Achievements and plans

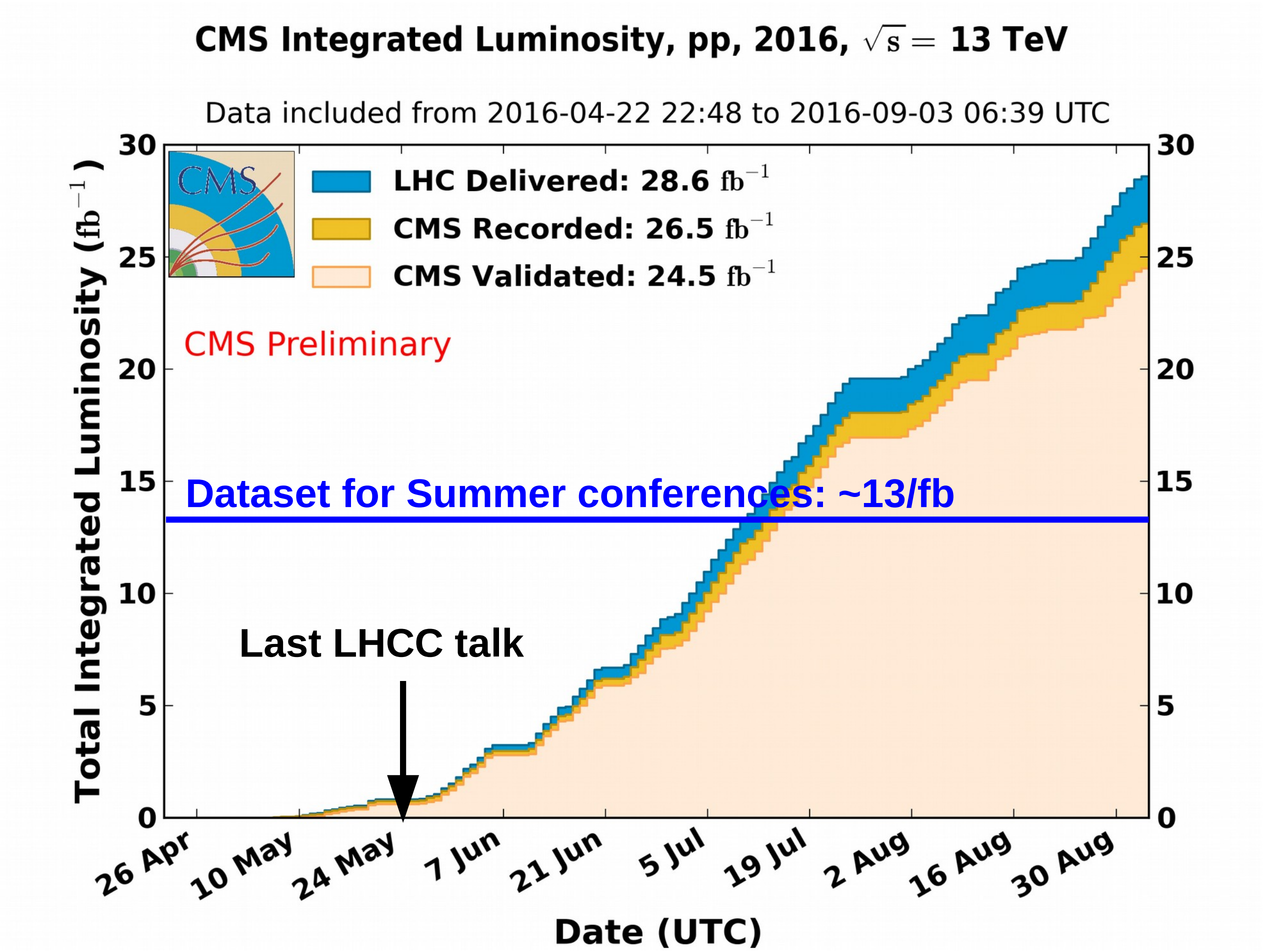
Petra Van Mulders
on behalf of the CMS collaboration

LHCC open session - 21st of September 2016

CMS is efficiently collecting data

Thanks to our LHC colleagues for the extremely smooth accelerator operation!

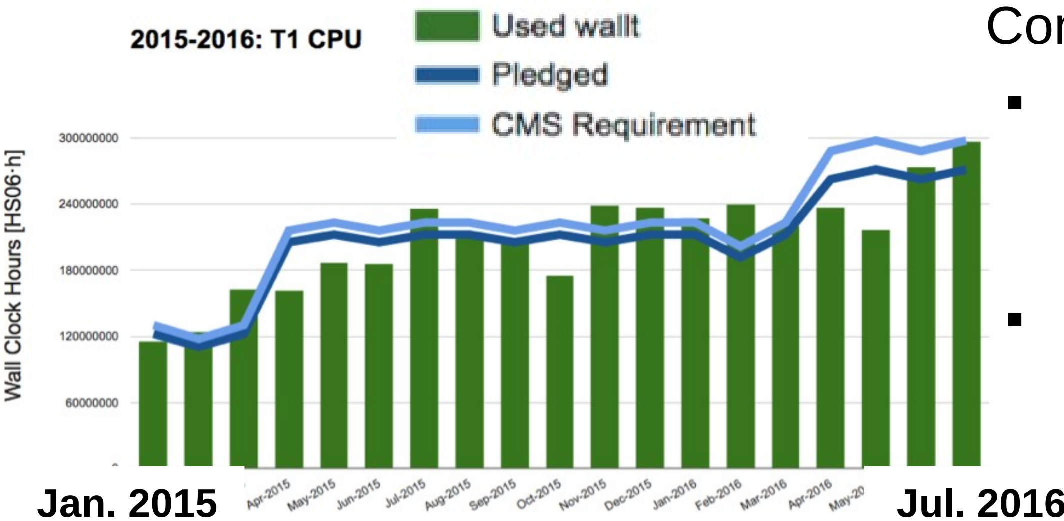
- Around 30/fb of data: 24M ttbar events and 1.5M Higgs boson events produced
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults



- Data collection efficiency: 92.5%
- Data certification efficiency: 92%

- Last year's issue with the cryogenic system of the magnet fully resolved

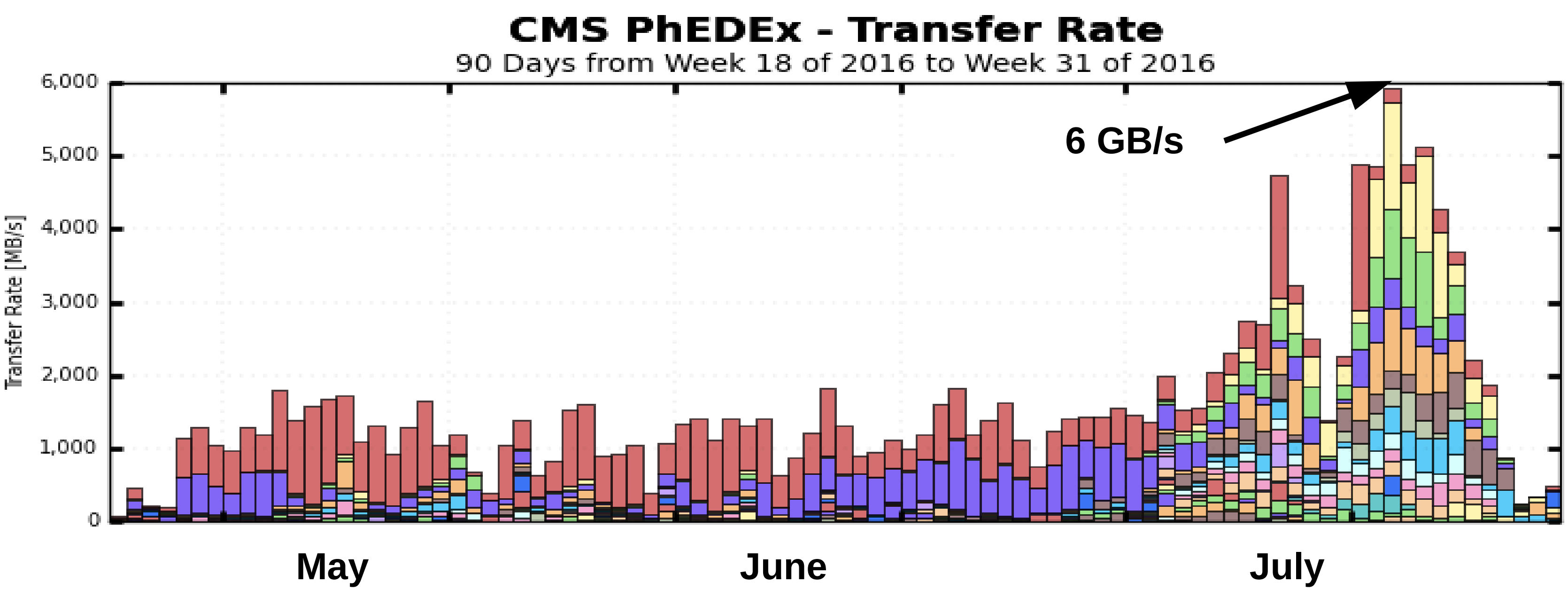
Computing highlights



Computing resources are heavily used:

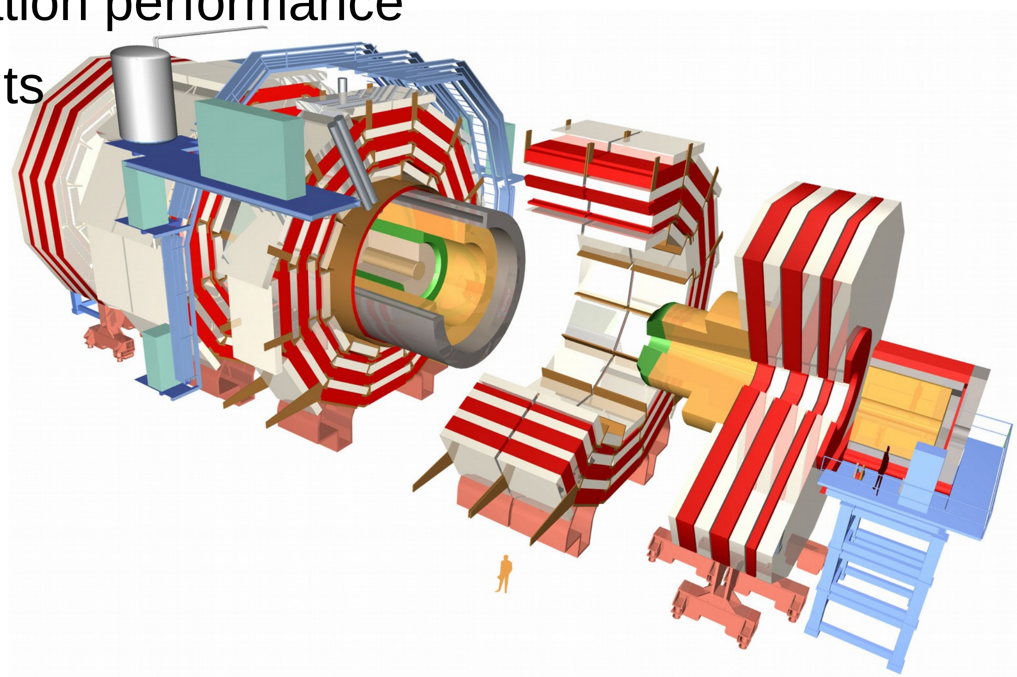
- Average CPU usage at T1 level is ~103% of the pledges
  - T1s are under-pledged in CPU/Disk/Tape
- Average CPU usage at T2 level is ~122% of the pledges

Improved the transfer rates out of CERN



Achievements in 2016 and plans

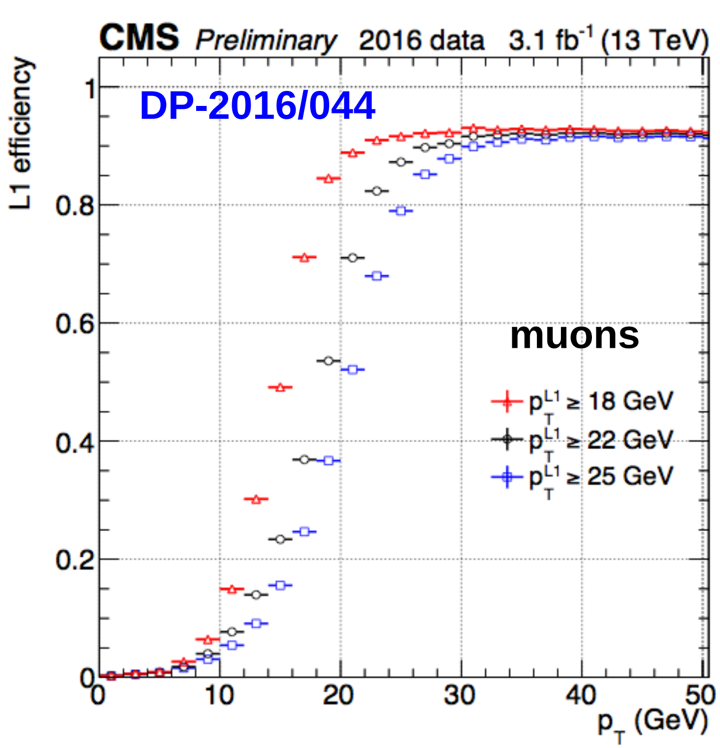
- Continue to ensure smooth operation
- **Status of detector systems**
  - L1 trigger successfully upgraded
  - High-Level Trigger
  - Muon system
  - Calorimeters
  - Silicon strip inefficiency and solution
  - CT-PPS runs together with CMS at high luminosity
- Object reconstruction and identification performance
- Selection of recent physics highlights
- Future plans: Phase 1

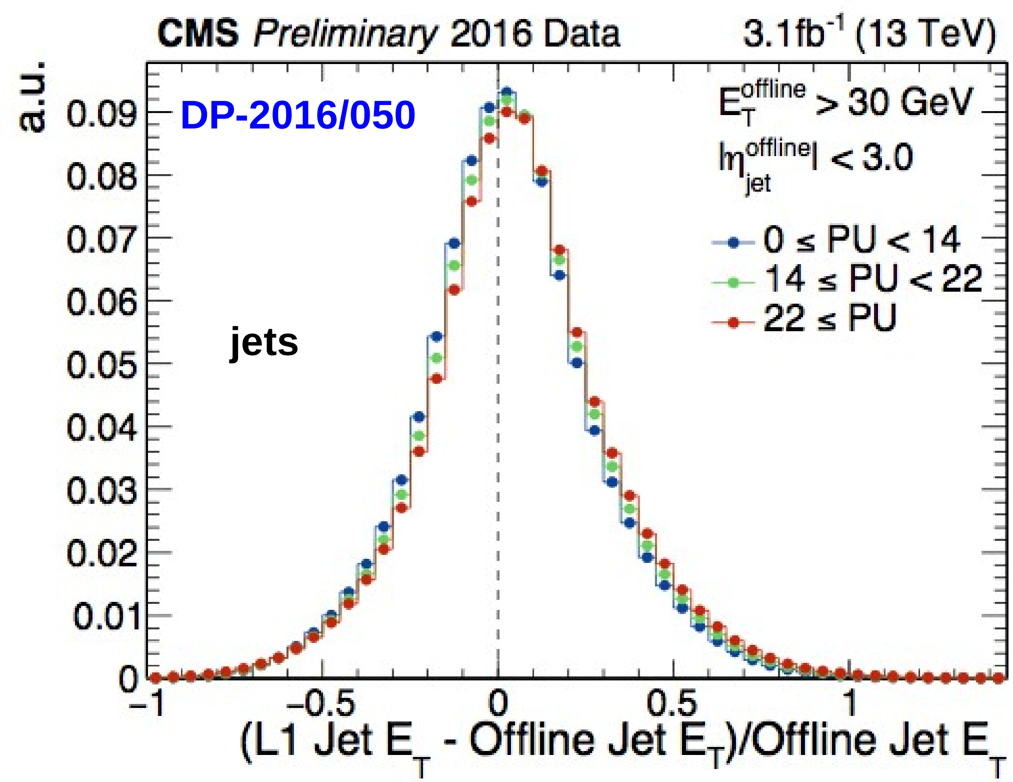


L1 trigger successfully upgraded

- Moved to regional muon track finders using redundancy of muon detector systems
- For the calorimeter system the data from one event is streamed into a single FPGA
- Global L1 trigger modified to allow more sophisticated triggering conditions

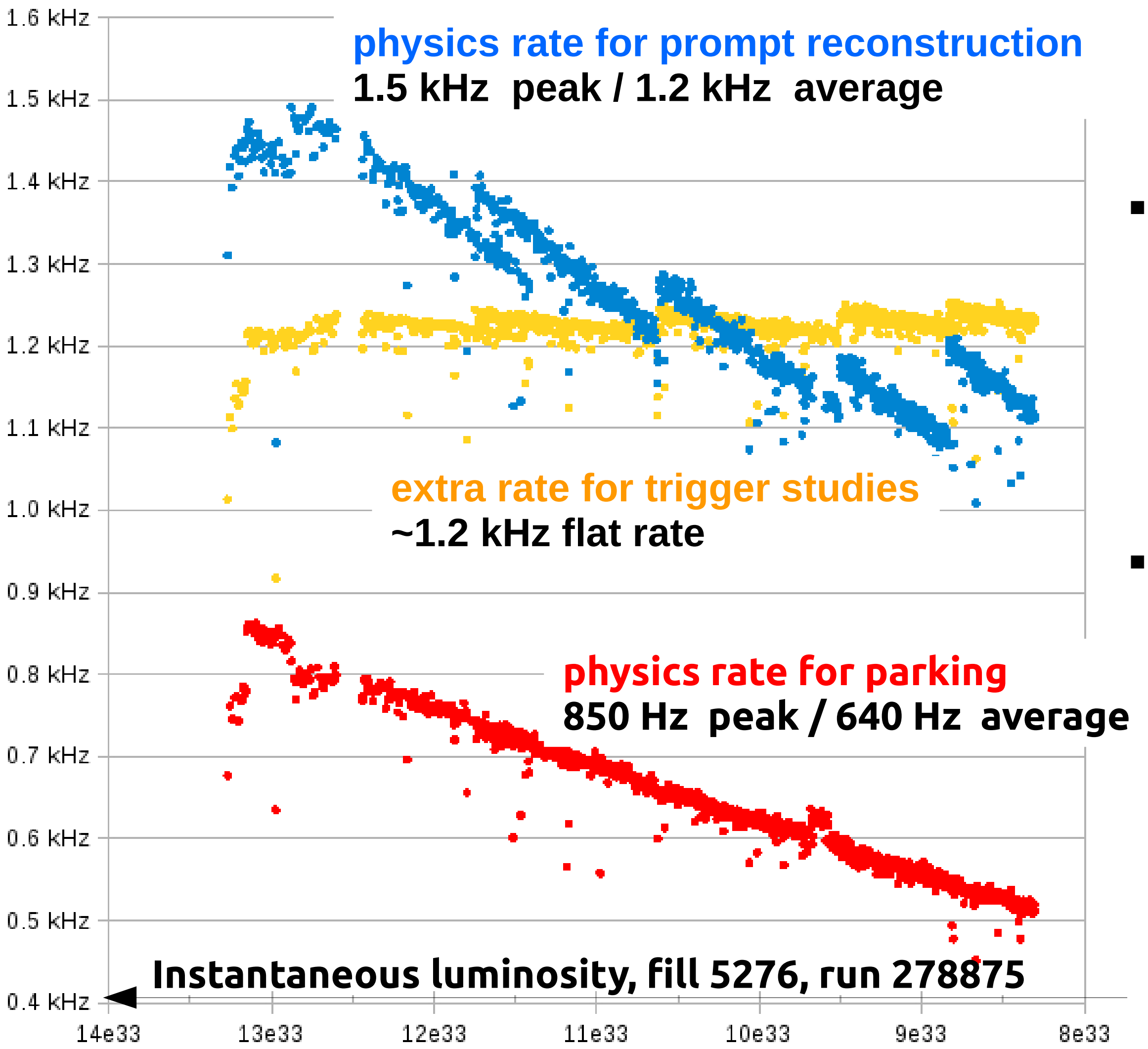
- Taking high quality data since May 2016 at higher luminosity running





HLT rates and extrapolation

The peak luminosity observed at CMS is $1.33 \cdot 10^{34}\ cm^{-2}s^{-1}$

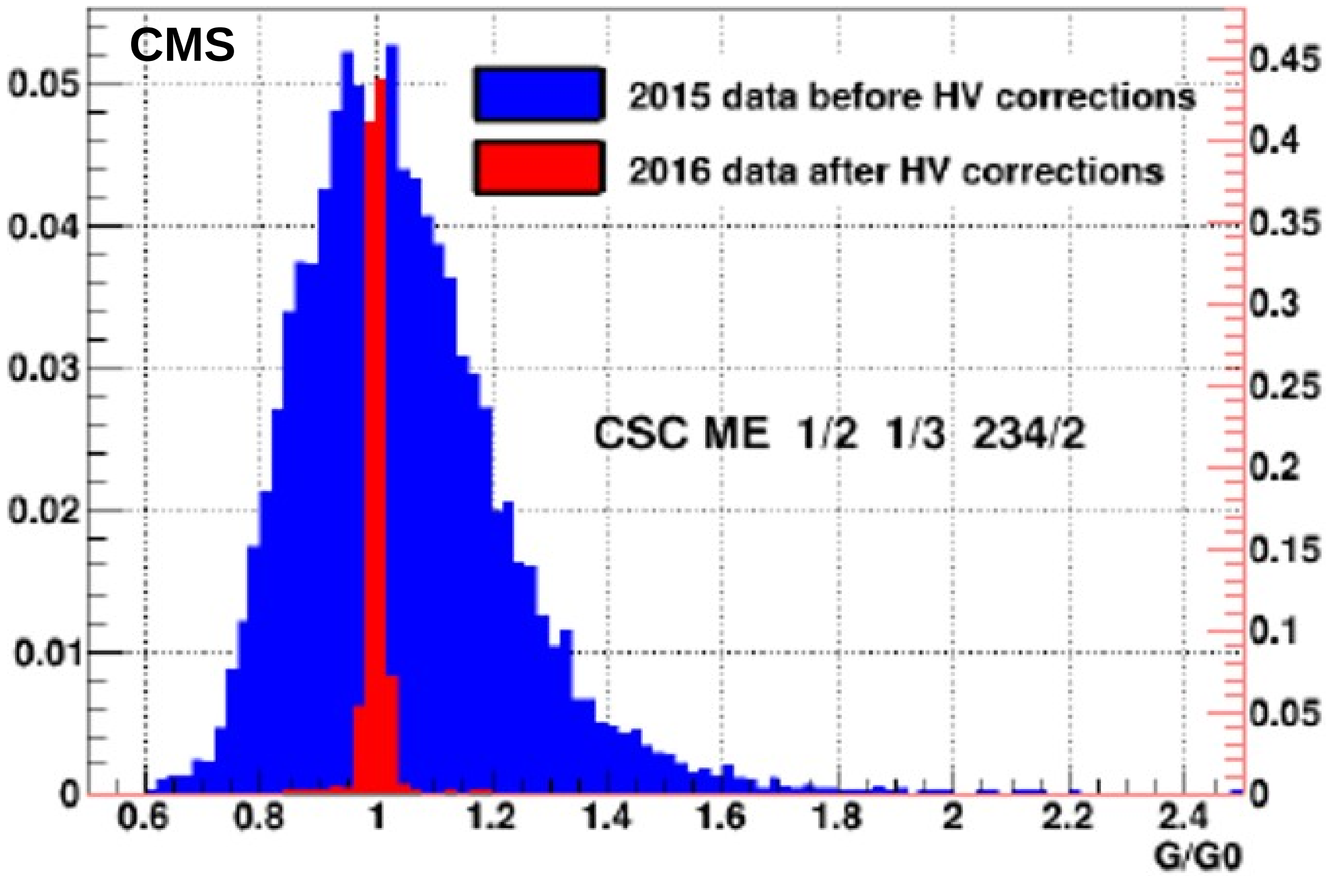


- the current HLT menu and CMS software release are able to cope with at least up to $1.5 \cdot 10^{34}\ cm^{-2}s^{-1}$
- further improvements:
  - 10% CPU reduction from new CMS software release used from this week onwards
  - + 10~15% capacity from HyperThreading

Excellent DAQ performance !

