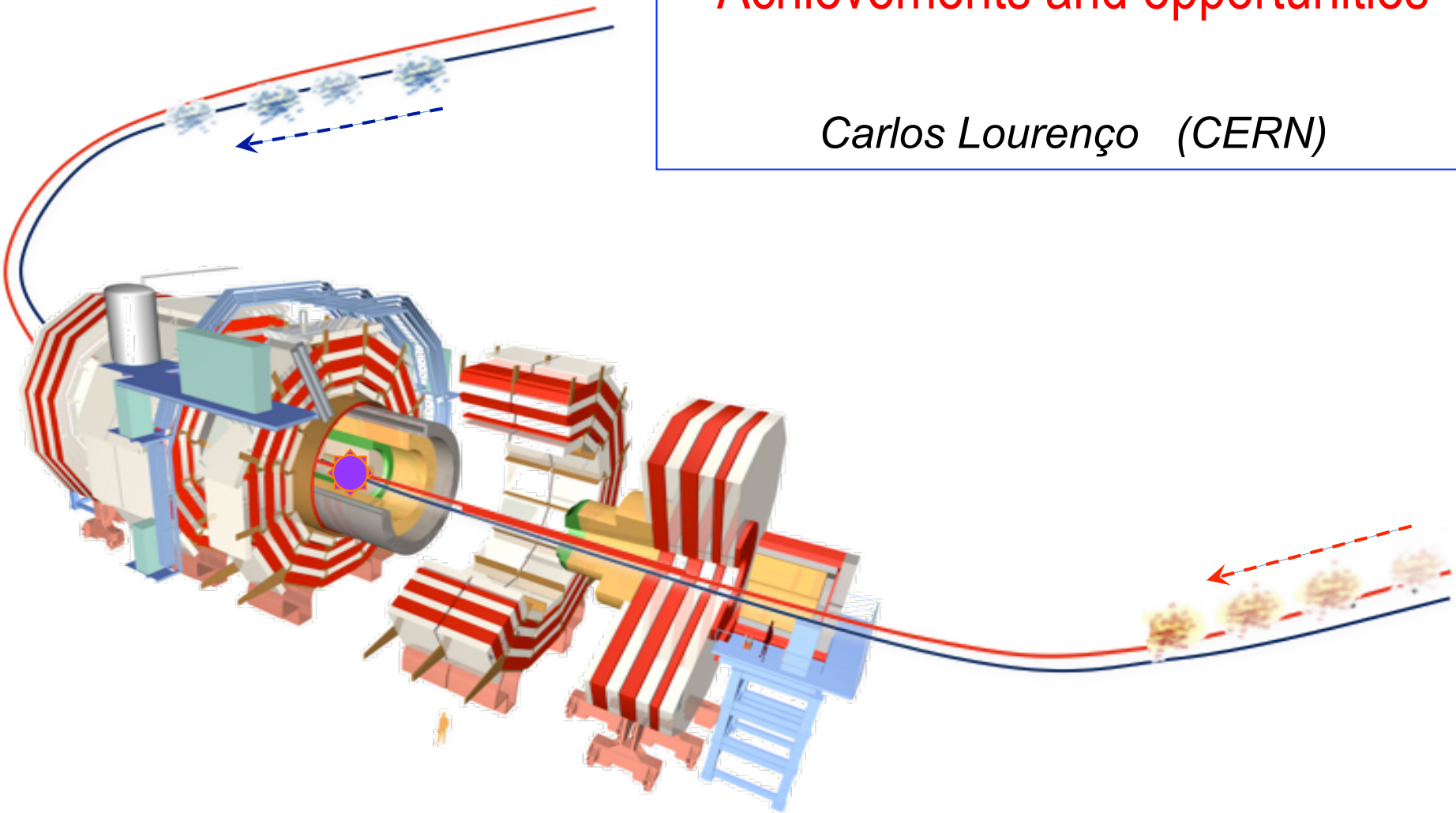
Quarkonium production in pp collisions with CMS

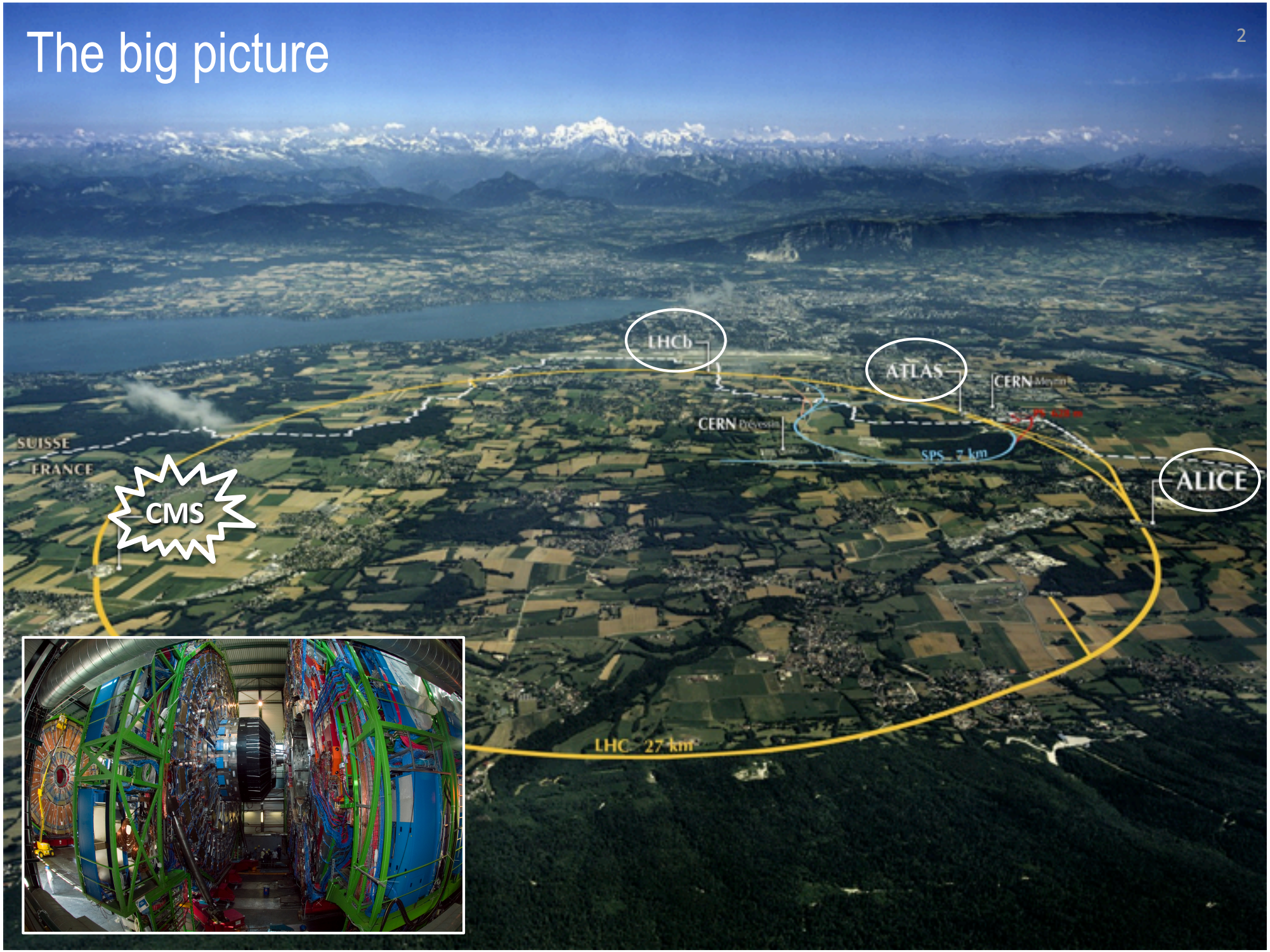
Achievements and opportunities

Carlos Lourenço (CERN)



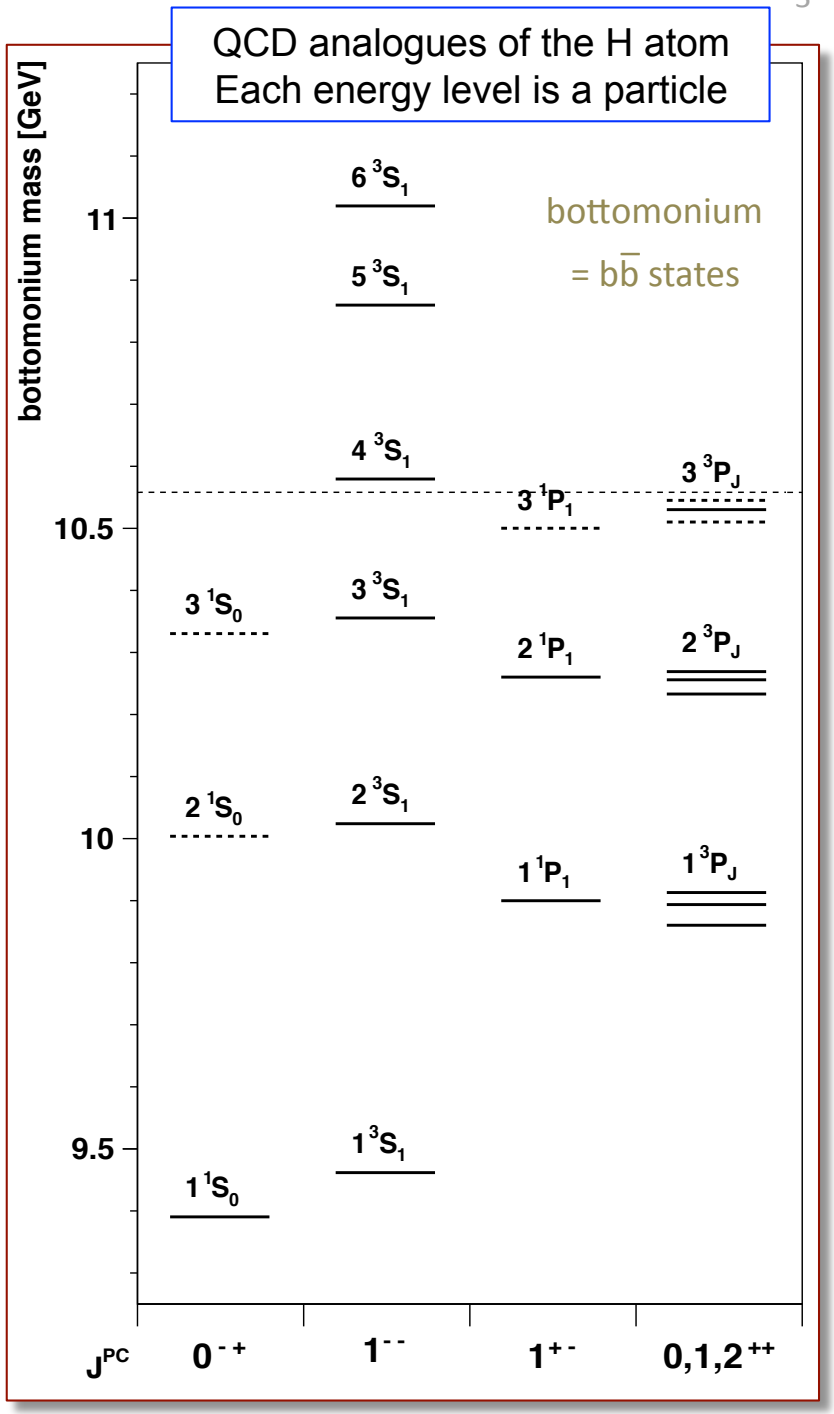
for the CMS collaboration Hard Probes 2012 *Cagliari, May 29th, 2012*

The big picture



Basics

Quarkonia:
bound states of *heavy* quark-antiquark pairs, studied with non-relativistic QCD



Basics

Quarkonia:
bound states of *heavy* quark-antiquark pairs, studied with non-relativistic QCD

