CMS Status Report

Run II Performance and Recent Physics Highlights

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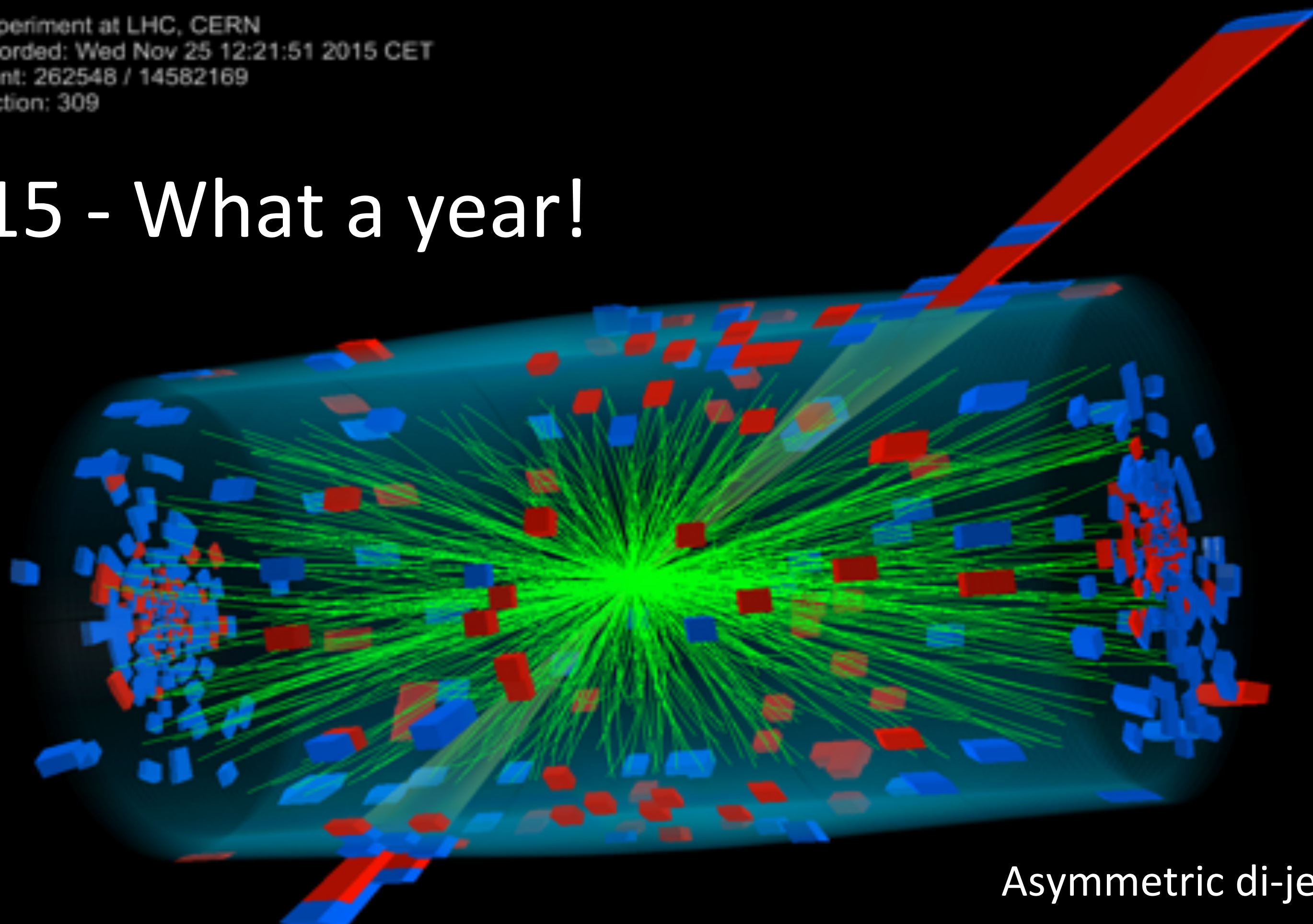
On Behalf of the CMS Collaboration

LHCC Open session, December 2nd 2015

CMS Experiment at LHC, CERN
Data recorded: Wed Nov 25 12:21:51 2015 CET
Run/Event: 262548 / 14582169
Lumi section: 309

2015 - What a year!



Asymmetric di-jet event PbPb

Robustness of Cryogenic system for CMS Magnet

- Much has been understood about the erratic behavior but mysteries remain.

- The first focus of the joint CMS-CERN TE task force has been increasing tolerance to contamination to maximise the "Up-Time" of the CMS magnet for Physics
  - Changes to cold-box absorbers, filters &turbines plus regular elective regeneration/ maintenance of the filters, absorbers and first heat exchanger

- This effort has resulted in:
  - ~ 3/4 of the 13 TeV luminosity delivered with the magnetic field ON
  - All reference p-p and all Pb-Pb (except today) luminosity delivered so far, with the magnetic field ON

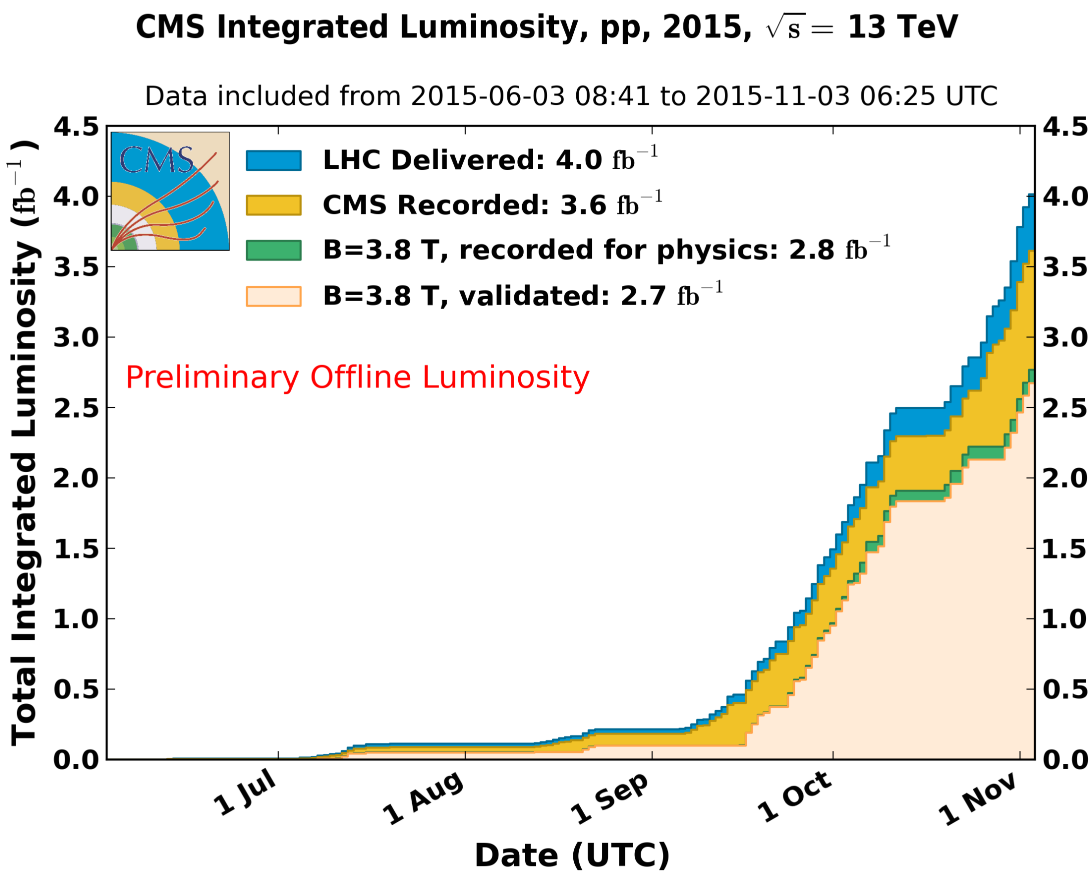
- For improved stability in 2016, the task force is implementing a detailed program to consolidate the system by changing or cleaning components. This plan is compatible with the agreed schedule for YETS 2015/2016.

- CMS Magnet risk review 7-8th December
  - Review YETS plan & future risks to magnet

CMS thanks CERN TE and EN departments for their exceptional efforts

Data validated for Physics @ 13 TeV

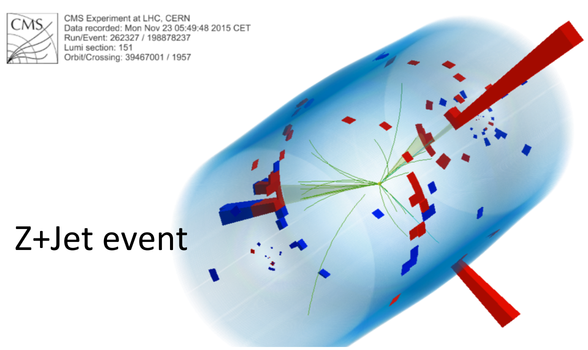
2.7 fb^{-1} validated for physics @ 13 TeV with B=3.8 T



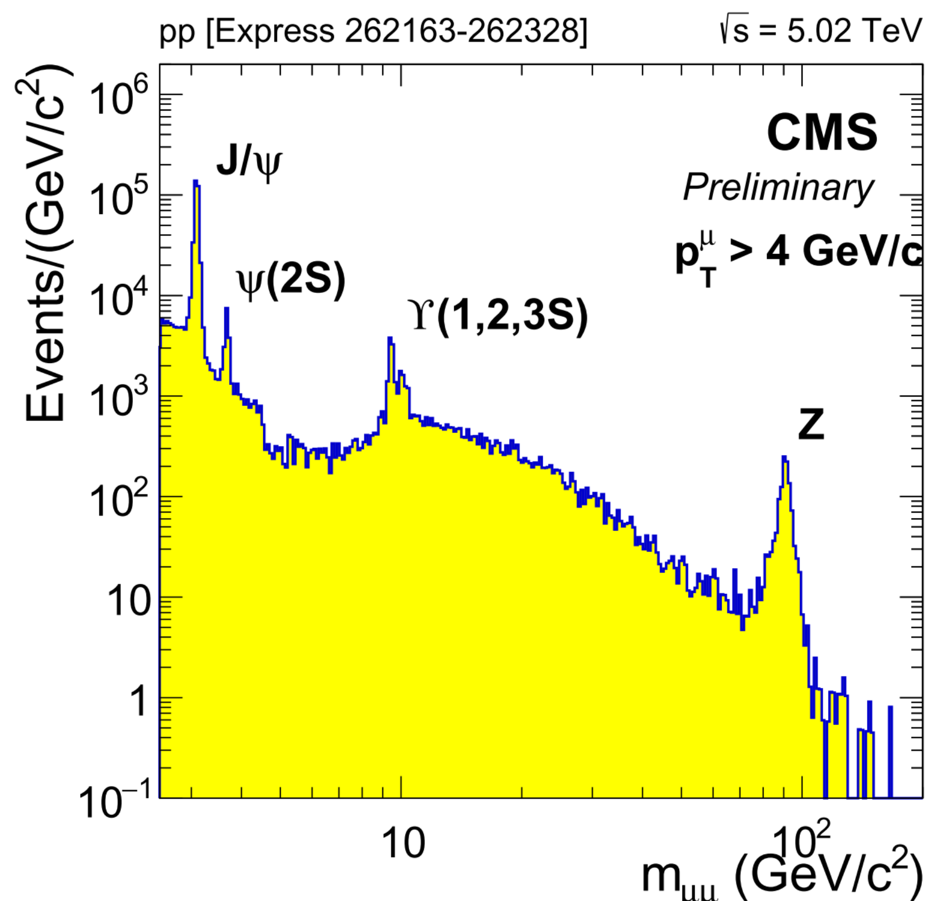
✓ *CMS appreciates the effort of the LHC and the other experiments in adjusting the beam schedule to minimize data taking periods without the CMS magnetic field*

Proton-Proton reference run @ 5.02 TeV

- ***28 pb^{-1} of data recorded for physics - all with B=3.8 T in 5 days!***
- ***Crucial for HI physics run***



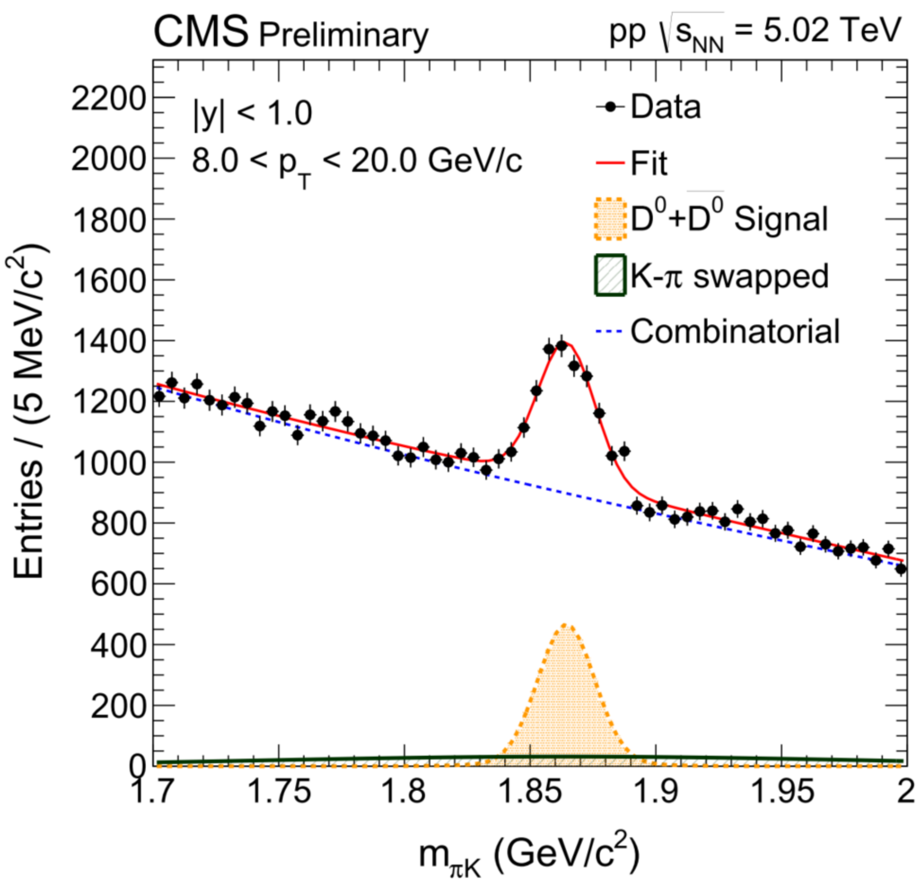
Z+Jet event



✓ *… excellent availability of the LHC to maximise delivered luminosity to the experiments! Thank you and congratulations to LHC crew!*

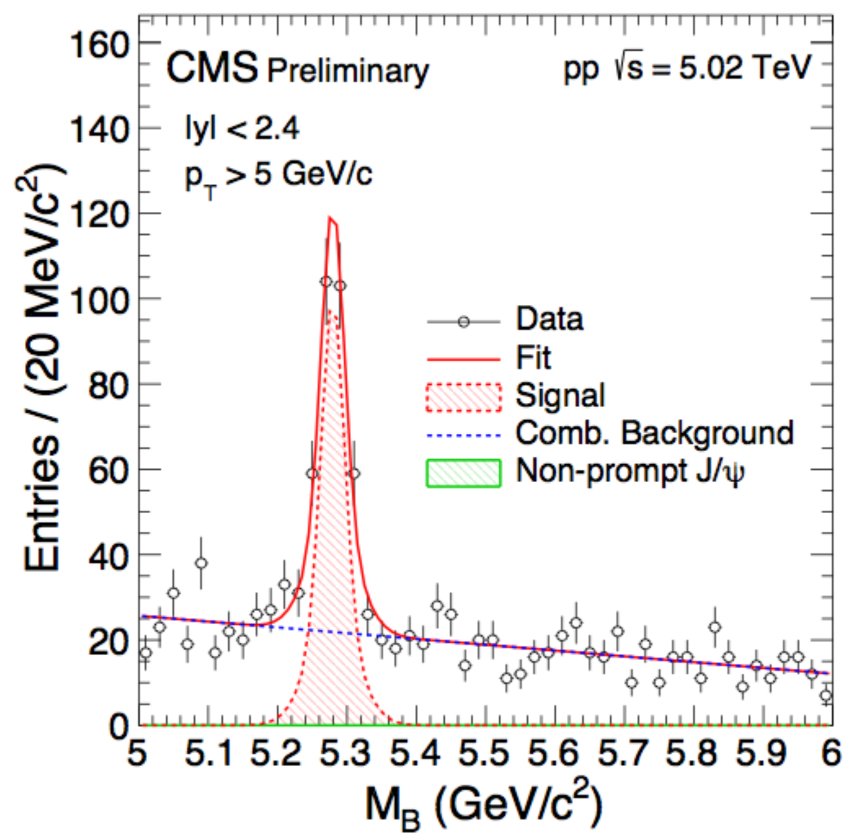
Data Quality Proton-Proton reference run @ 5.02 TeV

D^0 mesons peak from D^0 mesons online trigger



B^+ meson peak from dimuon triggered sample

$$B^+ \rightarrow J/\psi\, K^+ \rightarrow \mu^+\mu^- K^+$$

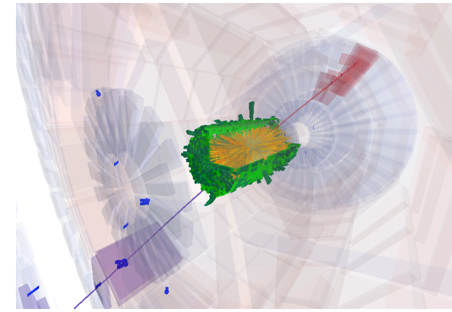


2.5 billion minimum-bias events recorded for low p_T D meson analysis

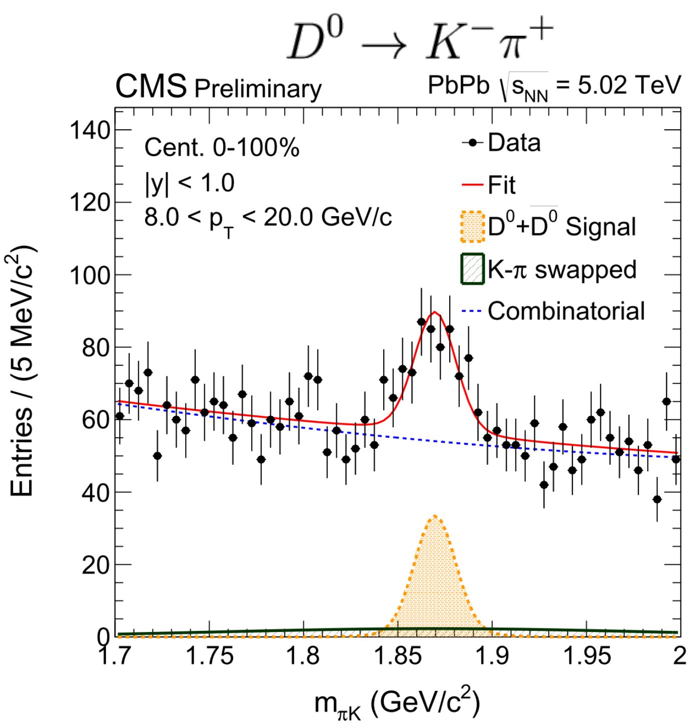
Today's Peak activity Pb-Pb @ 5.02 TeV/nucleon

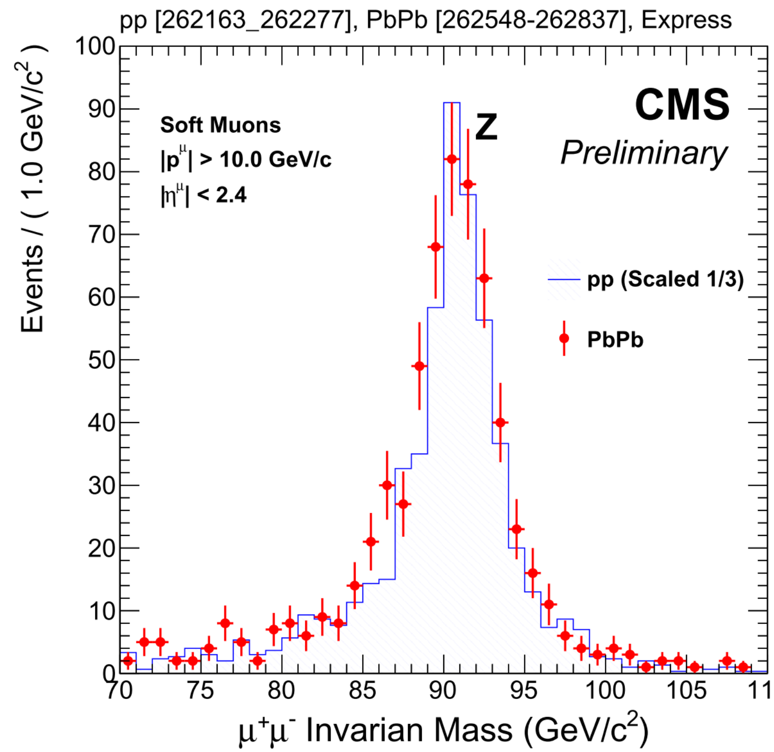
LHC Page1 Fill: 4664 E: 6369 Z GeV t(SB): 03:20:17 26-11-15 20:53:56

ION PHYSICS: STABLE BEAMS



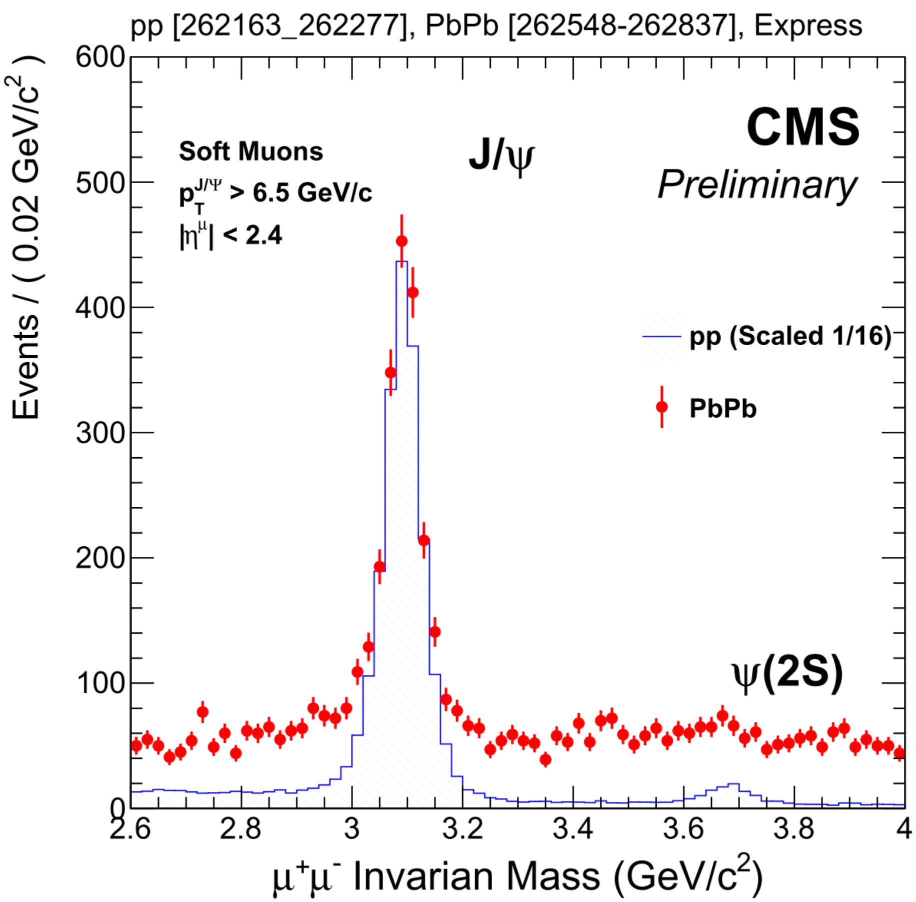
- ***143 ub^{-1} of data delivered for physics – all (except this morning's fill) with magnet ON***



