Quarkonium Results at the LHC

Giulia Manca
(University of Cagliari and INFN , Italy)
On behalf of the Alice, Atlas, CMS and LHCb Collaborations

Physics at LHC 2011
Perugia, Italy, 6^{th}–11^{th} June 2011

Onia Contributions

Speaker	Title	Experiment	Day
G.Manca	Quarkonium results at the LHC	Alice, Atlas, CMS, LHCb	7.06.2011 (morning)
K.Piotrzkowski	Exclusive measurements (di-leptons and vector mesons) at CMS	CMS	7.06.2011 (evening)
V.Niess	Exclusive Dimuon measurements at LHCb	LHCb	7.06.2011 (evening)
K.Reeves	Quarkonium production at Atlas	Atlas	9.06.2011
H.Woehri	Quarkonia production at CMS	CMS	9.06.2011
C.Hadjidakis	J/psi measurements in p-p and Pb-Pb collisions at LHC with ALICE	Alice	9.06.2011

…And four posters!

Outline

➡Motivation

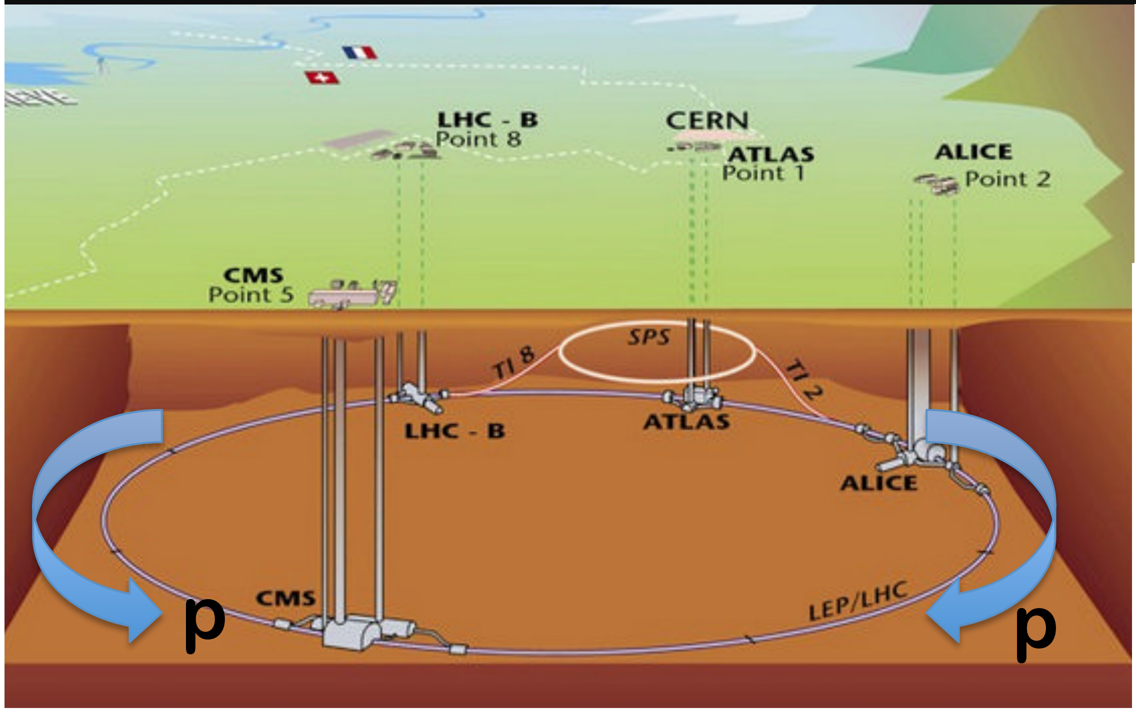
➡Cern and the LHC

➡The experiments

➡Some selected results

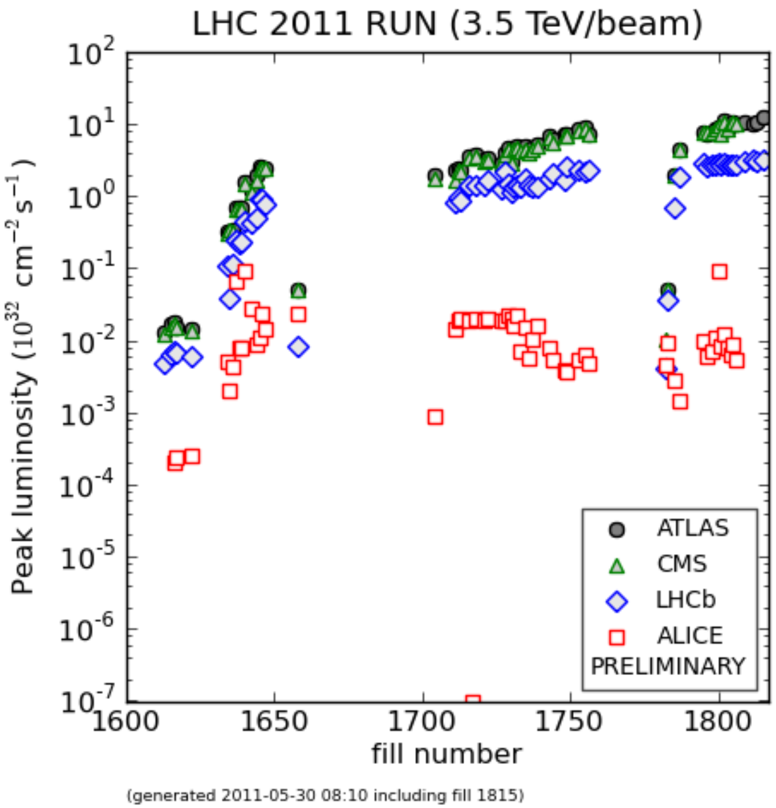
➡Conclusions and outlook

CERN and the LHC



pp collider 2010-11:

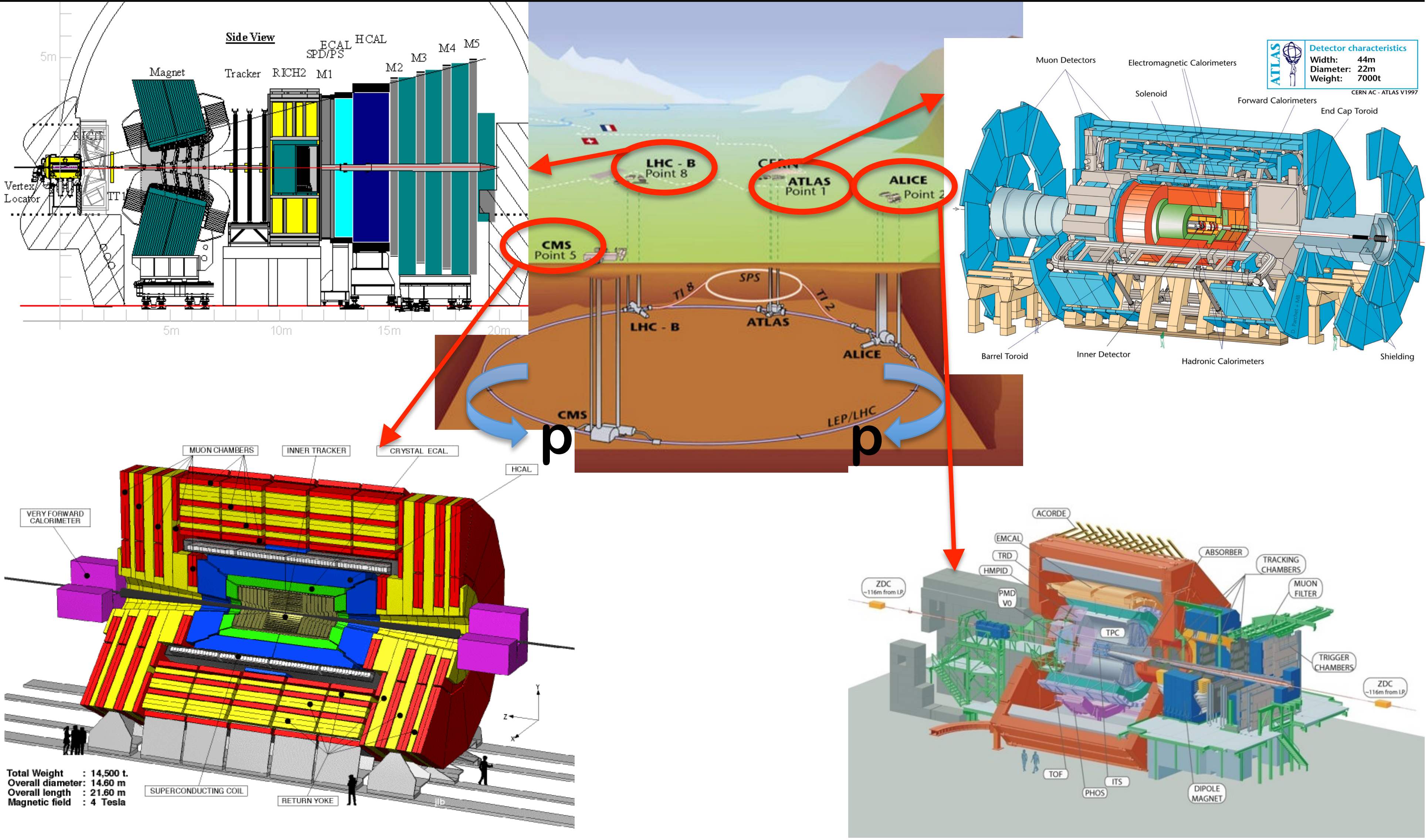
- @ $\sqrt{s}$ = 7 TeV
- L ≈ 10^{30} – 10^{33} cm^{-2} s^{-1}



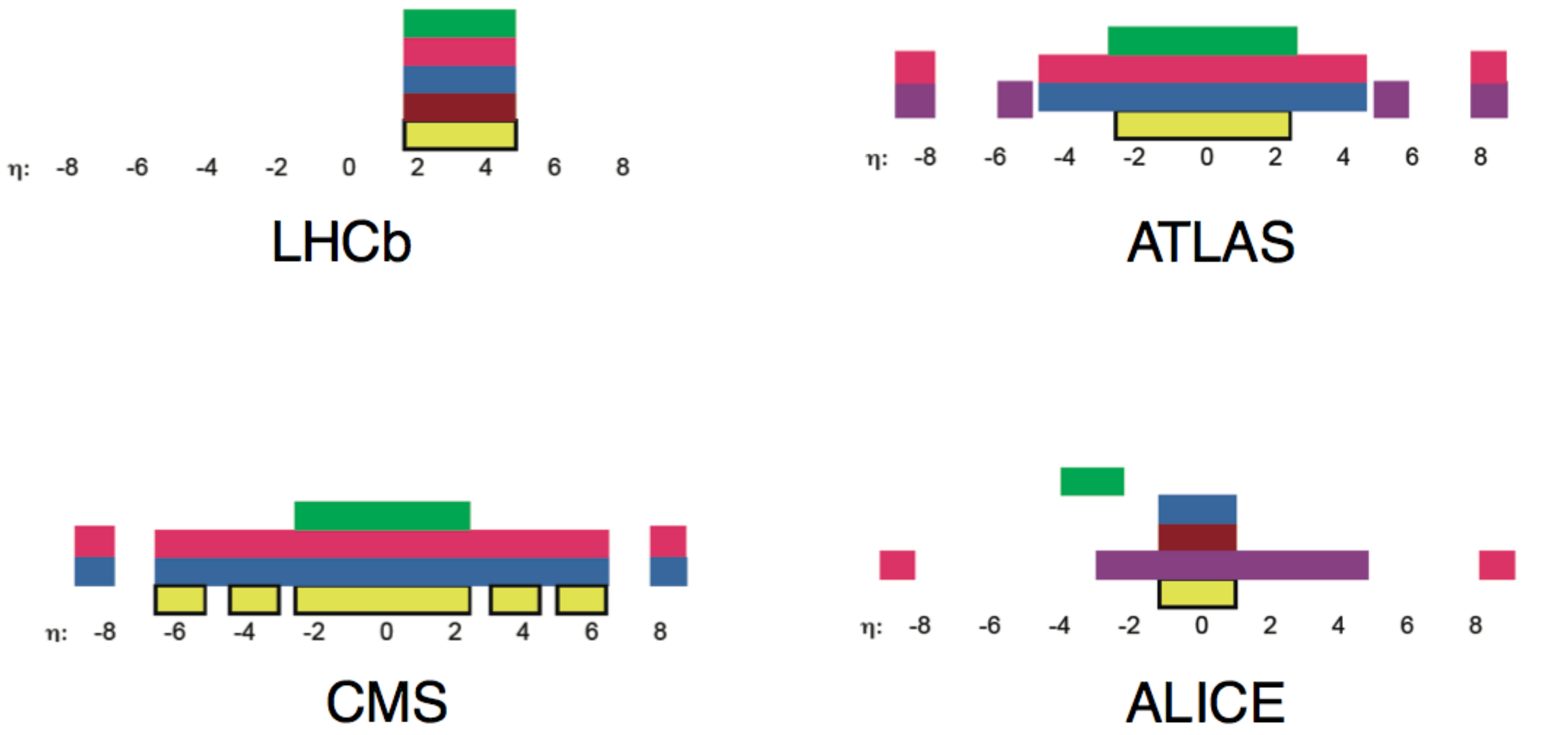
NOMINAL (2016):

$\sqrt{s}$ =14 TeV

The four LHC Detectors

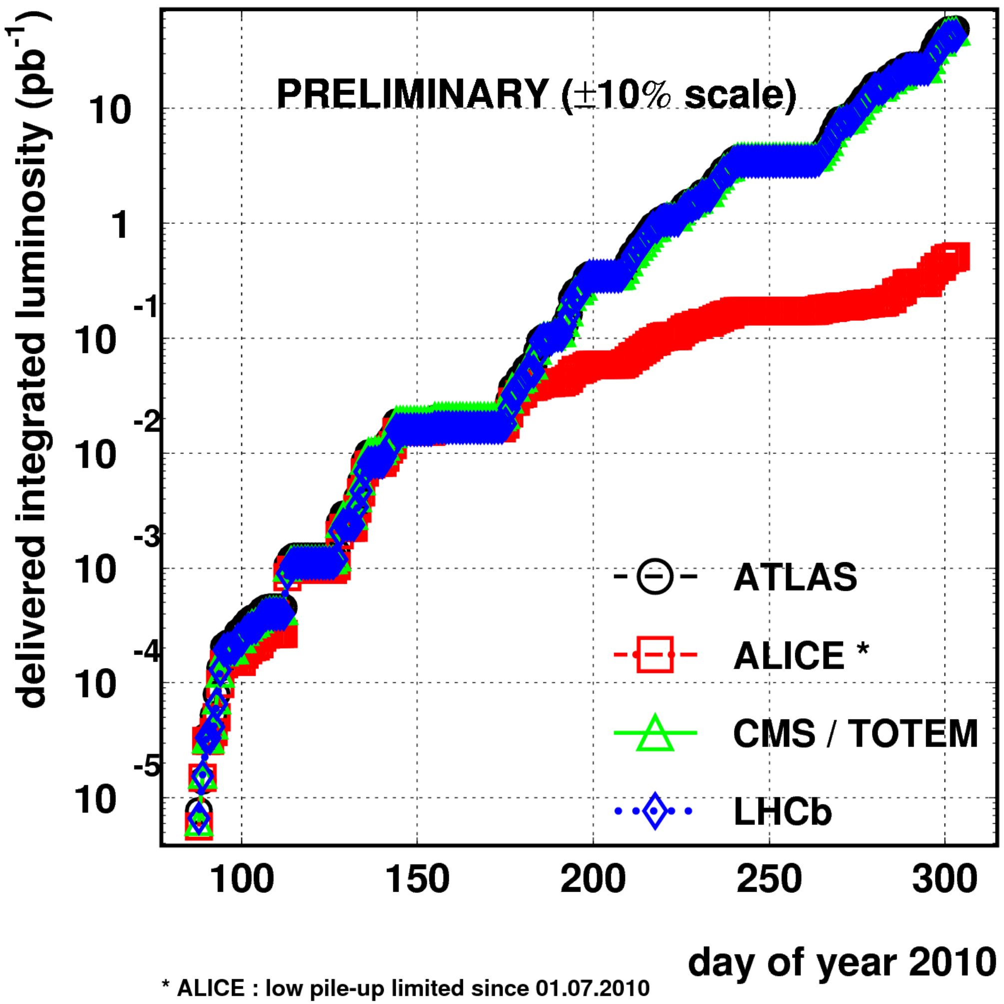


Rapidity Range



tracking, ECAL, HCAL, counters lumi, muon, hadron PID

Luminosity

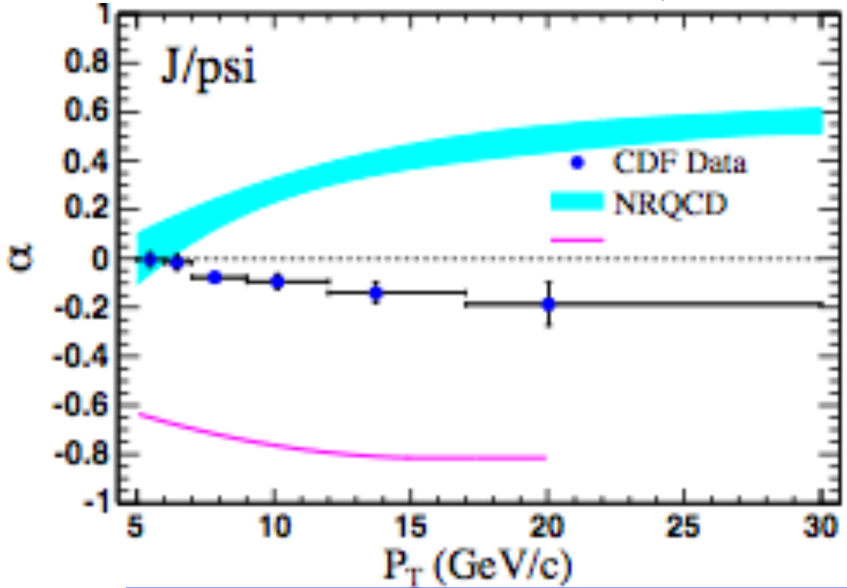


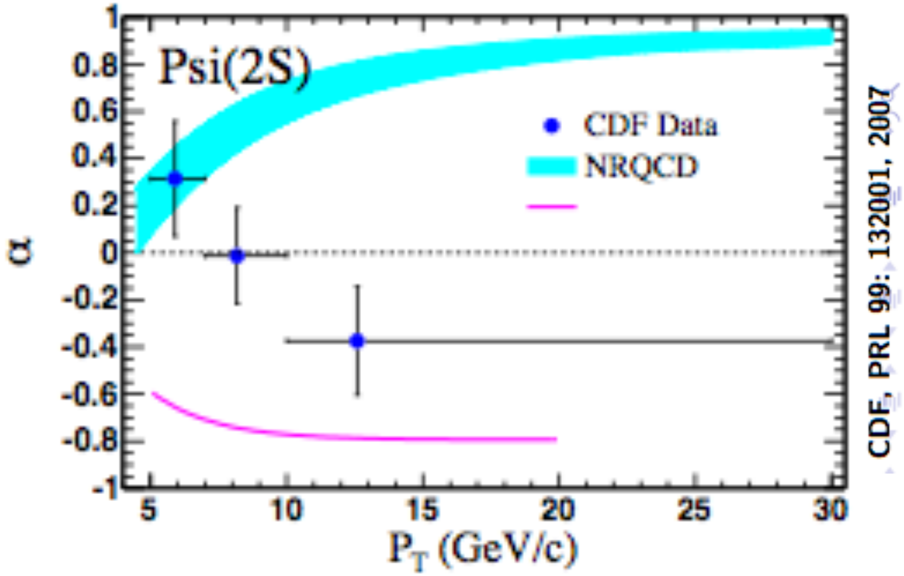
- LHC running well, all experiments have an efficiency ≈90%
- 2010+2011: pp≈200-500 pb^{-1}
- These analyses :

  L ≈ 0.1 - 40 pb^{-1} (pp)

Why Quarkonium Physics ?

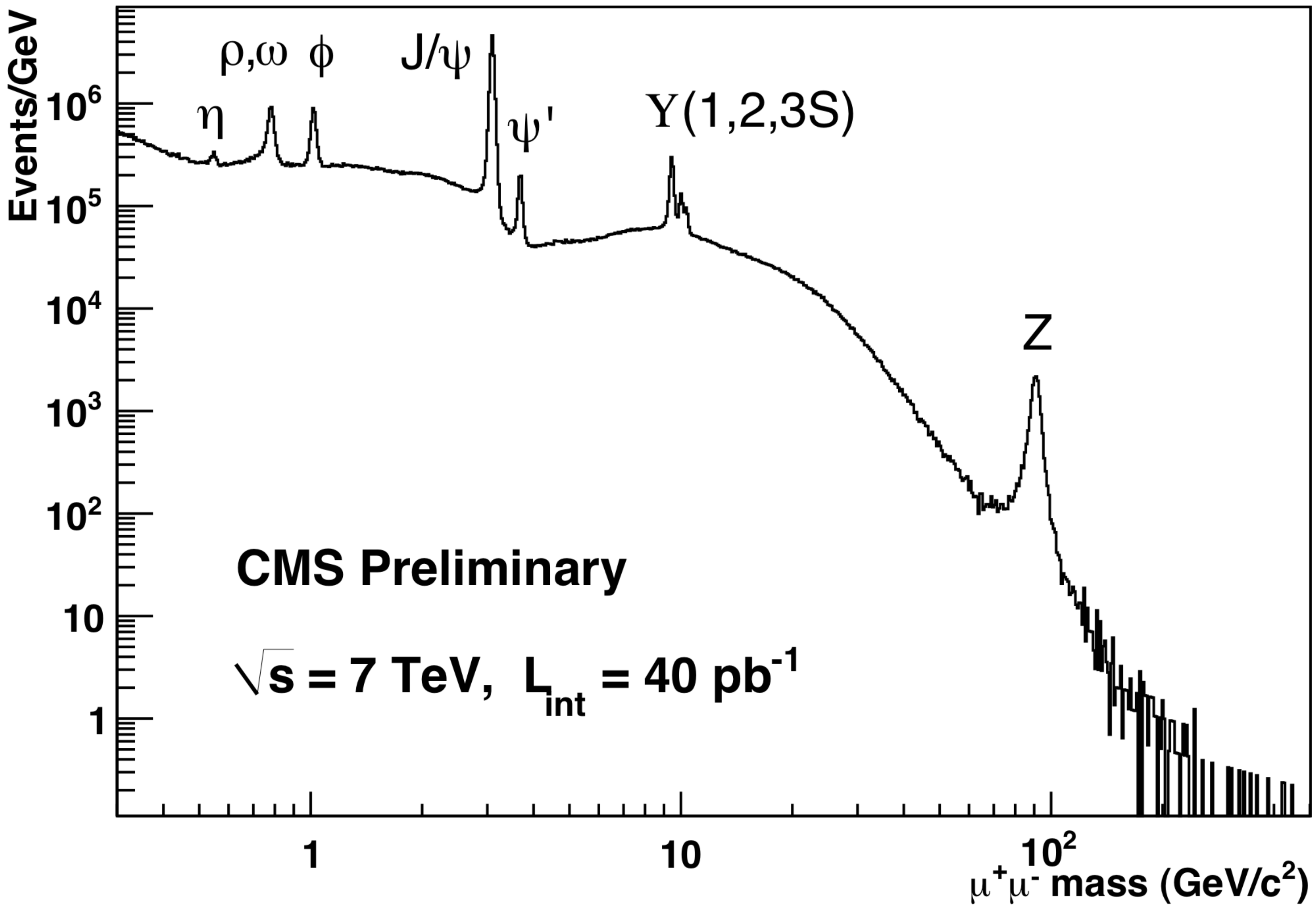
- ➡ The production mechanism in pp collisions still unclear
- ➡ Several models around :
  - Color singlet(CS) and color octet(CO) mechanisms (NRQCD) describe the p_T spectrum and cross section of the J/ψ as measured by Tevatron, but not the polarization
  - Other models such as color evaporation model (CEM), kt factorization, soft color interaction model cannot describe the data either
- ➡ New data from LHC experiments will help to resolve this issue





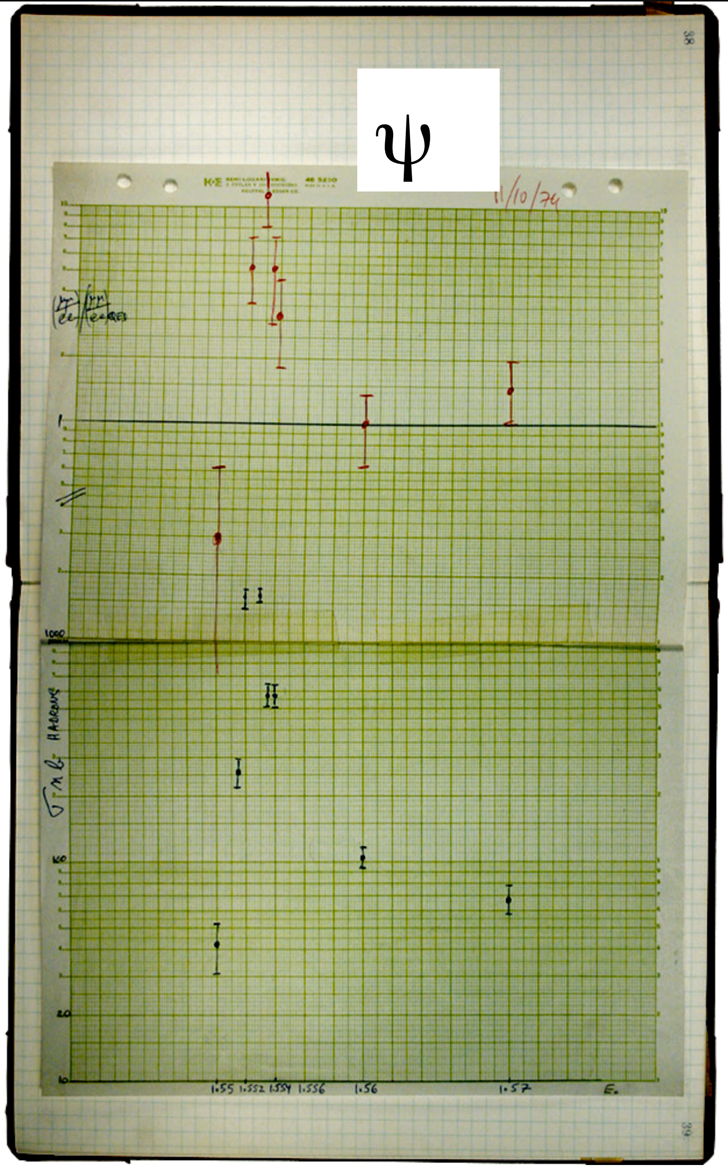
Production cross section crucial milestone in understanding detector and first step to more sophisticated measurements

Dimuon Spectrum



J/ψ Production

ψ



J

PHYSICAL REVIEW LETTERS 2 December 1974

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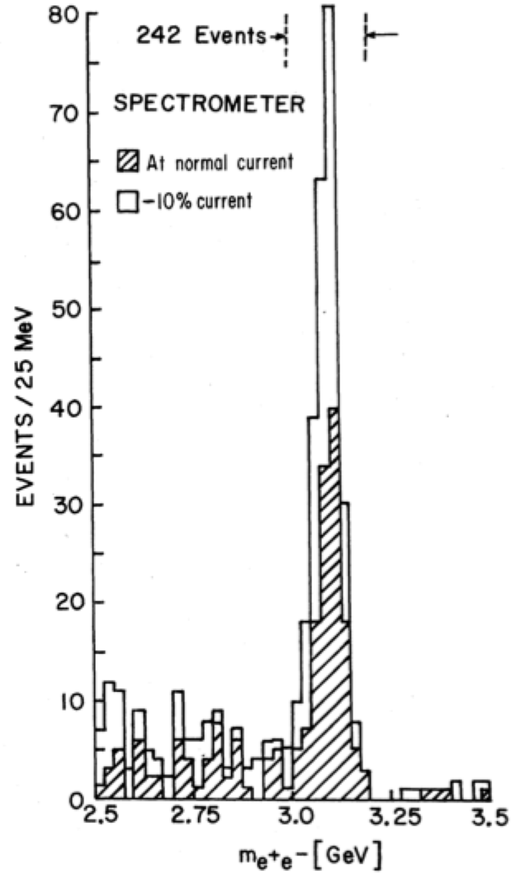
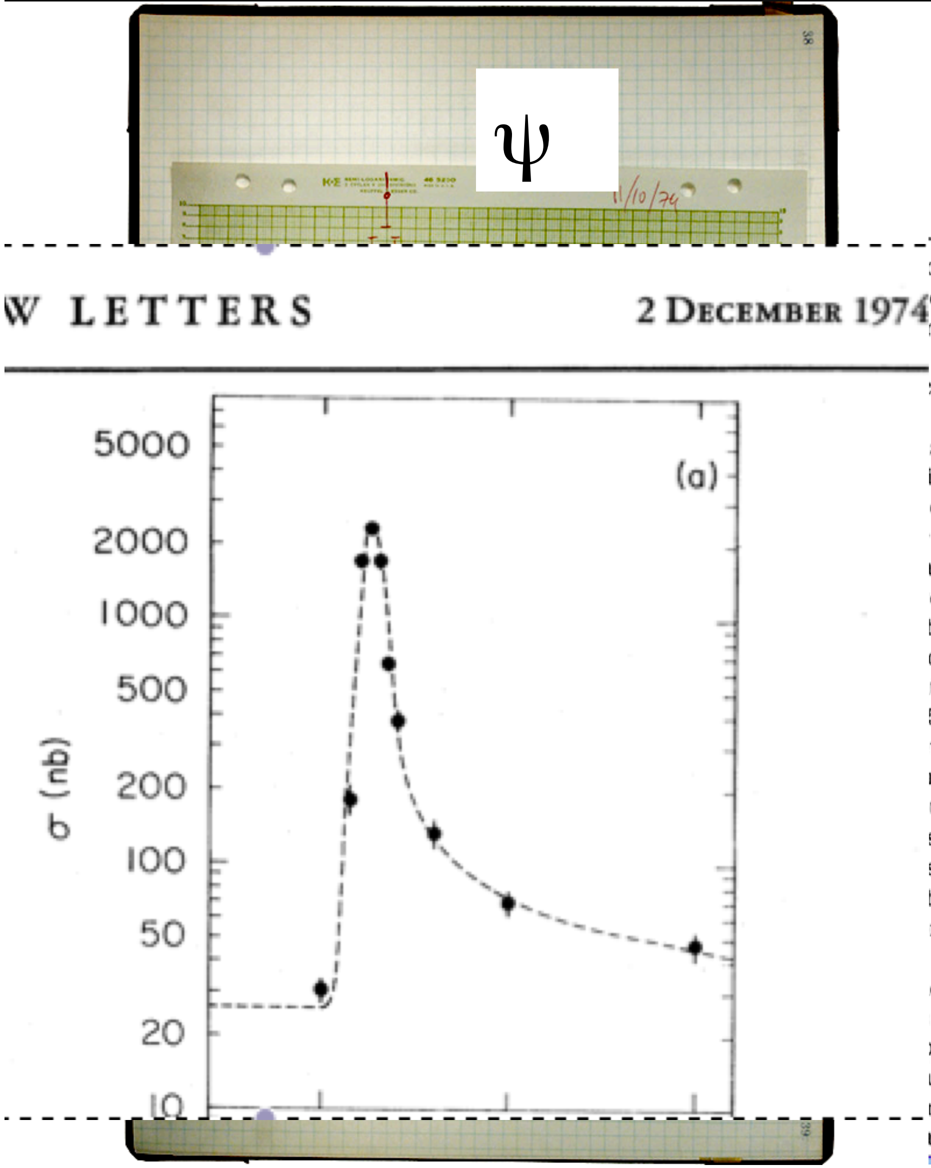


FIG. 2. Mass spectrum showing the existence of J.

J/ψ Production



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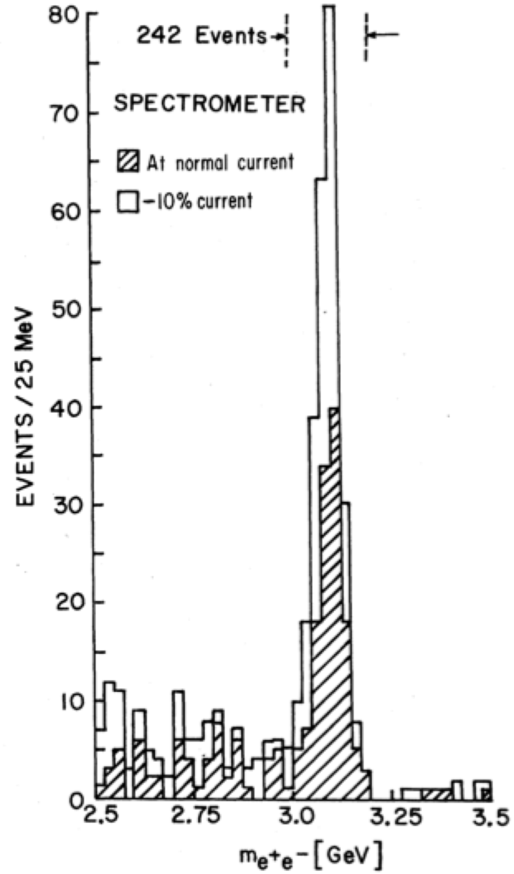


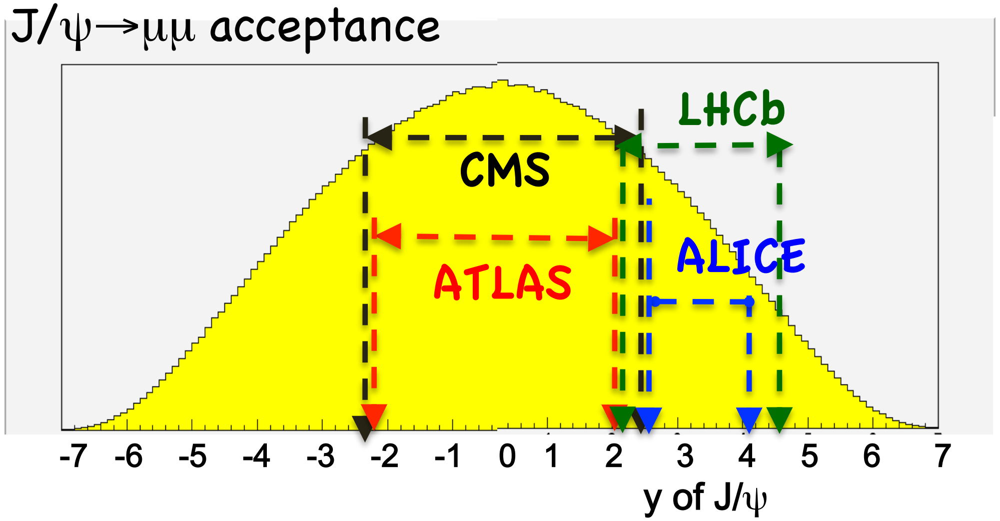
FIG. 2. Mass spectrum showing the existence of J.

