Heavy flavor measurements at LHC

Charm measurements in ALICE

- Charm mesons are measured in the decay channel
  - D^0, D^+, D^{*+}, D_s
- The mean proper length cτ :
  - D^0 : 123μm
  - D^+ : 312 μm
  - D_s : 150 μm
- Their decay secondary vertices are displaced by a few hundred μm from the primary vertex of the pp interaction.
- To remove the large combinatorial background, these secondary vertex are reconstructed and selected.
- In the $D^{*+} \rightarrow D^0\pi^+$ case, the decay vertex cannot be resolved from the primary vertex.
- The identification of the charged kaons in the TPC and TOF detectors provides additional background rejection in the low-momentum region.
- An invariant mass analysis was used to extract the signal yield.
- In $D^{*+} \rightarrow D^0\pi^+$ case, topological selections are applied on the D^0 together with the sharp peak in the difference between the invariant mass of the three final state hadrons and that of the two D^0 decay prongs. Given that the mass difference $\Delta m = mD^{*+} - mD^0 \approx$ 145.4 MeV/c2.

Charm

D^0:

- e+ anything : 6.49 %
- μ+ anything : 6.7 %
- $K^- \pi^+$: 3.88 %
- $K_s^0 \pi^0$: 1.19 %

D^+ :

- e+ anything : 16.07 %
- μ+ anything : 17.6 %
- K^{0bar} $e^+ \nu_e$: 8.83 %
- $K- \pi^+ \pi^+$: 9.13 %
- $K^0 \pi^+$: 1.46 %

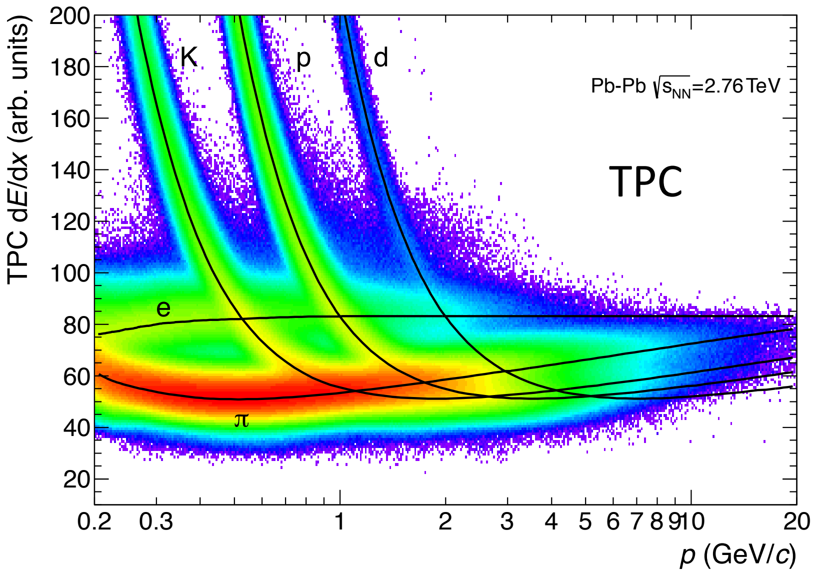
D^+_s :

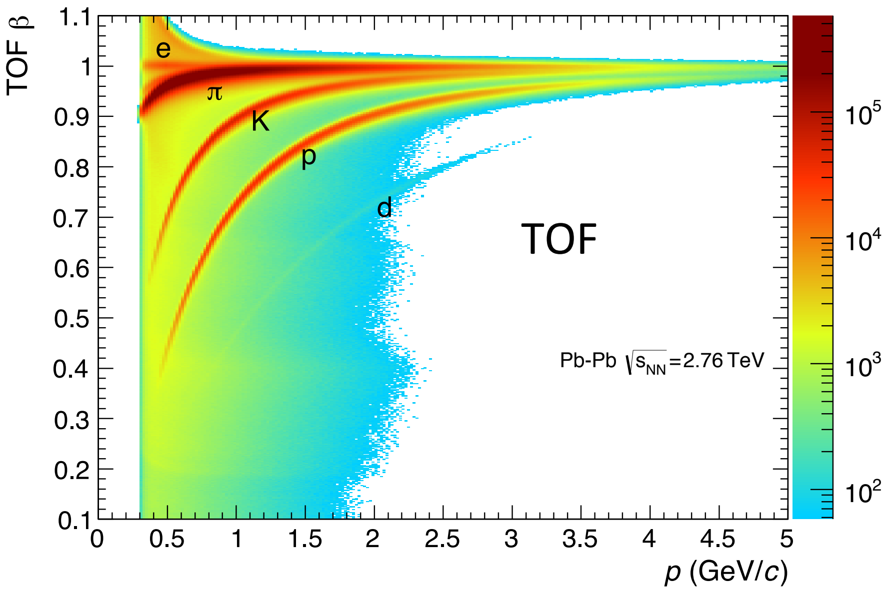
- e+ anything : 6.5 %
- $K^+ k^0_s$: 1.49 %
- $K^+ k^{0bar}$: 2.29%
- $\phi\pi^+ \rightarrow K^+ K^- \pi^+$: 2.28 %

D^{*+} :

