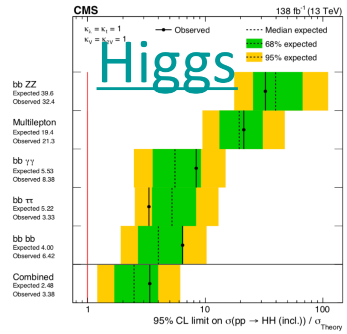
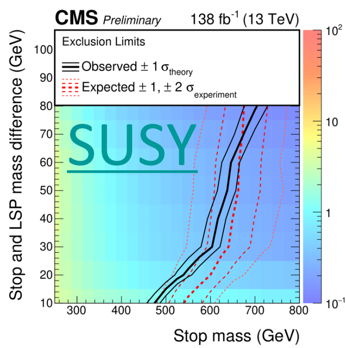
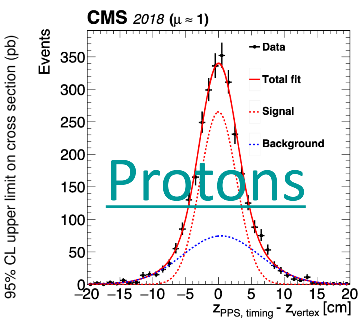
LIP-CMS group

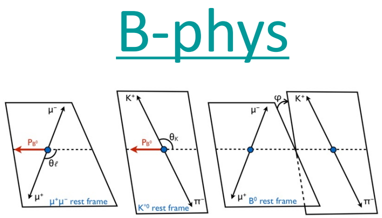
M. Araújo, P. Bargassa, D. Bastos, A. Boletti, R. Bugalho, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, T. Niknejad, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, J. Varela, J.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

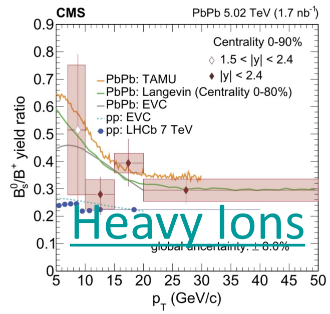
- Physics analyses
  - pp ($\gamma\gamma$) & HI collisions
  - precision measurements & searches (rare processes, BSM)
  - Top, Higgs, B, EWK, SUSY, Dark matter, Heavy Ions, Quarkonia
- Detector maintenance & operations
  - Precision Proton Spectrometer (PPS), ECAL, Computing
- Upgrades
  - PPS, Timing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

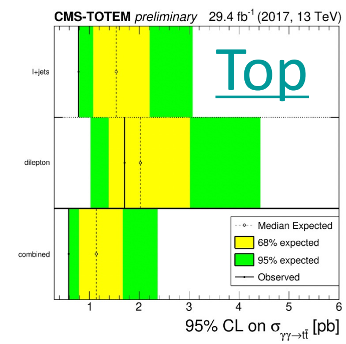




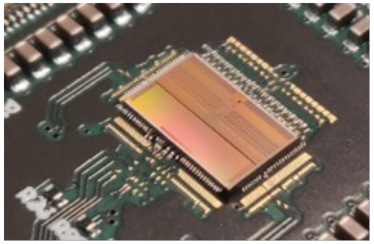


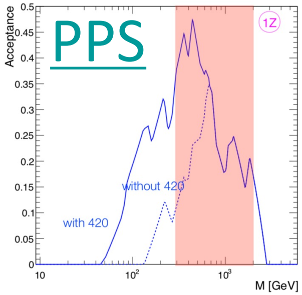


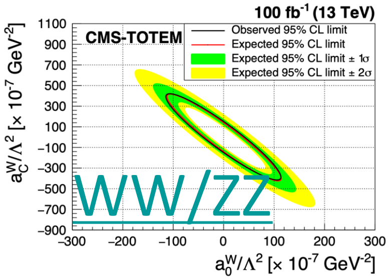




MTD







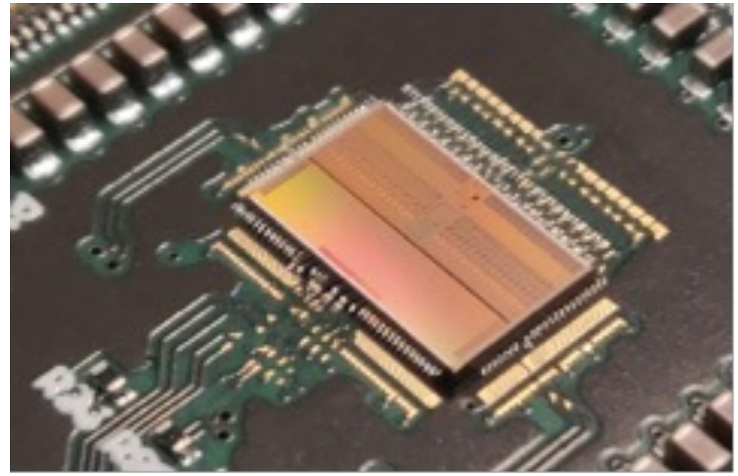
Fundação para a Ciência e a Tecnologia

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

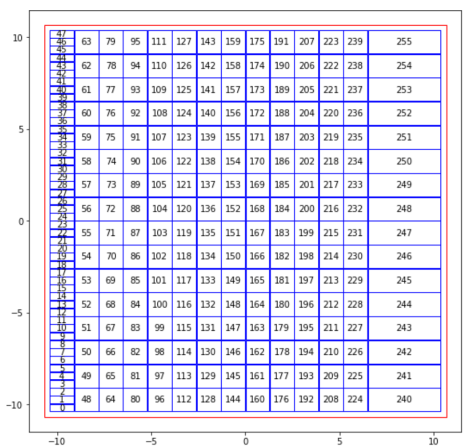
Detector Upgrades

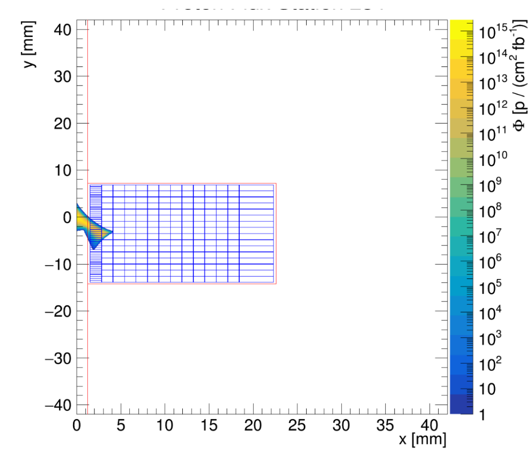
M. Araújo, P. Bargassa, D. Bastos, A. Boletti, R. Bugalho, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, T. Niknejad, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, J. Varela, J.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





SWOT

M. Araújo, P. Bargassa, D. Bastos, A. Boletti, R. Bugalho, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, T. Niknejad, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, 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 and leading role in several physics analyses. Leadership in areas of the Phase-2 Upgrades

Weaknesses

- Difficulty in attracting researchers to Portugal. Difficult and lengthy evaluation process to award fellowships and/or long-term positions to outstanding candidates in HEP

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
- Funding not matched to increasing prices

backup

Report 2022

The Compact Muon Solenoid (CMS) experiment at the LHC is a major scientific endeavour, and the research at the LHC is central to the quest for the fundamental physics laws of nature. LIP is member of the CMS Collaboration 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 rare B_s to dimuon decay, studies of B and Y mesons in pp and heavy ion collisions; measurement of the J/Psi, upsilon and chi_c polarizations; searches for a charged Higgs, a top squark, Dark Matter and exclusive processes. A group member (João Varela) served as Deputy Spokesperson of the CMS Collaboration in 2012-13.

The group contributed to the Phase-I 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 Run 2 (2015-2018) at an energy of 13 TeV, and it started taking data again in 2023 at an energy of 13.6 TeV after a period of maintenance and upgrades. During the long-shutdown (LS2), the group has been involved in the preparation of the PPS (Precision Proton Spectrometer) 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 (Jonathan Hollar) is presently serving as PPS Project Deputy Coordinator.

Report 2022 - 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 ASIC for time-of-flight (TOF) measurements (TOF ASIC). In collaboration with industry, LIP provides 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 collaborates with industry by supplying a high-current low voltage regulator (LVR) resistant to radiation for the High-Granularity Calorimeter (HGCAL) front-end system.

The group is actively involved and contributing to the physics analyses in the areas of Top quark, Higgs boson, 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.

It is worth noting that in the most recent (July 2019) institutional evaluation performed by an international review panel under the initiative of FCT, LIP received the highest quality grade (Excellent). The contribution of the CMS group was explicitly recognized in the panel's report: "The CMS group, while small in size, is really outstanding and world-class".

Report 2022 - III

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

- *"Vector Boson Scattering Processes: Status and Prospects"*, M. Gallinaro et al., Rev.Phys. 8 (2022) 100071
- *"Observation of Bs0 mesons and measurement of the Bs0/B+ yield ratio in PbPb collisions at 5.02 TeV"*, CMS Collaboration, Phys. Lett. B 829 (2022) 137062
- *"Search for nonresonant Higgs boson pair production in final state with two bottom quarks and two tau leptons in proton-proton collisions at 13 TeV"*, CMS Collaboration, arXiv:2206.09401
- *"A portrait of the Higgs boson by the CMS experiment ten years after the discovery"*, CMS collaboration, Nature 607 (2022) 7917, 60-68
- *"Search for high-mass exclusive gammagamma→ WW and gammagamma→ ZZ production in proton-proton collisions at sqrt(s) = 13 TeV"*, CMS and TOTEM Collaborations, arXiv:2211.16320
- *"Proton reconstruction with the CMS-TOTEM Precision Proton Spectrometer"*, CMS and TOTEM Collaborations, arXiv:2210.05854

5 PhD Theses

- Diogo de Bastos: *"Search for the supersymmetric stop quark in the CMS experiment"*, 2017-11-19, (ongoing), IST, Supervisor(s): Pedrame Bargassa, João Varela
- 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, Pedro Silva
- Giovanni Marozzo: *"Search for New Physics in gauge boson scattering with the CMS experiment at the Large Hadron Colliderics in gauge boson scattering with the CMS experiment at the Large Hadron Collider"*, (ongoing), IST, Supervisor(s): Jonathan Hollar, Michele Gallinaro

2 Master

- Henrique Legoinha: *"Probing the properties of the plasma of quarks and gluons with heavy flavour"*, 2021-10-01, (ongoing), IST, Supervisor(s): Nuno Leonardo
- Simão Costa: *"Quark hadronization with B mesons at the LHC"*, 2022-09-15, (ongoing), IST, Supervisor(s): Nuno Leonardo

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

- PPS Coordinator (Level-1), since 2021 (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 of the, 2020-2021 (T. Niknejad)

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, P.Faccioli)

- ECAL Executive Board (J.C.Silva)

- ECAL, MTD and HGCAL Institution Boards (J.Varela)

- PPS Institution Board (M.Gallinaro)

- MTD Steering Committee (J.Varela)

Report 2022 - IV

3) Experiment operation and maintenance

a) Physics objects development:

LIP members pursued the participation in the activities of POGs (Physics Object Groups) in the validation of forward proton alignment and reconstruction efficiency (M. Pisano), and PPS high-level trigger (M. Araújo). 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 submitted for publication. Tag-and-probe tools for muon measurements with CMS open data were contributed (N. Leonardo with non-LIP CMS members).

