

CMS Status

HEPAP Meeting

April 1, 2016

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Princeton University



CMS Publication Status

478 Publications

submitted or published

Exotica: 100

Standard Model: 84

Higgs boson: 64

Supersymmetry: 59

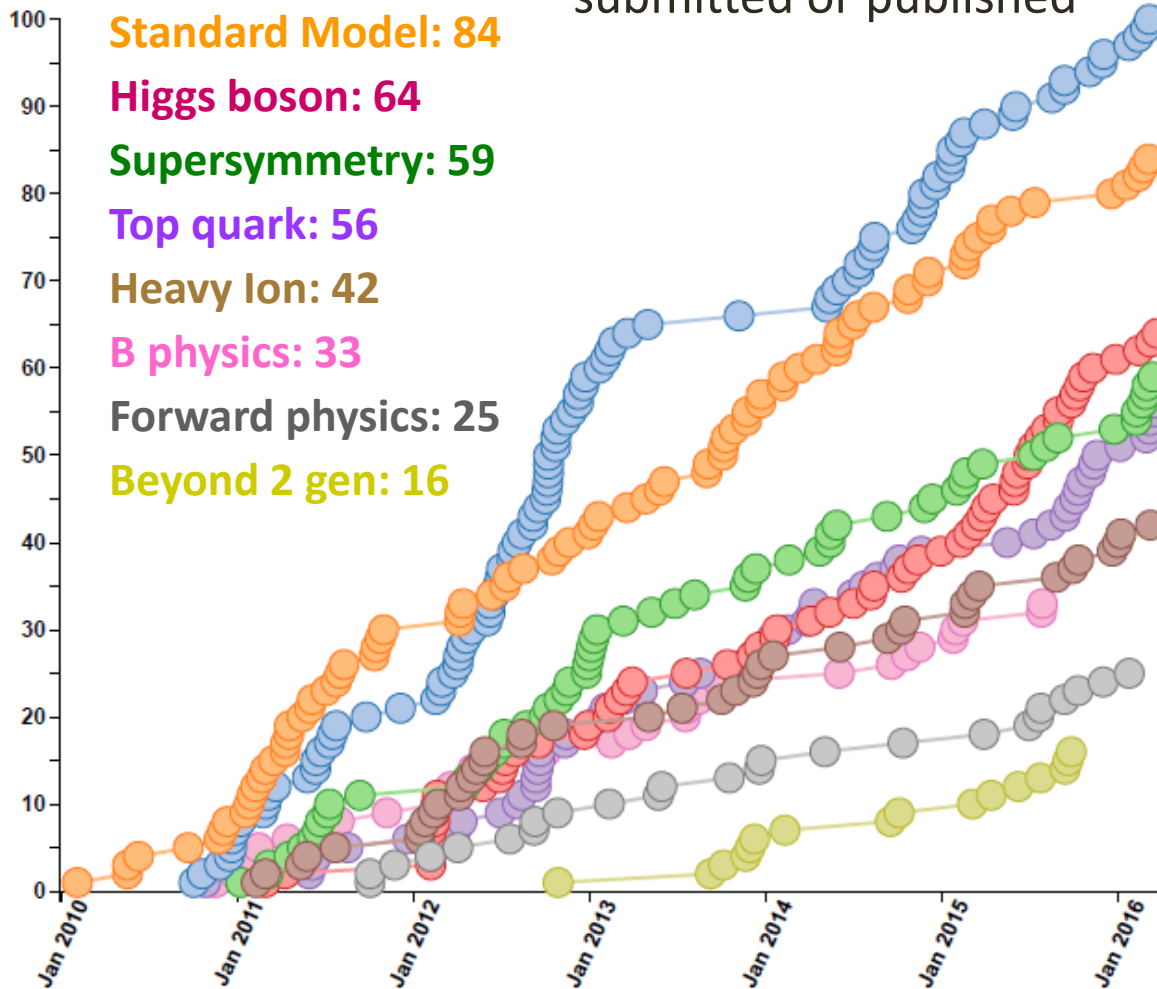
Top quark: 56

Heavy Ion: 42

B physics: 33

Forward physics: 25

Beyond 2 gen: 16



Run 2 publications:

6 papers submitted

- $dN/d\eta$ – first 13 TeV paper (**published**)
- **Search for dijet resonances** (**published**)
- $t\bar{t}$ cross section in dileptons (**published**)
- Two-particle correlations “the ridge” (submitted)
- **SUSY search in jets+MET** (submitted)
- **SUSY search in all-hadronic** (submitted)

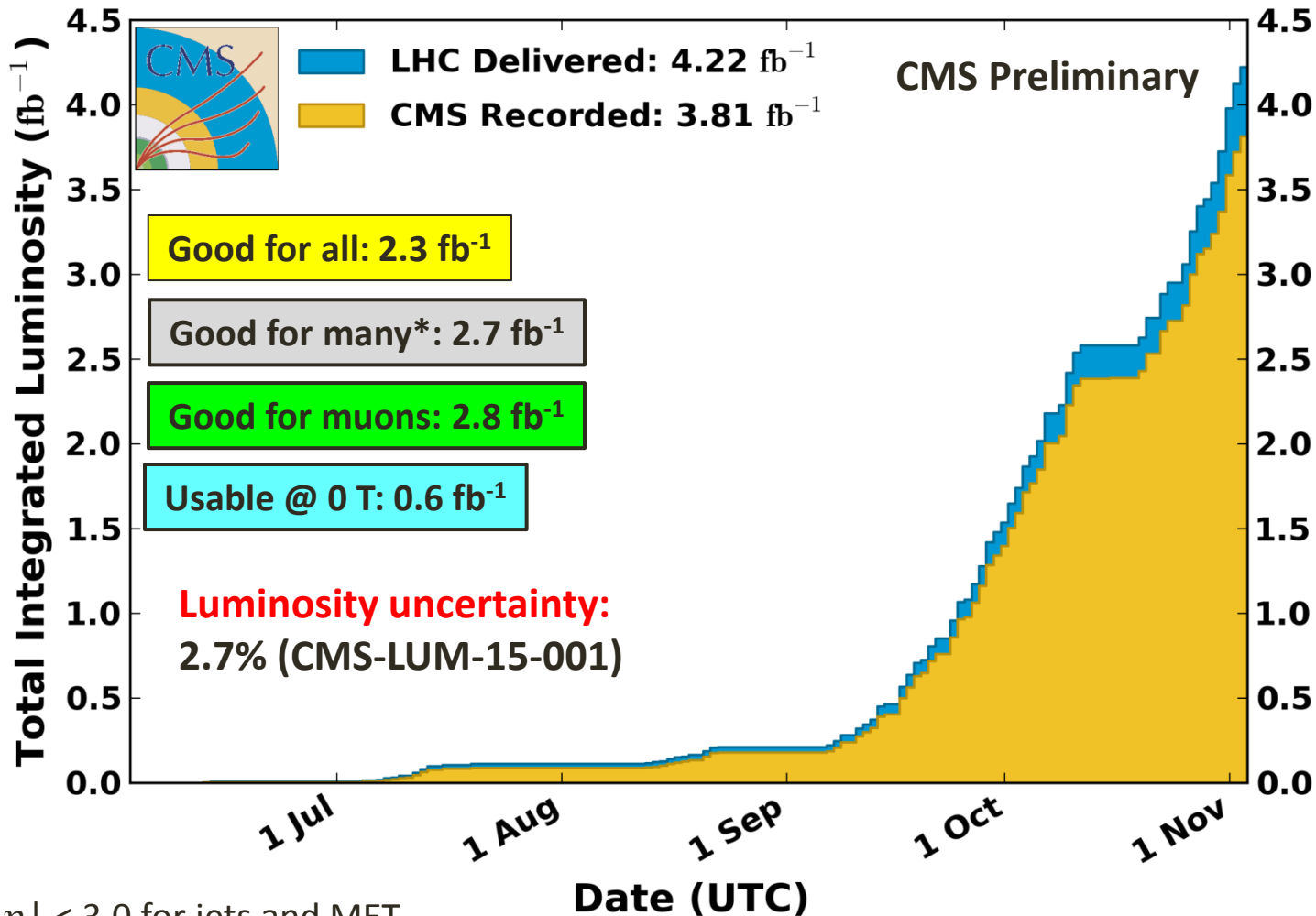
All CMS pubs: <http://cms-results.web.cern.ch/cms-results/public-results/publications/>



13 TeV dataset

CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13$ TeV

Data included from 2015-06-03 08:41 to 2015-11-03 06:25 UTC



* $|\eta| < 3.0$ for jets and MET



57 new results since Dec 15

18 new SM results (9 @ 13 TeV)

BPH-13-009: Observation of $BR(B^+ \rightarrow \psi(2S) \phi K^+)f$

BPH-15-005: Quarkonium production cross sections in pp collisions at $\sqrt{s} = 13$ TeV

FSQ-15-008: $dN/d\eta$ in different final states at 13 TeV

FSQ-12-004: Exclusive di-hadron production at 7 TeV

SMP-16-002: WZ cross section at 13 TeV with the full 2015 datasample

SMP-15-001: aTGC combination ATLAS+CMS using 7 TeV data

SMP-15-008: $V\gamma\gamma$ cross sections and limits on aQGC at 8 TeV

SMP-14-007: W-like mass measurement at 7 TeV

SMP-15-011: Differential measurements of inclusive Z boson production at 13 TeV

TOP-16-011: Top quark pair differential cross sections in the dilepton channel at 13 TeV

TOP-15-014: Measurement of the top quark mass in $t\bar{t}$ events with a J/psi from pp collisions at 8 TeV

TOP-16-009: Measurement of the top pair-production in association with a Z boson in pp collisions at 13 TeV

TOP-15-001: top quark mass from single top events

TOP-16-002: Determination of the top quark mass from leptonic observables at $\sqrt{s}=8$ TeV

TOP-16-005: Inclusive $t\bar{t}$ cross section in the dilepton channel at 13 TeV

TOP-16-001: Search for CP violation in top quark pair events at $\sqrt{s}=8$ TeV

TOP-16-008: Differential $t\bar{t}$ cross section in the $l+jets$ channel at 13 TeV

TOP-16-003: Inclusive single top cross section in t-channel at 13 TeV



57 new results since Dec 15

18 new Higgs results (12 @ 13 TeV)

HIG-16-008: Z(ll)H Higgs invisible search with 2015 data

HIG-14-041: Search for exotic decays of the Higgs boson to a pair of new light bosons with two muon and two b jets in final states

HIG-14-039: Search for doubly charged Higgs bosons at 8 TeV

HIG-15-011: Search for H to a1a1 to muon tau with 8 TeV data

HIG-15-005: First results on Higgs to gamma gamma at 13 TeV

HIG-16-012: Search for H(bb)H(tau tau) decays from non-resonant production (13 TeV)

HIG-16-013: Search for H(bb)H(tau tau) decays from resonant production (13 TeV)

HIG-15-004: First results on Higgs to ZZ to 4l at 13 TeV

HIG-15-008: First results on ttH multileptons at 13 TeV

HIG-16-001: First results on high mass H to ZZ to 2l2v at 13 TeV

HIG-16-004: Study of ttH, H to bb decays using the 2015 data sample

HIG-16-010: Search for A/H to Z(ll)+H/A(bb) with 2015 data

HIG-15-013: Model independent search for Higgs boson pair production in the bbt tau tau final state (8 TeV)

HIG-16-007: Summary results of high mass BSM Higgs searches using CMS run-I data

HIG-16-002: Search for H(bb)H(bb) decays using the 2015 data sample

HIG-16-014: Search for Higgs to Zg decays in an extended mass range at 8 TeV

HIG-16-011: Search for H(WW)H(bb) decays using the 2015 data sample

HIG-16-009: VBF Higgs invisible search with 2015 data



57 new results since Dec 15

21 new searches (18 @ 13 TeV)

