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Status and performance of physics objects at 13 TeV for CMS

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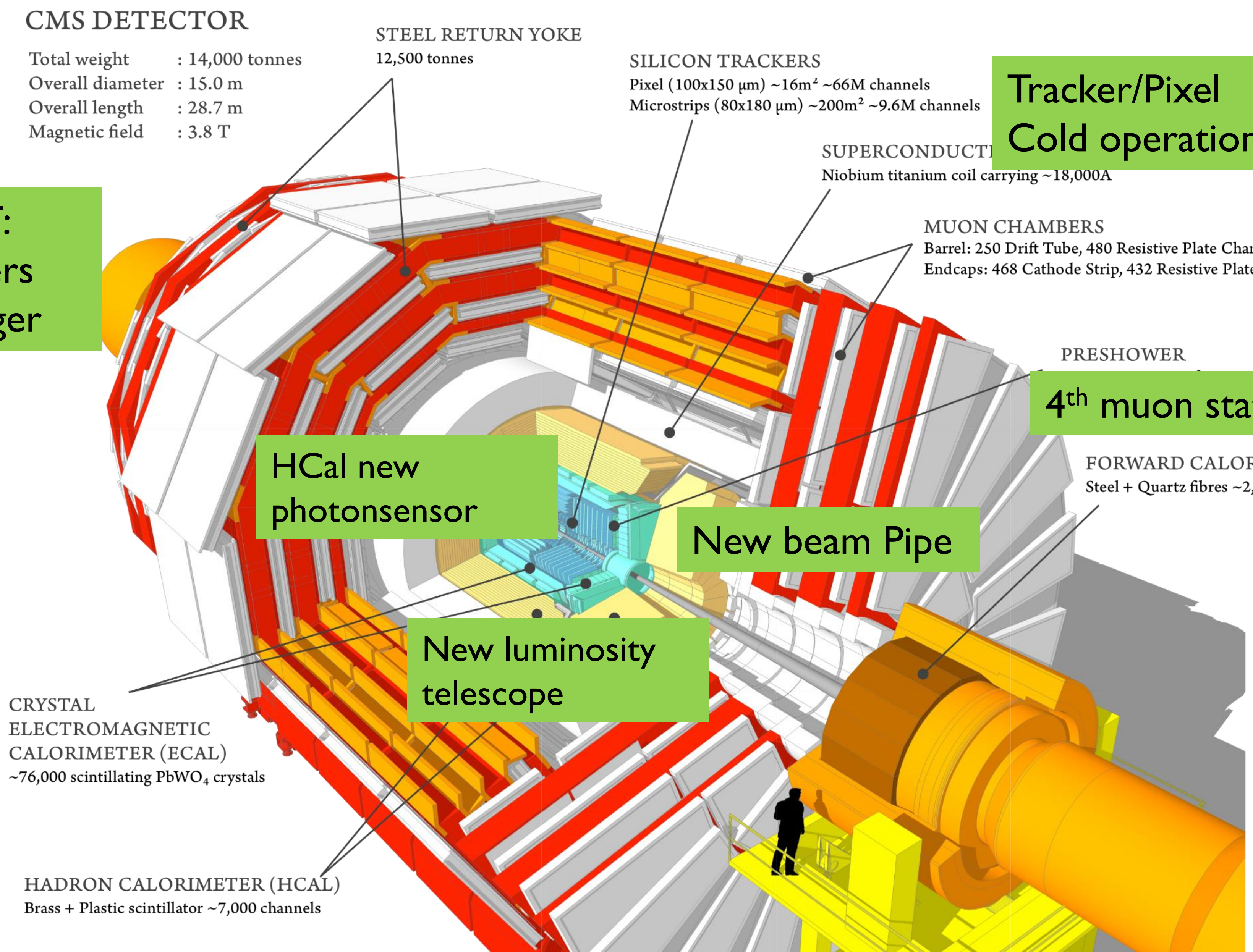
Outline

- Introduction
- CMS detector and status
- Particle flow algorithm
- Pileup mitigation algorithm
- Performance results for physics objects at 13 TeV
  - Jets, b-tag, MET, muon, electron, photon, tau
- Conclusion

CMS detector



Tracker/Pixel
Cold operation

DAQ and HLT:
New computers
Improved trigger

4th muon station

HCal new photonsensor

New beam Pipe

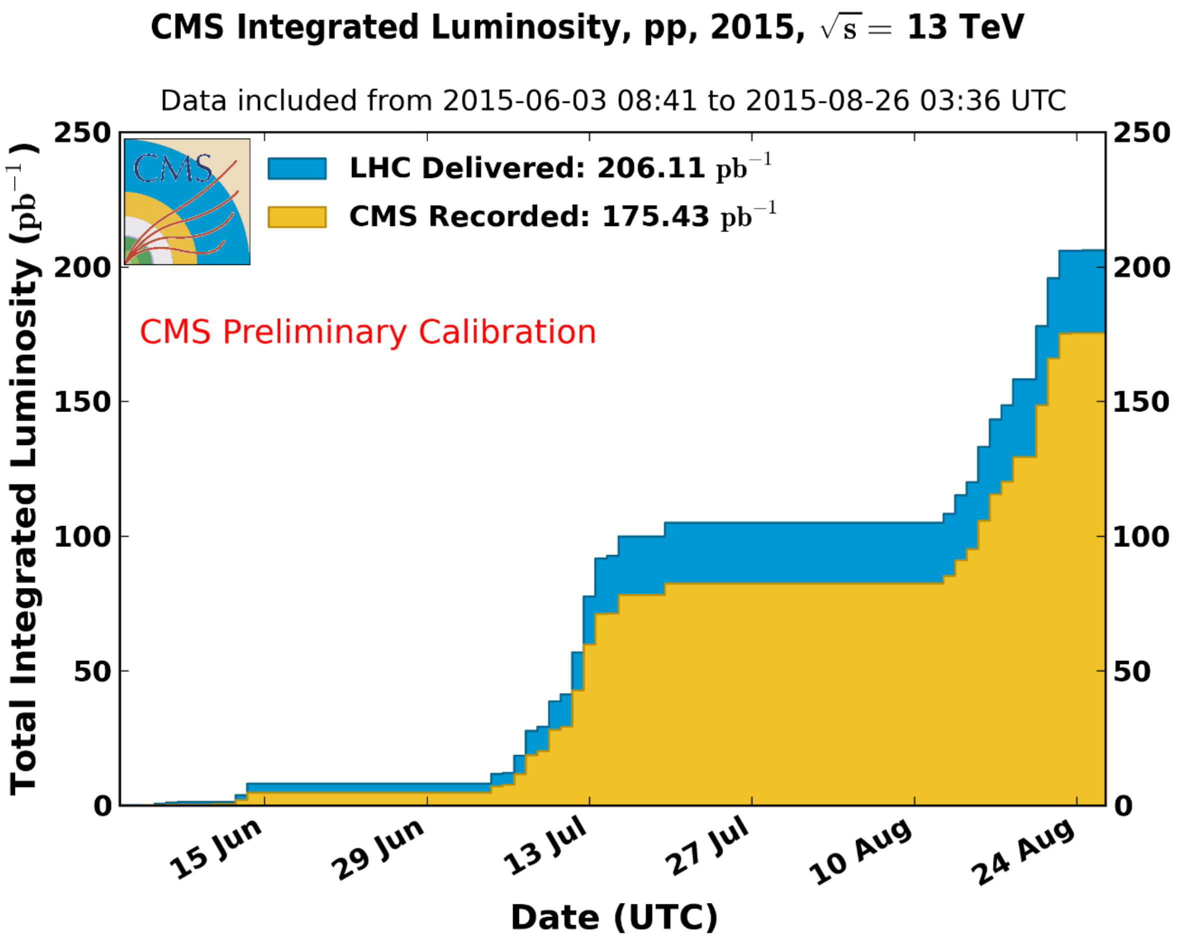
New luminosity telescope

Improvement during the long shut down (LS1)

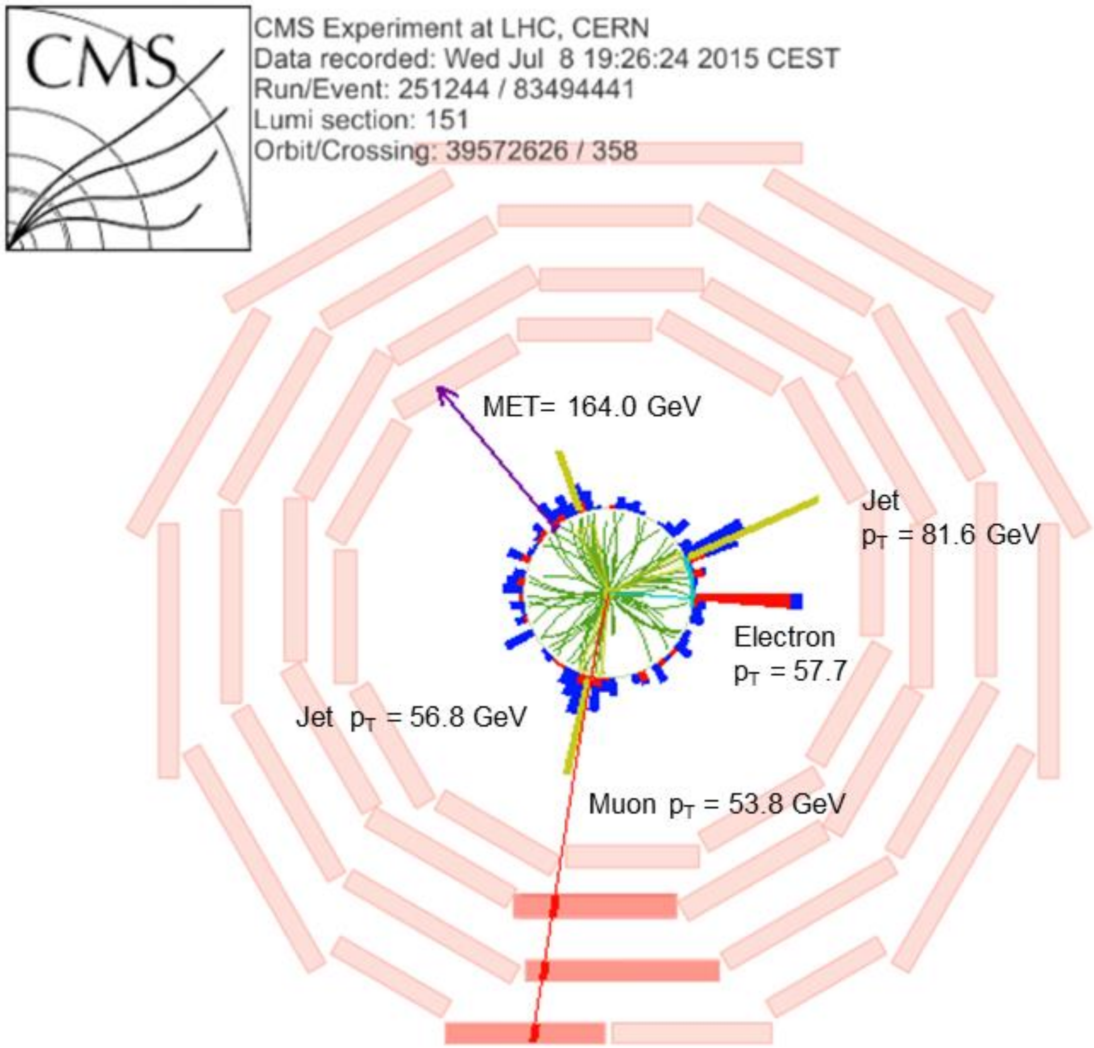
Total integrated luminosity in 2015

- Cumulative luminosity versus day delivered to (blue), and recorded by CMS (orange) during stable beams and for p-p collisions at 13 TeV center-of-mass energy in 2015.
- Recorded luminosity
  - 101 pb^{-1} for 50 ns.
  - 63 pb^{-1} for 25 ns.

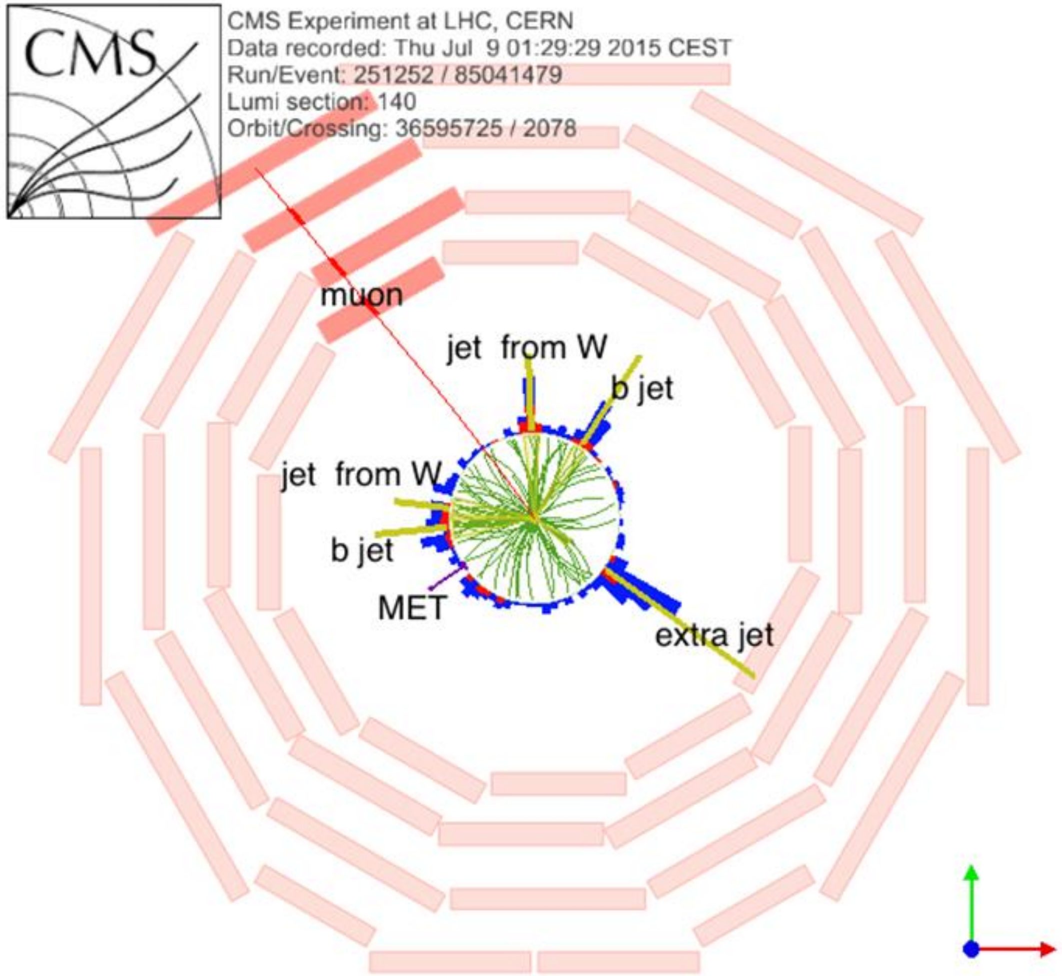
- ~17% of the data for 50 ns and ~67% for 25 ns were taken without B field due to a problem with cryogenic supply. (page 33)
- After data qualification with magnetic on.
  - 42.5 pb^{-1} for 50 ns (for plots in this talk)
  - 16.1 pb^{-1} for 25 ns



