New B Physics Results from CMS

Stefan Spanier
University of Tennessee
for the
CMS Collaboration

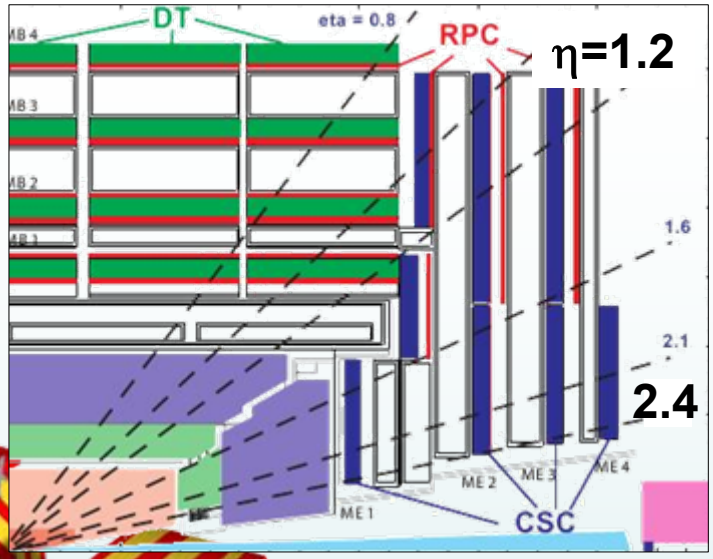
- Observation of a new b-Baryon
- Upper Limit Measurement for $B \rightarrow \mu^+\mu^-$

The CMS Detector

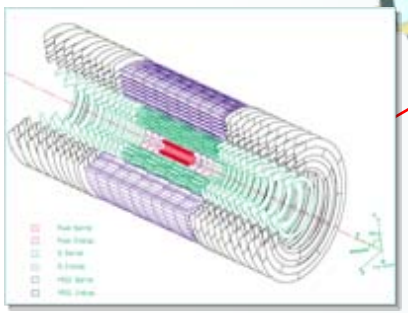
ECAL Scintillating $PbWO_4$ Crystals

HCAL
Plastic scintillator&Brass

SOLENOID
B = 3.8 T

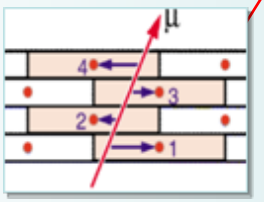


TRACKER

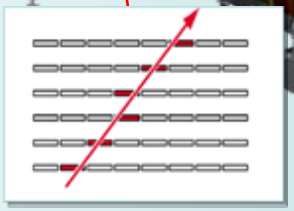


66M Silicon Pixels,
3layers (barrel), 2 forward disks
Silicon Strips: 10 barrel layers,
3+9 disks

MUON BARREL

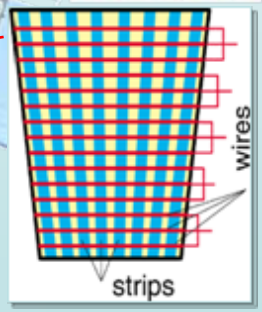


Drift Tubes (**DT**)
→ position



Resistive Plate
Chambers (**RPC**)
→ timing

MUON ENDCAPS



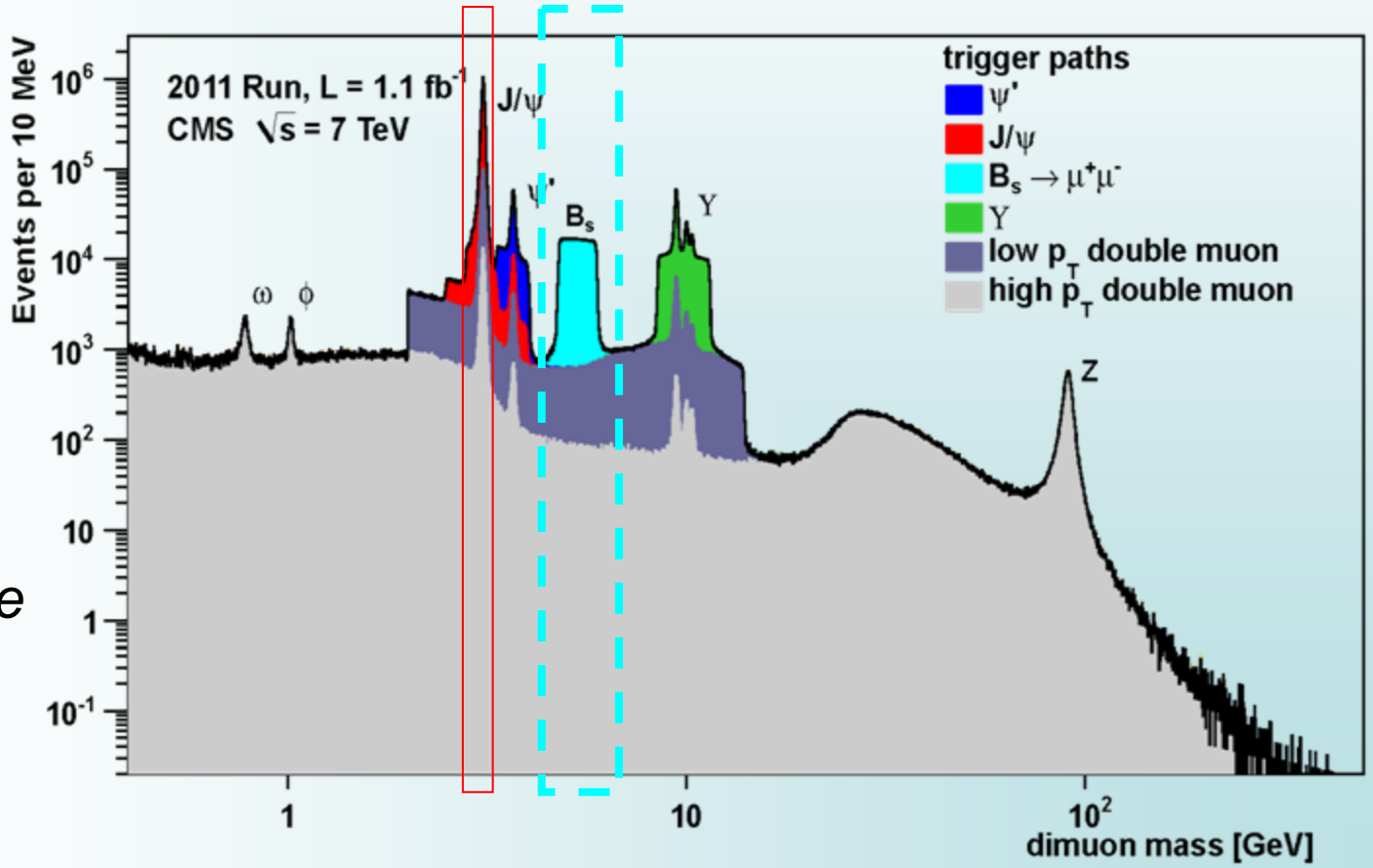
Cathode Strip Chambers (**CSC**)
→ position
Resistive Plate Chambers (**RPC**)
→ time

Muon Trigger

- L1 hardware trigger (~1μs)
- High-level trigger: tracking/vertexing

  invariant $\mu^+\mu^-$ mass combinations

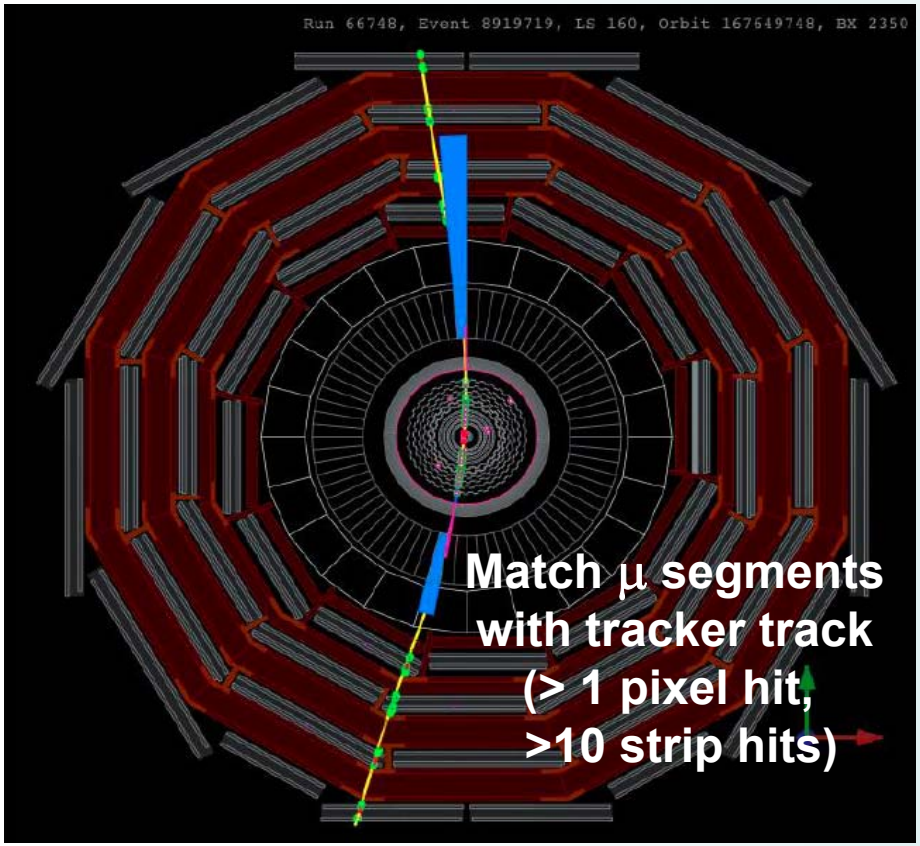
  $J/\psi \rightarrow \mu^+\mu^-$ displaced (Δm=200 MeV)/prompt (250 MeV)



