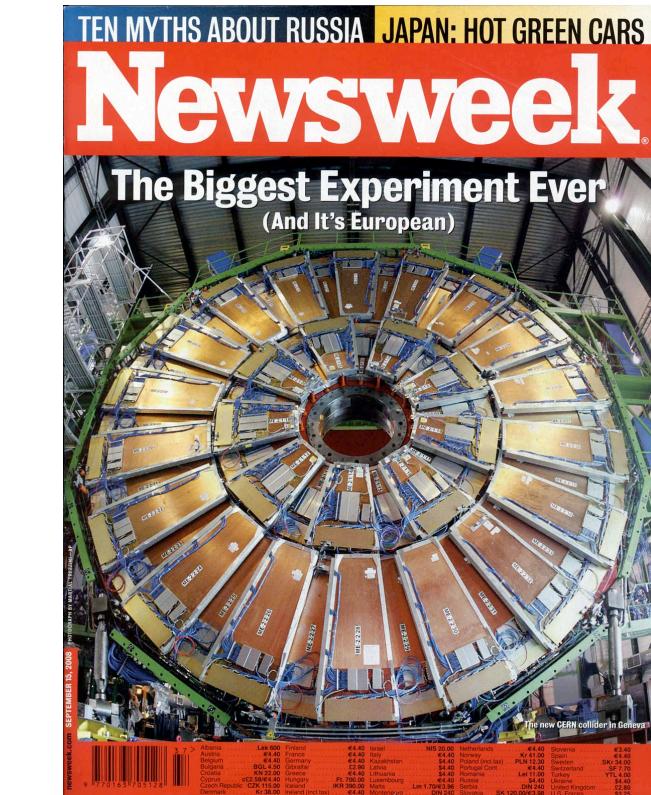


CMS Results on B-Physics



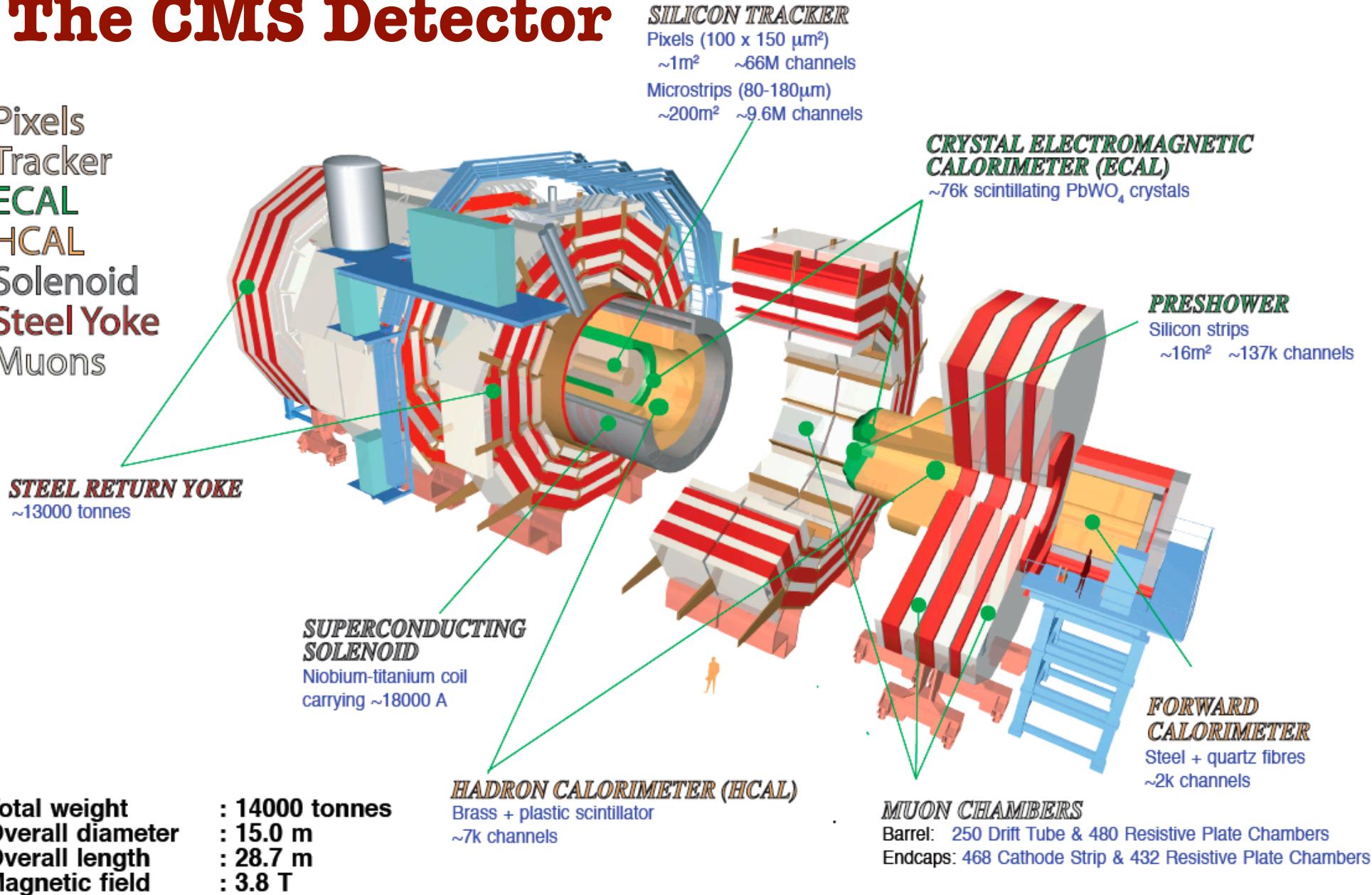
Bora Akgün
(Rice University)
on behalf of CMS Collaboration

Outline

- The CMS Detector
- $\Delta\Gamma_s$ measurement in the $B_s \rightarrow J/\psi \phi$ system
- B^0, B^+, B_s, Λ_b cross sections
- Ξ_b^* observation
- B_c^+ decays
- $D^0 \rightarrow \mu\mu$ branching fraction
- $B_s \rightarrow \mu\mu$ and $B^0 \rightarrow \mu\mu$ branching fractions

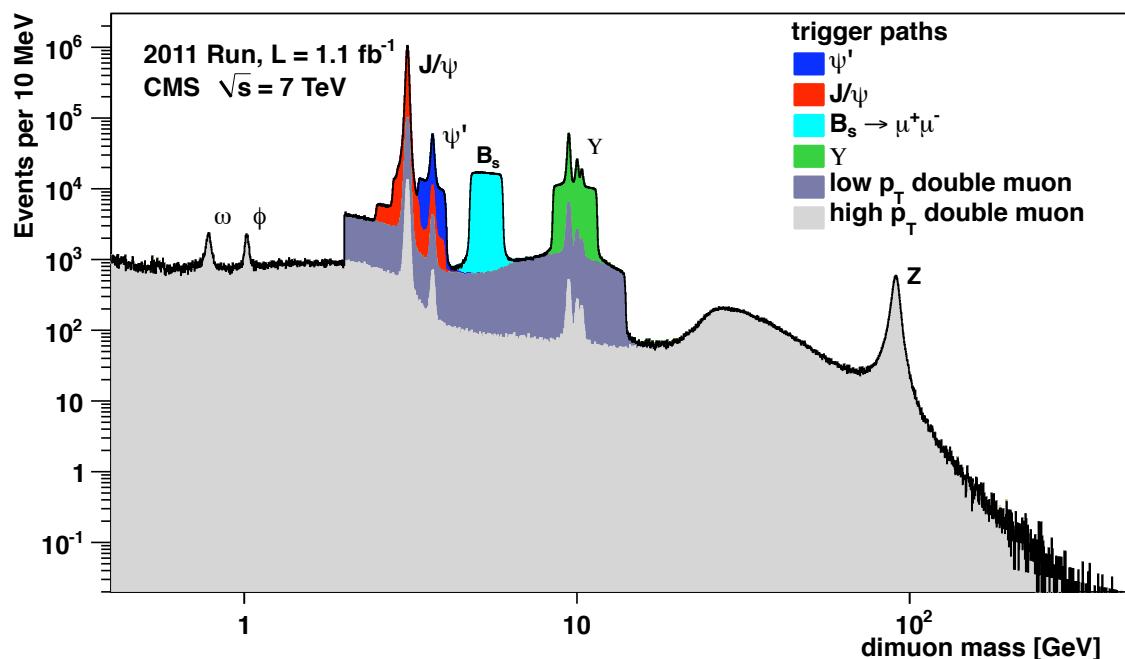
The CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



The CMS Detector

- Muon high purity (mis-identification of π , K , p as muons of the order of per mill)
- Excellent p_T resolution ($\sim 1\%$ in the barrel region)
- Great primary vertex resolution ($10-20 \mu m$)
- Flexible high level trigger



$\Delta\Gamma_s$ in $B_s \rightarrow J/\psi \phi$

CMS-PAS-BPH-11-006

- B_s neutral meson which can oscillate between the flavour eigenstates
- In SM a small CP violation is predicted $\phi_s \approx -2\beta_s = -(0.0362 \pm 0.0017)$
- Two CP eigenstates of $B_s \approx$ mass eigenstates B_L and $B_H \rightarrow \Delta\Gamma_s = \Gamma_L - \Gamma_H$
- An angular analysis is required to disentangle the different states [$CP=(-1)^L$]

