Measurement of the associated production of Z boson and b jets with the CMS experiment

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Outline

- LHC collider
- CMS detector

Introduction

- Process studied
- Physics motivation

what and why

- Event selection

how

- Distributions

results

- Next steps

...

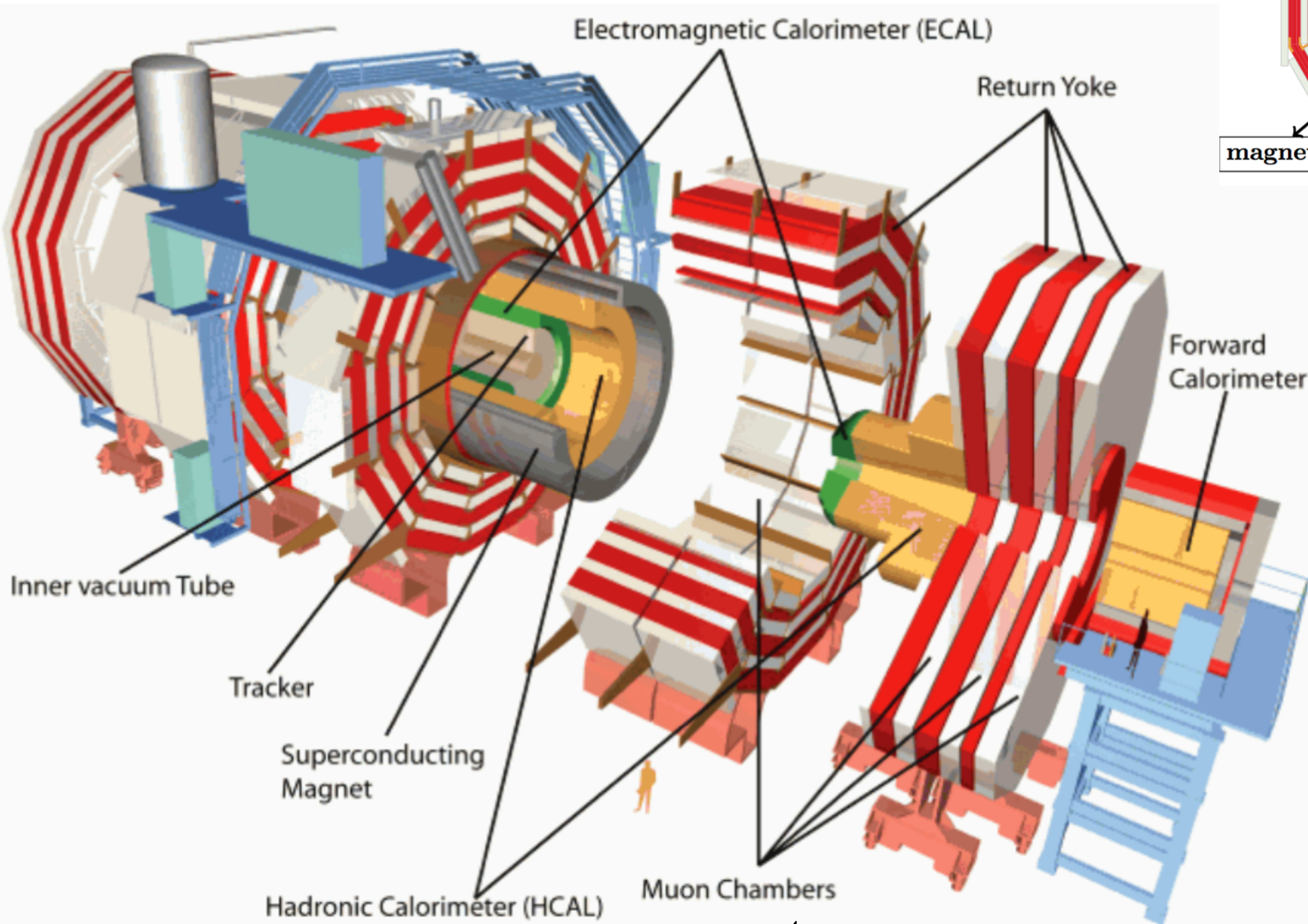
Large Hadron Collider

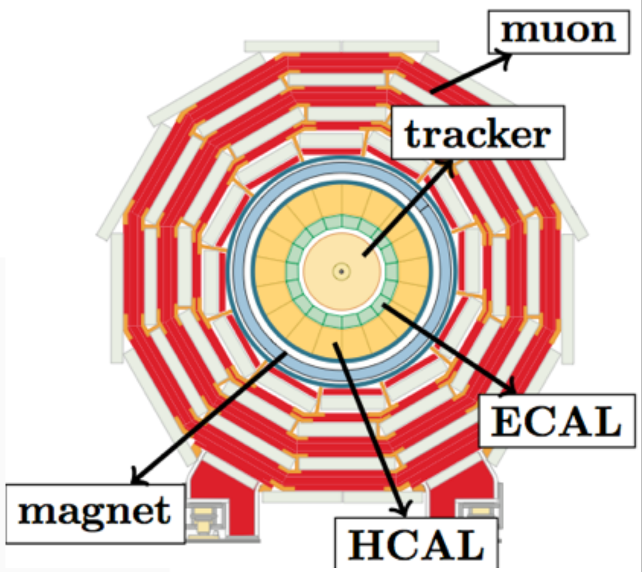
	2010-2011	2012
Center mass energy [TeV]	7	8
Peak inst. luminosity [10^{33} cm^{-2} s^{-1}]	3.5	7.7
Collision rate [MHz]	20	20

Integrated Luminosity at 8 TeV

$19.7\ fb^{-1}$ for muons
$19.8\ fb^{-1}$ for electrons

Compact Muon Solenoid experiment





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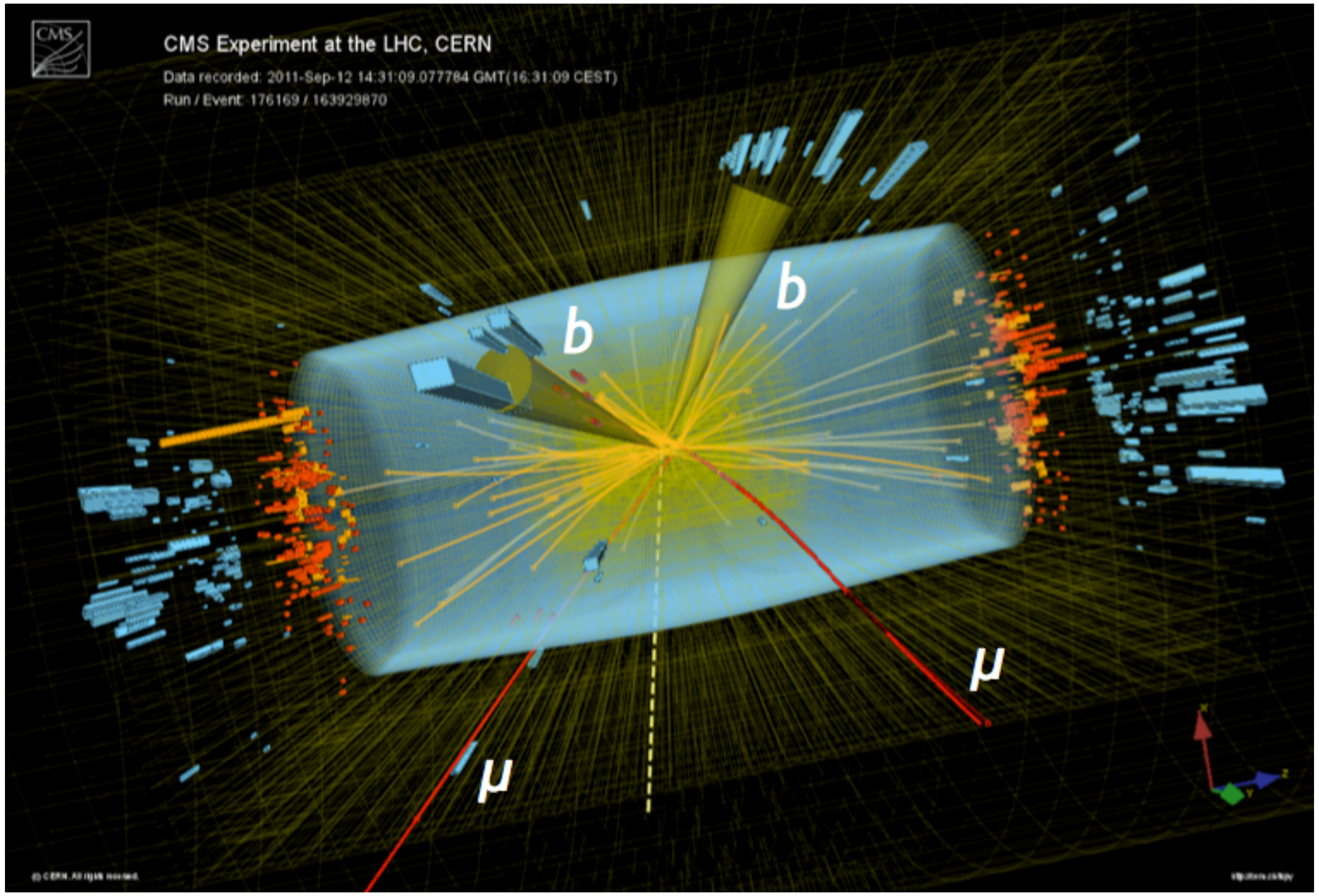
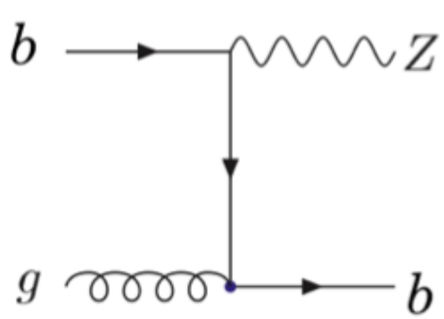
Z + b-jets process

Final state:

- Z boson
- b jet



1 b-jet



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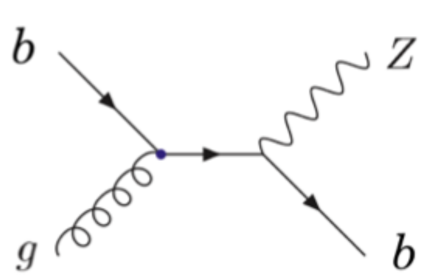
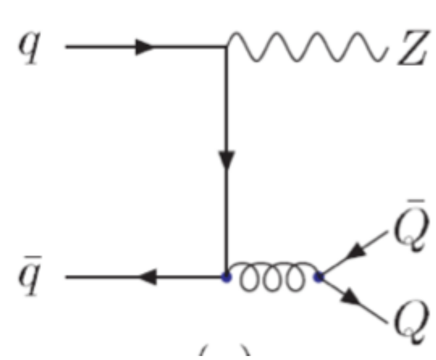


≥ 2 b-jets



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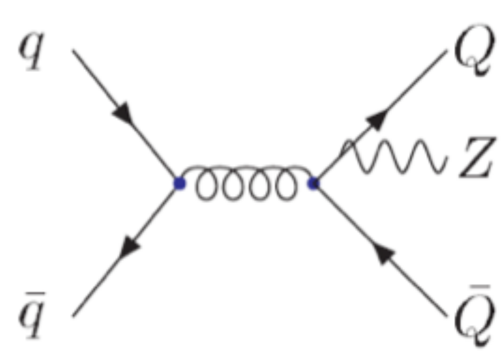
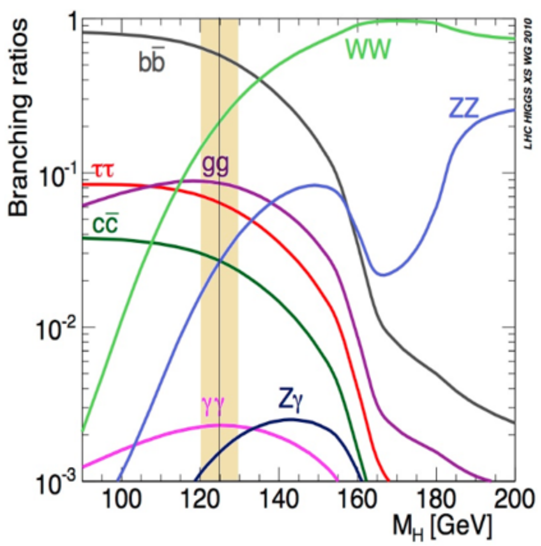


Z+1b-jet and Z+2b-jets need to be estimated simultaneously due to inefficiencies and misidentification

Motivations

Standard Model

- Significant background for the H → bb



- Z polarization asymmetry

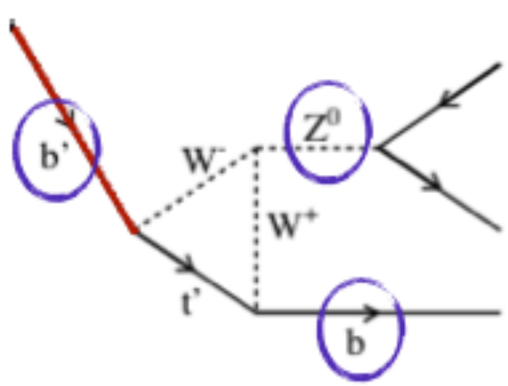
	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ_{had}^0 [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21562
R_c	0.1721 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.389
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.5

QCD

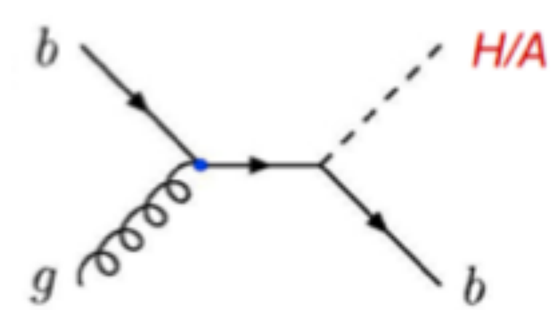
- test for the **perturbative Quantum Chromodynamics** predictions (pQCD)
➔ different approaches to treat b-quark production