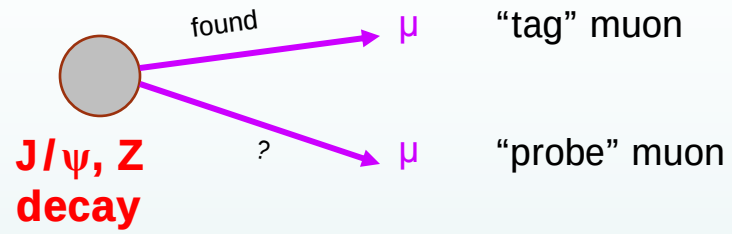
More restrictive with higher luminosity

Muon Efficiency

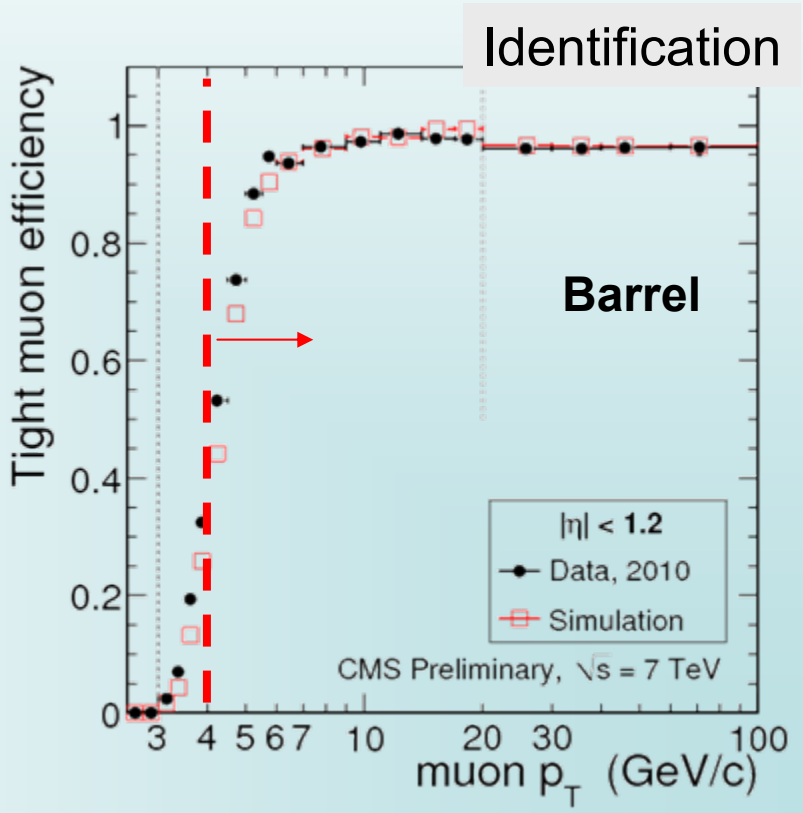
- Muon tracking
  - excellent σ_{pT}/p_T ~ 1%
  - efficiency > 99% for central μ
  - excellent vertex reconstruction impact parameter σ ~15um



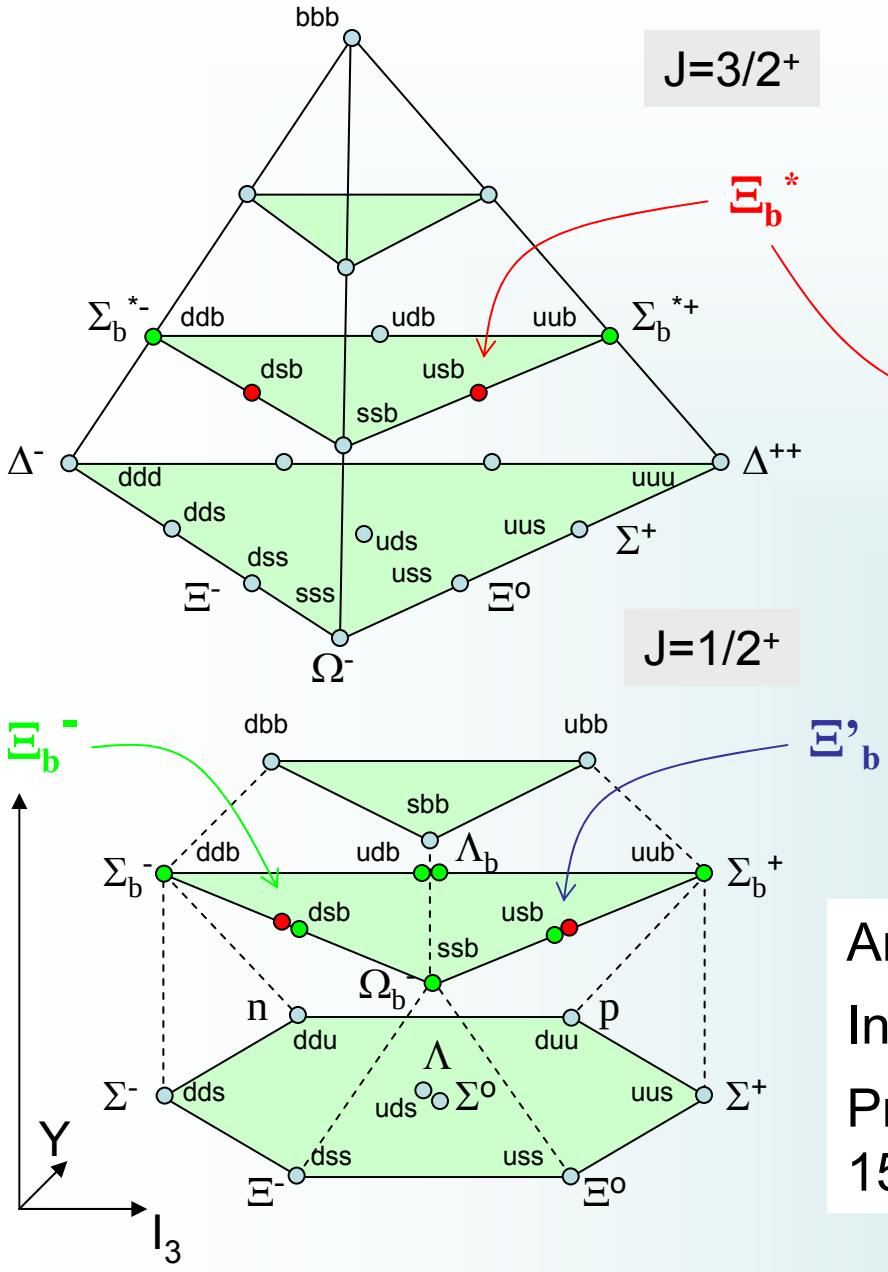
- Muon Efficiency
  - "tag and probe" in data

