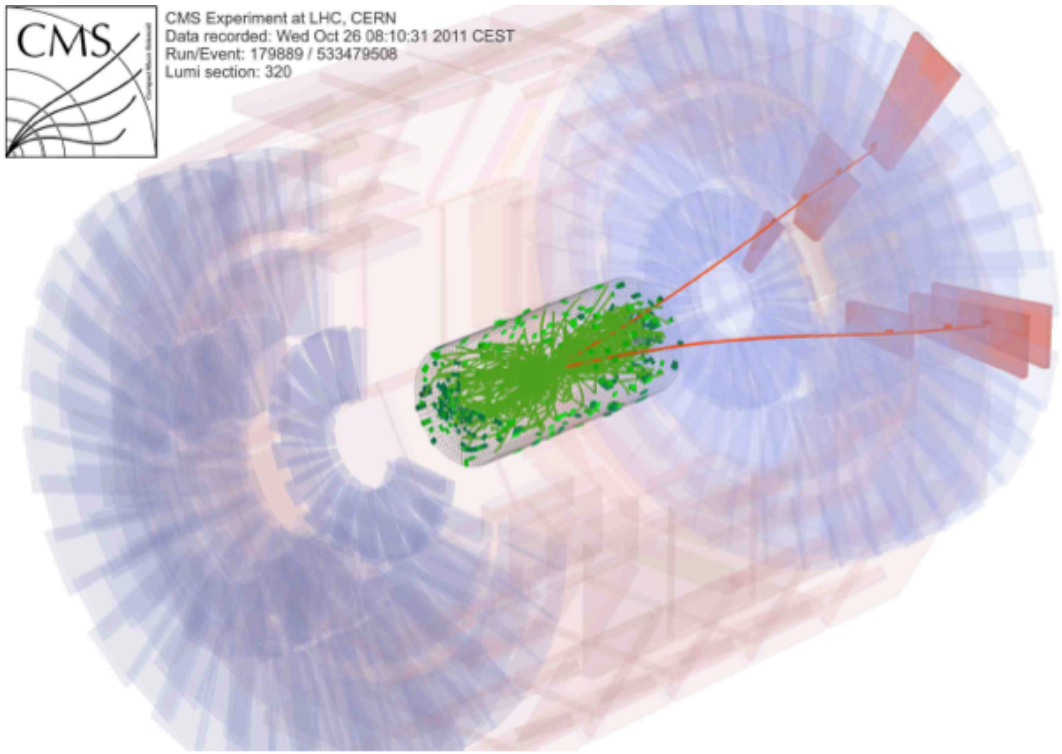
Search for the rare decays $B^0 \to \mu^+\mu^-$, $B_s \to \mu^+\mu^-$ with the CMS detector

Beauty 2013
14th International Conference on B-Physics at Hadron Machines
Bologna 9/4/2013

M. De Mattia
Purdue University
On behalf of the CMS collaboration

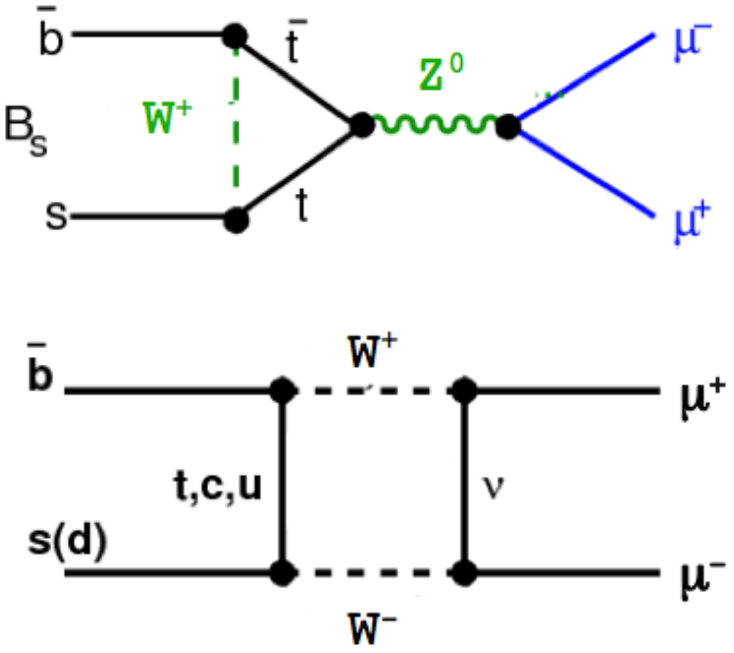
Outline

- Motivations
- Signal & Background
- Analysis
- Results
- Conclusions



Motivations

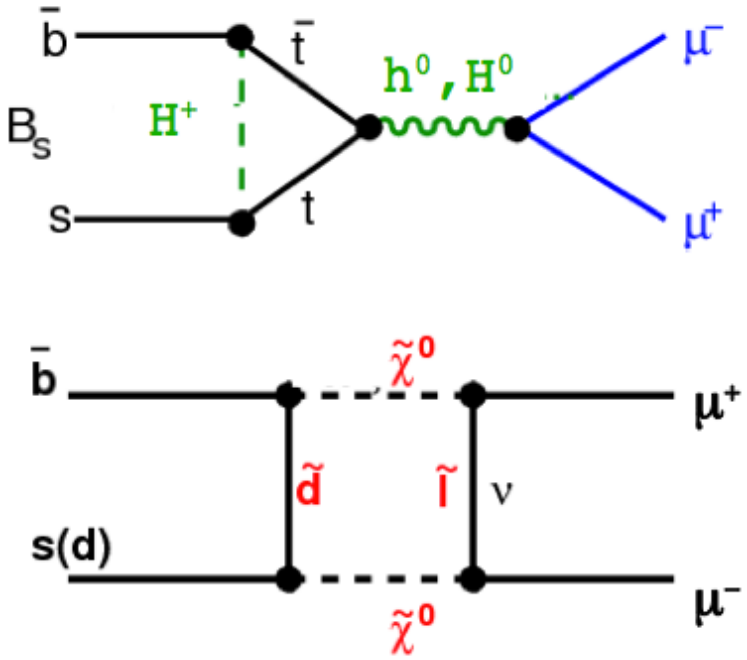
- B->mumu rare process in the SM
  - 2nd order graphs
  - Cabibbo suppressed $|V_{ts(td)}|^2$
  - Helicity suppressed $(m_\mu/m_B)^2$
  - Bag factor $(f_B/m_B)^2$
- *Br*(B_s->$\mu^+\mu^-$) = (3.23 ± 0.27) 10^{-9}
- *Br*(B^0->$\mu^+\mu^-$) = (1.07 ± 0.10) 10^{-10}



