Recent flavor physics results at CMS

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Motivations

Several motivations to study HF physics at CMS

- Advance *b*,*c* spectroscopy
- Test QCD and effective theories
- Look for indirect evidence or constraints to new physics
- Improve environment description in NP searches

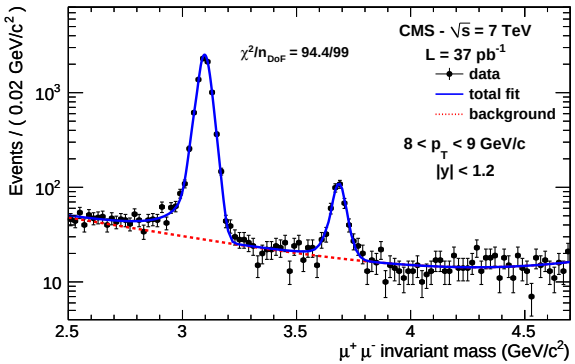
Compact Di-Muon Solenoid?

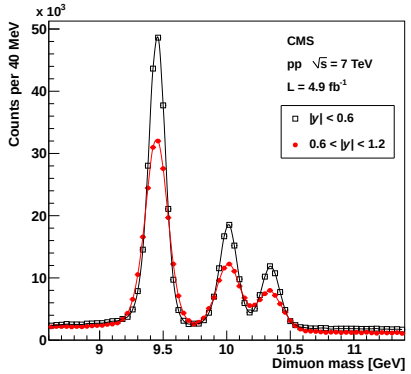
Data samples

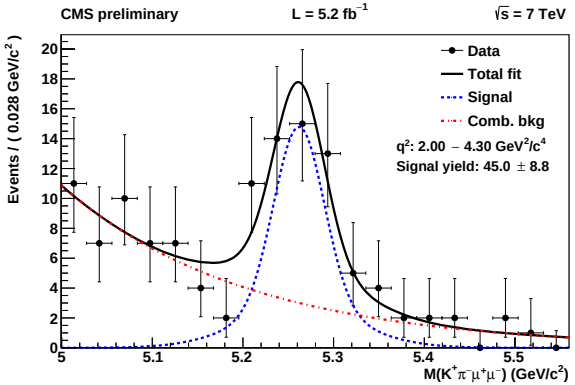
- $\sqrt{s} = 7$ TeV , $\mathcal{L} = \ \ 5$ fb^{-1} (2011 run)
- $\sqrt{s} = 8$ TeV , $\mathcal{L} = 20$ fb^{-1} (2012 run)

All shown results involve di-muons

- With definite invariant mass (J/ψ , Υ) ...







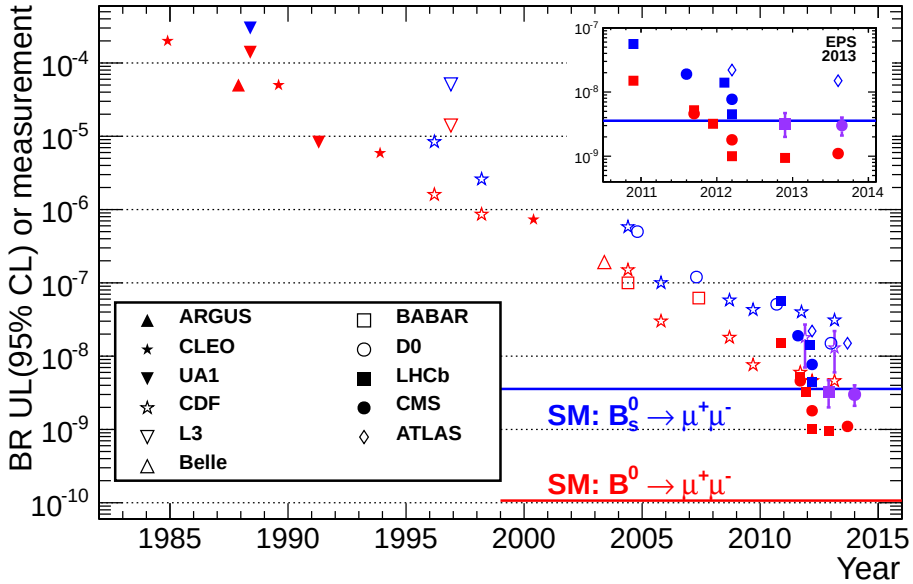
- ...or not ($B^0 \to K^{*0}\mu^+\mu^-$)
- Useful to reduce trigger rate

Mesons

- Mesons:
  - $\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-)$
  - $B^0 \to K^{*0}\mu^+\mu^-$ decay angles
  - B^0_s lifetime difference
  - $B_c \to J/\psi\pi/3\pi$ production and B.R.
- Quarkonia:
  - J/ψ , $\psi(2S)$, $\Upsilon(n\mathrm{S})$ polarization
  - Prompt J/ψ , $\psi(2S)$ production
  - Double J/ψ production
  - χ_b production
- Exotica:
  - Search for $X_b \to \Upsilon(1S)\pi^+\pi^-$
  - Observation of peaks in $B^\pm \to J/\psi\phi K^\pm$

$\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-)$

- Very rare decay
- B.R. possibly increased by NP processes
- Studied since a very long time



B.R. determined by comparison with other channels

- $B^+ \to J/\psi K^+$ used as normalization
- $B^0_s \to J/\psi\phi$ used as control

$$\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-) = \frac{N_{\text{sig}}}{N_{\text{nrm}}} \frac{\epsilon_{\text{nrm}}}{\epsilon_{\text{sig}}} \frac{f_u}{f_{d,s}} \mathcal{B}(B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm)$$

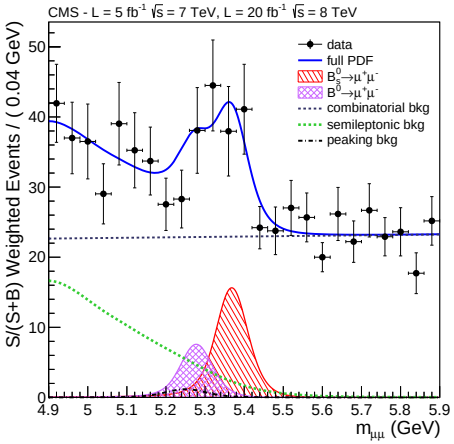
$f_s/f_u = 0.256 \pm 0.020$ from LHCb [JHEP 04 (2013) 001]

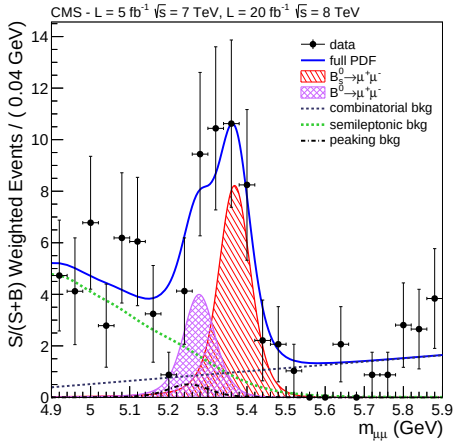
$\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-)$

Signal/background discriminated by BDT

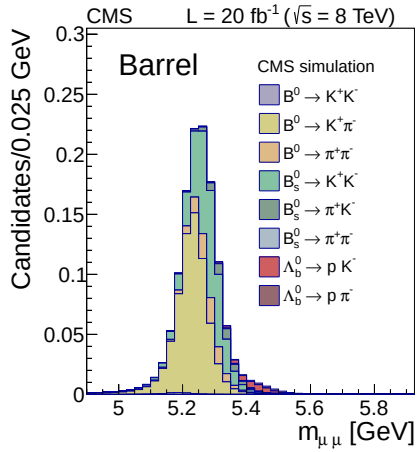
- Invariant mass fit in BDT-output event categories to extract $B^0_s \to \mu^+\mu^-$ yield
- BDT-output cut to estimate $B^0_d \to \mu^+\mu^-$ yield or upper limit

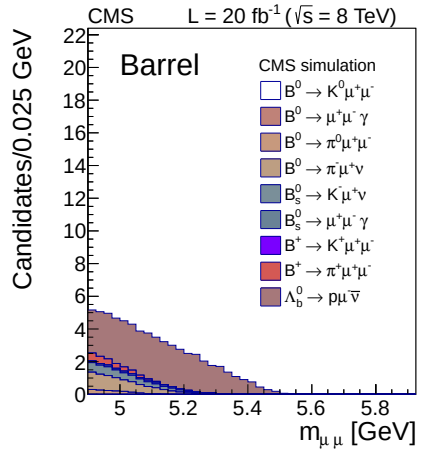
Reconstructed invariant mass





Background: peaking + non-peaking



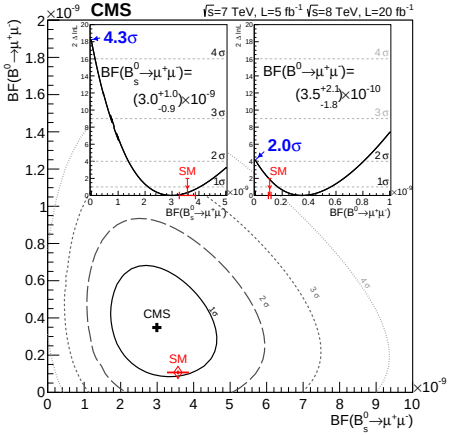


$\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-)$

Results (full sample)

PRL 111 (2013) 101804

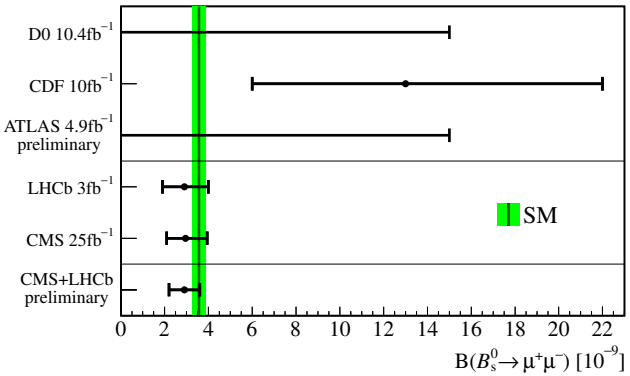
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9} \quad \mathcal{S} = 4.3\sigma$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) = (3.5^{+2.1}_{-1.8}) \times 10^{-10} \quad \mathcal{S} = 2.0\sigma$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) < 1.1 \times 10^{-9} \text{ @ 95\% C.L.}$$

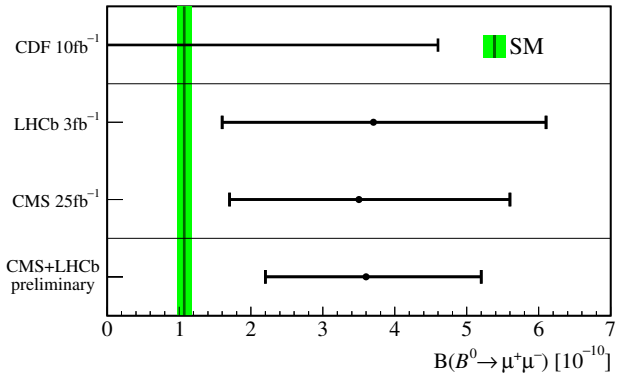


Combination with LHCb [PRL 111 (2013) 101805] (preliminary)

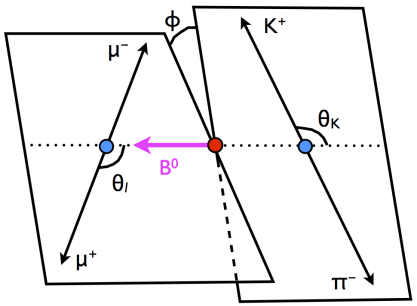
CMS PAS BPH-13-007

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9} \; (f_s/f_u = 0.259 \pm 0.015)$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10}$$





$B^0 \to K^{*0}\mu^+\mu^-$, $K^{*0} \to K^+\pi^-$ angular analysis



$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\vartheta_K d\cos\vartheta_l dq^2} = \frac{9}{16}\Big\{\Big[\frac{2}{3}F_S + \frac{4}{3}A_S\cos\vartheta_K\Big](1-\cos^2\vartheta_l) + (1-F_S)\Big[2F_L\cos^2\vartheta_K(1-\cos^2\vartheta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\vartheta_K)(1+\cos^2\vartheta_l) + \frac{4}{3}A_{FB}(1-\cos^2\vartheta_K)\cos\vartheta_l\Big]\Big\}$$

- A_{FB} : muons forward-backward asymmetry
- F_L : K^{*0} longitudinal polarization
- F_S , A_S : $K^+\pi^-$ system S-wave contribution and interference
- $d\mathcal{B}/dq^2$: differential branching fraction

- Events divided in q^2 bins, $B^0 \to K^{*0}(J/\psi\ ,\psi')$ regions removed
- A_{FB} , F_L from unbinned max-likelihood fit to $M_{K\pi\mu\mu}$, ϑ_μ , ϑ_K
- $B^0 \to K^{*0}J/\psi$ decay used to:
  - fit F_S , A_S
  - normalize B.R.: $\frac{d\mathcal{B}(B^0\to K^{*0}\mu^+\mu^-)}{dq^2} = \frac{Y_S}{Y_N}\frac{\epsilon_N}{\epsilon_S}\mathcal{B}(B^0 \to K^{*0}J/\psi)$

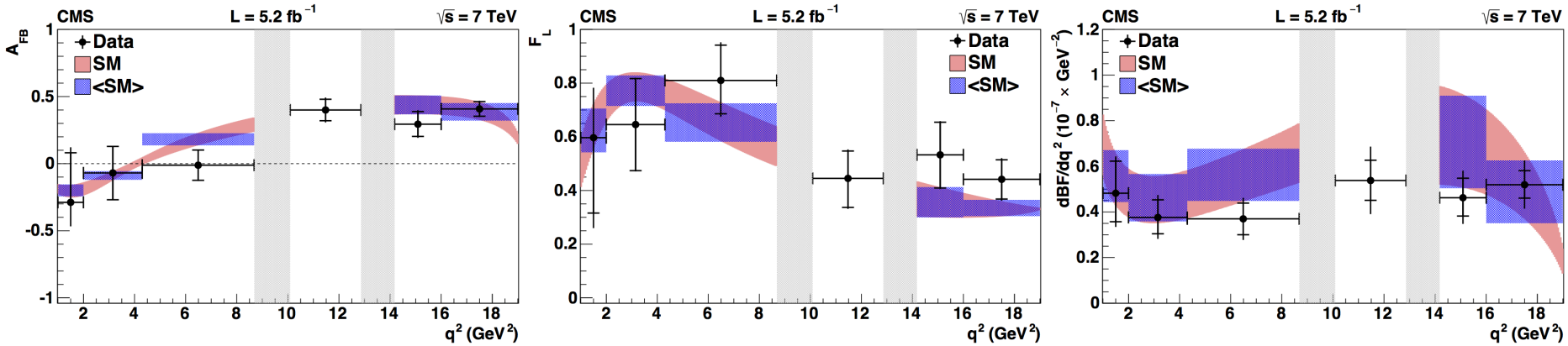
More infos at slide 25

$B^0 \to K^{*0}\mu^+\mu^-$, $K^{*0} \to K^+\pi^-$ angular analysis

Results ($\sqrt{s} = 7$ TeV)

