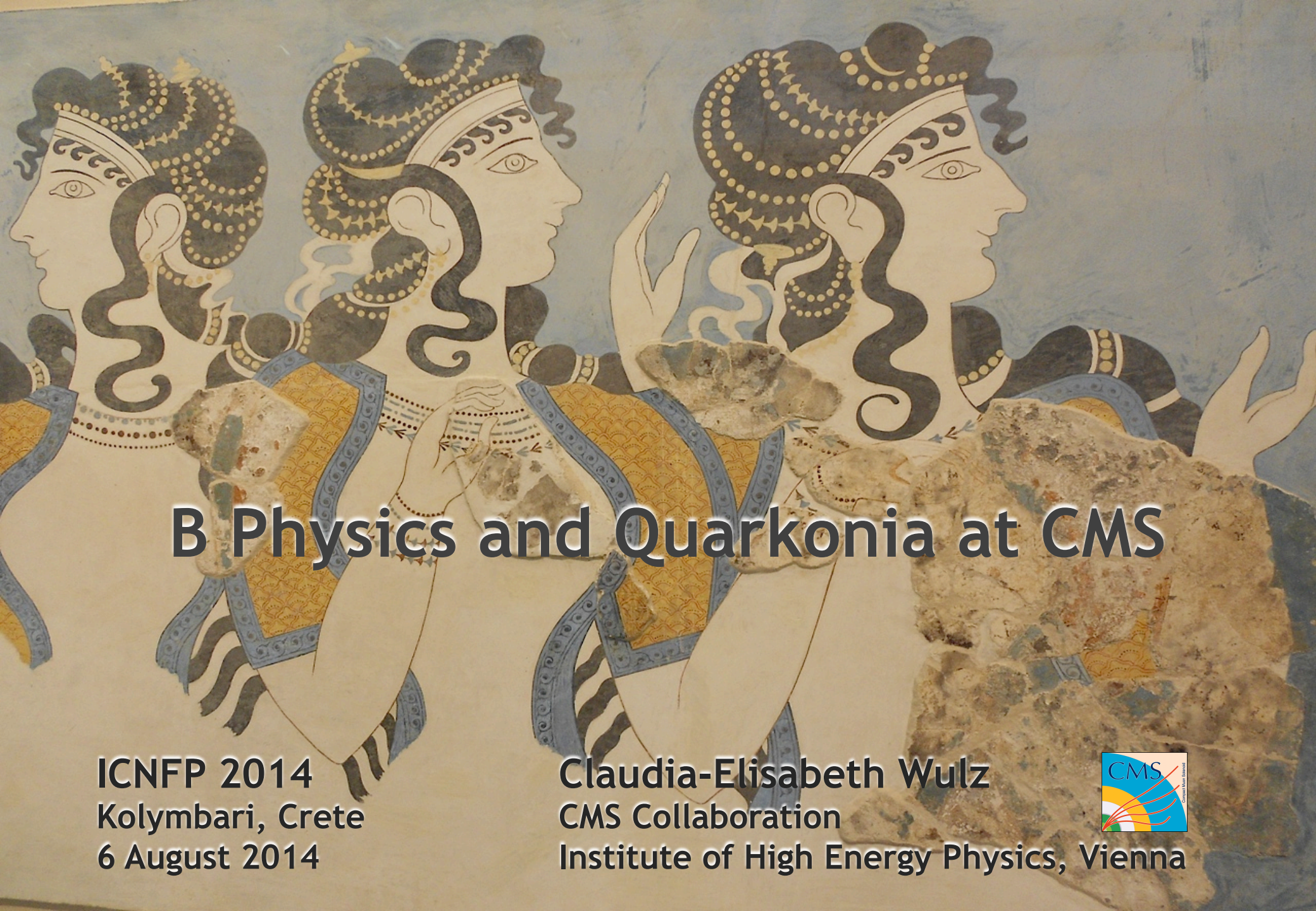


B Physics and Quarkonia at CMS

ICNFP 2014
Kolymbari, Crete
6 August 2014

Claudia-Elisabeth Wulz
CMS Collaboration
Institute of High Energy Physics, Vienna

Overview

Selected recent results:

- CP-violating phase ϕ_s and decay width difference $\Delta\Gamma_s$ of B_s with B_s -> J/ψ ϕ(1020)

  CMS PAS BPH-13-012

- Production cross sections
  - J/ψ and ψ(2S) prompt double-differential

  CMS PAS BPH-14-001

- Polarization
  - J/ψ, ψ(2S), Υ(1S), Υ(2S), Υ(3S)

  PLB 727 (2013) 381

  PRL 110 (2013) 081802

All CMS public B physics results:

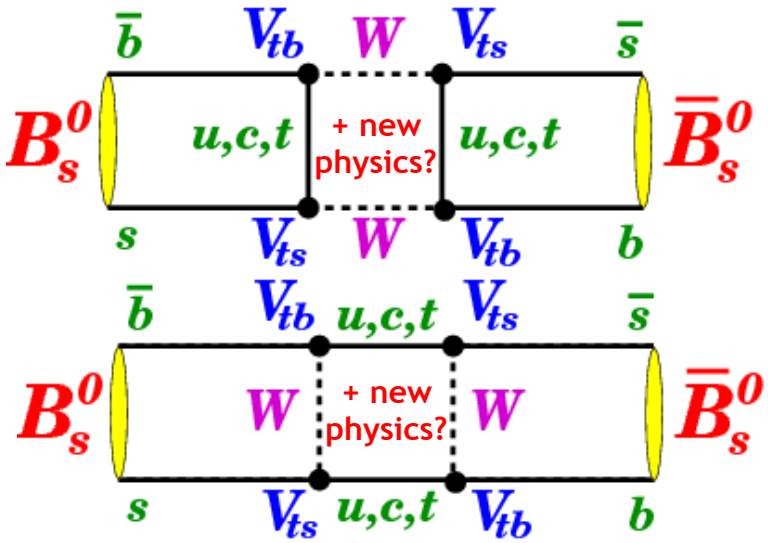
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

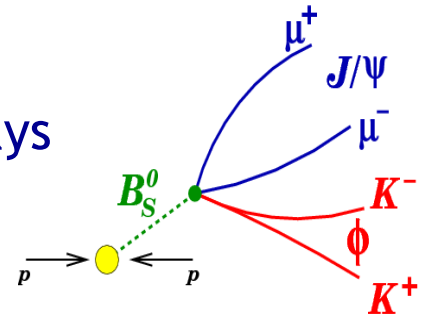
B_s -> $J/\psi(\mu^+\mu^-)\,\Phi(K^+K^-)$

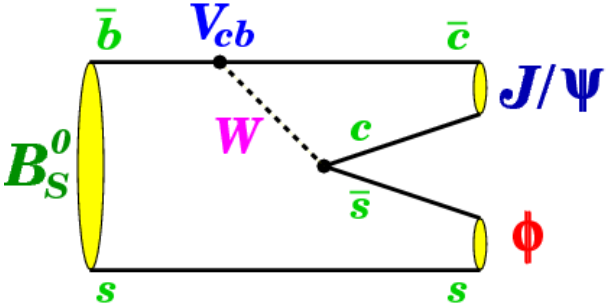
Decay channel: B_s -> $J/\psi(\mu^+\mu^-)\,\Phi(K^+K^-)$

