BSM flavour physics signatures from ATLAS and CMS

Implications of LHC results for TeV-scale physics

29 August - 2 September 2011
CERN, Switzerland

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On behalf of the CMS and ATLAS Collaborations

Flavour physics at CMS and ATLAS

- Searches for rare decays:
  - $B_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$
  - $B^0 \to K^{*0}\mu^+\mu^-$
  - $D^0 \to \mu^+\mu^-$
  - $\tau \to 3$ leptons

http://arxiv.org/abs/1107.5834, submitted to PRL
CMS PAS BPH-11-019

Ongoing analyses

- CP violation in the B_s system:
  - $B_s \to J/\psi\phi$ and $B_s \to J/\psi f_0$

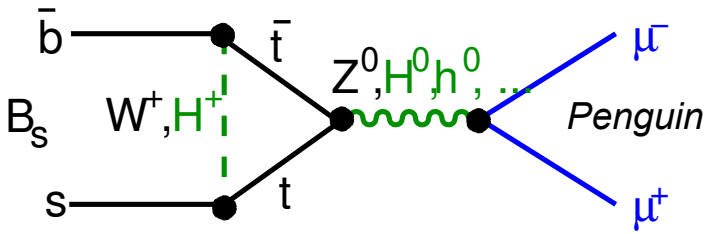
http://arxiv.org/abs/1106.4048, submitted to PRD
ATLAS-CONF-2011-092

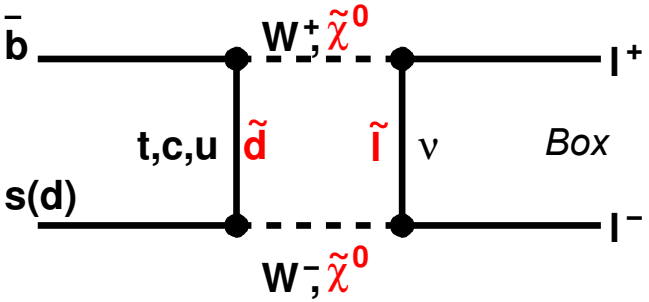
- Conclusions and outlook

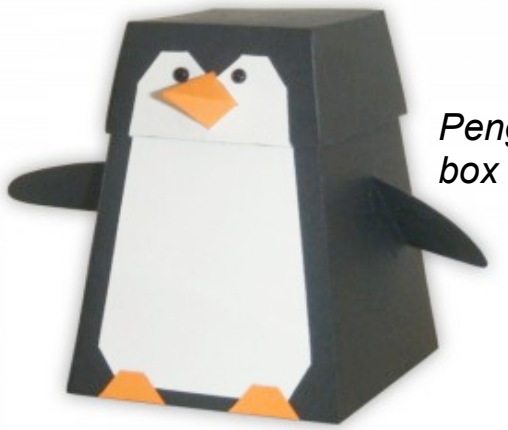

Searches for rare decays

Why searching for $B_{s,d} \to \mu^+\mu^-$?

- **Decays highly suppressed in SM**
  - Forbidden at tree level
  - b →s(d) FCNC transitions only through *Penguin* or *Box* diagrams
  - Helicity suppressed by factors of $(m_\mu/m_B)^2$
- **Standard Model predictions**
  - $\mathcal{B}(B_s \to \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$
  - $\mathcal{B}(B^0 \to \mu\mu) = (1.0 \pm 0.1) \times 10^{-10}$
- **Sensitivity to new physics**
  - MSSM Br proportional to $(\tan\beta)^6$
  - Very effective at high $\tan\beta$



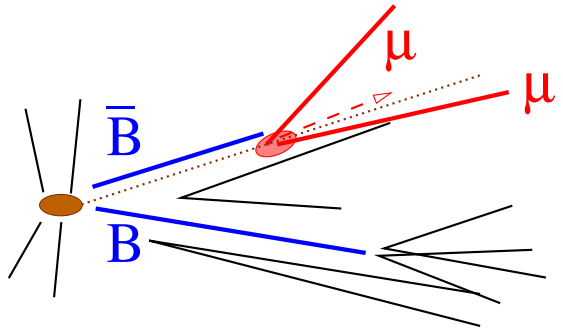




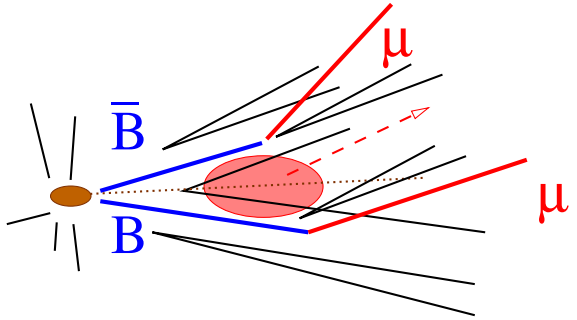
Penguin box

Event characteristics

- **Signal characteristics:**
  - Two muons from a single decay vertex
  - Mass compatible with B_s (or B^0)
  - Well reconstructed secondary vertex
  - Momentum aligned with flight direction



- **Background sources:**
  - Two semi-leptonic B decays (gluon splitting)
  - One semi-leptonic B decay + misidentified hadron
  - Rare B decays (e.g. $B_s \to KK$, $B_s \to K^- \mu^+ \nu$)

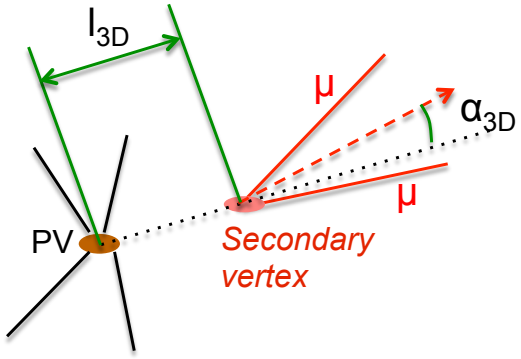


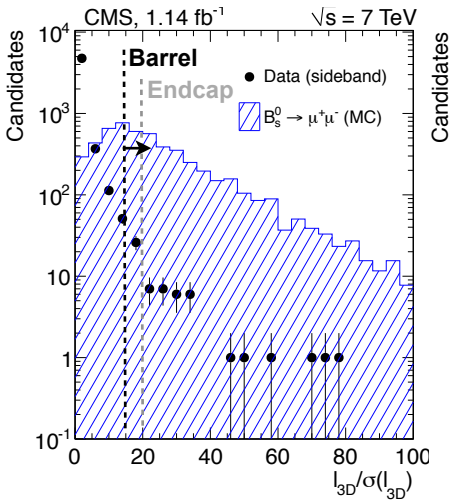
Key ingredients:
Good di-muon vertex, correct B mass assignment, momentum pointing to interaction point

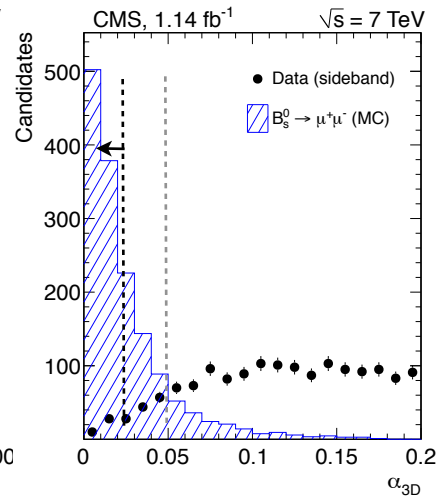
Signal event selection

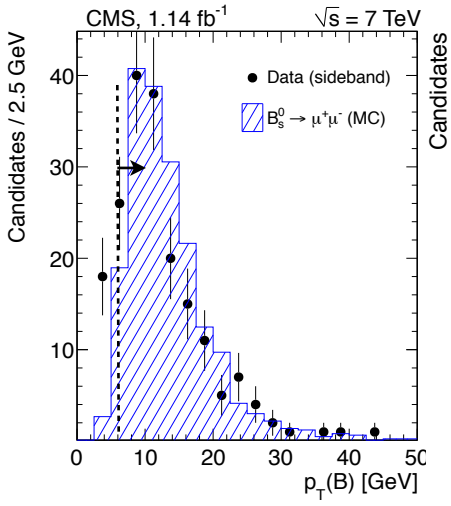
All selection criteria optimized for limit sensitivity <u>before</u> unblinding of signal window

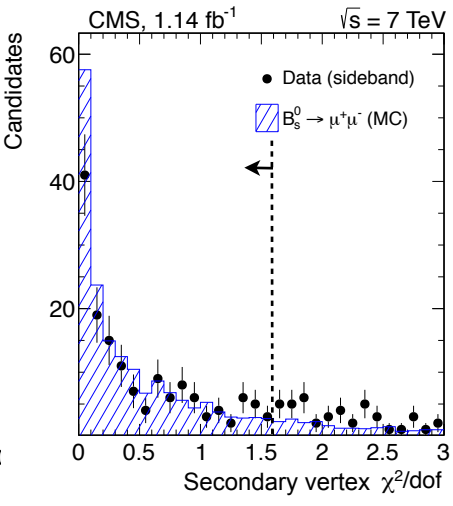
- Mass window requirement:
  - Resolution: **36 (85) MeV** in barrel (endcap)
  - **5.3-5.45 (5.2-5.3) GeV** for B_s (B^0)
- Selection cuts differentiated for **barrel** (both $|\eta(\mu)|<1.4$) and **endcap** region (all other μ pairs)
- Primary vertex consistent with **p**(B) direction
- Secondary vertex fit χ^2/dof<1.6
- Decay length and flight direction:
  - $l_{3D}/\sigma(l_{3D})>15$ (20), $\alpha_{3D}<50$ (25) mrad
- Single muon and B candidate selection:
  - $p_T(\mu)>4.5$ or 4.0 GeV, $p_T(B)>6.5$ GeV





