Bottom quark charge identification using muons in jets

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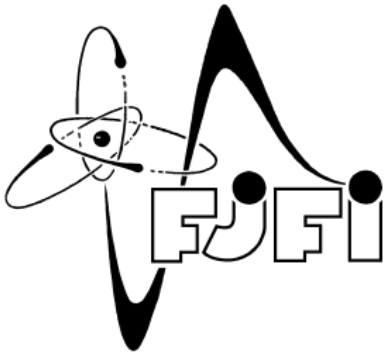

1. CP Violation
   - CP Violation in $B_s \to J/\psi\phi$
   - Flavour Tagging
2. $B^{\pm} \to J/\psi K^{\pm}$ Tagging
   - $B^{\pm}$ Mass Fit
   - Tagging Variables
3. Single Muon Tagging
4. Cone Charge Tagging
5. B^{+} Tag Probability

CP Violation

- Discrete symmetries: Parity, Charge conjugation, Time reversal
- Parity violated (^{60}Co decay, Wu, 1956)
- CP also violated (K_S^0 and K_L^0)
  - CP violation in decay
  - CP violation in mixing
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  - CP violation in interference of mixing and decay
- CKM triangle with angle

$$\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

  - sensitive to CP violation
- Weak phase (PDG value)

$$\phi_s = -2\beta_s = -0.0363^{+0.0016}_{-0.0015}$$

CP Violation in $B_s \to J/\psi\phi$

- Differential decay rate with combination of time-dependent and angular terms

$$\frac{\mathrm{d}^4\Gamma}{\mathrm{d}t\mathrm{d}\Omega} = \sum_{k=1}^{10} \mathcal{O}^k(t) g^k(\theta_T, \psi_T, \phi_T)$$

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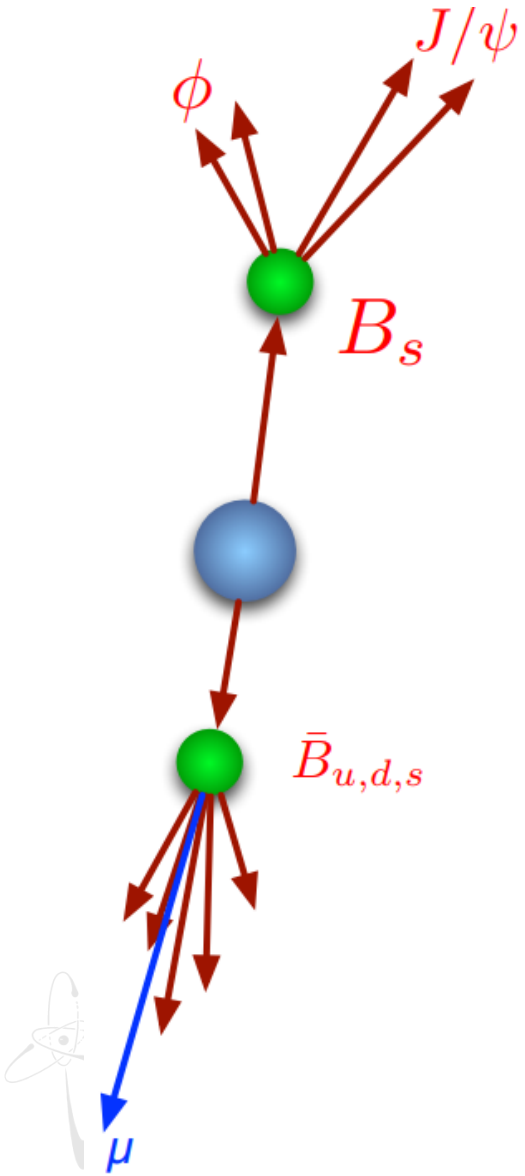
Flavour Tagging



Flavour Tagging

- Opposite side tagging
  - b quarks produced in $b\bar{b}$ pair
  - the initial state of the B_s^0 determined by the flavour tagging
  - $b \to \mu$ (b flavour given by the muon charge)
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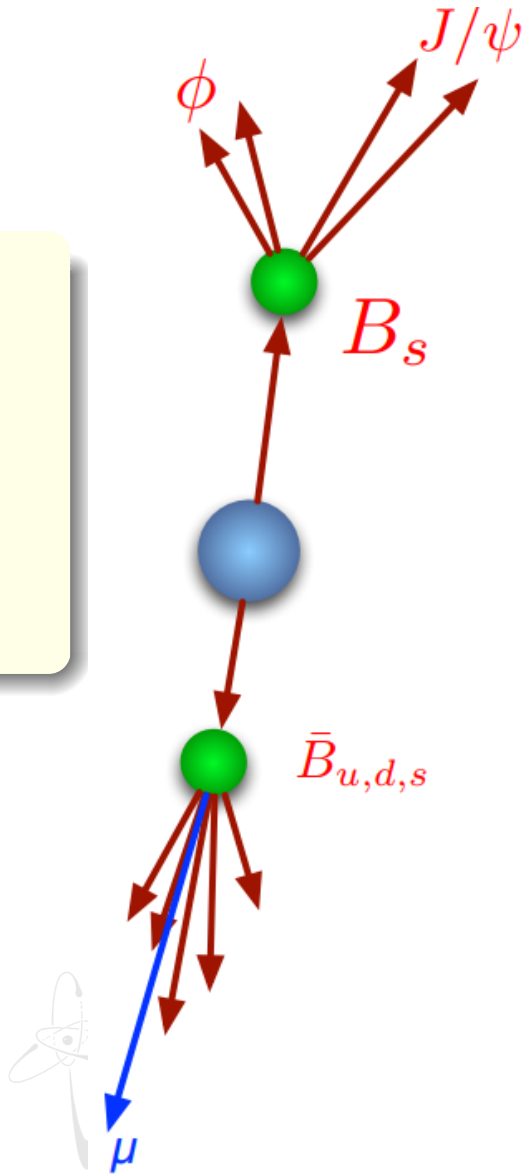

