A detector for the measurement of the ultrarare decay $K^+ \rightarrow \pi^+\nu\nu$: *NA62 at CERN SPS*

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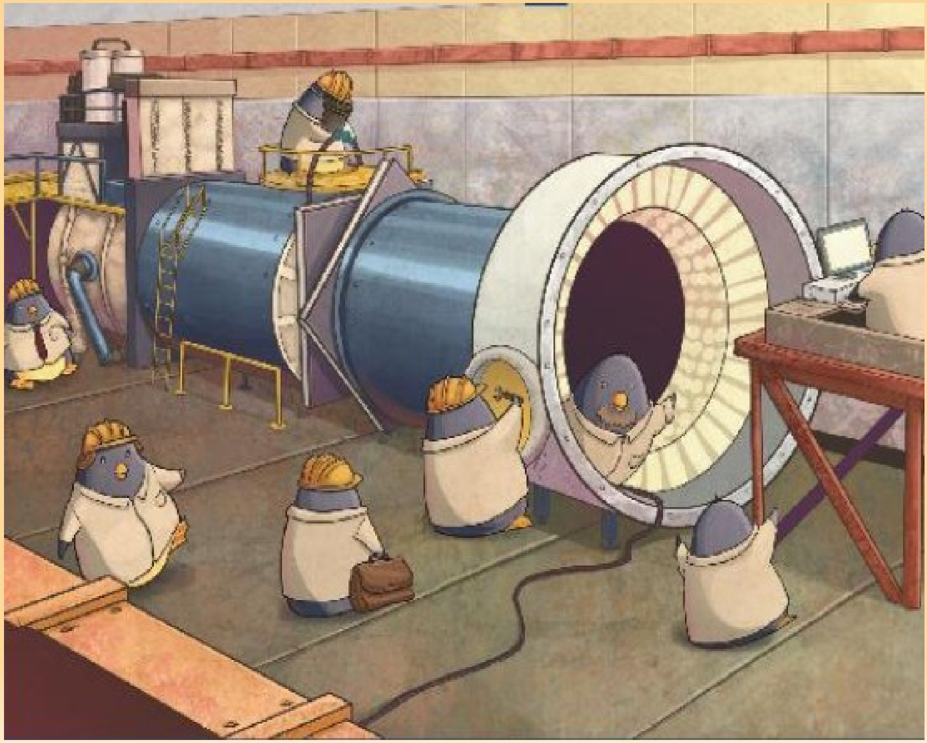
On behalf of the NA62 Collaboration

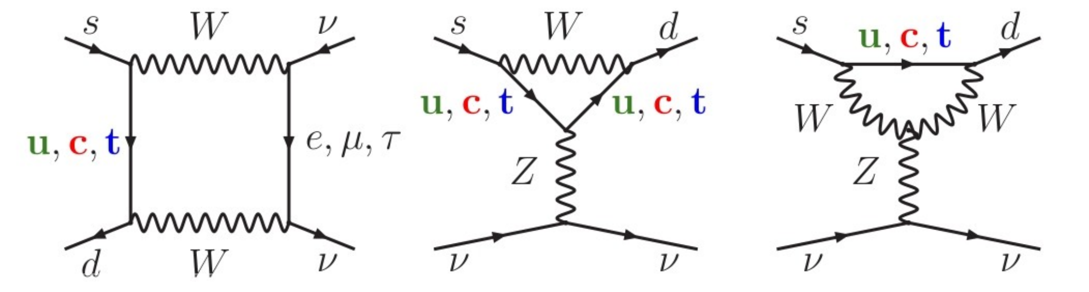
Outline

- ✔ The $K \to \pi\nu\nu$ in the SM and beyond
- ✔ NA62 experimental technique
- ✔ NA62 experiment:
  - ✗ Signal & background
  - ✗ Detectors
  - ✗ Trigger
  - ✗ Sensitivity
- ✔ NA62 Schedule
- ✔ NA62 Phase I
- ✔ Conclusions



$K^+ \to \pi^+ \nu\nu$ in the Standard Model

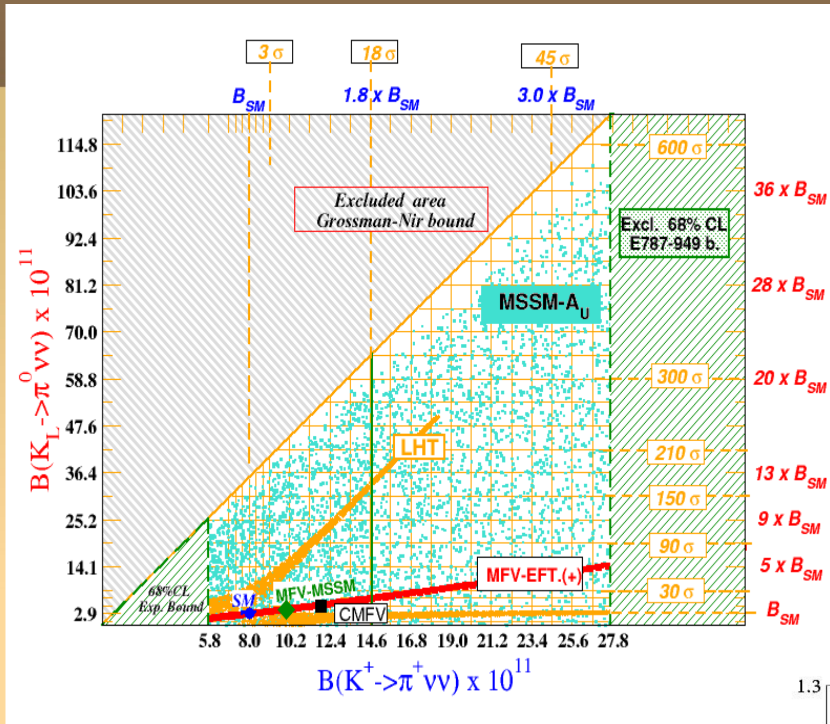
- FCNC process forbidden at tree level
- Short distance contribution dominated by Z penguins and box diagrams
- Negligible contribution from u quark, small contribution from c quark
- Very small BR due to the CKM top coupling → λ^5



- ✔ Amplitude well predicted in SM (measurement of Vtd without QCD inputs)
- ✔ Residual error in the BR due to parametric uncertainties (mainly due to charm contributions): ~7%

