CDF note 8241

Opposite Side Kaon Tagger

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The CDF Collaboration

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We illustrate a cut-based Opposite Side Kaon Tagger algorithm at CDF, developed using a combined Particle Identification technique which exploits a particle's Time-Of-Flight and its ionization dE/dx measured in the central drift chamber (COT). We look for a Kaon displaced from the Primary Vertex, using its Impact Parameter significance. The track-based jets found in an event are also considered to determine the accompanying b direction. The tagger performances are:

$$\varepsilon D^2 = 0.229 \pm 0.016(\text{stat.}) \pm 0.001(\text{syst.})\ \%.$$

evaluated on a calibration sample of semileptonic decays triggered with a dedicated $\ell + SVT$ trigger. The analysis is based upon 355 pb^{-1} of data collected up to August 2004.

I. INTRODUCTION

b-Flavour tagging is about determining the flavour of a neutral B meson at creation. This is a necessary information for any time-dependent analysis, like the measurement of the CP asymmetry or the determination of the frequency ΔM with which the neutral B^0 mesons mix into their partners $\bar{B}^0$. This measurement has been performed recently by the CDF Collaboration in the B_s^0 system [1] using several combined flavour taggers. Both the information of the tracks produced in the same hadronization process as the mixing candidate (*Same Side Tagging*) and the decay products of the accompanying b (*Opposite Side Tagging*) were considered. The final figure-of-merit assigned to a tagger is the product εD^2 of the fraction ε of events with a tag and the dilution D, defined as $D = 1 - 2W$, where W is the mistag rate. Among the possible Opposite Side Taggers, CDF already utilized the Soft Lepton Taggers ([3],[4]) and a Neural Network driven Jet Charge Tagger ([5]). All of those exploit the correlation between the flavour of the Opposite Side b and the electric charge of one or more of its decay products. For the SLT, it is a μ or an e from the $b \to \ell X$ decay, for the Jet Charge it is the ensemble of tracks contained in a cone around the b direction.
The introduction of a Combined Particle Identification technique using the information from both the Time-Of-Flight detector and the specific ionization dE/dx in the central COT allows us to add a further tagger to the CDF OST. The two sub-detectors are described in detail in [2]. We look for a Kaon coming from the $b \to c \to s$ decay chain to predict the b flavour: thus, first we need to separate Kaons from the overwhelming background of pions. Then, we need to use vertexing and be able to discriminate between a signal Kaon (displaced from the Primary Vertex) and the background of fragmentation tracks attached to it. The Kaon selection is finally complemented with the determination of the OS b direction by using a track-based jet. We categorize our tagger in different classes according to the confidence with which the jet is associated with the OS b.
In the following we show that at CDF, in a hadron collider environment, it is feasible to develop an Opposite Side Kaon Tagger with a dilution of the same order of magnitude as the other OST. The final performances are primarily limited by the acceptance to the Kaon.

II. THE TAGGING ALGORITHM

A. Data sample

To evaluate the performances of a flavour tagger in the Opposite Side one can use a pure and high-statistics calibration sample and compare the flavour of the Same Side b with that provided by the tagger for the OS b. In our case, we make use of a semileptonic sample selected by a dedicated trigger. This requires a lepton (μ or e) with a $p_t \geq 4\ GeV/c$ plus a track with an impact parameter $d_0 \geq 120\ \mu m$ and $p_t \geq 2\ GeV/c$ (SVT track). A photon conversion veto is applied in the case of the $e + SVT$ sample. In order to have an as-pure-as-possible set of events from b semileptonic decays, a cut is also applied on the combined $\ell + SVT$ mass:

$$2\ GeV/c^2 \leq M(\ell + SVT) \leq 4\ GeV/c^2$$

MOreover, we alway perform a background subtraction based on the SVT track I.P. *signed* according to the product $\vec{d_0} \cdot \vec{P}_{\ell+SVT}$ of the I.P. and the B^0 momentum vector, for which the fake pairs are expected to be symmetric around 0, while signal should be shifted toward positive values. The flavour of the candidate B is inferred from the charge of the trigger lepton and the dilution of the OST measured consequently. The possibility that the SS b has mixed before it decayed is accounted for by applying a correction factor to the final dilution of the tagger.

