Experiment 949
Technical Note No. K-0xx

$K_{\pi 2}$ Branching Ratio.

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Abstract

Results of $K_{\pi 2}$ branching ratio using current set of PNN2 analyses cuts are presented. The procedure used the results of technotes K034 [2] as control ones and the values of f_s and of $\epsilon^{ng}_{T.2}(K_{\pi 2})$ measured their in. It was shown that the $K_{\pi 2}$ branching ratio value 0.2150 ± 0.0050 in agreement with PDG2007 [5] value 0.2092 ± 0.0012, and the result obtained in previous analyses, for instance with value 0.2150 ± 0.0050 of technotes K034 [2]. The run dependence of the $K_{\pi 2}$ branching ratio value shows the difference in a run sets with a different prescale factors (the runs with a different K^+ beam intensity) even if the $A_{K_{\pi 2,Br}}$ has been measured separately for this runs and appears equal to 0.3049 ± 0.0008 for all runs together having 128115 $K_{\pi 2}$ events, and 0.3049 ± 0.0008 for runs with prescale 131072 (the majority of runs having 115515 $K_{\pi 2}$ events), and 0.3106 ± 0.0044 for runs with prescale 163840 (having 2796 $K_{\pi 2}$ events).

1 Introduction

The purpose of $K_{\pi 2}$ branching ratio measurement is well enough described in technote K-034 [2]. One of the main reason to make this measurement is to check up consistency and correctness of the different parts of the analyses procedure in blind PNN2 analyses before opening box to exclude possible flaws.

2 Experimental data

The $K_{\pi 2}(1)$ monitoring data set (called KP21_FINAL in current analyses) of the 2002 data taking run has been used in this analysis. Data have been taking by following trigger conditions:

$$(ONLINE\ \ TRIGGER)_{K_{\pi 2}} = KB \times T \cdot 2 \times (6_{ct} + 7_{ct}) \times \overline{19_{ct}} \tag{1}$$

and with prescales factors 163840 (at the beginning of run, runs number in range 47737-48045)) and 131072 after run 48045. The number of $K_{\pi 2}$ events, prescale factor, and number of beam K^+-mesons versus run are shown on Fig. 1 a), b) c), correspondingly. It need to be noted that a small fraction of $K_{\pi 2}(1)$ monitoring data was not used in analyses because of absence end of spill information at the moment. The runs with existing information on number of beam K^+ mesons and prescaler for $K_{\pi 2}$ events have been used. For some runs (about50) the prescaler in the prescaler file wasn't defined and have been taken equal to prescaler of previous run.

