$b\bar{b}$ quarkonia production at LHCb

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on behalf of LHCb collaboration

“LHC on the March”, IHEP, Protvino, 16-18 November 2011

The talk layout

- LHCb detector
- $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ cross sections measurement
- $\chi_b(1P)$ observation
- Conclusions

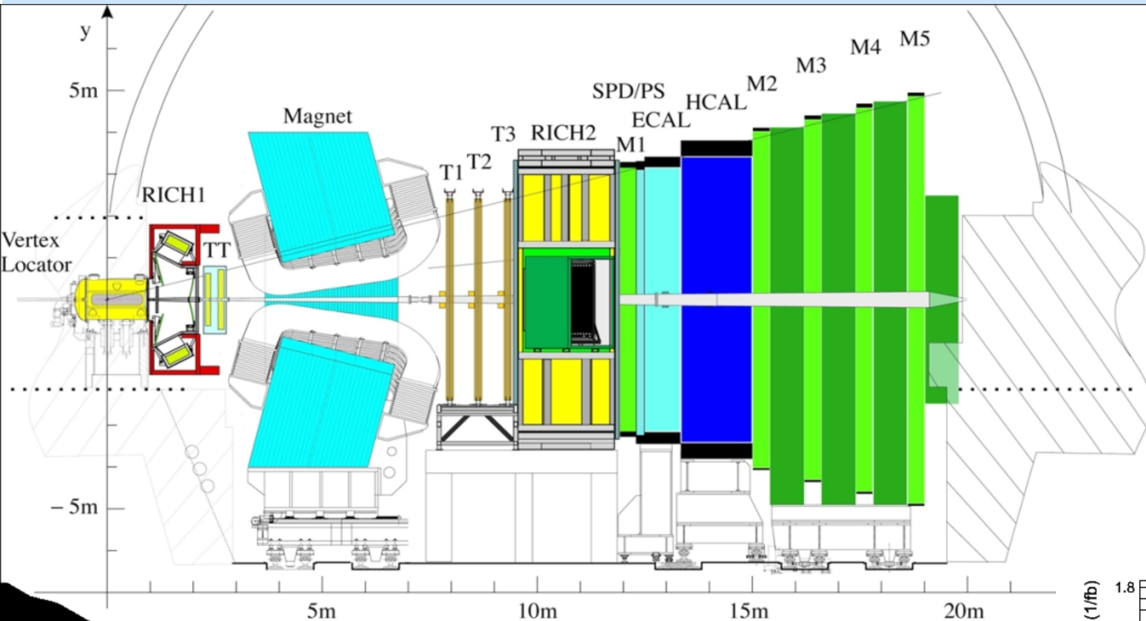
LHCb experiment

LHC is good for b-physics: the $b\bar{b}$ xsection is large: $\sqrt{s}$=7 TeV $\sigma(b\bar{b})\sim300\ \mu b$; B_s, B_c, Λ_b available

$b\bar{b}$ production peaks at low angles → forward spectrometer $2<\eta<5$ ($0.9^o<\theta<16^o$) $\sim1/4\ \sigma(b\bar{b})$

Designed to work @ $L=2x\ 10^{32}$ → 2 fb^{-1} /year (10^7 sec);

Features: PV @ IP resolution; particle ID: p, K, π, γ, μ, e



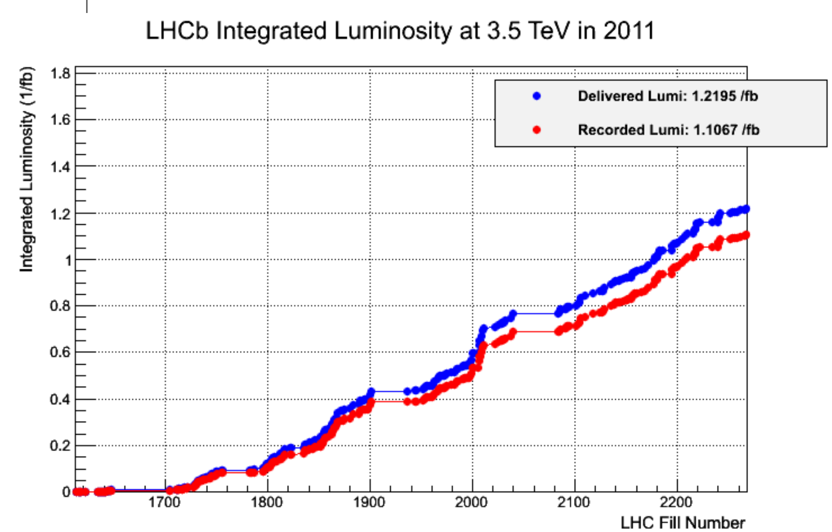
Main parts of LHCb

- vertex detector
- Tracking system (+magnet)
- RICH1,2
- Calorimeters
- Muon system
- Trigger&DAQ

37 pb-1 $\sqrt{s}$ = 7 TeV in 2010

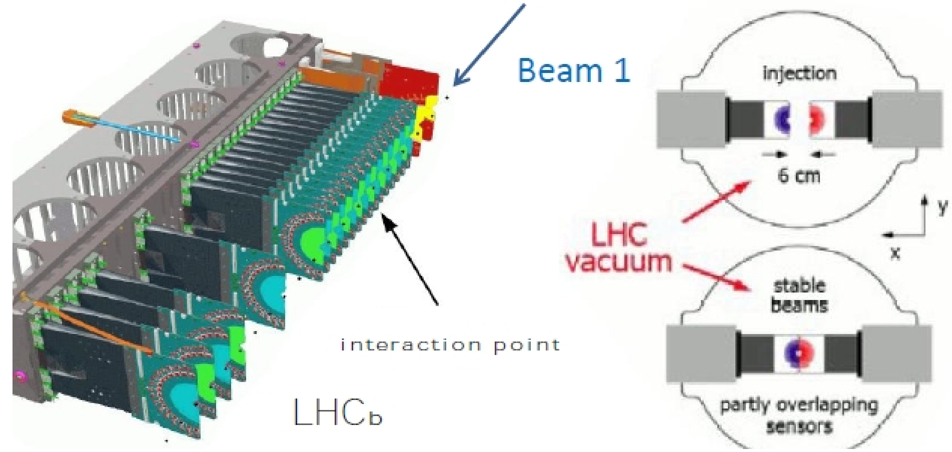
1.1 fb-1 $\sqrt{s}$ = 7 TeV in 2011

Only 2010 data are used for the present analysis



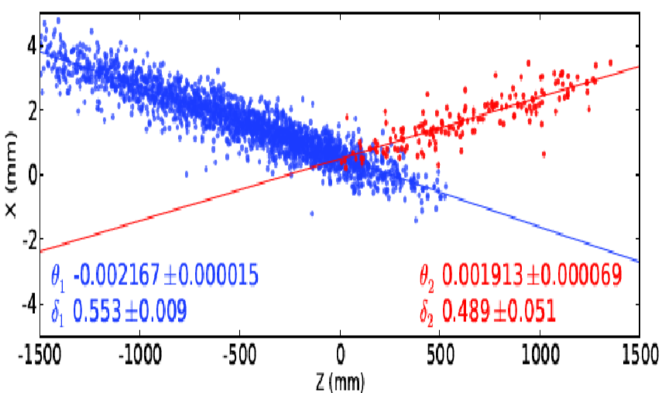
Vertex Locator (VELO)

2 retractable halves; 21 stations/half R/φ-strips; pitch 40-100μm; 8 mm from beam (physics); 172K channels



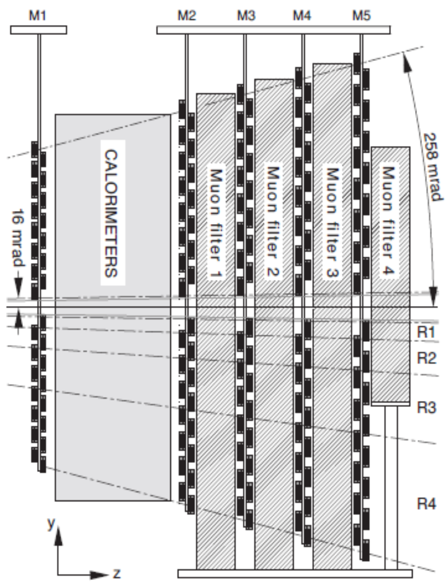
Primary Vertex resolution : $\sigma_{x,y}$ ~13 μm ; σ_z ~70 μm (>20 trk)

Impact Parameter resolution : $\sigma_{x,y}$ ~13 μm (large P_T)



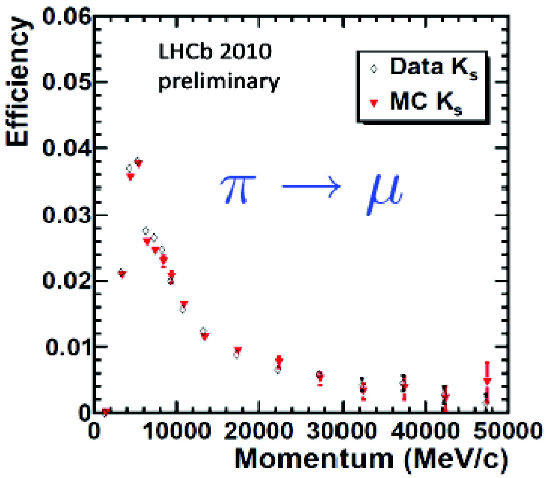
VELO provides new method of luminosity measurement «beam-gas imaging» method by reconstructing vertexes of beam-gas interactions.