B. Combined Particle Identification

To select our final set of Kaons, we combine the information of the CDF Time-Of-Flight detector and the dE/dx in the COT into a Likelihood Ratio

$$LR(K) = log\left(\frac{P_{TOF}(K) \cdot P_{dE/dx}(K)}{0.2 \cdot P_{TOF}(K) \cdot P_{dE/dx}(K) + 0.7 \cdot P_{TOF}(\pi) \cdot P_{dE/dx}(\pi) + 0.1 \cdot P_{TOF}(p) \cdot P_{dE/dx}(p)}\right)$$

where $P(h_i)$ indicates the probability to obtain a certain measurement given the mass hypotesis h_i. To do that, we need for the track to have a valid TOF measurement, which happens in $\approx 65\%$ of the tracks within TOF fiducial

volume ($\eta \leq 1$). The two sub-detectors used have a p_t dependent K/π separation. In the case of our tagging candidates, peaking at around $p_t = 1\ GeV/c$, the bulk of the separation is given by TOF ($\approx 2\sigma\ K/\pi$ separation at $p_t = 1.6\,GeV/c$); nevertheless dE/dx information is useful at very low momenta ($p_t \leq 0.7\,GeV/c$) and for $p_t \geq 2\,GeV/c$. The combination of the two provides us with a more stable separation power over all the momentum range, extending the tagger acceptance to Kaons. This is especially important to us, as our main source of background is represented by the low-p_t pions.
The distribution of the LR(K) variable is shown in FIG.1. The same for the various charged particle species is displayed in FIG.2. In this plot, the performances of K/π separation can be noticed.

C. Displacement from Primary Vertex

Once we identify a set of candidate Kaons, we still have to deal with the fragmentation tracks that passed the PID cut but whose information is completely uncorrelated with the OS b flavour. To do that, we determine the position of the event's Primary Vertex using the average beamline. Then we make use of the absolute value of the track's impact parameter significance

$$I.P.\ significance = |d_0|/\sigma(d_0)$$

and apply a selection over this variable. In order to reduce the uncertainty on the I.P. measurement ($\sigma(d_0)$) as much as possible, the hits on the CDF innermost silicon layer (Layer00) are also used in the track extrapolation. The distribution of the absolute I.P. significance for our set of tagging candidates is shown in FIG.3, along with the agreement with our MC.
In the events when a Secondary Vertex (SV) is explicitly identified by the SecVtx algorithm, that is evidence for a b decay, we sign the impact parameter with the position $\vec{x}_{SV}$ of the SV with respect to the PV:

$$I.P.\ significance = |d_0|/\sigma(d_0) \times sign(\vec{d_0} \cdot \vec{x}_{SV})$$

In fact, while the signal comes preferentially with a positive signed d_0, prompt background is expected to be symmetric around 0: thus, using this information, when available, enhances our signal efficiency for a fixed rejection of fragmentation background.

D. Determination of the OS b direction

In order to categorize our tagger in classes according to the purity of the tagging sample in terms of $b-$ decays, we make use of the track-based jets that were clustered in an event starting from seed tracks with a $p_t \geq 1\ GeV/c$ and associating softer tracks to them. No calorimeter information is used. Only jets with a $\Delta R \geq 1$ with respect to the $\ell + SVT$ momentum are considered to estimate the OS b direction. We divide events into 3 classes, according to the final dilution D we measure on our calibration sample:

1. events containing a jet with a reconstructed SV: the SV jet is picked as the OS b estimator;
2. events without a SV identified, but with isolated tracks (tracks that satisfied the requirements to be defined as jets but could not be spatially associated with any other track): the highest momentum jet in the eventx is taken as the reference one;
3. events not included in the former classes, where the tagging candidate track was found to be in a jet: the jet containing the candidate track is the reference one.

We optimize all the cuts on the above quantities using half of our mixed $(e + SVT)$ + $(\mu + SVT)$ sample and evaluate the tagger performances over the rest of it. Tracks are considered for tagging if they passed the cuts in TAB.I. We also perform a rejection of the daughters of the SS b within the OS by applying a combined invariant mass-ΔR cut: we reject tracks having

$$M(\ell + SVT + track) \geq 5.3\ GeV/c^2 \quad and \quad \Delta R(\ell + SVT, track) \leq 1.6$$