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 publication.

c) ECAL: A member of the group (J.C. Silva) maintained the ECAL trigger and DAQ system.

d) Computing: A member of the group (D. Bastos) served as LIP/CMS interface with the LIP Tier2 group.

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

HL-LHC Phase-II Upgrades

In the High-Luminosity phase of the LHC physics program, the accelerator will provide CMS with an additional integrated luminosity of 3000 fb^{-1} over 10 years of operation, starting in 2029. To meet the experimental challenges of this unprecedented proton-proton luminosity, the CMS collaboration will undertake the Phase-II upgrade program to maintain the excellent performance of the detector.

The LIP participation in the CMS Phase-II Upgrades is concentrated in the MIP Timing Detector and in the ECAL and HGCAL Calorimeters and PPS detector. The generic goals of these upgrades are the following:

1. MIP Timing Detector: addition of a timing layer in front of the Calorimeters for precise timing measurement of all charged particles;

2. Electromagnetic Calorimeter: full replacement of the ECAL barrel electronics;

3. High Granularity Calorimeter: complete replacement of the endcap calorimeters with a new high-granularity sampling calorimeter;

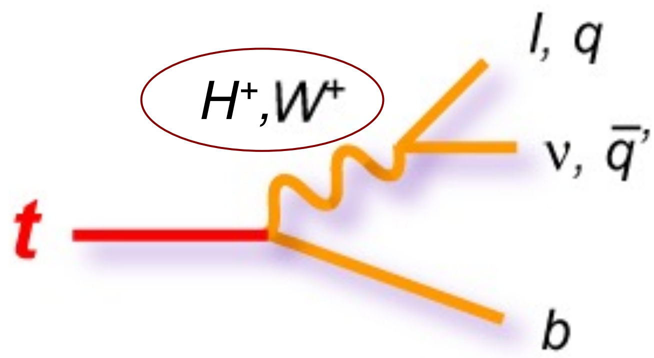
4. Precision Proton Spectrometer: Participation in the upgrade of the PPS for the HL-LHC started with the LoI and will continue with the preparation of the Technical Design Report addressing specific physics and detector R&D studies. Explore LGAD sensors and associated electronics for use as timing detectors in the HL-LHC PPS upgrade.

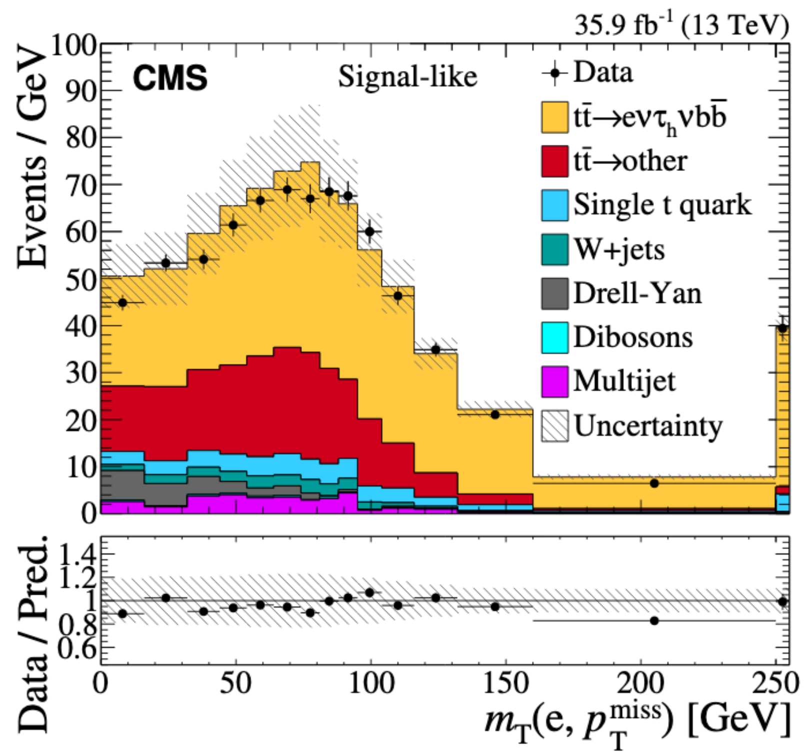
Top quarks and tau leptons

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
- $t \longrightarrow (\tau\nu)b$ 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

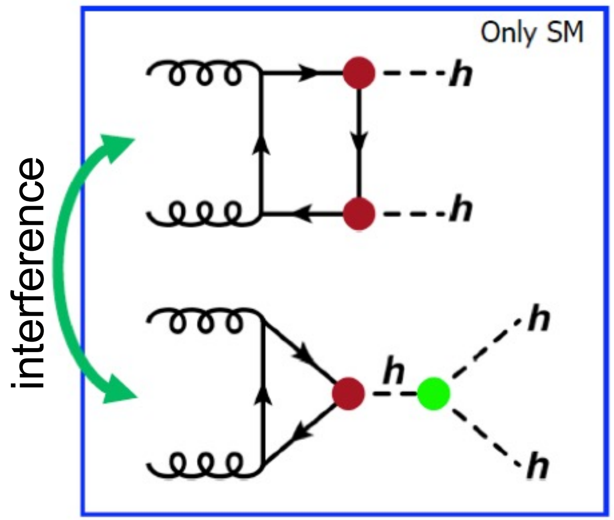
$$R_{\ell\tau_h/\ell\ell} = 0.973 \pm 0.009\,(\mathrm{stat}) \pm 0.066\,(\mathrm{syst})$$