Top quark candidate

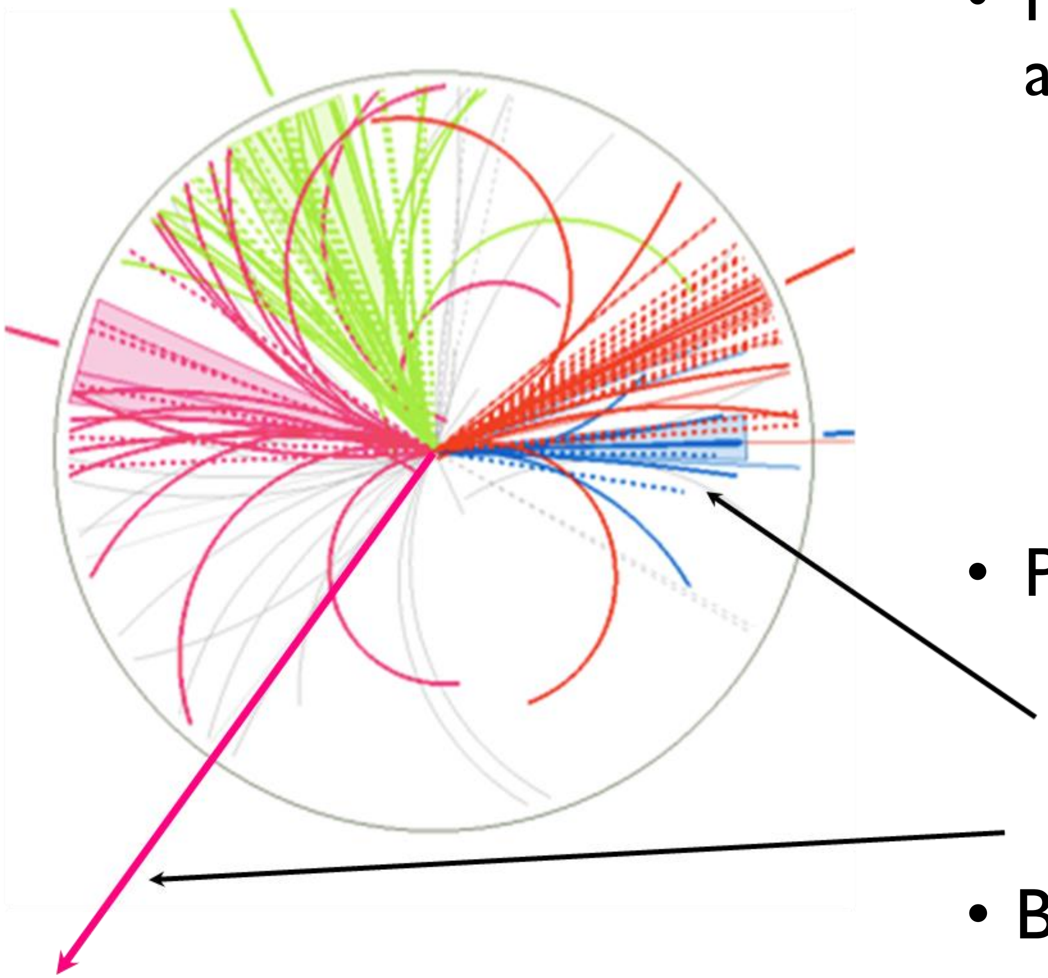


$e\mu$ final sate top candidate event



μ+jets final state top candidate event

Particle Flow Algorithm

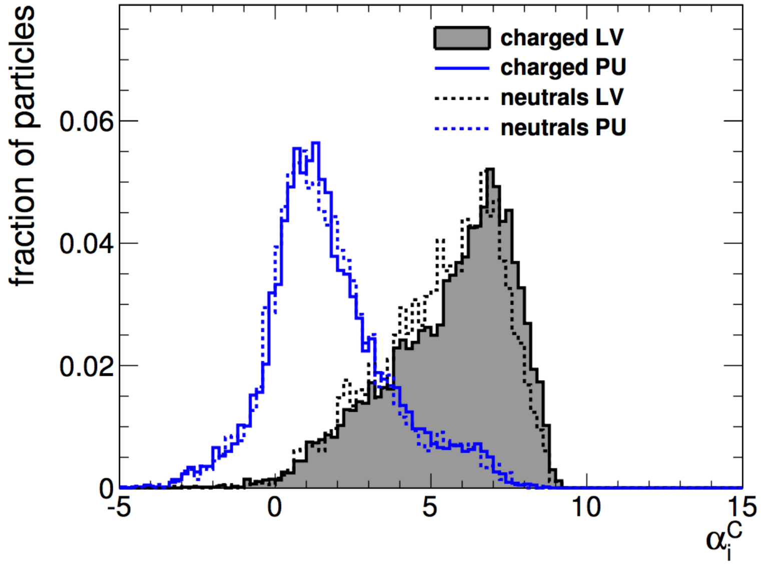


- Particles using pattern recognition using all sub-detector information.
  - charged hadrons
  - photons
  - neutral hadrons
  - electrons
- Physics objects
  - particle-based isolation
  - jets
  - MET
- Better jet and MET resolution
- Pileup mitigation

Pileup mitigation method

JHEP 10 (2014) 059

- Pileup condition in Run 2
  - In Run 2, typical events contain 40 additional pileup events on average while 20 pileup events in Run 1.
- Multiple techniques are available for Run 2.
  - Constituent subtraction, jet cleansing and pileup per particle identification.
- Pile-Up Per Particle Identification (PUPPI)
  - Select a shape α to distinguish pileup-like radiation using vertex information.
  - Defines a unique weight for each particle before jet clustering based on α.
  - The weight tends to be 0 if the particle is from pileup.
  - The weight is used to rescale their four-momentum of the particle.



$$\alpha_i = \log \sum_{j \in \text{event}} \frac{p_{T\,j}}{\Delta R_{ij}} \times \Theta(\mathrm{R}_{\min} \le \Delta R_{ij} \le R_0)$$

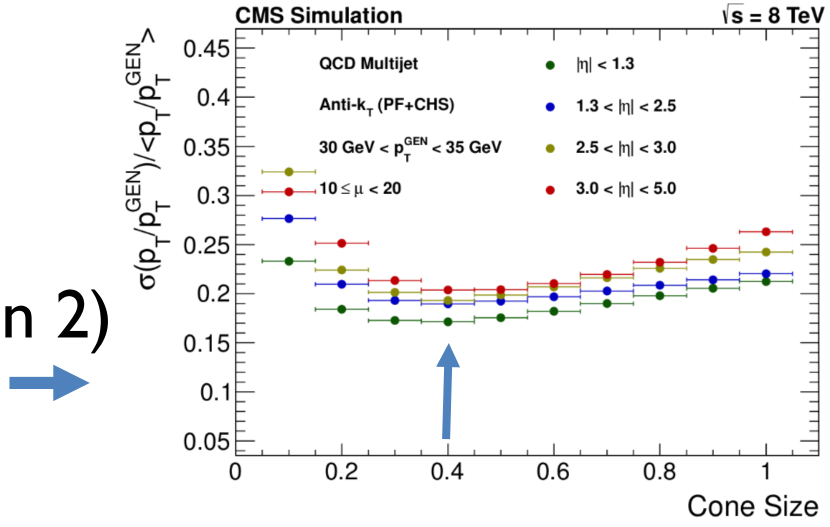
$$\chi_i^2 = \Theta(\alpha_i - \bar{\alpha}_{PU}) \times \frac{(\alpha_i - \bar{\alpha}_{PU})^2}{\sigma_{PU}^2}$$

$$w_i = F_{\chi^2, NDF=1}(\chi_i^2)$$

Jet

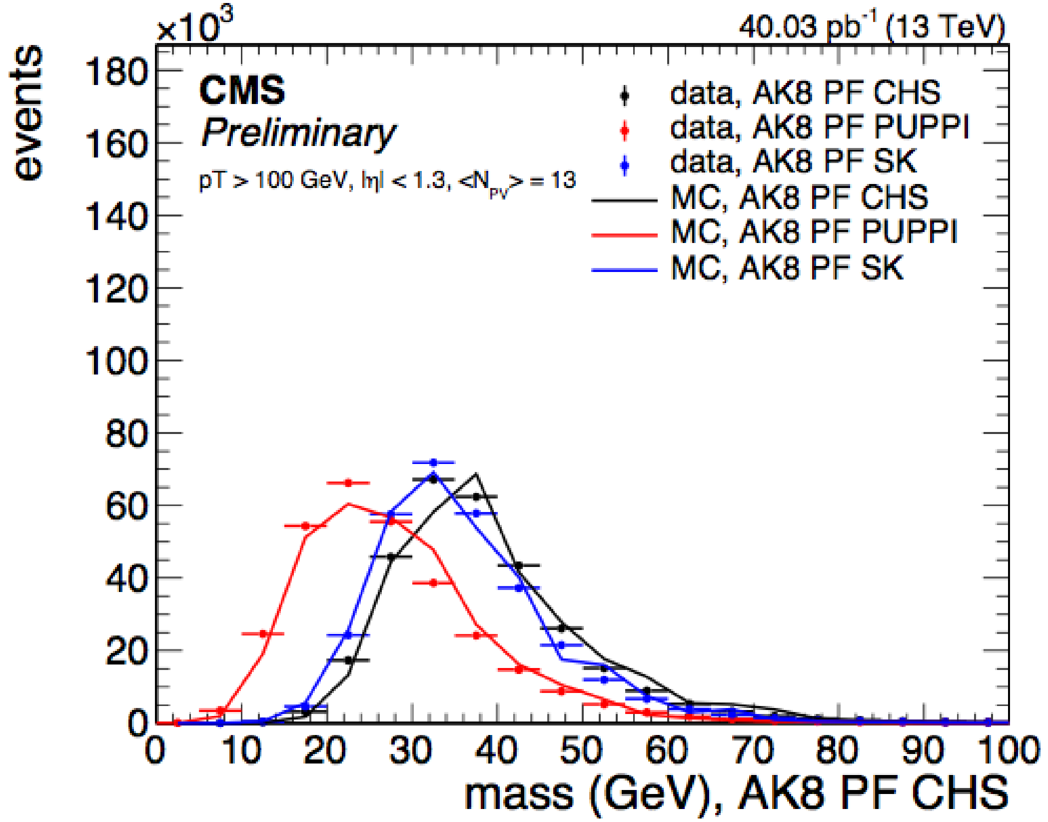
- Pileup mitigation will affect jets, MET, isolation.

- Jets are clustered from objects reconstructed
by the particle-flow algorithm with parameter R=0.4 (Run 2)
(It was R=0.5 for Run 1)

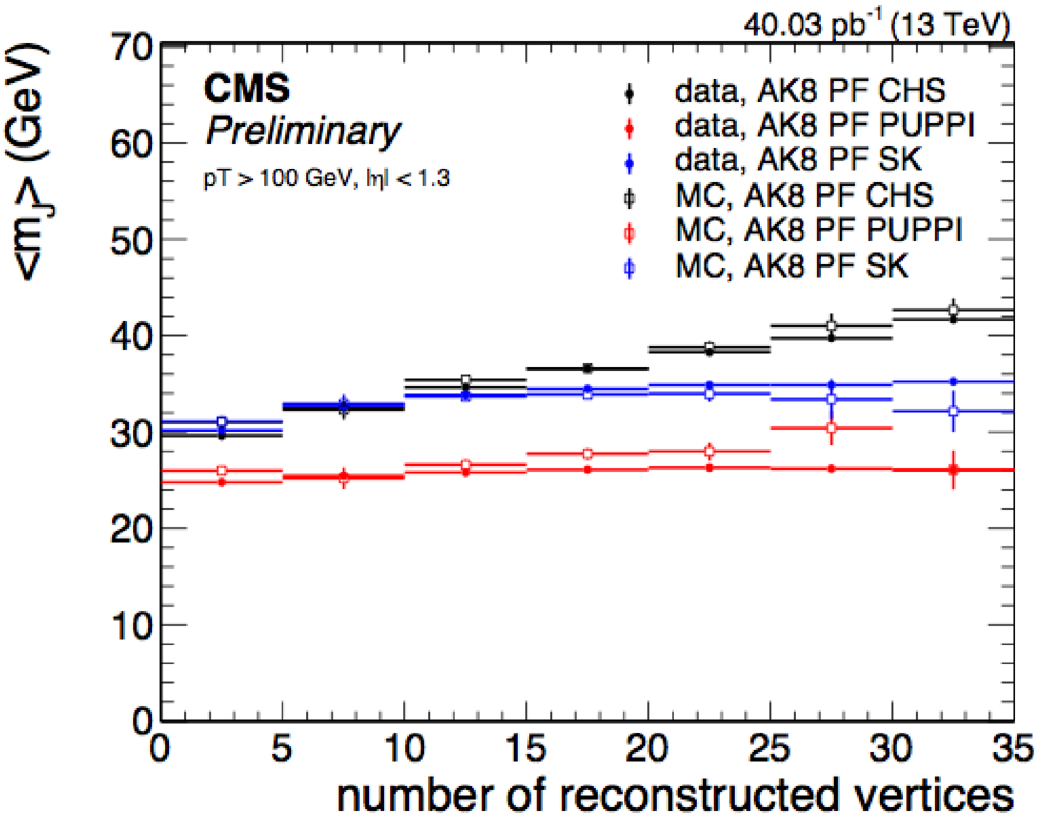


- Pileup mitigation for Run 2
  - PF PUPPI – particle flow candidates after running PUPPI algorithm.
  - PF CHS – particle flow candidates after removing charged particles associated with pileup vertices.
  - PF SK – particle flow candidates after applying the Soft Killer algorithm[arXiv:1407:0408], for comparison.

Jet performance using data



AK8 ungroomed jet mass distribution



AK8 ungroomed jet mass versus pileup

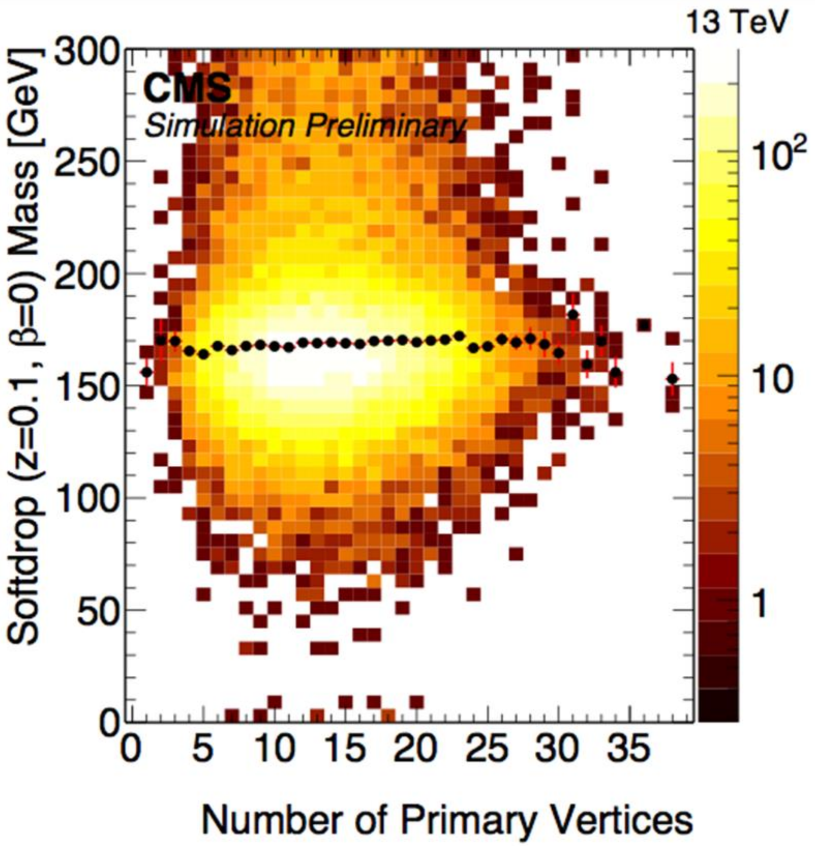
(Grooming : discards a subset of a jet's constituents that are believed to obscure the signal process.)

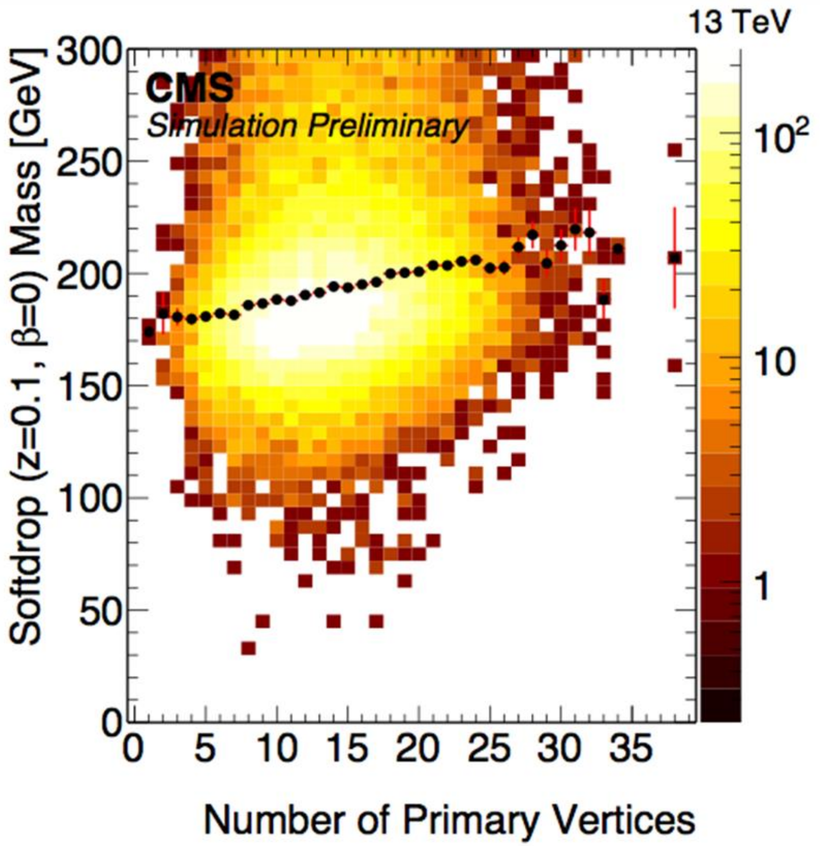
See the talk, *"Top reconstruction and boosted top"*, from Louise Skinnari for more details.

Top tagging

Top quark tagging to identify jets from top quark decays.