J/ψ Production in pp

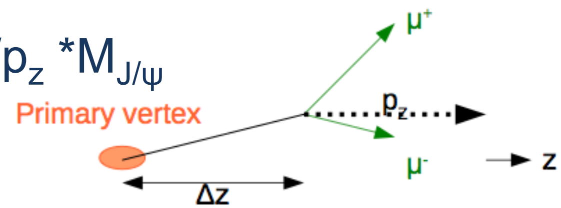
1st step	2nd step	3rd step	Production type
$pp \to c\bar{c}, b\bar{b} + X$	$c\bar{c} \to J/\psi + X$		Prompt,direct
	$c\bar{c} \to \psi', \chi_c + X$	$\psi', \chi_c \to J/\psi + X$	Prompt,indirect
	$b\bar{b} \to B + X$	$B \to J/\psi + X$	Delayed,indirect

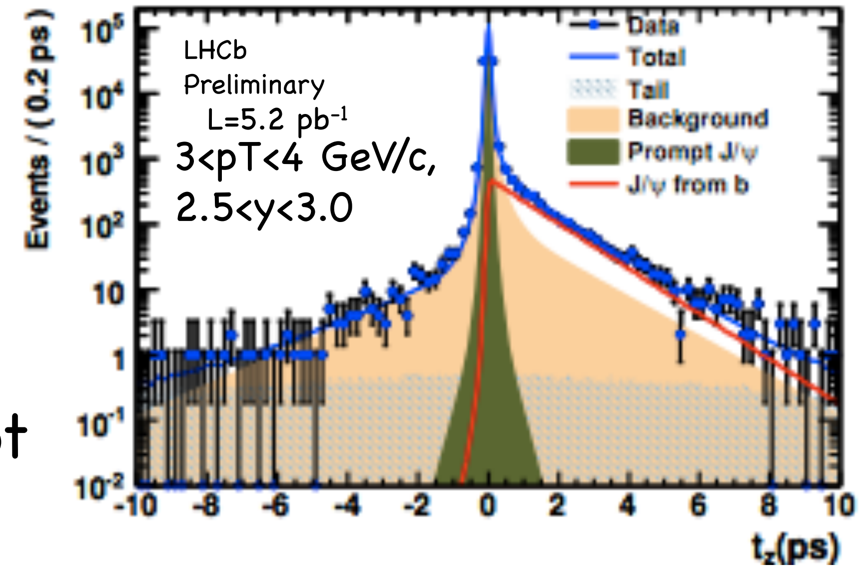
BR(J/ψ→μμ)≈6%

J/ψ→μμ acceptance



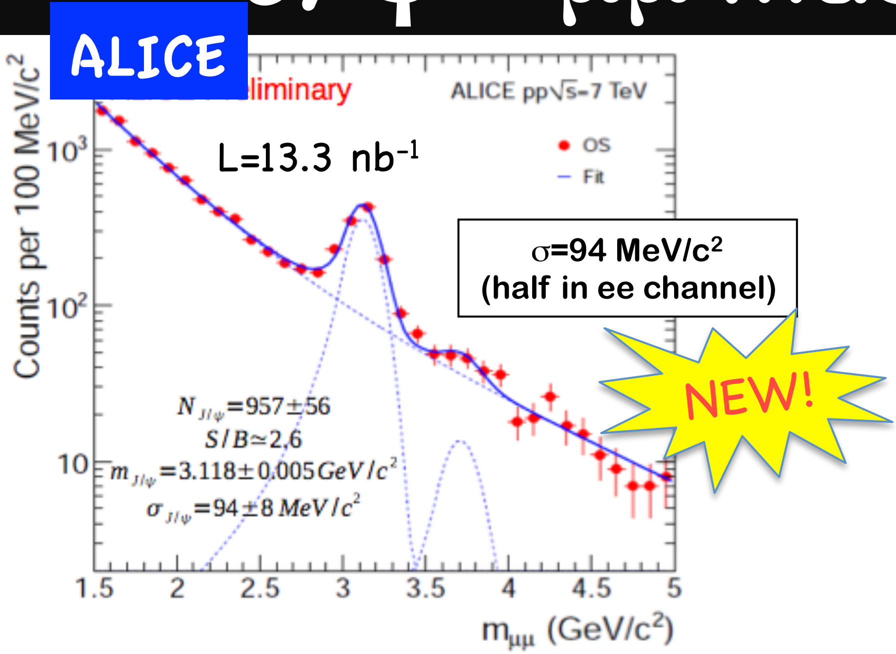
$t_z = \Delta z / p_z * M_{J/\psi}$

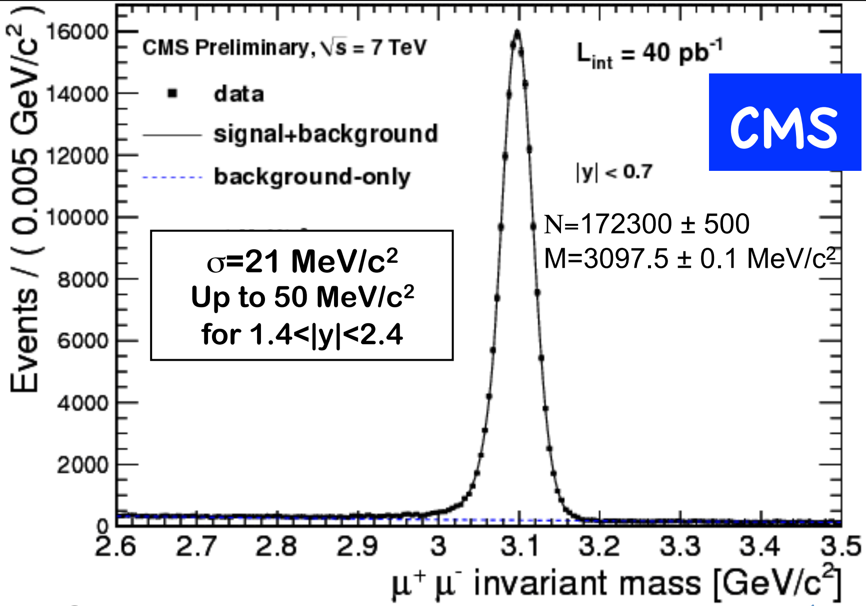


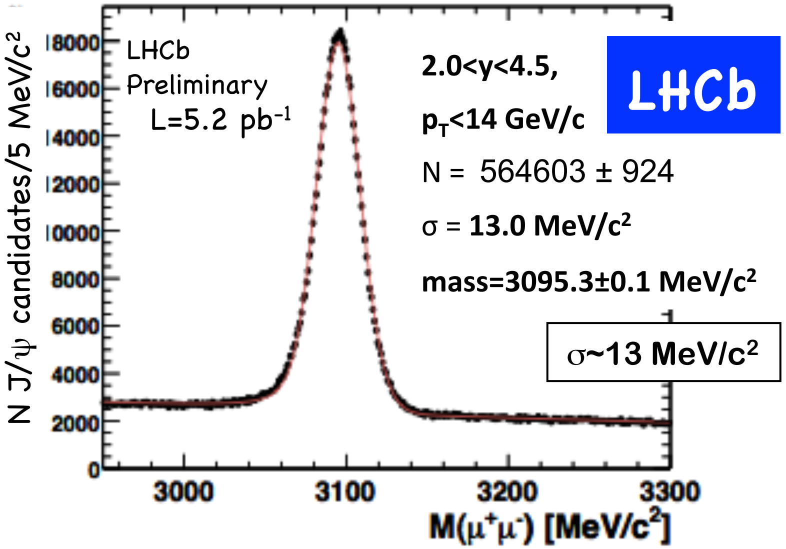


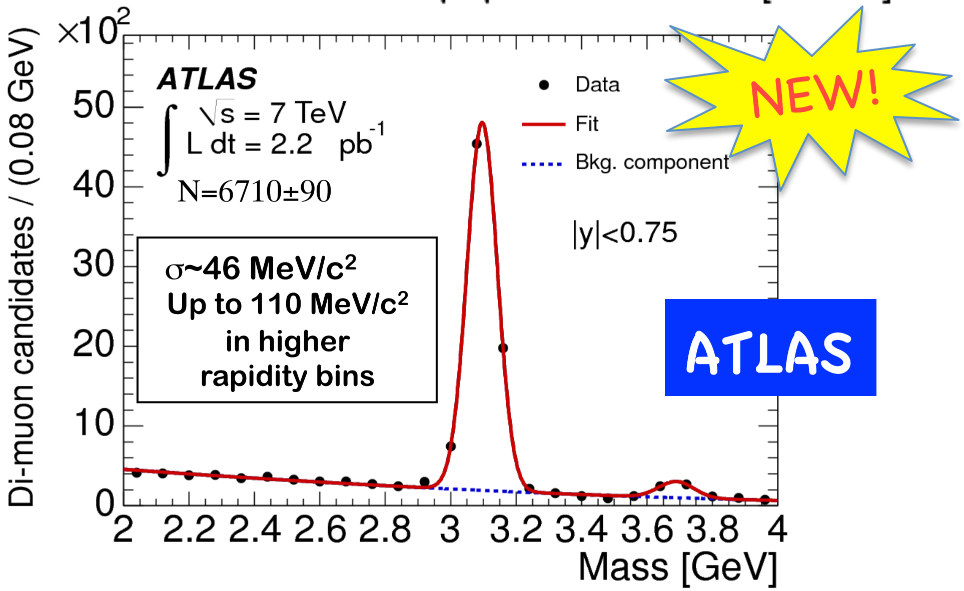
t_z used to separate J/ψ prompt from J/ψ from B

J/ψ→μμ mass distribution

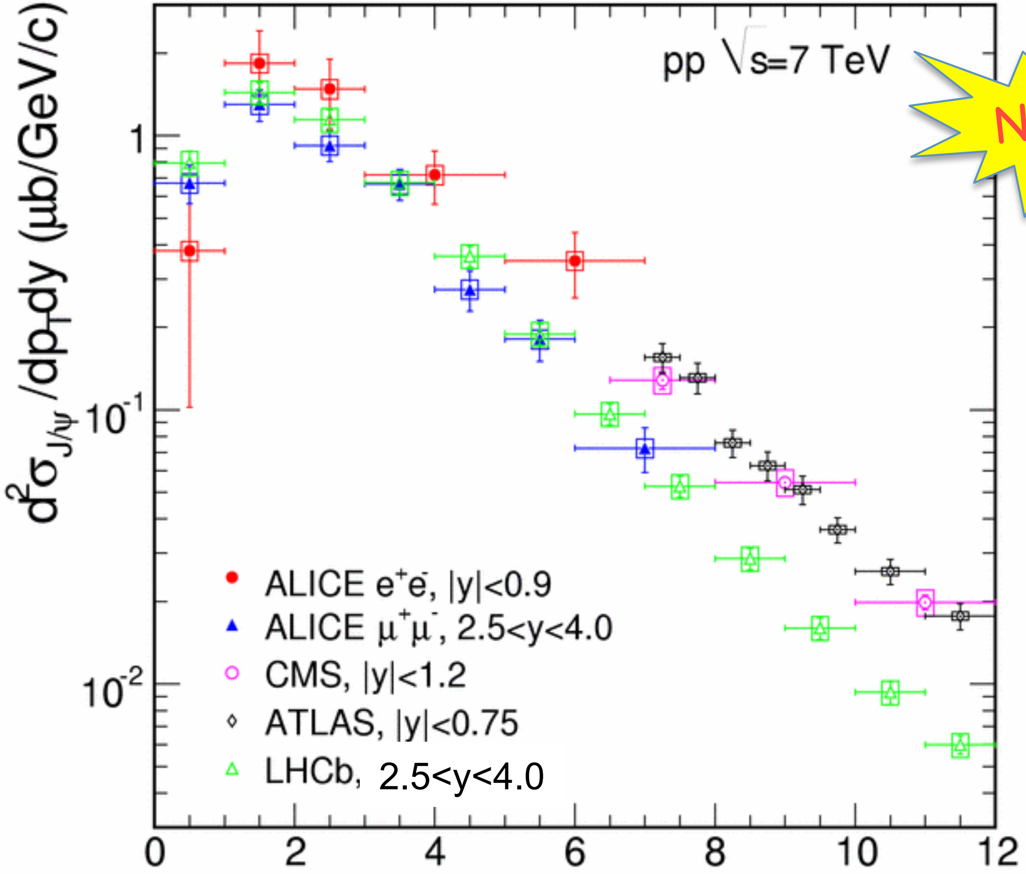




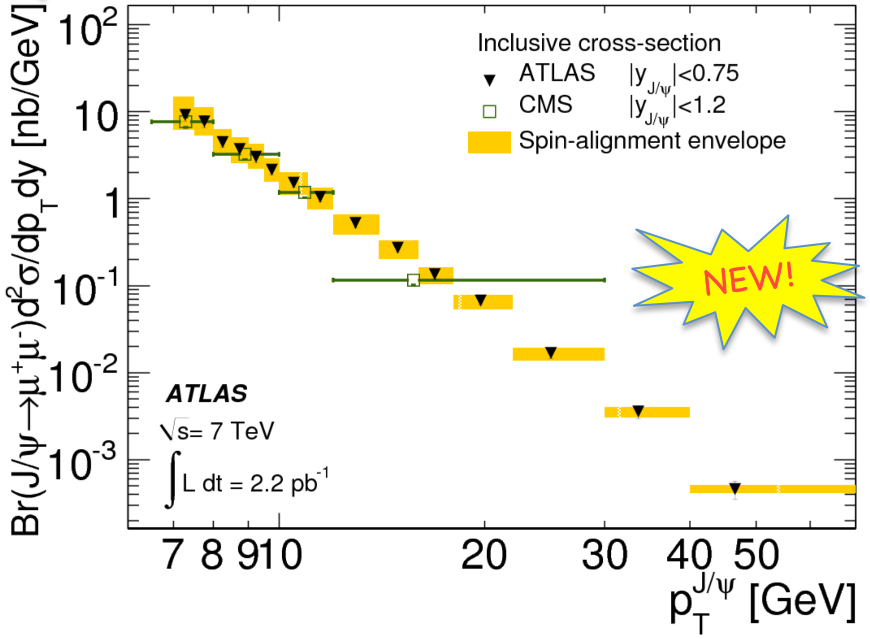




Inclusive J/ψ cross section results



ALICE Coll,arXiv:1105.0380,
ATLAS Coll, arXiv:1104.3038,
CMS Coll, arXiv:1011.4193,
LHCb Coll, arXiv:1103.0423



ATLAS: $Br(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to J/\psi X; |y^{J/\psi}| < 2.4, p_T^{J/\psi} > 7.0 \text{ GeV})$

$= 81 \pm 1 \text{ (stat.)} \pm 10 \text{(syst.)} \pm^{25}_{20} \text{ (spin)} \pm 3 \text{ (lumi.) nb}$

ALICE:

$\sigma_{J/\psi}$ (|y|<0.9)= 10.7±1.2(stat)±1.7(syst)+1.6(λ_{HE}=1)-2.3(λ_{HE}=-1) μb

$\sigma_{J/\psi}$ (2.5<y<4)= 6.31±0.25(stat)±0.80(syst)+0.95(λ_{CS}=1)-1.96(λ_{CS}=-1) μb

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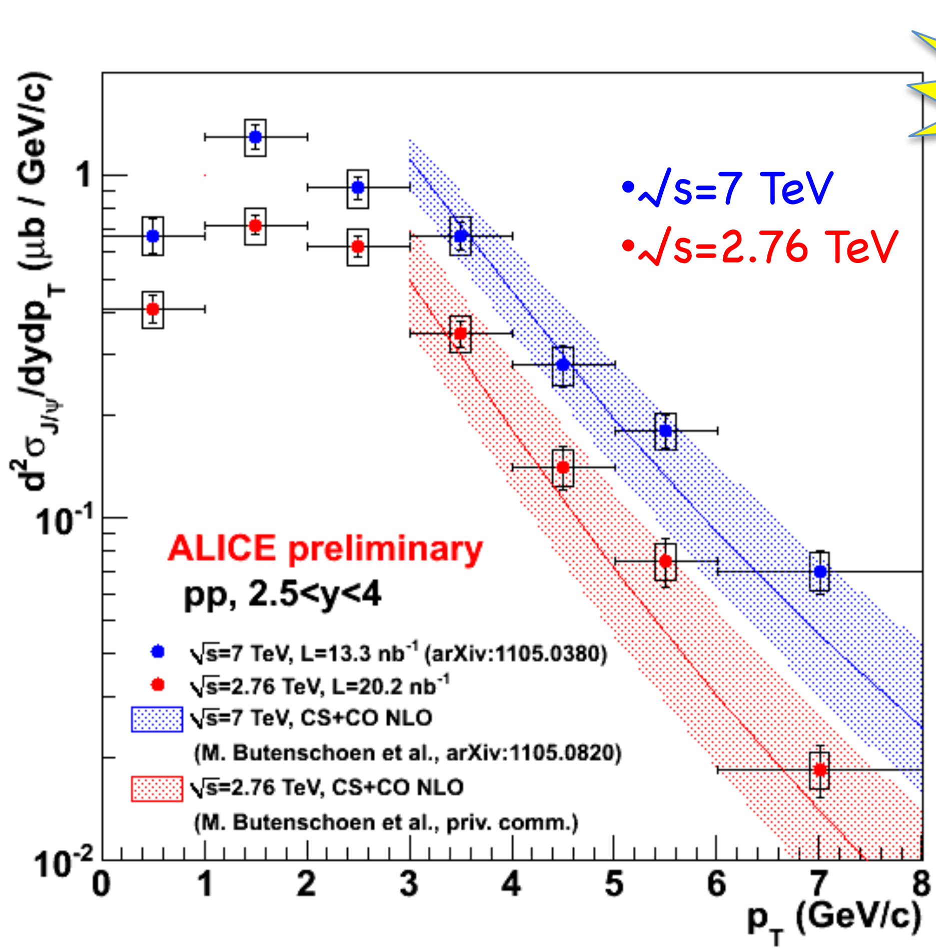

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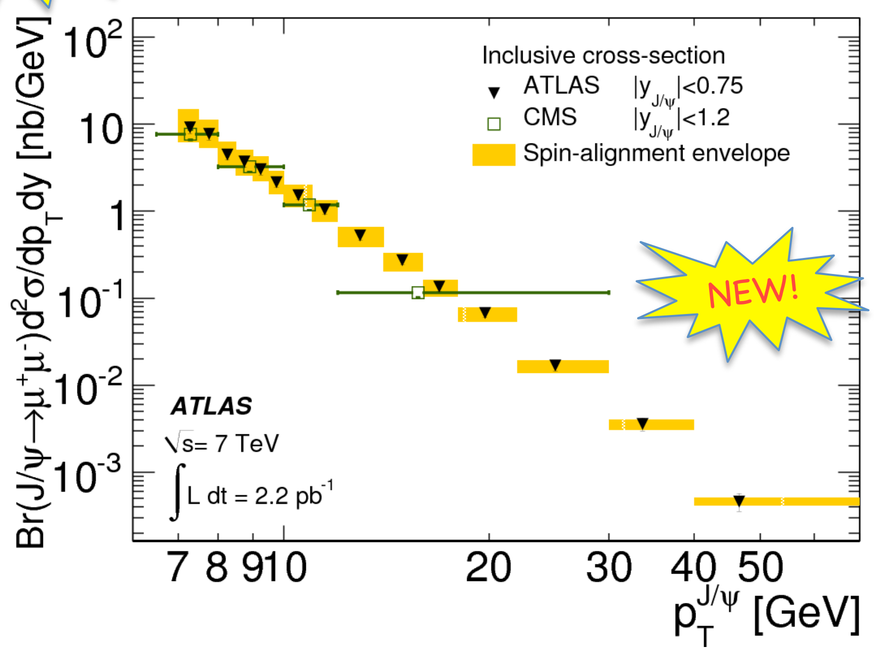

$\to J/\psi X; |y^{J/\psi}| < 2.4, p_T^{J/\psi} > 7.0$ GeV)

$= 81 \pm 1$ (stat.) ± 10(syst.) $\pm^{25}_{20}$ (spin) ± 3 (lumi.) nb

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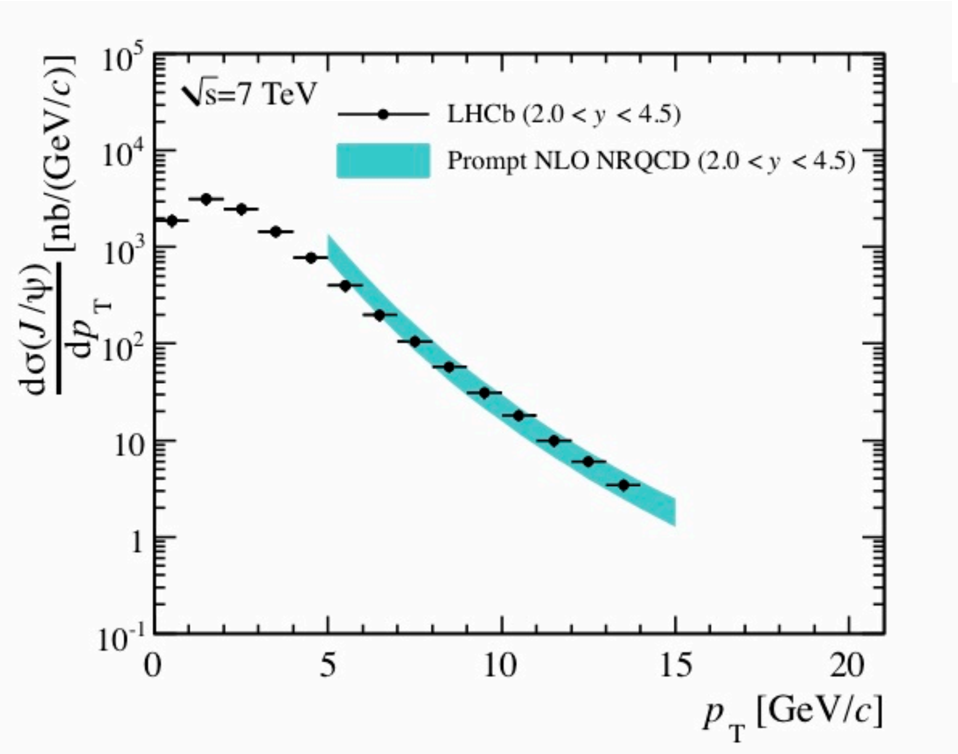
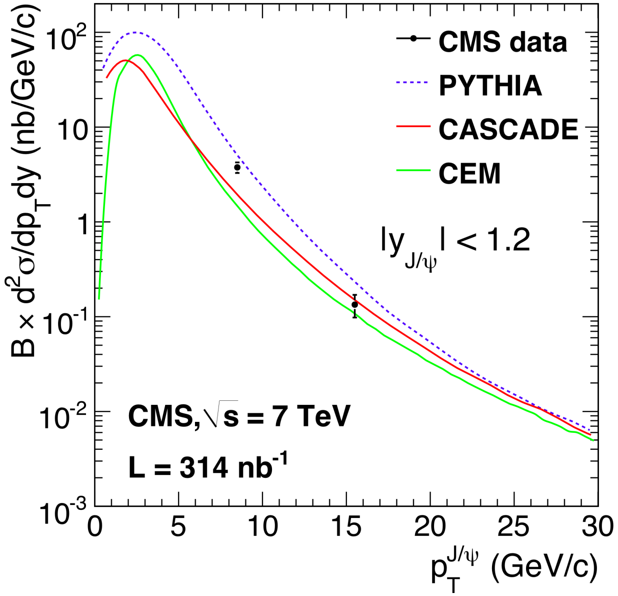
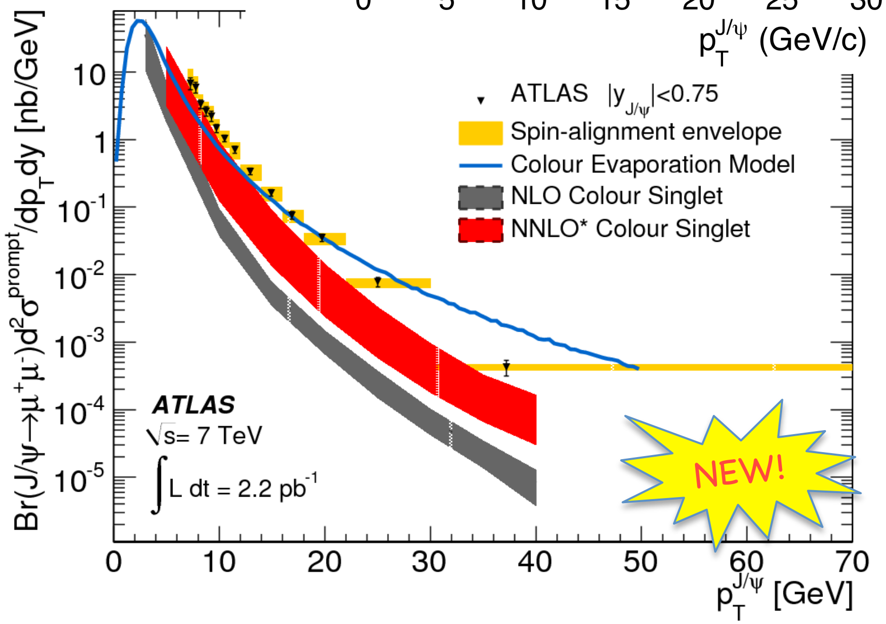
Prompt J/ψ cross section results