New Physics

- 4th generation of heavy quarks ➔ b' → Zb



- Supersymmetric Higgses ➔ production of Susy Higgses coupled with a b quark



Measurement

number of signal events

number of background events

$$\sigma\ (pp \rightarrow Z(ll)+b) = \frac{(N_{sign} - N_{tt} - N_{VV} - N_{charm} - N_{light})}{\varepsilon_l\ \varepsilon_b \int L(t)\ dt}$$

lepton efficiency

$\varepsilon = \varepsilon_{RECO} \times \varepsilon_{HLT} \times \varepsilon_{SEL}$

b-tagging efficiency

differential cross section measurement as function of:

- leading *b*-jet pT
- leading b-jet η
- Z boson pT
- M(bb)
- M(Zbb)
- angular distributions

Strategy of the analysis

- Z selection through the decay modes into electrons and muons

- b-jet selection → only 1 b-tagged jet / → at least 2 b-tagged jets } 2 different samples selected

- Scale factor correction applied in MC

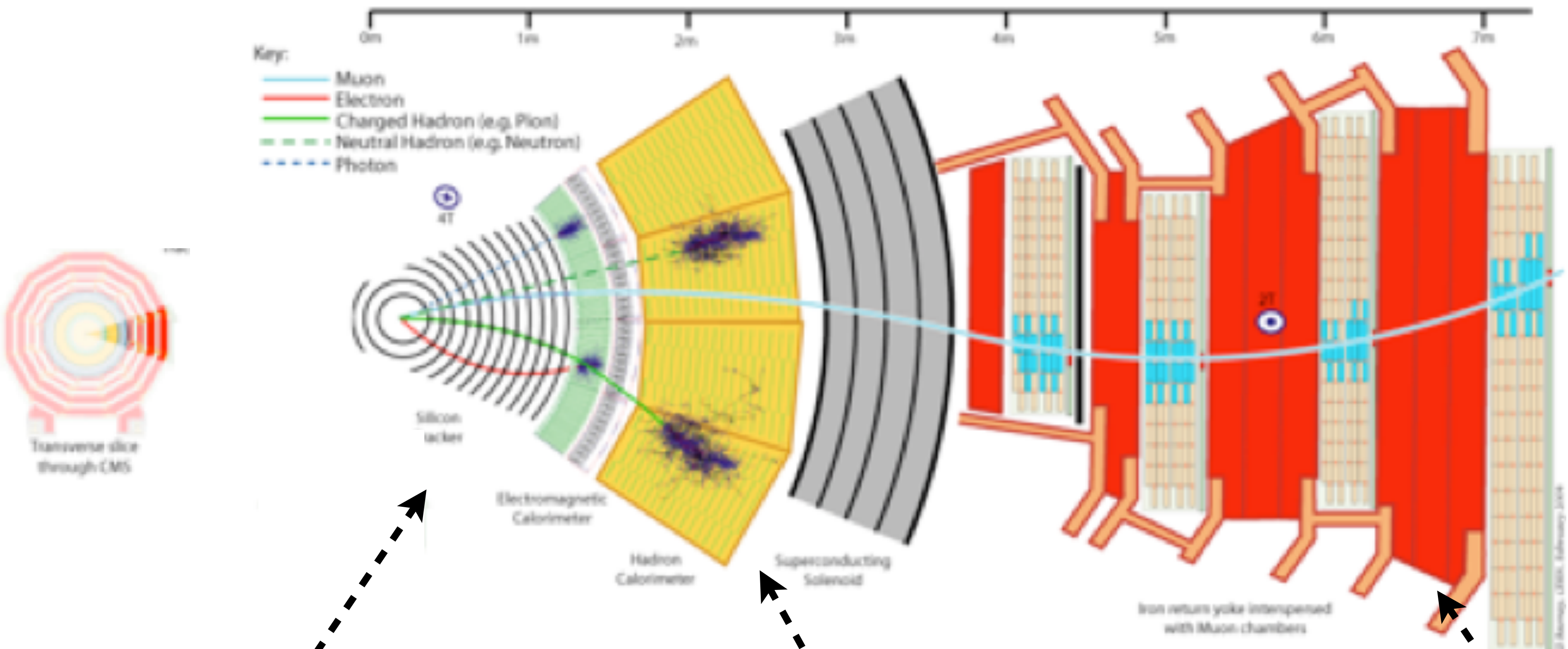
- tt background estimation -> *data driven* approach using the eμ sample

- Event purity estimation for the 2 samples -> from the fit of the BJP distribution

- Detector level distributions -> comparison data/MC

Objects Reconstruction

Physics objects in CMS reconstructed
by the **Particle Flow** algorithm

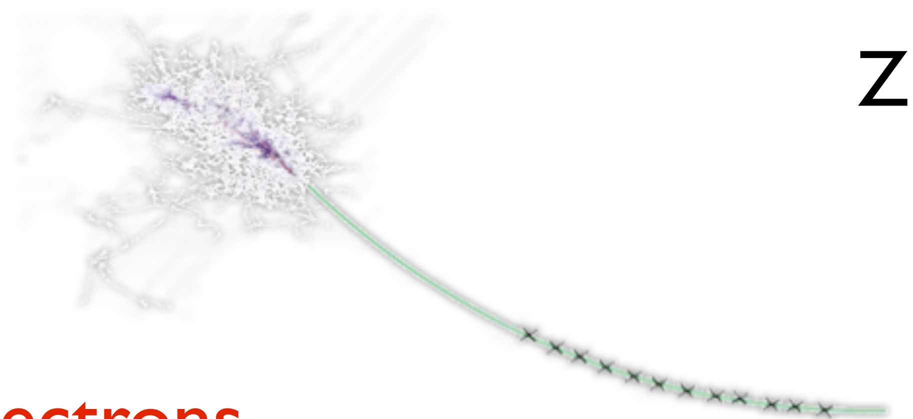


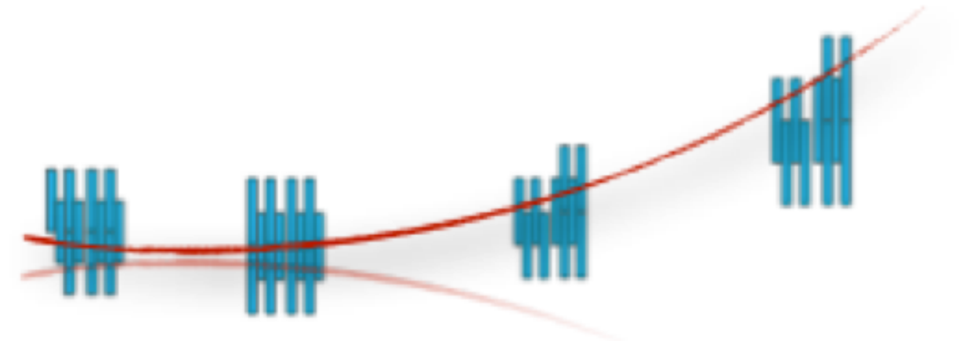
hits in the **tracker**	cells in the **calorimeter**	hits in the **muon detector**
↓	↓	↓
tracker tracks	calorimetric clusters	muon tracks

- Combination of all these objects to characterize the single particle (neutral and charged hadrons, electrons, photons, muons and tau)
- List of individual particles is then used to build the final state topology

Lepton Selection

$Z \rightarrow$
- $e^+ e^-$
- $\mu^+ \mu^-$





electrons

online *selection:*

- **dielectron** trigger: $\begin{cases} - E_{T1} > 17 \text{ GeV} \\ - E_{T2} > 8 \text{ GeV} \end{cases}$

muons

online *selection:*

- **dimuon** trigger: $\begin{cases} - E_{T1} > 17 \text{ GeV} \\ - E_{T2} > 8 \text{ GeV} \end{cases}$

offline *selection:*

- $pT > 20$ GeV
- $|\eta| \leq 1.442$ || $1.566 \leq |\eta| \leq 2.4$

- m_Z in [71,111] GeV
- isolation requirements in tracker and calorimeters

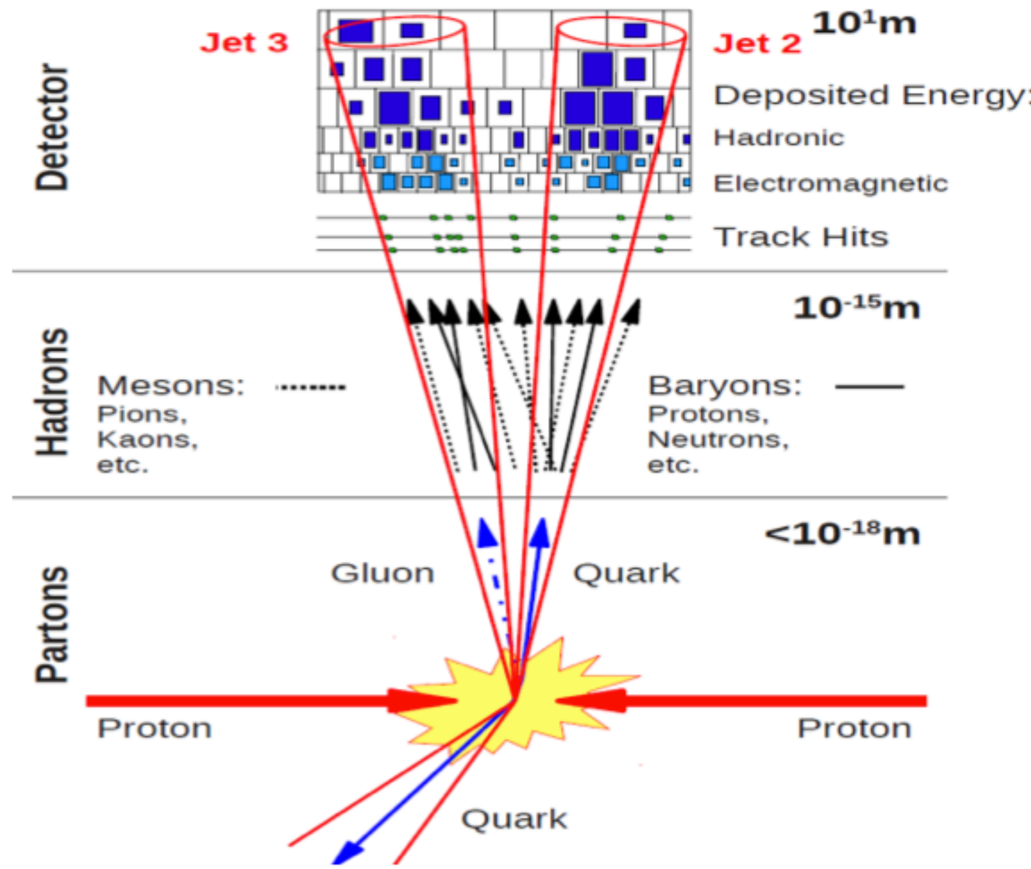
$$\eta = -ln(tan(\frac{\theta}{2})) \qquad p_T = p \cdot sin(\theta)$$

e: $I_e = \frac{1}{p_T^e}\left[\sum_{trk} E_T + \sum_{ECAL} E_T + \sum_{HCAL} E_T\right]_{\Delta R \leq 0.3}$ μ: $I_\mu = \frac{1}{p_T^\mu}\left[\sum_{trk} p_T + \sum_{ECAL} E_T + \sum_{HCAL} E_T\right]_{\Delta R \leq 0.3}$

Jet clustering

• In a p-p collision with high luminosity and energy many hadronic jets are produced.
➔ we need an efficient algorithm

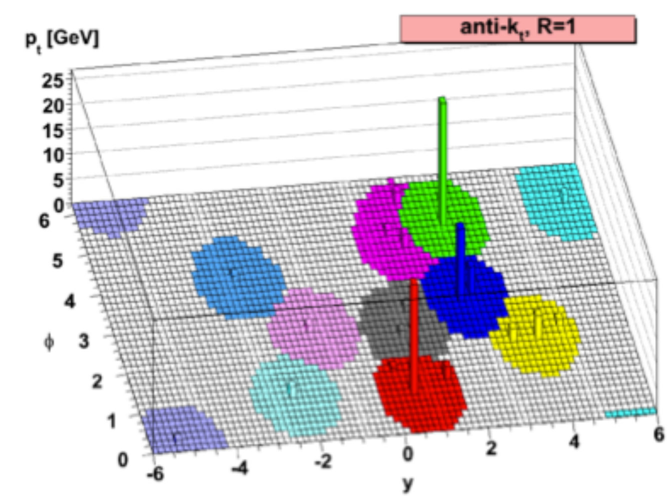
• Applied the anti-kt (R=0.5) algorithm ➔ based on a distance definition to discriminate the particle that belong to a jet



