

# CMS Highlights from Spring 2013

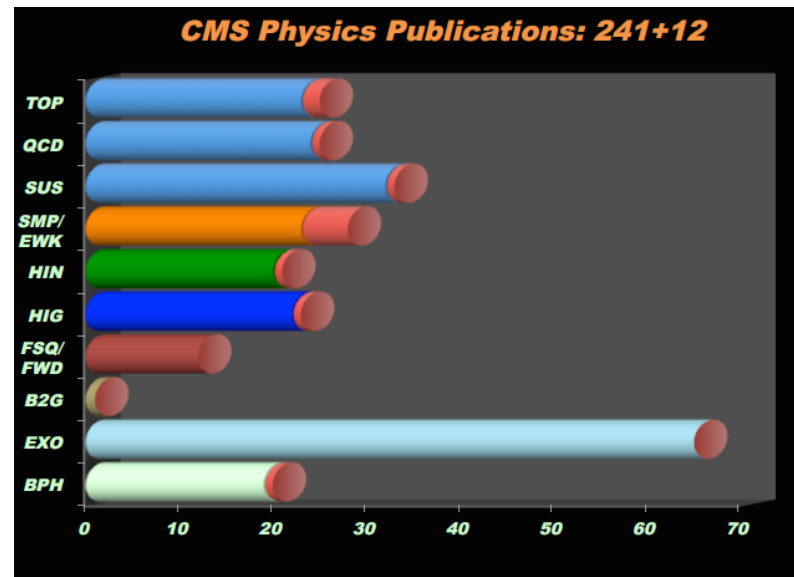
LHCC open session  
June 12, 2013

Jeffrey Berryhill (Fermilab)  
On behalf of the CMS  
collaboration

Digital art courtesy of Xavier Cortada (with the participation of physicist Pete Markowitz) "In search of the Higgs boson:  $H \rightarrow ZZ$ "

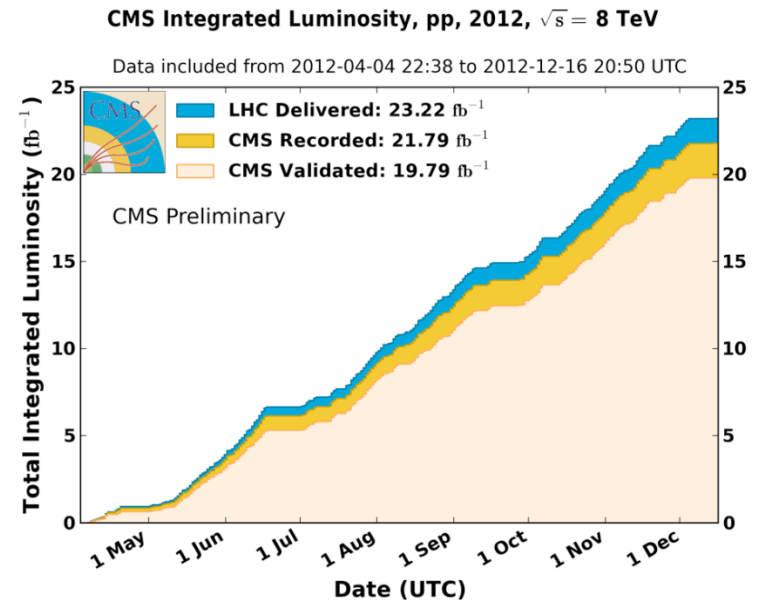
# CMS Collaboration status

- 241+ physics publications with collision data; Higgs discovery paper has nearly 1200 citations
- 33 new physics results since Moriond 2013, including new Higgs combination
- Manpower shifting to upgrades/LS1 activities as Run 1 analysis is completed
- Welcoming new spokesperson-elect Tiziano Camporesi in 2014.



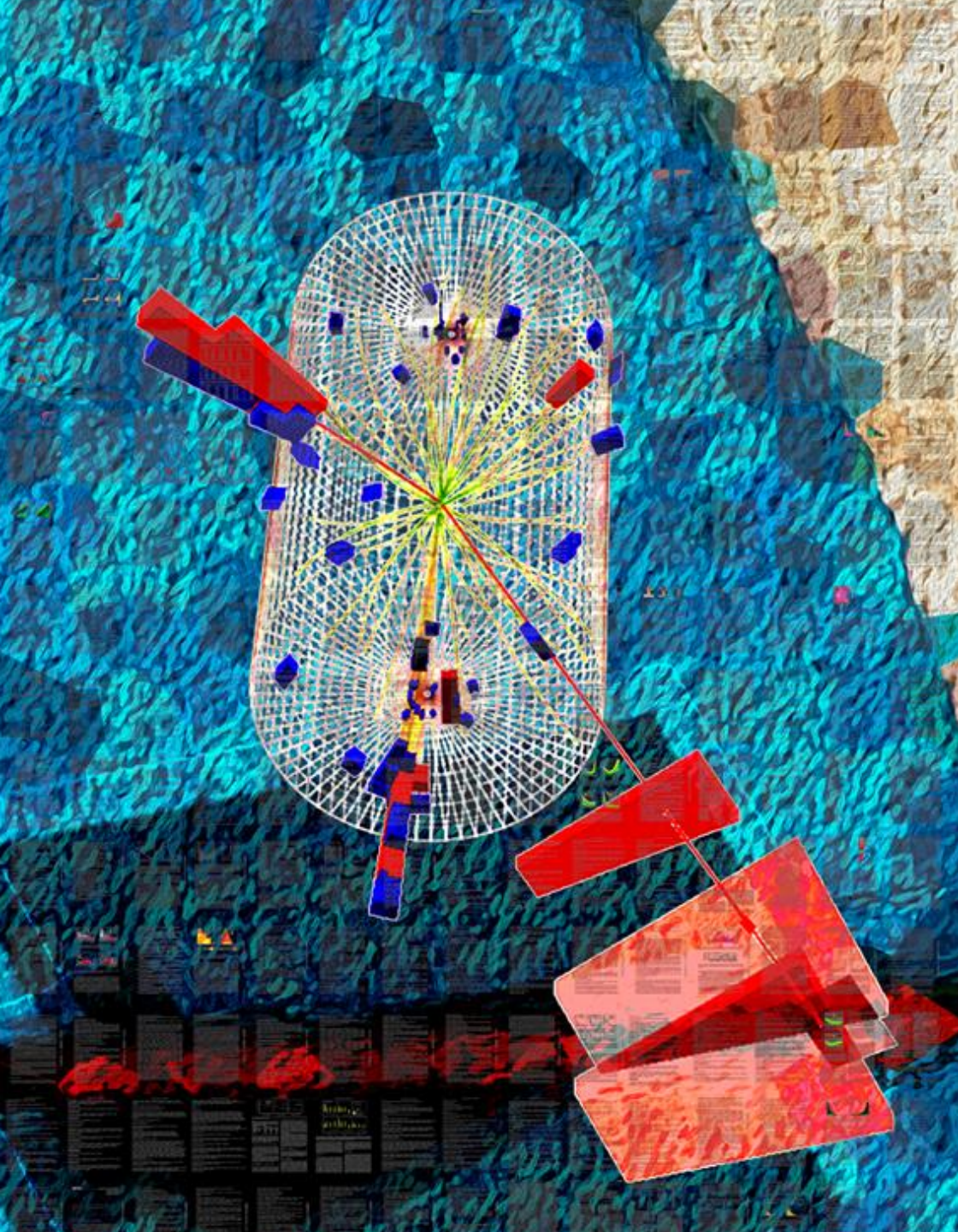
# CMS Collaboration status

- 2012 data and MC reprocessing with final calibrations and alignments is complete!
  - (Core + Parked) with improved conditions has been delivered!
  - This is the legacy 2012 dataset



- And fully certified!
  - Golden: 19.79 /fb (**91% of recorded**)
  - Muon: 20.65 /fb (95% of recorded)
    - Jet Energy Corrections and Btag scale factors based on new reprocessing signed of and available to analyzers since June 7<sup>th</sup>
  - Improved MC for  $H \rightarrow \gamma\gamma$  (with run dependent ECAL conditions)

# Heavy Ion and Standard Model Results



Digital art courtesy of Xavier Cortada (with the participation of physicist Pete Markowitz) "In search of the Higgs boson:  $H \rightarrow \tau\tau$ "

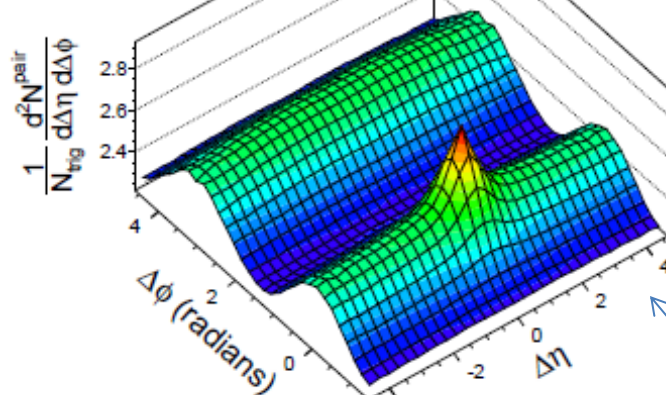
# p-Pb results: 2013 ridge analysis

Submitted to PLB  
arXiv:1305.0609

31/nb of 2013  
pPb collisions, a  
comprehensive  
follow-up on 1/ $\mu$ b  
2012 observation  
of near-side long-  
range correlations  
in pPb

(a) CMS PbPb  $\sqrt{s_{NN}} = 2.76$  TeV,  $220 \leq N_{trk}^{offline} < 260$

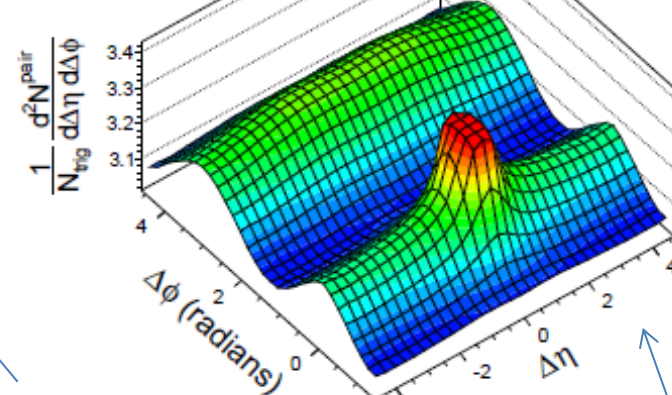
$1 < p_T^{trig} < 3$  GeV/c  
 $1 < p_T^{assoc} < 3$  GeV/c



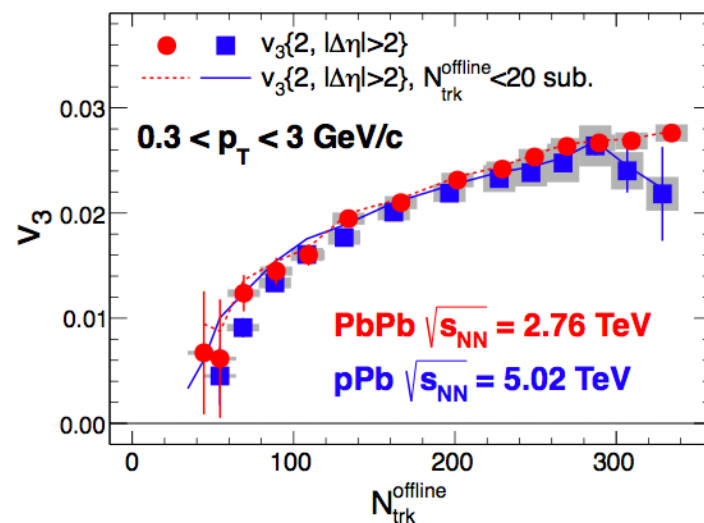
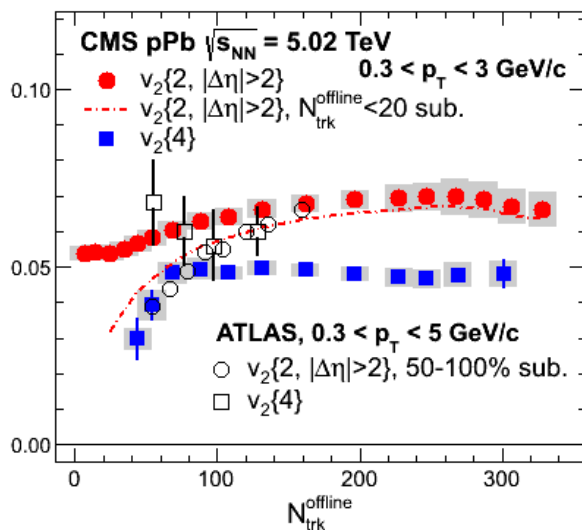
PbPb ridge

(b) CMS pPb  $\sqrt{s_{NN}} = 5.02$  TeV,  $220 \leq N_{trk}^{offline} < 260$

$1 < p_T^{trig} < 3$  GeV/c  
 $1 < p_T^{assoc} < 3$  GeV/c



pPb ridge

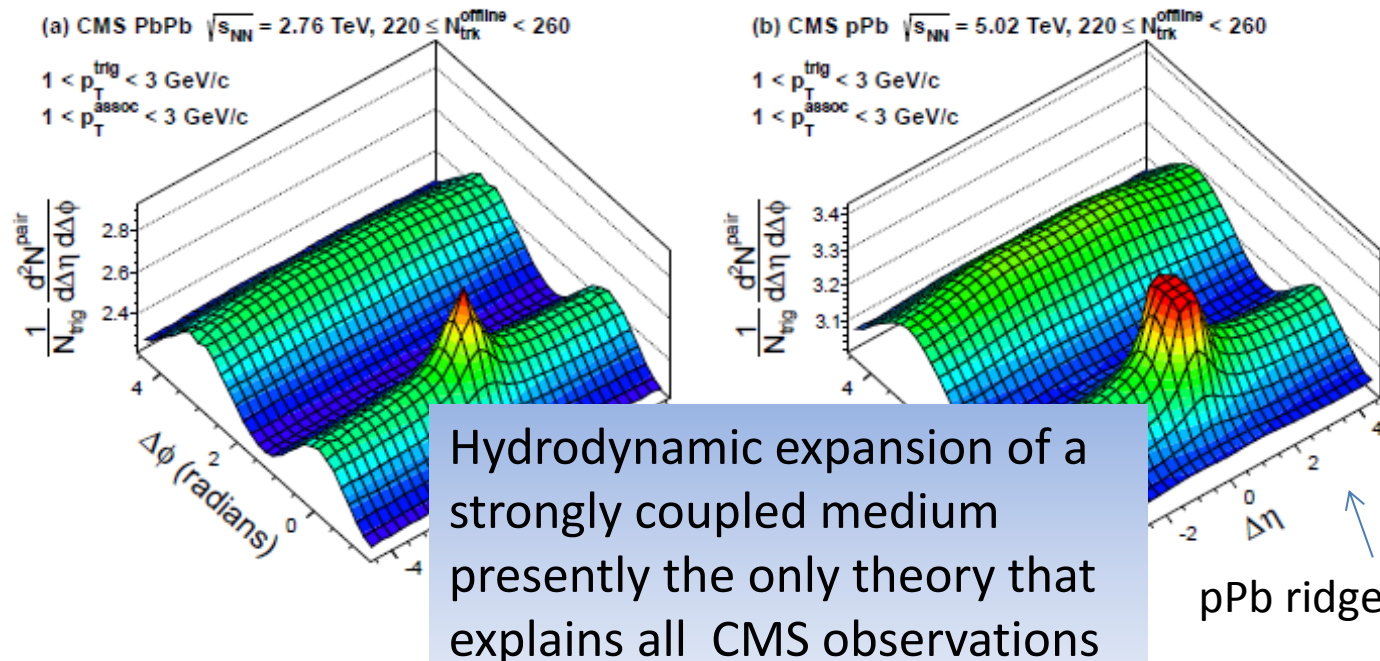


Ridge phenomena can  
now be compared with  
PbPb at similar  
multiplicity ( $> 200$ ), as  
well as 4-particle  
correlations and  
multipole harmonics  
( $v_2, v_3$ )