- B2G-15-007: Search for Dark Matter with b quarks (13 TeV)
- B2G-15-002: Search for $t\bar{t}$ resonances in the semileptonic final state at $\sqrt{s}=13$ TeV
- B2G-15-008: Search for single production of $T' \rightarrow tH$ with a lepton and Higgs tag (13 TeV)
- B2G-16-002: Search for VLQ pair production in leptonic final states (13 TeV)
- B2G-16-004: Search for VW in semileptonic final states: low mass extension (13 TeV)
- B2G-15-001: Search for monotop in the muon channel in proton-proton collisions at 8 TeV
- B2G-16-003: Search for VH in the $(l l, l \nu, \nu \nu)bb$ final state (13 TeV)
- EXO-16-007: Search for pair production of second generation leptoquarks (13 TeV)
- EXO-16-018: Updated search for high mass-resonances in diphoton final state including OT data (13 TeV)
- EXO-14-006: Search for leptophobic Z' decaying into four leptons in the final state at $\sqrt{s} = 8$ TeV
- EXO-16-019: Search for high-mass resonances in $Z(l\bar{l})\gamma$ final states (13 TeV)
- EXO-16-006: Search for W' in tau plus MET final state (13 TeV)
- EXO-16-002: Search for type-III seesaw mechanism in multilepton final states (13 TeV)
- SUS-15-006: Search for supersymmetry in events with one lepton (13 TeV)
- SUS-16-003: Search for SUSY with multileptons in 13 TeV data
- SUS-16-004: Further SUSY Simplified Model interpretations for Moriond 2016 (13 TeV)
- SUS-14-022: Search for stau and chargino pair production in di-tau final states (8 TeV)
- SUS-16-002: Search for stop pairs in the 1L final state with 13 TeV data
- SUS-16-007: Search for stop pairs in the 0L final state at 13 TeV (Combined)
- SUS-15-012: Search for SUSY in diphoton plus Jets and MET (13 TeV)
- SUS-16-001: Search for sbottom quarks with 13 TeV data

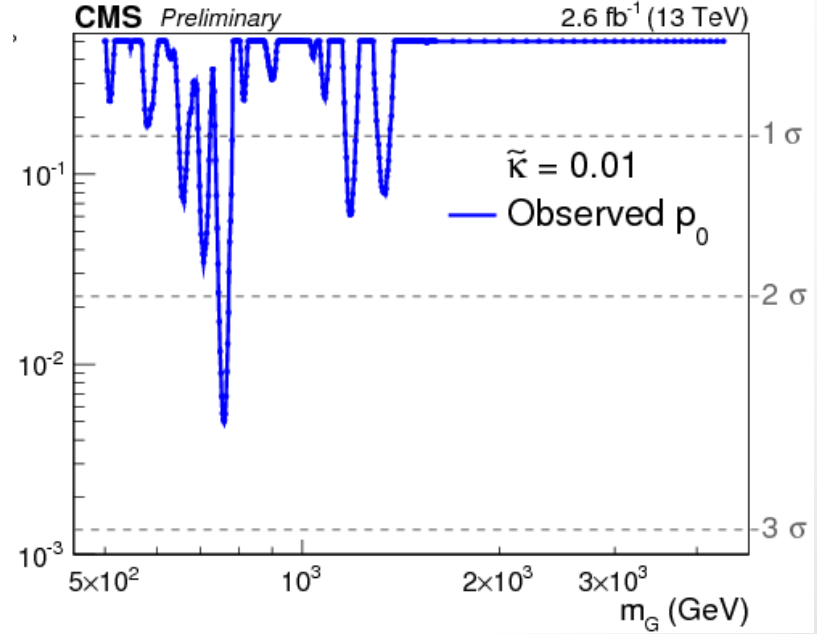
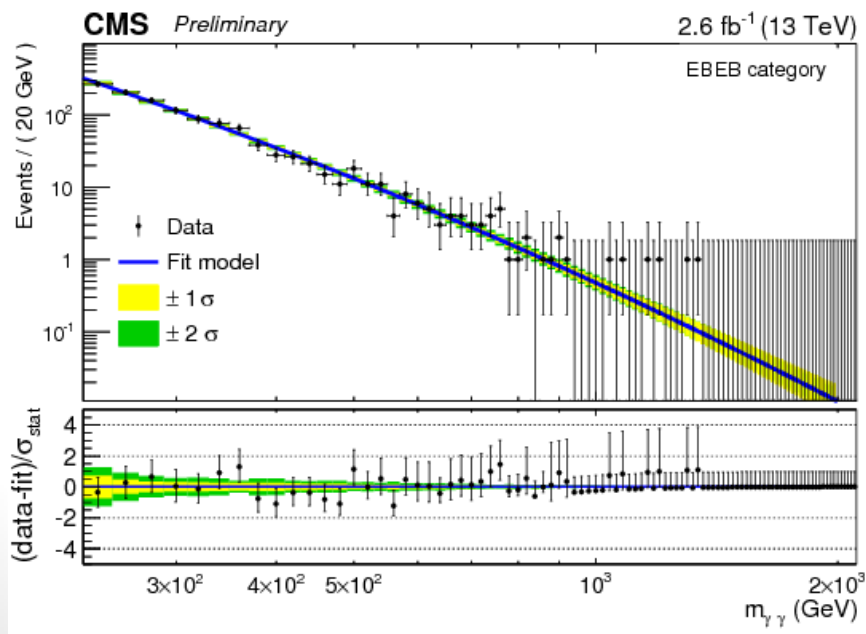
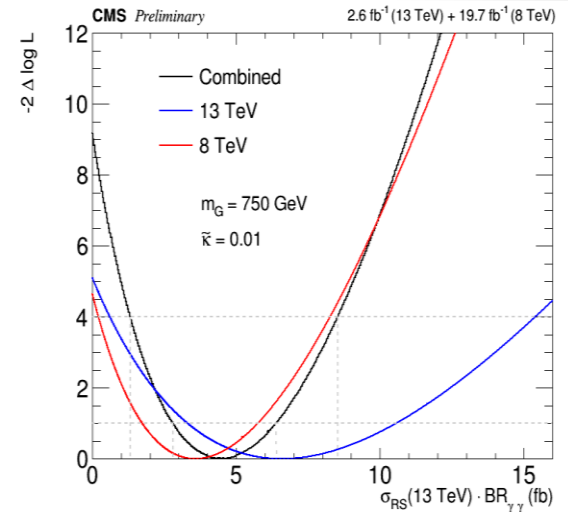


Recent Physics Highlights



Diphoton search (Dec 2015)

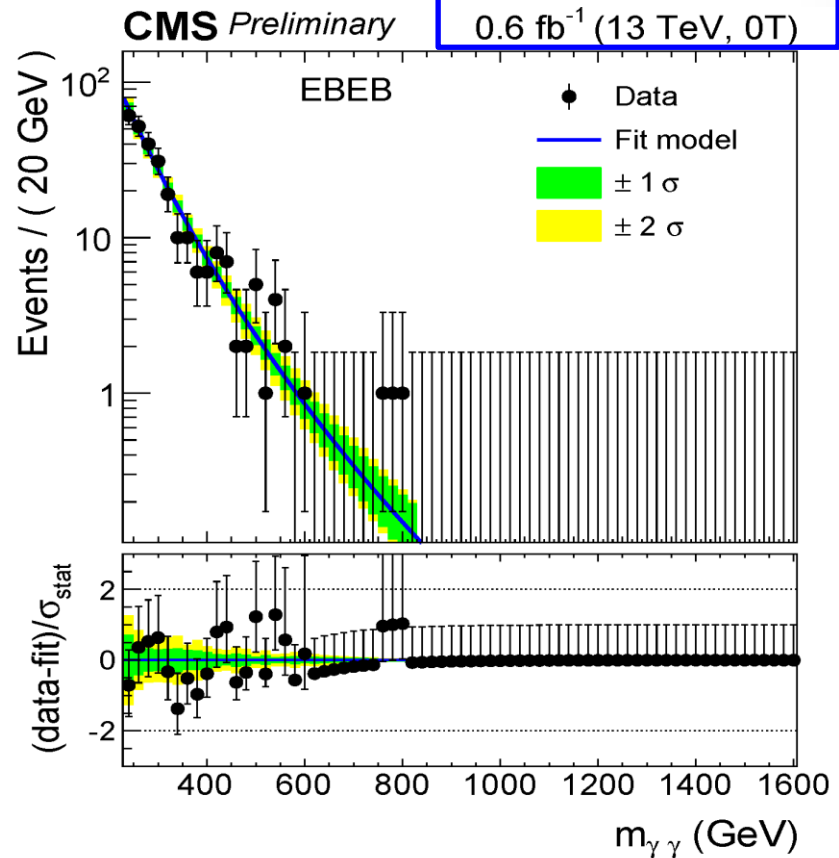
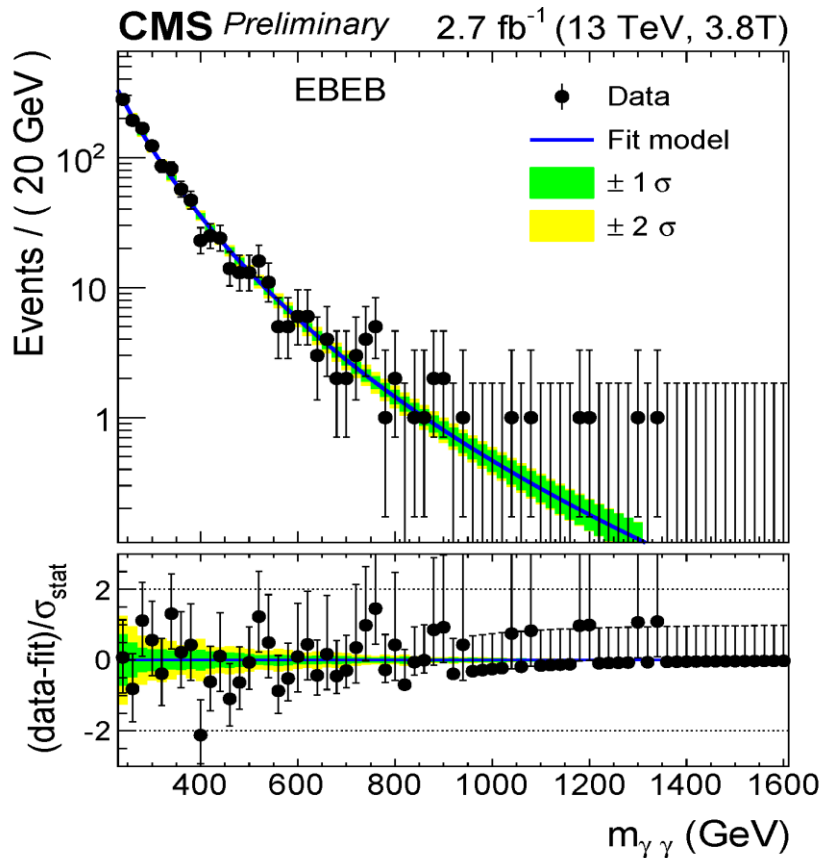
- **Small excess seen near 750 GeV**
 - 13 TeV: 2.6σ local significance @ 760 GeV
 - Combination with 8 TeV: 3σ @ 750 GeV
 - ATLAS sees 'something similar'
 - CMS favors narrow width, but compatible with larger width implied by ATLAS result (and vice versa)



Updated results (Mar 2016)

