$B_s \to D_s K\pi\pi$: BR measurement and γ determination

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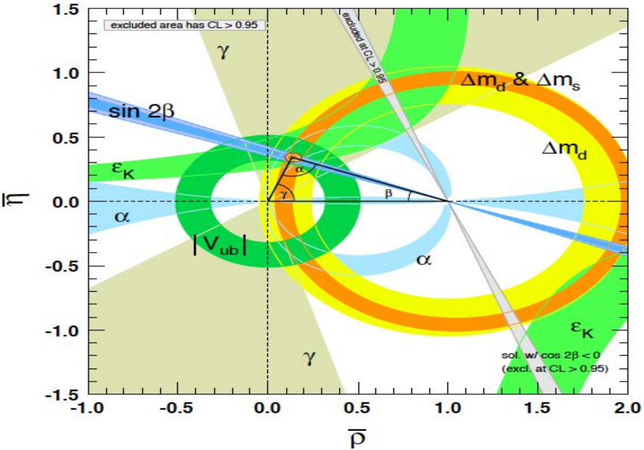
Theory



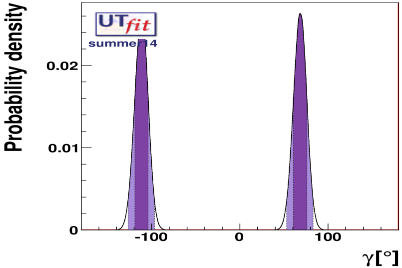
$$\gamma \equiv arg[-(V_{ud}V_{ub}^*)/(V_{cd}V_{cb}^*)]$$

γ can be studied using the interference between $b \to u$ and $b \to c$ transitions at tree level

Why bother?

γ is the least well measured phase of the CKM triangle. Following results are obtained by averaging over several decay modes:

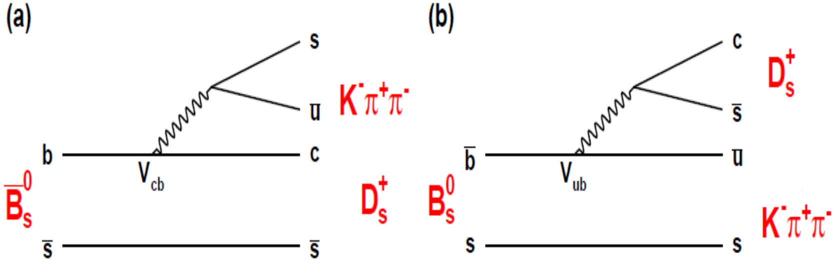
- LHCb: $\gamma = 73^{+9}_{-10}$
- BaBar: $\gamma = 73^{+17}_{-16}$
- Belle: $\gamma = 68^{+15}_{-14}$



Precision of global fit $\approx 7\%$ v.s. the theory uncertainty of $<< 1\%$

$\rightarrow$ many unexplored channels left to improve the overall precision!

And why this channel?



interference between a) and b) with same final state via mixing

complimentary to γ determination in $B_s \to D_s K$

technically interesting application of time dependent amplitude analysis

What has been done

First observation and BR mesurement done with 1 fb^{-1} and $N_{D_s K\pi\pi} = 216 \pm 22$ in 2012 (LHCb-ANA-2012-076):

$$\frac{\mathcal{B}(B_s \to D_s K\pi\pi)}{\mathcal{B}(B_s \to D_s\pi\pi\pi)} = (5.2 \pm 0.5 \pm 0.3) \cdot 10^{-2}$$

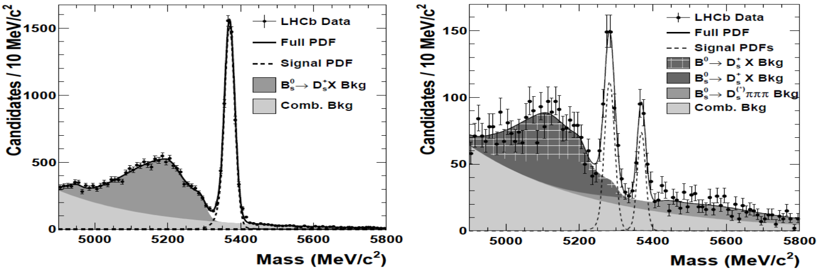


Figure: left: $D_s\pi\pi\pi$, right: $D_s K\pi\pi$

Our plan

We like to:

- redo the BR measurement with $3fb^{-1}$ using $B_s \to D_s\pi\pi\pi$ as normalization channel
- do a full time dependent daliz plot analysis to get strong phase difference and amplitude ratio across phase space to measure γ

The analysis follows principle of γ measurement in $B_s \to D_s K$, but with additional pion pair the dalitz analysis is necessary

Stripping

We produced Data and MC ntuples for 2011 and 2012:

Year	Channel	Stripping
2011	$D_s K\pi\pi$	B02DKPiPiD2HHHPIDBeauty2Charm, S21
2012	$D_s K\pi\pi$	B02DKPiPiD2HHHPIDBeauty2Charm, S21
2011	$D_s\pi\pi\pi$	B02DPiPiPiD2HHHPIDBeauty2Charm, S21
2012	$D_s\pi\pi\pi$	B02DPiPiPiD2HHHPIDBeauty2Charm, S21

Additionally, we produced $B_s \to D_s^* X$ MC samples to constrain peaking background (see later)

The plan is to use all possible final states, with $D_s \to KK\pi, K\pi\pi, \pi\pi\pi$

We expect O(1k) signal events

Stripping Selection

Stripping and (pre-)selection cuts include:

- all tracks: $p > 1\ GeV$, $p_t > 100\ MeV$, $track\chi^2/ndof < 3$ and $IP\chi^2 > 4$
- D_s daughter: $\Sigma p_t > 1.8\ GeV$, max DOCA 0.5mm and $M_{KK\pi}$ within 100 MeV of M_{D_s}
- D_s: $Vertex\chi^2/ndof < 10$ and min $FD\chi^2 > 36$
- B_s: $DIRA > 0.99$, min $IP\chi^2 > 20$, $FD\chi^2 > 100$ and vertex fit $\chi^2/ndof < 8$
- loose PID requirements on the final state kaons ($\Delta LL(K-\pi) > -5$) and pions ($\Delta LL(K-\pi) < 10$)

Physical Background

In addition to the previous cuts, we veto some specific backgrounds such as:

- $B_s \to D_s D_s$:
  $|M(K\pi\pi) - m_{D_s}| > 20\ MeV$
- $B^0 \to D^+(\to K\pi\pi)K\pi\pi$:
  possible with single miss-ID. Vetoed by changing $K^+ \to \pi^+$ mass hypothesis and check $|M(K^+\pi^-\pi^+) - m_{D^+}| > 20\ MeV$ $||\ \Delta LL(K-\pi) > 10$ for the K^+
- $\Lambda_b^0 \to \Lambda_c^+(\to Kp\pi)K\pi\pi$:
  possible with single miss-ID. Vetoed by assigning $K^+ \to p$ and check $|M(pK^-\pi^+) - m_{\Lambda_c^+}| > 15\ MeV$ $||\ \Delta LL(K-p) > 0$ for the K^+

TMVA

We take the upper mass sideband of B_s data candidates as background and MC signal events

Variables used for BDTG training, with $X_s = (K\pi\pi)$:

- $log(min(IP\chi^2))$ and $log(max(IP\chi^2))$ of D_s daughters
- $log(min(IP\chi^2))$ and $log(max(IP\chi^2))$ of X_s daughters
- $log((IP\chi^2))$ of X_s
- $log((IP\chi^2))$ of B_s
- FD significance of B_s and D_s
- $log(min(p_t))$ of D_s and X_s daughters
- B_s vertex fit χ^2
- $max(track\chi^2)$
- Cone p_t asymmetry of all tracks
- max(track-ghostProb)

