B-Physics from ATLAS and CMS

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Fermilab

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Outline

- ATLAS and CMS as detectors to study B-Physics
  - Design strengths and limitations of these "general purpose high P_t detectors" relative to a dedicated B physics detector like LHCb
- Results from 2010 and 2011 runs of the LHC and prospects for the 2012 Run
  - Open and Bound Beauty and charm cross section measurements
  - New particles
  - Rare decays

Goal of the talk is to show selected recent results and to raise awareness of ATLAS and CMS capabilities in flavor physics .

B Physics at Hadron Colliders

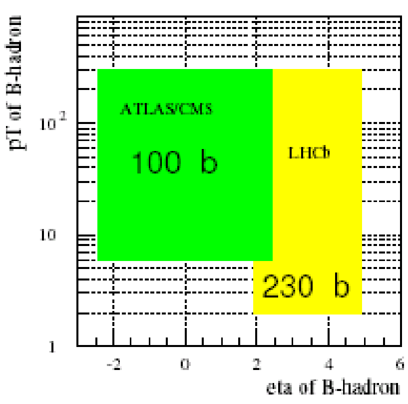
- **The Opportunity**
  - **The LHC has very high B cross sections, σ(pp->b-bar) :**
    - **238 μb (7 GeV) , 270 μb (8 GeV); 457 μb (14GeV) vs 63 μb (2 TeV)**
    - **at $L=7x10^{33}$ $cm^{-2}s^{-1}$, the LHC produces $8X10^{12}$ b-pairs per year at 8 TeV CM energy**
  - **It is a "Broadband, High Luminosity B Factory", giving access to B_d, B_u, B_s, all b-baryon, and B_c states.**
  - **Because one gluon from each of the incoming protons is colliding, the LHC is intrinsically an asymmetric collider**

- **The Challenge (compare with e^+e^-)**
  - **The b events are accompanied by a very high rate of "typical" or "minimum bias" events**
  - **The center of mass energy of the b-bbar system is not fixed by initial conditions**
  - **The b's are produced over a very large range of momentum**
  - **Even in the b events of interest, there is a complicated underlying event so one does not have the stringent constraints that one has in an e^+e^- machine**
  - **At the LHC, multiple interactions per crossing (pileup), can confuse the reconstruction of the b-event**
    - **Pileup of 30 has to be handled at the luminosity expected at the LHC in 2012**

These lead to challenges in triggering, tagging, and reconstruction efficiency and the background rejection that can be achieved at a hadron collider

B- Physics with “General Purpose (high Pt)” Detectors - I

- Detectors searching for new high mass or high P_t phenomena focus on the central region, where the production and acceptance are highest for those states , and on running at the highest luminosity
- However, because they must detect all of the “physics objects” of the SM, they have many of the features needed for B physics
  - High acceptance for B production with kinematics complementary to forward detectors
  - Excellent tracking, momentum/mass resolution, vertex reconstruction, b-tagging (for b-jets)
  - Excellent lepton triggering and identification
  - Excellent single photon reconstruction
  - Ability to run at much higher luminosity and to handle radiation damage and “pileup” of ~30
    - Massive segmentation
    - sophisticated triggering and
    - high capacity data acquisition system



B- Physics with "General Purpose (high Pt)" Detectors - II

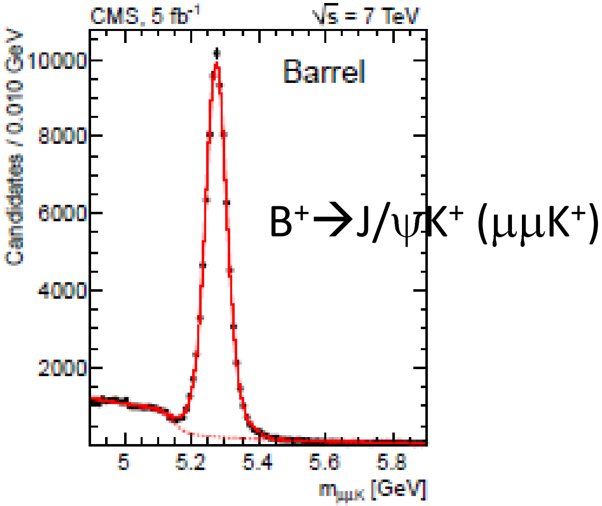
- But they generally suffer from some significant deficiencies
  - Lack of charged hadron identification
  - Triggering problems that force a choice between B physics and the main goal of "discovery physics" that always wins out
    - Typically, must rely on single and double lepton triggers with P_t cuts
    - Can only devote <10% of the trigger "bandwidth" (~25 Hz) to B physics (but see "data parking" discussion below)

But because many important B decays contain dileptons, central detectors can mount competitive B physics program in some key areas, especially if they can effectively use the full luminosity of the LHC

