



RECENT RESULTS FROM THE
CMS EXPERIMENT

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10/07/2020

REUNIÓN ANUAL

DIVISIÓN DE PARTÍCULAS Y CAMPOS DE LA SMF

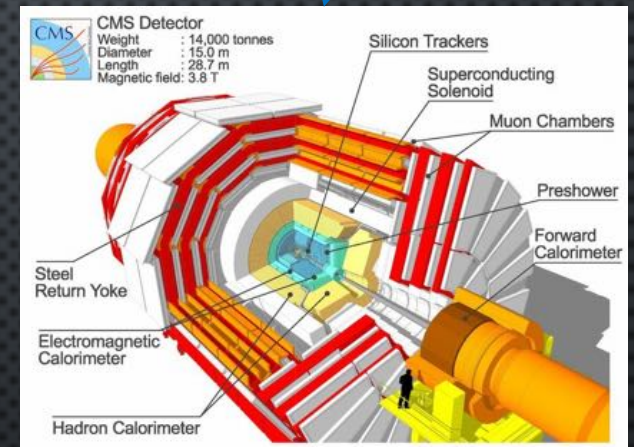
[HTTPS://INDICO.NUCLEARES.UNAM.MX/EVENT/1546/](https://indico.nucleares.unam.mx/event/1546/)





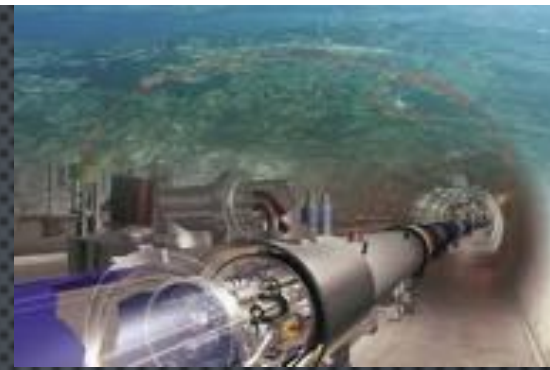
OUTLINE

- LHC STATUS AND LUMINOSITY
- CMS PUBLICATIONS
- A FEW SELECTED RESULTS IN:
 - OBJECT RECONSTRUCTION
 - ELECTROWEAK
 - TOP PHYSICS
 - SUSY/EXOTICA
- CMS DETECTOR UPGRADES
- SUMMARY



This talk gives an overview of the recent activities in CMS. A small sample of recent results in each area is presented.

LHC STATUS



We are here



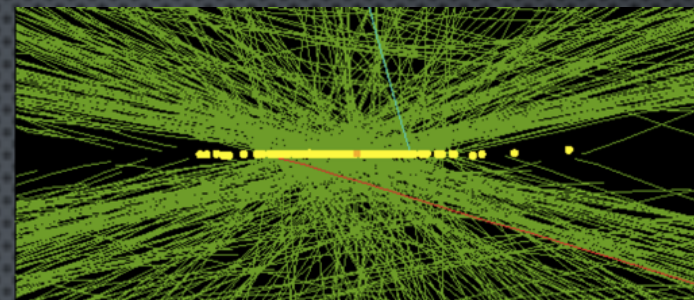
LHC / HL-LHC Plan



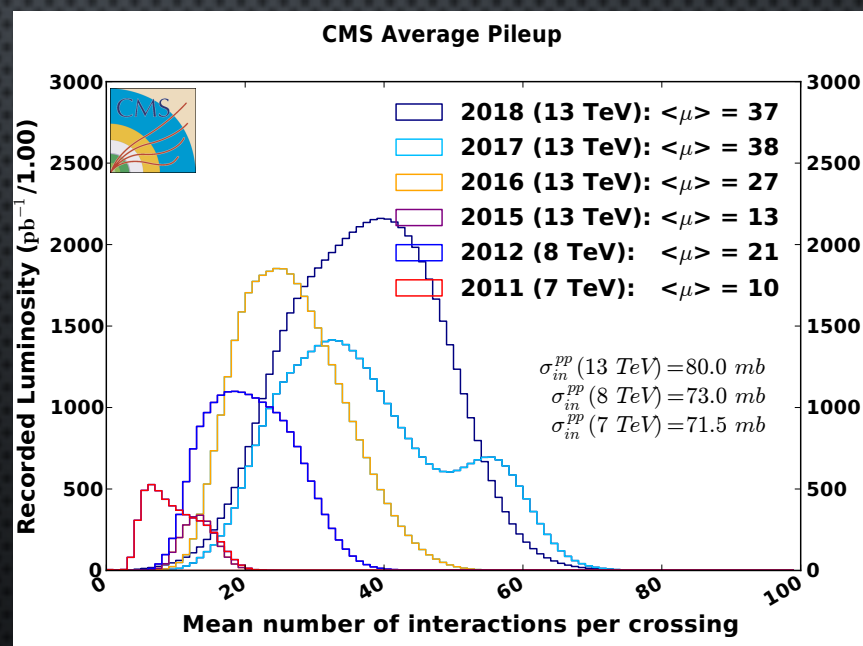
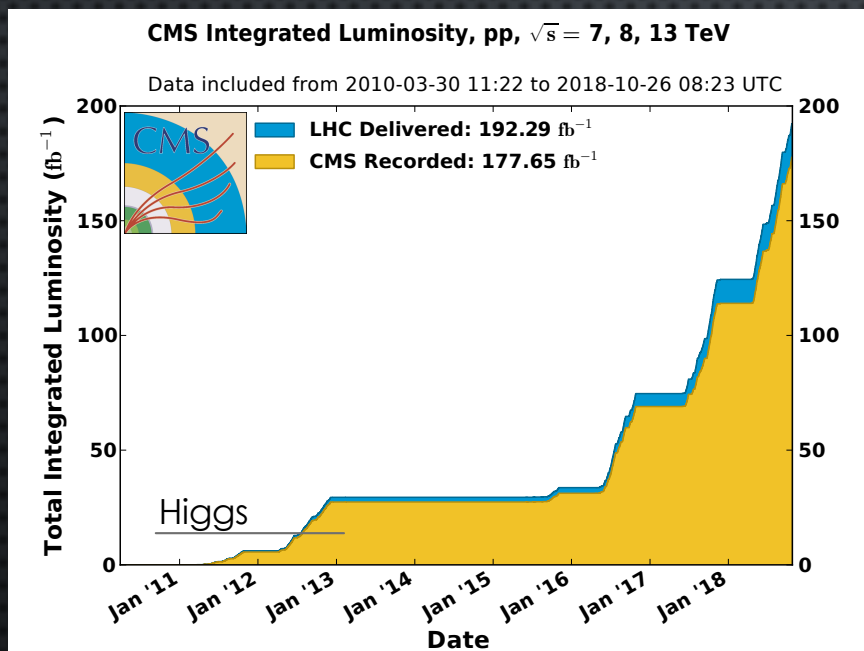
- RUN 2 OF THE LHC PROGRAM COMPLETED IN 2018.
- LONG SHUTDOWN 2 ONGOING: LHC AND CMS PHASE 1 UPGRADES
- DUE TO COVID-19 DELAYS, NO PHYSICS RUNS EXPECTED DURING 2021

[CERN-2017-007-M](#)

INTEGRATED LUMINOSITY



- With the 2018 dataset, CMS and ATLAS accumulated ~ 15 times the dataset used for the discovery of the Higgs boson in 2012
- The instantaneous luminosity (reflected in the pile-up) is now ~ 2 times the design value.



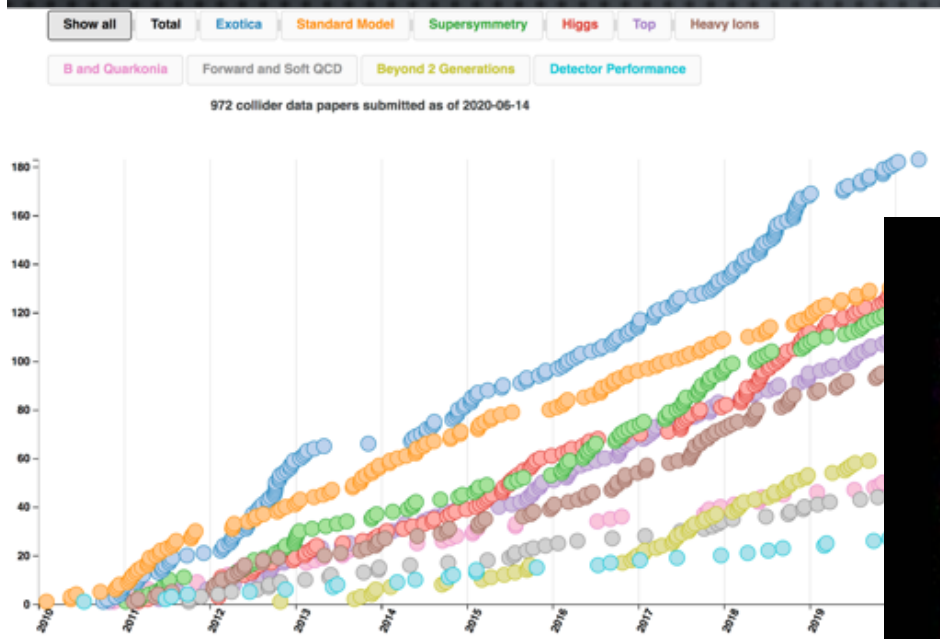
[HTTPS://TWIKI.CERN.CH/TWIKI/BIN/VIEW/CMSPUBLIC/LUMIPUBLICRESULTS#MULTI_YEAR_PLOTS](https://twiki.cern.ch/twiki/bin/view/CMSPUBLIC/LUMIPUBLICRESULTS#MULTI_YEAR_PLOTS)

“ON FRIDAY 19 JUNE 2020, SCIENTISTS AT THE CMS EXPERIMENT AT CERN'S LARGE HADRON COLLIDER SUBMITTED THEIR 1,000TH PAPER. THIS MONUMENTAL ACHIEVEMENT REFLECTS AN OUTSTANDING CONTRIBUTION TO HUMANITY'S UNDERSTANDING OF THE UNIVERSE — AND IT'S JUST THE BEGINNING.”

