First Run 2 Results from CMS

Exploring the Unknown

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Congratulations and many thanks to the LHC Team

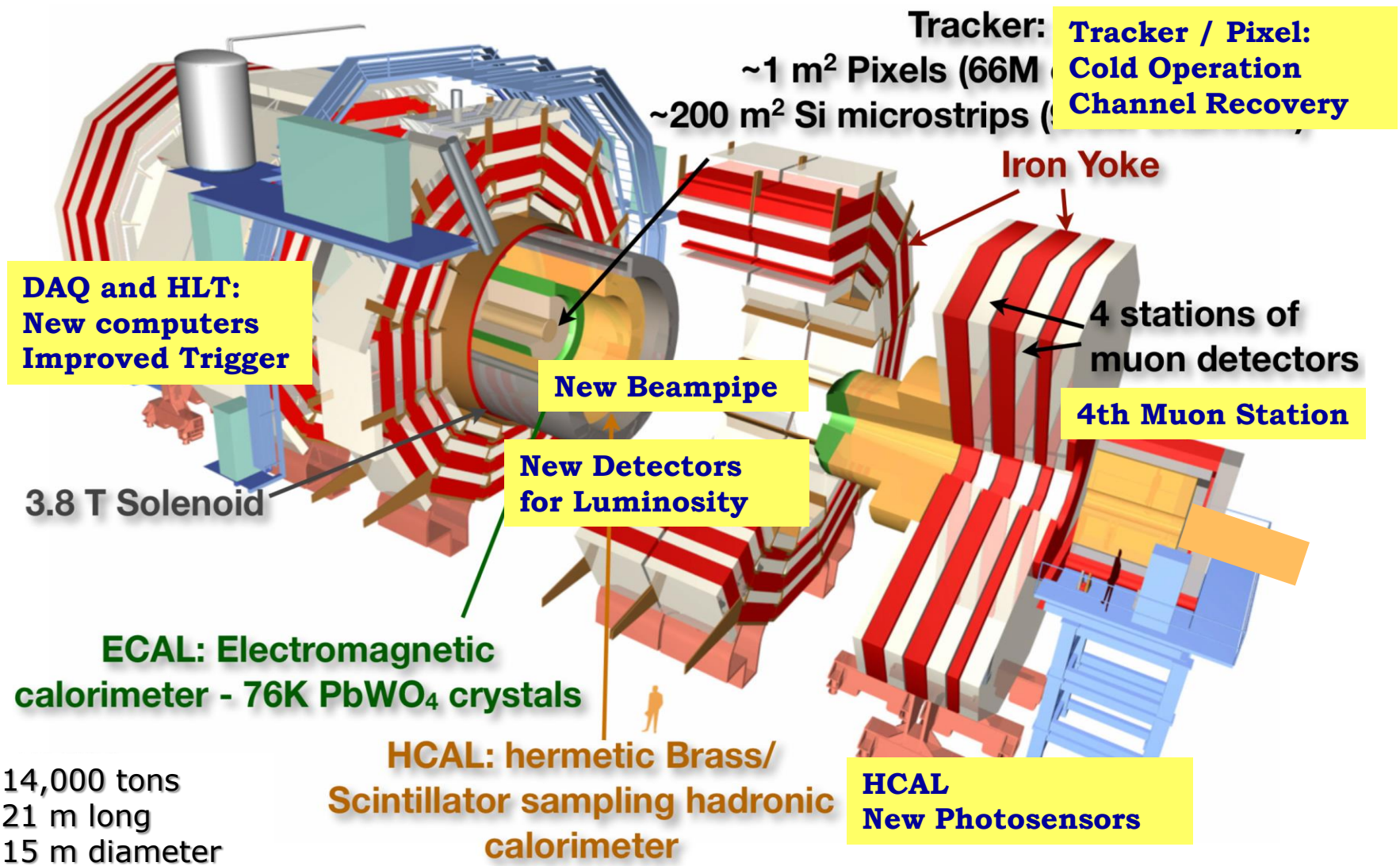
The CMS Collaboration

Many: 5000 members,
1900 physicists,
1800 students,
950 eng./ techn.

Global: 200 institutes from 43 countries

One Goal:
Unveil what our universe is made of !

CMS after Long Shutdown 1

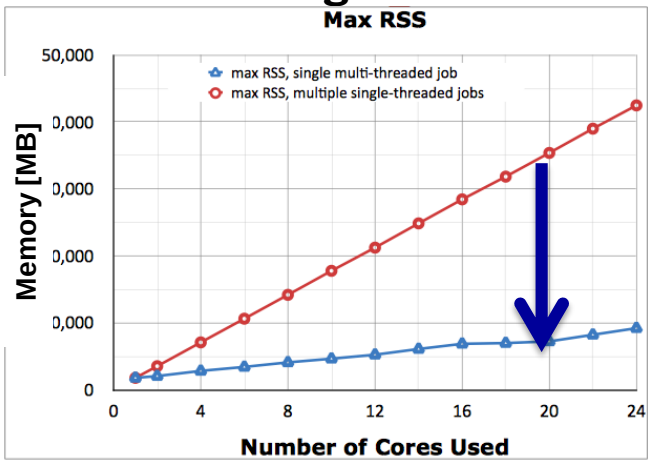


14,000 tons
21 m long
15 m diameter

DAQ & Computing & Offline

- New DAQ2 concept realized for the online part
- Replaced all 500 DAQ Computers, and 1/2 of the High Level Trigger (HLT) CPUs → increase budget to 0.3s/event from 0.2s/event
- HLT Farm now also used for production and other offline tasks

Multi-threading now standard

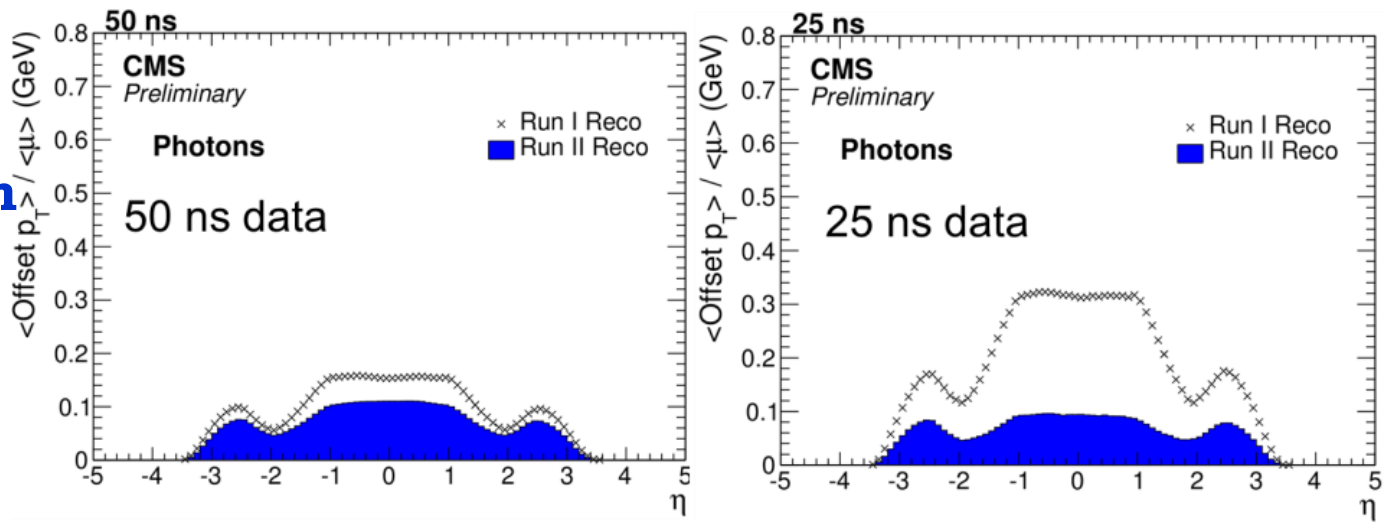


- Move to multi-threading with multi-core queues at CERN and Tier-1 centers
- New, more flexible and efficient workflow and data management systems
- Improvements in Distributed Analysis
- Faster event reconstruction
- New miniAOD data format for many physics object improvements:
  - compact high level data objects (30-50 kb/event) → gain factor ~10
  - covering needs of mainstream analyses → avoid duplications

Reconstruction Algorithms

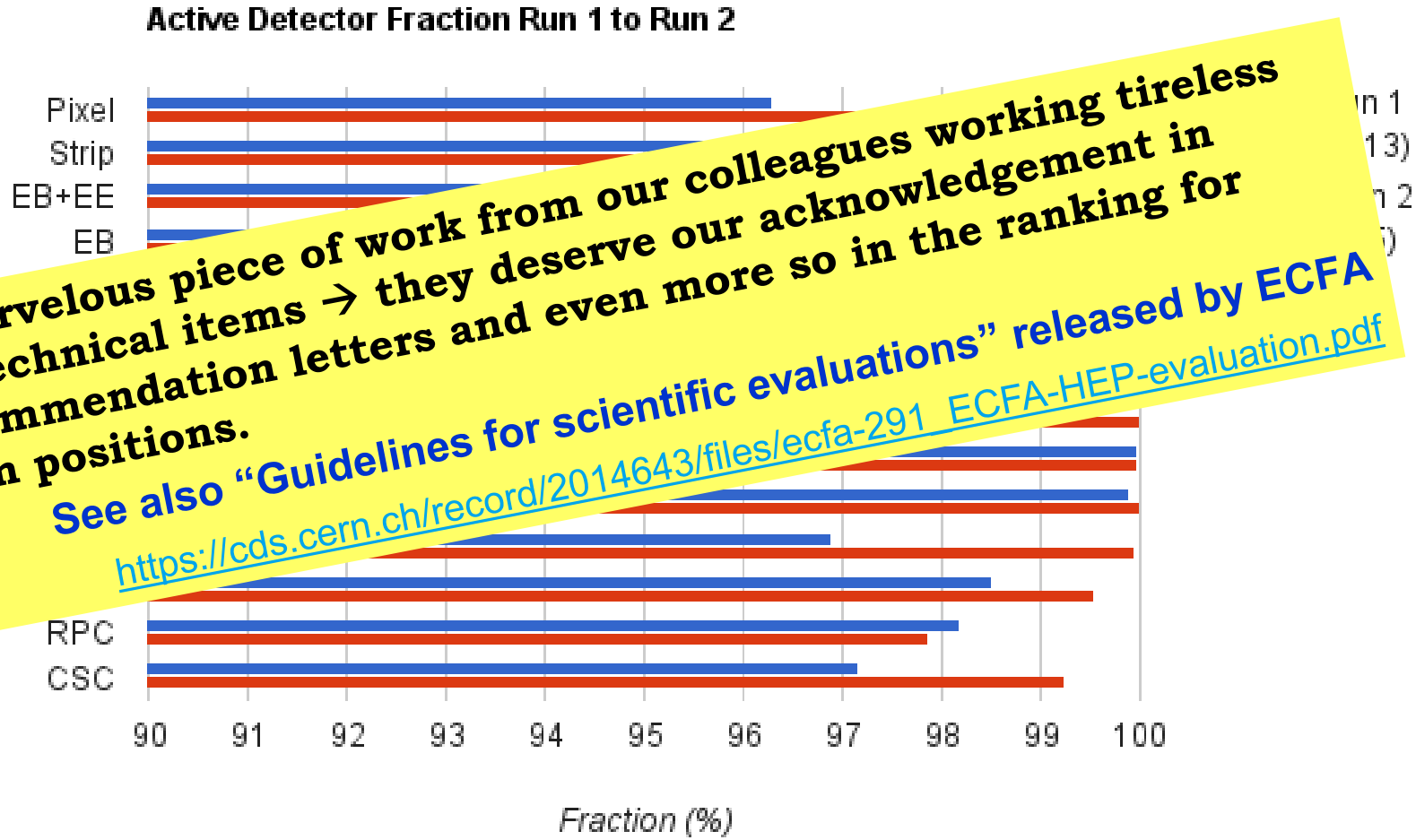
- **Significant effort on algorithm improvements with emphasis on pile-up mitigation**
  - **Improvement on track reconstruction**
  - **Out of time PU mitigation in the calorimeters**
  - **Pulse fit in ECAL/HCAL to extract the in-time energy per cell**
  - **Revisiting of Particle Flow event reconstruction**
- **Improvements evaluated on 8 TeV data**

Photon Reconstruction



Detector Commissioning

- All sub-detectors ready for data-taking
- Active channel fraction higher than Run 1

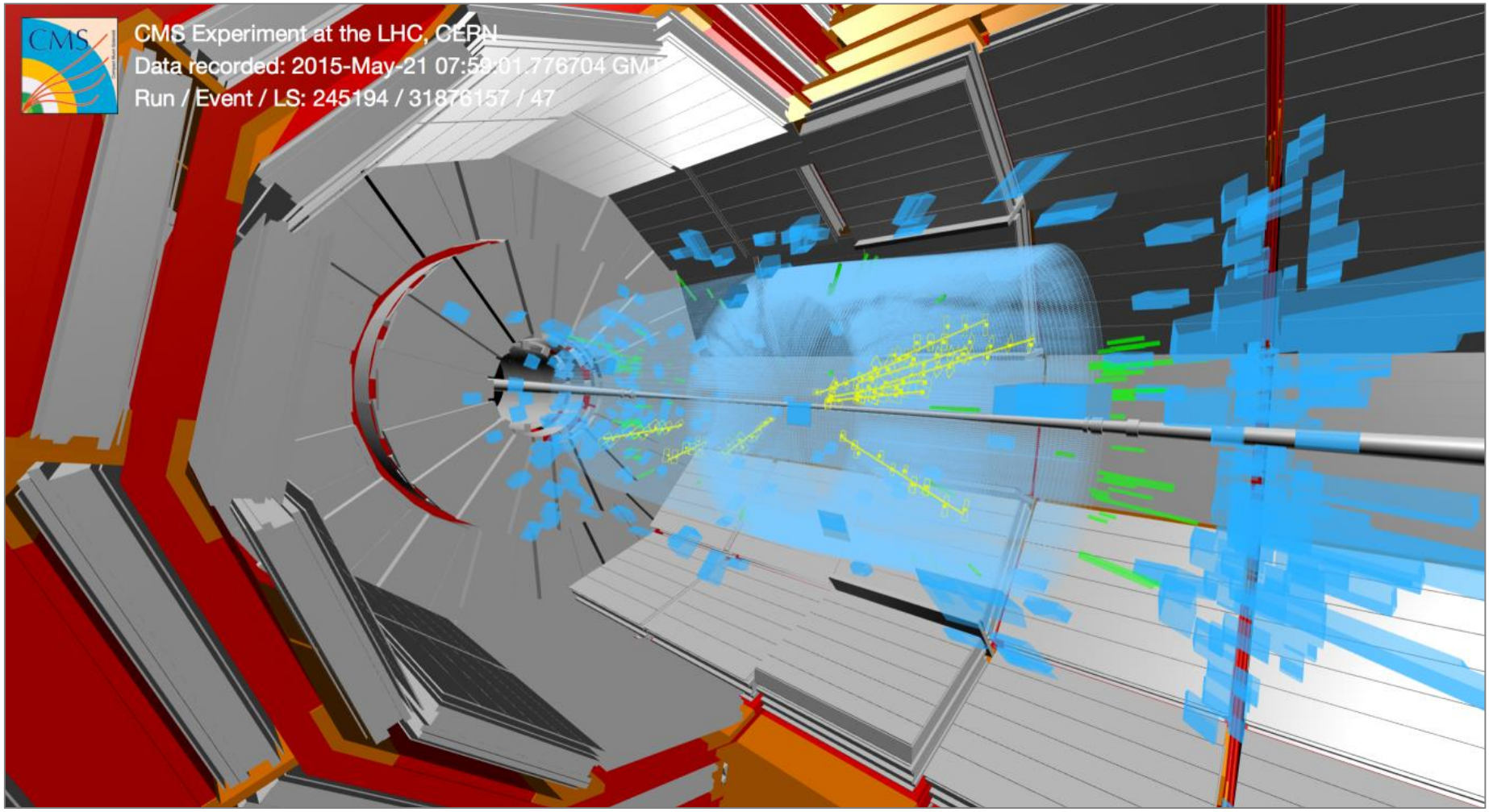


A marvelous piece of work from our colleagues working tireless on technical items → they deserve our acknowledgement in recommendation letters and even more so in the ranking for open positions.

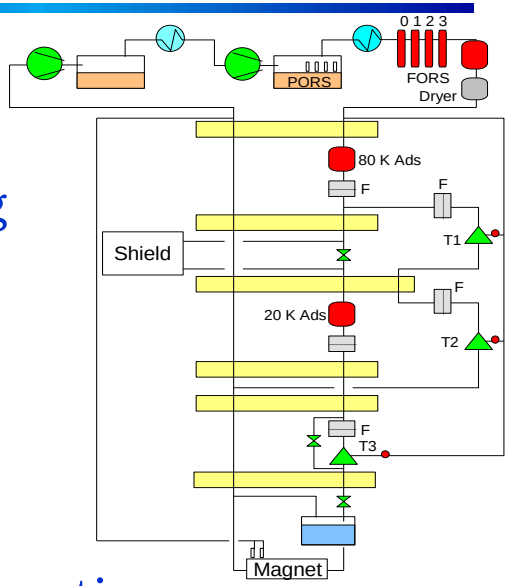
See also "Guidelines for scientific evaluations" released by ECFA

https://cds.cern.ch/record/2014643/files/ecfa-291_ECFA-HEP-evaluation.pdf

First Physics Collisions @ 13 TeV !



Magnet Cryogenics



- The restart of the CMS magnet after LS1 was more complicated than anticipated due to problems with the cryogenic system in providing liquid Helium.
- Inefficiencies of the oil separation system of the compressors for the warm Helium required several interventions and delayed the start of routine operation of the cryogenic system.
- Currently the magnet can be operated, but the continuous up-time is still limited by the performance of the cryogenic system requiring more frequent maintenance than usual.
- A comprehensive program to re-establish its nominal performance is underway. These recovery activities for the cryogenic system will be synchronized with the accelerator schedule in order to run for adequately long periods.
- A consolidation and repair program is being organized for the next short technical stops and the long TS at the end of the year.

First LHC Physics Paper @ 13 TeV !

The first CMS paper based on 13 TeV LHC data

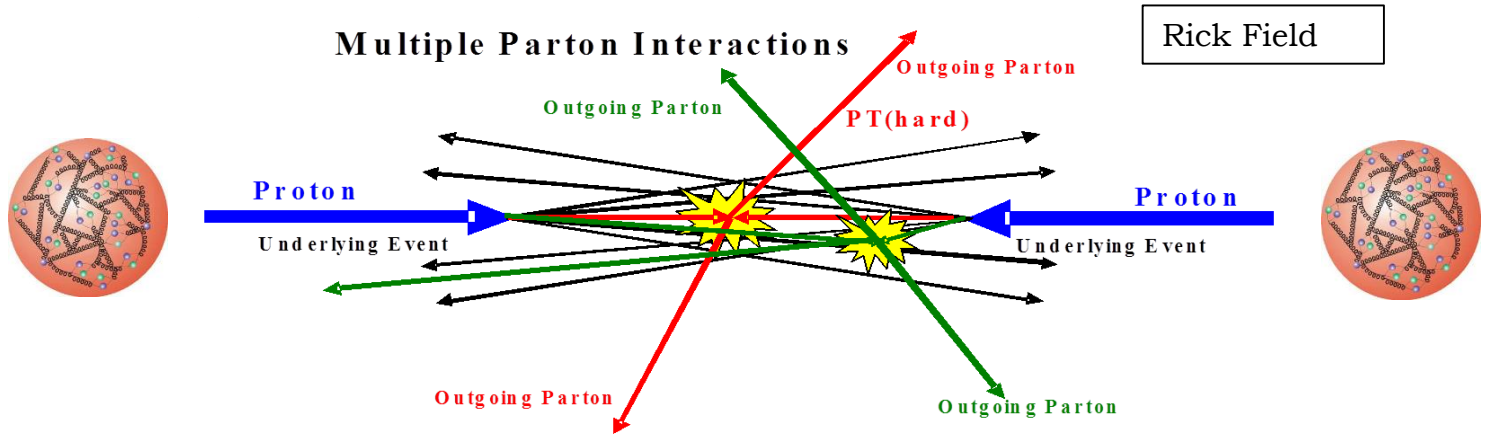
Pseudorapidity distribution of charged hadrons in proton-proton collisions at $\sqrt{s}$ = 13 TeV

has been submitted to PLB.

The post on arXiv is http://arxiv.org/abs/1507.05915

It is the first paper from LHC exploring the novel territory !

First Goal: Tune MC Models



In addition to the single hard interaction with large p_T:

- **(soft) interactions with low p_T → Underlying Event remnant-remnant interactions and parton showers … → additional energy offset**
- **more hard interactions → Multi – Parton Interactions (evidence from CDF 1997: need >50% double parton interaction for γ + 3 jet)**

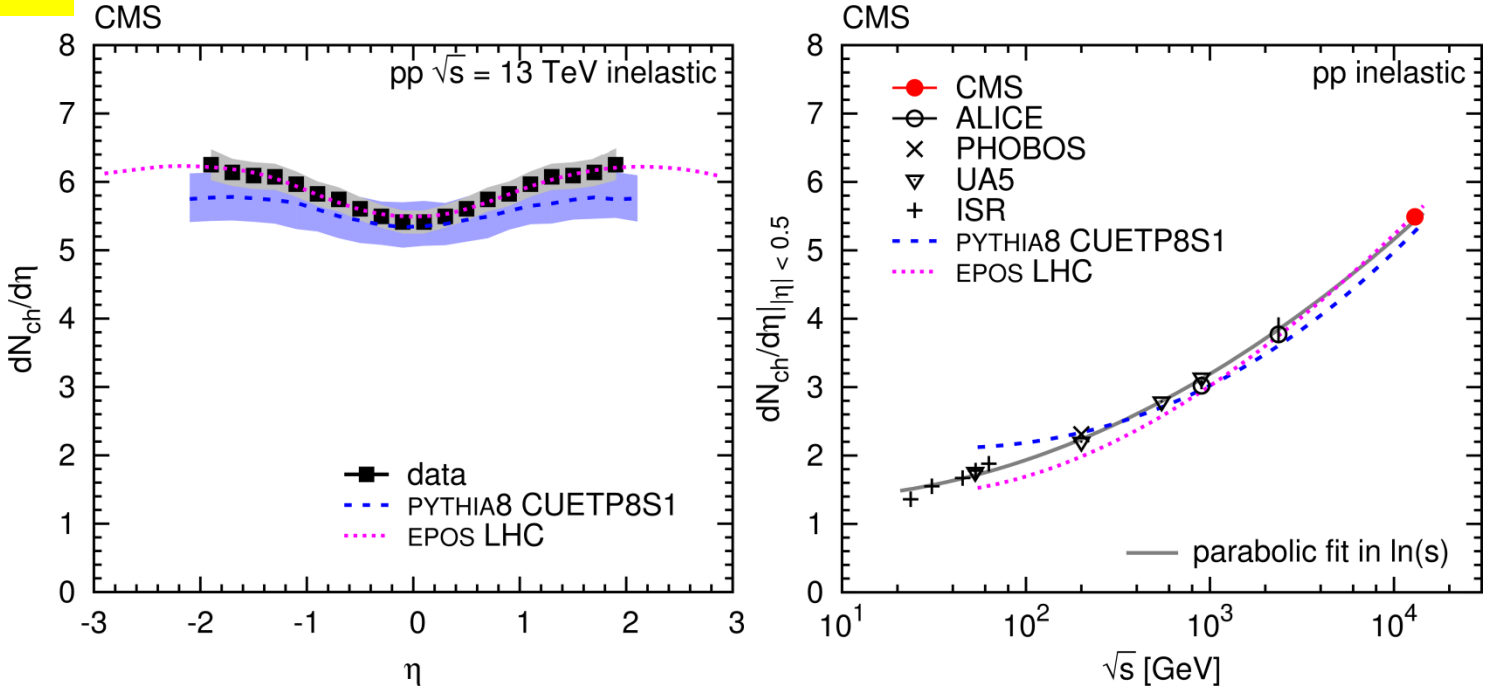
→ important for jet analyses (additional UE energy) or pile-up modelling or $pp \to W+H+X$ with $W \to l+\nu$ and $H \to b\bar{b}$ (MI: $pp \to W+X_W + b\bar{b}+X_b$ without any Higgs!)

Good tune of the MC Genertors is important to model Underlying Event, Pile-Up and Multi – Parton Interactions → crucial for all precision measurements !