PF PUPPI



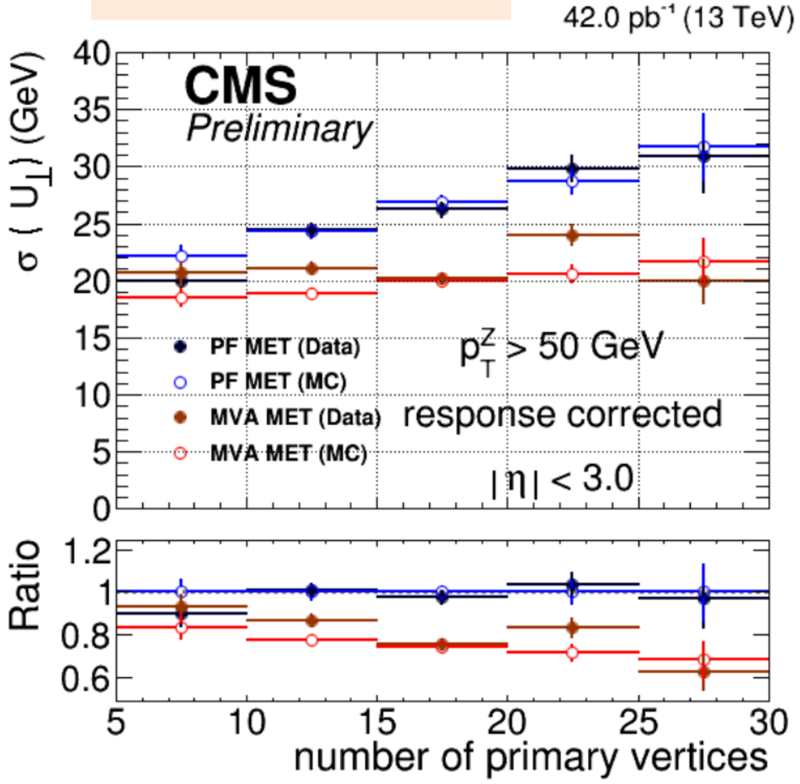


PF CHS

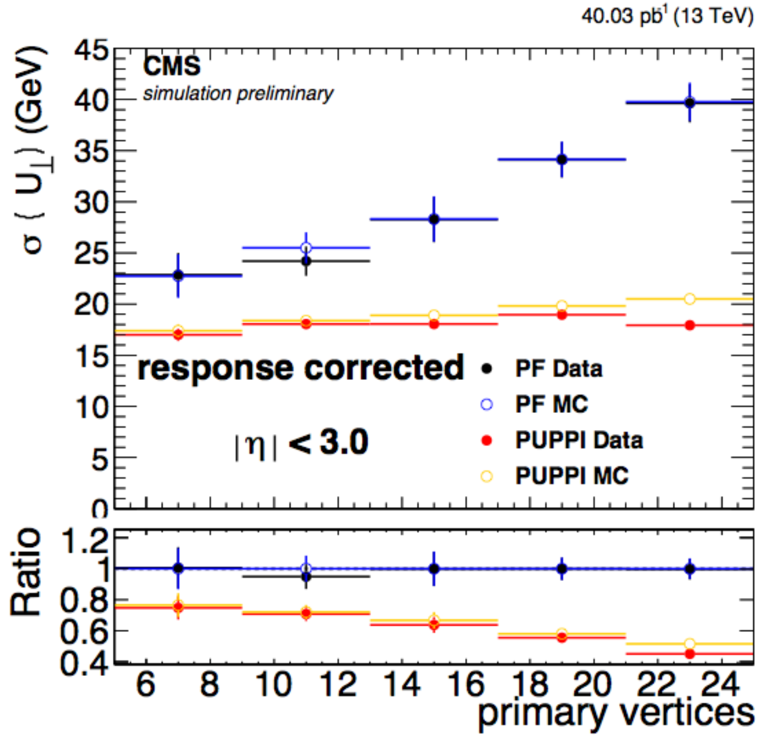
Pileup dependency of the CA15 soft drop groomed mass for a Z' to ttbar sample in the p_T bin 300-470 GeV.

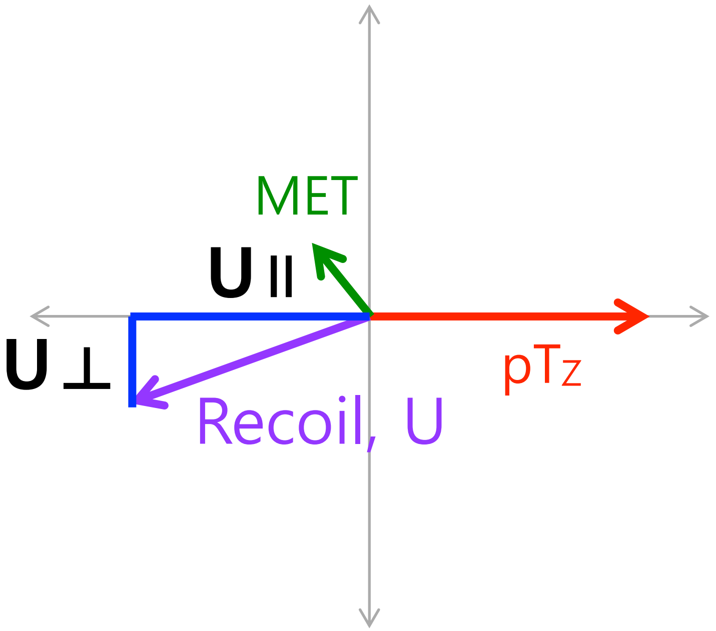
MET

CMS DP-2015/042



CMS DP-2015/034



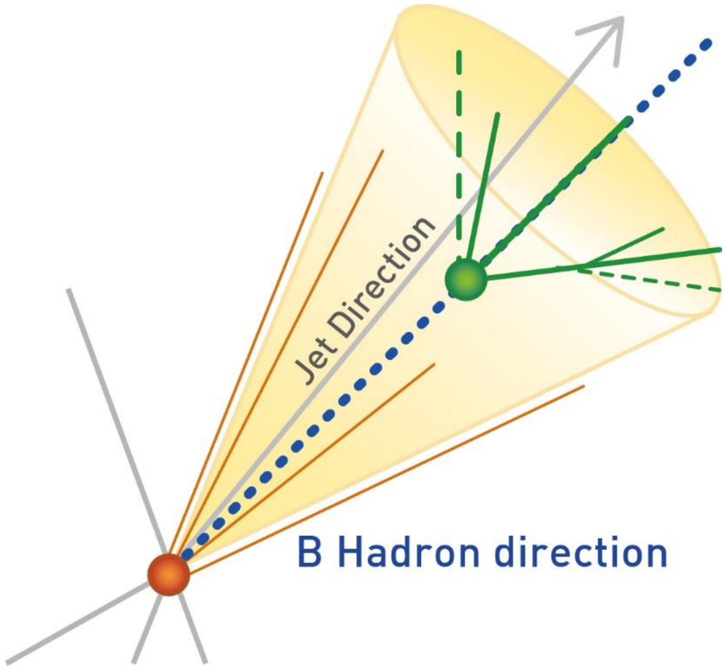


U = MET - pTz

- MVA MET developed during Run 1 is applied to Run 2 data.
- Modeling of MET and the resolution is good.
- PUPPI works also well.

B-tagging

- b-quarks hadronize
  - jets of particles : need to associate tracks to jet.
- B-hadron decay tracks are in a forward cone.
  - B flight ~ jet direction
- A dedicated selection to maximize purity and reject fakes.
  - Inclusive Vertex Finder (IVF) to reconstruct secondary vertices.
  - Independent of the jet direction.



- Long lifetime $c\tau$~ 5 mm at 50 GeV
- Large mass ~ 5 GeV
- Weak b-decay often produces leptons.

  $b \rightarrow l\nu$ (25%)

  $b \rightarrow c \rightarrow l\nu$ (20%)

Details about b-tagging in CMS.

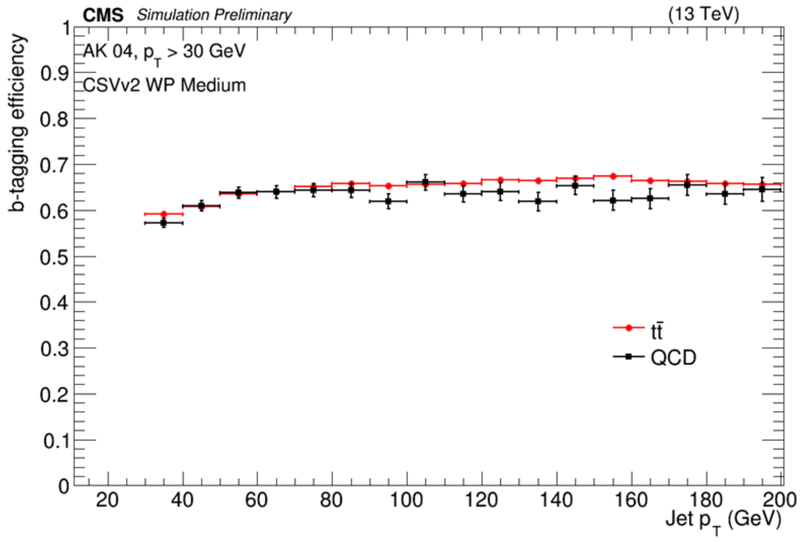
- 7TeV, JINST 8 (2013) P04013
- 8 TeV, CMS-PAS-BTV-13-001

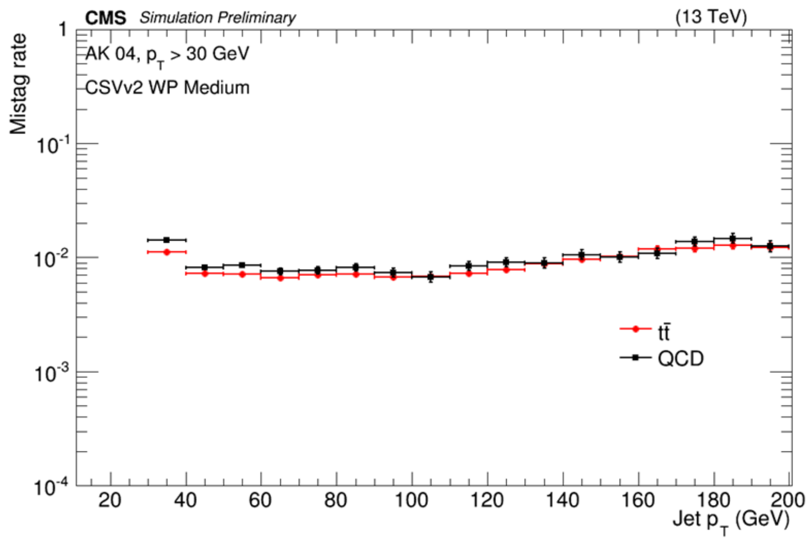
CSVv2 b-tagging algorithm

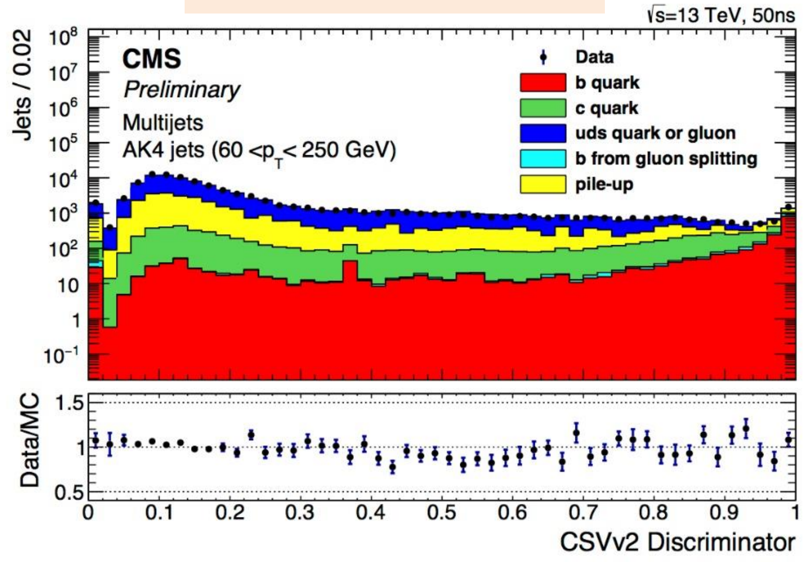
- Combined Secondary Vertex using MVA technique
  - Track information – 3D IP significance of the most displaced tracks
  - Vertex information