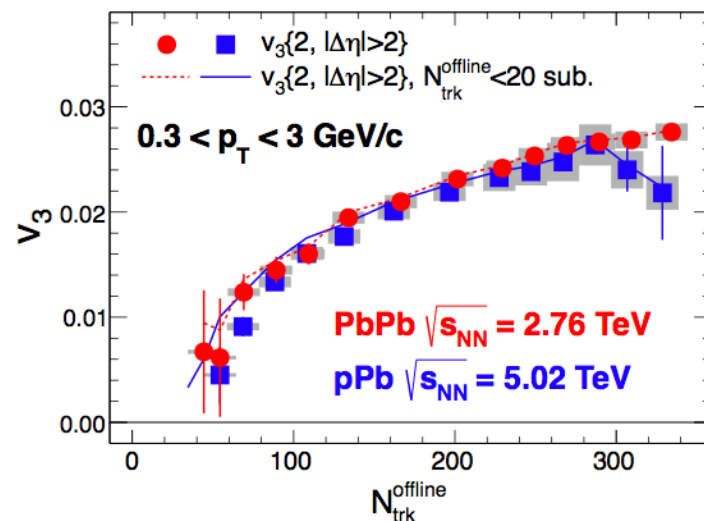
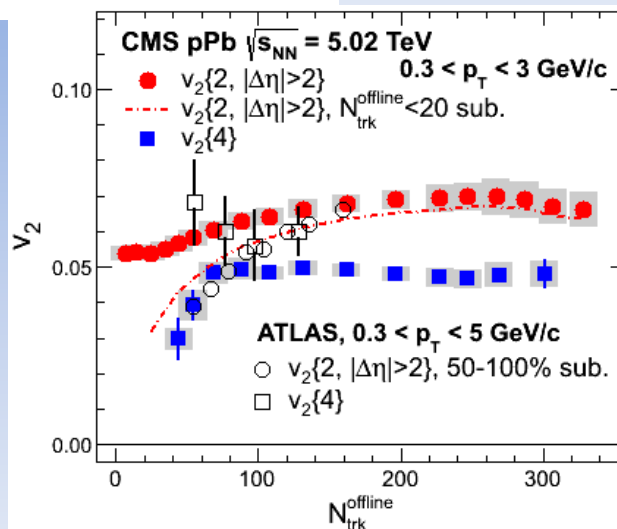
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Ridge phenomena can now be compared with PbPb at similar multiplicity ( $> 200$ ), as well as 4-particle correlations and multipole harmonics ( $v_2, v_3$ )



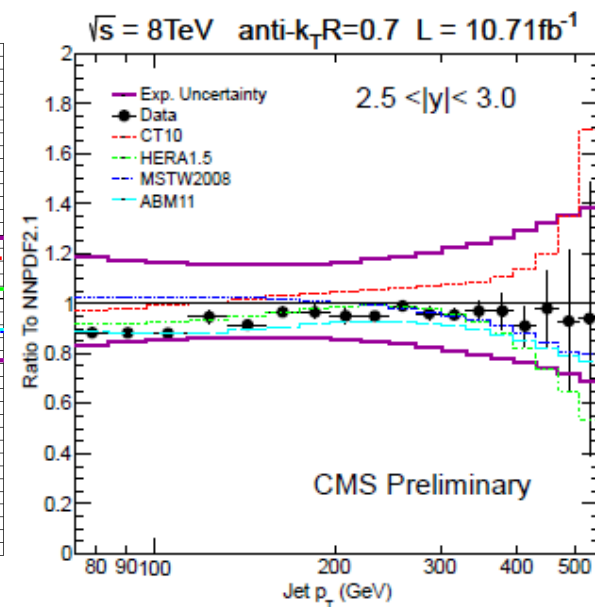
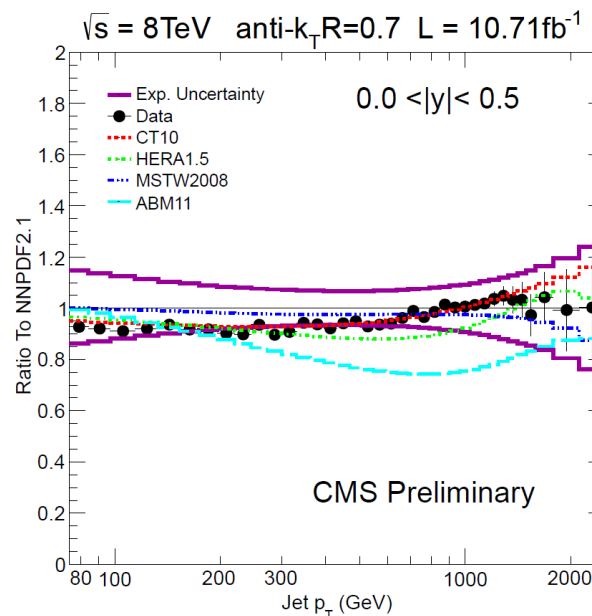
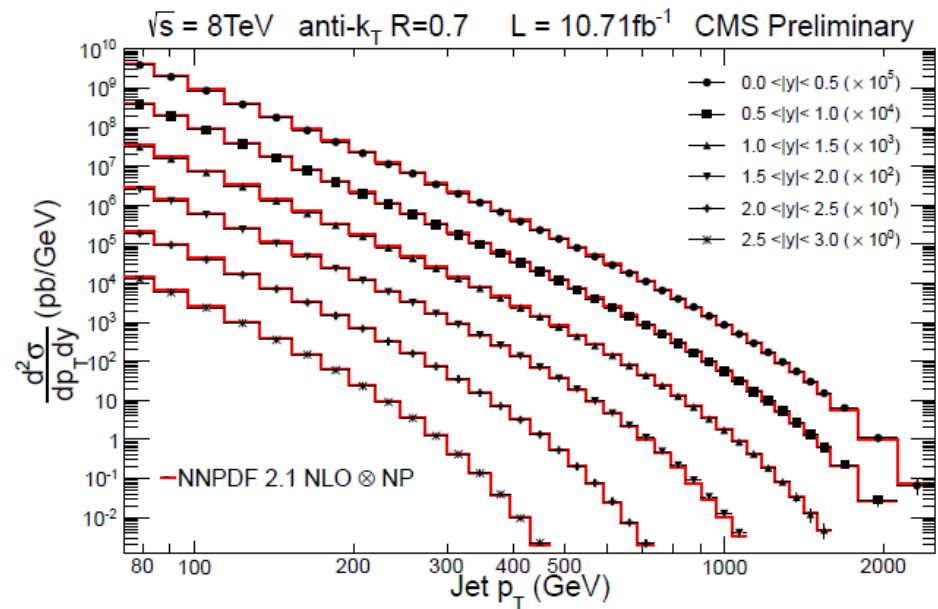
# Standard Model: 8 TeV inclusive jets

CMS-PAS-SMP-12-012

Double-differential inclusive jet cross section obtained with 11/fb at 8 TeV

Agreement with NLO QCD over 11 orders of magnitude, with sensitivity beyond 2 TeV

- 2-5% jet energy scale uncertainty for PF jets
- 4-8% jet energy resolution
- 10-30% cross section uncertainty per bin
- Improvement to high  $x$   $q/g$  PDF expected

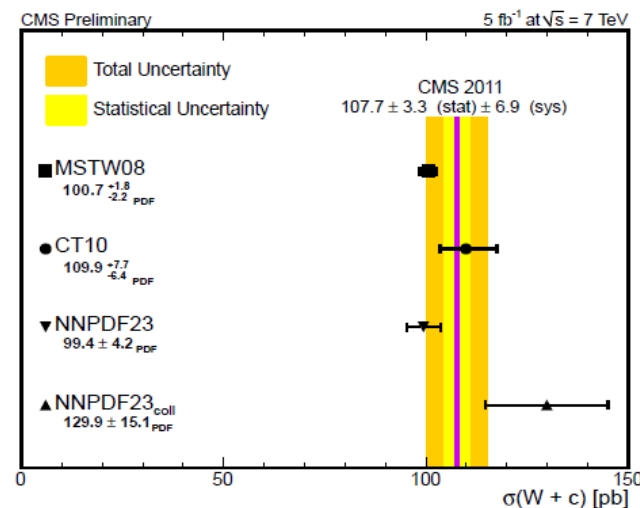
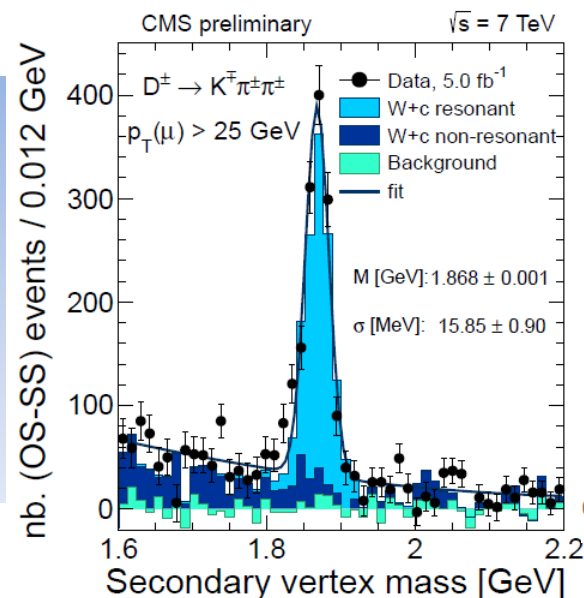


# Standard Model: W+heavy flavor studies

CMS-PAS-SMP-12-002

Large W+c rate exploited for a high-purity W+c cross section measurement at 7 TeV.

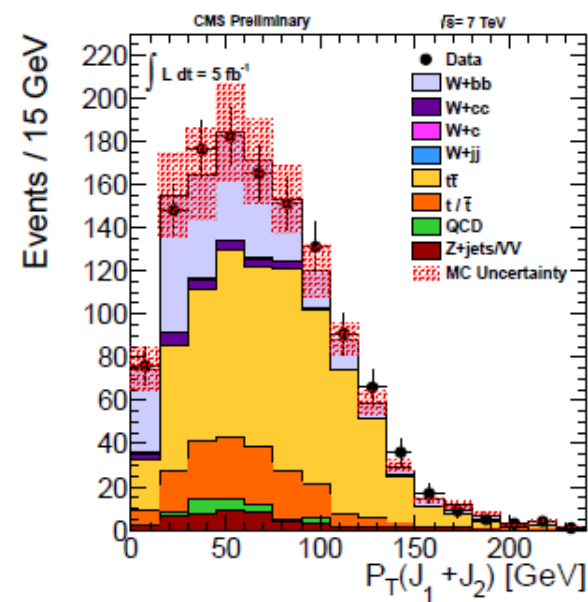
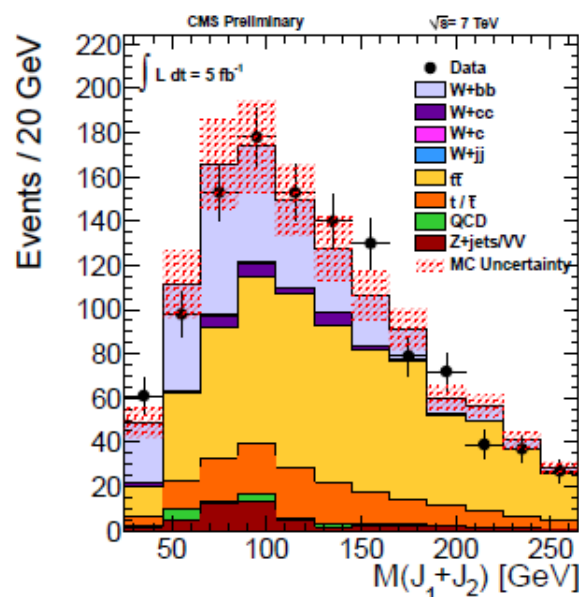
Sensitivity to strange PDF now an interesting alternative to fixed target neutrino data.



CMS-PAS-SMP-12-026

W+bb exclusive final state extracted for the first time at 7 TeV

Rate and production dynamics consistent with MadGraph and NLO QCD (MCFM) within errors (22%)





# “Forward” Physics: VBF Z and WW aQGC

Submitted to JHEP,  
arXiv:1305.7389

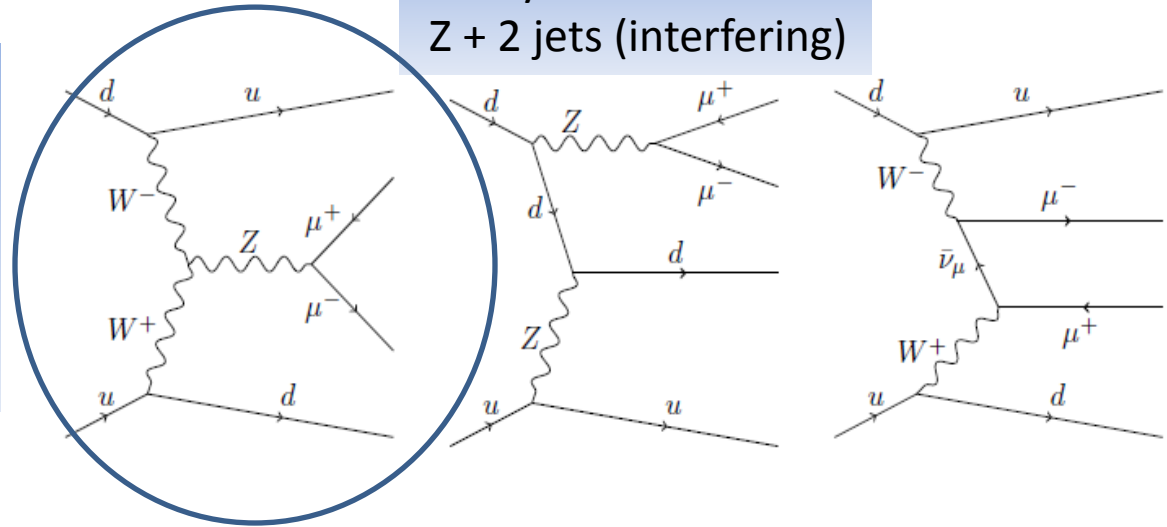
Comprehensive study of  
Z+forward dijet production at 7  
TeV.