<https://cms.cern/news/cms-collaboration-celebrates-1000th-paper>

Similar number of papers by ATLAS:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome#papers_table

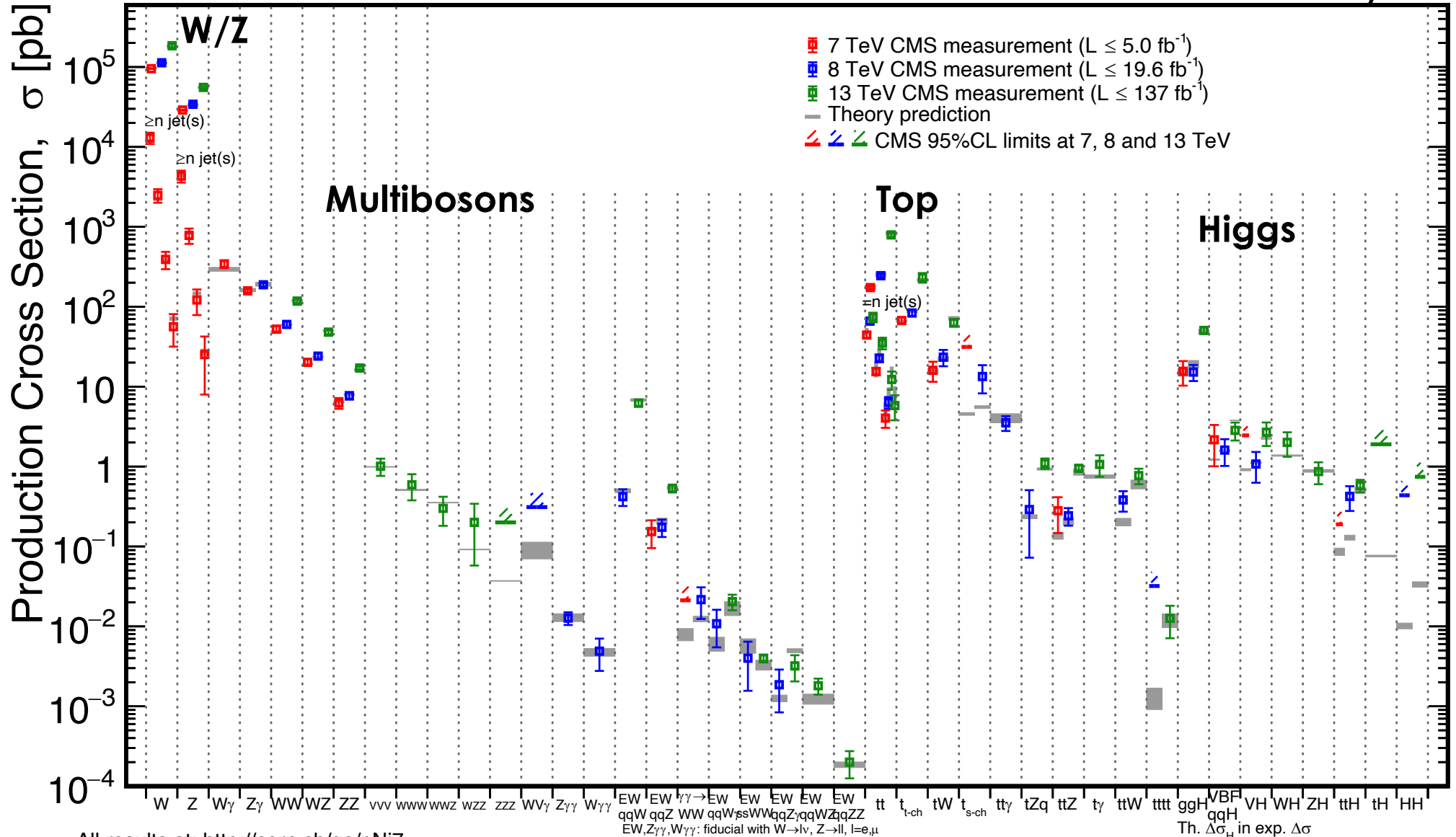


SM PROCESSES MEASURED AT THE LHC

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined>

May 2020

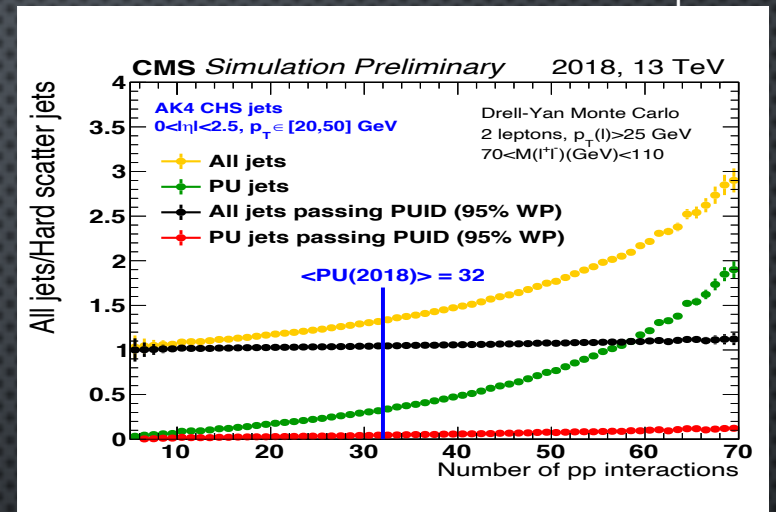
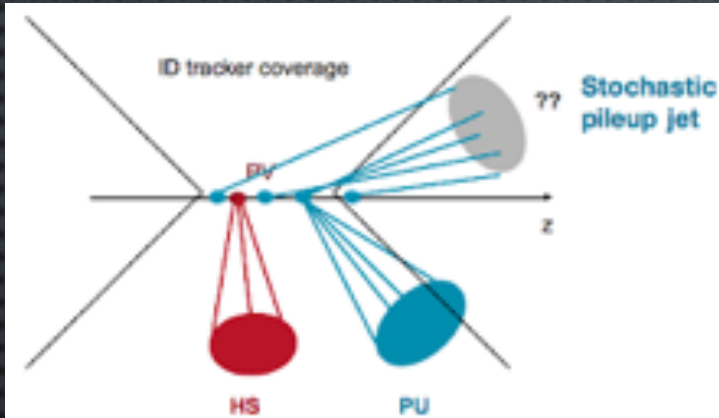
CMS Preliminary



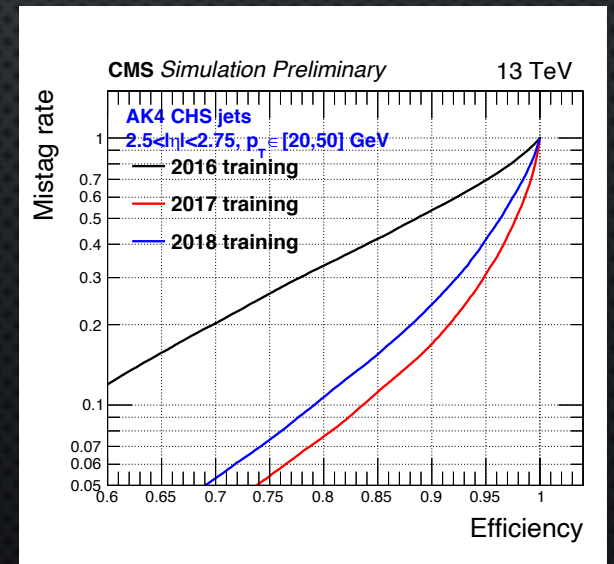
OBJECT RECONSTRUCTION

PERFORMANCE OF THE PILE-UP JET IDENTIFICATION IN CMS FOR RUN 2

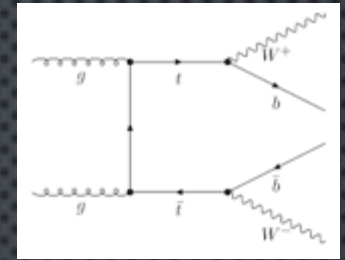
Z → l+l MC sample



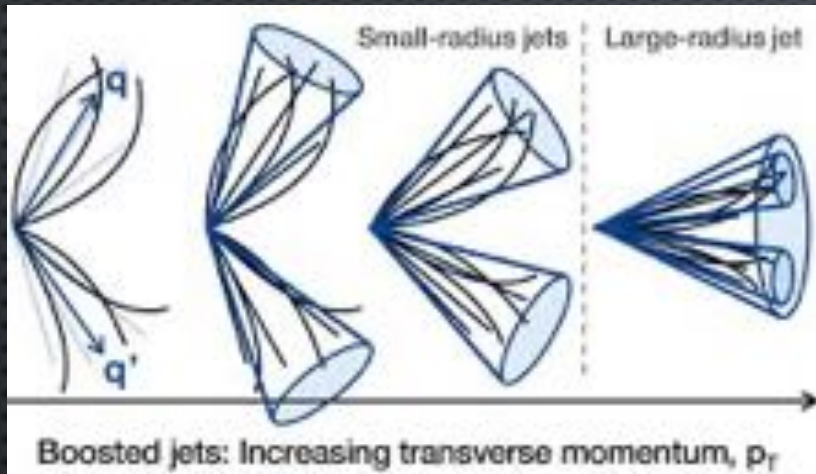
- PILE UP JETS ARISE FROM PROTON COLLISIONS OTHER THAN THE INTERESTING ONE “HS”. PU JETS CAN BE REAL OR STOCHASTIC (FROM RANDOM ENERGY DEPOSITS)
- INCREASE THE BACKGROUND NOISE FOR MOST MEASUREMENTS AND DEGRADE ENERGY RESOLUTION FOR SIGNAL.
- LARGE IMPROVEMENT IN FORWARD REGION ACCOMPLISHED LARGELY PHASE 1 UPGRADE OF PIXEL TRACKER INSTALLED IN 2016-2017 TECHNICAL STOP



