The NA48/3 experiment at CERN (proposal P-326)

Giuseppe Ruggiero (CERN)

"Heavy quark & Leptons 2006"

Munich, 18/10/2006

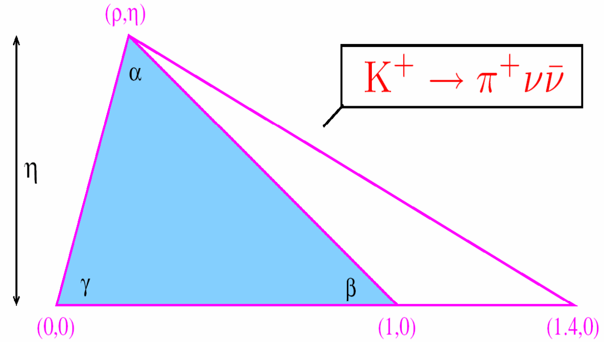
Rare Kaon Decays and CKM matrix

P326

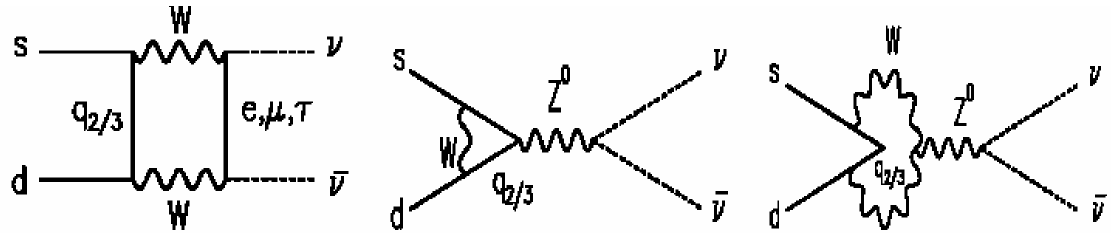
~~CP~~

$K_L \to \pi^0 \nu \bar{\nu}$

$K_L \to \pi^0 e^+ e^-$ $\left\{ \begin{array}{l} K_S \to \pi^0 e^+ e^- \\ K_L \to \pi^0 \gamma\gamma \\ K_L \to e e \gamma\gamma \end{array} \right.$



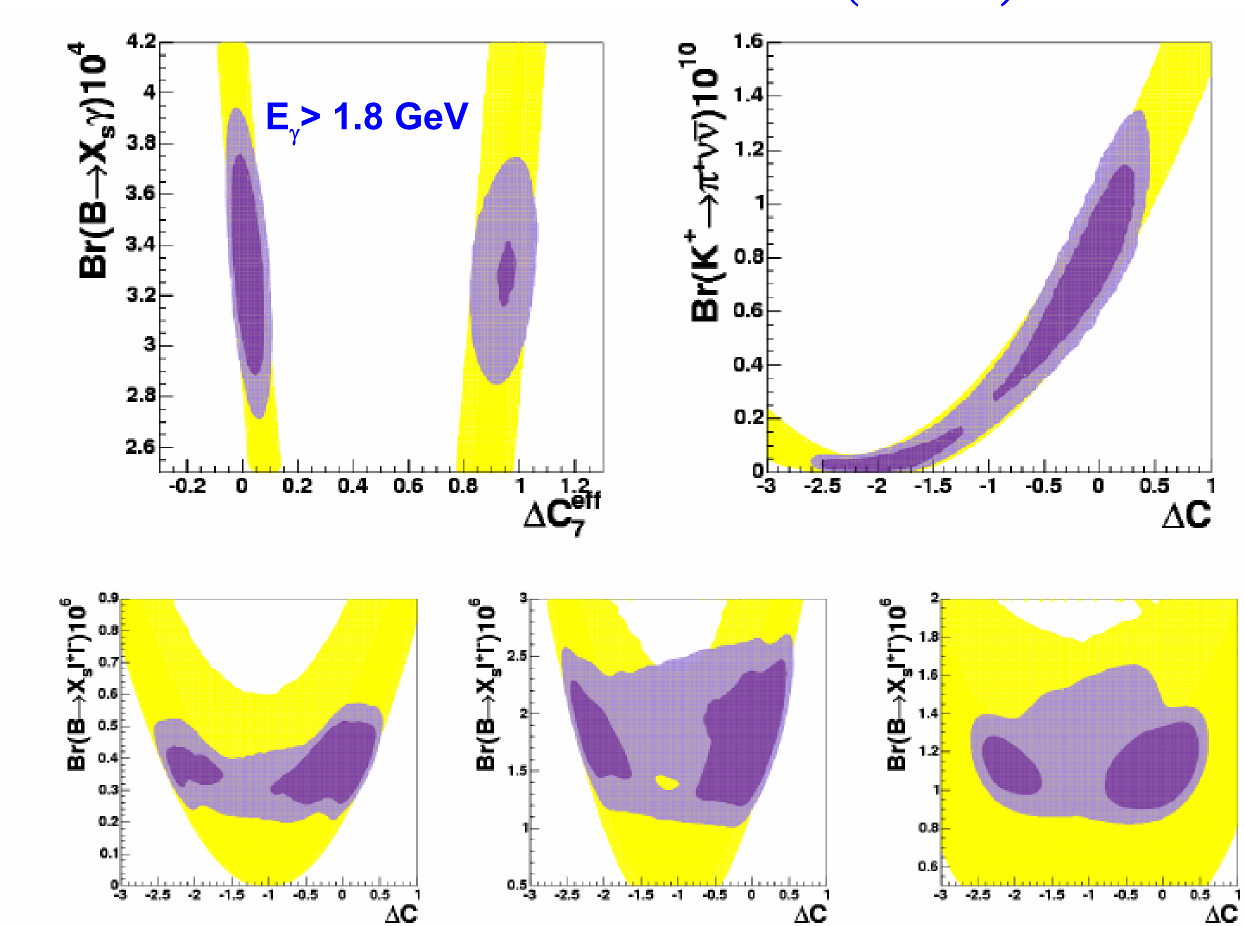
- $K \to \pi \nu \bar{\nu}$ decay is sensitive to V_{td}
- $|V_{td}|$ determination independent on B^0-$\bar{B}^0$ mixing
- Theoretically the <u>cleanest</u> processes in K and B physics



- <u>Standard Model predictions</u>
  - **$BR(K^+ \to \pi^+ \nu \bar{\nu}) \approx (1.6\times10^{-5}) |V_{cb}|^4 [\sigma\eta^2 + (\rho_c - \rho)^2] \to (8.0 \pm 1.1)\times10^{-11}$**
  - **$BR(K_L \to \pi^0 \nu \bar{\nu}) \approx (7.6\times10^{-5}) |V_{cb}|^4 \eta^2 \to (3.0 \pm 0.6)\times10^{-11}$**

MFV: Sensitivity to Z^0 Penguin

from Bobeth et a. (2005)



$14.4 < q^2\ (GeV^2) < 25$ $1 < q^2\ (GeV^2) < 6$ $0.04 < q^2\ (GeV^2) < 1$

Setting the bar for future Kaon experiments

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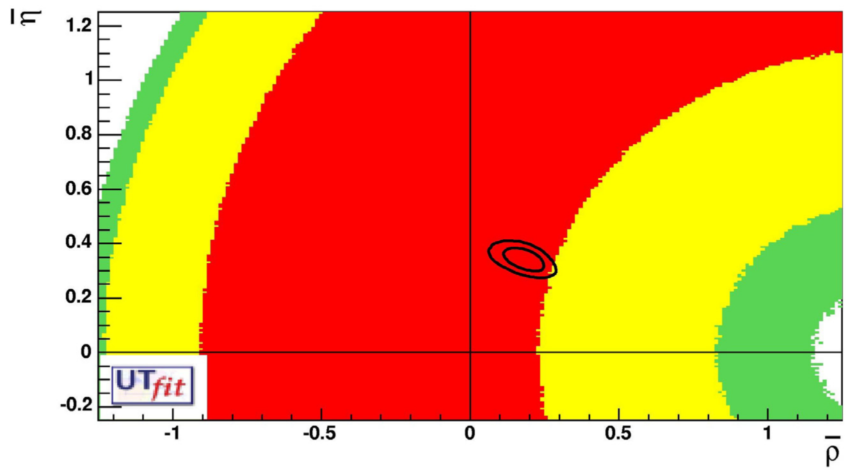
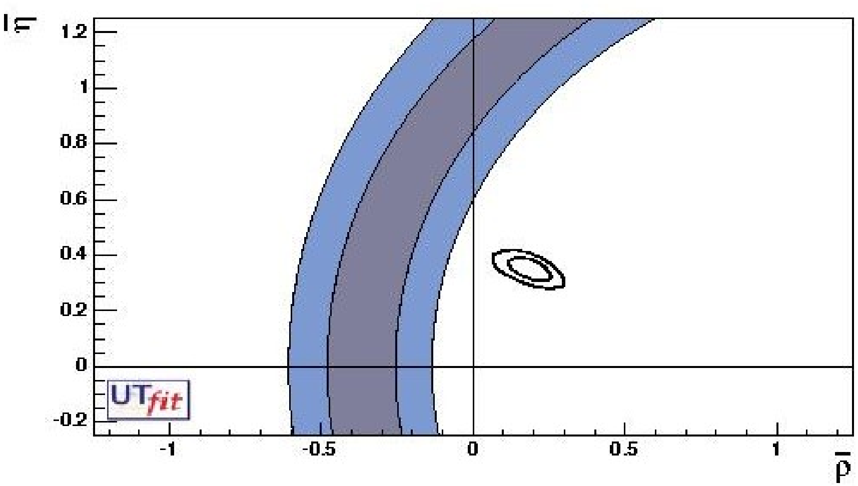
- Present (E787/949): **$BR(K^+ \to \pi^+ \nu\bar{\nu}) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$**