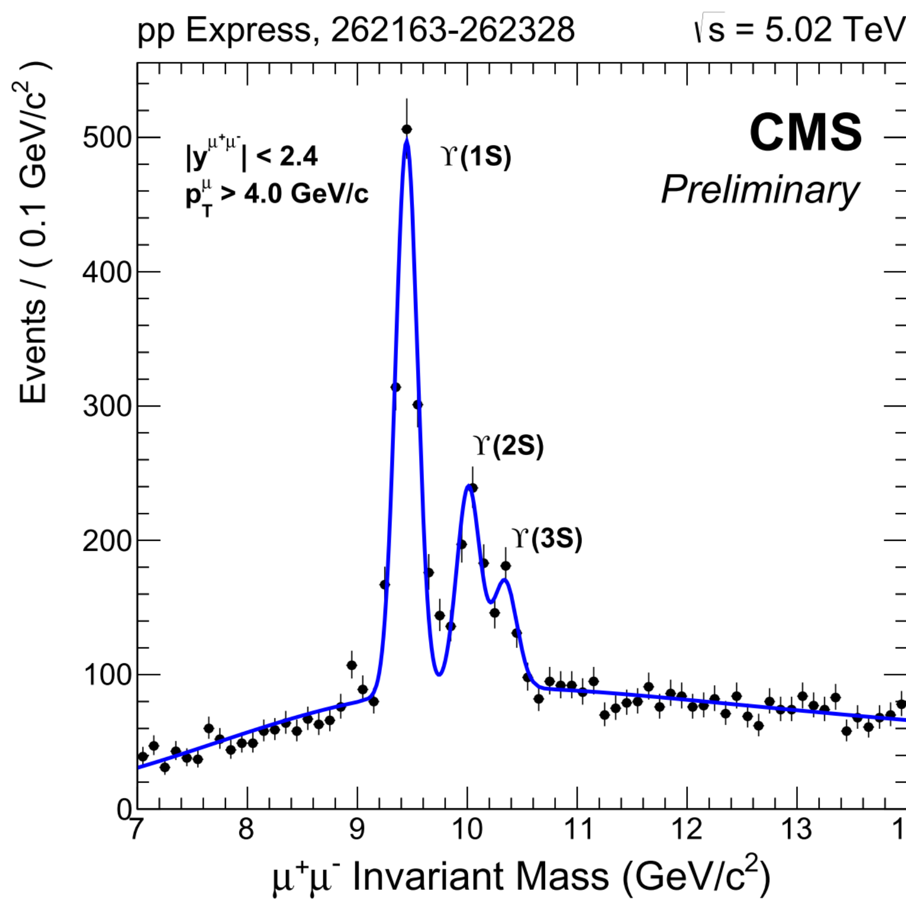


Quarkonia production in **pp and Pb-Pb @ 5.02 TeV/nucleon**

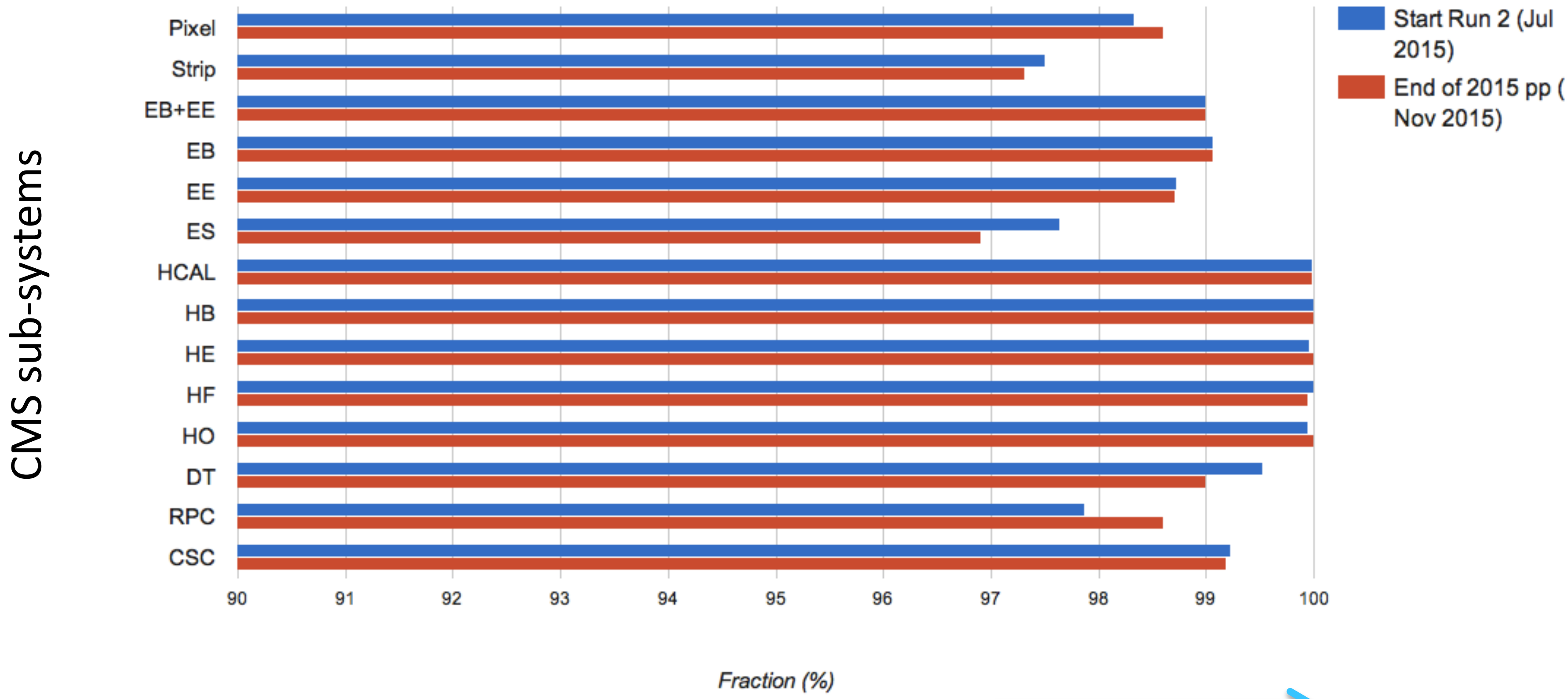
Charmonia



Bottomonia



Active channels throughout the √s=13 TeV p-p run



> 97 % availability

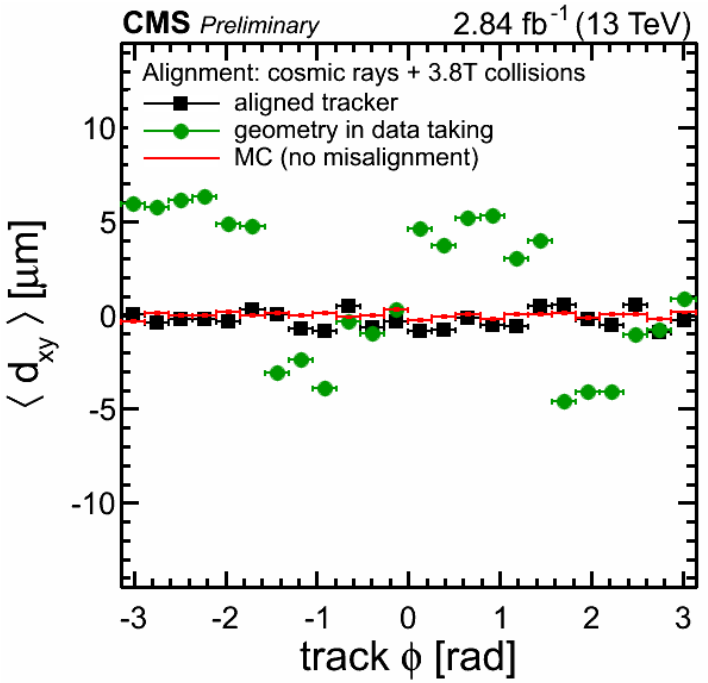
Excellent availability of the CMS detector

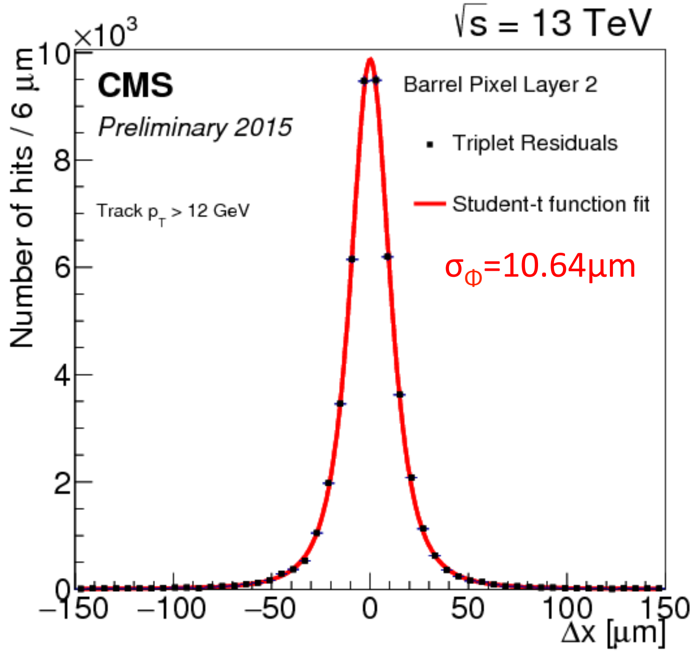
Preparing CMS data-sets

- New release of offline software available since November
- First MC samples for winter conferences have been submitted
  - 2.8 billion events in the queue
  - Target 3-4 billion events
- Inputs before re-reconstruction of Run-II data being collected:
  - Final alignment
  - Calibration corrections
  - Reconstruction algorithms
  - …

- On track for launching re-reconstruction of Run II data before Christmas

Tracker alignment & resolution





- Prompt reconstruction
  - Compensate for effect of magnet cycles
- **Final alignment** at the module level
  - ✓ **Performance is close to ideal case (MC)**
- ✓ Ready for data reprocessing

Pixel Detector Resolution:

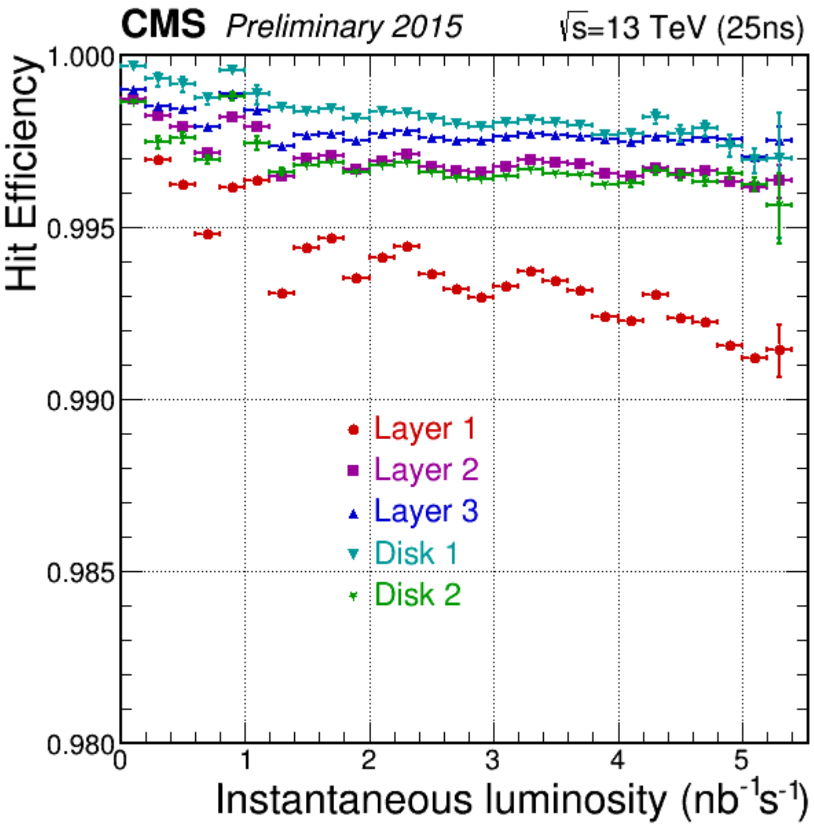
- Transverse to the beam: σ_ϕ=10.64 μm
- Parallel to the beam: σ_z=29.09 μm

As good or better than Run-1

Pixel hit efficiency

Excellent Hit efficiency

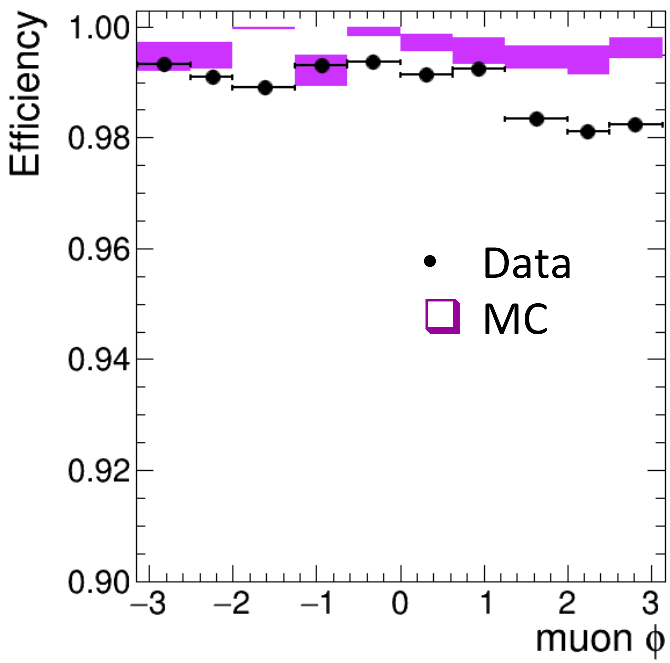
- Slightly better performance than in Run-I
- Dynamic inefficiency most visible on layer 1
- Efficiency above 99% on all layers/disks



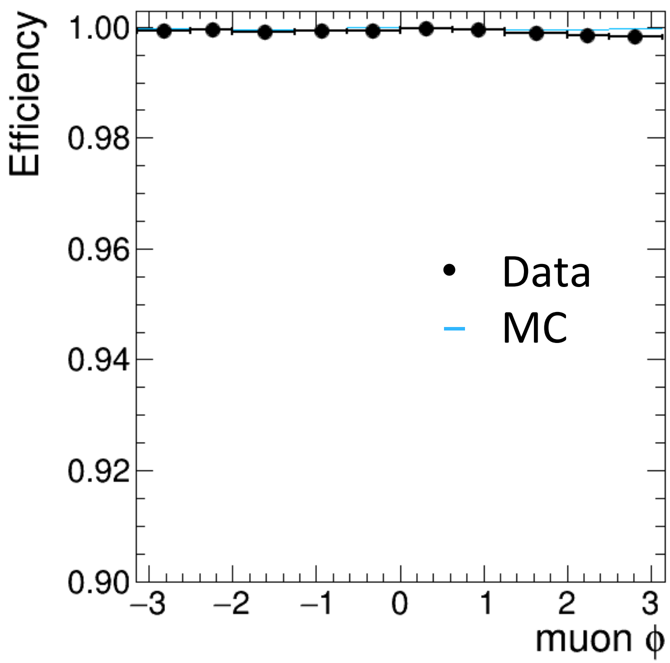
Tracking performance

Tracking efficiency excellent for both "inside-out" and "outside-in" reconstructions

"Inside-out" reconstruction efficiency



"outside-in" reconstruction efficiency

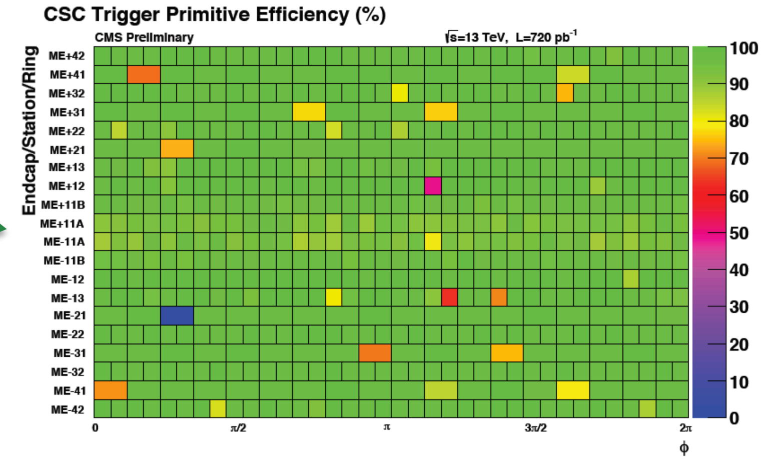


- Small ~2% inefficiency in data in region 1< ϕ < 3 due to absence of modules in layer 2 of Pixel BMO_3
  - Now included in MC description for winter conferences

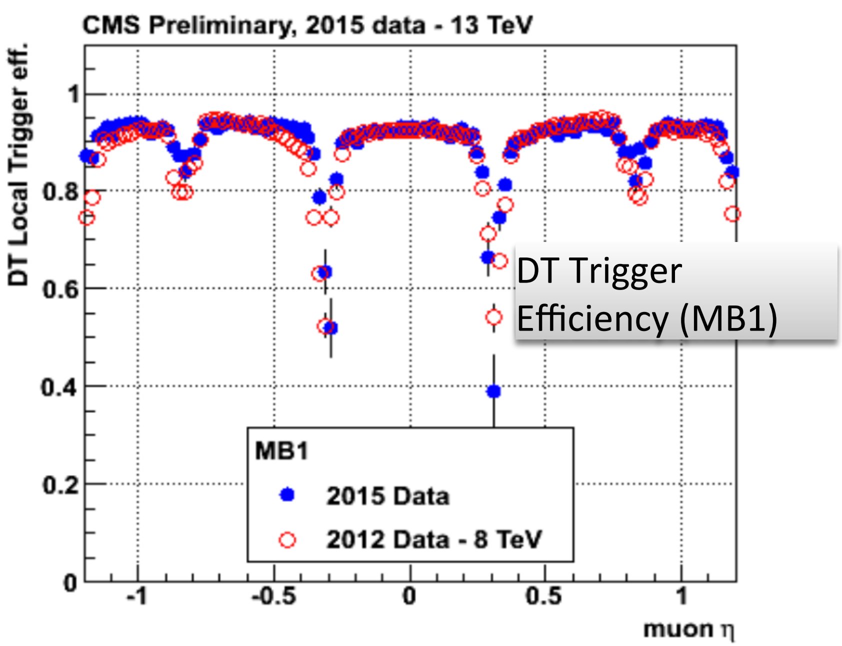
Muon Detectors

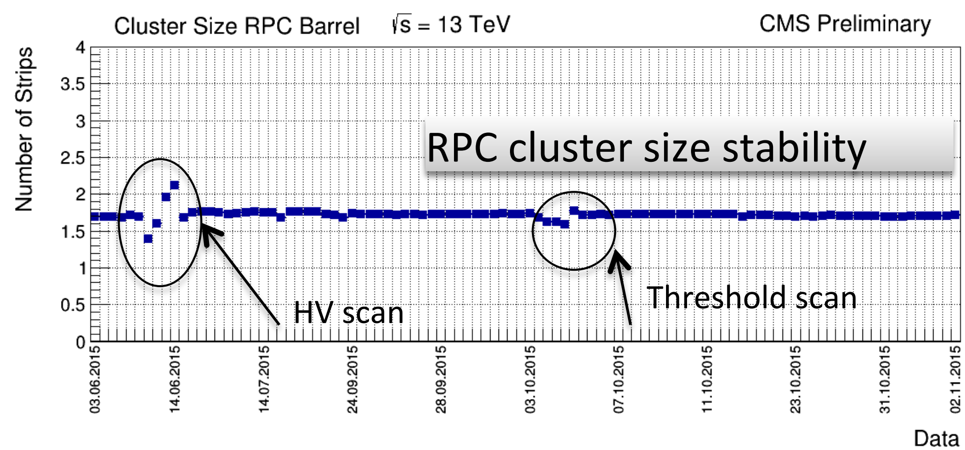
Excellent performance in 2015 p-p run

- **New** CSC ME4 and RPC RE4 **muon stations**
- **Upgrades to forward inner CSC readout electronics**
  - hit resolutions improves by 20% wrt. Run I
- **DT Trigger primitives efficiency** improved in 2015
- Good **stability of RPC cluster size**, important for L1 p_T assignment



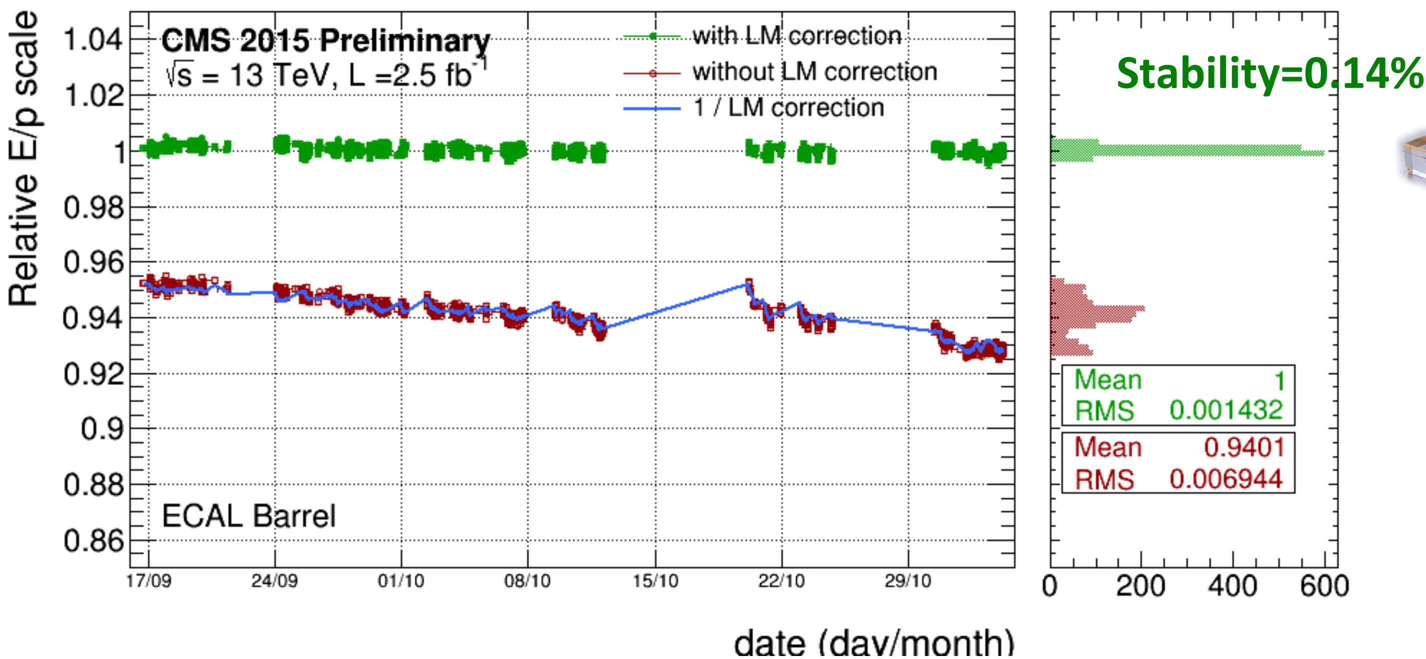
map of efficiency of CSC local trigger.

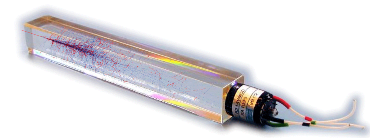




ECAL Performance

ECAL energy scale corrections & reconstruction algorithms ready for data reprocessing





- ✓ Excellent stability achieved in the prompt reconstruction of ECAL data using laser measurement
  - ✓ Stability of response is comparable to 2012 data

- ✓ Multi-fit algorithm for amplitude reconstruction optimized for high pileup and deployed as default
  - ✓ Isolated colliding bunch was useful to provide data sample for pulse distributions

Level-1 and High-Level Triggers

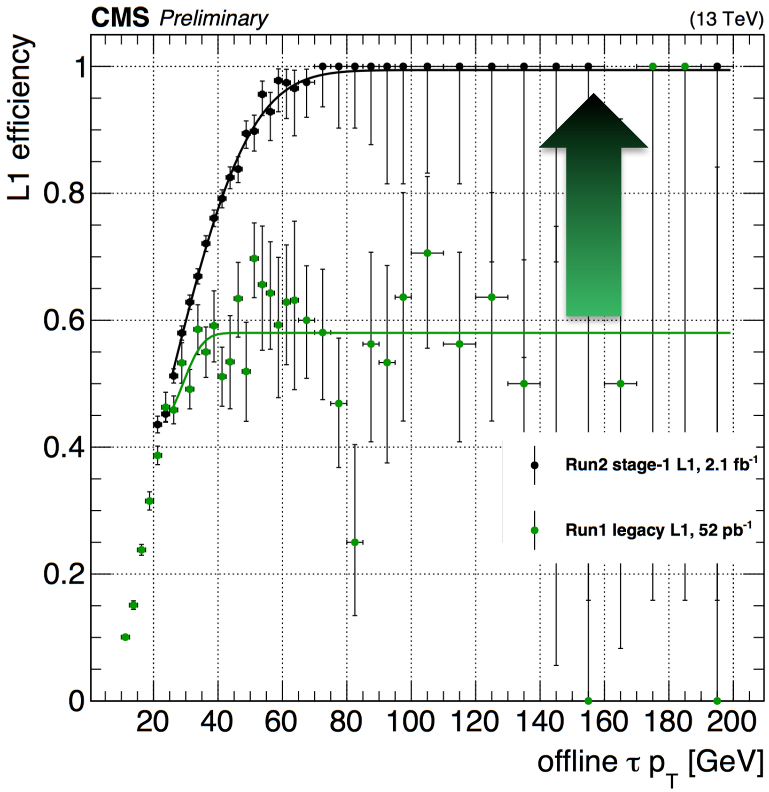
Successful operation of trigger for physics data-taking during 2015 pp run

- Menus put in place targeting different scenarios:
  - 50 ns runs: peak luminosity of 5E33cm^{-2}s^{-1} (PU ~ 30)
  - 25 ns runs: peak luminosities of 3.6E33-1E34 cm^{-2}s^{-1} (PU 20 – 40)
  - Deployed special menus: VDM scan and low pileup runs for FSQ/HIN
  - Dedicated menus for the Heavy Ions Pb-Pb run and p-p reference run
  - Also collected data for detector calibration/alignment & commissioning
- Menus included significant improvements in trigger algorithms:
  - Handle the expected increases in rate (due to the increase in center of mass energy)
  - Handle pileup
- Significant improvements made to online rate monitoring
  - Continuing to monitor performance of triggers with data

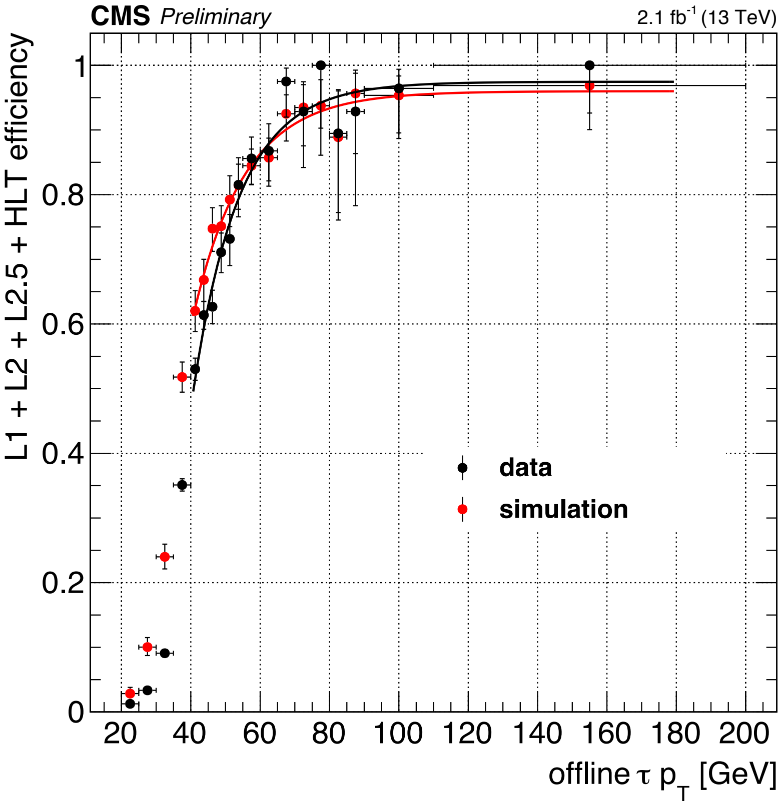
- **Multi-threading validated** and **deployed online** since the previous LHCC