A. J. Buras et al., Eur.Phys.J. C72 (2012) 2172 [arXiv:1208.0934]

New Physics

- 2HDM[1] $Br \propto \tan^4 \beta, m(H^+)$
- MSSM[2] $Br \propto \tan^6 \beta$
- Leptoquarks[3]
- Sensitivity comparable
  $\mu \to e\gamma, B \to \nu\nu$
- Minimal Flavor Violation
  $Br(B^0 / B_s) \propto \left|V_{td} / V_{ts}\right|^2$
- Non deviation from SM:
  - Bounds to parameter space
- Complementary to direct searches at LHC



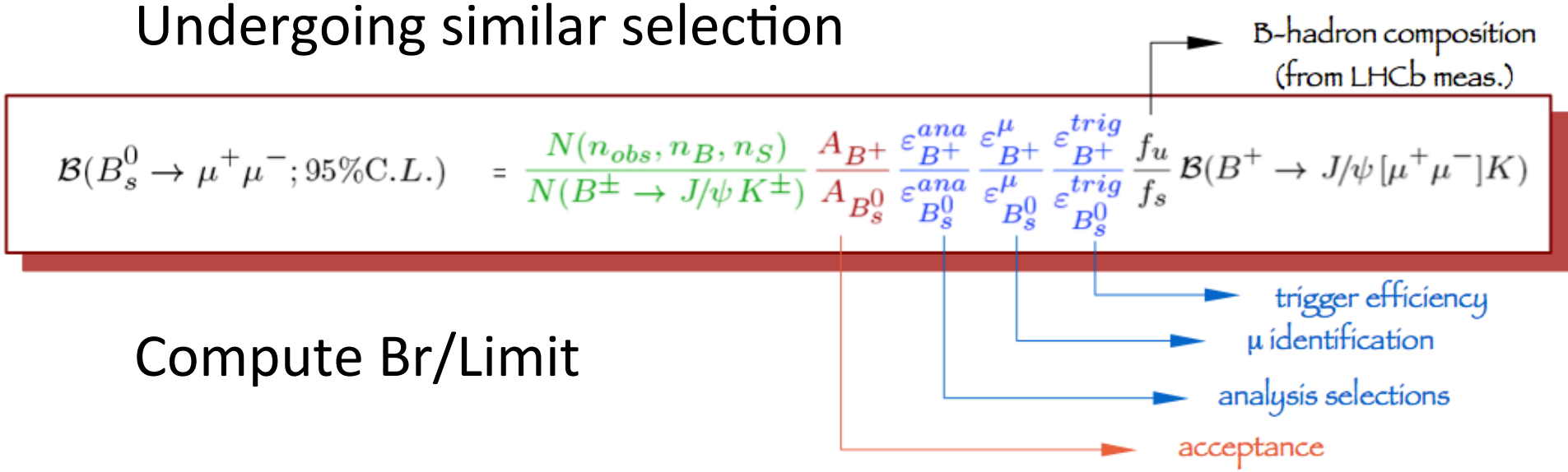
1. J. R. Ellis, K. A. Olive, Y. Santoso et al, JHEP **05** (2006) 063,
2. J.Parry, Nucl. Phys. B **760** (2007) 38
3. S. Davidson and S. Descotes-Genon, JHEP **11** (2010) 073

Analysis

- Dimuon trigger & identification
- Background rejection
- Efficiency & Normalization vs Reference