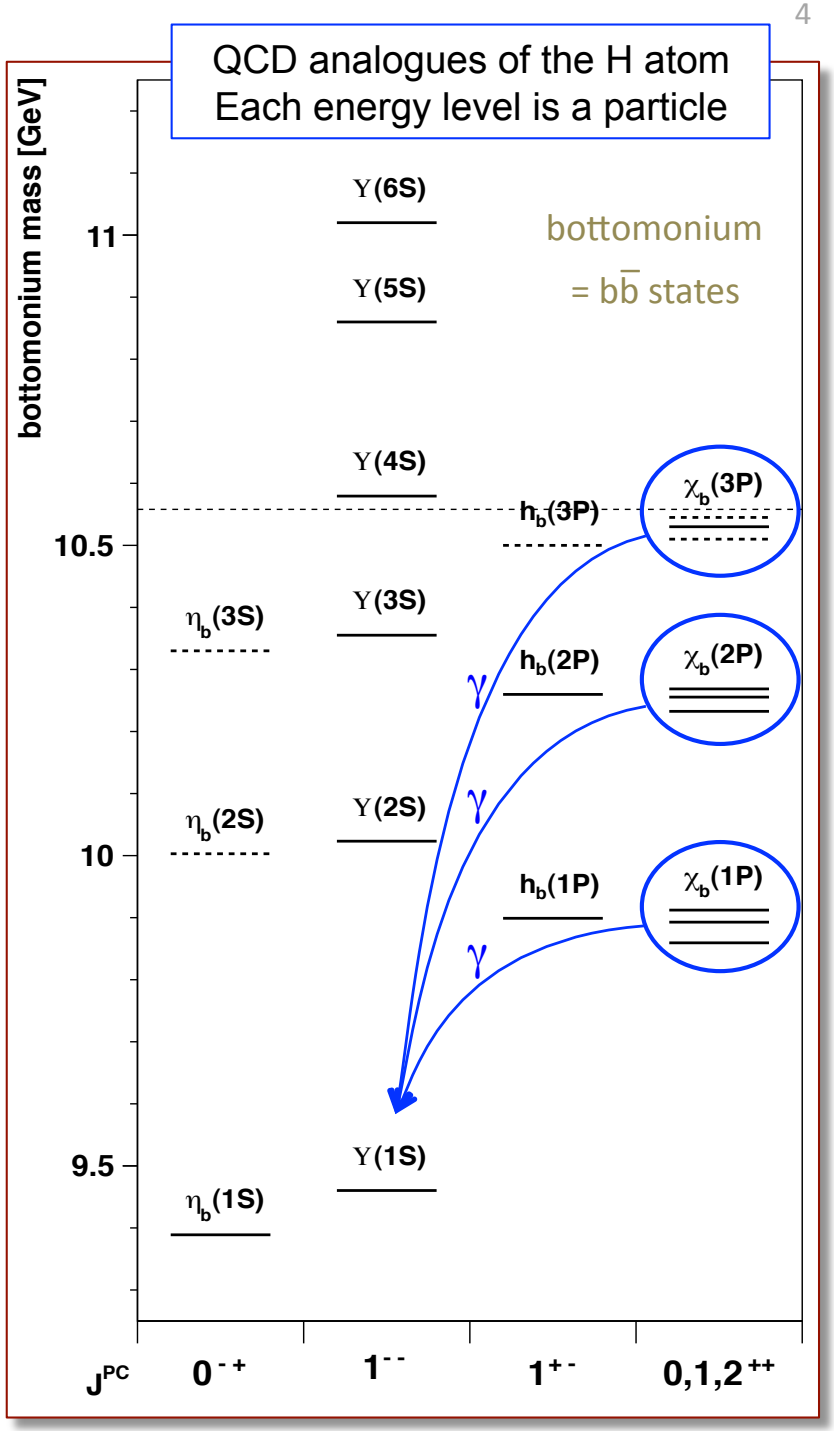
<u>An important goal for CMS:</u>

Cross section and polarization measurements of S and P states in high-energy pp collisions

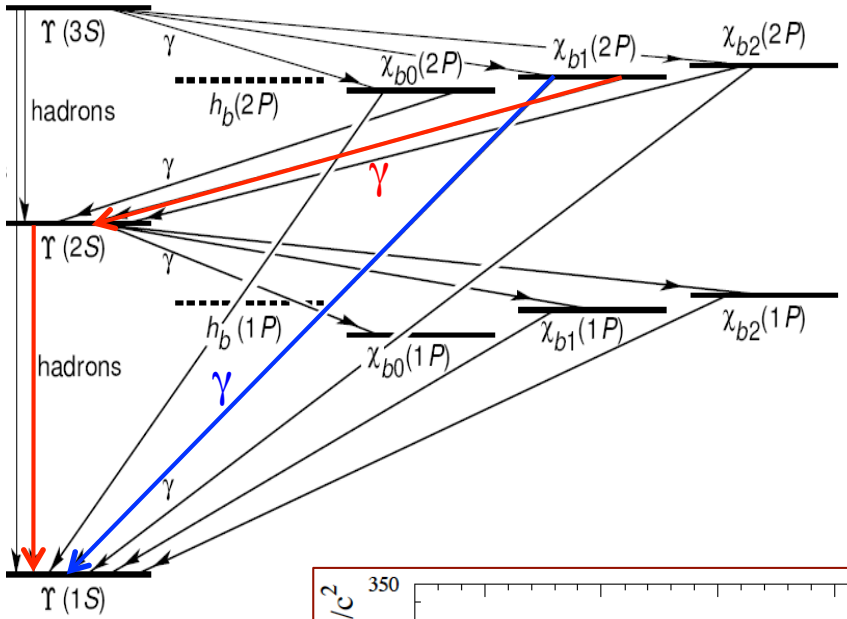
Extremely challenging measurements !

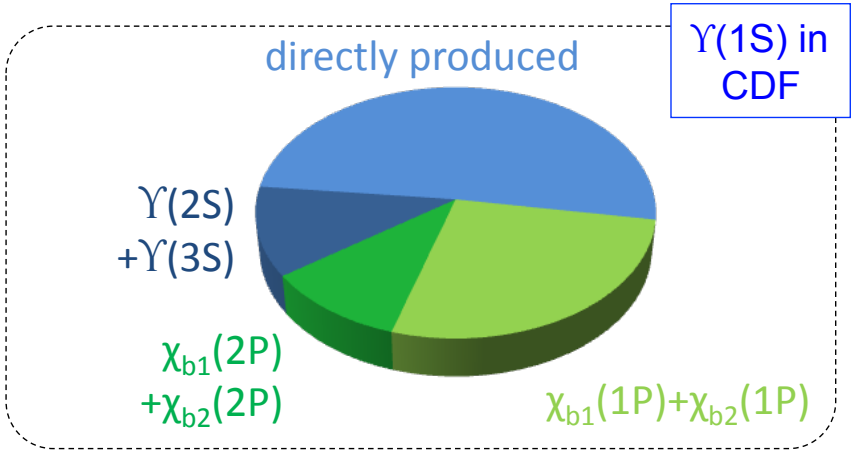
Especially the polarizations of the χ_c and χ_b states, which will provide very effective tests of QCD

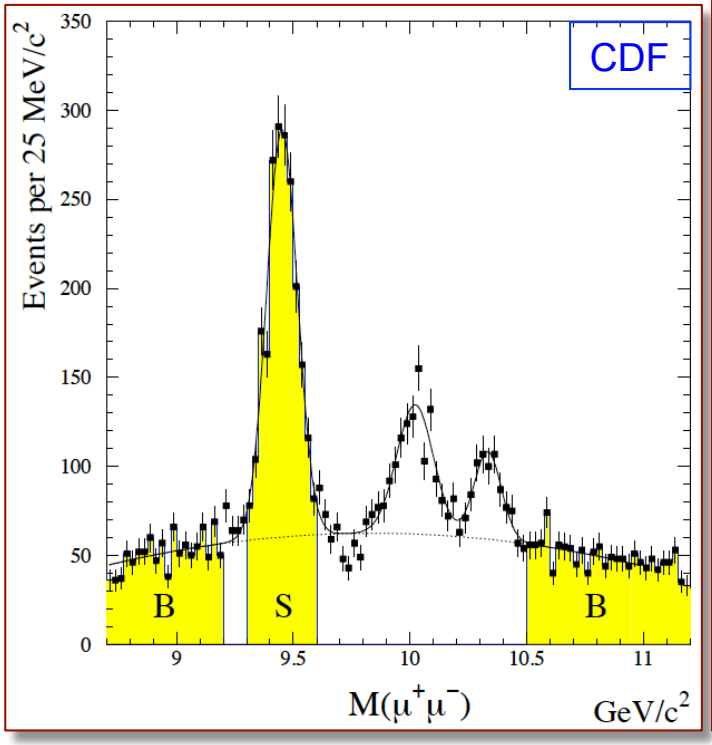
Upsilons are easy to detect via dimuon decays; the χ_b states are very challenging: difficult to detect low energy photons