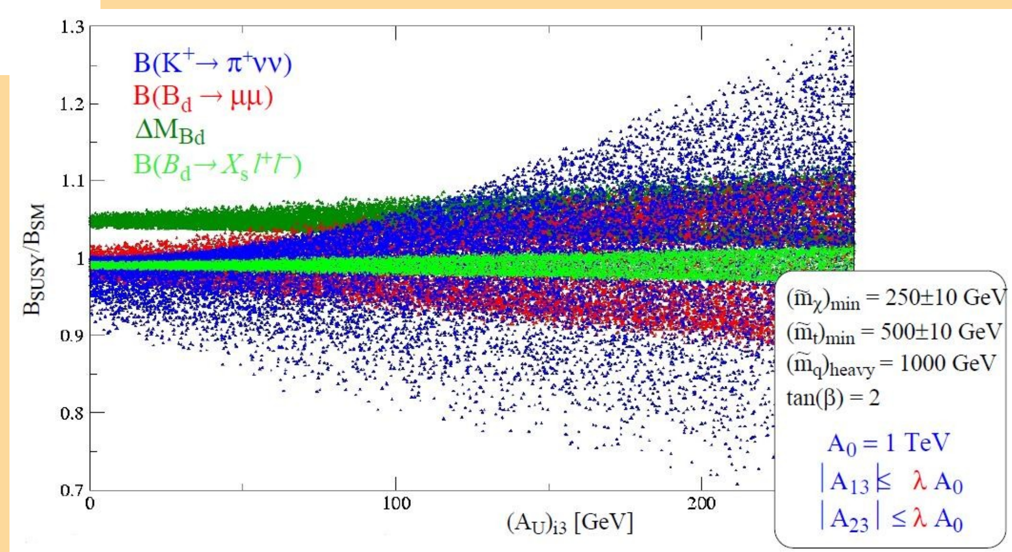
	Γ_{SD}/Γ	Irr. theory err.	BR x 10^{-11}
$K_L \to \pi\nu\nu$	>99%	1%	3
$K^+ \to \pi^+\nu\nu$	88%	3%	8
$K_L \to \pi^0 e^+ e^-$	38%	15%	3.5
$K_L \to \pi^0 \mu^+ \mu^-$	28%	30%	1.5

$K^+ \to \pi^+ \nu\nu$ beyond the SM

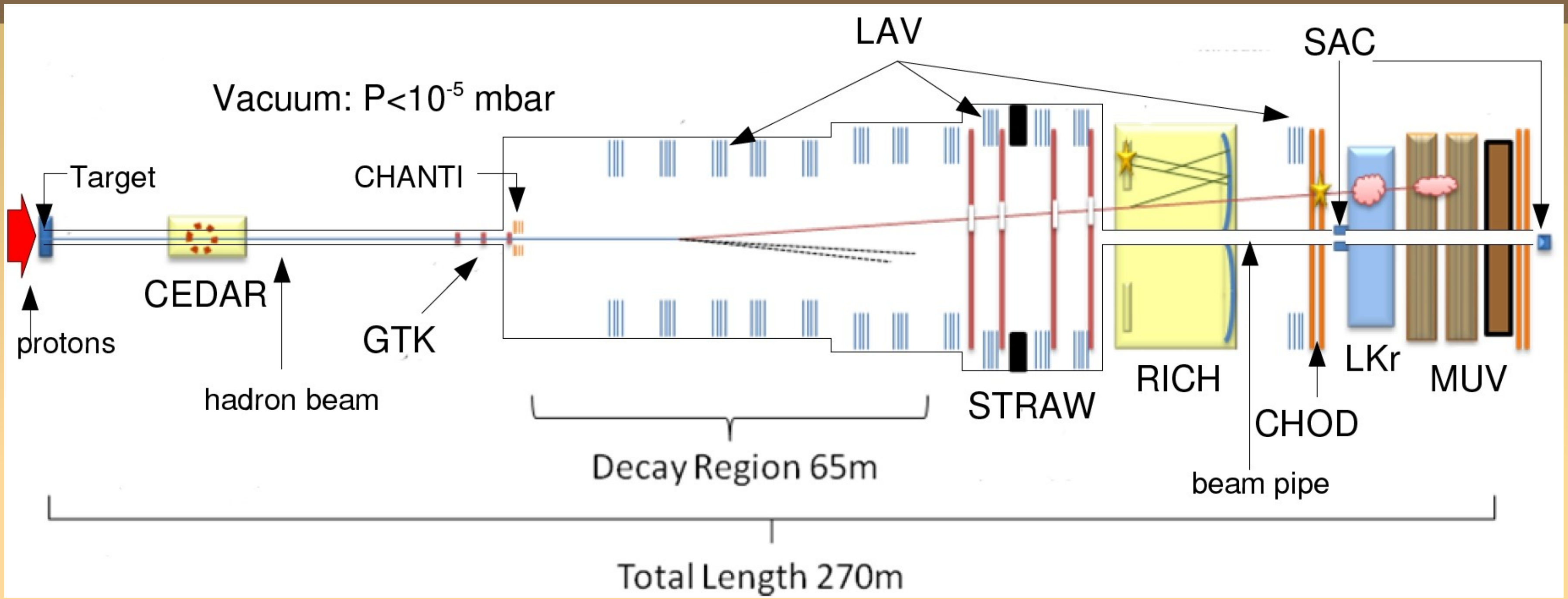


- ✗ Stringent test of the SM
- ✗ Several SM extensions predict different value for the BR
- ✗ Possibility not only to identify new physics but also to distinguish among different models: *SUSY, MSSM (with or without new sources of CPV or FV) ….*

- ➢ Example: in MSSM the departure from the SM should reach 10%-20% for reasonable parameters values
- ➢ Higher effects with respect to the B decays



Experimental technique



- Kaon decay in-flight from an unseparated 75 GeV/c hadron beam, produced with 400 GeV/c protons from SPS on a fixed berilium target
- ~800 MHz hadron beam with ~6% kaons
- The pion decay products in the beam remain in the beam pipe
- Goal: measurement of O(100) events in two years of data taking with % level of systematics
- Present result (E787+E949): 7 events, total error of ~65% (Phys.Rev. D79 (2009) 092004).

Experimental technique

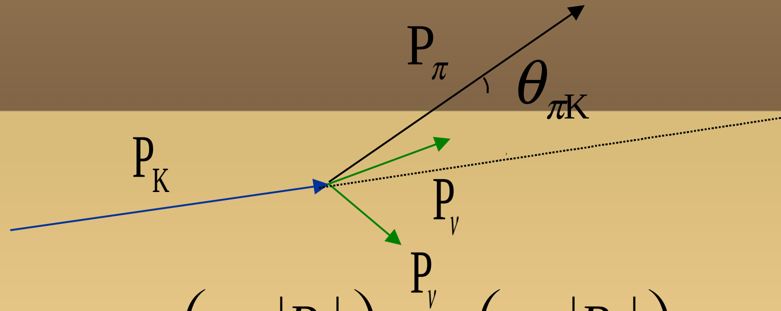
- Very challenging experiment:
  - Weak signal signature: BRSM=8x10^{-11}
  - Potentially huge background from kaon decays

Key points:

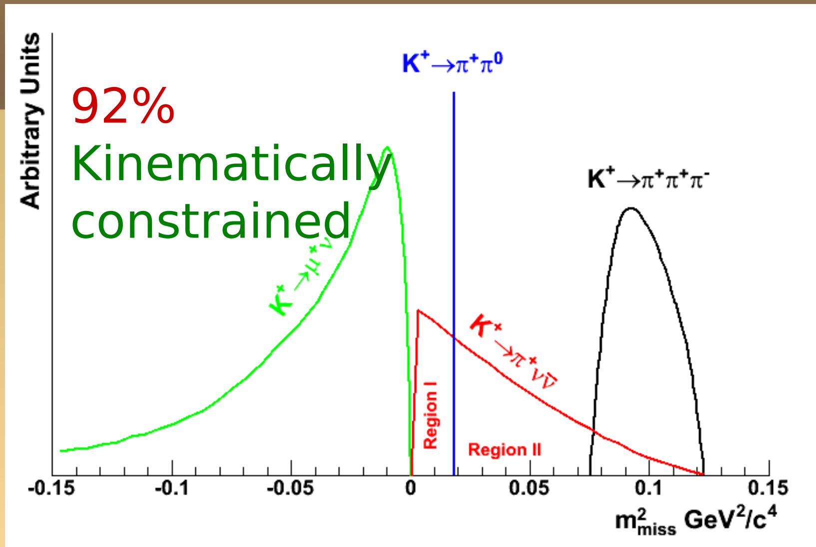
1. Kinematical rejection
2. Vetos
3. Particle identification
4. Trigger

Decay	BR
$\mu^+\nu$ (Kμ2)	63.5%
$\pi^+\pi^0$ (Kπ2)	20.7%
$\pi^+\pi^+\pi^-$	5.6%
$\pi^0e^+\nu$ (Ke3)	5.1%
$\pi^0\mu^+\nu$ (Kμ3)	3.3%
$\pi^+\pi^0\pi^0$	1.8%
$\mu^+\nu\gamma$ (K$\mu2\gamma$)	0.62%
$\pi^+\pi^0\gamma$	2.7×10^{-4}
$\pi^+\pi^-e^+\nu$ (Ke4)	4.1×10^{-5}
$\pi^0\pi^0e^+\nu$ (Ke400)	2.2×10^{-5}
$e^+\nu$ (Ke2)	1.5×10^{-5}
$\pi^+\pi^-\mu^+\nu$ (Kμ4)	1.4×10^{-5}

1) Kinematic rejection



$$m^2_{miss} \cong m^2_K\left(1-\frac{|P_\pi|}{|P_K|}\right)+m^2_\pi\left(1-\frac{|P_K|}{|P_\pi|}\right)-|P_K||P_\pi|\theta^2_{\pi K}$$



✗ The missing mass will be used to identify two regions with lower background level

✗ Measurement of kaon and pion momenta

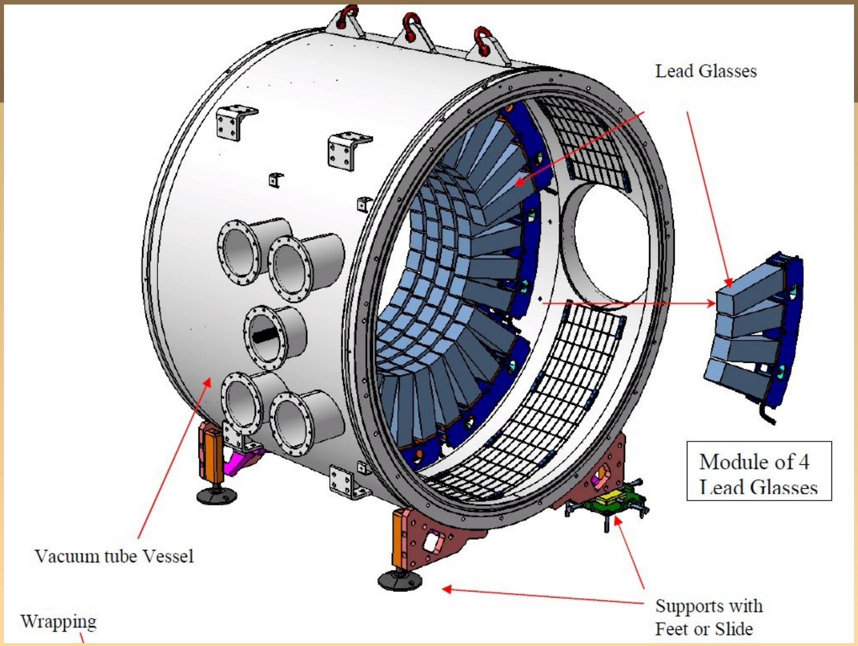
Kaon momentum : Gigatracker

- Thin detector → 200 µm pixel sensor+100 µm readout chip (< 0.5% X_0 per station)
- 18000 pixels, 150 kHz rate per single pixel in the central part
- Excellent time resolution to match the measurement with the other detectors → <200 ps per station achieved in test beam

Charged pion momentum: Straw tracker

- 4 chambers with 4 redundant views each (4 staggered layer per view)
- Magnet with Ptkick = 256 MeV/c
- 2.1 m long straws, 9.6 mm mylar tubes
- <0.1% X_0 per view

2) Vetos: LAV and LKr



LAV:

- 12 rings along the decay region (in vacuum)
- Fully angular coverage in the 8.5-50 mrad range
- OPAL calorimeter lead glass reused: 5 staggered rings per station
- Block tested at BTF@Frascati: inefficiency $< 10^{-4}$ for 476 MeV e^+
- Time resolution: 700 ps

The old NA48 electromagnetic calorimeter, cryogenic liquid kripton (Lkr):

- ✔ Quasi homogeneous ionization chamber
- ✔ more than 13000 channels
- ✔ 27 X_0
- ✔ Excellent energy resolution
- ✔ very good time resolution: 100 ps
- ✔ New readout electronics: 14 bits 40 MHz ADC with large buffers

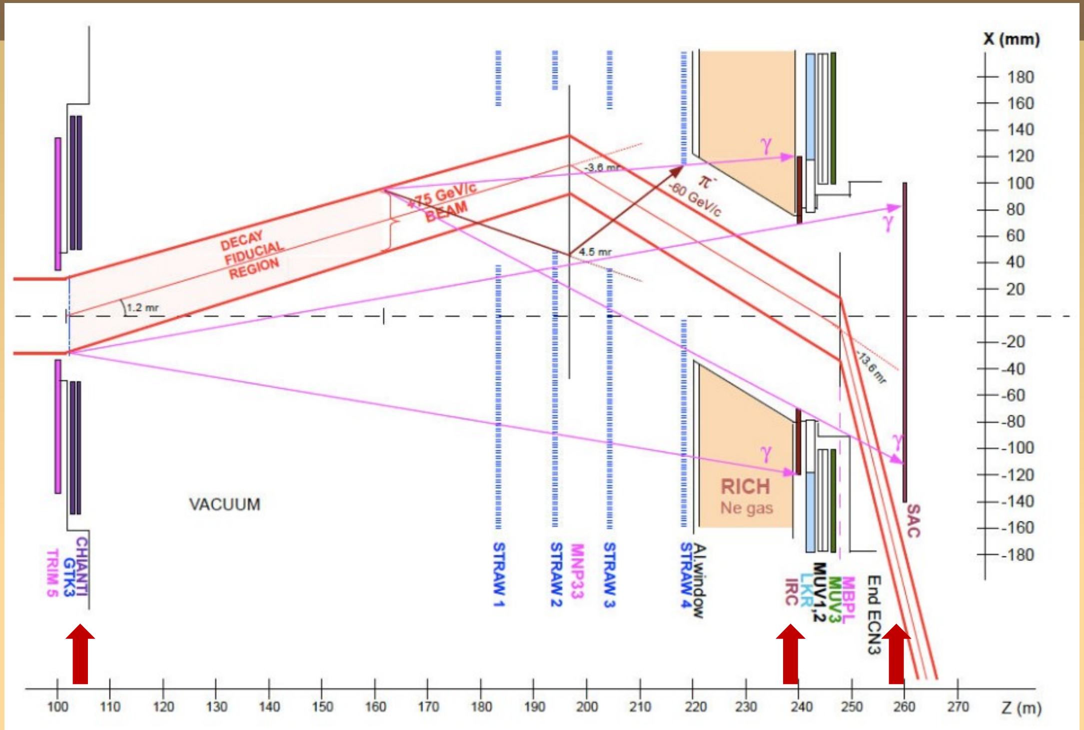
✔ The performances as photon veto has been measured in a special run with 75 GeV kaon decays:

Energy(GeV)	Inefficiency
2.5-5.5	10^{-3}
5.5-7.5	10^{-4}
7.5-10	$5x10^{-5}$
>10	$8x10^{-6}$

For more detail see the next talk of Andrea Salamon

2) Vetos: CHANTI,SAC & IRC

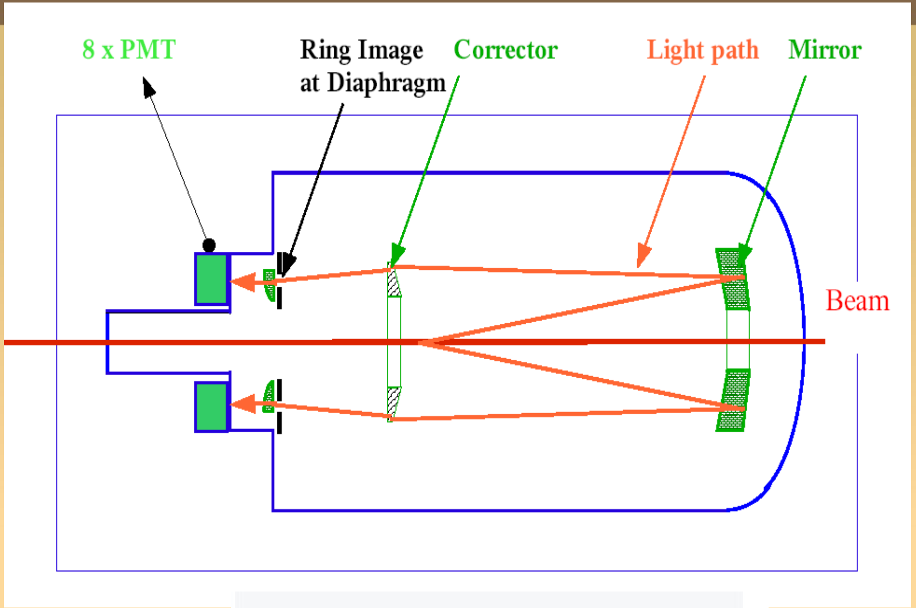
- Small angle calorimeters: IRC & SAC
- IRC: to increase the acceptance for small angle γ in the region not covered by the LKr
- SAC: to detect γ in the beam pipe region

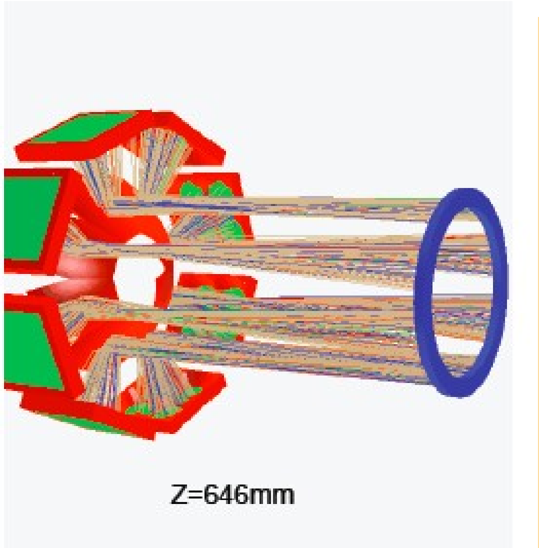


- The IRC is located around the beam pipe in front of the LKr, the SAC is located in the beam dump, at the very end of the experiment.
- The CHANTI is located after the GTK station three in order to detect interaction in the beam spectrometer
- IRC, SAC and CHANTI are in advanced R&D status

3) PID: CEDAR

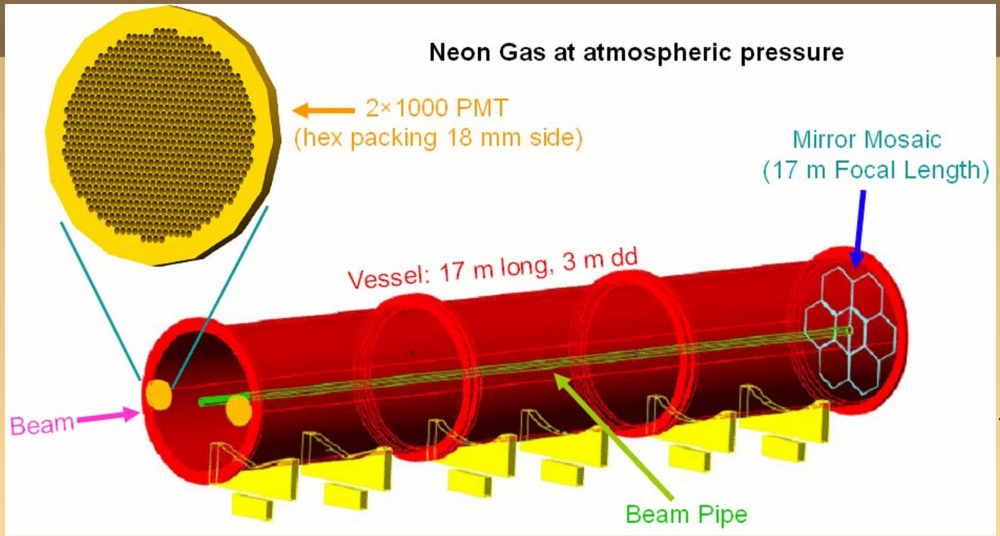
✗ Positive identification of the kaon in the hadron beam
✗ Purpose: tagging the kaon to decrease the requirements for the vacuum in the decay region (10^{-5} mbar).
✗ Technique: differential H2 cherenkov detector.
✗ Old detector built at CERN in the ’70
✗ New readout (PMs and electronics)
✗ New deflecting mirrors system to decrease the rate per single channel on the readout.