B_s-$\bar{B}_s$ mixing -> time-dependent, flavour-tagged analysis

Data: $\sqrt{s}$ = 8 TeV, L_{int} = 20 fb^{-1}, 49000 reconstructed B_s decays





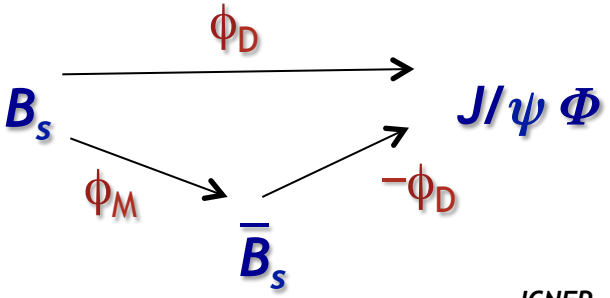


Weak phase from interference of direct decays and decays from mixing, and decay width difference of light and heavy B_s mass eigenstates:

$$\phi_s \approx -2\beta_s = -2\,\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$$

$$\phi_s\ (\mathrm{SM}) = -\,0.0363^{+0.0016}_{-0.0015}\ \mathrm{rad}$$

$$\Delta\Gamma_s\ (\mathrm{SM}) = (0.087 \pm 0.021)\ \mathrm{ps}$$



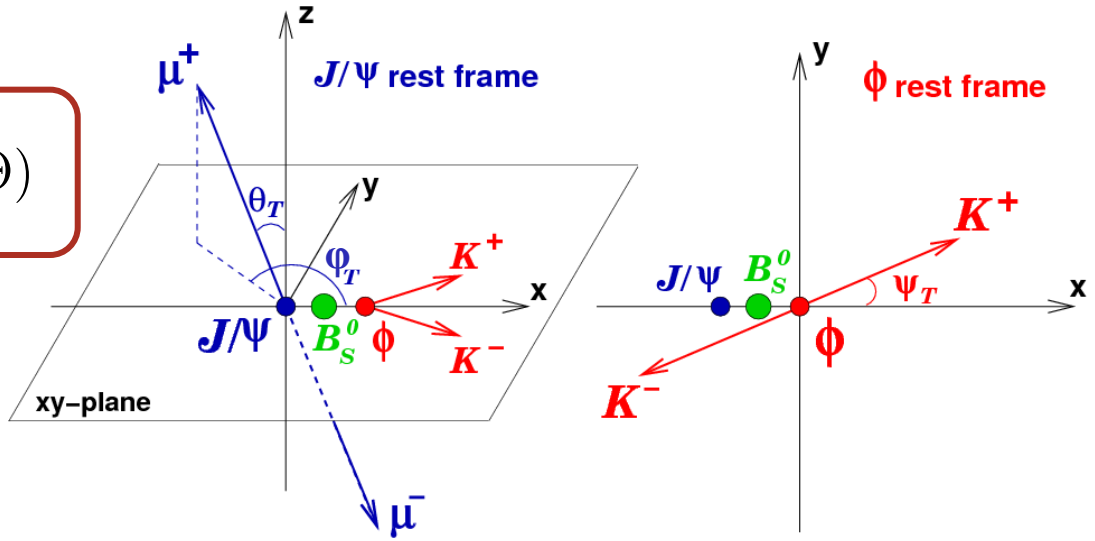
Angular analysis

Time-dependent, angular analysis to disentangle CP-odd and CP-even final states:

- Measure decay angles $\Theta(\theta_T,\varphi_T,\psi_T)$ and proper decay length *ct* of B_s

Signal model

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



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

α parameter set: $\Delta\Gamma_s$, ϕ_s, $c\tau$, $|A_0|^2$, $|A_{||}|^2$, $|A_T|^2$, $|A_S|^2$, $\delta_{||}$, δ_T, δ_{ST}

b_i and d_i depend on ϕ_s

PRD 87 (2013) 112010 - LHCb

Extended maximum likelihood fit with signal model used to extract parameters.

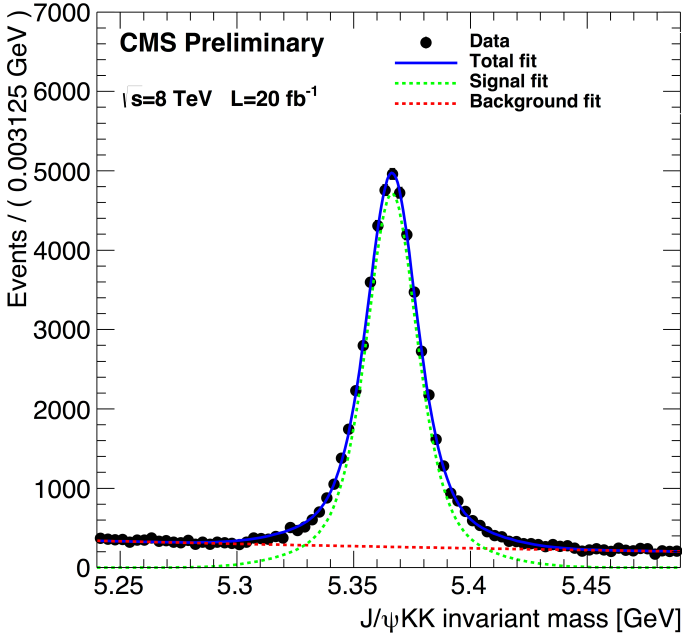
Event selection and B_s reconstruction

Trigger: displaced J/ψ, optimized for b hadrons

- 2 muons with $p_T(\mu) > 4$ GeV, $p_T(\mu\mu) > 6.9$ GeV
- Mass window for μμ : [2.9,3.3] GeV
- Common decay vertex, $L_{xy}/\sigma_{xy} > 3$, $d_{ca3D} < 0.5$ cm
- χ^2 vertex fit probability > 15%

Offline selection:

- $p_T(\mu^+)$, $p_T(\mu^-) > 4$ GeV, $|\eta_\mu| < 2.1$
- Dimuons from common vertex from Kalman fit
- J/ψ mass constraint: $|m_{\mu^+\mu^-} - M_{J/\psi}| < 150$ MeV
- $p_T(K^+)$, $p_T(K^-) > 0.7$ GeV
- ϕ mass constraint: $|m_{K^+K^-} - M_\Phi| < 10$ MeV



B_s (μμKK) reconstruction by combined kinematic and vertex fit:

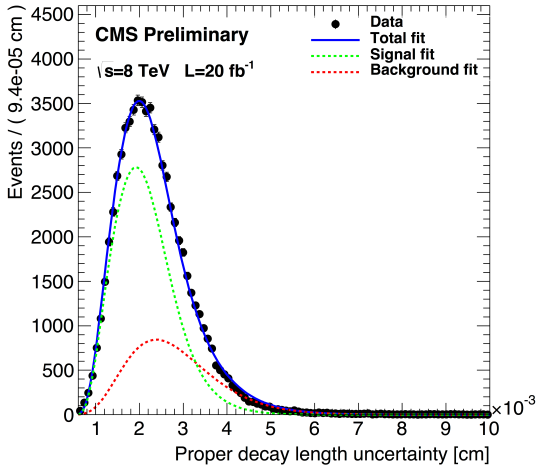
- χ^2 vertex fit probability > 2%
- Mass within [5.24, 5.49] GeV
- Selected primary vertex in case of multiple primary vertices: closest to B_s

CMS PAS BPH-13-012

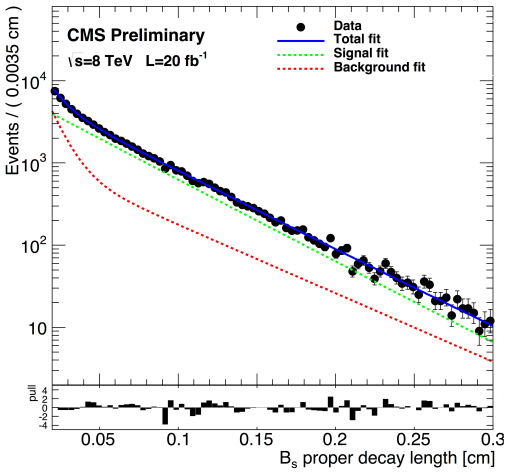
Background, efficiencies, resolution

Main background: non-prompt J/ψ from b hadrons
Lifetime and angular resolution and efficiencies: from simulation

- Angular efficiency: modeled by 3D-function of decay angles
- Angular resolution: not in nominal fit, but included as systematic uncertainty
- Proper decay time efficiency: not in nominal fit, flat in fitting range [0.02,0.3] cm, variations included as systematic uncertainty
- Proper decay time resolution (70 fs or 21 μm): per-event uncertainty from B_s vertex finding + scale factor κ(cτ) taking into account the difference with respect to the actual resolution



CMS PAS BPH-13-012



Flavor tagging

Flavor of B_s at production time determined by tagging e or μ from opposite side B and considering its charge

Tagging performance optimized by maximizing tagging power $P_{tag} = \varepsilon_{tag}(1-2\omega)^2$ separately for e and μ (ω … mistag fraction)

ε_{tag} measured from data, using channel $B^+ \to J/\psi\, K^+$, and checked by simulation with $B^+ \to J/\psi\, K^+$ and $B_s \to J/\psi\, K^{*0}$ events