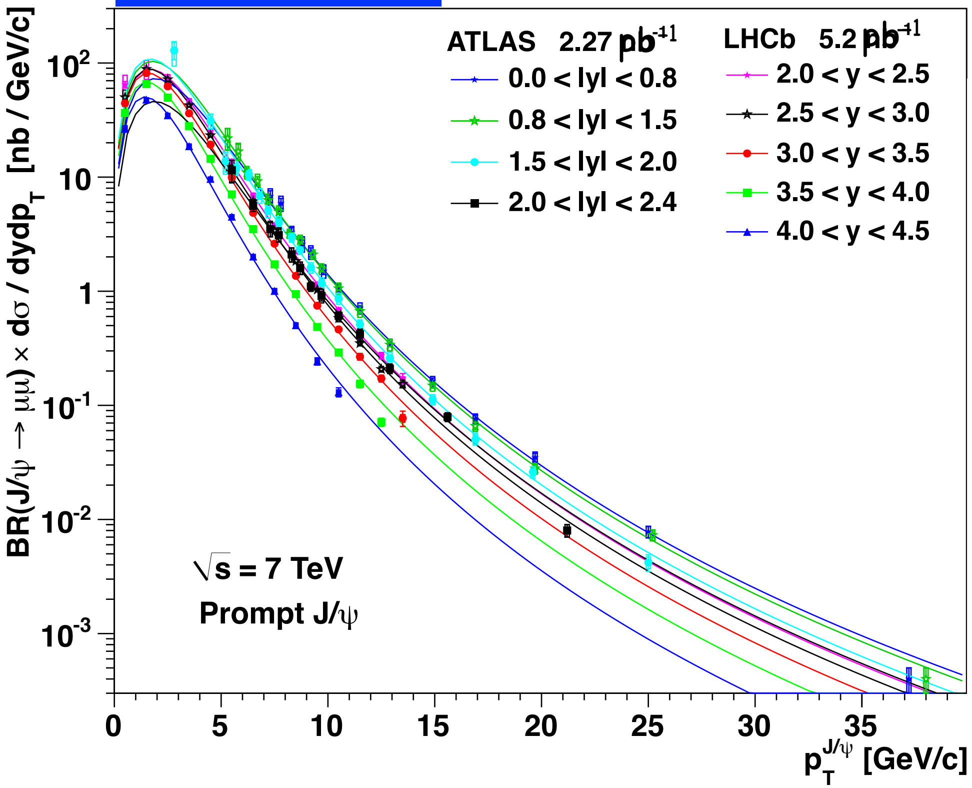






Prompt J/ψ cross section results

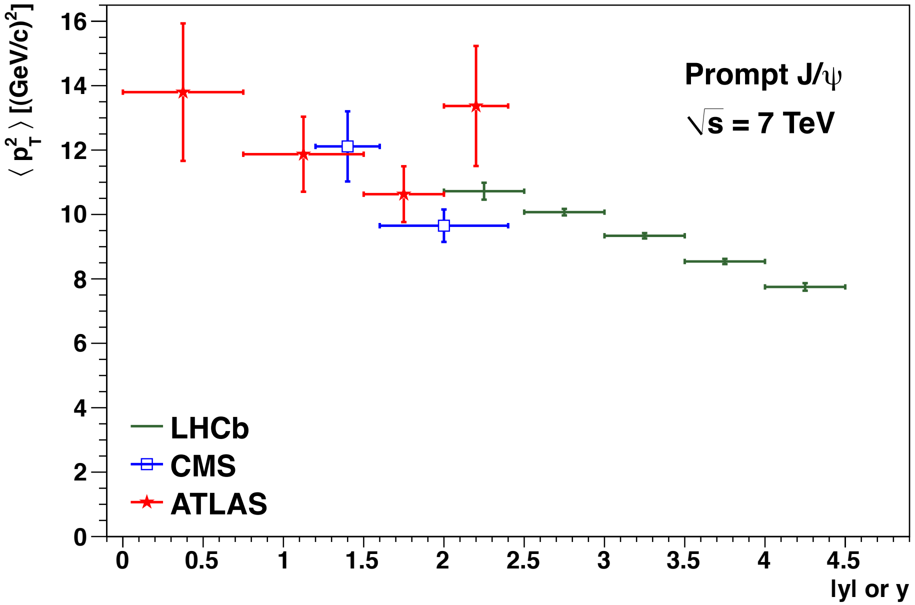
Cross section



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

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

$<p_T>$ shape

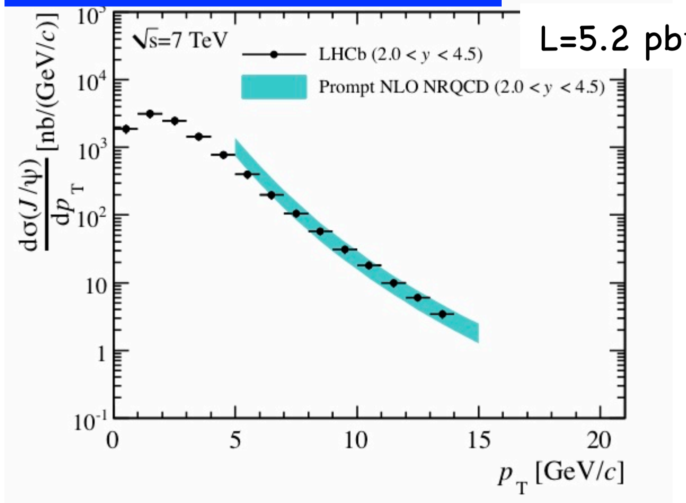


$<p_T^2>$ clearly increases from forward to central rapidity

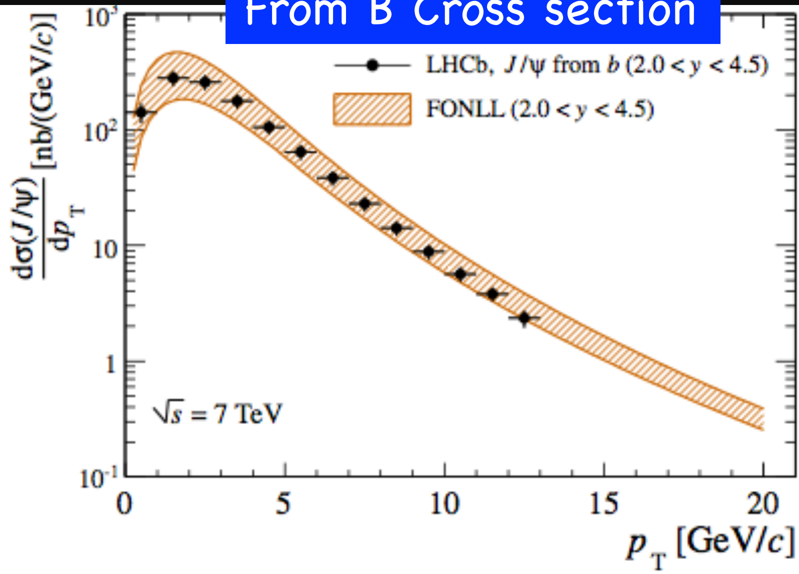
Courtesy of H.Woehri

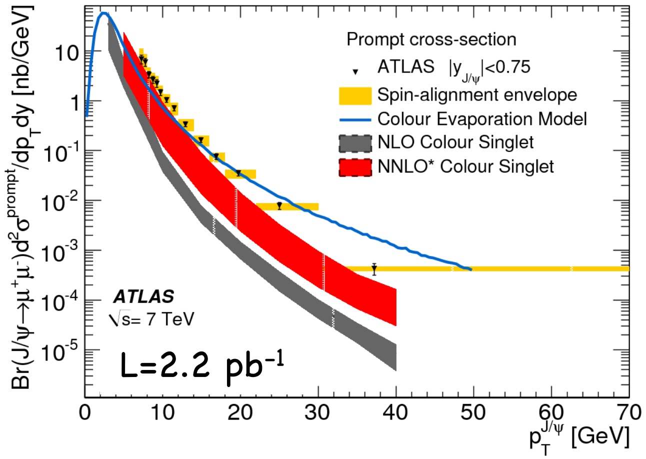
"J/ψ from B" cross section results

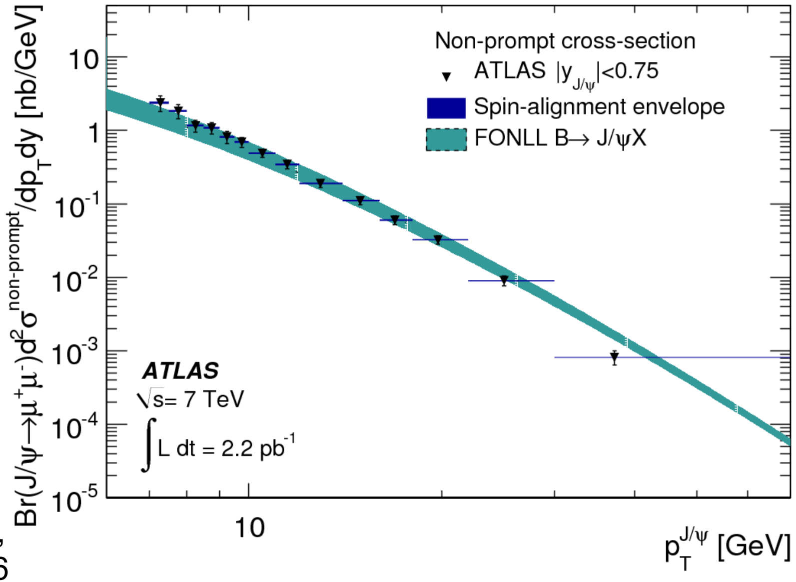
Prompt Cross section



From B Cross section



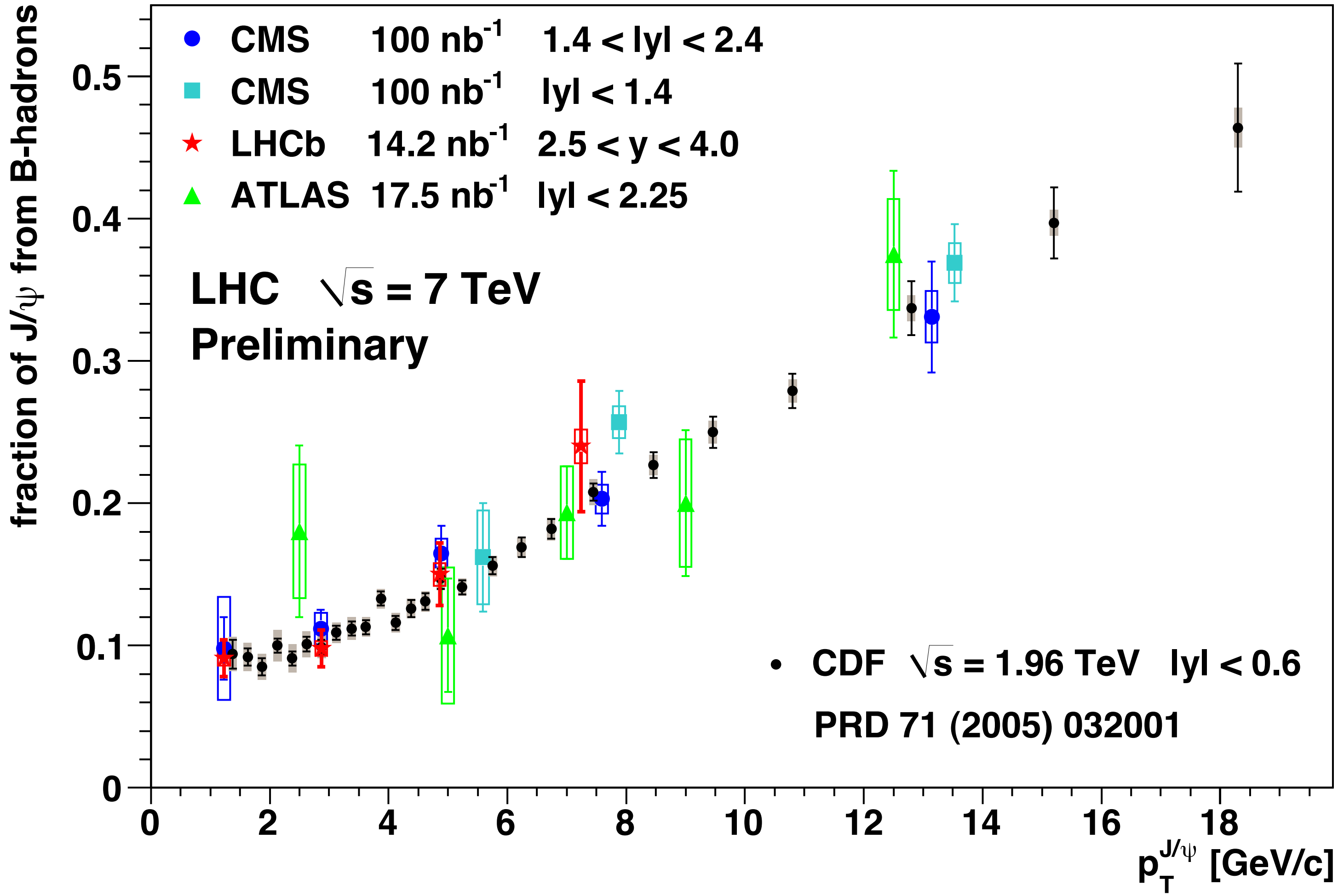




M. Cacciari, M. Greco and P. Nason, J. High Energy Phys. 9805 (1998) 007,
M. Cacciari, S. Frixione and P. Nason,J. High Energy Phys. 0103 (2001) 006

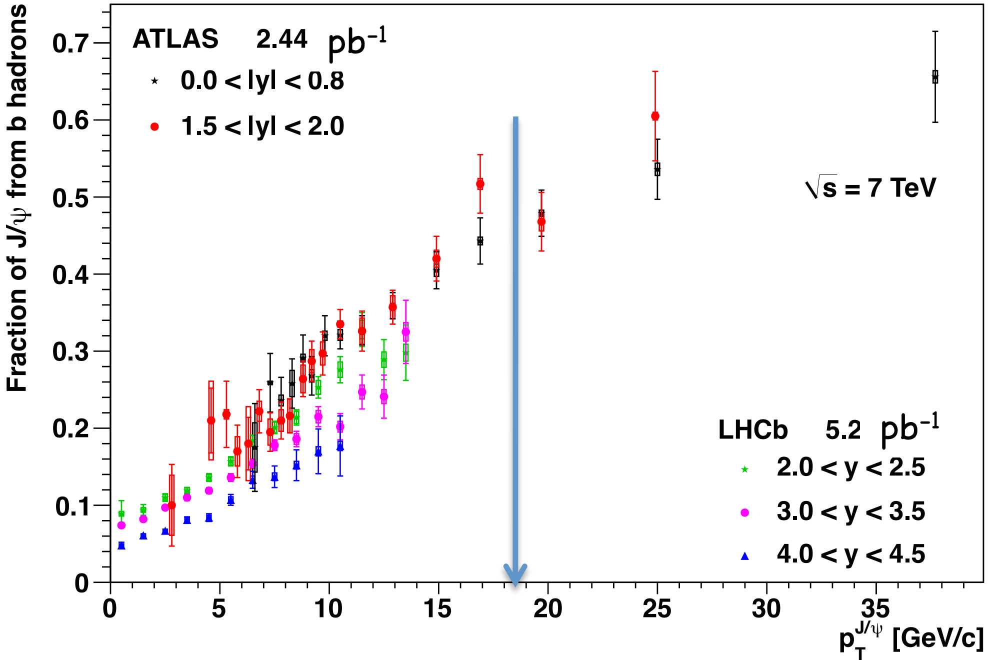
Fraction of J/ψ from B

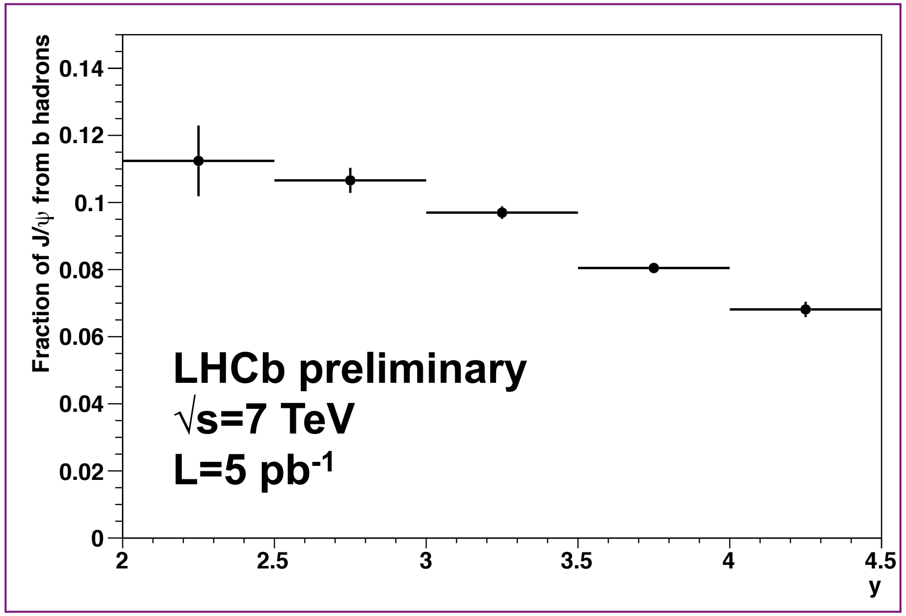
➡ ICHEP 2010 : LHC experiments confirm the trend seen from CDF



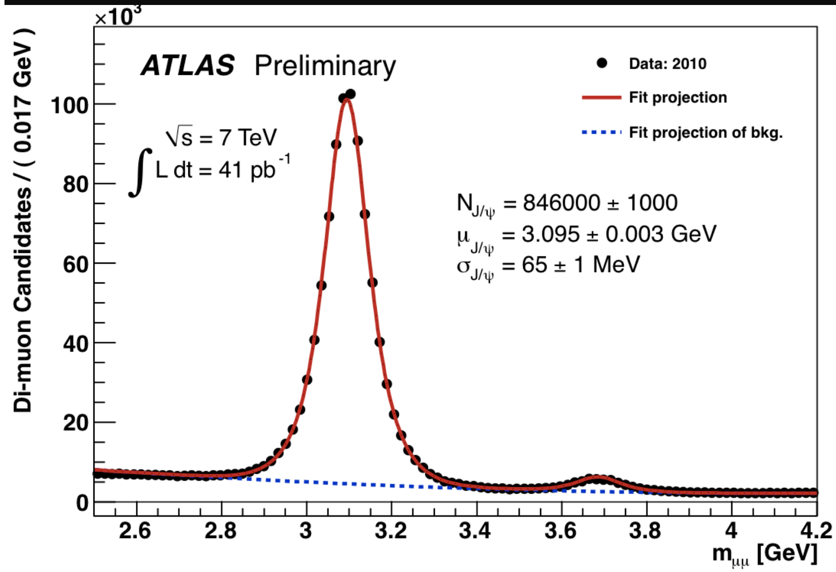
Fraction of J/ψ from B

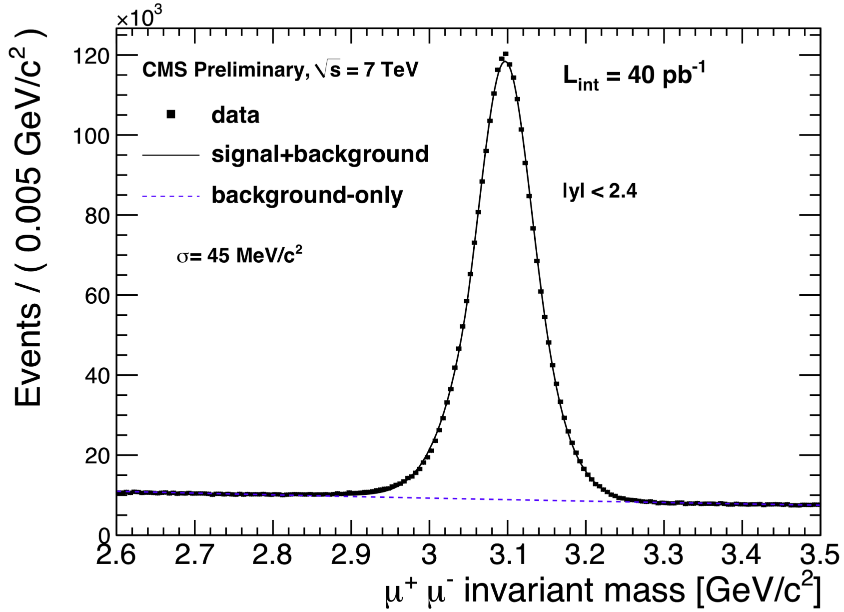
- Spring 2011 :
  - new data from Atlas show some saturation at high p_T
  - LHCb shows decreasing trend at forward rapidity

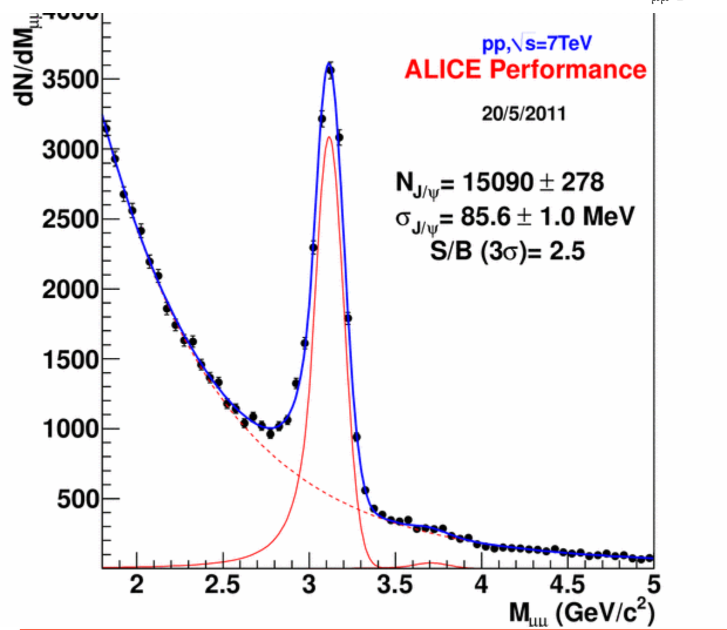




J/ψ->μμ : outlook





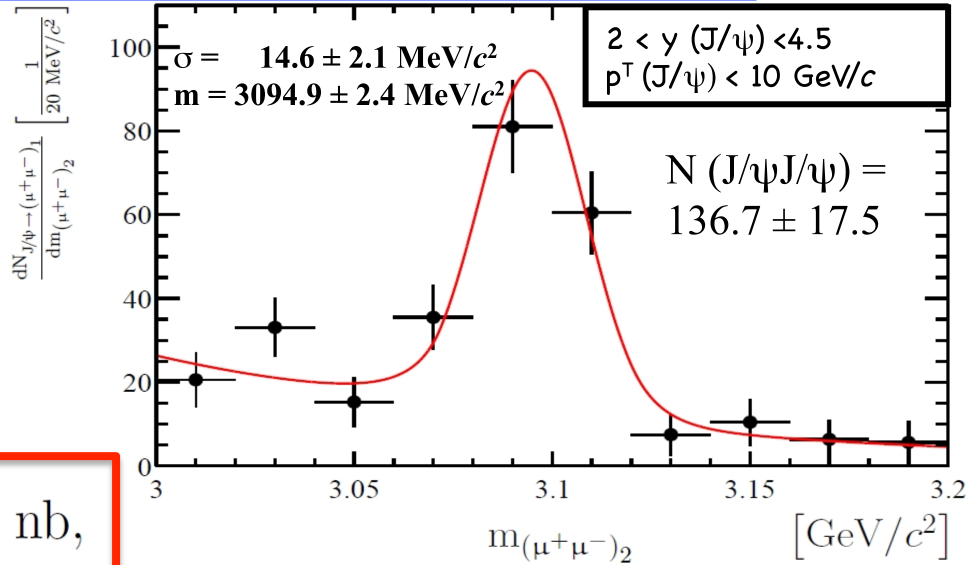


Experiments already have a much larger sample of J/ψ, good for the polarisation measurements !

LHCb : Double J/ψ production

- ➡ First of searches in charmonium+?
  $J/\psi\rho^0$, $J/\psi\omega^0$, $J/\psi\phi$, $\Upsilon\psi$, …
- ➡ Interesting for:
  - Test of QCD: sensitive to CSM vs. COM
  - Test of possible tetraquark production

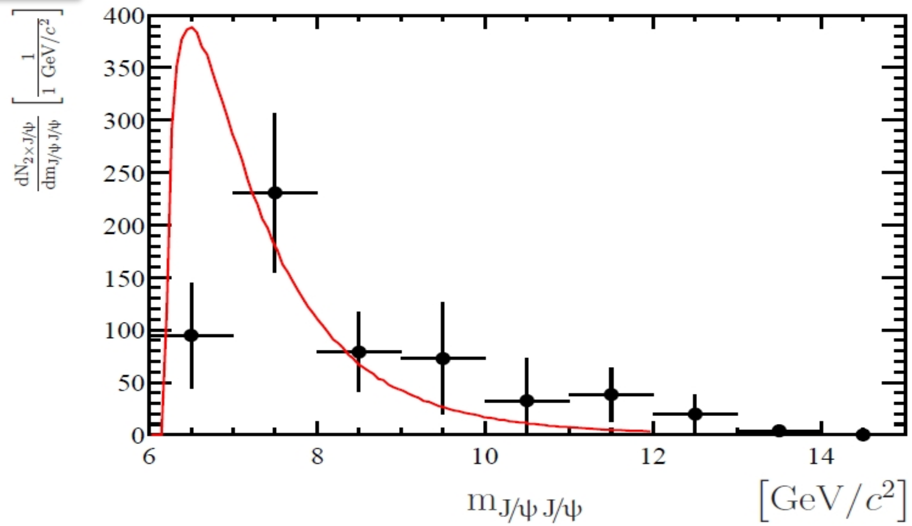
First observation at hadron colliders!



$$\sigma^{J/\psi\,J/\psi} = 5.6 \pm 1.1 \pm 0.5 \pm 0.9|_{tr} \pm 0.6|_{\mathcal{L}}\ \text{nb},$$

Theory (direct only)* :

$\sigma^{J/\psi J/\psi}$ $(2<y^{J/\psi}<4.5)$=4.34 - 4.15 nb,



- Towards publication.
  (LHCb-CONF-2011-009)

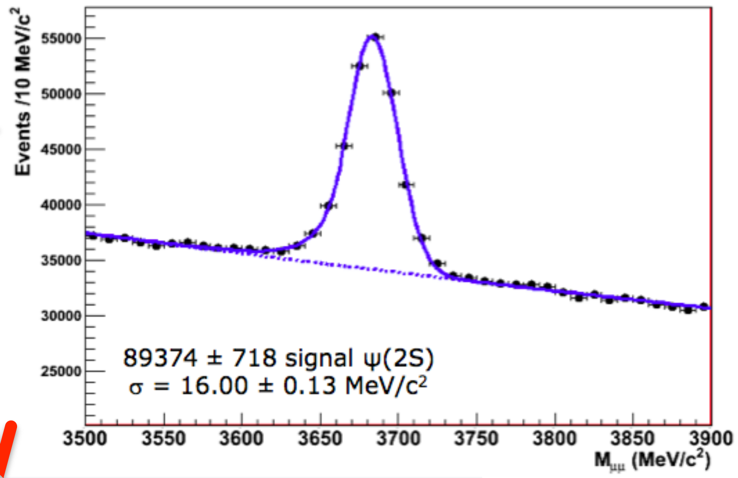
* A.V.Berezhnouy et al., arXiv:1101.5881

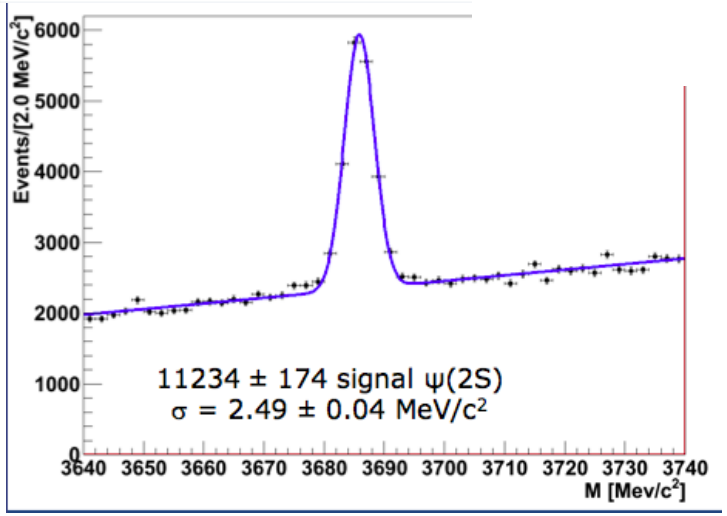
LHCb : ψ(2S) Production

NEW!

- Exploited in two modes
  - $\psi(2S) \to \mu^+\mu^-$[BR=7.7±0.8 × 10^{-3}]
  - $\psi(2S) \to J/\psi(\mu^+\mu^-)\,\pi^+\pi^-$[BR=19.9±0.3 × 10^{-3}]

  Cross section in bins $0<p_T<12$ GeV/c, $2<y<4.5$





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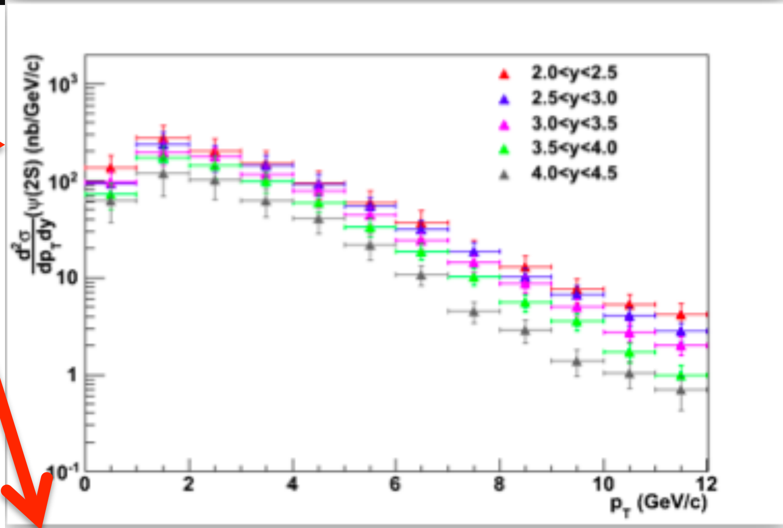

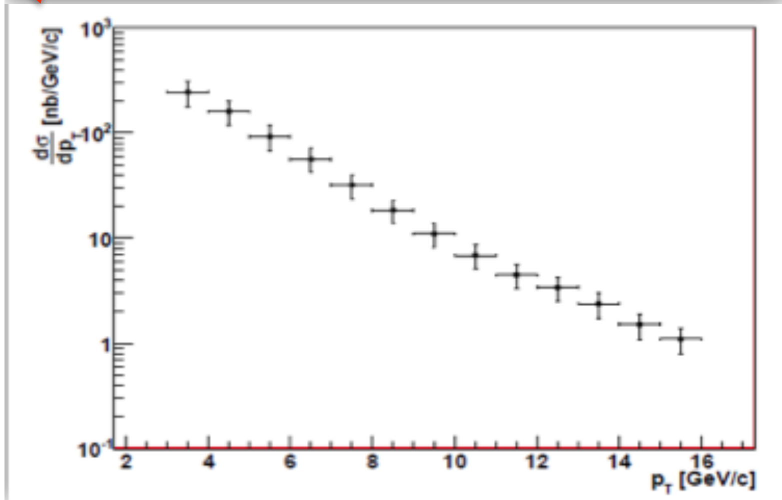

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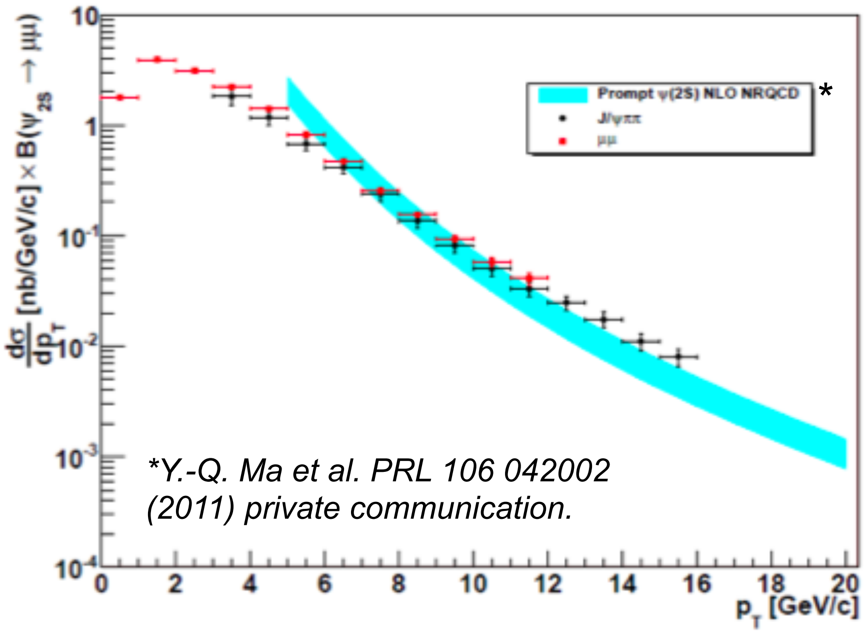
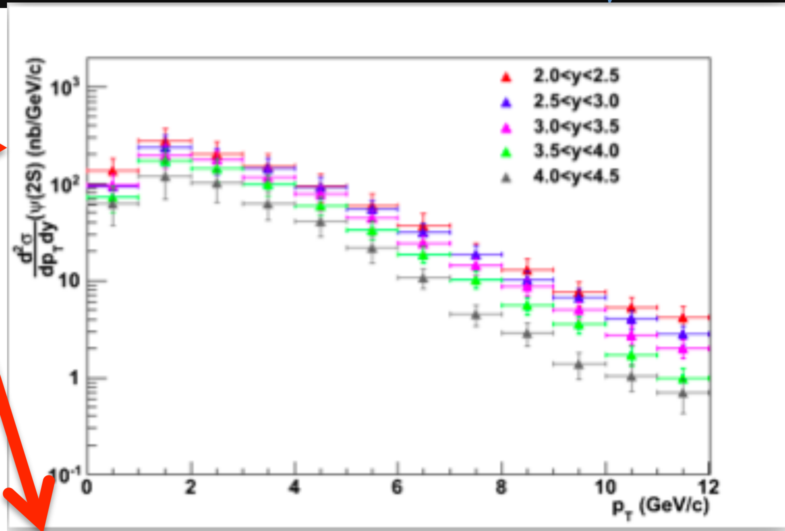
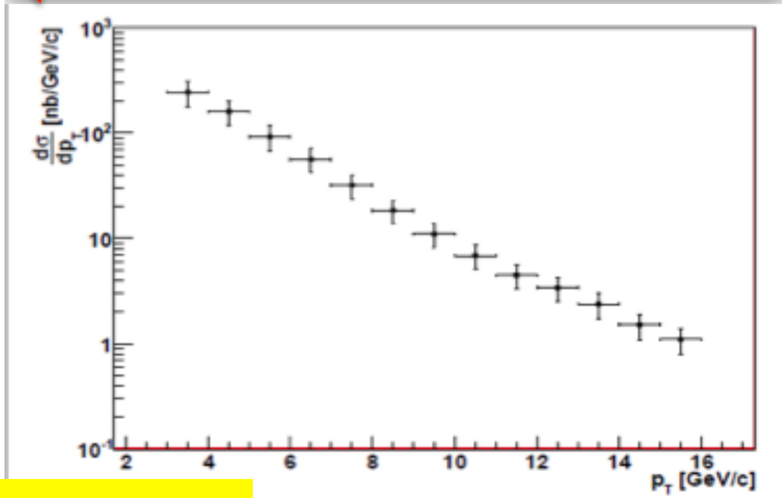




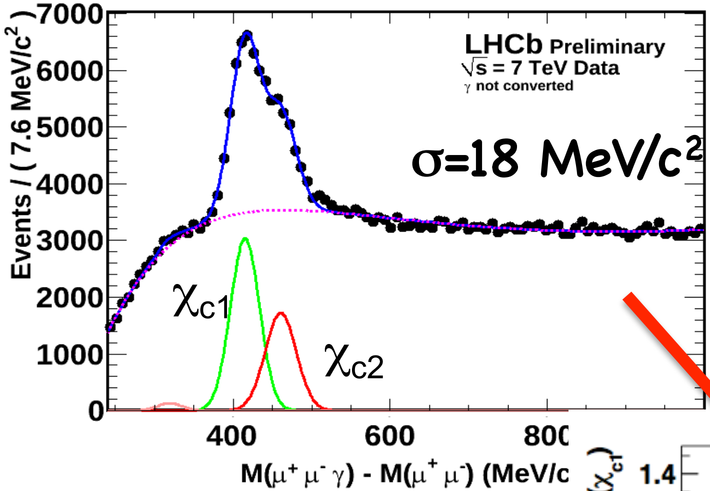


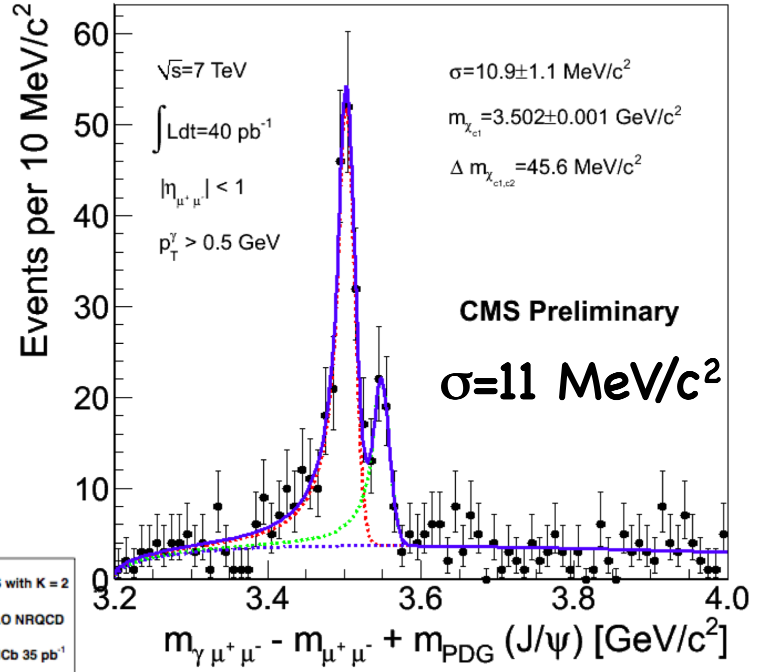
σ(inclusive ψ ;$0< p \leq 12$GeV/c,$2< y\leq 4.5$)=$1.88\pm0.02\pm0.31^{+0.25}_{-0.48}$ μb
σ(inclusive ψ ;$3< p \leq 16$GeV /c,$2< y\leq 4.5$)=$0.62\pm0.04\pm0.12^{+0.07}_{-0.14}$ μb

Main systematics : polarisation (up to 12%), trigger (18%) & tracking efficiencies (16%)

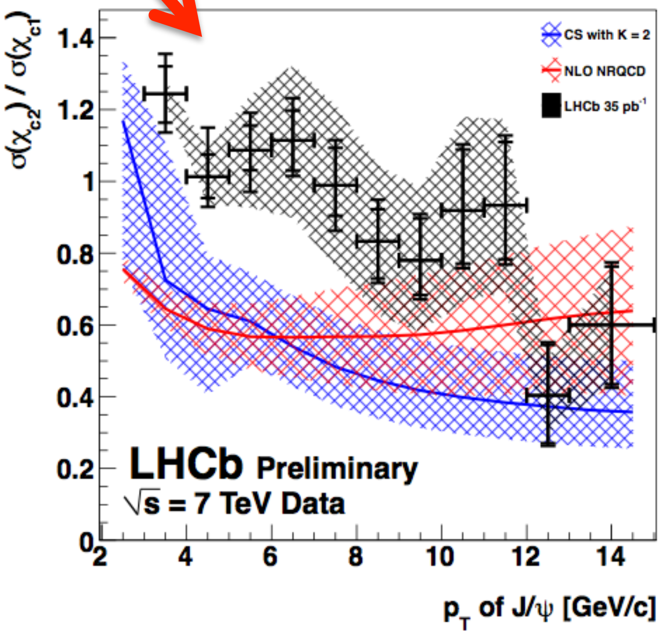
χ_c first appearance

➡ Decays into $J/\psi+\gamma$->low p_T:challenge!!