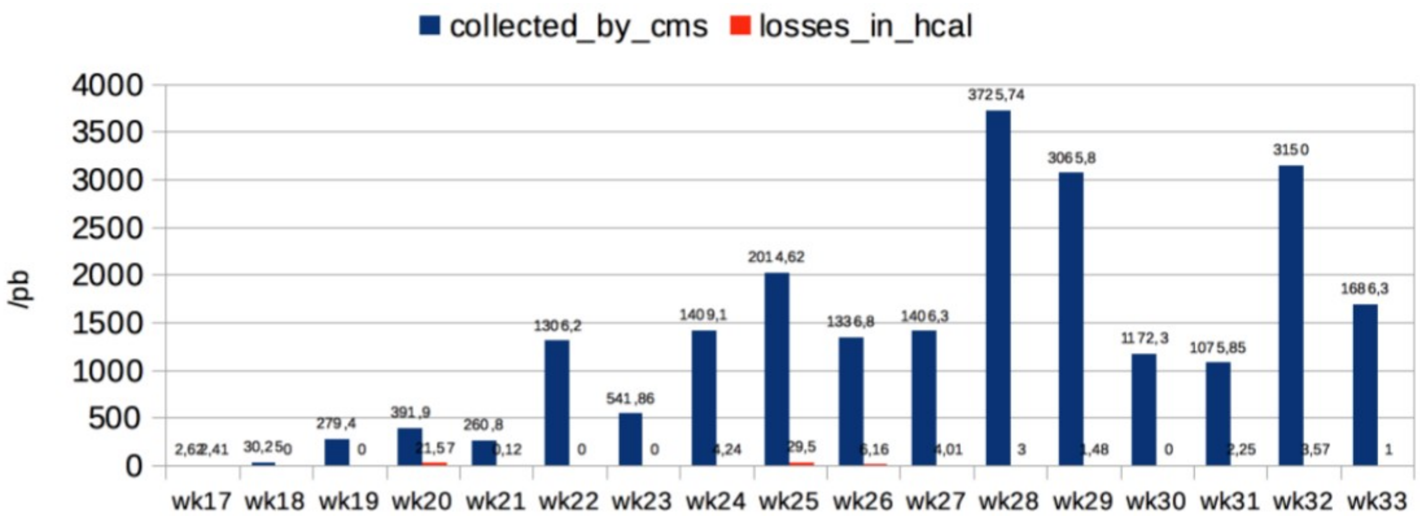
Gain of CSC chambers optimized

- The muon system is performing well
- Tuning of high voltages of CSC chambers to better equalize their gains
- This equalization should improve the efficiency of low-gain chambers and reduce the ageing effects in high-gain chambers



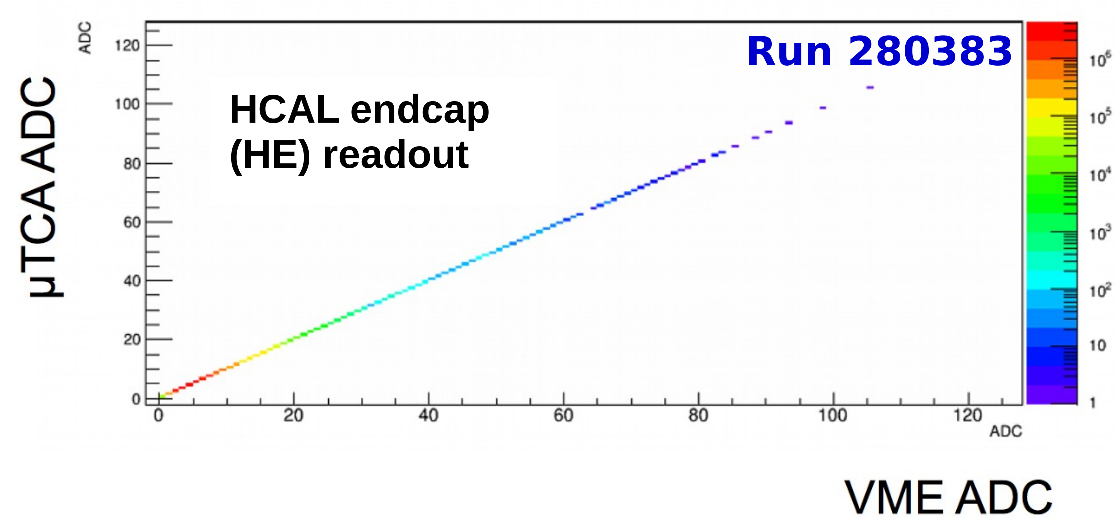
HCAL operating stably

- HCAL behaves very stably during data taking (~98% fully available)



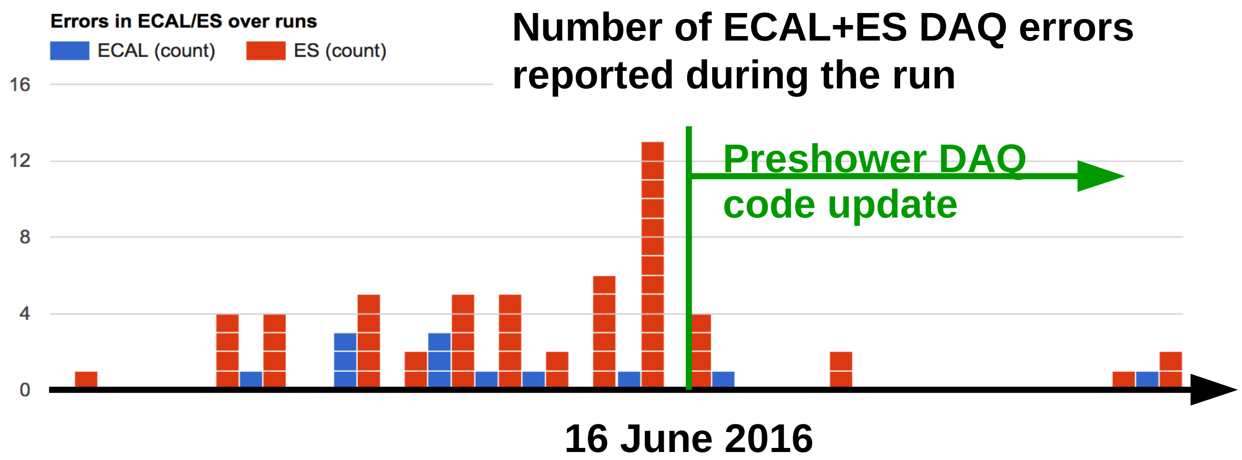
- Overall less than 0.2% of dead channels

- Backend electronics for HCAL successfully migrated to μTCA
- Perfect agreement between trigger primitives for old (VME) and new backend electronics
- VME now turned off

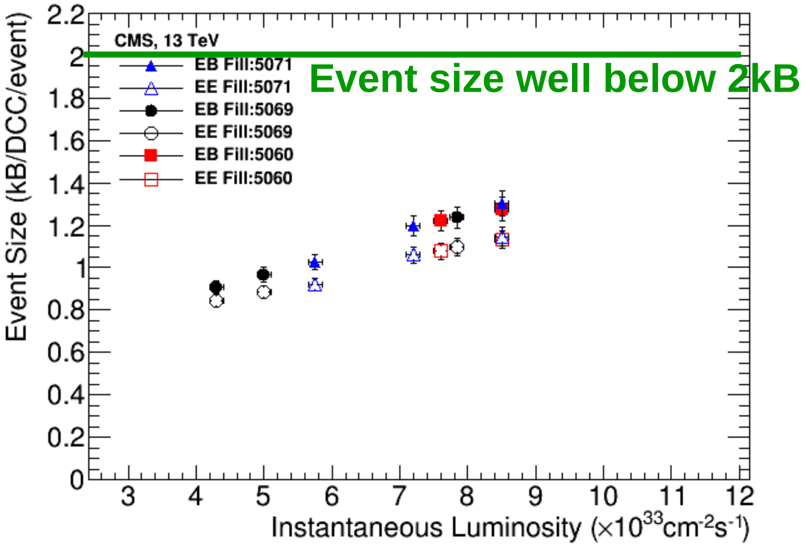


ECAL is performing well

- Updates deployed in DAQ firmware and software to improve data taking efficiency



- Readout settings tuned for high luminosity running, can handle 1.5×10^{34} $cm^{-2}s^{-1}$

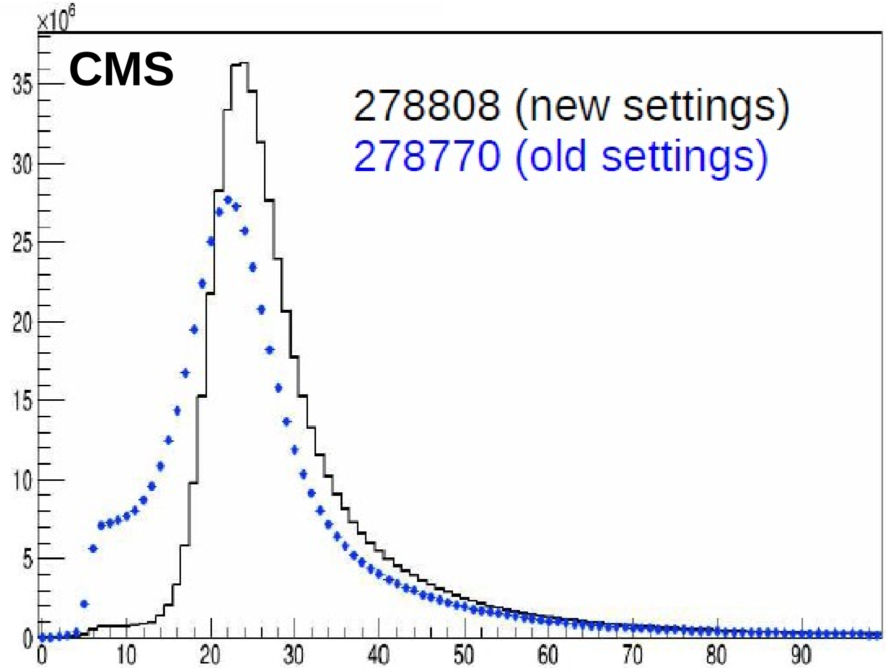


- The energy resolution in prompt reconstruction is comparable to the best performance obtained from the legacy reprocessing of the Run 1 data

Issue with silicon strip tracker solved

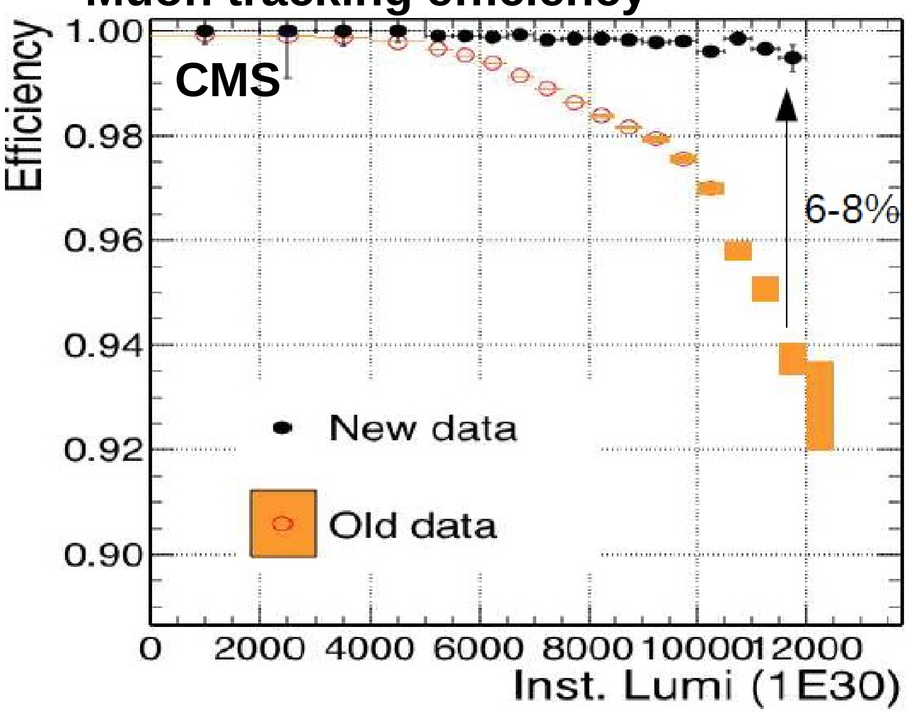
- During late 2015 and early 2016 we observed a decrease in the signal to noise for the strip tracker associated also with a loss of hits on tracks
- Problem was initially believed to be due to heavily ionizing particles (HIPs)
- Later traced to saturation effects in the pre-amplifier of the APV25 readout chip
- Early August the drain speed of the pre-amplifier was changed to allow for faster recovery

  → signal to noise ratio improved and fully recovered hit efficiency



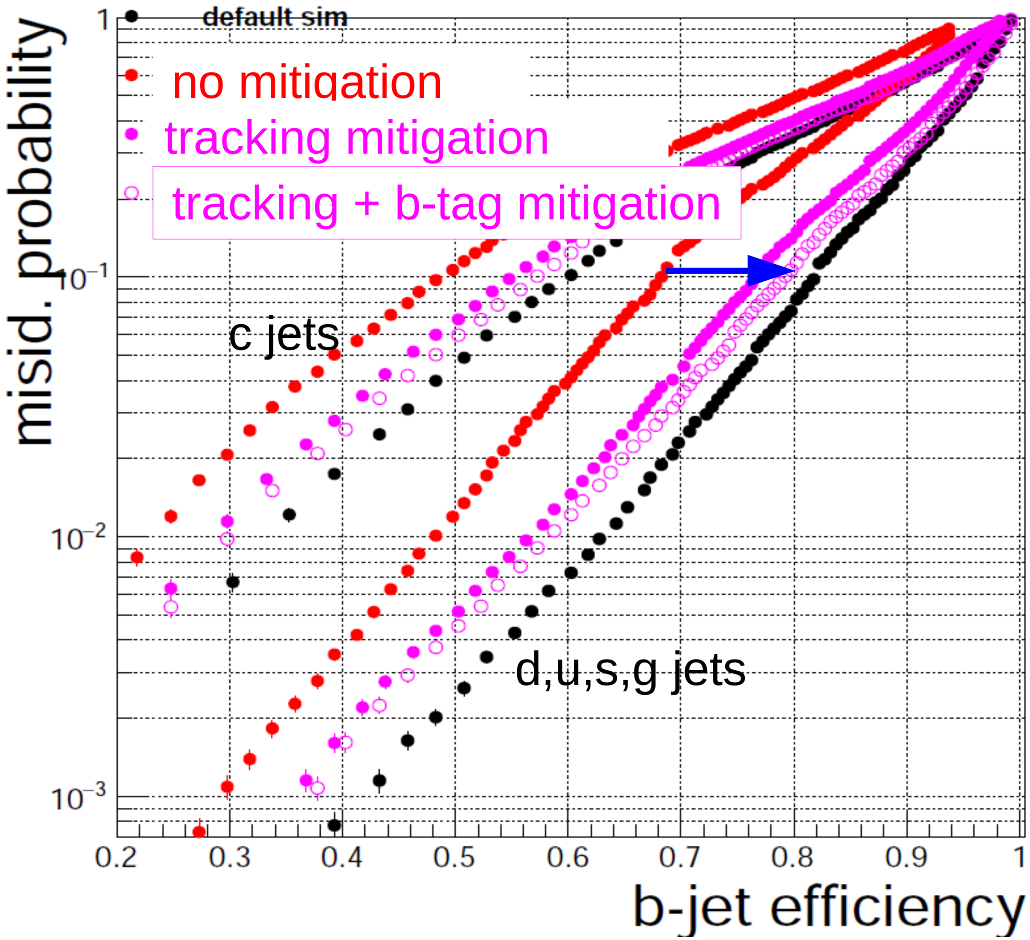
Cluster signal to noise on track

Muon tracking efficiency



Silicon strip inefficiency: mitigation

- Around 20/fb of data was collected with the old setting for the pre-amplifier
- Largest impact on b-tagging → mitigation strategies developed

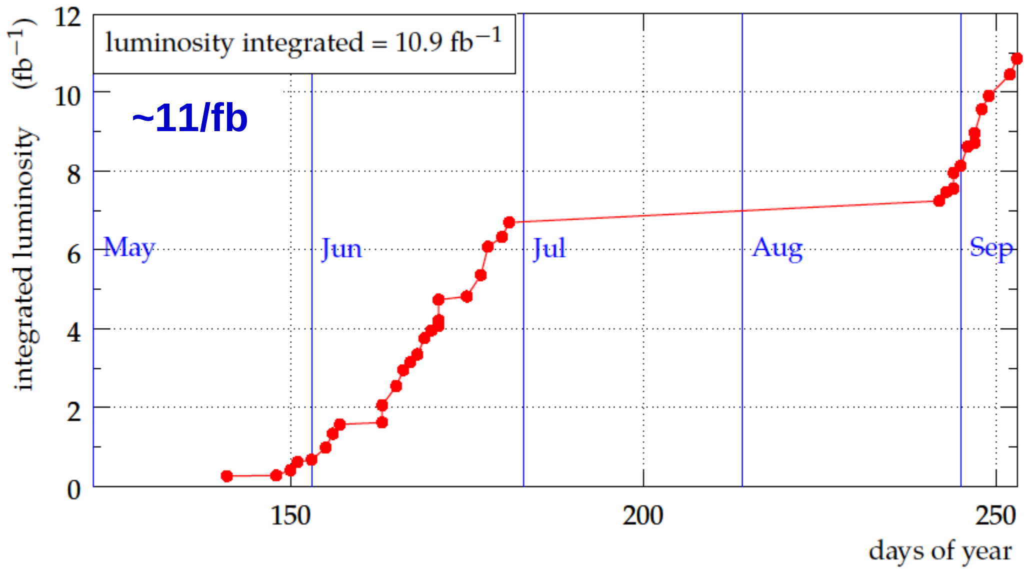


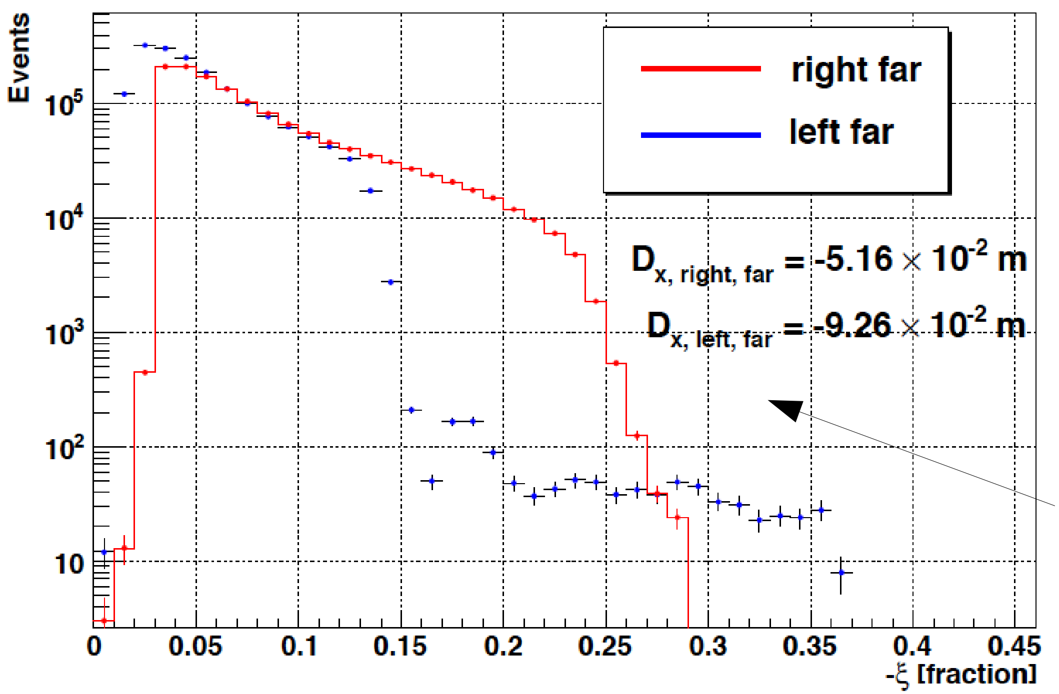
Tracking + b-tag mitigation together for e.g. ttH with 4 b-tags results in a signal efficiency change of a factor 1.8 (11% absolute efficiency improvement)

- Dedicated mitigation recovers most of the efficiency loss
- The affected dataset will be reprocessed

CMS Totem Precision Proton Spectrometer (CT-PPS)

- Fully integrated in readout and trigger
- Deflected protons are tracked using silicon strips [in 2017: 3D pixels a la Phase 2]
- Precise timing using diamond detectors [in 2017: adding ultra fast silicon]
- Recorded ~11/fb of data

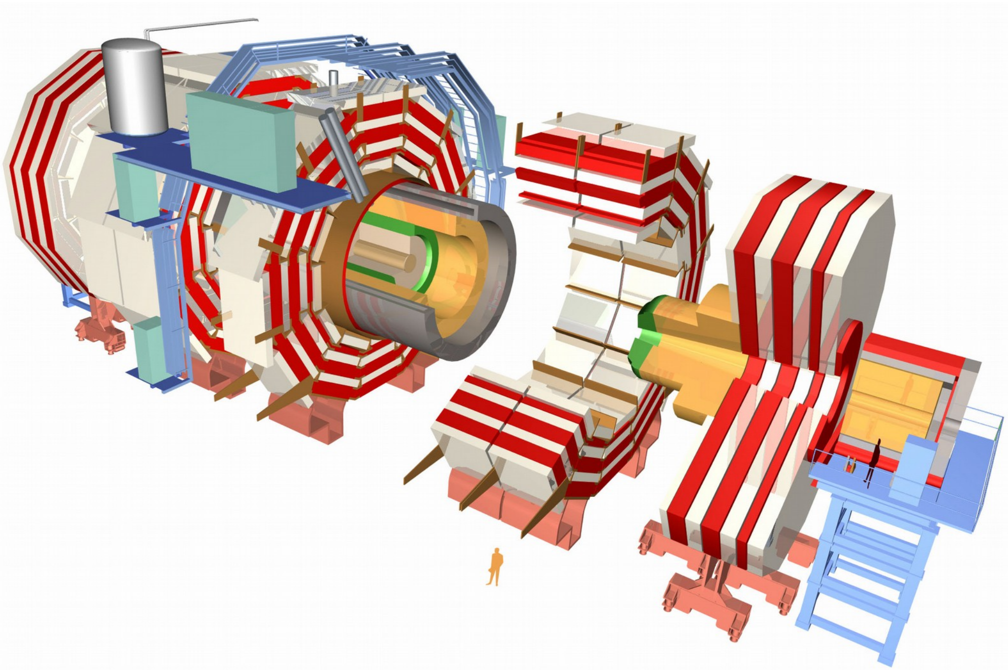




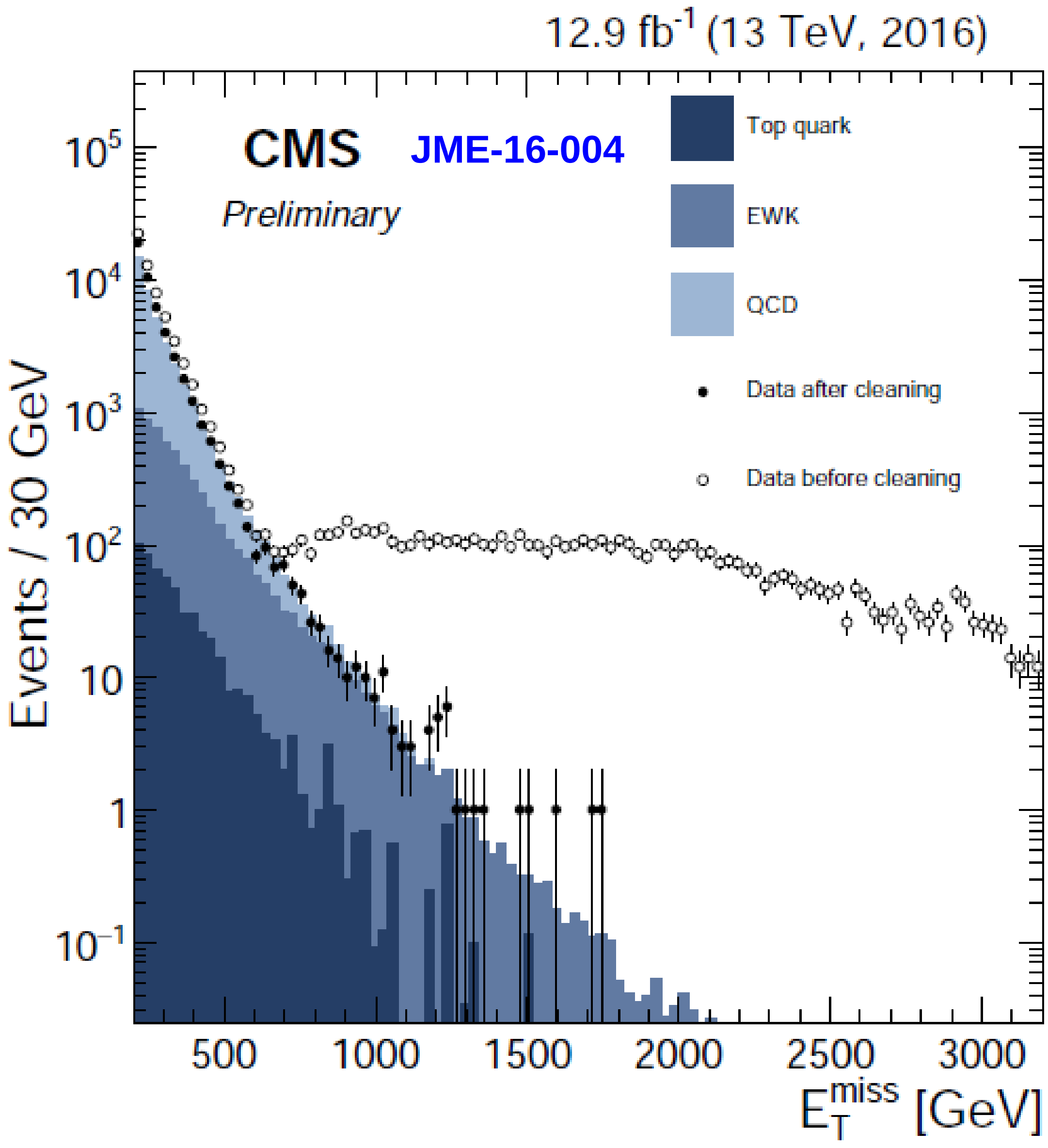
- Detector aligned w.r.t. beam
- Determined beam optics parameters
- Measured the energy fraction lost by protons

