Beam-residual gas interactions

Expected background to $K^+ \to \pi^+ \nu\nu$ in NA48/3 exp.

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Vacuum Level and background

NA48 make use of a ~50 m long decay region in a vacuum tank
The achieved vacuum level in the past was around 10^{-5} mbar

Beam particles (K^+,p, π^+) may interact with the residual air (N_2 , O_2) and outgoing charged particles may cause **background**

Which is the maximum pressure we can live with?

$$\frac{N_{BKG}}{N_{signals}} = \frac{\Sigma \Phi_i \, n(P) \sigma \, \Delta Z \, \epsilon_{bkg}}{\Phi_K \, BR(K^+ \to \pi^+ \nu \nu) \epsilon_{signal}} \qquad (i = K^+, p, \pi^+)$$

Basic formula !

n(P) = density of scattering center depending on pressure P
σ = cross section (particle/gas) (estimated with FLUKA)
Φ_i = Flux of i-type particle (i= K^+,p, π^+, e^+)
ΔZ = decay volume length
ε = acceptance (estimated by Toy Montecarlo with NA48 geometry)

Beam and fluxes

Total flux	250 x 10^7 particles per pulse
Spill	4.8 s
Duty cycle	4.8/16.8 ~ 0.30%
Energy	75 GeV ± 1%
charge	+1

The beam approsimated as a mixture of

π : p : K = 55 : 37 : 8

the small fraction of positrons is ignored

Cross sections

FLUKA package has been used to compute hadrons onto Oxygen cross sections and to simulate final states.

(See next talk for details)

Reaction	σ(mb)	events
π O --> X	220	10^5
p O --> X	295	10^5
K O --> X	195	10^5

Oxygen target at rest and hadrons energy at 75 GeV

We warmly thank **Alfredo Ferrari** for his helpful support.

Typical final state

Particle		px	py	pz	m	Z	A
Initial state							
	2100211	0.0000	0.0000	75.0000	0.1396	1	0
	2109999	0.0000	0.0000	0.0000	14.8951	8	16
Final state							
n	102112	-0.0745	0.1869	0.0336	0.9396	0	1
	102112	-0.0238	0.0113	-0.0195	0.9396	0	1
	102112	-0.2857	-0.4098	0.2939	0.9396	0	1
	102112	-0.0879	0.0289	0.9447	0.9396	0	1
	102112	-0.4969	0.4321	-0.1159	0.9396	0	1
π^-	-100211	0.1968	-0.5720	0.7997	0.1396	-1	0
	100211	-0.2153	0.1342	0.7236	0.1396	1	0
	-100211	0.0367	0.0704	0.9362	0.1396	-1	0
	100211	0.1263	-0.1414	0.6533	0.1396	1	0
	-100211	-0.2164	-0.0334	2.7464	0.1396	-1	0
	100211	0.2092	0.3103	0.8512	0.1396	1	0
	-100211	0.3839	-0.2815	6.0369	0.1396	-1	0
	100211	0.3769	0.1178	3.5049	0.1396	1	0
	100211	-0.2388	-0.1356	0.0606	0.1396	1	0
π^0	100111	0.5304	0.0106	0.4749	0.1350	0	0
	100111	-0.0675	0.3797	2.4015	0.1350	0	0
	100111	**-0.6527**	**0.4946**	**47.1403**	**0.1350**	**0**	**0**
	100111	0.5698	-0.3927	6.2058	0.1350	0	0
p	102212	0.0758	-0.2708	0.9107	0.9383	1	1
	102212	-0.1073	-0.2531	0.0414	0.9383	1	1
	102212	0.0915	0.0698	0.1194	0.9383	1	1
	102212	-0.0977	-0.0297	0.0732	0.9383	1	1
	109999	0.3723	0.2385	0.1144	2.8084	2	3
	109999	-0.4052	0.0348	0.0688	3.7274	2	4

Reaction:

$\pi^+ O \rightarrow 4p + 5n + He^3 + He^4 + 4\pi^0 + 4\pi^- + 5\pi^+$

$\downarrow$

8γ

Neutrons

Charged pions

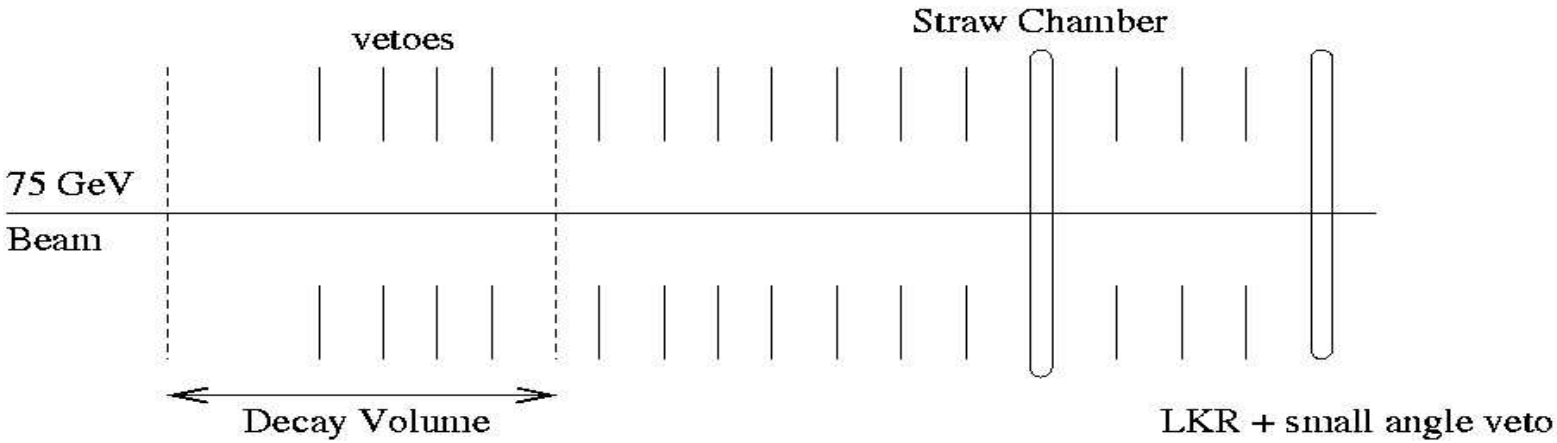
Neutral pions

(leading particle)

Protons

Nuclear fragments

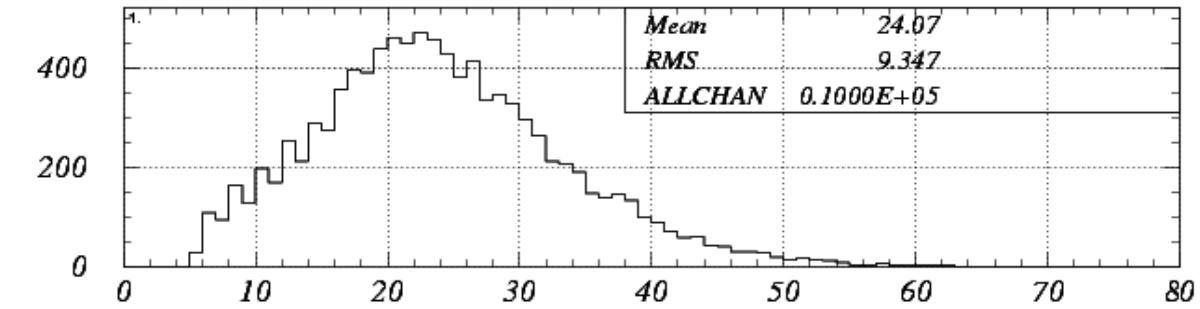
Acceptance (toy montecarlo)



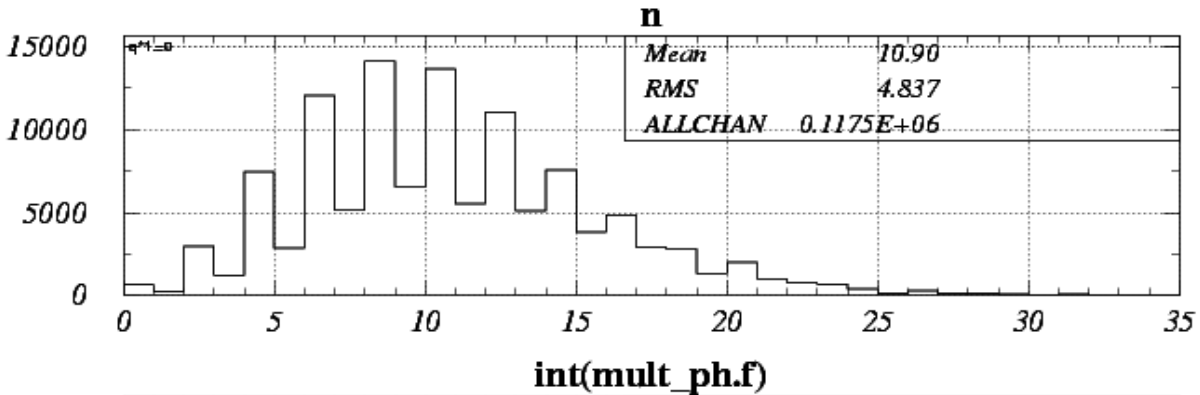
Simplified Geometry:

1) Vetoes, straw and LKR are circular corona
2) Decay vertex: flat random inside the decay volume
3) Charged particles and photons propagate along the geometry
4) π^o **--> $\gamma\gamma$, (eta mesons are fews and ignored)**
5) **Kaons are considered stable, no decay in flight**
6) **Blindness for any objects with E < 50 MeV**
7) **Blindness to neutrons with any energy**

Multeplicities in reaction π^+ O

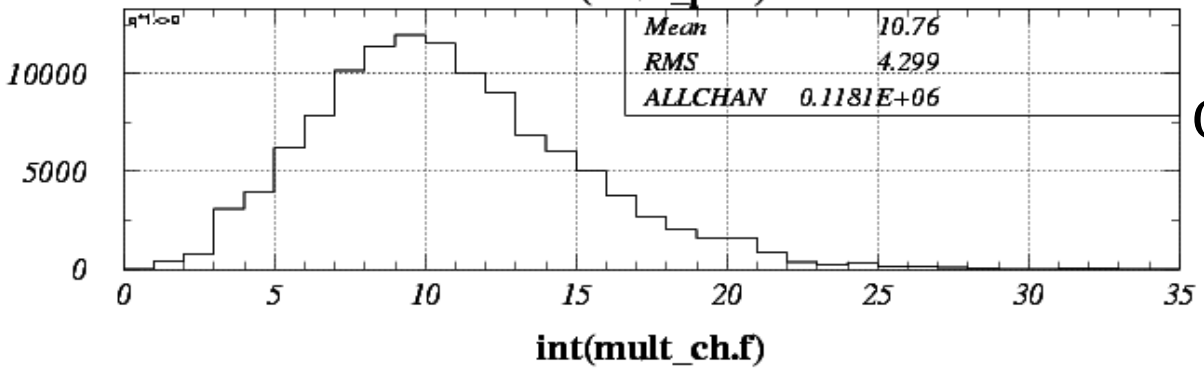


All final objects



Photons (**E > 50 MeV**)

Stucture because π^o --> $\gamma\,\gamma$



Charged tracks (**E > 50 MeV**)

$K^+ \to \pi^+ \nu\nu$ reconstuction

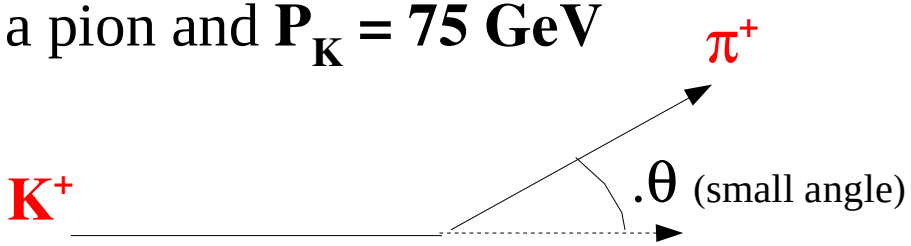
Ntrack = 1

momentum 8 < p < 40 GeV

charge = +1

no signal in Vetoes and no extra-hit in LKR

missing mass squared $\mathbf{m^2_{\nu\nu}}$ computed assuming the track is a pion and $\mathbf{P_K = 75\ GeV}$



