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Workshop on the CKM Unitarity Triangle

Durham

K_{l3} prospects from NA48/2.

1 Motivation

In the most precise test of the unitarity condition of CKM matrix:

$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9957 \pm 0.002$ the result is smaller than 1 by more than the combined error, and $|V_{us}|$ contributes near 30% of the total uncertainty. So it would be important to measure $|V_{us}|$ with the per mill precision.

The values of $\Gamma(K_{e3})$ and $\Gamma(K_{\mu 3})$ are the input for the $|V_{us}|$ calculation (they enters as a multiplicative factors), so the precise measurements of these rates would improve the precision of the CKM unitarity test.

2 Largest $K^{\pm}$ decay modes (PDG)

The present experimental situation:

- Decay rates based on the normalization with the kaons (ident. by Cherenkov counters) beam flux. ($\mu^+\nu$ - 1967, $\pi^+\pi^+\pi^-$ - 1970, some less then 2×10^6).
- 20 branching ratios, normalizing each other.
- Constrained fit, increasing the errors for compatibility.

Results for the 6 largest fractions (including most of corresponding radiative decays) :

#	Mode	Fraction	Relative error
1	$\mu^+\nu_\mu$	0.6351 ± 0.0018 %	0.003
2	$\pi^+\pi^0$	0.2116 ± 0.0014 %	0.007
3	$\pi^+\pi^+\pi^-$	0.0559 ± 0.0005 %	0.009
4	$\pi^+\pi^0\pi^0$	0.0173 ± 0.0004 %	0.023
5	$\pi^0\mu^+\nu_\mu$	0.0318 ± 0.0008 %	0.025
6	$\pi^0 e^+\nu_e$	0.0482 ± 0.0006 %	0.012