Achievements in 2016 and plans

- Continue to ensure smooth operation
- Status of detector systems
- **Object reconstruction and identification performance**
  - Missing transverse energy tails
  - Charm jet identification algorithm
- Selection of recent physics highlights
- Future plans: Phase 1



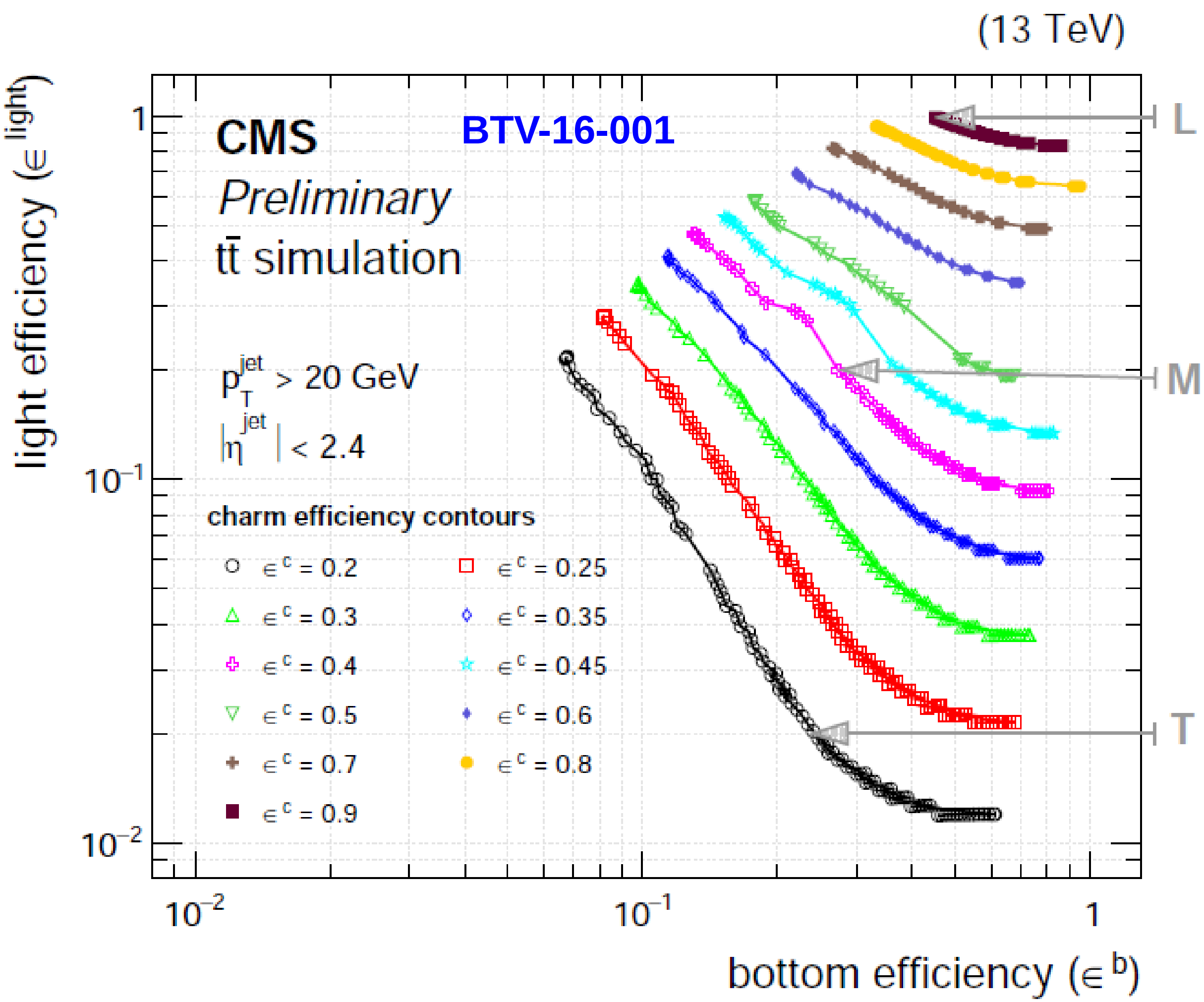
Missing transverse energy



- Various cleaning algorithms have been developed to deal with anomalous noise causing high tails for the missing transverse energy
- After the cleaning the simulation describes the data quite well

Identification of charm quark jets

- A charm tagger was developed

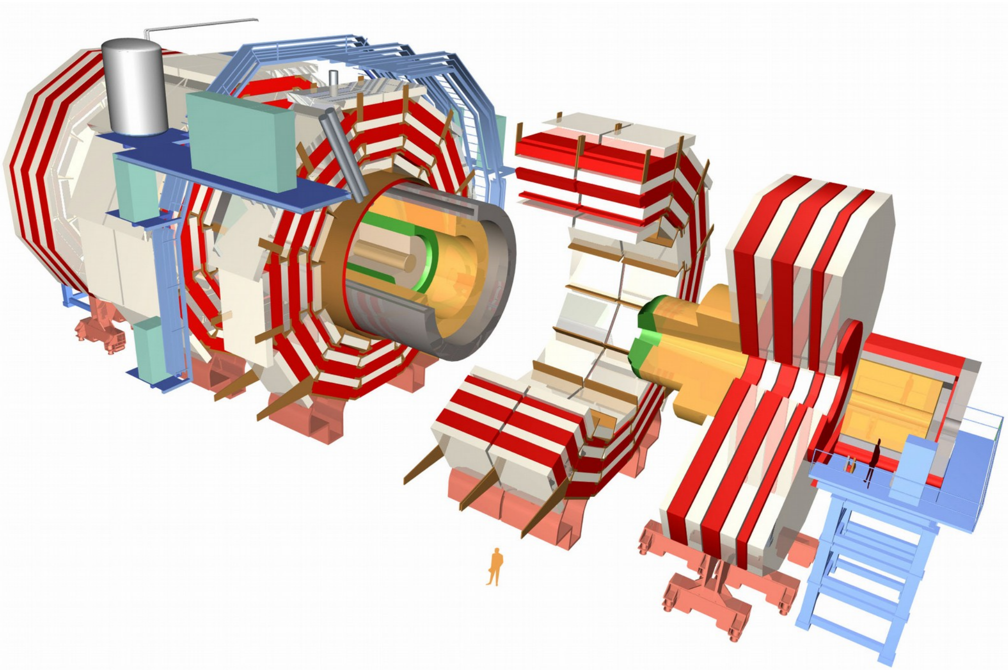


- Two separate discriminators are constructed, one optimized for c against light-jet and one for c against b-jet discrimination

- Scale factors correcting for the difference between simulation and data are derived using W+c and top quark pair events

Achievements in 2016 and plans

- Continue to ensure smooth operation
- Status of detector systems
- Object reconstruction and identification performance
- **Selection of recent physics highlights**
  - Top quark pair production
  - Higgs boson production
  - ttH production
  - Searches for supersymmetry
  - Dark matter searches
- Future plans: Phase 1



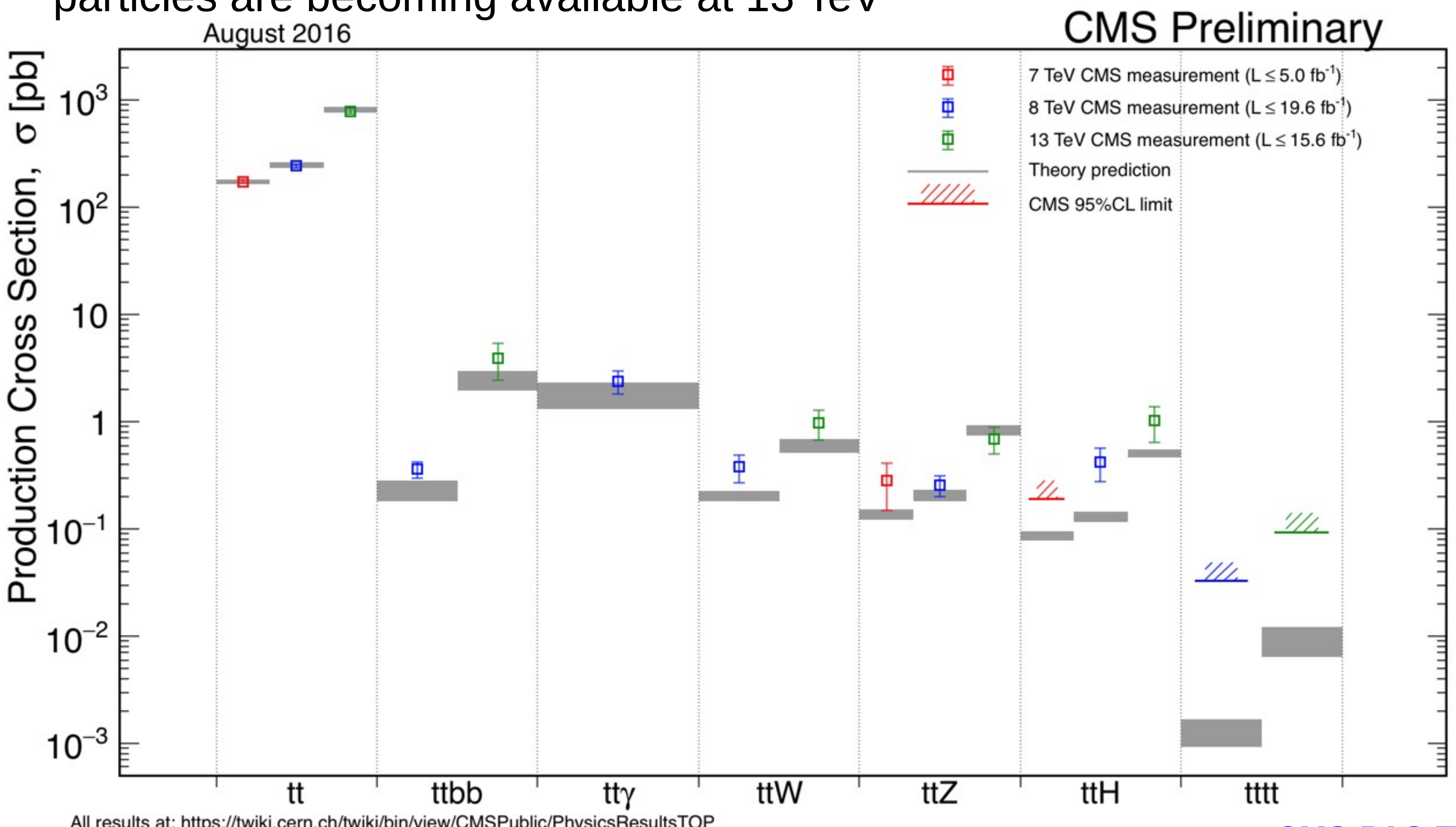
Physics results

Topic	Number
Exotica	31
SUSY	21
Higgs	12
Top	10
Electroweak	4
Jet and Hadrons, Forward physics	3
Vector Boson Production	3
Heavy Flavours	2
Heavy Ions	5
Total	91

- Over 90 new results presented at the Summer conferences
- Covering a broad range of physics topics
    - Scrutinizing the standard model (both at Run 1 and Run 2)
    - Searching for (exotic) phenomena of physics beyond the standard model

Top quark production cross section

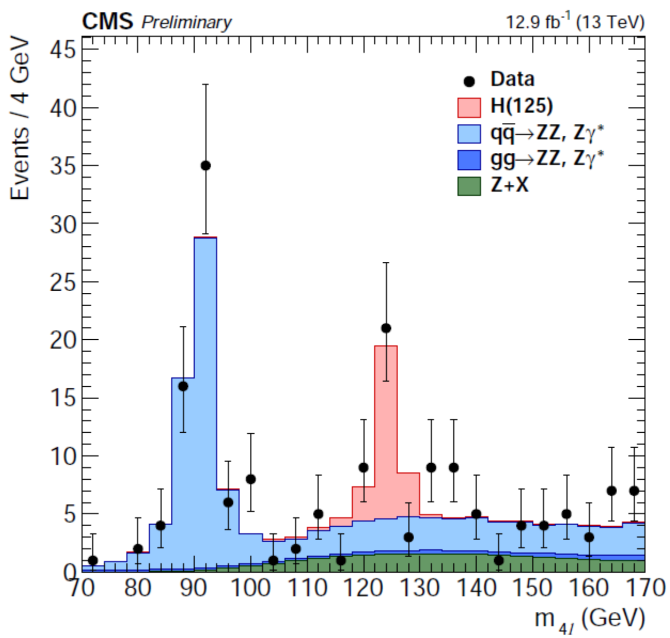
- The top quark pair production cross section at 8TeV is measured with a precision of 3.7% (uncertainty on the theoretical prediction is 5.7%)
- Precision measurements of top quark production in association with other particles are becoming available at 13 TeV



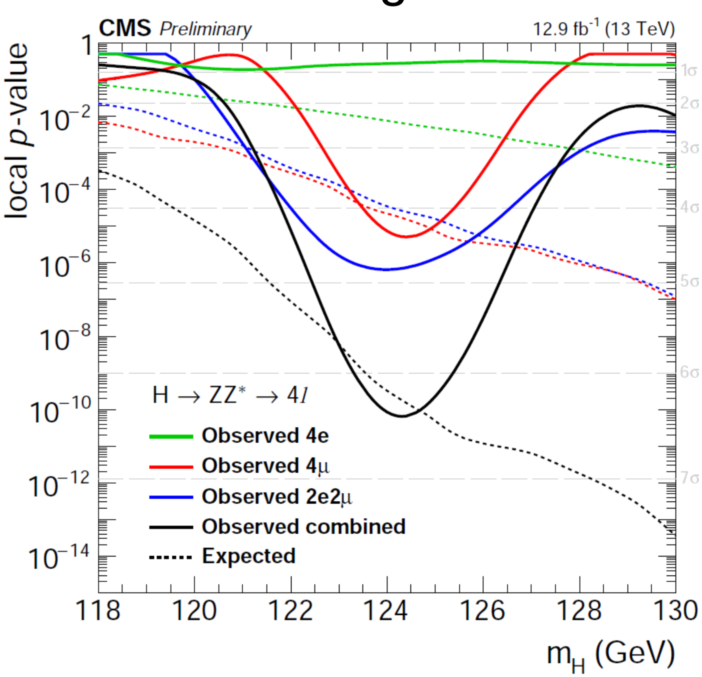
CMS-PAS-TOP-16-019

- Direct measurement of the top quark width: $0.6 < \Gamma_t < 2.5$ GeV @ 95% C.L.

Higgs boson @13TeV, e.g. H → ZZ (4l)

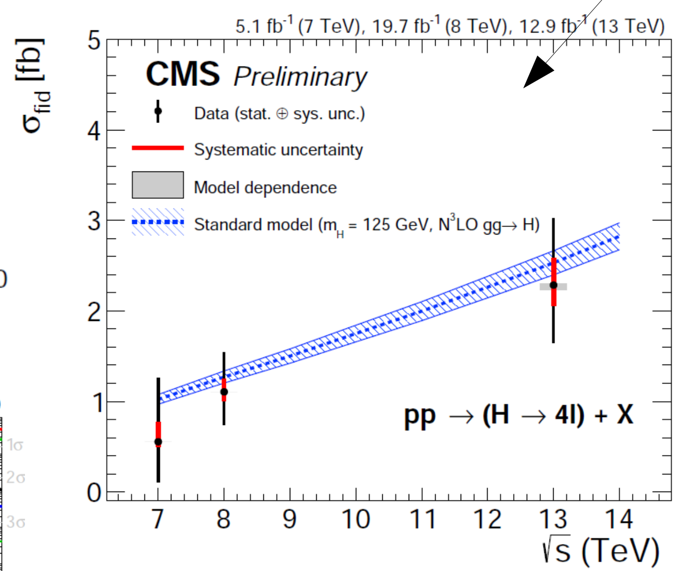


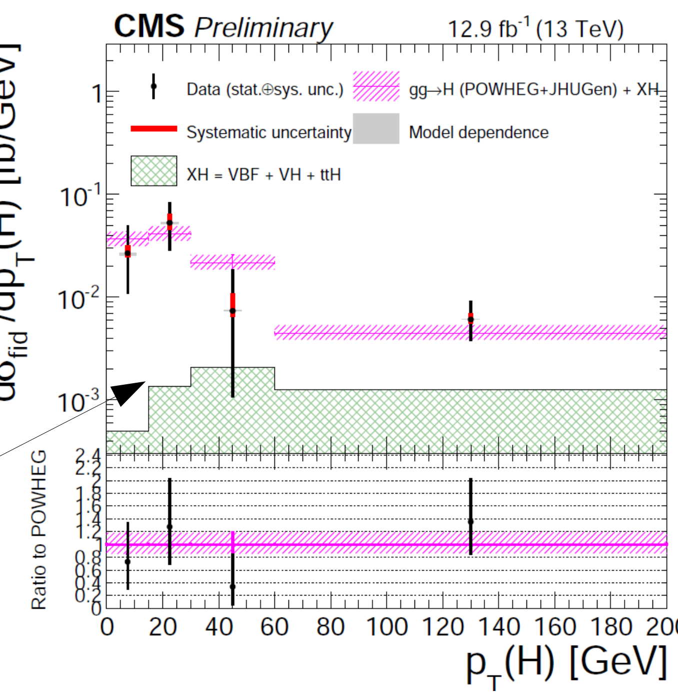
6.2σ local significance



- H→ZZ just as example, also H→γγ results available
- Much more than measuring mass and signal strength
- Fiducial cross section as a function of the center-of-mass energy

CMS-PAS-HIG-16-033

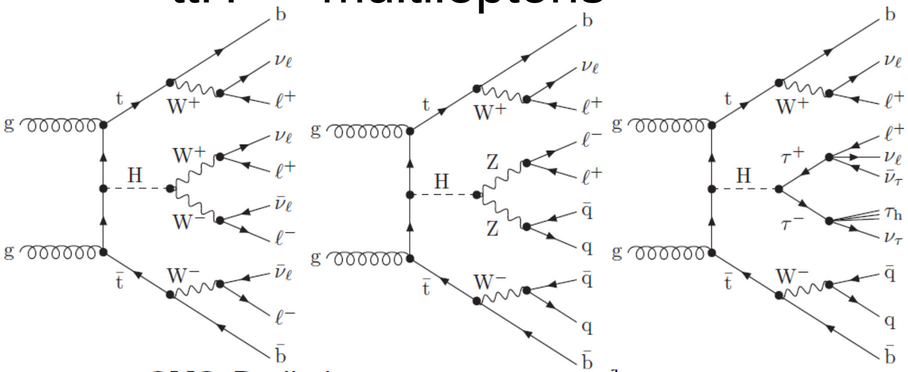




- In 2016 explore differential cross section measurements and detailed measurements of the Higgs boson properties

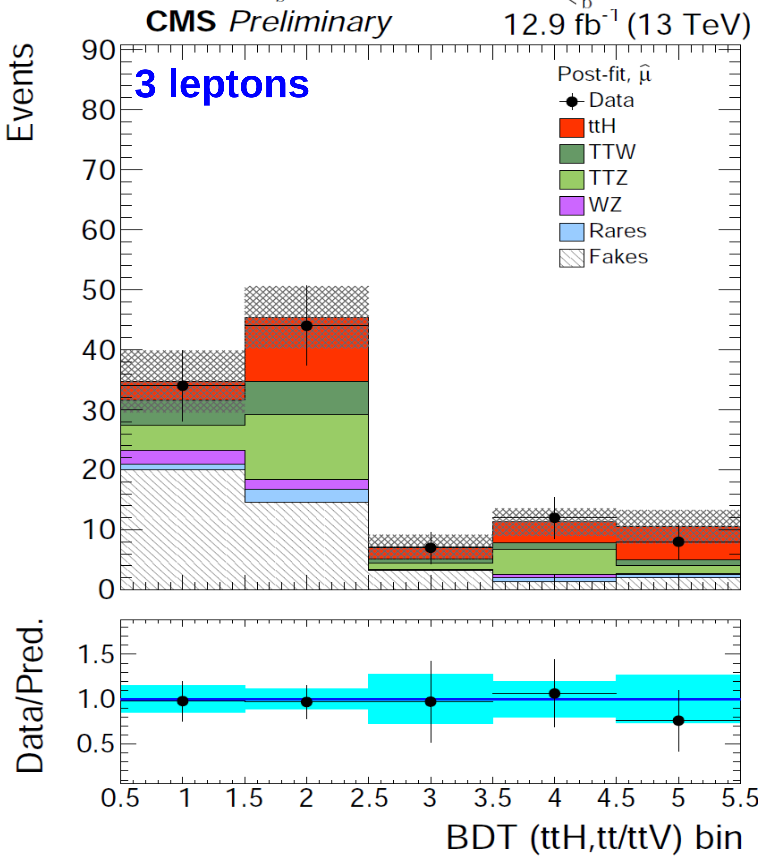
Top quark Yukawa coupling: ttH

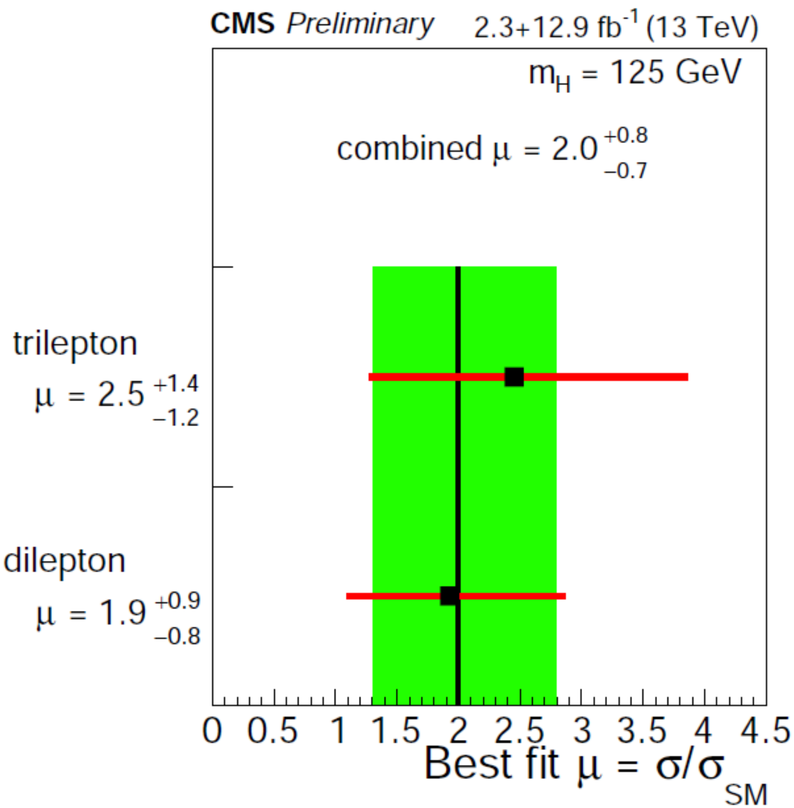
- Direct measurement of top Yukawa coupling through observation of ttH process
- ttH → multileptons