1. Definition of the distance:

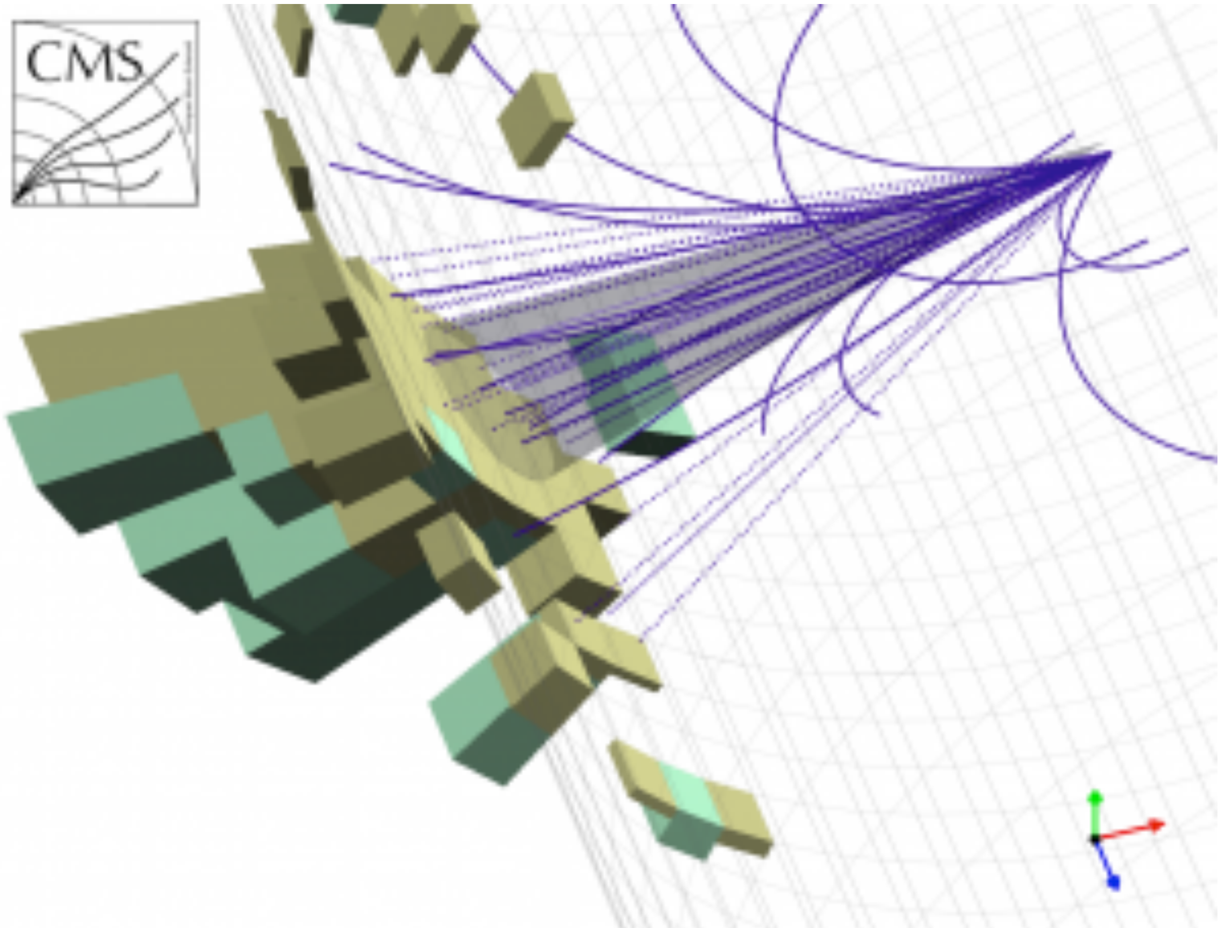
$$d_{ij} = \min(p_t^{2p}(i), p_t^{2p}(j))\frac{\Delta R_{ij}^2}{R^2}, \quad \Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

$$d_{iB} = p_t^{2p}(i) \qquad R = \sqrt{\phi^2 + \eta^2}$$



2. Given two particles i,j. If $d_{ij} < d_{iB}$ the two particles are combined together

Jet Selection



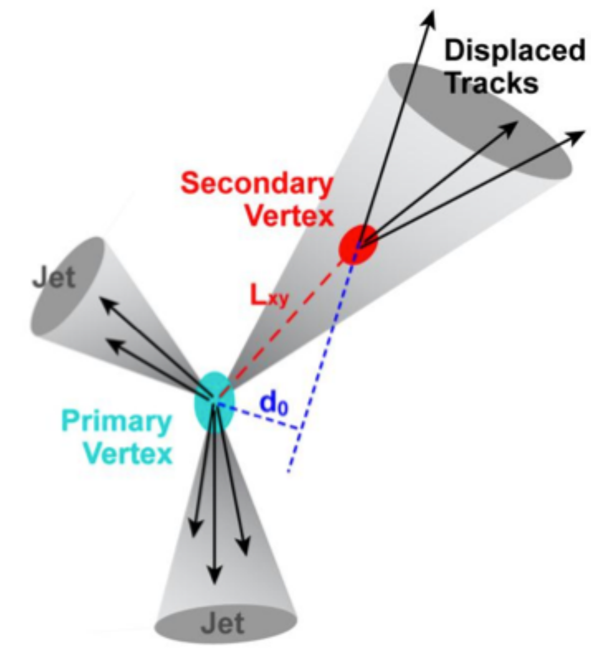
offline selection:

- $p_T > 30$ GeV
- $|\eta| \leq 2.4$
- $\Delta R(\text{jet, lepton}) \geq 0.5$

- Leptons removed from particle before the clustering
- Energy measured summing the energy of all the particles that belong to the jet
- Correction to Jet energy scale to consider bias in the reconstruction algorithm
- Jet energy correction applied:
  - energy coming from pile-up events removed
  - corrections to obtain the uniformity in pseudorapidity (η) and transverse momentum p_T

B-tagging

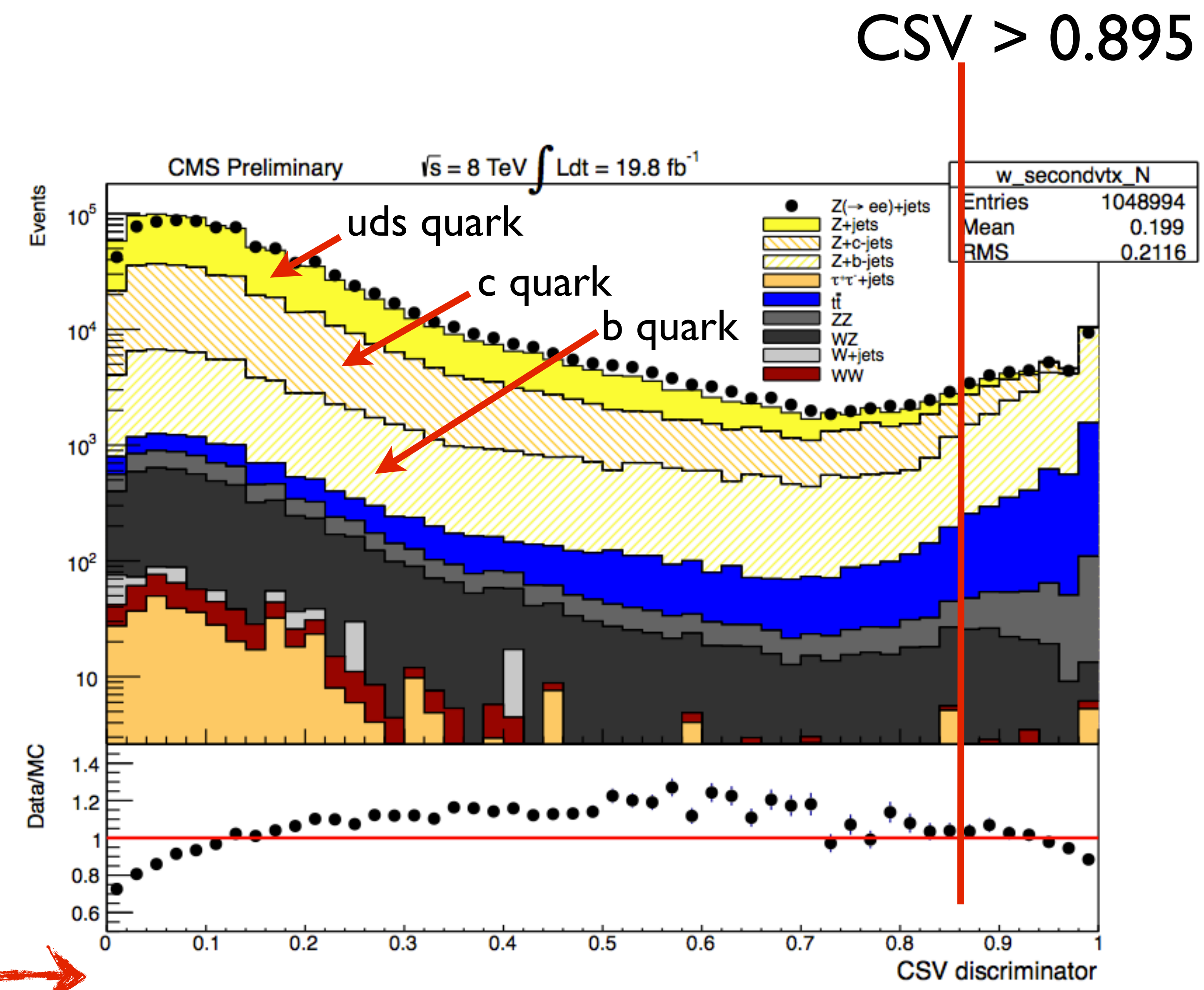
We need an algorithm for the identification ("tagging") of jets from the b quark hadronization



B hadrons lifetime is long (τ ~1.5ps) ➔ important role of the CMS tracking system to reconstruct the secondary vertex

Secondary vertex reconstruction:

- kinematic cuts on tracks applied
- distance between secondary vertex and primary vertex between 100 μm - 2.5 cm
- invariant mass of charge particle from secondary vertex mass reconstructed ($M_{charged}$ < 6.5 GeV)
- b-tagging done using tracks even when the secondary vertex is not reconstructed



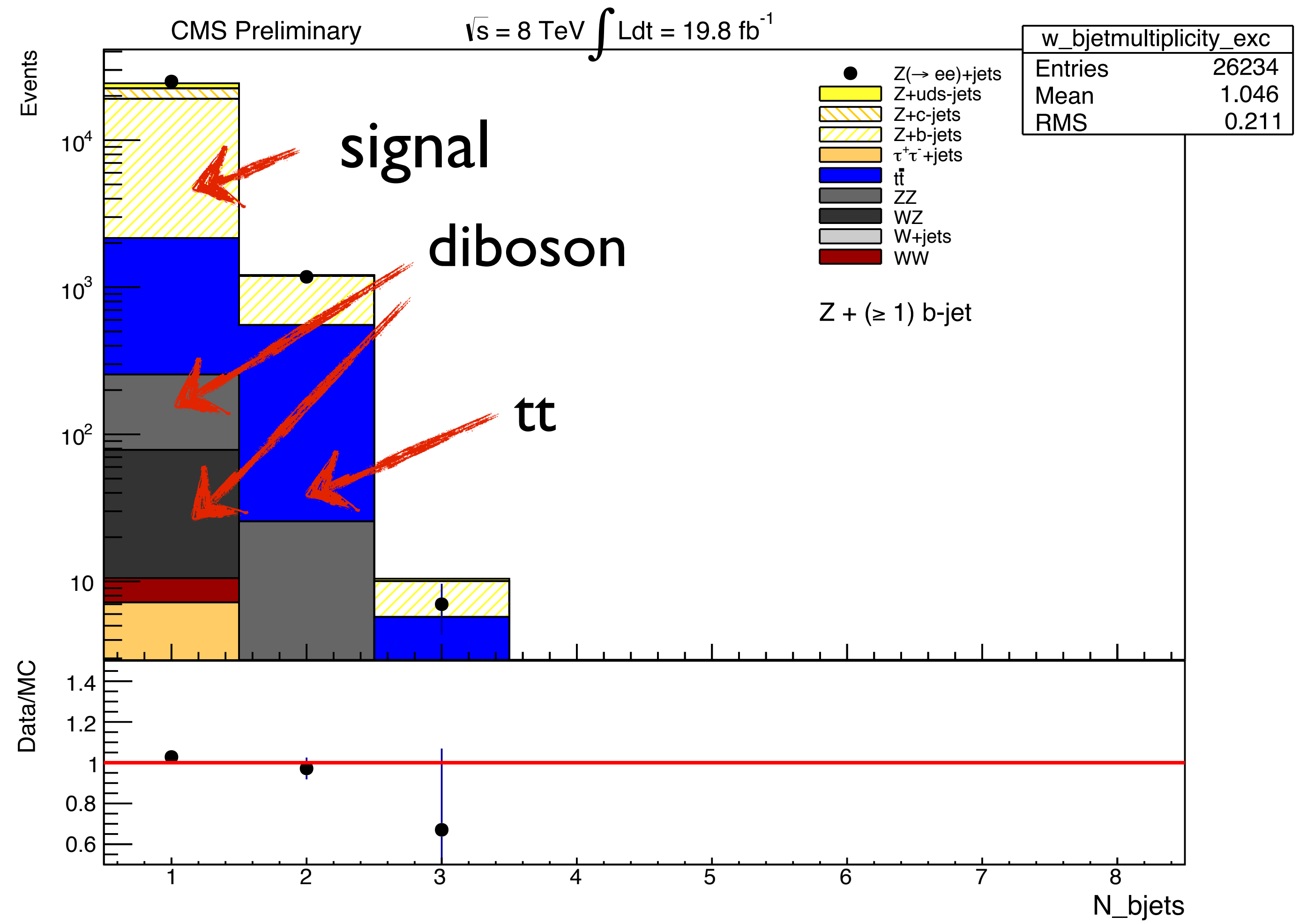
Combined Secondary Vertex discriminator

Background events

Different processes can give a similar signal that mimic a "good" event

DIBOSON

- W^+W^- + jets → $2l^\pm + 2\nu$ + jets
- ZZ + jets → $4l^\pm$ + jets
- $W^\pm Z$ + jets → $3l^\pm + \nu$ + jets



SINGLE W + jets: one lepton wrongly identified, produced in association with jets

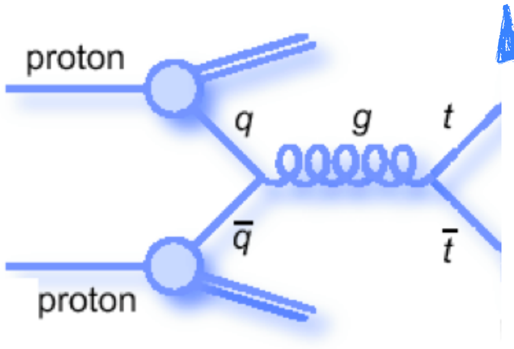
$\tau^+\tau^-$: $\tau^+\tau^-$ + jets → $2l^\pm + 4\nu$ + jets

