

Current status of SST + OST combination for B_s -mixing

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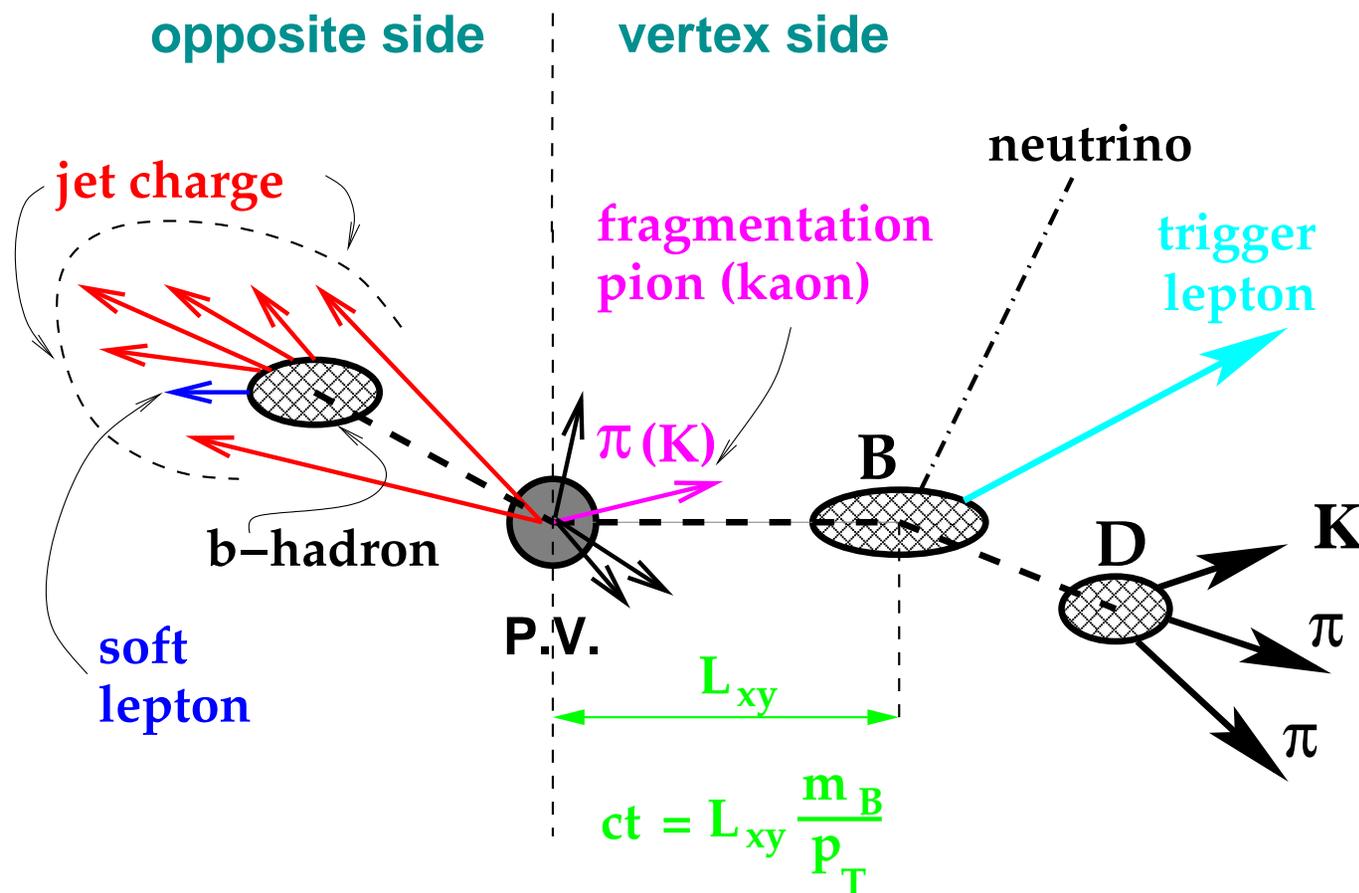
B Meeting



Short introduction

To know initial state flavor of B -meson we can use:

- Same-side tagger
- Opposite-side tagger (jet-charge, soft-lepton)



I am going to talk first about **SST** and then about OST



List of used same-side taggers:

We are using the following SSTs (one-track and many-track taggers):

➔ Min. p_t^{rel}

➔ Max. p_L^{rel}

➔ Max. p_t

➔ Min. $|\Delta\vec{P}| \equiv |\vec{p}(B_s) - \vec{p}(K)|$

➔ **Best: Min. ΔR**

➔ Max. $\cos \alpha$

➔ Min. $\cos \theta^*$

➔ Max. $\cos \theta^*$

➔ Min. $m(B_s K)$

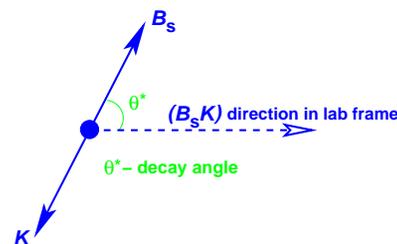
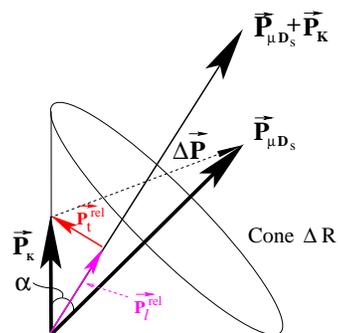
➔ Random track

➔ $Q_{jet}(p_t, \kappa) = \frac{\sum q \cdot p_t^\kappa}{\sum p_t^\kappa}$

➔ $Q_{jet}(p_t^{rel}, \kappa) = \frac{\sum q \cdot (p_t^{rel})^\kappa}{\sum (p_t^{rel})^\kappa}$

➔ $Q_{jet}(p_L^{rel}, \kappa) = \frac{\sum q \cdot (p_L^{rel})^\kappa}{\sum (p_L^{rel})^\kappa}$

➔ **Best: $Q_{jet}(p_t, \kappa = 0.6)$**

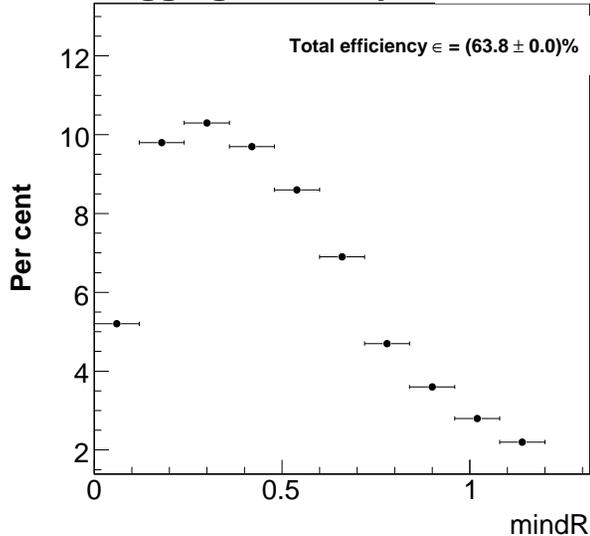


- One-track: p_t^{rel} and p_L^{rel} are \perp and \parallel components of SST candidate's momentum $\vec{p}(K)$ w.r.t $\vec{p}(B_s K)$
- $\Delta R \equiv \sqrt{\Delta\phi^2 + \Delta\eta^2}$ and angle α are taken between $\vec{p}(B_s)$ and $\vec{p}(K)$
- θ^* - decay angle of $B_s K$ -system, *i.e.* angle between directions of $\vec{p}(B_s K)$ and $\vec{p}(B_s)$ in reference frame of $B_s K$ system
- $\kappa = 0.0, 0.1, 0.2, \dots 1.0$
- Q_{jet} : p_t^{rel} and p_L^{rel} are \perp and \parallel components of SST candidate's momentum $\vec{p}(K)$ w.r.t $\vec{p}(B_s)$