About 2% of events tagged by SS daughters are estimated from MC to pass this cut. More, making use of their dE/dx, we can also reject protons up to a $p_t \approx 0.8\ GeV/c$, in a region where they are well separated from the other particles. To discard such low β particles, in part coming from the beam halo, we ask for a high ionization ($< dE/dx > \ \geq 25\ ns$) and that they be not compatible with the expected Kaon dE/dx.
Finally, pairs of candidate tracks that passed all the above cuts are rejected if they are likely to come from a ϕ meson ($\phi \to K^+K^-$): as a matter of fact, in such cases we can equally pick any of the two Kaons, with a random correlation to the OS b flavour. Since we observe a peak at the ϕ mass, after applying our displacement and PID requirements, we dismiss pairs of tracks passing the above selections and with a combined mass within the window:

$$1.010\ GeV/c^2 \leq M_{KK} \leq 1.030\ GeV/c^2$$

After all these selections, we end up with a tagging track multiplicity as in FIG.5. Approximately 15% of the events with a tag have > 1 tagging candidate. In such cases, to choose the final tagging track we proceed as follows: if all the candidates belong to the same class, we pick the one most likely to be a Kaon (that is the one with the highest LR(K)). If candidates come from different classes, we choose them according to the order in sec.II D. Eventually, our dilution D is evaluated starting from the number of Right Sign tags (RS), when $Q(K) \cdot Q(\ell) < 0$, and Wrong Sign tags, when $Q(K) \cdot Q(\ell) > 0$.
From the definition of *figure-of-merit* we have that binning the dilution increases the final εD^2 with respect to the averaged case. For example, in the case of two bins we would have:

$$\varepsilon_1 D_1^2 + \varepsilon_2 D_2^2 = \varepsilon D^2 + \frac{\varepsilon_1 \varepsilon_2 (D_1 - D_2)^2}{\varepsilon} \geq \varepsilon D^2$$

We choose to bin the dilution D using the two variables that proved from MC to be more sensitive to differences between signal and fragmentation Kaons. In the case when a SV is reconstructed (i.e. *Class 1 tags*), we evaluate D in bins of the fraction of jet momentum carried by the Kaon:

$$P_{FRAC} = \frac{P(K)}{P(jet)}$$

From MC, one can see that signal is expected at higher values of P_{FRAC}, while prompt tracks are less correlated with the Class 1 jet (FIG.6). This is not the case when the estimation of the b direction by the reference jet (i.e. *Class 2 and 3 tags*) is not as good. For those cases, we bin D using the absolute I.P. significance. The results of the binning are in FIG.7.
We find that the dependence is well fitted by an exponential function of the type

$$D(x) = A \times e^{Bx}, \quad x = P_{FRAC}, |d_0|/\sigma(d_0)$$

for all the different classes. The values of the A, B parameters are summarized in TAB.II for the various classes. With these templates in hand, it is possible to assign a dilution to each event separately for the future analyses to which the tagger is applied. Tags with a $|d_0|/\sigma(d_0) \geq 4$ are assigned the value of dilution D measured from data, also listed in TAB.II.

III. FINAL PERFORMANCES AND UNCERTAINTIES

With the algorithm described above, we measure the following performances. The average dilution case, when no binning is considered, is shown in TAB.III. On the other hand, after binning we have:

$$\begin{aligned}
\varepsilon D^2_{tot} &= 0.229 \pm 0.016\ (stat.)\ \%\ \ \pm 0.001\ (syst.)\ \% \\
\varepsilon_{tot} &= 18.11 \pm 0.07\ (stat.)\ \% \\
effective\ Dilution = \sqrt{\varepsilon D^2_{tot}/\varepsilon_{tot}} &= 11.09 \pm 0.88\ (stat.)\ \% \\
< D > (class\ 1) &= 16.6 \pm 1.2\ \% \\
< D > (class\ 2) &= 12.3 \pm 1.4\ \% \\
< D > (class\ 3) &= 8.1 \pm 0.8\ \%
\end{aligned}$$

As one can see, binning the dilution gains $\approx 30\%$ relative in εD^2 with respect to the average case.
The systematic uncertainty quoted comes from the correction factor accounting for the effect on the dilution evaluation caused by the SS b mixing and the sequential decays like $B \to DDX$, where a lepton from one of the two D mesons mimics a lepton from the b decay, spoiling our knowledge of the SS b flavour.

