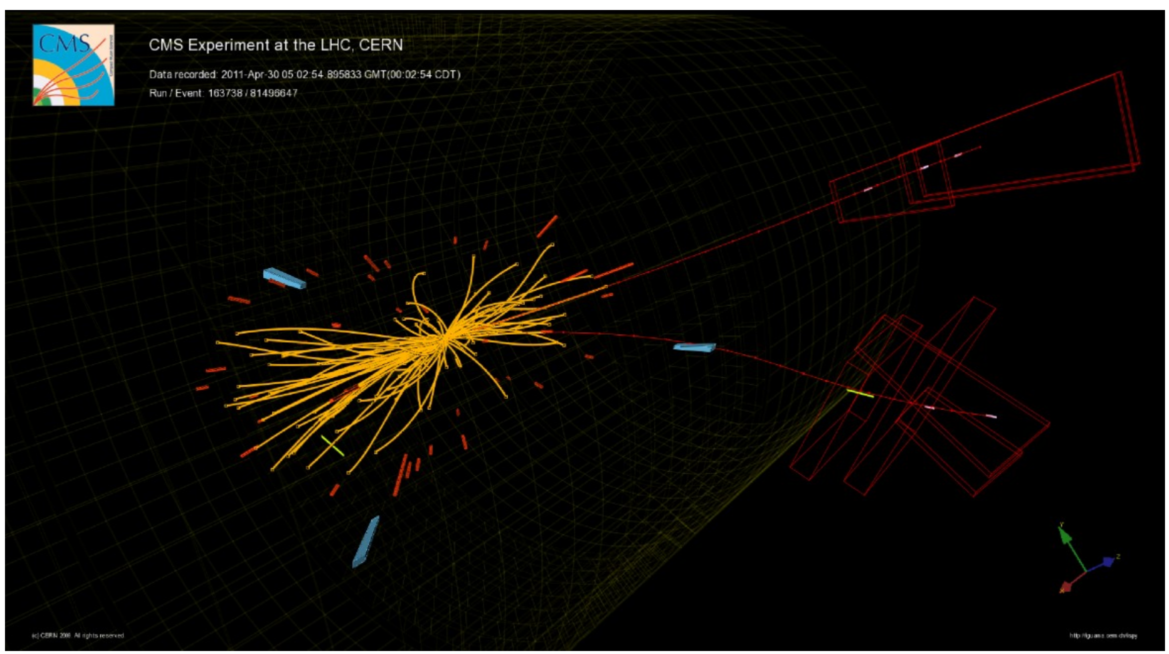
Search for $B_s^0 \to \mu\ \mu$ and $B^0 \to \mu\ \mu$ at CMS

ESHEP Student Presentations

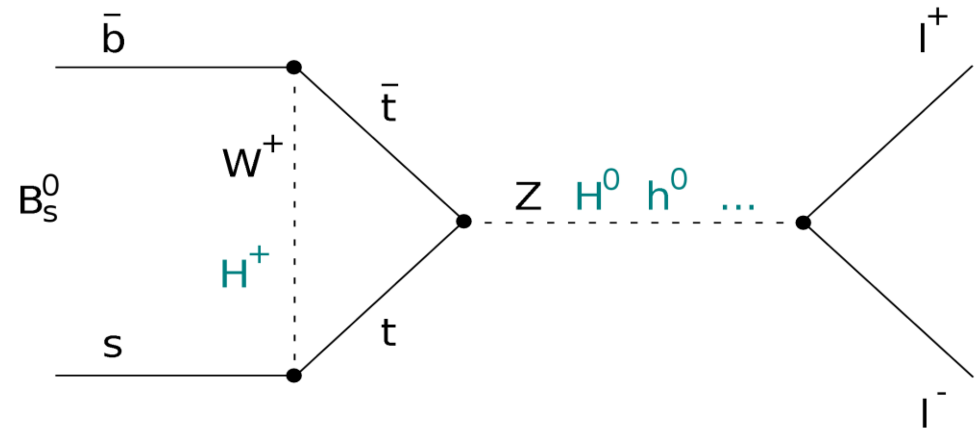
Group C



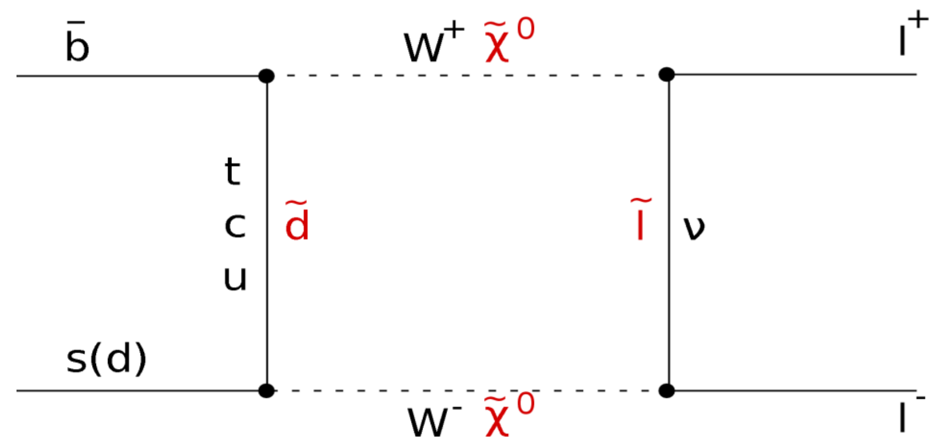
Motivation

- Decay rate **highly suppressed** in SM
- Enhancement originating in BSM physics
- Small theoretical uncertainties + clean signature