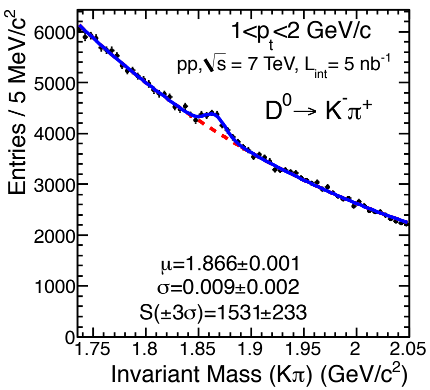
- D^0 π^+ : 67.7 %

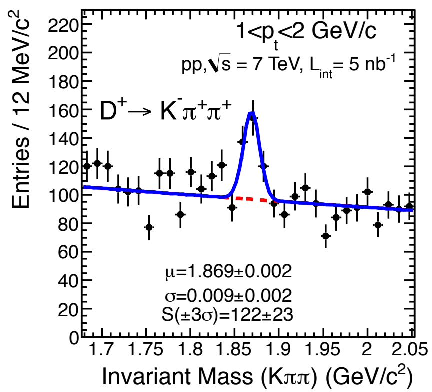
Charm measurements

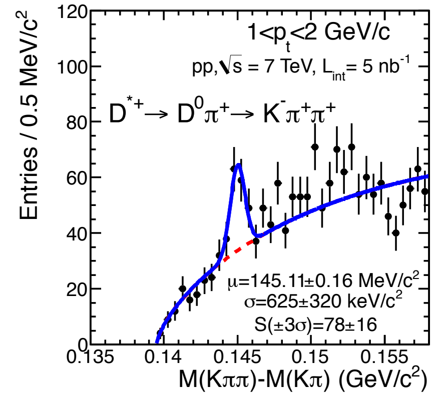


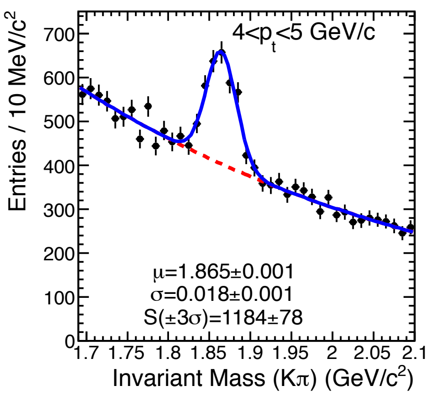


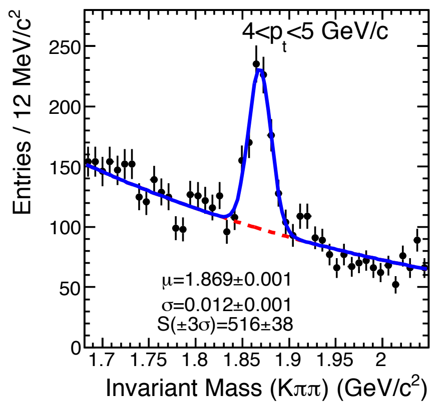
Charm measurements in ALICE

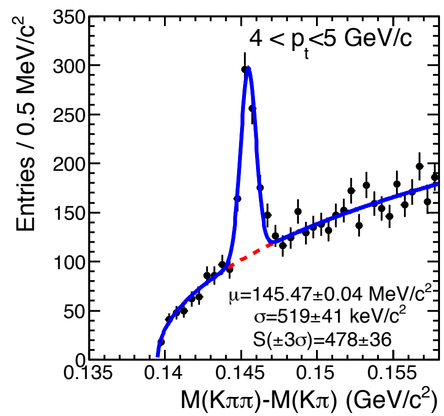


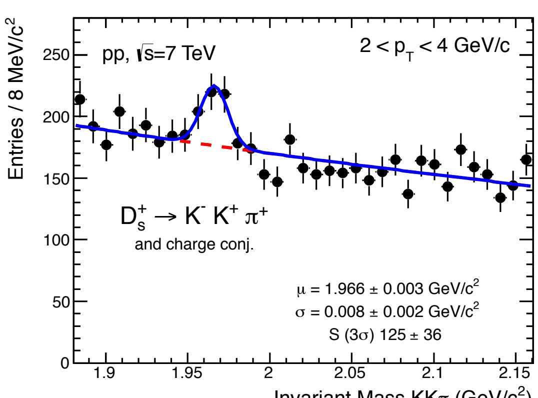






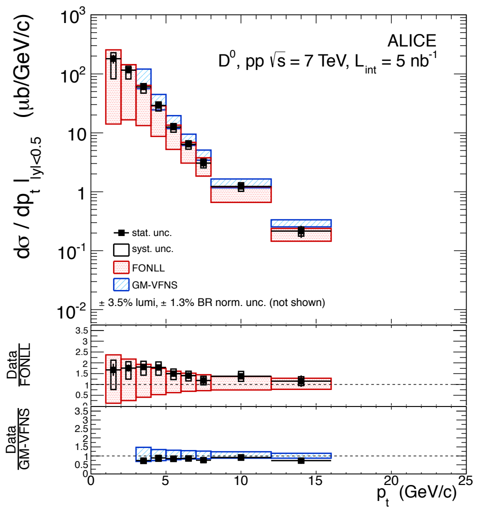


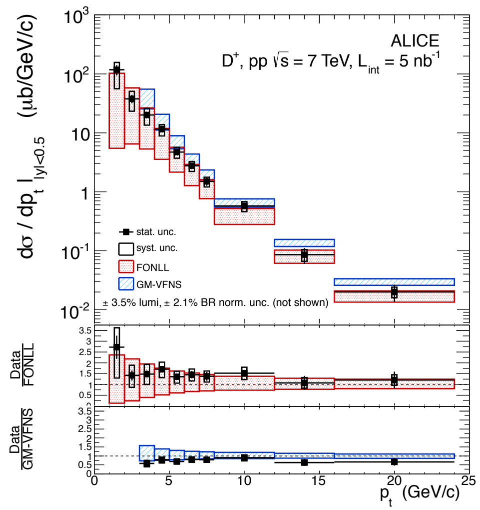


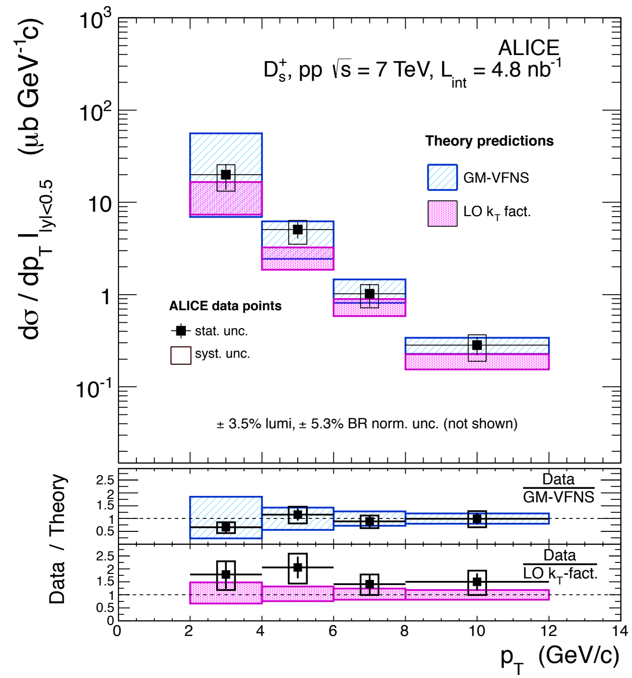


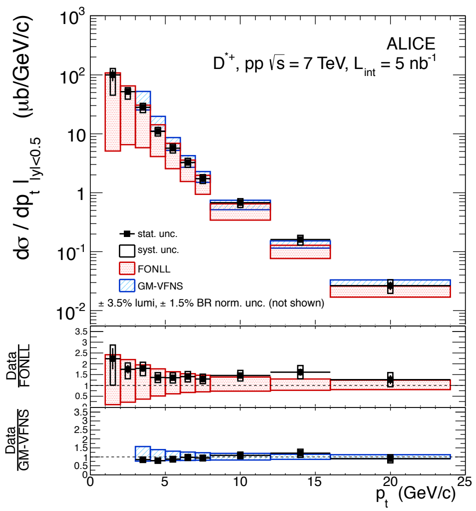
- The raw signal yields are extracted by a fit to the invariant mass distributions (or mass difference for the D*+).
- The fitting function consists of a Gaussian describing the signal and an exponential term for the background.