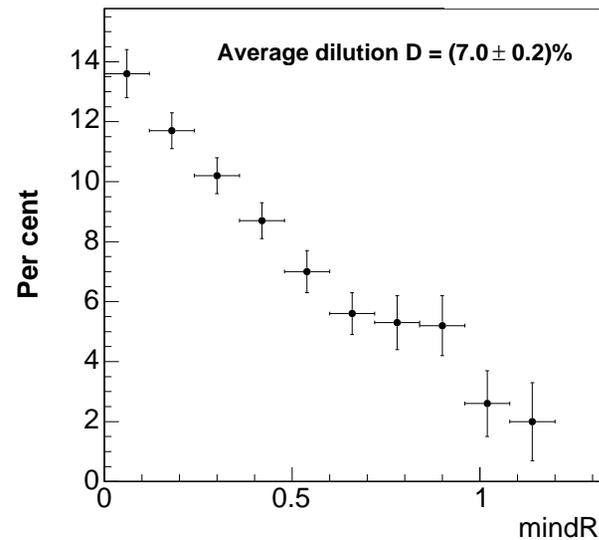


Best one-track tagger: “Min. ΔR ”

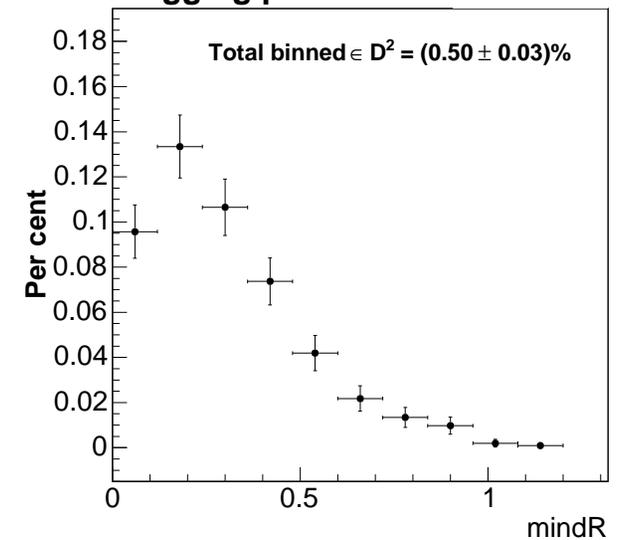
True tagging efficiency ϵ D0 Run II Monte Carlo



True dilution D D0 Run II Monte Carlo



True tagging power ϵD^2 D0 Run II Monte Carlo



Calibration curves for “Min. ΔR ” tagger for Monte Carlo

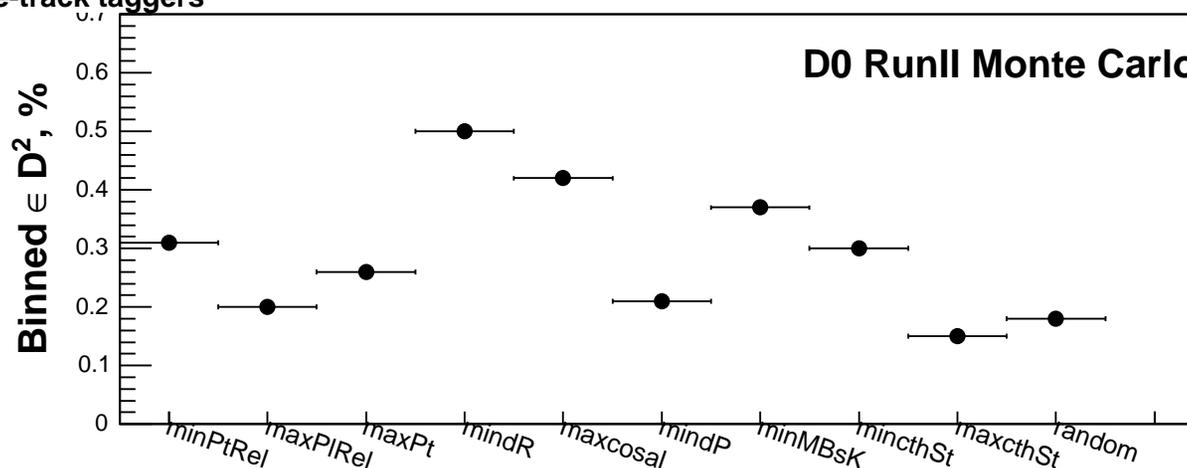
- We calculate “binned” ϵD^2 as a sum of ϵD^2 's in separate bins
- “Binned” ϵD^2 is expected to be higher than direct product of ϵ and D^2 (which we call “unbinned” ϵD^2)
- The difference between them stems from difference between $\langle D^2 \rangle$ and $\langle D \rangle^2$ and may be significant



One-track taggers in MC

Tagger	ϵ , %	D, %	“Unbinned” ϵD^2 , %	“Binned” ϵD^2 , %
Min. p_t^{rel}	74.6 ± 0.2	6.2 ± 0.2	0.29 ± 0.02	0.32 ± 0.02
Max. p_L^{rel}	74.6 ± 0.2	4.7 ± 0.2	0.17 ± 0.02	0.23 ± 0.02
Max. p_t	74.6 ± 0.2	5.1 ± 0.2	0.19 ± 0.02	0.26 ± 0.02
Min. ΔR	74.6 ± 0.2	7.0 ± 0.2	0.36 ± 0.02	0.50 ± 0.03
Max. $\cos \alpha$	74.6 ± 0.2	6.9 ± 0.2	0.36 ± 0.02	0.43 ± 0.03
Min. ΔP	74.6 ± 0.2	4.9 ± 0.2	0.18 ± 0.02	0.21 ± 0.02
Min. $m(B_S K)$	74.6 ± 0.2	6.6 ± 0.2	0.33 ± 0.02	0.38 ± 0.02
Min. $\cos \theta^*$	74.6 ± 0.2	6.1 ± 0.2	0.27 ± 0.02	0.31 ± 0.02
Max. $\cos \theta^*$	74.6 ± 0.2	4.0 ± 0.2	0.12 ± 0.01	0.15 ± 0.01
Random	74.6 ± 0.2	4.6 ± 0.2	0.16 ± 0.02	0.18 ± 0.02