$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} = f(\Theta, t; \alpha) = \sum_{i=1}^6 O_i(\alpha, t) \cdot g_i(\Theta),$$

untagged
analysis model

$$O_1 = |A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma_s t} [\cosh(\Delta\Gamma_s t/2) - \cos \phi_s \sinh(\Delta\Gamma_s t/2)]$$

$$O_2 = |A_{||}(t)|^2 = |A_{||}(0)|^2 e^{-\Gamma_s t} [\cosh(\Delta\Gamma_s t/2) - \cos \phi_s \sinh(\Delta\Gamma_s t/2)]$$

$$O_3 = |A_{\perp}(t)|^2 = |A_{\perp}(0)|^2 e^{-\Gamma_s t} [\cosh(\Delta\Gamma_s t/2) + \cos \phi_s \sinh(\Delta\Gamma_s t/2)]$$

$$O_4 = Im(A_{||}^*(t) A_{\perp}(t)) = |A_{||}(0)| |A_{\perp}(0)| e^{-\Gamma_s t} [-\cos(\delta_{\perp} - \delta_{||}) \sin \phi_s \sinh(\Delta\Gamma_s t/2)]$$

$$O_5 = Re(A_0^*(t) A_{||}(t)) = |A_0(0)| |A_{||}(0)| \cos \delta_{||} e^{-\Gamma_s t} [\cosh(\Delta\Gamma_s t/2) - \cos \phi_s \sinh(\Delta\Gamma_s t/2)]$$

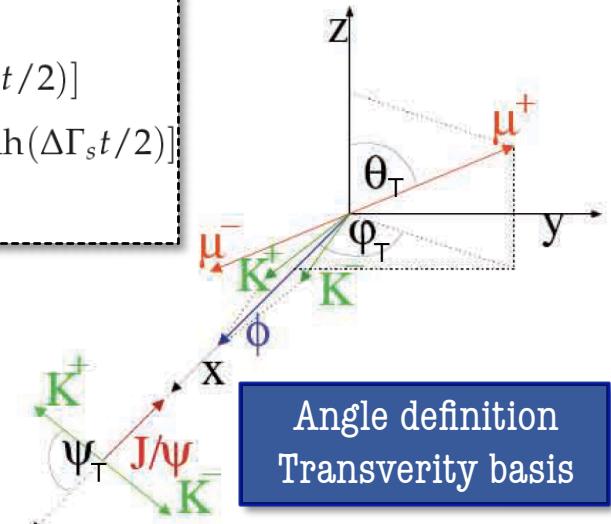
$$O_6 = Im(A_0^*(t) A_{\perp}(t)) = |A_0(0)| |A_{\perp}(0)| e^{-\Gamma_s t} [-\cos \delta_{\perp} \sin \phi_s \sinh(\Delta\Gamma_s t/2)]$$

Simplifying assumptions (treated as systematics unc.)

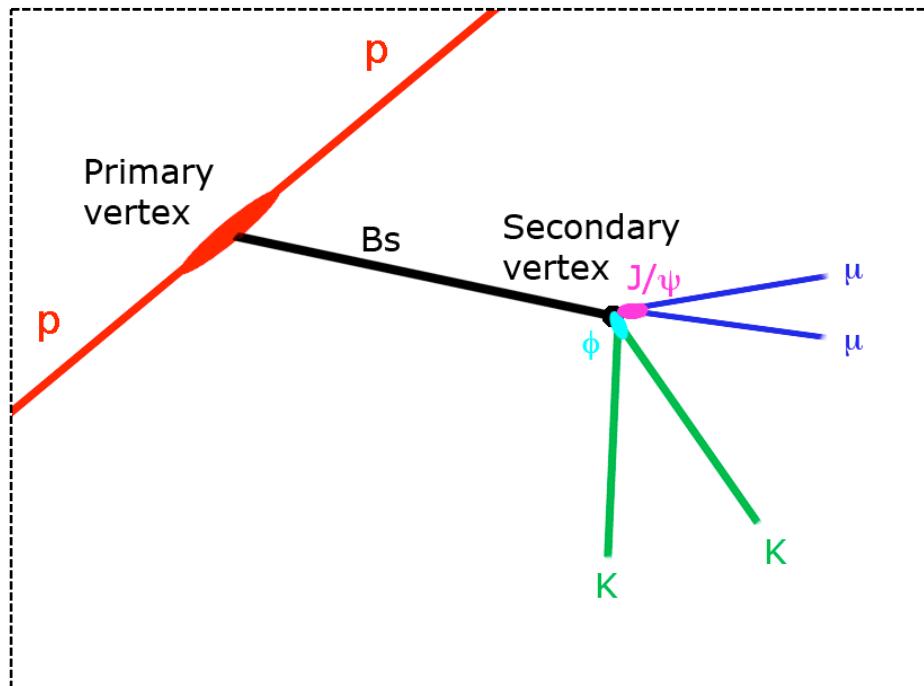
- $\phi_s = 0$ rad
- No S-wave contribution ($B_s \rightarrow J/\psi KK$)

Measured physical variables:

$$\alpha = \{|A_0|^2, |A_{\perp}|^2, \delta_{||} [\text{rad}], \Delta\Gamma_s [\text{ps}^{-1}], c\tau [\text{cm}]\}$$



$\Delta\Gamma_s$ - $B_s \rightarrow J/\psi \phi$ reconstruction



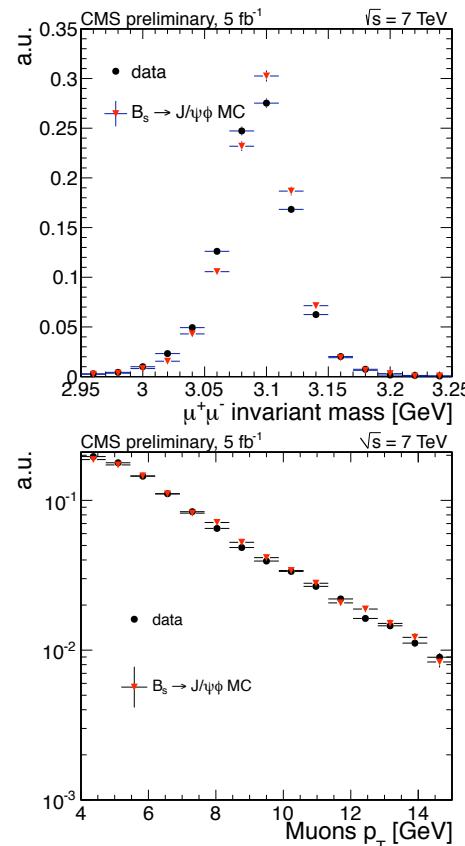
Decay channel: $B_s \rightarrow J/\psi \phi \rightarrow \mu^+ \mu^- K^+ K^-$

Selection

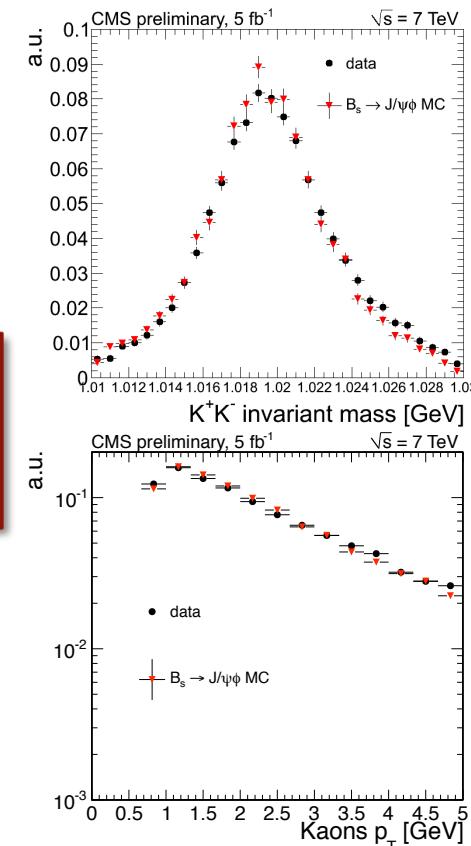
- Muons (tracker & muon stations) with $p_T > 4$ GeV and $|\eta| < 2.2$
- J/ψ candidate: $L_{xy}/\sigma_{xy} > 3$, $p_T > 7$ GeV, vertex probability $> 15\%$, mass within 150 MeV of the PDG value, $\cos\alpha_{xy} > 0.9$, distance of closest approach of muons < 0.5 cm
- ϕ candidate: pair of opposite sign tracks (assumed to be kaons) with $p_T > 0.7$ GeV, mass of ϕ within 10 MeV of the PDG value
- B_s candidate: built from 4 tracks vertex, constraining dimuon to J/ψ PDG mass, vertex probability $> 2\%$

$\Delta\Gamma_s$ - $B_s \rightarrow J/\psi \phi$ efficiencies

- Used factorized efficiencies $\varepsilon(ct) \cdot \varepsilon(\cos\theta_T) \cdot \varepsilon(\cos\psi_T) \cdot \varepsilon(\phi_T)$ since the correlations in the 4D efficiencies are very small
- Obtained using simulation (MC validated with data)
- Cut on $c\tau > 200 \mu\text{m}$ in order to remove the turn on efficiency curve due to the $L_{xy}/\sigma_{xy} > 3$, selected B_s candidates are in the efficiency plateau



