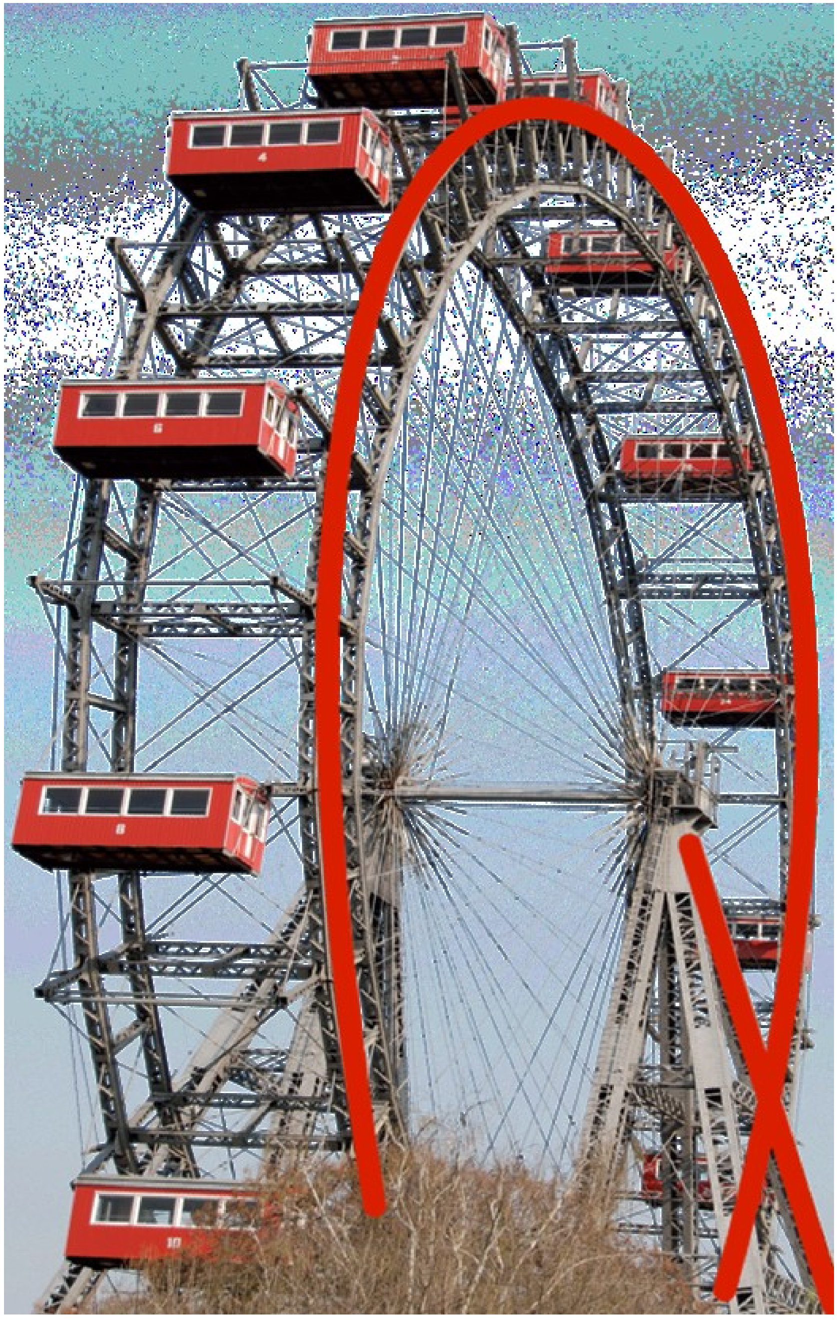
Achievements and perspectives in quarkonium physics at the LHC



- Achievements from the recent past
- Perspectives and challenges for the near future

Hermine K. Wöhri, CERN

Quarkonium Production Workshop
18 – 21 April 2011, Vienna, Austria

Early plans ("I have a dream")

Well before the first LHC run, some of us prepared a "wish list" of the measurements we wanted to perform in the coming years, including the following topics:

- Prompt and non-prompt J/ψ differential cross section in p_T and y
- Upsilon differential cross section in p_T and y for the 1S, 2S and 3S states
- $\psi(2S)$ differential cross section in p_T and y and ratio $\psi(2S)$ / J/ψ
- X(3872) observation and cross section ratio to $\psi(2S)$, using the $J/\psi\ \pi^+\pi^-$ decay channel
- Observation of χ_c production and χ_{c2} / χ_{c1} cross section ratio vs. p_T
- χ_b production cross section and feed-down fraction to $\Upsilon(1S)$
- Polarization of prompt and non-prompt J/ψ mesons
- Polarization of $\Upsilon(1S)$ mesons
- Polarization of $\psi(2S)$ mesons
- Polarization of χ_{c1} and χ_{c2} mesons
- Polarization of χ_b (1P) and χ_b (2P) mesons

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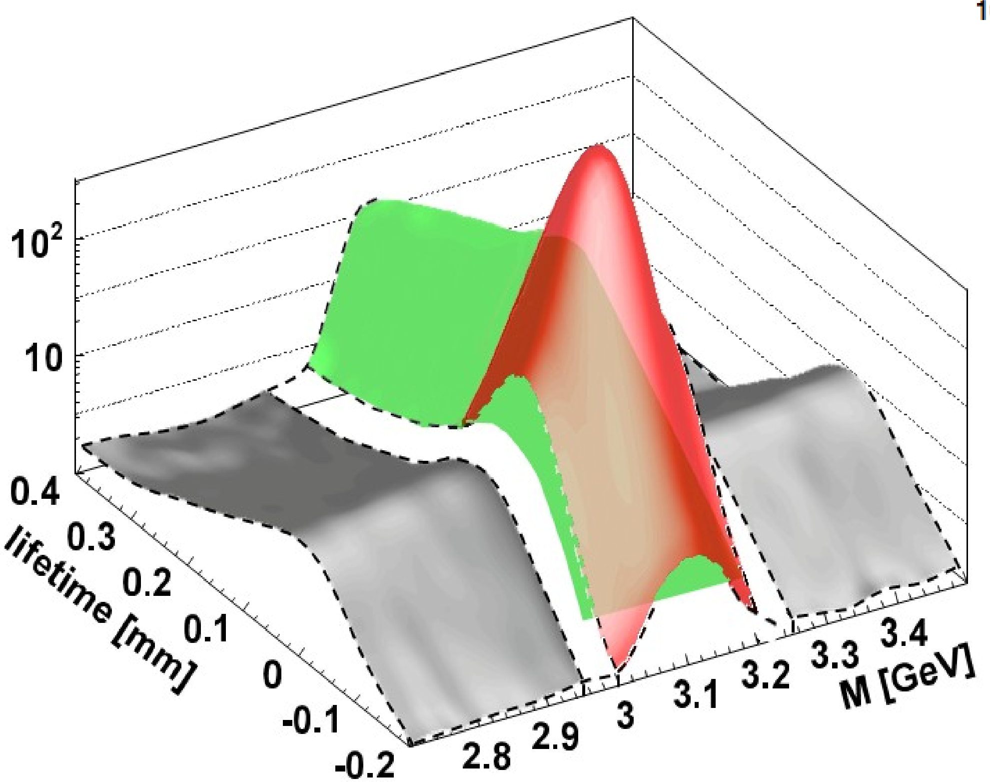
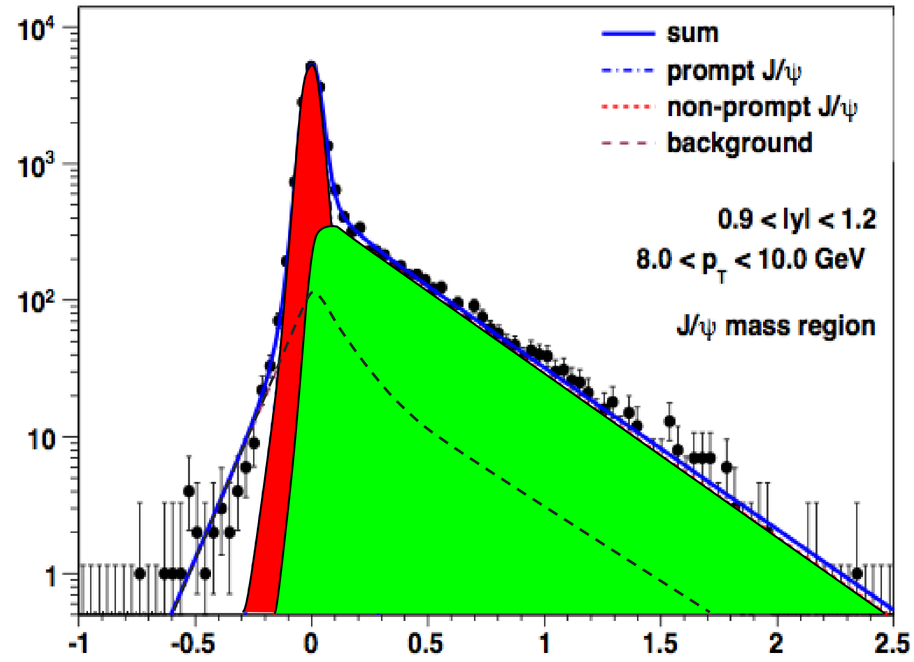
- ☑ Double J/ψ production cross section

J/ψ fraction from B decays

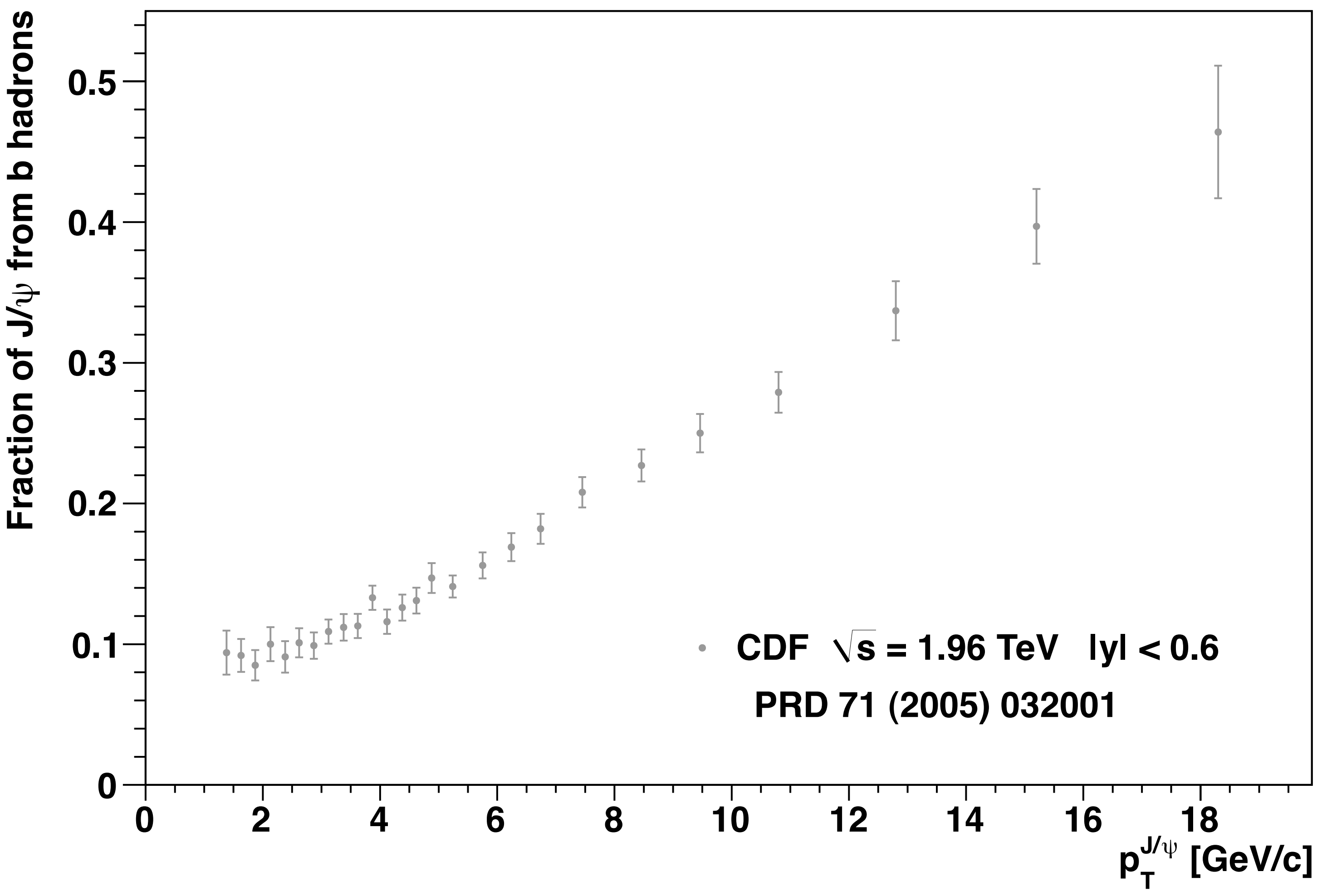
Prompt and non-prompt J/ψ mesons are separated through the "lifetime" dimension