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

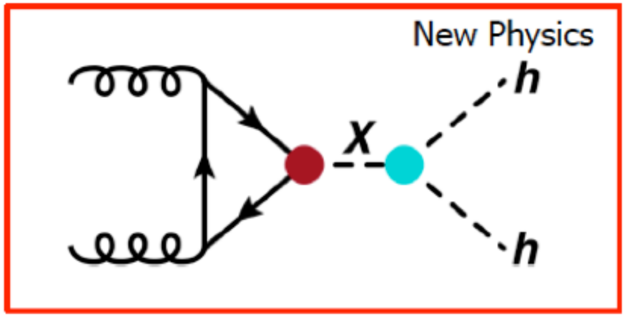
Double Higgs production

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

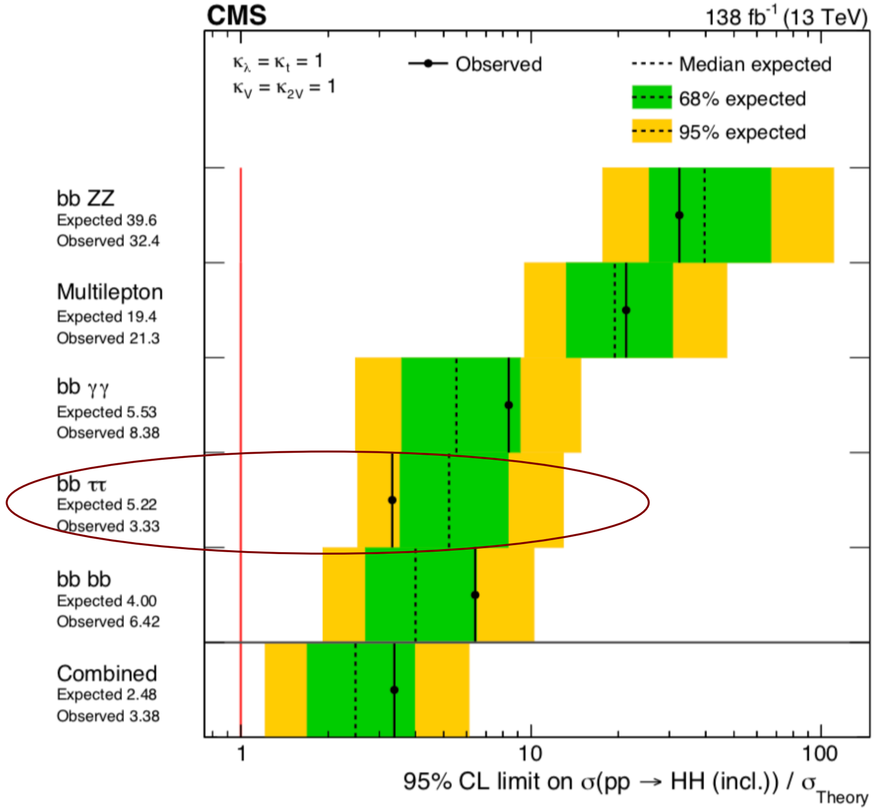
non-resonant production



resonant production



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

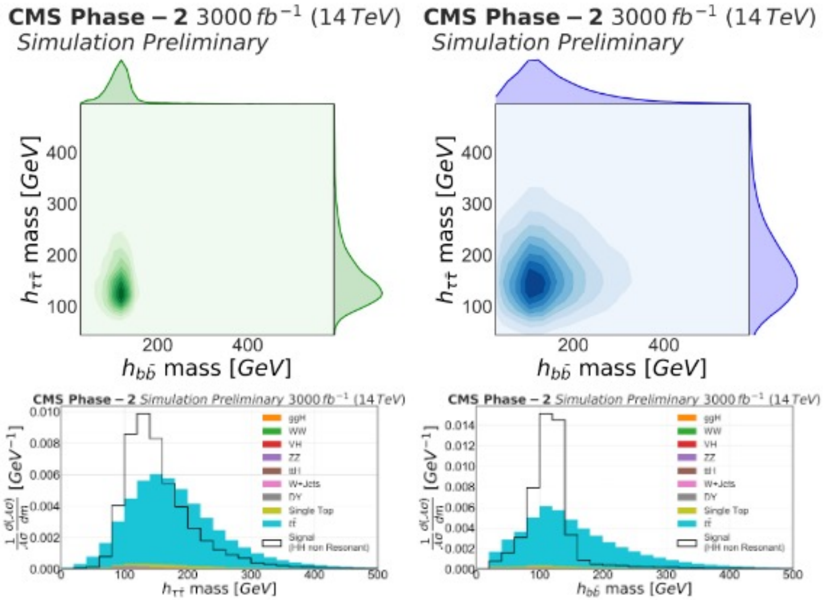


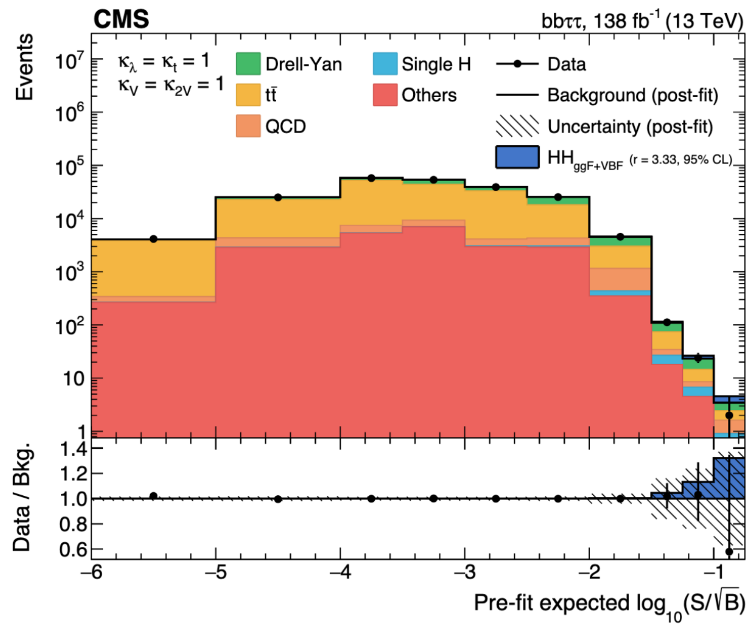
- Destructive interference in SM
- In SM, only σ=33fb at 13 TeV
- Not yet at the SM sensitivity

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



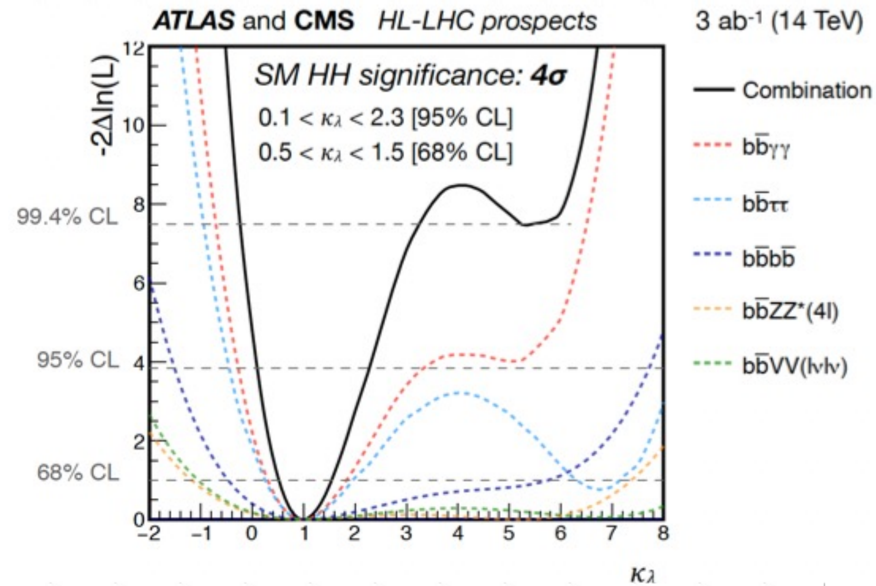


⇒ Results are better (x2-3) than 2016 results alone after scaling for luminosity

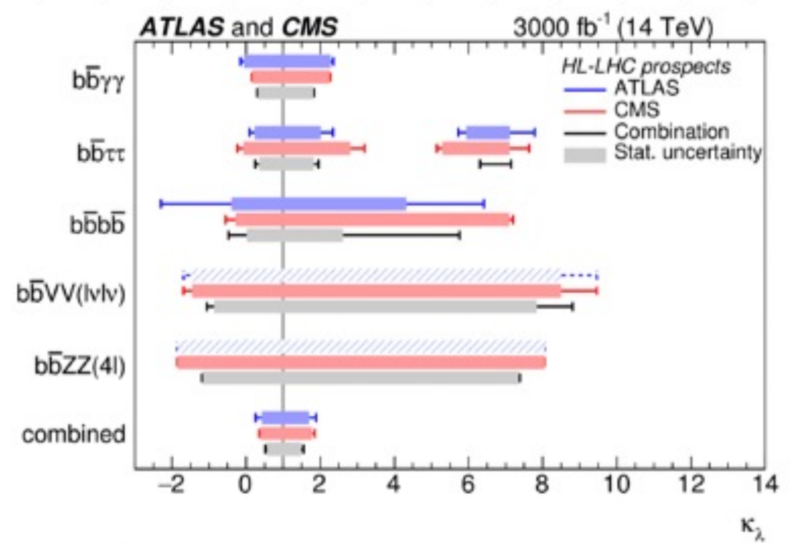
HL-LHC: Higgs self-coupling

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 4.5		Combined 4.0	



MTD: Particle reconstruction

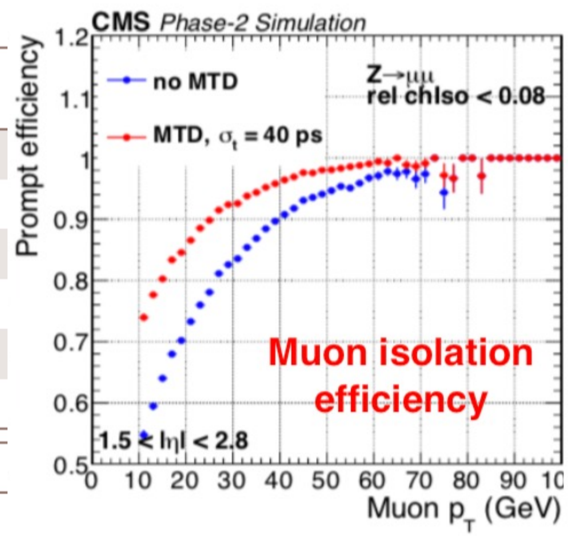
CERN-CMS-TDR-020

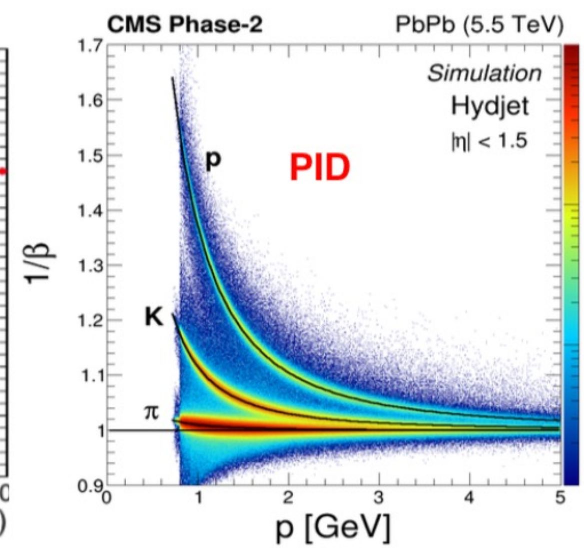
- Improve particle reconstruction/ID
  - Increase b-tagging efficiency
  - Increase photon and lepton Id, efficiency and isolation
  - Improve missing transverse momentum resolution
  - Reduce fake jet reconstruction
- 10%-20% gain in S/B in many Higgs decay channels

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

Channel	No MTD	$\langle\sigma_t\rangle$ 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