VBF Z one of the interfering  
amplitudes

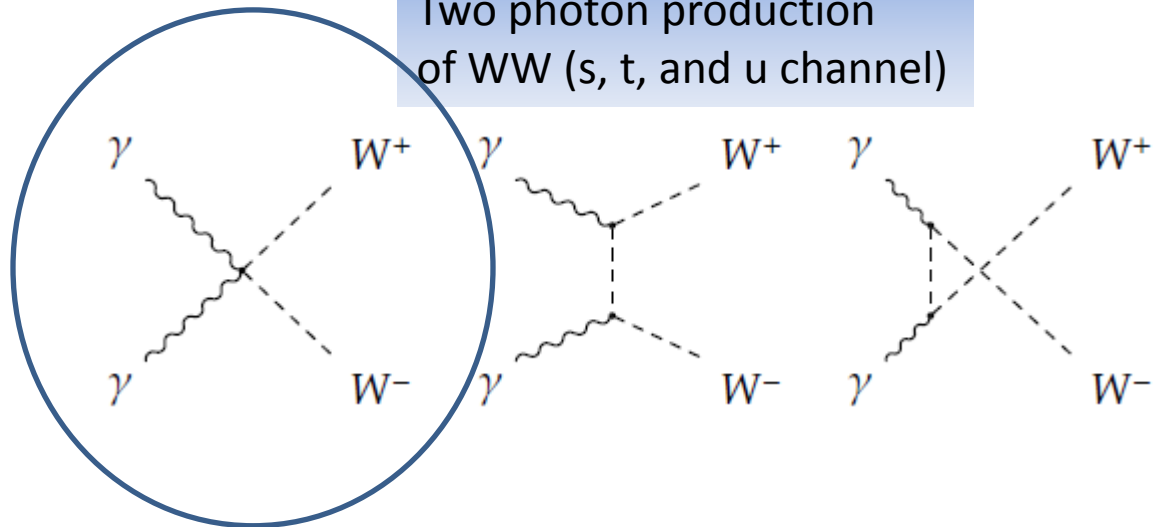
Submitted to JHEP,  
arXiv:1305.5596

- First search for  
photon-photon  
scattering production  
of WW
- $WW\gamma\gamma$  quartic gauge  
coupling one of the  
amplitudes

Purely electroweak  
Z + 2 jets (interfering)



Two photon production  
of WW (s, t, and u channel)



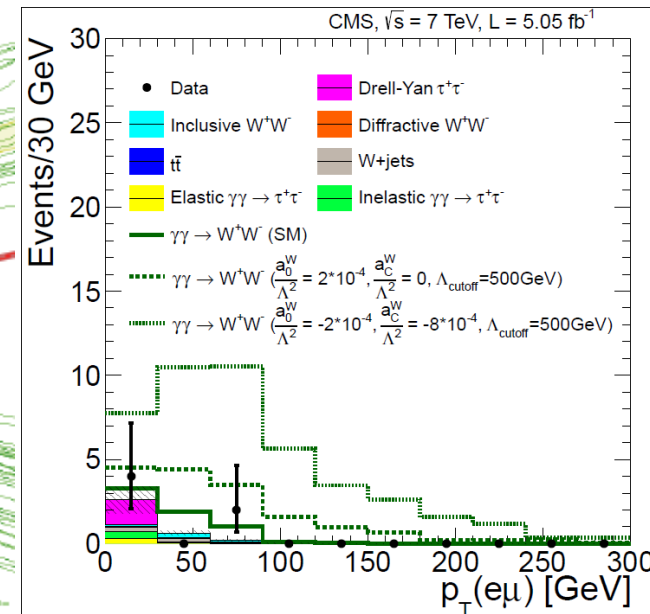
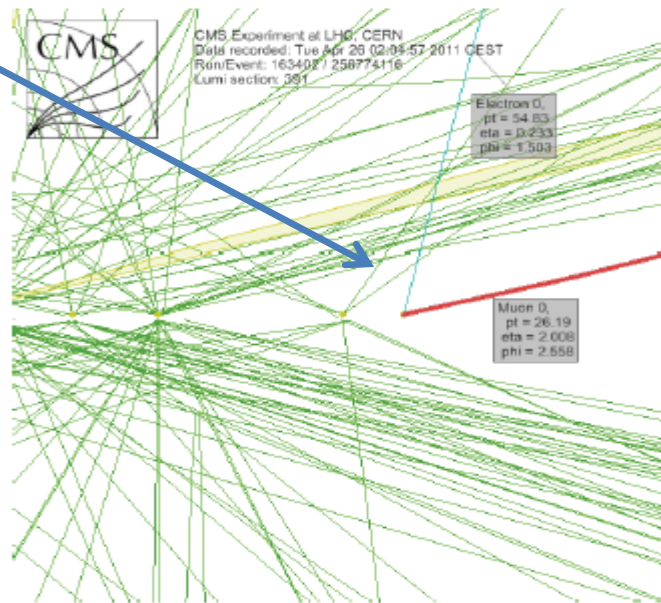
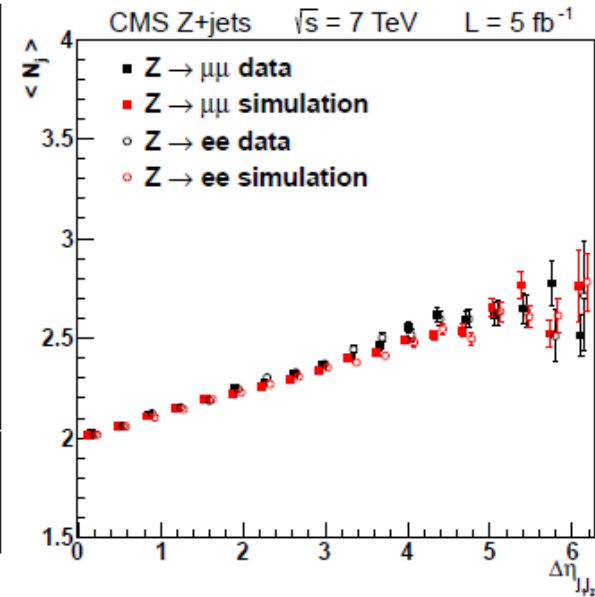
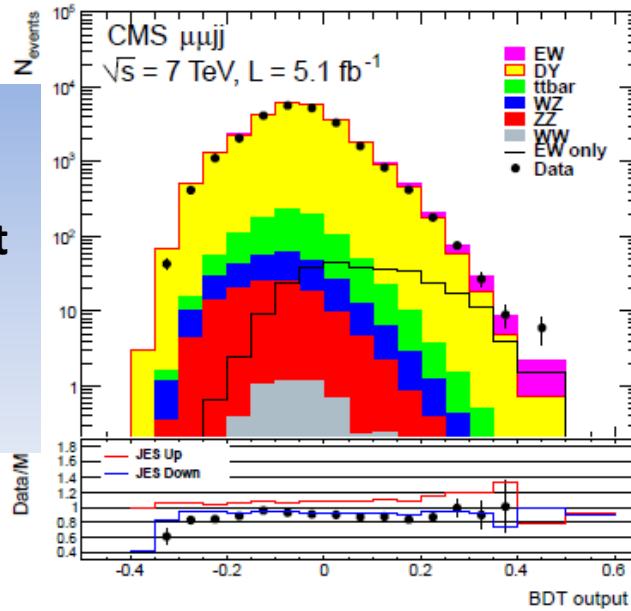
# “Forward” Physics: VBF Z and WW aQGC

Submitted to JHEP,  
arXiv:1305.7389

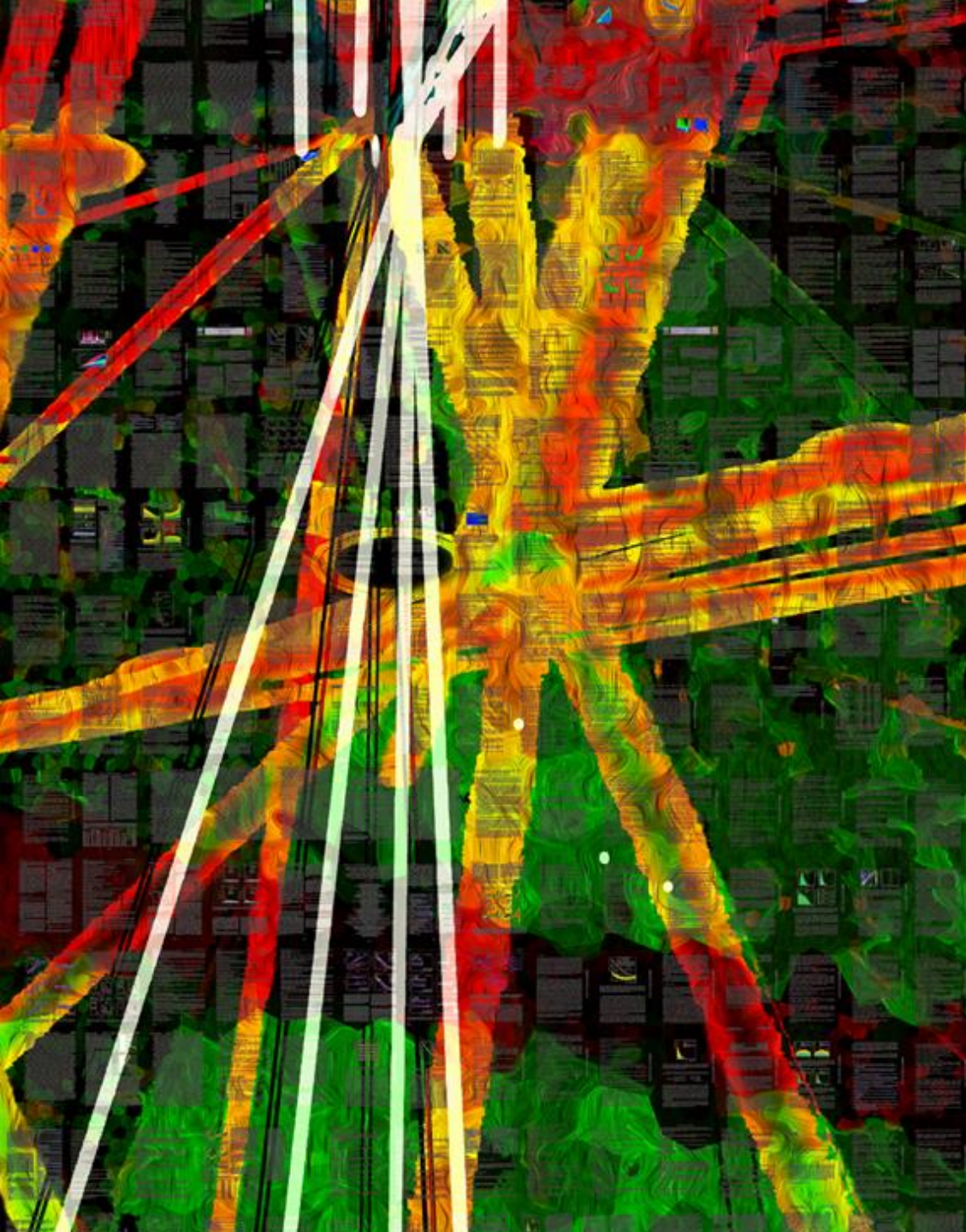
Comprehensive study of  
Z+forward dijet production at  
7 TeV. **Electroweak component**  
has **2.6 sigma significance**.  
Forward dijet dynamics in  
agreement with MadGraph

Submitted to JHEP,  
arXiv:1305.5596

- Two  $e\mu$  events observed with **no UE present**
- First quartic gauge coupling limits at LHC;  $WW\gamma\gamma$  limit two orders better than LEP or Tevatron!



# Higgs Results

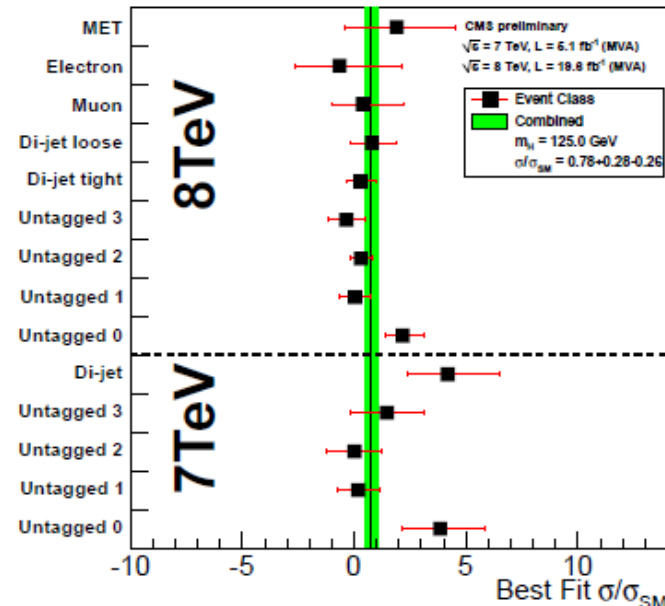
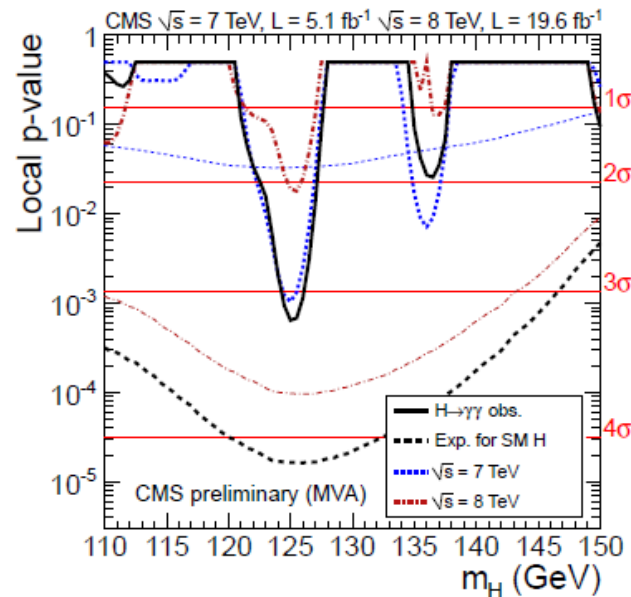
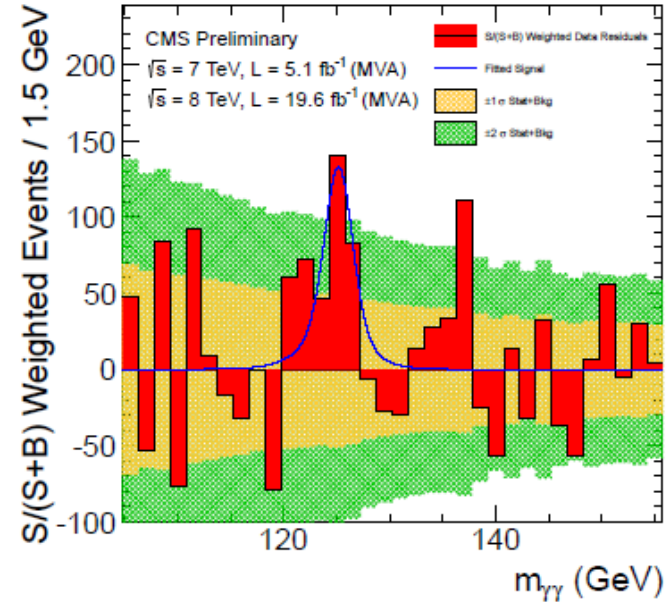
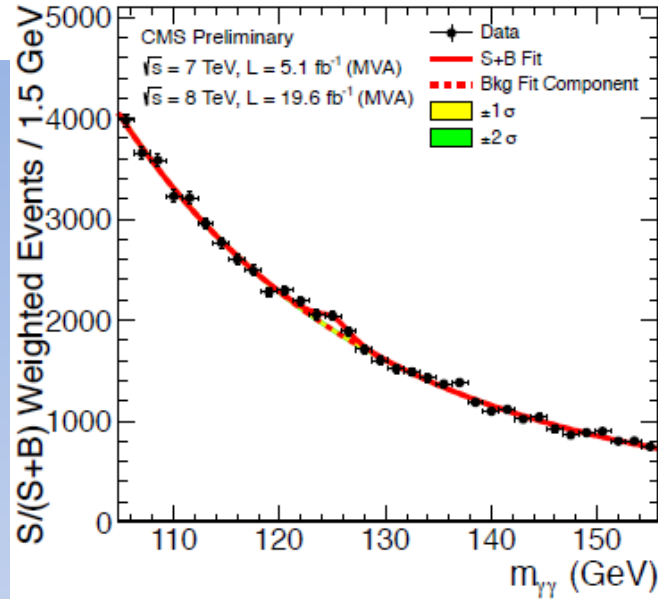