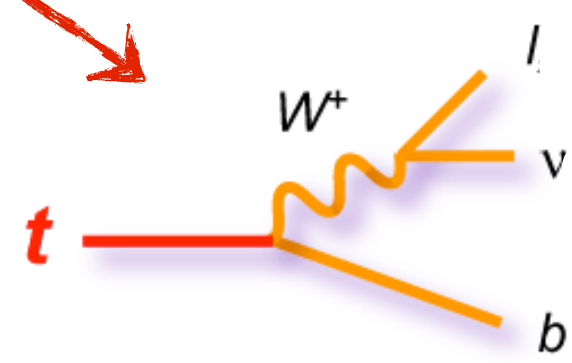
TOP - ANTITOP → tt → W^+W^- bb → $l^+l^- + 2\nu$ + bb

main background

tt estimation

pp → tt → W⁺ W⁻ bb → l⁺ l⁻ + 2ν + bb

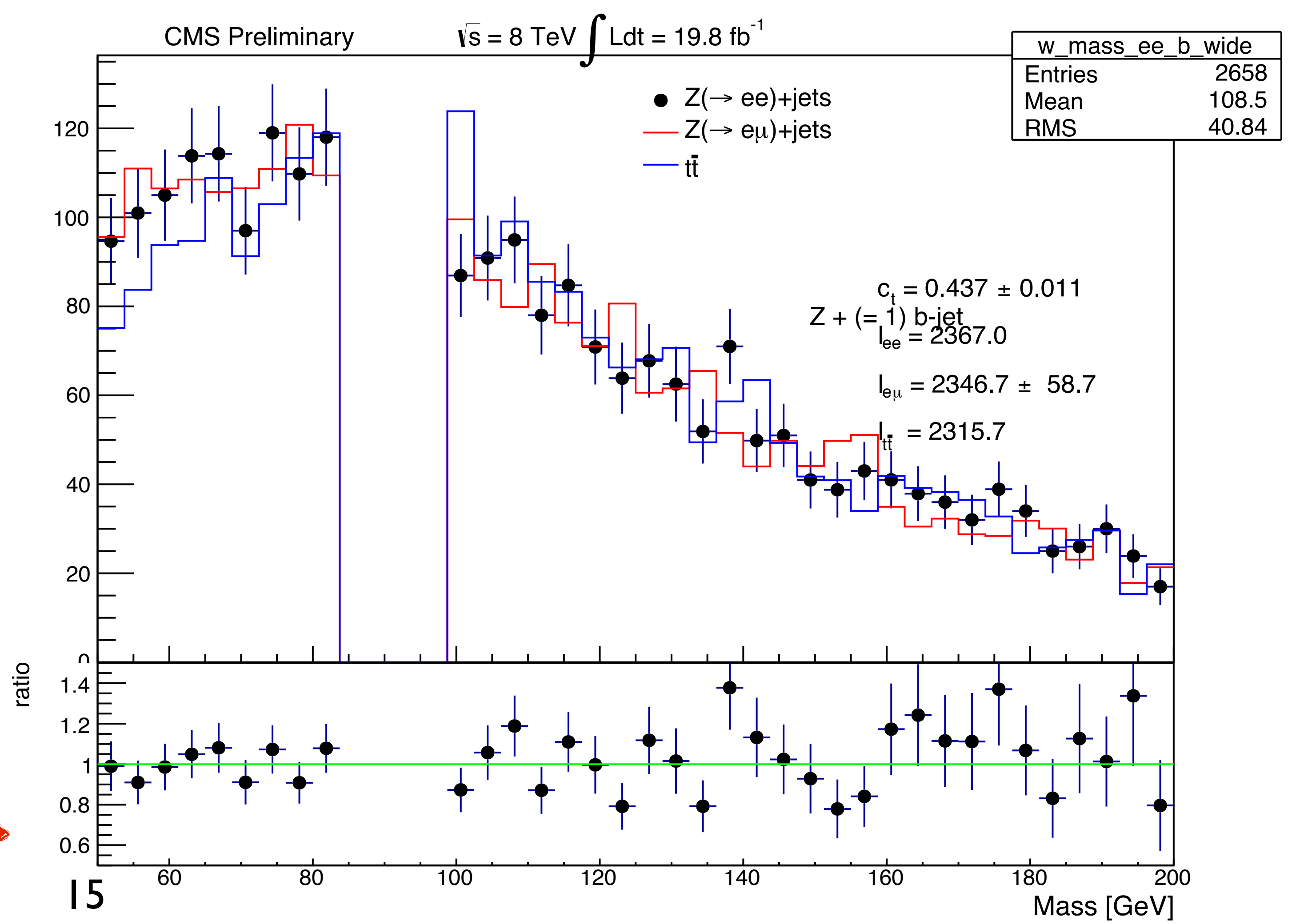




evaluated from (eμ) + b sample of data with the same selection as Z+b

Strategy

- additional cut on the missing energy to enhance the top quarks component (due to neutrinos)
- shape of tt background from eμ sample
- normalization of tt background from fit to the dielectron (dimuon) invariant mass distribution sidebands using the sideband of the eμ sample as template

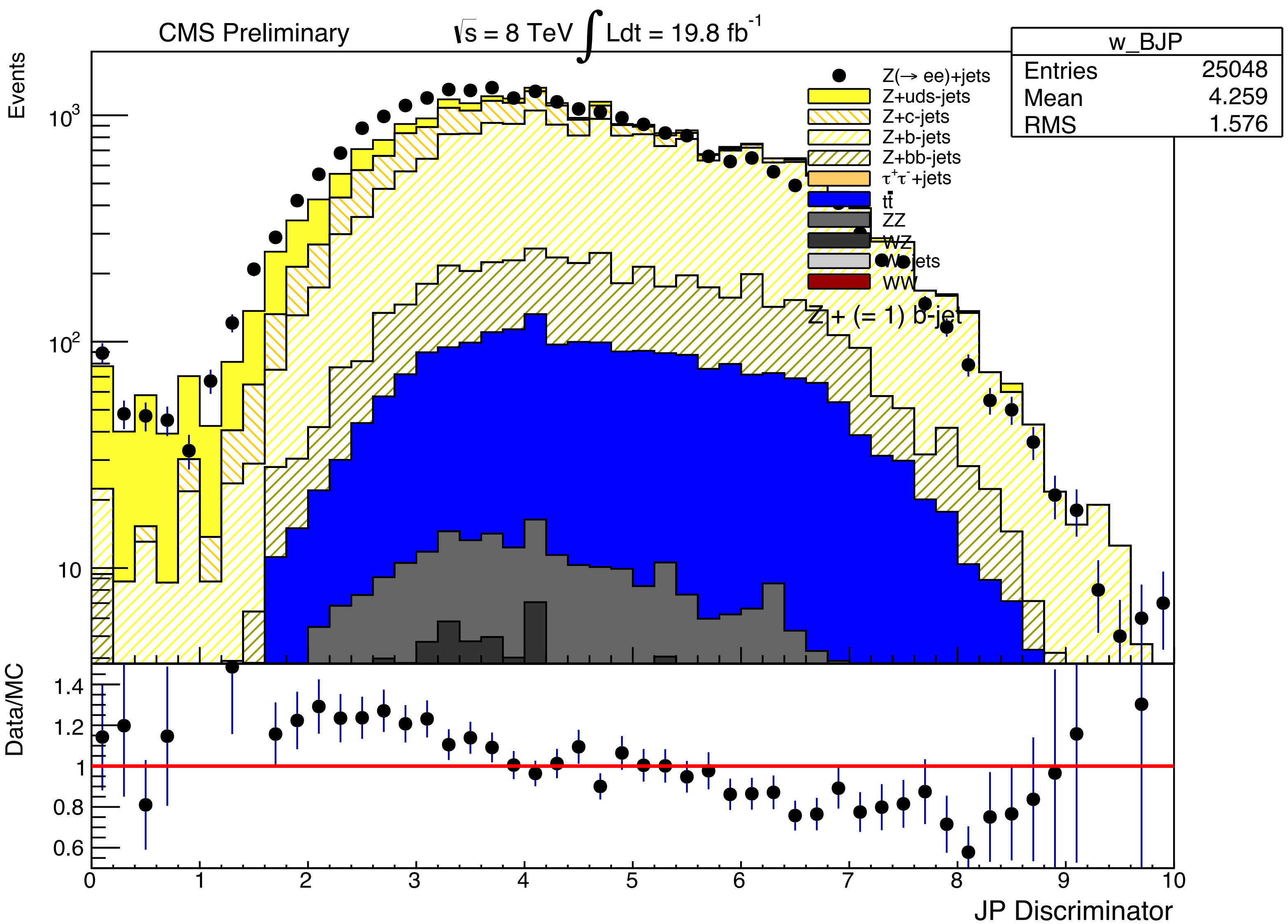


b-purity estimation

The b-jets fraction is the number of events after the Z + b selection that truly contains b-tagged jet

➔ it has to be evaluated for the 2 samples (Z+=1b / Z+≥2b)

b-jet Probability Discriminators built from the impact parameter calculation

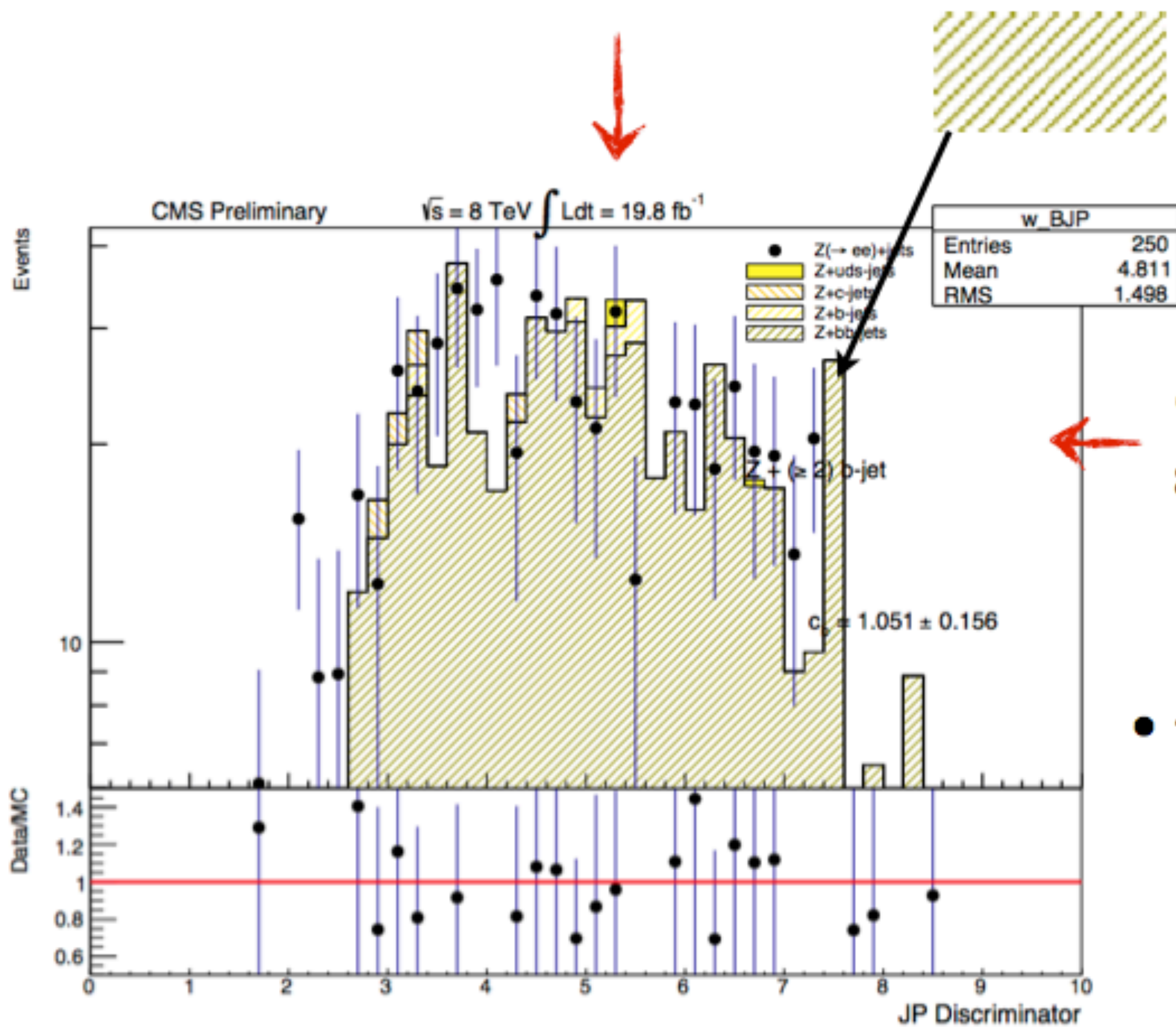


Strategy

- background subtraction
- fit the different MC templates
- the light, b, c correction factors extracted

b-signal extraction (1)

- Event purity Z + (≥2) b sample
  - tt background is subtracted
  - Z+2b and Z+bx (x =l,c) separated