Charm measurements in ALICE









Total cross-section per rapidity:

$$d\sigma^{D^0}/dy = 516 \pm 41(\text{stat.})^{+\ 69}_{-175}(\text{syst.}) \pm 18(\text{lumi.}) \pm 7(\text{BR})^{+120}_{-\ 37}(\text{extr.})\ \mu\text{b},$$

$$d\sigma^{D^+}/dy = 248 \pm 30(\text{stat.})^{+52}_{-92}(\text{syst.}) \pm 9(\text{lumi.}) \pm 5(\text{BR})^{+57}_{-18}(\text{extr.})\ \mu\text{b},$$

$$d\sigma^{D^{*+}}/dy = 247 \pm 27(\text{stat.})^{+36}_{-81}(\text{syst.}) \pm 9(\text{lumi.}) \pm 4(\text{BR})^{+57}_{-16}(\text{extr.})\ \mu\text{b}.$$

$$d\sigma^{D_s^+}/dy = 118 \pm 28(\text{stat.})^{+28}_{-34}(\text{syst.}) \pm 4(\text{lumi.}) \pm 6(\text{BR})^{+38}_{-35}(\text{extr.})\ \mu\text{b}.$$

Figure 5: (colour online) p_t-differential inclusive cross section for prompt D^0, D^+, and D^{*+} mesons in pp collisions at $\sqrt{s} = 7$ TeV compared with FONLL [1, 30] and GM-VFNS [9, 31] theoretical predictions. The symbols are positioned horizontally at the centre of each p_t interval. The normalization uncertainty is not shown (3.5% from the minimum-bias cross section plus the branching ratio uncertainties, as of Table 2).

Charm measurements in ALICE

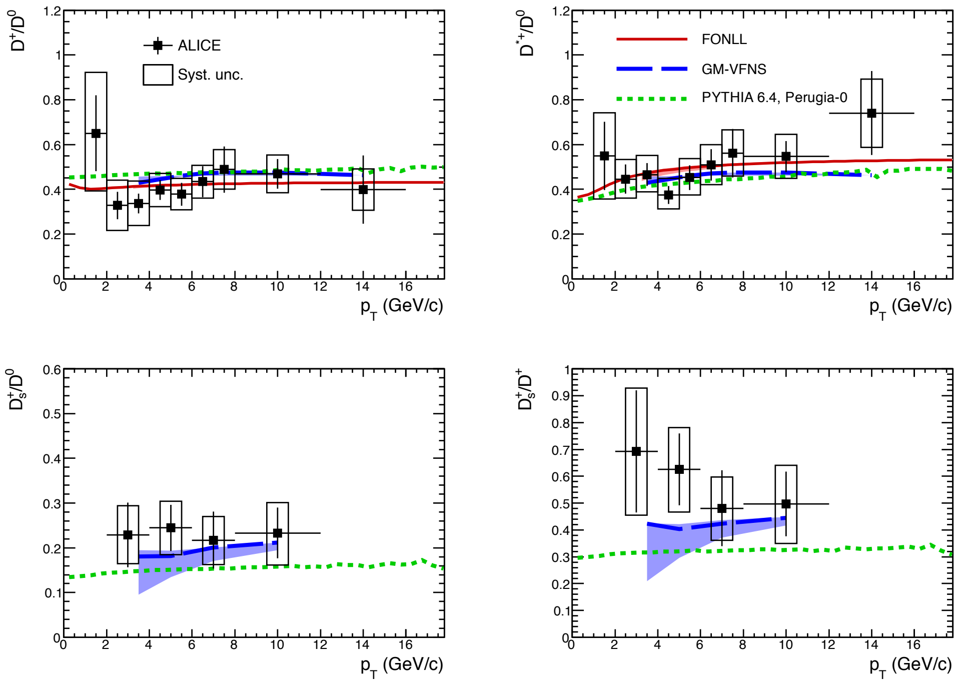
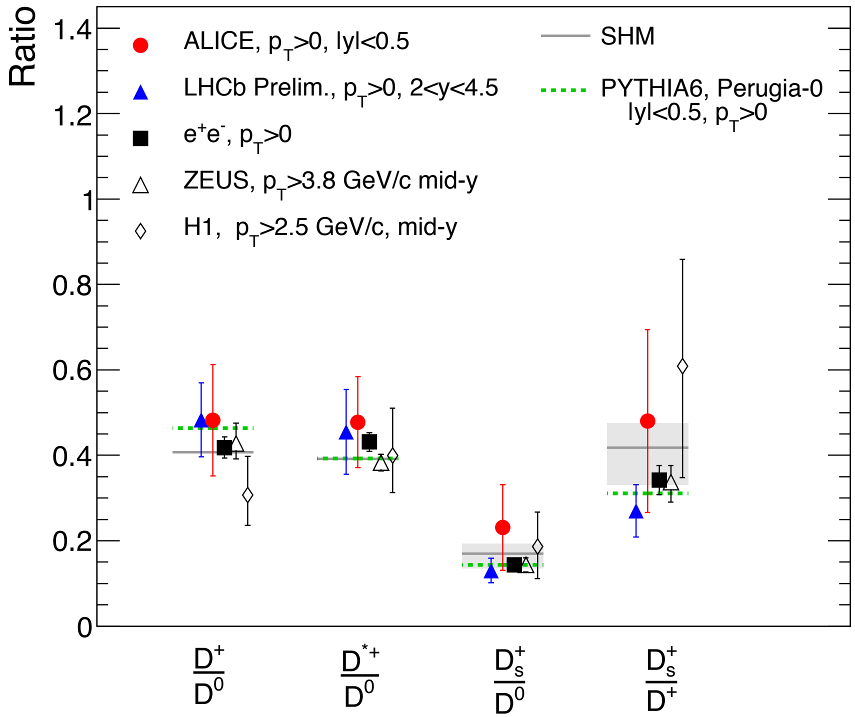


Figure 4: Ratios of D meson production cross sections as a function of p_T. Predictions from FONLL, GM-VFNS and PYTHIA 6.4.21 with the Perugia-0 tune are also shown. For FONLL and GM-VFNS the line shows the ratio of the central values of the theoretical cross section, while the shaded area is defined by the ratios computed from the upper and lower limits of the theoretical uncertainty band.