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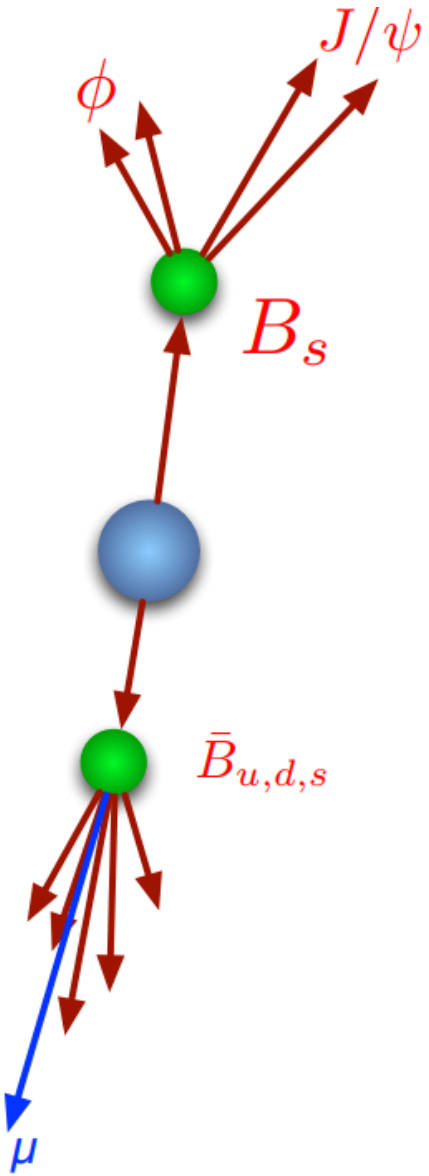
- Calibration channel $B^{\pm} \to J/\psi K^{\pm}$
  - Charge of B meson is provided by the kaon charge
  - Give the probability of correct tagging



CP Violation in $B_s \to J/\psi\phi$ with Flavour Tagging

- With flavour tagging, ϕ_s (and δ_s) gains sensitivity in the differential decay rate

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$B^{\pm} \rightarrow J/\psi K^{\pm}$ Tagging - Cuts

- data: main stream 2016 - whole year
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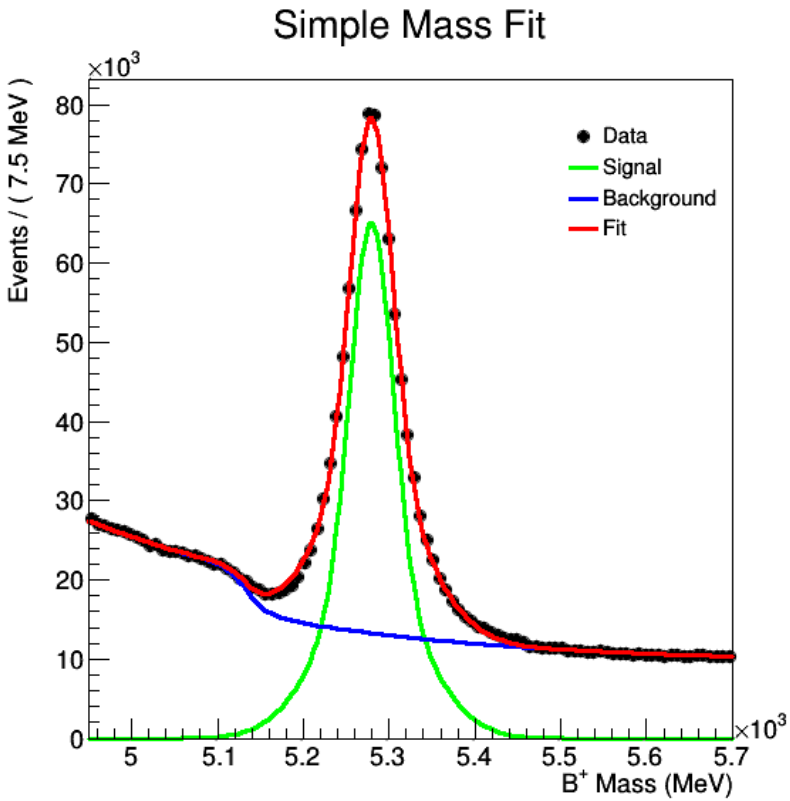
$K^{\pm}$