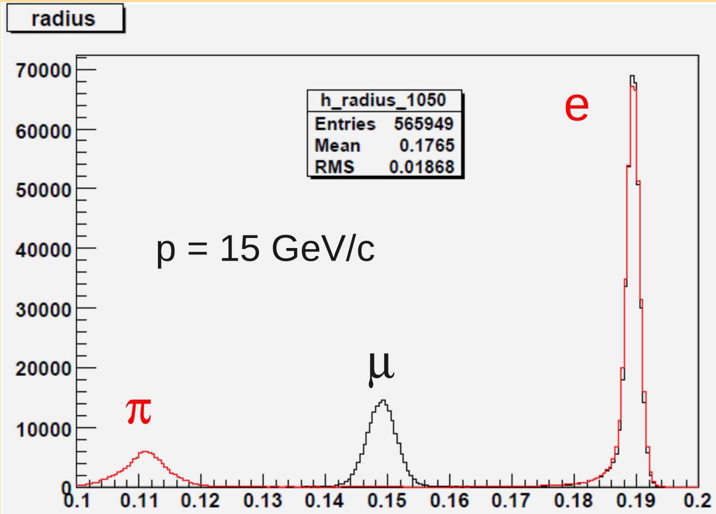


For more detail see the talk of Angela Romano (tomorrow)

3) PID: RICH

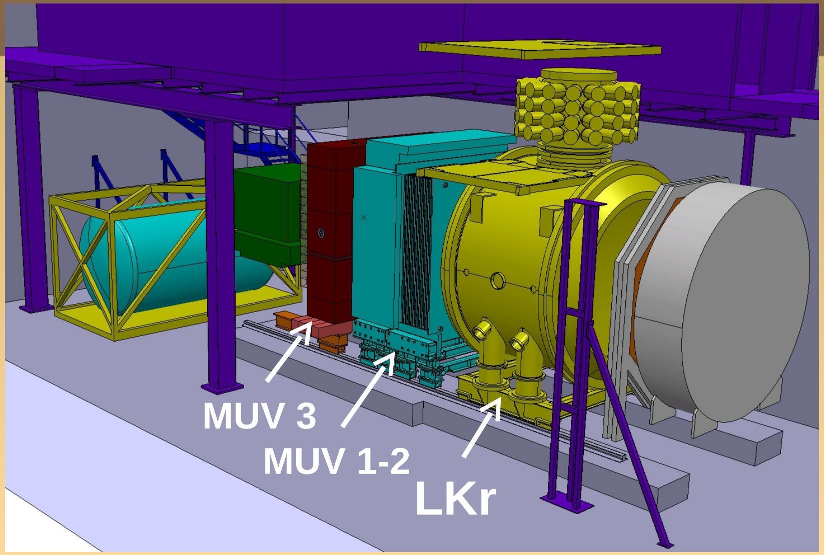


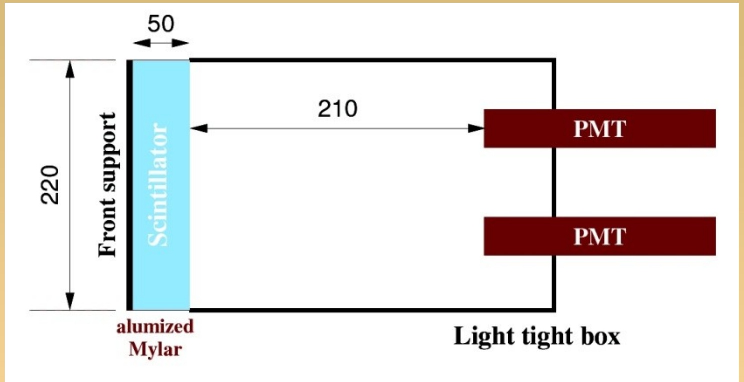
- 17 m long, 3 m in diameter
- Filled with 1 atm Neon
- π–μ separation in the 15-35 GeV/c range
- Cherenkov light collected in two spots: 1000 PM each
- Full length prototype tested in 2009
- Average time resolution: 70 ps
- Integrated mis-indentification probability: $\sim 5\times10^{-3}$



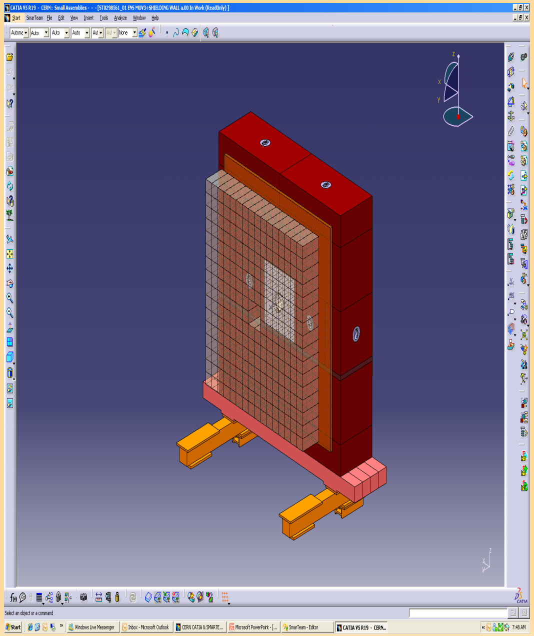
For more detail see the talk of Francesca Bucci (tomorrow)