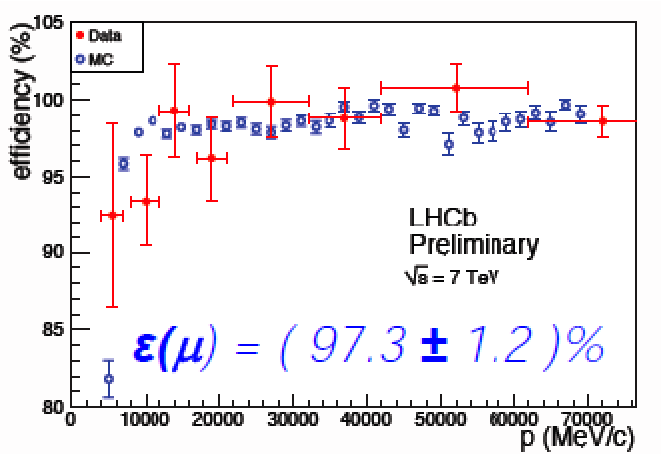
Muon system



M1-M5 1380 MWPC's ; 435 m^2 3M wires Ar: CO_2: CF_4=40:55:5

The system provides L0 μ–trigger (with p_T cut) and μ–identification

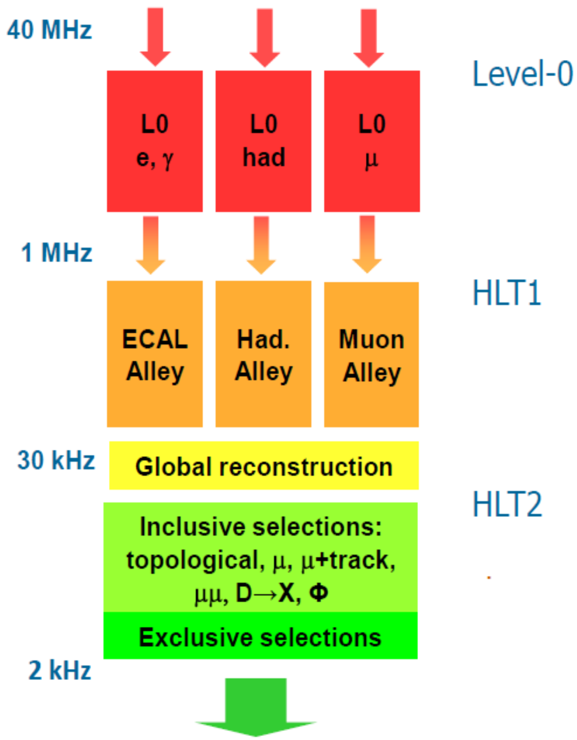




μ–efficiency and π–μ misidentification determined using $K_s \to \pi\pi$ and $J/\Psi \to \mu\mu$ decays

Trigger

LHCb trigger is a challenge:
$\sigma_{b\bar{b}}/\sigma_{in} \sim 0.005$



L0 is hardware trigger with fixed latency (4μs) @ $L = 2 \times 10^{32}$:
ε_B ~90% for μ $P_T > 1.1$ GeV ; $\Sigma_{PT} > 1.3$GeV;
~50% for B→hh $E_T > 4.5$ GeV ;
~70% for e.m. $E_T > 3$ GeV for prompt D's ε_D ~10%

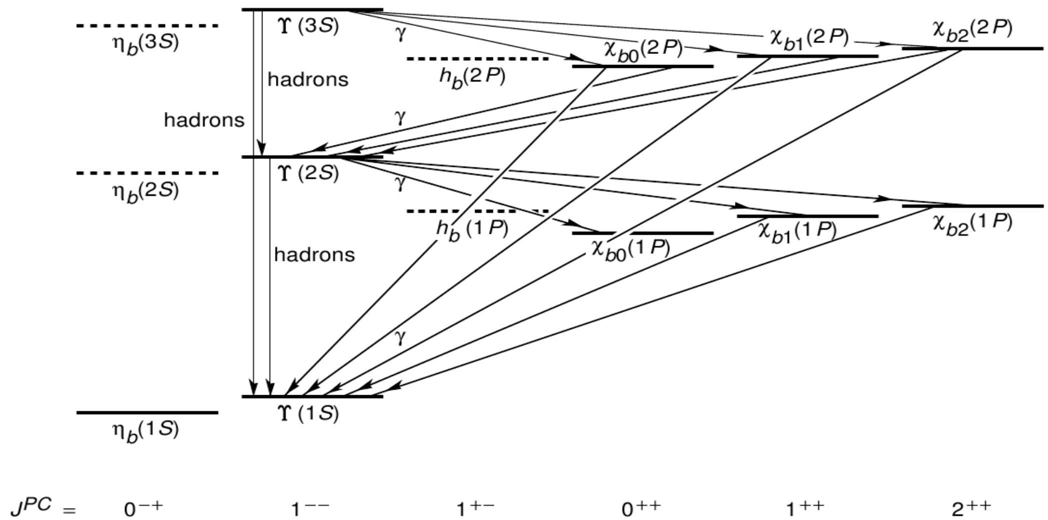
HLT runs on event filter farm ~2000 nodes
HLT1 confirms L0 using tracking system, local reconstruction
HLT2: use full detector information

Trigger lines important for $\Upsilon \to \mu^+\mu^-$ events

L0 Trigger	Single Muon	$p_T > 1.4$ GeV/c
	Di-Muon	$p_{T1} > 0.56$ GeV/c, $p_{T2} > 0.48$ GeV/c
LT1 Trigger	Single Muon	Confirm L0 Single Muon and $p_T > 1.8$GeV/c (*Prescaled)*
	Di-Muon	Confirm L0 Di-Muon and $m(\mu^+\mu^-) > 2.5$ GeV/c^2
HLT2 Trigger	Di-Muon	$m(\mu^+\mu^-) > 2.9$ GeV/c^2 or cuts on vertex and track quality

Motivation

• Quarkonia production has been under study for a long time nevertheless the production mechanism in pp-collision is not fully understood
• Large cross-section is expected at LHC
• Several theoretical models are around
– Color singlet (CSM)
Under-predicts xsection, no polarization prediction
– Extended to Color octet (COM) mechanisms, (NRQCD)
better agreement for xsections; predicts transverse polarization, not confirmed by experiments
– NLO CSM better describes xsection and allows longitudinal polarization
– Other models (Color evaporation (CEM), kt factorization, soft color interaction)
• New data from LHC experiments will help to resolve these issues
• $b\bar{b}$ system has advantages as compared to $c\bar{c}$ (real NR)