Charged Hadron Multiplicity @ 13 TeV

B=0

$$dn_{ch}/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01\ (stat) \pm 0.17\ (syst)$$



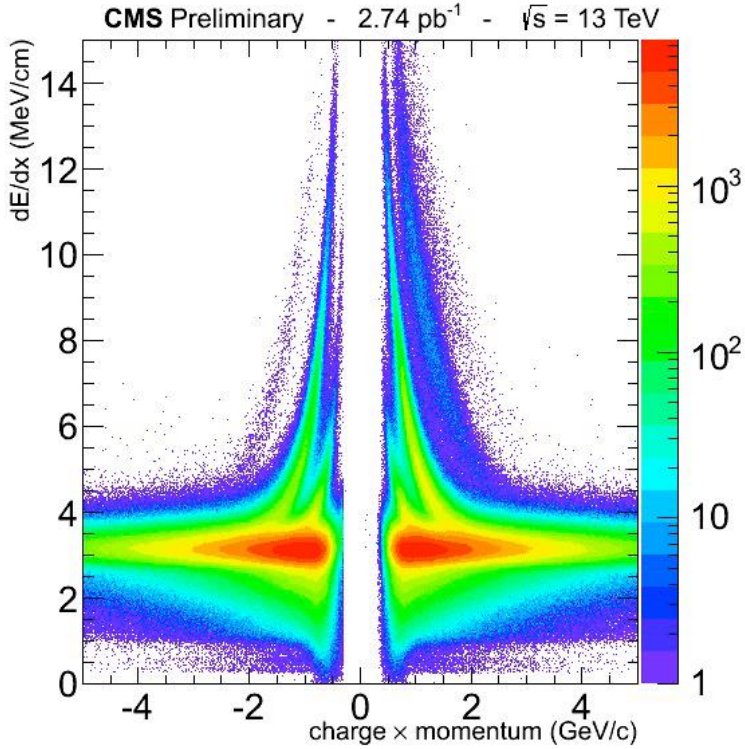
- **First measurement of inelastic $dN_{ch}/d\eta$ at 13 TeV pp collisons.**
- **Mid-rapidity: EPOS LHC and PYTHIA8 CUETP8M1 consistent with data.**
- **Rapidity dependence better described by EPOS LHC**

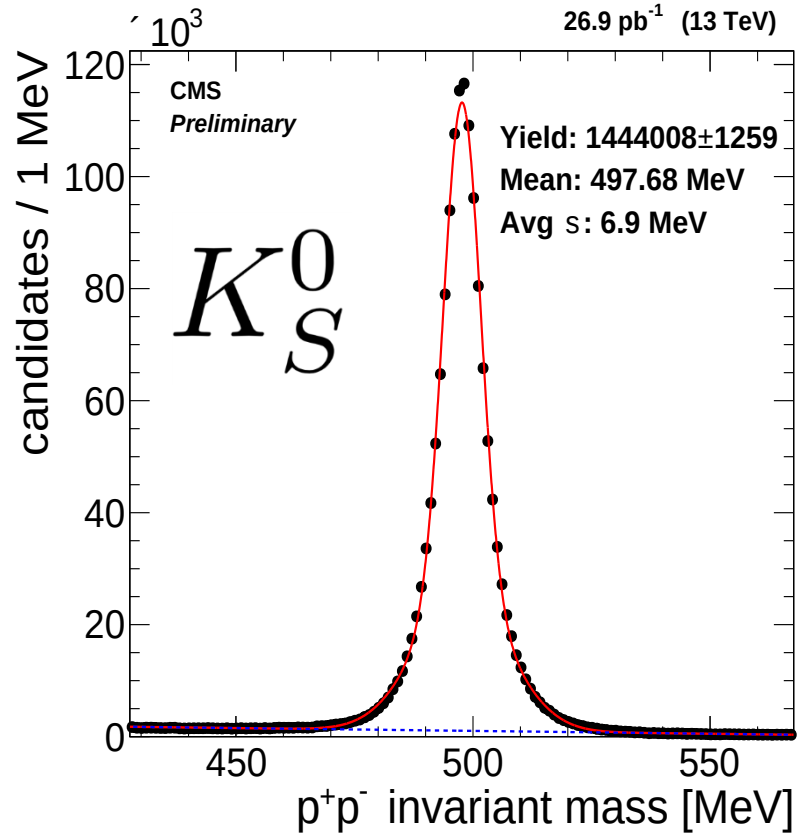
First Scan with Magnet On

CMS back in business

- **Analyzed up to ~40 pb-1 with magnet and all detectors on.**
- **Re-Discovery of Standard Model Physics**
  - **Resonances**
  - **Z → ee, μμ, ττ**
  - **Top**
- **Commencing Searches**
  - **highest di-lepton and (lepton+MET) mass events**
  - **boosted top signatures**
  - **first di-jet spectrum**
- **All released Run 2 results can be found here:** https://twiki.cern.ch/twiki/bin/view/CMSPublic/PublicPlotsEPS2015

Tracker Performance



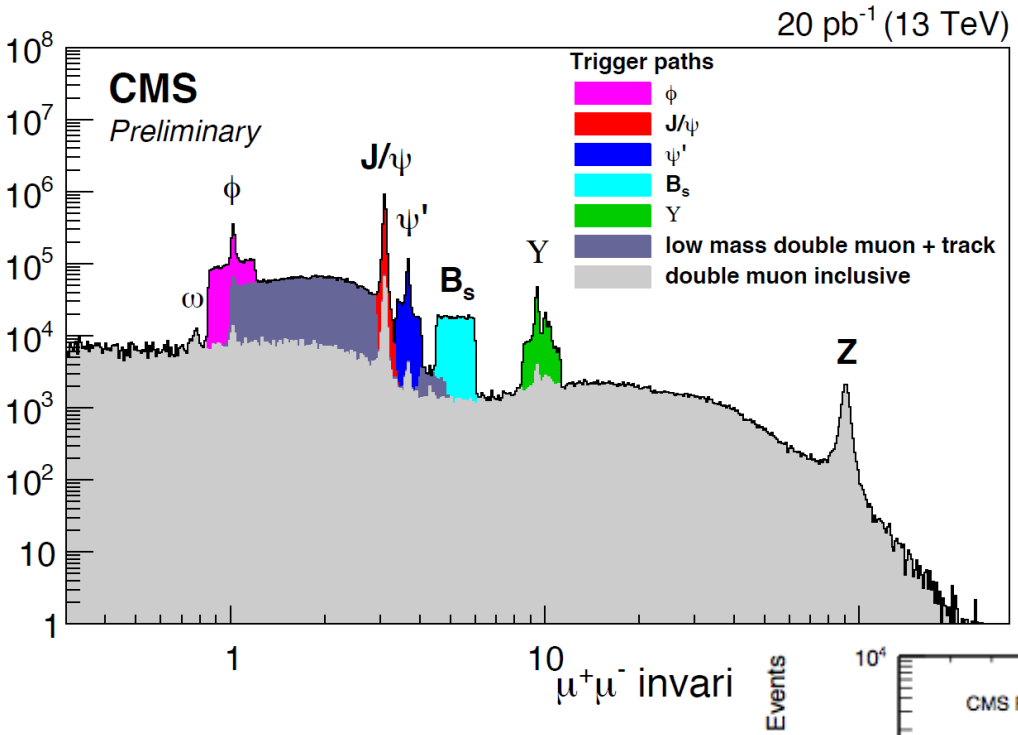


PDG: 497.614 ± 0.006 MeV

From right to the left Deuteron, Proton and Kaon bands clearly visible. Particles shown depending on their charge → observe an expected asymmetry in the production of particles/antiparticles for pp collisions.

Invariant mass of the pion pairs fitted with a double gaussian and a first order polynomial for the background.

Scan for Resonances

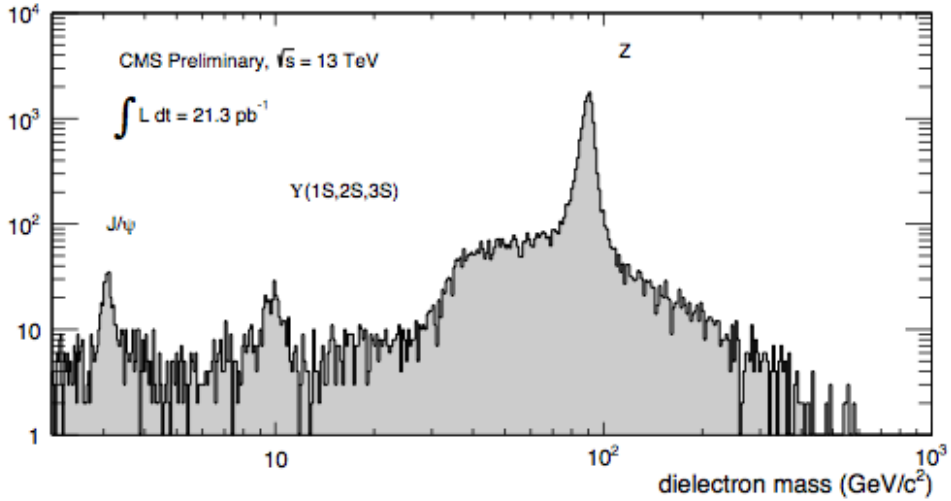


Di-muon mass spectrum:

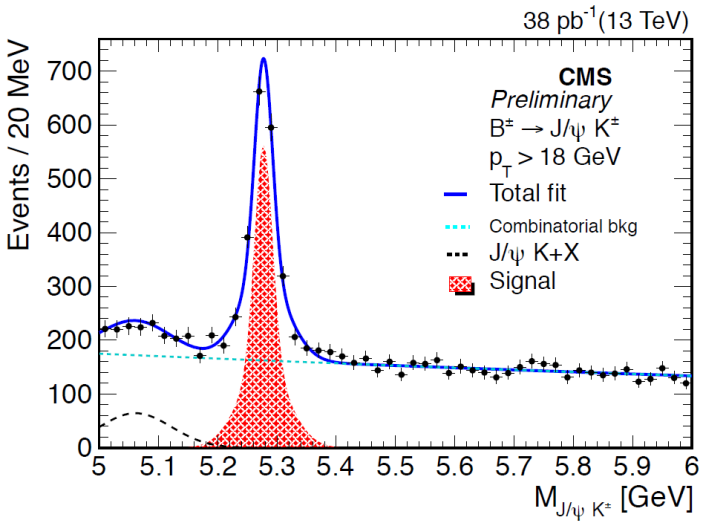
special triggers
in certain mass regions
and with different p_T cuts

Di-electron mass spectrum:

$p_T > 10$, $|\eta|<2.5$,
cut-based Electron ID



Resonances

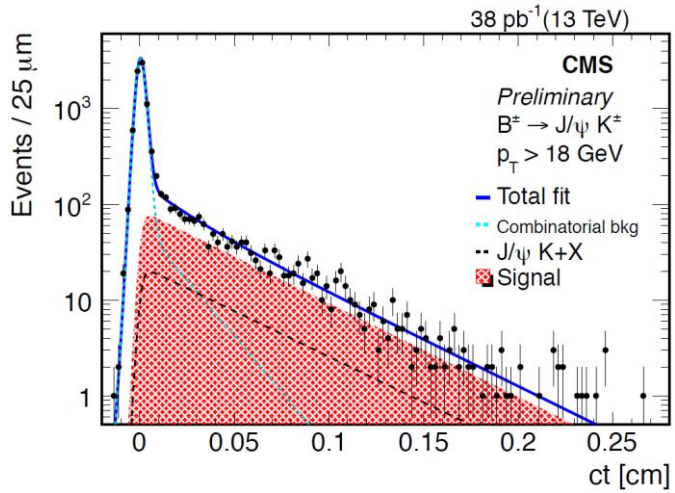


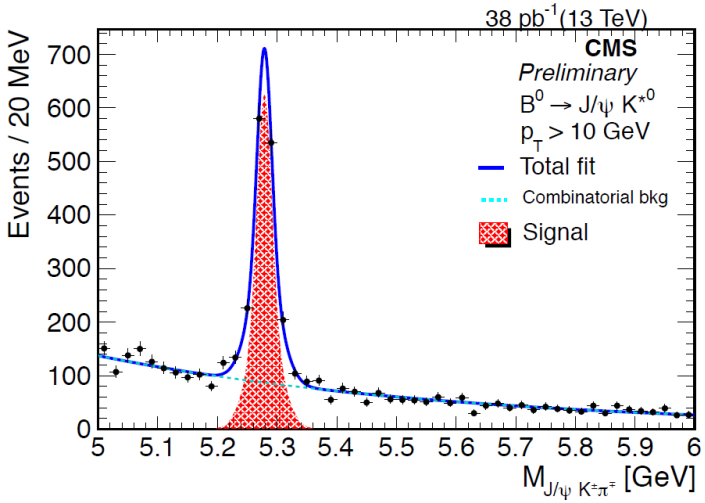
$B^{\pm} \to J/\psi\ K^{\pm}$

Inclusive J/ψ trigger with p_T >16 GeV

Mass: 5.277 ± 0.001(stat.) GeV

PDG: 5279.26 ± 0.17 MeV





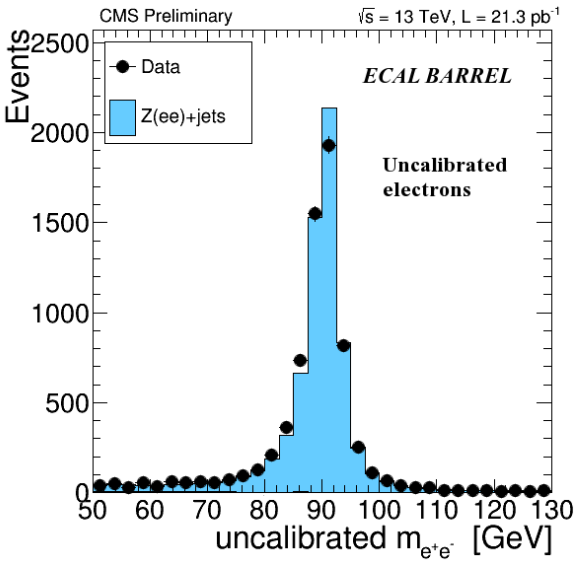
$B^0_s \to J/\psi\ \varphi$

with displaced J/ψ and track trigger

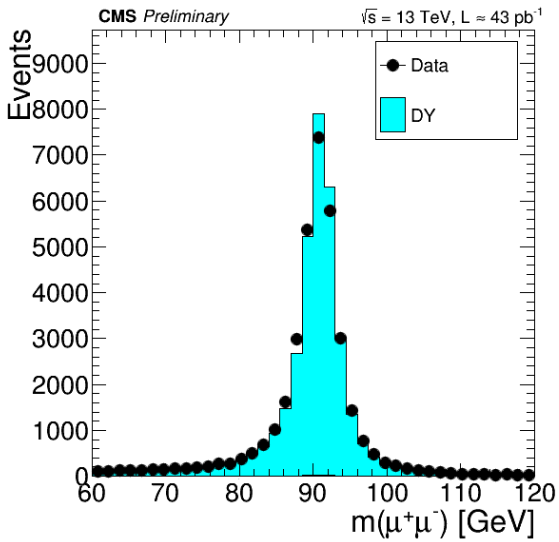
Mass: 5.369 ± 0.001(stat.) GeV

PDG: 5366.7 ± 0.4 MeV

Detector & Algorithm Performance

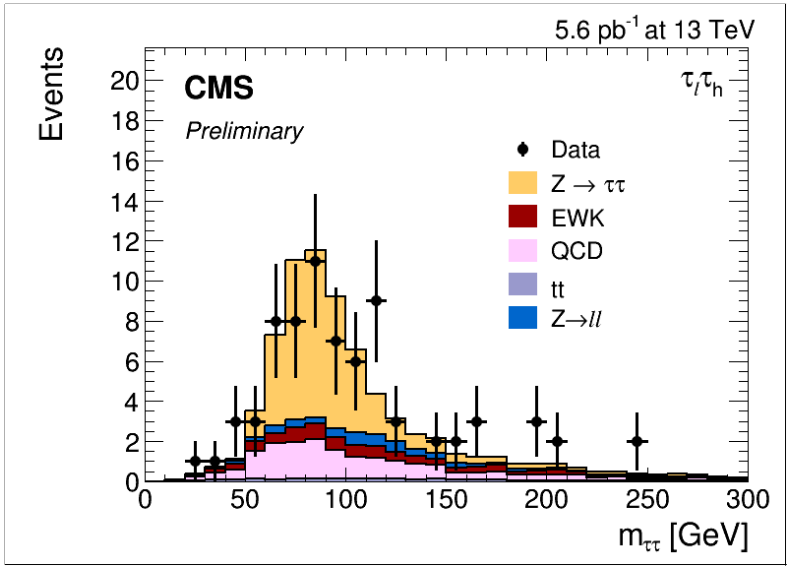


$Z \rightarrow ee$



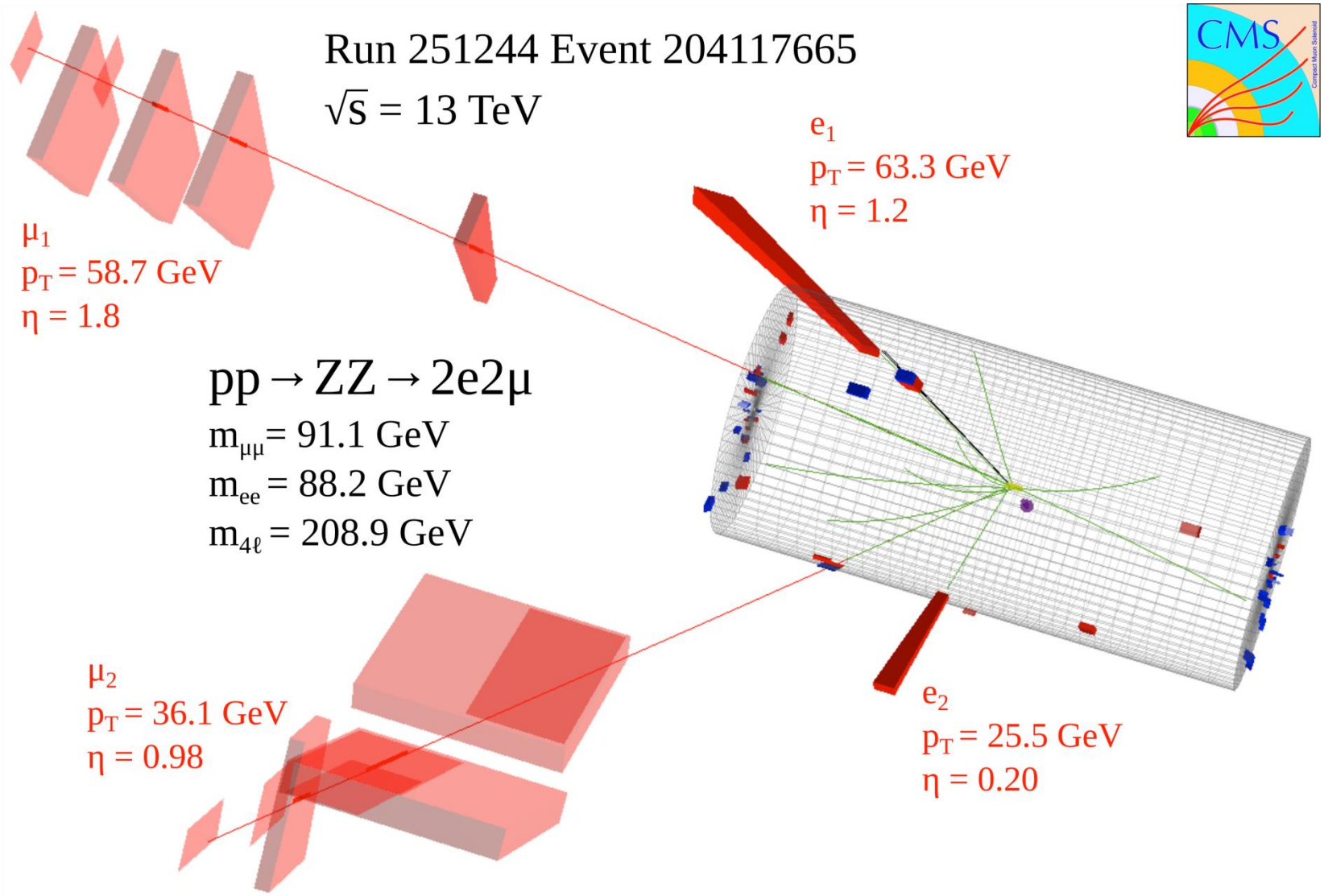
$Z \rightarrow \mu\mu$

$Z \rightarrow \tau\tau$



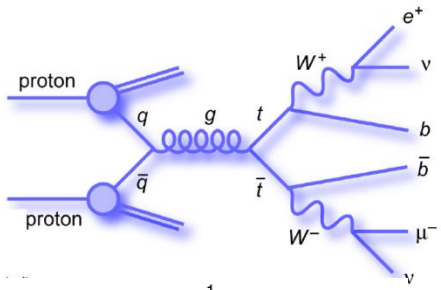
Z – Boson as standard physics candle

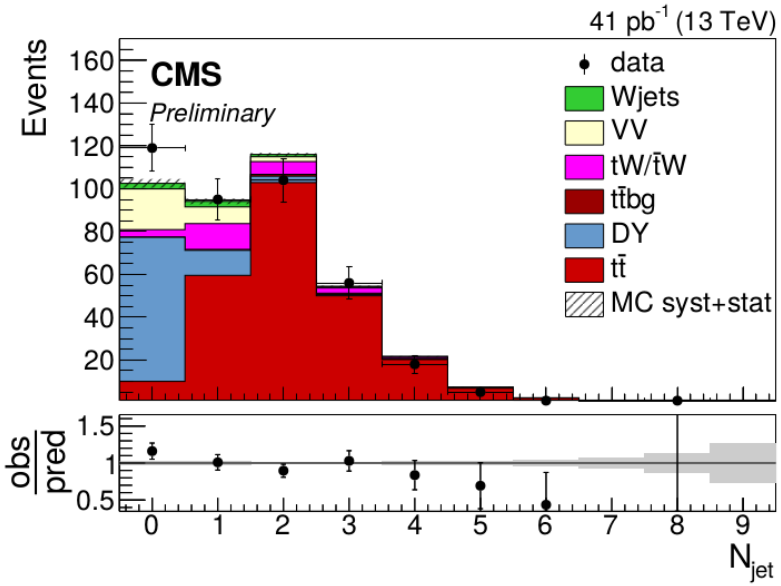
Spectacular ZZ in 4l decay



Top Re-Discovery

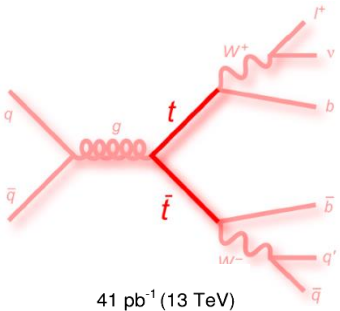
Top pair to di-leptons

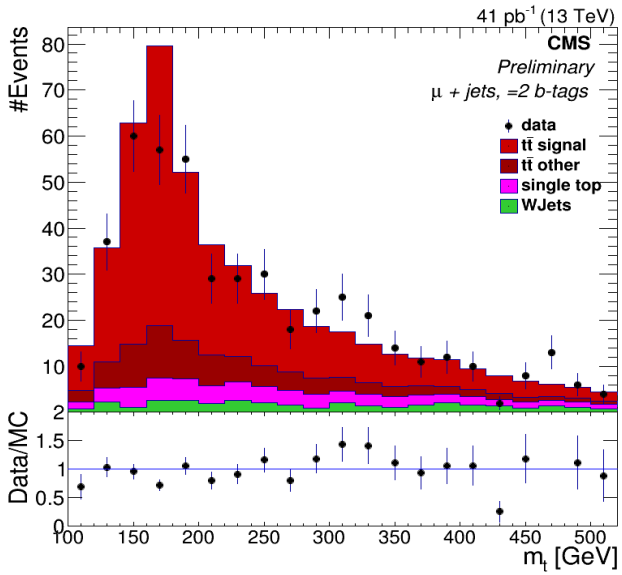




Number of hadronic jets for events containing one isolated muon and one isolated electron forming an invariant mass greater than 50 GeV.

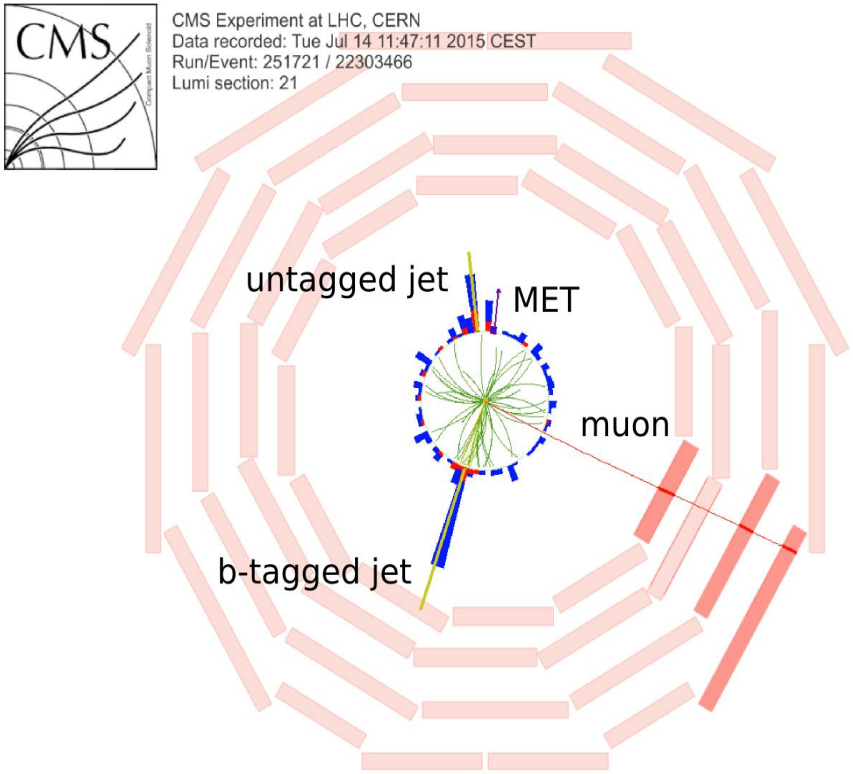
Top pair to lepton+jets

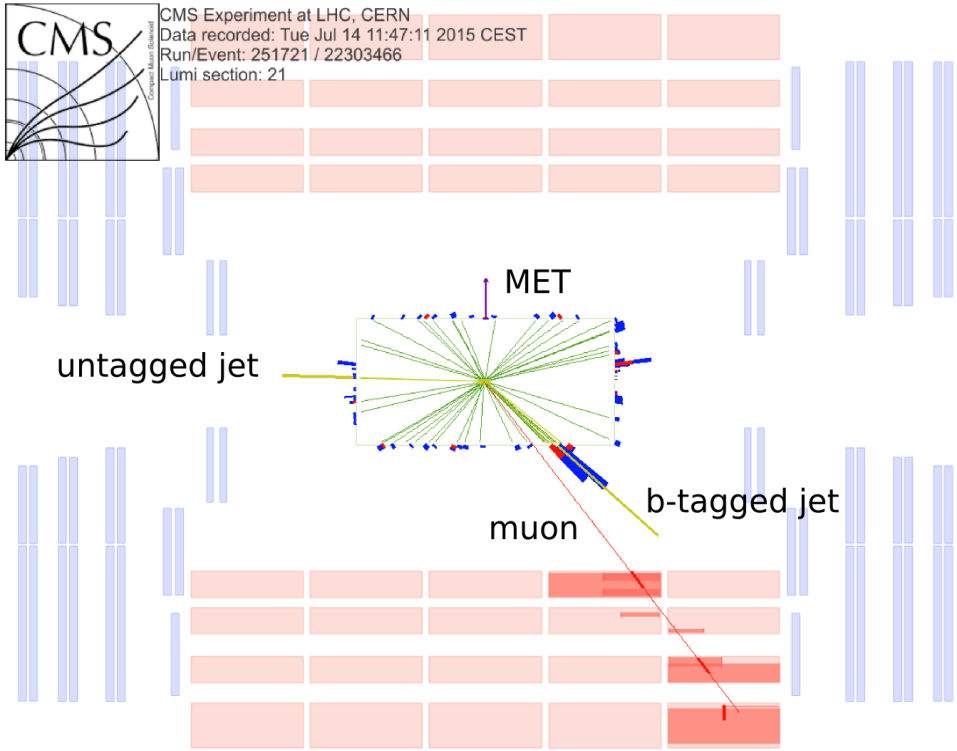


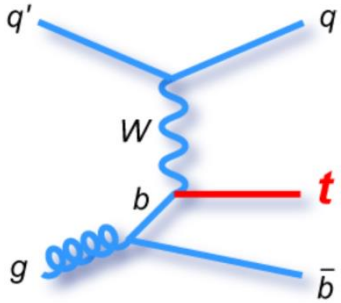


Reconstructed hadronic top quark candidate mass for events containing 1 isolated muon (p_T>30 GeV, $|\eta|$<2.4, passing medium identification), four jets (p_T>30 GeV, $|\eta|$<2.5), out of which 2 pass the tight b-tagging threshold.