Digital art courtesy of Xavier Cortada (with the participation of physicist Pete Markowitz) "In search of the Higgs boson:  $H \rightarrow b\bar{b}$ "

# $H \rightarrow \gamma\gamma$ : Full Run 1 result

CMS-PAS-HIG-13-001

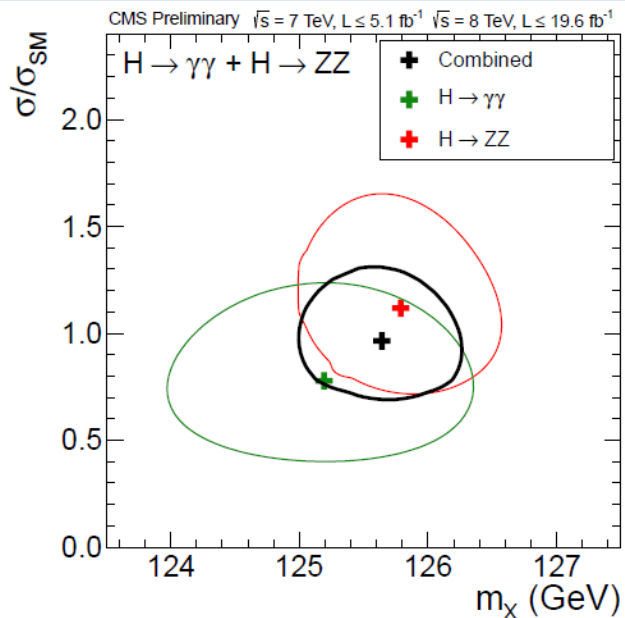
- Most sensitive MVA-based analysis finds an excess with local significance of  **$3.2 \sigma$**  at  **$125 \text{ GeV}$**  mass ( $4.2 \sigma$  expected).
- Signal strength  $\mu = 0.78 \pm 0.27$  consistent with SM Higgs and consistent across categories
- Alternative cut-based analysis has significance of  $3.9 \sigma$  ( $3.5$  expected)
- Different analyses compatible with each other at  $1.5 \sigma$  level, including correlations.



# Moriond 2013 combination

CMS-PAS-HIG-13-005

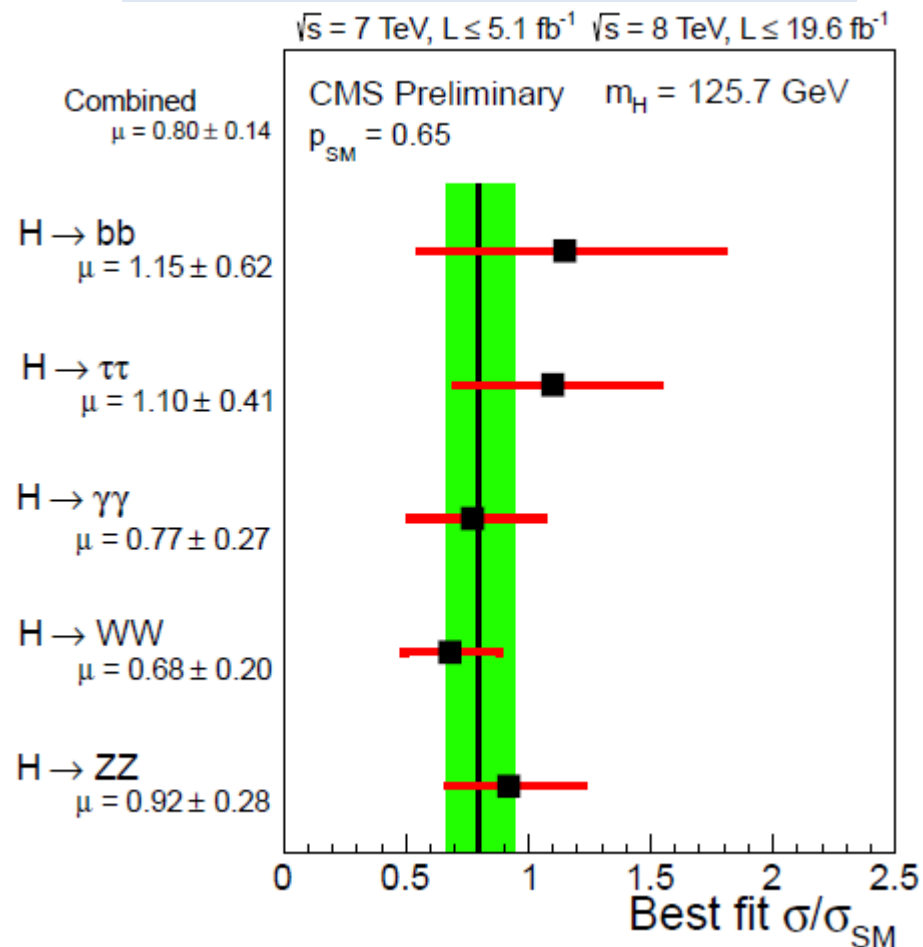
A consistent mass is measured for  $ZZ^*$  and  $\gamma\gamma$ :  $125.7 \pm 0.3 \pm 0.3$  GeV



- A consistent signal strength is measured w.r.t production mode, fermion vs. boson couplings, and custodial symmetry
- JCP 2++/0-+ disfavored at 2.8/3.3  $\sigma$  level

A consistent signal strength is measured for 5 decay modes

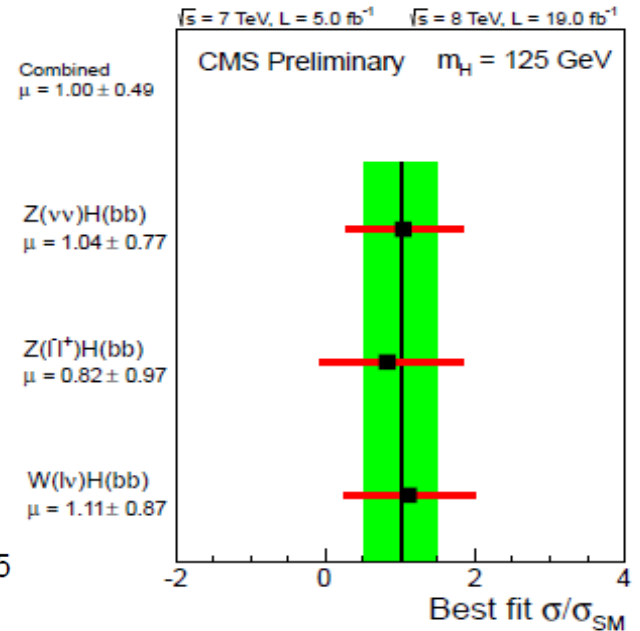
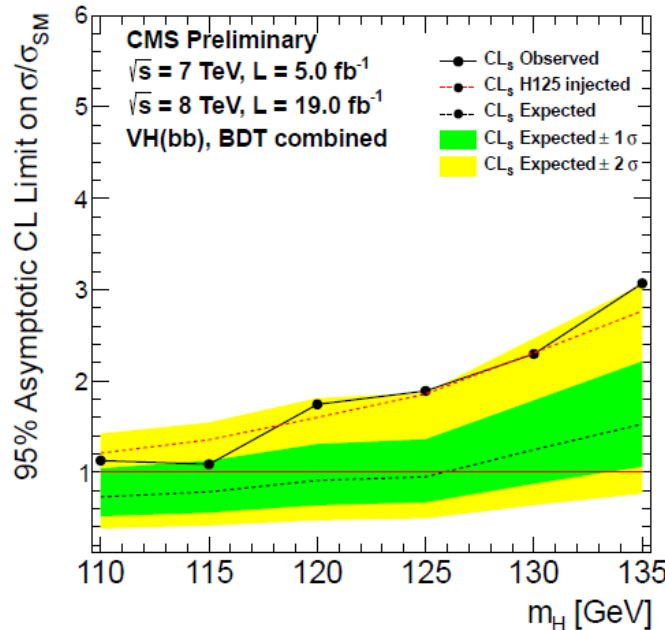
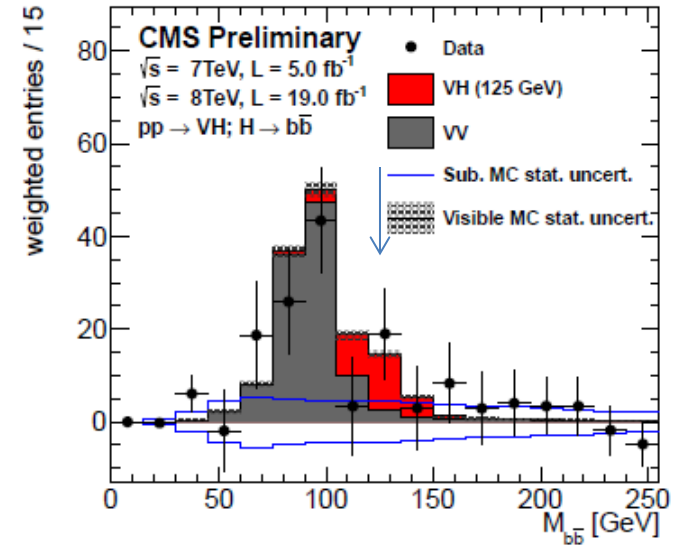
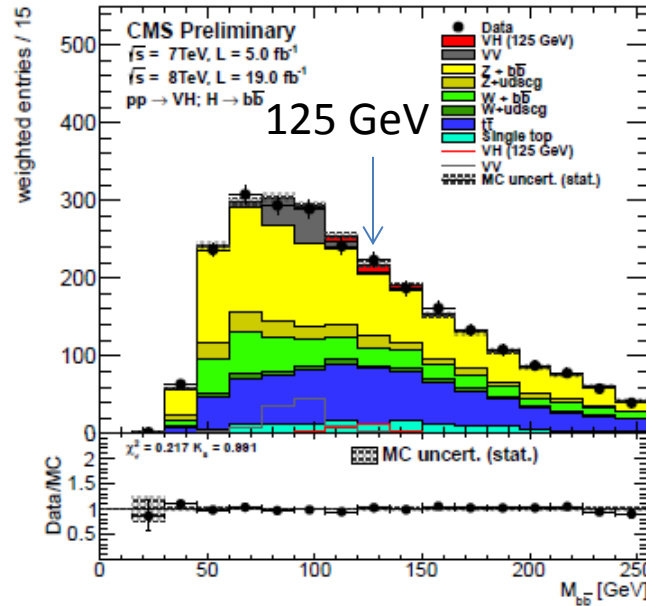
$\mu = 0.80 \pm 0.14$



# V+H, H→bb: Full Run 1 result

CMS-PAS-HIG-13-012

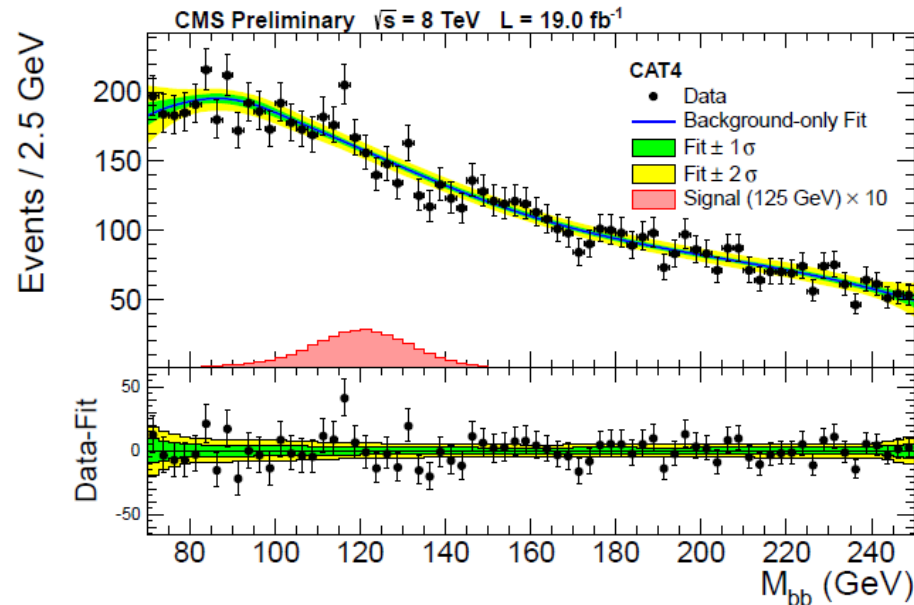
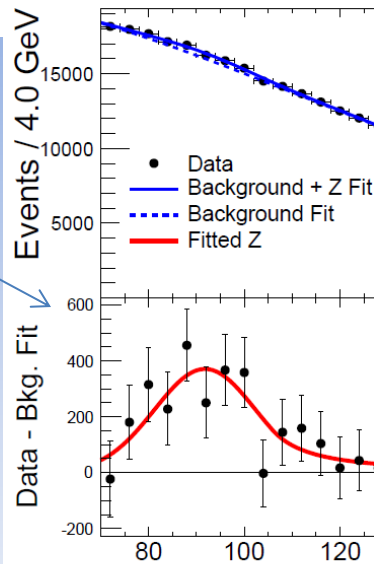
- BDT shape-based analysis finds an excess with local significance of  $2.1 \sigma$  at **125 GeV** mass ( $2.1 \sigma$  expected).
- VZ diboson peak clearly visible ( $7.5\sigma$ )**, consistent with SM rate
- Signal strength  $\mu = 1.0 \pm 0.50$  consistent with SM Higgs and consistent across V modes