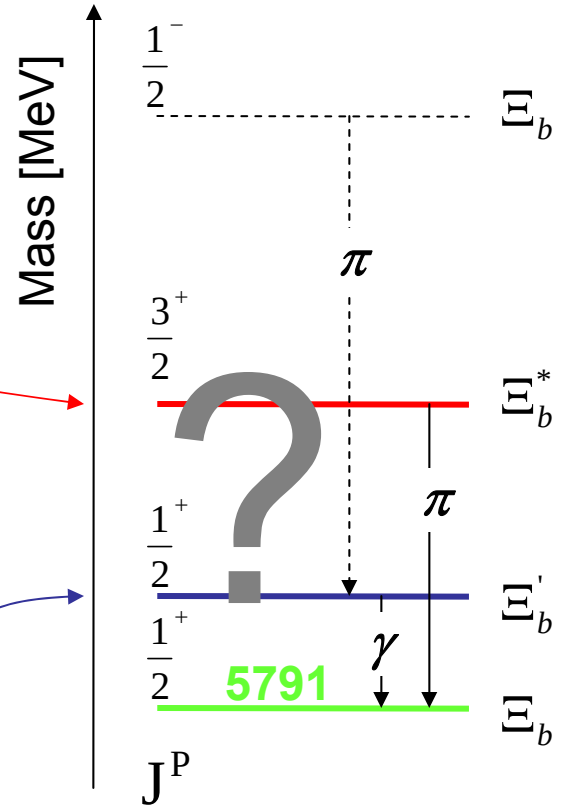


  - Monte Carlo *(compatible with data)*



B Baryon Searches



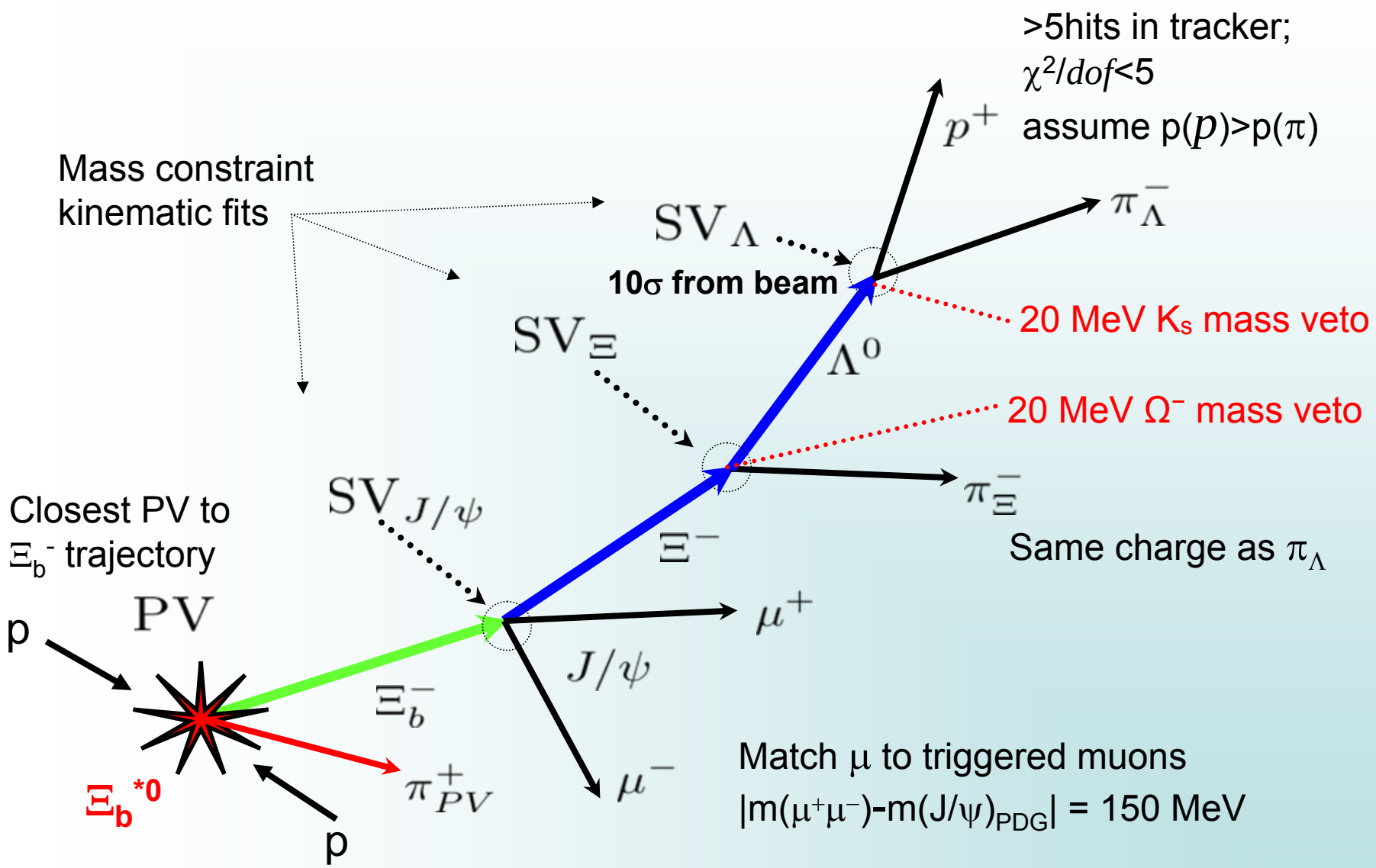


Analog to charmed baryon spectrum

Inter-quark potential + color hyperfine

Predicted masses for higher states:
150 – 160 MeV higher; width ~ 1MeV

Ξ_b^- Reconstruction (+ c.c.)

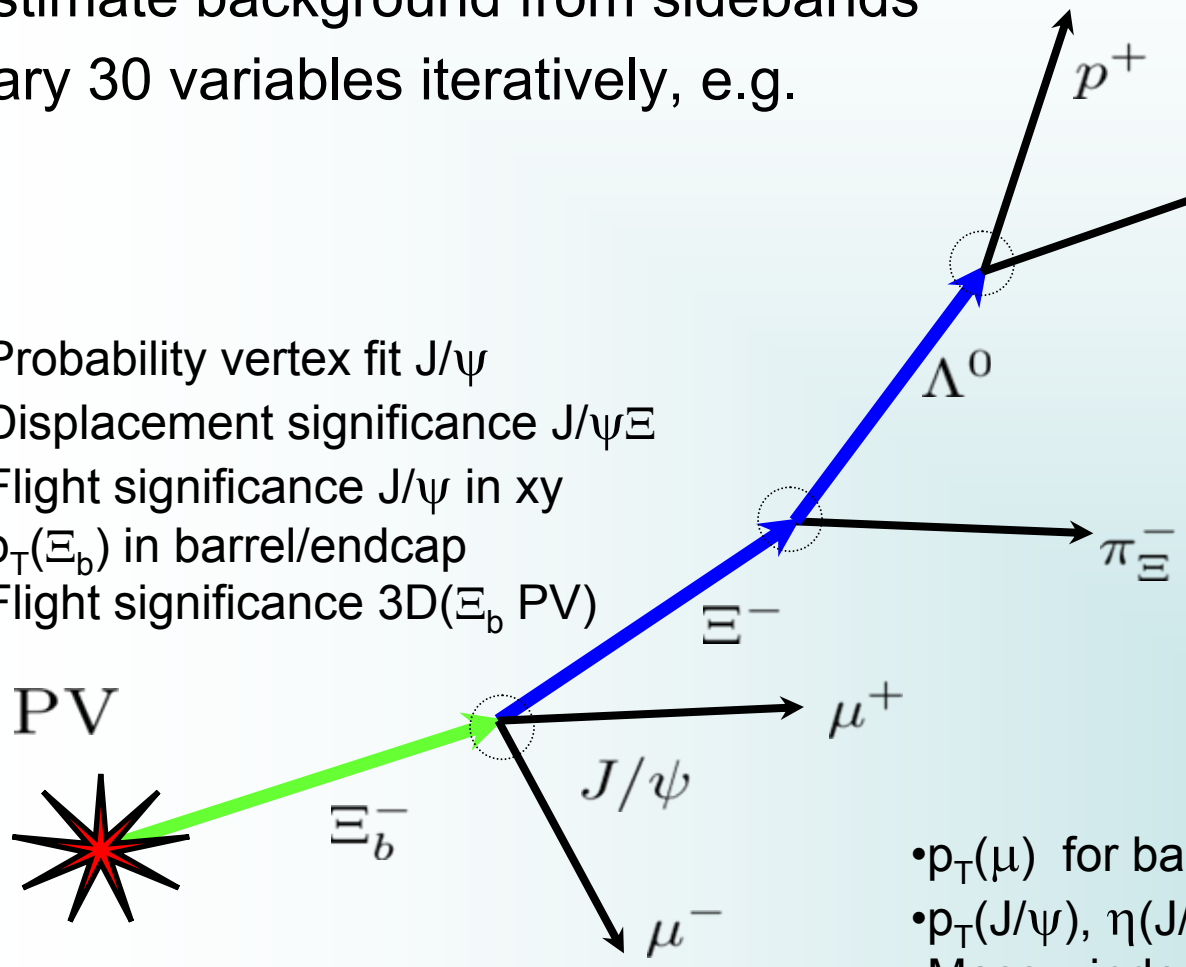


Ξ_b^- Reconstruction

Cut&count optimizing FOM $S/\sqrt{S+B}$

Estimate background from sidebands

Vary 30 variables iteratively, e.g.

