# Future Kaon Program at CERN

**Giuseppe Ruggiero (CERN)**

**"Flavour in the era of LHC"**

**CERN, 09/11/2005**

# The Present: NA48/2

**Goal** — **Measurement of the Dalitz plot asymmetry of the $K^{\pm} \to 3\pi$ decays**

*Method*

- **60 GeV/c Kaon beams produced using ~$10^{12}$ protons per pulse @400 GeV/c from SPS**
- **Decays from $K^+$ and $K^-$ collected simultaneusly**

*Data taking*

- **2003: ~$1.6\times10^9$ $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{+}$, ~$4.8\times10^7$ $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ collected**
- **2004**

*Data analysis*

- ✓ **Exploit $K^{\pm}$ simultaneity and frequent magnets polarity alternations for systematics cancellations**

**Results** (preliminary 2003)

- $A_g = (0.5\pm2.4_{stat}\pm2.1_{stat(trig)}\pm2.1_{syst})\times10^{-4}$ $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{+}$
- $A_g = (1.7\pm1.7_{stat}\pm1.2_{stat(trig)}\pm1.3_{syst}\pm0.2_{ext})\times10^{-4}$ $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$
  - ~10 times better precision than previous measurements
  - Results consistent with SM predictions: $A_g<10^{-4}$

**Near future**

- **2004 analysis:**
  **Same amount of data, more checks on systematics**

# The Present: NA48/2

**Unexpected effect**

**Observation of a cusp-like effect in the $\pi^0\pi^0$ invariant mass at $(2m_{\pi\pm})^2$ from $K^\pm \to \pi^\pm\pi^0\pi^0$ decay**

***Interpretation***

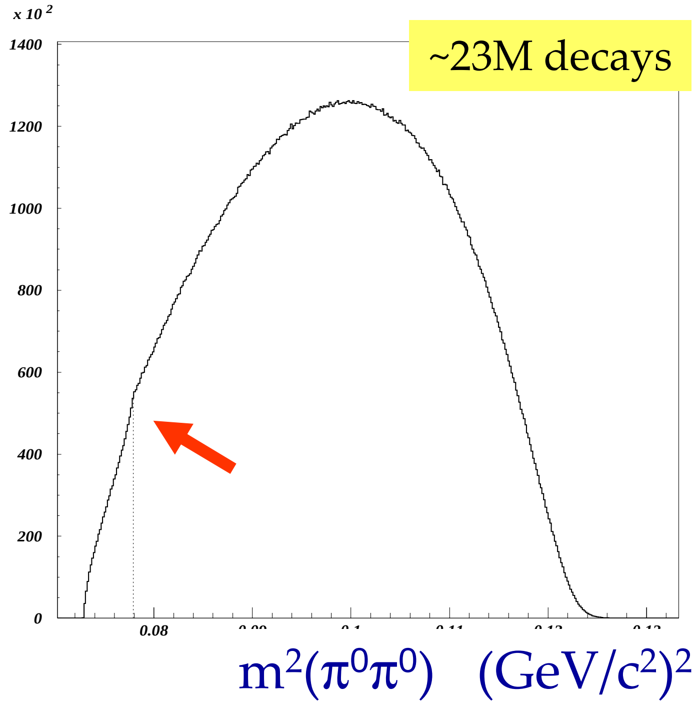
- **Rescattering $\pi^+\pi^- \to \pi^0\pi^0$ in the decay $K^\pm \to \pi^\pm\pi^+\pi^- \to \pi^\pm\pi^0\pi^0$**

***Measurement***

- **Determination of the $\pi\pi$ scattering lengths (amplitudes at threshold)**

***Method***

- **Fit to the $m^2(\pi^0\pi^0)$ distribution around the cusp using theoretical models** *(Cabibbo – Isidori, JHEP03(2005)021)*

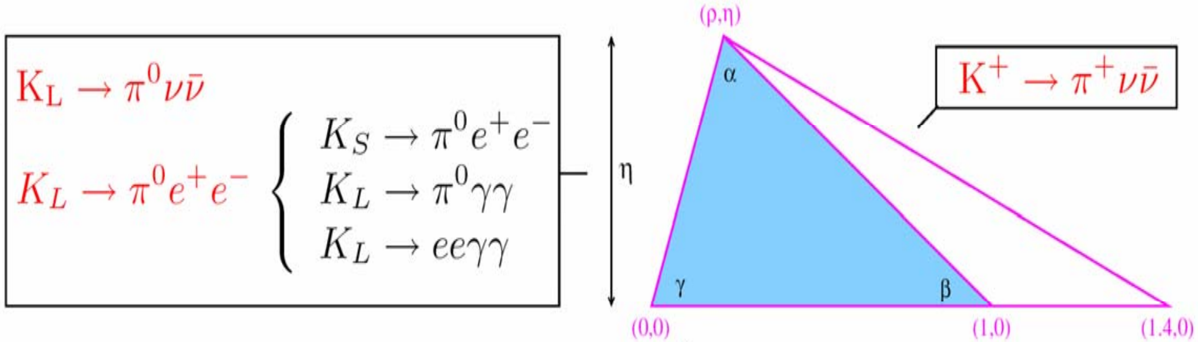



**Results**

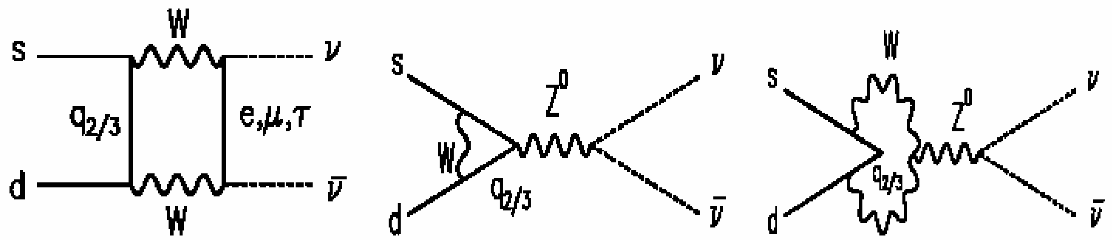
- $(a_0 - a_2)m_+ = 0.268 \pm 0.010_{stat} \pm 0.004_{syst} \pm 0.013_{ext}$
- $a_2 m_+ = -0.041 \pm 0.021_{stat} \pm 0.014_{syst}$