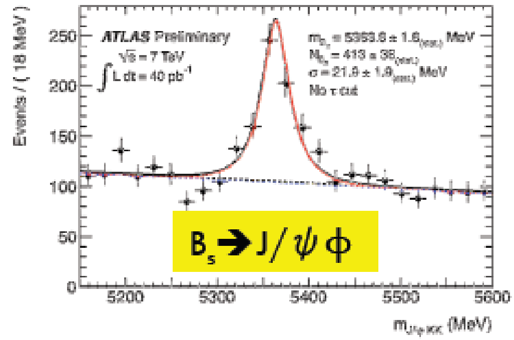
b Cross Sections

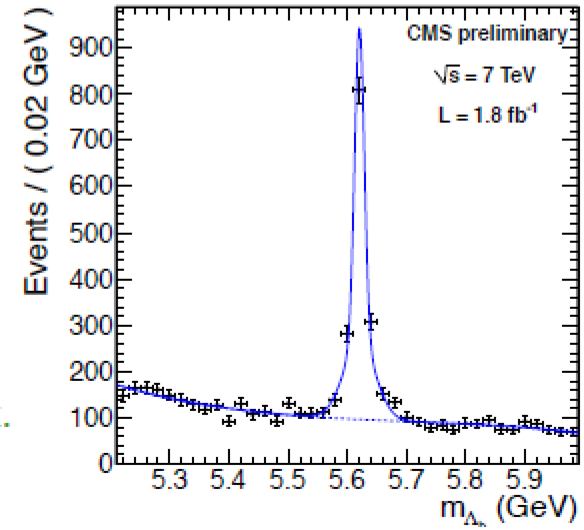
- Inclusive b-production
  - $b \rightarrow \mu X$,
  - $b \rightarrow$ jet (μ tagged and b vertex tagged),
  - B^+, B^0, B_s, Λ_b
  - B_c^+, B_s^{**}, Ω_b, Ξ_b
  - Ξ_b^*
  - $B \rightarrow c\,c$ (non-prompt J/ψ)
- Inclusive b pair production
  - $bb \rightarrow \mu\mu + X$
  - $bb \rightarrow$ hadrons
  - $bb \rightarrow$ b-tagged dijets
- Charm Production
- Production of quarkonium and exotic states

These are mostly 2010 results done at LOW luminosity because statistics are not the issue

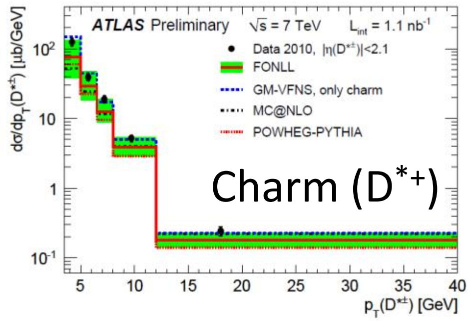


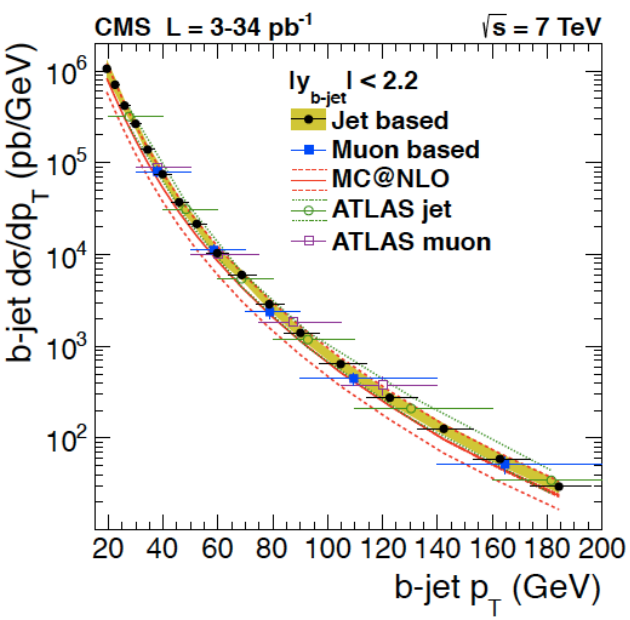
(82.7+/- 4.2) x 10^3
$B^+ \to J/\psi K^+$ ($\mu\mu K^+$)
in the CMS barrel

