B hadron properties from CMS

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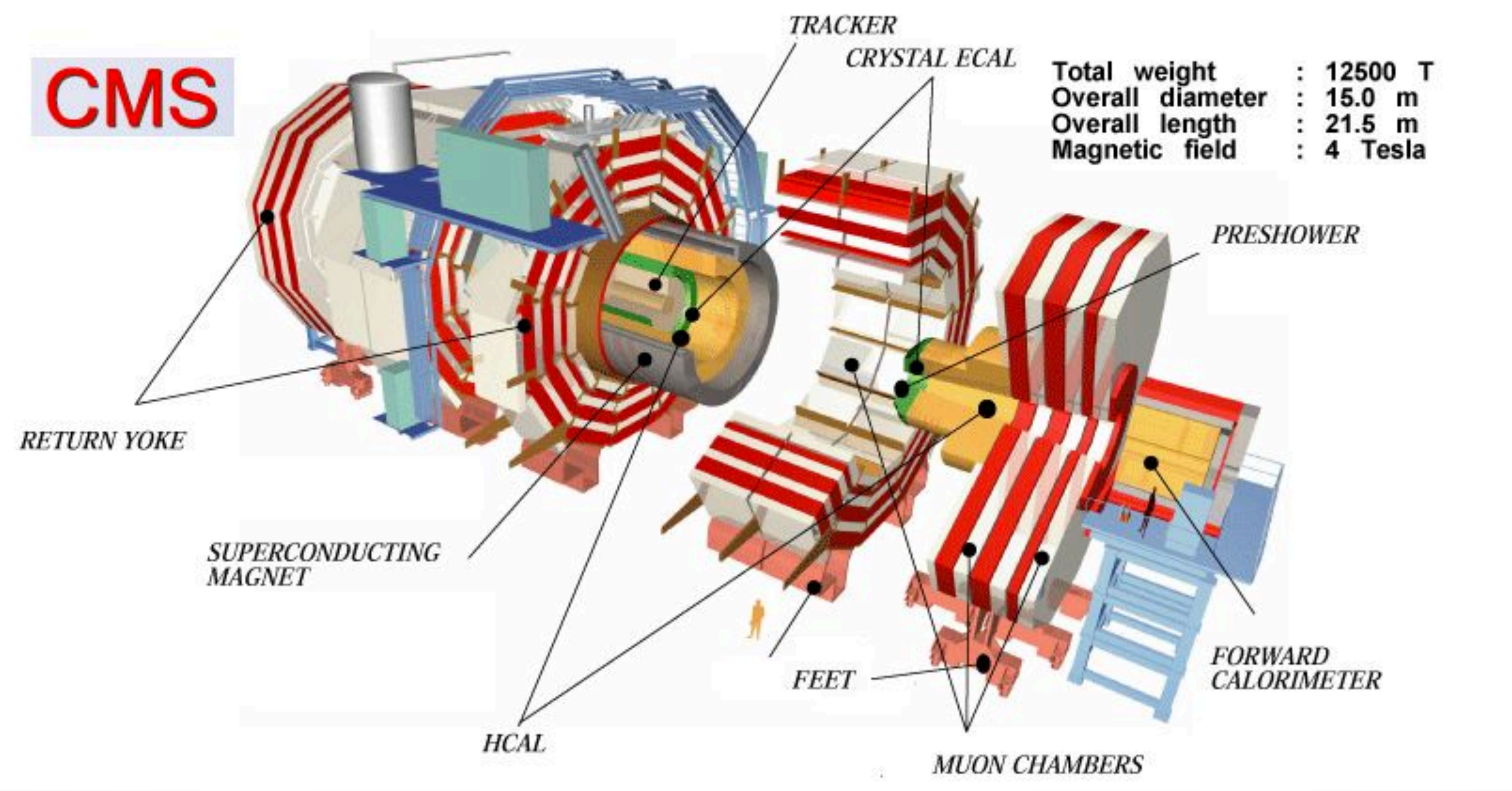
Outline

- Introduction
- The CMS detector & the B physics program
- CP-Violation in B^0_s.
- $\mathcal{B}(B^0_s \to J/\psi \; f_0(980))$
- B_c meson decays:
  - $\mathcal{B}(B_c^+ \to J/\psi \; \boldsymbol{n} \pi^\pm)$
- Rare decays as new physics probes:
  - $B^0_{(s)} \to \mu^+\mu^-$ & $B \to K\mu^+\mu^-$
- Summary and outlook

Introduction

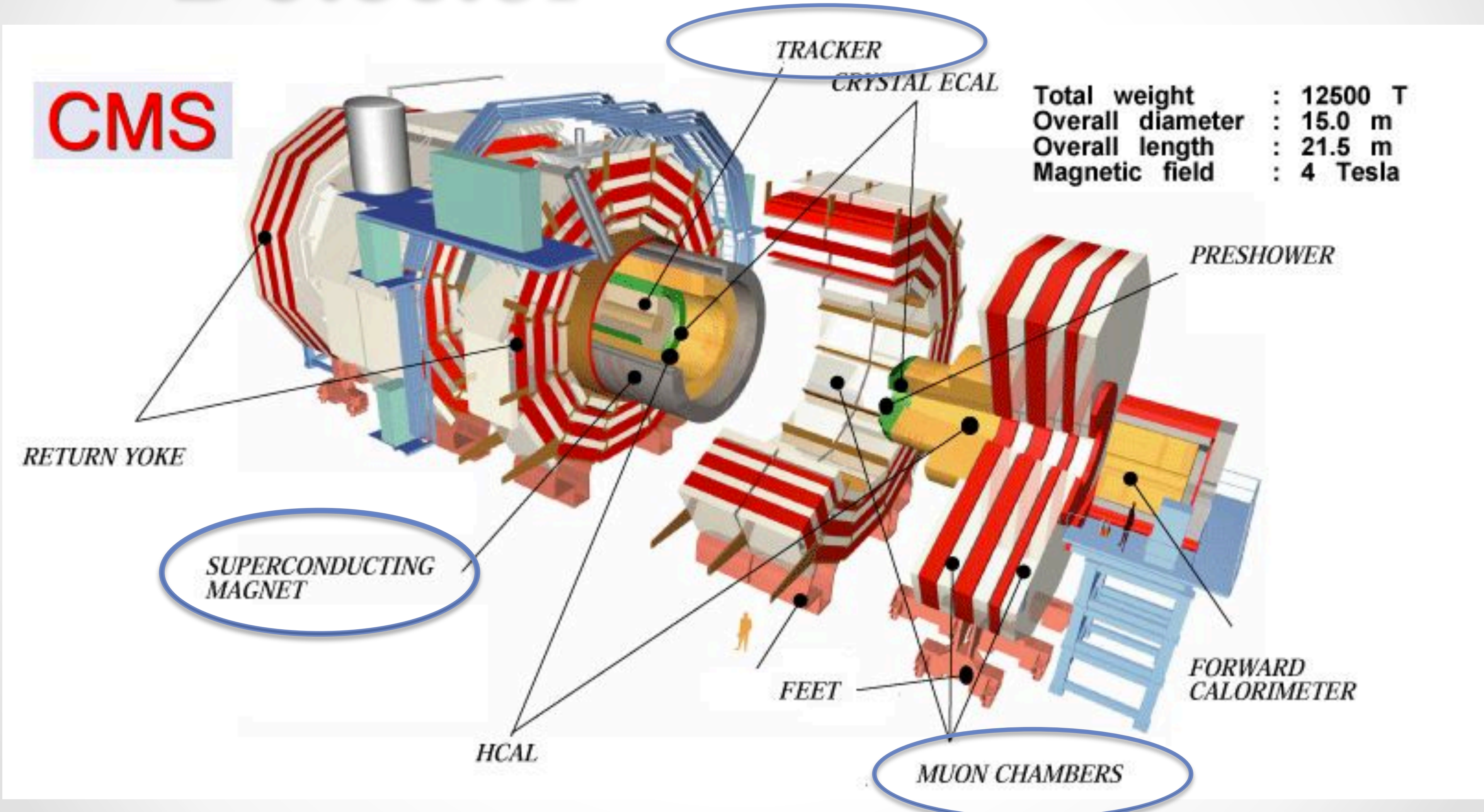
- LHC: pp collisions @ 7-8 (Run I) & 13 TeV (Run II) $\Rightarrow$ large B hadron production.
- Precise measurements of B hadrons properties help to improve or constrain QCD models, and could provide signs of new physics or constrain BSM models.
- CMS is able to provide several measurements of B hadrons properties that are competitive with results from other experiments, such as in:
  - B mesons and baryons: masses, lifetimes, BRs, polarizations, etc.
  - CP-Violation in B mesons.
  - B rare decays: branching ratios, angular parameters.
  - …