- Analysis performed with photons reconstructed in the ECAL (LHCb) or via conversions in the tracker (CMS)

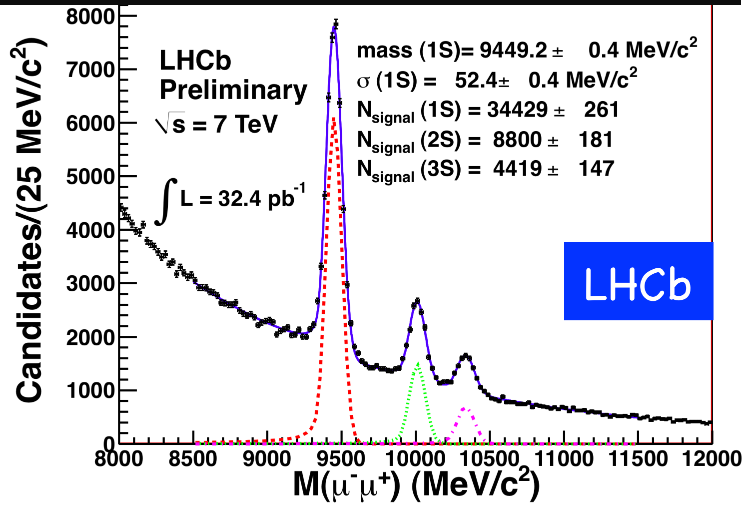


- $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ disagrees with NLO NRQCD (!)
- Next step: $\sigma(\chi_{c1}\text{->}J/\psi\gamma)/\sigma(J/\psi)$

LHCb-CONF-2011-020

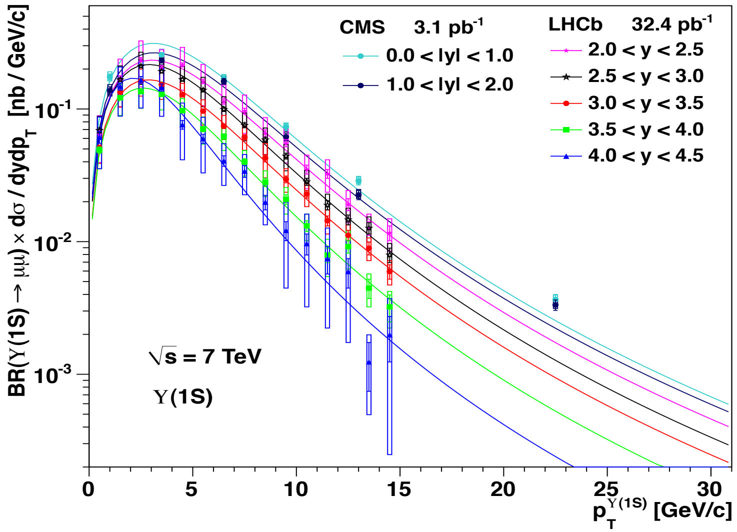
Upsilon family

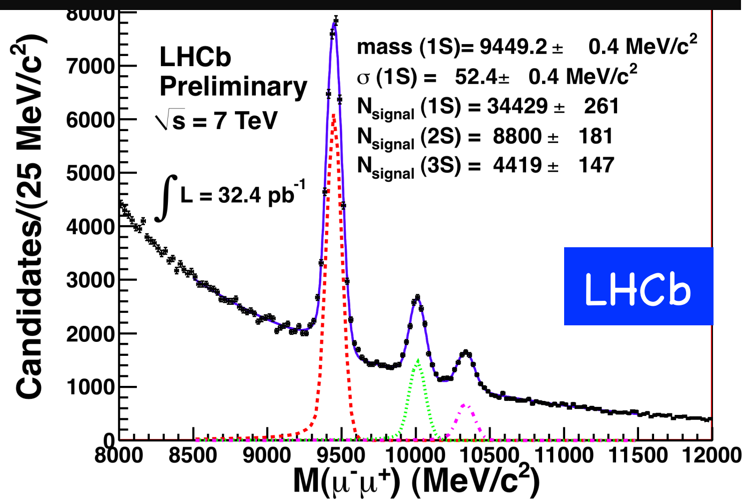
➡ Three states decay into μμ



Upsilon family

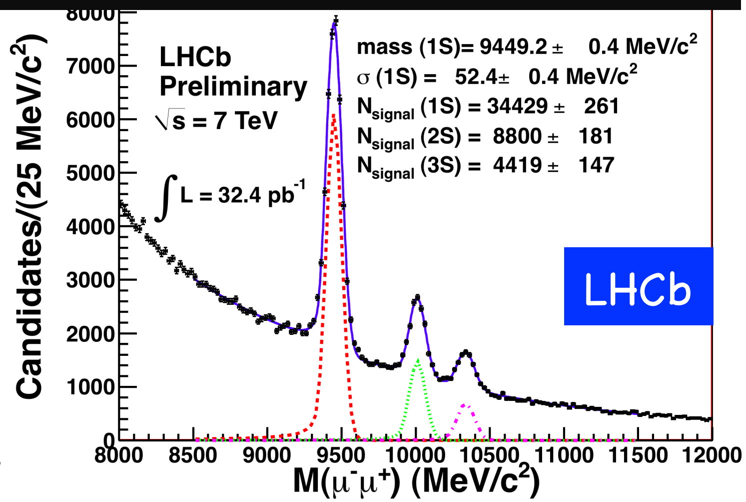
- ➡ Three states decay into μμ
- ➡ Cross section in pt-y bins

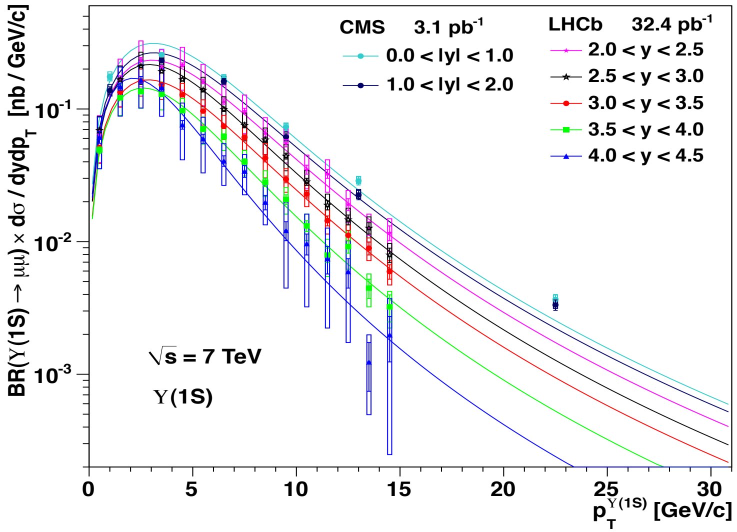




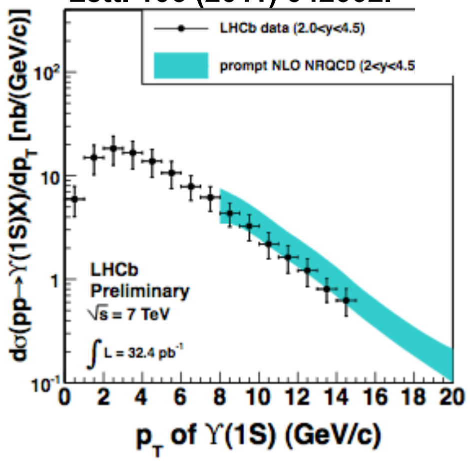
Upsilon family

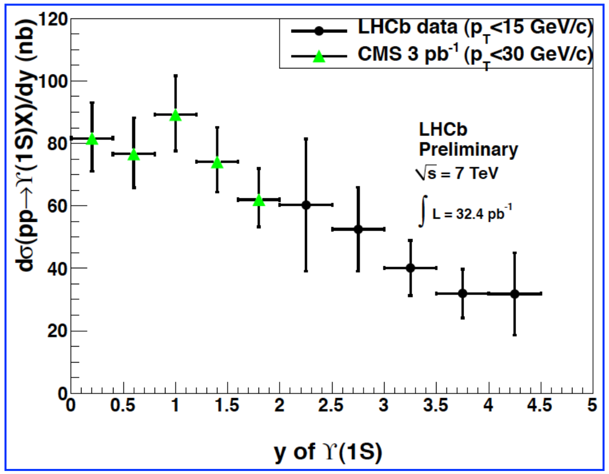
- Three states decay into μμ
- Cross section in pt-y bins





Y. Q. Ma, K. Wang and K. T. Chao, Phys. Rev. Lett. 106 (2011) 042002.

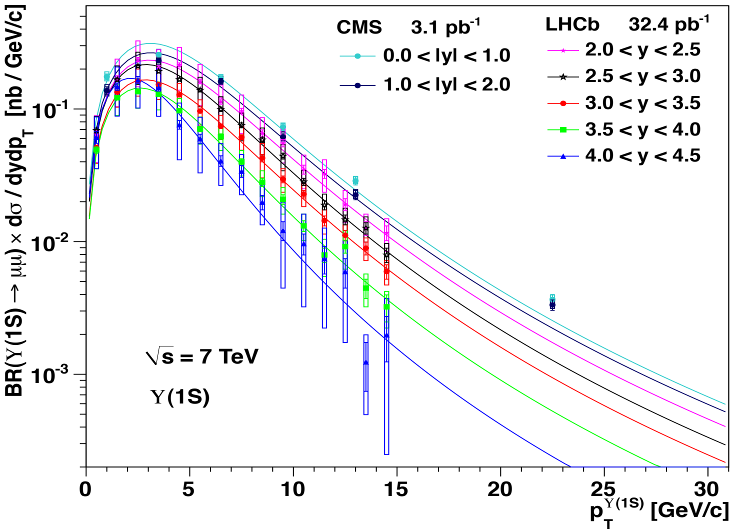


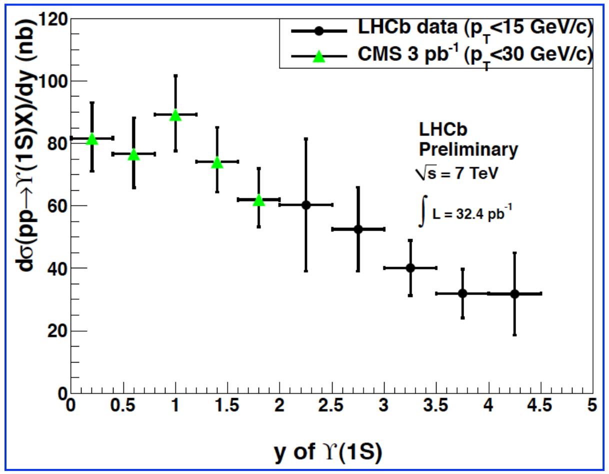


CMS: arXiv:1012.5545
LHCb: LHCb-CONF-2011-016

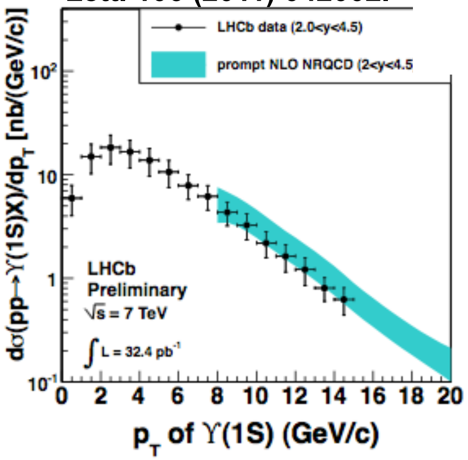
Upsilon family

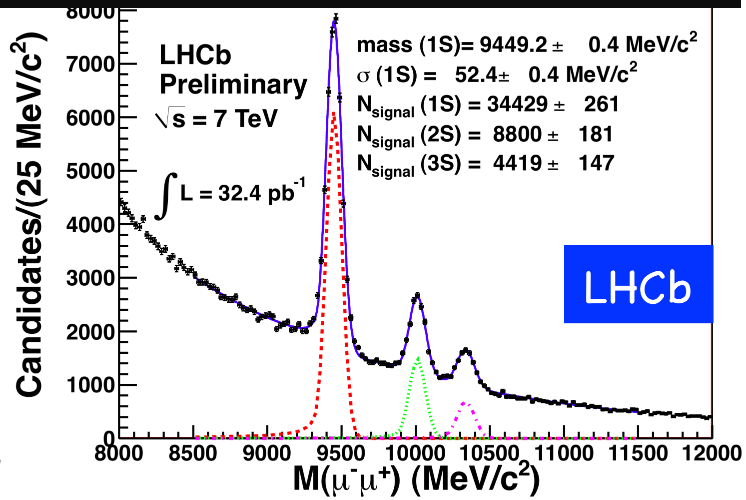
- Three states decay into μμ
- Cross section in pt-y bins



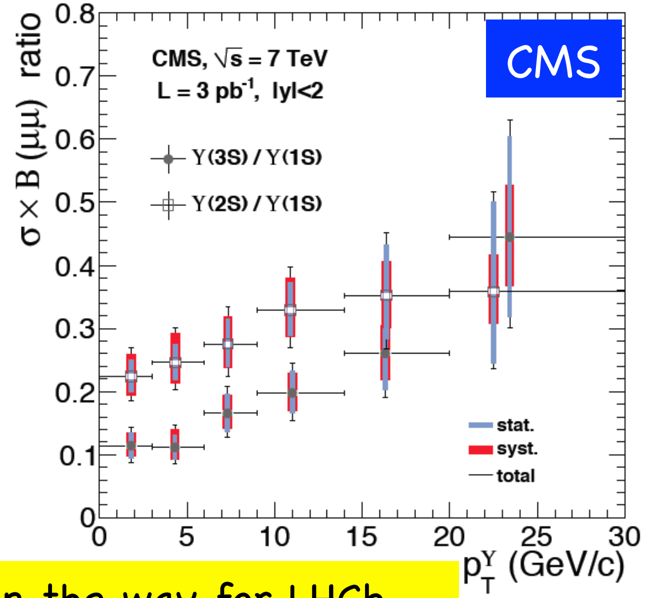


Y. Q. Ma, K. Wang and K. T. Chao, Phys. Rev. Lett. 106 (2011) 042002.



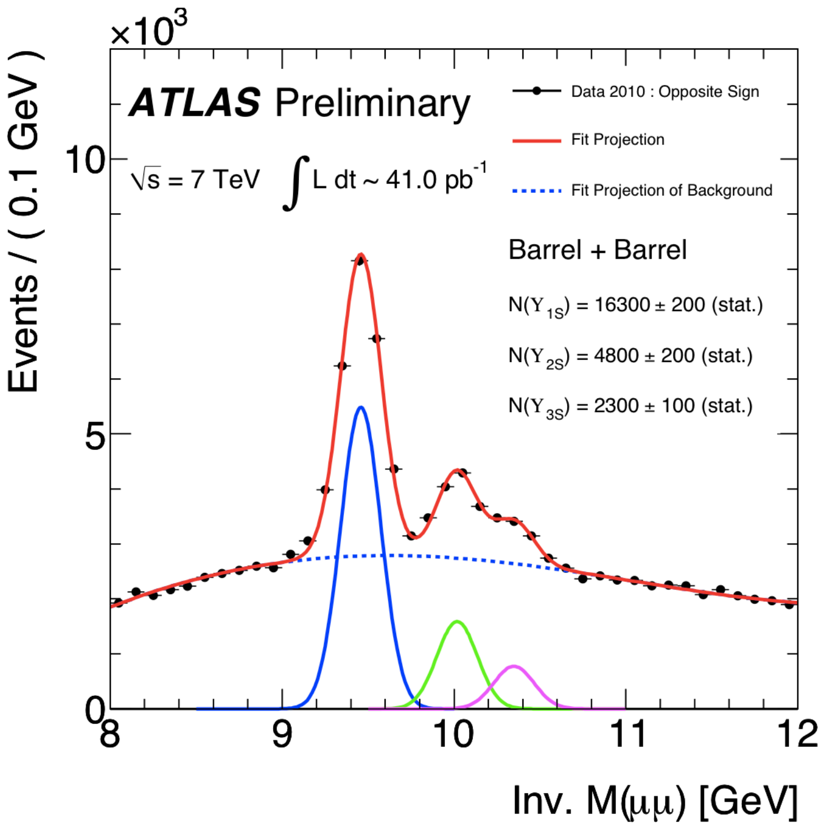


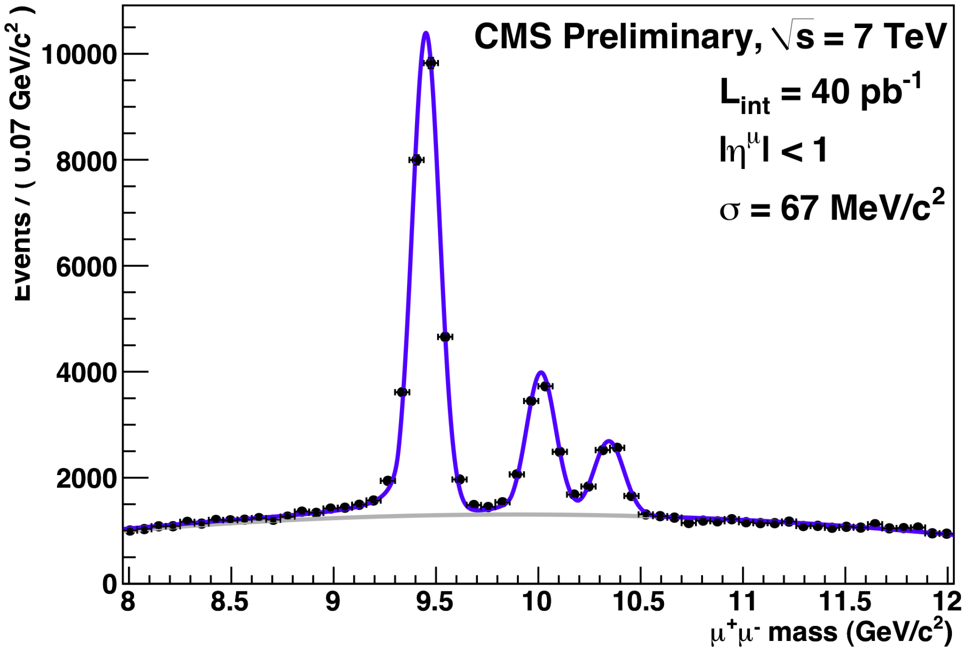
CMS: arXiv:1012.5545
LHCb: LHCb-CONF-2011-016



Measurement of 2s and 3s on the way for LHCb, 1S for Atlas. Wish list : Y(3S) polarisation...

Upsilon family: outlook

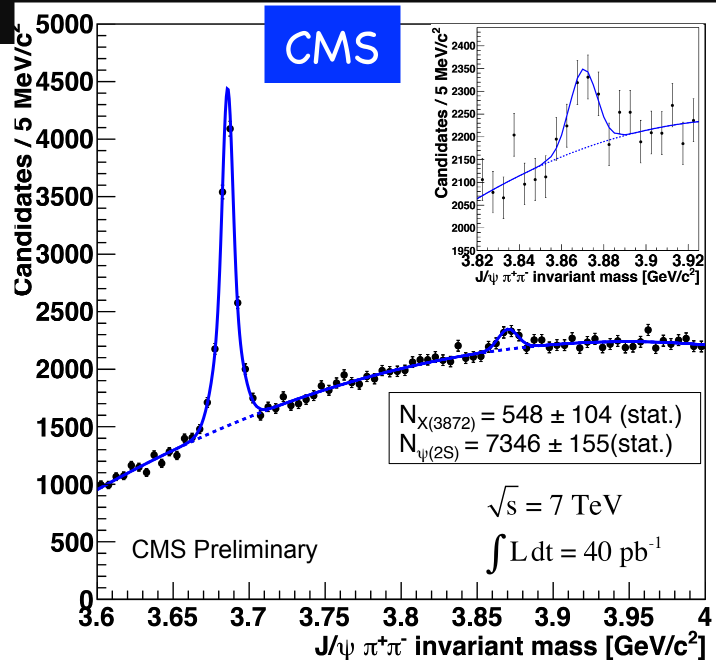


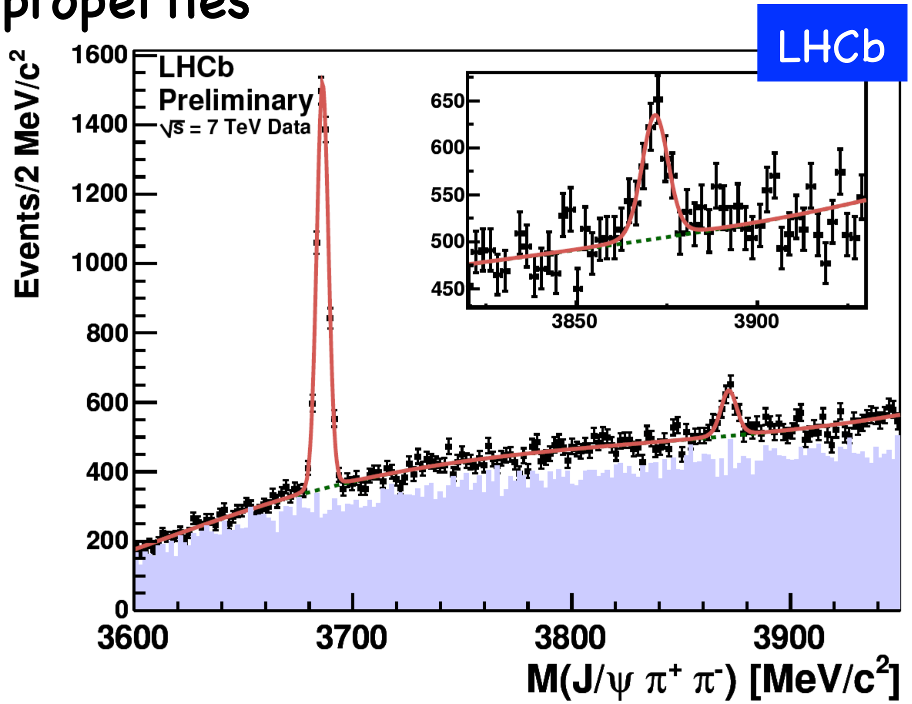


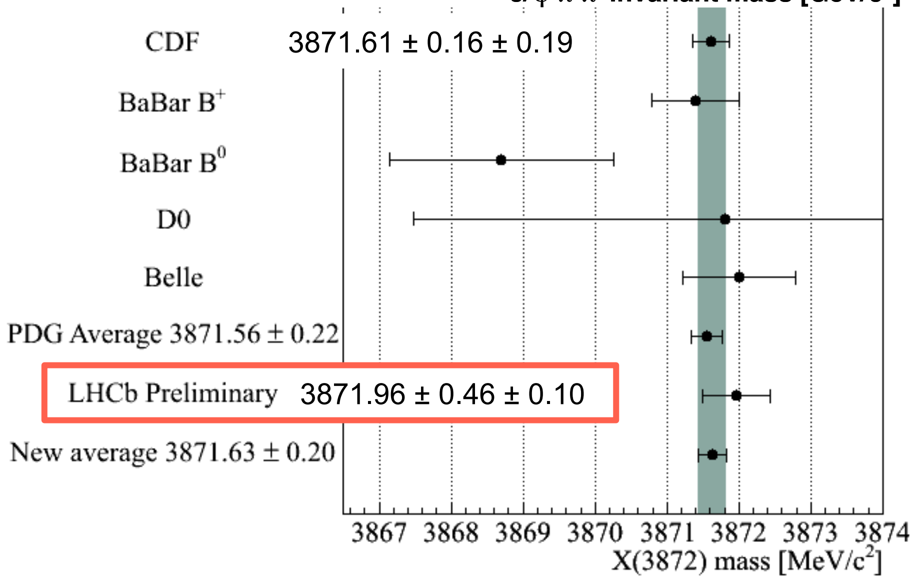
Measurement of 2s and 3s on the way for LHCb,
1S for Atlas (and update from CMS). Wish list : Y(3S) polarisation...

X(3872)

- First observation of X(3872) at LHC !!
- Its decay channel into J/ψ ππ
- Measured mass (LHCb) and cross section relative to ψ(2S) (CMS):
  - R = 0.087 ± 0.017 (stat) ± 0.009 (syst)
- With 2012 data will be able to study the properties



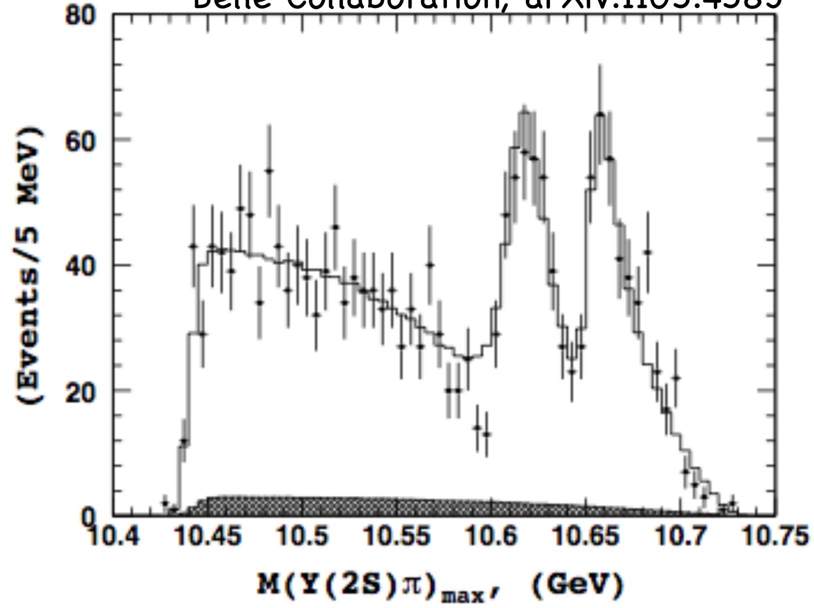




Results and Prospects

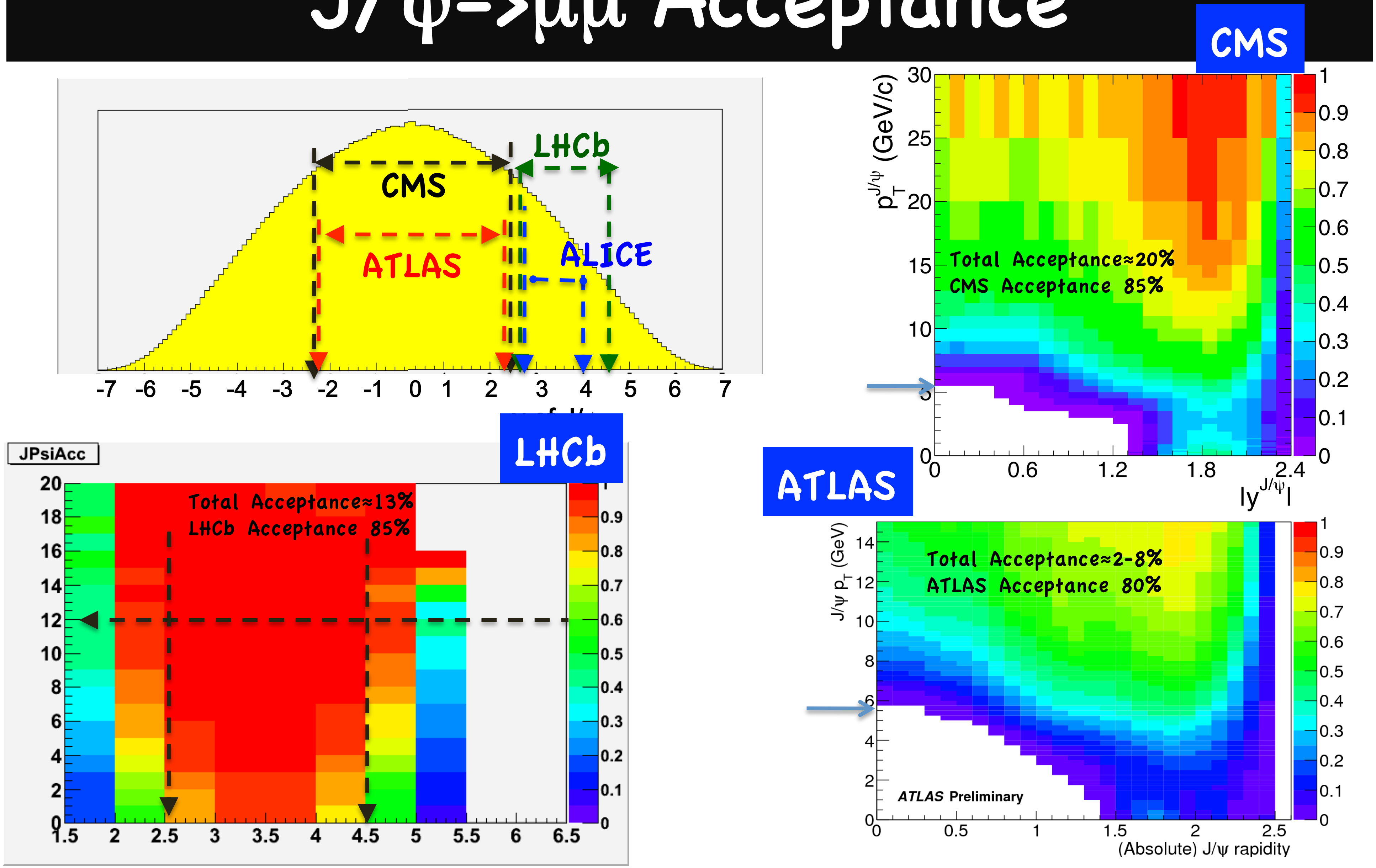
- Quarkonium physics flowering with new interesting results and investigating a completely new area!
- All four experiments extremely active and productive
- Statistics of 2011 will start to be enough
  - to strenghten production measurements
  - to explore XYZ spectroscopy
- New physics could be just round the corner!

