



CMS Status Report

Yurii Maravin (KSU)

On behalf of the CMS Collaboration

116th LHCC – Open Session

December 4th, 2013

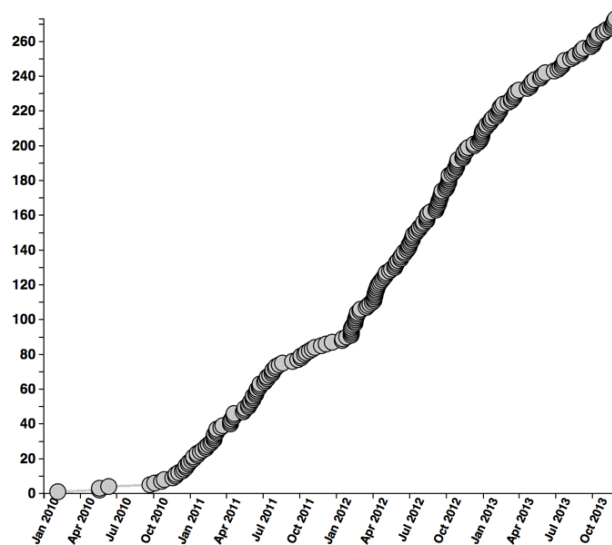
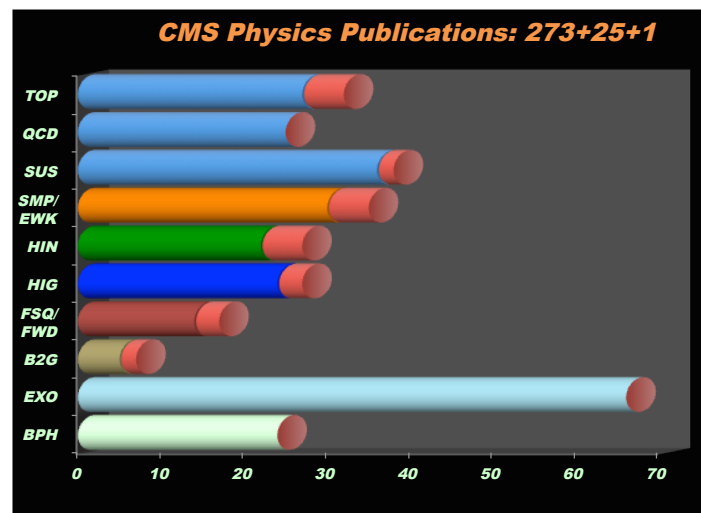


CMS Status in a nutshell

- **Physics of Run 1**
 - Very exciting physics program with many analyses on track to reach our goals
- **Long Shutdown 1 (LS1)**
 - Excellent progress on updating the CMS detector including many phase 1 upgrade tasks
- **Preparation for Run 2**
 - Progress on CPU-efficiency, development of the data analysis tools and procedures, Global Event Description (particle flow) reconstruction software
- **Upgrades beyond LS1**
 - Good technical progress

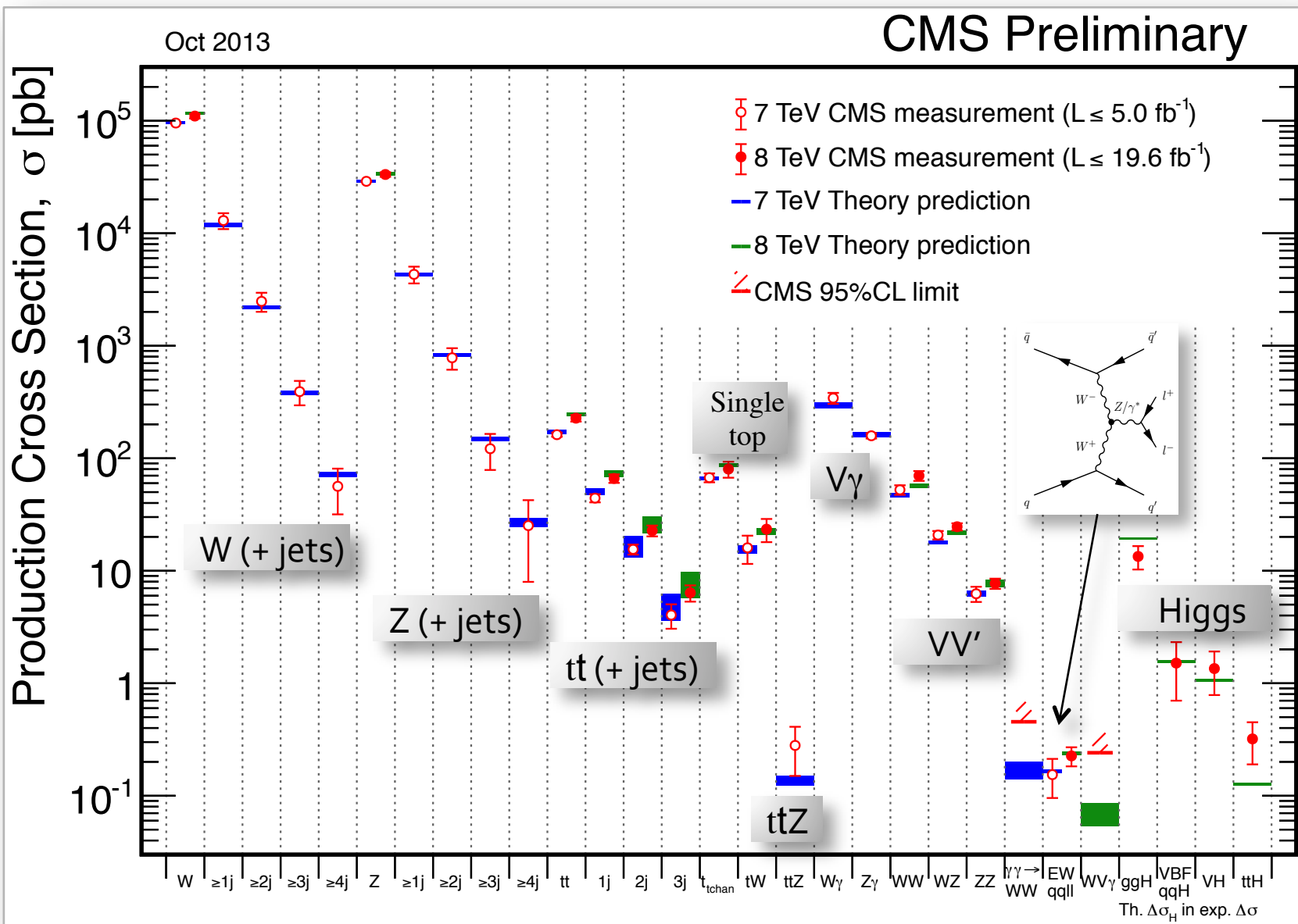
Very rich Run 1 physics program

- CMS continue to produce a lot of beautiful new results with Run 1 data
 - 273 papers with collision data
25 on the way
 - 307 publications total, including performance papers
 - h-index 62
 - Higgs discovery paper has 1977 citations as of today
 - Steady rate of > 100 citations per month!
- A lot of effort is going in finalizing “legacy” papers on Run 1 data analyses
 - Expect more than 100 papers on Run 1 data in 2014



Cross Sections at a Glance

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

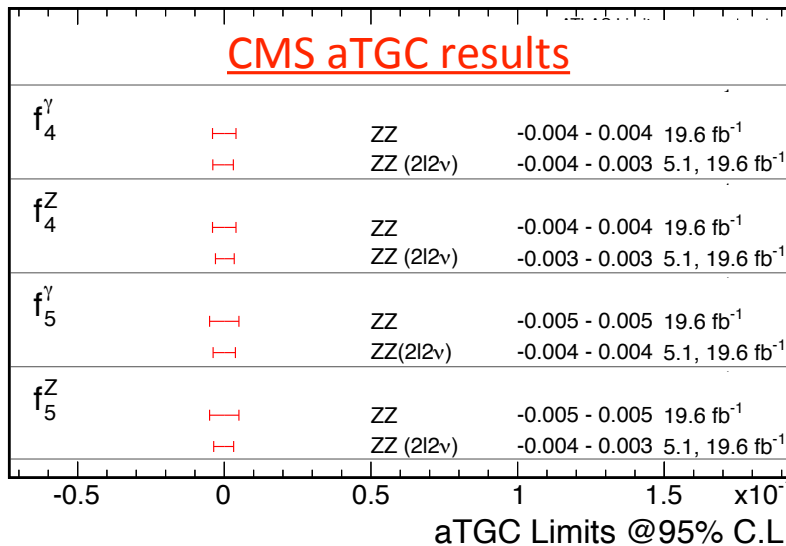


Electroweak highlights

[CMS-SMP-12-016](#)

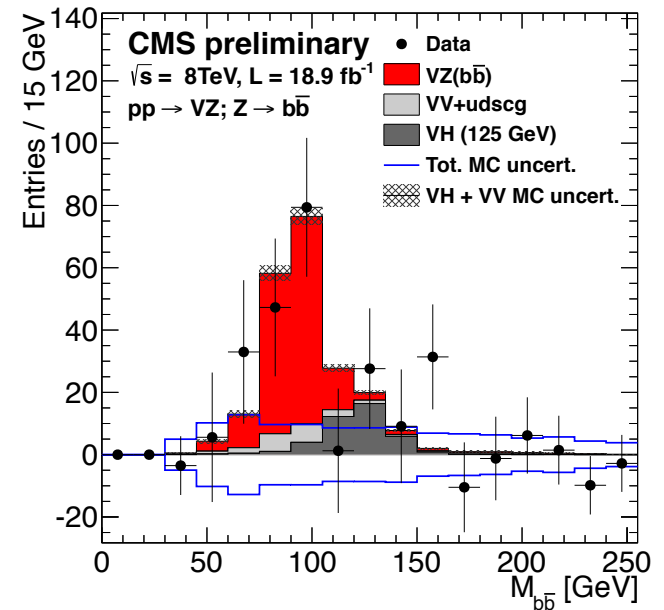
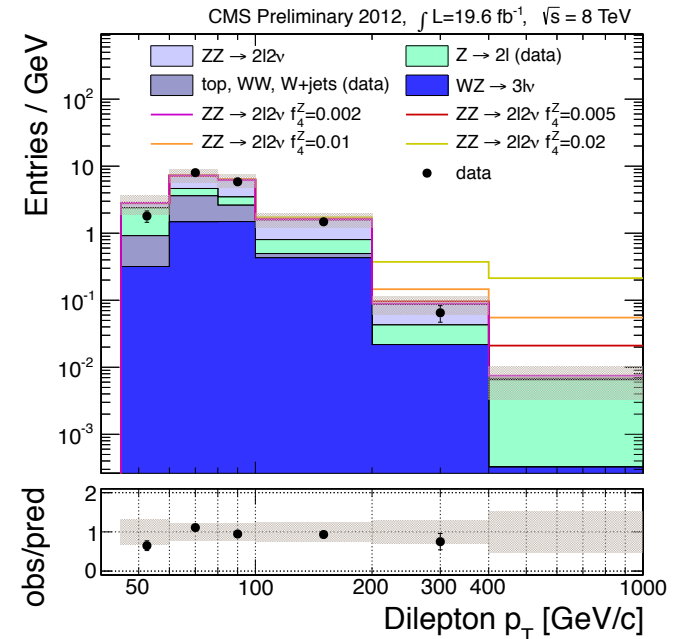
- Measurement of $ZZ \rightarrow 2\ell 2\nu$
 - ℓ is an electron or a muon
 - Even stronger limits on aTGC

Nov 2013



[CMS-SMP-13-011](#)

- Measurement of $VZ \rightarrow Vb\bar{b}$
 - $Z \rightarrow \nu\nu, Z \rightarrow 2\ell, W \rightarrow \ell\nu$ ($\ell = e, \mu$)
 - 6σ significance

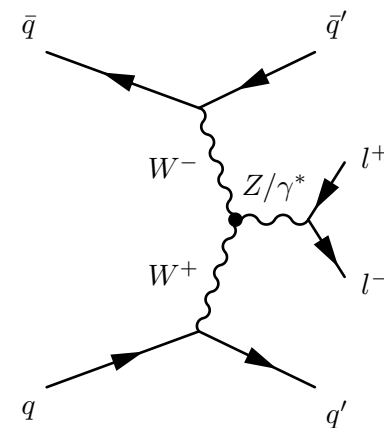
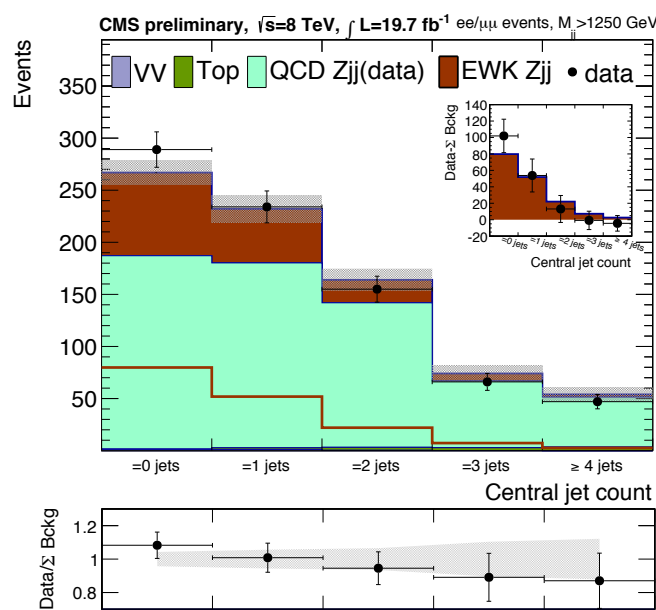
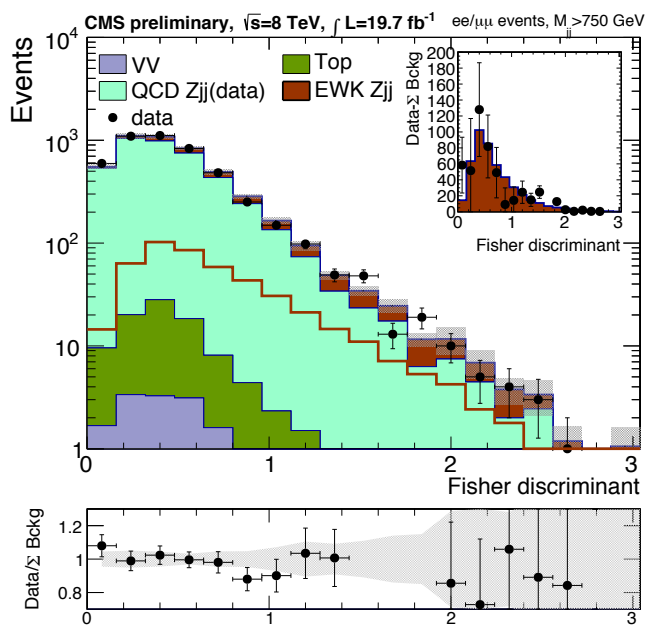