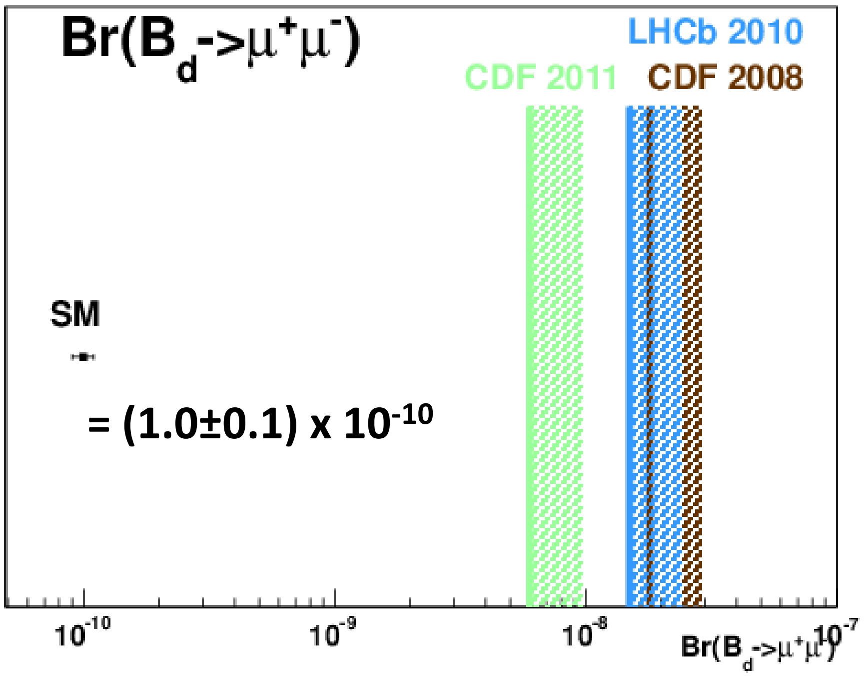
2HDM

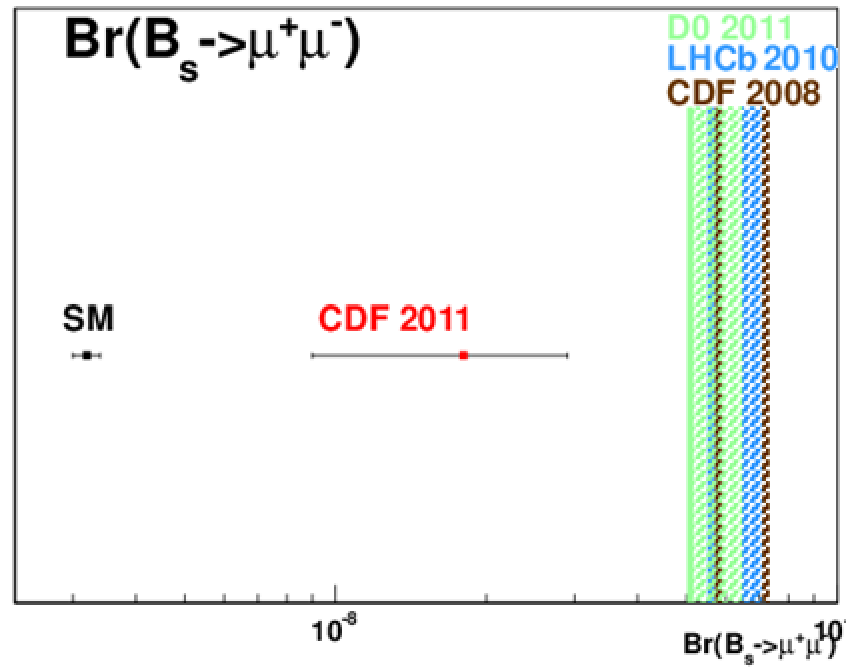


MSSM



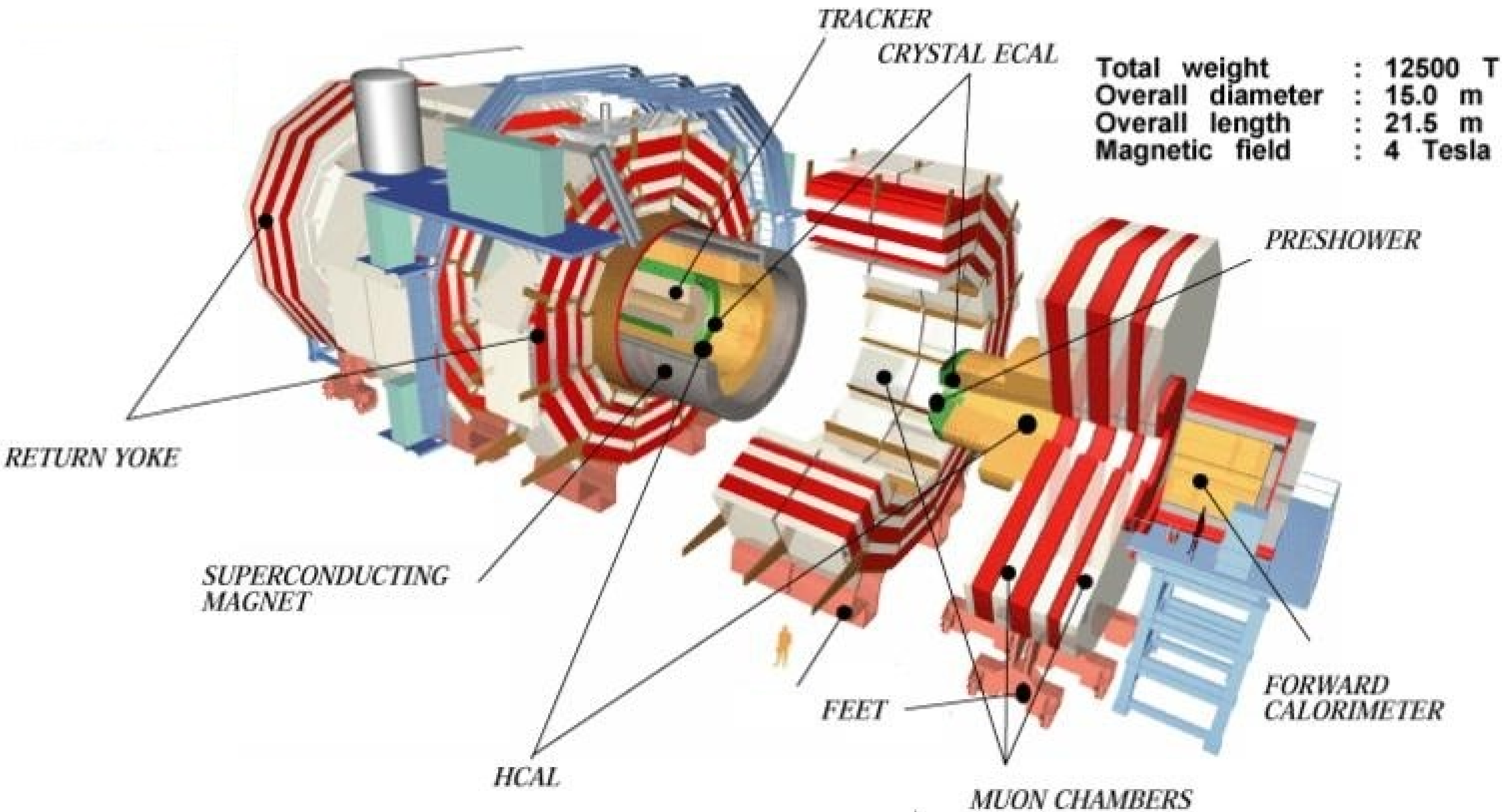
Previous Measurements





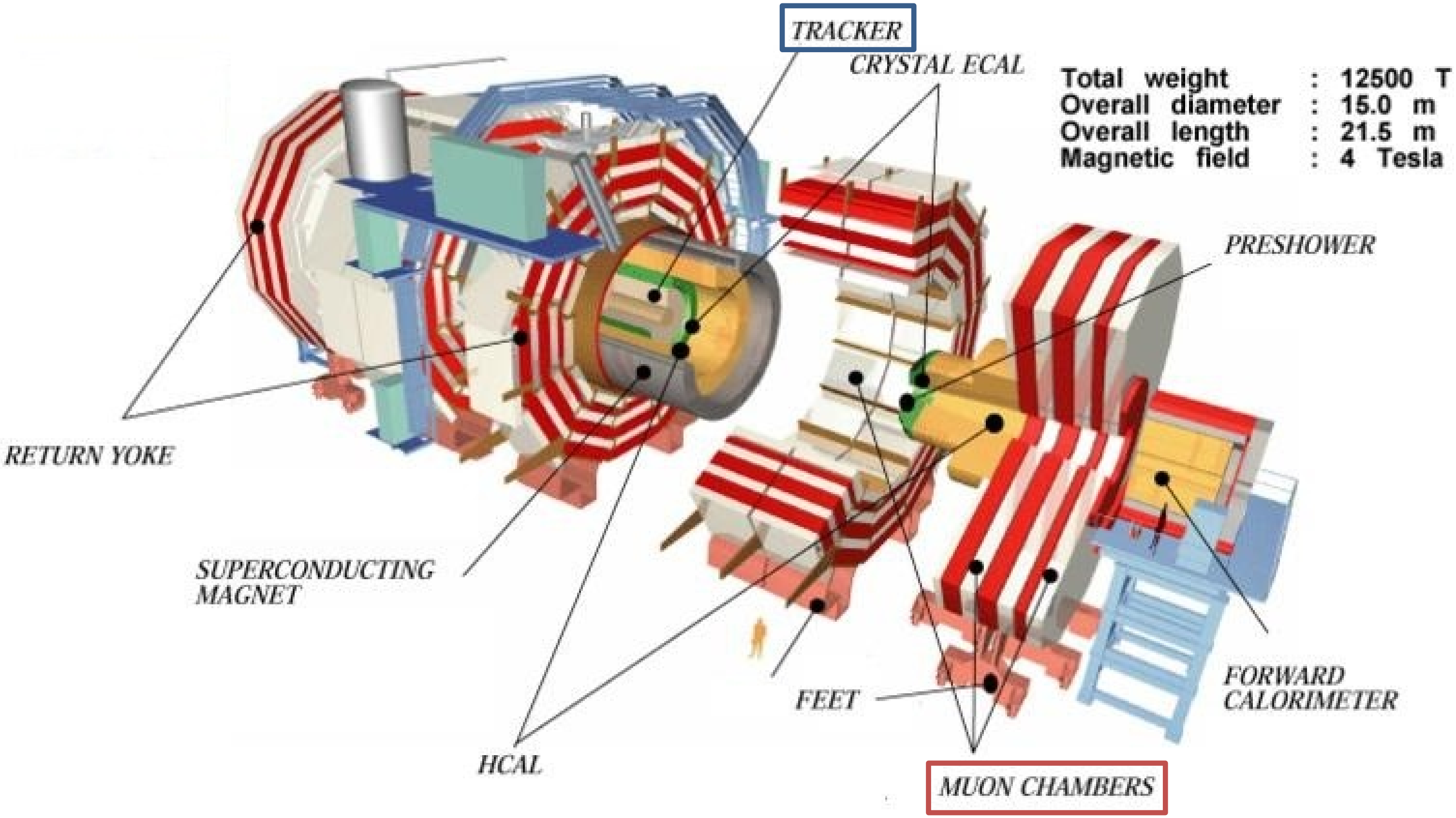
- Current sensitivity still orders of magnitudes over SM predictions
- Excess measured in Tevatron II dataset recently reported by CDF