Belle Collaboration, arXiv:1105.4583

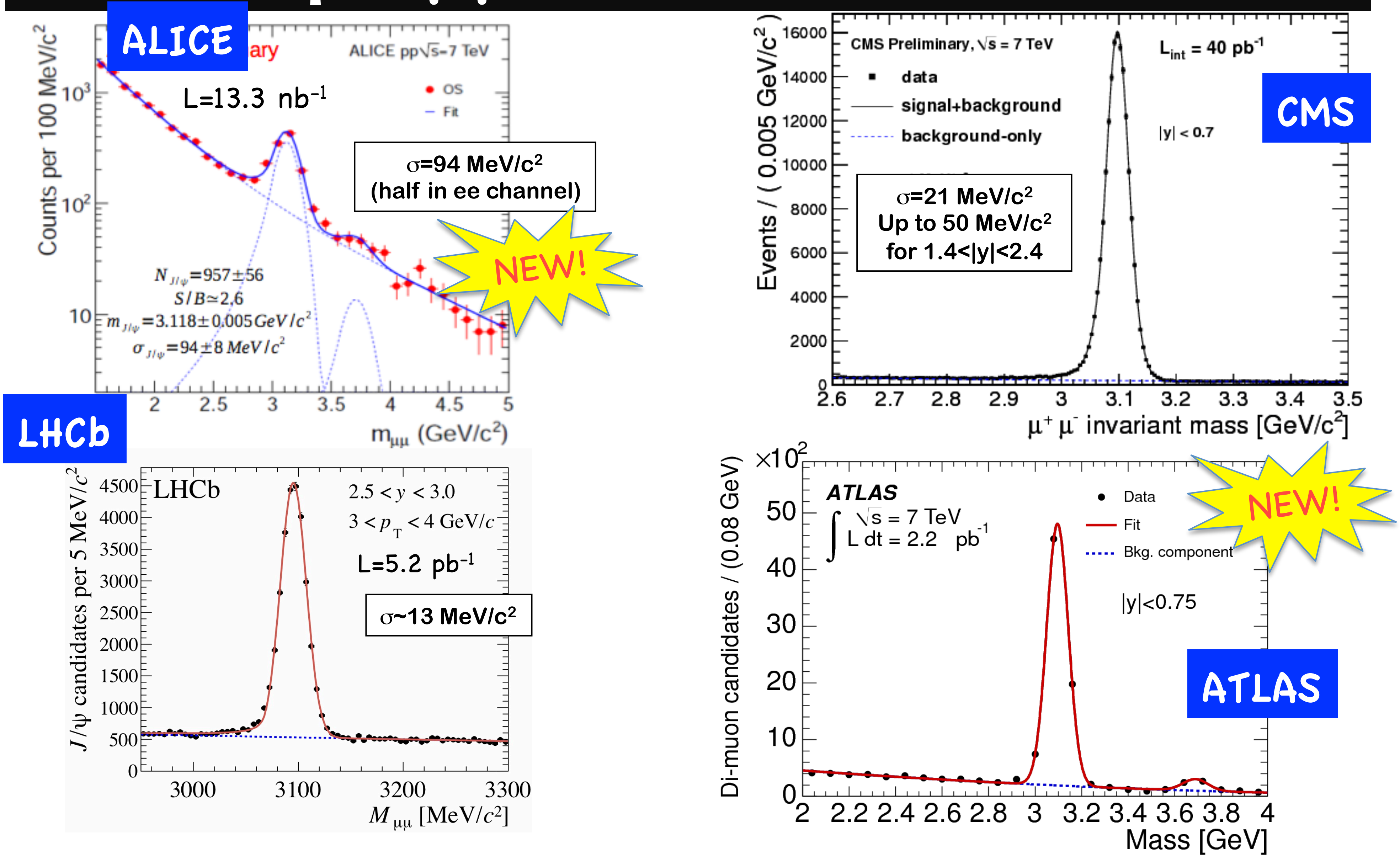


Back-up

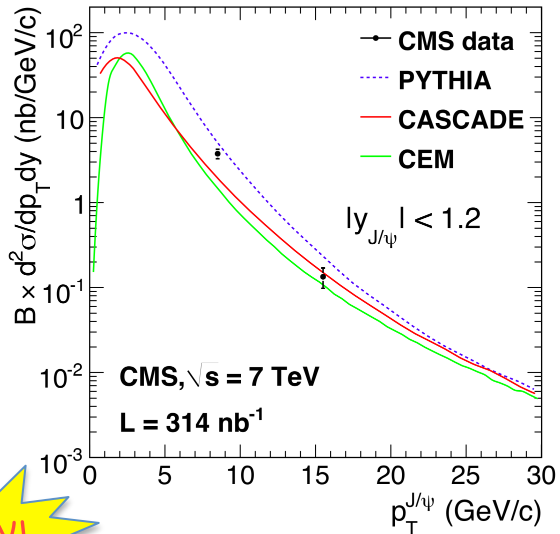
J/ψ->μμ Acceptance

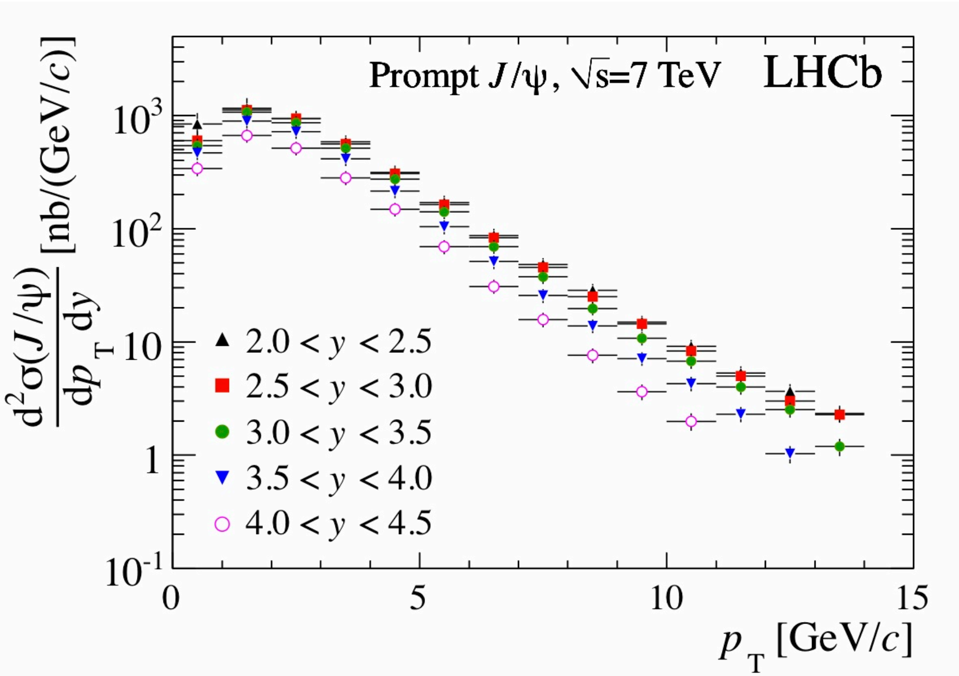


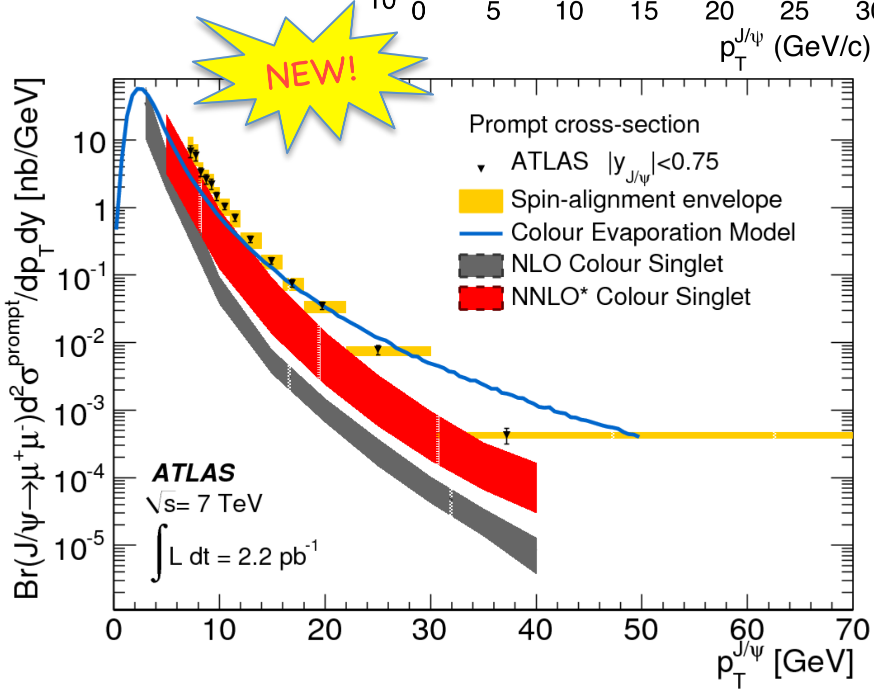
J/ψ→μμ mass distribution



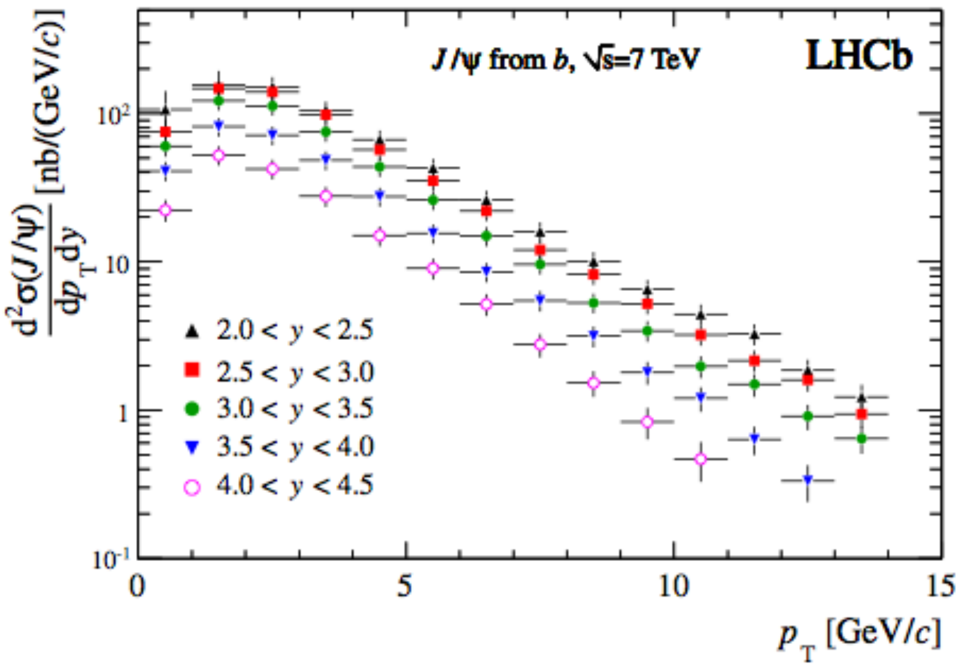
Prompt J/ψ cross section results

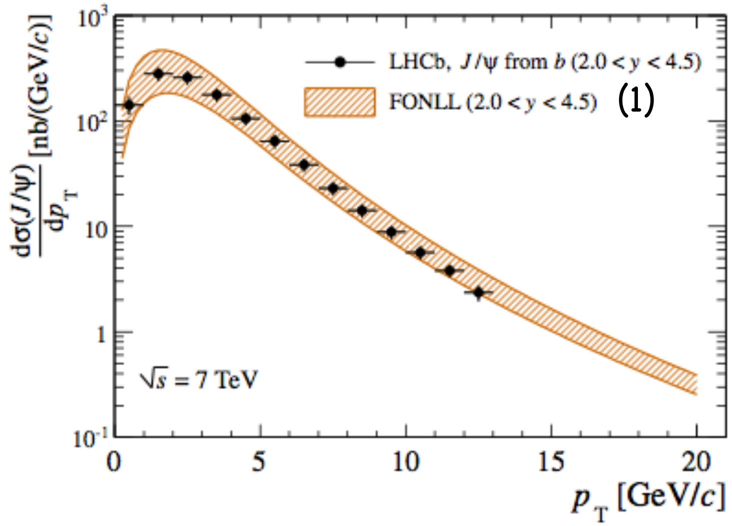


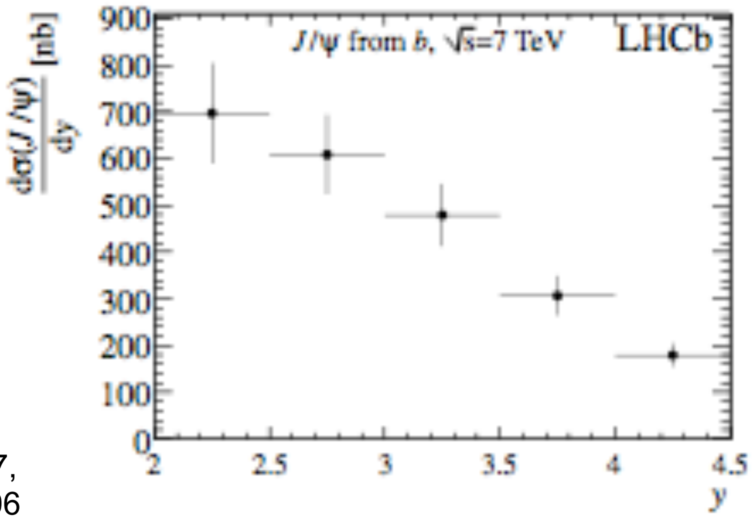




J/ψ from B cross-section







M. Cacciari, M. Greco and P. Nason, J. High Energy Phys. 9805 (1998) 007,
M. Cacciari, S. Frixione and P. Nason,J. High Energy Phys. 0103 (2001) 006

LHCb : Integrated Cross-section Results

$$\sigma(prompt - J/\psi, p_T < 14GeV/c, 2.0 < y < 4.5) = 10.52 \pm 0.04 \pm 1.40^{+1.64}_{-2.20}\,\mu b$$

$$\sigma(J/\psi - from - b, p_T < 14GeV/c, 2.0 < y < 4.5) = 1.14 \pm 0.01 \pm 0.16\,\mu b$$

Using the LHCb acceptance from Pythia, we extrapolated :

$$\sigma(pp \to b\bar{b}X) = \alpha_{4\pi} \frac{\sigma(J/\psi - from - b, p_T < 14GeV/c, 2.0 < y < 4.5)}{2Br(b \to J/\psi X)}$$

$$\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 48\,\mu b$$

$\alpha_{4\pi}^{FONLL} = 5.21$

$Br(b \to J/\psi X) = (1.2 \pm 0.1)\%$

In good agreement with: $\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49\,\mu b$
measured in $B \to D^0 \mu \nu X$ at LHCb

Integrated J/ψ->μμ cross section measurements

Experiment Range Luminosity	LHCb (in μb) pT<15 GeV, 2.0<y<4.5 5.2 pb^{-1}	CMS (in nb) 6.5<pT<30 GeV, |y|<2.4 312 nb^{-1}	ATLAS (in nb) |y|<2.4, p_T>7 GeV 1.5<|y|<2, pT>1 GeV 2.2 pb^{-1}	ALICE(in μb) 2.5<y<4.0, 0<pT<12 GeV 13.3 nb^{-1}
Inclusive J/ψ		97.5±1.5±3.4±10.7 (lum)	$81.1\pm1\pm10^{+25}_{-20}\pm3$ 510±70+84-123+919-134±17	$6.31\pm0.25\pm0.80^{+0.95}_{-1.96}$
Prompt J/ψ	$10.52 \pm 0.04 \pm 1.40^{+1.64}_{-2.20}$	70.9 ± 2.1 (stat) ± 3.0 (syst) ± 7.8 (lum.)	59±1±8+9-6±2 450±67+85-114+741-105±15	
J/ψ from B	1.14 ± 0.01 ± 0.16	26.0 ± 1.4 (stat) ± 1.6 (syst) ± 2.9 (lum.)	23.0±0.6±2.8±0.2±0.8 61±24±19±1±2	
Total bb*	288 ± 4 ± 48			

* Extrapolating to the LHCb acceptance using Pythia 6.4

Uncertainties : First stat, second syst, third spin, fourth lum

Systematics on J/ψ cross section measurement

Source of systematic uncertainties considered:

Source	Systematic uncertainty (%)
Correlated between bins	
Inter-bin cross-feed	0.5
Mass fits	1.0
Radiative tail	1.0
Muon identification	1.1
Tracking efficiency	8.0
Track χ^2	1.0
Vertexing	0.8
GEC	2.0
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	1.0
Luminosity	10.0
Uncorrelated between bins	
Bin size	0.1 to 15.0
Trigger	1.7 to 4.5
Applied only to J/ψ from b cross-sections, correlated between bins	
GEC efficiency on B events	2.0
t_z fits	3.6
Applied only to the extrapolation of the $b\bar{b}$ cross-section	
b hadronisation fractions	2.0
$\mathcal{B}(b \to J/\psi X)$	9.0

- CMS :Main systematic uncertainties:
  - Resolution model (0.8 up to 30% for the lowest p_T bin in the endcap)
  - Primary vertex (0.3 up to 60% for the lowest p_T bin in the endcap)

J/ψ @2.76 TeV: systematic uncertainties

Source of systematic uncertainty	$J/\psi \rightarrow \mu^+\mu^-$	$J/\psi \rightarrow e^+e^-$
signal extraction	6 %	8.5 %
Acceptance inputs	2.5%	1 %
Trigger efficiency	4%	-
Reconstruction efficiency	4%	11 %
Trigger enhancement	3%	-
Luminosity	8%	8 %
Total systematic uncertainty	**12.1 %**	**16.1%**

Polarization	λ=-1 λ=+1	λ=-1 λ=+1
Collins-Soper	+32 -16 %	+19 -13 %
Helicity	+24 -12 %	+21 -15 %

➡ Total systematic uncertainties similar to the ones at 7 TeV

Atlas jpsi : Systematic studies: “acceptance”

Acceptance map MC statistics:

Obtained from dedicated MC simulation. Statistical uncertainties on maps bin-to-bin propagated through to final result (contribution at level of 1-2%)

Bin migration effects

Bin migration effects were studied, corrections applied (0.1—3%) and variation of bin migration within bin considered as systematic on correction

ID track reconstruction

ID track reco efficiency correction 99.5% per muon track with 0.5% uncertainty per track added linearly

Kinematic dependence

Variation of MC spectra to make acceptance maps, and correction for slight differences in non-prompt/prompt acceptance assigned as systematic (max 1.5%)

Final state radiation

Central result is corrected back to J/ψ kinematics rather than final state muon kinematics, systematic due to FSR is $<0.1\%$ (NB: taking effect of FSR on/off is overestimate)

Atlas jpsi : Systematic studies: "other components"

Spin alignment

Spin-alignment uncertainty is maximum envelope of cross-section re-casted under different spin-alignment hypothesis

Luminosity

Quoted 3.4% uncertainty from Van der Meer scans

Muon reconstruction efficiency

Uncertainties on J/ψ reco. efficiency maps from data and uncertainties on MC/data scale factors propagated through to final result (5—10%)

Fit uncertainty

Derived via pseudo-experiments – approx. 1—3% contribution

Trigger efficiency

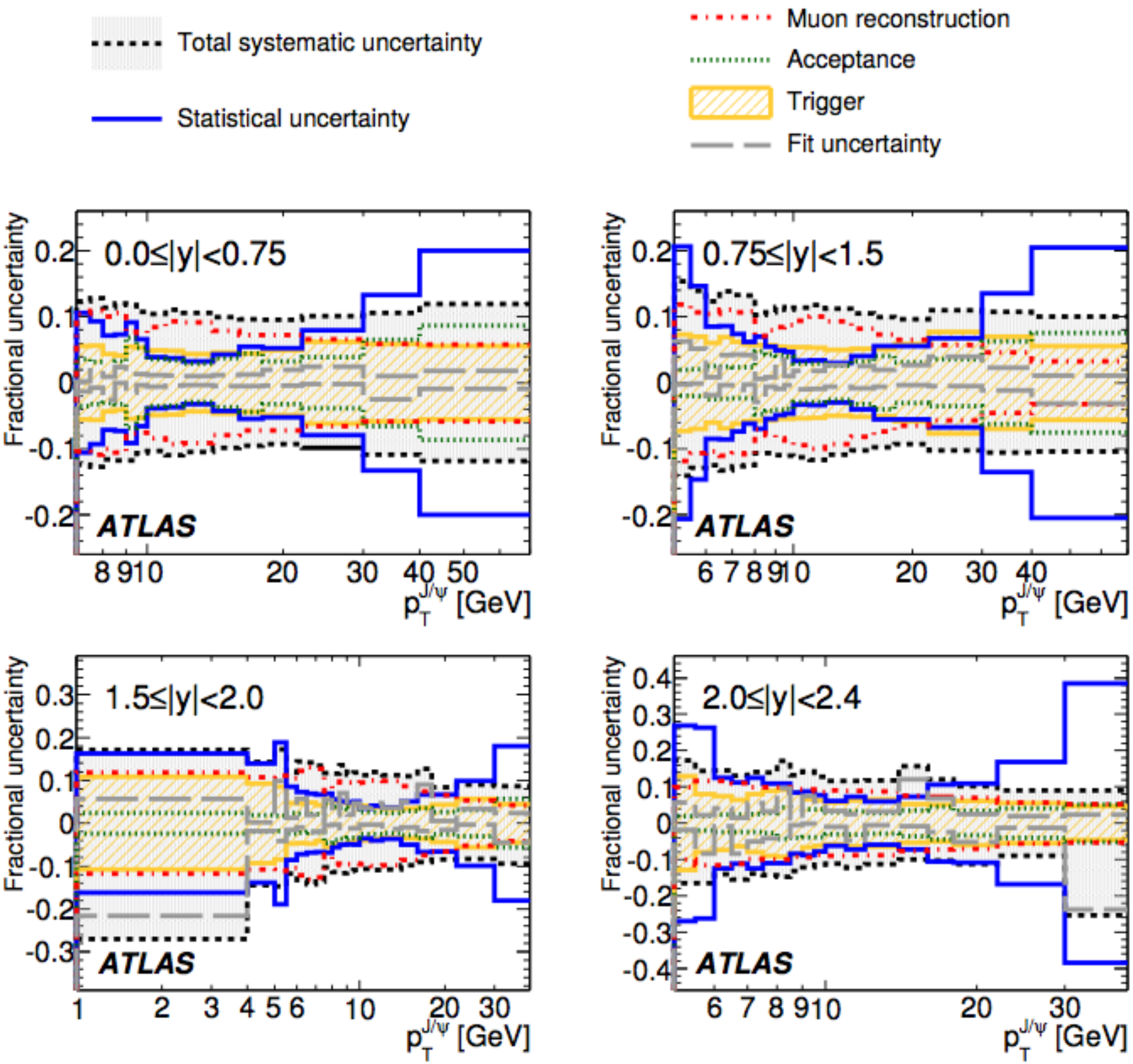
Similarly, uncertainties from data maps propagated through to final result (~5% effect)

J/ψ vertex finding and primary vertex efficiencies

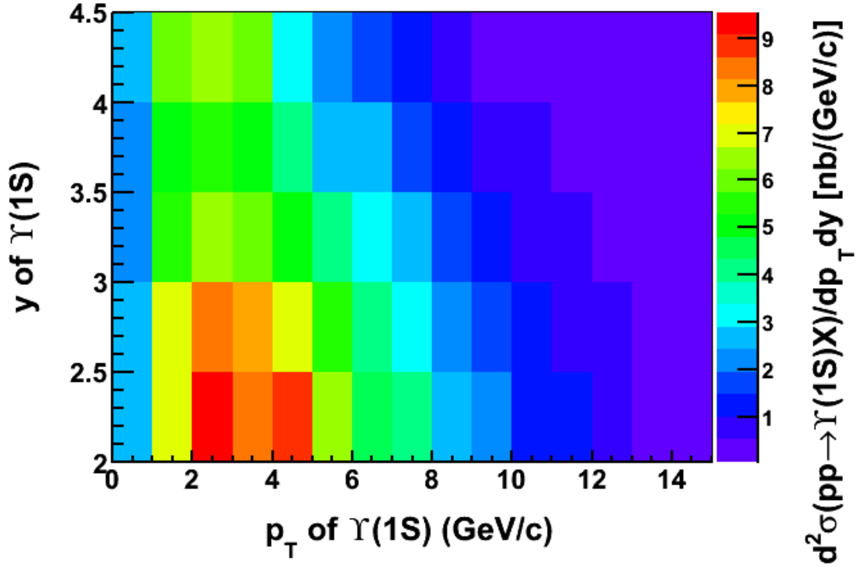
Both these efficiencies retain more than 99.9% signal, no uncertainty assigned

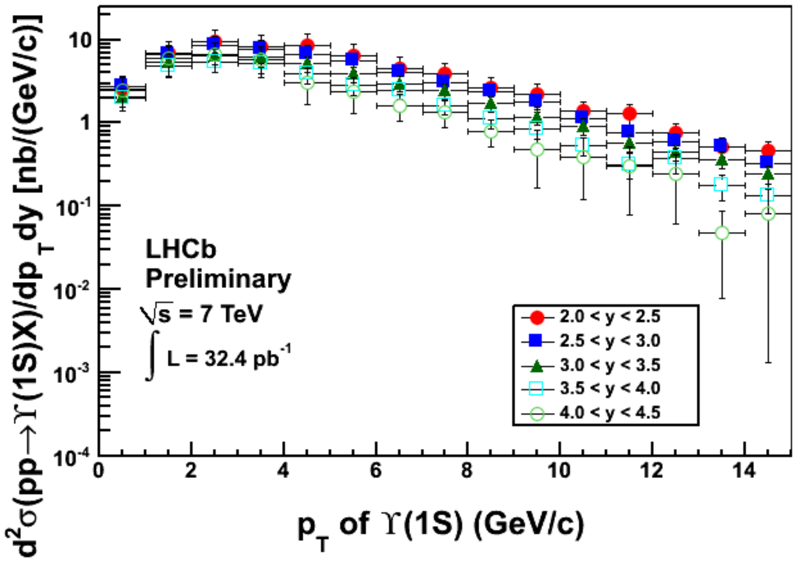
Atlas jpsi : Systematic studies

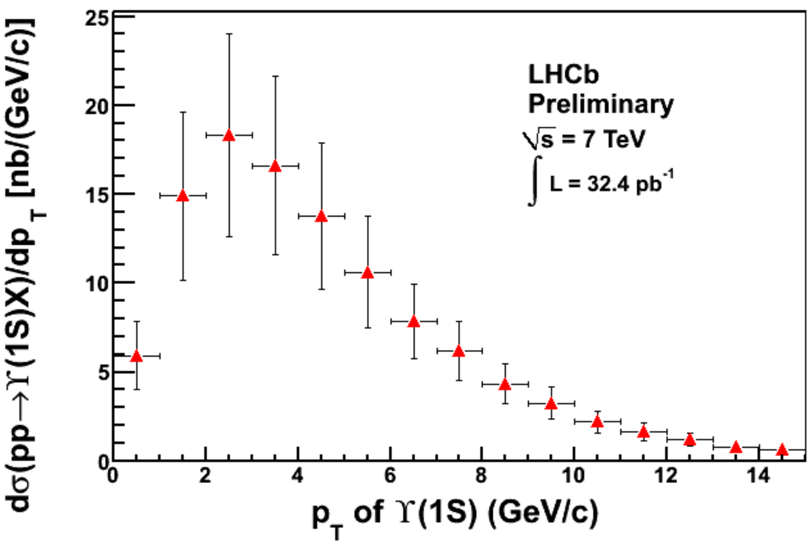
Sources of systematic uncertainty, and total uncertainties in each analysis bin

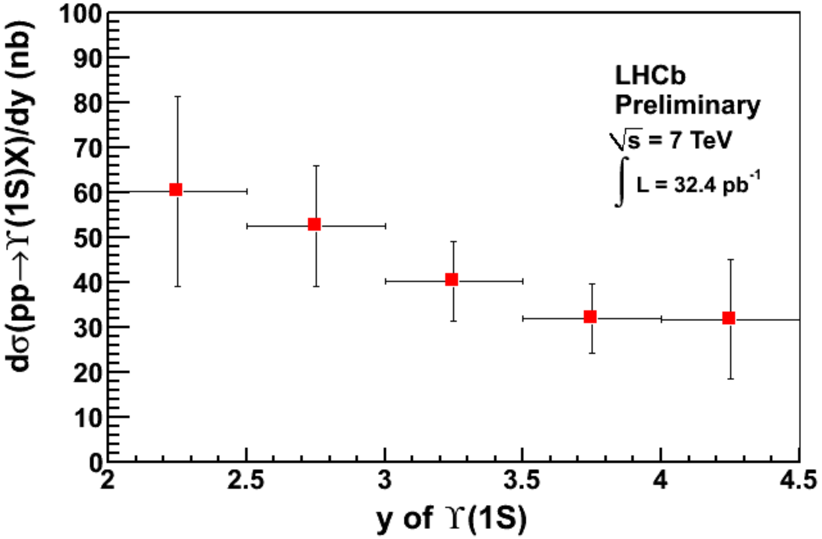


LHCb : Upsilon Cross Section









$$108.3 \pm 0.7(\text{stat})\ ^{+18.8}_{-7.9}(\text{pola}) \pm 22.0(\text{osys}) \pm 10.8(\text{lumi})\ \text{nb} = 108.3 \pm 0.7(\text{stat})\ ^{+30.9}_{-25.8}\ (\text{syst})\ \text{nb}$$

LHCb : $\Upsilon(1S)$ Systematic Uncertainties

SOURCE	METHOD	VALUE	COMMENTS
luminosity	see section 3.2.2	10%	correlated among bins
ϵ^{trig} calculation	difference MC-MC truth	2-67%	correlated among bins
polarisation on A	extreme polarisation scenarios	0-33%	correlated among bins
polarisation on ϵ^{rec}	extreme polarisation scenarios	0-21%	correlated among bins
choice of fit function	different function	1%	correlated among bins
unknown p_T spectrum	p_T spectrum distribution	1%	correlated among bins[2]
GEC	statistical uncertainty of data	2%	correlated among bins
$\epsilon^{trackquality}$	difference data-MC	0.5% per track	correlated among bins
$\epsilon^{track-finding}$	difference data-MC	4% per track	correlated among bins
vertexing	difference data-MC	1%	correlated among bins
ϵ^{muonID}	tag and probe [20]	1.1%	correlated among bins

CMS: Υ(1S) Systematic Uncertainties

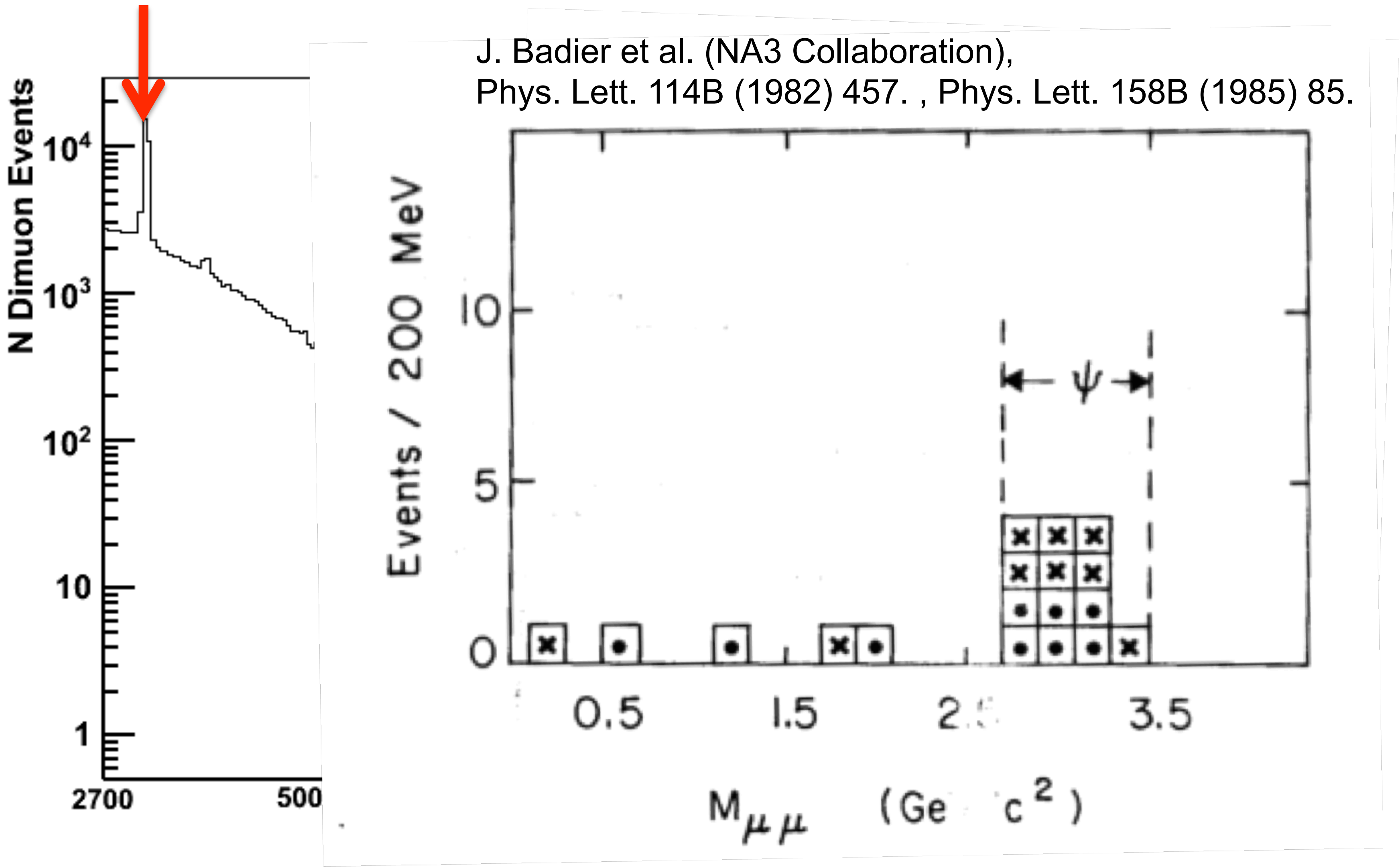
Y(nS) Cross Section Results

- Measured cross section for |y| < 2:

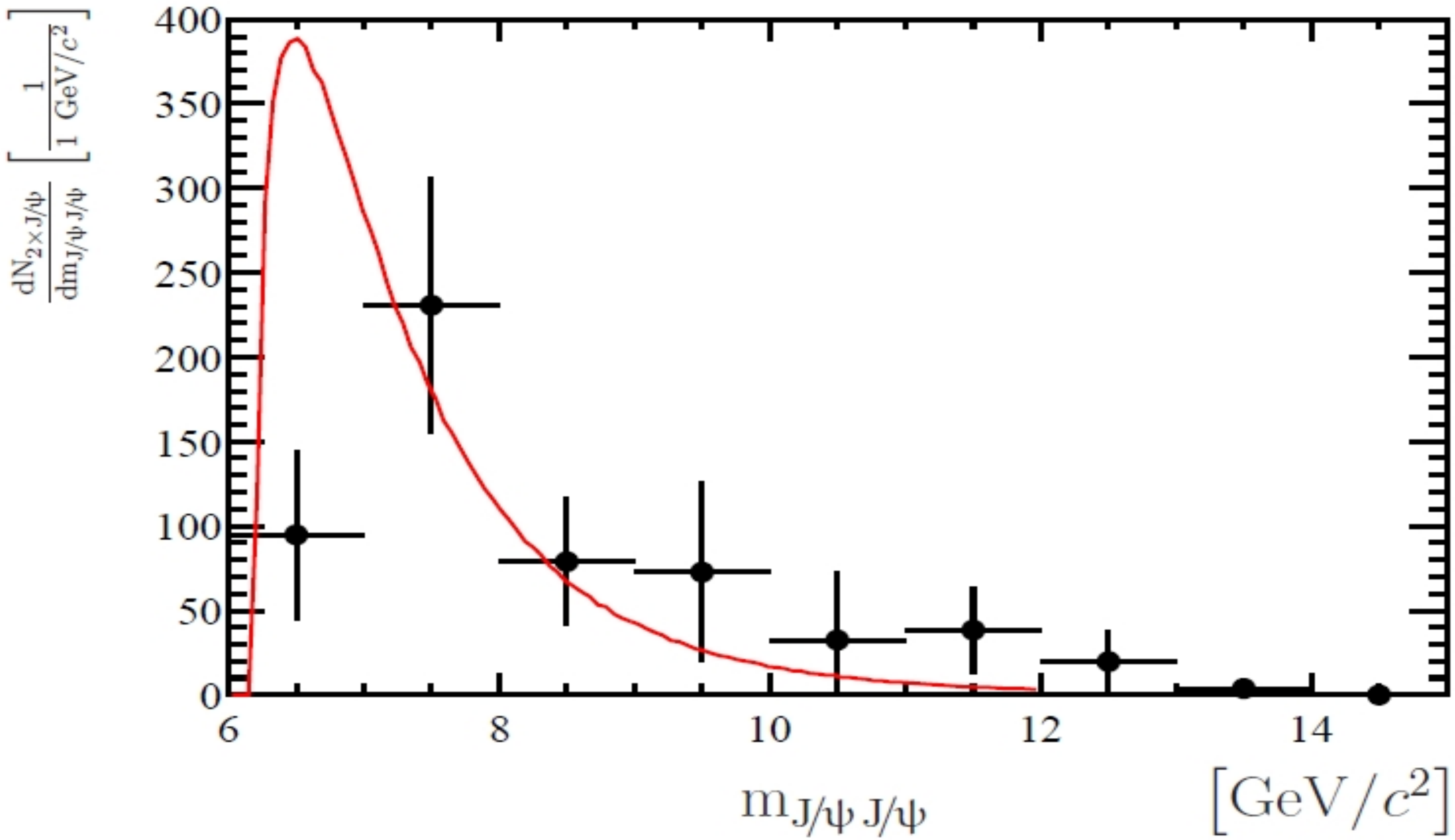
$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = 7.37 \pm 0.13(\text{stat.})^{+0.61}_{-0.42}(\text{syst.}) \pm 0.81(\text{lumi.})\ \text{nb}\,,$$
$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = 1.90 \pm 0.09(\text{stat.})^{+0.20}_{-0.14}(\text{syst.}) \pm 0.24(\text{lumi.})\ \text{nb}\,,$$
$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = 1.02 \pm 0.07(\text{stat.})^{+0.11}_{-0.08}(\text{syst.}) \pm 0.11(\text{lumi.})\ \text{nb}\,.$$