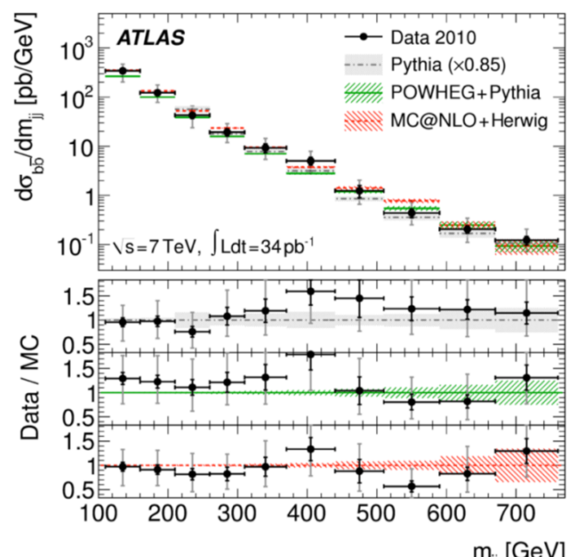


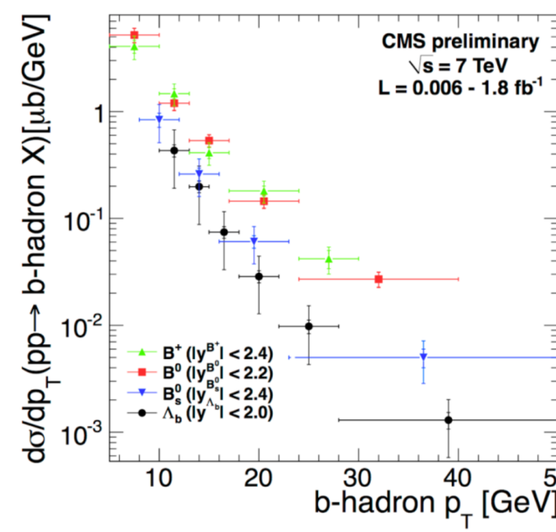


$\Lambda_b^0 \to J/\psi \Lambda^0$



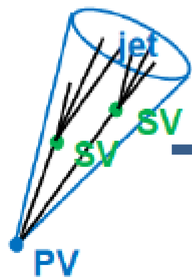


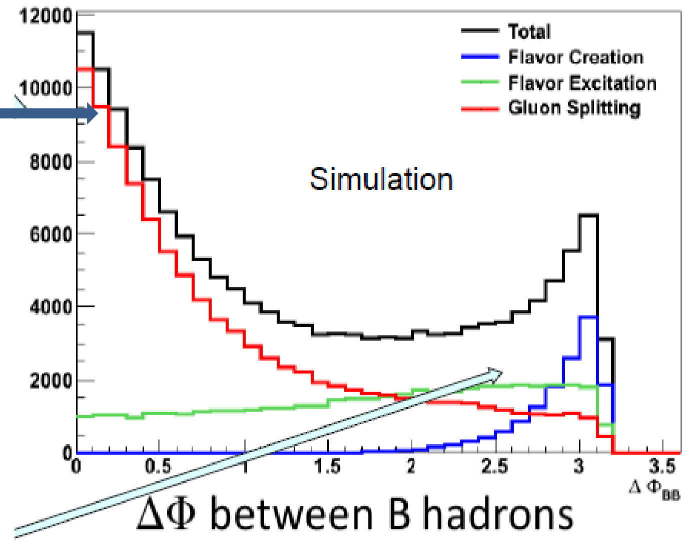


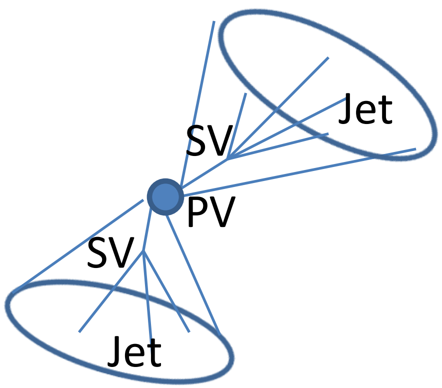


Production Mechanisms over a Large Kinematic Range

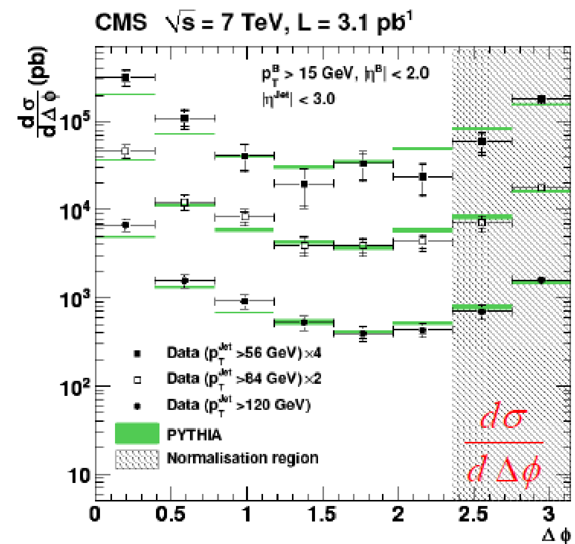
Merged jets from gluon splitting.
<u>Shows power of vertex detectors</u>







Small angular separation region is dominant
Collinear emission process



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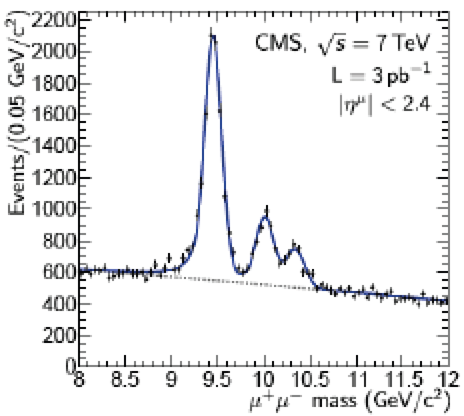
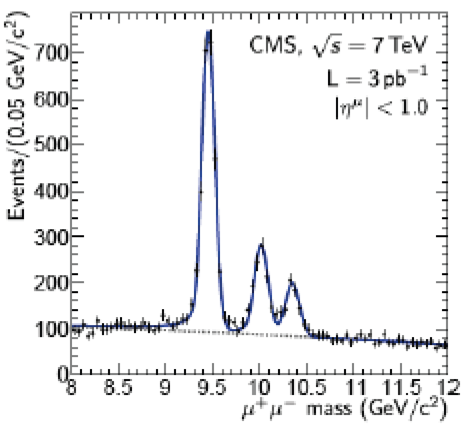
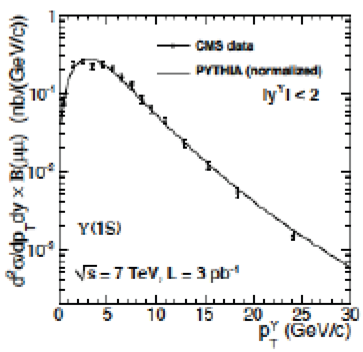
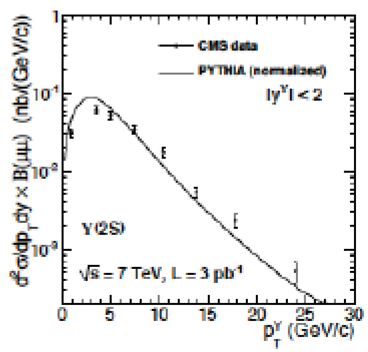
Phys. Lett. **B705** (2011) 9-27