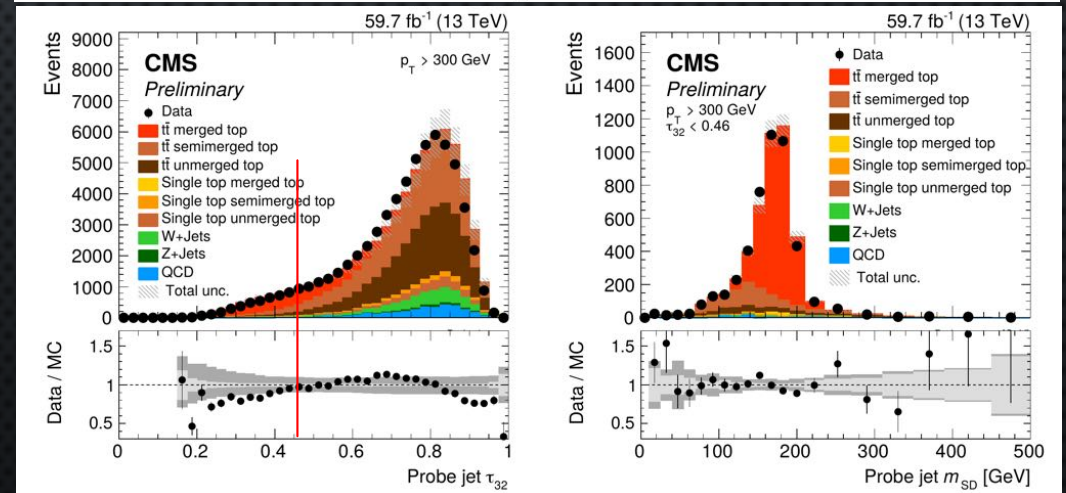
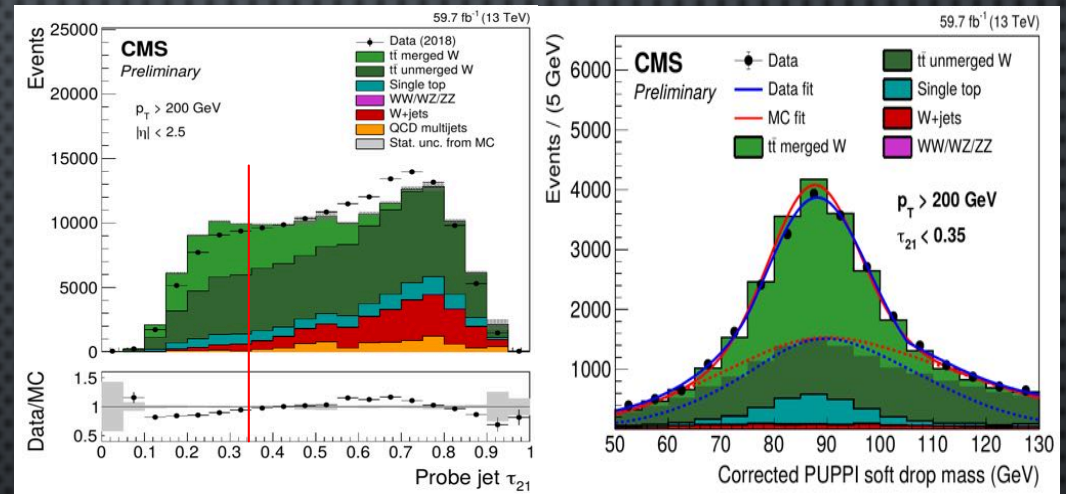
LARGE-R JET TAGGING (W & TOP)



Data from a t-tbar tagged sample

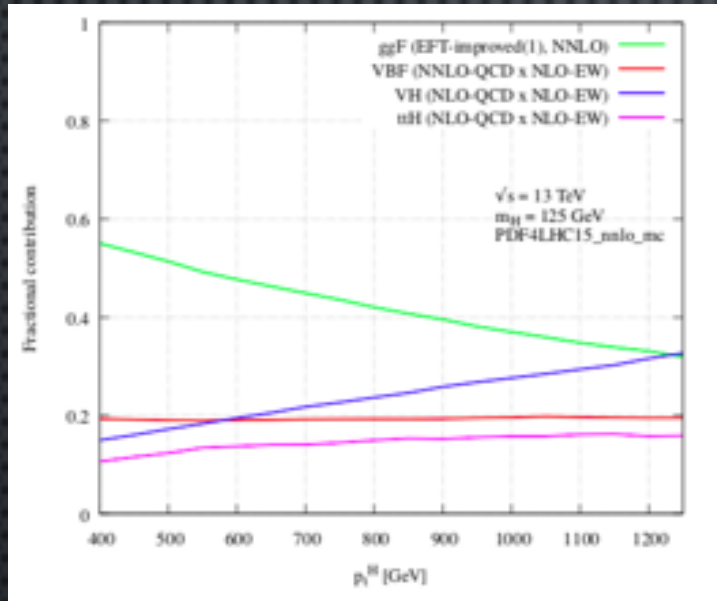
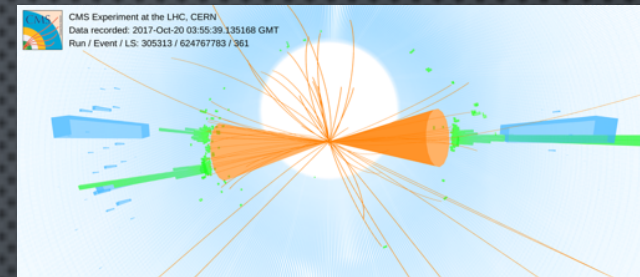


- ALGORITHM FOR THE RECONSTRUCTION OF BOOSTED W AND TOP
- JETS RECONSTRUCTED WITH LARGE RADIUS (R=0.8) PARAMETER ARE TAGGED AS MERGED W OR TOP USING THE "N-SUBJETTINESS" VARIABLE τ_{21} OR τ_{32}
- THE NOTE PRESENTS DATA-TO-SIMULATION SCALE FACTORS USED IN THE IDENTIFICATION OF HADRONICALLY DECAYING TOP QUARKS AND W BOSONS USING THE FULL RUN 2 DATASET,

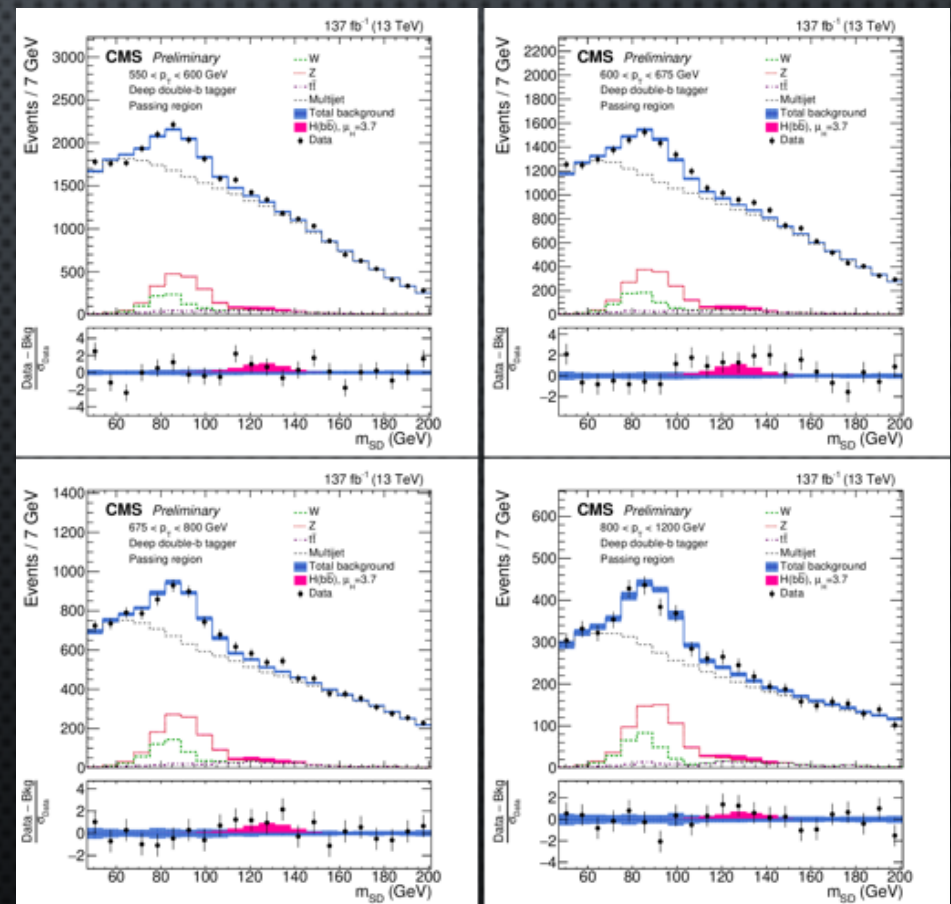


ELECTROWEAK

BOOSTED HIGGS SEARCH



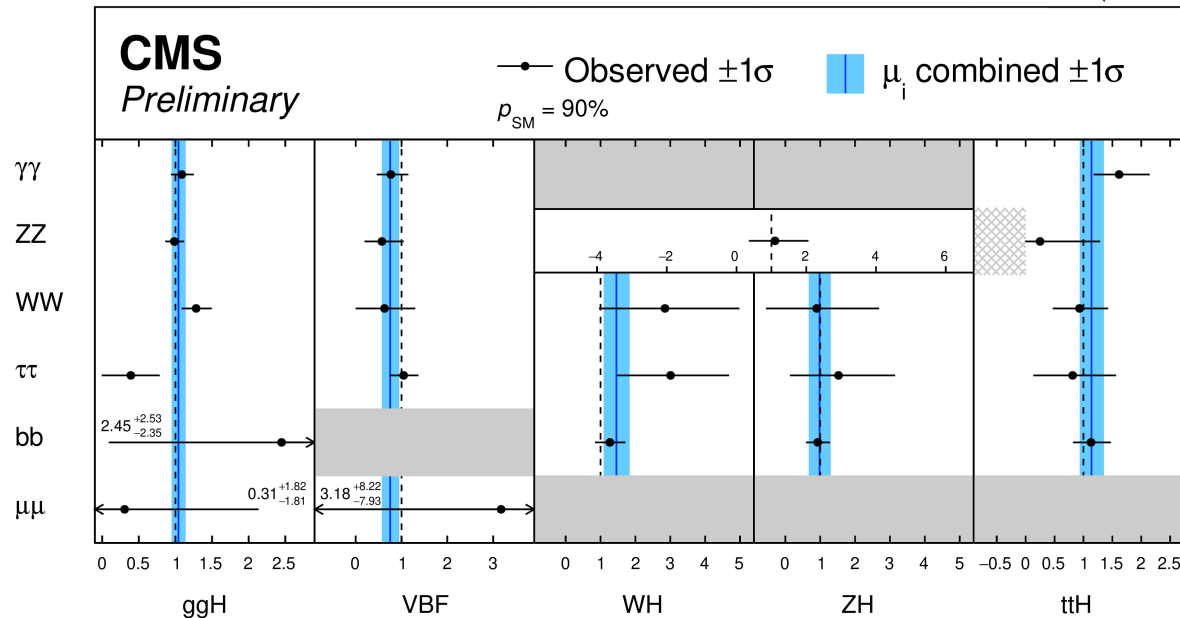
- NOVEL WAY TO UNDERSTAND NATURE OF HIGGS PRODUCTION AT VERY LARGE MOMENTUM WHERE PRODUCTION MODES ARE SIMILAR
- THE ANALYSIS USES LARGE-R JET TAGGING AND EXTRACTS SIGNAL STRENGTH IN BINS OF p_T
- THE SIGNAL STRENGTH MEASURED HAS A TOTAL SIGNIFICANCE OF ONLY 2.5 SIGMA