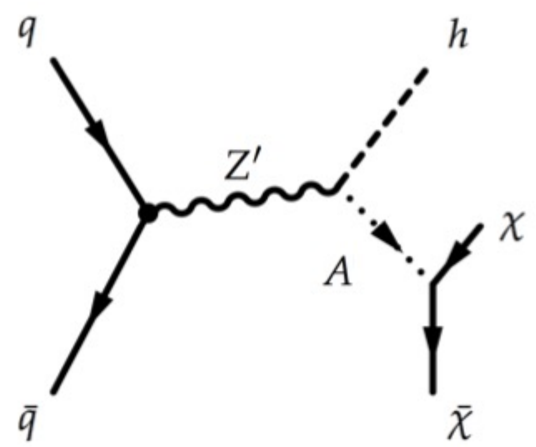




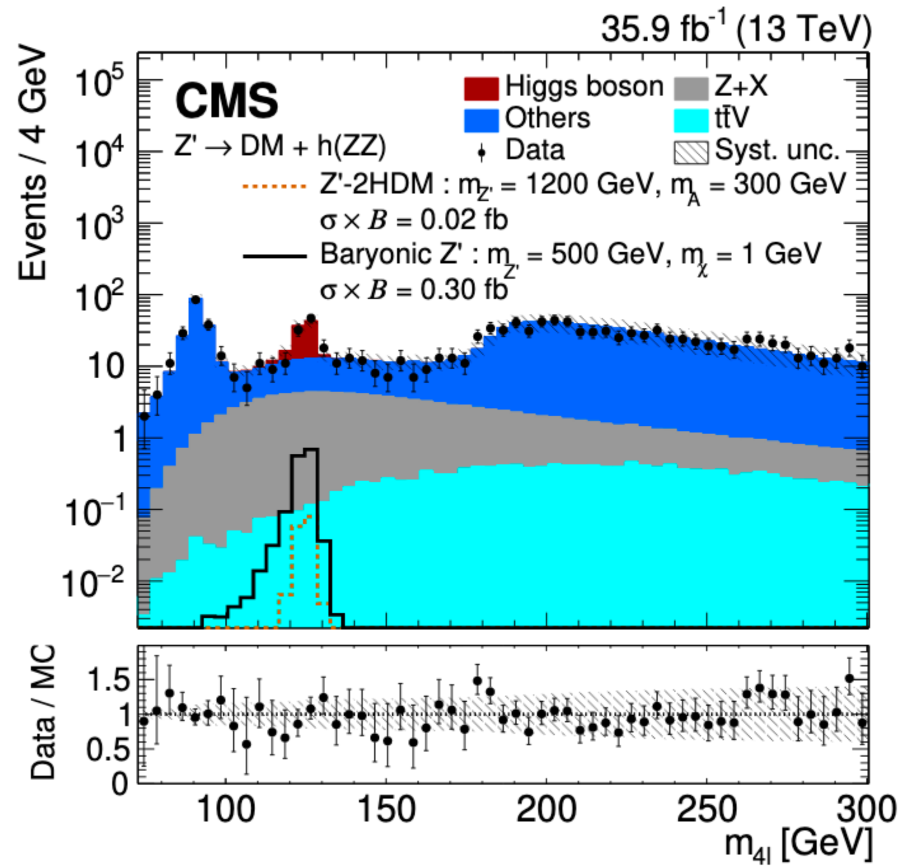
Higgs + Dark Matter

JHEP 03 (2020) 025

- 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

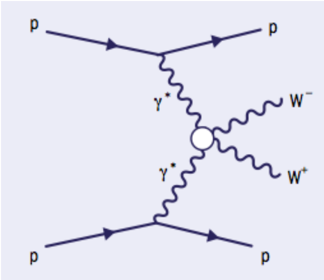
Exclusive production

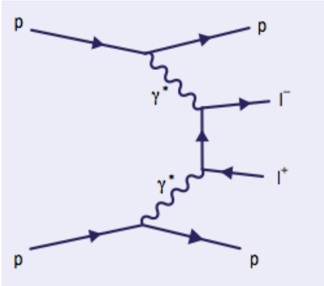
JHEP 07(2018)153

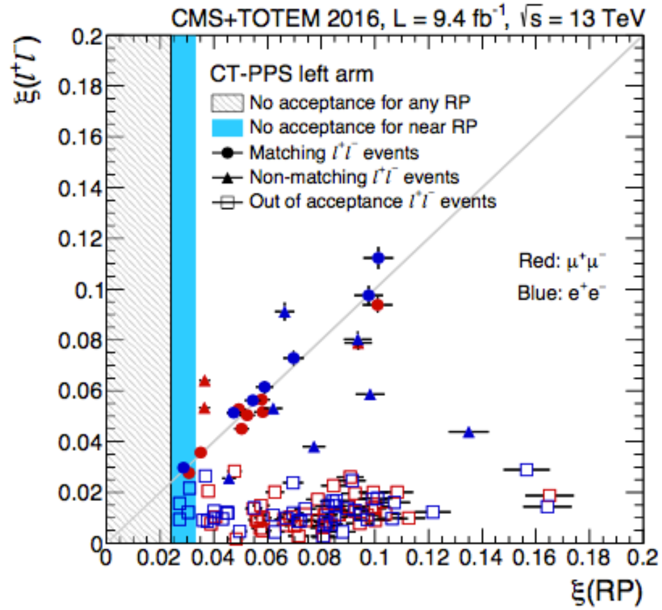
- LHC as photon collider
- EWK processes with small cross sections
- Study $\gamma\gamma$ interactions at high energies in exclusive processes with leading protons
- High-mass system in central detector, together with very forward protons in PPS
  - momentum balance between central system and forward 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)

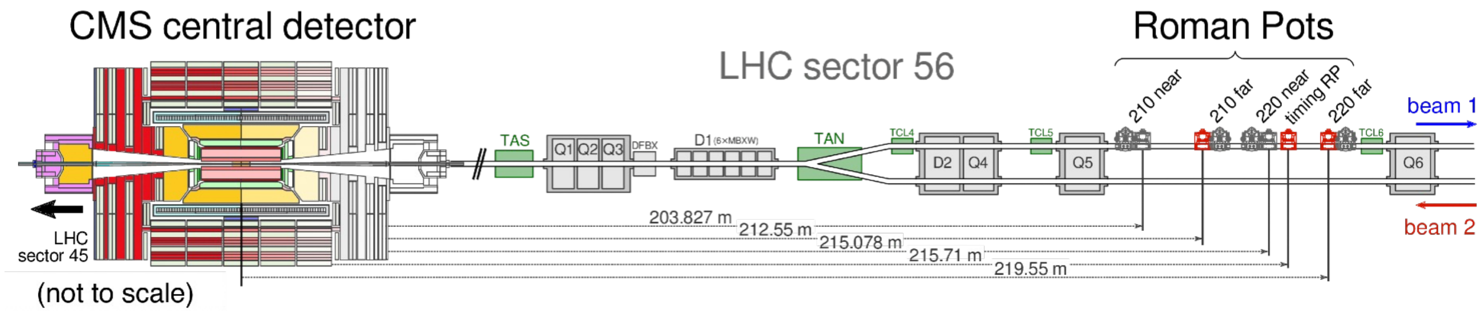






Physics w/ forward protons

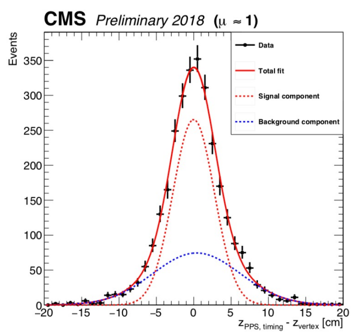
JHEP 07(2018)153, arXiv:2210.05854, CMS-TOP-21-007, arXiv:2211.16320



Proton reconstruction

arXiv:2210.05854

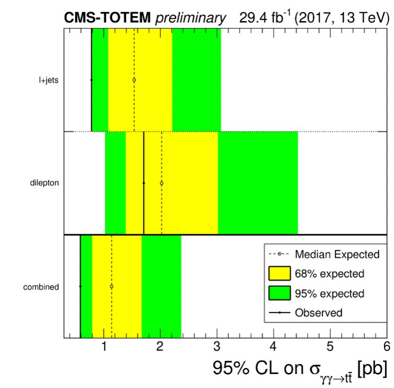
PPS collected more than 100/fb of data in Run2



Exclusive top quark pairs

CMS-TOP-21-007

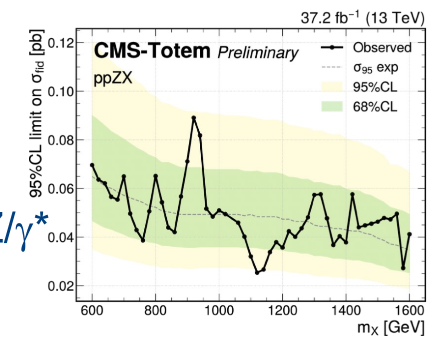
Search for central exclusive production of ttbar pairs in pp interactions with tagged protons



Zγ+X production

arXiv:2303.04596

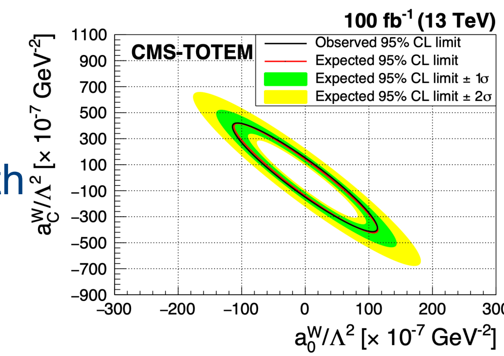
Search for anomalous Z/γ* central production with 2017 data



Exclusive WW/ZZ

arXiv:2211.16320

Search for $\gamma\gamma \longrightarrow WW/ZZ$ with forward protons



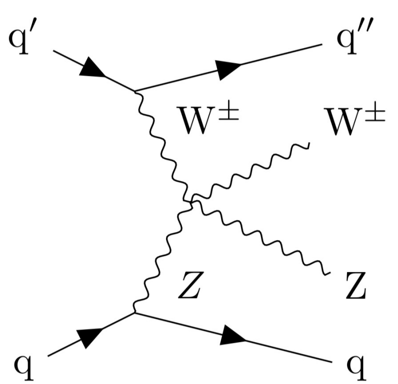
Vector Boson Scattering

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

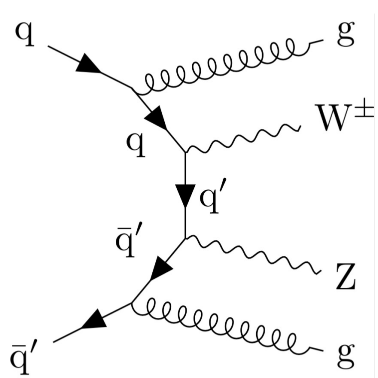
Ongoing with full Run2 dataset (PhD student: G.B. Marozzo and U.Perugia)

