Measuring $K^+ \to \pi^+ \nu\bar{\nu}$ with NA48/3

Rainer Wanke

Institut für Physik, Universität Mainz

on behalf of

CERN, Dubna, Ferrara, Florence, Frascati, Mainz, Merced, Moscow, Naples, Perugia, Pisa, Protvino, Rome, Saclay, Sofia, Torino

K-RARE Meeting

Frascati, May 26, 2005

Outline

- **Introduction**
- **K^+ Beam**
- **Detector Design**
- **Time Schedule**
- **Summary and Conclusion**

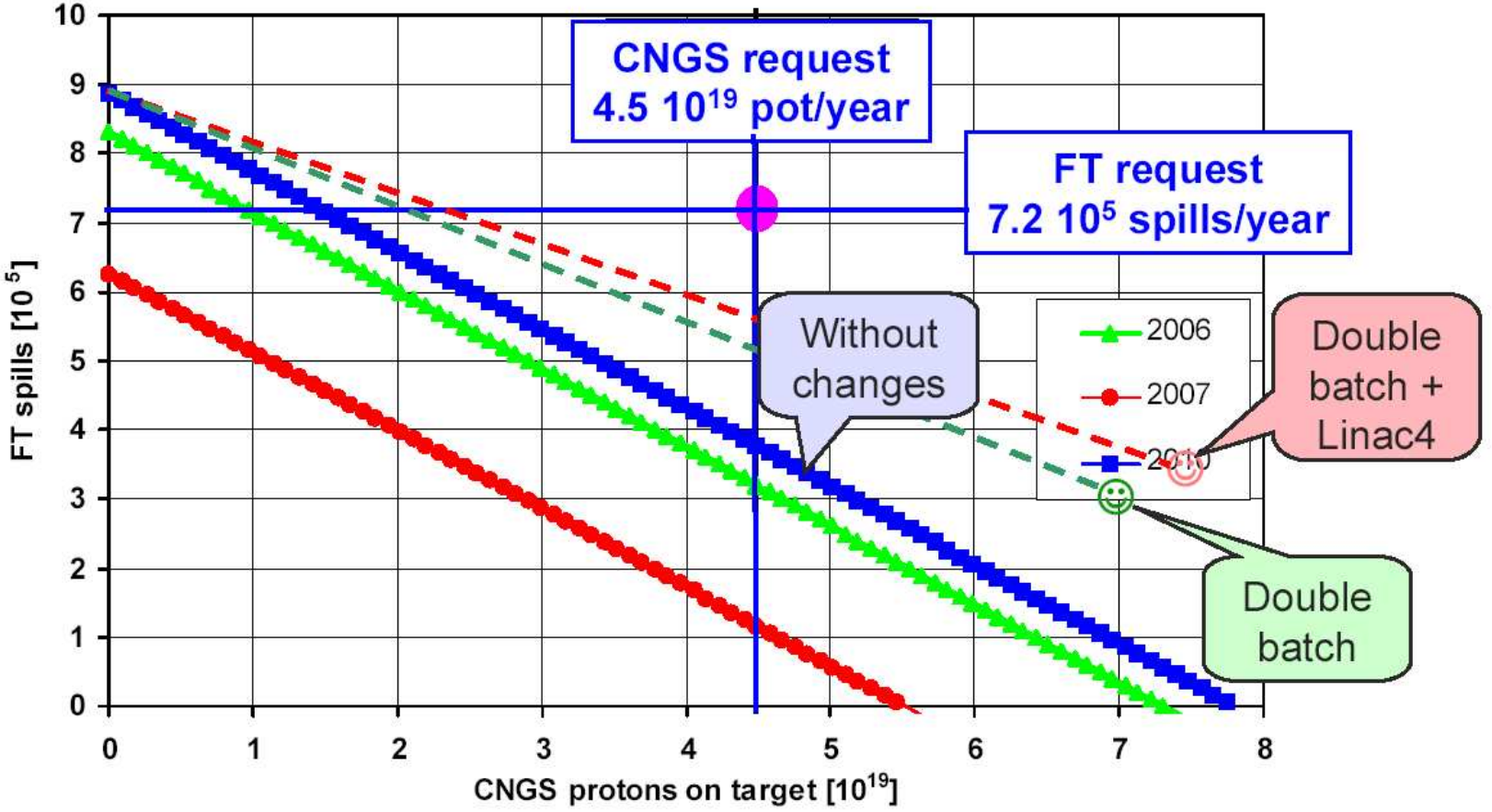
Nota bene:

Exp. historically dubbed NA48/3, but *not* direct successor of NA48/2!
Mainly new detectors, and will get new name when approved.

Correct name at the moment: **P326** (Proposal no. 326)

The Opportunity

Expected SPS Performance for Fixed-Target: (R. Garoby, Villars 2004)



$\Longrightarrow$ $\geq 3 \times 10^5$ **proton spills per year** for fixed-target.

High Intensity K^+ Beam

Parameters of the high intensity K^+ beam:

	K12 in 2004 (NA48/2)	**HI-K^+ $\geq$ 2007** (NA48/3)
Eff. run time/year (pulses)	3×10^5	3×10^5
SPS protons/pulse	1×10^{12}	3×10^{12}
K^+ momentum	60.0 ± 2.5 GeV/c	75.0 ± 0.8 GeV/c
Acceptance solid angle	0.4 μsterad	16 μsterad
Total beam flux/pulse	5.5×10^7	250×10^7
kaons/pulse	0.3×10^7	15×10^7
K^+ decays/year	$\mathbf{1.0 \times 10^{11}}$	$\mathbf{4.8 \times 10^{12}}$

$K^+ \to \pi^+ \nu\bar{\nu}$ at the CERN SPS

NA48/3:

- 4.8×10^{12} K^+ decays/year
- $\mathrm{Br}(K^+ \to \pi^+ \nu\bar{\nu}) \sim 10^{-10}$
- Acceptance $\sim 10\%$
- Dead time $\sim 20\%$

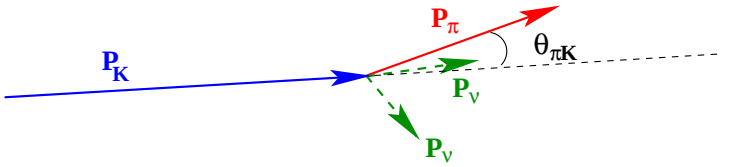
$\Longrightarrow$ About **$80\ K^+ \to \pi^+ \nu\bar{\nu}$** events in 2009/10.