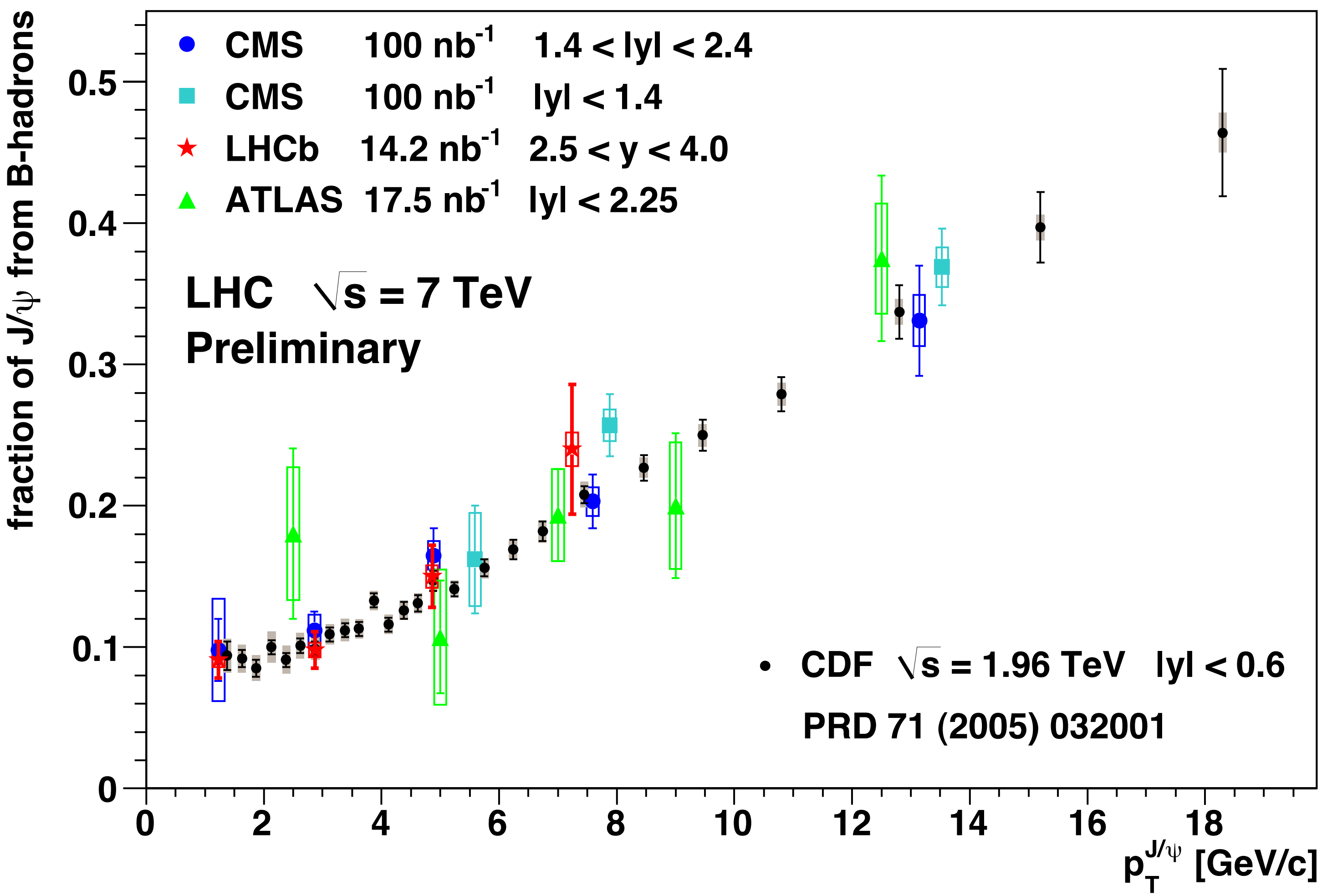
J/ψ fraction from B decays vs. p_T and y (2005)

At the beginning there was CDF : the B fraction increases with pT, at mid-rapidity



J/ψ fraction from B decays vs. p_T and y (2010)

At ICHEP, in July 2010, CMS and LHCb and ATLAS presented early measurements

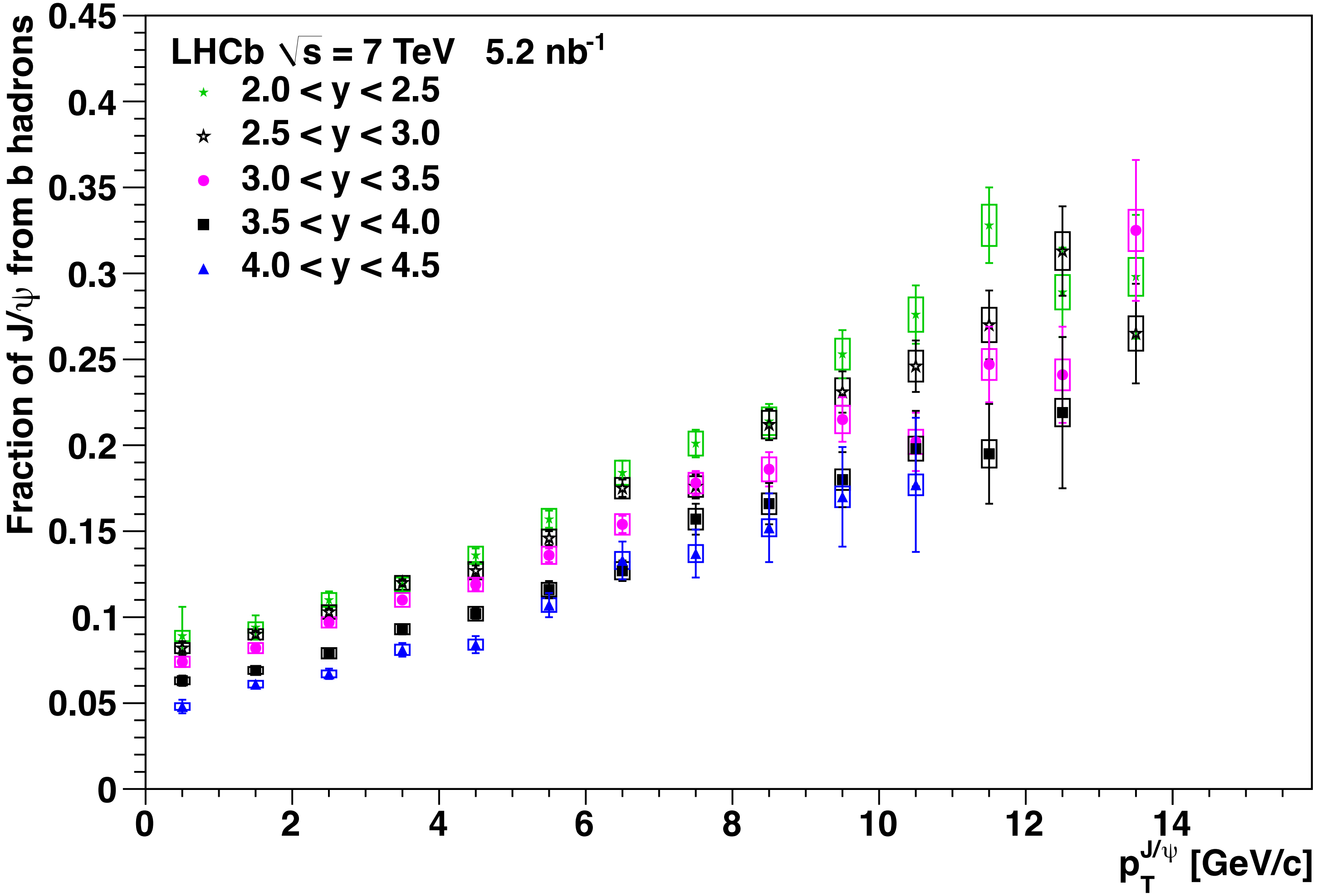


No significant change visible between sqrt(s) = 2 and 7 TeV

A first result after only 3 months of LHC running !