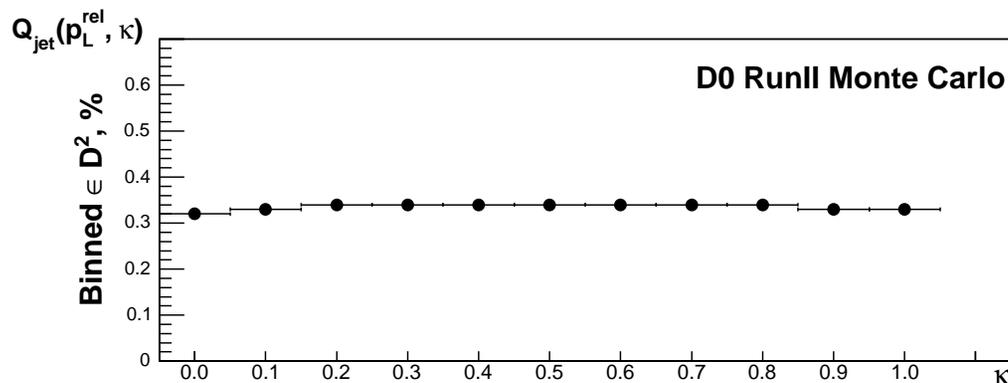
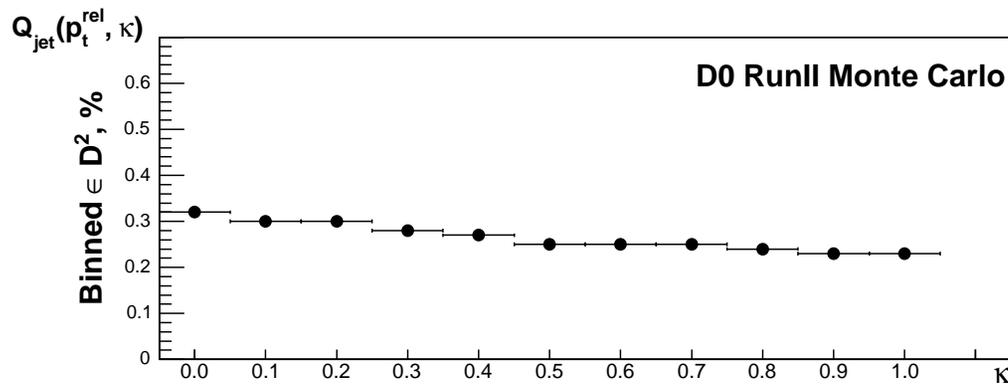
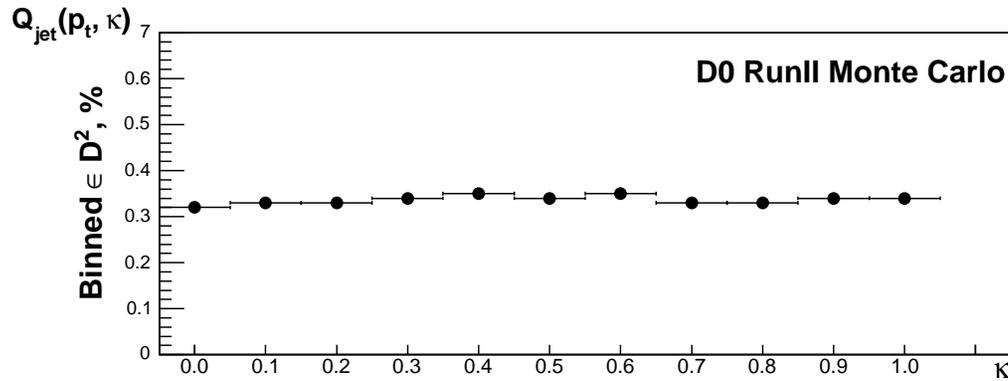
One-track taggers



“Binned” ϵD^2 is greater than “unbinned” one



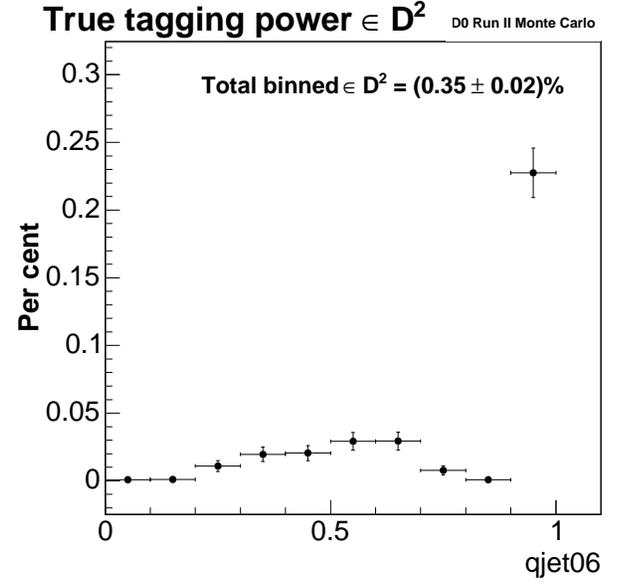
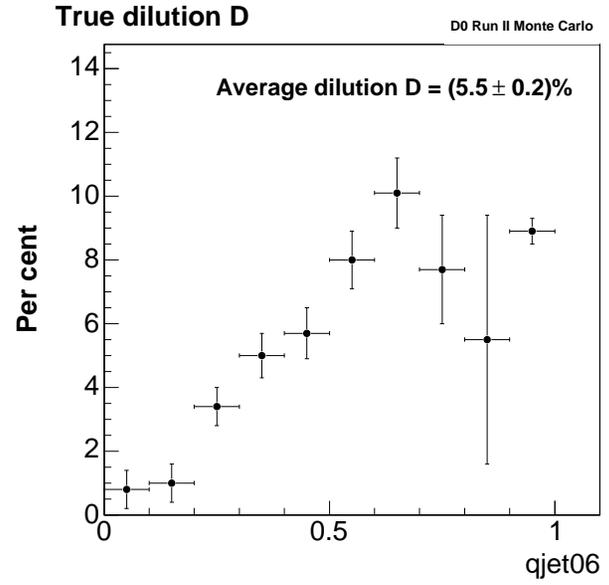
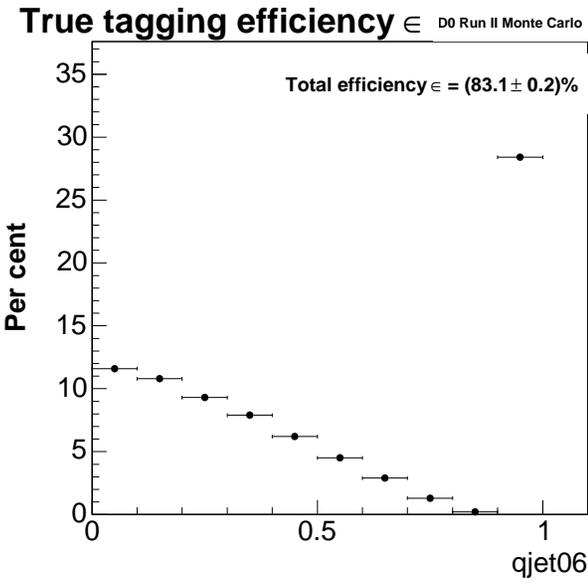
Many-track taggers in MC



- Graphical comparison of “binned” tagging powers $\in D^2$ of many-track taggers weighted with p_t^κ , $(p_t^{rel})^\kappa$, $(p_L^{rel})^\kappa$ in Monte Carlo
- None of them is significantly better than others - choose $Q_{jet}(p_t, \kappa = 0.6)$ following example of OST



Best many-track tagger: “ $Q_{jet}(p_t, \kappa = 0.6)$ ”



Calibration curves for “ $Q_{jet}(p_t, \kappa = 0.6)$ ” tagger for Monte Carlo

Tagger	$\epsilon, \%$	D, %	“Unbinned” $\epsilon D^2, \%$	“Binned” $\epsilon D^2, \%$
$Q_{jet}(\kappa = 0.6)$	83.3 ± 0.2	5.5 ± 0.2	0.25 ± 0.02	0.35 ± 0.02



Combination of same-side *B*-flavor taggers:

Combination algorithm (developed for OST):

