CMS Status Report

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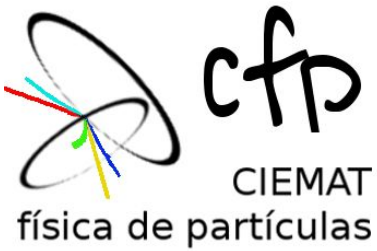
On behalf of the CMS Collaboration

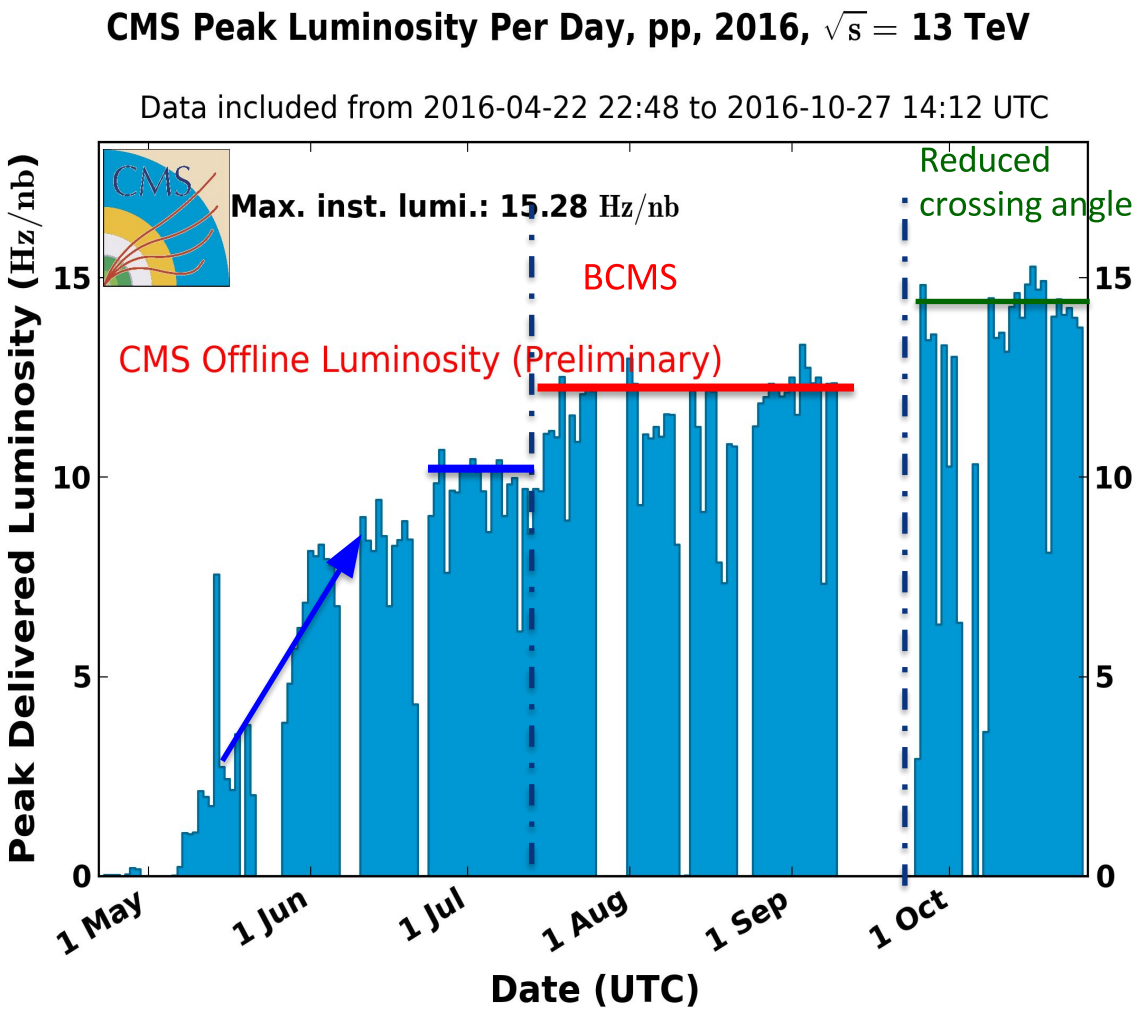
LHCC Open Session, 30 November 2016



Outline

- 2016 running
- Trigger and detector performance
- Selected Physics Results
- Heavy Ion 2016 run (p Pb collisions)
- End-of-year activities and preparation for 2017 running

2016: great LHC performance!



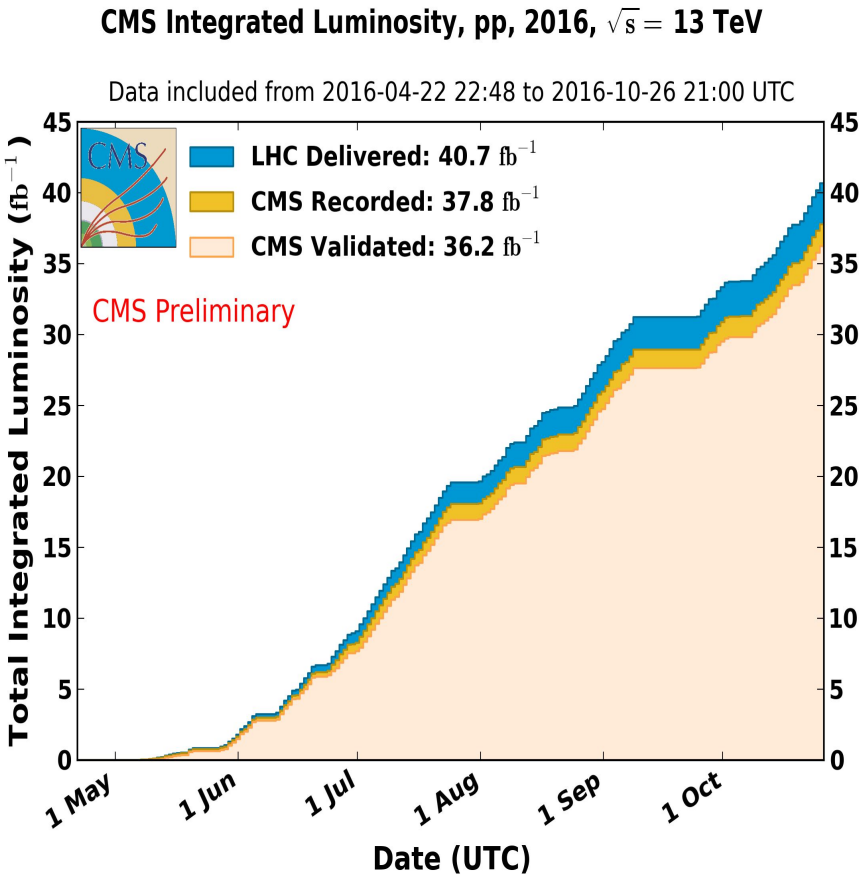
https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

… and challenging conditions for the CMS detector!

Typical peak lumi at end of year ~1.4 10^{34} cm^{-2} s^{-1}

2016 max peak lumi 1.5 10^{34} cm^{-2} s^{-1} with <pileup> = 49.4 (2208 colliding bunches)

CMS Good Data Collection Efficiency



https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

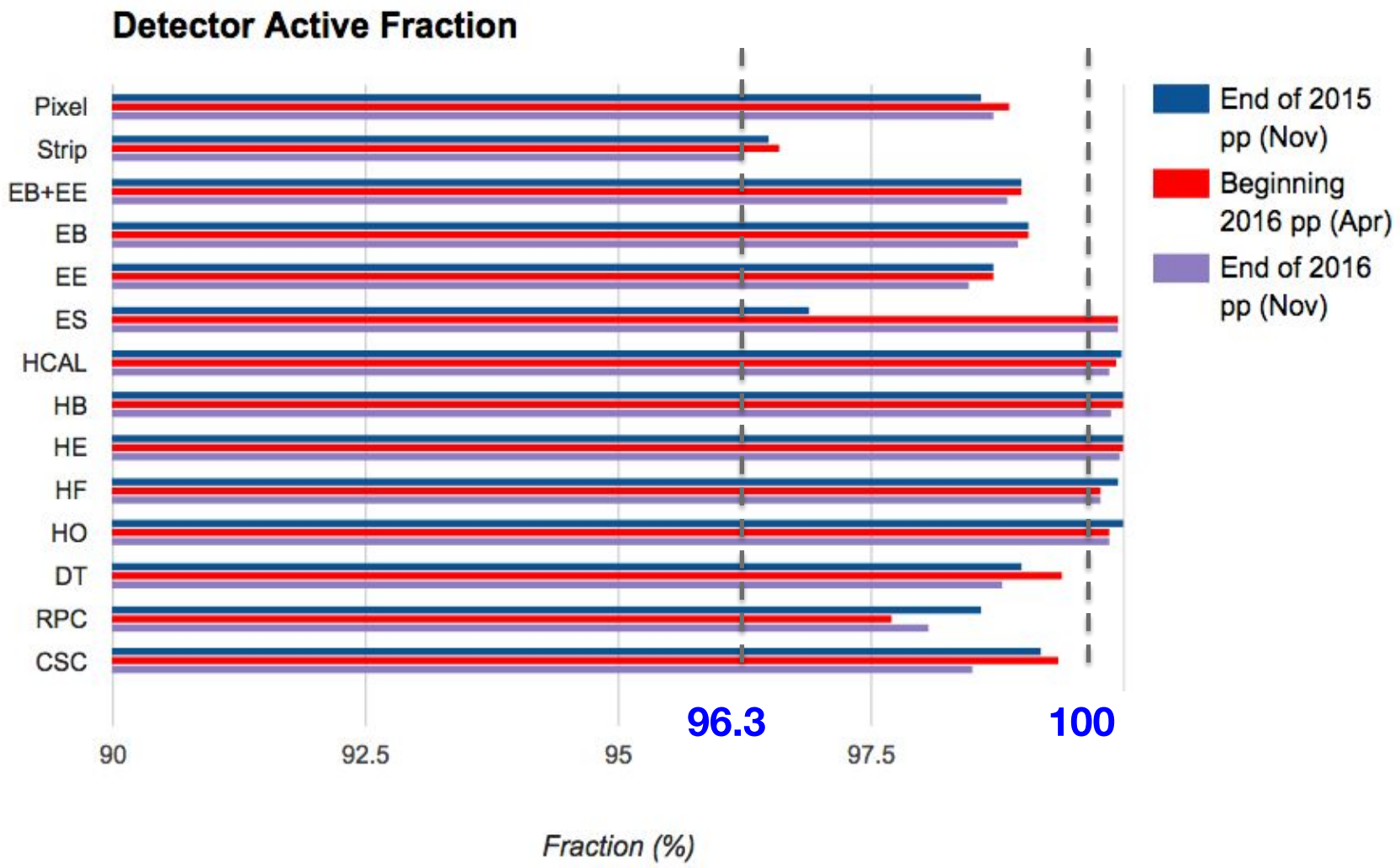
CMS data collection efficiency: 93%

CMS data certification efficiency: 96%

This outstanding performance, underpinned by excellent reliability from the detector, magnet & services, is the result of a huge effort from CERN's technical groups and from CMS collaborators at CERN and around the world

Data available with consistent calibration and alignment parameters.
5 billion events re-processed

Detector performance. Active channels



L1 Trigger in 2016

Key conceptual changes:

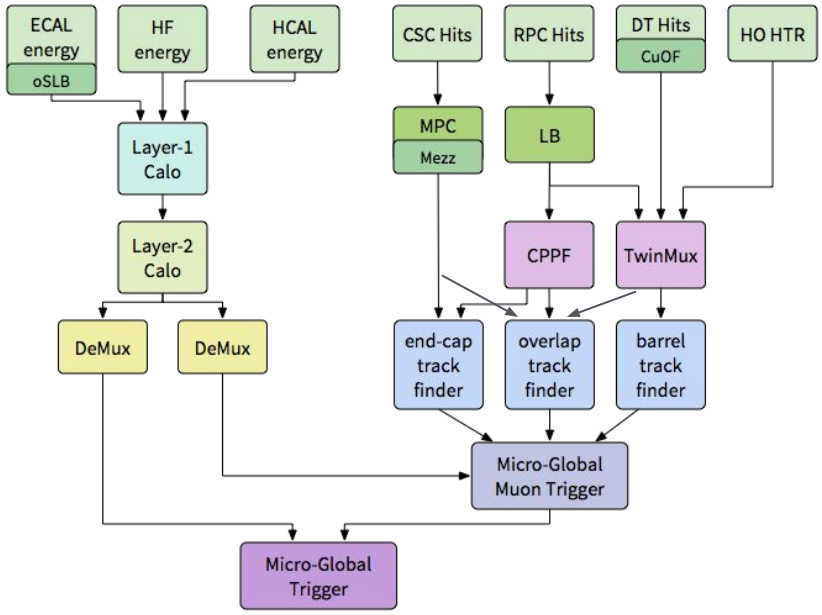
- Muon system: use redundancy of three muon detector systems and make a high resolution muon trigger
- Calorimeter system: remove boundaries by streaming data from single event into one FPGA
- Global trigger — expandable to many more possible conditions and more sophisticated quantities, to give a richer menu à la Higher Level Trigger

Generally smooth and reliable running in 2016, with acceptable thresholds:

- 32 GeV for single isolated e/γ, 20 GeV for single muons

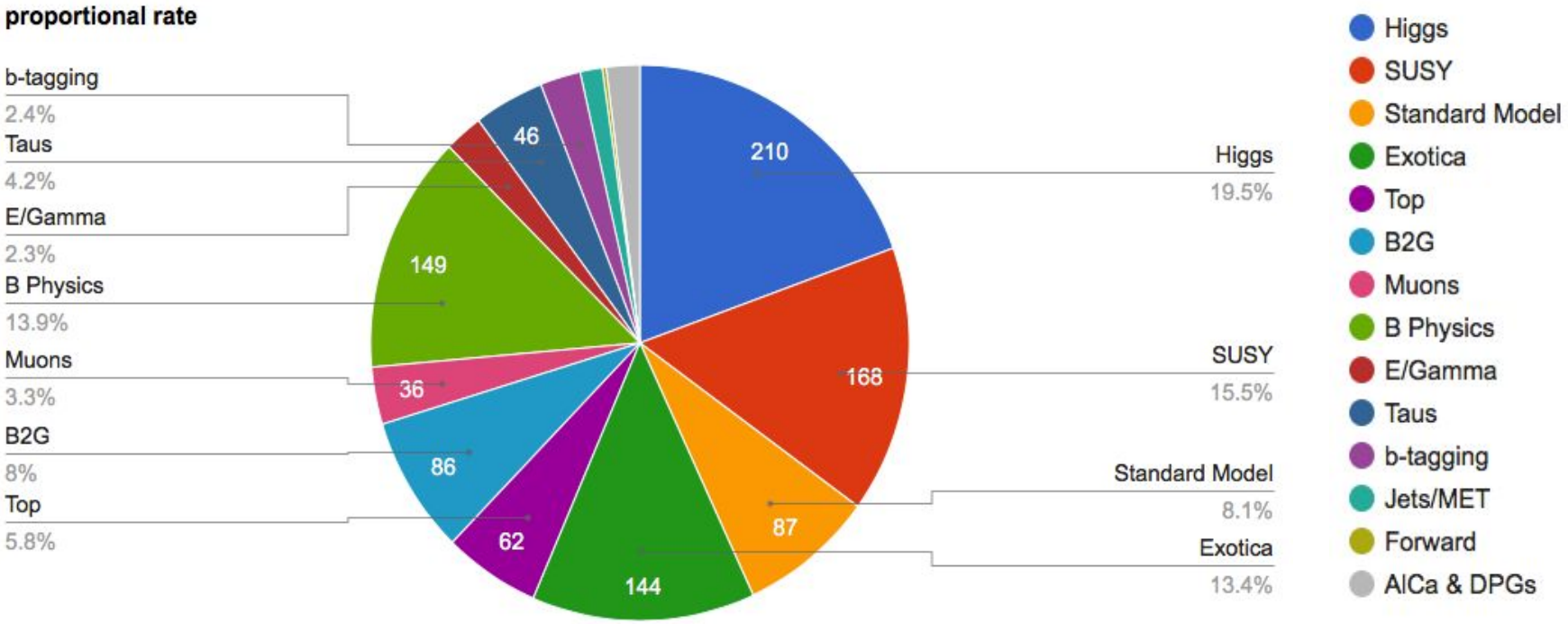
Successfully collected data during the high pile-up run

- useful for improving the trigger algorithms in preparation for 2017



High Level Trigger (HLT)

Typical CMS event output rate in 2016 ~ 1.1 kHz

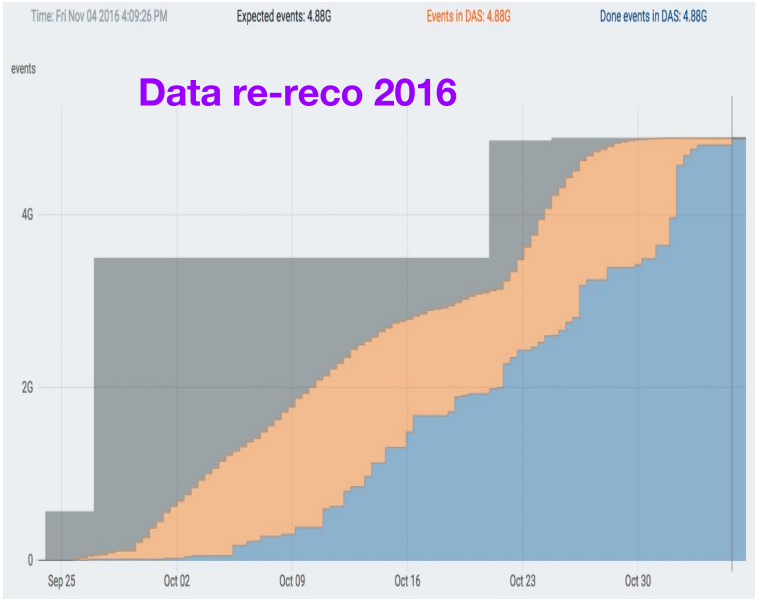


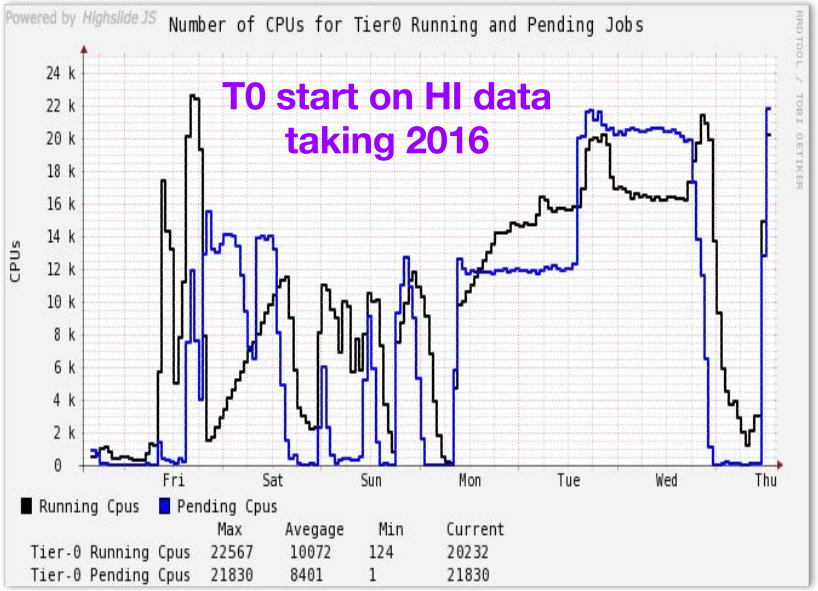
(Proportional rate is computed considering the sharing between groups. If a path is owned by n groups the events triggered by that path are assigned to each individual group with a 1/n weight)