J/ψ fraction from B decays vs. p_T and y (2011)

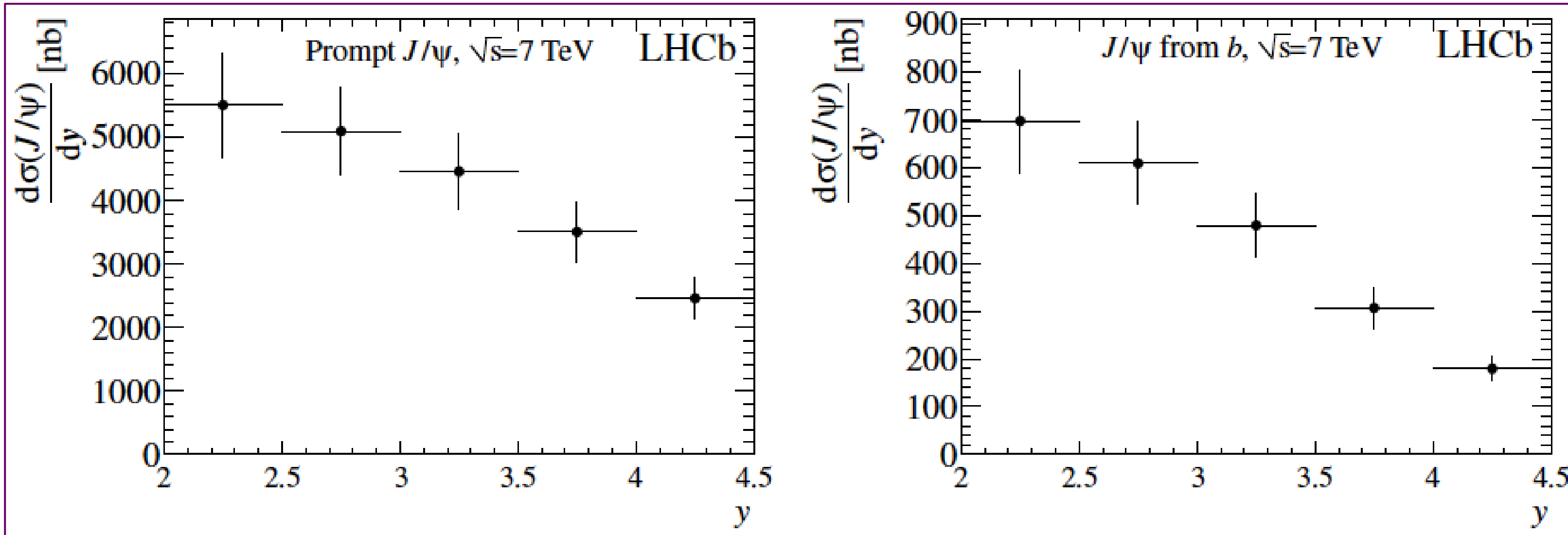
In Vienna, this week, LHCb presented very detailed measurements, in 5 rapidity bins



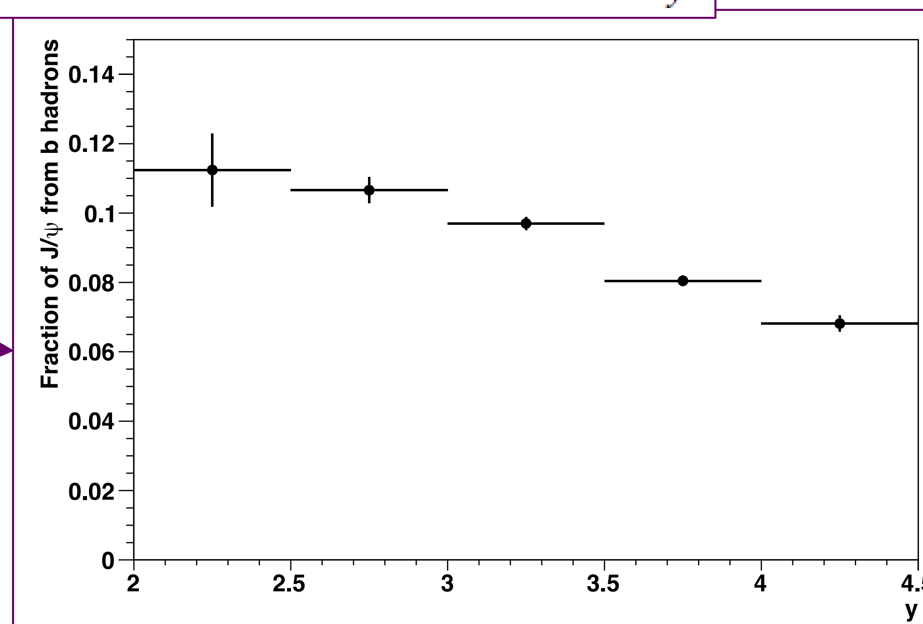
The B fraction, for a given p_T, increases from forward to central rapidity

J/ψ fraction from B decays vs. p_T and y (2011)

LHCb also provided measurements in 5 rapidity bins, integrated in p_T



$$\frac{\text{J/}\psi\text{ from B}}{\text{J/}\psi\text{ from B + prompt J/}\psi}$$

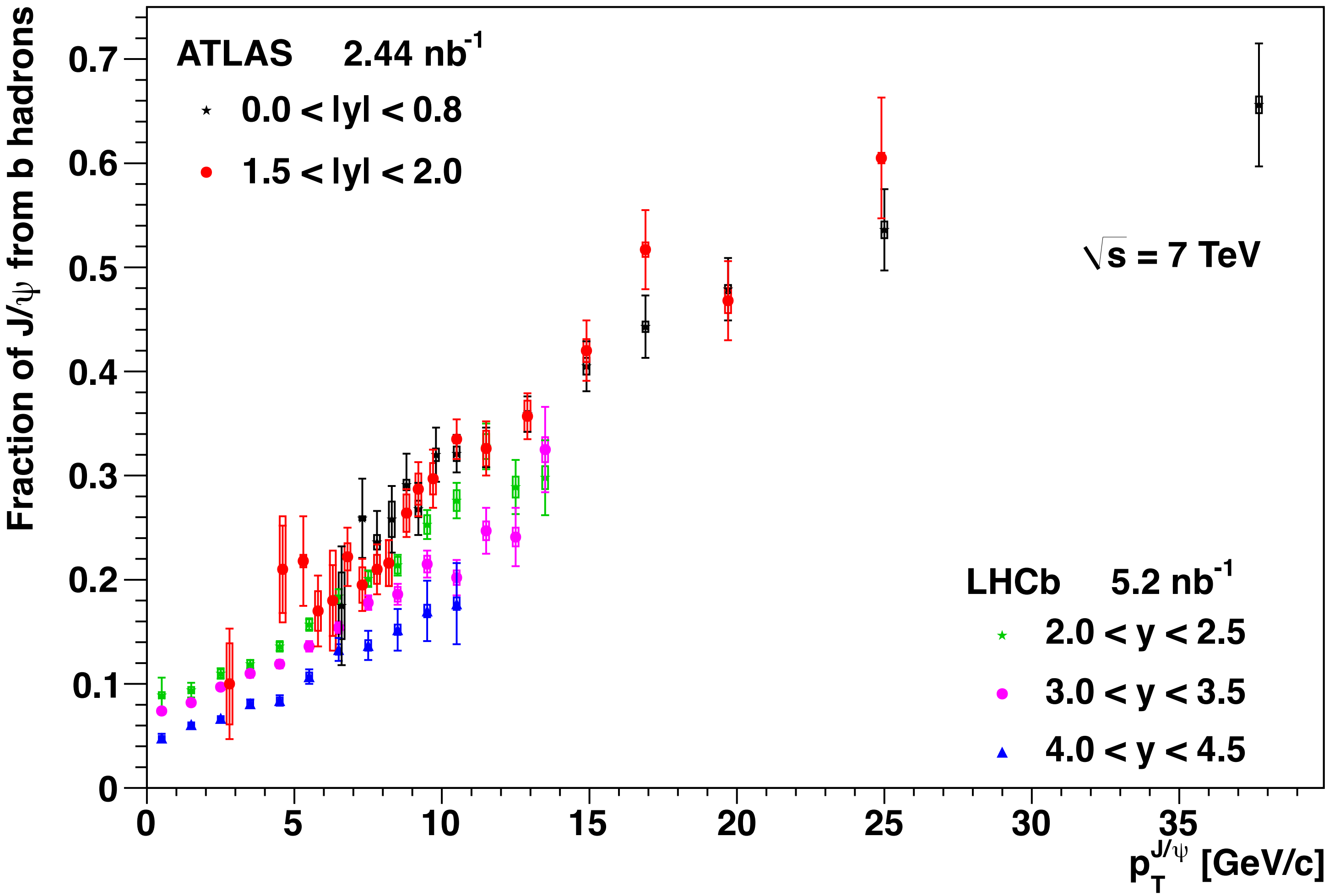


There is a larger B fraction at mid-rapidity than at forward rapidity !

Who ordered that ?

J/ψ fraction from B decays vs. p_T and y (2011)

Also ATLAS presented very detailed measurements

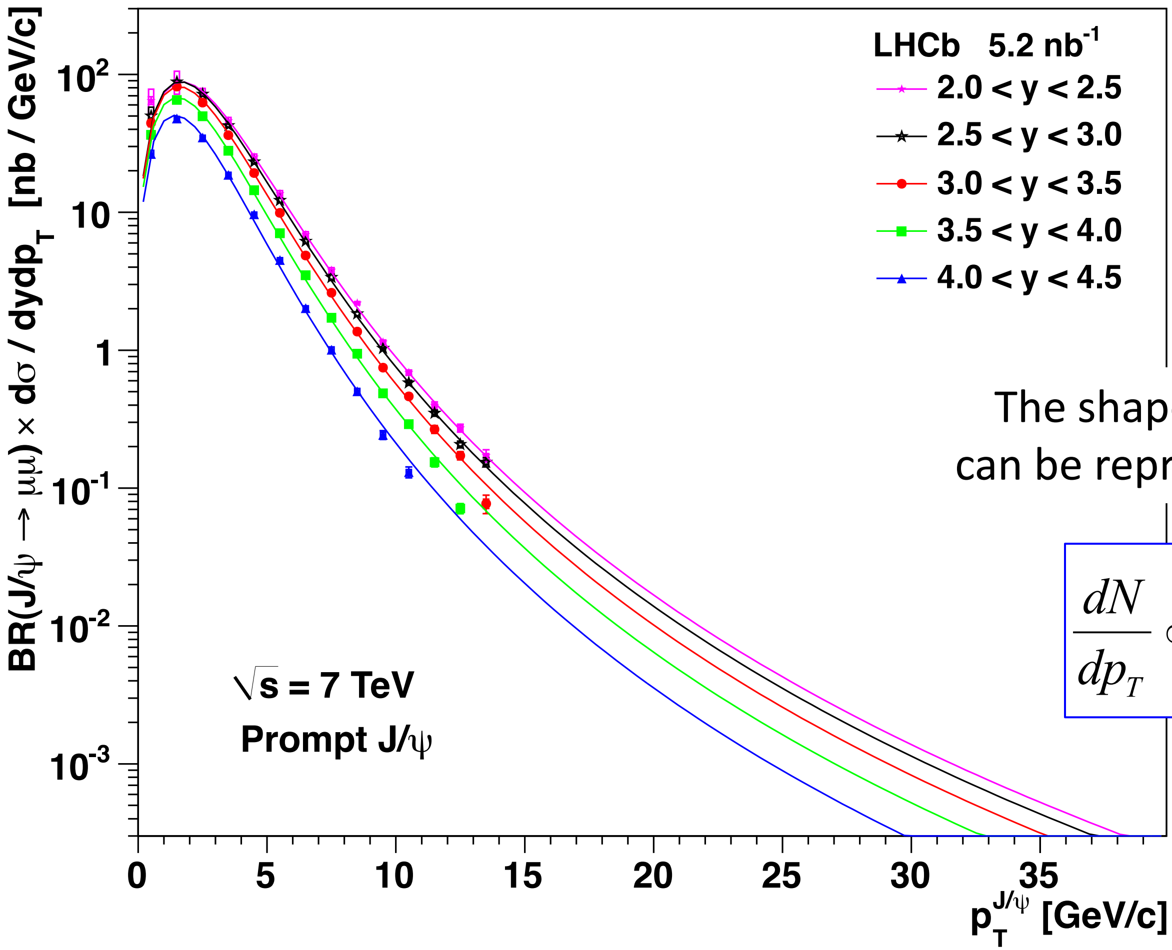


The ATLAS mid-rapidity data nicely follows the trend of the LHCb data

We see that at high p_T the fraction tends to saturate (as expected)

Prompt J/ψ p_T distributions from LHCb

LHCb presented very high quality measurements, in 5 rapidity bins, up to p_T ~ 15 GeV