Current constraint on ρ,η plane

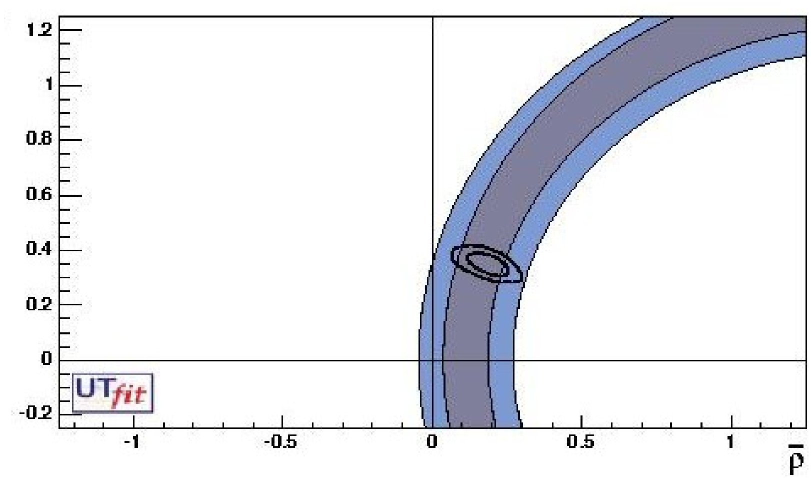


100 events
Mean: E787/949



?

100 events
Mean: SM



Proposal to Measure the Rare Decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the CERN SPS (NA48/3 – P326)

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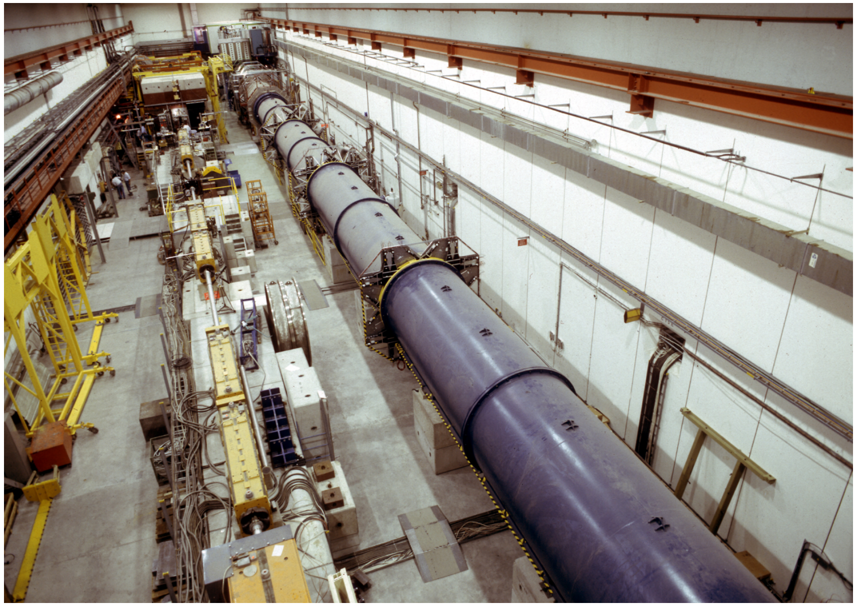
CERN-SPSC-2005-013
SPSC-P-326

CERN, Dubna, Ferrara, Florence, Frascati, Mainz, Merced, Moscow, Naples, Perugia, Protvino, Pisa, Rome, Saclay, San Luis Potosi, Sofia, Turin

Located in the same hall of NA48



Schedule

- Presented at CERN SPSC in September 2005
- R&D endorsed by CERN Research Board on December 2005
- Test beams in October - November 2006
- Test beam for RICH in 2007
- Aims to complete the R&D by the end of 2007
- Start of data taking 2011

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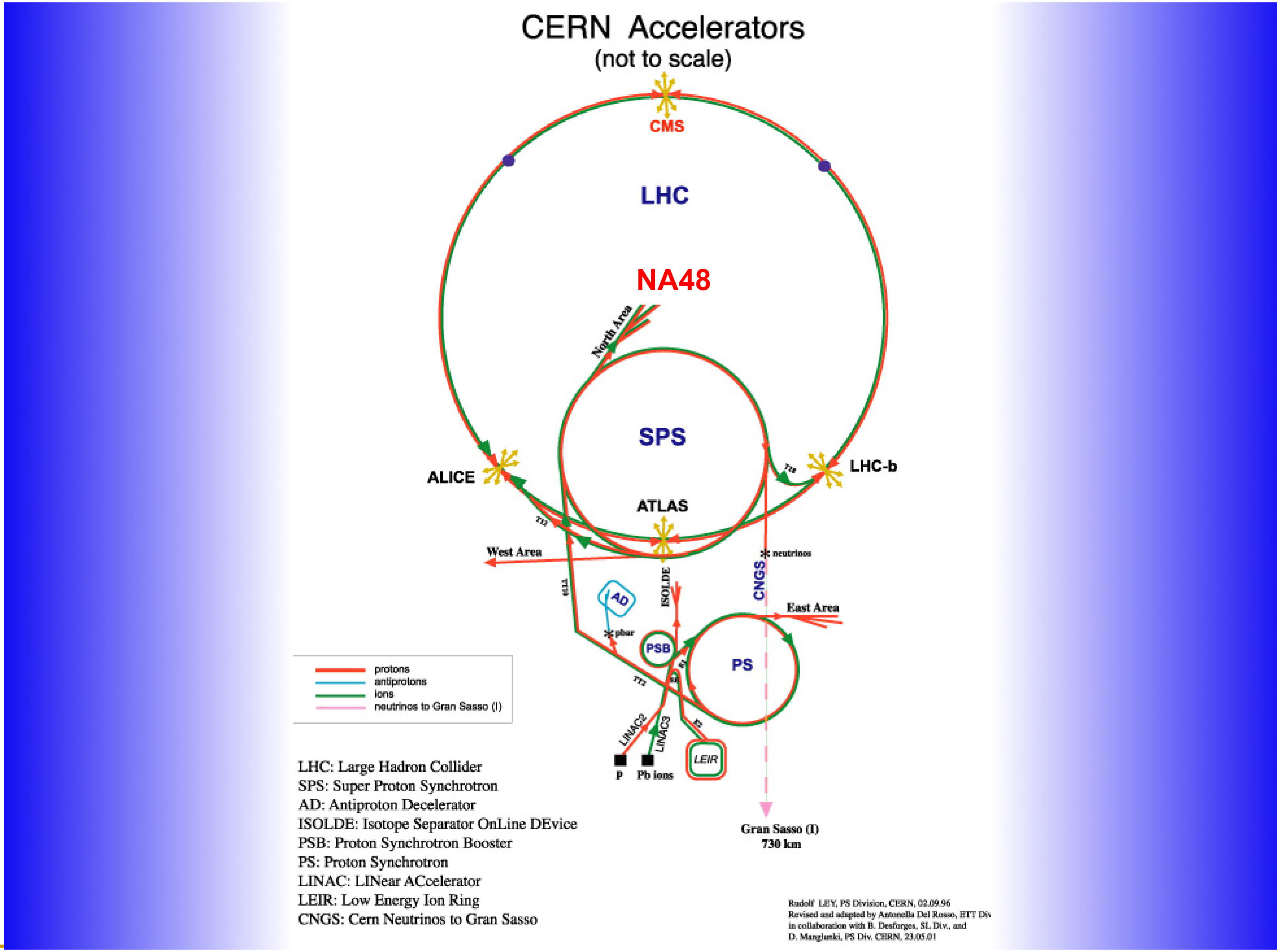
CERN Accelerators
(not to scale)
CMS
LHC
NA48
North Area
SPS
ALICE
ATLAS
LHC-b
West Area
neutrinos
CNGS
ISOLDE
AD
East Area
pbar
PSB
PS
LINAC2
LINAC3
LEIR
p
Pb ions
Gran Sasso (I)
730 km
protons
antiprotons
ions
neutrinos to Gran Sasso (I)
LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso
Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