PLB 727 (2013) 77

- A_{FB} , F_L, F_S , A_S in $B^0 \to K^{*0}(J/\psi\ , \psi')$ decays compatible with world averages
- Parameter dependence on q^2 compatible with SM predictions at low and high q^2
- No reliable prediction in the region between J/ψ and ψ'

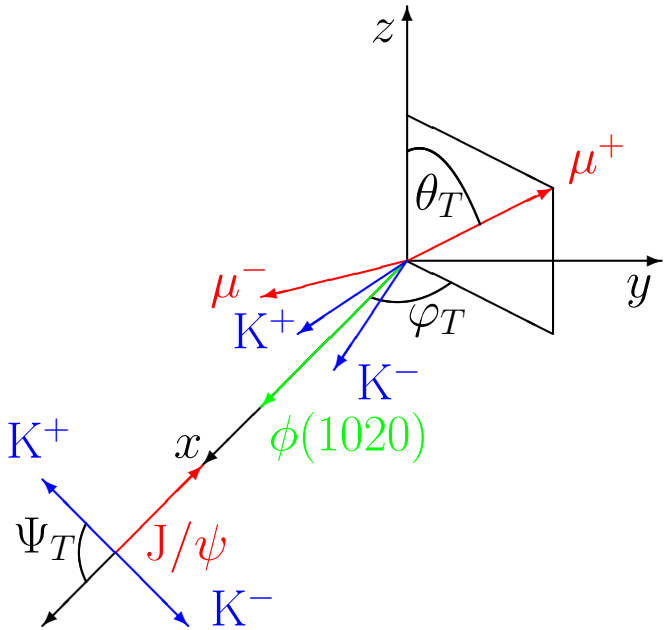


More infos at slide 25

B_s^0 lifetime difference and CPV phase in $B_s^0 \to J/\psi\phi$

- Unflavoured final state:
  - direct and mixing-mediated decays
  - interference: phase ϕ_s
- Non-definite CP final state:
  - admixture of CP odd and even
  - components disentangled by angular analysis: $\Theta = \vartheta, \varphi, \psi$

$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} \propto \sum_{i=1}^{10} O_i(\alpha, ct) \cdot g_i(\Theta)$$



$$O_i(\alpha, ct) = N_i e^{-t/\tau} \left[a_i \cosh(\tfrac{1}{2}\Delta\Gamma_s ct) + b_i \sinh(\tfrac{1}{2}\Delta\Gamma_s ct) + c_i \cos(\Delta m_s ct) + d_i \sin(\Delta m_s ct) \right]$$

- α parameters: $A_\perp$, A_0 , $A_\parallel$, A_S , $\delta_\perp$, δ_0 , $\delta_\parallel$, δ_S
- $|\lambda|$: direct CP violation
- ϕ_s inside b_i , d_i ; $\bar{B}_s^0$ decay described by switching c_i , d_i sign

More infos at slide 26

B_s^0 lifetime difference and CPV phase in $B_s^0 \to J/\psi\phi$

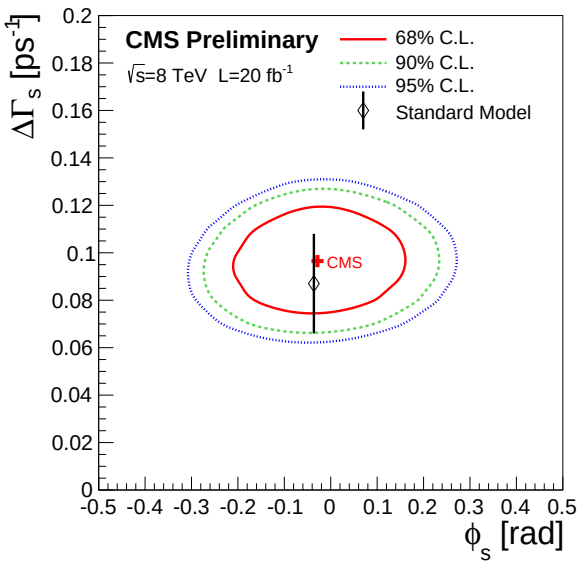
Flavour tagging:

- search for a second *b*-hadron in the event, decaying semi-leptonically
- charge-flavour correlation diluted (cascade, oscillations, ...)
- tagging efficieny: $\epsilon_{\text{tag}} = (7.67 \pm 0.04(\text{stat}))\%$
- mistag fraction: $\omega = (32.2 \pm 0.3(\text{stat}))\%$
- PDF modified to include tagging information in c_i and d_i

Mass difference constrained to world average: $\Delta m_s = (17.69 \pm 0.08)\ \text{ps}^{-1}$
No direct CP-violation: $|\lambda| = 1$

Results ($\sqrt{s} = 8$ TeV) CMS-PAS-BPH-13-012

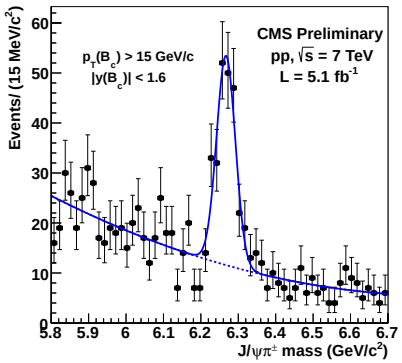
$\phi_s = (-0.03 \pm 0.11 \pm 0.03)$ rad
$\Delta\Gamma_s = (0.096 \pm 0.014 \pm 0.007)\ \text{ps}^{-1}$

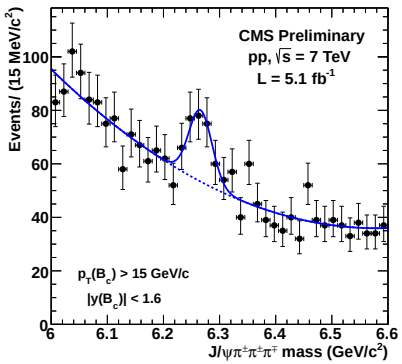


More infos at slide 26

$B_c^{\pm} \to J/\psi\pi^{\pm}(\pi^+\pi^-)$: production and decay

- $B_c^{\pm}$ carries two heavy flavours:
  - Higher-order processes at production
  - c and b quark competing in decay
- Cross section and b.r. measurements:
  - Help understanding process
  - Propaedeutic for more refined investigations





Unbinned max. likelihood fit to mass distribution

Results ($\sqrt{s} = 7$ TeV)

CMS-PAS-BPH-12-011

$$\frac{\sigma(B_c^{\pm})\times\mathcal{B}(B_c^{\pm}\to J/\psi\pi^{\pm})}{\sigma(B^{\pm})\times\mathcal{B}(B^{\pm}\to J/\psi K^{\pm})} = \left(0.48 \pm 0.05 \pm 0.04^{+0.05}_{-0.03}(\tau_{B_c})\right) \times 10^{-2}$$

$$\frac{\mathcal{B}(B_c^{\pm}\to J/\psi\pi^{\pm}\pi^+\pi^-)}{\mathcal{B}(B_c^{\pm}\to J/\psi\pi^{\pm})} = 2.43 \pm 0.76^{+0.05}_{-0.03}$$

More infos at slide 28

Quarkonia

- Mesons:
  - $\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-)$
  - $B^0 \to K^{*0}\mu^+\mu^-$ decay angles
  - B^0_s lifetime difference
  - $B_c \to J/\psi\pi/3\pi$ production and B.R.
- Quarkonia:
  - J/ψ , ψ(2S) , $\Upsilon(n\text{S})$ polarization
  - Prompt J/ψ , ψ(2S) production
  - Double J/ψ production
  - χ_b production
- Exotica:
  - Search for $X_b \to \Upsilon(1\text{S})\pi^+\pi^-$
  - Observation of peaks in $B^\pm \to J/\psi\phi K^\pm$

Quarkonia polarization

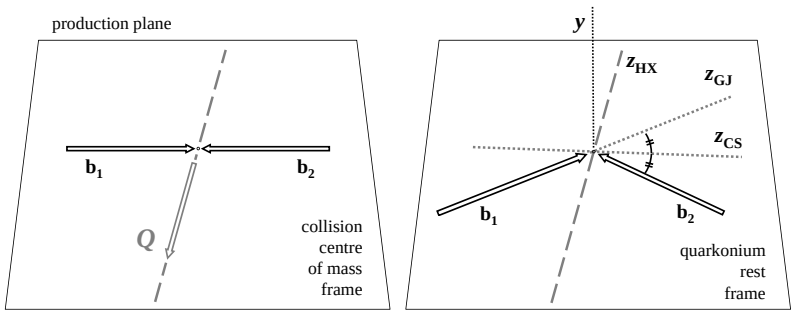
- Quarkonium production in hadron collisions not yet fully settled
- J/ψ polarization description in NRQCD:
  - purely perturbative color-singlet production
  - nonperturbative transitions from coloured quark pairs
- S-wave states predicted to be transversely polarized
- Small longitudinally polarization observed by CDF [PRL 99 (2007) 132001]
- Υ polarization: contradictory results from CDF [PRL 108 (2012) 151802] and D0 [PRL 101 (2008) 182004]

$$W(\cos\vartheta,\varphi|\vec{\lambda}) = \frac{3}{4\pi(3+\lambda_\vartheta)}(1+\lambda_\vartheta\cos^2\vartheta + \lambda_\varphi\sin^2\vartheta\cos 2\varphi + \lambda_{\vartheta\varphi}\sin 2\vartheta\cos\varphi)$$

Polarization frames: HX(helicity), CS(Collins-Soper), PX

"Invariant polarization parameter":

$$\tilde{\lambda} = \frac{\lambda_\vartheta + 3\lambda_\varphi}{1-\lambda_\varphi}$$



$\Upsilon(n\mathrm{S})$ and prompt $\psi(n\mathrm{S})$ polarization

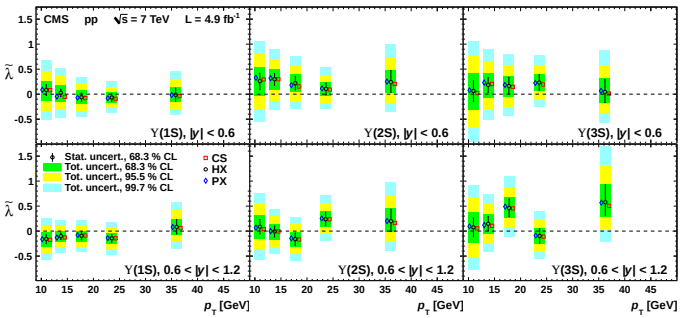
Parameters fit ($\sqrt{s} = 7$ TeV)

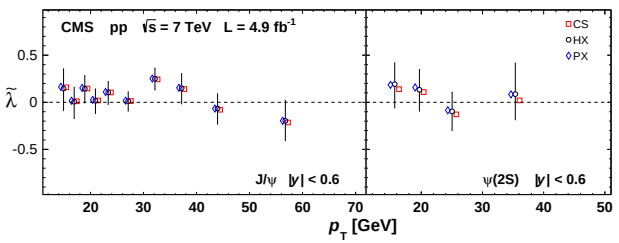
PRL 110 (2013) 081802 , PLB 727 (2013) 381

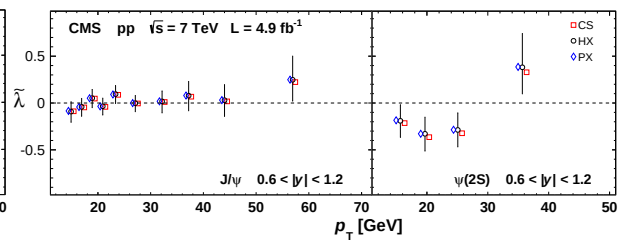
- Events divided in p_T and rapidity (y) bins:
  - $J/\psi, \Upsilon(n\mathrm{S})$: $|y| < 0.6$, $0.6 < |y| < 1.2$
  - $\psi(2\mathrm{S})$: $|y| < 0.6$, $0.6 < |y| < 1.2$, $1.2 < |y| < 1.5$
- Charmonium from B decay separated by flight distance

- Dimuon mass fit in each region to estimate background fraction
- Background angular distribution taken from sidebands
- Efficiency estimated event by event

$$\mathcal{P}(\vec{\lambda}) = \prod_i \mathcal{E}\left(\vec{p}_1^{(i)}, \vec{p}_2^{(i)}\right) \;\; ; \;\; \mathcal{E}\left(\vec{p}_1^{(i)}, \vec{p}_2^{(i)}\right) = \frac{1}{N(\vec{\lambda})} W(\cos\vartheta, \varphi|\vec{\lambda})\epsilon(\vec{p}_1, \vec{p}_2)$$







More infos at slides 29,33

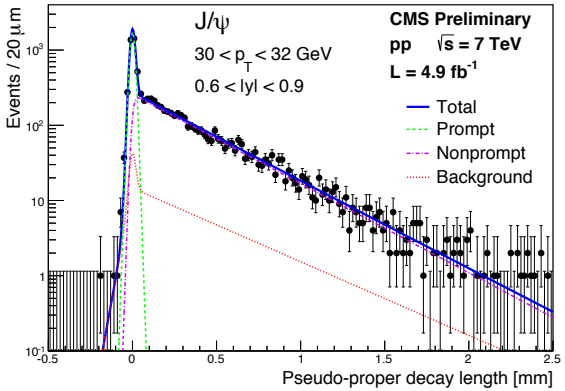
Prompt J/ψ , $\psi(2S)$ production

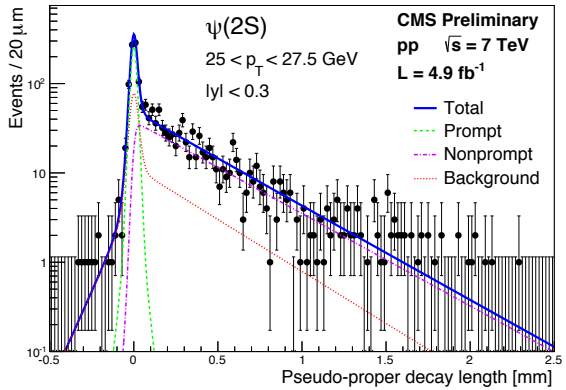
New measurement of $\frac{d^2\sigma(pp \to \psi(nS))}{dp_T dy}$ with 2011 data (integrated luminosity 100 times higher than in 2010)

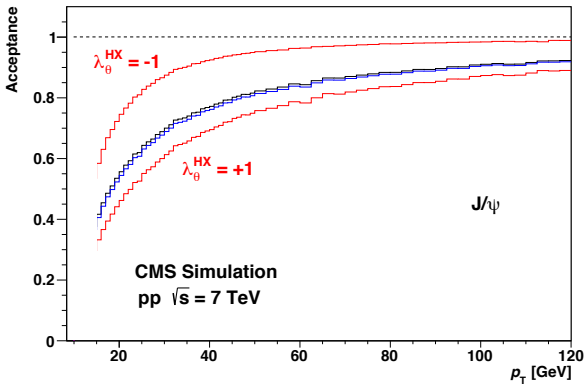
- Muon acceptance:
  $|\eta_\mu| < 1.6$, $p_{T\mu} > (3.0 \div 4.5)$ GeV
- J/ψ , $\psi(2S)$ acceptance: $|y_{\psi(nS)}| < 1.2$
  - $15 < p_T < (75 \div 95)$ GeV in 4 $|y|$ bins
  - $15 < p_T < (100 \div 120)$ GeV integrated over $|y|$

Cross section fit ($\sqrt{s} = 7$ TeV) CMS-PAS-BPH-14-011

- Simultaneous fit to invariant mass and flight distance in p_T, y bins
- Acceptance in several polarization scenarios: $\lambda_\theta^{HX} = -1, 0, +(0.1, 0.03), +1$