The shape of the p_T distributions can be reproduced by the function

$$\frac{dN}{dp_T} \propto p_T \left(1 + \frac{1}{(\beta-2)} \frac{p_T^2}{\langle p_T^2 \rangle}\right)^{-\beta}$$

Prompt J/ψ p_T distributions from LHCb and ATLAS

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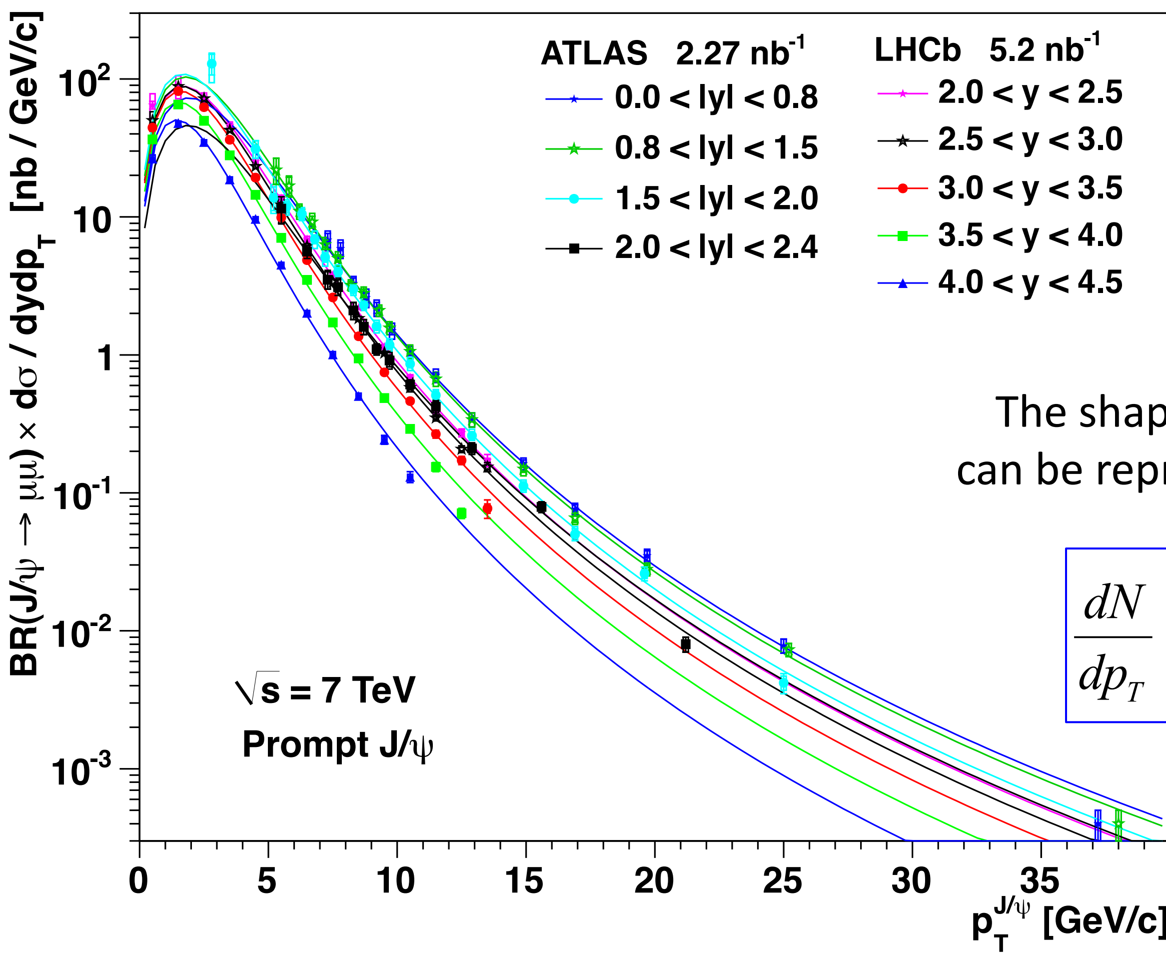

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Also ATLAS presented very detailed measurements, extending to higher p_T values

Prompt J/ψ p_T shape vs. rapidity

The two parameters are strongly correlated: 30–73% depending on the y bin
$\langle p_T^2 \rangle$ shows a clear trend; β seems to fluctuate around a single value
We can fix β to a constant value and look at the y-dependence of $\langle p_T^2 \rangle$
Helps extracting $\langle p_T^2 \rangle$ from the less accurate ATLAS and CMS data

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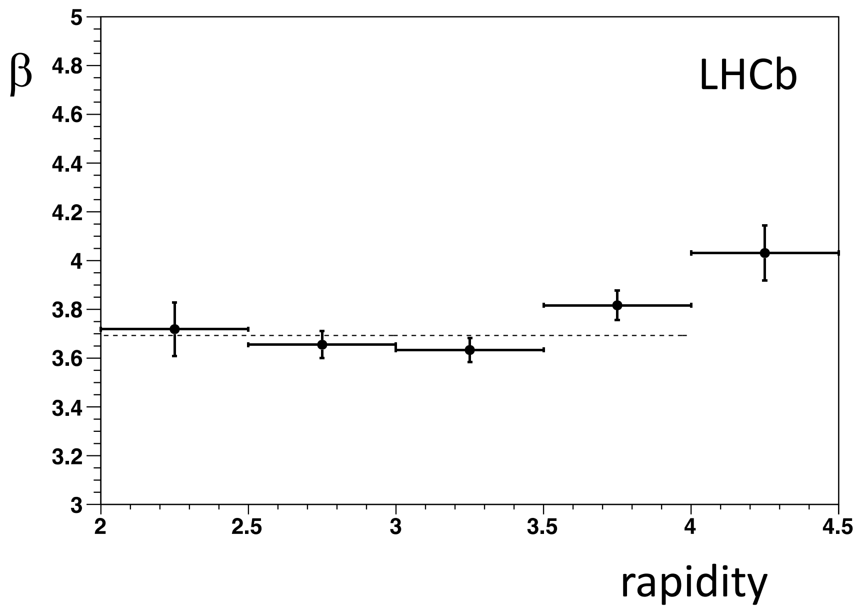
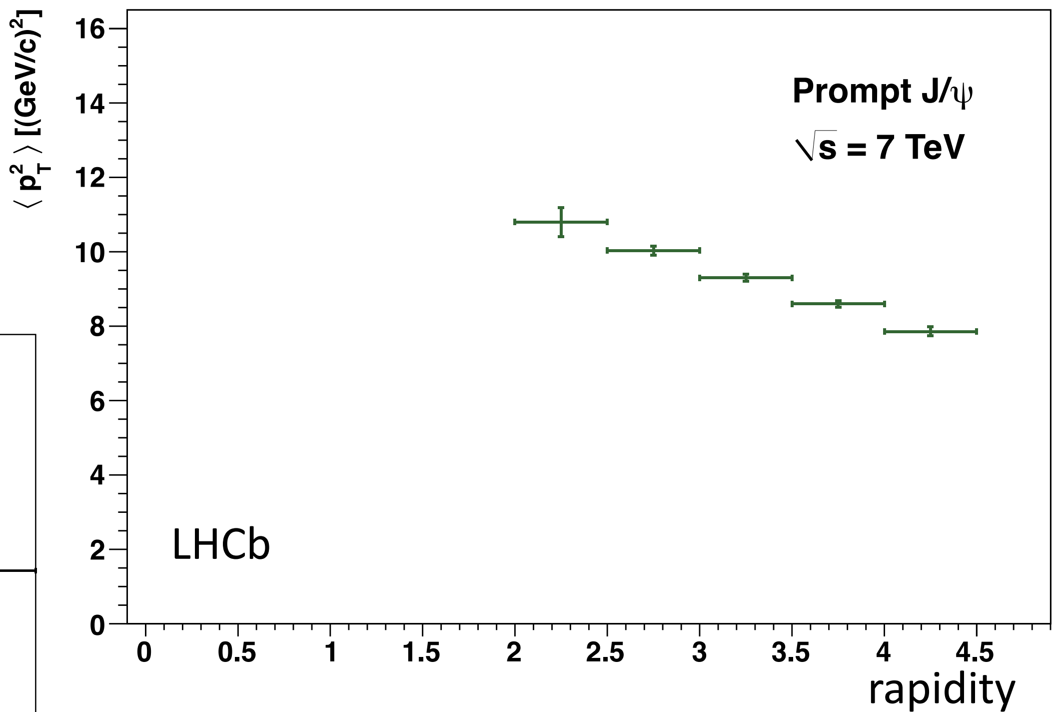
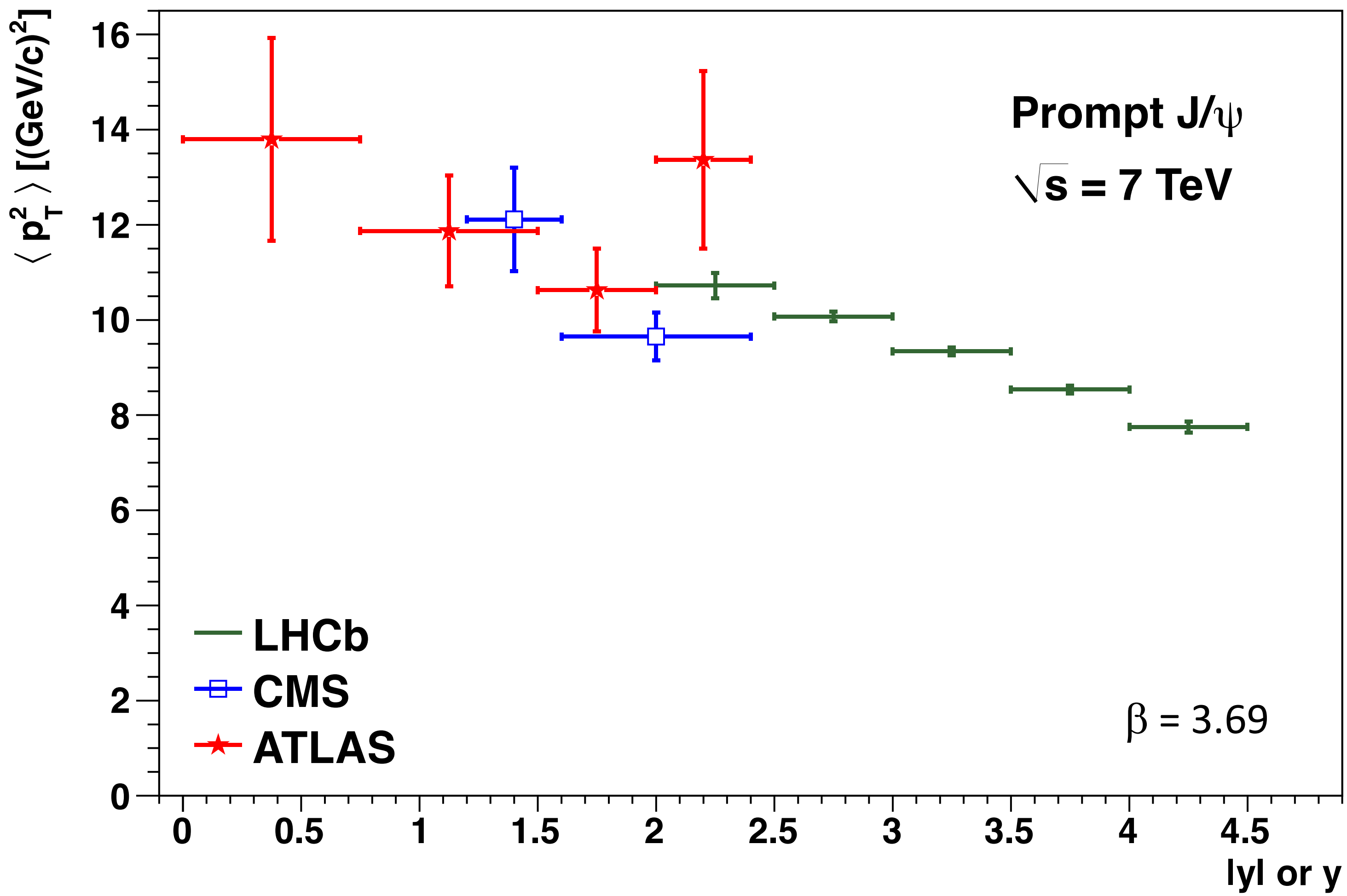