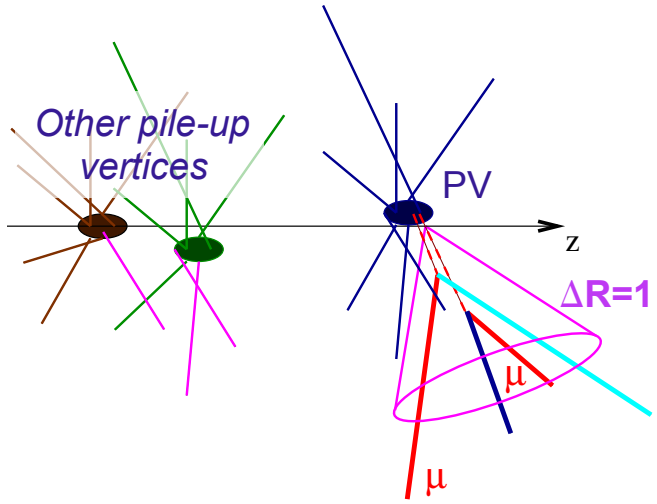




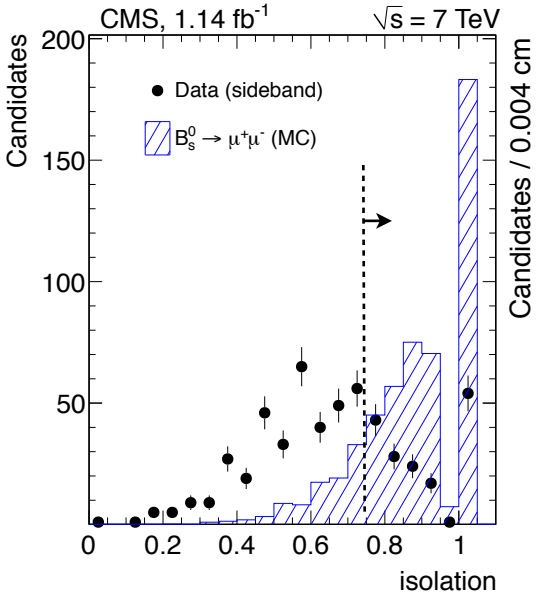


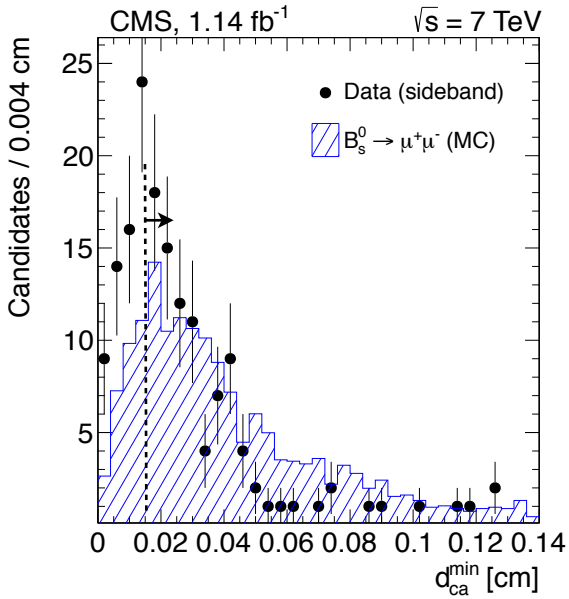
Signal event selection: isolation

- Relative isolation of muon pairs
  - Cone with $\Delta R=1$ around di-muon momentum
  - Include all tracks with $p_T>0.9$ GeV from same PV or $d_{CA}<500$ μm from B vertex
  - Require isolation larger than 75%
- Distance of closest approach of any track w.r.t. B vertex larger than 150 μm (endcap region only)



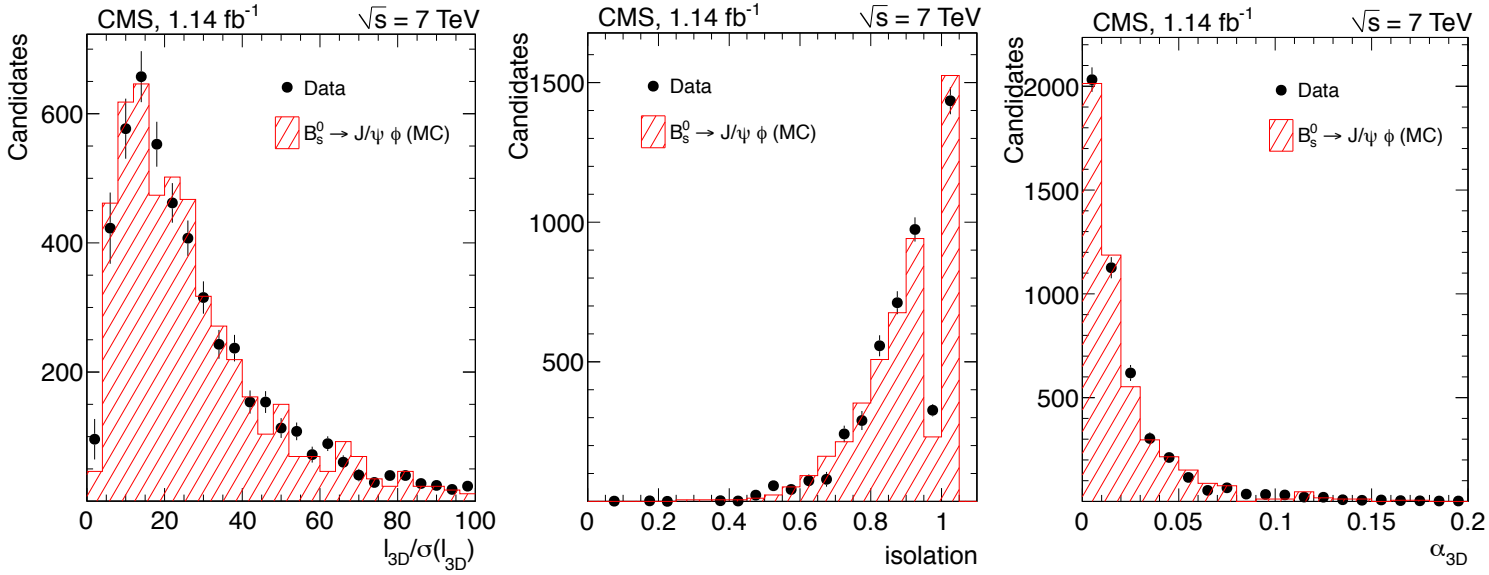
$$\text{Isolation} = \frac{p_T(\mu^+\mu^-)}{p_T(\mu^+\mu^-) + \sum_{\Delta R<1} p_T} > 75\%$$





Selection efficiency

- Validation of MC simulation performed with **two exclusive decays**
  - $B_s \rightarrow J/\psi(\mu^+\mu^-)\phi(KK)$
  - $B^+ \rightarrow J/\psi(\mu\mu)K^+$
- Signal and normalization efficiencies from simulation
  - **Signal efficiency:** 0.4% (0.2%) in barrel (endcap)
  - **Normalization efficiency:** 0.08% (0.03%) in barrel (endcap)
- Good agreement with simulation after sideband subtraction
  - Residual differences adopted as systematics

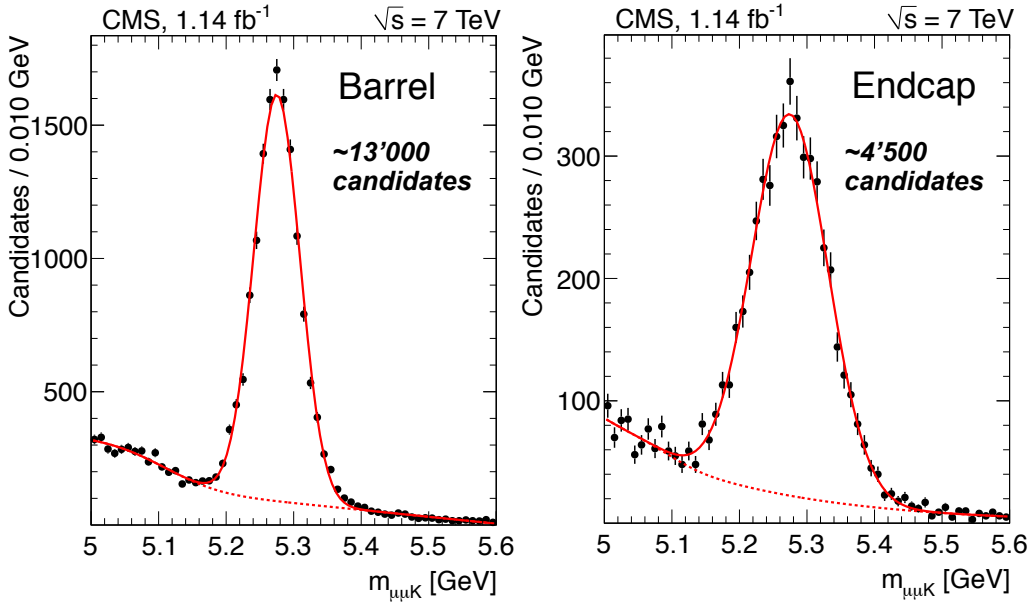


Branching ratio calculation

- Branching ratios calculated w.r.t. normalization channel $B^+ \to J/\psi(\mu\mu)K^+$
  - Many systematic uncertainties cancel in ratio
  - No need for absolute luminosity and b-quark cross section
  - Large B^+ yield and well known branching ratio to $J/\psi K^+$ (3% uncert.)
  - Ratio of fragmentation fractions, f_u/f_s, from PDG (13% uncert.)

