$B_s^0 \to \mu^+\mu^-$ in CMS & ATLAS

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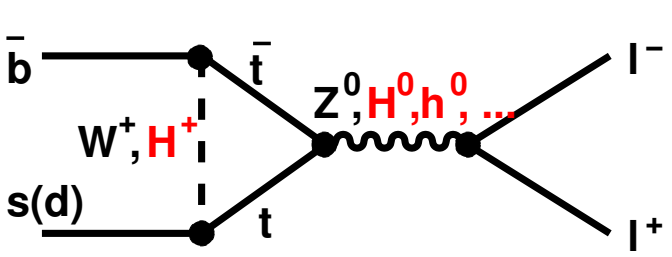
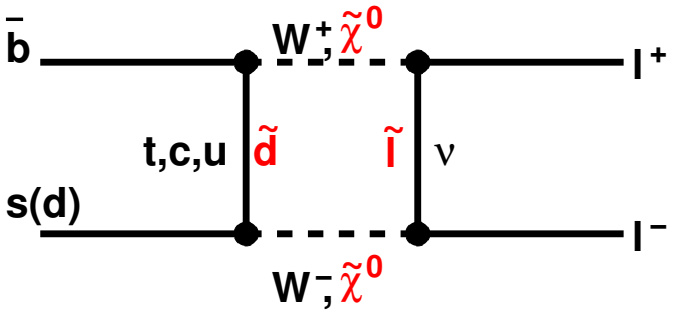
Outline

- Motivation
- $B_s^0 \to \mu^+\mu^-$ analysis
  - Trigger strategy
  - Offline analysis
- Results

Motivation



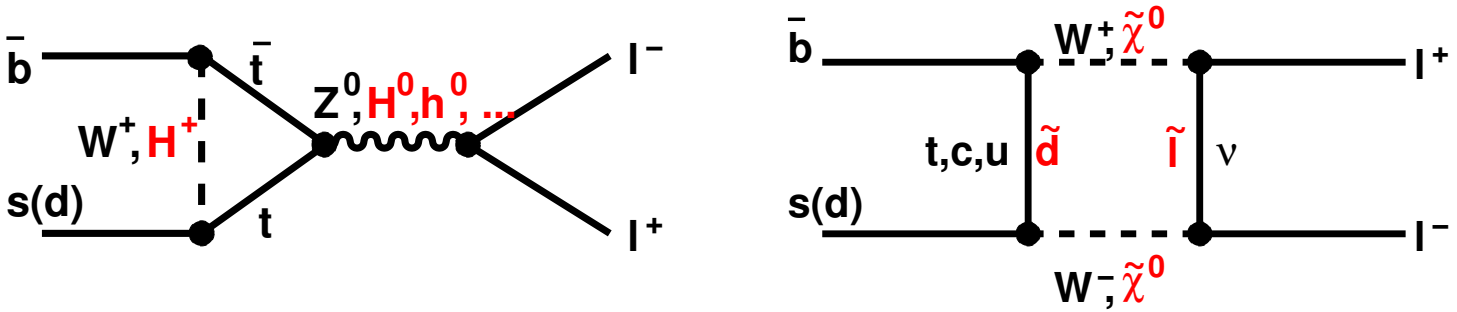


$B_s^0 \to \mu^+\mu^-$

- Highly supressed in SM: $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.42 \pm 0.54) \times 10^{-9}$
- Sensitive to BSM: $\mathcal{B} \propto \tan^6 \beta$ (MSSM) and $\mathcal{B} \propto \tan^4 \beta, m_{H^+}$ (2HDM)
- Current limit (CDF): $\mathcal{B}^{95\%} \leq 5.8 \times 10^{-8}$ [PRL 100,101802 (2008)]

$\tan \beta =$ ratio of the two vacuum expectation values of the neutral Higgs fields