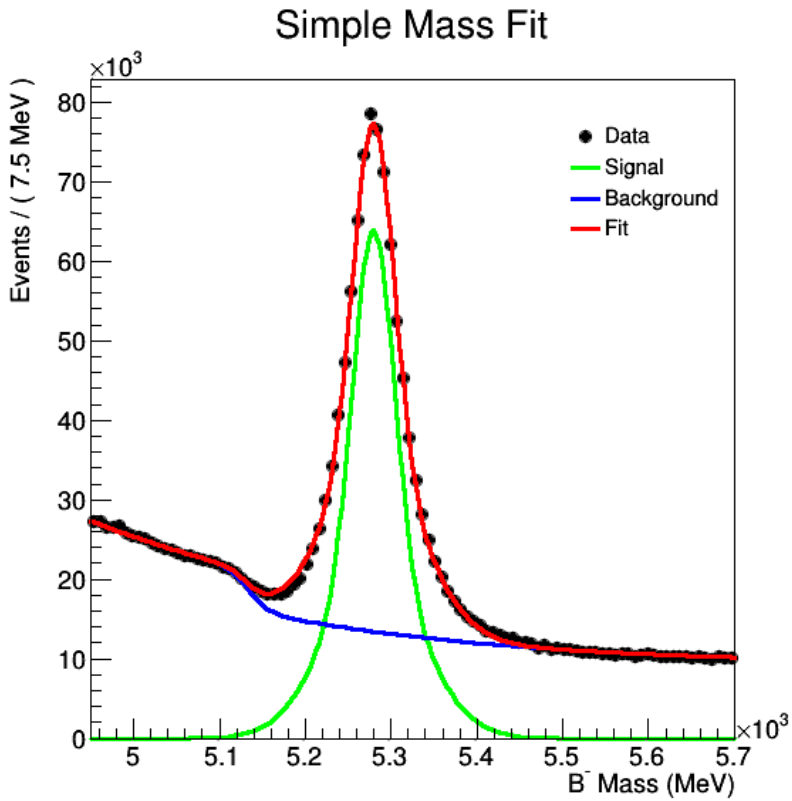
- $p_{\mathrm{T}} > 1$ GeV and $|\eta| < 2.5$

$B^{\pm}$ Mass Fit

Fit Model

$$\begin{aligned}\mathrm{PDF} =& f_{sig}[f_{gauss}G_1(\mu,\sigma_1) + (1-f_{gauss})G_2(\mu,\sigma_2)] + \\ &+ (1-f_{sig})[f_{bck1}E(\lambda) + f_{bck2}C + (1-f_{bck1}-f_{bck2})AT(sc,of)],\end{aligned}$$





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Methods, how to remove background contribution of variable (muon charge) with unknown background and signal distribution

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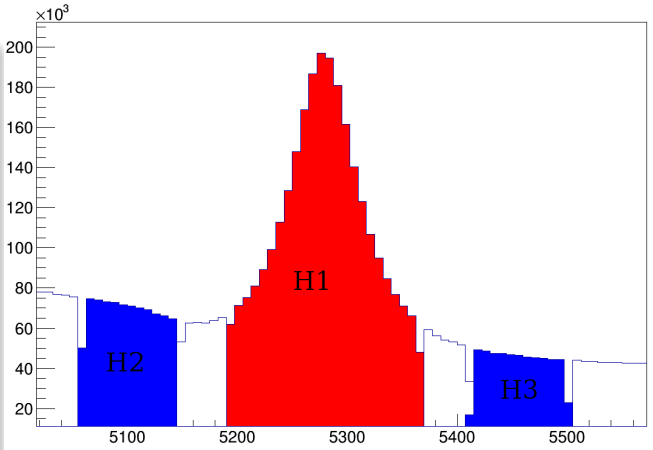

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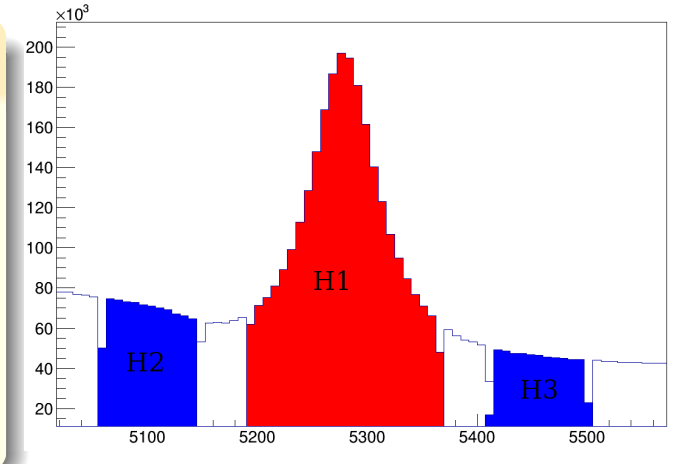

*s*Plot

- Discriminating variables
  - Signal and background distributions known
  - Particular weight (signal or background type) calculated
- Control variables
  - Weights applied on control variables, signal and background distributions obtained

Tagging Variables

- N_r correctly and N_w incorrectly tagged muons, N_B B candidates

Efficiency

- The ratio of the events used for tagging over the total number of events

$$\epsilon_{tag} = \frac{N_r + N_w}{N_B}$$

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Tag power

- Combining the efficiency and dilution

$$P_{tag} = \epsilon D^2 = \sum_i \epsilon_i D_i^2$$

Single Muon Tagging

Different Selection Criteria Order

- $|\Delta z| < 5$ mm applied in order to remove pile-up
- Muons divided into group according their qualities in each event, only best group selected
- Then, the highest p_{T} muon candidate from this group used

