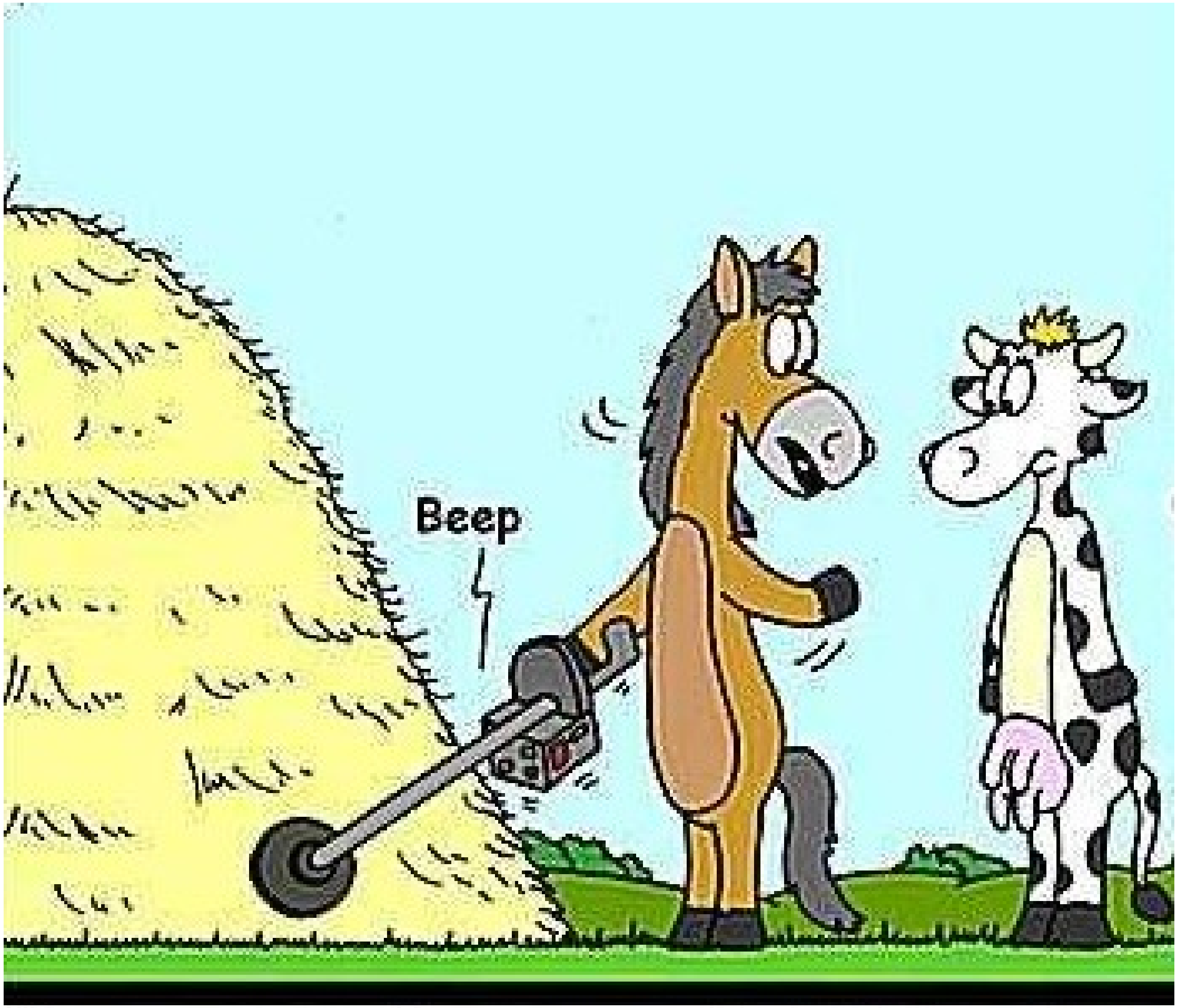
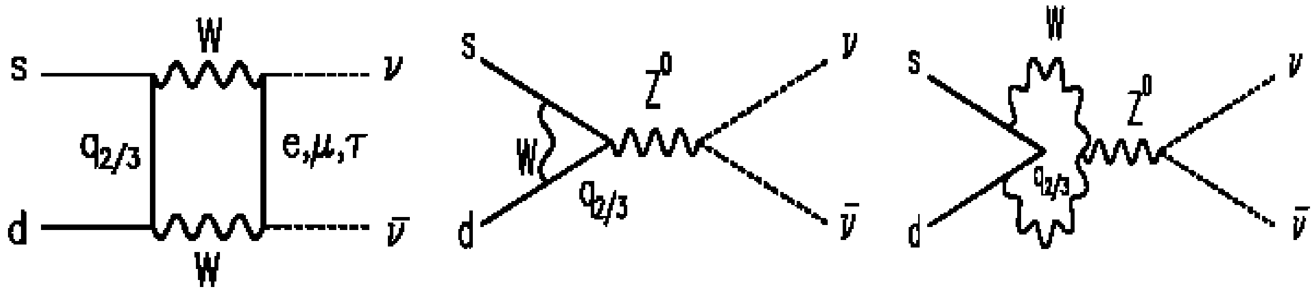
# How to find a needle in a Haystack?




You were right: There's a needle in this haystack..

# Ultra Rare Kaon Decays

## $K \rightarrow \pi \nu \bar{\nu}$: theoretically pure and almost unexplored experimentally




Goal of NA62
Measure BR
to 10%
precision

Decay — Branching Ratio (x $10^{11}$)

| Decay | Theory (SM) | | | | Experiment | | |
|---|---|---|---|---|---|---|---|
| $K^+ \longrightarrow \pi^+ \nu\bar{\nu}$ | 7.81 | +0.8 / -0.71 | ±0.29 | [1] | 17.3 | +11.5 / -10.5 | [2] |
| $K^0 \longrightarrow \pi^0 \nu\bar{\nu}$ | 2.43 | +0.4 / -0.37 | ±0.06 | [1] | <670 (90%CL) | | [3] |

[1] J.Brod, M.Gorgahn, and E.Stamou, Phys. Rev. D83, 034030 (2011)
[2] CKM 08 Procs.
[3] KEK E391 arXiV:0712.4164v2

This experimental effort allows to determine the CKM parameter $|V_{td}|$ to ≤ 10% accuracy.

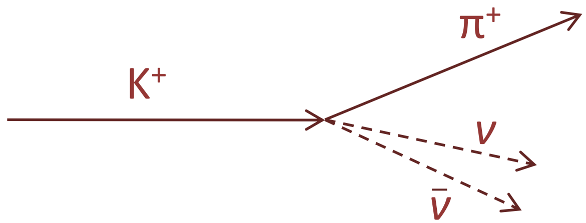
# The Problem is the Background

Slide adapted from Steve Kettell, BNL

**For 10 Billion ($10^{10}$) $K^+$ decays we get:**

Tools:

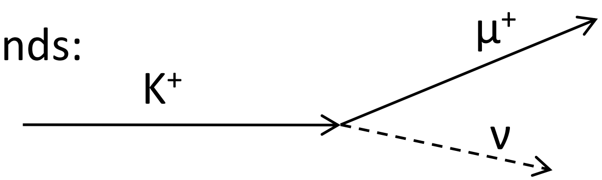
Signal:




≈ 1 event

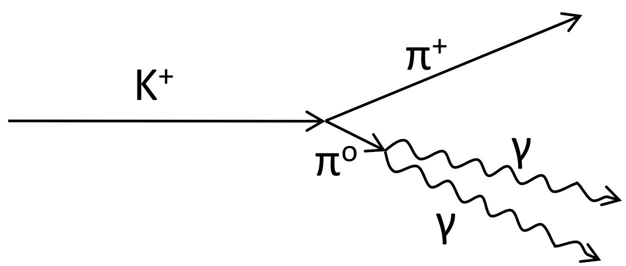
particle - id
Invariant Mass
Tracking
Timing

Main Backgrounds:



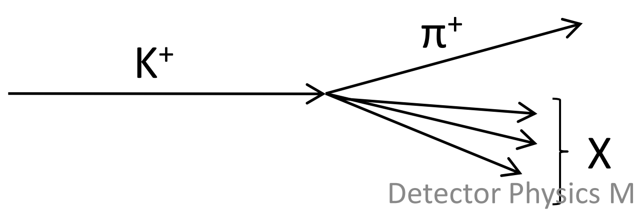

6,350,000,000 events
BR = 63.5%

μ - id
Invariant Mass




2,120,000,000 events
BR = 21.2%

γ - veto
Invariant Mass




lots

Particle id
Tracking
Invariant Mass

# Target Signal / Noise

| Decay Mode | Events |
|---|---|
| Signal: $K^+ \to \pi^+ \nu\nu$ [ *flux* = $4.8\times10^{12}$ *decay/year*] | 55 *evt/year* |
| $K^+ \to \pi^+\pi^0$ [$\eta_{\pi 0} = 2\times10^{-8}$ ($3.5\times10^{-8}$) ] | 4.3% (7.5%) |
| $K^+ \to \mu^+\nu$ | 2.2% |
| $K^+ \to e^+\pi^+\pi^-\nu$ | ≤3% |
| Other 3 – track decays | ≤1.5% |
| $K^+ \to \pi^+\pi^0\gamma$ | ~2% |
| $K^+ \to \mu^+\nu\gamma$ | ~0.7% |
| $K^+ \to e^+(\mu^+)\ \pi^0\nu$, others | negligible |
| Expected background | ≤13.5% (≤17%) |

(2007 estimation)

# Na62 Beam

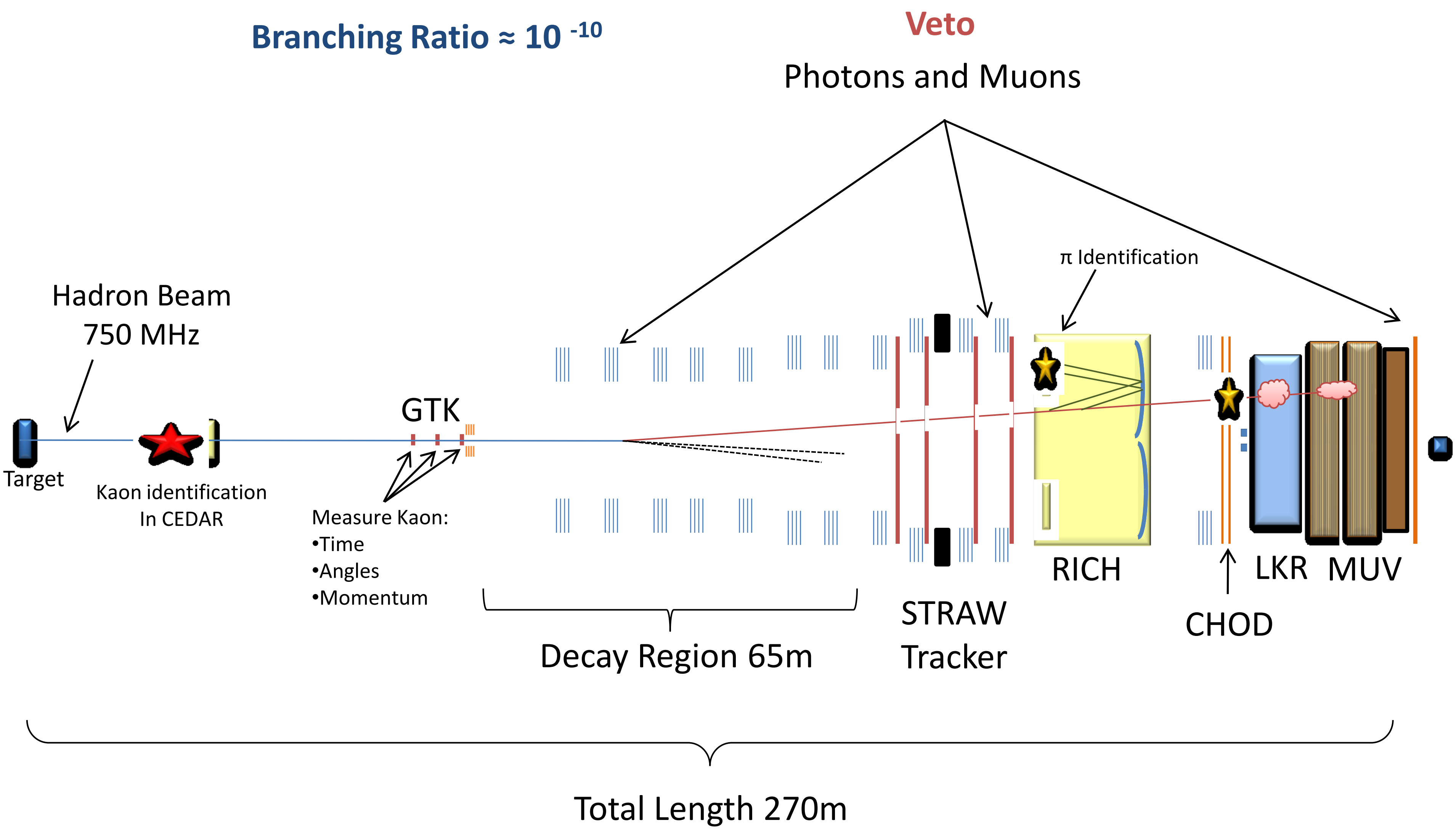
- SPS primary ***p*** at 400 Gev/c
  - High intensity $1.1*10^{12}$ protons/eff. s on target
- Secondary Beam -> unseparated hadrons ($\pi$ / $K$ / $p$)
  - High momentum Beam 75±0.75 GeV/c
  - High intensity hadron beam (≈ 750 MHz) with an optimum content of $K^+$ (≈6%)
- Leads to:
  - 4.5 MHz of Kaon decays in fiducial region
  - Ratio ($K^+$ decays / Hadron Flux) ≈ 6‰
- Expected signal: $K^+ \to \pi^+ \nu \bar{\nu}$ events:
  - 380 decays in fiducial region /y (1y=100d, 60% eff.)
  - ≈ 55 detected $K^+ \to \pi^+ \nu \bar{\nu}$ events/y