Acknowledgments

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[4] The CDF Collaboration, Muon B Flavor Tagging - A Likelihood Approach URL http://www-cdf.fnal.gov/physics/new/bottom/072204.blessed-like-mu-tag/
[5] The CDF Collaboration, Neural Network based Jet Charge Tagger URL http://www-cdf.fnal.gov/physics/new/bottom/050303.blessed-jqtnn/

TABLES

quantity	cut
Silicon Hits r-ϕ	≥ 3
COT Hits	$\geq 10+10$ [a]
p_t	$\geq 0.35\ GeV/c$
$\Delta R(\ell+SVT, track)$	> 0.7 [b]
Track has a TOF measurement	Yes
$\lvert d_0 \rvert$	$\leq 0.1\ cm$
$\lvert z_0(trk) - z_0(SS\ b) \rvert$	$\leq 1.2\ cm$
$signed\ d_0/\sigma(d_0)$	≥ 2.0 [c]
$\lvert d_0 \rvert/\sigma(d_0)$	≥ 1.5 [d]
$LR(K)$	$\geq -0.3\ cm$

[a] 10 in a COT Superlayer + 10 in a different SL
[b] $\Delta R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$
[c] if SV reconstructed
[d] if NO SV reconstructed

TABLE I: Selections applied to tracks

	A	B	D($\lvert d_0 \rvert/\sigma(d_0) \geq 4$) (%)
Class 1	-2.11 ± 0.19	1.31 ± 0.45	
Class 2	-4.01 ± 0.45	0.66 ± 0.15	18.1 ± 2.0
Class 3	-5.03 ± 0.45	0.85 ± 0.14	11.9 ± 1.0

TABLE II: Parameters of the exponential fit to the dilution dependence on P_{FRAC} (Class 1 tags) and aboslute I.P. significance (Class 2 and 3 tags). The D for the last bin of class 2 and 3, that averages all the contributions with $|d_0|/\sigma(d_0 \geq 4$ is not included in the fit and is reported separately in the last column for the relative class.

NOT BINNED	ε(%)	D(%)	εD^2(%)
Class 1	3.66 ± 0.03	16.3 ± 1.3	0.0973 ± 0.0098
Class 2	3.48 ± 0.03	10.3 ± 1.5	0.0369 ± 0.0068
Class 3	10.97 ± 0.06	6.2 ± 0.9	0.0418 ± 0.0073
Combined	18.11 ± 0.07	9.9 ± 0.9	0.176 ± 0.014

TABLE III: Performances of the OSKT over the $\ell + SVT$ sample considered.

FIGURES

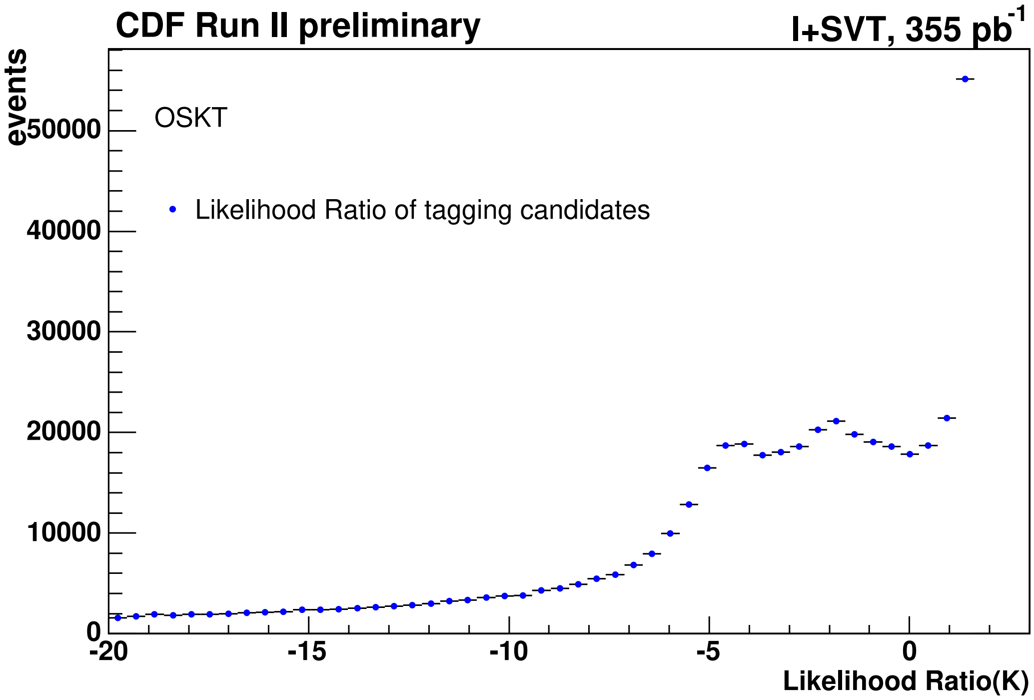

FIG. 1: The Likelihood Ratio distribution for the OSKT tagging candidates.