Forward Physics Highlights

- Important foundation for a study of VBF production processes

[CMS-FSQ-12-035](#)

– Sensitivity to new physics via aTGC



$$\sigma(\text{EWK } lljj) = 226 \pm 26(\text{stat.}) \pm 35(\text{syst.}) \text{ fb}$$

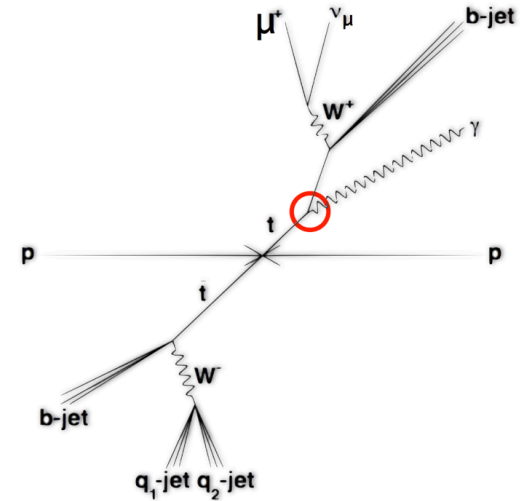
- Cross section agrees with the SM prediction (239 fb)
 - 5σ observation of the pure EWK production of the Z boson

Top Physics Highlights

CMS-TOP-13-011

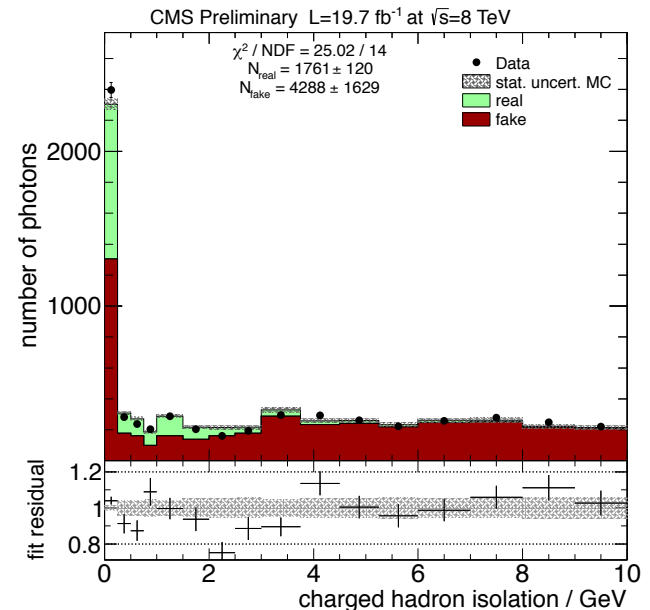
- Measurement of the $tt+\gamma$ production

- $\Delta R(\gamma, \text{jet}) > 0.1$ and $p_{T}(\gamma) > 20$ GeV
- Difficult analysis as genuine photons need to be distinguished from photon-like jets in a very jetty $t\bar{t}$ environment
- Use charged hadron isolation to separate genuine photons from the photon-like jets



- Good agreement with the SM predictions

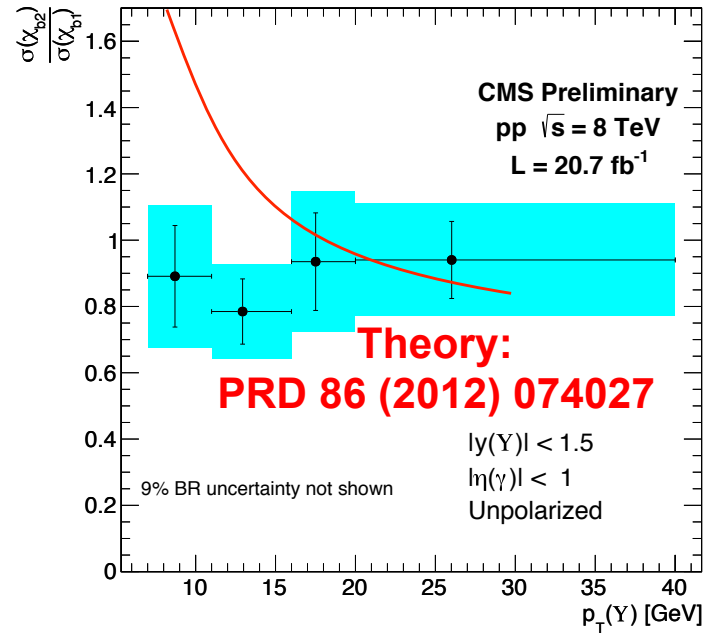
- $\sigma_{tt+\gamma} = 2.4 \pm 0.2$ (stat.) ± 0.6 (syst.) pb
 - Theory: 1.8 ± 0.5 pb



B-Physics Highlights

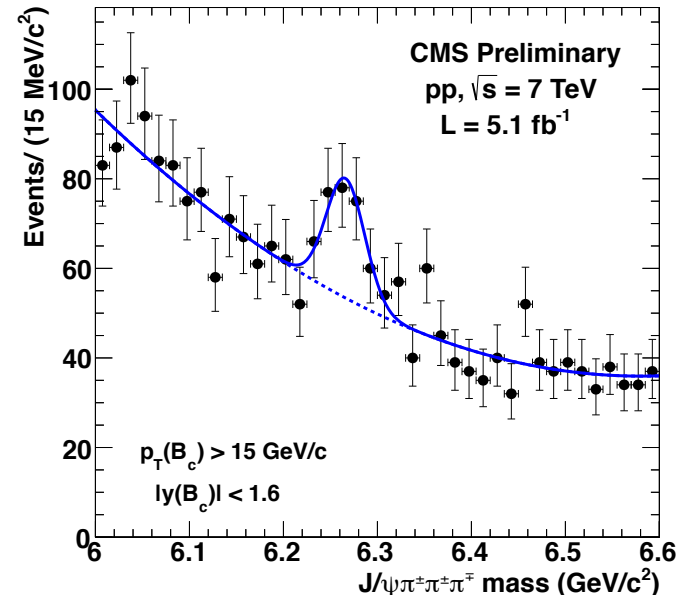
- Measurement of the χ_{b2} and χ_{b1} cross section ratio in the $Y\gamma$ final state
 - First measurement in hadron colliders

[CMS-BPH-13-005](#)



- Measurement of the $B_c^\pm \rightarrow J/\psi\pi^\pm$ and $J/\psi\pi^\pm\pi^\pm\pi^\mp$
 - Rich heavy-quark dynamics
 - Complementary to LHCb measurements

[CMS-BPH-12-011](#)



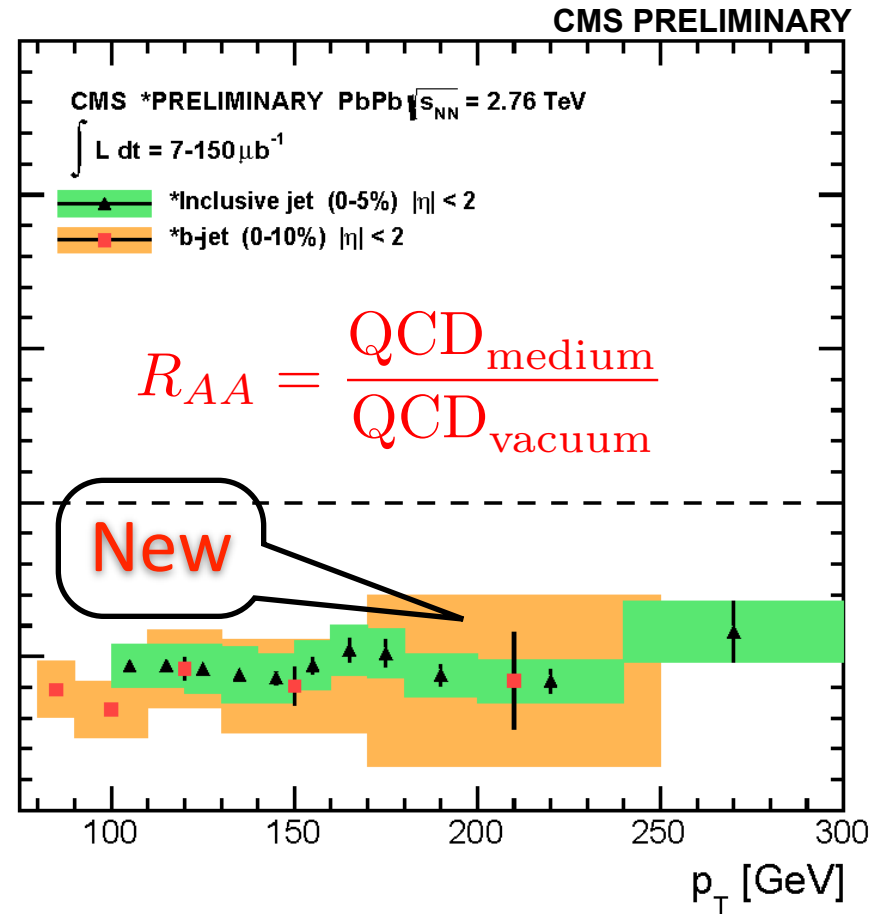
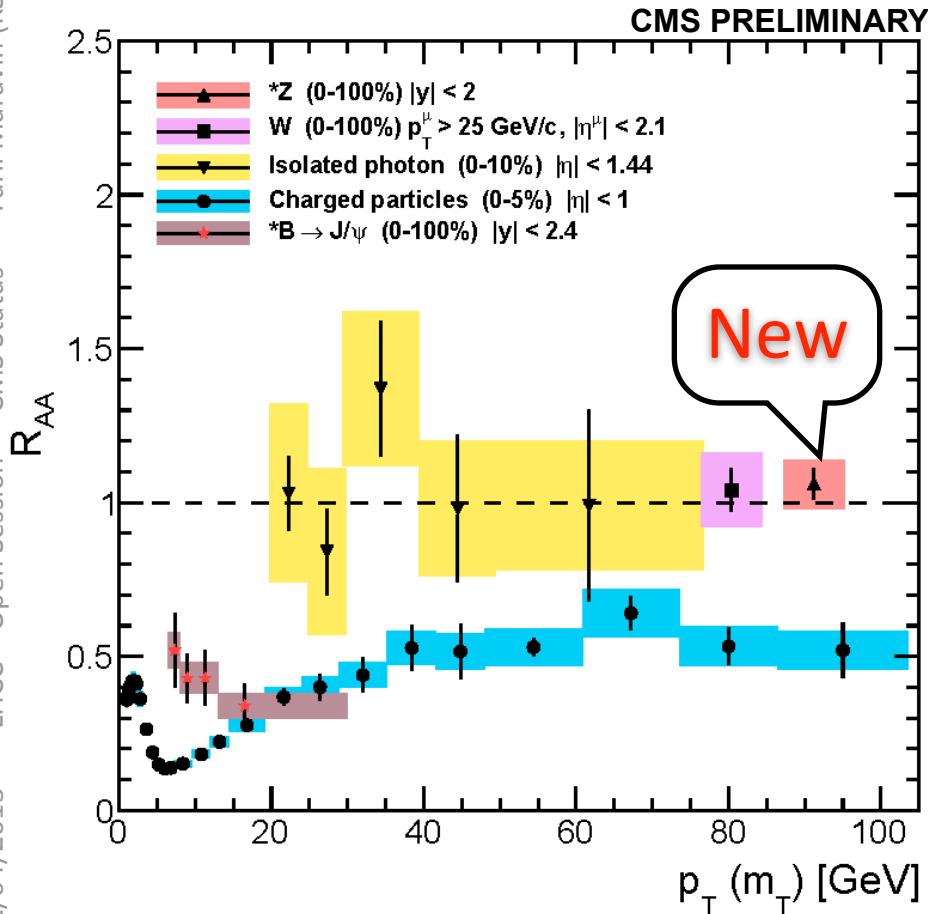
Heavy-Ion Highlights: PbPb

- Several interesting new results were presented in Hard Probes conference earlier this month

$$R_{AA} = \frac{1}{\langle N \rangle} \frac{d^2 N_{AA} / dp_T d\eta}{d^2 N_{pp} / dp_T d\eta}$$

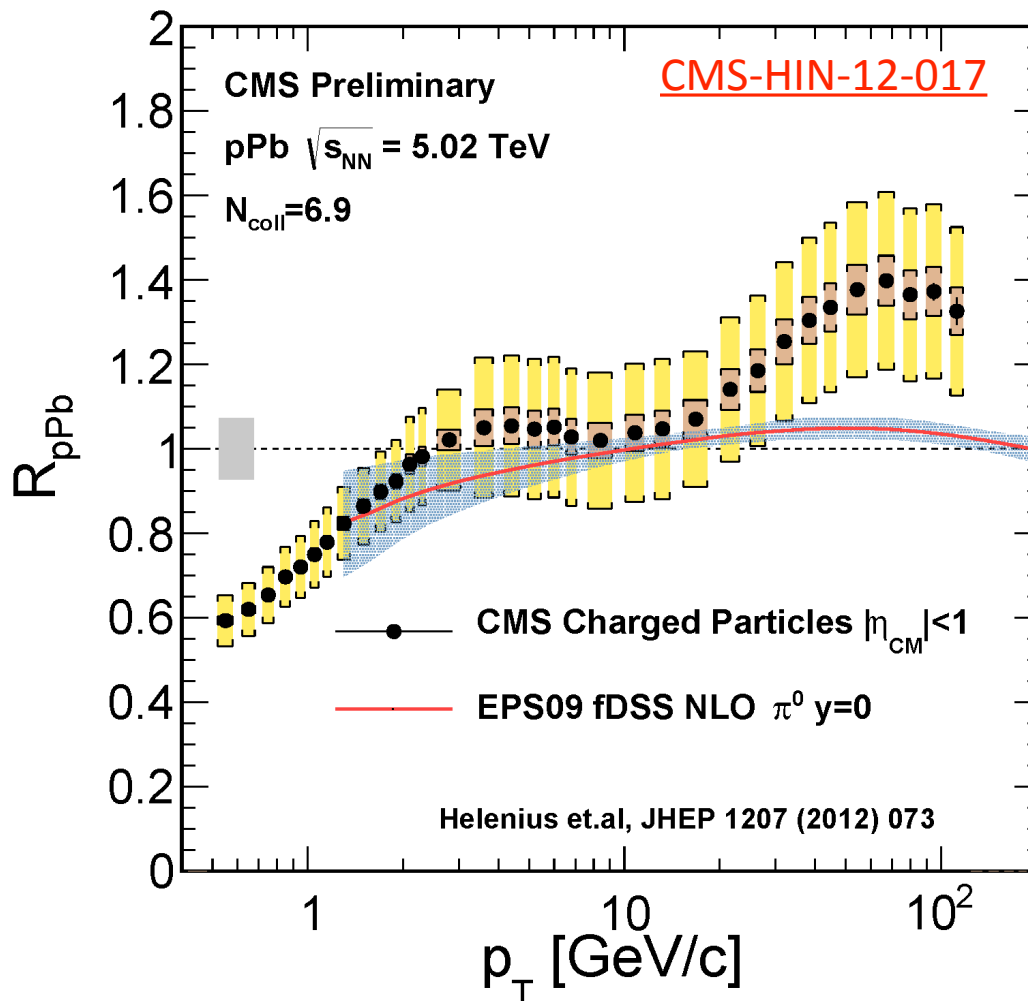
[EPJC 72 \(2012\) 1945](#), [PLB 715 \(2012\) 66](#), [PLB 710 \(2012\) 256](#)