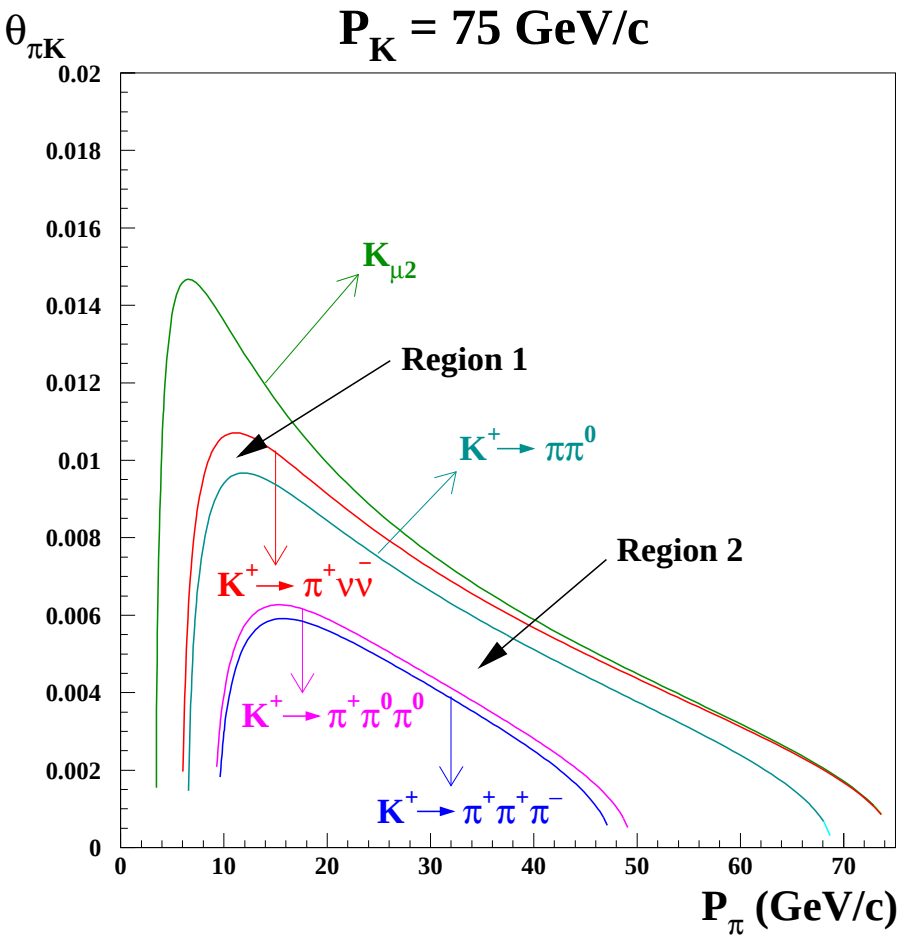
- Background:

  $K^+ \to \pi^+ \pi^0$ (Br ≈ 0.2),
  $K^+ \to \mu^+ \nu$ (Br ≈ 0.6)

  $\Longrightarrow$ Photon/muon vetos, exact momentum meas.

- **Signal/Background ≈ 10.**



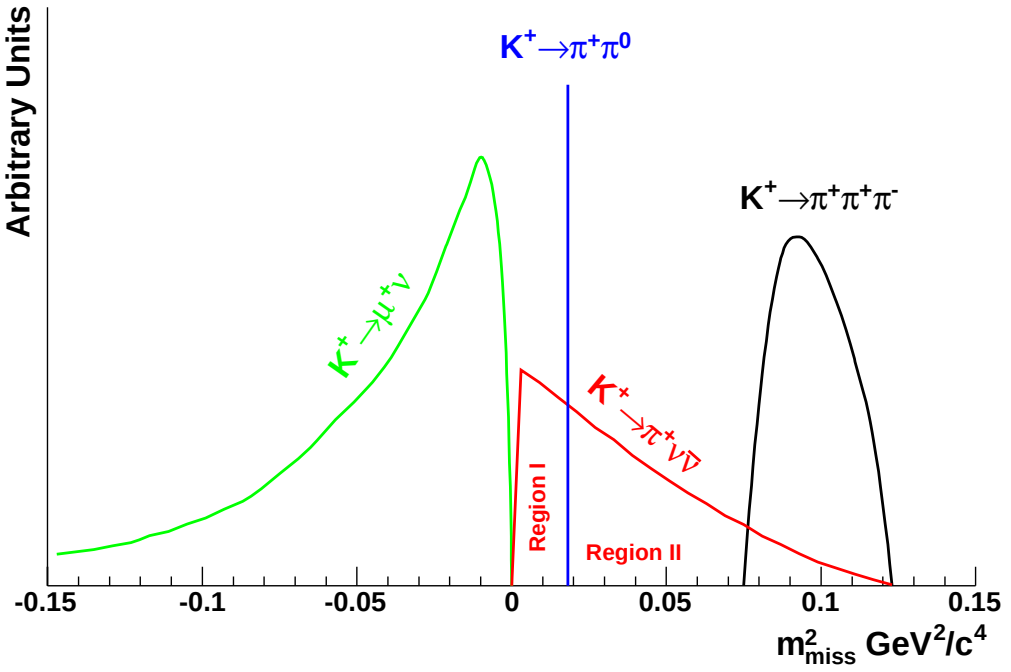


Acceptance

Two regions for measuring $K^+ \to \pi^+ \nu\bar{\nu}$:

- **Region 1:** $0 < m^2_{\text{miss}} < 0.01$ GeV$^2/c^4$ $\Longrightarrow$ **Acc** $\approx 4.5\,\%$
- **Region 2:** $0.026 < m^2_{\text{miss}} < 0.068$ GeV$^2/c^4$ $\Longrightarrow$ **Acc** $\approx 14.5\,\%$