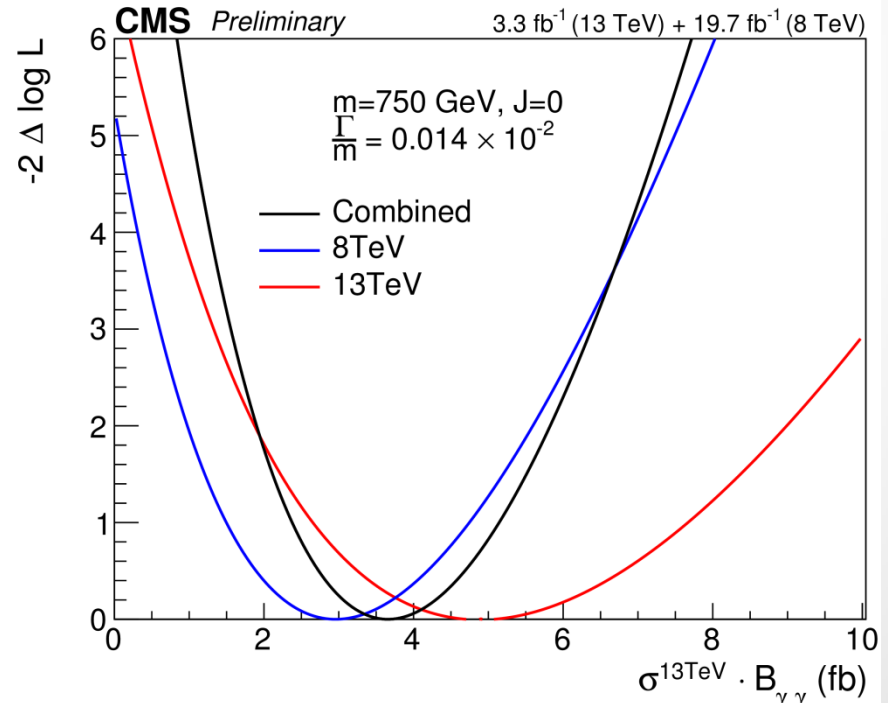
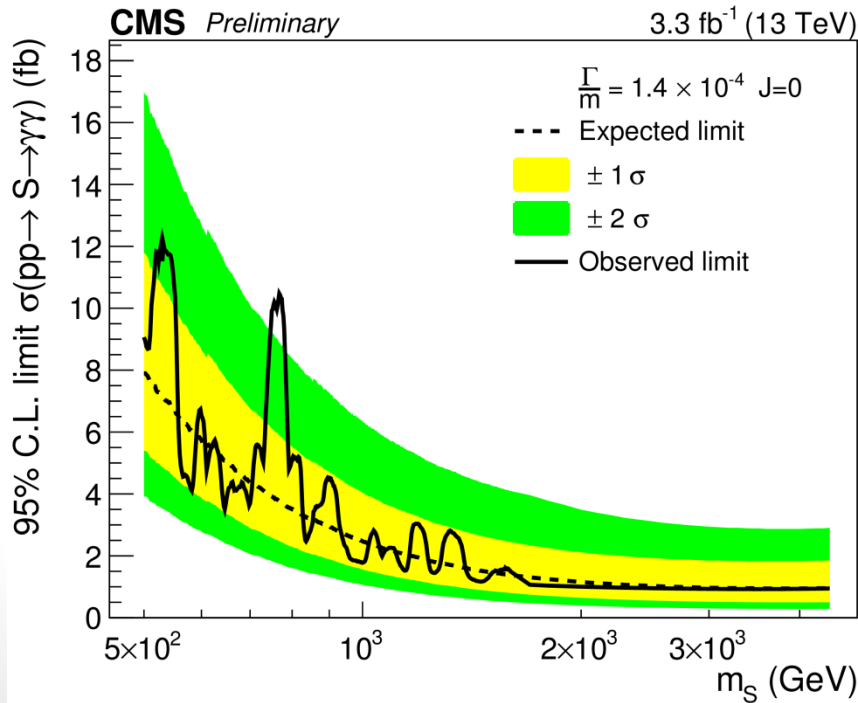
- **Updated analysis relative to results shown in December**

- Data re-reconstructed with latest calibrations (resolution 30% better)
- OT data added to analysis (quite a challenge!)
 - > **Together, expected sensitivity improves by 20%**
- Also added spin 0 interpretation



Updated results (Mar 2016)

- **New result compatible with previous result**
 - Local significance now 3.4σ , slight increase coming from 0T data (1 event)
 - **Global significance 1.6σ** accounting for mass range, spin, and width
 - **Eagerly awaiting 2016 data!**



Bounds on other decay modes

CMS has first 13 TeV results on 6 related channels

final state f	σ at $\sqrt{s} = 8$ TeV		implied bound on $\Gamma(S \rightarrow f)/\Gamma(S \rightarrow \gamma\gamma)_{\text{obs}}$
	observed	expected	
$\gamma\gamma$	< 1.5 fb	< 1.1 fb	< 0.8 ($r/5$)
$e^+e^-, \mu^+\mu^-$	< 1.2 fb	< 1.2 fb	< 0.6 ($r/5$)
$\tau^+\tau^-$	< 12 fb	< 15 fb	< 6 ($r/5$)
$Z\gamma$	< 11 fb	< 12 fb	< 6 ($r/5$)
ZZ	< 12 fb	< 20 fb	< 6 ($r/5$)
Zh	< 19 fb	< 28 fb	< 10 ($r/5$)
hh	< 39 fb	< 42 fb	< 20 ($r/5$)
W^+W^-	< 40 fb	< 70 fb	< 20 ($r/5$)
$t\bar{t}$	< 450 fb	< 600 fb	< 300 ($r/5$)
invisible	< 0.8 pb	-	< 400 ($r/5$)
$b\bar{b}$	$\lesssim 1$ pb	$\lesssim 1$ pb	< 500 ($r/5$)
jj	$\lesssim 2.5$ pb	-	< 1300 ($r/5$)

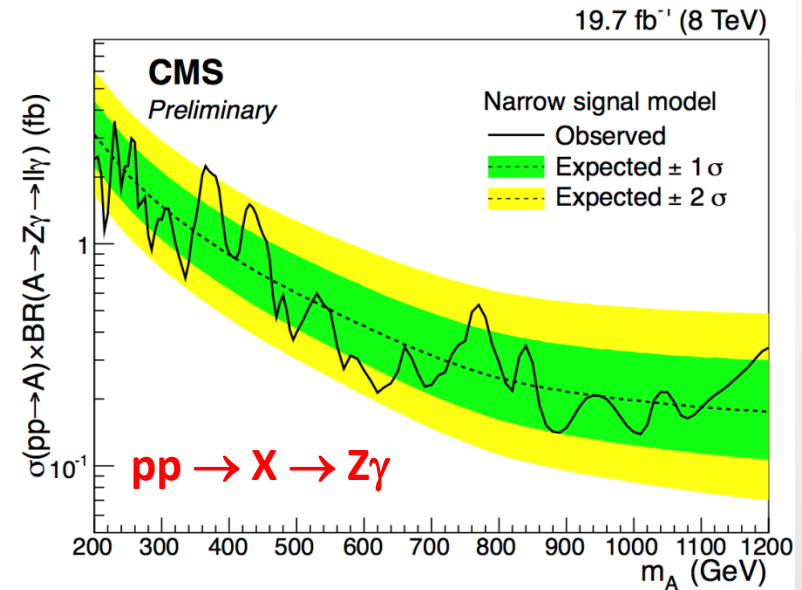
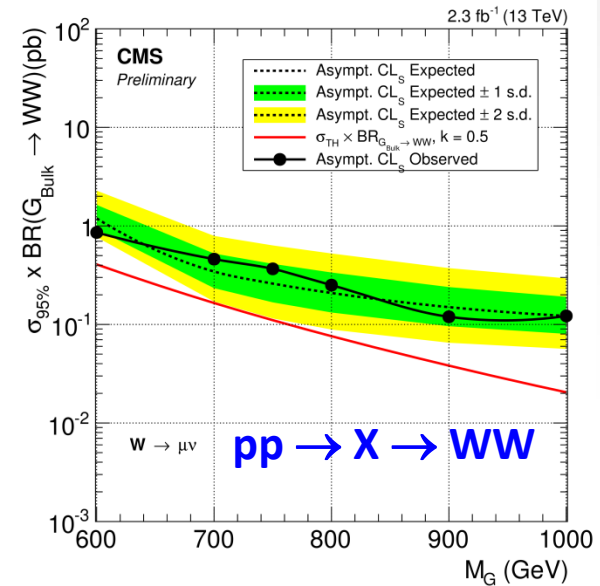
Here $r = \sigma_{13 \text{ TeV}}/\sigma_{8 \text{ TeV}}$. Using run 2 data only would be safer. Run 2 jj ?

Even invisible modes are constrained

Slide from talk by A. Strumia, Moriond EW 2016

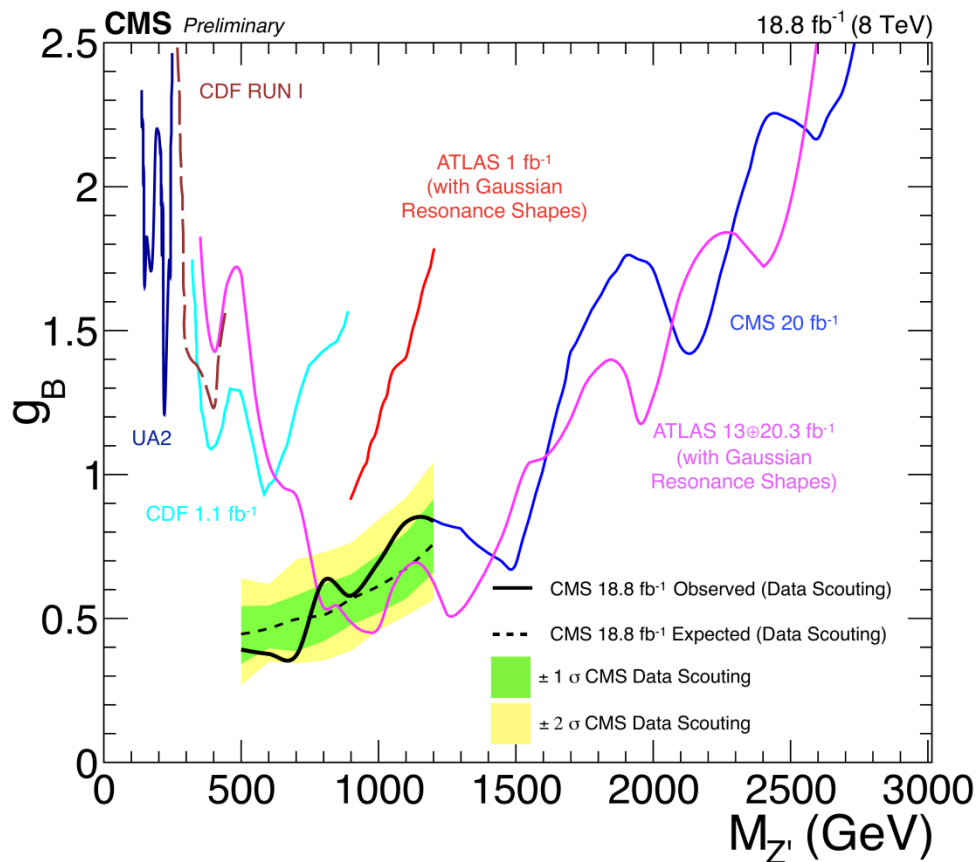
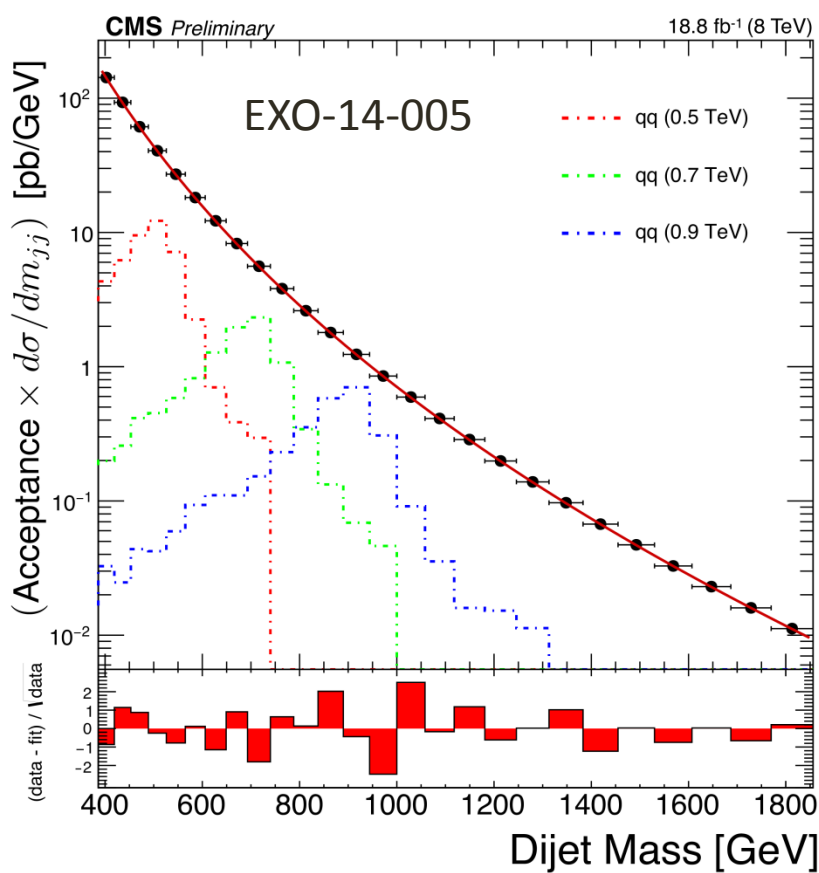
Searches relevant for X(750)

- **$pp \rightarrow X \rightarrow Z\gamma \rightarrow (\mu\mu, ee)\gamma$**
 - EXO-16-010 (13 TeV), HIG-16-014 (8 TeV)
- **$pp \rightarrow X \rightarrow ZZ$**
 - 4 lepton: HIG-15-004
 - 2l 2 ν : HIG-16-001
- **$pp \rightarrow X \rightarrow ZH(125)$**
 - H(125) \rightarrow bb: B2G-16-003
- **$pp \rightarrow X \rightarrow HH$**
 - bbbb: HIG-16-002
 - bb $\tau\tau$: HIG-16-013 (13 TeV), HIG-15-013 (8 TeV)
 - WWbb: HIG-16-011
- **$pp \rightarrow X \rightarrow WW$**
 - lvqq: B2G-16-004
- **$pp \rightarrow X \rightarrow t\bar{t}$**
 - B2G-15-002



Searching for $X(750) \rightarrow jj, bb$?