[CMS-HIN-12-014](#), [CMS-HIN-13-004](#), [CMS-HIN-12-004](#), [CMS-HIN-12-003](#)



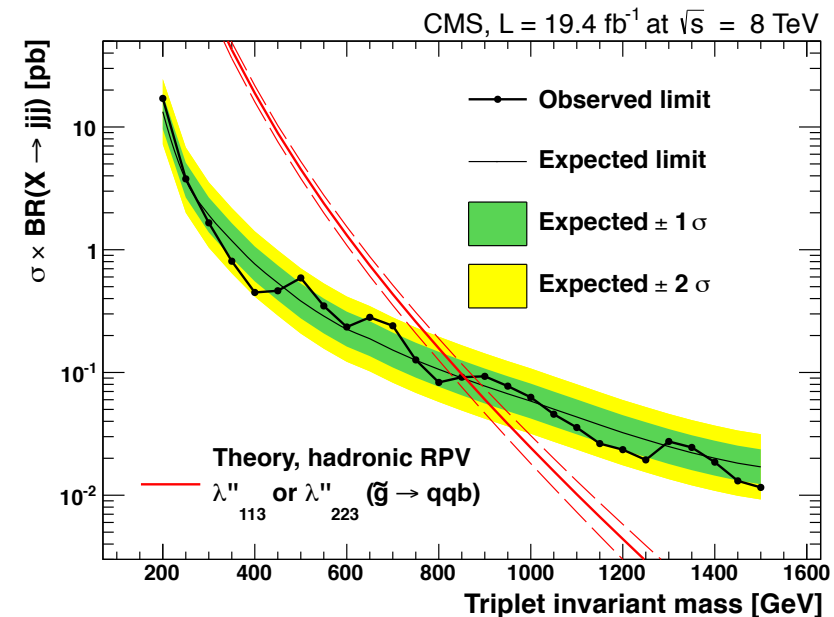
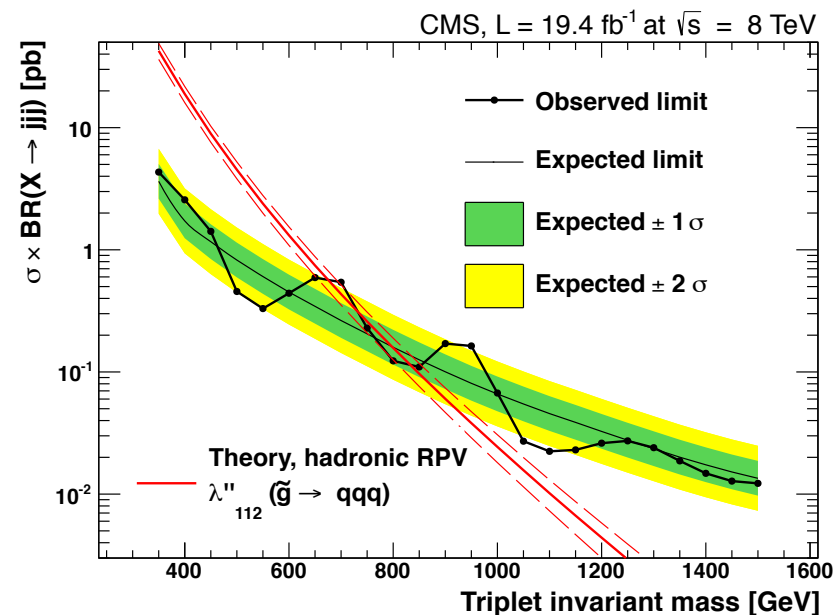
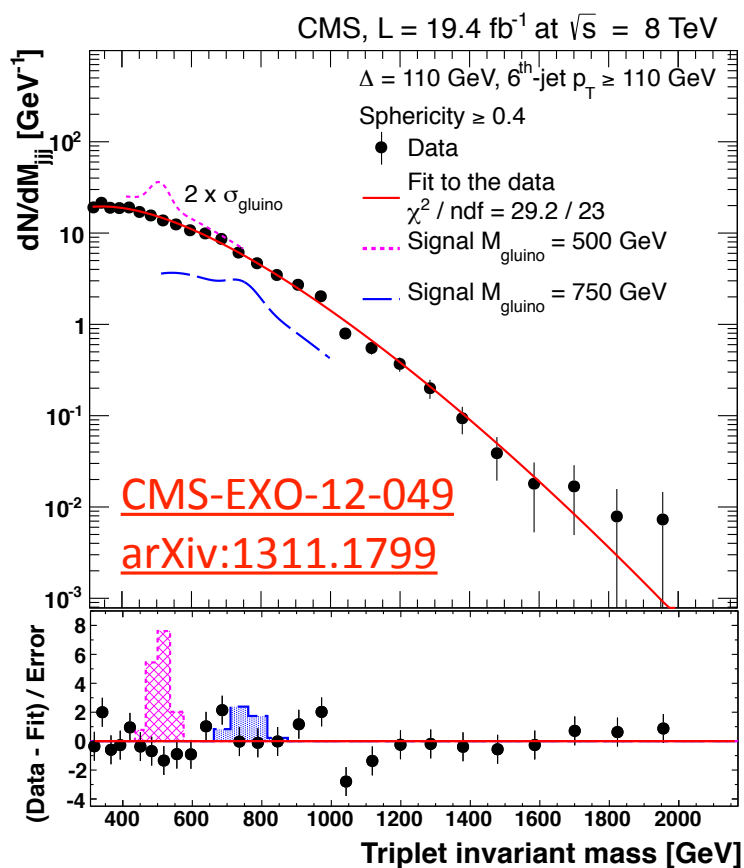
Heavy Ion Highlights: pPb

- Very unexpected “bump” at high p_T
 - Parton anti-shadowing at $x \sim 0.02 - 0.20$?



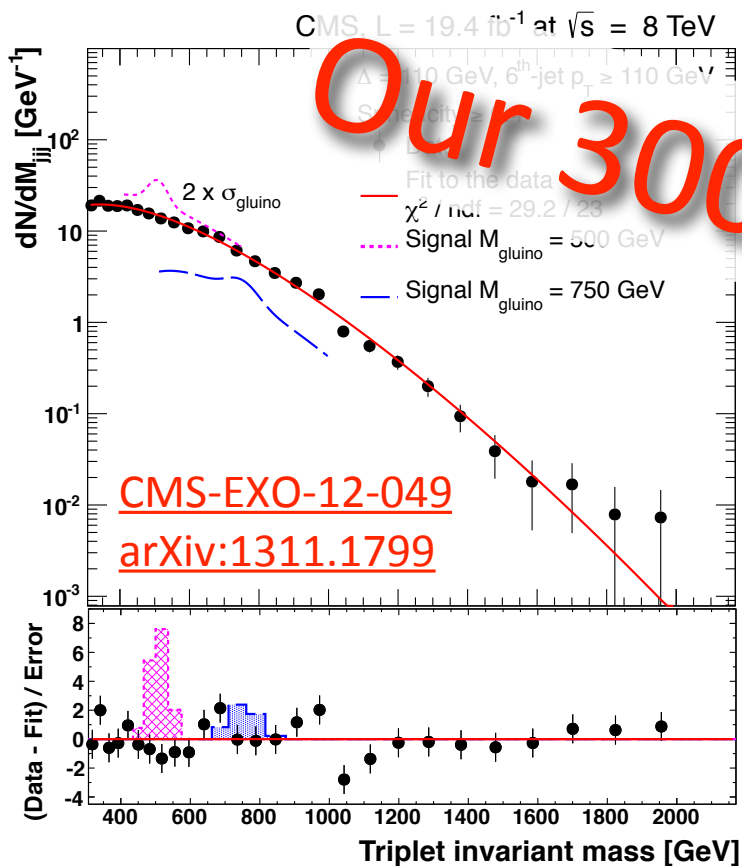
Exotica Highlights

- Search for RPV decays of a gluino in 3 jets
 - qq̄q̄ or bqq̄ jets

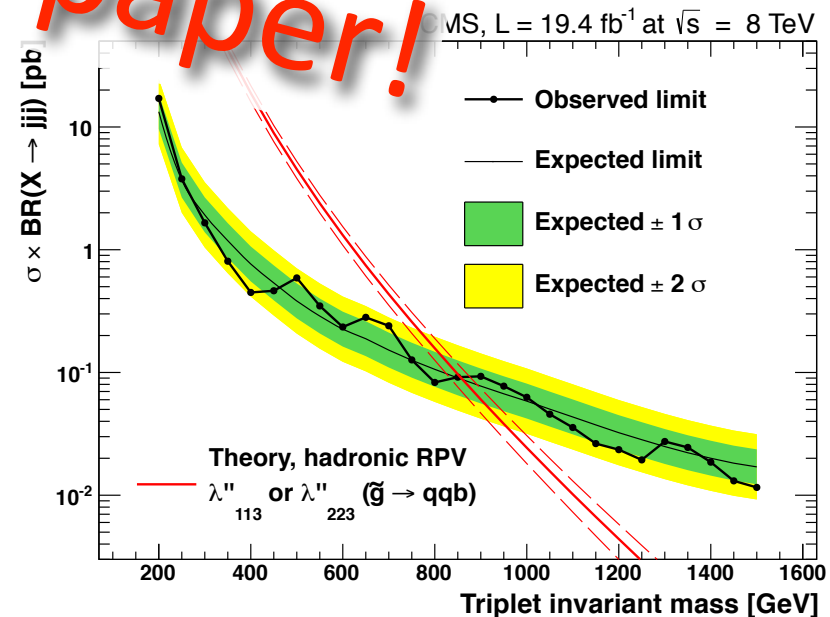
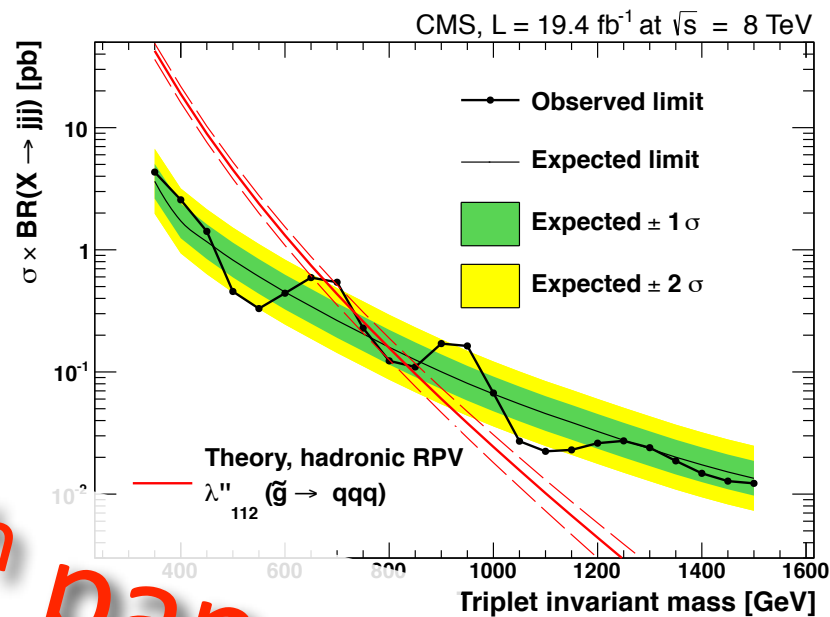


Exotica Highlights

- Search for RPV decays of a gluino in 3 jets
 - qqq or bqq jets



Our 300th paper!

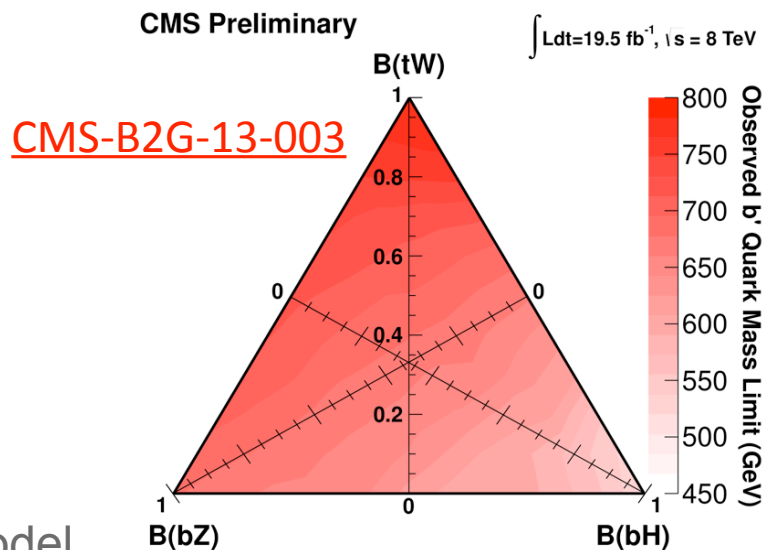


Beyond Two Generations

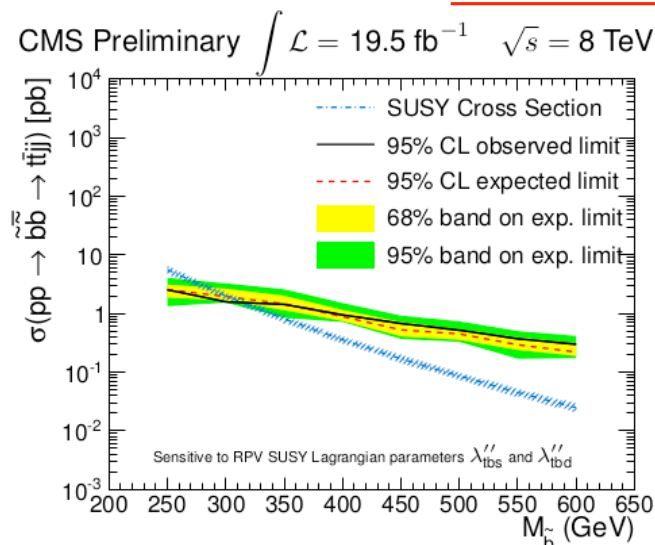
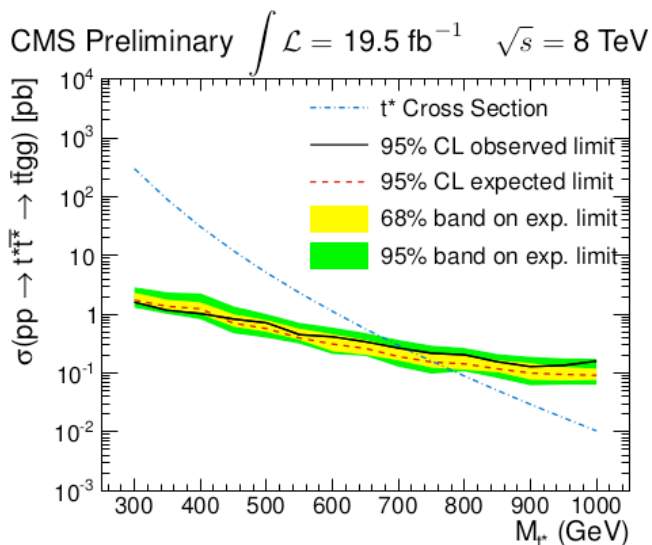
- Search for vector-like b' in multilepton final state
 - All possible decays: tW , bZ , bH
 - Limits in 500–800 GeV depending on the decay mode