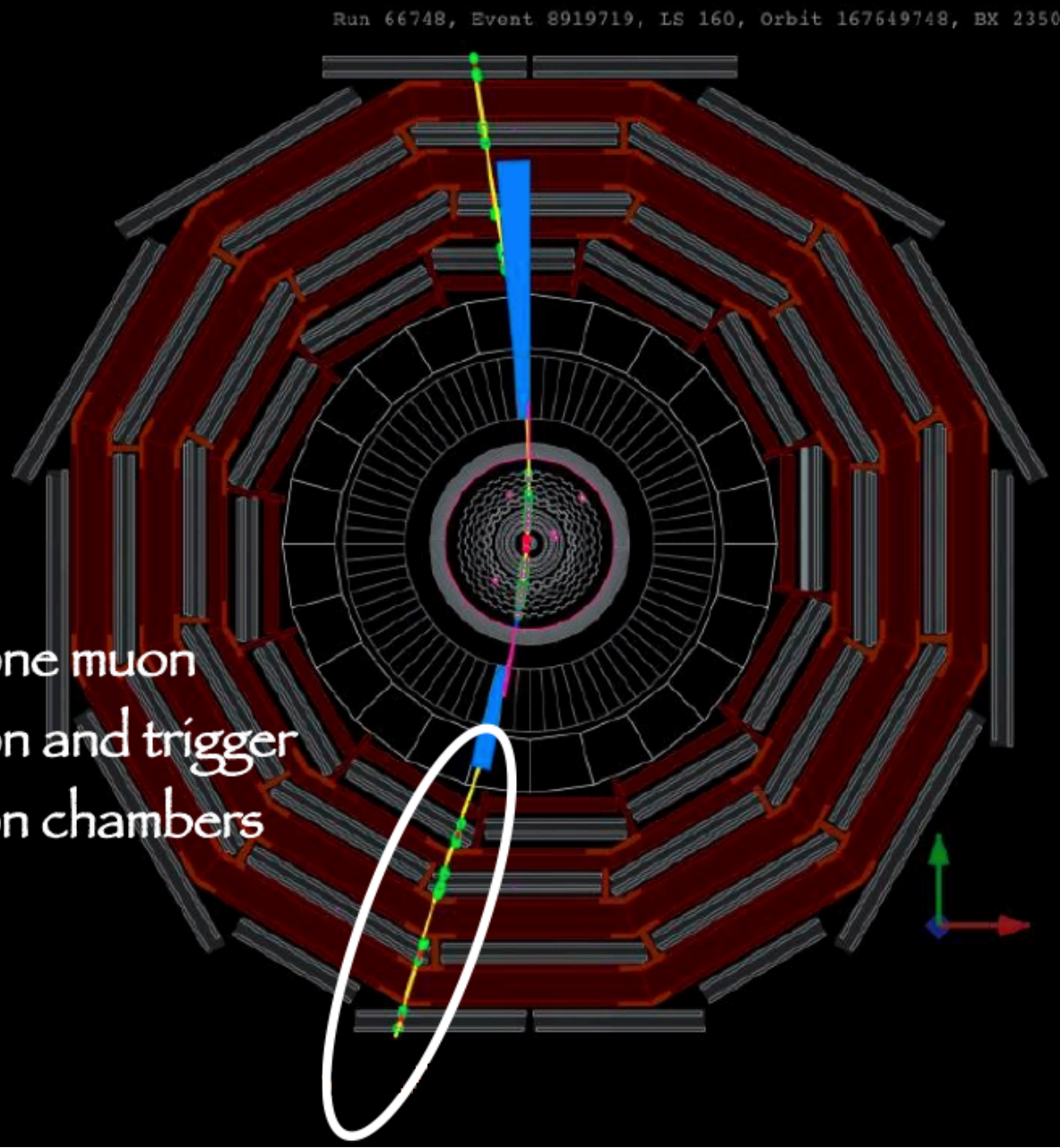
$B^+ \to J/\psi(\mu^+\mu^-)K^+$

Undergoing similar selection



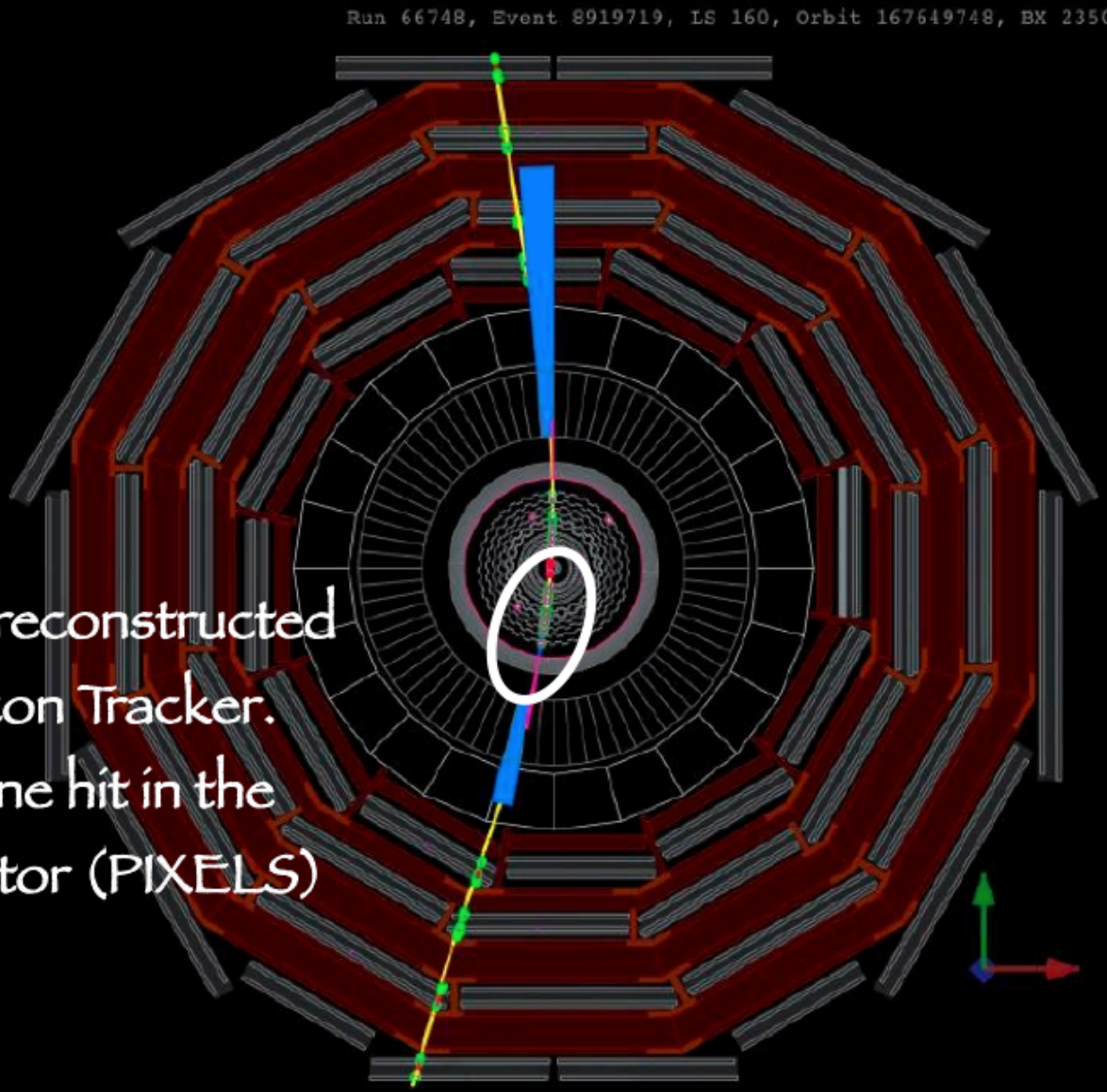
Compute Br/Limit

Muon Reconstruction @ the CMS