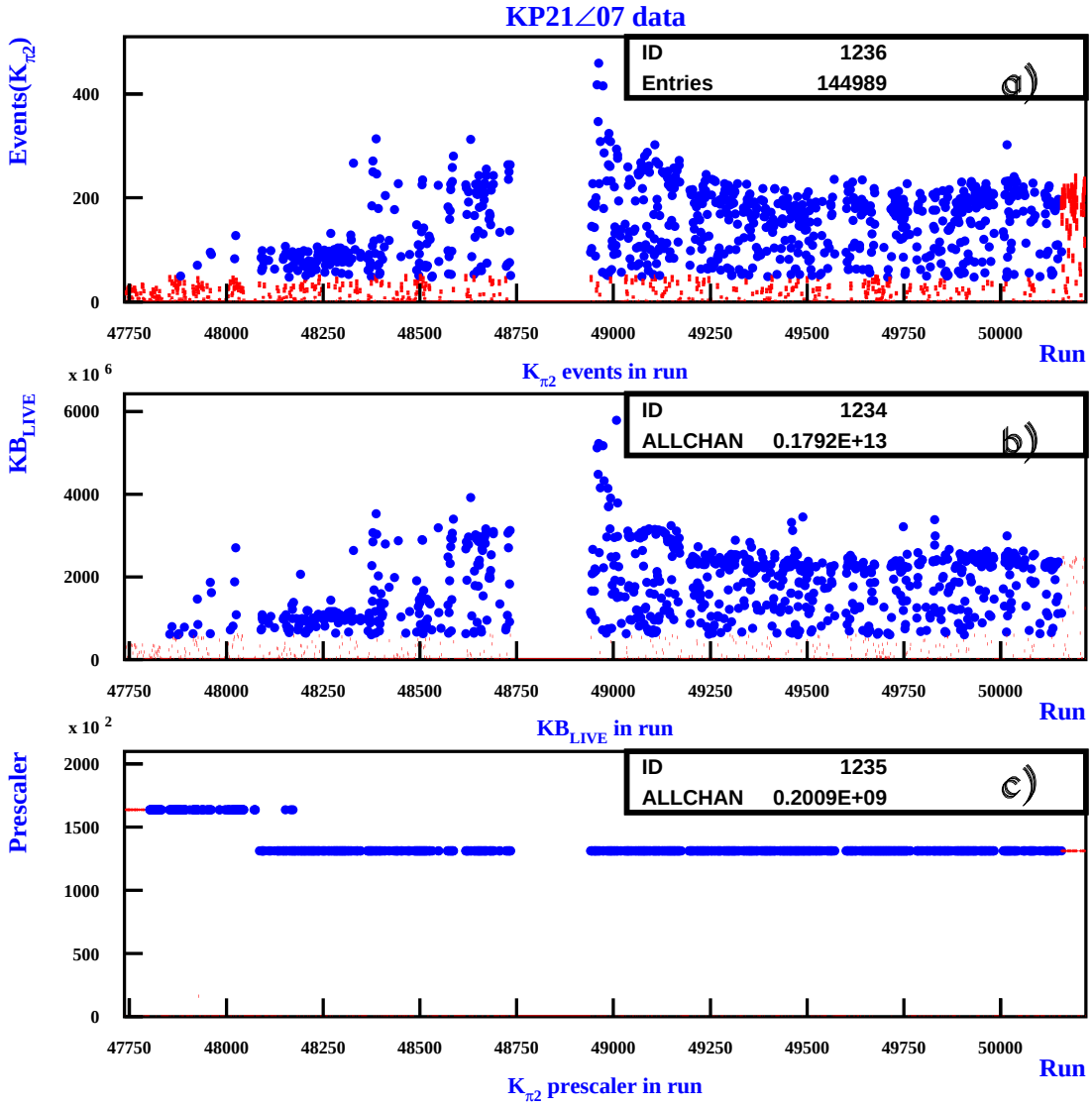

Figure 1: The $K_{\pi2}$ a) events, b) prescale factor and c) beam K^+-mesons versus run number.

3 Description of the method

The method used for the $K_{\pi2}$ branching ratio measurement is described in detail elsewhere [2]. The $K_{\pi2}$ branching ratio is calculated according to following equation:

$$BR(K_{\pi2}) = \frac{N_{K_{\pi2}}}{\epsilon T \cdot 2 \cdot IC(K_{\pi2}) \cdot (KB_{live})_{K_{\pi2}} \cdot A_{K_{\pi2,Br}} \cdot A^{UMC}_{K_{\pi2,kin}} \cdot f_S \cdot A^{UMC}_{K_{\pi2,trig}}} \quad (2)$$

where :

$$A_{K_{\pi2},Br} = A_{RD,Br} \times A_{RECO,Br} \times A_{REST,Br} \times A_{IPIFLG} \times A^{acc}_{\mu} \quad (3)$$

The values of f_s, and of $\epsilon^{ng}_{T.2}(K_{\pi2})$, and of A^{acc}_{μ} for loss due to $\overline{19_{ct}}$ condition inefficiency have not been measured in this analyses and have been taken from previous 2002 year PNN1 analyses [2].

The value A_{IPIFLG} has been measured in PNN2 analyses procedure using π_{scat} data with loose and tight cut conditions and the tight A_IPIFLG= 0.82700 ± 0.00120 has been applied.

4 Monte Carlo kinematic and trigger acceptances

The kinematic and trigger acceptances for $K_{\pi 2}$ events have been defined by Monte Carlo simulation and are presented on table 1. The result of previous 2002 year analyses [2] are presented for comparison too. **UMC cut definitions could be found in Appendix A.**

Cut	2002 (acc.)	2007 (acc.)
KT	49997	99993
T•A	22697(0.45397)	44891(0.44894)
Reach Layer B	19090(0.84108)	37605(0.83769)
$\overline{19_{ct}}$	18797(0.98465)	36986(0.98354)
UFATE	15910(0.84641)	31222(0.84416)
USTMED	15568(0.97850)	30518(0.97745)
USTOPHEX	13909(0.89344)	27426(0.89868)
$A^{UMC}_{K_{\pi 2},trig}$	0.27820 ± 0.00200	0.27428 ± 0.00141
RDUTM	13909(1.00000)	27426(1.00000)
UTCQUAL	13489(0.96980)	26910(0.98119)
TARGET+TGQUALT	13348(0.98955)	25659(0.95351)
$A^{UMC}_{K_{\pi 2},recon}$	0.95967 ± 0.00167	0.93557 ± 0.00148
KPI2STOP	12831(0.96127)	24639(0.96025)
COS3D	12305(0.95901)	23671(0.96071)
KPI2BOX_MOD	11225(0.91223)	20213(0.85391)
$A^{UMC}_{K_{\pi 2},kin}$	0.84095 ± 0.00317	0.78775 ± 0.00255
$A^{UMC}_{K_{\pi 2}}$	0.22451 ± 0.00187	0.20214 ± 0.00127

Table 1: **UMC $K_{\pi 2}$ acceptance of cuts applied in the$K_{\pi 2}$ branching ratio analysis. NIDIF is on. In E949, the $(\overline{19_{ct}+20_{ct}+21_{ct}})$ trigger condition has been changed to $\overline{19_{ct}}$.**

5 The $K_{\pi 2}$ event selection branch of cuts.

The cuts applied to $K_{\pi 2}$(1) monitoring data to select the $K_{\pi 2}$ events in the $K_{\pi 2}$ branching ratio analysis and their acceptances are shown in table 2. The result of technical note k-034 [2] are shown also as the control result.