3) PID: MUV

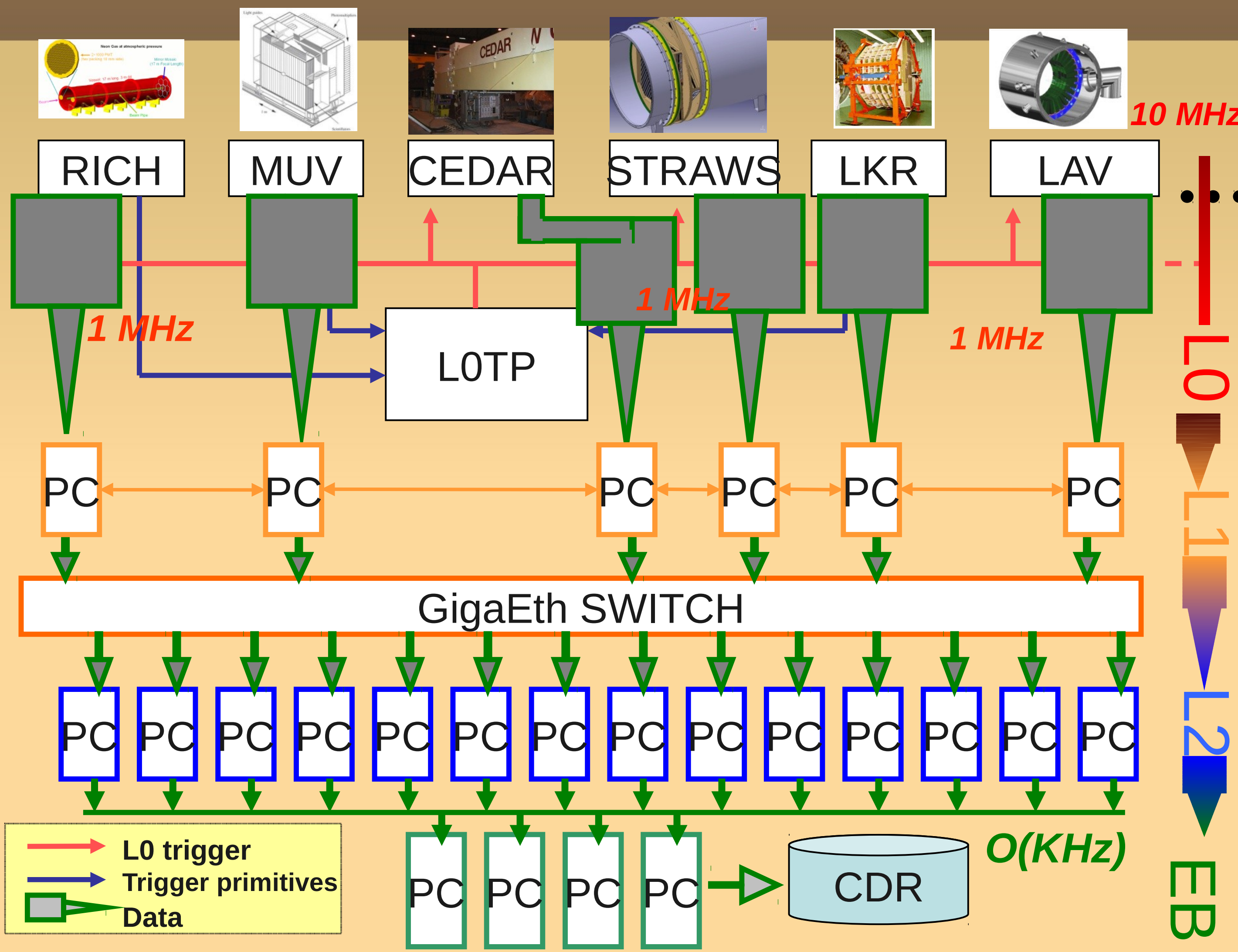




- MUV1-2 : to reach a factor of 10^6 in muon rejection (combined with the RICH)
  - Iron and scintillator
- MUV3: fast muon identification plane for trigger
  - modules of 22x22 cm2 with 5 cm thick scintillator readout with 2 PMs
  - <1ns time resolution achieved in test beam



4) Trigger



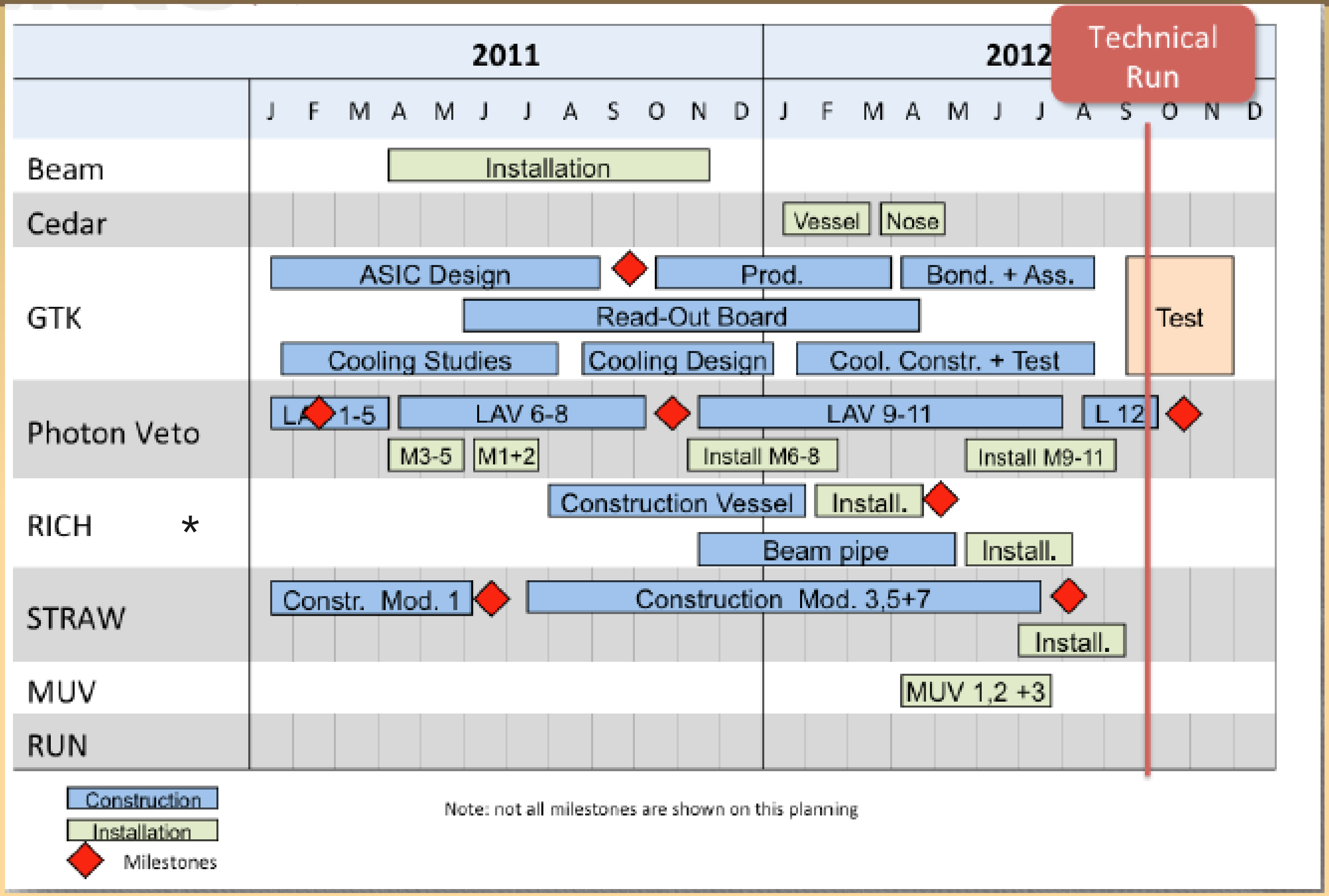
- L0: Hardware level. Decision based on primitives produced in the RO card of detectors partecipating to trigger
- L1: Software level. "Single detector" PCs
- L2: Software level. The informations coming from different detectors are merged together

NA62 sensitivity

$K^+ \to \pi^+ \nu \nu$ (signal)	45 events/year
$K^+ \to \pi^+ \pi^0$	4.3% (2.3 evts)
$K^+ \to \mu^+ \nu$	2.2% (1.2 evts)
$K^+ \to \pi^+ \pi^- e^+ \nu$	<3% (1.7 evts)
3 tracks	<1.5% (0.8 evts)
$K^+ \to \pi^+ \pi^0 \gamma$	~ 2% (1.1 evts)
$K^+ \to \mu^+ \nu \gamma$	~ 0.7% (0.4 evts)
others	negligible
Expected bkg	<13.5% (7.4 evts)

- $\sim 5 \cdot 10^{12}$ decay per year
- O(10%) signal acceptance
- 100% trigger efficiency assumed

NA62 Schedule



✔ Physics Run: 2014/15 after the LHC shutdown.