*Submitted to Phys. Rev. Lett.*

# The future: Kaons and CKM matrix




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

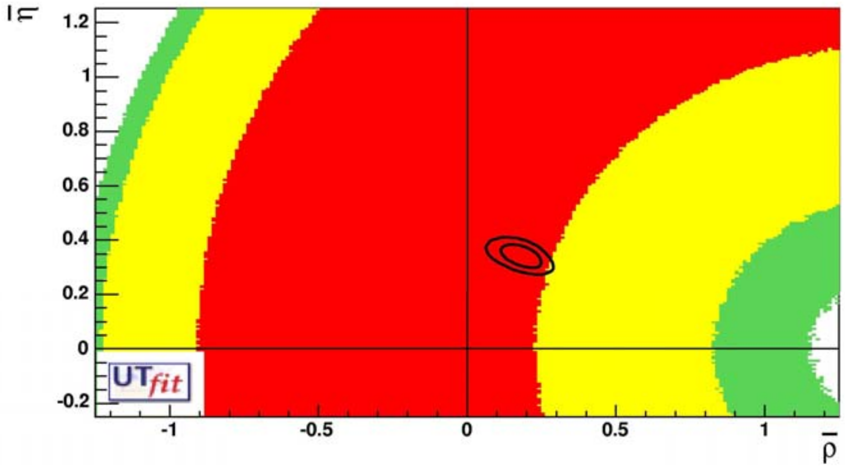



- <u>Standard Model predictions</u>
  - **$BR(K^+ \to \pi^+ \nu \bar{\nu}) \approx (1.6\times10^{-5})|V_{cb}|^4[\sigma\eta^2+(\rho_c-\rho)^2] \to (8.0 \pm 1.1)\times10^{-11}$**
  - **$BR(K_L \to \pi^0 \nu \bar{\nu}) \approx (7.6\times10^{-5})|V_{cb}|^4\eta^2 \to (3.0 \pm 0.6)\times10^{-11}$**

# Setting the bar for future Kaon experiments

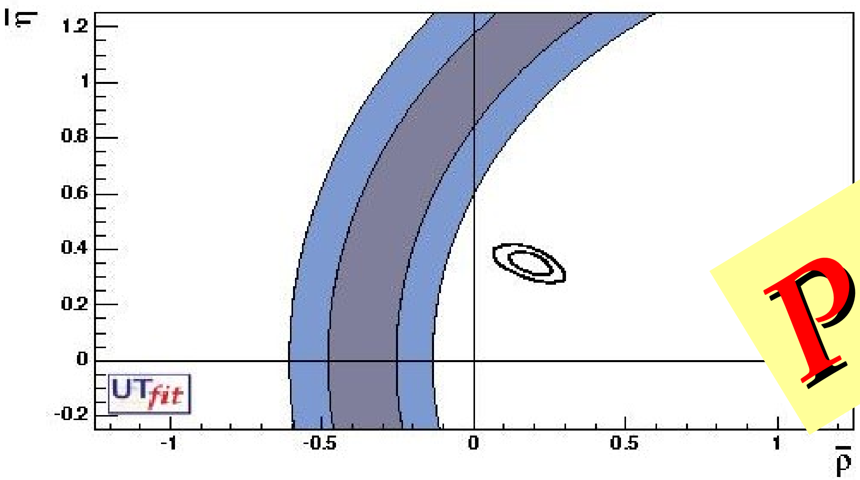
- <u>Measurement of the BR($K^+ \to \pi^+ \nu\nu$)</u>
- Present (E787/949): **BR($K^+ \to \pi^+ \nu\nu$) = $1.47^{+1.30}_{-0.89} \times 10^{-10}$**

*Current constraint on $\rho,\eta$ plane*

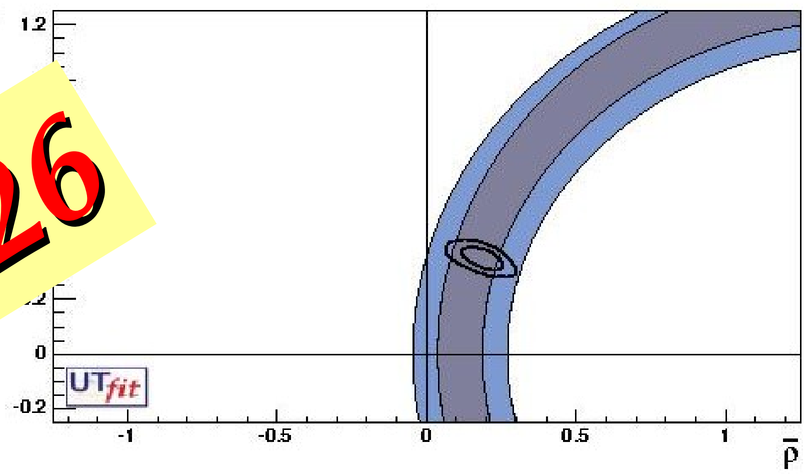



**100 events**
**Mean: E787/949**

**100 events**
**Mean: SM**




**P-326**



# P-326 guidance principles

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

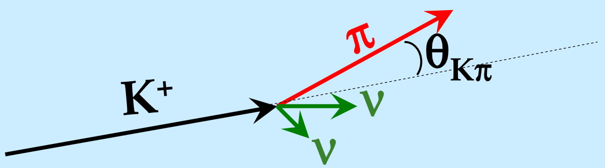
$BR(K^+ \to \pi^+\nu\nu) \sim 8\times10^{-11}$
Signal acceptance ~10%
K decays ~$10^{13}$

- K decay in flight technique

- Intense proton beam from SPS
- High energy K (75 GeV/c)
- *Unseparated secondary beam p/π/K/e*
  - Kaon ID → CERENKOV

## Low level of background

**Kinematics**




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

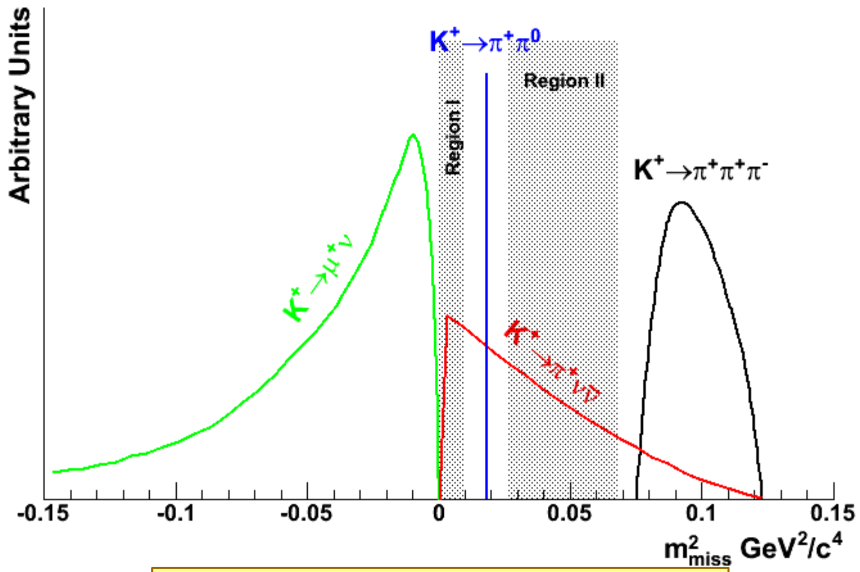
- Kaon → BEAM TRACKER
- Pion → SPECTROMETER