Motivation



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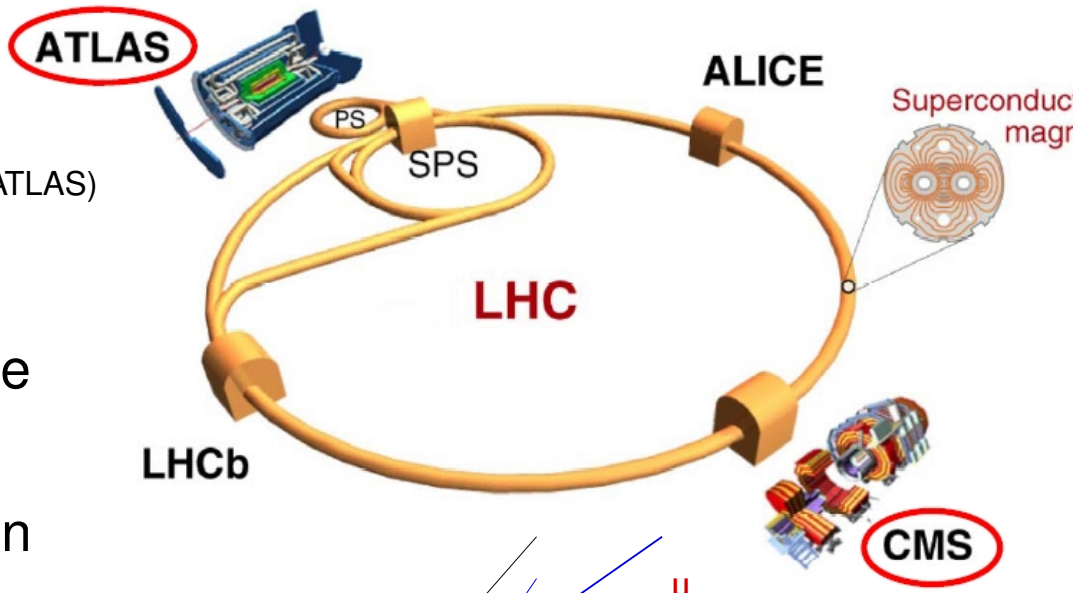
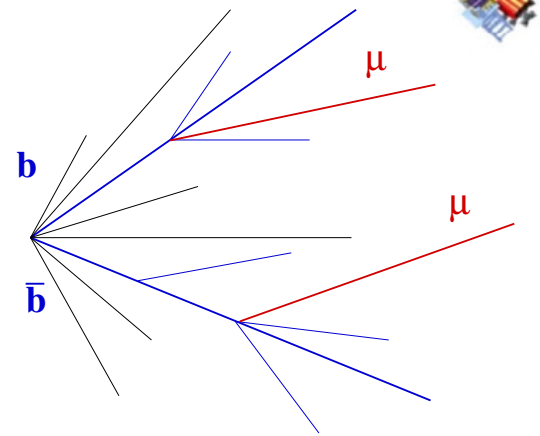
$B_s^0 \to \mu^+\mu^-$ at LHC

- b-hadron production at LHC
  - $\sigma_{b\bar{b}} \sim 500\,\mu$b
  - 10^{12} $b\bar{b}$-pairs in 1 year (CMS/ATLAS)
- Search for $B_s^0 \to \mu^+\mu^-$
  - clean experimental signature
  - low p_T dimuon trigger
  - precise vertex reconstruction
- Background composition
  - combinatorial from $b\bar{b} \to \mu^+\mu^- + X$
  - misidentified hadrons from QCD
  - rare B-decays





→ **efficient signal selection / background reduction** ←

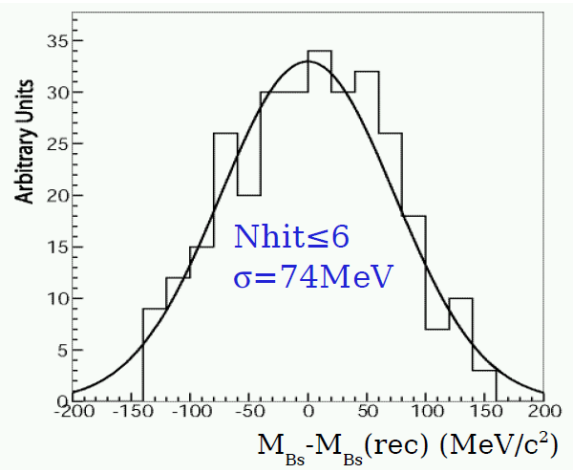
Online Selection (CMS)