Di-muon reconstruction

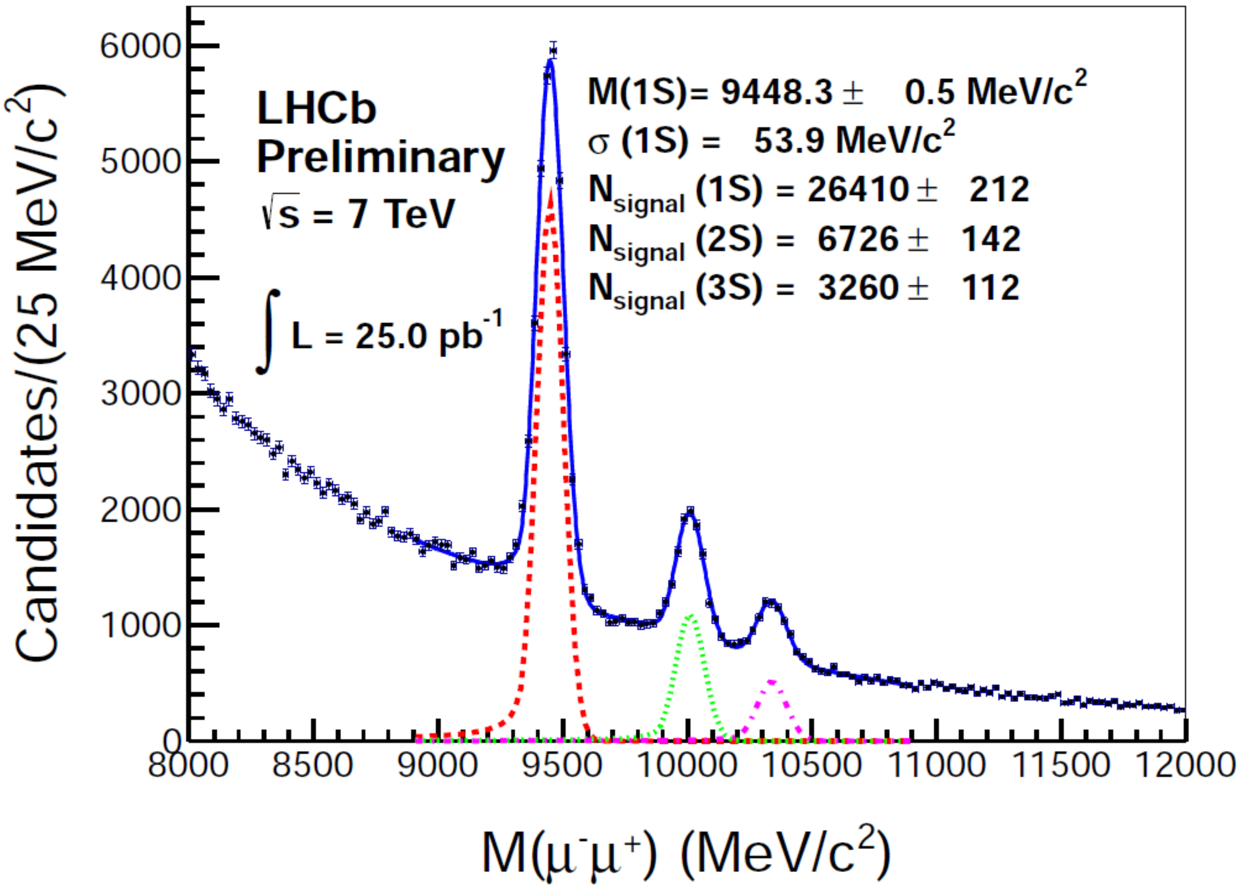
25 pb^{-1} of 2010 data μ-tracks: well reconstructed tracks identified as muons in muon detector, $p_T > 1$ GeV/c, Track fit quality, vertex fit quality Prob(χ^2) > 0.5%

3 Crystal Ball(CB) +

exp. *for background*

Parameters α and n of CB are fixed:
$\alpha = 2,\ n = 1$

The same function is used for individual bin fits



Cross section measurement

$$\frac{d\sigma(pp\to\Upsilon)}{dp_T\,dy}=\frac{N^{fit}(p_T,y,\epsilon_{tot})}{Br(\Upsilon\to\mu^+\mu^-)\cdot\int Ldt\cdot\Delta p_T\cdot\Delta y}$$

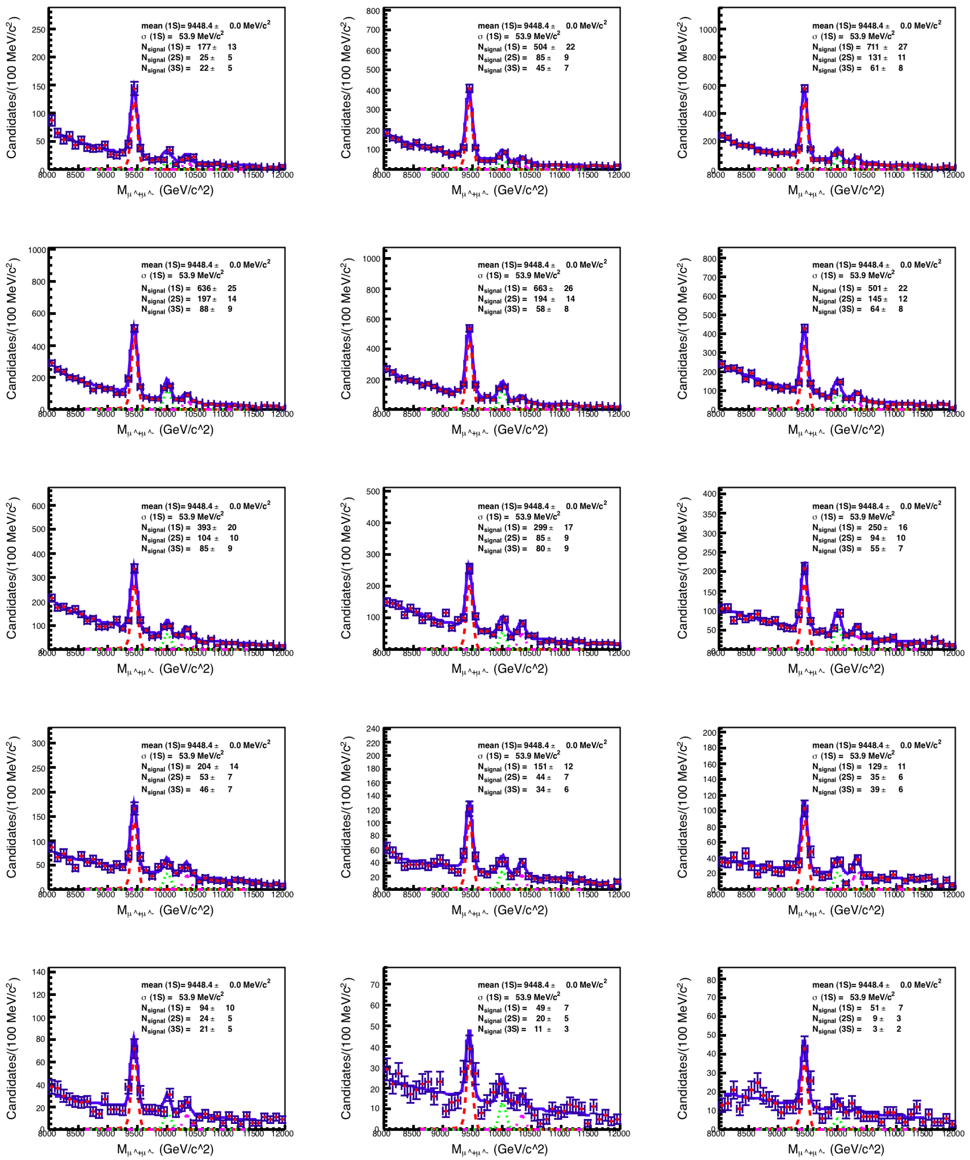
- $\mathbf{N^{fit}}$ – number of candidates in the mass peak in each Δp_T, Δy bin, obtained from the fit and corrected for efficiency
- $\boldsymbol{\varepsilon_{tot}}$ – total efficiency *(including acceptance)*
- $\boldsymbol{\Delta p_T, \Delta y}$ – bins of p_T and y $0< p_T<15$ GeV/c ; $2<y<4.5$
- $\int \mathbf{L}\,dt$ – integrated luminosity
- $\varepsilon_{tot} = \varepsilon_{Acc}\times\ \varepsilon_{rec}\times\ \varepsilon_{trig}$