CMS-PAS-HIG-16-022

- Multiple MVA-discriminators
- Used to define bins of different signal-to-backgrounds ratios





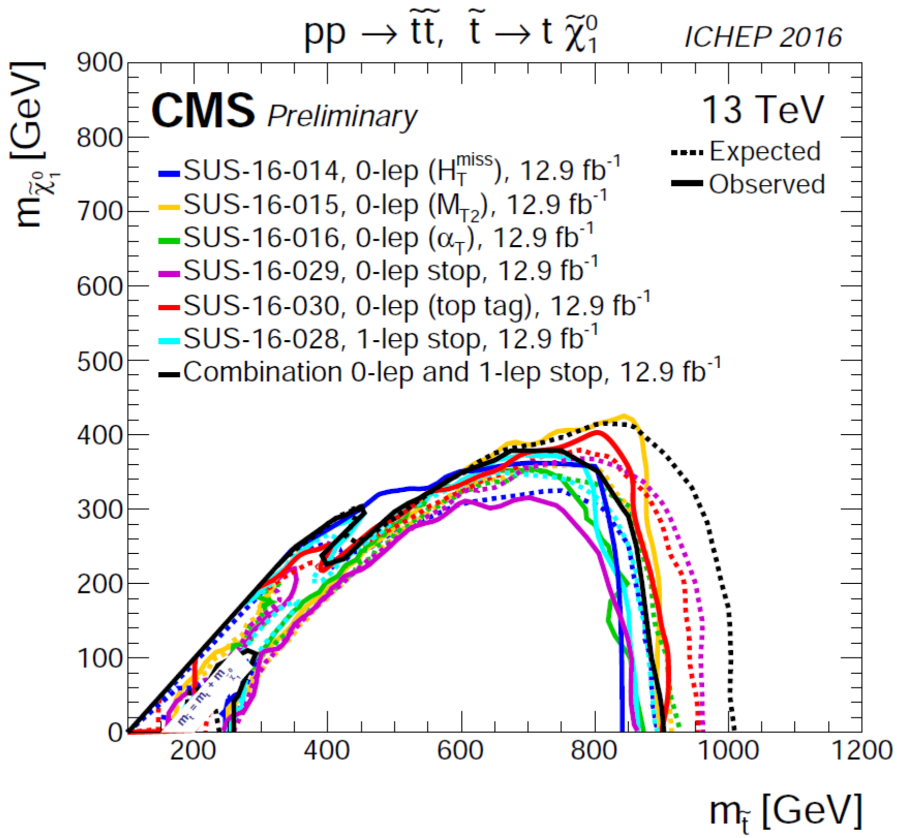
Limits at 95% C.L:

- Obs.: 3.4
- Exp.: $1.3^{+0.6}_{-0.4}$

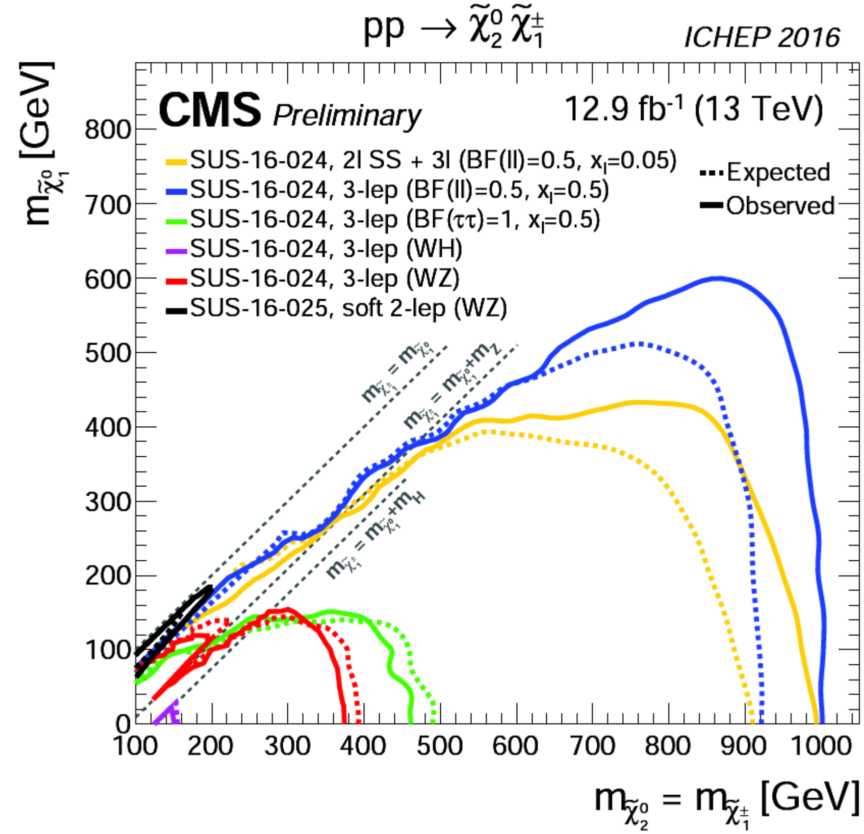
Huge jump in sensitivity for SUSY

- 21 SUSY searches updated for ICHEP covering a wide variety of topologies
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

- Direct stop production decaying to top and neutralino (LSP)



- Direct electroweak production of charginos and neutralinos

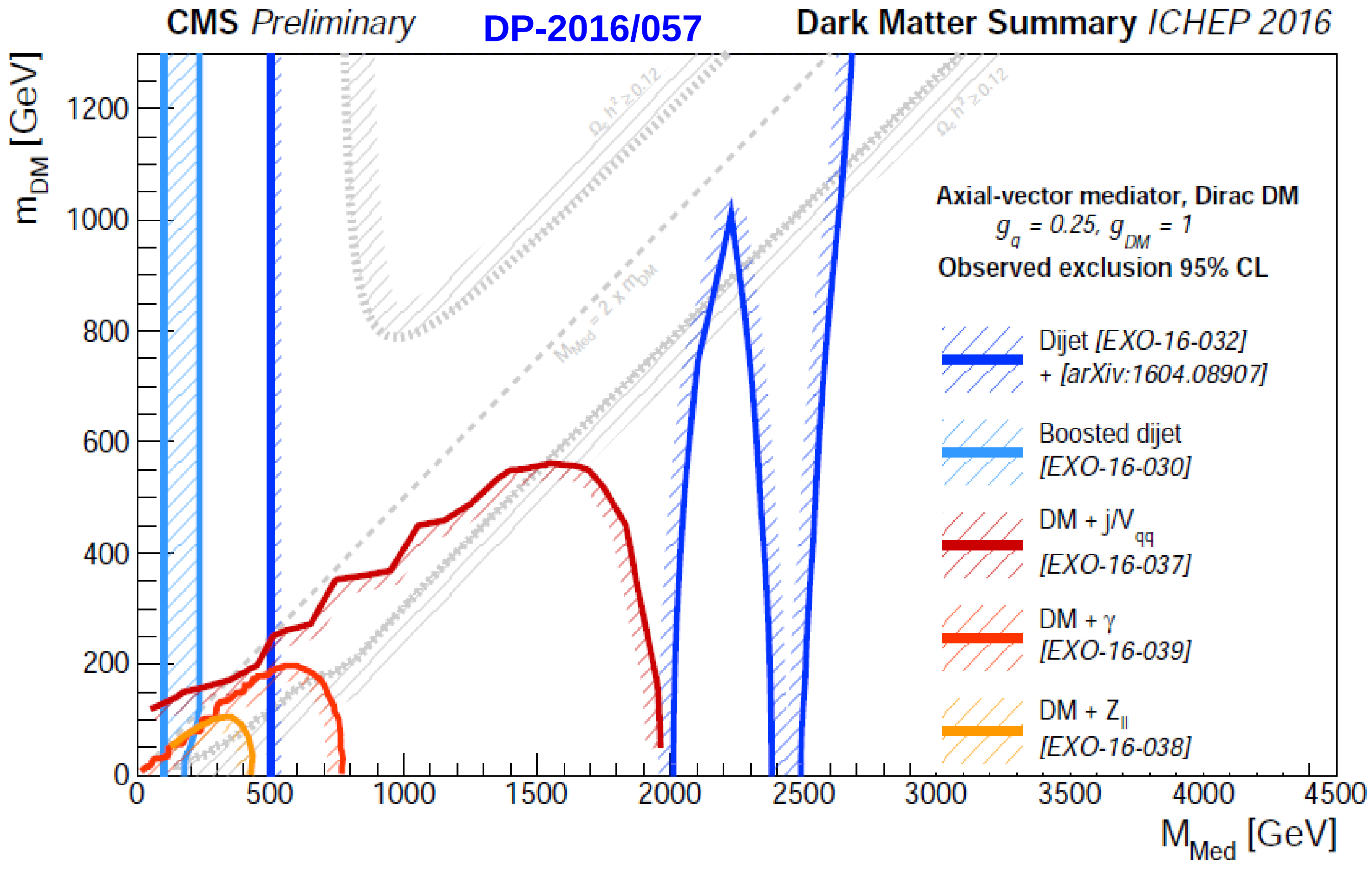


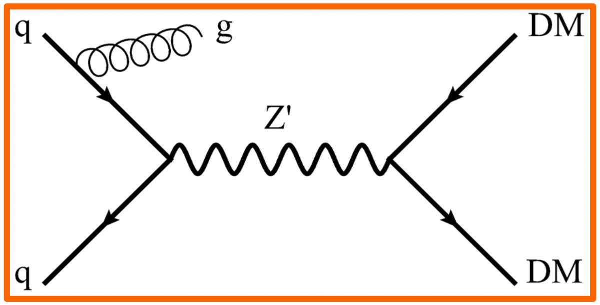
- For a massless LSP, limit on stop quark mass is 150 GeV higher compared to LHC Run 1

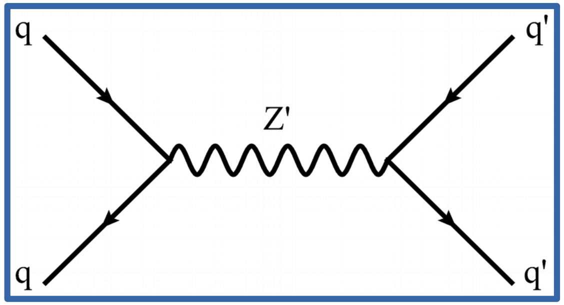
- Over 100 search regions!
- For a massless LSP, limit on the chargino mass is already 300 GeV higher

Looking for signatures of dark matter

- Searches for MET+X with X = j, γ, Z, H, tt, bb
- Low-/high-mass dijet resonance searches
- Sensitive to the spin of the mediator

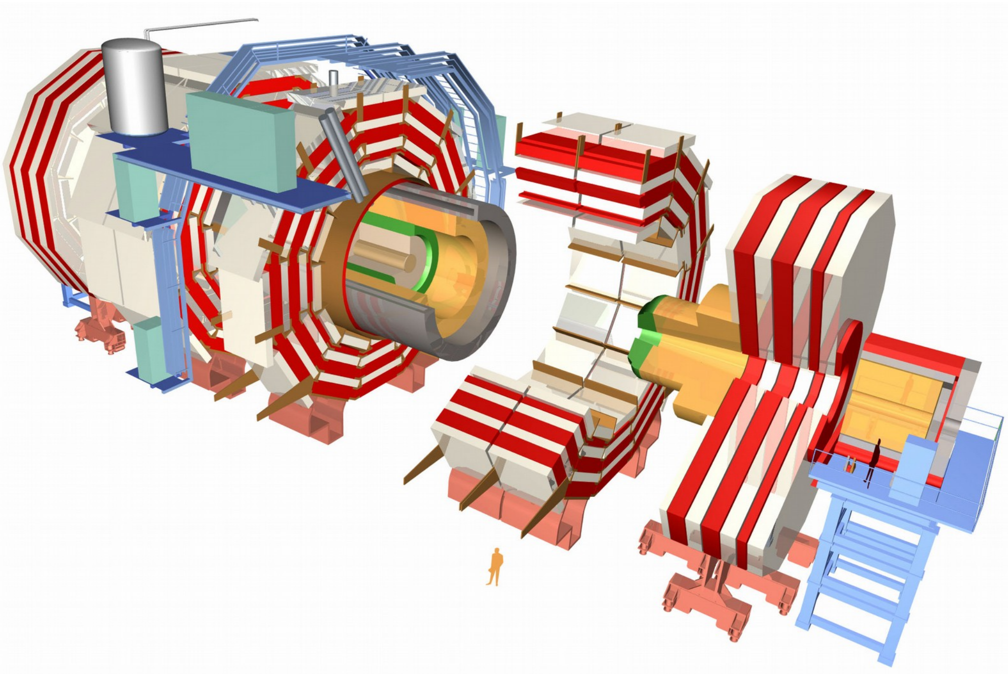






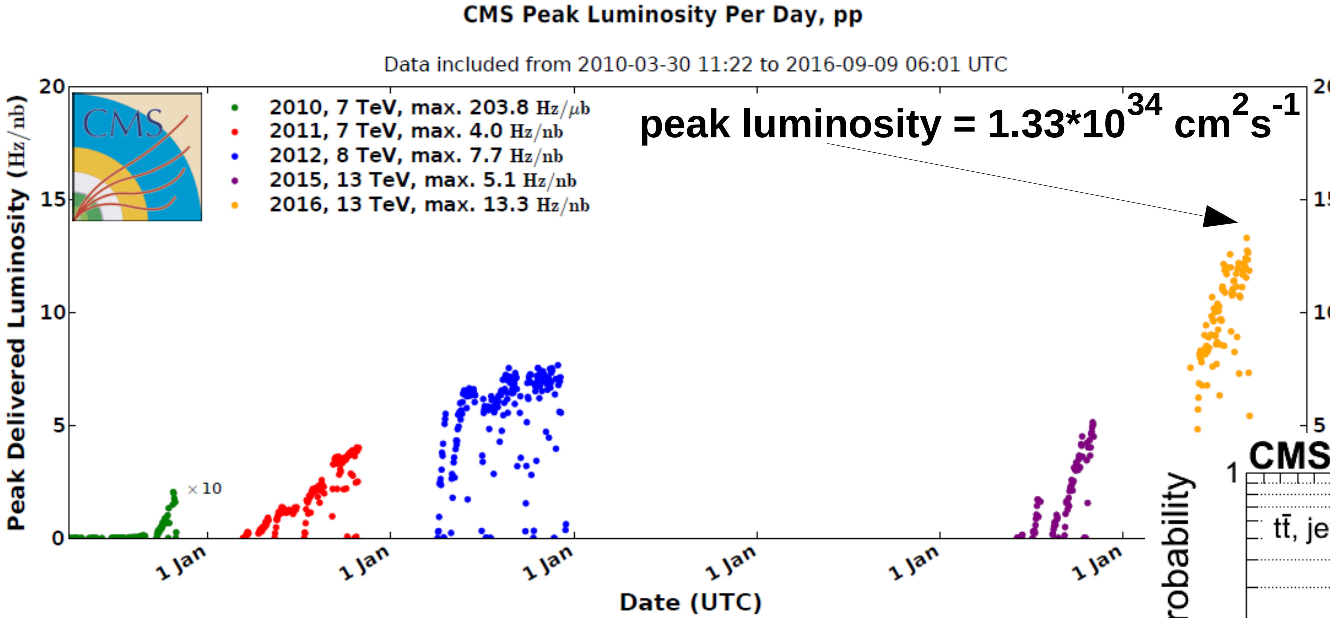
Achievements in 2016 and plans

- Continue to ensure smooth operation
- Status of detector systems
- Object reconstruction and identification performance
- Selection of recent physics highlights
- **Future plans: Phase 1**
  - High luminosity and pile up
  - Phase 1 silicon pixel tracker
  - HF/HE

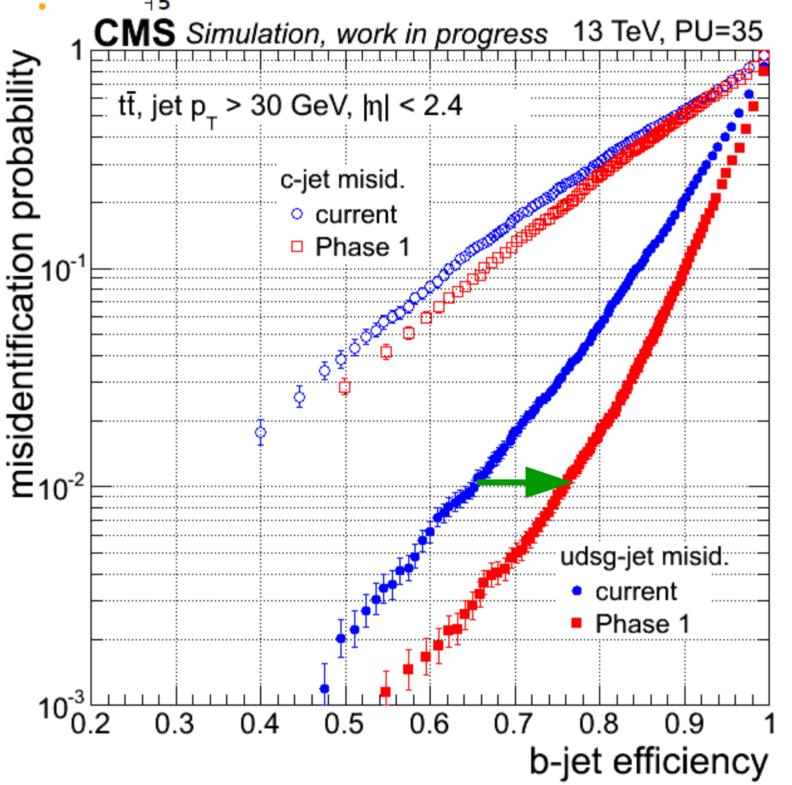


Higher luminosity and PU for 2017 run

The peak luminosity in 2016 is already above the LHC design luminosity!

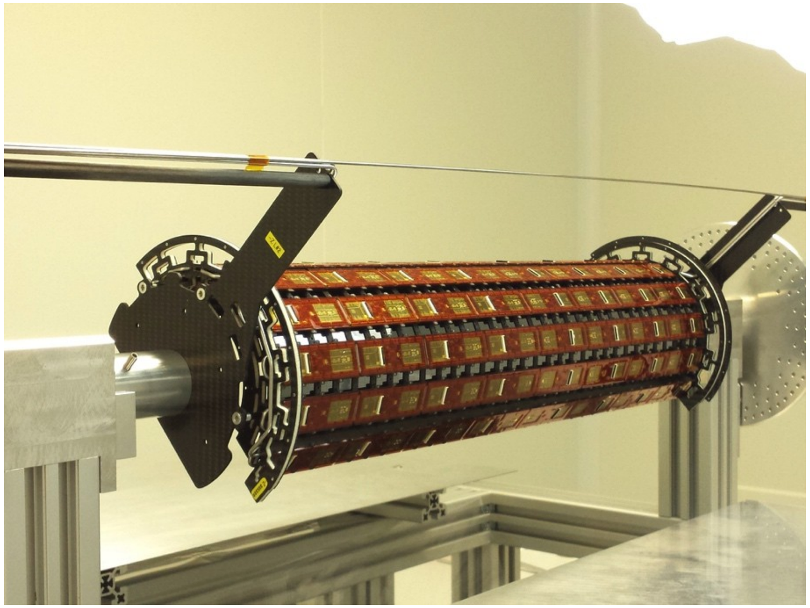


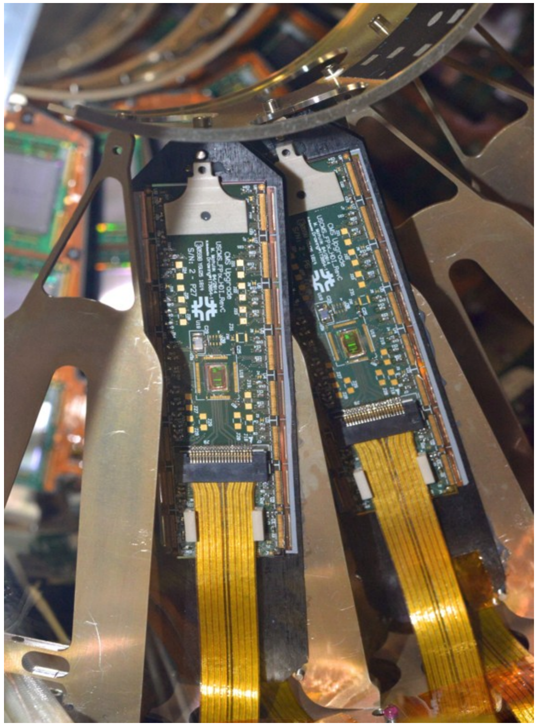
- Upgrades to be installed will allow us to handle up to ~$2*10^{34}$ cm^{-2}s^{-1}
  - Especially the new silicon pixel tracker with four barrel pixel layers
    → e.g. huge impact for b-tagging



Phase 1 upgrade: pixel tracker

- Module production in its last phase
- Integration in progress
- On track for installation during the end of year technical stop