Level-1 Trigger

- di-muon trigger stream with threshold at $p_\perp > 3\,\text{GeV}$ (0.9 kHz)

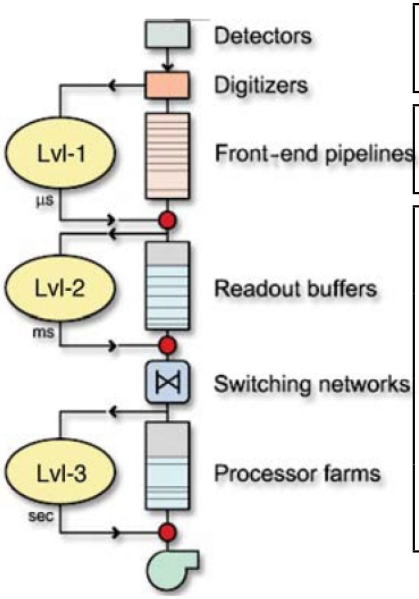
HLT strategy for $B_s^0 \to \mu^+\mu^-$

1. Verification of two L1 muons
2. Primary vertex reconstruction with pixel detector
   → use three most significant
3. Regional track reconstruction in cones around L1 muons
   → partial reconstruction using $\leq$ 6 hits
   → $p_\perp > 4\,\text{GeV}$
4. Track pairs
   → opposite charge
   → mass window for signal (and background)
5. Vertex fit (< 1.7 Hz)
   → secondary vertex fit quality: $\chi^2 < 20$
   → three-dimensional flight length: $L_{3D} > 150\ \mu\text{m}$



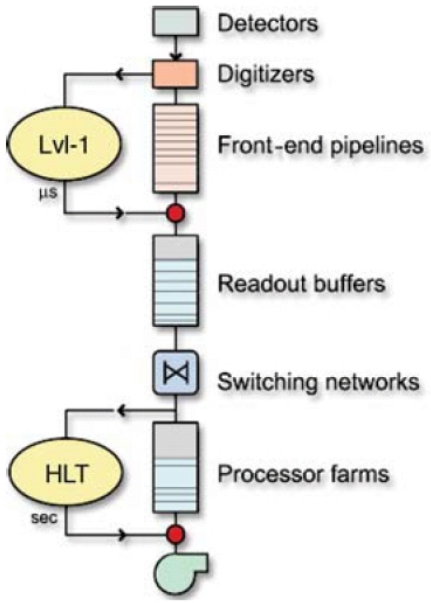
CMS & ATLAS: Online selection

ATLAS



	ATLAS	CMS
L1: $p_T^{\mu 1,\mu 2}$	$p_T \geq 6$ GeV	$p_T \geq 3$ GeV
HLT: p_T^{μ}	$p_T \geq 6$ GeV	$p_T \geq 4$ GeV
Vertex quality	$\chi^2 \leq 20$	$\chi^2 \leq 20$
Decay length*	$L_{xy} \geq 200\ \mu$m	$L_{3D} \geq 150\ \mu$m
Mass cut	$4 - 6$ GeV	$m_{B_s} \pm 150$ MeV

CMS



* Pixel size in $R\phi \times z$:
-50 μm $\times$ 400 μm ATLAS
-100 μm $\times$ 150 μm CMS

Offline analysis: Variables (CMS)

- muon separation in $\eta\phi$: $0.3 < \Delta R(\mu\mu) < 1.2$

  $\longrightarrow \Delta R(\mu\mu) = \sqrt{(\eta_{\mu_1} - \eta_{\mu_2})^2 + (\phi_{\mu_1} - \phi_{\mu_2})^2}$

- Isolation of muon pair: $I > 0.850$

  $\longrightarrow I = \frac{p_\perp(B_s)}{(p_\perp(B_s) + \sum_{trk} |p_\perp|)}$ with trk = tracks in cone