BR(Υ(1S)→μμ)=(2.48±0.05)%
BR(Υ(2S)→μμ)=(1.93±0.17)%
BR(Υ(3S)→μμ)=(2.18±0.21)%

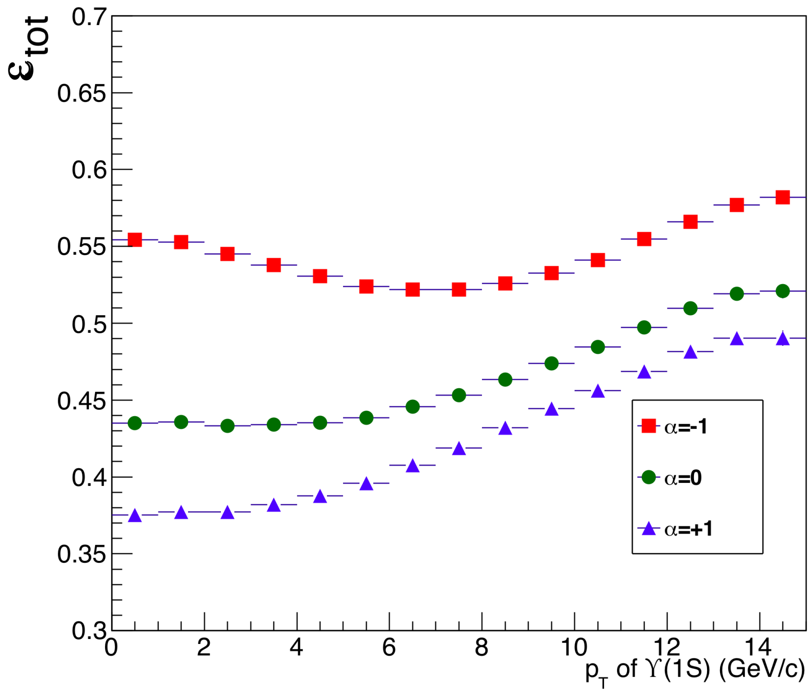
N^{Υ} in bins of p_T

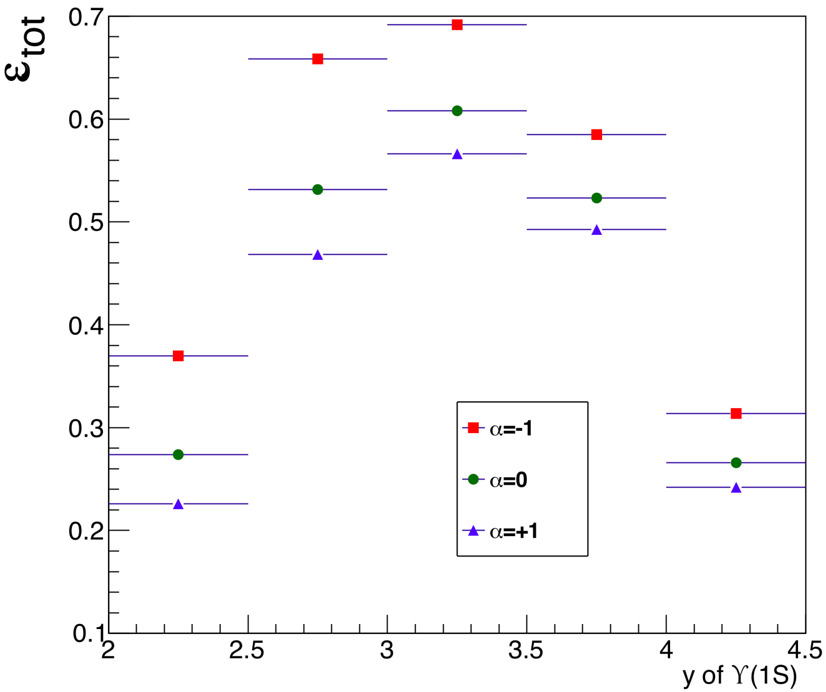
•Numbers of ϒ candidates are extracted from Crystal Ball (CB) part of the fit with 3·CB+exponential.

- Rapidity interval $2.0 < y < 4.5$



Total efficiency : $\Upsilon(1S)$





$\alpha = -1$ – full longitudinal polarization

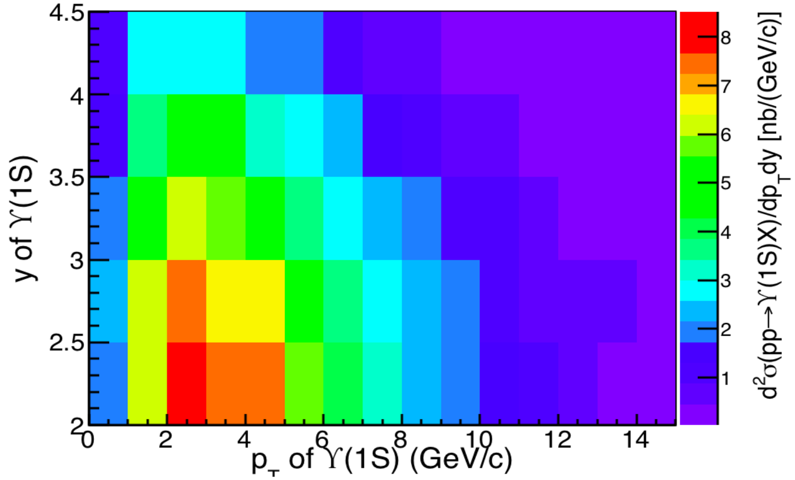
$\alpha = +1$ – full transverse polarization

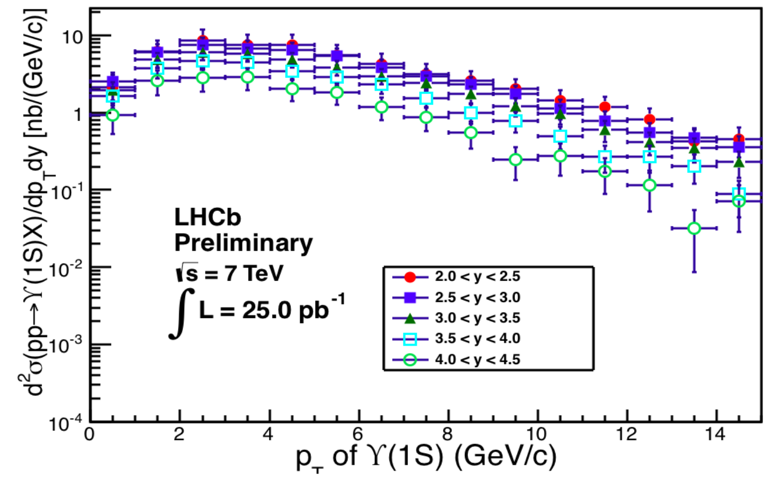
$\alpha = 0$ – no polarization

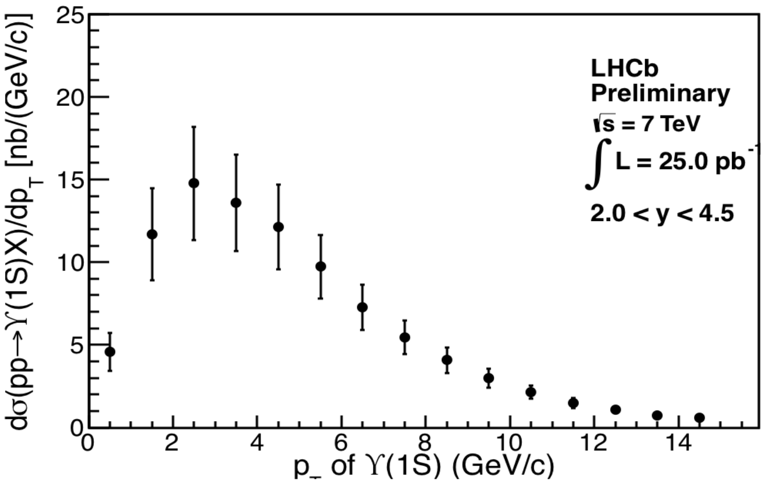
Systematic uncertainties

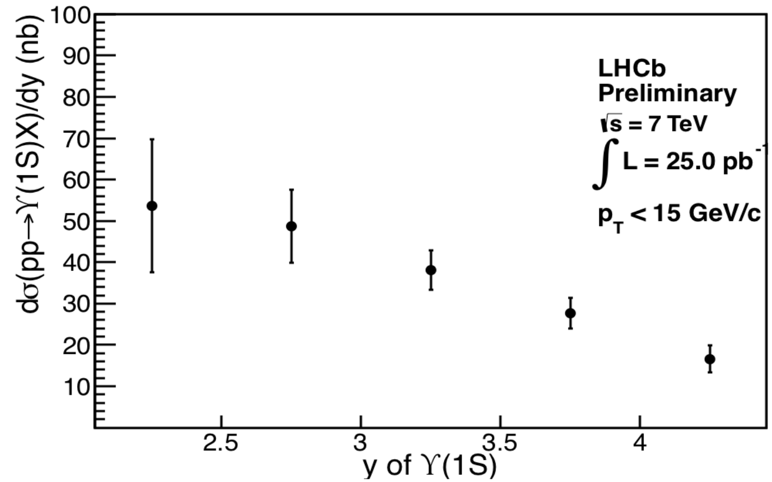
SOURCE	METHOD	VALUE $\Upsilon(1S)$	VALUE $\Upsilon(2S)$	VALUE $\Upsilon(3S)$
statistics MC samples		0-2.5%	0-6.8%	0-5.9%
luminosity	see section 3.2.2	3.5%		
ϵ^{trig} measurement	difference data-MC	3%		
polarisation on A	extreme scenarios	0-33%	0-37%	0-37%
polarisation on ϵ^{rec}	extreme scenarios	0-18%	0-18%	0-17%
polarisation on ϵ^{trig}	extreme scenarios	0-2.5%	0-2.2%	0-2.0%
choice of fit function	different function	1%	1%	1.5%
unknown p_T spectrum	p_T spectrum distribution	1%		
GEC	statistical uncertainty of data	0.6%		
$\epsilon^{trackquality}$	difference data-MC	0.5% per track		
$\epsilon^{track-finding}$	difference data-MC	2.4%		
$\epsilon^{track-finding}$	difference data-MC	0.7% per track		
vertexing	difference data-MC	1%		
ϵ^{muonID}	tag and probe [21]	1.1%		
$BR(\Upsilon \to \mu^+\mu^-)$	[7]	2%	8.8%	9.6%
statistics of data		0.02-0.5%	0.06-0.5%	0.08-0.6%