CMS Detector

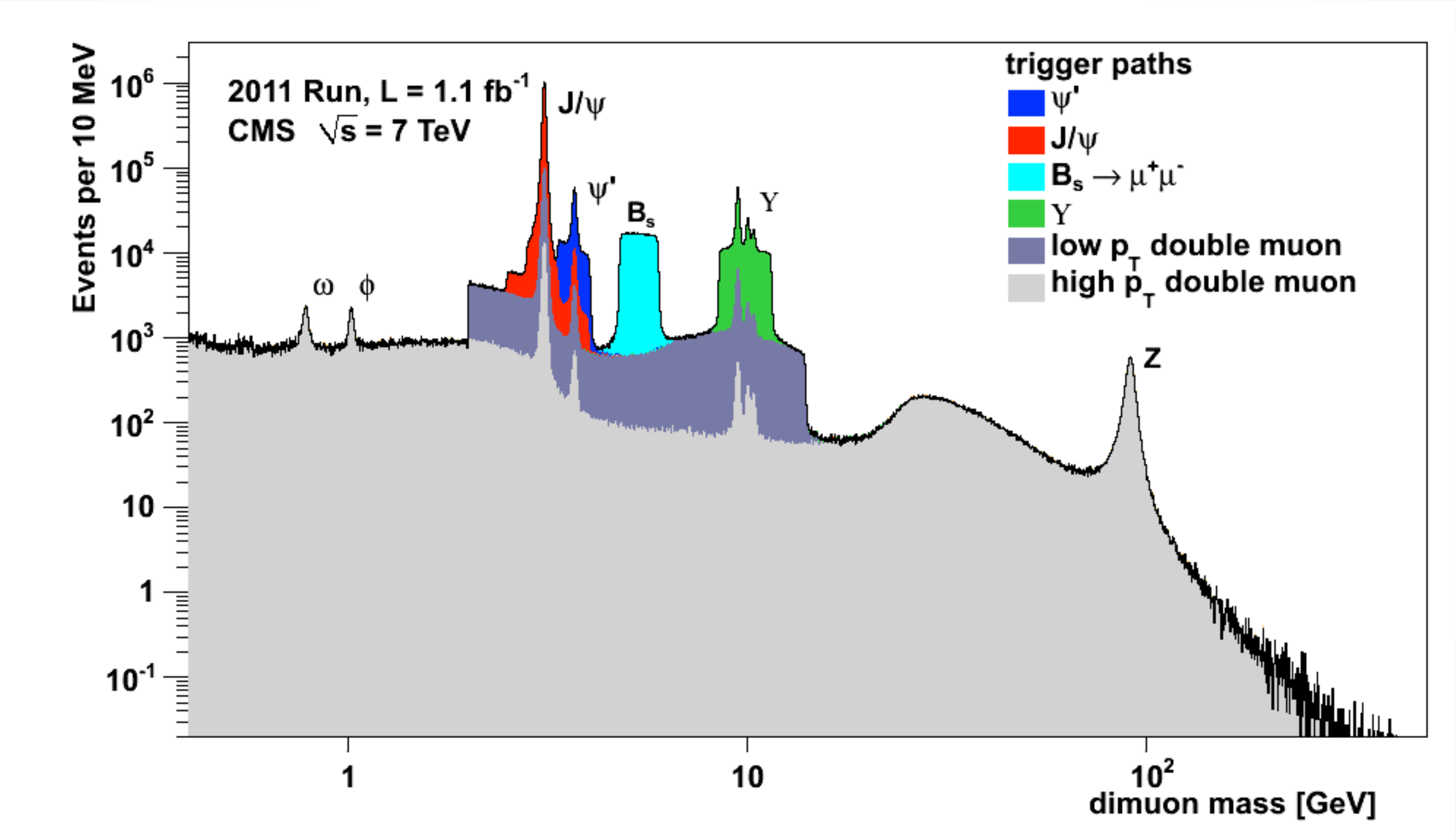


CMS Detector

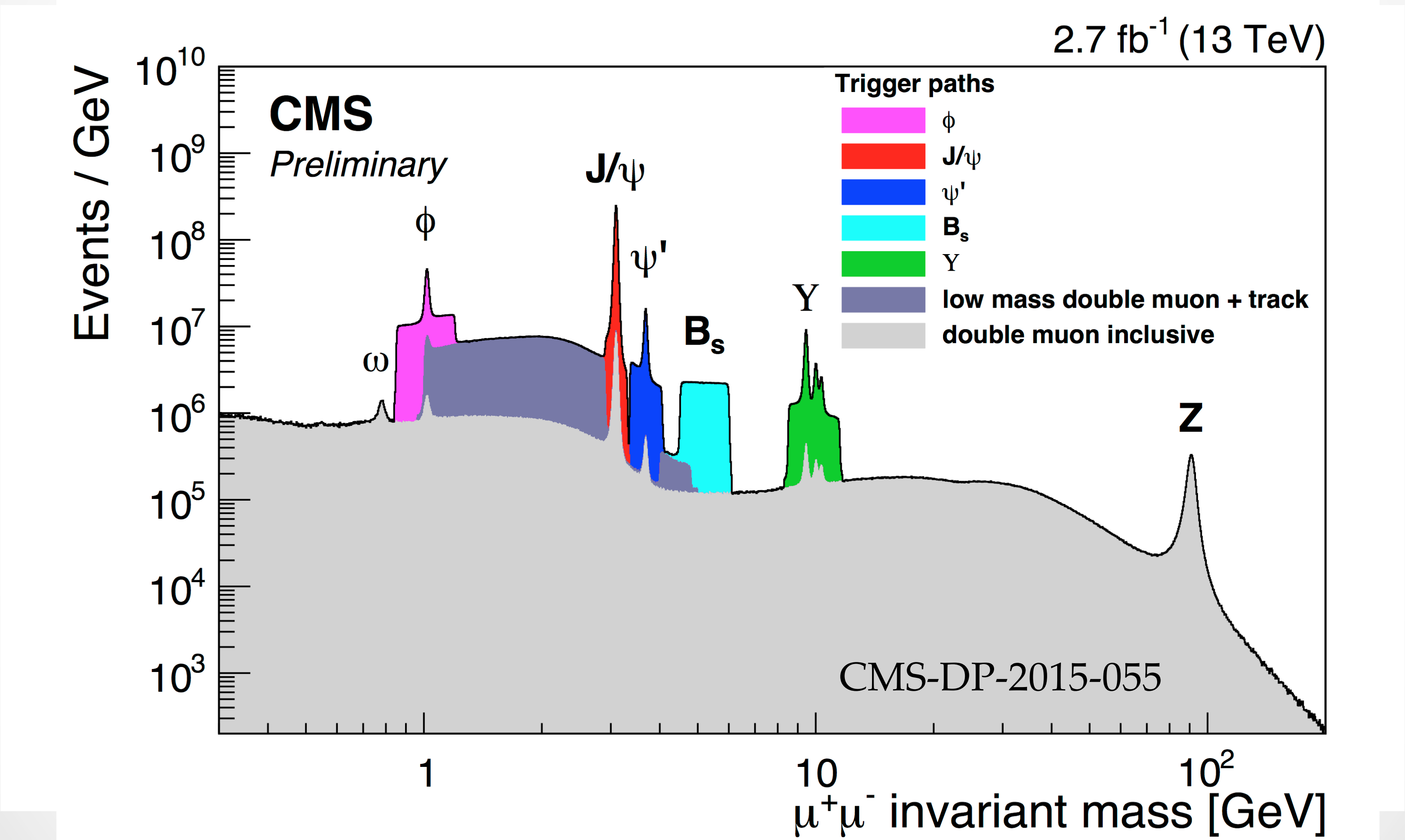
CMS B Physics program ↔ Excellent μ ID + Track and vertex reconstruction