BDTG output

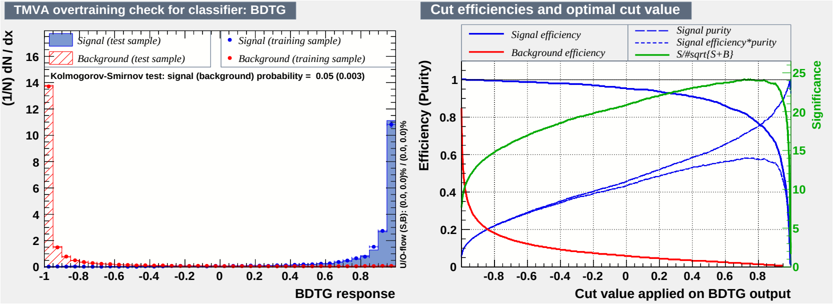


Figure: left: BDTG response, right: BDTG efficiency curves

We optimize our response cut using a massfit in the $B_s \to D_s\pi\pi\pi$ channel after pre-selection and scale the obtained value for S with the PDG BR and relative efficiency to $B_s \to D_sK\pi\pi$

Background Shape for normalization channel

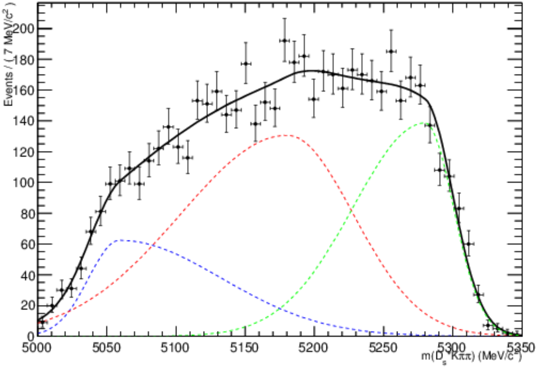


Figure: partially reconstructed $B_s \to D_s^* \pi\pi\pi$

Background Shapes for signal channel

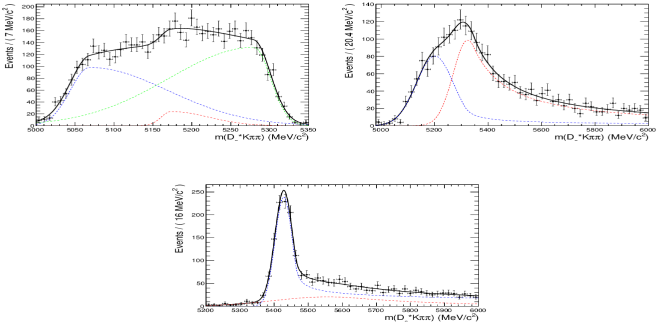


Figure: top left: partially reconstructed $B_s \to D_s^* K\pi\pi$,
top right: $B_s \to D_s^* \pi\pi\pi$ miss-id, bottom: $B_s \to D_s \pi\pi\pi$ miss-id

Dangerous: $B_s \to D_s^{(*)}\pi\pi\pi$ miss-id peaks in signal region $\to$ control contributions using PID calib

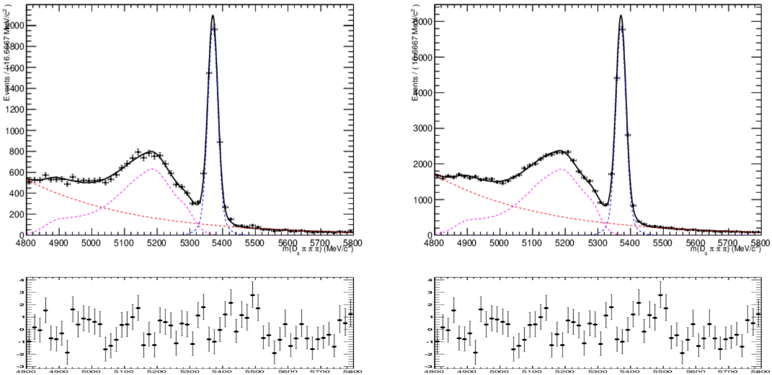


Figure: Invariant mass distribution for $B_s \to D_s\pi\pi\pi$ candidates for (left) 2011 and (right) 2012

