CMS Albania UT - UPT team

Albanian-American Development Foundation

SCIENCE WEEK TIRANA, 2^{nd} : From the theoretical model to the experimental observation

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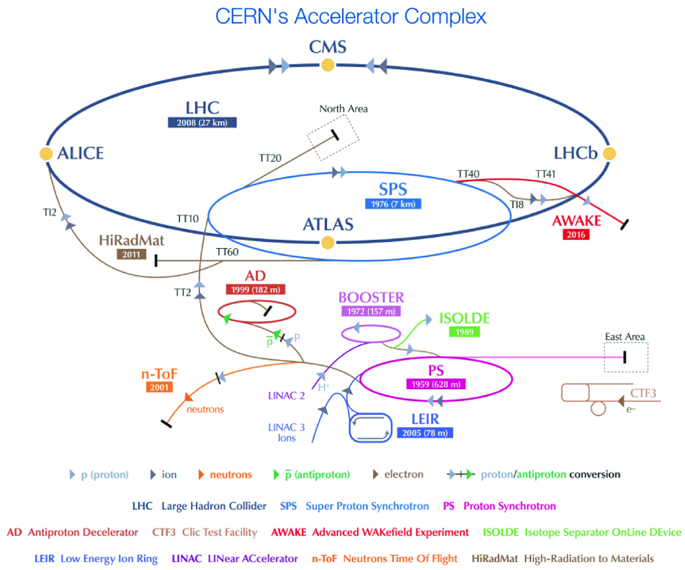
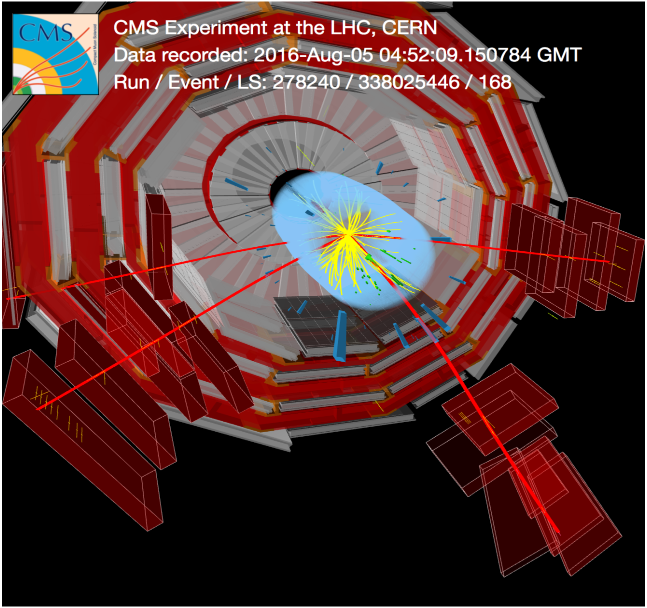
The CMS Experiment & INFN of Bari

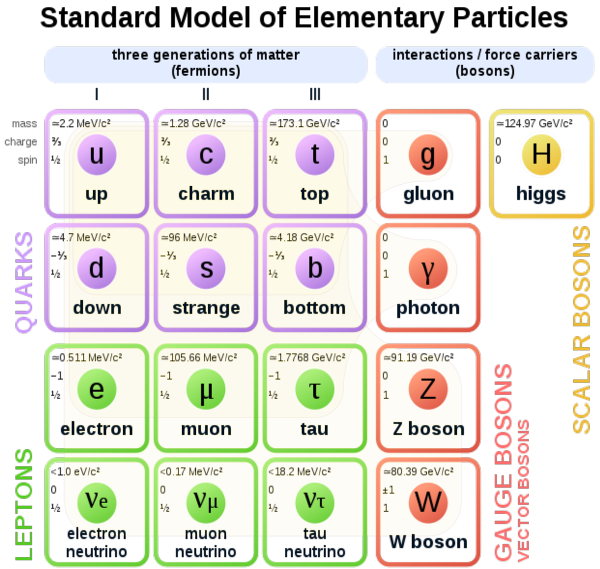
The Large Hadron Collider



CMS Collision Events



The Standard Model of Elementary Particles



Possible Analysis research at the CMS Experiment

$\Rightarrow$ SM based theories:

- Higgs Physics anb all decay modes of the Higgs boson
- EM, EWK particle Physics
- The full range of elementary particle Physics discovered and predicted from the SM (no gravitation related particles)

$\Rightarrow$ BSM based theories:

- Every possible deviation of the Higs boson invariant mass (Higgs Singlet Model, 2-Higgs-Doublet model)
- Minimal Supersymmetric Extansion of the SM (MSSM Theory)
- Kaluza-Klein and Randall-Sundrum model on the bulk graviton spin-2 and radion spin-0 gravitational particles
- SUSY particles (charginos, neutralinos, higgsinos, etc ...)
- Dark matter particles (Z-prime, Monohiggs, dark photons, etcc ...) and long lived / displaced particle