# Higgs newcomers since Moriond:

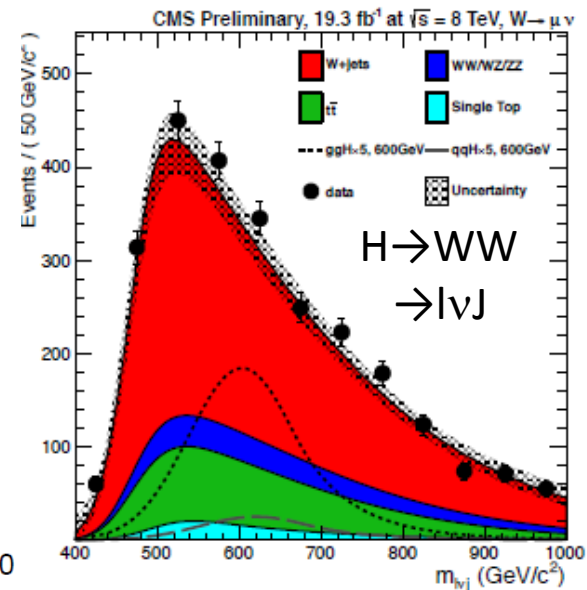
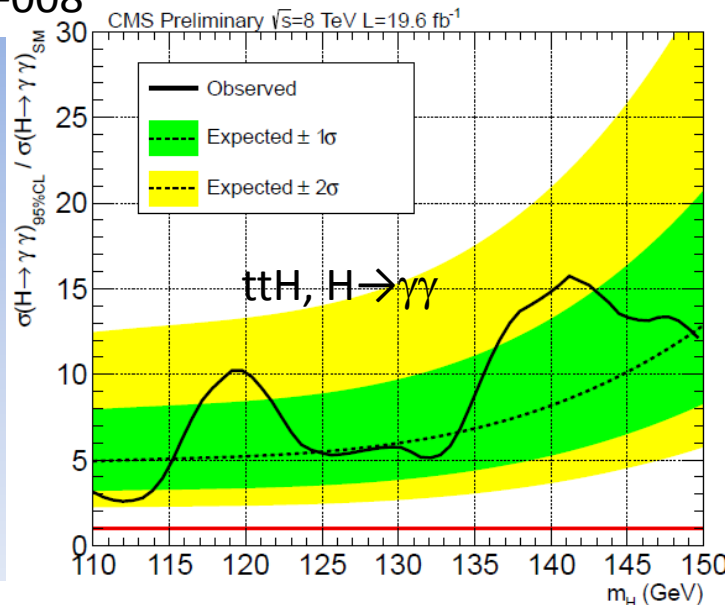
## CMS-PAS-HIG-13-011

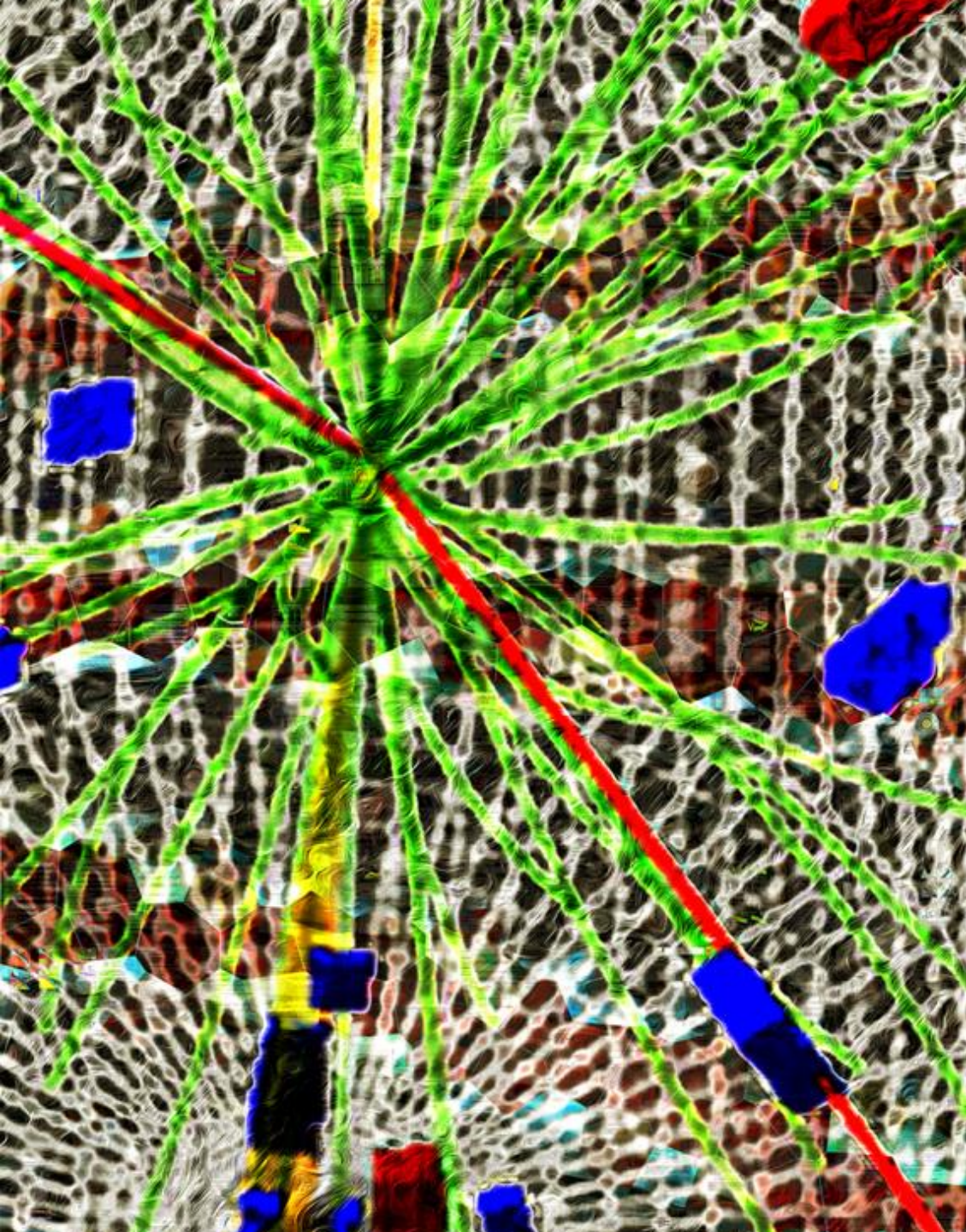
- First search for **VBF**  $H \rightarrow b\bar{b}$ .
- **$Z \rightarrow b\bar{b}$  peak clearly visible** ( $8\sigma$ ,  $6.8\sigma$  exp.)
- $b\bar{b}$  Mass fit in MVA categories
- At 125 GeV  $\mu = 0.7 \pm 1.4$ , 95% CL UL of 3.6 (3.0 exp.)



## CMS-PAS-HIG-13-015, HIG-13-008

- **$t\bar{t}H$  now extended to  $\gamma\gamma$  decay mode.** At 125 GeV,  $\mu < 5.4$  (95% CL, 5.3 expected)
- $H \rightarrow WW \rightarrow l\nu J$  search. First Higgs search to include **merged dijet W-tagging** (pruned CA8 with n-subjettiness cut).





# Beyond Standard Model Search Results

Digital art courtesy of Xavier Cortada (with the participation of physicist Pete Markowitz) "In search of the Higgs boson:  $H \rightarrow \gamma\gamma$ "

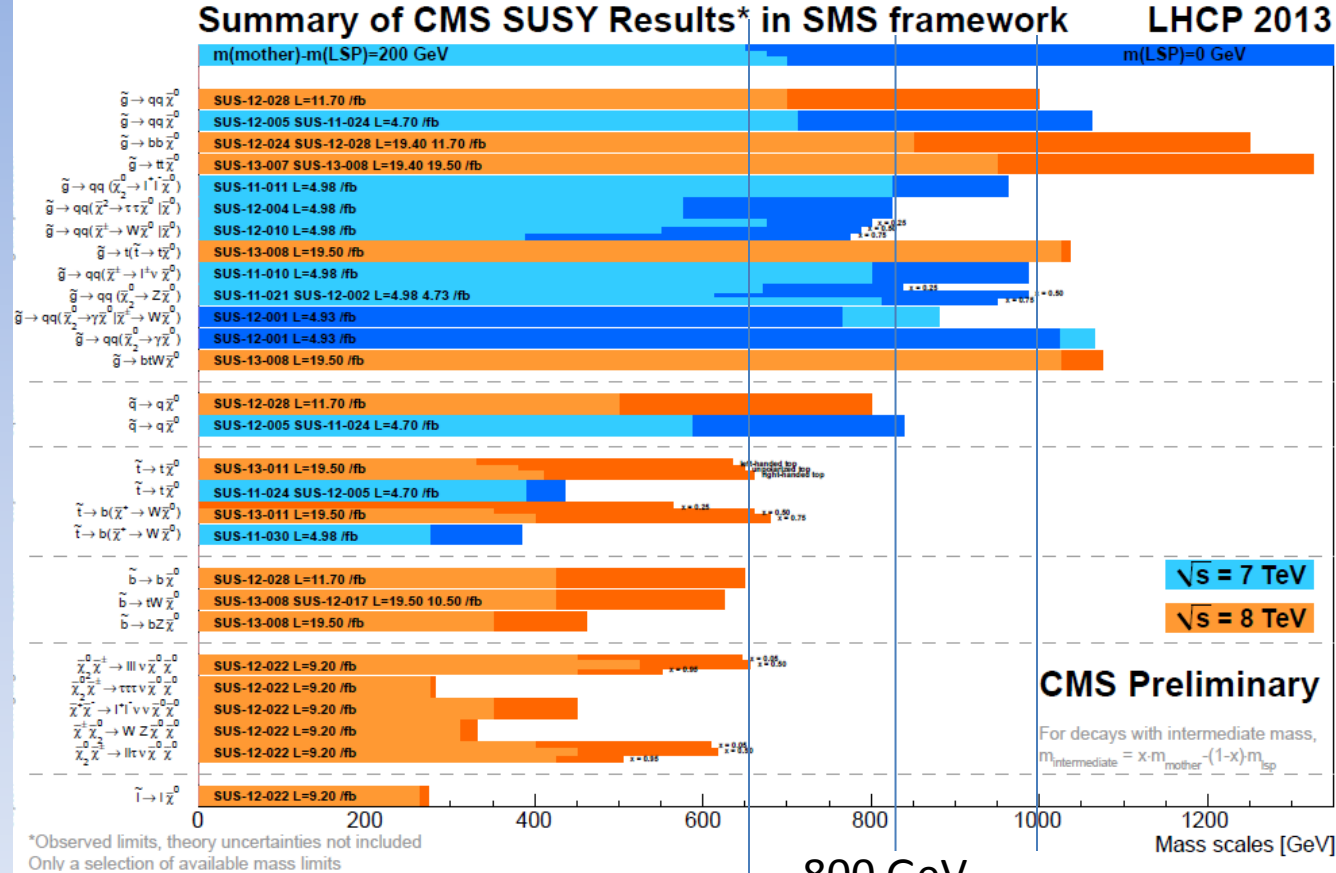


# SUSY: Remaining strategies for Run 1

- Natural R-parity-conserving SUSY offered possibility of light squark/gluino discovery. **Exclusions up to 800-1300 GeV mass complete.**

- Now searching for more general realizations of natural SUSY:

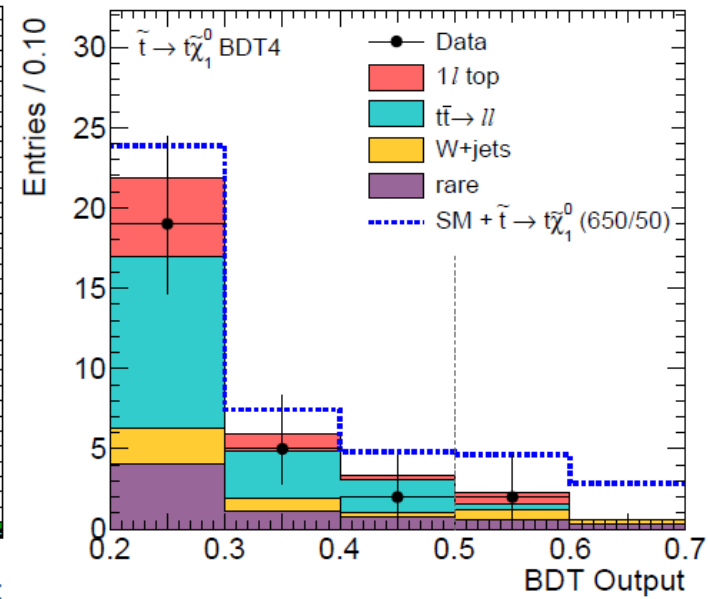
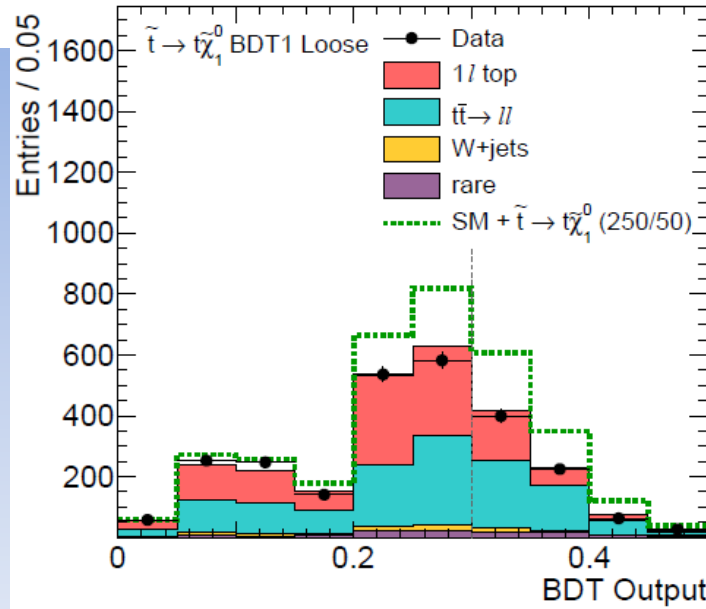
- R-parity violation
- Electroweak gaugino production
- Light stop/sbottom
- Compressed spectra



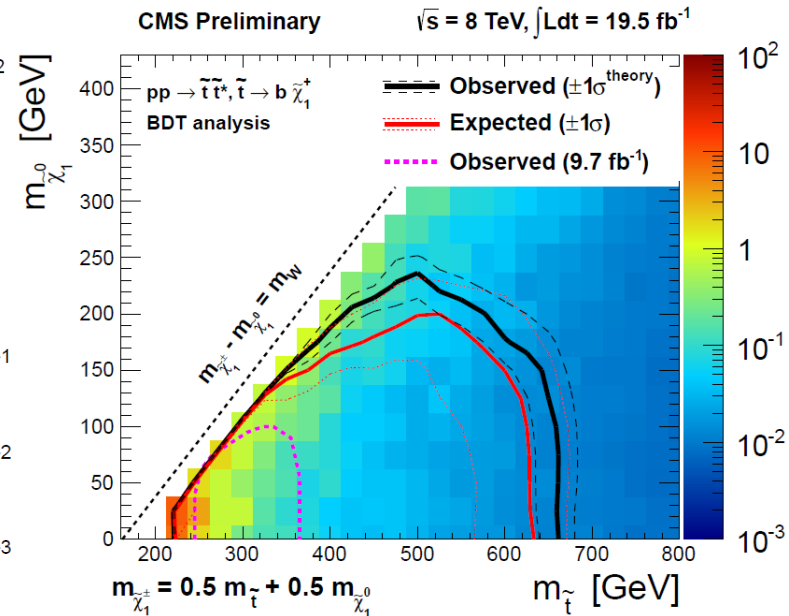
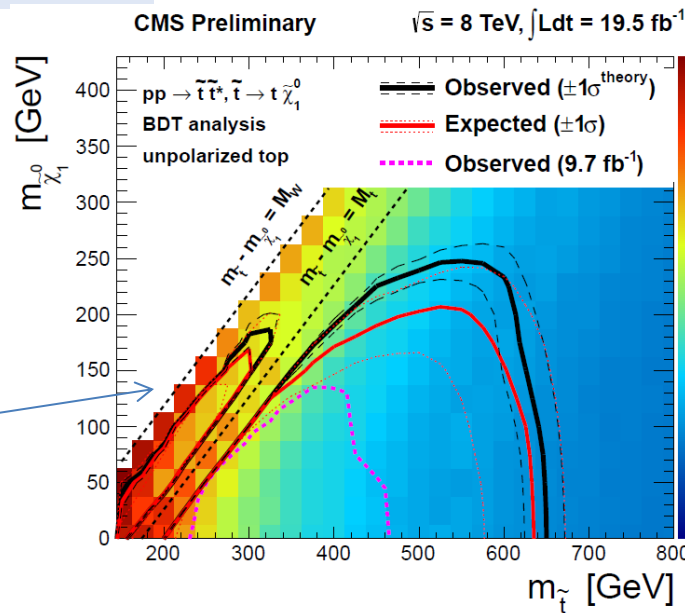
# SUSY: stop search in lepton+jets