3 NA48/2 experiment

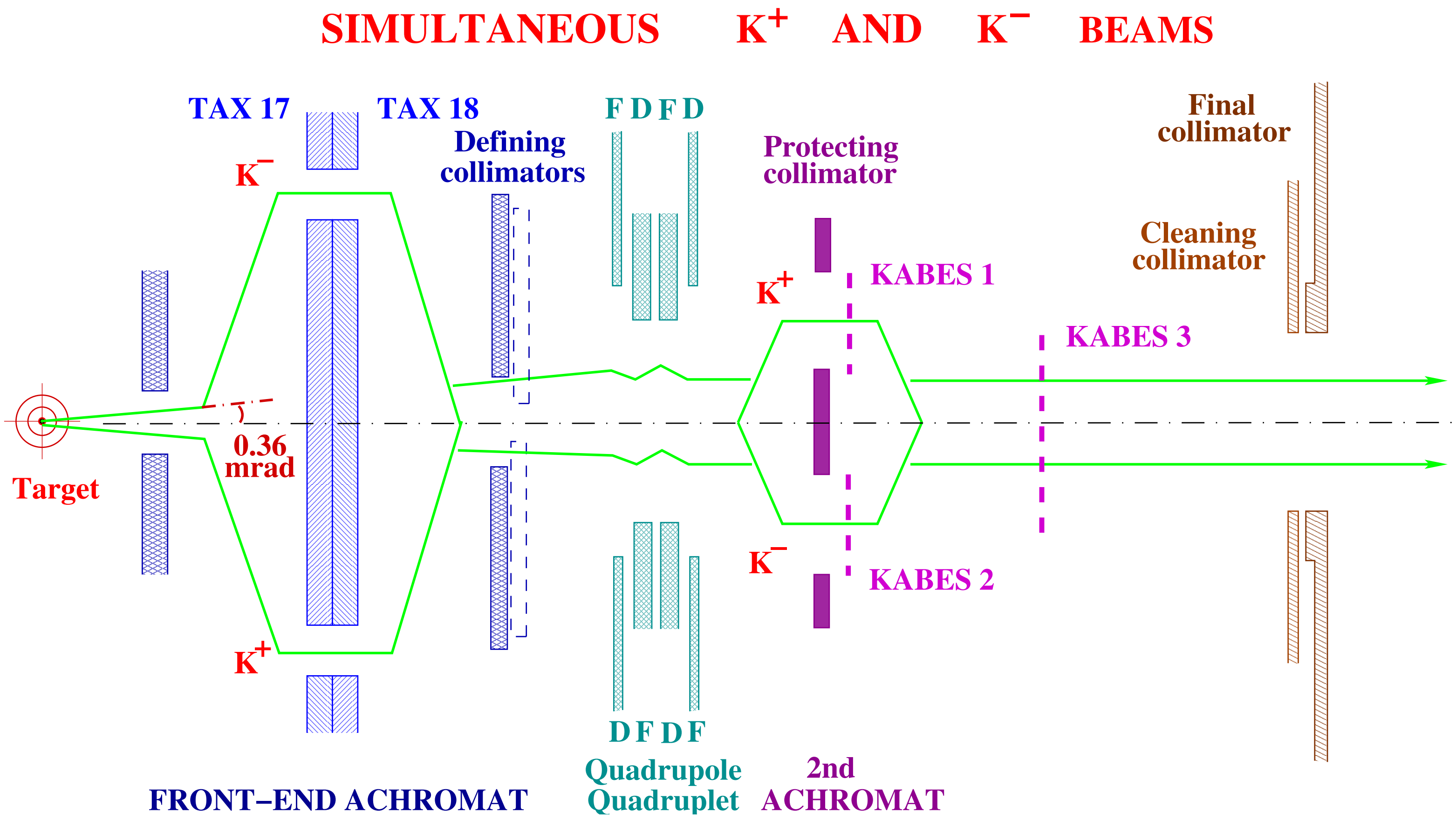

Figure 1: NA48/2 beam line

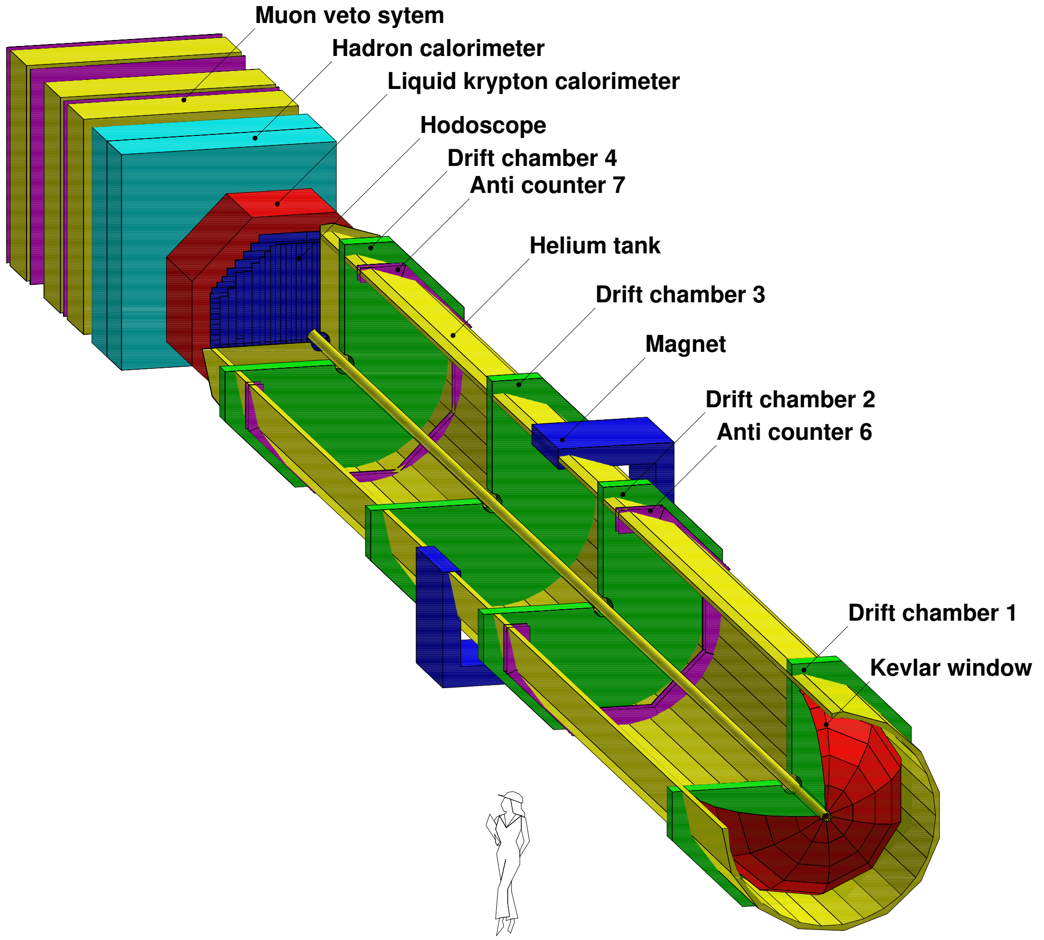

Figure 2: NA48 detector

- The main NA48/2 goal is a search for the CP violation in the asymmetry of $\pi^+\pi^+\pi^-$ and $\pi^+\pi^0\pi^0$ Dalitz plots between the kaons of the opposite charge. The additional tasks have not to disturb the main data taking process.
- The narrow momentum spectrum $(60 \pm 3$ GeV$)$ of charged kaons.
- KABES will provide the kaon momentum measurement with 1% precision.