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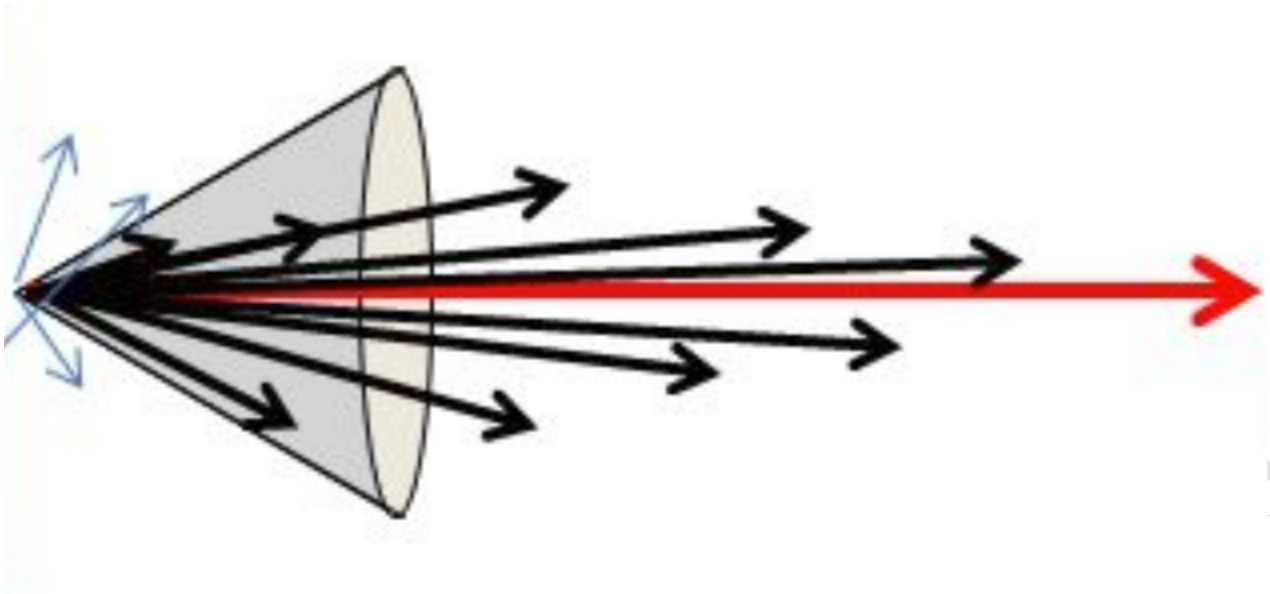
Release 21 with Δz Cut, sPlot Method

	$\epsilon_{\mathbf{tag}}$ (%)	$\mathbf{D_{tag}}$	$\mathbf{w_{tag}}$	$\mathbf{P_{tag}}$ (%)
tight	6.50	0.451	0.275	1.32
medium	2.41	0.253	0.373	0.15
loose	0.98	0.175	0.413	0.03
very loose	17.7	0.062	0.469	0.07

Cone Charge Tagging

Cone Charge

- Cone $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.5$
- Tracks in cone $\Delta R < 0.5$ around B candidate excluded
- Tracks with $|\Delta z| > 3$ mm from B candidate excluded



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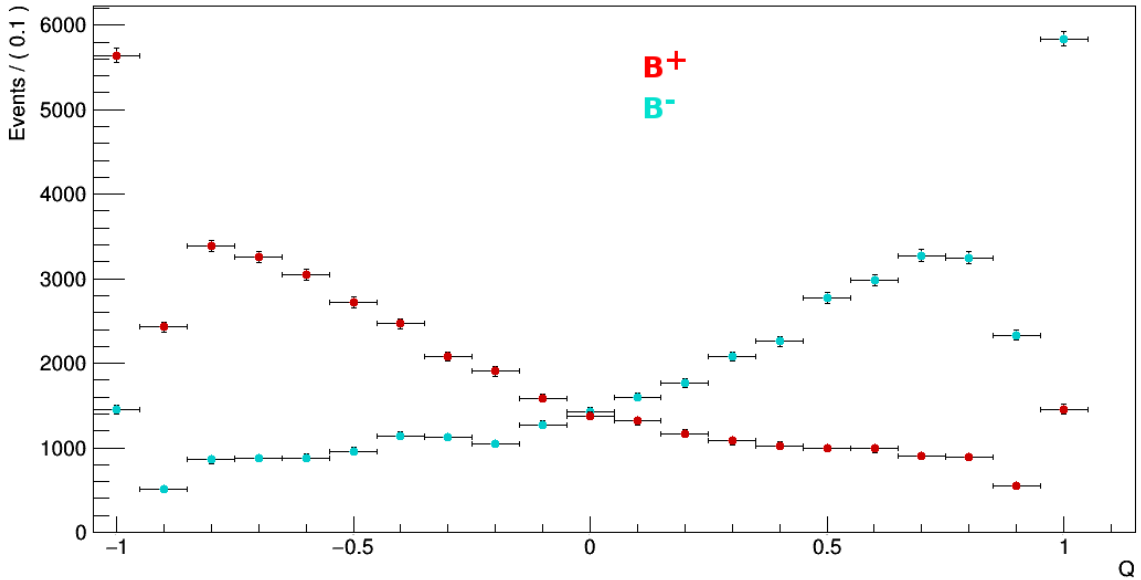
$$Q_\mu = \frac{\sum_i^{Ntracks} q_i \, (p_\mathrm{T})^\kappa}{\sum_i^{Ntracks} (p_\mathrm{T})^\kappa}$$

- $\kappa = 1.1$



Cone Charge Tagging

Tag Power

- All cuts applied
- The tag power is

$$P_{tag} = \sum_i (\epsilon_{tag})_i \left(2P_i(B^+|Q_i) - 1\right)^2,$$

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Tag Power - Result

$$P_{tag} = (1.42 \pm 0.02)\,\%$$

B^+ Tag Probability

$$P(B|Q) = \frac{P(Q|B^+)}{P(Q|B^+) + P(Q|B^-)}$$

- $P(\bar{B}|Q) = 1 - P(B|Q)$
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B^+ Tag Probability