- $HH(SM) \rightarrow b\bar{b}Z^0Z^0 \rightarrow b\bar{b}4l, \quad l = e^{\pm}, \mu^{\pm}$
- $X/A(BSM) \rightarrow HH \rightarrow b\bar{b}Z^0Z^0 \rightarrow b\bar{b}4l, \quad l = e^{\pm}, \mu^{\pm}$

How to "observe" particles in a particle detector

- We don't see any of the Physics particles either with our eyes nor with our experiments!
- We measure (detect) them and we recostruct them

⇒ **PROCEDURES and METHODS of particle analysis and observation:**

- High energy particle collider, Particle Detectors and Trigger (particle counting) system
- From analog signals (differential of potentials and micro-currents) to digital signals (binary code)
- Very fast algorithms to select, to sort and accept/reject events at the spot (Level 1, High Level Trigger)
- Very sophisticated algorithms of Physics objects reconstructions
- Cut based analysis (`if(){} else(), for(){}`, etj in C++, Python, ...
- Machnine earning techniques and/or neural networks algortihmes for signal to backgrounds discrimination
- Statistical analysis of signal, background and experimental data estimations

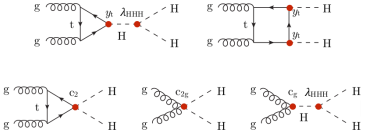
⇒ **VERY IMPORTANT: Physics motivations (THEORY) !!!**

Motivation on the analysis work

$$V = \frac{1}{2} m_H^2 H^2 + \lambda_{HHH} v H^3 + \frac{1}{4} \lambda_{HHHH} H^4, \quad \lambda_{HHH} = \lambda_{HHHH} = \frac{m_H^2}{2v^2} \approx 0.13$$

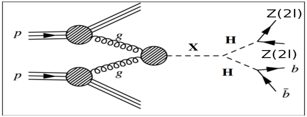
1) Non-resonant double Higgs $HH \rightarrow b\bar{b}ZZ(4l, l = e, \mu)$ production

$$\mathcal{L}_{HH} = \frac{1}{2}\partial_\mu \partial^{mu} h - \frac{1}{2} m_h^2 h^2 - k_\lambda \lambda_{SM} v h^3 - \frac{m_t}{v}\left(v + k_t h + \frac{c_2}{v} hh\right)(\bar{t}_L t_R + h.c.) + \frac{\alpha_s}{12}\left(c_{1g} h - \frac{c_{2g}}{2v} hh\right) G^A_{\mu\nu} G^{A\mu\nu}$$

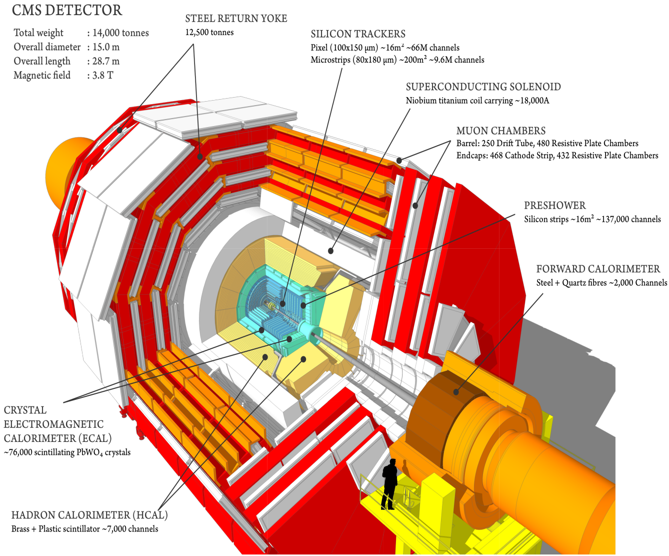


2) Resonant $HH \rightarrow b\bar{b}ZZ(4l, l = e, \mu)$, Analysis Note: CMS AN-21-115
Well-motivated signatures according to several scenarios:

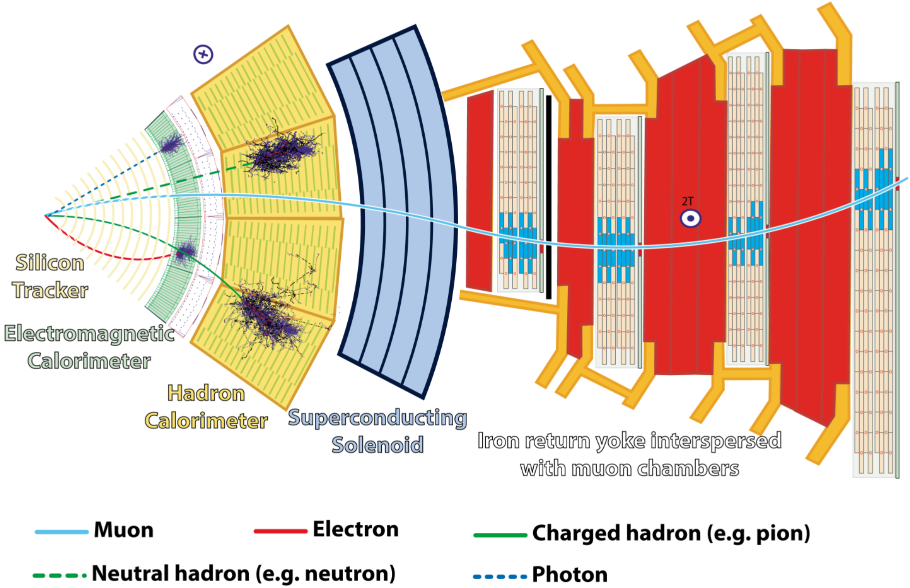
- Looking for a narrow resonance X with a mass m_X using the invariant mass spectrum m_{HH}
- Kaluza-KleinKK graviton (spin-2) and Radion (spin-0)
- Randall-Sundrum warped extra dimension (up to 3TeV!)



The CMS Dectector



Physics object selections



Physics object selections

- Four momentum vector: $p^{\mu} = \{E_0, p_x, p_y, p_z\} \Leftrightarrow p^{\mu} = \{p_T, \eta, \theta, \phi\}$
- Transverse momentum : $p_T = \sqrt{p_x^2 + p_y^2}$
- Pseudorapidity : $\eta = -ln\left[\left(tan\frac{\theta}{2}\right)\right] = arctanh\left(\frac{p_z}{\mid p^{\mu} \mid}\right)$
- Angular separation: $\Delta R = \sqrt{\Delta\theta^2 + \Delta\phi^2}$

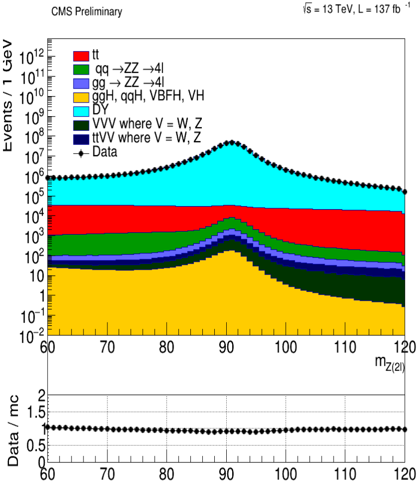
- **Requirement for the leptons :**

	Muon	**Electron**
Loose ID	$p_T > 5$ GeV $\mid \eta \mid < 2.4$ $dxy < 0.5$cm, $dz < 1$cm	$p_T > 7$ GeV $\mid \eta \mid < 2.4$ $dxy < 0.5$cm, $dz < 1$cm
Tight ID	PF muon	MVA (ID + ISO)
ZZ candidate	$\mid SIP_{3D} \mid < 4$	$\mid SIP_{3D} \mid < 4$

- **Requirements for the additional 2b jets:**

	Jets
Tight ID	$p_T > 20$ GeV $\mid \eta \mid < 2.4$ $\Delta R > 0.3$
Categorisation	AK4
b-tagging	DeepCSV

Plots Full RunII ($137 fb^{-1}$): mass Z



Analysis strategy

$\Rightarrow$ The same used as the approved non resonant $HH \rightarrow bb4l$ Analysis HIG-20-004 ;

- $H \Rightarrow b\bar{b}$:
  - We select the two jets with the highest-b tagging score
- $H \Rightarrow ZZ(4l, l = e, \mu)$ (the same as the HZZ4l HIG-19-001):

1)Leptonic Z-boson as lepton pairs:

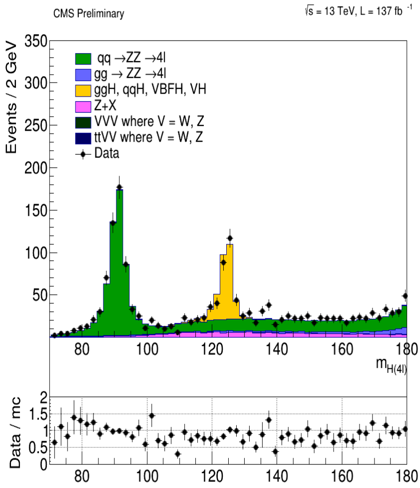
- Opposite charge, same flavour $(\mu^+\mu^-, e^-e^+)$ and mass restriction $12 < m_{Z_{ll}} < 120 GeV$