- Dedicated efforts to maintain low thresholds in 2016-2017 for:
  - Most relevant analyses in HIG, as well as TOP and SM
  - Challenging phase space regions in searches
  - Special B physics triggers

Some computing/processing highlights

- The CMS teams managed to cope with the load arising from an extraordinary year in terms of LHC availability: limit of 5 million live-secs reached in early September!
- Unexpectedly high data volume required: ad-hoc actions to mitigate the impact of the resulting resource limitations (tape deletion / disk cleanup operations)
- In addition: opportunistic computing (after Amazon, experiences with NERSC, Google, ..), R&D to study / improve system performances





MC re-processing in progress (several billion events):

- Final 2016 pileup profile
- Most realistic detector response for better data vs MC agreement
- Most accurate trigger simulation

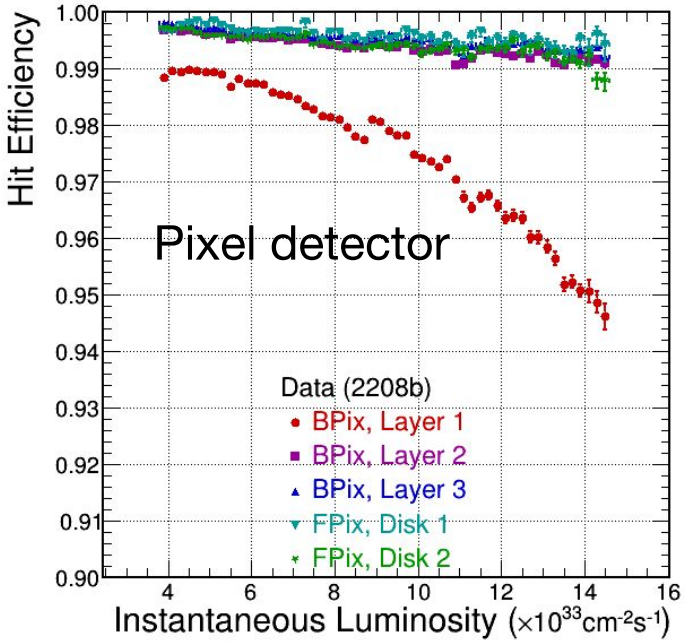
Detector/data-taking behavior

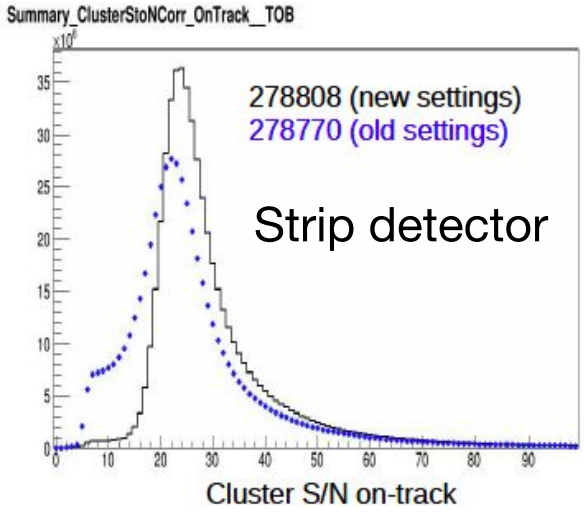
Tracker in 2016

- **Large data-taking efficiency: ~98%**

- **High luminosity:**
  - Occupancy: <0.1% in Pixel and <3.5% in Strip
    - Readout bandwidth OK
    - Pixel readout dynamic inefficiency up to 5% in innermost layer: expected – will be fixed by Phase 1 upgrade
    - Unexpected saturation and inefficiency of Strip ASIC completely fixed in August with new chip settings
  - No unexpected radiation effect
    - Periodic monitoring and tuning of Pixel readout ASIC to control power consumption with no performance loss

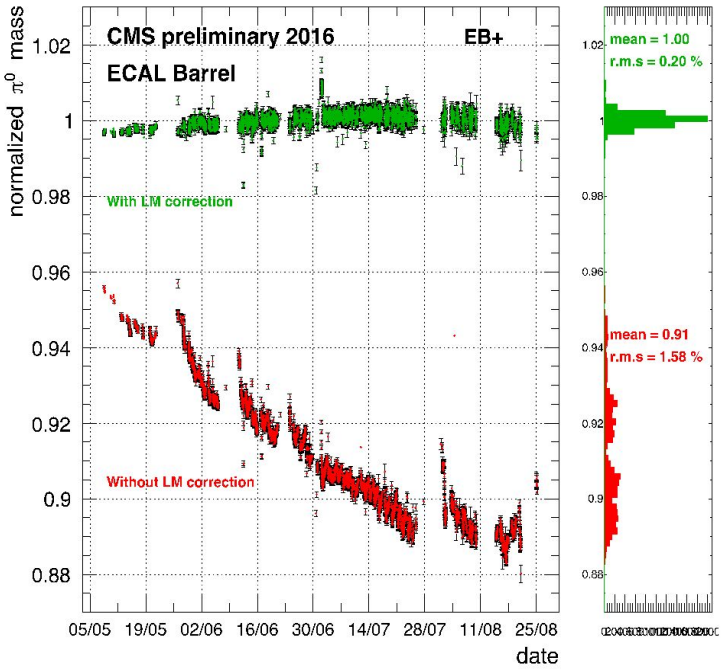
- **Pixel Phase 1 Upgrade Pilot detector**
  - Succeeded in collecting data stably for entire fills from six pixel module prototypes
    - Crucial for the new readout board firmware development





ECAL in 2016

- EB/EE/ES ran stably during LHC pp and p-Pb collisions in 2016, data-taking efficiency > 99%
- Good performance of ECAL calibration in 2016
  - Delivered improved conditions for 2017 Winter conferences
- 2016 data taking experience reviewed, forming plans for 2017
  - Working to minimise ECAL-related downtimes based on 2016 experience
  - No obvious issues identified for running at higher luminosity in 2017



Normalised $\pi^0 \rightarrow \gamma\gamma$ invariant mass history in 2016, plotted **before** and **after** laser monitoring corrections are applied.
The green points show the good stability of the ECAL energy scale achieved in 2016

HCAL in 2016

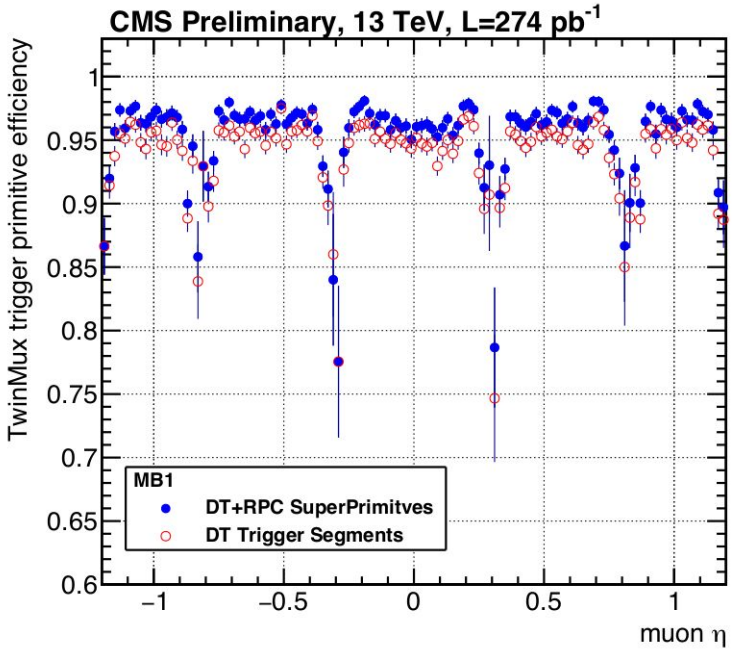
- **Data-taking efficiency ~98%**
- **Substantial improvements in monitoring of hardware, electronics, and data quality, both locally and in remote centers (EU, Asia, US)**

- **Many other improvements:**
  - **Completely new µTCA-based backend electronics for the barrel and endcap in 2016**
    - **Fundamental prerequisite for the upcoming Phase I HE upgrades**
  - **New laser calibration system in the beam orbit gap**
    - **Used to monitor the overall health of HCAL during data-taking (spot new dead channels, readout synchronization issues, etc.)**
  - **Dual DAQ links recently installed for HF (to prepare for a ~4x increase in event size after the upcoming Phase I HF upgrade)**

Muon spectrometer in 2016

- **Excellent performance over all years**
- **During early 2016, five new crates of TwinMux electronics that link the DT, RPC, and HO to the Phase I muon trigger have been installed and commissioned, along with more than a thousand optical fibre connections**
- **The TwinMux have provided DTmuon trigger primitives in 2016 as good as previously**
- **DT-RPC matching, implemented at the end of the run, reduces out of time triggers**
  - **Local efficiency increased by ~1.3%**
- **Planned for 2017:**
  - **Generation of RPC-only trigger primitives**
  - **Inclusion of HO in the trigger algorithm**

x60



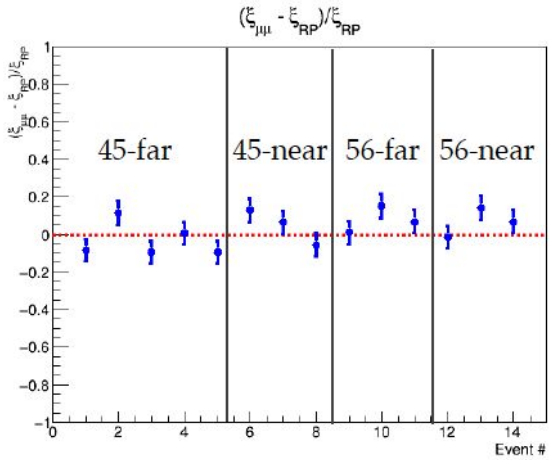
CT-PPS in 2016

CT-PPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at high luminosity on a regular basis

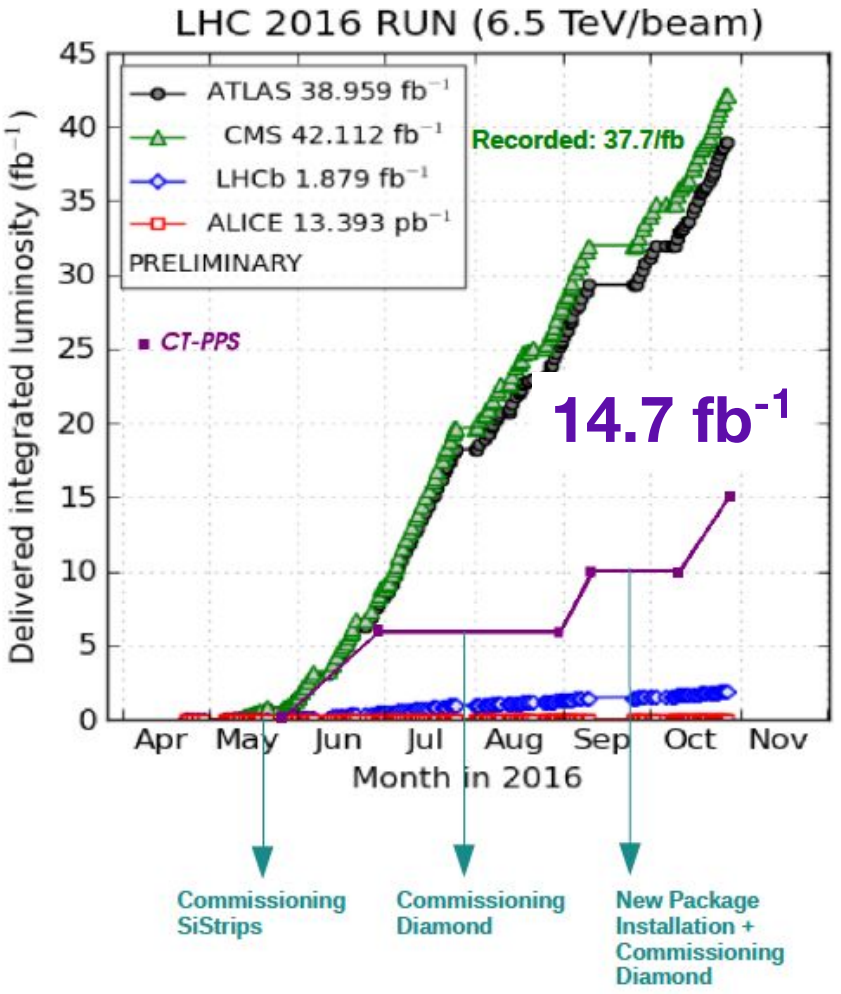
Luminosity in 2016 with CT-PPS included:

- **Strips tracking only: 14.7 fb^{-1}**
- **Strips & Diamond timing: 2.5 fb^{-1}**

Preliminary results on dimuon Central Exclusive Production: good kinematic correlation between dimuon mass estimates from "Roman Pot" protons and central information

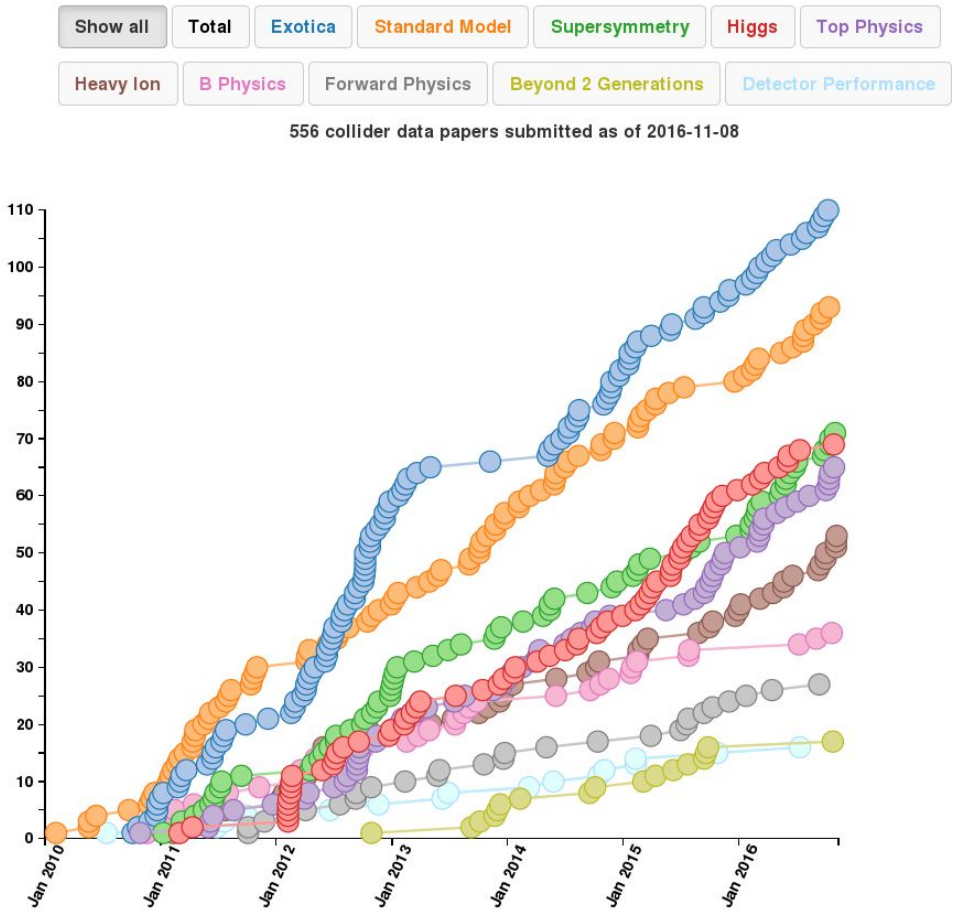


$\xi = M(\mu\mu)/\sqrt{s}$



A few recent physics results

Publication/analysis status



556 physics papers submitted

Run2: 195 public results

- Many of them are preliminary results with 2015/ICHEP16 data

Change of phase in physics strategy:

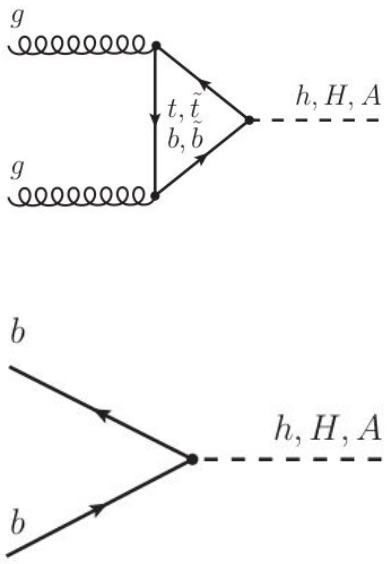
- Last big jump in energy in 2015
- Last big jump in luminosity by ICHEP 2016 (3->13 fb^{-1})
- Significant increase in sensitivity requiring more precise/realistic simulations and close to ultimate performances in data

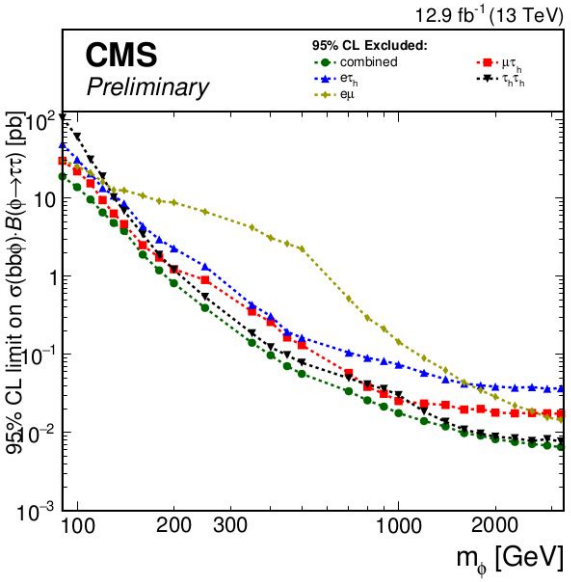
All info from CADI and from our publication page:
http://cern.ch/cms-results/public-results/publications/

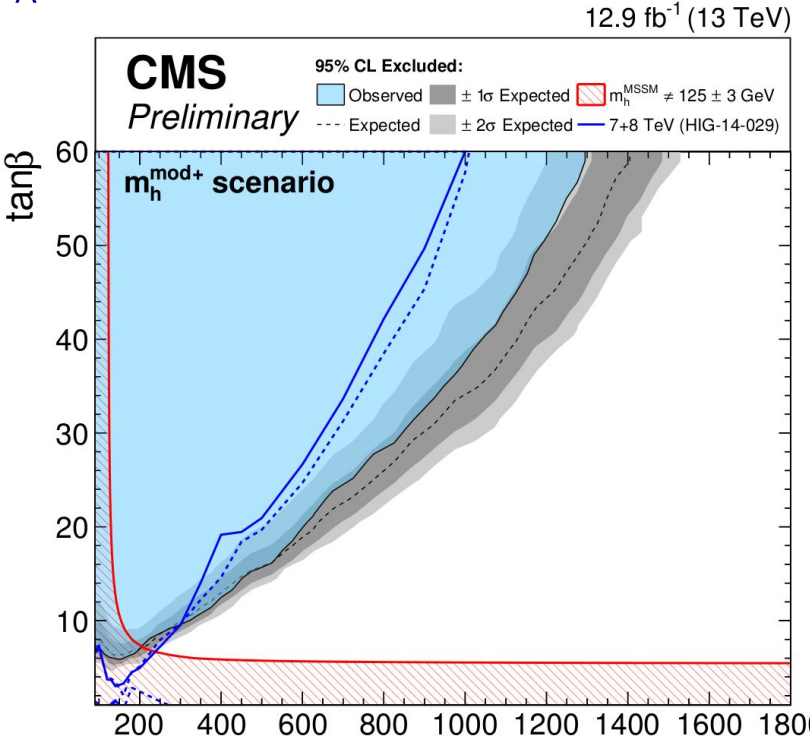
MSSM Higgs searches, $\Phi \to \tau\tau$

HIG-16-037

- ICHEP16 statistics (13 fb^{-1}), both gg$\to\Phi\to\tau\tau$ and bbbar$\to\Phi\to\tau\tau$ channels considered (down-type Higgs-fermion couplings enhanced at large tanβ).
- All tautau final states are exploited: e-mu, e-tau_h, mu-tau_h, tau_h tau_h. No excess observed. Backgrounds reduced using m_T and topological cuts.
- Two benchmark scenarios considered, driven by consistency with m_H=125 GeV. No excess observed. Improved limits with respect to Run1, particularly at high masses of the pseudoscalar Higgs boson m_A (by ~300 GeV at high tanβ).