	Muons	Electrons
Mistag fraction ω [%]	$30.7 \pm 0.4 \pm 0.7$	$34.8 \pm 0.3 \pm 1.0$
Tagging efficiency ϵ_{tag} [%]	$4.55 \pm 0.03 \pm 0.08$	$3.26 \pm 0.02 \pm 0.01$
Tagging power P_{tag} [%]	$0.68 \pm 0.03 \pm 0.05$	$0.30 \pm 0.02 \pm 0.04$

Combined average tagging performance:
$\omega = (32.3 \pm 0.3)\%$, $\varepsilon_{tag} = (7.67 \pm 0.04)\%$, $P_{tag} = (0.97 \pm 0.03)\%$

CMS PAS BPH-13-012

Systematic uncertainties

Source of uncertainty	$\lvert A_0\rvert^2$	$\lvert A_S\rvert^2$	$\lvert A_\perp\rvert^2$	$\Delta\Gamma_s$ [ps^{-1}]	$\delta_\parallel$ [rad]	$\delta_{S\perp}$ [rad]	$\delta_\perp$ [rad]	ϕ_s [rad]	$c\tau$ [μm]
Statistical uncertainty	0.0058	0.016	0.0077	0.0138	0.092	0.24	0.36	0.109	3.0
Angular efficiency	0.0060	0.008	0.0104	0.0021	0.674	0.14	0.66	0.016	0.8
$\lvert\lambda\rvert$ as a free parameter	0.0001	0.005	0.0001	0.0003	0.002	0.01	0.03	0.015	-
Model bias	0.0008	-	-	0.0012	0.025	0.03	-	0.015	0.4
Kaon p_T re-weighting	0.0094	0.020	0.0041	0.0015	0.085	0.11	0.02	0.014	1.1
Proper decay length resolution	0.0009	-	0.0008	0.0021	0.004	-	0.02	0.006	2.9
PDF modelling assumptions	0.0016	0.002	0.0021	0.0021	0.010	0.03	0.04	0.006	0.2
Flavour tagging	-	-	-	-	-	-	0.02	0.005	-
Background mistag modelling	0.0021	-	0.0013	0.0018	0.074	1.10	0.02	0.002	0.7
Proper decay length efficiency	0.0015	-	0.0023	0.0057	-	-	-	0.002	1.0
Total systematics	0.0116	0.022	0.0117	0.0073	0.684	1.12	0.66	0.032	3.5

CMS PAS BPH-13-012

Fit results

Multi-dimensional maximum likelihood fit applied with tagged signal model, Gaussian constraint on Δm_s to PDG value

Fit range:
B_s mass in [5.24, 5.49] GeV
ct in [0.02, 0.3] cm

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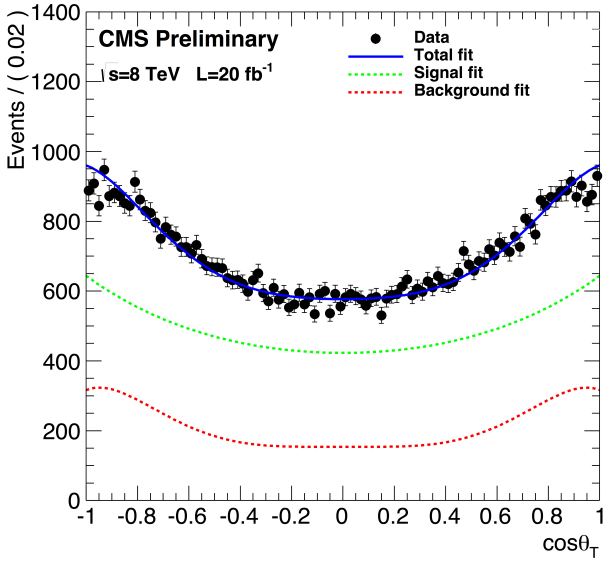
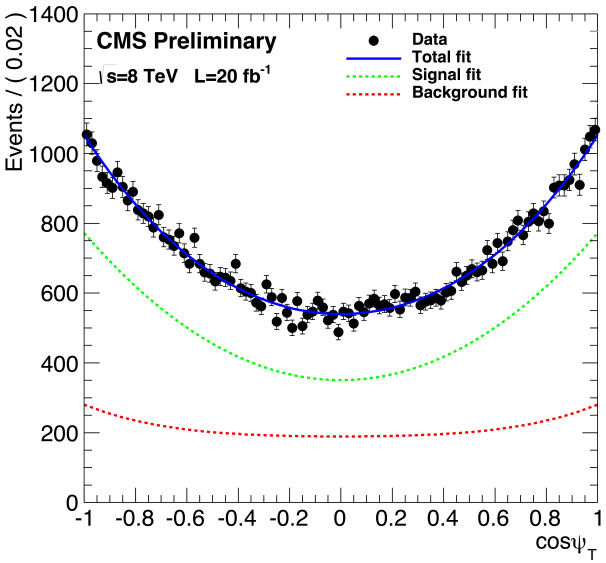
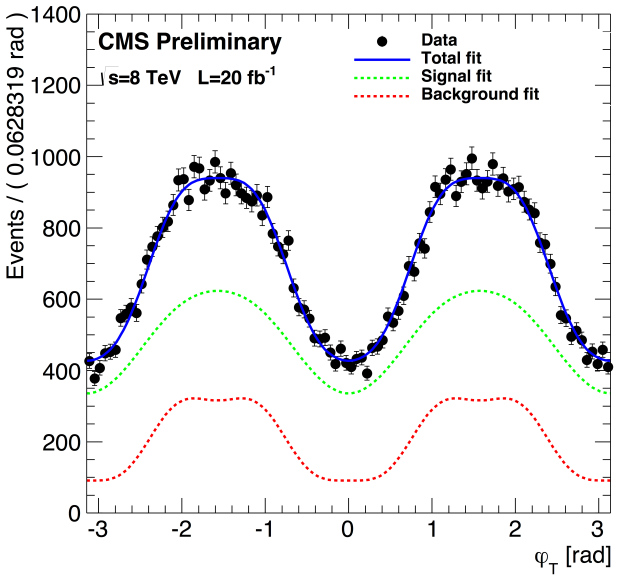
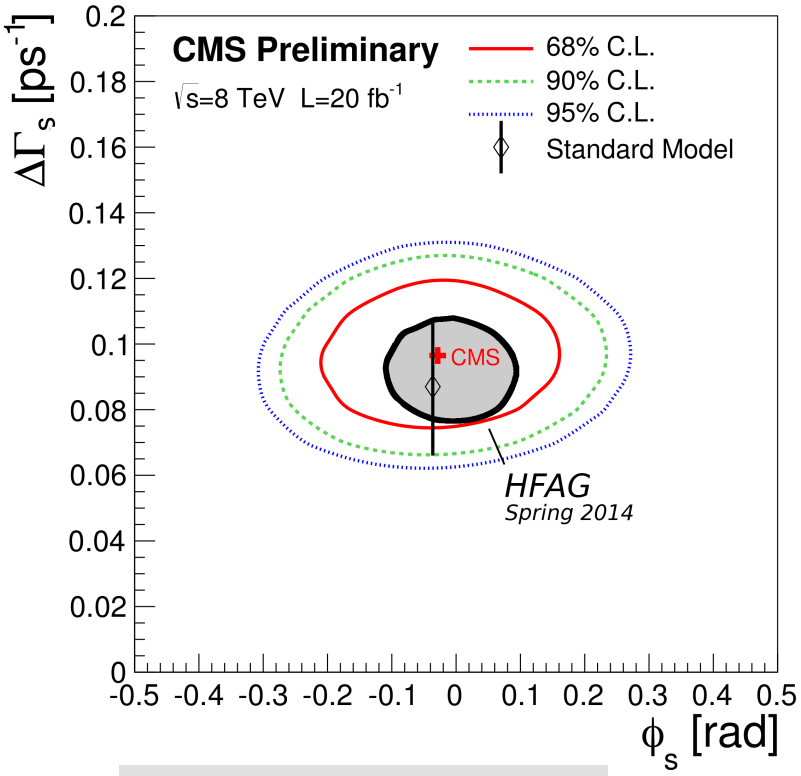
Parameter	Fit result
$\|A_0\|^2$	0.511 ± 0.006
$\|A_S\|^2$	0.015 ± 0.016
$\|A_\perp\|^2$	0.242 ± 0.008
$\delta_\parallel$ [rad]	3.48 ± 0.09
$\delta_{S\perp}$ [rad]	0.34 ± 0.24
$\delta_\perp$ [rad]	2.73 ± 0.36
$c\tau$ [μm]	447.3 ± 3.0
$\Delta\Gamma_s$ [ps^{-1}]	0.096 ± 0.014
ϕ_s [rad]	-0.03 ± 0.11