Mass fits in signal channel

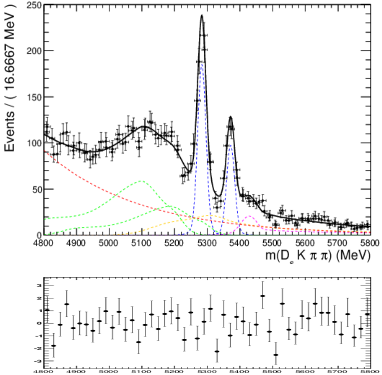


Figure: Invariant mass distribution for $B_s \to D_s K\pi\pi$ candidates for (left) 2011 and (right) 2012

Yields (not final, only $D_s \to KK\pi$)

for the normalization channel we extract:

- 2011: $N_{B_s \to D_s\pi\pi\pi} = 4927 \pm 85$
- 2012: $N_{B_s \to D_s\pi\pi\pi} = 14566 \pm 141$

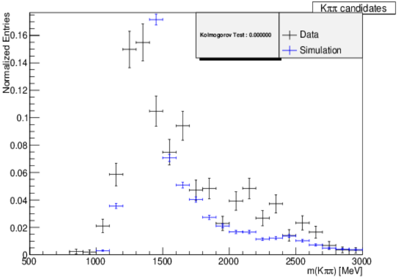
and for the signal channel:

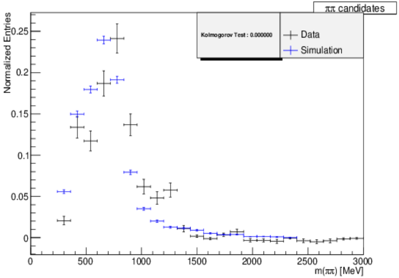
- 2011: $N_{B_s \to D_s K\pi\pi} = 201 \pm 21$
- 2012: $N_{B_s \to D_s K\pi\pi} = 474 \pm 32$

MC-Data comparison 1

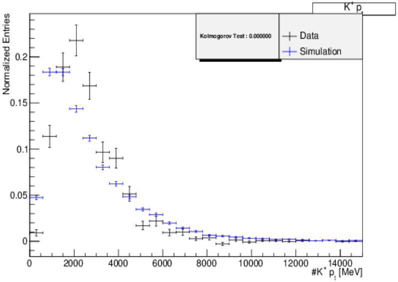
using the shown massfit we can get signal sWeights for data

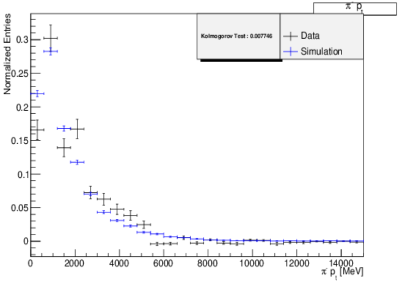
$\rightarrow$ compare distributions of sWeighted data and signal MC