- FONLL and GM-VFNS, the relative abundances of the various D meson species are not predicted by the theory: the fragmentation fractions f (c → D) are taken from experimental measurements.
- On the other hand, the different fragmentation functions used to model the transfer of energy from the charm quark to a specific D meson species and from the different contribution from decays of higher excited states.
  - Effects p_T dependence of the ratios of the D meson production cross sections

The measured D+/D0 and D$+_s$ /D+ ratios do not show a significant p_T dependence within the experimental uncertainties.

Suggesting a small difference between the fragmentation functions of c quarks to strange and non-strange mesons.



Fragmentation fraction previously shown.

Charm quark

Meson	Frag Fraction	Mass (GeV/c^2)
D^0 (c ubar)	55.3 +- 5 %	1.864
D^+ (c dbar)	23.4 +- 2 %	1.869
D_s (c sbar)	9.1 +- 2 %	1.968
Λ_c^+ (cud)	5.8 +- 0.9 %	2.286
D^{*+} (c dbar)	24.1 +- 1.5 %	2.010
D^{*0} (c ubar)	~ 24 %	2.006

Quarkonia measurements

- Quarkonia are bound state of same quark-anti quark pairs.
  - c-cbar, b-bbar

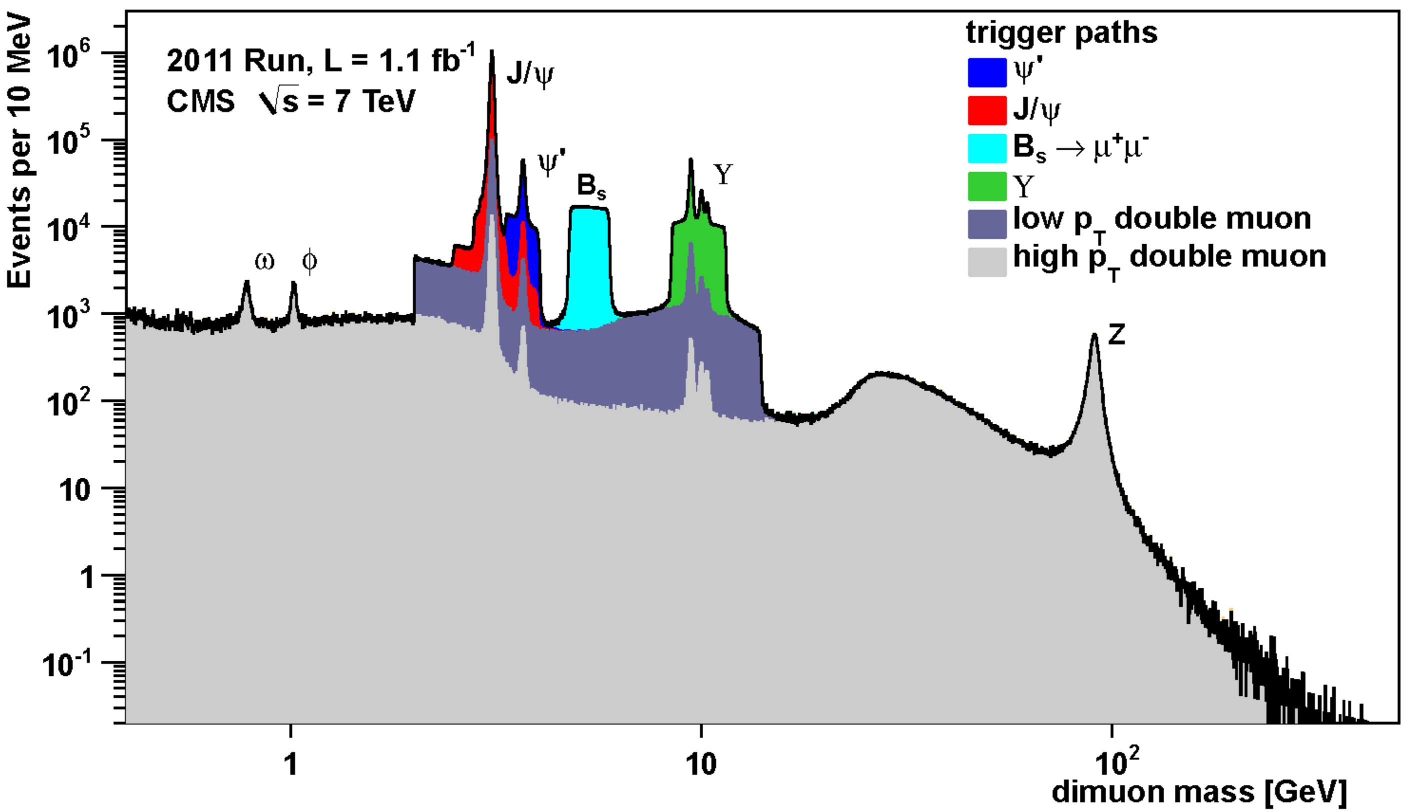
- The mechanisms of quarkonia production are still not fully understood.

- Considerable progress made in recent years but none of the existing theoretical models describes satisfactorily prompt J/ψ and Υ differential cross sections.

- Therefore, measurements at the LHC will shed light to the quarkonium production mechanisms, by providing differential cross sections in wider rapidity ranges and to higher transverse momenta than before.

Quarkonia measurements at CMS

- At CMS, the decay channel used : J/ψ → $\mu^+\mu^-$, Υ → $\mu^+\mu^-$
- In both J/ψ and Υ analyses, the data are collected with a trigger requiring the detection of two muons at the hardware level.
- The resonant states are reconstructed through their decay in two opposite sign muons, and the production cross sections are measured diffentially in p_T and y intervals.



Quarkonia measurements at ATLAS

Charmonium Spectroscopy: Observation of χcJ (1P) State

- ATLAS has performed the observation of the $\chi_c1(1P)$ and $\chi_c2(1P)$ charmonium states in $\chi_c \rightarrow J/\psi\ \gamma$.
- J/ψ candidates are reconstructed from the decay $J/\psi \rightarrow \mu^+\mu^-$ while photons are reconstructed using calorimetric measurements.

Bottomonium Spectroscopy: Observation of χb state

- The b-bbar χ_b states are reconstructed in ATLAS through the radiative decay to Y.
- The $\chi_b(1P)$ and $\chi_b(2P)$ states have already been observed through this decay mode.
- Now the first observation of the $\chi_b(3P)$ state.
- Photons are reconstructed either directly in the calorimeter or through a conversion to e+e−.
- The mass distribution for unconverted photons and converted photons.
- The measurement with converted photons is used for the final mass determination of 10.539 ± 0.005(stat.)±0.009(syst.) GeV.