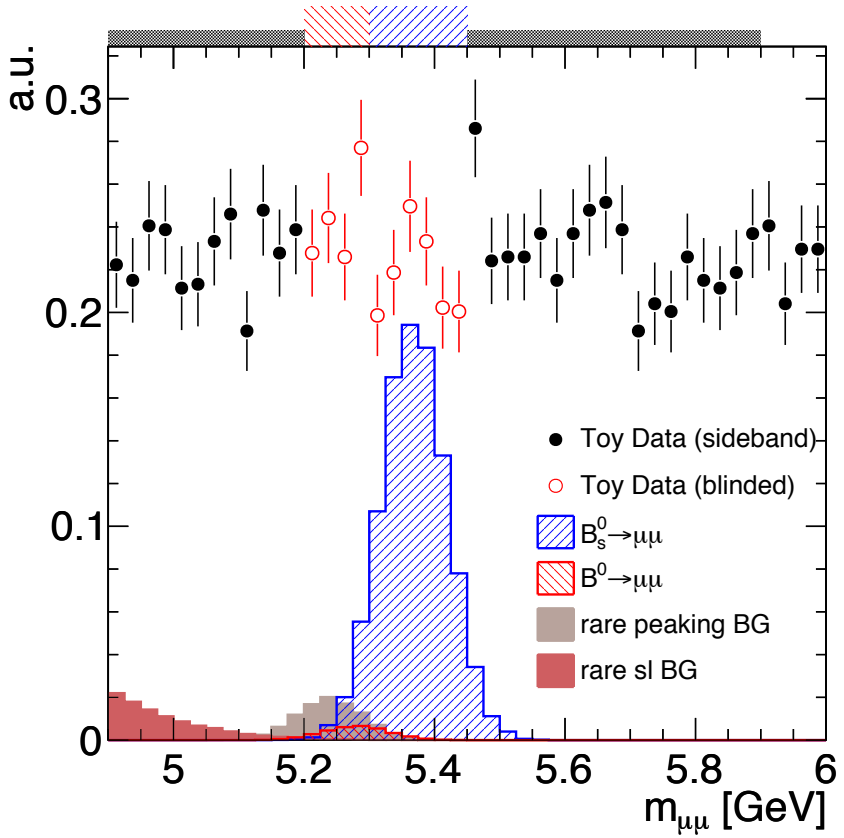
From PDG

$$\mathrm{Br}(\mathrm{B_s} \to \mu^+\mu^-) = \frac{\mathrm{N}(\mathrm{B_s} \to \mu^+\mu^-)}{\mathrm{N}(\mathrm{B^+} \to \mathrm{J}/\psi\mathrm{K^+})} \frac{\mathrm{f_u}}{\mathrm{f_s}} \frac{\epsilon_{\mathrm{tot}}^{\mathrm{B^+}}}{\epsilon_{\mathrm{tot}}^{\mathrm{B_s}}} \mathrm{Br}(\mathrm{B^+} \to \mathrm{J}/\psi\mathrm{K^+})$$



Background estimates

- Combinatorial background:
  - Measured in data from B mass sidebands
  - Interpolate to signal region under flat-shape assumption
- Peaking backgrounds:
  - B→hh backgrounds with two muons from misidentified hadrons
  - Muon mis-ID in data from $K_s \to \pi\pi$, $\phi \to KK$, $\Lambda \to p\pi$ decays
  - MC background samples with mis-ID probability from data
  - B^0 search more affected than B_s because of lower mass

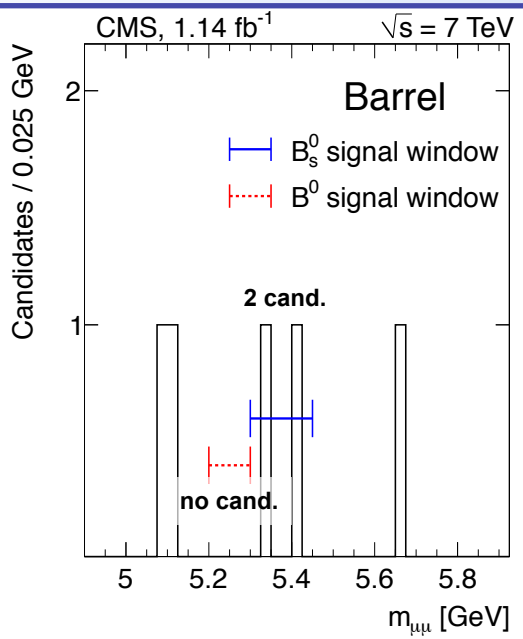


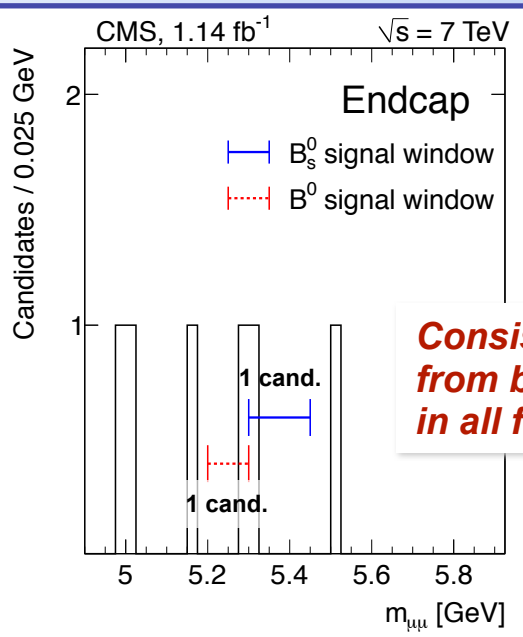
Toy MC

Systematic uncertainties

Fragmentation fractions from PDG	**13%**
Background estimation: *loosen cuts, invert isolation cut*	4%
Signal acceptance: *vary b-quark production processes*	4%
Signal selection efficiency: *cut-by-cut data/MC differences*	**8%**
Track momentum scale: *from J/ψ resonance*	3%
Normalization selection efficiency: *cut-by-cut data/MC differences*	5%
Hadron tracking efficiency: *from D* decays*	4%
Normalization yield: *vary fit functions*	5%
Muon identification efficiency ratio: *data/MC differences*	5%
Trigger efficiency ratio: *data/MC differences*	3%
Total	**19%**