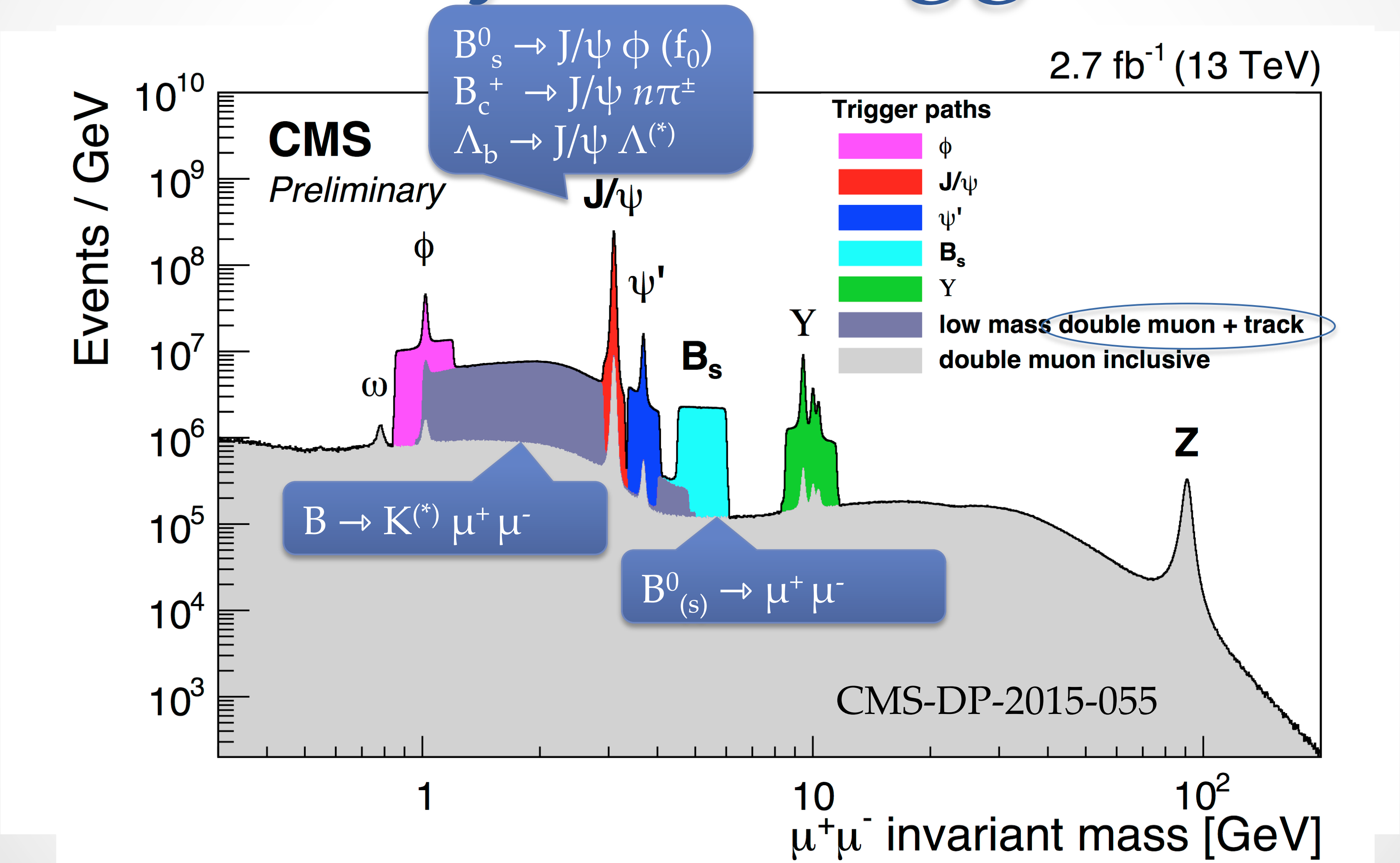
B Physics Triggers

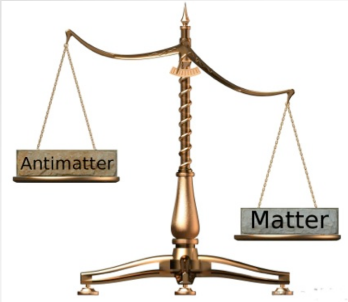


B Physics Triggers

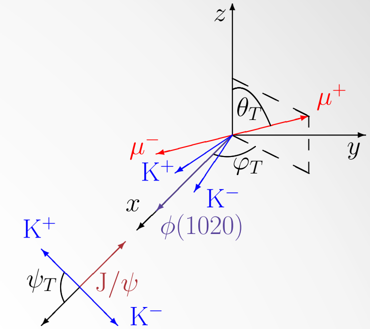


B Physics Triggers





CPV in $B^0_s \to J/\psi\,\phi$



- CPV phase ϕ_s from interference btw direct and through mixing decays.
- Non-standard particles in loops could change the SM prediction of ϕ_s.
- 3+1 angular-time analysis to disentangle CP-odd/even contributions.

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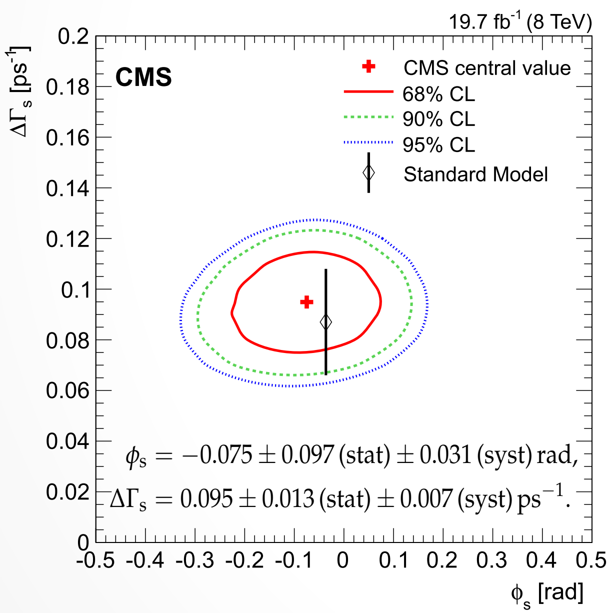
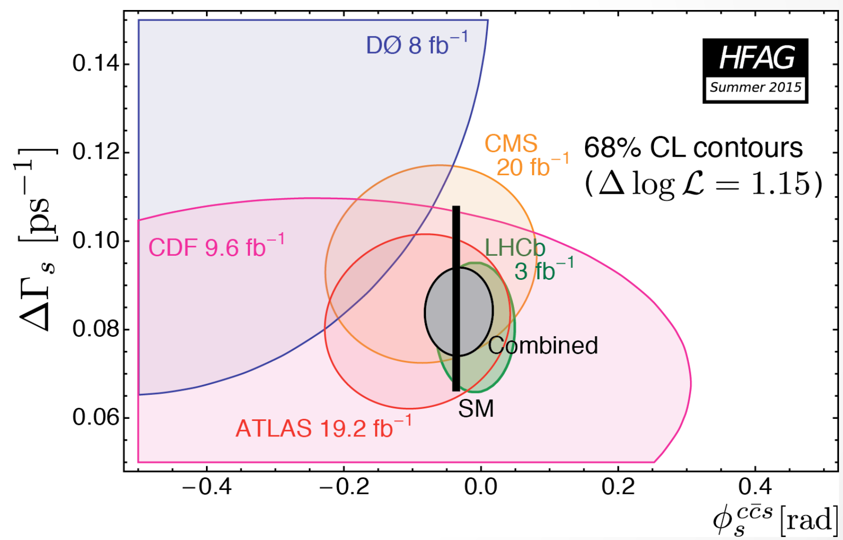
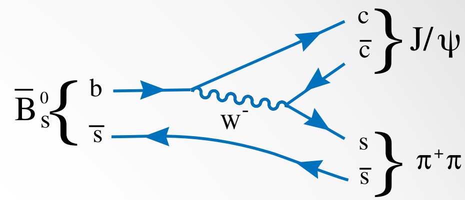




$B^0_s \to J/\psi\,\phi$: ATLAS, CDF, CMS, D0.
$B^0_s \to J/\psi KK$: LHCb.
$B^0_s \to J/\psi\pi\pi$: LHCb.
$B^0_s \to J/\psi\, D_s D_s$: LHCb.
[Refs. in http://www.slac.stanford.edu/xorg/hfag/osc/summer_2015/HFAG_phis_inputs.pdf]

See "Mixing and CPV at CMS" talk (T. Tuuli Jarvinen) given on May 2

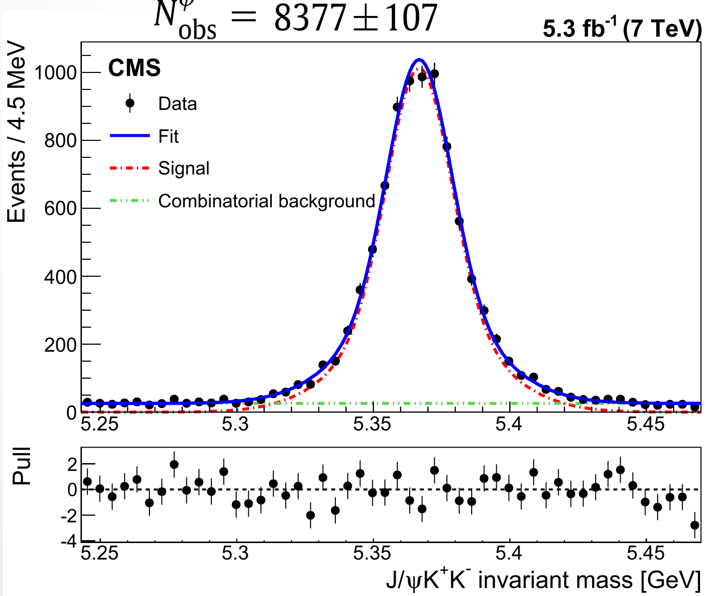
$B^0_s \to J/\psi\ f_0(980)$



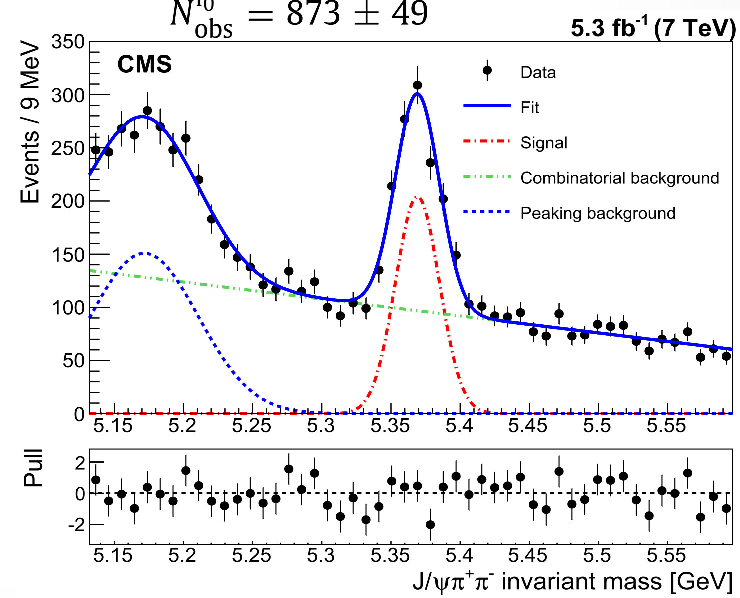
- CPV analysis is simplified using $B^0_s \to J/\psi\ f_0(\pi^+\pi^-)$ wrt $B^0_s \to J/\psi\ \phi\,(K^+K^-)$ decays. It is also a pure CP-odd eigenstate.
- In any case, it is important to measure its production relative to $B^0_s \to J/\psi\ \phi\,(1020)$:

$$R_{f_0/\phi} = \frac{\mathcal{B}(B^0_s \to J/\psi f_0)\,\mathcal{B}(f_0 \to \pi^+\pi^-)}{\mathcal{B}(B^0_s \to J/\psi\phi)\,\mathcal{B}(\phi \to K^+K^-)} = \frac{N^{f_0}_{obs}}{N^{\phi}_{obs}}\,\epsilon^{\phi/f_0}_{reco}$$

$N^{\phi}_{obs} = 8377 \pm 107$

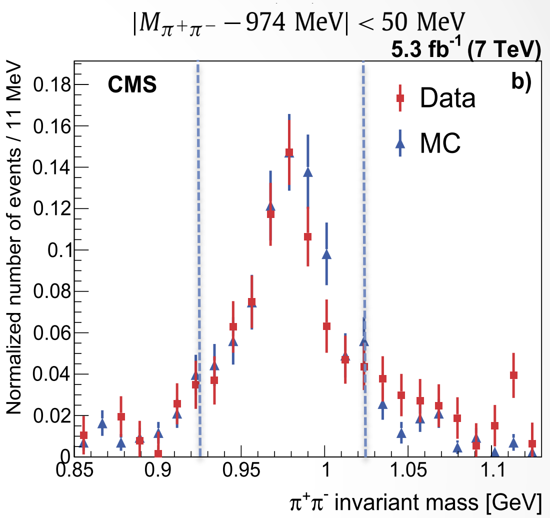


$N^{f_0}_{obs} = 873 \pm 49$



Analysis around the $f_0(980)$ state

- Di-pion mass around Δ = 50 MeV ~ $\Gamma^{(BW)}_{f0(980)}$ of the fitted mass in data.
  - Region around the $f_0(980)$ is pure enough to be used to measure $\tau(B^0_s)_{CP\text{-odd}}$ and ϕ_s.
- MC ($\Gamma^{(BW)}_{f0(980)} \equiv 50$ MeV) describes data well in the selected region:
  - No significant deviation from BW model found. Flatté model also tested.
  - Interferences (mainly w/ $f_0(1370)$) effects on $\epsilon^{\varphi/f0}_{reco}$ are estimated small by comparing the fitted model by LHCb for different f_0 fraction scenarios* and the simple BW.
  - Other Res. or Non-Res. contaminations are suppressed; effects estimated to be small.