Υ(1S) cross-section





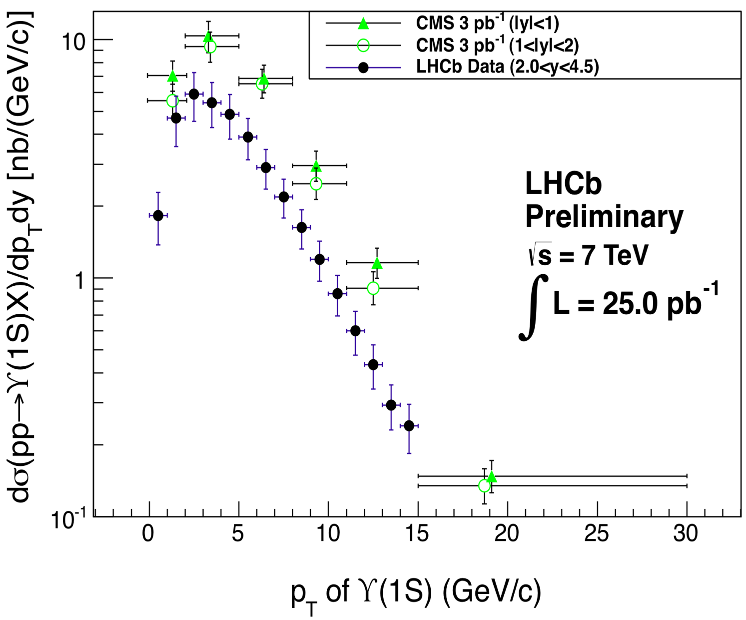


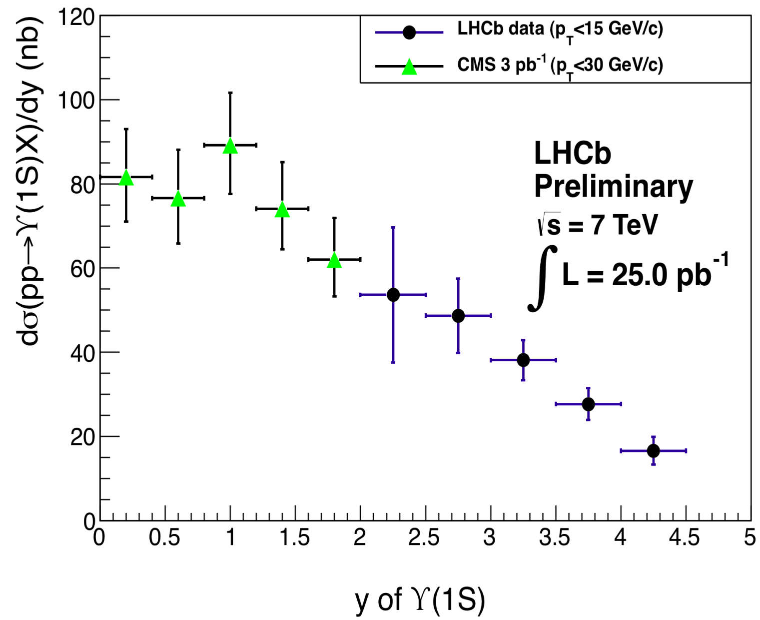


$$92.3 \pm 2.9(\text{stat})\,^{+15.8}_{-8.3}(\text{pola}) \pm 4.8(\text{osys}) \pm 3.2(\text{lumi})\ \text{nb} = 92.3 \pm 2.9(\text{stat})\,^{+16.9}_{-10.1}(\text{syst})\ \text{nb}$$

LHCb-CMS comparison

CMS publication: [Phys. Rev. **D**83 (2011) 112004; arXiv: hep-ex/1012.5545v1]

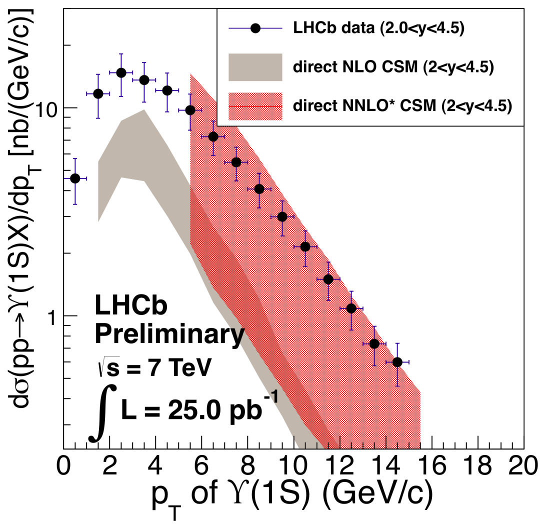


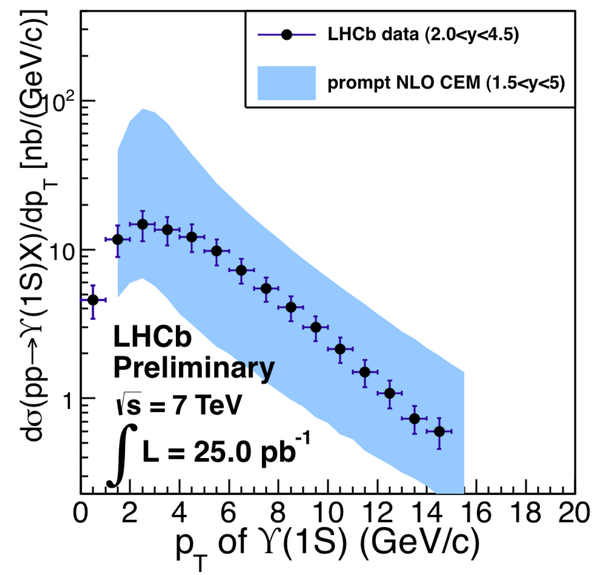


- CSM measurement as a function of p_T is higher, but it should be noted that CMS measures cross-section for |y|<2, while LHCb for 2.0<y<4.5.
- These two measurements supplement each other and are in a good agreement.

Comparison with theory for $\Upsilon(1S)$

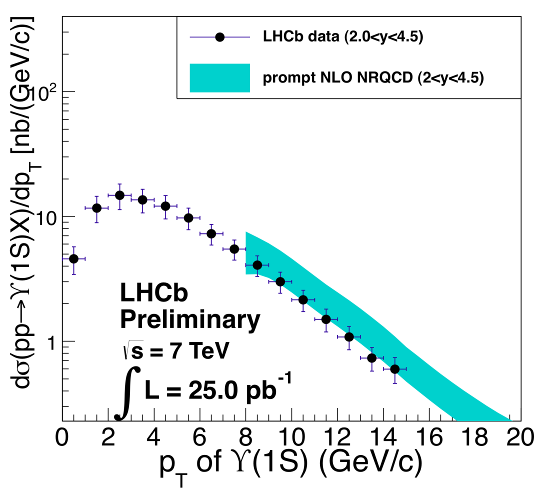
NLO & NNLO CSM
J.-P.Lansberg,Eur.Phys.J. **C** 61 (2009)693