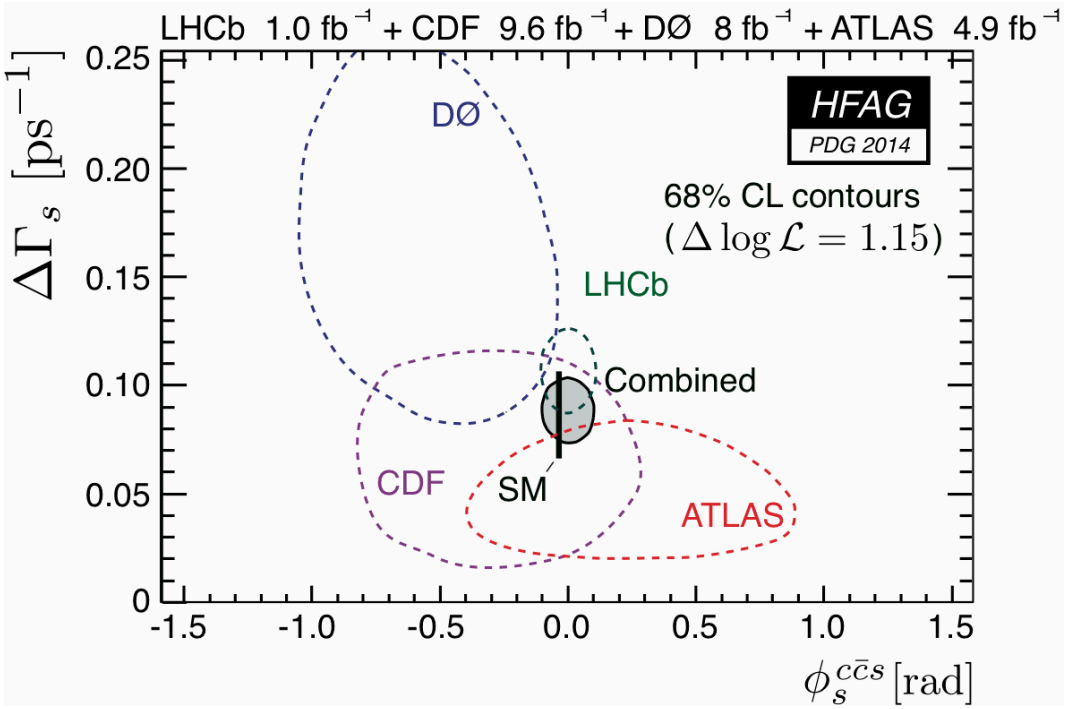






Results on Φ_s, $\Delta\Gamma_s$





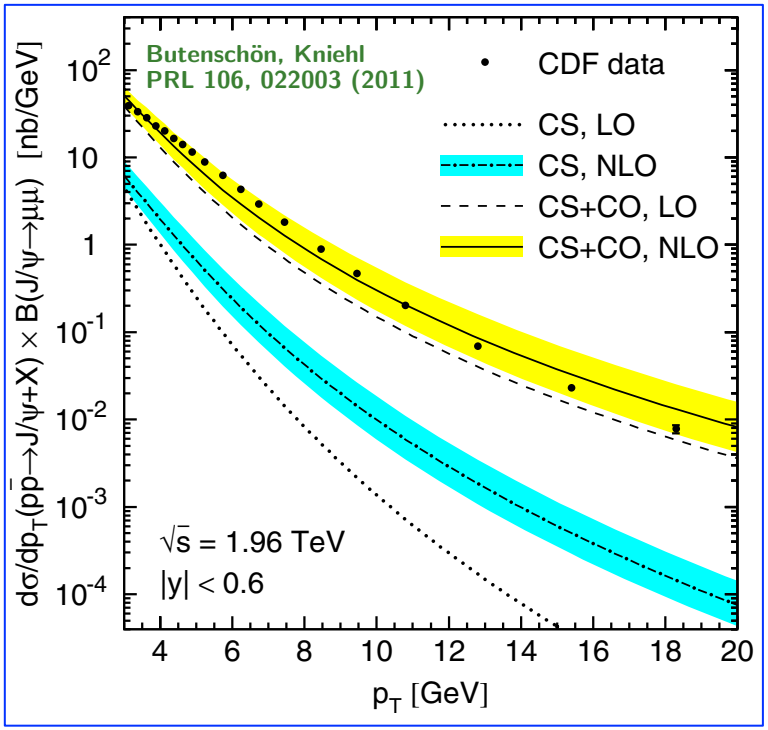
CMS PAS BPH-13-012

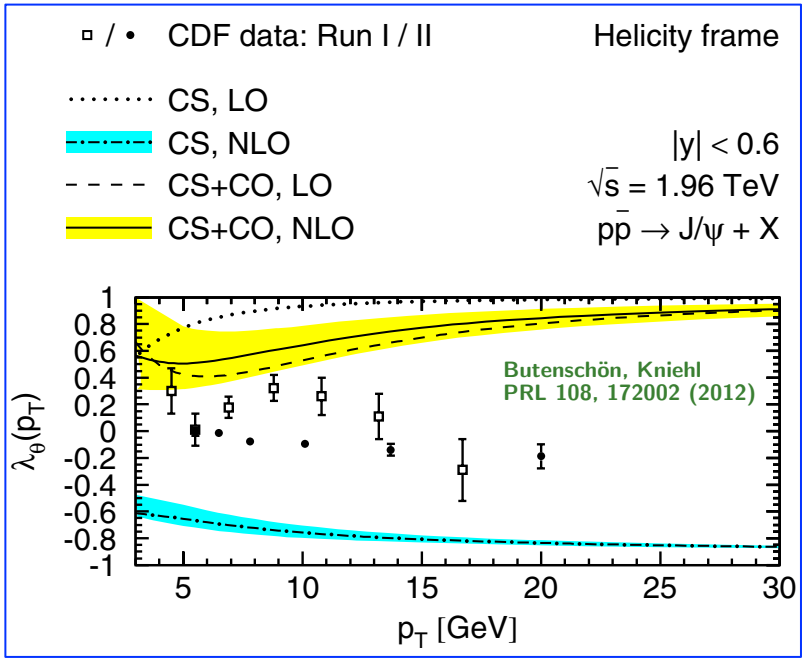
ϕ_s = - 0.03 ± 0.11 (stat.) ± 0.03 (syst.) rad

$\Delta\Gamma_s$ = 0.096 ± 0.014 (stat.) ± 0.007 (syst.) ps^{-1}

Quarkonia cross sections and polarization

Heavy quarkonia interesting to understand hadron formation.
S-wave vector quarkonia formed from heavy $q\bar{q}$ pairs created as:
color singlet (CS) $^3S_1^{[1]}$ or one of 3 color octets (CO) $^1S_0^{[8]}$, $^3S_1^{[8]}$, $^3P_J^{[8]}$ ->
similar cross section shapes, but different polarizations.
Experimental situation on polarization not clear up to now,
cross sections only measured in lower p_T range.



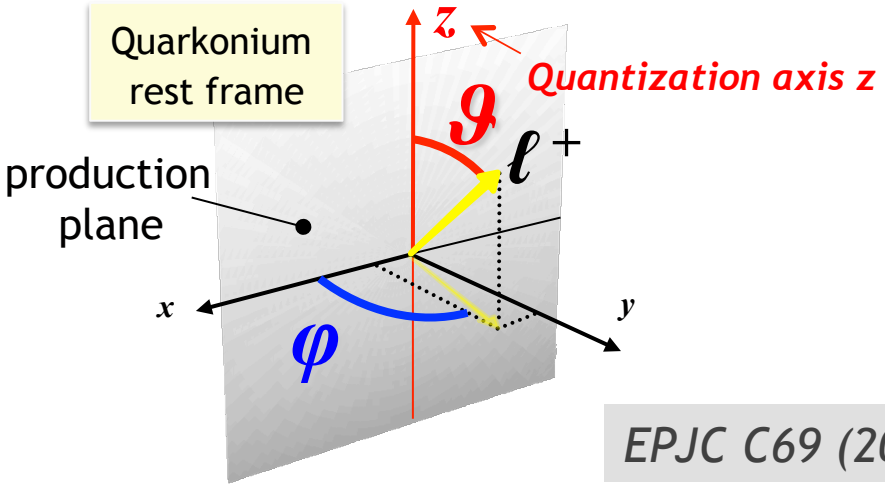


Quarkonium polarization

Polarization of $J^{PC} = 1^{--}$ quarkonium states measured through angular distribution of dileptons from J/ψ or Υ decay