- Search for a t^*t^* production with $t^* \rightarrow t \text{ jet} \rightarrow \ell \nu b \text{ jet}$

- Also interpret results in RPV SUSY model
 - $\tilde{b} \rightarrow st$



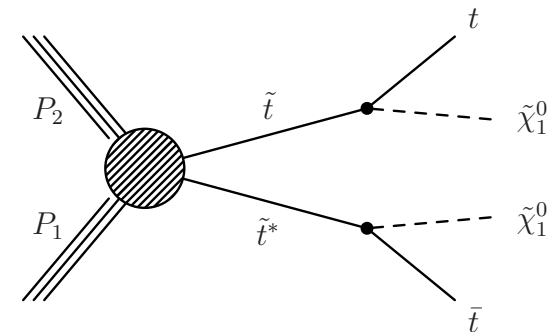
CMS-B2G-12-008



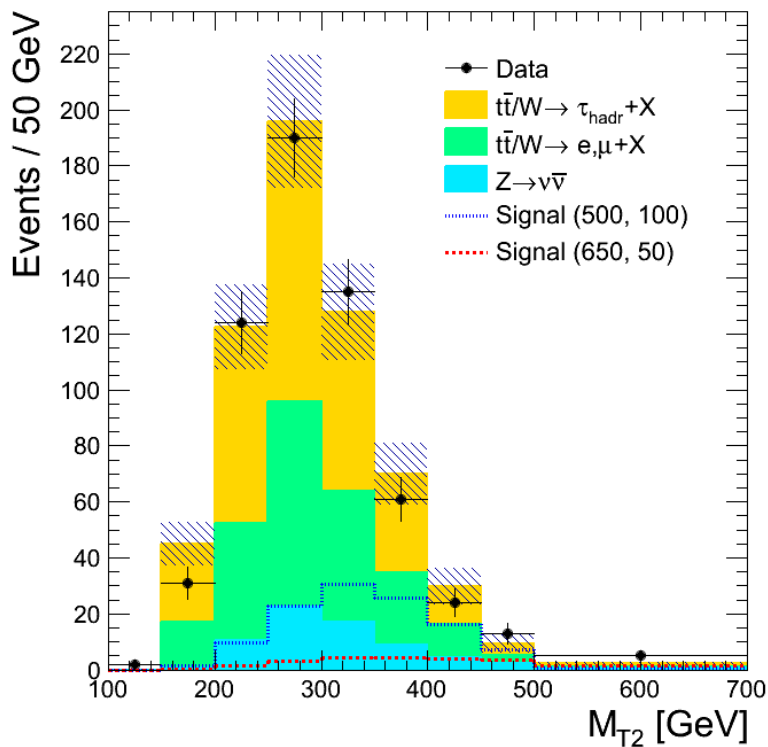
SUSY Highlights: Light Stops

CMS-SUS-13-015

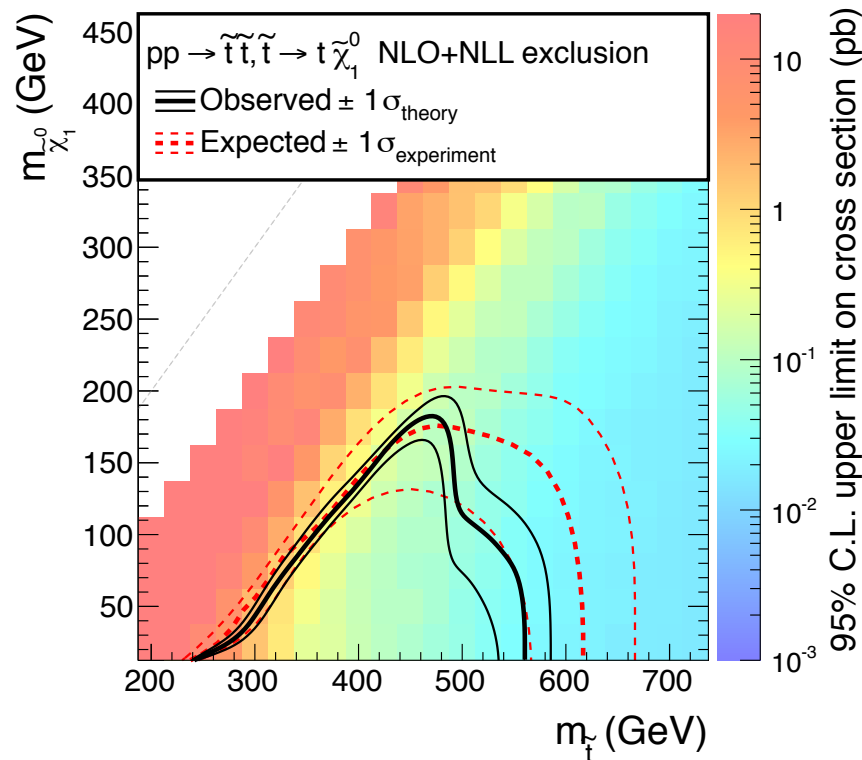
- Search for direct stop production
 - Light stops demanded by naturalness
 - New all-hadronic channel result:



CMS Preliminary, $L = 19.4 \text{ fb}^{-1}$, $\sqrt{s} = 8 \text{ TeV}$



CMS Preliminary, 19.4 fb^{-1} , $\sqrt{s} = 8 \text{ TeV}$

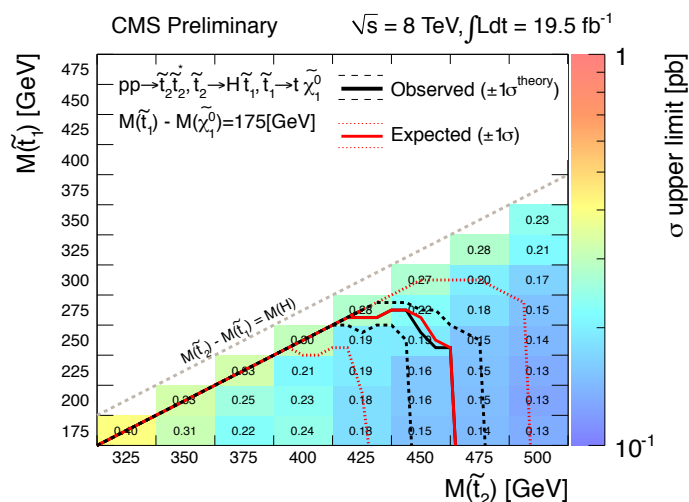
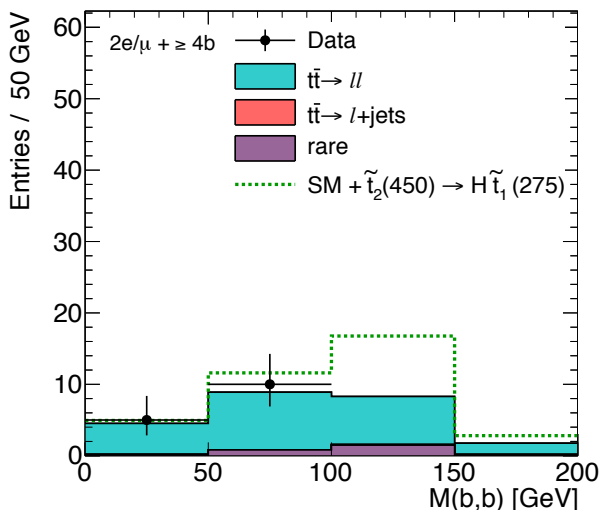
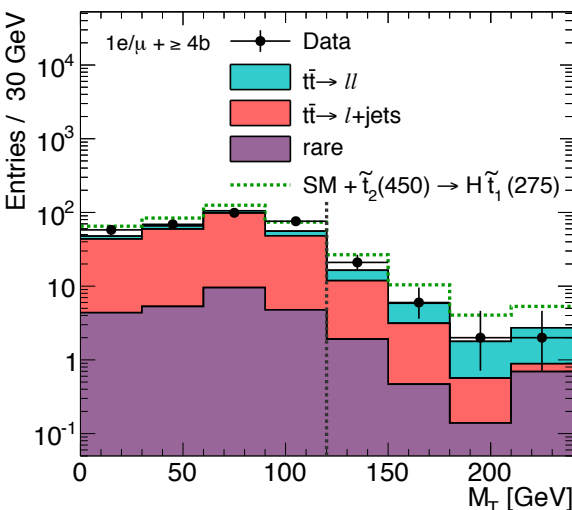
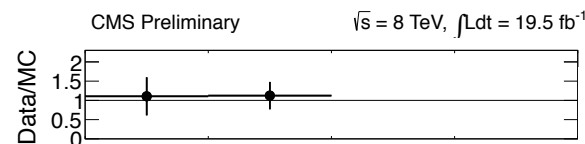
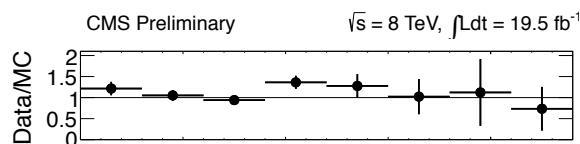
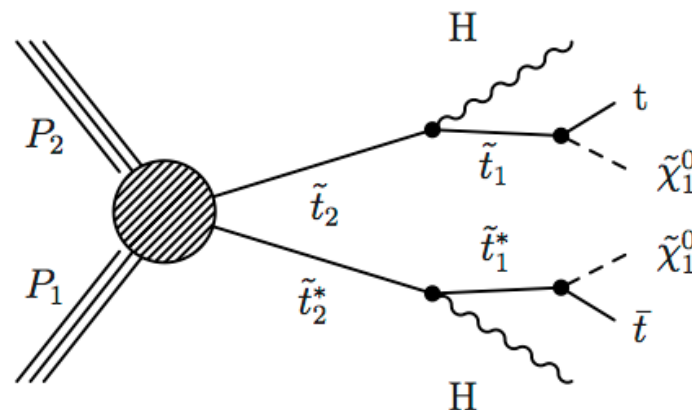


SUSY Highlights

- We usually searched for SUSY with W and Z: now we have a new boson!

– Several new results:

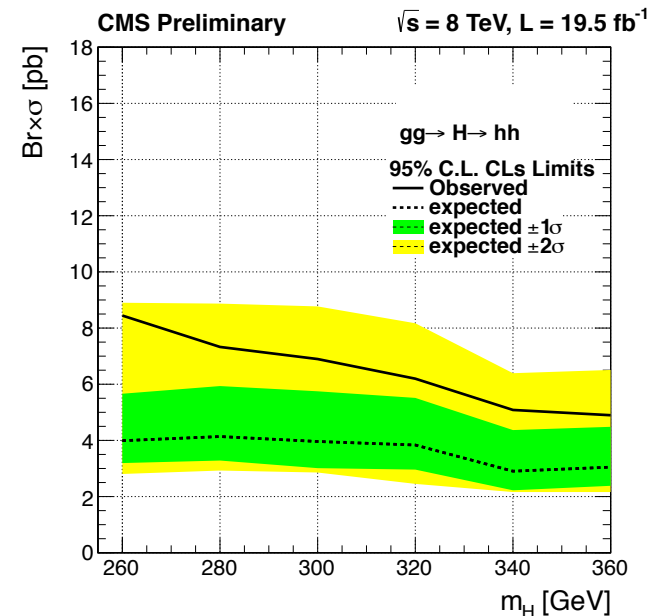
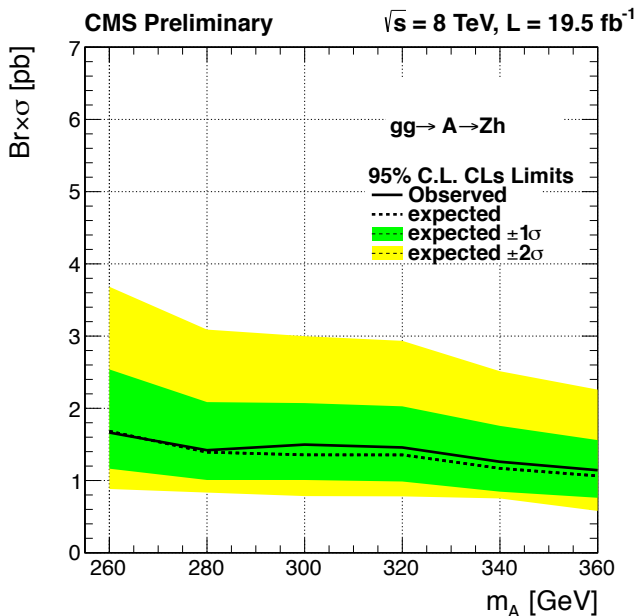
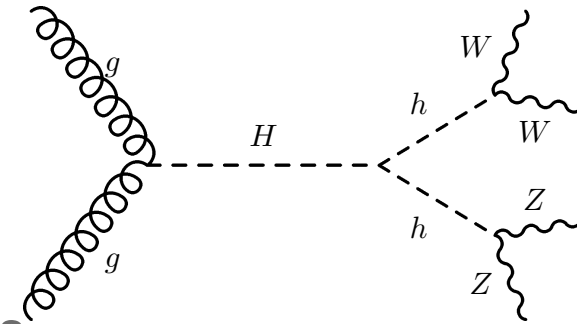
- $H(\gamma\gamma)bb+\text{MET}$ [CMS-SUS-13-014](#)
- $\text{HW}+\text{MET}$ [CMS-SUS-13-017](#)
- $\text{HH}+\text{tt}+\text{MET}$ [CMS-SUS-13-021](#)