$\chi_c1(1P)$: 3.510 GeV/c2
$\chi_c2(1P)$: 3.556 GeV/c2

$\chi_b(1P)$: 9.859 GeV/c2
$\chi_b(2P)$: 10.232 GeV/c2

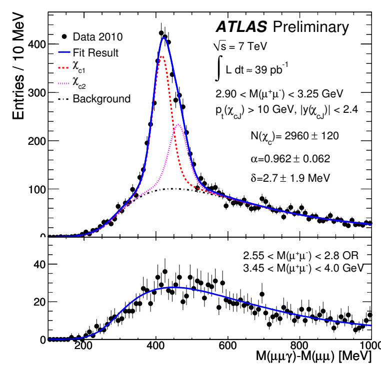


Figure 3. The result of a simultaneous fit to the signal sample (top) and background (J/ψ sideband) sample (bottom) [7]. The individual signal components follow the colour convention: χ_{c1} (red dashed line), and χ_{c2} (magenta dashed line).

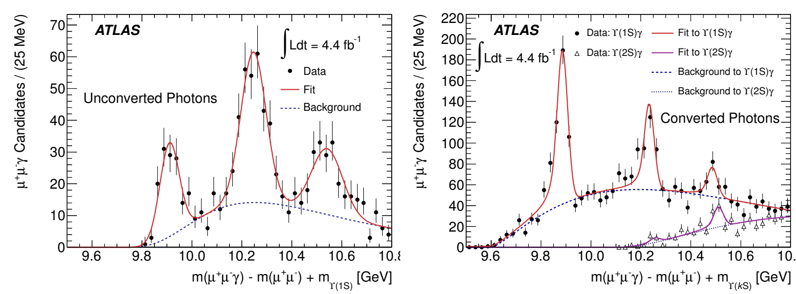
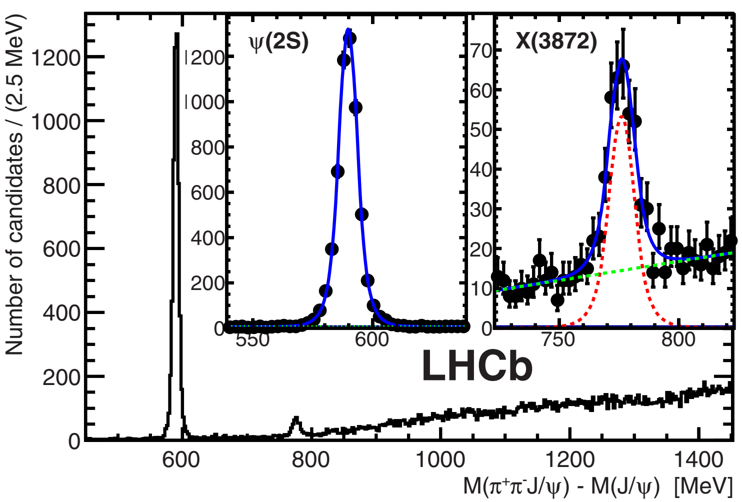


Figure 4. *Left*: The mass distribution of $\chi_b \rightarrow \Upsilon(1S)\gamma$ candidates for unconverted photons from energy deposits in the electromagnetic calorimeter [8]. *Right*: The mass distributions of $\chi_b \rightarrow \Upsilon(kS)\gamma$ (k = 1, 2) candidates formed using converted photons reconstructed in the inner detector [8]. Data are shown before the correction for the energy loss of the photon conversion electrons. The data for decays of $\chi_b \rightarrow \Upsilon(1S)\gamma$ (circles) and $\chi_b \rightarrow \Upsilon(2S)\gamma$ (triangles) are plotted. Solid lines represent the total fit result for each mass window. The dashed lines represent the background components only.

Quarkonia measurements

- In addition to conventional mesons and baryons, the QCD Lagrangian allows for more exotic possibilities such as tetraquark and molecular states.
- The unexpected discovery of the X(3872) state by the Belle collaboration led to interests in exotic spectroscopy and subsequently many new “XYZ” states have been claimed.
- The X(3872) state has been studied in detail both at the e+e− B factories and the Tevatron but the nature of this particle remains unclear.
- Its properties do not match the predictions for the conventional charmonium states and it has been interpreted as a candidate for a tetraquark state or a loosely bound deuteron-like $D^{*0}D^{0}$ “molecule”
- At the LHC the X(3872) is produced both directly in pp collisions and also in b-hadron decays.
- Both LHCb and CMS have studied inclusive X(3872) production in pp collisions at 7 TeV.
- The cross-sections measured by both experiments are significantly less than those expected from calculations.



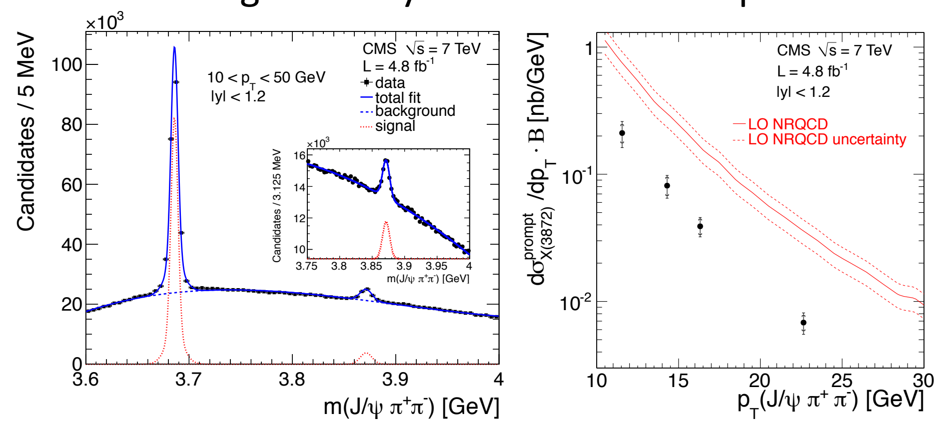


Figure 2: (Left) $J/\psi\pi^+\pi^-$ mass spectrum observed by CMS (with $10 < p_T < 50$ GeV and $|y| < 1.2$). Clear signals for both the $X(3872)$ and $\psi(2S)$ states are seen. (Right) Differential cross-section for prompt $X(3872)$ versus p_T compared to the NRQCD predictions [20]. Both plots are taken from Ref. [19].