PRD 16 (1977) 2219
PRD 19 (1979) 207

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



Transverse

$J_Z = \pm 1$

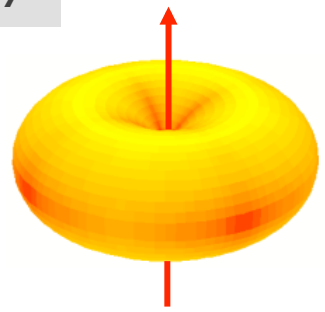
$\lambda_\vartheta = +1$

$\lambda_\varphi = 0$

$\lambda_{\vartheta\varphi} = 0$

$\tilde{\lambda} = +1$

EPJC C69 (2010) 657



Longitudinal

$J_Z = 0$

$\lambda_\vartheta = -1$

$\lambda_\varphi = 0$

$\lambda_{\vartheta\varphi} = 0$

$\tilde{\lambda} = -1$

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

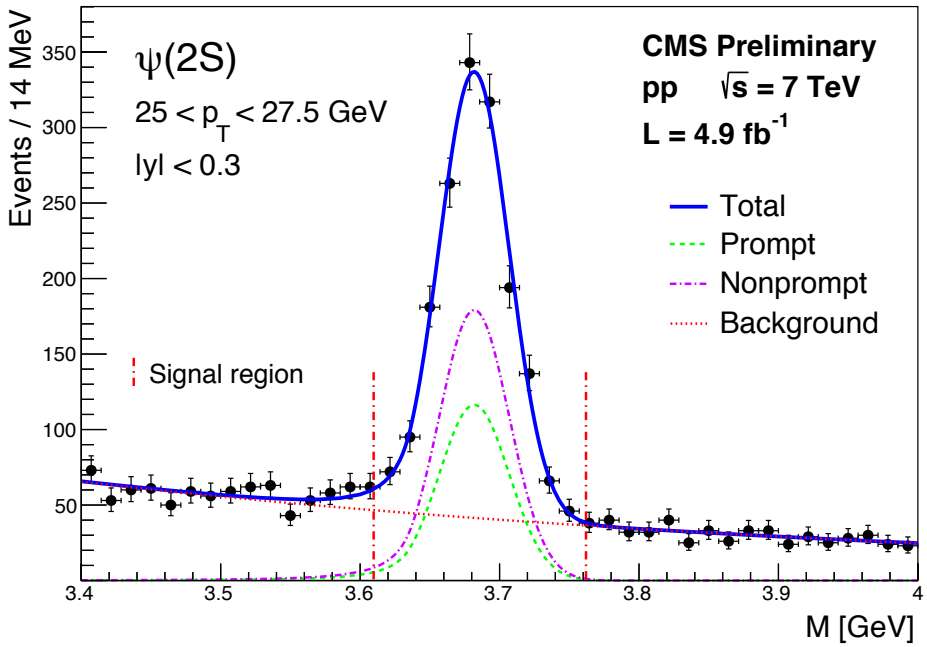
Selection of prompt charmonia

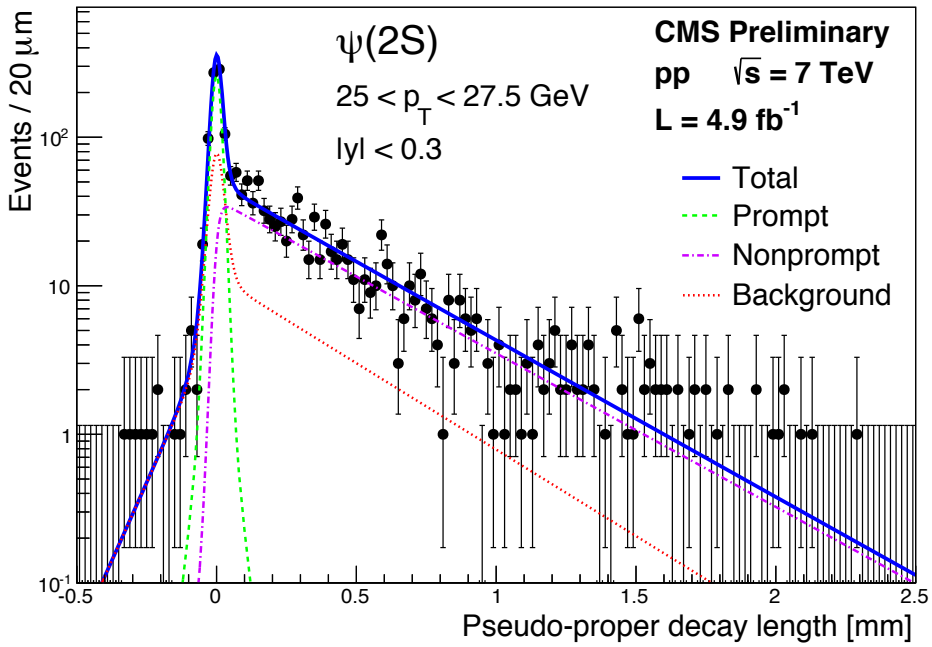
Prompt charmonia distinguished from B-hadron decays through μμ pseudo-proper decay length ℓ (L_{xy} ... most probable transverse decay length)

$$\ell = L_{xy} \cdot m_{\psi(nS)} / p_T$$

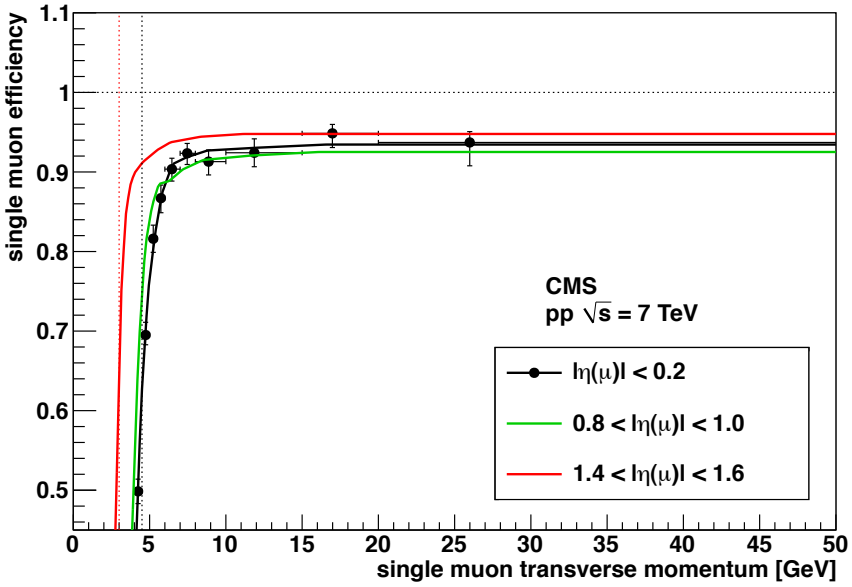
EPJC 71(2011) 1575

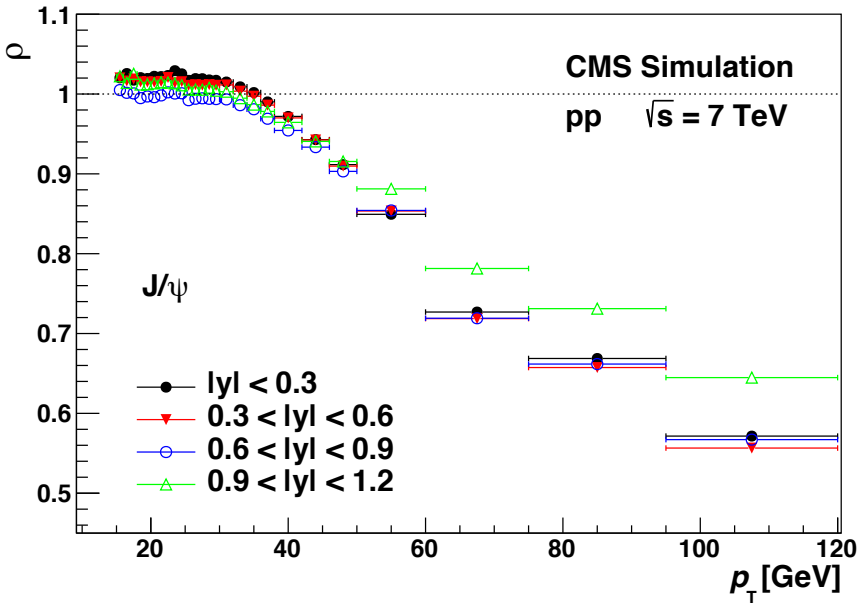
Yield: extended unbinned maximum-likelihood fit to 2D M-ℓ distribution

