Search for the $B_s^0 \to \mu^+\mu^-$ and $B_d^0 \to \mu^+\mu^-$ decays at LHCb

Mathieu Perrin-Terrin
Supervisor: Giampiero Mancinelli

CPPM, Aix-Marseille Univ, IN2P3 CNRS, France

Dec 12th, 2011

CPPM Seminar

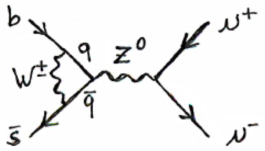
Why Studying $B_s \to \mu^+\mu^-$?

Looking for Physics Beyond SM requires:

Why Studying $B_s \to \mu^+\mu^-$?

Looking for Physics Beyond SM requires:

clean SM prediction

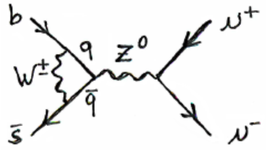


$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (0.32 \pm 0.2) \times 10^{-8}$$

Why Studying $B_s \to \mu^+\mu^-$?

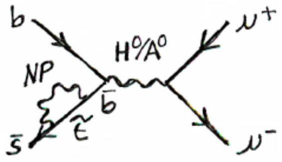
Looking for Physics Beyond SM requires:

clean SM prediction



$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (0.32 \pm 0.2) \times 10^{-8}$

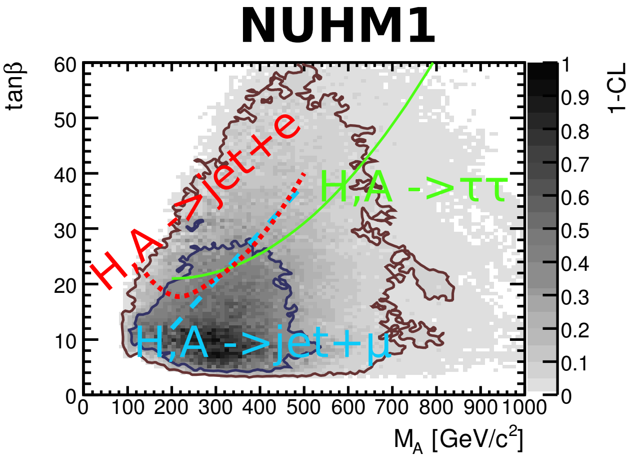
clear NP signature



$\mathcal{B}(B_s^0 \to \mu^+\mu^-) \propto \tan^6 \beta$
(MSSM)

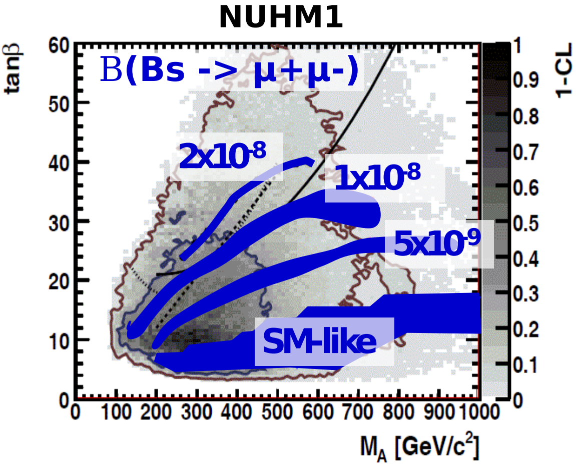
Sensitivity to New Physics.

Constraints from Direct Searches (CMS, 30 fb^{-1}):



arXiv:0907.5568

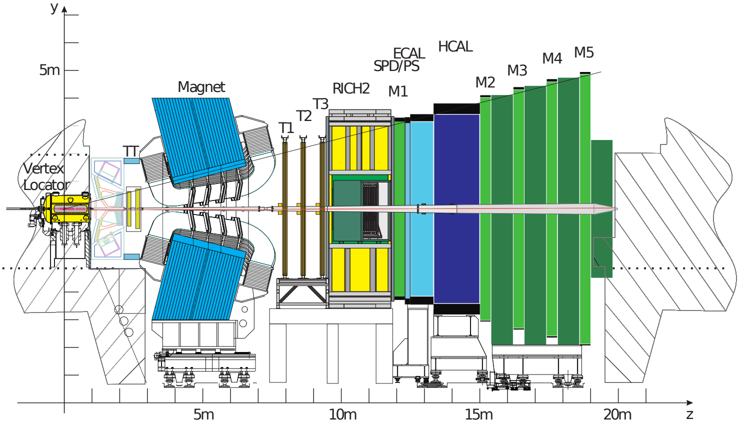
Constraints from $B_s \to \mu^+\mu^-$:



arXiv:0907.5568

The LHCb detector

A detector design to study rare B decays like $B_s \to \mu^+\mu^-$:



The LHCb detector

A detector design to study rare B decays like $B_{s,d} \to \mu^+\mu^-$:

The LHCb detector

A detector design to study rare B decays like $B_{s,d} \to \mu^+\mu^-$:

High Bs, Bd statistics

- **Large cross section**: $\sigma(pp \to b\bar{b}X \simeq 300\mu b)$ at 7 TeV.
- **Large acceptance for $b\bar{b}$ pairs** produced mostly forward/backward: LHCb covers $1.9 < \eta < 4.9$
- **Efficient trigger on low pT muons**.

The LHCb detector

A detector design to study rare B decays like $B_{s,d} \to \mu^+\mu^-$:

High Bs, Bd statistics

- **Large cross section**: $\sigma(pp \to b\bar{b}X \simeq 300\mu b)$ at 7 TeV.
- **Large acceptance for $b\bar{b}$ pairs** produced mostly forward/backward: LHCb covers $1.9 < \eta < 4.9$
- **Efficient trigger on low pT muons**.

Bkg/Sig separation:

- **Large boost**: the B meson decay vertex is displaced in average 1 cm from the PV .
- **Good mass resolution**: $\sigma_m(B_s \to \mu^+\mu^-) = 24.6\,\mathrm{MeV}/c^2$
- **Good impact parameter resolution**: $\sigma_{IP} \simeq 25\,\mu\mathrm{m}(\mathrm{pT} = 2\,\mathrm{GeV}/c)$
- **MuonID performance**: $\epsilon(\mu \to \mu) \simeq 97\%(p > 10\,\mathrm{GeV}/c), \epsilon(\mathrm{h} \to \mu) < 1\%(\mathrm{p} > 10\,\mathrm{GeV}/c)$.

Analysis Strategy

Normalisation to $B_s^0 \to J/\psi\phi$, $B^0 \to K^+\pi^-$, $B^+ \to J/\psi K^+$

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = \frac{N(B_s \to \mu^+\mu^-)}{N(B_s)} \propto \frac{N(B_s \to \mu^+\mu^-)}{N(B_s^0 \to J/\psi\phi)} \frac{N(B_s^0 \to J/\psi\phi)}{N(B_s)}$$

Analysis Strategy

Normalisation to $\mathrm{B_s^0} \to \mathrm{J/\psi}\phi$, $\mathrm{B^0} \to \mathrm{K^+}\pi^-$, $\mathrm{B^+} \to \mathrm{J/\psi K^+}$

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = \frac{N(B_s \to \mu^+\mu^-)}{N(B_s)} \propto \frac{N(B_s \to \mu^+\mu^-)}{N(\mathrm{B_s^0} \to \mathrm{J/\psi}\phi)} \frac{N(\mathrm{B_s^0} \to \mathrm{J/\psi}\phi)}{N(B_s)}$$

Selection

- similar selection between Signal and Control Channel

Analysis Strategy

Normalisation to $B_s^0 \to J/\psi\phi$, $B^0 \to K^+\pi^-$, $B^+ \to J/\psi K^+$

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = \frac{N(B_s \to \mu^+\mu^-)}{N(B_s)} \propto \frac{N(B_s \to \mu^+\mu^-)}{N(B_s^0 \to J/\psi\phi)} \frac{N(B_s^0 \to J/\psi\phi)}{N(B_s)}$$

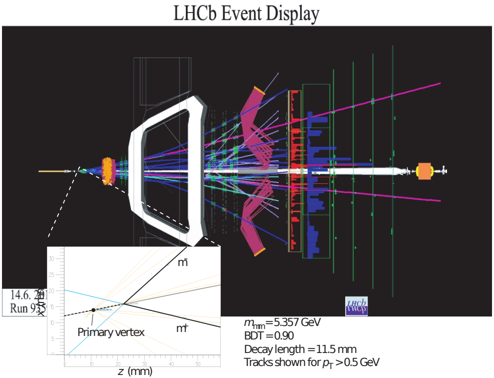
Selection

- similar selection between Signal and Control Channel

Sig/Bkg discrimination

- combinatorics: $b\bar{b} \to \mu^+\mu^- X$
- use 2 uncorrelated variables: BDT, $m_{\mu\mu}$.
- BDT: Boosted Decision Tree, use the geometry and kinematics of the events.