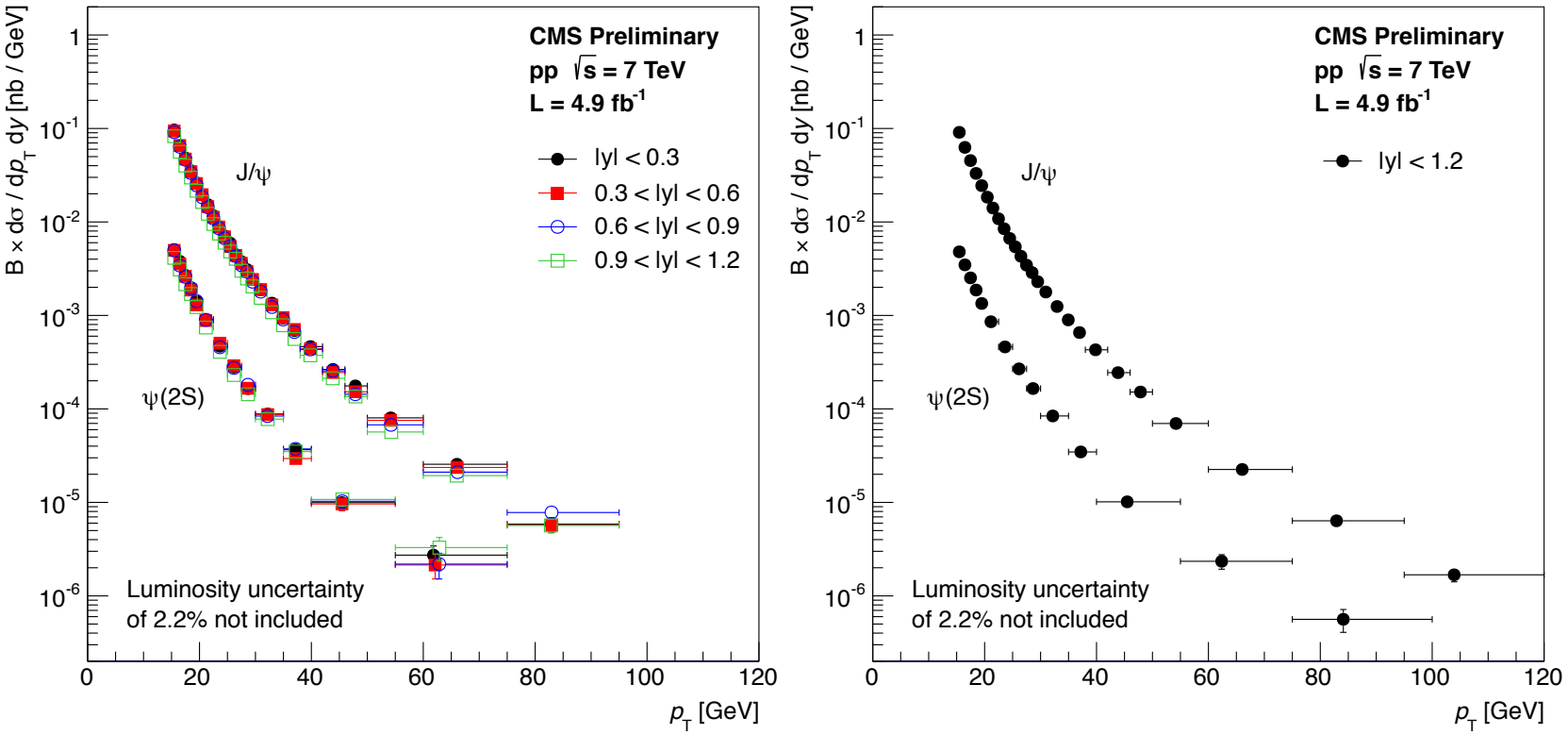






Prompt J/ψ , $\psi(2S)$ production

Cross section computed assuming unpolarized production: results directly comparable with other measurements



More infos at slides 38,39

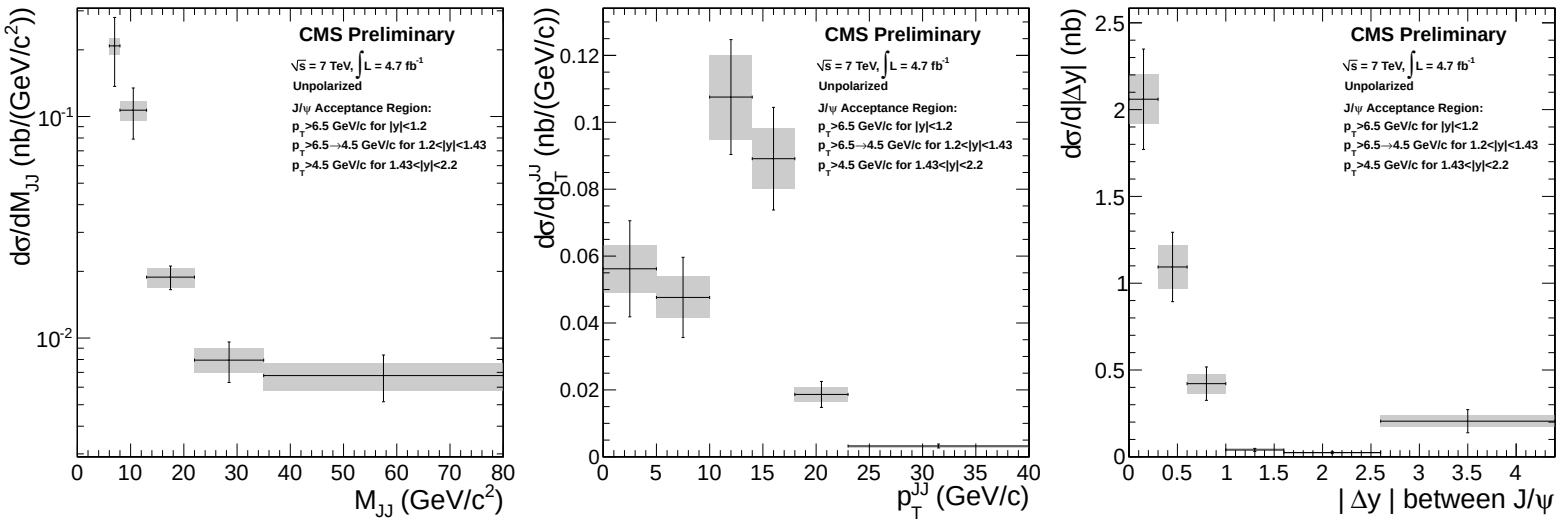
Double J/ψ production

Production of J/ψ pairs:

- double-parton scattering
- color-octet states

Cross section measured vs:

- $J/\psi J/\psi$ invariant mass
- $J/\psi J/\psi$ total p_T
- Δy



No excess in η_b mass region; DPS hint at $\Delta y > 2.6$

Total cross section ($\sqrt{s} = 7$ TeV) CMS-PAS-BPH-11-021

$$\sigma(pp \to J/\psi J/\psi X) = (1.49 \pm 0.07 \pm 0.14)\ \text{nb}$$

More infos at slide 41

$\chi_{b2}(1P)$ vs $\chi_{b1}(1P)$ relative production

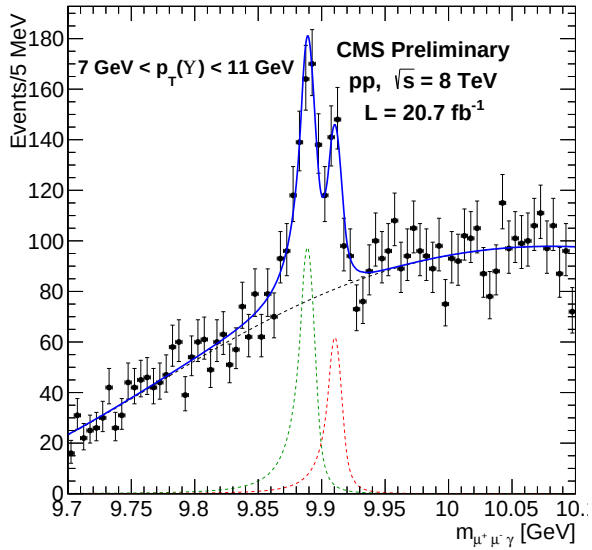
P-wave quarkonia:

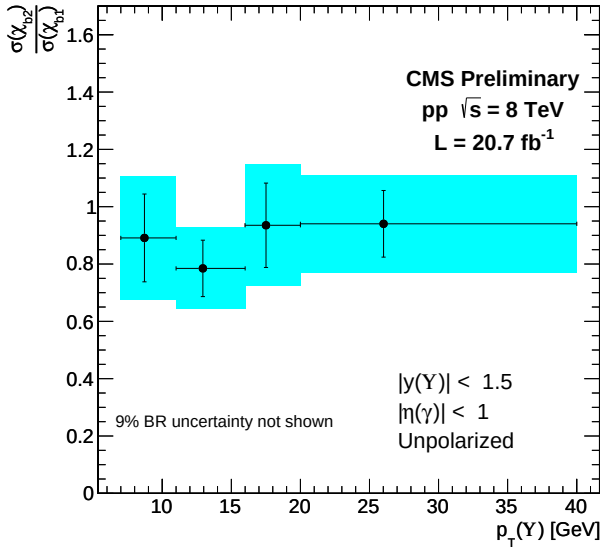
- feed-down contribution to 1S state production
- relative production sensitive to singlet/octet production mechanisms
- reconstructed in the channels
  $\chi_c \to J/\psi\gamma$ [EPJ C (2012) 72:2251], $\chi_b \to \Upsilon(1S)\gamma$
  followed by the photon conversion

$\sigma(\chi_{b2})/\sigma(\chi_{b1})$ ($\sqrt{s} = 8$ TeV) CMS-PAS-BPH-13-005

$$m_{\chi_{b2}} - m_{\chi_{b1}} = 19.4 \text{ MeV}$$
$$|y_{\Upsilon(1S)}| < 1.5 \, , \, |\eta_\gamma| < 1.0$$

No significant
p_T dependence observed





More infos at slides 42,43

Exotica

- Mesons:
  - $\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-)$
  - $B^0 \to K^{*0}\mu^+\mu^-$ decay angles
  - B^0_s lifetime difference
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- Quarkonia:
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- Exotica:
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  - Observation of peaks in $B^\pm \to J/\psi\phi K^\pm$

Heavy flavour exotic states

Unexpected heavy charmonium states

- $X(3872)$ first observed in $B^+ \to J/\psi K^+\pi^+\pi^-$ decay
- Their nature is not well understood
- Interpreted as tetraquark or hadronic molecules
- Bottomonium partners are looked for

Search for $X_b \to \Upsilon(1S)\pi^+\pi^-$

- $X(3872)$ first exotic charmonium seen, in the channel $J/\psi\pi^+\pi^-$

  [PRL 91 (2003) 262001, PRD 71 (2005) 071103, PRL 93 (2004) 072001, PRL 93 (2004) 162002, JHEP 04 (2013) 154]

- Bottomonium-state looked for in the final state $\Upsilon(1S)\pi^+\pi^-$ as a counterpart of $X(3872) \to J/\psi\pi^+\pi^-$
- $\Upsilon(1S)$ combined with 2 opposite charge tracks
- Common vertex reconstructed

Results ($\sqrt{s} = 8$ TeV)

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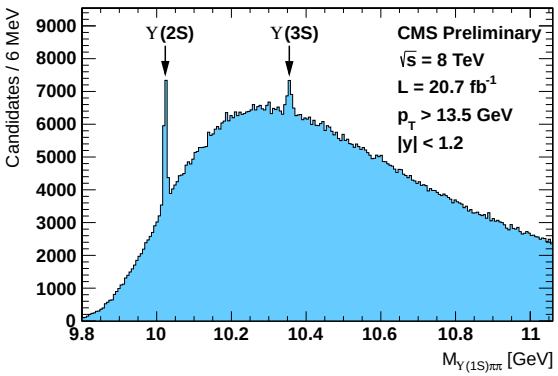
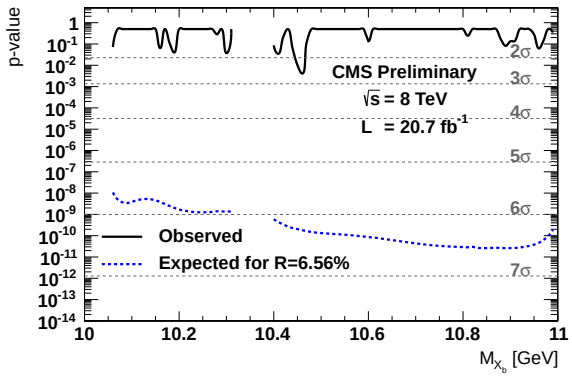
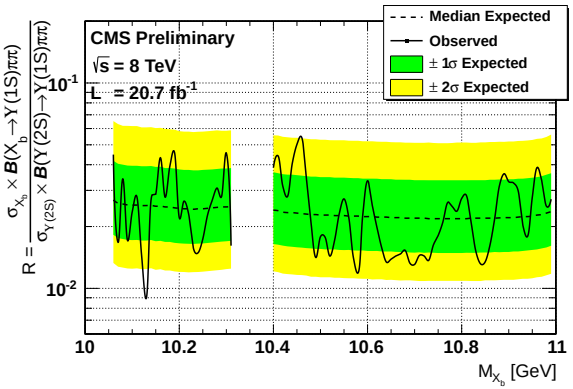
$$\frac{\sigma(pp \to X_b \to \Upsilon(1S)\pi^+\pi^-)}{\sigma(pp \to \Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-)} < (0.9 \div 5.4)\% \text{ @ 95\% C.L.}$$







More infos at slide 44

Peaks in $B^{\pm} \to J/\psi\phi K^{\pm}$

- $Y(4140)$ evidence in $B^{\pm} \to J/\psi\phi K^{\pm}$ decay reported by CDF

[PRL 102 (2009) 242002]

- J/ψ reconstructed and combined with 3 charged tracks with total charge $\Sigma_i q_i = \pm 1$
- Lowest-mass K^+K^- pair compatible with ϕ
- Fit $\Delta m = m(\mu^+\mu^- K^+K^-) - m(\mu^+\mu^-)$ distribution

Results ($\sqrt{s} = 7$ TeV)

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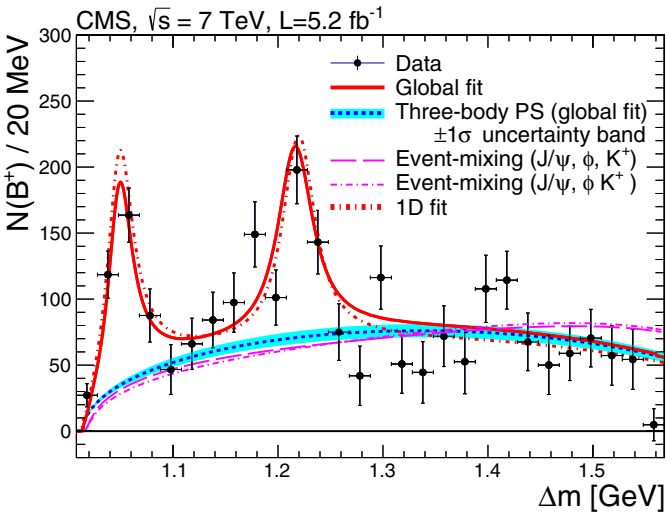
	yield	Δm (MeV)
low	310 ± 70	1051.3 ± 2.4
high	418 ± 170	1217.1 ± 5.3
	m (MeV)	Γ (MeV)
low	$4148.0 \pm 2.4 \pm 6.3$	$28^{+15}_{-11} \pm 19$
high	$4313.8 \pm 5.3 \pm 7.3$	$38^{+30}_{-15} \pm 16$