6 $K_{\pi 2}$ branching ratio acceptances

The cuts were used in definition of acceptances for $K_{\pi 2}$ are shown on table 3. In this table shown also acceptances weren't defined in this analyses and were taken from technical note k-034 [2] or present PNN2 analyses.

Cut name and difference of acceptances 2002 and 2007	$N_{K_{\pi 21}}$ 2002 (Acceptance)	$N_{K_{\pi 21}}$ 2007 (Acceptance)	$N_{K_{\pi 21}} \times Prescale \times 10^{-10}$ 2007 (Acceptance)
ALL 0.000%	81214	1938973	25.4999
BAD_RUN 1.303%	81214(1.00000)	1913712(0.98697)	25.3029(0.99227)
TRIGGER 54.108%	81214(1.00000)	878246(0.45892)	11.6109(0.45888)
BAD_STR -0.008%	80802(0.99493)	873864(0.99501)	11.5521(0.99494)
RD_TRK 0.000%	80802(1.00000)	873864(1.00000)	11.5521(1.00000)
TRKTIM 0.000%	80802(1.00000)	873864(1.00000)	11.5521(1.00000)
RDUTM 0.000%	80802(1.00000)	873864(1.00000)	11.5521(1.00000)
UTCQUAL 0.125%	70119(0.86779)	757238(0.86654)	10.0093(0.86645)
TARGET+TGQUALT 5.014%	67908(0.96847)	695393(0.91833)	9.19259(0.91841)
COS3D 0.915%	64911(0.95587)	658341(0.94672)	8.70245(0.94668)
B4DEDX 0.526%	63298(0.97515)	638520(0.96989)	8.43952(0.96979)
CPITRS 0.428%	62406(0.98591)	626788(0.98163)	8.28465(0.98165)
CPITAIL 0.003%	62352(0.99913)	626228(0.99911)	8.27728(0.99911)
ICBIT 0.003%	62328(0.99962)	625970(0.99959)	8.27389(0.99959)
TIC -0.514%	61766(0.99098)	623545(0.99613)	8.24150(0.99608)
TIMCON 0.180%	61285(0.99221)	617564(0.99041)	8.16218(0.99038)
TGTCON 1.433%	61285(1.00000)	608715(0.98567)	8.04531(0.98568)
DCBIT -0.371%	52030(0.84898)	519045(0.85269)	6.86302(0.85305)
DELC -0.500%	44934(0.86362)	450851(0.86862)	5.96163(0.86866)
CKTRS 0.068%	43547(0.96913)	436628(0.96845)	5.77414(0.96855)
CKTAIL -0.026%	42268(0.97063)	423918(0.97089)	5.60547(0.97079)
BWTRS -0.032%	39879(0.94348)	400092(0.94380)	5.28988(0.94370)
RVUPV 0.324%	39114(0.98082)	391120(0.97757)	5.17075(0.97748)
TARGF 0.258%	37126(0.94917)	370232(0.94659)	4.89491(0.94665)
DTGTTP -0.023%	37116(0.99973)	370219(0.99996)	4.89474(0.99996)
RTDIF -0.108%	36697(0.98871)	366439(0.98979)	4.84457(0.98975)
TGQUALT 0.000%	36697(1.00000)	366439(1.00000)	4.84457(1.00000)
PIGAP 0.148%	36298(0.98913)	361912(0.98765)	4.78419(0.98754)
TGB4 1.108%	34123(0.94008)	336217(0.92900)	4.44510(0.92912)
KIC -0.118%	33611(0.98499)	331568(0.98617)	4.38364(0.98617)
TGGEO 0.024%	27745(0.82547)	273622(0.82524)	3.61775(0.82528)
B4EKZ 4.300%	26719(0.96302)	251738(0.92002)	3.32839(0.92002)
B4ETCON 0.439%	26719(1.00000)	250633(0.99561)	3.31343(0.99550)
TGZFOOL 1.266%	26719(1.00000)	247461(0.98734)	3.27153(0.98735)
PV_noBV 0.000%	26719(1.00000)	247461(1.00000)	3.27153(1.00000)
IPIFLG 2.033%	19321(0.72312)	173913(0.70279)	2.29944(0.70286)
KPI2BOXM 4.568%	17037(0.88179)	145410(0.83611)	1.92215(0.83592)
KP2STOP -0.092%	16972(0.99618)	144989(0.99711)	1.91660(0.99711)
RTOT40 0.000%	16972(1.00000)	144989(1.00000)	1.91660(1.00000)
$N_{K_{\pi 2}}$ 4.389%	16972(0.209)	144989(0.165)	1.91660

Table 2: For the $K_{\pi 2}$, cuts applied in the $K_{\pi 2}$ BR analysis.