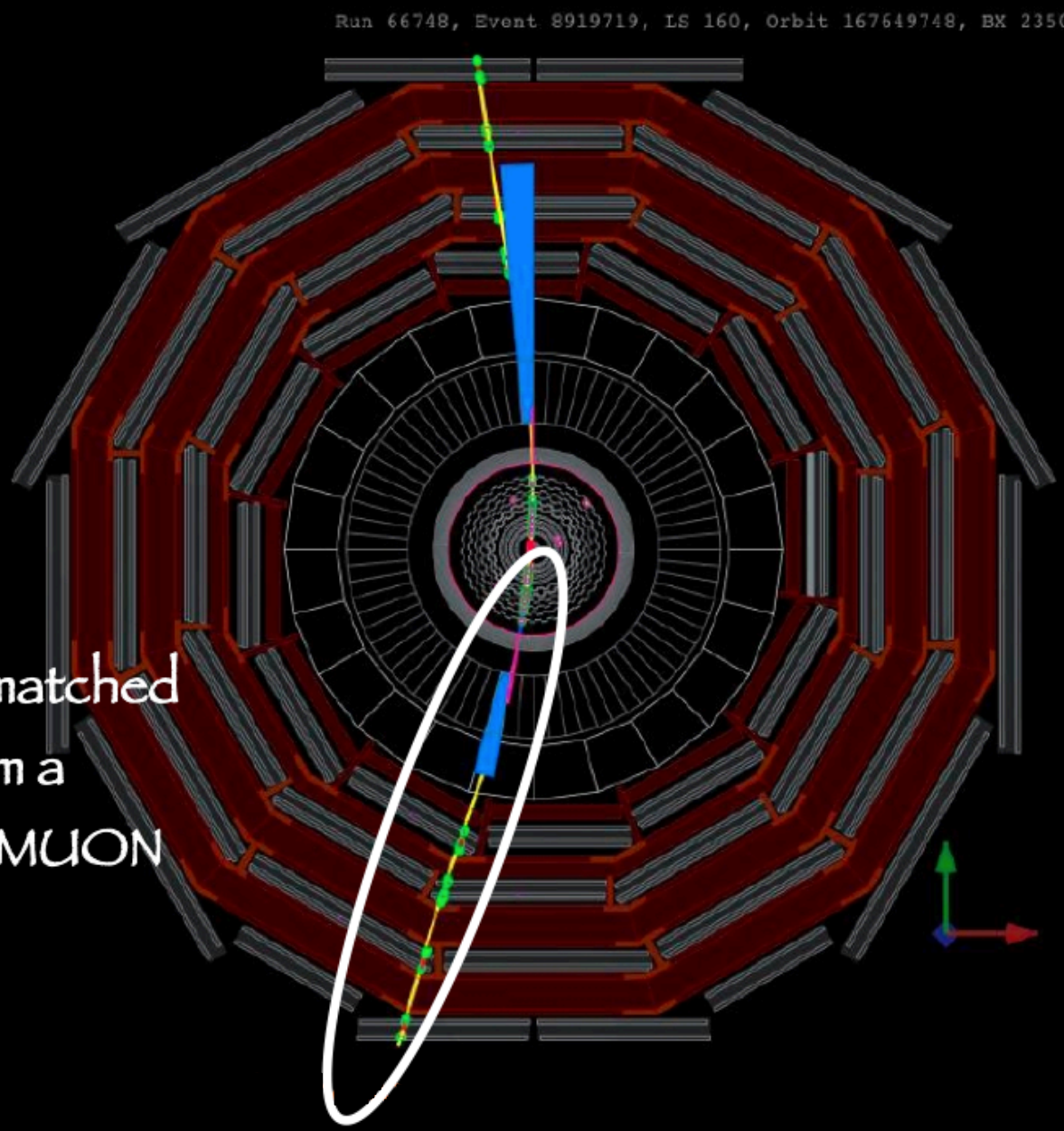
Standalone muon reconstruction and trigger in CMS muon chambers

Muon Reconstruction @ the CMS



Muon track reconstructed in the Silicon Tracker. At least one hit in the inner detector (PIXELS)