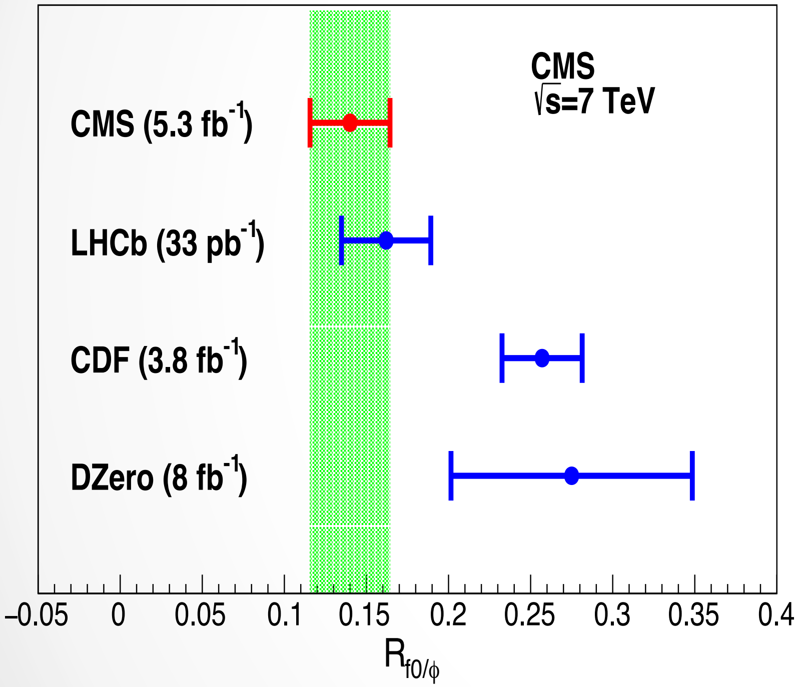
Systematic sources	%
B^0_s fit variant	2.1
Decay models in MC	6.2
f_0 width in MC (±10 MeV)	8.6
BW vs Flatté models in MC	5.8
Finite MC sample	7.1
R or NR contaminations (Δ = 100 MeV)	6.4
Interferences	5.6
Total uncertainty	**16.5**

* PRD 86, 052006 (2012)

$\mathcal{B}(B^0_s \to \psi f_0(\pi\pi))/\mathcal{B}(B^0_s \to \psi\phi(KK))$

$$R_{f_0/\phi}\big|_{|M_{\pi^+\pi^-}-974\text{ MeV}|<50\text{ MeV}} = 0.140 \pm 0.008\ (\text{stat})\ \pm 0.023\ (\text{syst})$$

PLB 756 (2016) 84–112



- Other experiments measure ratio in different M($\pi^+\pi^-$) ranges:

$$R_{f_0/\phi}\big|_{|M_{\pi^+\pi^-}-974\text{ MeV}|<90\text{ MeV}} = 0.162 \pm 0.022\ (\text{stat})\ \pm 0.016\ (\text{syst})$$

LHCb [PLB 698 (2011) 115–122]

$$R_{f_0/\phi}\mathcal{B}(\phi \to K^+K^-) = 0.139 \pm 0.006\ (\text{stat})\ \pm\ ^{0.025}_{0.012}\ (\text{syst})$$

LHCb [PRD 86, 052006 (2012)]*

$$R_{f_0/\phi}\big|_{0.85<M_{\pi^+\pi^-}<1.2} = 0.257 \pm 0.020\ (\text{stat})\ \pm 0.014\ (\text{syst})$$

CDF (PRD 84, 052012 (2011))

$$R_{f_0/\phi}\big|_{0.91<M_{\pi^+\pi^-}<1.05} = 0.275 \pm 0.041\ (\text{stat})\ \pm 0.061\ (\text{syst})$$

D0 [PRD 85, 011103(R) (2012)]

Consistent with theoretical expectation of $R_{f0/\phi} \approx 0.2$ [Stone & Zhang, PRD 79, 074024 (2009)].

$^*\mathcal{B}(\phi \to K^+K^-) = (48.9 \pm 0.5)\%$

$\mathcal{B}(B^0_s \to \psi f_0(\pi\pi)) / \mathcal{B}(B^0_s \to \psi \phi(KK))$

$$R_{f_0/\phi}\big|_{|M_{\pi^+\pi^-}-974\ \mathrm{MeV}|<50\ \mathrm{MeV}} = 0.140 \pm 0.008\ (\mathrm{stat})\ \pm 0.023\ (\mathrm{syst})$$

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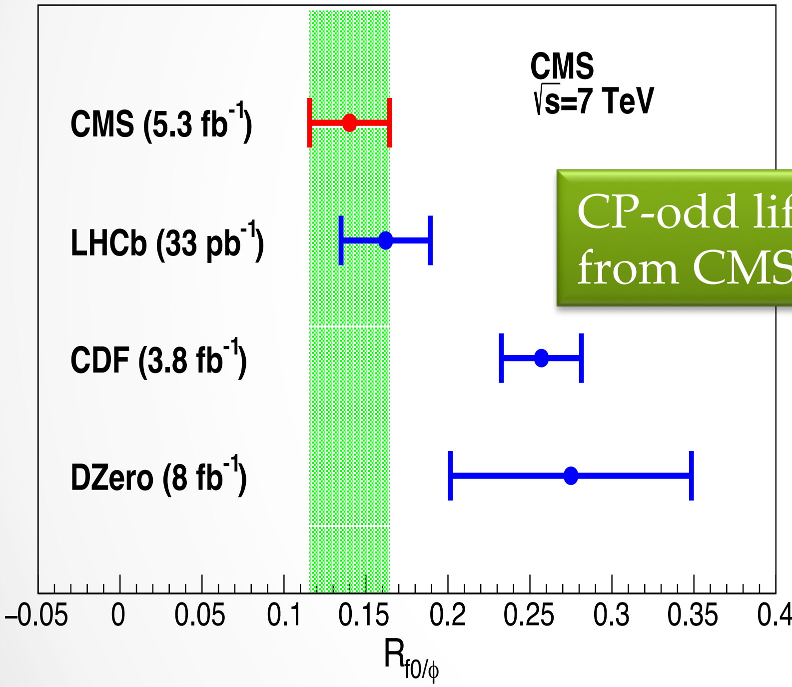

- Other experiments measure ratio in different $M(\pi^+\pi^-)$ ranges:

$R_{f_0/\phi}\big|_{|M_{\pi^+\pi^-}-974\ \mathrm{MeV}|<90\ \mathrm{MeV}} =$ ... (syst) — LHCb [PLB 698 (2011) 115–122]

CP-odd lifetime measurement from CMS is coming soon!

... $) =$ $0.139 \pm 0.006\ (\mathrm{stat})\ \pm {}^{0.025}_{0.012}\ (\mathrm{syst})$ — LHCb [PRD 86, 052006 (2012)]*

$R_{f_0/\phi}\big|_{0.85<M_{\pi^+\pi^-}<1.2} =$ $0.257 \pm 0.020\ (\mathrm{stat})\ \pm 0.014\ (\mathrm{syst})$ — CDF (PRD 84, 052012 (2011))

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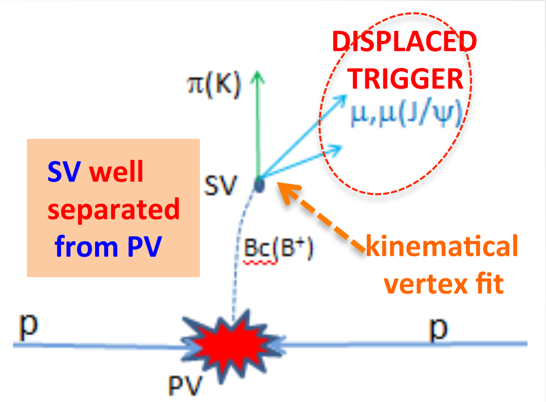
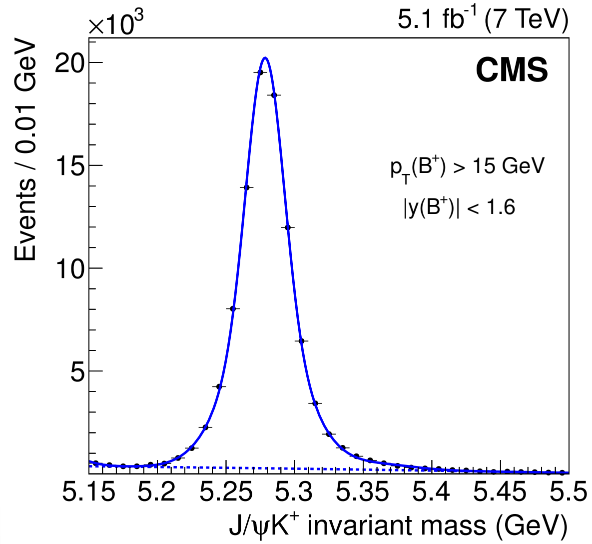
$B_c^+ \rightarrow J/\psi\ n\pi^{\pm}$



- B_C : Unique laboratory to study heavy-quark dynamics.
- *b* and c quarks competing in decay (B_C decays faster than other B hadrons).
- $R_{c/u}$ and R_{Bc} measured in a kinematic region complementary to LHCb.
- X-section measurements can improve/constrain B_C production models.