Cut name	Acc2002-Acc2007	$N_{K_{\pi 21}}$(Acc) 2002	$N_{K_{\pi 21}}$(Acc) 2007
$SETUP_{RD}$		49651	490579
RD_TRK	0.000%	49651(1.00000)	490579(1.00000)
TRKTIM	0.000%	49651(1.00000)	490579(1.00000)
A_RD,Br	0.000%	1.00000 ± 0.00000	1.00000 ± 0.00000
$SETUP_{RECON}$		32370	449621
RDUTM	0.000%	32370(1.00000)	449621(1.00000)
UTCQUAL	0.122%	29370(0.90732)	407402(0.90610)
TARGET+TGQUALT	4.088%	29063(0.98955)	386491(0.94867)
A_RECO,Br	3.825%	0.89784 ± 0.00168	0.85959 ± 0.00052
$SETUP_{REST}$		32875(0.40480)	336407(1.00000)
TIC	-0.192%	32789(0.99738)	336173(0.99930)
TIMCON	-0.014%	32657(0.99597)	334866(0.99611)
TGTCON	1.142%	32657(1.00000)	331041(0.98858)
DCBIT	-0.244%	28892(0.88471)	293685(0.88716)
DELC	-0.519%	25149(0.87045)	257163(0.87564)
CKTRS	-0.037%	24469(0.97296)	250305(0.97333)
CKTAIL	-0.043%	23767(0.97131)	243233(0.97175)
B4DEDX	-0.145%	23357(0.98275)	239389(0.98420)
CPITRS	0.020%	23130(0.99028)	237015(0.99008)
CPITAIL	0.029%	23119(0.99952)	236833(0.99923)
TARGF	-0.157%	22120(0.95679)	226972(0.95836)
DTGTTP	-0.024%	22114(0.99973)	226965(0.99997)
RTDIF	0.068%	21917(0.99109)	224789(0.99041)
TGQUALT	0.000%	21917(1.00000)	224789(1.00000)
PIGAP	0.175%	21731(0.99151)	222488(0.98976)
TGB4	1.328%	20560(0.94611)	207545(0.93284)
KIC	0.595%	20409(0.99266)	204785(0.98670)
TGGEO	-0.681%	16788(0.82258)	169847(0.82939)
B4EKZ	4.101%	16240(0.96736)	157338(0.92635)
B4ETCON	0.423%	16240(1.00000)	156673(0.99577)
TGZFOOL	1.257%	16240(1.00000)	154703(0.98743)
BWTRS	-0.214%	15503(0.95462)	148013(0.95676)
RVUPV	0.355%	15278(0.98549)	145339(0.98193)
A_REST,Br	3.270%	0.46473 ± 0.00275	0.43203 ± 0.00085
loose A_IPIFLG	1.100%	0.8350 ± 0.0054	0.8240 ± 0.0012
tight A_IPIFLG	0.800%		0.8270 ± 0.0012
A_{μ}^{acc}	0.000%	0.9931 ± 0.0002	0.9931 ± 0.0002
is loss due to	19ct-bar		
tight IPIFLG $A_{K_{\pi 2},Br}$	4.140%	0.3460 ± 0.0031	0.3049 ± 0.0008

Table 3: $K_{\pi 2}$-based acceptances of cuts applied in the $K_{\pi 2}$ BR analysis. The IPIFLG acceptance is measured using π_{scat}'s (counting method) similar to the $\pi\nu\bar{\nu}$ measurement of IPIFLG acceptance, except that here the π_{scat}'s are selected using KP2BOX and KP2STOP instead of BOX and LAYV4. The SETUP cuts are defined in Table 6. (similar to Table 69 on page 217 tn-k034)

7 $K_{\pi 2}$ branching ratio

The value of $K_{\pi 2}$ branching ratio has been calculated using equation 2. The appropriate values can be found in Tables 1, 2, 3 and Fig. 1 b). The values of f_s== 0.8098± 0.0011 (see table 70 on p. 219 in k034 [2]) and of $\epsilon^{ng}_{T.2}(K_{\pi 2}) = \epsilon T \cdot 2 \cdot IC(K_{\pi 2})$=0.9302±0.0025 (see table 64 on p. 212 in k034 [2]) have been taken from previous 2002 year PNN1 analyses [2].

$$BR(K_{\pi 2}) = \frac{155631 \times 10^5}{0.9302 \cdot 1.459 \times 10^{12} \cdot 0.3049 \cdot 0.78775 \cdot 0.8098 \cdot 0.27428} \quad (4)$$

$$= 0.2149 \pm 0.0008 \quad (5)$$

is in agreement with PDG2007 [5] value 0.2092 ± 0.0012

The run dependence of $K_{\pi 2}$ branching ratio is shown in Fig.2 a) for all runs and b) for sets of data corresponding to approximately equal number of beam K^+ defined by:

$$\sum_{i=1}^{N_{\mathbf{Spill}}} \frac{KBLIVE_i}{Prescale_i} \geq 3000$$

The calculation of $K_{\pi 2}$ branching ratio for runs with different prescale have been done using $A_{K_{\pi 2},Br}$ defined by this runs. The result are shown on Table 4.