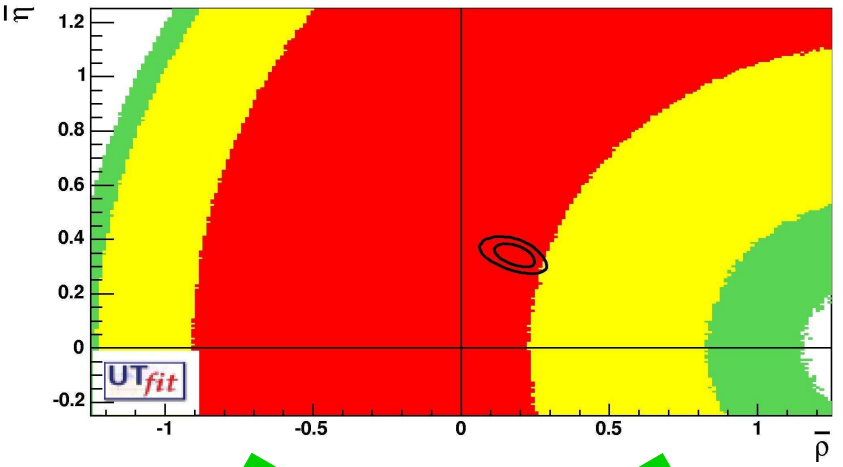
(Both with $15 < p_\pi < 35$ GeV/c, no analysis cuts, no dead time yet)



$$m^2_{\text{miss}} = (p_K - p_\pi)^2 = m_K^2 + m_\pi^2 - 2\,E_K\,E_\pi + 2\,\vec{p}_K\,\vec{p}_\pi\,\cos\theta_{K\pi}$$

In 2010?

Now:
(3 events)



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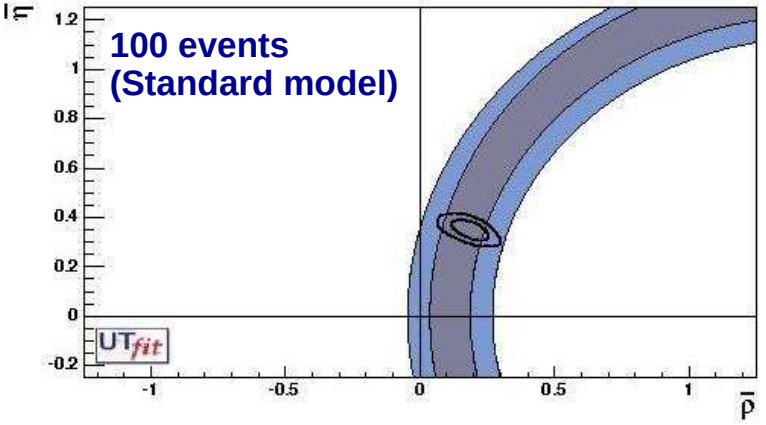
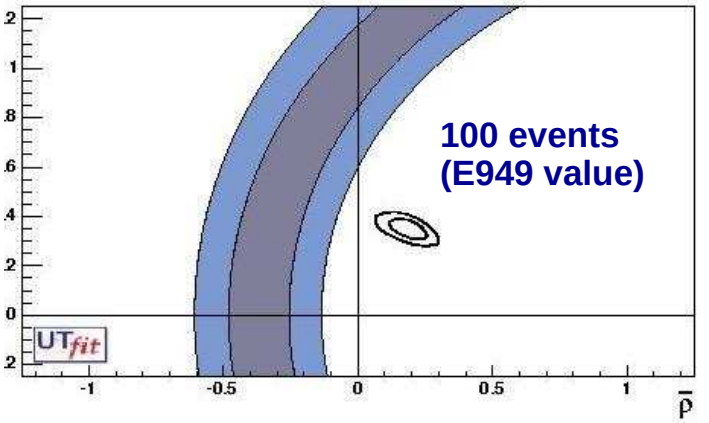
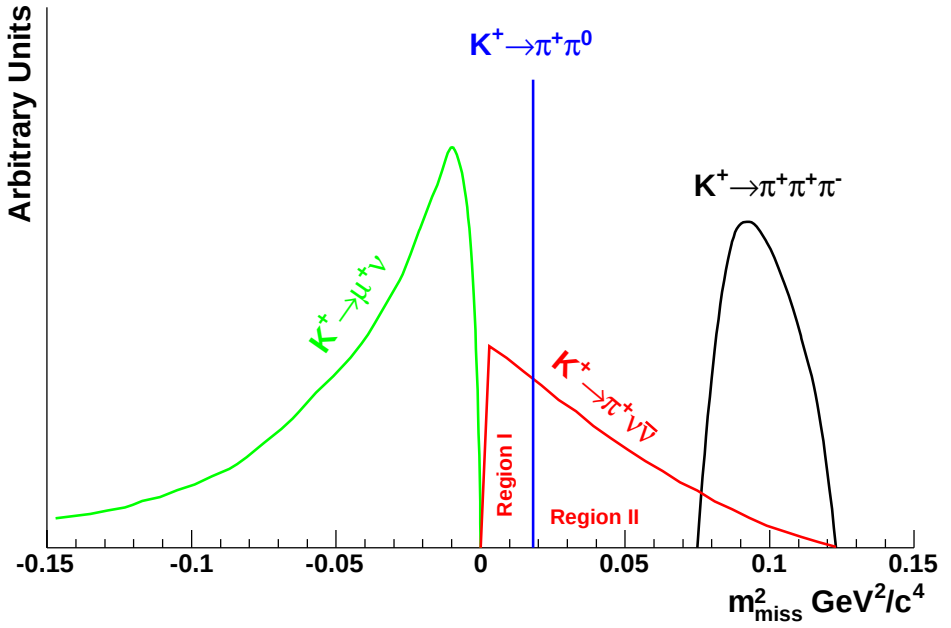




Backgrounds for $K^+ \to \pi^+ \nu \bar{\nu}$

Decay	B.R. [%]	Type of rejection
$K^+ \to \mu^+ \nu$ ($K_{\mu 2}$)	63	μ particle ID, kinematics
$K^+ \to \mu^+ \nu \gamma$ ($K_{\mu 2 \gamma}$)	0.55	μ particle ID, photon veto
$K^+ \to \pi^+ \pi^0$	21	photon veto, kinematics
$K^+ \to \pi^+ \pi^+ \pi^-$	6	charged veto, kinematics
$K^+ \to \pi^0 \pi^0 \pi^+$	2	photon veto, kinematics
$K^+ \to \pi^0 \mu^+ \nu$ ($K_{\mu 3}$)	3	photon veto, μ particle ID
$K^+ \to \pi^0 e^+ \nu$ (K_{e3})	5	photon veto, E/p



Detector Design

Detector design follows from need for maximum background rejection:

- Precise knowledge of K^+ momentum for m^2_{miss} determination.