Trigger Performance

From start of 25ns running period switched to the "Stage-1" calorimeter upgrade



New L1 single isolated Tau hadronic trigger efficiency p_T > 28GeV compared to legacy

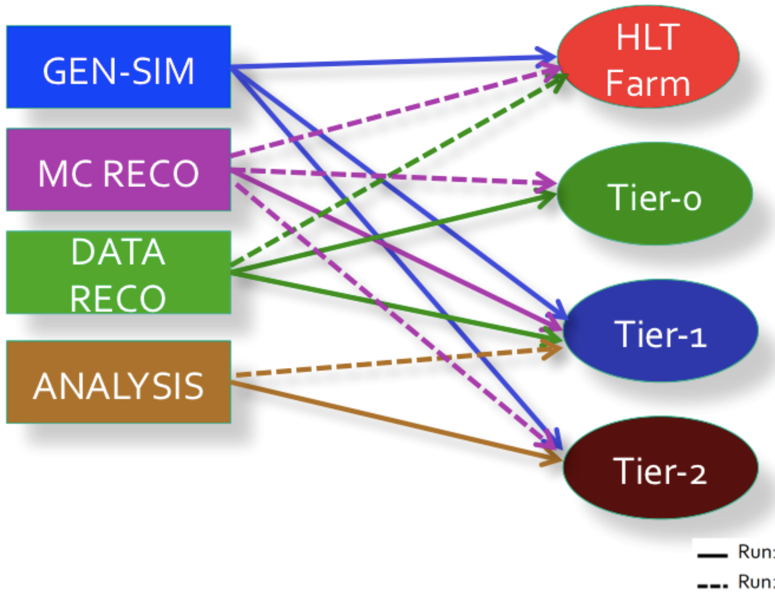


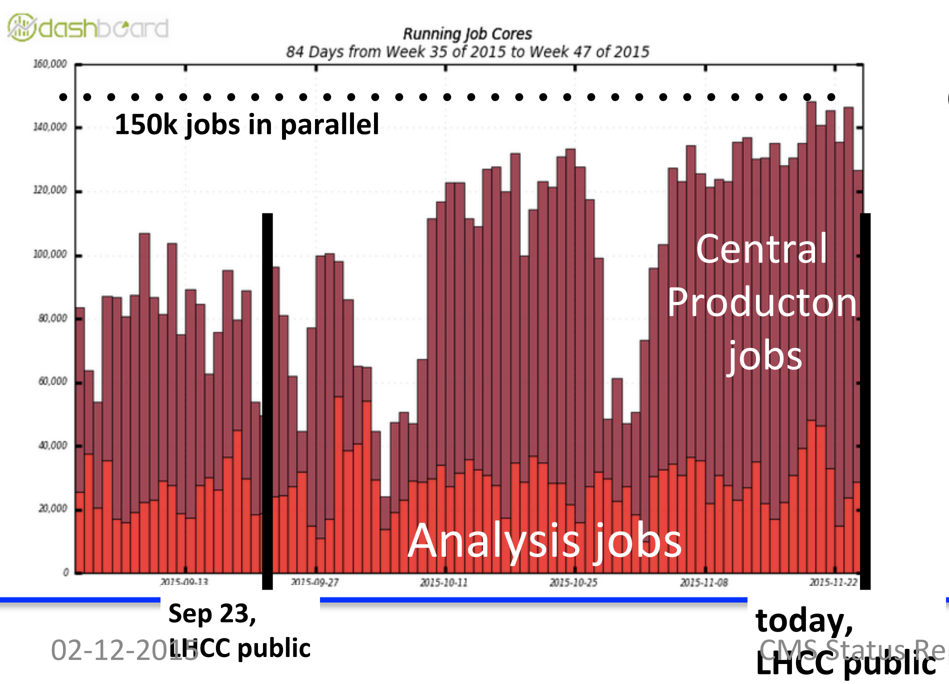
L1+HLT efficiency as a function of offline tau p_T for isolated double tau hadronic trigger with p_T > 35 GeV

Offline and Computing in Run-2

Exploited in Run-2:

- Threaded framework
- SIM & RECO code improvements
- Less Tier boundaries in the Comp. model
- More automation in Comp. operations





Global Pool for job submission management to better handle overall priorities

- Reached ~150k jobs running in parallel
- Can operate all T1/T2/opportunistic resources in a single pool
- MC for 2.8 billion events started

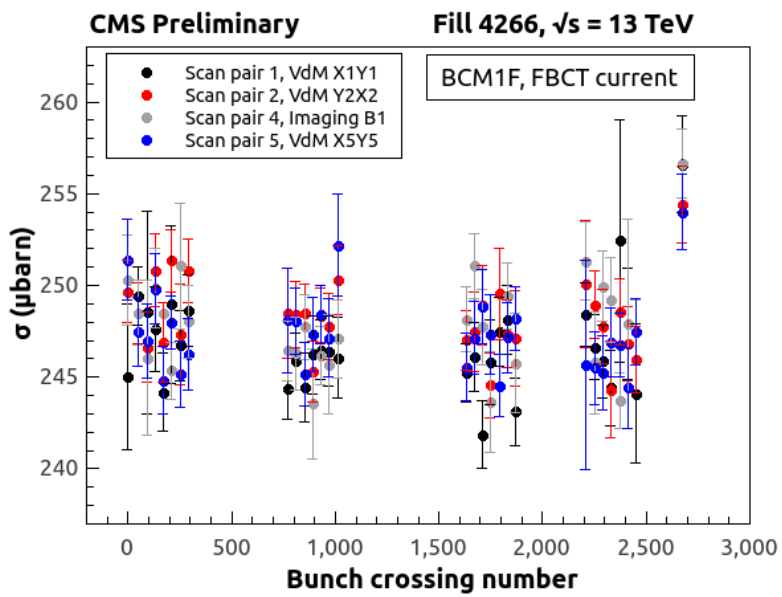
Luminosity calibration

CMS sends online per-bunch luminosity to the LHC at a frequency of 0.5 Hz.

- Multiple detectors are useful to understand beam and detector systematics
  - PLT, HF-lumi, BCM1F, pixel cluster counting

Each Luminometer calibrated offline using the Van der Meer (VDM) scan technique

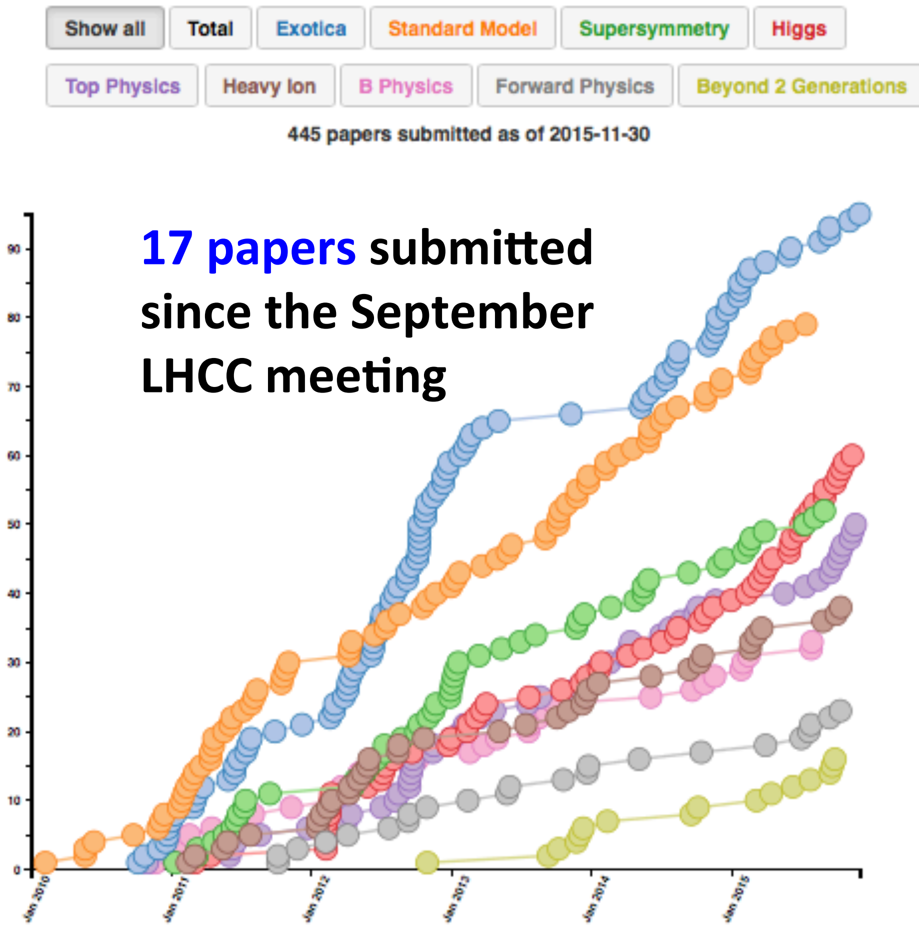
VDM-calibrated-BCM1F used as primary offline luminometer for physics for 50 ns recorded data.



Source	Uncertainty [%]
VDM calibration using fill 4266	
Uncertainty from VDM	2.6
Detector behavior during 50 ns	
Linearity and stability	4
TOTAL uncertainty (for 50 ns)	**4.8**

Work ongoing for 25 ns offline luminosity uncertainty (presently 12%)

CMS Publications



17 papers submitted since the September LHCC meeting

485 CMS Submitted papers:

- **445 physics papers**
- **24 papers based on cosmic ray data**
- **15 detector performance papers**
- **1 CMS detector paper**

http://cms-results.web.cern.ch/cms-results/public-results/publications/

CMS Publications - Run II data

Run 2 Publications			
TOP-15-003	Measurement of the top quark pair production cross section in proton-proton collisions at √s = 13 TeV	Submitted to PRL	18th October 2015
FSQ-15-002	Measurement of long-range near-side two-particle angular correlations in pp collisions at √s = 13 TeV	Submitted to PRL	11th October 2015
FSQ-15-001	Pseudorapidity distribution of charged hadrons in proton-proton collisions at √s = 13 TeV	PLB 751 (2015) 143	22nd July 2015
SMP-15-004	Measurement of inclusive W and Z boson production cross sections in pp collisions at √s = 13 TeV		CMS approved
FSQ-15-007	Underlying Event Measurements with Leading Particles and Jets in pp collisions at √s = 13 TeV		CMS approved
EXO-15-001	Search for narrow resonances using the dijet mass spectrum with 2.4 fb^{-1} of pp collisions at √s = 13 TeV		CMS approved
Additional analyses in the pipeline for LHC Physics Jamboree, 15th December 2015			

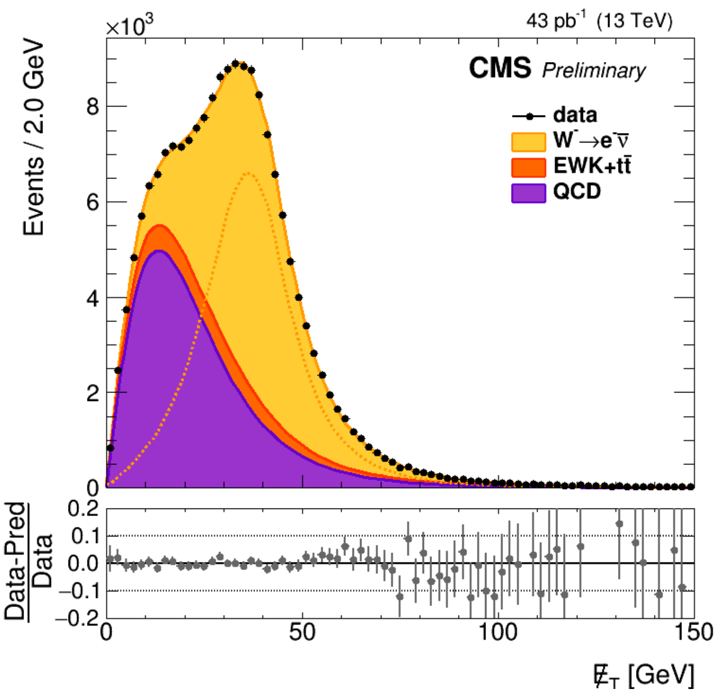
Shown LHCC Sept.

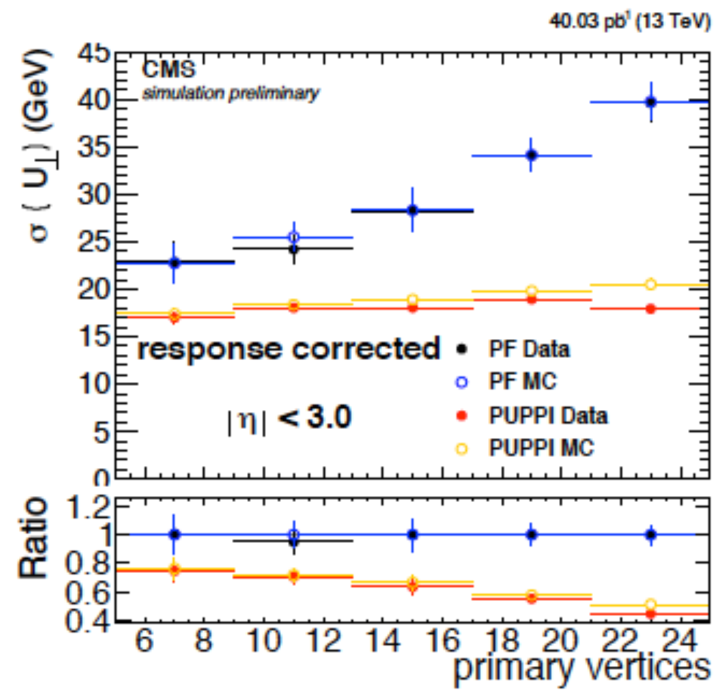
Present Highlights today

Inclusive W/Z boson cross section

Commissioning muon ID, electron ID & missing transverse energy with novel methods

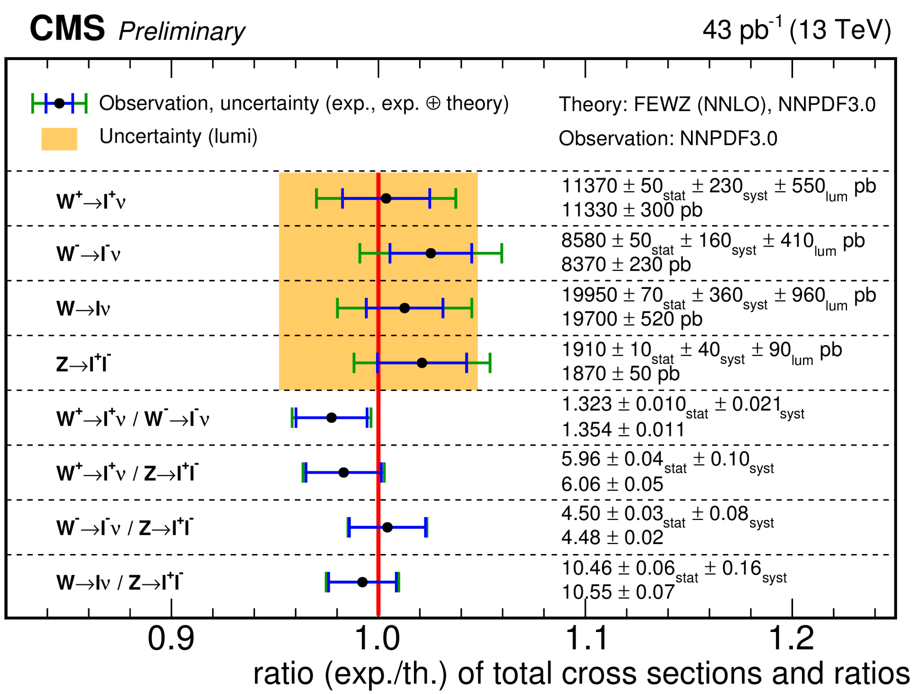
- 8 TeV analysis done at low pileup special run conditions
- 13 TeV done in high pileup environment using 50 ns data sample
  - PUPPI MET* for pileup mitigation, becomes essential in the W case to improve resolution and signal/background separation at low values of MET

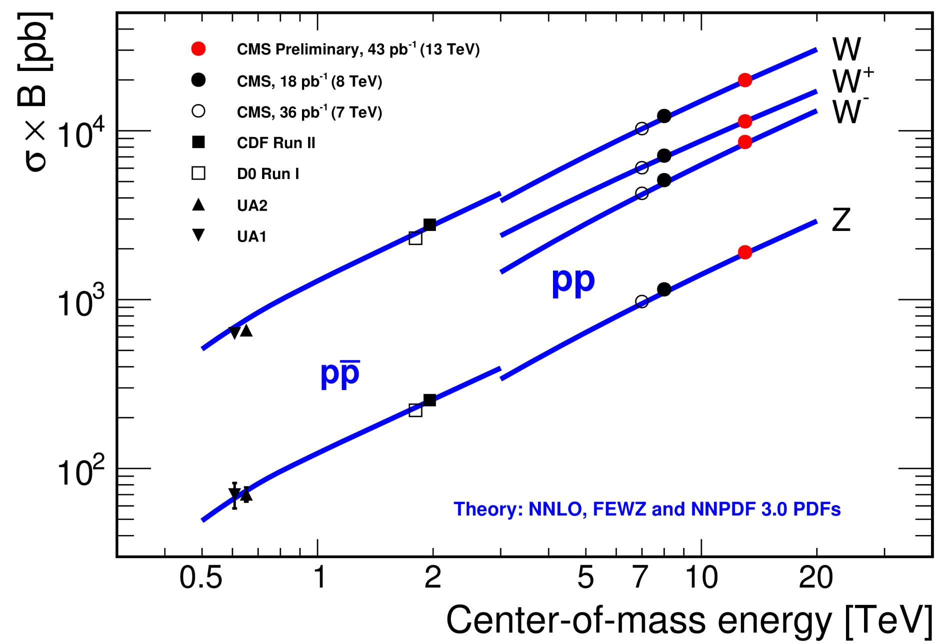




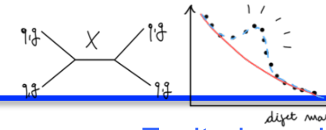
Inclusive W/Z boson cross section

- Consistent results between electron and muon channels
- Agreement with SM
  - Precision tests on next-to-next leading order QCD calculations
- Uncertainties expected to reduce before final publication



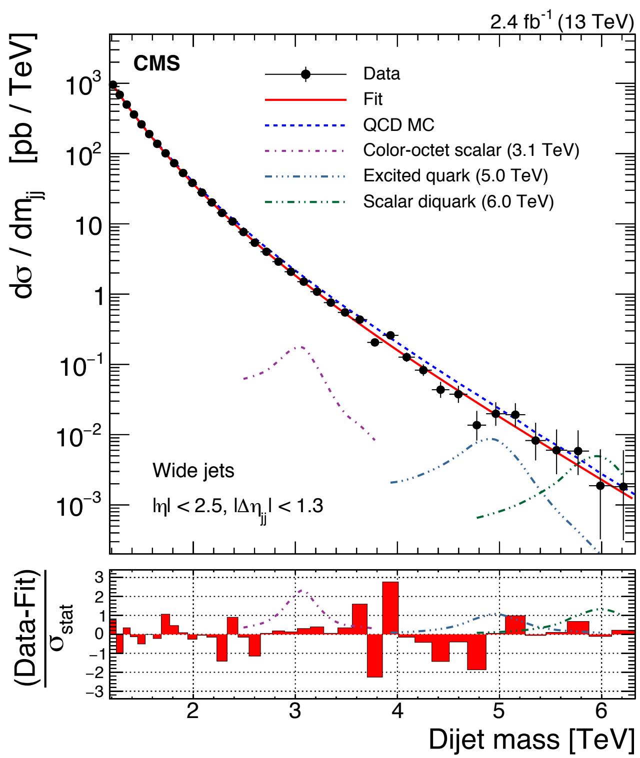


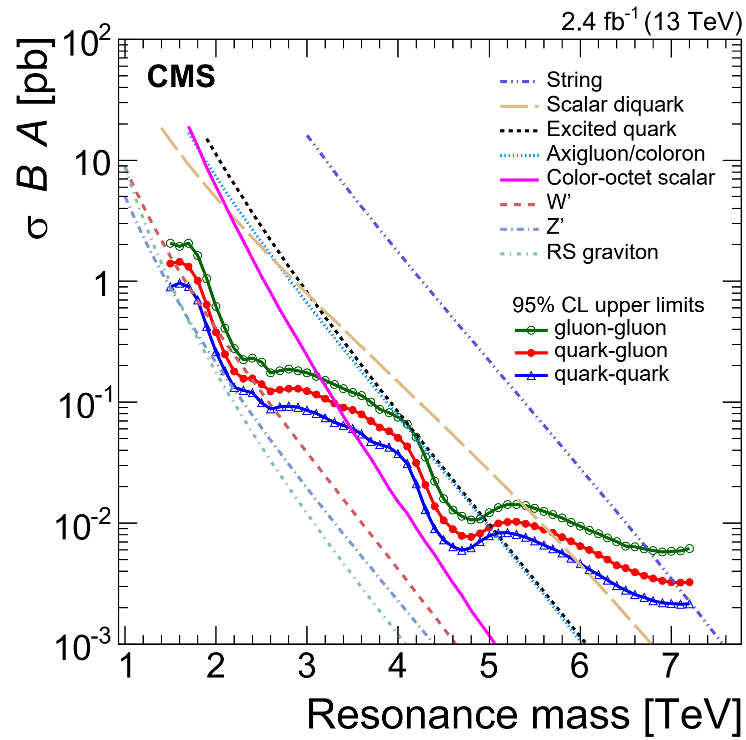
Dijet resonance search @ 13 TeV



Excited quark
RS Graviton,
W'/Z'
string resonance,
...