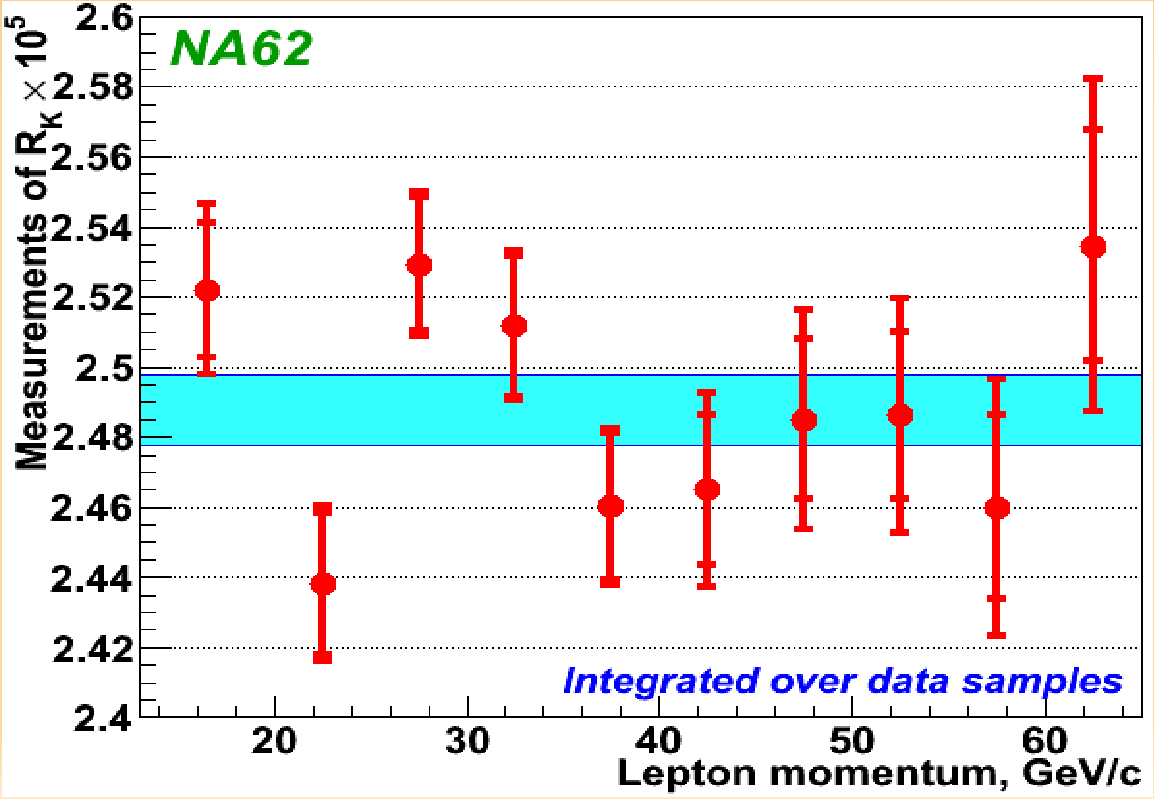
* 4 months of delay due to the new specification of the vessel, the new one has to work in vacuum.

NA62 Phase I

The NA62 collaboration performed a precision measurement of $R_K = BR(K^+ \to e^+\nu)/BR(K^+ \to \mu^+\nu)$ using data collected in 2007 and 2008.

$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}$$
$$= (2.488 \pm 0.010) \times 10^{-5}$$

Uncertainty source	$\delta R_K \times 10^5$
Statistical	0.007
$K_{\mu2}$ background	0.004
$K^\pm \to e^\pm \nu\gamma$ (SD+)	0.002
$K^\pm \to \pi^0 e^\pm \nu$, $K^\pm \to \pi^\pm \pi^0$	0.003
Beam halo background	0.002
Helium purity	0.003
Acceptance correction	0.002
DCH alignment	0.001
Electron identification	0.001
1TRK trigger efficiency	0.001
LKr readout efficiency	0.001
Total uncertainty	0.010

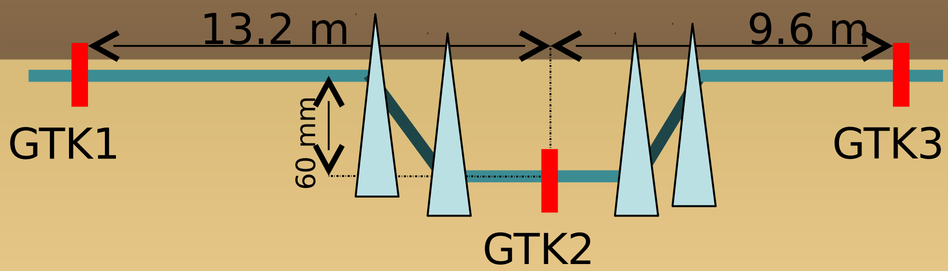


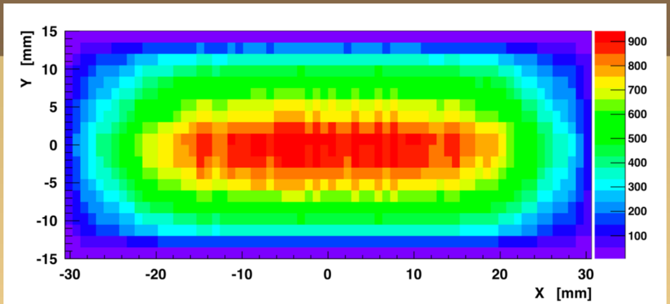
Conclusions

- Clear physics case, sensitivity to New Physics: complementary to LHC
- Goal to reach O(100) SM events in 2 years of data taking.
- Very challenging experiment:
  - High intensity beam
  - High resolution in kinematical reconstruction
  - High time resolution in all the detectors
  - High veto efficiency
  - Good particle identification
  - NA62 detectors have been carefully designed and validated (R&D,tests and Monte Carlo.)
- Schedule:
  - 2006-2009: R&D
  - 2010-2012: Construction
  - End of 2012: Technical run
  - 2014/15: Physics run
- The Phase I of the NA62 has obtained a precise measurement of the ratio RK (~0.4%)