CMS detector



Component	Characteristics	resolutions
Pixel	3/2 Si layers	$\delta_z \approx 20\ \mu$m, $\delta_\phi \approx 10\ \mu$m
Tracker	10/12 Si strips	$\delta(p_\perp)/p_\perp \approx 1\%$
ECAL	$PbWO_4$	$\delta E/E \approx 3\%/\sqrt{E} \oplus 0.5\%$
HCAL (B)	Brass/Sc, $> 7.2\lambda$	$\delta E/E \approx 100\sqrt{E}\%$
HCAL (F)	Fe/Quartz	$\delta(\not{E}_T) \approx 0.98\sqrt{\sum E_T}$
Magnet	3.8 T solenoid	
Muons	DT/CSC + RPC	$\delta(p_\perp)/p_\perp \approx 10\%$ (STA)

CMS detector



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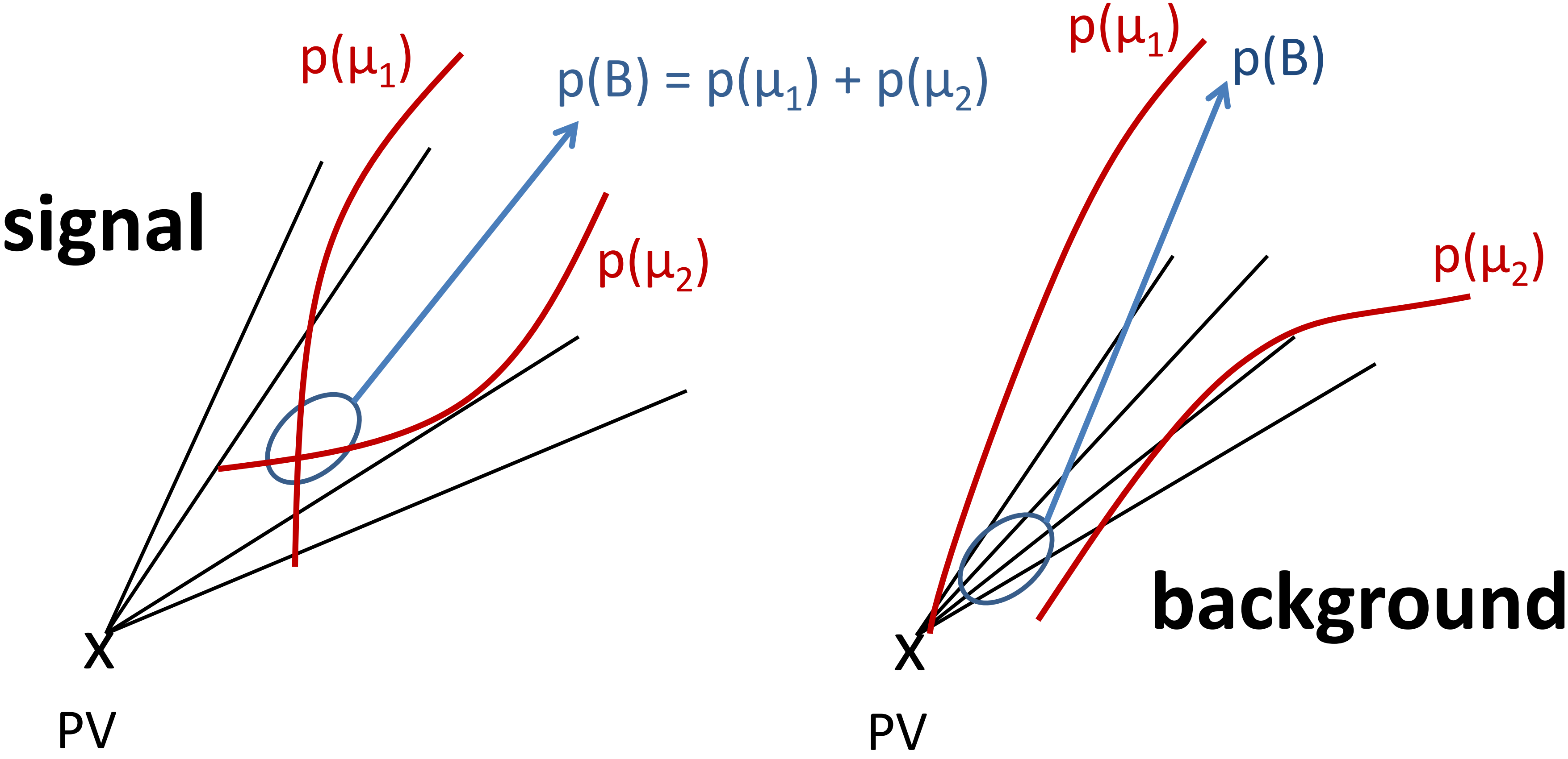
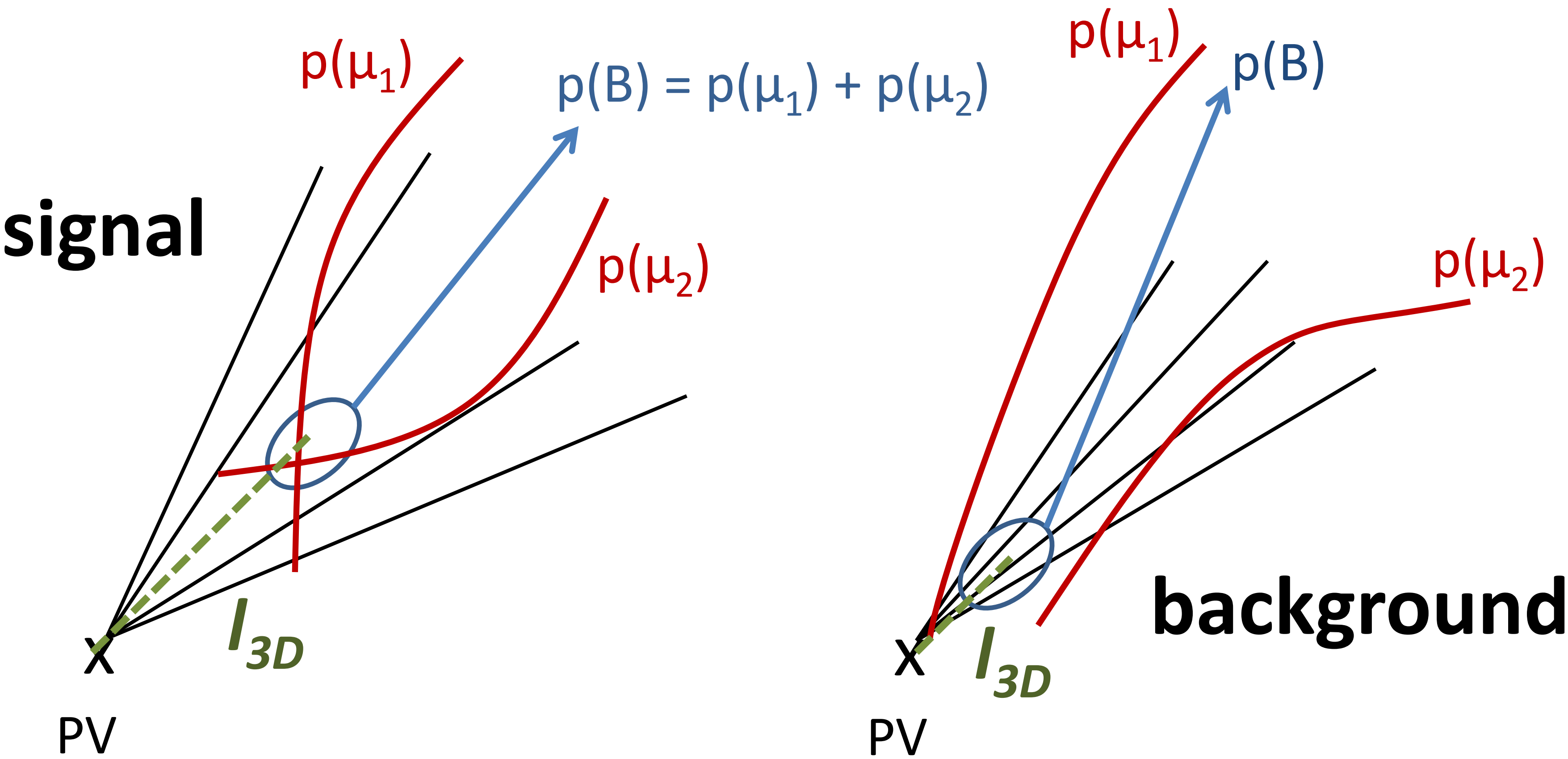
Discriminating Variables