# Key Detector Requirements

- Excellent timing:
  - To associate outgoing π with parent K
  - To suppress decays containing μ's or γ's in the 1st level trigger
- Particle Identification for γ's, μ's, π's, K's
- Hermetic Vetoing of photon's in the acceptance (0 to 50mrad); Inefficiency $\leq 10^{-4}$
- Ultra light tracking detectors installed in vacuum
  - To reduce fake events from beam gas collisions
  - To reduce multiple scattering
- Redundancy

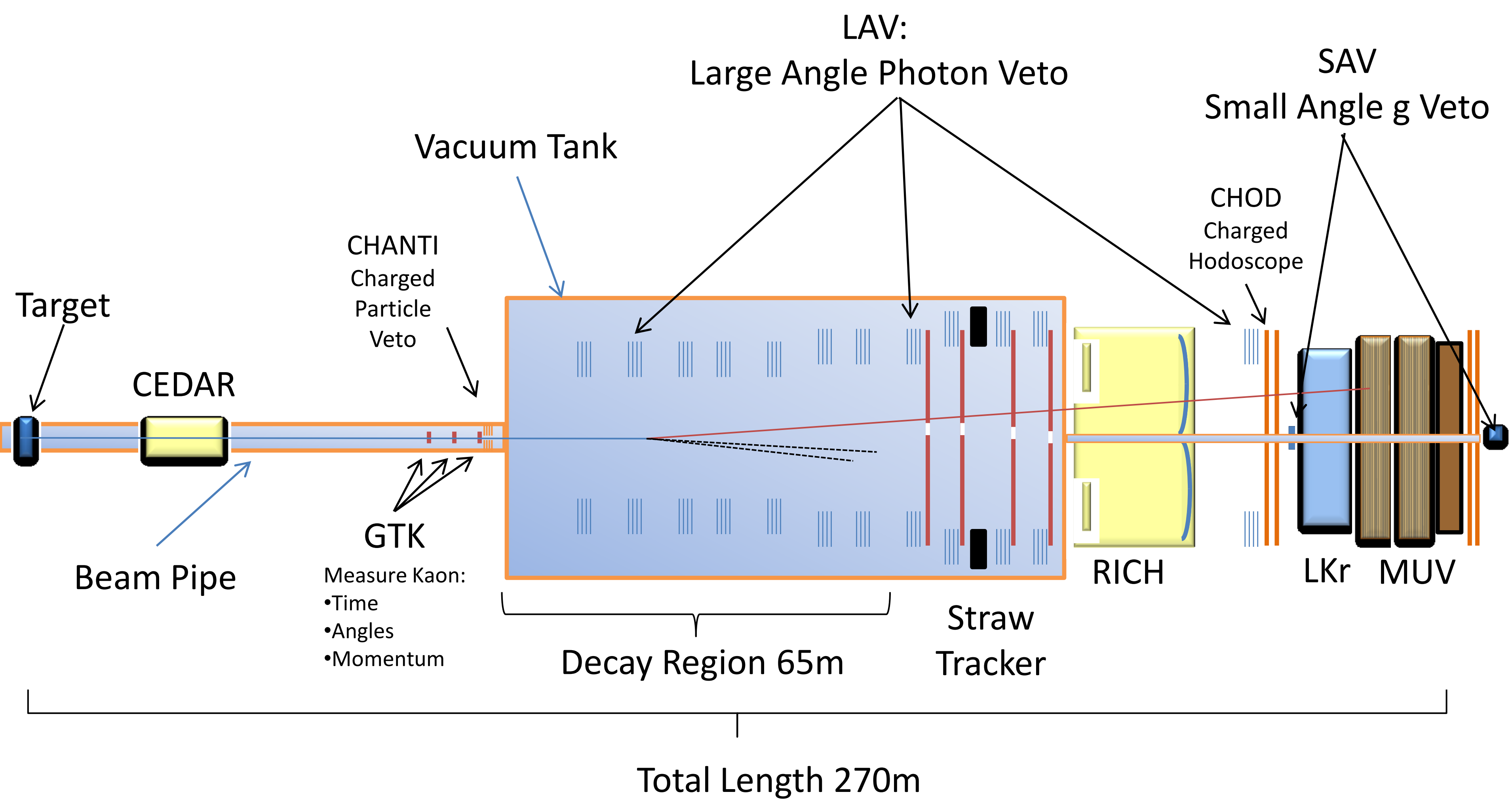
# $K^+ \to \pi^+ \nu \bar{\nu}$ Events

**Branching Ratio ≈ $10^{-10}$**

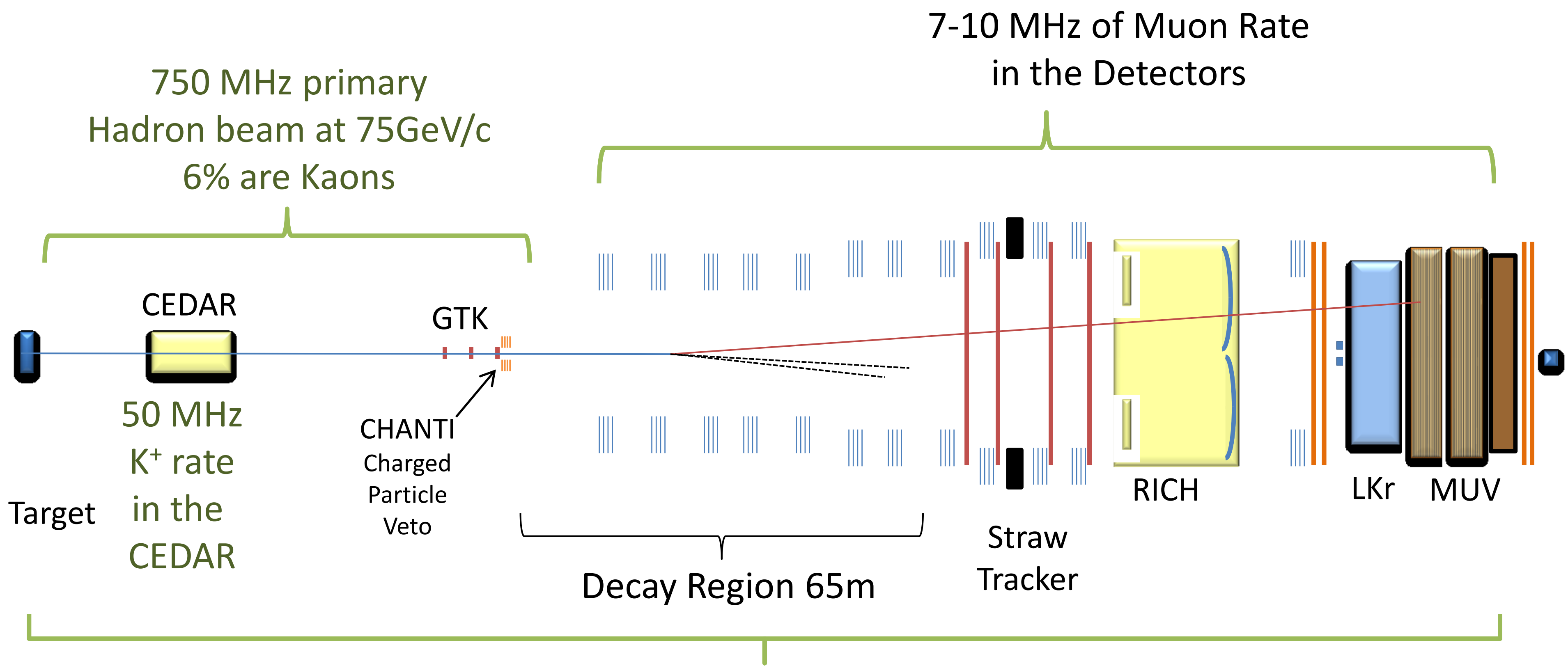


# Na62 Detectors

## Overview



# Particle Rates

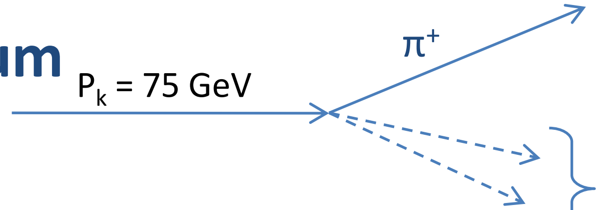



$4.5\ 10^{12}\ K^{+}$ decays/ year in fiducial region

The muons originating from $\pi^{\pm}$ and $K^{\pm}$ decays (produced at the target) generate a significant and permanent particle flux for the detector ($\mu$ ”Halo”) .