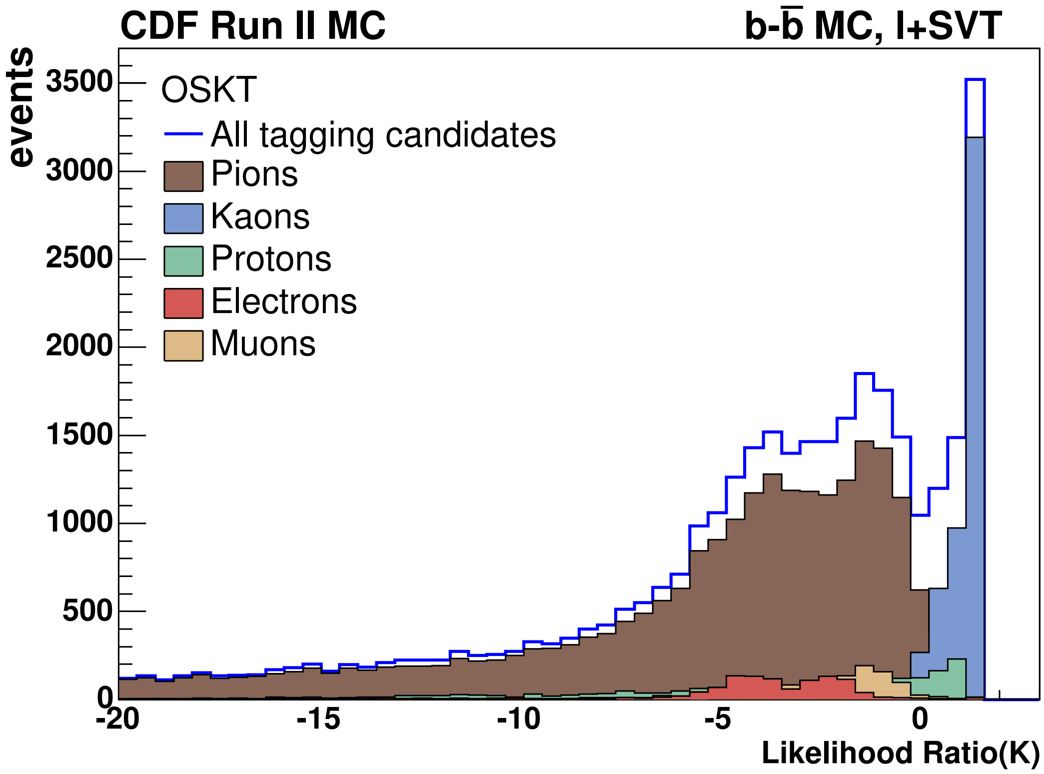

FIG. 2: The MC Likelihood Ratio distribution for the various charged particle species. Kaons are expected at $log(1/0.2) = 1.6$.