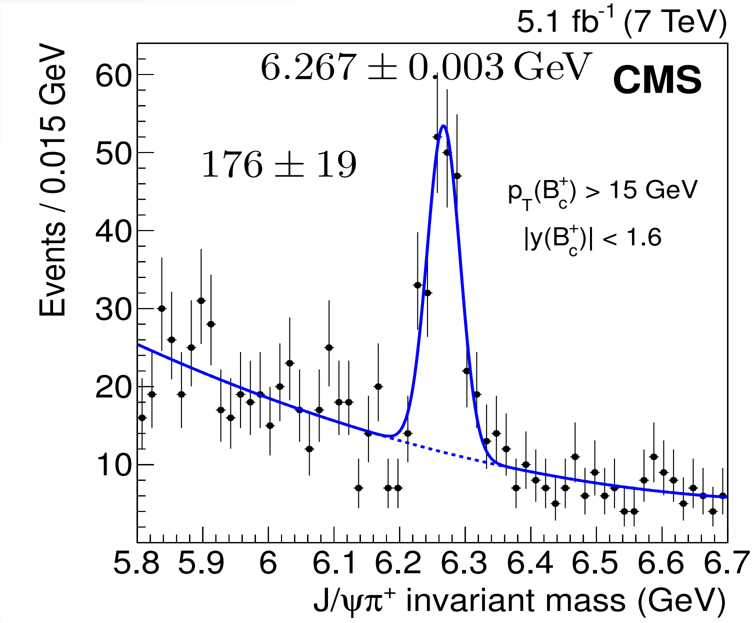
$$R_{c/u} = \frac{\sigma(B_c^+)\mathcal{B}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+)\mathcal{B}(B^+ \to J/\psi K^+)} = \frac{Y_{B_c^+ \to J/\psi\pi^+}}{Y_{B^+ \to J/\psi K^+}}$$

$$R_{B_c} = \frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = \frac{Y_{B_c^+ \to J/\psi\pi^+\pi^+\pi^-}}{Y_{B_c^+ \to J/\psi\pi^+}}$$



Efficiency corrected yields in pT bins using BcVEGPY (B_c) and Pythia (B^+)

$\sigma(B_c^+)\mathcal{B}(B_c^+\to J/\psi\pi^+)$ / $\sigma(B^+)\mathcal{B}(B^+\to J/\psi K^+)$



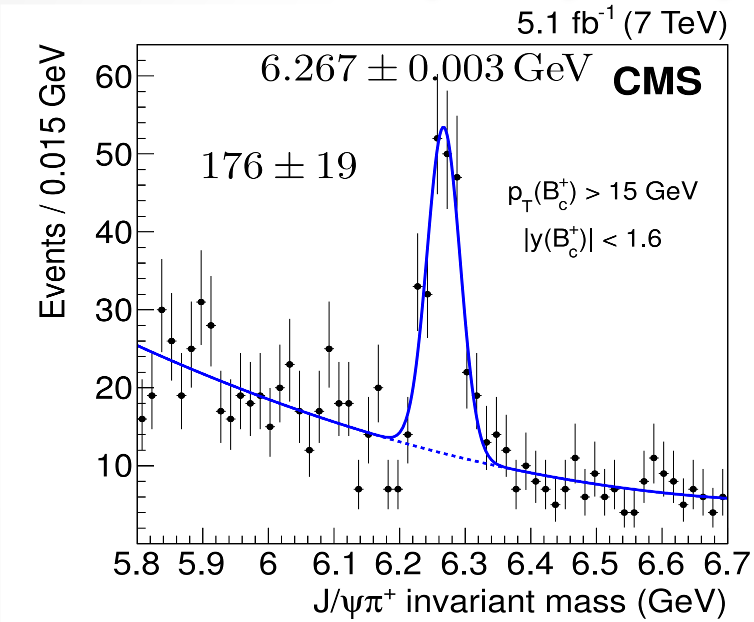
Systematic source	%
Fit variant	5.3
MC sample size	2.1
Efficiency binning	3.1
Total uncertainty	6.5
B_c lifetime	10.4

$$R_{c/u} = [0.48 \pm 0.05\,(\mathrm{stat}) \pm 0.03\,(\mathrm{syst}) \pm 0.05\,(\tau_{B_c})]\%$$

JHEP 01 (2015) 063

- LHCb [PRL 109 (2012) 232001] in the kin. region $p_T > 4$ GeV, $2.5 < |\eta| < 4.5$ measures: $[0.68 \pm 0.10\,(\mathrm{stat}) \pm 0.03\,(\mathrm{syst}) \pm 0.05\,(\tau_{B_c})]\%$
- Difference expected since $\langle p_T(B_c^+)\rangle < \langle p_T(B^+)\rangle$ in the central region.

$\sigma(B_c^+)\mathcal{B}(B_c^+\to J/\psi\pi^+)$ / $\sigma(B^+)\mathcal{B}(B^+\to J/\psi K^+)$



Systematic source	%
Fit variant	5.3
MC sample size	2.1
Efficiency binning	3.1
Total uncertainty	6.5
B_c lifetime	10.4

B_c lifetime measurement from CMS will come soon!

$$R_{c/u} = [0.48 \pm 0.05\,(\text{stat}) \pm 0.03\,(\text{syst}) \pm 0.05\,(\tau_{B_c})]\%$$

JHEP 01 (2015) 063

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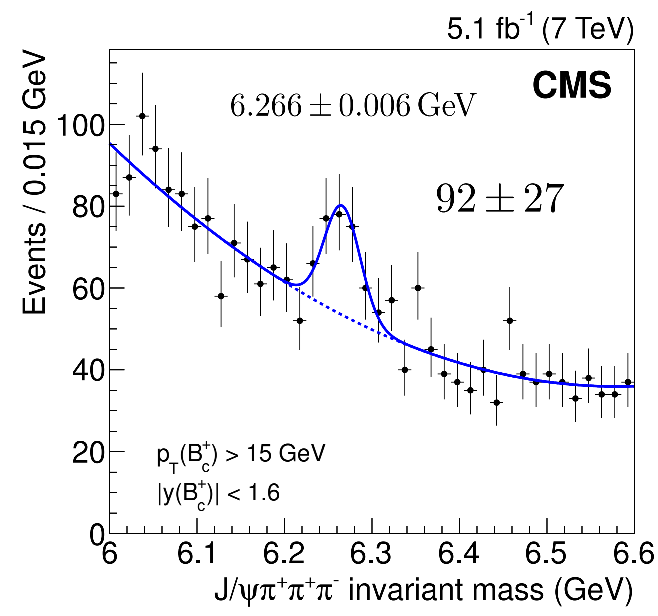
$\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)$ / $\mathcal{B}(B_c^+ \to J/\psi\pi^+)$



Systematic source	%
Fit variant	9.4
MC sample size	4.1
Efficiency fit function	1.0
Efficiency binning	1.9
Tracking efficiency	7.8
Total uncertainty	13.1
Lifetime	$^{+1.6}_{-0.4}$

$$R_{B_c} = 2.55 \pm 0.80\,(\text{stat}) \pm 0.33\,(\text{syst})^{+0.04}_{-0.01}\,(\tau_{B_c})$$