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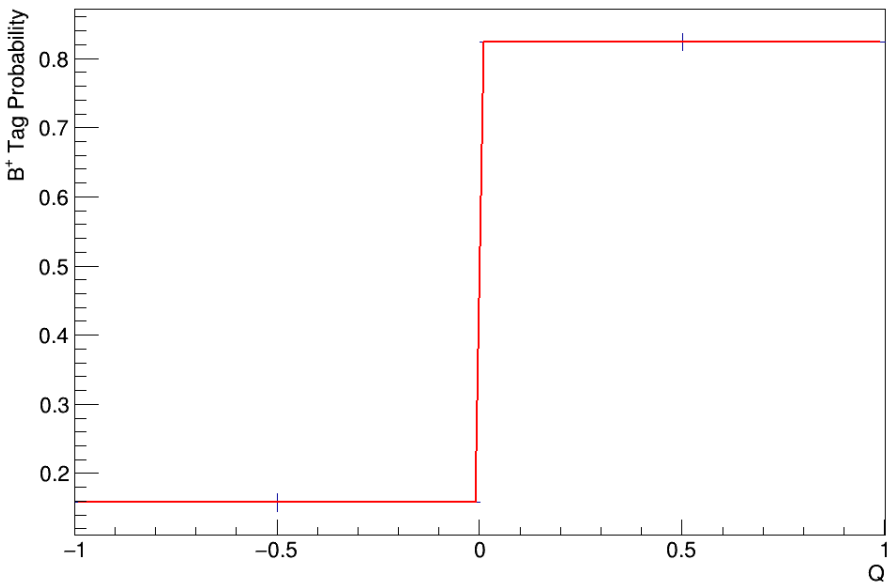
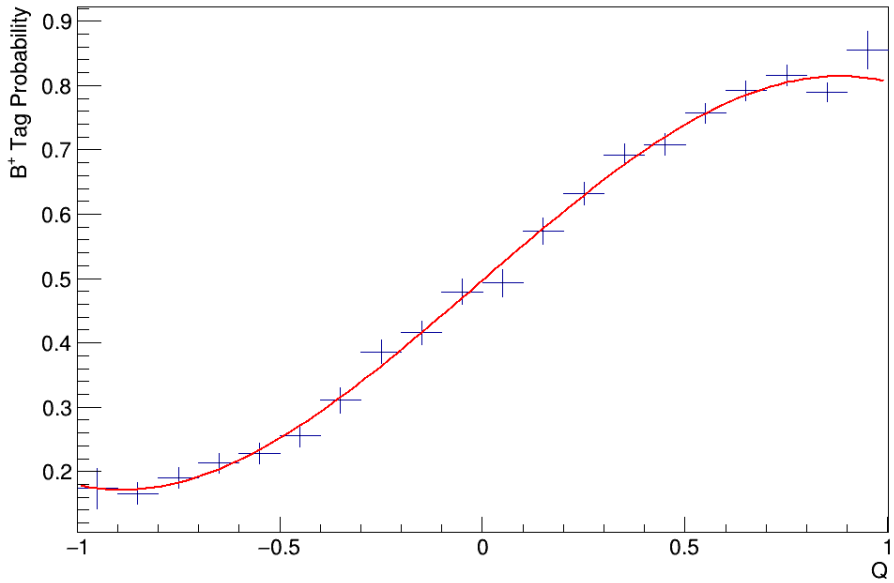
- $P(\bar{B}|Q) = 1 - P(B|Q)$
- Produced separately for muons with tracks in a cone and single muons
- Fit: two constant functions (single muons), 4th order polynomial function (cone charge)





Summary and Plans

Summary

- Tag power for cone charge calculated

$$\mathbf{P_{tag}} = (\mathbf{1.42 \pm 0.02})\,\%$$

- Significantly higher than in Run1: $P_{tag} = (0.92 \pm 0.02)\,\%$
- B^+ tag probability distributions produced and fitted
- B_s^0 cone charge and tag probability distributions produced

Plans

- Fit the B_s^0 cone charge and tag probability distributions
- Produce Punzi terms for the main fit of the differential decay rate

Back-up Slides

$B^{\pm}$ Mass Fit

Fit Model

$$\begin{aligned}\mathrm{PDF} = & f_{sig}[f_{gauss}G_1(\mu,\sigma_1) + (1-f_{gauss})G_2(\mu,\sigma_2)] + \\ & + (1-f_{sig})[f_{bck1}E(\lambda) + f_{bck2}C + (1-f_{bck1}-f_{bck2})AT(sc,of)],\end{aligned}$$

	μ	σ_1	σ_2	λ	sc	of	f_{sig}	f_{gauss}	f_{bck1}	f_{bck2}
value	5279.38	24.5	58.8	-0.00360	-0.042	5133.9	0.331	0.506	0.282	0.627
uncertainty	0.06	0.2	0.5	0.00006	0.002	0.79	0.001	0.006	0.006	0.004
value	5279.45	23.9	56.5	-0.00340	-0.043	5133.4	0.325	0.481	0.311	0.605
uncertainty	0.06	0.2	0.5	0.00007	0.003	0.9	0.001	0.006	0.009	0.005