Towards Single Top (t-channel)







- **One isolated muon**
- **MET: 27 GeV**
- **Mass : 177 GeV**
- **Two hadronic jets:**
  - b-tagged jet from top decay
  - un-tagged jet

Searches Commenced

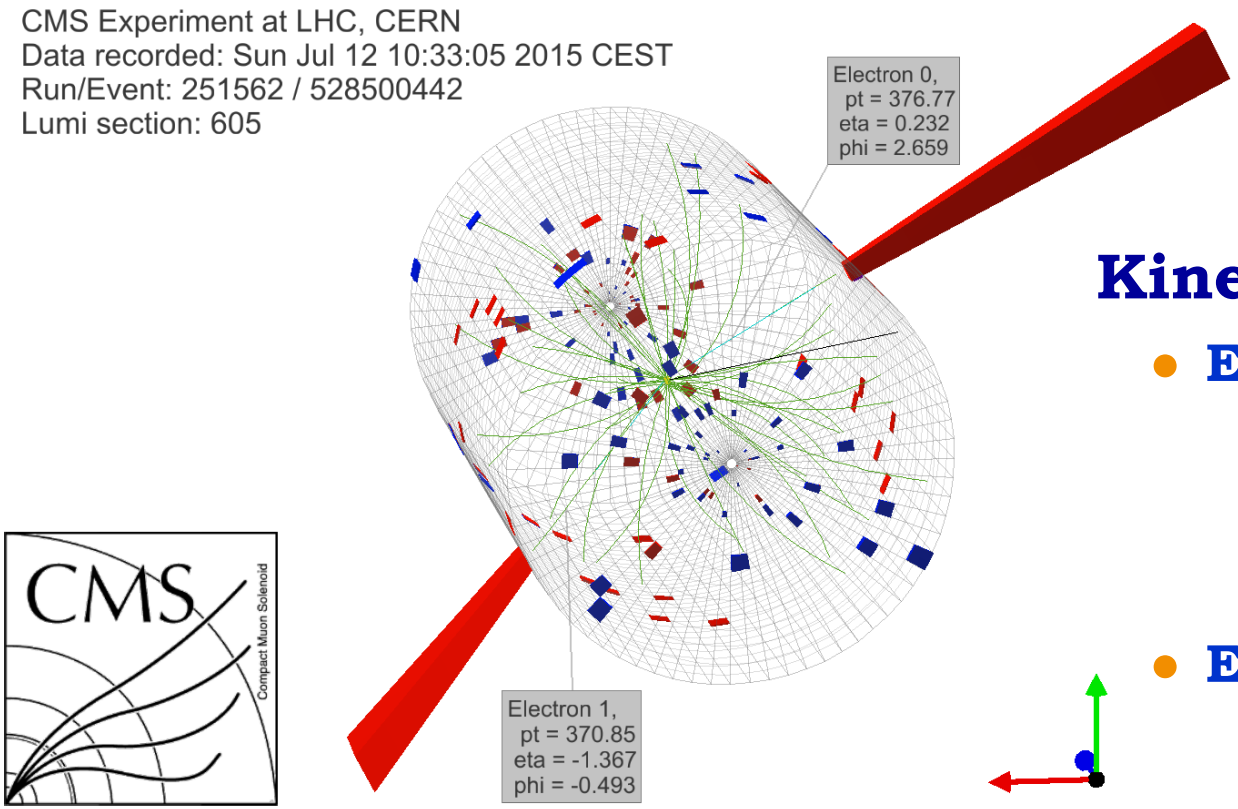
LHC at 13TeV is a resonance factory at a new energy scale, for example:

- **Di-jets and multi-jet mass spectra**
- **Di-lepton (ee, μμ, ττ) mass spectra**
- **Di-photon mass spectrum**
- **Lepton + MET final state**
- **Boosted Topologies**

First look at the Run 2 data with preliminary initial results:

- **Events with highest mass in di-lepton and lepton+MET final state**
- **Event with boosted top signature**
- **Di-jet invariant mass spectrum**

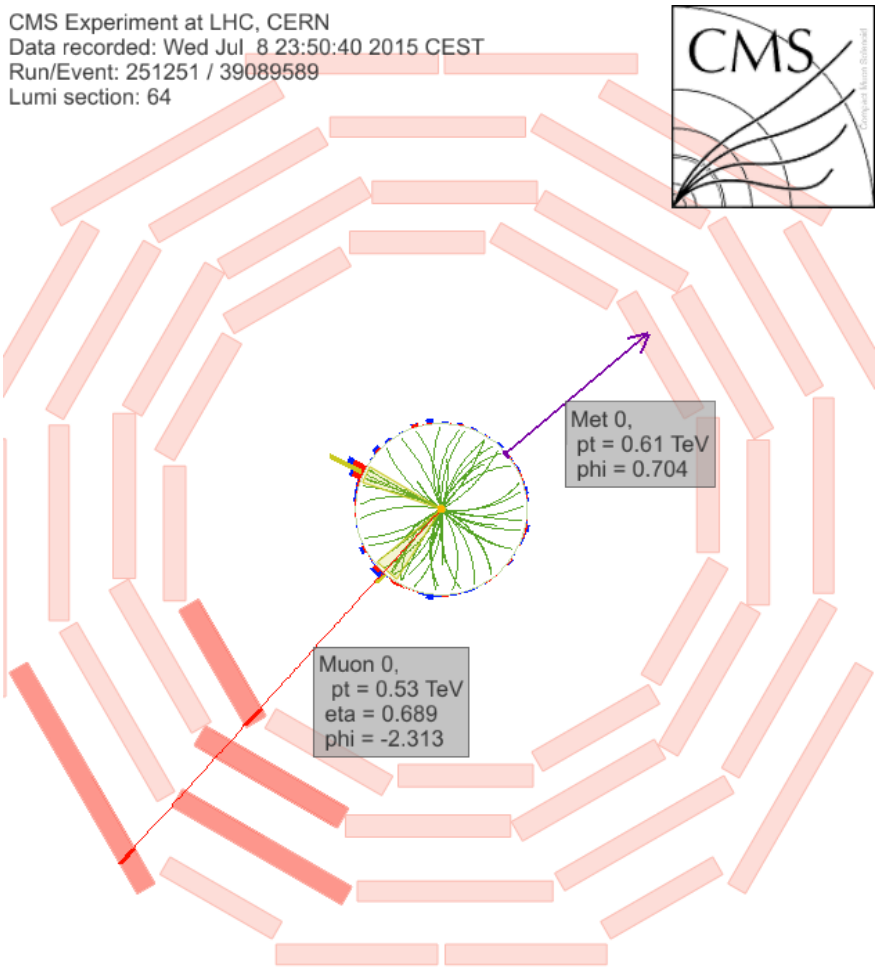
TeV Electron - Positron Candidate



Kinematic Quantities:

- **Electron 1:**
  - p_T = 377 GeV,
  - η = 0.232,
  - φ = 2.66 rad
- **Electron 2:**
  - p_T = 371 GeV,
  - η = -1.37,
  - φ = -0.493 rad
- **MET :** 9.2 GeV
- **Mass (ee) : 999 GeV**

Single muon + missing E_T @ m_T = 1.1 TeV



Kinematic Quantities:

- **Muon:**
- p_T= 0.53 TeV
- η = 0.69
- ϕ = -2.3
- **MET:** 0.62 TeV

- $\Delta\phi$ (μ-MET) = 3.0
- **m_T = 1.1 TeV**

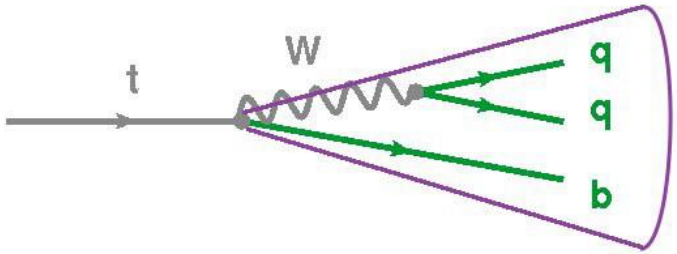
1 event expected with m_T > 700 GeV for the luminosity analyzed

Boosted Top Candidate

- **Search for Heavy Masses:**
  - For example: vector-like quarks, Z', ...
  - boosted decay products
  - merged jets

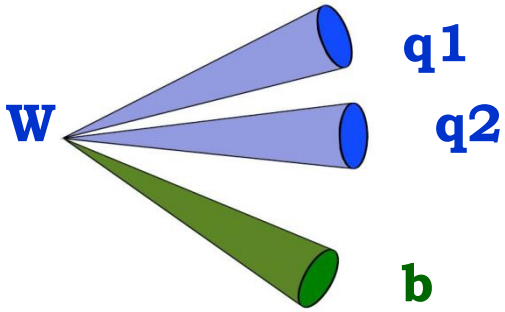
  ➔ challenging hadronic final states

  Accessing for example with substructures (or clean signatures with photons)



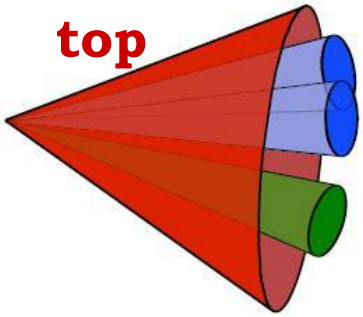
- **Non-boosted top:**

➔b and W decays in different jets

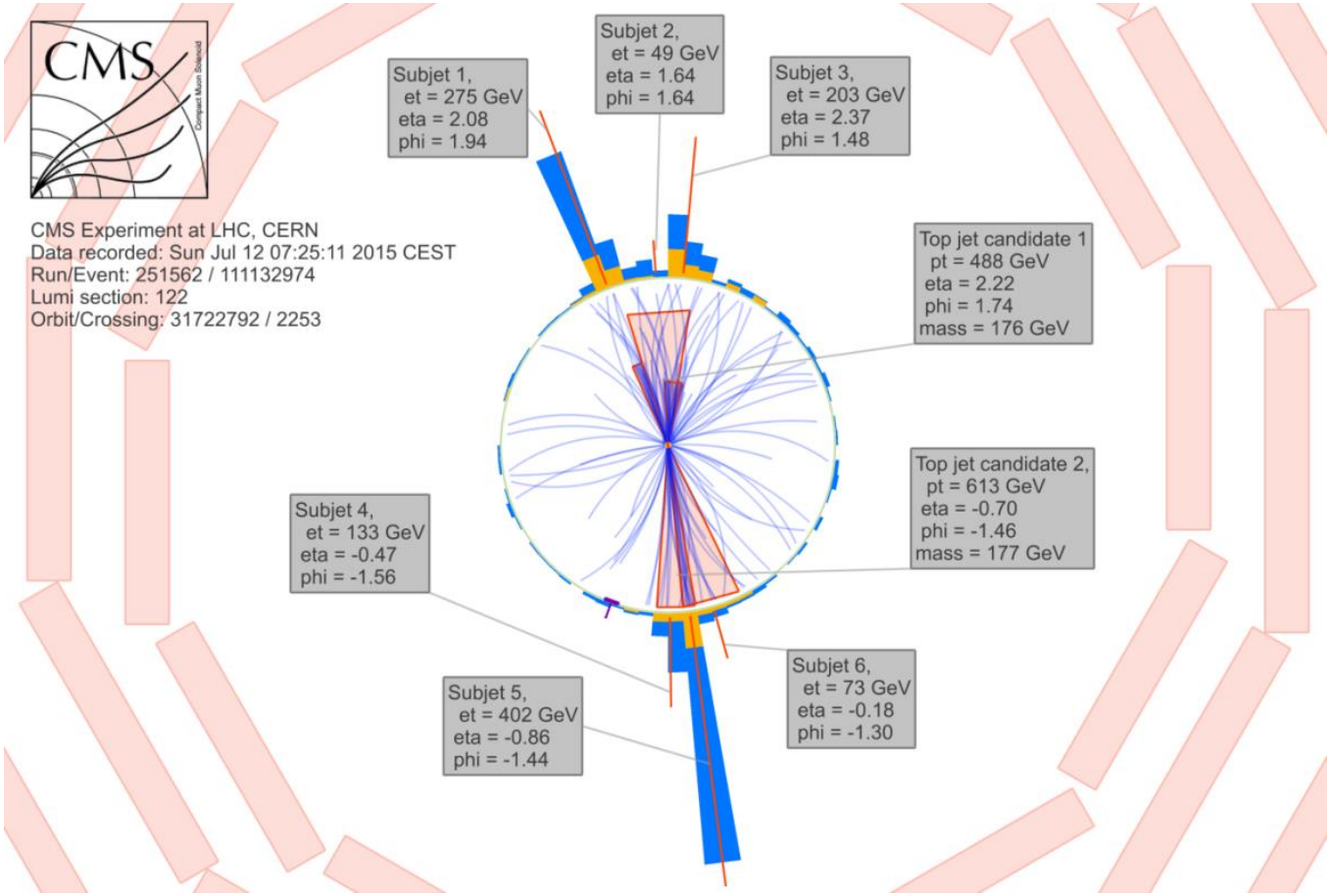


- **Boosted top:**

➔ b and W decays in same jet

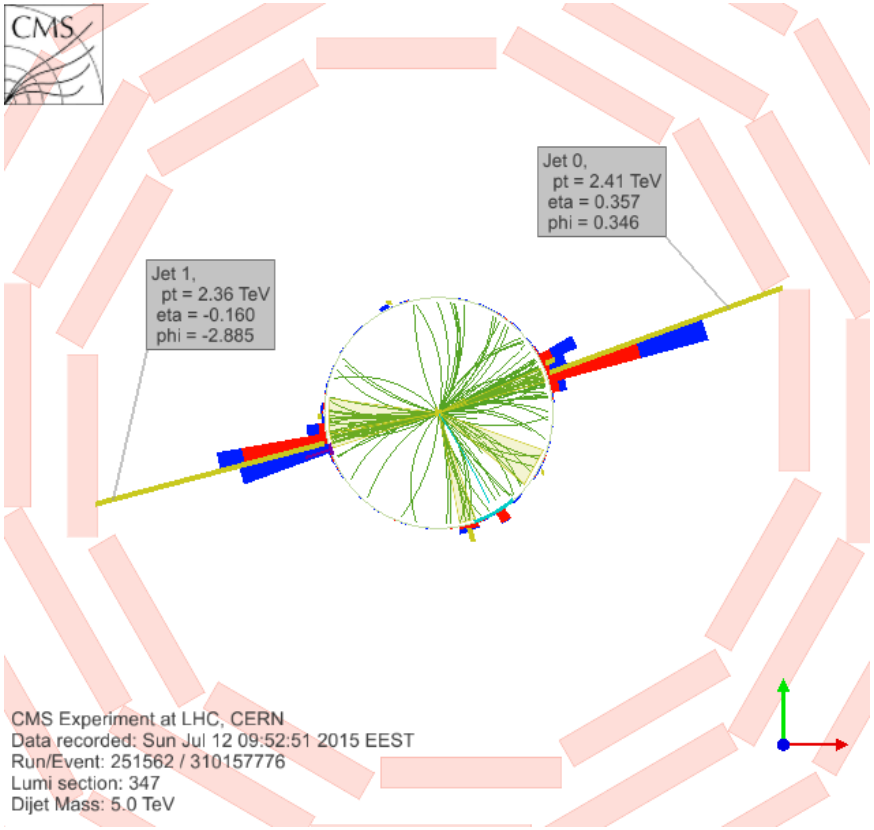


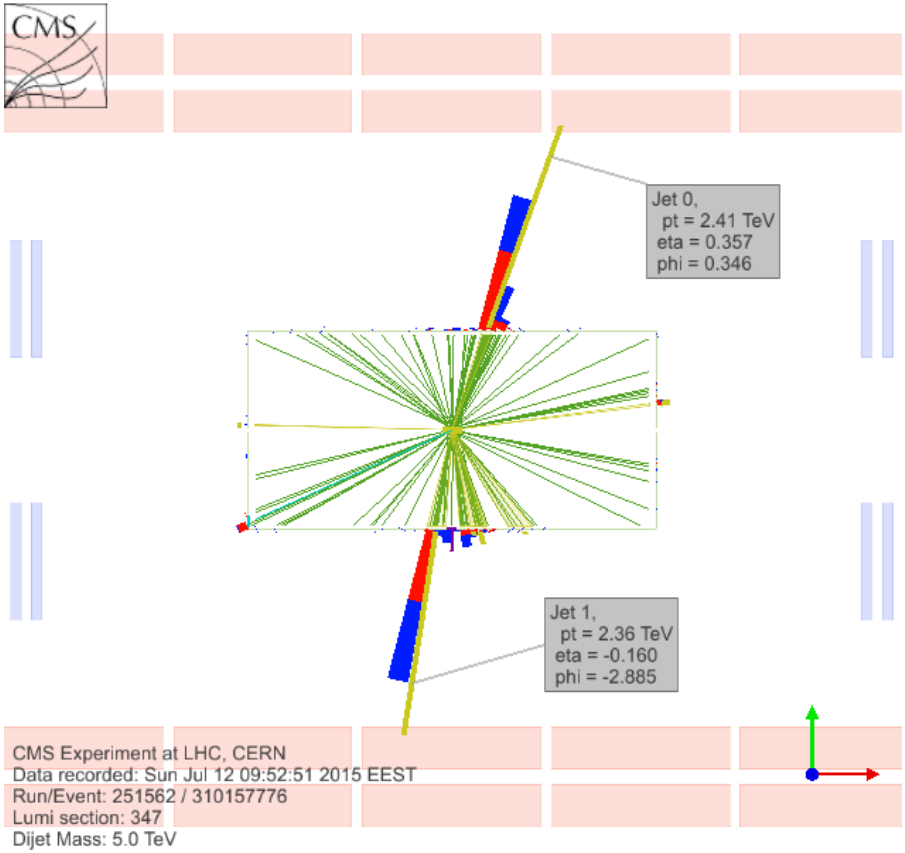
Boosted Top Candidate



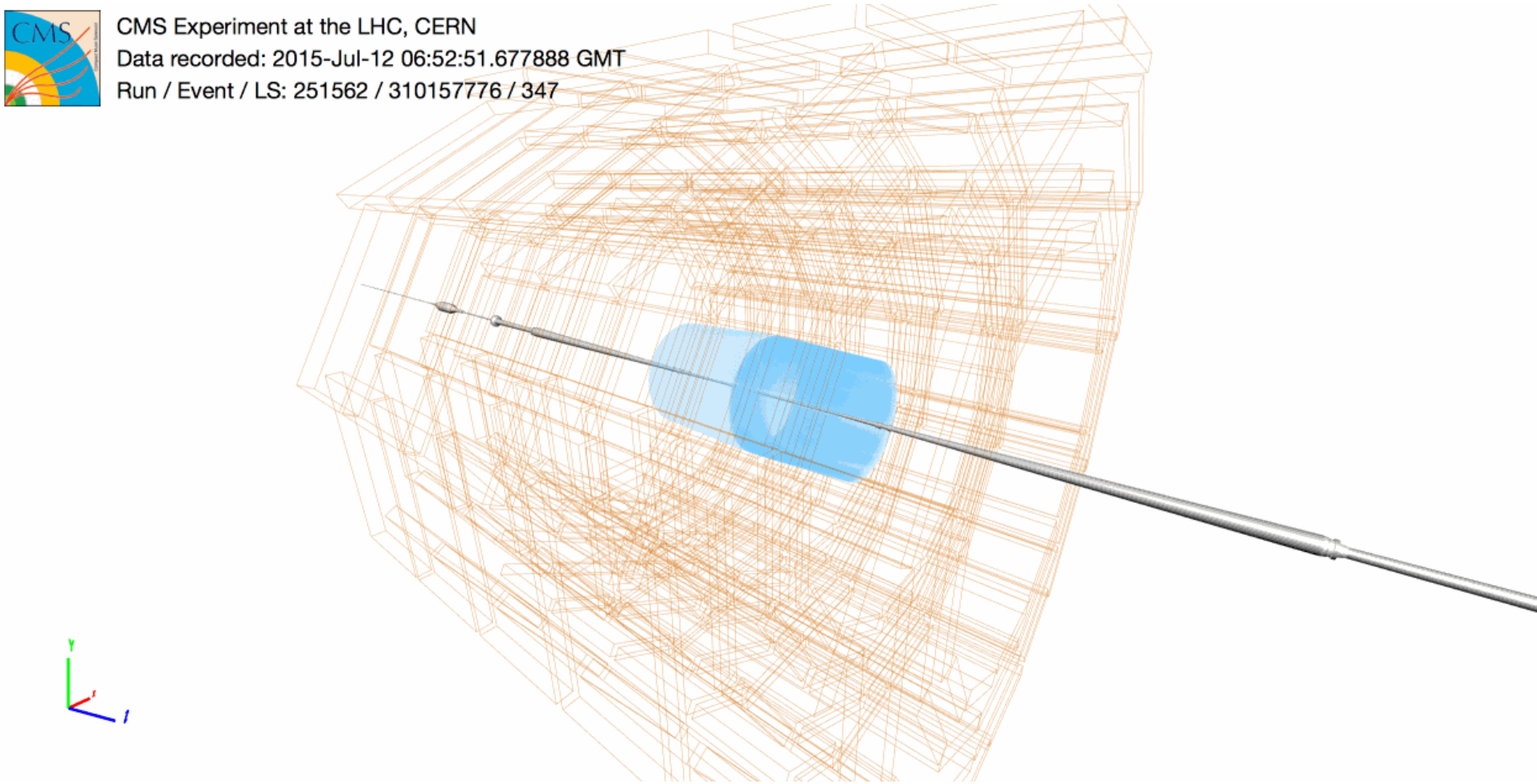
- **Top – jet 1:**
  - m =177 GeV, p_T =613 GeV
- **Top – jet 2:**
  - m =176 GeV , p_T = 488 GeV
- **Di-top jet Mass: 2491 GeV**

Di-Jet Event with Mjj = 5 TeV

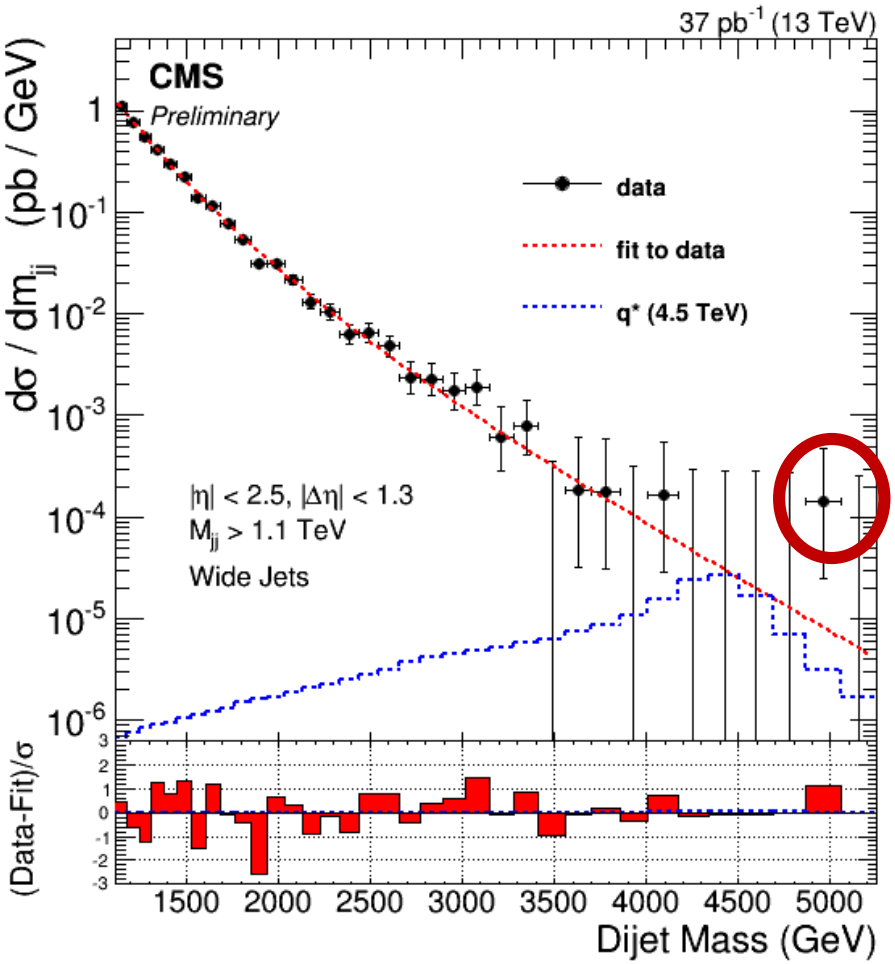




Di-Jet Event with Mjj ~ 5 TeV



Di-Jet Mass Spectrum

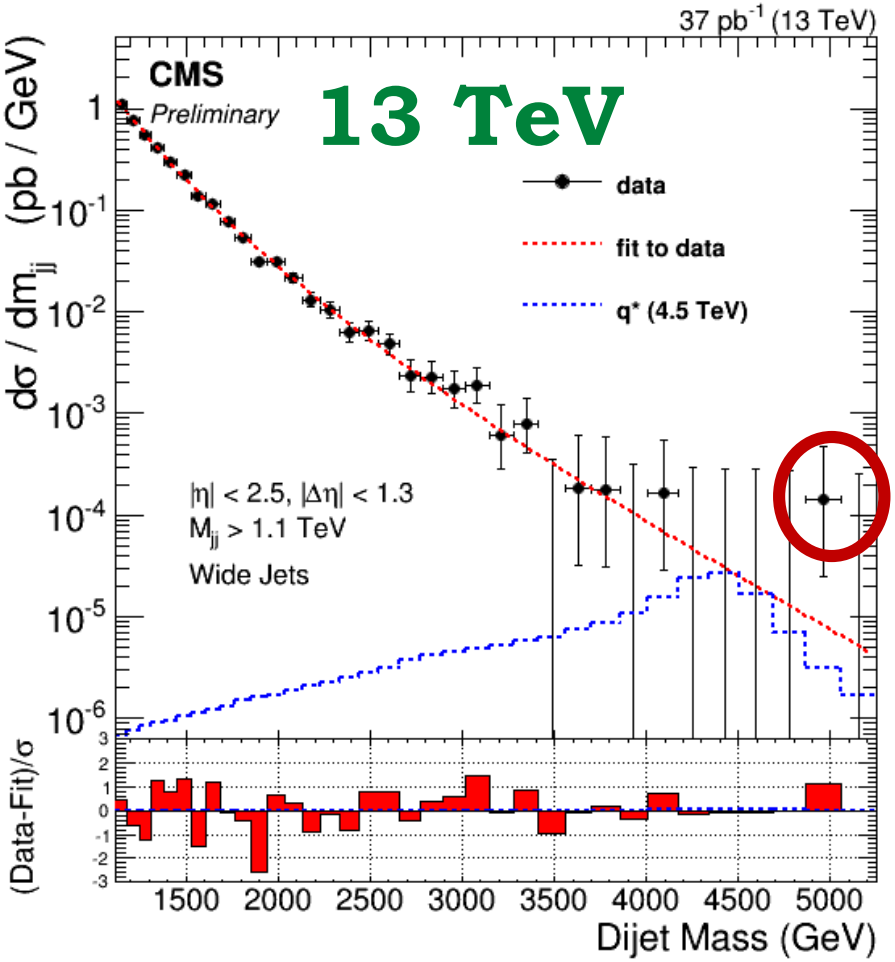


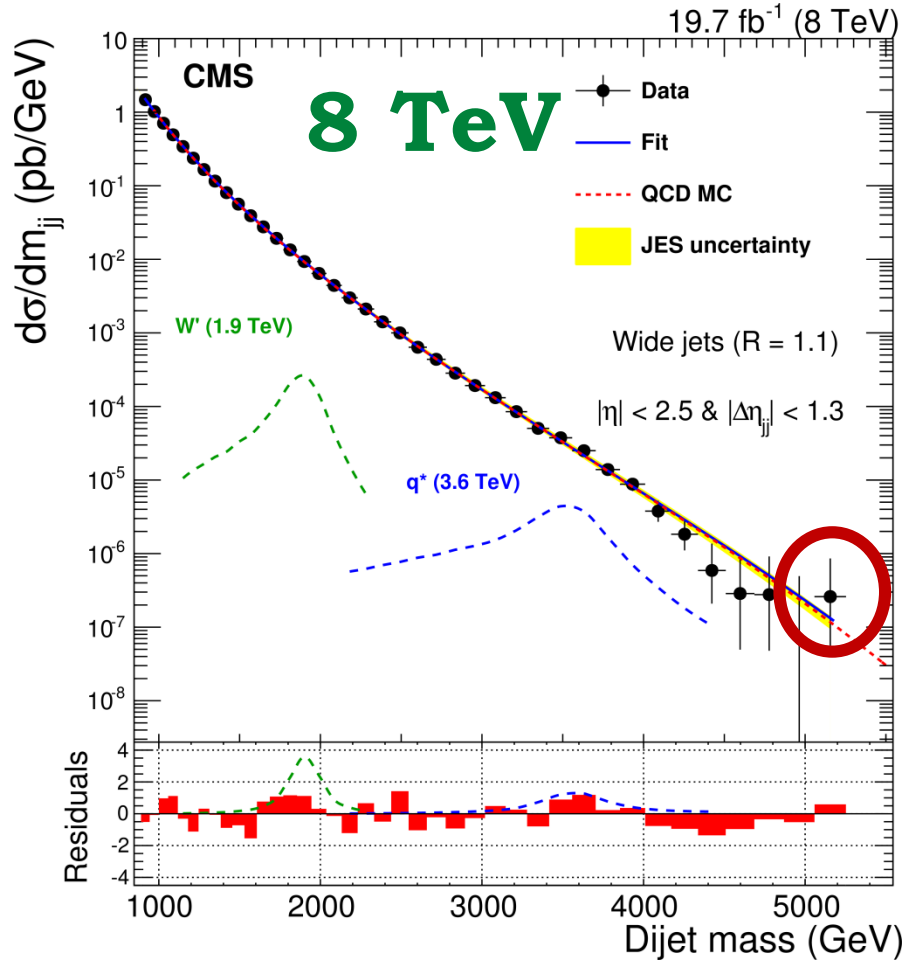
- **Luminosity 37 pb-1**
- **The dijet mass distribution is fitted using 4-parameter function:**

$$\frac{d\sigma}{dm_{jj}} = \frac{p_0(1-\frac{m_{jj}}{13000})^{p_1}}{(\frac{m_{jj}}{13000})^{p_2+p_3\ln(\frac{m_{jj}}{13000})}}$$