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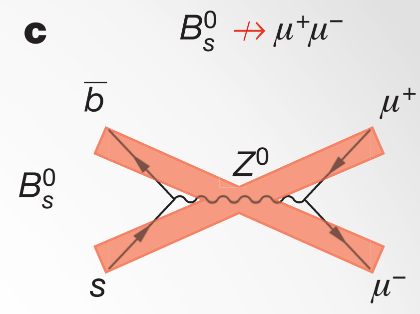
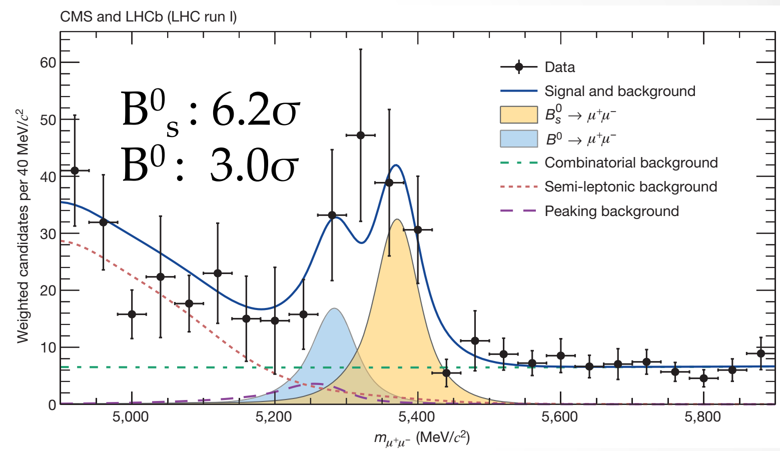
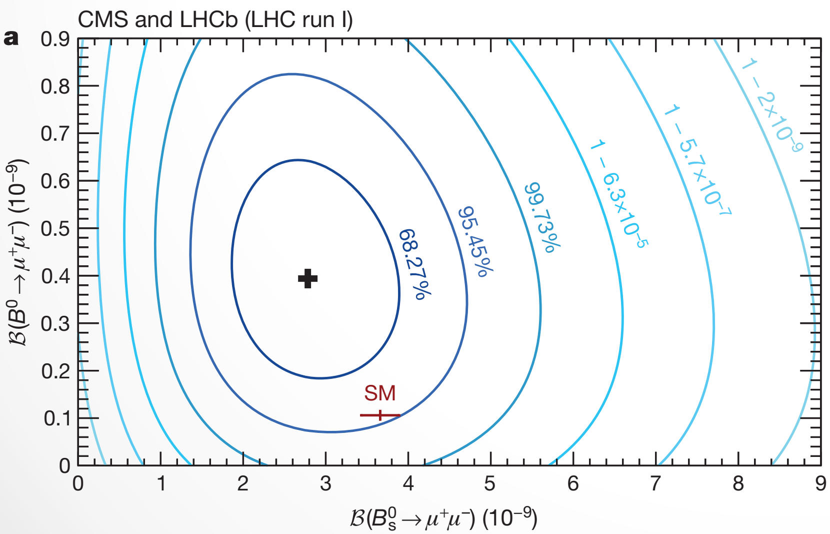
- First confirmation. LHCb measured R_{Bc} = 2.41 ± 0.30(stat) ± 0.33(syst) [PRL 108 (2012) 251802], in complementary kin. region.
- Predictions of R_{Bc}, assuming factorization into $B_c \to J/\psi\, W^{+*}$ and $W^{+*} \to n\,\pi^+$, range btw = 1.5 – 2.3 [PRD 81 (2010) 014005, PRD 81 (2010) 014015].

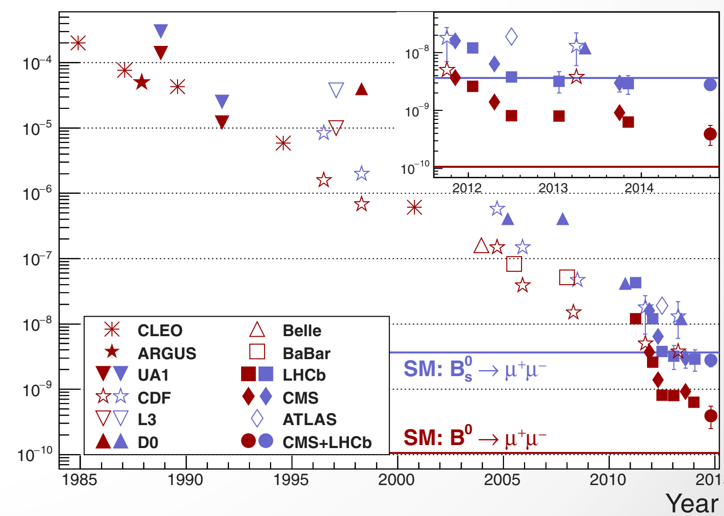
Rare B decays as new physics probes



- Rare decays: FCNC decays forbidden @LO. NP (in penguins/boxes) could modify Wilson coefficients.
- Complementary info: S/P-S ($B^0_s \to \mu^+\mu^-$) vs. V/A ($B \to K^{(*)}\mu^+\mu^-$) interactions.
- Reliable BR predictions within the SM for $\mathcal{B}(B^0_s \to \mu^+\mu^-)$.







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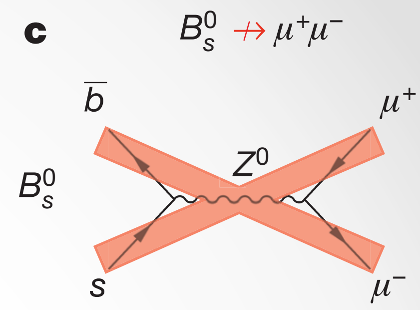

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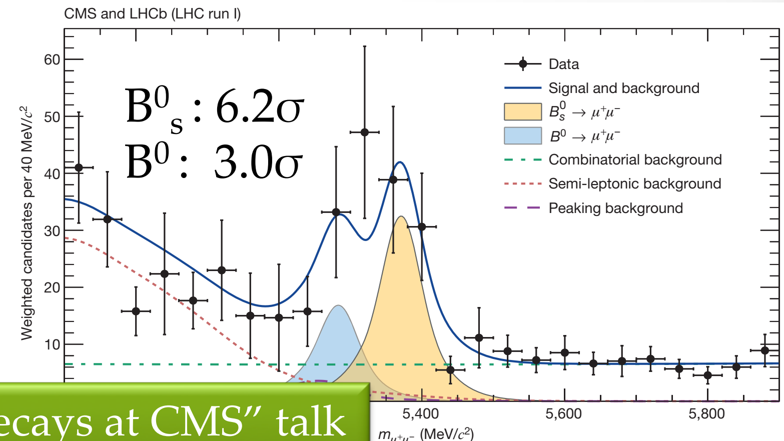
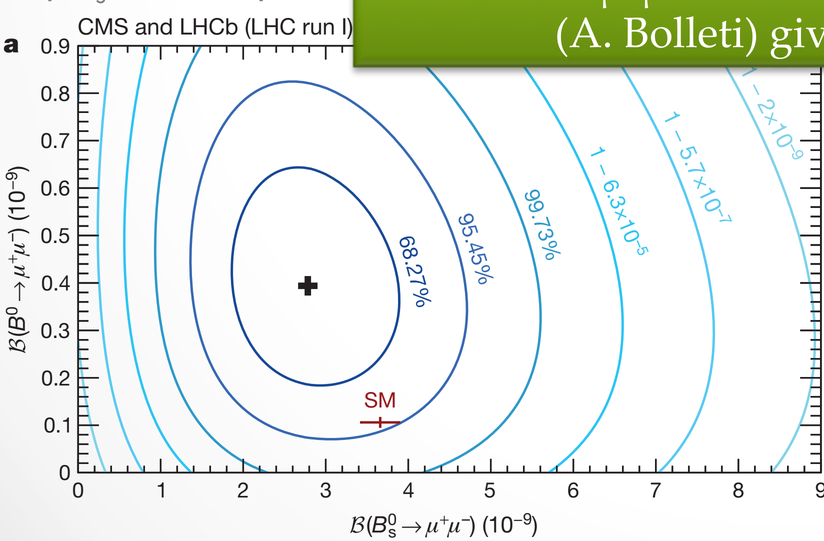
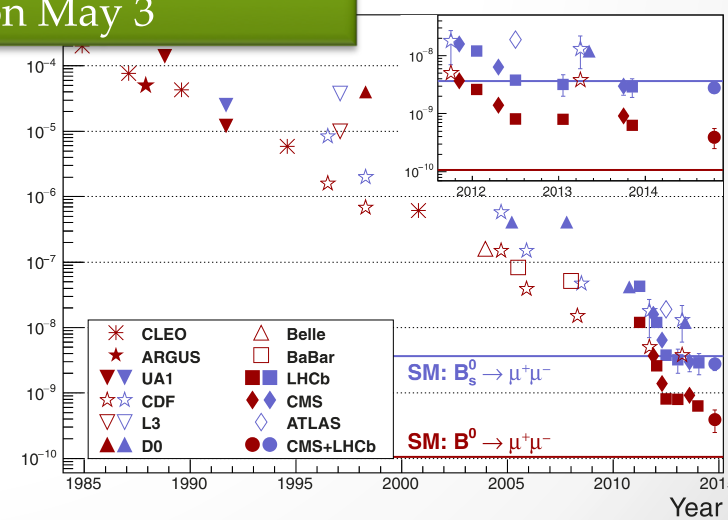
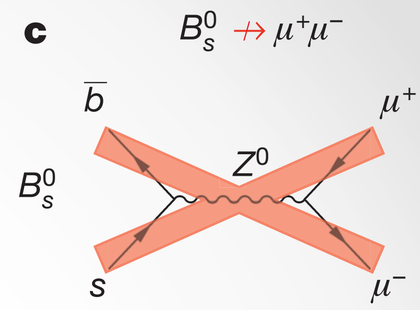


See "$B \to K^{(*)}\mu^+\mu^-$ and rare decays at CMS" talk (A. Bolleti) given on May 3