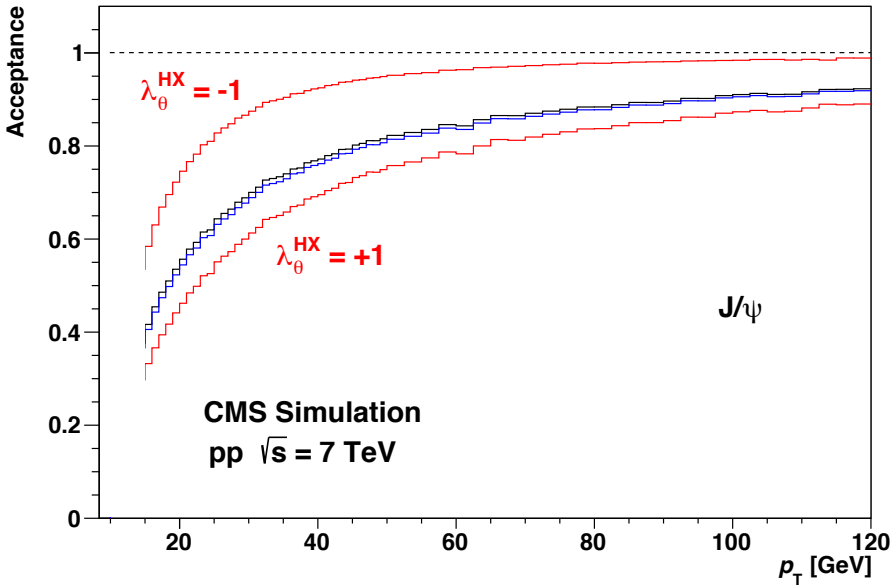




Single μ efficiencies, correlations and acceptance







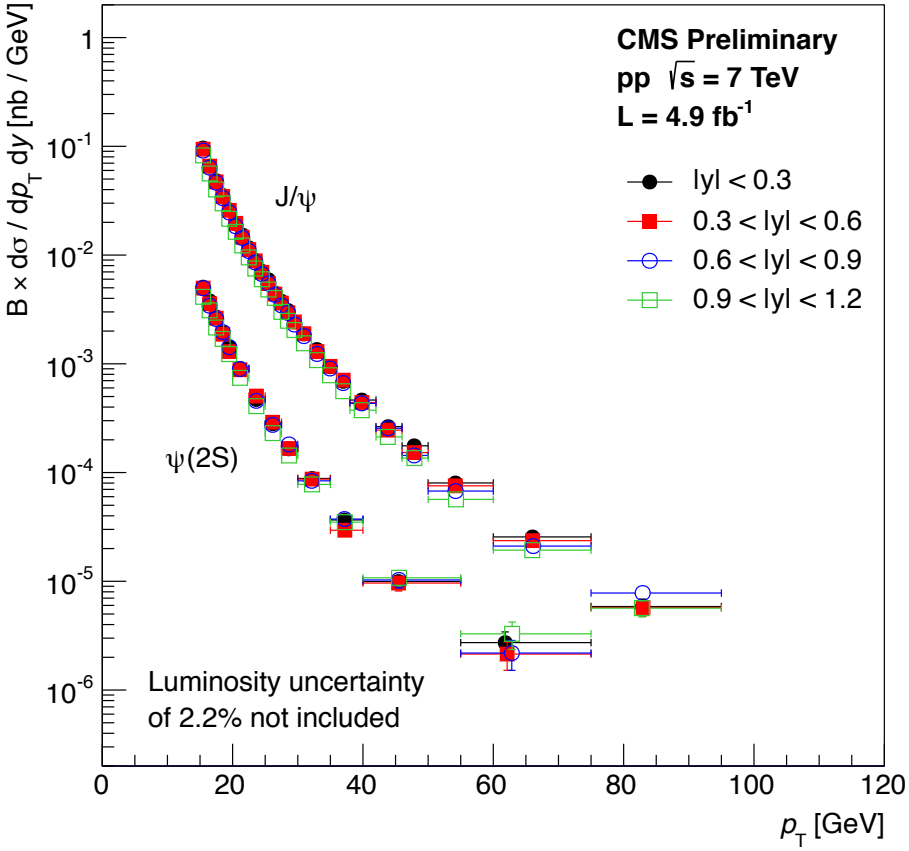
Single muon efficiencies: tag&probe method

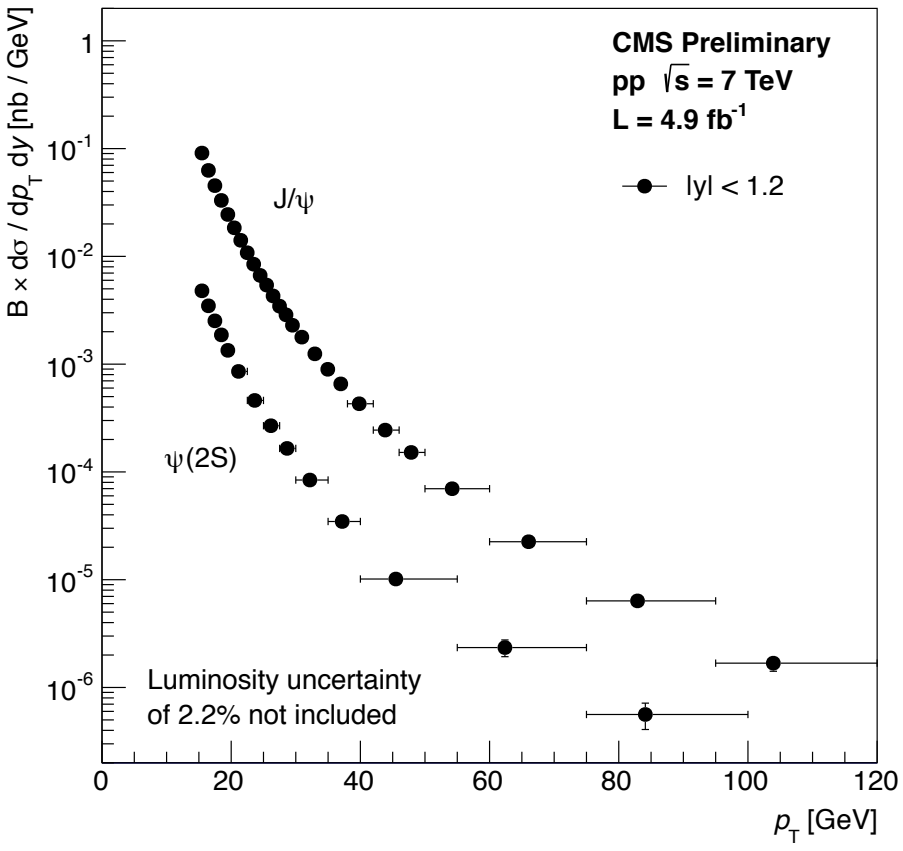
ρ: trigger-induced muon pair correlations

Acceptance: polarization-dependent
Unpolarized scenario used for cross section measurements