Exotic states

- LHC experiments have also studies of other “XYZ” states.
- One very important result is the confirmation by LHCb of the existence and resonant nature of the Z(4430)+ state first seen by the Belle collaboration.
- As this state is charged its minimal quark content is ccud, and thus it provides clear evidence for the existence of non-qq mesons.
- A puzzle that remains open concerns the existence of the X(4140) state.
- Evidence for this J/ψϕ resonance was reported by the CDF collaboration based on studies of the B+ → J/ψϕK+ decay chain.
- However, a subsequent LHCb study found no evidence for this state and set upper limits on its existence.
- An analysis by CMS confirmed the existence of a peaking structure in the same region, and in addition found evidence for a second structure with m(J/ψϕ) ~ 4300 MeV/c2, in same decay mode.
- Further study is needed to clarify whether these structures are resonant in nature.

Beauty hadron measurements

- Measurements of B-hadron production at higher energies than before at LHC is an important test of various theoretical calculations.

- Measurements of b-quark production cross section require identification of events in which a b-quark has been produced in pp collisions.

- Discrimination of the heavy quark events can been achieved either
  - reconstructing the whole decay channel of a B meson
  - Measuring a decay product.

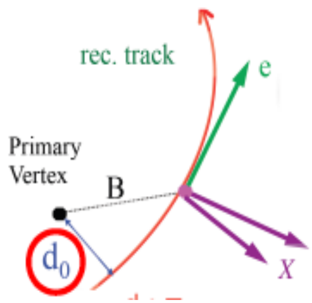
- Various measurements include
  - b–tagging with secondary vertices
  - b–jets with muons
  - Exclusive production of B-mesons
  - Observation of other heavy hadrons

- Here I show a very few examples.

Beauty-decay electron cross sections in ALICE

pp @ √s=7 TeV

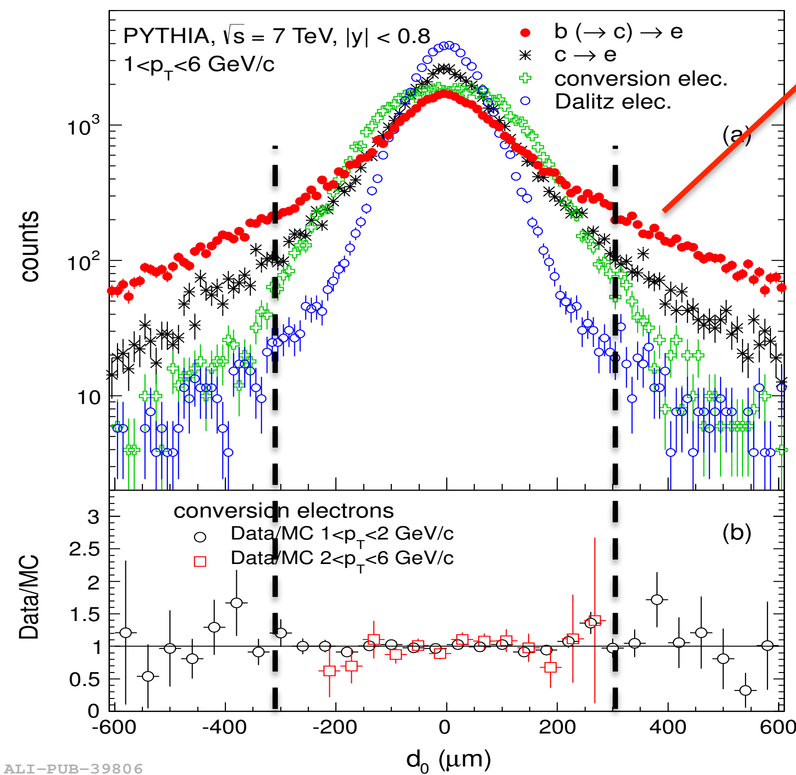
B meson lifetime ~ 500 μm.