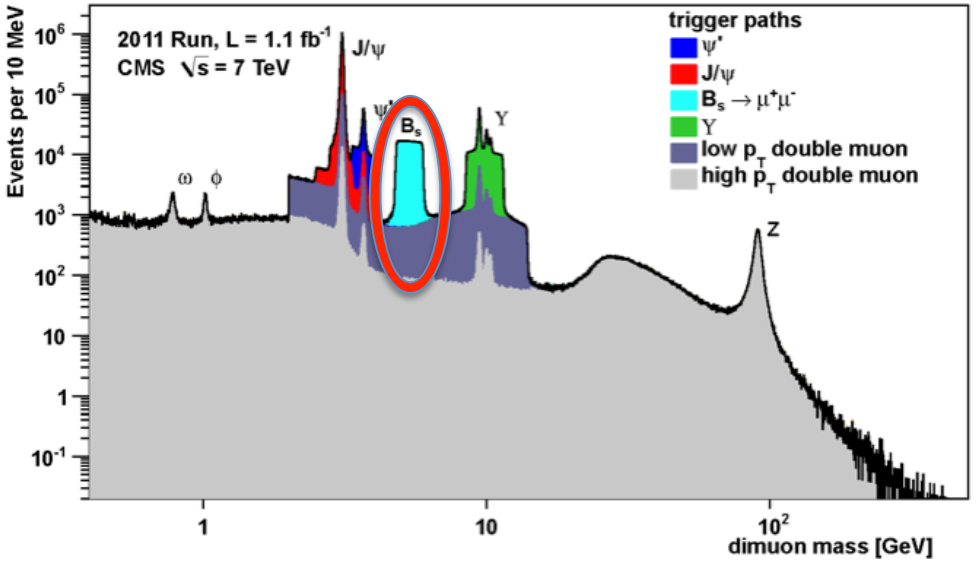
Muon Reconstruction @ the CMS



Segments matched to form a GLOBAL MUON

Trigger

- Hardware (L1) dimuon trigger
- HLT with tracking & vertex
- Cuts tightened with instantaneous lumi increase
- Similar (not identical) for signal & reference



B -> μμ

- $4.8 < m_{\mu\mu} < 6$ GeV
- $\Pi^{vertex}(\mu\mu) > 0.5\%$
- Distance of closest approach $d_{ca}^{\mu\mu}<0.5$ cm
- $p_T^{\mu} > 4$ GeV, $p_T^{\mu\mu} > 3.9$ GeV (5.9 endcaps)

B -> J/ΨK (Ψϕ)

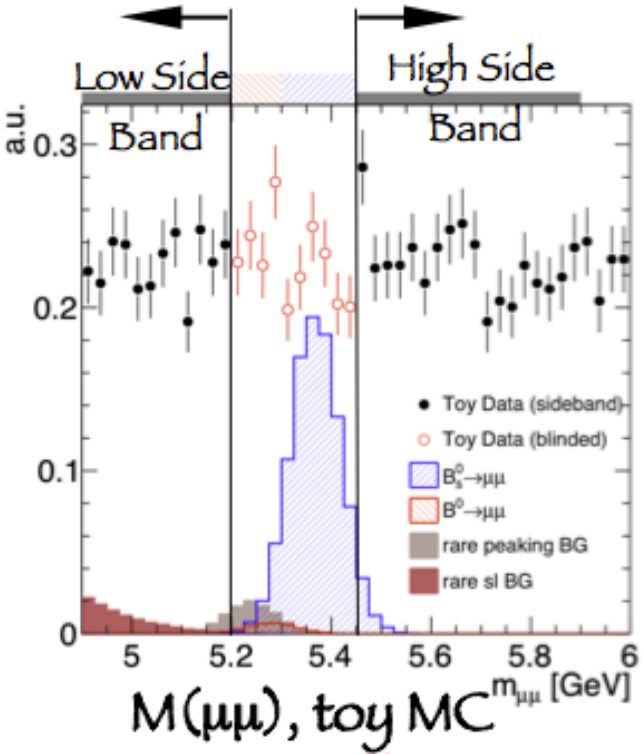
- $2.9 < m_{\mu\mu} < 3.3$ GeV
- $\Pi^{vertex}(\mu\mu) > 15\%$
- $d_{ca}^{\mu\mu} < 0.5$ cm
- $p_T^{\mu} > 4$ GeV, $p_T^{\mu\mu} > 6.9$ GeV
- $L_{(\mu\mu)} > 3\sigma(L_{(\mu\mu)})$
- $\cos \alpha_{xy} > 0.9$ (pointing angle)