Higgs Highlights: Search for Heavy Higgs / A

CMS-HIG-13-025

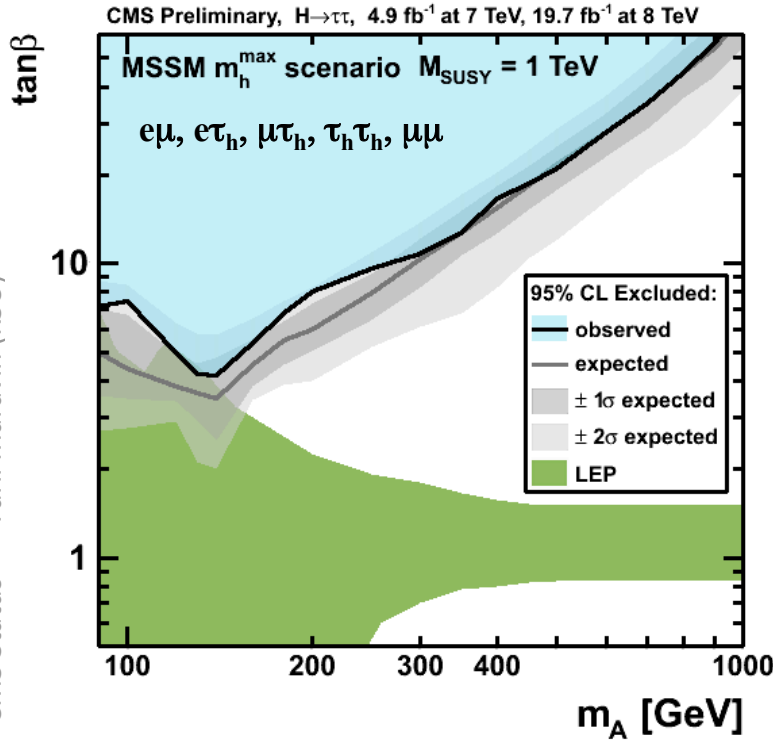
- Search for decays of heavy scalar $H \rightarrow hh$ and pseudo-scalar Higgs boson $A \rightarrow Zh$
 - h is a SM-like Higgs boson
 - h is assumed to have SM branching fractions
- Use multileptons and $\gamma\gamma$ +leptons channels



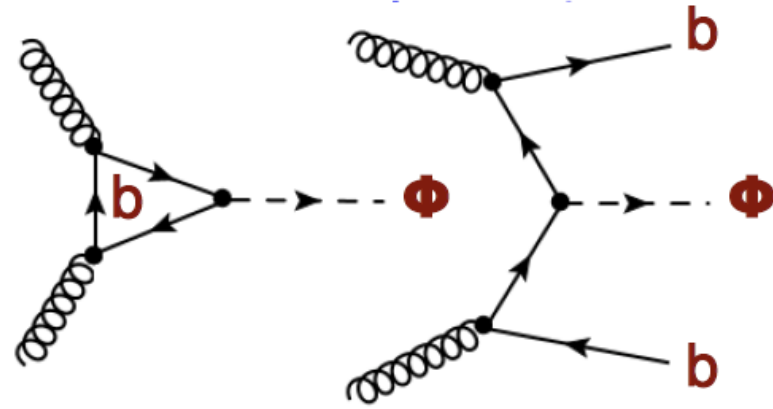
- 2HDM – specific limits and further details to follow soon

Search for MSSM $H \rightarrow \tau\tau$

[CMS-HIG-13-021](#)



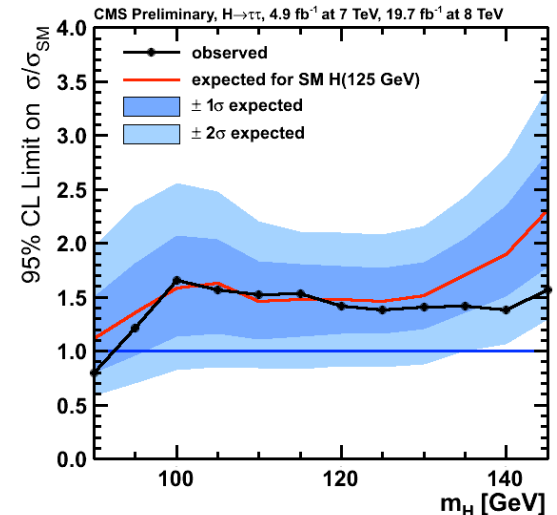
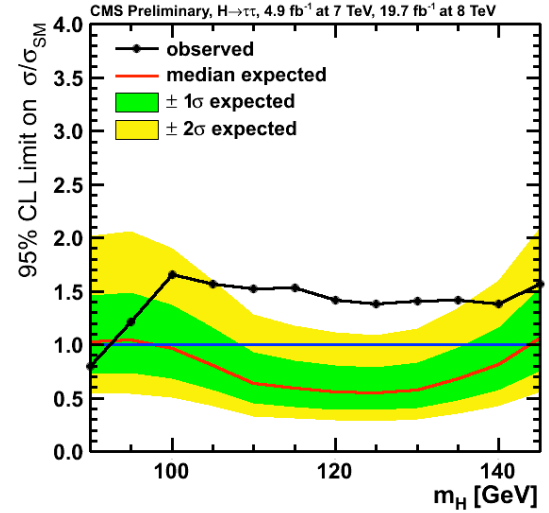
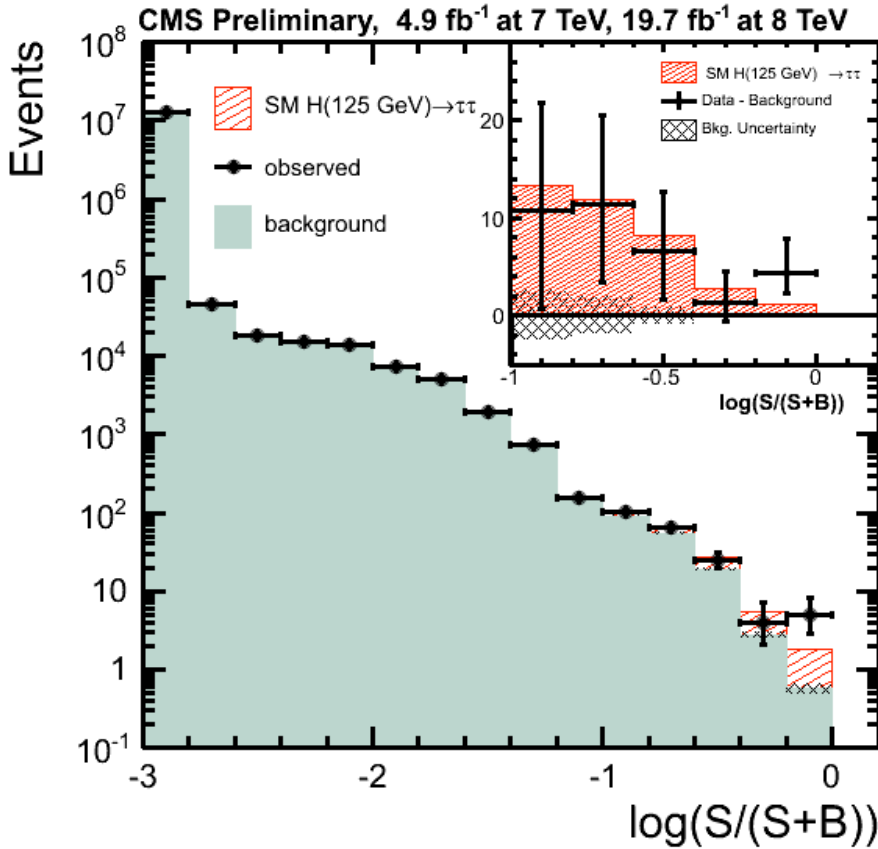
- $H \rightarrow \tau\tau$ is enhanced in MSSM for large $\tan\beta$



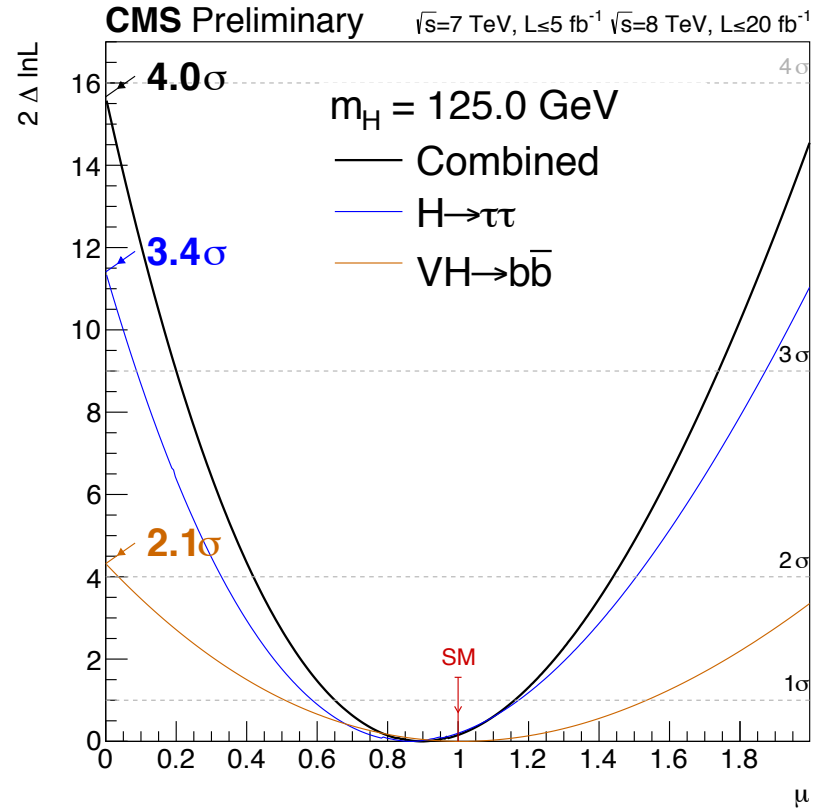
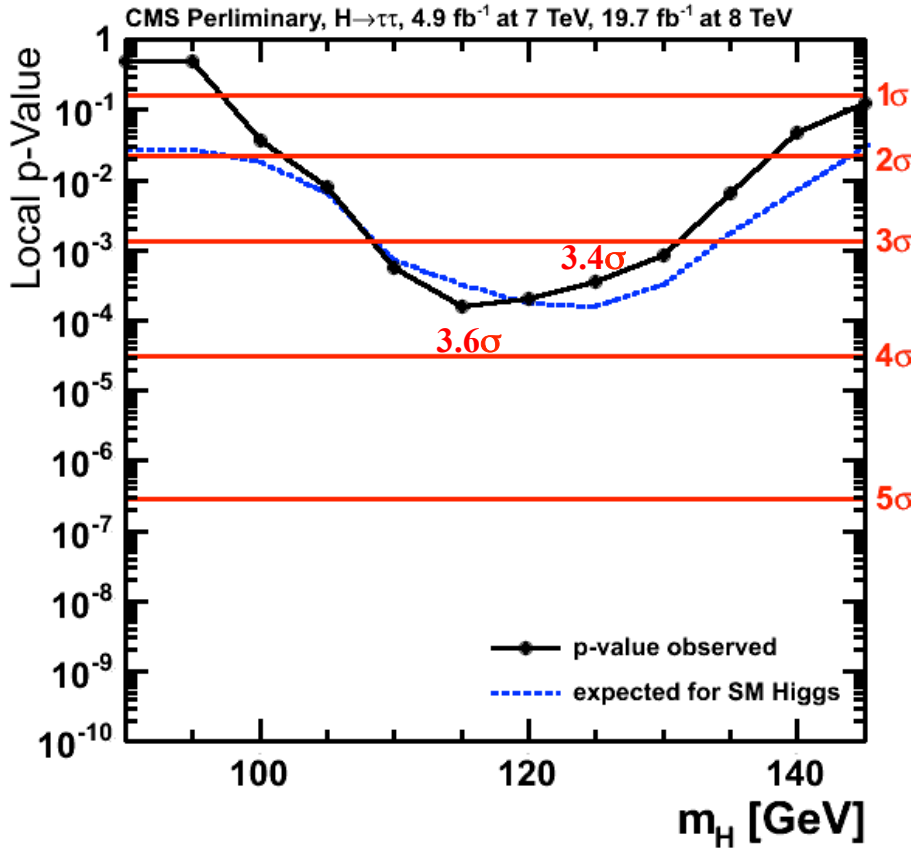
- Sensitivity is increased by selecting events with and without one b -tagged jet
 - New channel: $\tau_h\tau_h$ is the second most sensitive channel
 - First public results utilizing “parked” data (data collected with high-bandwidth trigger and processed after data-taking period was over)
- Large region of $\tan\beta$ – M_A plane excluded
 - m_H^{max} scenario is used (interpretation in other scenarios are being prepared)

Higgs Highlights $H \rightarrow \tau\tau$

- Evidence for the $H \rightarrow \tau\tau$ decay (PH-LHC Seminar)
 - <https://indico.cern.ch/conferenceDisplay.py?confId=285650>
 - Large excess, compatible with the SM Higgs boson



Higgs Highlights: $H \rightarrow \tau\tau$



- $VH(b\bar{b}) + H(\tau\tau)$ combination yields 4σ significance
 - Strong direct evidence for couplings to third generation fermions!