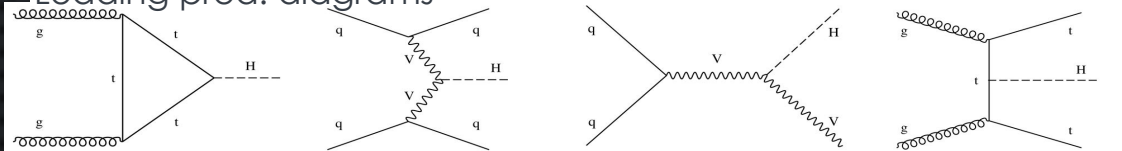
COMBINED HIGGS PRODUCTION AND DECAY MEASUREMENTS

Signal strengths

35.9-137 fb⁻¹ (13 TeV)



Leading prod. diagrams



μ_i^f

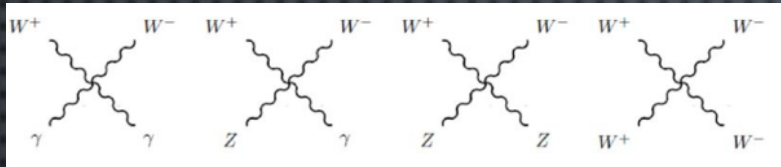
Global fit

Coupling modifiers κ_i

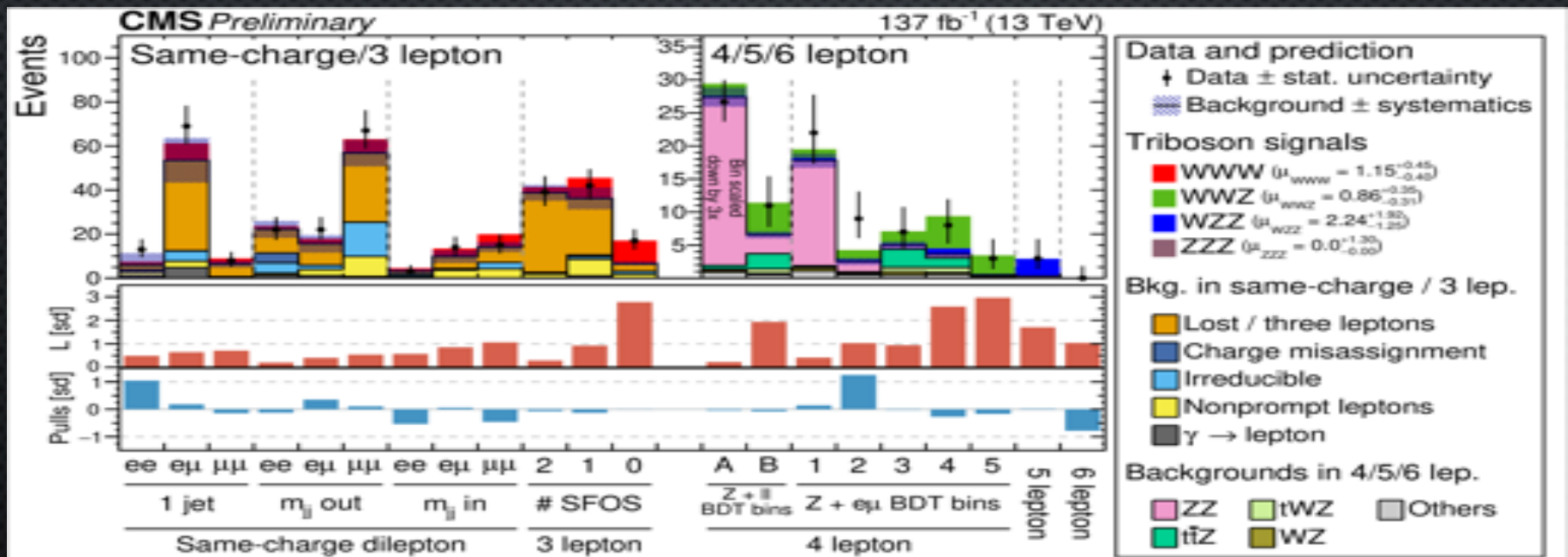
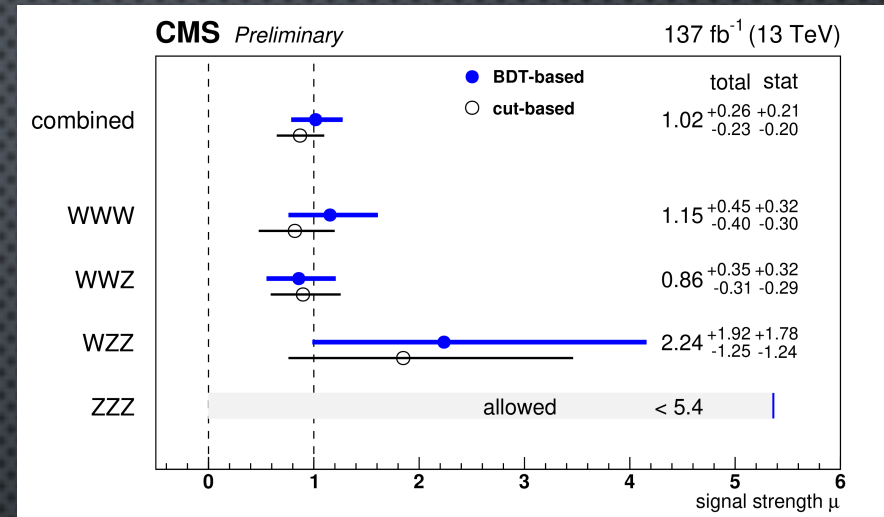
Parameters	Best-fit	Uncertainty	
		Stat.	Syst.
κ_Z	0.96 ^{+0.07} _{-0.07}	+0.06 -0.06	+0.04 -0.05
κ_W	-1.11 ^{+0.14} _{-0.09}	+0.13 -0.07	+0.05 -0.06
κ_t	1.01 ^{+0.11} _{-0.11}	+0.06 -0.06	+0.09 -0.08
κ_τ	0.94 ^{+0.12} _{-0.12}	+0.08 -0.11	+0.09 -0.06
κ_b	1.18 ^{+0.19} _{-0.27}	+0.14 -0.13	+0.13 -0.24
κ_g	1.16 ^{+0.12} _{-0.11}	+0.08 -0.08	+0.08 -0.08
κ_γ	1.01 ^{+0.09} _{-0.14}	+0.07 -0.07	+0.06 -0.12
κ_μ	0.92 ^{+0.55} _{-0.87}	+0.54 -0.87	+0.10 -0.01

- COMBINED MEASUREMENTS OF THE PRODUCTION AND DECAY RATES OF THE HIGGS BOSON, ITS COUPLINGS TO VECTOR BOSONS AND FERMIONS.
- DATA CORRESPONDS TO AN INTEGRATED LUMINOSITY OF UP TO 137/FB, DEPENDING ON THE DECAY CHANNEL.
- ALL RESULTS ARE FOUND TO BE COMPATIBLE WITH THE STANDARD MODEL WITHIN THE CURRENT UNCERTAINTIES.

HEAVY TRIBOSON PRODUCTION

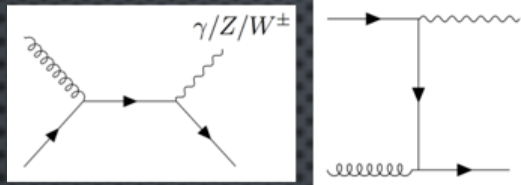


- RARE PROCESSES PROBING THE QUARTIC GAUGE COUPLINGS OF THE SM
- EVENTS RECONSTRUCTED USING 2-6 E/MU LEPTONS
- THE OBSERVED SIGNIFICANCES ARE
 $WWW : 3.3$, $WWZ : 3.4$, AND $WZZ : 1.7$
 WITH A COMBINED VALUE OF 5.7 SIGMA

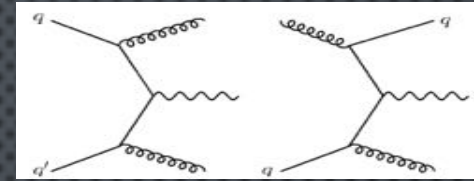


Z+JETS AND γ +JETS DIFFERENTIAL CROSS SECTIONS

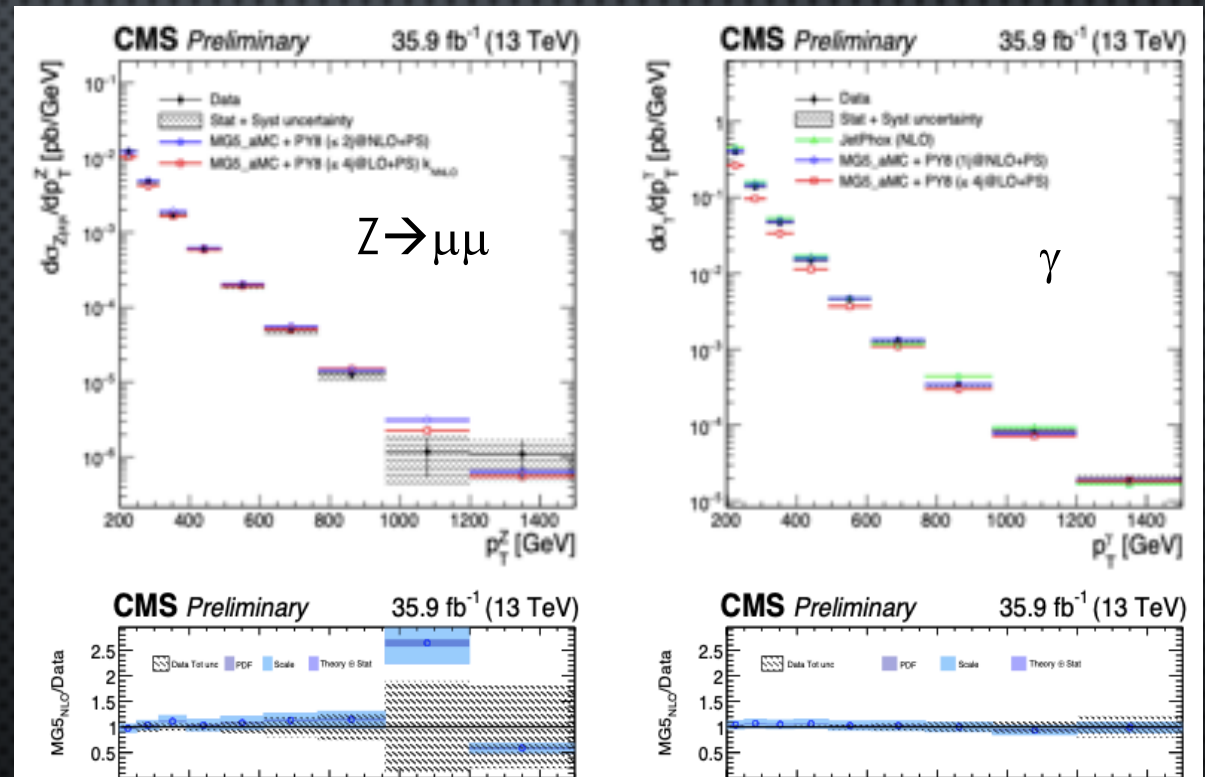
Z/ γ +jet



Z/ γ +2jet



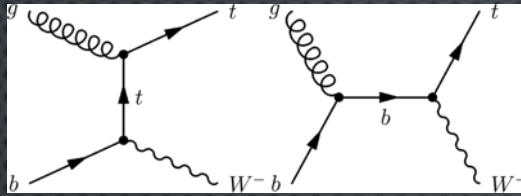
- **PRECISION TESTS** OF PERTURBATIVE QCD AND EW CALCULATIONS, AS IMPLEMENTED IN STATE-OF-THE-ART MC EVENT GENERATORS.
- ELUCIDATE OUR UNDERSTANDING OF THE SM IN THE REGION OF HIGH BOSON P_T ,