NA48/3 guidance principles

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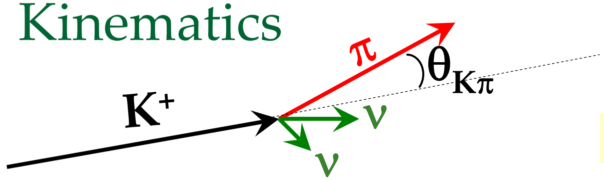
~80 $K^+ \to \pi^+ \nu\nu$ events

- **BR(SM) = 8×10^{-11}**
- **Signal acceptance 10%**
- **K decays ~10^{13}**

- Kaon decay in flight technique
- Intense proton beam from SPS
- High energy K (P_K = 75 GeV/c)
- **Cerenkov counter for kaon ID**

Low Level of background

- Kinematics



$m^2_{miss} = (P_K - P_\pi)^2$

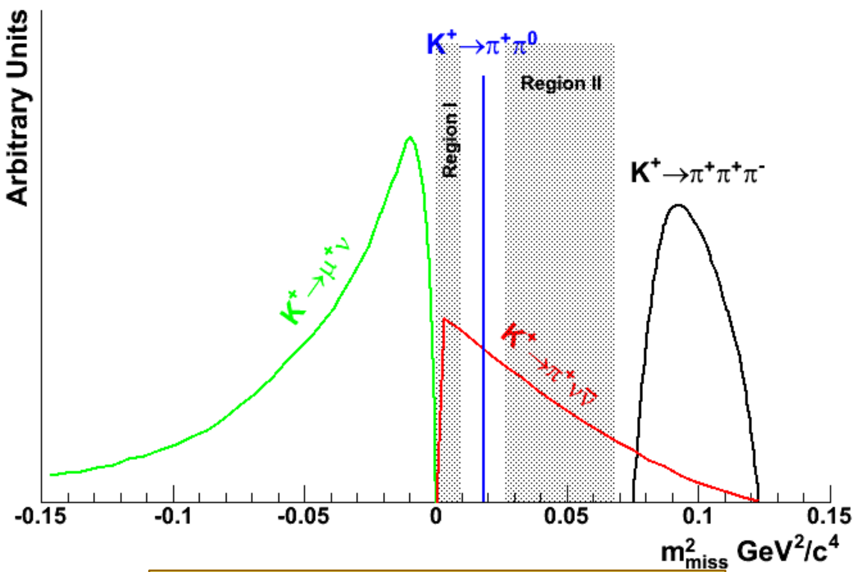
- **Kaon:** Beam Tracker
- **Pion:** Spectrometer

- Vetoes & Particle ID

- Calorimeter for γ/μ detection
- RICH (π/μ separation)
- Spectrometer for charged particle rejection

Backgrounds

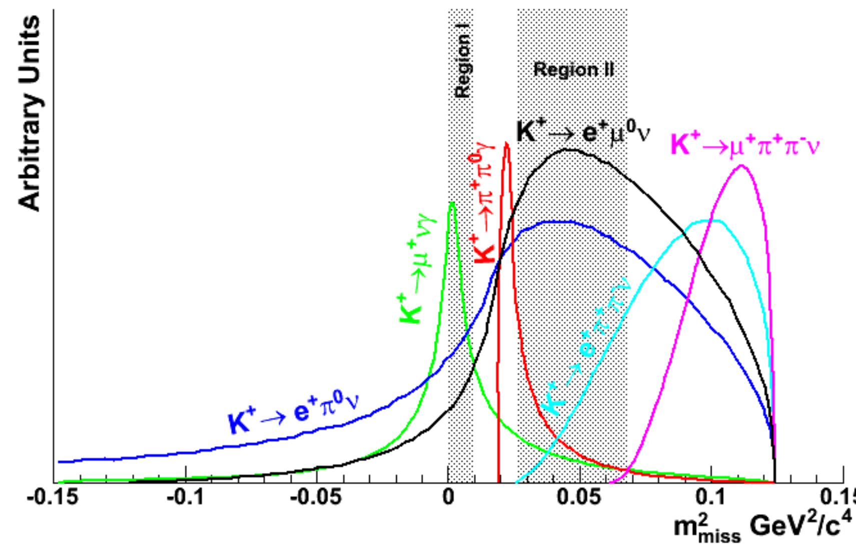
Kinematically constrained



92% of total background

- Allows us to define a signal region
- $K^+ \to \pi^+\pi^0$ forces us to split it into two parts (Region I and Region II)