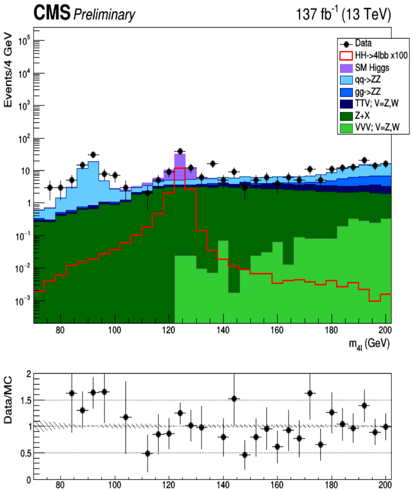
2) ZZ- boson pair as Z_1 (on-mass shell) and Z_2 (off-mass shell):

- $m_{Z_1} > 40$ GeV
- $p_T(l_1) > 20 GeV$ and $p_T(l_2) > 10$ GeV
- $\Delta R > 0.02$ for 4 leptons
- QCD supression for lepton pairs with $m_{ll} > 4 GeV$ for the opposite-charge lepton pairs
- $m_{4l} > 70 GeV$
- In case of more than one ZZ candidate $\rightarrow$ those with the highest value of $\sum p_T(l^- l^+)$

- **Signal region** HH**:** $\mid mass_{4l} - 125.09 \mid < 10$ **&&** $2jets$

Plots Full RunII ($137 fb^{-1}$): mass 4l

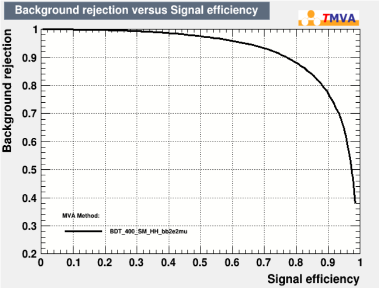


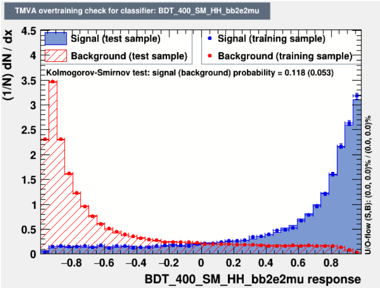


TMVA using Bosted Decision Tree (BDT)

- $H \to 4l$ full selection
- $\mid m_{4l} - 125 \mid < 10$ GeV
- at least 2 jets in the event and if more then 2, the those with the highest b-disc. jet value

Rank	Variable	Variable Importance
1	ΔR_{HH}	15.47 %
2	b-disc. jet1	13.19 %
3	$m_{H(jj)}$	12.22 %
4	b-disc. jet2	9.882 %
5	$p_{T(jet_2)}$	9.618 %
6	$p_{T(l_1)}$	9.299 %
7	$p_{T(jet_1)}$	9.102 %
8	$p_{T(l_2)}$	7.717 %
9	$p_{T(l_3)}$	7.006 %
10	$p_{T(l_4)}$	6.491 %

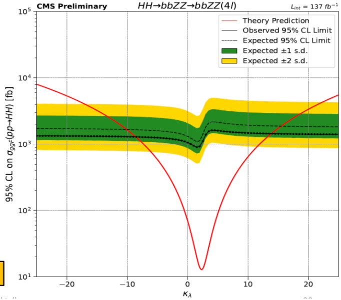




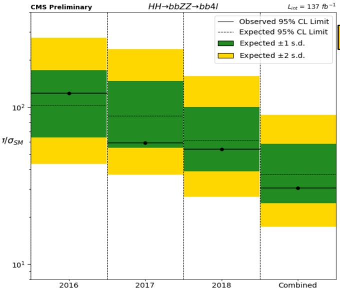
Upper limits on different hypotheses of k_λ
Results extracted following the procedure explained here:
https://indico.cern.ch/event/904966/contributions/3832774/attachments/2023843/3384862/HH_combine_model_21Apr2018.pdf

Observed (expected) constraints on k_λ at 95% CL:

$$-9\ (-10.5) < k_\lambda < 14\ (15.5)$$



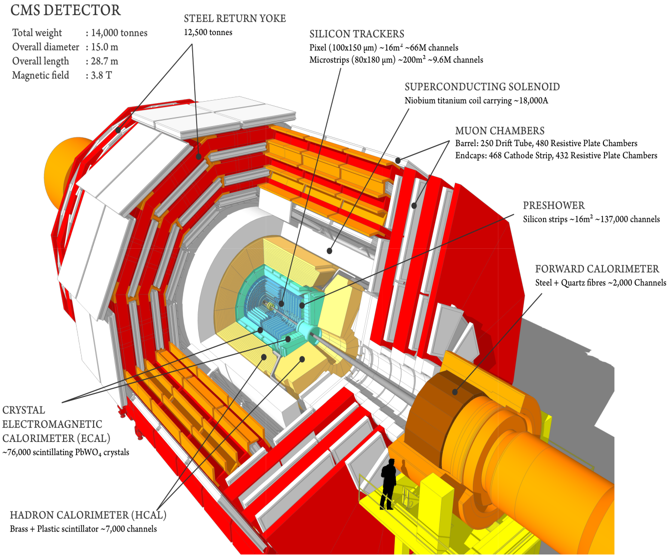
PAS



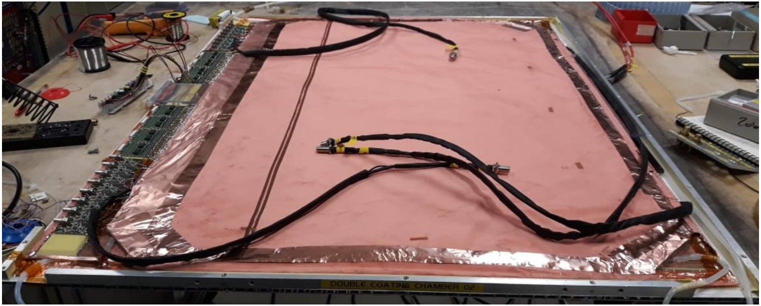
PAS

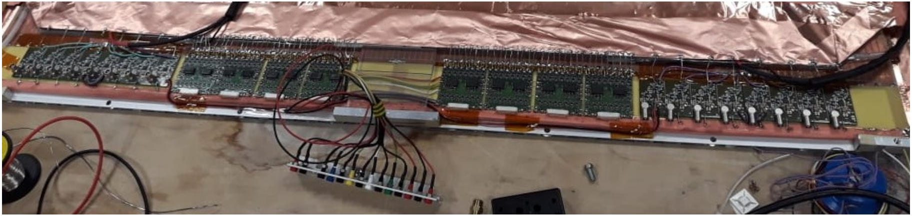
	UL @95% CL Obs (Exp)
2016	122 (102)
2017	59 (88)
2018	53 (61)
Comb	**30 (37)**

The CMS Dectector

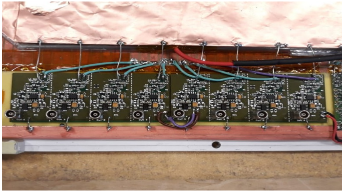


Muon system: Resistive Plate Chambers (RPC)





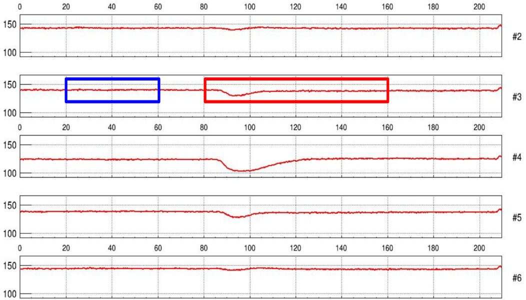
1) Eight Custom ASIC discriminators with eight channels each in the center; 2) Two fast charge pre-amplifiers with four channels (right and left)



$\Rightarrow$ Fast timing pre-amplifiers mounted on strips:

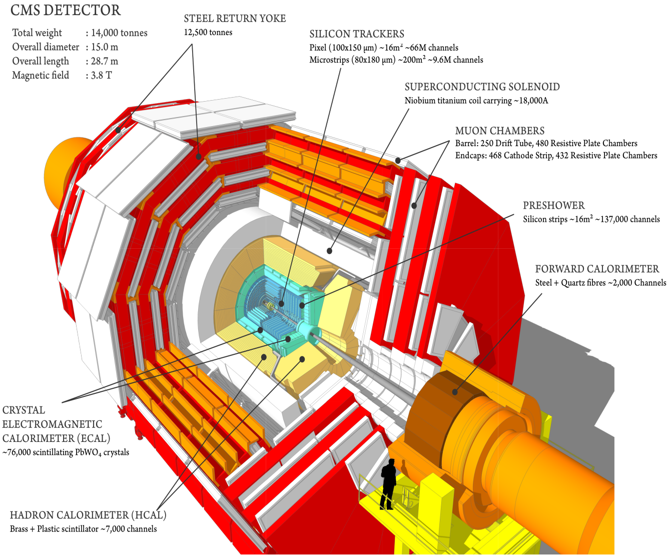
- 8 on low ($50k\Omega$) resistivity graphite region, 8 on high ($600k\Omega$) resistivity graphite region
- amplification voltage applied 2.5 V (high ampl.)