Difficult, but not impossible with “data scouting” technique...

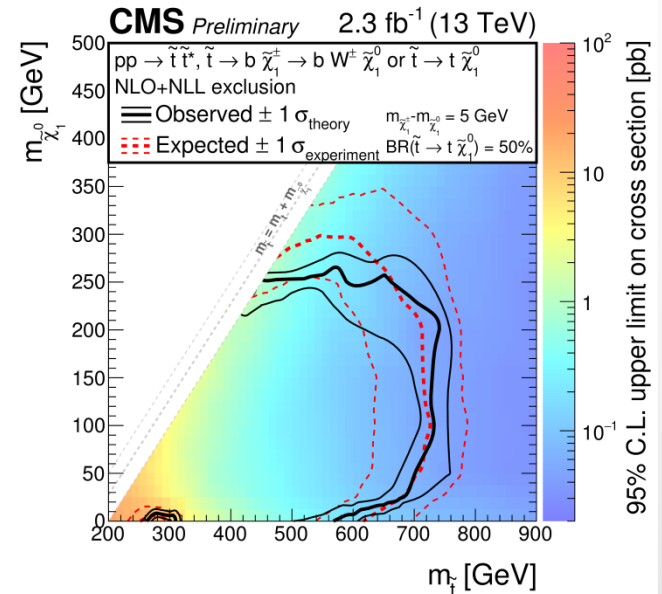
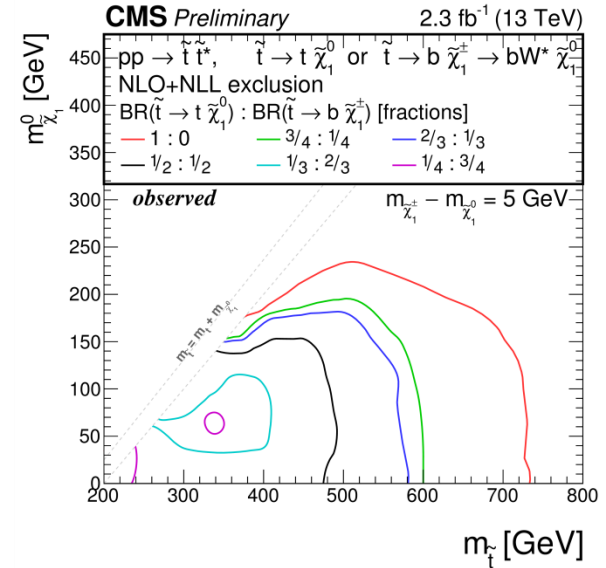
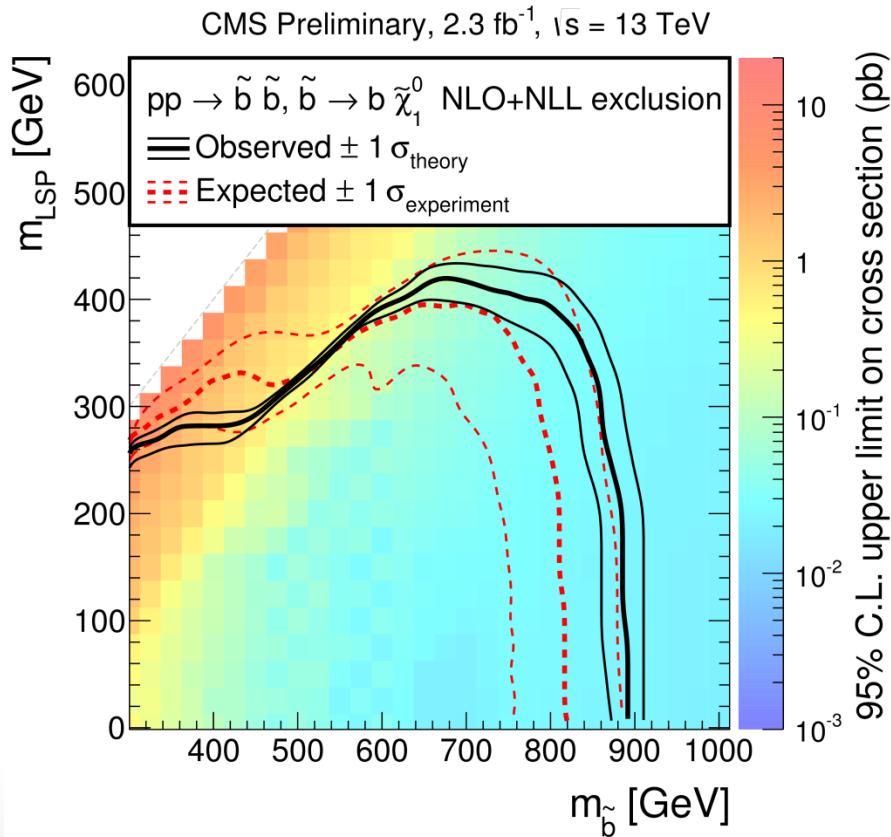


... scouting with b tagging also possible



Other searches: stop and sbottom

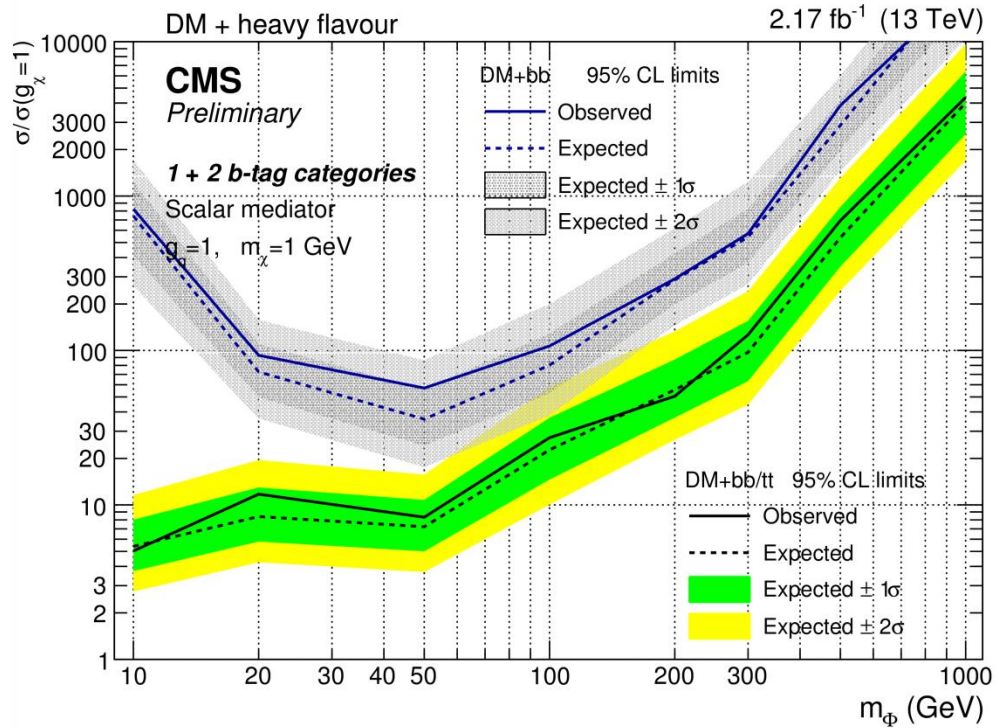
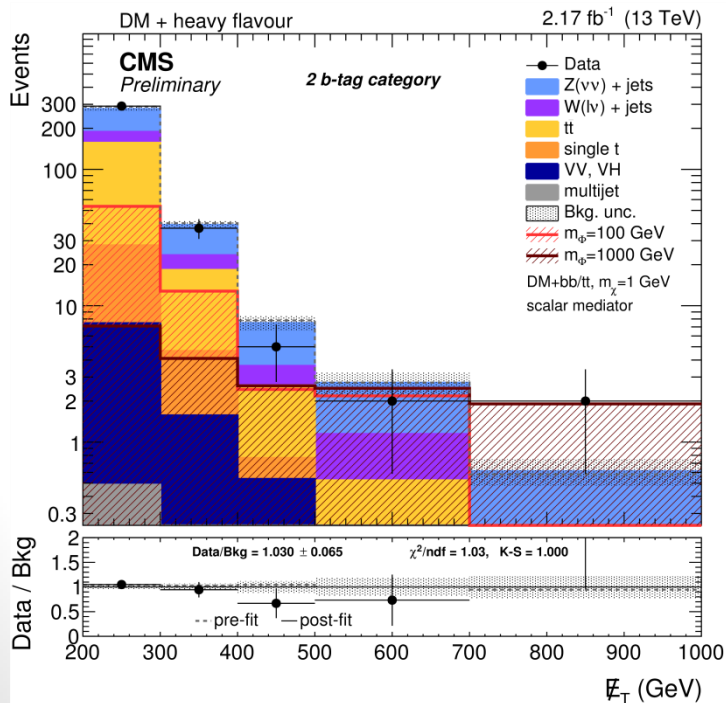
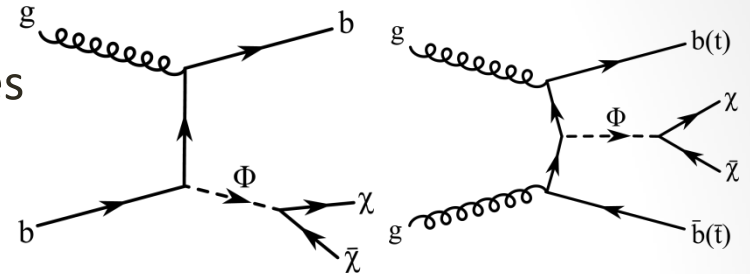
- **8 new results from the SUSY group**
 - stop searches in 1-lepton and all-hadronic
 - sbottom search
 - SUSY searches with leptons, γ +MET+jets



Other searches: dark matter

- First searches in CMS for dark matter produced in association with bottom or top quarks**