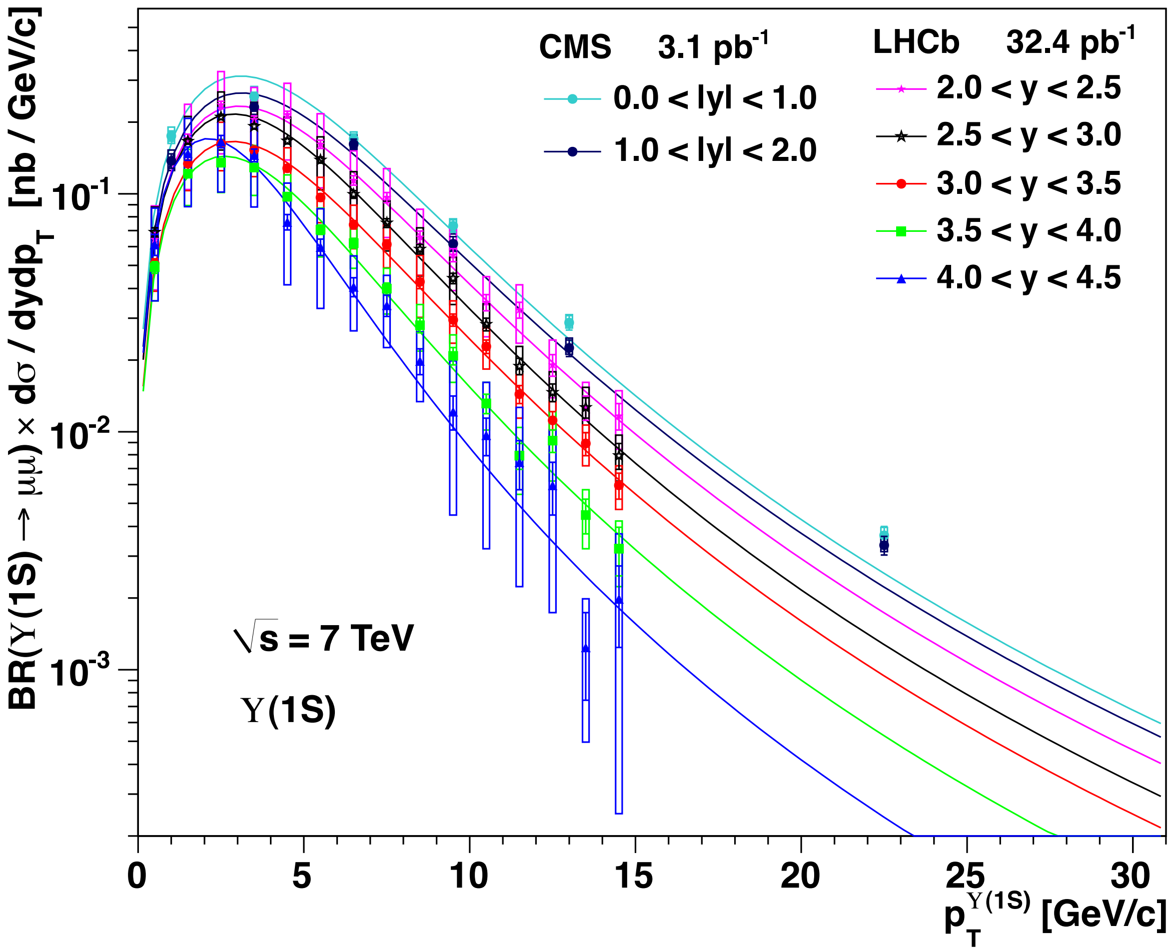
Prompt J/ψ p_T shape vs. rapidity

$\langle p_T^2 \rangle$ clearly increases from forward to central rapidity
To keep in mind when comparing ALICE J/ψ in dimuons and dielectrons



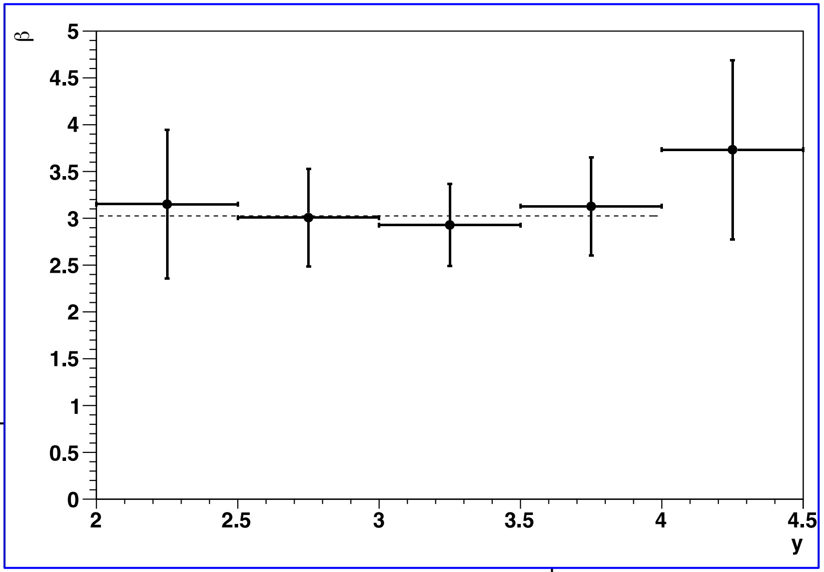
Υ(1S) p_T distributions from CMS and LHCb

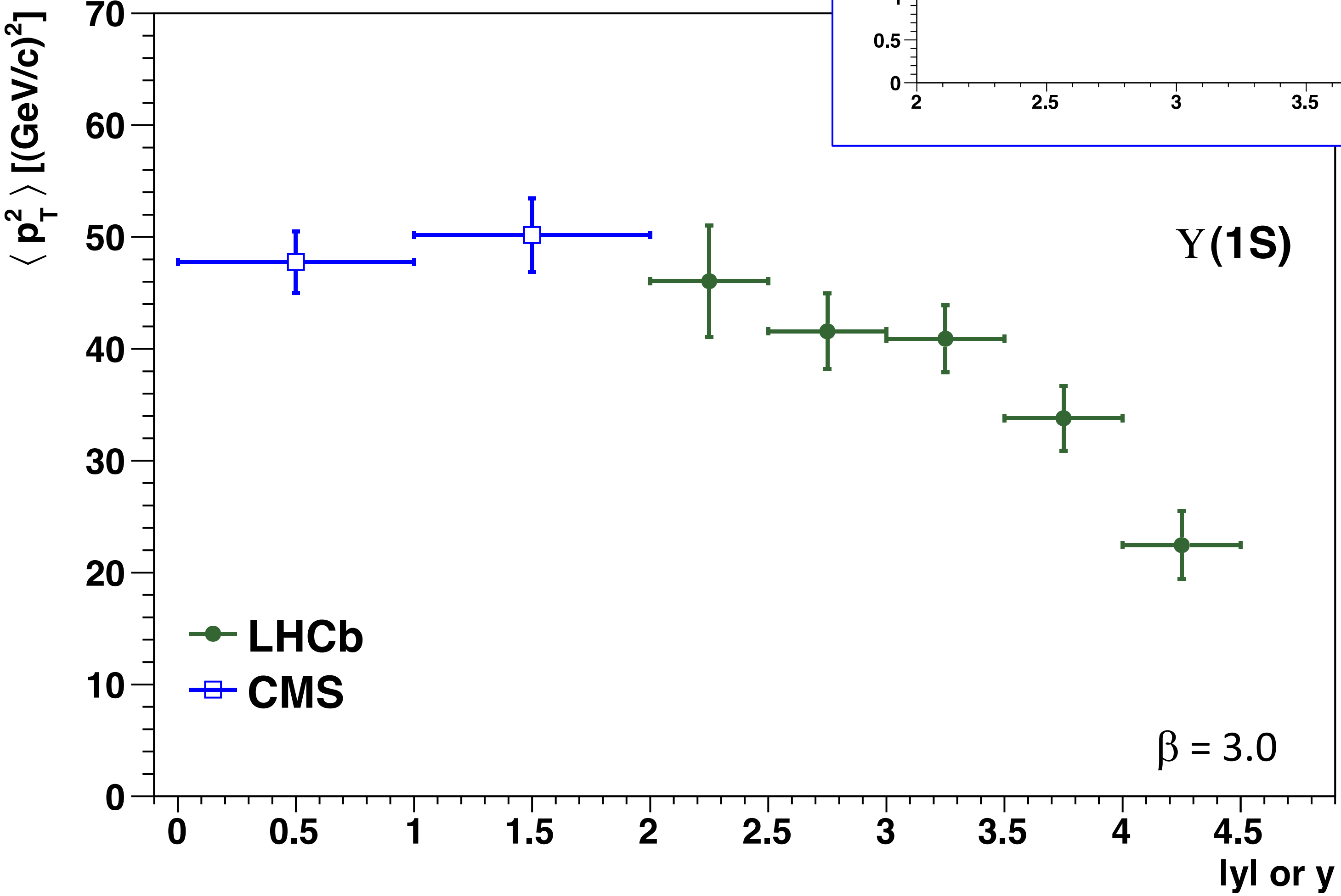
Also the bottomonium states are now available from more than one LHC experiment



ϒ : p_T shape vs. rapidity

Also in the case of the Υ(1S) we see that
β is essentially independent of rapidity