Data sideband subtracted
vs.
Signal simulation



$\Delta\Gamma_s$ - fit

5D Unbinned Maximum Likelihood fit

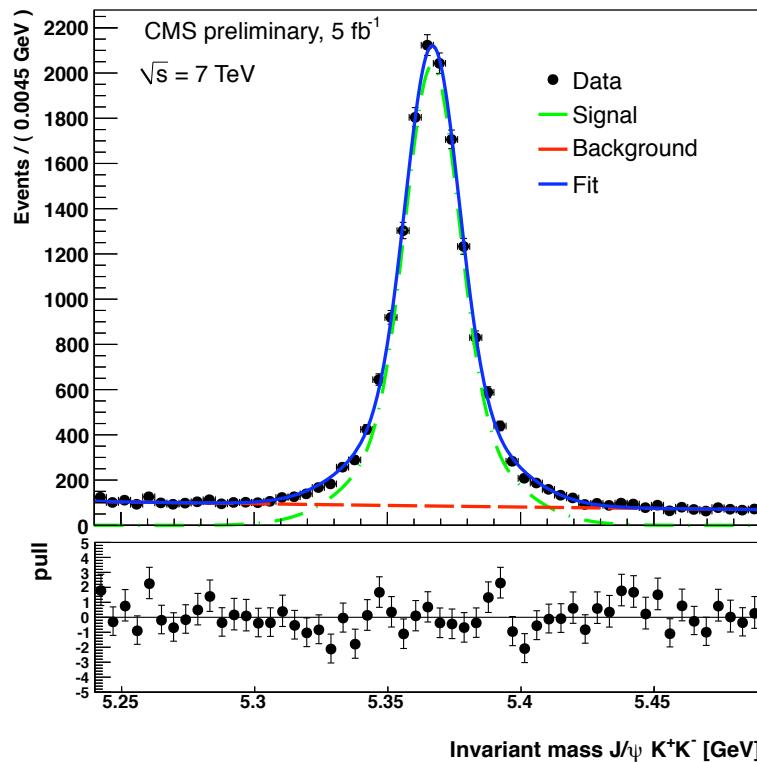
$$N_S \varepsilon(c\tau) \varepsilon(\cos\theta_T) \varepsilon(\cos\psi_T) \varepsilon(\phi_T) [f_S(c\tau, \cos\theta_T, \cos\psi_T, \phi_T, M | \alpha) \otimes G(c\tau | \sigma_i)] + \\ N_{BG} \cdot f_{BG}(c\tau, \cos\theta_T, \cos\psi_T, \phi_T, M)$$

Main systematic uncertainties on $\Delta\Gamma_s$ evaluated with MC pseudo-experiments

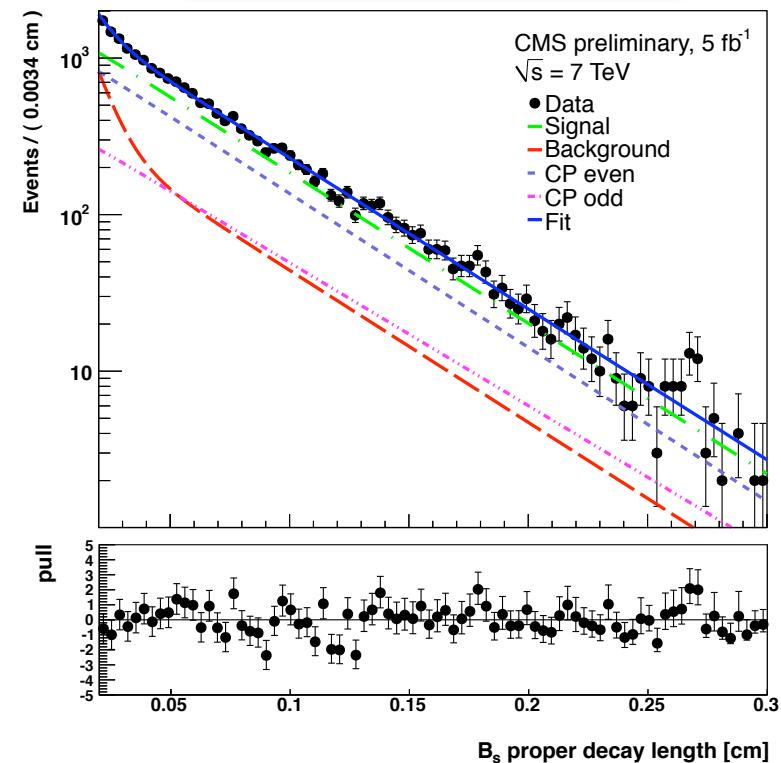
- **cτ resolution:** per-event proper time error, calibrated using MC and lifetime-unbiased data sample (collected w/o decay length cuts)
- **S-wave:** effect estimated assuming S-wave component with $|A_S| = 0.03$
- **Background angular model:** used 3D histogram, $\{\cos\theta_T, \cos\psi_T, \phi_T\}$ which includes possible background correlation instead of the singular angle histograms
- **cτ efficiency (fit on data):** uncertainty estimated using various parameterizations of the proper time efficiency curve

$\Delta\Gamma_s - B_s \rightarrow J/\psi \phi$ results

J/ ψ KK invariant mass



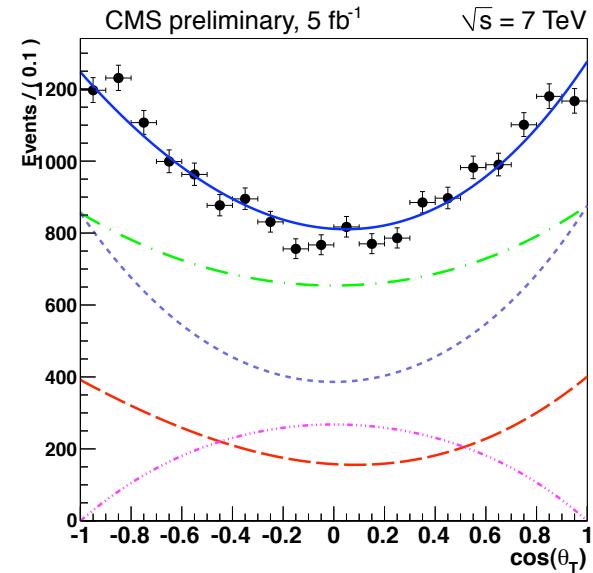
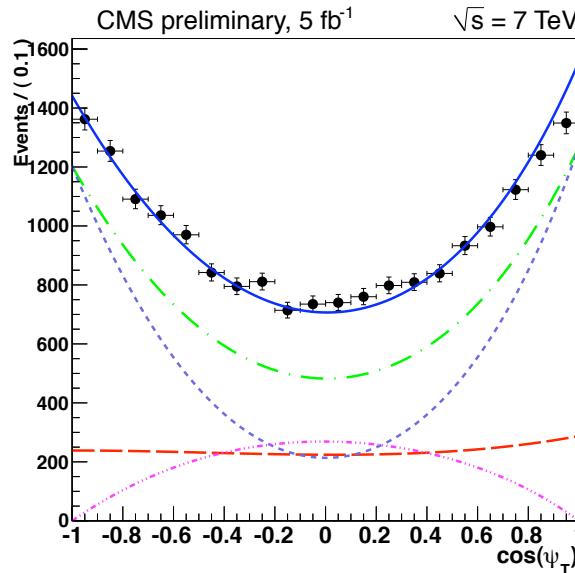
B_s proper decay length



2011 data, 5 fb^{-1}
Number of signal events ~ 14400
Number of background events ~ 4700

$\Delta\Gamma_s - B_s \rightarrow J/\psi \phi$ results

- Data
- Signal
- Background
- - CP even
- · CP odd
- Fit



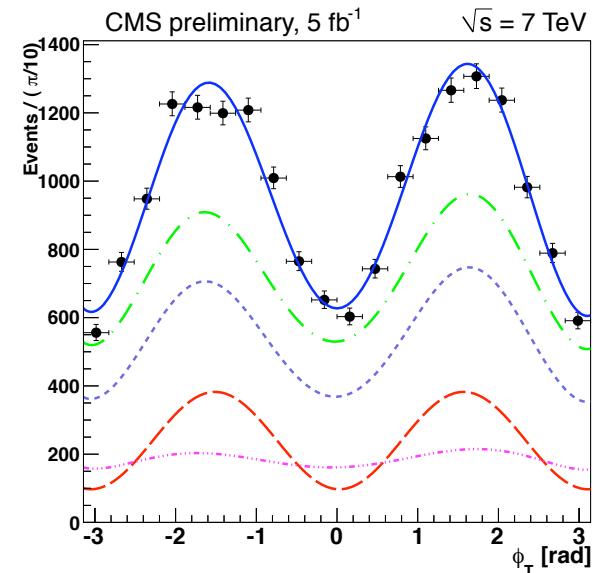
$$\Delta\Gamma_s = 0.048 \pm 0.024 \text{ (stat.)} \pm 0.003 \text{ (syst.)} \text{ ps}^{-1}$$

$$C\tau_{BS} = 0.04580 \pm 0.00059 \text{ (stat.)} \pm 0.00022 \text{ (syst.) cm}$$