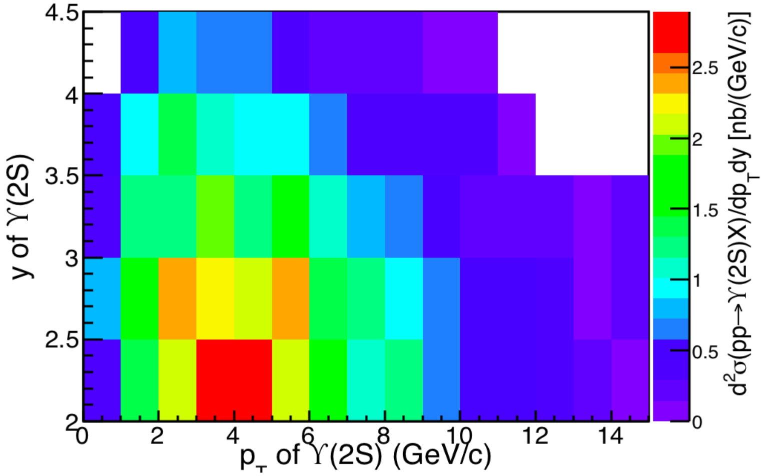


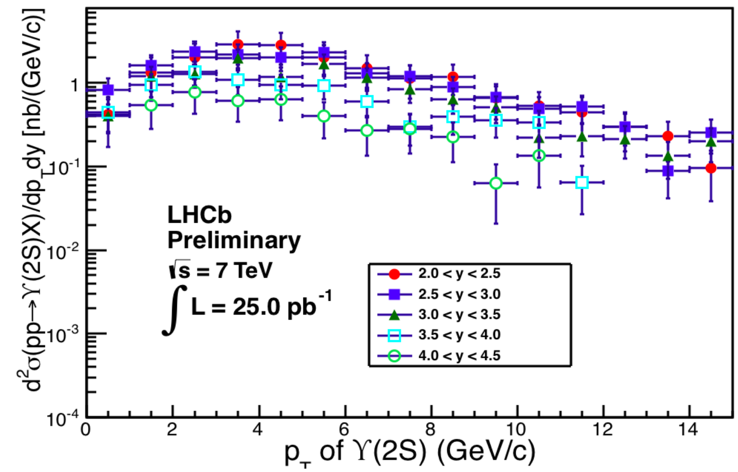
NLO CEM
A.D.Frawley, et al., Phys. Rep.462 (2008) 125.

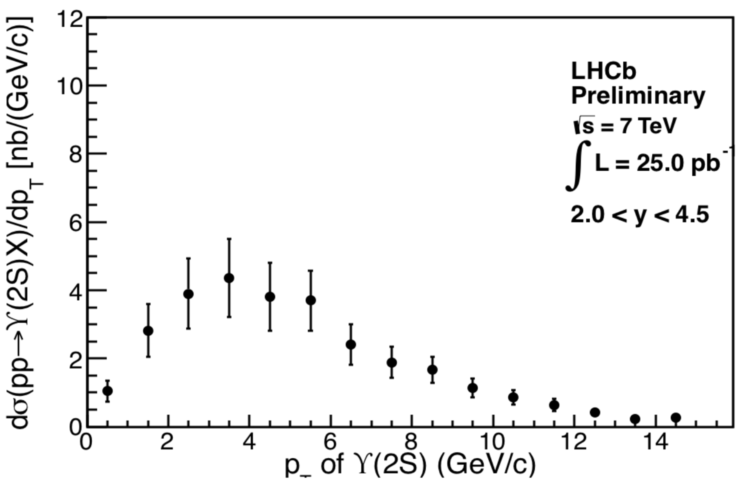
NLO NRQCD
Y.Q.Ma, et al.,Rev.Lett. 106 (2011) 042002.

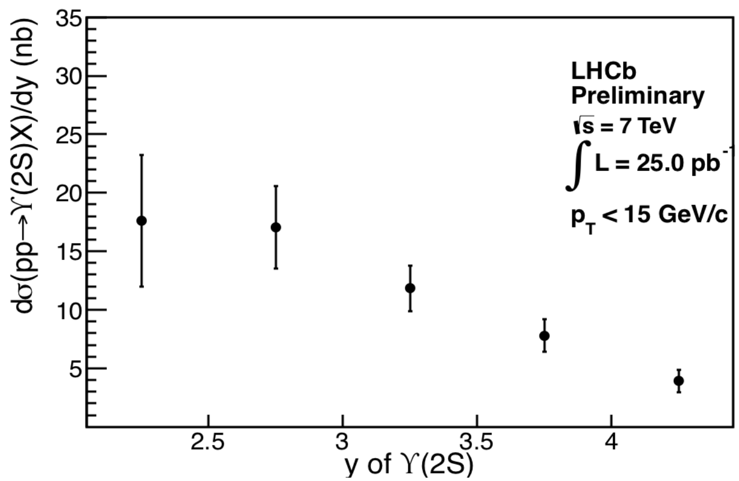


$\Upsilon(2S)$ Cross section New result!



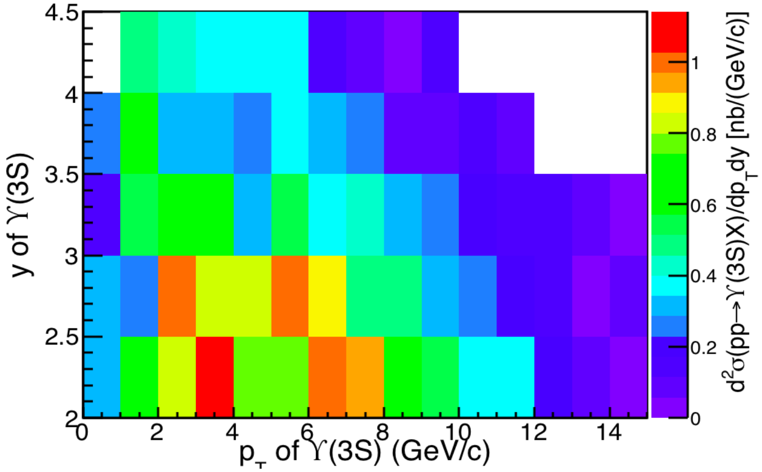


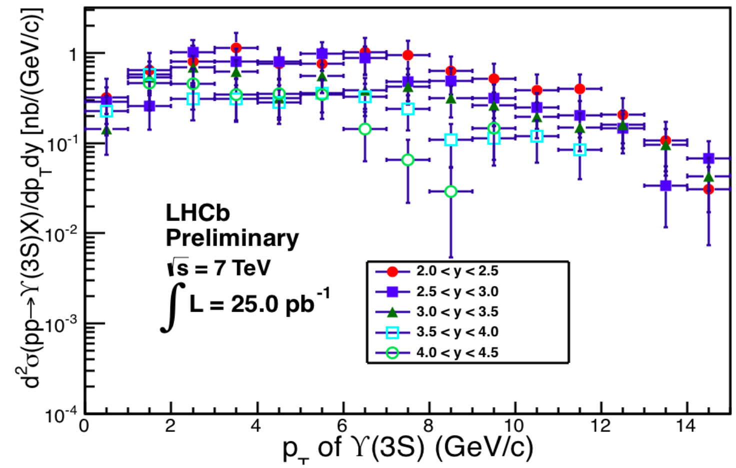


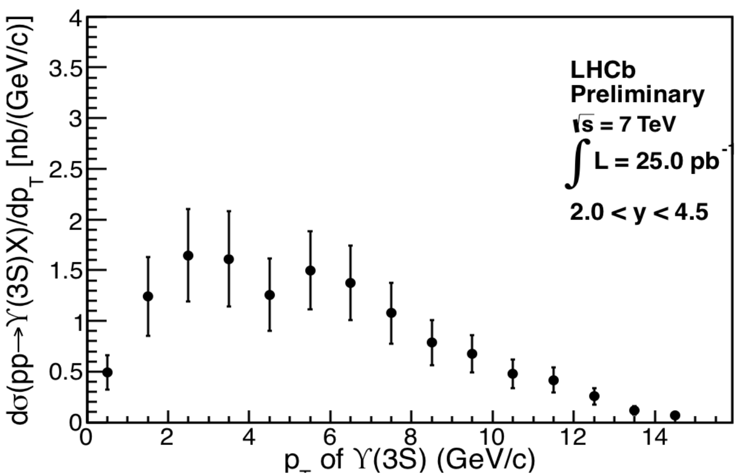


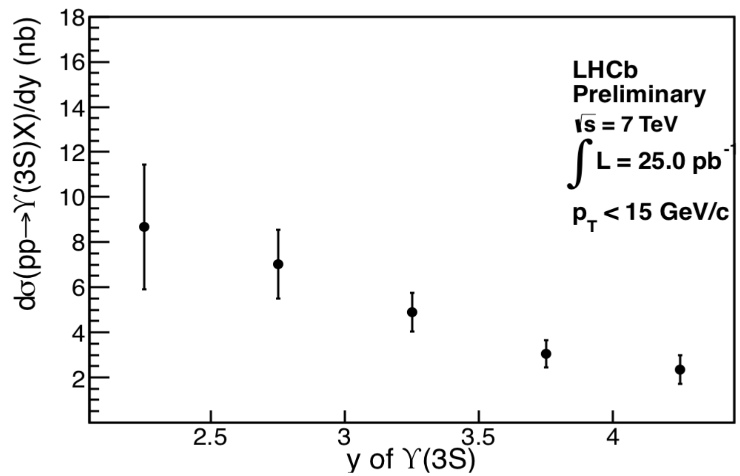
$$29.1 \pm 1.3(\text{stat})\,^{+5.0}_{-2.6}(\text{pola}) \pm 2.9(\text{osys}) \pm 1.0(\text{lumi})\text{ nb} = 29.1 \pm 1.3(\text{stat})\,^{+5.9}_{-4.1}(\text{syst})\text{ nb}$$