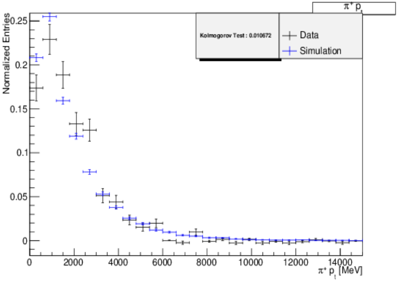


MC-Data comparison 2

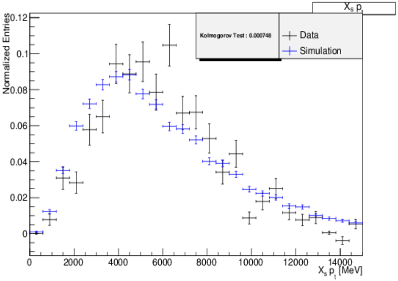


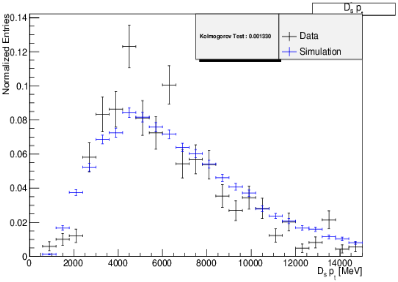


MC-Data comparison 3

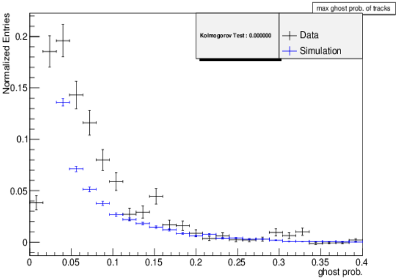


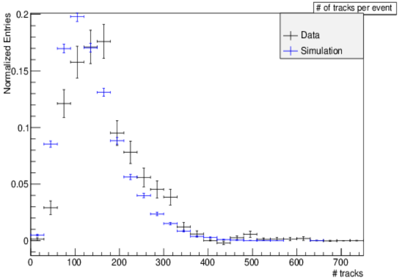
MC-Data comparison 4





MC-Data comparison 5





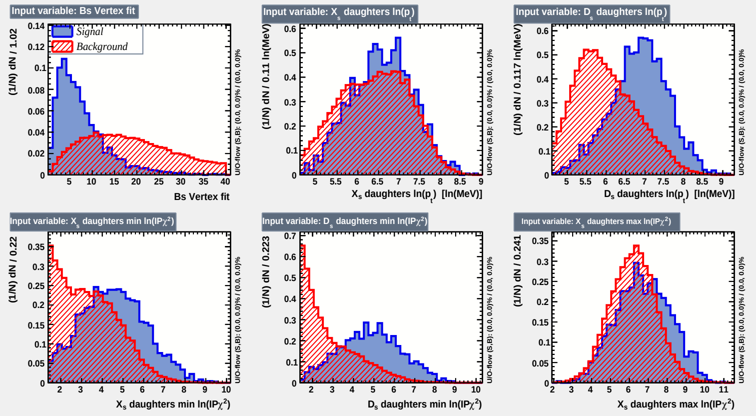
Outlook

Next steps:

- check efficiencies between normalization and signal channel
- make sure the PIDCalib samples are correct (some problems were reported): results crucial to fix yields of physical background which affects signal yield directly
- finalize the BR measurement: could be finished very quick, but depends strongly on my/our hardware occupancy (atm 99% since November Testbeam)
- write ANA Note
- move on to amplitude analysis