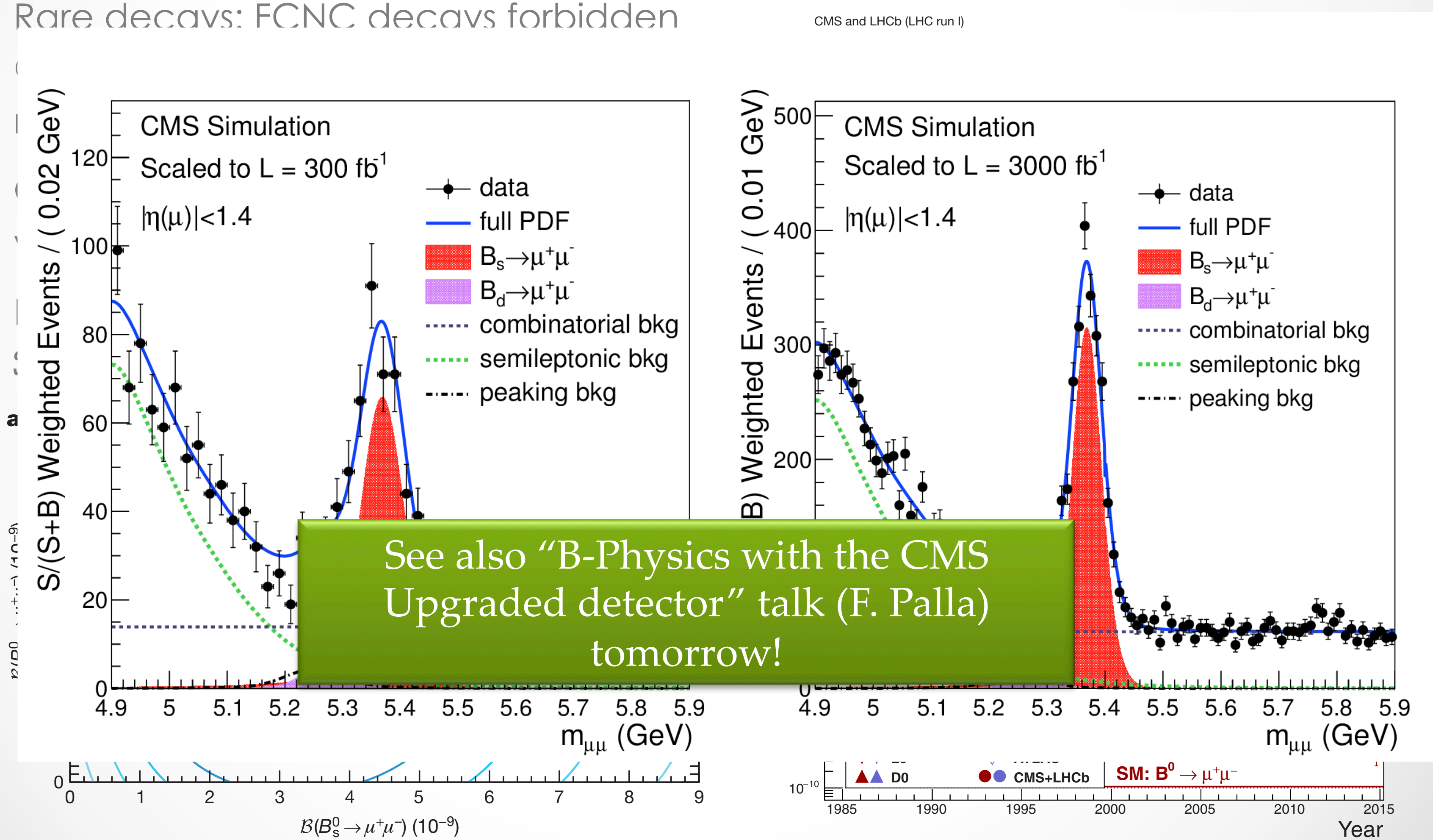




Rare B decays as new physics probes

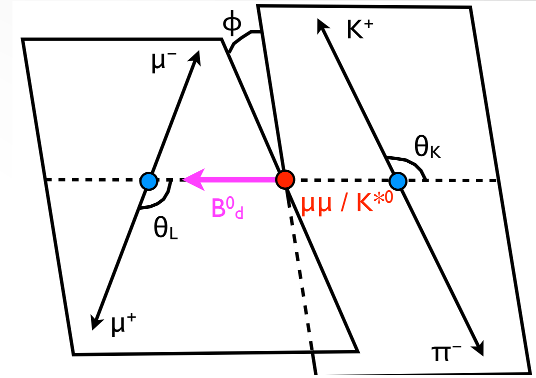


- Rare decays: FCNC decays forbidden



See also “B-Physics with the CMS Upgraded detector” talk (F. Palla) tomorrow!

$B^0 \rightarrow K^*\mu^+\mu^-$



- Search for deviations of BR, F_L (frac. of K* longitudinal. Pol.) and A_{FB} ($\mu^+\mu^-$ F-B asym.) from SM in bins of $q^2 = m^2_{\mu\mu}$.

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_K\,\mathrm{d}\cos\theta_l\,\mathrm{d}q^2}$$
$$= \frac{9}{16}\left\{\frac{2}{3}\left[F_S + A_S\cos\theta_K\right]\left(1-\cos^2\theta_l\right) + (1-F_S)\left[2F_L\cos^2\theta_K\left(1-\cos^2\theta_l\right)\right.\right.$$
$$\left.\left. + \frac{1}{2}(1-F_L)\left(1-\cos^2\theta_K\right)\left(1+\cos^2\theta_l\right) + \frac{4}{3}A_{FB}\left(1-\cos^2\theta_K\right)\cos\theta_l\right]\right\}$$

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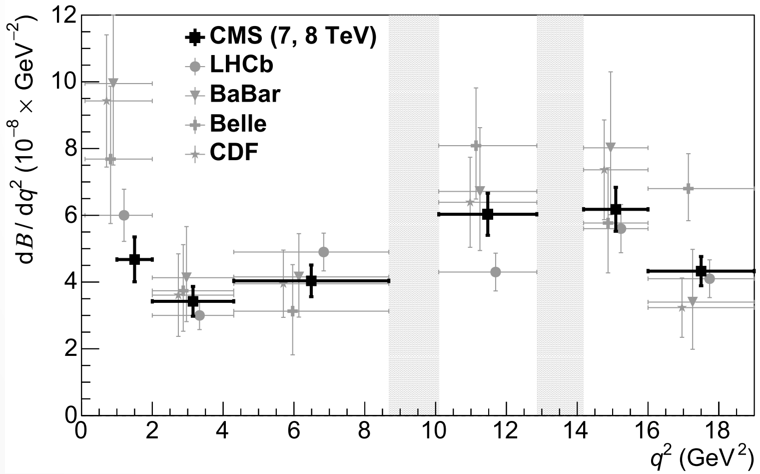
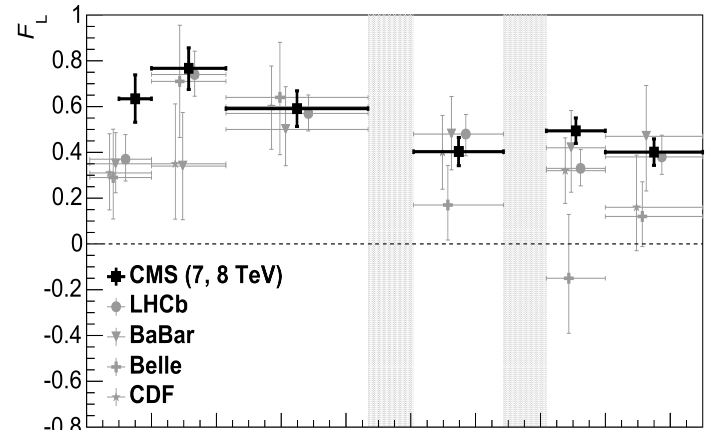
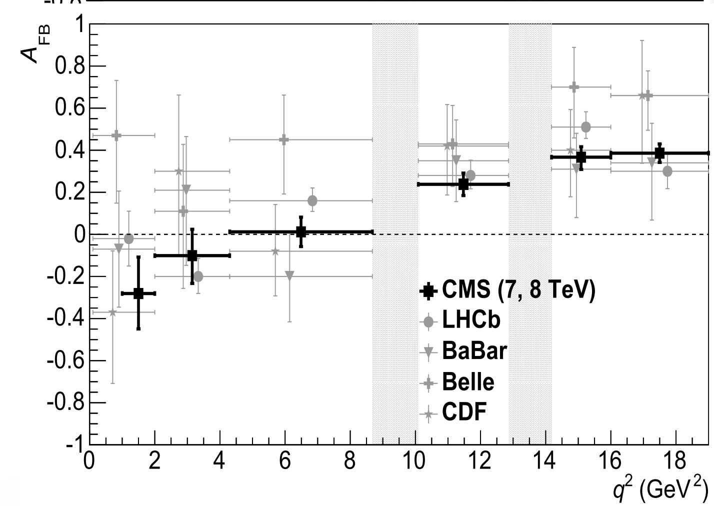
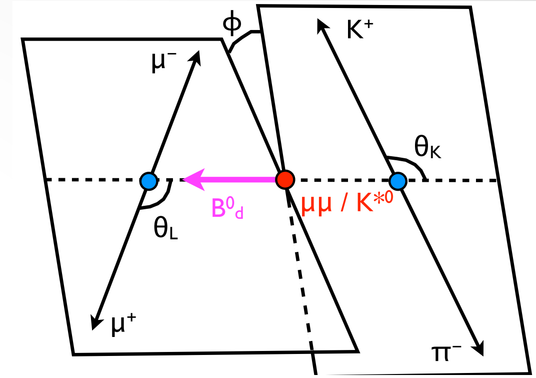






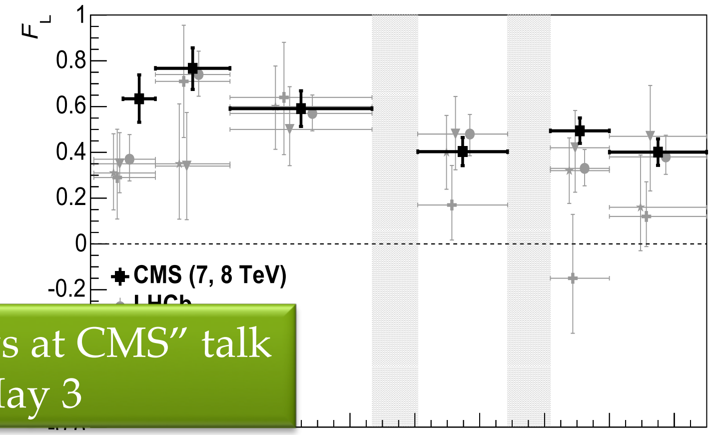
- CMS results consistent with other experiments and with predictions of LCSR and Lattice.

$B^0 \rightarrow K^*\mu^+\mu^-$



- Search for deviations of BR, F_L (frac. of K* longitudinal. Pol.) and A_{FB} ($\mu^+\mu^-$ F-B asym.) from SM in bins of $q^2 = m^2_{\mu\mu}$.