- Superimposed for illustration **q* → qg signal** with resonance mass M=4.5 TeV (blue dashed).
- **With 37 pb-1 expect to exceed the sensitivity of 8 TeV analyses only for narrow resonances with masses >≈ 5 TeV**

Di-Jet Mass Spectra 13 TeV ↔ 8 TeV



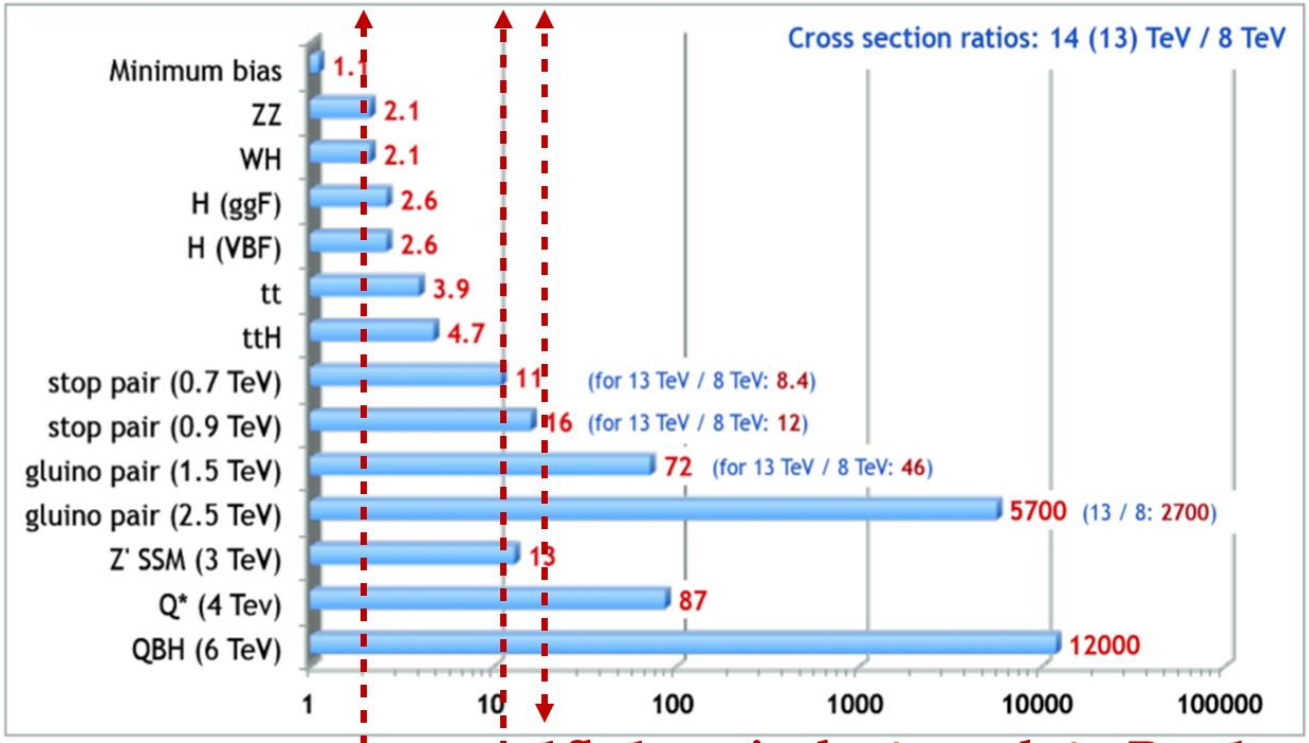


- **13 TeV: 37 pb-1, Mjj = 5 TeV, 8 TeV:19.7 fb-1, Mjj = 5.15 TeV**
- **Close to Run 1 limit ➔ interesting times ahead of us ☺**

A Glance at Run 2 Expectations

A different way to look at the Stirling plot:

How much luminosity @ 13TeV is needed to equal the 8 TeV discovery potential (a really rough guestimate)



1fb-1 equivalent reach to Run1

2 fb-1 equivalent reach to Run1

10 fb-1 equivalent reach to Run1

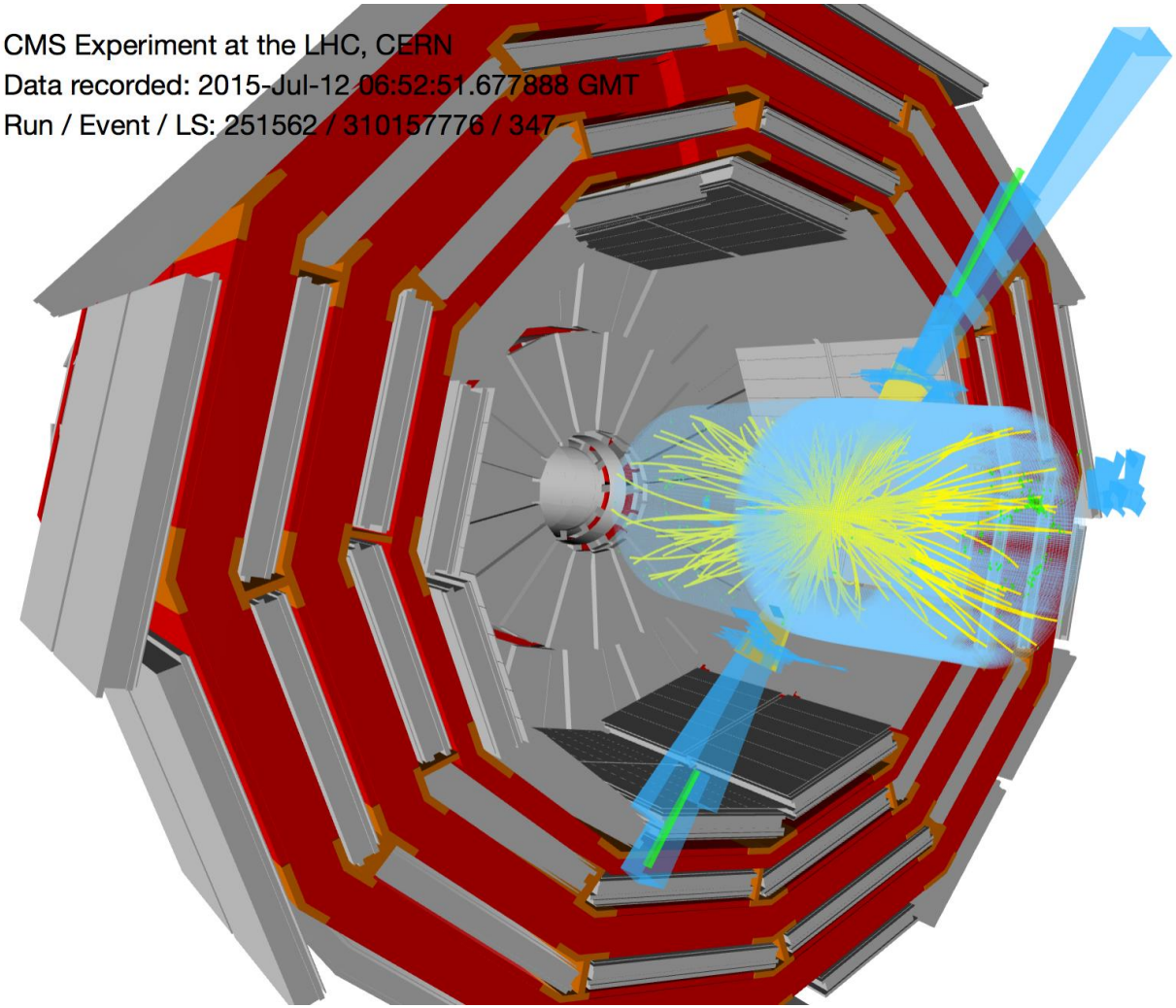
Summary

- CMS mastered successfully all novel installations, consolidations and developments in Long Shutdown 1
- Data taking at world-record energy has commenced, several obstacles overcome
- First LHC physics paper at novel collision energy accomplished: charged hadron multiplicity
  → tuned MCs describe data well
- Full suite of performance checks done
- Standard Model re-discovered, spectacular ZZ → 4l seen
- Searches commenced: interesting events seen,
  di-jet events @ $\sqrt{s}$ = 13 TeV even with very low luminosity
  already at a similar level as the $\sqrt{s}$ = 8 TeV results

CMS returned to precision and discovery mode

Thanks to my colleagues for making it happen for this conference ☺

Our Future has just started



Let's see, what Nature has in stock for us !

Any questions?

BACKUP

Luminosities

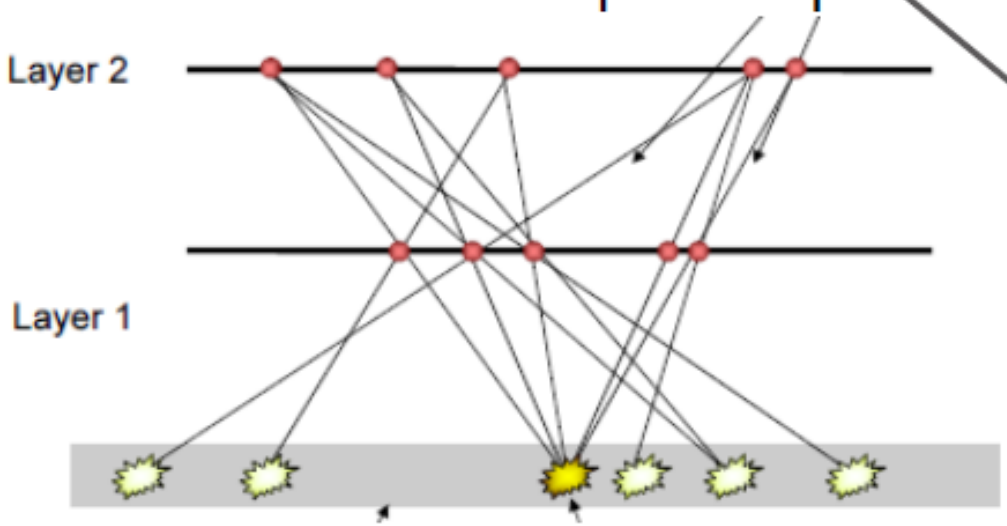
- **Total delivered: 106/pb**
- **Total recorded: 83.5/pb**
- **Total recorded @ 3.8T: 61.8/pb**
- **Results @ EPS presented up to 43/pb**

dN/dη of charged hadrons at 13 TeV

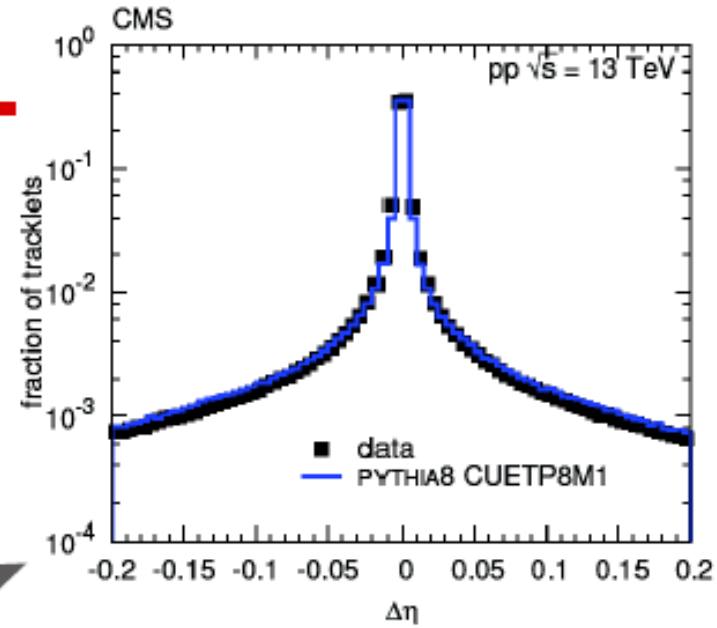
- Several methods employed
  - tracking, tracklets, pixel counting
- Trigger:
  - zero bias, PU = 0.05, ~170k collisions in a special run
- Definition of a 'collision':
  - inelastic (leads to a few % MC dependence)
- Datasets:
  - data taken June 7, 2015
  - number of collisions per bunch crossing: ~0.05
  - CMS tracker and pixel detectors ON
  - CMS magnet off, B=0 (straight tracks)
- First LHC publication at 13 TeV

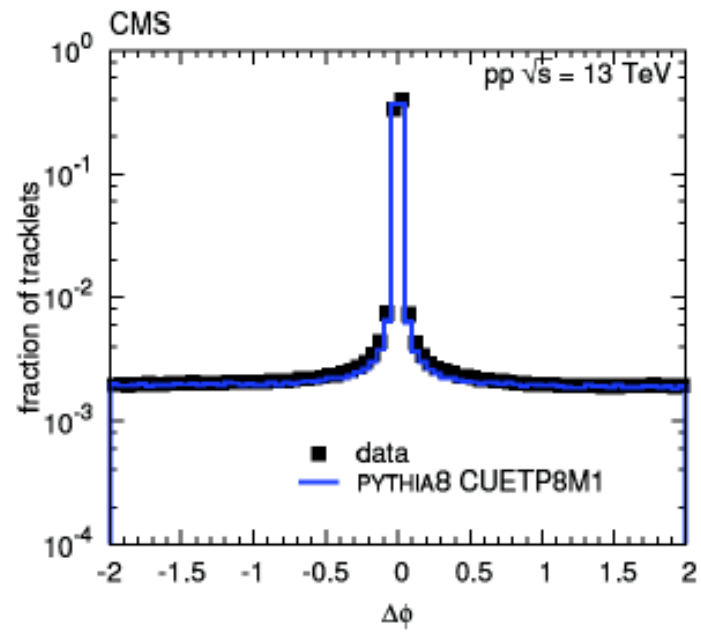
dN/dη: tracklets

- Using pairs of pixel barrel layers (3 combinations)
- Insensitive to alignment, very robust
- Has its own vertexing (extremely efficient)
- straight tracklets, sharp correlations in Δη and Δφ



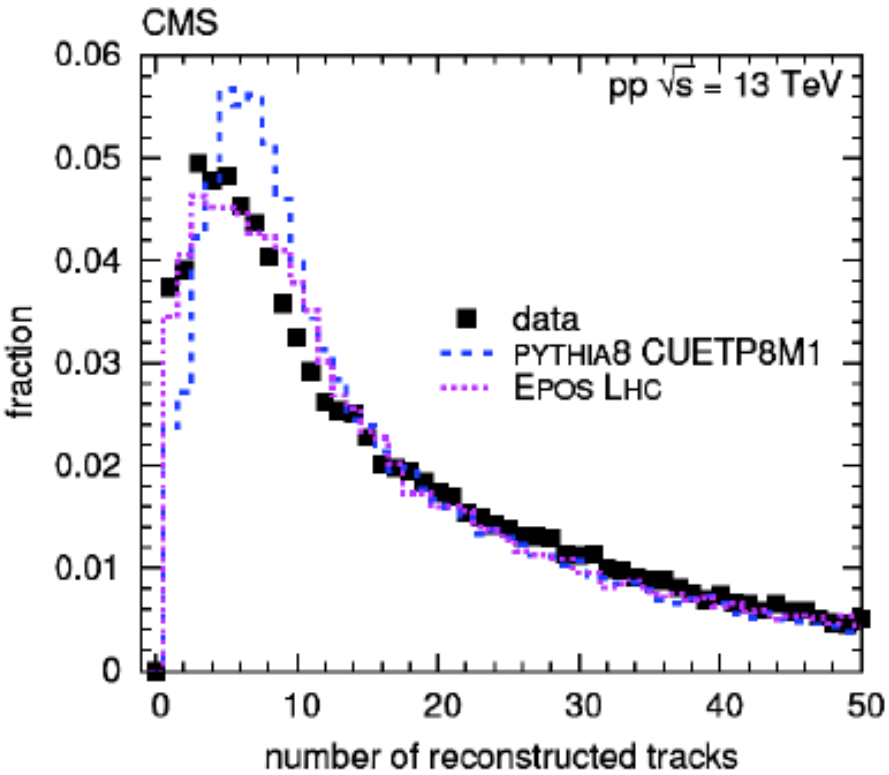
http://arxiv.org/abs/1507.05915



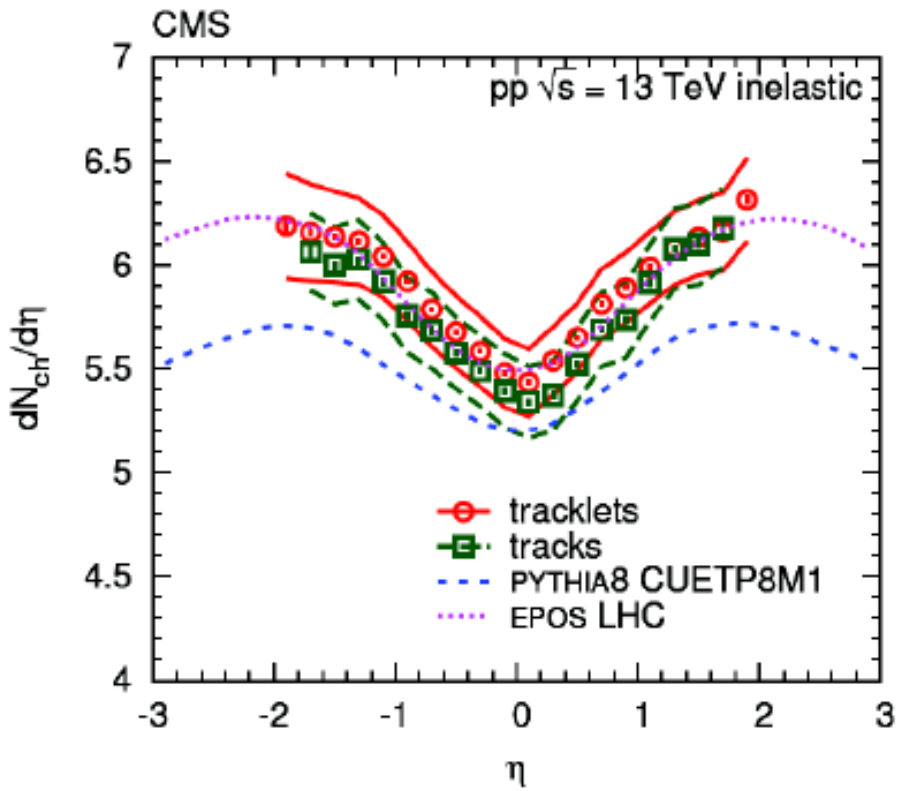


dN/dη: tracks

- Multiplicity distribution of reconstructed tracks



- Comparison of corrected dN/dη results: tracks and tracklets



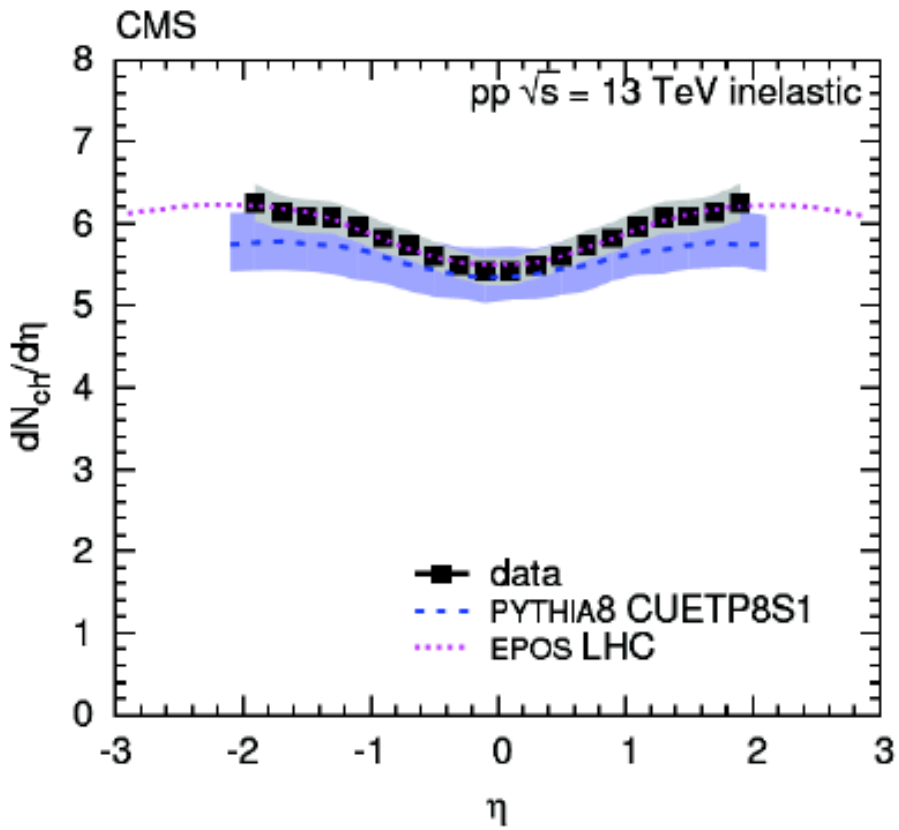
- In both cases, agreement is better with EPOS LHC

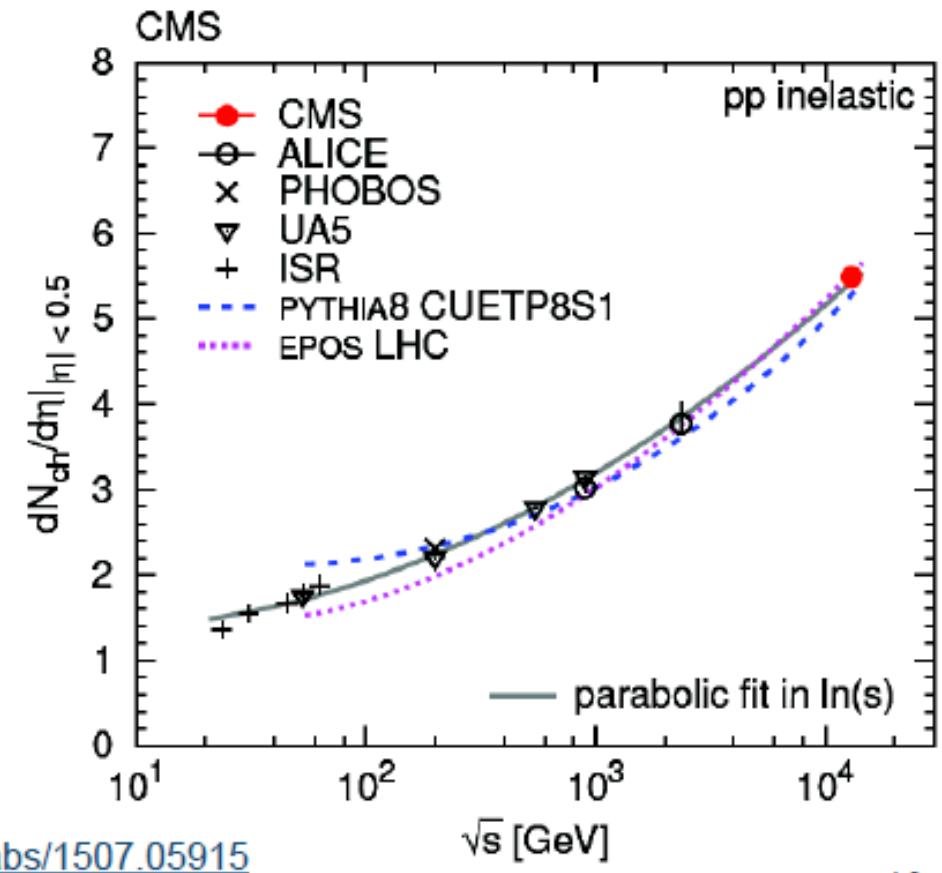
http://arxiv.org/abs/1507.05915

dN/dη of charged hadrons at 13 TeV

- Averaged main dN/dη result for *inelastic* events

- Collision energy dependence
- Central value: 5.49±0.01(stat)±0.17(syst)

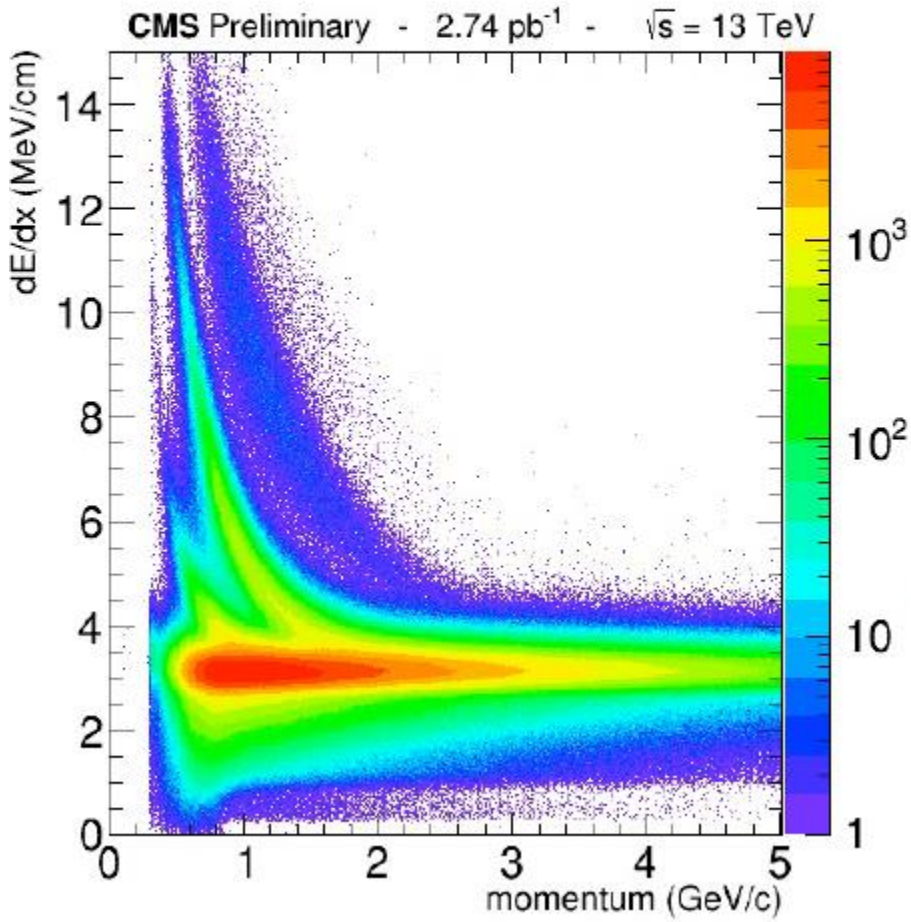




http://arxiv.org/abs/1507.05915

Tracker Performance

dE/dx vs P at Run 2

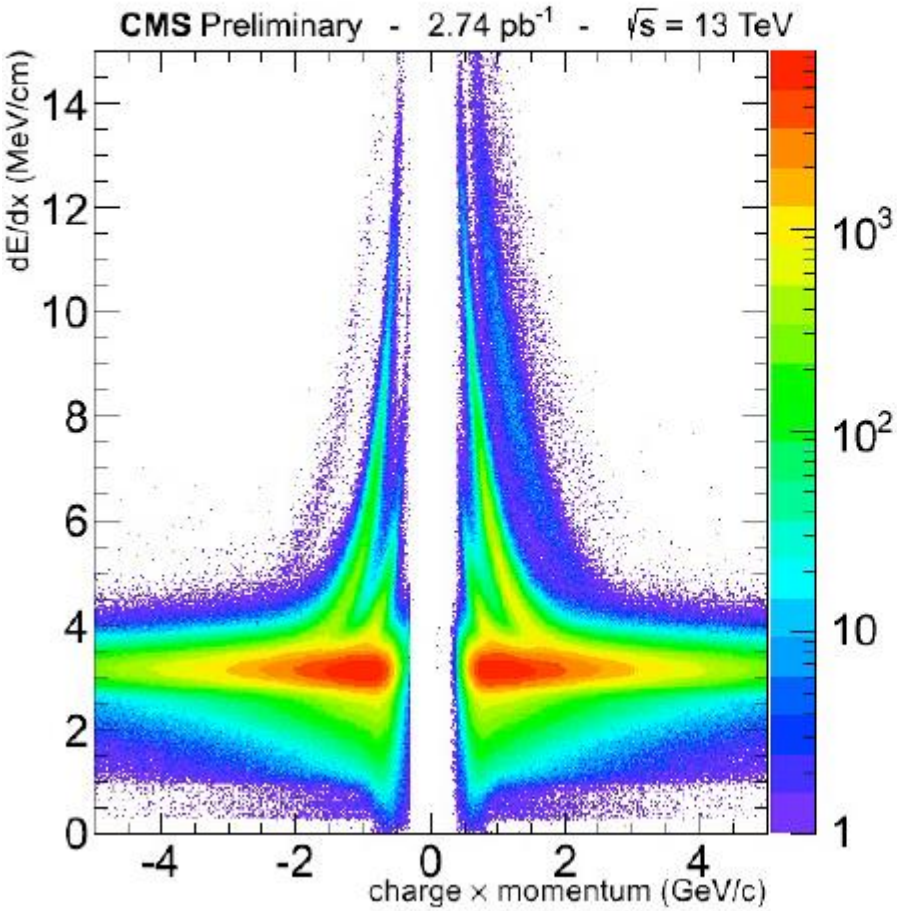


From right to left we can clearly see the Deuteron, Proton and Kaon bands.