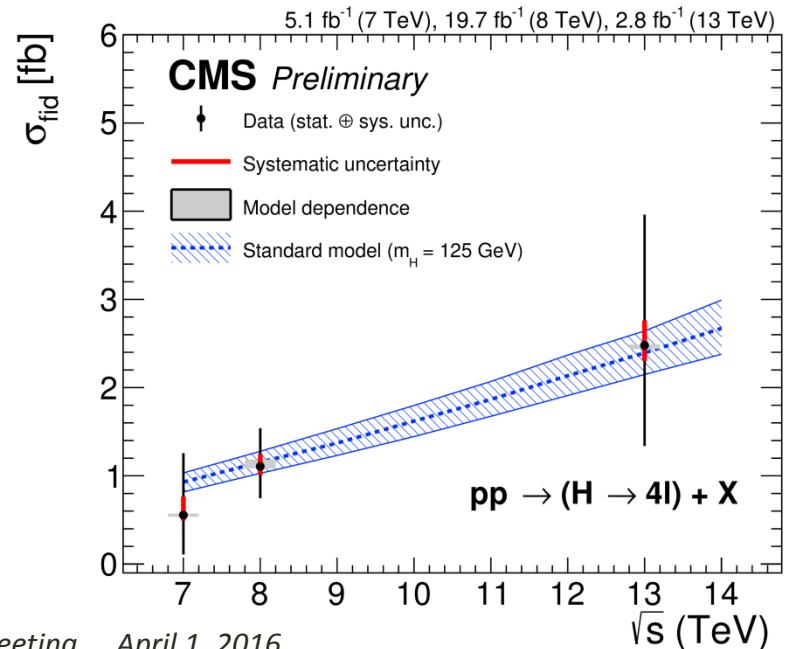
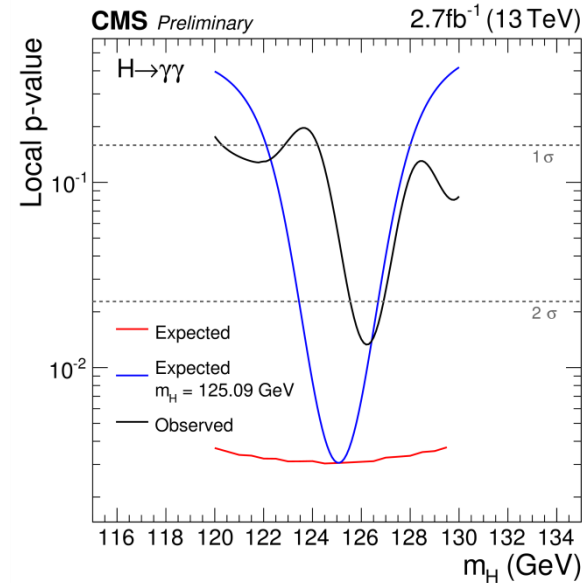
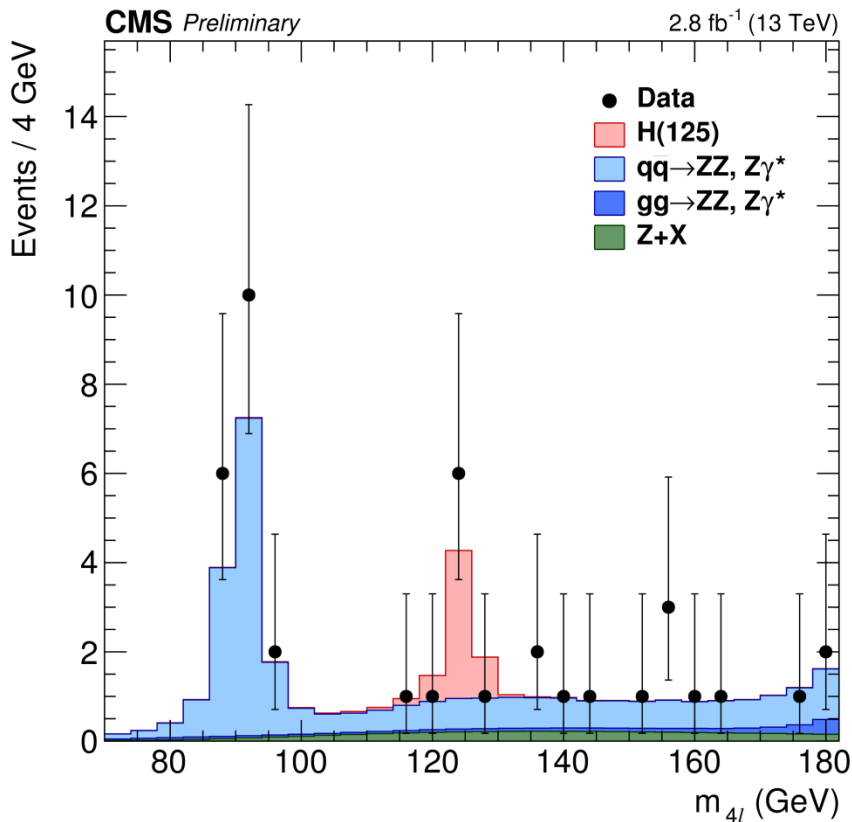
- Analysis searches in 1- and 2-tag samples
- Sensitive to $b(b)+DM$ and $t(t)+DM$
- Cross section limits set for scalar and pseudoscalar mediator assumptions



Re-establishing H(125) @ 13 TeV

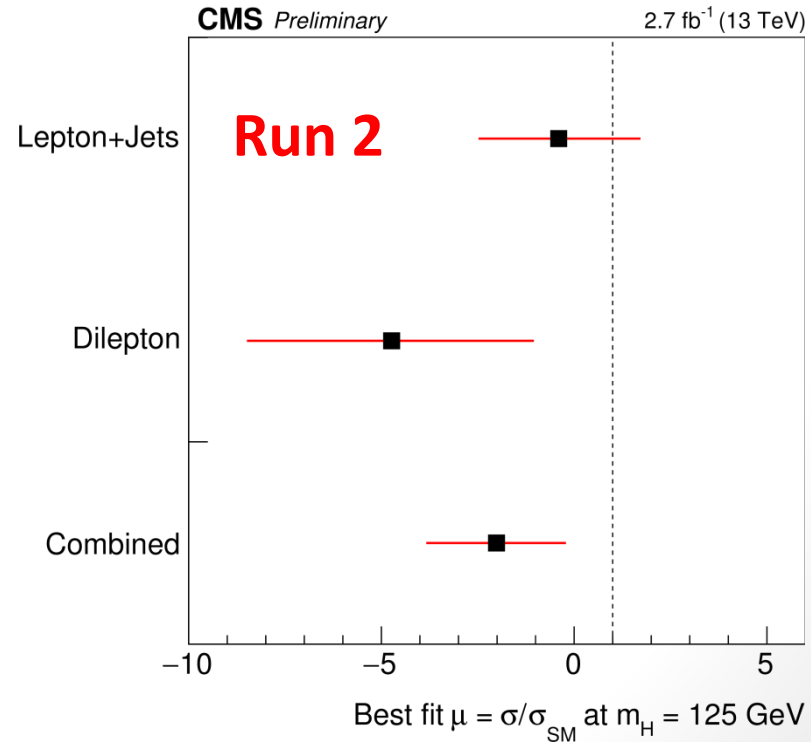
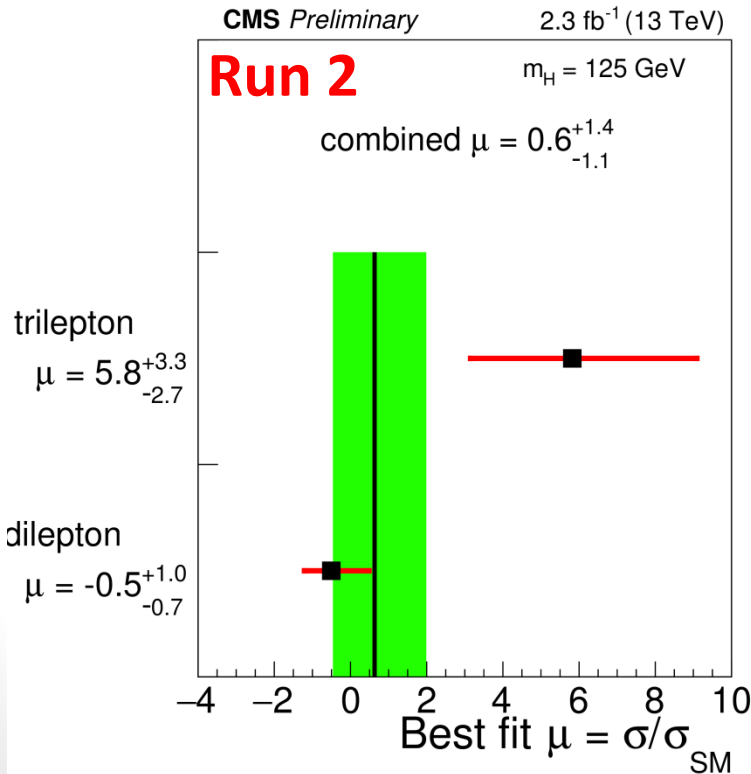
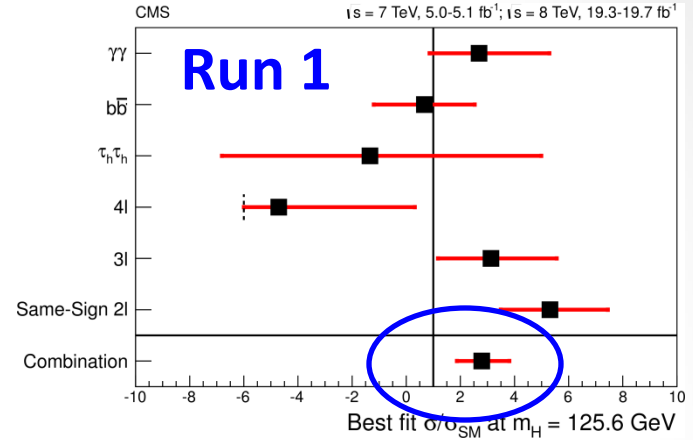
- First look at H(125) in Run 2**

- ZZ(4l): $\sigma_{\text{fid}} = 2.48_{-1.14}^{+1.48}$ fb [2.5σ]
- $\gamma\gamma$: $\mu = 0.69_{-0.42}^{+0.47}$ [1.7σ]
- Results consistent with SM expectation



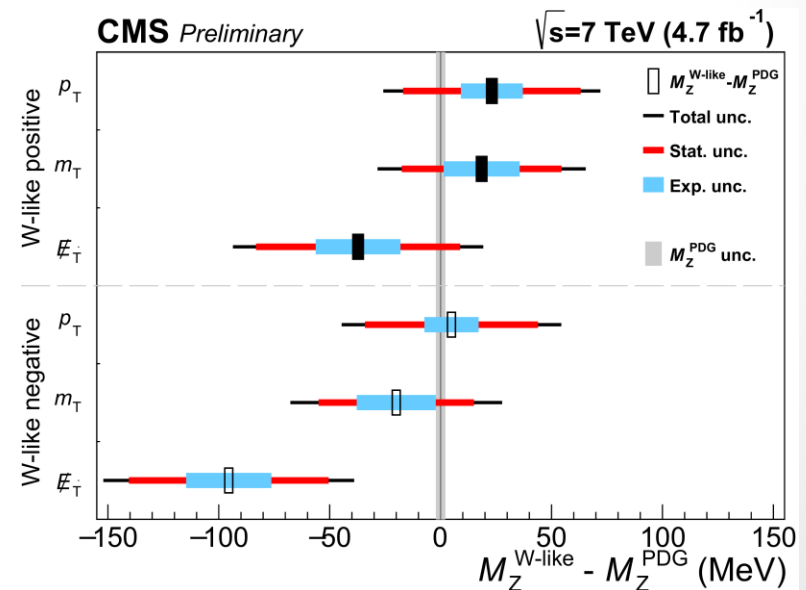
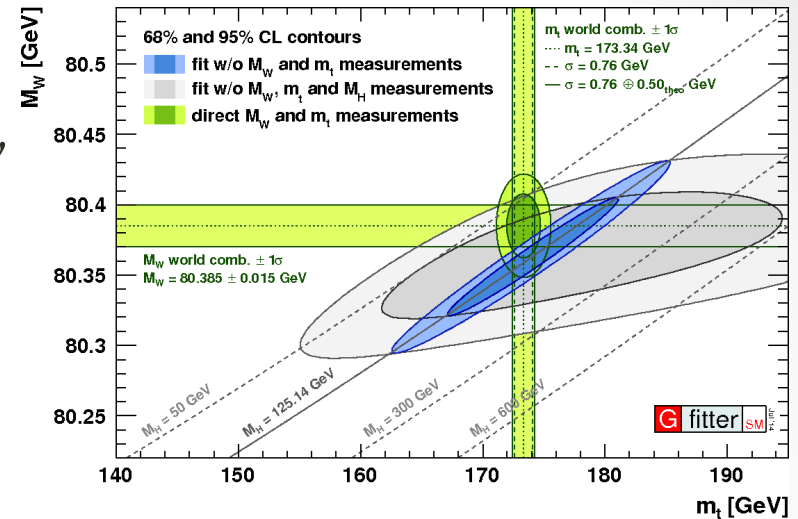
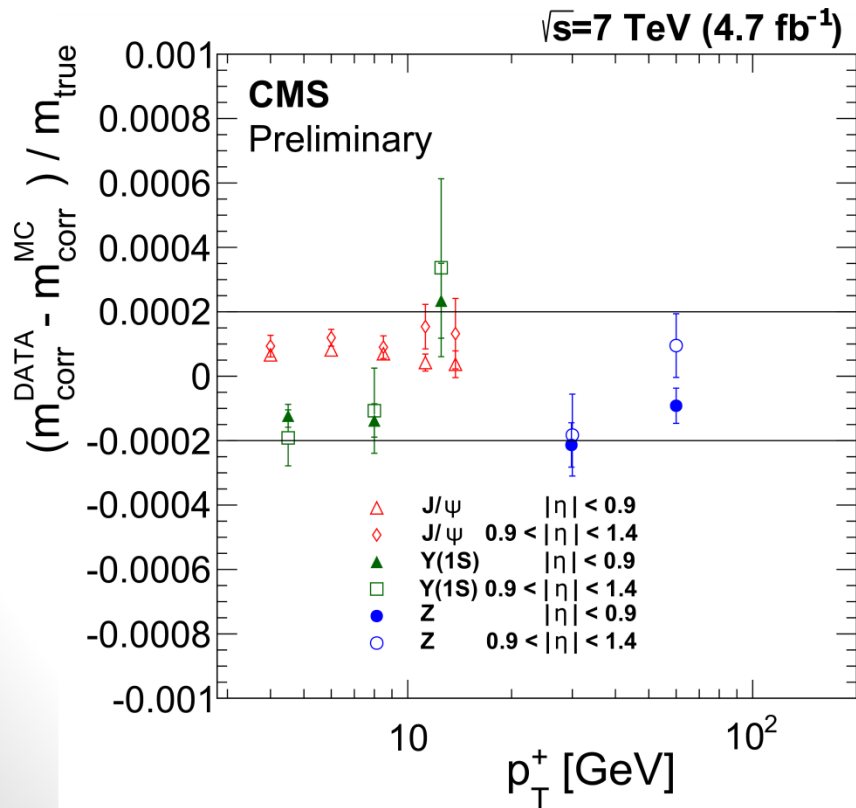
Revisiting a Higgs anomaly: ttH