• Analog signals directly read by CAEN digitizer: direct analysis of pulse shape

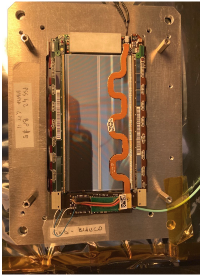


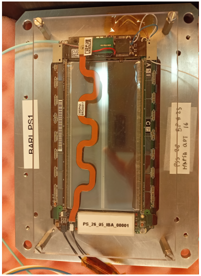
Blue box: Noise window; Red Box: Muon

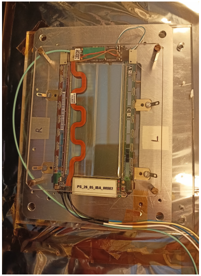
The CMS Dectector

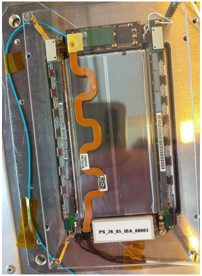


The CMS Tracker Phase2: Pixel-Strip (PS) modules



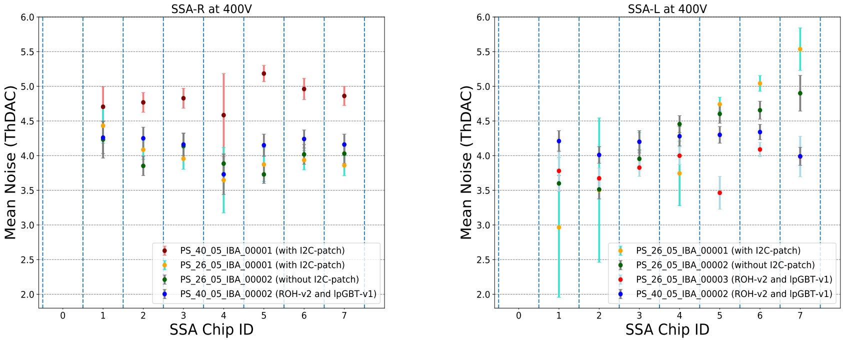






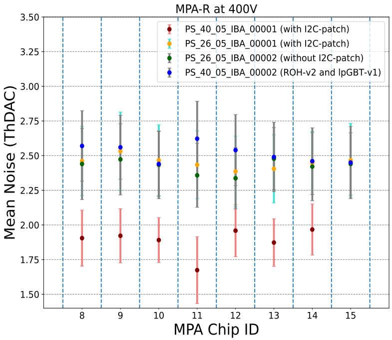
Module	PS_40_05_IBA_00001	PS_26_05_IBA_00001	PS_26_05_IBA_00002	PS_26_05_IBA_00003
ROH	PSROH40-20100036 lpGBT-v0, (**I2C patch done**)	PSROH26-20100024 lpGBT-v0 (**I2C patch included**)	PSROH26-20100026 lpGBT-v0 (**I2C patch not needed !**)	CMSOH2-BRD00528 (V2) lpGBT-v1 (**no I2C patch**)
POH	PSPOH-301000011 (REMOTE SENSING 1V25)	PSPOH-301000012 (REMOTE SENSING)	PSPOH-301000026	PSPOH-301000003 REMOTE SENSING
FEH-L	PSFEH40L-201000055 CIC1, SSA1, MPA1	PSFEH26L-301000005 CIC1, SSA1, MPA1	PSFEH26L-301000007 CIC1, SSA1, MPA1	PSFEH26L-201000040 CIC1, SSA1, MPA1
FEH-R	PSFEH40R-201000081 CIC1, SSA1, MPA1	PSFEH26R-201000075 CIC1, SSA1, MPA1	PSFEH26R-201000072 CIC1, SSA1, MPA1	PSFEH26R-201000067 CIC1, SSA1, MPA1
MaPSA	QPT no 11	QPT no 16	QPT no 37-1	QPT no 20 p 1
PSS SENSOR	HPK VPX33234-042_PSS_MAINB	HPK VPX33234-028_PSS_MAINB	HPK VPX33234-037_PSS_MAINB	HPK VPX33234-031_PSS_MAINB

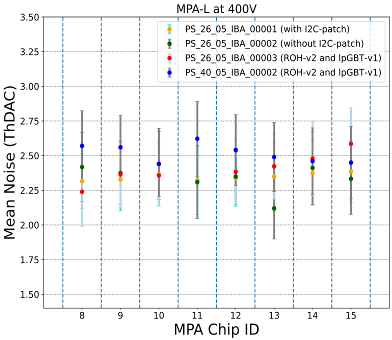
SSA Noise Values comparisions at HV=400V