CMS-PAS-SUS-13-011

Stop pair search in stop  
 $\rightarrow$  top + LSP and  
 $b+W+LSP$  decays .  
 Signature is  
 semileptonic  $t\bar{t}$   
 candidates with large  
 MET. Kinematic BDT  
 identifies loose (tight)  
 selection for light  
 (heavy) stop



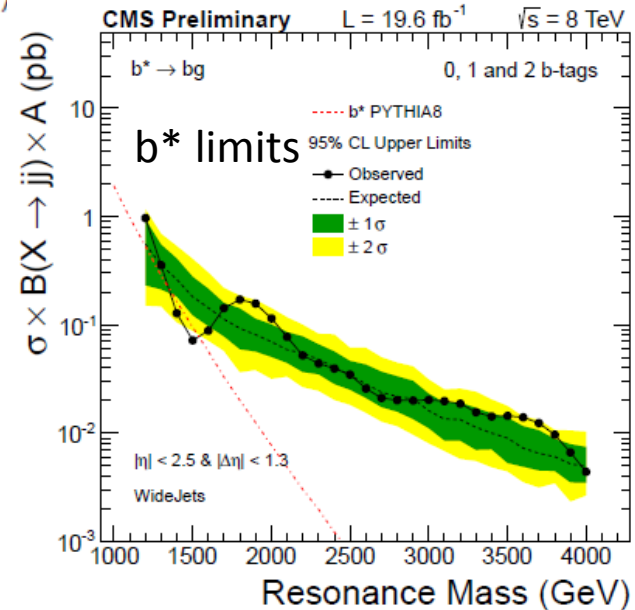
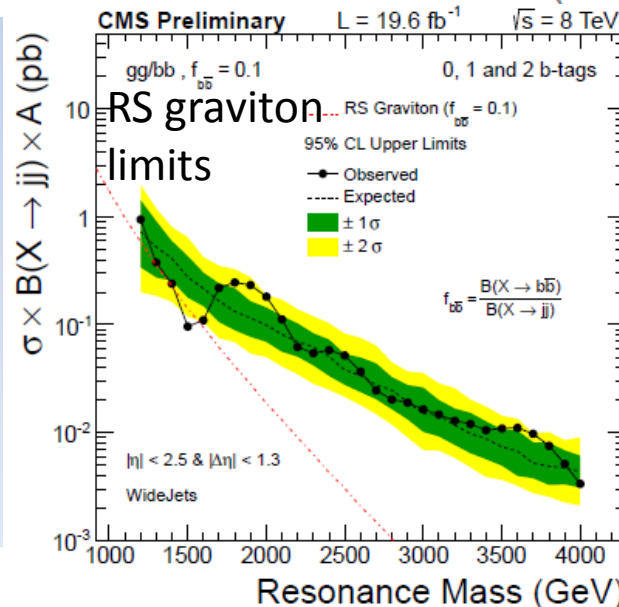
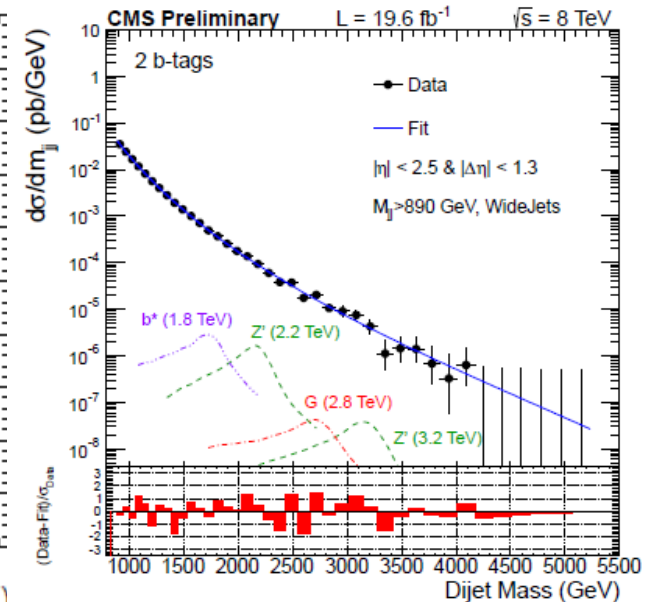
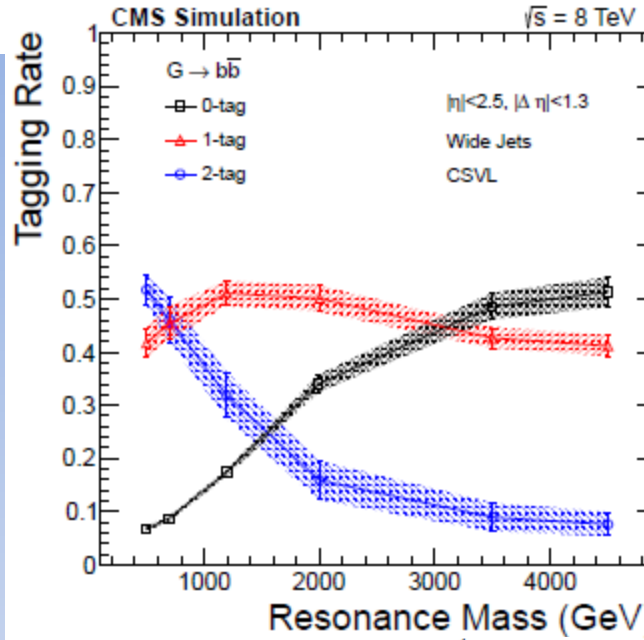
Stop mass  
 limits  
 obtained **150-  
 650 GeV** in  
 mass,  
 including the  
**off-shell top**  
 sector



# BSM: bb resonances

CMS-PAS-EXO-12-023

- bb and bg resonance search
- **Wide central ( $\eta < 2.5$ ) jets of radius 1.1 reconstructed from anti-kt jets of radius 0.5,  $|\Delta\eta| < 1.3$**
- 0, 1, and 2 b-tagged jet categories analyzed to maximize efficiency at high mass
- Data consistent with smooth background
- RS graviton bounds  $> 1.42$ - $1.57$  TeV
- Narrow topcolor  $Z'$   $> 1.20$ - $1.68$  TeV
- Excited  $b^* \rightarrow bg$   $> 1.34$ - $1.54$  TeV



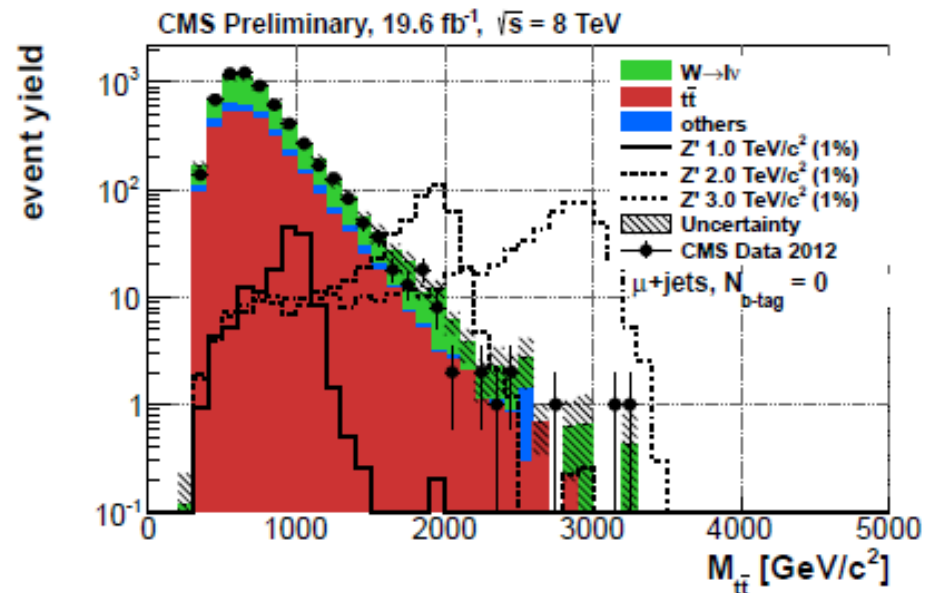
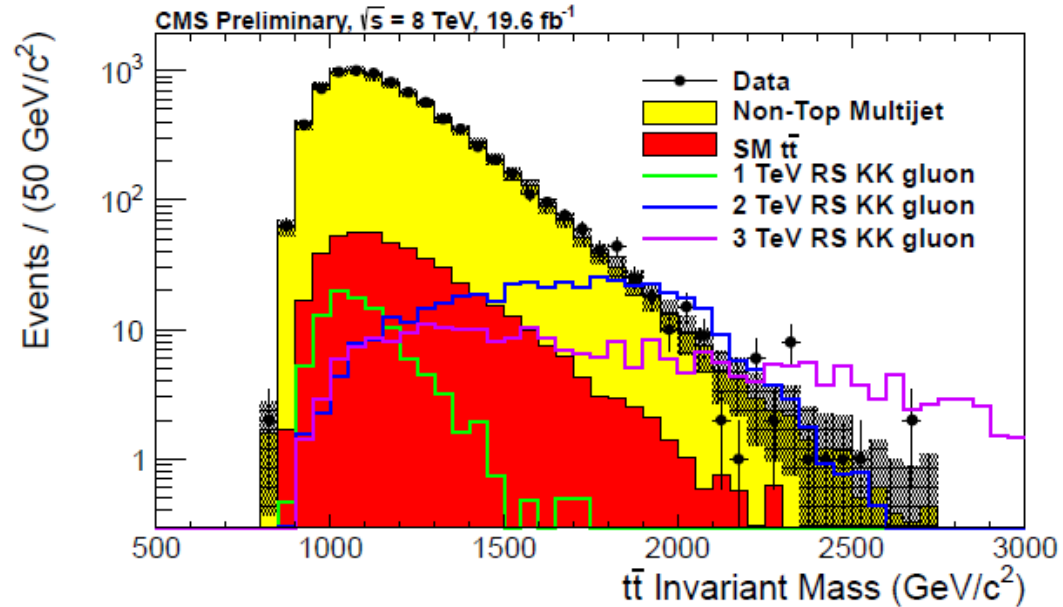
# BSM: $t\bar{t}$ resonances

CMS-PAS-B2G-12-005

- $t\bar{t}$  resonance search in the all-hadronic state
- **400 GeV CA8 dijets selected for 3-jet, top-like substructure (JHUTopTagger)**
- Top tagger performance calibrated with  $t\bar{t}$  control samples
- RS KK gluon bounds  $> 1.8$  TeV
- Narrow topcolor  $Z' > 1.65$  TeV

CMS-PAS-B2G-12-006

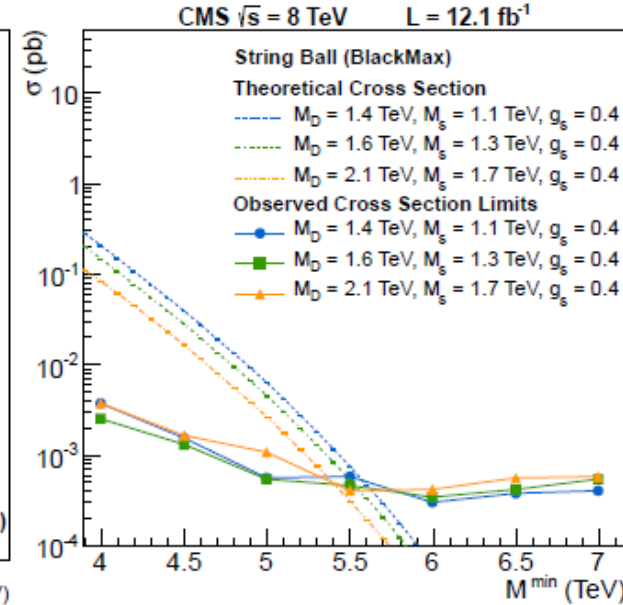
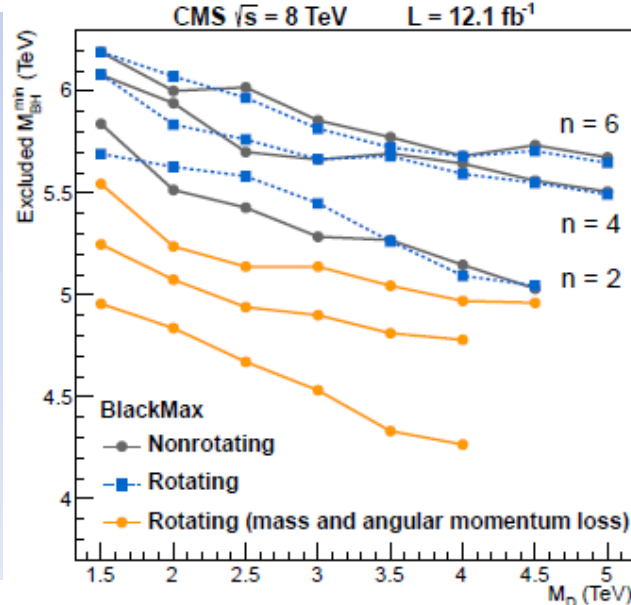
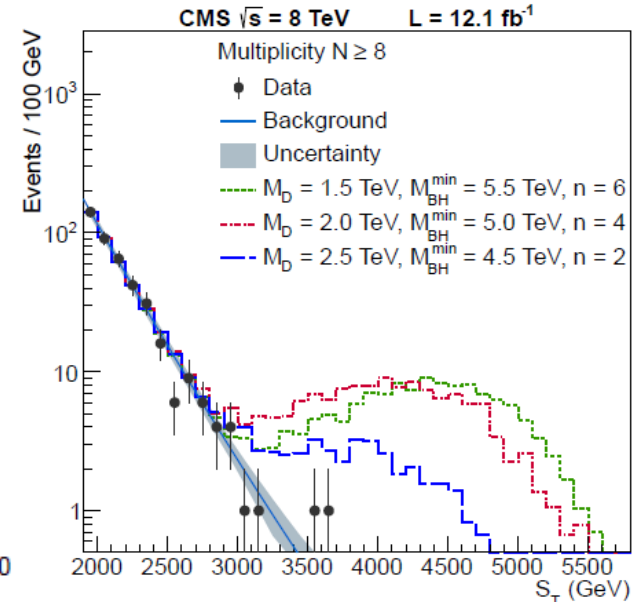
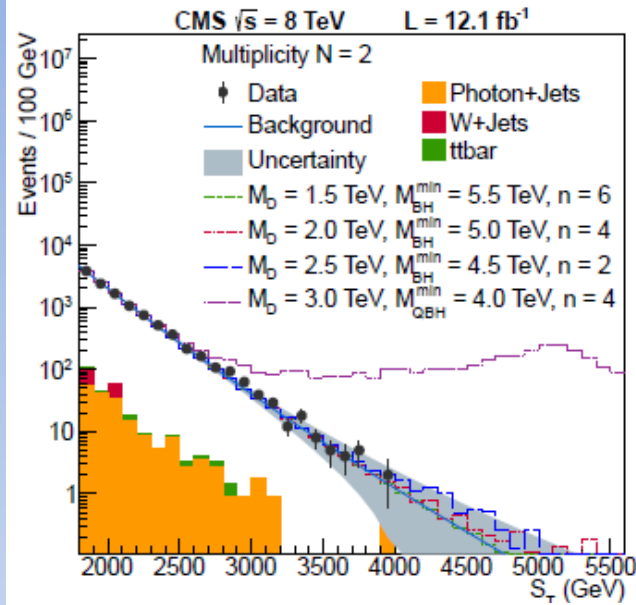
- $t\bar{t}$  resonance search in the lepton+jets state
- Threshold, low mass selection: isolated lepton + 4 jets
- Boosted, high mass selection: non- or isolated lepton + 2 jets
- Both 0 and 1 b-tagged categories examined
- RS KK gluon bounds  $> 2.5$  TeV
- Narrow topcolor  $Z' > 2.1$  TeV