$$|A_0|^2 = 0.528 \pm 0.010 \text{ (stat.)} \pm 0.015 \text{ (syst.)}$$

$$|A_\perp|^2 = 0.251 \pm 0.013 \text{ (stat.)} \pm 0.014 \text{ (syst.)}$$

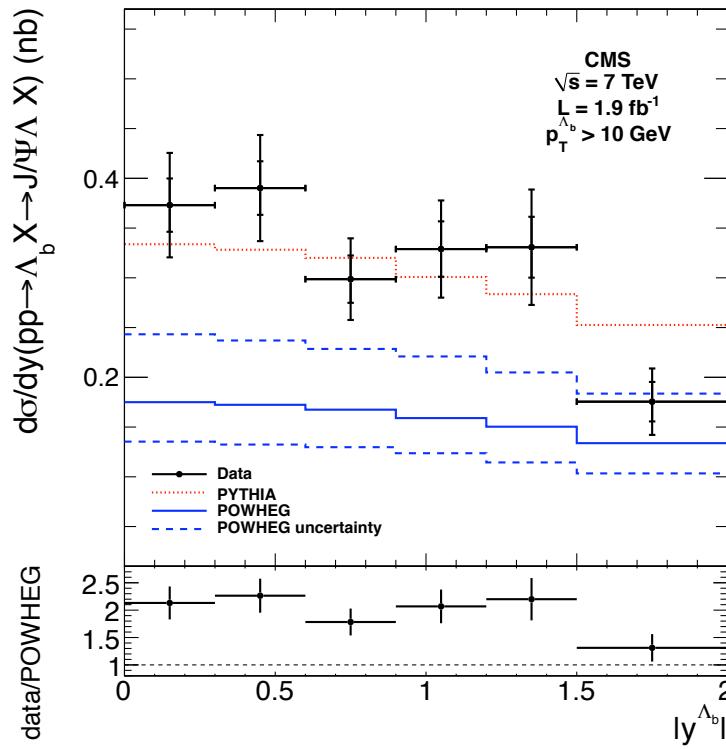
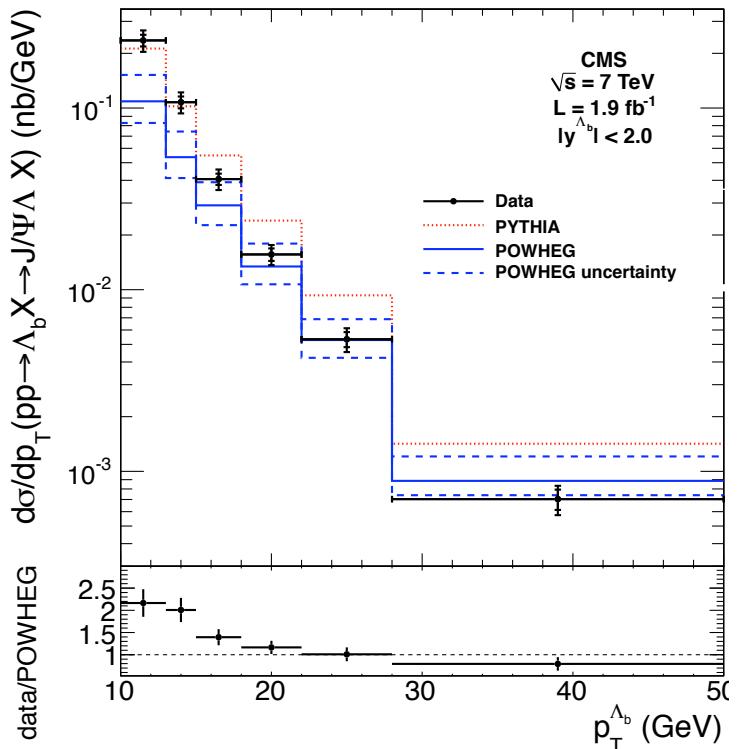
$$\delta_{||} = 2.79 \pm 0.14 \text{ (stat.)} \pm 0.19 \text{ (syst.) rad}$$



Λ_b production measurement

Phys. Lett. B714, 136

- Λ_b production measured in decays to $J/\psi \Lambda$
- Yields and efficiencies computed in bins of $p_T(\Lambda_b)$ and $y(\Lambda_b)$ to obtain differential cross section



Uncertainty on
 $B(\Lambda_b \rightarrow J/\psi \Lambda) = 54\%$
So report on
 $\sigma(pp \rightarrow \Lambda_b X)^* B(\Lambda_b \rightarrow J/\psi \Lambda)$

Λ_b cross section compared to B mesons

- New Λ_b measurement allows for comparison to B^+ , B^0 and B_s mesons
- Baryon spectrum falls faster than meson spectra

Summary of $d\sigma/dp_T$

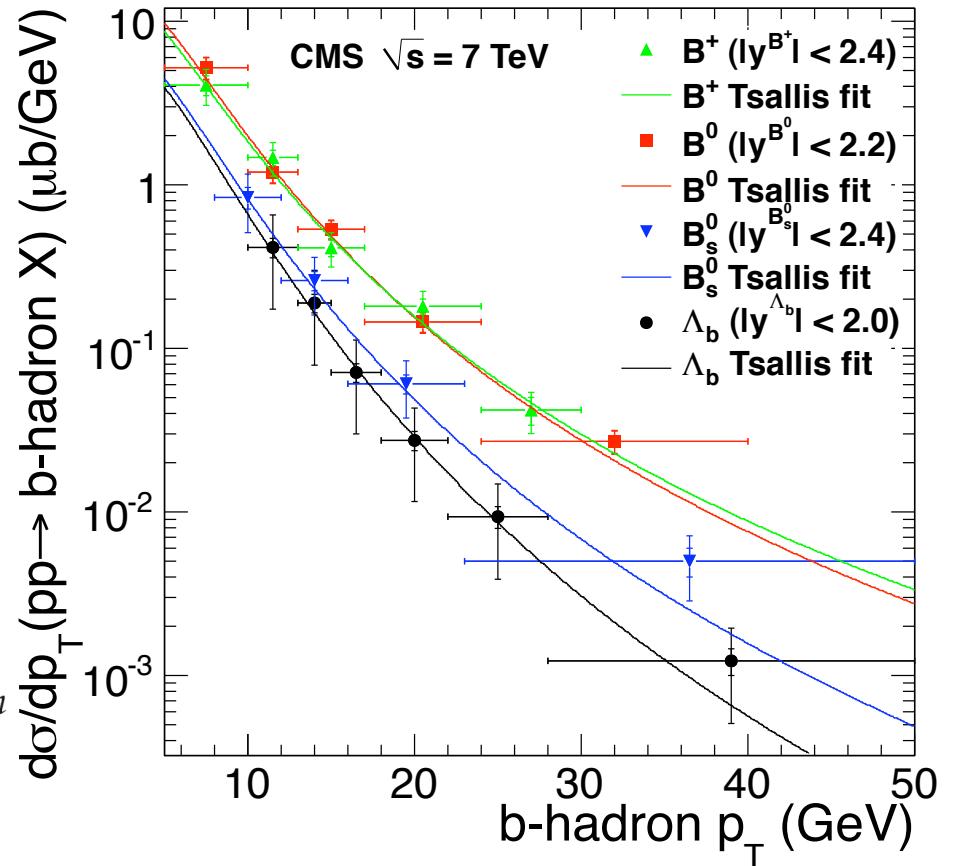
$$\frac{1}{N} \frac{dN}{dp_T} = C p_T \left[1 + \frac{\sqrt{p_T^2 + m^2} - m}{nT} \right]^{-n}$$