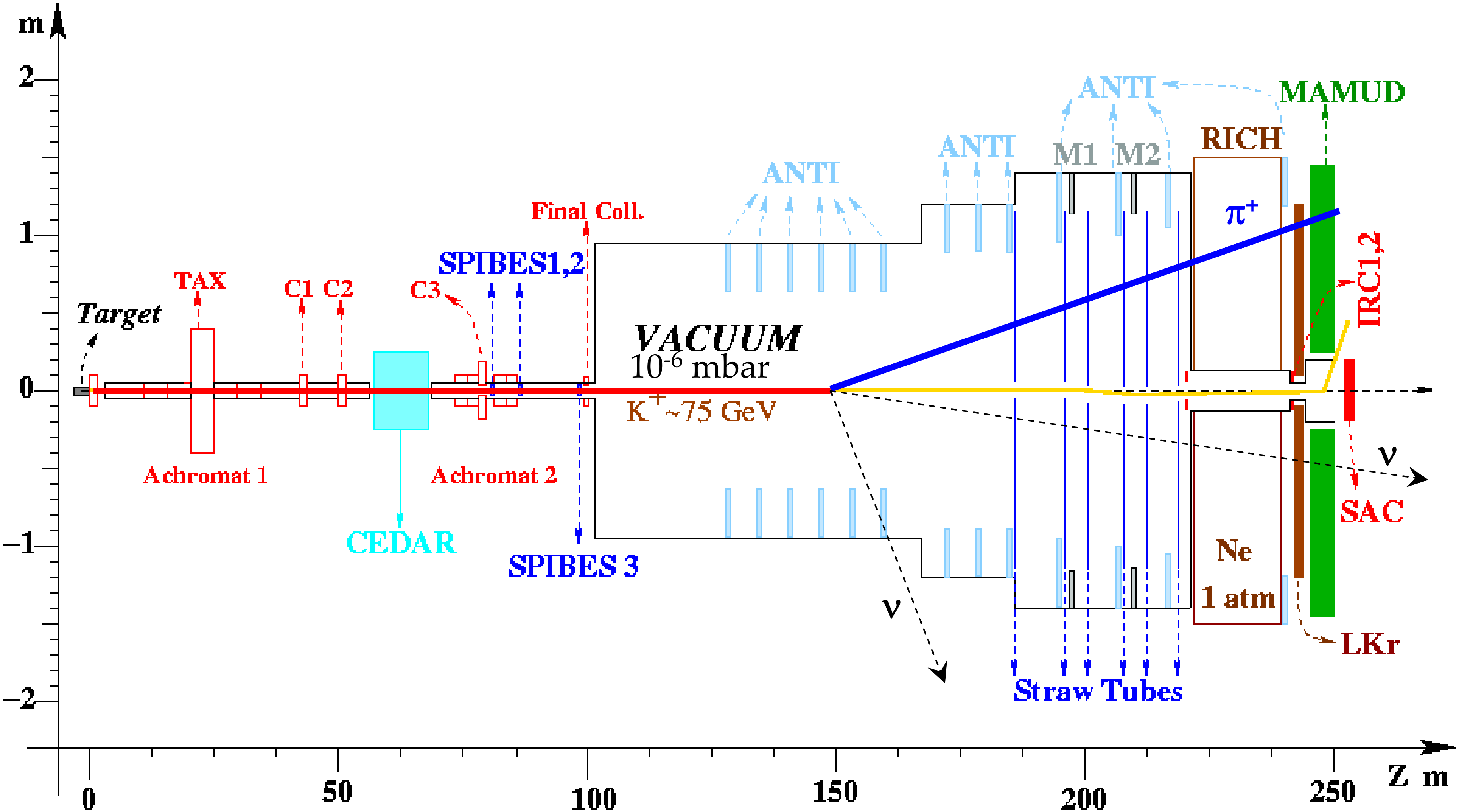
Not kinematically constrained



8% of total background

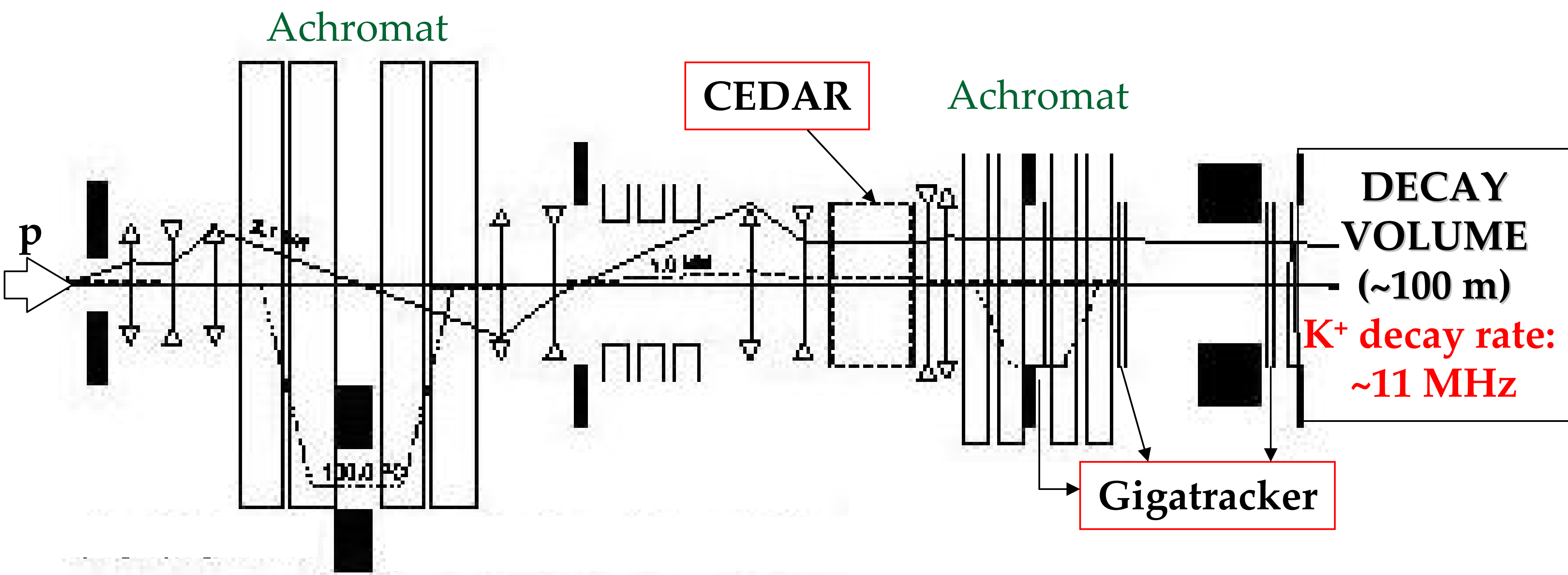
- Span across the signal region
- Rejection must rely on veotes

P-326 Layout



m
2
1
0
−1
−2
Target
TAX
C1 C2
C3
SPIBES1,2
Final Coll.
Achromat 1
Achromat 2
CEDAR
SPIBES 3
VACUUM
10-6 mbar
K+~75 GeV
ANTI
ANTI
ANTI
M1
M2
RICH
MAMUD
π+
IRC1,2
SAC
LKr
Ne
1 atm
ν
ν
Straw Tubes
0
50
100
150
200
250
Z m

The Beam



Primary beam

- P proton = 400 GeV/c
- Proton/pulse 3×10^{12} (×3 NA48/2)
- Duty cycle 4.8/16.8 s

Secondary beam

- P Kaon = 75 GeV ($\Delta P/P = 1\%$)
- Fraction of kaons ~ 6%
- Beam acceptance = 15 μstr (×30 NA48/2)
- Area @ beam tracker = 16 cm^2
- Integrated average rate = 800 MHz
- Kaon decays / year = 4.8×10^{12}

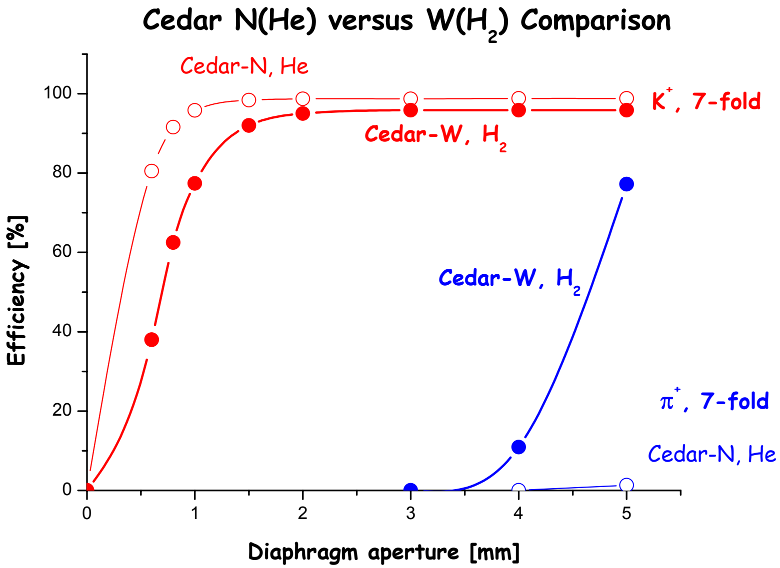
Kaon ID

Cerenkov counter on the beam

Requirements

- Tag the kaon to keep the beam background under control
- Good time resolution
- Minimal material budget

Existing detector: CEDAR
Filled with H_2 instead of Ne



R&D program

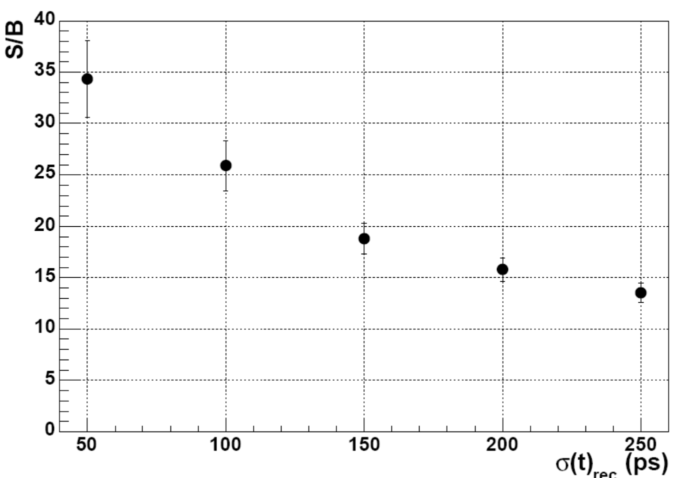
- November 2006: test of a not modified CEDAR detector on the H8 beam line @ CERN

Beam tracker

- Si pixel stations across the 2nd achromat: size 36 mm (X)× 48 mm (Y)
- Rate: 800 MHz (charged particles) ~50MHz/cm^2

Requirements

- Good space resolution not to spoil the downstream tracker resolution → **300×300 μm pixels** $\left(\begin{array}{l}\sigma(P_K)/P_K \sim 0.4\% \\ \sigma(\theta_K) \sim 16\ \mu rad\end{array}\right)$
- Low X/X_0 not to spoil the beam → **200 Si μm sensor+ 100 Si μm chip**
- Excellent time resolution needed for K+/π+ association: **σ(t)~200 ps** per station → **Complex readout chip bump-bonded on the sensor (0.13 μm CMOS technology)**