- Find uncorrelated discriminating variables x_i
with p.d.f. $f_i^b(x_i)$ and $f_i^{\bar{b}}(x_i)$ being different for b and \bar{b} quarks
- Define tagging variables $y_i = \frac{f_i^b(x_i)}{f_i^{\bar{b}}(x_i)}$; $y_i > 1$ – b -quark, $y_i < 1$ – \bar{b} -quark
- Define combined tagging variable $y = \prod y_i$
- Introduce combined tagging variable $d = \frac{1-y}{1+y}$ for each event
- Infer B -flavor from sign of variable d
- **Determine “unbinned” combined tagging power:**
 - ☞ Multiply efficiency by dilution squared
- **Determine “binned” combined tagging power:**
 - ☞ Bin sample in this variable d
 - ☞ Plot dependence of efficiency and dilution vs. d
 - ☞ Obtain “binned” combined ϵD^2 as a sum of ϵD^2 's in each bin

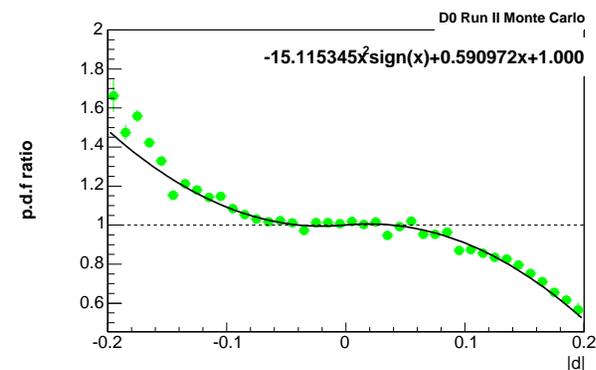
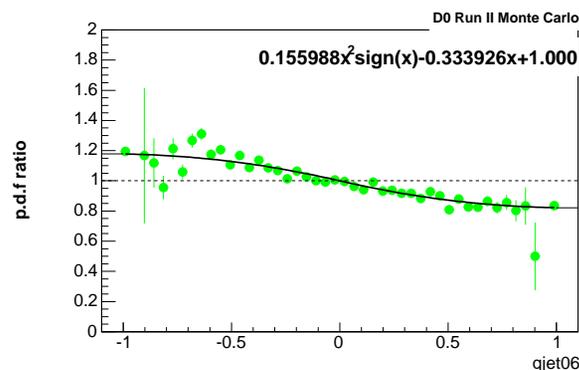
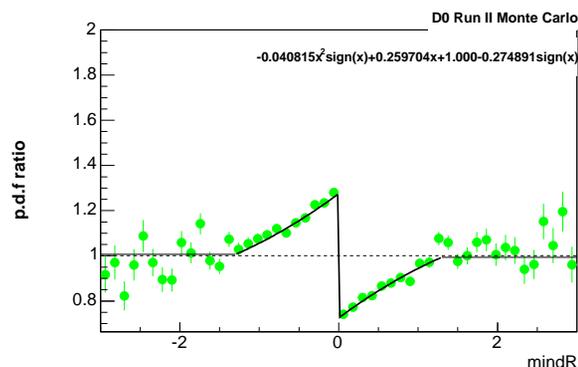
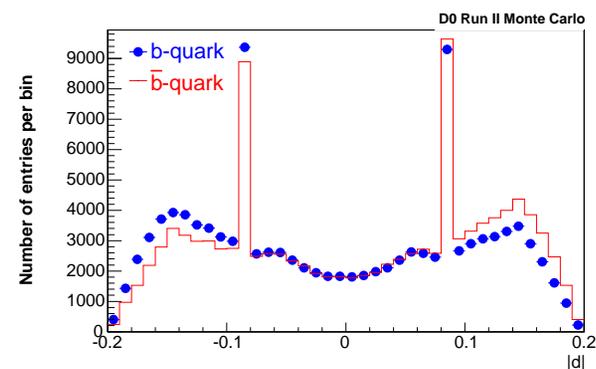
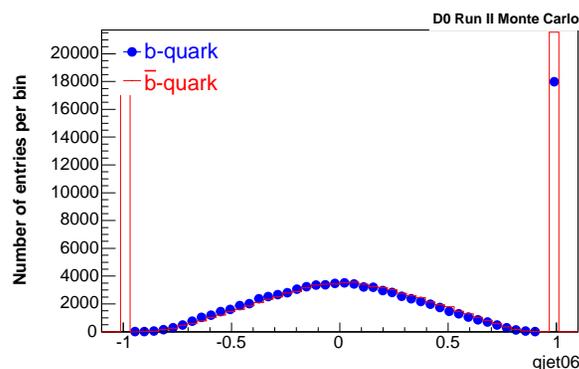
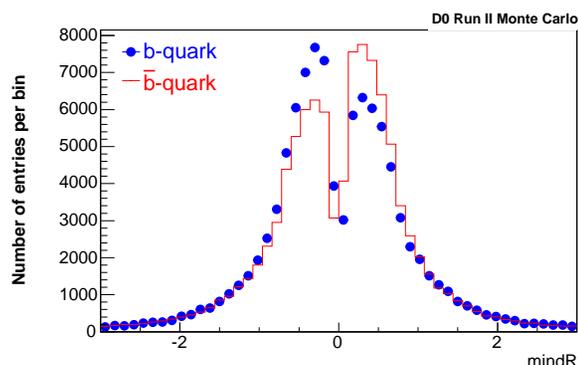


P.d.f.'s for “Min. ΔR ” and “ $Q_{jet}(p_t, \kappa = 0.6)$ ” taggers:

“Min. ΔR ”

“ $Q_{jet}(p_t, \kappa = 0.6)$ ”

“Comb. SST”

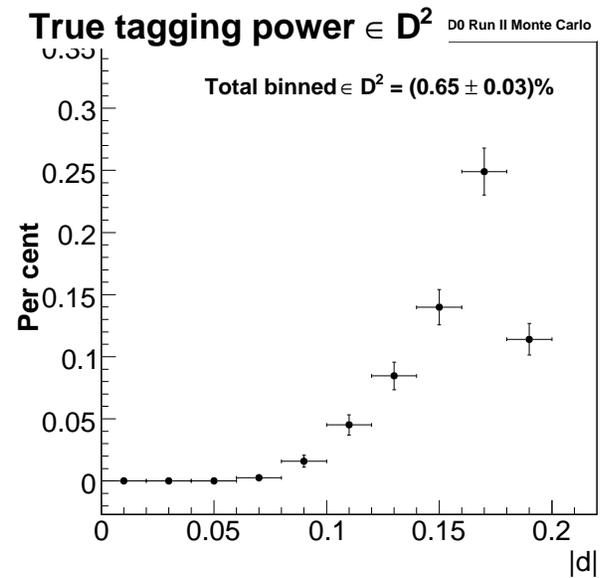
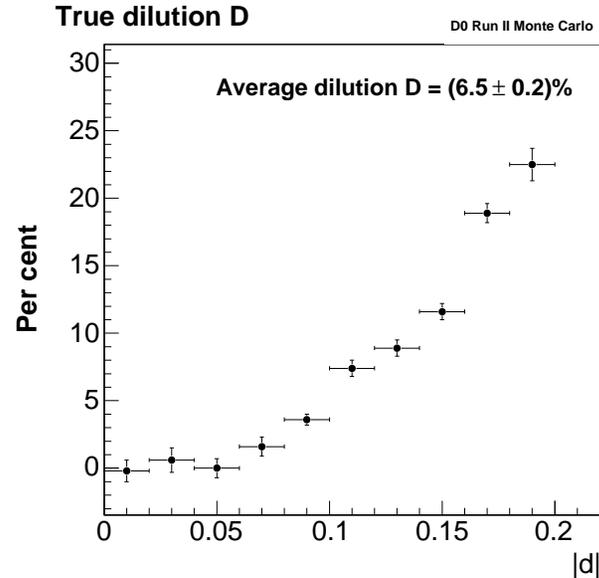
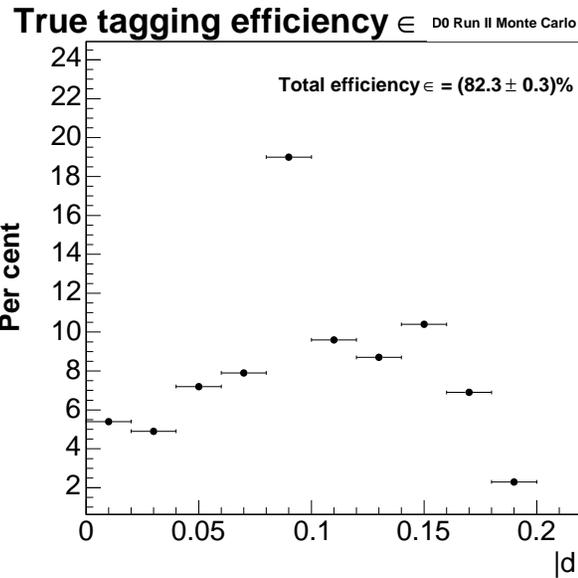