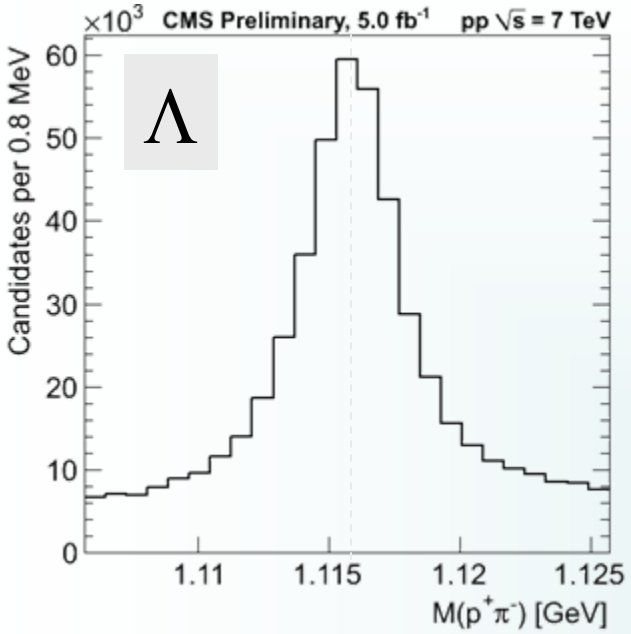


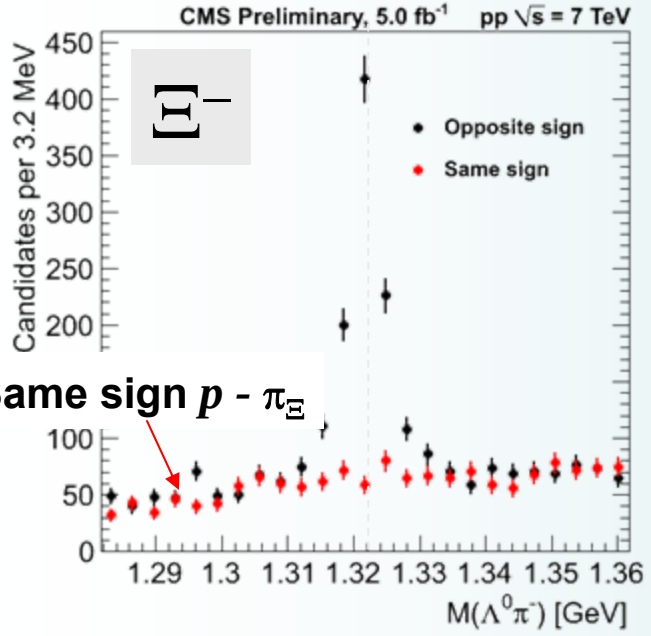
- Probability vertex fit J/ψ
- Displacement significance J/ψΞ
- Flight significance J/ψ in xy
- $p_T(\Xi_b)$ in barrel/endcap
- Flight significance 3D(Ξ_b PV)

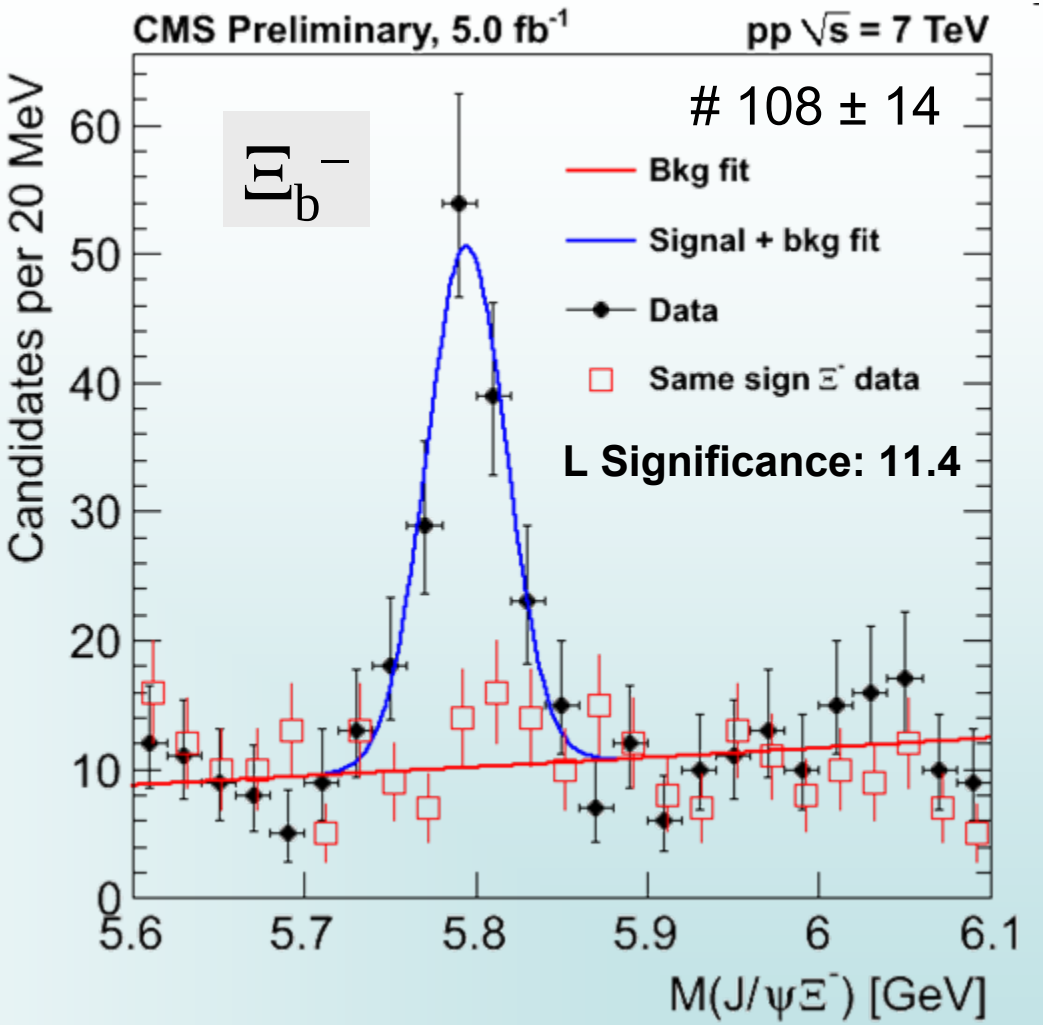
- $p_T(p)$, $p_T(\pi)$
- Impact parameter 3D I/σ_I
- Probability of vertex fit
- Flight significance Λ in xy
- Proper decay time
- Mass window