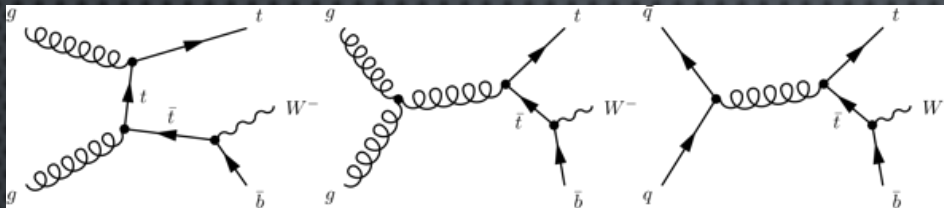
TOP PHYSICS

DIFFERENTIAL CROSS SECTIONS FOR TOP+W PRODUCTION

tW

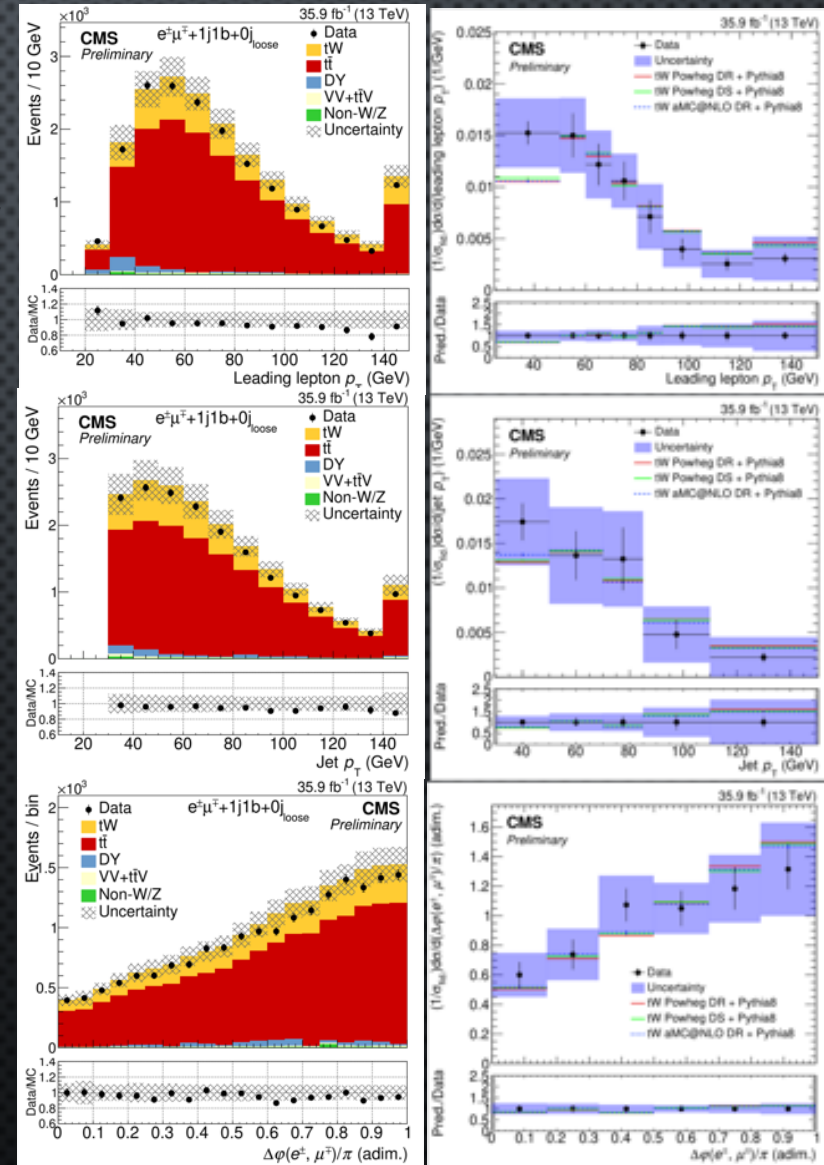


t-tbar



Measured: events, cross-section

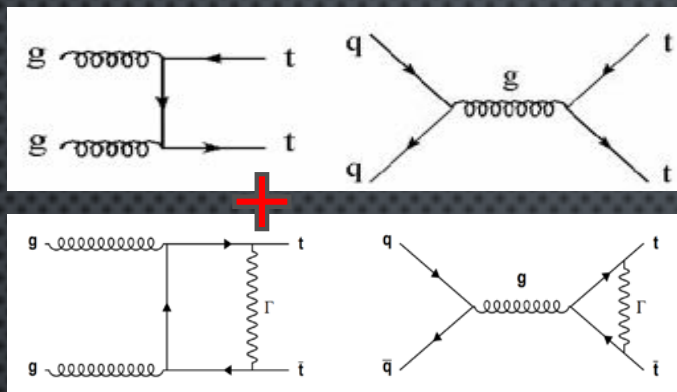
- "tW PROVIDES A UNIQUE OPPORTUNITY TO UNDERSTAND THE SM AND ITS EXTENSIONS THROUGH THE INTERFERENCE OF THE PROCESS AT NEXT-TO-LEADING ORDER (NLO) WITH TOP PAIR PRODUCTION, IT ALSO PLAYS AN IMPORTANT ROLE IN PHYSICS BEYOND THE SM."
- EVENTS CONTAINING ONE MUON, ONE ELECTRON, AND ONE B-JET ARE ANALYZED
- THE PRODUCTION CROSS-SECTION IS MEASURED AS A FUNCTION OF LEADING LEPTON PT, JET PT AND DPHI(E,MU)



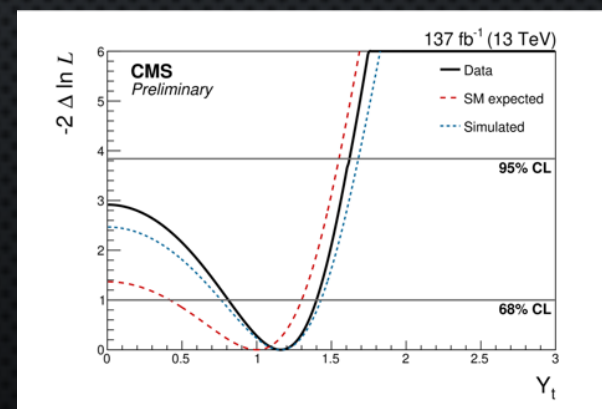
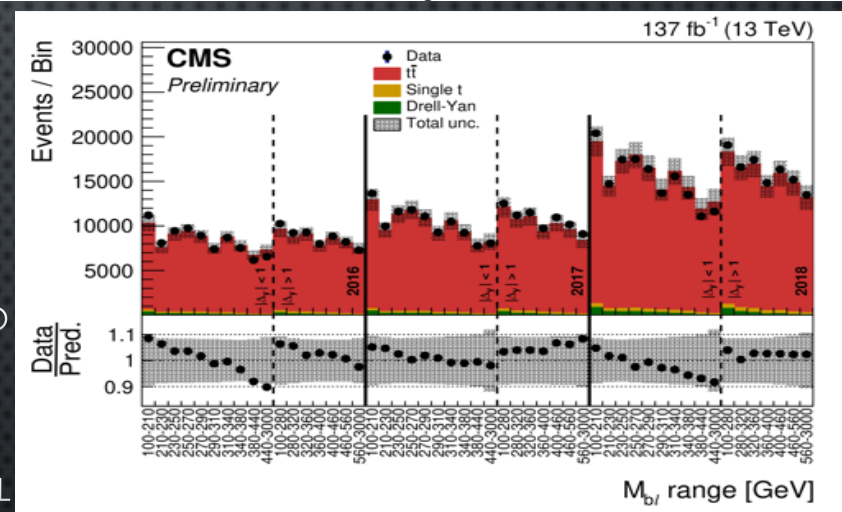
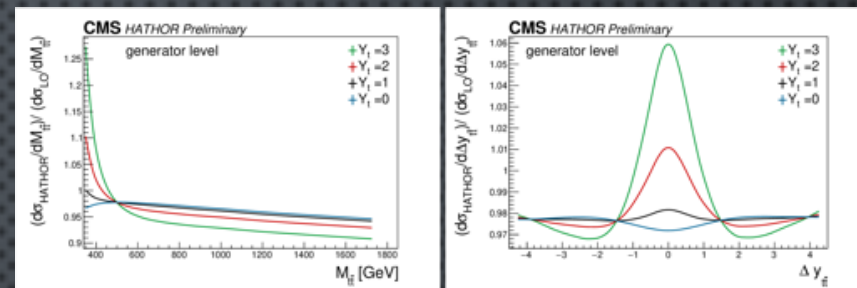
Number of leptons	≥ 2
$p_T(\ell_1)$	$> 25 \text{ GeV}$
$m_{e\mu}$	$> 20 \text{ GeV}$
Number of jets	1
Number of loose jets	0
Number of b jets	1

TOP YUKAWA FROM KINEMATIC DISTRIBUTIONS

Interference in the t-tbar production diagrams modifies the kinematic distributions depending on the coupling to the exchanged boson.