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K\, d\cos\theta_l\, dq^2}$$
$$= \frac{9}{16}\left\{\frac{2}{3}\left[F_S + A_S\cos\theta_K\right]\left(1-\cos^2\theta_l\right) + (1-F_S)\left[2F_L\cos^2\theta_K\left(1-\cos^2\theta_l\right)\right.\right.$$
$$\left.\left. + \frac{1}{2}(1-F_L)\left(1-\cos^2\theta_K\right)\left(1+\cos^2\theta_l\right) + \frac{4}{3}A_{FB}\left(1-\cos^2\theta_K\right)\cos\theta_l\right]\right\}$$



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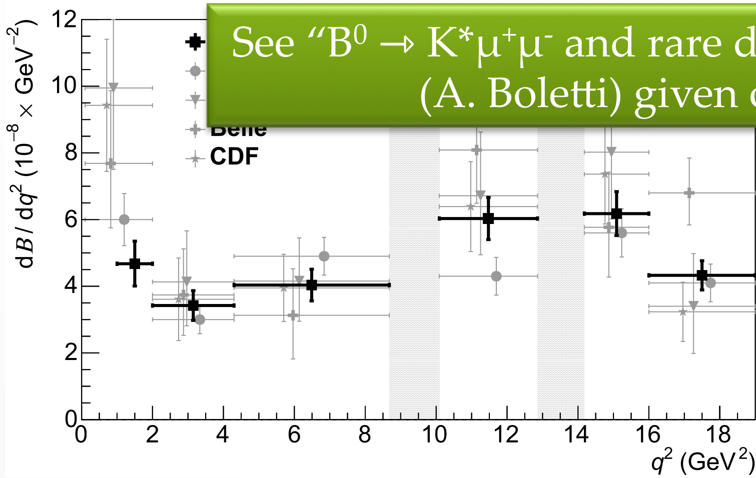
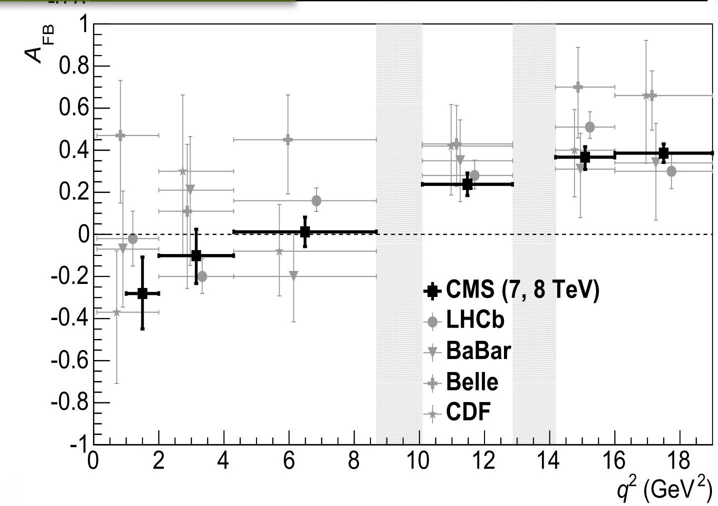
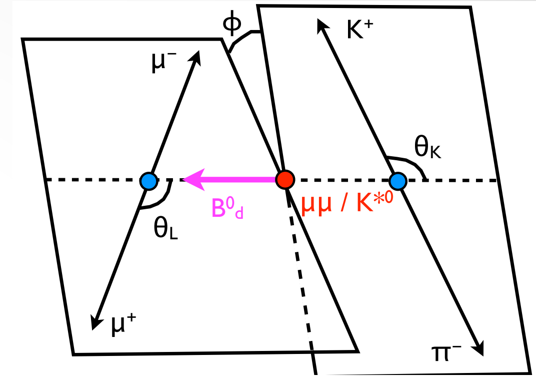


See "$B^0 \rightarrow K^*\mu^+\mu^-$ and rare decays at CMS" talk (A. Boletti) given on May 3



- CMS results consistent with other experiments and with predictions of LCSR and Lattice.

$B^0 \to K^*\mu^+\mu^-$



- Search for deviations of BR, F_L (frac. of K* longitudinal. Pol.) and A_{FB} ($\mu^+\mu^-$ F-B asym.) from SM in bins of $q^2 = m^2_{\mu\mu}$.

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K\, d\cos\theta_l\, dq^2}$$
$$= \frac{9}{16}\left\{\frac{2}{3}\left[F_S + A_S\cos\theta_K\right]\left(1-\cos^2\theta_l\right) + (1-F_S)\left[2F_L\cos^2\theta_K\left(1-\cos^2\theta_l\right) + \frac{1}{2}(1-F_L)\left(1-\cos^2\theta_K\right)\left(1+\cos^2\theta_l\right) + \frac{4}{3}A_{FB}\left(1-\cos^2\theta_K\right)\cos\theta_l\right]\right\}$$

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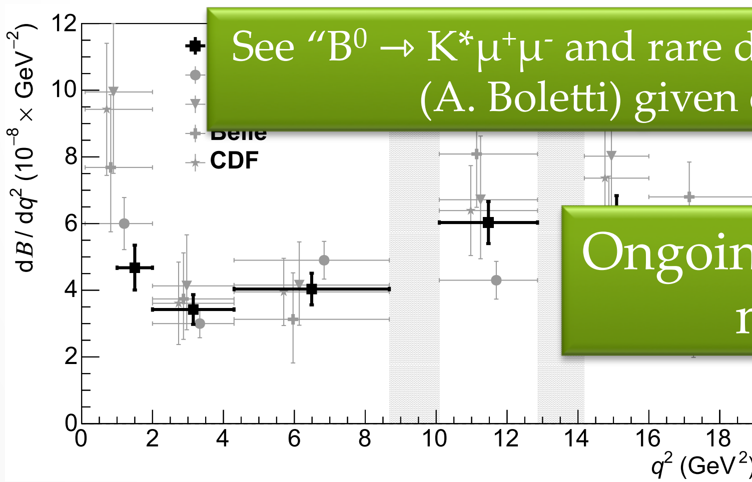

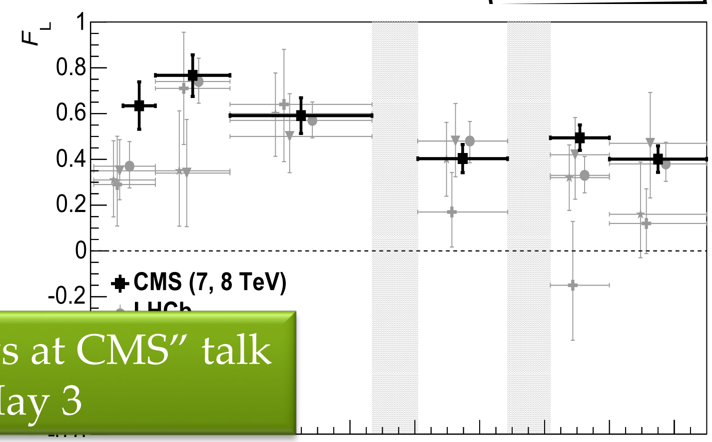

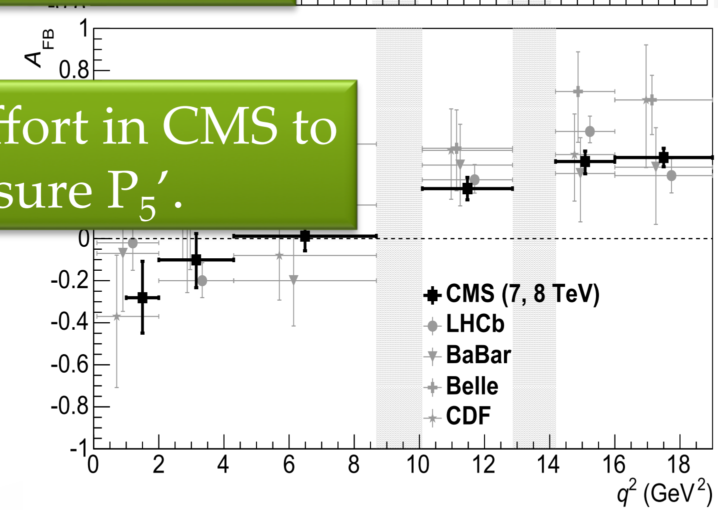

See "$B^0 \to K^*\mu^+\mu^-$ and rare decays at CMS" talk (A. Boletti) given on May 3

Ongoing effort in CMS to measure P_5'.

- CMS results consistent with other experiments and with predictions of LCSR and Lattice.

Summary

- The CMS experiment has produced several competitive results related to production, branching ratios, CPV, lifetimes, polarizations, and other properties of B hadrons.
- CMS will continue studying the B^0_s system to search for anomalous CPV using decays to $J/\psi K^+K^-$ and $J/\psi\,\pi^+\pi^-$ with 13 TeV data.
- The B_c program will also continue and benefit from the additional data in Run II.
- The observation of $B^0 \rightarrow \mu^+\mu^-$ is one of the main long term goals of CMS. Detector upgrades will improve its sensitivity.
- Similarly, $b \rightarrow s\,\mu^+\mu^-$ analyses are now within the core of the CMS B physics program. Special trigger paths have been incorporated for their detailed study with 13 TeV data.

… and more B hadron results from CMS are coming soon

- Run I legacy measurements of B hadron lifetimes.
- Angular analysis of $B^+ \to K^{(*)+}\mu^+\mu^-$, $B^0 \to K^*\mu^+\mu^-$, $\Lambda_b \to \Lambda\mu^+\mu^-$, …
- Bottom baryon polarization.
- Bottomonium properties.
- Etc.

… and more B hadron results from CMS are coming soon

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Stay tunned!