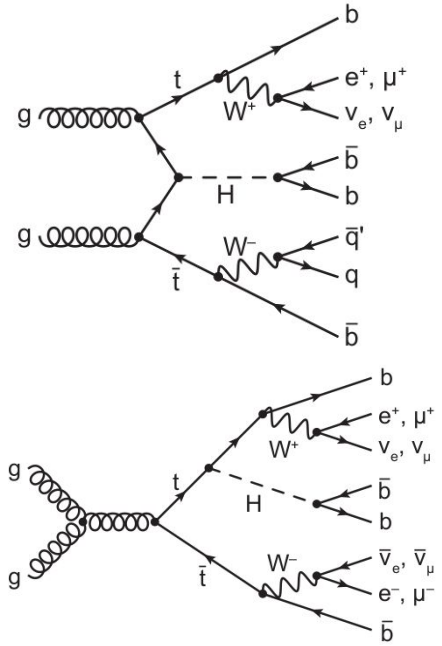


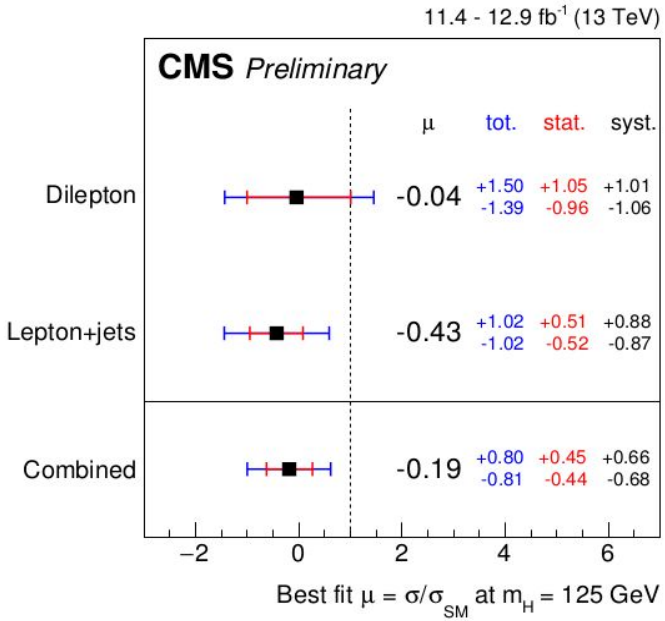


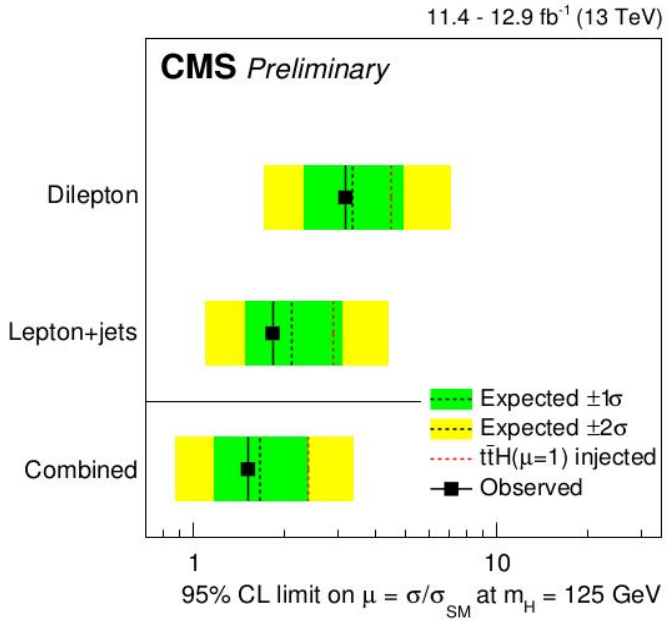
ttH search, H→bb channel

HIG-16-038

- ttH: key search in the Run2 Higgs physics program. Indications of slight excesses in previous 8 and 13 TeV analyses in ATLAS and CMS (but still consistent with SM)
- ICHEP16 statistics (13 fb^{-1}) , using 1-lepton and 2-lepton ttbar decays.
- BDT and matrix-element discriminators are used to separate signal from background (ttH vs tt+jets and ttH vs tt+bbbar, respectively). Several event categories with different number of jets and b-tagged jets are defined. Relevant sensitive variables in each category are b-tagging discriminants, invariant masses and other kinematic/angular properties.
- Observed (expected) limit: $\mu=\sigma/\sigma_{SM}$ <1.5 (1.7) at 95% CL, in agreement with SM.
- Systematics dominated: need better theory and/or new data-drive analysis methods to improve with full Run2 statistics





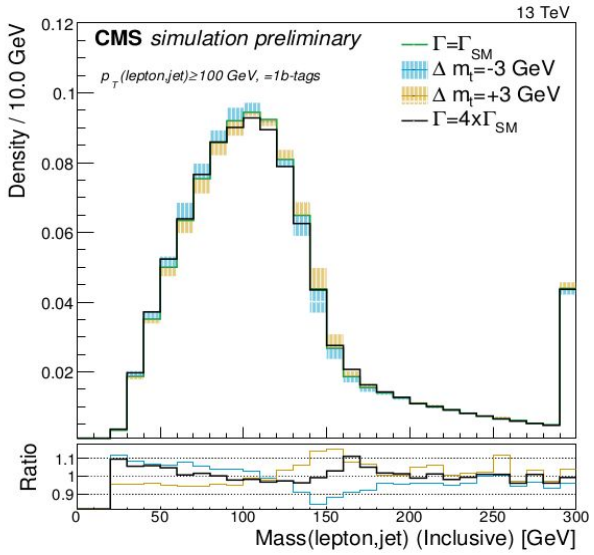


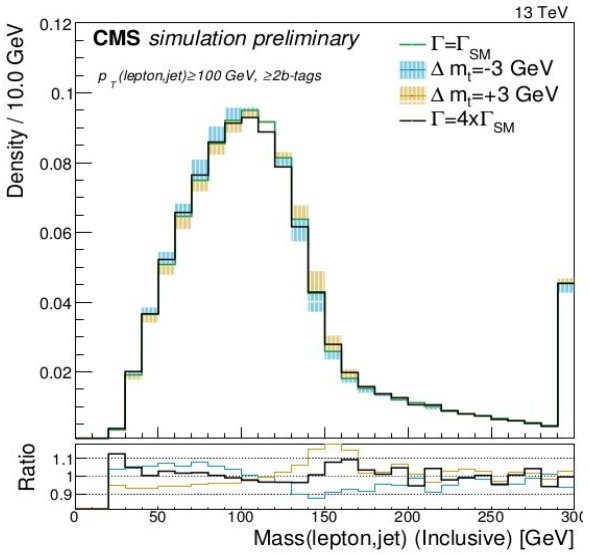
Top width measurement

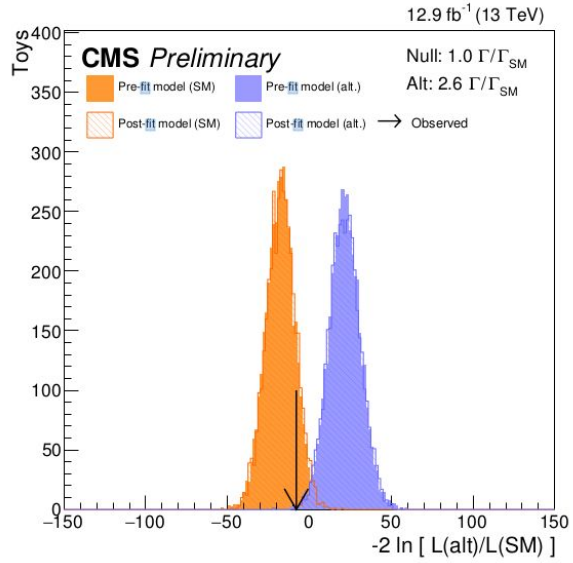
TOP-16-019

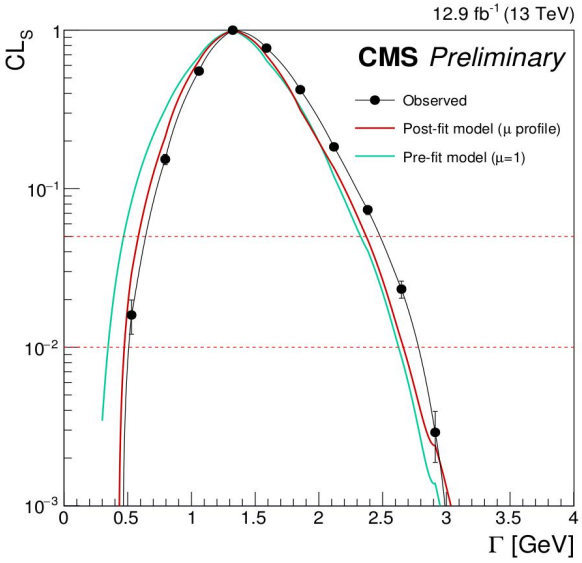
- **ICHEP16 statistics (13 fb^{-1}) , using 2-lepton+jet tW(b) final states and exploiting the sensitivity of the bl invariant mass observable**
- **Promising method, obviously depending on an accurate understanding of theoretical predictions (LO used for the description of decays)**
- **First direct measurement at LHC, most precise direct bound too. At 95% CL for m_t=172.5 GeV:**

$0.6<\Gamma_{top}<2.5$ GeV



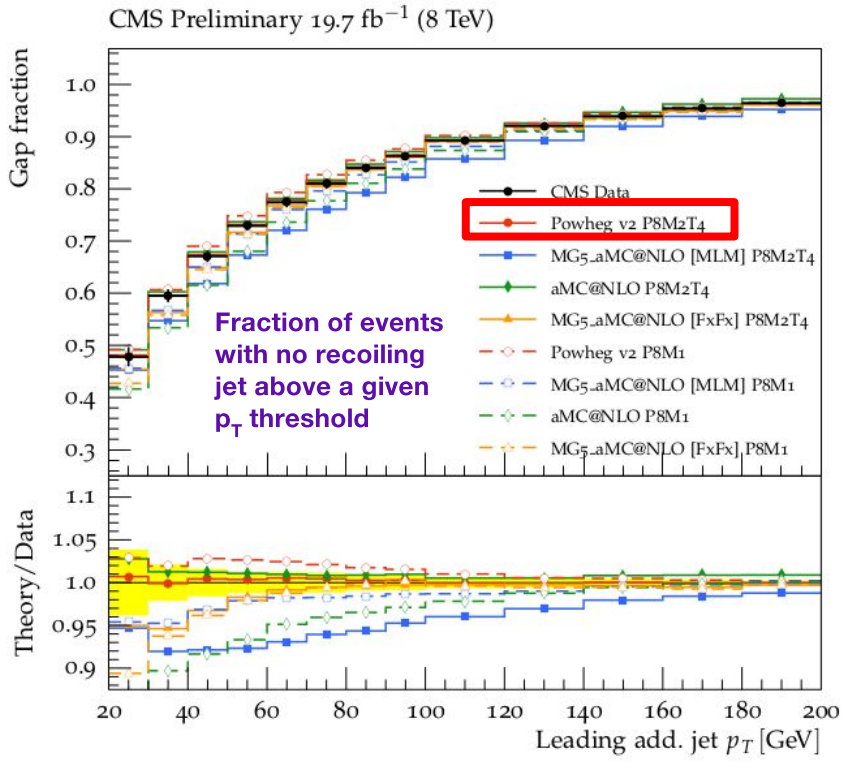


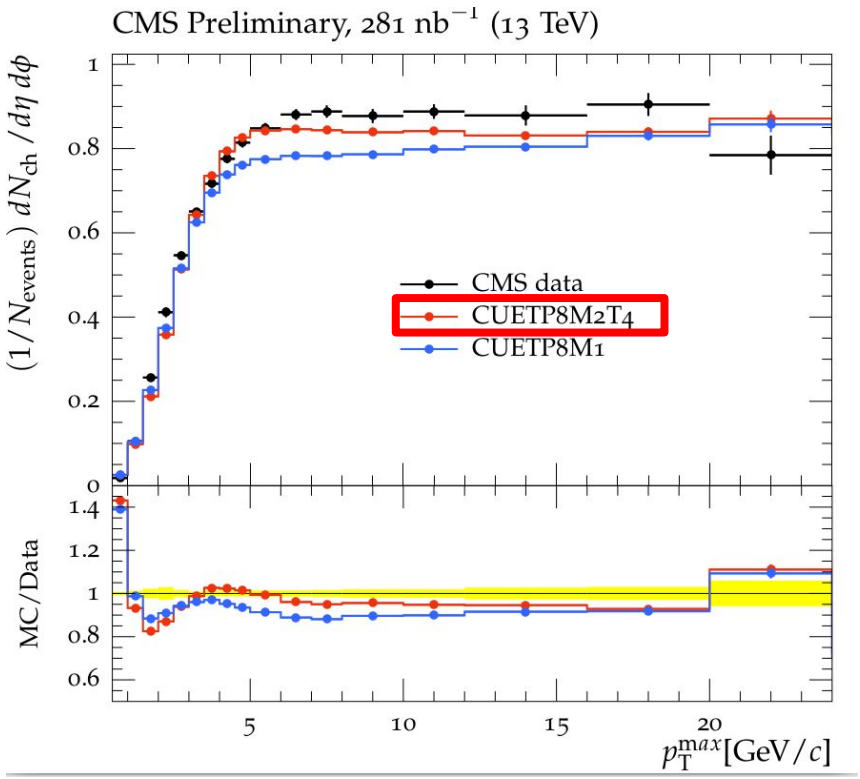




MC tuning and top pair production

- **Top distributions in dilepton+jets final states used to improve our tuning of the parton shower (mostly α_S^{ISR} default value in PYTHIA8)**
  - **Impact in the modelling of jet multiplicities and top pair recoil activity**
  - **No impact on global event observables, top kinematics (p_T, η, ...)**
- **New tuning CUETP8M2T4 derived, leading to better agreement in typical charged multiplicity distributions (right plot)**



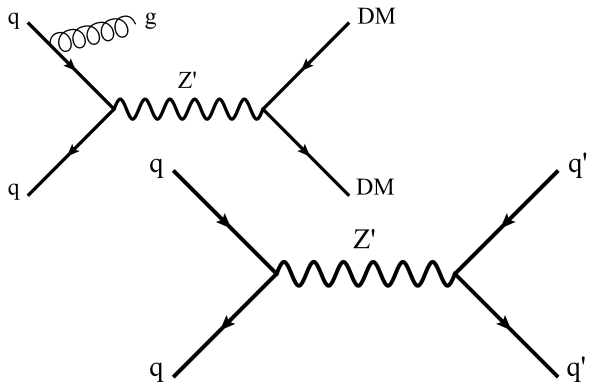


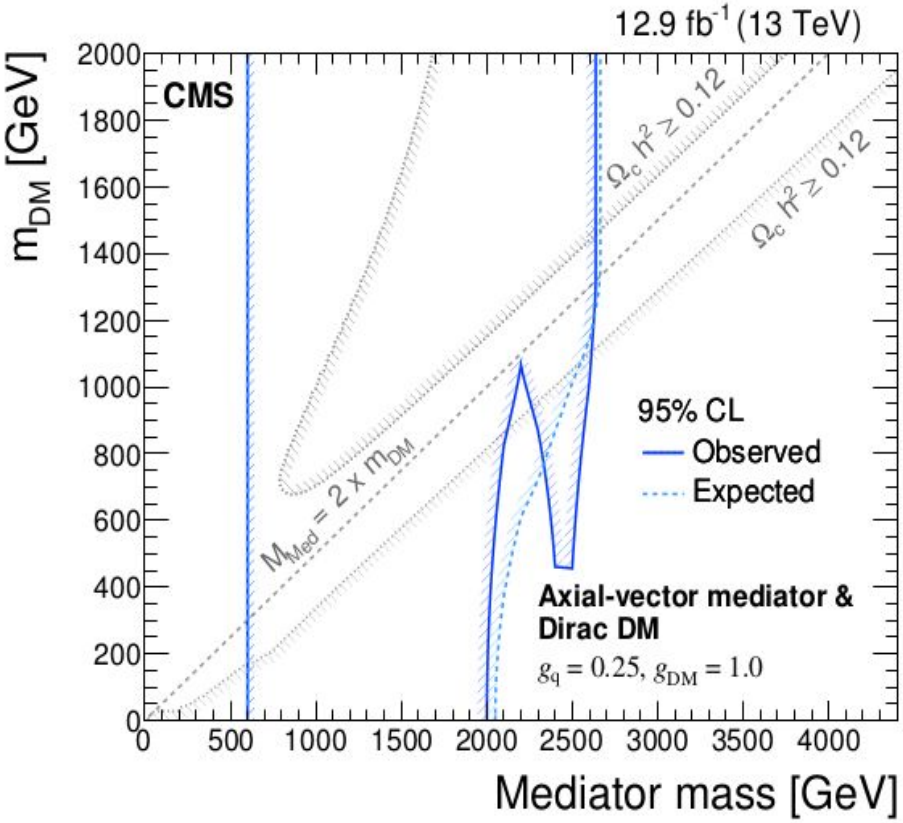
Searches for the 'dark' mediator

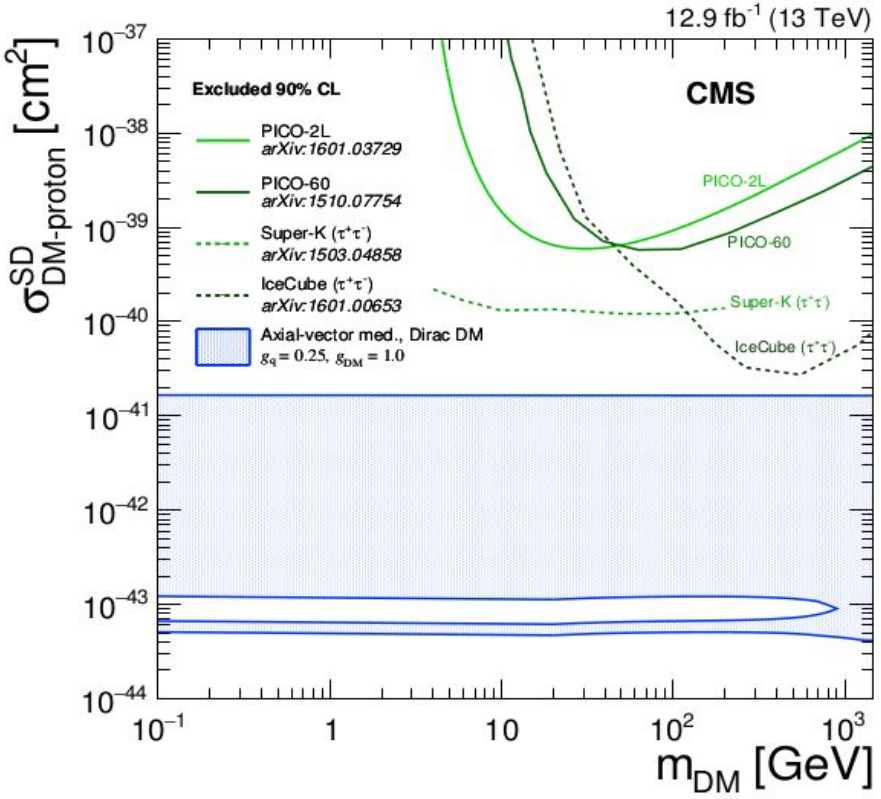
EXO-16-032

Dijet bump search completed with a search for dark matter mediators decaying into quarks:

- **More sensitive that pure dark matter searches in significant 'natural' regions of couplings in the 500 GeV -2 TeV range**



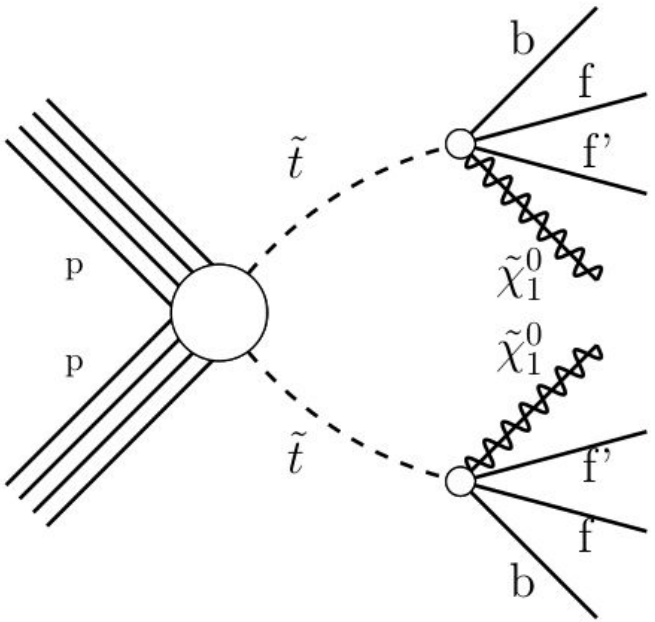


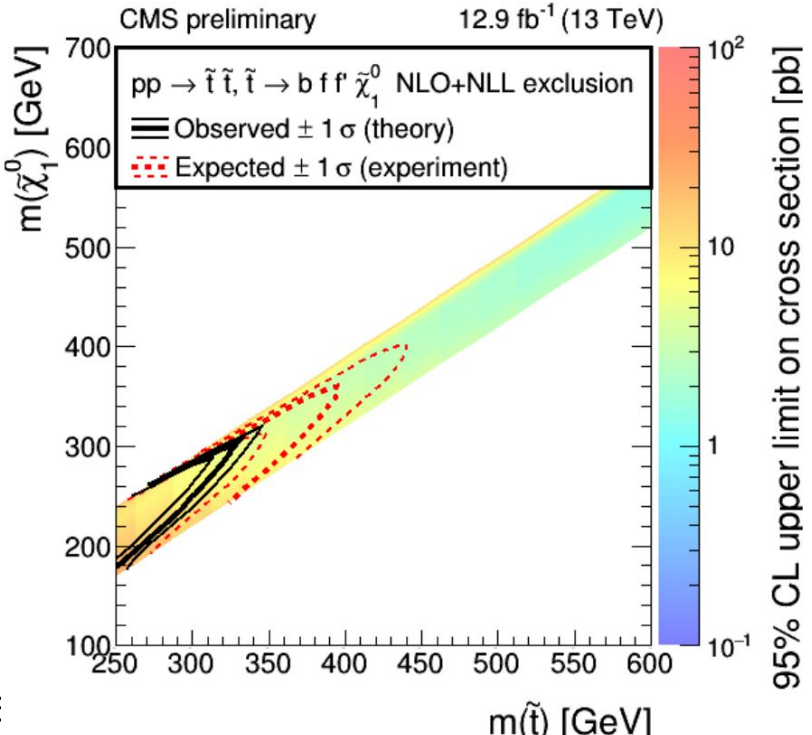


SUSY compressed scenarios

SUS-16-031

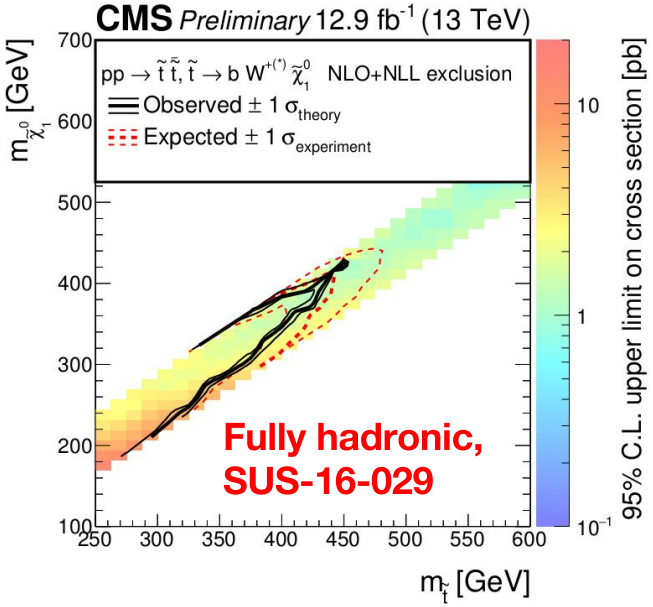
- Search for stops in very compressed scenarios: stop decays into 4-body LSP+b l+nu final states
- The analysis considers scenarios with m(stop)-m(LSP) below the W mass, with a “soft” lnu system coming from “off-shell W” decays.
- Final states with low-p_T leptons and an energetic ISR jet producing sizeable MET are the target. No excess is found in 13 fb^{-1} (2016). Sensitivity is similar to other CMS compressed analyses at 13 TeV.
- Paving the path towards more sensitive SUSY searches with larger statistics, trying to close all “natural” gaps

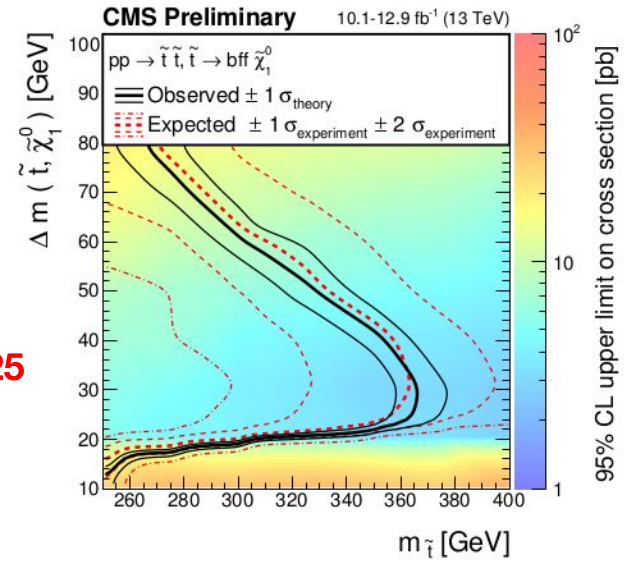




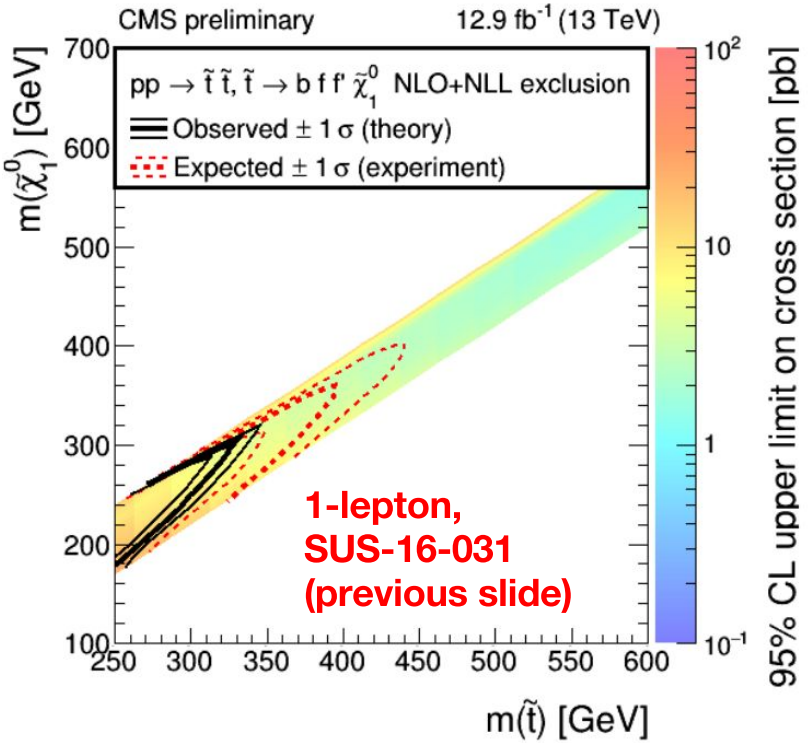
SUSY compressed scenarios

SUS-16-031
SUS-16-025
SUS-16-029





Dileptons,
SUS-16-025



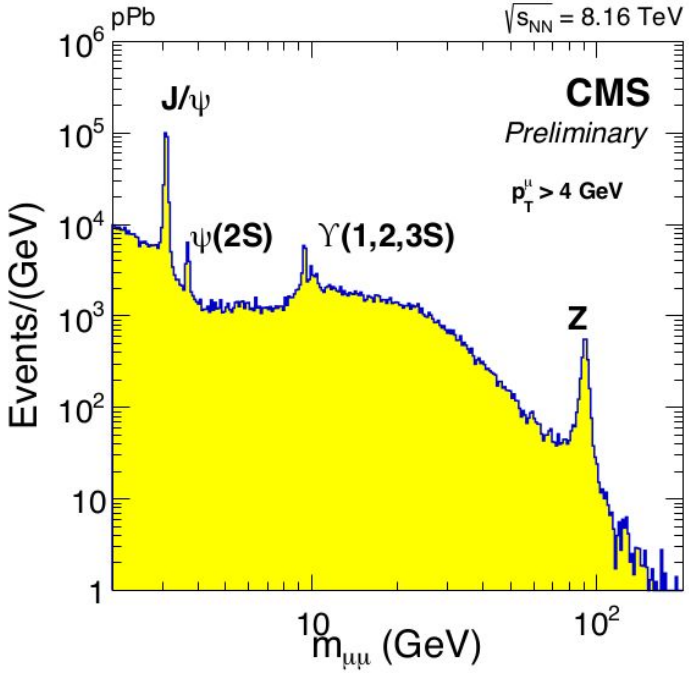
Results from p Pb running

2016 p Pb running

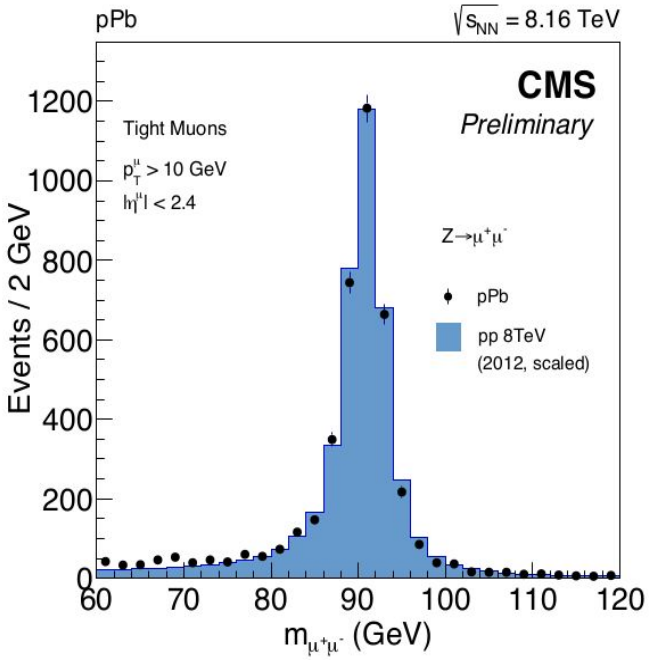
DP-2016/072

- Strong start&end of data-taking at 5.02 TeV center-of-mass
  - 830M minimum bias events
- Strong start at 8.16 TeV center-of-mass
  - Surpasses the 2013 collected luminosity in ~2 days, 100 nb^{-1} target reached
- Nice performance “out-of-the-box”:

$\mu^+\mu^-$ invariant mass spectrum



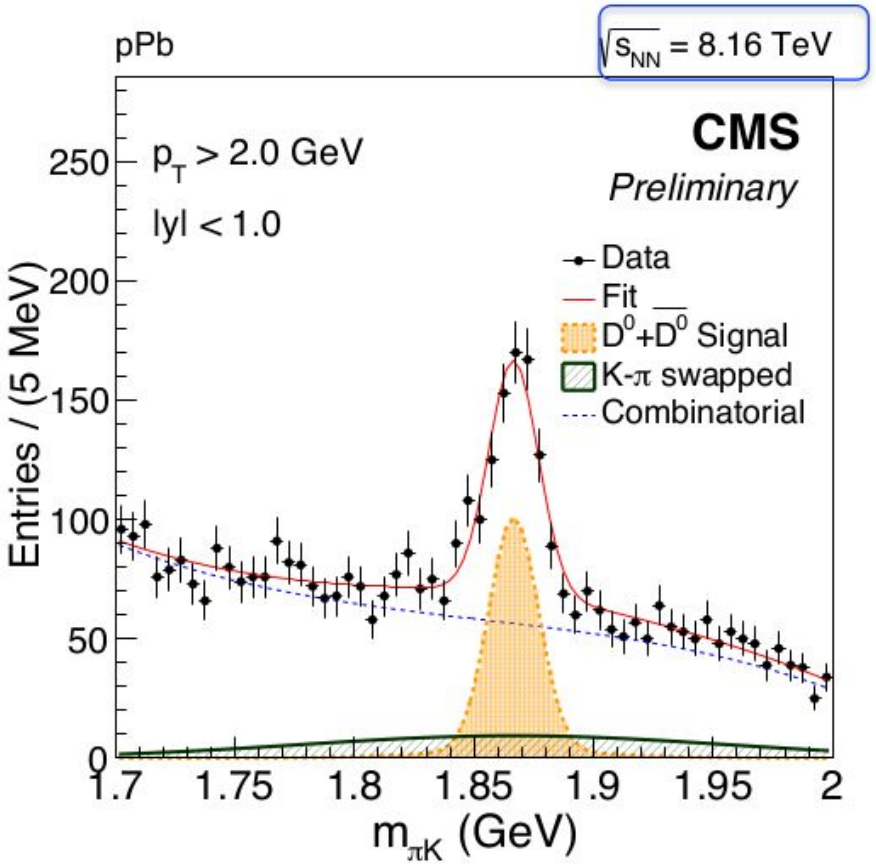
$Z \rightarrow \mu^+\mu^-$ invariant-mass spectrum



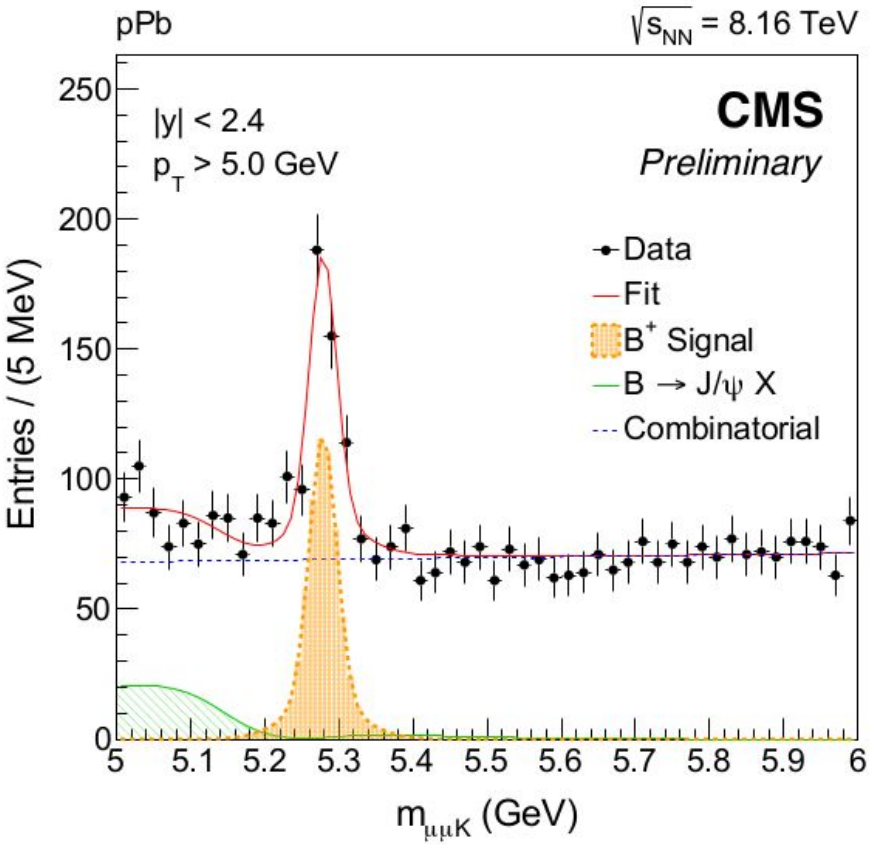
2016 p Pb running: meson identification

DP-2016/072

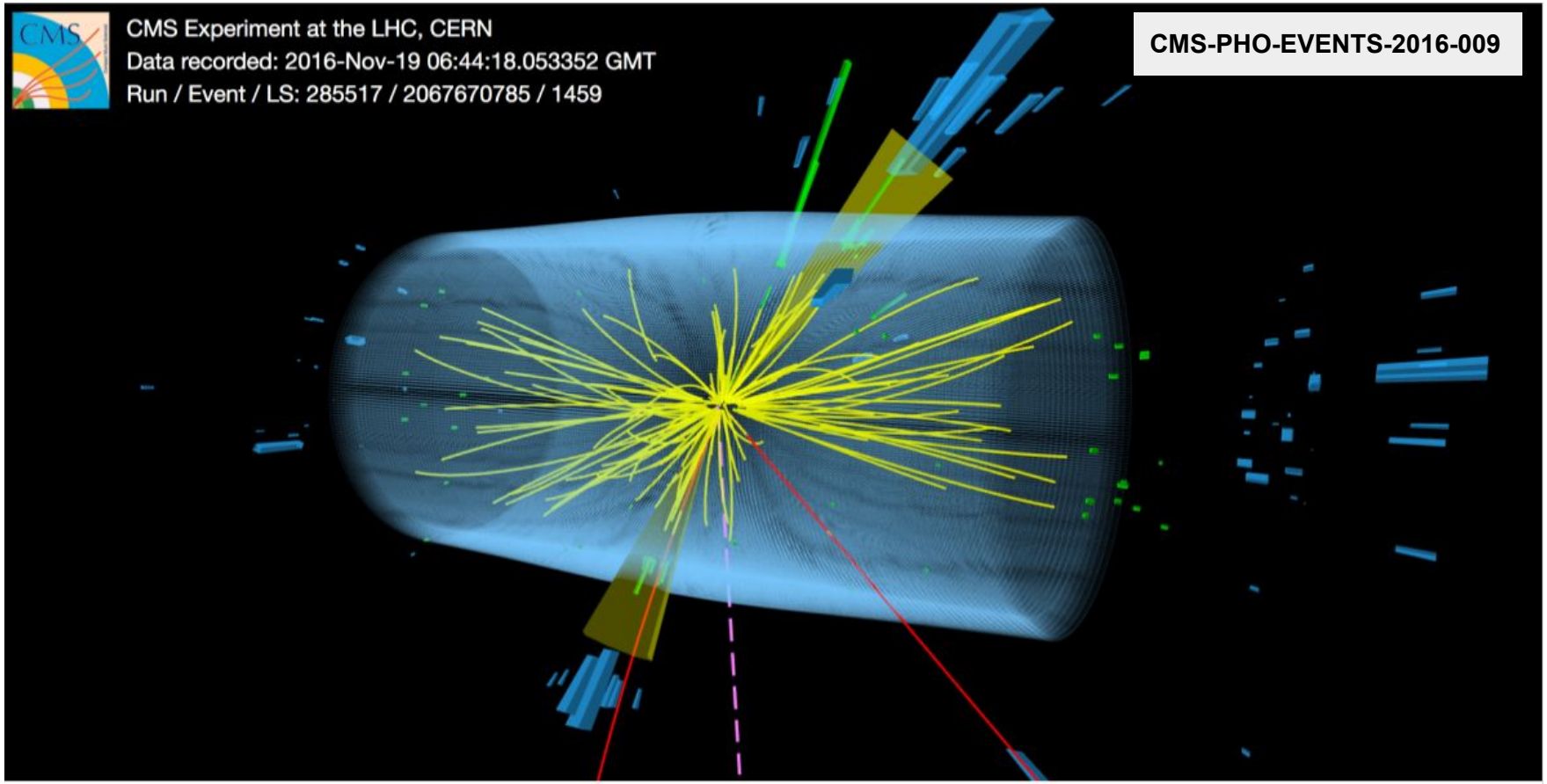
$D^0 \rightarrow \pi K$ invariant-mass spectrum



$B \rightarrow J/\psi K$ invariant-mass spectrum



2016 p Pb running: first ttbar candidate!