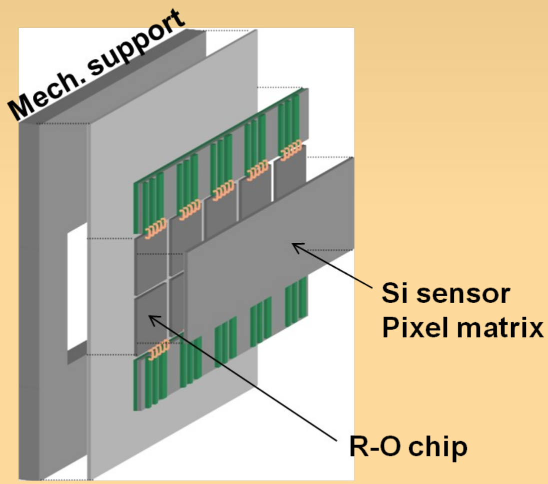
Spares

1) Kinematic rejection: Gigatracker





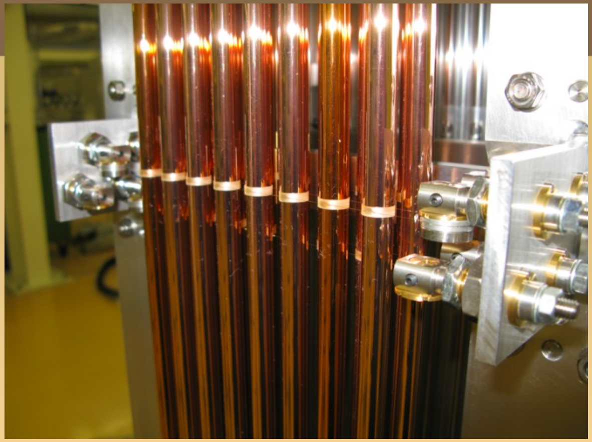
- Momentum reconstruction on high intensity beam → three stations in an achromath dipole system
- Thin detector → 200 μm pixel sensor+100 μm readout chip (<0.5% X_0 per station)
- 18000 pixels, 150 kHz rate per single pixel in the central part
- Excellent time resolution to match the measurement with the other detectors → <200 ps per station achieved in test beam



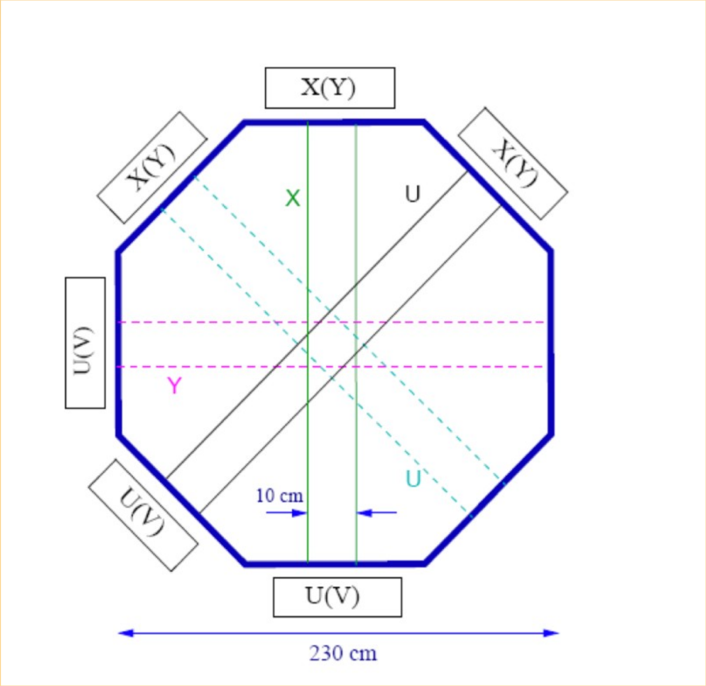
- Cooling system to control the leakage current given by the radiation damage → microchannel cooling or standard cooling in light material vessel.

$\sigma(PK)/PK \sim 0.2\%$ $\sigma(dX/dZ)/(dX/dZ) \sim 16\ \mu rad$

1) Kinematical rejection: Straws tracker



- Spectrometer in vacuum to decrease MS effects
- 4 chambers with 4 redundant views each (4 staggered layer per view)
- Magnet with Ptkick = 256 MeV/c
- 2.1 m long straws, 9.6 mm mylar tubes
- <0.1% X_0 per view
- Central "hole" (6 cm radius) for the beam obtained removing straw tubes in the central region
- Full length prototype built and tested in vacuum at SPS@CERN in 2007 and 2010

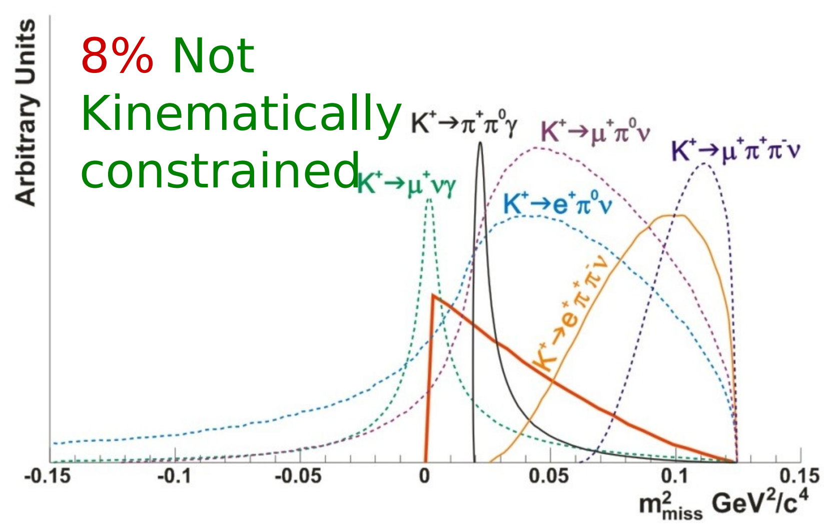


$\sigma(P\pi)/P\pi \sim 0.3\% + 0.007\% * P\pi$ (GeV/c)

$\sigma(dX/dZ)/(dX/dZ) \sim 45\text{-}15\ \mu rad$

Not kinematically constrained background

✗ ~8% of the Kaon decays is not kinematically constrained.
✗ Rejection is based solely on veto and particle identification.
✗ The veto and PID are exploited to reach the 10^8 rejection factor in the kinematical constrained background



Veto system requirements:

- ✗ Large angle (8.5-50 mrad): inefficiency $<10^{-4}$ for γ between 100 MeV and 35 GeV
- ✗ Forward veto (1-8.5 mrad): inefficiency $<10^{-5}$ for E>10 GeV
- ✗ Small angle (<1 mrad): $<10^{-3}$ for E>10 GeV

PID system requirements:

- ✗ Positive kaon identification in the hadron beam
- ✗ π–μ separation: 10^{-3} mis-identification probability

4) Trigger

- L0 selection: RICH+!LKR+!MUV3
  - RICH: hit multiplicity positive signal
  - !LKR: no 2 clusters more than 30 cm apart
  - !MUV3: no signal in MUV3
- Very good time resolution is required to avoid random veto
- At the software levels a more complete analysis will be performed (missing mass, Z vertex,…)

	Initial rate (MHz)	After L 0 (MHz)
$\pi\pi^0$	1.9	0.22
$\mu\nu$	5.7	0.04
$\pi\pi\pi$	0.5	0.1
$\pi\pi\pi^0$	0.16	0.002
$\pi^0 e\nu$	0.3	0.05
$\pi^0\mu\nu$	0.2	0.002
TOT	6.7	0.4
$\pi\nu\nu$ (eff.)		82%