More infos at slide 46

Conclusions

- CMS has produced several results in HF physics
- B_s^0 decay to $\mu^+\mu^-$ has been observed
- Angular analysis in $B_{s,d}^0$ decays performed to probe for NP
- Heavy quarkonia cross sections and polarizations give informations about production mechanisms
- Study of exotic heavy quarkonia is going on

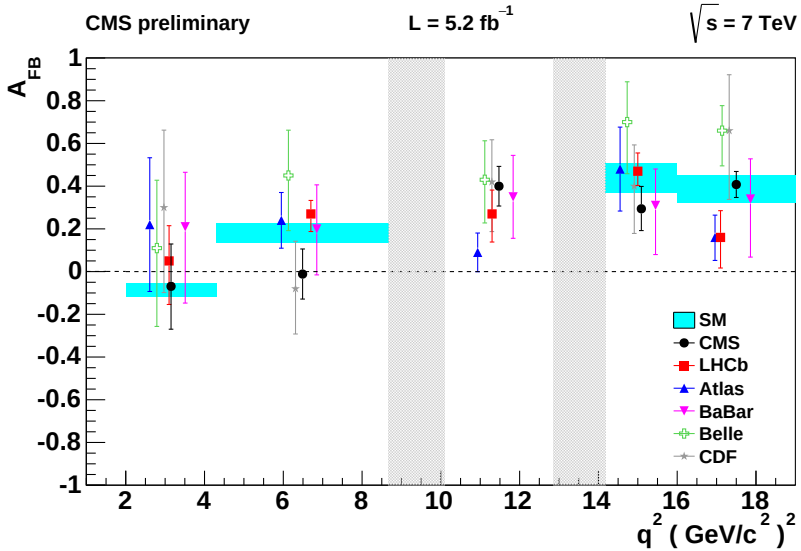
$B^0 \to K^{*0}\mu^+\mu^-$, $K^{*0} \to K^+\pi^-$ angular analysis

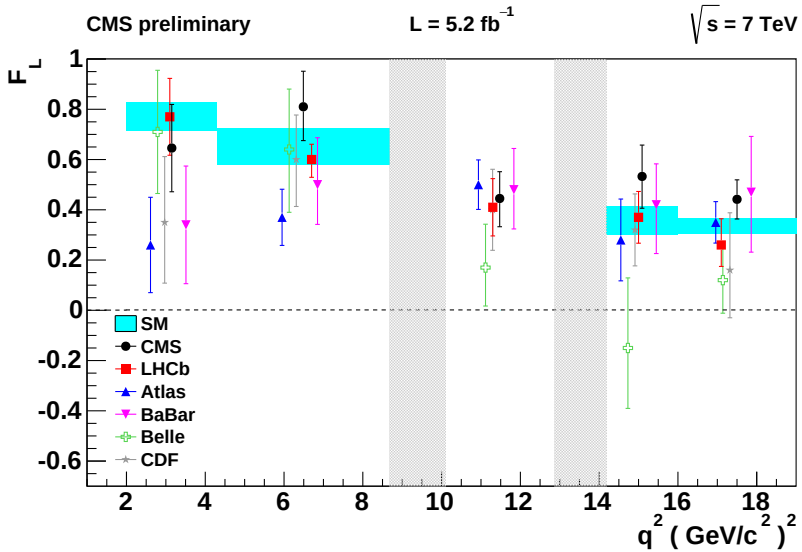
Comparison with other experiments

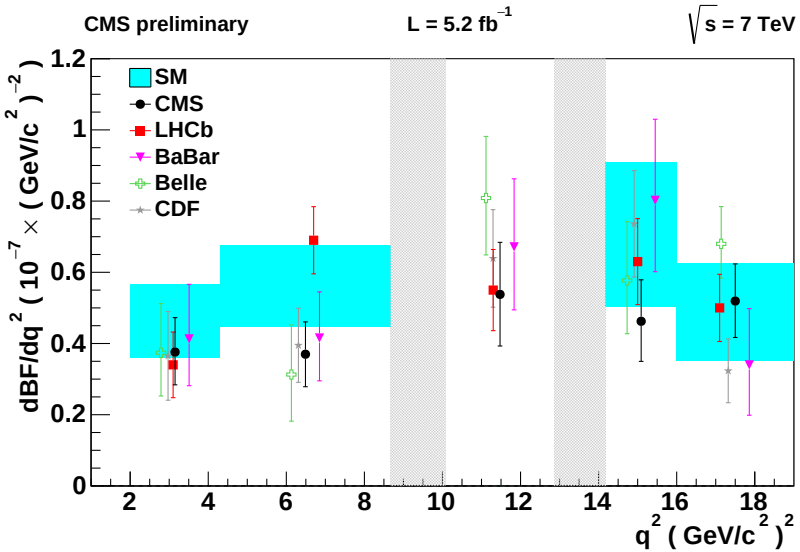
[PRL 103 (2009) 171801, PRD 86 (2012) 032012,

PRL 106 (2011) 161801, PRL 108 (2012) 081807,

JHEP 1308 (2013) 131, ATLAS-CONF-2013-038]







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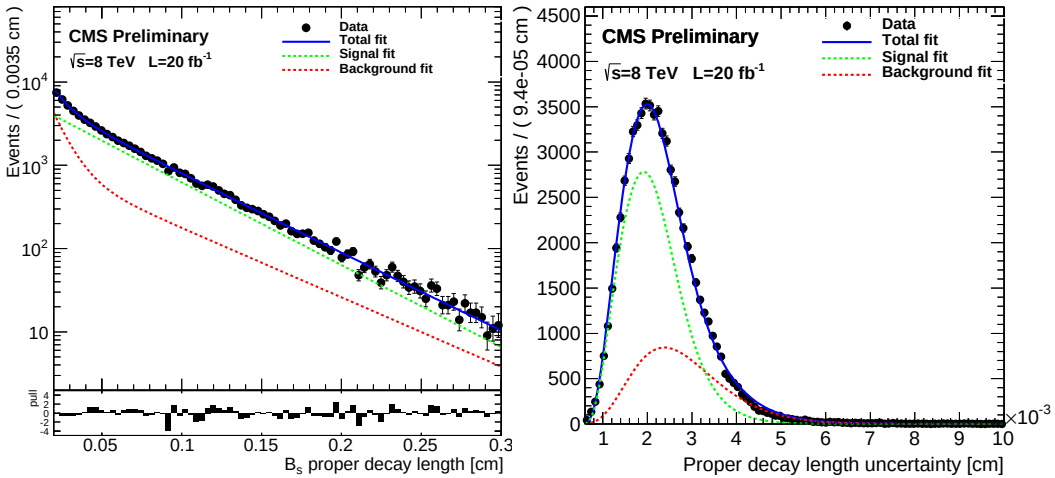
B_s^0 lifetime difference and CPV phase in $B_s^0 \to J/\psi\phi$

$$\mathcal{L} = N_S \cdot (\tilde{f}(\Theta, \alpha, ct) \otimes G(ct, \sigma_{ct}) \cdot \epsilon(\Theta)) \cdot P_S(m_{B_s}) \cdot P_S(\sigma_{ct}) \cdot P_S(\zeta)) +$$
$$N_{BG} \cdot P_{BG}(\cos\theta_T, \phi_T) \cdot P_{BG}(\cos\psi_T) \cdot$$
$$P_{BG}(ct) \cdot P_{BG}(m_{B_s}) \cdot P_{BG}(\sigma_{ct}) \cdot P_{BG}(\zeta)$$

	muons	electrons
ϵ_{tag}	$(4.55 \pm 0.03 \pm 0.08)\%$	$(3.26 \pm 0.02 \pm 0.01)\%$
ω	$(30.7 \pm 0.4 \pm 0.7)\%$	$(34.8 \pm 0.3 \pm 1.0)\%$



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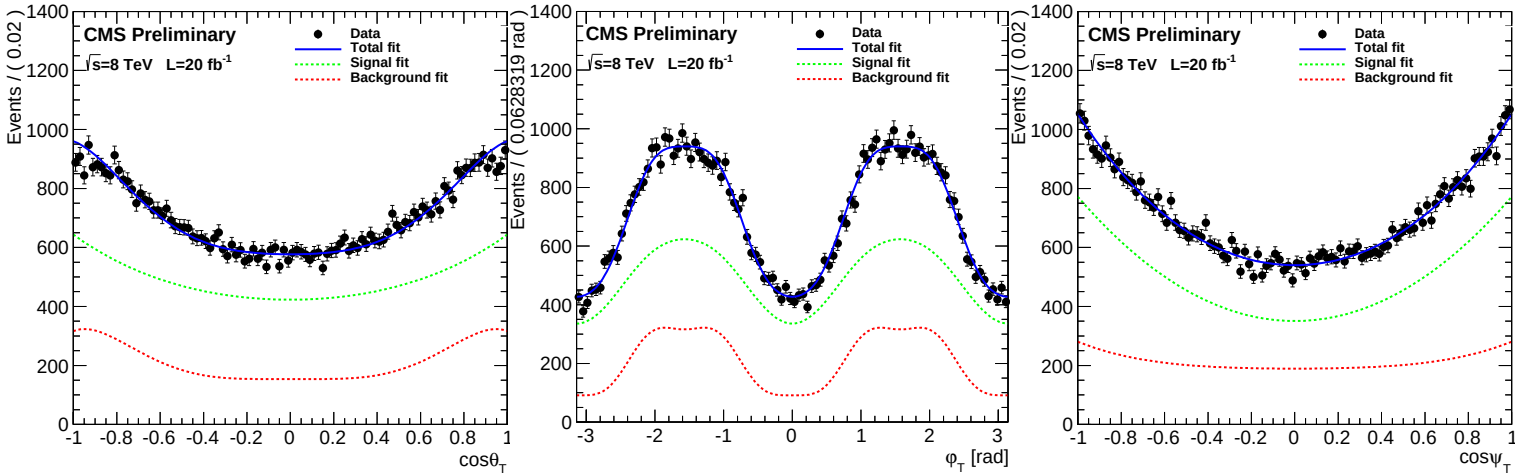
B_s^0 lifetime difference and CPV phase in $B_s^0 \to J/\psi\phi$

$\lvert A_0 \rvert^2$	$0.511 \pm 0.006 \pm 0.012$
$\lvert A_S \rvert^2$	$0.015 \pm 0.016 \pm 0.022$
$\lvert A_\perp \rvert^2$	$0.242 \pm 0.008 \pm 0.012$
$\delta_\parallel$[rad]	$3.48 \pm 0.09 \pm 0.68$
δ_S[rad]	$0.34 \pm 0.24 \pm 1.12$
$\delta_S\perp$[rad]	$2.73 \pm 0.36 \pm 0.66$
$c\tau[\mu$m]	$447.3 \pm 3.0 \pm 3.5$



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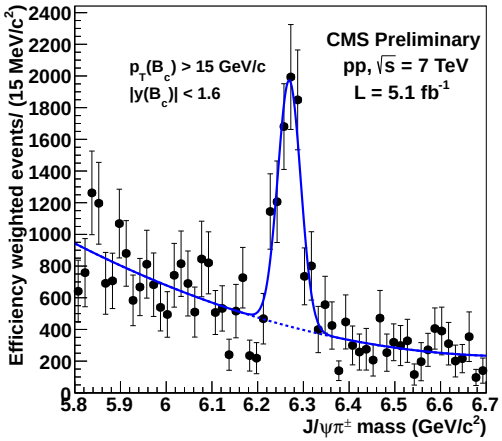
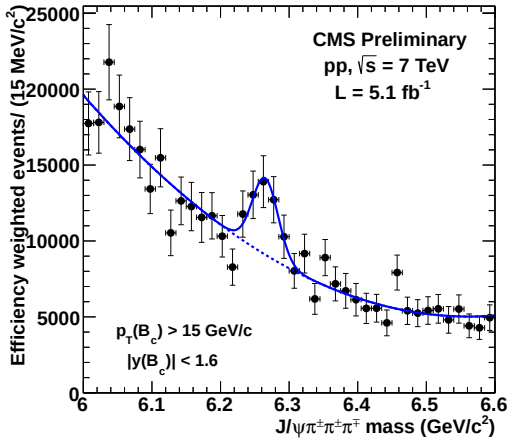
$B_c^{\pm} \to J/\psi\pi^{\pm}(\pi^+\pi^-)$: production and decay