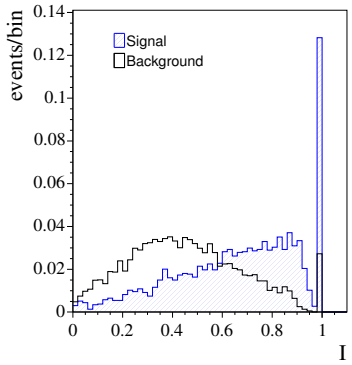
  with $r = \sqrt{\eta^2 + \phi^2} < 1.0$ and $p_\perp > 0.9\,\text{GeV}$

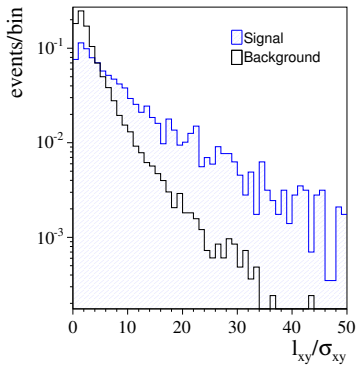
- decay length significance: $l_{xy}/\sigma_{xy} > 18.0$

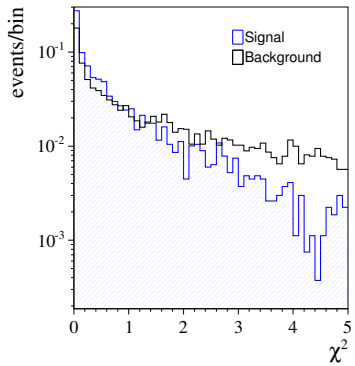
- pointing angle: $\cos\alpha > 0.99500\ (5.7°)$

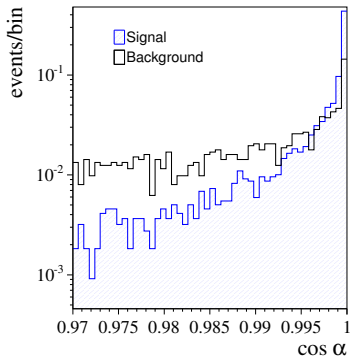
  $\longrightarrow \alpha = \measuredangle(\vec{P}_T, \vec{V}_T)$

- vertex fit quality: $\chi^2 < 1.0$

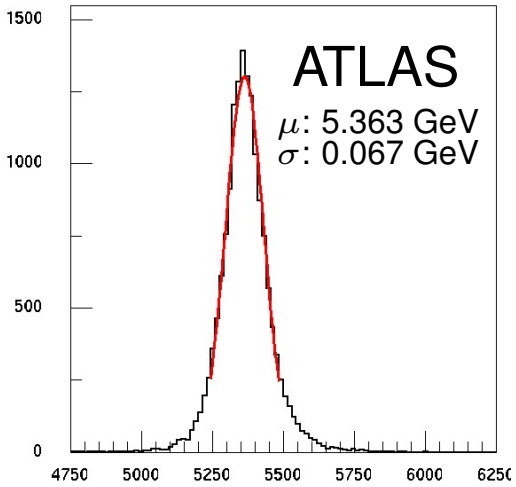


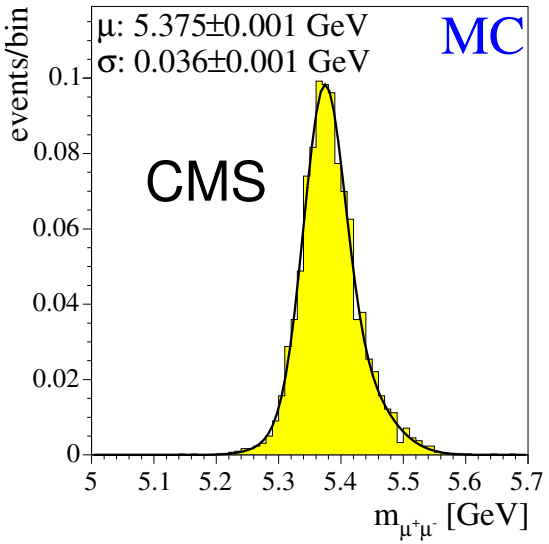






Mass reconstruction





Fit of the mass peak

	ATLAS	CMS
single Gauss	**67 MeV**	32 MeV
double Gauss	-	**36 MeV**

Good mass resolution

- essential against rare BG
- separation from $B_d^0 \to \mu^+\mu^-$

Mass cut

- ATLAS: $m_{B_s}\ ^{+140\,\text{MeV}}_{-70\,\text{MeV}}$
- CMS: $m_{B_s} \pm 100\,\text{MeV}$