- $p_T(\mu)$ for barrel/endcap
- $p_T(J/\psi)$, $\eta(J/\psi)$
- Mass window

Ξ_b^- Reconstruction







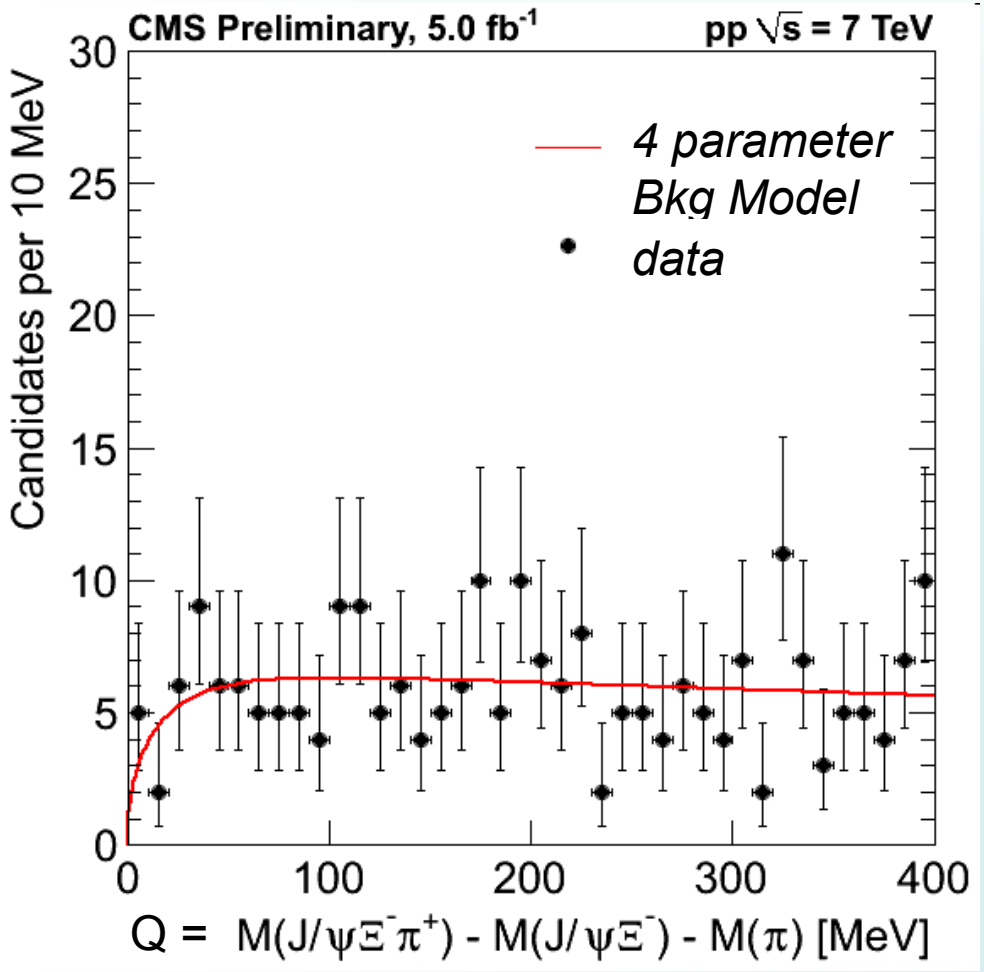
m = 5795.0 + 3.1 MeV

σ = 23.7 MeV in agreement with MC

Ξ_b^{*0} Selection

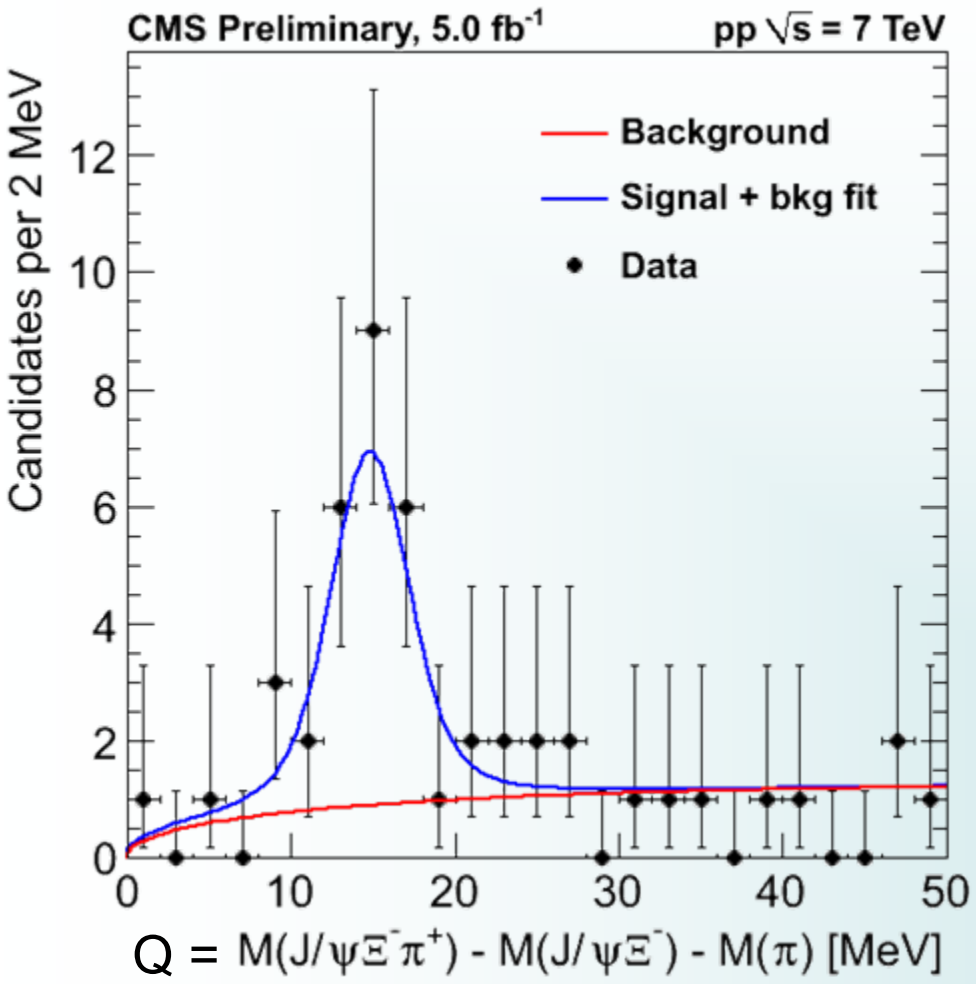
Combine Ξ_b^- candidate ($\Delta m < 2.5\sigma$) with

Track: opposite sign wrt Ξ_b^- (right sign) – wrong sign for background model
at least 2 pixel (5 tracker) hits; 3D distance to PV < 3σ



Wrong-sign distribution
(randomize Ξ_b^- ,π opening angle, momenta)

Ξ_b^{*0} Result



Voigtian (σ=1.9±0.1 MeV from MC)
+combinatorial background

Significance: 6.9 σ

Width: Γ = 2.1±1.7 MeV

(Theory: 0.93 MeV)

Mean: Q = 14.84 + 0.74 MeV

Simulation → no excess due to other b-hadrons (B^0,B^+,B_s,Λ_b)

Systematic Uncertainties
- different background models
- differences data – simulation

→ m = 5945.0 ± 2.7 $_{PDG}$ ± 0.7 $_{stat}$ ± 0.3 $_{syst}$ MeV

.. the first particle discovered by CMS, and the first b-baryon @ LHC

Standard Model Physics

$B_s^0 \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow \mu^+\mu^-$
strongly suppressed in the **SM**

Decay	BF SM
$B_s^0 \rightarrow \mu^+\mu^-$	$(3.2 \pm 0.2) \times 10^{-9}$
$B^0 \rightarrow \mu^+\mu^-$	$(1.1 \pm 0.1) \times 10^{-10}$

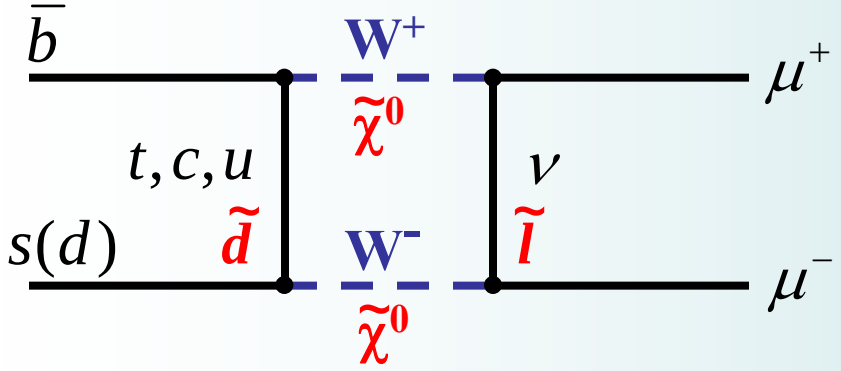
Buras arXiv:1009.1303.

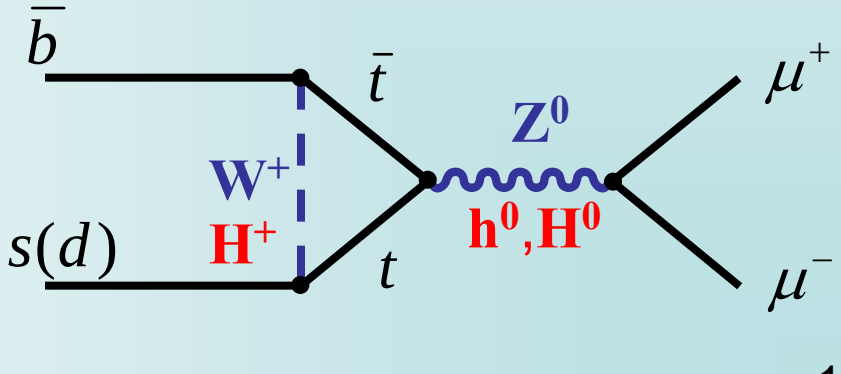
- **forbidden at tree level**
- **Cabibbo suppressed**
- **helicity suppressed**
- **require an internal quark annihilation**

New Physics sensitivity comparable to $\mu \rightarrow e\gamma$, $B \rightarrow \nu\nu$

→ Non-Observation binds parameter space

→ Complementary to direct searches at LHC





Analysis Strategy

Region	Mass (GeV)
$B^0 \to \mu^+\mu^-$	5.20 - 5.30
$B_s^0 \to \mu^+\mu^-$	5.30 - 5.45

$$M_{B_s^0} - M_{B^0} = 90 \pm 3\,\text{MeV}$$

- Search in $\mu^+\mu^-$ invariant mass region *simultaneously* for B_s and B^0 signals
- **Blind Analysis** – optimized cut-&-count
  - Barrel: ($|\eta_\mu|<1.4$) → higher sensitivity, resolution $\sigma(m_{\mu\mu}) \sim 40$MeV
  - Endcap ($|\eta_\mu|>1.4$) → add statistics, $\sigma(m_{\mu\mu}) \approx 60$ MeV
- Measure with respect to $B^+ \to J/\psi(\mu^+\mu^-)\,K^+$ *(similar selection)*

$$Br_{95\%}\left(B_s^0 \to \mu^+\mu^-\right) = \frac{N(n, n_S, n_B)}{N_{obs}^{B^+}} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \frac{f_u}{f_s} Br\left(B^+\right)$$