- **$\sim 2\sigma$ excess for ttH search in Run 1**
 - High priority to investigate in Run 2
- **First look at ttH in 13 TeV data**
 - Multilepton, bb, and gg final states
 - All results consistent with SM



Toward a measurement of m_W

- **First “W-like” measurement of m_Z**
 - Remove one muon, treat like W $\rightarrow \mu\nu$
 - Three techniques using p_T , m_T , E_{miss}
 - **Exquisite control of muon momentum scale (at 10^{-4} level)**

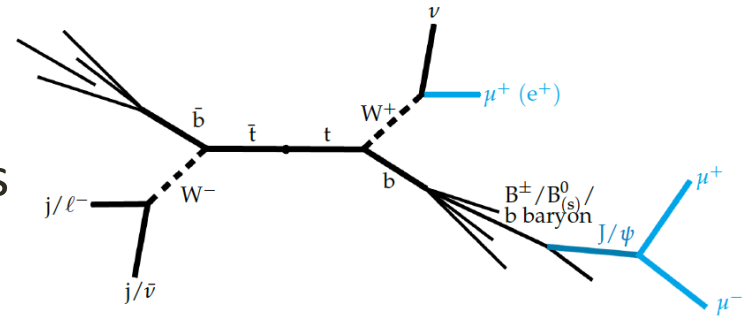


Experimental uncertainty < 20 MeV

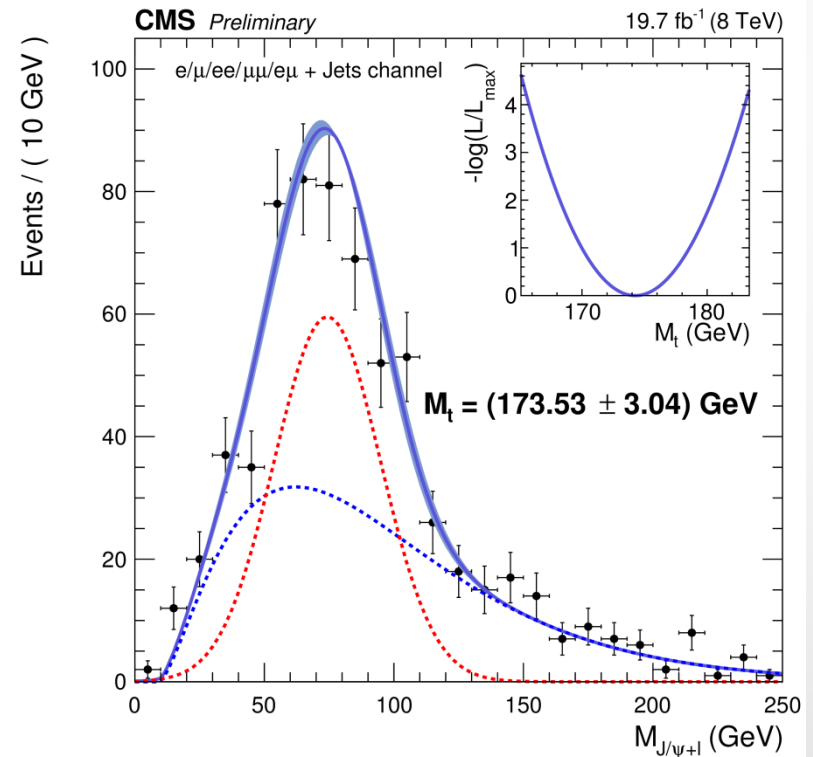
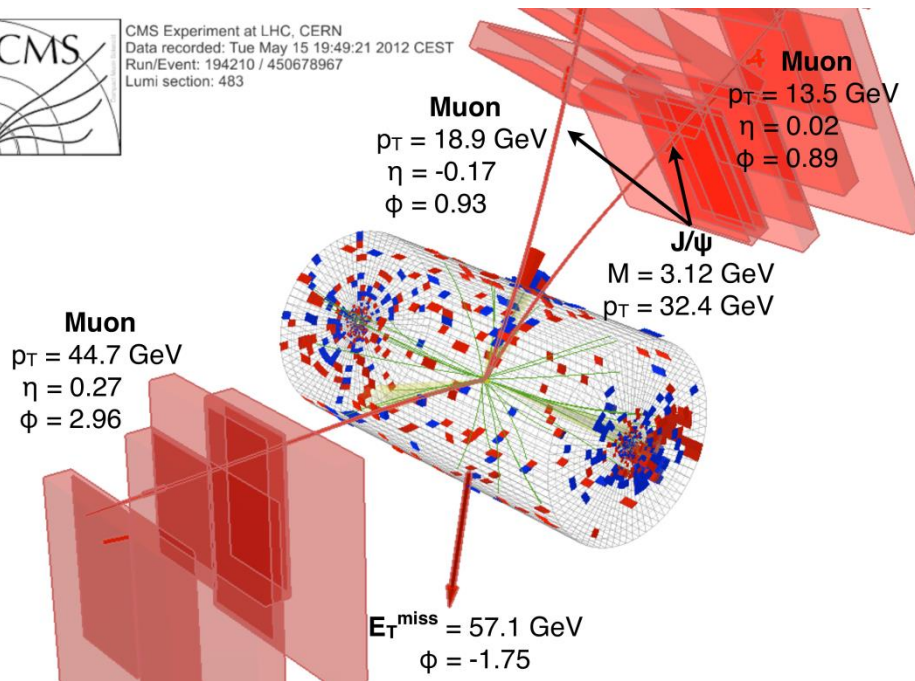


New technique to measure m_t

- Use $t\bar{t}$ events where b hadron from top quark decays to J/ψ
- top quark mass approximated by mass of J/ψ -lepton pair (only leptons used!)
- $M_t = 173.5 \pm 3.0$ (stat) ± 0.9 (syst) GeV



CMS Experiment at LHC, CERN
Data recorded: Tue May 15 19:49:21 2012 CEST
Run/Event: 194210 / 450678967
Lumi section: 483



US CMS activity: LPC contribution

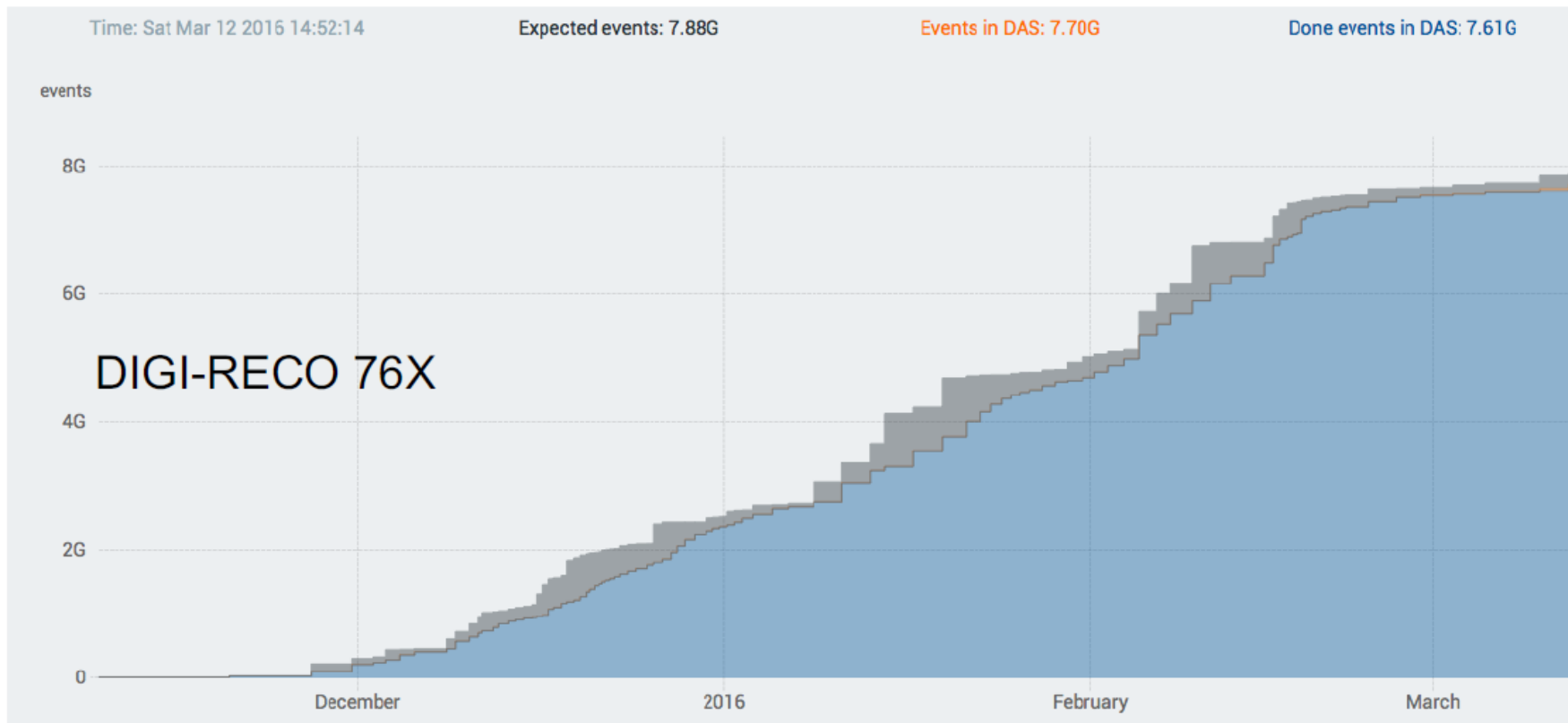
- **The LPC is an established regional center of excellence for CMS**
- It acts as a catalyst for contributions of US CMS Collaborators (and others) to the experiment.
 - **Serves as a critical link for remote physicists to participate directly in the CMS experiment, economically and transparently.**
 - Develops opportunities for LPC members to make major contributions to CMS
- The LPC is a powerhouse of talent, experience and resources
 - It concentrates on **Training, Enrichment and Physics**
- The overall focus of “current” activities at the LPC (see backup slide)
 - Physics analysis: X(750GeV), SUSY, B2G, Higgs, Exotica, Dark Matter
 - Operations of the CMS detector as well as Hardware/software/computing
 - Phase 1 and Phase 2 Upgrades
 - Workshops, analysis schools, hands-on-tutorials, seminars, chalk-talks
- Few keywords to describe its community heard often by colleagues are: **Vibrant, Active, Stimulating, Engaging, Productive**
- It is steadily growing in its attractiveness within the HEP community. It is referred to, and being duplicated in many places
- **Continuation of strong financial support, in particular teaching buyouts and travel (often through generous LPC support), is critical for maintaining US leadership roles within CMS**



Activity during the Year End Technical Stop (YETS)



Computing very busy!