Results



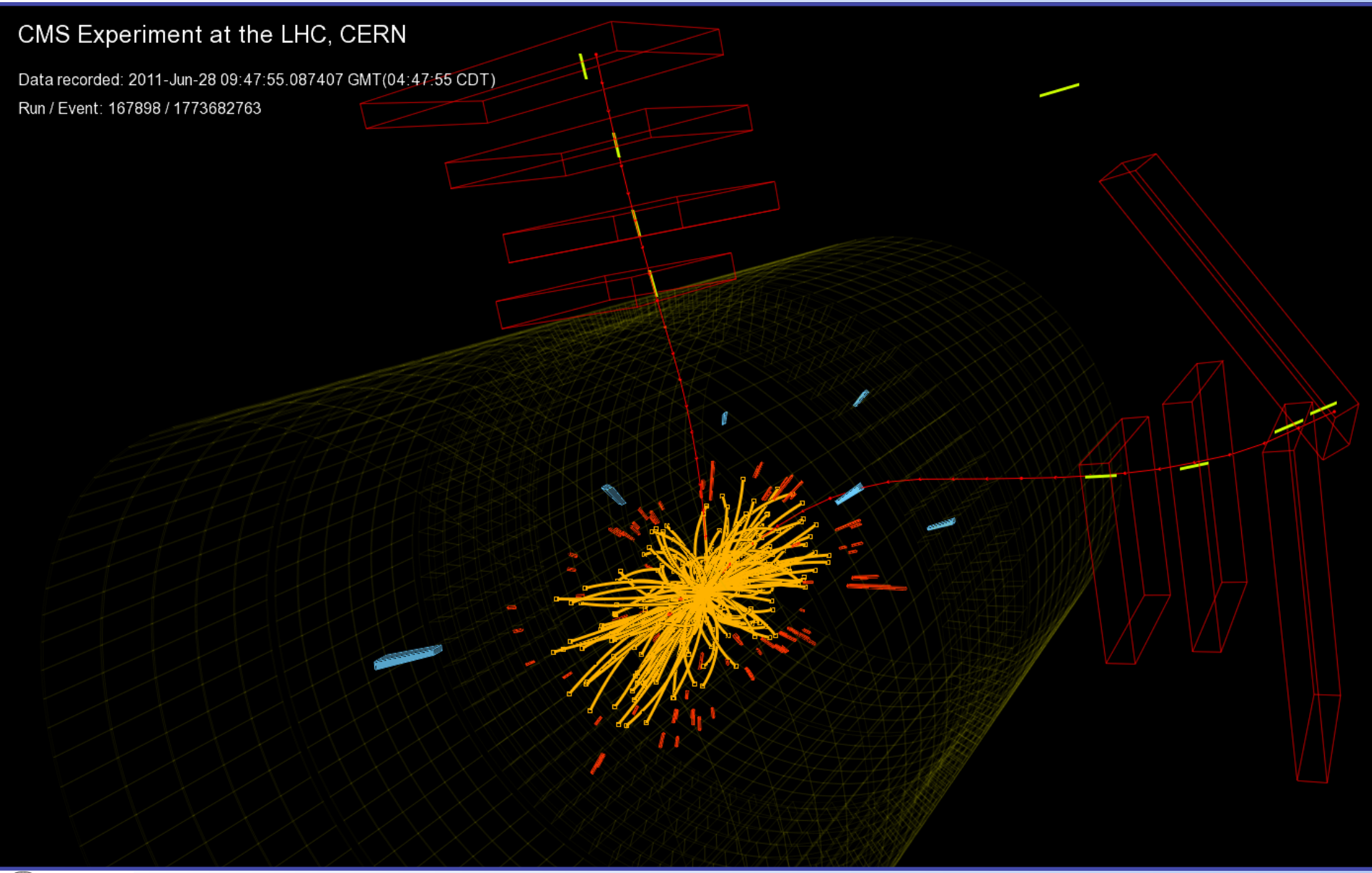


Consistent with expectation from background and SM signal in all four channels

	Barrel		Endcap	
	$B^0 \to \mu^+\mu^-$	$B_s^0 \to \mu^+\mu^-$	$B^0 \to \mu^+\mu^-$	$B_s^0 \to \mu^+\mu^-$
ε_{tot}	$(3.6 \pm 0.4) \times 10^{-3}$	$(3.6 \pm 0.4) \times 10^{-3}$	$(2.1 \pm 0.2) \times 10^{-3}$	$(2.1 \pm 0.2) \times 10^{-3}$
N_{signal}^{exp}	0.065 ± 0.011	0.80 ± 0.16	0.025 ± 0.004	0.36 ± 0.07
N_{comb}^{exp}	0.40 ± 0.23	0.60 ± 0.35	0.53 ± 0.27	0.80 ± 0.40
N_{peak}^{exp}	0.25 ± 0.06	0.07 ± 0.02	0.16 ± 0.04	0.04 ± 0.01
N_{obs}	0	2	1	1

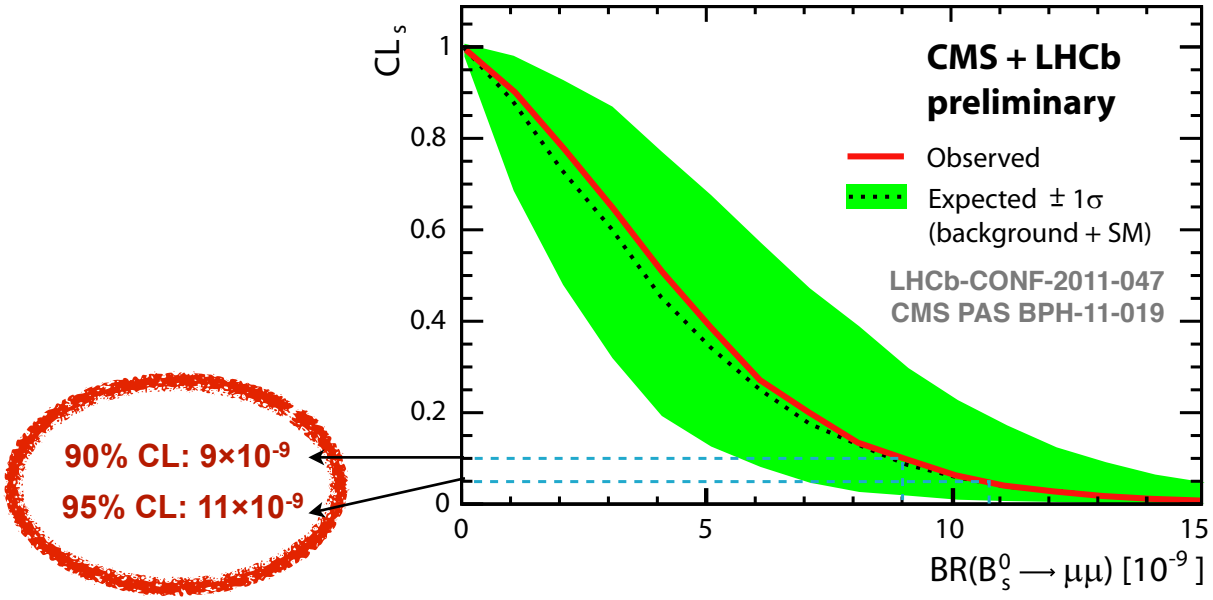
Decay	Expected (95% CL)	Observed (95% CL)	Background-only p value
$B_s \to \mu^+\mu^-$	1.8×10^{-8}	**1.9×10^{-8}**	11% (1.2σ)
$B^0 \to \mu^+\mu^-$	4.8×10^{-8}	**4.6×10^{-9}**	40% (0.3σ)

Candidate event



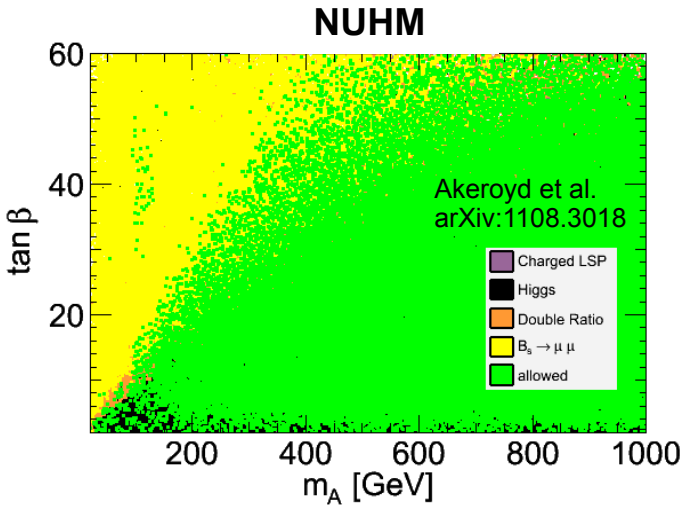
CMS+LHCb combination

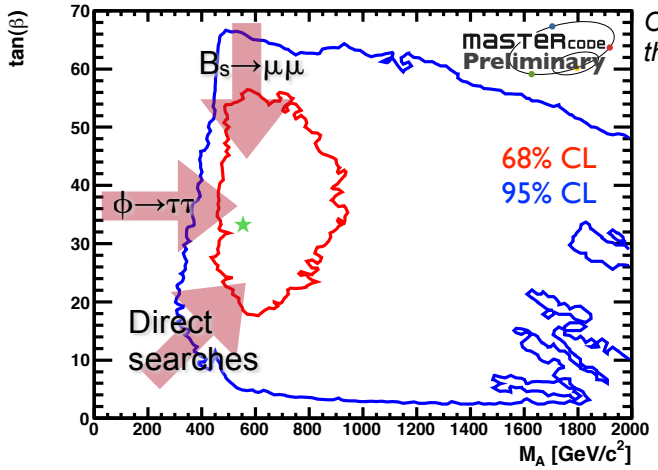
- LHCb analysis released at EPS 2011, based on 370 pb^{-1}
  - Upper limit = 1.6×10^{-9} at 95% CL (1.5×10^{-9} combining with 2010 result)
- CMS and LHCb upper limits combined
  - Utilize recent LHCb f_s/f_u value (8% uncert.)
    - Assumed 100% correlated between 48 LHCb bins and 2 CMS bins for signal expectation
  - p-value for background only = 8%
  - p-value for background+signal = 57%