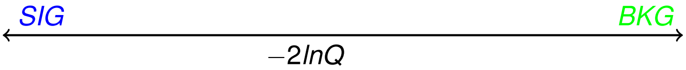
Limit Extraction



- Too few $B_s \to \mu^+\mu^-$ signal event to measure its $\mathcal{B}$ but
  “*if* $\mathcal{B}(B_s \to \mu^+\mu^-)$*was such then we would have observed it!*”
- Set an upper limit by comparing data with expected distributions in bins of BDT and $m\mu\mu$ for given $\mathcal{B}$

Limit Extraction - my contribution

- Define a scale of Signal-likeness, Q:



Limit Extraction - my contribution

- Define a scale of Signal-likeness, Q:

SIG ⟵⟶ *BKG*

$-2 lnQ$

- Calibrate the scale (generating pseudo-experiments):

if $\mathcal{B}$ was such then Bkg Only / Sig+Bkg *would give Q of* such / such

Limit Extraction - my contribution

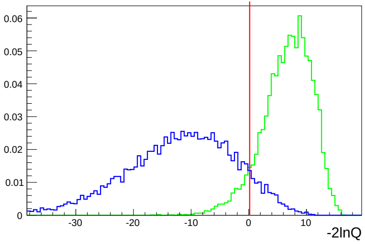
- Define a scale of Signal-likeness, Q:

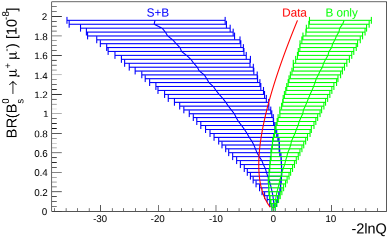
SIG ⟵⟶ *BKG*

$-2lnQ$

- Calibrate the scale (generating pseudo-experiments):

if $\mathcal{B}$ was such then Bkg Only / Sig+Bkg *would give Q of* such / such





Limit Extraction - my contribution

- Define a scale of Signal-likeness, Q:

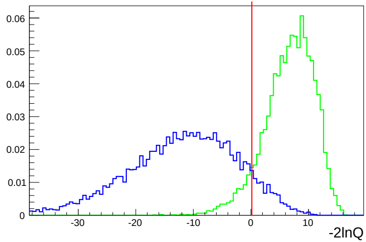
SIG ←――――――――――――――→ *BKG*

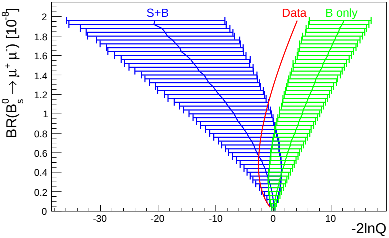
$-2lnQ$

- Calibrate the scale (generating pseudo-experiments):

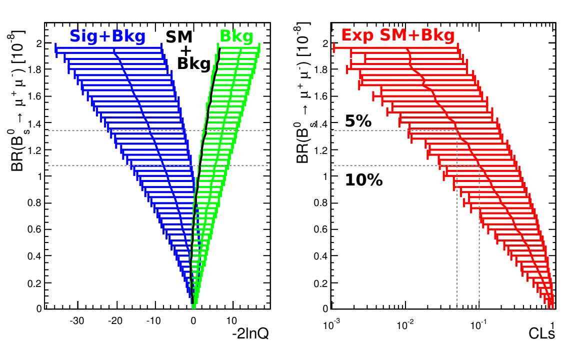
if $\mathcal{B}$ was such then Bkg Only / Sig+Bkg *would give Q of* such / such

- Compute for each $\mathcal{B}$ the Q for the data





- Measure the probability, **CLs**, for each $\mathcal{B}$ that the Sig+Bkg gives the data Q.
- all $\mathcal{B}$ values giving **CLs** smaller than 5% are excluded.