ssWW EW signal: σ=27 fb

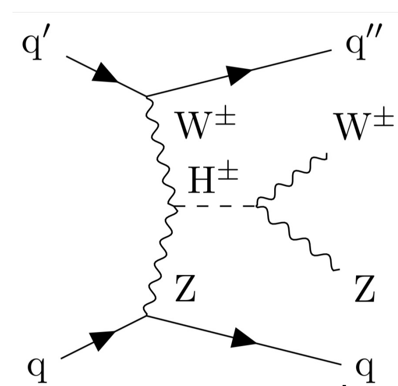


VBS WZjj

QCD bkg: σ=26 fb



Non-VBS WZjj

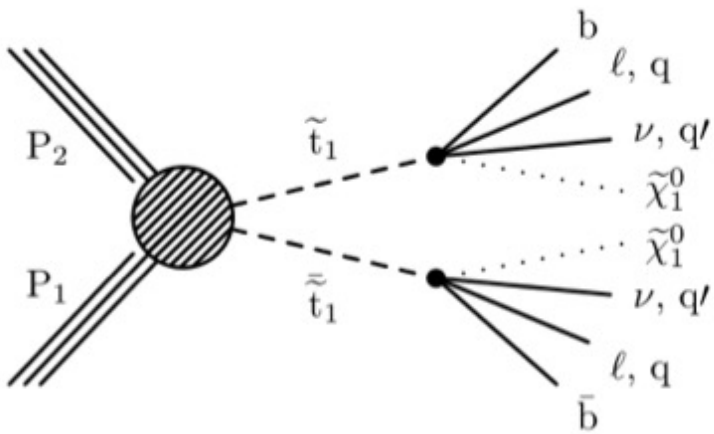


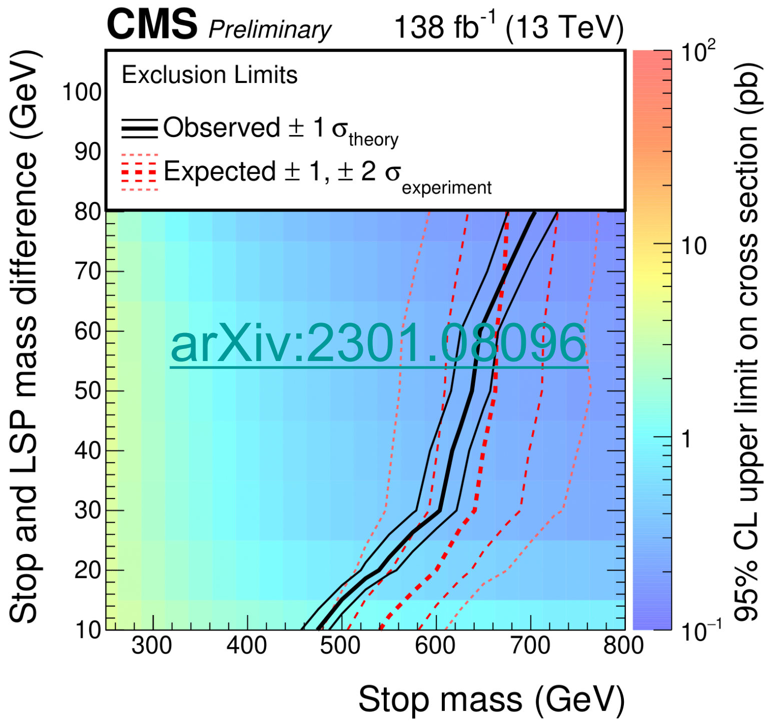
BSM $H^\pm$

SUSY

- 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)



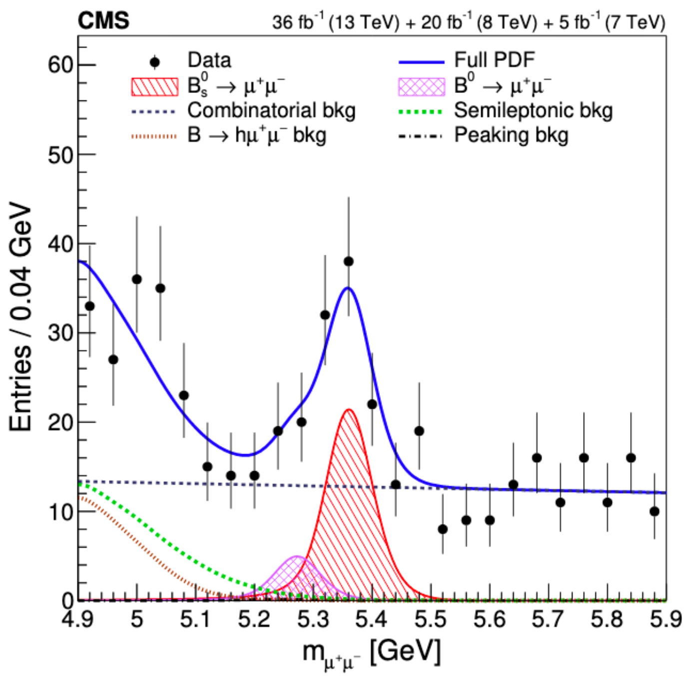


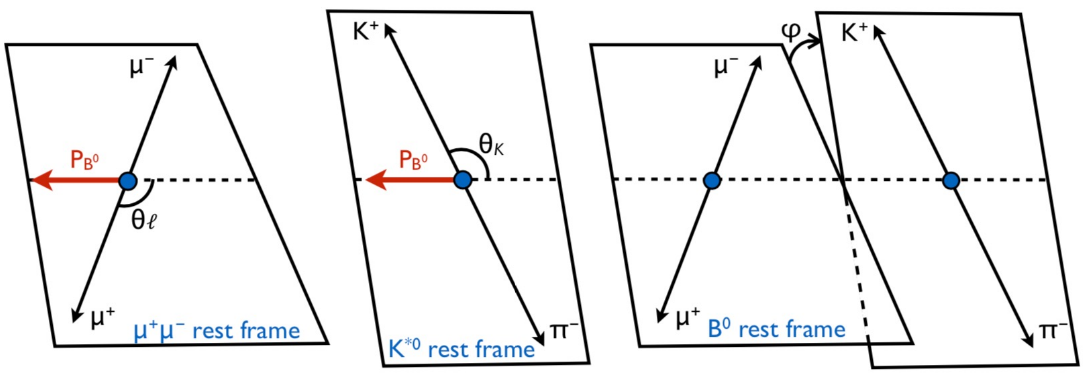
B-physics

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 $b \longrightarrow s\mu\mu$ transitions
  - $B \longrightarrow \mu\mu$, $B \longrightarrow K^*\mu\mu$
- Study decay rates and angular variables
  - Measure BRs and lifetime
  - $B \longrightarrow K^*(K^+\pi^-)\mu\mu$
  - $B \longrightarrow J/\psi(\mu\mu)\phi(KK)$
- Goldmine in "parked" dataset

Ongoing (A. Boletti)



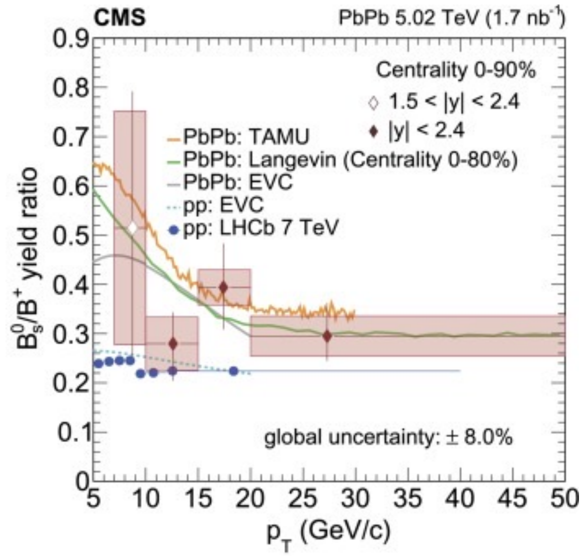


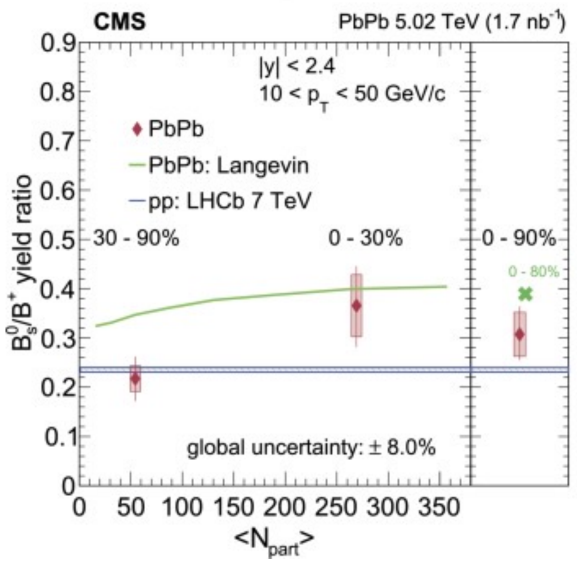
Heavy Ions

PLB 829(2022)137062

- 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

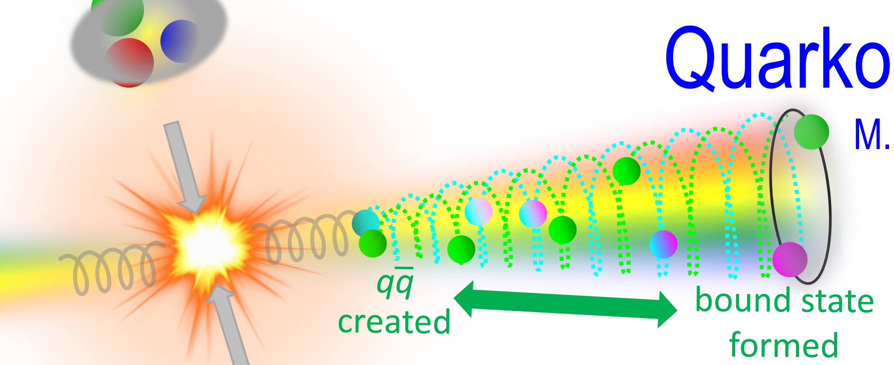
Work ongoing (Master students:
H. Legoinha, S. Costa)