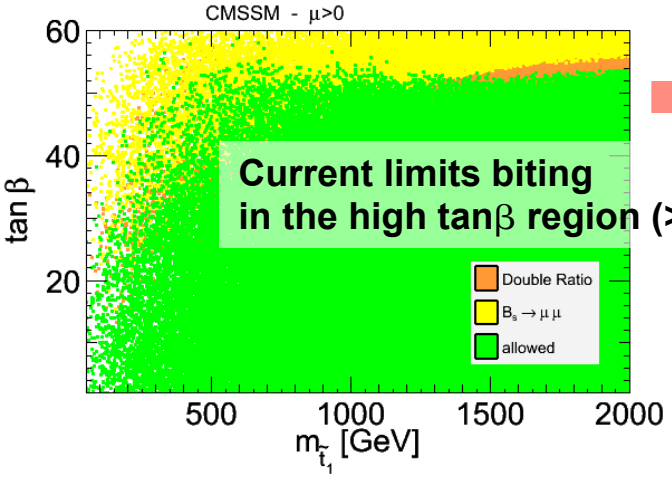
Implications on new physics

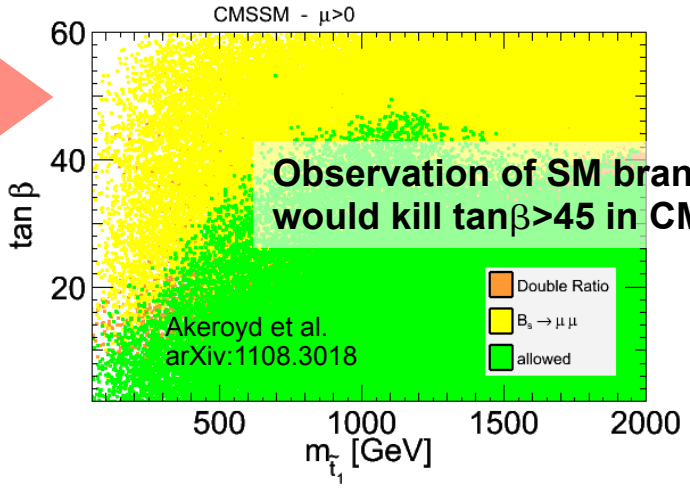
- Relevant impact on various SUSY scenarios at large tanβ
  - For large tanβ (50) can extend limits from direct searches in some models





O.Buchmueller et al. this workshop

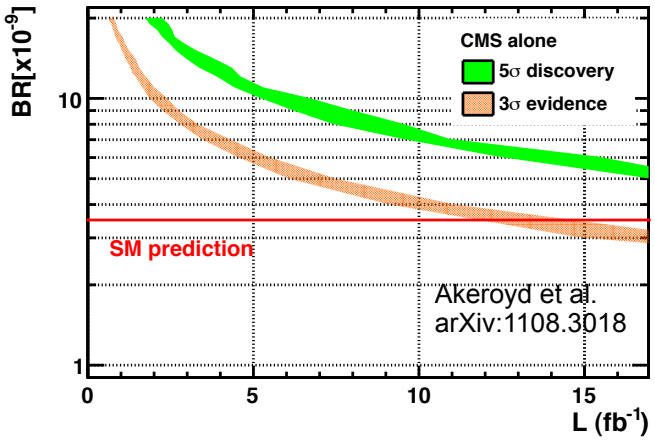




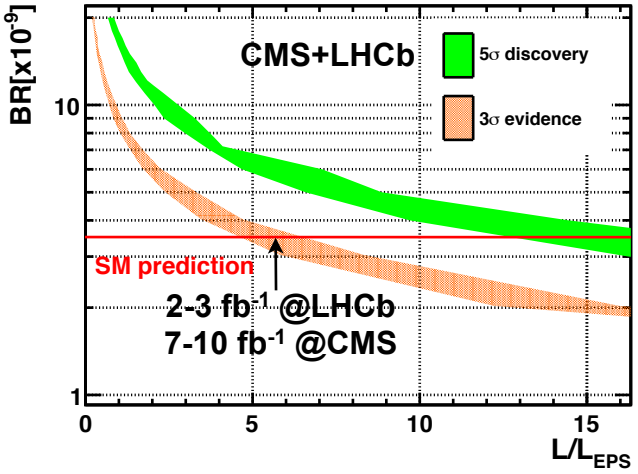
Many other global fitters available...

Closing fast?

- A three sigma evidence of SM branching may be at reach by early 2012
  - Improvement in sensitivity may be expected moving from cut&count to MV analyses



Simple scaling of current limits with no improvement in sensitivity!

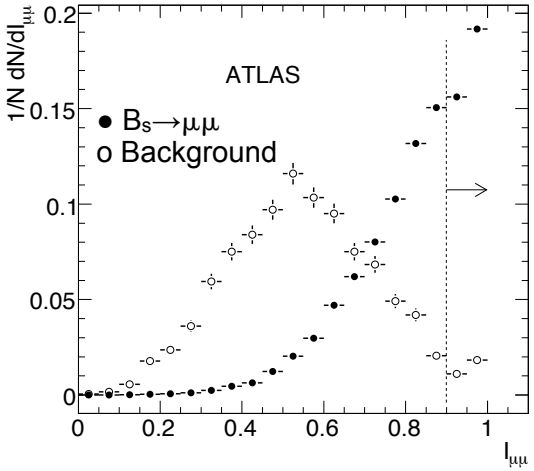


5-7 times EPS11 luminosity needed for 3σ evidence of SM prediction with CMS+LHCb combination (35% already on tape!)

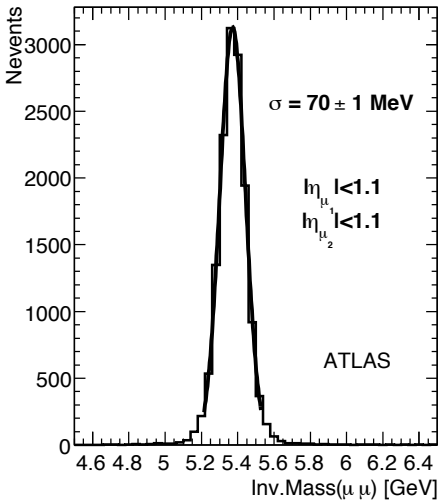
Prospects at Atlas

- Feasibility study based on MC:
  - Trigger:
    - L1 trigger p_T threshold at 6 GeV
    - Track+muon segment combination at L2, $M(\mu^+\mu^-)<7$ GeV
  - Offline selection:
    - $l_{2D}>500$ μm, $\alpha<17$ mrad, Isolation>90%
    - Asymmetric search window: **4-7 GeV**
    - Mass resolution: **70 (124) MeV** in barrel (endcap)

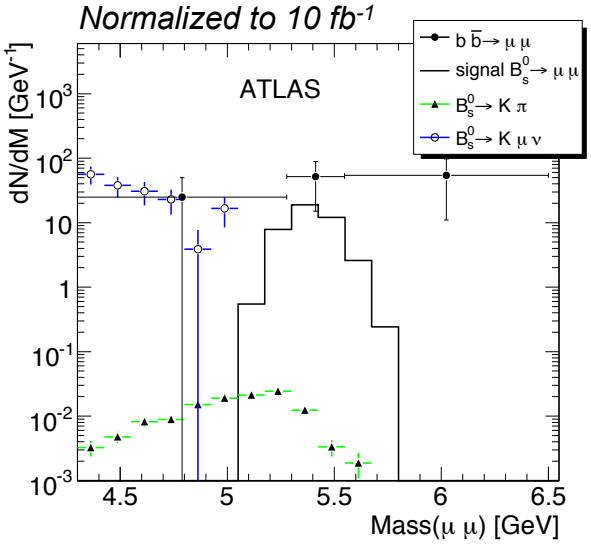
Isolation cut



B_s mass resolution



Normalized to 10 fb^{-1}



Normalized to 10 fb^{-1}

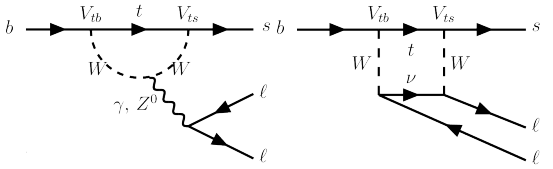
Selection cut	$B_s^0\to\mu^+\mu^-$ efficiency	$b\bar{b}\to\mu^+\mu^-X$ efficiency	
$I_{\mu\mu}>0.9$	0.24	$(2.6\pm0.3)\cdot10^{-2}$	
$L_{xy}>0.5$mm	0.26	$(1.4\pm0.1)\cdot10^{-2}$	$(1.0\pm0.7)\cdot10^{-3}$
$\alpha<0.017$ rad	0.23	$(8.5\pm0.2)\cdot10^{-3}$	
Mass in $[-\sigma,2\sigma]$	0.76	0.079	
TOTAL	0.04	$0.24\cdot10^{-6}$	$(2.0\pm1.4)\cdot10^{-6}$
Events yield	5.7		14^{+13}_{-10}