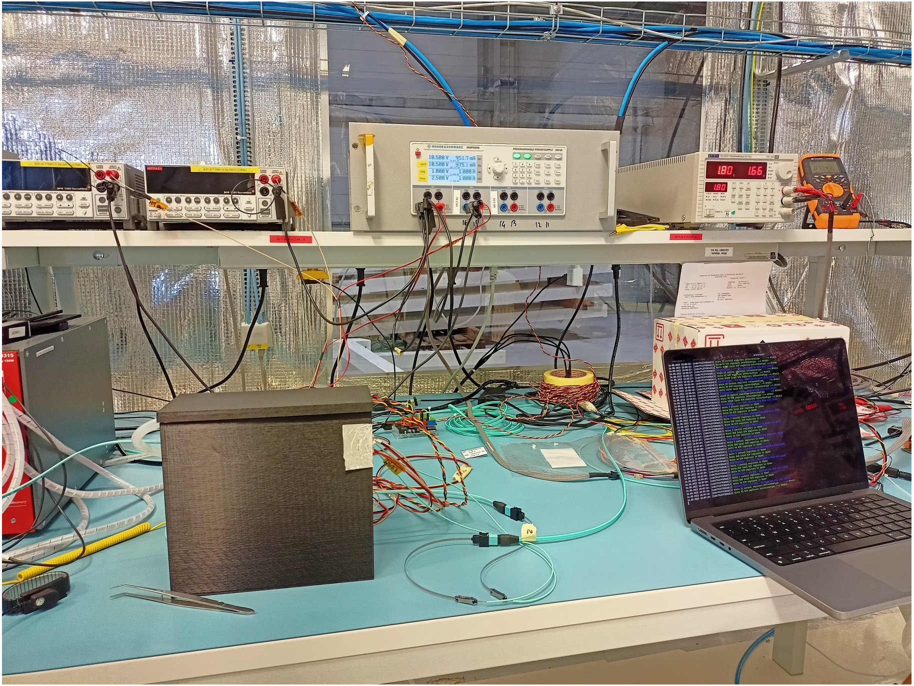
Module	**PS_40_05_IBA_00001**	**PS_26_05_IBA_00001**	**PS_26_05_IBA_00002**	**PS_26_05_IBA_00003**
Mean noise value SSA-R at 400V	4.69±0.32 Vcth	3.997±0.34 Vcth	3.923±0.29 Vcth	None
Mean noise value SSA-L at 400V	left side not working	4.247±1.03 Vcth	4.12±0.54 Vcth	3.832±0.2861 Vcth
Leakage current I_{leak} at 20°C	$\sim$ 4.5 μA	$\sim$ 7.5 μA	$\sim$ 3.8 μA	$\sim$ 1.88 μA
Noise strips $\geq$ 10 Vcth	None	None	None	None

MPA Noise Values comparisions at HV=400V



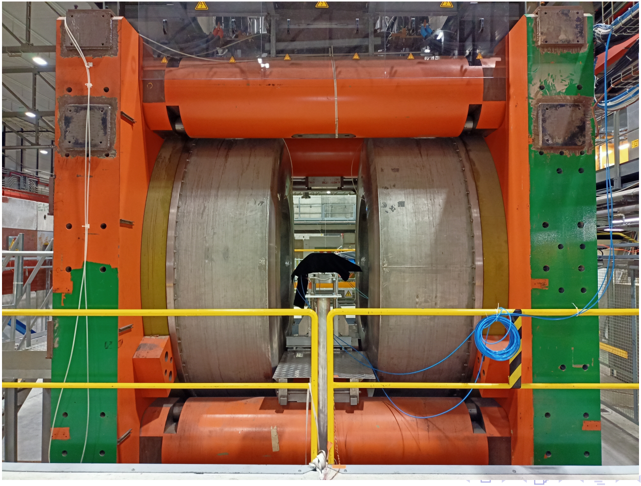


Module	**PS_40_05_IBA_00001**	**PS_26_05_IBA_00001**	**PS_26_05_IBA_00002**	**PS_26_05_IBA_00003**
Mean noise value MPA-R at 400V	1.84±0.21 Vcth	2.42±0.24 Vcth	2.45±0.26 Vcth	None
Mean noise value MPA-L at 400V	left side not working	2.35±0.26 Vcth	2.35±0.23 Vcth	2.40±0.26 Vcth
Leakage current I_{leak} at 20°C	$\sim$ 4.5 μA	$\sim$ 7.5 μA	$\sim$ 3.8 μA	$\sim$ 1.88 μA
Noise strips $\geq$ 10 Vcth	None	None	None	None

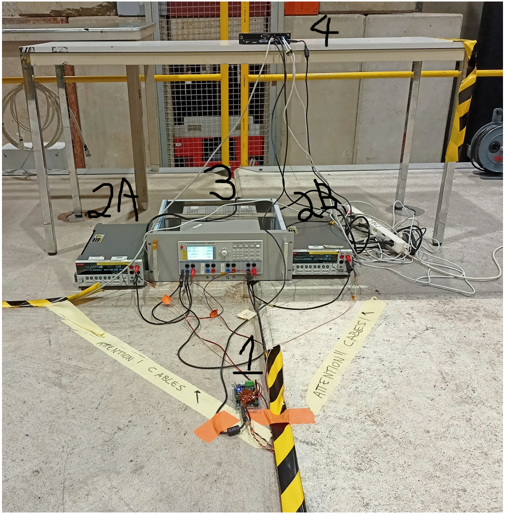


The M1 Magnet in the CERN north area

- The box with the modules was positioned in the center of the superconducting M1 magnet
- Helmholtz-type with 1.4 m bore
- 82 cm distance between cryostats for superconductiong coils
- Maximal field at 3 T, perpendicular to the beam direction in H2 line of the CERN-SPS accelerator
- It operates with a DC current up to 4×10^3 A
- Maximal stored energy of 56 MJ