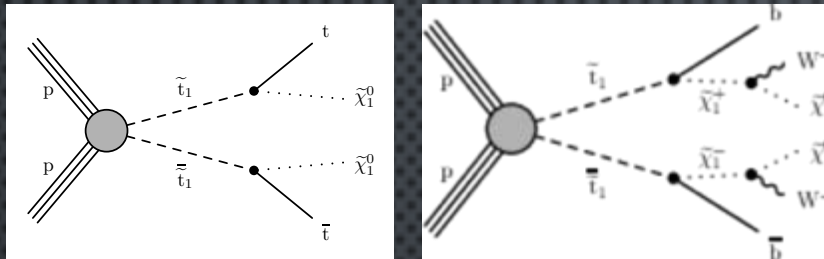


- AN INDIRECT MEASUREMENT OF THE HIGGS YUKAWA COUPLING TO THE TOP QUARK Y_T IS PRESENTED.
- SENSITIVITY TO THE YUKAWA COUPLING ORIGINATES FROM ALTERED DISTRIBUTIONS OF T-TBAR PRODUCTION IN THE PRESENCE OF VIRTUAL HIGGS BOSON EXCHANGE.
- ANALYZE KINEMATIC DISTRIBUTIONS IN T-TBAR PRODUCTION FINAL STATES CONTAINING EE, MM, OR EM PAIRS.
- THE MEASUREMENT YIELDS A BEST-FIT VALUE OF $Y_T = 1.16^{+0.24}_{-0.35}$

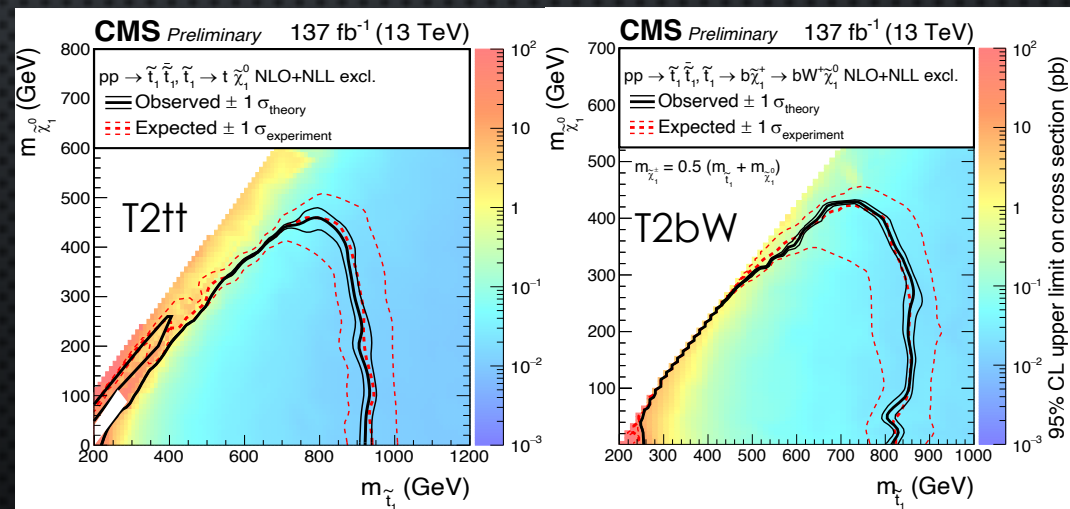
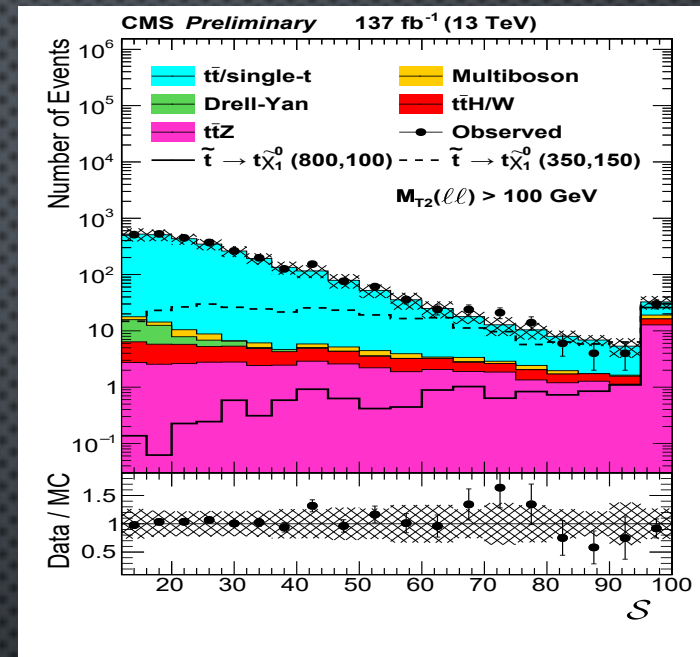


SUSY & EXOTICA

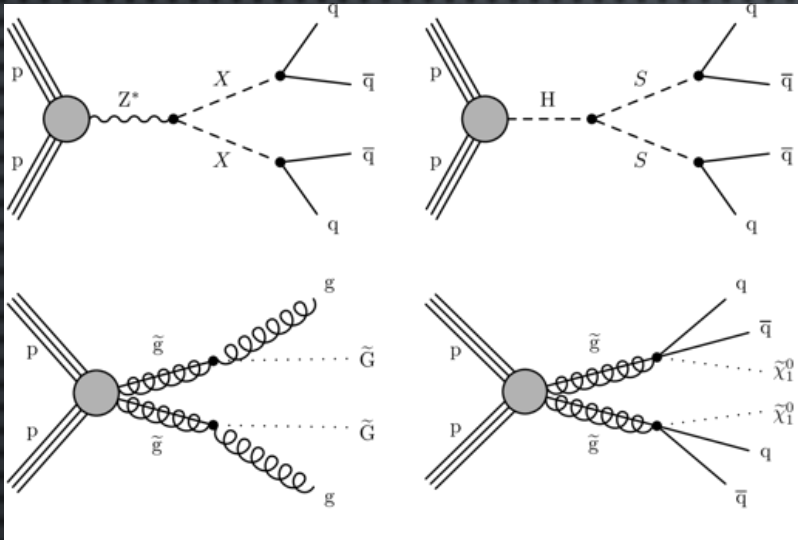
STOP PAIR PRODUCTION



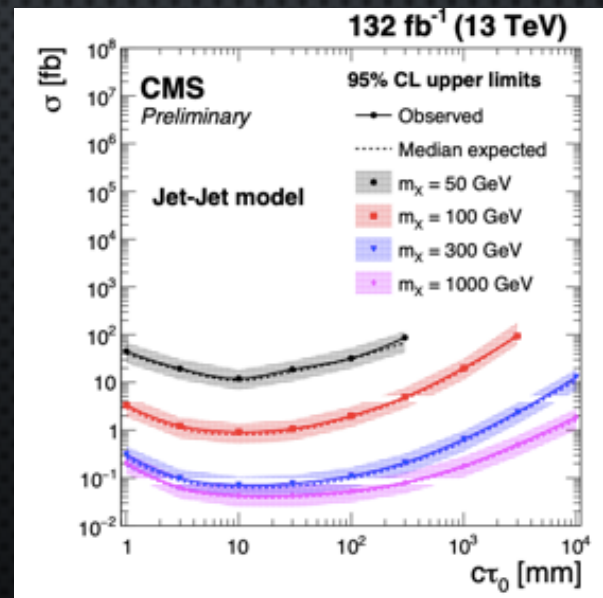
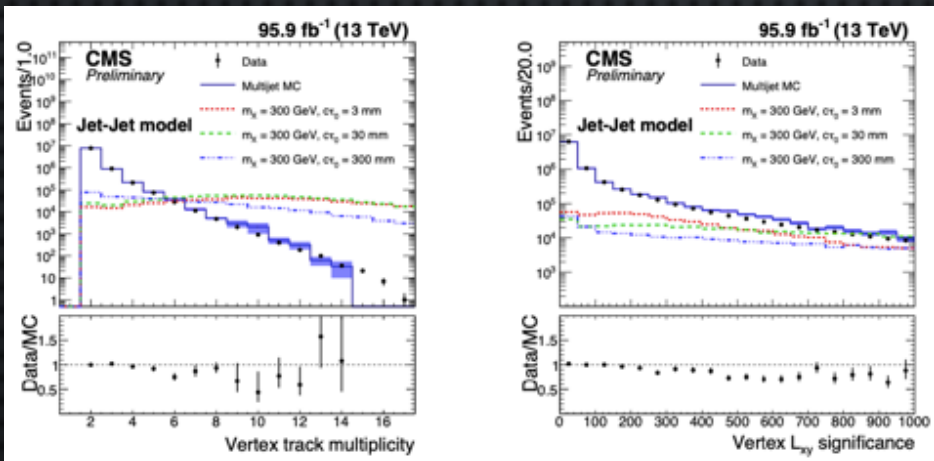
- A SEARCH FOR SUPERSYMMETRIC PARTNERS OF THE TOP QUARK IS PRESENTED IN FINAL STATES WITH TWO OPPOSITELY CHARGED LEPTONS (ELECTRONS OR MUONS), JETS IDENTIFIED AS ORIGINATING FROM B QUARKS, AND MISSING TRANSVERSE MOMENTUM.
- NO SIGNIFICANT DEVIATION IS OBSERVED FROM THE EXPECTED BACKGROUND. EXCLUSION LIMITS ARE SET IN THE CONTEXT OF SIMPLIFIED SUPERSYMMETRIC MODELS (T2tt,T2bW,...) WITH PAIR-PRODUCED TOP SQUARKS.
- FOR TOP SQUARKS DECAYING EXCLUSIVELY TO A TOP QUARK AND A NEUTRALINO, EXCLUSION LIMITS ARE PLACED AT 95% CONFIDENCE LEVEL ON THE MASS OF THE LIGHTEST TOP SQUARK UP TO 925 GeV AND ON THE LIGHTEST NEUTRALINO UP TO 450 GeV.



LONG LIVED PARTICLES - DISPLACED JETS

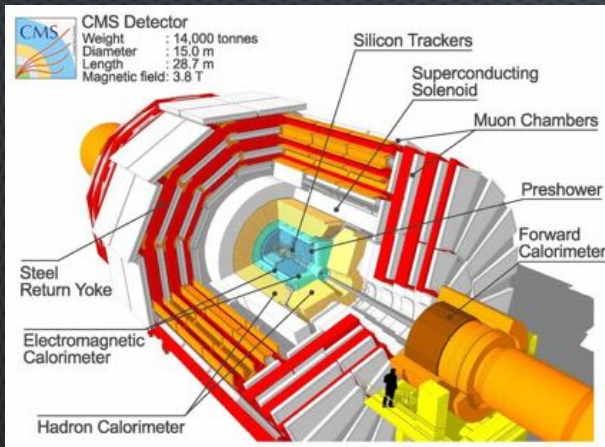


- EXAMPLES OF MODELS WITH LONG LIVED PARTICLES: SPLIT SUPERSYMMETRY; SUSY WITH WEAK R-PARITY VIOLATION; SUSY WITH GAUGE-MEDIATED SUPERSYMMETRY BREAKING; “STEALTH SUSY”; “HIDDEN VALLEY” MODELS; DARK MATTER CANDIDATES;
- DATA IS COLLECTED WITH DEDICATED **DISPLACED JET TRIGGERS** AND H_T . THE ANALYSIS EXAMINES THE DISTINCTIVE TOPOLOGY OF DISPLACED TRACKS AND DISPLACED VERTICES WITHIN A **DIJET** SYSTEM.
- FOR A SIMPLIFIED MODEL, WHERE PAIR-PRODUCED LONG-LIVED NEUTRAL PARTICLES DECAY INTO QUARK-ANTIQUARK PAIRS, PAIR PRODUCTION **CROSS SECTIONS LARGER THAN 0.07 FB ARE EXCLUDED AT 95% CONFIDENCE LEVEL** FOR PARTICLE MASSES LARGER THAN 500 GeV AND MEAN PROPER DECAY LENGTHS BETWEEN 2 AND 250 MM.