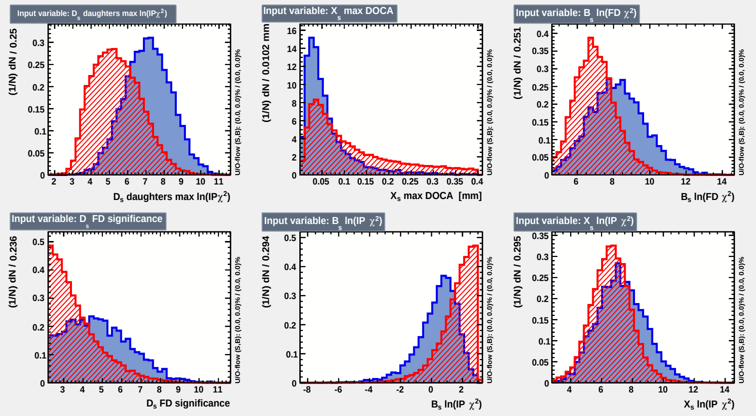
BACKUP

BDT Input 1



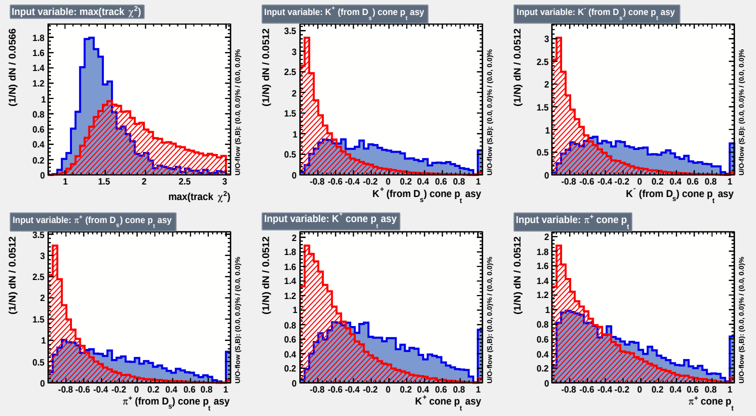
Input variable: Bs Vertex fit
Signal
Background
(1/N) dN / 1.02
Bs Vertex fit
Input variable: X_s daughters ln(p_t)
(1/N) dN / 0.11 ln(MeV)
X_s daughters ln(p_t) [ln(MeV)]
Input variable: D_s daughters ln(p_t)
(1/N) dN / 0.117 ln(MeV)
D_s daughters ln(p_t) [ln(MeV)]
Input variable: X_s daughters min ln(IPχ²)
(1/N) dN / 0.22
X_s daughters min ln(IPχ²)
Input variable: D_s daughters min ln(IPχ²)
(1/N) dN / 0.223
D_s daughters min ln(IPχ²)
Input variable: X_s daughters max ln(IPχ²)
(1/N) dN / 0.241
X_s daughters max ln(IPχ²)
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

BDT Input 2



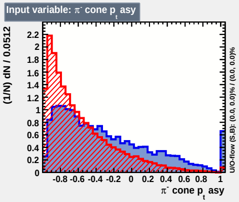
Input variable: D_s daughters max ln(IPχ^2)
(1/N) dN / 0.25
D_s daughters max ln(IPχ^2)
Input variable: X_s max DOCA
(1/N) dN / 0.0102 mm
X_s max DOCA [mm]
Input variable: B_s ln(FD χ^2)
(1/N) dN / 0.251
B_s ln(FD χ^2)
Input variable: D_s FD significance
(1/N) dN / 0.236
D_s FD significance
Input variable: B_s ln(IP χ^2)
(1/N) dN / 0.294
B_s ln(IP χ^2)
Input variable: X_s ln(IP χ^2)
(1/N) dN / 0.295
X_s ln(IP χ^2)
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

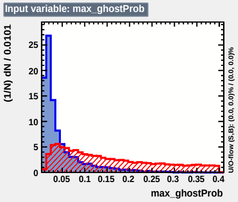
BDT Input 3



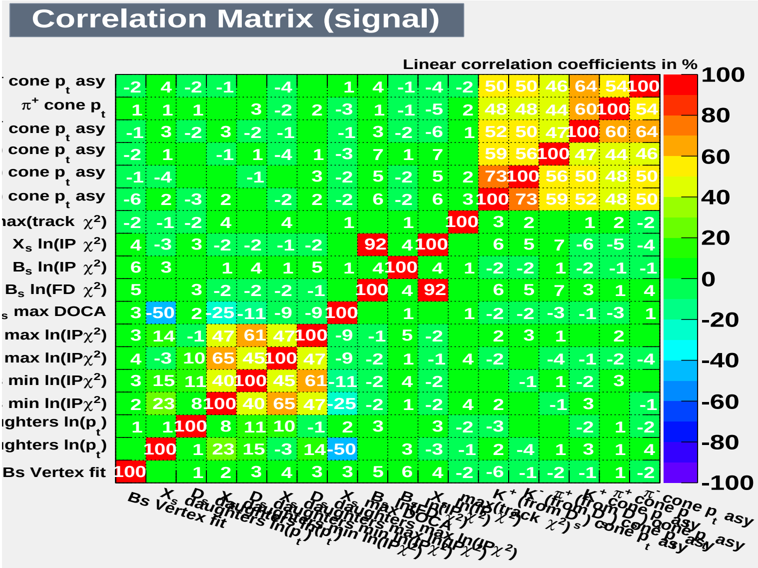
Input variable: max(track χ^2)
(1/N) dN / 0.0566
max(track χ^2)
Input variable: K^+ (from D_s) cone p_t asy
(1/N) dN / 0.0512
K^+ (from D_s) cone p_t asy
Input variable: K^- (from D_s) cone p_t asy
(1/N) dN / 0.0512
K^- (from D_s) cone p_t asy
Input variable: π^+ (from D_s) cone p_t asy
(1/N) dN / 0.0512
π^+ (from D_s) cone p_t asy
Input variable: K^+ cone p_t asy
(1/N) dN / 0.0512
K^+ cone p_t asy
Input variable: π^+ cone p_t
(1/N) dN / 0.0512
π^+ cone p_t
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