- Model independent search for narrow qq, qg, or gg resonances
  - Uses 2.4 fb^{-1} of Run II data
  - Various models considered
    - For example, CMS can exclude string resonances (q-g) with masses below 7.0 TeV
  - Surpass Run 1 limits for resonances above 2 TeV

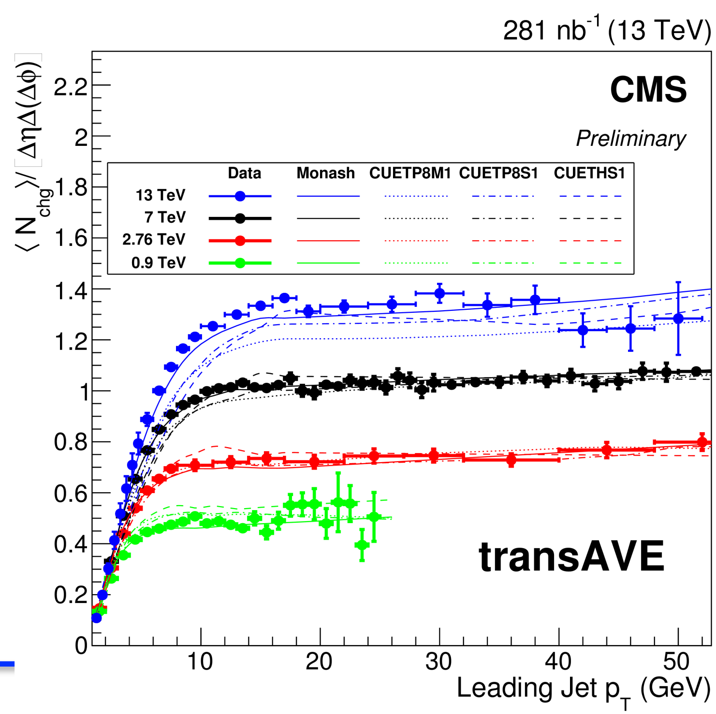




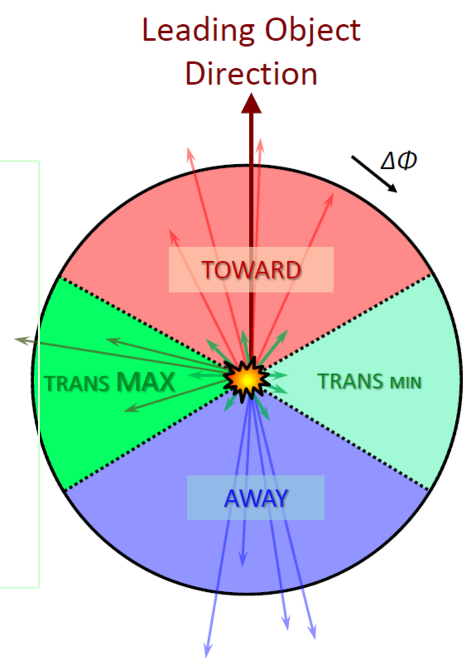
Underlying Event (UE) @ 13 TeV

Key measurement to improve our current MC tunes at 13 TeV

- Study of the **average multiplicity** density and **scalar transverse momentum** density in the **orthogonal direction** to the thrust of the leading event activity
- Compare quantities in the transverse region as a function of track or jet P_T of leading particle with various MC models (Phythia8,Herwig++,EPOS) with various tunes.
- Data is in reasonable agreement (10-20%) with all tunes
- "Monash PYTHIA8" gives the best agreement among all studied tunes



- **TransMAX**: density in region of maximum activity
- **TransMIN**: density in region of minimum activity
- TransDIF: **TransMAX-TransMIN**
- TransAVE:(**TransMAX+TransMIN**)/2

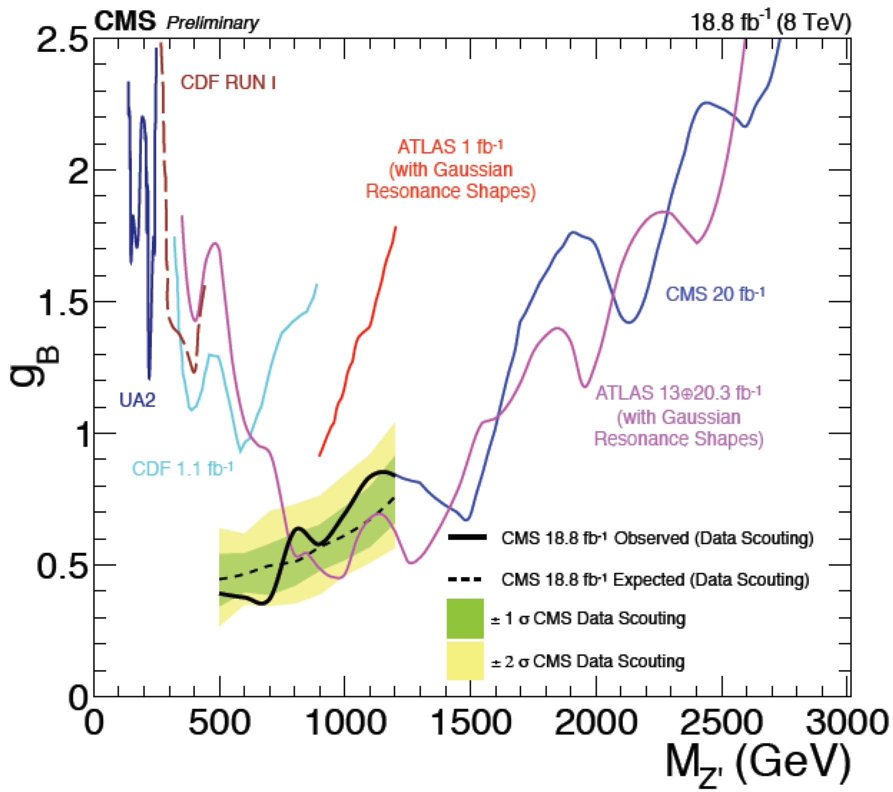


RUN I RESULTS

Data-scouting & search for low-mass dijet resonances @ 8TeV

Data-scouting => save additional events with lower than typical HLT thresholds

- Standard HLT triggers:
  - Typically 500kB/event
- Scouting:
  - 10 kB/event, saving only the 4-momenta of jets and lepton
- No offline reconstruction of data possible, but for many analyses, the HLT online resolution is sufficient
- Run 1, Saved with high rate (~1kHz) hadronic triggers > 250 GeV
  - Window to low mass resonances > 500 GeV



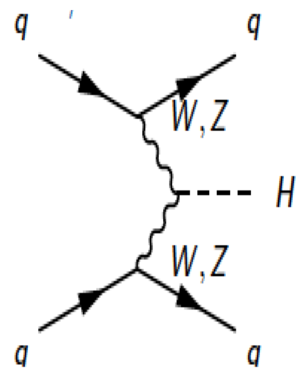
Exclusion limit on the coupling strength g_B of a hypothetical baryonic Z'_B that decays to a final state of 2 jets, as a function of the Z'_B mass

CMS-PAS-EXO-14-005
http://cds.cern.ch/record/2063491

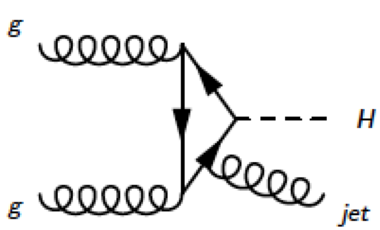
Run 1: Higgs → invisible combination @ 8TeV

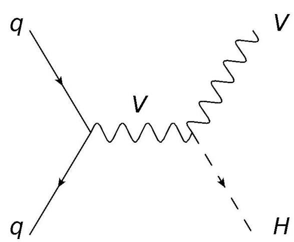
CMS-PAS-HIG-15-012

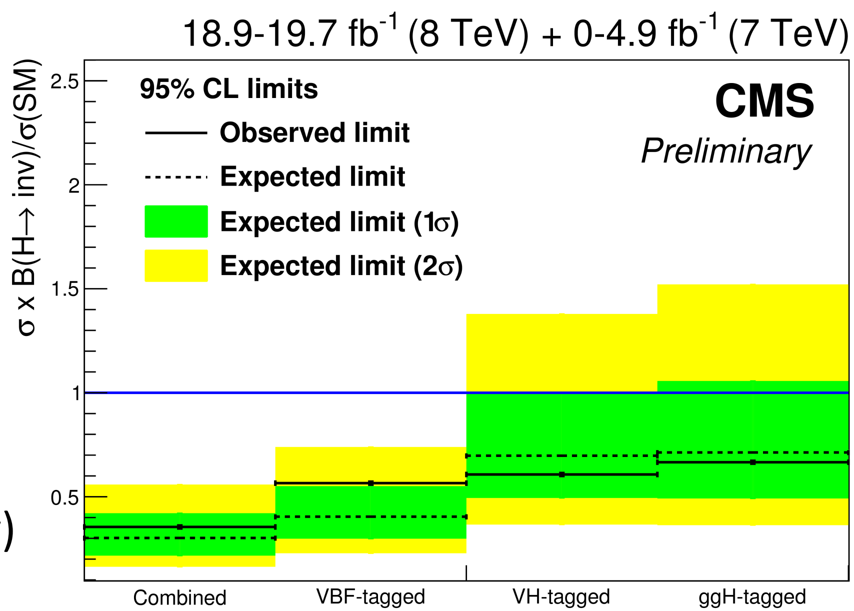
- Predicted by SM at very low rate BR ($H \rightarrow ZZ \rightarrow 4\nu$) ~0.1%
- Complementary to Dark Matter searches.
- Signatures of missing transverse energy tagged in the follow channels:
  - qqH (VBF): two forward/backward jets with large $\Delta\eta_{jj}$ & m_{jj}
  - $Z(\rightarrow ll)H$: two lepton compatible with a Z boson
  - $Z(\rightarrow bb)H$: two b-jets compatible with a Z boson



- Updated to also include
  - $Z/W(\rightarrow qq)H$: resolved and merged jets compatible with Z/W boson
  - gg→ H+jet: one high p_T jet







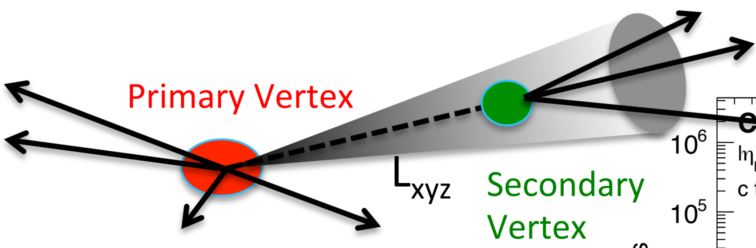
- 30% improvement in sensitivity.
- Observed (expected) upper limit set on BR(H→inv) for m_H=125 GeV is 0.36 (0.30) at 95% CL

Charm-tagged jet production in p-Pb @ 5.02 TeV & p-p @ 2.76 TeV

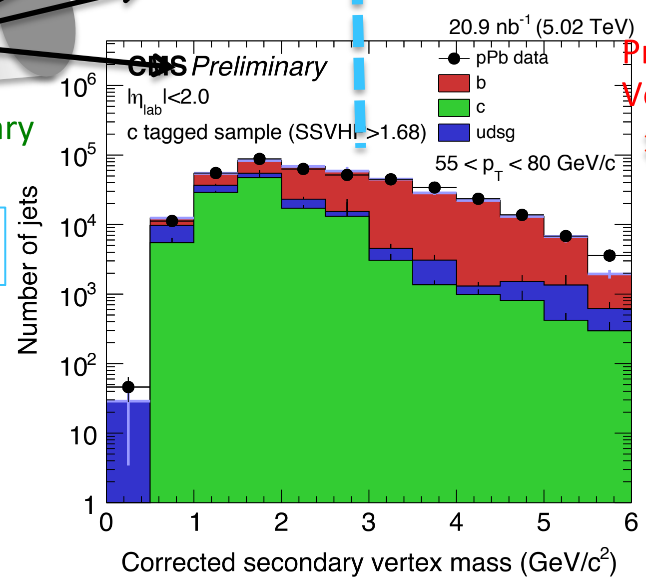
- b-jets tagged at CMS by selecting on displaced vertices
- Charm jets have smaller displacement, therefore trickier to tag
  - Developed a set of variables that provide discrimination power to extract c-jets

CMS-PAS-HIN-15-012

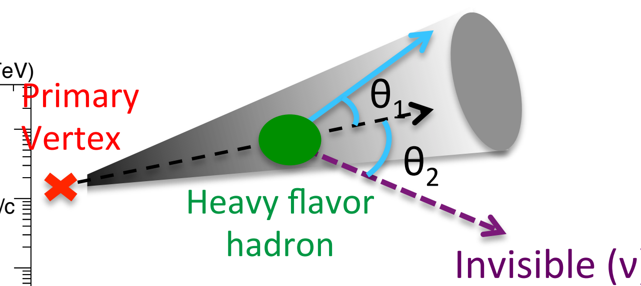
3+ Body Secondary Vertex Tagging



Separation of Heavy + Light



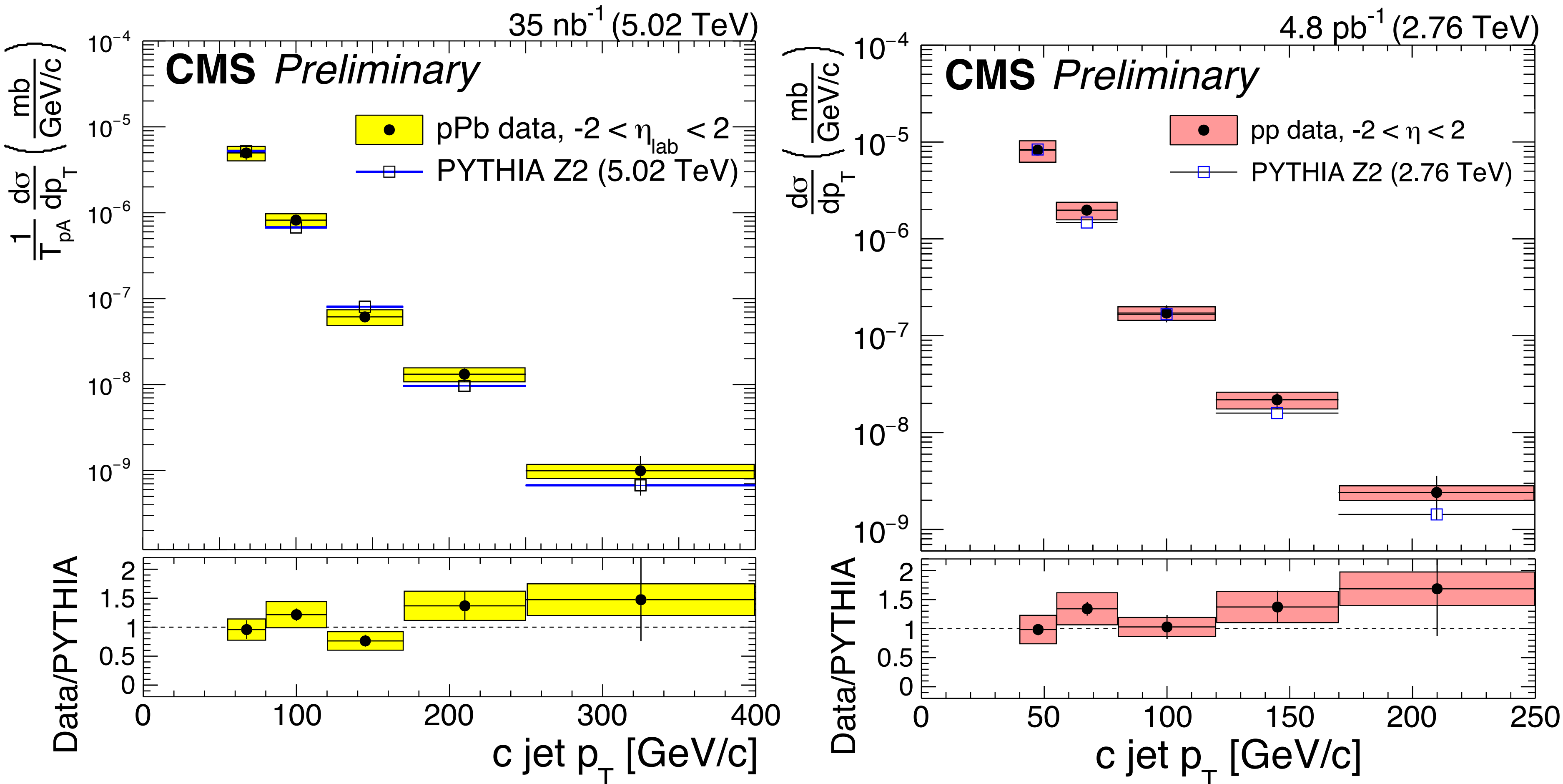
Corrected Secondary Vertex Mass



Separation of Charm + Bottom

Feed into template shapes – charm jet contribution extracted

Charm-tagged jet production in pPb @ 5.02 TeV & pp @ 2.76 TeV



CMS-PAS-HIN-15-012

- First charm jet measurement in heavy-ion collisions!
  - pPb and pp tackled so far – both consistent with PYTHIA predictions
    1.00 +/- 0.19 (stat.+syst. pPb) 1.15 +/- 0.27 (stat.+syst. pp)
  - Charm jet fraction (not shown) also consistent with PYTHIA

Conclusions

- Up-time of the CMS magnet was the main limitation in 2015
  - A plan is in place for maintenance in 2015/2016 YETS and CMS appreciates all parties for their efforts
- CMS took high good quality data with high efficiency during Run 2
  - Improved detectors, trigger and data-acquisition
  - Event reconstruction robust against 25 ns pile-up conditions
- Computing and software algorithms much improved for Run 2
  - Multi-threading already deployed is online HLT framework and also offline software (MC and data-RECO)
  - Data-reco on schedule for submission before the Christmas break
- Run 2 Physics analyses are moving forward
  - New analyses in the wings for the jamboree
- HI data taking and prompt analyses are at the highest level of activity
  - Looking forward to what is in store for physics

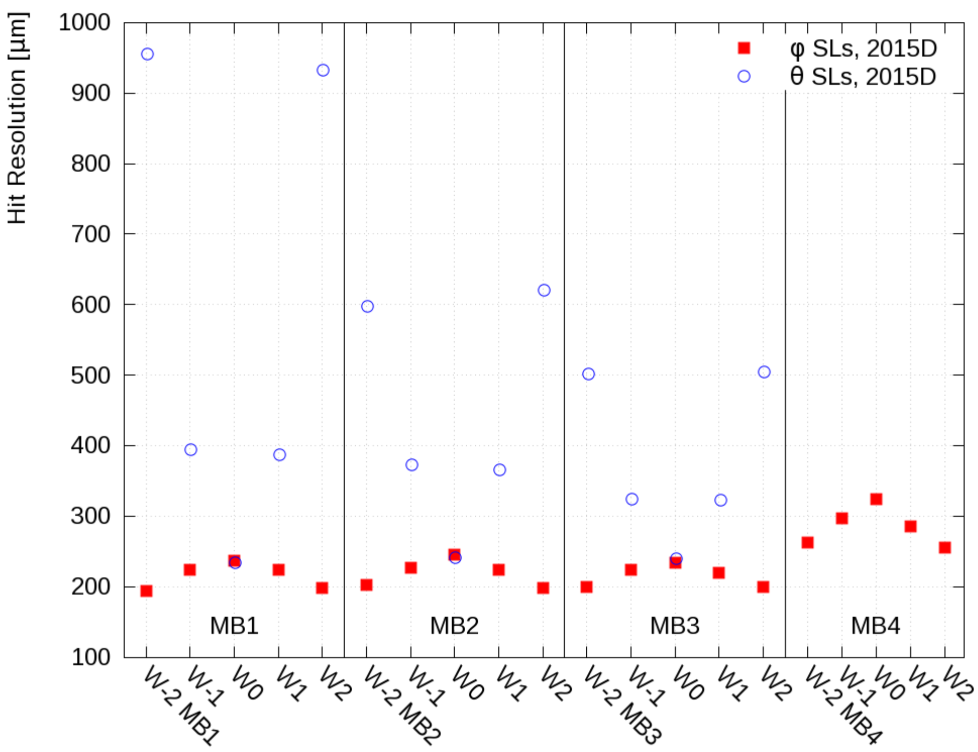
EXTRA SLIDES

DETECTOR PERFORMANCE

Muon Detector performance

DT measured resolution for Phi and Theta Super Layers, shown station by station

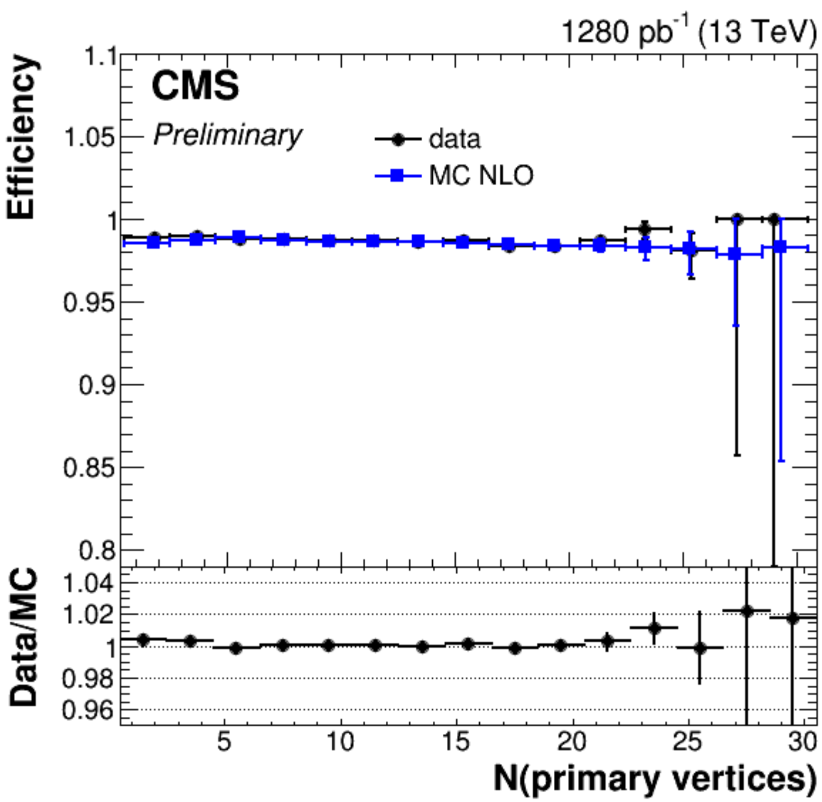
Apart from Theta SL's in MB1 stations of external wheels (where in any case the track inclination and the transverse component of magnetic field bias the residual distributions and make the Gaussian fit unstable), the resolution observed this year is compatible or slightly better than the one obtained with 2012 data.



Muon Identification

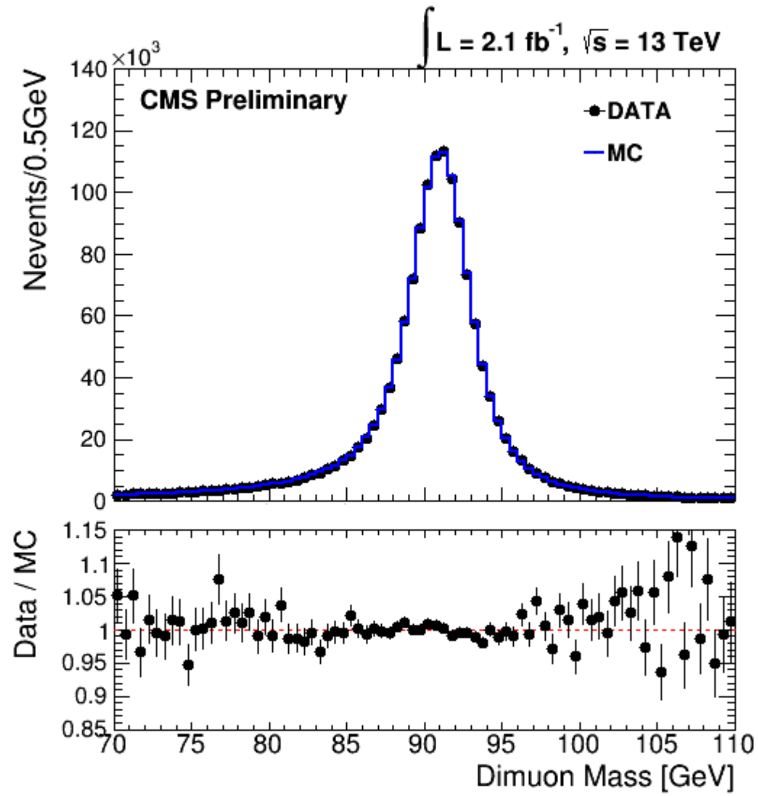
Muon ID robust against pileup and in good agreement with MC

Muon ID with loose isolation vs number of primary vertices



P_T > 20 GeV |η| < 2.4

Z line shape in data and MC

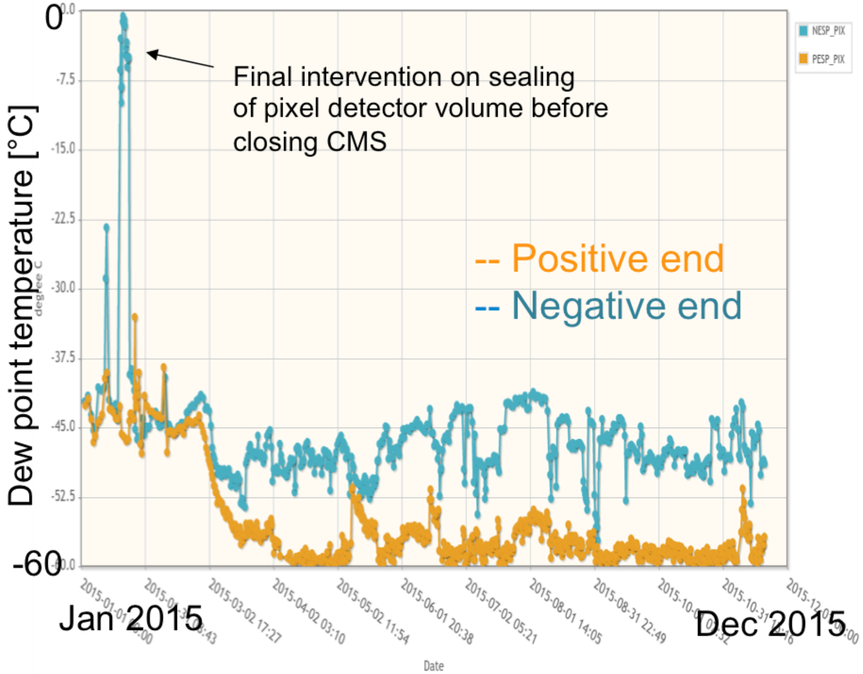


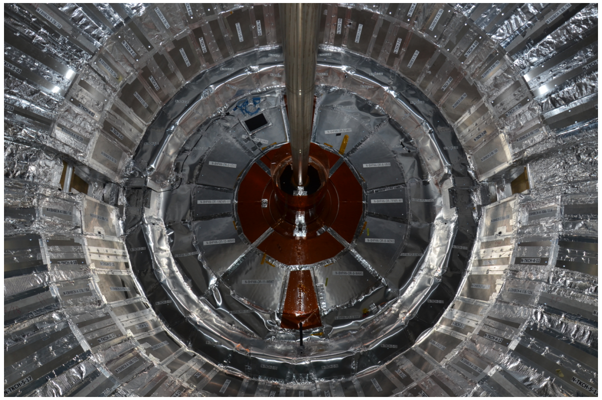
After data driven P_T calibration correction

Pixel volume sufficiently dry to run Trackers cold in 2015

- Dew point excellent
  - "originally" Pixel volumes and Bulkhead not sufficiently well sealed for lower temperature
    - Major work during LS1
  - < -40 °C for both ends of CMS
  - All gas systems ran without downtime
    - Redundancy available in case of failures

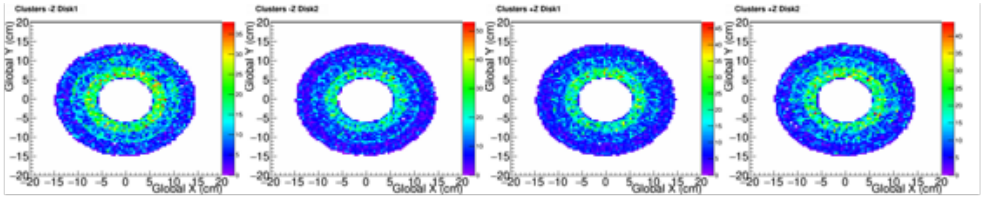
Dew point temperature in pixel detector volume



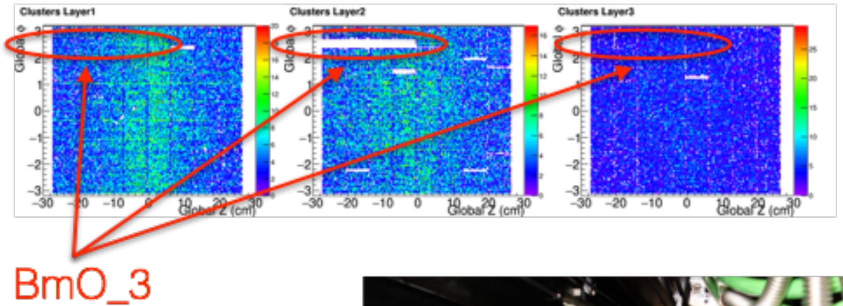


Tracker Operations

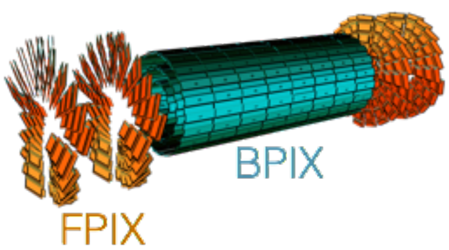
Excellent performance at -10 degrees (pixels) -15 (silicon strip) throughout 2015