  $\Longrightarrow$ **Gigatracker** — K^+ beam spectrometer

- Photon rejection.

  $\Longrightarrow$ **Photon-Vetos** — LAV, Lkr, SAC

- Precise π^+ momentum measurement to reject two-body decays

  $\Longrightarrow$ **Straw Tracker** — double magnetic spectrometer

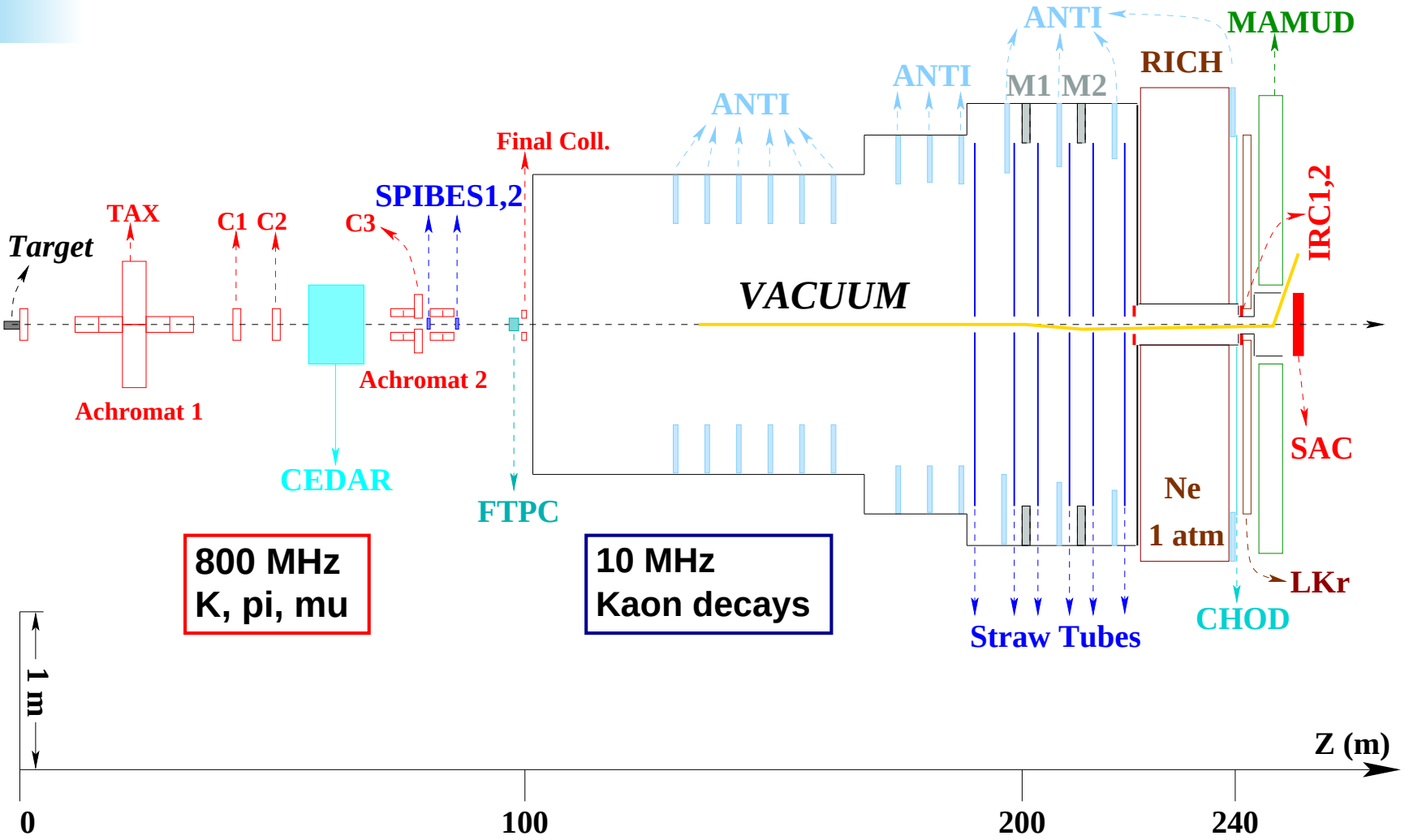
- Optimal π^+/μ^+ separation for $K^+ \to \mu^+\nu$ rejection

  $\Longrightarrow$ **Muon Detector, RICH**

- K^+–π^+ matching

  $\Longrightarrow$ **CEDAR** in K^+ beam, **Hodoscope** for charged particles

Detector Layout



CEDAR — K^+ Identification

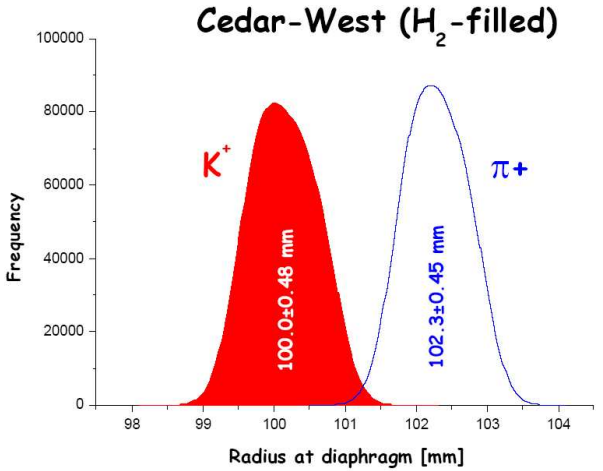
Requirement: K^+/π^+ separation in charged particle beam.