Z+ b b

- the sample selected is an almost pure sample of Z+2b

fbb ~ 100%

- fit of the MC Z+2b to data

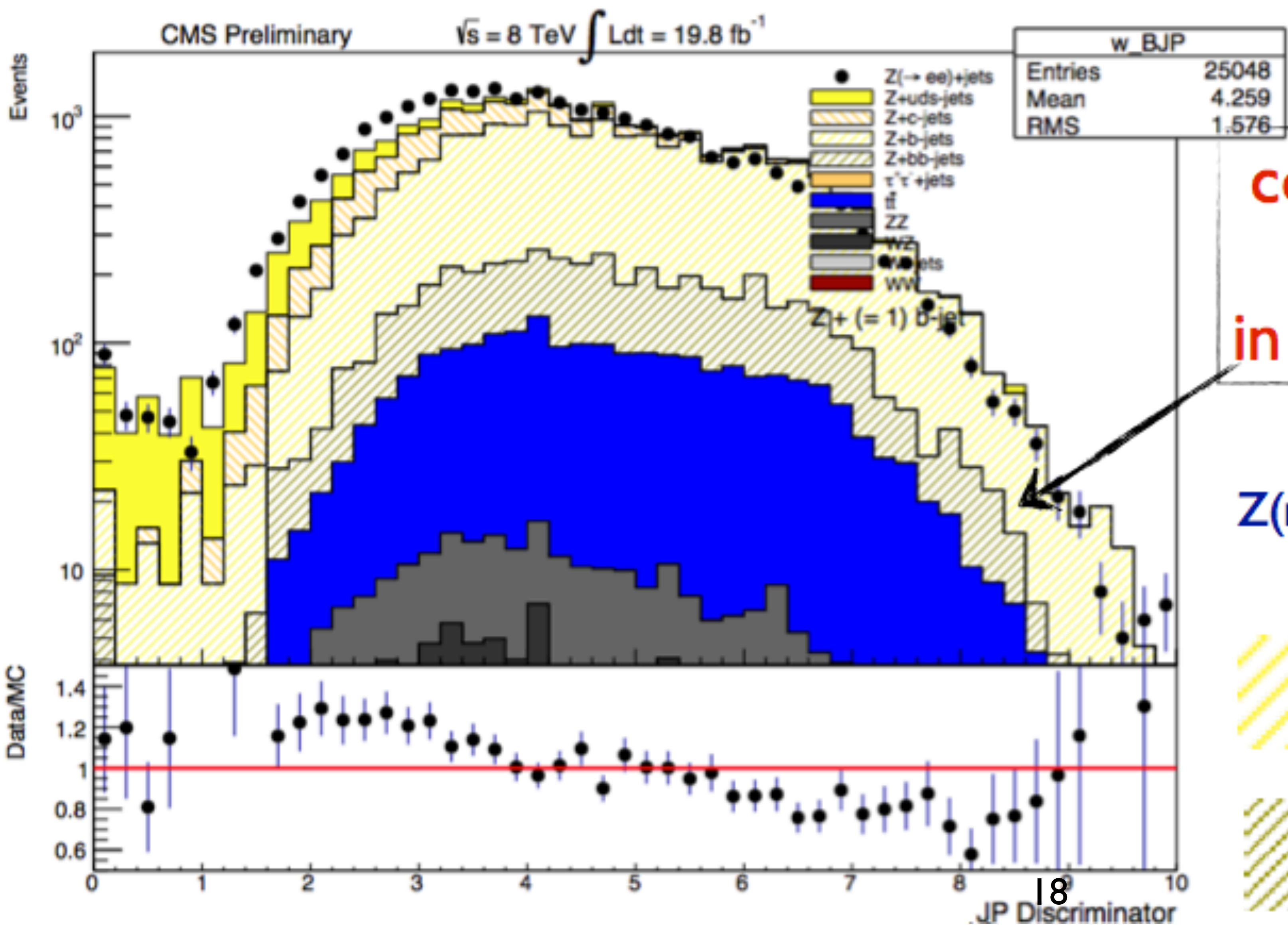
⇓

MC scale factor: C_b = 1.051 ± 0.156

b-signal extraction (2)

- event purity Z + (=1) b sample

1. events with Z and 1 b-tagged jet
2. check if 2 b-jets are found using MC truth information
3. Z+2b rescaled for the factor C_b extracted for the Z+2b sample (previous slide)
4. the Z+2b rescaled is subtracted as a background