4 Measurement with similar normalizing mode

If one try to normalize the branching measurement with the similar decays, one can measure the branching ratios $\frac{Br(\pi^0 e^+ \nu_e)}{Br(\pi^+ \pi^0)}$ and $\frac{Br(\pi^0 \mu^+ \nu_\mu)}{Br(\pi^+ \pi^0)}$.

Pro: the same number of γ and charged tracks may decrease the sensitivity to the Monte Carlo acceptance calculations.

The error of the measured fraction Br with B_2 as normalizing one is (ignoring the acceptance errors):

$$\delta Br = \frac{N}{N_n} B_2 \left(\frac{\delta B_2}{B_2} + \sqrt{\frac{1}{N} + \frac{1}{N_n}}\right) \tag{1}$$

Contra: We can not decrease the relative error of K_{l3} fractions better than 0.007 (error of $Br(\pi^+\pi^0)$) in this way. To be realistic, it is not better than 1% (the statistics doesn't limit us here, but Monte Carlo uncertainty will contribute something).

One can try to measure $\frac{Br(\pi^0\mu^+\nu_\mu)}{Br(\mu\nu)}$.

Pro: Better precision of the $Br(\mu\nu)$ (relative error 0.003). May be some cancelling of the Muon Veto efficiency.

Contra: $(\mu\nu)$ doesn't have γ and the event is not very similar to $K_{\mu 3}$ from the detector point of view. We will rely more on the precision of the acceptances calculation.

5 Using all large modes for normalizing

One can record all the large fractions (with a proper downscalings), including $(\mu^+\nu_\mu)$ **together with the corresponding radiative**

processes: $\mu^+\nu_\mu\gamma$, $\pi^+\pi^0\gamma$ etc..

In this case the sum of 6 fractions is $0.9999 \pm 0,0026$. This error doesn't take into account a constrain. One can see the sum of all the PDG rare non-radiative decay modes (excluding the exotical ones), the result is 0.00011 ± 0.00013. This contribution is negligible for our purposes.

Assuming that 6 largest modes together are ≈ 1 , we may calculate the specific large branching ratio Br_x as follows:

$$Br_x = \frac{N_x D_x / A_x}{\Sigma N_i D_i / A_i} = (\Sigma \frac{D_i}{D_x} \frac{A_x N_i}{A_i N_x})^{-1} \tag{2}$$

Here N_i is the number of reconstructed i-th mode decays, A_i is the acceptance of the mode, D_i is the corresponding constant downscaling. The sum is running over the first 6 modes, indexed by i.

The expression for the error is:

$$\frac{\sigma Br_x}{Br_x} = \sqrt{(1 - Br_x)^2((\frac{\sigma A_x}{A_x})^2 + \frac{1}{N_x}) + \Sigma_{i \neq x} Br_i^2((\frac{\sigma A_i}{A_i})^2 + \frac{1}{N_i})} \tag{3}$$

We have possibility to collect a lot of data, so the error will be $\approx$ the acceptance calculation error. In the very optimistic case the acceptance precisions may reach per mill level, so one need not more than 10^6 events for each large mode (or less than 10 good events per burst in each mode, as normally we have 200 000 - 300 000 bursts a year in NA48).

6 Possible triggers and statistics

The simplified Monte Carlo estimations: In the decay volume 108 m. we will have near 1.04×10^6 charged kaon decays and about 1.75 times more pion decays. From the test run 2001 year we expect a considerable flux of muons from target, but it will be much weaker in 2003 due to the beam line development.

#	Mode	acceptance	events/burst
1	$\mu^+\nu_\mu$	76 %	503000
2	$\pi^+\pi^0$	22 %	48000
3	$\pi^+\pi^+\pi^-$	26 %	15000
4	$\pi^+\pi^0\pi^0$	7 %	1300
5	$\pi^0\mu^+\nu_\mu$	24 %	8000
6	$\pi^0e^+\nu_e$	17 %	8500