**Vetoes**

- Particle ID → RICH
- γ/μ detection → CALORIMETERS
- Charged → SPECTROMETER

# Backgrounds

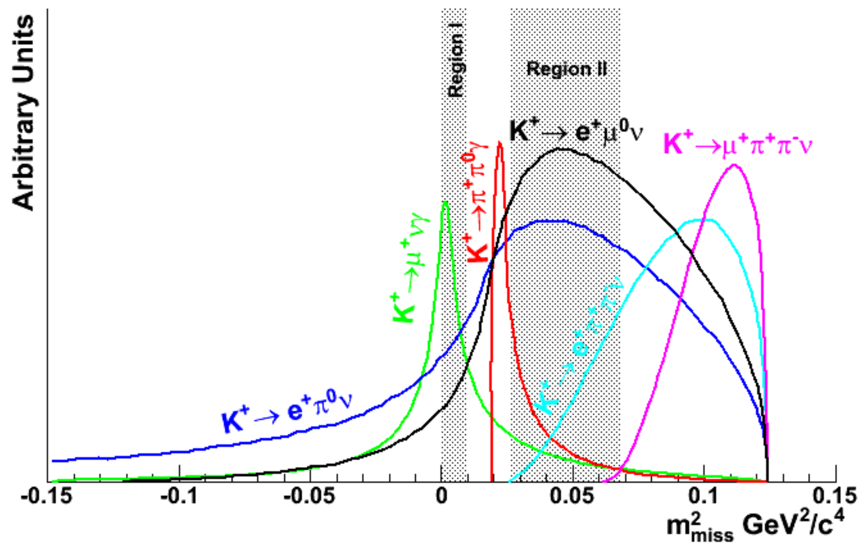
**Kinematically constrained**




**92% of total background**

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

**Not kinematically constrained**

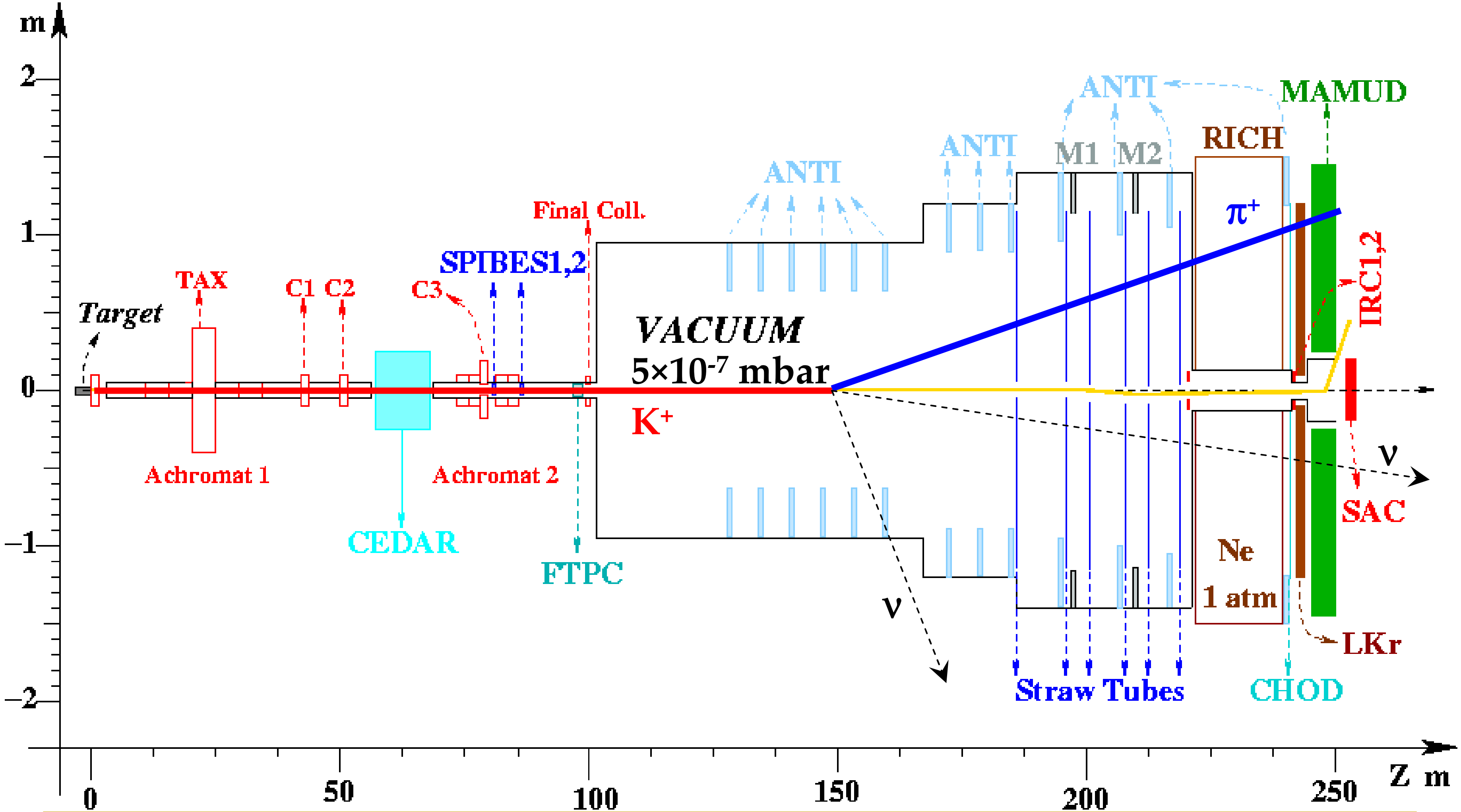



**8% of total background**

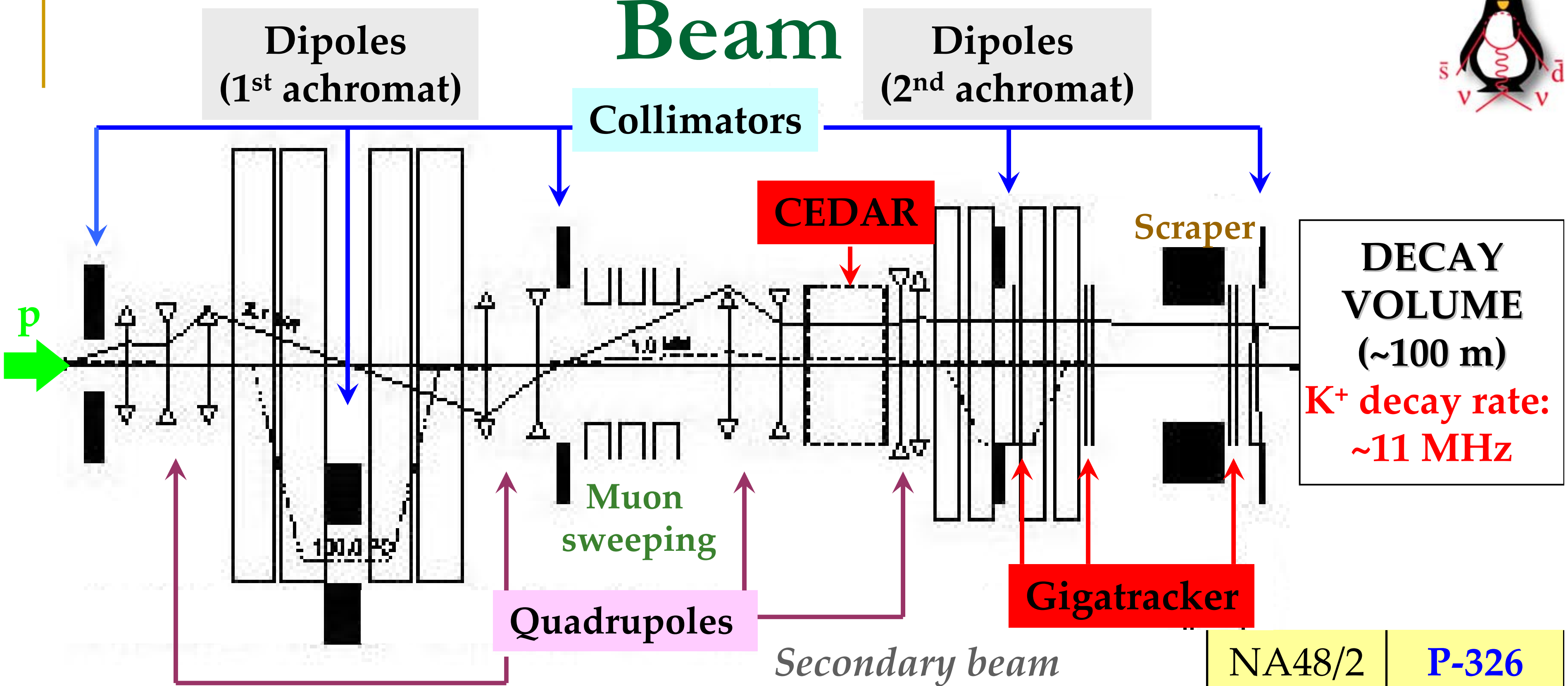
- Span across the signal region
- Rejection must rely on veotes

# P-326 Layout

- Located in the same hall of NA48



# Beam




| *Primary beam* | NA48/2 | **P-326** |
|---|---|---|
| **Pp (GeV/c)** | 400 | **400** |
| **p/pulse $10^{12}$** | 1 | **3** |
| **Duty cycle (s)** | 4.8/16.8 | **4.8/16.8** |
| **Eff. n pulses/year** | $3\times10^5$ | **$3\times10^5$** |

| *Secondary beam* | NA48/2 | **P-326** |
|---|---|---|