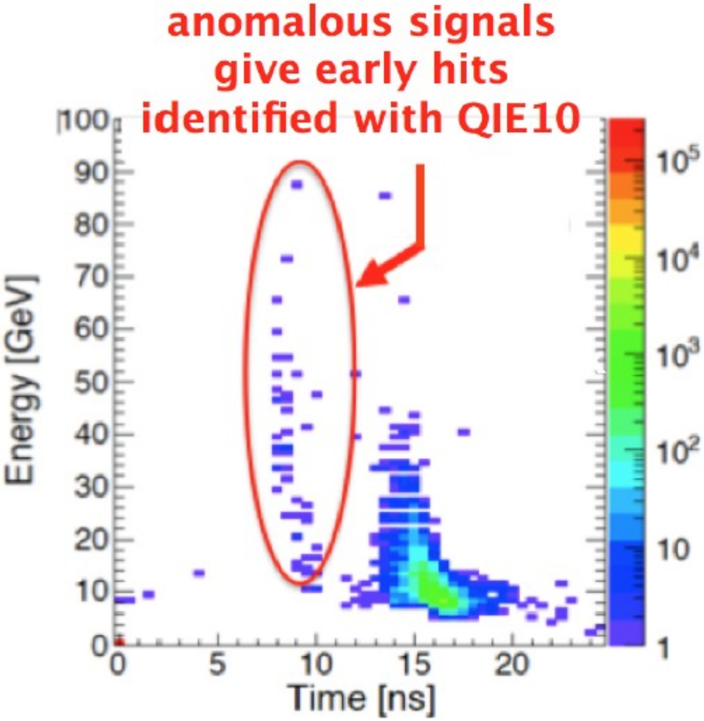


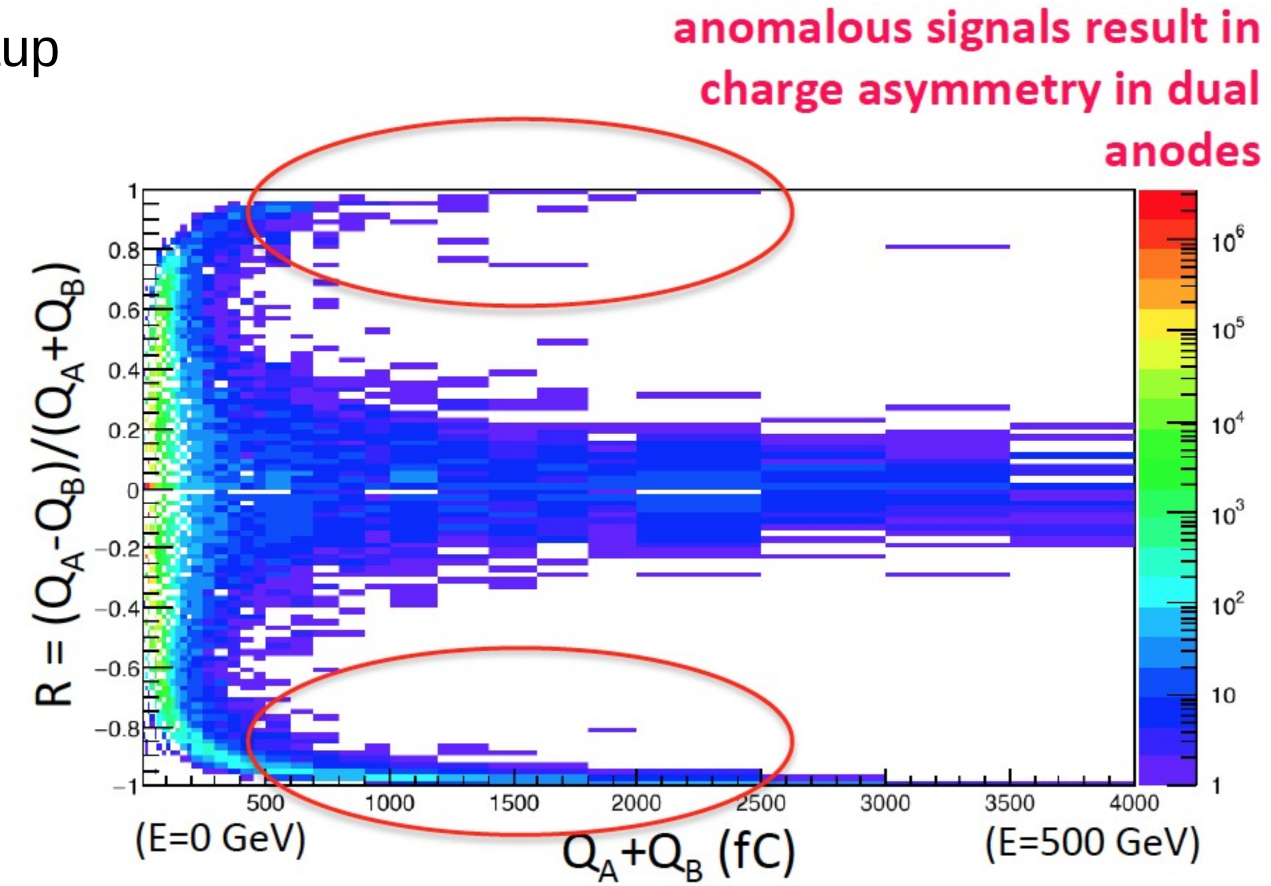


- “Pilot blades” regularly included in runs
- Installation of the services being prepared
- Offline software is being developed
- On track for collisions in 2016

Phase 1 upgrade: HCAL Forward (HF)

- Front-end electronics will be updated to suppress anomalous noise
  - Exploit early arrival time for anomalous signals using QIE10 chip
  - Dual anode readout of the PMTs to identify anomalous signals
- Result of pilot Phase-1 setup





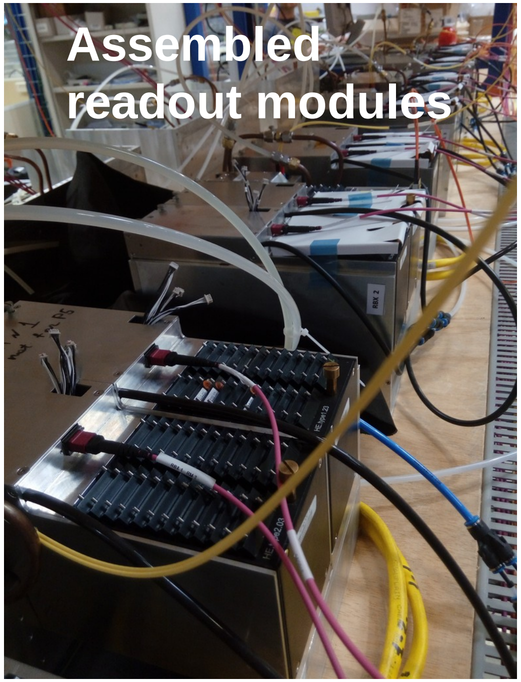
On track for installation during
the end of year technical stop

Phase 1 upgrade: HCAL endcap (HE)

- Radiation damage: signal reduction up to 18% ($|\eta|=1.79$) to 55% ($|\eta|=2.93$)

→ accelerated the phase-1 upgrade for the HE w.r.t. the original schedule

- Hybrid Photodiodes (HPD) will be replaced by Silicon Photomultipliers (SiPM)
  - More channels → finer depth segmentation (recalibration of radiation damage)
  - 3x higher photodetection efficiency w.r.t. HPD
- New front-end electronics (QIE11 chip)
  - Add timing information
- Burn-in and assembly of readout modules has started



On track for installation during the end of year technical stop

Summary

- Excellent detector operation
- We are continuously improving object identification techniques
- Working hard on the detector upgrades for Phase 1 (and Phase 2)
- Many new results for the Summer conferences
- So far no sign for new physics in the data but we are prepared to see the first glimpses

Many thanks to our LHC colleagues for the many nice collisions!

Summary

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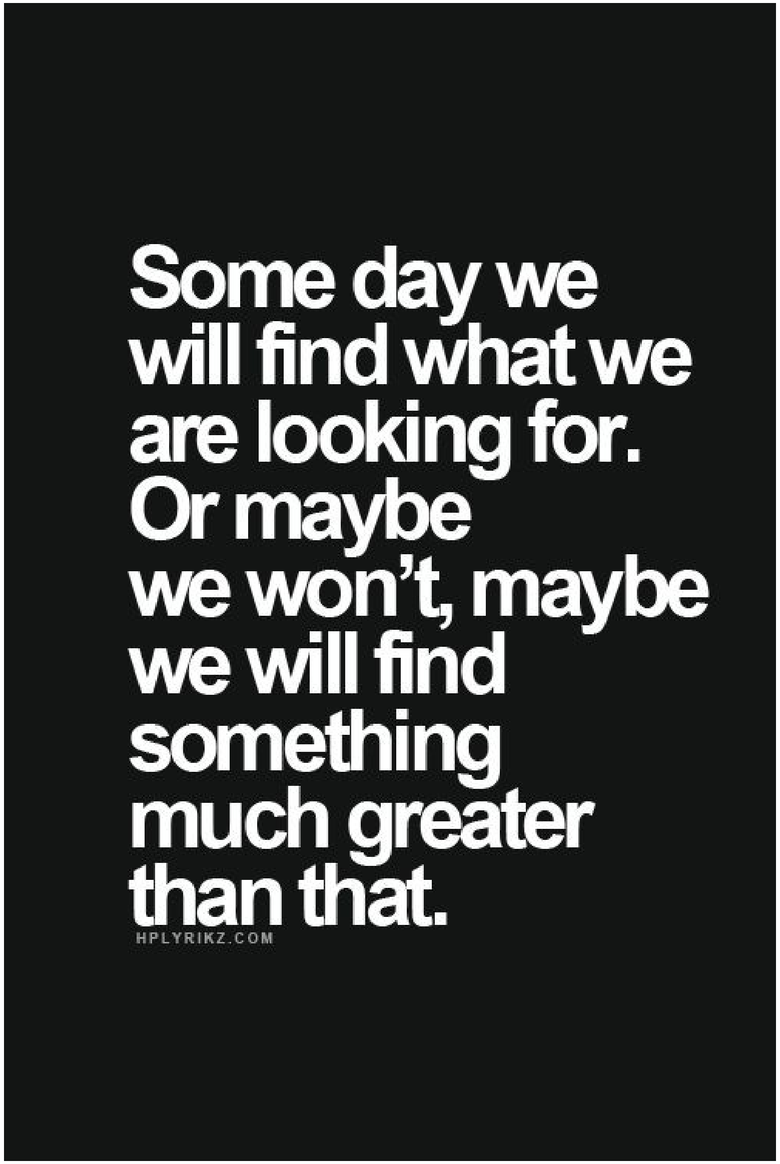
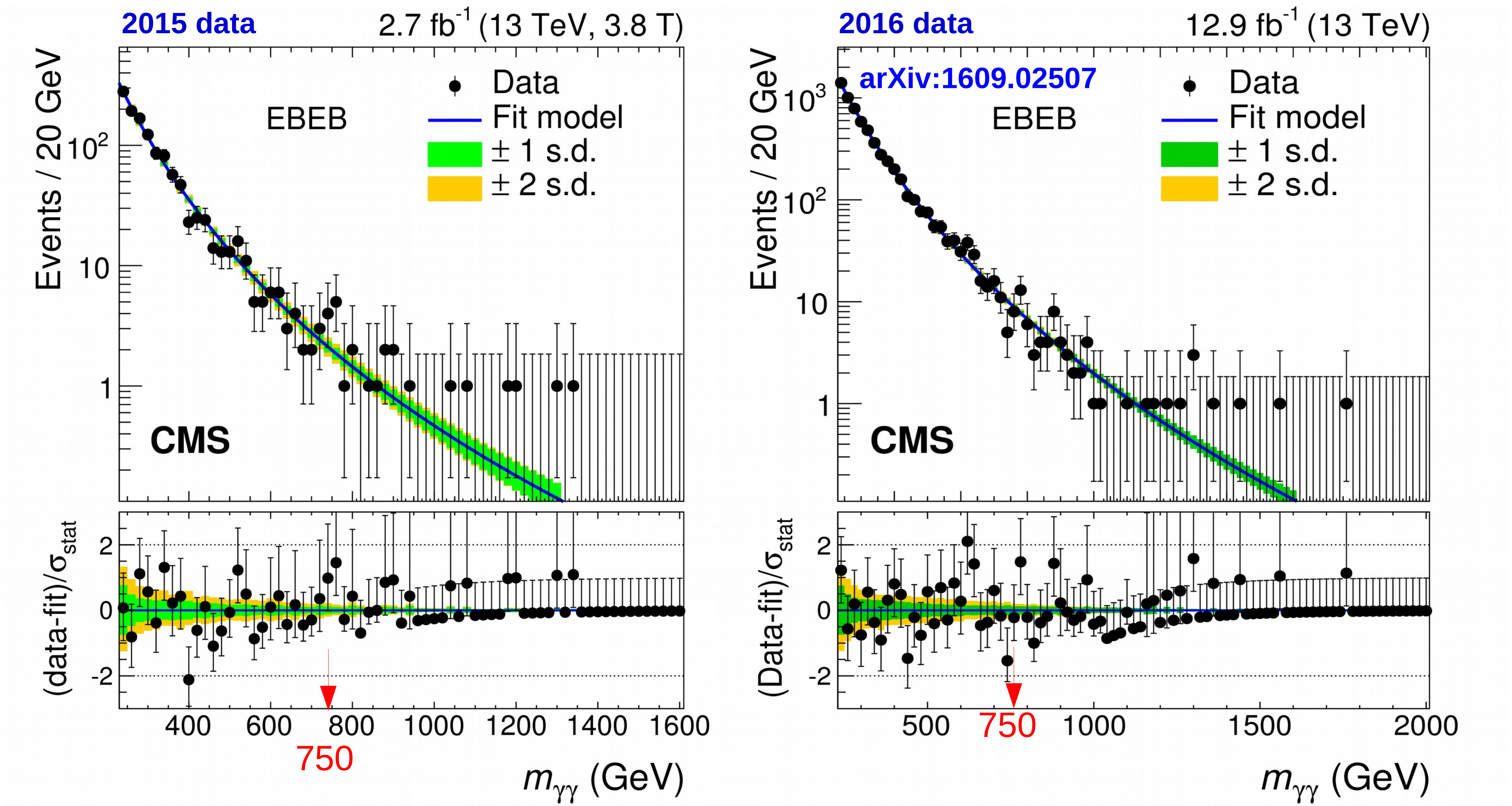


Many thanks to our LHC colleagues for the many nice collisions!

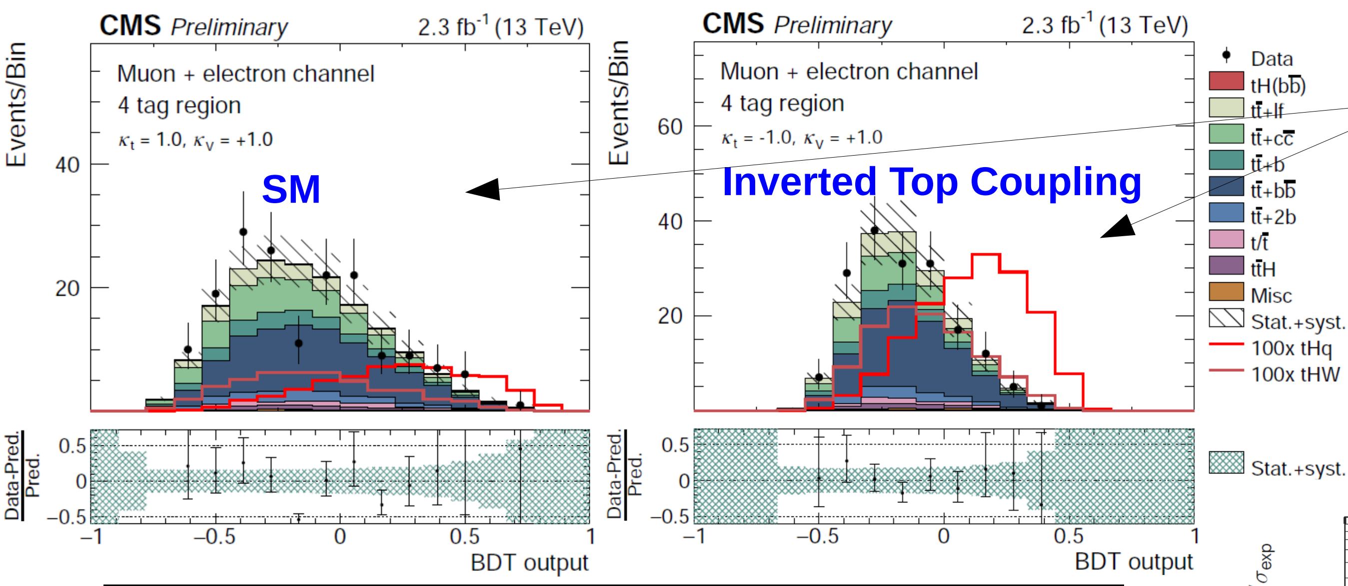
Heavy diphoton resonance @ 750 GeV



- No sign of an excess in the 2016 data around 750 GeV
- “Search for high-mass diphoton resonances in proton-proton collisions at 13 TeV and combination with 8 TeV search” submitted to Phys. Lett. B

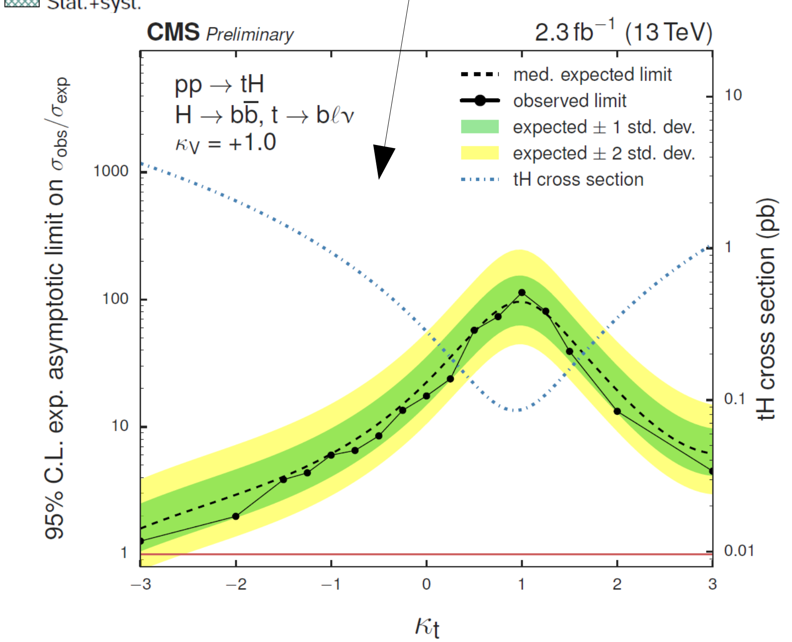
Top quark Yukawa coupling: tHq/tHW

- Important to determine the sign of the top coupling **CMS-PAS-HIG-16-019**
- H→bb, 2 signal regions: 3 and 4 b-tagged jets
- BDTs for jet assignment under tt and tHq hypothesis (for different couplings)



- A different BDT to discriminate tt(H) from tHq (for different couplings)
- 95% CL limits on production rate for the various coupling scenarios

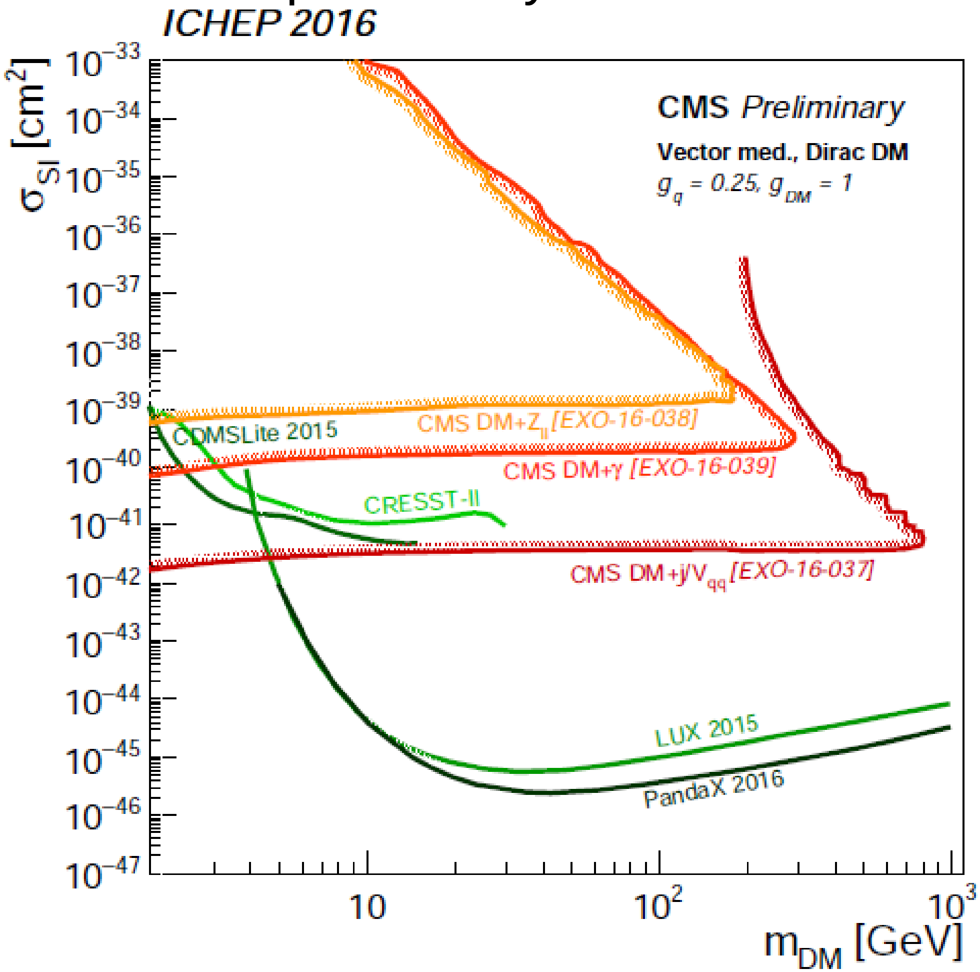
	Region	Observed Limit	Expected Limit Median	±1σ	±2σ
SM scenario	3 tag	124.0	114.3	[73.6, 184.4]	[52.0 , 295.2]
	4 tag	195.8	174.6	[112.9, 287.4]	[78.8 , 464.4]
	Combination	**113.7**	**98.6**	**[64.0 , 159.2]**	**[45.3 , 254.8]**
ITC scenario	3 tag	7.4	7.4	[4.9 , 11.6]	[3.5 , 17.8]
	4 tag	9.2	10.0	[6.5 , 16.3]	[4.5 , 26.3]
	Combination	**6.0**	**6.4**	**[4.2 , 10.1]**	**[3.0 ,15.7]**

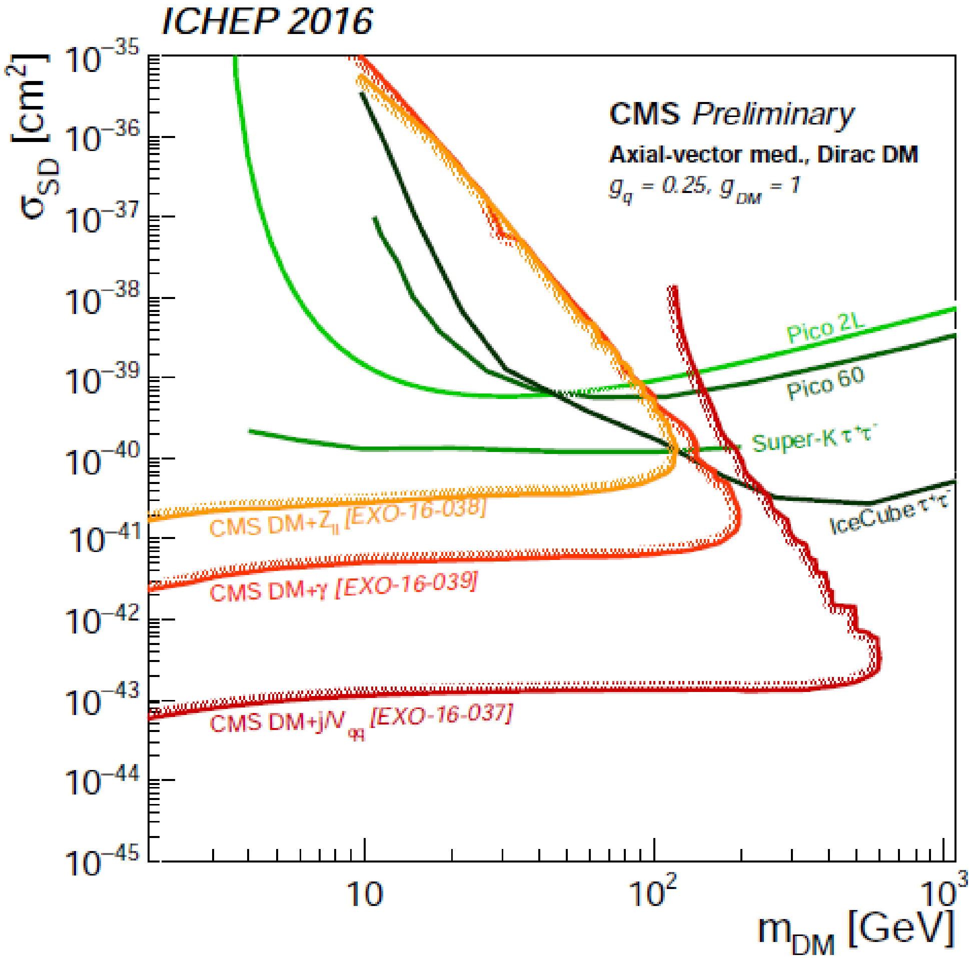


Looking for signatures of dark matter

- Searches for MET+X with X = j, γ, Z, H, tt, bb
- Sensitive to low-mass dark matter
- Particularly powerful for spin-dependent searches
- Complementary to direct detection experiments