WP	b-jets	c-jet	light
Loose	85%	32%	10%
Medium	70%	10%	1%
Tight	43%	2%	0.1%

CMS DP-2015/045





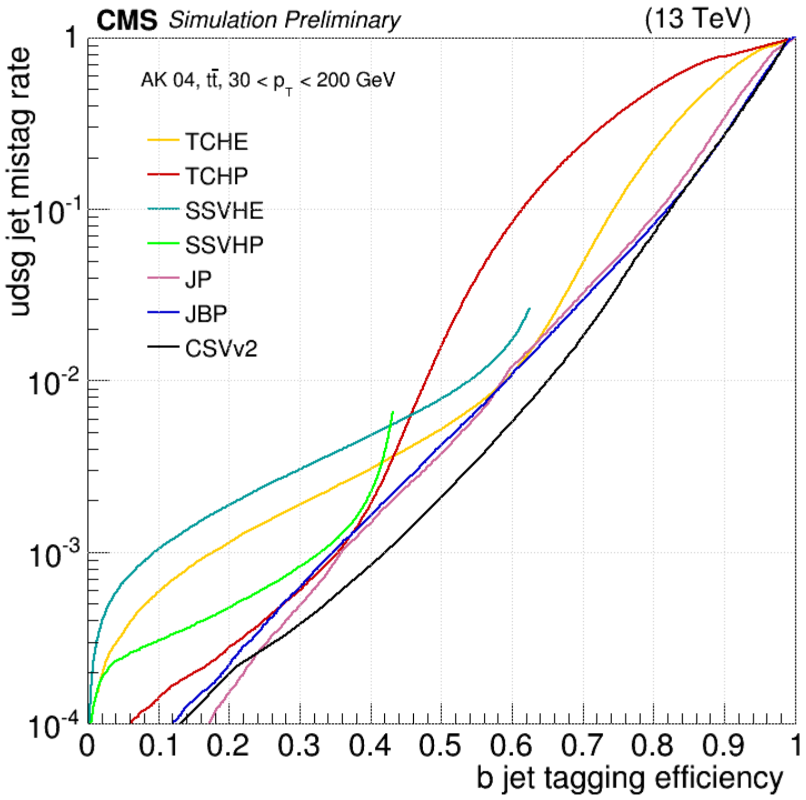


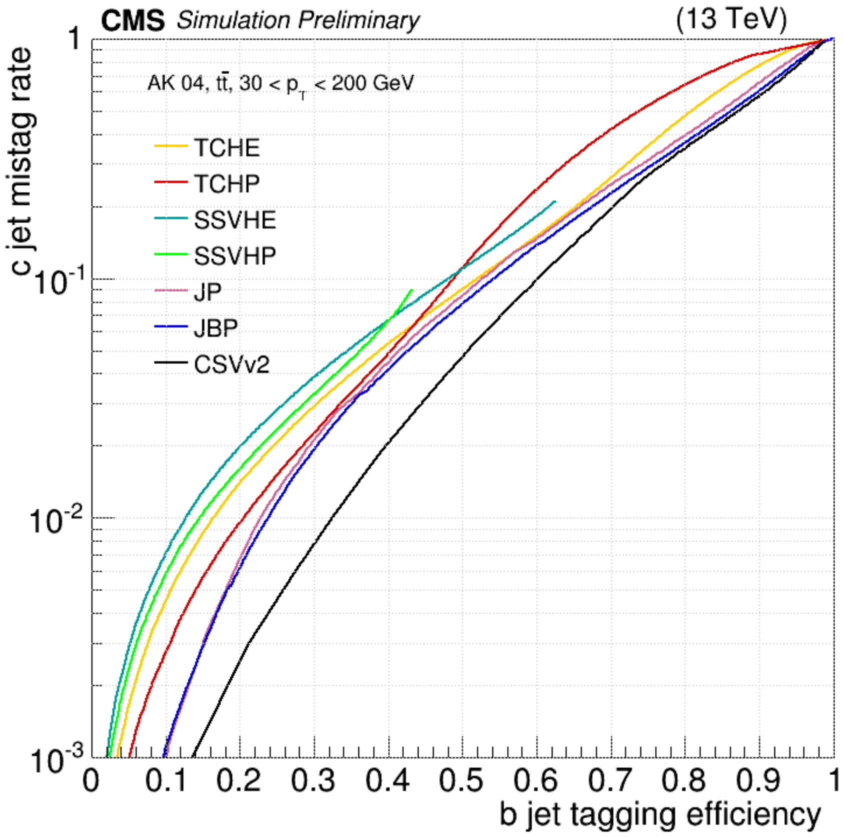
CMS DP-2015/038

CSVv2 discriminator of ak4 jets with 60 < p_T < 250 GeV

B-tagging performance

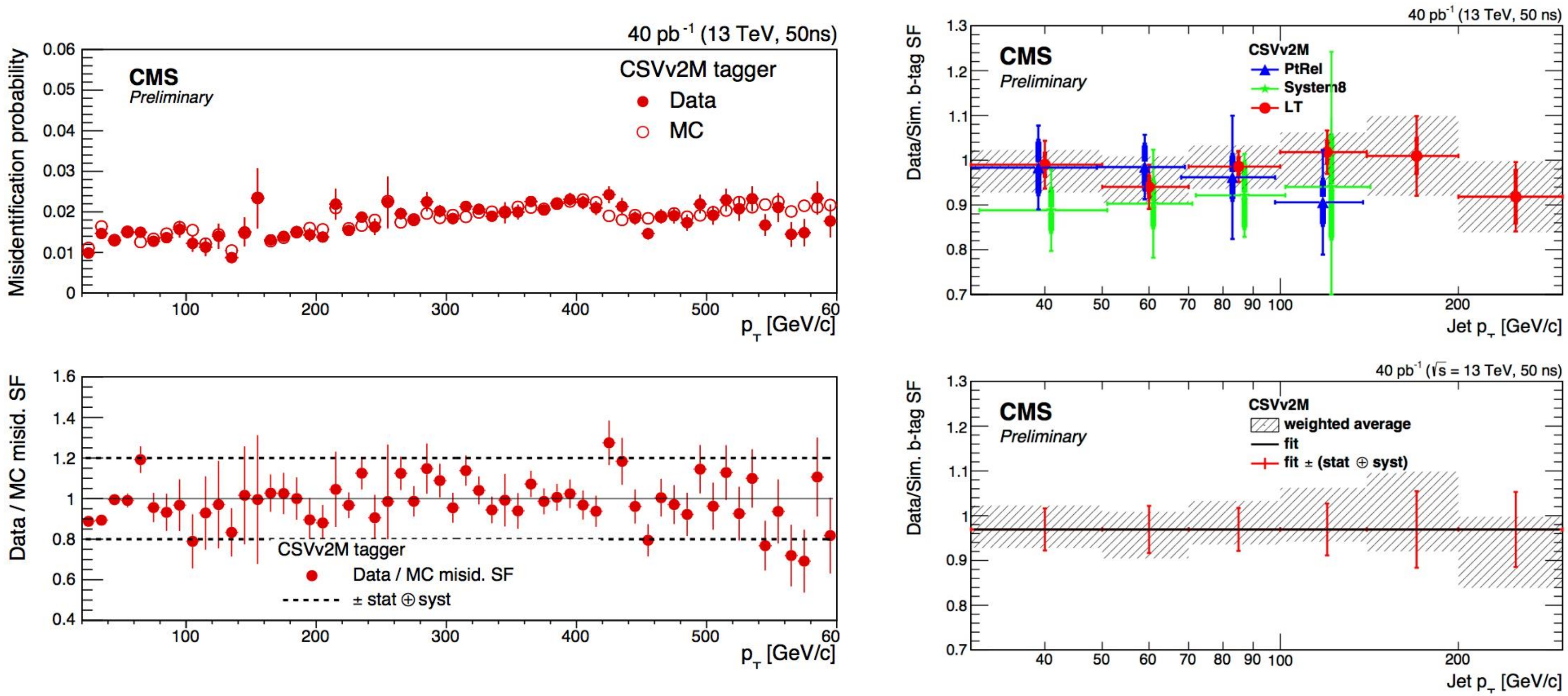
CMS DP-2015/038





Signal and Mistagging efficiency for udsg (left) and c-jets (right) in ttbar events.

Scale factor Data/MC



CMS DP-2015/045

Three methods
- PtRel
- Lifetime Tagger (LT)
- System 8

(see the reference)

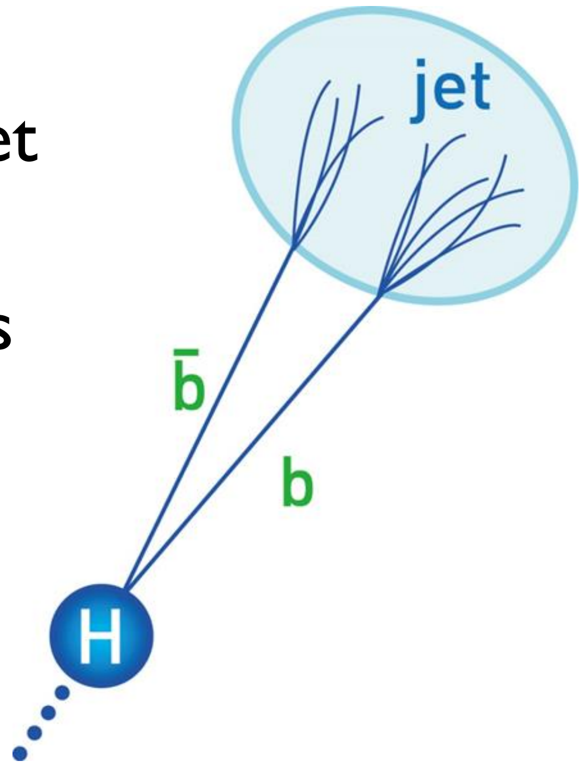
Combination using BLUE method [Nucl. Instrum. Meth. A270 (1988) 110]

20 % uncertainty for mist-tag SF for CSVv2M (medium WP)

5-9% uncertainty between 30 and 300 GeV for b-tag SF for CSVv2M (medium WP)

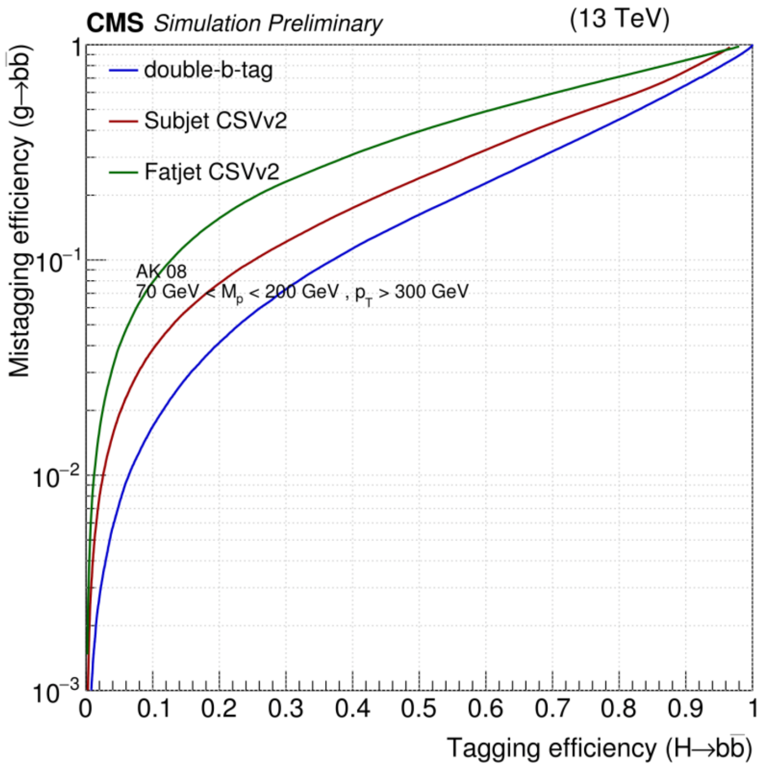
Double b-tagging

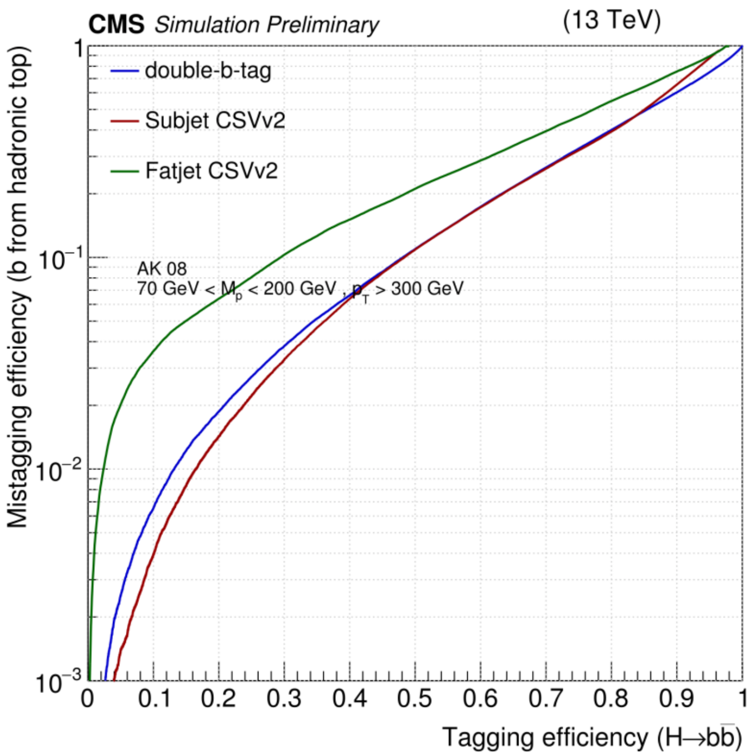
- Reconstruct two B hadrons within the fat jet.
- Use IVF to identify secondary vertex independently of jet direction.
- p_T independent – BDT in TMVA training for each p_T bins from 600 GeV to 2 TeV in steps of 200 GeV.
  - signal : Radion to H($b\bar{b}$) and H($b\bar{b}$), background : QCD
- Input variables
  - Tracking, Secondary Vertex, Soft Lepton



Double b-tagging performance

CMS DP-2015/038



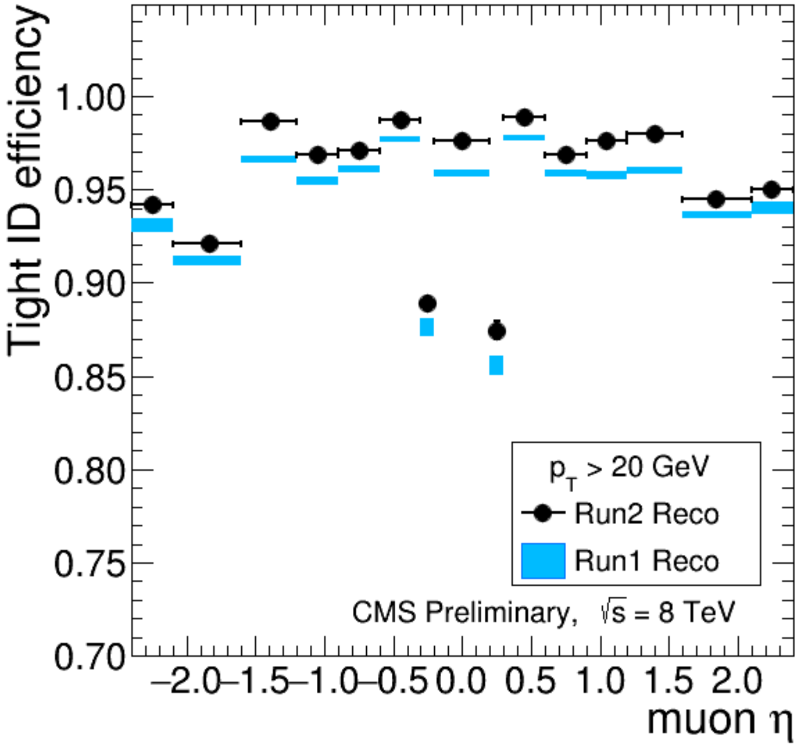


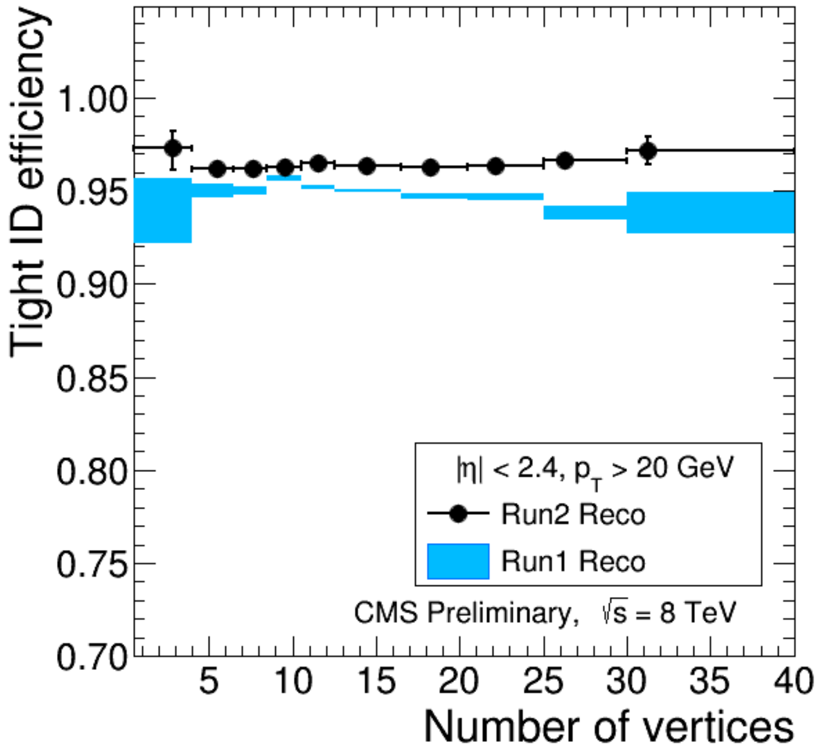
- Signal efficiency is evaluated using boosted H to bb signal. Mistagging efficiency is evaluated for gluon splitting in simulated QCD multi-jets events (left) and for single-b production in simulated ttbar events (right)

Muon identification

- Run 2 reconstruction improves the average efficiency by 1-2% for tight identification, in particular in pileup events.
- The improved Run 2 performance is mainly due to new muon-specific tracking iterations.

CMS DP-2015/015

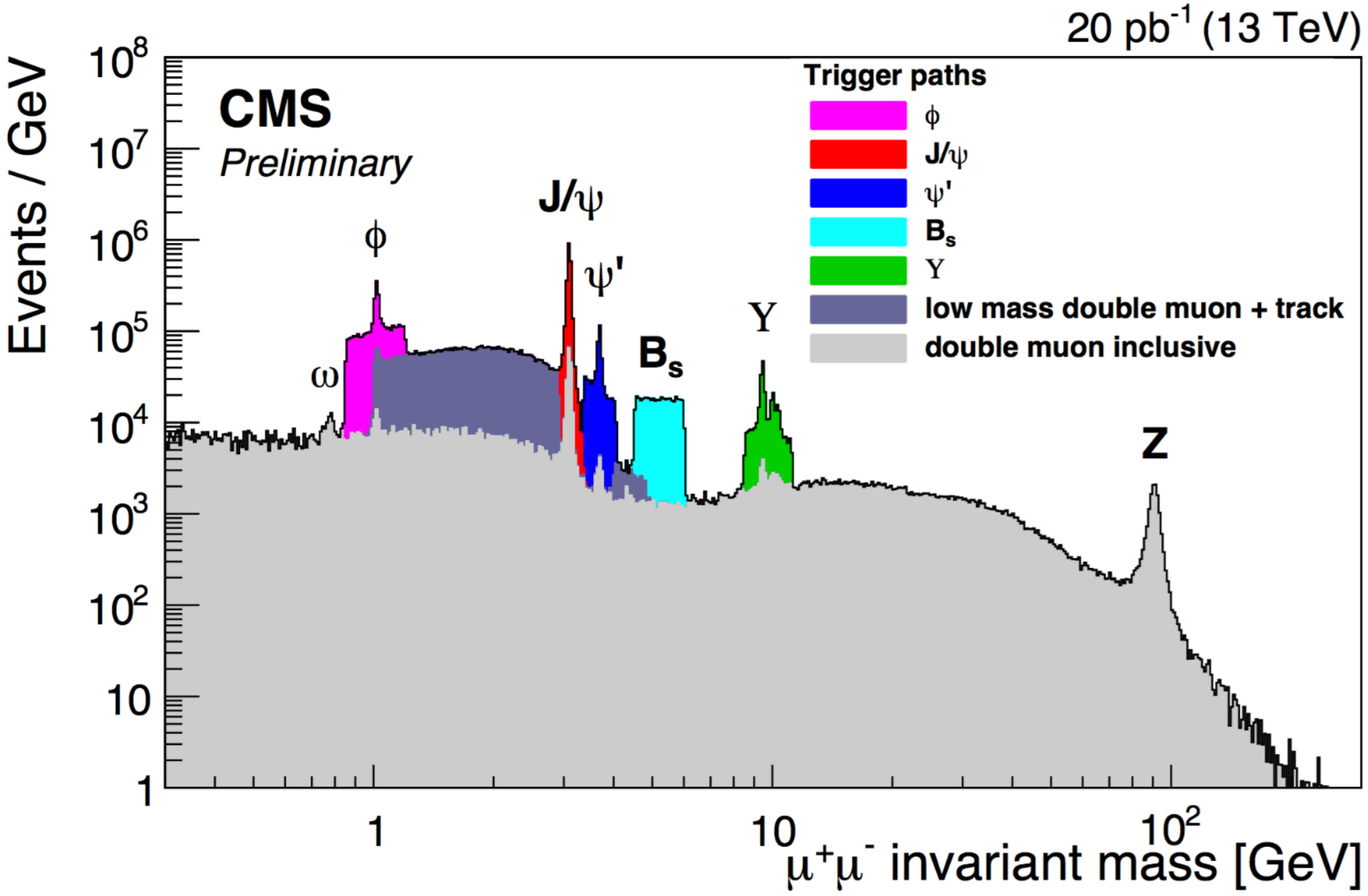




Tight muon

Global Muon
Particle Flow Muon
globalTrack.normalizedChi2 < 10
globalTrack.numberOfMuonValidHits > 0
numberOfMatchedStations > 1
|dxy| < 0.2 cm, |dz| < 0.5 cm
numberOfValidPixelHits > 0
trackerLayersWithMeasurement > 5