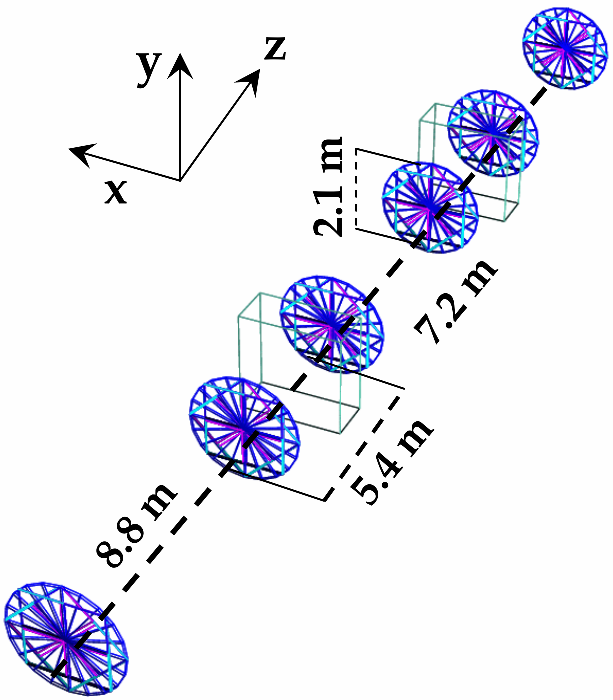


R&D program

- First sensor prototypes
- Radiation tests started
- Chip design under study
- Cooling and technical implementation design in progress

Spectrometer

- 6 chambers with 4 double layers of straw tubes each (∅ 9.6 mm)
- Rate: ~45 KHz per tube (max 0.5 MHz) ($\mu+\pi$)



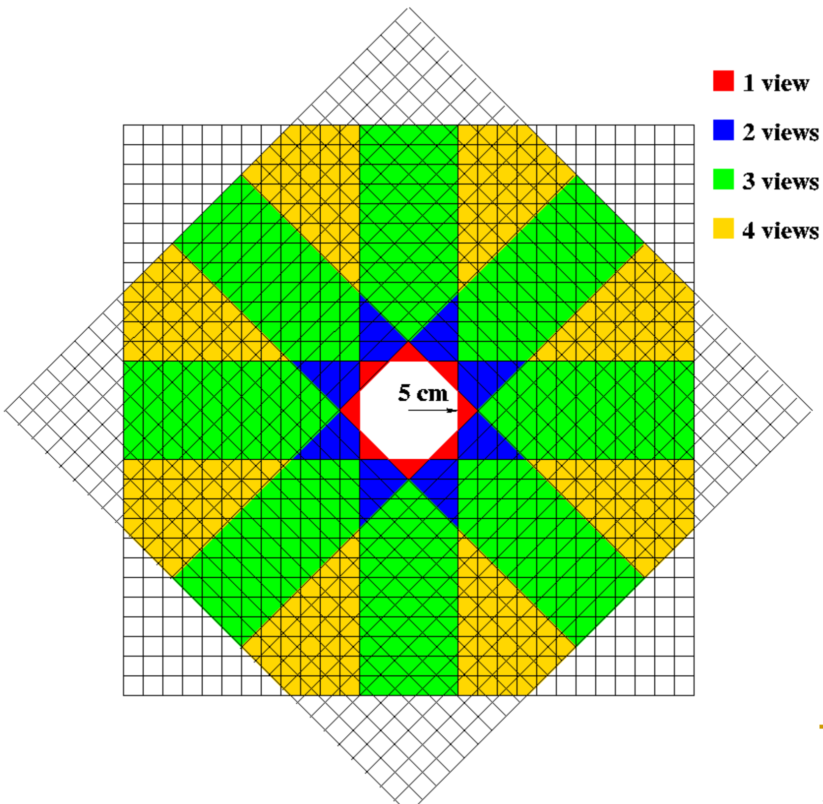
Requirements

Low X/X_0	**Operate in vacuum, X/X_0~0.1% per view**
Good space resolution	**130 μm per hit**
Redundant p measurement	**2 magnets 360 & 270 Pt kick**
Veto for charged particles	**5 cm radius beam hole displaced in the bending plane according to the 75 GeV/c beam path**

Spectrometer

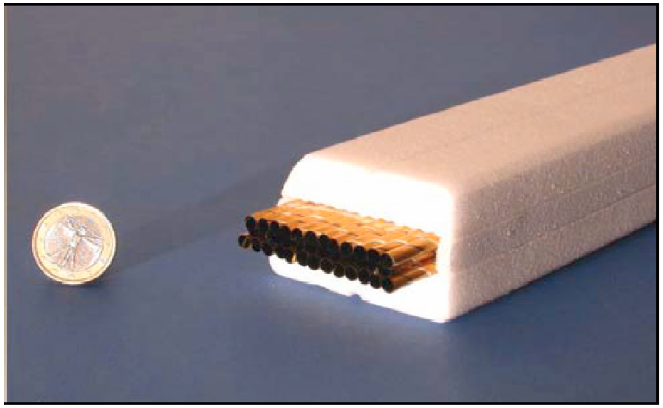
Tube characteristics

- Tube of mylar (36 μm)
- D = 1 cm, L = 2.1 m
- Gas CF_4-CO_2-isoC_4H_{10}

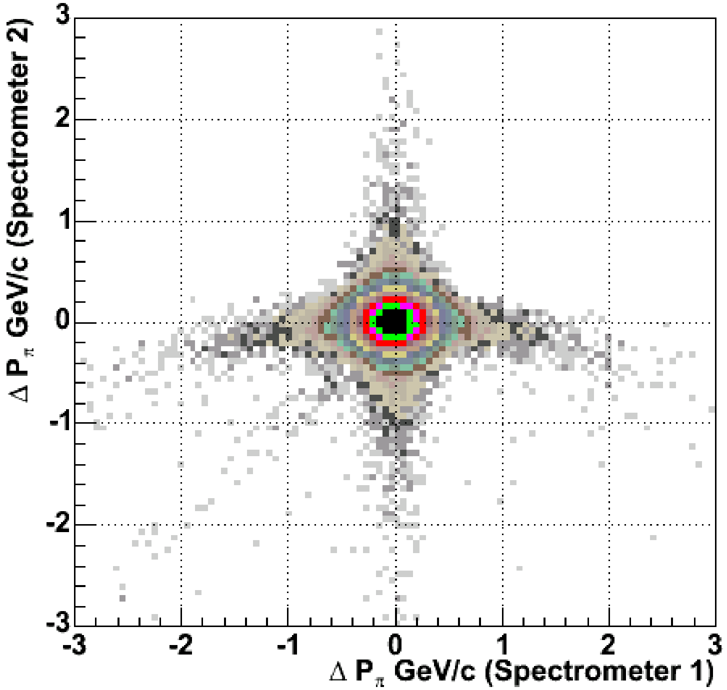


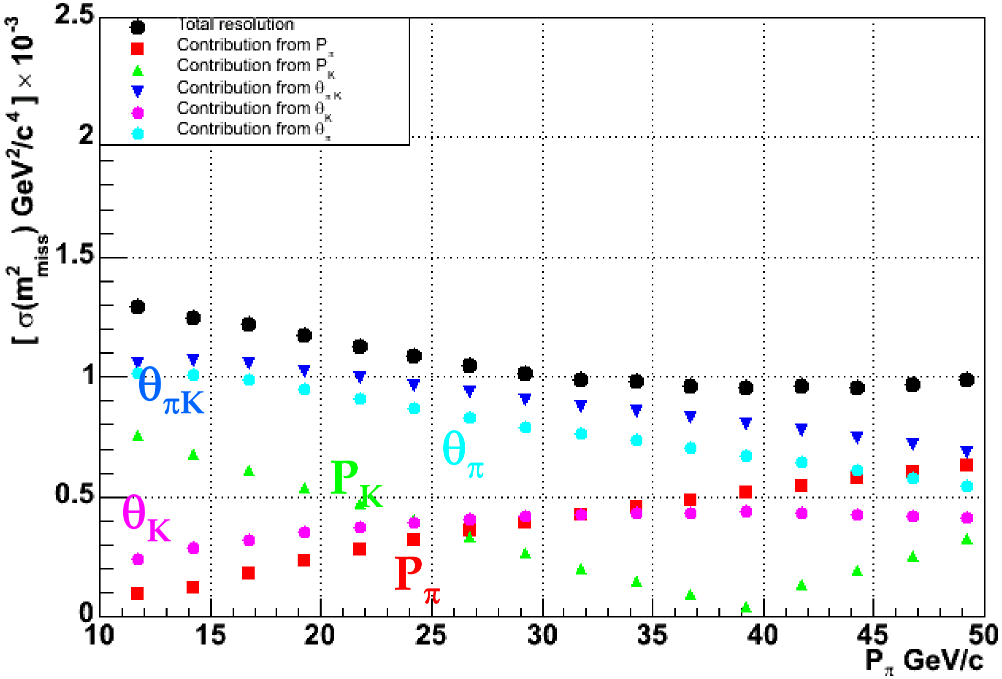
R&D program

- Tests on gas leakage
- Tests on tube expansion in vacuum
- Prototype under construction at Dubna (2007).