P.d.f. ratio for “Comb. SST” differs from unity more than p.d.f.s of components



Combined SST

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Calibration curves for combined same-side tagger in Monte Carlo

Tagger	$\epsilon, \%$	D, %	"Unbinned" $\epsilon D^2, \%$	"Binned" $\epsilon D^2, \%$
"Min. ΔR "	74.6 ± 0.2	7.0 ± 0.2	0.36 ± 0.02	0.50 ± 0.03
" $Q_{jet}(\kappa = 0.6)$ "	83.3 ± 0.2	5.5 ± 0.2	0.25 ± 0.02	0.35 ± 0.02
"Min. ΔR " + " $Q_{jet}(\kappa = 0.6)$ "	83.3 ± 0.2	6.4 ± 0.2	0.34 ± 0.02	0.65 ± 0.03

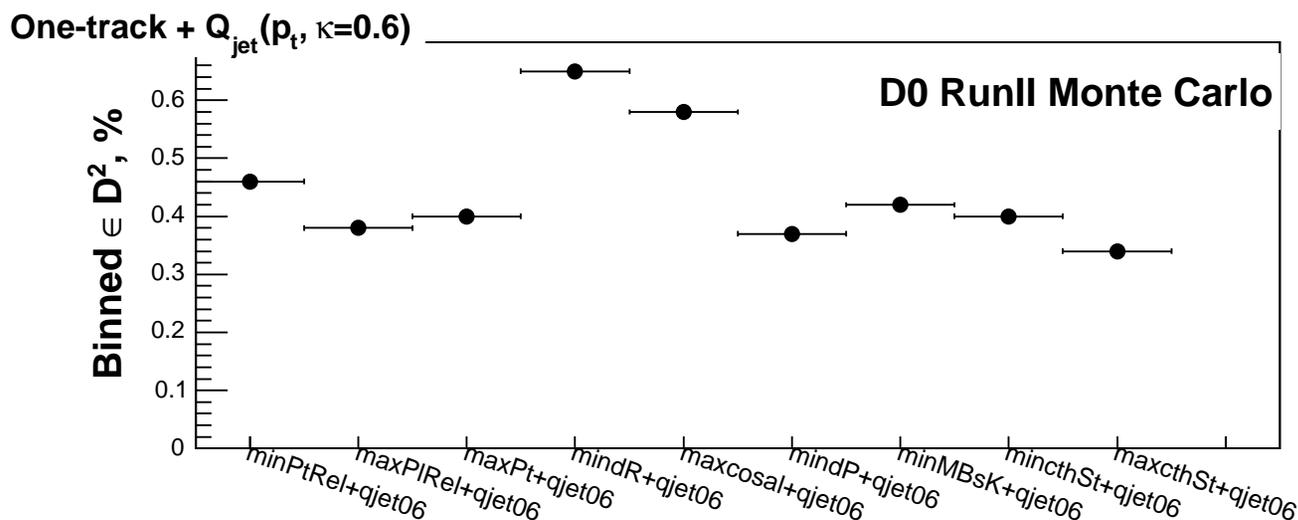
We see increase in "binned" ϵD^2 due to tagger combination



Other one-track SST's

We check if "Min. ΔR " + " $Q_{jet}(\kappa = 0.6)$ " is really the best combination:

Tagger	ϵ , %	D, %	"Unbinned" ϵD^2 , %	"Binned" ϵD^2 , %
Min. $p_t^{rel} + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	5.9 ± 0.2	0.29 ± 0.02	0.46 ± 0.03
Max. $p_L^{rel} + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	4.9 ± 0.2	0.20 ± 0.02	0.38 ± 0.03
Max. $p_t + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	5.0 ± 0.2	0.20 ± 0.02	0.40 ± 0.03
Min. $\Delta R + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	6.4 ± 0.2	0.34 ± 0.02	0.65 ± 0.03
Max. $\cos \alpha + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	6.5 ± 0.2	0.36 ± 0.02	0.58 ± 0.03
Min. $\Delta P + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	4.9 ± 0.2	0.20 ± 0.02	0.37 ± 0.02
Min. $m(B_s K) + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	6.4 ± 0.2	0.34 ± 0.02	0.42 ± 0.03
Min. $\cos \theta^* + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	5.8 ± 0.2	0.28 ± 0.02	0.40 ± 0.02
Max. $\cos \theta^* + Q_{jet}(p_t, \kappa = 0.6)$	83.3 ± 0.2	5.0 ± 0.2	0.21 ± 0.02	0.34 ± 0.02



SST-only part is ready to be published



Opposite-side tagger

- Developed previously (BANA package)
- P.d.f. taken from data
- Mis-represented by most of existing MC samples (factor of 2 lower dilution)
- Best representation: “unbiased” MC sample (similar dilution but factor of 2 lower efficiency)

Tagger	ϵ , %	D, %	“Unbinned” ϵD^2 , %	“Binned” ϵD^2 , %
“Comb. OST” ($ d > 0.3$, PRD)	11.14 ± 0.15	44.3 ± 2.2	2.19 ± 0.22	–
“Comb. OST” ($ d > 0.3$, our Monte Carlo)	20.7 ± 0.1	40.0 ± 0.4	3.31 ± 0.07	–
“Comb. OST” (no cut on $ d $, PRD)	19.95 ± 0.21	–	–	2.48 ± 0.21
“Comb. OST” (no cut on $ d $, our Monte Carlo)	33.10 ± 0.13	–	–	–

- Not clear which dilution to use when combining with SST
- Not clear how to compare ϵD^2 's
- Not clear if we can use this MC for simulating OST at all

Nevertheless let's use this MC to see if SST and OST are independent of each other

- they must be independent by construction
- SST uses tracks inside cone $\cos \alpha > 0.8$ and OST uses tracks outside this cone



SST-OST correlations



Reminder: “Comb. OST” consists of “ μ OST”, “ e OST” and “SV OST”

Tagger	D_{SST} with OST	D_{SST} without OST	D_{OST} with SST	D_{OST} without SST
“Comb. SST” + “Comb. OST”	7.6 ± 0.5	6.1 ± 0.2	39.4 ± 0.4	42.9 ± 0.9
“Min. ΔR ” + “Comb. OST”	7.8 ± 0.5	6.7 ± 0.2	38.9 ± 0.5	43.0 ± 0.7
“ $Q_{jet}(p_t, \kappa = 0.6)$ ” + “Comb. OST”	7.6 ± 0.5	5.0 ± 0.2	39.4 ± 0.4	42.9 ± 0.9
“Min. p_t^{rel} ” + “Comb. OST”	6.7 ± 0.5	6.1 ± 0.2	38.9 ± 0.5	43.0 ± 0.7
“Min. ΔR ” + “ μ OST”	8.1 ± 0.6	6.8 ± 0.2	35.6 ± 0.6	39.9 ± 1.0
“ $Q_{jet}(p_t, \kappa = 0.6)$ ” + “ μ OST”	7.6 ± 0.6	5.2 ± 0.2	36.2 ± 0.6	38.9 ± 1.2
“Min. p_t^{rel} ” + “ μ OST”	6.3 ± 0.6	6.2 ± 0.2	35.6 ± 0.6	39.9 ± 1.0