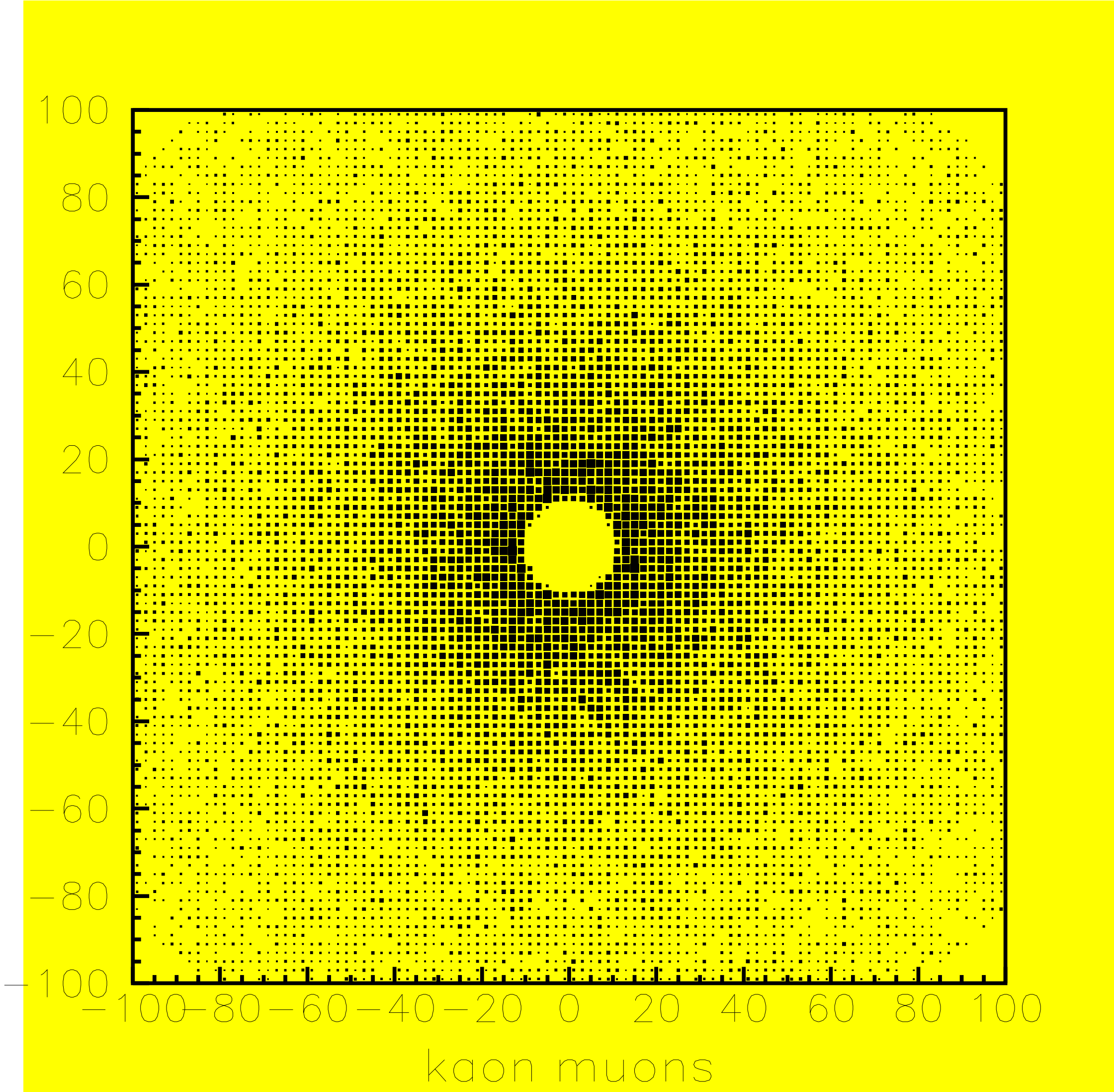

Figure 3: Muons from the kaon decays on the calorimeter plane

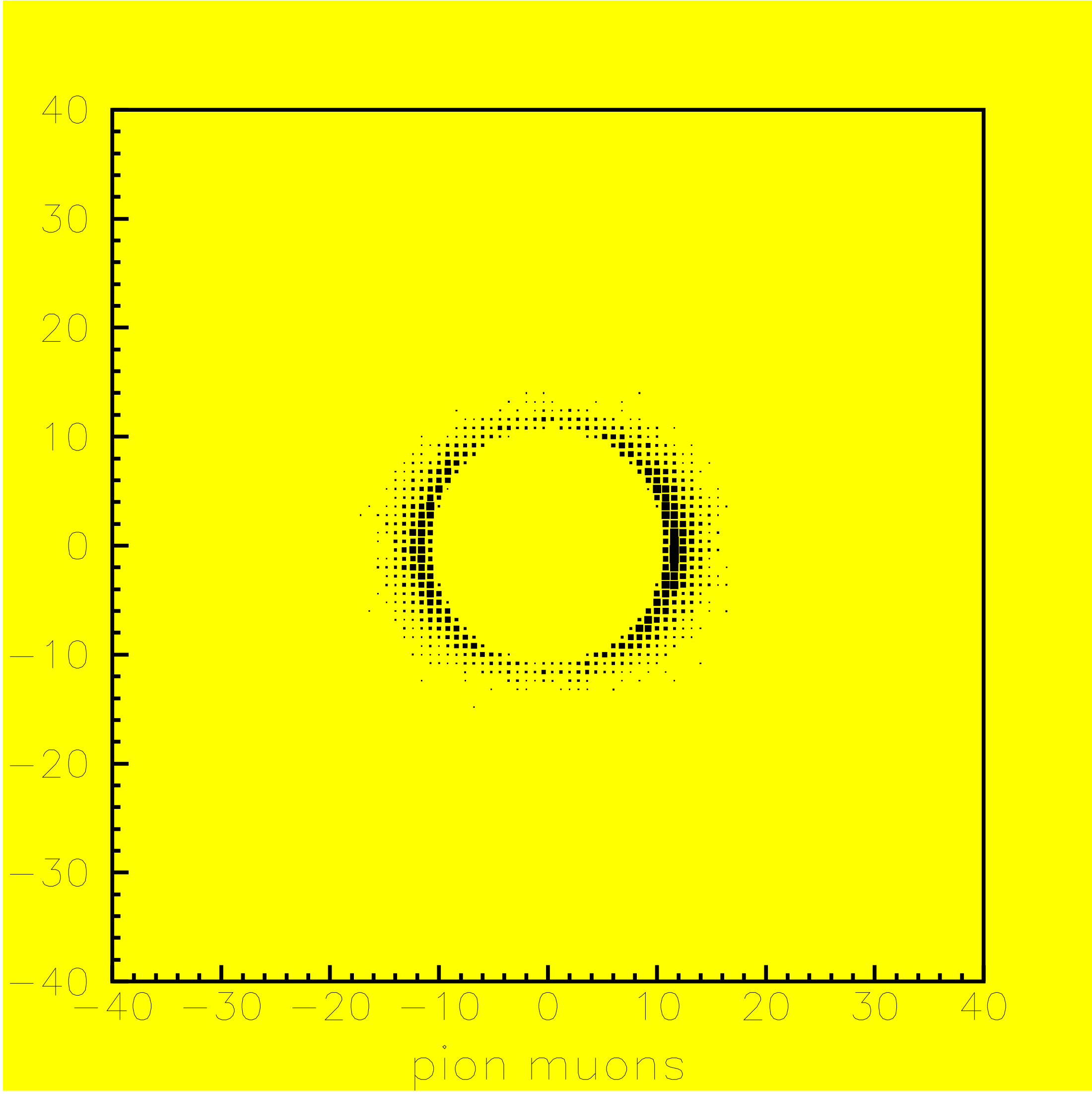

Figure 4: Muons from the pion decays on the calorimeter plane

A huge amount of $\pi^+\pi^+\pi^-$ and $\pi^+\pi^0\pi^0$ (billions) will provide a chance to make a precise tuning of the Monte Carlo (beam geometry, acceptances, spectra).

Maximum trigger readout rate is 60K in 5.2 s spill (as in 2002). Main triggers for 3π may use 50-55 K (the purity of the trigger for $\pi^+\pi^+\pi^-$ in the worst case is 0.4, for $\pi^+\pi^0\pi^0$ the expected trigger rate is 16K). So only few thousands could be used for other purposes. Is it enough to take the other 4 large modes?

If we consider a rather conservative scenario of data taking (simple, but efficient triggers with a proper downscalings), we can collect more than 20 good events for each of the above modes, taking less than 1700 extra triggered events in total. Smarter triggers will decrease this amount.

The estimations are based on the test run 2001 data and Monte Carlo.

7 Conclusion

- The K_{e3} and $K_{\mu 3}$ branching ratios measurement is foreseen in the charged kaon beam of NA48/2 experiment as a second-priority task.
- The dominating contribution to the uncertainties will be systematic rather than statistical error.
- The data can be taken without disturbing the main NA48/2 tasks. The additional output triggers rate will be less than 2000 / burst.
- The relative branching error achieved will be between 1% and 1%%, depending on the Monte Carlo acceptances calculation precision.