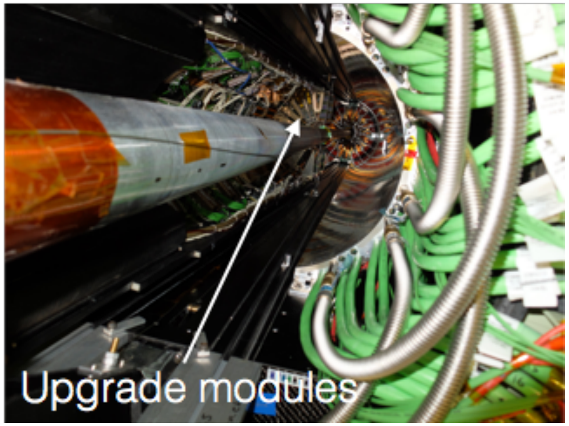


- Both detectors running smoothly



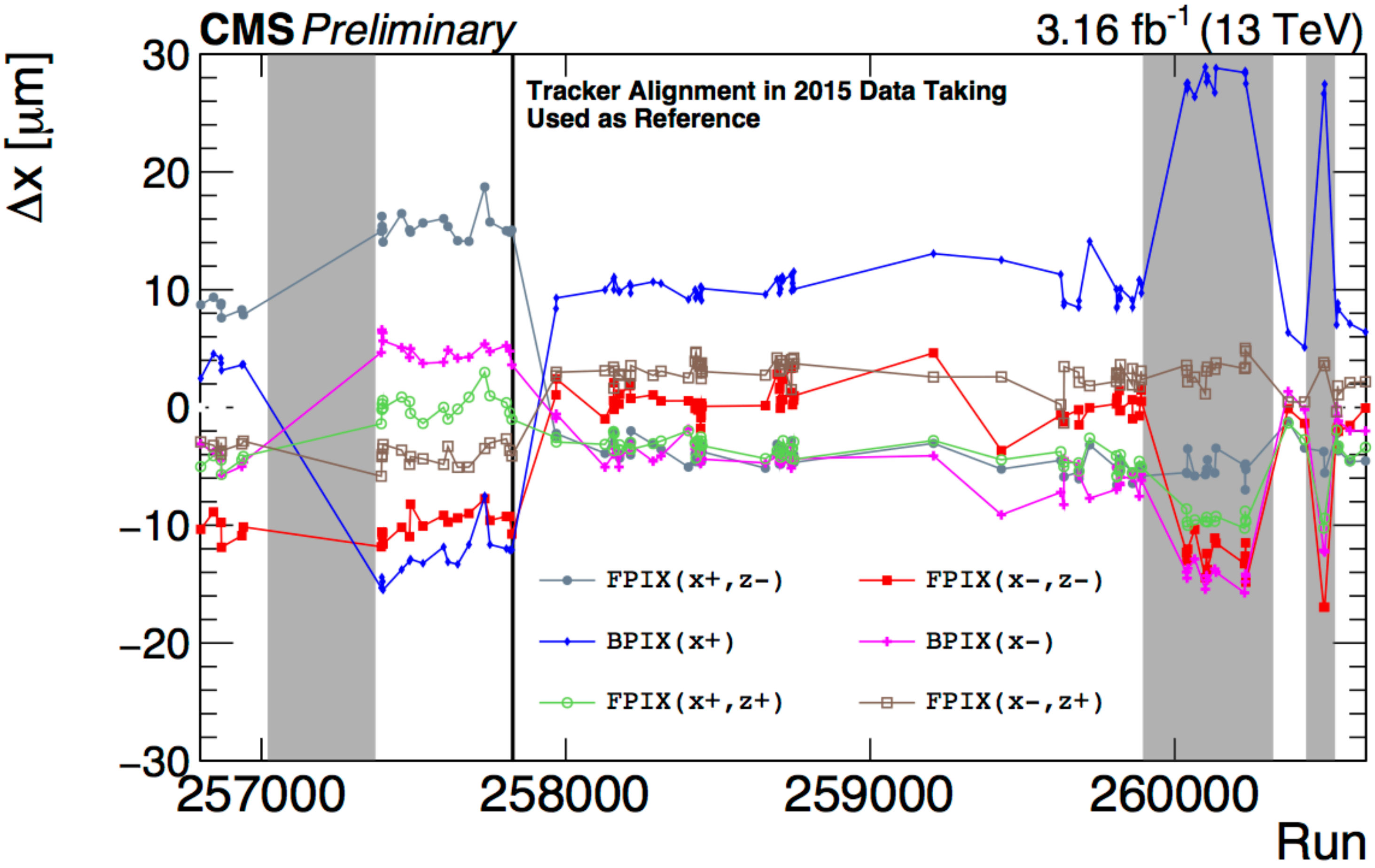
- Minor Pixel sector problem limited to only 1 layer out of 3
  - Negligible effect on track seeding and b-tagging and will be taken into account in MC



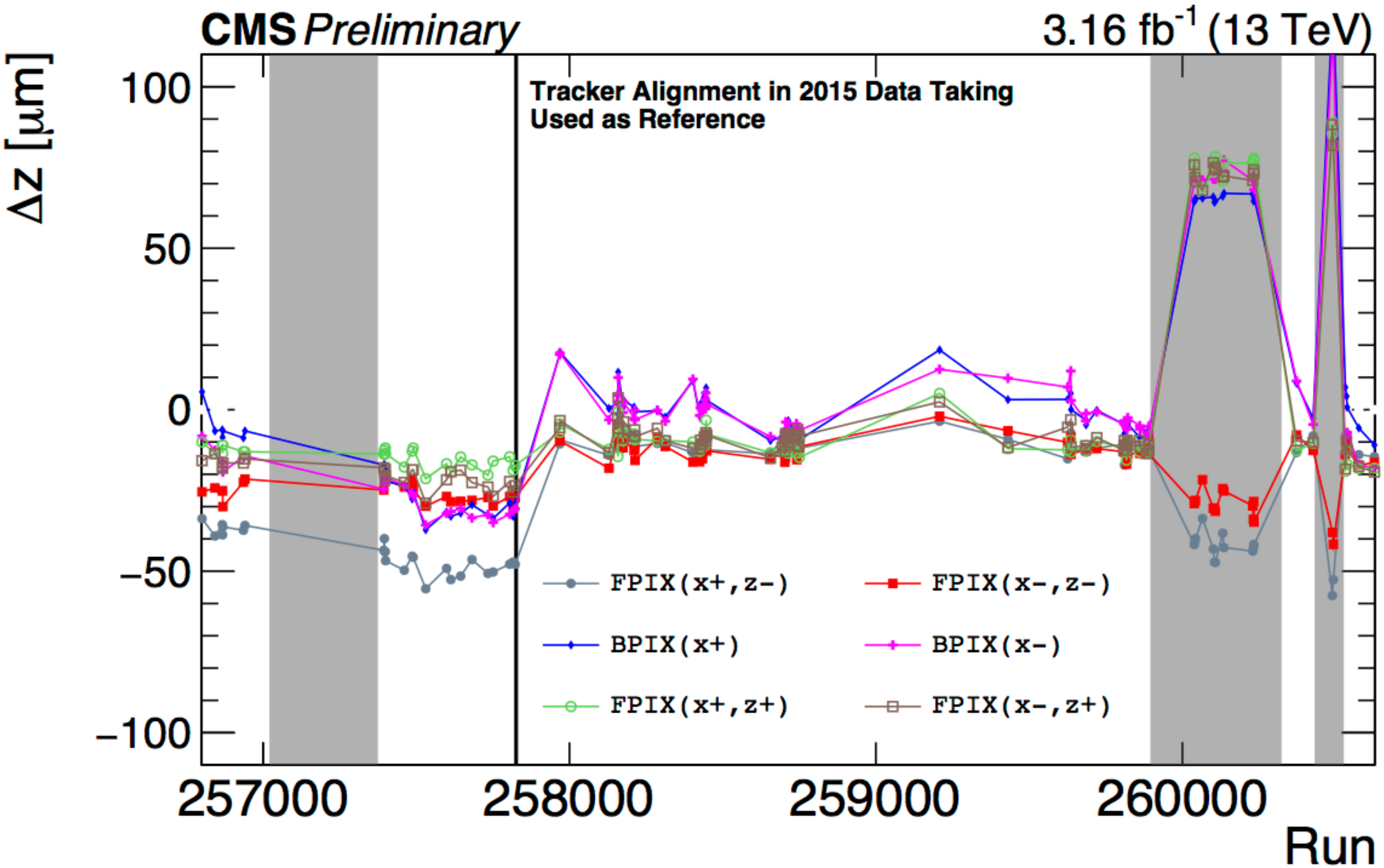


✓ Reading out prototype Phase I upgrade modules installed in FPIX
  - firmware development in realistic data taking conditions
  - Ensure CMS has fully debugged readout with new Phase I detector (2017)

Pixel movements during magnet cycles



Pixel movements during magnet cycles

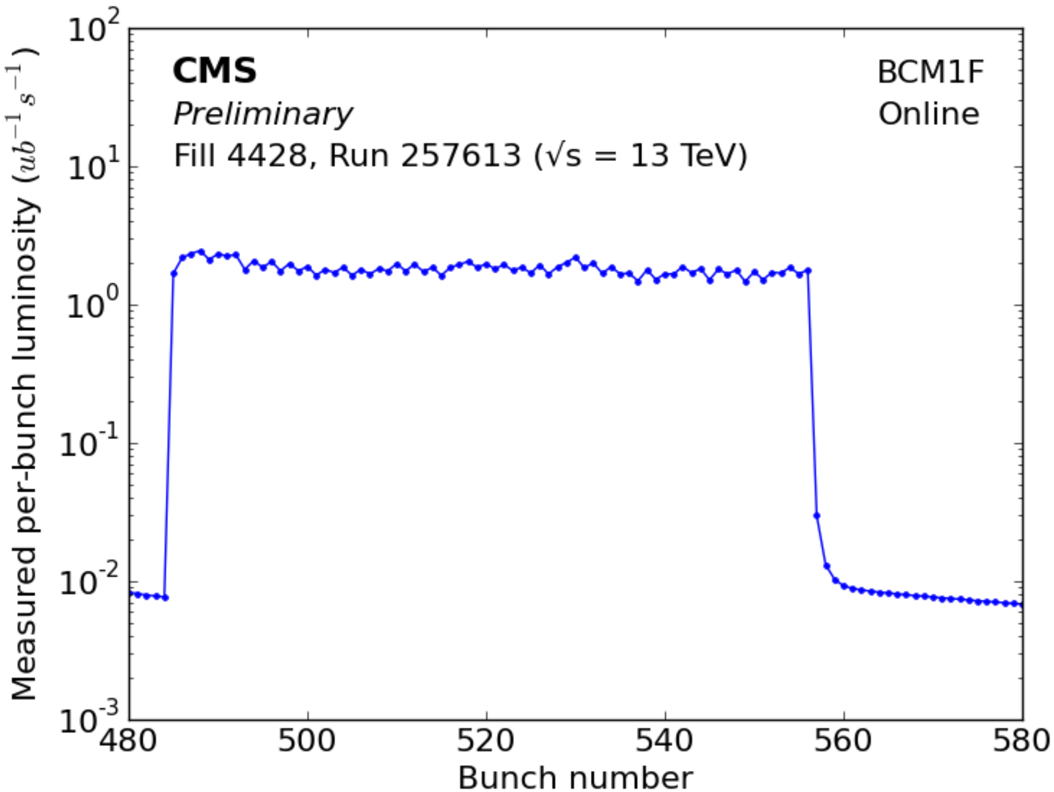


LUMINOSITY

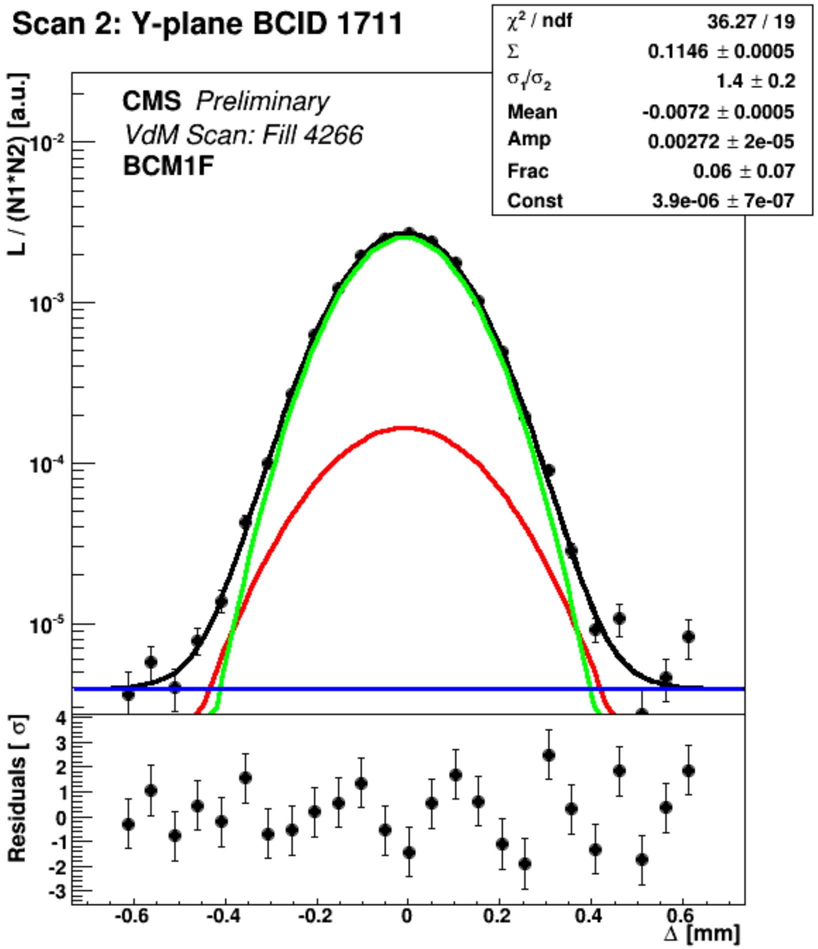
Luminosity – detector performance - linearity

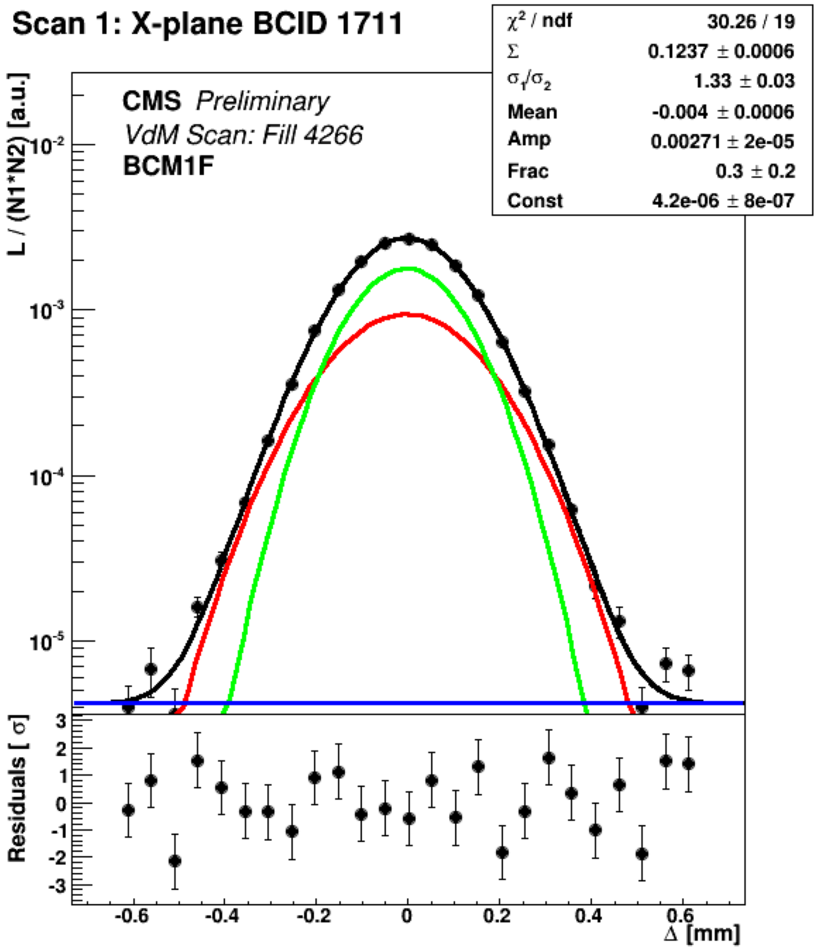
CMS sends per bunch luminosity to the LHC at 0.5 Hz from 3 online luminosity systems

- Below example from BCM1F, where the contribution of luminosity products in the bunch crossing after the colliding bunch is measured to be less than 1.5%

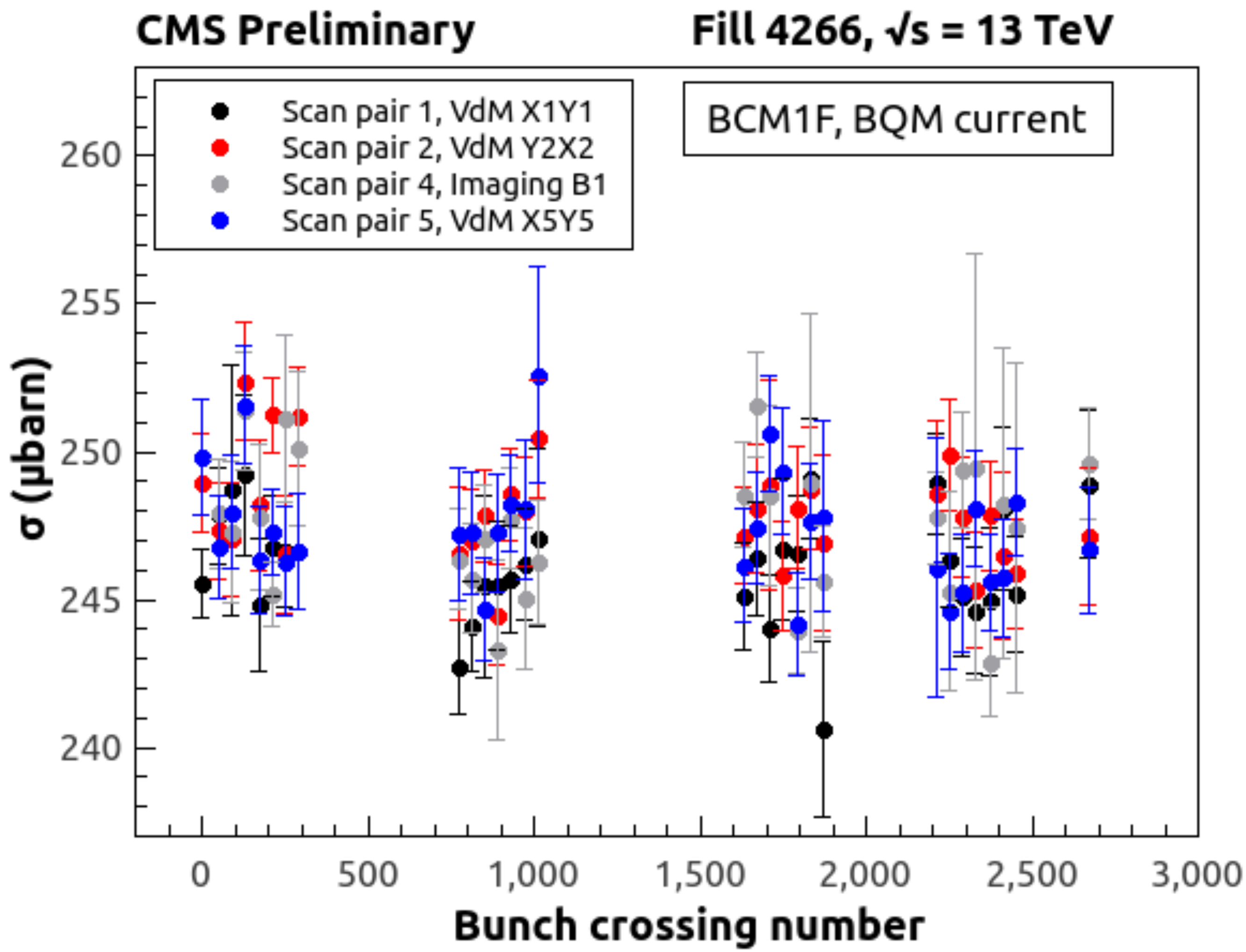


Luminosity – detector performance

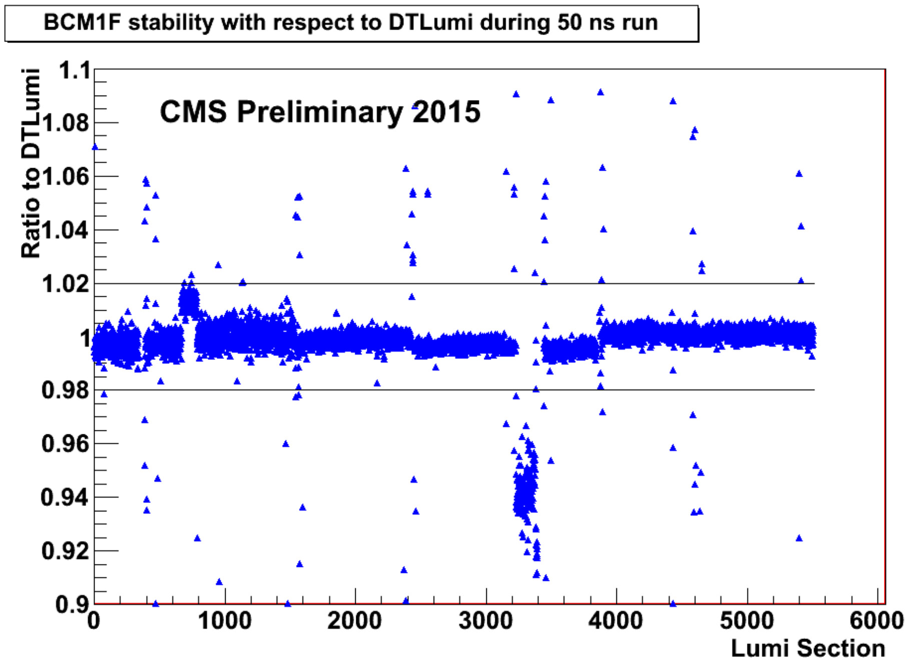


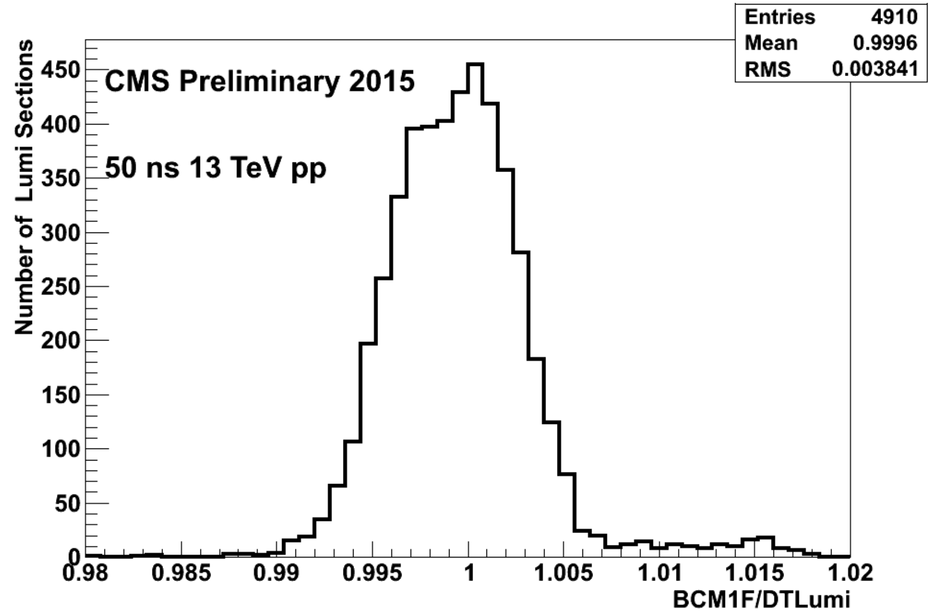


Luminosity calibration using BQM for current normalisation



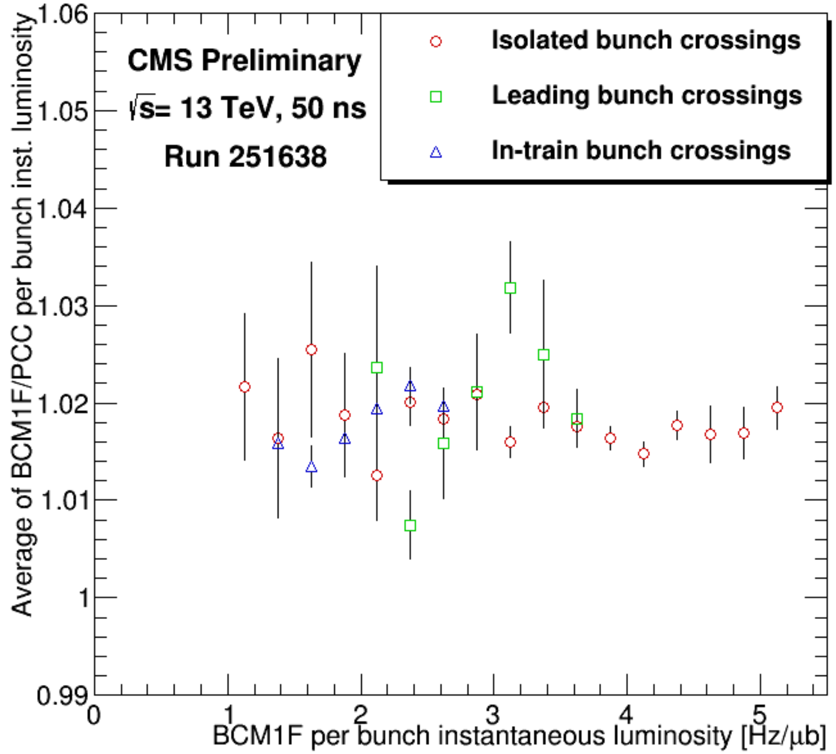
BCM1F luminosity relative stability with respect to DTlumi Collisions 2015 at 13 TeV, 50 ns data





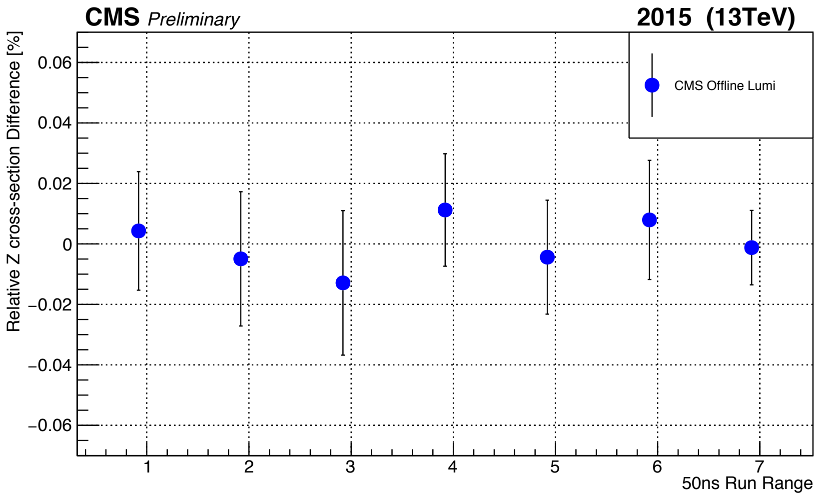
The ratio of luminosity measured from the BCM1F diamond array to that estimated from the rate of muon trigger candidates measured with Drift Tube barrel muon detector and associated trigger electronics (DTLumi) for all Lumi Section periods (~23.3 s) of the 50 ns 2015 pp run, as well as the profile of the same ratio across lumi sections. The group of low points corresponds to the low pileup data (end of fill 3996), where the bias comes from DTLumi, which is less sensitive at low luminosity values. Fill boundaries are visible as slight discontinuities; these variations are within the current uncertainty on the luminosity. The stability of BCM1F in this data is confirmed comparing to other luminometers (not shown). The large excursions come from Lumi Sections at the beginning of the fill not used for physics, where the imperfect synchronization of the time periods between the two luminometers plays a role.