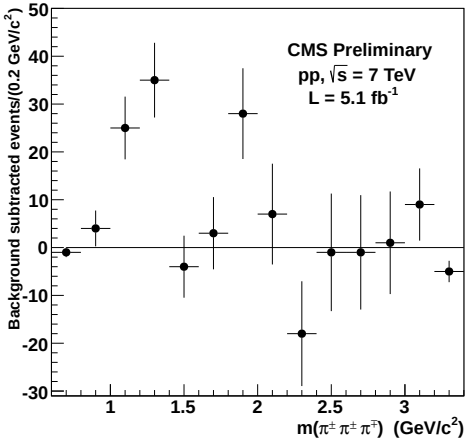
Efficiency corrected yield

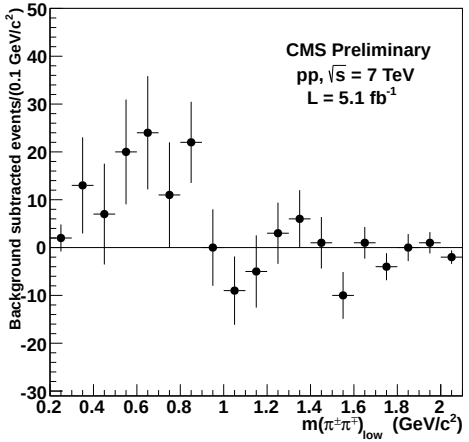
$\tau_{B_c} = 0.452 \pm 0.032$ ps

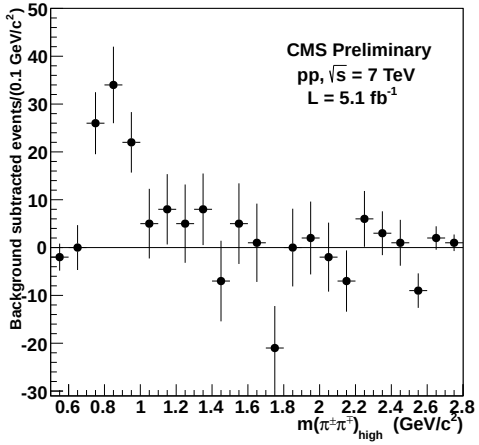




$\pi^{\pm}\pi^+\pi^-(a_1(1260)?)$, $\pi^+\pi^-(\rho_0(770)?)$ mass projections







Events simulated with BCVEGPY interfaced with PYTHIA

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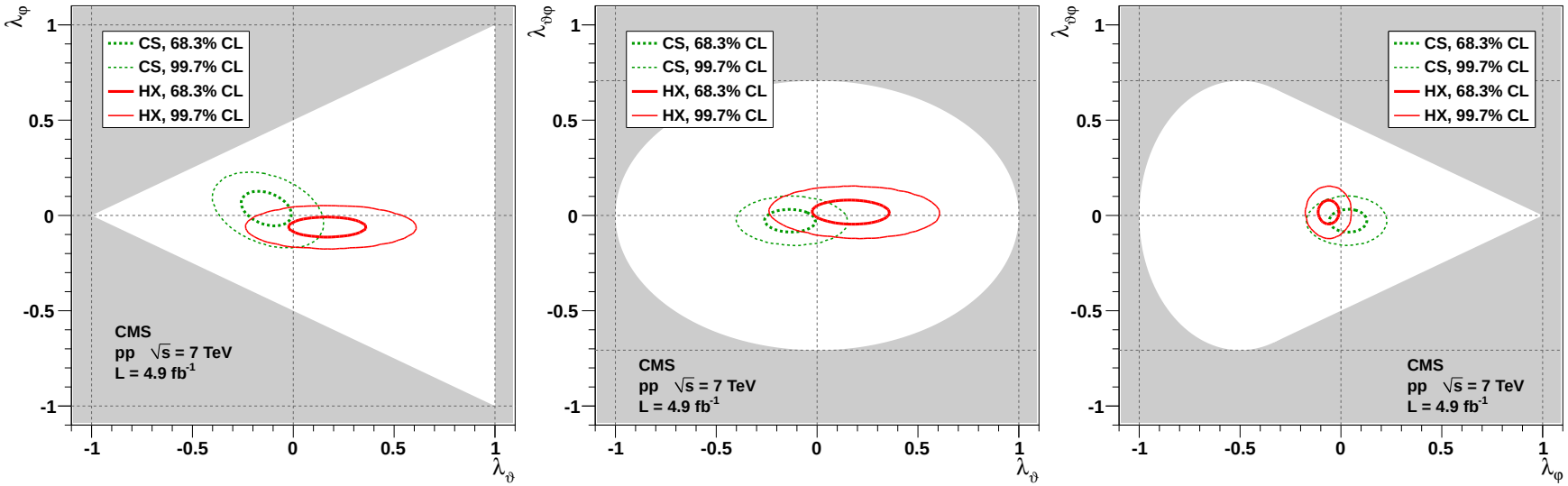
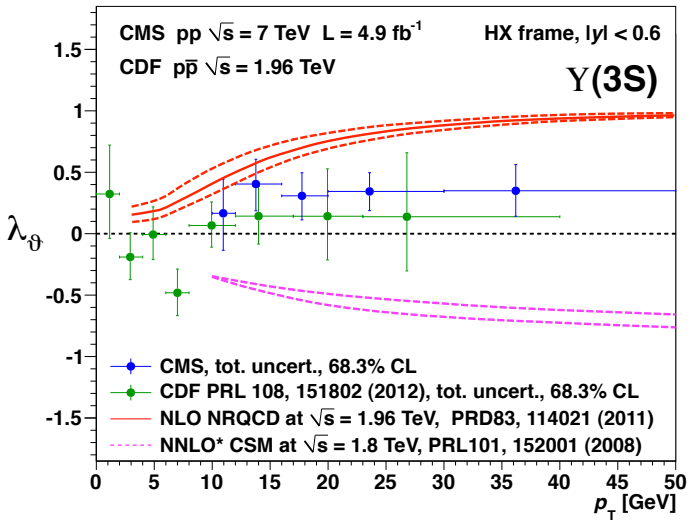
$\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ polarization



- $|y| < 0.6$
- $30\ \text{GeV} < p_T < 50\ \text{GeV}$



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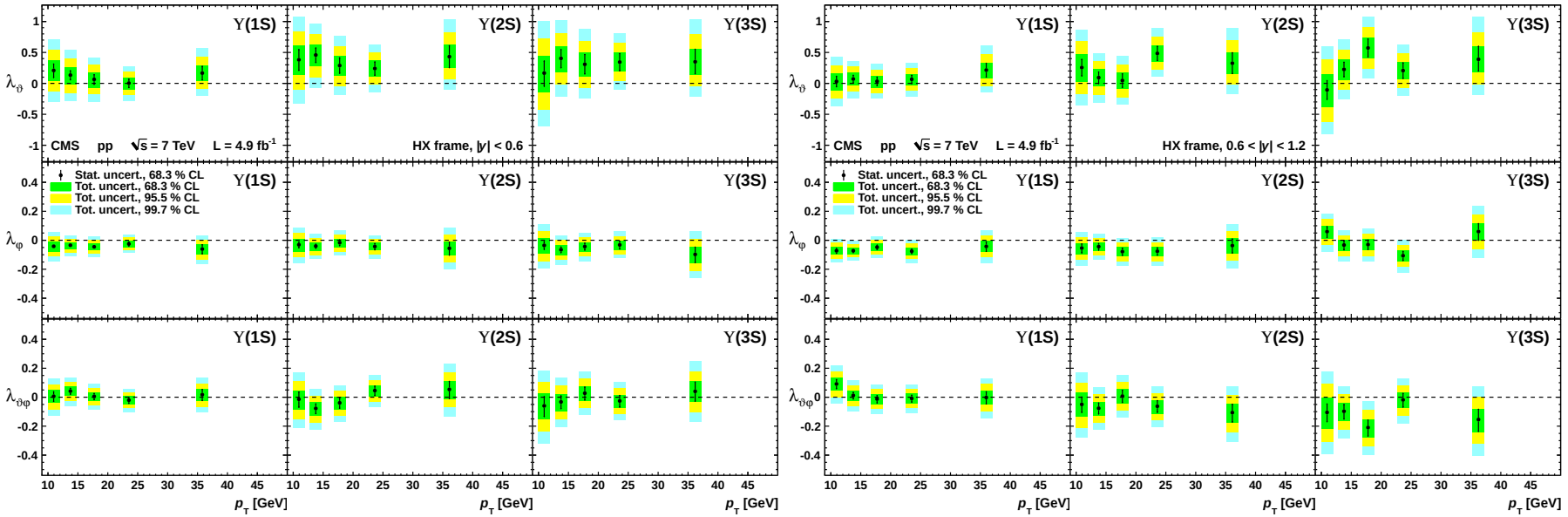
$\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ polarization

HX frame



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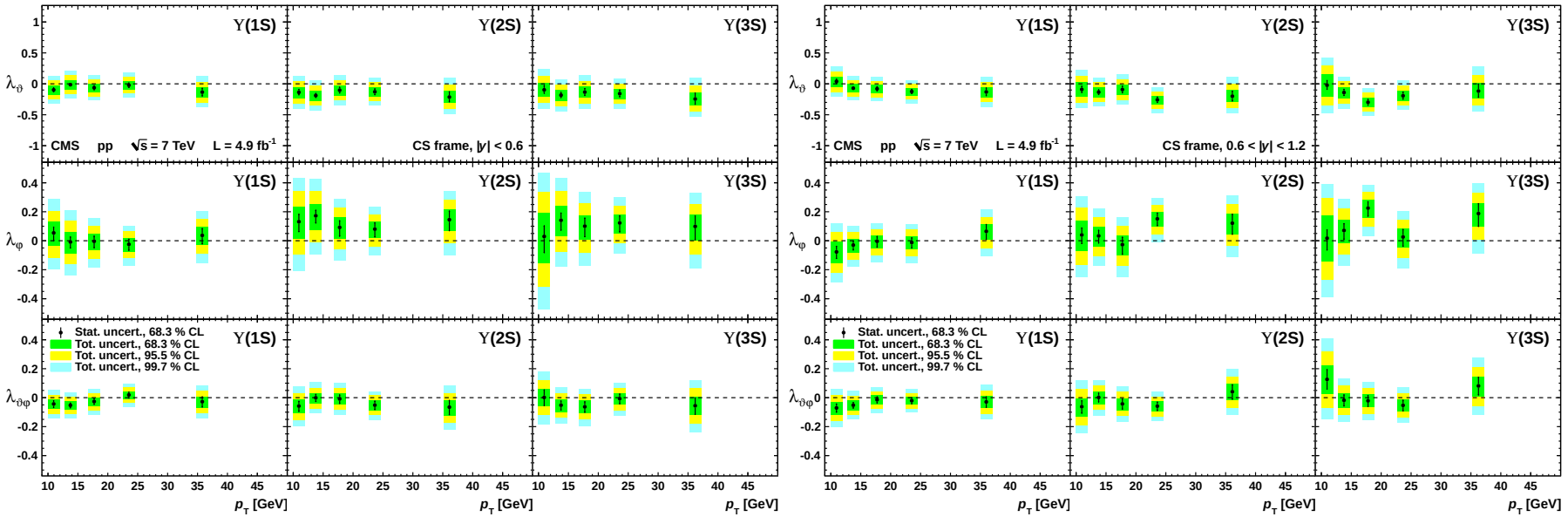
$\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ polarization

CS frame



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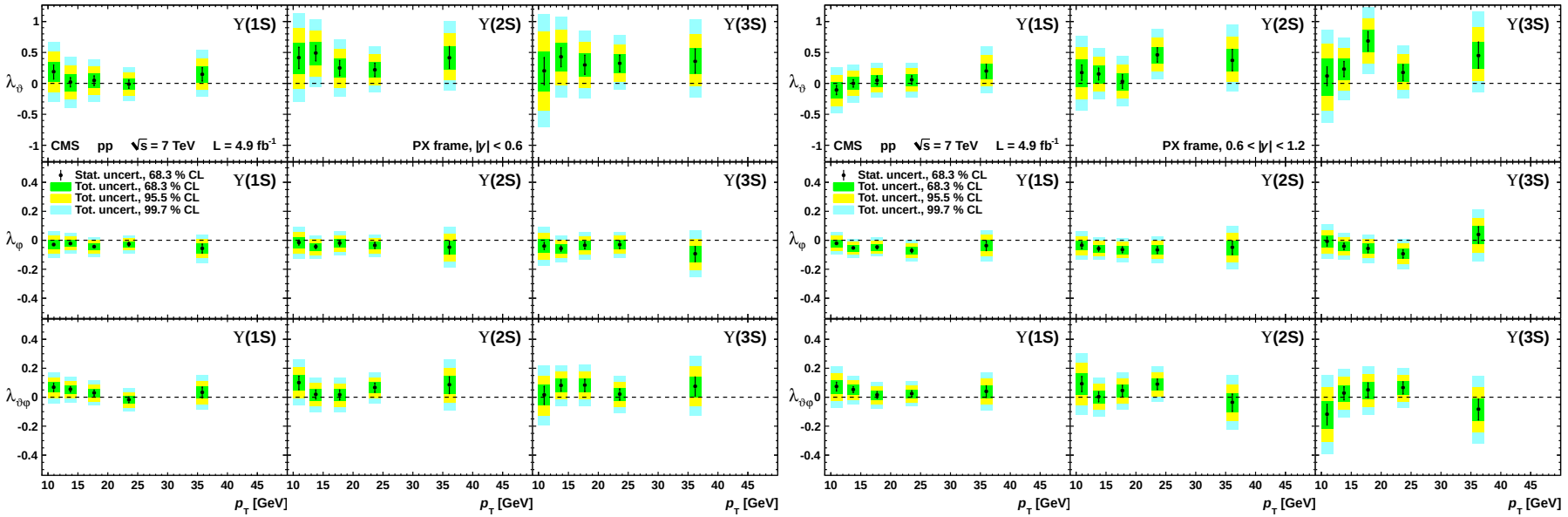
$\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ polarization

PX frame



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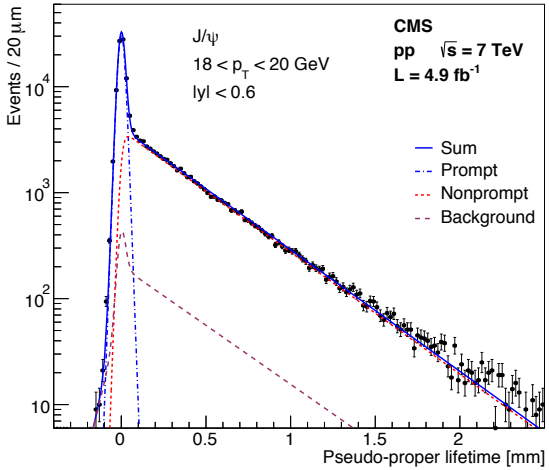
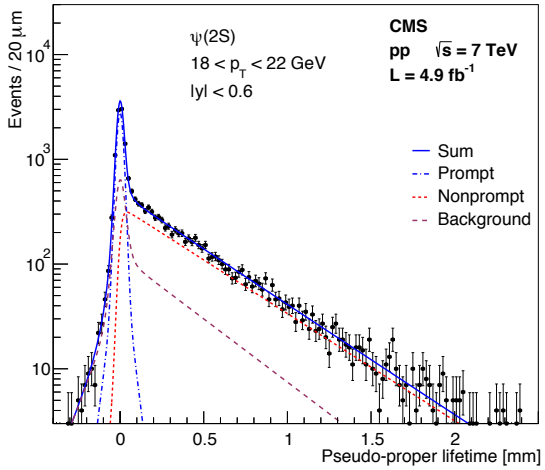
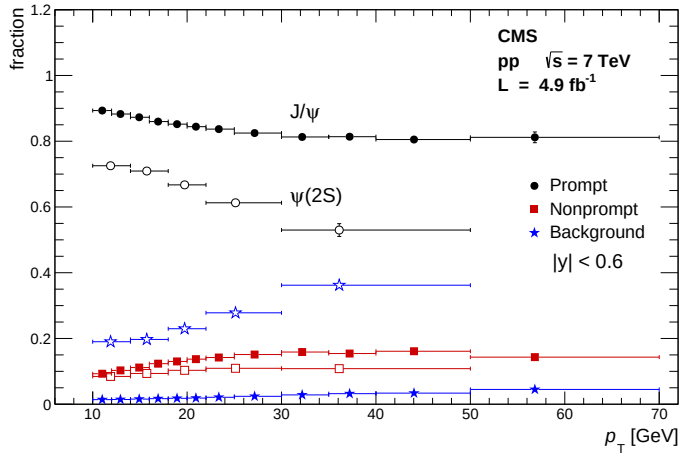
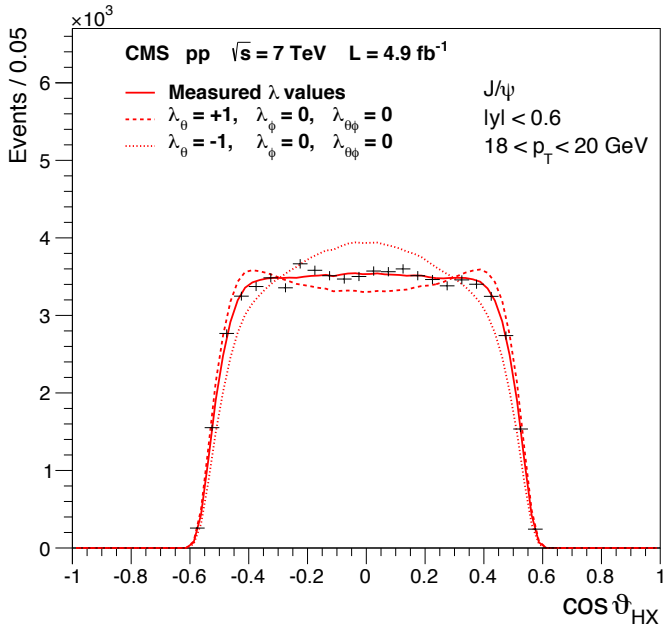
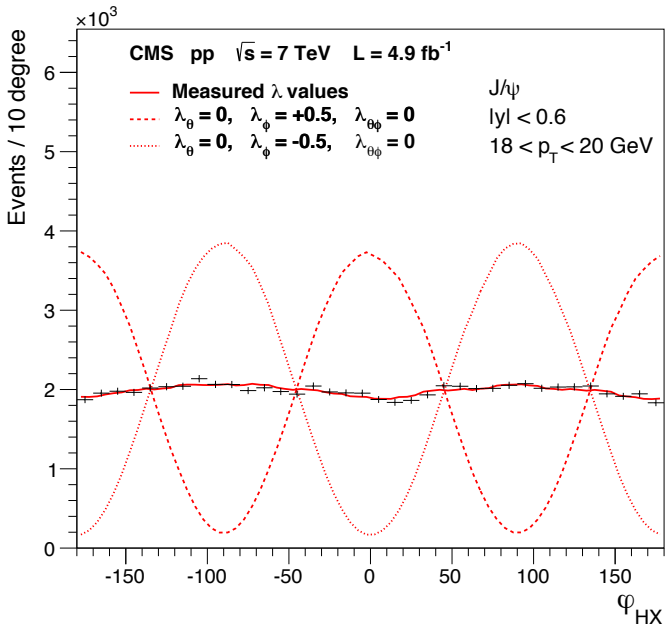
Prompt J/ψ and $\psi(2S)$ polarization