The dE/dx estimator relies on gain calibration. The first calibration of run 2 data (tracker cooled to -15°C) allows already to clearly distinguish particles in this plot.

Tracker Performance

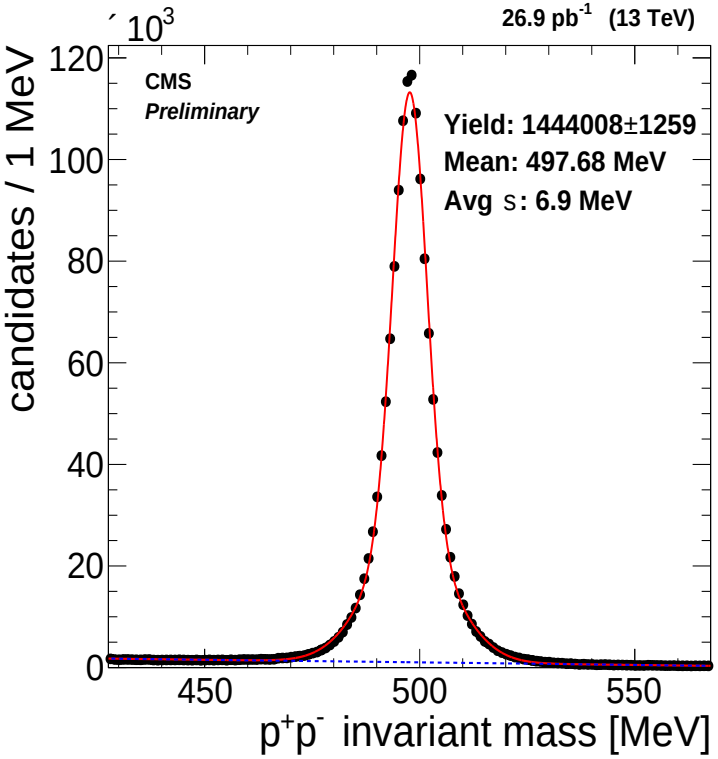
dE/dx vs Q.P at Run 2

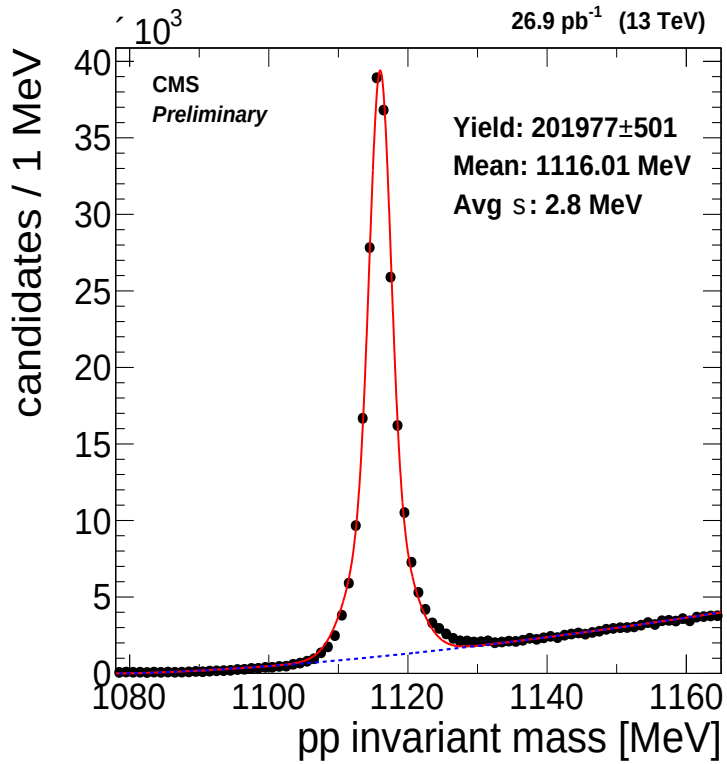


In this plot the particles are shown separatly depending on their charge.

We observe an expected asymmetry in the production of particles/ antiparticles for pp collisions.

Reconstruction of K^0_S and Λ^0 in 13 TeV data





- Invariant mass of the pion pairs fitted with a double gaussian and a first order polynomial for the background
- Invariant mass of the proton-pion pairs fitted with a double gaussian and a first order polynomial for the background

- Tracks selected with p_T>350 MeV. Selection requires displaced vertex wrt the primary vertex by 10σ and cosθ>0.9998

Dimuon invariant mass spectrum

Dimuon mass distribution collected with various dimuon triggers

The light gray continuous distribution represents events collected with inclusive dimuon triggers with high p_T thresholds

The dark gray band is collected by a trigger with low-mass non-resonant dimuon plus a track

The other colored spectra are acquired using specialized triggers which require a pair of muons with opposite charge, a vertex-fit probability greater than 0.5%, and specific dimuon invariant mass and p_T regions:

Magenta: dimuon mass within (0.85, 1.2) GeV, dimuon $p_T > 0$ GeV, dimuon $|y| < 1.25$

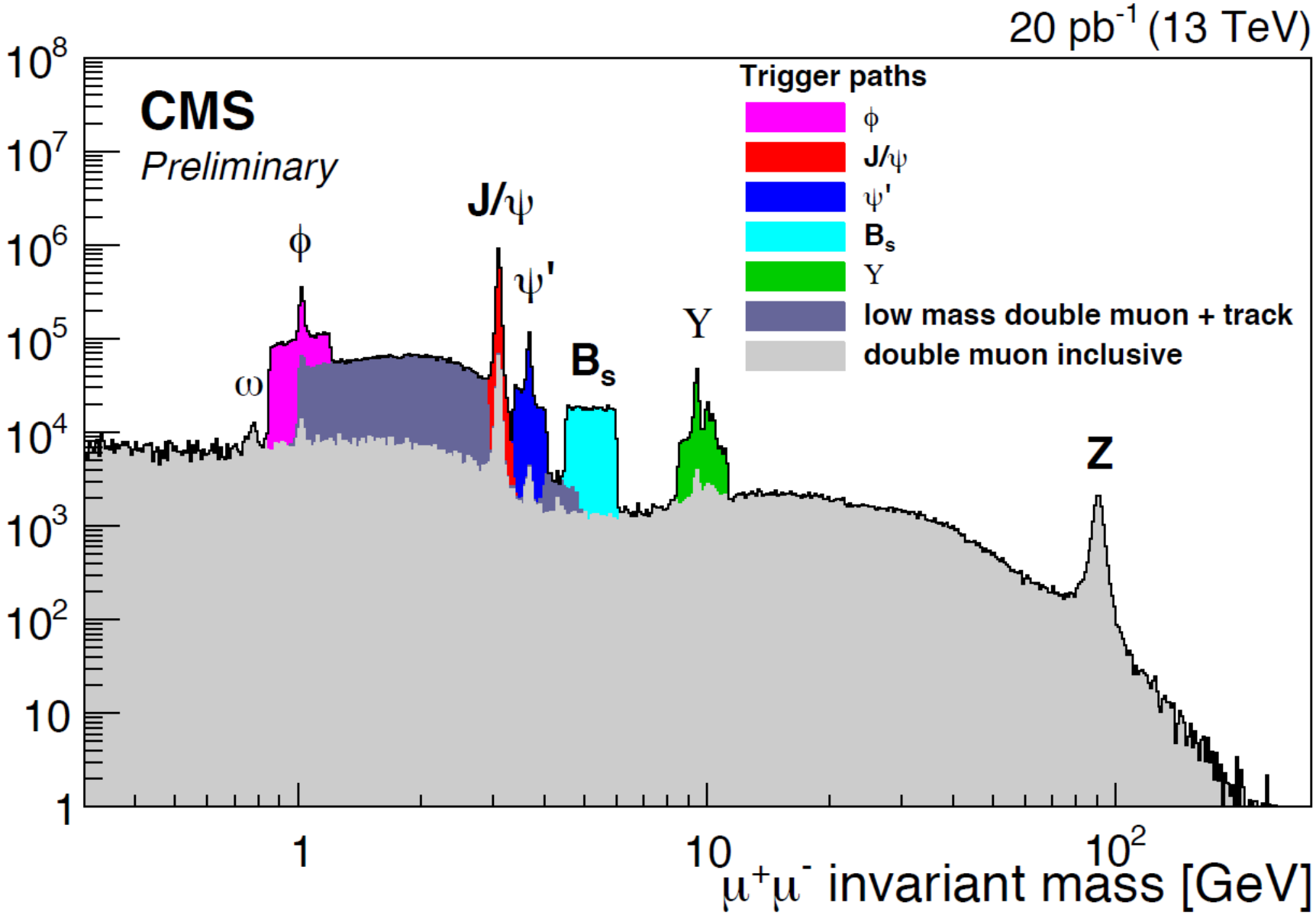
Red: dimuon mass within (2.95, 3.3) GeV, dimuon $p_T > 16$ GeV; or dimuon mass within (2.95, 3.3) GeV, dimuon $p_T > 10$ GeV, dimuon $|y| < 1.25$

Blue: dimuon mass within (3.4, 4) GeV, dimuon $p_T > 13$ GeV; or dimuon mass within (3.4, 4) GeV, dimuon $p_T > 8$ GeV, dimuon $|y| < 1.25$

Cyan: dimuon mass within (4.5, 6) GeV, the leading muon $p_T > 4$ GeV and the sub-leading muon $p_T > 3$ GeV

Green: dimuon mass within (8.5, 11) GeV, dimuon $p_T > 13$ GeV; or dimuon mass within (8.5, 11) GeV, dimuon $p_T > 8$ GeV, dimuon $|y| < 1.25$

Dimuon invariant mass spectrum



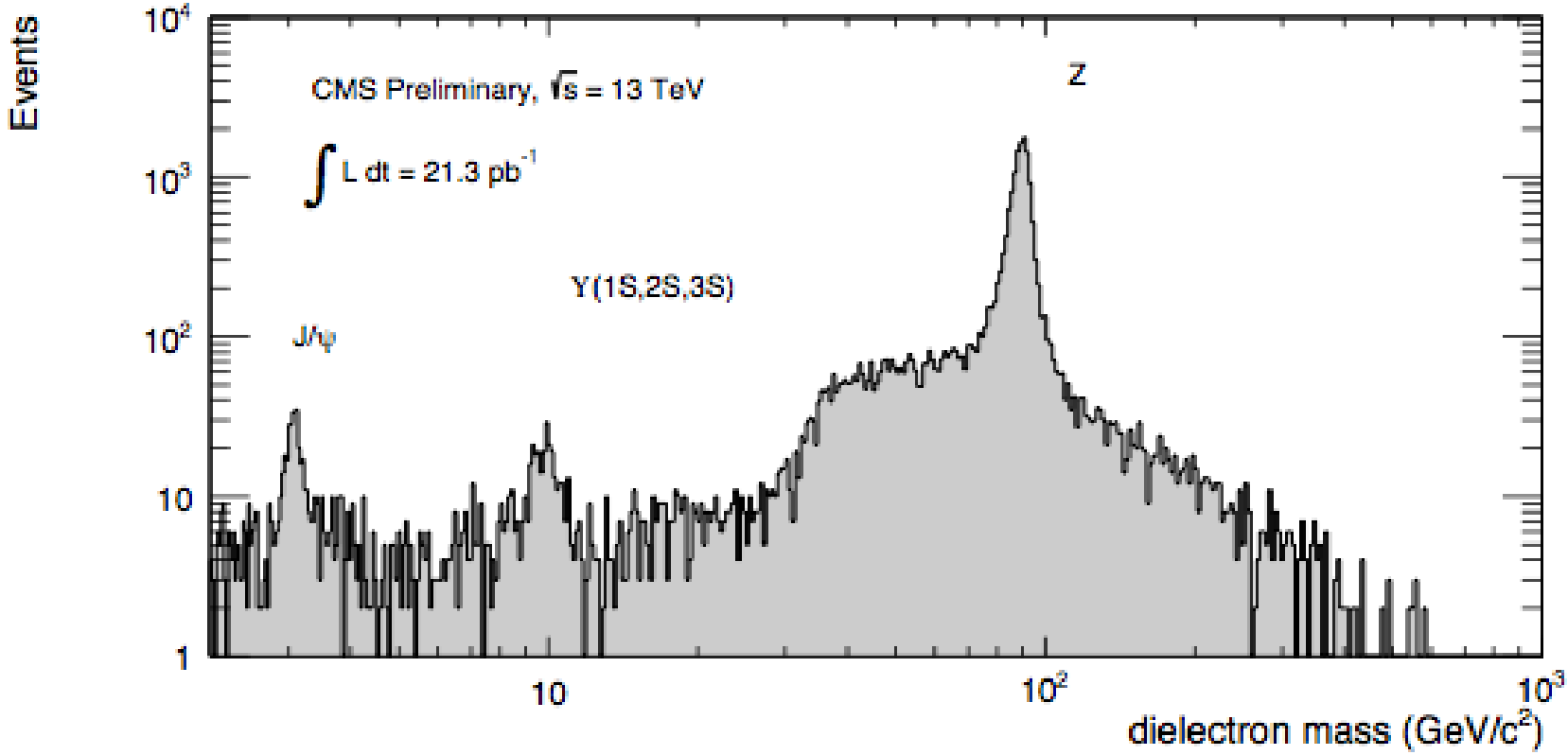
Electron Commissioning

- SingleElectron PD:
  - ~42/pb, with run selection based on [1], see backup
- RunII 50ns DY-M50 Monte Carlo
- Tag selection
  - Pass POG tight ID , $p_T > 30$ and $|\eta| < 2.1$
  - Matched to `HLT_Ele27_eta2p1_WPLoose_Gsf` in data
- Probe is reco electron with $p_T > 10$ and $|\eta| < 2.5$
  - Z window: $80 < m_{ll} < 100$
  - POG medium ID required for kinematic plots
  - Relative isolation cut (0.1) for track and cluster plots
  - POG Veto ID track and cluster cuts for isolation plots
- Pile-up re-weighting applied

[1] https://twiki.cern.ch/twiki/bin/view/CMS/CollisionsJuly2015

Di-Electron Spectrum

Dielectron mass spectrum for electrons in the DoubleEG dataset with $p_T > 10$ and $|\eta|<2.5$ which pass the cut-based Electron ID Veto working point.



Data set with charmonium triggers analyzed

$J/\psi \to \mu^+\mu^-$ reconstruction:

$|M(\mu^+\mu^-) - M(J/\psi)| < 150 MeV$

J/ψ mass constraint

$p_T^\mu > 4$ GeV

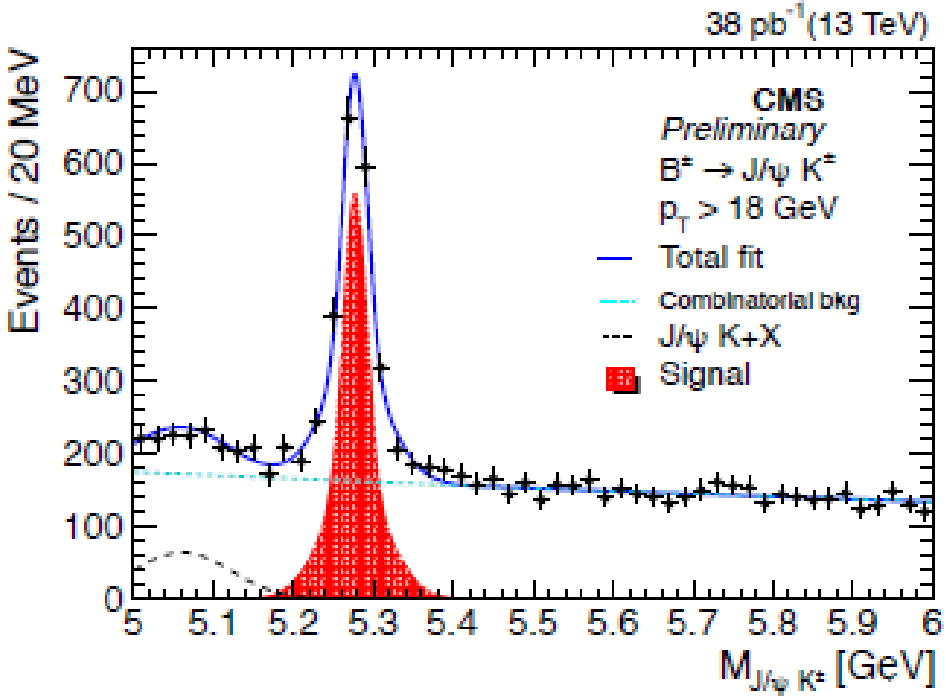
$|\eta^\mu| < 2.4$

$p_T(J/\psi) > 8$ GeV

Muon identification: soft muon ID

- Tracker track matched with at least one muon segment
- Number of hits in the tracker > 10
- Number of pixel layers > 1
- X^2/ndf of the tracker-muon track fit < 1.8
- Transverse and longitudinal impact parameter cuts:
  - $d_{xy} < 3$ cm & $d_z < 30$ cm w.r.t. primary vertex

Inclusive J/ψ trigger with p_T > 16 GeV



$B^{\pm} \to J/\psi\ K^{\pm}$

2D (mass, proper time)

fitting method: mass projection

Quality cuts:

$p_T(K^{\pm})$ > 2.0 GeV

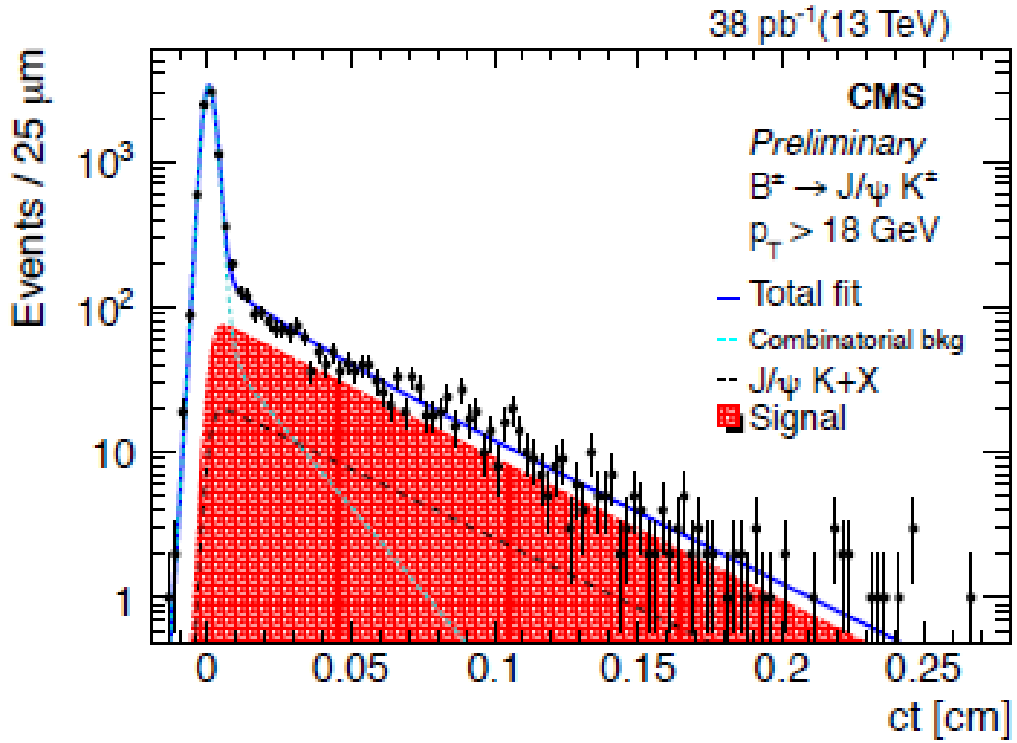
Vertex probability > 15%

$p_T(J/\psi)$ > 16 GeV

PDF shape:

- Signal: double Gaussian
- Combinatorial background: exponential
- J/ψ K+X: Gaussian

Mass: 5.277 ± 0.001(stat.) GeV



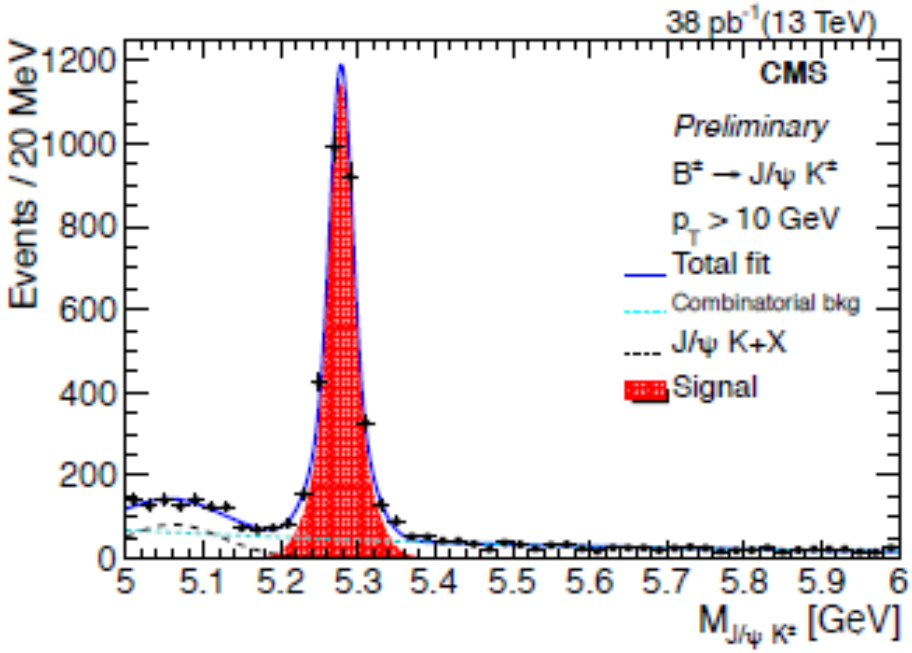
$B^{\pm} \rightarrow J/\psi K^{\pm}$

2D (mass, proper time) fitting method: proper time projection

PDF shape for ct distribution:

- Decaying exponential terms: $e^{-ct/\lambda}$ convolved with a Gaussian resolution function using per-event uncertainties
- Signal, J/psi K+X background: decaying exponential function
- combinatoric background: prompt Gaussian + decaying exponential function

Displaced J/ψ + track trigger



$B^{\pm} \to J/\psi K^{\pm}$

1D fitting method

Quality cuts:

- $\cos\alpha > 0.99$
- $l_{xy}/\sigma(l_{xy}) > 3.0$
- Vertex probability > 10%
- $p_T(J/\psi) > 8$ GeV
- $p_T(K) > 1.6$ GeV
- $|\eta(K)| < 2.4$

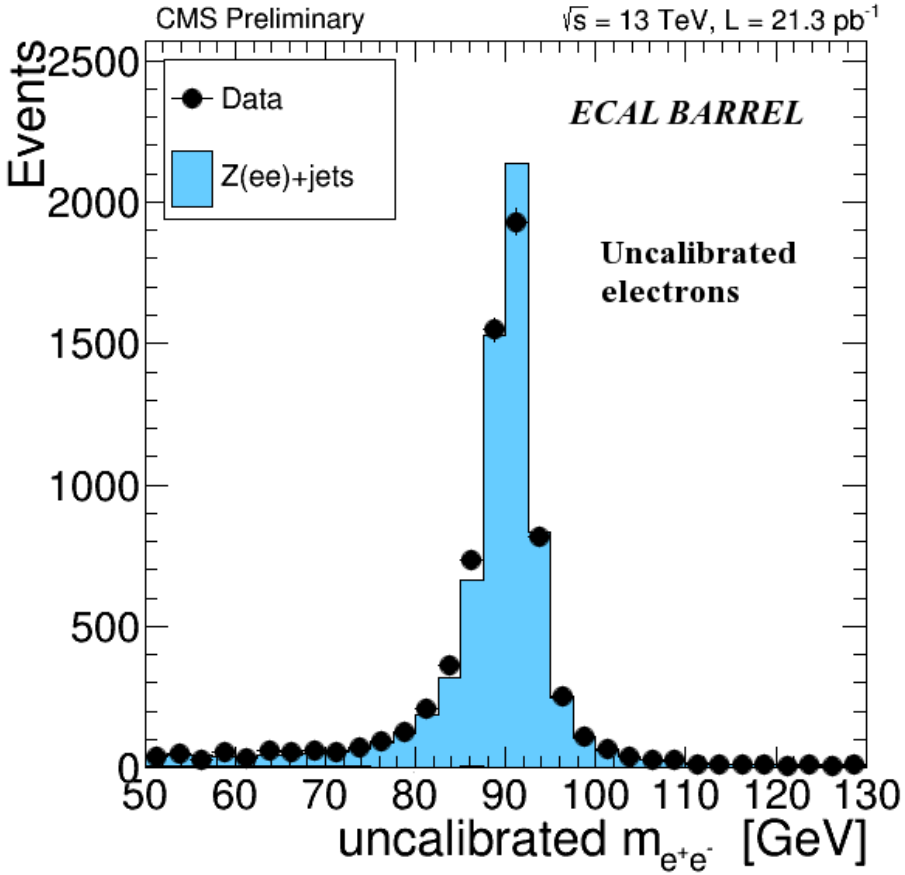
PDF shape:

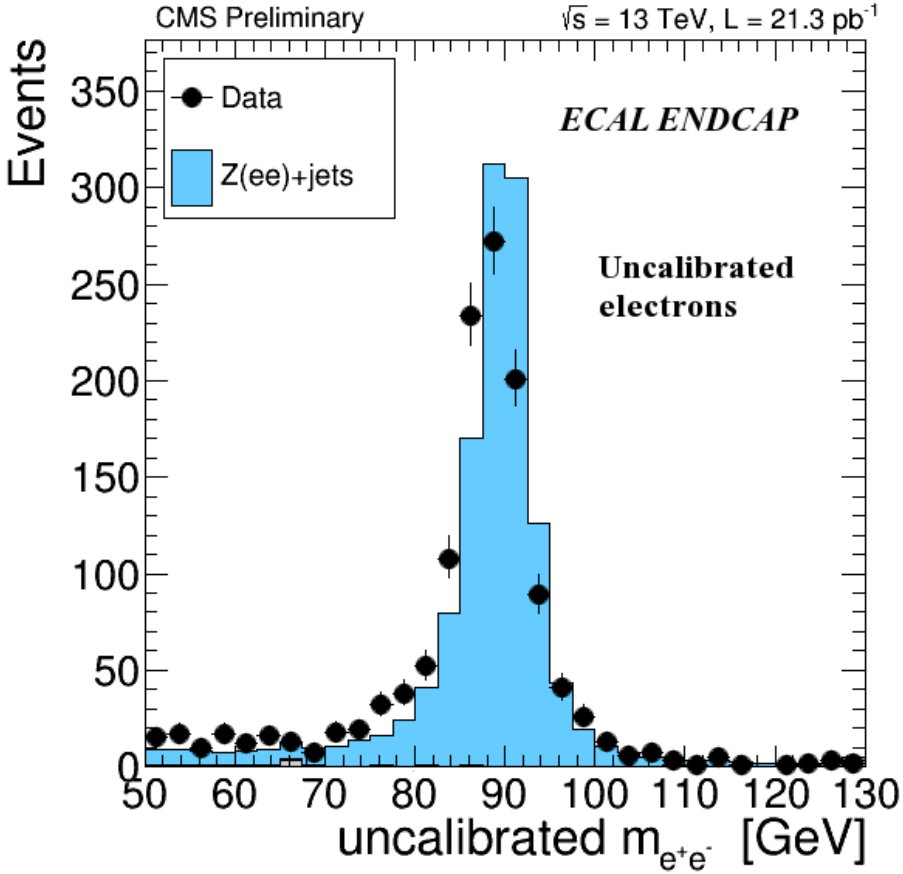
- Signal: double Gaussian
- Combinatorial background: exponential
- J/ψ K+X: Gaussian