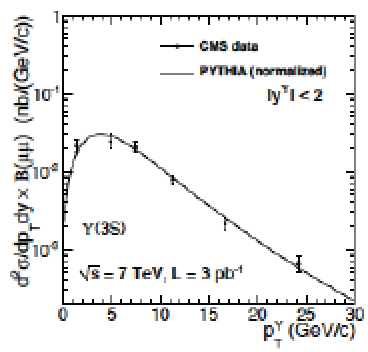
Phys.Rev. **D83** (2011) 112004

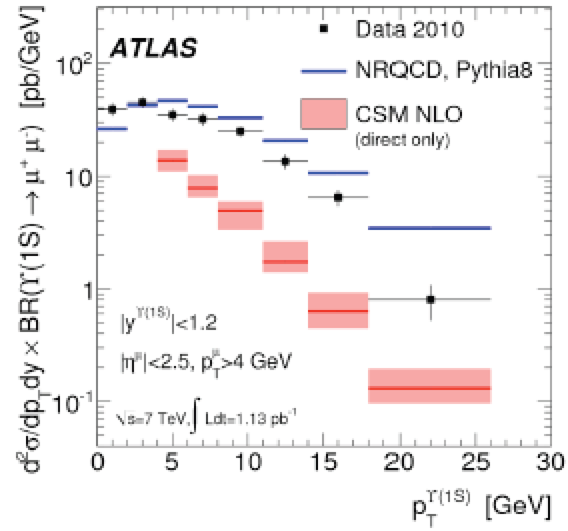


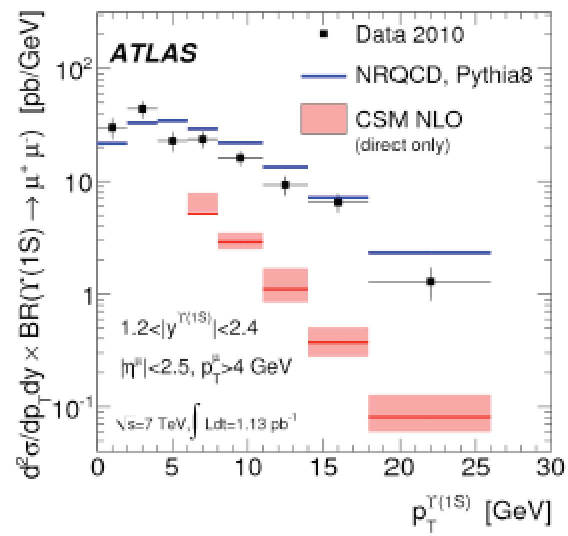








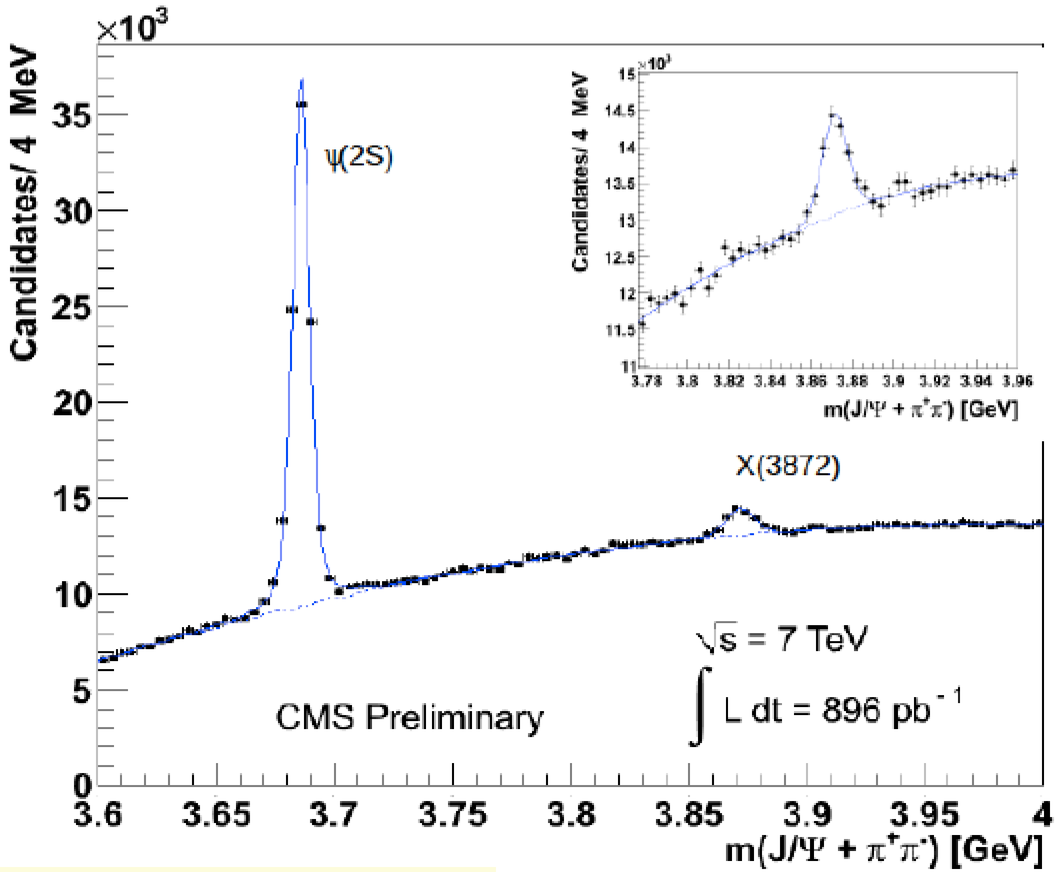




Exotic Charmonium-like Mesons

CMS-PAS-BPH-10-018

$p_T(X) > 9$ GeV && $|\eta(X)| < 1.25$

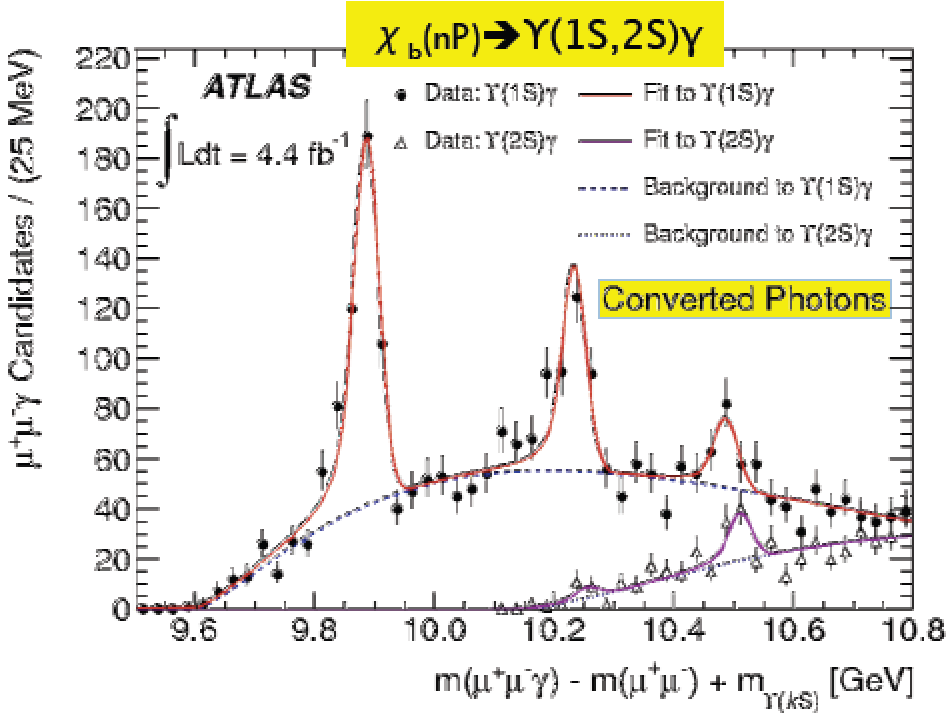


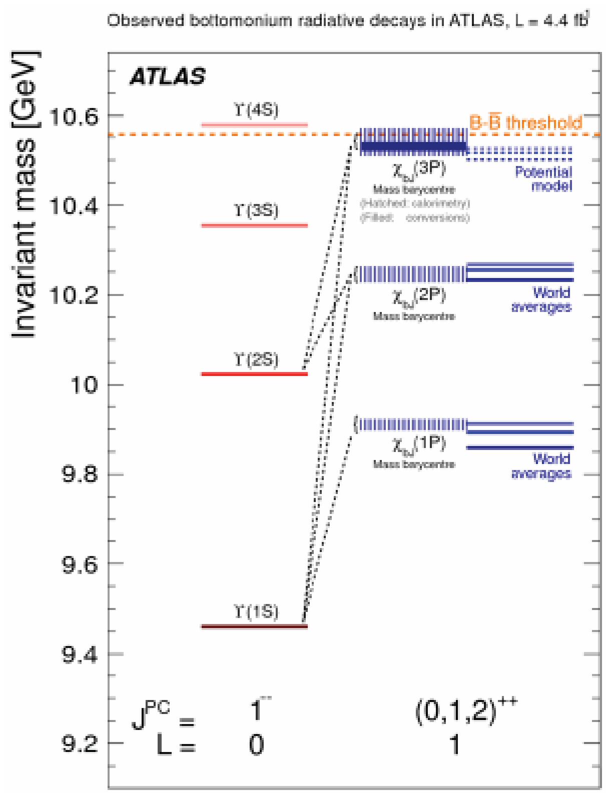
With 40 pb^{-1}:

$$R = \frac{\sigma(pp \to X(3872) + \text{anything}) \times BR(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to \psi(2S) + \text{anything}) \times BR(\psi(2S) \to J/\psi\pi^+\pi^-)}$$

$$R = 0.087 \pm 0.017(stat.) \pm 0.009(syst.)$$

ATLAS: χ_b (3p)





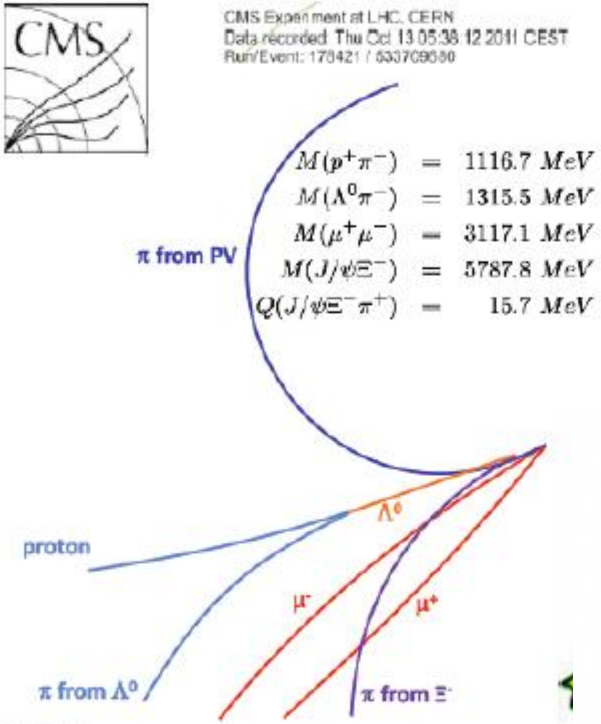
New state at 10.5 GeV confirmed with Y(2S) data and with converted photons Significance > 6 σ.

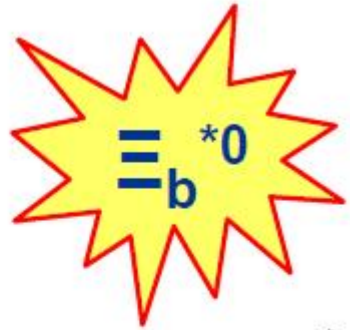
M[χ_b(3P)]=10.530±0.005 (stat)±0.009 (syst) GeV