contamination Z+2 b-jet events
in the sample DY Z+1b

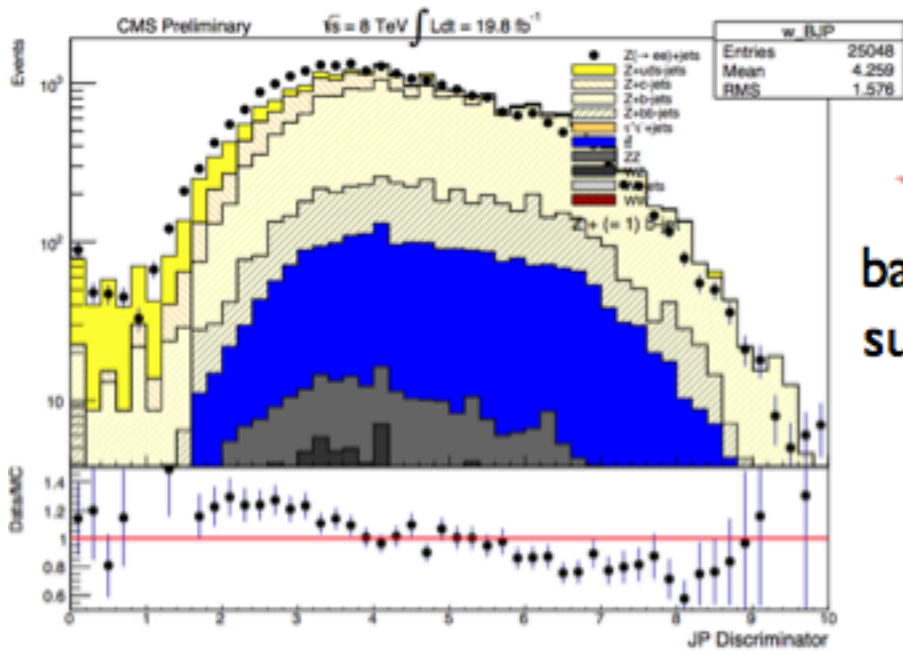
BJP

Z(mm) + (=1) b-jet

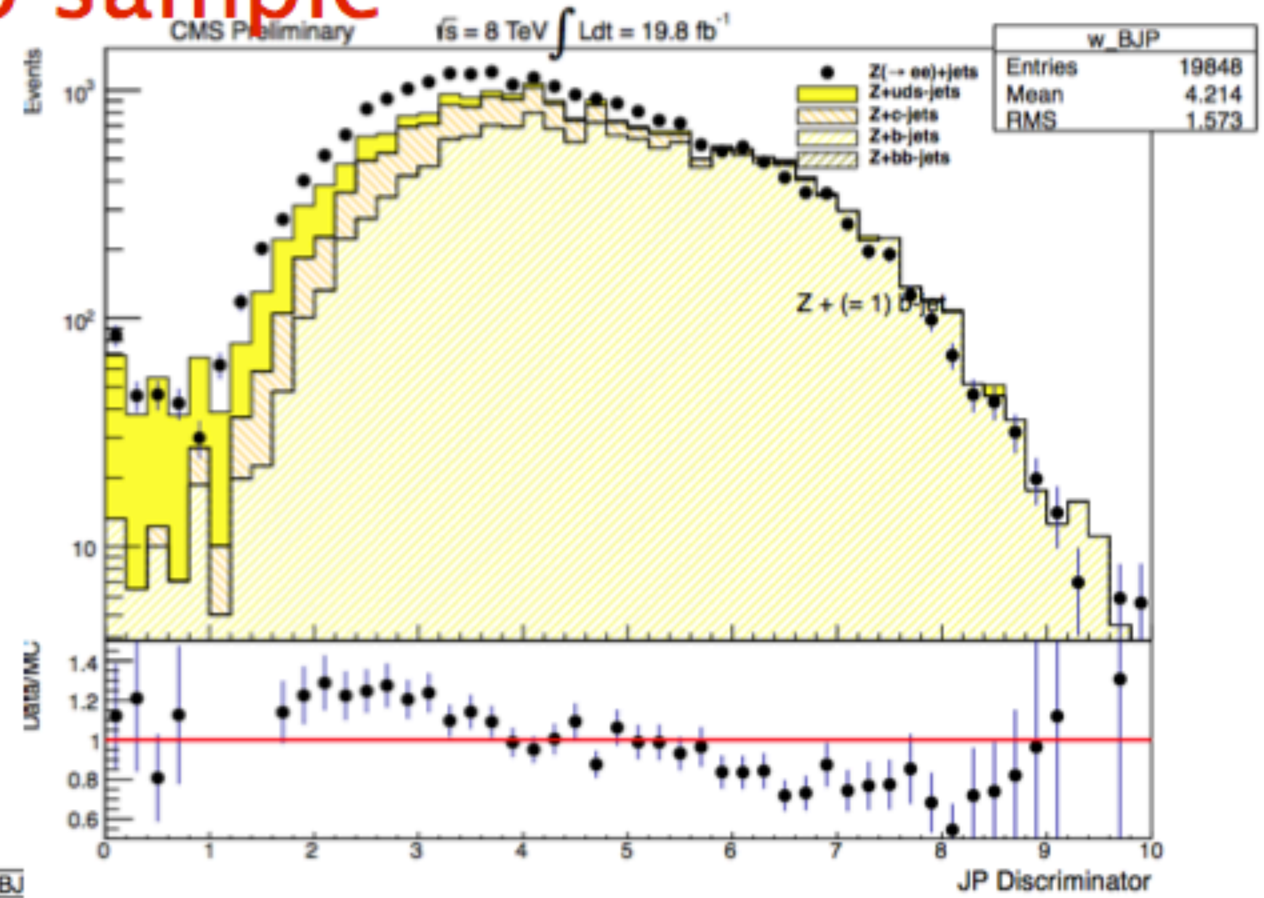
Z+ (=1)b signal

Z+ b b background

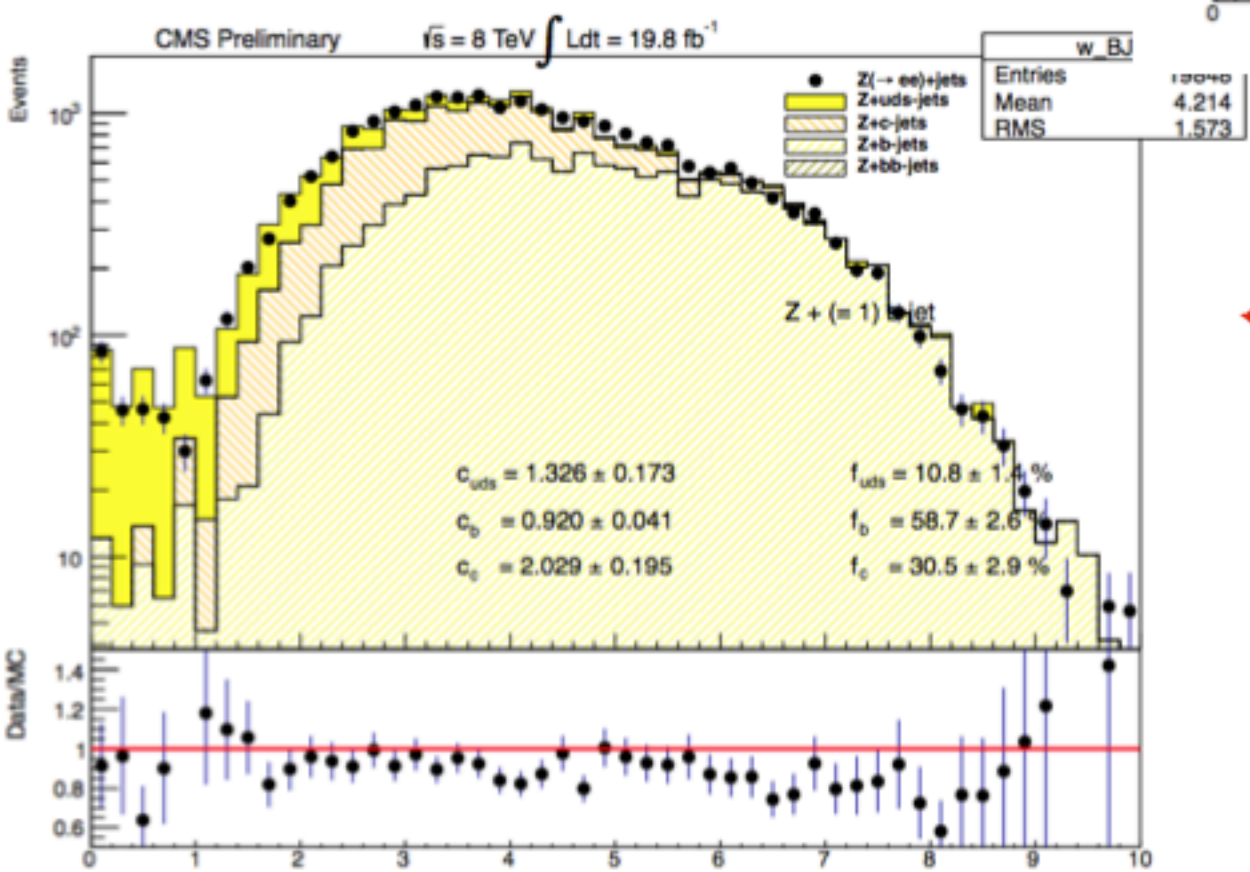
• event purity Z + (=1) b sample



background subtraction



fit of the fraction Z+1b after the subtraction of the Z+2b background



c_{uds} = 1.326 ± 0.173

c_b = 0.920 ± 0.041

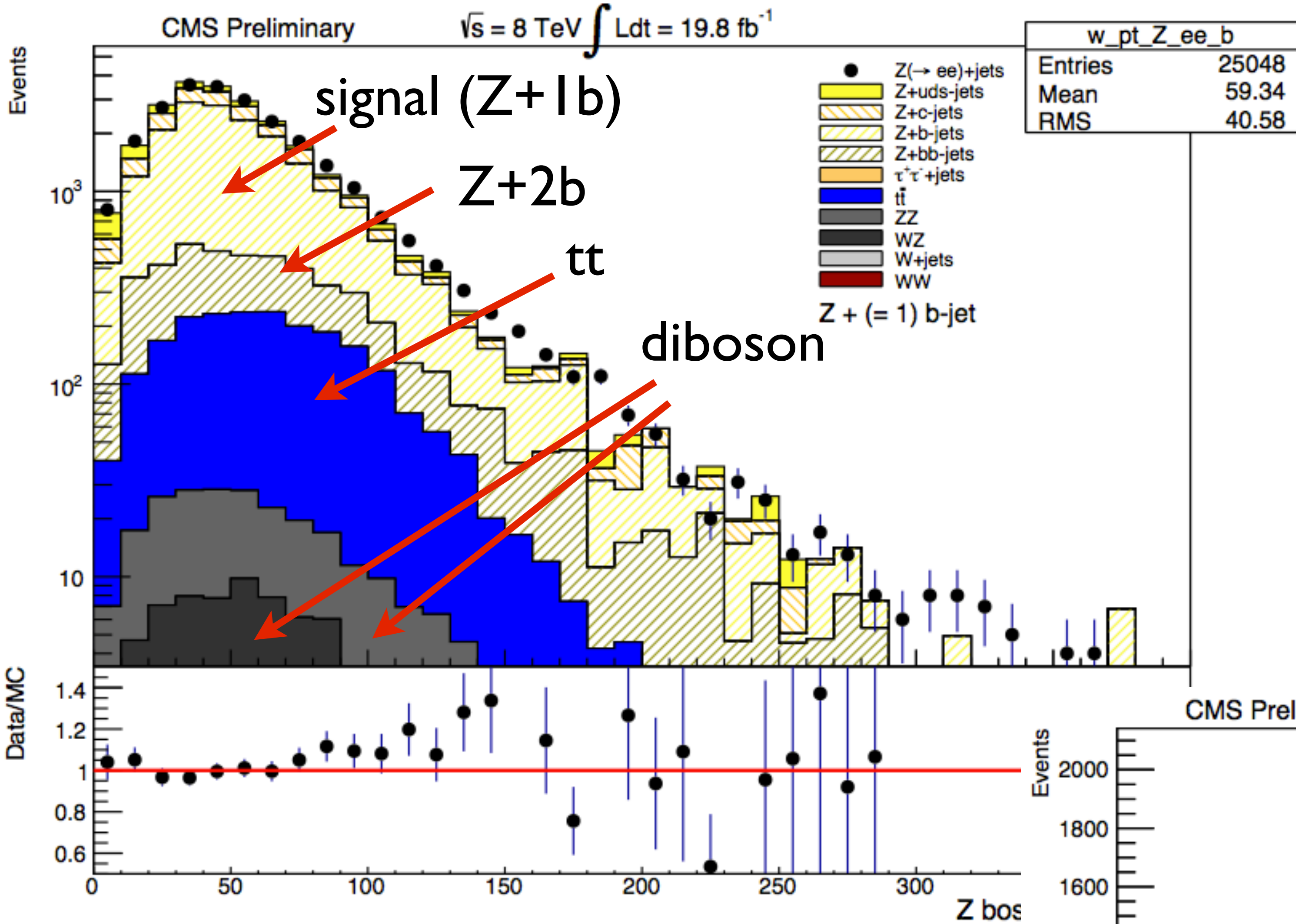
c_c = 2.029 ± 0.195

f_b = 58.6 ± 2.5%

Detector level distributions

Z distributions

Z + (=1) b sample

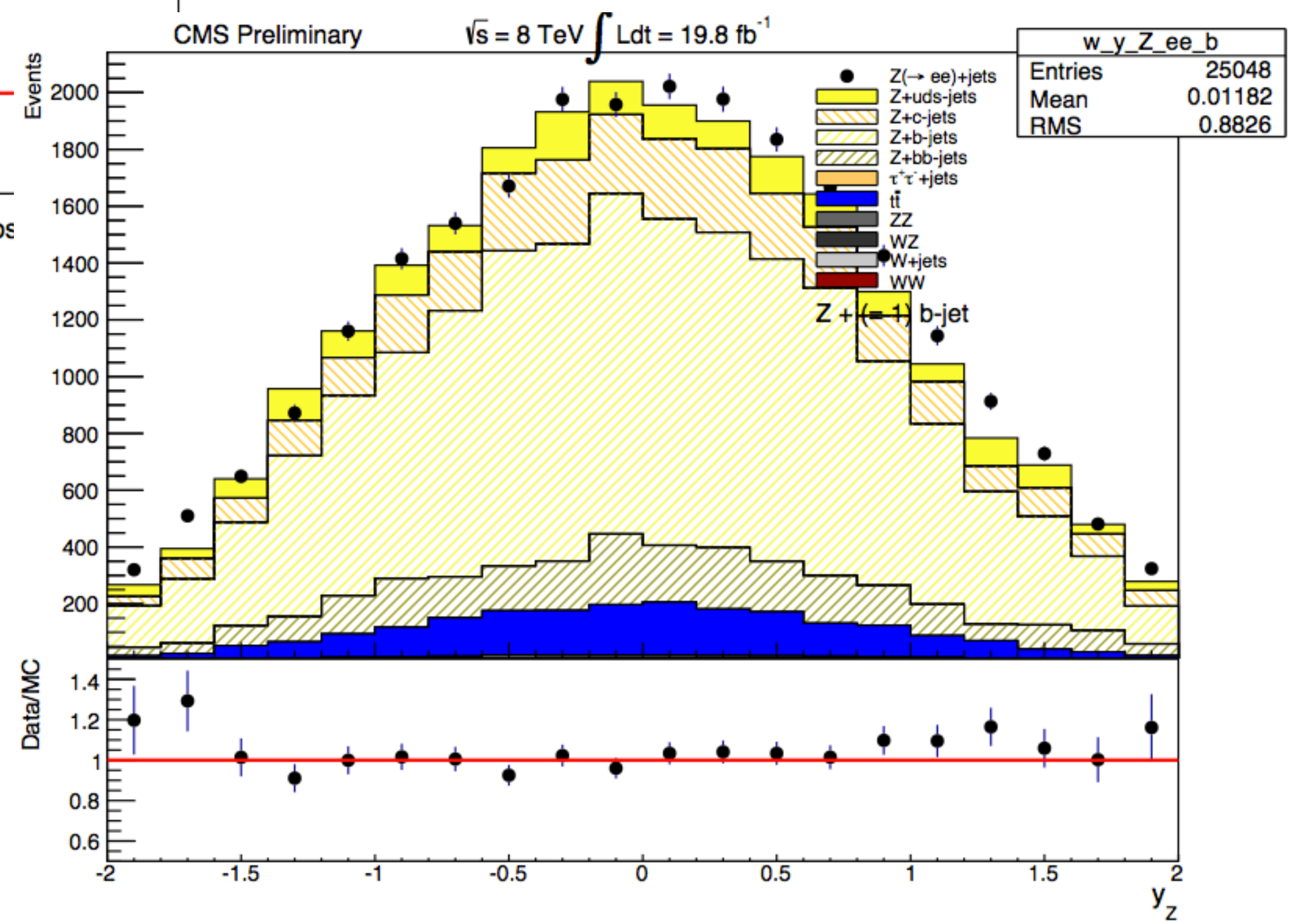


p_T Z

Z(ee) + (=1) b-jet

y Z