# Kinematic Signature

## 1) Large missing momentum

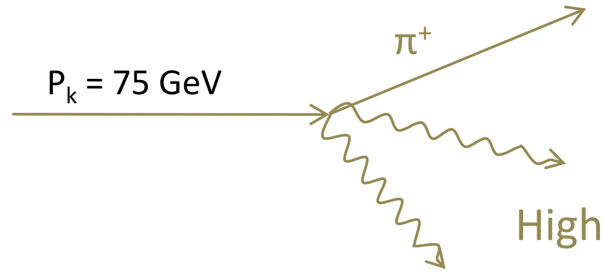



Require:
$P_\pi$= 15 -35 GeV

Neutrinos
carry ≥ 40 GeV momentum

Consequence for the background

$K \rightarrow \pi^+ \pi^o$
↳ $\gamma\gamma$



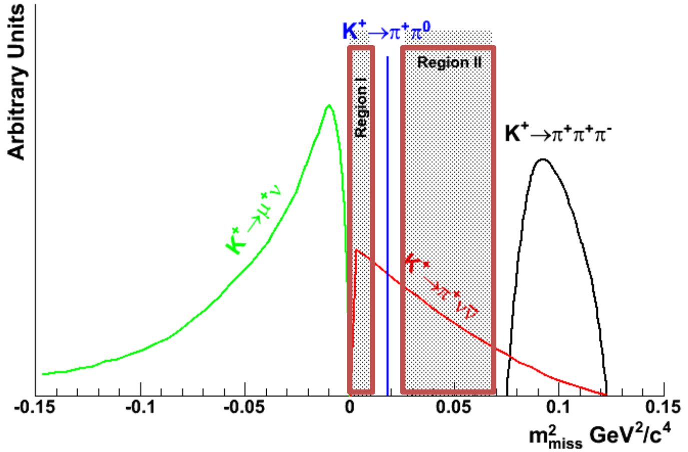

High Energy

## 2) Invariant Mass constrains

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

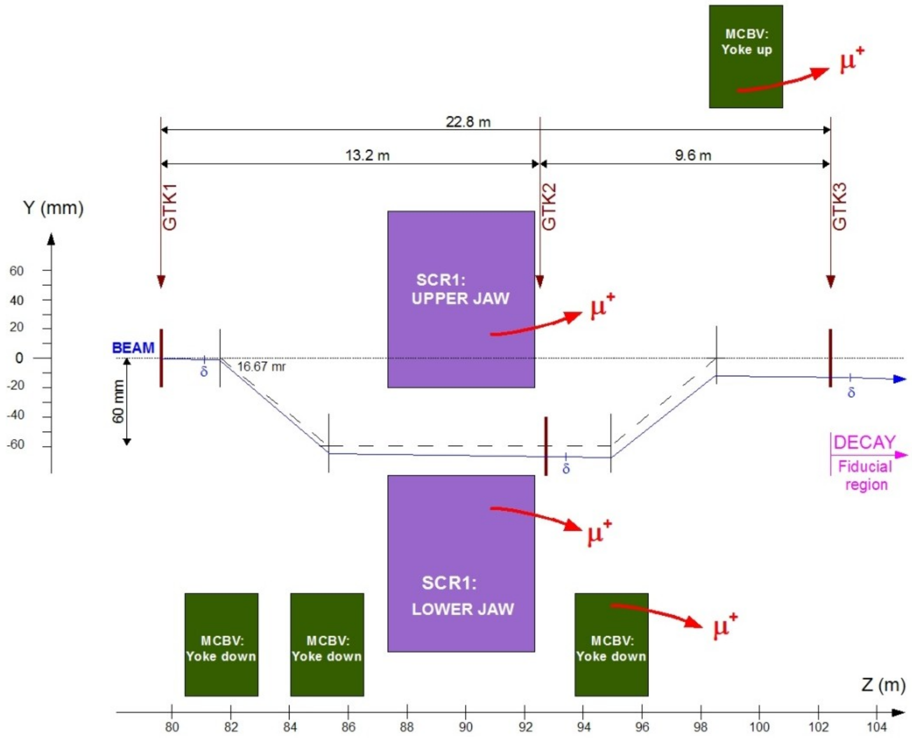
Rejects ≈92% of Kaon decays

Background constraint by Missing Mass



# Giga TRACKER

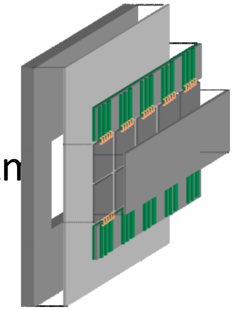
## GTK



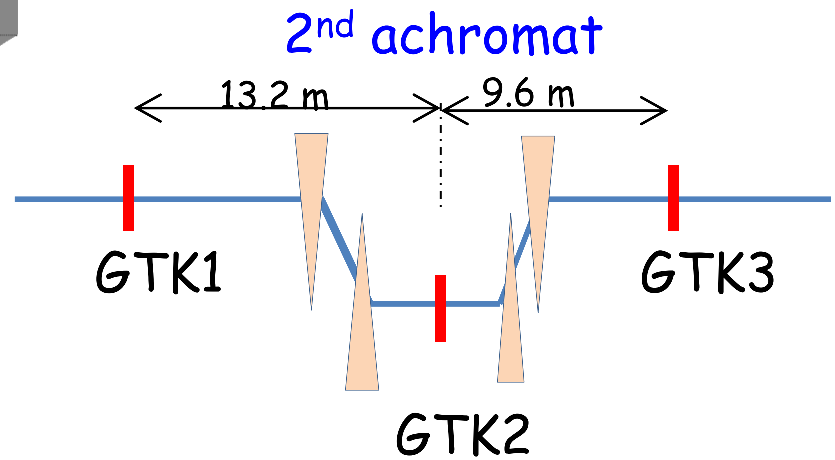
# GTK / Giga Tracker

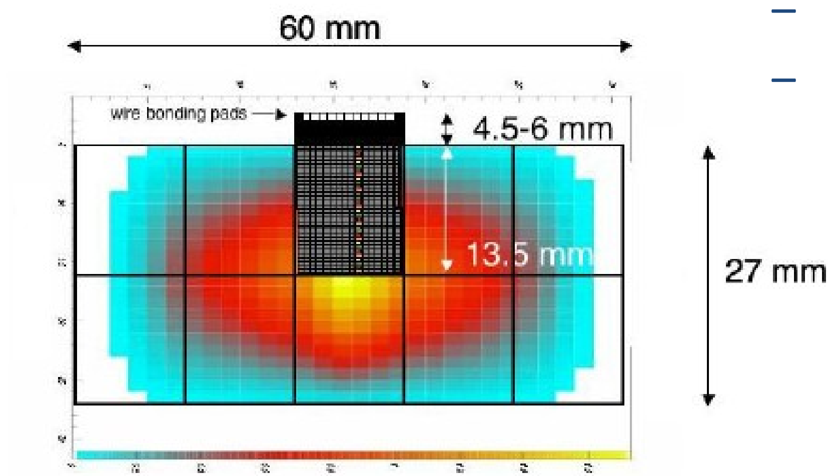
## 3 stations of Si pixel detectors

- Pixel size:
  - 300 x 300 $\mu m^2$ or 300 x 400 $\mu m^2$
  - 18’000 pixels/ station
  - 54’000 pixels grand total
- Thickness:
  - 300 -500 µm = 200(sensor) + 100(readout) + Cooling
  - 0.5% of $X_0$ (per Station)
- Active area ≈ 60 (X) * 27 (Y) $mm^2$
- Divided in 10 read-out chips



Mounted inside beam pipe around 4 achromat magnets




## Beam Conditions:

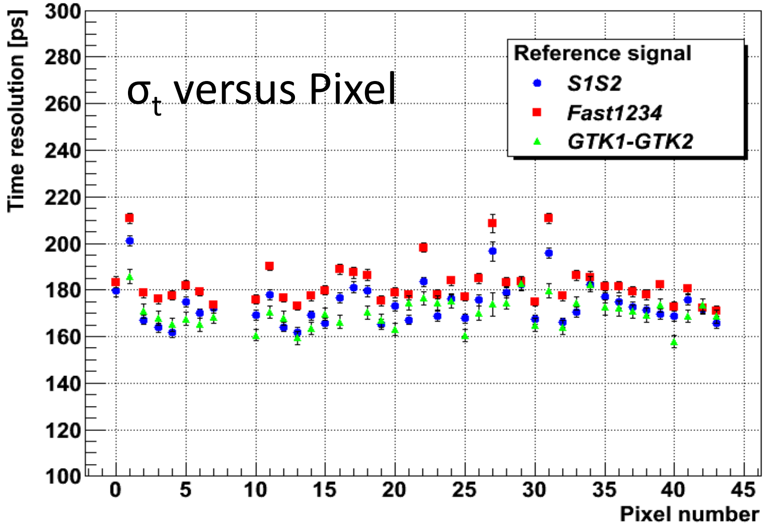
- **Overall Rate 750MHz**
- In beam centre 140kHz/pixel

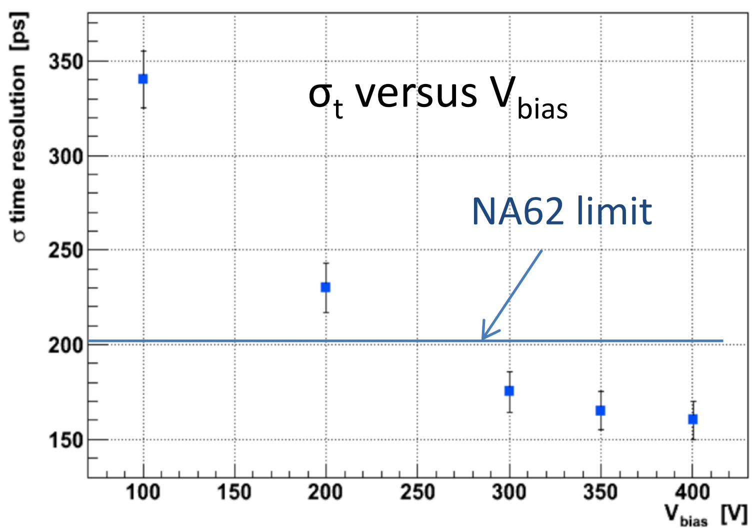
## Meaures precisely Kaon

- **Time ($\sigma_t$ ≈ 200ps per station)**
- Direction ($\sigma_{dx,dy}$ ≈ 0.016mrad)
- Momentum ($\Delta P/P < 0.4\%$)

# GTK: Test Beam Analysis

From Massimiliano FIORINI

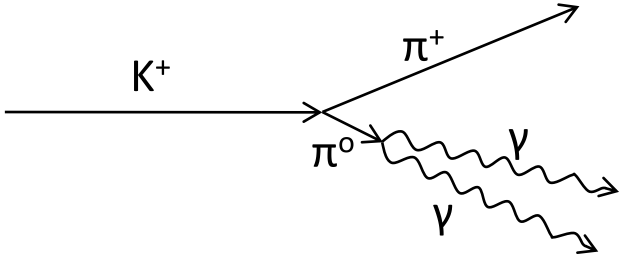



- Test beam results confirms a time resolution of better than 200 ps per hit for sensor bias voltages higher than 300 V.
- Time-walk correction and alignment procedures have been validated with real data
- Clear dependence of time resolution on sensor bias voltage
- The operation at 300 V over-depletion is mandatory
- Paper on test-beam results under preparation

# Photon Vetos

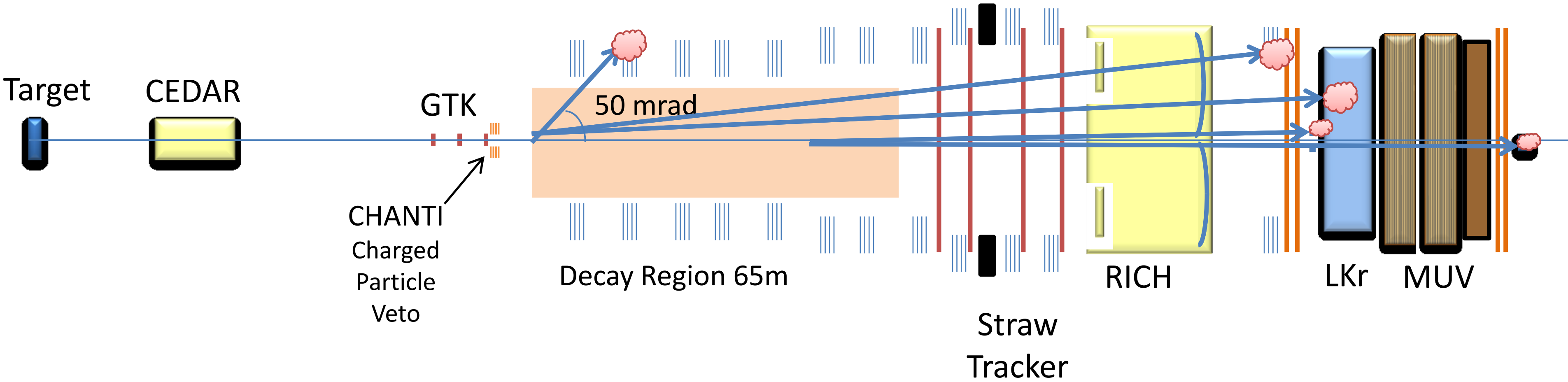
One of the most difficult Background:



# Veto Hermiticity

- suppression of dominant background $K^+ \to \pi^+ \pi^0$
- Inefficiency for rejection of the $\pi^0$ must be at the level of $10^{-8}$
- Within acceptance inefficiency for photons $<10^{-4}$ (for LKR $<10^{-5}$)

→ Hermetic Photon Veto up to 50 mrad




**Photon Veto's**

- Large Angle Veto: 8.5 -50mrad
- LKR: 1 – 8.5 mrad
- Small Angle Veto ≤ 1mrad

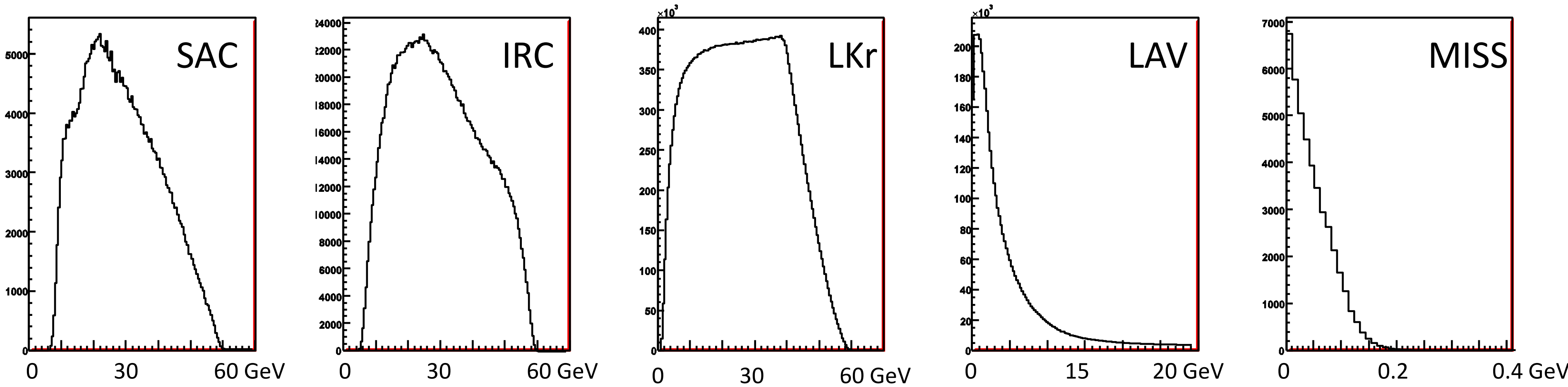
# Kinematics of $K^+ \rightarrow \pi^+\pi^0$

- $\pi^+\pi^0$ generated
  - $105 < Z_{vtx} < 165$ m
  - $15 < P_\pi < 35$ GeV
  - $\pi$ in detector acceptance

Photon Acceptance [%] for $\pi^+\pi^0$

| | SAC | IRC | LKR | LAV | MISS |
|---|---|---|---|---|---|
| SAC | 0 | 0 | 1.66 | $1.26 \times 10^{-2}$ | $2.08 \times 10^{-4}$ |
| IRC | | 0 | 8.17 | 0.40 | $5.65 \times 10^{-3}$ |
| LKR | | | 70.35 | 19.08 | 0.21 |
| LAV | | | | 0 | 0 |
| MISS | | | | | 0 |

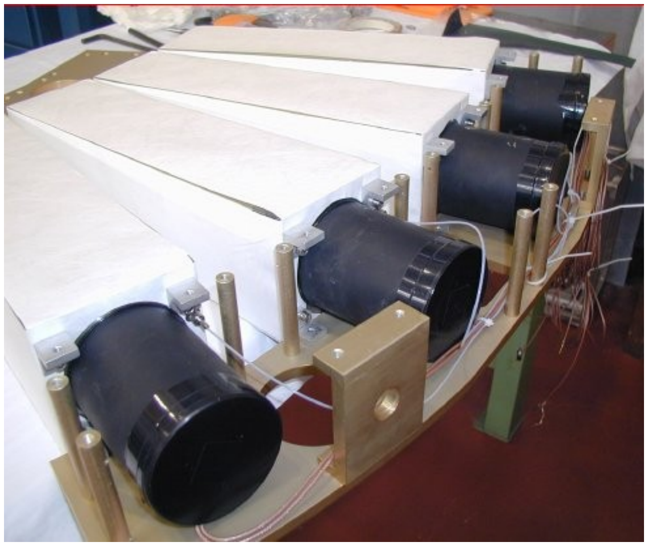
## Photon Energy



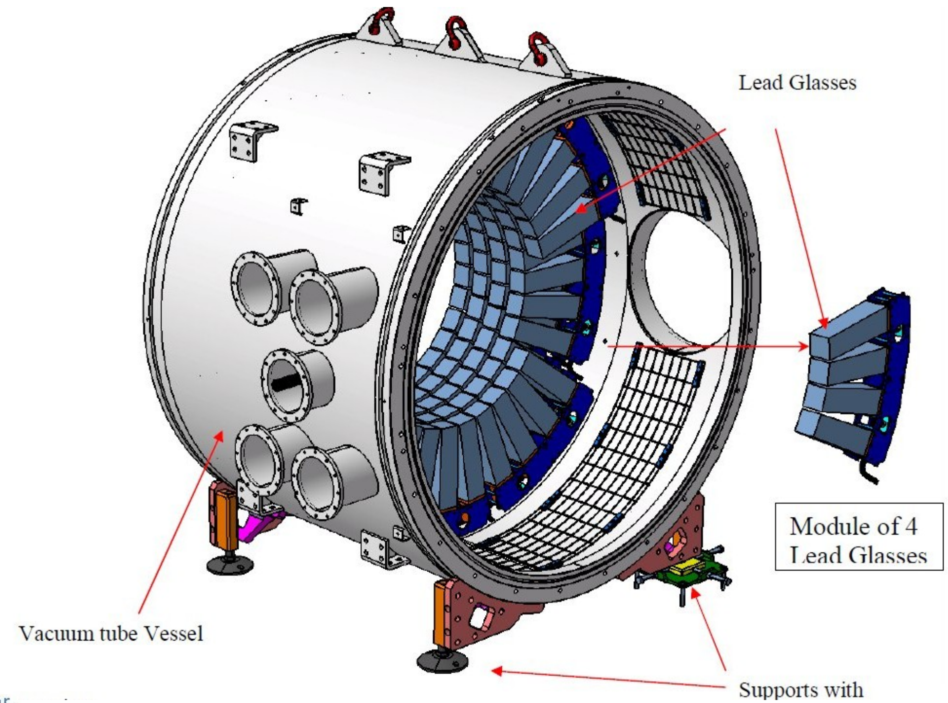

MC Studies from Spasimir BALEV

# Large Angle Veto

Lead-Glass Crystals with attached PMT
From former OPAL EM calorimeter.