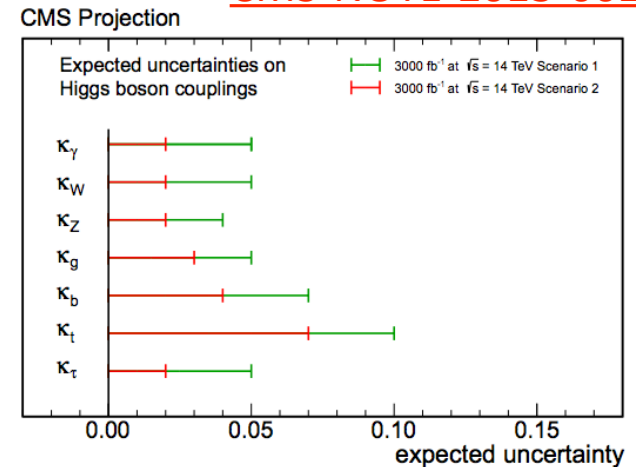
What's in the future

- Discovery of the Higgs opened a rich program to study its properties

- Quantum numbers, couplings, rare decays

- $H \rightarrow \mu\mu$ discovery at $> 5\sigma$ with $\sim 1000 \text{ fb}^{-1}$
- 2–10% precision on Higgs couplings with 3000 fb^{-1}

[CMS-NOTE-2013-002](#)

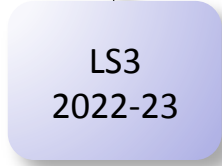


L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]	[7, 11]

- New phenomena

- Low mass stops with masses $< 900 \text{ GeV}$ can be discovered as early as with 300 fb^{-1}

CMS Upgrade program



LS1 consolidation: Complete/consolidate for nominal LHC beam conditions:
Prepare for: 13 TeV, 10^{34} Hz/cm², Ave. Pileup (<PU>)~25

- Complete Muon system (4th endcap station) and improve readout electronics
- Replace HCAL photo-detectors and backend electronics in a couple of regions
- Make it possible to operate the Tracker -20°C (almost 25 C colder than before)

Phase 1 upgrades: Prepare for 1.6×10^{34} Hz/cm², <PU> ~40, ≤ 200 fb⁻¹ by LS2
Prepare for 2.5×10^{34} Hz/cm², <PU> ~ 60, ≤ 500 fb⁻¹ by LS3

- New L1-trigger system ready for 2016 data taking
- New Pixels ready for installation in 2016/17 Year End Technical Stop (YETS)
- Install new HCAL photodetectors and electronics in 2015 YETS and LS2

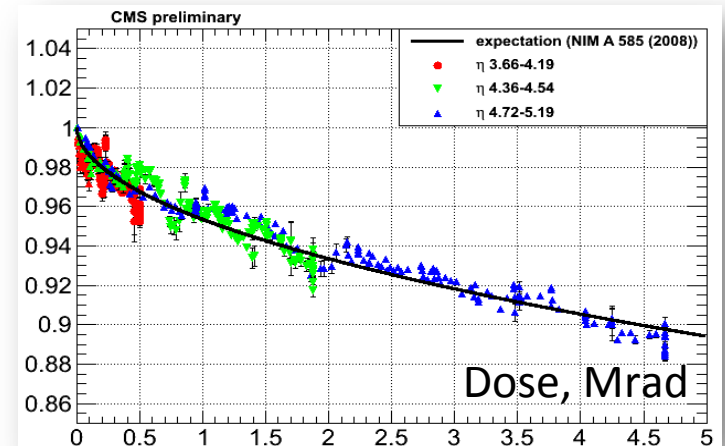
Phase 2 upgrades: Prepare for $\geq 5 \times 10^{34}$ Hz/cm², PU 140 to 200
Total of 3000 fb⁻¹ in ~10 yrs operation

- Replace subsystems that no longer function due to radiation damage
 - Tracker including Pixels, Endcap calorimeters
- Maintain physics performance at very high PU
 - New Electronics and Trigger, enhanced detector coverage

LS1: Preparing for Run 2

- Nearly doubling the center-of-mass energy offers a unique opportunity for an early discovery
- CMS is preparing for the nominal LHC beam conditions of Run 2:
 - $\sqrt{s} = 13$ TeV, 25 ns bunch spacing, and peak instantaneous luminosity $\sim 1.6 \cdot 10^{34}$ Hz cm²
 - Also preparing for early discoveries with 50 ns at the LHC ramp-up
 - High pileup environment
 - Estimate $\langle \text{PU} \rangle \approx 40$ by LS2
 - Radiation damage
 - Light loss (calorimeters)
 - Increased leakage current (Si)

Observed signal loss in HF quartz fibers, 2011+2012 Laser data vs Radiation dose



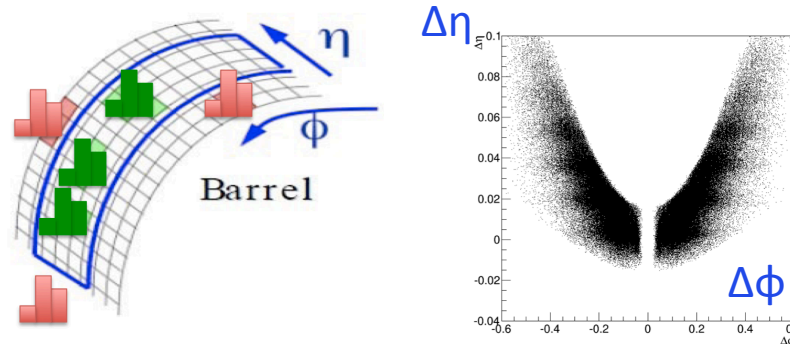


E
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295

Raw $\sum E_T \sim 2 \text{ TeV}$
14 jets with $E_T > 40 \text{ GeV}$
Estimated PU ~ 50

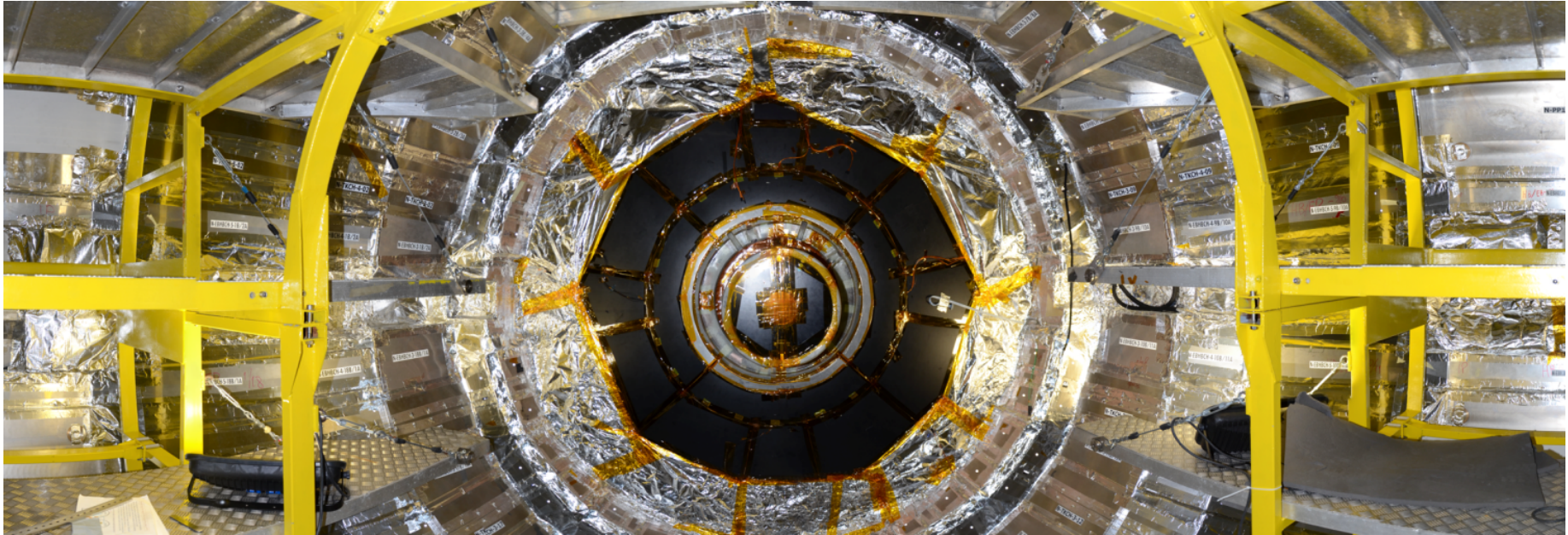
Preparing for Run 2

- HLT: path for Run 2 is defined and big improvements have been already achieved
 - Trigger: faster track finding, purification of physics objects
- Reconstruction software
 - CMS switched to particle-flow framework
 - Significant improvement in MET resolution, much better mitigation of the PU effects, etc.
 - Example: e/γ EM energy clustering



LS1 Highlights: Tracker

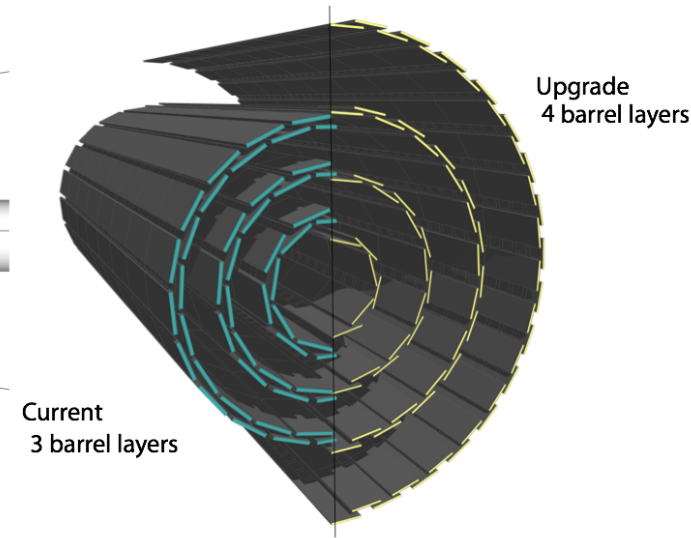
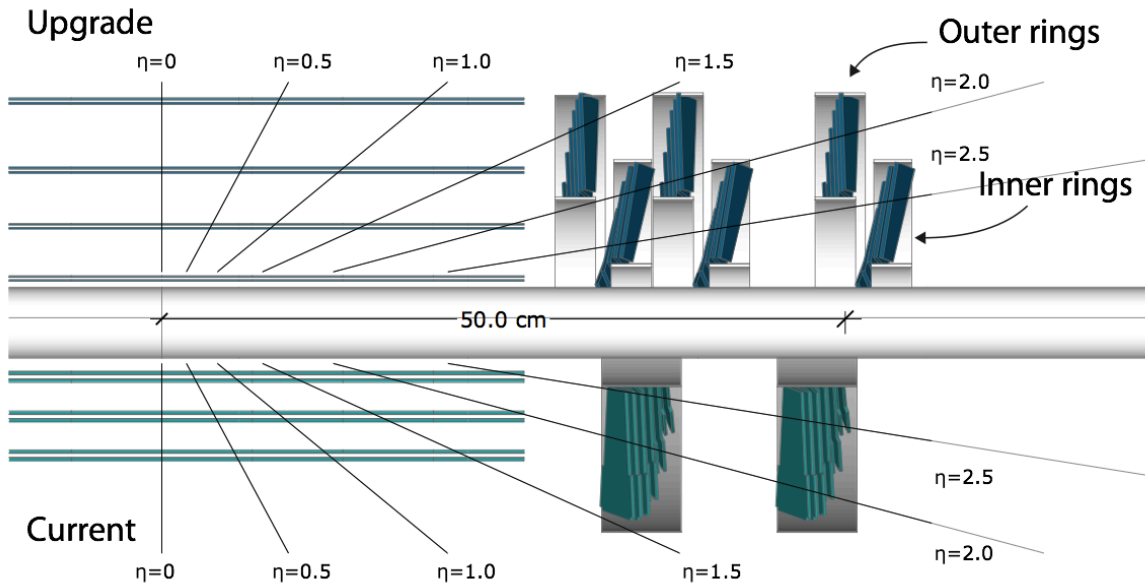
- “Tracker going cold” operation is a success
 - To ensure long-term performance of tracker



- Services are installed and commissioned and working
- Pixel work in P5
 - BPIX will be 98.9%, FPIX will be 100% operational
 - Calibration runs at low temperatures before insertion
 - More calibration will be necessary to get the best quality data

New Pixel Detector for Phase 1

[TDR: CMS-TDR-011](#)

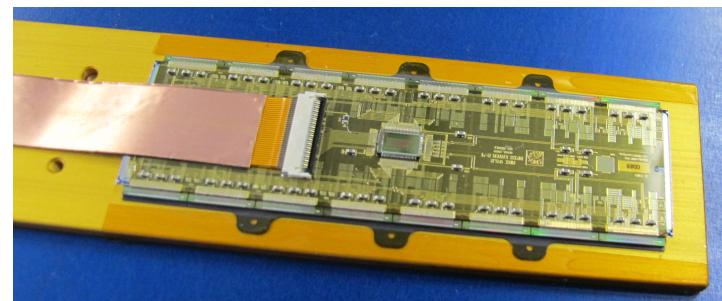


- **4 layers / 3 disks**
 - One more space point: smaller inner radius (3 cm)
- **New readout chip**
 - Recovers inefficiency at high rate and PU
- **Less material**
 - CO₂ cooling, new cabling and powering scheme (DC–DC)
- **Longevity**
 - Tolerate 100 PU and survive to 500 fb⁻¹, with exchange of innermost layer

New Pixel Detector Status

- Thorough understanding of system due to extensive test beam campaign
- Components
 - Final readout chip submitted (layer 2–4 & FPIX)
 - BPIX sensor ordered
 - BPIX pre-series HDI delivered and OK
 - FPIX pre-series sensors (6”) delivered and OK
 - Several BPIX modules built and tested
 - First FPIX modules back from bump bonding
 - HDI design finished – order after EDR
 - Good progress on mechanics prototyping including cooling pipes
 - Optical hybrid prototypes under test – look OK
- Common System and Integration
 - CO₂ cooling plant in TIF fully commissioned
 - Vacuum-jacketed CO₂ steal pipes will be installed January 2014
 - DAQ system design underway – μ TCA chosen as technology
 - DC-DC chip – prototypes work well
- **Pilot Blade system for installation in 2014 in preparation**

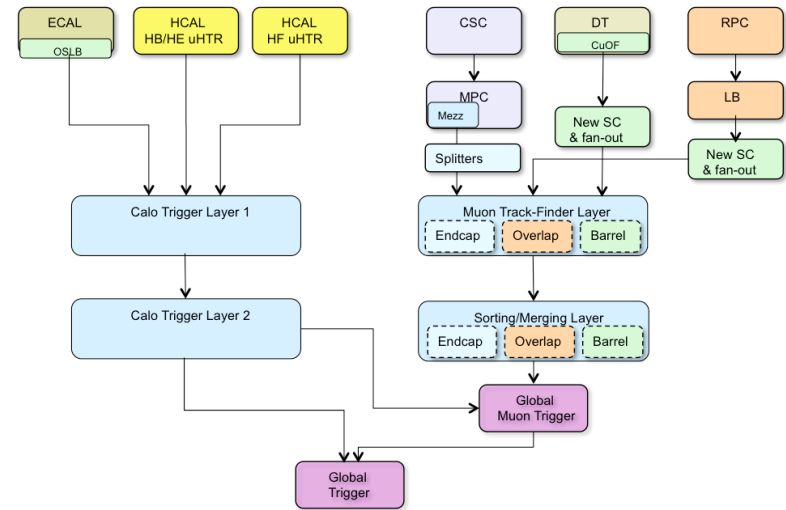
New BPIX module



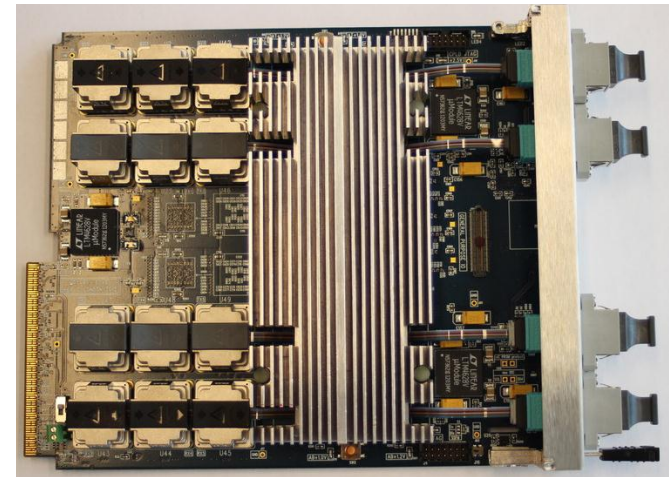
LS1/Phase 1: L1 Trigger

- Powerful FPGAs and high bandwidth optical links
- Upgrade the entire L1 Trigger
 - Calorimeter, Muon, Global
- Three types of boards
 - Using Virtex 7 FPGA
- Trigger input split during LS1
 - Full commissioning of new trigger in parallel to operating legacy system
- Staged approach:
 - Grow from slice tests to full system commissioning during 2015 → ready for physics in 2016