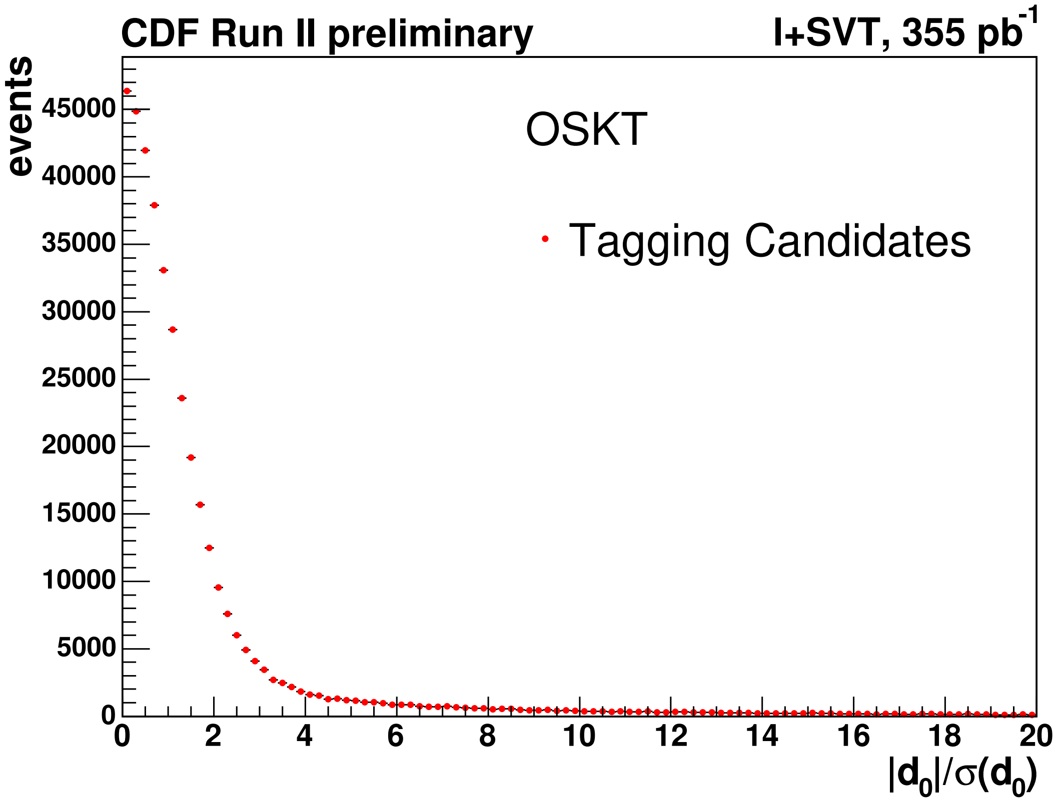

FIG. 3: The I.P. significance distribution for the OSKT tagging candidates.

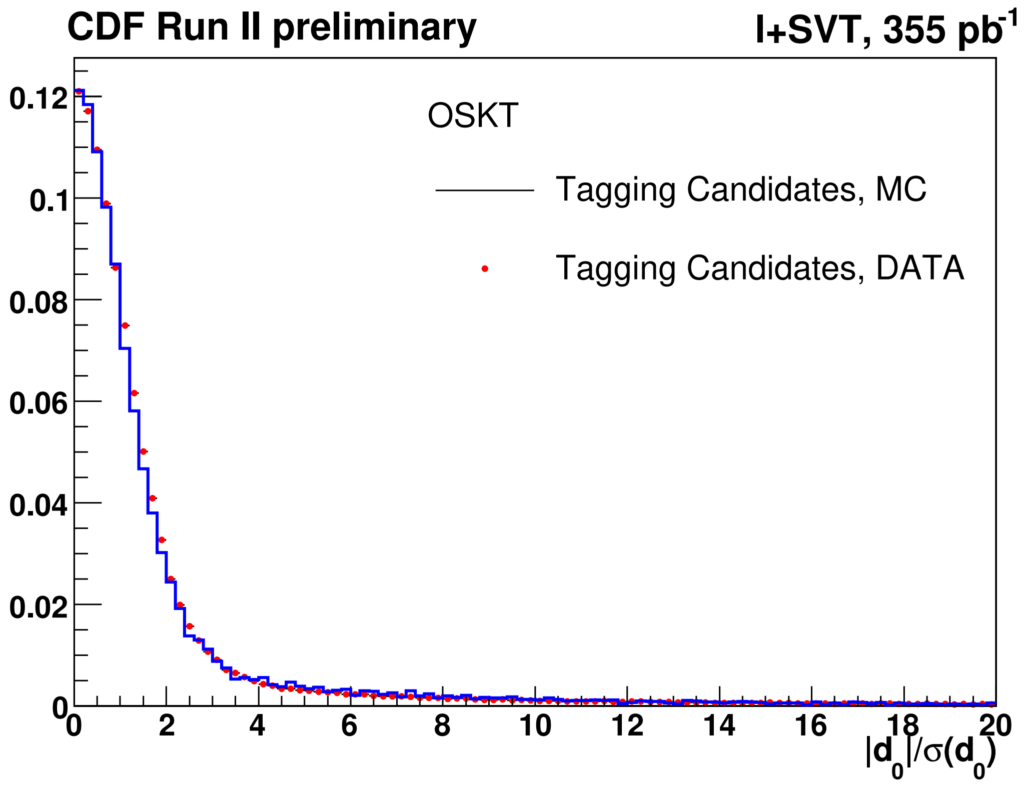

FIG. 4: Agreeement on the I.P. significance of the tagging candidates between data (red dots) and MC (blue line).