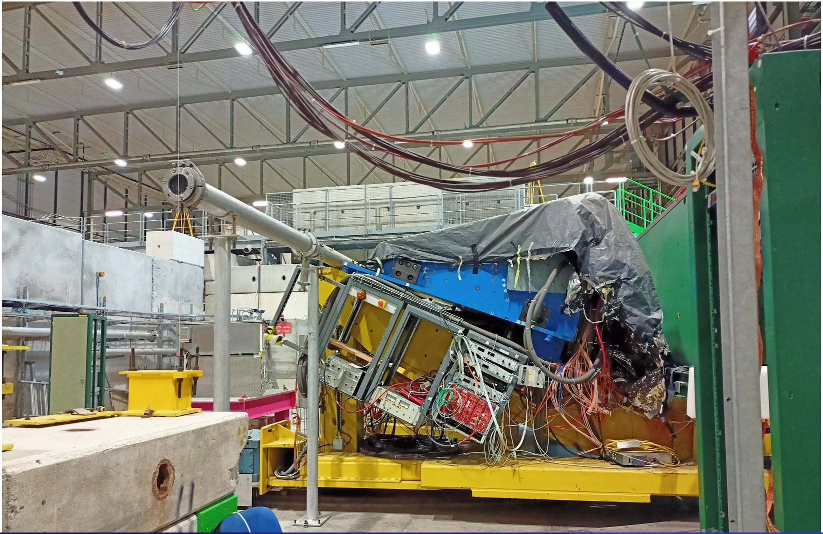


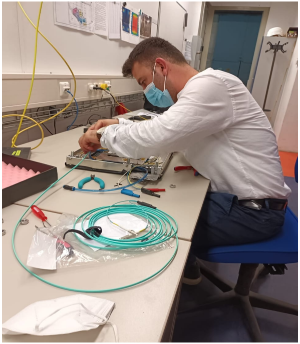
- 1) The ARDUINO for temperature and humidity measurements and monitoring
- 2a) HV power supply for the **PS_26_05_IBA_00002** module
- 2b) HV power supply for the **PS_16_05_FNL_00001** module
- 3) LV power supply for both modules
- 4) Mini pc for the controll and monitoring of the devices

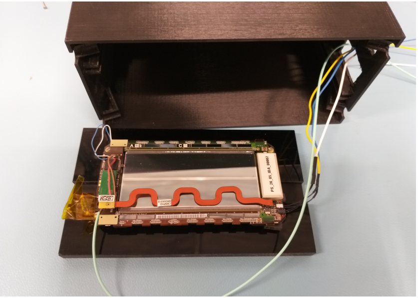


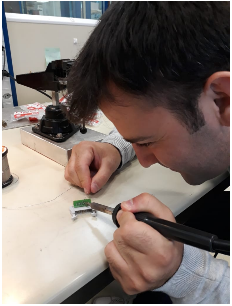
The SPS beam at the H2/NA64 test beam area

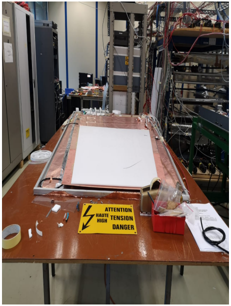
- The particle beam "cannon": Pions at 180 GeV with 4s-5s spills up to 3000 trigger events per spill.

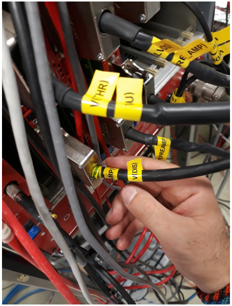


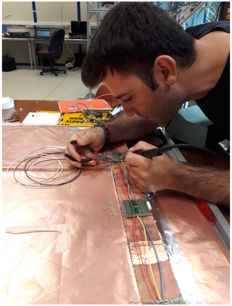



PS_26_05_IBA_00002




ATTENTION
HAUTE TENSION
HIGH
DANGER





Conclusions

- The CMS experiments provides a large range of scientific reasearch opportunities
- It is a team work environment
- All countries, all religions, all people working together
- We stay tunded with the latest ideas
- A great opportunity to grow, specially for the students

JU FALEMINDERIT!