NA62 status report

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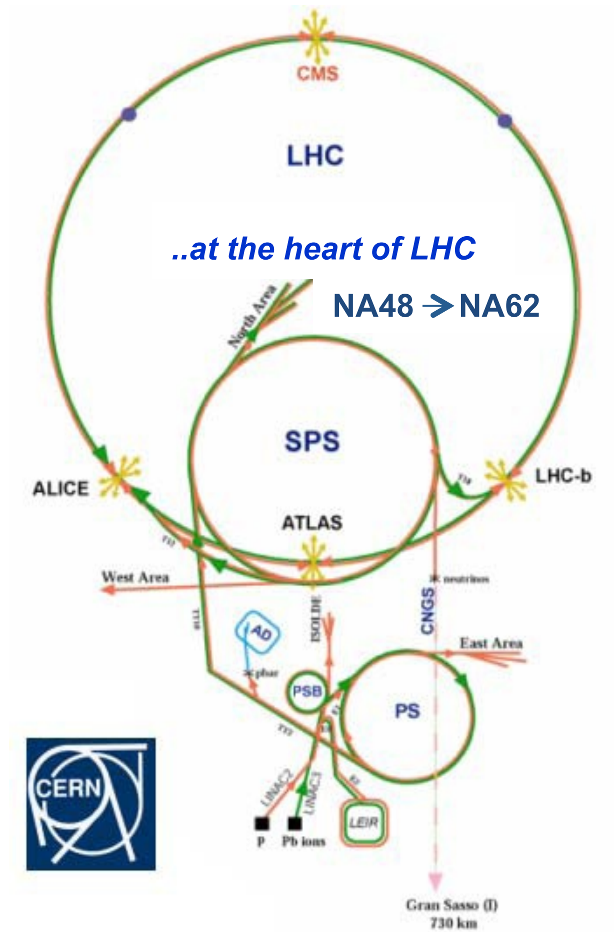
Outline

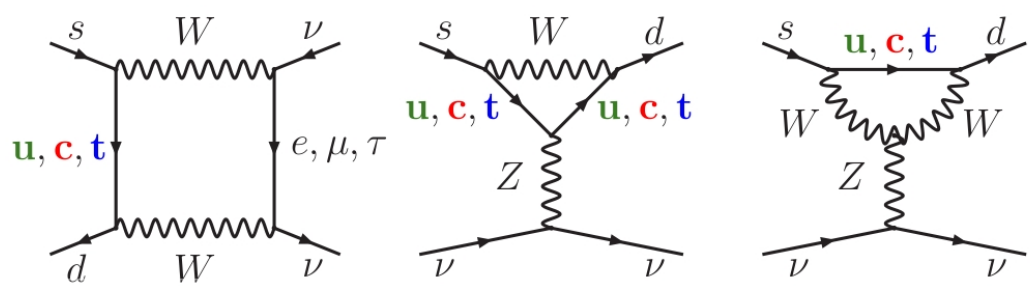
NA62: $K^+ \to \pi^+ \nu \bar{\nu}$ experiment

- experimental strategy
- main detectors description
- detectors developed in Naples
- future measurements



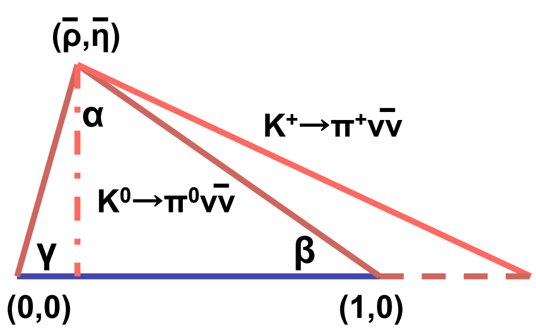
$K^+ \to \pi^+ \nu\bar{\nu}$: motivation

- FCNC process forbidden at tree level
- Only one loop contributions: Boxes and Penguins



Theoretical prediction:

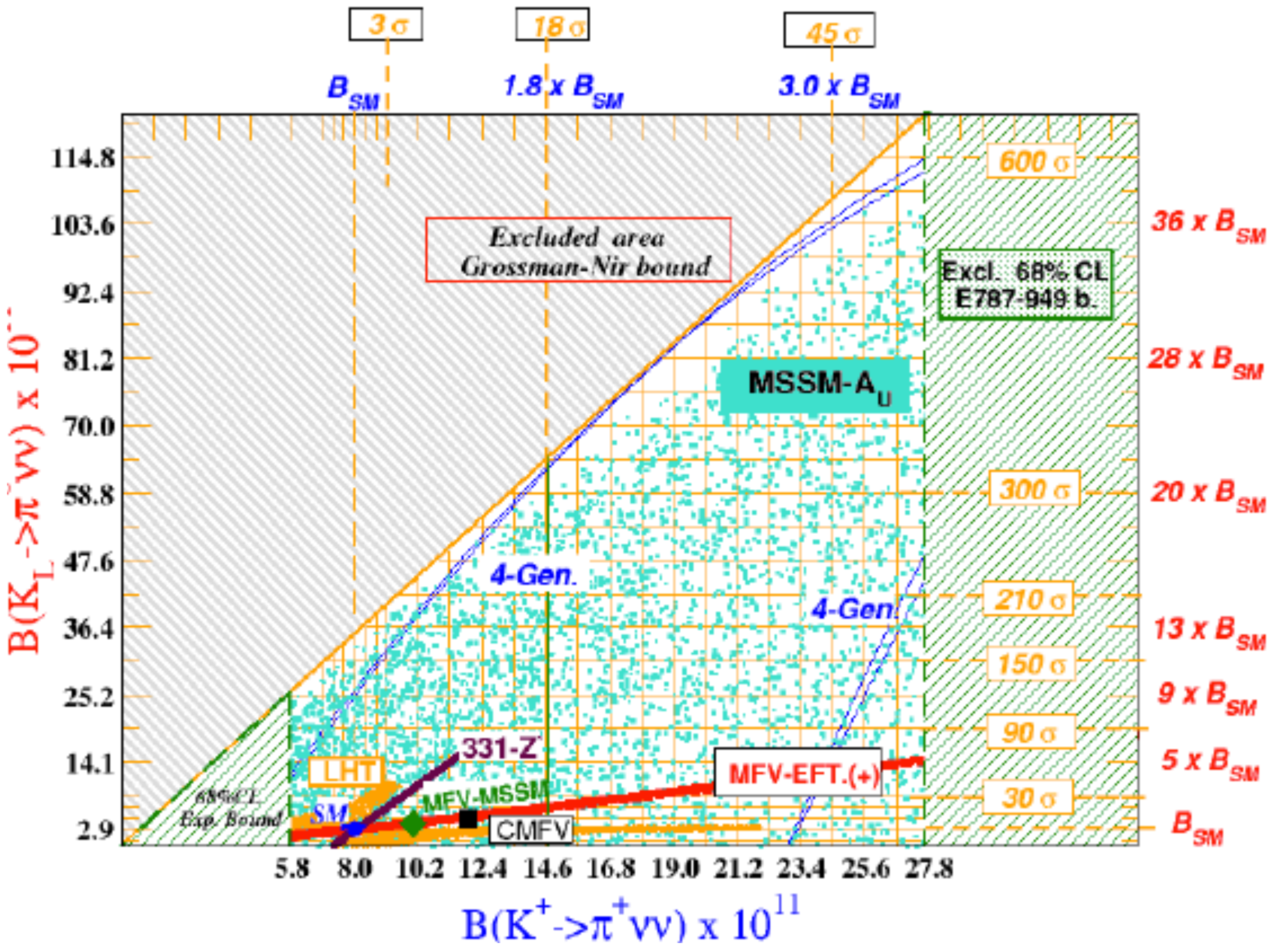
$BR(K^+ \to \pi^+ \nu\nu) = (8.5 \pm 0.7) \times 10^{-11}$ **8% error**



- Cleanest way to extract $\mathbf{V_{td}} \times \mathbf{V_{ts}}$ and to give independent determination of the unitarity triangle
- Complementarity with B physics
- Very sensitive to New Physics