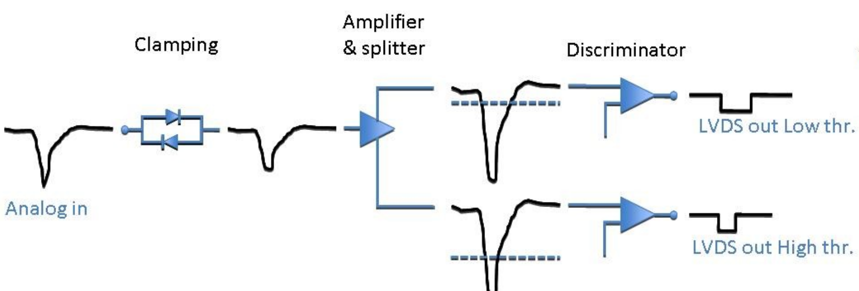


All in all 12 Stations
11 in vacuum
1 behind the RICH

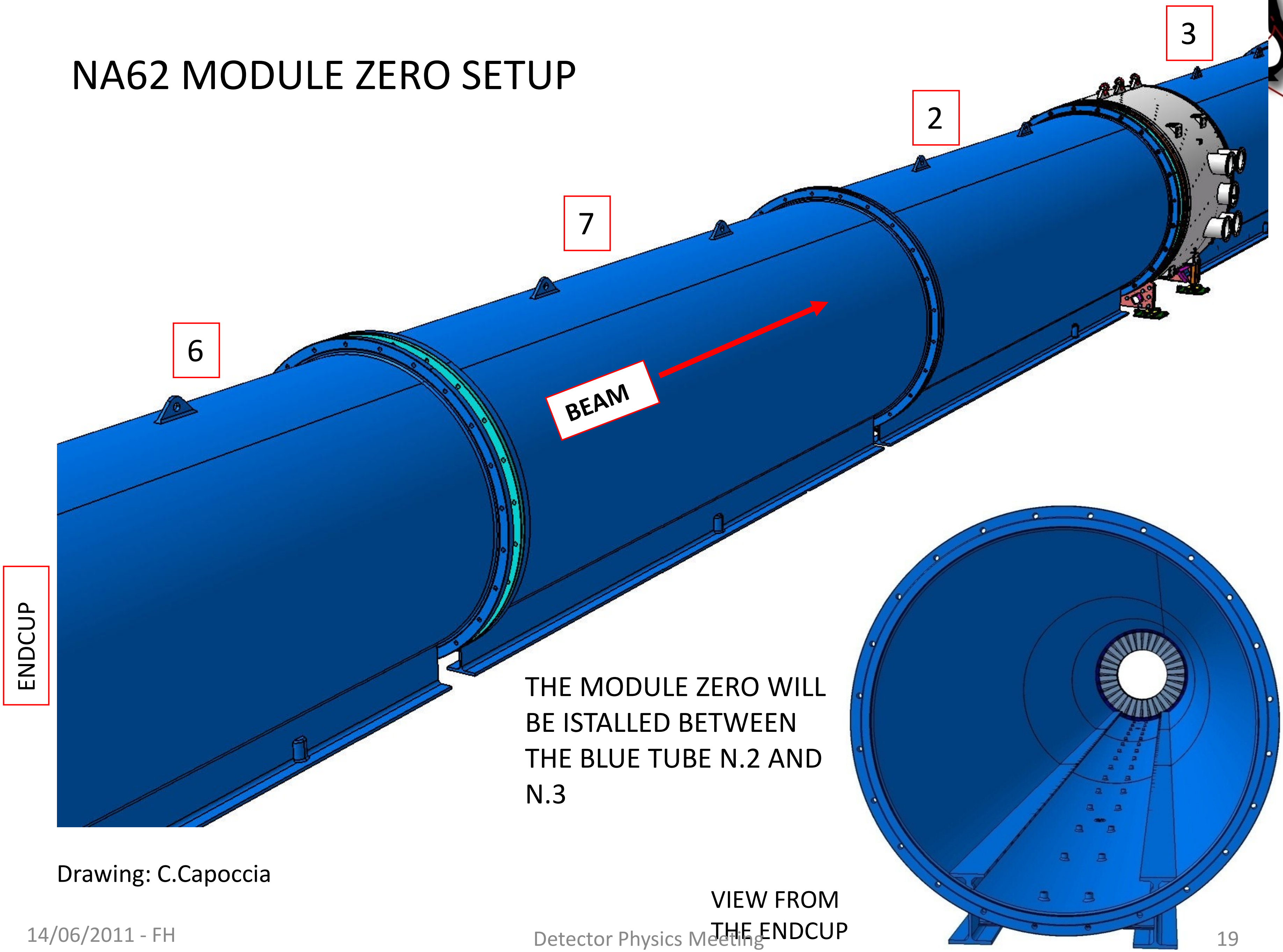



Drawing: C.Capoccia

Frontend Electronics



# NA62 MODULE ZERO SETUP

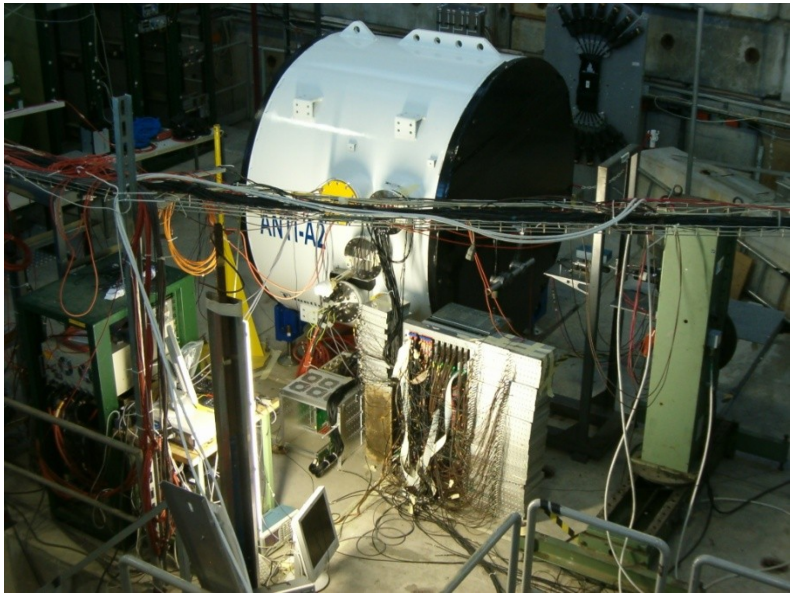



THE MODULE ZERO WILL BE ISTALLED BETWEEN THE BLUE TUBE N.2 AND N.3

VIEW FROM THE ENDCUP

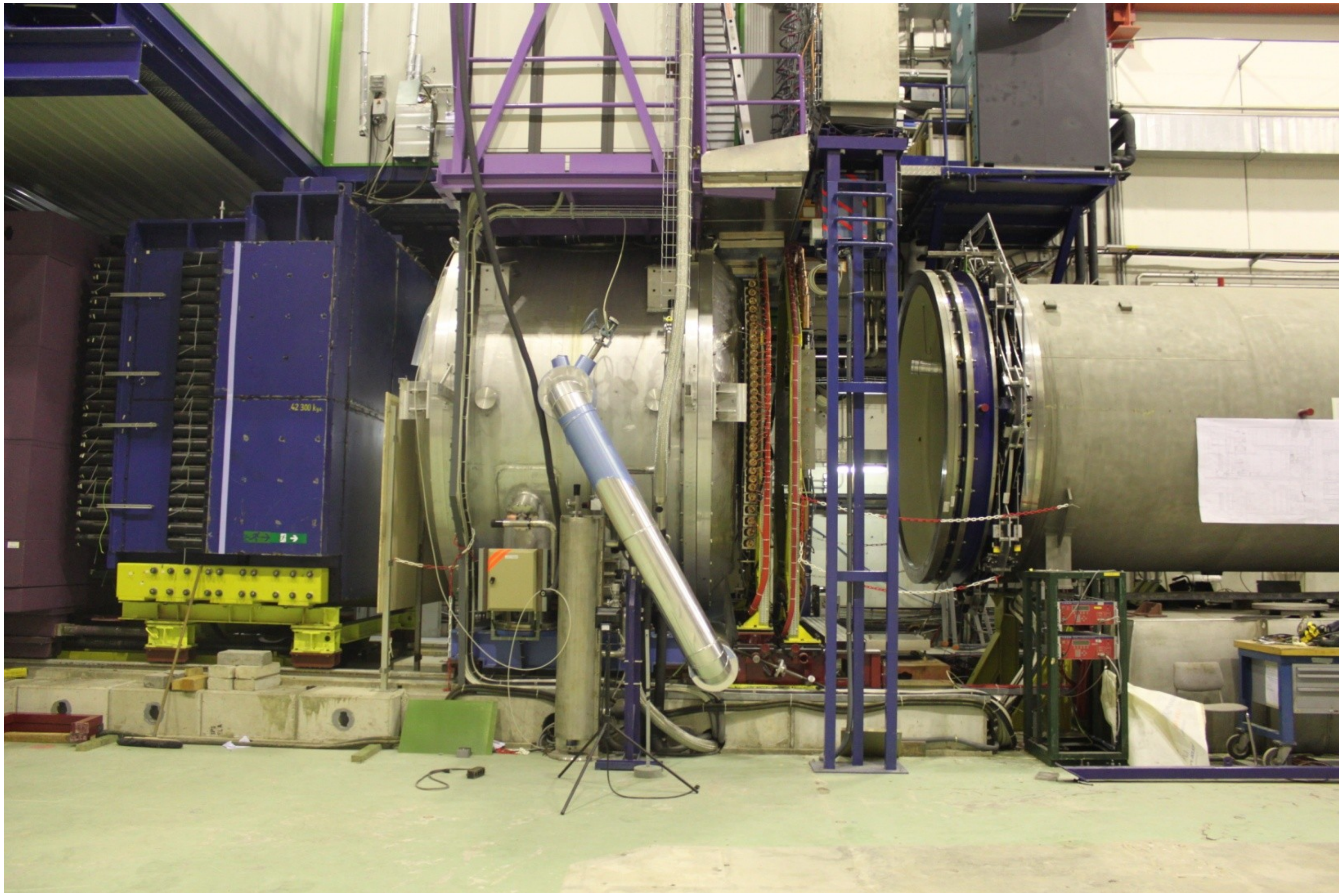
Drawing: C.Capoccia

# Large Angle Veto

# Liq. Krypton Calorimeter

## (the Jewel Calorimeter from NA48)

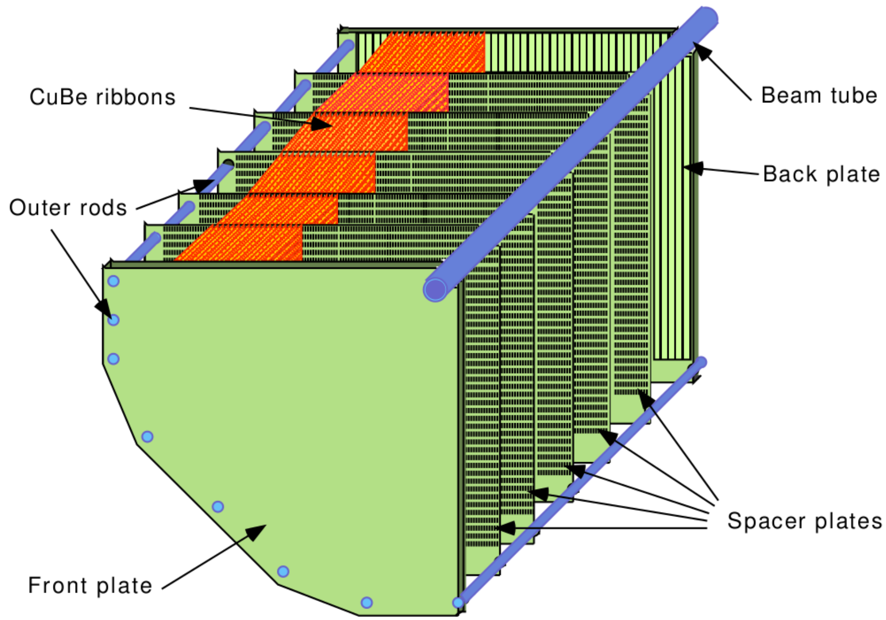


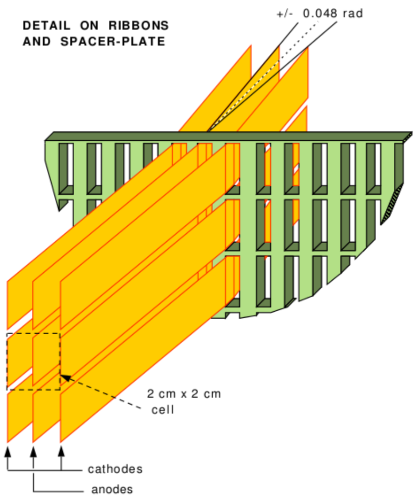
# Liquid Krypton Calorimeter

**Homogenous noble gas calorimeter (9'000 ltr. liquid Krypton)**

**Excellent energy, time and space resolution:** $\sigma_E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ ; $\sigma_t < 500$ ps