BDT Input 4

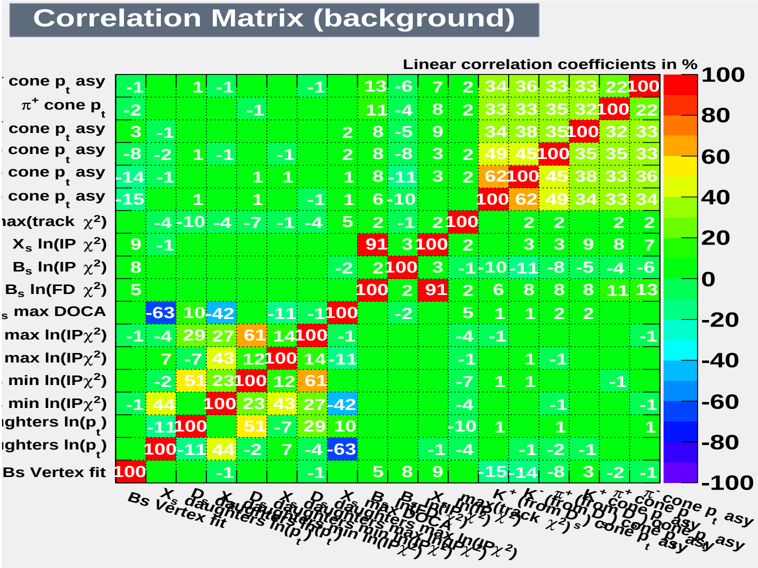

Input variable: π^- cone p_t asy
(1/N) dN / 0.0512
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
π^- cone p_t asy


Input variable: max_ghostProb
(1/N) dN / 0.0101
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
max_ghostProb

BDT Input correlation Signal



BDT Input correlation Background



Time-dependent γ determination

$$\frac{d\Gamma_{B_s\to f}(t)}{dt} = \frac{1}{2}(1+|\lambda_f|^2)e^{-\Gamma_s t}[\cosh(\frac{\Delta\Gamma_s t}{2}) - D_f \sinh(\frac{\Delta\Gamma_s t}{2}) + C_f \cos(\Delta m_s t) - S_f \sin(\Delta m_s t),]$$

with coefficients:

$$D_f = \frac{2r_{D_s K\pi\pi}\cos(\Delta-(\gamma-2\beta_s))}{1+r^2_{D_s K\pi\pi}}, \; C_f = \frac{1-r^2_{D_s K\pi\pi}}{1+r^2_{D_s K\pi\pi}},$$
$$S_f = \frac{2r_{D_s K\pi\pi}\sin(\Delta-(\gamma-2\beta_s))}{1+r^2_{D_s K\pi\pi}},$$

with:

$r_{D_s K\pi\pi} = \frac{A(\overline{B_s}\to D_s^- K^+\pi^-\pi^+)}{A(B_s\to D_s^- K^+\pi^-\pi^+)}$ = ratio of decay amplitudes and

Δ = strong phase difference

both vary over phase space