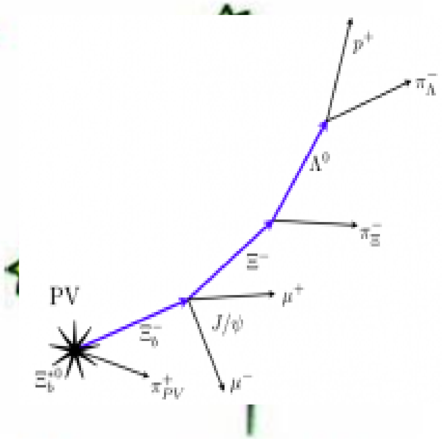
CMS: Observation of the Ξ_b^{*0}

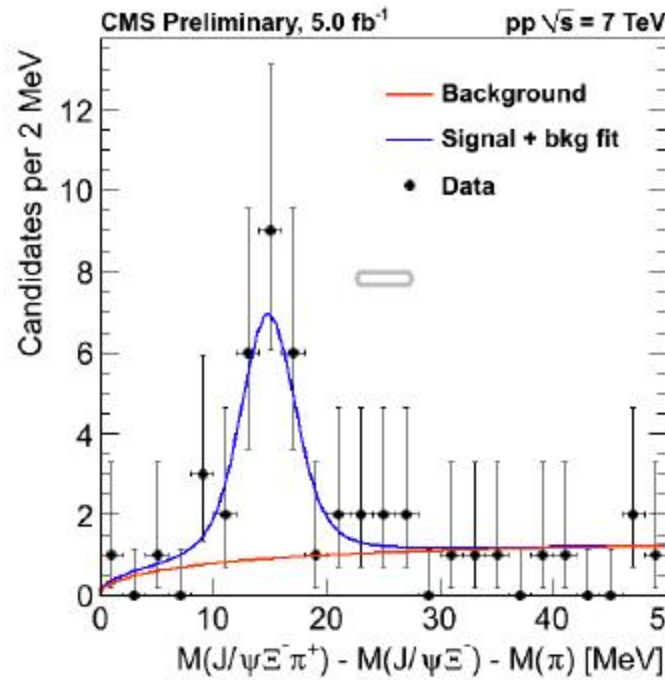
- First observation of Ξ_b^{*0} (bound usb-state: J=3/2+ ?)

BPH-12-001 approved









Signal yield: 24.4 ± 5.7 (stat) candidates

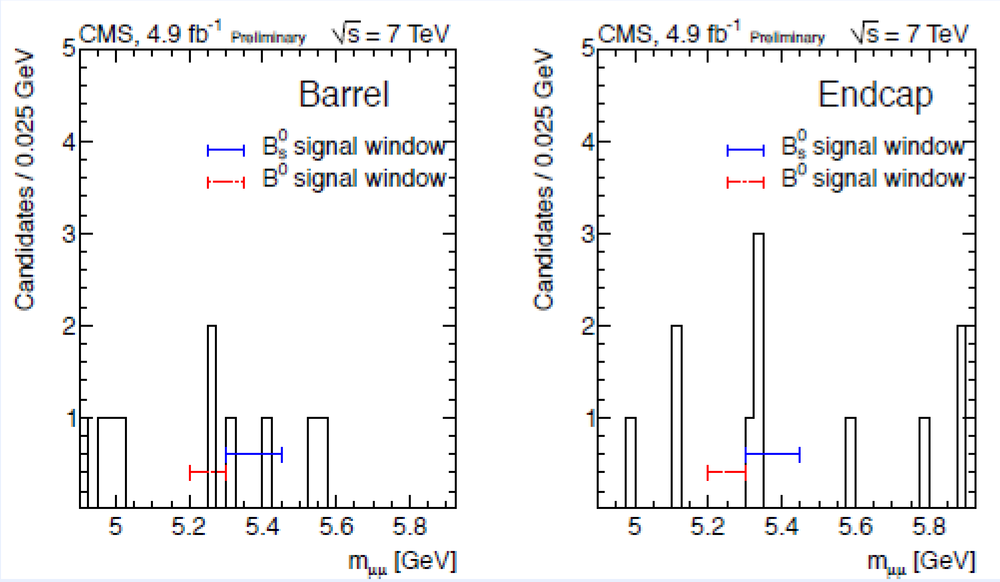
5945.0 +/-2.7 (PDG)+/- 0.7 (stat) +/-0.3(syst)MeV.

Rare Decays that ATLAS and CMS Can Study

- FCNC decays
  - $D^0 \rightarrow \mu^+\mu^-$
  - B_s, $B_d \rightarrow \mu^+\mu^-$
  - $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ ($B^+ \rightarrow K^{*+} \mu^+ \mu^-$)
  - $B^+ \rightarrow K^+ \mu^+ \mu^-$
  - $\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$
  - $\tau^+ \rightarrow \mu^+ \mu^- \mu^+$

CMS Result on B_s, $B_d \rightarrow \mu^+\mu^-$

Variable	$B^0 \to \mu^+\mu^-$ Barrel	$B_s^0 \to \mu^+\mu^-$ Barrel	$B^0 \to \mu^+\mu^-$ Endcap	$B_s^0 \to \mu^+\mu^-$ Endcap
Signal	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



unblinded di-muon invariant mass in the barrel (left) and endcap (right)

High Level Trigger (HLT) "TARGETS" $B_{s,d} \rightarrow \mu\mu$ And the normalization Channel $B^+ \rightarrow J/\psi K^+$ and The "control" sample $Bs \rightarrow J/\psi\phi$

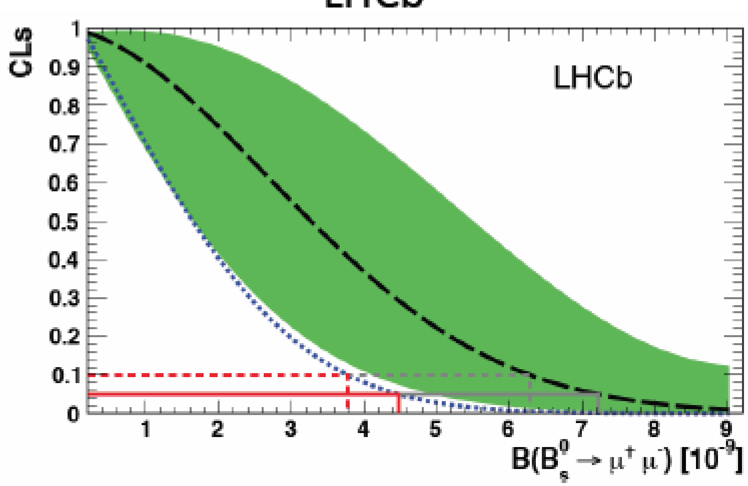
B_s, $B_d \rightarrow \mu^+\mu^-$ at the LHC