- We observe some correlation
- Presence of OST increases SST dilution
 - Effect almost vanishes for “Min. p_t^{rel} ” SST and “ μ OST”
- Presence of SST decreases OST dilution (totally unclear)

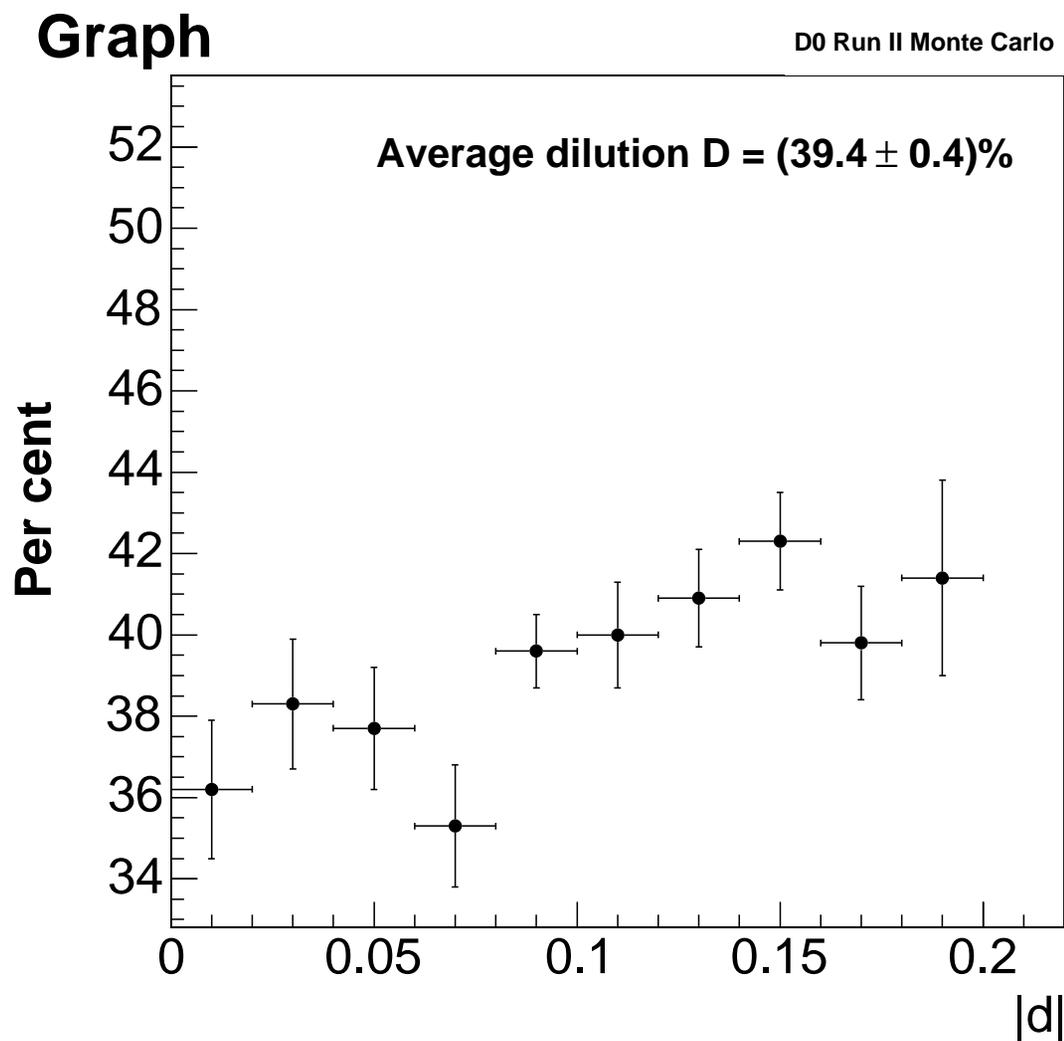
There are two reasons for correlations:

- Using the same tracks (being checked, found nothing so far)
- p_t correlations between tracks in OST-cone and SST-cone (© S. Burdin)



SST-OST correlations

The correlation between taggers can be better observed in the plot of OST dilution vs. SST $|d|$ variable





SST-OST correlations in $B \rightarrow J/\psi K$ MC sample

Tagger	D_{SST} with OST	D_{SST} without OST	D_{OST} with SST	D_{OST} without SST
"Comb. SST" + "Comb. OST"	15.9 ± 1.6	18.6 ± 0.5	36.9 ± 1.5	49.1 ± 3.9
"Min. ΔR " + "Comb. OST"	14.9 ± 1.7	19.3 ± 0.5	36.0 ± 1.6	47.6 ± 3.0
" $Q_{jet}(p_t, \kappa = 0.6)$ " + "Comb. OST"	17.0 ± 1.6	20.3 ± 0.5	37.1 ± 1.5	48.7 ± 4.1
"Min. p_t^{rel} " + "Comb. OST"	10.7 ± 1.7	15.3 ± 0.5	36.0 ± 1.6	47.6 ± 3.0
"Min. ΔR " + " μ OST"	13.7 ± 3.0	19.1 ± 0.5	38.4 ± 2.8	36.2 ± 6.1
" $Q_{jet}(p_t, \kappa = 0.6)$ " + " μ OST"	19.5 ± 2.8	20.1 ± 0.4	38.7 ± 2.7	32.3 ± 8.3
"Min. p_t^{rel} " + " μ OST"	6.4 ± 3.0	15.2 ± 0.5	38.4 ± 2.8	36.2 ± 6.1

- We again observe some correlation
- Presence of OST **decreases** SST dilution
 - The effect does not vanish for "Min. p_t^{rel} " SST and " μ OST"
- Presence of SST still decreases "Comb. OST" dilution but increases " μ OST" dilution



Combination of SST + OST:

- Despite all these correlations let's try to combine SST and OST
- Combination algorithm is the same as for combination of SSTs:
 - Multiply p.d.f.s for SST and OST
 - Introduce combined tagging variable $d = \frac{1 - \prod \frac{f^b(x)}{f^{\bar{b}}(x)}}{1 + \prod \frac{f^b(x)}{f^{\bar{b}}(x)}}$ for each event
 - Infer B -flavor from sign of this variable d