**New readout for NA62: from 10kHz to 1MHz**

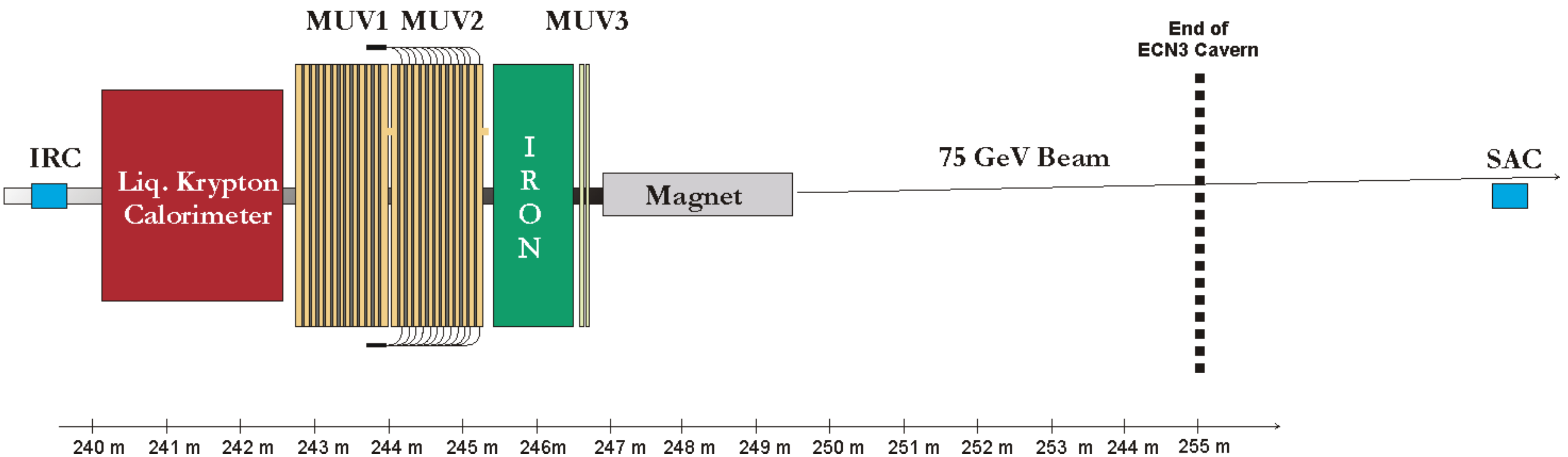



LKR cell design

# Small Angle Veto's

1. The IRC covering the region around the inner radius of the Liquid Krypton Calorimeter.
2. The SAC situated behind the experimental cavern in the prolongation of the beam axis covering the angular region down 0 degrees.



# STRAW Tracker

# The Straw Tracker

## Detector Performance

Kinematical rejection relies on:

- π - Momentum resolution

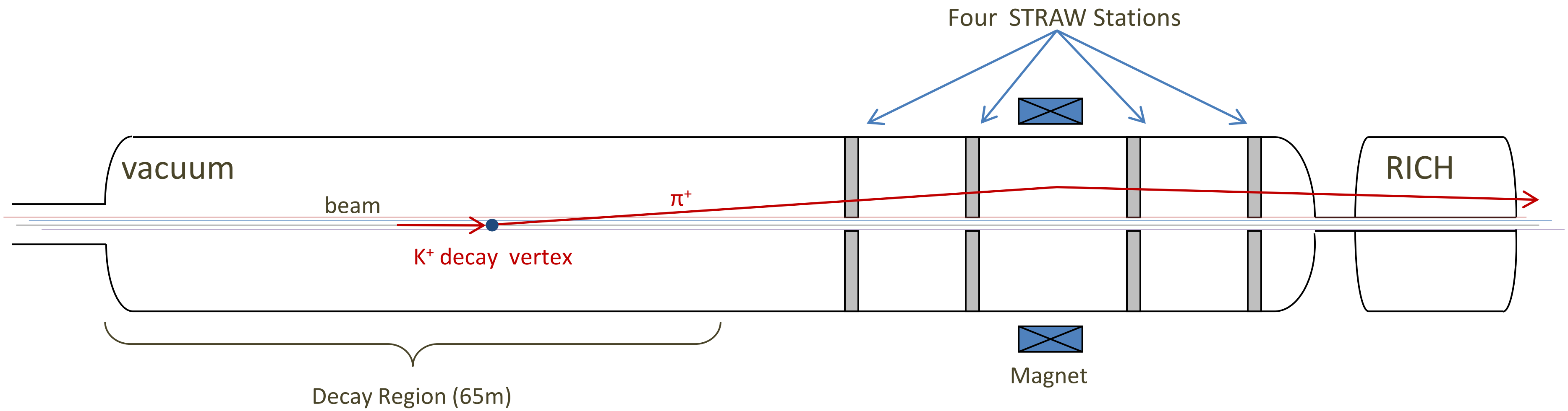
  σ(P)/P < 1%

- π - Angular resolution : < 60 μrad
- Decay Vertex Extrapolation

  σ(CDA)≈ 1mm

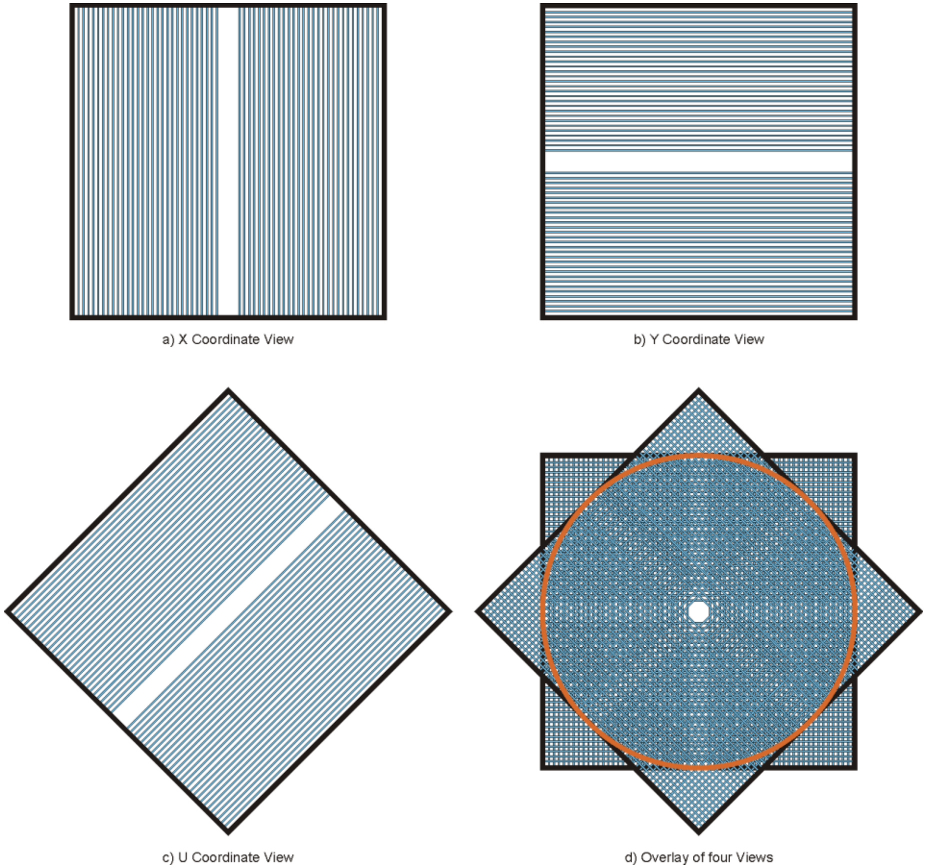
## Detector Requirements

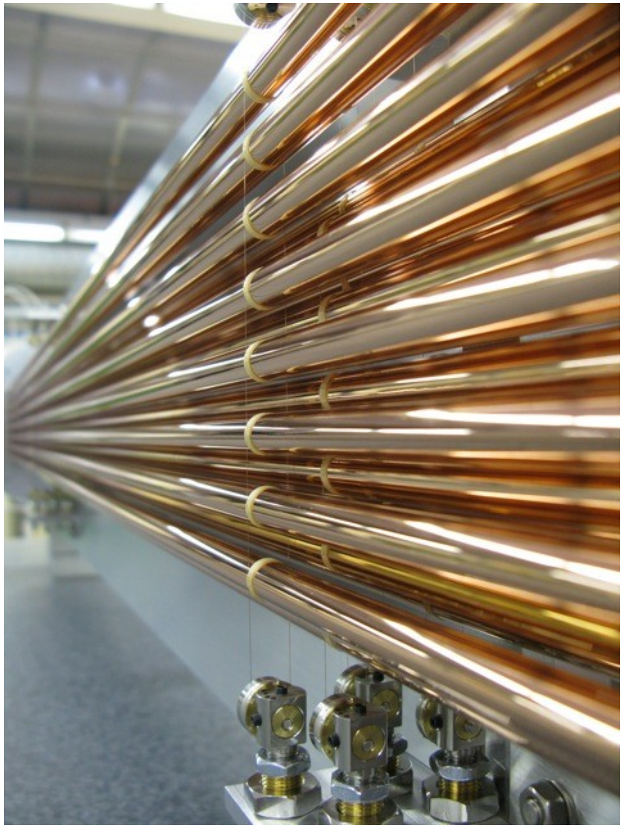
- Ultra light (≈ 0.1 % of $X_0$ per view) (no beam windows and no surrounding gas)
- Max. Rate 0.5 MHz/Straw
- High accuracy (130μm per View) and high efficiency



# Straw Tracker Layout

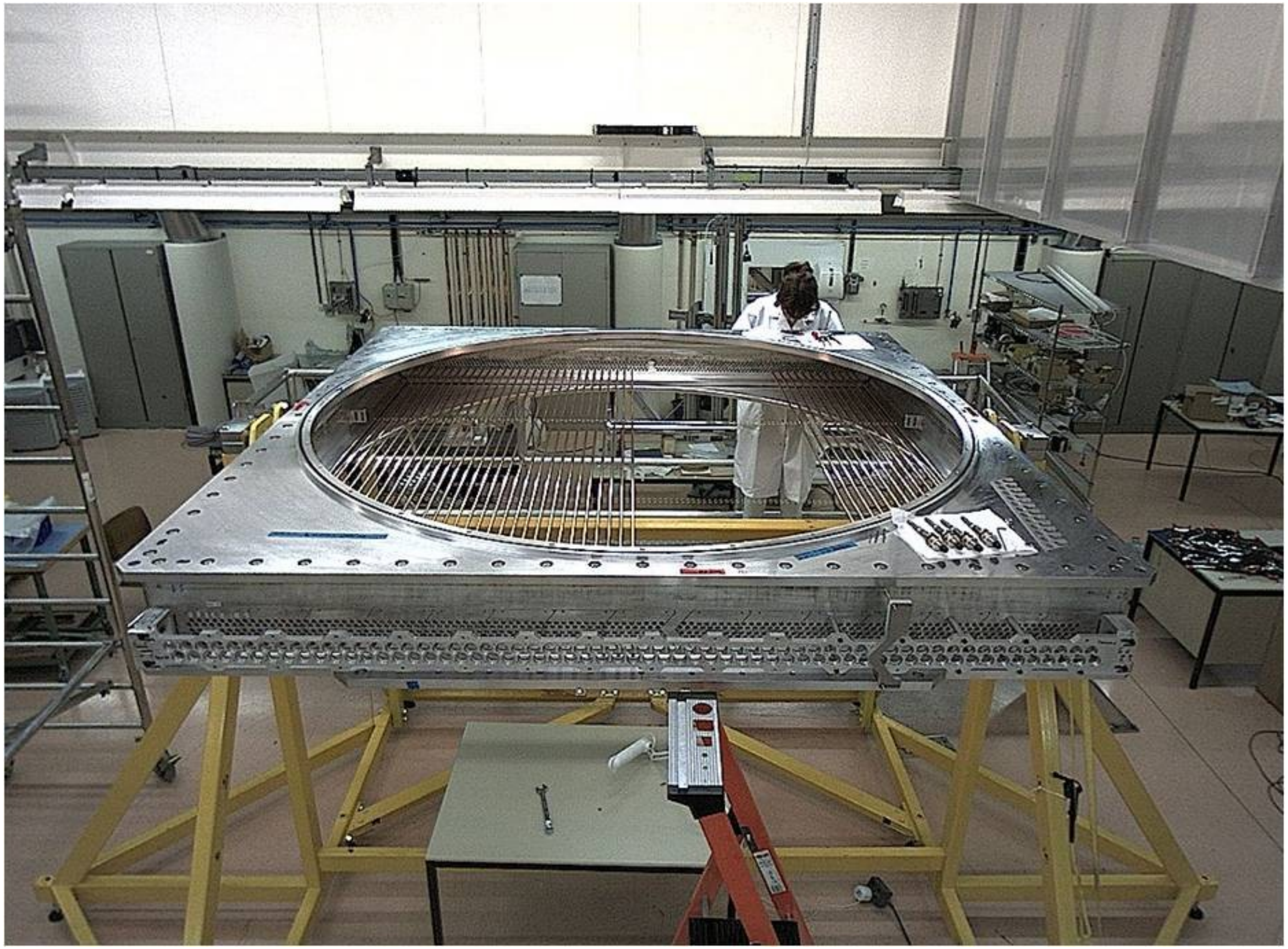
4 views in each Station



- Straws: 2.1m long and $\phi_i$ =9.8mm; Installed in vacuum;
- Straw Material: 50 nm Cu + 20 nm Au on 36 µm of Mylar
- Total 7168 Straws (4x4x4x112)