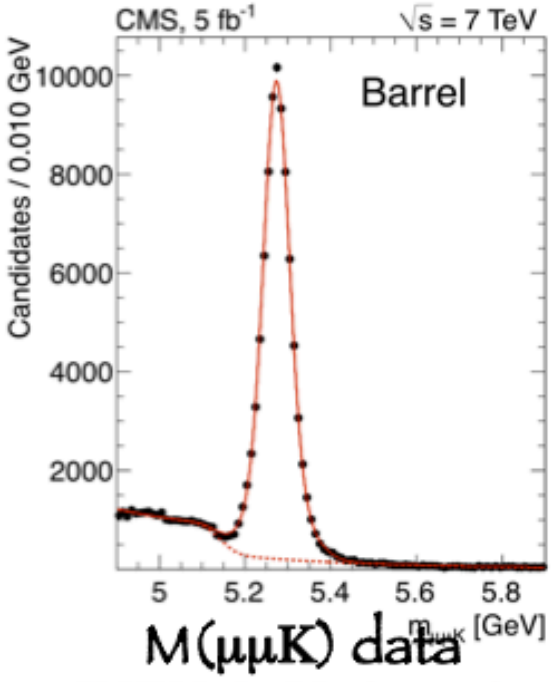
Background

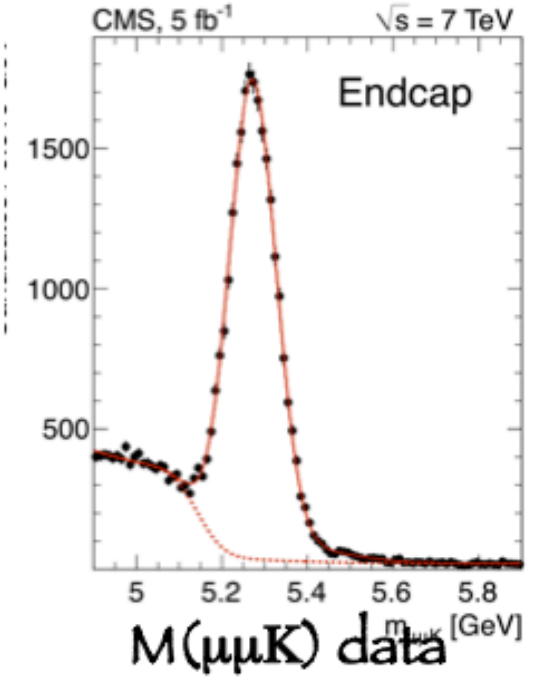
- Random dimuon correlation, including fake
- Rare B decays:
  - B->hh' ($h^{(')}$=π,K,p), both mis-identified as muon ~ $Br^*(\varepsilon_{h->\mu})^2$
  - B->hνμ ~ $|V_{ub}|^2*\varepsilon_{h->\mu}$
  - Rejected by:
    - Constraints from B decay vertex
    - Isolation Criteria
    - Invariant Mass Requirements

Data Selection: M(μμ)

- Benefit from high precision Silicon Tracking, resolution depends on η
  - $\sigma(M_{\mu\mu}) \sim 40/80$ MeV (barrel/forward)
  - $M_{Bs} - M_{B0} = 90 +/- 3$ MeV
- Two parallel searches:
  - Barrel, both muons within $|\eta| < 1.4$
  - Forward, else
  - Use similar, yet non identical, cuts





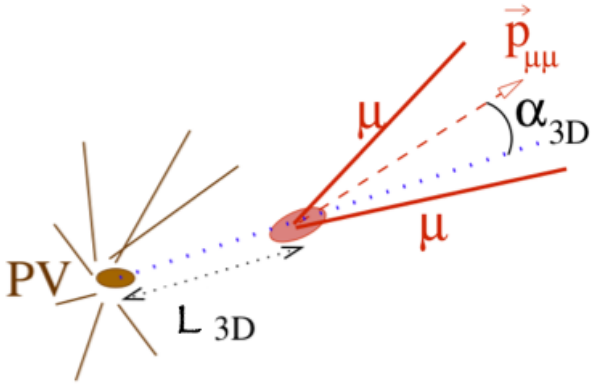


Blind Analysis

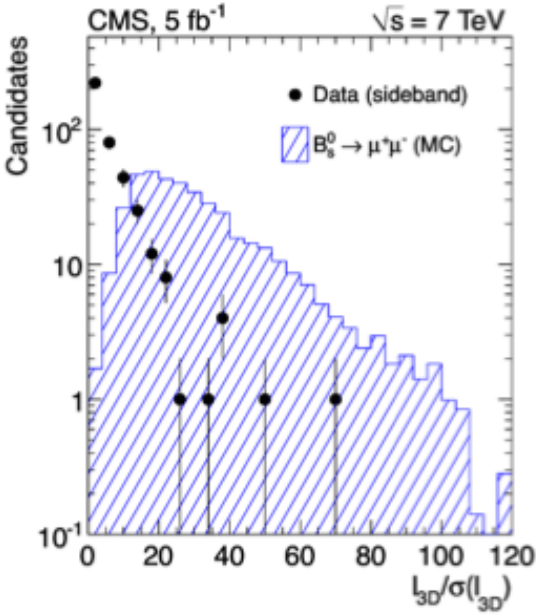
- Signal Region 5.20 < M(mm) < 5.45 inspected only at the end of the analysis, with all the selection requirements validated, efficiency corrections computed, and systematic uncertainties evaluated

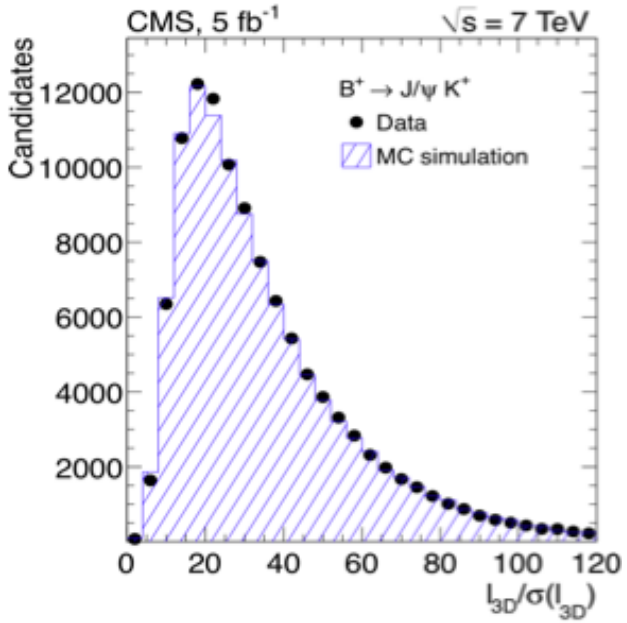
Data Selection: dimuon Vertex

- Primary Vertex
  - Minimal distance along beam axis
  - Refit without the muons
- Secondary Vertex
  - $\Pi(\chi^2)$
  - Significance $L_{3D}/\sigma(L_{3D})$, pointing angle α_{3D}, B impact parameter (all 3D)



$L_{3D}/\sigma(L_{3D})$, signal MC and Data sidebands



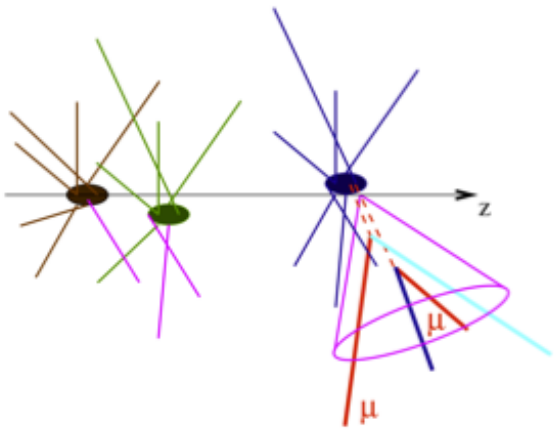


$L_{3D}/\sigma(L_{3D})$, ref. sample data & MC (for ε correction)