$$n(B^+) = 5.5 \pm 0.3$$

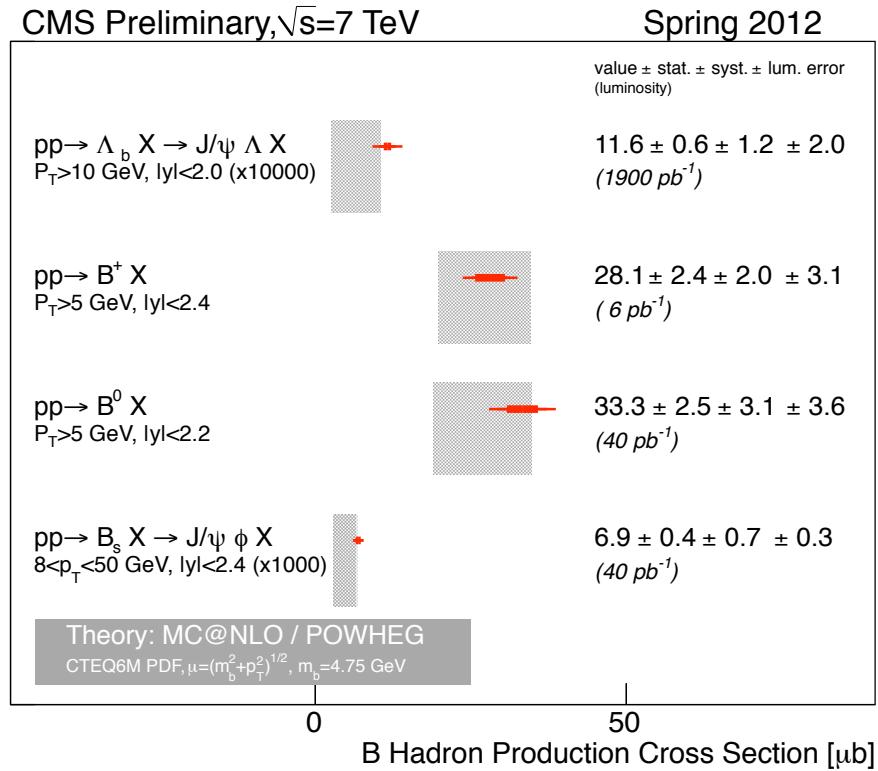
$$n(B^0) = 5.8 \pm 0.3$$

$$n(B_s^0) = 6.6 \pm 0.4$$

$$n(\Lambda_b) = 7.6 \pm 0.4$$



Λ_b cross section compared to B mesons

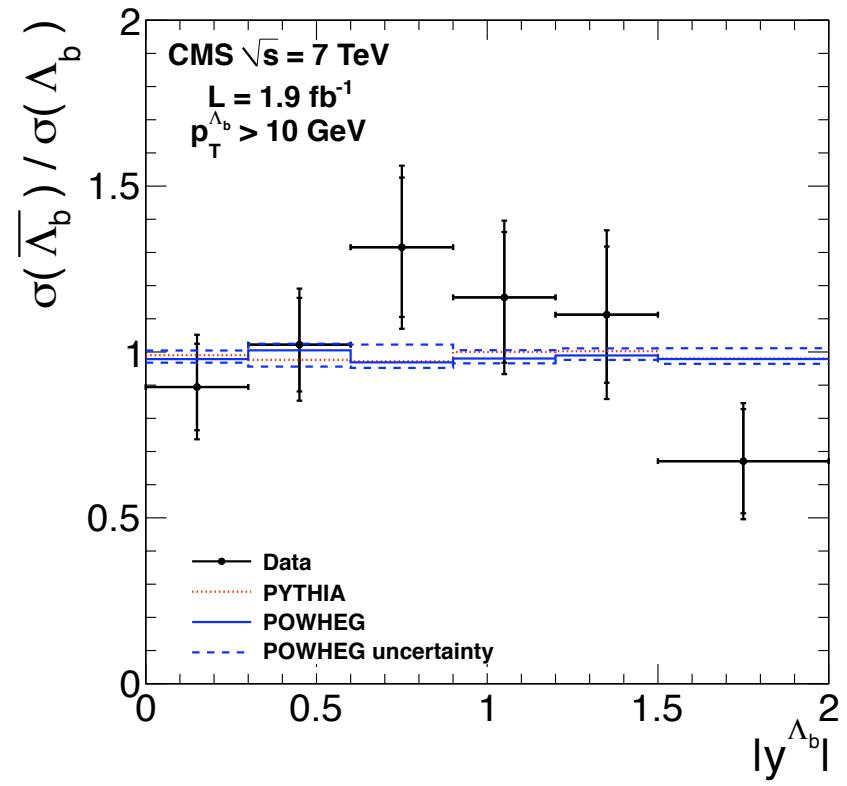
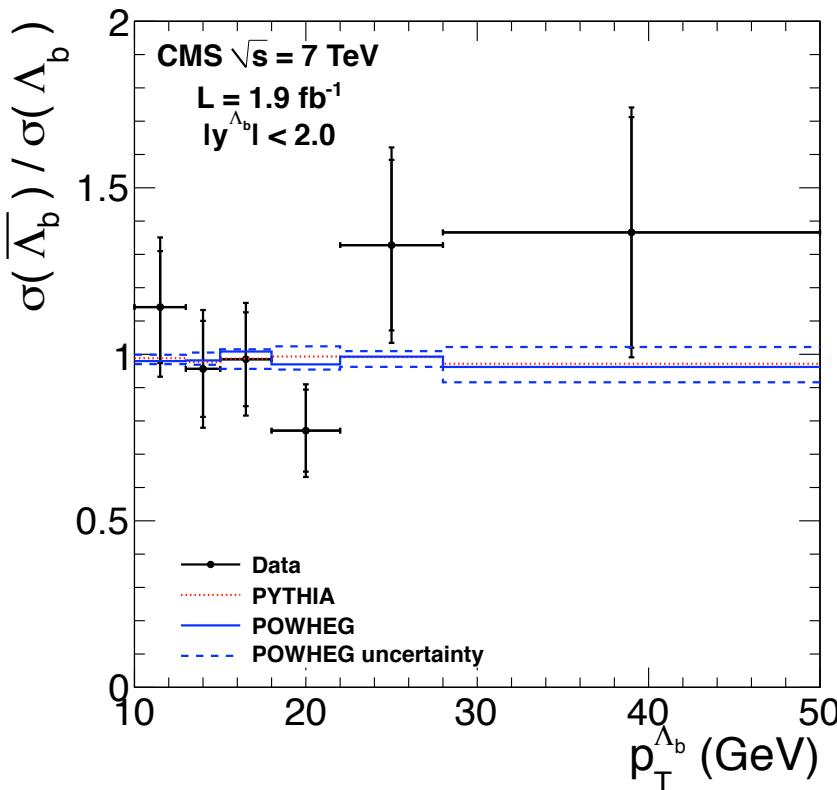


- Measured integrated cross sections for B^+ , B^0 , B_s , Λ_b and NLO predictions are in agreement, but data sit mostly at the upper edge of the theory uncertainty

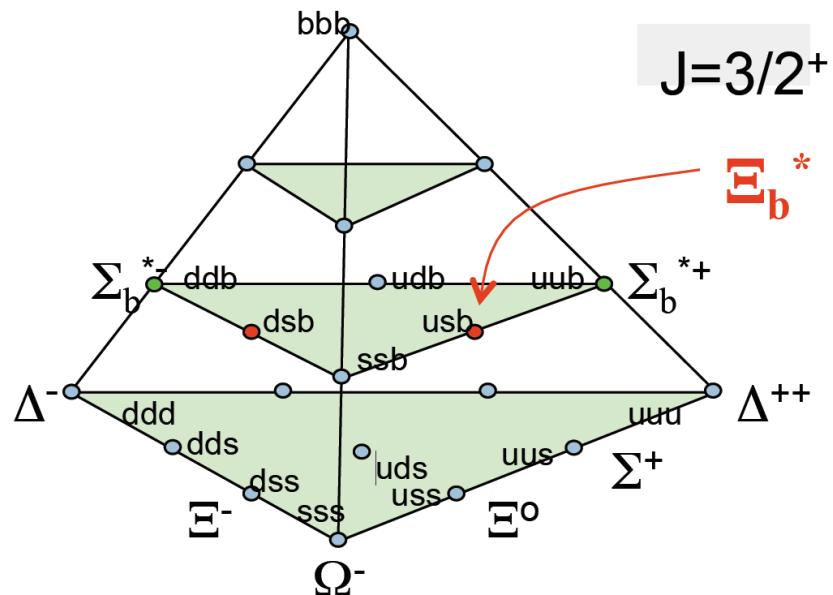
$\bar{\Lambda}_b/\Lambda_b$ asymmetry results

- Also measure yields and efficiencies as ratios between particles and anti-particles
 - Use charge of higher momentum Λ track to identify the (anti-)proton
- Results are consistent with no asymmetry – within large uncertainties

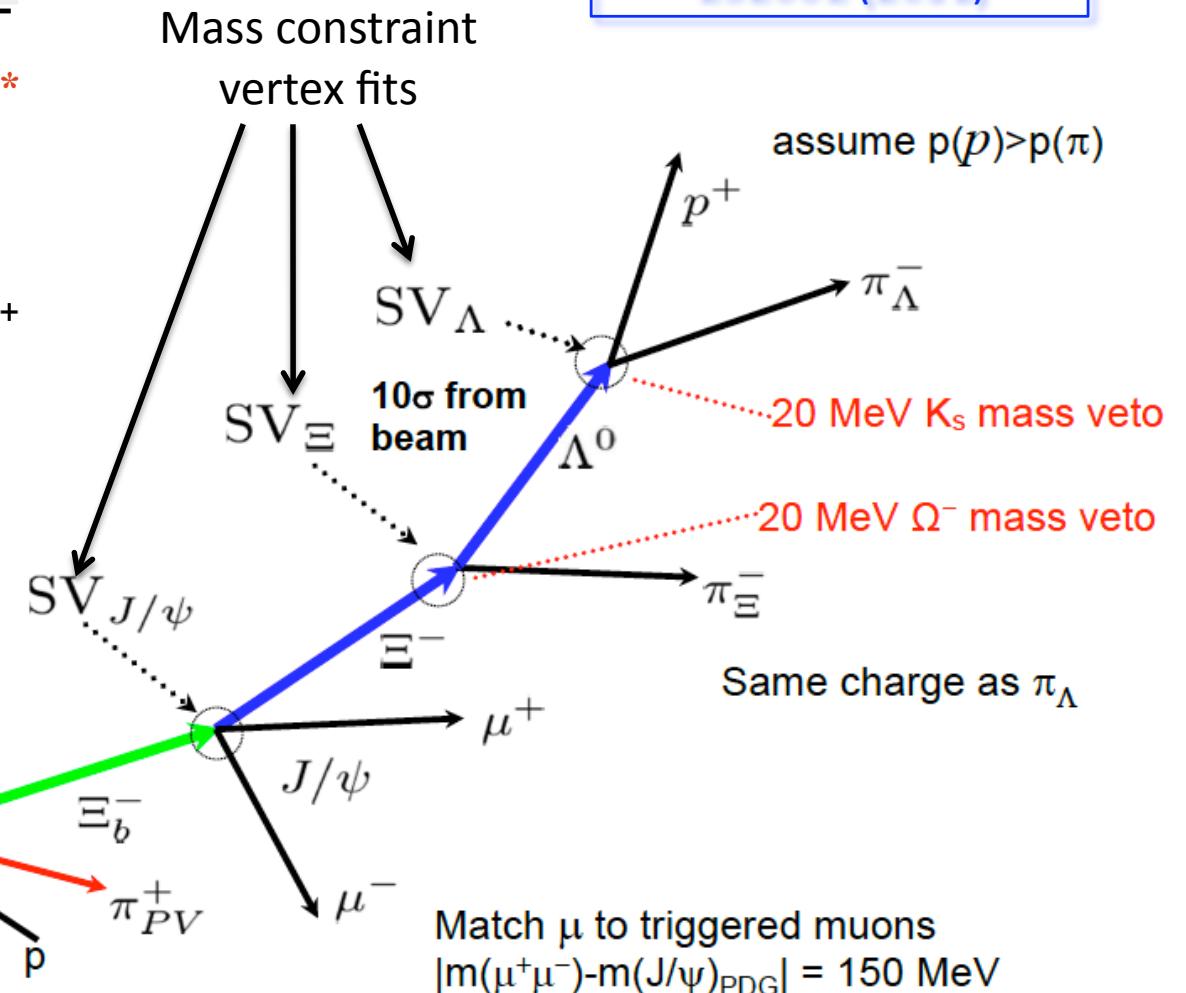
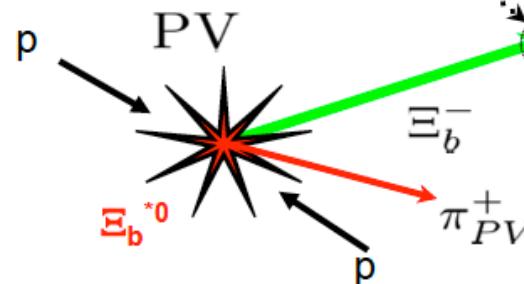
$$\sigma(\bar{\Lambda}_b)/\sigma(\Lambda_b) = 1.02 \pm 0.07(\text{stat.}) \pm 0.09(\text{syst.})$$