CMS & ATLAS: Offline analysis

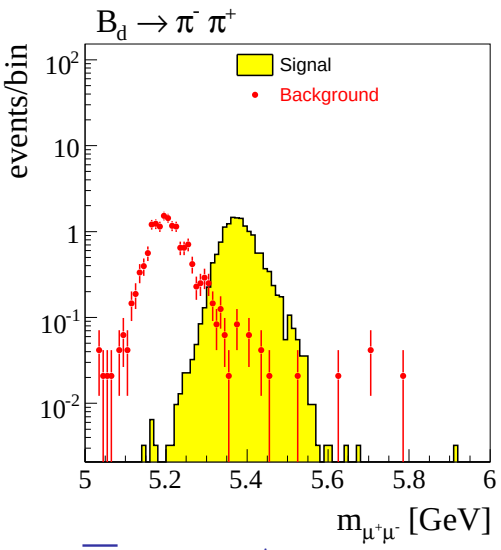
	ATLAS	CMS
Muon separation	$\Delta R \leq 0.9$ [1)]	$0.3 \leq \Delta R \leq 1.2$ [1)]
Pointing angle	$\alpha \leq 1°$	$\alpha \leq 5.7°$
Flight distance	$\frac{L_{xy}}{\sigma_{xy}} \geq 11$	$\frac{L_{xy}}{\sigma_{xy}} \geq 18$
Vertex fit	$\chi^2 \leq 15$	$\chi^2 \leq 1$
Isolation around B_s candidate	no charged tracks $p_T > 0.8$ in angular cone $\theta < 15°$	$I \geq 0.85$ [2)] tracks $p_T > 0.9$ in cone $r = 1$
Mass window	$m_{B_s}\ ^{+140\,\text{MeV}}_{-70\,\text{MeV}}$	$m_{B_s} \pm 100\,\text{MeV}$
Expected signal events in $10\,\text{fb}^{-1}$	$\mathbf{7.0 \pm 2.6}$	$\mathbf{6.1 \pm 0.6_{stat} \pm 1.5_{sys}}$

[1)] $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$, [2)] $I = \frac{p_\perp(B_s)}{p_\perp(B_s) + \sum_{trk} |p_\perp|}$