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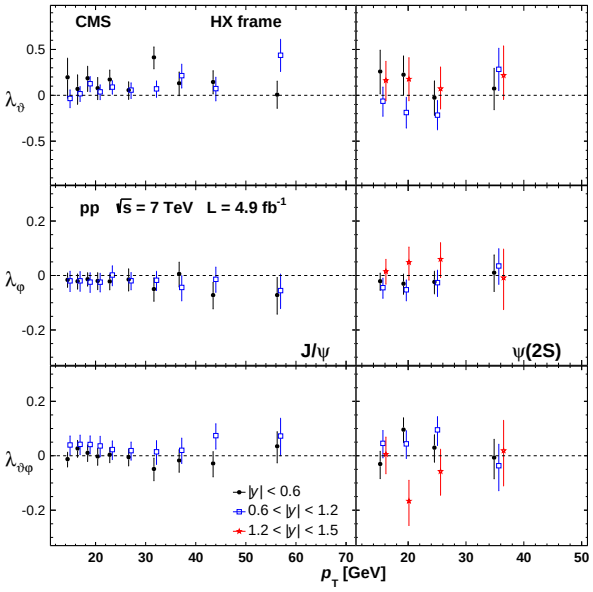
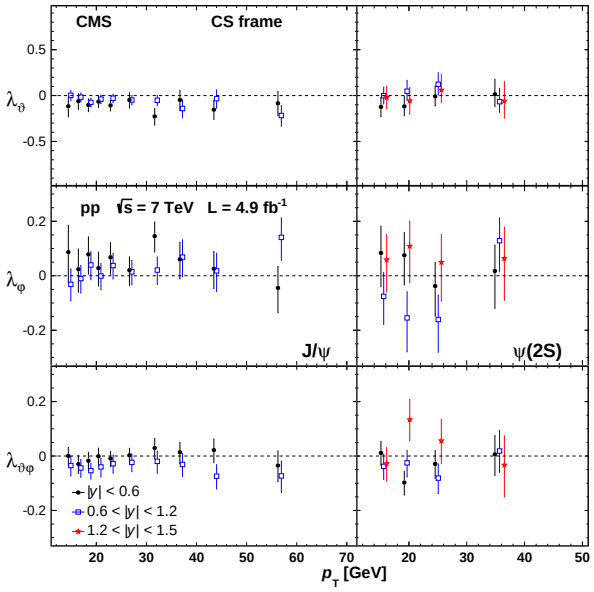
Prompt J/ψ and $\psi(2S)$ polarization

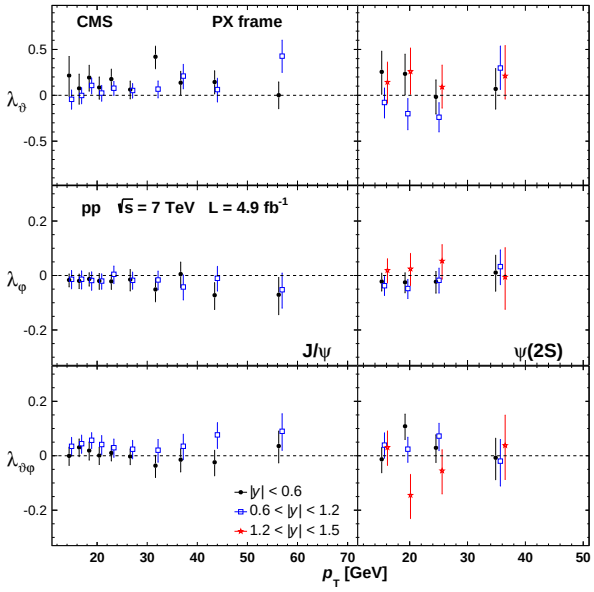
HX frame



CS frame



PX frame



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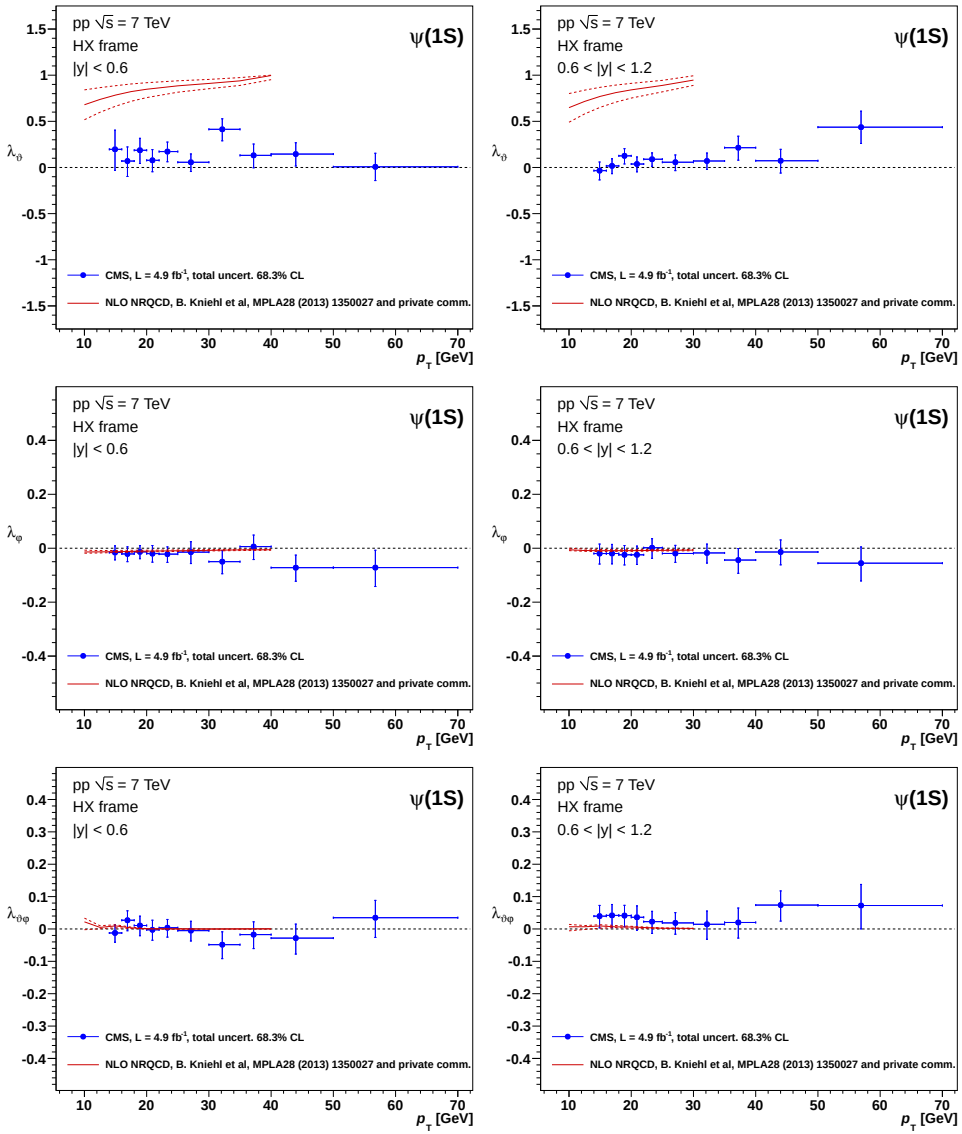
Prompt J/ψ and $\psi(2S)$ polarization

HX frame



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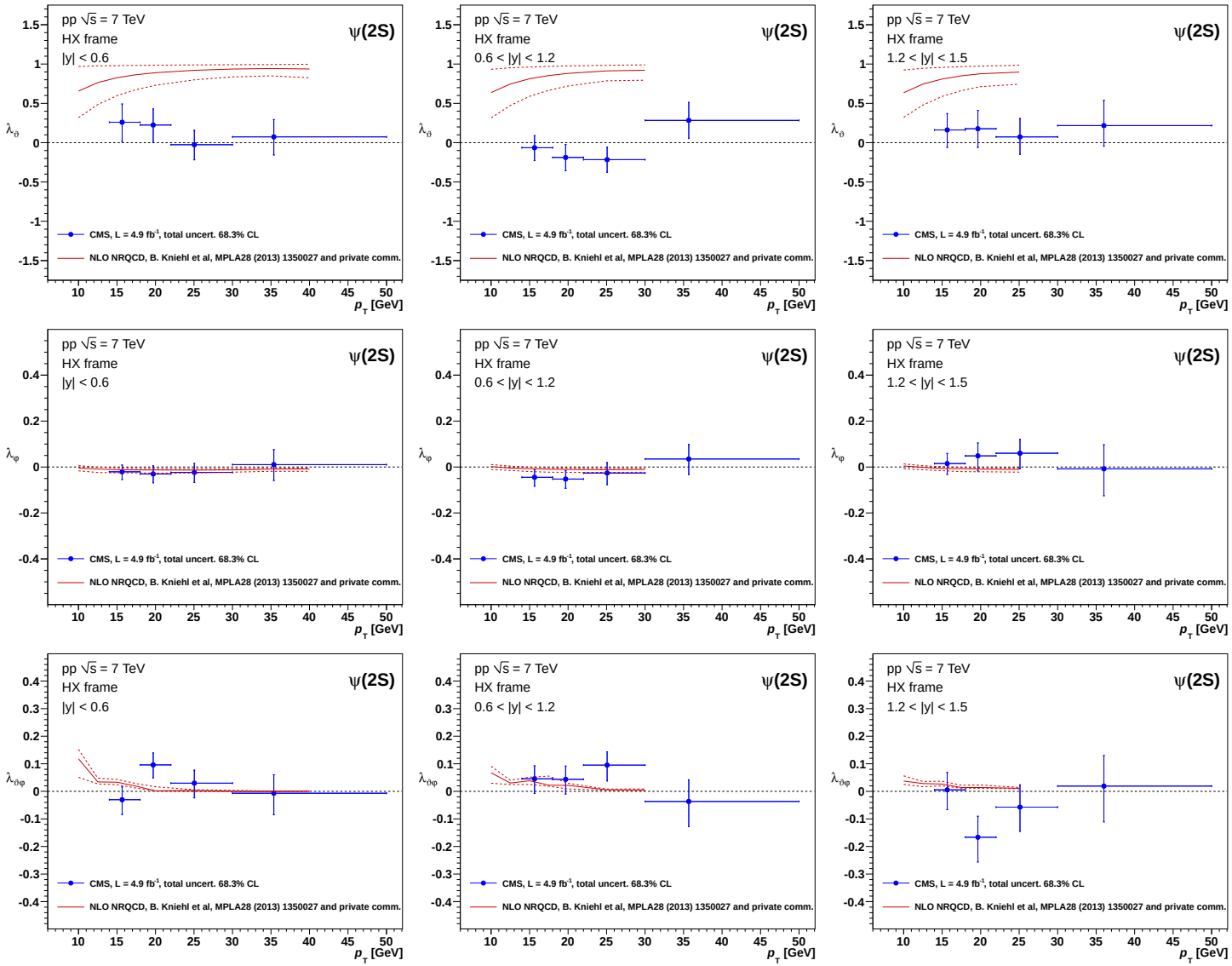
Prompt J/ψ and $\psi(2S)$ polarization

HX frame



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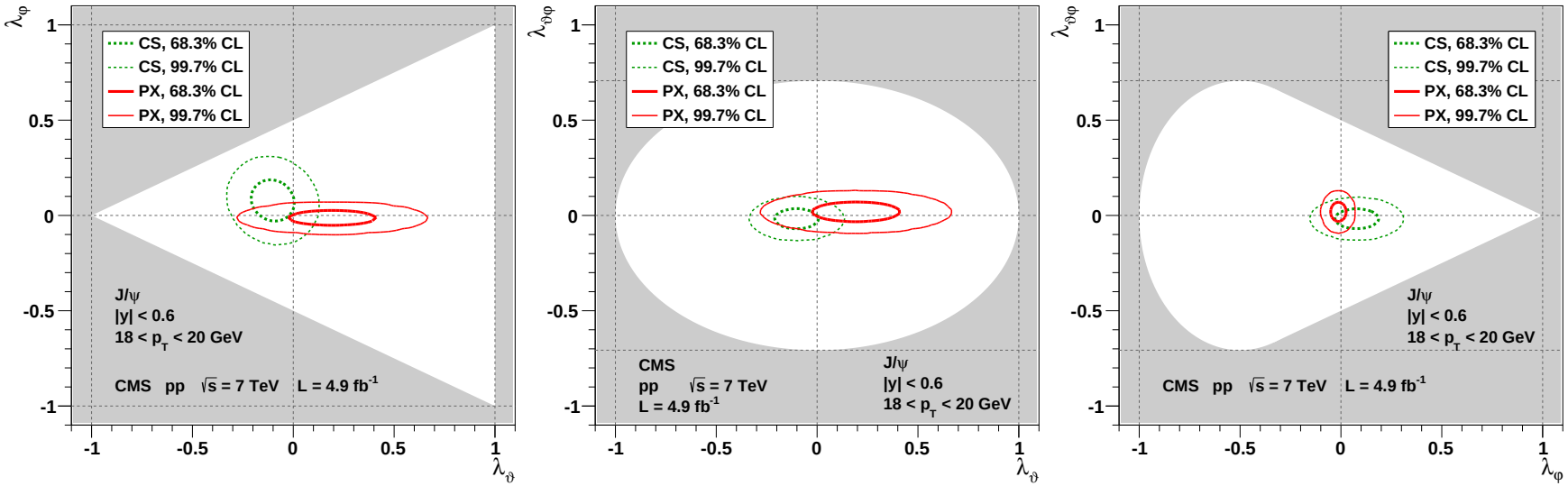
Prompt J/ψ and $\psi(2S)$ polarization