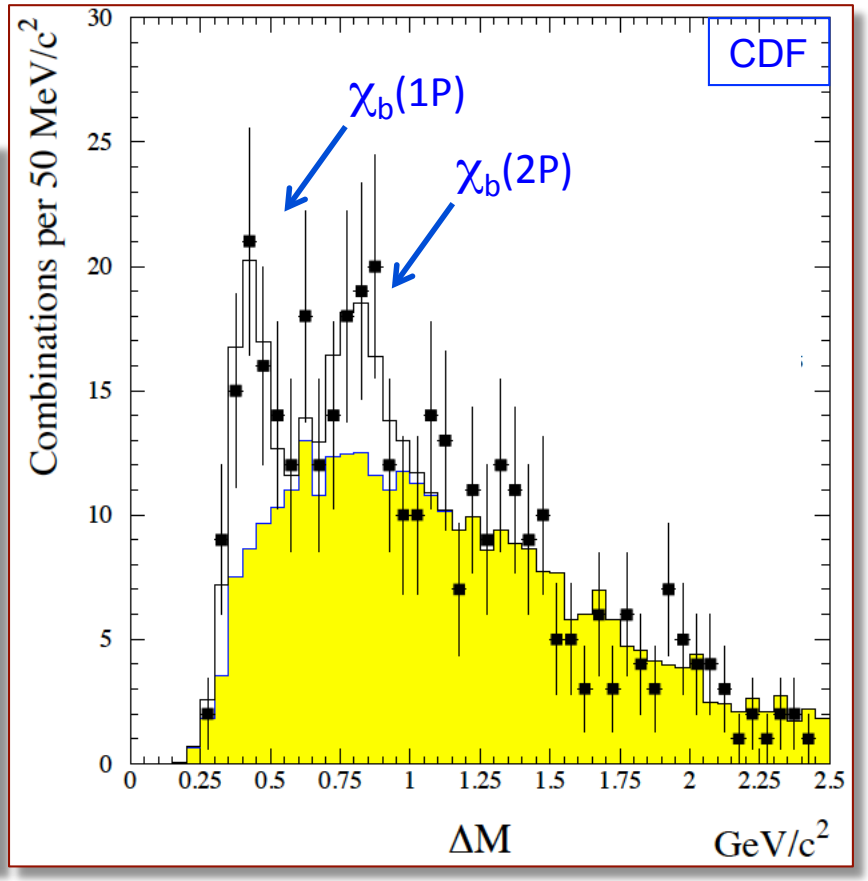
Previous knowledge to give the context







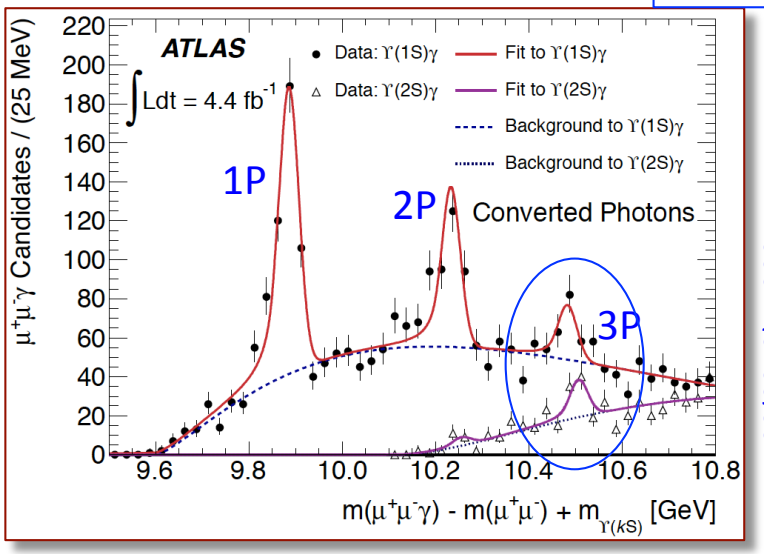
PRL84 (2000) 2094



Headlines ☺

ATLAS: $\chi_b \rightarrow \Upsilon + \gamma$ decays

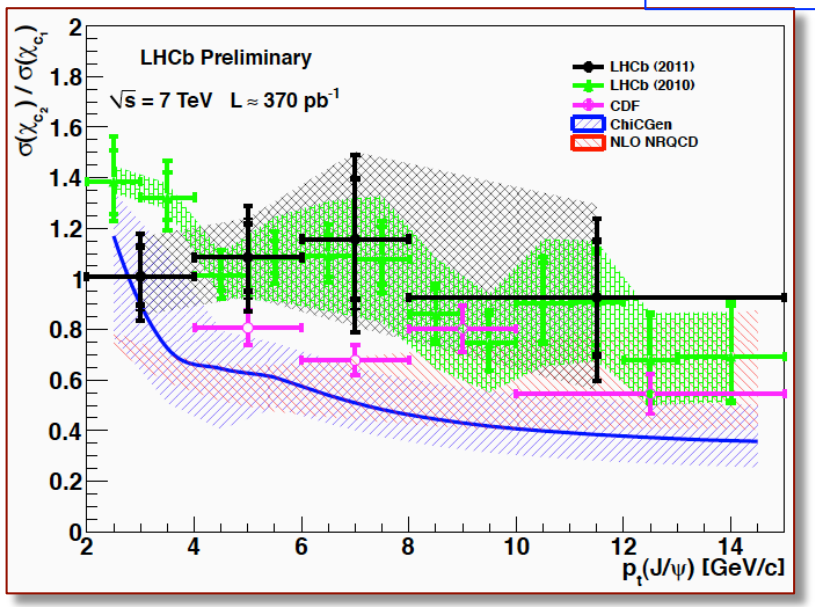
χ_b mass spectrum



PRL108(2012)152001

LHCb: $\chi_c \rightarrow J/\psi + \gamma$ decays

χ_{c2} / χ_{c1} cross-section ratio

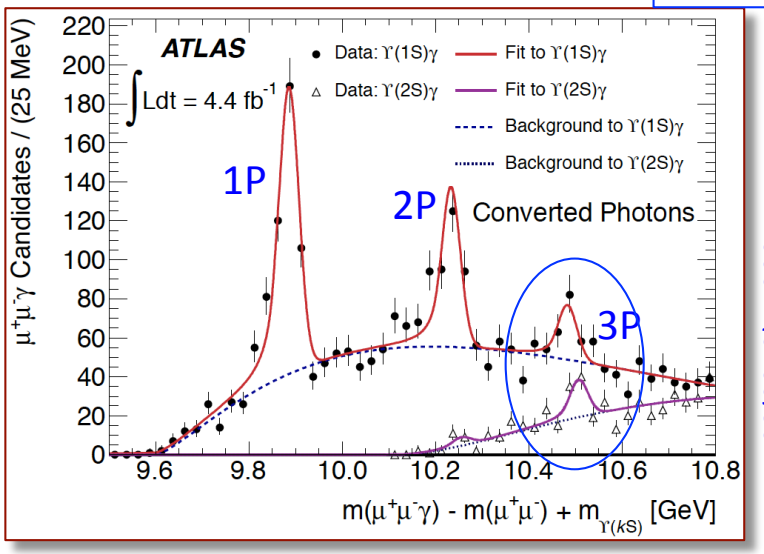


LHCb-CONF-2011-062

Behind the headlines

ATLAS: $\chi_b \rightarrow \Upsilon + \gamma$ decays

χ_b mass spectrum



PRL108(2012)152001

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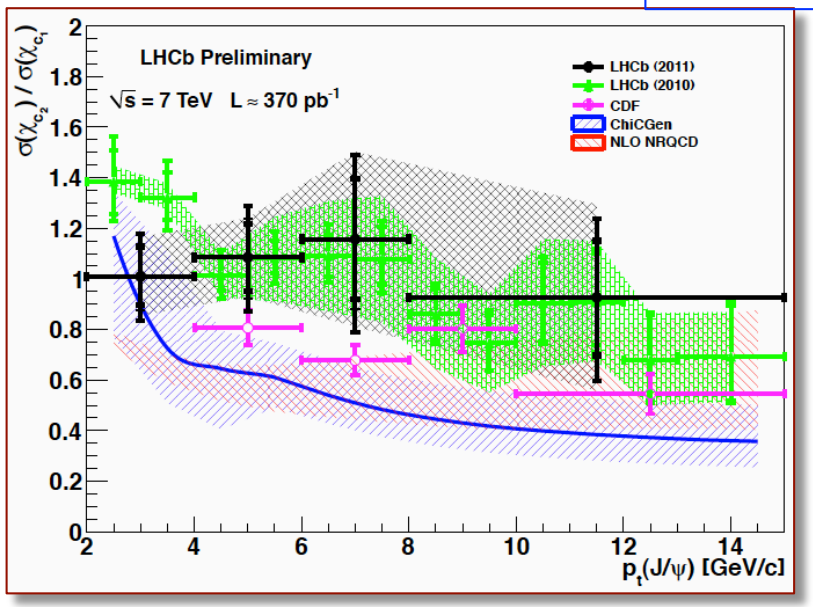
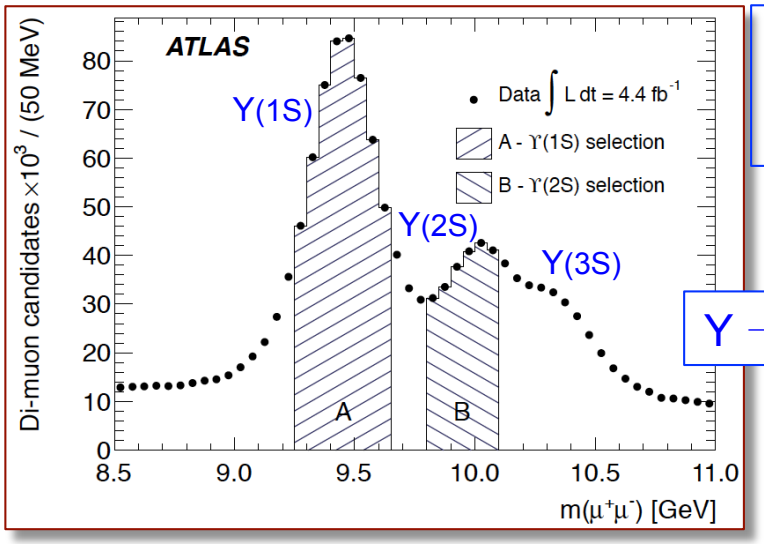
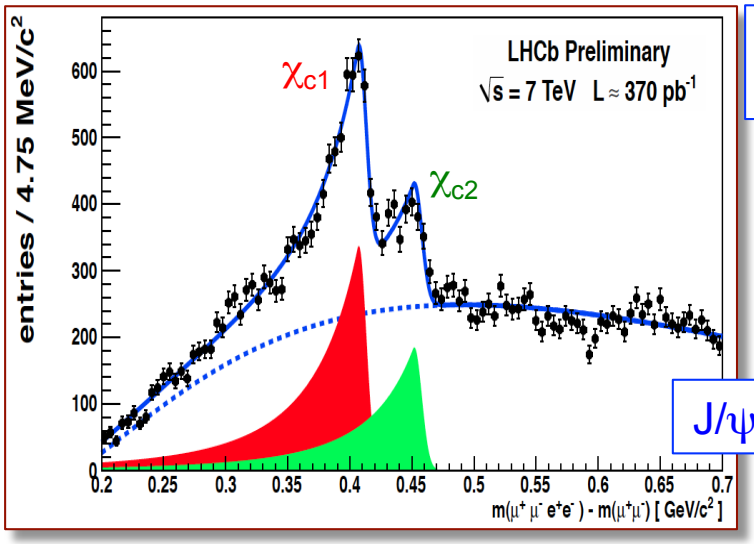