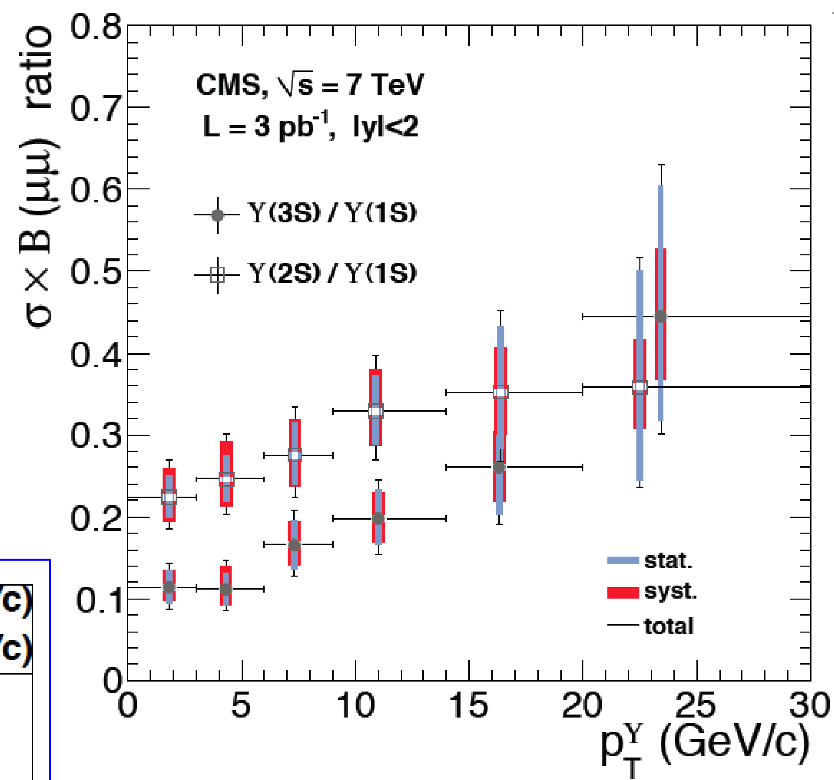


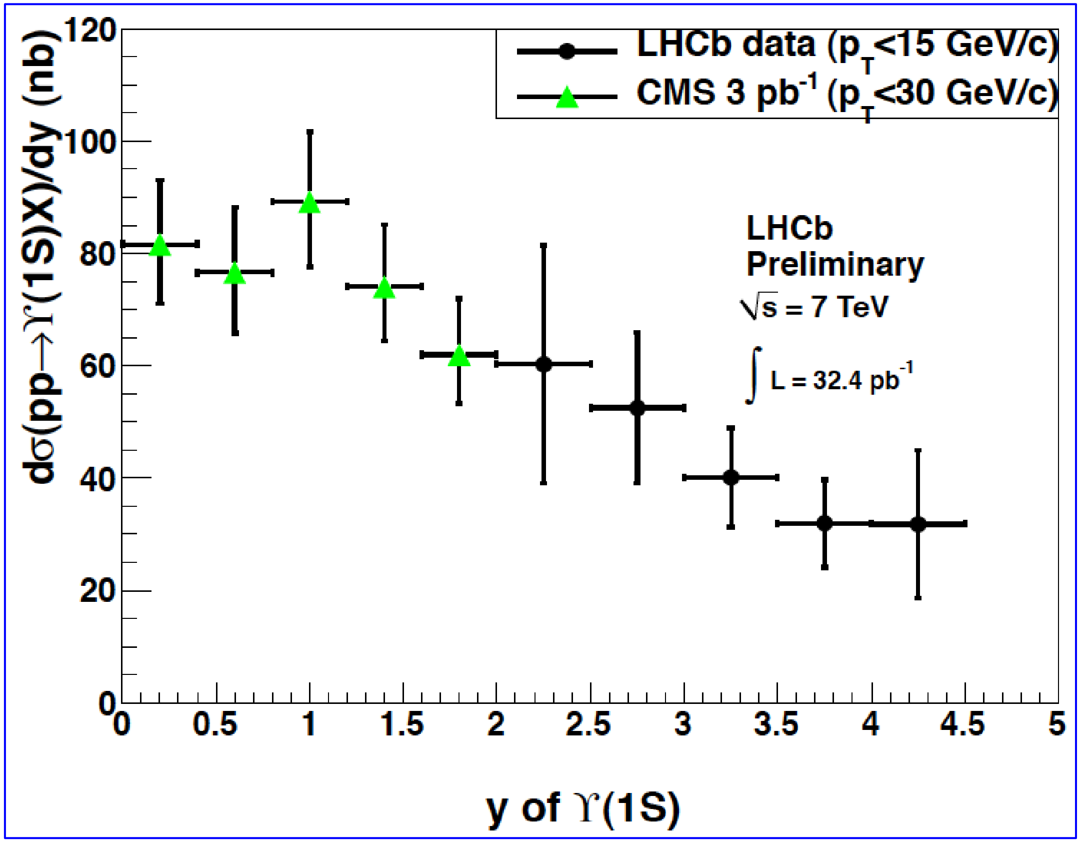


ϒ : rapidity and 2S, 3S data

Good compatibility between LHCb and CMS for the dσ/dy 1S production cross section

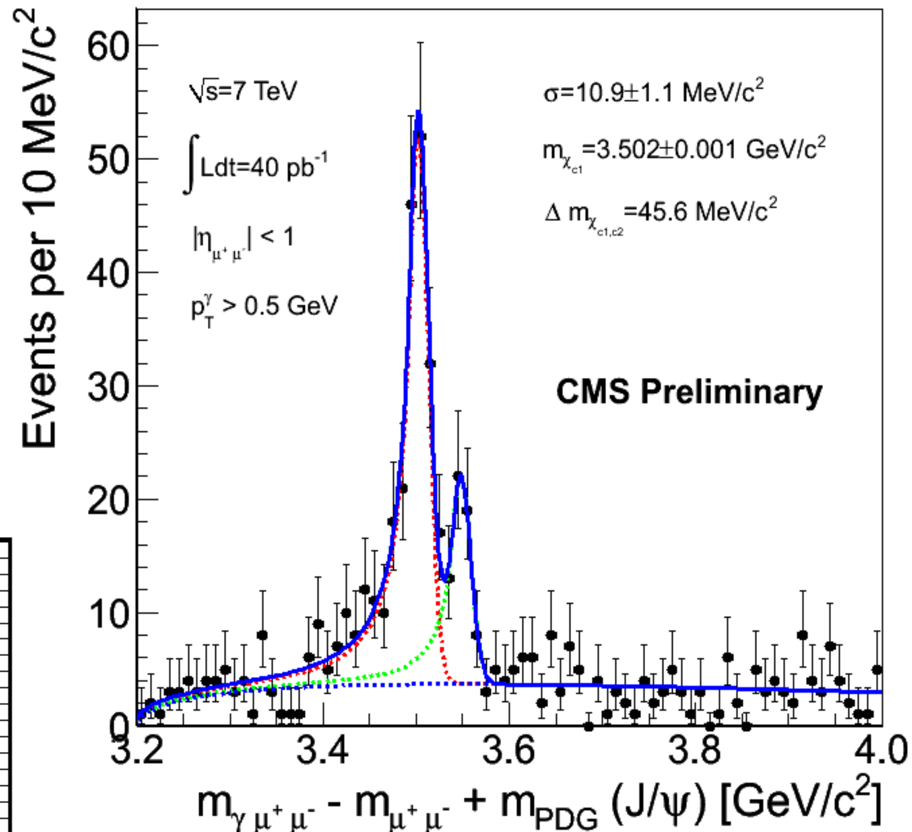
Heavier 2S and 3S states have flatter $d\sigma/dp_T$

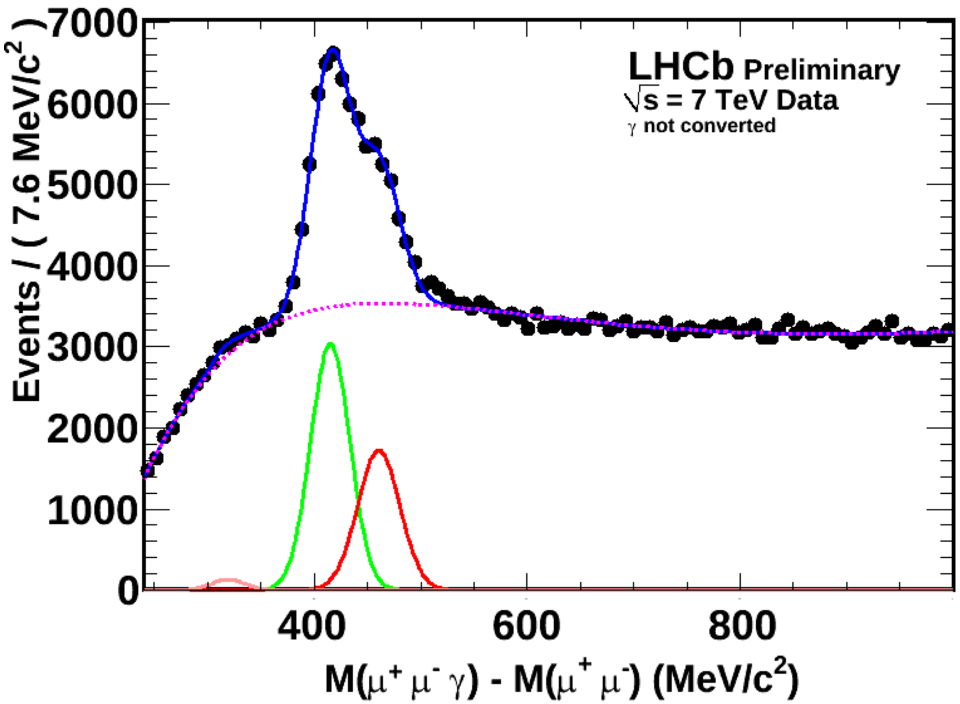




The χ_c already made a first appearance !