Linearity of BCM1F with corrected Pixel cluster counting



The ratio of BCM1F luminosity to Pixel Cluster Counting (PCC) luminosity is flat over a wide range of instantaneous luminosity, for isolated, leading, and in-train bunch crossings. The value plotted is the average ratio of the points falling into a given instantaneous luminosity bin; the error bars represent the standard error on the mean. The co-linearity of these two detector systems is used to quantify the linearity components of the systematic uncertainty in luminosity measurement for the 50ns data.

Relative stability of luminosity for 50ns from Z-counting



$$\frac{\sigma^{Z}_{\mathrm{avg}} - \sigma^{Z}(\mathrm{RunRange})}{\sigma^{Z}_{\mathrm{avg}}}$$

The stability of CMS Offline luminosity is measured using yields of Z bosons decaying into two Muons during the 50ns data-taking period. Muons are required to have a transverse momentum higher than 25 GeV and to be within 2.4 absolute pseudorapidity. The plot shows the relative difference of Z cross-section measurements performed in 7 successive 50ns data-taking periods with respect to the average cross-section. The statistical uncertainties of the reconstruction, selection and trigger efficiency estimates for Z bosons decaying into two Muons and the statistical uncertainty of the yields themselves are added in quadrature and correspond to the error bars in this plot. CMS offline luminosity is measured with BCM1f with a precision of 4.8%.

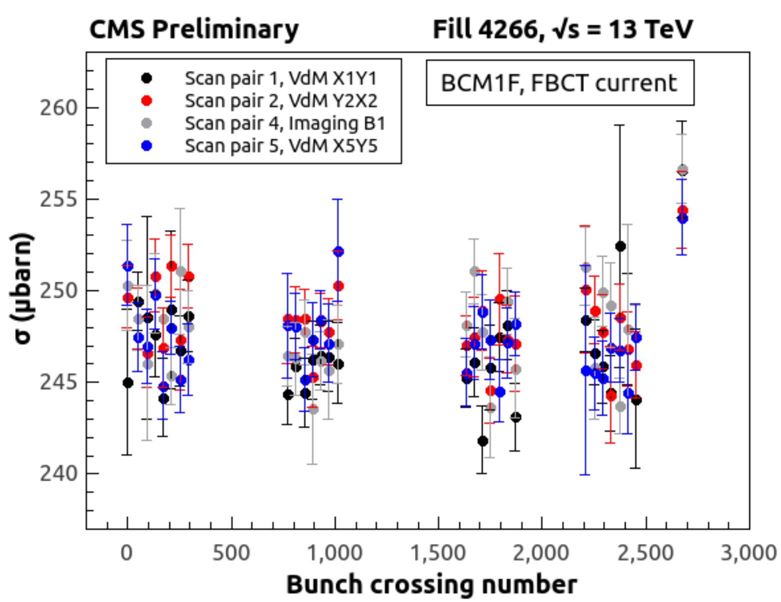
Luminosity calibration

CMS sends online per-bunch luminosity to the LHC at a frequency of 0.5 Hz.

- Multiple detectors useful to understand beam and detector systematics
  - PLT, HF-lumi, BCM1F, pixel cluster counting

Each Luminometer calibrated offline using the Van der Meer (VDM) scan technique

VDM-calibrated-BCM1F used as primary offline luminometer for physics for 50 ns recorded data.

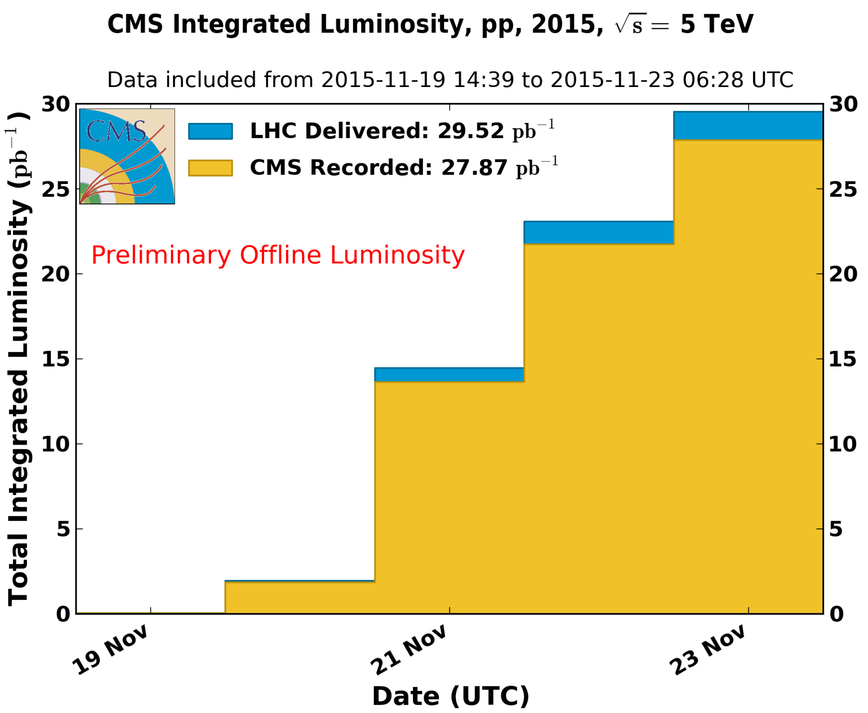


	Source	Uncertainty [%]
VDM calibration using fill 4266		
	BCID variations	1
	Reproducibility between scans	1
	Length scale	0.5
	X/Y correlations	2
	Beam-beam corrections	0.7
	Bunch current	0.3
	Ghosts, Satellites	0.2
Detector behavior during 50 ns		
	Linearity and stability	4
	TOTAL uncertainty (for 50 ns)	**4.8**

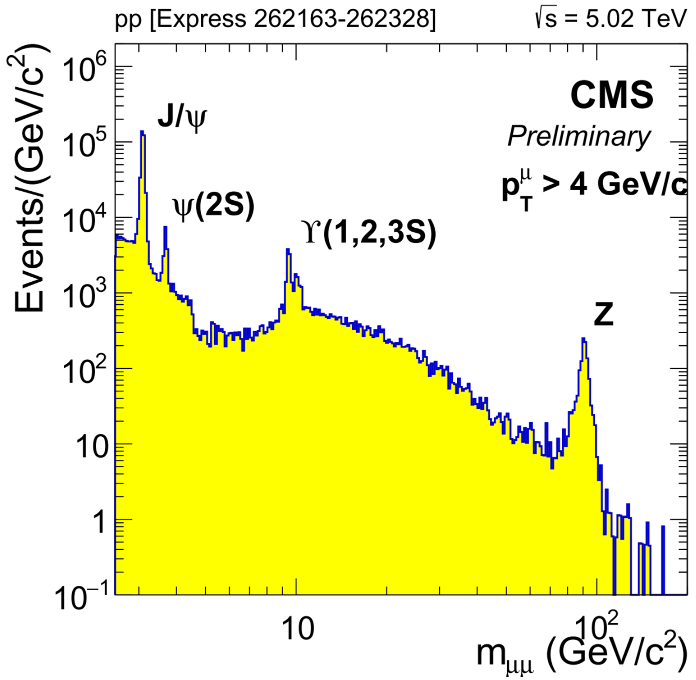
HI AND LOW ENERGY P-P

Proton-Proton reference run @ 5.02 TeV

28 pb-1 of data recorded for physics @ 5.02 TeV with B=3.8 T



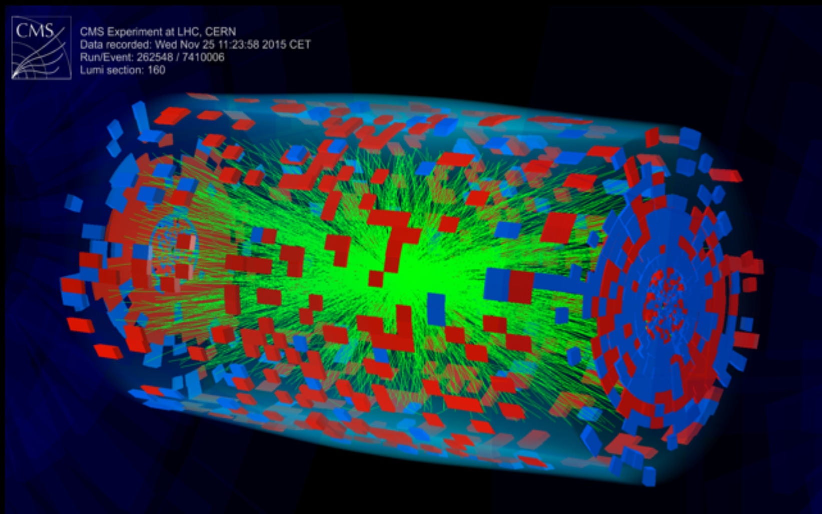
Quick look at data quality from di-muon spectrum from express stream



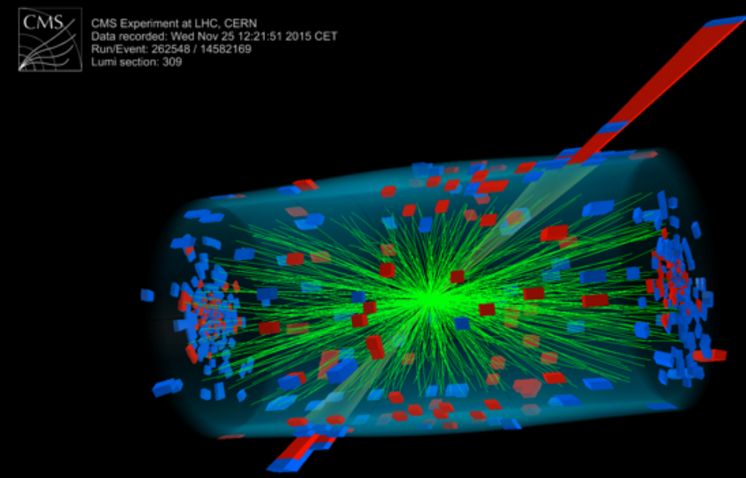
✓ *94 % efficient in recording data for Pb-Pb reference run … excellent availability of the LHC to maximise delivered luminosity to the experiments! Congrats to LHC crew!*

Event displays from PbPb collisions

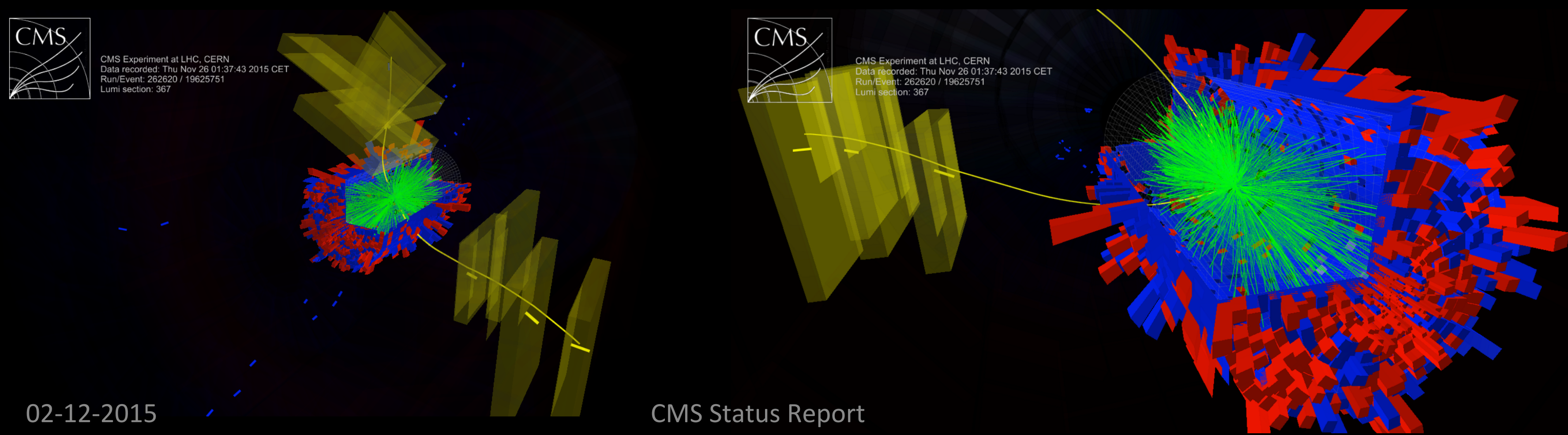
Head-on collision



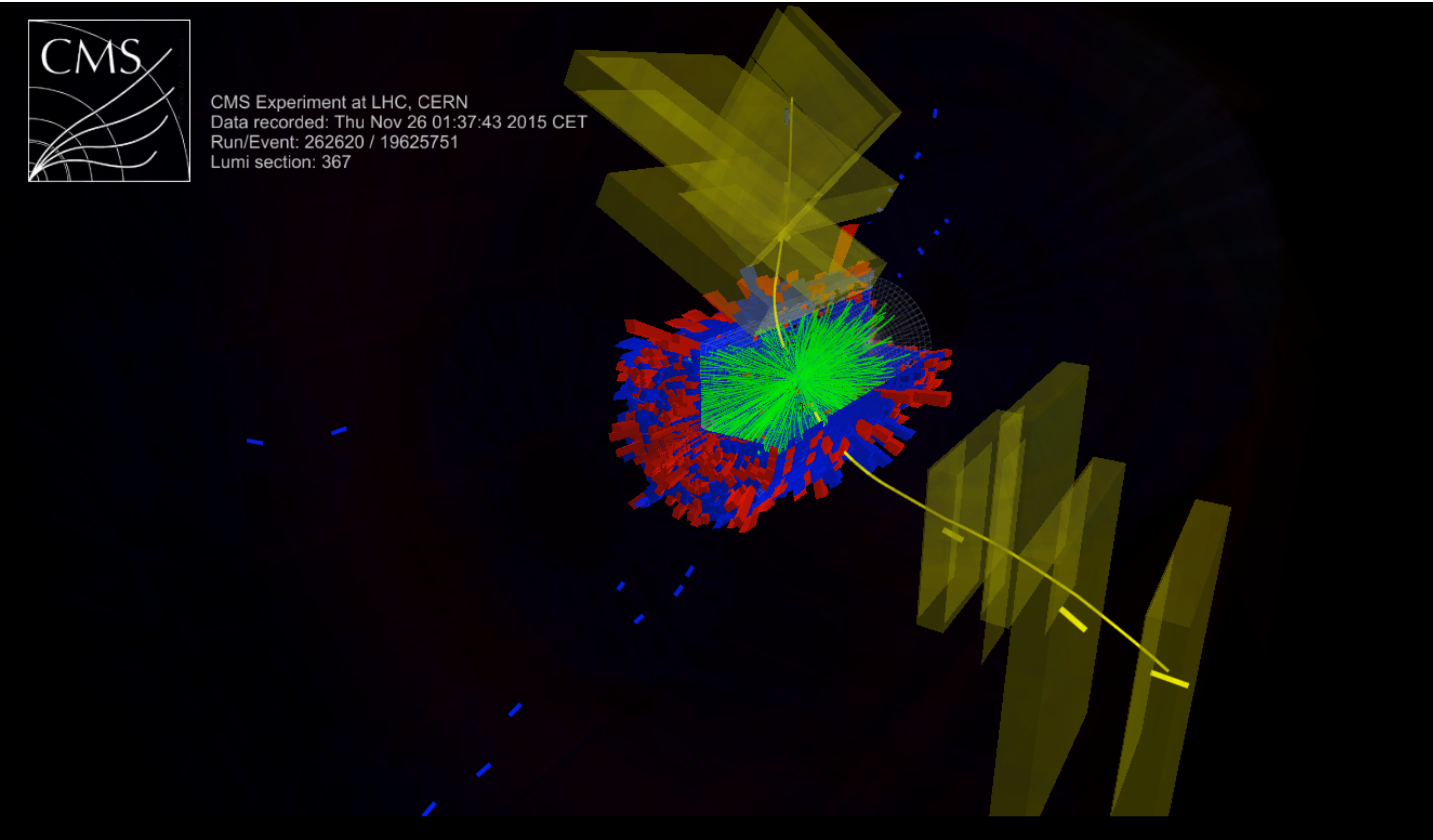
The first dijet event



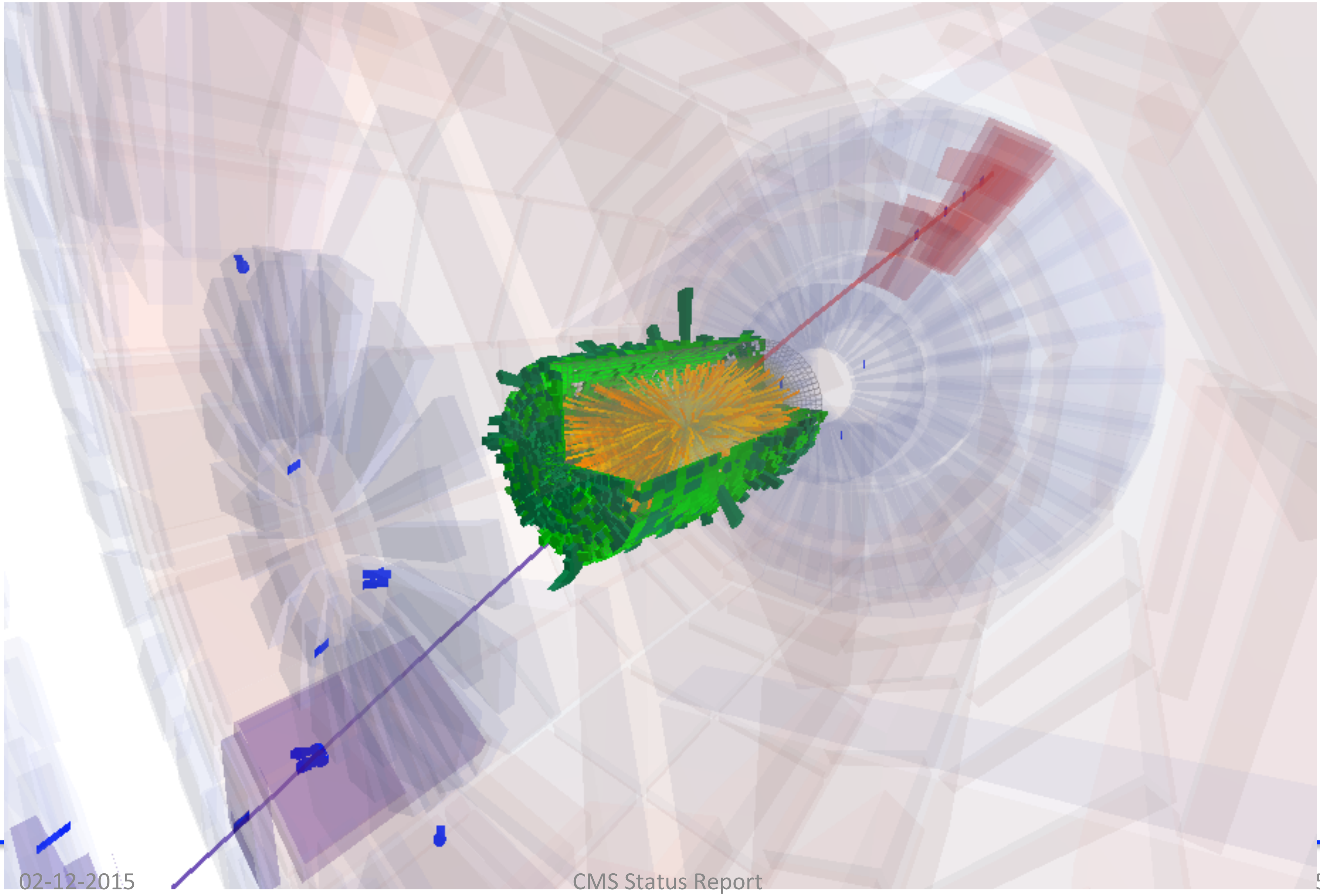
The first Upsilon Candidate



PbPb: first upsilon candidate



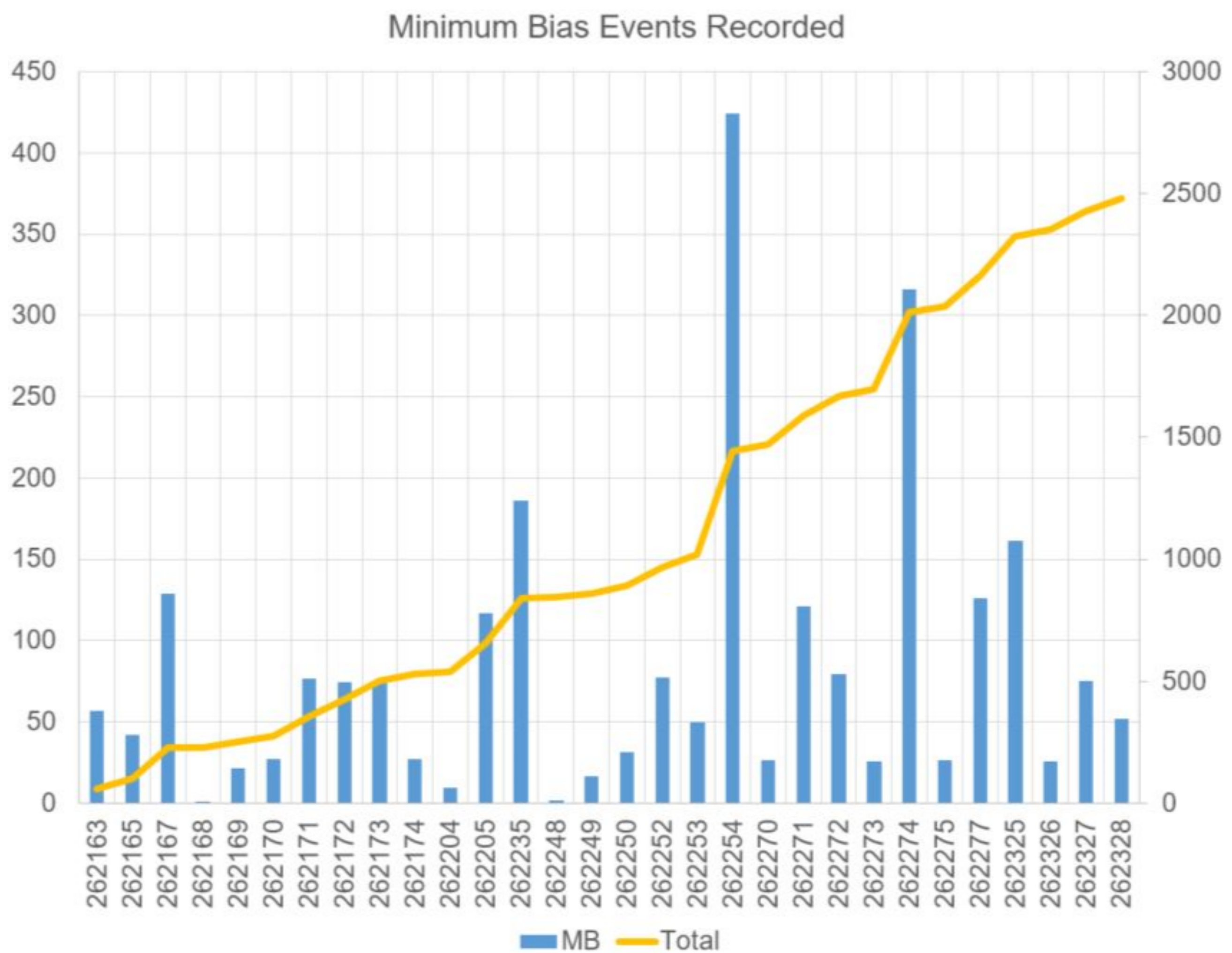
Z boson event in PbPb collision at 5 TeV