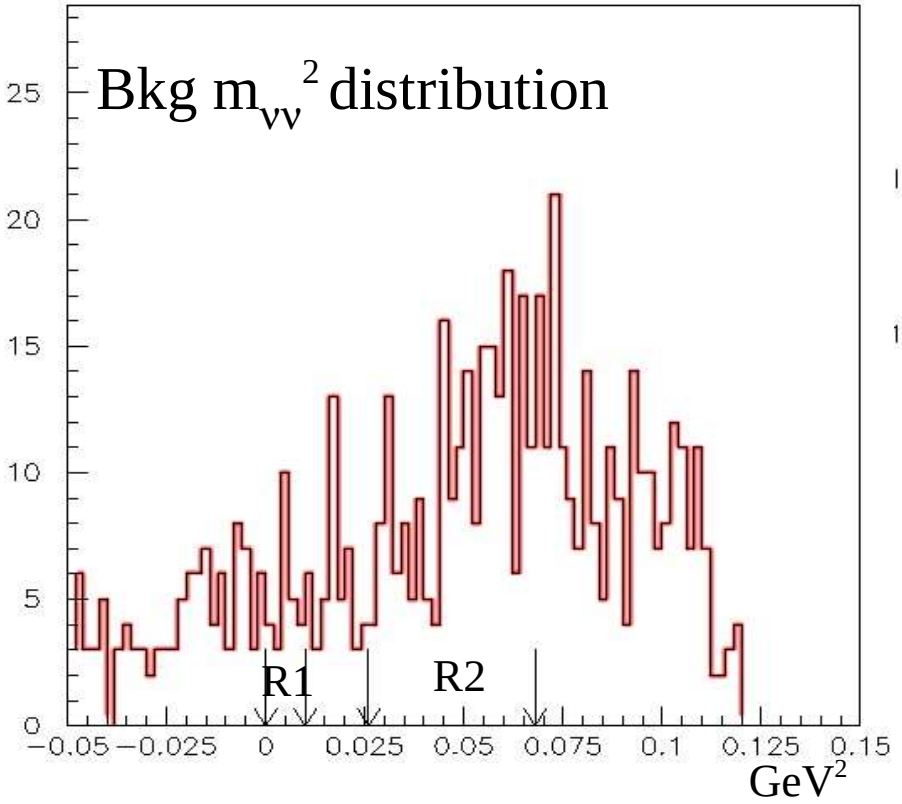
$$m^2_{\nu\nu} = m^2_K + m^2_\pi - P_K\, p\, \theta^2 - m^2_K \frac{p}{P_K} - m^2_\pi \frac{P_K}{p}$$

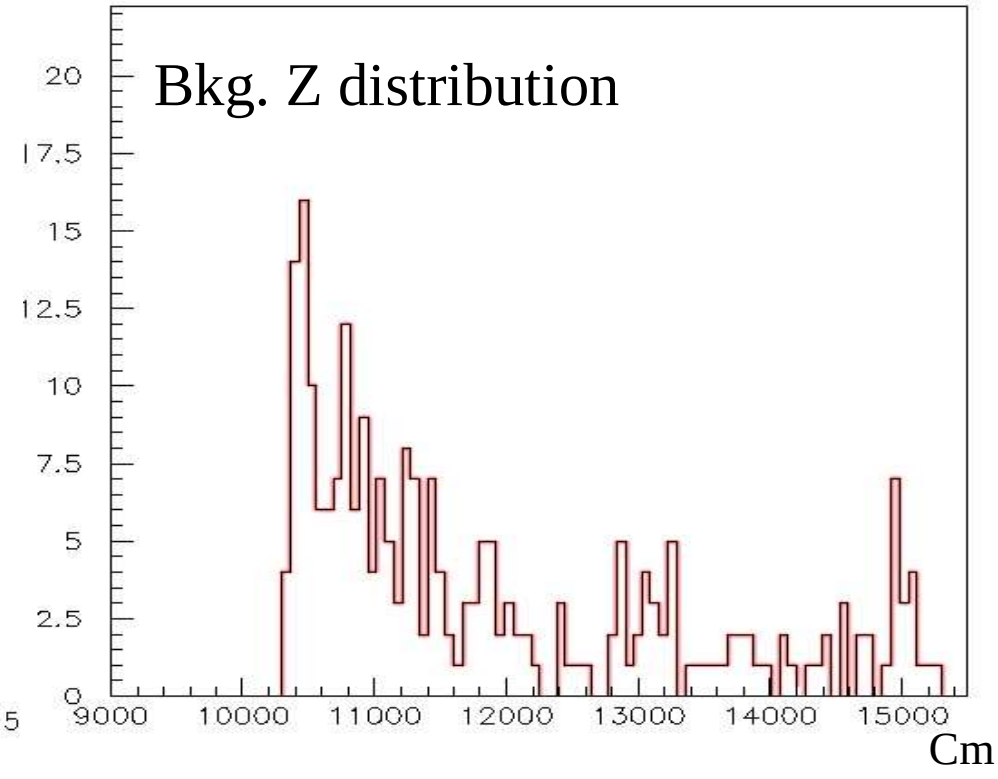
$0 < m^2_{\nu\nu} < 0.01\ GeV^2$ (Signal Region I)