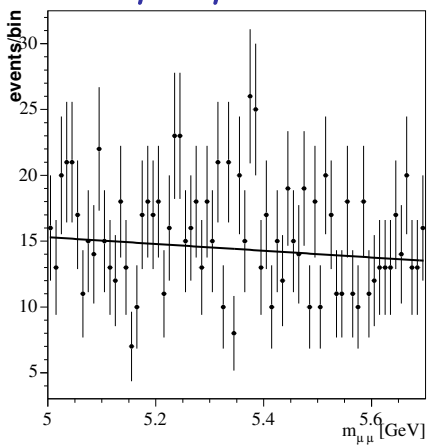
Combinatorial & rare backgrounds

	Combinatorial BG	$\mathcal{L}_{\text{gen}}$	**CMS**	**ATLAS**
	$b\bar{b} \to \mu^+\mu^- + X$ [1)]	$8\,\text{pb}^{-1}$ ($10\,\text{pb}^{-1}$)	14^{+22}_{-14}	20 ± 12
	QCD	$0.02\,\text{nb}^{-1}$ (-)	0.0	-
	Rare BG	$\mathcal{B}$	**CMS**	**ATLAS**
2μ+ soft μ	$B^+ \to \mu^+\mu^-\mu^+\nu_\mu$	5×10^{-6}	0.0	negl.
	$B_c^+ \to \mu^+\mu^-\mu^+\nu_\mu$	5×10^{-6}	0.0	negl.
	$B_c^+ \to J/\psi(\to \mu^+\mu^-)\mu^+\nu$	1.2×10^{-3}	0.0	-
2μ+ soft γ, π	$B^0_{(s)} \to \mu^+\mu^-\gamma$	2.0×10^{-8}	0.0	negl.
	$B^0 \to \mu^+\mu^-\pi^0$	1.4×10^{-4}	-	negl.
	$B^+ \to \mu^+\mu^-\pi^+$	2.0×10^{-8}	-	negl.
μ+ misid. hadron	$B_s^0 \to K^-\mu^+\nu_\mu$	1.4×10^{-4}	0.0	negl.
	$B^0 \to \pi^-\mu^+\nu_\mu$	2.0×10^{-8}	0.0	negl.
2 misid. hadrons	$B_s^0 \to K^-K^+$	24.4×10^{-6}	< 0.3	negl.
	$B_s^0 \to \pi^-\pi^+$	0.5×10^{-6}	< 0.3	negl.
	$B_s^0 \to K^-\pi^+$	5.0×10^{-6}	< 0.3	negl.
	$B^0 \to \pi^-\pi^+$	5.2×10^{-6}	< 0.3	-
	$B^0 \to \pi^-K^+$	20.0×10^{-6}	< 0.3	-
	$\Lambda_b^0 \to p^+\pi^-$	1×10^{-6}	< 0.3	-
	$\Lambda_b^0 \to p^+K^-$	2×10^{-6}	< 0.3	-
Signal	$B_s \to \mu^-\mu^+$	3.42×10^{-9}	6.1 ± 2.1	7.0 ± 2.6