Ξ_b^* discovery

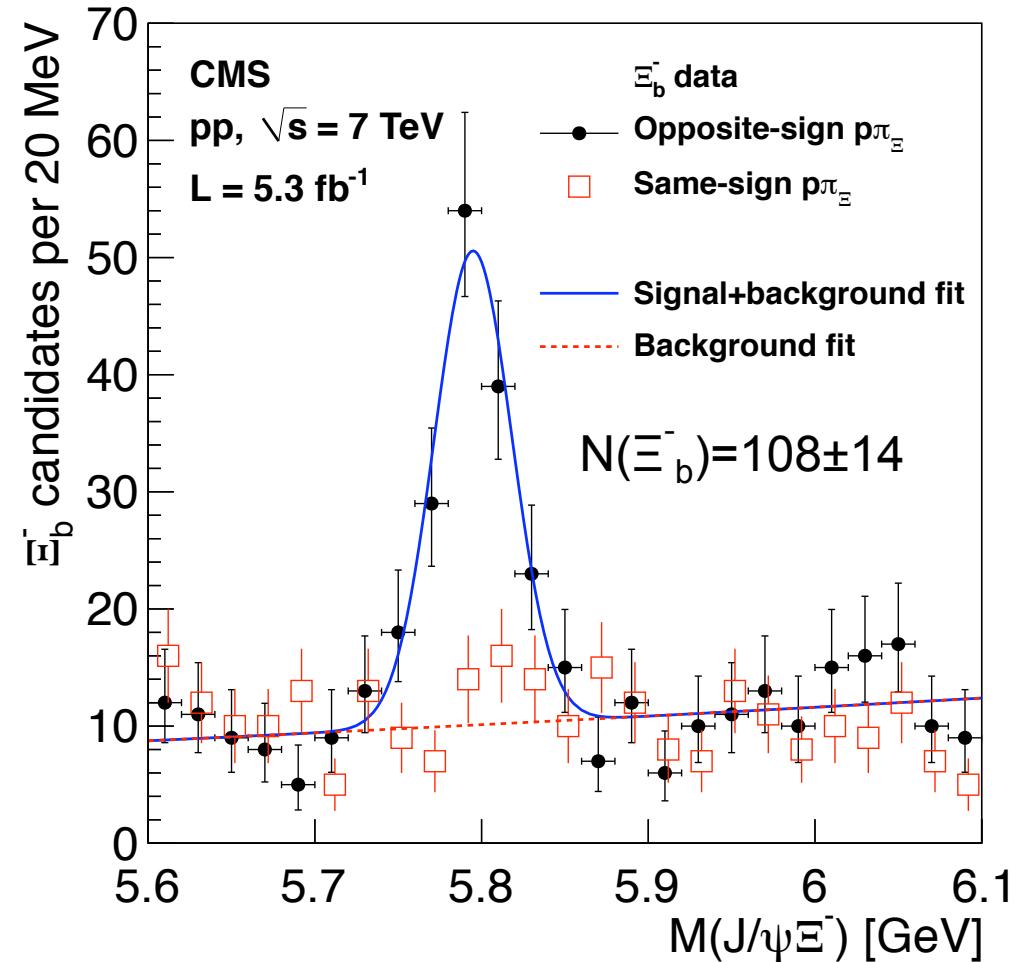


Closest PV to
 Ξ_b^* trajectory



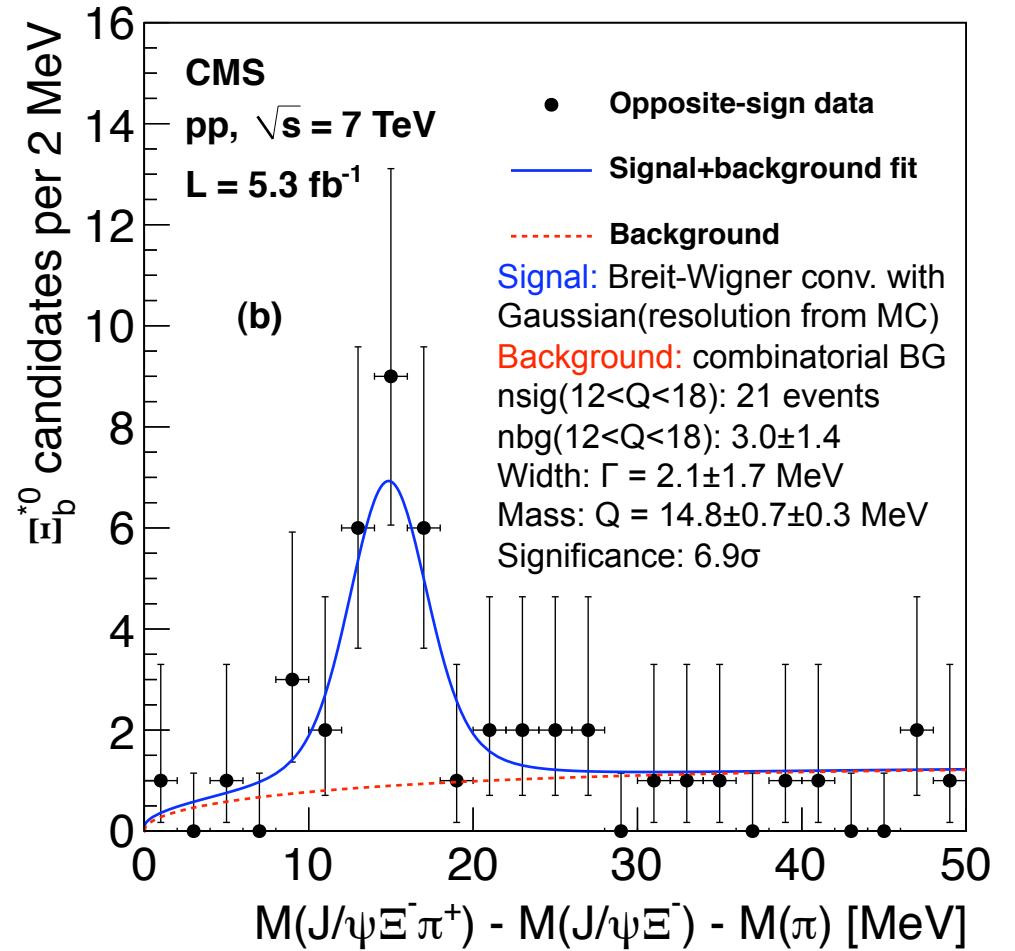
Ξ_b^- reconstruction

- Search strategy to maximize Ξ_b^- yield
 $\Xi_b^- \rightarrow J/\psi(\mu\mu)\Xi^-(\Lambda\pi^-)$ with $\Lambda \rightarrow p\pi^-$
- Selection cuts determined with optimization algorithm on data
 - Randomly vary selection and keep better combination
 - Select on track d_0/σ , vertex displacement significance, pointing angles, vertex confidences, and track and resonance p_T
 - 30 variables in total
- Last step to add prompt π consistent with Ξ_b^- direction with $p_T > 250$ MeV



Ξ_b^* signal

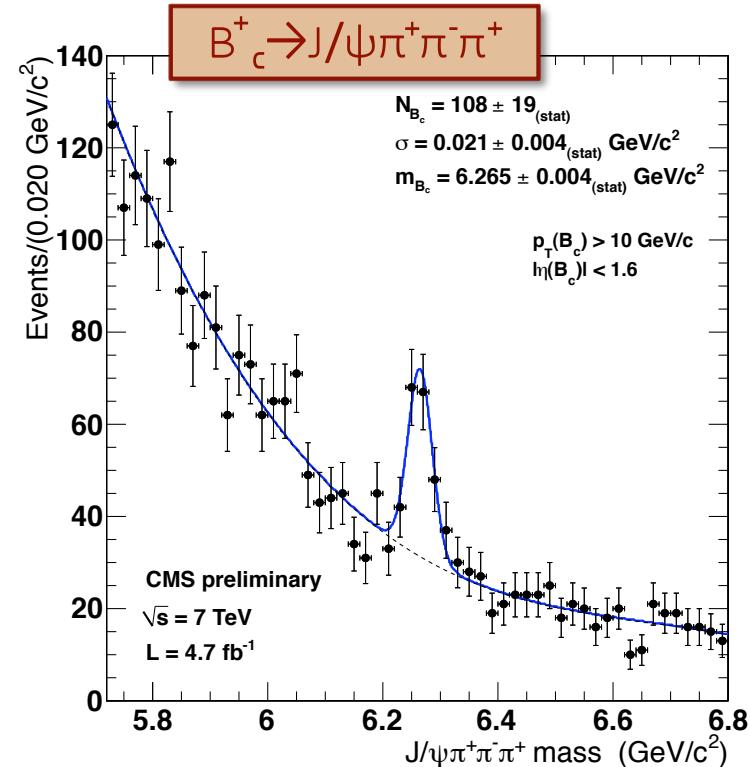
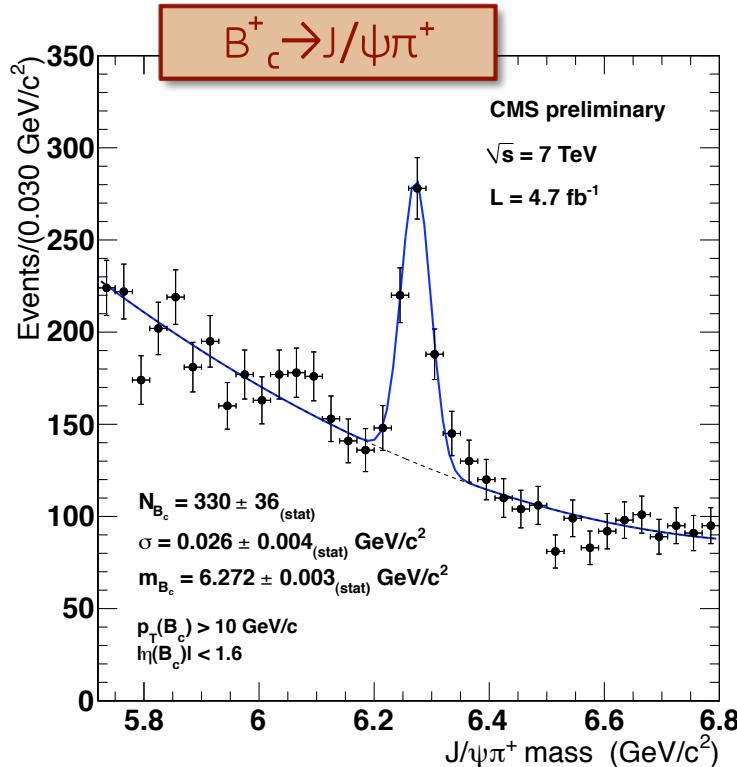
- Background dominated by random $\Xi_b \pi^+$ combinations
 - Obtain with toy model from data shapes for $p(\Xi_b)$, $p(\pi)$ and opening angle
 - Consistent with wrong-sign Q value distribution
- Significance determination from $\ln(\mathcal{L}_{s+d}/\mathcal{L}_0) = 6.9$
- Confirmed with toys varying backgrounds within uncertainties including LEE = 5.7σ
- Measured mass: $M(\Xi_b^*) = 5945.0 \pm 0.7 \pm 0.3 \pm 2.7$ (PDG) MeV