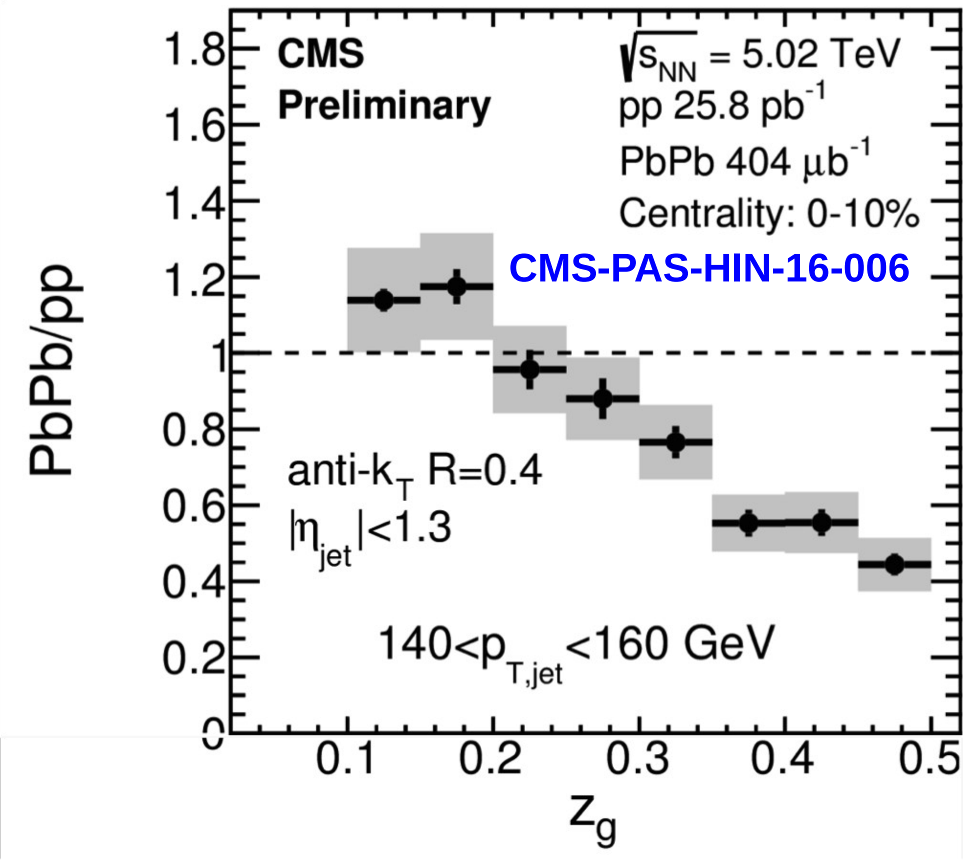
DP-2016/057

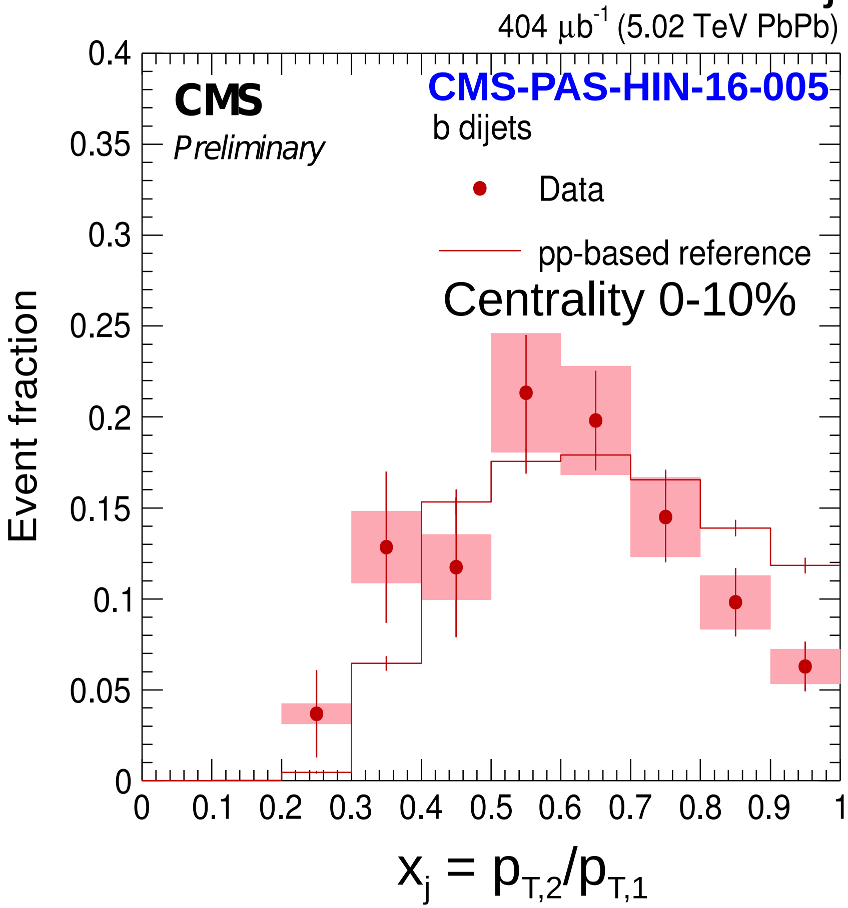




New indications for jet quenching

- CMS has a very rich heavy ion program and there are many Run-2 results!
- Modification of jet splitting function
- Momentum imbalance of di-b-jets





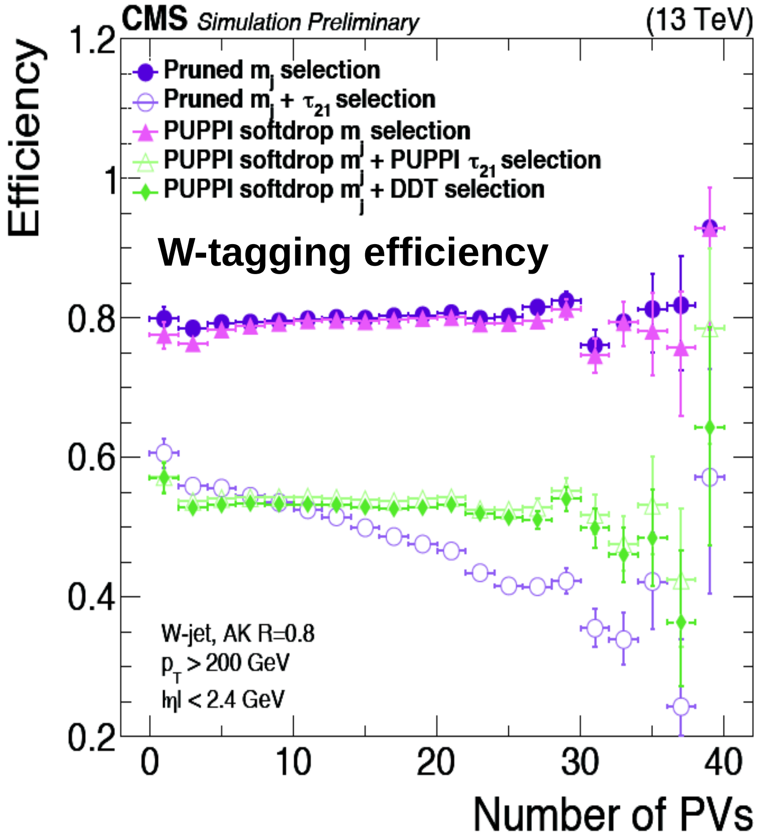
- More new Run-2 results to be presented at Hard Probes 2016
- Currently large focus on preparation of the 2016 pPb run

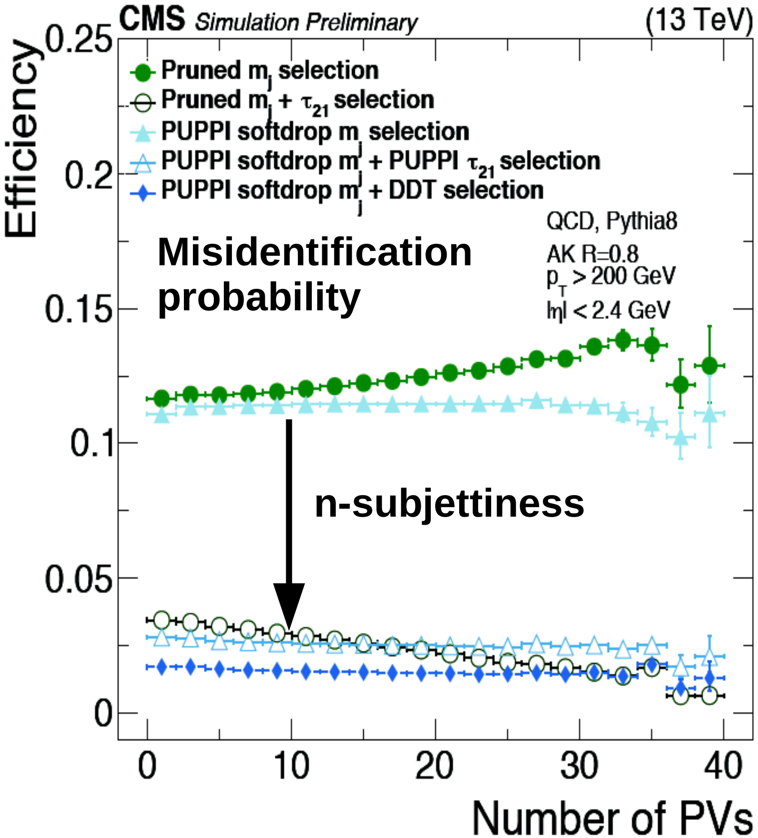
Boosted W-tagging

DP-2016/039

- Identification of boosted W → qq reconstructed in a single fat jet
- Efficiencies are evaluated using simulated Graviton → WW samples

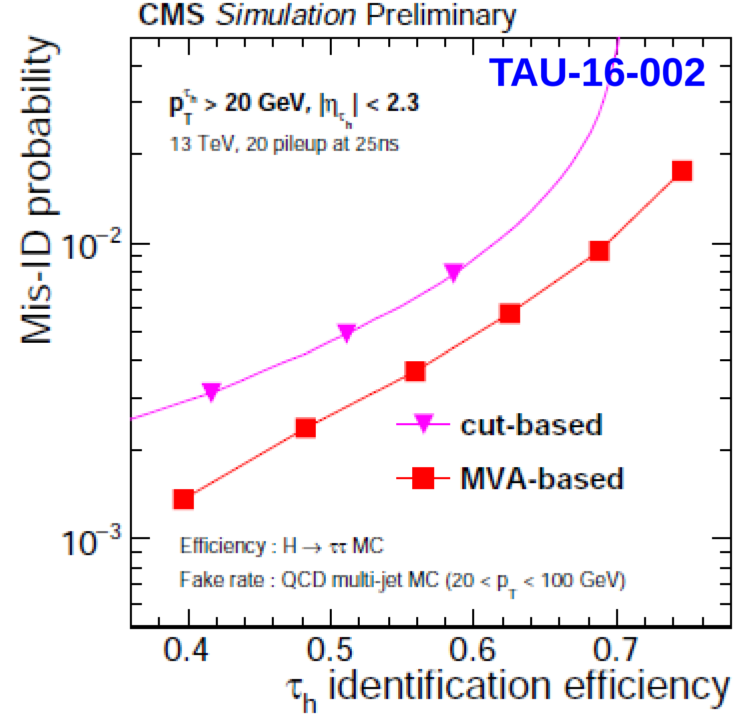
- W-tagging algorithms with PUPPI are more robust against pile up
- Algorithms with n-subjettiness reduce the misidentification probability with a factor ~5 (while keeping over 60% of the signal)

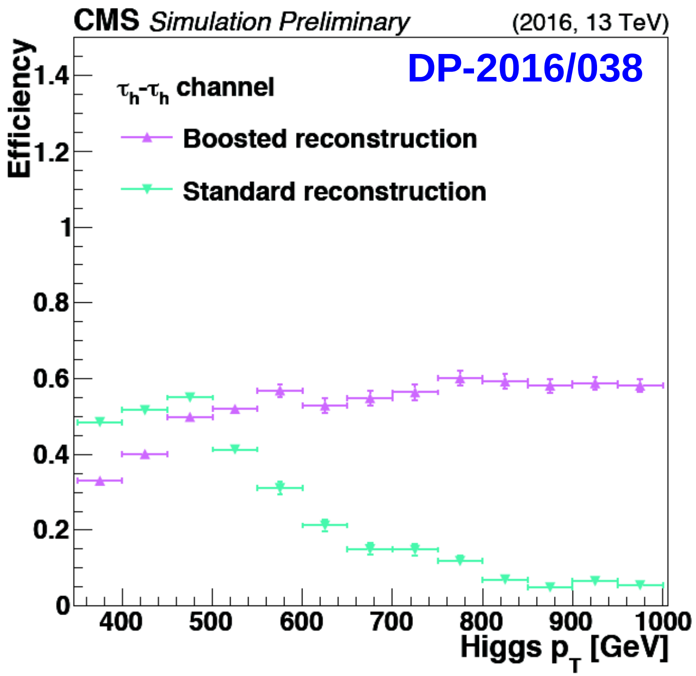




Identification of hadronic tau leptons

- The MVA-based hadronic tau discriminator was optimized for Run 2
- The MVA-based approach shows a reduction of a factor 2 for the misidentification probability w.r.t. the cut-based approach at a similar efficiency.

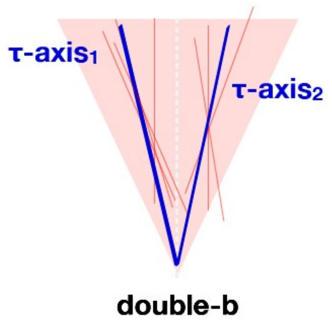


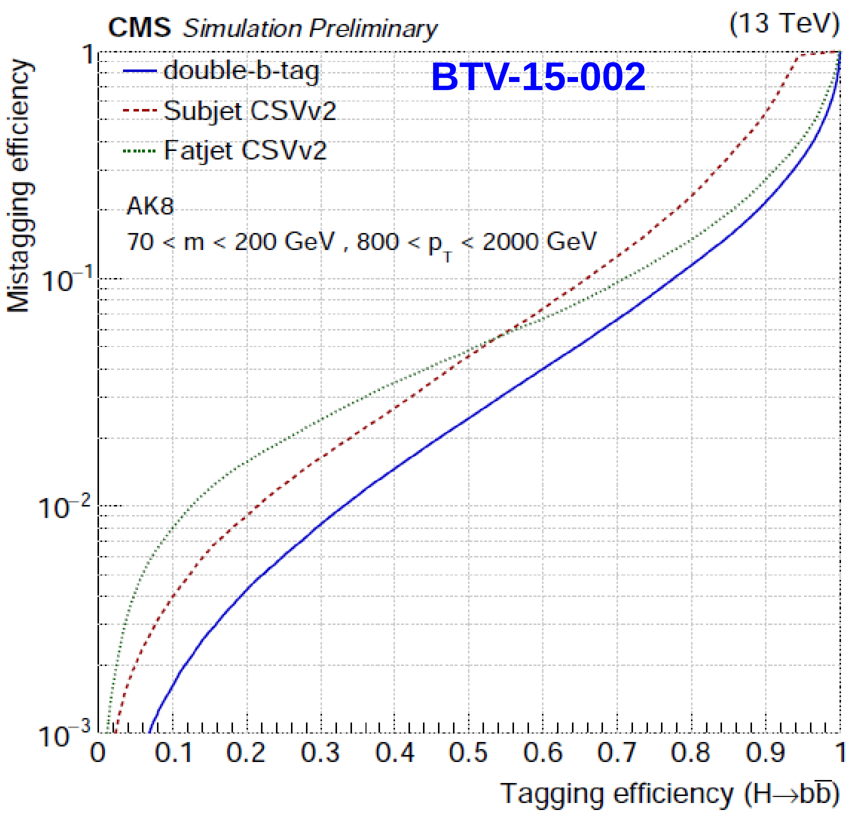


- Identification of boosted H → ττ
- Important for e.g. heavy resonances decaying to HH
- A reconstruction technique for boosted τ was developed and outperforms the standard reconstruction at high Higgs p_T

Double-b tagging

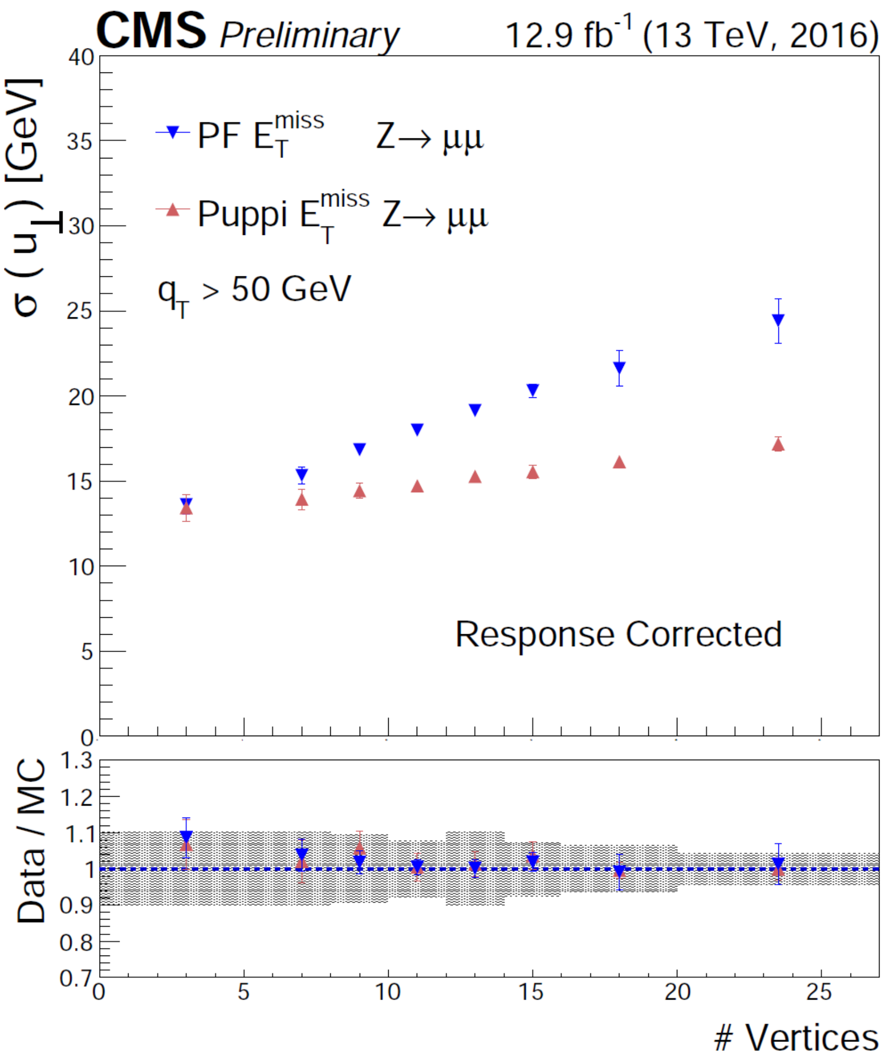
- Identification of boosted H →bb
- Important for e.g. heavy resonances decaying to HH



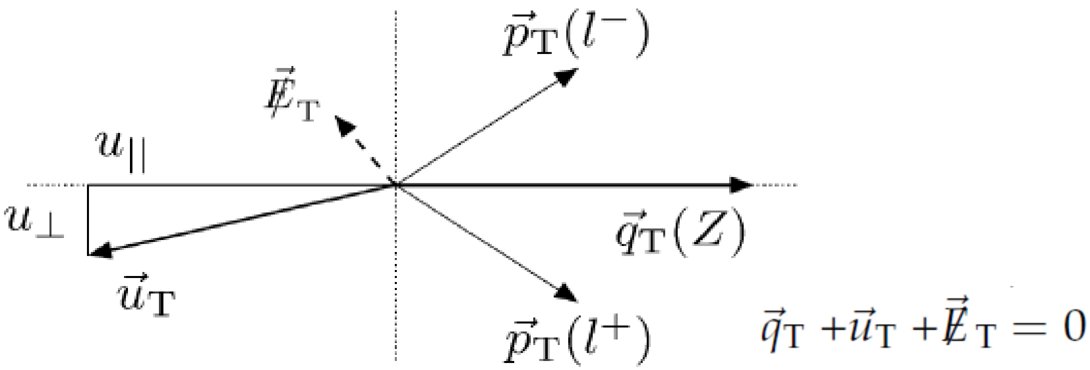


- In case of the boosted double-b jet we exploit the presence of 2 b jets in a single fat jet
- The performance of the double-b tagger is compared to subjet b-tagging and fat jet b-tagging using our standard CSVv2 tagger

Missing transverse energy



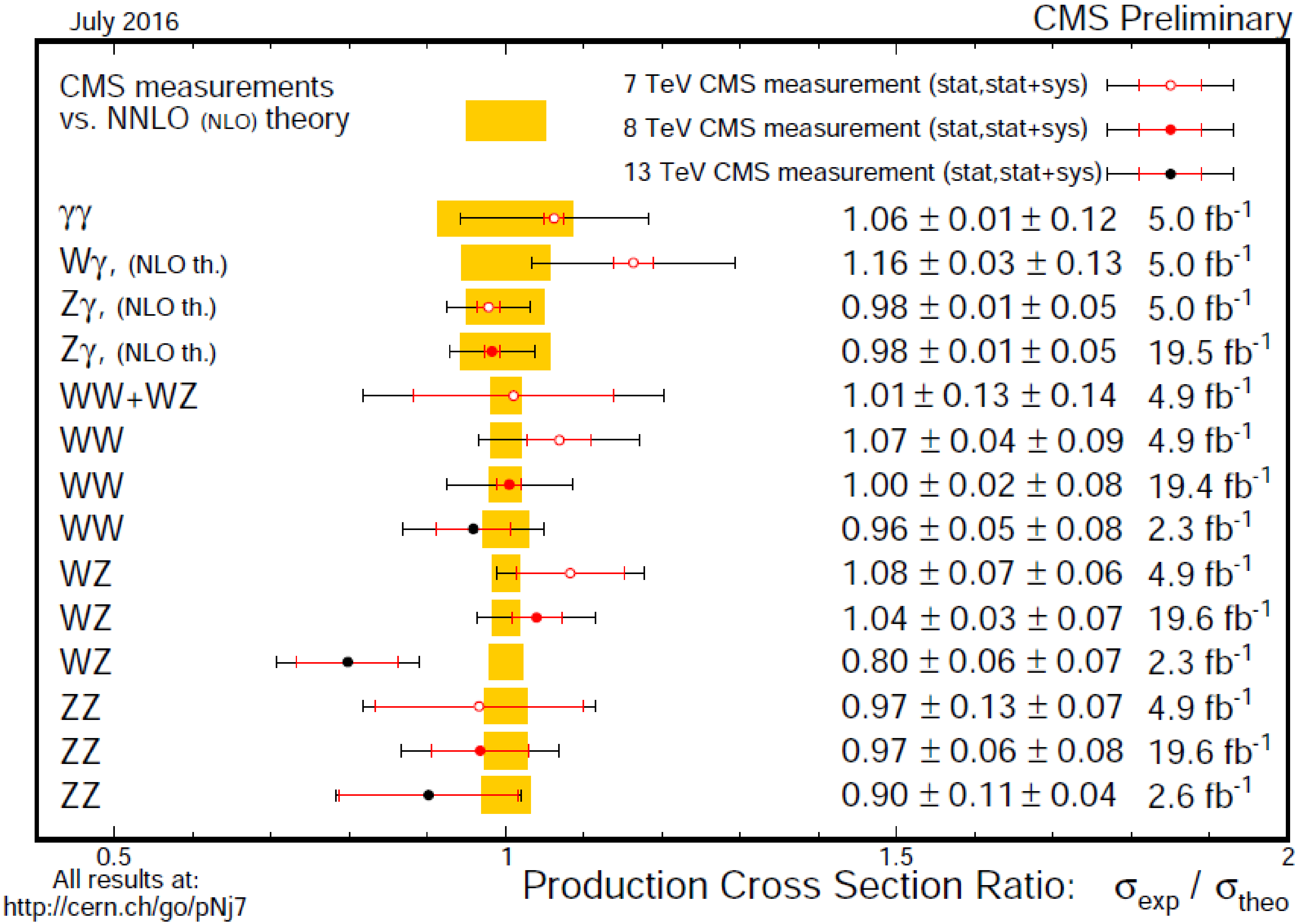
JME-16-004



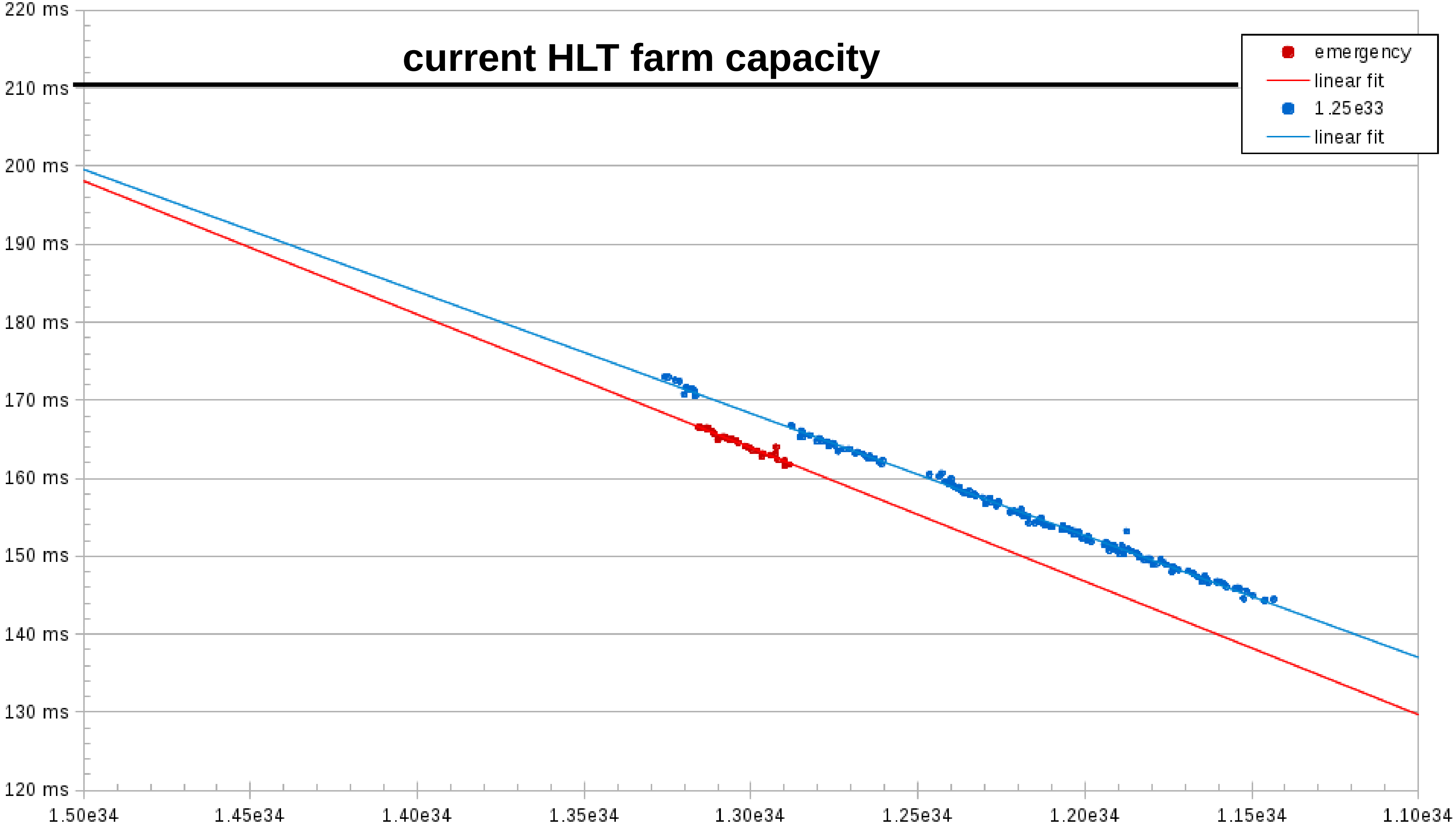
- The performance and resolution of the MET reconstruction is measured by comparing the momentum of the Z boson to that of the hadronic recoil system
- Our “pile up per particle identification” (Puppi) makes the resolution more stable against pile up