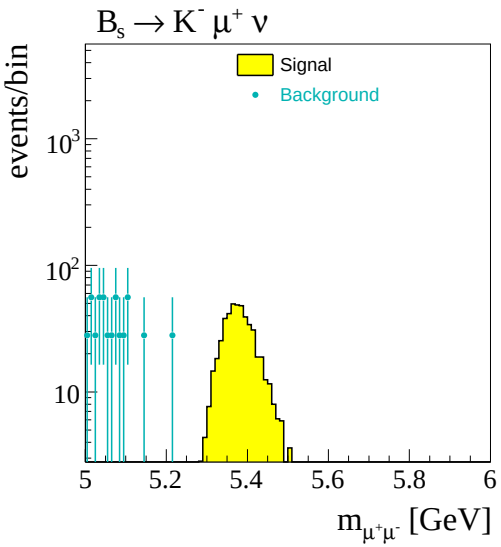
2h from B-meson

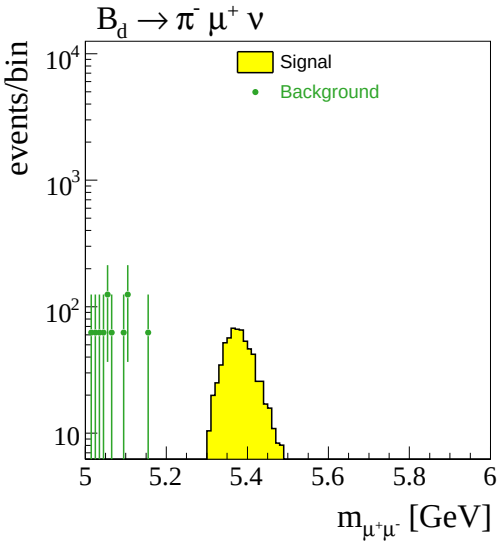


$b\bar{b} \to \mu^+\mu^- + X$

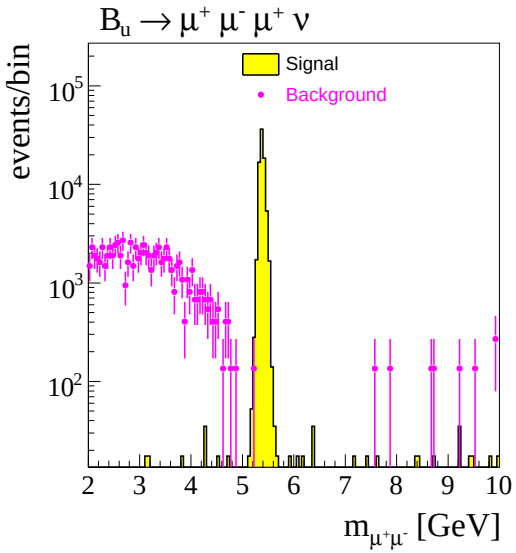


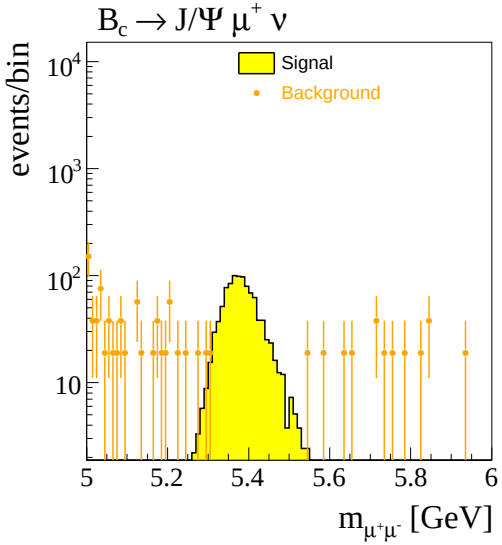
1h + 1 μ + X





2 μ + X





Results 10 fb^{-1}

CMS

- Signal: $\varepsilon_S = 0.016 \pm 0.002_{stat}$, $n_S = 6.1 \pm 0.6_{\text{stat}} \pm 1.5_{\text{sys}}$
- Background: $\varepsilon_B = 2.7 \times 10^{-7}$, $n_B = 13.8^{+22.0}_{-13.8}$ $(n_B^{rare} = 0.3)$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) \leq \frac{N(n_{obs}, n_B, n_S)}{\varepsilon_{\text{gen}}\, \varepsilon_{\text{total}}\, N_{B_s}} \leq 1.4 \times 10^{-8} \quad (90\%\ \text{C.L.})^*$$

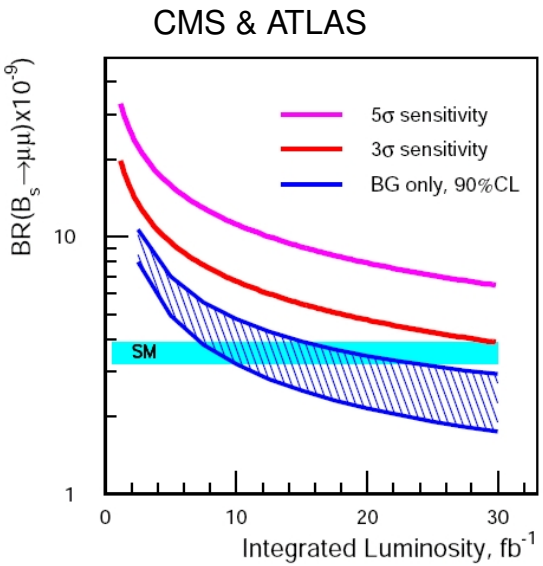
ATLAS

- Signal: $n_S = 7.0 \pm 2.6$
- Background: $n_B = 20 \pm 12$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) \leq 1.2 \times 10^{-8} \quad (90\%\ \text{C.L.})$$

* UL extracted with Bayesian approach (CDF)

Conclusions



Status: CMS

- including normalization channel $B^+ \to J/\Psi K^+$
- trigger efficiency, μ-ID efficiciency etc. from data
- optimizing analysis selection