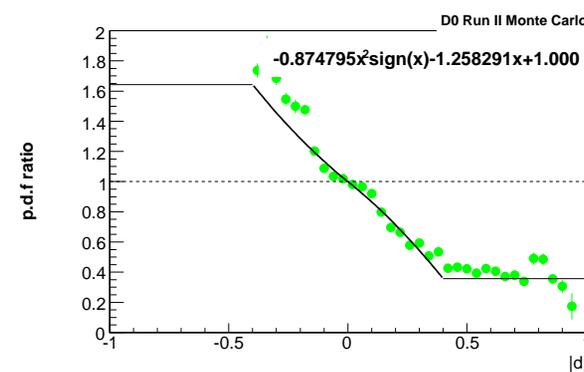
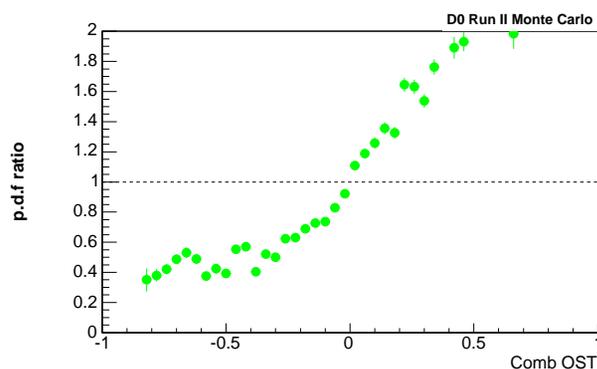
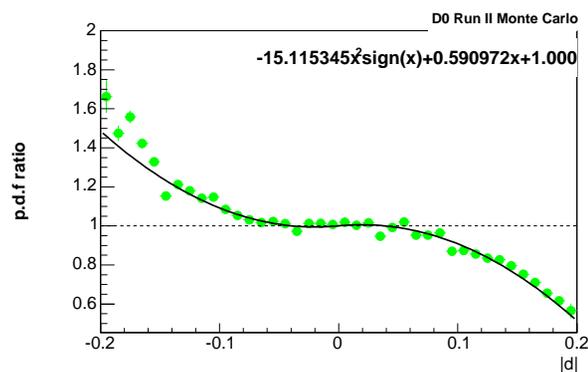
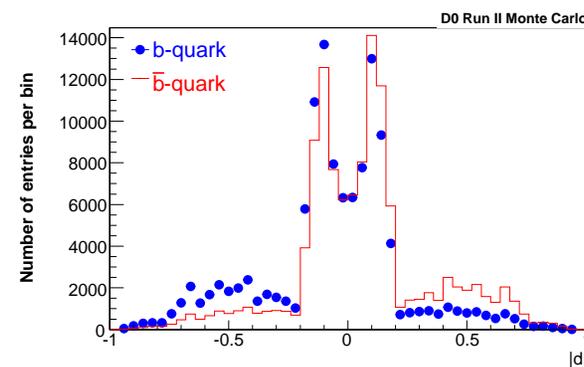
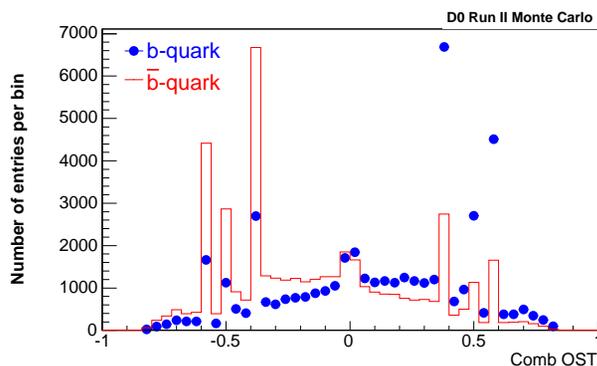
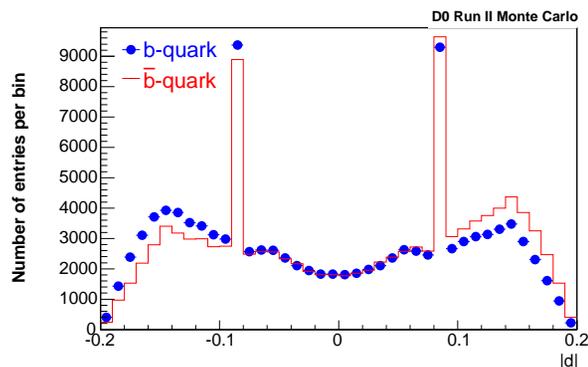
P.d.f.s from Monte Carlo:



SST

OST

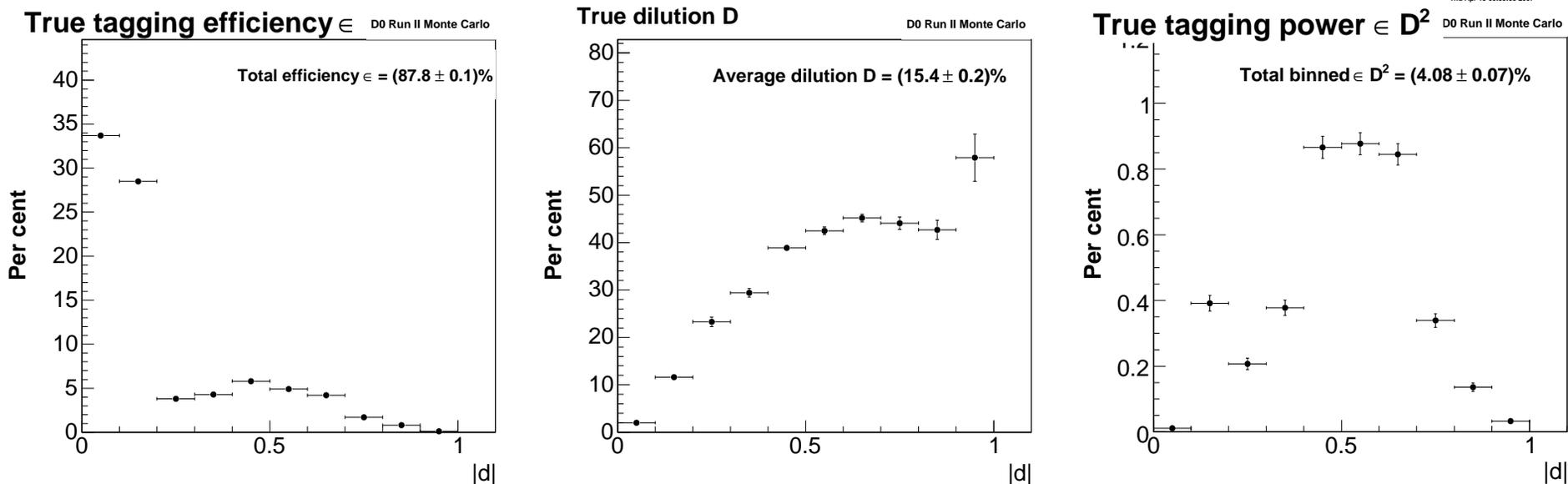
SST+OST





SST + OST in MC:

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Calibration curves for combined SST + OST in Monte Carlo.

Tagger	$\epsilon, \%$	D, %	"Unbinned" $\epsilon D^2, \%$	"Binned" $\epsilon D^2, \%$
"Comb. SST" only	83.3 ± 0.2	6.4 ± 0.2	0.34 ± 0.02	0.65 ± 0.03
"Comb. OST" (PRD)	11.14 ± 0.15	44.3 ± 2.2	2.19 ± 0.22	2.48 ± 0.21
"Comb. OST" (in our Monte Carlo)	20.7 ± 0.1	40.0 ± 0.4	3.31 ± 0.07	–
"Comb. SST" + "Comb. OST"	88.4 ± 0.2	15.2 ± 0.2	2.05 ± 0.05	4.08 ± 0.07

- Very low "unbinned" ϵD^2 for "Comb. SST" + "Comb. OST"
- Dip in the calibration curve



Double-tag method

- The p.d.f.-based method suffers from relying on Monte Carlo
- Double-tag method uses data only:
 - Uses events tagged with SST and OST simultaneously
 - Let N_{12} such events be tagged identically, \bar{N}_{12} tagged oppositely
 - Then $D_{SST} \cdot D_{OST} = \frac{N_{12} - \bar{N}_{12}}{N_{12} + \bar{N}_{12}}$ (provided that taggers uncorrelated)
 - Knowing D_{OST} from PRD we can measure D_{SST}
- Double-tag method inherently has larger uncertainty
- We apply double-tag method to MC (to check if it works) and data
 - Due to SST-OST correlations measured dilution in MC is factor of 2 higher than true dilution