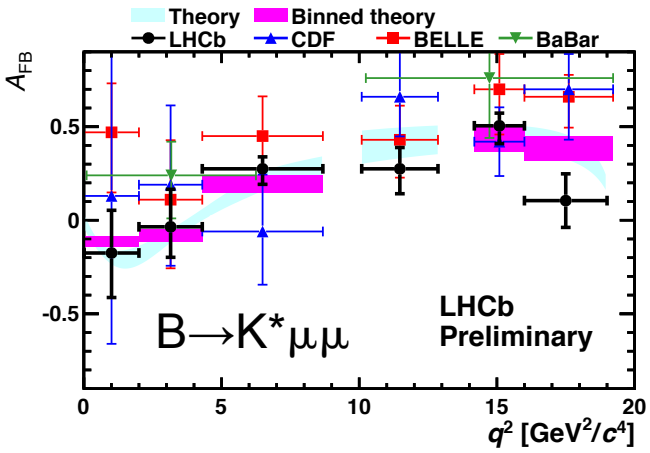
First results expected in autumn 2011

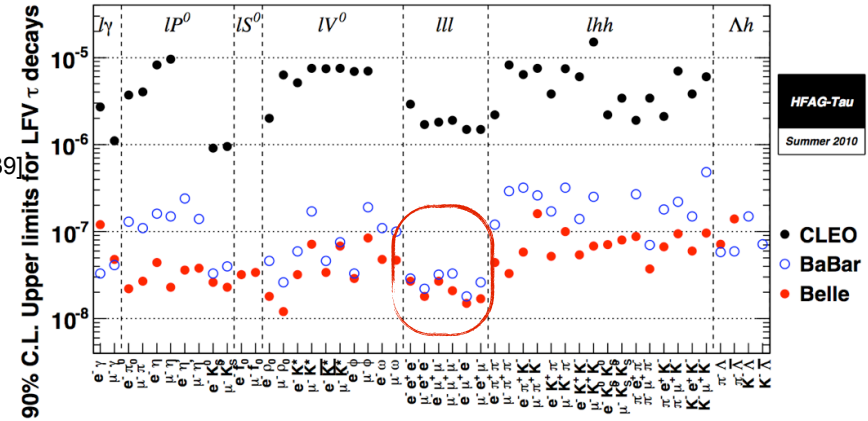
CERN-OPEN-2008-020

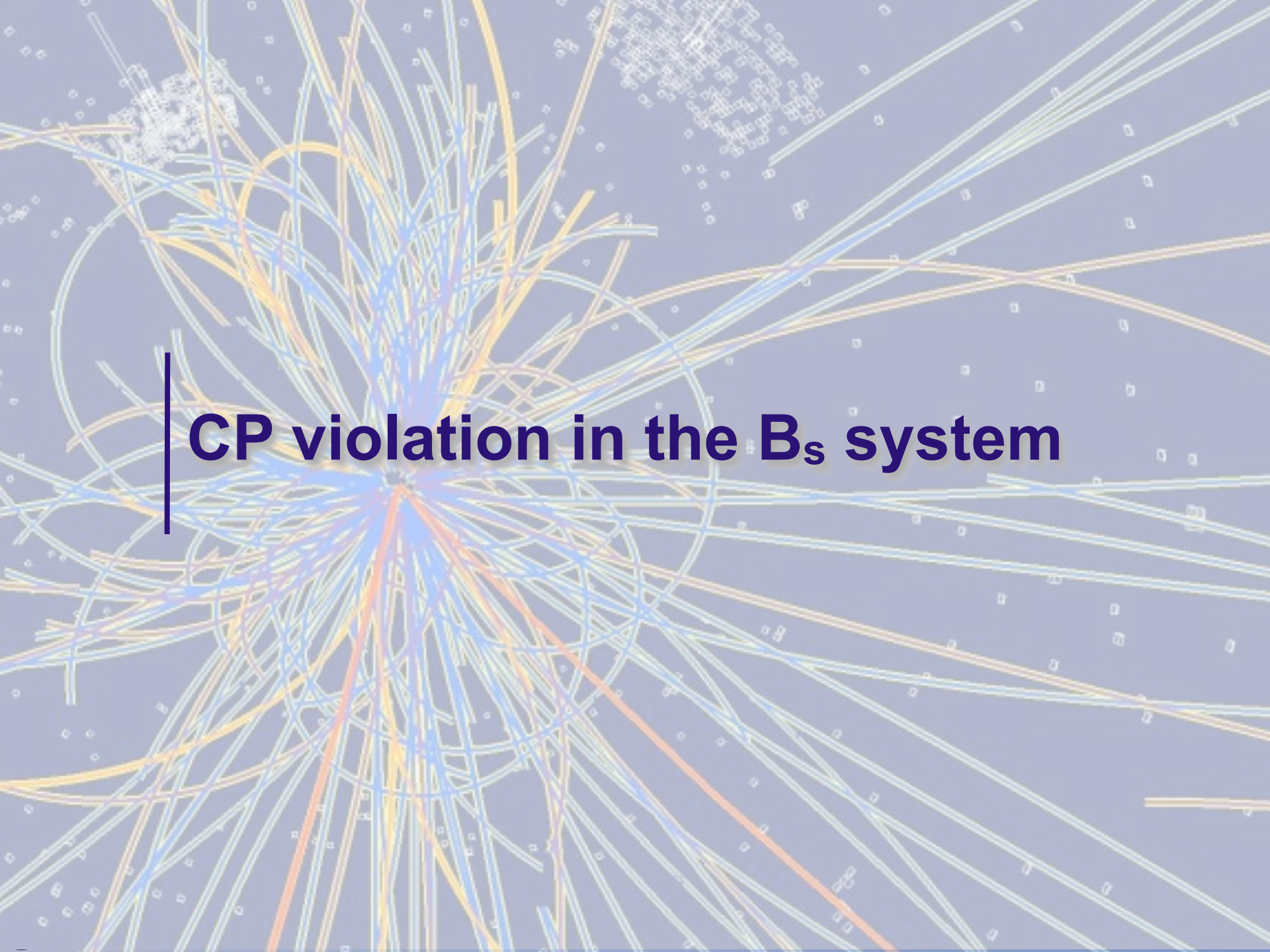
Other rare decays

- $B^0 \to K^{*0}\mu^+\mu^-$
  - FCNC decay, Br = $(3.3\pm1.0)\times10^{-6}$
  - Angular lepton asymmetries and polarization sensitive to helicity structure of new physics
  - Hints from b-factories and CDF unconfirmed by LHCb results (A_{FB}, F_L, $d\Gamma/dq^2$) at LP2011
- $D^0 \to \mu^+\mu^-$
  - FCNC decay, Br~4×10^{-13} [PRD **66**, 014099]
  - NP could enhance Br to 10^{-10}-10^{-8}
  - Best published limit from Belle: 1.4×10^{-7} (90%CL)
- $\tau \to 3$ leptons
  - SM branching $\propto(m_\nu/m_W)^4$~10^{-50}
  - NP could enhance Br to as much as 10^{-7}
  - Best limit for 3μ: 2.1×10^{-8} (90%CL) [PLB **687** (2010) 139]
  - CMS simulation:
    - 3.8×10^{-8} (95%CL) with 30 fb^{-1}
    - Single and di-muon triggers
    - Room for improvements at trigger level





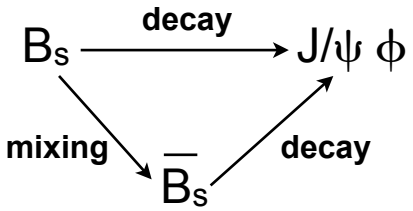




CP violation in the B_s system

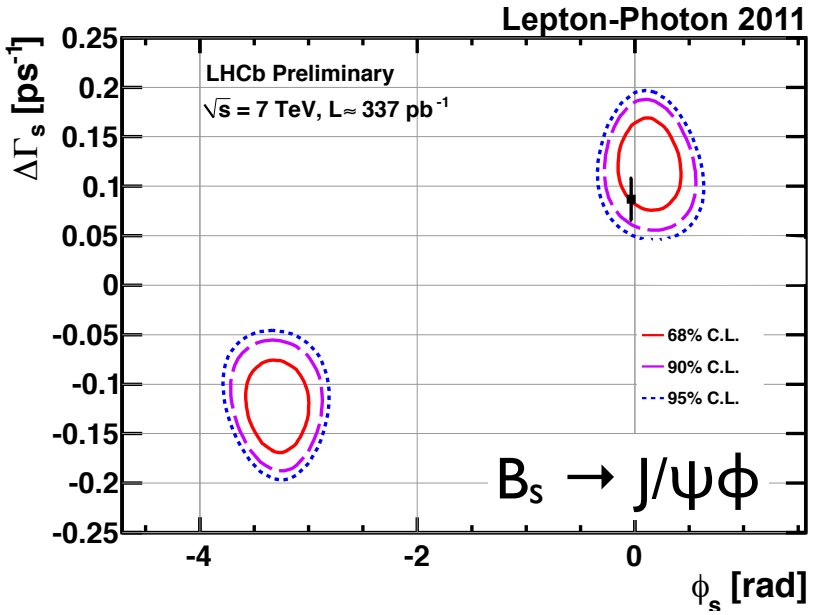
CP violation in $B_s \to J/\psi\,\phi$

- CP violating phase induced by mixing
  - Very small SM prediction (-36±2) mrad
- Polarization amplitudes depend on CP of final state
  - Requires flavour tagged, time dependent angular analysis
  - Combined fit of 5 variables (mass, lifetime, three polarization angles)



$$\phi_s = \phi_M - 2\phi_D$$

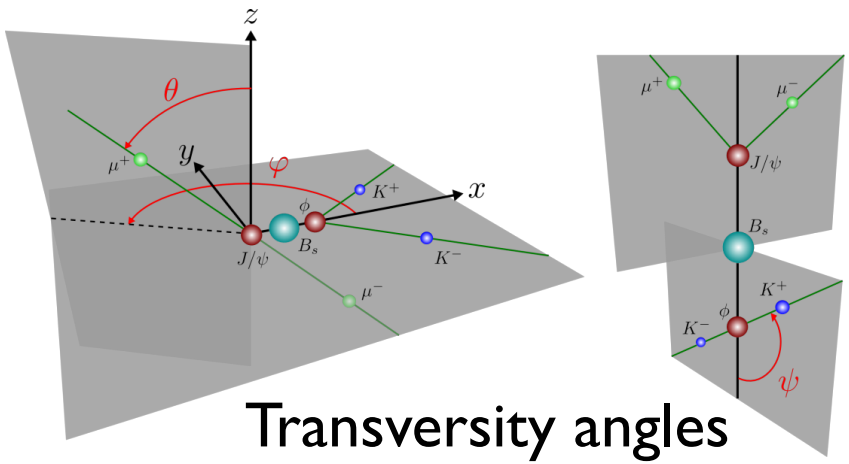
$$\phi_s = -2\beta = -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$