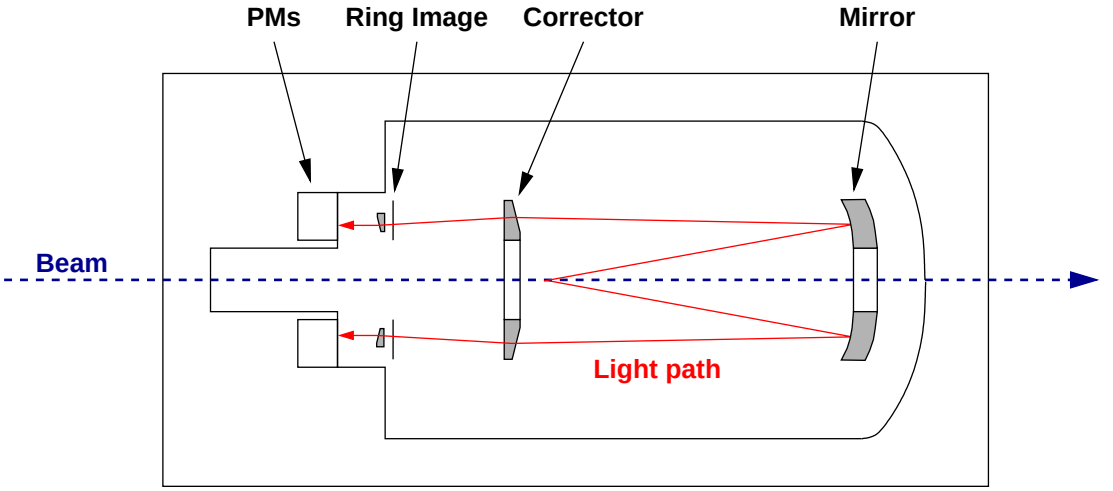
$\Longrightarrow$ **CEDAR Differential Cerenkov Counter**

- CEDAR counters have been in use in SPS beams.

  (Two versions: He-filled “North-CEDAR”, N_2-filled “West-CEDAR”.)

- West-CEDAR, filled with hydrogen, perfect for NA48/3 application.





Gigatracker — K^+ Momentum

Requirements:

- K^+ momentum resolution $\sim$ 0.3%.
- Angular resolution $\sim$ 10 μrad.
- Time resolution $\sim$ 150 ps per station.
- Material budget $\leq 0.5\ X_0$ per station.
- Survive 1 GHz hadron beam (60 MHz/cm^2).

Design: Hybrid detector

- **SPIBES (Fast Si micro-pixels)**
  - Momentum and time measurement.
  - 2 stations of hybrid silicon pixel detectors.
- **FTPC**
  - Angular measurement (track direction).
  - Micromegas TPC's as in NA48/2 (but with FADC read-out).

$\Longrightarrow$ See presentation by M. Scarpa tomorrow!

Photon Vetos

Requirement:

Suppression of $K^+ \to \pi^+\pi^0$, $K^+_{\mu 3}$, $K^+ \to \pi^+\gamma\gamma$, ...

$\Longrightarrow$ Inefficiency $\leq 10^{-4}$ for $E_\gamma > 100$ MeV (and $\leq 10^{-5}$ for $E_\gamma > 1$ GeV).

Components:

- **Large Angle Vetos (ANTI)**

  Lead-scintillator sandwich calorimeter around decay region.

- **Liquid-Krypton Calorimeter (LKr)**

  Use existing NA48 calorimeter.

- **Small Angle Vetos (IRC, SAC)**

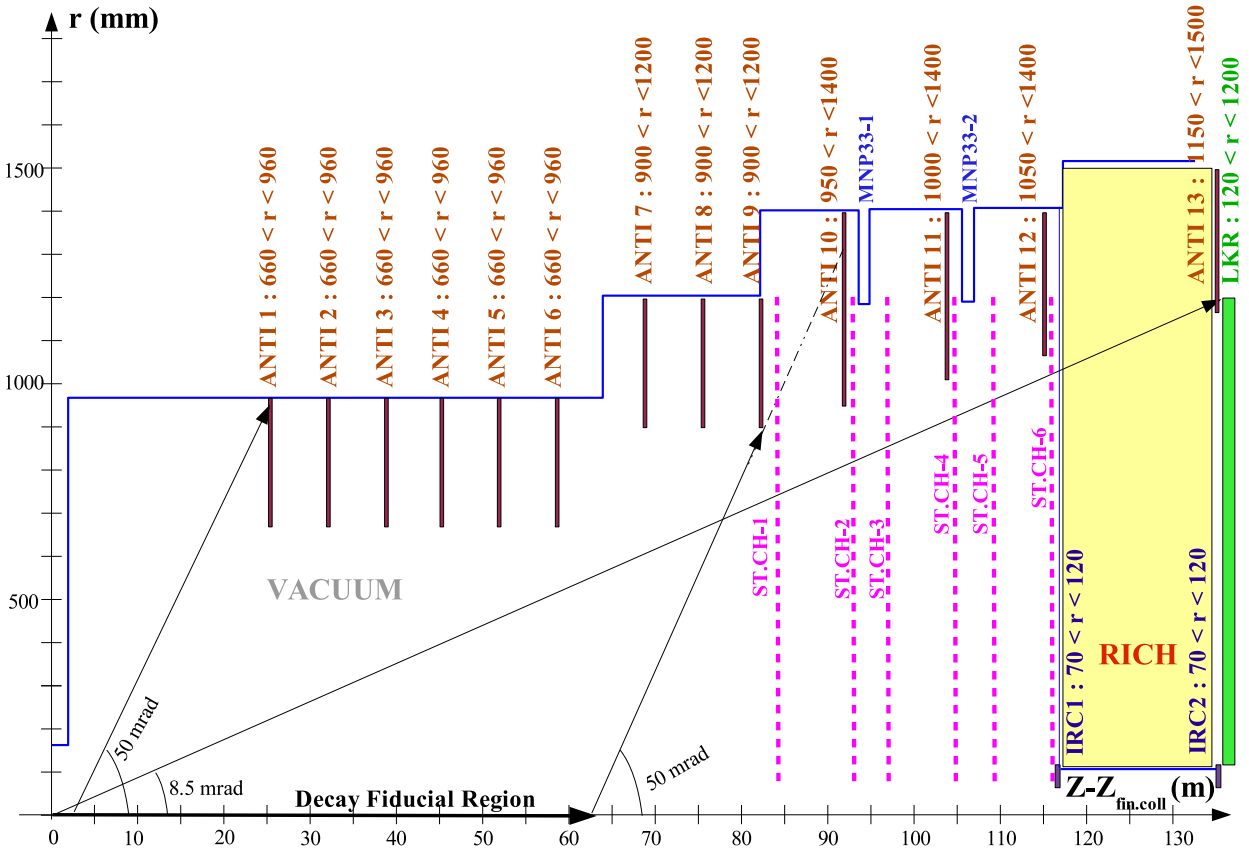
  Covering of the beam pipe, lead-scintillator sandwich.

Large Angle Photon Vetos (ANTI)

Coverage: > 8.5 mrad (LKr calorimeter)

< 50 mrad (kinematical limit for γ's from $K^+ \to \pi^+\pi^0$)

$\Longrightarrow$ **13 veto counters** around decay region.