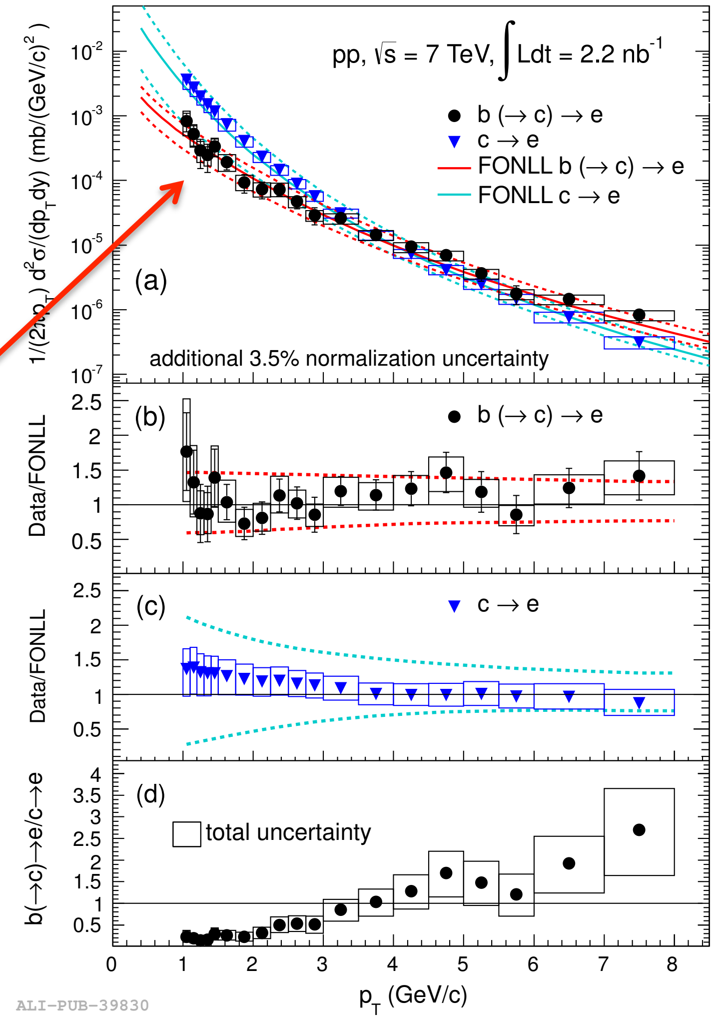


Select electrons with large impact parameter to primary vertex

Subtract background using simulations

d_0 : transverse impact parameter



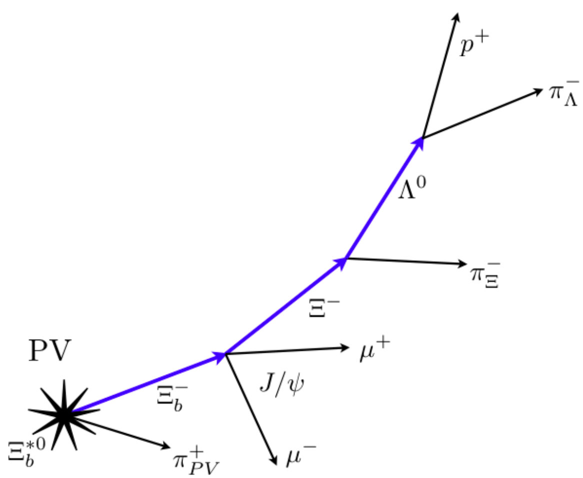


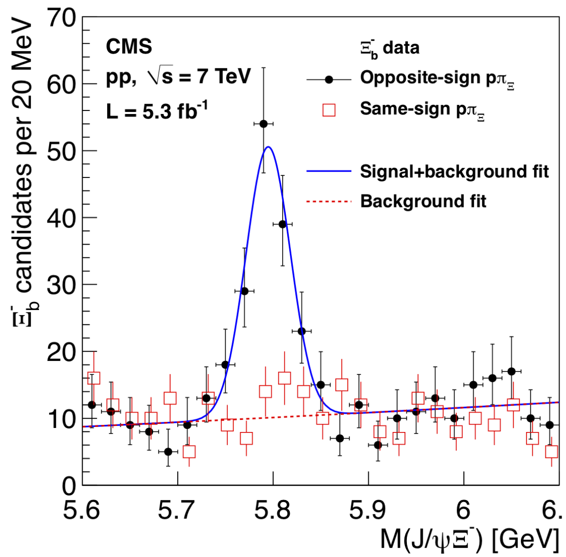
- p_T-differential cross section of b→e.
- Well described by FONLL calculations[2].
- Beauty takes over as dominant source of HF-decay electrons at p_T ~ 4 GeV/c

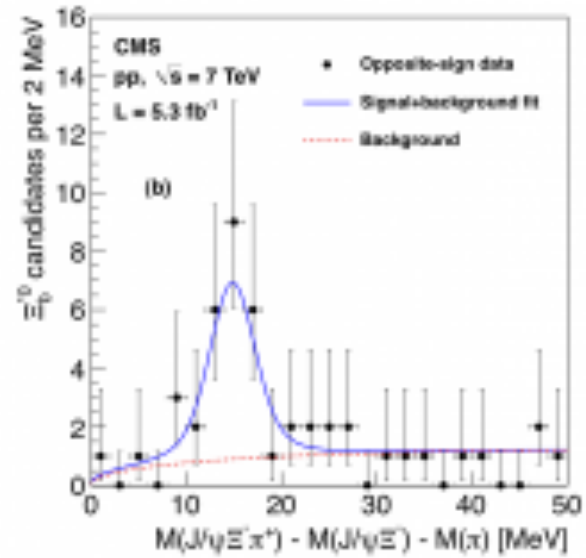
[2]. FONLL : JHEP 1210 (2012) 37

Beauty hadron measurements

- A new baryon resonance Ξ^{*0} containing a b quark flavour has been observed via its strong decay into $\Xi_b^{\pm}\pi^{\mp}$.
  - The known $\Xi_b^{\pm}$ baryon is reconstructed via the decay.
  - $\Xi b^{\pm} \rightarrow J/\psi\ \Xi^{\pm}$ with $J/\psi \rightarrow \mu^+\mu^-$ and $\Xi^{\pm} \rightarrow \Lambda_0\pi^{\pm}$ whereas the Λ_0 in turn is reconstructed via its decay into $p\pi^-$
  - A peak is observed in the distribution of the difference between the mass of the $\Xi_b^{\pm}\pi^{\mp}$ system and the scalar sum of the masses of the $\Xi_b^{\pm}$ and the $\pi^{\mp}$, with a statistical significance of 6.9 standard deviations.
  - The mass difference of the peak corresponds to 14.84 ± 0.74(stat) ± 0.28(syst) MeV.







Other interesting particles studied:

The B_c^+ meson, the ground state of the bc system, is unique as it is the only weakly decaying heavy quarkonium system.

Top quark measurement

- After the discovery of the top quark in 1995, much work has been devoted to the precise measurement of its mass.
- The present average value = 173.2 ± 0.6stat ± 0.8syst GeV is obtained from measurements at the Tevatron.
- At the LHC, mtop has been measured by CMS/ATLAS in $t\bar{t}$ events.
  - t → Wb ; W → lepton and neutrino.
- The measurement of the top quark mass also portrays an important benchmark for detector performance and calibration.
- To measure precise values of mass, new method (kinematic fitter) is used.
- The input to the fitter are the four-momenta of the muon and the four leading jets, the missing transverse energy, and their respective resolutions.
- The two *b*-tagged jets are candidates for the *b* quarks in the $t\bar{t}$ hypothesis, while the two untagged jets serve as candidates for the light quarks from the *W* decay.

Top quark measurement

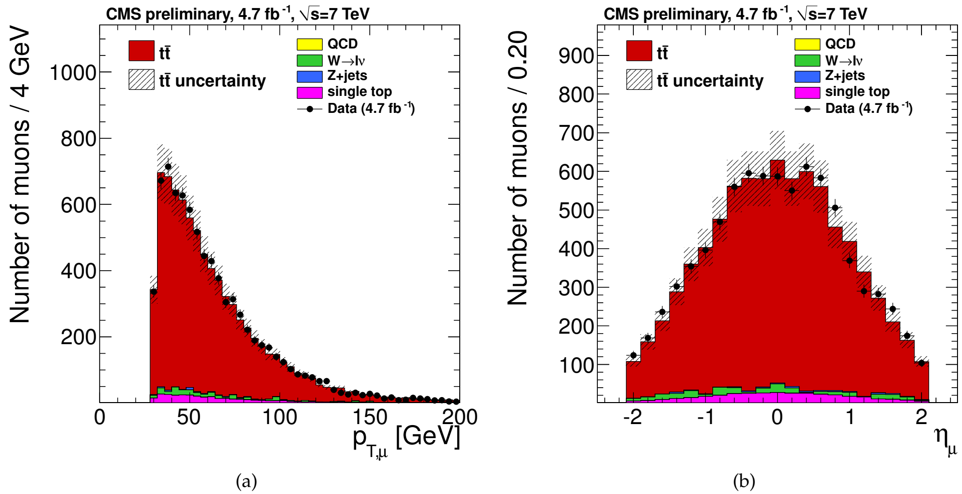
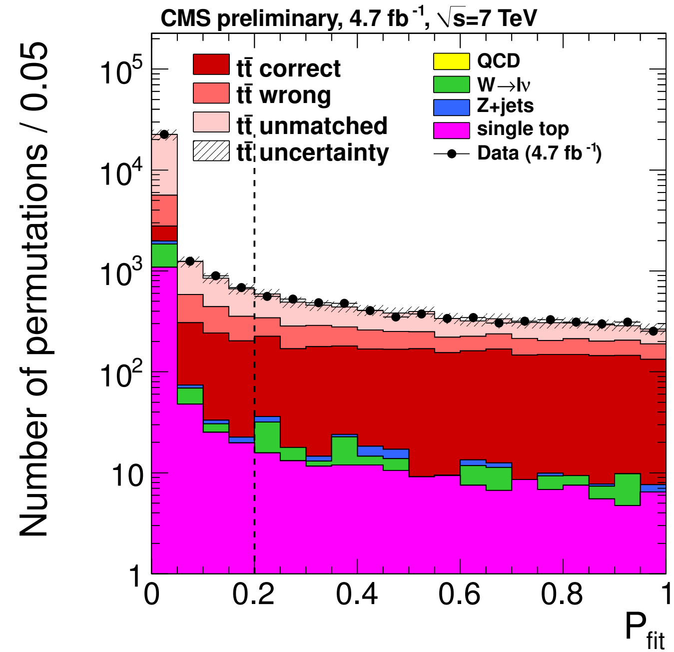