Υ(3S) Cross section **New !**





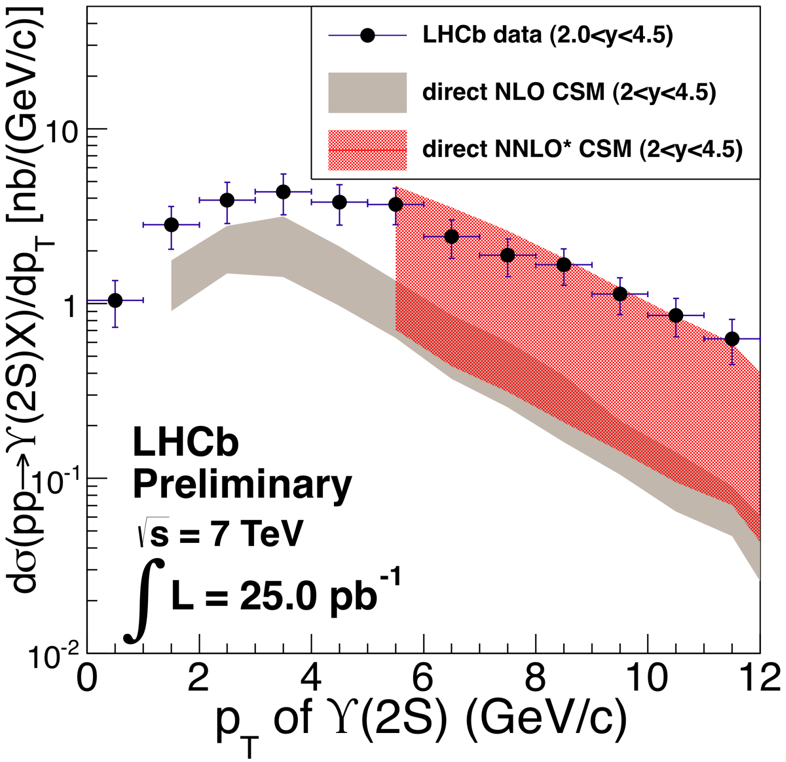


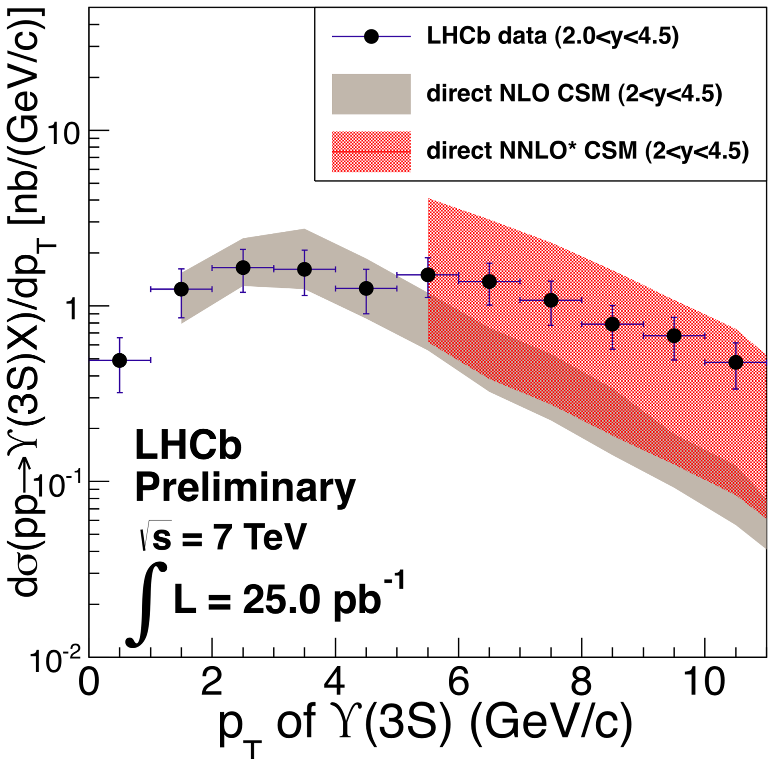


$$13.0 \pm 0.7(\text{stat})^{+2.3}_{-1.2}(\text{pola}) \pm 1.4(\text{osys}) \pm 0.5(\text{lumi})\ \text{nb} = 13.0 \pm 0.7(\text{stat})\ ^{+2.8}_{-1.9}\ (\text{syst})\ \text{nb}$$

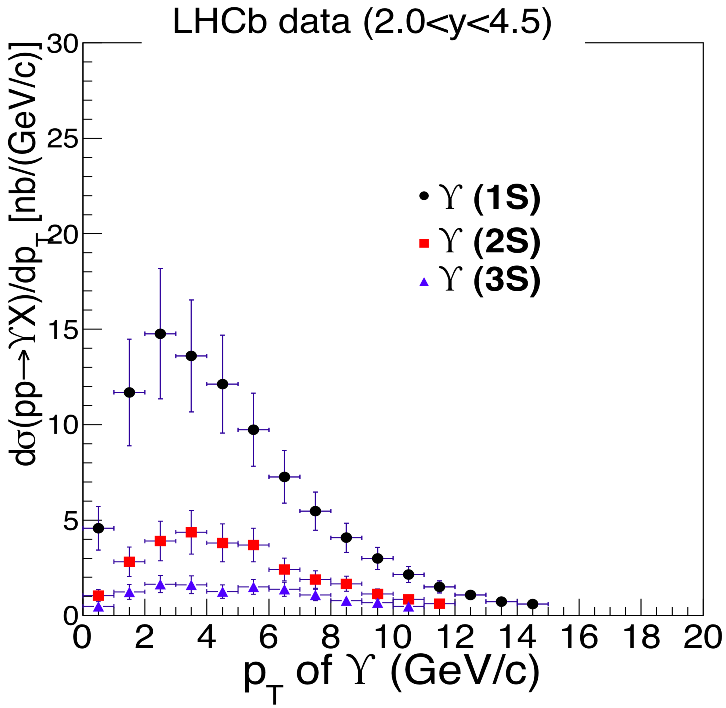
Υ(2S),Υ(3S) comparison with theory

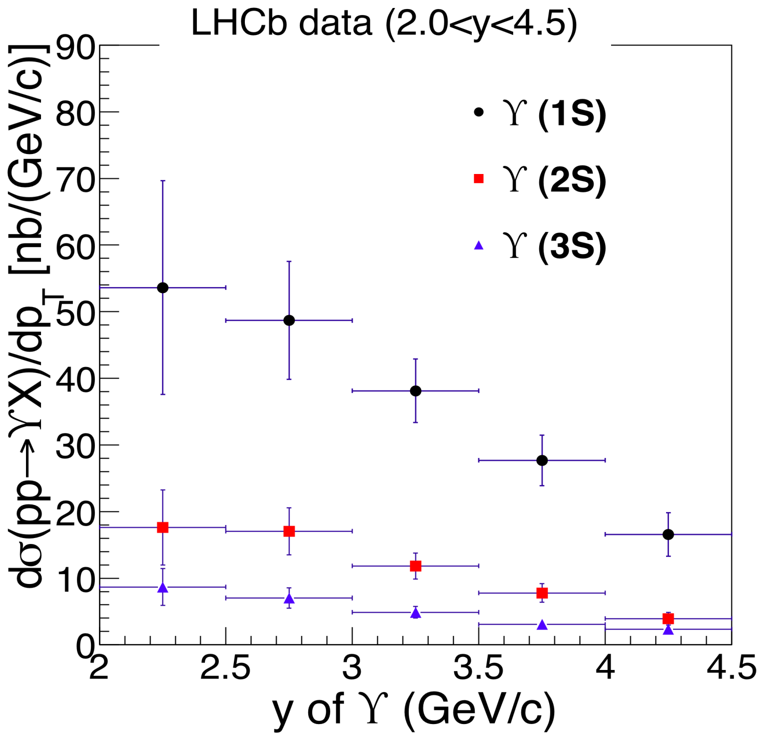
NLO & NNLO CSM
J.-P.Lansberg, Eur.Phys.J. **C** 61 (2009)693