| **$P_K$ (GeV/c) ($\Delta P_K/P_K$)** | 60 (4%) | **75 (1%)** |
| **Fraction of K** | 5.7% | **6.0%** |
| **Beam acceptance (μstr)** | 0.4 | **16** |
| **Area (@beam tracker)** | 0.40 cm$^2$ | **16 cm$^2$** |
| **Rate (MHz)** | 18 | **800** |
| **K decay/year** ***(60m volume)*** | $10^{11}$ | **$4.8\times10^{12}$** |

# Beam tracker: Gigatracker

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

**Low $X/X_0$ not to spoil the beam** → **300 Si µm sensor+ 100 Si µm chip**

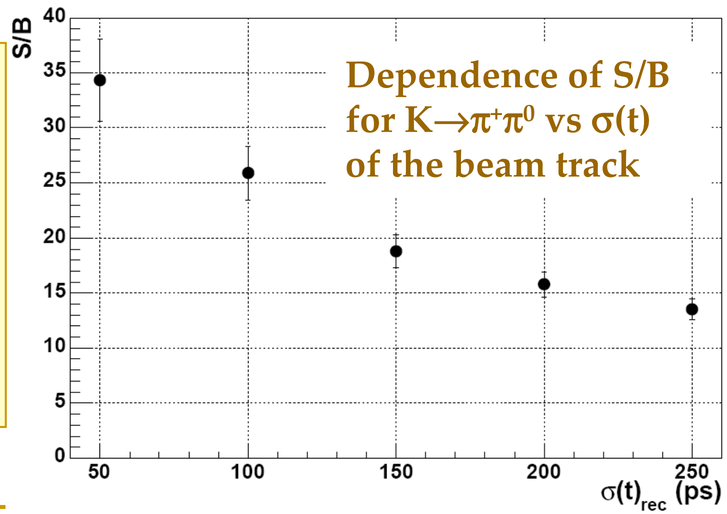
**Good space resolution not to spoil the downstream tracker performances** → **300×300 µm pixels**

**$\sigma(P_K)/P_K$ ~ 0.4%**
**$\sigma(\theta_K)$ ~ 16 µrad**

**Time coincidence with the downstream track to select the right K track** →

**$\sigma(t)$ ~ 200 ps**
(per station)

*Complex readout chip bump-bonded on the sensor (0.25 or 0.13 µm CMOS technology)*