LHCb-CONF-2011-062



Upsilon mass spectrum

$\Upsilon \rightarrow \mu^+\mu^-$

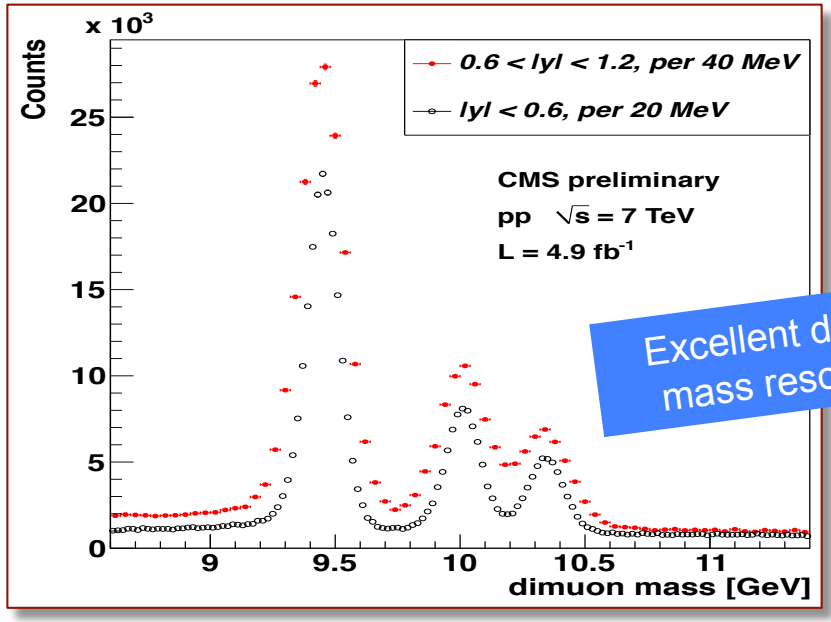


χ_c mass spectrum

$J/\psi \rightarrow \mu^+\mu^-$

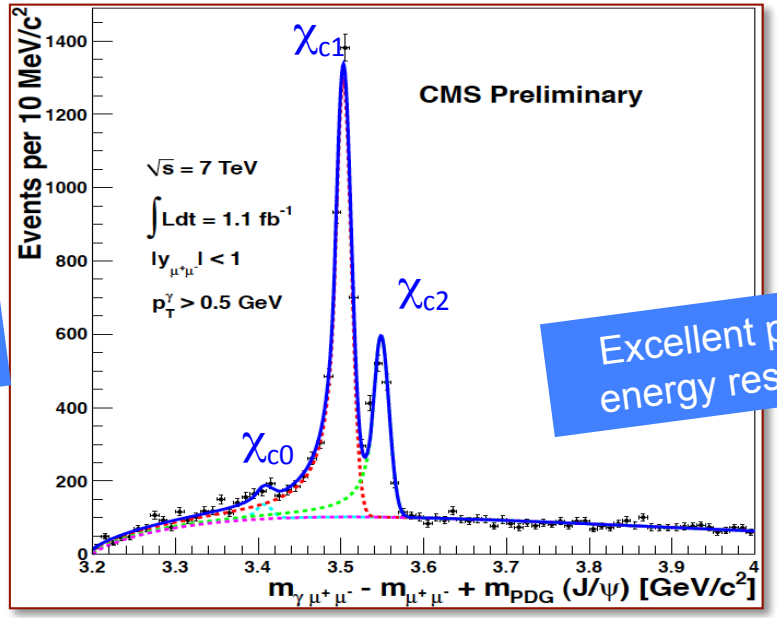
CMS potential

CMS: $\Upsilon \rightarrow \mu^+\mu^-$ decays

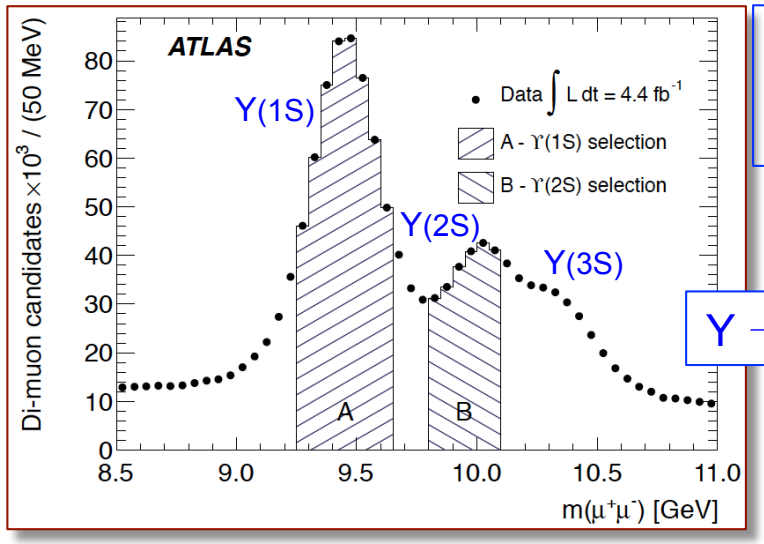


Excellent dimuon mass resolution

CMS: $\chi_c \rightarrow J/\psi + \gamma$ decays



Excellent photon energy resolution



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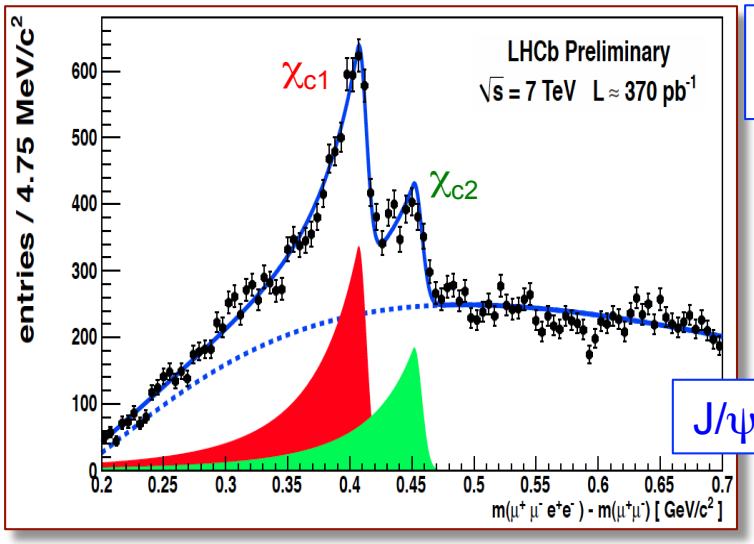
$\Upsilon \rightarrow \mu^+\mu^-$

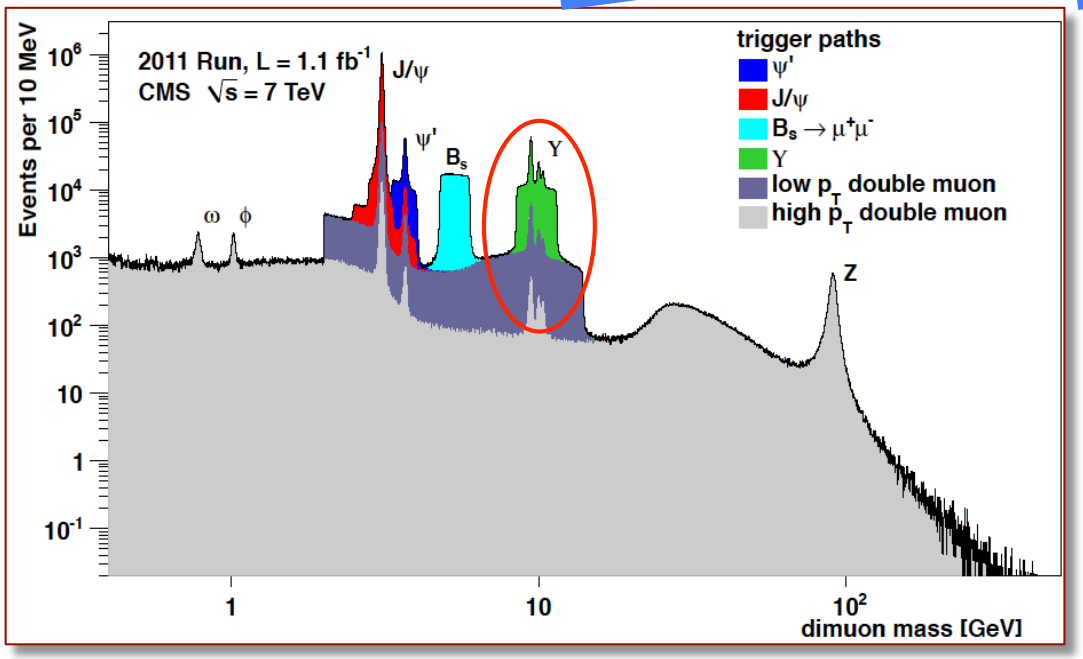


χ_c mass spectrum

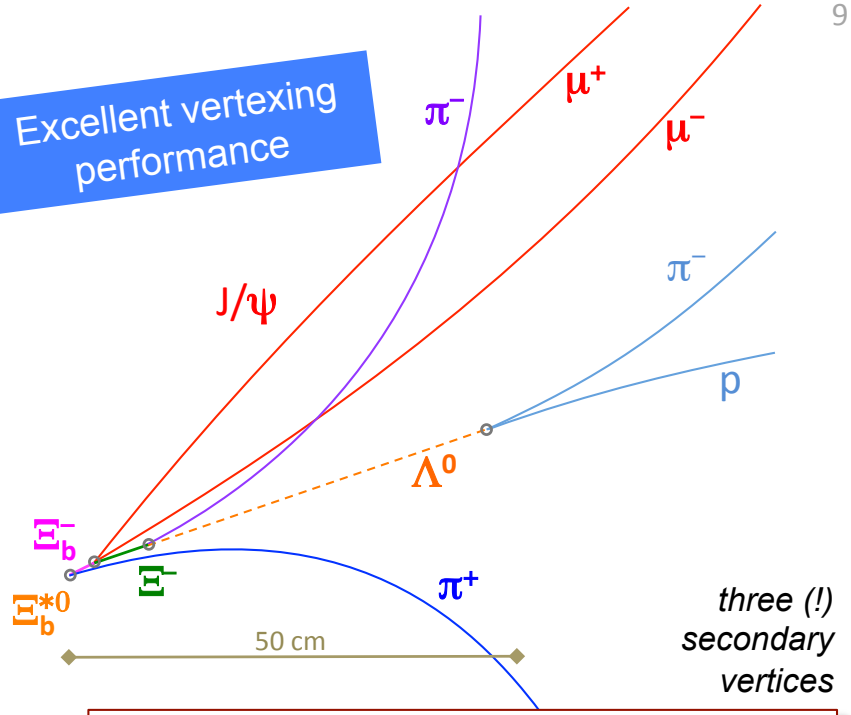
$J/\psi \rightarrow \mu^+\mu^-$

CMS potential

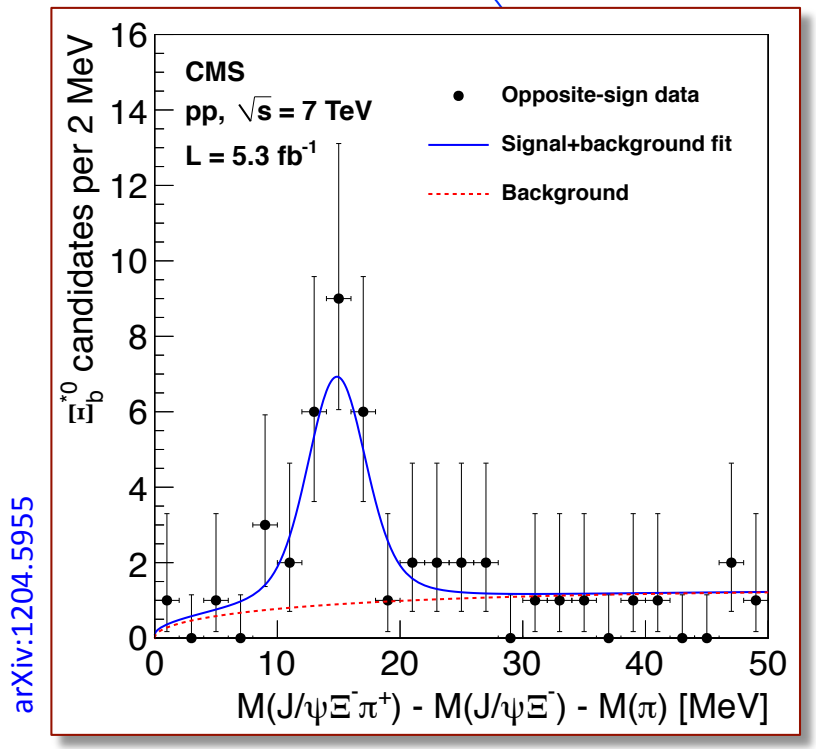
Very flexible L1+HLT trigger



Excellent vertexing performance



three (!) secondary vertices

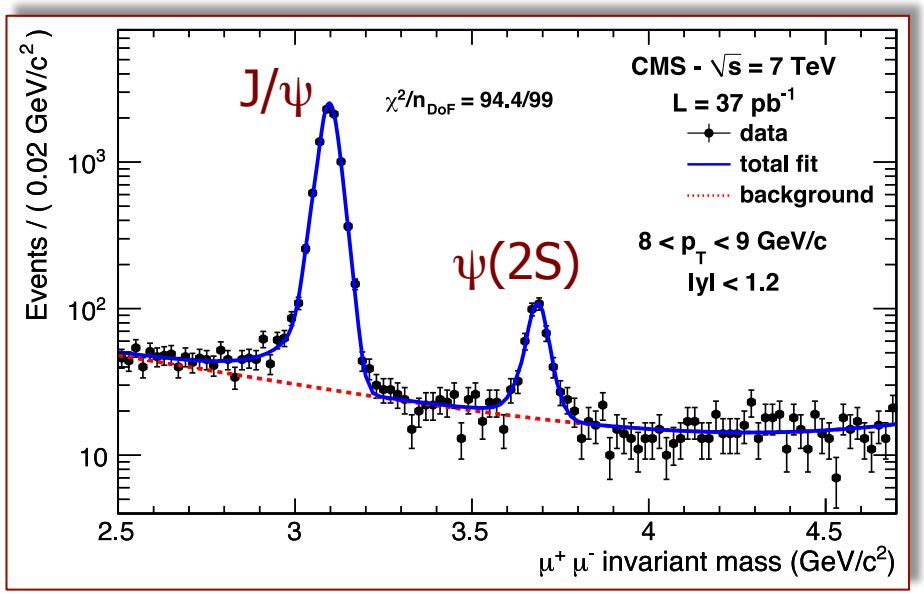


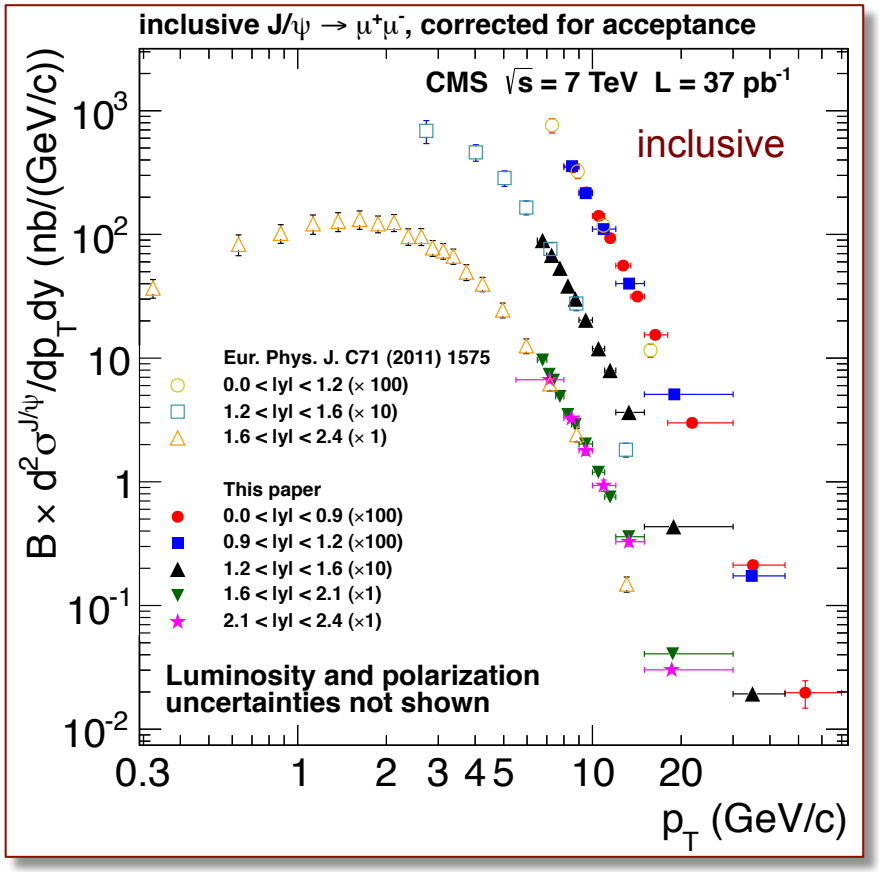
arXiv:1204.5955

Large silicon tracker, strong magnetic field, very broad acceptance, powerful trigger and DAQ