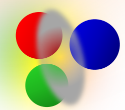




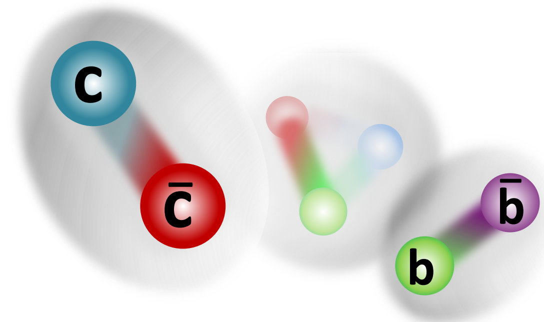
Quarkonium production

M. Araújo, P. Faccioli, C. Lourenço



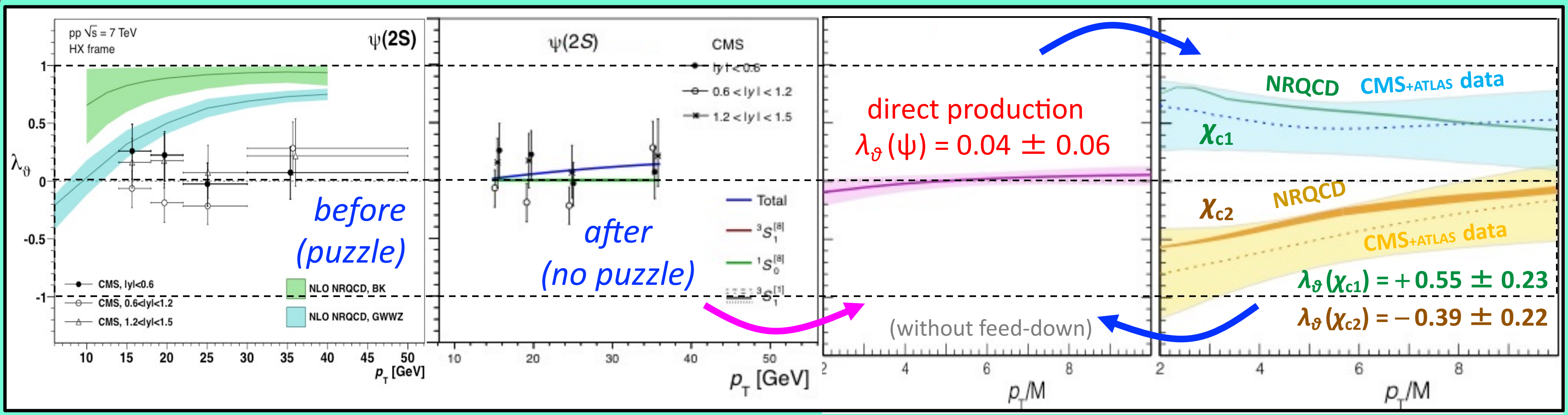


An ideal probe to study
hadron formation



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.

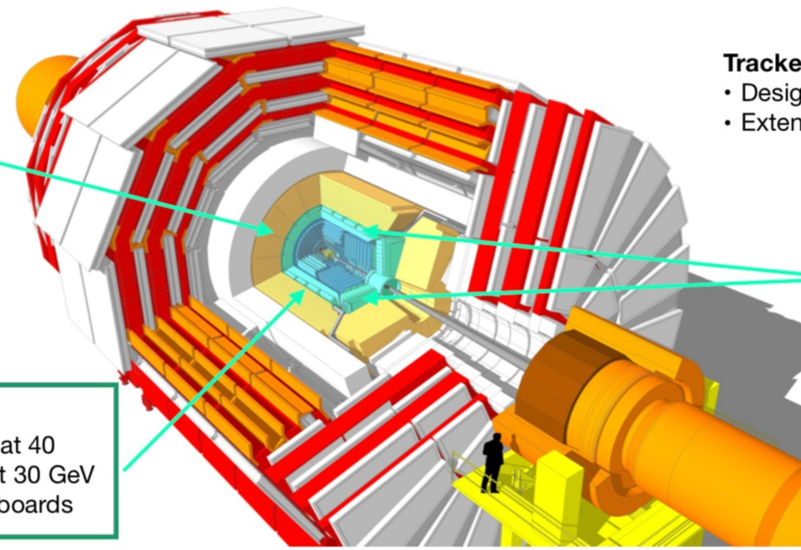
LIP Contributes to

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 < η < 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

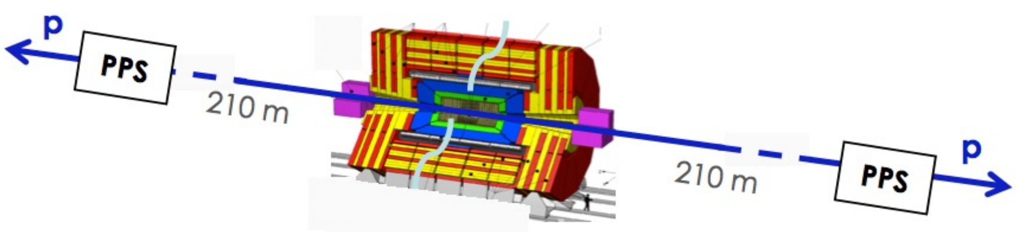


Tracker Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

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



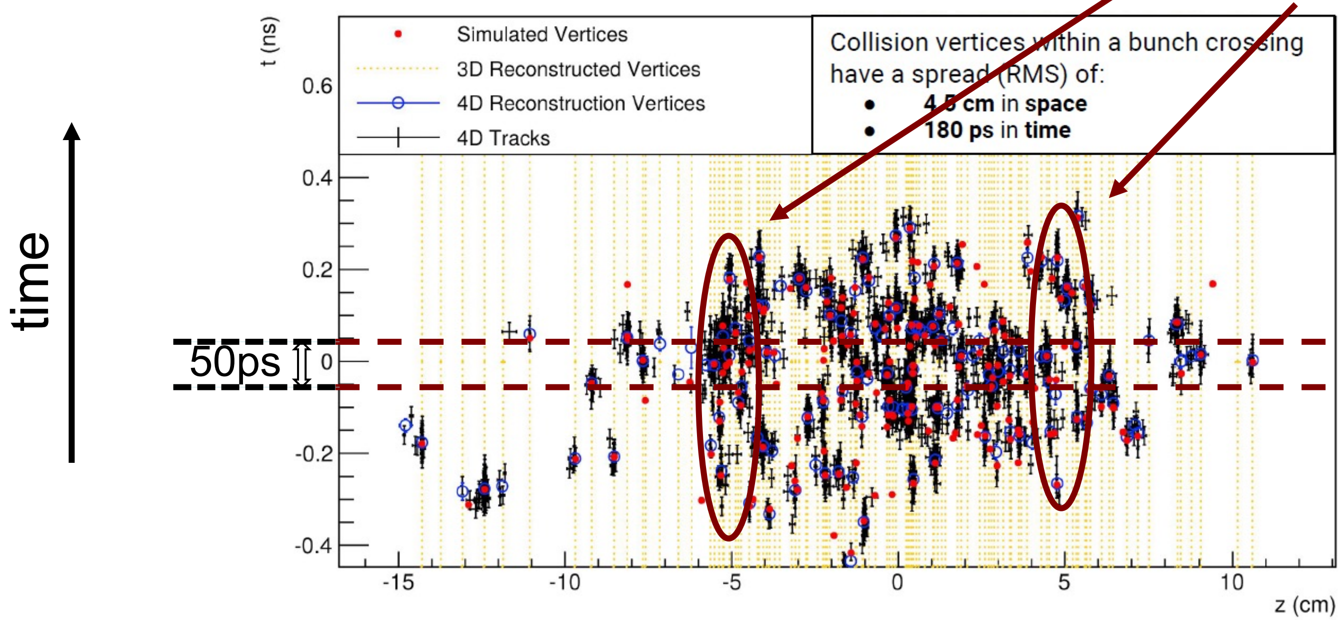
LIP contributes to

Precision Proton Spectrometer
Detector design and physics prospects

MIP Timing Detector

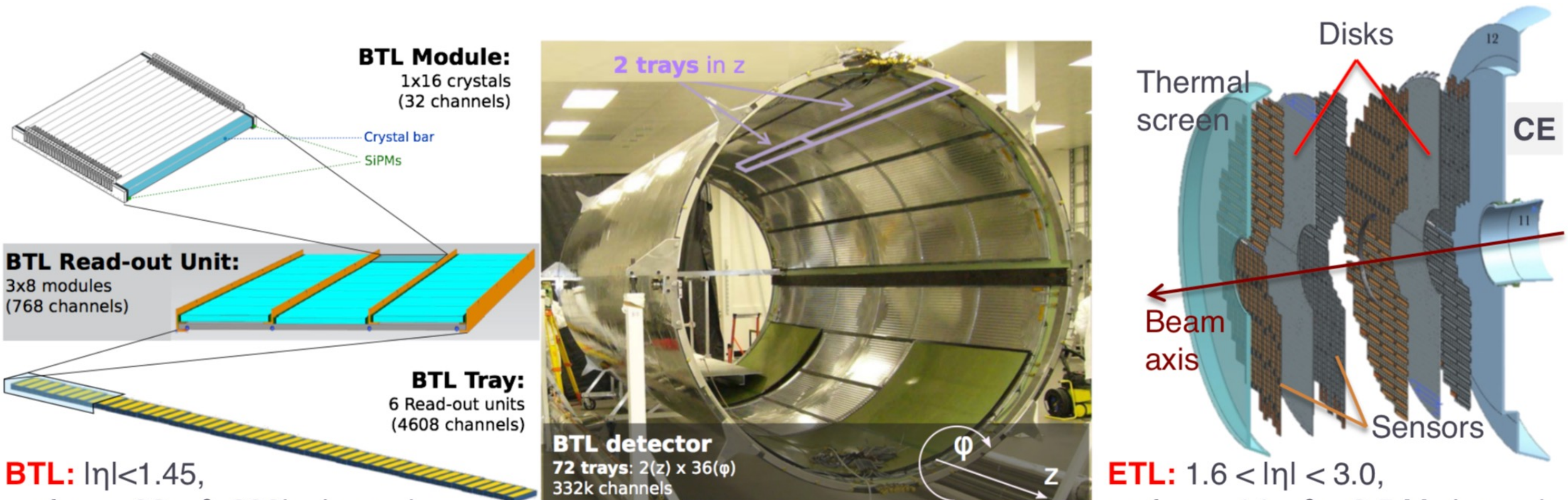
- Time-tagging tracks with a resolution of ~30-40 ps
  - 4D vertex reconstruction
  - Track-vertex association
- Reduce effective PU to the LHC Run2 level
  - Slice beam spot (time spread 180 ps)