# Downstream tracker

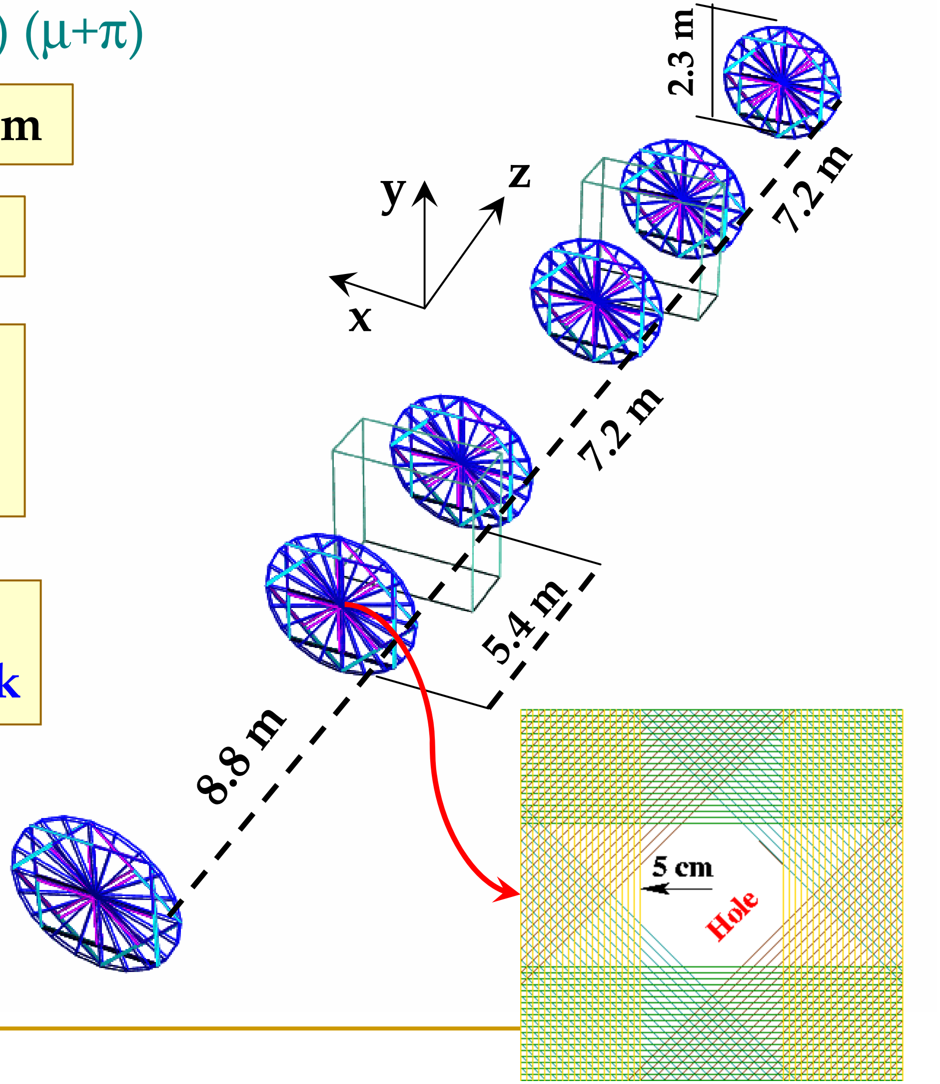
- 6 chambers with 4 double layers of straw tubes each (∅ 9.6 mm)
- Rate: ~45 KHz per tube (max 0.5 MHz) ($\mu+\pi$)

**Low $X/X_0$** →
- Operate in high vacuum
- $X/X_0$ ~ 0.1% per view

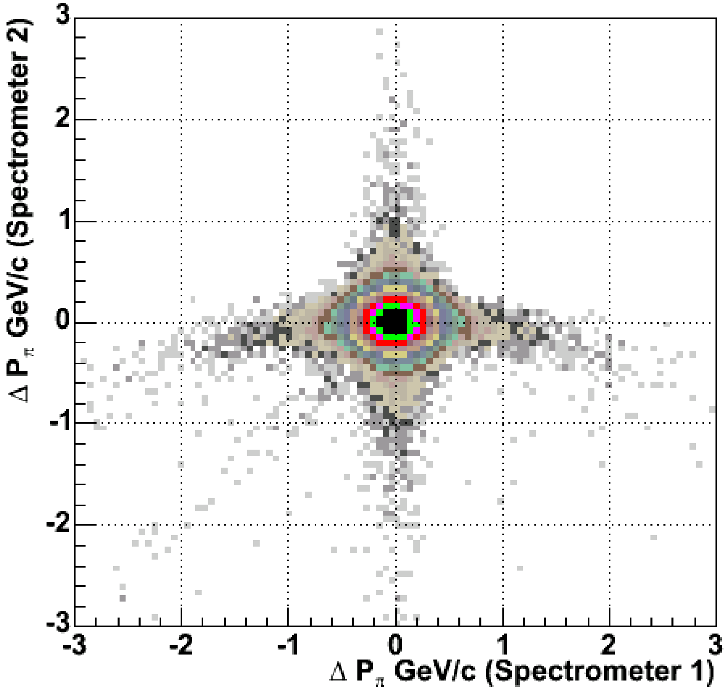
**Good space resolution** →
- 130 μm / hit
- $\sigma(P)/P = 0.23\% \oplus 0.005\%P$
- $\sigma(\theta) \sim 50 \div 20$ μrad

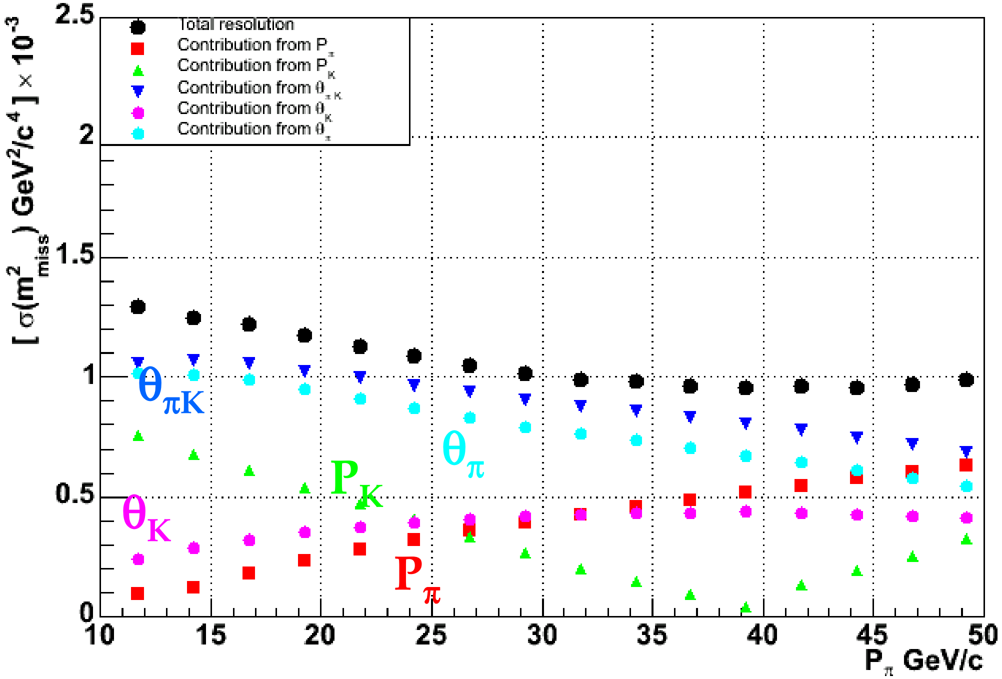
**Redundant momentum measurement** →
- 2 magnets:
- 270 and 360 MeV $P_t$kick

**Veto for charged negative particles up to 60 GeV/c** →
- 5 cm radius beam holes displaced in the bending plane according to the 75 GeV/c beam path