Data Selection: Isolation

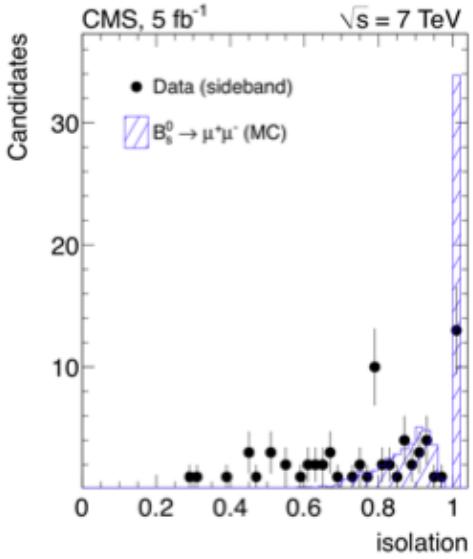
- From high p_T tracks from the same Primary Vertex, or not-associated nearby tracks

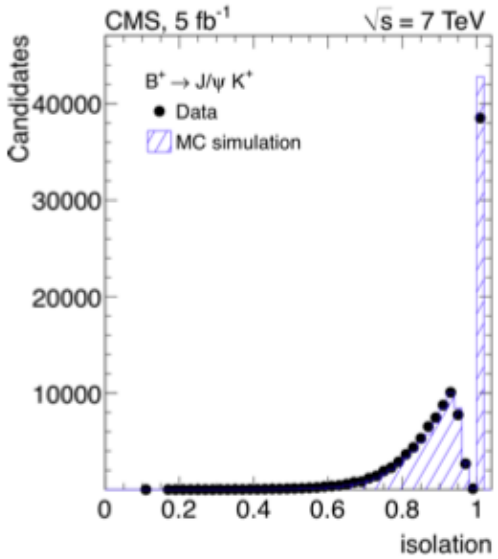
$$I = \frac{p_T(\mu\mu)}{p_T(\mu\mu) + \sum_{\Delta R<0.7} p_T}$$



- From tracks close in space to the B vertex

Isolation, signal MC and Data sidebands





Isolation, ref. sample data & MC (for ε correction)

Final Selection

- Published 2010 data included and reanalyzed
- Cut&Count; selection optimized for best limit with 1.4 10^6 tests

Variable	Barrel	Endcap	units	comparison to old analysis
$p_{\perp\mu,1} >$	4.5	4.5	GeV	same
$p_{\perp\mu,2} >$	4.0	4.2	GeV	tighter in endcap
$p_{\perp B} >$	6.5	8.5	GeV	tighter in endcap
$\ell_{3d} <$	1.5	1.5	cm	tighter
$\alpha <$	0.050	0.030	rad	looser
$\chi^2/dof <$	2.2	1.8		looser
$\ell_{3d}/\sigma(\ell_{3d}) >$	13.0	15.0		looser
$I >$	0.80	0.80		redefined
$d^0_{ca} >$	0.015	0.015	cm	redefined
$\delta_{3D} <$	0.008	0.008	cm	new
$\delta_{3D}/\sigma(\delta_{3D}) <$	2.000	2.000		new
$N_{trk} <$	2	2	tracks	new

Efficiency	Barrel	Endcap
$B^0_s \to \mu^+\mu^-$	0.0029 ± 0.0002	0.0016 ± 0.0002
$B^\pm \to J/\psi\, K^\pm$	0.00110 ± 0.00009	0.00032 ± 0.00004

Systematic Uncertainties

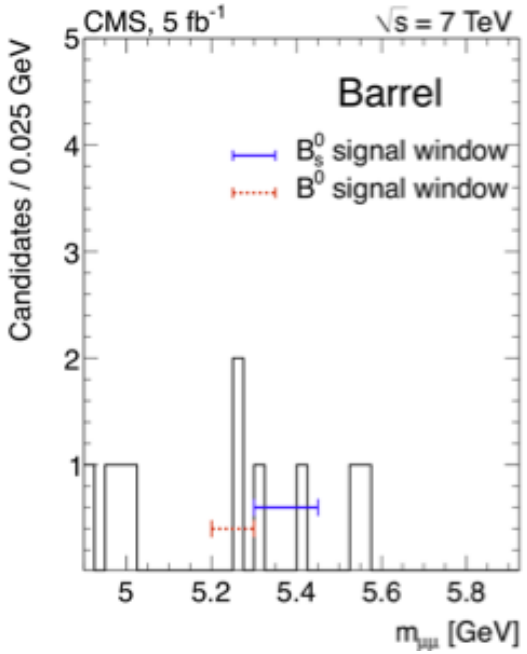
- Acceptance
  - B production: g-fusion/g-splitting/bb-excitation
- μ id & trigger
  - Tag & Probe (unbiased J/Ψ sample)
  - Data/MC for J/ΨK
  - Cut variation
- Selection
  - Data/MC for J/ΨK
- Normalization & Bck.
  - Measured fake rates
  - W.A. values for Br
  - LHCb error on f_s/f_u