Name of value	All runs	Prescale 163840	Prescale 131072
$K_{\pi 2}$ Events	144989	2973	141926
$< Prescale >$	131926	163840	131072
$KB_{LIVE} \times 10^{-12}$	1.79229	0.052475671	1.737988
$A_{K_{\pi 2},Br}$	0.3049 ± 0.0008	0.3106 ± 0.0044	0.3049 ± 0.0008
$K_{\pi 2}$ branching	0.2154 ± 0.0008	0.1836 ± 0.0043	0.2158 ± 0.0008

Table 4: $K_{\pi 2}$ branching ratio results

Difference of the $K_{\pi 2}$ branching ratios for data with prescale 131072 and 163840 is 0.0322 ± 0.0044, i.e. more than 7 standard deviation from zero. The run dependence of the $K_{\pi 2}$ branching ratios for both values of prescale are shown in Fig. 4. The $N_{K_{\pi 21}}$ selection branch for runs with different prescale factor are shown on Table 5 to make a comparison. Statistical error on acceptances' differences has to be ∼ 0.3%.

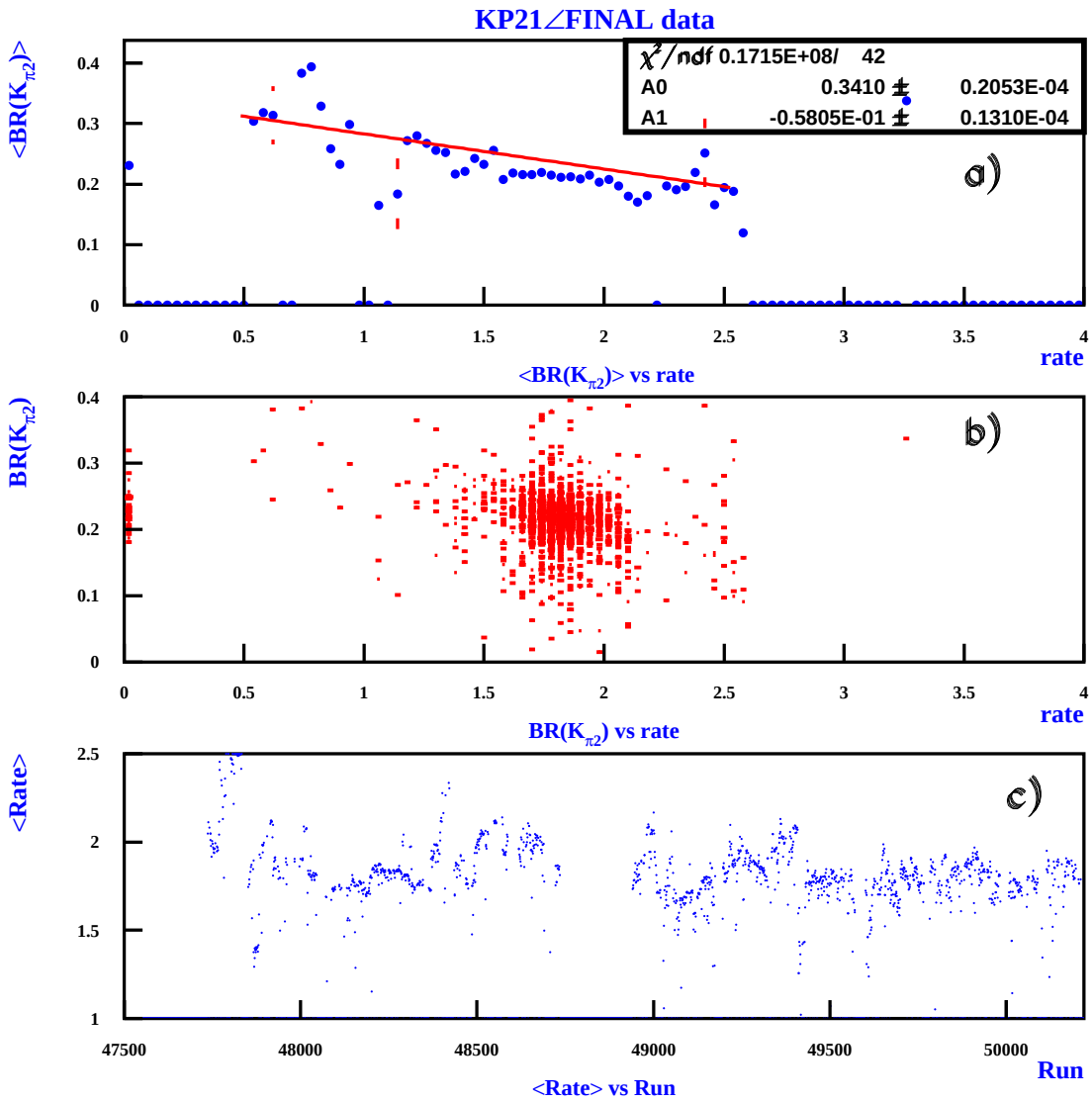

Figure 2: The $K_{\pi 2}$ branching ration a) versus run number and b) versus sets of data with approximately the same beam K^+ mesons