# Kinematics reconstruction




Two almost independent measurements of the downstream track momentum

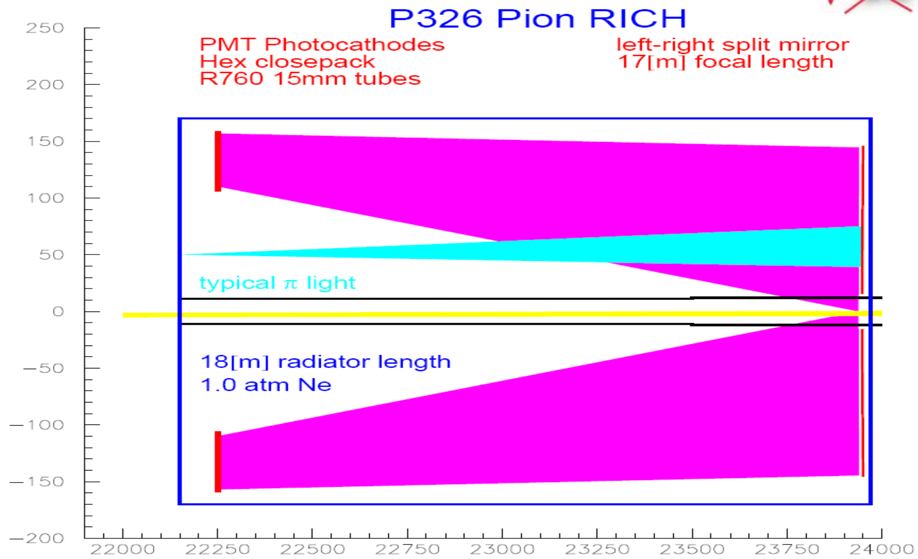
$m^2_{miss}$ resolution ~$1.1\times10^{-3}$ GeV$^2$/c$^4$
main contribution from $\Theta_{\pi K}$ measurement

# Particle ID: RICH

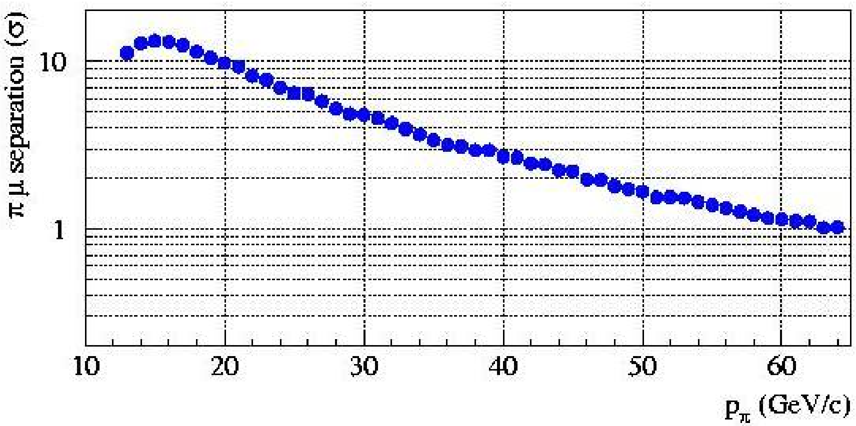
| pion / muon separation |
| --- |
| Velocity spectrometer |

**18 m Ne @ 1.0 atm**

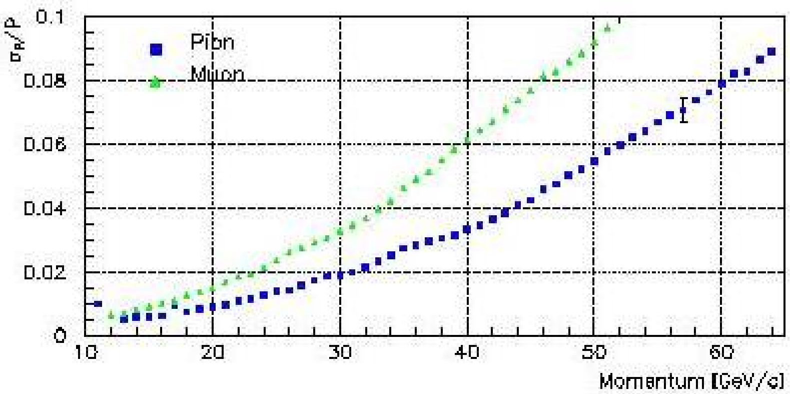
- Threshold: 12 GeV/c for π
- 3σ separation for P < 35 GeV/c