Mass: 5.278 ± 0.001(stat.) GeV

PDG is 5366.7 ± 0.4 MeV

Reconstruction of Z→ee in 2015 data





- Invariant mass of di-electron pairs for both electrons in the barrel (left) and in the endcap (right). The calibrations applied in the data are the Run I ones extrapolated using the laser measurements. Simulation not tuned and assumes a calibration that will be achieved by the end of 50ns run. Data and simulation normalized to the same area

Muons in 13 TeV Collisions
Data and MC

- Data
  - Collision data at 13 TeV and 50 ns bunch spacing
  - Prompt reconstruction, certified only on the basis of DCS detector status
  - DoubleMuon dataset
  - Integrated luminosity ~ 43 pb^{-1}

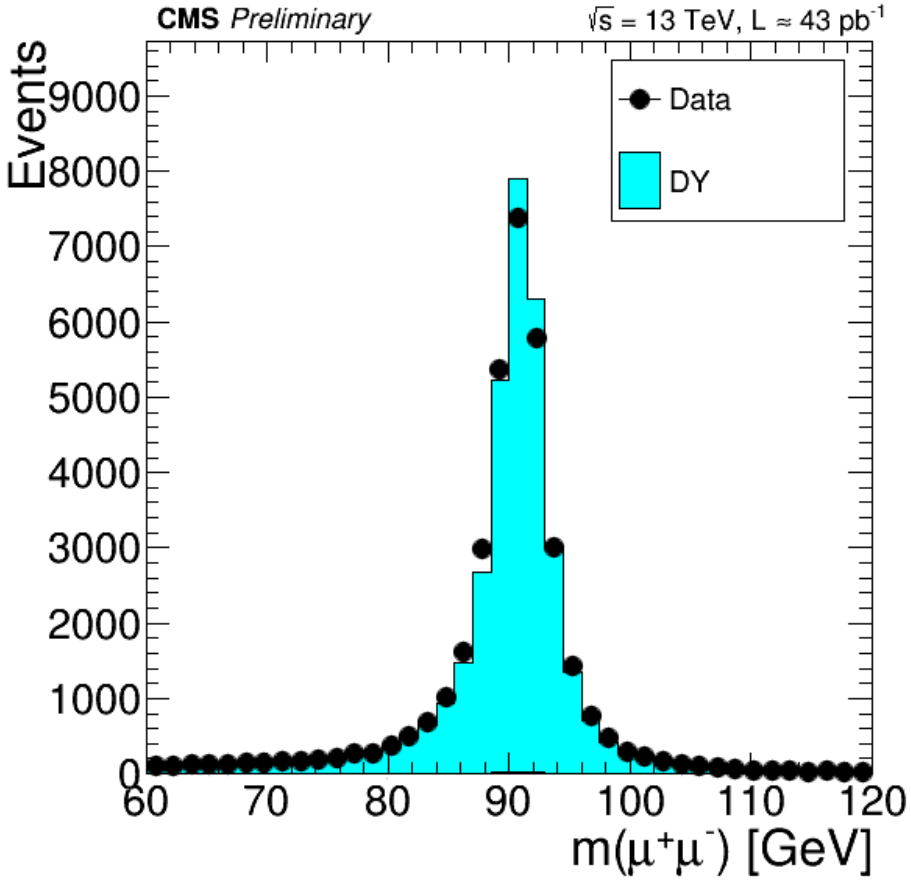
- Monte Carlo
  - Samples of Drell–Yan, W + jets, top-top, single-top, dibosons generated with MadGraph_aMC@NLO
  - Detector alignment and calibration conditions as expected after about 1 fb^{-1} of integrated luminosity
  - Overall normalization of simulated distributions scaled to the data yield
  - No event re-weighting is applied to match the pileup distribution in data

Muons in 13 TeV Collisions Selection

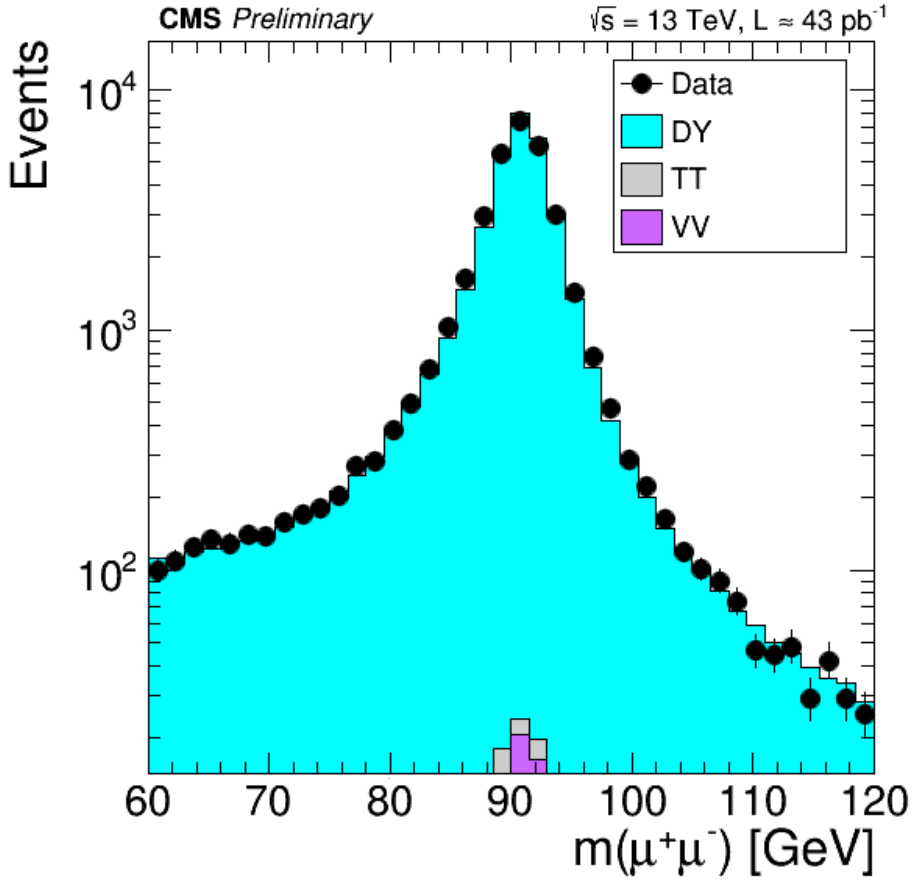
- Trigger
  - double-muon trigger with p_T thresholds of 17 and 8 GeV on higher- and lower-p_T muon, loose tracker-based isolation on each muon

- Offline selection
  - at least two opposite-sign muons passing the Loose ID
  - $p_T > 20$ and 10 GeV, $|\eta| < 2.4$
  - both muons passing a loose isolation requirement:
    $\Sigma\, p_T(\text{tracks}) + \max(0, \Sigma\, E_T(\text{ECAL}) + \Sigma\, E_T(\text{ECAL}) - k \cdot \rho) < 0.2 \cdot p_T(\text{muon})$
    (where ρ is the average energy density in the event)
  - di-muon invariant mass between 60 and 120 GeV
  - if more than one muon pair satisfies the requirements above, the pair with invariant mass closest to the nominal Z boson mass is selected

Muons in 13 TeV Collisions
Invariant Mass

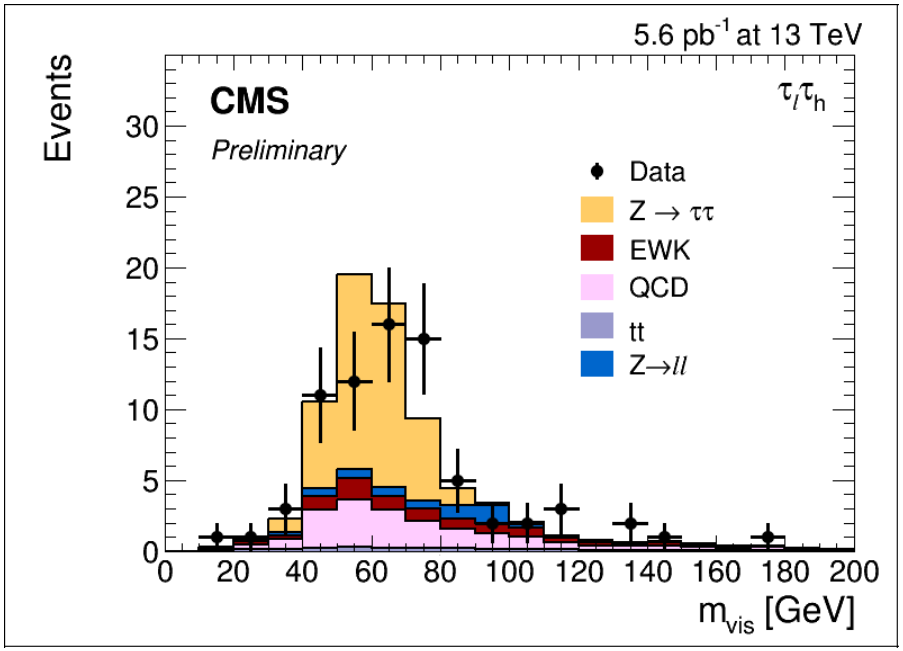


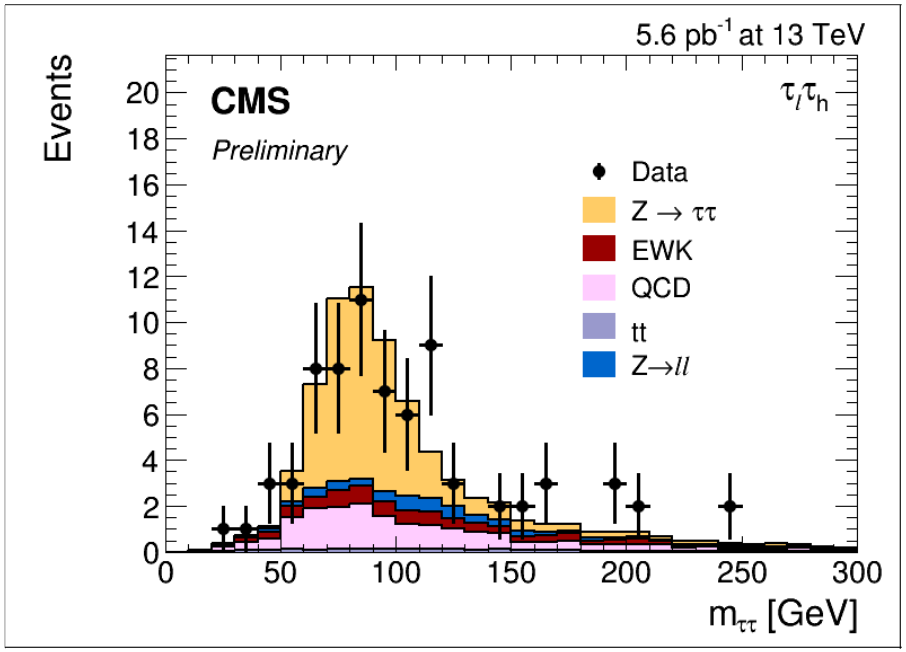
linear scale



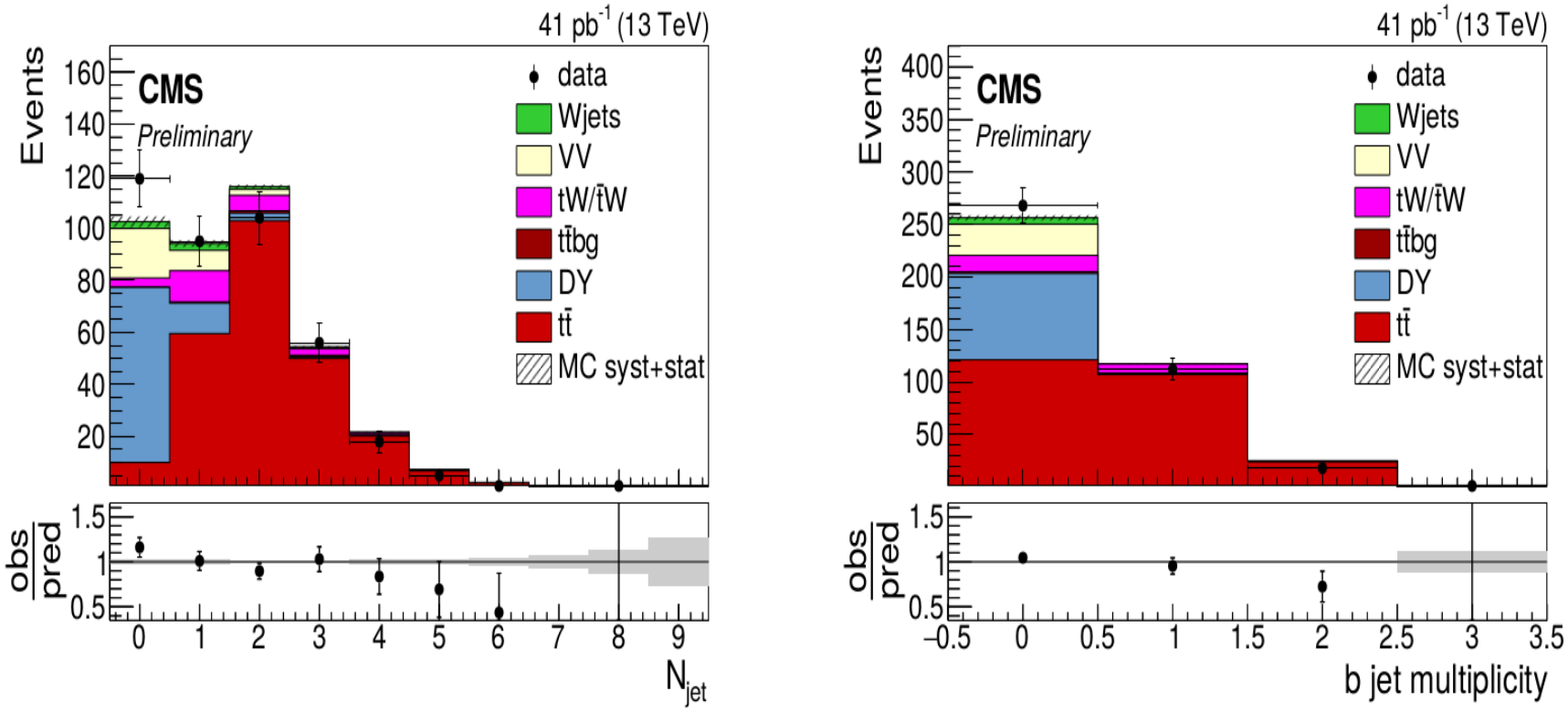
logarithmic scale

Reconstruction of Z → ττ in 13 TeV data

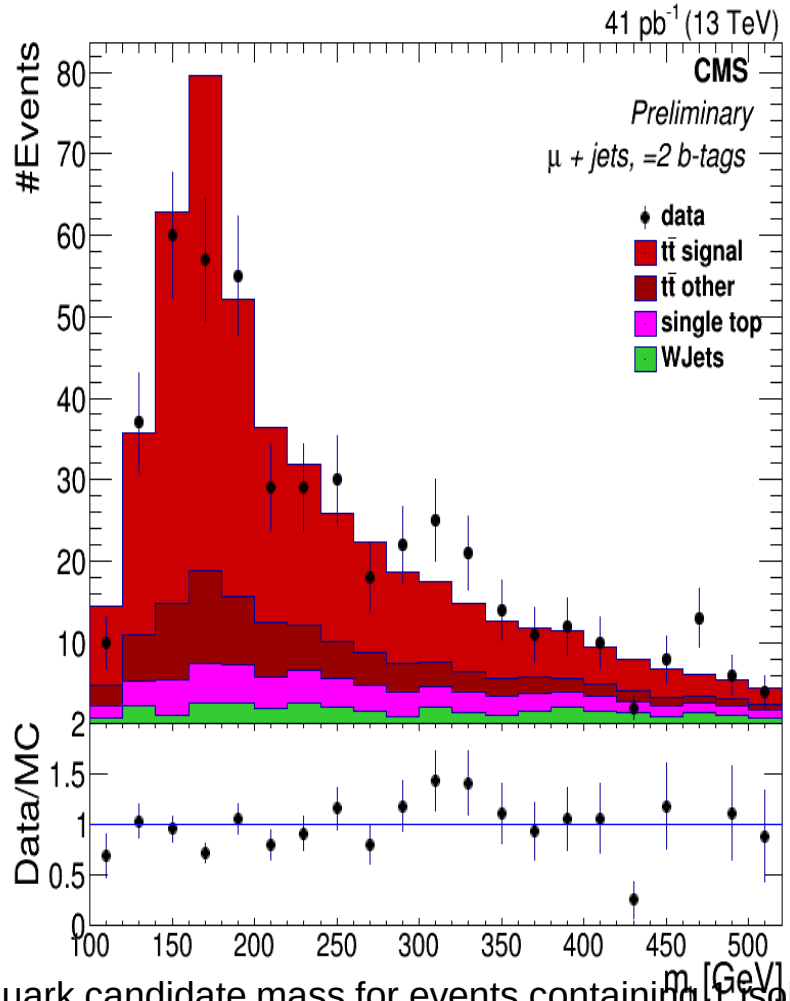




- Visible mass distribution (left) and fully reconstructed mass using the SVFit algorithm (right) for lepton (e,μ) and hadronically decaying taus in 13 TeV data.The simulation is normalized to the total integrated luminosity for all contributions except from the QCD background that is estimated by same sign data
- **Selection**
  - Muons: p_T>18 GeV, η<2.1
  - Electrons: p_T>20 GeV η<2.1
  - Taus: p_T>20, η<2.3
  - Event: lepton,tau have opposite sign , M_T(μ,τ)<40 GeV

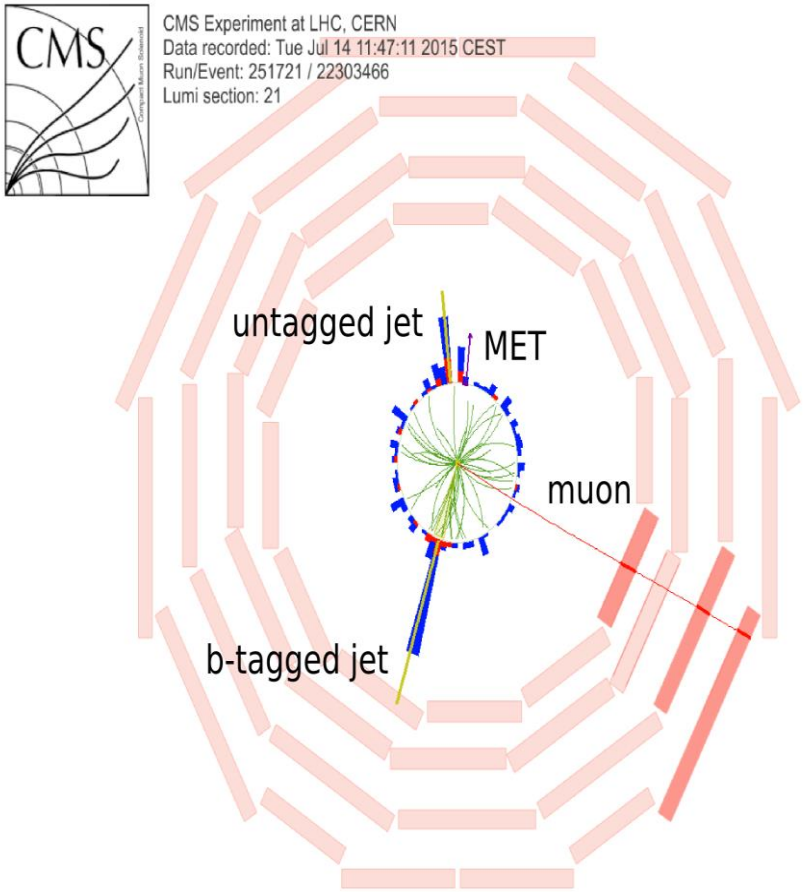


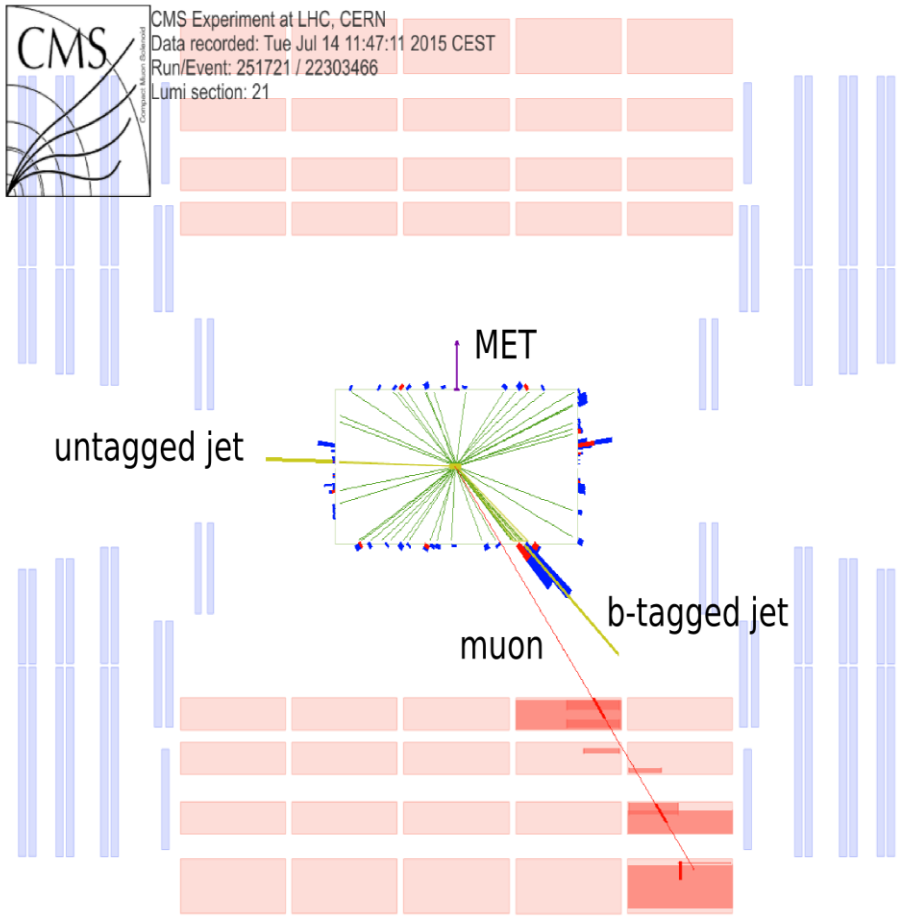
Distribution of the number of hadronic jets with p_T>30 GeV, $|\eta|$<2.4 (left) and jets passing the tight threshold on the b-tagging discriminant (right) for events containing one isolated muon (p_T> 20 GeV, $|\eta|$<2.4, passing tight identification criteria) and one isolated electron (p_T> 20 GeV, $|\eta|$<2.4, excluding barrel-endcap gap, passing medium identification criteria) with opposite charge, forming an invariant mass greater than 50 GeV.



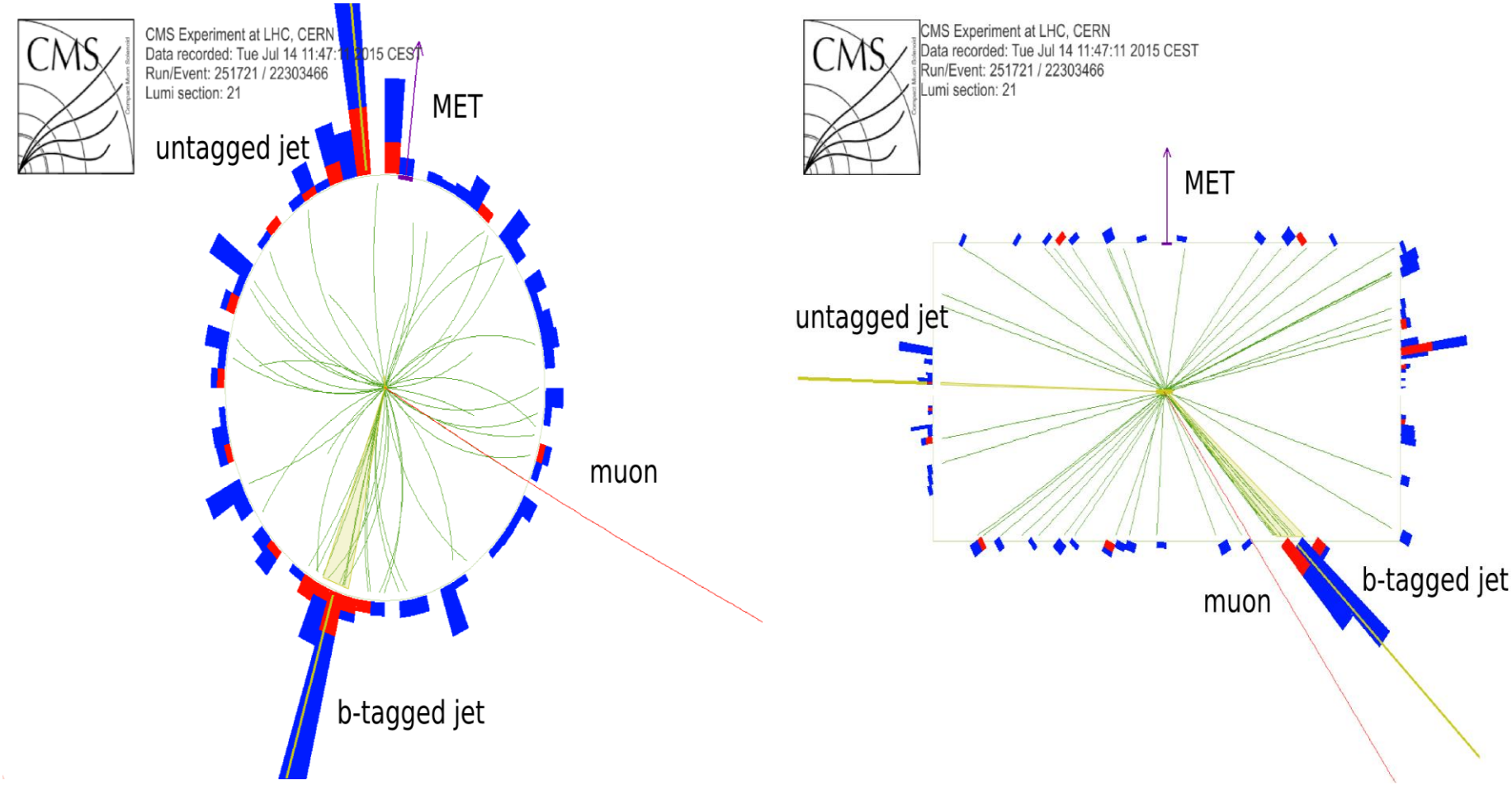
Reconstructed hadronic top quark candidate mass for events containing 1 isolated muon (p_T>30 GeV, $|\eta|$<2.4, passing medium identification), four jets (p_T>30 GeV, $|\eta|$<2.5), out of which 2 pass the tight b-tagging threshold. Leptonically decaying W boson is reconstructed using the lepton momentum and missing energy. The longitudinal component of the neutrino momentum is determined using the W boson mass constraint, with a 2-fold ambiguity. Then, the jet pair giving the best W boson mass is selected among the jets failing the b-tagging selection and assigned to the hadronic top quark. Finally, the b-tagged jet assignment and the neutrino solution that give the closest leptonic top mass to the world average are retained.