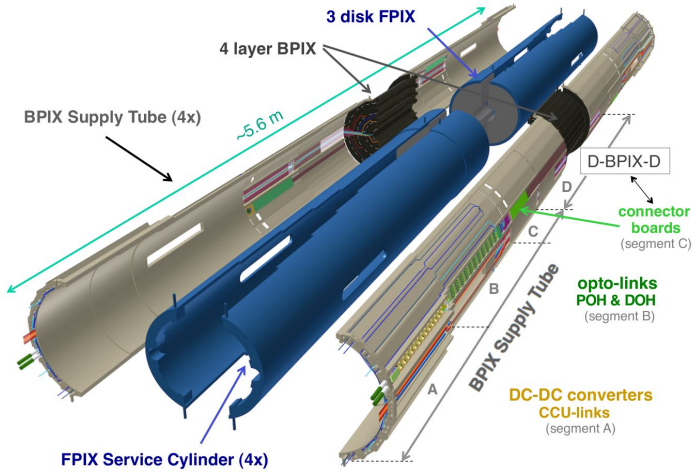
- ak4PFJetsCHS:
  - E_{T1} = 104 GeV, eta1 = 0.7, phi1 = 1.27, csvV2 = 0.995
  - E_{T2} = 87 GeV, eta2 =-0.2, phi2 =-2.05, csvV2 = 0.983
- Global muons:
  - (muon1) p_{T1} = 89 GeV, eta1 = 1.1, phi1 = -2.1
  - (part of jet) p_{T2} = 14 GeV, eta2 =-0.2, phi2 = -2.0
- Electron:
  - p_T = 91 GeV, eta = 0.1, phi = 1.
- MET:
  - p_T = 49 GeV, phi = -1.54

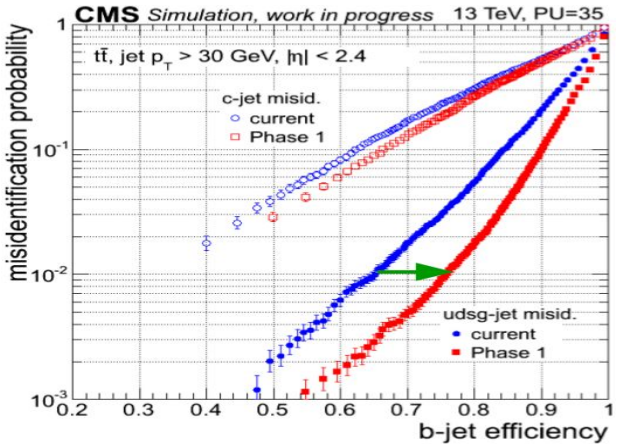
m_T(muon1, electron,jets, MET) = 418.74 GeV

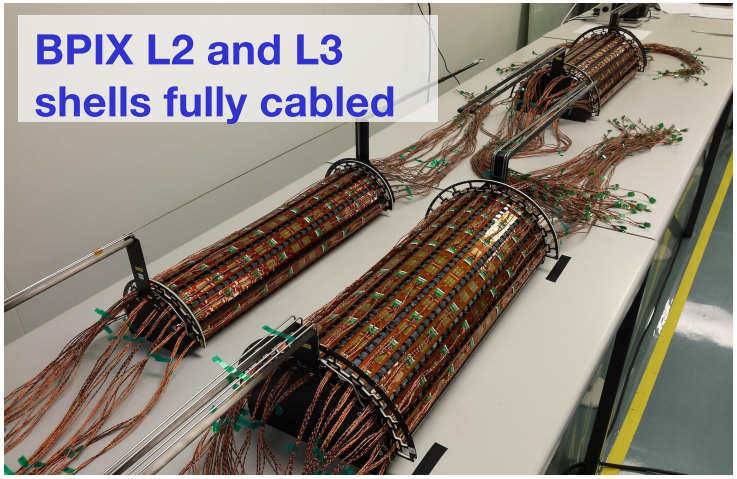
Work towards 2017

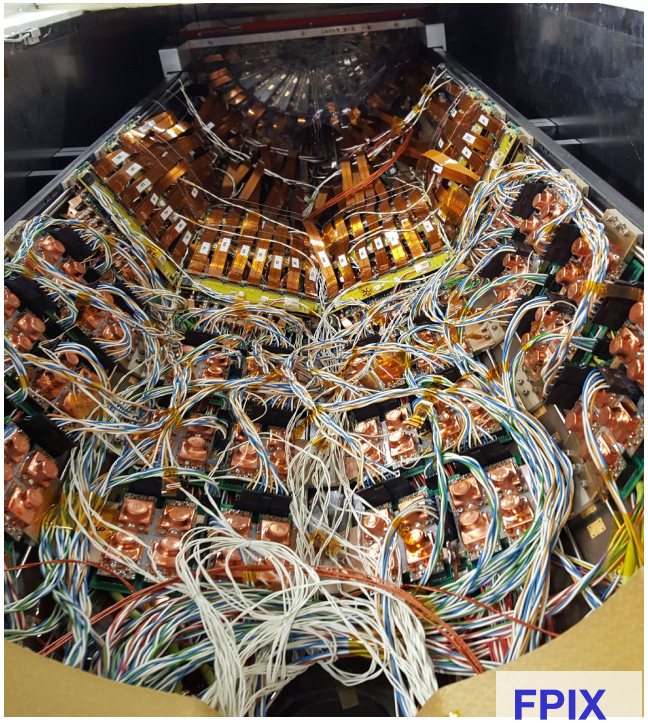
New Pixel Detector

- **Barrel pixel: all layers fully assembled and tested OK**
  - **Merging started, 2/4 Supply Tube quadrants ready and tested OK**
- **Forward pixel: complete detector at CERN**
  - **All four half-shells fully assembled, and under final testing (3/4 fully tested)**



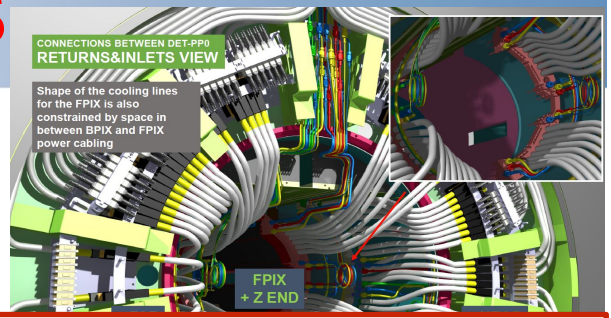




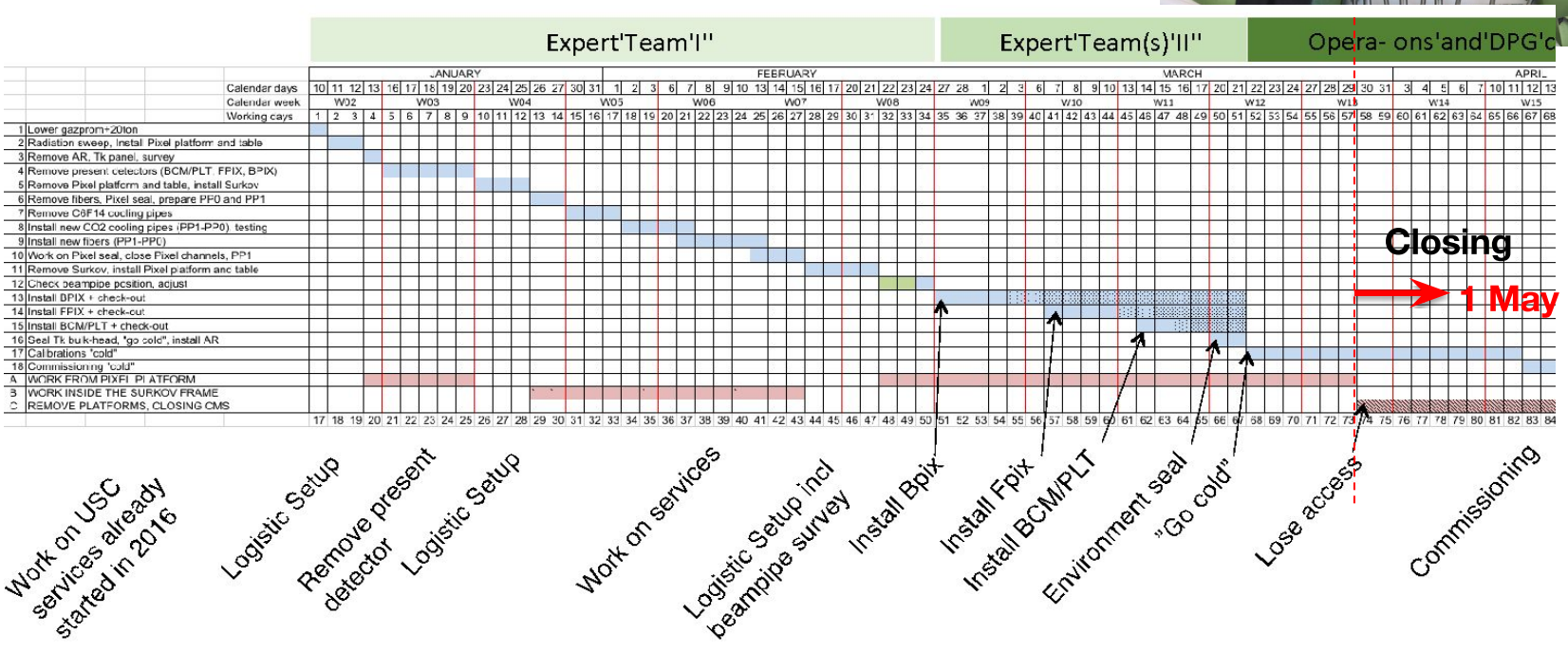


Pixel tracker upgrade in EYETS

- General strategy is:
  1. Power and DAQ installation (Dec & Jan)
  2. Open detector and install “work platforms”
  3. Extract present detector
  4. Setup for working on services (install special frame)
  5. Work on services
     - remove old fibers and cooling pipes, install new
  6. Remove frame & setup work platforms for installation
  7. **Installation and check-out of the new detector**
  8. Seal and “go cold”
  9. Commissioning
  10. Remove work platforms and close detector

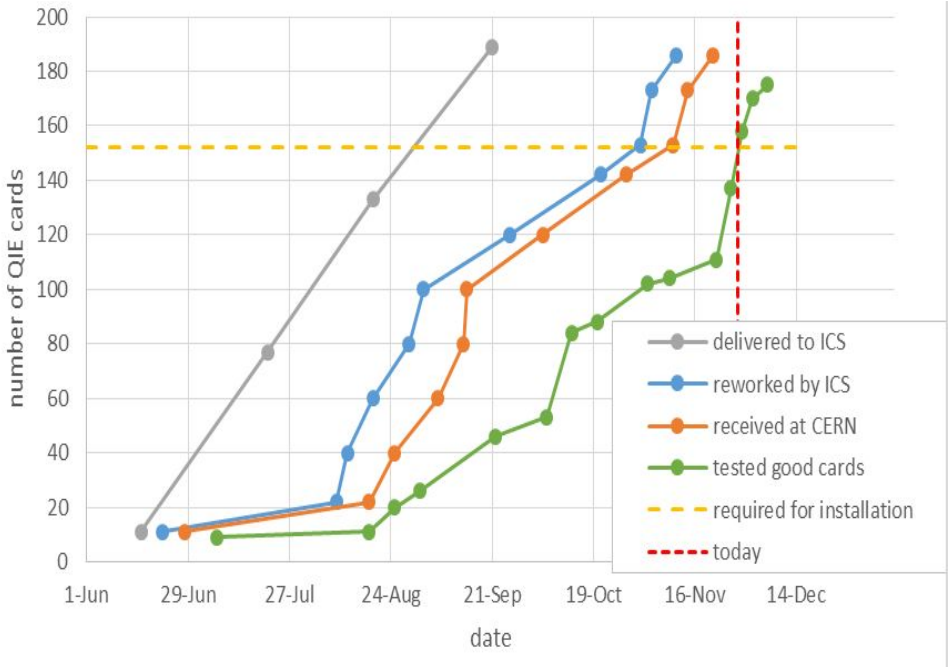


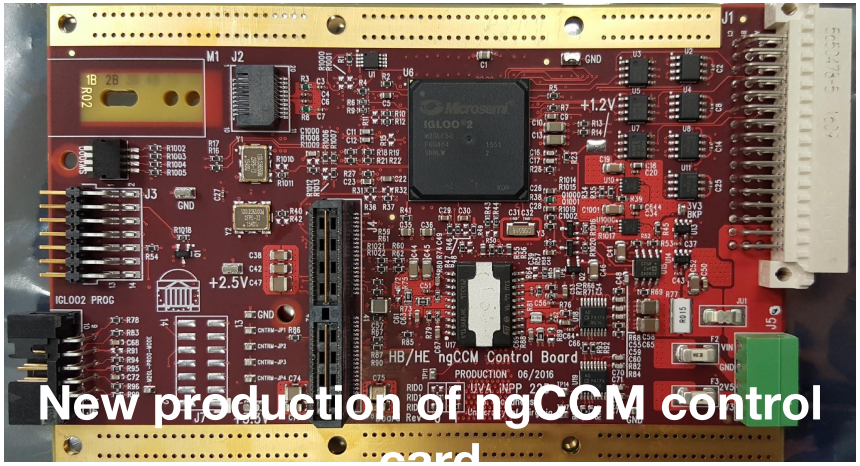
All in 3D CAD and tested on mockups



HCAL Phase1 Upgrade (in shadow of pixel upgrade)

- **HF upgrade:**
  - Preparation for the HF Phase I Upgrade is approaching completion for EYETS installation
  - The rework of the front-end cards (to replace the 2015 version of the QIE10 chips with the 2016 version) is almost completed
  - Burn-in of currently available cards proceeds without any failures: completion by Dec 15th
- **HE upgrade:**
  - Assembly of the Readout Modules (RM) is completed
  - Burn-in of first 72 RMs completed
  - Very good progress on firmware development
  - A manufacturing problem affected the ngCCM production (new generation Clock and Control Module):
    - Problem understood; second production in progress, in time for installation in EYETS

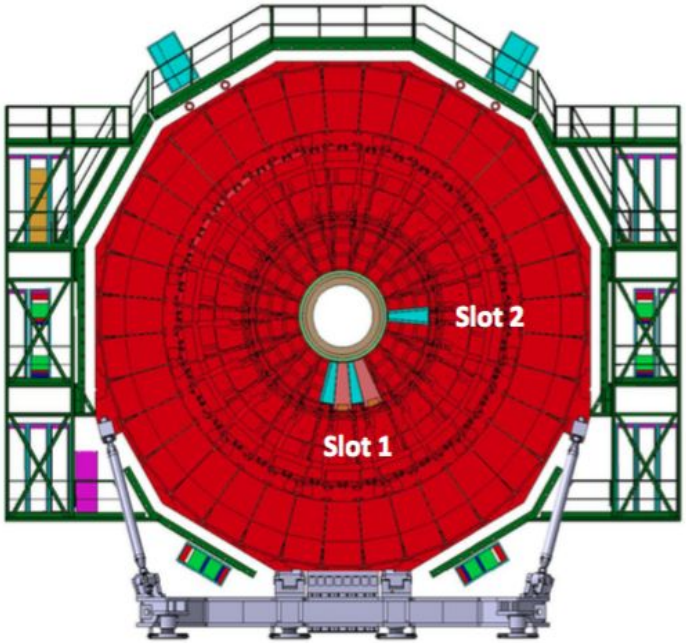




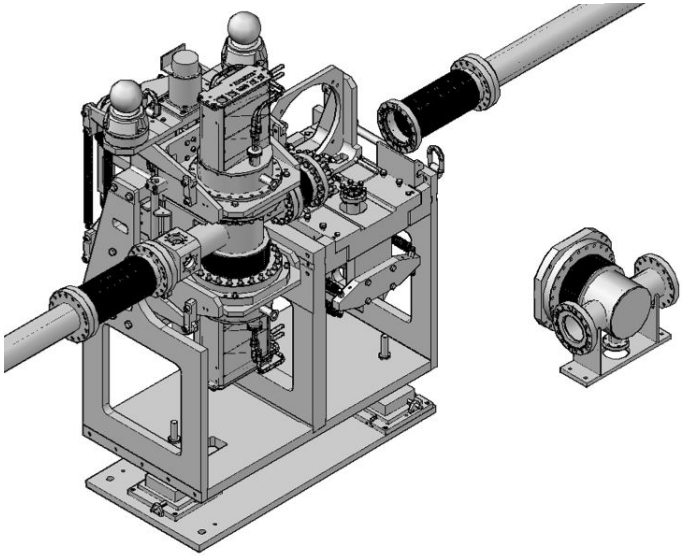
New production of ngCCM control

GEM chambers in 2017, CT-PPS upgrades

- 5 GEM super-chambers (2 layers each) covering 40° and 10° will be installed on the YE-1 endcap disk during EYETS



- Installation of new Roman Pot (RP) Pixel (RPIX) detector packages & timing detectors
- Upgrade of RPs at 220 m for operation of RPIX detectors at high luminosity