- Values shown for unpolarized assumption
  - Extreme scenarios yield variations at the 20% level
- Dominant systematic uncertainties:
  - Luminosity normalization (11%) [note: a 4% level has been more recently achieved]
  - Muon reconstruction/trigger efficiency from T&P (8%)

Double J/ψ production

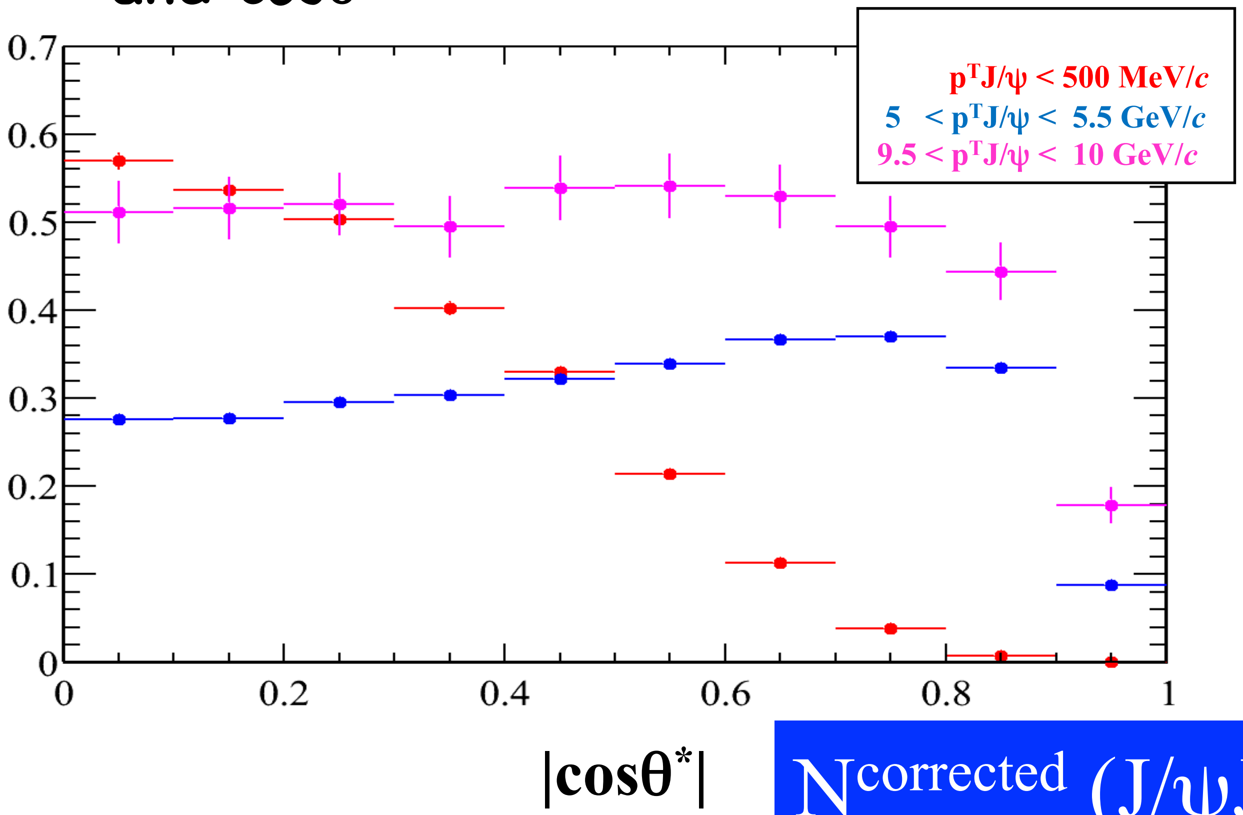


J/ψ J/ψ Invariant Mass



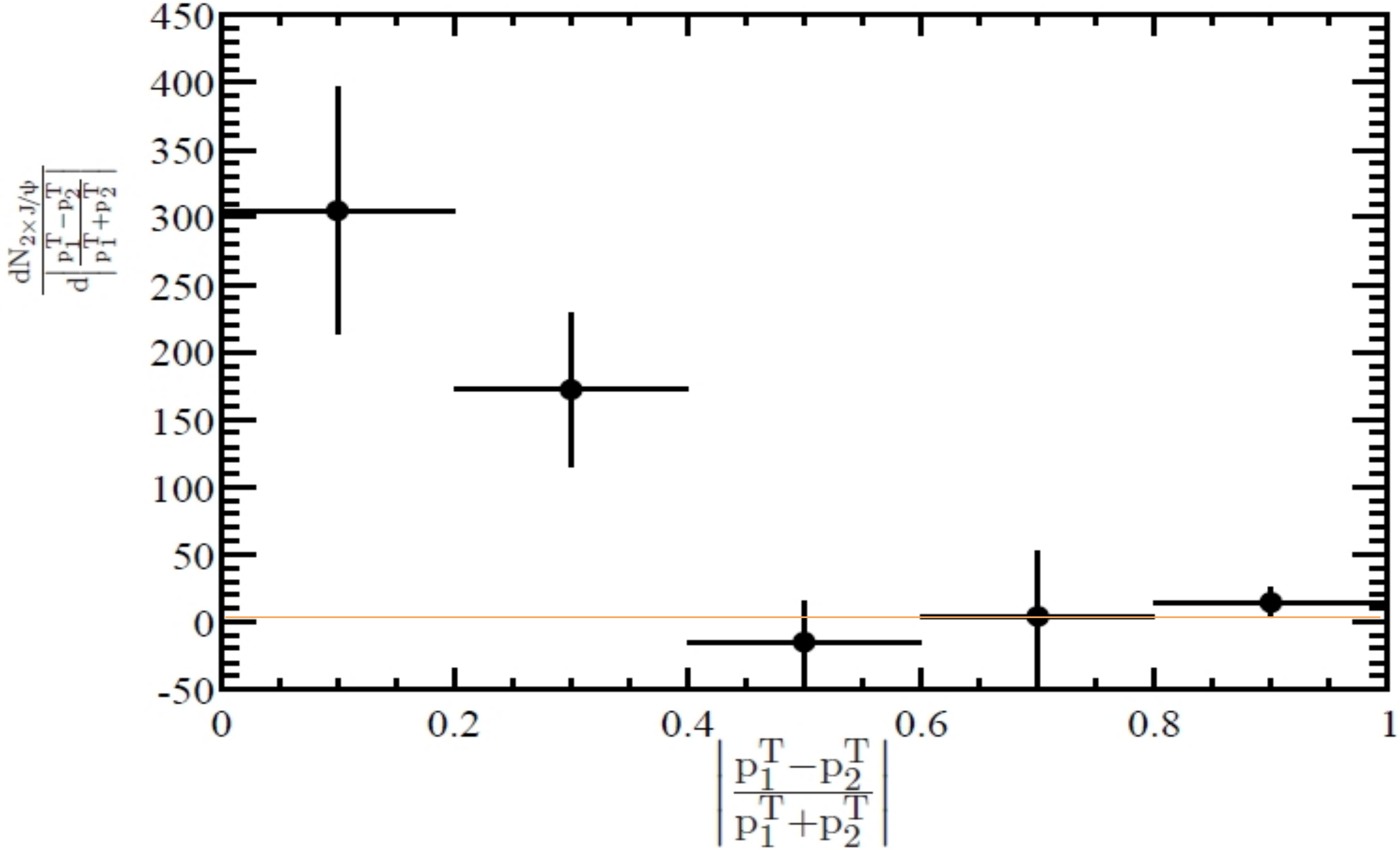
Efficiency

- Each event : weight $w = \varepsilon^{-1}$, with $\varepsilon = \varepsilon_{rec} \times \varepsilon_{trig} \times acceptance$
- Assume factorisation : $\varepsilon_{J/\psi J/\psi} = \varepsilon_{J/\psi} \times \varepsilon_{J/\psi}$, ε binned vs. p_T, y and $\cos\theta^*$

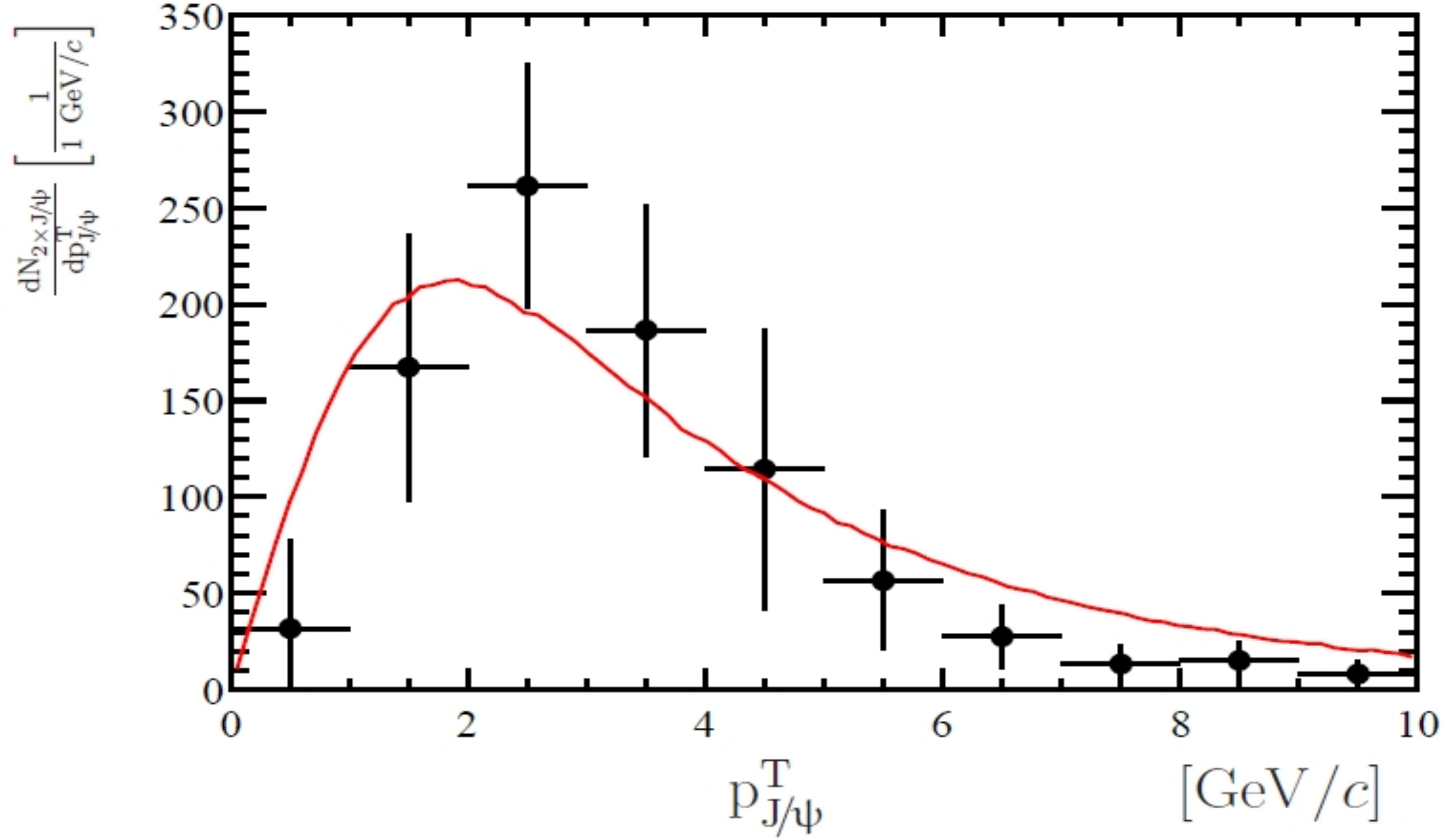


$N^{corrected}(J/\psi J/\psi) = 700 \pm 133$

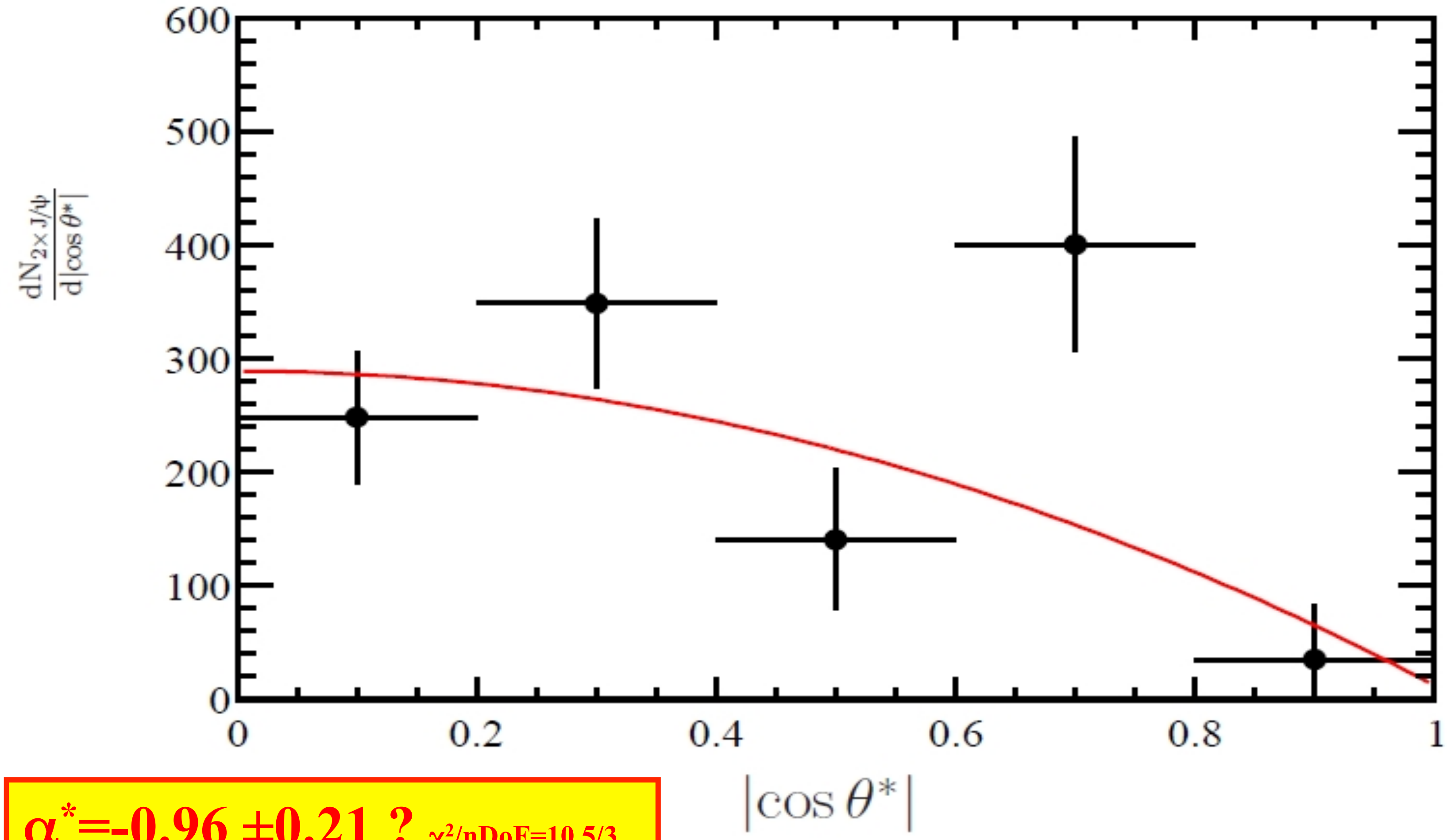
Efficiency corrected p^T-asymmetry



Efficiency corrected $p^T_{J/\psi}$ from $2\times J/\psi$



J/ψ polarization: $\cos\theta^*$



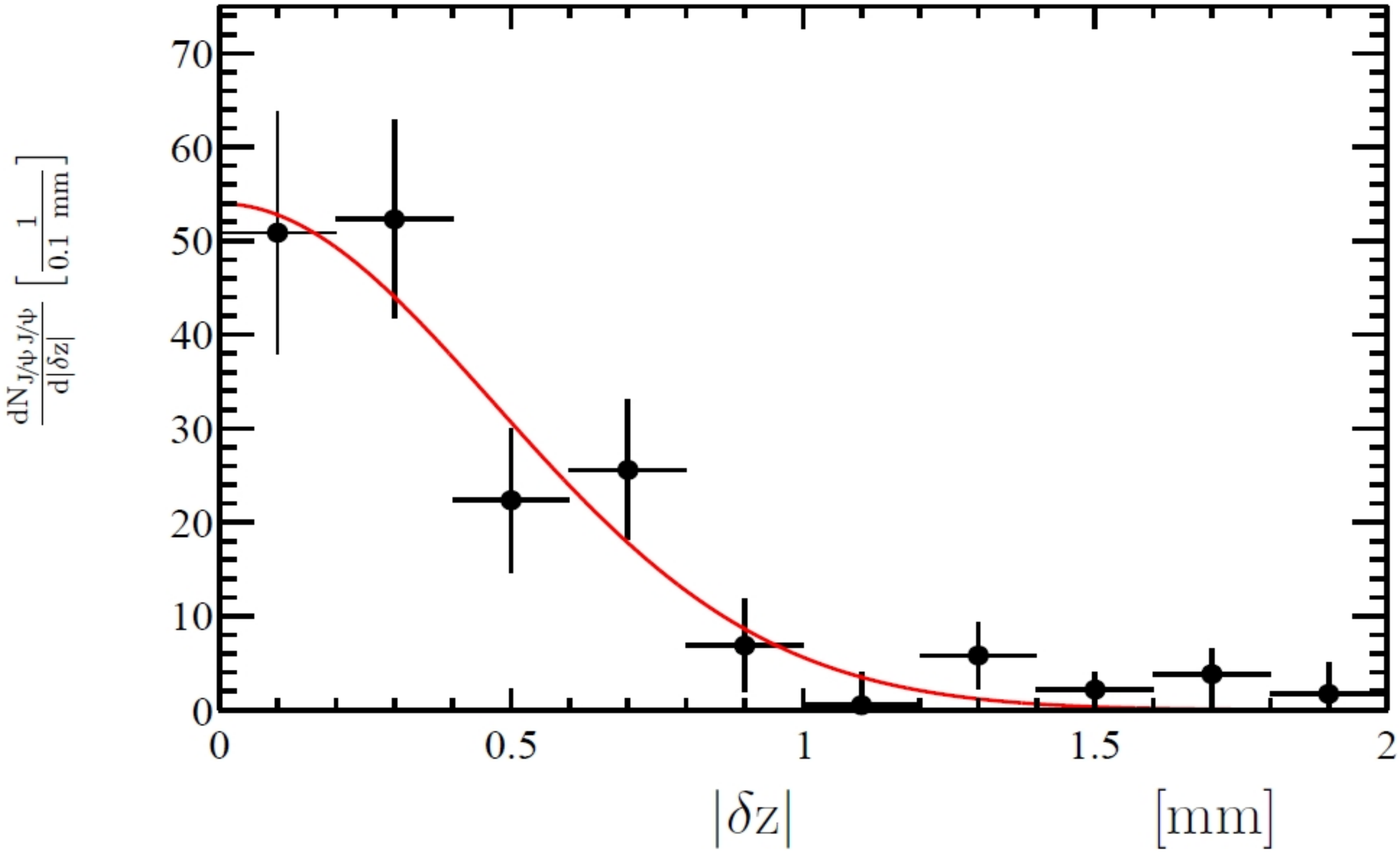
α^*=-0.96 ±0.21 ? χ^2/nDoF=10.5/3

Pileup: $J/\psi J/\psi$ versus $J/\psi+J/\psi$

➡How to prove that it is *NOT* pileup?

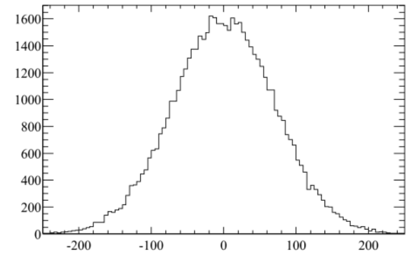
- Monte Carlo
- Look for data:
  - Distance between J/ψ vertices
  - Track in PV: $\times 2$ larger for pileup
  - PV-multiplicity: -1 for pileup
  - Wide range $\chi^2_{DTF}/nDoF$ scan

$J/\psi J/\psi$ distance

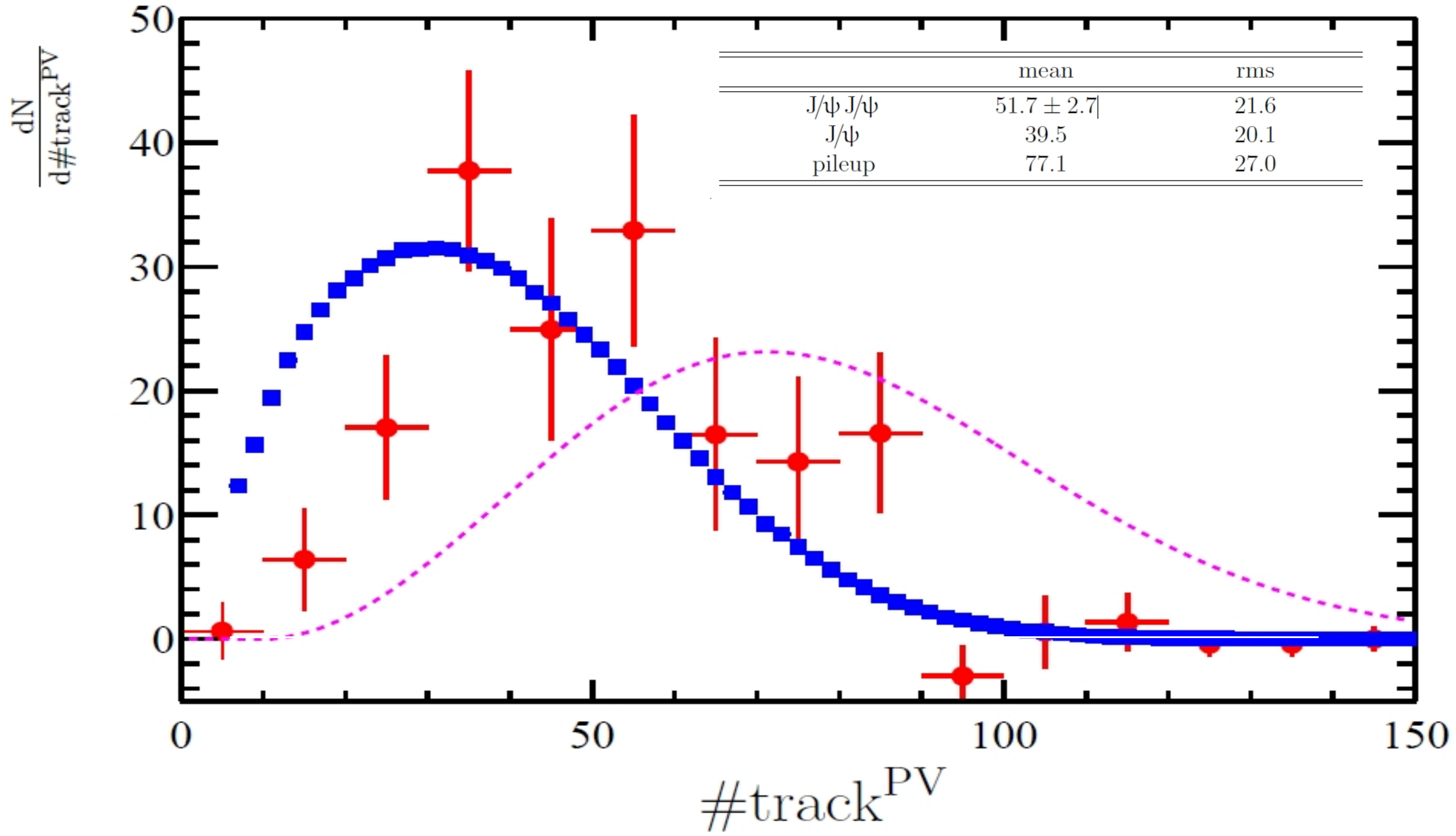


J/ψJ/ψ distance

- $\sigma^{|\delta z|} = 470 \pm 62\ \mu m$
- All signal is collected from 1.5/2mm
- Monte Carlo:
  - take events with J/y+J/y in inclusive J
    - Different pp-collisions!
  - signal window
  - correct for cross-section
  - [CONSERVATIVELY]: ~9.4 events in 2mm
  - apply trigger & reconstruction efficiency
    - <1.5 events

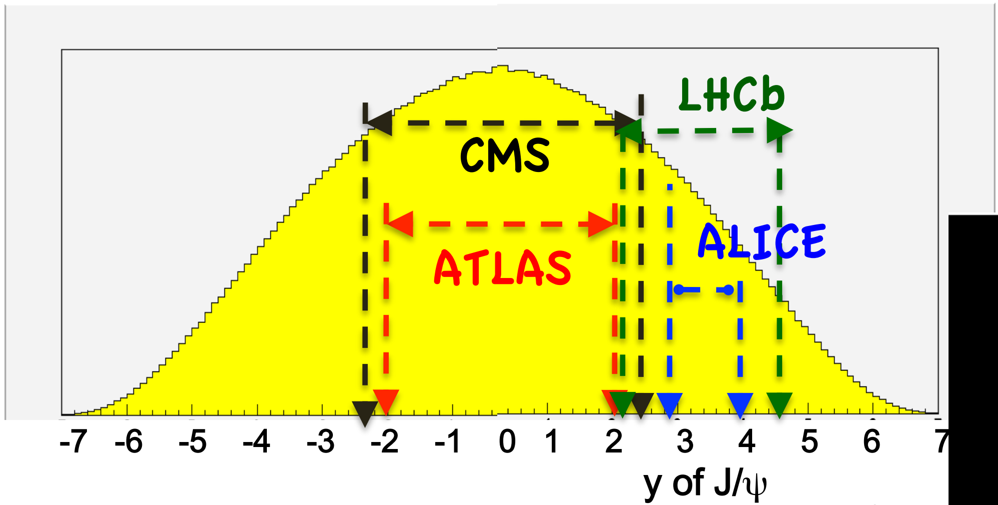


#tracks in PV



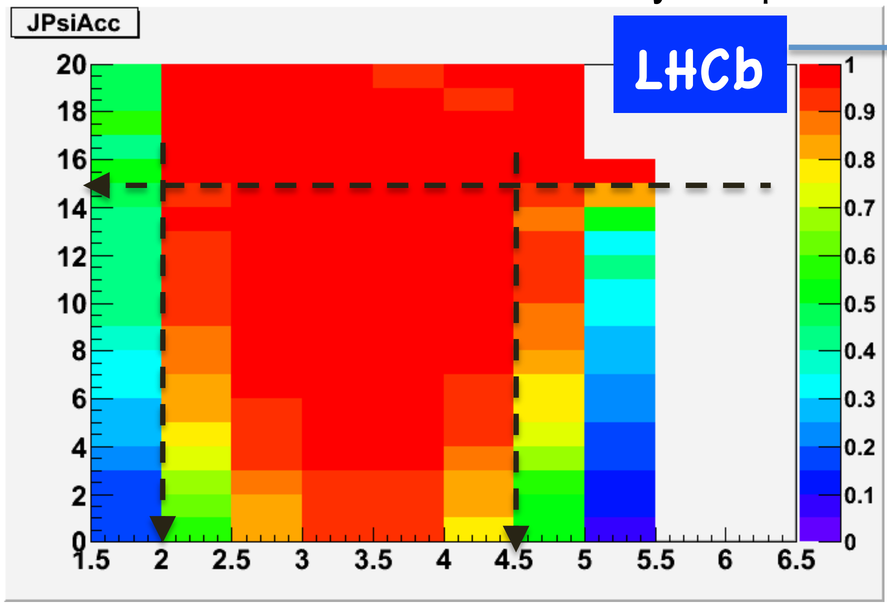
$\frac{dN}{d\#track^{PV}}$
mean
rms
J/ψ J/ψ
51.7 ± 2.7
21.6
J/ψ
39.5
20.1
pileup
77.1
27.0
50
40
30
20
10
0
0
50
100
150
$\#track^{PV}$