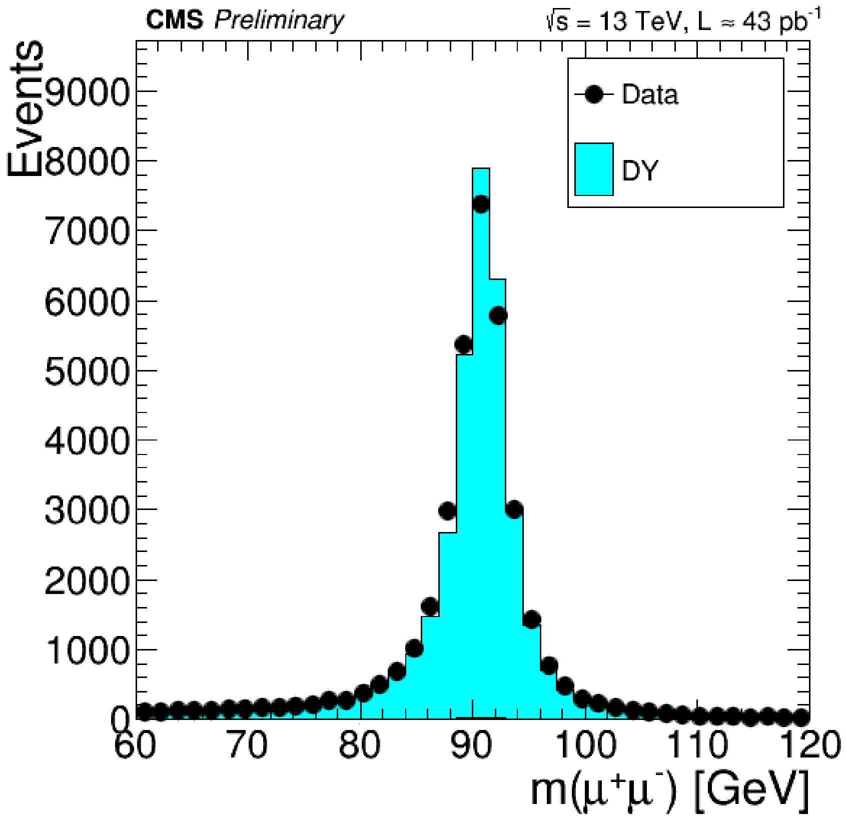
Di-muon spectrum



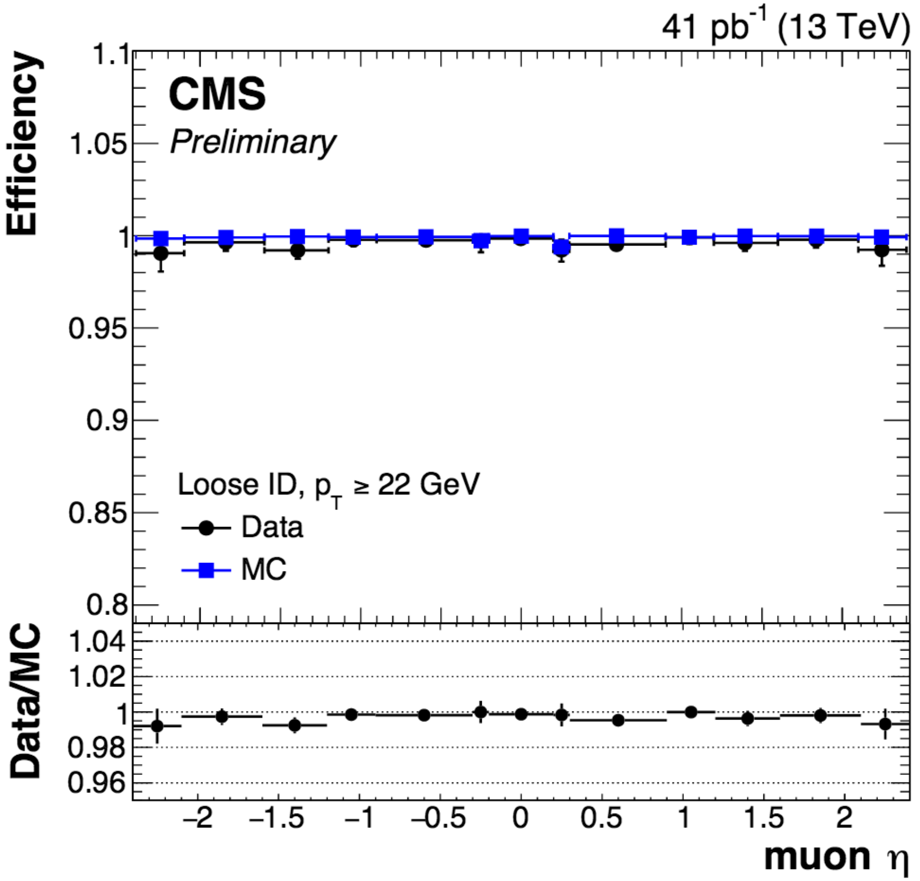
Muon selection for 13 TeV collisions

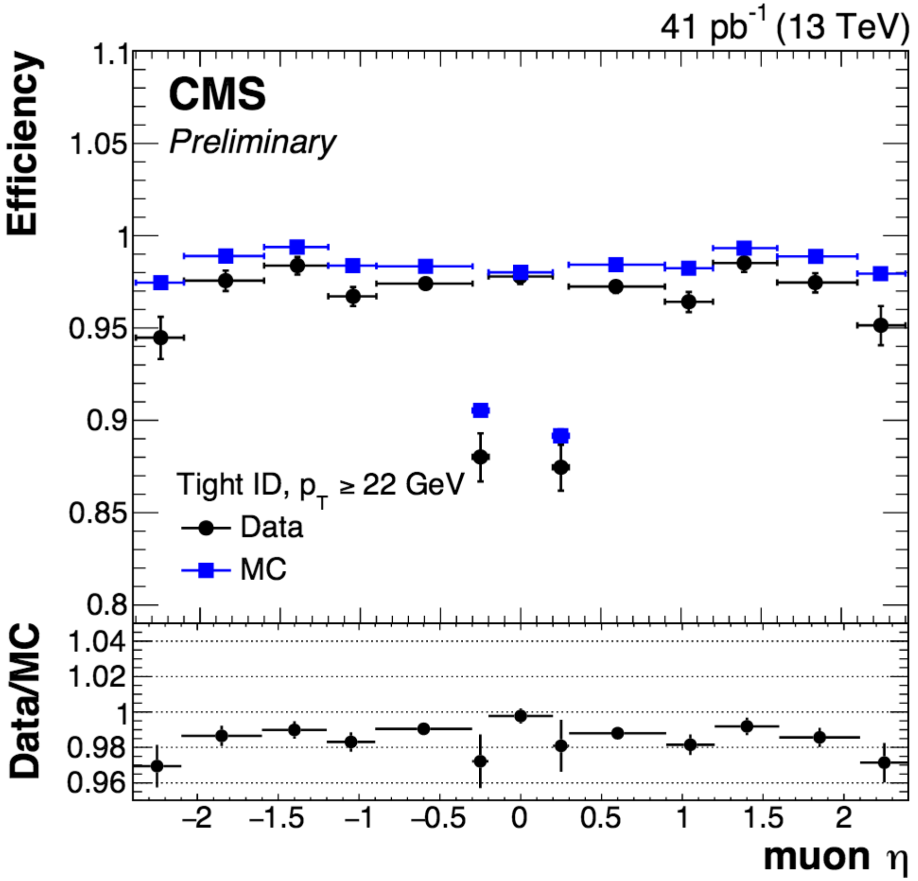
- Trigger
  - Double-muon trigger with p_T thresholds of 17 and 8 GeV on higher-and lower-p_T muon, loose tracker-based isolation on each muon.
- Offline selection for di-muon kinematic distributions
  - At least two opposite-sign muons with Loose ID
  - Loose ID - PF muon and Global or Tracker muon (see DP-2013/009 for details)
    - p_T > 20 and 10 GeV, $|\eta|$ < 2.4
  - Isolation requirement
    - $I_{rel} = \frac{\left(\sum p_T^{tracks} + \max\left(0, \sum E_T^{ECAL} + \sum E_T^{HCAL} - k \cdot \rho\right)\right)}{p_T} < 0.2$, $\Delta R = 0.4$

The pair with invariant mass closest to the nominal Z boson mass is selected.



Muon ID efficiency using T&P for Run2





- Tag muons - Loose muon or Tight muon with p_T > 25 GeV
- Probe muons - general tracks with p_T > 22 GeV
- Fitting to Z mass window of 70-130 GeV

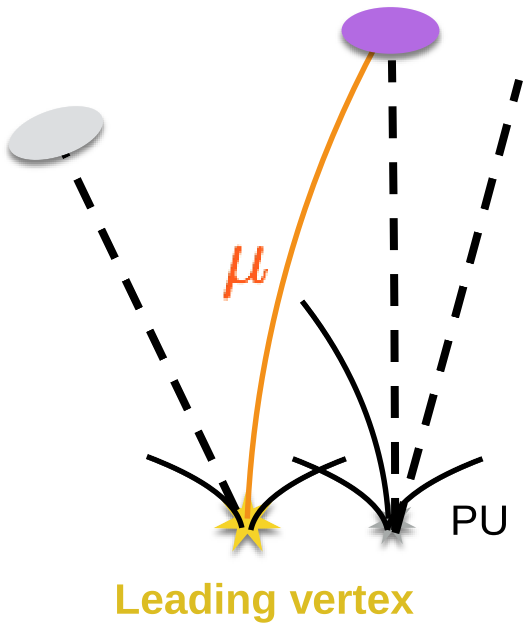
Muon isolation

- $\Delta\beta$ corrected : subtract pileup neutral contribution rescaling from tracks associated to PU vertices (Run1)

- PUPPI isolation
  - With muon

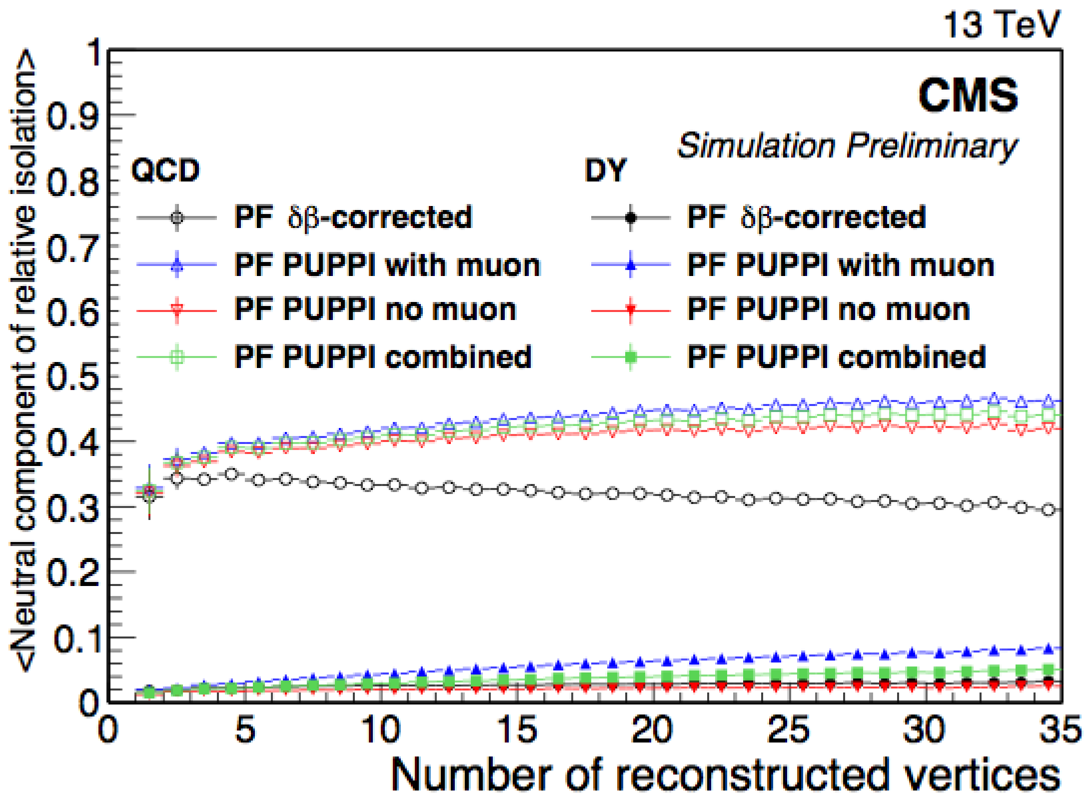
$$\sum_{CH} w_{PUPPI}^{i} P_T^{i} + \sum_{PH} w_{PUPPI}^{i} P_T^{i} + \sum_{NU} w_{PUPPI}^{i} P_T^{i}$$

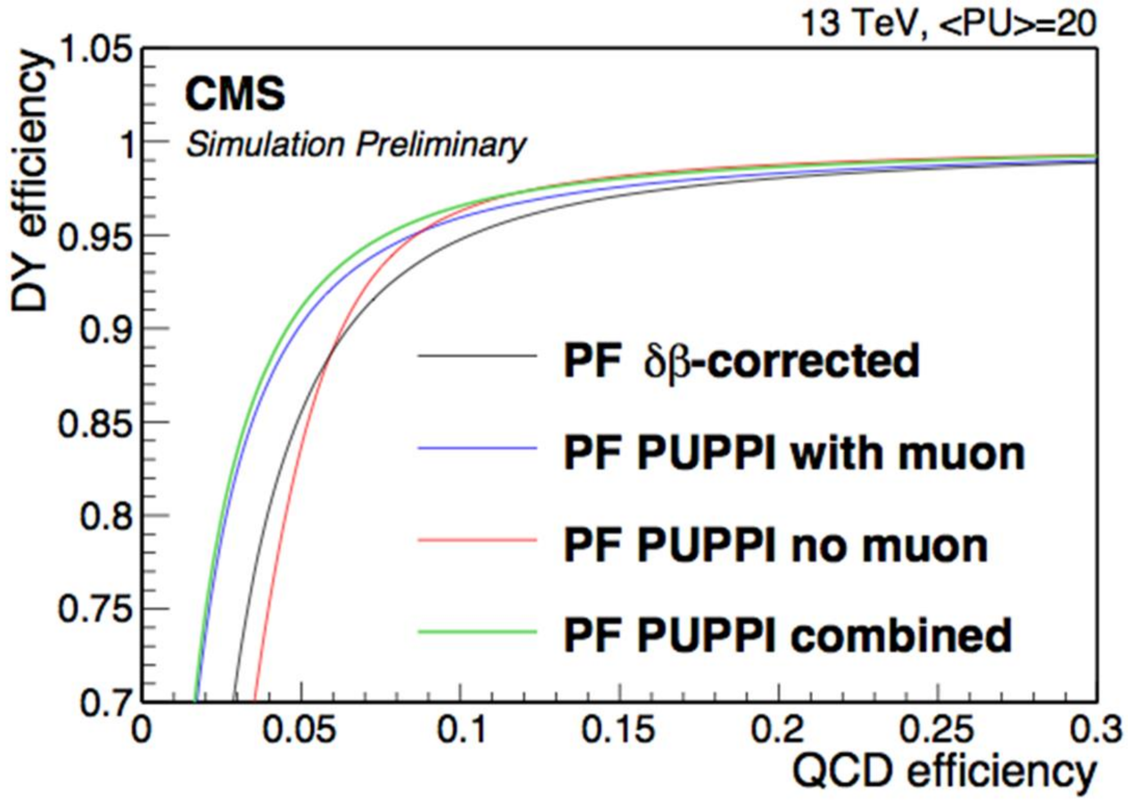
  - Without muon - remove muons as isolation tends to assign larger weights to them based on the hypothesis that muons are prompt.
  - Combined : average the two approaches.



Muon Isolation

CMS DP-2015/015

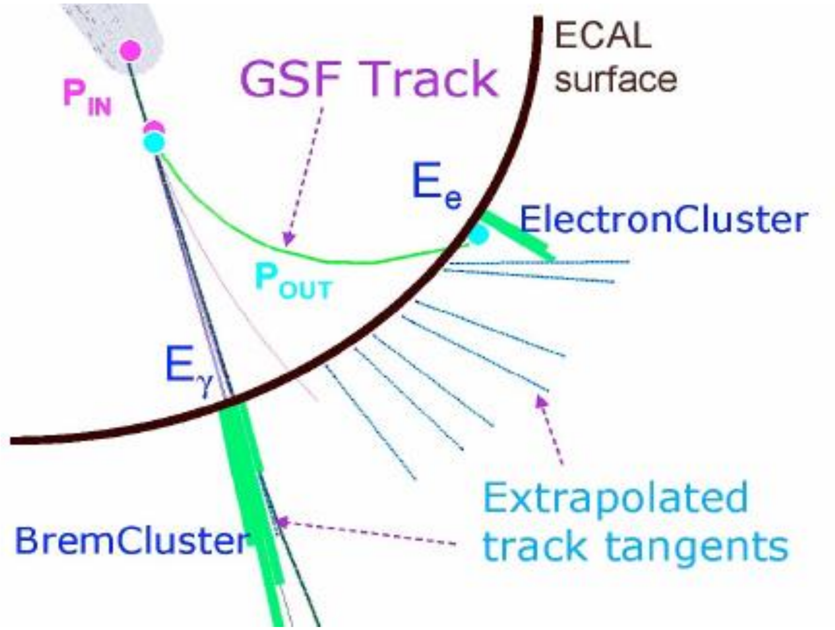




- Prompt (signal) muons from Drell-Yan
- Non-prompt (background) muons from QCD (muon-enriched)
- PUPPI is still being commissioned with data.