Ideally suited to study quarkonium physics

Charming achievements





The J/ψ cross section has been measured over a large p_T range and in several rapidity bins, before and after separating the prompt and non-prompt components

The dimuon acceptance strongly depends on the assumed polarization
Default assumption = unpolarized production

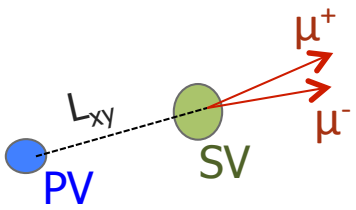
Inclusive = prompt + non-prompt

JHEP02 (2012) 011

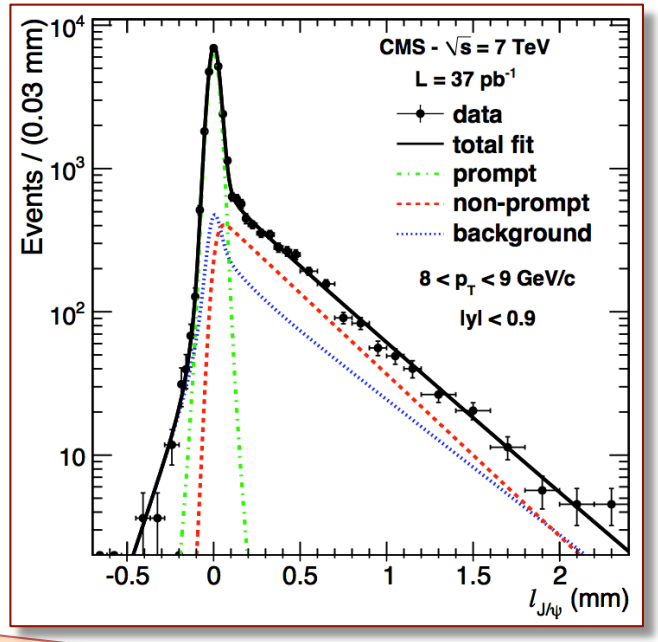
Charming achievements

Two-dimensional fit of invariant mass and "pseudo-proper" decay length resolves the prompt, non-prompt and background components

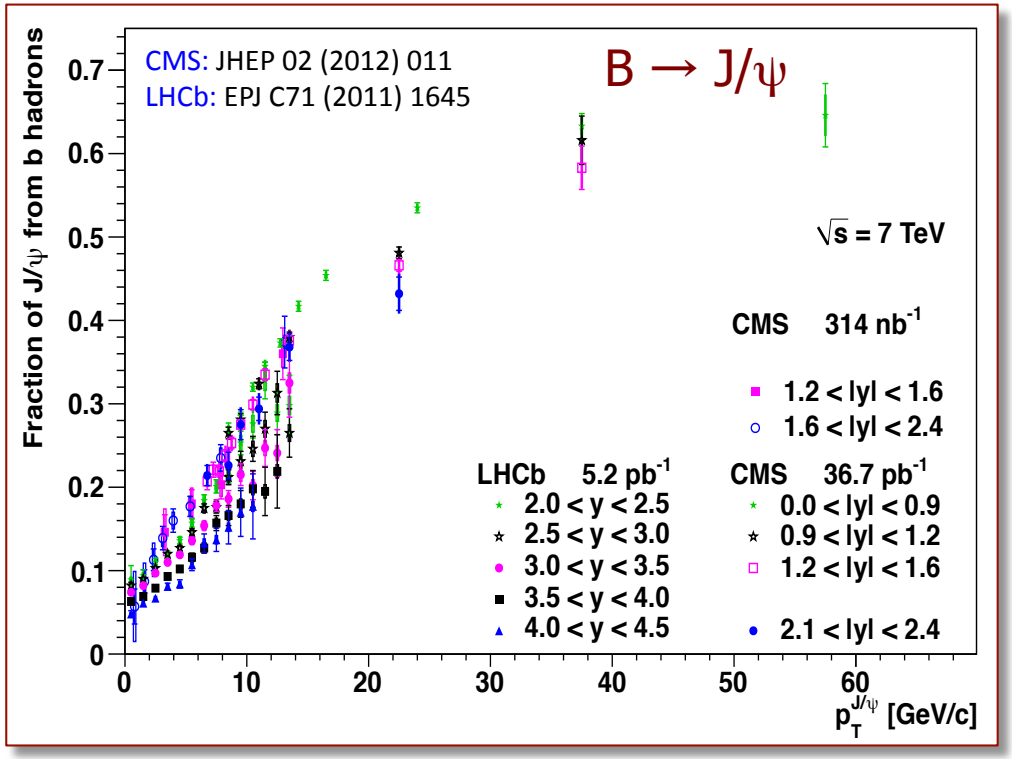
$$l_{J/\psi} = \frac{L_{xy} \cdot m_{J/\psi}}{p_T}$$

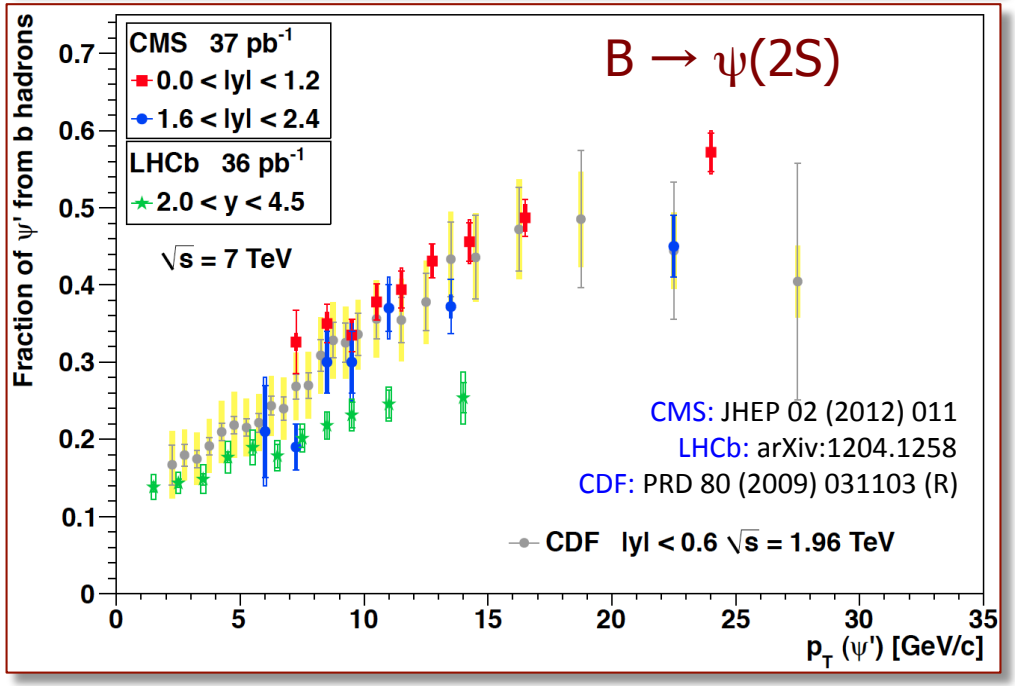


Above p_T ~ 20 GeV, more than half of the J/ψ and ψ(2S) mesons are from B decays



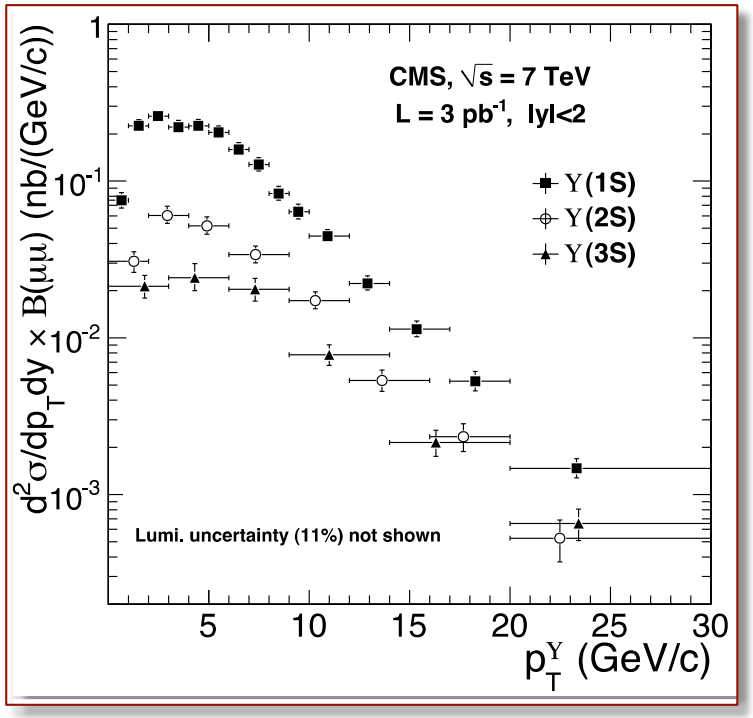
JHEP02 (2012) 011

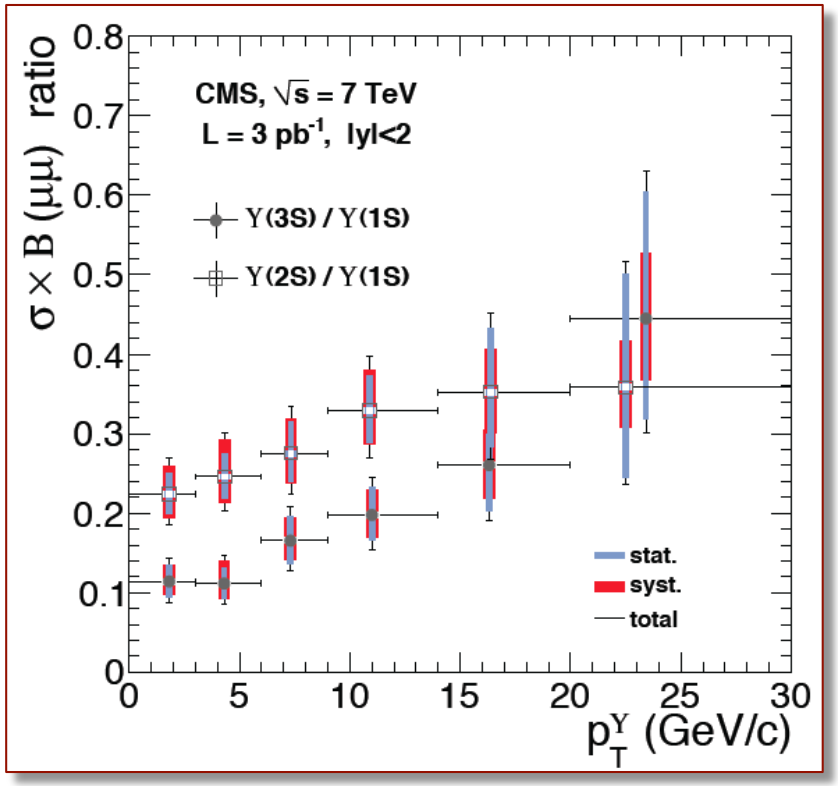


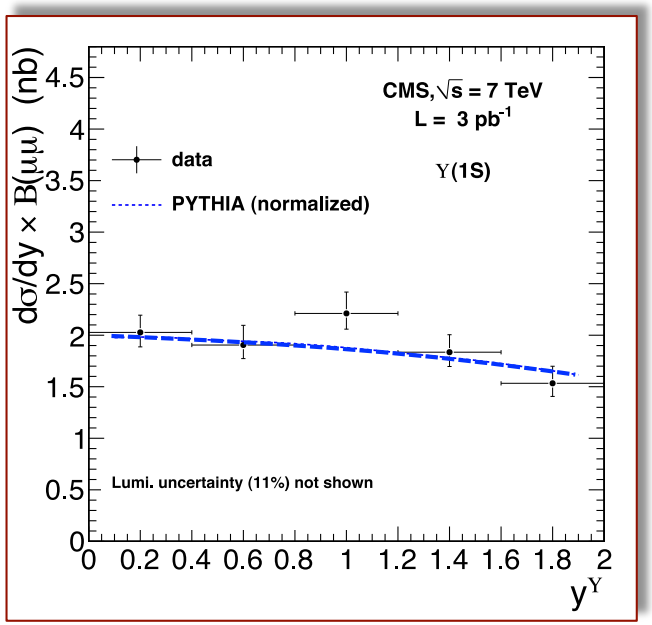


compilations by H.K. Wöhri

Beautiful achievements







CMS has good acceptance for Upsilon detection, down to zero p_T

Heavier states have harder p_T distributions

Feed-down contributions to the Υ(1S) state change with p_T and are particularly large at high p_T