Single Muon Tagging - Different Selection Order

- The left table shows results for order of selection criteria, where higher p_{T} has higher priority than muon quality
- The right table shows results selection criteria, where muon quality has higher priority than higher p_{T}
- Tables are produced using the sPlot

	$\epsilon_{\mathbf{tag}}$ (%)	$\mathbf{D_{tag}}$	$\mathbf{w_{tag}}$	$\mathbf{P_{tag}}$ (%)
tight	3.016	0.392	0.304	0.463
medium	0.158	0.143	0.429	0.003
loose	0.121	0.091	0.455	0.001
very loose	6.017	0.031	0.485	0.006

	$\epsilon_{\mathbf{tag}}$ (%)	$\mathbf{D_{tag}}$	$\mathbf{w_{tag}}$	$\mathbf{P_{tag}}$ (%)
combined	5.270	0.244	0.378	0.313
segmentTag	0.512	0.044	0.478	0.001
caloTag	3.531	0.026	0.487	0.002

	$\epsilon_{\mathbf{tag}}$ (%)	$\mathbf{D_{tag}}$	$\mathbf{w_{tag}}$	$\mathbf{P_{tag}}$ (%)
tight	4.18	0.355	0.323	0.526
medium	0.21	0.114	0.443	0.003
loose	0.17	0.088	0.456	0.001
very loose	7.93	0.028	0.486	0.006

	$\epsilon_{\mathbf{tag}}$ (%)	$\mathbf{D_{tag}}$	$\mathbf{w_{tag}}$	$\mathbf{P_{tag}}$ (%)
combined	7.44	0.219	0.391	0.356
segmentTag	0.75	0.037	0.482	0.001
caloTag	4.30	0.021	0.490	0.002