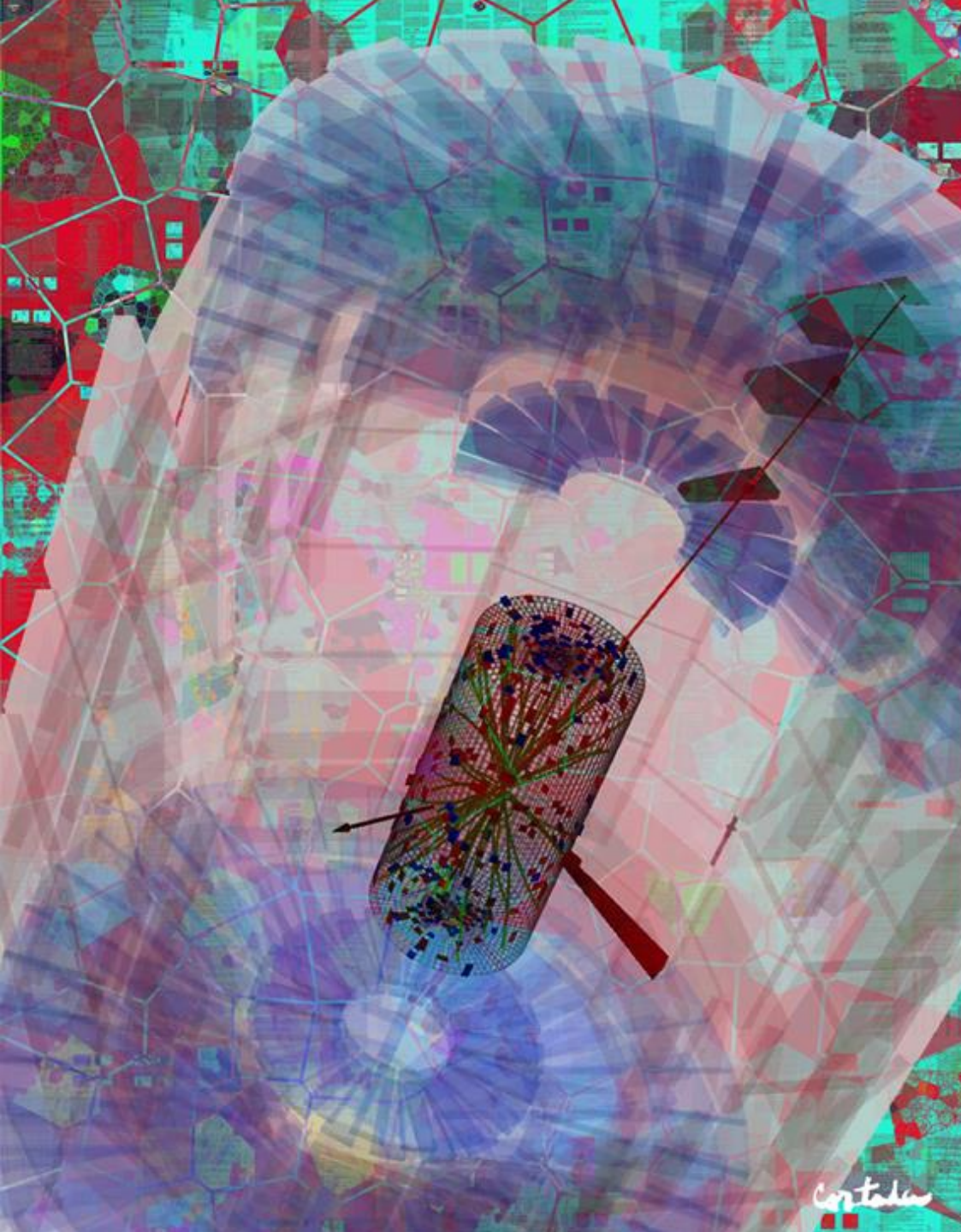
# BSM: black holes

Submitted to JHEP, arXiv:1303.5338

- Microscopic black hole or string-ball production results in high-multiplicity, high sum-ET events
- Select 2 jets + X events, count N physics objects with  $ET > 50$  GeV and compute their scalar sum-ET,  $S_T$  for  $N=2-10$
- $N=2$  control sample for  $ST$  background shape
- $ST$  1.9-2.3 TeV sideband for background norm vs. N
- **Semi-classical BH bounds from 4.3-6.2 TeV**
- Minimum string ball bounds  $\sim 5.5$  TeV
- +model-independent xsec limits
- Final result for Run 1



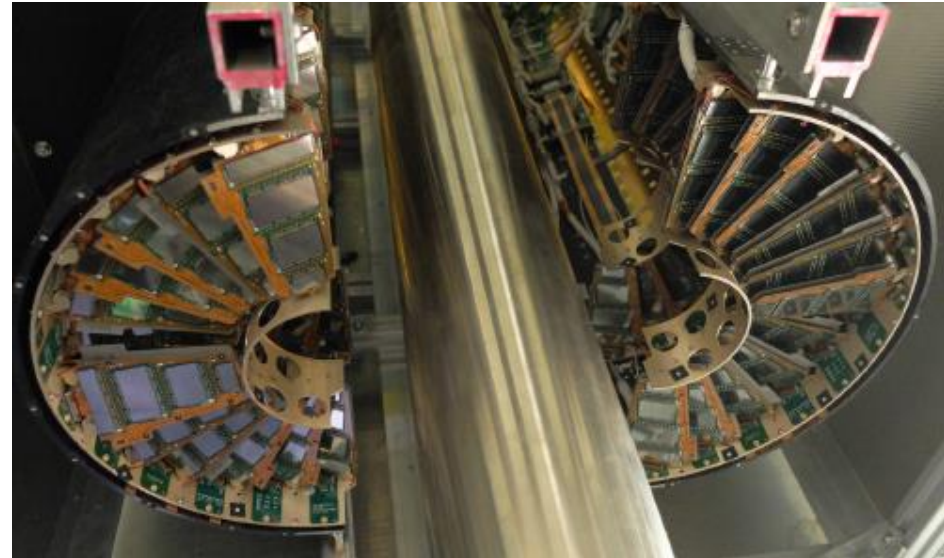
# Shutdown and Upgrade Activities



Digital art courtesy of Xavier Cortada (with the participation of physicist Pete Markowitz) "In search of the Higgs boson:  $H \rightarrow WW$ "

# Current CMS detector status

- Beam pipe HF/CT2, and endcap sections removed at both ends
- Barrel and forward pixels have been removed to cold lab
- ME1/1 chamber removal begun
- Water cooling has returned, power to racks soon to follow



# Near term plans for LS1

- Full ME1/1 chamber removal to surface for electronics refurbishing
- HO SiPM, HF PMT testing and installation at Pt 5 test-stand
- Strip tracker "Going Cold" activities in full swing; recommissioning cold in September
- CSC and RPC chambers in layer 4, installation in Oct. and Feb.
- Global run planned for end October

ME 1/1 chambers

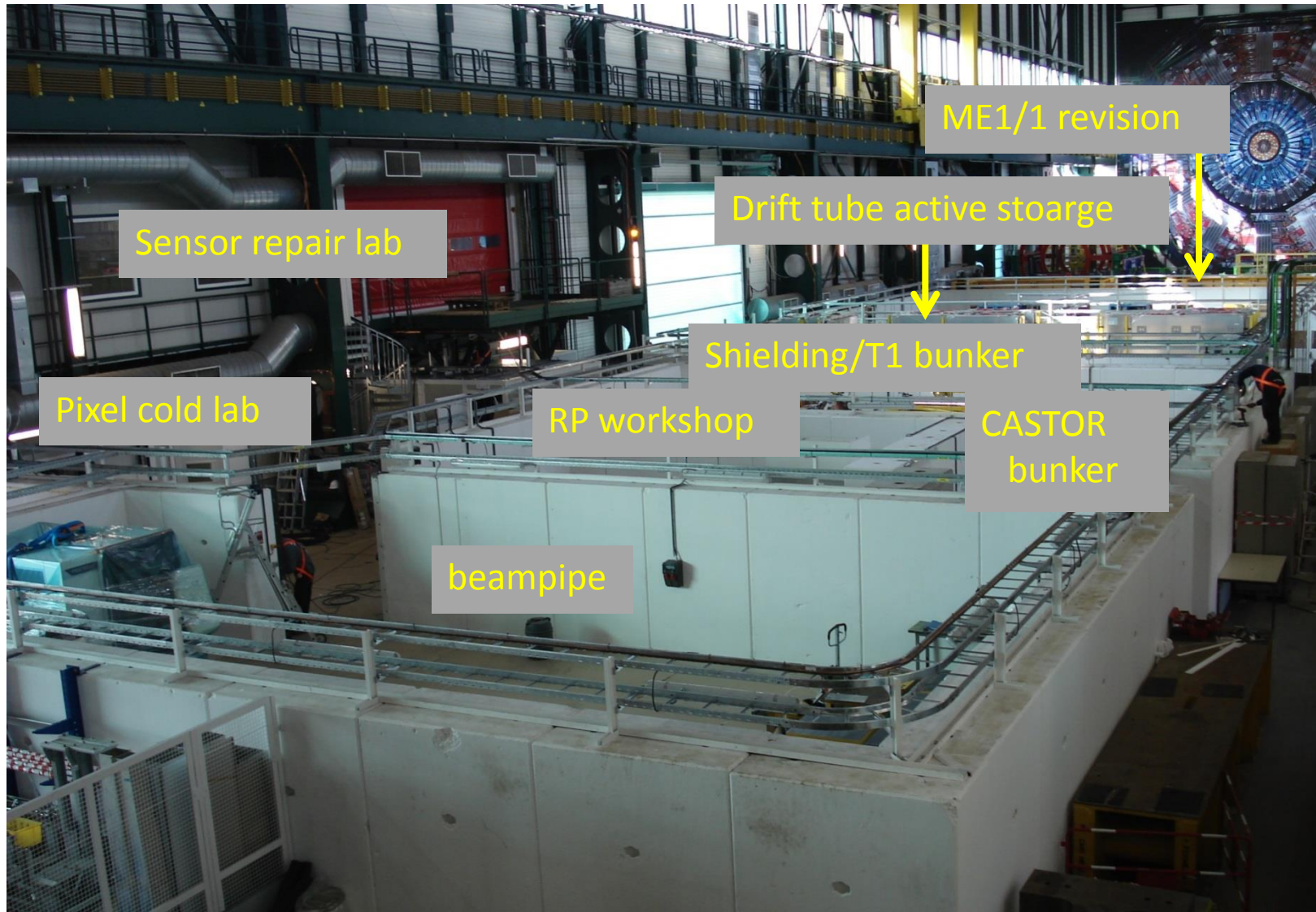


ME 4/2 production



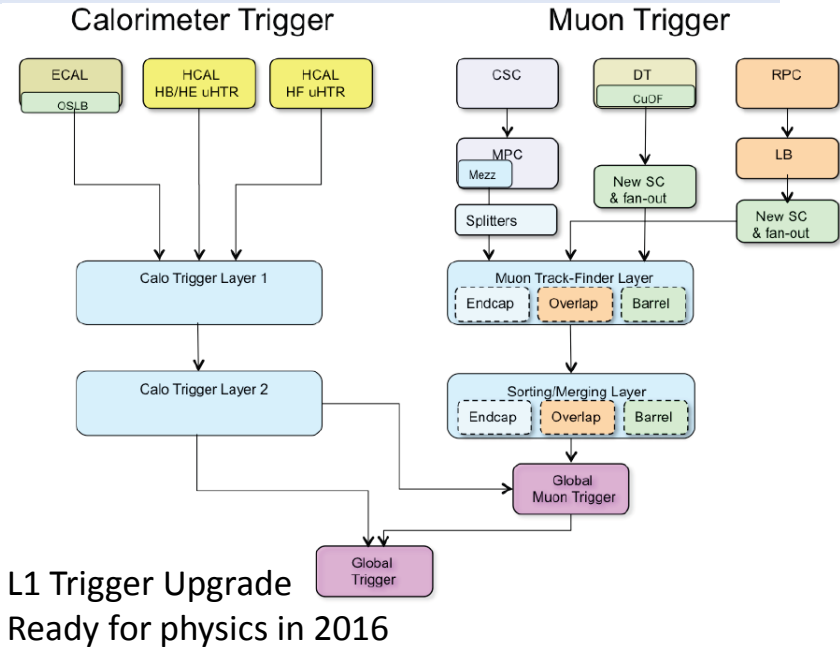


# LS1: Surface Facilities



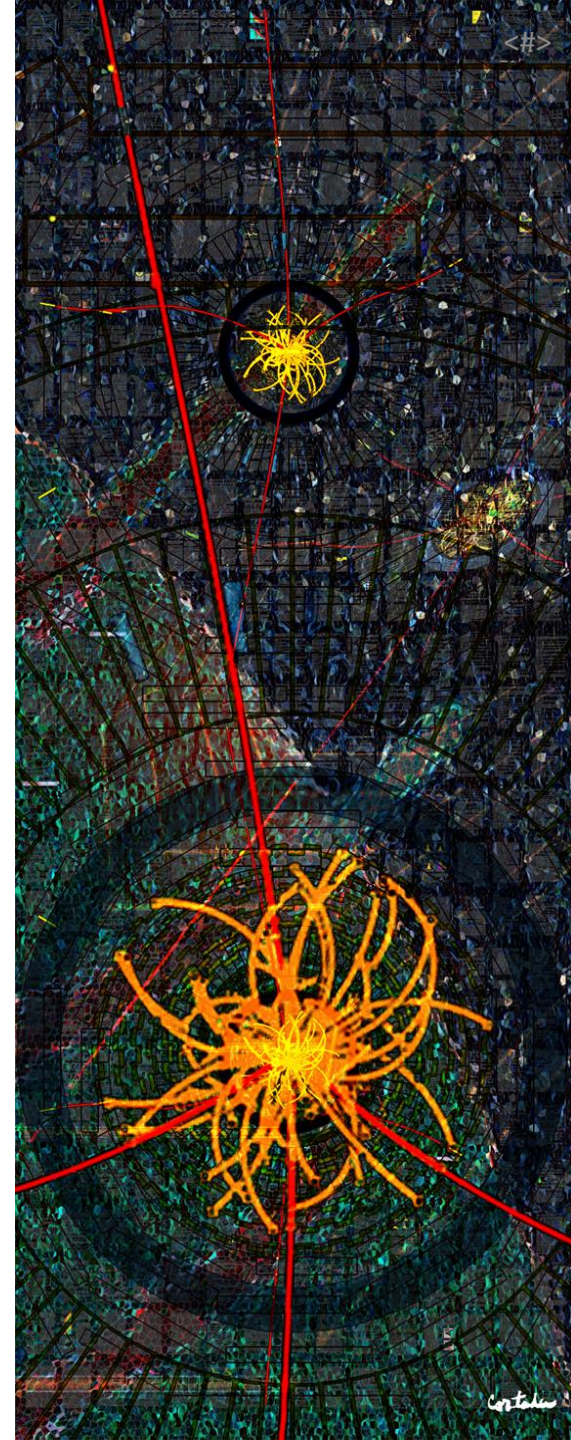
# Longer term

- LHCC this week: **L1 Trigger Upgrade TDR**  
Asking for approval at this meeting
- With approval this joins the Pixel and HCAL Upgrade TDRs for Phase 1
- CMS held an upgrade workshop last week at DESY, focused on the upgrade scenarios and R&D for Phase 2
- Preparing for Snowmass, End of June (Seattle), Start of August (Minneapolis): Variety of physics studies for HL-LHC
- And for ECFA HL-LHC Workshop, Oct 1-3
- Developing upgrade scenarios with cost scale for Phase 2 (HL-LHC) based on physics performance and detector longevity requirements – by October
- Phase 2 Technical Proposal planned in 2014