Yield: 8276±96 candidates in 337/pb

ϕ_s=0.13±0.18(stat)±0.07(syst) from J/ψφ only

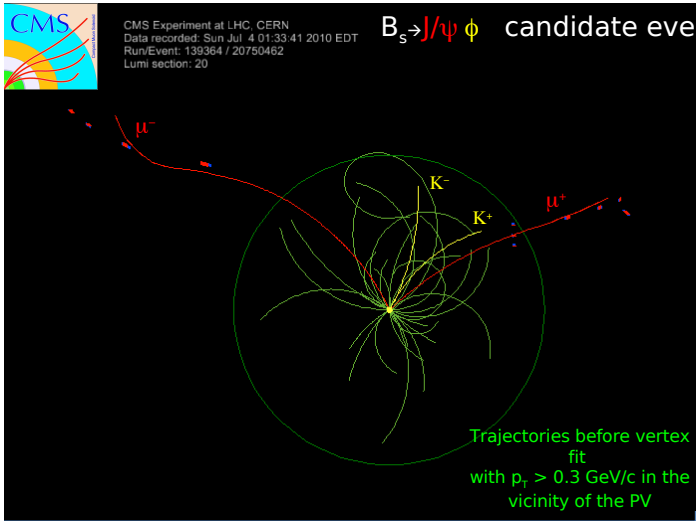
ϕ_s=0.03±0.18(stat)±0.07(syst) combined with J/ψf_0



Transversity angles

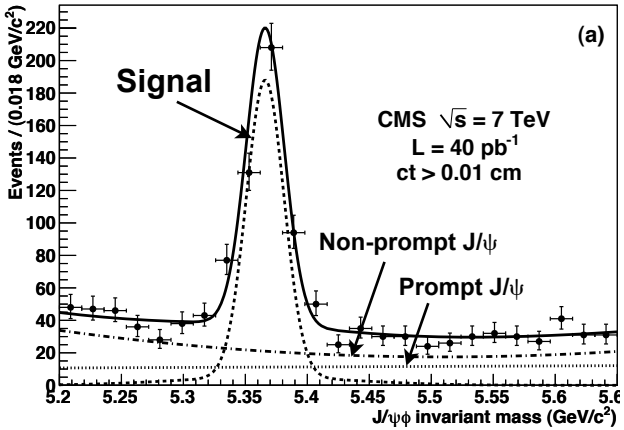
$\Omega = \{\theta, \phi, \psi\}$

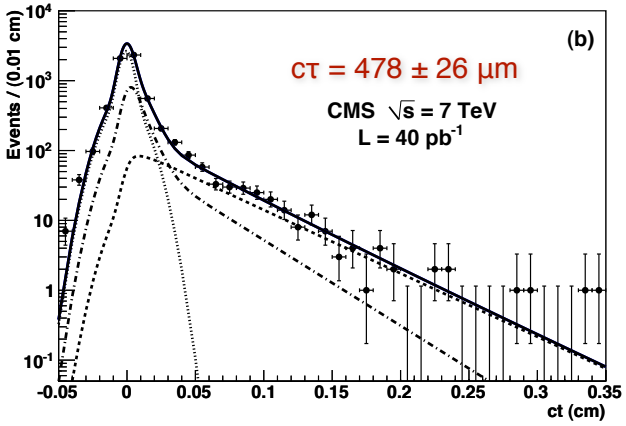
Studies at CMS

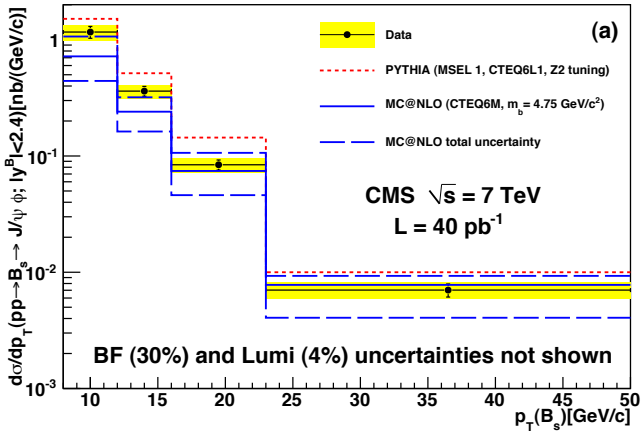


- Roadmap for J/ψϕ studies:
  - Cross section and average lifetime:
    - In agreement with NLO and PDG
    - Yield: ~550 signal candidates in 40 pb^{-1}
  - (Un)tagged angular analysis with >2 fb^{-1} ongoing
    - Lower yields observed in 2011 due to higher trigger thresholds but overall samples larger than Tevatron

arXiv:1106.4048, accepted by PRD





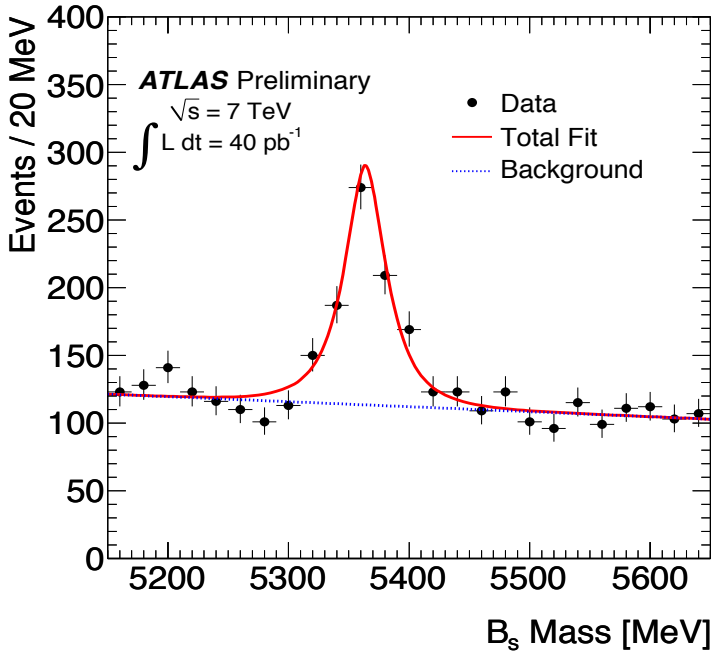


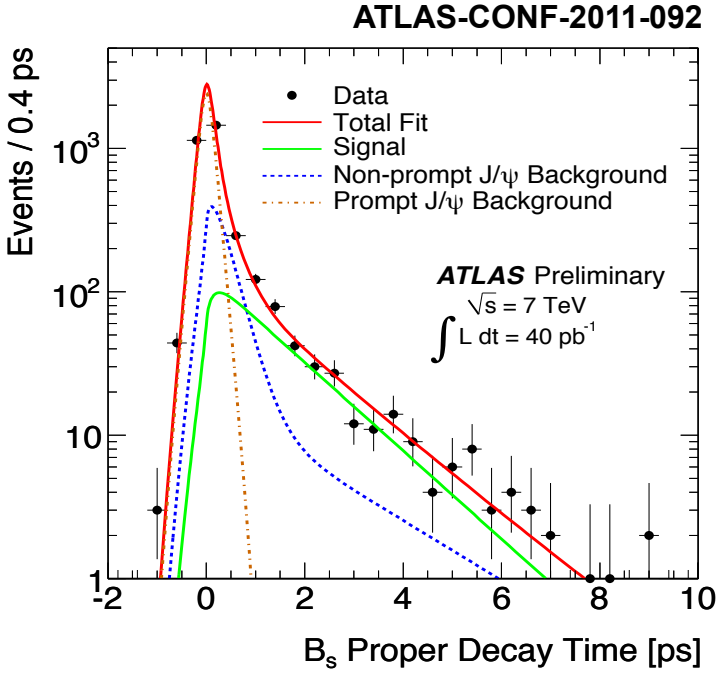
$8<p_T(B_s)<50$ GeV, $|y(B_s)|<2.4$, $\sigma = 6.9 \pm 0.6(\text{stat}) \pm 0.6(\text{syst})$ nb

$\sigma(\text{MC@NLO}) = 4.6^{+1.9}_{-1.7}(\text{scale}) \pm 1.4(\text{Br})$ nb

Studies at Atlas

- Average lifetime measured with 2010 data:
  - Yield: 463 signal candidates in 40/pb
  - In good agreement with PDG, first step towards angular fit