- $|y| < 0.6$
- 18 GeV $< p_T <$ 20 GeV

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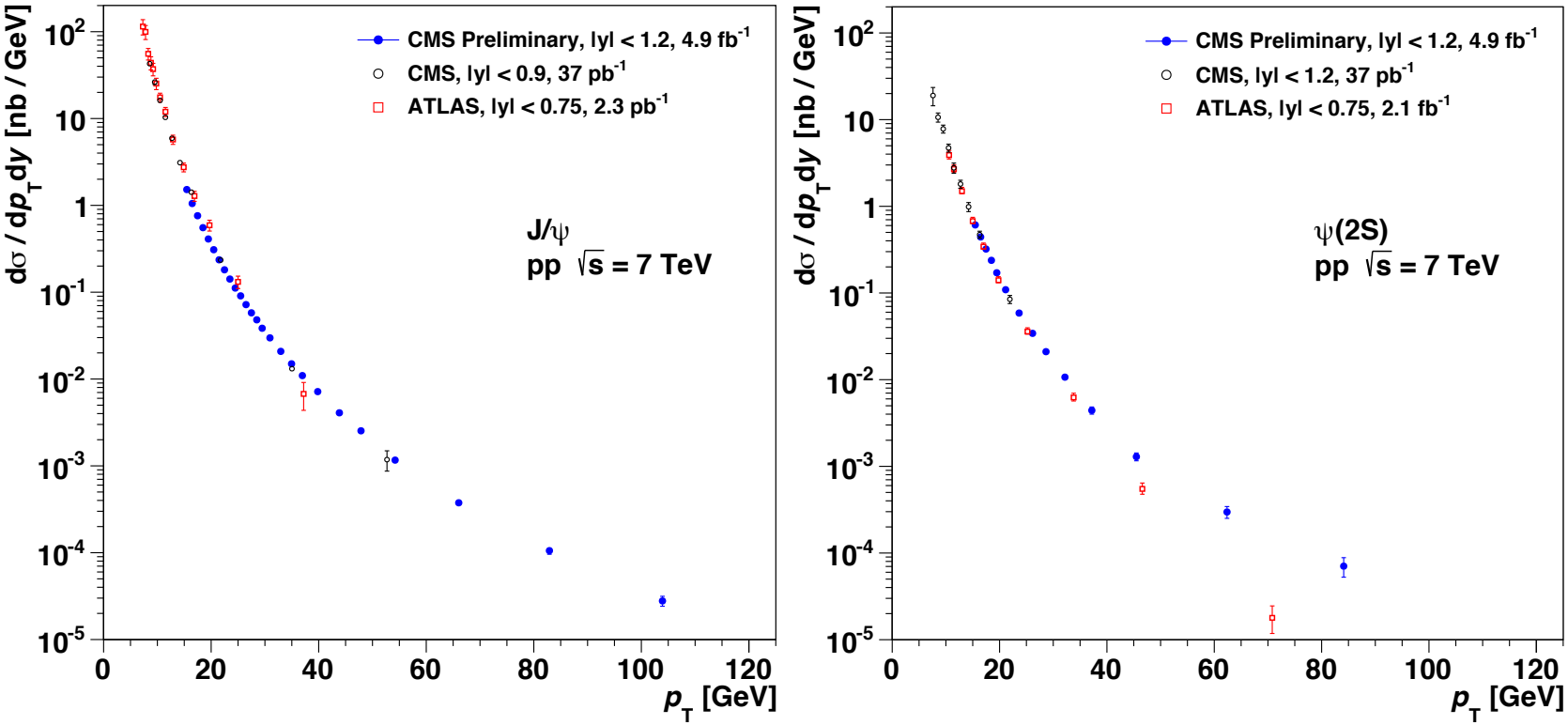
Prompt J/ψ , $\psi(2S)$ production

Comparison with ATLAS [NPB 850 (2011) 98], [ATLAS-CONF-2013-094] and old CMS [JHEP 02 (2012) 011] results



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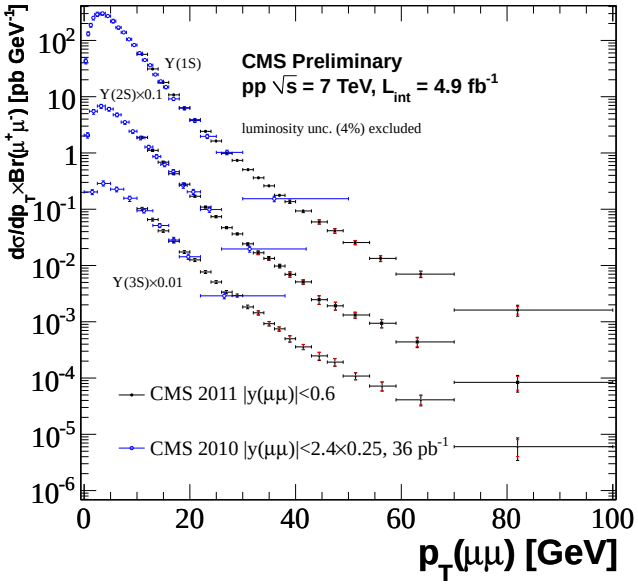
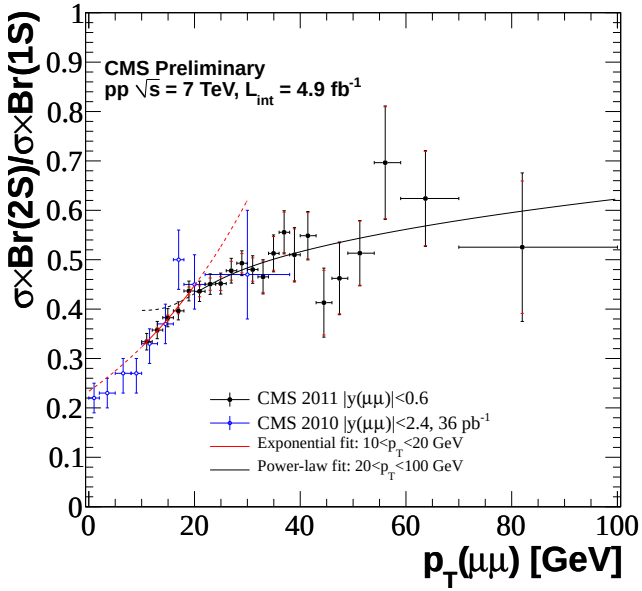
$\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ production

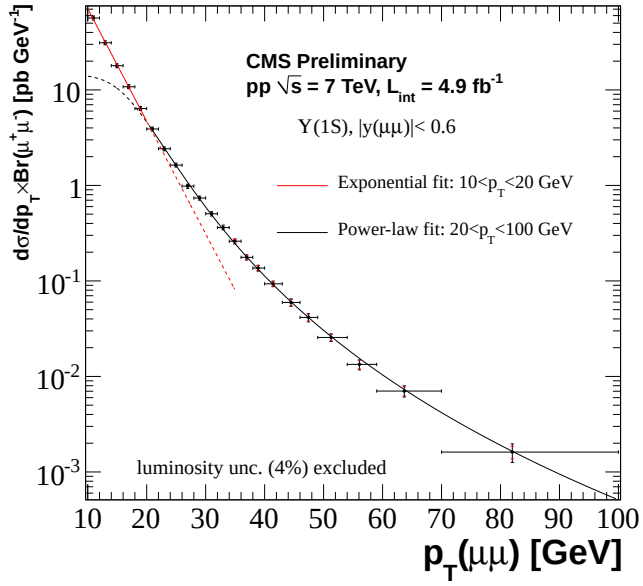
Bottomonium cross sections: acceptance computed according to measured polarization

Cross section fit ($\sqrt{s} = 7$ TeV) CMS-PAS-BPH-12-006

- exponential for 10 GeV $< p_T <$ 20 GeV
- $\frac{A}{C+\left(\frac{p_T}{p_0}\right)^{\alpha}}$ for $p_T >$ 20 GeV







$\Upsilon(n\mathrm{S})$ cross section integrated over $|y_\Upsilon| < 0.6$

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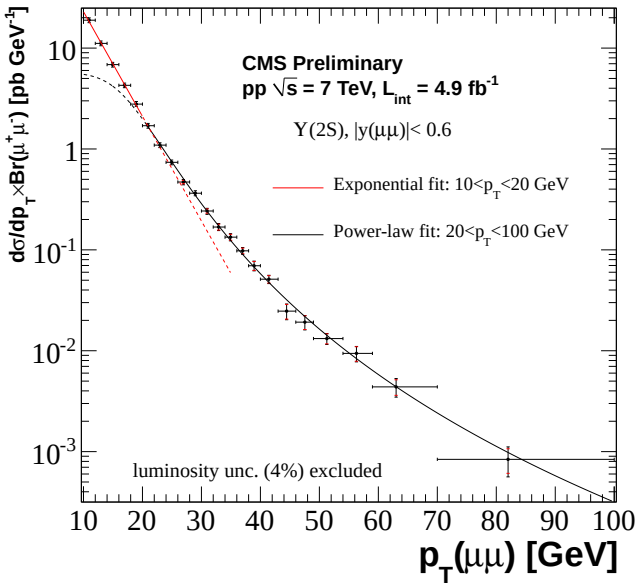
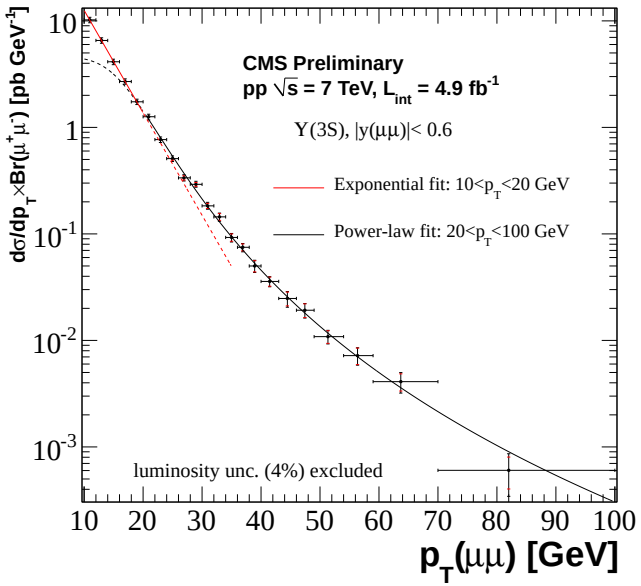
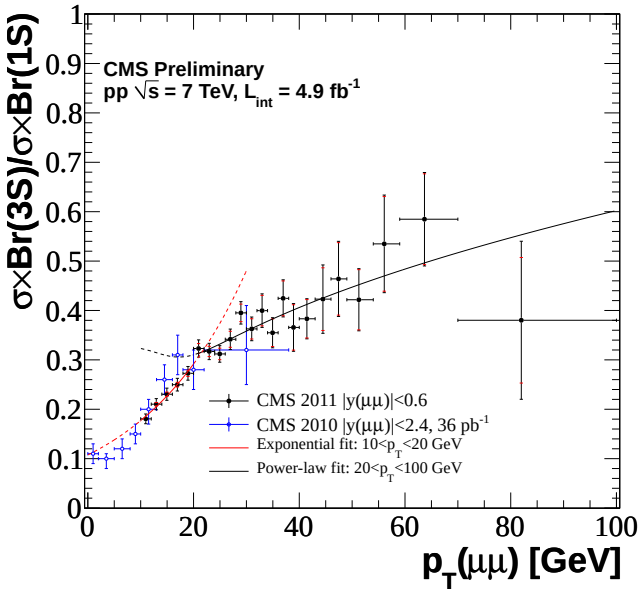
$\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ production

$$|\eta_\mu| < 1.2 : p_{T\mu} > 4.5 \text{ GeV}$$
$$1.2 < |\eta_\mu| < 1.4 : p_{T\mu} > 3.5 \text{ GeV}$$
$$1.4 < |\eta_\mu| < 1.6 : p_{T\mu} > 3.0 \text{ GeV}$$
$\Upsilon(n\text{S})$ cross section integrated over $|y_\Upsilon| < 0.6$







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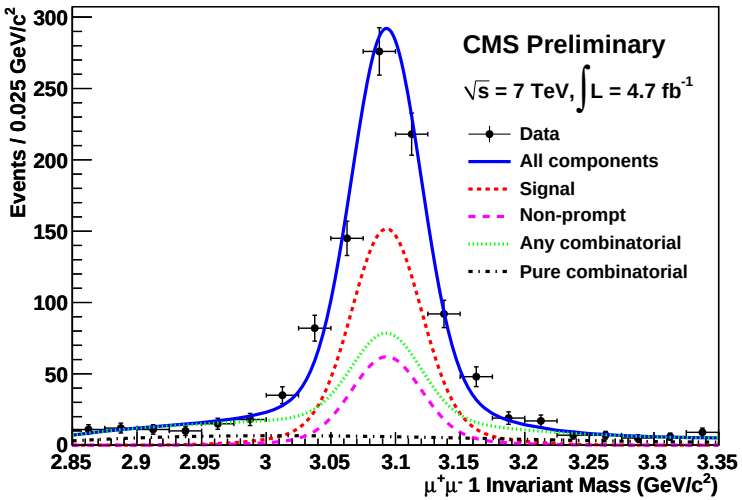
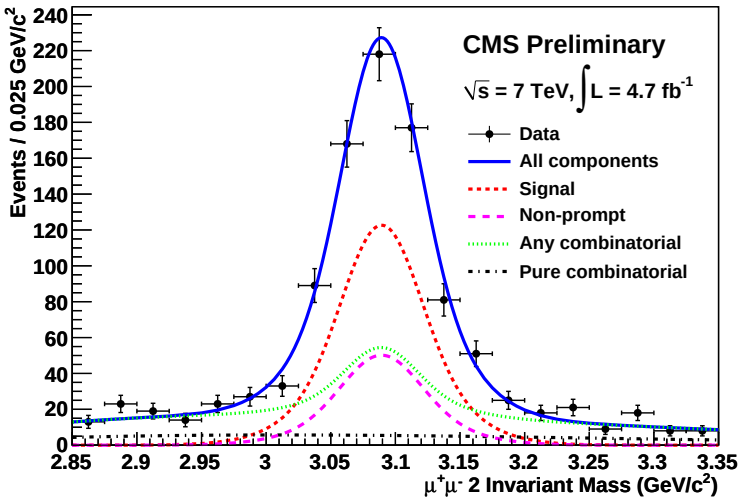
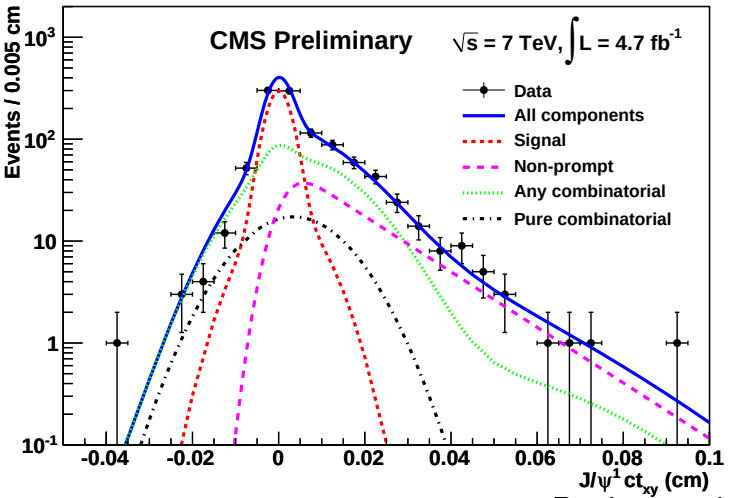
Double J/ψ production