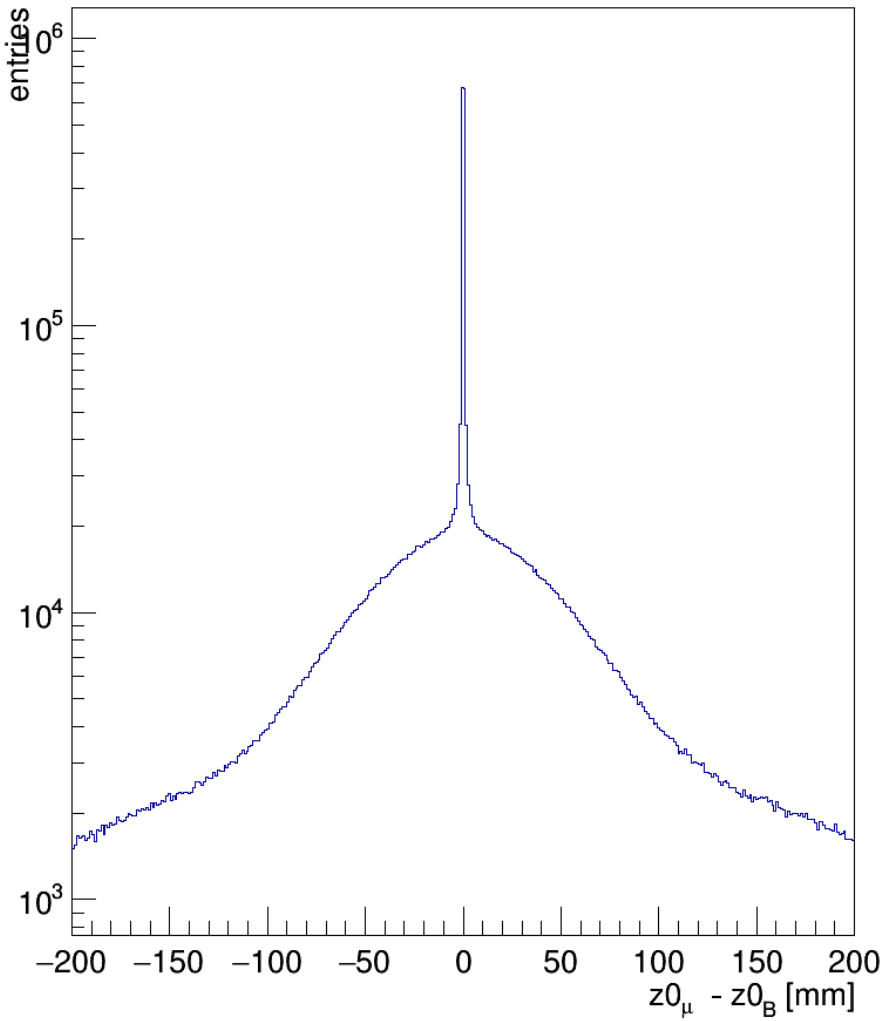
Single Muon Tagging - SB vs sPlot

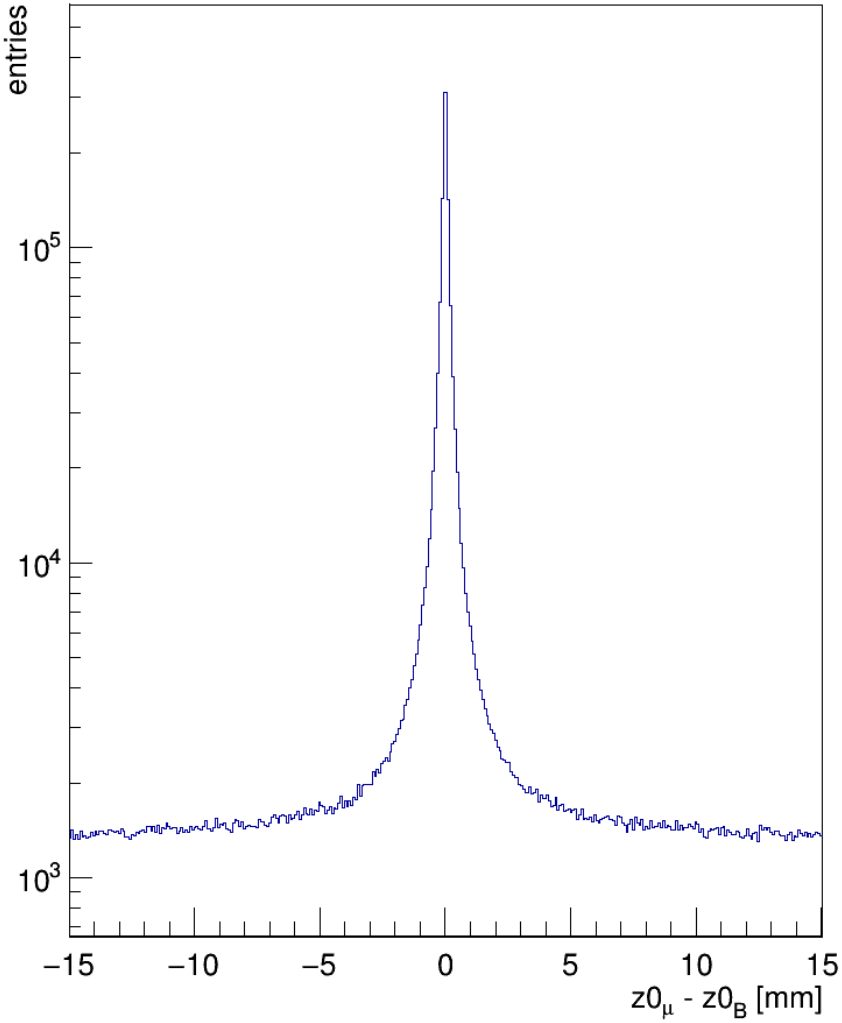
- Left table contains results using the sPlot method
- Right table shows results obtained using the sideband subtraction method

	ϵ_{tag} (%)	D_{tag}	w_{tag}	P_{tag} (%)
combined	7.44	0.219	0.391	0.356
segmentTag	0.75	0.037	0.482	0.001
caloTag	4.30	0.021	0.490	0.002

ϵ_{tag} (%)	D_{tag}	w_{tag}	P_{tag} (%)
7.88	0.215	0.393	0.366
0.80	0.030	0.484	0.001
4.40	0.025	0.488	0.003

Single Muon Tagging - $|\Delta z|$ cut





Single Muon Tagging - Software Releases

- with applied Δz cut, sPlot method
- Left table for release 20.7
- Right table for release 21

	ϵ_{tag} (%)	D_{tag}	w_{tag}	P_{tag} (%)
tight	7.75	0.358	0.32	0.996
medium	0.47	0.122	0.44	0.007
loose	0.35	0.093	0.45	0.003
very loose	12.52	0.044	0.48	0.024

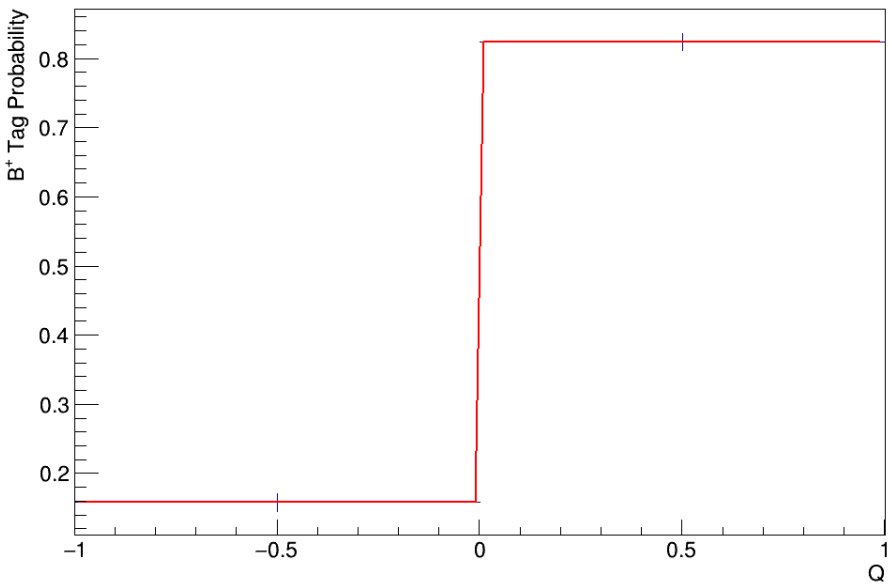
ϵ_{tag} (%)	D_{tag}	w_{tag}	P_{tag} (%)
6.50	0.451	0.275	1.32
2.41	0.253	0.373	0.15
0.98	0.175	0.413	0.03
17.7	0.062	0.469	0.07