J/ψ→μμ Acceptance

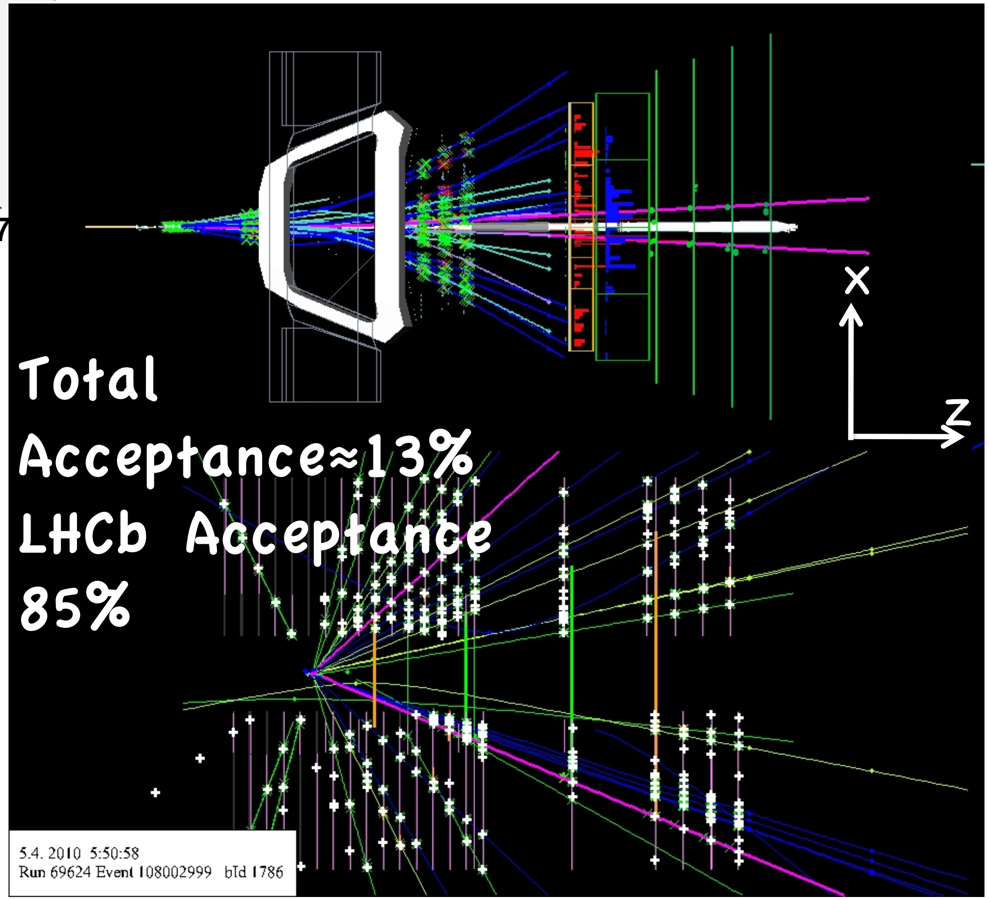


CMS → Total Acceptance≈20%
CMS 85%

ATLA → Total Acceptance≈2-8%
ATLAS Acceptance 80%



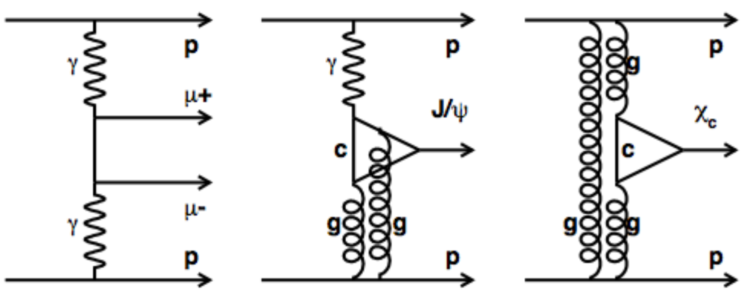
LHCb →

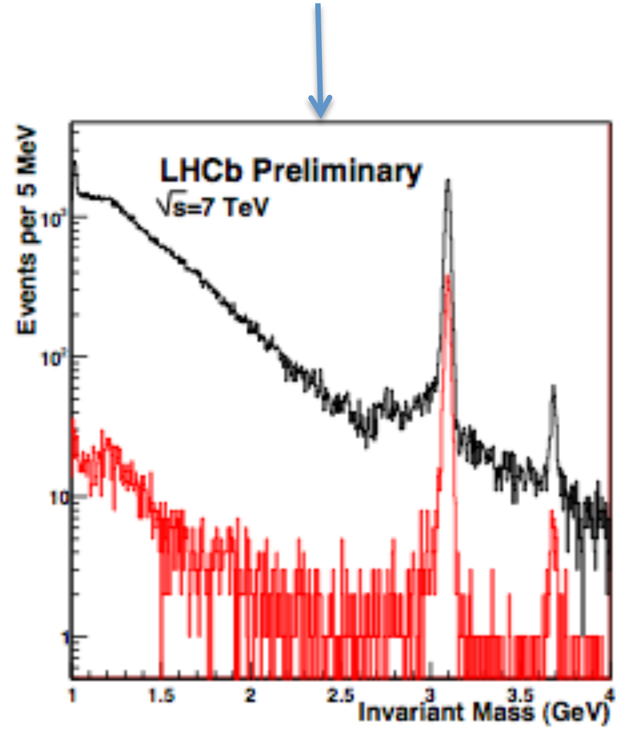


Total Acceptance≈13%
LHCb Acceptance 85%

Exclusive Production

- J/ψ,χ_c,$\gamma\gamma$ produced with nothing else

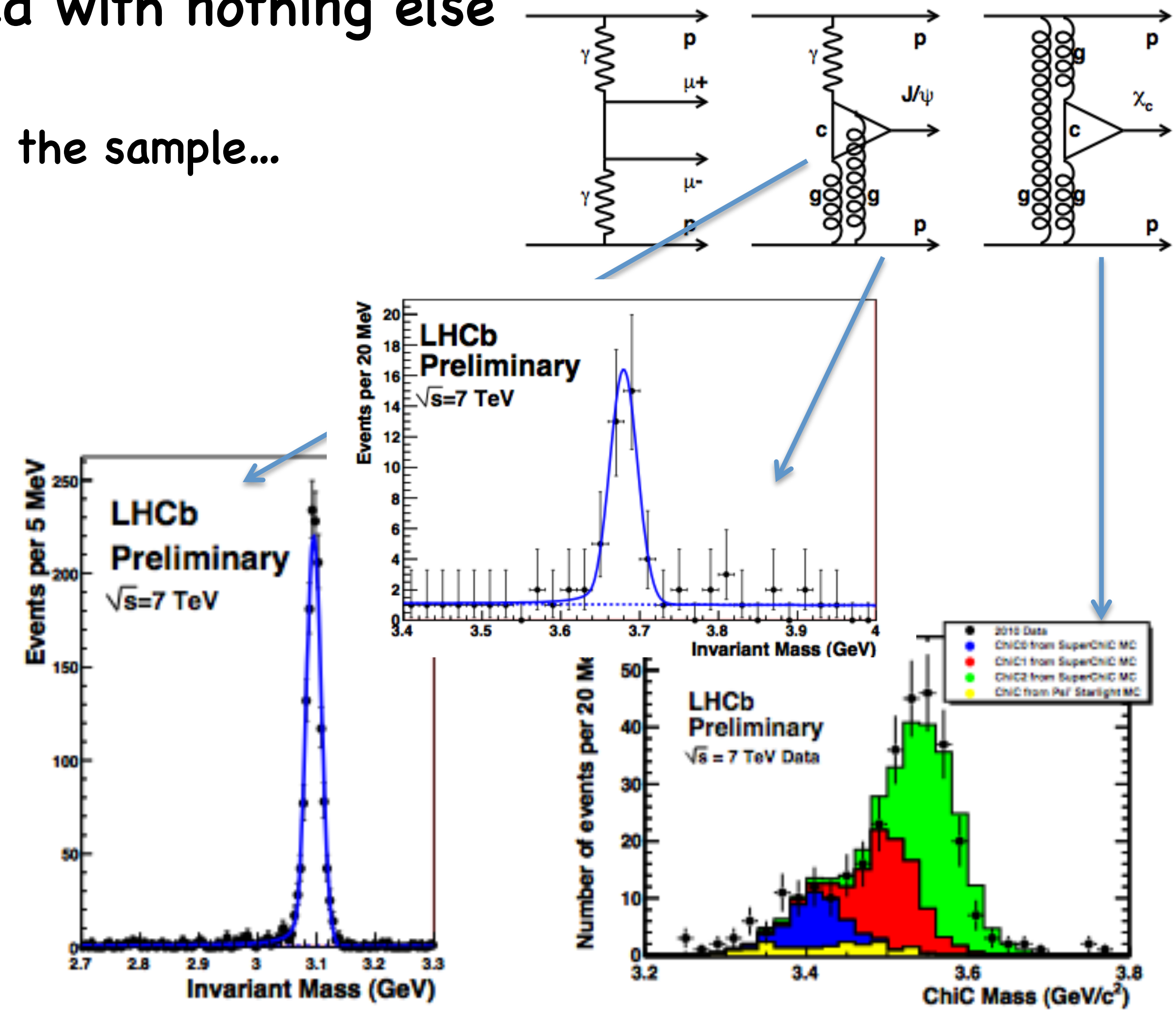




Exclusive Production

➡ $J/\psi, \chi_c, \gamma\gamma$ produced with nothing else

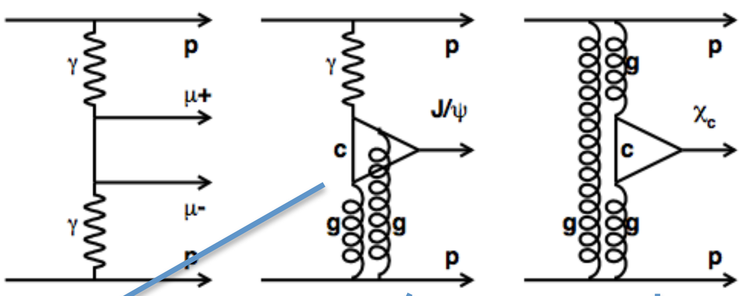
After cleaning up the sample…



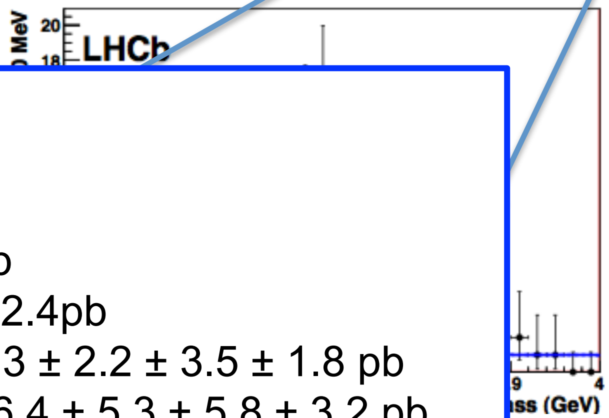
Exclusive Production

LHCb

➡ $J/\psi, \chi_c, \gamma\gamma$ produced with nothing else

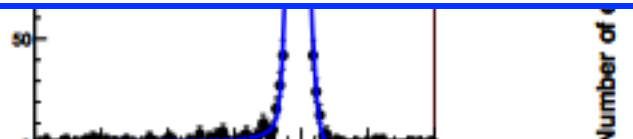


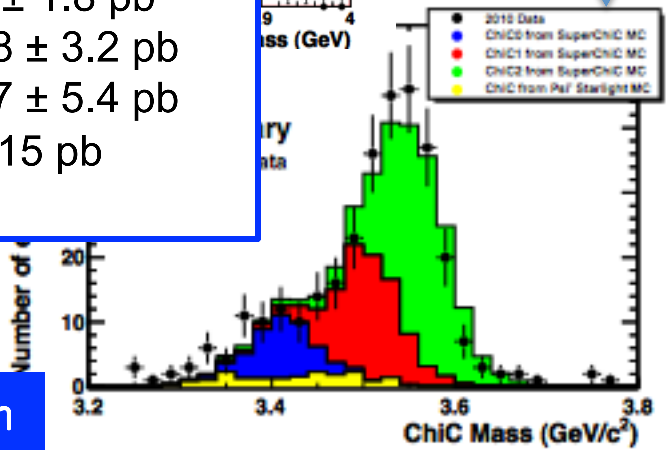
After cleaning up the sample…



Cross section measurements :

- $\sigma(J/\psi \to \mu^+\mu^-)(2<\eta\mu^+,\eta\mu^- <4.5)=474\pm12\pm51\pm92$pb
- $\sigma(\psi(2S) \to \mu^+\mu^-)(2<\eta\mu^+,\eta\mu^- <4.5)=12.2\pm1.8\pm1.3\pm2.4$pb
- $\sigma(\chi c0 \to J/\psi\gamma \to \mu^+\mu^-\gamma)(2 < \eta\mu+,\eta\mu-,\eta\gamma < 4.5) = 9.3 \pm 2.2 \pm 3.5 \pm 1.8$ pb
- $\sigma(\chi c1 \to J/\psi\gamma \to \mu^+\mu^-\gamma)(2 < \eta\mu+,\eta\mu-,\eta\gamma < 4.5) = 16.4 \pm 5.3 \pm 5.8 \pm 3.2$ pb
- $\sigma(\chi c2 \to J/\psi\gamma \to \mu^+\mu^-\gamma)(2 < \eta\mu+,\eta\mu-,\eta\gamma < 4.5) = 28.0 \pm 5.4 \pm 9.7 \pm 5.4$ pb
- $\sigma(pp \to p\mu^+\mu^-p)(2<\eta\mu^+,\eta\mu^- <4.5;M_{\mu+\mu-} >2.5GeV/c^2)=67\pm10\pm7\pm15$ pb





CMS: see dedicated talk K.Piotrzkowski this afternoon

CMS Uncertainty on X /psi2s xsec ratio

- Background parameterization and signal extraction **5.3%**
- Variation of the the non-prompt fraction for X(3872) and ψ(2S) in a range 30% ± 20% **6.0%**
- Lack of knowledge of the X(3872) production mechanism **3.5%**
  - Study on the effect of changes in the X(3872) p_T shape
- Uncertainty due to limited statistics in MC samples **1.8%**
- Uncertainty on the pion tracking efficiency **4.0%**
  - Data-driven cross check comparing the decay channels $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ and $\psi(2S) \rightarrow \mu^+\mu^-$

Total systematic uncertainty: 10%

12

LHCb X Mass Measurement

Signal Modeling
- Vary fit range
- Vary natural width from 0 – 2.6 MeV
- Embed MC in same-sign background and check for bias from background fit model

Calibration
- Vary momentum scale by ± 0.1 per mille [quoted uncertainty]
- Parameterize residual η bias and make dependent scale factor
- Vary amount of material by 10 %

Alignment
- Drop TT hits and repeat procedure
- Scale track slopes in velo by per mille

Source of uncertainty	Value $[MeV/c^2]$
Mass fitting:	
Natural width	0.02
Background model	0.02
Fit range	0.01
Momentum calibration:	
Average momentum scale	0.05
η dependence of momentum scale	0.03
Detector description:	
Energy loss correction	0.05
Detector alignment:	
Tracking stations (TT information)	0.05
Vertex detector (track slopes)	0.01
Quadratic sum	0.10

LHCb : Chic ratio syst (I)

Four types of systematics

- Systematics coming from the fit
  - From fixed parameters: s1, si/s1, mi-m1
  - From background shape: fit range, χ_{c0} in the fit
- Systematics from efficiencies
  - Error from Monte Carlo statistic
- Systematics from MC fit
  - Uncertainty from the difference in percentage between generated and reconstructed $N(\chi_{c2})/N(\chi_{c1})$. Due to wrong MC photon association.
- Systematic From the Br($\chi_c(1,2) \rightarrow J/\psi\, \gamma$)
  - Correlated systematic

- Evaluation of all the systematics for results in converted and not converted samples
- Combination of the results with the statistical errors
- Combination of the uncorrelated systematics
- Evaluation of the correlated systematic using the combined results

LHCb Chic ratio : syst (II)

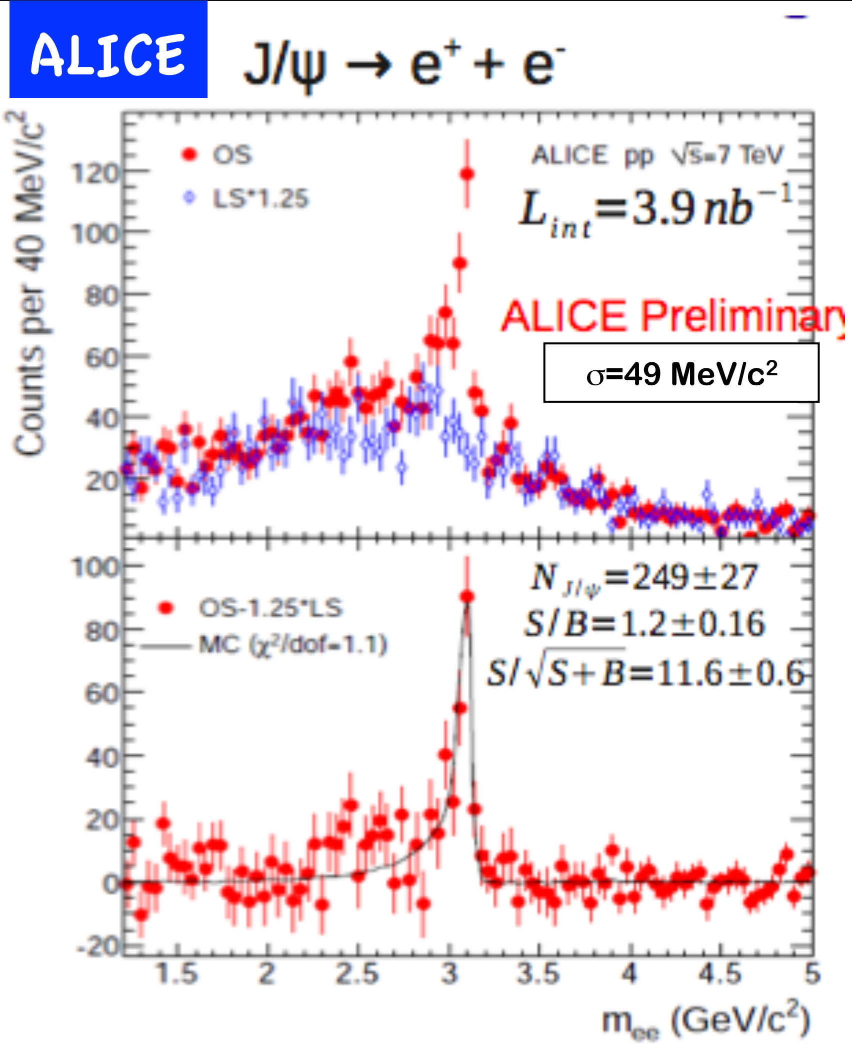
γ not converted

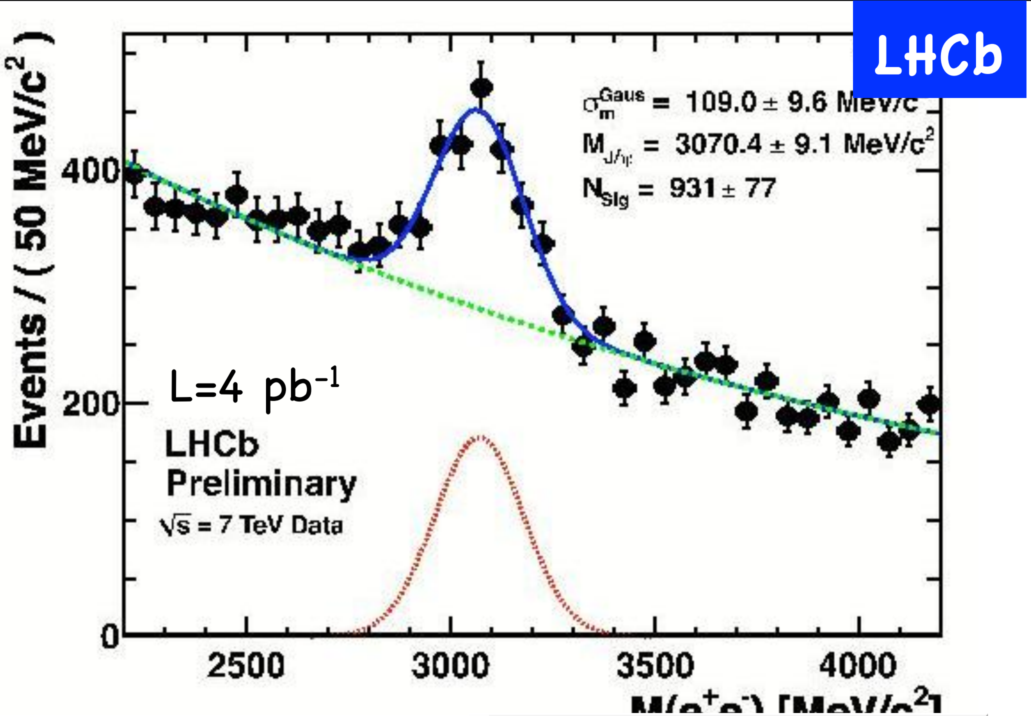
$p_T^{J/\Psi}$ (GeV/c)	$2-3$	$3-4$	$4-5$
$Br(\chi_c \to J/\psi\gamma)$	–	$^{+0.070}_{-0.070}$	$^{+0.070}_{-0.053}$
Efficiencies	–	$^{+0.012}_{-0.011}$	$^{+0.015}_{-0.011}$
Systematics from fit	–	$^{+0.040}_{-0.040}$	$^{+0.029}_{-0.033}$
$p_T^{J/\Psi}$ (GeV/c)	$5-6$	$6-7$	$7-8$
$Br(\chi_c \to J/\psi\gamma)$	$^{+0.070}_{-0.061}$	$^{+0.079}_{-0.061}$	$^{+0.061}_{-0.053}$
Efficiencies	$^{+0.015}_{-0.013}$	$^{+0.021}_{-0.019}$	$^{+0.021}_{-0.020}$
Systematics from fit	$^{+0.029}_{-0.033}$	$^{+0.043}_{-0.036}$	$^{+0.029}_{-0.033}$
$p_T^{J/\Psi}$ (GeV/c)	$8-9$	$9-10$	$10-11$
$Br(\chi_c \to J/\psi\gamma)$	$^{+0.061}_{-0.044}$	$^{+0.061}_{-0.044}$	$^{+0.070}_{-0.061}$
Efficiencies	$^{+0.025}_{-0.024}$	$^{+0.034}_{-0.032}$	$^{+0.058}_{-0.053}$
Systematics from fit	$^{+0.027}_{-0.024}$	$^{+0.024}_{-0.029}$	$^{+0.027}_{-0.036}$
$p_T^{J/\Psi}$ (GeV/c)	$11-12$	$12-13$	$13-15$
$Br(\chi_c \to J/\psi\gamma)$	$^{+0.061}_{-0.035}$	$^{+0.017}_{-0.018}$	$^{+0.044}_{-0.035}$
Efficiencies	$^{+0.053}_{-0.046}$	$^{+0.026}_{-0.023}$	$^{+0.055}_{-0.052}$
Systematics from fit	$^{+0.020}_{-0.020}$	$^{+0.022}_{-0.013}$	$^{+0.022}_{-0.043}$

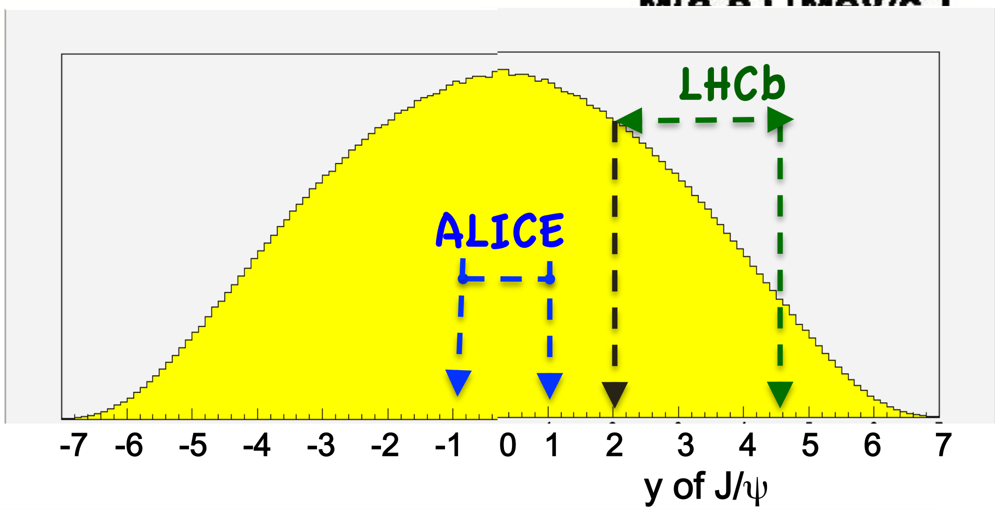
γ converted

$p_T^{J/\Psi}$ (GeV/c)	$2-3$	$3-4$	$4-5$
$Br(\chi_c \to J/\psi\gamma)$	–	$^{+0.105}_{-0.079}$	$^{+0.061}_{-0.044}$
Efficiencies	–	$^{+0.024}_{-0.022}$	$^{+0.018}_{-0.013}$
Systematics from fit	–	$^{+0.066}_{-0.089}$	$^{+0.045}_{-0.045}$
$p_T^{J/\Psi}$ (GeV/c)	$5-6$	$6-7$	$7-8$
$Br(\chi_c \to J/\psi\gamma)$	$^{+0.061}_{-0.053}$	$^{+0.053}_{-0.053}$	$^{+0.070}_{-0.053}$
Efficiencies	$^{+0.018}_{-0.019}$	$^{+0.021}_{-0.018}$	$^{+0.032}_{-0.031}$
Systematics from fit	$^{+0.045}_{-0.038}$	$^{+0.036}_{-0.040}$	$^{+0.052}_{-0.087}$
$p_T^{J/\Psi}$ (GeV/c)	$8-9$	$9-10$	$10-11$
$Br(\chi_c \to J/\psi\gamma)$	$^{+0.044}_{-0.035}$	$^{+0.044}_{-0.017}$	$^{+0.035}_{-0.026}$
Efficiencies	$^{+0.028}_{-0.028}$	$^{+0.029}_{-0.025}$	$^{+0.040}_{-0.036}$
Systematics from fit	$^{+0.047}_{-0.052}$	$^{+0.040}_{-0.047}$	$^{+0.029}_{-0.036}$
$p_T^{J/\Psi}$ (GeV/c)	$11-12$	$12-13$	$13-15$
$Br(\chi_c \to J/\psi\gamma)$	$^{+0.087}_{-0.061}$	$^{+0.053}_{-0.035}$	$^{+0.026}_{-0.026}$
Efficiencies	$^{+0.125}_{-0.098}$	$^{+0.091}_{-0.078}$	$^{+0.055}_{-0.050}$
Systematics from fit	$^{+0.158}_{-0.045}$	$^{+0.029}_{-0.024}$	$^{+0.038}_{-0.070}$

J/ψ→ee mass distribution

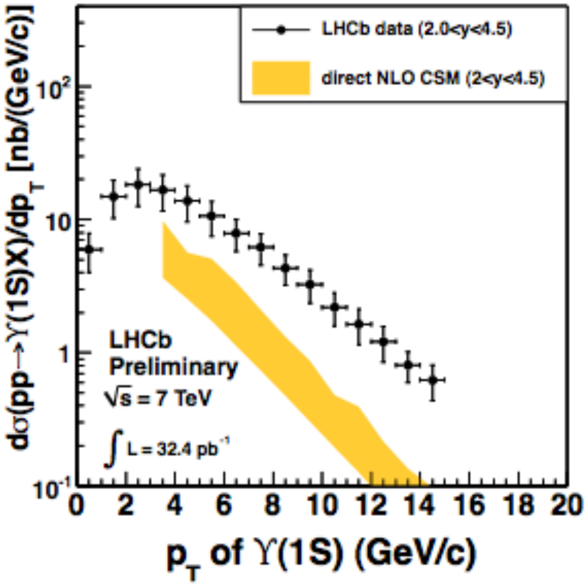




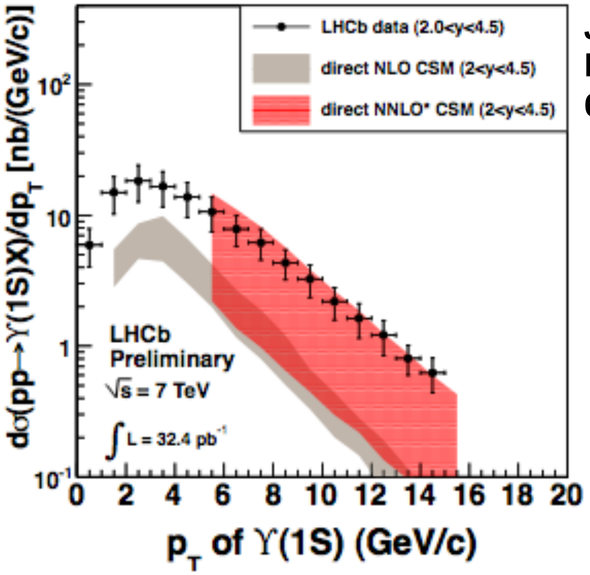


Comparison with Theory

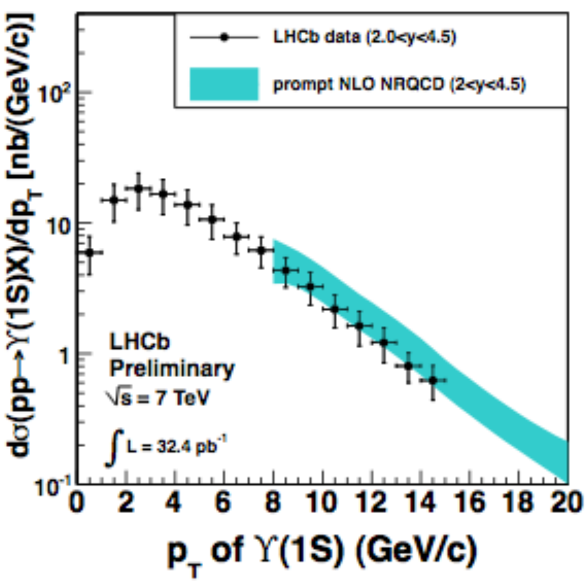
P. Artoisenet, PoS ICHEP 2010 (2010) 192.

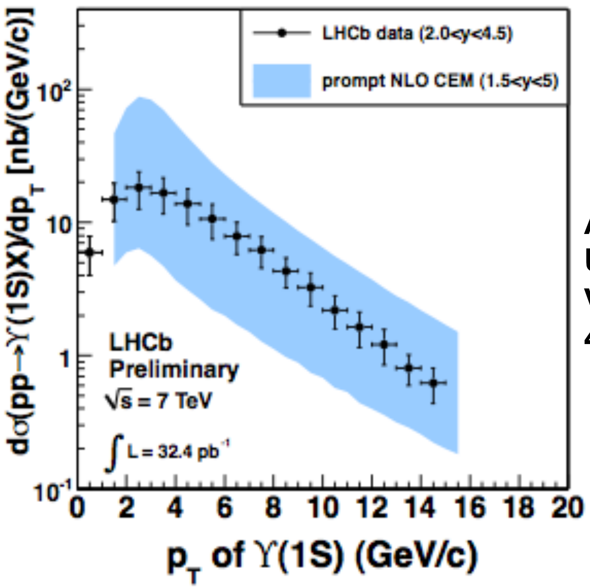


J.-P. Lansberg, Eur. Phys. J. C 61 (2009) 693



Y. Q. Ma, K. Wang and K. T. Chao, Phys. Rev. Lett. 106 (2011) 042002.

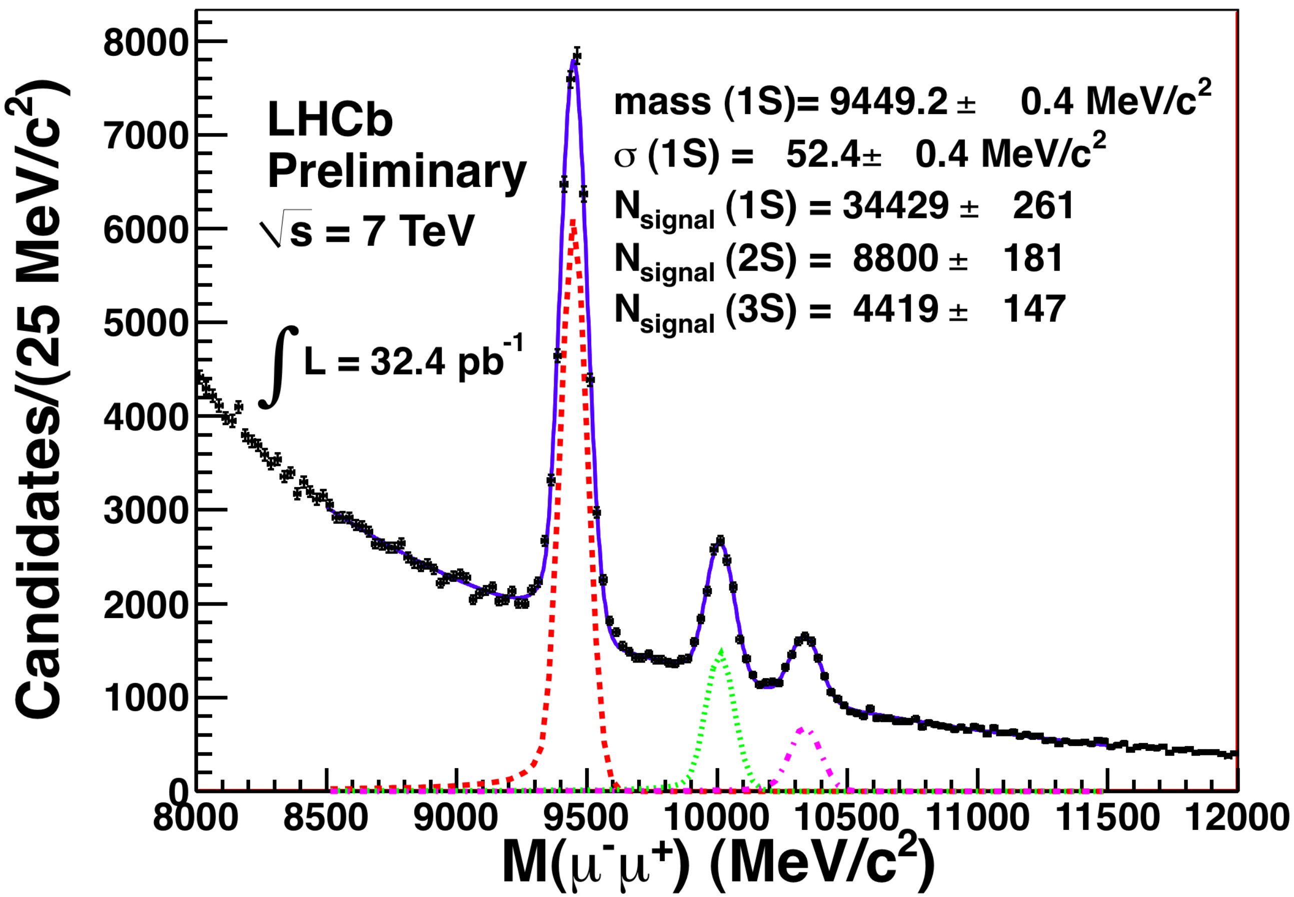




A. D. Frawley, T. Ullrich and R. Vogt, Phys. Rep. 462 (2008) 125.

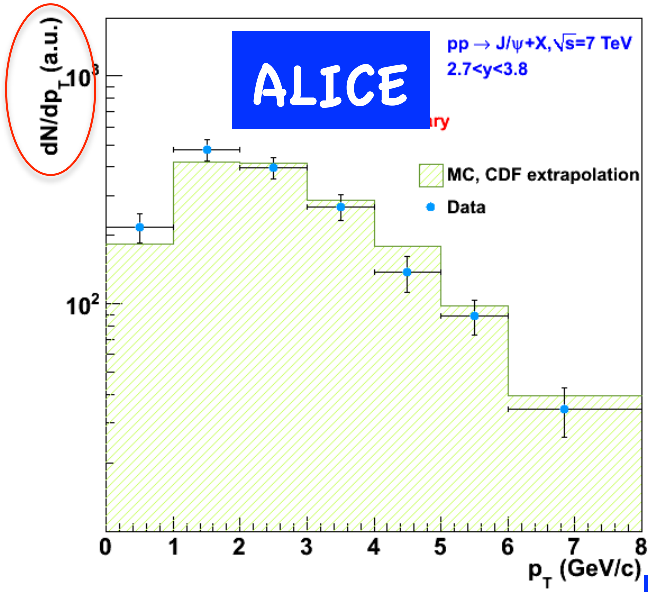
a) Number of $\Upsilon(1S)$ candidates

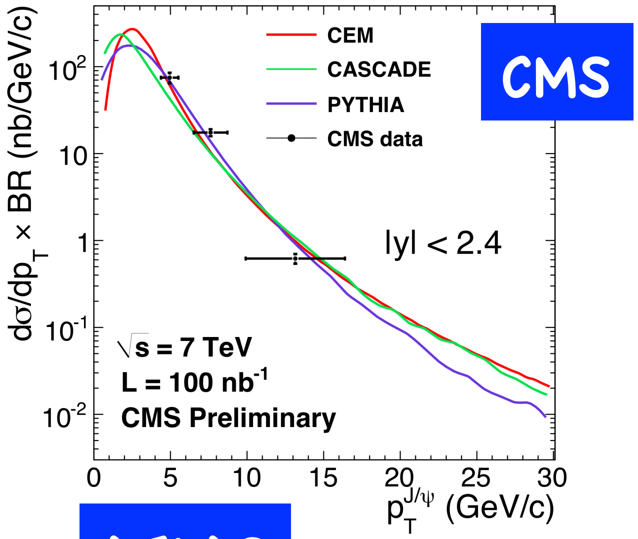
- N^{fit} : function=3 Crystal Balls(CB)+exponential for background. Fixed (α=2,n=1) and width (2S,3S) to scale with the masses.