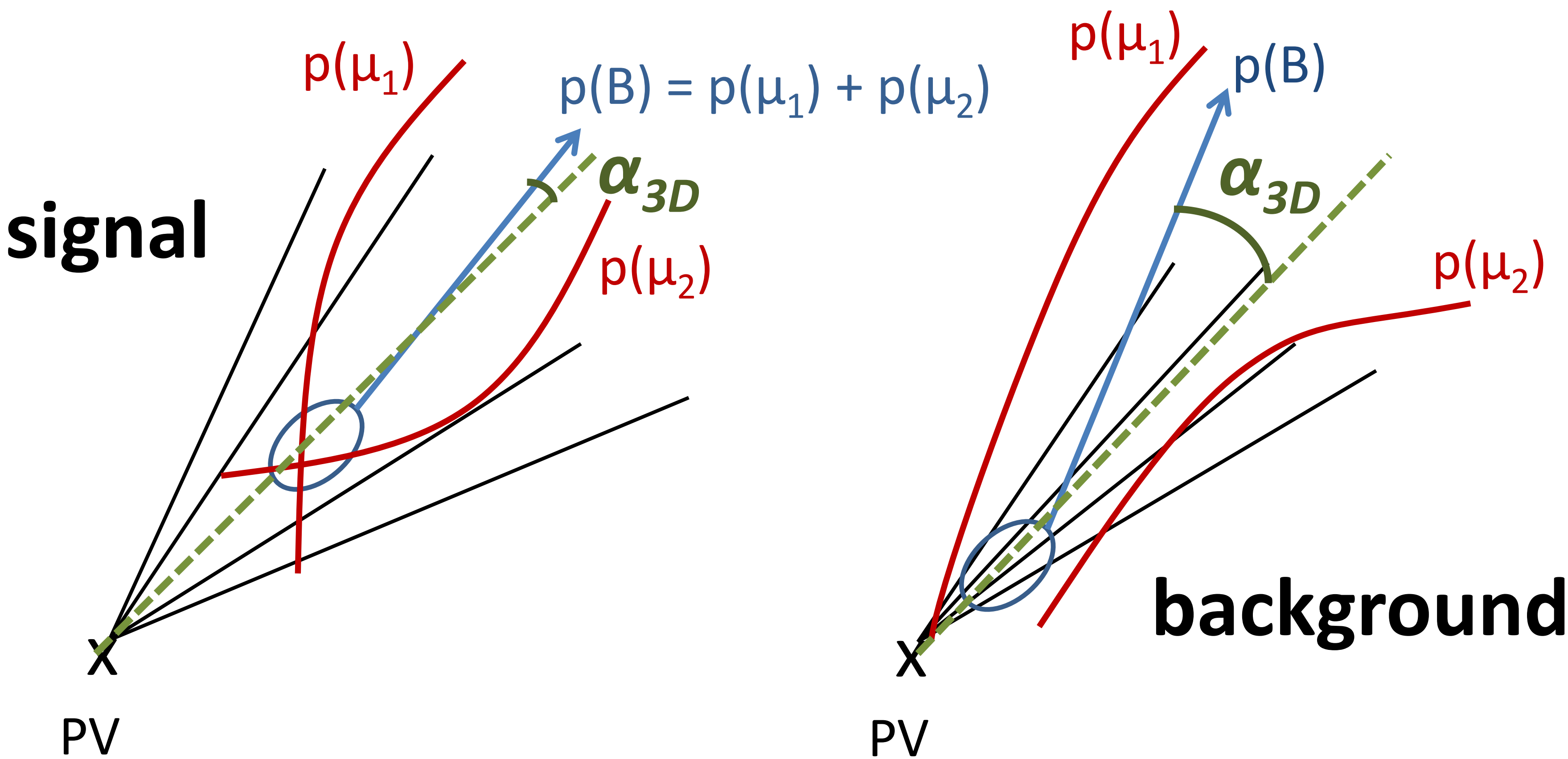


Significance of Flight Distance $\frac{l_{3D}}{\sigma(l_{3D})}$



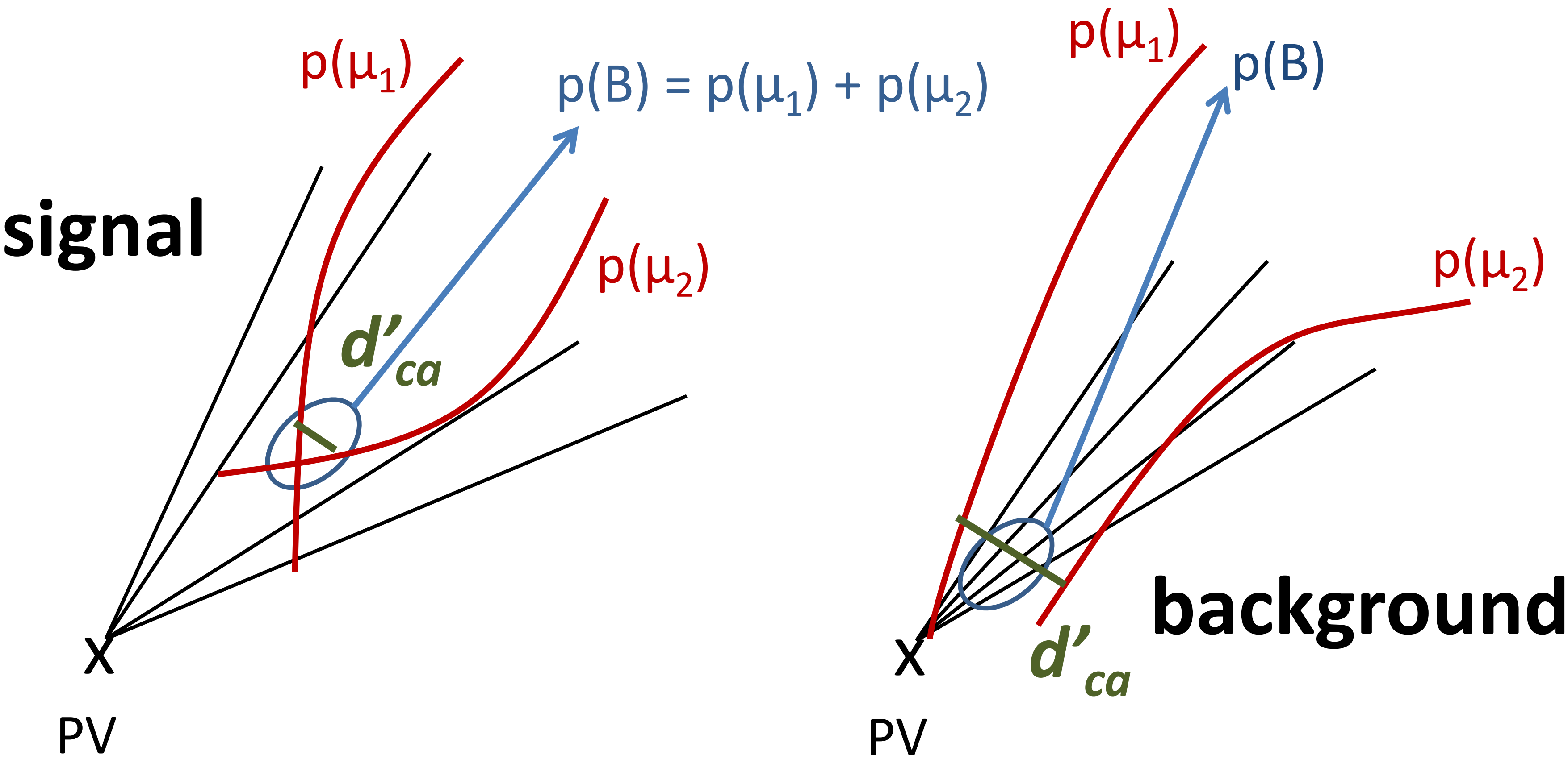
Distance between PV and dimuon vertex divided by its uncertainty

Pointing angle α_{3D}



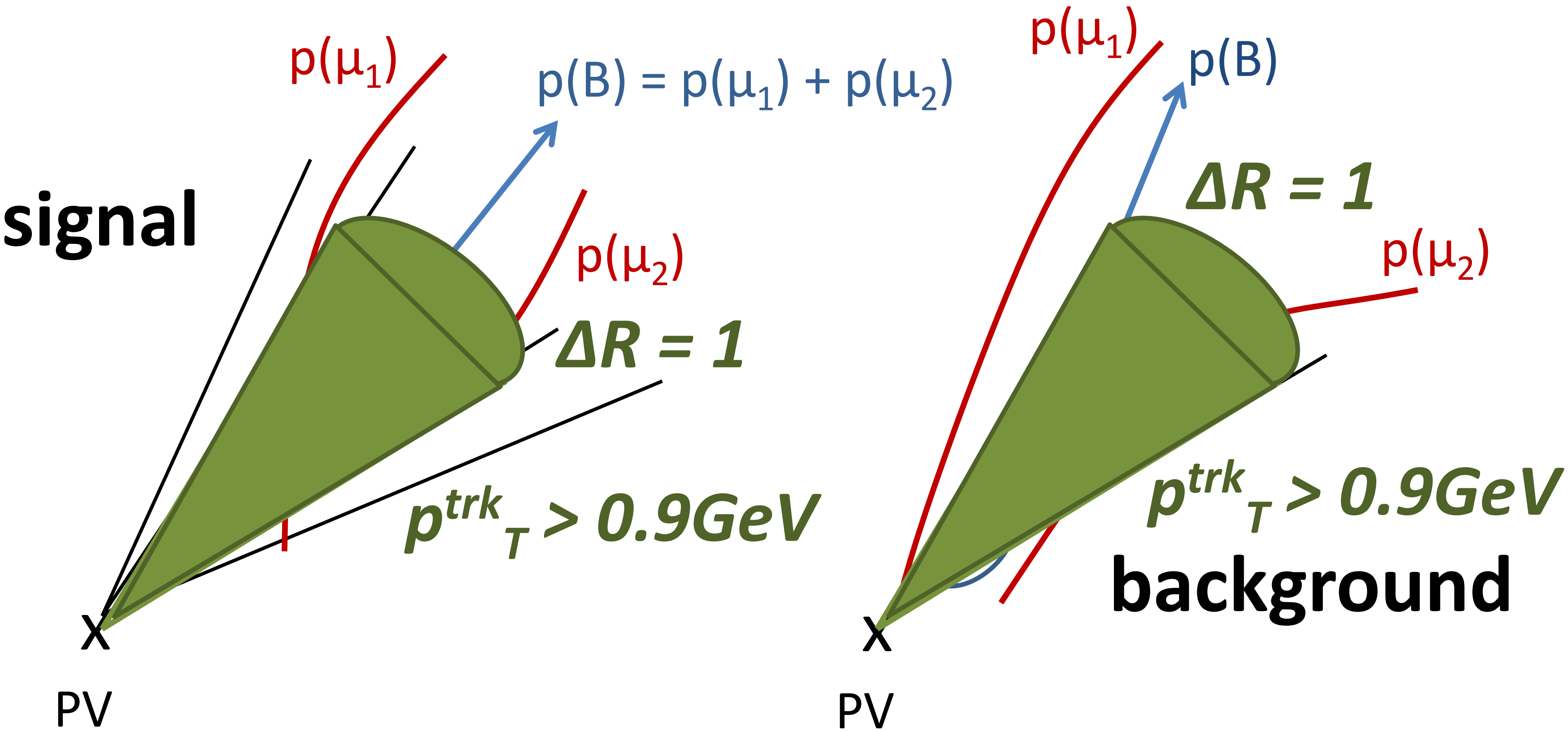
Angle between p(B) and vector between PV and dimuon vertex

Distance of Closest Approach d'_{ca}



3D distance of closest approach between the two muons

Isolation $I = \frac{p_T(B)}{\sum_{track} p_T(track)}$



Fraction of track p_T carried by the B meson

Analysis Strategy

- We measure $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_S}{N_{obs}^{B^+}} \frac{f_u}{f_s} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \mathcal{B}(B^+)$
  - N_s: events in the signal region (background subtraction)
  - N^{B+}: $B^{\pm} \to J/\psi \quad \to \mu \quad \mu \quad)K^{\pm}$ ($m_{\mu\mu K}$ fit)
  - ε_{tot}: total selection efficiencies
  - f_s/f_u = 0.282 ± 0.037, $B(B^+) = (6.0 \pm 0.2) \times 10^{-5}$ [PDG]
- Normalisation sample from $B^{\pm} \to J/\psi \quad \to \mu \quad \mu \quad)K^{\pm}$
  - minimise uncertainties on b-bbar cross section and luminosity
- Control sample from $B_S^0 \to J/\psi \quad \to \mu \quad \mu \quad)\phi \to K^+K^-)$
  - signal MC validation
- Blind analysis separating barrel and endcap regions