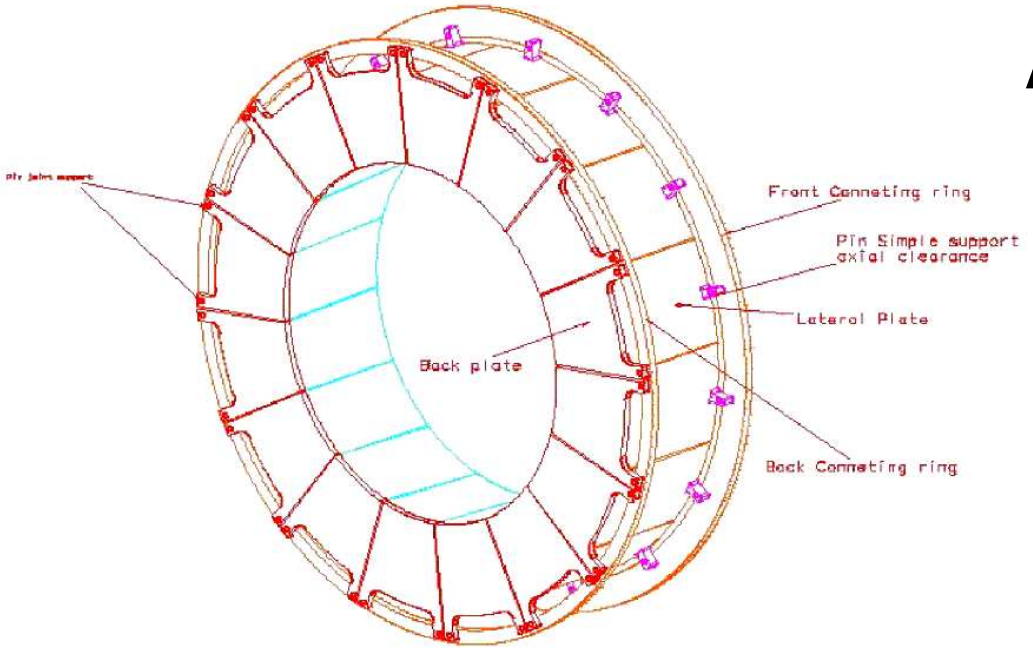


Large Angle Photon Vetos (ANTI)

Design of each veto counter:

- 80 layers lead-scintillator sandwich, each 16 X_0 deep.
- Arrangement in segmented rings *inside* vacuum tank.
- Read-out by WLS fibers.

$\Longrightarrow$ $\sim$ 20 photo electrons/minimum ionizing particle.



Alternative design:

- Lead with embedded scintillator (“spaghetti calorimeter”).
- Better time, energy resolution.
- Currently investigated.

Liquid-Krypton Calorimeter

- Main detector element for NA48/0/1/2.
- 13212 cells of 2×2 cm^2 along beam axis in ~ 10 m^3 liquid krypton.
- Very good energy resolution ($3.2\%/\sqrt{E\,[\mathrm{GeV}]}$)
- Noise about 90 MeV.

- Veto capabilities to be verified.
- Few upgrades necessary (Read-out, kryogenic system).

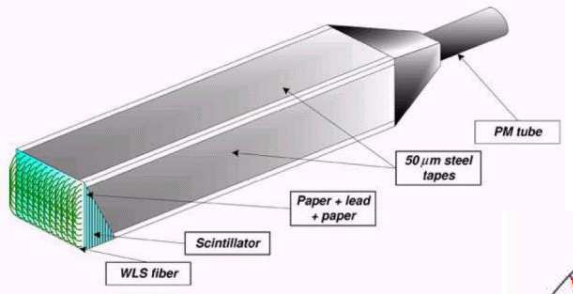
Small Angle Photon Vetos

Detectors:

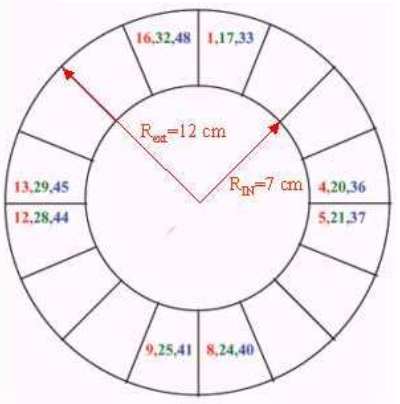
- **IRC:** Coverage of beam pipe inside calorimeters.
- **SAC:** Coverage down to $\theta = 0$.

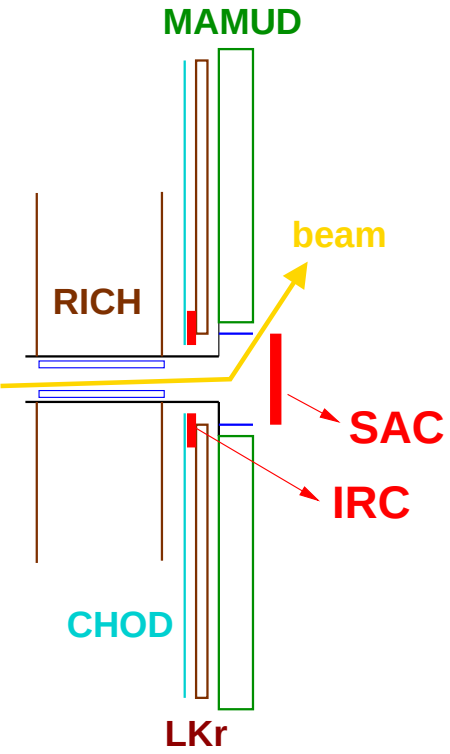
Design: Two possibilities considered:

- **Shashlik technique.**
  Layers of Pb + scintillator (total $\approx 17\ X_0$)