$0.026 < m^2_{\nu\nu} < 0.068\ GeV^2$ (Signal Region II)

Background acceptance

Interaction	events	Region I	Region II	Total	Acceptance (10^{-4})
π O	10^5	2	33	35	3.5 ± 0.6
p O	10^5	11	103	114	11.4 ± 1.1
K O	10^5	13	79	92	9.2 ± 1.0





All ingredients are ready

$$\frac{N_{BKG}}{N_{signals}} = \frac{\Sigma \Phi_i \, n(P) \sigma \, \Delta Z \, \epsilon_{bkg}}{\Phi_K \, BR(K^+ \to \pi^+ \nu \nu) \epsilon_{signal}} \qquad (i = K^+, p, \pi^+)$$

Basic formula !

$N(P) \cong 2 \times 2.5 \times 10^{16}$ P (mbar)

Density of atoms per cm^3 at T=300 K and pressure P (mbar)
target is common air (20% O_2 , 80% N_2)
The cross sections for Nitrogen have been scaled as $(14/16)^{2/3}$

$BR(K^+ \to \pi^+ \nu\nu)$ ε(signal) $\cong$ $10^{-10} \times 0.1$

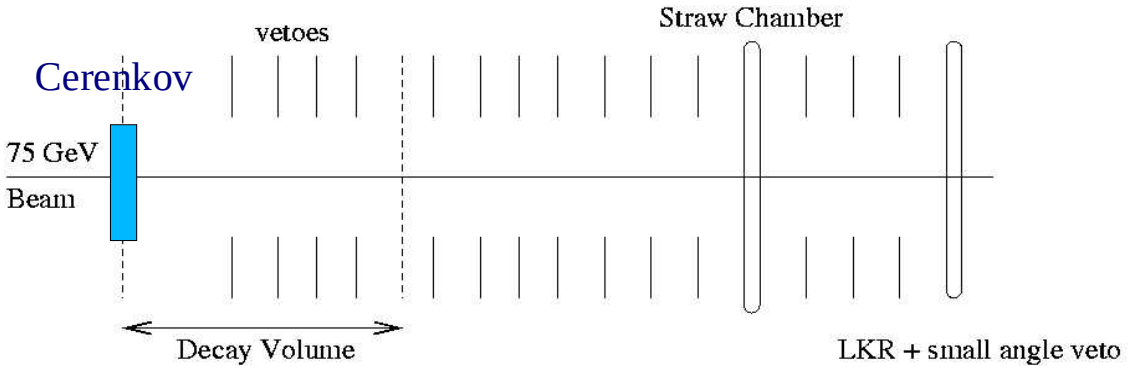
Bkg/signal $\cong$ 5×10^4 P(mbar)

P $\cong 2 \times 10^{-7}$ mbar is to be mantained in the 50 m long decay volume to limit the background at the 1% level
The vacuum should be 2 order of magnitude better than NA48/2

If we add a Cerenkov counter....

Let's suppose a 100% efficiency detector to tag Kaon upstream the decay volume

The requirement for a $\pi\nu\nu$ candidate to have in coincidence a signal in the Cerenkov rejects the bkg component due to pions or protons



$$\frac{N_{BKG}}{N_{signals}} = \frac{n(P)\sigma\,\Delta Z\,\epsilon_{bkg}}{BR(K^+ \to \pi^+ \nu\,\nu)\epsilon_{signal}}$$

Bkg/signal $\cong 4.5 \times 10^3$ P(mbar)

Basic formula !

Factor ~ 10 gained

Conclusions

According to the cross section predicted by FLUKA, the NA48/3 set up to measure $\mathbf{K^+ \to \pi^+ \nu\nu}$ requires a 2 order of magnitude increase of the vacuum level in the 50 m long decay volume to reach the value

$$\mathbf{P \cong 2 \times 10^{-7}\ mbar}$$

If **high efficient and high purity Cerenkov** detector is placed along the beam line, 1 order of magnitude better would be enough.

Room to improve the toy montecarlo: decay in flight, resolution, etc..

Many thanks to FLUKA