J/ψ invariant masses





J/ψ decay length



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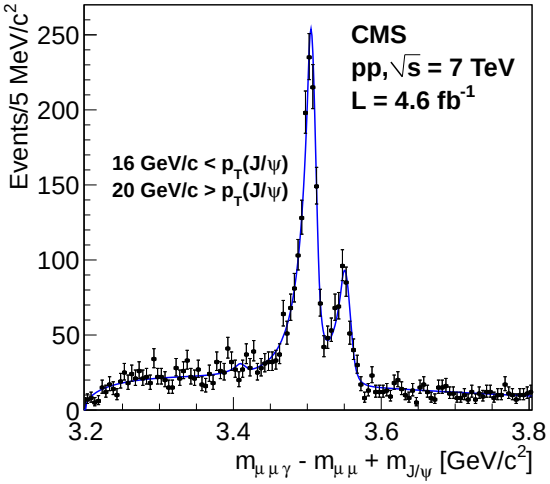
χ_{c2} vs χ_{c1} relative production

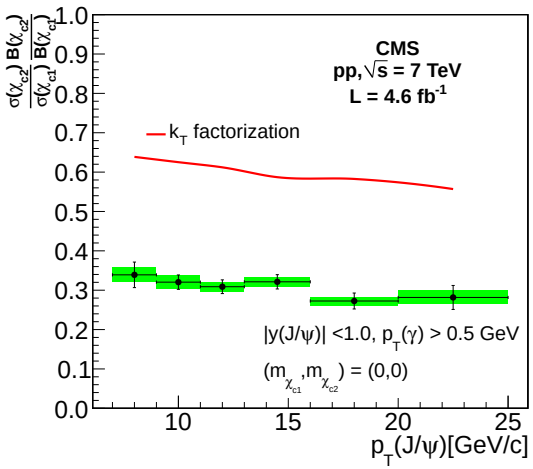
P-wave charmonia:

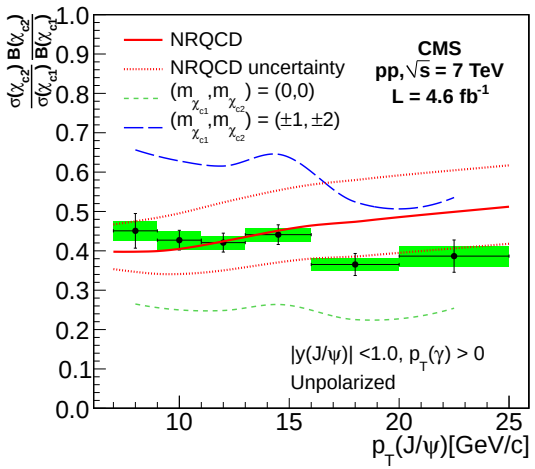
- feed-down contribution to J/ψ production
- relative production sensitive to singlet/octet production mechanisms
- reconstructed in the channel $\chi_c \to J/\psi\gamma$ followed by the photon conversion



$\sigma(\chi_{c2})/\sigma(\chi_{c1})$ ($\sqrt{s} = 7$ TeV) EPJ C (2012) 72:2251

Measured vs. $p_{TJ/\psi}$ for $|y_{J/\psi}| < 1.0$





- Prompt J/ψ selected by flight distance
- Different polarization scenarios assumed

- k_T factorization: predicts trend, factor 2 higher
- NRQCD: compatible

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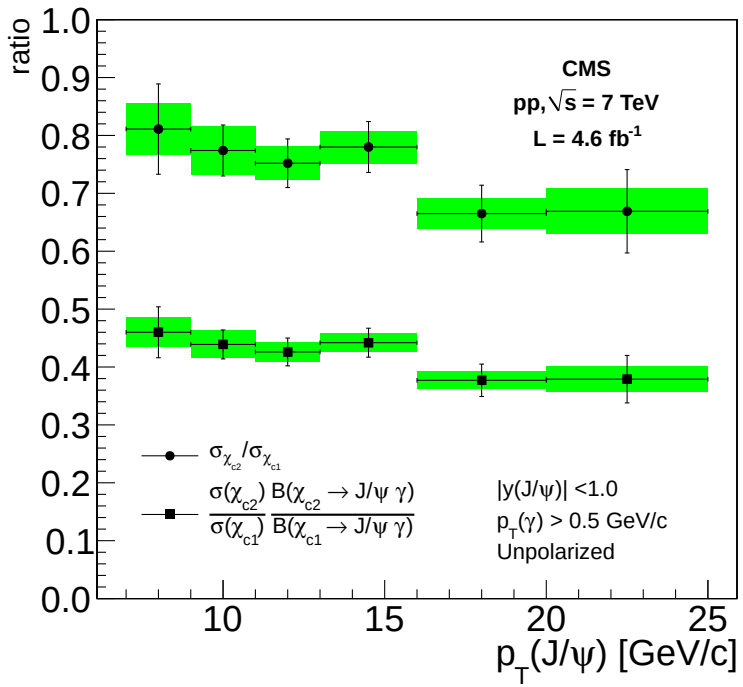
χ_{c2} vs χ_{c1} relative production

"Pure" cross-sections (divided by B.R.), assuming unpolarized production



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$X(3872)$ production

- $X(3872)$ first exotic charmonium seen
- Reconstructed at CMS in the channel $X(3872) \to J/\psi\pi^+\pi^-$
- Cross section measured as ratio to $\psi(2S) \to J/\psi\pi^+\pi^-$
- Prompt-nonprompt components separated by flight distance

Mass fit ($\sqrt{s} = 7$ TeV)

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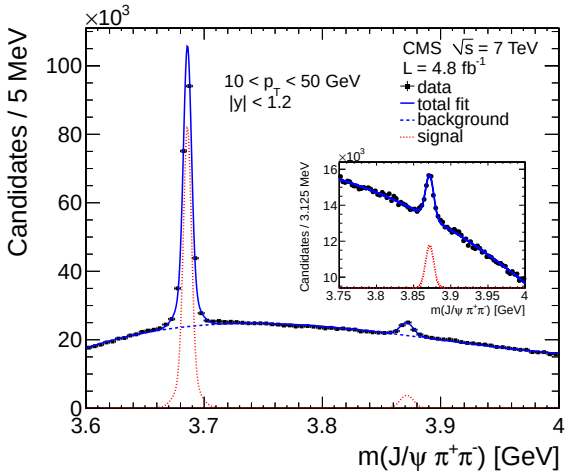
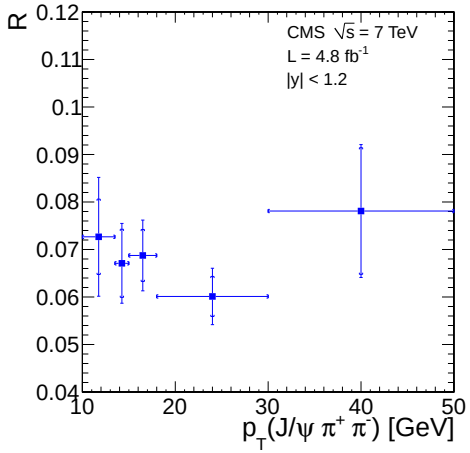
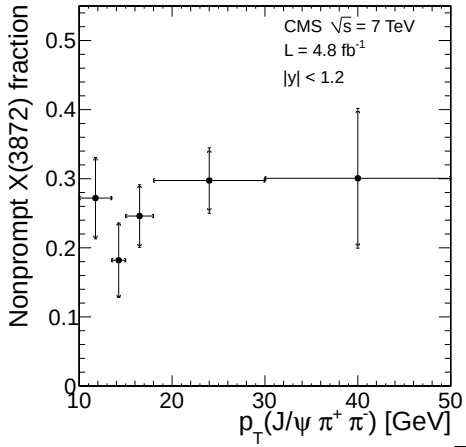
Unpolarized $J^{PC} = 1^{++}$ state assumed

$$R = \frac{\sigma(pp \to X(3872) + any) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to \psi(2S) + any) \times \mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)} = 0.0656 \pm 0.0029 \pm 0.0065$$







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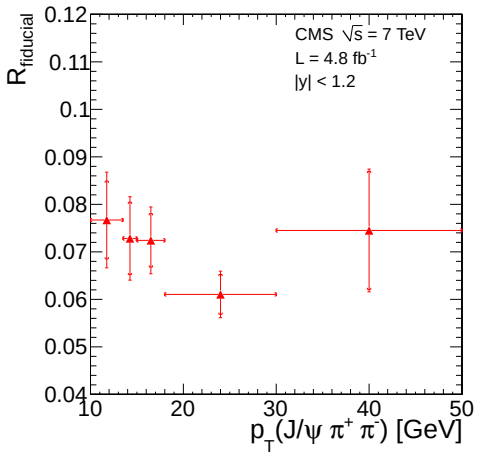
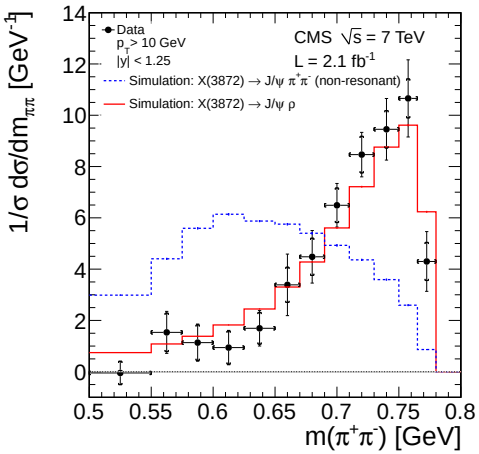
$X(3872)$ fiducial cross section

$$|\eta_\mu| < 1.2 : p_{T\mu} > 4.0 \text{ GeV}$$
$$1.2 < |\eta_\mu| < 2.4 : p_{T\mu} > 3.3 \text{ GeV}$$

Cross section integrated over
$$|y_{J/\psi}| < 1.25$$
$$p_{TJ/\psi} > (7 \div 10) \text{ GeV}$$
$$|y_X| < 1.2$$
$$(10.0 \div 13.5) \text{ GeV} < p_{TX} < 50.0 \text{ GeV}$$

$$R = \frac{\sigma(pp \to X(3872) + any) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to X(3872) + any) \times \mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)} = 0.0694 \pm 0.0029 \pm 0.0036$$





Dipion mass compatible with an intermediate ρ^0

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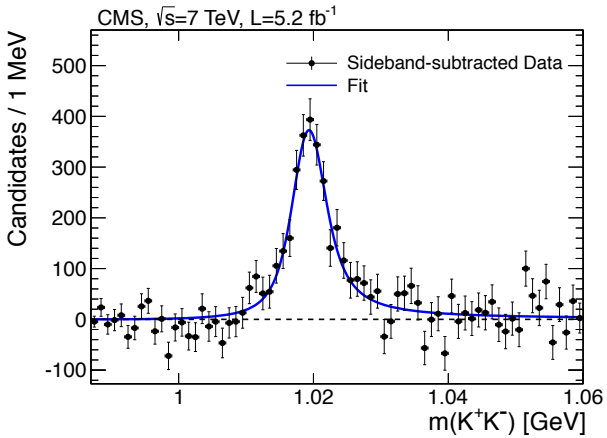
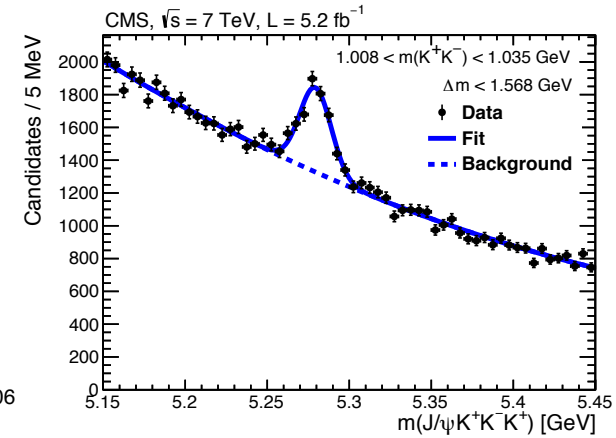
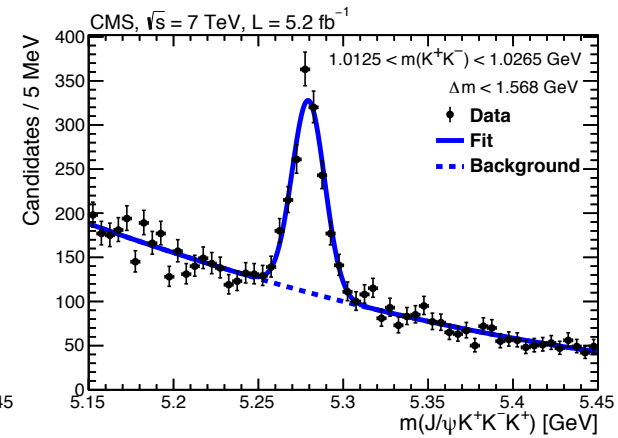
Peaks in $B^{\pm} \to J/\psi\phi K^{\pm}$

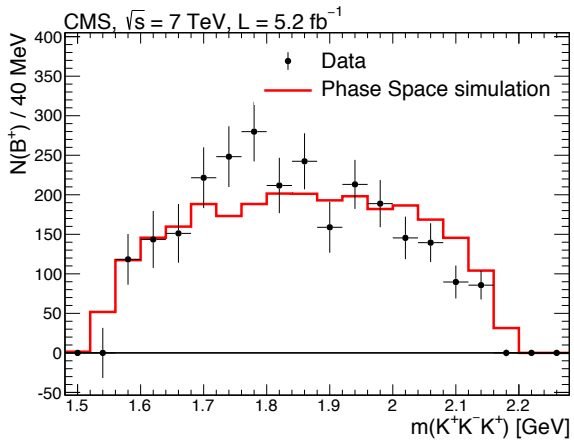
m_{ϕ} , m_{B^+} (loose and tight cuts):

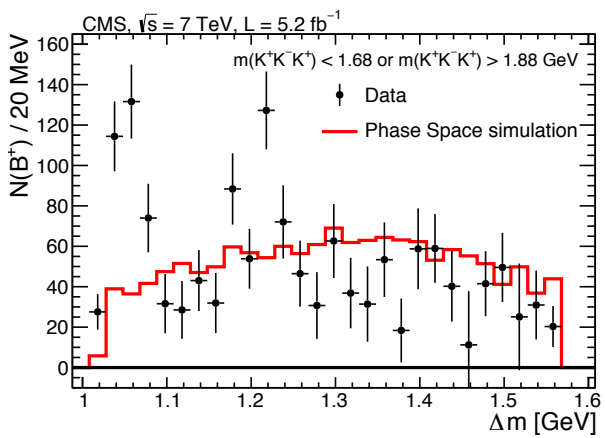


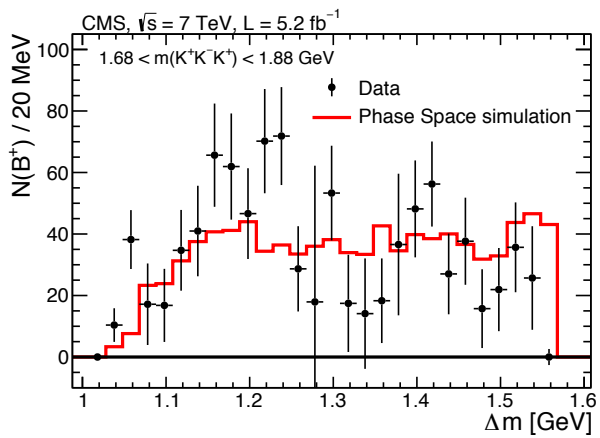




$m(K^+K^-K^+)$ spectrum:







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