Diboson production cross section

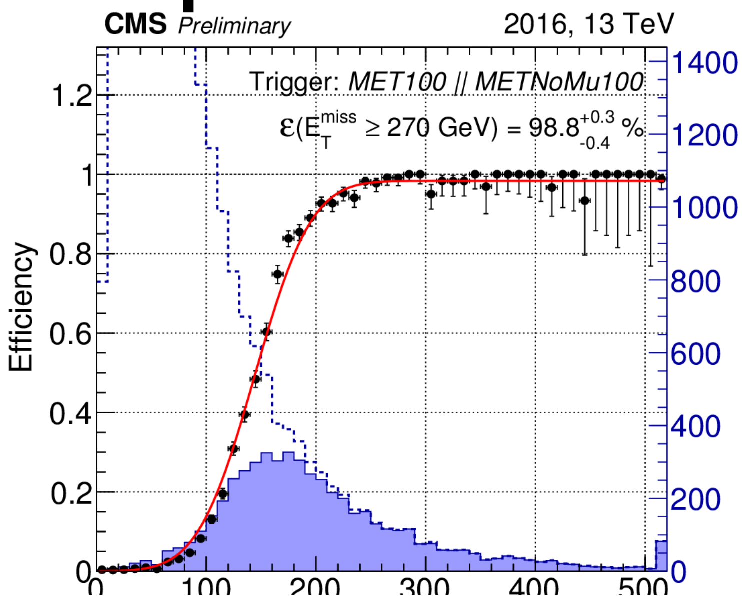
- Already 3 measurements at 13 TeV (WW, WZ and ZZ)
- No significant deviations from the NNLO predictions



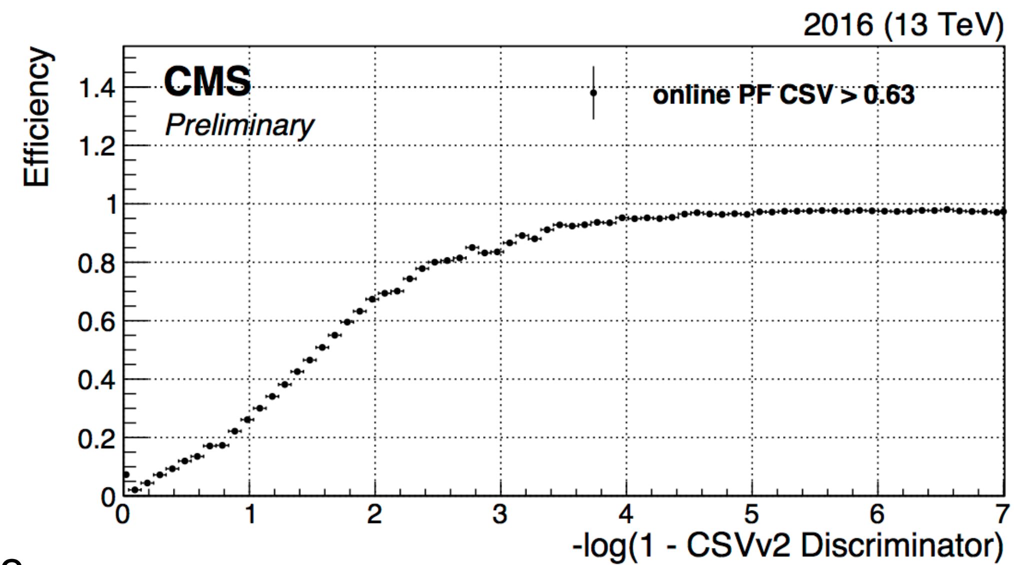
HLT extrapolation to 1.5*10^{34} cm^{-2}s^{-1}



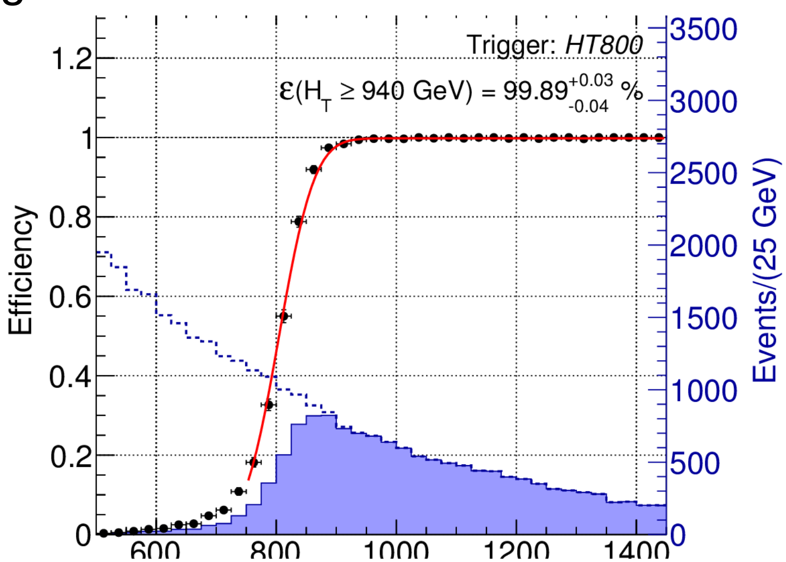
HLT performance



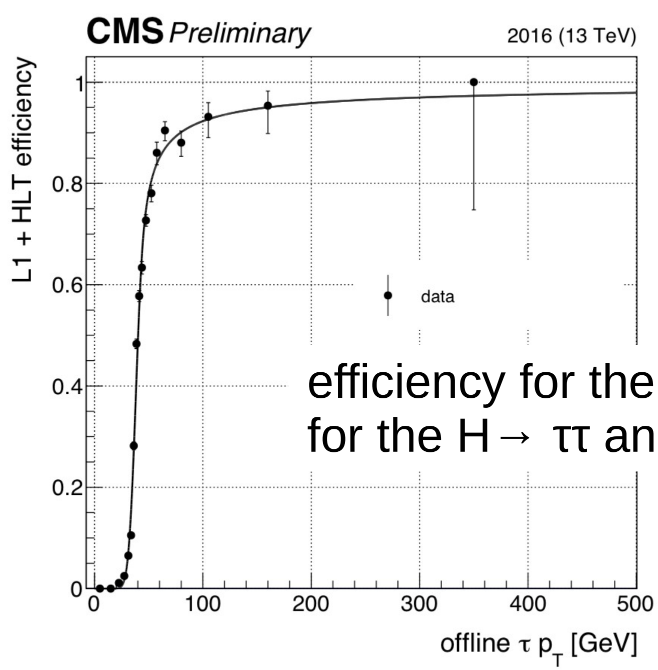
efficiency of the PFMET100_PFMHT100 triggers as a function of offline ETmiss



online b-tagging performance for Particle Flow jets



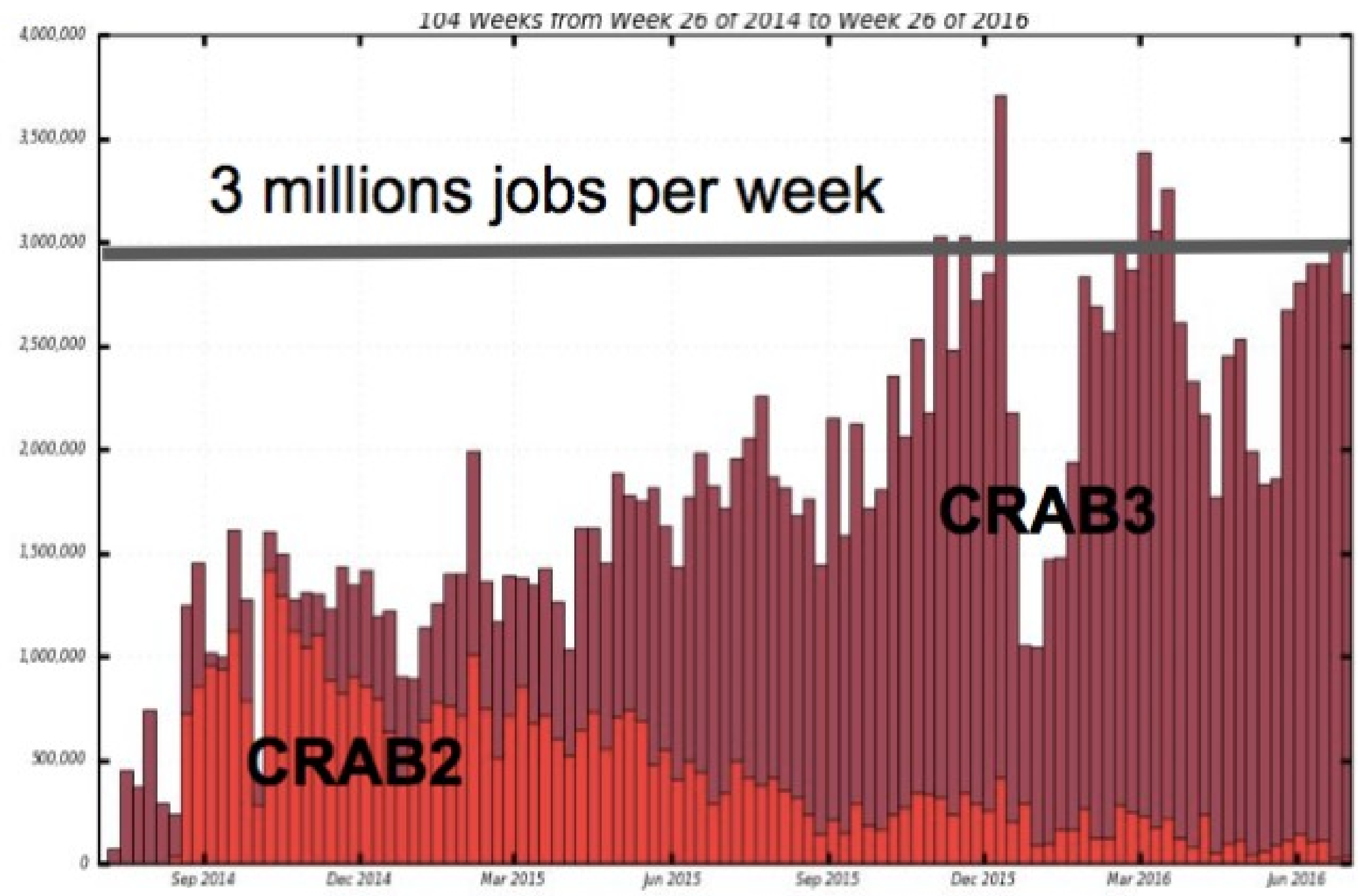
efficiency of the HLT_PFHT800 trigger as a function of offline HT



efficiency for the di-τ trigger for the H→ ττ analysis

Migration of the CMS analysis tool for remote jobs

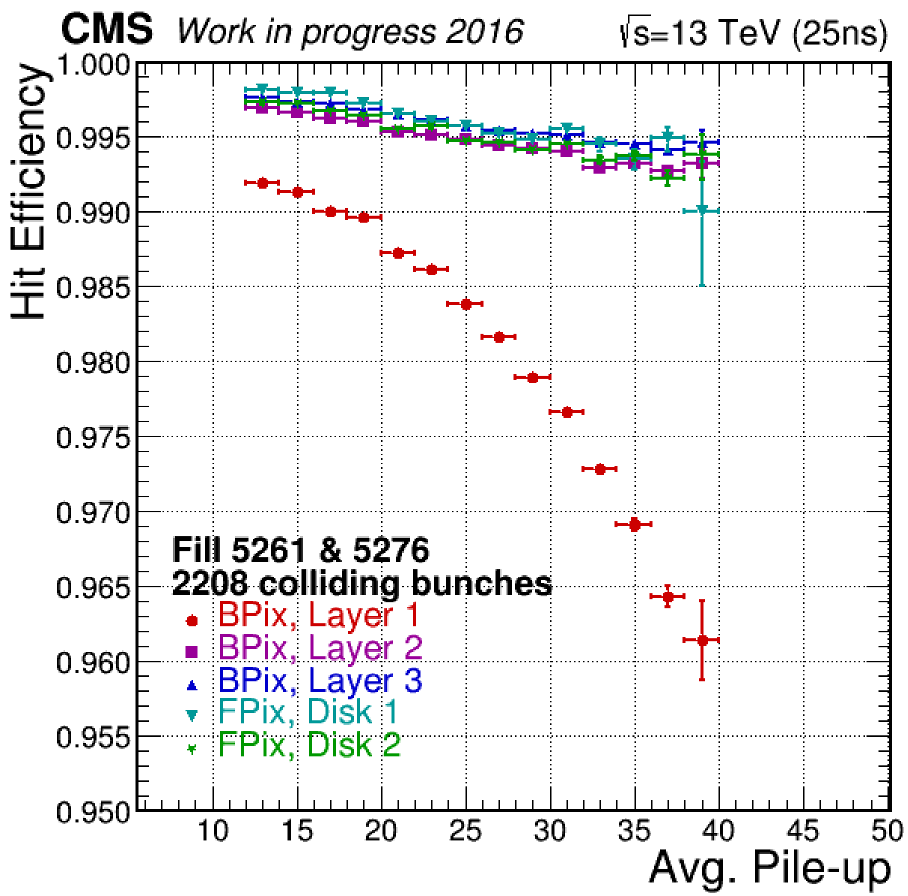
Successfully completed the migration to CRAB3 for analysis jobs



Sep. 2014 **Jun. 2016**

Silicon pixel tracker performance

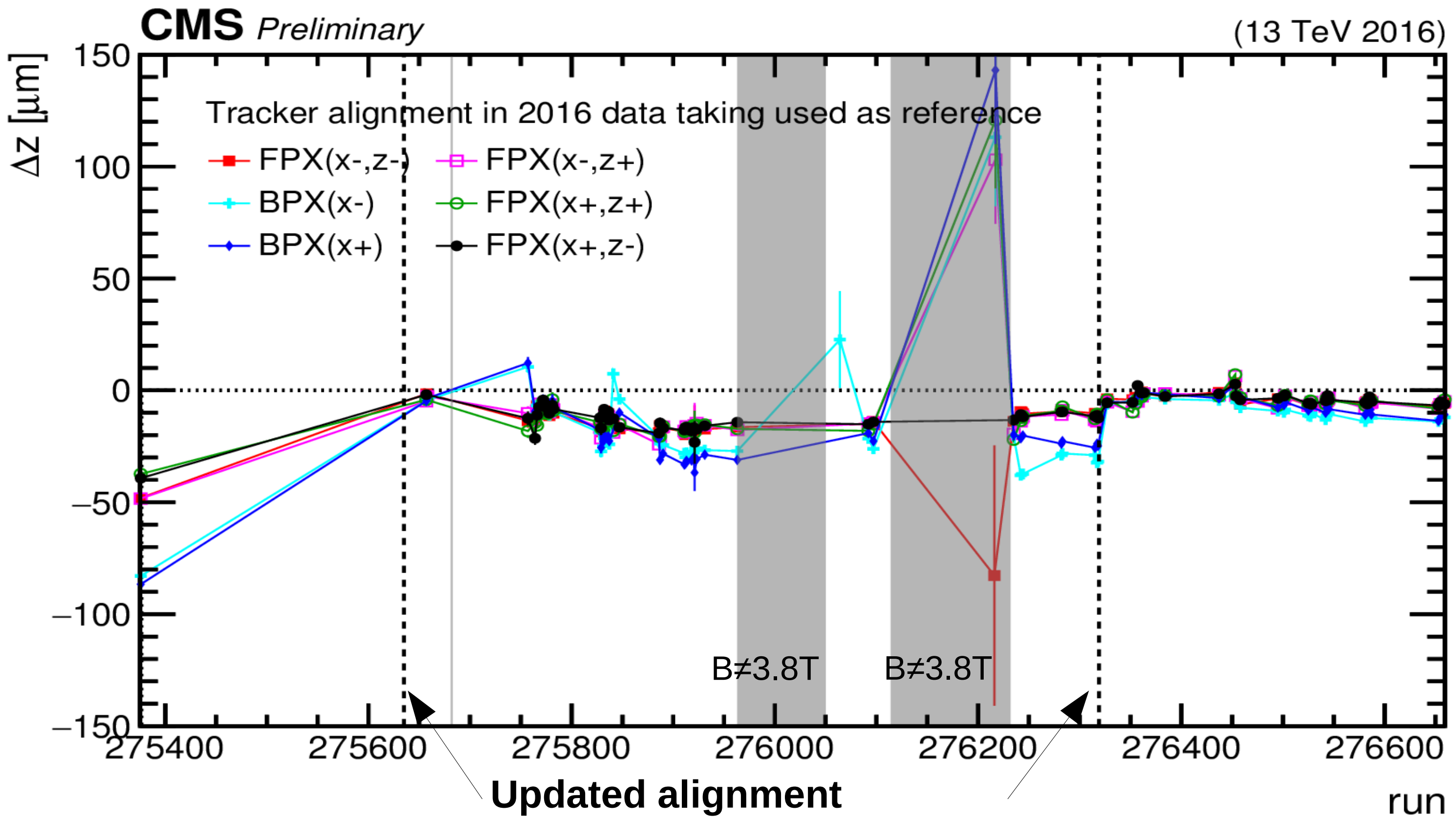
- Despite the increase in luminosity, pileup and trigger rate, the current pixel detector still behaves reasonably well.
- The limit of the pixel tracker bandwidth will be around $1.5*10^{34}$ $cm^{-2}s^{-1}$ and 50 pile up collisions



- The dynamic inefficiency is increasing, we expect 6% efficiency loss at the luminosity and pile up mentioned above → serious impact on e.g. b-tagging
- For the remainder of data taking in 2016, we can deal with the current situation
- Also, a better simulation of the pixel dynamic inefficiency is available in the next CMS software releases (for physics results with the full 2016 dataset)

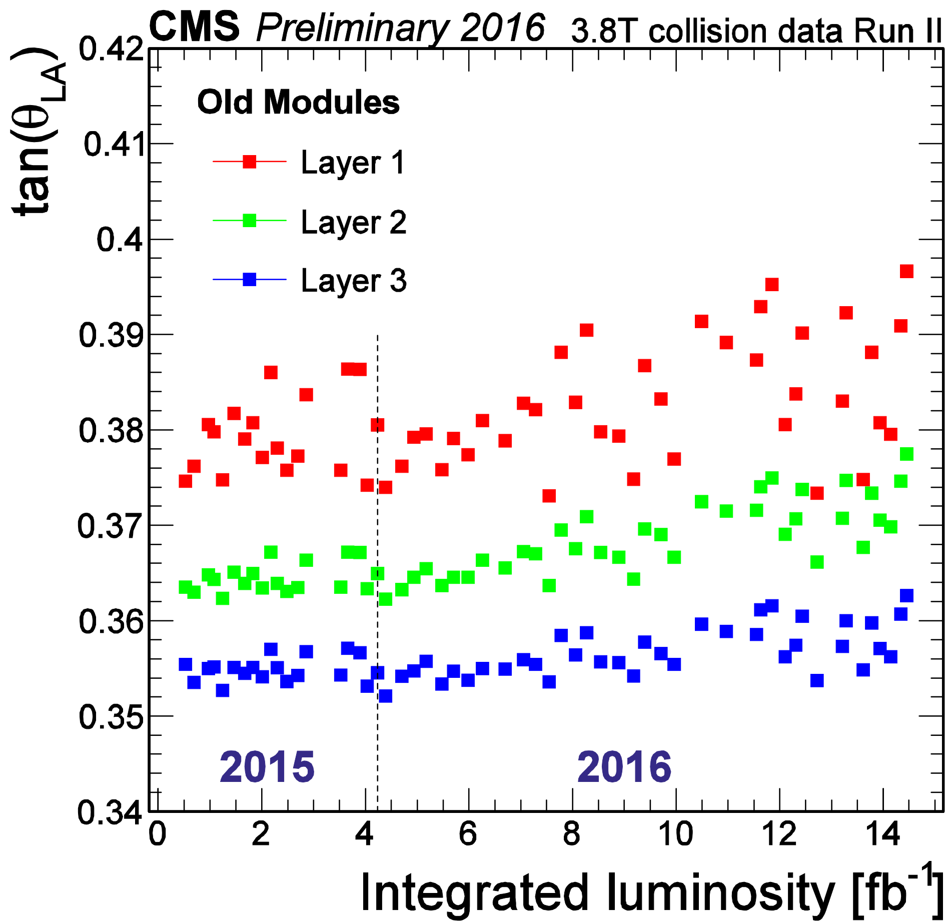
Pixel alignment

- Pixel tracker may move due to changes in temperature and magnet cycles
- Automatic procedure measures the movement relative to geometry used in data taking using 20k events online
- Movements during magnet-off periods:
  - < 50 μm in x and y
  - < 150 μm in z