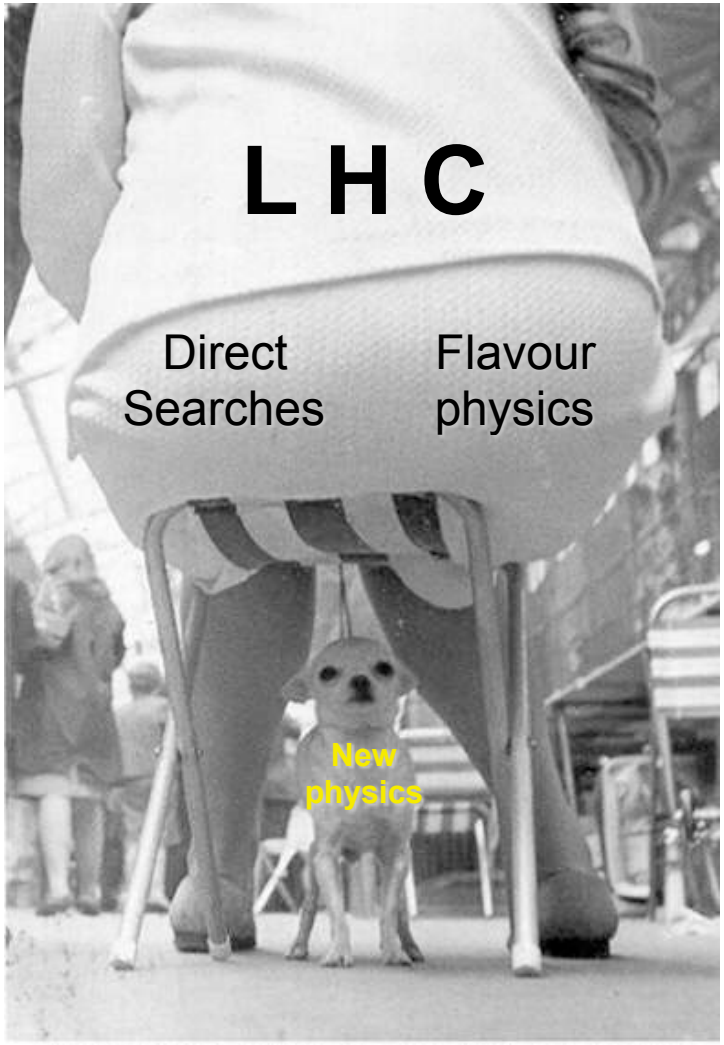
	τ_B,ps	m_B MeV	σ_m, MeV	N_{sig}
B_d^0	1.51 ± 0.04	5279.0 ± 0.8	34.3 ± 0.9	2750 ± 90
B_s^0	1.41 ± 0.08	5363.7 ± 1.2	24.8 ± 1.2	463 ± 26

	τ_B, ps - ATLAS	τ_B, ps - PDG value
B_d^0	1.51 ± 0.04 (stat) ± 0.04 (syst)	1.525 ± 0.009
B_s^0	1.41 ± 0.08 (stat) ± 0.05 (syst)	1.472 ± 0.026

Conclusions and outlook

- **Competitive flavour physics program at CMS and ATLAS**
- **Search for rare decays $B_s \to \mu\mu$ and $B^0 \to \mu\mu$**
  - New results from CMS and LHCb with comparable sensitivity
  - CMS data sample ~ 3 times LHCb
  - New world best limit from LHC combination: 11×10^{-9} (95%CL)
  - Atlas result expected in Autumn 2011
  - 5-7 times the EPS11 luminosity could lead to 3σ evidence of SM decay
  - Important constraint on SUSY models at large $\tan\beta$
- **Searches for more FCNC decays ongoing**
- **CP violation in $B_s \to J/\psi\phi$ and $J/\psi f_0$:**
  - Cross section and average lifetime already measured by CMS and ATLAS
  - Measurement of lifetime difference by end of the year

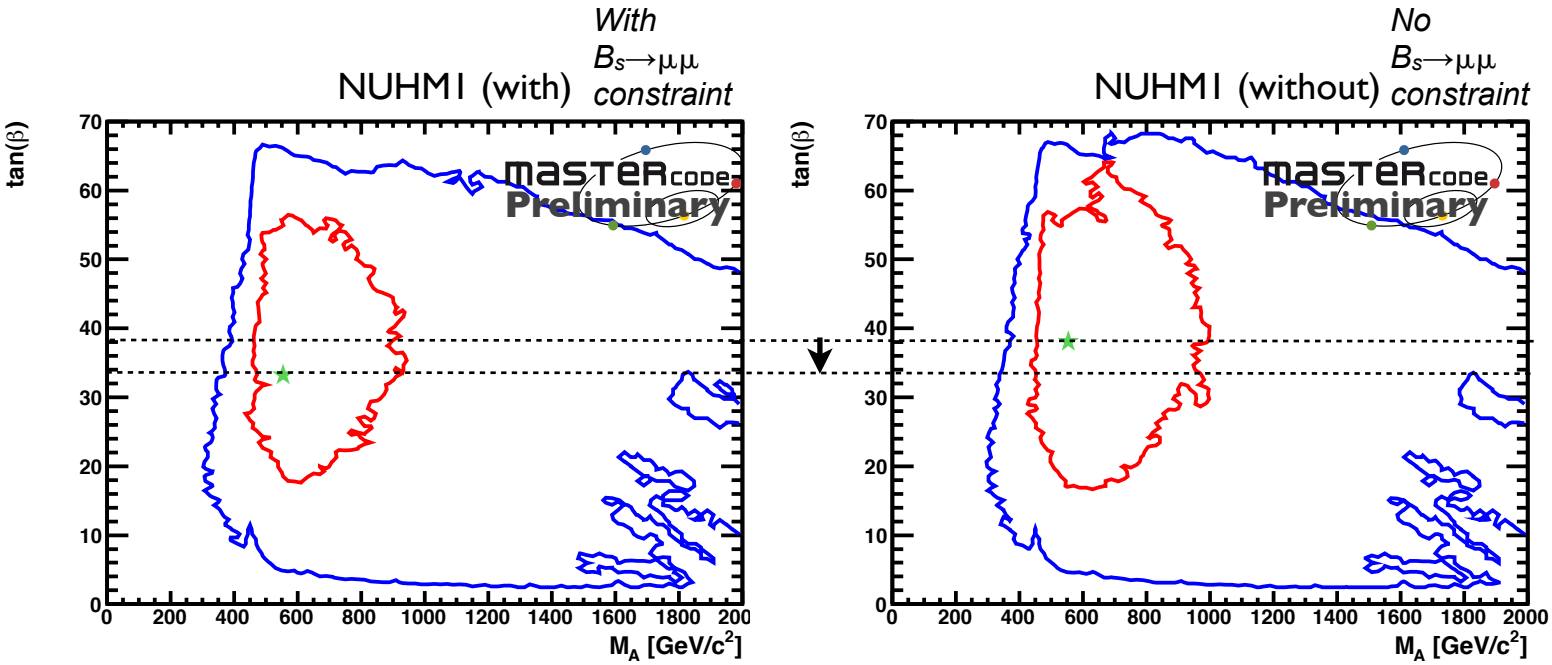
New physics is under stress...

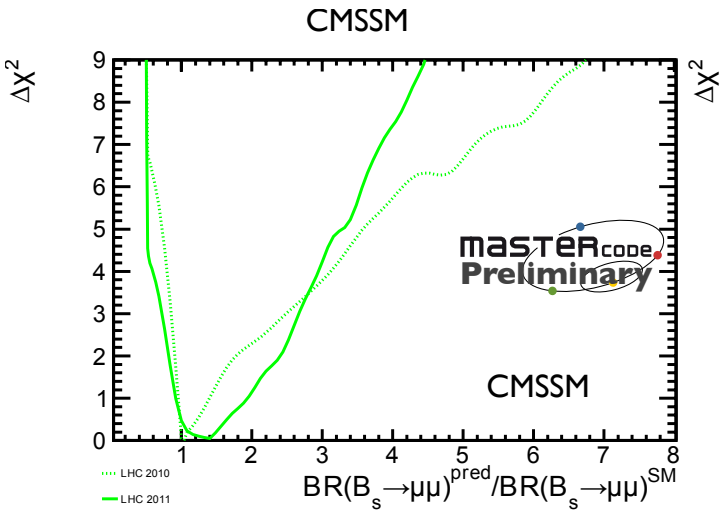


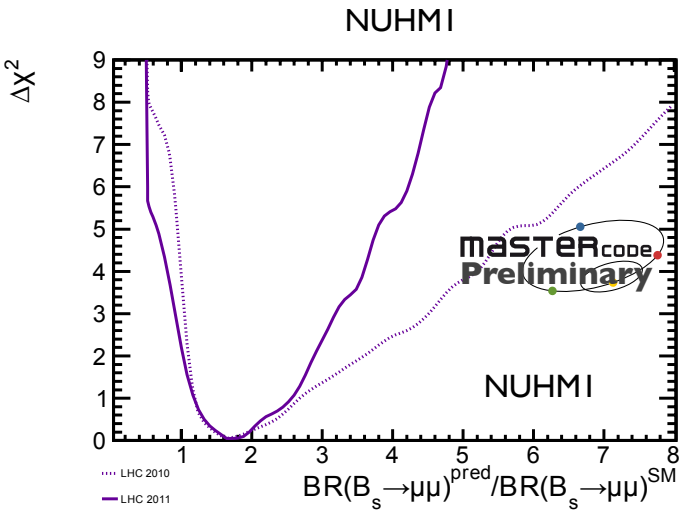
But don't be desperate (yet)


BACKUP MATERIAL

Constraints on Susy







O.Buchmueller et al. this workshop