Results

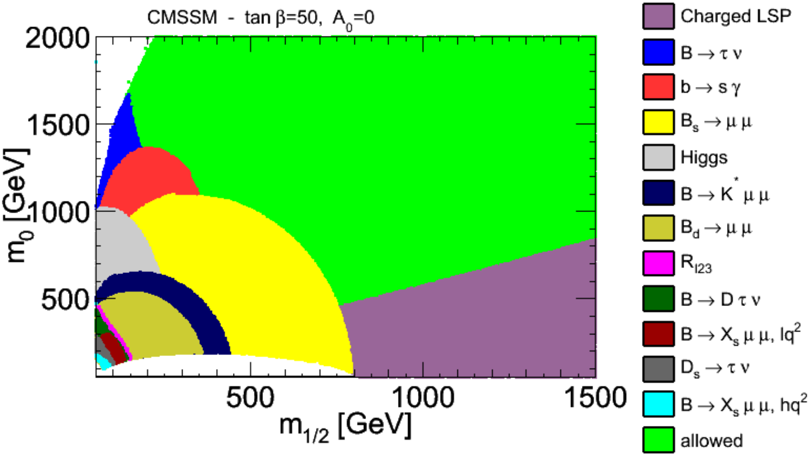
With 370 pb^{-1} LHCb has set the world best limit on $B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$:

$$\mathcal{B}(B_s \to \mu^+\mu^-) < 1.4 \cdot 10^{-8} \quad at\ 95\% C.L.$$
$$\mathcal{B}(B_d \to \mu^+\mu^-) < 3.2 \cdot 10^{-9} \quad at\ 95\% C.L.$$

These results put stringent constrains of New Physics scenarios.

Sensitivity to New Physics

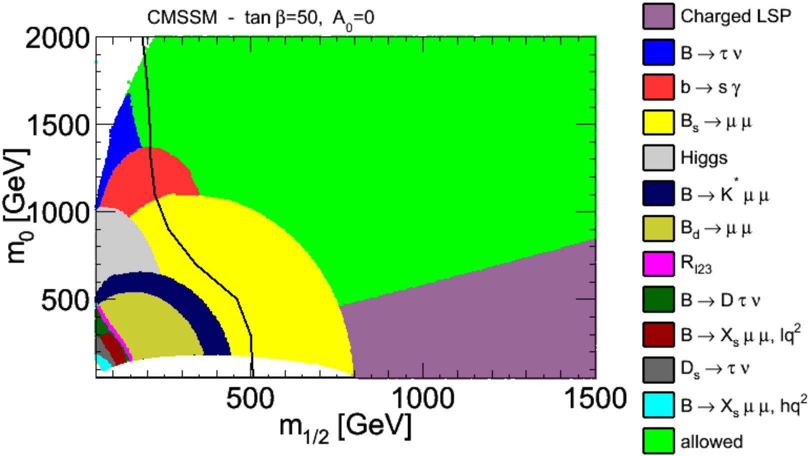
Constrains from Indirect Searches Summer 2011 ($B_s \to \mu^+\mu^-$) :



N. Mahmoudi (SuperIso v3.2+)

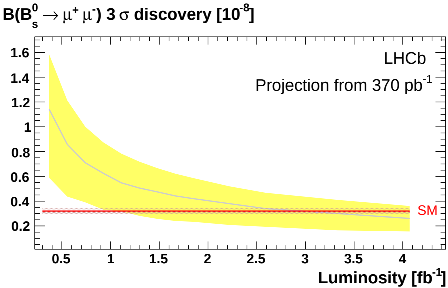
Sensitivity to New Physics.

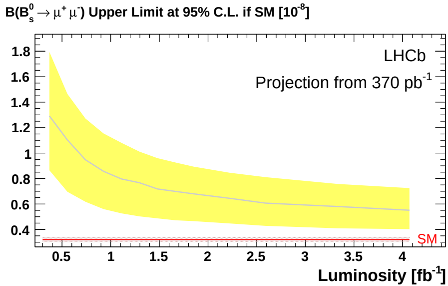
Indirect Searches Vs Direct (Atlas CMS) Summer 2011:



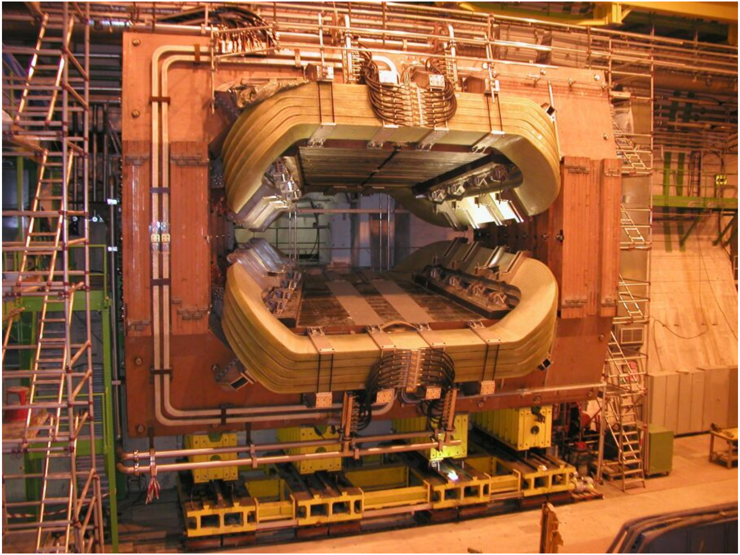
N. Mahmoudi (SuperIso v3.2+)

Prospect: 3σ observation is possible for this Winter



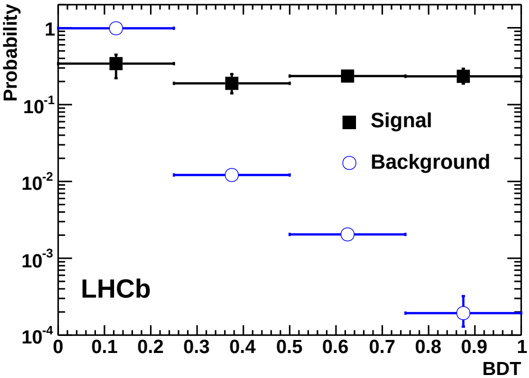


The End



BDT Variables

- B lifetime,
- impact parameter,
- transverse momentum,
- the minimum impact parameter significance (IP/Ï(IP)) of the muons
- the distance of closest approach between the two muons
- the isolation of the two muons with respect to any other track in the event
- the minimum pT of the two muons
- the cosine of the angle between the muon momentum in the B rest frame and the vector perpendicular to the B momentum and the beam axis
- the B isolation


Probability
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
BDT
Signal
Background
LHCb