SM $\mathcal{B}(B_s \rightarrow \mu\mu) = (3.2 \pm 0.2)\ 10^{-9}$

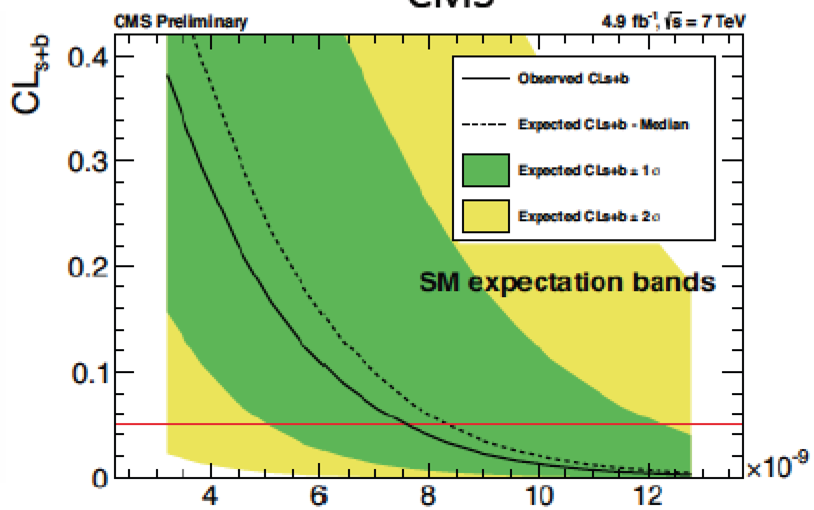
SM $\mathcal{B}(B \rightarrow \mu\mu) = (0.1 \pm 0.01)\ 10^{-9}$

Observed	Expected
ATLAS: $Br(B_s \rightarrow \mu^+\mu^-) < 2.2 \times 10^{-8}$ (2.4 fb^{-1})	2.3×10^{-8}
CMS: $Br(B_s \rightarrow \mu^+\mu^-) < 7.7 \times 10^{-9}$ (4.9 fb^{-1})	8.4×10^{-9}
LHCb: $Br(B_s \rightarrow \mu^+\mu^-) < 4.5 \times 10^{-9}$ (1 fb^{-1})	7.2×10^{-9}

LHCb



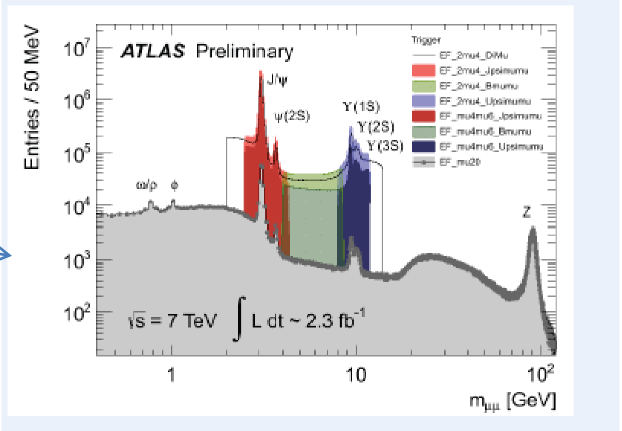
CMS



Number of events	LHCb	CMS
Expected Signal	5.3	3.9
Expected Background	10.6	2.0
Observed	11	6

Prospects for the 2012 Run

- LHC 2012 aims at >15 fb^{-1}, peak luminosity of > 7x 10^{33} $cm^{-2}s^{-1}$, with 50 ns bunch spacing
  - This gives about 30 interactions/crossing
- Can we trigger efficiently at the highest luminosities?
- Can we handle high pileup (# of interactions per crossing, ~30)?
- Can we preserve output bandwidth for B physics?
  - The systems really are not limited by output bandwidth at current levels, but by analysis resources and a two year shutdown of the LHC is approaching
  - **“Data parking” , storing data for later analysis during the shutdown, will expand the resources available for B physics (and allow to take perhaps 50-80 Hz of additional B triggers in CMS)**



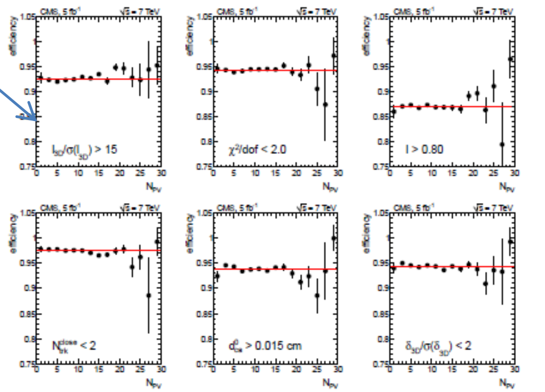


Figure 4: Efficiency versus number of primary vertices, measured with $B^+ \to J/\psi K^+$ candidates in data for the requirements $\ell_{3D}/\sigma(\ell_{3D}) > 15$, $\chi^2/dof < 2$, $I > 0.8$, $N_{trk}^{close} < 2$, and $d_{ca}^0 > 0.015$ cm, and $\delta_{3D}/\sigma(\delta_{3D}) < 2$ (top left to bottom right). The line indicates a fit to a constant. The error bars represent the statistical uncertainty only.

While not the main focus of our effort, prospects for B physics at ATLAS and CMS remain bright. We can compete with LHCb favorably on some key measurements and provide a check on others.

Conclusion

- "Principles articulated by CMS for the Intensity Frontier Workshop with a similar statement by ATLAS:
  - The main workhorse for CMS heavy flavour physics is dimuon triggers combined with precise tracking and vertexing capabilities.
  - The flexibility of the CMS trigger system has made it possible to adapt the triggers to the increasing luminosity in a prompt and intelligent manner, by making use of selections on invariant mass, decay length, distance of closest approach, transverse momentum, and rapidity.
  - At the same time, strict physics priorities at the trigger level have already been made, and with increasing instantaneous luminosities CMS will have to make even more difficult choices, targeting those decay channels with significant scientific interest and potential for competitive measurements."