CMS-PAS-BPH-14-001

J/ψ and ψ(2S) production





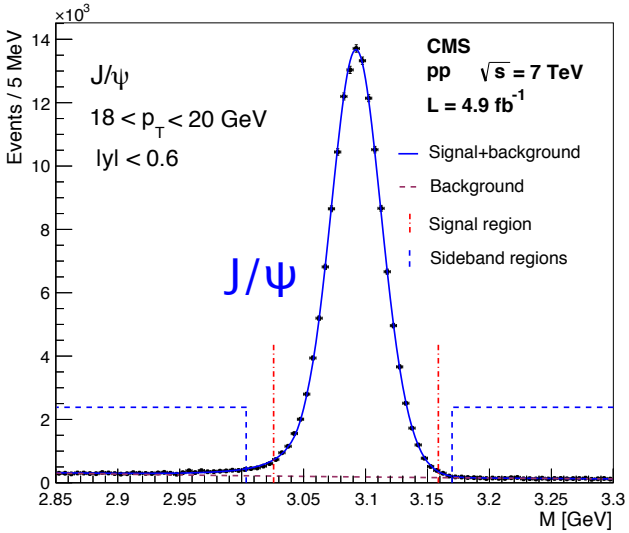
CMS PAS BPH-14-001

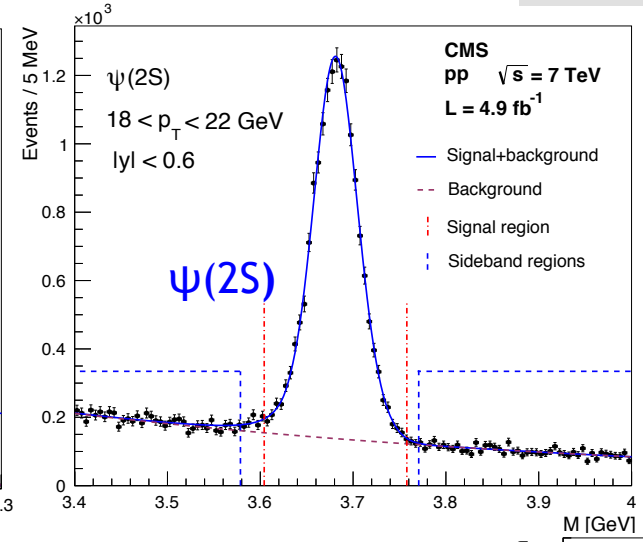
ψ(nS) and Υ(nS) polarizations

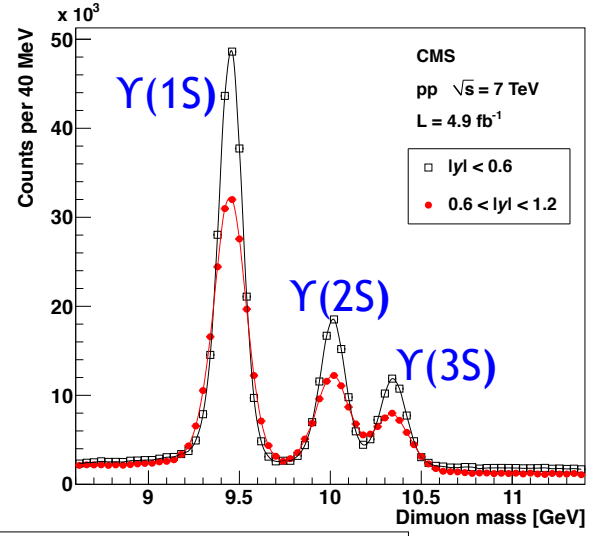
J/ψ and ψ(2s) polarizations, 7 TeV
Υ(1s), Υ(2s), Υ(3s) polarizations, 7 TeV

PLB 727(2013) 381

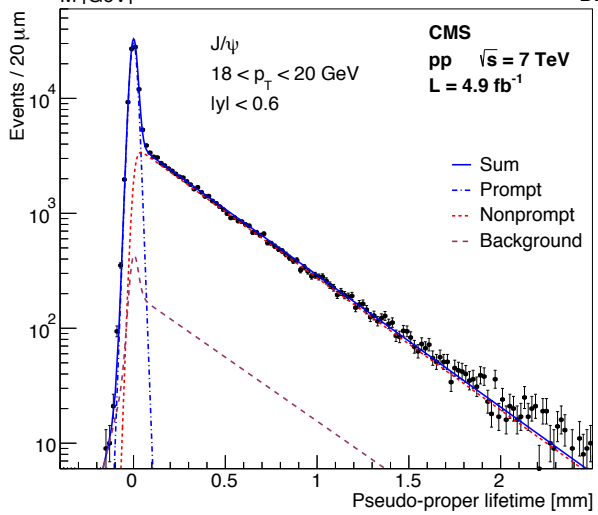
PRL 110 (2013) 081802



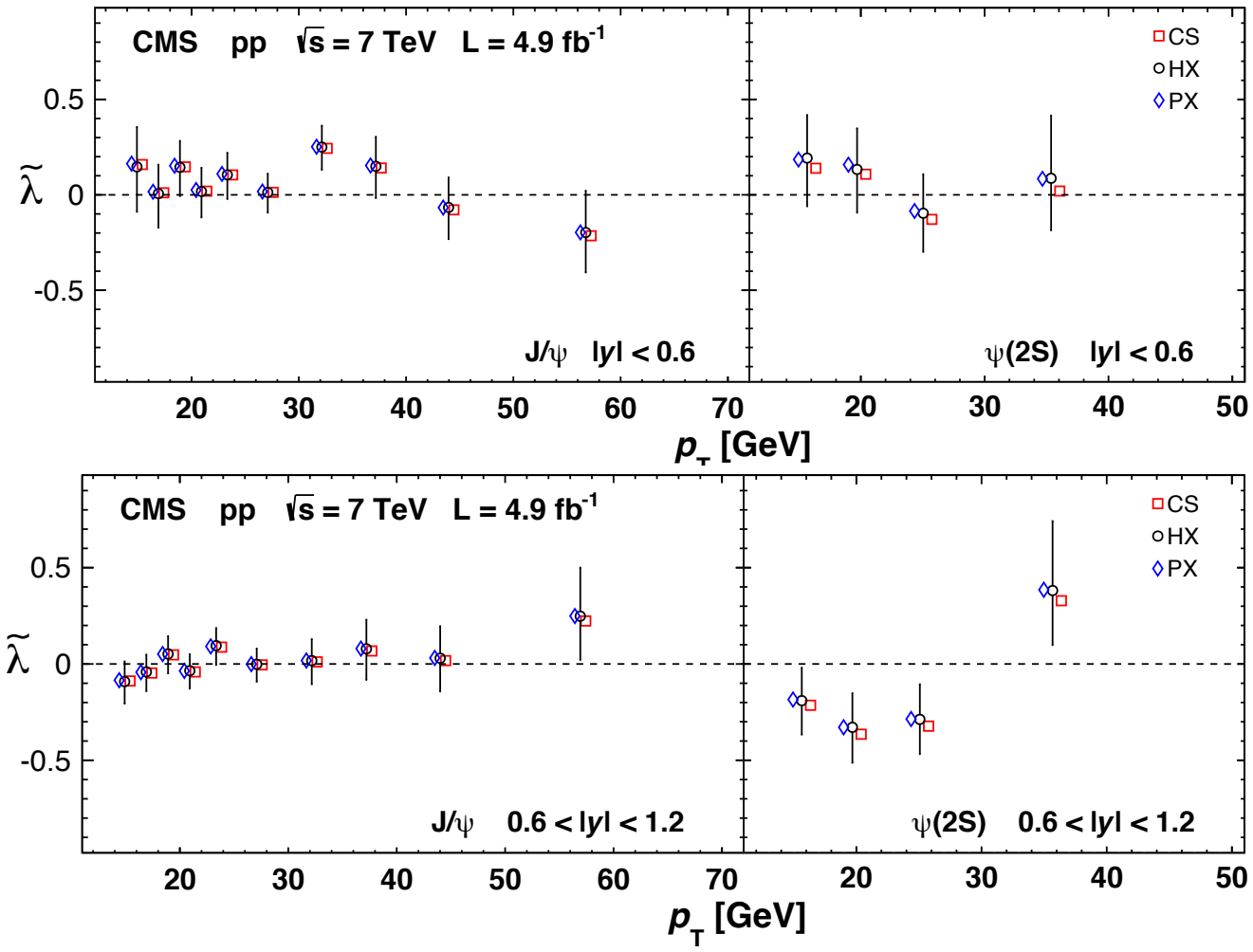




- Full angular decay distributions measured in 3 frames and frame-independently
- Continuum background from sidebands in the invariant mass distribution
- Non-prompt charmonium contributions removed using decay length