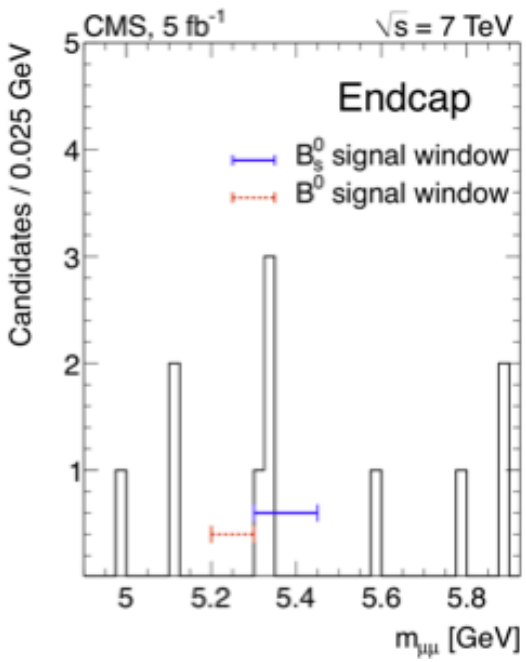
Systematic Uncertainties (%)

Category	Uncertainty	Barrel	Endcap
f_s/f_u	production ratio of u and s quarks	8.0	8.0
acceptance	production processes	3.5	5.0
P_{ij}^B	mass scale and resolution	3.0	3.0
efficiency (signal)	discrepancies data/MC simulation	3.0	3.0
efficiency (normalization)	discrepancies data/MC simulation	4.0	4.0
efficiency (normalization)	kaon track efficiency	4.0	4.0
efficiency	trigger	3.0	6.0
efficiency	muon identification	4.0	8.0
normalization	fit pdf	5.0	5.0
background	shape of combinatorial background	4.0	4.0
background	rare decays	20.0	20.0

Unblinding

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

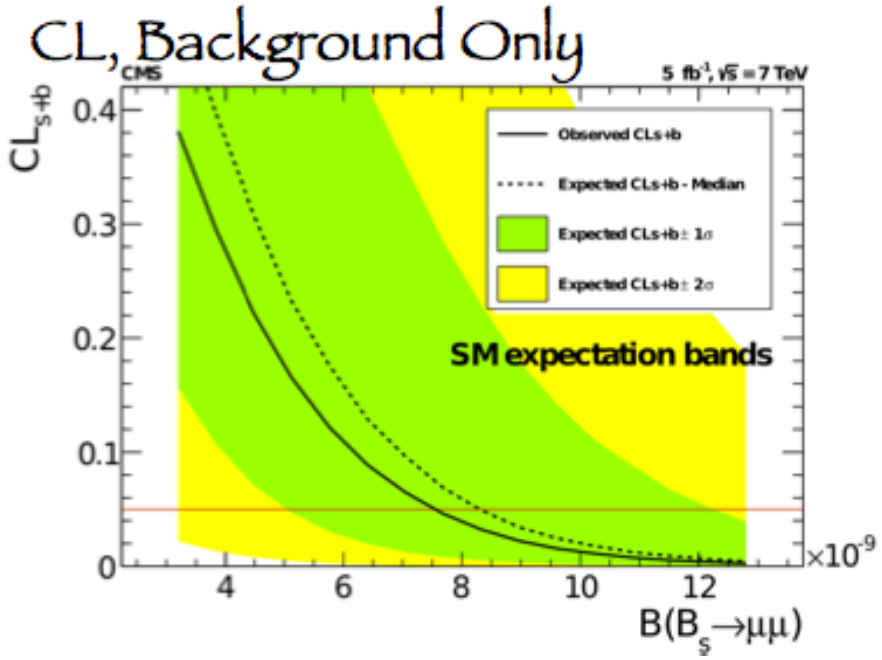


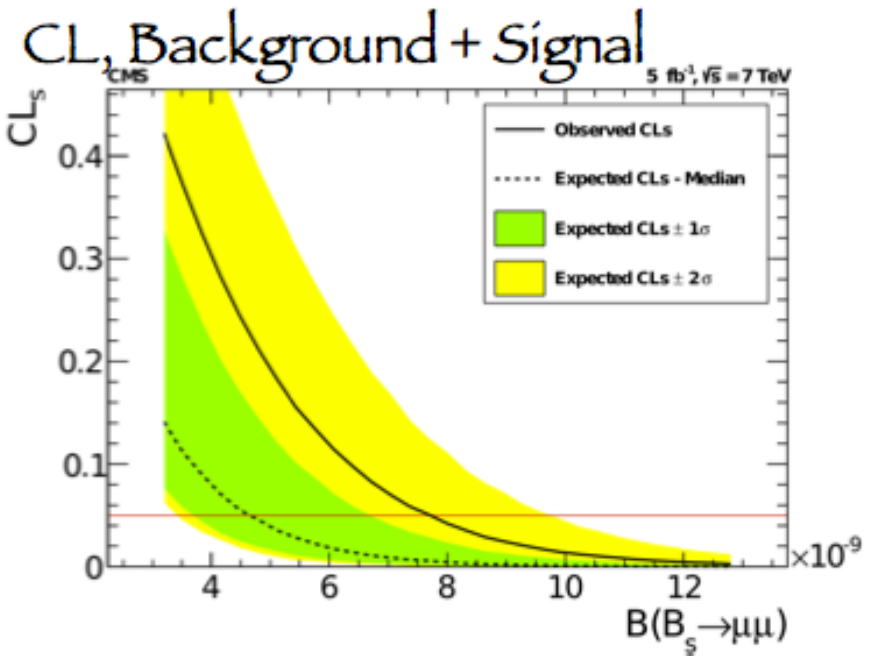


- No significant excess observed
- Expectations include systematic uncertainties
- Compute 95% CL

Results: JHEP 04 (2012) 033

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





Conclusions

- CMS has set tight constraint on B->μμ branching ratios

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

- Analysis of the 2012 dataset ongoing
- Sensitivity to reach SM expectation