PbPb: first Z candidate

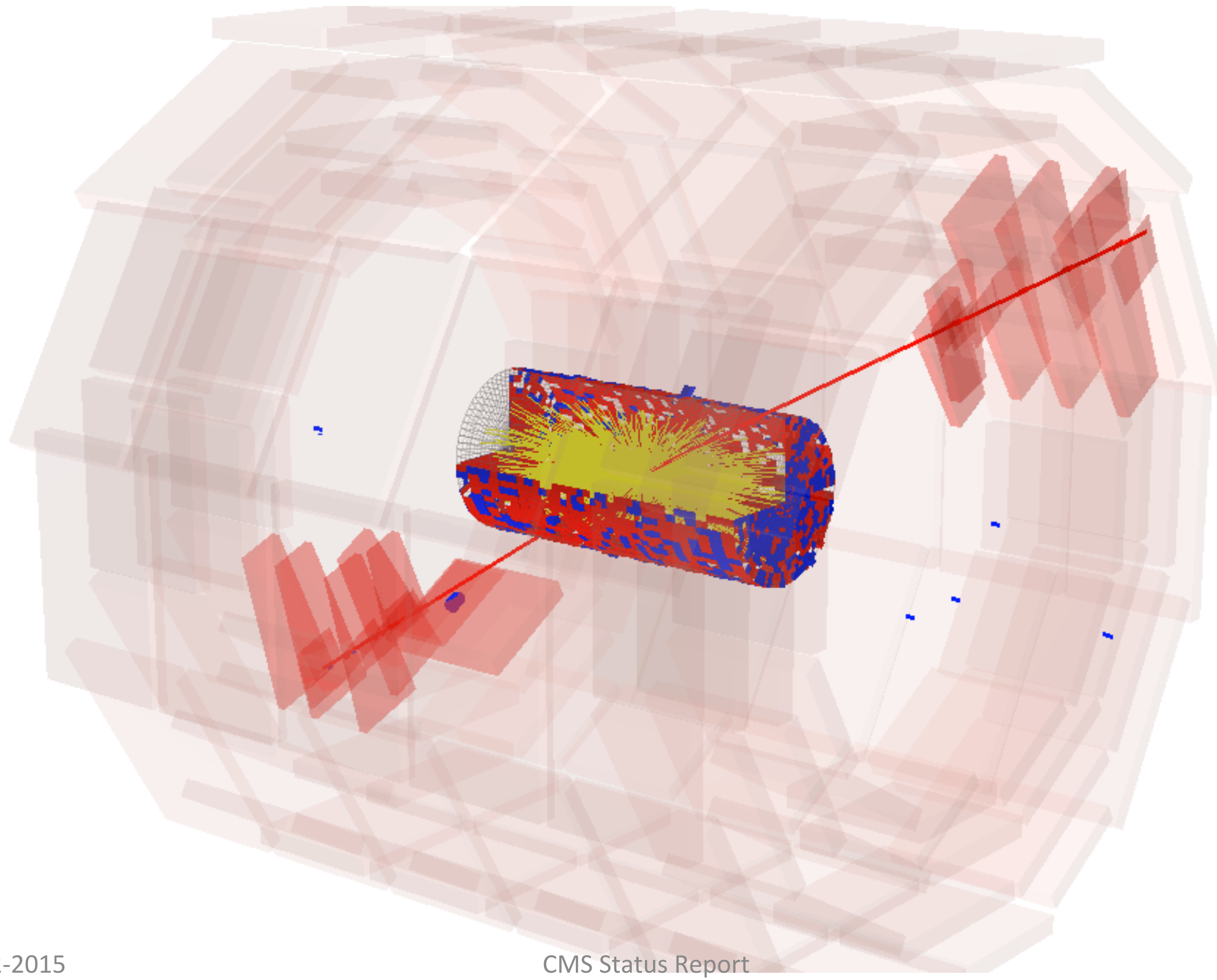
- Dimuon mass 92GeV
- 2 back-to-back muons, pt=22 and 27GeV/c

2.5 billion minimum-bias events recorded!!

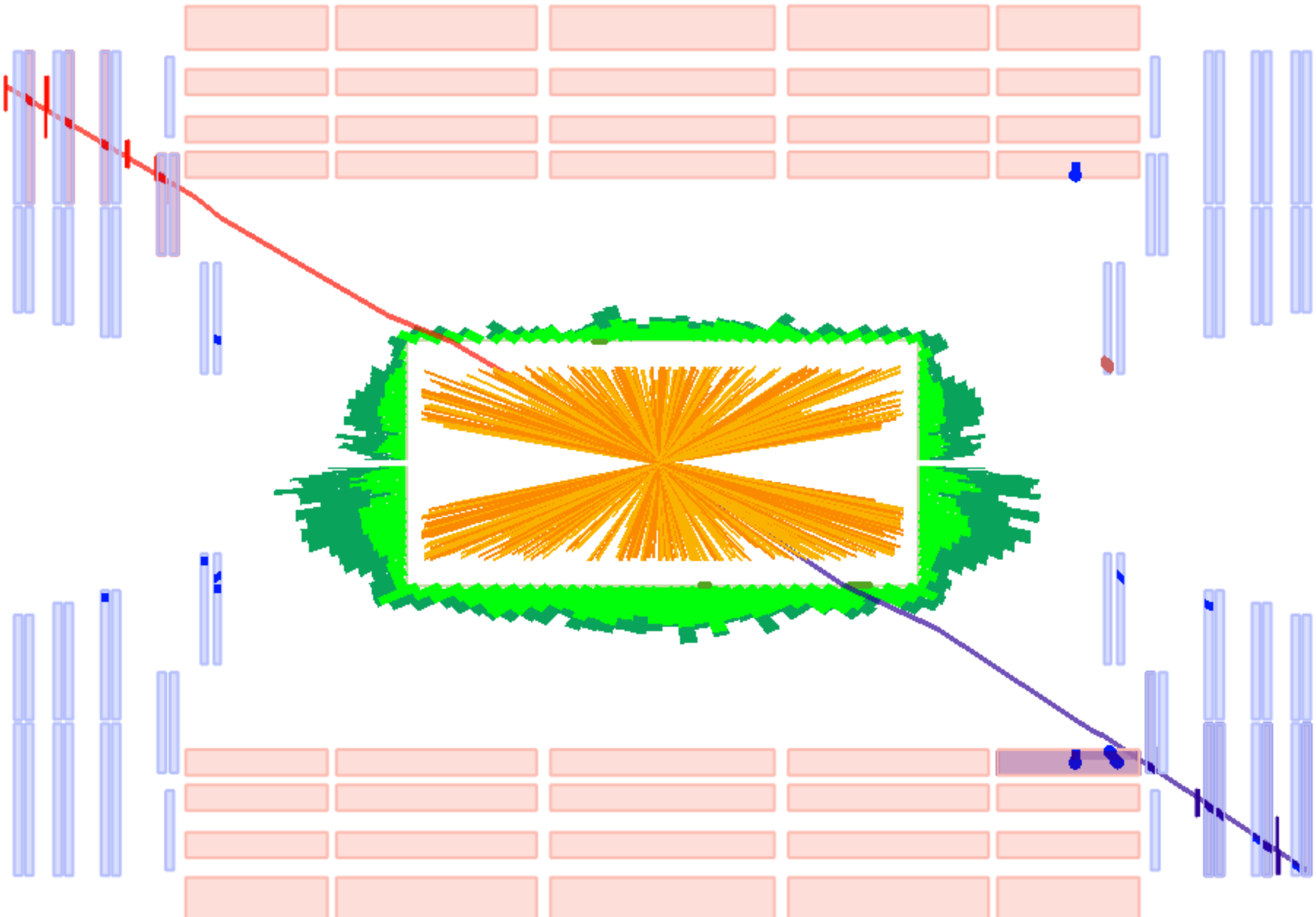


Important reference for low p_T heavy flavor mesons

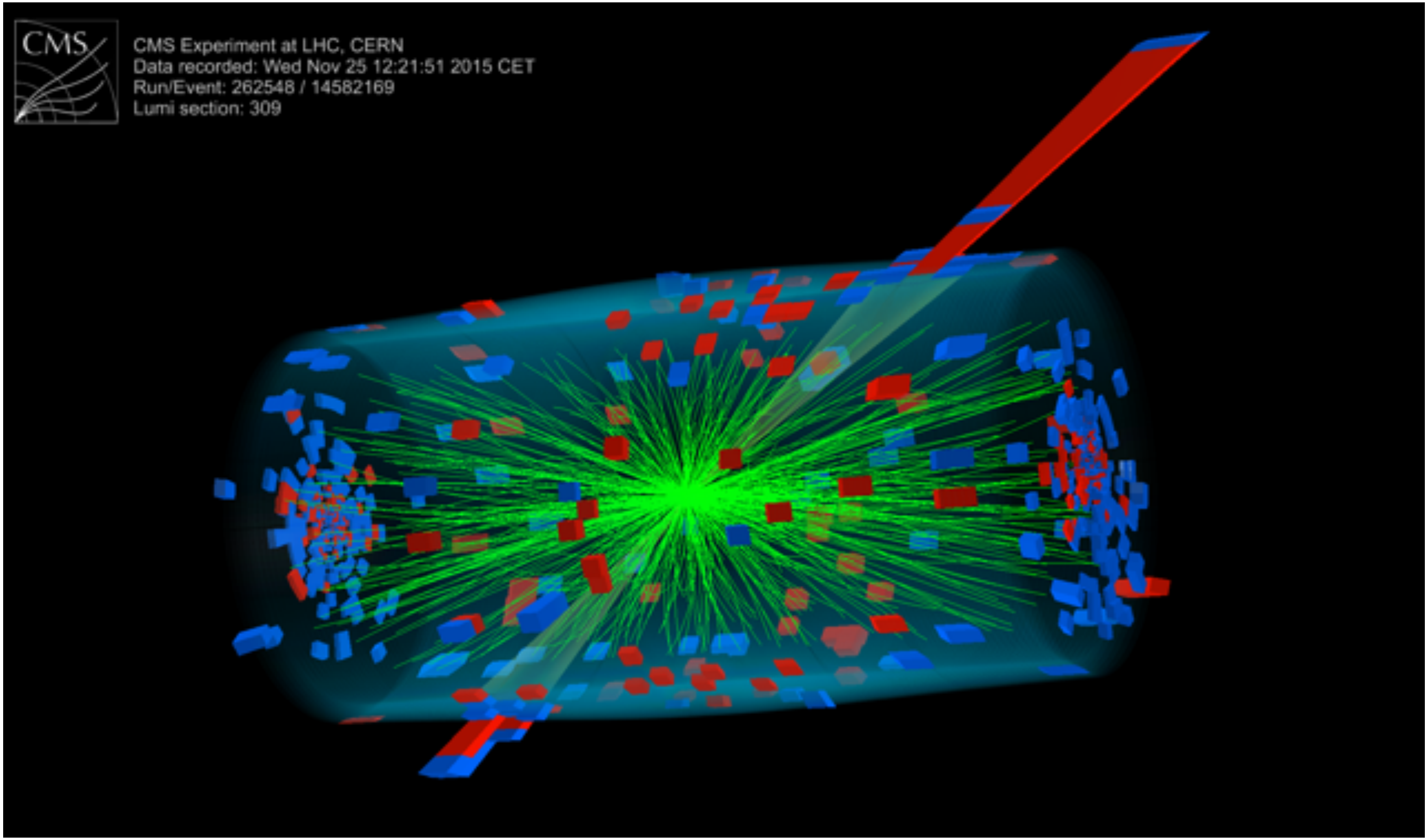
Z boson event in PbPb collision at 5 TeV



Z boson event in PbPb collision at 5 TeV



Event displays from PbPb collisions

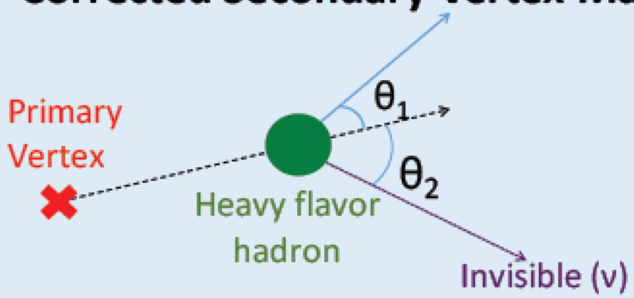


PHYSICS RESULTS

Corrected secondary vertex mass

Differences between b-jet and c-jet tagging

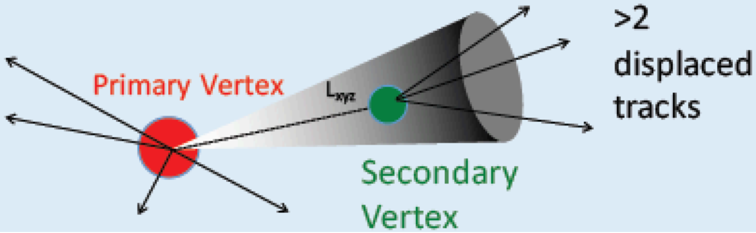
- **Corrected Secondary Vertex Mass**



$$M_{corr}(\min) = \sqrt{M_1^2 + p_1^2 \sin^2\theta_1} + p_1 \sin\theta_1$$

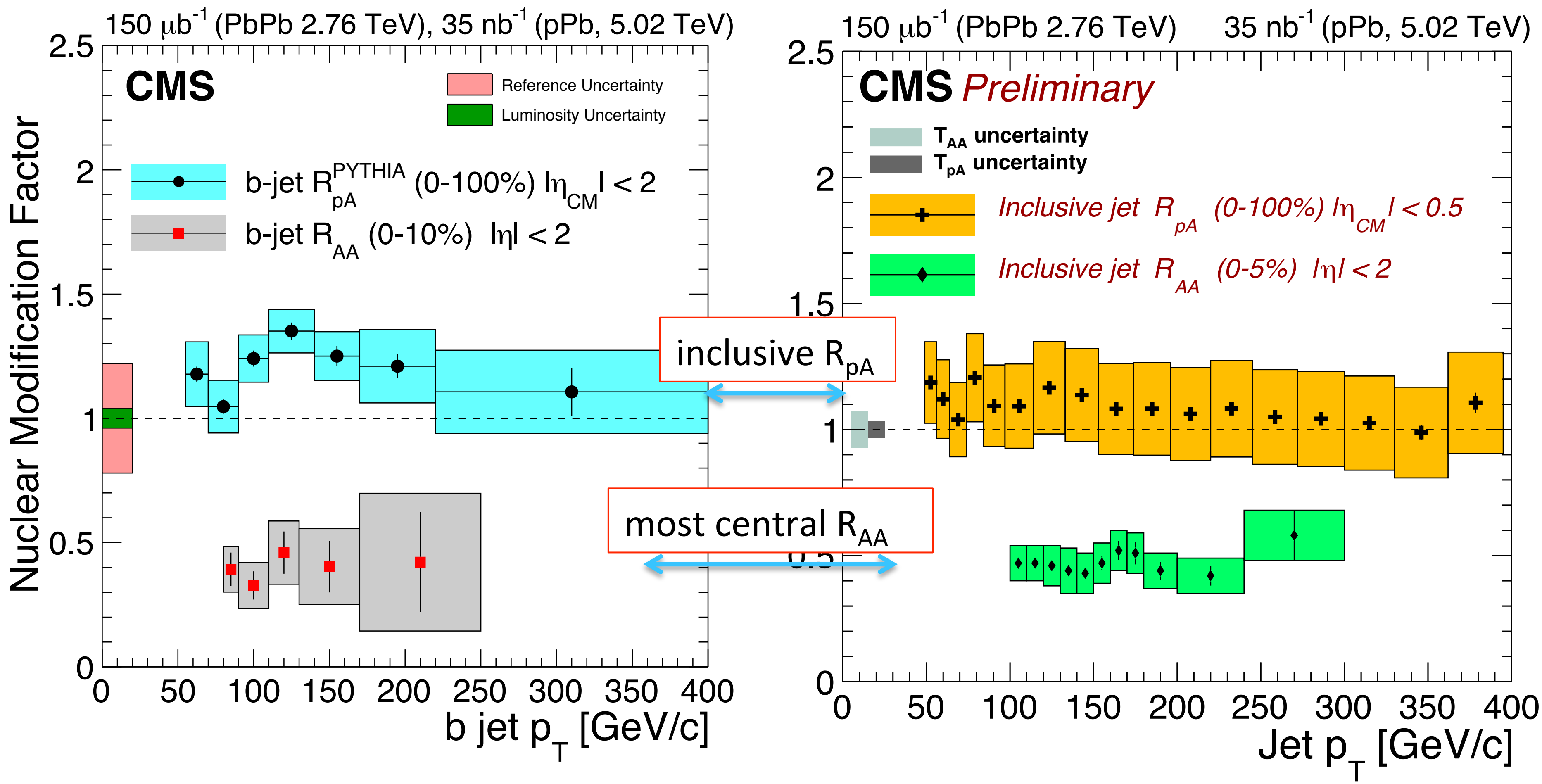
- Partially corrects for neutrals/invisibles in the secondary vertex decay via comparing the reconstructed particle momentum to the vertex decay length vector
- This variable calculates the minimum possible missing energy of the decay

- **Secondary Vertex "High Purity" Working Point**



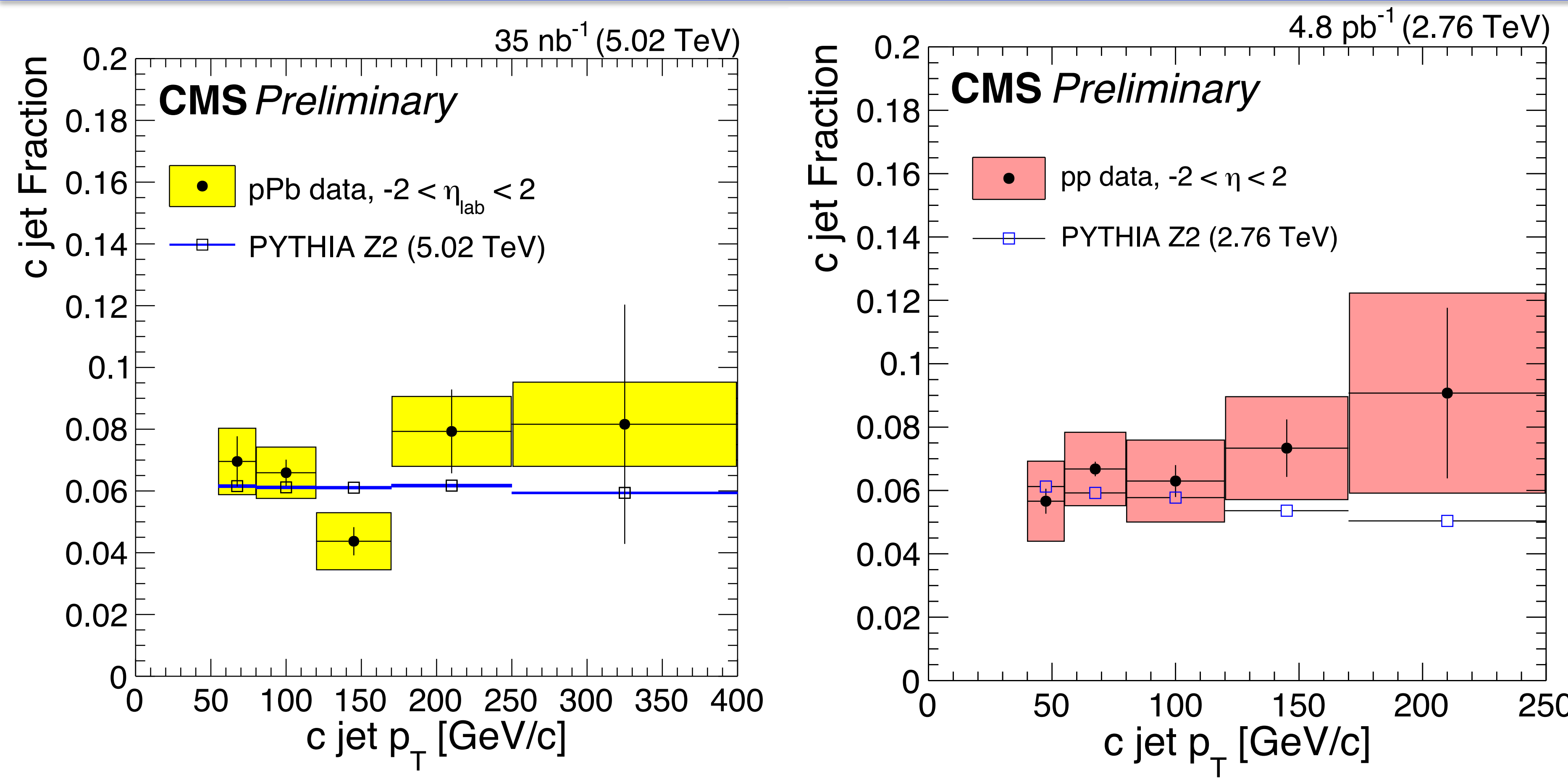
- Requires a 3+ body decay from the reconstructed secondary vertex.
- Reduction of the light jet fraction in the tagged sample 3x -> more precise charm jet template fitting

Pre-QM Heavy Flavored Jet Status



- CMS showed b-jets in PbPb (and pPb) are modified to a similar extent as light jets
- Can we say anything about charm jets? *(yes)*

C-Jet Fraction Results



- Claim c Jet fraction is consistent with PYTHIA to within systematic uncertainties both in pA and pp

Calculating the Heavy Flavour Jet fraction

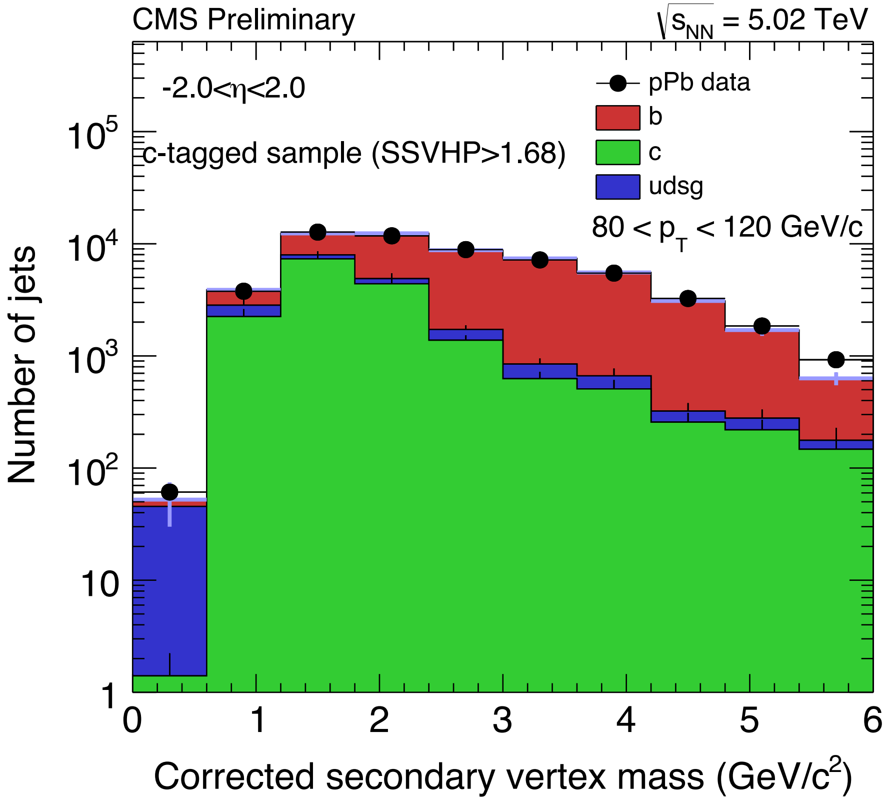
$$\varepsilon_c = \frac{C_c f_c^{tag} N_{jets}^{ctagged}}{f_c^{untagged} N_{jets}^{untagged}} \quad (1)$$

$$N_{cjets} = N_{jets}^{ctagged} \frac{f_c}{\varepsilon_c} \quad (2)$$

f_c = purity from template fit
ε_c = efficiency of tagger
C_c = Fraction of jets with JP information (=1)

$N^{untagged}$ = Jets that do not pass the tagger
$f_c^{untagged}$ = Purity of anti-tagged jets

- Purity (f_c) is found via fitting distribution of M_{corr}
- Efficiency (ε_c) is found in MC and via the tagging and anti-tagging purity [eq. 1]



Jet tagging efficiency

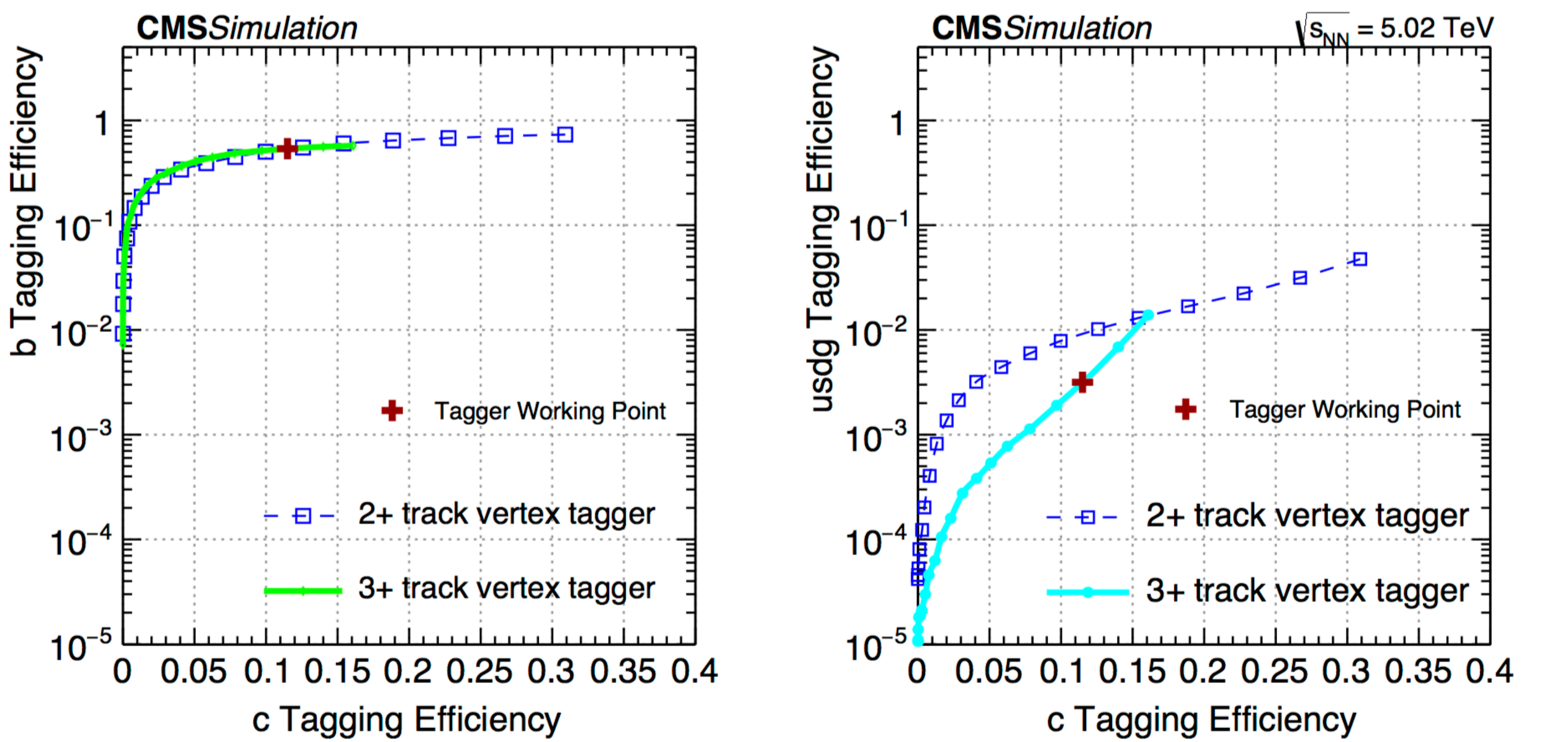
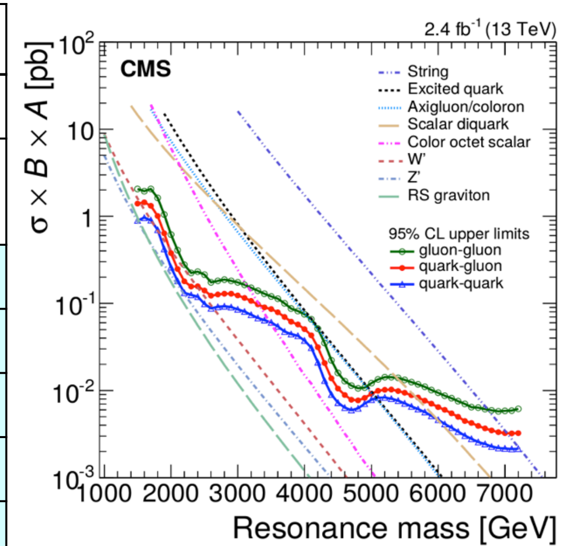


Figure 1: Efficiency curves are plotted for the high purity (HP), and high efficiency (HE) versions of the simple secondary vertex (SSV) tagger for both bottom (left) and light (right) jets as a function of c jet tagging efficiency. The charm-to-bottom discrimination power is virtually unchanged between the SSVHE and SSVHP taggers, while the light jet mistag rate is reduced by a factor of three at the SSVHP working point, shown as the closed red cross on the plot.