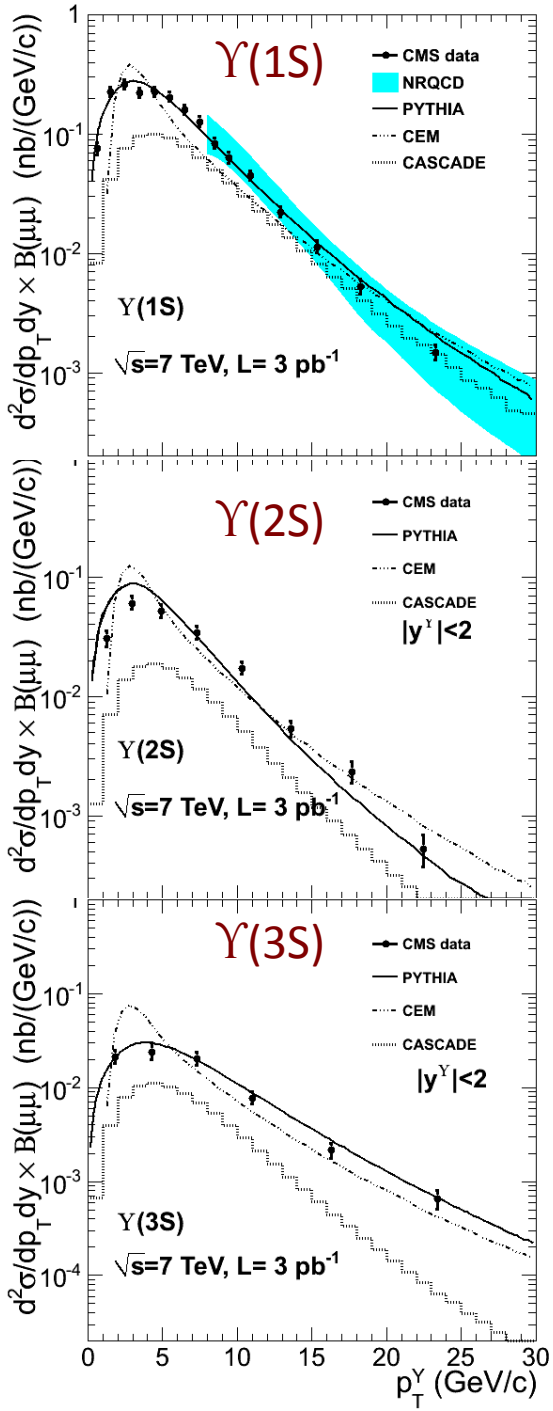
Υ(1S) production is relatively flat in rapidity

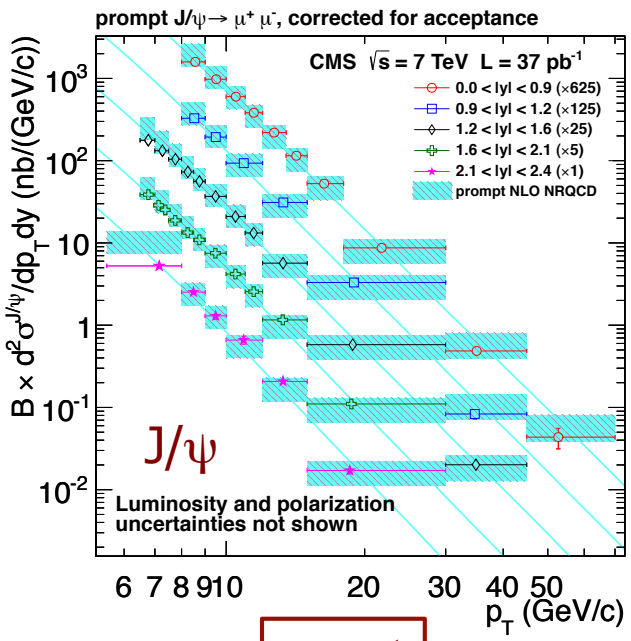
PRD 83 (2011) 112004

Theory meets data

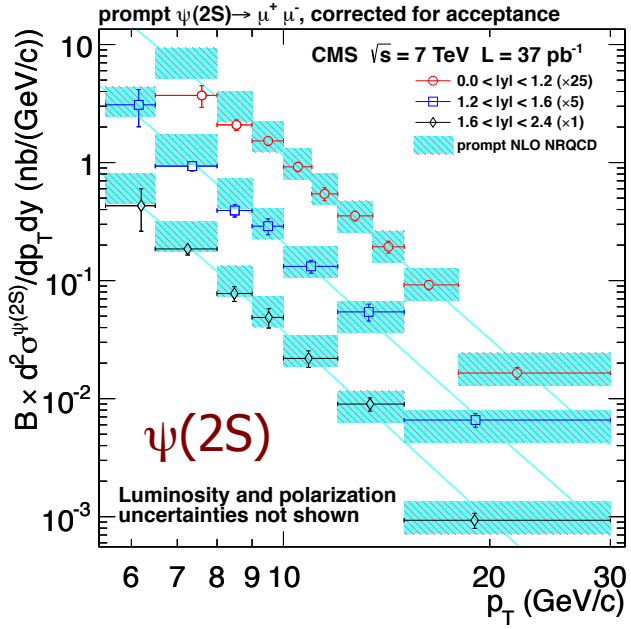
Good agreement between the measured cross sections and the theory calculations, for the five S-wave states

Extreme polarization scenarios change results by around 20–30 %





prompt

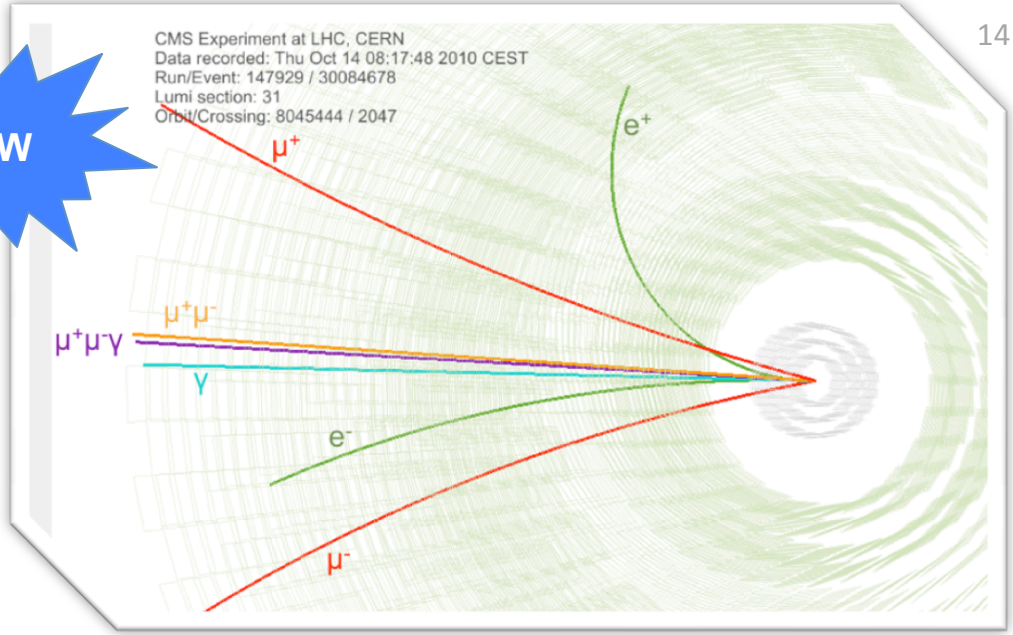


Surfing the P waves

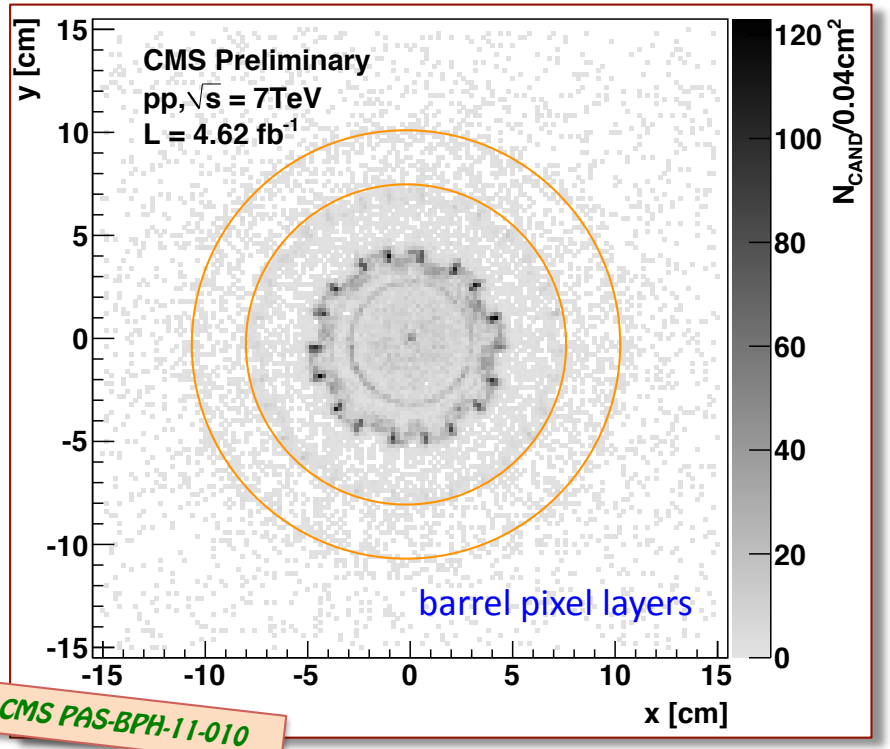
Production of χ_c mesons studied via $\chi_c \rightarrow J/\psi + \gamma$ radiative decays, with tracker-seeded γ conversions to e^+e^-