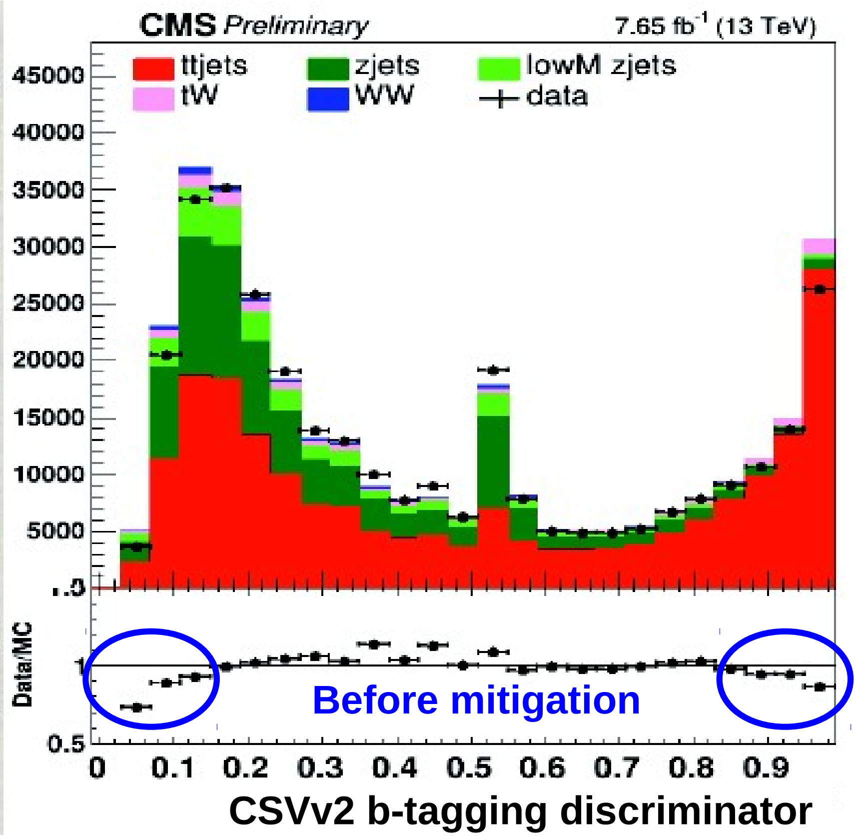
Pixel hit reconstruction

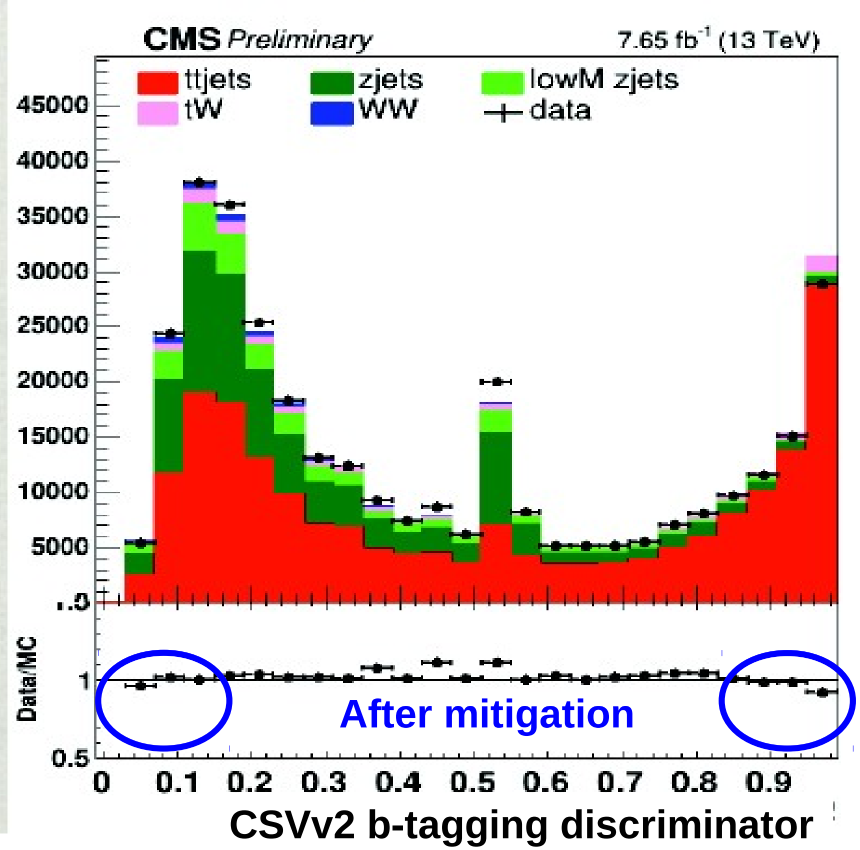
- Lorentz angle (LA) measured using tracks with shallow impact angle
- tan(LA) is the slope of the function relating the average drift of charges with their creation depth in the silicon
- Irradiation damages silicon causing a shift in the cluster position
- Corrections are applied to the cluster position and the global module alignment



Silicon strip inefficiency: mitigation

- Around 20/fb of data collected with the old setting for the pre-amplifier
- Impact mostly visible for tracking, muon identification and b-tagging
- Mitigation strategies were developed: recovering most of the efficiency loss

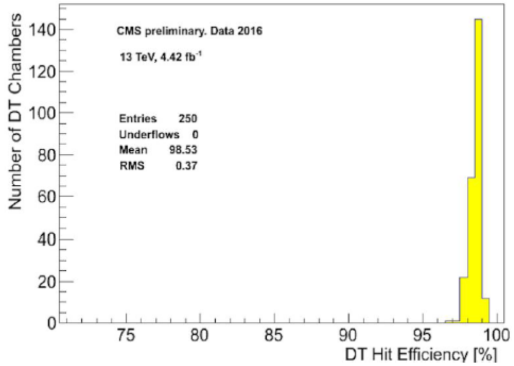




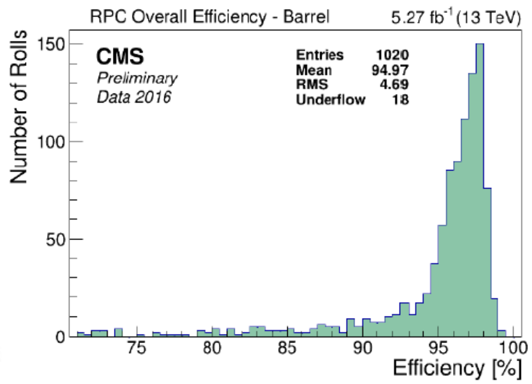
- The data collected before the change in the pre-amplifier settings is about to be reprocessed with mitigation for tracking and b-tagging including also updated alignment and calibration conditions

Muon detector efficiency and timing

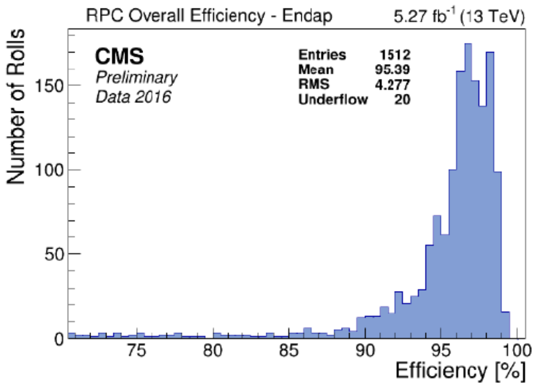
Single Hit efficiency



DT

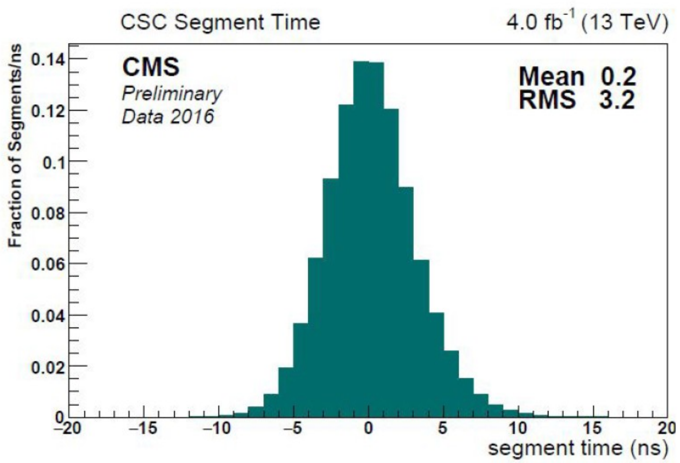


RPC barrel

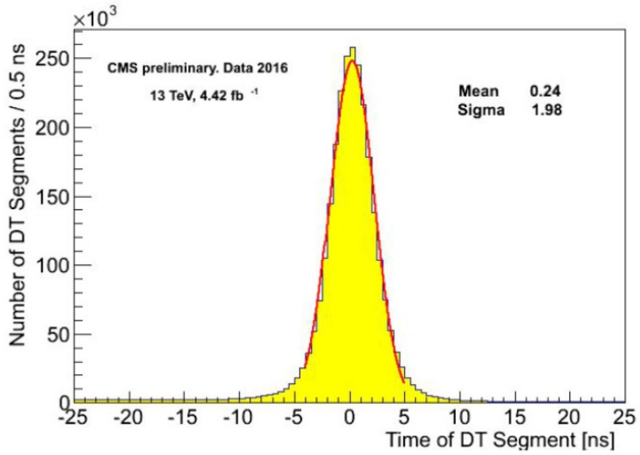


RPC endcap

Times from reconstructed segments

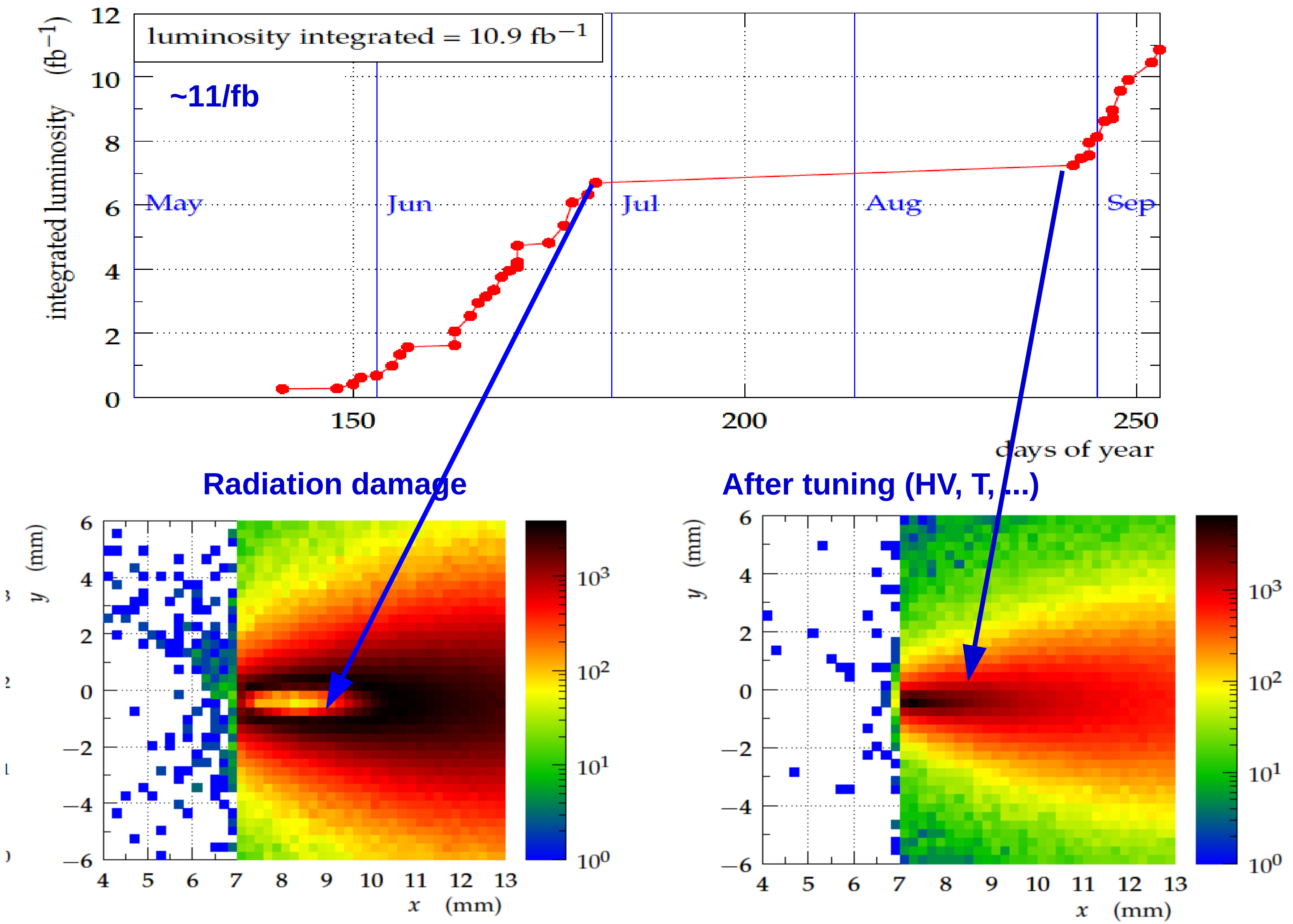


CSC



DT

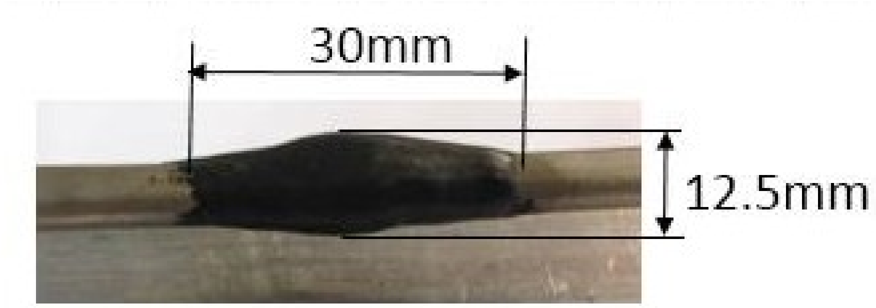
CT-PPS integrated in CMS data taking



Note: silicon strips replaced last week

Water leak in CSC last December

- Regarding the water leak from a faulty brazed joint in the cooling circuit on one CSC chamber in the ME1/1 station that occurred last December:
  - No additional leaks were encountered, so it is possible that this was a one-time occurrence
  - Nonetheless, a method for reliably reinforcing the joints in situ during a YETS was developed and tested, in case such replacement were to become necessary

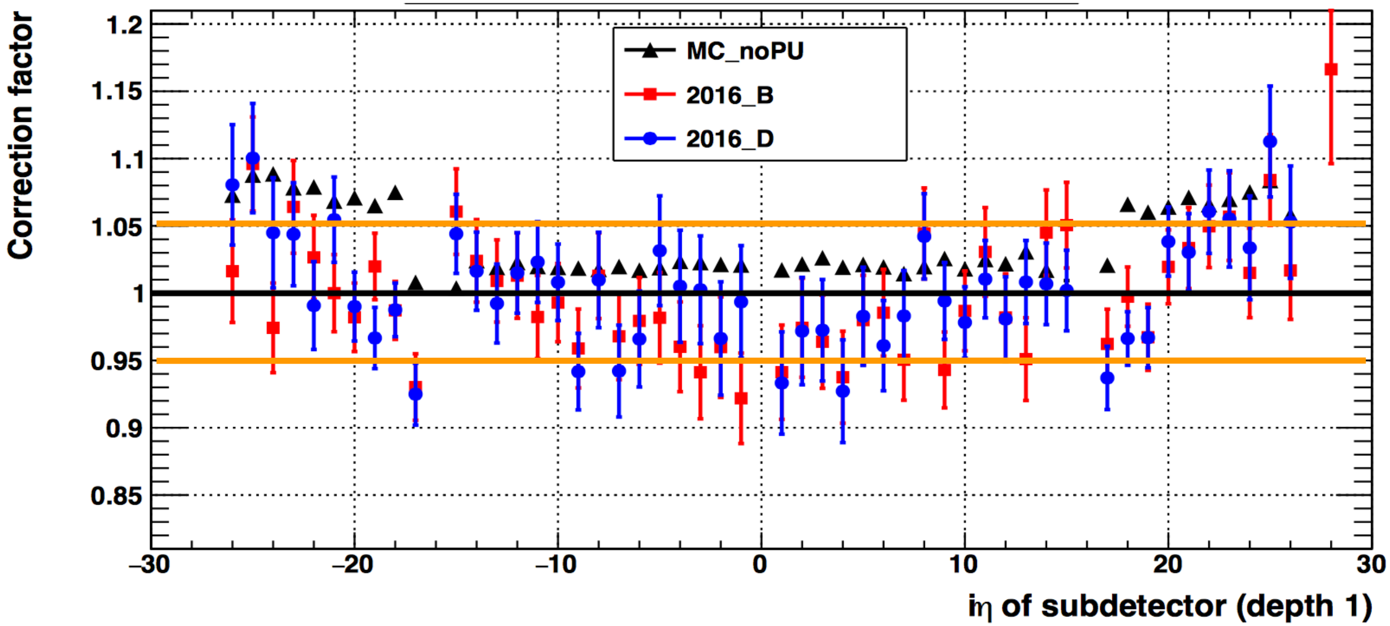


Epoxy over the joint

Protection of epoxy against mechanical stress

HCAL energy calibration

- The ratio between track momentum and HCAL energy is typically kept within 5%
  - Thanks to a more robust selection for isolated charged hadrons to cope with higher PU



- In 2015 we were not able to measure this because the selection for isolated charged hadrons needed tuning for higher PU
- Intrinsic uncertainty of the method is 2% (aiming for this precision with the legacy reprocessing)

Phase 2 time line

Illustrating different phases of the project and approval process (TDRs and EDRs)

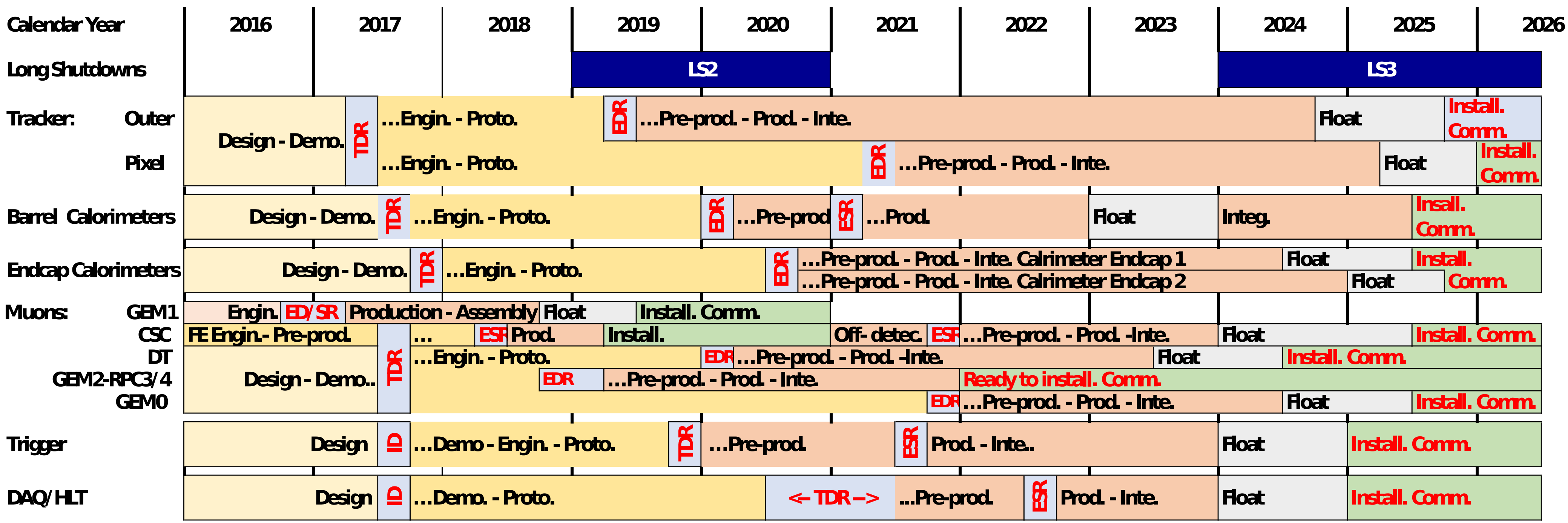
Detector design, Technology R&D, specification and demonstration of major component feasibility

Engineering, prototyping and validation of final components, assemblies and systems

Pre-production of final grade components, assemblies and systems

Production, Integration and commissioning of detector and systems

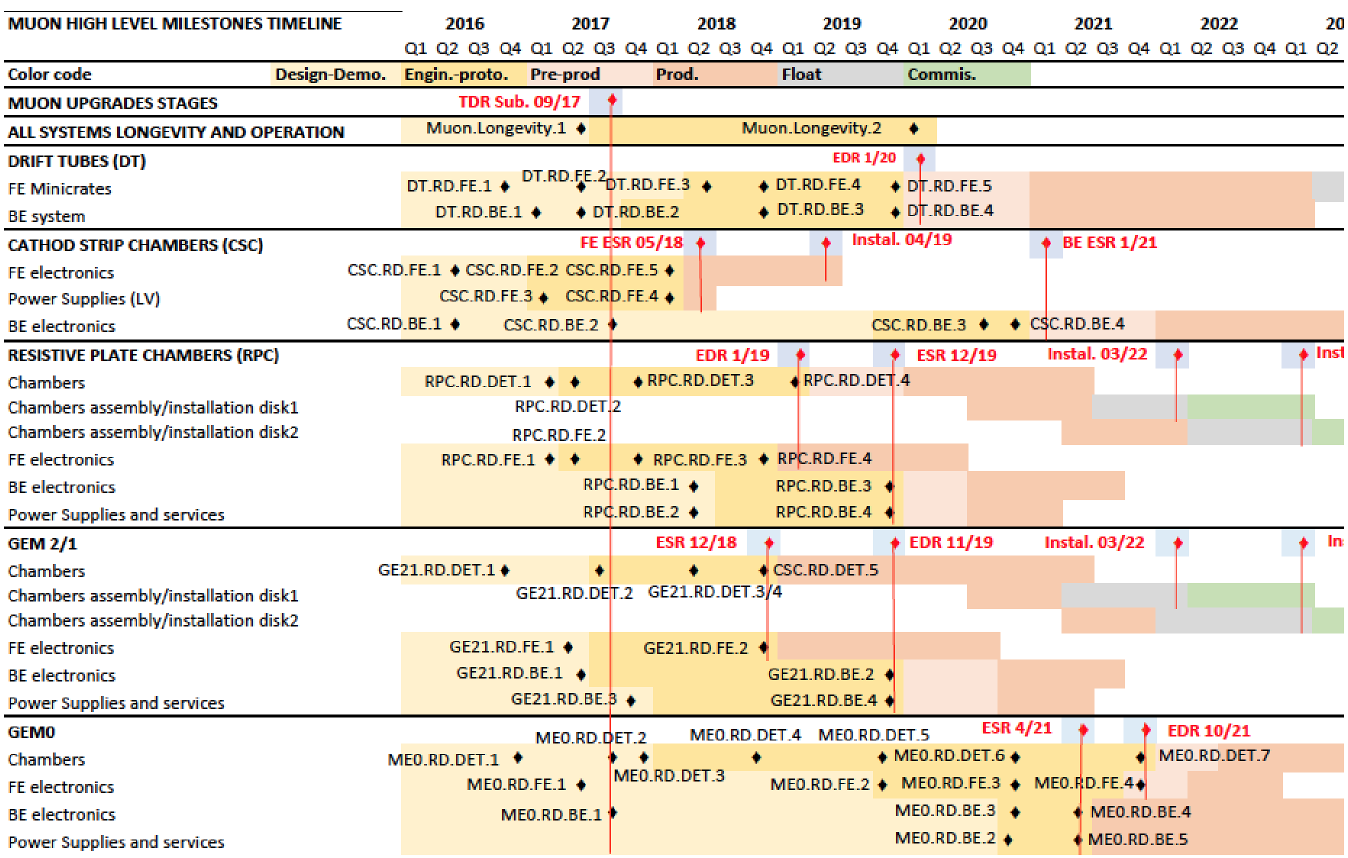
Installation at P5, cabling and commissioning of detectors and systems



Phase 2 muon upgrade

- Irradiation and muon performance tests on all types of chambers at the GIF++
- Schedule and milestones for the Phase 2 muon upgrade are being prepared
- GEM chambers and electronics continue to be produced for installation in CMS during early 2017 of a four-“superchamber” slice test, integration tests
- Work on writing the TDR will start soon

Draft schedule and milestones for muon upgrade



GE1/1 integration with ME1/1 at CERN