Vertices merged in 3D, and separated in 4D



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)



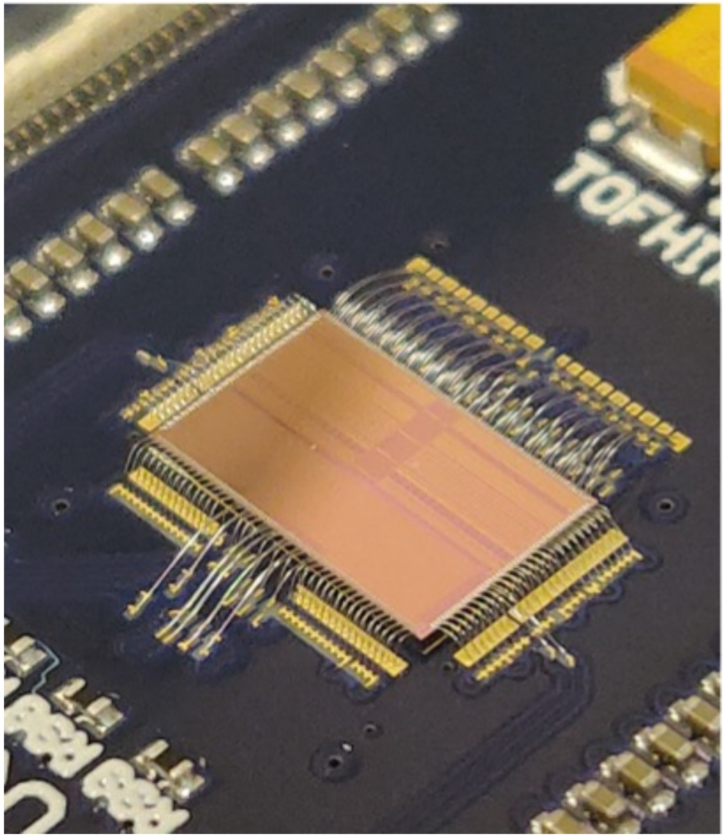
BTL: |η|<1.45,
surface ~38 m²; 332k channels

ETL: 1.6 < |η| < 3.0,
surface ~14 m²; ~8.5 M channels

MTD/BTL electronics

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

- 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

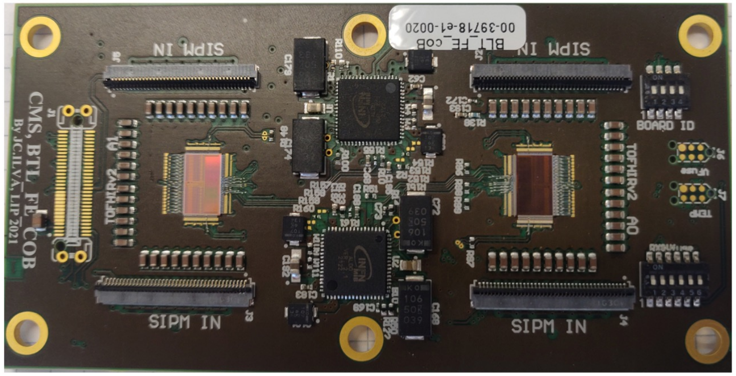


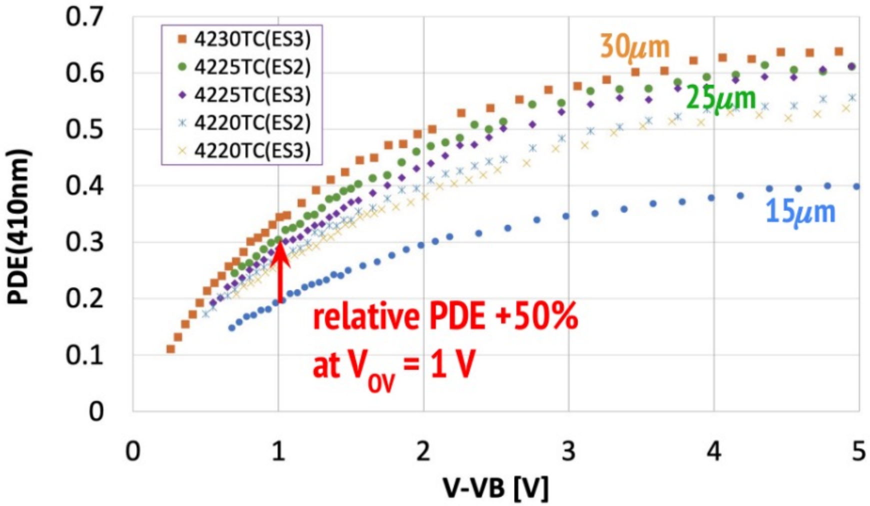
MTD/BTL performance optimization

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

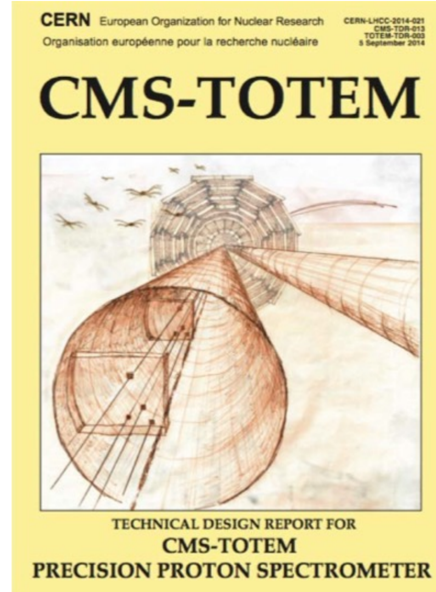


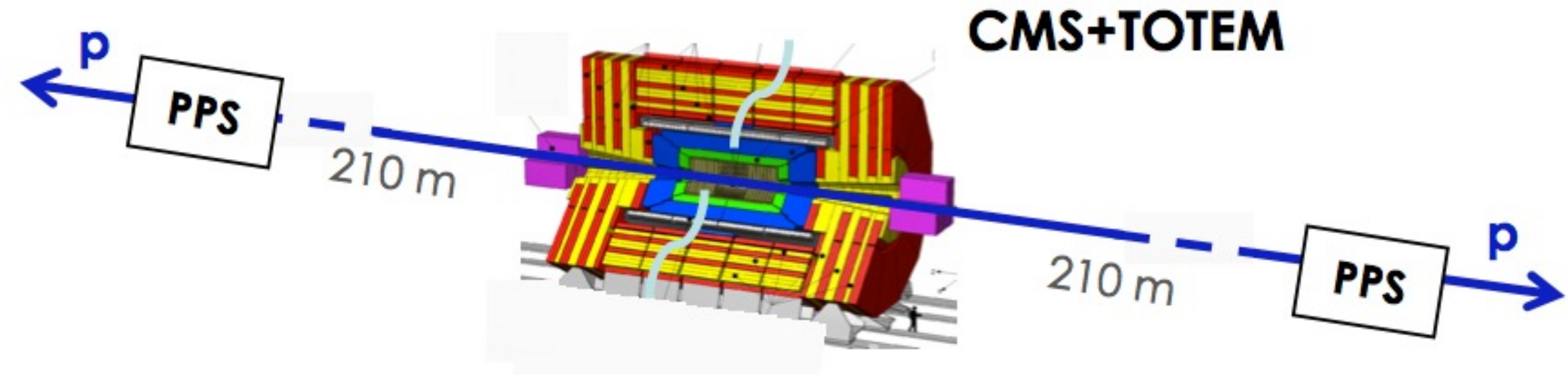


Precision Proton Spectrometer

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

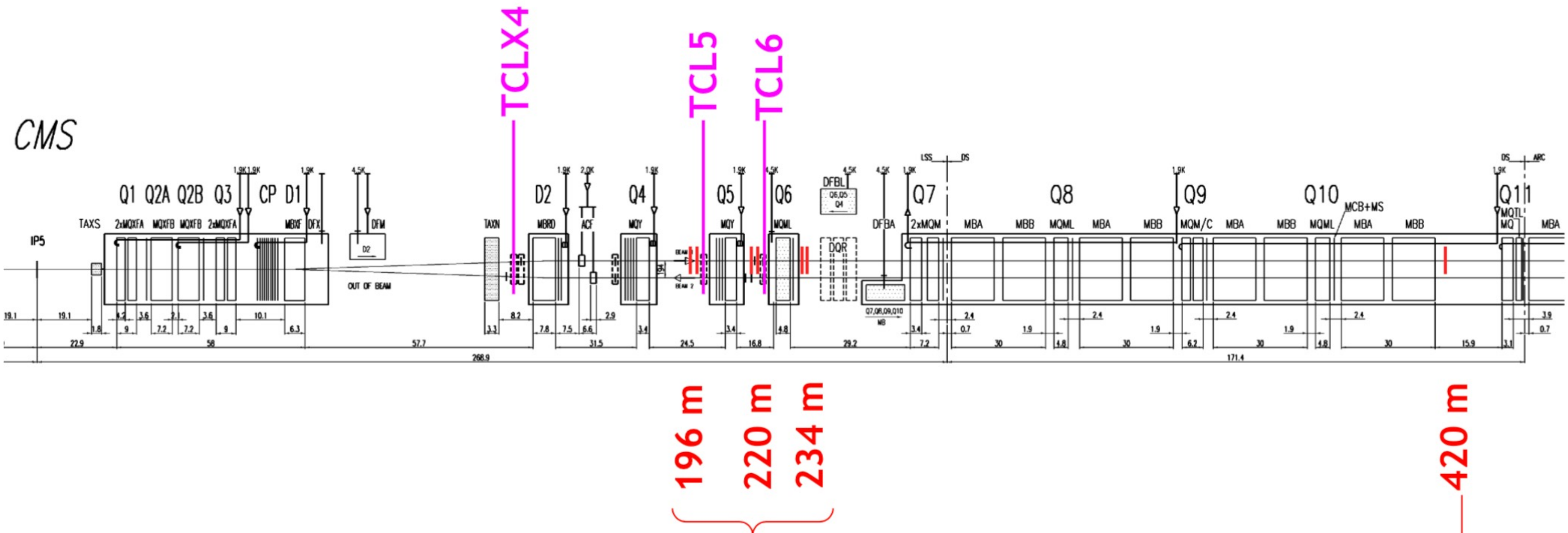
The CMS Collaboration intends to pursue the study of central exclusive production (CEP) events, $\mathrm{pp} \rightarrow \mathrm{pXp}$, at the High-Luminosity LHC (HL-LHC) by means of a new near-beam proton spectrometer. In CEP events, the state X is produced at central rapidities, and the scattered 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