Main goals of the test:

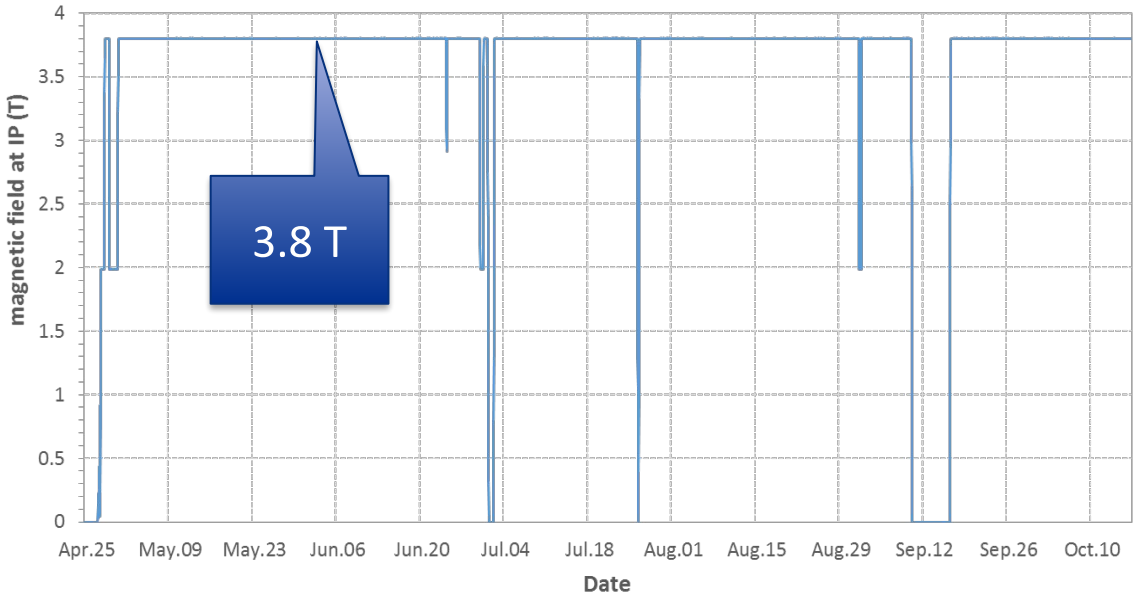
1. Gain installation and integration experience
2. Reduce the commissioning period in LS2
3. Trigger commissioning
4. Study chamber and electronics performance under realistic background conditions

Summary & Outlook

- **Extraordinary delivered luminosity in 2016 (many thanks from CMS to LHC teams!)**
- **Smooth data-taking and performance of the CMS detector in 2016, despite all challenges (trigger/electronic changes, increases in luminosity and pileup, …)**
- **Excellent physics performance in 2016. All collected data already reprocessed with the best available calibrations and alignment. Realistic MC being produced now**
  - **Change of phase in CMS physics strategies: significant increase in sensitivity requires more precise simulations and ultimate performances in data**
  - **First bunch of physics results with full 2016 statistics expected for Winter 2017 conferences**
- **Exciting and promising first results from the p Pb collisions at 8 TeV**
- **Phase 1 upgrades planned during EYETS on track**

Backup

Performance of Cold Box for CMS Solenoid



April 29 – CERN-wide power glitch cut at P8. CB re-connexion at 2T

June 24 – Power glitch. Cooling water pumps stopped. Ramp down to 2.9T

June 30 – power glitch. CB stopped. CB re-connexion at 2T

July 1st – 3rd turbine membrane replaced. Cryo PLC com issue. Ramp down to zero.

July 26 - Full stop of demineralized cooling pumps. Busbar circuit OFF. Magnet SD

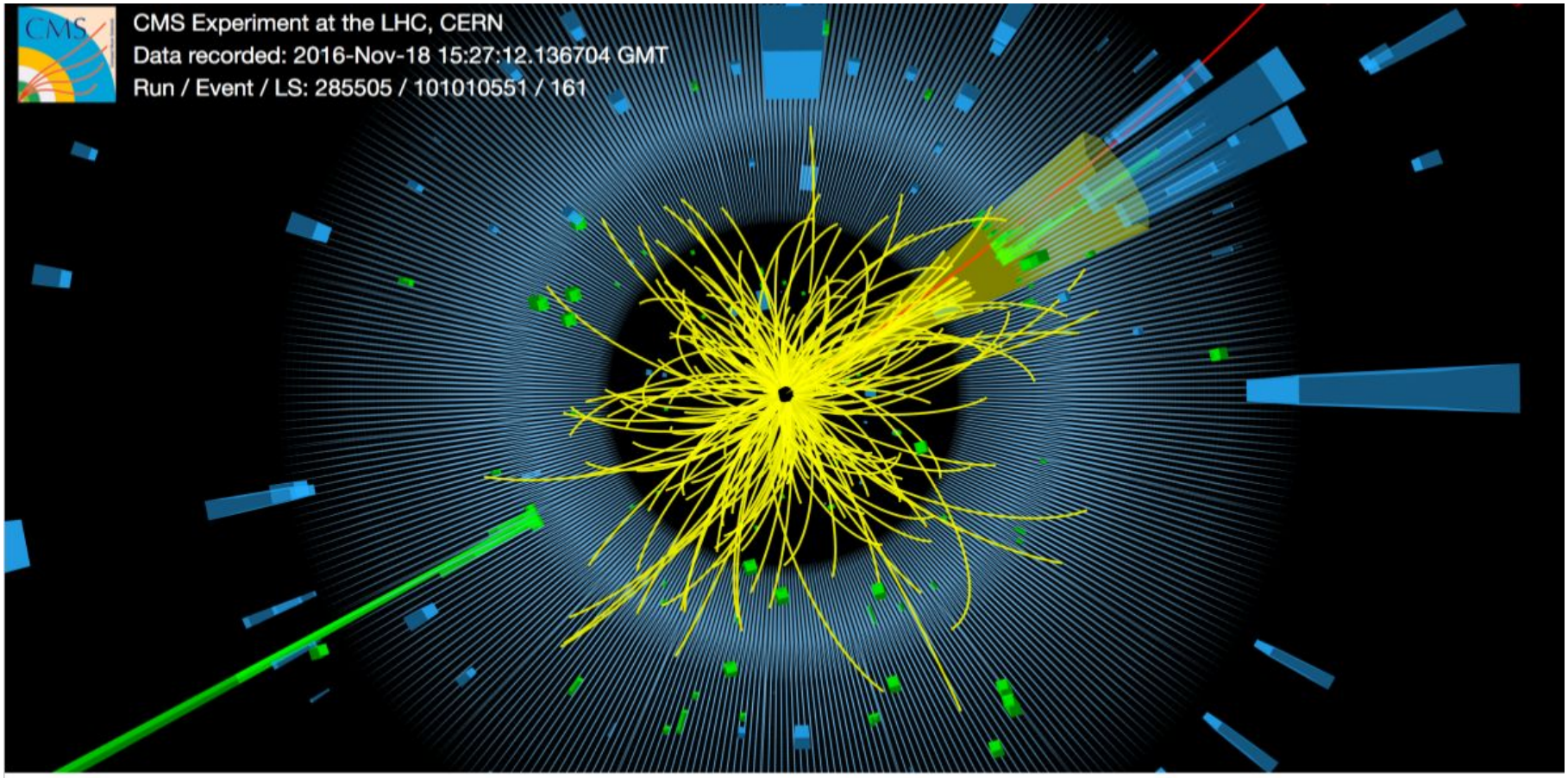
Sept. 1st - Cryo PLC com issue. CB re-connexion at 2T

Sept. 12 - TS2. 3rd turbine membrane replaced.

COLD BOX performed beautifully

- Repair/refurbishment plan succeeded
- No clogging of the adsorbers and turbines filters in the cold box.
- NO regenerations necessary in 2016!

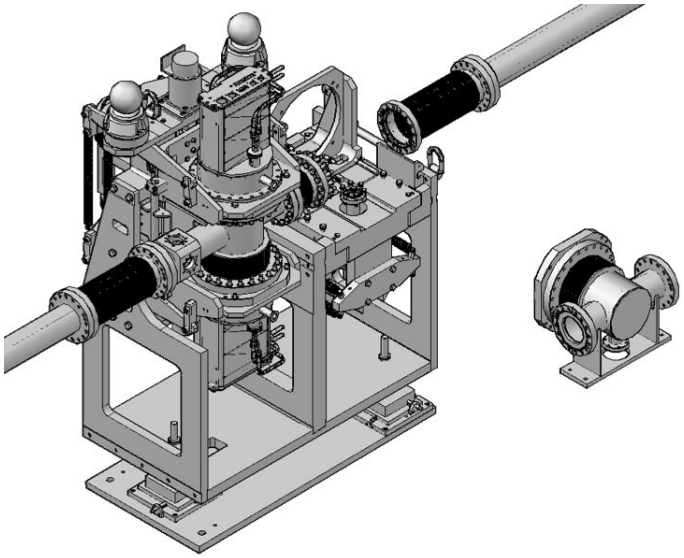
2016 p Pb running: photon + b-jet

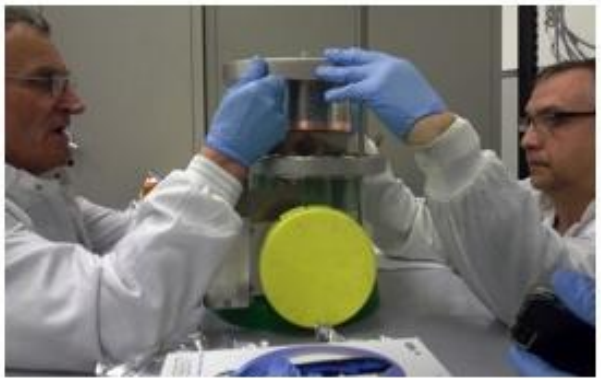


- gedPhotons:
  - E_T = 208 GeV, eta = 0.4, phi = -3.0
- ak4PFJetsCHS:
  - E_T=246GeV, eta = 0.07, phi = 0.3, csvV2 = 0.995
- Global muon:
  - p_{T1} = 18 GeV, eta1 =0.05, phi1 = 0.3

dPhi(photon,b-jet) = 3.02

CT-PPS upgrades during EYETS





Upgrade of Roman Pots at 220 m for operation of RPIX detectors at High Luminosity

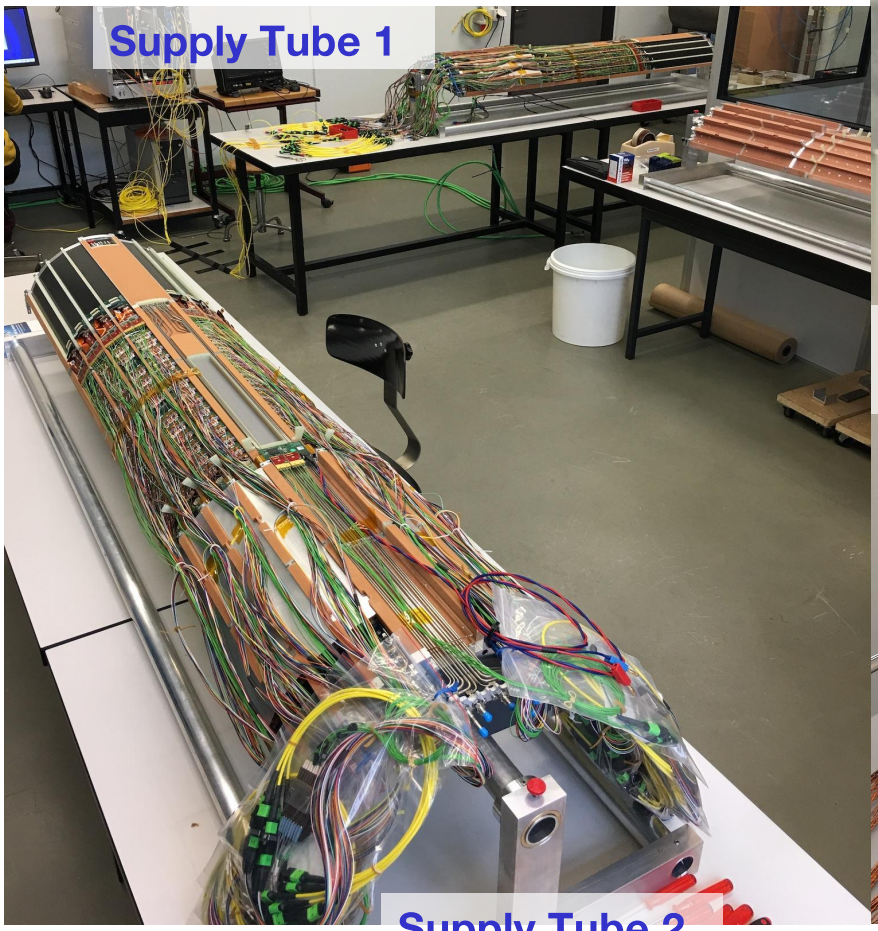
- exchange ferrites & install RF shields in RP220 far
- separate the vacuum and cooling of the tracking and timing detectors for independent pressure/temperature operation points.

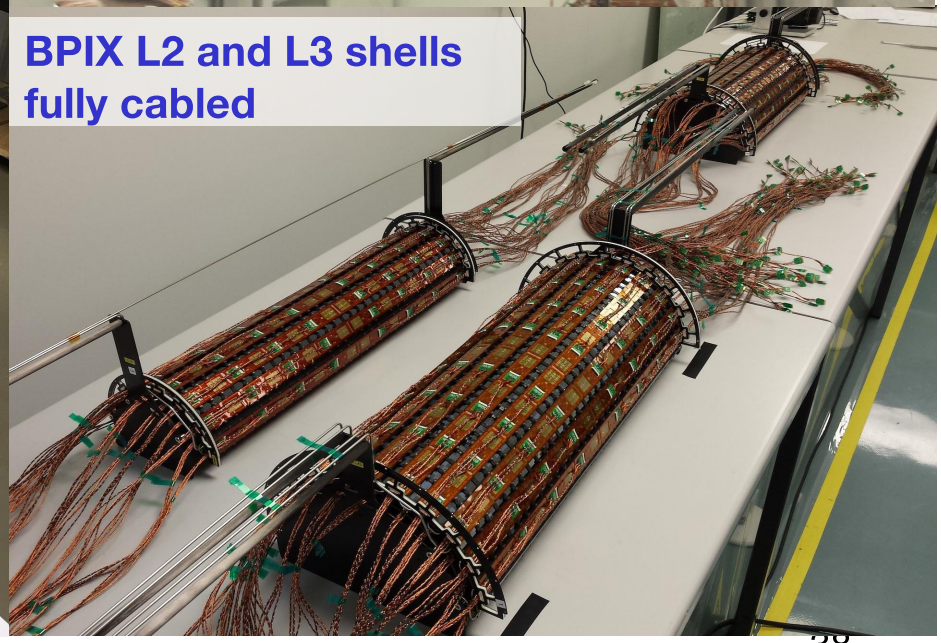
Installation of new CT-PPS detectors

- installation of RPIX detector packages
- integration of one layer of UFSD timing detectors in Cylindrical RPs

New Pixel Detector: Barrel

All layers fully assembled and tested OK. Merging started
2/4 Supply Tube quadrants ready and tested OK

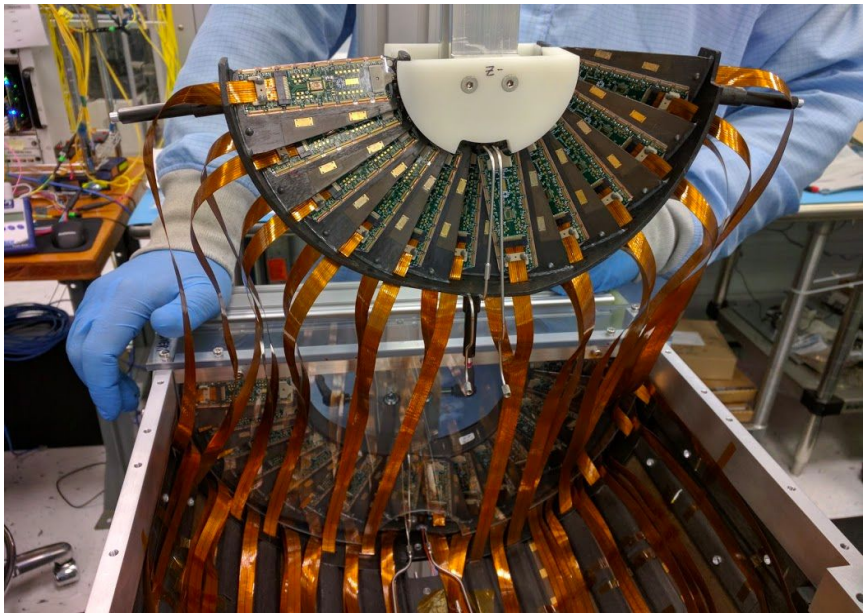


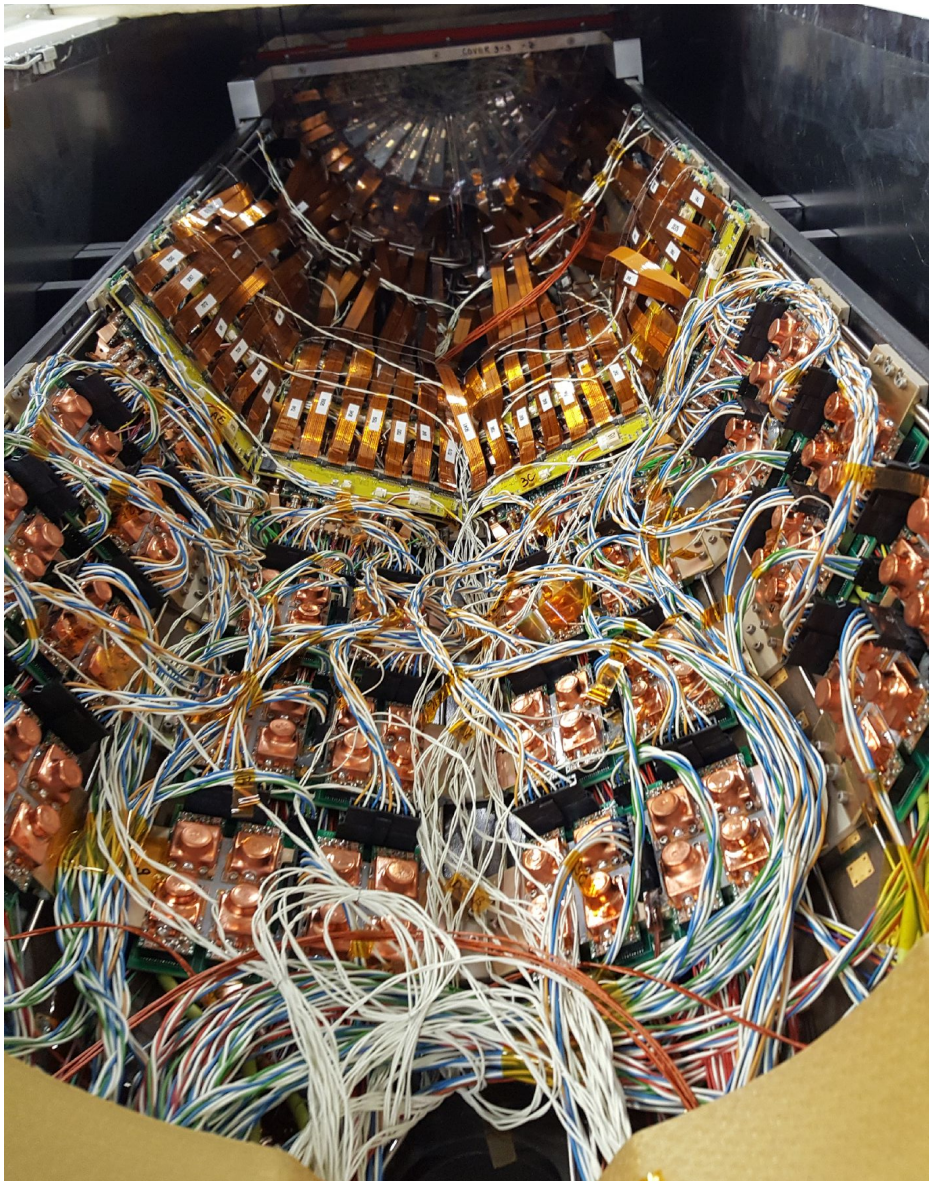


New Pixel Detector: Forward

Complete FPIX detector at CERN

All four half-shells fully assembled, and under final testing (3/4 fully tested)