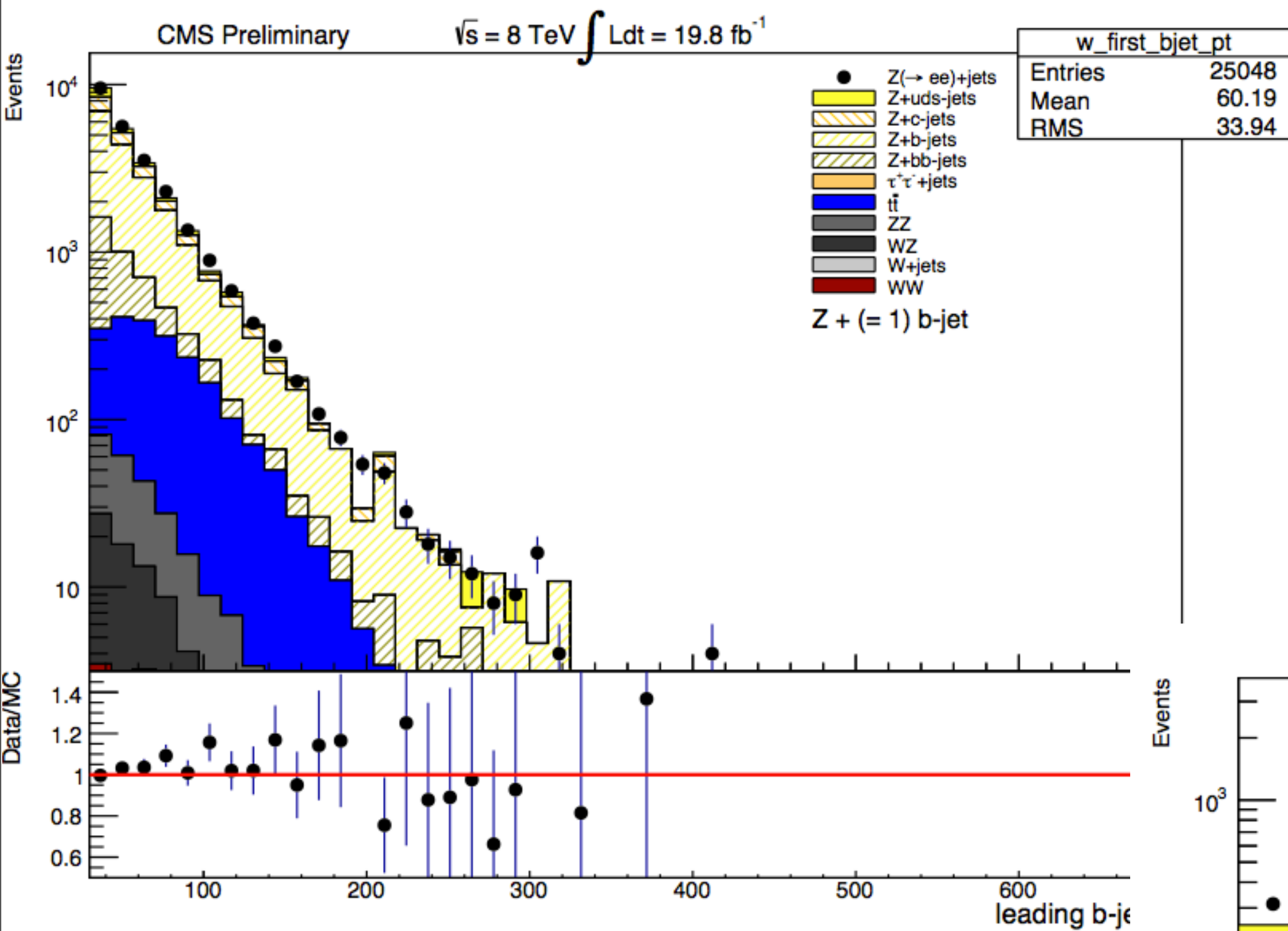
Z(ee) + (=1) b-jet



b-jet distributions

leading b-jet distributions

Z + (=1) b sample

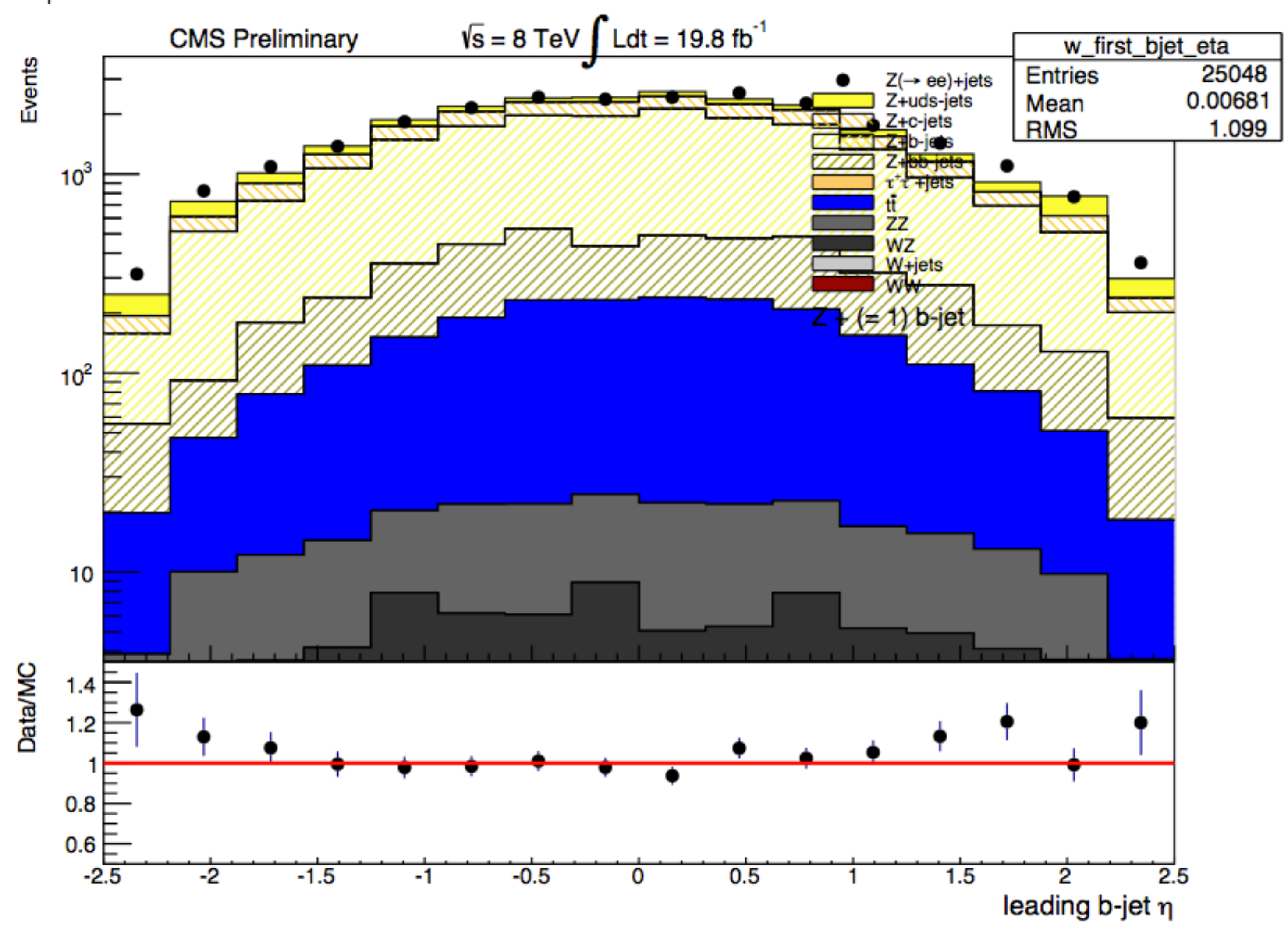


pT leading b-jet

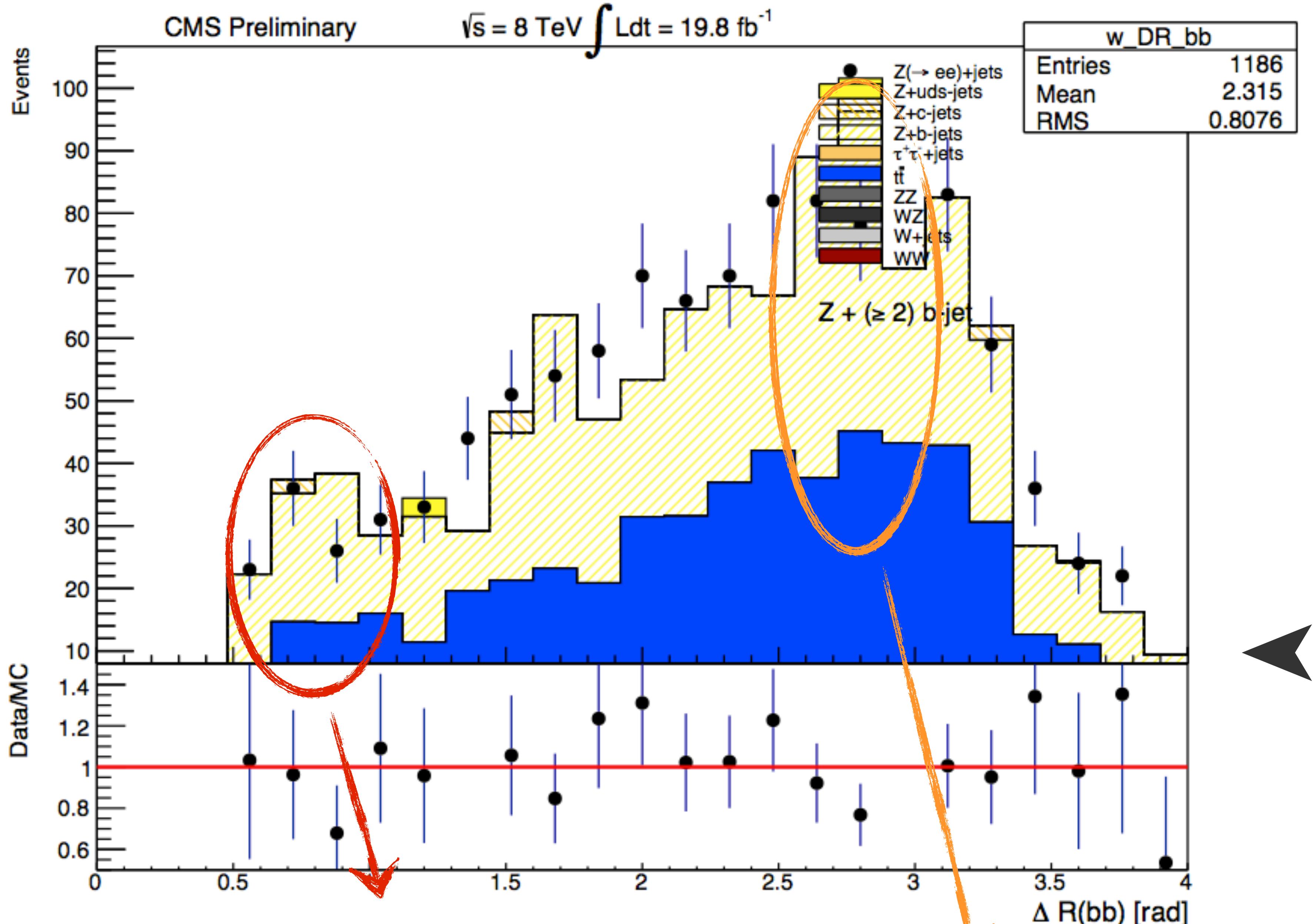
Z(ee) + (=1) b-jet

η leading b-jet

Z(ee) + (=1) b-jet



Angular distributions (1)



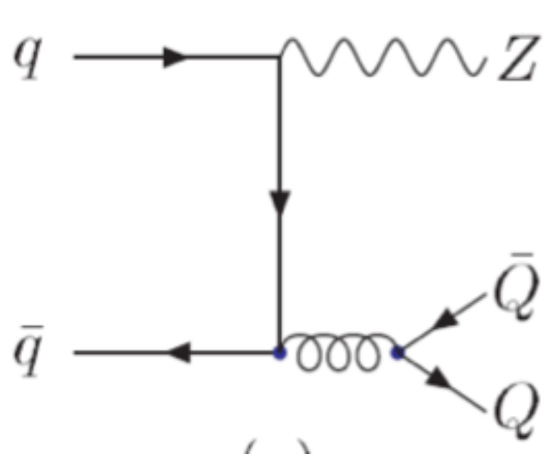
angular correlation between 2 b-jets

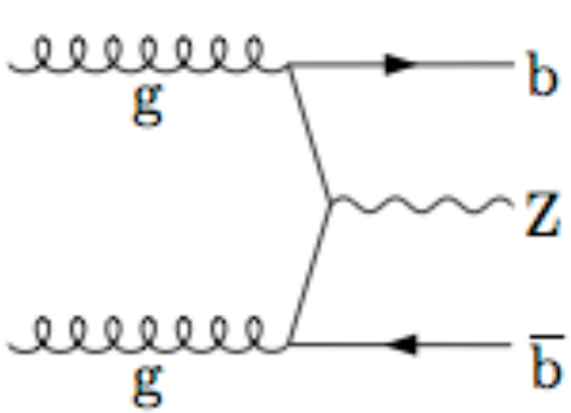
Z + (≥2) b sample

ΔR between the 2 b-tagged jet

ΔR(bb)

Z(ee) + (≥2) b-jet

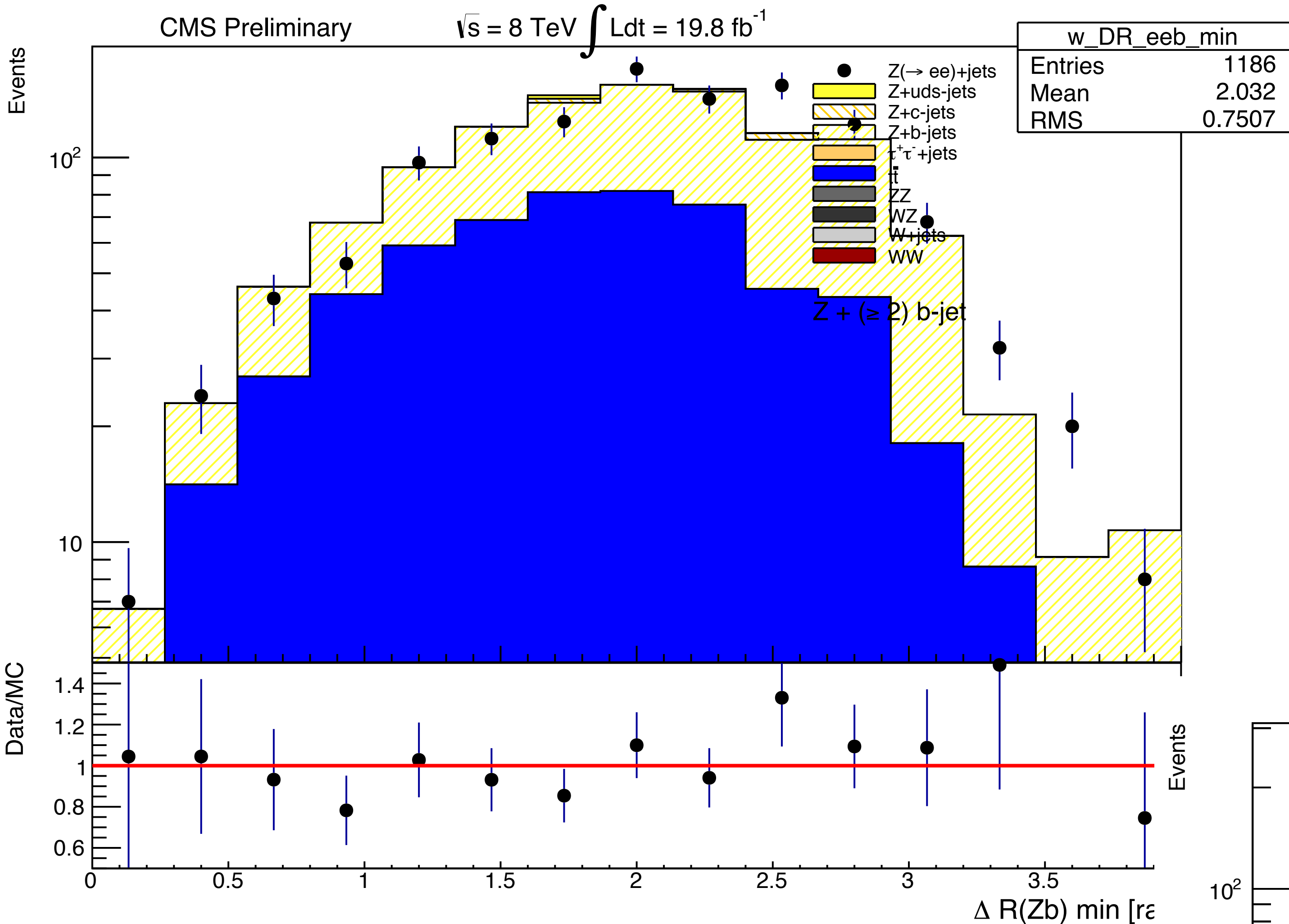




- ΔR (bb) < 1
  ➔ gluon splitting
- ΔR (bb) >3
  ➔ gluon gluon fusion

Angular distributions (2)