TDR: CMS-TDR-012

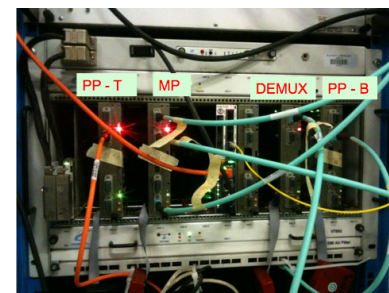
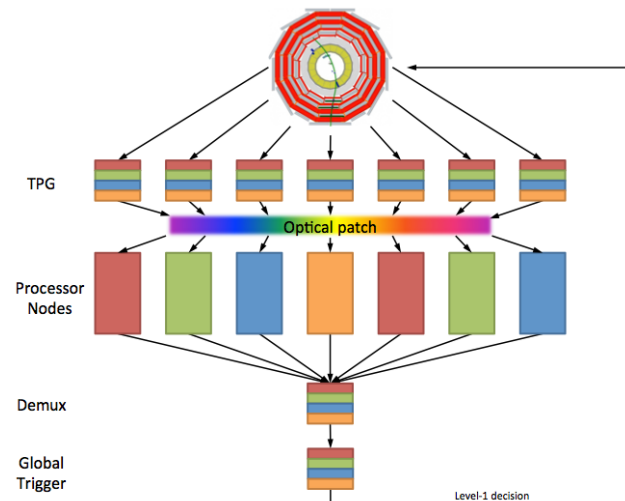


MP7 Processor Board
(Virtex 7, 72TX + 72RX links @ 10Gb/s)



L1 Trigger: Status

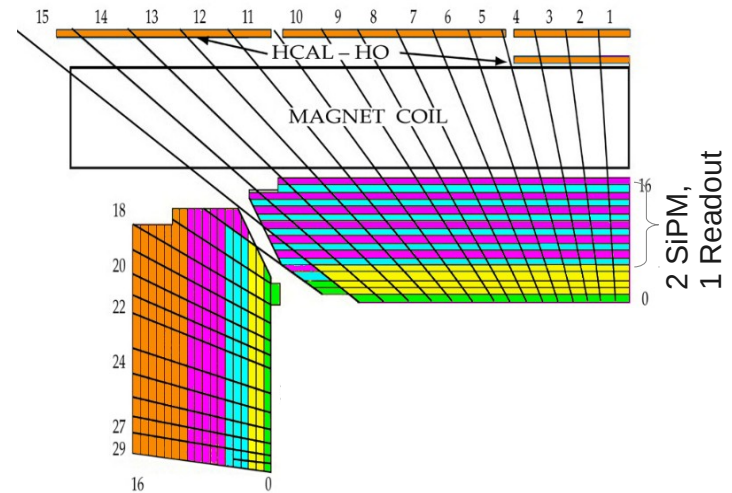
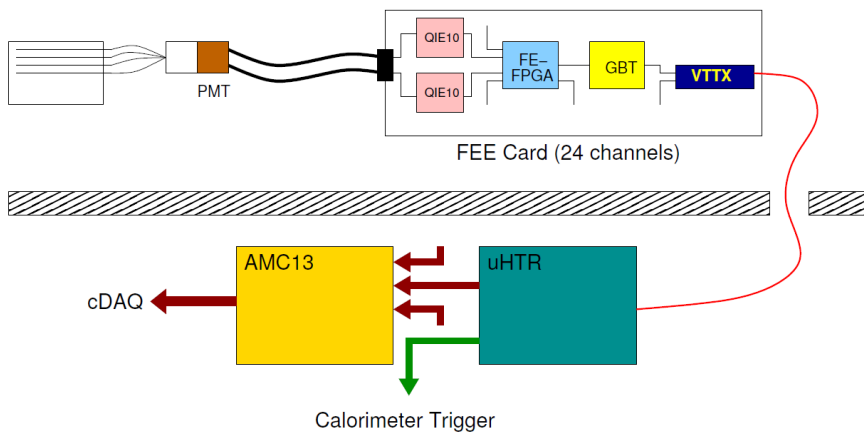
- Optical SLB and RM mezzanine boards
 - Allow parallel operation
 - New prototype with improved jitter cleaning
 - Test is successful
 - Full crate slice test (~30 cards) completed successfully
- CTP7 (calorimeter stage 1) and MTF7 (muon) prototype boards in production
 - Expected back this month
- MP7 (calorimeter stage 2 and global trigger) prototype boards fully tested
- Slice test of Time Multiplexed Calorimeter Trigger
 - 2 layer-1, 1 layer-2 processing nodes, demux card
 - Reliable transmission of data at 10 Gb/s, alignment on all links
 - Implementation of representative algorithms
 - Verification of latency expected



HCAL Upgrade

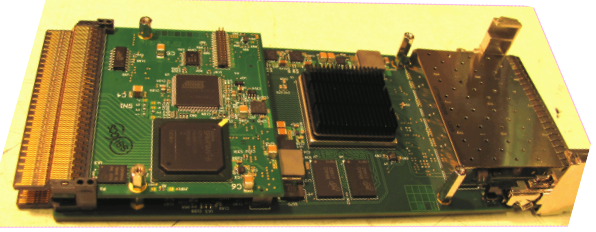
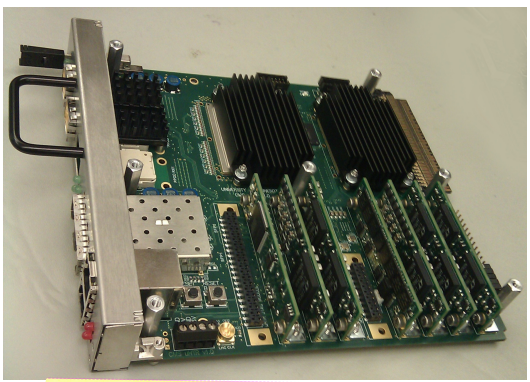
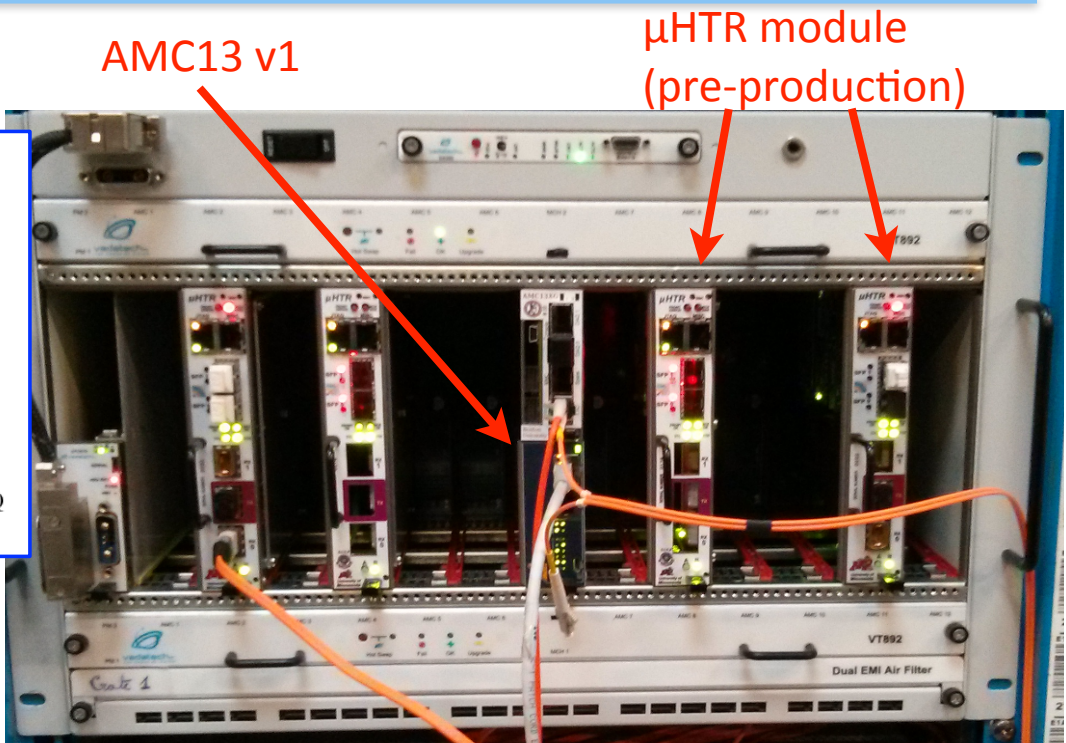
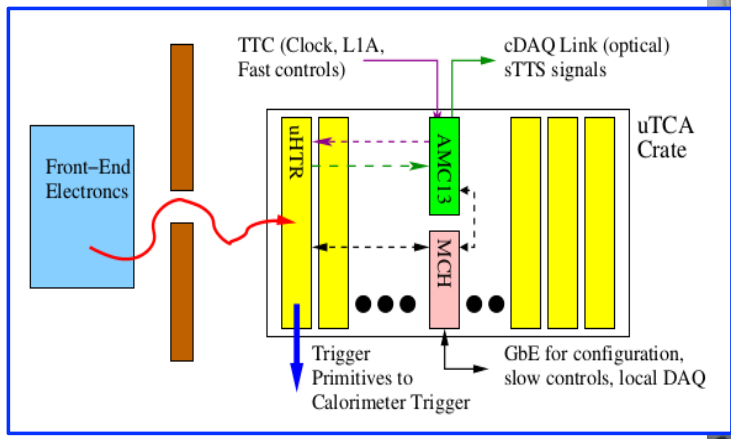
TDR: CMS-TDR-010

- **LS1: HO: HPD** → SiPMs
 - Small radiation tolerant package, stable in magnetic field
- **HF: PMT** → MAPMT, backend electronics upgrade to μ TCA
- **Phase 1: Replace HPDs in HB and HE with SiPMs**
 - Allows depth segmentation for improved measurement of hadronic showers, rejection of backgrounds, and re-weighting for radiation damage



- **New readout chip (QIE10)** optimized for SiPM, and in including a TDC
 - Improved rejection of beam-related backgrounds, particularly HF

HCAL Upgrade Status



- Pre-production backend board μHTR
 - Now in production for HF
 - Installation targeted for early 2014
- 10 Gb/s AMC13 DAQ board ready for production
 - Link tests with new trigger successful

LS1 Highlights: Muon

- Muon Endcap system

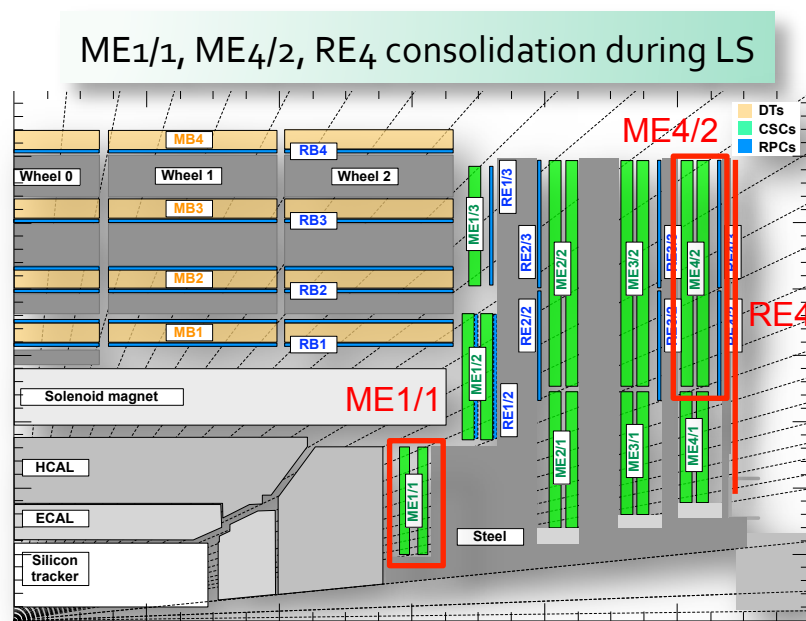
- ME1/1 with finer granularity
 - Optimize use of $2.1 < |\eta| < 2.4$
 - Replace chambers (+z: 23/36), FEE, and cabling

- ME4/2 stations & shielding
 - +z side is cabled up; gas flow began. Commissioning started

- RE4 installation
 - Super-modules for the first disk are ready to be installed; up to 6 SM per day is feasible

- Muon Barrel system

- Replacing trigger boards, installation of new electronics



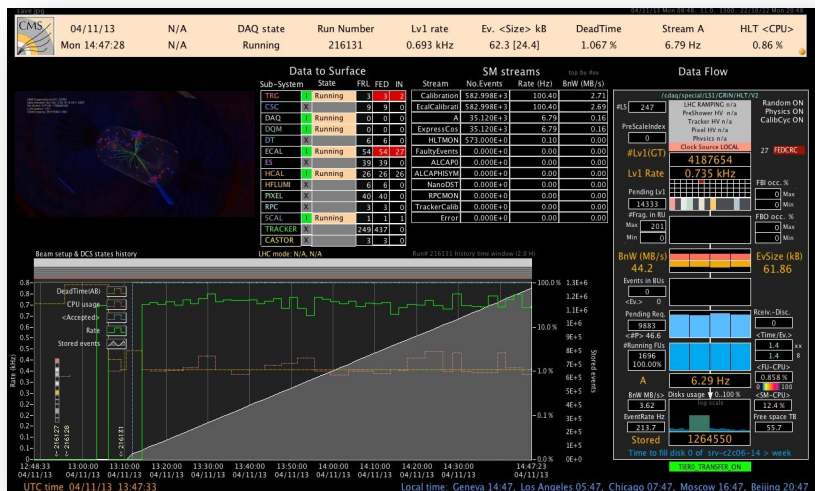
Commissioning for Run 2

- Dedicated commissioning time is necessary to ensure the detector readiness for 2015
- Global Run In November (GRIN):
 - Confirm ability to run and reconstruct cosmic data
 - Success!
 - DQM tested new features
 - Strips performance is fine for +4, 0, -5, and -10 °C
 - ECAL: EB- and EE- most of the time, monitoring data for transparency recovery
 - HCAL: HB, HE, parts of HO with new SiPMs
 - DTs successful run with three sectors in 2015 configuration
 - RPC participated with trigger and readout
 - CSC switched on 108/467 chambers