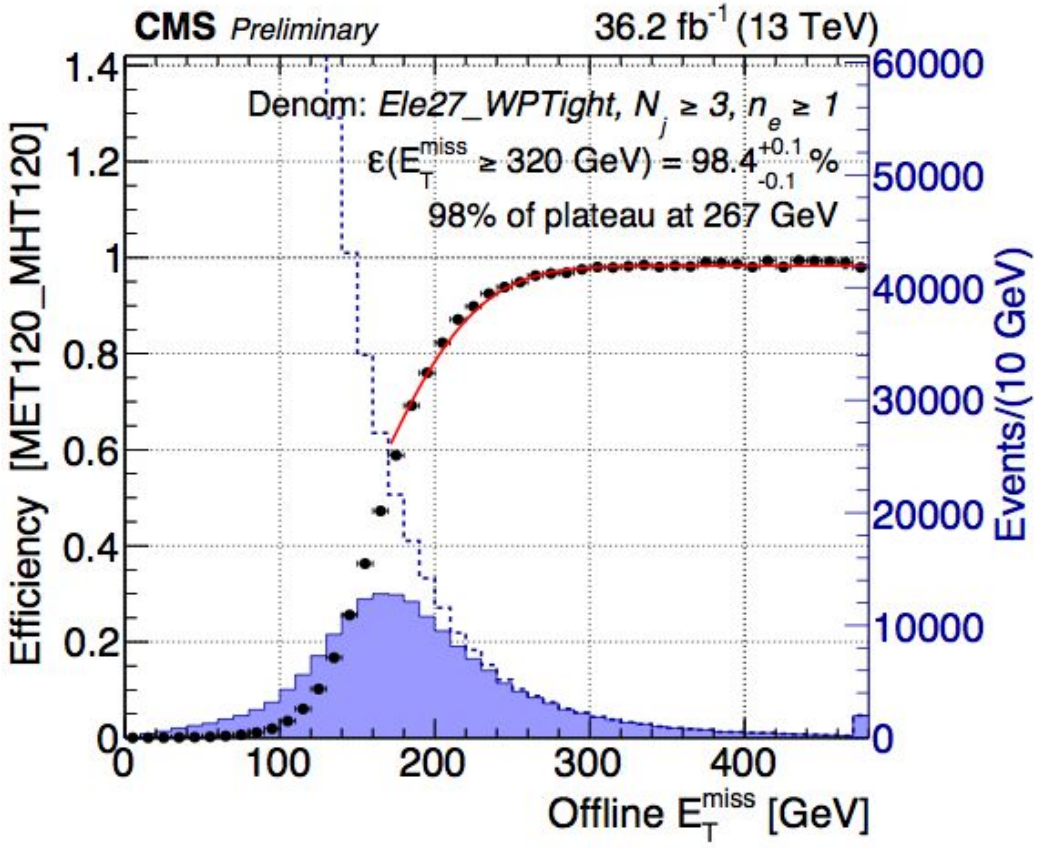




Reconstructed Physics objects

HLT example: missing energy triggers

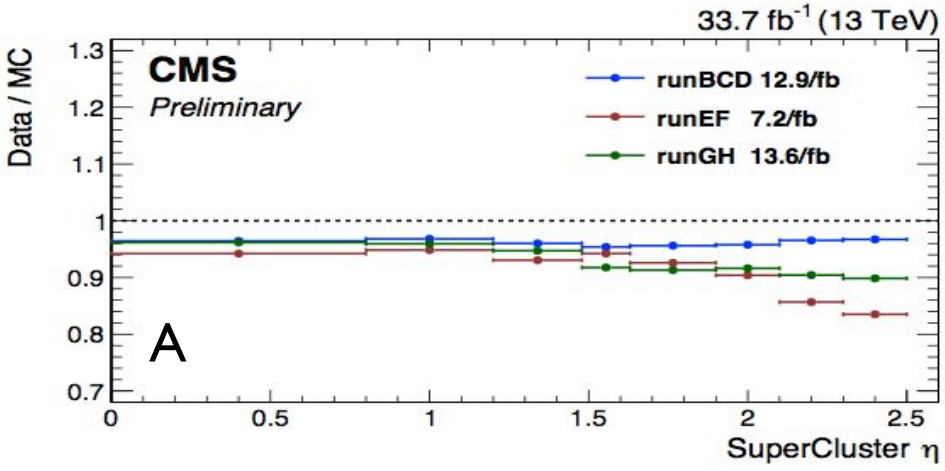
Main paths for SUSY and dark matter searches in fully hadronic final states

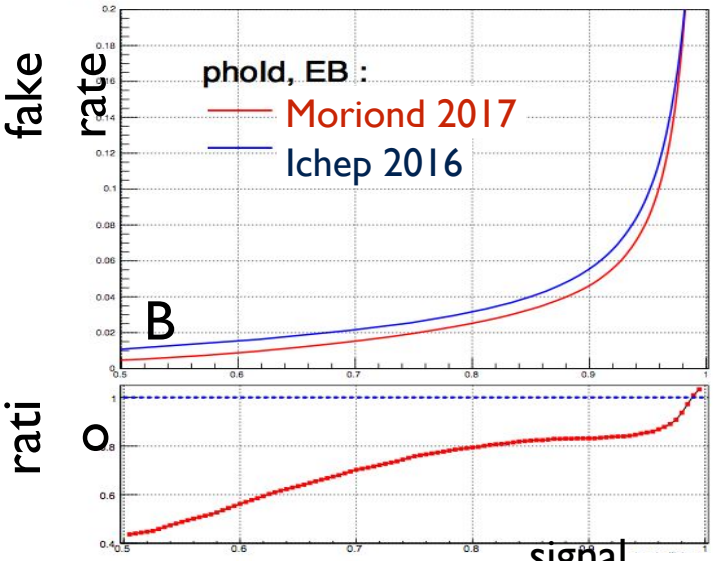


Efficiency for the path HLT_PFMET120_PFMHT120:

- Missing transverse energy cut at HLT (using all particles and using jets) of 120 GeV
- Measured with respect to single-electron triggered events
- Turn-on curve as a function of offline Particle Flow Missing transverse energy
- Histograms correspond to the number of total and accepted events

Electrons and photons

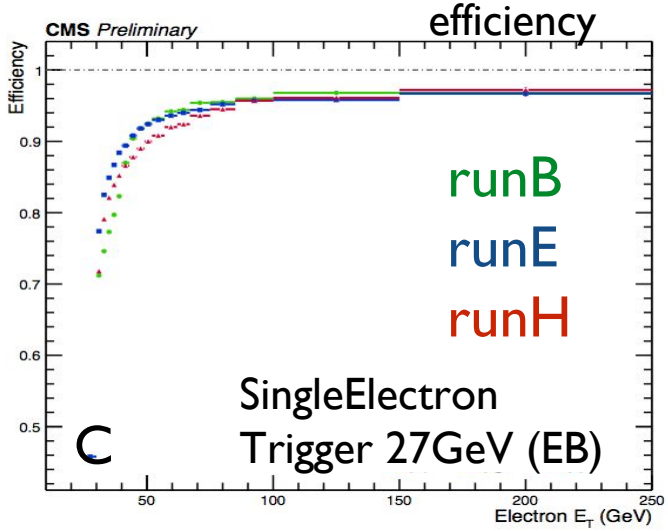




A. Data/MC efficiency ratio for the electron identification over 2016: stable in EB while in EE sensitive to crystal transparency loss

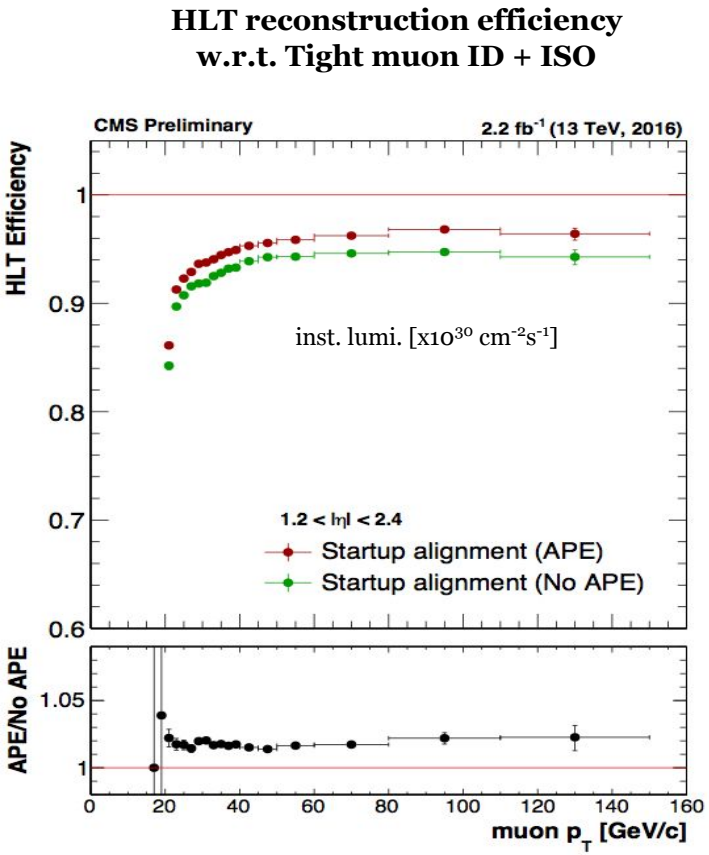
B. New photon identification in EB with better usage of detector conditions over 2016

C. Single Electron trigger efficiency is stable over 2016 (Ecal Barrel)



Muon reconstruction

- Impact of the deployment of the muon alignment position errors in reconstruction was studied in 2016 start-up data:
  - up to ~5% of HLT efficiency increase in the endcap thanks to the gain in resolution on tracks in muon spectrometer (CMS endcaps opened during 2015 EOY shutdown)
  - in offline reconstruction, track hit pattern and quality made closer to what obtained with an asymptotic alignment

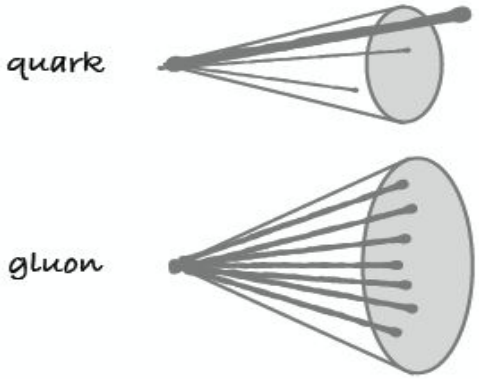


Quark-Gluon Discriminator

CMS-DP-2016-070

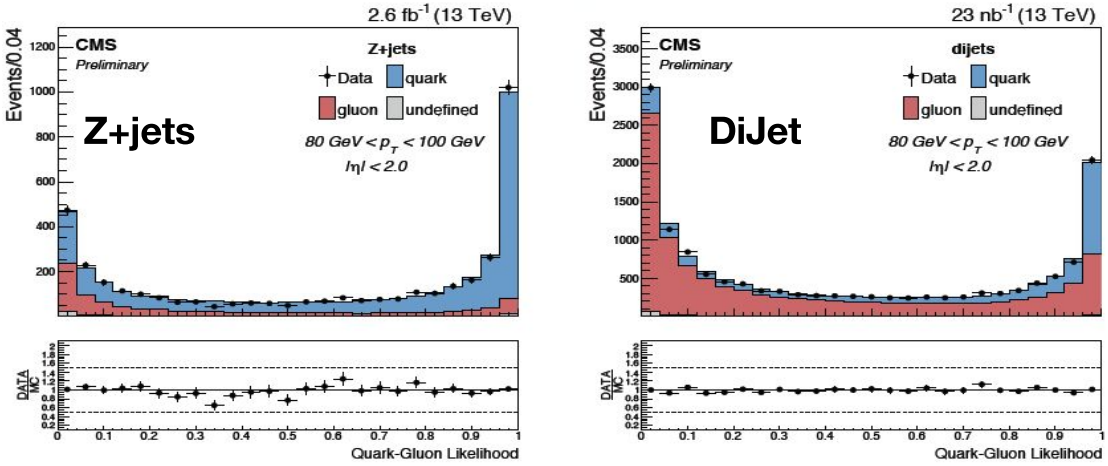
Jets from light quarks ≠ jets from gluons

- The particle multiplicity is higher in gluon jets is higher than quark jets.
- The fragmentation function of gluon jets is considerably softer than that of a quark jet.
- Gluon jets are less collimated than quark jets.

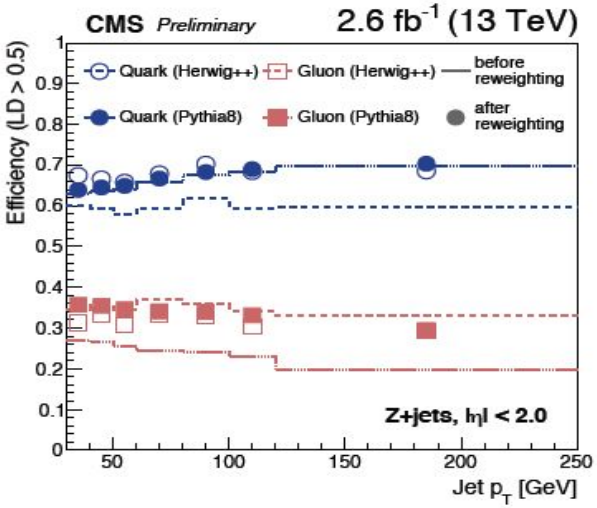


Construct a discriminator based on multiplicity, and -log(σ_2) where σ_2 is the ellipse minor axis.

$$p_T D = \frac{\sqrt{\Sigma_i p_{T,i}^2}}{\Sigma_i p_{T,i}}$$



Quark-Gluon Likelihood (LD)



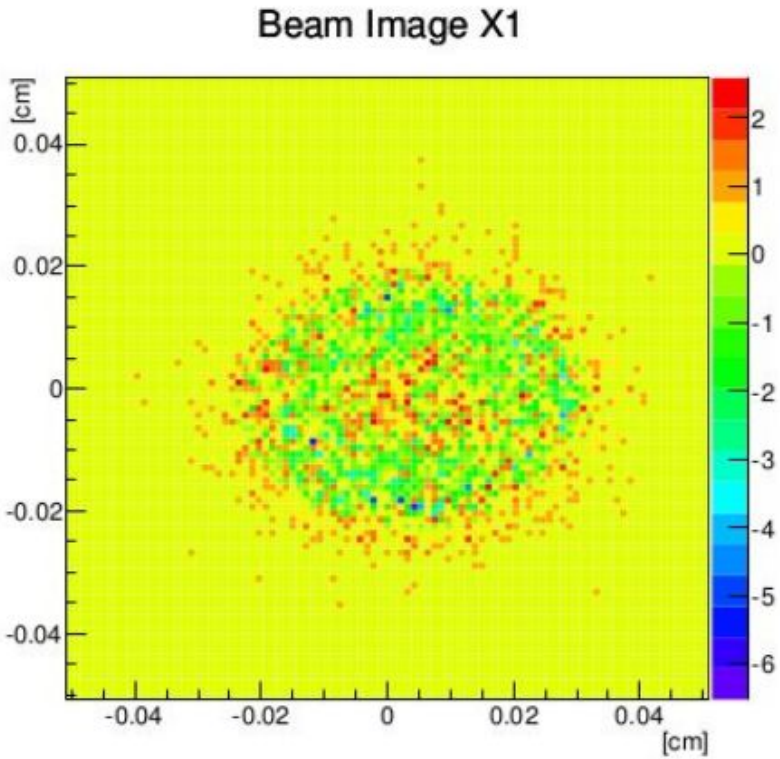
Tagging Eff. (LD>0.5)

Other CMS Recent Physics Results

Precise luminosity for Heavy Ions

LUM-16-001

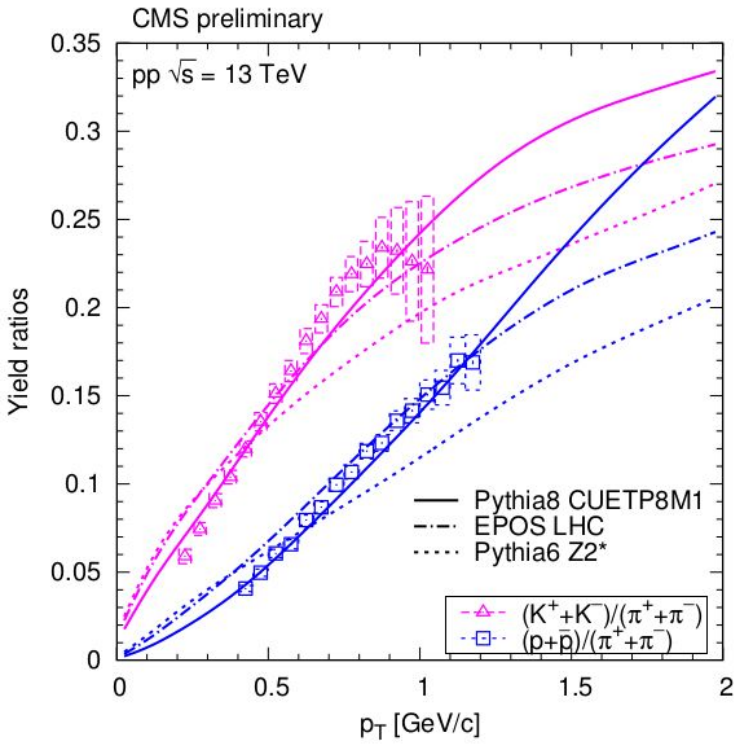
- **Reference luminosity for our HIN 2015 analyses, with a 2.3% relative precision!**
- **Plot: pull distribution of a 2D beam scan with respect to a two-dimensional Gaussian beam model reference, which is used to search for potential XY correlation effects. They are the dominant source of systematics (1.5%)**

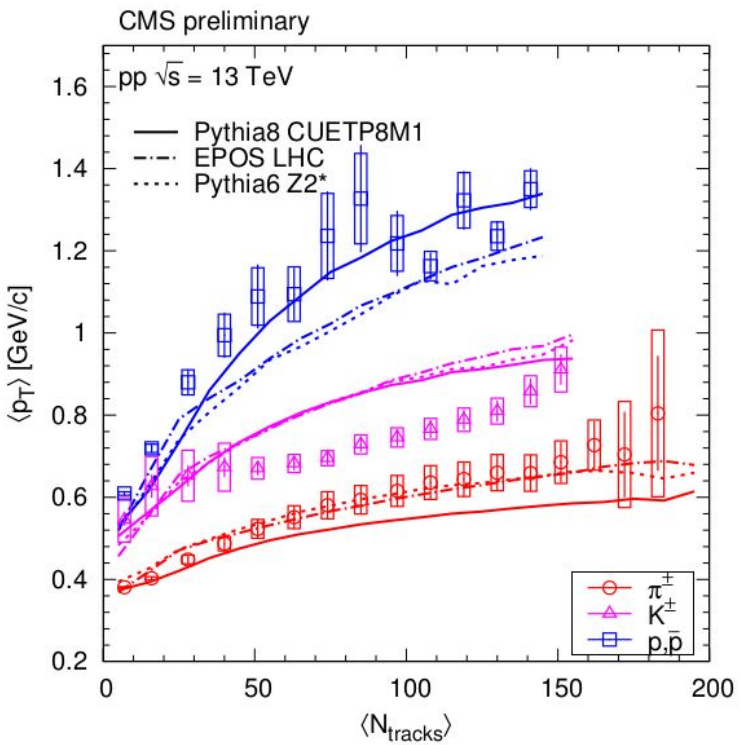


	Systematic	correction (%)	uncertainty (%)
Integration	Stability	-	1
	type 1/2	7	1
	CMS deadtime	-	0.5
	Dynamic Inefficiency	-	0.4
Normalization	XY-Correlations	-	1.5
	Beam current calibration	-	0.3
	Ghosts and satellites	1.8	0.2
	Length scale	1	0.15
	Orbit Drift	-	0.4
	Beam-beam deflection	1	0.2
	Dynamic-β	-	0.5
	Total		2.3

FSQ and MC tuning

- Detailed measurement of rates for different types of charged particles (pions, kaons, protons) as a function of track multiplicity and transverse momentum, compared with various MC predictions
- Acceptable agreement with our reference tune CUTEP8M1 in most phase space regions; EPOS LHC also give reasonable results
- These data are precious input for further tuning and understanding of non-perturbative effects in hadron collisions.