Figure 1: Distribution of (a) muon transverse momentum and (b) muon pseudorapidity after the event selection. The simulated $t\bar{t}$ sample assuming a top quark mass of 172.5 GeV and the backgrounds, QCD, Z+jets, W+jets, and single top, are compared to the analyzed collision data. The simulated samples are rescaled to a luminosity of 4.7 fb^{-1}. For the $t\bar{t}$ normalization a previous CMS cross-section measurement [16] is used, its uncertainty is indicated by the shaded area.



Fit the kinematic distributions of muons and obtain probabilities.

Various contributions obtained from MonteCarlo simulations.

Apply selection on probability. P > 0.2

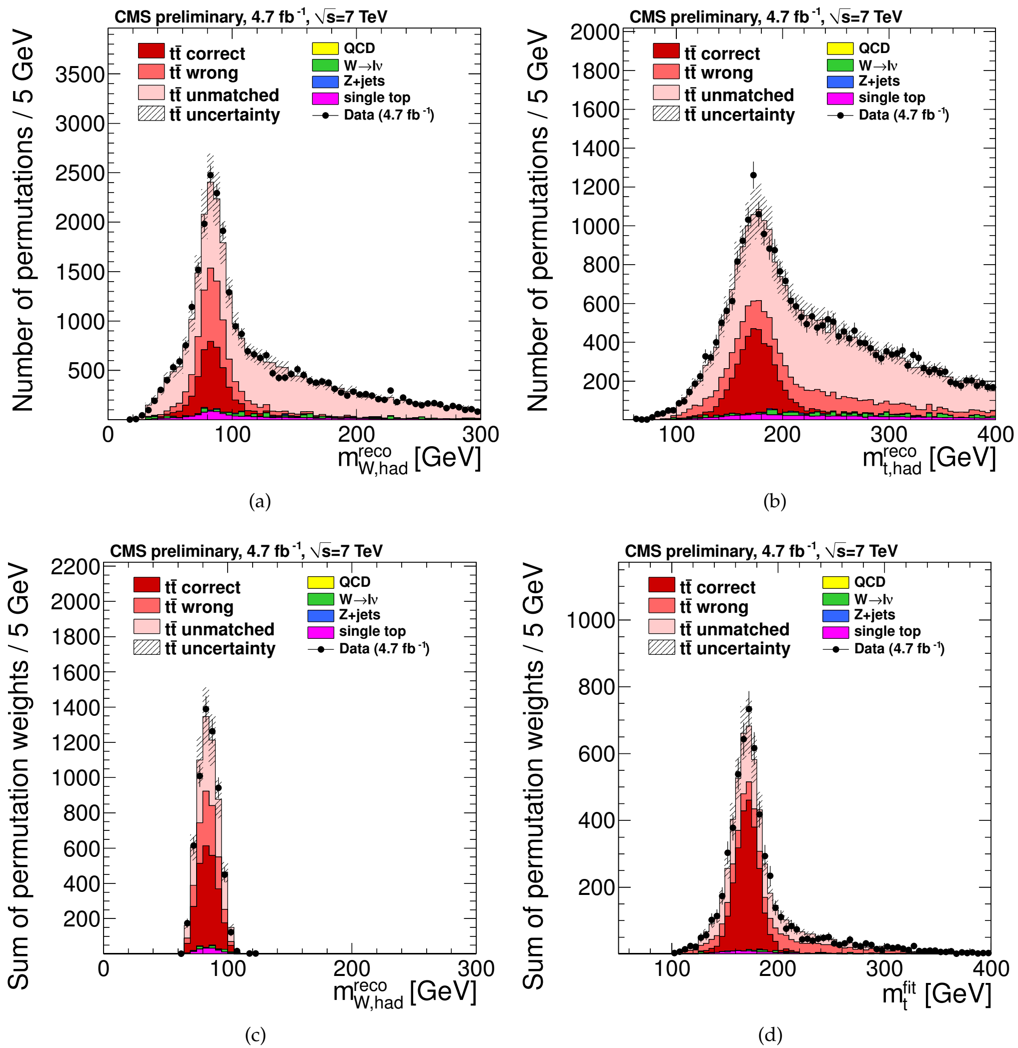


Figure 3: The upper row diplays the reconstructed W boson mass (a) and reconstructed top mass (b) for the hadronically decaying top quark before the cut on the kinematic fit probability. The lower row shows the reconstructed W boson mass (c) and the top quark mass from the kinematic fit (d) after the fit probability cut and the weighting by P_{fit}. The simulated samples are rescaled to a luminosity of 4.7 fb^{-1}. For the $t\bar{t}$ normalization a previous CMS cross-section measurement [16] is used, its uncertainty is indicated by the shaded area. The top quark mass in the simulation is 172.5 GeV.

Select 2391 μ+jets events out of 4.7 fb−1 of 2011 data taken by the CMS detector.

Top mass = 172.64 ± 0.57 (stat+JES) ± 1.18 (syst) GeV JES = 1.004 ± 0.005 (stat) ± 0.012 (syst).

The overall uncertainty of this measurement improves the precision of the 2010 CMS measurements by more than a factor of two.