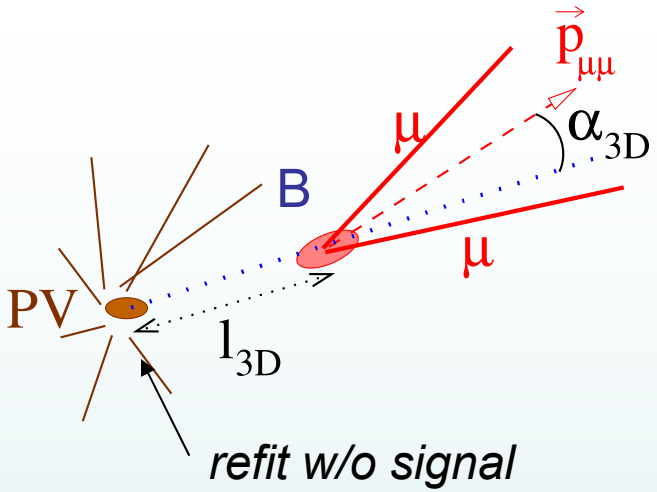
[PDG]

f_s/f_u = 0.267 ± 0.021 [LHCb]

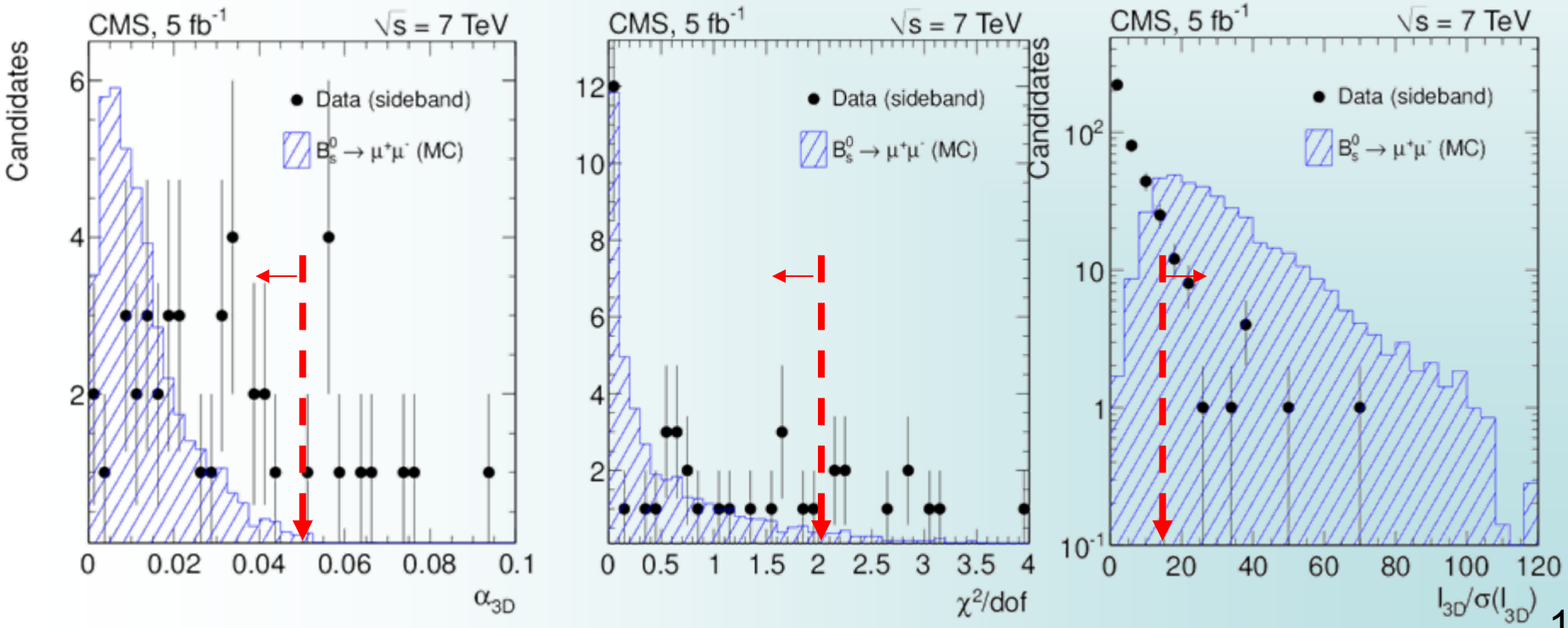
  - luminosity cancels
  - reduce efficiency uncertainties
  - no uncertainties from $\bar{b}b$ production cross section
- Reconstruct $B_s \to J/\psi(\mu^+\mu^-)\,\phi(K^+K^-)$ as control channel to validate B_s mesons in data and MC simulations *(similar selection)*

Signal Selection Variables

- Pointing angle α_{3D}
- Vertex fit χ^2/dof
- Flight length significance $l_{3D}/\sigma(l_{3D})$
- Impact parameter 3D significance



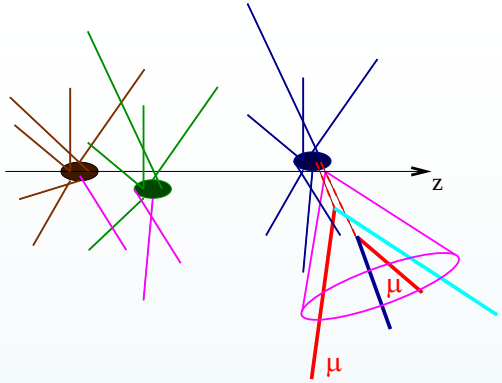
Data Sideband % Signal MC



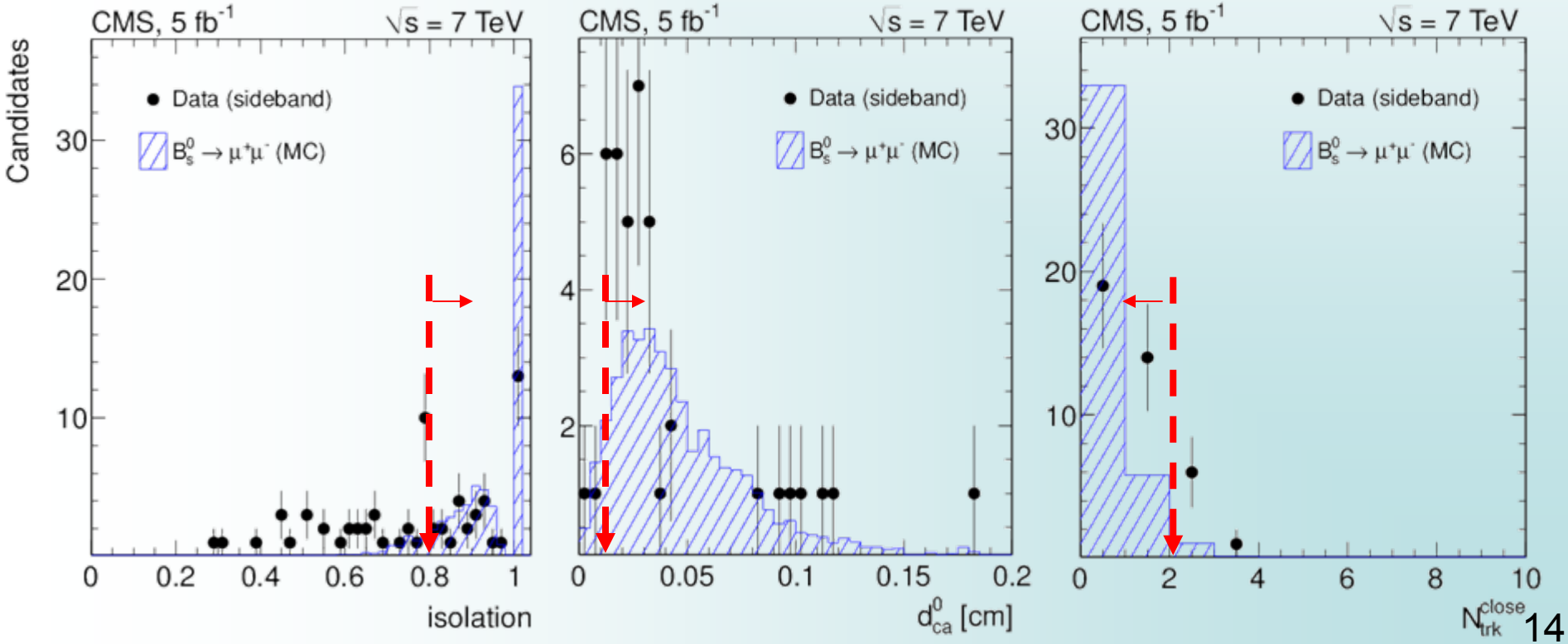
Signal Selection Variables

- Isolation cone around primary vertex

for $\Delta R < 0.7$ along B, $p_\perp > 0.9$ GeV $\quad I = \dfrac{p_\perp(B)}{p_\perp(B) + \sum_{trk} |p_\perp|}$