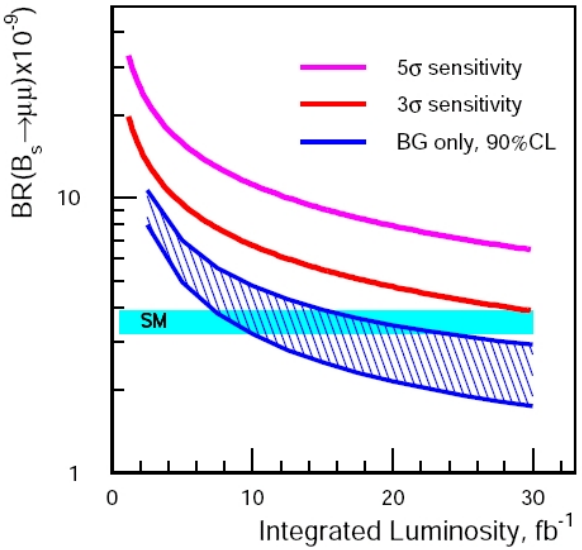
Status: ATLAS

- Study was updated as part of the Computing System Comissioning project (CSC)
- Publication expected in the next few weeks

Table: Number of signal events vs integrated luminosity

Experiment	**2 fb^{-1}**	**10 fb^{-1}**	**30 fb^{-1}**	**100 fb^{-1}**
ATLAS	1.4	7.0	21.0	92*
CMS	1.2	6.1	18.3	26*
LHCb	20	100	-	-

(∗) - results of 2000, to be redone

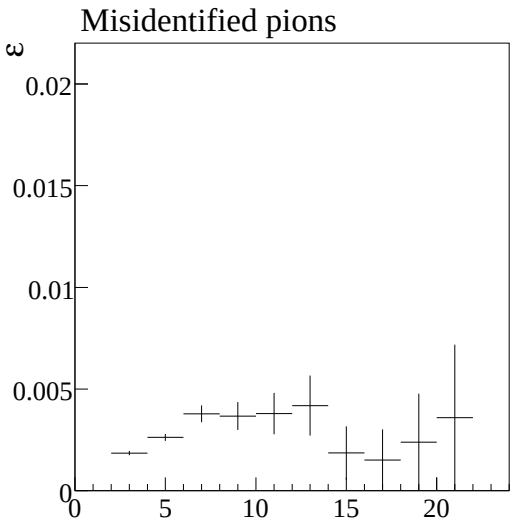


Rare B-decays

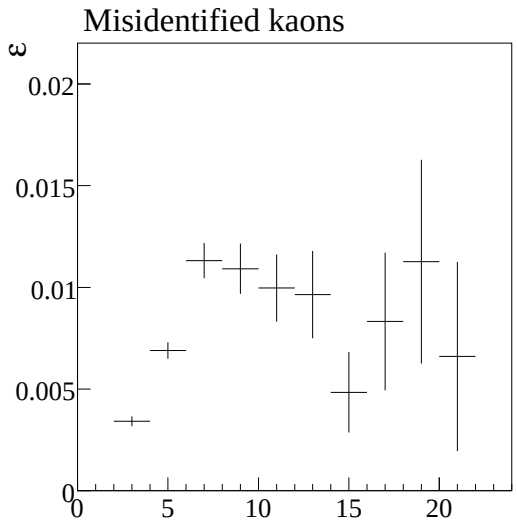
Hadron misidentification

- punch-through of high-momentum hadron
- in-flight decays of pions and kaons into muons

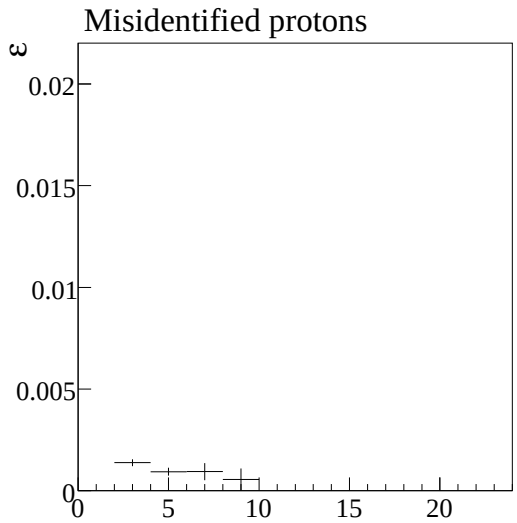
Misidentification rate as a function of transverse momentum



$\varepsilon_\pi = 0.5\ \%$



$\varepsilon_K = 1.0\ \%$



$\varepsilon_p = 0.1\ \%$