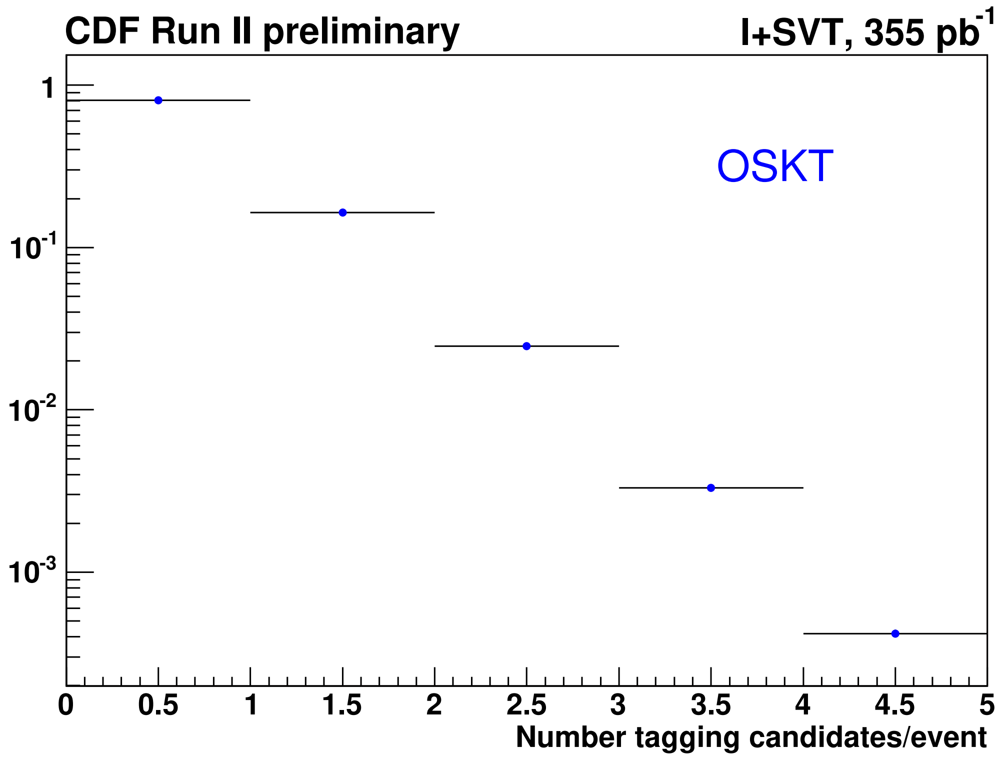

FIG. 5: Number of tracks passing all the tagging selections. About 15% of the events with a tag have > 1 candidates.