- **$PbWO_4$ crystals.**





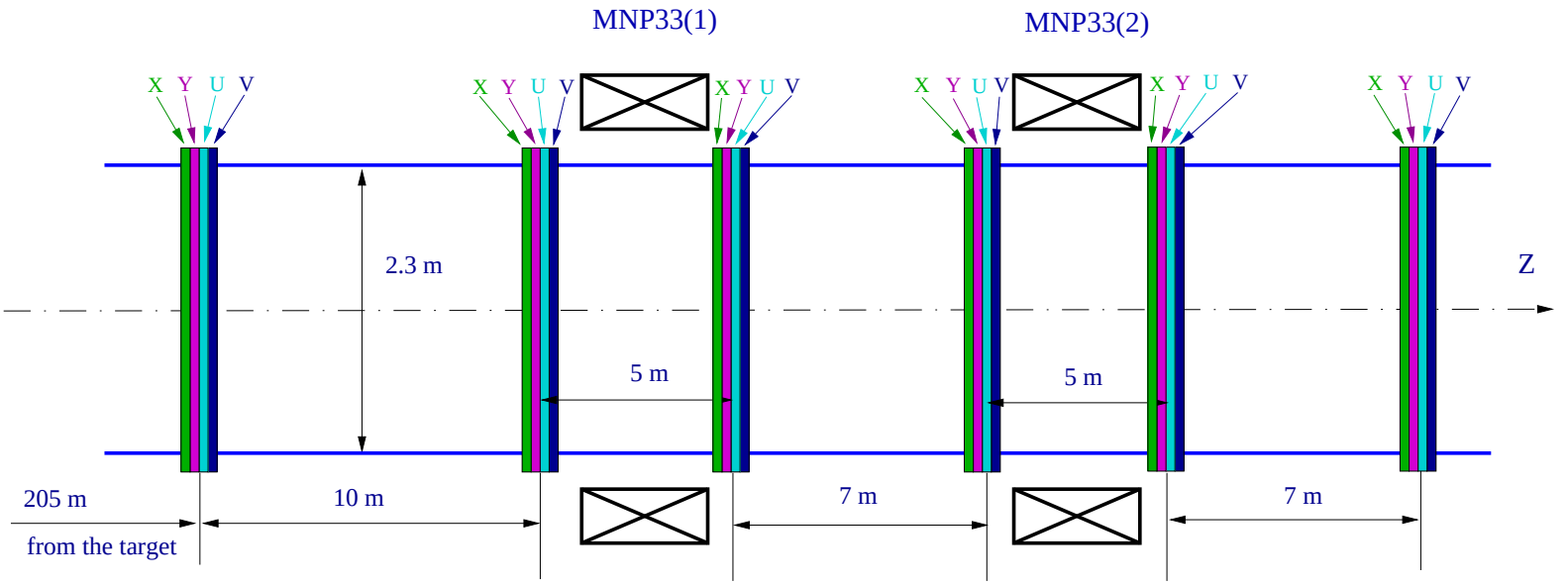
Magnetic Spectrometer

Requirements:

Suppress $K^+ \to \mu^+\nu$ by 10^{-8} $\Longrightarrow$ Exact momentum measurement

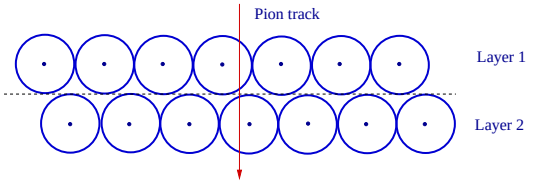
- Minimum material $\Longrightarrow$ Minimum of multiple scattering.
- Redundancy $\Longrightarrow$ Suppression of non-gaussian errors.

$\Longrightarrow$ **Design:** **Double spectrometer,** **operation in vacuum.**

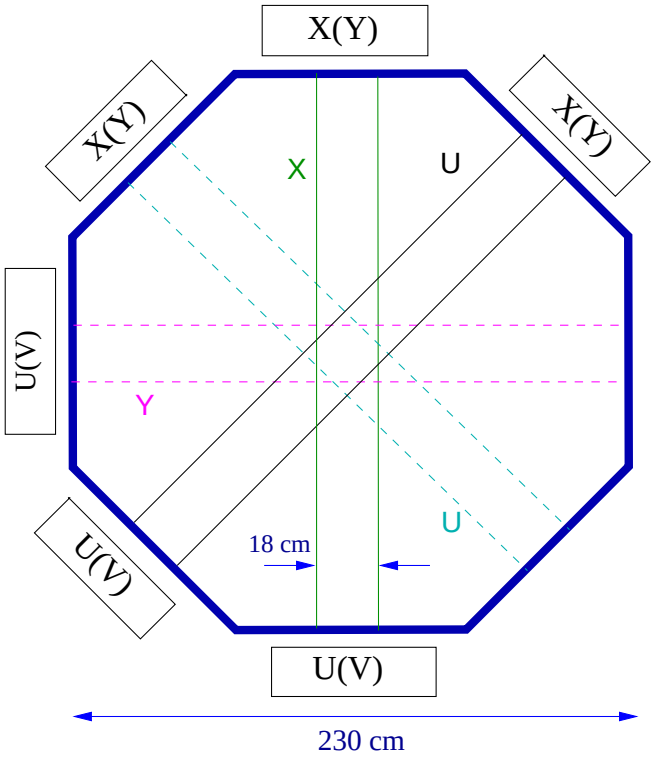


Magnetic Spectrometer

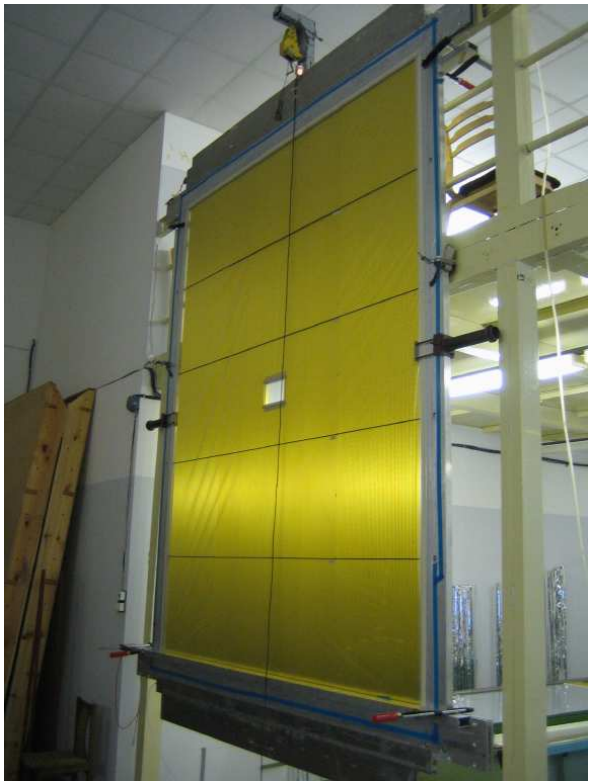
Chamber design: **Straw chambers**



- Operation in vacuum possible.
- Well-known technology (ATLAS TRT, COMPASS).
- Experience available (JINR, Dubna).