# Straw Chamber Assembly

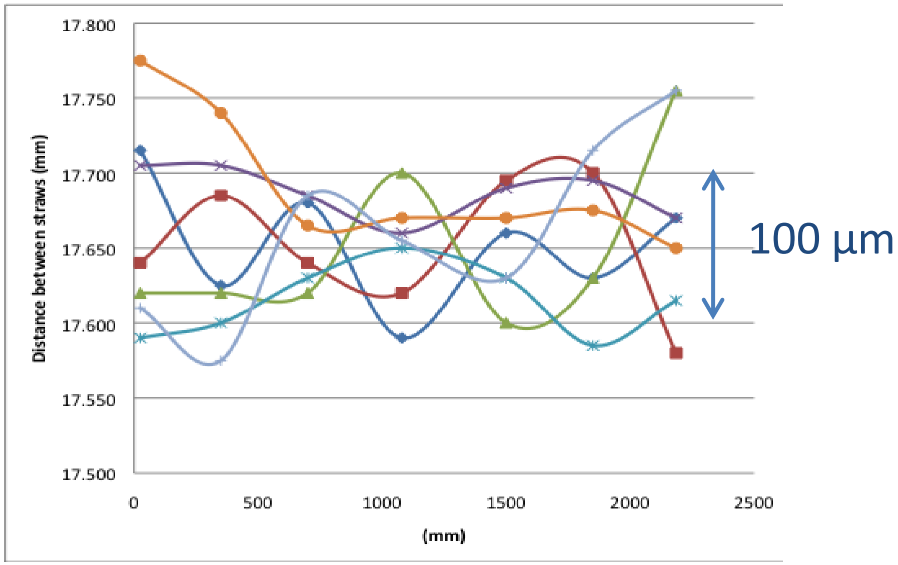


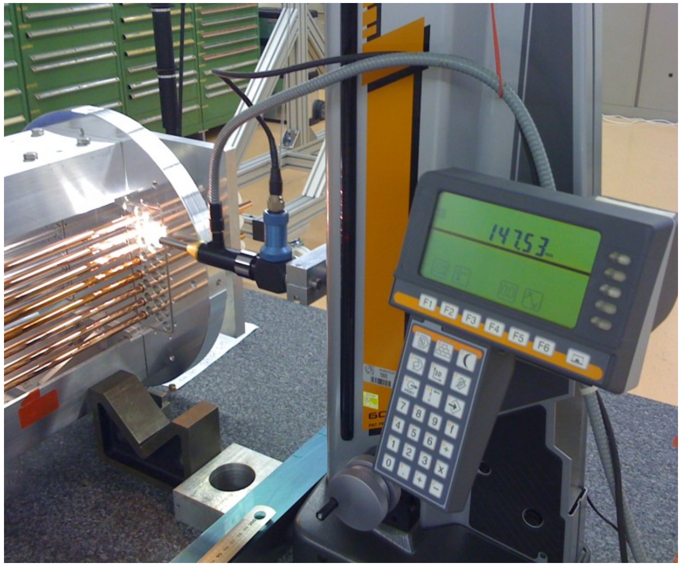
The straws are installed in horizontal position, Pretension is 1.5 kg, than glued vertically

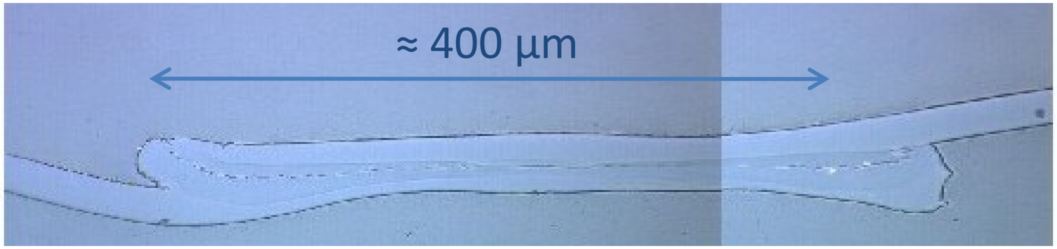
DT activity (Hans D.) can be visited in B154….

# Straw Straightness + Welding

Distance between Straws versus length

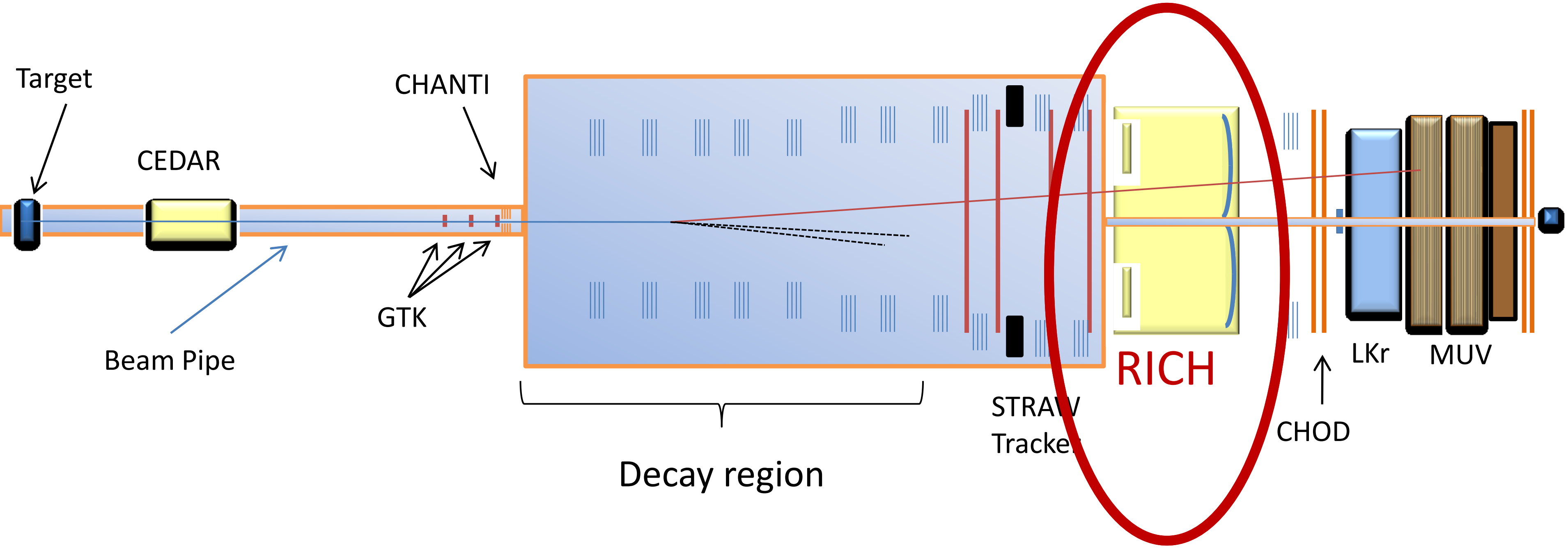





Ultra sonic Weld

# RICH Detector



# RICH Requirements + Prototype

A very challenging RICH is needed for NA62:

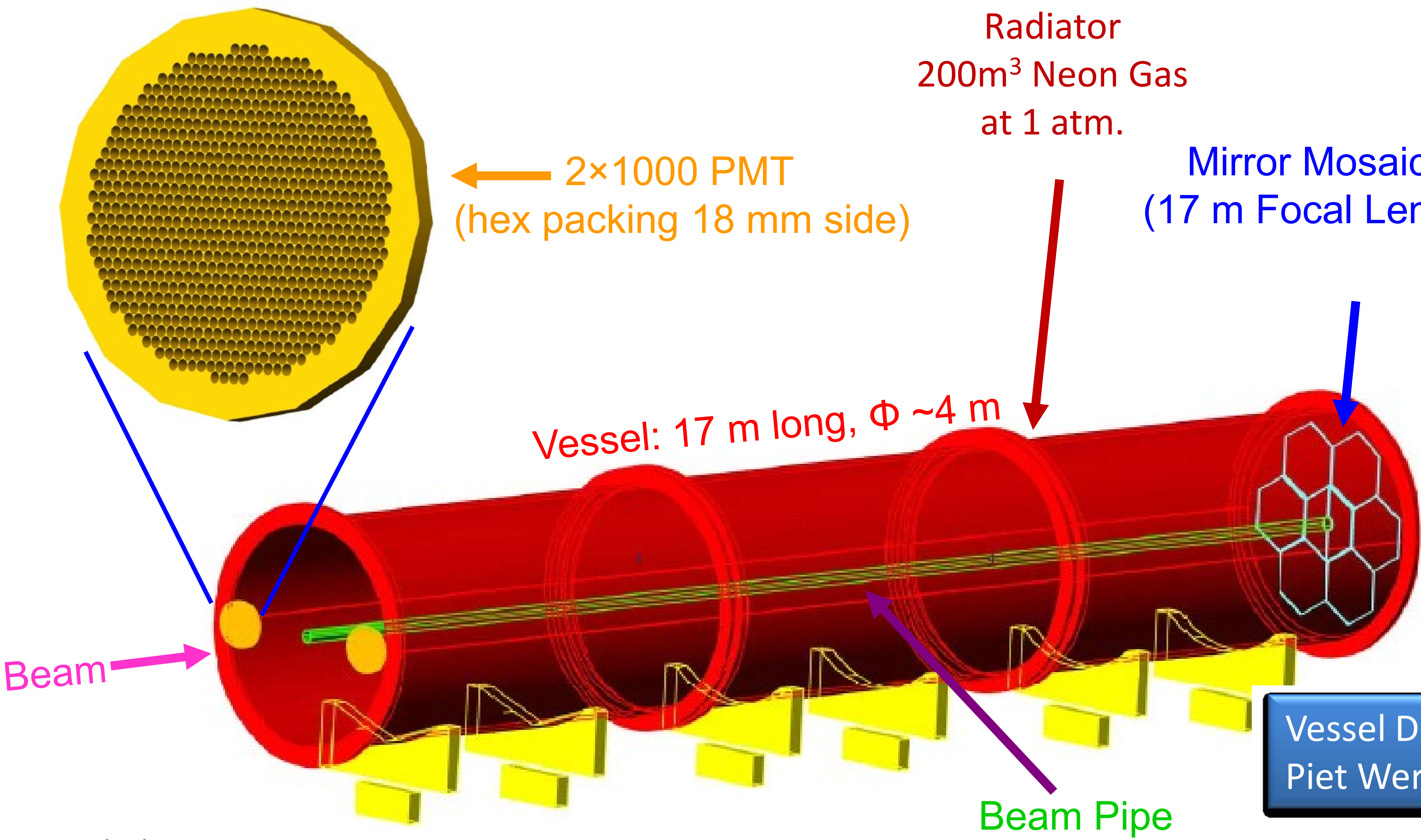
- μ/π separation between 15 and 35 GeV/c
- μ suppression factor of at least 100
- Time resolution of 100 ps
- Provide Level 0 trigger for charged tracks

Design Validated in Prototype (operated 2007-2009)

- 17m long Radiator , 1 mirror, and 400 PM's (20% of final).
- Intensively testes