Double-tag method in Monte Carlo:

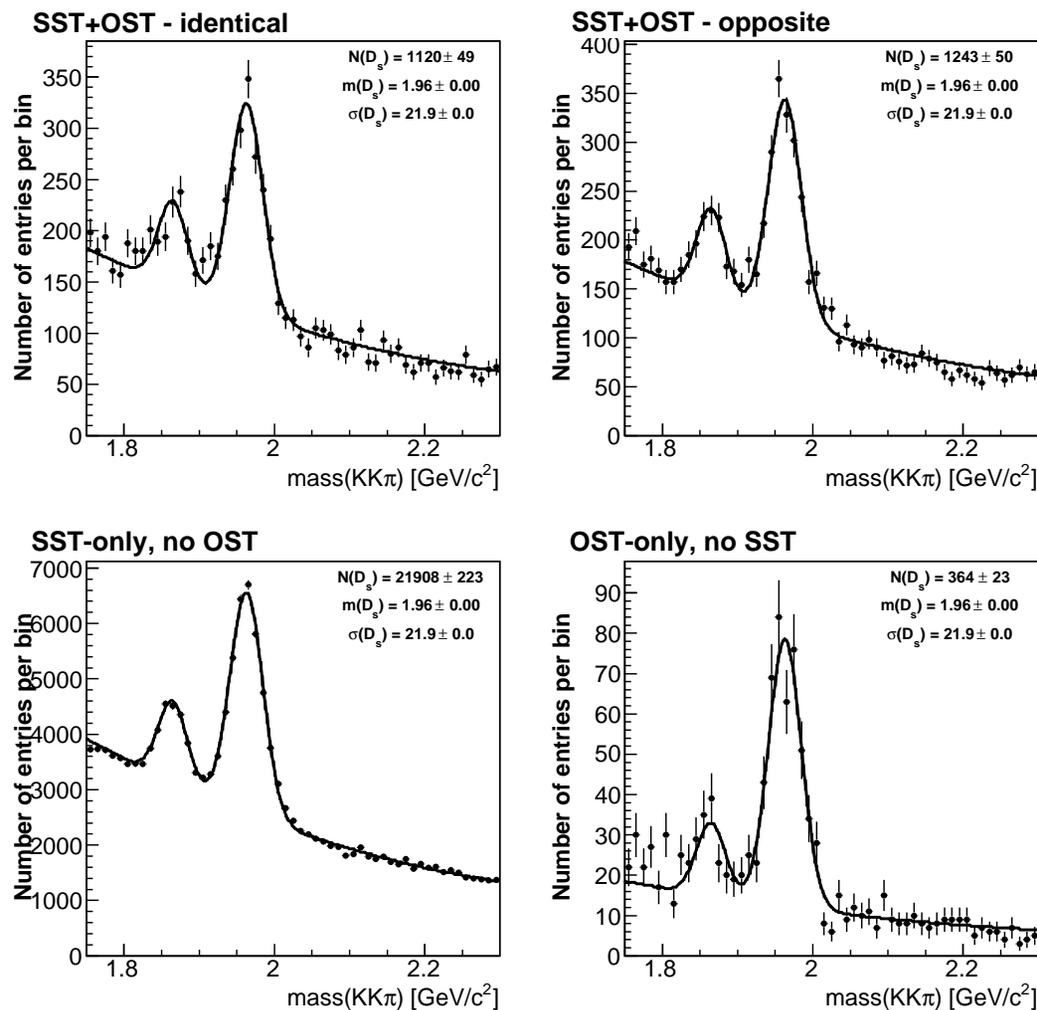
Tagger	N_{12}	\bar{N}_{12}	D_{SST}^{meas}	D_{SST}^{true}	$\epsilon D^2_{SST+OST}, \%$ ("unbinned")
(Min. $p_t^{rel} + Q_{jet}(0.6)$)+OST	24470±156	22469±150	9.62±1.15	5.9±0.2	4.79±0.32
(Max. $p_L^{rel} + Q_{jet}(0.6)$)+OST	24576±157	22363±150	10.64±1.17	4.9±0.2	4.95±0.31
(Max. $p_t + Q_{jet}(0.6)$)+OST	24527±157	22412±150	10.17±1.16	5.0±0.2	4.87±0.32
(Min. $ \Delta\vec{P} + Q_{jet}(0.6)$)+OST	24579±157	22360±150	10.67±1.17	6.4±0.2	4.95±0.31
(Min. $\Delta R + Q_{jet}(0.6)$)+OST	24557±157	22382±150	10.46±1.16	4.9±0.2	4.92±0.31
(Max. $\cos \alpha + Q_{jet}(0.6)$)+OST	24763±157	22176±149	12.44±1.21	6.4±0.2	5.27±0.31
(Min. $\cos \theta^* + Q_{jet}(0.6)$)+OST	24573±157	22366±150	10.61±1.17	5.8±0.2	4.94±0.31
(Max. $\cos \theta^* + Q_{jet}(0.6)$)+OST	24470±156	22469±150	9.62±1.15	5.9±0.2	4.79±0.32
(Min. $m(B_s K) + Q_{jet}(0.6)$)+OST	24763±157	22176±149	12.44±1.21	6.4±0.2	5.27±0.31

- Measured dilutions are twice as high as true dilutions
- “Min. ΔR ” is not the best SST algorithm now

Now let's look at double-tag method in data...



Example: Data fit for double-tag method for “Min. ΔR ” tagger





Double-tag method in data:

Tagger	N_{12}	\bar{N}_{12}	D_{SST}^{meas}	$\epsilon D^2_{SST+OST}, \%$ ("unbinned")
(Min. $p_t^{rel} + Q_{jet}(0.6)$)+OST	1246±50	1127±49	11.34±6.70	3.02±1.28
(Max. $p_L^{rel} + Q_{jet}(0.6)$)+OST	1275±51	1100±49	16.63±6.73	4.27±1.88
(Max. $p_t + Q_{jet}(0.6)$)+OST	1271±51	1098±49	16.51±6.75	4.23±1.87
(Min. $\Delta R + Q_{jet}(0.6)$)+OST	1120±49	1243±50	11.80±6.74	3.03±1.30
(Min. $\Delta P + Q_{jet}(0.6)$)+OST	1288±51	1088±48	19.01±6.68	4.99±2.13
(Min. $m(B_s K) + Q_{jet}(0.6)$)+OST	1258±51	1118±48	13.35±6.65	3.44±1.49
(Min. $\cos \theta^* + Q_{jet}(0.6)$)+OST	1298±51	1077±48	21.02±6.71	5.66±2.36
(Max. $\cos \theta^* + Q_{jet}(0.6)$)+OST	1223±50	1155±49	6.37±6.68	2.28±0.73
(Max. $\cos \alpha + Q_{jet}(0.6)$)+OST	1266±50	1103±49	15.49±6.74	3.95±1.75

Measured dilutions in data are reasonably close to measured dilutions in Monte Carlo, but very far from true dilutions in Monte Carlo



Conclusion

- SST-only part of the analysis is ready to be published (at NIM)
- Combinations SST + OST still needs to be fixed
- Questionable OST Monte Carlo
- We observe correlations between SST and OST
- P.d.f.-based method: too low “unbinned” ϵD^2 for SST + OST
- Double-tag method: Measured dilutions in MC are twice as large as true dilutions due to above mentioned correlations