Angular correlation between Z boson and b-jet



ΔR between the Z and the closest b-jet

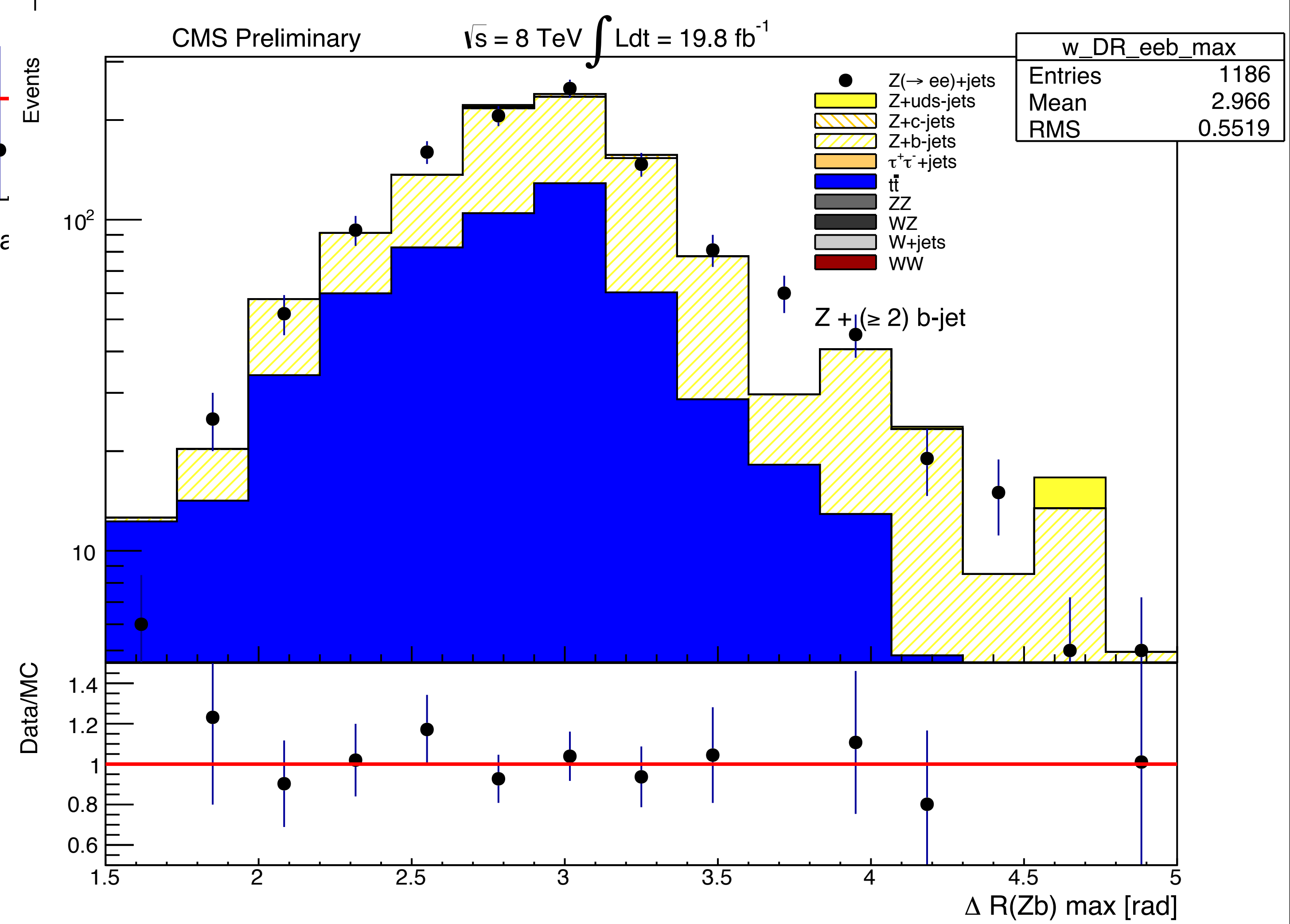
ΔR(Zb) min

Z(ee) + (≥2) b-jet

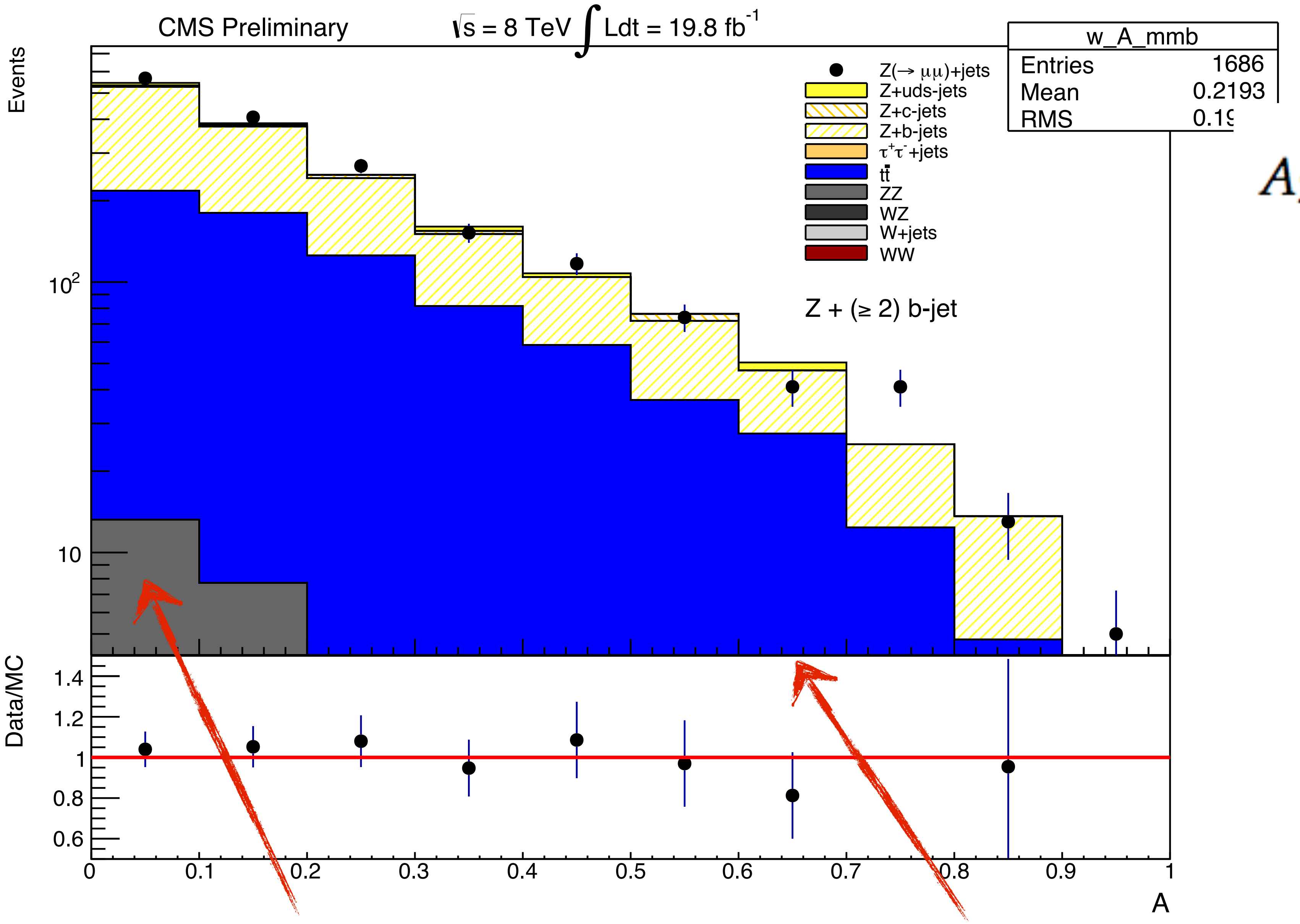
ΔR between the Z and the further b-jet

ΔR(Zb) max

Z(ee) + (≥2) b-jet



Angular distributions (3)



Z + (≥2) b sample

$$A_{ZBB} = \frac{\max\Delta R_{ZB} - \min\Delta R_{ZB}}{\max\Delta R_{ZB} + \min\Delta R_{ZB}}$$

Asymmetry between b-jet and Z boson production direction

A_{Zbb}

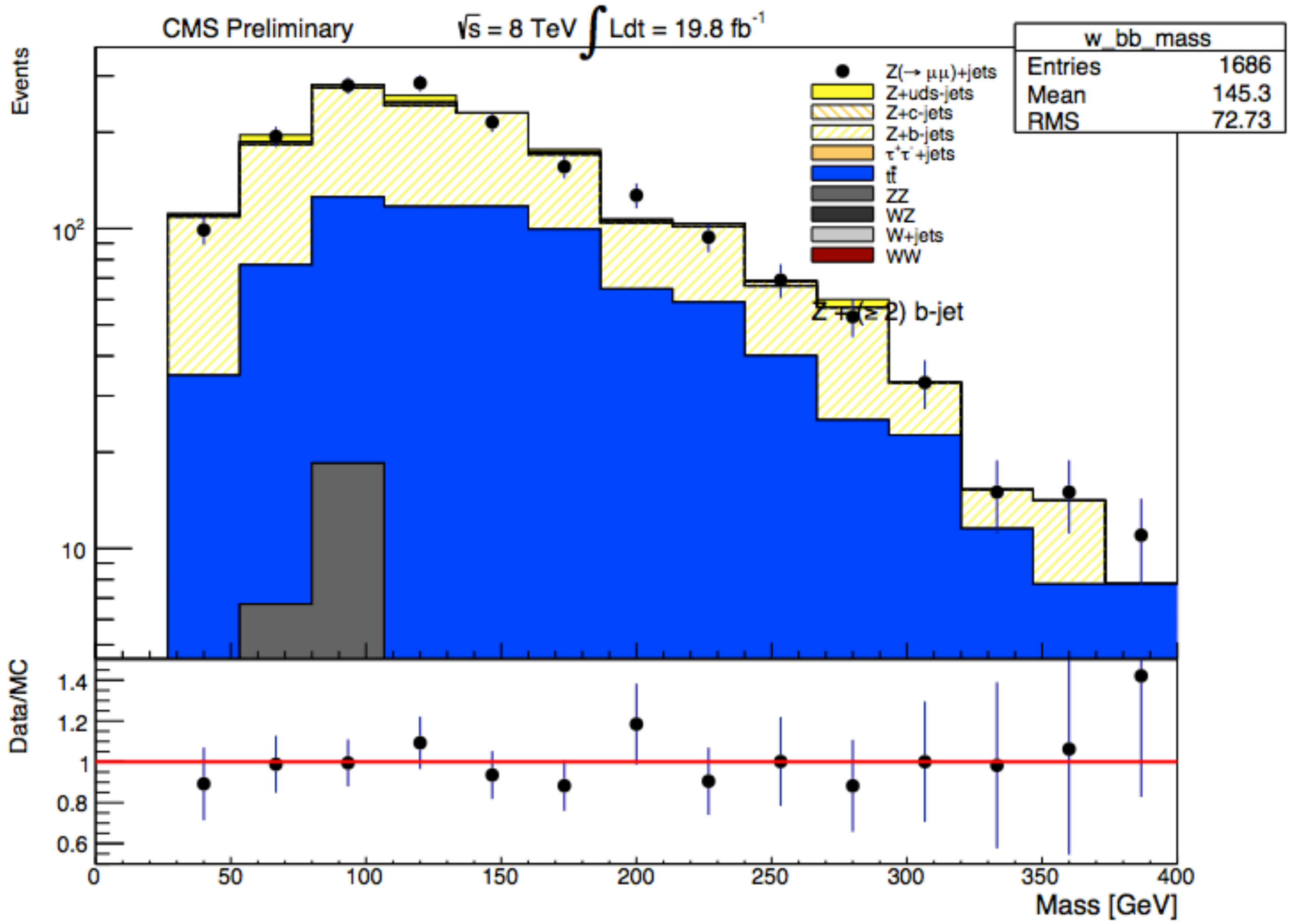
Z(ee) + (≥2) b-jet

2 b-jets emitted symmetrically with respect to Z direction

Emission of additional gluon radiation in the final state ($A_{Zbb} \neq 0$)

Mass distributions

Z + (≥2) b sample



invariant mass of 2 b-tagged jets

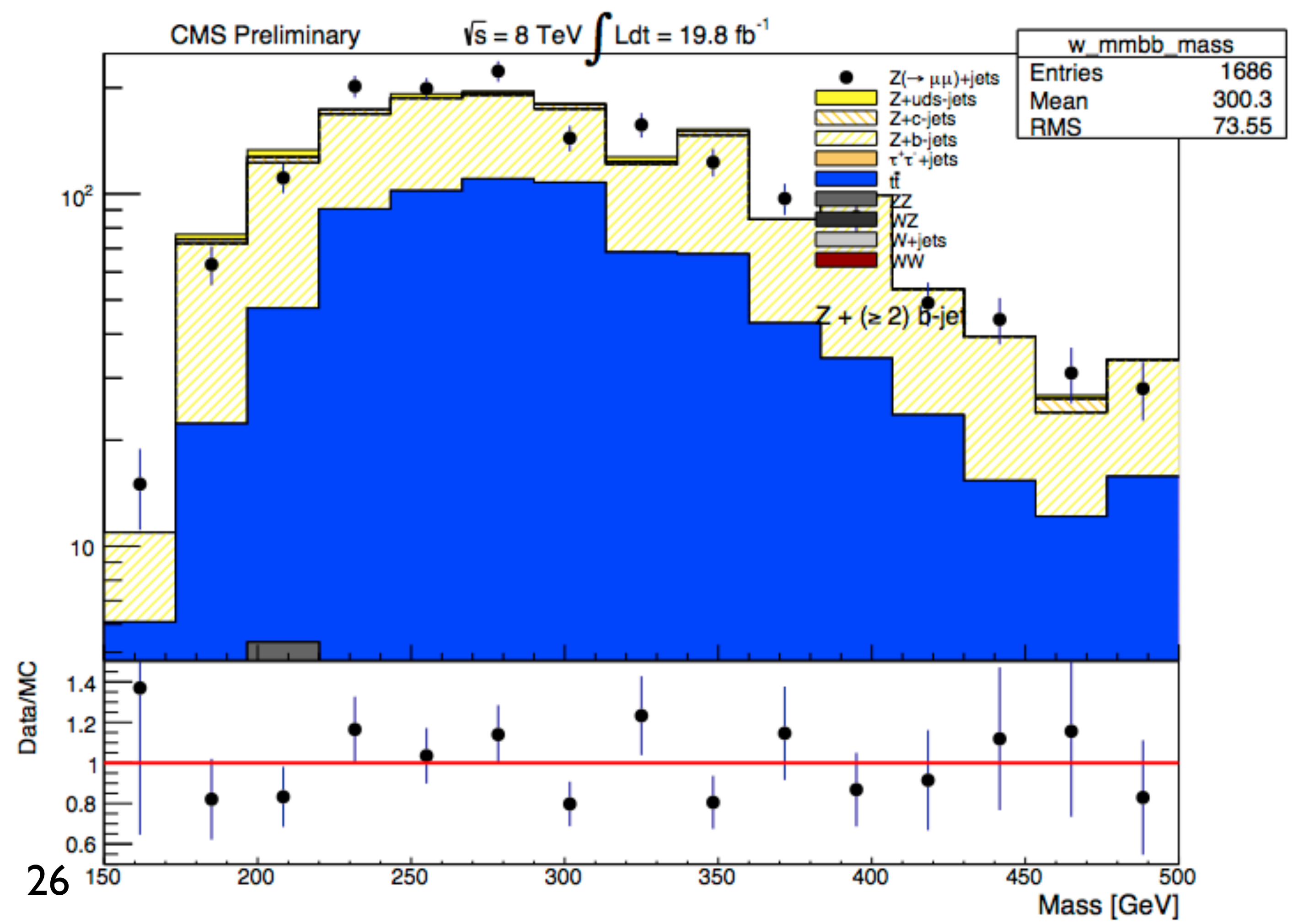
M(bb)

Z(mm) + (≥2) b-jet

invariant mass of Z and 2 b-tagged jets

M(Zbb)

Z(mm) + (≥2) b-jet



Next steps...

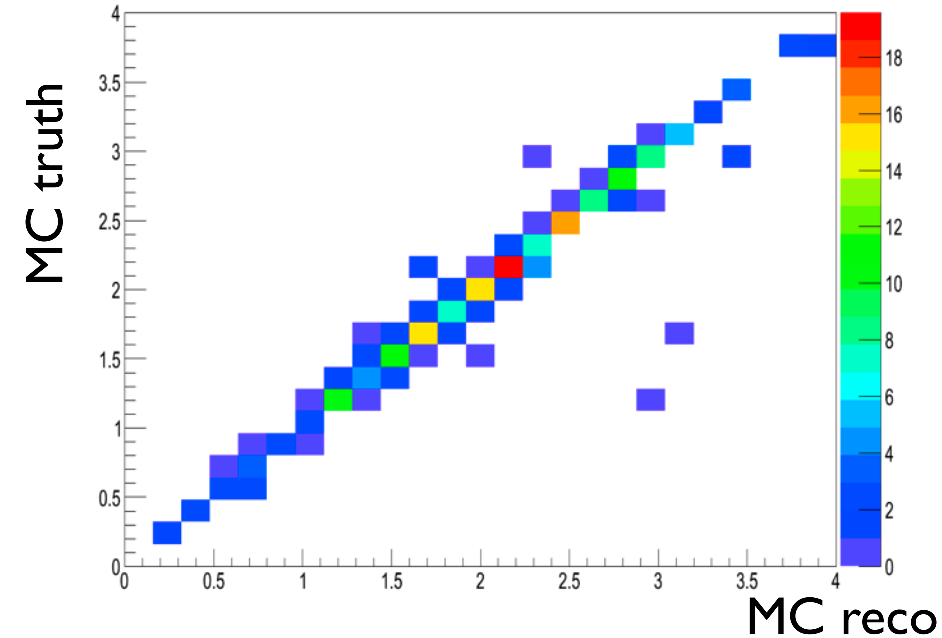
unfolding

➔ deconvolution of measured distributions from detector effects

unfolded data measured data

$$y = A(y,x) \cdot x$$

response matrix



systematics

➔ study of the different systematic uncertainties sources

theory comparison

➔ comparison with different theoretical predictions

Conclusions

- Z+=1b and Z+≥2b samples selected

- Detector level distributions

- Next steps:

TO DO

  - comparison with theoretical predictions
  - e+μ channel combination
  - systematic uncertainties
  - final results

- Possible development:
the study of the Z polarization asymmetry in Zb events