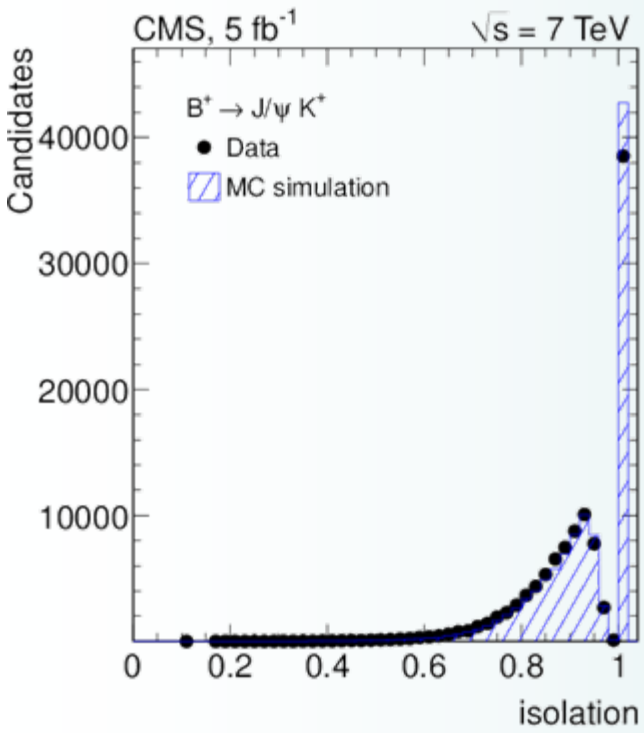
- Distance of closest track to B vertex d^0_{ca}
- Number of close tracks (d_{ca}<300um, $p_\perp$>0.5 GeV)

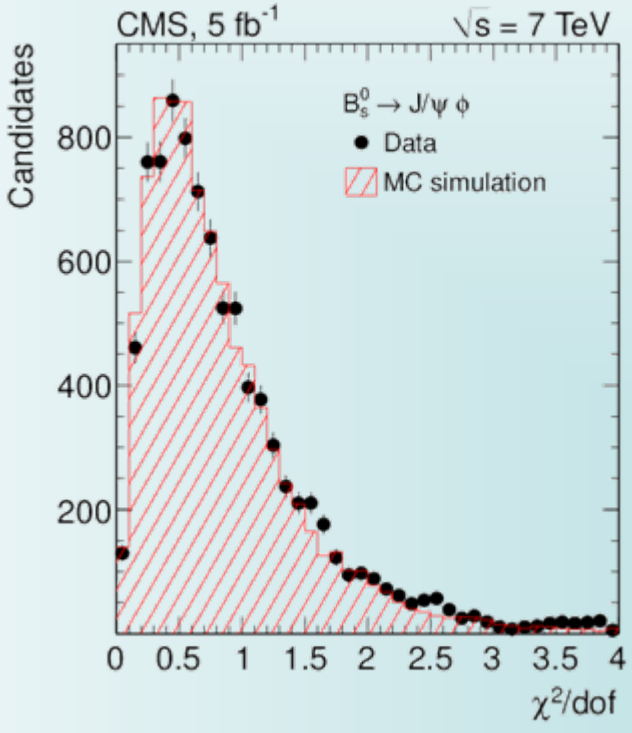


Data % Simulation Validation

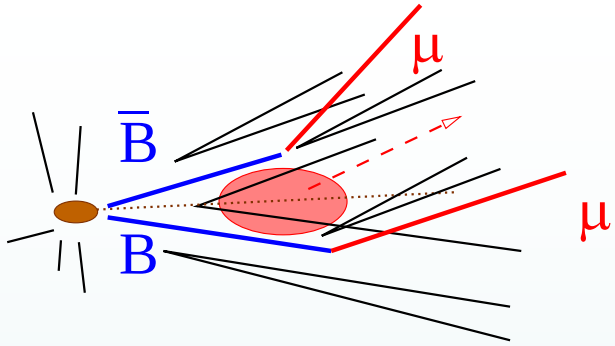
- Differences data – MC taken as systematic uncertainties:
  - On $B^{\pm} \rightarrow J/\psi K^{\pm}$, max diff = 2.5% (isolation) tot = 4%
  - On $B_s^0 \rightarrow J/\psi\varphi$, max diff = 1.6% (SV χ^2/ndof) tot = 3%
- Excellent MC – data comparison

Sideband subtracted data % control Monte Carlo





Backgrounds



Combinatorial

- Two semi-leptonic B decays
- One semi-leptonic B decay and one mis-identified hadron

→ Flat / estimated from sidebands

Single B Decays

- peaking ($B_s^0 \rightarrow K^+K^-$)

  shifted to lower mass

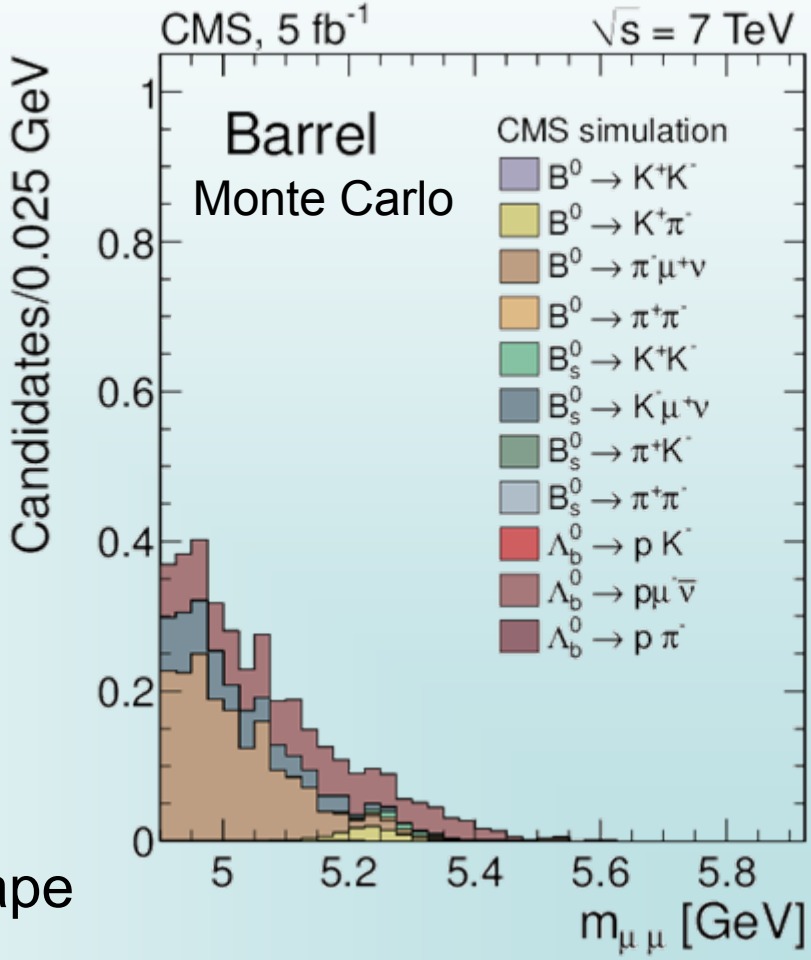
- non-peaking ($B_s^0 \rightarrow K^- \mu^+ \nu_\mu$)

  one fake μ, lower mass

→Shape from MC

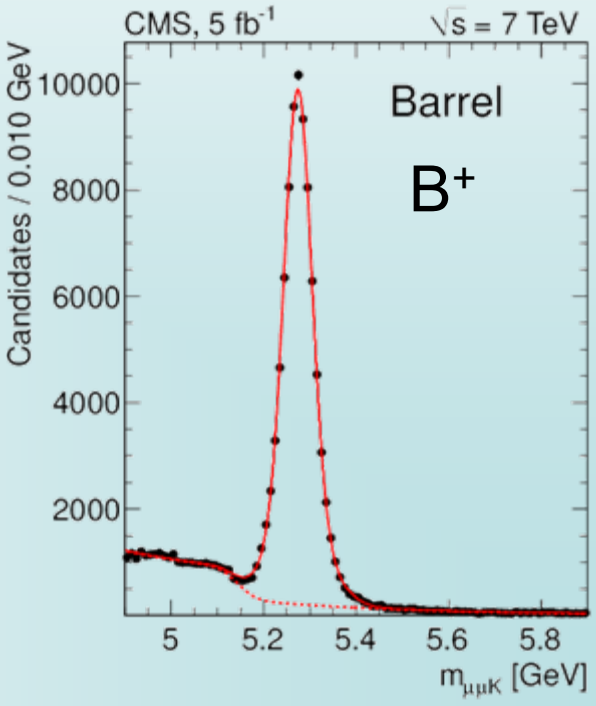
→Rate from normalization to B^+

~ 4% systematic uncertainty from shape



Systematic Uncertainties

	Barrel | Endcap
• Acceptance with mixture of hadronic production gluon fusion/flavor excitation/gluon splitting	~ 4% | 5%
• Selection criteria (data % Monte Carlo) efficiency signal, normalization, kaon tracking	~ 7% | 7%
• Muon trigger and identification efficiency	~ 5% | 10%
• Yield in control channel #82700 + #23800 observed	~ 5% | 5%