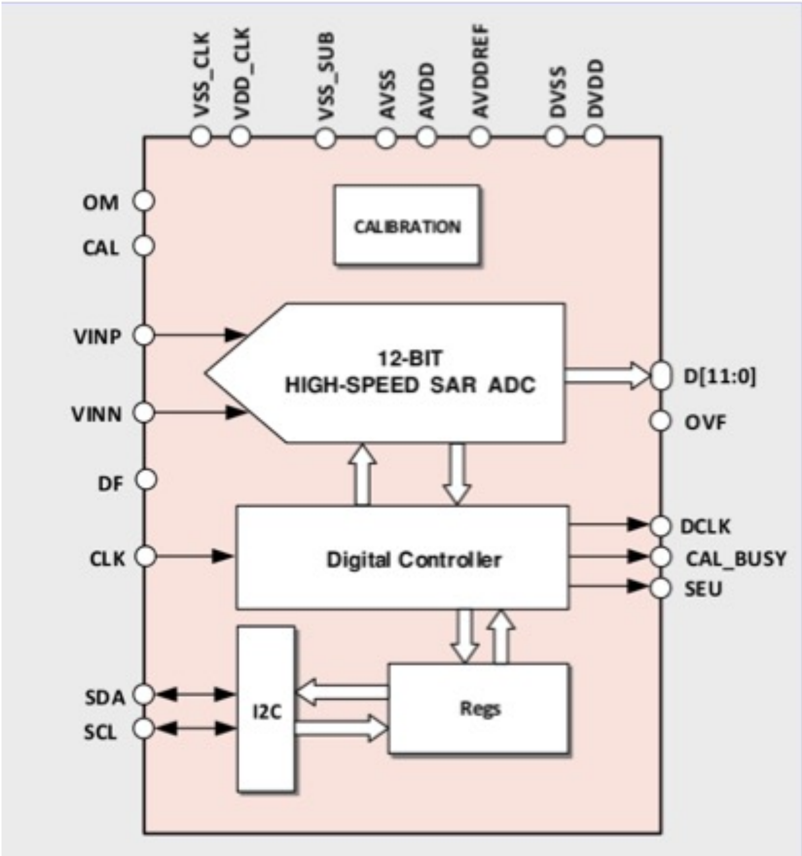
suitable for standard Roman Pot technology
in each location 2 units
with a few metres lever arm
(→track angles)

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

→new developments needed

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

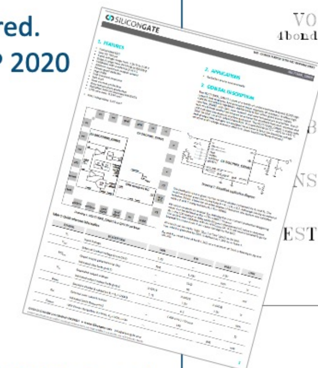
New rad-hard ASIC developed by Portuguese industry performs well

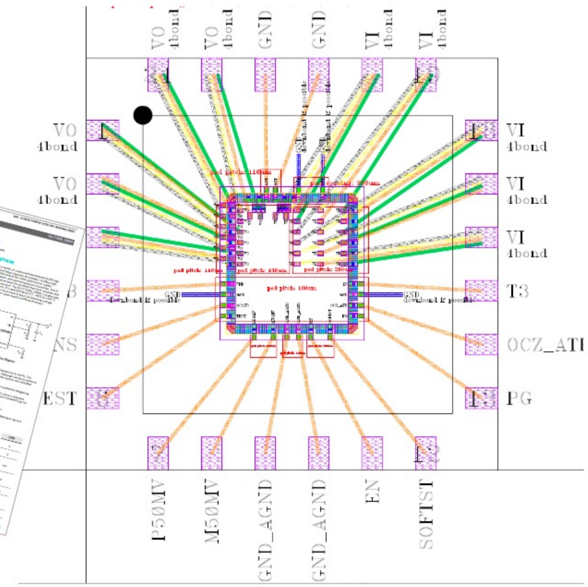
CERN contract placed with SiGate in Portugal for the design and electrical characterization.

- 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.

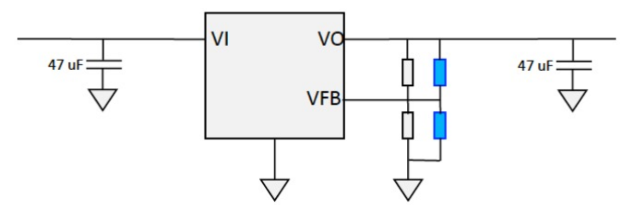




QFN24 Package

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

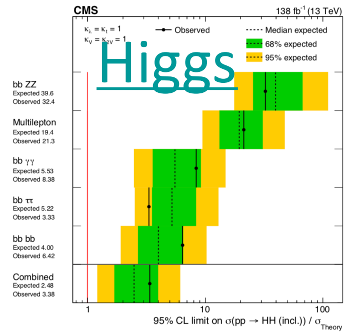
LD bPOL12 module

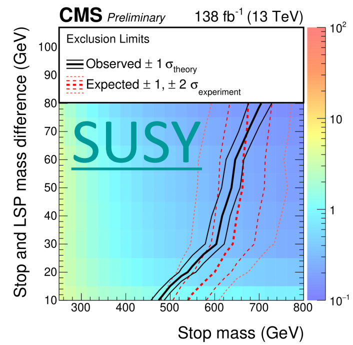
Slide from presentation at CMS week (April 2021)

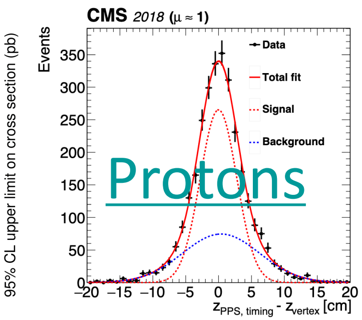
LIP-CMS group

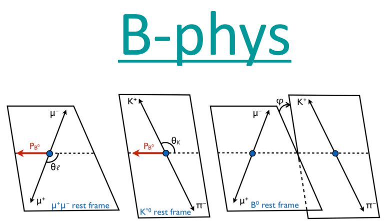
M. Araújo, P. Bargassa, D. Bastos, A. Boletti, R. Bugalho, S. Costa, G. Da Molin, P. Faccioli, L. Ferramacho, M. Gallinaro, J. Hollar, N. Leonardo, H. Legoinha, C. Lourenço, G.B. Marozzo, T. Niknejad, M. Pisano, J. Seixas, C. Silva, P. Silva, J.C. Silva, R. Silva, M. Silveira, G. Strong, J. Varela, J.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

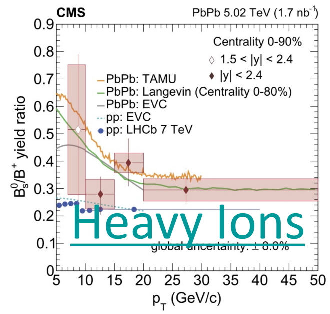
- Physics analyses
  - pp ($\gamma\gamma$) & HI collisions
  - precision measurements & searches (rare processes, BSM)
  - Top, Higgs, B, EWK, SUSY, Dark matter, Heavy Ions, Quarkonia
- Detector maintenance & operations
  - Precision Proton Spectrometer (PPS), ECAL, Computing
- Upgrades
  - PPS, Timing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

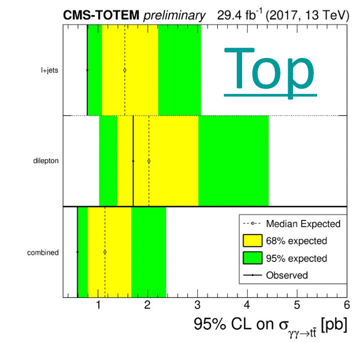


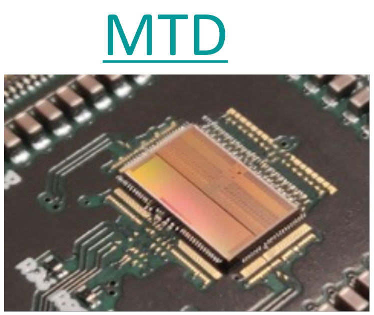


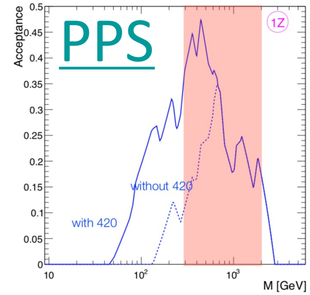


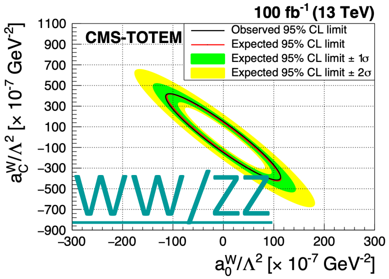












Fundação
para a Ciência
e a Tecnologia

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

MSCA-RISE2020 (aMUSE), INFRA-2022-DEV-01-01 (MuCol)