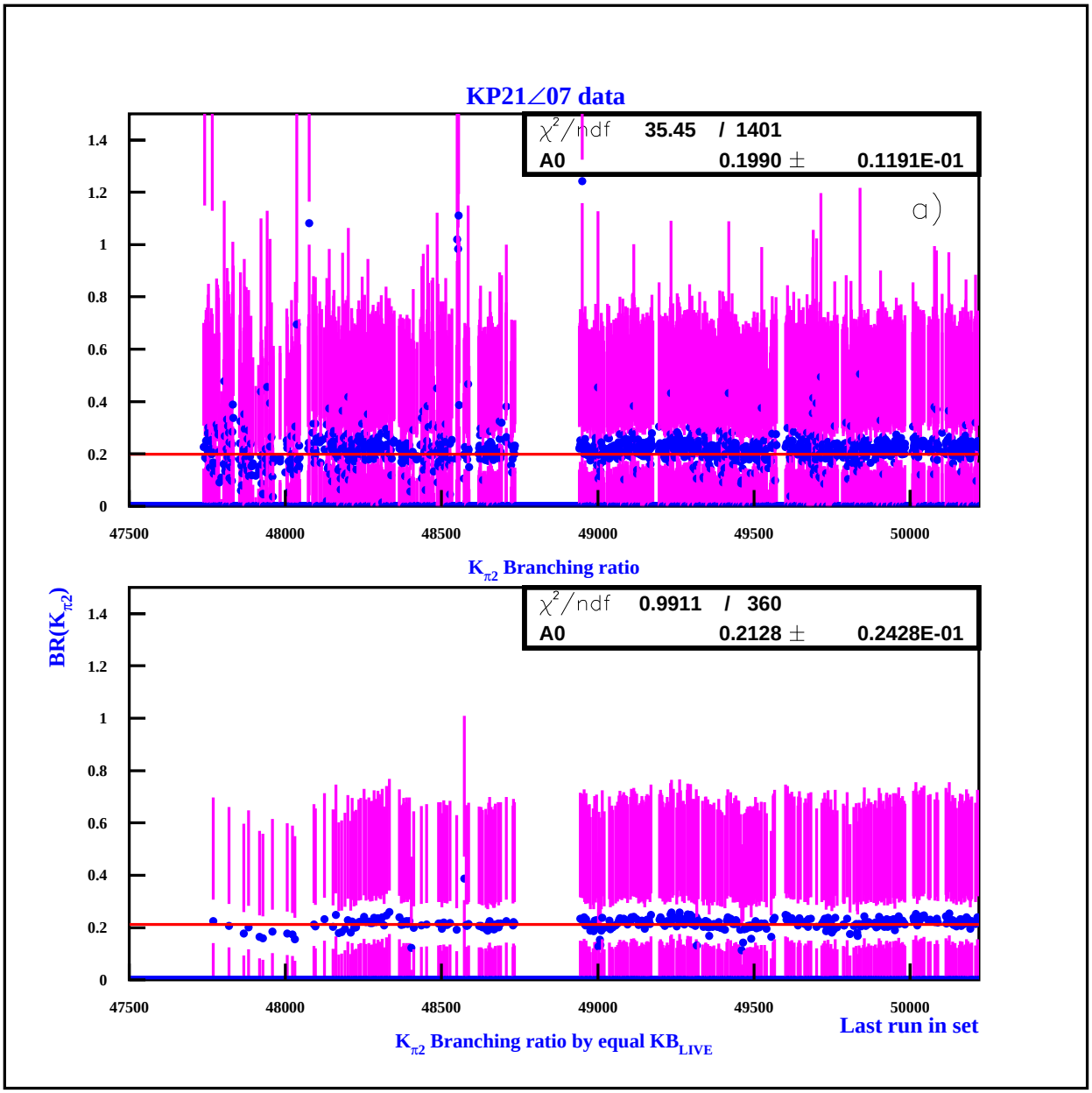

Figure 3: The $K_{\pi 2}$ branching ration a) avarage versus average rate in run and b) versus average rate in run