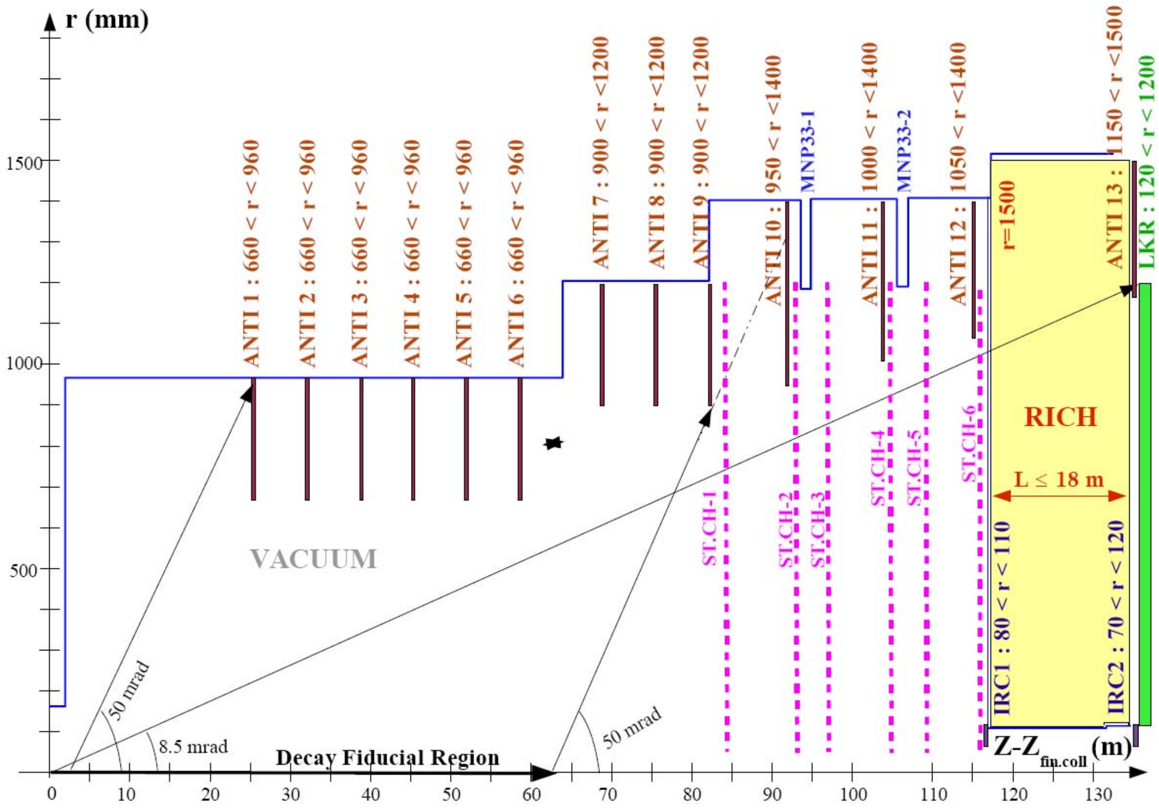

**RICH as particle ID**




**RICH as velocity spectrometer**



# Photon vetoes layout



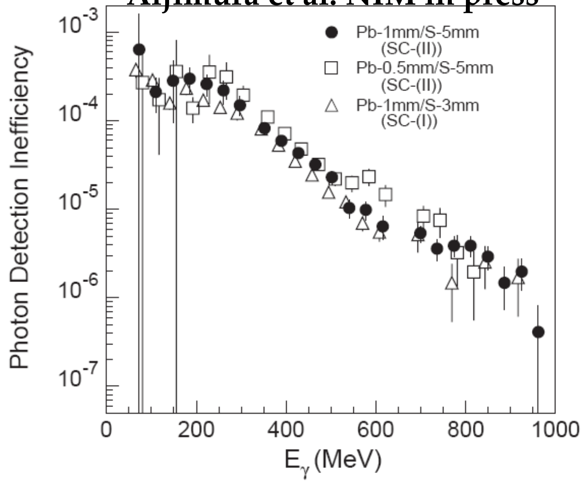

- <u>Large angle:</u> 13 ANTIs (10 < acceptance < 50 mrad), lead-scintillators
- <u>Medium angle:</u> NA48 LKr (1 < acceptance < 10 mrad), homogenous calorimeter
- <u>Small angle:</u> IRC1,2 SAC (acceptance < 1 mrad)

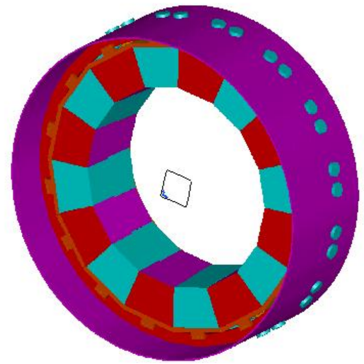
# Photon Vetoes

- ANTI: Rate ~4 MHz (μ)+~0.5 MHz (γ) (OR of 13 ANTI's)

| | $E_\gamma$ GeV | Ineff. |
|---|---|---|
| ANTIs | < 0.05 | 1 |
| | 0.05,1 | $10^{-4}$ |
| | >1 | $10^{-5}$ |

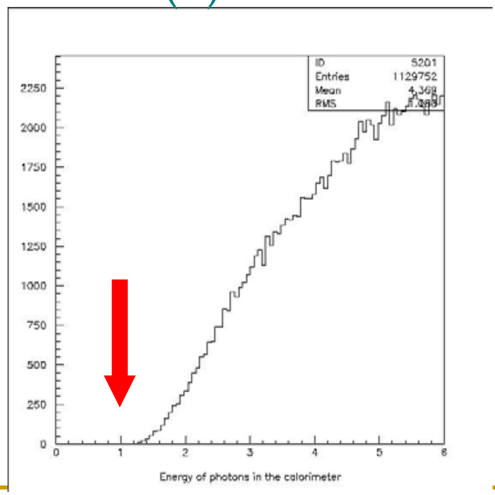
Aijimura et al. NIM in press



- LKr: Rate ~7 MHz (μ) + ~4 MHz (γ)+~3 MHz (π)

| | $E_\gamma$ GeV | Ineff. |
|---|---|---|
| LKr | < 1 | 1 |
| | 1,3 | $10^{-4}$ |
| | 3,5 | $10^{-4}$,$10^{-5}$ |
| | >5 | $10^{-5}$ |




# Muon Veto (MAMUD)

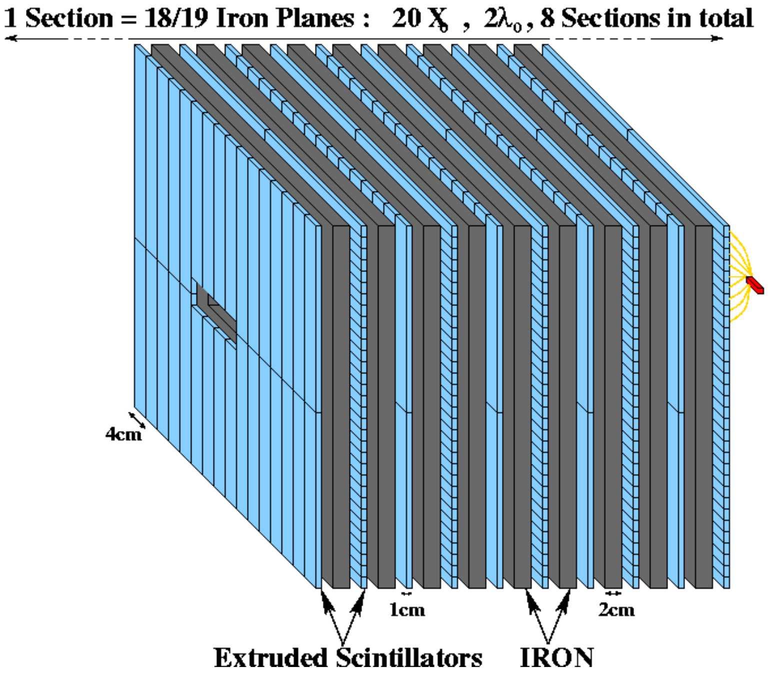
- Sampling calorimeter + Magnet for beam deflection
- Rate: ~7 MHz (μ)+ ~3 MHz (π)