DETECTOR UPGRADES TOWARDS HL-LHC

TDR'S PUBLISHED TOWARDS PHASE II (HL-LHC)



- **2013: HL-LHC PLACED AT HIGHEST PRIORITY BY THE EUROPEAN STRATEGY, APPROVED IN 2016 [TDR CERN-2017-007-M]**
- **2015: TECHNICAL PROPOSAL FOR THE PHASE-II UPGRADE OF CMS [CMS-TDR-15-02]**
- **2017:**
 - **PHASE-2 UPGRADE OF THE CMS TRACKER [CMS-TDR-014]**
 - **PHASE-2 UPGRADE OF THE CMS BARREL CALORIMETERS [CMS-TDR-015]**
 - **PHASE-2 UPGRADE OF THE CMS MUON DETECTORS [CMS-TDR-016]**
 - **PHASE-2 UPGRADE OF THE CMS DAQ [CMS-TDR-018]**
- **2018: PHASE-2 UPGRADE OF THE CMS ENDCAP CALORIMETER [CMS-TDR-019]**
- **2020: PHASE-2 UPGRADE OF CMS LEVEL-1 TRIGGER [CMS-TDR-021]**
- **MTD, BRIL, ... TDR'S COMING IN NEAR FUTURE**
 Jose Benitez (Sonora), CMS Experiment Results, DPyC July 2020

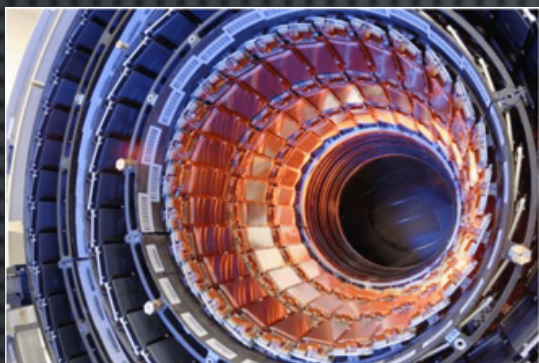
Peak luminosity

- Run 2 ~ $2 \times 10^{34} / \text{cm}^2/\text{s}$
 - HL-LHC ~ $5-7 \times 10^{34} / \text{cm}^2/\text{s}$
- pile-up up to 200 interactions per bunch crossing.

Accumulated Radiation at

- inner tracker layer 1:
- $2.3 \times 10^{16} \text{ neq/cm}^2$
 - 12 MGy Ionizing dose for 3000/fb.

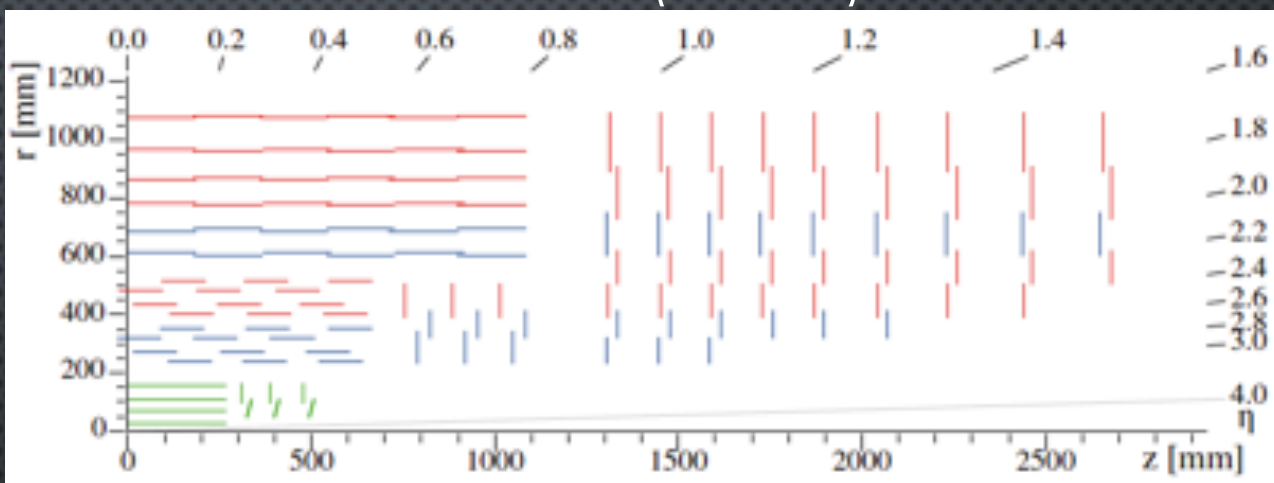
CMS TRACKER UPGRADE



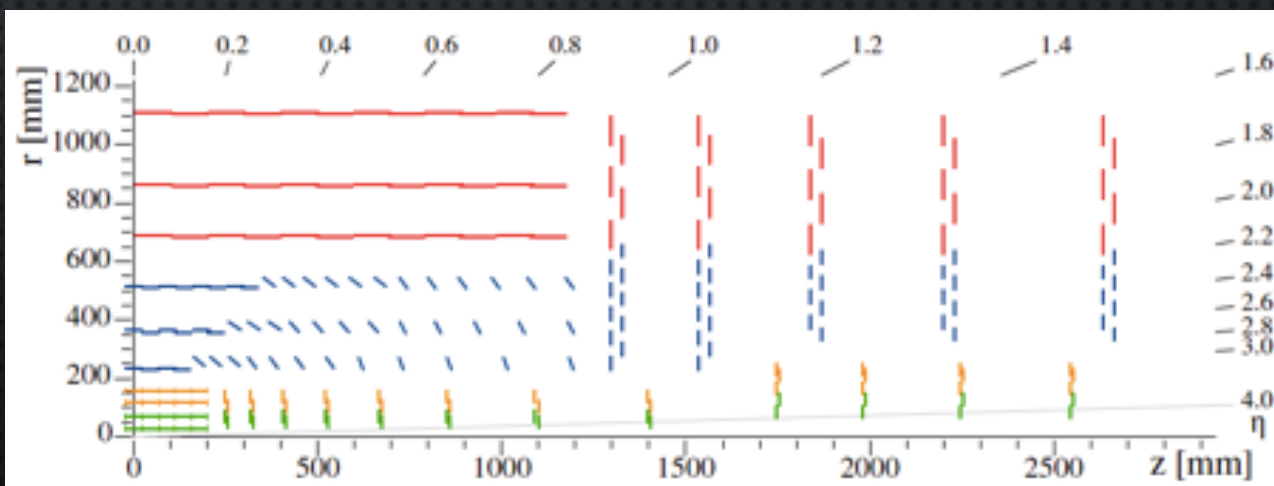
View of CMS inner barrel tracker

- FULL REPLACEMENT NECESSARY DUE TO ACCUMULATED RAD UP TO RUN3
- INNER TRACKER (SI PIXELS)
 - ENDCAP WITH 8+4 DISKS EXTENDS COVERAGE UP TO $|\eta| = 4$.
 - EXPECTED MAIN LUMINOMETER
- OUTER TRACKER (SI STRIPS):
 - IMPROVED SENSOR LAYOUT FOR TRACK RECO.
 - CONTRIBUTE TO L1 TRIGGER (FE TRACK STUBS).

Phase 1 (current)



Phase 2

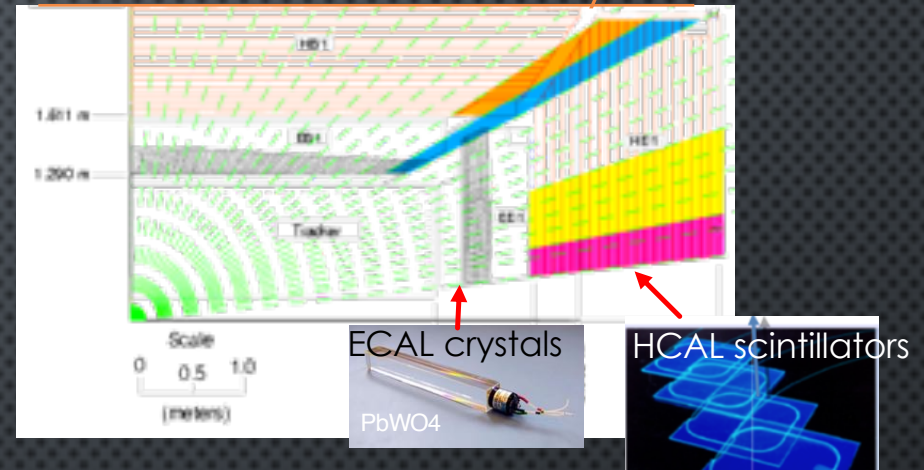


ENDCAP CALORIMETER (HGICAL)