Dimuon sample, L = 4.6 fb^{-1}
Collected with a J/ψ trigger

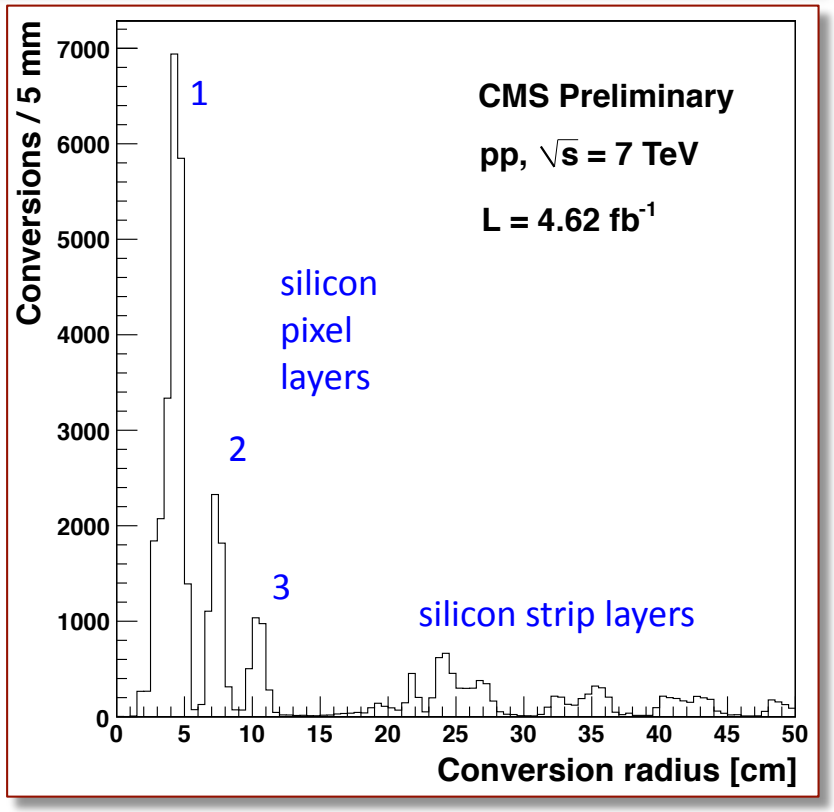
NEW



Conversions reconstructed for R > 1.5 cm



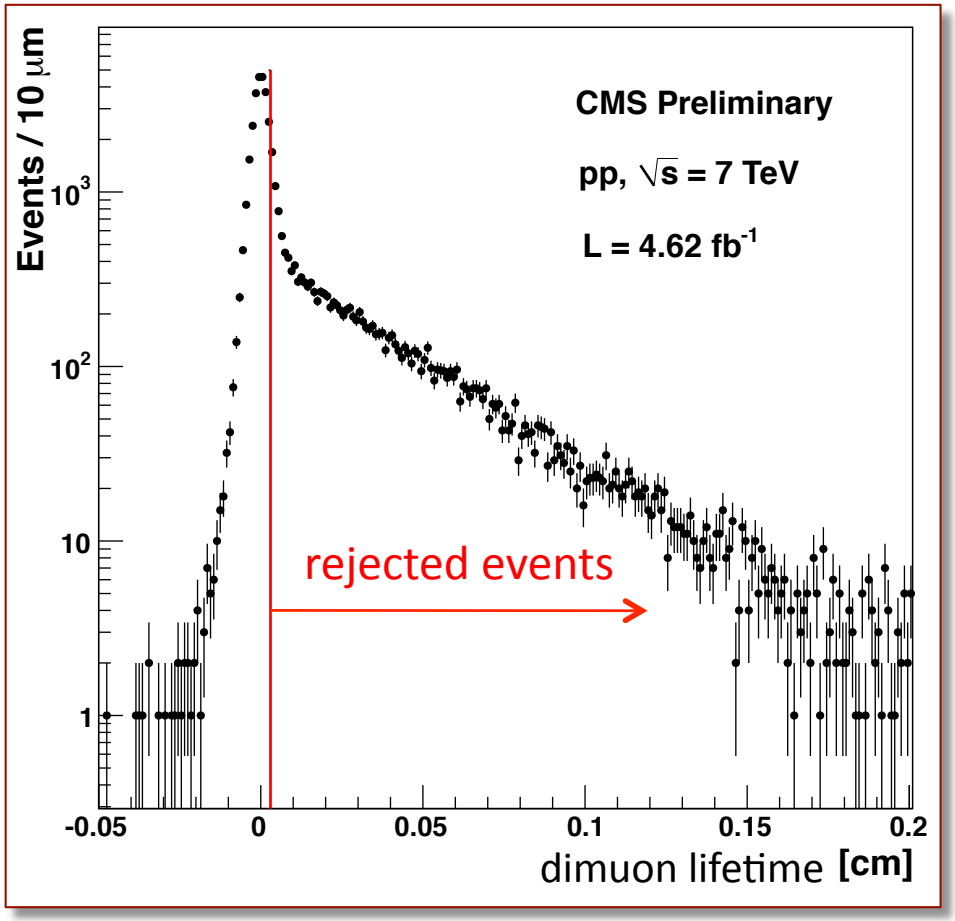
CMS PAS-BPH-11-010

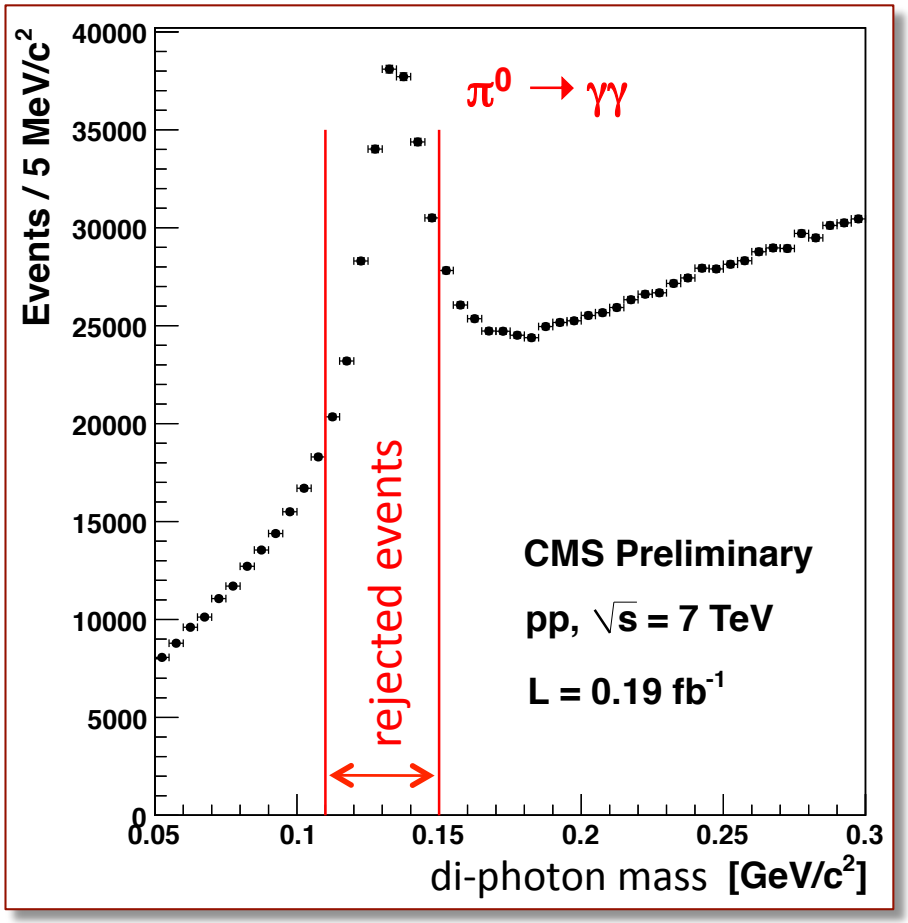


Backgrounds from B and π^0 decays

To study χ_c *prompt* production, we minimize feed-down from B decays by rejecting the displaced dimuons

To minimize the photon background from π^0 decays, we reject photons that, combined with other photons in the event, give the π^0 mass





CMS PAS-BPH-11-010

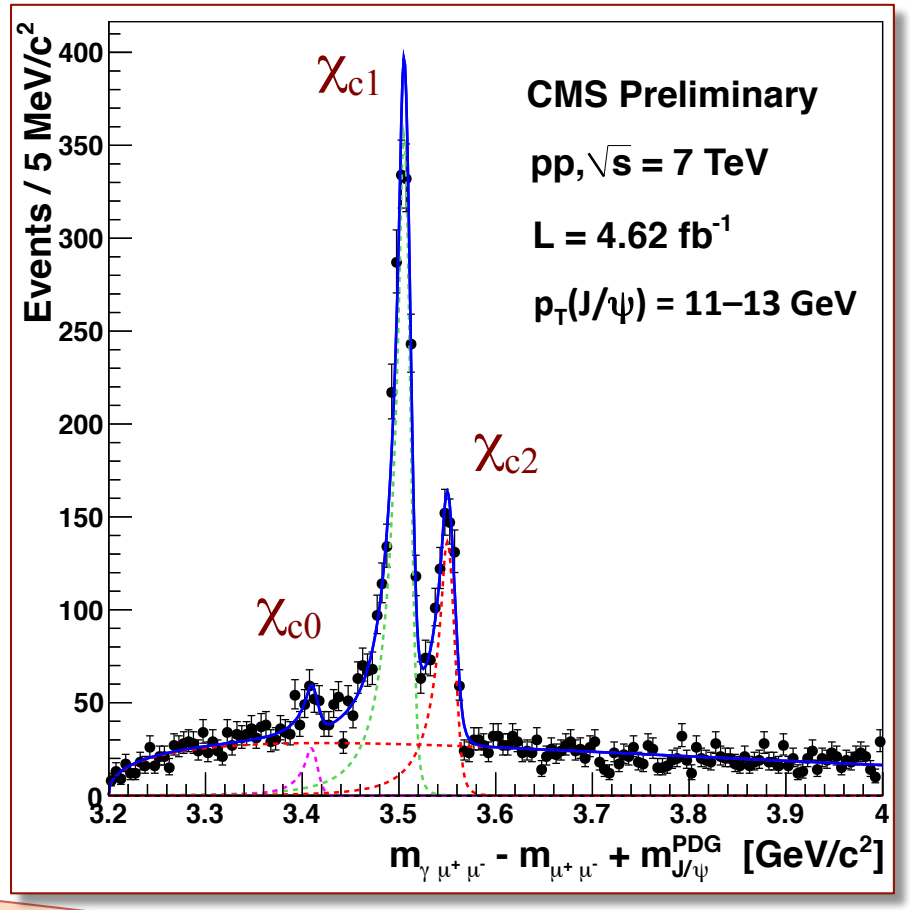
Mass resolution vs. detection efficiency

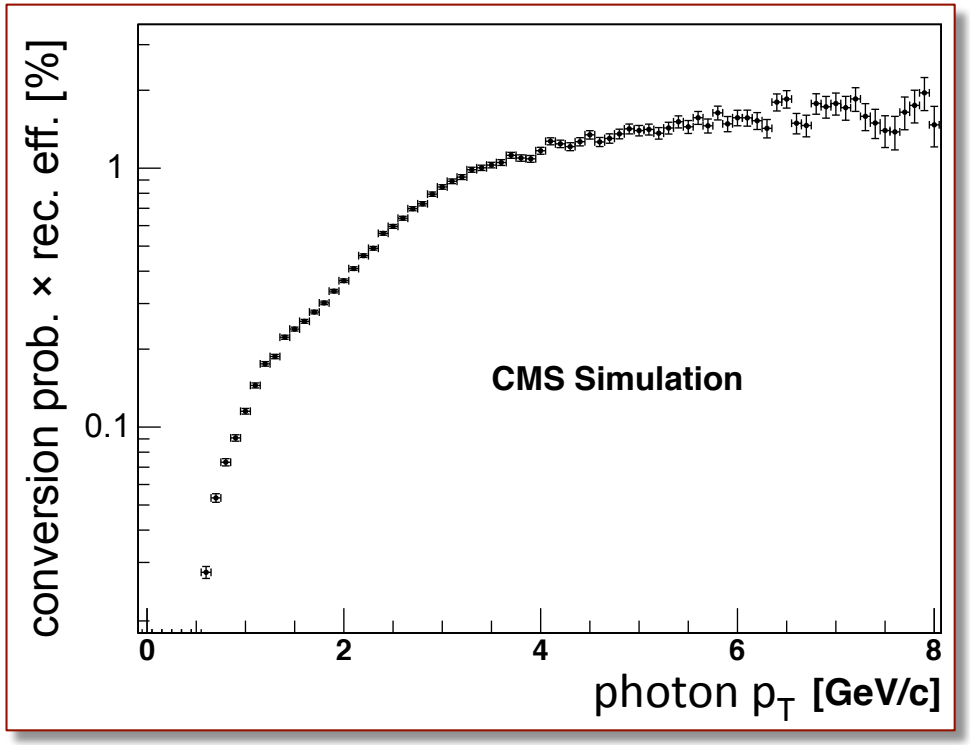
Excellent mass resolution (~6 MeV) provided by the photon conversions comes together with a low identification efficiency