Electron reconstruction

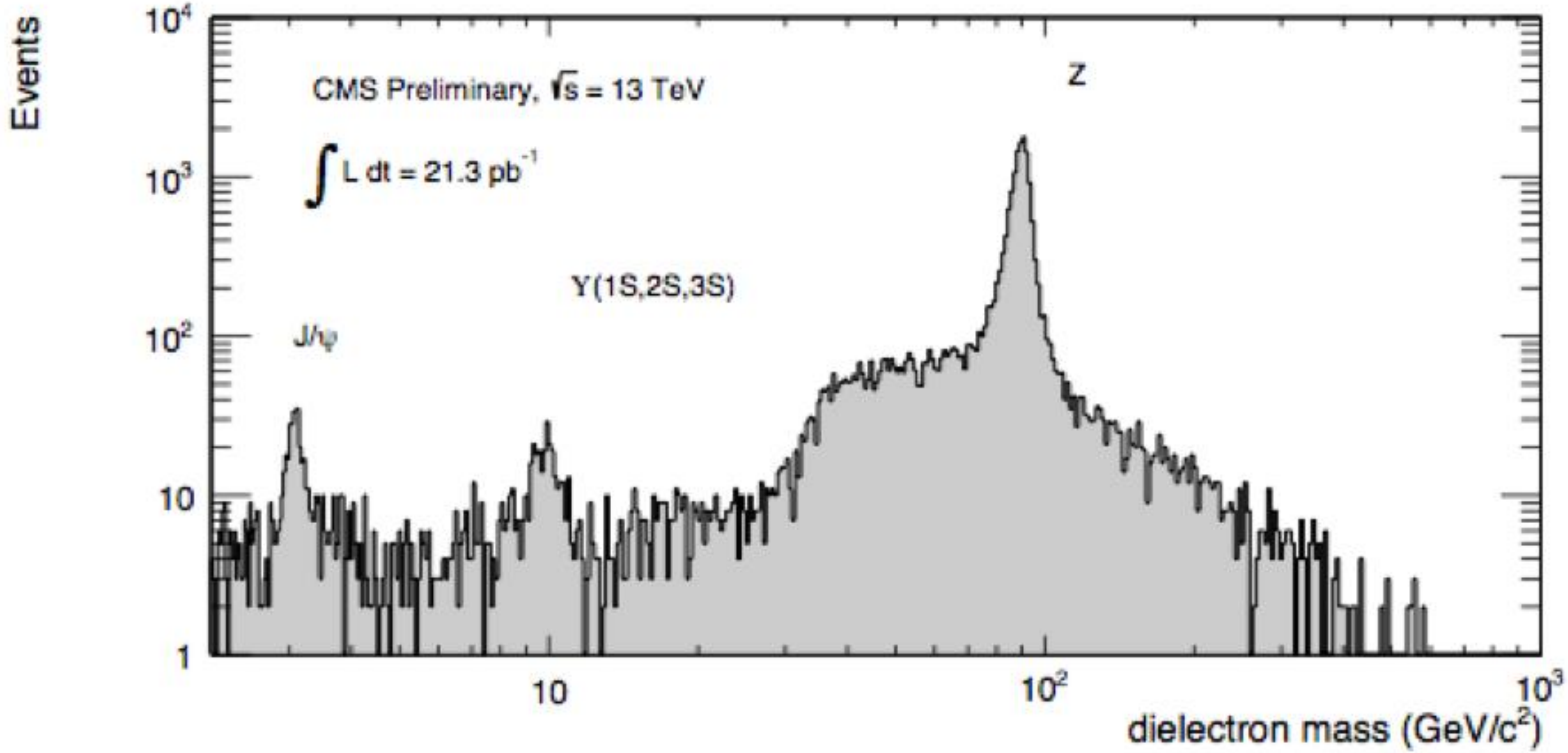
- Thanks to excellent ECAL we reconstruct electromagnetic energy deposits with very good resolution down to low p_T.
- CMS material is heavy so…
  - Electrons and photons traverse multiple radiation lengths.
  - Electrons produce bremsstrahlung heavily.
  - Brems. can lead to photon conversion.



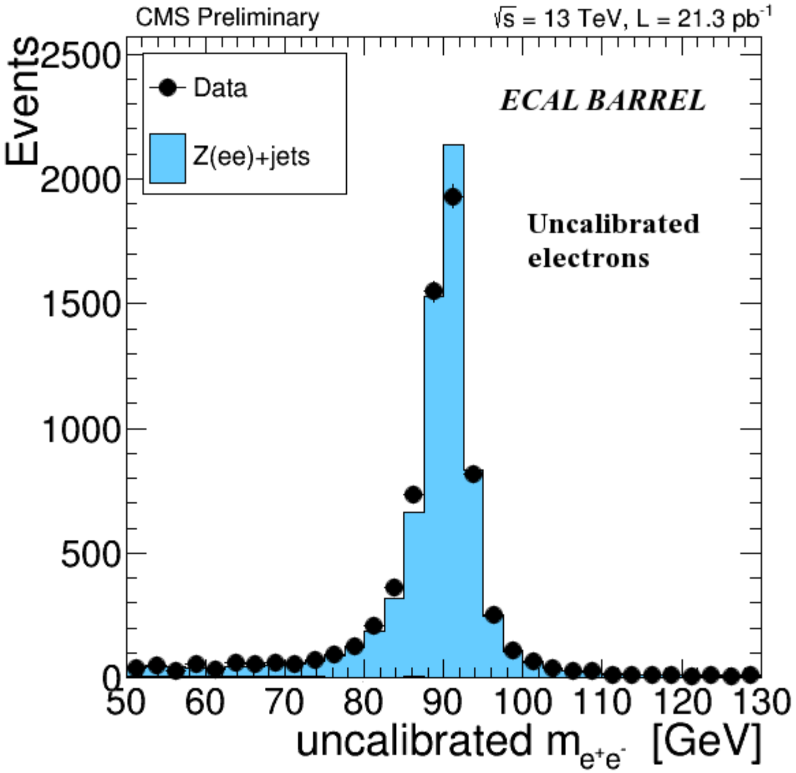
- CMS electron and photon reconstruction completely overhauled to reconstruct simultaneously all possible electron and photon candidates for Run 2
  - Electrons/photons have similar characteristics.
- New reconstruction completely integrated with particle flow, and provides additional flexibility at analysis level

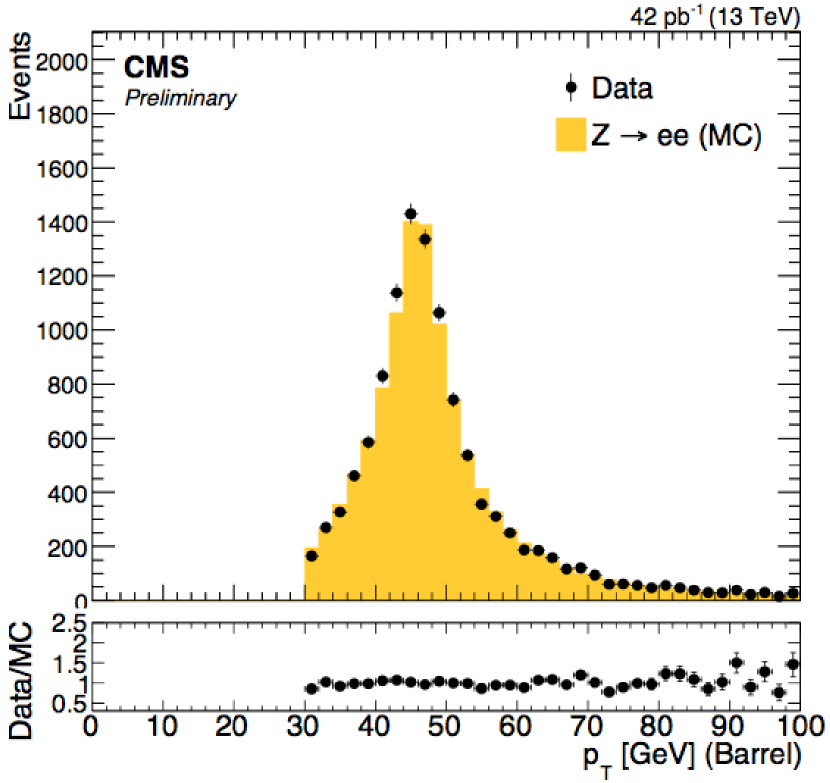
Di-electron spectrum

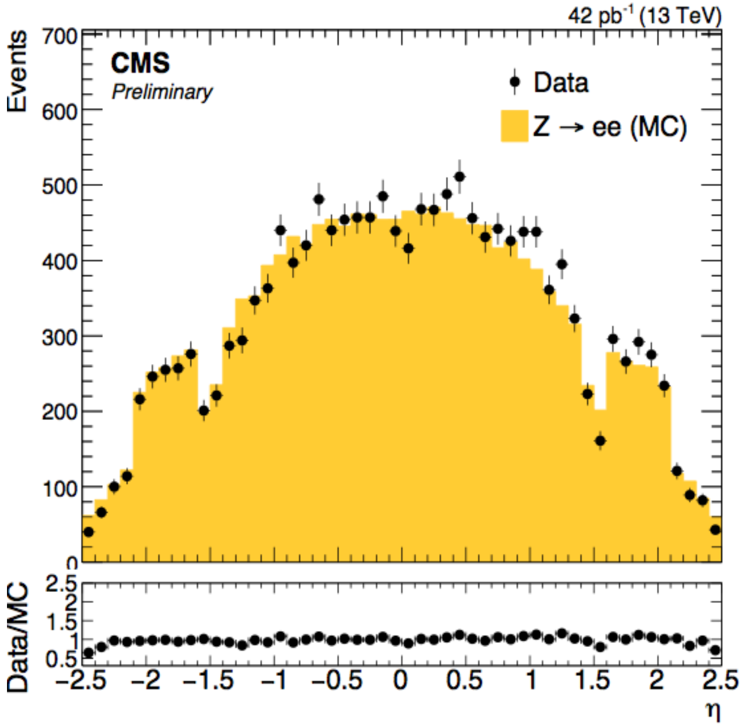
Di-electron mass spectrum for electrons with p_T > 10 and |η|<2.5 which pass the cut-based Electron ID Veto working point.



Di-electron mass and leading electron p_T, η



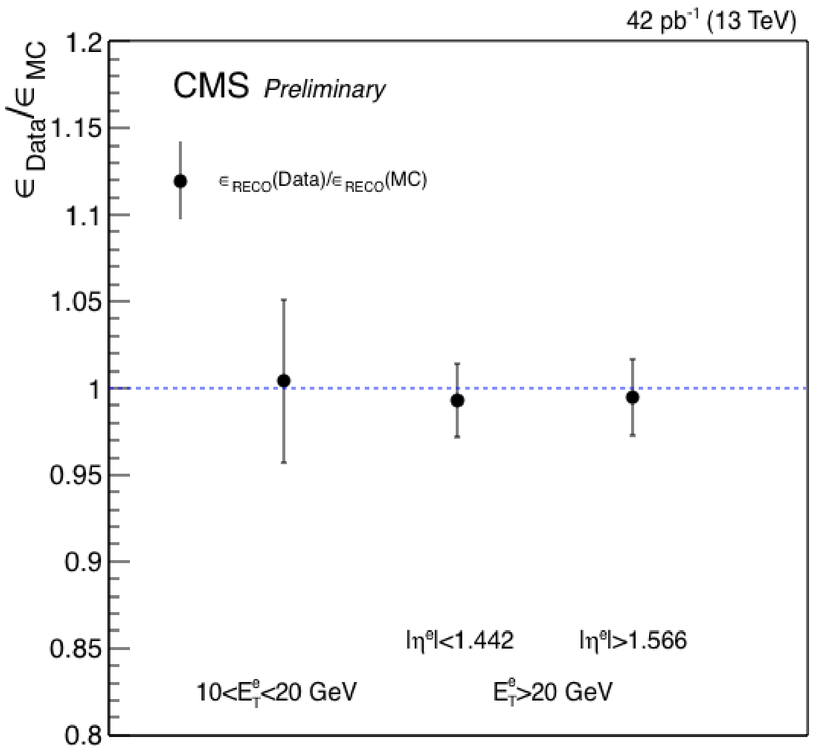


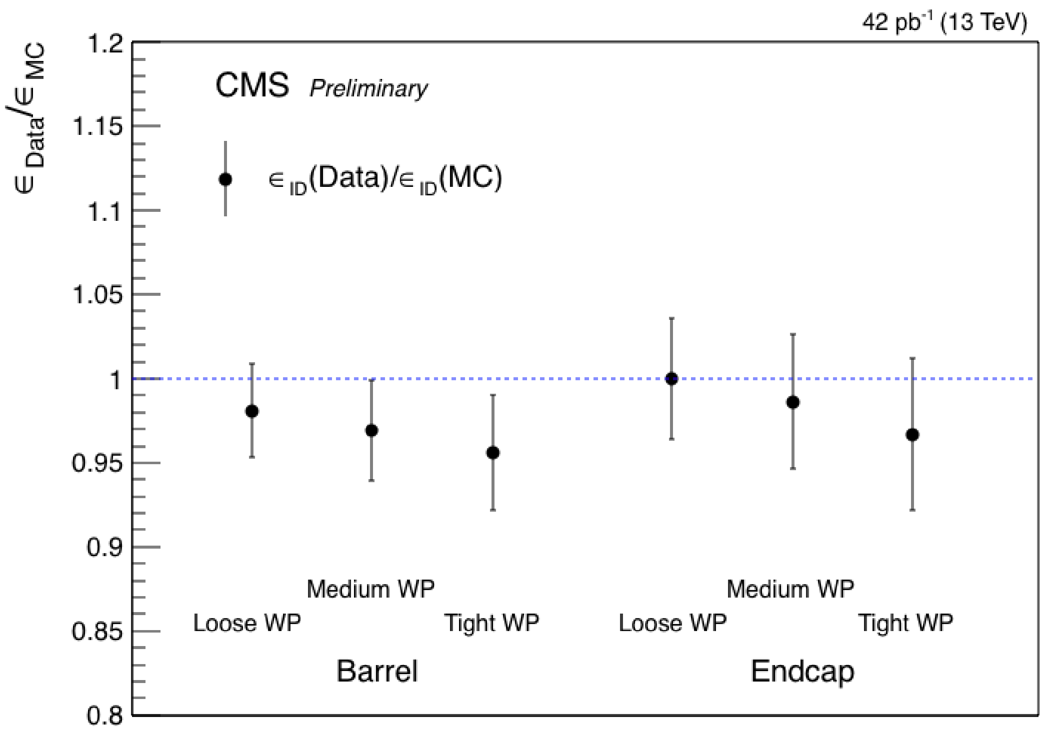


Un-calibrated Z peak already agrees well with data.

Electron p_T, $|\eta|$ spectrum for the leading electron which passes the medium identification working point.