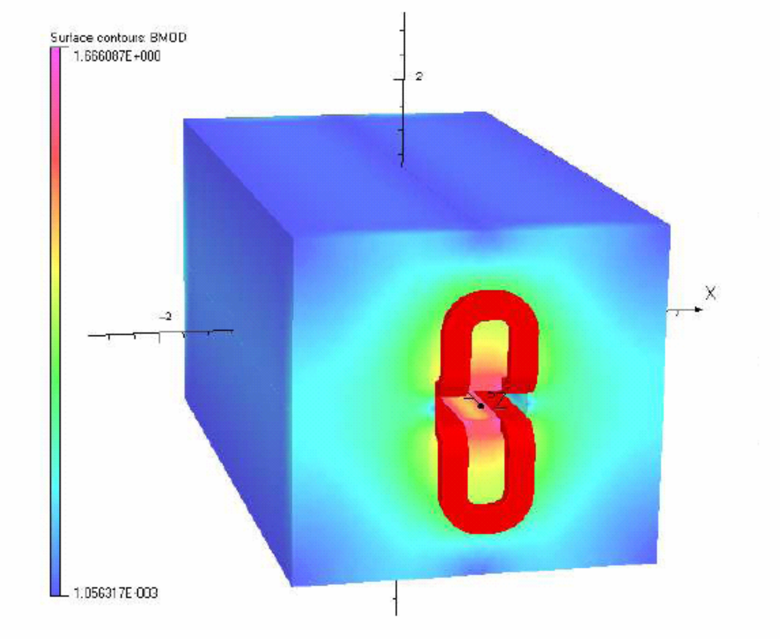
**μ rejection ~$10^{-5}$**

- **Sensitivity to the MIPs**
- **e.m. & hadronic shower detection**

**Deflect the beam out from the SAC**

**Coils providing 5 Tm field integral in the beam region**

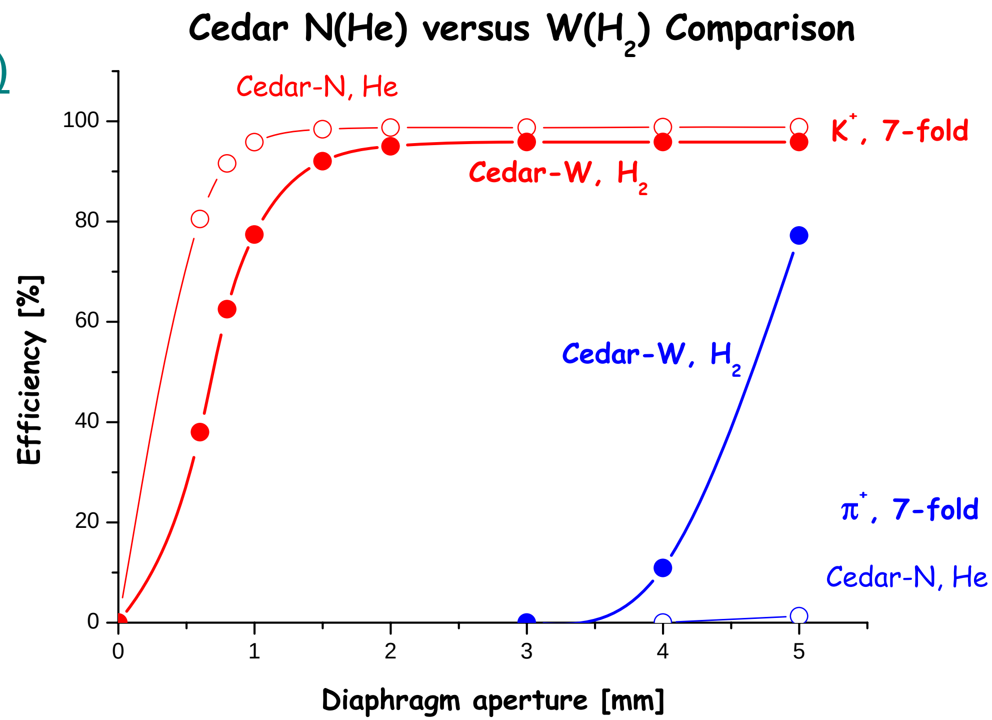


Magnetic field on iron surface

# Other detectors

- Cerenkov on the beam (CEDAR)




- Keep the beam background under control
- Provide an a posteriori check at the analysis level

- Fast Hodoscope

- Provide timing of the event (high resolution $\sigma(t)<100$ ps)
- Trigger for charged particles

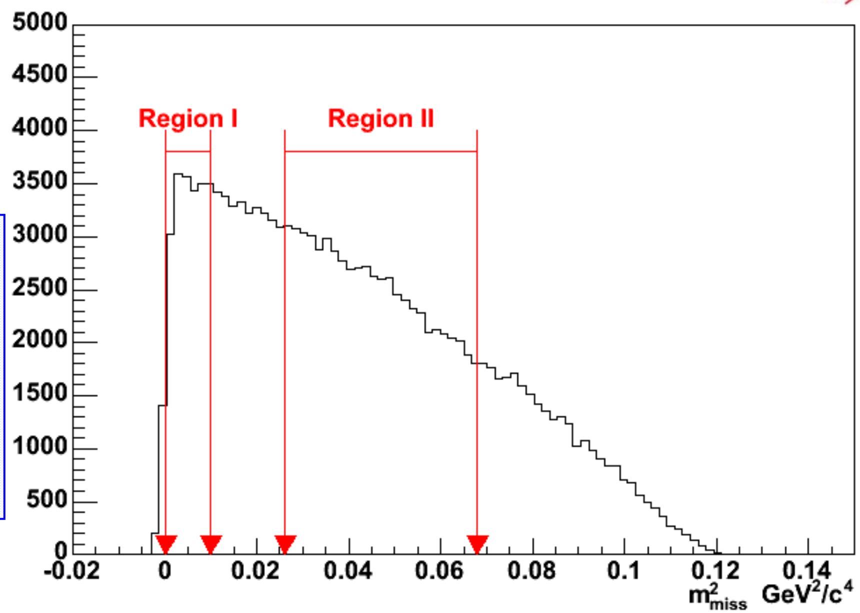
**Propose to use the Multi-gap Glass RPC (ALICE-TOF technology)**

*Prototype is under study*

# Analysis: signal acceptance

P326

**Simulation of the P-326 apparatus**




- **Region I and II**
- **Momentum range: 15 < $P_\pi$ < 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

- <u>P-326 Kaon Flux ~100 times NA48/2 Kaon Flux</u>

- <u>Other physics opportunities can be addressed:</u>
  - Cusp – like effects:
    - ✓ $K^+ \to \pi^0 \pi^0 e^+ \nu$
  - Lepton – flavour violation:
    - ✓ $K_{e2}/K_{\mu 2}$, $K^+ \to \pi^+ \mu^+ e^-$, $K^+ \to \pi^- \mu^+ e^+$
  - Search for new low mass particles:
    - ✓ $K^+ \to \pi^+ \pi^0 X$
    - ✓ $K^+ \to \pi^+ \pi^0 P$ *(pseudoscalar sGoldstino)*
  - Improve greatly on rare radiative kaon decays

# Conclusions

- Excellent NA48/2 results about $K^{\pm} \to 3\pi$ have been presented
- 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 $K^{+} \to \pi^{+}\nu\bar{\nu}$ decay
- We propose an experiment able to reach a $\sim 10^{-12}$ sensitivity per event at an existing machine and employing the infrastructures of an existing experiment. *[CERN-SPSC-P-326, 11/06/2005]*