# RICH Detector

Schematic Visualisation




Vessel Design
Piet Wertelaers

# RICH Mirrors

Mirror Assembly

– 18 hexagonal mirrors

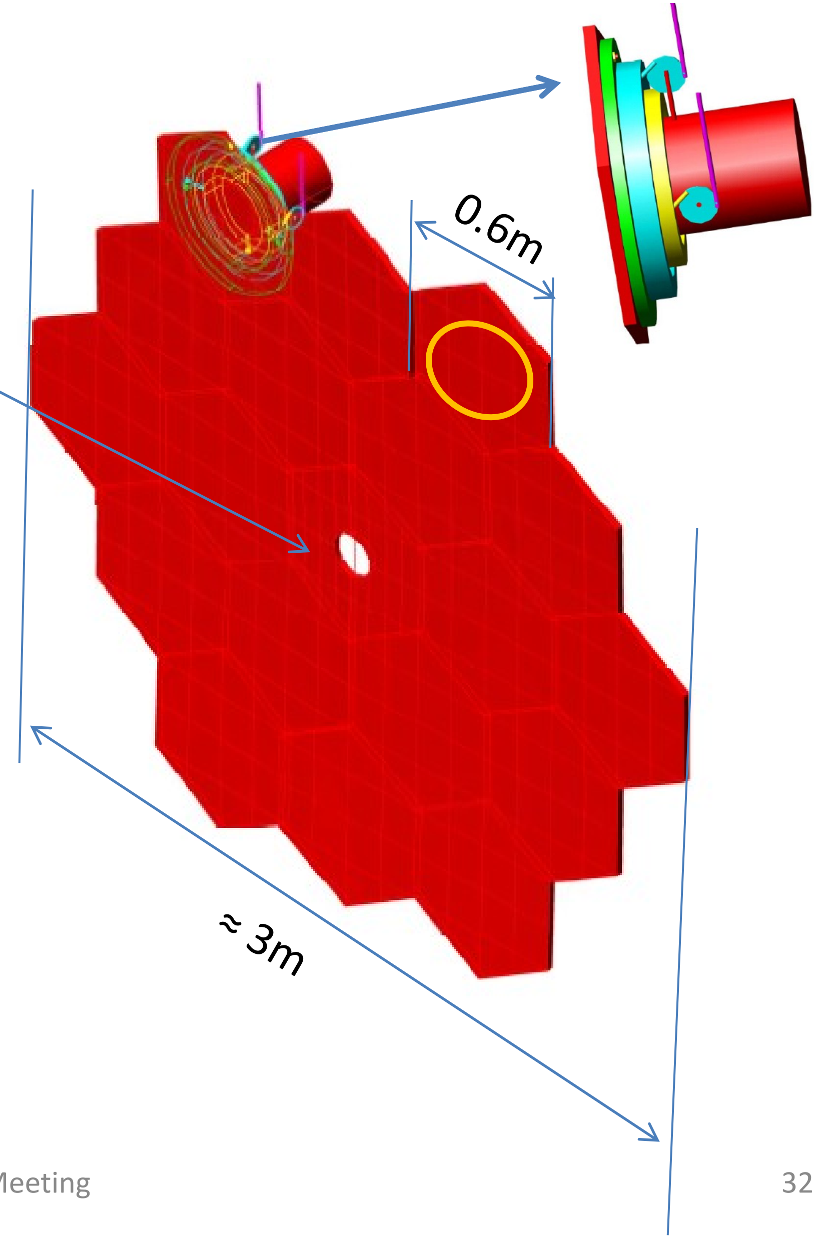
– 2 half mirrors around the beam pipe.

– Online Alignment:

The inclination of the 18 hexagonal mirrors is remotely adjustable using piezo-micrometric actuators

Mirror Parameters + Quality:

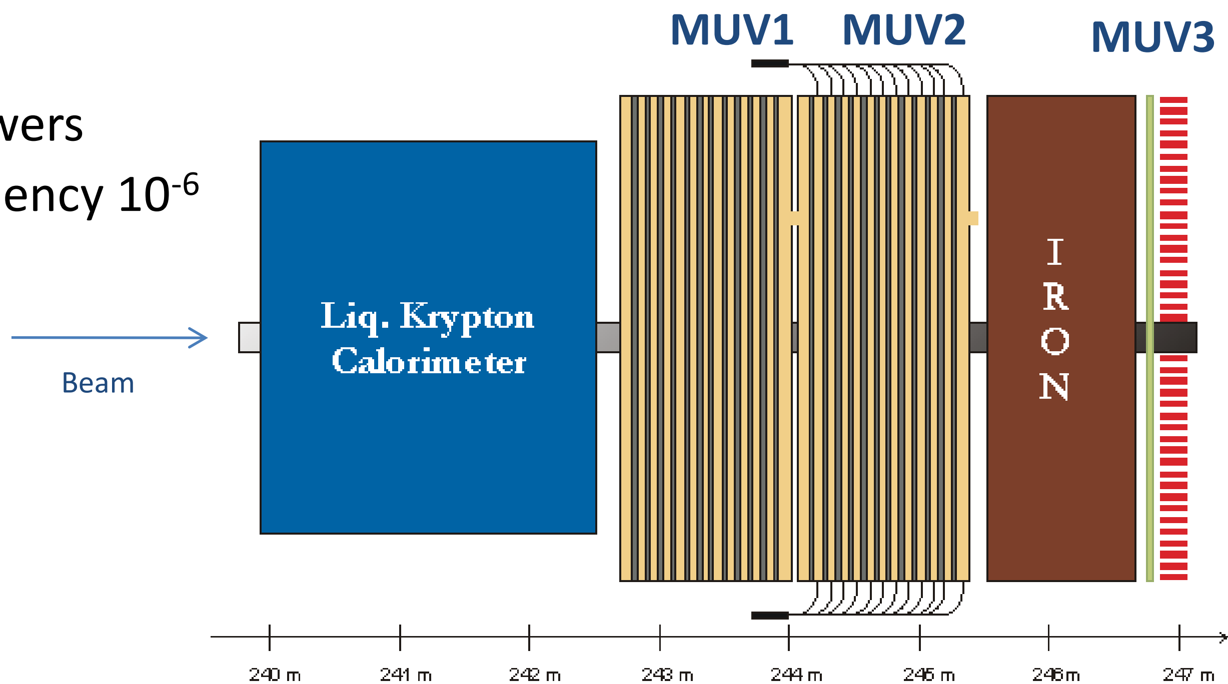
- Spherical mirrors f= 17±0.1 m
- Reflectivity > 90% (195 – 650nm)
- $D_o \leq$ 4mm (circle which collects 90% of the reflected light.)



# MUV Muon Veto

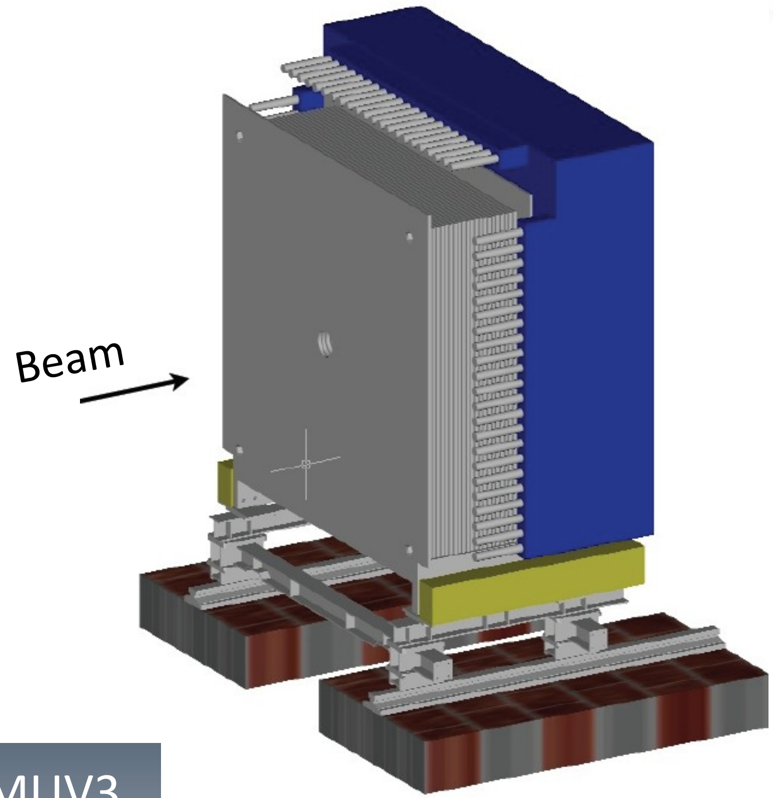
**Two functions:**

- Online: Muon Veto => MUV3
  - Requires very fast detector / time resolution ≈ 0.5 ns
  - Reduce L0 trigger by factor 20
  - 10 MHz Muon rate + coincidence window ≤ 2.5ns => dead time ≤ 2.5%
- Offline:
  - Muon identification
  - Energy of hadron showers
  - Target muon < inefficiency $10^{-6}$ (together with RICH)

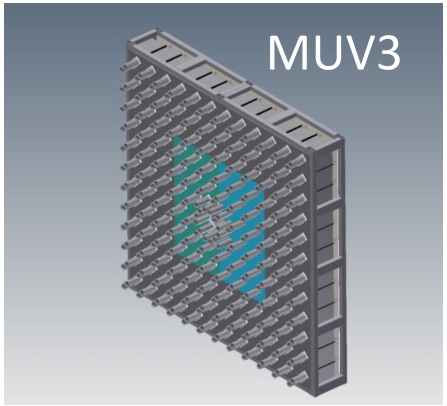


# MUV Muon Veto

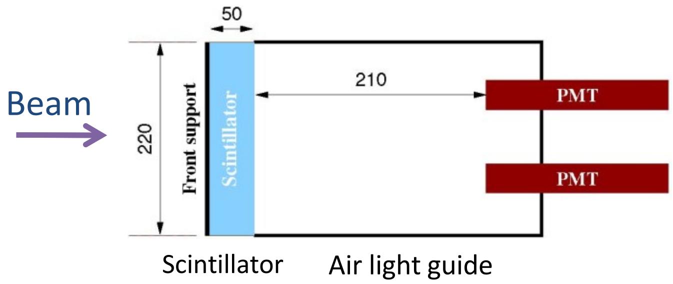
- MUV 1 + 2
  - iron/scintillator sandwich
  - 24(MUV1) and 22(MUV2) detection layers
  - Alternating horizontal and vertical scintillator strips
  - PMT's




- MUV3 (trigger layer)
  - Fast muon trigger after 80 cm of iron
  - Design: Tiles scintillators, air light guide, 2 PMT 21 cm behind.




One cell of MUV3



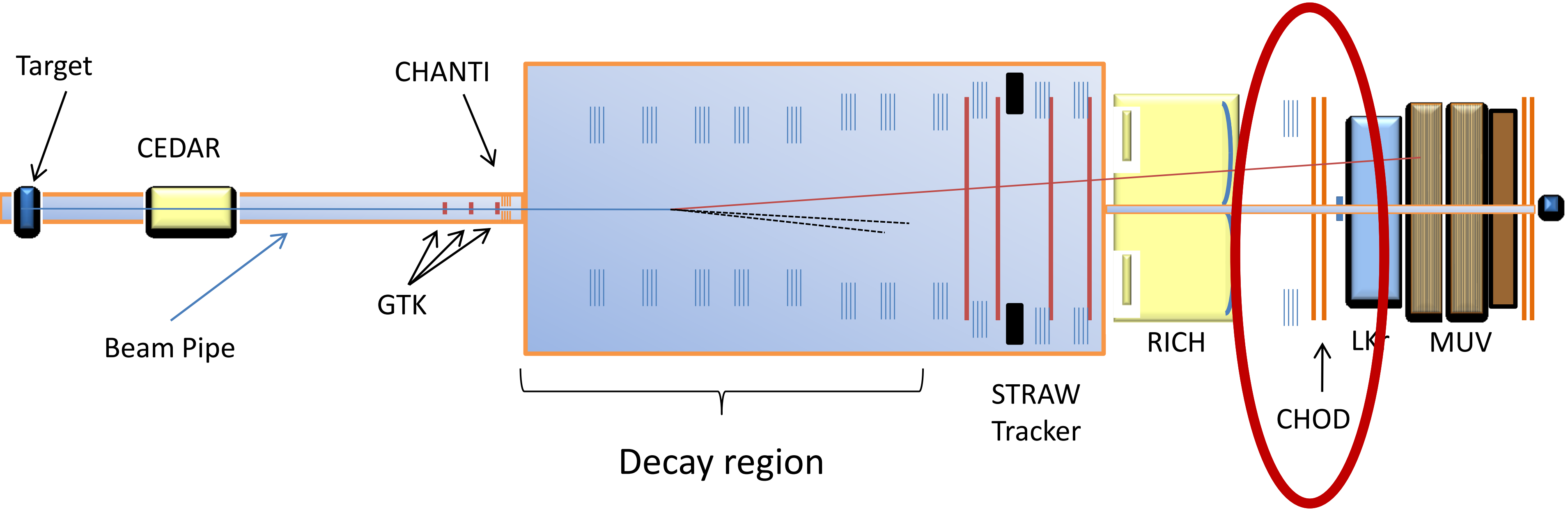
# Conclusions

- NA62 will build a very demanding detector to measure extremely rare K decays.
- This entails:
  - To build 7 new sub-detectors: (GTK, STRAW Tracker, RICH, LAV, CHANTI, IRC/SAC + MUV1+3)
  - Renovate 4 existing detectors: (CEDAR,LKR, CHOD, HAC)
  - Re-use large parts of the NA48 infrastructure
- Timescale:
  - Technical Run in Fall 2012 (partially complete detector)
  - Physics Run after the LS1