Kinematics reconstruction





Two almost independent measurements of the downstream track momentum

m^2_{miss} resolution ~1.1×10^{-3} GeV^2/c^4 main contribution from $\Theta_{\pi K}$ measurement

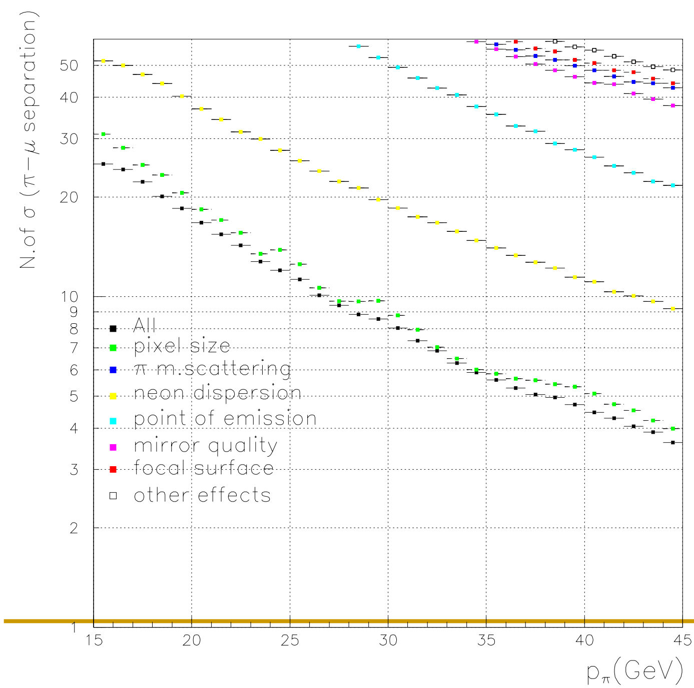
RICH (I)

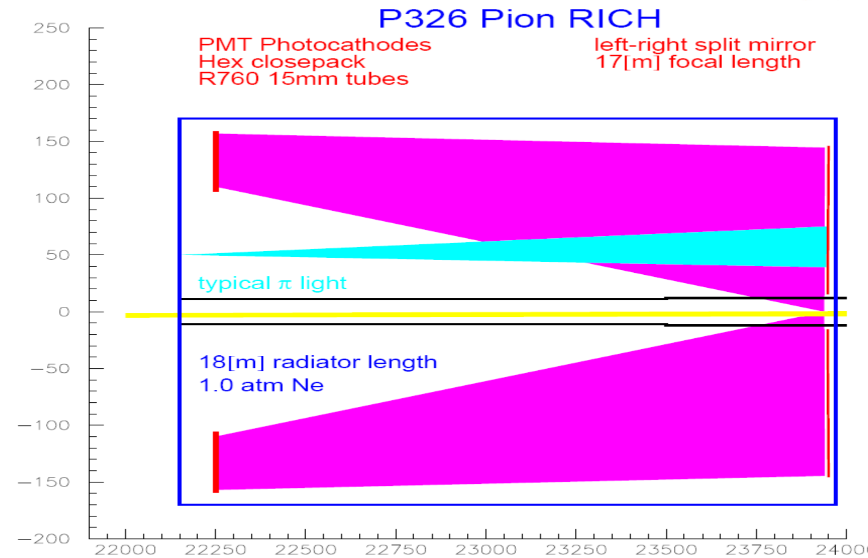
Requirements

- >3σ pion/muon separation @ 35 GeV/c
- Time resolution 100 ps
- Velocity spectrometer (redundancy)

18 m tube filled with Ne @ 1 atm

(13 GeV/c threshold for pions)





Optics and photo detector

- 2 tilted mirrors (17 m focal lenght)
- 2000 PMT
- Pixel size 18 mm
- Single anode PMTs matrix on the focal plane with compact hex packing

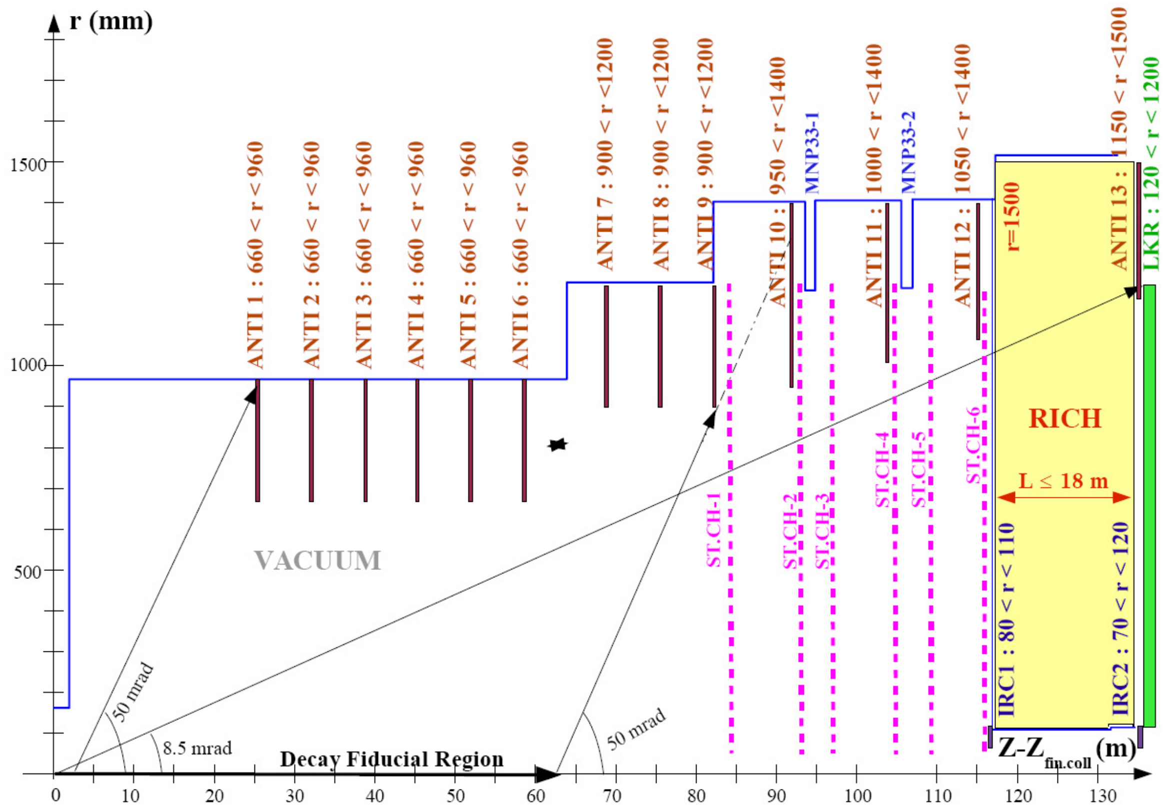
RICH (II)

R&D program (2007)

- Build a full scale (longitudinal) prototype
- One mirror: f=17 m, 1 cm thick
- Vessel in stainless steel
- 32 PMT Hamamatsu in 8 spots
- Test on SPS K12 (NA48) beamline

Check Cherenkov angle resolution
Check number of photoelectrons
Check time resolution

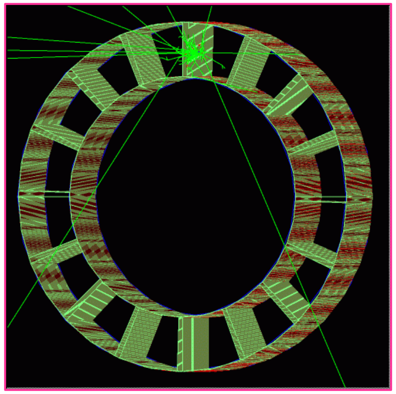
Photon vetoes layout



- **Large angle:** 13 ANTIs (10 < acceptance < 50 mrad)
- **Medium angle:** NA48 LKr (1 < acceptance < 10 mrad)
- **Small angle:** IRC1,2 SAC (acceptance < 1 mrad)

Large angle veto

- 13 ring em calorimeter placed in vacuum
- Rate ~4 MHz (μ)+~0.5 MHz (γ) (OR of 13)