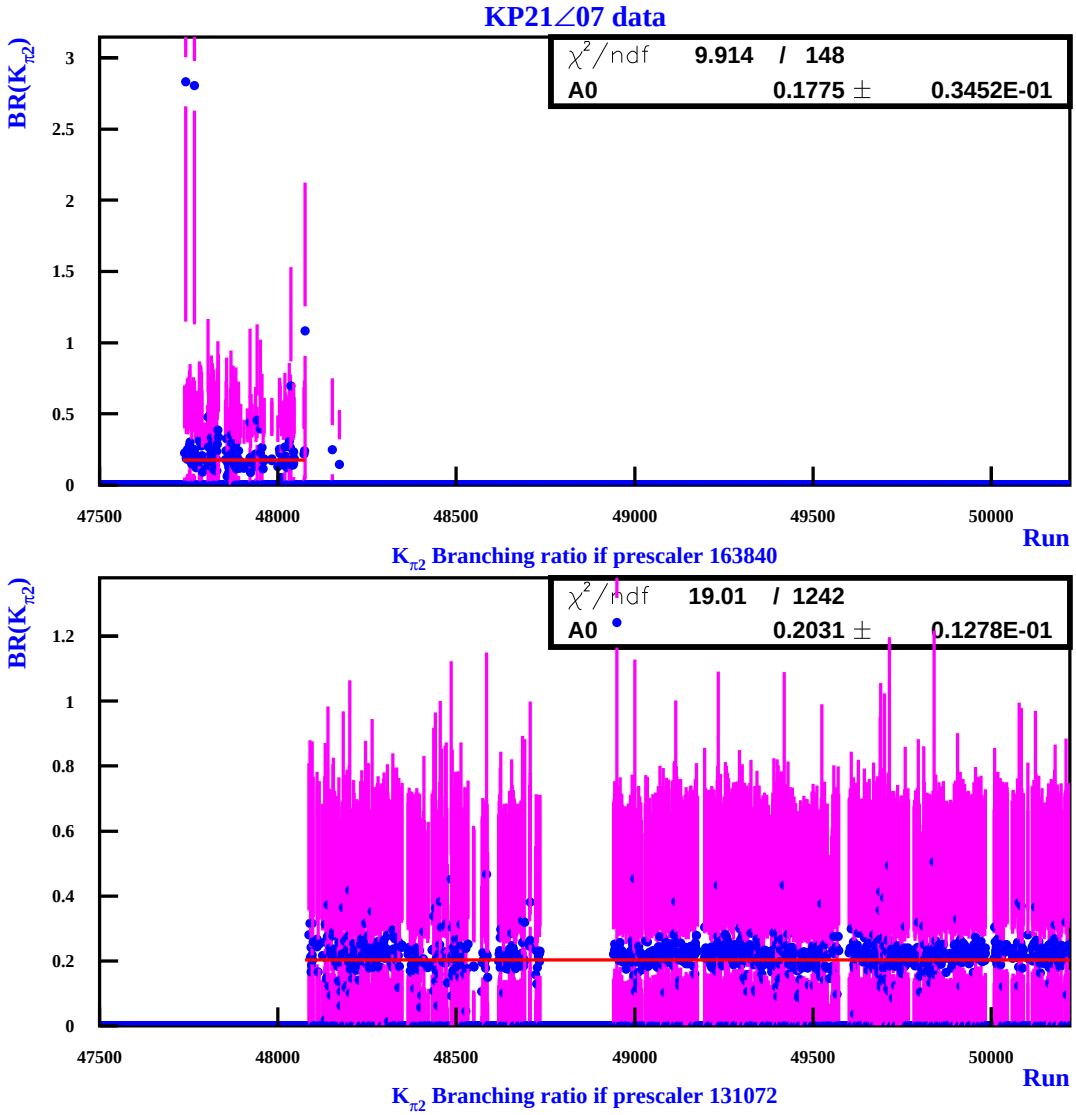

Figure 4: The $K_{\pi 2}$ branching ration versus run number a) for runs with prescaler 163840 and b) for runs with prescaler 131072

Cut name	$N_{K_{\pi 21}}$	
	163840	131072
TRIGGER+Prescaler	18535	859195
BAD_STR -1.839%	18109(0.97702)	855246(0.99540)
RD_TRK 0.000%	18109(1.00000)	855246(1.00000)
TRKTIM 0.000%	18109(1.00000)	855246(1.00000)
RDUTM 0.000%	18109(1.00000)	855246(1.00000)
UTCQUAL -0.729%	15563(0.85941)	741238(0.86670)
TARGET+TGQUALT 0.643%	14390(0.92463)	680603(0.91820)
COS3D -0.804%	13510(0.93885)	644454(0.94689)
B4DEDX 0.247%	13136(0.97232)	625022(0.96985)
CPITRS 0.562%	12967(0.98713)	613466(0.98151)
CPITAIL 0.028%	12959(0.99938)	612914(0.99910)
ICBIT 0.011%	12955(0.99969)	612660(0.99959)
TIC -0.117%	12890(0.99498)	610302(0.99615)
TIMCON 0.068%	12775(0.99108)	604443(0.99040)
TGTCON 0.184%	12615(0.98748)	595759(0.98563)
DCBIT 3.939%	11243(0.89124)	507499(0.85185)
DELC -3.480%	9383(0.83456)	441201(0.86936)
CKTRS 0.076%	9094(0.96920)	427275(0.96844)
CKTAIL -0.284%	8804(0.96811)	414865(0.97096)
BWTRS -0.026%	8307(0.94355)	391554(0.94381)
RVUPV -0.624%	8070(0.97147)	382826(0.97771)
TARGF 0.431%	7673(0.95081)	362341(0.94649)
DTGTTP 0.004%	7673(1.00000)	362328(0.99996)
RTDIF 0.004%	7595(0.98983)	358630(0.98979)
TGQUALT 0.000%	7595(1.00000)	358630(1.00000)
PIGAP 0.239%	7519(0.98999)	354183(0.98760)
TGB4 1.425%	7090(0.94295)	328929(0.92870)
KIC -0.042%	6989(0.98576)	324383(0.98618)
TGGEO 0.635%	5811(0.83145)	267649(0.82510)
B4EKZ 0.488%	5374(0.92480)	246216(0.91992)
B4ETCON -0.027%	5349(0.99535)	245138(0.99562)
TGZFOOL -0.751%	5242(0.98000)	242075(0.98750)
PV_noBV 0.000%	5242(1.00000)	242075(1.00000)
IPIFLG -0.642%	3651(0.69649)	170158(0.70291)
KPI2BOXM -1.890%	2985(0.81758)	142334(0.83648)
KP2STOP -0.115%	2973(0.99598)	141926(0.99713)
RTOT40 0.000%	2973(1.00000)	141926(1.00000)
$N_{K_{\pi 2}}$ -0.479%	2973	141926