Compass



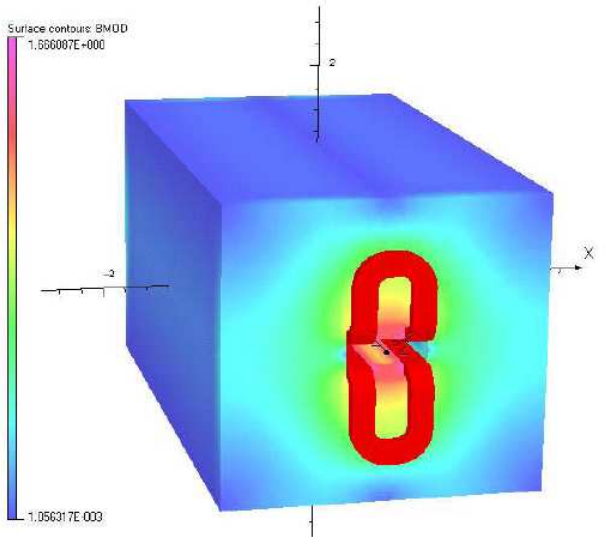
MAMUD — Magnetized Muon and hadron Detector

Requirements:

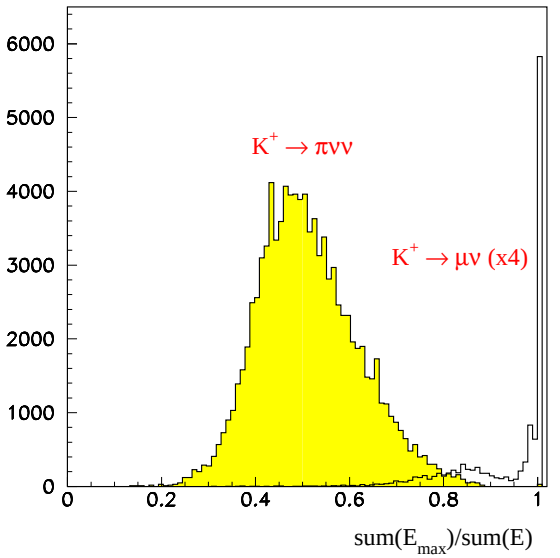
- π/μ separation for $K_{\mu 2}$ suppression
- Beam sweeping for SAC operation.

Design:

- Magnetised iron $\Longrightarrow$ 0.9 T field in beam region.
- Instrumented by scintillators $\Longrightarrow$ muon rejection $\sim 10^5$.



Magnetic field on iron surface



Charged Hodoscope, RICH

Charged Hodoscope (CHOD)

- Excellent time resolution < 100 ps.
- Rejection of high-multiplicity events ($K^+ \to \pi^+\pi^+\pi^-, \ldots$).
- Trigger (together with photon vetos and CEDAR).
- **Design:** Multigap glass RPC, similar to ALICE TOF.

RICH

- Needed for additional $K_{\mu 2}$, $K_{\mu 2\gamma}$ rejection.
  (π/μ seperation at 2 sigma level is sufficent.)
- **Design** currently under investigation (e.g. KPLUS design).

Expected Background

Decay	B.R. [%]	Bkg. Estim.
$K^+ \to \mu^+\nu$ $(K_{\mu 2})$	63.4	$\sim \mathbf{1.6}$
$K^+ \to \mu^+\nu\gamma$ $(K_{\mu 2\gamma})$	0.6	$\sim \mathbf{0.4}$
$K^+ \to \pi^+\pi^0$	21.1	$\sim \mathbf{4.4}$
$K^+ \to \pi^+\pi^0\gamma$	0.03	$< \mathbf{0.1}$
$K^+ \to \pi^0 e^+\nu$ (K_{e3})	4.9	$\sim \mathbf{1.6}$
$K^+ \to \pi^0\mu^+\nu$ $(K_{\mu 3})$	3.3	$< \mathbf{0.1}$
$K^+ \to \pi^+\pi^+\pi^-$	5.6	in progress
Total:		~ 8 (+ 3-track)

$\Longrightarrow$ See presentation by G. Ruggiero this afternoon!

Timeline

- **2005:**
  - Proposal to the SPSC — being submitted.
    (CERN-SPSC-2005-013)
  - Design and Development of main detector components.
    (Beam spectrometer, magnet spectrometer, photon vetos, muon detector, RICH)
- **2006 – 2008:**
  - Building, tests and installation of detector components.
    ($\Longrightarrow$ SPS test-beam in 2006.)
- **2009/2010:**
  - Beam time at the CERN SPS.
  - Til 2011/2012: Data analysis.

CERN Recommendation for NA48/3

- **From the Villars report** (CERN-SPSC-2005-010, Feb 28, 2005):

3.3 Flavour Physics

There is a strong physics case for pursuing an ambitious program of kaon physics at CERN, exploiting the high-energy proton beams available at the SPS for rare K-decay in-flight measurements. Building on its expertise in high-intensity neutral and charged kaon beams and on the outstanding physics achievements of the NA48, NA48/1 and NA48/2 experiments in the last decade, CERN should remain in the future a major laboratory for kaon physics at the sensitivity frontier.

The possibility of a precise measurement of the $K^+ \to \pi^+ \nu\nu$ transition is exciting. The goal is to detect more than 100 signal events over two years starting in 2009. The challenge is for experimental sensitivity to a K-decay BR of order 10^{-11}. A major upgrade of the present NA48/2 set-up would be necessary and the required R&D and detector developments should be supported. According to present studies this measurement appears globally competitive.

$\Longrightarrow$ Formally invited by the SPSC to submit a proposal.

Summary and Conclusion

- **NA48/3:** Impressive opportunity to measure
  $\geq$ **80** $K^+ \to \pi^+ \nu\bar{\nu}$ **events** in 2009/2010 at the CERN SPS.
- Backgrounds are challenging, but under control!
  Expect: **Signal/background** ≈ 10.
  (Even better when using RICH detector!)
- **NA48/3 detector** currently developped.
  - Main components: Beam spectrometer, photon vetos, straw tracker, muon rejection.
  - Rely if possible on well-known technology.
  - Reuse of few components (Lkr) from old NA48.
- **Proposal** written, signed by about 80 physicists.
- We are still open to **new collaborators.**