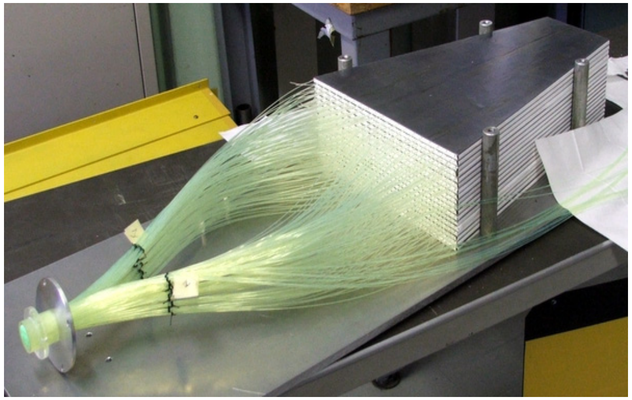


Requirements

- 10^{-4} inefficiency for E_γ in 0.05,1 GeV
- 10^{-5} inefficiency for E_γ>1 GeV

R&D program

- Lead scintillator tiles read out by WLS fibers
  - Inefficiency measurement at the e- beam of LNF in progress.
  - Out-gassing studies performed at CERN proved that the scintillator can be placed in the same vacuum of the decay region.
- Structure with lead and scintillating fibers
  - Prototype under construction at LNF
  - Test planned on the γ-tagged beam facility at LNF



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Medium angle veto: the NA48 LKr calorimete

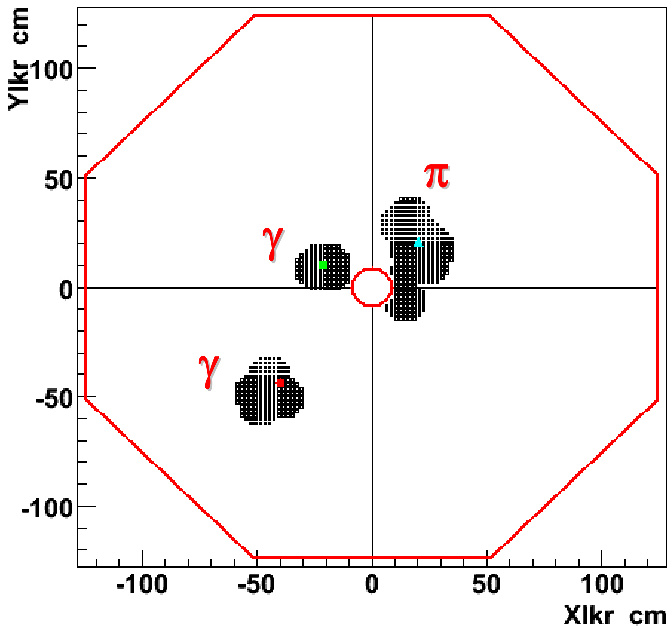
- Existing NA48 electromagnetic calorimeter at liquid Kripton
- Rate ~7 MHz (μ) + ~4 MHz (γ)+~3 MHz (π)

Requirements

- 10^{-4} inefficiency for E_γ in 1,5 GeV
- 10^{-5} inefficiency for E_γ>5 GeV

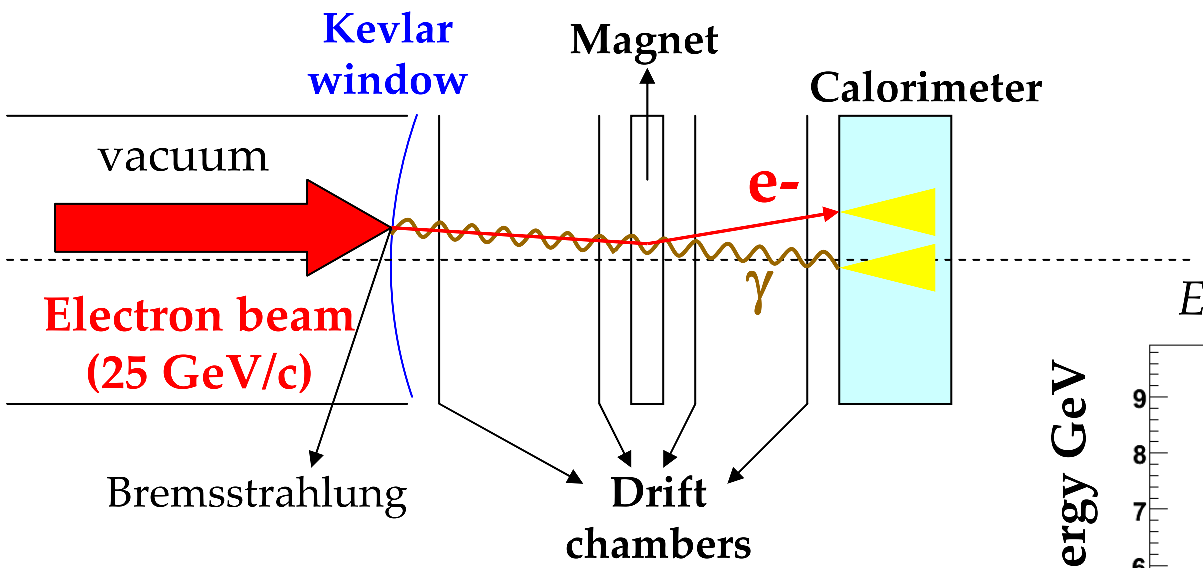
R&D program

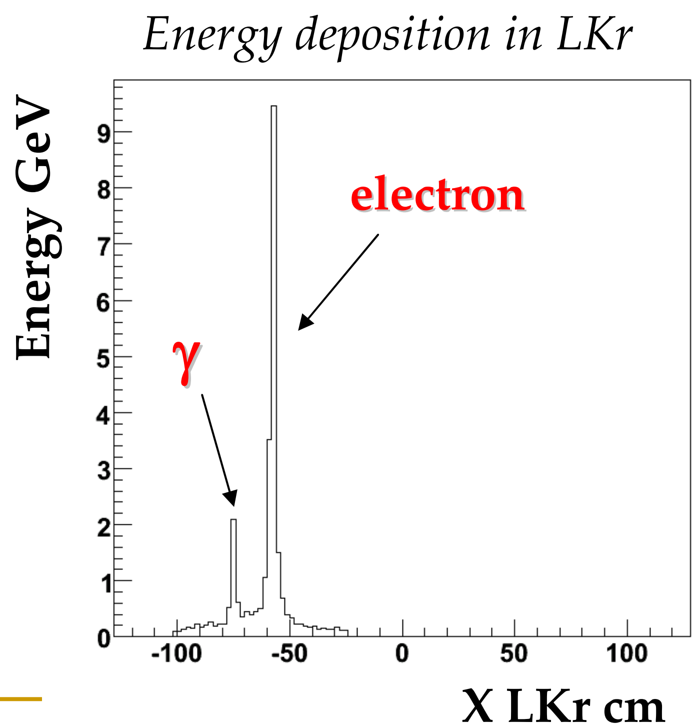
- Inefficiency @ E_γ > 10 GeV measured with **data** using $K^+ \rightarrow \pi^+\pi^0$ events: Result: **$\eta < 10^{-5}$** *(preliminary)*
- Test with a photon tagged beam at CERN in October 2006 to measure the inefficiency at energies < 10 GeV
- Consolidation of the readout in progress



The 2006 test run for LKr

- Bremsstrahlung photon produced using electron from CERN SPS
- NA48 setup to detect the photons on the LKr





- Run from 2-16 October
- $> 2\times10^{8}$ electron collected
- 10^{-5} sensitivity at $E_{\gamma}<10$ GeV
- Electron momentum 25 GeV/c
- Minimum e-γ separation @ LKr 13 cm

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Small angle veto

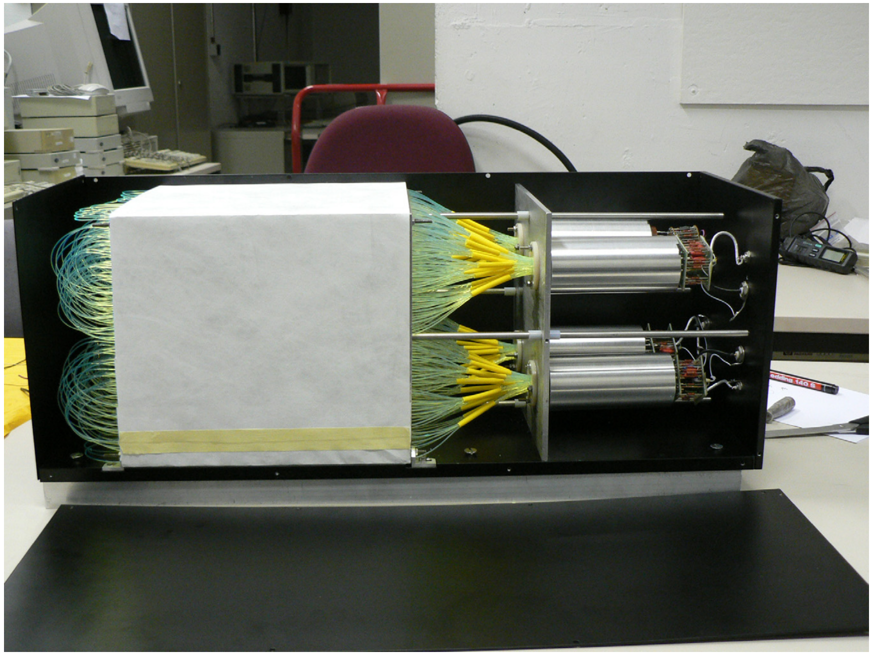
- Calorimeter shashlyk placed on the beam axis