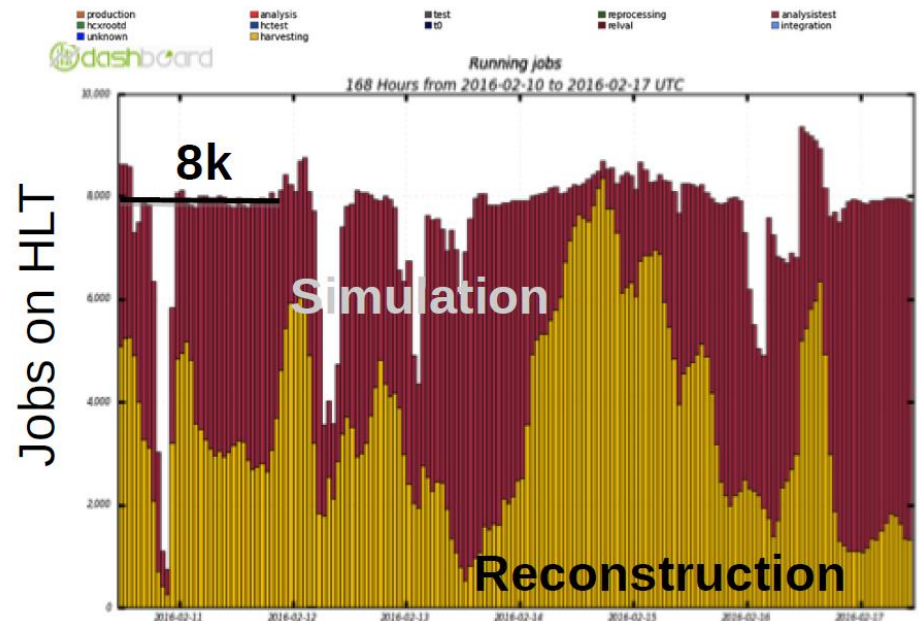
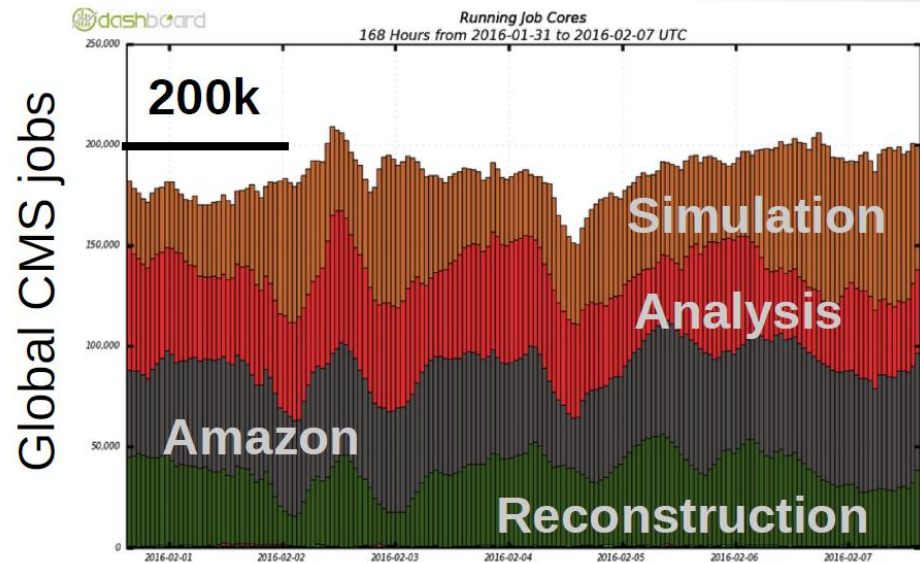


~8B events re-reconstructed and ready for Moriond, also re-reconstructed 2015 data with latest release



Looking to the clouds...

- Successful marriage of commercial cloud computing from Amazon and **FNAL HEPCloud**
 - Stable operation of 60k jobs running CMS simulation and reconstruction (MC)
- **CMS infrastructure has successfully scaled up to a global pool of 200k jobs**
 - using commercial cloud and internal CMS resources (HLT cluster)



Detector Work during YETS

- **Trigger**
 - New Stage 2 trigger hardware installed, commissioning ongoing
- **Tracker**
 - No major interventions, ready for higher luminosity / pileup
- **ECAL**
 - Refurbishment of LV power supplies and preshower LV connectors
 - New readout thresholds defined to deal with higher pileup
- **HCAL**
 - Commissioning of new trigger primitives from μ TCA (Stage 2 trigger)
 - Recommissioned improved laser system to monitor effect of radiation damage in HE scintillators
- **Muons**
 - L1 muon trigger upgrade work, thousands of optical fibers installed, new Stage 2 trigger benchmarked against legacy trigger system
- **CMS operations**
 - Ongoing global runs, new trigger operational in cosmics datataking



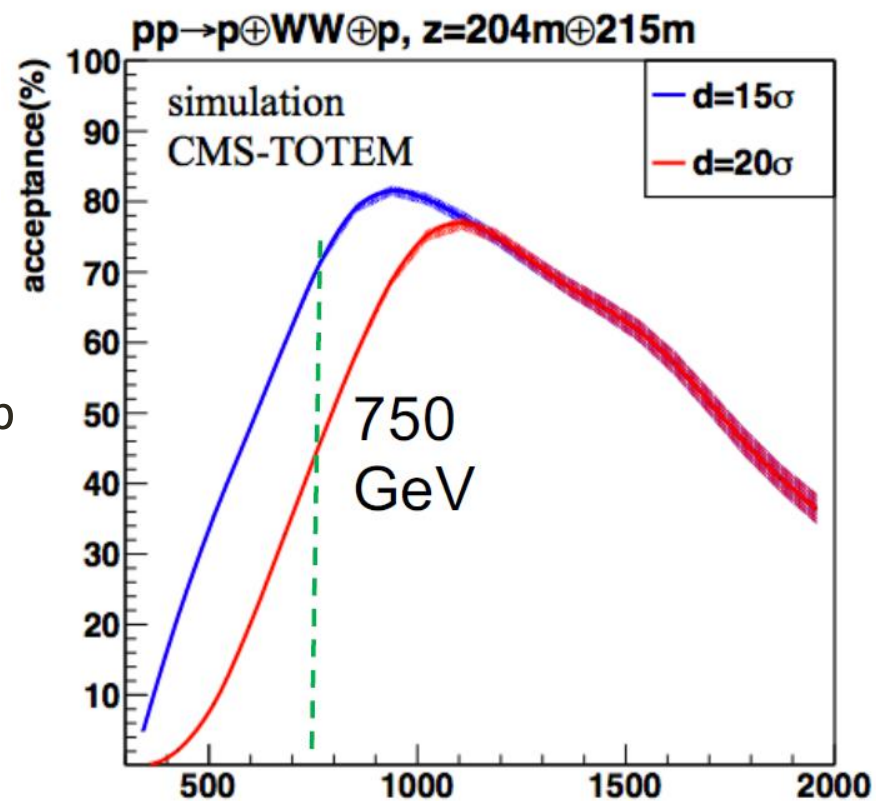
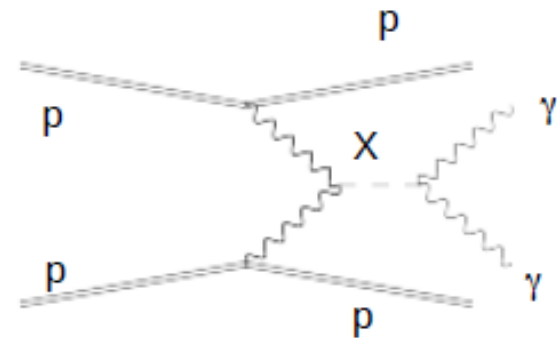
CMS-TOTEM Precision Proton Spectrometer (CT-PPS)

- **Advanced by one year the integration of CT-PPS into CMS data acquisition**

- Originally foreseen in YETS 16-17
- Acceptance happens to peak in an 'interesting' mass region

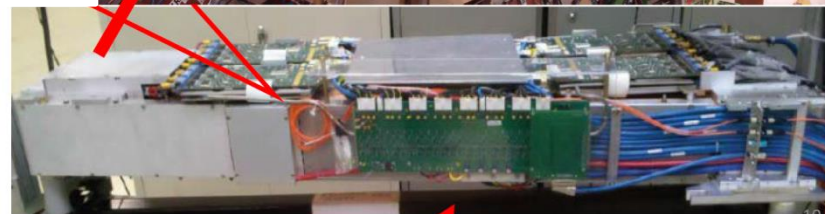
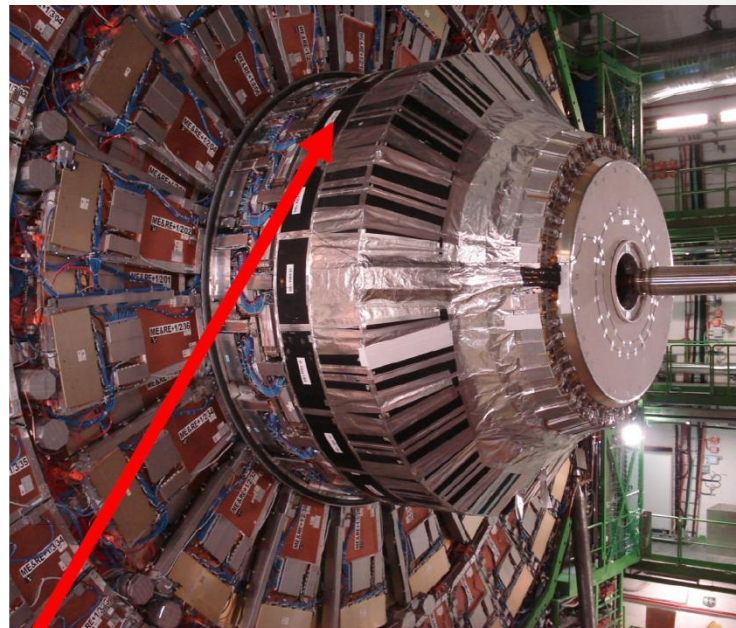
- **CT-PPS status**

- Successful Roman Pot insertion tests performed in 2015
- Currently using TOTEM silicon strip detectors (lifetime $\sim 10\text{-}20 \text{ fb}^{-1}$)
- Replace with 3D pixel detectors in Fall 2016
- Expected mass resolution $\sim 1\text{-}2\%$



When it rains it pours: water leak @ P5

- **Mid-December: slow water leak discovered from CSC chamber on the +endcap nose**
 - For safety of the detector, decision to shut off CMS before end of HIN run
- **Resulted in unplanned opening of CMS detector to repair the leak**
 - Leaky braised joint was replaced, no significant damage to CMS
 - Improved leak detection system
 - Eventually, cooling circuits on ME1/1 chambers need to be replaced
- **Opening presented opportunity:**
 - For example, repaired preshower connectors



CMS Operation in 2015

- At the end of the Long Shutdown 1 we realized that the **performance of the cryogenic system feeding Liquid He to our Magnet was severely impaired by a contamination of the Cold box**
- This has affected our operation in 2015: a large effort from the **CERN cryogenic and technical departments associated to our Technical Coordination have limited the impact, allowing to collect $\sim\frac{3}{4}$ of the delivered luminosity with full magnetic field.**
- The detector and new acquisition system was ready from the start of LHC running at 13 TeV: **we have logged data with efficiency well above 90% with trigger thresholds similar or lower than the ones at Run I**
- **A detailed plan of repair and cleaning of the cryo system, to be executed during the Year End Technical Stop, is ready** and foresees the system to be ready for Physics production by the first week of April, i.e. well ahead of the start of physics production of LHC in 2016

Slide from Dec 15 seminar, planned cryo intervention completed successfully during YETS



The moment of truth...