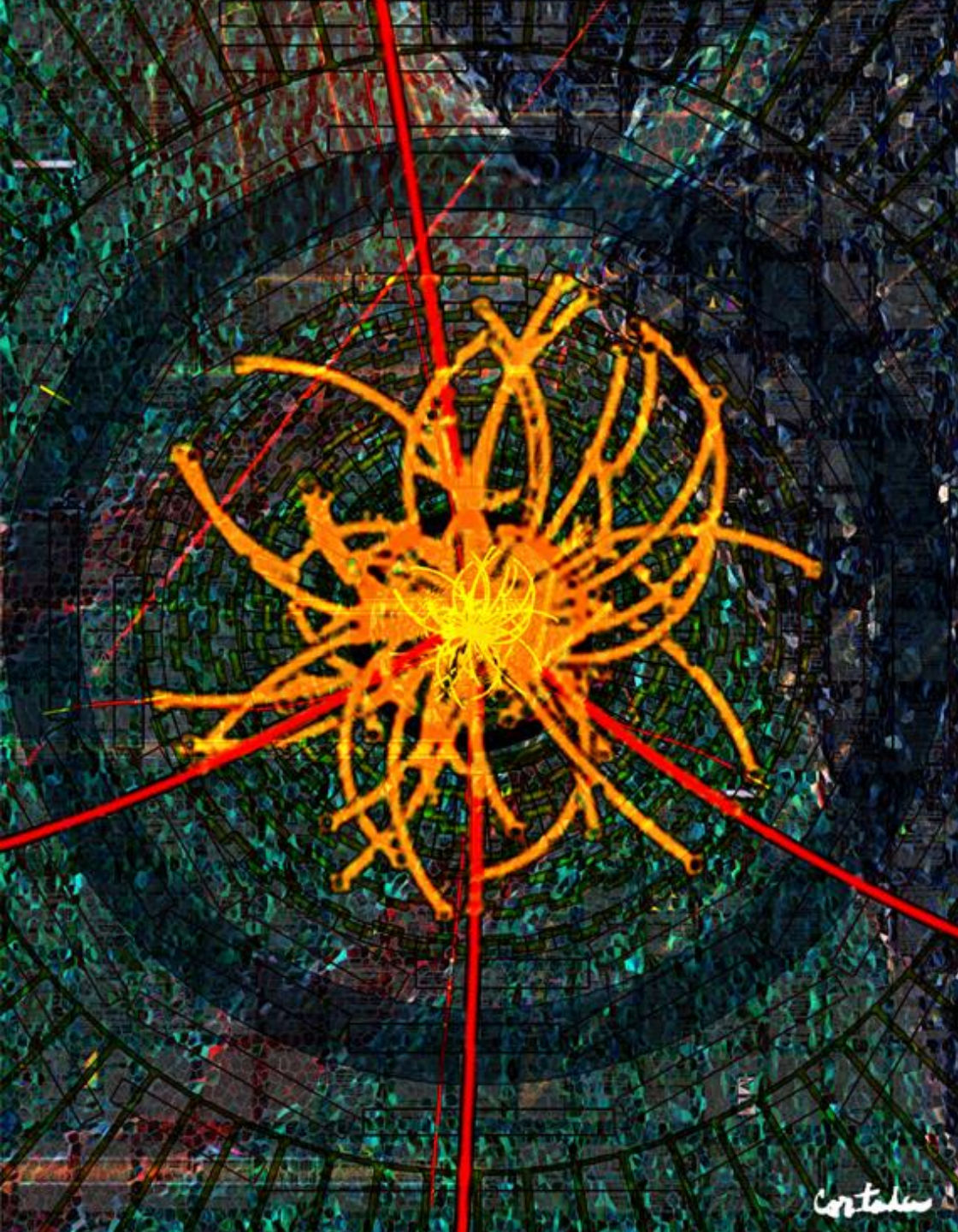


# Summary

- Run 1 pp, pPb, PbPb data being successfully exploited for novel insights into heavy ion and SM physics.
- 2013 Run 1 Higgs results validate and improve upon the 2012 Higgs-like boson discovery. SM Higgs hypothesis is holding up well; now on the offensive in new SM and BSM modes.
- BSM search data continue to confront TeV scale physics (and beyond). New avenues in natural SUSY under exploration.
- LS1 improvements proceed on schedule. Phase 1 projects are underway. Converging on plans for Phase 2 Technical Proposal.



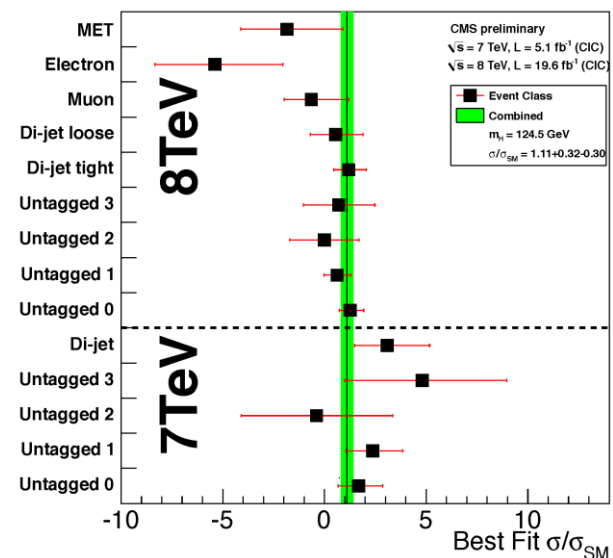
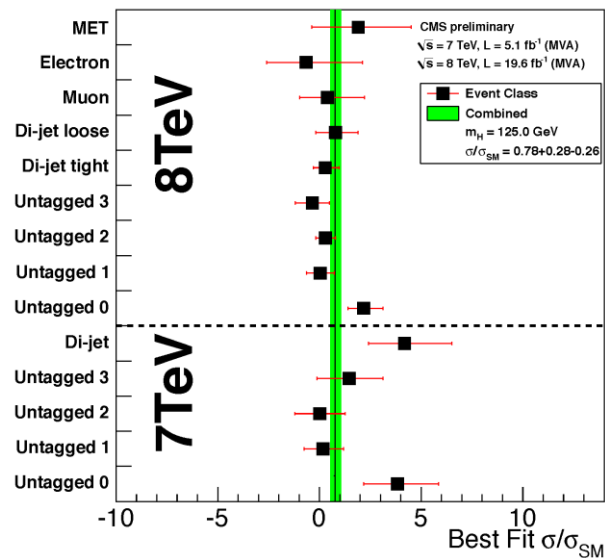
# Backups



# $H \rightarrow \gamma\gamma$ : Full Run 1 result

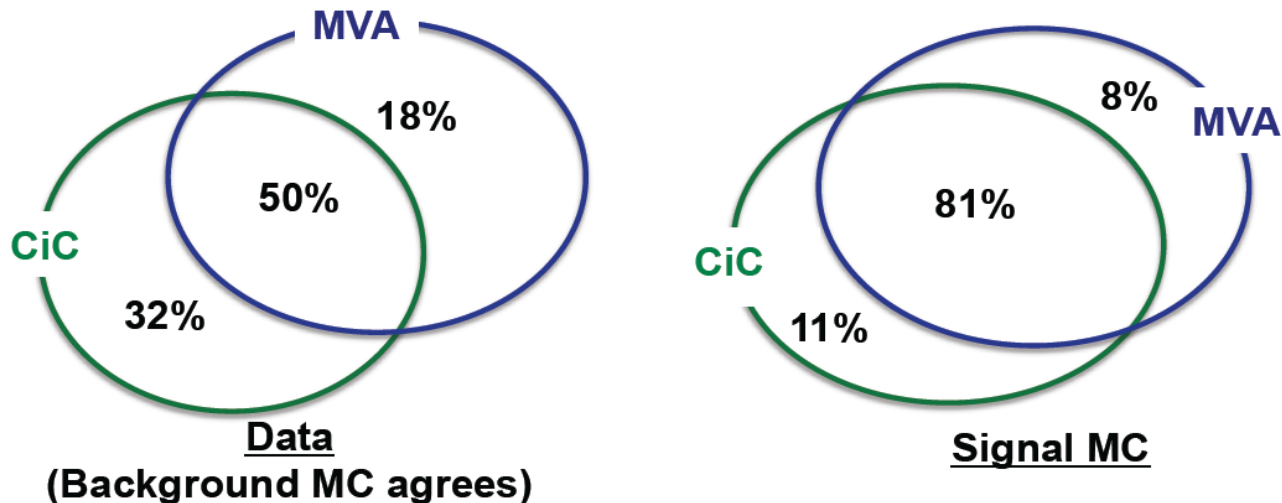
Signal strength by analysis and year

	MVA analysis (at $m_H=125$ GeV)	cut-based analysis (at $m_H=124.5$ GeV)
7 TeV	$1.69^{+0.65}_{-0.59}$	$2.27^{+0.80}_{-0.74}$
8 TeV	$0.55^{+0.29}_{-0.27}$	$0.93^{+0.34}_{-0.32}$
7 + 8 TeV	$0.78^{+0.28}_{-0.26}$	$1.11^{+0.32}_{-0.30}$



# $H \rightarrow \gamma\gamma$ : Full Run 1 result

The correlation coefficient between the MVA and cut-based signal strength measurements is found to be  $r=0.76$  (estimated using jackknife techniques). Taking account of the correlation, the compatibility between the MVA and cut-based analysis measurements of the signal strength is found to be within  $1.5\sigma$  for the combined 7 and 8 TeV measurement, and within  $1.8\sigma$  for the 8 TeV measurement alone.



# CMS Upgrade: L1 trigger TDR for LS1

EM and muon object isolation using calorimeter energy with pile-up subtraction.

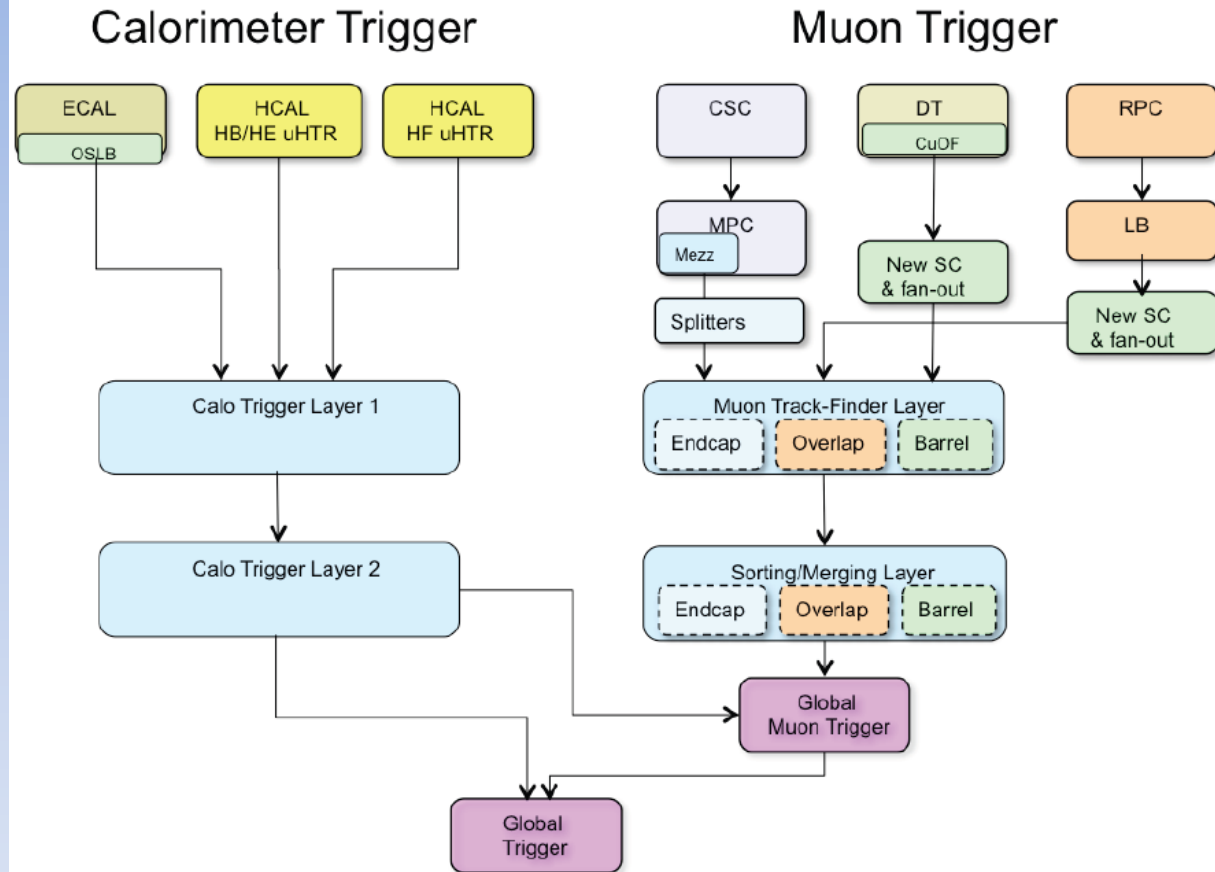
Improved jet finding with pile-up subtraction.

Improved hadronic tau ID with a much narrower cone.

Improved muon  $p_T$  resolution.

Improved global Level-1 trigger menu with larger capacity and more complex object combination

Realized with new high-bandwidth optical links ( $\mu$ TCA) and large FPGAs (Xilinx Virtex 7)



Commissioning system in 2015

Complete system ready for physics in 2016