CMS has a very good resolution (11 MeV) but the photon conversion is challenging

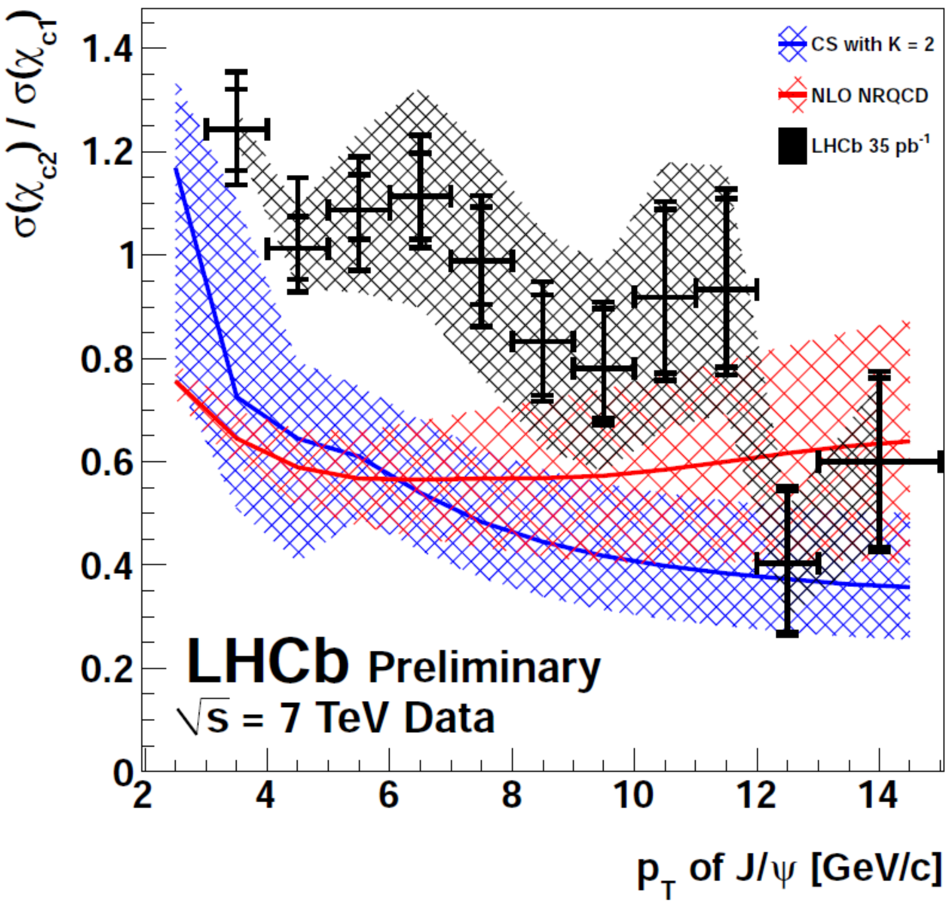


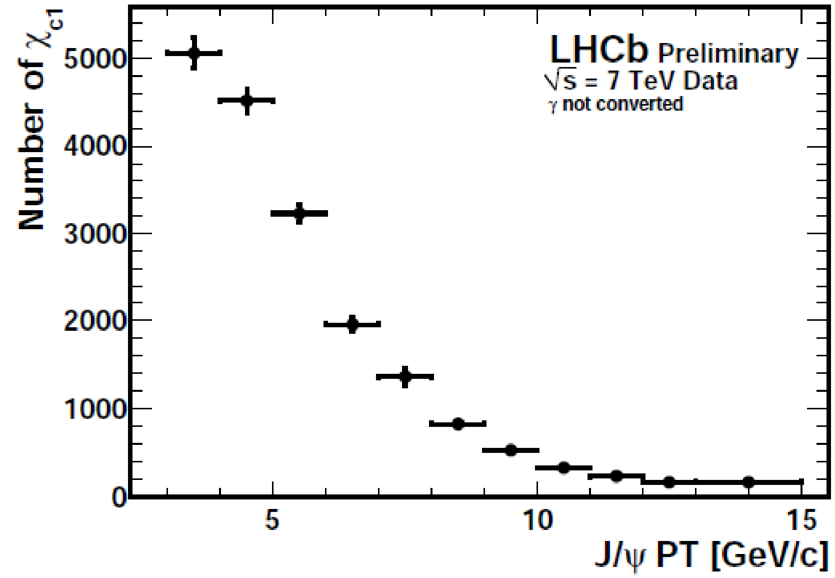


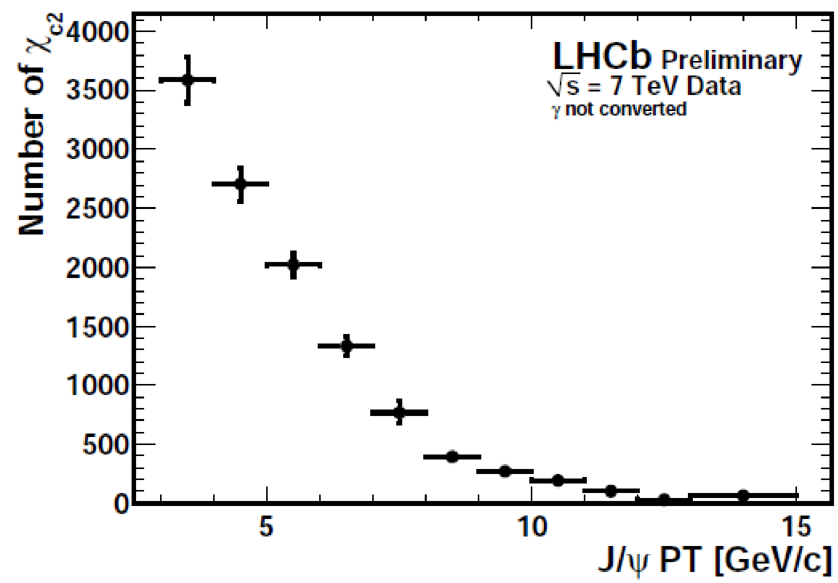
The χ_c already made a first appearance !

LHCb reported a first measurement of the χ_{c2} / χ_{c1} cross section ratio…

…and it disagrees with NLO NRQCD ☺



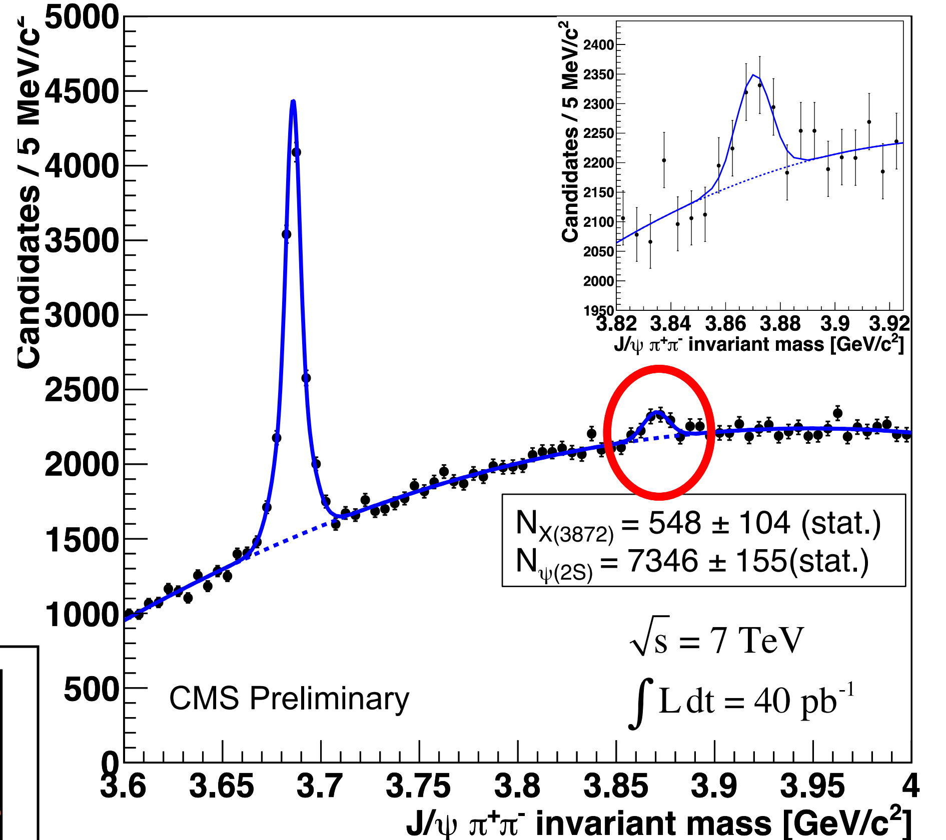


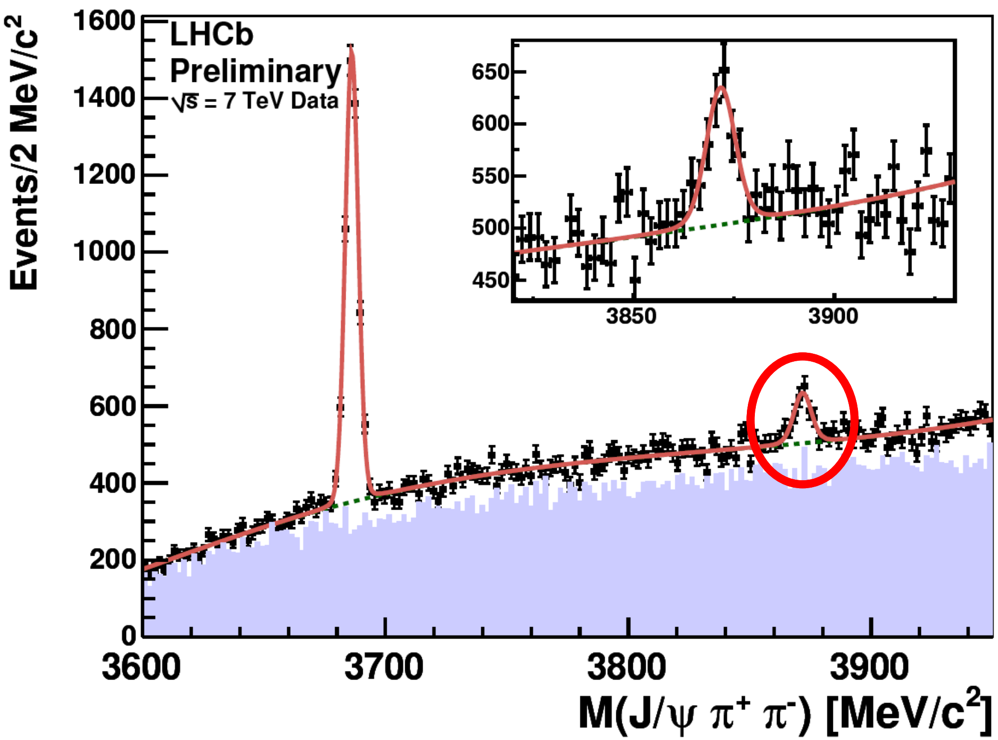


More "exotic" measurements

LHCb and CMS reported first observations of the X(3872) resonance

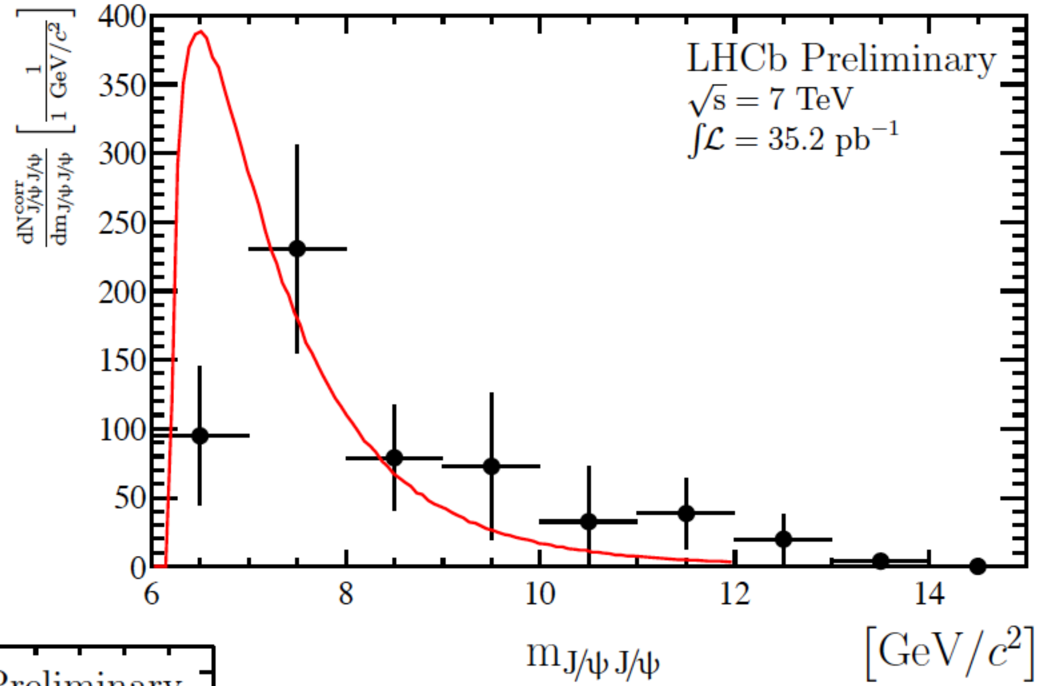
- LHCb measured its mass
- CMS measured its relative cross section w.r.t. the $\psi(2S)$