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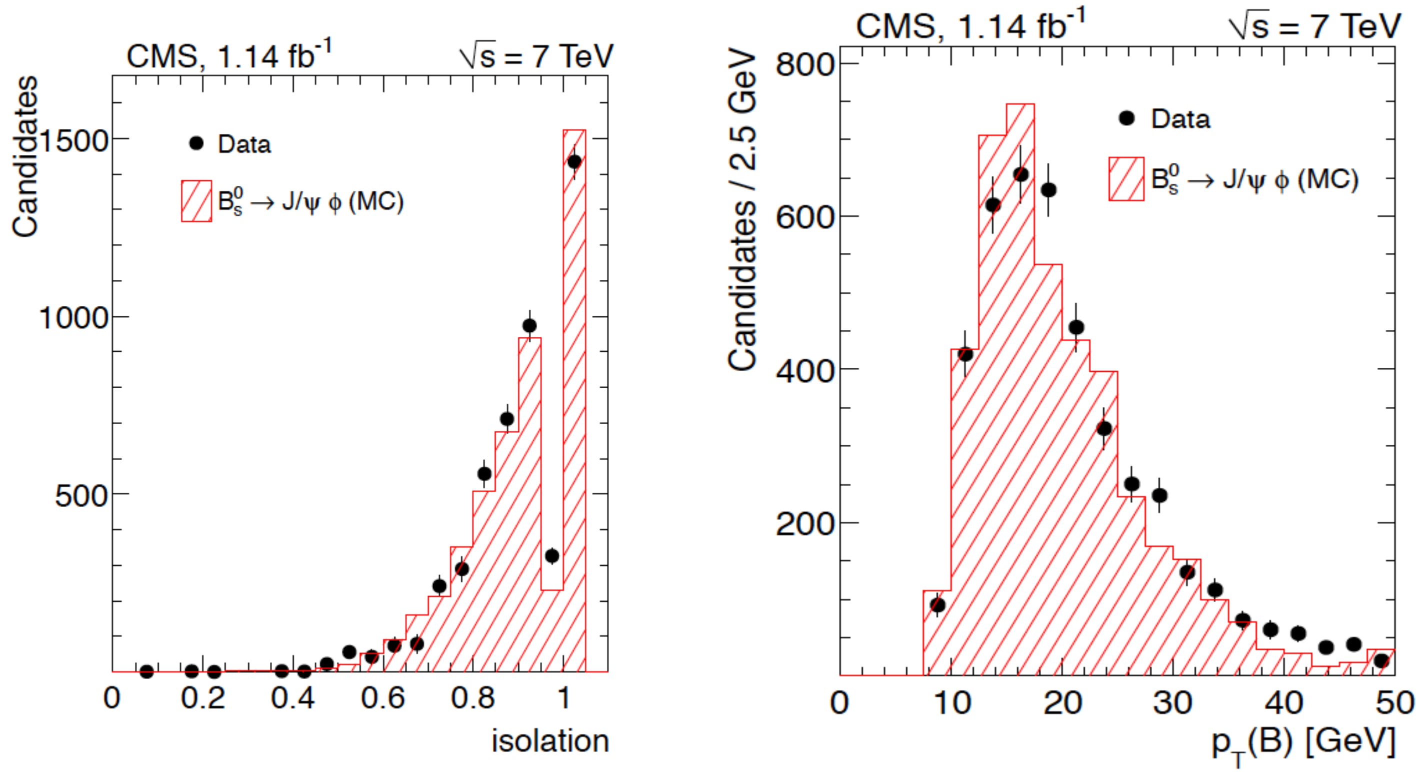
Control Channel: $B_S^0 \to J/\psi\ (\to \mu\ \mu\ )\phi\ (\to K^+K^-)$



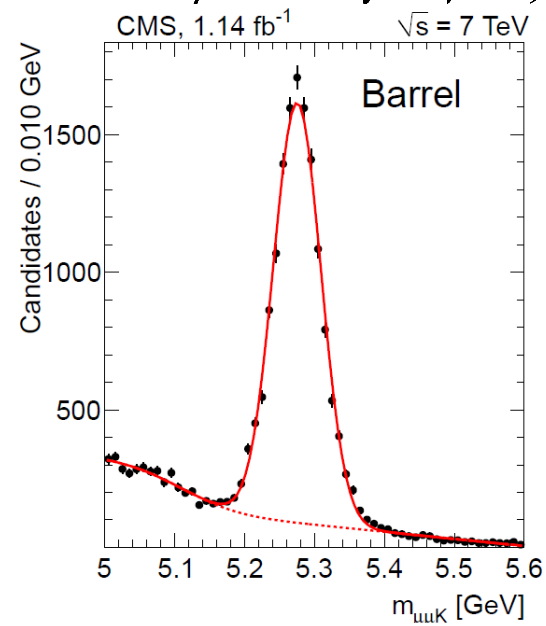
MC normalized to the number of events in the data

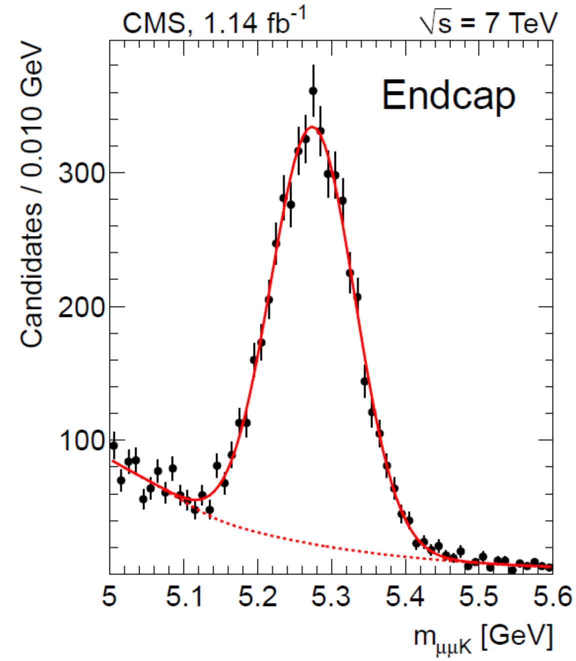
- Validation of simulation of exclusive B_s^0 decays in data
  - Estimate confidence in signal MC
  - Differences in fragmentation between $B^{\pm}$ and B_s^0 decays

Normalisation Channel: $B^{\pm} \to J/\psi \;\; \to \mu \;\; \mu \;\;)K^{\pm}$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_S}{N_{obs}^{B^+}} \frac{f_u}{f_s} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \mathcal{B}(B^+)$$

- Results in a μμK final state
- Large and experimentally measured branching fraction
- Normalisation to this channel minimises uncertainties related to bb production cross section and integrated luminosity
- MC: Used to extract ε^{B+}_{tot}
  - $(7.7 \pm 0.8)\times10^{-4}$ barrel,
  - $(2.7 \pm 0.3)\times10^{-4}$ endcap
- Data: Measure N^{B+}_{obs}
  - 13045 ± 652 barrel
  - 4450 ± 222 endcap