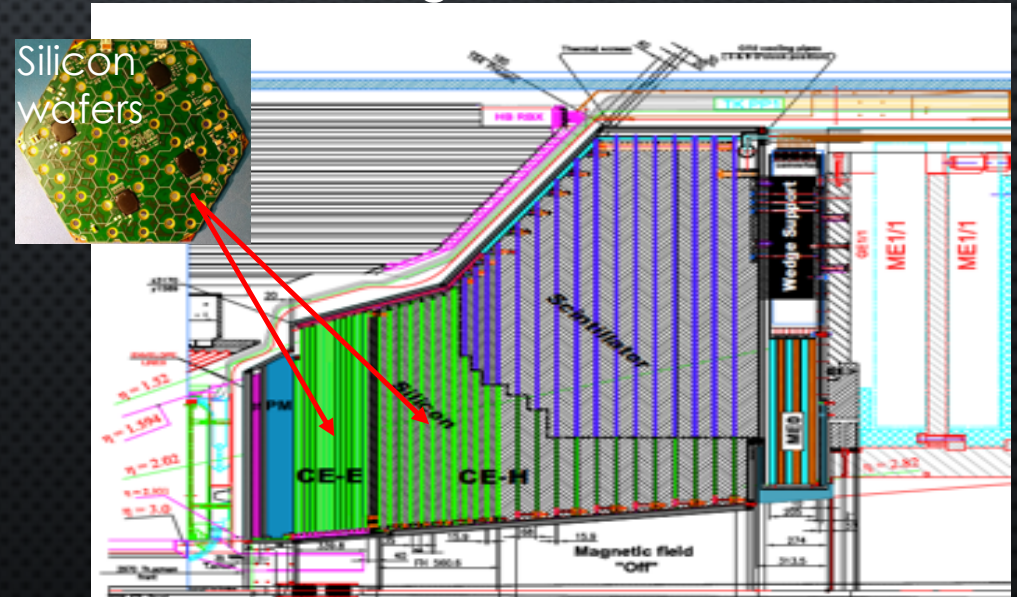
CMS endcap calorimeter

Current calorimeter layout

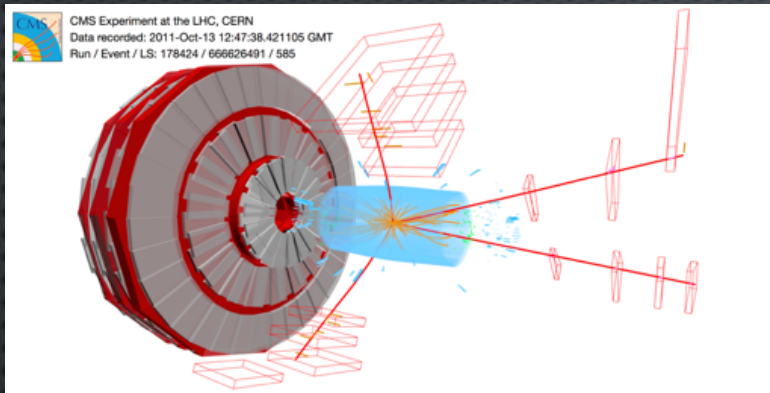


Phase 2 design

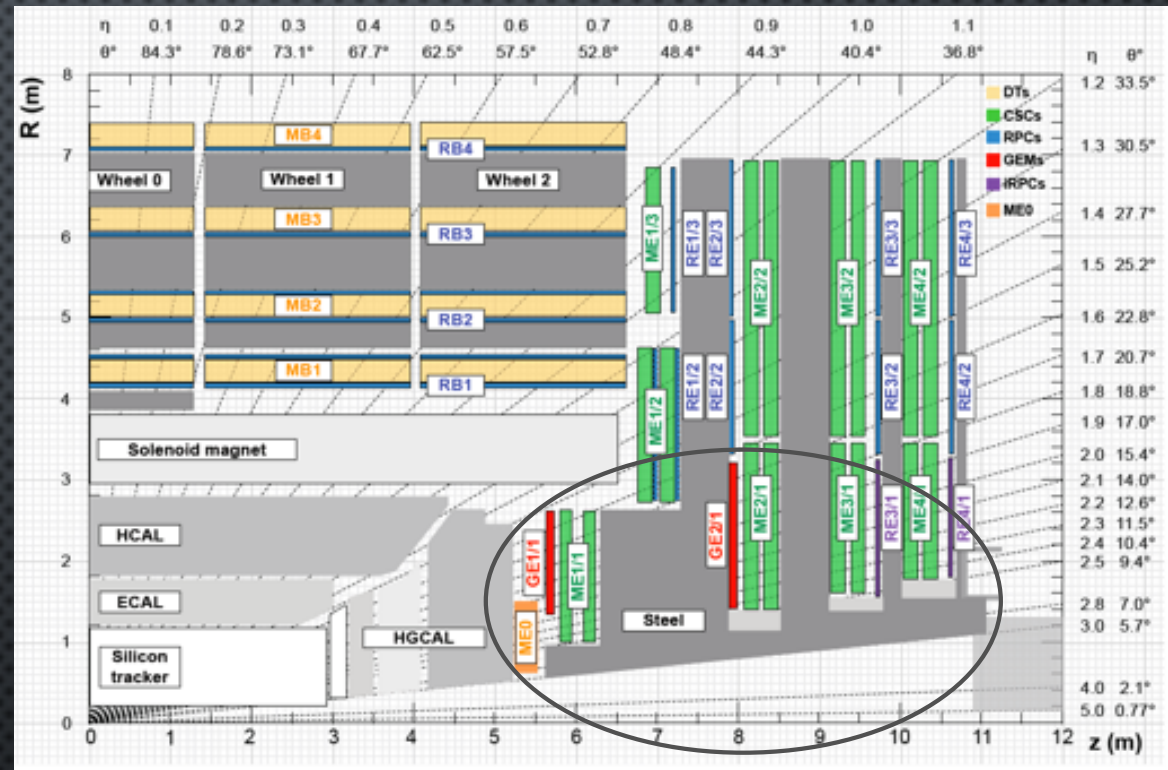
- THE EXISTING FORWARD CALORIMETERS WERE DESIGNED FOR AN INTEGRATED LUMINOSITY OF 500/FB.
- THE PERFORMANCE DEGRADATION LEADS TO AN UNACCEPTABLE LOSS OF PHYSICS PERFORMANCE. FOR EXAMPLE VBF PHYSICS AND MISSING ET RECONSTRUCTION.
- THE ENDCAP WILL BE REBUILT BASED ON A SAMPLING DESIGN USING RAD-HARD SILICON SENSOR LAYERS.



MUON SYSTEM UPGRADES



An event with 4 muons.



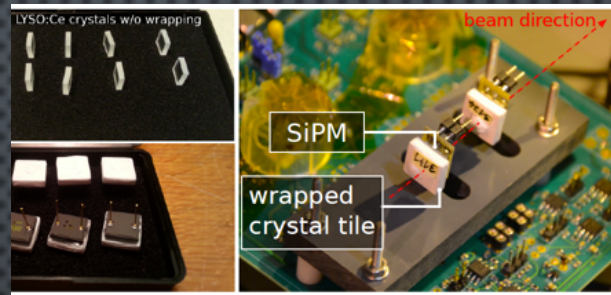
- DETECTOR AND ELECTRONICS MUST BE UPGRADED
 - TO HANDLE HIGH PARTICLE RATES USING LATEST TECHNOLOGY SUCH AS HIGH BANDWIDTH OPTICAL DATA TRANSFER.
 - NEW REQUIREMENTS ON THE LEVEL-1 TRIGGER AND DAQ REQUIRE A READOUT IN “STREAMING” MODE WHERE FULL DETECTOR RAW HITS ARE SENT TO THE BACK-END FOR EVERY BUNCH CROSSING (40 MHz)

- IN THE FORWARD REGION, TO COMPLETE COVERAGE AT LARGE $|\eta|$, NEW DETECTORS WILL BE INSTALLED (IRPC’s, GEM, ME0) USING NEW TECHNOLOGIES FOR HIGH PARTICLE RATES.

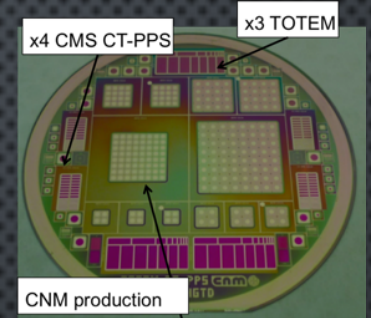
MIP TIMING DETECTOR (MTD)

- MTD IS A NOVEL DETECTOR LAYER TO BE INSTALLED IN FRONT OF THE BARREL AND ENDCAP CALORIMETERS WITH PRECISION TIMING CAPABILITIES.

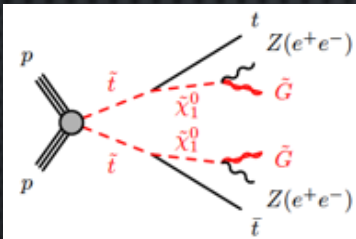
Barrel : LYSO crystals



Endcap: LGAD silicon

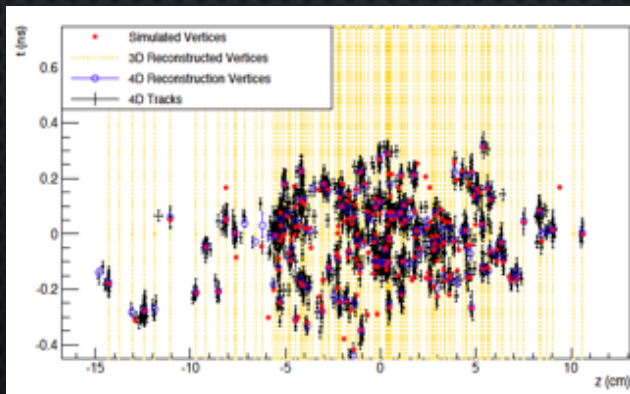


Beam test timing resolution per hit:
LYSO ~ 20 ps and LGAD ~ 20-30ps
Tested for radiation aging



Improve searches for long lived particles

Crucial for pile-up vertex identification.



MEXICO'S CONTRIBUTIONS IN CMS

4 institutions , 15 physicists

- **FLAVOR PHYSICS** (SEE TALK BY *J. MEJIA*)
 - CINVESTAV
- **HIGGS/TOP/BSM/HEAVY-IONS**
 - BUAP, UNISON, IBERO
- **RPC MUON SYSTEM**
 - BUAP, IBERO, CINVESTAV
- **LUMINOSITY / RADSIM (BRIL)**
 - UNISON, IBERO, BUAP
- **COMPUTING**
 - CINVESTAV, BUAP



SUMMARY

- THE LHC CONTINUES TO PRODUCE A RICH SPECTRUM OF INTERESTING PHYSICS
- SO FAR NO "NEW PHYSICS" OBSERVED, BUT MANY NEW SM PROCESSES AND PRECISION MEASUREMENTS HAVE BEEN PERFORMED IMPROVING OUR OUR UNDERSTANDING OF THE SM MODEL.
- LHC TO RESTART IN 2021 FOR RUN 3 WITH SOME DELAY DUE TO COVID-19, UPGRADE PROGRAMS ARE ON TRACK.
- HL-LHC UPGRADE WORK WELL ADVANCED WITH MANY SYSTEMS ALREADY PRODUCED TECHNICAL DESIGN REPORTS. SOME SYSTEMS ARE ALREADY IN PRE-PRODUCTION AND QUALITY CONTROL. LS3 WILL A VERY BUSY PERIOD.
- MEXICO IS PARTICIPATING ACTIVELY IN SEVERAL AREAS AND WITH LEADING ROLES.

THANKS FOR YOUR ATTENTION.