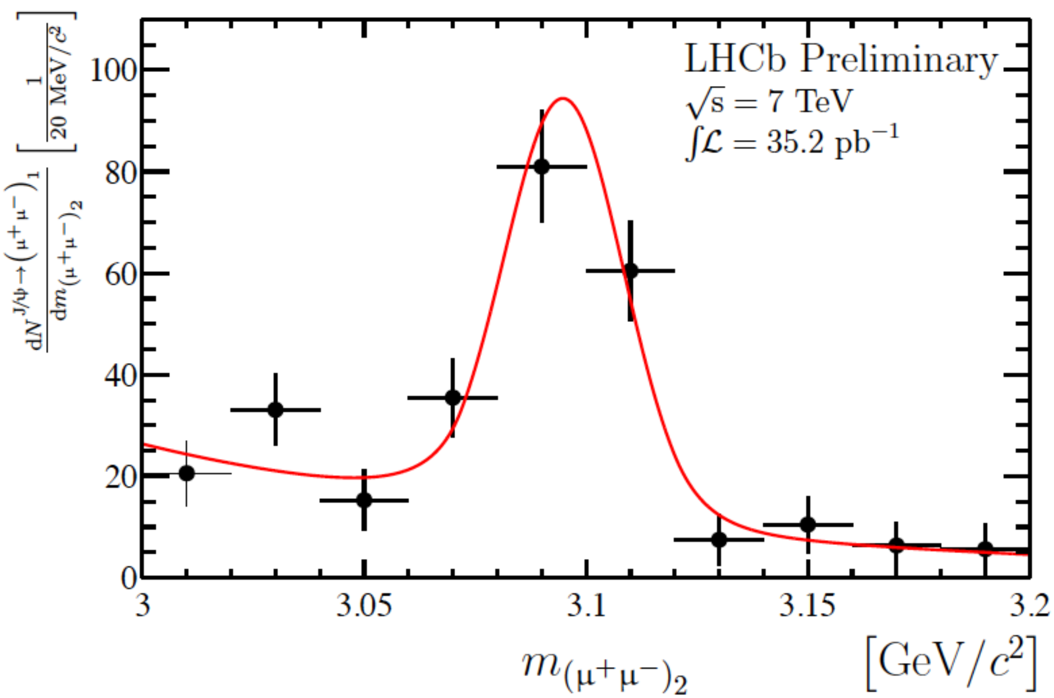




Double J/ψ production !

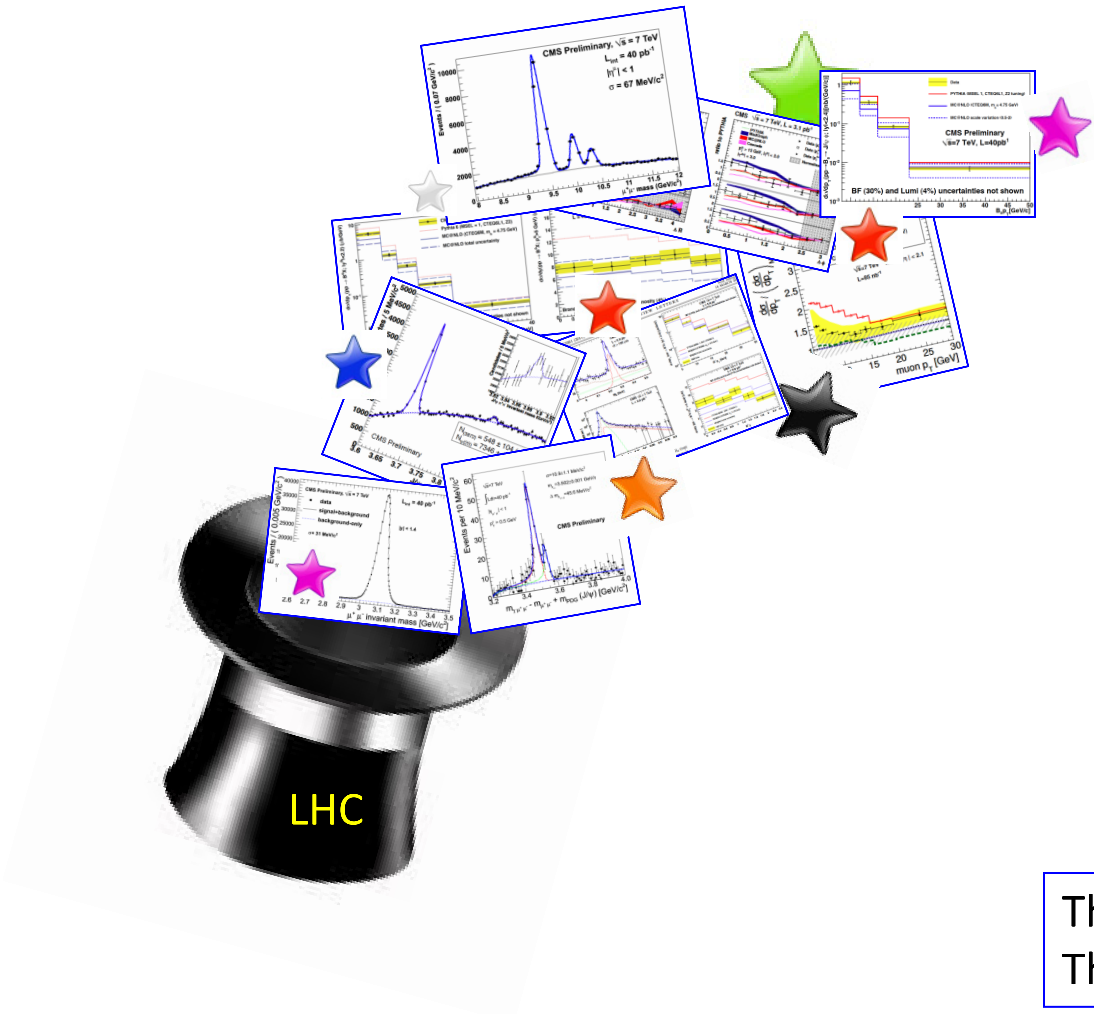
LHCb opened the door for correlation measurements with two J/ψ !





2010 has been a good year for Onia physics at the LHC

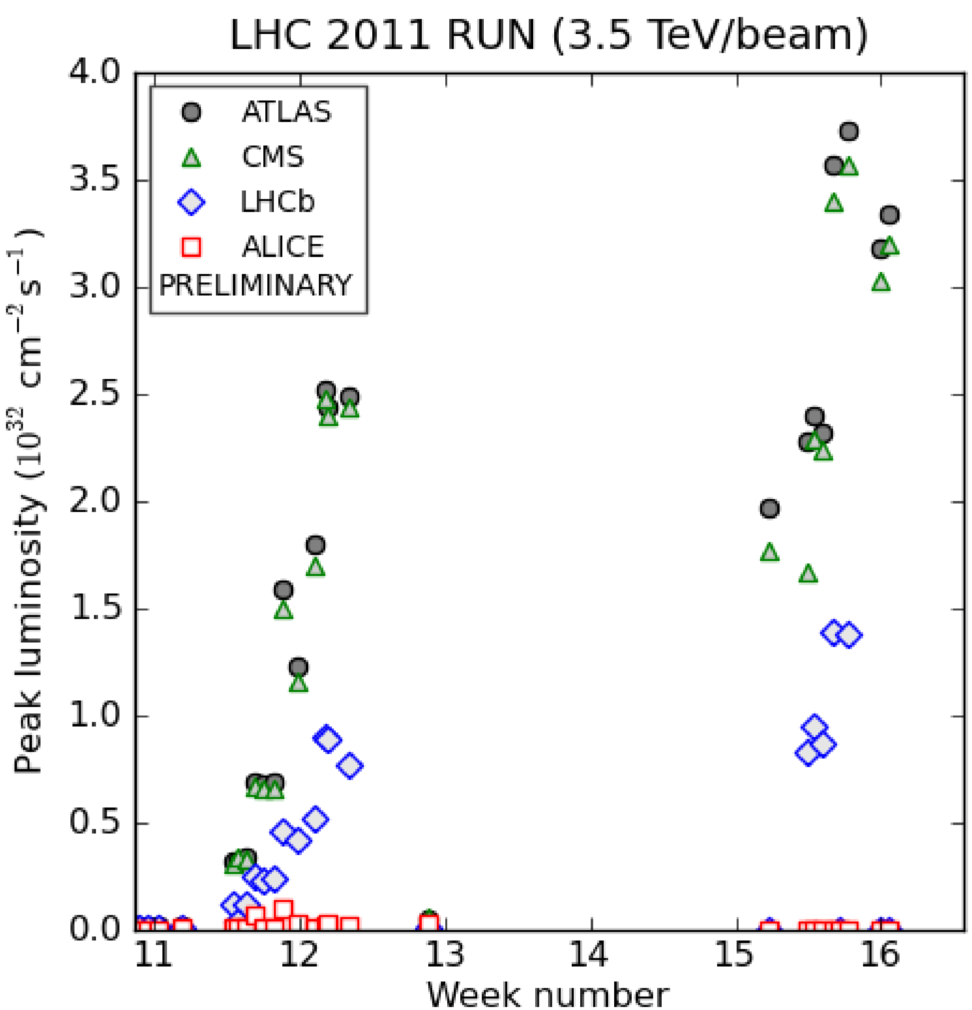
Many high-quality physics papers have been published already...
and there are many more to come



The LHC is a quarkonium factory !
There is a huge potential out there

Perspectives and challenges in 2011

The LHC will be running at challenging peak luminosities, soon in excess of 10^{33} $cm^{-2}s^{-1}$!!!
ATLAS and CMS will be hunting the Higgs and the neutralino… exploiting every lumi drop…



Limitations, complementarities, challenges, needs

CMS and ATLAS cover mid-rapidity (and high p_T); LHCb and ALICE cover forward y and low p_T

It is difficult for ATLAS to resolve the three Υ states; easy for LHCb and CMS

It is difficult for LHCb to study high p_T quarkonium production; easy for ATLAS and CMS

Only ALICE can study J/ψ production at low p_T and mid-y, but with low statistics (electrons)

LHCb will not run at more than around 2 x 10^{32} $cm^{-2}s^{-1}$ or so; good to reduce pileup, which might be important for correlation analyses like J/ψ plus photon, Υ plus open beauty, etc

All experiments have limited trigger bandwidth and need to set priorities !
Some triggers will have to be prescaled:

1 fb^{-1} will not give us 100 times more Υ(3S) events than 10 pb^{-1} ☹

Quarkonium physics is not the main priority of the LHC experiments; manpower is an issue

All LHC experiments need a realistic MC event generator for quarkonium physics

Early plans revisited

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- ❑ Polarization of χ_{c1} and χ_{c2} mesons
- ⌘ Polarization of χ_b (1P) and χ_b (2P) mesons ☺

The really hard measurements

The hardest challenges

⌘ Correlations between J/ψ mesons and leptons, photons, jets, surrounding hadrons

⌘ Correlations between Υ mesons and open beauty (b hadrons or b-tagged jets)

⌘ Measurement of the χ_c and χ_b polarizations

By the end of 2011, CMS could collect enough events to measure the polarizations of the quarkonia J/ψ, ψ(2S), Υ(1S), Υ(2S), and Υ(3S), with several 10^5 events in the worst case

To measure the χ_{c1} and χ_{c2} polarizations we would also need the 2012 data and significant improvements in the reconstruction of low-energy photon conversions

Can LHCb and ATLAS do better ?

Dreams do not (yet) pay taxes ☺