3. Towards single top (t-channel production)





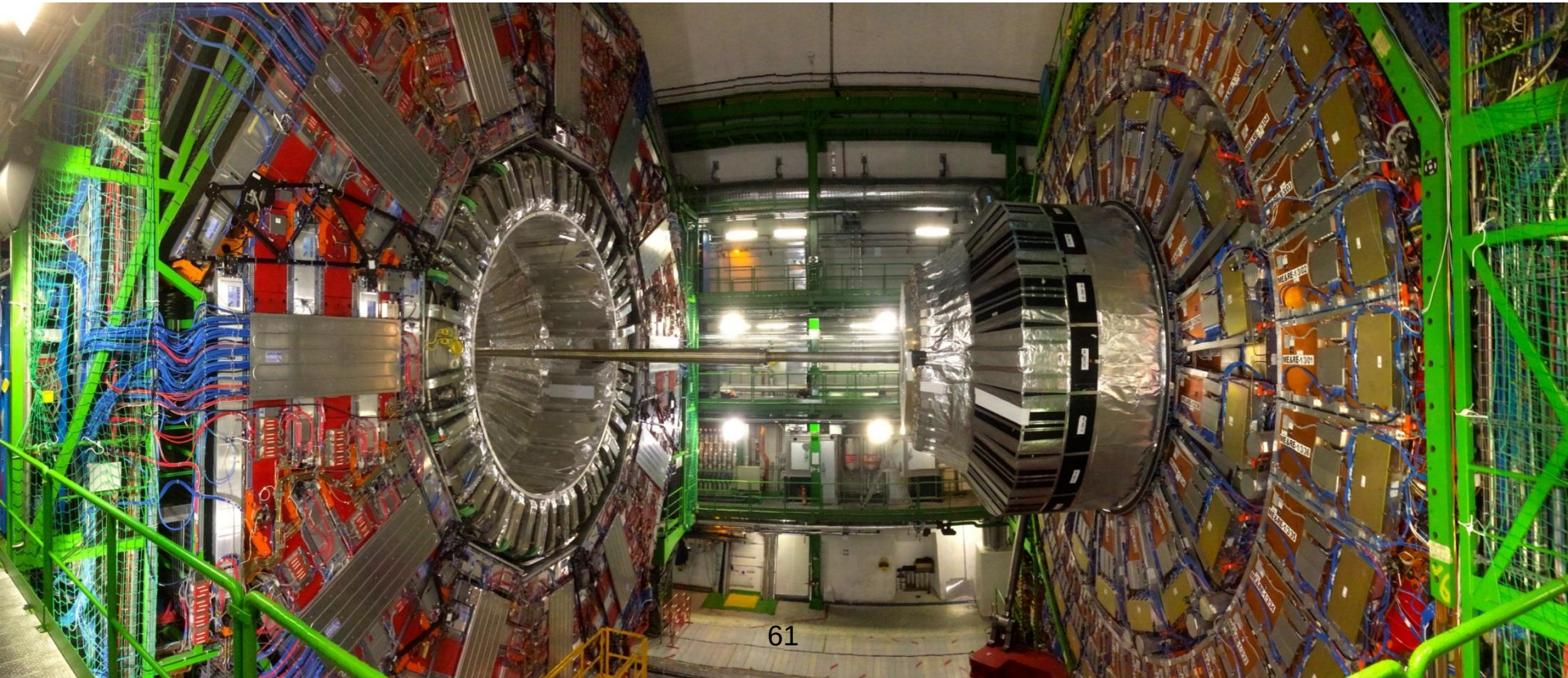
Event display of a single top quark t-channel candidate in x-y (left) and r-z (right) views. This event has one isolated muon, transverse missing energy of 27 GeV, and two hadronic jets. One of the jets passes the tight threshold on the Combined Secondary Vertex b-tagging discriminant and is interpreted as originating from the b quarks from top quark decay. The other jet has a pseudorapidity of -4.3 and in the signal ansatz it is interpreted as originating from a light quark recoiling against the top quark. The mass of the reconstructed top quark is 177 GeV.



Event display of a single top quark t-channel candidate in x-y (left) and r-z (right) views. This event has one isolated muon, transverse missing energy of 27 GeV, and two hadronic jets. One of the jets passes the tight threshold on the Combined Secondary Vertex b-tagging discriminant and is interpreted as originating from the b quarks from top quark decay. The other jet has a pseudorapidity of -4.3 and in the signal ansatz it is interpreted as originating from a light quark recoiling against the top quark. The mass of the reconstructed top quark is 177 GeV. (Zoom-in of the previous figures.)

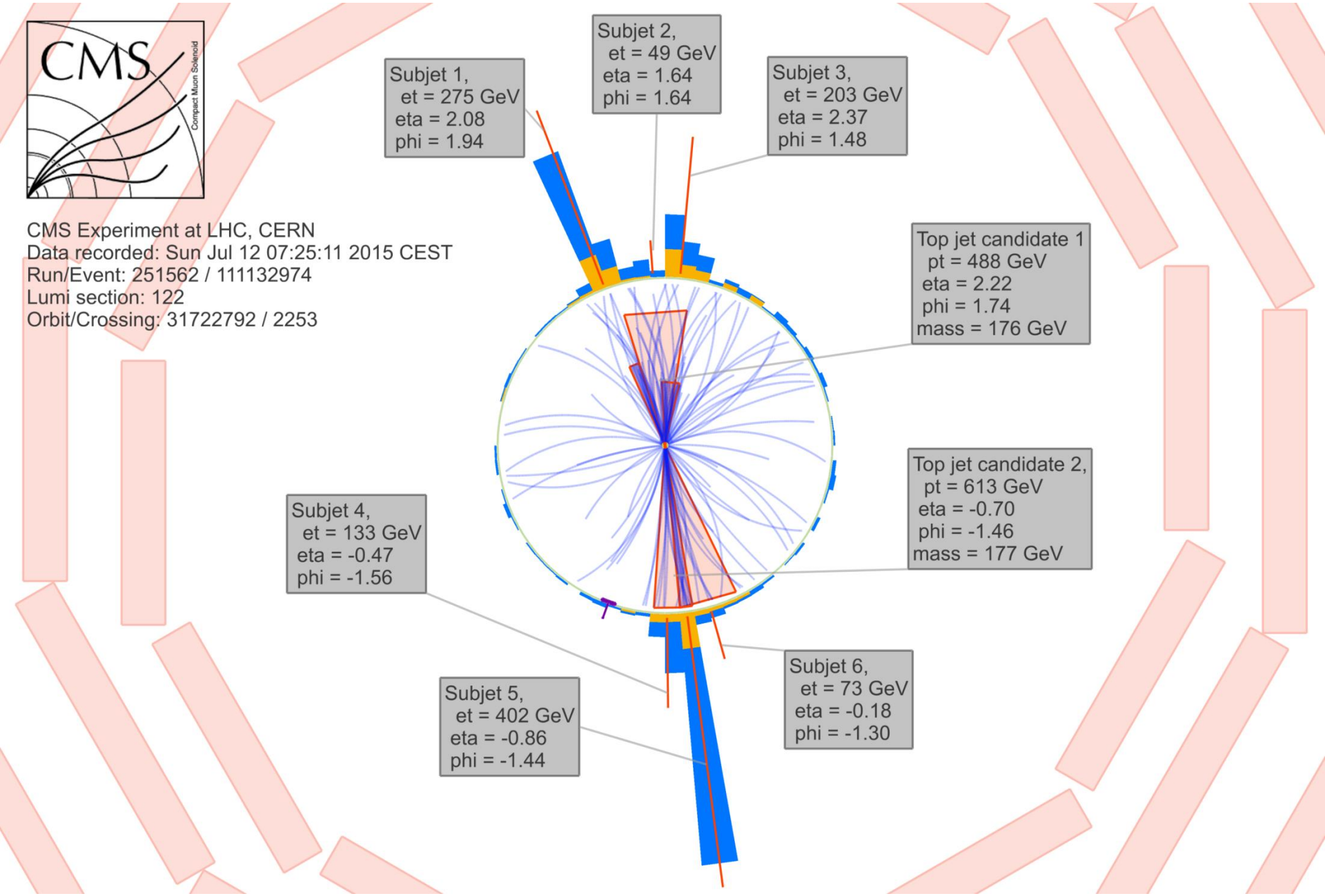
Top-antitop candidate event display

CMS Collaboration

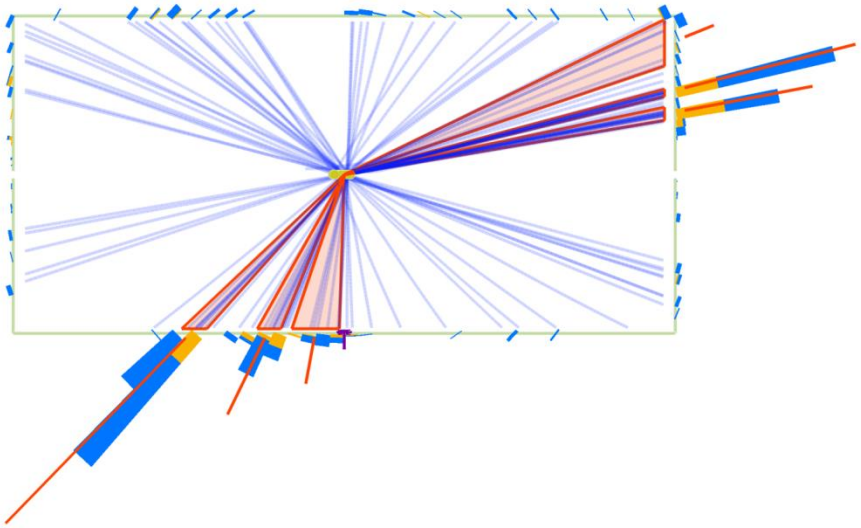


Details

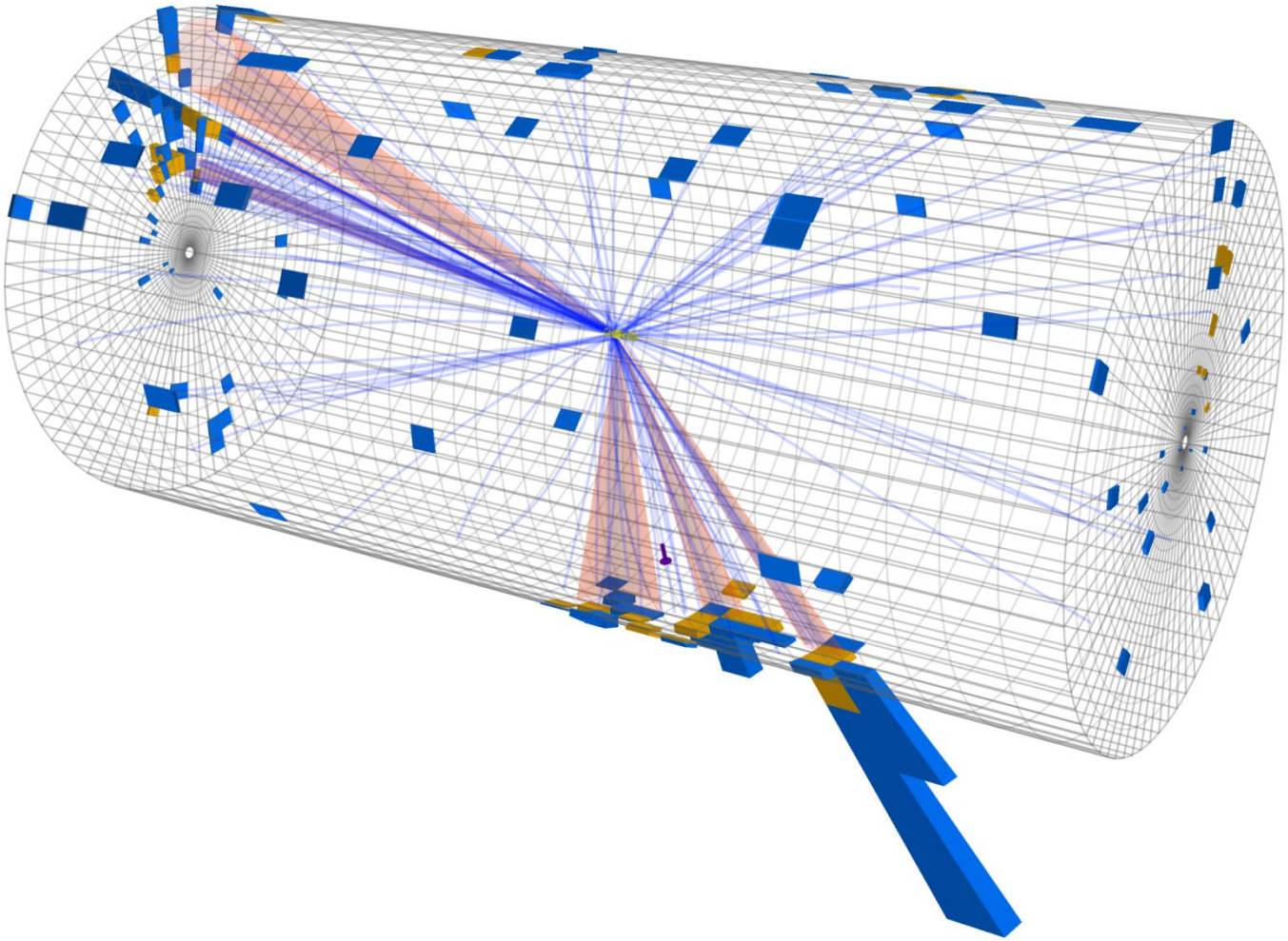
- DCS-only lumi selection
- Selected with: 2xCMSTopTagged jets, pT>300GeV, m(ttbar)>2TeV, deltaPhi(topjets)>2.1
- Plotted: (apart from the usual) CMSTopJet subjets in yellow
- Coordinates: 251562:122:111132974
- Kinematics:
  m(topjet1)=177 GeV, pt(topjet1)=613 GeV,
  m(topjet2)=176 GeV, pT(topjet2)=488 GeV,
  ditopjet mass = 2491 GeV,
  1 btagged subjet (CSVIVFv2 medium OP)


CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 07:25:11 2015 CEST
Run/Event: 251562 / 111132974
Lumi section: 122
Orbit/Crossing: 31722792 / 2253
Subjet 1,
et = 275 GeV
eta = 2.08
phi = 1.94
Subjet 2,
et = 49 GeV
eta = 1.64
phi = 1.64
Subjet 3,
et = 203 GeV
eta = 2.37
phi = 1.48
Top jet candidate 1
pt = 488 GeV
eta = 2.22
phi = 1.74
mass = 176 GeV
Top jet candidate 2,
pt = 613 GeV
eta = -0.70
phi = -1.46
mass = 177 GeV
Subjet 4,
et = 133 GeV
eta = -0.47
phi = -1.56
Subjet 5,
et = 402 GeV
eta = -0.86
phi = -1.44
Subjet 6,
et = 73 GeV
eta = -0.18
phi = -1.30

CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 07:25:11 2015 CEST
Run/Event: 251562 / 111132974
Lumi section: 122
Orbit/Crossing: 31722792 / 2253



CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 07:25:11 2015 CEST
Run/Event: 251562 / 111132974
Lumi section: 122
Orbit/Crossing: 31722792 / 2253



Event Display information

Run: 251251, LumiSection:64, Event Number: 39089589

Event: Single high p_T muon (red line) detected in the barrel muon chambers with a large imbalance in the transverse momentum (Missing ET) (arrow).

Kinematic quantities:

Muon: p_T= 0.53 TeV

η = 0.69

ϕ = -2.3

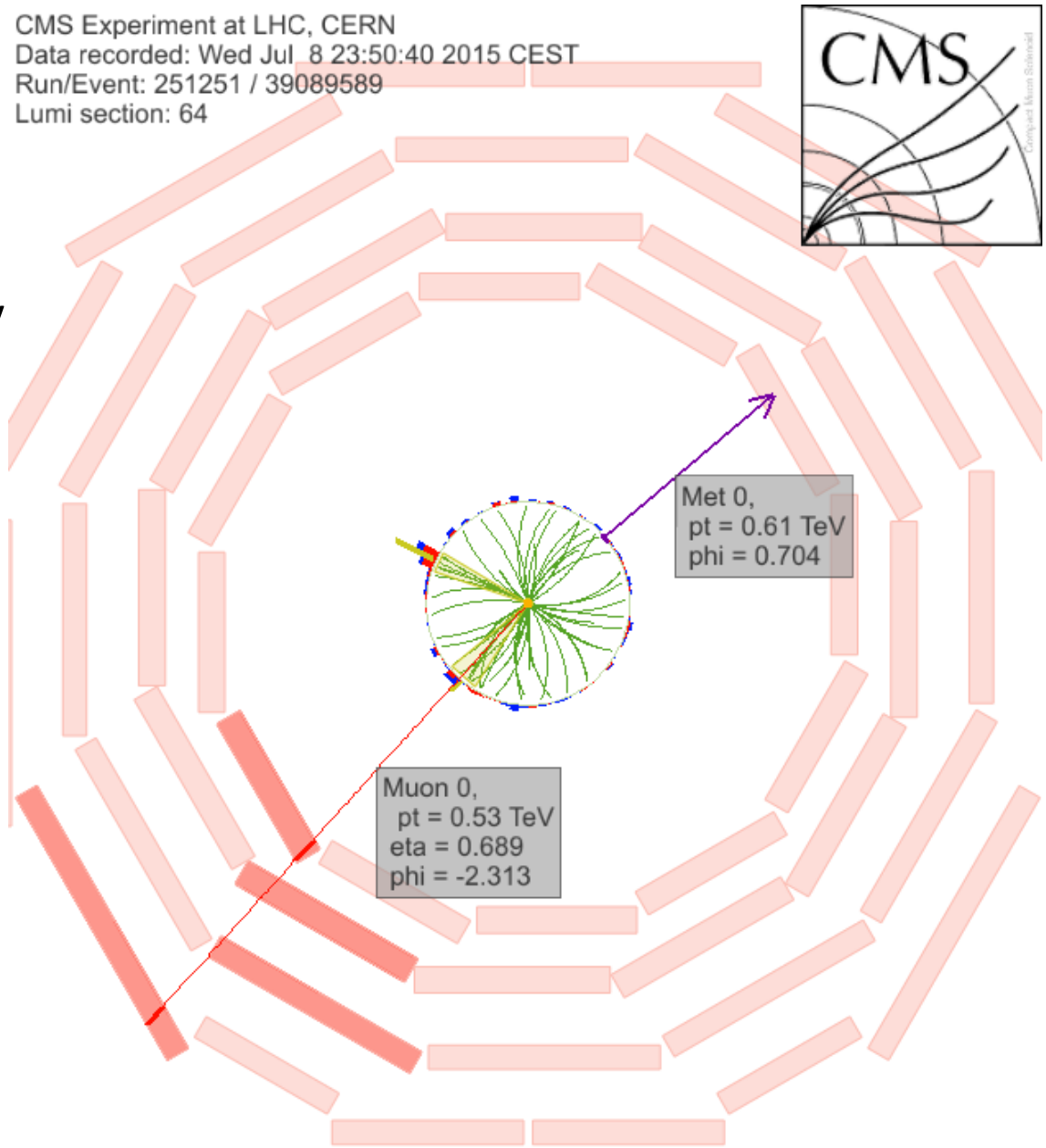
MET : 0.62 TeV

$\Delta\phi$ (μ-MET) = 3.0

m_T = 1.1 TeV

Single muon + missing E_T @ m_T = 1.1 TeV

1 event expected with m_T > 700 GeV for the luminosity analyzed



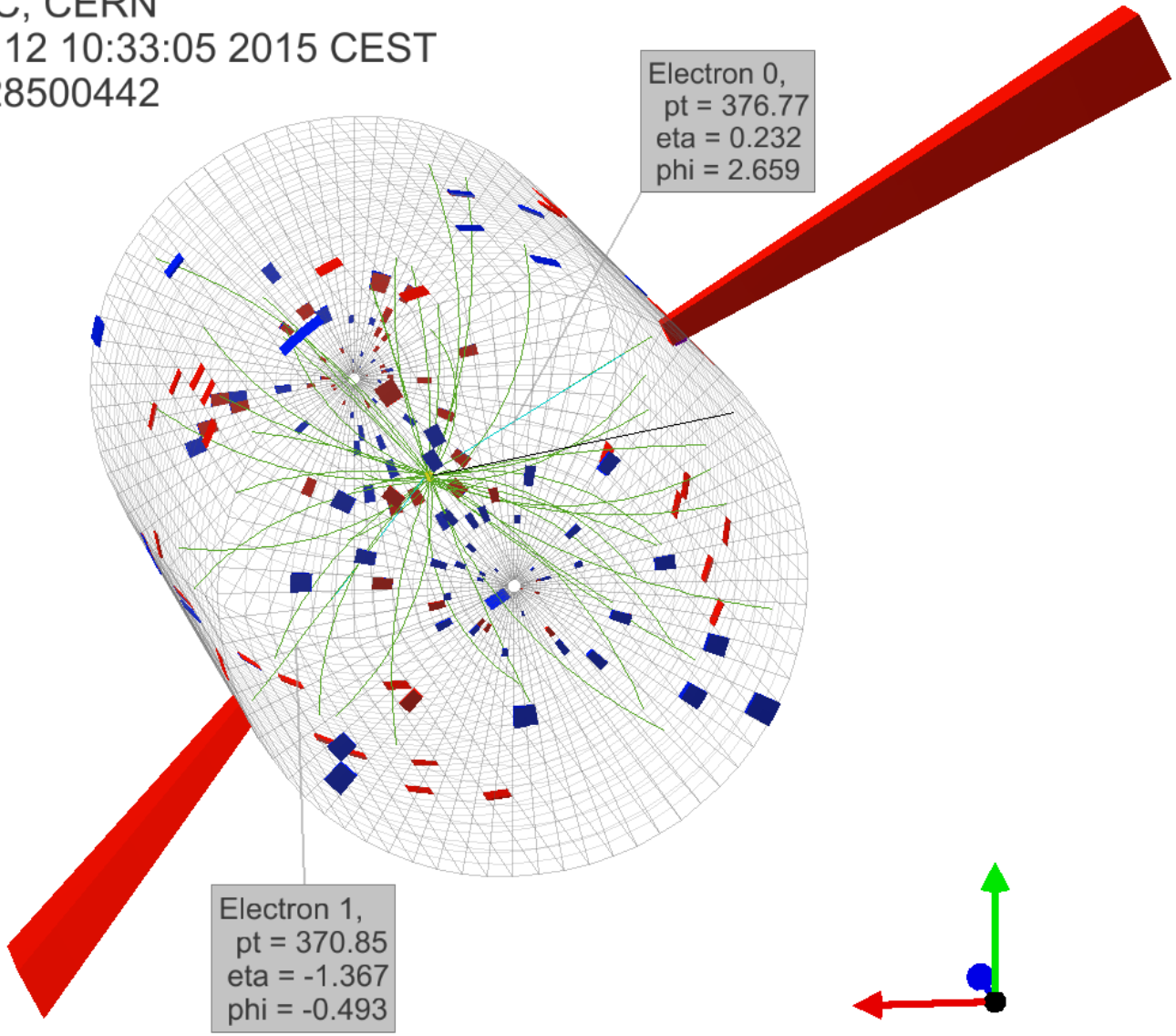
W prime candidate

Details

- DCS-only lumi selection
- selected with two events passing the high energy electron ID tuned for 50ns data taking (HEEP ID V6.0)
- event details:
  - run: 251562
  - luminosity section: 605
  - event number: 528500442
- kinematics:
  - ele1 : pt = 377 GeV, η = 0.232, ϕ = 2.66 rad
  - ele2 : pt = 371 GeV, η = -1.37, ϕ = -0.493 rad
  - mass(ee) : 999 GeV
  - missing transverse energy : 9.2 GeV

Z prime candidate

CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 10:33:05 2015 CEST
Run/Event: 251562 / 528500442
Lumi section: 605



CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 10:33:05 2015 CEST
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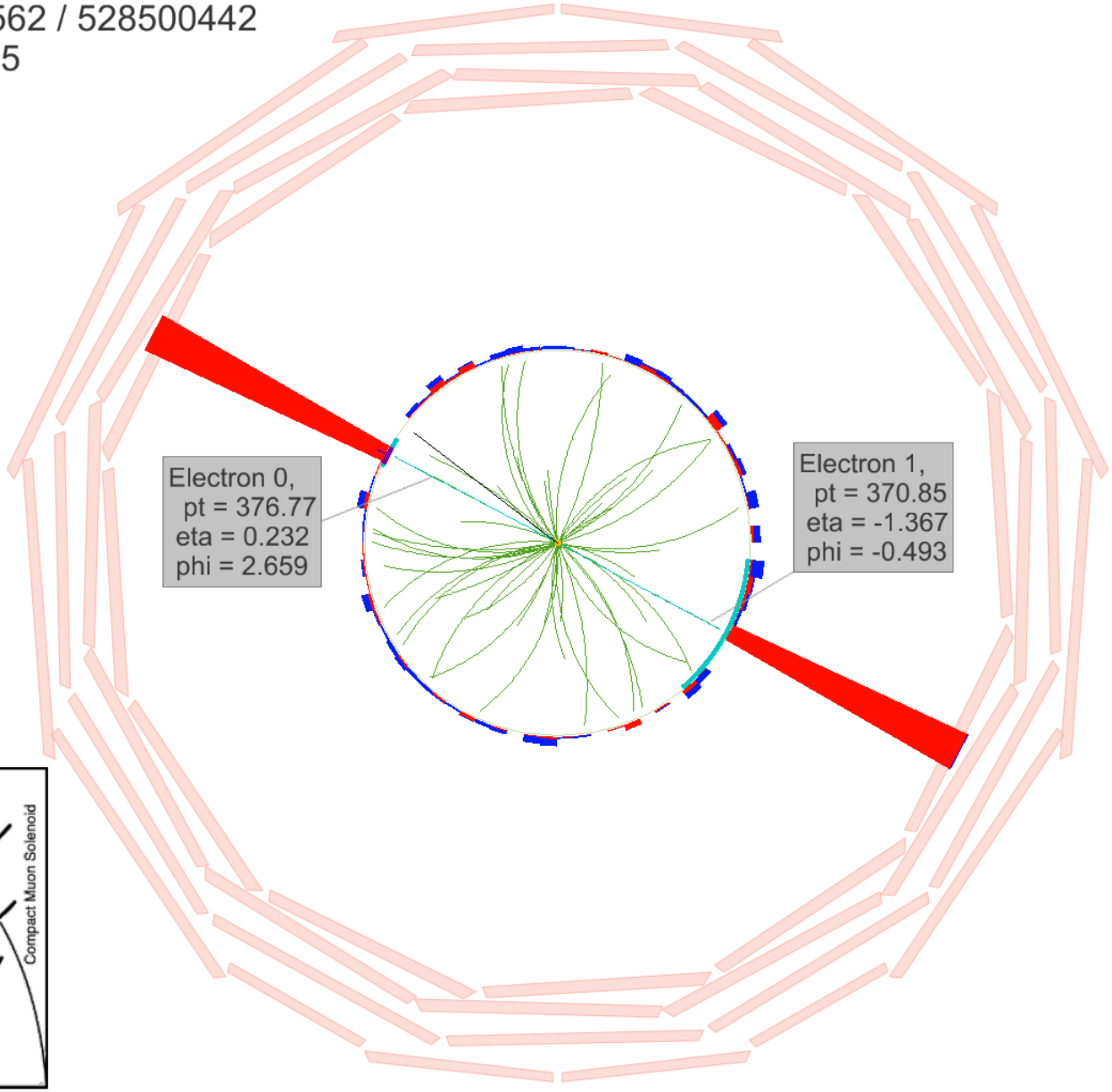
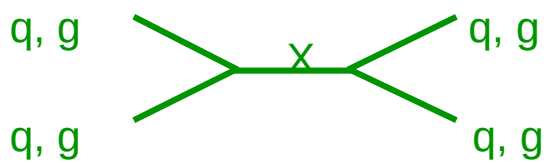
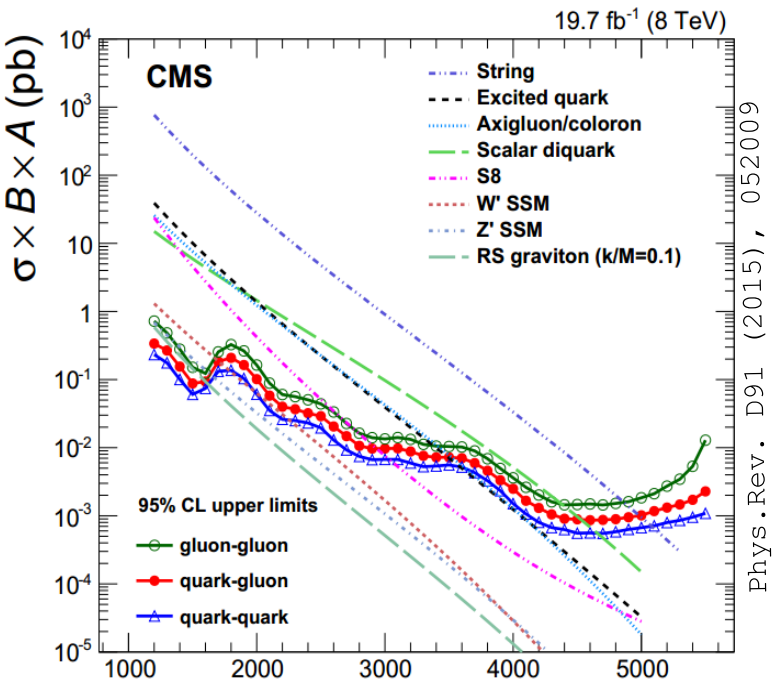


Dijet resonance search

- Many extensions of the standard model predict the existence of new massive particles (X) that couple to quarks or antiquarks (q) and gluons (g). These new particles could produce resonant bumps in the dijet invariant mass distribution associated with strong interaction processes.