Electron efficiency using T&P for Run2

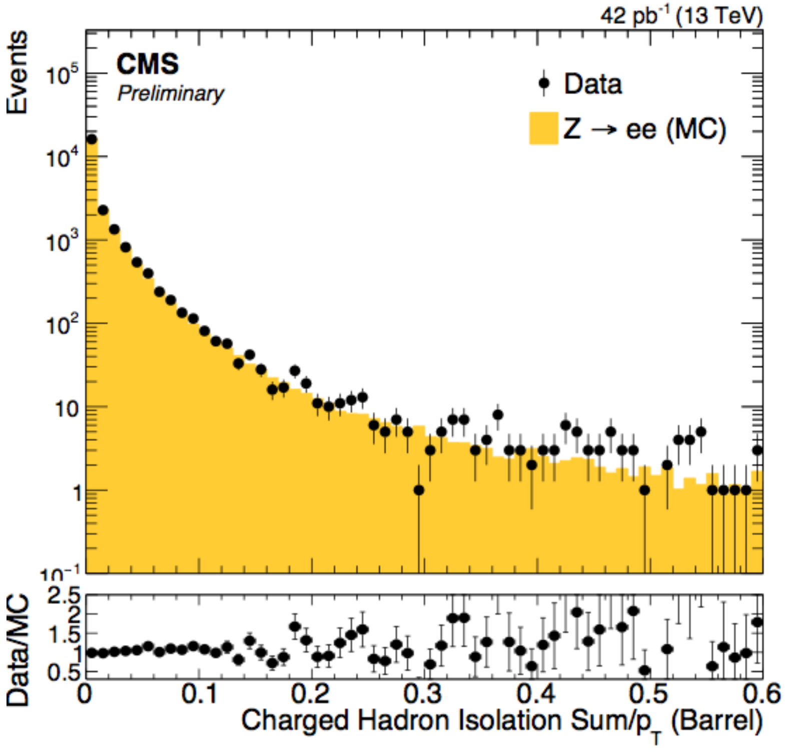




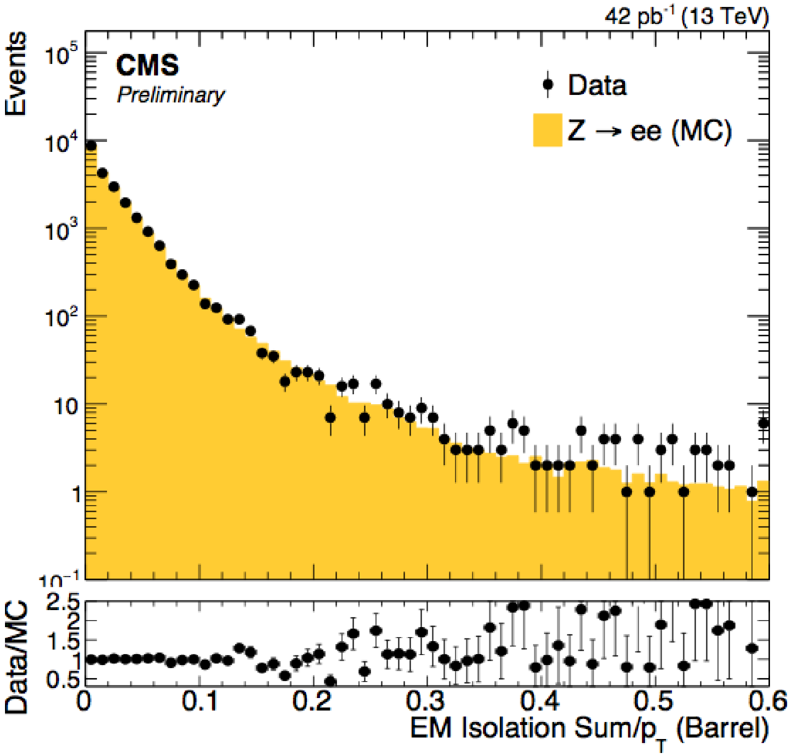
- Tag selection - tight ID, p_T > 25 and $|\eta|$ < 2.1
- Probe selection - Super cluster with p_T> 10 GeV
- Electrons with 1.442 < $|\eta|$ < 1.566 are excluded.
- Fitting the invariant mass of 60 < M_Z < 120 GeV

Loose WP : ~ 70%
Medium WP : ~ 80%
Tight WP : ~90%

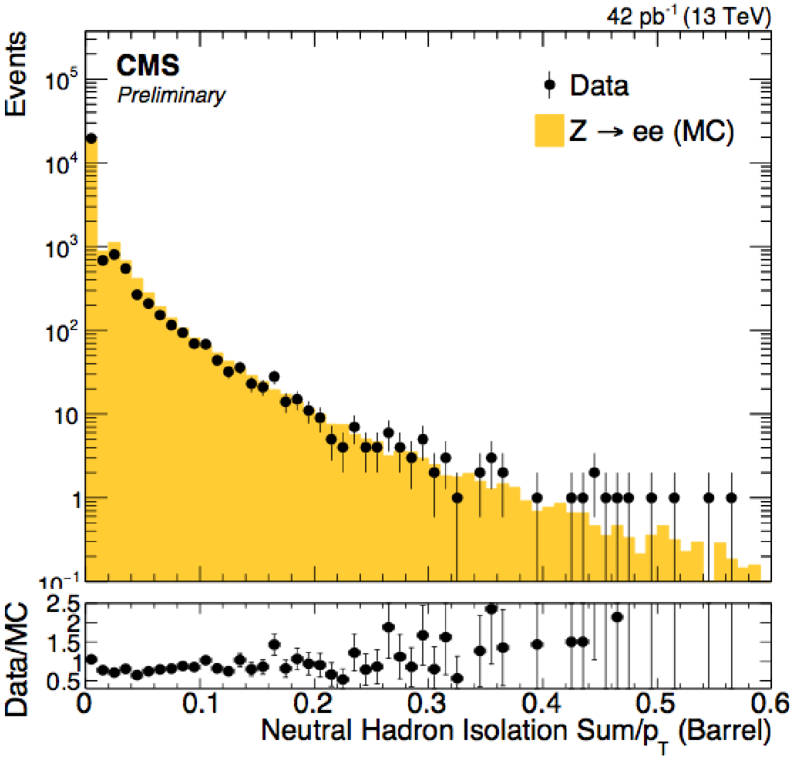
Electron Isolation



Charged hadron isolation (Barrel)

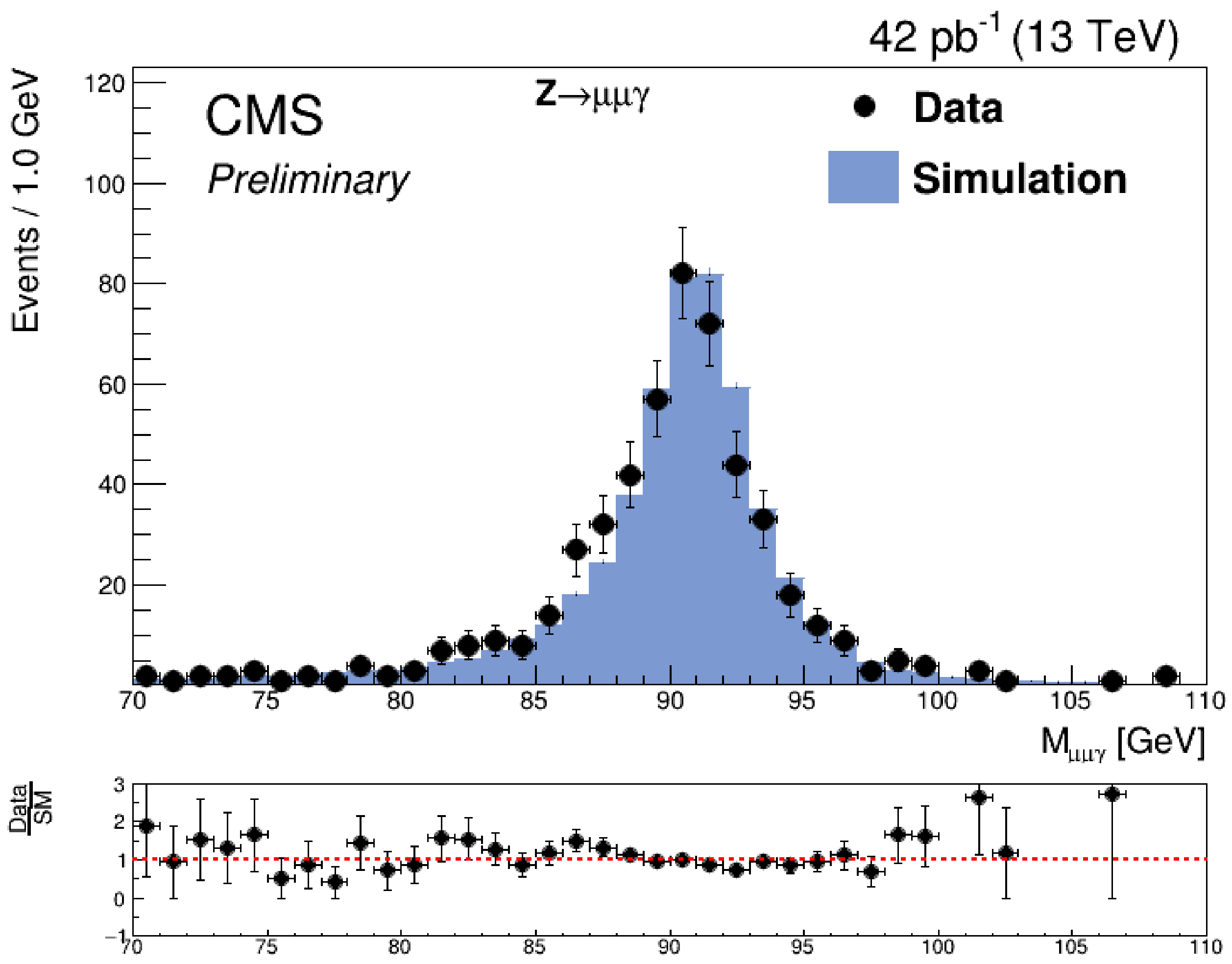


Photon isolation (Barrel)



Neutral hadron Isolation (Barrel)

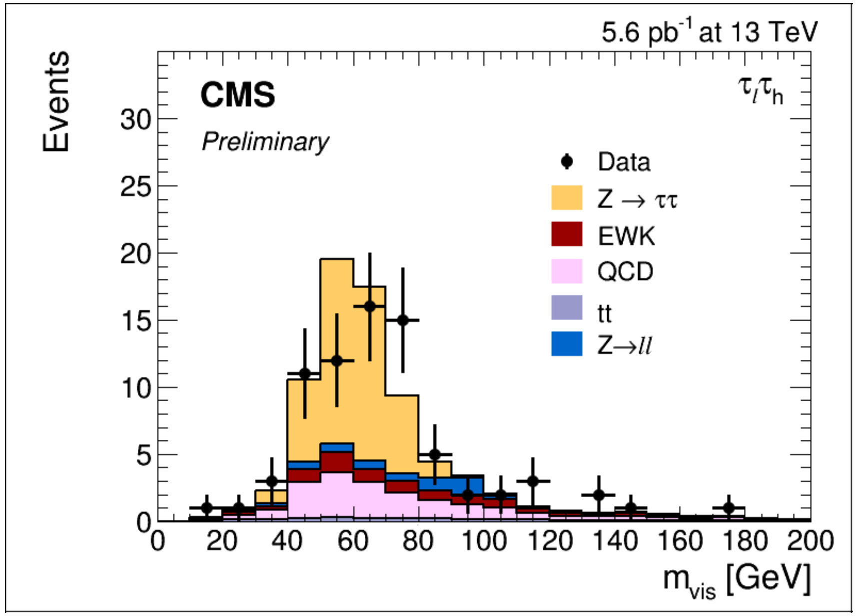
Photon

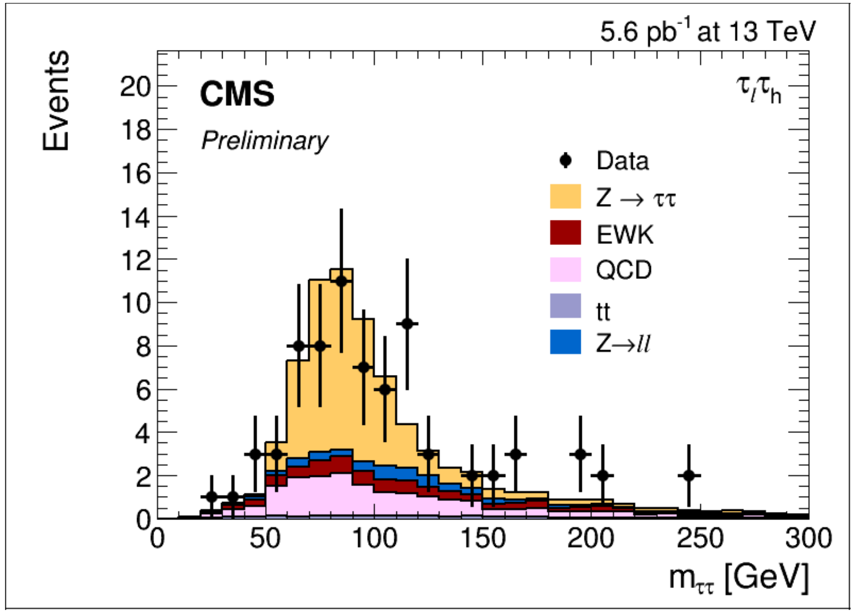


$M_{\mu\mu\gamma}$ distribution

- Muon p_T > (20) 10 GeV
  - Tight muon ID
- Photon p_T > 10 GeV
  - H/E < 0.05
  - $\sigma_{i\eta i\eta}$ < 0.011(0.031) for EB(EE)
  - Isolated
  - $\Delta R(\mu,\gamma)$ < 0.8
  - p_T > 20 GeV for muon farthest from the photon
- $M_{\mu\mu\gamma} + M_{\mu\mu}$ < 180 GeV
- 70 < $M_{\mu\mu\gamma}$ < 110 GeV

Reconstruction of Z → $\tau\tau$ at 13 TeV





- Hadron plus strip (HPS) to take into account the broadening in ϕ of calorimeter signature from early showering photons from π^0.
- QCD background estimated by the same sign data.
- Visible (top) and fully reconstructed mass (bottom) using the SVFit (to reconstruct four-momentum of tau and better resolution of the invariant mass)

Muons: $p_T > 18$ GeV, $|\eta| < 2.1$
Electrons: $p_T > 20$ GeV, $|\eta| < 2.1$
Taus: $p_T > 20$ GeV, $|\eta| < 2.3$
l and τ should have opposite sign
$M_T(\mu, \tau) < 40$ GeV

Conclusion

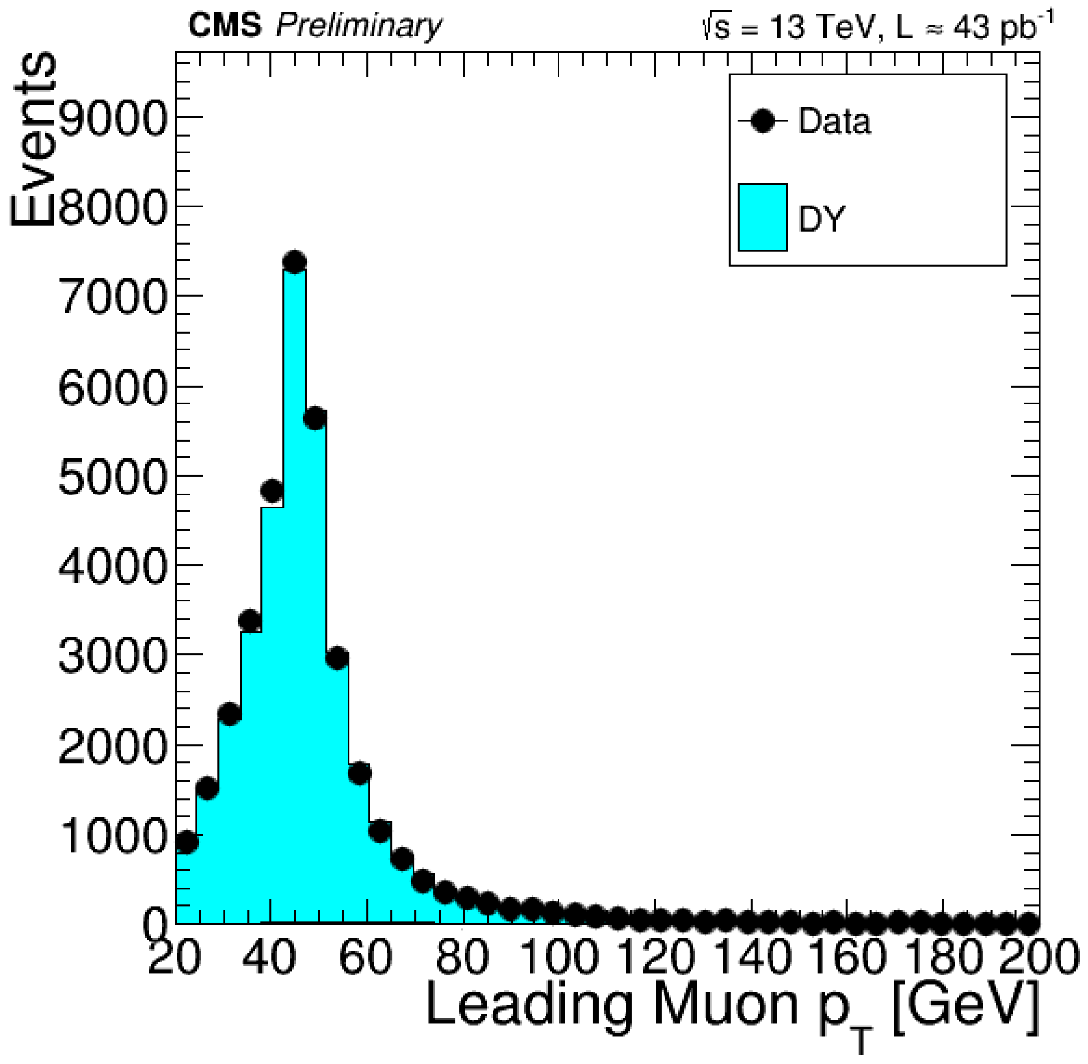
- The object performance study is the key for the future precision measurements and also searches beyond the SM.
- We understand better our detector and physics objects using top quark decay particles with early run data.
- Advanced pileup mitigation techniques are already available to use against larger pileup events in Run 2.
- With all remarkable physics object agreements, our journey towards discovering nature using top quark events from Run 2 data is ready.