Requirements

- 10^{-5} inefficiency (high energy photons)

R&D program

- **Prototype built by Dubna & Sofia groups**
- Lead plane + fibers, 18 X/X_0
- Tested on 15-16 October with the 25 GeV SPS electron beam using the NA48 setup

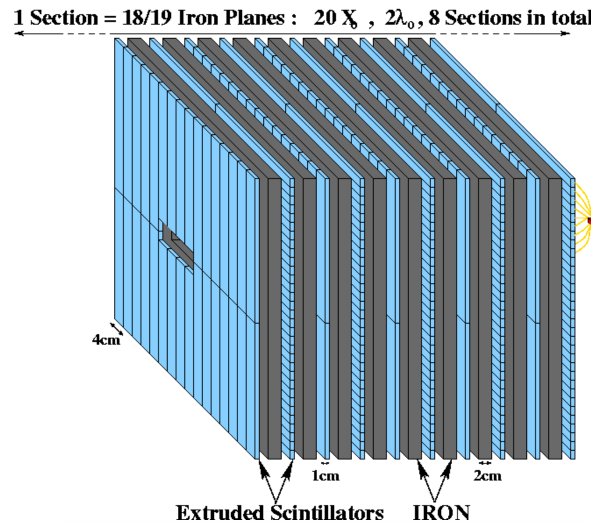


Muon Veto (MAMUD)

- Sampling calorimeter + Magnet for beam deflection
- Rate: ~7 MHz (μ)+ ~3 MHz (π)

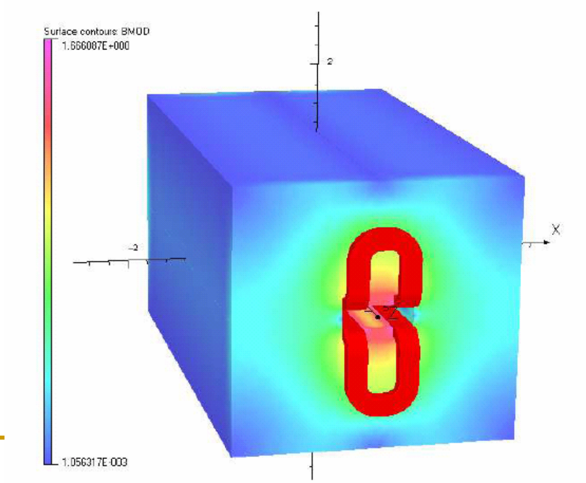
Requirements

- 10^{-5} inefficiency μ detection
  - em/hadronic clusters separation
  - Sensitivity to the MIPs
- Deviate the beam out from the SAC



R&D program

- Started in Protvino

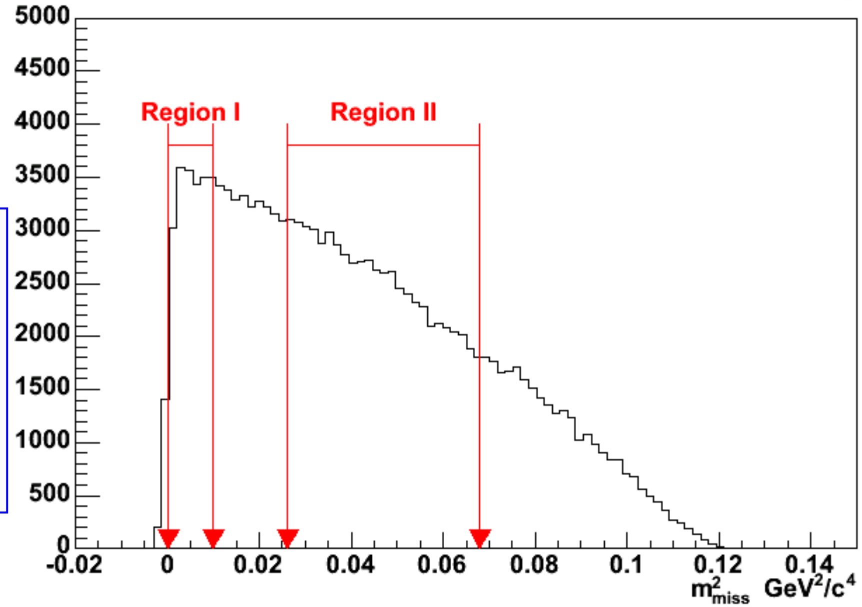


Magnetic field on iron surface

Analysis: signal acceptance

Simulation of the P-326 apparatus

- **Region I and II**
- **Momentum range: 15 < P_π < 35 GeV/c**
  - Against muons
  - RICH operational reasons
  - Plenty of energy in photon vetoes



Acceptance **(60 m fiducial volume):**

- **Region I: 4%**
- **Region II: 13%**
- **Total: 17%**

To be reduced because of losses due dead time, reconstruction inefficiencies…

Acceptance ~ 10% is achievable

Analysis: background rejection

Events/year	Total	Region I	Region II
Signal *(acc=17%)*	65	16	49
$K^+ \to \pi^+\pi^0$	2.7	1.7	1.0
$K^+ \to \mu^+\nu$	1.2	1.1	<0.1
$K^+ \to e^+\pi^+\pi^-\nu$	~2	negligible	~2
Other 3 – track decays	~1	negligible	~1
$K^+ \to \pi^+\pi^0\gamma$	1.3	negligible	1.3
$K^+ \to \mu^+\nu\gamma$	0.5	0.2	0.2
$K^+ \to e^+(\mu^+)\ \pi^0\nu$, others	negligible	–	–
Total bckg.	9	3.0	6

➡ **S/B ~ 8 (Region I ~5, Region II ~9)**

Other Physics Opportunities

- P-326 Kaon Flux ~100 times NA48/2 Kaon Flux
- Other physics opportunities can be addressed:
  - Cusp – like effects:
    - ✓ $K^+ \rightarrow \pi^0 \pi^0 e^+ \nu$
  - Lepton – flavour violation:
    - ✓ $K_{e2}/K_{\mu 2}, K^+ \rightarrow \pi^+ \mu^+ e^-, K^+ \rightarrow \pi^- \mu^+ e^+$
  - Search for new low mass particles:
    - ✓ $K^+ \rightarrow \pi^+ \pi^0 X$
    - ✓ $K^+ \rightarrow \pi^+ \pi^0 P$ *(pseudoscalar sGoldstino)*
  - Study rare π^+ & π^0 decays
  - Improve greatly on rare radiative kaon decays
  - And possibly, given the quality of the detector, topics in hadron spectroscopy

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Conclusions

- Near future: test of the CKM matrix using rare Kaon decays
- P-326 experiment: measurement of $|V_{td}|$ with a ~10% of accurancy, from the $K^+ \rightarrow \pi^+ \nu\nu$ decay
- R&D program for the most part of detectors started
- We propose an experiment able to reach a ~10^{-12} sensitivity per event at an existing machine and employing the infrastructures of an existing experiment. *[CERN-SPSC-P-326, 11/06/2005]*

A forward look (personal choice)

Year: 20XX

Quantity	Exp	09 10 11 12 13 14 15 16
$\delta(\mathrm{Sin}2\beta_{Peng})\sim0.05$	Belle/Babar	
$\delta(\Phi_{Bs})\sim0.02$	LHCb	
$\delta(\gamma)\sim4^{o}$ ($B\rightarrow DK$)	LHCb	
$B_{(s)}\rightarrow\mu^{+}\mu^{-}$ (SM sens.)	LHC	
$\delta(BR(K^{+}\rightarrow\pi^{+}\nu\nu))\sim 0.10$	P326 (NA48/3)	
$BR(K^{0}\rightarrow\pi^{0}\nu\nu)$ (SM sens.)	J-PARC	
$\delta(BR(B\rightarrow\tau\nu))\sim0.05$	Super-B	