$\Upsilon(1S)$, $\Upsilon(2S)$,$\Upsilon(3S)$ comparison





χ_b(1P) observation

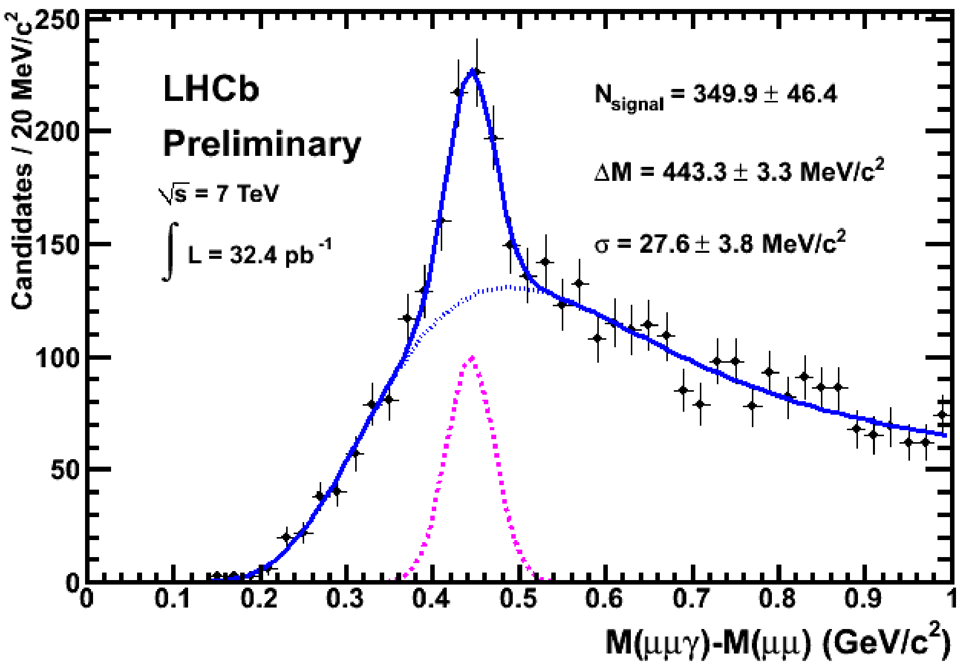
χ_b selection criteria:

Υ(1S) mass band	9.36÷9.56 GeV/c^2
Polar angle of μ^+ in Υ rest frame	$\lvert\cos\theta^*_\mu\rvert < 0.7$
p_T of photon	$p_T(\gamma) > 700$ MeV/c
Polar angle of γ in χ_b rest frame	$\cos\theta^*_\gamma > 0$
p_T of χ_b candidate	$p_T(\chi_b) > 7$ GeV/c

$$\frac{dN}{dx} = A1\cdot\frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{(x-\Delta M)^2}{2\sigma^2}} + A2\cdot(x-x_0)^\alpha\cdot e^{-(a1\cdot x+a2\cdot x^2+a3\cdot x^3)}$$

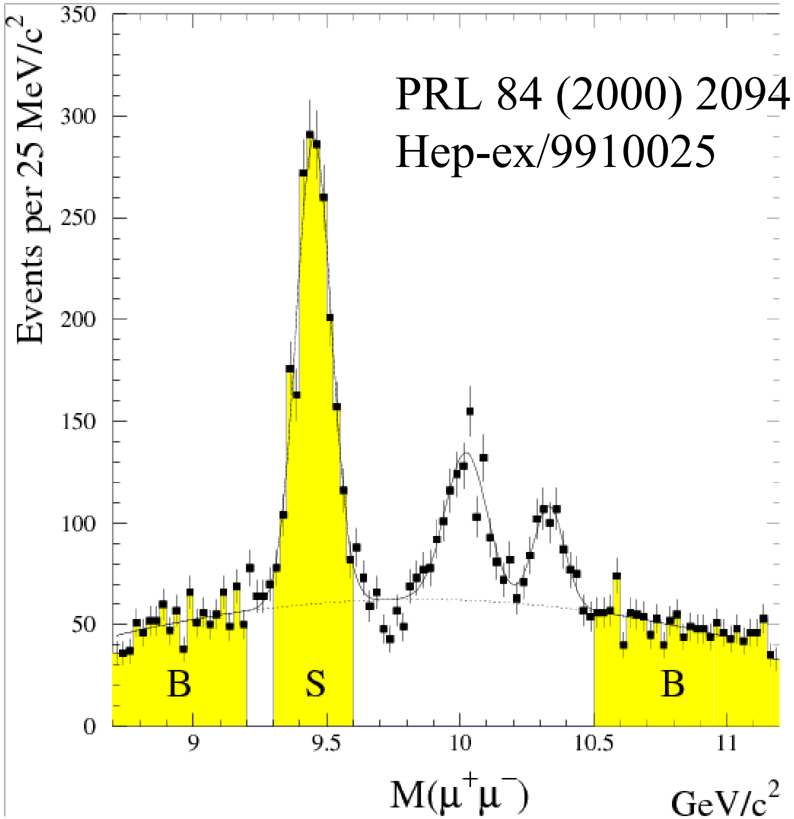
Gaussian *(for signal)* + smooth background function is used for fitting to obtain the number of signal events.

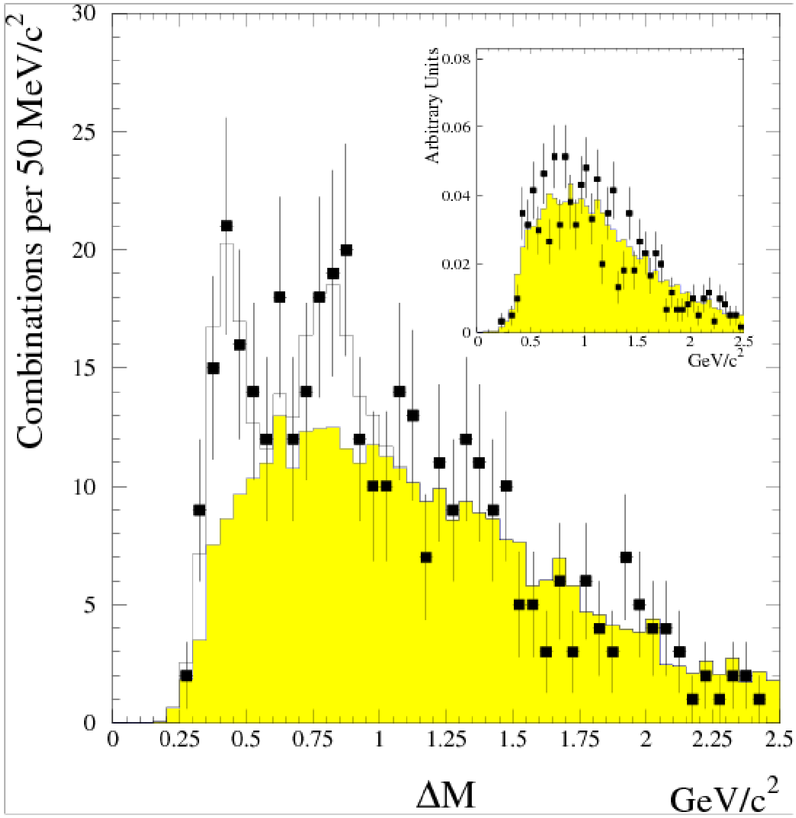
- clear χ_b(1P) signal is seen.
- No hint for χ_b(2P) signal ($\Delta M \approx 800$MeV/c^2).
- Cannot resolve states χ_{b0}(1P), χ_{b1}(1P), χ_{b2}(1P) .



CDF results on $\chi_b(1P)$

- CDF Collaboration with 30 times less statistics of $\Upsilon(1S)$ measure the fractions of $\Upsilon(1S)$ from $\chi_b(1P)$ and $\chi_b(2P)$ for $p_T(\Upsilon)>8$ GeV/c:
  - (27.1±6.9(stat.)±4.4(sys))% from $\chi_b(1P)$
  - (10.5±4.4(stat.)±1.4(sys))% from $\chi_b(2P)$





Conclusions

- $\Upsilon(1S)$, $\Upsilon(2S)$,$\Upsilon(3S)$ xsections measured in bins of y and pt for $2<y<4.5$; $0<p_T<15$ GeV

- Results agree with other experiments and reasonably agree with theory

- Clear $\chi_b(1P)$ signal has been observed, the measurement of the fraction of $\Upsilon(1S)$ from $\chi_b(1P)\rightarrow \Upsilon(1S)\gamma$ is in progress

- With 1 fb^{-1} of 2011 detailed studies are possible: polarization, χ_{b0}, χ_{b1}, χ_{b2} separation etc.