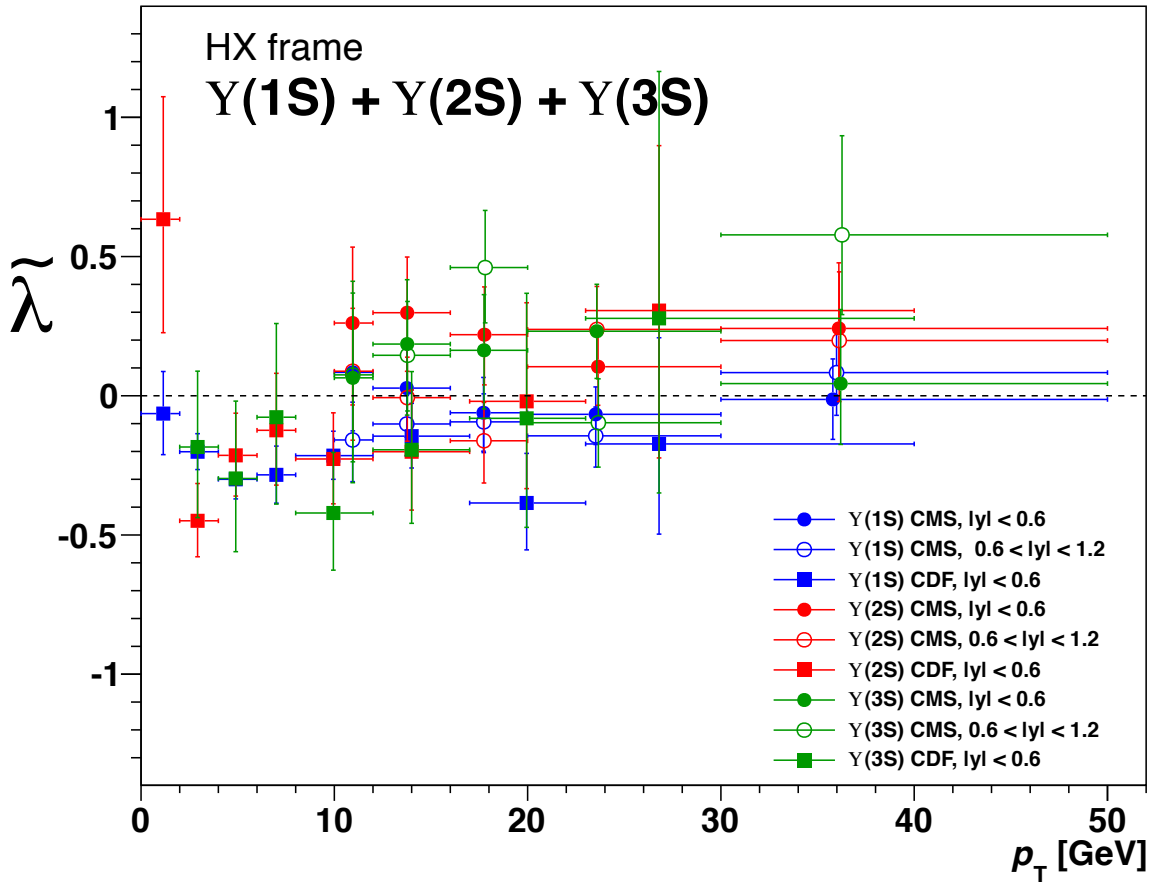


J/ψ and ψ(2S) polarization



- No strong polarization
- No strong p_T or y dependence

Υ(nS) polarization



- No strong polarization
- No strong p_T or y dependence

PRL 110 (2013) 081802

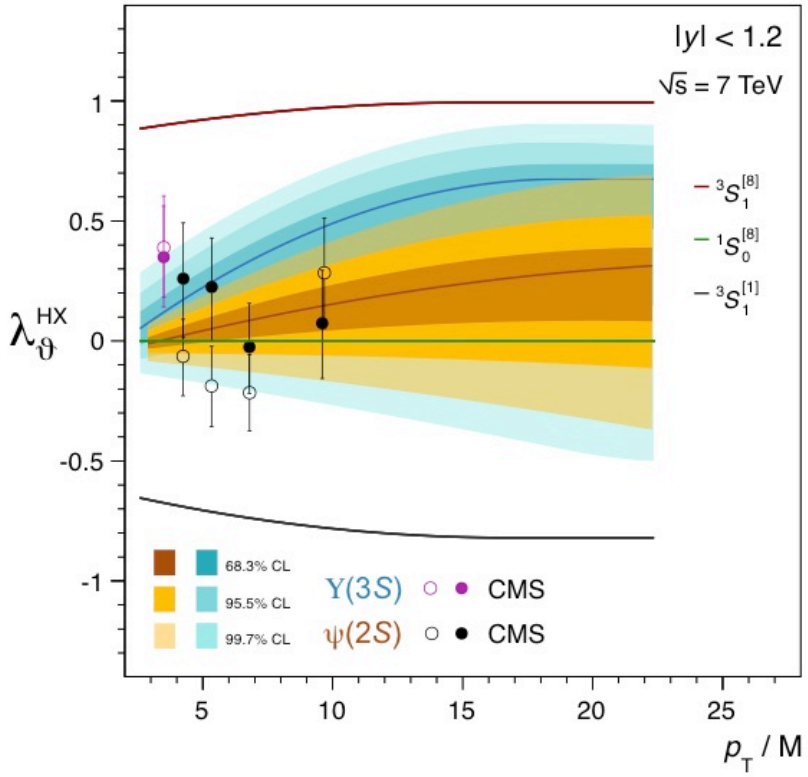
PRL 108 (2012) 151802

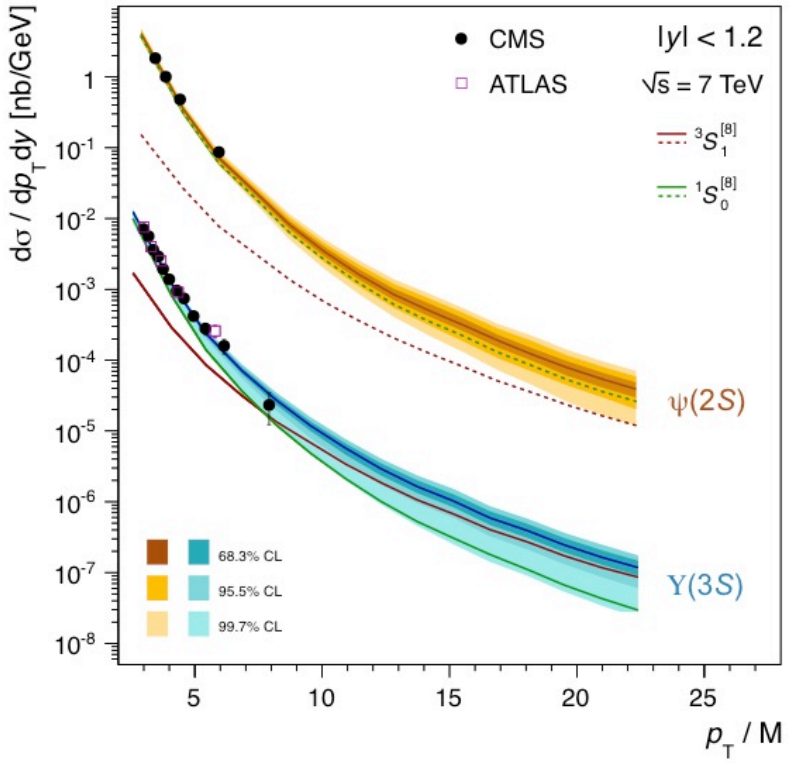
ψ(2S), Υ(3S) production versus NRQCD

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

PLB 736 (2014) 98

JHEP 02 (2012) 011
PRD 87 (2013) 052004
CMS-PAS-BPH-12-006





- χ_b(3P) feed-down to Υ(3S) neglected
- Unpolarized $^1S_0^{[8]}$ component dominates quarkonium production

Conclusions on new CMS results

- CMS has measured with very good precision CP-violating phase ϕ_s and decay width difference $\Delta\Gamma_s$ of B_s with B_s -> $J/\psi(\mu\mu)$ $\phi(KK)$, in agreement with standard model ($\sqrt{s}$ = 8 TeV, L_{int} = 20 fb^{-1}).

- CMS has measured J/ψ and $\psi(2S)$ prompt double-differential cross sections up to O(100 GeV) in p_T ($\sqrt{s}$ = 7 TeV, L_{int} = 4.9 fb^{-1}).

- CMS has measured polarization of $J^{PC} = 1^{--}$ quarkonium states through angular distribution of dileptons from J/ψ or Υ decays ($\sqrt{s}$ = 7 TeV, L_{int} = 4.9 fb^{-1}). No strong polarization is seen. Unpolarized $^1S_0^{[8]}$ component dominates quarkonium production.

- CMS is preparing to take new B physics data at $\sqrt{s}$ = 13 TeV in 2015.