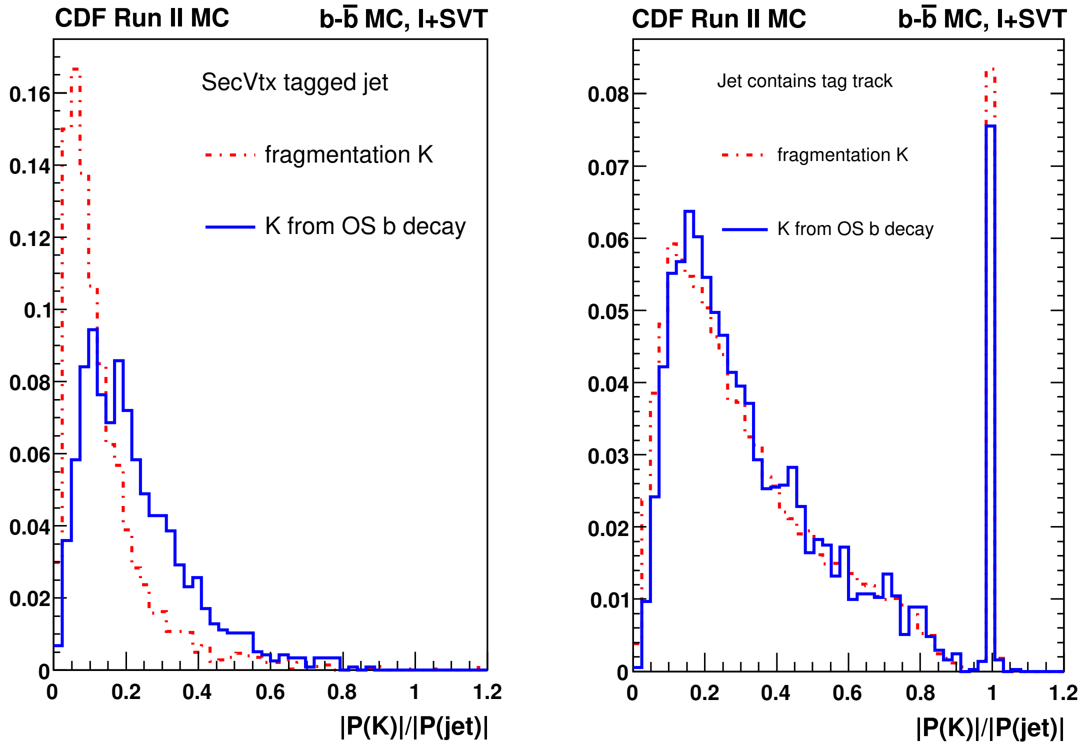

FIG. 6: Number of tracks passing all the tagging selections. About 15% of the events with a tag have > 1 candidates.

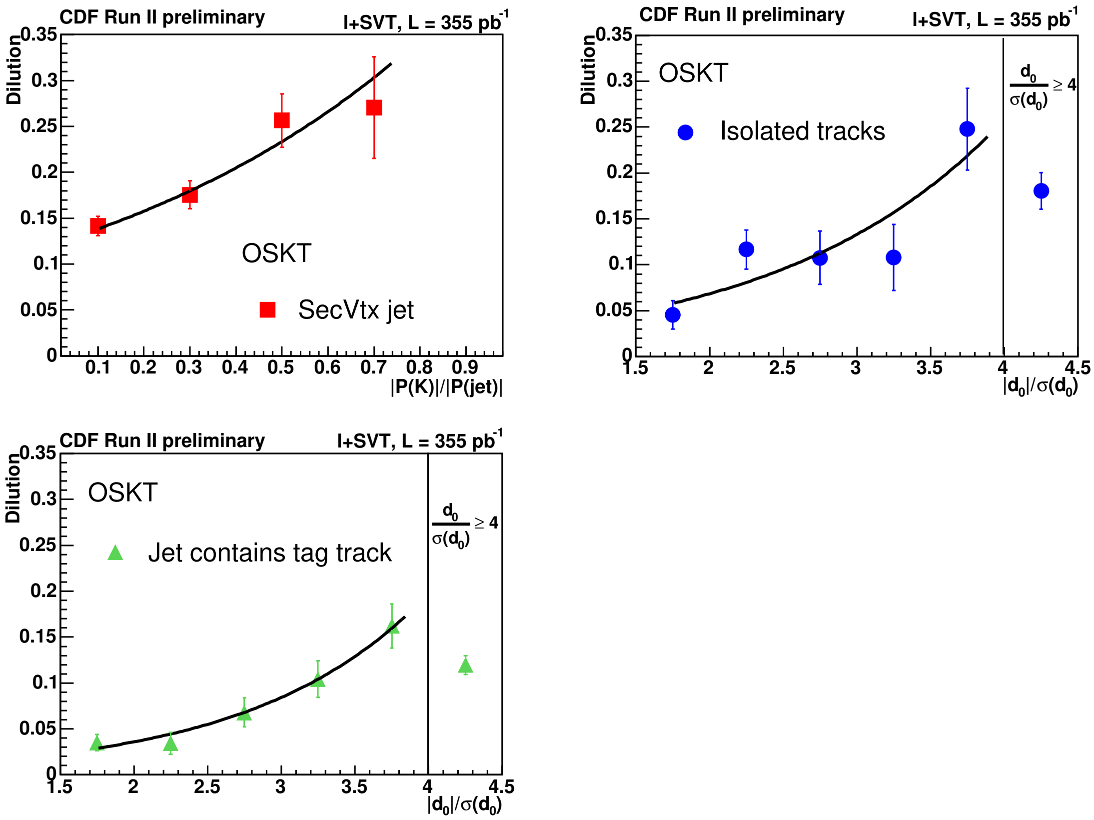

FIG. 7: Dependence of the tagger dilution on the fraction of jet momentum carried by the SecVtx jet (upper left plot); and on the absolute I.P. significance for Class 2 (upper right) and 3 (bottom left) tags. The exponential fitting function D(x) is overlaid for the three cases.