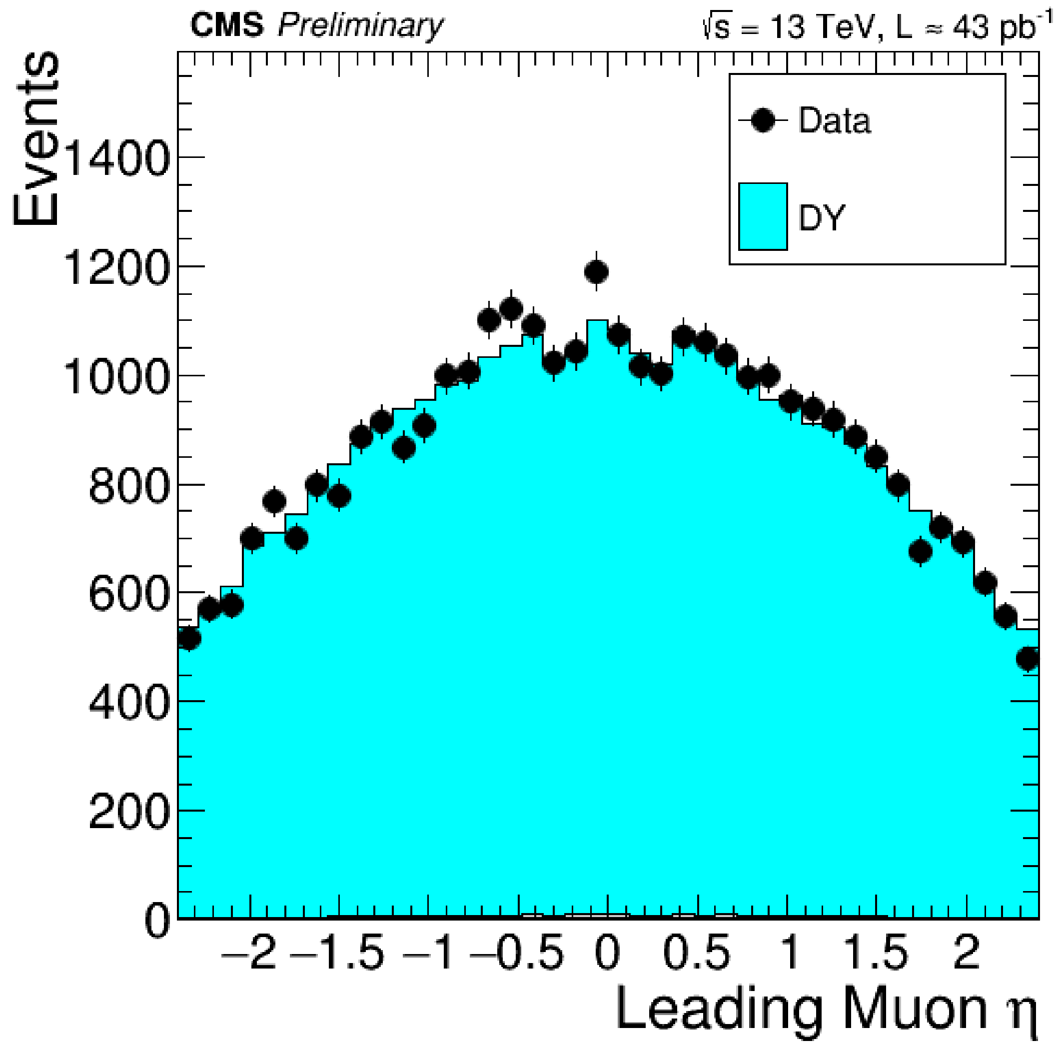
Backup

Magnet Cryogenics

- The restart of the CMS magnet after LS1 was more complicated than anticipated due to pr oblems with the cryogenic system in providing liquid Helium.
- Inefficiencies of the oil separation system of the compressors for the warm Helium require d several interventions and delayed the start of routine operation of the cryogenic system.
- The data delivered during the first two weeks of LHC re-commissioning with beams at low luminosity have been collected with B=0
- Currently the magnet can be operated, but the continuous up-time is still limited by the pe rformance of the cryogenic system requiring more frequent maintenance than usual.
- A comprehensive program to re-establish its nominal performance is underway. These rec overy activities for the cryogenic system will be synchronized with the accelerator schedul e in order to run for adequately long periods.

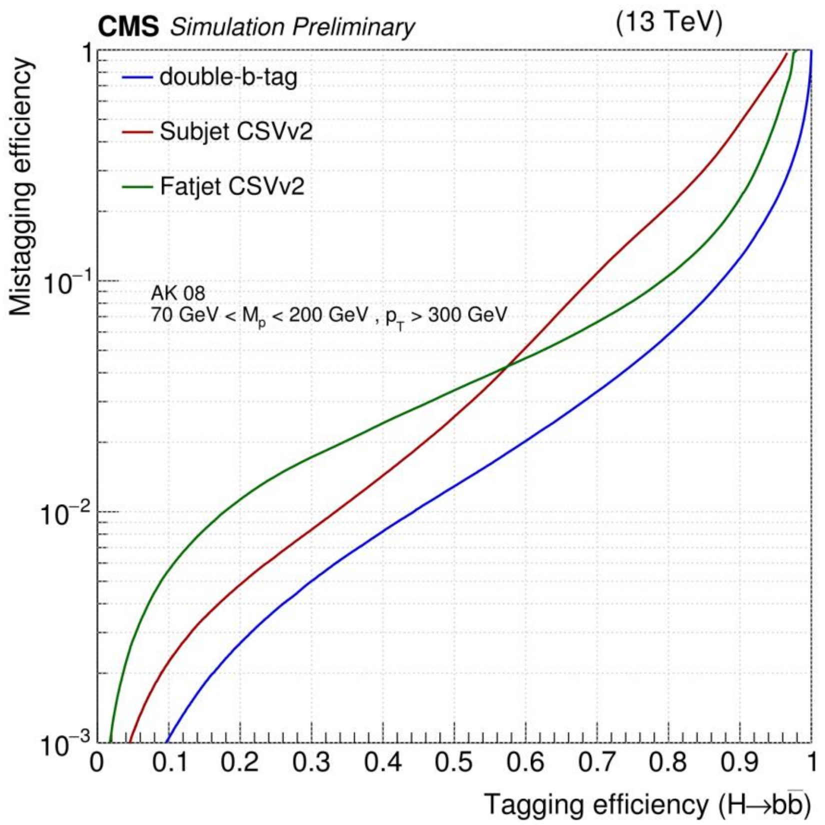
Leading muon p_T, η

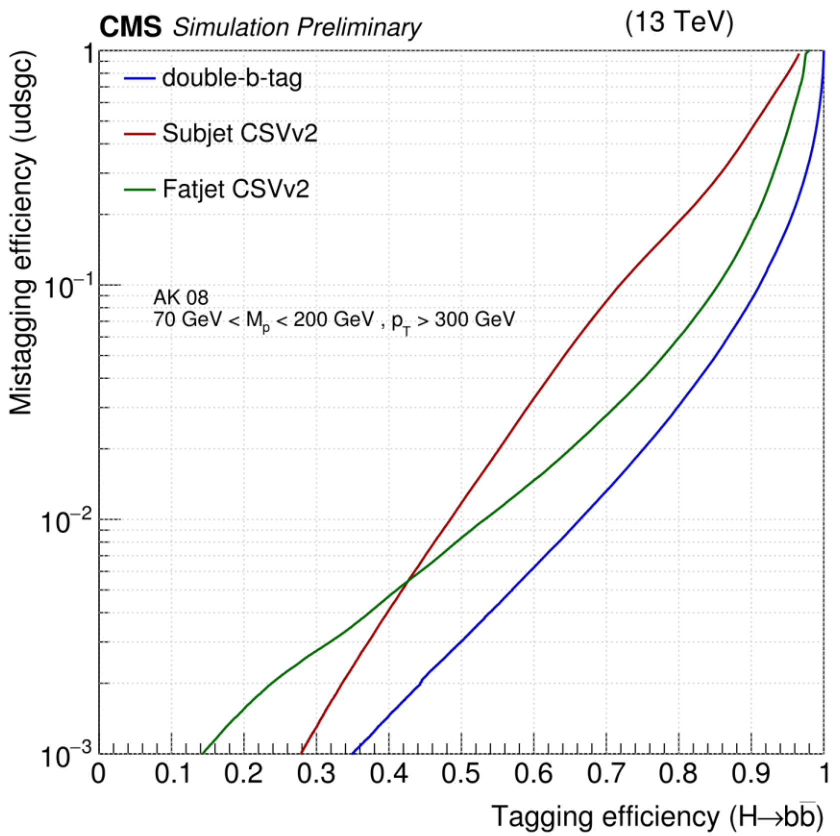




Double b-tagging performance

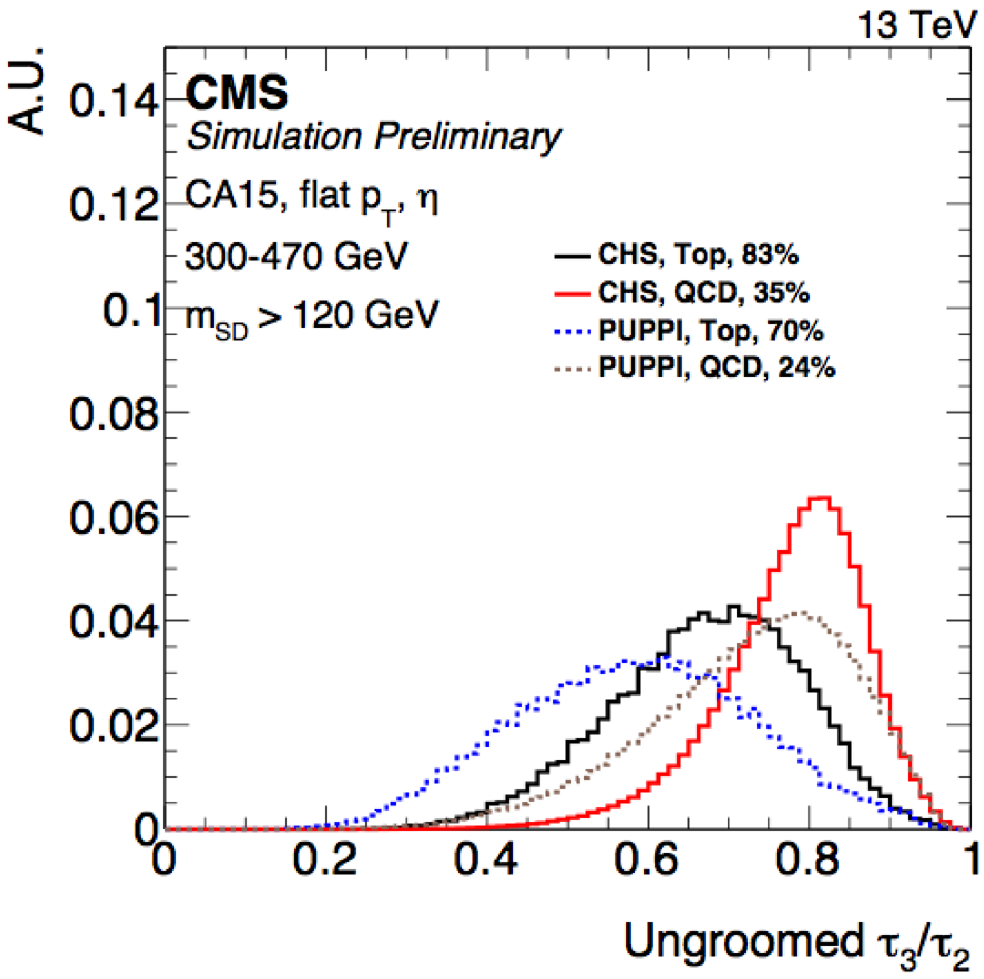
CMS DP-2015/038

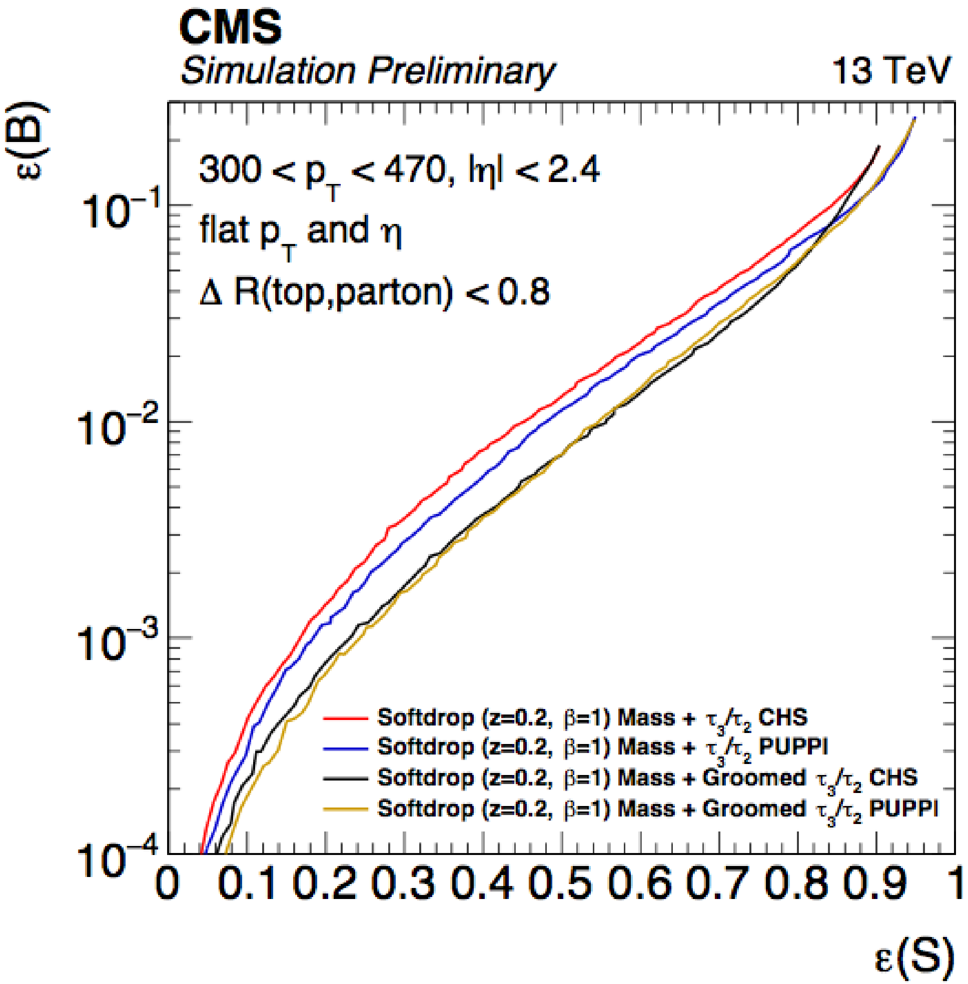




- Signal efficiency is evaluated using boosted H to bb signal. Mistagging efficiency is evaluated for QCD multi-jets events and for light flavor and gluon jets from QCD multi-jet events.

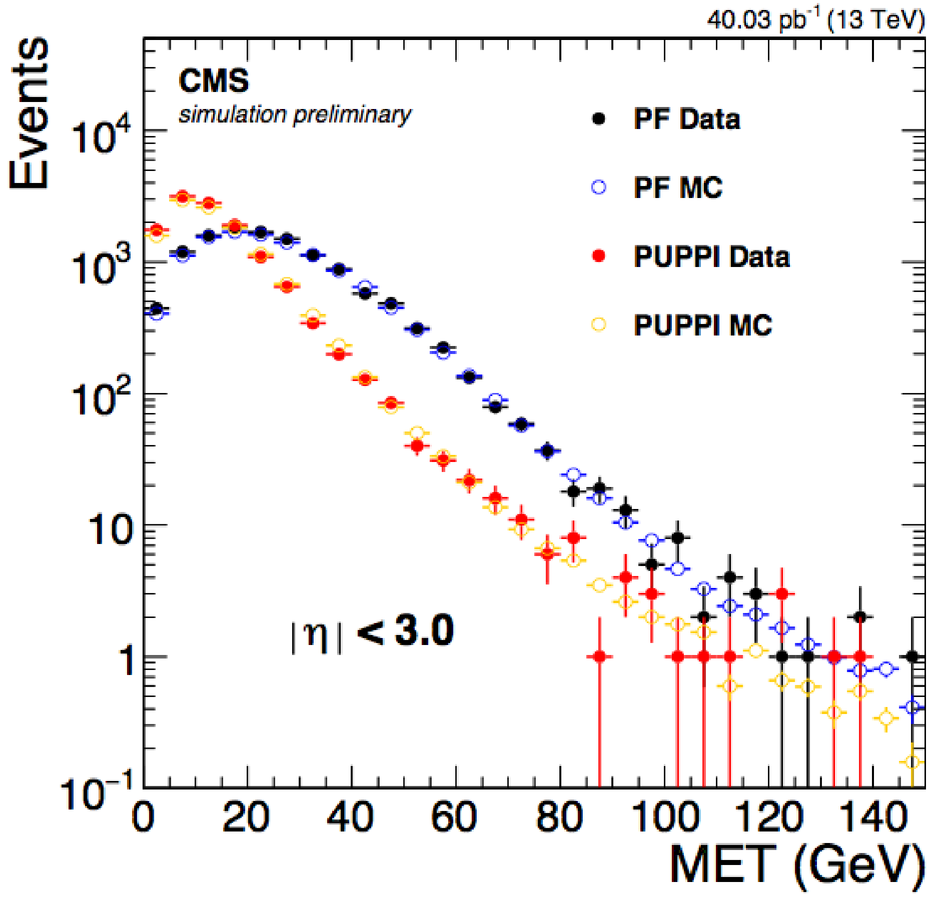
Top tagging





- Merged top selection efficiency versus QCD background jet rejection for inputs from PF PUPPI and PF CHS.

MET



40.03 pb⁻¹ (13 TeV)
CMS
simulation preliminary
PF Data
PF MC
PUPPI Data
PUPPI MC
|η| < 3.0
Events
MET (GeV)