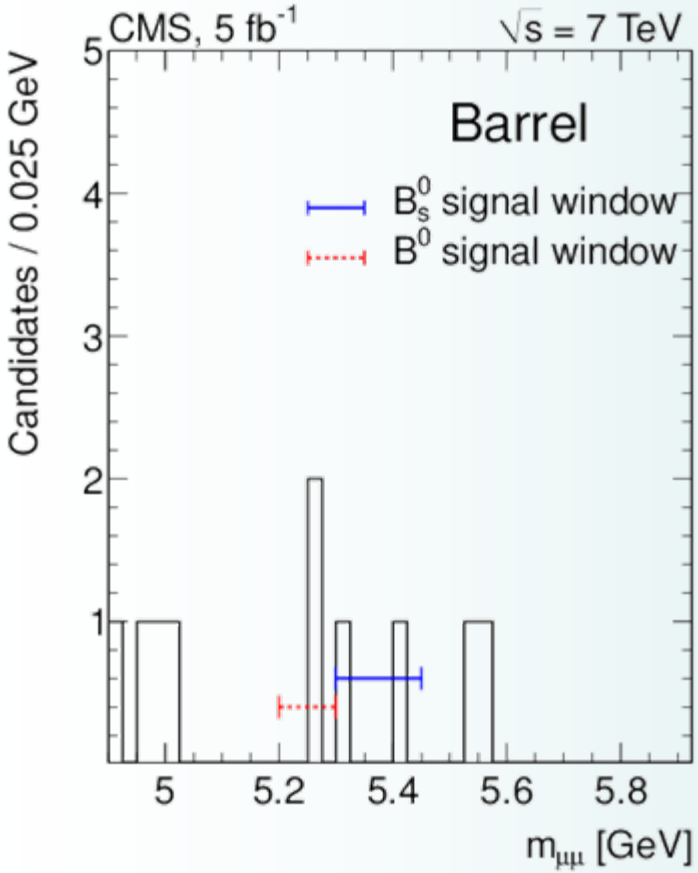


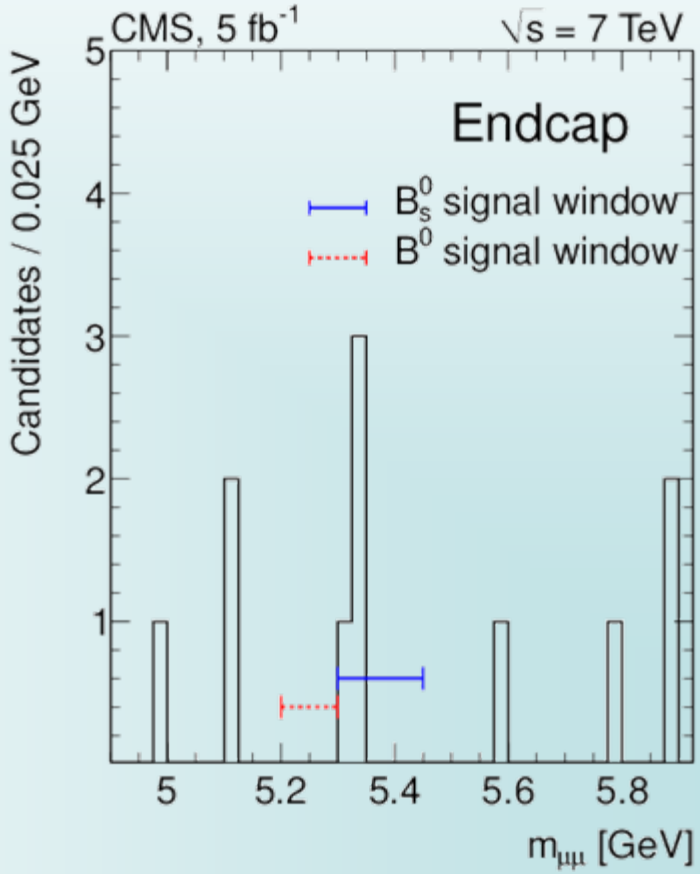
Cross Checks

- Estimate background for anti-isolation cut
- Evaluate BF($B_s \rightarrow J/\psi\ \phi$)/BF($B^+ \rightarrow J/\psi\ K^+$)
- Signal in samples for different periods

Result

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
ε_{tot}	**0.0029 ± 0.0002**	**0.0029 ± 0.0002**	**0.0016 ± 0.0002**	**0.0016 ± 0.0002**
N_{signal}^{exp}	0.24 ± 0.02	2.70 ± 0.41	0.10 ± 0.01	1.23 ± 0.18
N_{total}^{exp}	**0.97 ± 0.35**	**3.47 ± 0.65**	**1.01 ± 0.35**	**2.45 ± 0.56**
N_{obs}	**2**	**2**	**0**	**4**





Result

Population in B_s sample:

$$N = N\left(N_B^{flat} + N_B^{rare} + N_S^s \Gamma_{ss} \, BF_s \Big/ BF_s^{SM} + N_S^d \Gamma_{sd} \, BF_d \Big/ BF_d^{SM} \right)$$

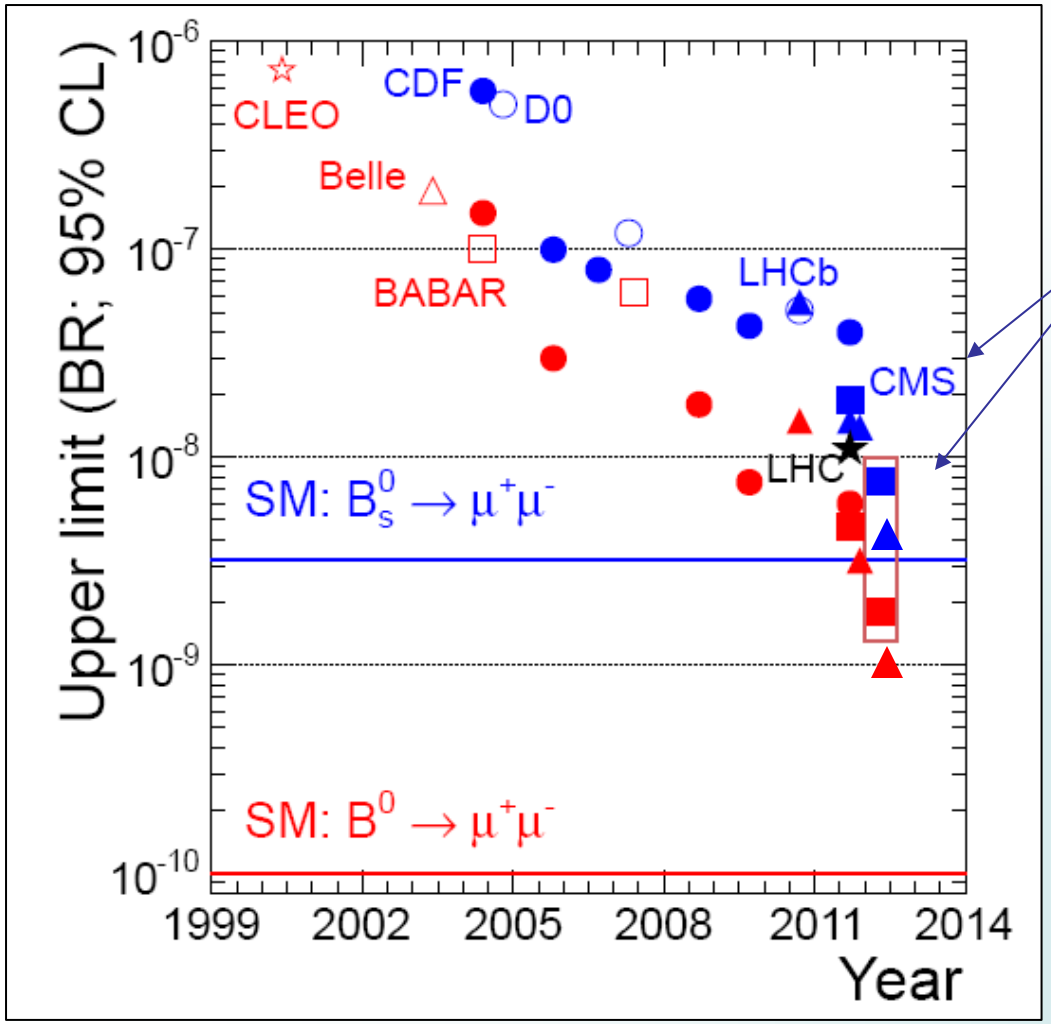
With CLs at 95%CL (including systematic uncertainties):

	observed	median expected
BR($B_s^0 \rightarrow \mu\mu$)	**7.7×10^{-9}**	**8.4×10^{-9}**
BR($B^0 \rightarrow \mu\mu$)	**1.8×10^{-9}**	**1.6×10^{-9}**

toy

The observed number of events is consistent with background plus Standard Model signals.

Conclusion



Significantly improved
$< 1.9 \times 10^{-8}$ @ EPS2011

- Higher purity
- Improved sensitivity
- Pile-up robustness

→ **Accepted by JHEP** arXiv:1203.3976

→ **Expect competitive new result from 2012 dataset**