- A search for narrow resonances in dijet final states have been performed at CMS using 20 fb^{-1} of pp collisions at $\sqrt{s}$= 8 TeV [1].



- In this document, the first results on the dijet resonance search using 37 pb^{-1} of pp collisions at $\sqrt{s}$= 13 TeV are presented.

Event reconstruction and selection

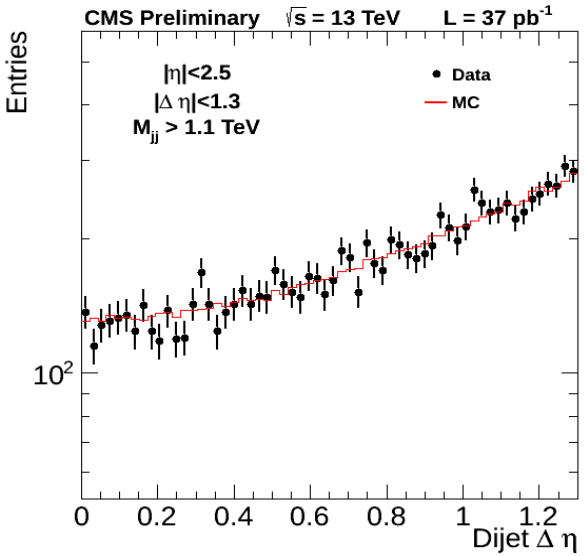
- The Particle Flow (PF) candidates (charged/neutral hadrons, muons, electrons, photons) [2] are clustered into jets using the anti-kT algorithm with distance parameter of 0.4
  - ➔ jet momenta are corrected using calibration constants derived from simulations;
  - ➔ jets are required to have p_T > 30 GeV and |η| < 2.5; leading jet is required to have p_T > 60 GeV
  - ➔ jet identification criteria are applied to the two jets in the event with the highest p_T (leading jets), in order to remove spurious events associated with calorimeter noise. The event is rejected if either of these two jets fails these criteria.
- Geometrically close jets are combined into "wide jets", which are used to measure the dijet mass spectrum (m_{jj})
  - ➔ the two jets with largest p_T are used as seeds. The Lorentz vectors of all other jets are then added to the closest leading jet, if within $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 1.1$

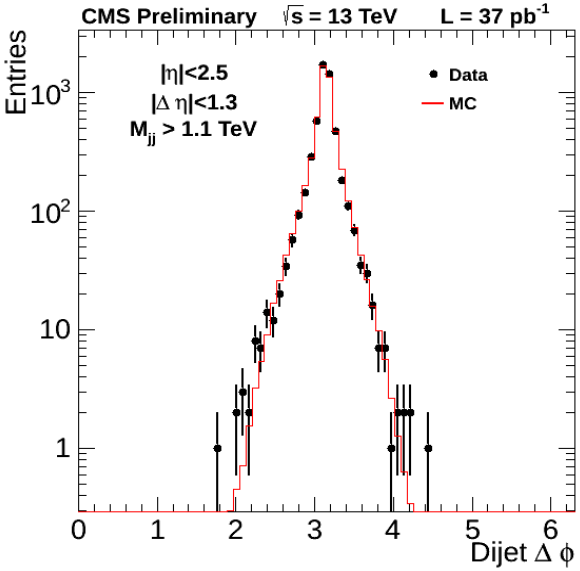
Dijet event selection using "wide jets"
Jet1: p_T > 60 GeV , $\lvert\eta\rvert$ < 2.5 Jet2: p_T > 30 GeV , $\lvert\eta\rvert$ < 2.5
$\lvert\Delta\eta_{jj}\rvert$<1.3
m_{jj} > 1.1 TeV

- The background from t-channel multijet events is suppressed by requiring the pseudorapidity separation of the two wide jets ($\lvert\Delta\eta_{jj}\rvert$) to be less than 1.3. This requirement maximizes the search sensitivity for isotropic decays of dijet resonances in the presence of multijet background .
- The high level trigger used for this search requires that the scalar sum of the PF jet p_Ts in the event be larger than 800 GeV.
  - ➔ Biases from the trigger requirements are avoided by requiring that the fully reconstructed events have m_{jj} >1.1 TeV. In this region the trigger selection is found to be fully efficient.

Data quality checks

- Basic jet and reconstructed event quantities are studied:
  - ➔ jet kinematics (p_T, η, ϕ)
  - ➔ particle flow composition of the jets
  - ➔ quantities sensitive to detector noise (such as missing transverse energy in the event)
  - ➔ rate of selected events above the m_{jj} threshold
  - ➔ kinematics of dijet system (m_{jj}, $|\Delta\eta_{jj}|$, $\Delta\phi_{jj}$)
- Various cross-checks are performed
  - ➔ data vs simulation comparison
  - ➔ stability as a function of time
  - ➔ stability as a function of number of pileup interactions
- The studies show we are selecting good dijet events
  - ➔ no signs of spurious events from detector noise in the data sample
  - ➔ good stability of all reconstructed quantities vs pileup and time



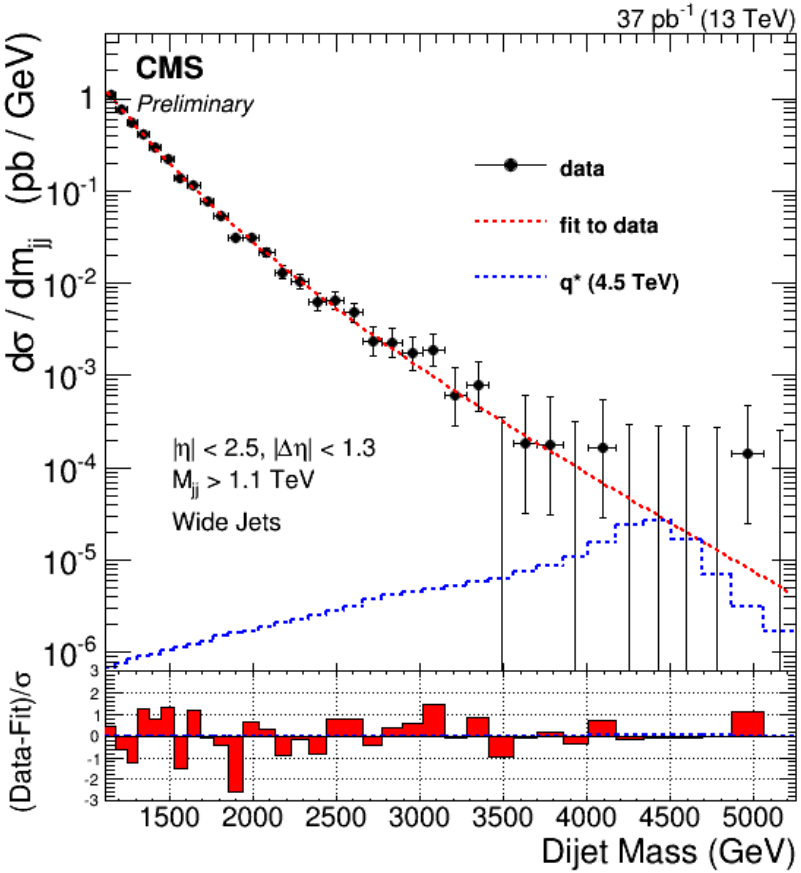


Simulation is normalized to the same area of the data
Standard selection applied (no $\Delta\phi$ cut)

Dijet mass spectrum

- The dijet mass distribution is fitted using the following 4-parameter function. This function is the same used in previous versions of this analysis at 7 and 8 TeV

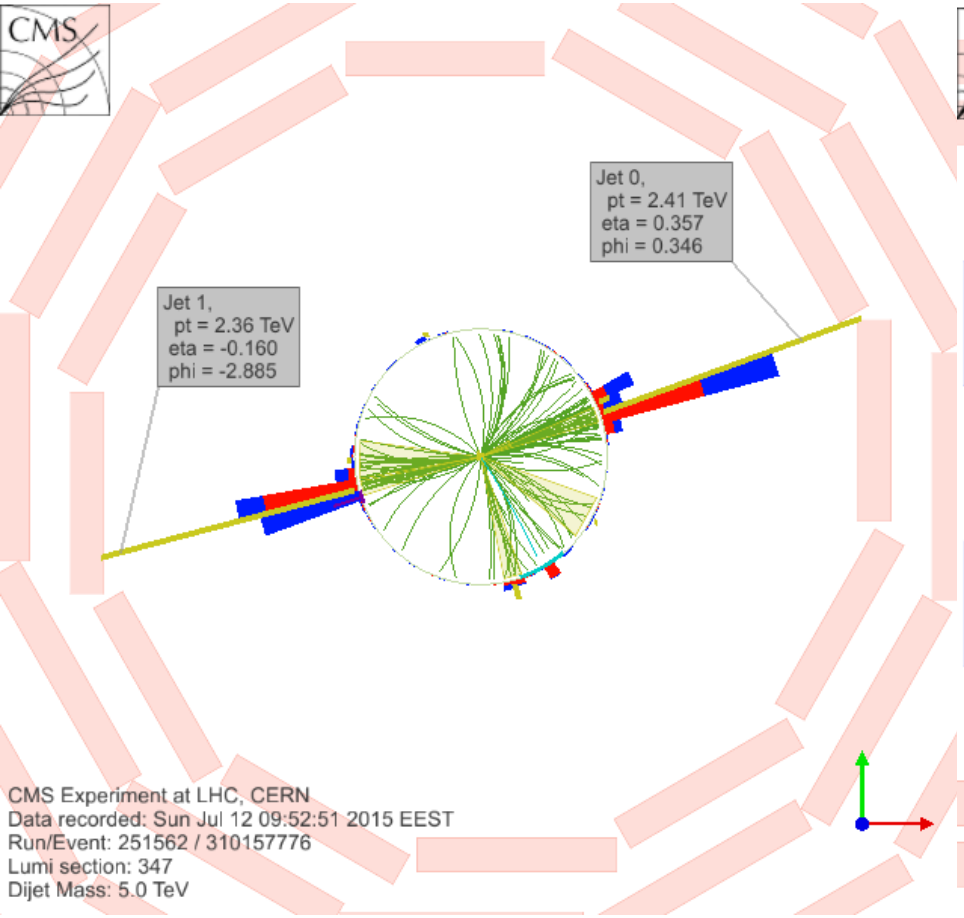
$$\frac{d\sigma}{dm_{jj}} = \frac{p_0(1-\frac{m_{jj}}{13000})^{p_1}}{(\frac{m_{jj}}{13000})^{p_2+p_3\ln(\frac{m_{jj}}{13000})}}$$

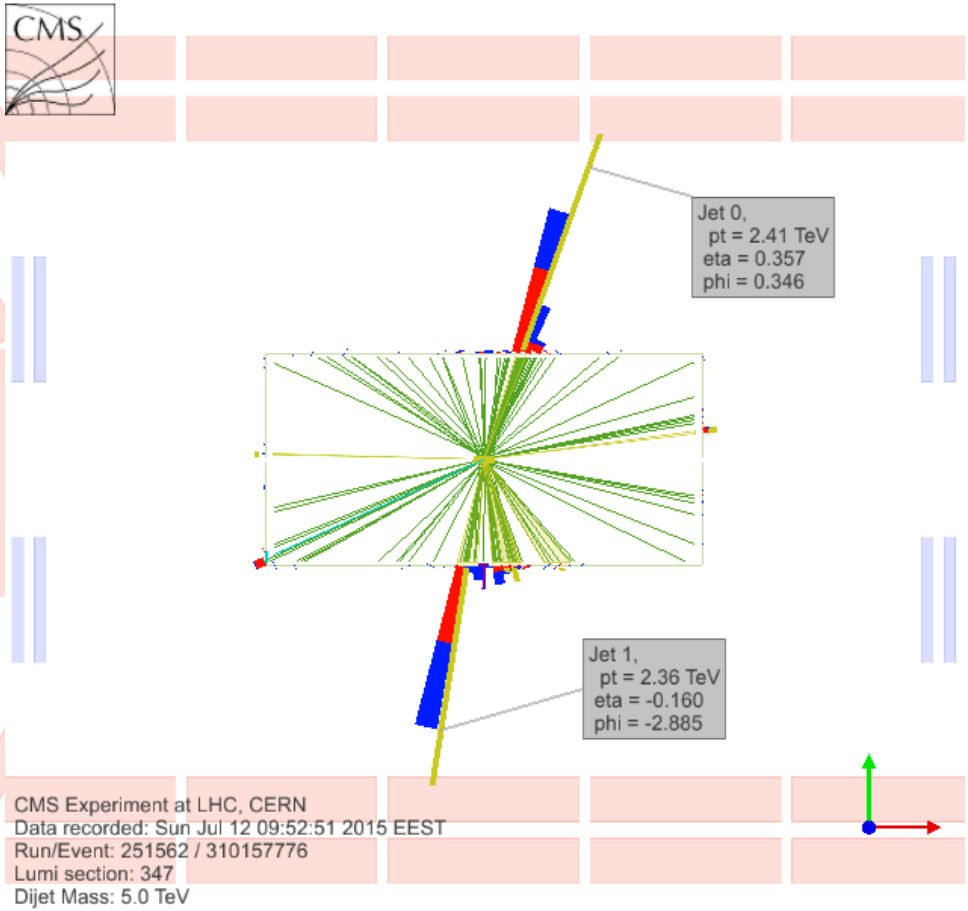


- The variable size binning corresponds to the estimated dijet mass resolution
- Black points are **data**
- Red dashed line is the **fit to data**
- For illustration, we superimpose a **q* -> qg signal** with resonance mass M=4.5 TeV (blue dashed).
- We perform a maximum likelihood fit
- To give a rough estimate of the goodness of fit we calculate the χ^2
  - ➔ χ^2 / ndof = 26.6 / 31
- The fit to the data using a background parameterization is good and there is no evidence for a dijet resonance.
- Above 3.5 TeV we expect ~4.6 background events (from fit to data) and ~0.8 events of signal from the considered q* model, and we observe 4 events in data.
- With the current integrated luminosity of the 13 TeV data sample, using an estimate based on 13TeV / 8TeV parton luminosity ratios, we expect to exceed the sensitivity of the 8 TeV analyses only for narrow resonances with masses greater than about 5 TeV.

Event Display of the highest dijet mass event in data

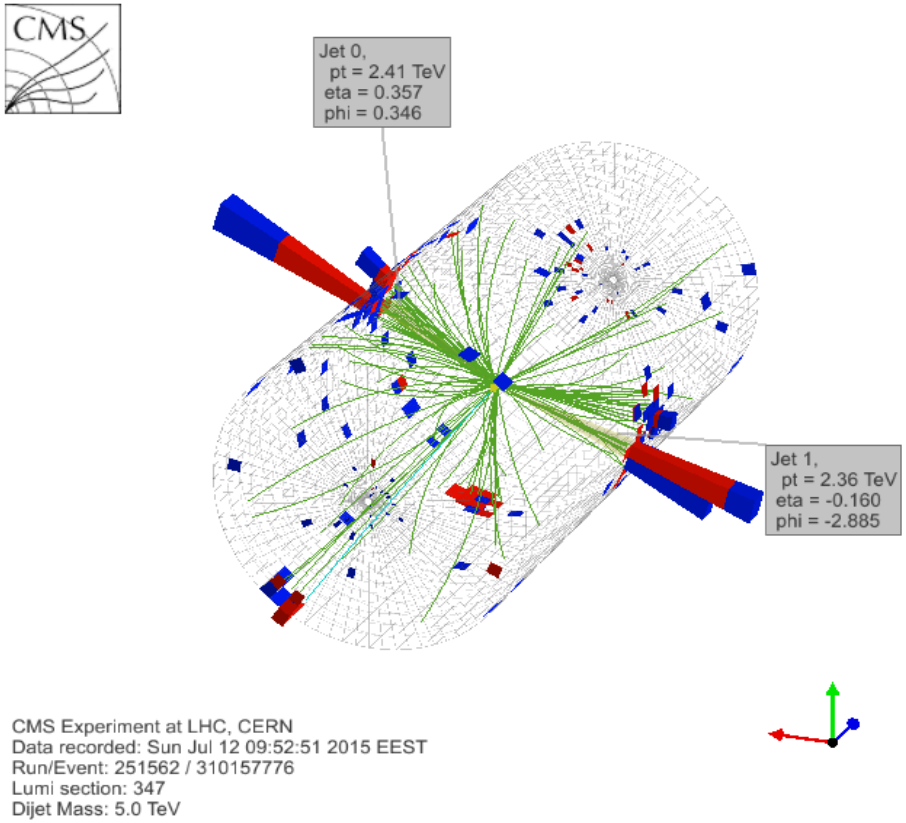
Rho-phi and x-z view of the highest dijet mass event (m_{jj}=5 TeV)
The labels show the the kinematic variables of the two wide jets

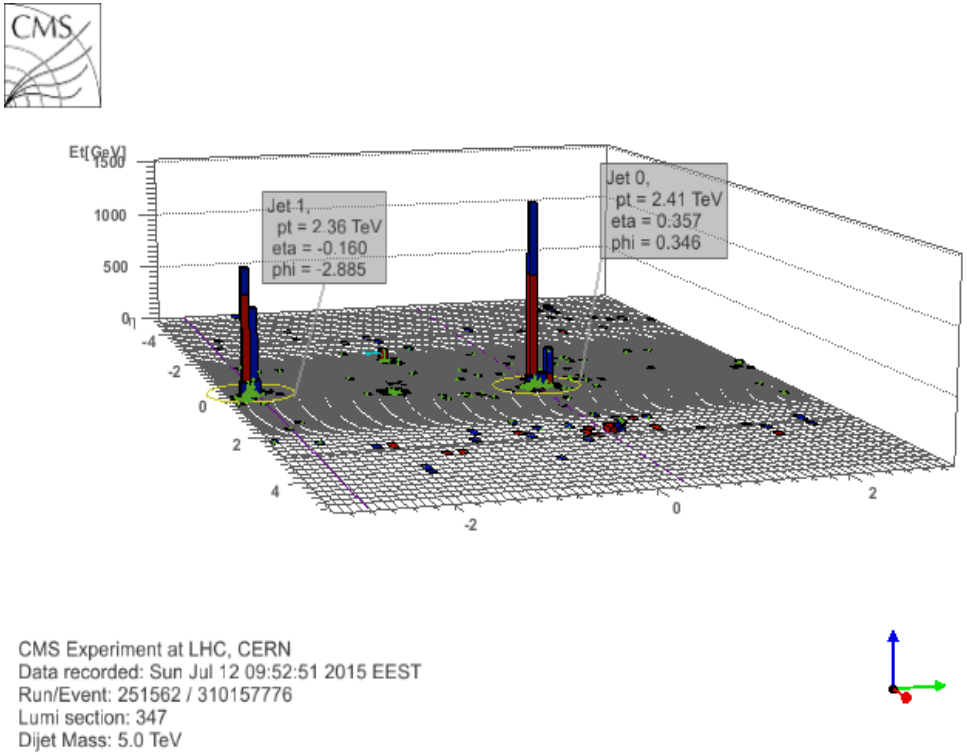




Event Display of the highest dijet mass event in data

3-D and “lego” view of the highest dijet mass event (m_{jj}=5 TeV)
The labels show the the kinematic variables of the two wide jets





References

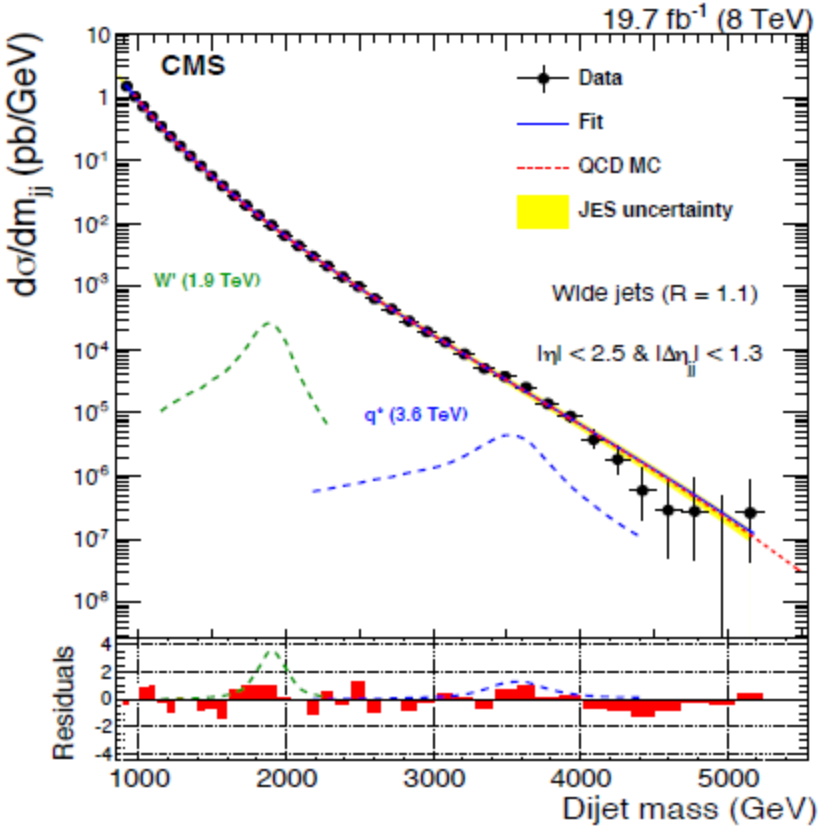
[1] CMS Collaboration, “Search for resonances and quantum black holes using dijet mass spectra in proton-proton collisions at = 8 $\sqrt{s}$, Phys.Rev. D91 (2015), no. 5, 052009,doi:10.1103/PhysRevD.91.052009, arXiv:1501.04198.

[2] CMS Collaboration, “Particle-Flow Event Reconstruction in CMS and Performance for Jets, Taus, and E T miss ”, CMS PAS PFT-09-001 (2009)

Di-jet mass spectrum @ 8

PRD 91, 052009, arXiv:1

- Search for hint of new physics in the di-jet mass spectra / narrow and wide reson
- Provide a model independent upper limits on sigmaxBR

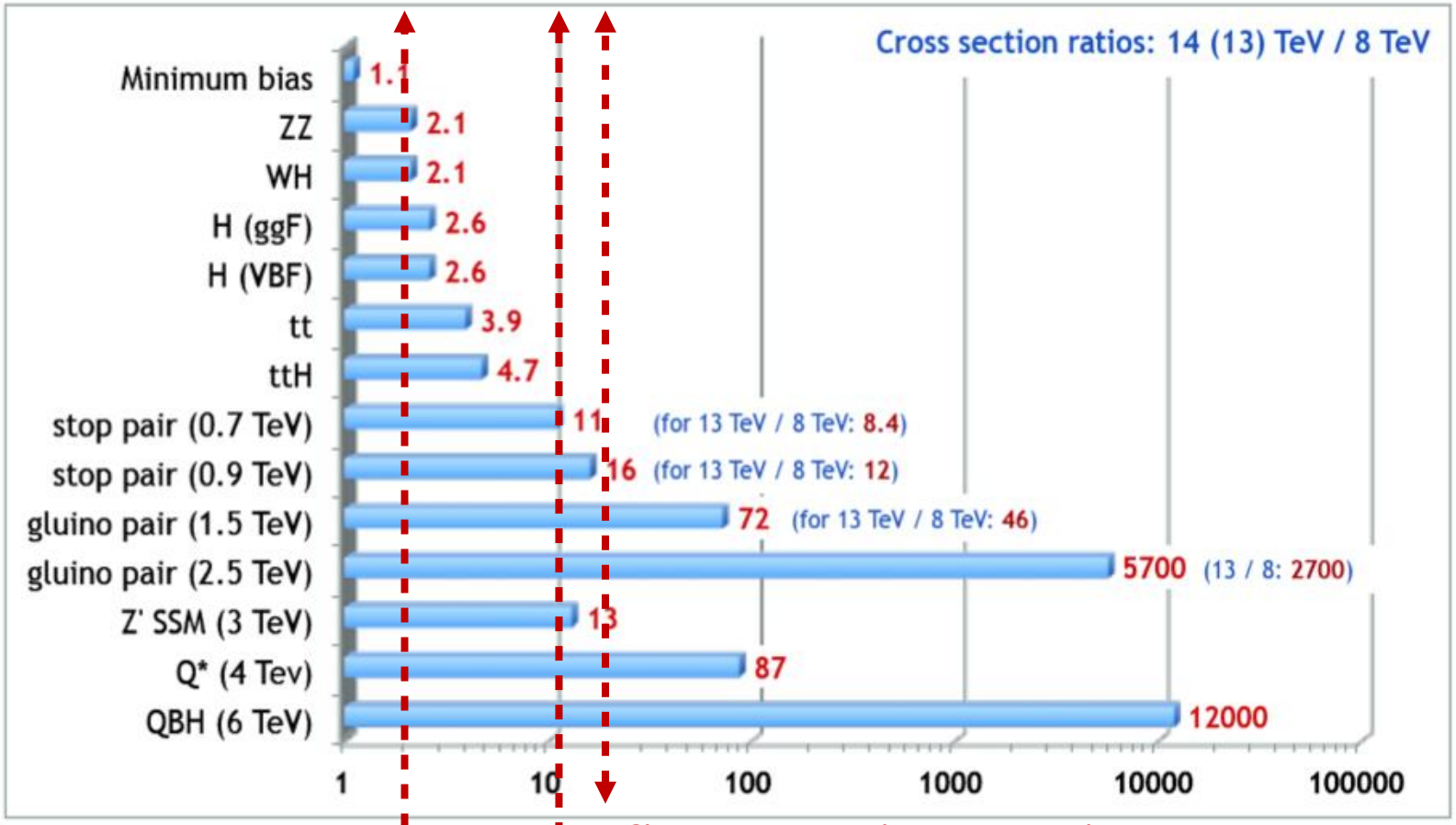


CMS
$p_T(j) > 30$ GeV
$\lvert\eta(j)\rvert < 2.5$ and $\lvert\Delta\eta_{jj}\rvert < 1$
$m(jj) > 890$ GeV to remove trig

- The Particle Flow candidates clu into jets using the anti-kT algorit with DR = 0.5
- Geometrically close jets (DR<1.1 combined into "wide jets", whic used to measure m_{jj}
- Also : spectrum divided in categ 0, 1, 2-btag jets

- Highest di-jet mass event at 5.15 TeV

A glance at Run 2 expectations



1fb-1 equivalent reach to Run1

2 fb-1 equivalent reach to Run1

10 fb-1 equivalent reach to Run1