# Thank You

# CHOD Detector

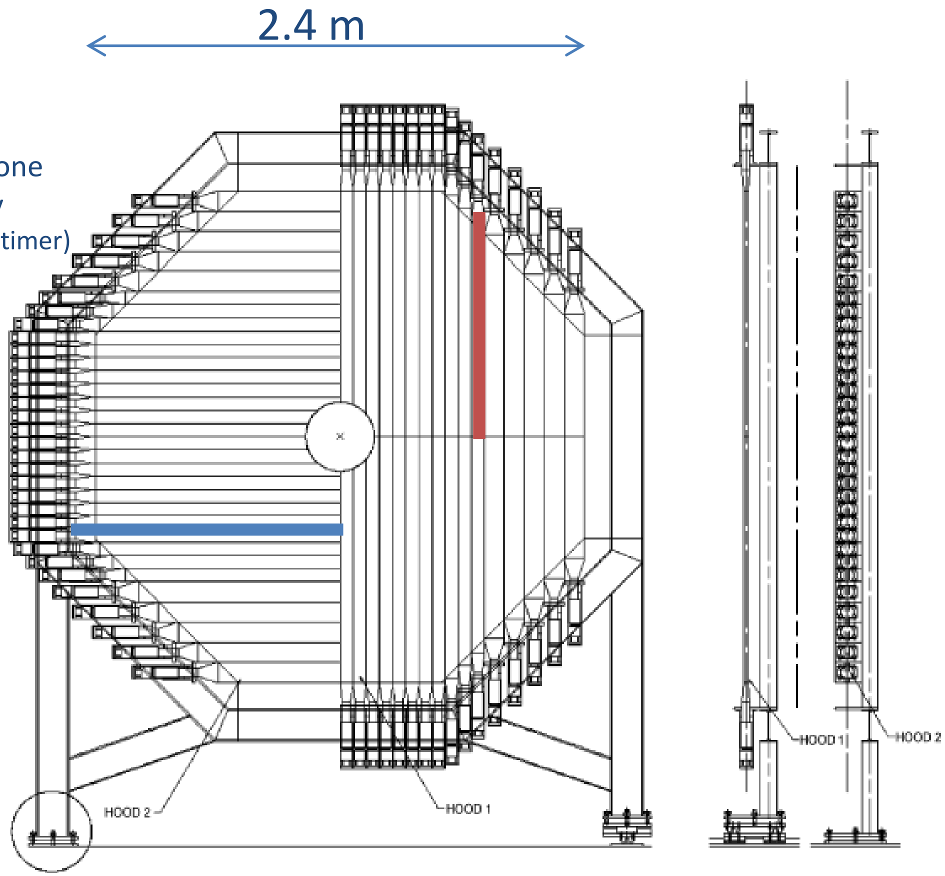
Charged Hodoscope



# NA48 Charged Hodoscope

Will be used for 2012 Run / Replacement foreseen afterwards

PMT on one
Side only
(no mean timer)




**Performance:**

Time resolution $\sigma_t$ = 0.2-0.3 ns (offline)

Number of detected pe/MIP = ??

**Detector Parameters:**

- 2 planes X-Y (2 x 64 channels)
- Scintillator BC408 (att. L≈1.5m) decay time 2.2ns
- Slab size (60-121) x 6.5 (9.9) x 2 cm; plastic light guides
- PMT's Philips XP2262B
- $X_0$ ≈ 10%

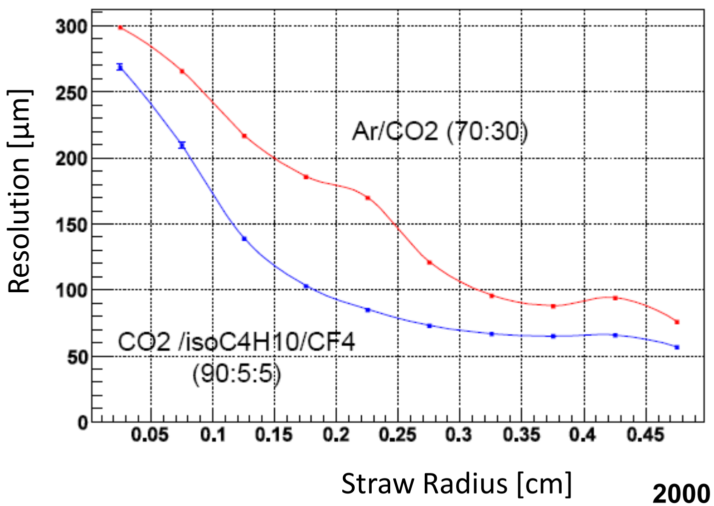
**Limitations for NA62:**

- Expected Rate > 1MHz in some channels
- X-y matching difficult bco ghost hits -> may impact $\sigma_t$
- Can't be used to cut multi track events (bco. ghost hits)
- Geometrical acceptance slightly to big.

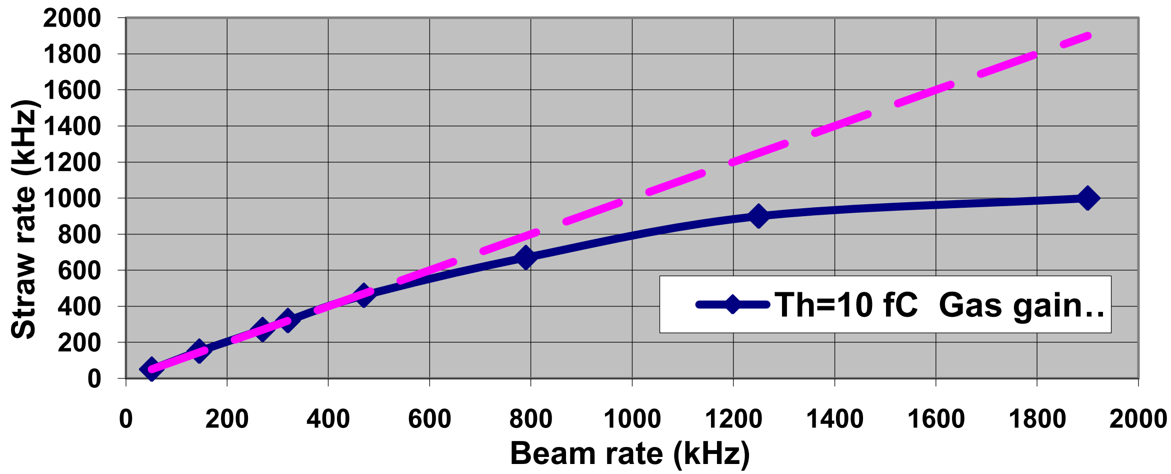
# Straw Tracker

## Test beam Results

### Resolution versus Radius




### Straw Rate in Pion Beam




Courtesy: S. Movchan

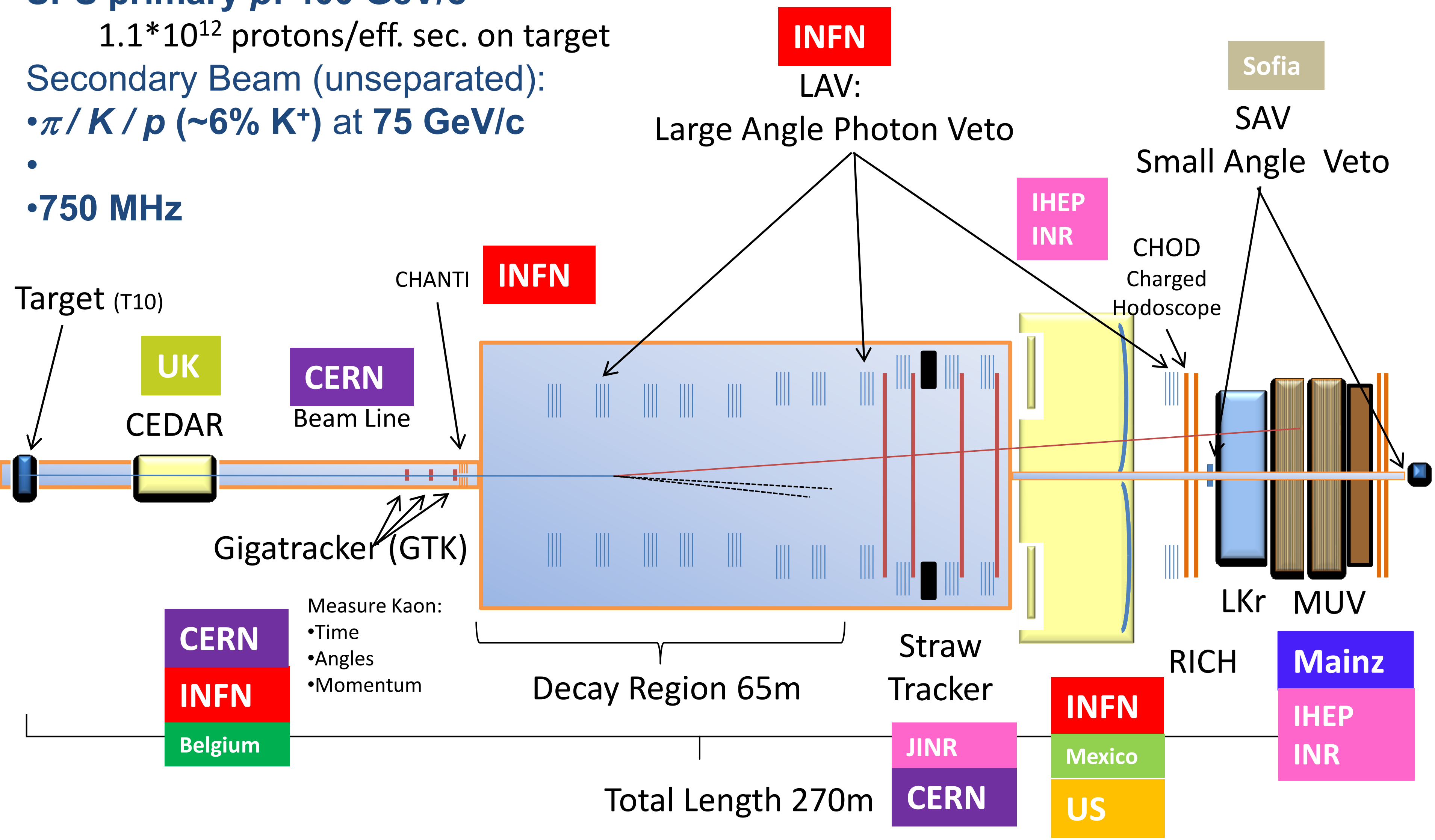
# NA62 Beam & Detectors

**SPS primary *p*: 400 GeV/c**

1.1*10[12] protons/eff. sec. on target

Secondary Beam (unseparated):

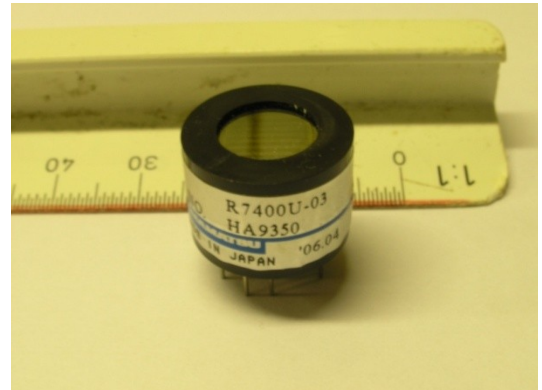
- **$\pi$ / K / p (~6% K$^+$)** at **75 GeV/c**
-
- **750 MHz**



# Photo-detectors

## Photomultiplier

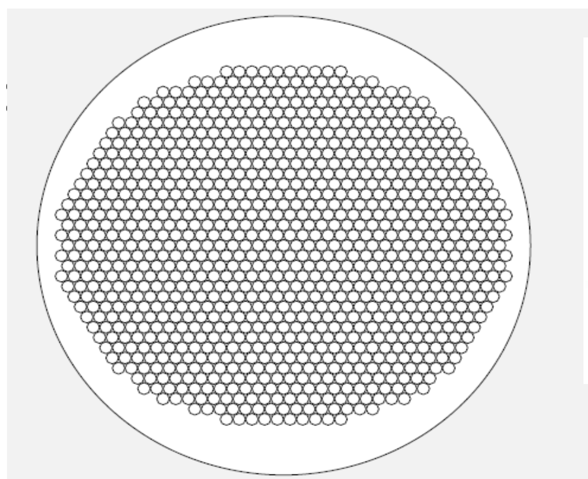
- Hamamatsu R7400 U03
- Metal housing, 8 dyn
- 185 nm – 650 nm, 420 nm peak sensitivity
- Gain: 7 x $10^5$ (typ.)
- Transit time: 5.4 ns  (Transit time spread: 0.28 ns)



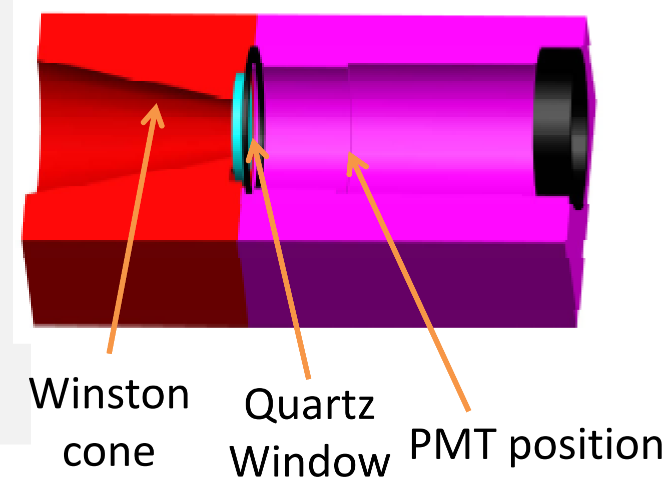

## Photomultiplier Plane:

- 2x 1000  PMT's
- PMT pitch 18mm
- All services mounted on one flange.

Photos: M. Lenti



Light Collection + Window:



# CEDAR

- **CEDAR: existing Cherenkov counter at CERN**
  - Adapted to NA62 need : $H_2$ Gas instead of Nitrogen, new photo detectors and electronics
- Why the CEDAR ?
  - Essential to make sure incoming particle is kaon (6% of total flux)
  - Kaon tagging will suppress the background:
    - due to scattering of beam particles in the residual gas (vacuum);
    - due to beam halo entering the vacuum tank;
    - due to beam pions decaying in the vacuum tank.