Invariant mass [MeV/c^2]			BDT 0. – 0.25	0.25 – 0.5	0.5 – 0.75	0.75 – 1.
	5298 – 5318	Exp. comb. bkg	$575.5^{+6.5}_{-6.0}$	$6.96^{+0.63}_{-0.57}$	$1.19^{+0.39}_{-0.35}$	$0.111^{+0.083}_{-0.066}$
		Exp. peak. bkg	$0.126^{+0.037}_{-0.030}$	$0.124^{+0.037}_{-0.030}$	$0.124^{+0.037}_{-0.030}$	$0.127^{+0.038}_{-0.031}$
		Exp. sig.	$0.059^{+0.023}_{-0.022}$	$0.0329^{+0.0128}_{-0.0095}$	$0.0415^{+0.0120}_{-0.0085}$	$0.0411^{+0.0135}_{-0.0099}$
		Obs.	533	10	1	0
	5318 – 5338	Exp. comb. bkg	$566.8^{+6.3}_{-5.8}$	$6.90^{+0.61}_{-0.55}$	$1.16^{+0.38}_{-0.34}$	$0.109^{+0.079}_{-0.063}$
		Exp. peak. bkg	$0.052^{+0.023}_{-0.018}$	$0.054^{+0.026}_{-0.019}$	$0.052^{+0.024}_{-0.018}$	$0.051^{+0.023}_{-0.018}$
		Exp. sig.	$0.205^{+0.073}_{-0.074}$	$0.114^{+0.040}_{-0.031}$	$0.142^{+0.036}_{-0.025}$	$0.142^{+0.042}_{-0.031}$
		Obs.	525	9	0	1
	5338 – 5358	Exp. comb. bkg	$558.2^{+6.1}_{-5.6}$	$6.84^{+0.59}_{-0.54}$	$1.14^{+0.37}_{-0.33}$	$0.106^{+0.075}_{-0.060}$
		Exp. peak. bkg	$0.024^{+0.028}_{-0.012}$	$0.025^{+0.026}_{-0.012}$	$0.024^{+0.027}_{-0.012}$	$0.025^{+0.025}_{-0.012}$
		Exp. sig.	$0.38^{+0.14}_{-0.14}$	$0.213^{+0.075}_{-0.058}$	$0.267^{+0.065}_{-0.047}$	$0.265^{+0.077}_{-0.058}$
		Obs.	561	6	2	1
	5358 – 5378	Exp. comb. bkg	$549.8^{+6.0}_{-5.4}$	$6.77^{+0.57}_{-0.52}$	$1.11^{+0.36}_{-0.32}$	$0.103^{+0.073}_{-0.057}$
		Exp. peak. bkg	$0.0145^{+0.0220}_{-0.0091}$	$0.0151^{+0.0230}_{-0.0091}$	$0.0153^{+0.0232}_{-0.0098}$	$0.015^{+0.023}_{-0.010}$
		Exp. sig.	$0.38^{+0.14}_{-0.14}$	$0.213^{+0.075}_{-0.057}$	$0.267^{+0.065}_{-0.047}$	$0.265^{+0.077}_{-0.057}$
		Obs.	515	7	0	0
	5378 – 5398	Exp. comb. bkg	$541.5^{+5.8}_{-5.3}$	$6.71^{+0.55}_{-0.51}$	$1.09^{+0.34}_{-0.31}$	$0.101^{+0.070}_{-0.054}$
		Exp. peak. bkg	$0.0115^{+0.0175}_{-0.0086}$	$0.0116^{+0.0177}_{-0.0090}$	$0.0118^{+0.0179}_{-0.0090}$	$0.0118^{+0.0179}_{-0.0088}$
		Exp. sig.	$0.204^{+0.073}_{-0.074}$	$0.114^{+0.040}_{-0.031}$	$0.142^{+0.036}_{-0.026}$	$0.141^{+0.042}_{-0.031}$
		Obs.	547	10	1	1
	5398 – 5418	Exp. comb. bkg	$533.4^{+5.7}_{-5.2}$	$6.65^{+0.53}_{-0.49}$	$1.07^{+0.34}_{-0.30}$	$0.098^{+0.068}_{-0.051}$
		Exp. peak. bkg	$0.0089^{+0.0136}_{-0.0065}$	$0.0088^{+0.0133}_{-0.0066}$	$0.0091^{+0.0138}_{-0.0070}$	$0.0090^{+0.0137}_{-0.0065}$
		Exp. sig.	$0.058^{+0.024}_{-0.021}$	$0.0323^{+0.0128}_{-0.0093}$	$0.0407^{+0.0120}_{-0.0087}$	$0.0402^{+0.0137}_{-0.0097}$
		Obs.	501	4	1	0