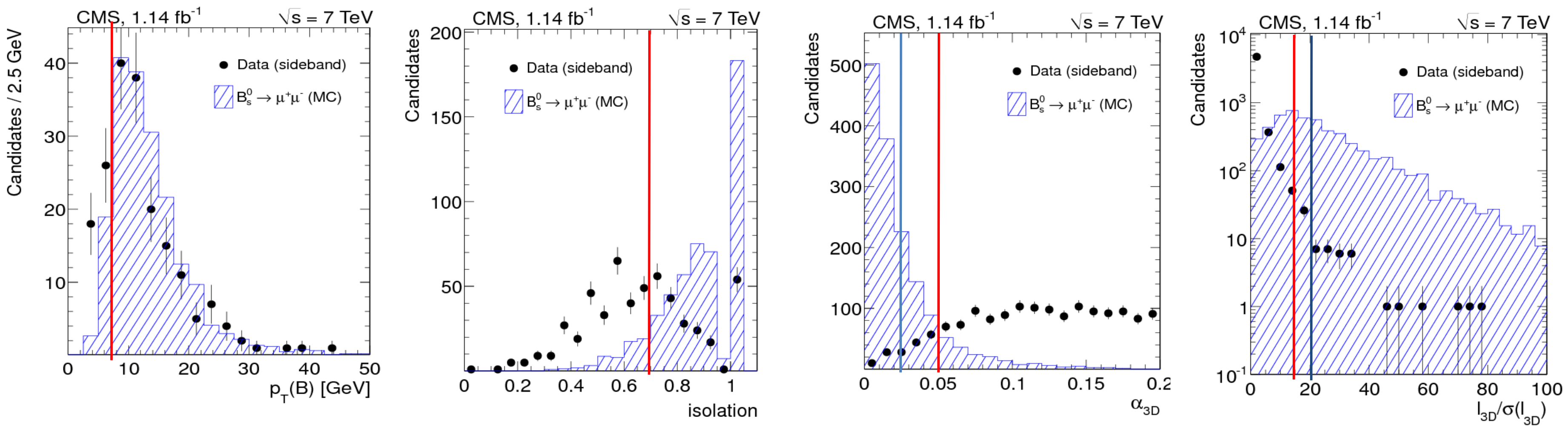
Signal

- Event selection optimised for best expected upper limit using MC signal & data sidebands (frozen before unblinding!)
- Sideband 4.9 < m < 5.2 GeV and 5.45 < m < 5.9 GeV

$p_T(\mu_1) > 4.5$GeV, $p_T(\mu_2) > 4.0$GeV
$p_T(B) > 6.5$ GeV, isolation >0.75
$\alpha_{3D} < 0.05$ (0.025), $l_{3D}/\sigma(l_{3D}) > 15$ (20)

Barrel ($|\eta|<1.4$)
Endcap ($|\eta|>1.4$)

Signal window: 5.2-5.3 GeV for B^0 5.3-5.45 GeV for B_s^0

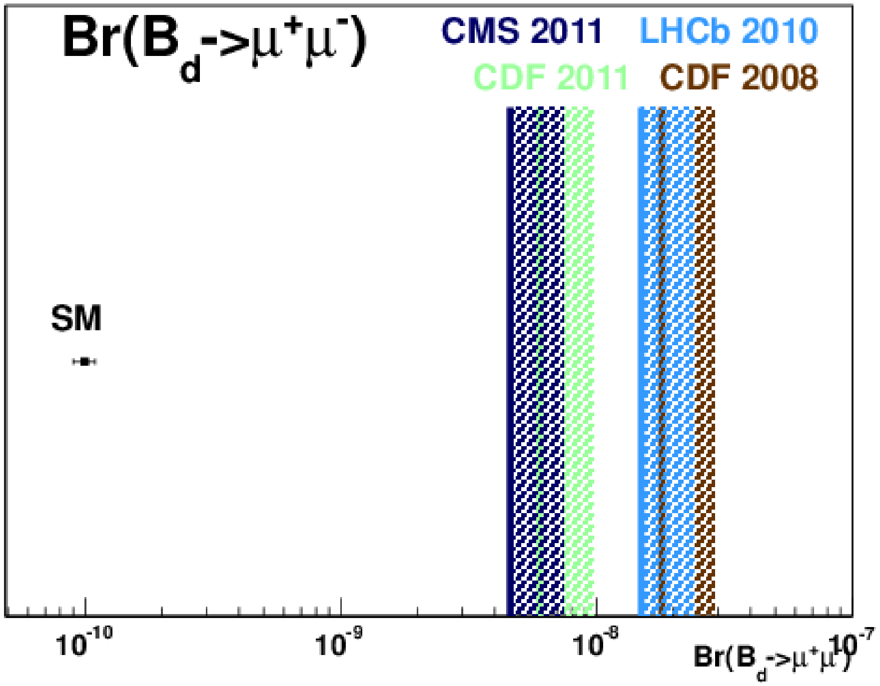


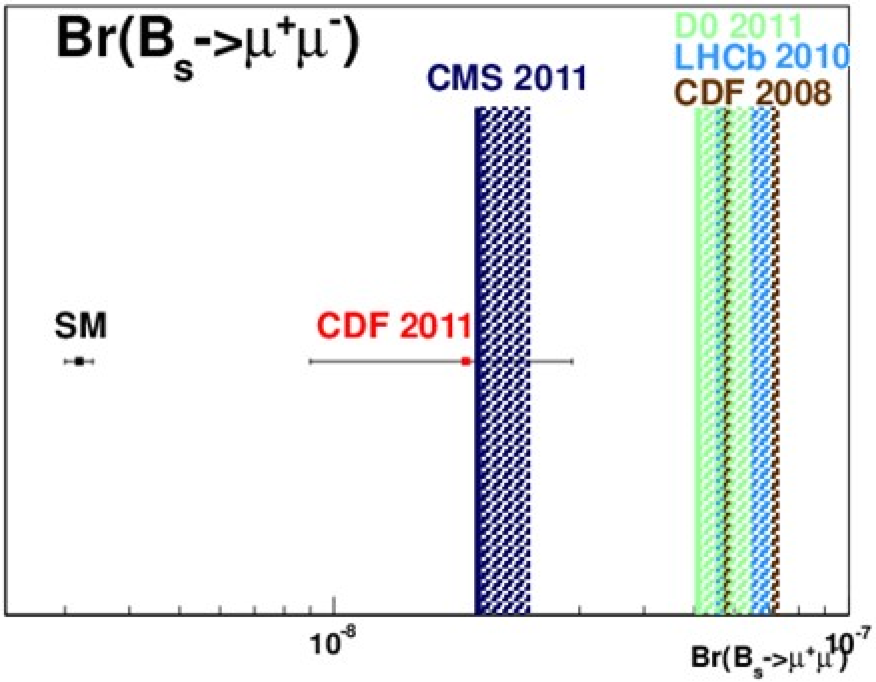
Results and Outlook

	Barrel		Endcap	
	$B^0 \to \mu^+\mu^-$	$B^0_s \to \mu^+\mu^-$	$B^0 \to \mu^+\mu^-$	$B^0_s \to \mu^+\mu^-$
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^{exp}_{signal}	0.065 ± 0.011	0.80 ± 0.16	0.025 ± 0.004	0.36 ± 0.07
N^{exp}_{comb}	0.40 ± 0.23	0.60 ± 0.35	0.53 ± 0.27	0.80 ± 0.40
N^{exp}_{peak}	0.25 ± 0.06	0.07 ± 0.02	0.16 ± 0.04	0.04 ± 0.01
N_{obs}	0	2	1	1

- Observations are consistent with SM background
- $Br(B^0_s \to \mu^+\mu^-) < 1.9 \times 10^{-8}$
- $Br(B^0 \to \mu^+\mu^-) < 4.6 \times 10^{-9}$

Results and Outlook





- Observations are consistent with SM background
  - Disfavours CDF excess
- No hints of new physics ☹
- More data will improve sensitivity

Thanks!