The key for ATLAS and CMS to be relevant for the next few years is to be able to utilize the high LHC luminosity for the study of rare decays.

Backup Slides

pp→ b + X

	Channel	CMS	ATLAS	LHCb
b→ muon	b→μ X	JHEP03(2011)090	arXiv:1109.0525	**B-fractions: P.R.D85:032008,2012** PRL 107 (2011) 211801
b→ jet	b tagged jets μ-tagged jets	arXiv:1202.4617, accep. JHEP.	Eur. Phys. J. C71 (2011) 1846	P. L. B 694 (2010) 209
b→b-hadrons	B^+	PRL106(2011)112001	Observation: ATLAS-CONF-2010-098	*LHCb-PAPER-2011-043* , arXiv:1202.4812
	B^0	PRL106(2011)252001	Observation: ATLAS-CONF-2011-105	*PRL 107 (2011) 211801*
	B_s	PRD84(2011)052008	Observation: ATLAS-CONF-2011-050	*PRL 107 (2011) 211801*
	Λ_b	CMS-BPH-11-007, approv.	Observation: ATLAS-CONF-2011-124	Ratio: LHCb-CONF-2011-036
	B_c^+, $B_{(s)}^{**}$, Ω_b^-, Ξ_b		Observation of: Bc:ATL-CONF-2012-028 Xb: PRL108 (2012) 152001	*Bc:LHCb-PAPER-2011-044* B_c: LHCb-CONF-2011-017 *Ω_b(m), Xb(m):LHCb-CONF-2011-060,/036*
	Ξ_b^{*0}	Observation: BPH-12-001, approved		
b→ (cc) states	J/ψ X (non-prompt)	Eur.Phys.J.C71(2011)1575 JHEP02(2012)011	Nucl.P. B850 (2011) 387 ATL-PHYS-PUB-2009-048, ATL-COM-PHYS-2009-138	

$pp \rightarrow b\bar{b} + X$

	Channel	CMS	ATLAS	LHCb
$bb \rightarrow \mu\mu$	$b \rightarrow \mu\mu X$	arXiv:1203.3458		
$bb \rightarrow$ hadrons	$\rightarrow$ B B /dihadrons	JHEP03(2011) 136 Angular correlations		
$bb \rightarrow$ di-jets	b-tagged dijets		Eur. Phys. J. C71 (2011) 1846	Phys. Lett. B 694 (2010) 209
	$\rightarrow$ B B + Z associated prod.	PAS-EWK-12-xxx * not strictly pure b-production..		

pp→ c + X

	Channel	CMS	ATLAS	LHCb
c → c-hadrons	D, D* ….	n.a.	ATLAS-CONF-2011-017 ATL-PHYS-PUB-2011-012	LHCb-CONF-2010-013
	D* in jets	na	Phys. Rev. D85 (2012) 052005	na
cc→ di-c states				

	Channel	CMS	ATLAS	LHCb
b→ muon	b→μ X	JHEP03(2011)090	arXiv:1109.0525	**B-fractions: P.R.D85:032008,2012** PRL 107 (2011) 211801
b→ jet	b tagged jets μ-tagged jets	arXiv:1202.4617, accep. JHEP.	Eur. Phys. J. C71 (2011) 1846	P. L. B 694 (2010) 209
b→b-hadrons	B^+	PRL106(2011)112001	Observation: ATLAS-CONF-2010-098	*LHCb-PAPER-2011-043* , arXiv:1202.4812
	B^0	PRL106(2011)252001	Observation: ATLAS-CONF-2011-105	*PRL 107 (2011) 211801*
	B_S	PRD84(2011)052008	Observation: ATLAS-CONF-2011-050	*PRL 107 (2011) 211801*
	Λ_b	CMS-BPH-11-007, approv.	Observation: ATLAS-CONF-2011-124	Ratio: LHCb-CONF-2011-036
	B_c^+, $B_{(s)}^{**}$, Ω_b^-, Ξ_b		Observation of: Bc:ATL-CONF-2012-028 Xb: PRL108 (2012) 152001	*Bc:LHCb-PAPER-2011-044* B_c: LHCb-CONF-2011-017 *Ω_b(m), Xb(m):LHCb-CONF-2011-060,/036*
	Ξ_b^{*0}	Observation: BPH-12-001, approved		
b→ (cc) states	J/ψ X (non-prompt)	Eur.Phys.J.C71(2011)1575 JHEP02(2012)011	Nucl.P. B850 (2011) 387 ATL-PHYS-PUB-2009-048, ATL-COM-PHYS-2009-138	

	Channel	CMS	ATLAS	LHCb
bb→ $\mu\mu$	b→$\mu\mu$ X	arXiv:1203.3458		
bb→ hadrons	→ B B /dihadrons	JHEP03(2011) 136 Angular correlations		
bb→di-jets	b-tagged dijets		Eur. Phys. J. C71 (2011) 1846	Phys. Lett. B 694 (2010) 209
	→ B B + Z associated prod.	PAS-EWK-12-xxx * not strictly pure b-production..		

- fs/fd is measured at LHCb with hadronic decays
  - $B^0 \to D^- K^+$ and $B_s \to D_s^- \pi^+$

$$f_s / f_d = 0.250 \pm 0.024_{stat} \pm 0.017_{syst} \pm 0.017_{theo}$$

  - $B^0 \to D^- \pi^+$ and $B_s \to D_s^- \pi^+$

$$f_s / f_d = 0.256 \pm 0.014_{stat} \pm 0.019_{syst} \pm 0.026_{theo}$$

- And semileptonic decays (preliminary, see talk by M. Artuso)

$$\frac{f_s}{f_d + f_u} = 0.134 \pm 0.004^{+0.011}_{-0.010}$$

- We compute the average: lhcb-conf-2011-034

$$f_s / f_d = 0.267^{+0.021}_{-0.020}$$