B_c^+ decays

- B_c^+ ground state of bound $b\bar{c}$ system
- Offers access to two different heavy quarks
- Large LHC datasets allows for hundred's of reconstructed B_c^+ at CMS
- Observed in two decay channels:
 - $B_c^+ \rightarrow J/\psi \pi^+$
 - $B_c^+ \rightarrow J/\psi \pi^+ \pi^- \pi^+$

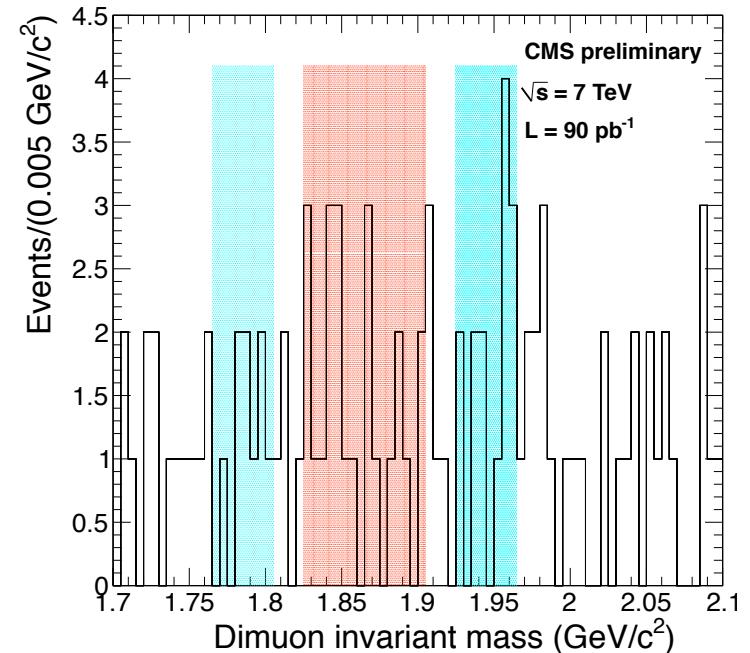
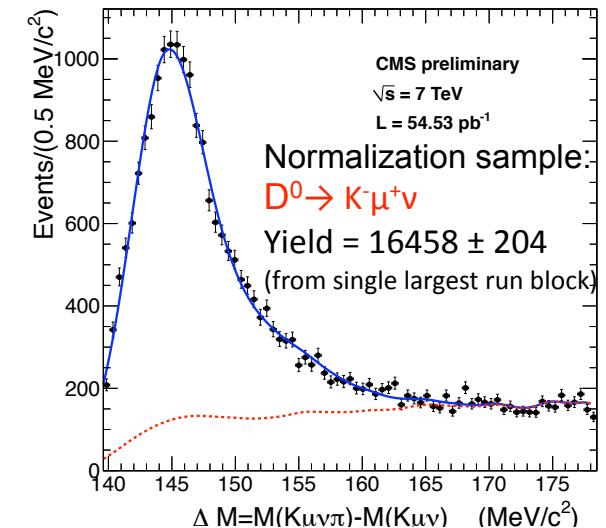
CMS-PAS-BPH-11-003



Search for $D^0 \rightarrow \mu^+ \mu^-$

CMS-PAS-BPH-11-017

- $D^0 \rightarrow \mu^+ \mu^-$ highly suppressed in SM ($\sim 10^{-13}$), but enhanced in many NP scenarios
- Analysis strategy
 - Use D^0 tagged by combination with prompt π to make D^*
 - Measure $\frac{D^{*+} \rightarrow D^0(\mu^-\mu^+)\pi^+}{D^{*+} \rightarrow D^0(K^-\mu^+\nu)\pi^+}$ to cancel many systematic unc.
 - Limitation: must use low p_T single μ trigger (from 7 run periods with different thresholds in 2010/11 data)
 - Estimation of background in signal region determined from sidebands



D⁰→ μ⁺μ⁻ results

- New Physics can enhance the branching ratio by several orders of magnitude

$$B(D^0 \rightarrow \mu^+ \mu^-) \leq B(D^0 \rightarrow K^- \mu^+ \nu) \times \frac{N(\mu\mu)}{N(K\mu\nu)} \times \frac{a(K\mu\nu)}{a(\mu\mu)} \times \frac{\epsilon_{\text{trig}}(K\mu\nu)}{\epsilon_{\text{trig}}(\mu\mu)} \times \frac{\epsilon_{\text{rec}}(K\mu\nu)}{\epsilon_{\text{rec}}(\mu\mu)}$$

- No signal evidence
 - Predicted background = 23 events
 - Signal region yield = 23 events
- $B(D^0 \rightarrow \mu^+ \mu^-) \leq 5.4 * 10^{-7}$ (90% CL)
- Although this upper limit is not the best limit for this FCNC decay, it is the first time a semi-leptonic decay has been used as the normalization
- Prospects for CMS: lots more data available, but requires new analysis strategy with double μ trigger

Search for $B^0_{(s)} \rightarrow \mu^+ \mu^-$

JHEP 04 (2012) 033

- $B^0_{(s)} \rightarrow \mu^+ \mu^-$ suppressed in SM, but highly sensitive to NP, such as high $\tan \beta$ SUSY or extended Higgs sectors
- Select a pair of oppositely charged, displaced, isolated muons to PV
- Reject background from
 - Combinatorial dimuons
 - Peaking B decays with decay-in-flight muons
- Signal efficiency observed to be independent of N_{PV}
- Normalize signal candidate to $B^+ \rightarrow J/\psi K^+$
- Blind analysis, optimized cut and count selections for two regions
 - **Barrel** $|\eta| < 1.4$ ($\sigma(m_{\mu\mu}) \sim 40$ MeV)
 - **Endcap** $|\eta| > 1.4$ ($\sigma(m_{\mu\mu}) \sim 60$ MeV)

$$SM-B(B_s \rightarrow \mu^+ \mu^-) = (3.2 \pm 0.1) \times 10^{-9}$$

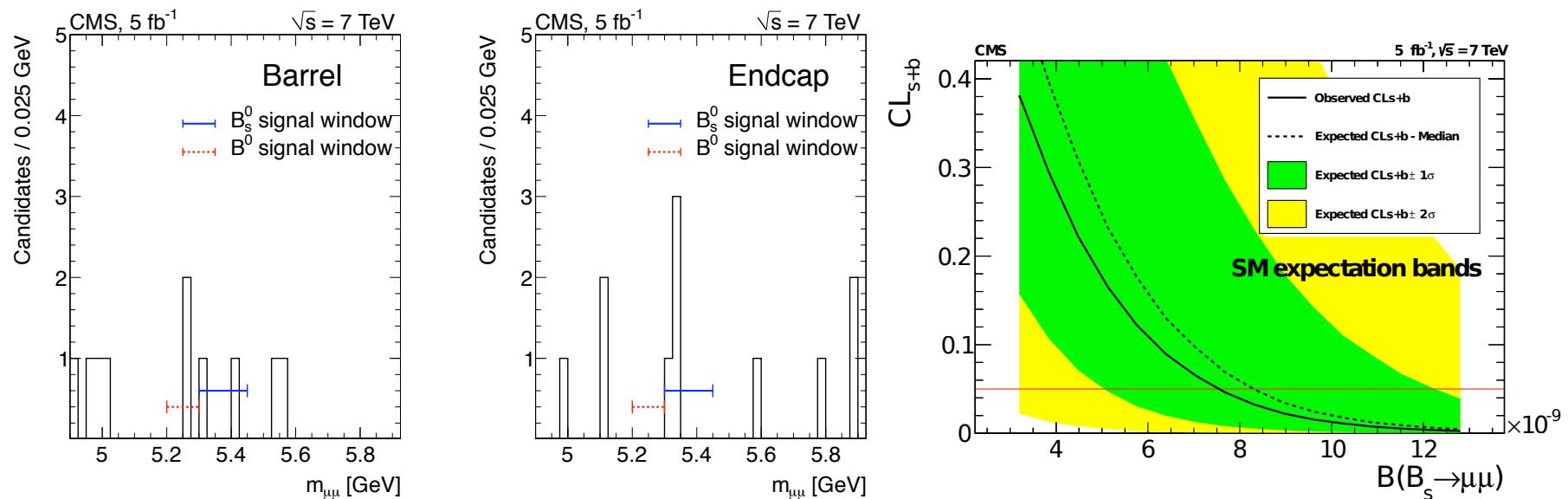
$$SM-B(B^0 \rightarrow \mu^+ \mu^-) = (1.1 \pm 0.1) \times 10^{-10}$$

