Data Sheet available.

TID testing at CERN to 1.1Grad, all fine.
SEE tests planned in May 2021

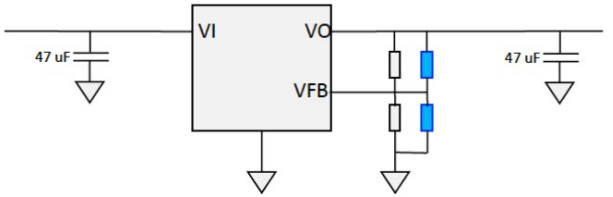
- A 2nd (slightly modified) design ongoing
- CRN02 design review April 2021
- Prototyping on Omega's ALTIROC Eng Run (~1000 pieces)
- Full production later this year
- Could be of interest to other projects.



QFN24 Package

Summary Specifications

- Tech : 130nm CMOS
- I_{max} : 3A
- Vin_{max} : 2 V
- Adjustable V_{out} : 1.0 - 1.5 V
- V_{out}-V_{in} : 175 mV @ I_{max}
- OverTemp, overI protection
- Digital adjust : +/- 50 mV control
- Digital enable
- Max dissipation : 500 mW**
- Small form factor



Binning into 2 or 3 types for voltage adjustment using resistors mounted on the boards

DCDC Module Design

LD bPOL12 module