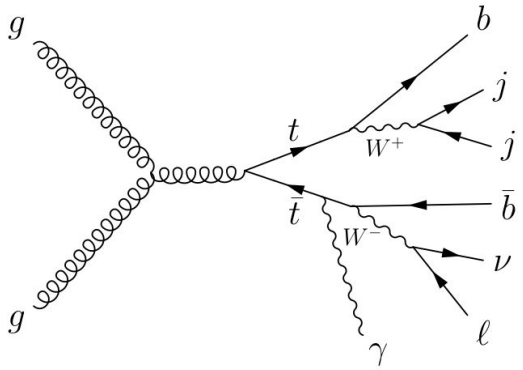


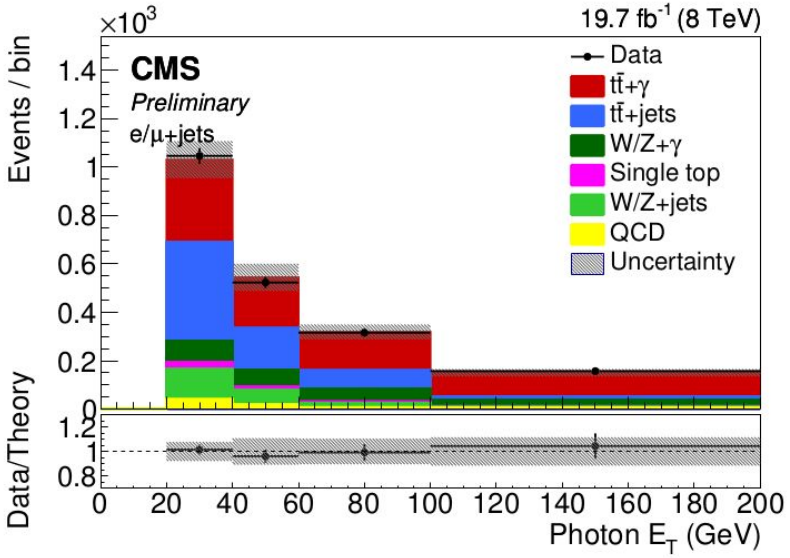


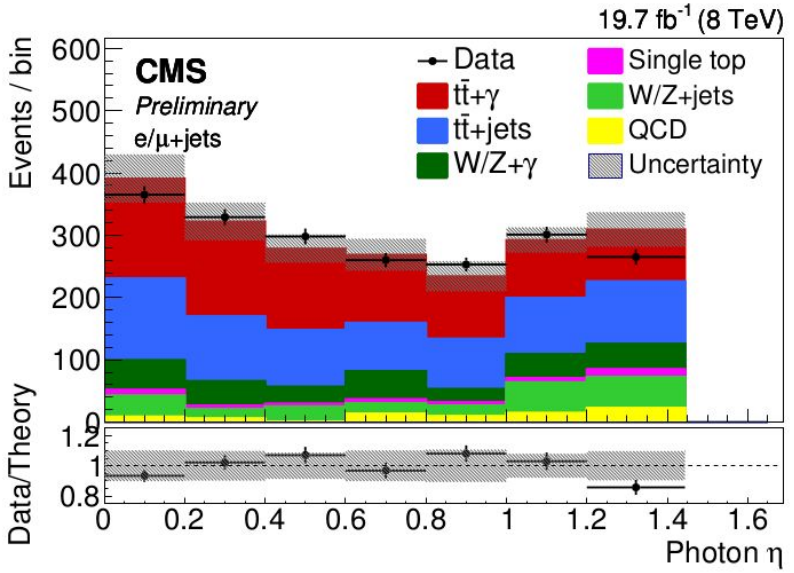
Measurement of ttγ cross sections

TOP-14-008

- 8 TeV measurement with ~20% uncertainty for photons with E_T>25 GeV:
  - $R = \sigma(tt+\gamma) / \sigma(tt) = (5.2 \pm 1.1) \times 10 - 4$
- Particularly sensitive to the charge of the top quark and deviations associated to it (anomalous dipole moment, exotic quarks "top-like" with different charge
- Differential distributions also studied as a function of photon E_T and photon pseudo-rapidity
- Improvements expected at 13 TeV (current measurement dominated by statistical uncertainties: ~15%)



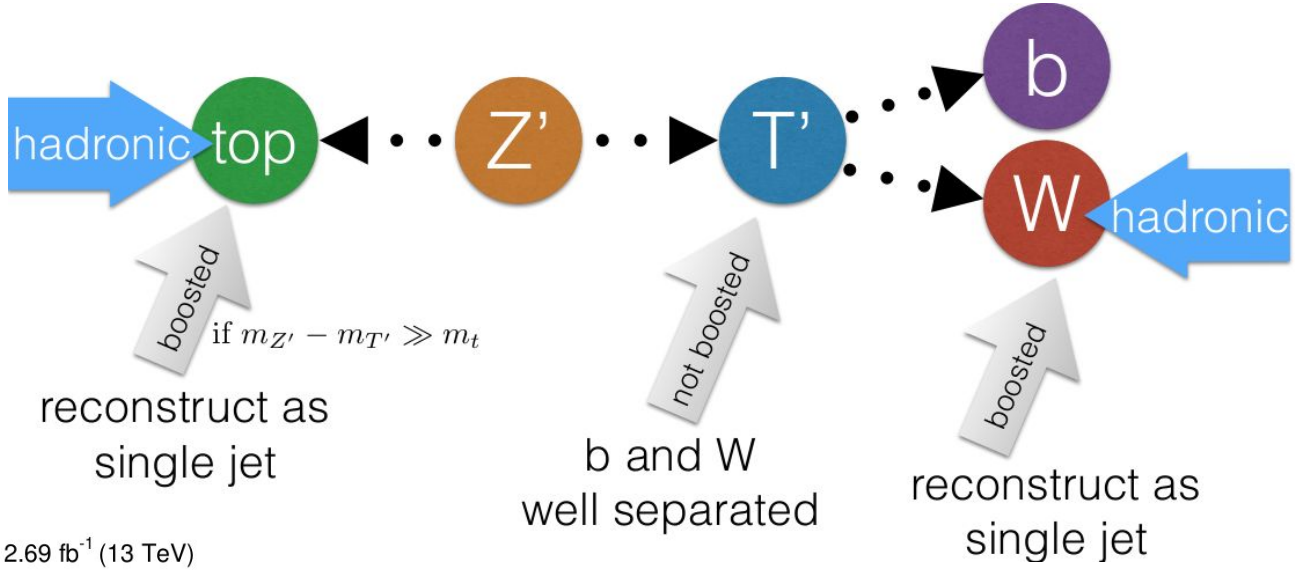


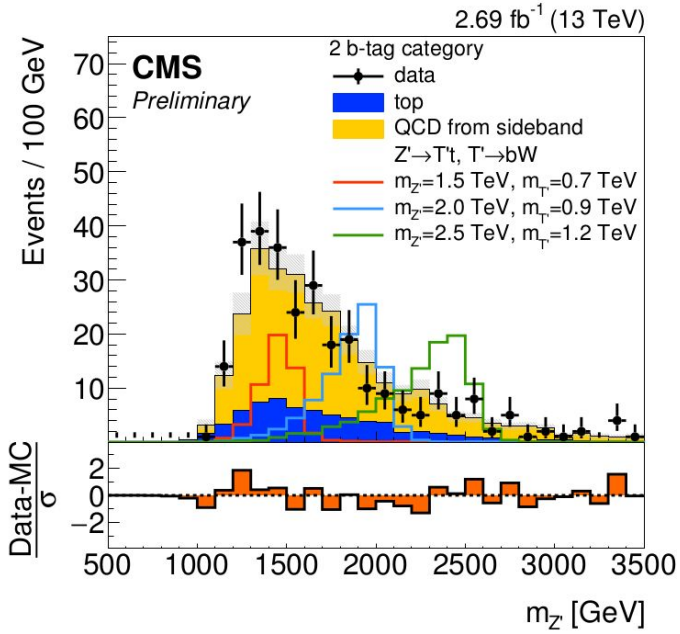


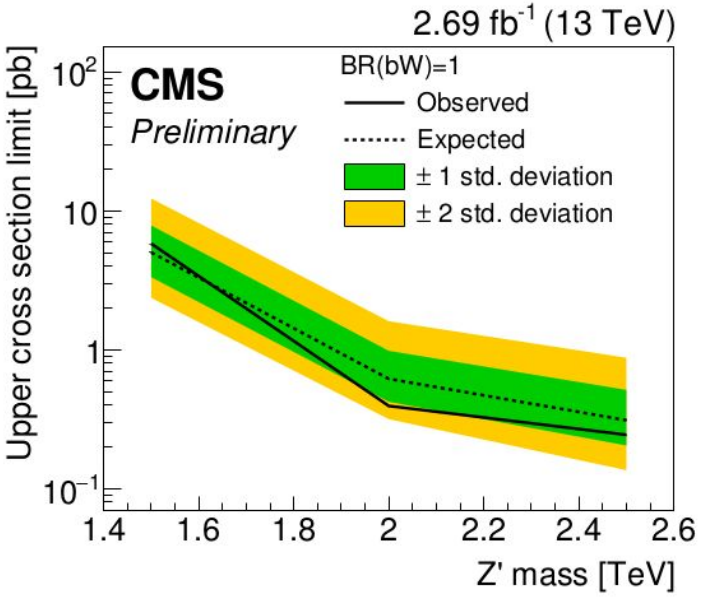
More on vector-like quark searches

B2G-16-013

- **Z'→T' t, relevant for: $m_t+m_{T'}<m_{Z'}<2m_{T'}$**
- **13 TeV search, L=2.7 fb^{-1}**



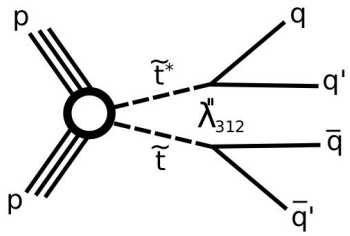


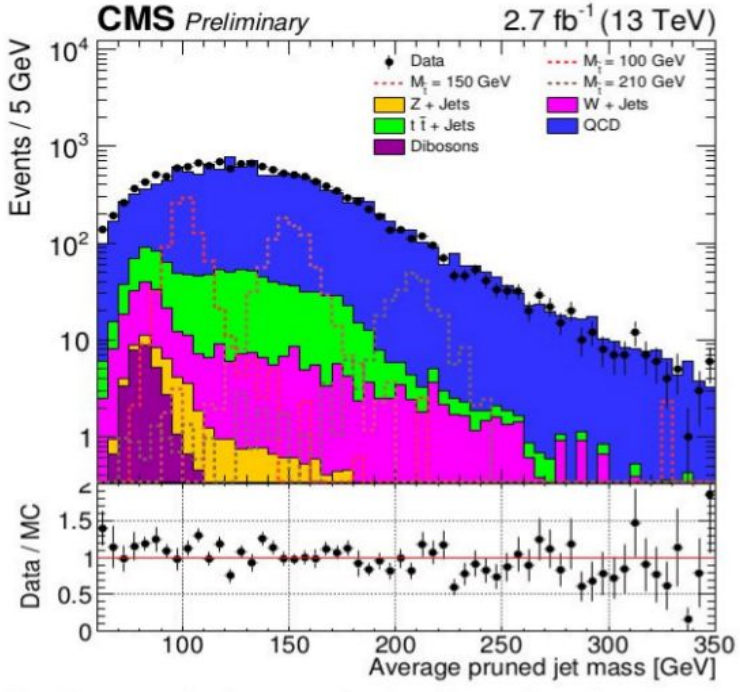


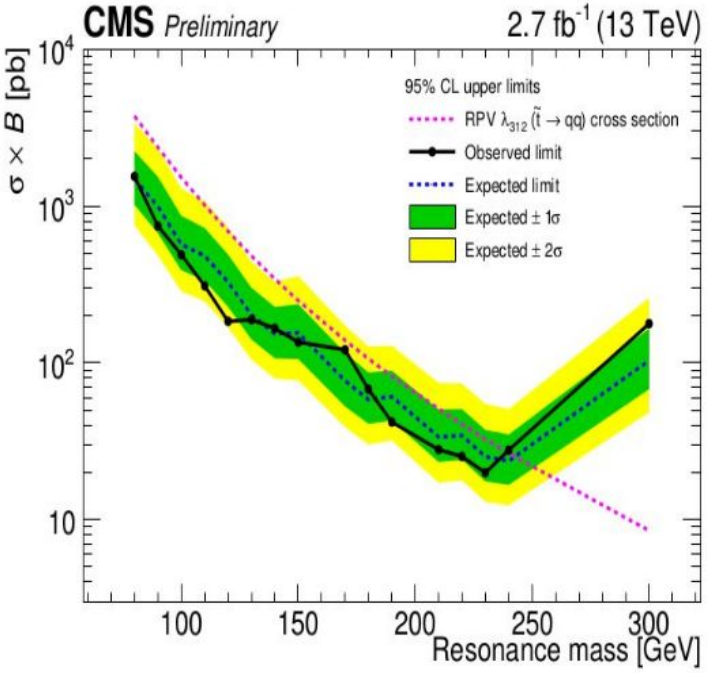
No stone unturned...

EXO-16-029

- Target scenario is RPV SUSY with low mass “boosted” stops decaying into two jets, using 2.7 fb^{-1} (2015)
- Stop mass regions below ~200 GeV only partially excluded by previous experiments (CDF below 100 GeV, ATLAS in b-tagged decays)
- Substructure techniques are used to disentangle two close jets in the final state
- RPV decaying stops excluded for 80-240 GeV masses (BR=100%)



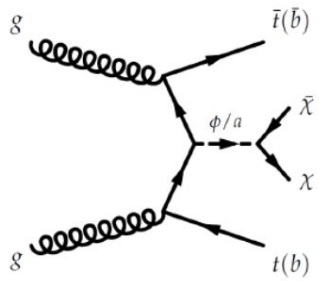


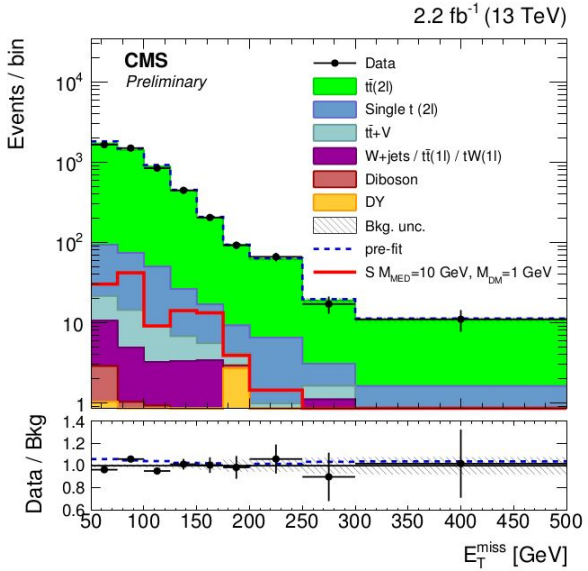


Dark matter searches, 3rd gen

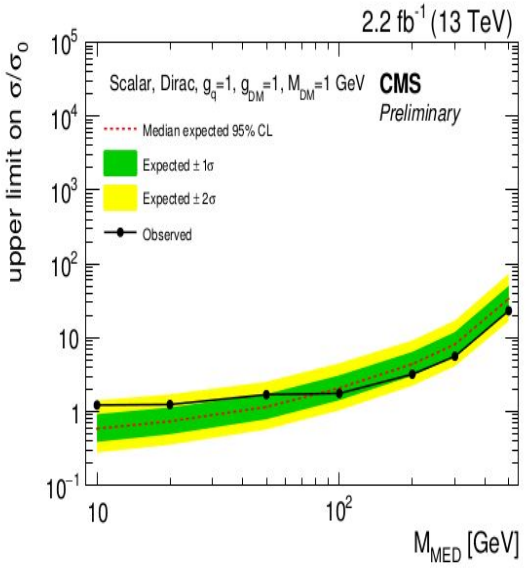
EXO-16-028

- DM searches specially sensitive to scalar and pseudo-scalar mediators (Yukawa-like couplings to avoid sizable flavor violations)
- tt+MET analysis in the dilepton+jets+MET channel, using 2015 statistics (2.2 fb^{-1})
- Result combined with 1-lepton and fully hadronic analysis, DM mass of 1 GeV assumed in limits for mass mediator
- Searches marginally sensitive to 'natural' benchmark models, but ready to absorb more statistics at 13 TeV (factor of ~4 larger in statistical sensitivity in 2016)

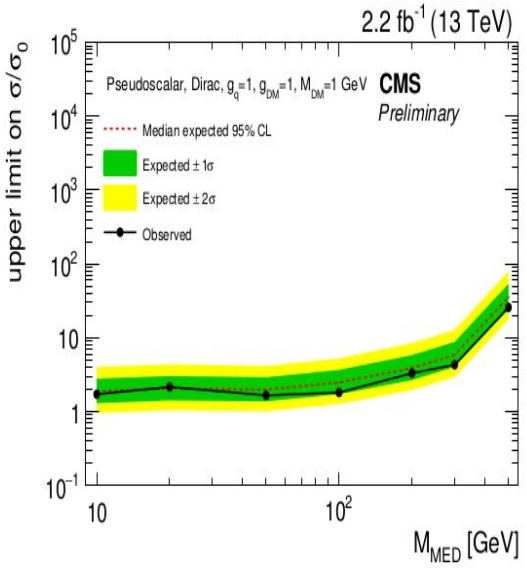




(b) $e\mu$



(a) scalar



(b) pseudoscalar