Eventually, 370g of oil removed from cryogenic system, all evidence consistent with this being the source of contamination

New Oil Removal System Installed

T. Camporesi, JOG Meeting, March 30

Capacity increased significantly

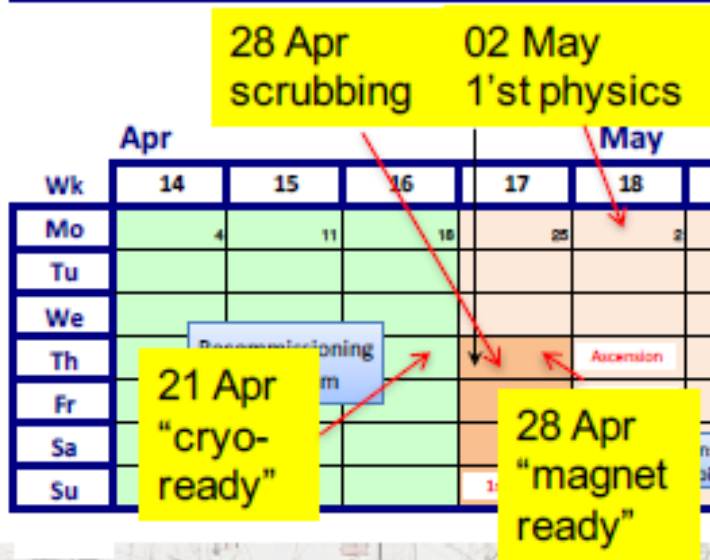
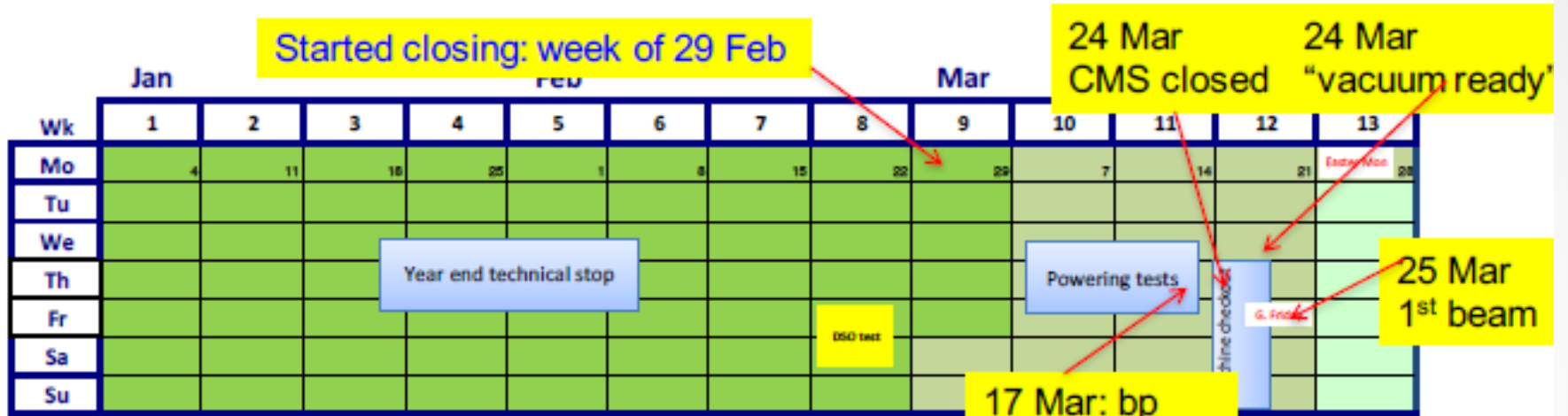


Commissioned, connected to the Coldbox ~~yesterday~~

Tuesday

Schedule: CMS on track

T. Camporesi, JOG Meeting, March 30



Closing for beam

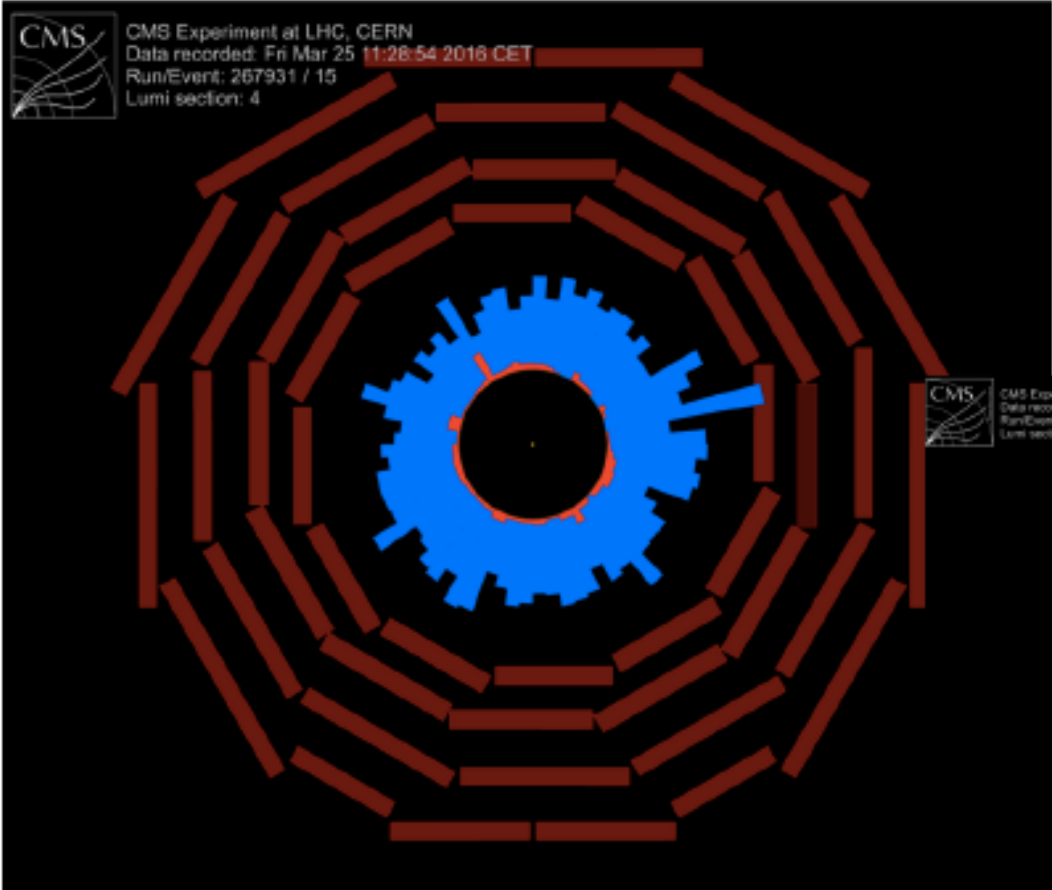
- slightly ahead of schedule at present
- earliest "beampipe pump-down" estimated for 17 March
- earliest date for "CMS closed" estimated 24 March

Cryogenics

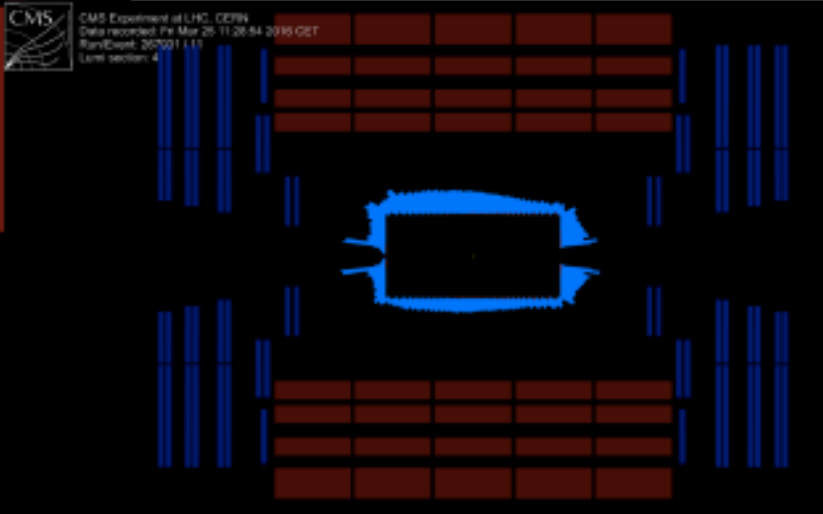
- cold box on schedule
- compressor hall work (oil removal) few days ahead
- earliest cryo-ready could be in week of 18 Apr
- taking into account magnet cold mass T management, earliest "magnet ready" could be in week of 25 April



Beam is Back!



Beam Splashes on Collimators on either side of CMS last Friday morning



Summary

- **CMS has entered “physics production mode” @ 13 TeV**
 - 72 results on Run 2 data so far, most are searches
 - > 50 new results (Runs 1 and 2) already in 2016
 - Highlights: diphoton excess and related searches, SUSY searches, Higgs physics, standard model precision measurements
- **Year-end technical stop was a productive time for CMS**
 - Cleaned and improved magnet cryogenic system
 - Installed hardware for Stage 2 trigger upgrade, with commissioning ongoing
 - Detector online for several weeks now, all systems go
- **CMS is ready for data in 2016!**



Backup



Examples of Recent Run 2 LPC Physics



- LPC members took lead in 3 of the first 6 CMS Run 2 publications (in RED below) **Early Analysis** (Dec 2015, in blue) **Winter** (March 2016, in green)

- EXO:
 - EXO-15-001: Search for dijet resonances (PRL)**
 - EXO-15-002: Search for diboson resonances**
 - EXO-15-003: Search for dark matter in monojets**
 - EXO-15-002: Search for massive resonances decaying to pairs boosted W and Z**
 - EXO-16-002: Search for type-III seesaw heavy fermions with multileptons**

X(750 GeV)

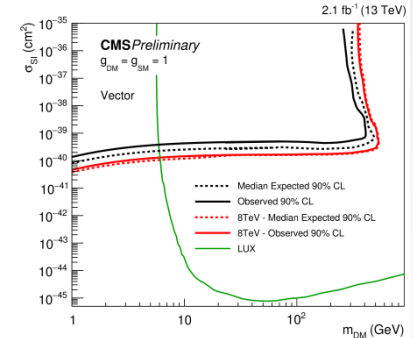
- EXO-15-004: Search for diphoton resonances**
 - EXO-16-018: Update on search for diphoton resonances**
- B2G:
 - B2G-15-004: Search for $W' \rightarrow tb$ (semi-leptonic)**
 - B2G-15-006: X53 in SS dilepton and lepton+jets**
 - B2G-16-002: Search for VLQ T quarks in the lepton plus jets final state**
 - B2G-15-007: Search for Dark Matter produced in association with bottom quarks**
 - B2G-15-002: $tt^{\bar{}}$ resonances in boosted semileptonic final states**

- SUSY:
 - SUS-15-002: Search for supersymmetry in multijet+MET (Sub. to PLB)**
 - SUS-15-003: New physics in the all-hadronic final state with the MT2 (sub. to JHEP)**
 - SUS-15-004: Inclusive search for supersymmetry using the razor variables**
 - SUS-16-002: direct top squark pair production in the single lepton final**
 - SUS-16-003: Search for SUSY with multileptons**
 - SUS-16-007: direct production of top squark pairs decaying to all-hadronic**

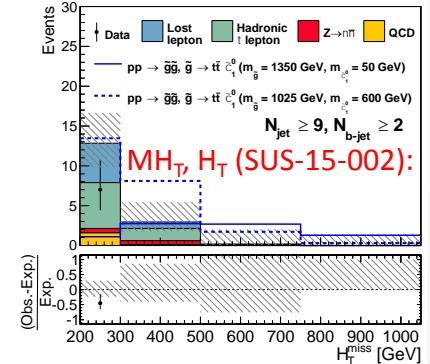
HIGGS

- HIG-16-002 Resonant pair production of Higgs bosons decaying to two b quark pairs**

EXO-15-003



CMS Preliminary 2.2 fb^-1 (13 TeV)



SUS-15-004