CMS Status

LHCC – Open Session

12/04/2013



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CMS Status

LHCC – Open Session

12/04/2013

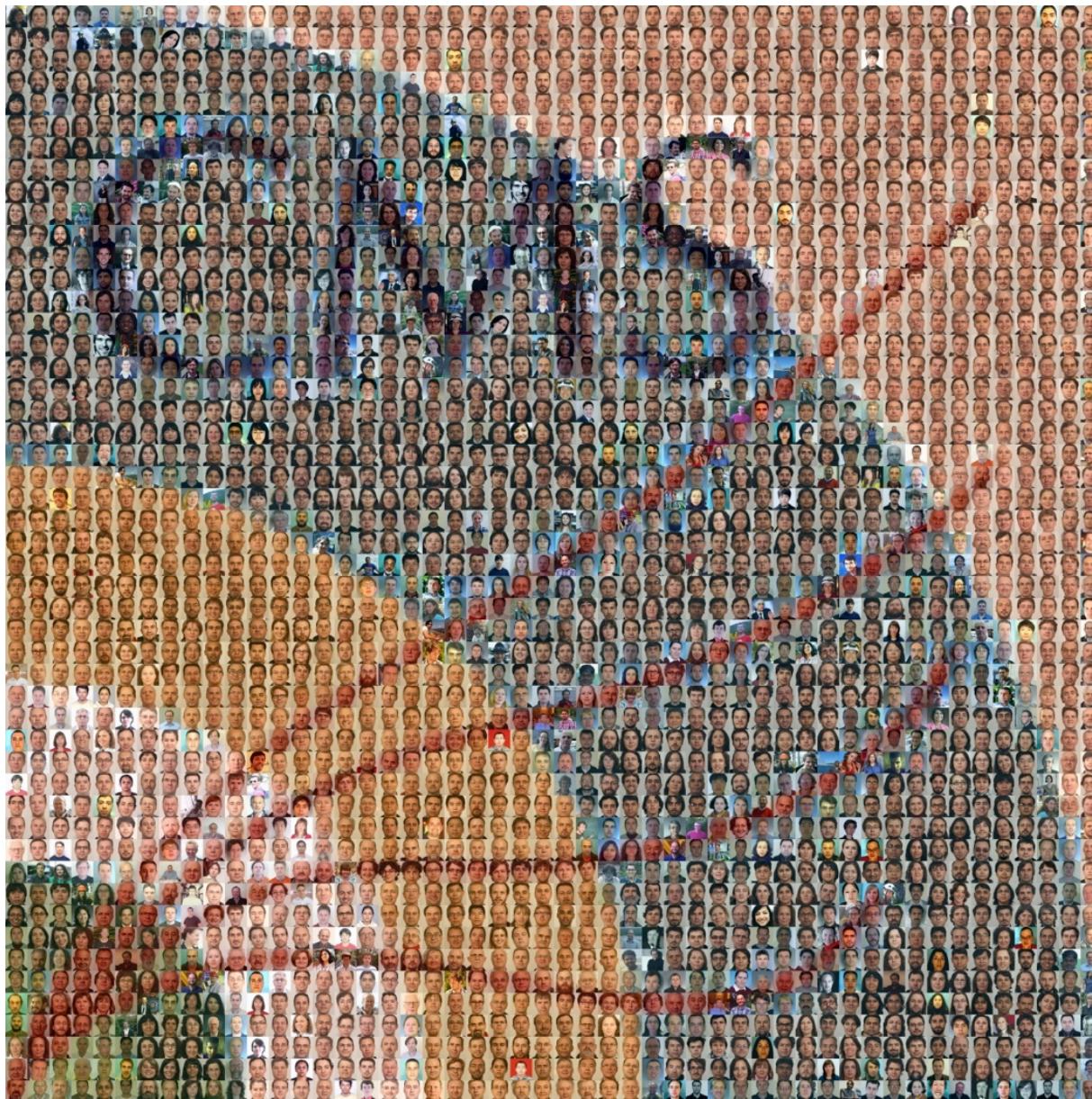


Both installation and commissioning activities are ongoing and on track for data taking in February 2015

Summary

- CMS is meeting all of its goals and challenges
 - Run 1 Physics
 - More than 300 papers submitted, expect > 100 by 2015
 - LS1
 - Work progress on schedule
 - Global run in November is a success!
 - In time to take physics data in 02/2015
 - Run 2 Preparations:
 - Much progress on better tools and procedures
 - Phase 1 Upgrades
 - All approved and moving forward on schedule
 - Phase 2 Upgrades
 - 27 physics studies for LH-LHC including performance tests of several proposed Phase 2 detectors
 - Work on documentation in progress

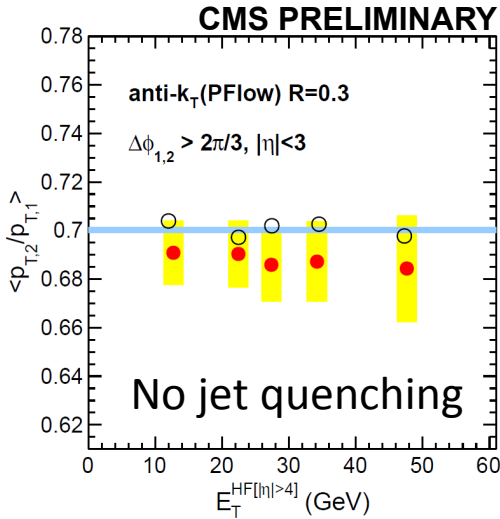
Backup



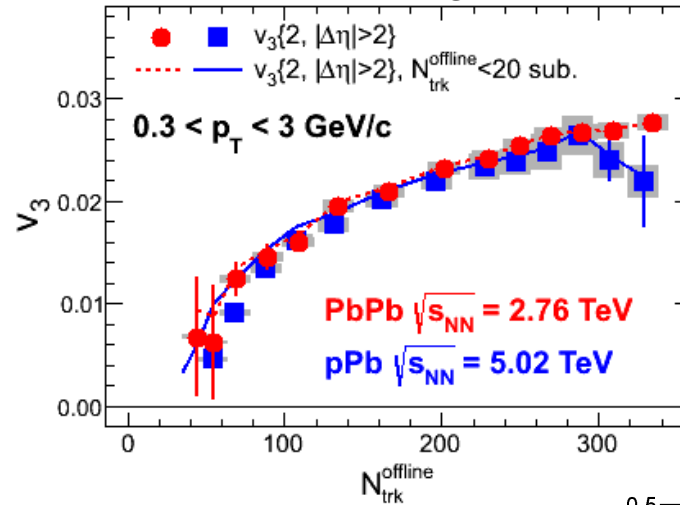
Heavy Ion Highlights: pPb

- Reference for PbPb, interesting in their own right

CMS-PAS-HIN-13-001



CMS PRELIMINARY

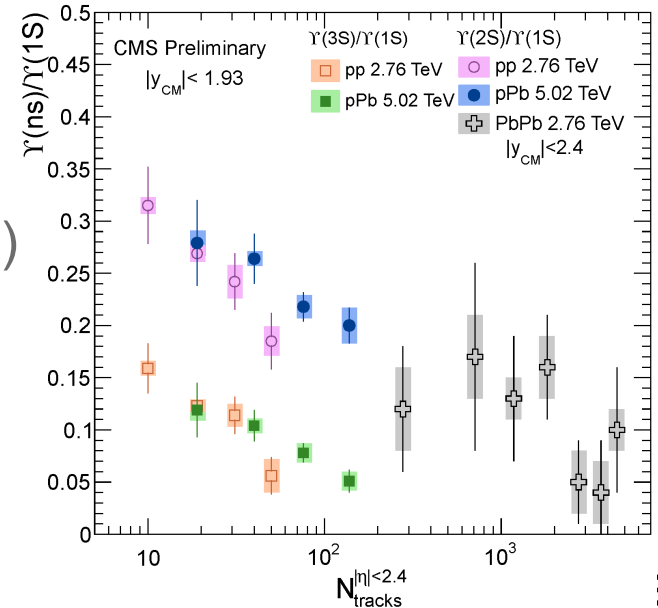


PLB 724 (2013) 213

Collective behavior in high-multiplicity events

- New analysis on $Y(nS)$ suppression
 - Significant dependence of the $Y(nS)/Y(1S)$ is observed
 - More data are needed to fully understand $Y(nS)$ production in pp, pPb, and PbPb collisions

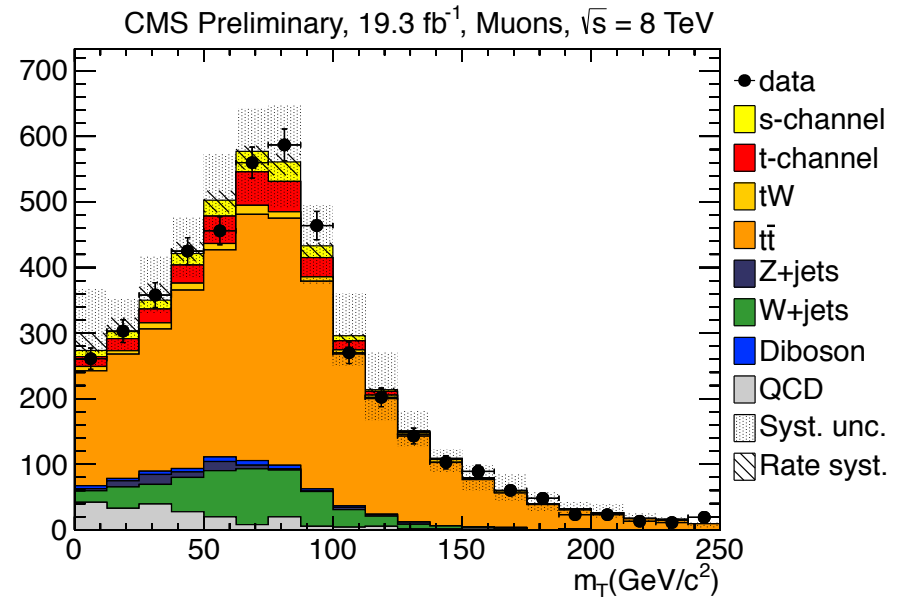
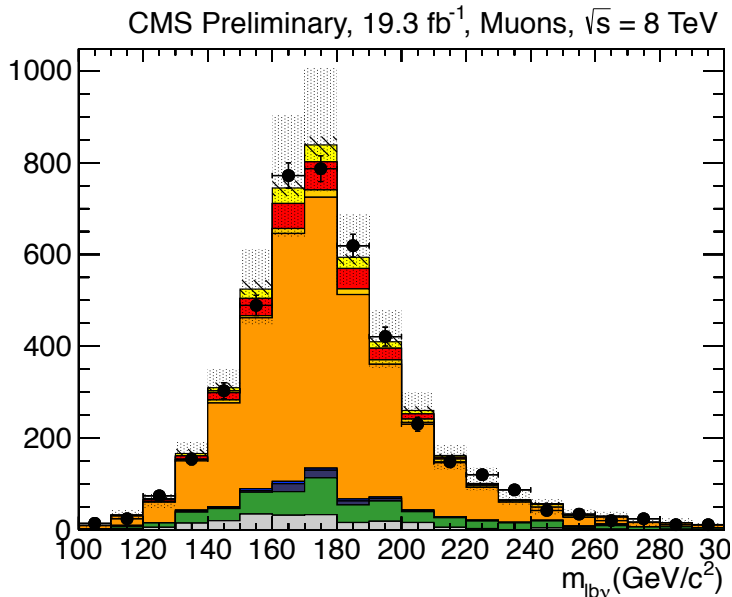
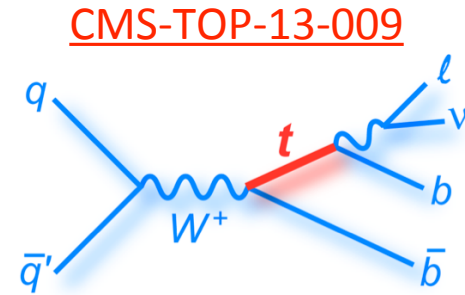
CMS-PAS-HIN-13-003



Top Physics Highlights

- Search for single top quark production in s -channel

- V_{tb} measurements; sensitivity to new physics

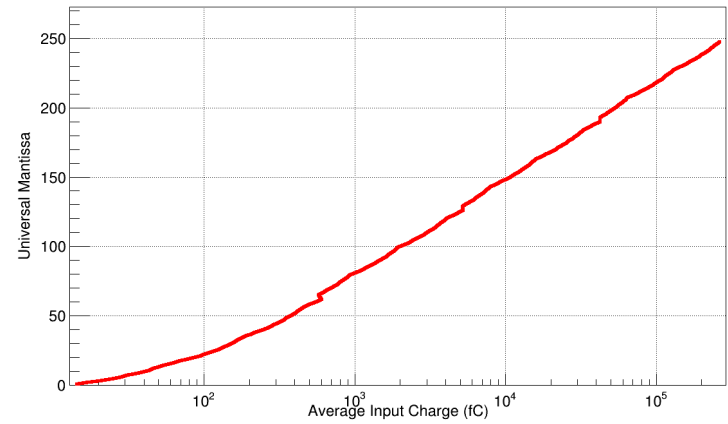


- $\sigma \cdot \text{Br} < 11.5 \text{ pb} @ 95\% \text{ C.L}$
 - Theory: $\sigma \cdot \text{Br} = 5.5 \pm 0.2 \text{ pb}$

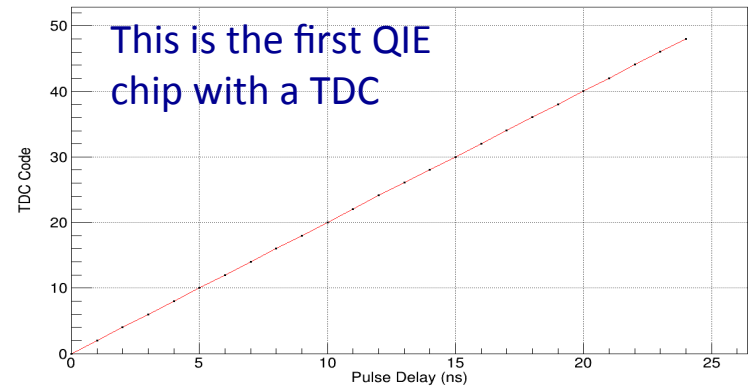
HCAL Frontend

- QIE10 (readout chip)
 - Preproduction chip performs extremely well for both charge and time measurements
 - SiPMs
 - Very successful R&D with several vendors
 - Improved PDE, radiation tolerance (up to 3000 fb^{-1}) and insensitivity to neutrons
 - S/N after 3000 fb^{-1} is better than present HPD
 - Pre-production SiPMs meet specification.
- Preparing for vendor selection

Mantissa Vs. Charge



TDC Code Vs. Delay



MPPCs, T=22 C