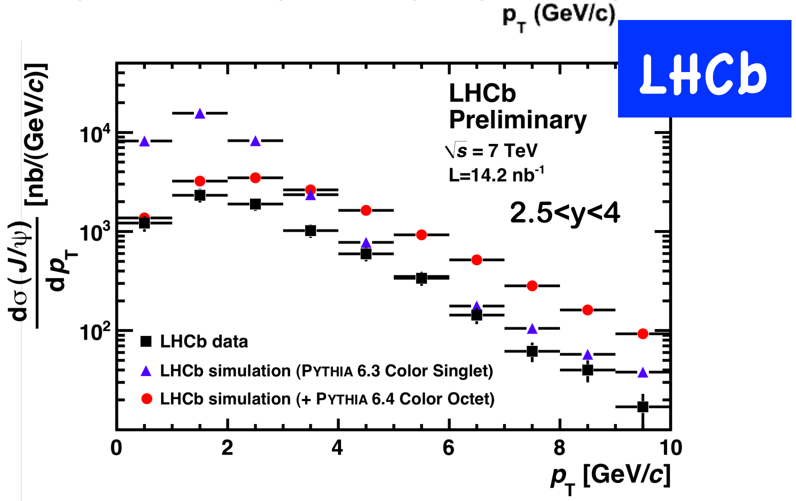


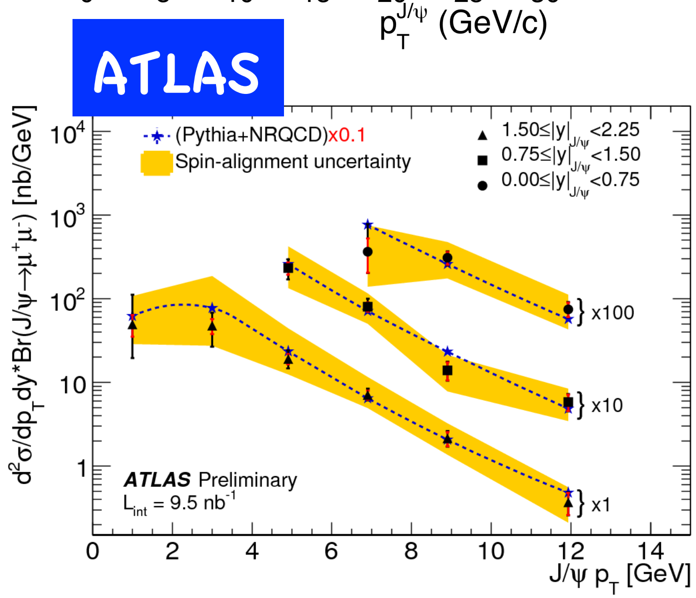
Same function used on individual bin fits

Inclusive cross section measurements

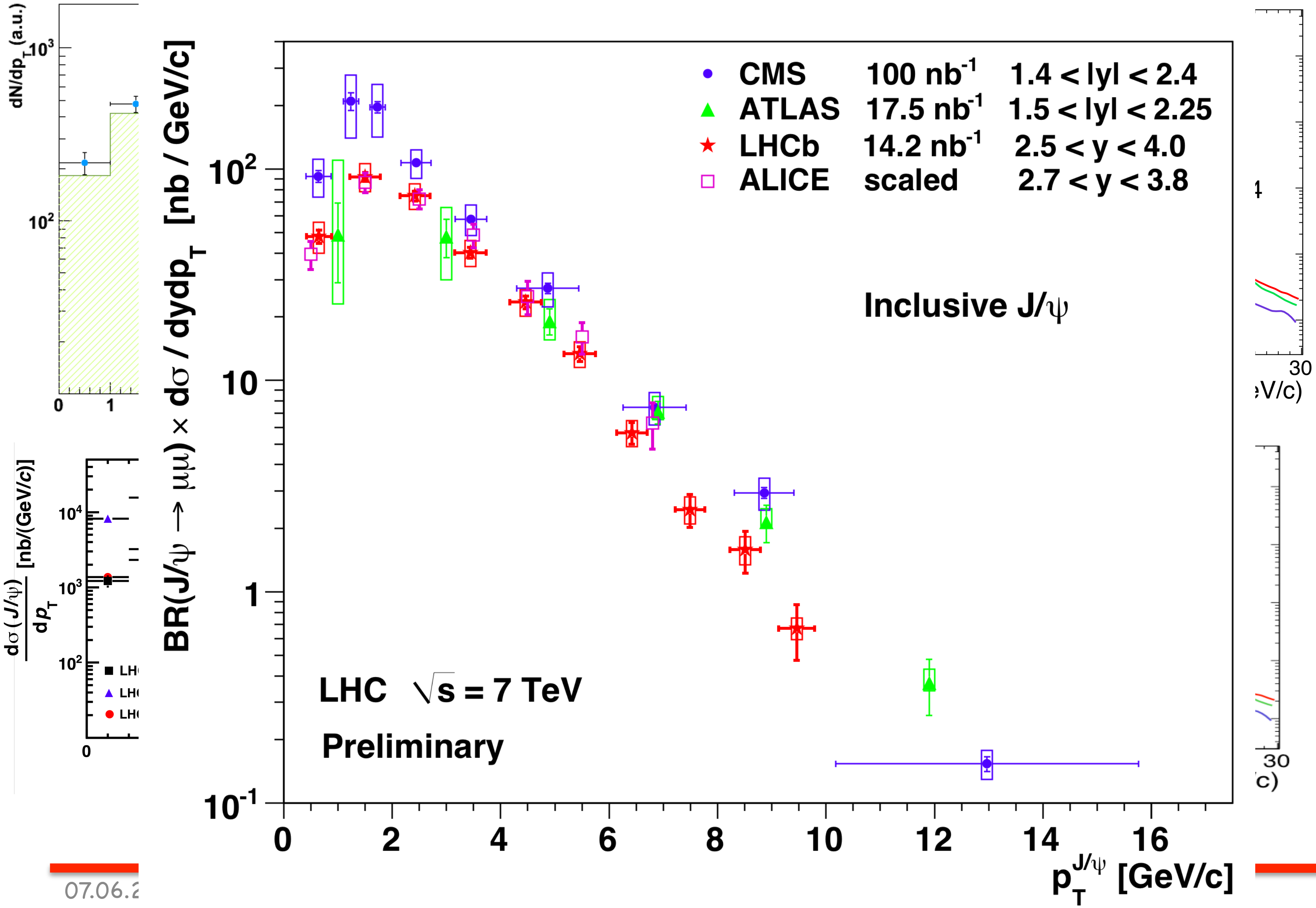






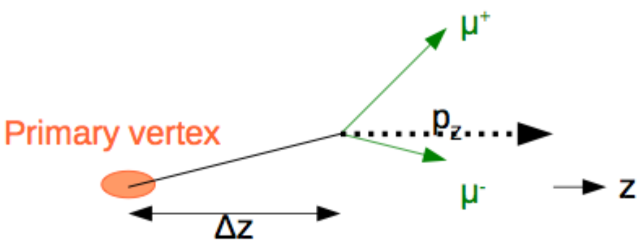


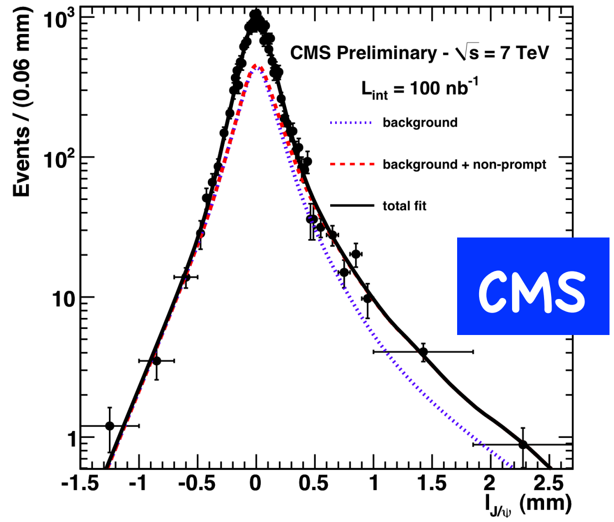
Cross section measurements



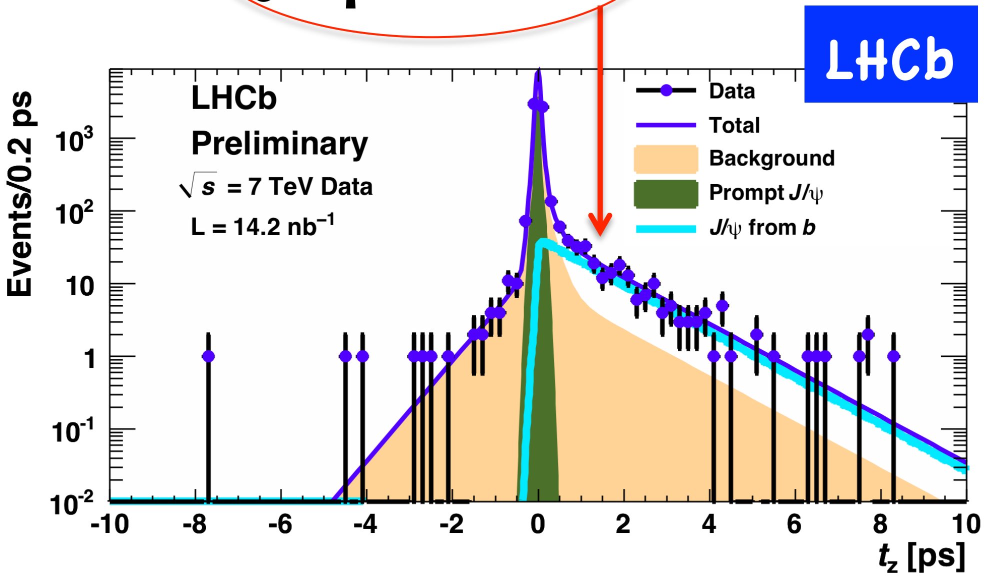
J/ψ proper time/decay lenght

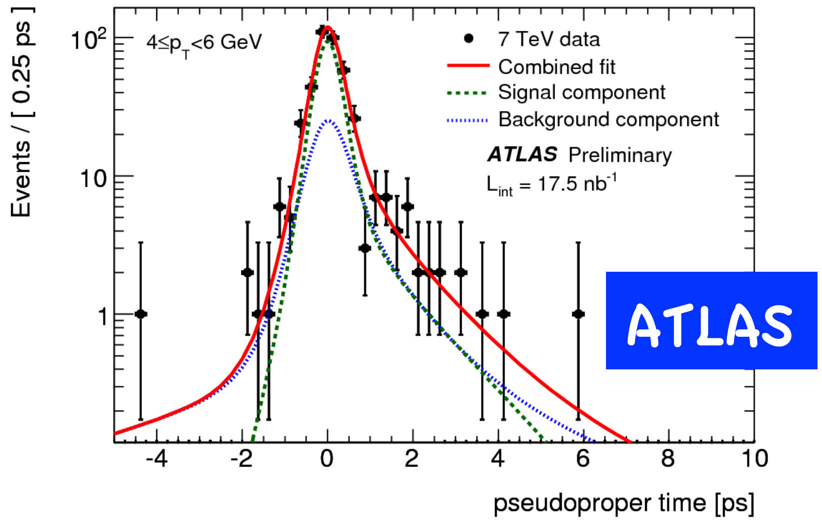
$t_z = \Delta z / p_z * M_{J/\psi}$





- t_z used to separate J/ψ prompt from J/ψ from B

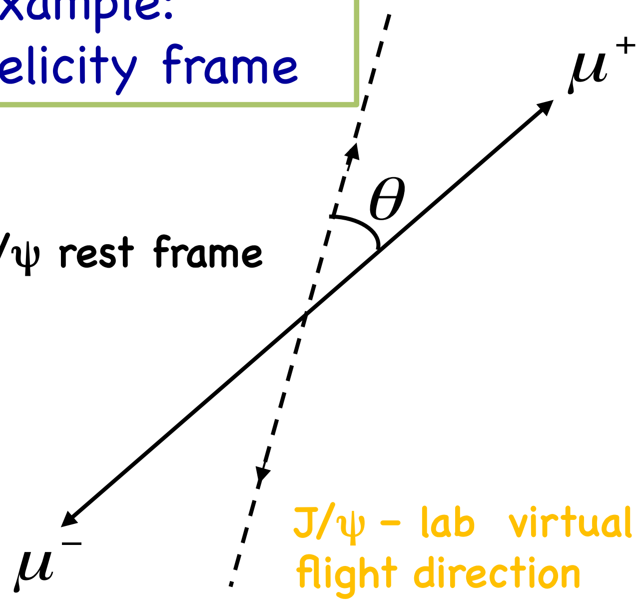




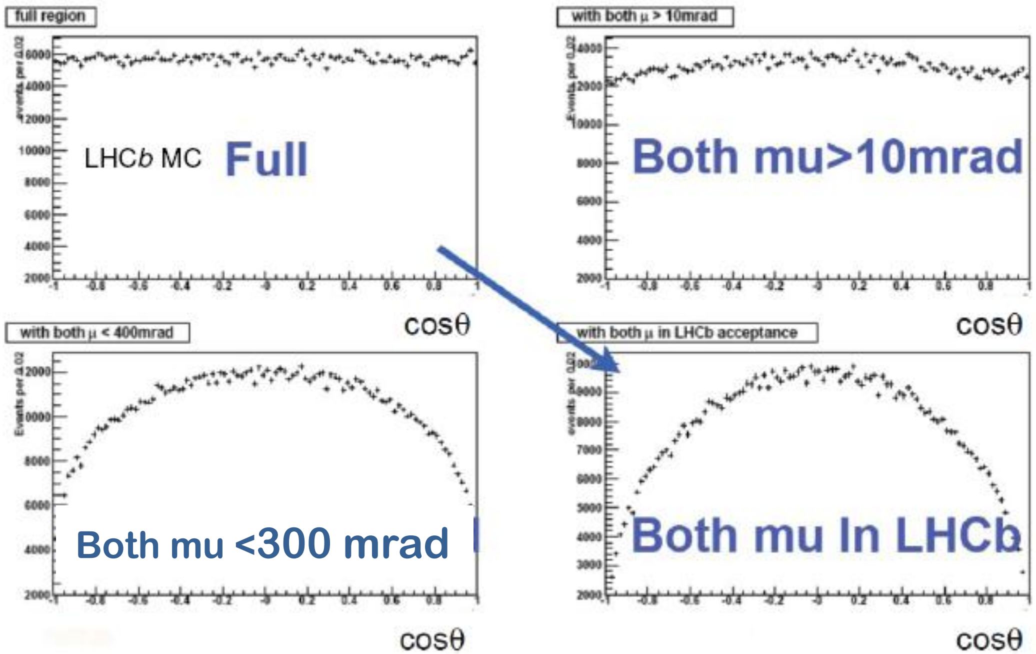
Influence of J/ψ Polarisation

- Detector acceptance as a function of helicity angle cosθ

Example:
helicity frame



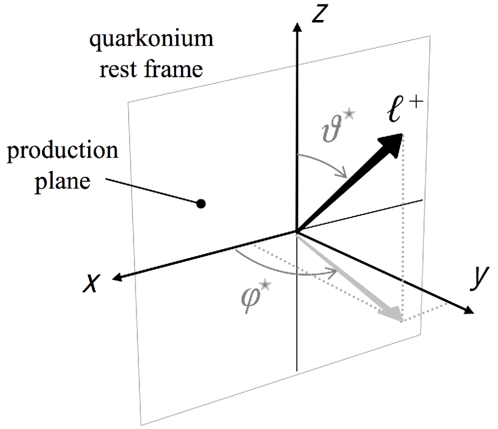
MC with no polarisation:LHCb

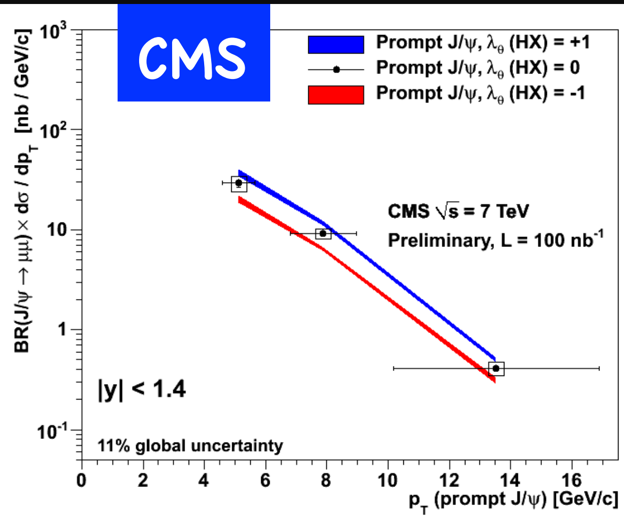


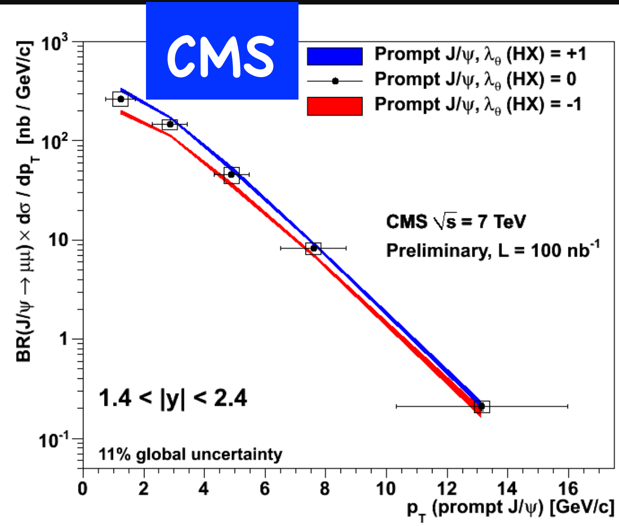
➡ acceptance generates an artificial polarisation
→ large influence of polarisation on measurement

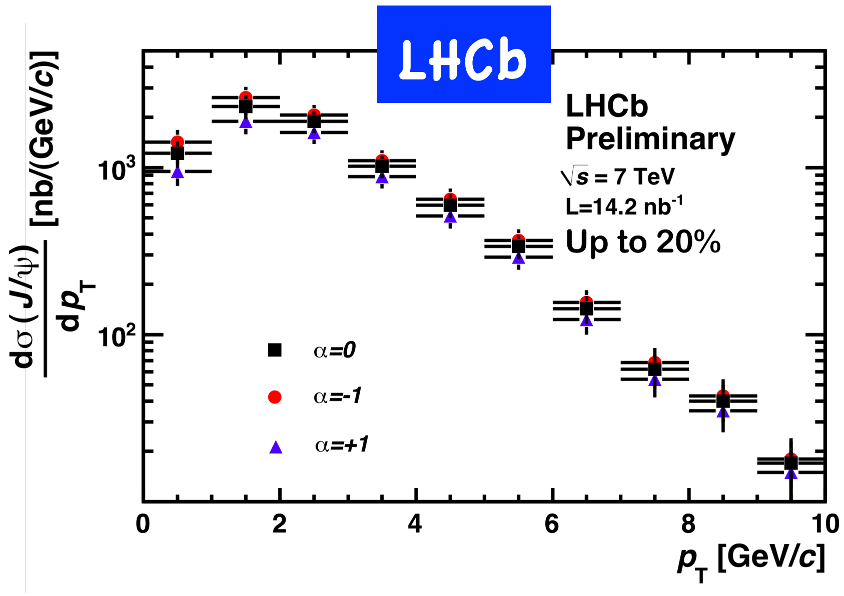
➡ First step: Treat polarisation as systematic error; present results in three different polarisation scenarios

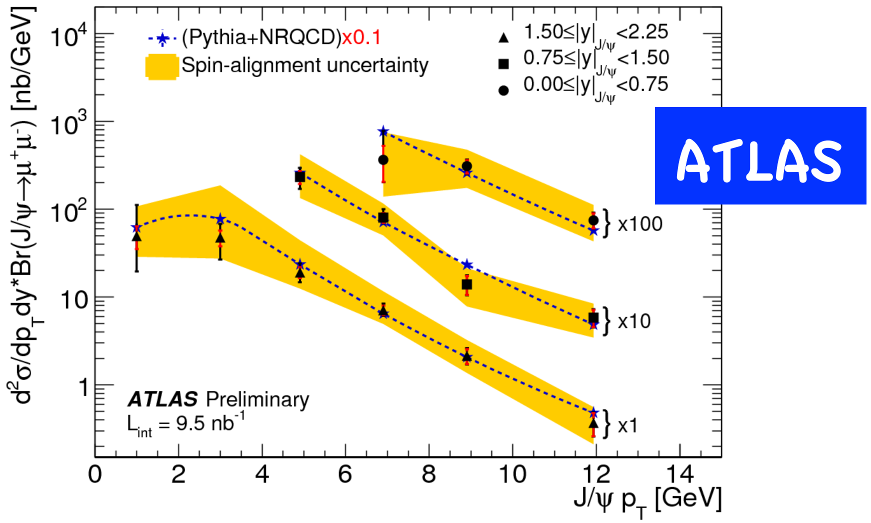
Different polarisation scenarios











2010 Ion Run Predictions

The Injectors ready

- ***The Pb^{82+} beam was injected into the LHC (first beam after the 2008 incident)***

The basic machine parameters are similar

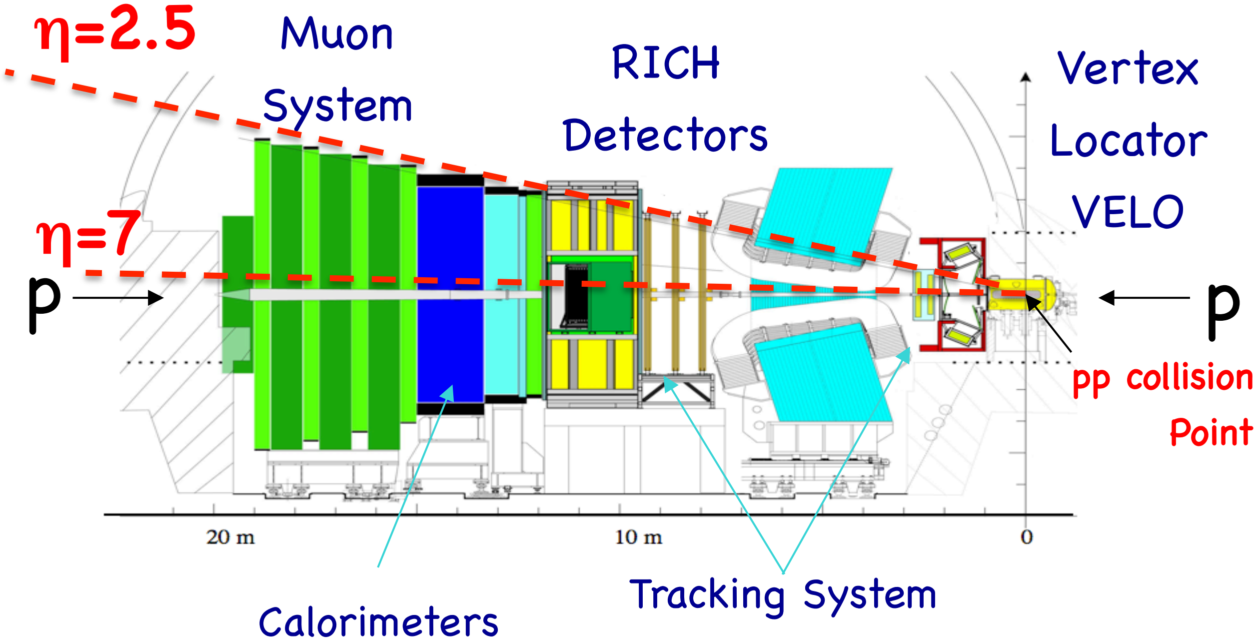
- ***But the collimation system needed some setting up***
- ***The behavior of the beam instrumentation– the low intensities make life difficult***

It will not look as impressive as protons as far as absolute performance is concerned:

- ***Peak Luminosity ~10^{+25} cm^{-2} s^{-1}(c.f. $2x10^{+32}$ for protons)***
- ***Integrated Luminosity ~3-10 μb^{-1} (c.f. 50,000,000 μb^{-1} for protons)***
- ***But each collision will look pretty impressive!***

The LHCb detector

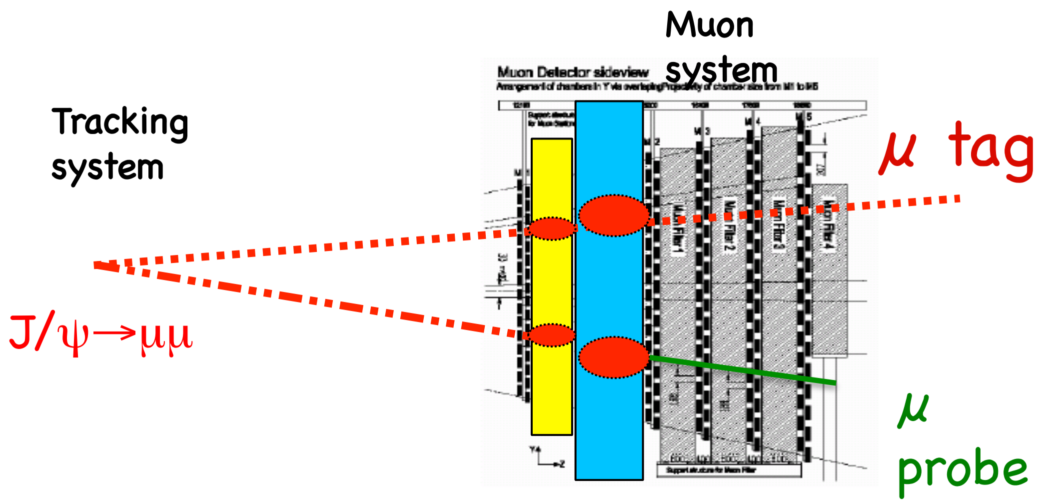
Angular acceptance : 10<θ<300 mrad



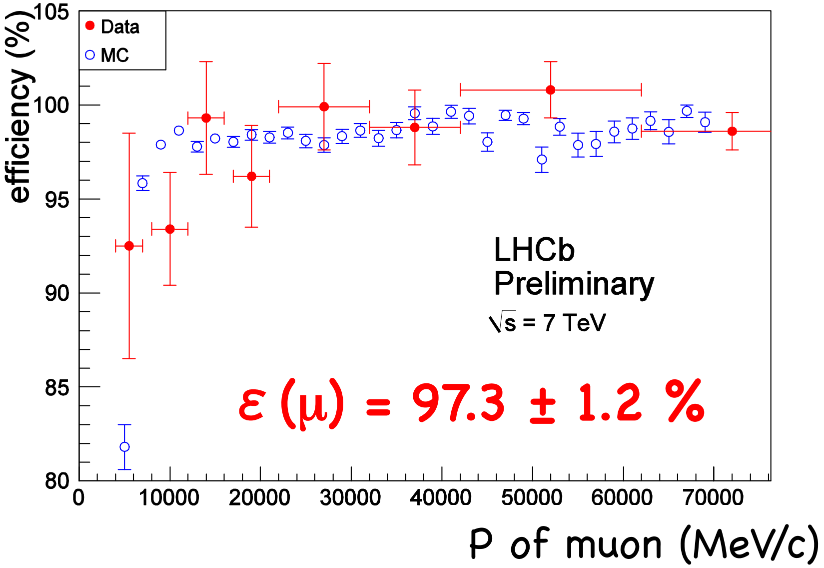
- Performance numbers relevant to quarkonium analyses:
  - Charged tracks $\Delta p/p$ = 0.35 % - 0.55%, $\sigma(m)$=10-25 MeV/c^2
  - ECAL $\sigma(E)/E$= 10% $(E/GeV)^{-1/2} \oplus$ 1 %
  - Muon ID: $\varepsilon(\mu \rightarrow \mu)$ = 97%, mis-ID rate $(\pi \rightarrow \mu)$ = 1-3 %
  - Vertexing: proper time resolution 30-50 fs
  - Trigger: dominantly software

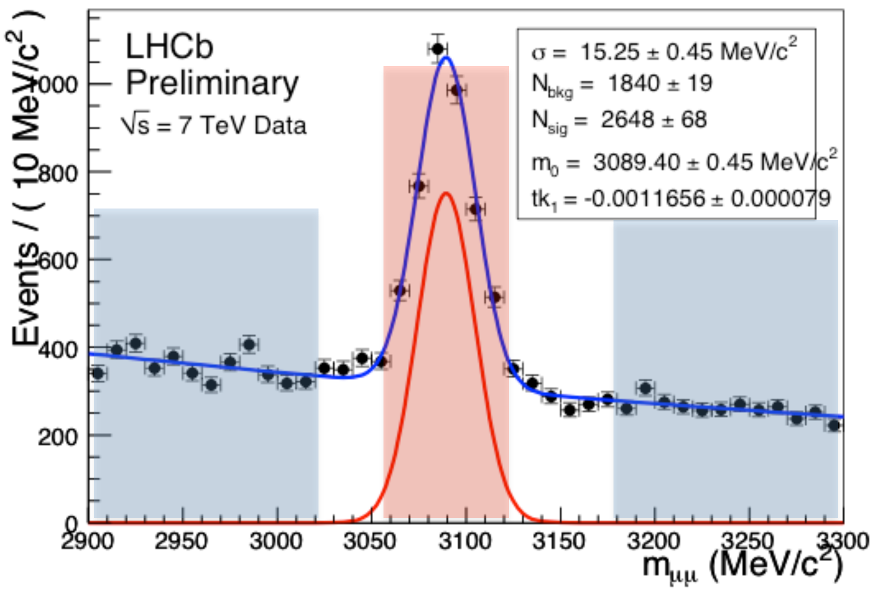
possibility to reverse field polarity to check for detector asymmetries

Muon Reconstruction Efficiency

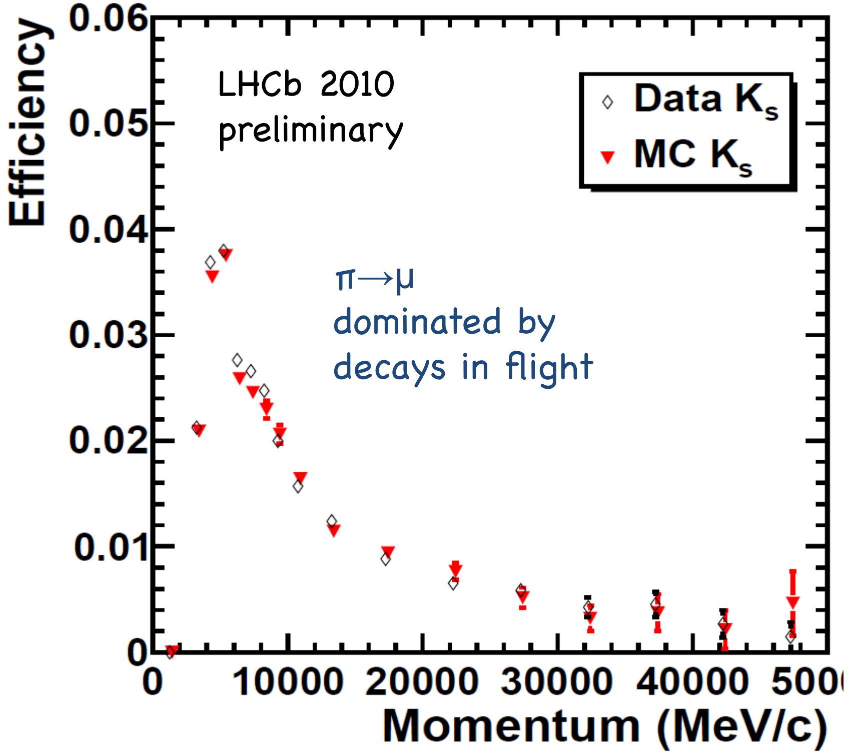


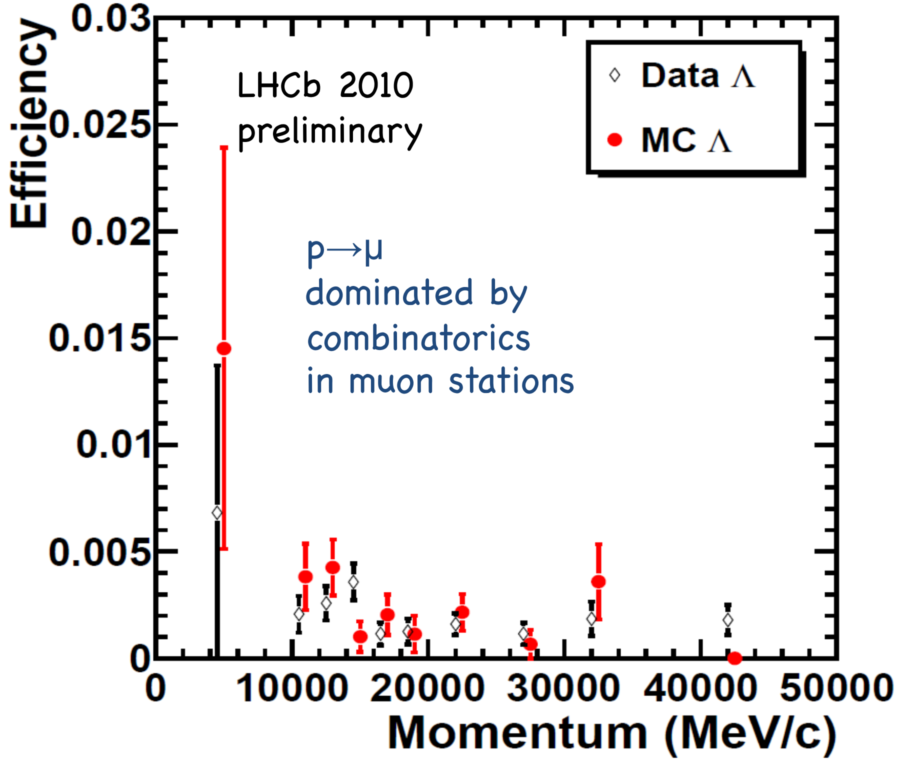
J/ψ used to measure the Muon reconstruction efficiency





Muon mis-identification





This plots shows the probability to misidentify a pion from Ks and a proton from Lambda as a muon as a function of momentum.

Primary Vertex resolution