Table 5: $K_{\pi 2}$ **selection branch for runs with prescale 131072 and 163840**

8 Discussion of the results.

k Acknowledgments

I am grateful to my BNL colleagues for numerous discussions and in particular to Benji Lewis for the fruitful comments and interesting and stimulating discussions and suggestions.

Appendix A : UMC cut definitions.

The following cuts have been used in the calculation of Monte Carlo kinematic and trigger acceptances for $K_{\pi 2}$ branching ratio measurement.

UMC cut definitions

- **T•A ≡ T•2** This trigger condition is applied in UMC codes and the acceptace is printed into logfile.
- **Reach layer B** The inner nine layers of 19 mm thick counters were ganged together into 3 superlayers reffered as the A, B and C having 4,3 and 2 layers of scintillator, respectively. [3] So the requirement has to be **layv4 $\geq$ 6**. But really this requirement means $(6_{ct} + 7_{ct})$ by Zhe Wang and applied in UMC codes like T•2. So I supposed that it was ≡ lct(6).and.lct(7)=.true. in UMC codes.
- $\overline{19_{ct}}$ μ-veto (see for detail in [2] p.207).
- **UFATE** [1] requires that the pion stopped without decaying or interacting, this is why it has no acceptance loss for the NIDIF-off case.
- **USTMED** requires that the pion stopped in the RS scintillator.
- **USTOP_HEX** The offline reconstructed stopping counter agrees with the real one.

- **UTC/RANGE** The track reconstructed in UTC matches with those reconstructed in Range Stack and Target [1]. It is **RDUTM** cut now.
- **UTCQUAL** The UTCQUAL cuts require a track with a minimum of four z position measurements in UTC.
  A second requirement is a minimum value of 10^{-5} for the likelihood function constructed from the number of used xy hits, the number of UTC layers and the number of unused xy hits in each super layer (see for detail in [2] p.71).
- **TARGET** is SWATH CCD reconstruction cut.
  TARGET ≡ ITGQUAL $\geq$ 2 in PNN1 and ITGQUAL $\geq$ 9 in PNN2.
- **KP2STOP** requires the stopping layer to be between layers 8 and 15 inclusive.
- **COS3D** Cut any event with a dip angle outside the effective detection region $-0.5 < cos3d < 0.5$.
- **KPI2BOX** is a 3σ cut on the $K_{\pi 2}$ range, energy and momentum.

KPI2BOX_MOD used now is:

$$199. < ptot < 215. \quad (6)$$

$$28. < rtot < 35. \quad (7)$$

$$100.5 < etot < 115. \quad (8)$$

[1] UFATE, USTMED and USTOP_HEX [4] are cuts based on UMC truth variables.

Appendix B : Setup cuts for $K_{\pi 2}$ acceptance measurements.

$K_{\pi 2}$ SETUP	component cuts
$SETUP_{RD}$	TRIGGER, ICBIT, $t_{IC} - t_{Ck} > 5$ ns^2, B4DEDX, UTC, TARGET
$SETUP_{recon}$	TRIGGER, ICBIT, $t_{IC} - t_{Ck} > 5$ ns, B4DEDX, CPITRS, CPITAIL, CKTRS, CKTAIL, BWTRS, RVUPV, A_{RD} cuts,
$SETUP_{rest}$	TRIGGER, ICBIT, A_{RD} cuts,A_{recon} cuts, KP2BOX, KP2STOP, IPIFLG, COS3D.

Table 6: **Setup cuts used in the $K_{\pi 2}$-based acceptance measurement and used in $K_{\pi 2}$ BR analysis.(Table 58 on page 201 tn-k034)**

References

[1] **Bipul Bhuyan, "Analyses of the 1997 data in the PNN2 region",E787 TN391.**

[2] **S. Chen, J. Hu, A. Konaka, J. Mildenberger, K. Mizouchi, T. Sekiguchi, D. Vavilov, 2002 $\pi^+\nu\bar{\nu}$ data analyses, E949 K-034, December 2003.**

[3] **André Spence Turcot, "Search for the decay $K+ \to \pi^+\nu\bar{\nu}$" The University of Victoria, Ph.D. Thesis (1994).**

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