EXO-15-001

Dijet resonance search @13 TeV

Narrow	Mass Limits (TeV)			
Resonance	CMS Run 1 (20 fb^{-1})		CMS Run 2 (2.4 fb^{-1})	
Model	Observed	Expected	Observed	Expected
String Resonance (S)	5.0	4.9	7.0	6.9
Scalar Diquark (D)	4.7	4.4	6.0	6.1
Axigluon (A)/Coloron (C)	3.7	3.9	5.1	5.1
Excited Quark (q*)	3.5	3.7	5.0	4.8
Color Octet Scalar (S8)	2.7	2.6	3.1	3.3
Heavy W (W')	1.9, 2.0-2.2	2.2	2.6	2.3
Heavy Z (Z')	1.7	1.8	--	--
RS Graviton (G)	1.6	1.3	--	--



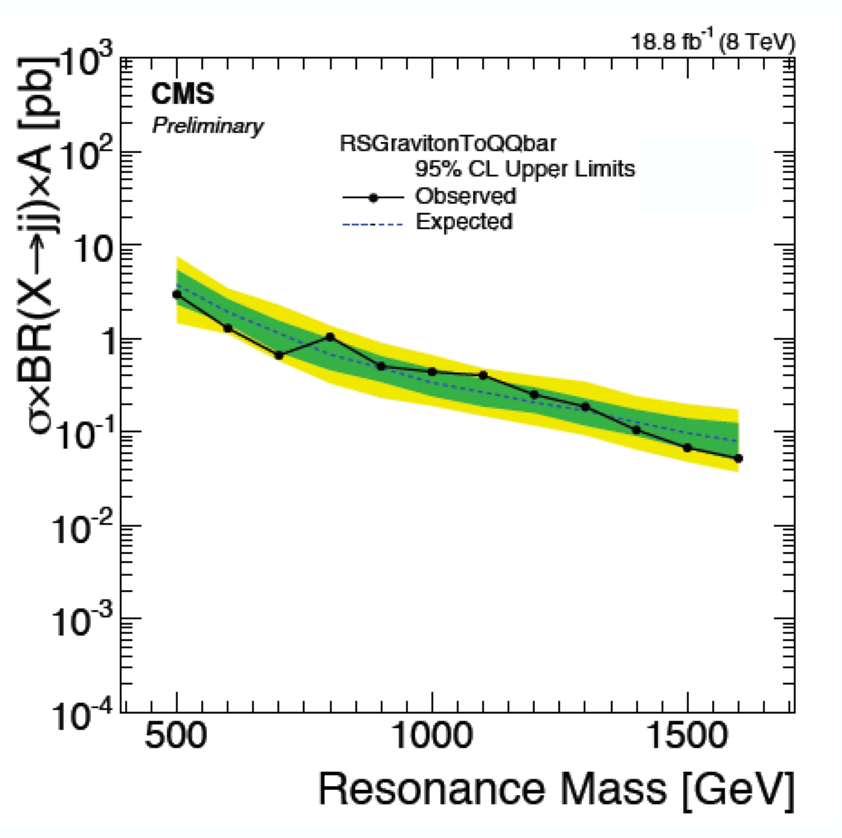
Set upper limits at 95% CL on cross section of qq, qg and gg resonances and compare them with predictions from 8 models of new physics

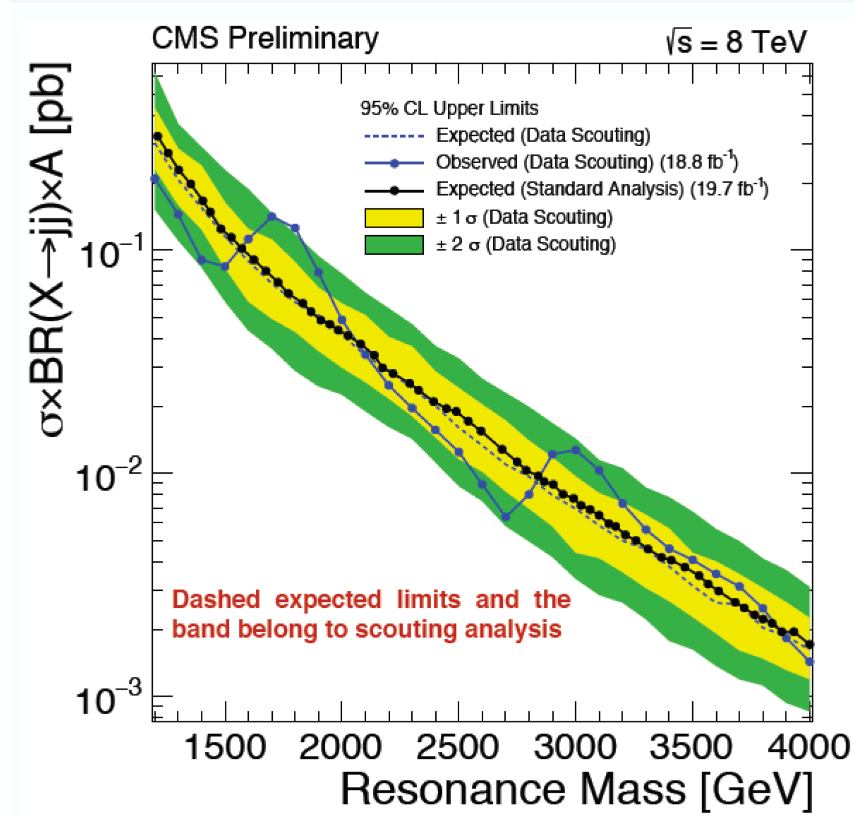
- String Resonances, Excited Quarks, Axigluons/Colorons, Scalar Diquarks, Color Octet Scalars, W', Z', and Randall-Sundrum Gravitons

- CMS limits extend above 7.0 TeV in dijet mass for the first time

Results dijet resonance and comparison standard analysis

upper limits on various production cross sections as a function of the resonance mass



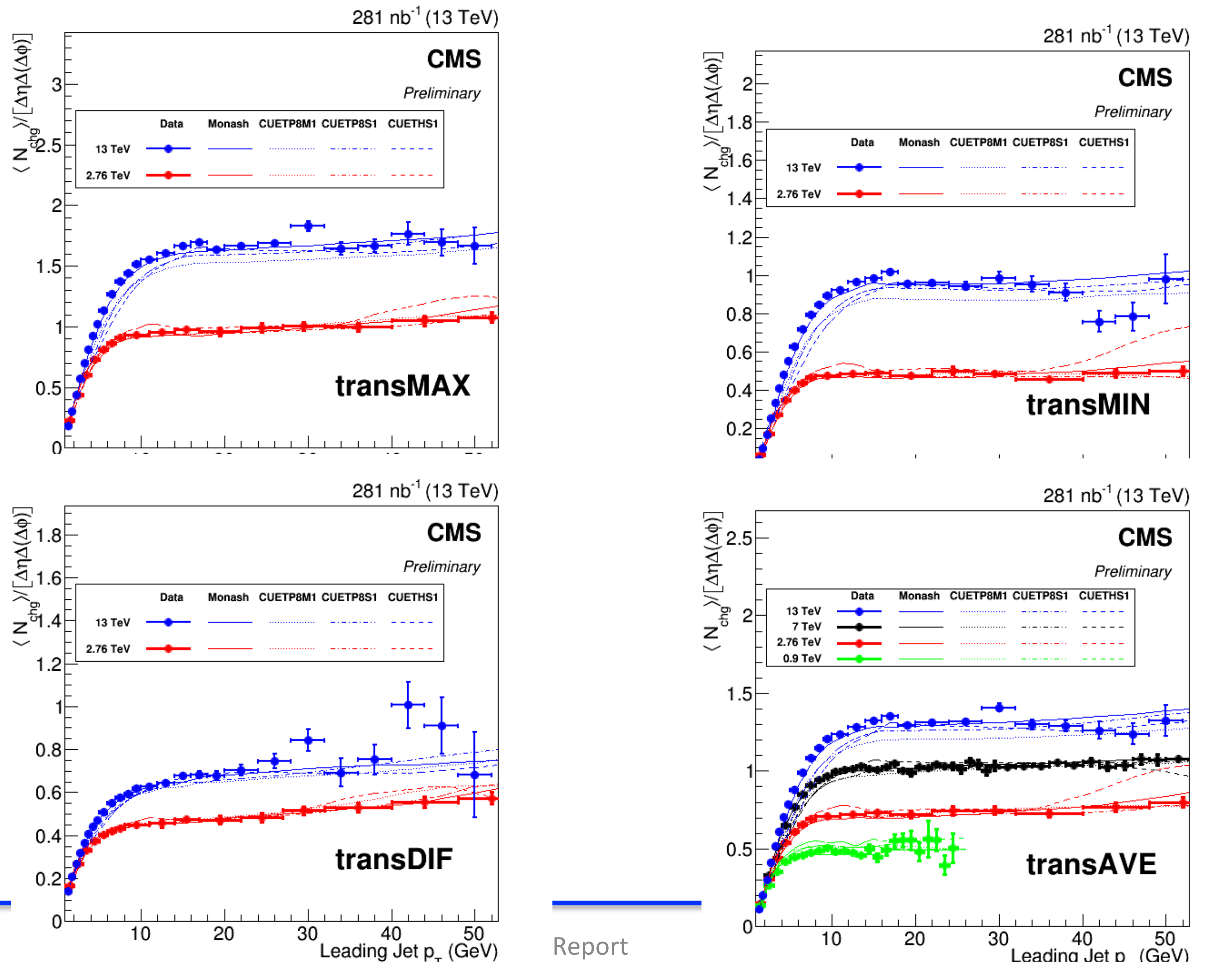


Example on limits on Randall-Sundrum graviton decaying into q-qbar

Comparison shows that the expected limits with scouting agrees well with the limits from standard analysis within the uncertainty band

UE results – Multiplicity density vs leading jet p_T

Monash tune of Pythia8 best describes the energy dependence of the leading jet p_T

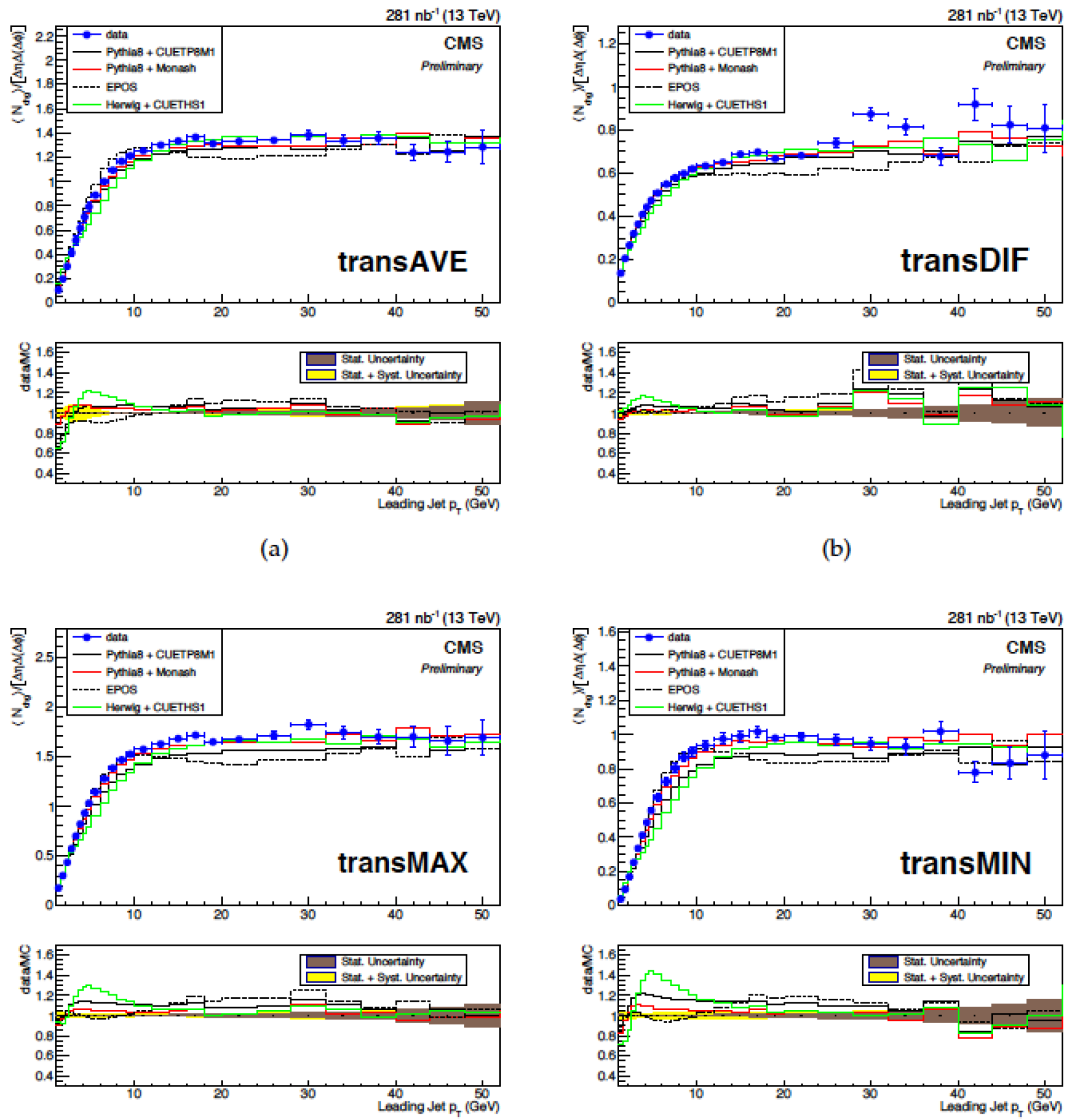


UE results – Multiplicity density vs leading jet p_T

Comparisons of corrected

(a) transAVE,
(b) transDIF,
(c) transMAX, and
(d) trans-MIN

average particle densities with the various simulations as a function of **p**jet$_T$.

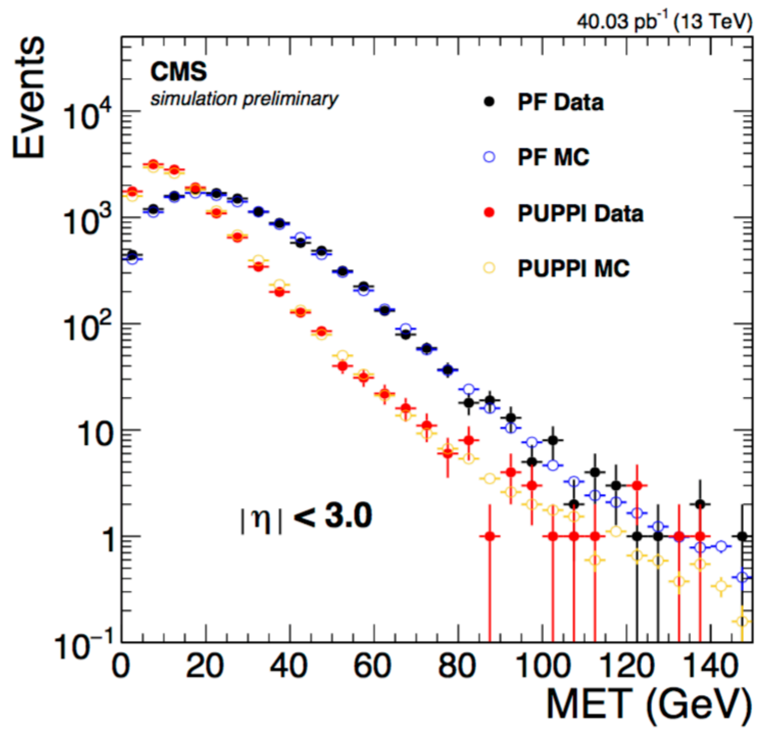


(a) (b) (c) (d)

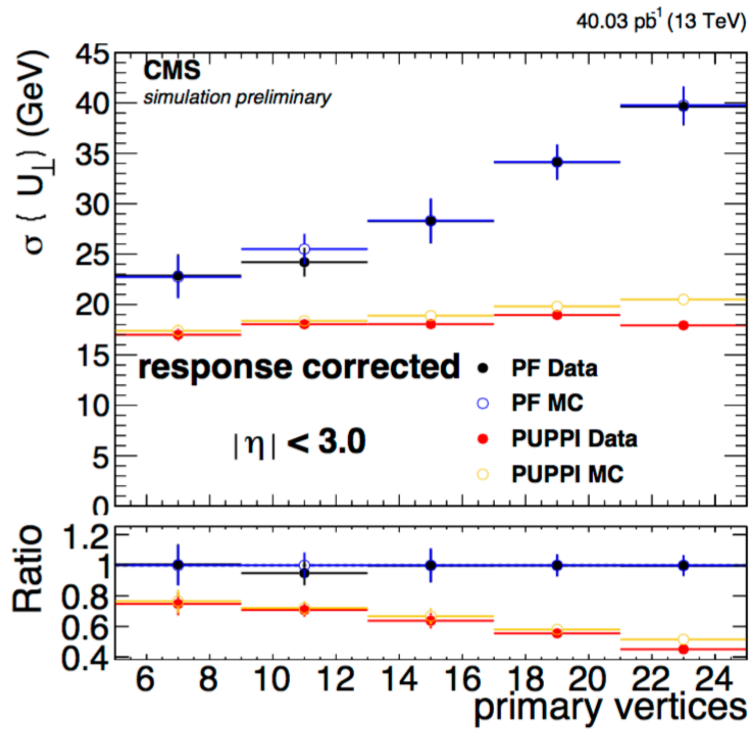
MET resolution, Particle flow with PUPPI

Most effective for low MET and high pileup

https://cds.cern.ch/record/2051942?ln=en



MET from PF and PF PUPPI inputs for data and simulation (log scale)



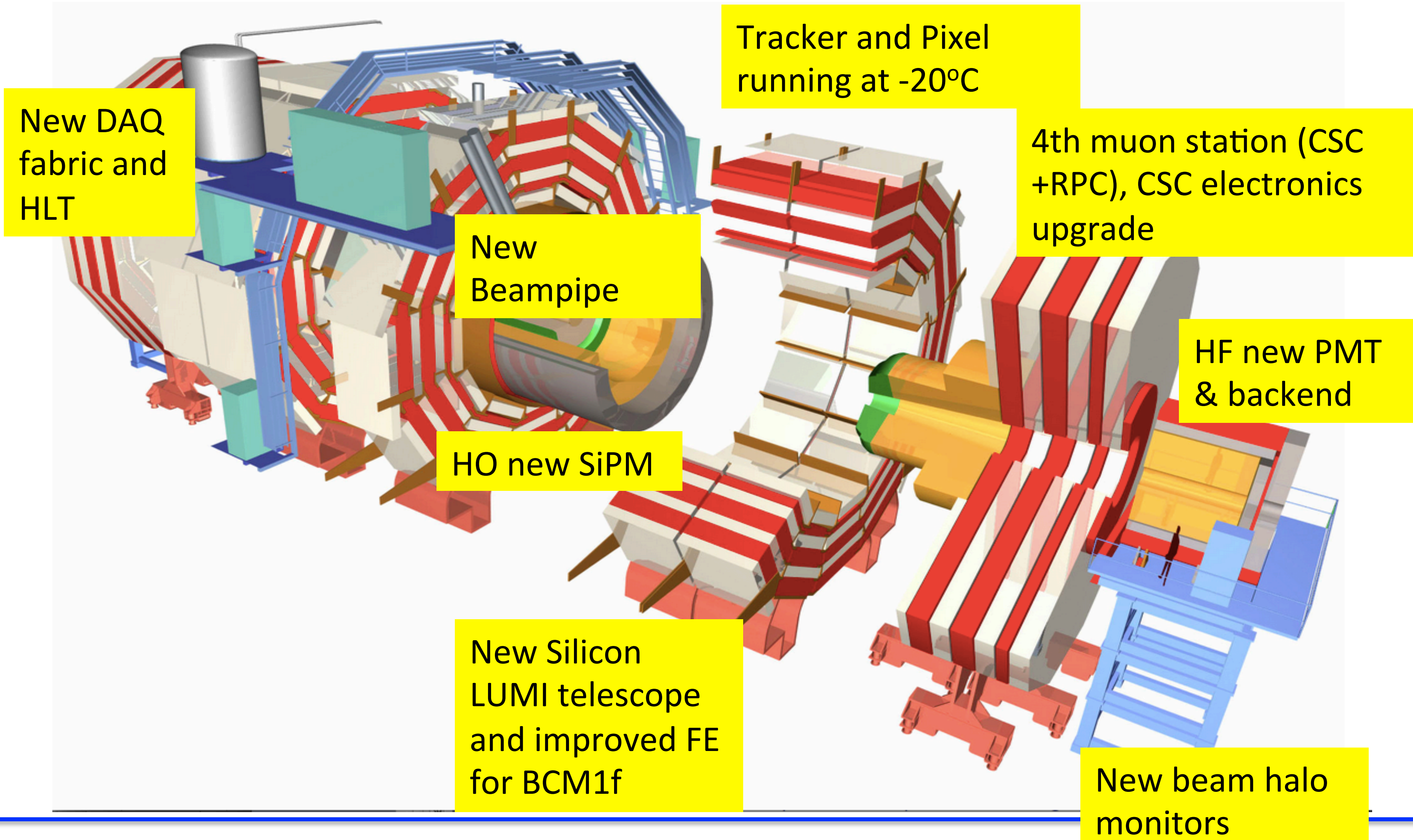
resolution of perpendicular recoil U⊥ for PF and PF PUPPI inputs versus number of reconstructed primary vertices

CMS Upgrades during LS1

All upgrades contributed to improved performance during 2015

- Data acquisition: new architecture, hardware, software
- Trigger Control and Distribution System: new (uTCA)
- Level-1 trigger: new calorimeter trigger (uTCA)
- Electromagnetic calorimeter: new trigger optical links
- Hadronic calorimeter: new SiPMs (HO), new PMTs (HF), HF back-end (uTCA)
- Drift Tube chambers: new trigger electronics
- Resistive Plate Chambers: new chambers
- Cathode Strip Chambers: new chambers & electronics
- Silicon pixels: lower temperature (–10°C) and recovered channels
- Silicon tracker: lower temperature (–15°C)
- Luminosity & Beam monitoring: new pixel luminosity telescope, fast beams conditions monitor and beam halo monitor, bril-daq software

Run II CMS


Tracker and Pixel running at -20°C
New DAQ fabric and HLT
4th muon station (CSC +RPC), CSC electronics upgrade
New Beampipe
HF new PMT & backend
HO new SiPM
New Silicon LUMI telescope and improved FE for BCM1f
New beam halo monitors