$B^0_{(s)} \rightarrow \mu^+ \mu^-$ results

Observation consistent with background + SM signal

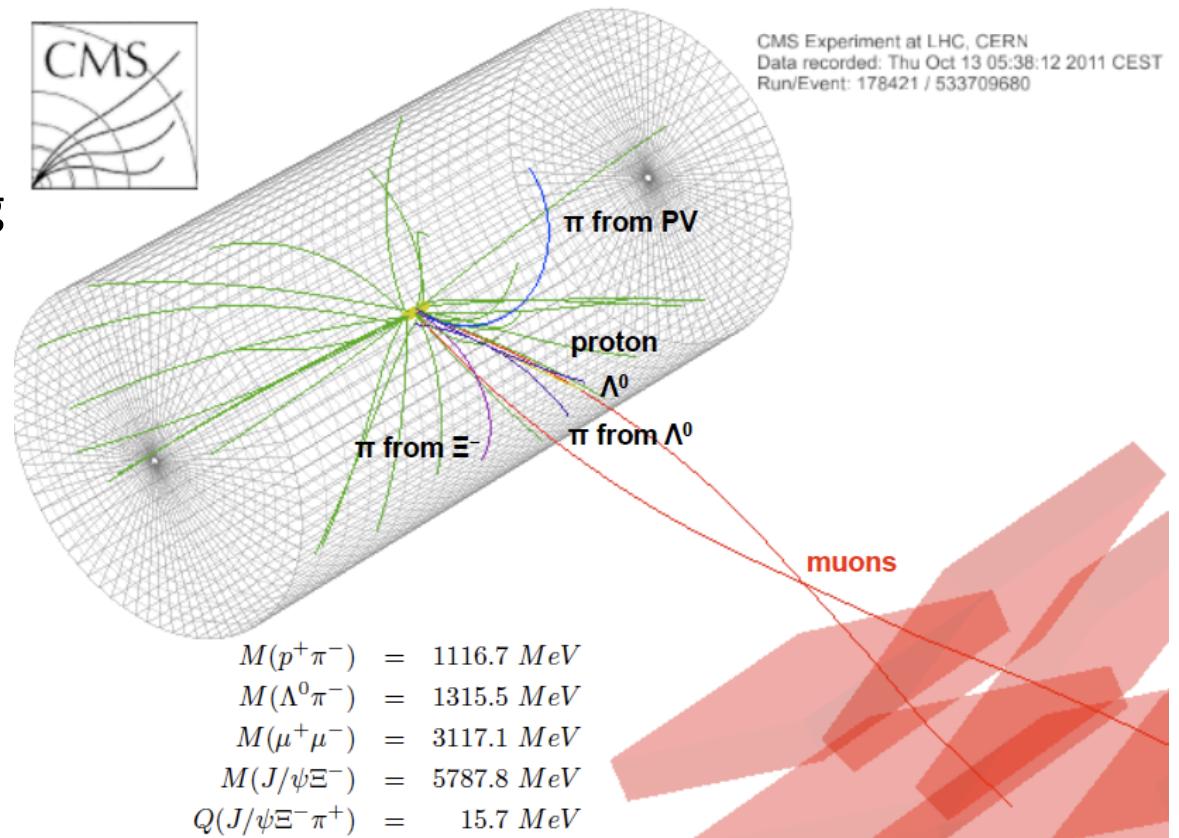
Variable	$B^0 \rightarrow \mu^+ \mu^-$ Barrel	$B_s^0 \rightarrow \mu^+ \mu^-$ Barrel	$B^0 \rightarrow \mu^+ \mu^-$ Endcap	$B_s^0 \rightarrow \mu^+ \mu^-$ Endcap
Signal (SM)	0.24 ± 0.02	2.70 ± 0.41	0.10 ± 0.01	1.23 ± 0.18
Combinatorial bg	0.40 ± 0.34	0.59 ± 0.50	0.76 ± 0.35	1.14 ± 0.53
Peaking bg	0.33 ± 0.07	0.18 ± 0.06	0.15 ± 0.03	0.08 ± 0.02
Sum	0.97 ± 0.35	3.47 ± 0.65	1.01 ± 0.35	2.45 ± 0.56
Observed	2	2	0	4

	upper limit (95%CL)	observed	(median) expected
$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$	7.7×10^{-9}		8.4×10^{-9}
$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)$	1.8×10^{-9}		1.6×10^{-9}



Conclusions

- $\Delta\Gamma_s$ in agreement with the SM expectation and some other experimental results, first step towards measurement of mixing phase ϕ_s at CMS
- Λ_b production shows unexpected meson/baryon differences
- First observation of new b baryon state, Ξ_b^*
- Search for $B_s \rightarrow \mu\mu$ closing in on SM sensitivity
- Many more measurements to come..



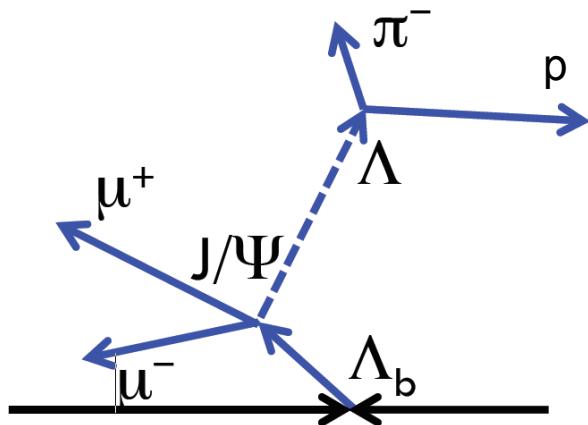
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH>

Backup

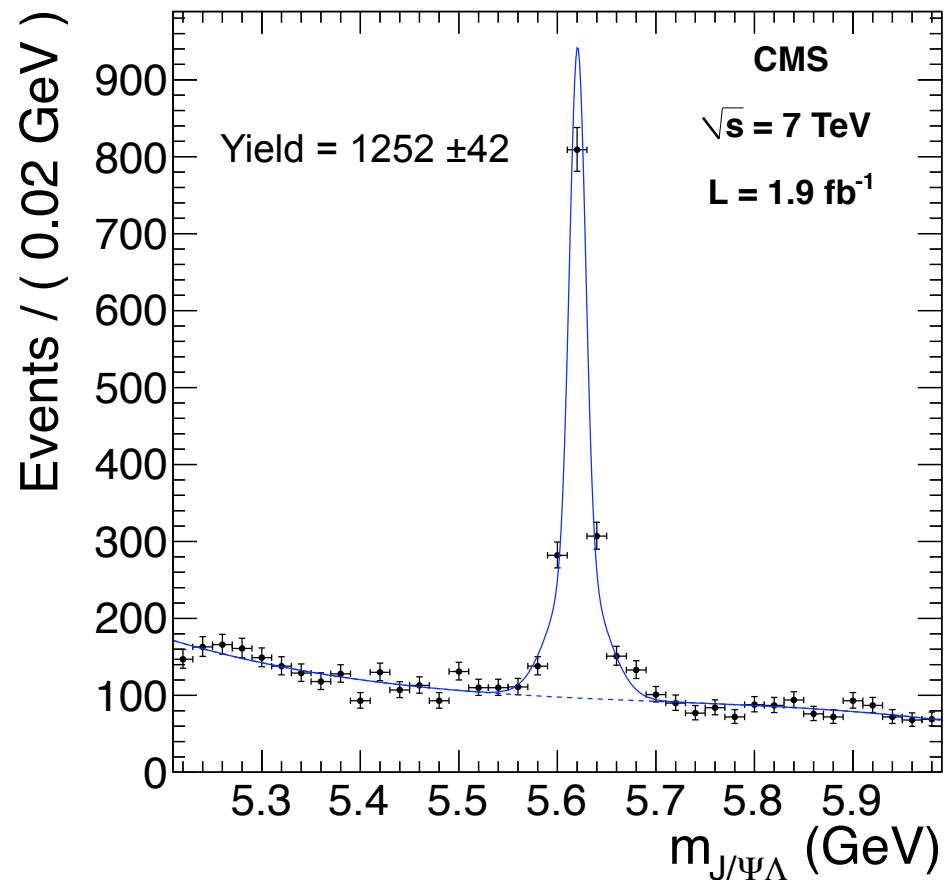
$\Delta\Gamma_s$ in $B_s \rightarrow J/\Psi \phi$ world results

Experiment	$\Delta\Gamma_s$	Stat. Unc.	Syst. Unc.	Ref.
D0	0.179	0.060	0.059	PRD85, 032006(2012)
CDF	0.068	0.026	0.007	CDF-Public- Note-10778
LHCb	0.116	0.018	0.006	LHCb- CONF-2012-002
ATLAS	0.053	0.021	0.008	arXiv:1208.0572
CMS	0.048	0.024	0.003	CMS-PAS- BPH-11-006

Λ_b production measurement



- Λ_b reconstructed in decays to $J/\Psi(\mu^+\mu^-)$ $\Lambda(p\pi)$
- Measure yield and efficiency in bins of p_T and rapidity to determine differential cross section
- Particle- antiparticle differences studied as well



Ξ_b^* background shape

- Background dominated by random $\Xi_b^- \pi^+$
- Background shape from wrong sign pions
 - Toy model from data shapes for $p(\Xi_b)$, $p(\pi)$ and angle between Ξ_b and π , assumed to be uncorrelated
 - Fit toy results for shape
 - Compares well with nominal sign distribution