Invariant mass [MeV/c^2]		BDT 0. – 0.25	BDT 0.25 – 0.5	BDT 0.5 – 0.75	BDT 0.75 – 1.
5212 – 5232	Exp. comb. bkg	$614.2^{+7.5}_{-7.0}$	$7.23^{+0.77}_{-0.68}$	$1.31^{+0.46}_{-0.40}$	$0.123^{+0.107}_{-0.072}$
	Exp. peak. bkg	$0.203^{+0.038}_{-0.034}$	$0.206^{+0.038}_{-0.034}$	$0.203^{+0.037}_{-0.034}$	$0.205^{+0.038}_{-0.034}$
	Exp. sig.	$0.0070^{+0.0027}_{-0.0026}$	$0.0039^{+0.0015}_{-0.0011}$	$0.0049^{+0.0014}_{-0.0010}$	$0.0048^{+0.0016}_{-0.0012}$
	Cross-Pollution	$0.0056^{+0.0021}_{-0.0020}$	$0.00312^{+0.00119}_{-0.00087}$	$0.00391^{+0.00107}_{-0.00078}$	$0.00387^{+0.00122}_{-0.00092}$
	Obs.	554	6	0	2
5232 – 5252	Exp. comb. bkg	$605.0^{+7.2}_{-6.8}$	$7.17^{+0.74}_{-0.65}$	$1.29^{+0.44}_{-0.39}$	$0.121^{+0.102}_{-0.072}$
	Exp. peak. bkg	$0.281^{+0.056}_{-0.049}$	$0.279^{+0.056}_{-0.049}$	$0.280^{+0.056}_{-0.049}$	$0.280^{+0.058}_{-0.050}$
	Exp. sig.	$0.0241^{+0.0086}_{-0.0087}$	$0.0135^{+0.0048}_{-0.0037}$	$0.0169^{+0.0042}_{-0.0031}$	$0.0167^{+0.0050}_{-0.0037}$
	Cross-Pollution	$0.0071^{+0.0027}_{-0.0026}$	$0.0039^{+0.0015}_{-0.0011}$	$0.00496^{+0.00134}_{-0.00099}$	$0.0049^{+0.0016}_{-0.0012}$
	Obs.	556	4	2	1
5252 – 5272	Exp. comb. bkg	$595.9^{+7.0}_{-6.5}$	$7.10^{+0.71}_{-0.63}$	$1.26^{+0.42}_{-0.37}$	$0.119^{+0.097}_{-0.072}$
	Exp. peak. bkg	$0.323^{+0.075}_{-0.061}$	$0.326^{+0.074}_{-0.061}$	$0.324^{+0.072}_{-0.060}$	$0.325^{+0.075}_{-0.062}$
	Exp. sig.	$0.045^{+0.016}_{-0.016}$	$0.0252^{+0.0088}_{-0.0067}$	$0.0317^{+0.0077}_{-0.0057}$	$0.0313^{+0.0093}_{-0.0068}$
	Cross-Pollution	$0.0097^{+0.0036}_{-0.0035}$	$0.0054^{+0.0021}_{-0.0015}$	$0.0068^{+0.0018}_{-0.0013}$	$0.0067^{+0.0021}_{-0.0016}$
	Obs.	588	11	1	0
5272 – 5292	Exp. comb. bkg	$586.9^{+6.7}_{-6.3}$	$7.04^{+0.68}_{-0.60}$	$1.23^{+0.41}_{-0.36}$	$0.117^{+0.092}_{-0.071}$
	Exp. peak. bkg	$0.252^{+0.058}_{-0.047}$	$0.252^{+0.056}_{-0.046}$	$0.253^{+0.059}_{-0.048}$	$0.250^{+0.056}_{-0.046}$
	Exp. sig.	$0.045^{+0.016}_{-0.016}$	$0.0251^{+0.0089}_{-0.0067}$	$0.0317^{+0.0077}_{-0.0057}$	$0.0313^{+0.0092}_{-0.0069}$
	Cross-Pollution	$0.0154^{+0.0058}_{-0.0055}$	$0.0086^{+0.0033}_{-0.0024}$	$0.0108^{+0.0029}_{-0.0021}$	$0.0106^{+0.0033}_{-0.0025}$
	Obs.	616	5	2	1
5292 – 5312	Exp. comb. bkg	$578.1^{+6.5}_{-6.1}$	$6.98^{+0.66}_{-0.58}$	$1.20^{+0.39}_{-0.35}$	$0.114^{+0.087}_{-0.067}$
	Exp. peak. bkg	$0.124^{+0.023}_{-0.021}$	$0.124^{+0.023}_{-0.021}$	$0.123^{+0.023}_{-0.021}$	$0.124^{+0.023}_{-0.021}$
	Exp. sig.	$0.0241^{+0.0086}_{-0.0087}$	$0.0134^{+0.0048}_{-0.0036}$	$0.0169^{+0.0042}_{-0.0030}$	$0.0167^{+0.0050}_{-0.0037}$
	Cross-Pollution	$0.038^{+0.015}_{-0.014}$	$0.0214^{+0.0086}_{-0.0061}$	$0.0270^{+0.0080}_{-0.0056}$	$0.0266^{+0.0089}_{-0.0064}$
	Obs.	549	7	0	0
5312 – 5332	Exp. comb. bkg	$569.3^{+6.3}_{-5.9}$	$6.92^{+0.63}_{-0.57}$	$1.18^{+0.38}_{-0.34}$	$0.111^{+0.083}_{-0.064}$
	Exp. peak. bkg	$0.047^{+0.023}_{-0.012}$	$0.047^{+0.022}_{-0.012}$	$0.047^{+0.021}_{-0.012}$	$0.047^{+0.021}_{-0.012}$
	Exp. sig.	$0.0068^{+0.0028}_{-0.0026}$	$0.0038^{+0.0015}_{-0.0011}$	$0.0048^{+0.0014}_{-0.0010}$	$0.0048^{+0.0016}_{-0.0012}$
	Cross-Pollution	$0.149^{+0.055}_{-0.054}$	$0.083^{+0.031}_{-0.022}$	$0.104^{+0.027}_{-0.019}$	$0.103^{+0.031}_{-0.023}$
	Obs.	509	10	1	1