The photons emitted in χ_c decays have around 1% probability to *convert* in the pixel layers and be reconstructed

In the χ_{c2} / χ_{c1} cross-section ratio, this efficiency cancels almost completely

dimuon |y| < 1.0; $p_T(\gamma)$ > 0.5 GeV





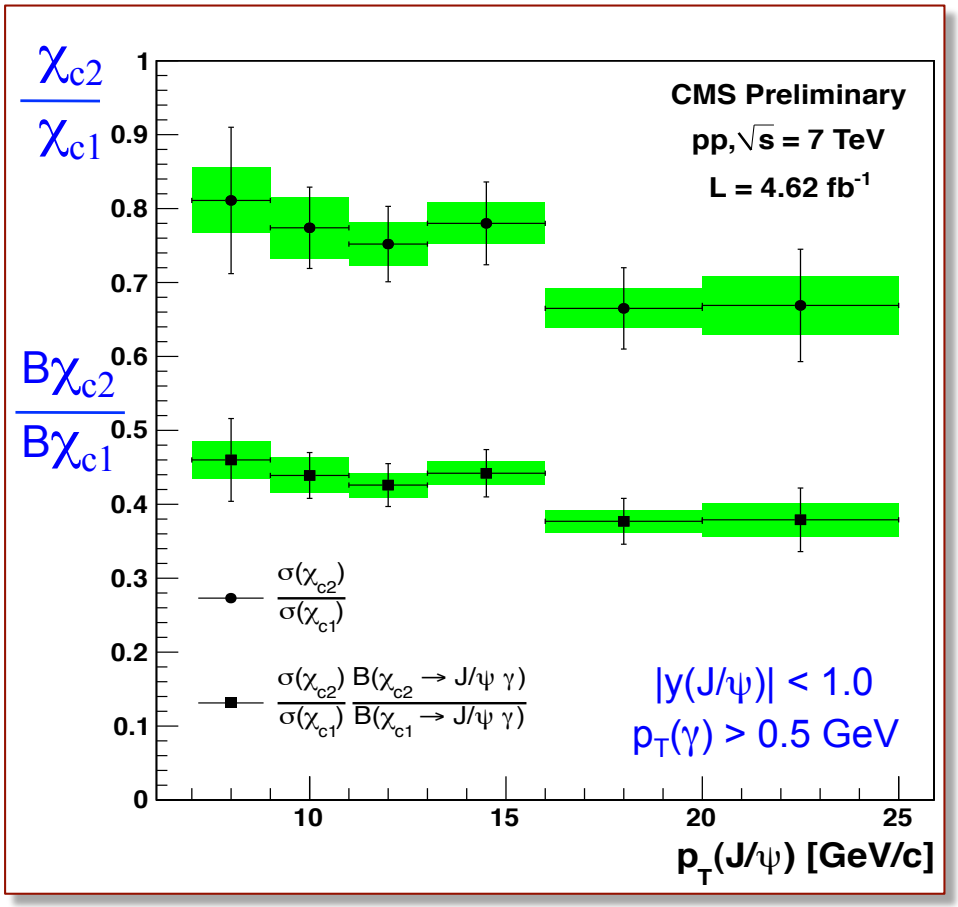
CMS PAS-BPH-11-010

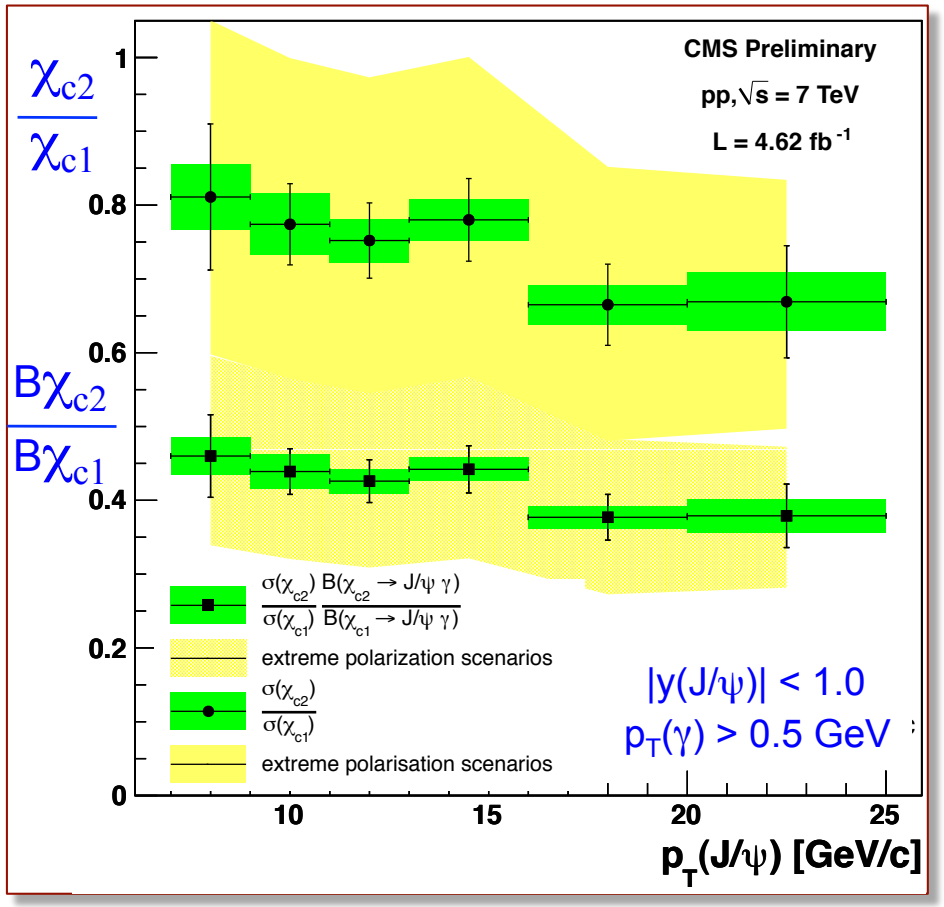
The results…

NEW

The χ_{c2} / χ_{c1} cross-section ratio has been measured vs. p_T
Up to much higher p_T and with smaller uncertainties than previous measurements
Systematic uncertainties dominated by fit to mass distribution

To compare with theory calculations, much care is needed regarding the polarizations (which can change the results by up to around ±25%)





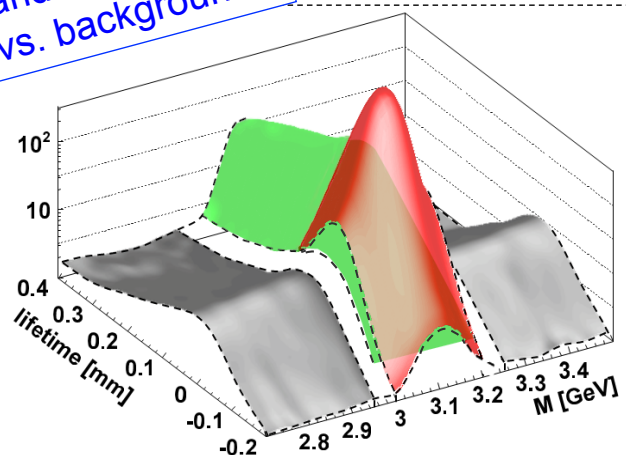
CMS PAS-BPH-11-010

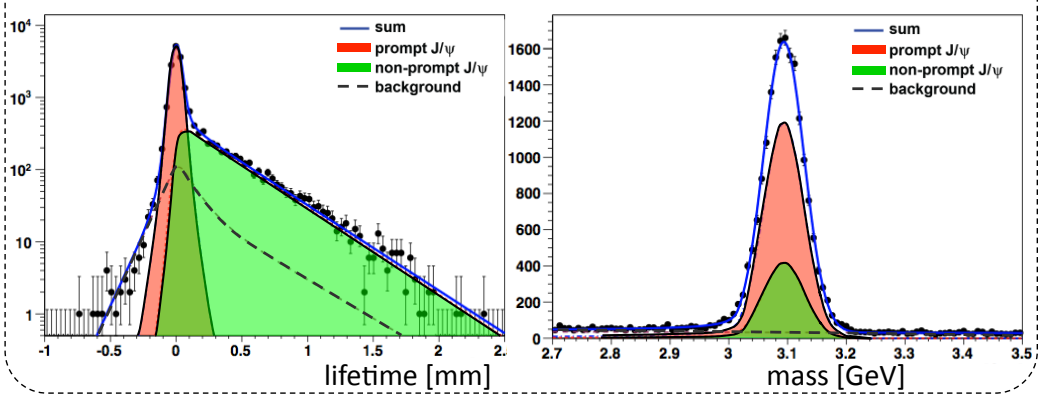
Perspectives: quarkonium polarization

Multidimensional analysis:
rapidity, p_T, dimuon mass, lifetime, cos θ, ϕ

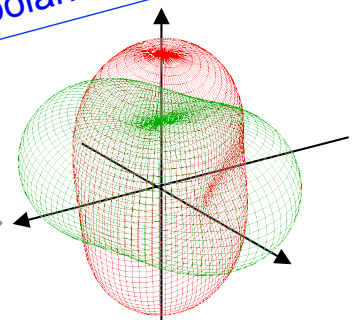
$$\frac{dN}{d\Omega} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi$$

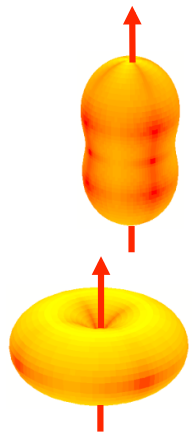
mass and lifetime
→ signal vs. background





cos θ & φ
→ polarization



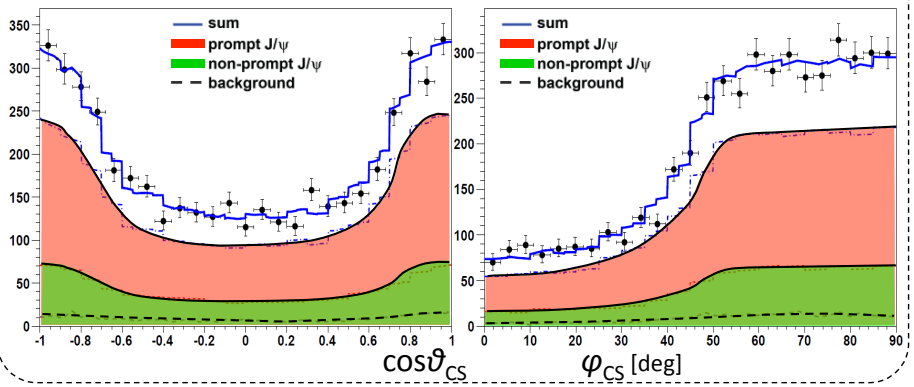


$J_z = \pm 1$

$\lambda_\theta = +1$

$J_z = 0$

$\lambda_\theta = -1$



Very interesting but also *very challenging* measurement; needs to be made with extreme care

Wrap up

CMS has a fantastic potential for high-quality quarkonium measurements

Several S-wave cross section measurements have been made with 2010 data
The χ_{c2} / χ_{c1} cross-section ratio has been measured with 2011 data

The menu will "soon" be complemented with:

- ✧ more studies of P-wave states: χ_c and χ_b (cross-section ratios, etc)
- ✧ polarizations of S-wave states: J/ψ, ψ(2S), Υ(1S), Υ(2S), Υ(3S)

Long-term perspectives (aka dreams) include polarizations of P-wave states ☺

Biblio

all information in
twiki/bin/view/CMSPublic/PhysicsResultsBPH

Prompt and non-prompt J/ψ production
EPJC 71 (2011) 1575 [L_{int} = 314 nb^{-1}]

J/ψ and ψ(2S) production
JHEP 02 (2012) 011 [L_{int} = 37 pb^{-1}]

Υ production cross section
PRD 83 (2011) 112004 [L_{int} = 3 pb^{-1}]

Backup: CMS vs. LHCb and CDF

χ_{c2} / χ_{c1} cross-section ratio by CMS, LHCb and CDF, for different rapidity windows and collision energies