Backups

(Largely “borrowed” from Urs Langenegger’s EPS talk)

High Level Trigger

Variable	Signal	Control & Normalisation
Charge(mu1,mu2)	Opposite sign	Opposite sign
m(mu1,mu2) (GeV)	4.8 – 6.0	2.9 – 3.3
d_{ca} (cm)	< 0.5	< 0.5
p_T(mu) (GeV)	> 2	> 3
p_T(B) (GeV)	> 4	> 6.9
cos(alpha)	N/A	> 0.9
P(chi^2/dof)	N/A	> 0.5%

Efficiency ≈ 80% after analysis selection (i.e. In plateau)
Estimated from MC and data
Difference gives systematic uncertainty

Analysis Cuts

Variable	Barrel	Endcaps
p_T(mu1) (GeV)	> 4.5	> 4.5
p_T(mu2) (GeV)	> 4.0	> 4.0
p_T(B) (GeV)	> 6.5	> 6.5
alpha (rad)	< 0.050	< 0.025
chi^2/dof	< 1.6	< 1.6
I	> 0.75	> 0.75
d_{ca} (cm)	N/A	> 0.015

Normalisation sample also requires muons bend away from each other

Systematics and cross checks

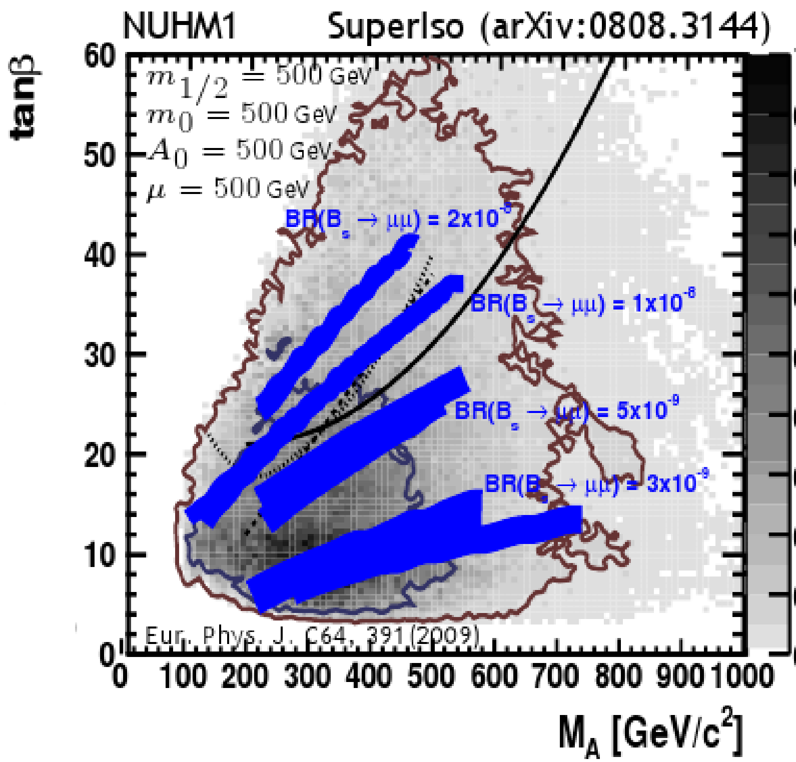
- Background, studied from 4%

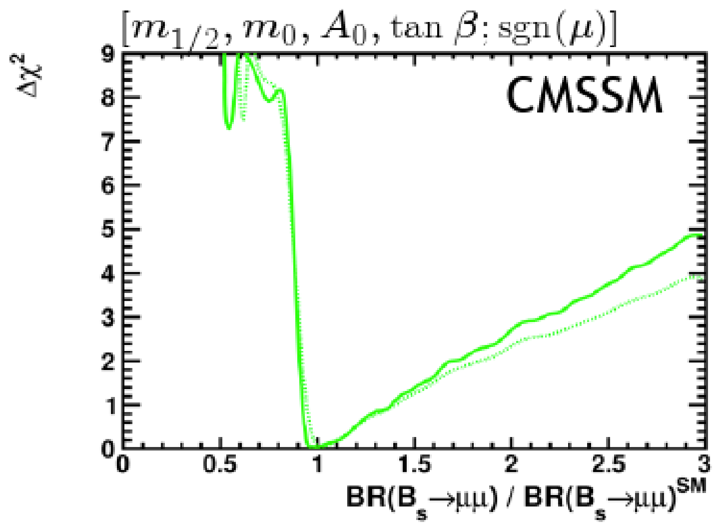
  inverted isolation sample: loosened selection

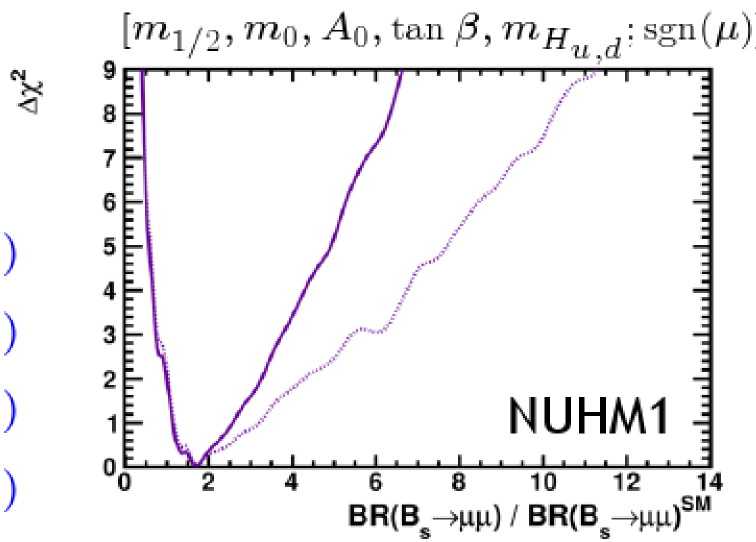
- Signal
  - acceptance: difference between production processes 4%
  - analysis efficiency: comparison of data and MC 7.9%
  - mass scale (resolution) from J/ψ and $\Upsilon(1S)$ 3%
- Normalization
  - analysis efficiency: comparison of data and MC 4%
  - kaon tracking efficiency 3.9%
  - yield fitting 5%
- Muon identification and trigger
  - estimated through difference of MC and data-driven methods
  - muon identification efficiency ratio 5%
  - trigger efficiency ratio 3%
- Cross checks performed

  sample yield vs time, $\mathcal{B}(B_s^0 \to J/\psi\,\phi)$, inverted isolation yield

BR values & new physics limits



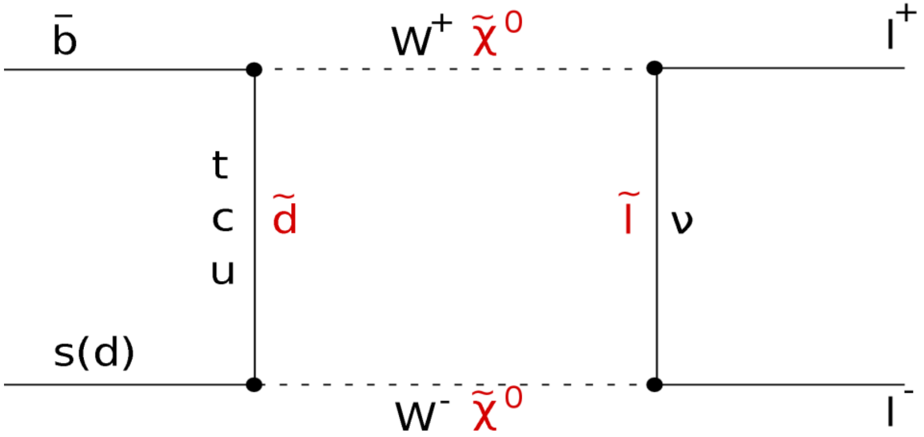




Eur. Phys. J. C71, 1634 (2011)

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.9 \times 10^{-8} \quad (95\%\ \mathrm{C.L.})$$
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.6 \times 10^{-8} \quad (90\%\ \mathrm{C.L.})$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.6 \times 10^{-9} \quad (95\%\ \mathrm{C.L.})$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.7 \times 10^{-9} \quad (90\%\ \mathrm{C.L.})$$

Where's the suppression?



Loop (2nd order weak process) → g_W^8

$|V_{ts}|^2$ or $|V_{td}|^2$ → 10^{-2} or 10^{-4}

Helicity (W couples to LH(RH) (anti-)fermions) → $(m_l / m_B)^2$

Annihilation of internal quarks→ $(f_B / m_B)^2$