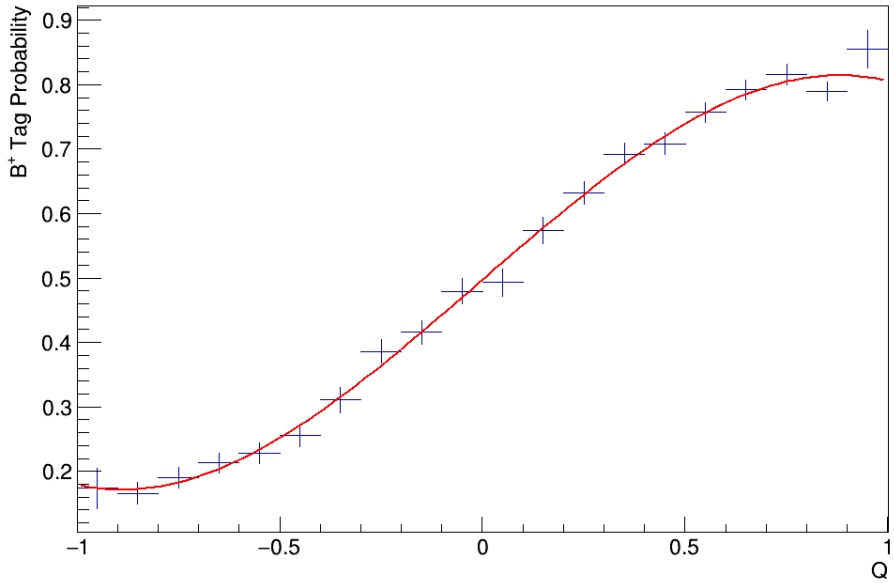
B^+ Tag Probability

- Fit: two constant functions (single muons), 4th order polynomial function (cone charge)

	c_1	c_2
value	0.18	0.82
uncertainty	0.03	0.03

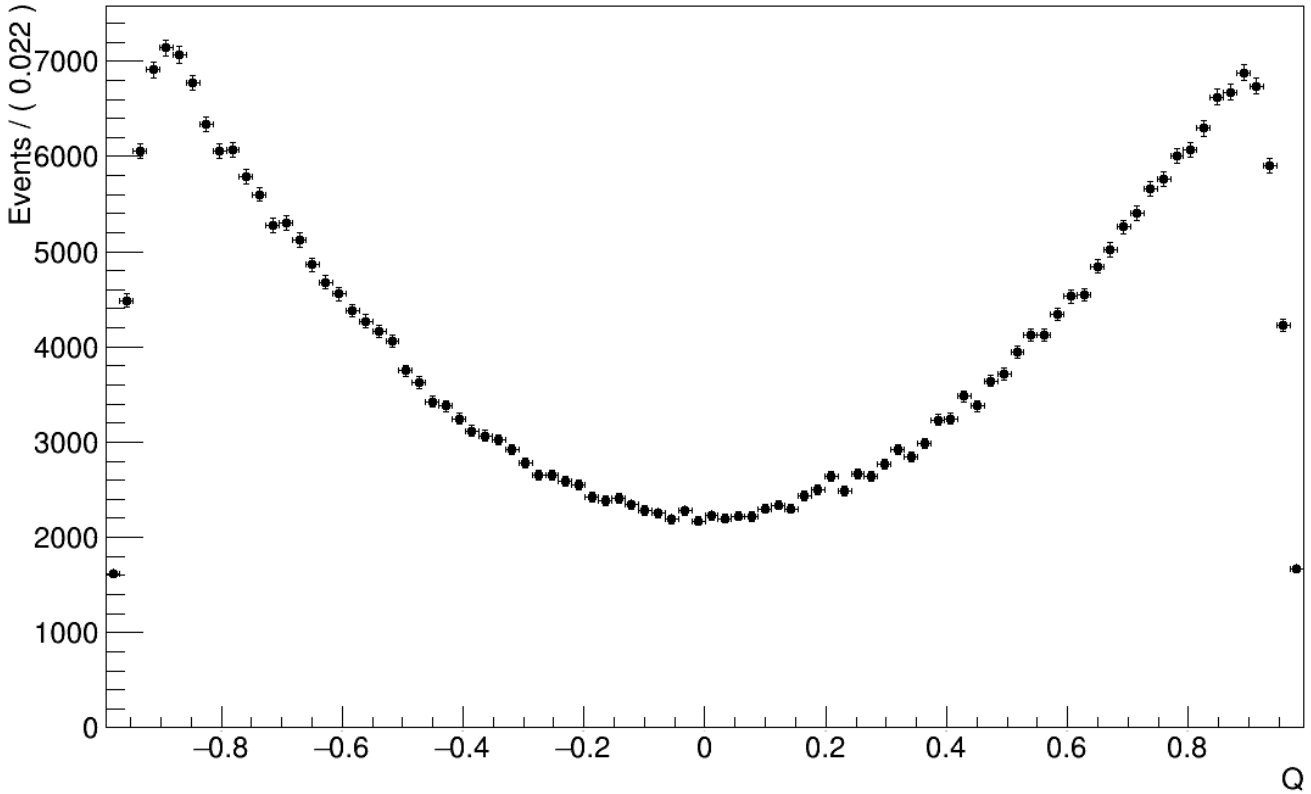
p_0	p_1	p_2	p_3	p_4
0.4970	0.520	-0.02	-0.221	0.02
0.0005	0.006	0.01	0.008	0.01





B_S^0 Tag Value (Cone Charge)

- peaks with cone charge $Q = \pm 1$ were removed, they will by applied in the B_s^0 main fit in different way



B_s^0 Tag Probability)

- High number of B_s^0 candidates with high and low tagging probability (approximately 0.8 and 0.2) will has assistant role during the main fit of the diferential decay rate, because the untagged B_s^0 candidates has default tag probability 0.5 and it is unknown, whether it is B_s^0 or $\bar{B}_s^0$