$K^+\to\pi^+\nu\bar{\nu}$: motivation (II)

Several NP models and possibility to distinguish among different models

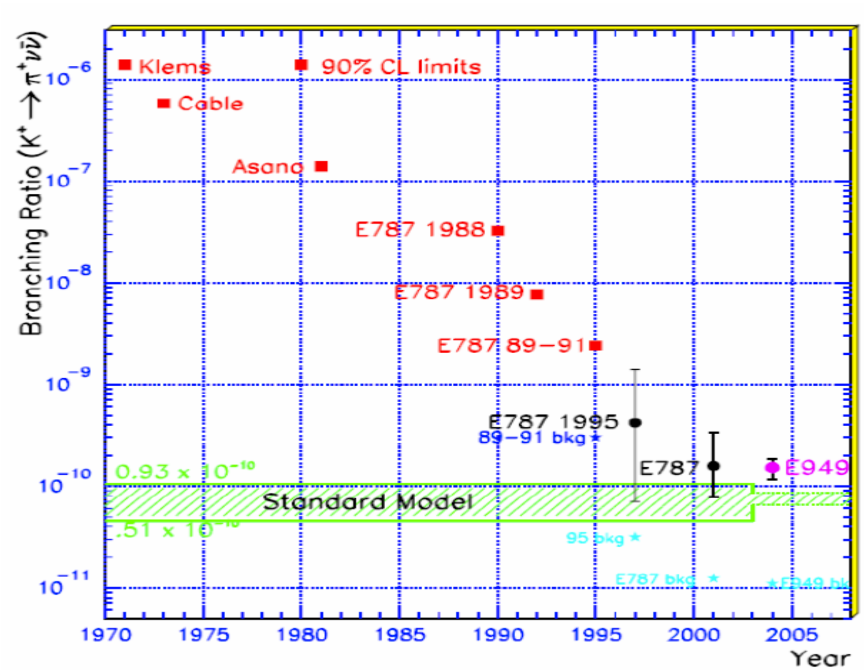


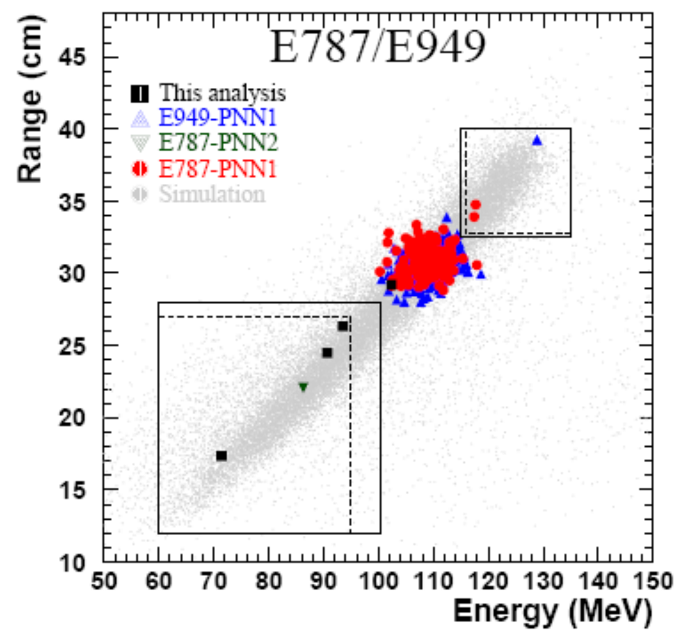
BR($K^+\to\pi^+\nu\nu$) $\times 10^{10}$: selected models	
SM	0.82±0.08
MFV (hep–ph/0310208)	1.91
EEWP (NPB697 (2004) 133, hep–ph/0402112)	0.75±0.21
EDSQ (PRD70 (2004) 093003, hep–ph/0407021)	up to 1.5
MSSM (NPB713 (2005) 103, hep–ph/0408142)	up to 4.0

Experimental status

$BR(K^+ \to \pi^+ \nu\nu)_{exp} = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$

based on 7 candidates at BNL E787+E949



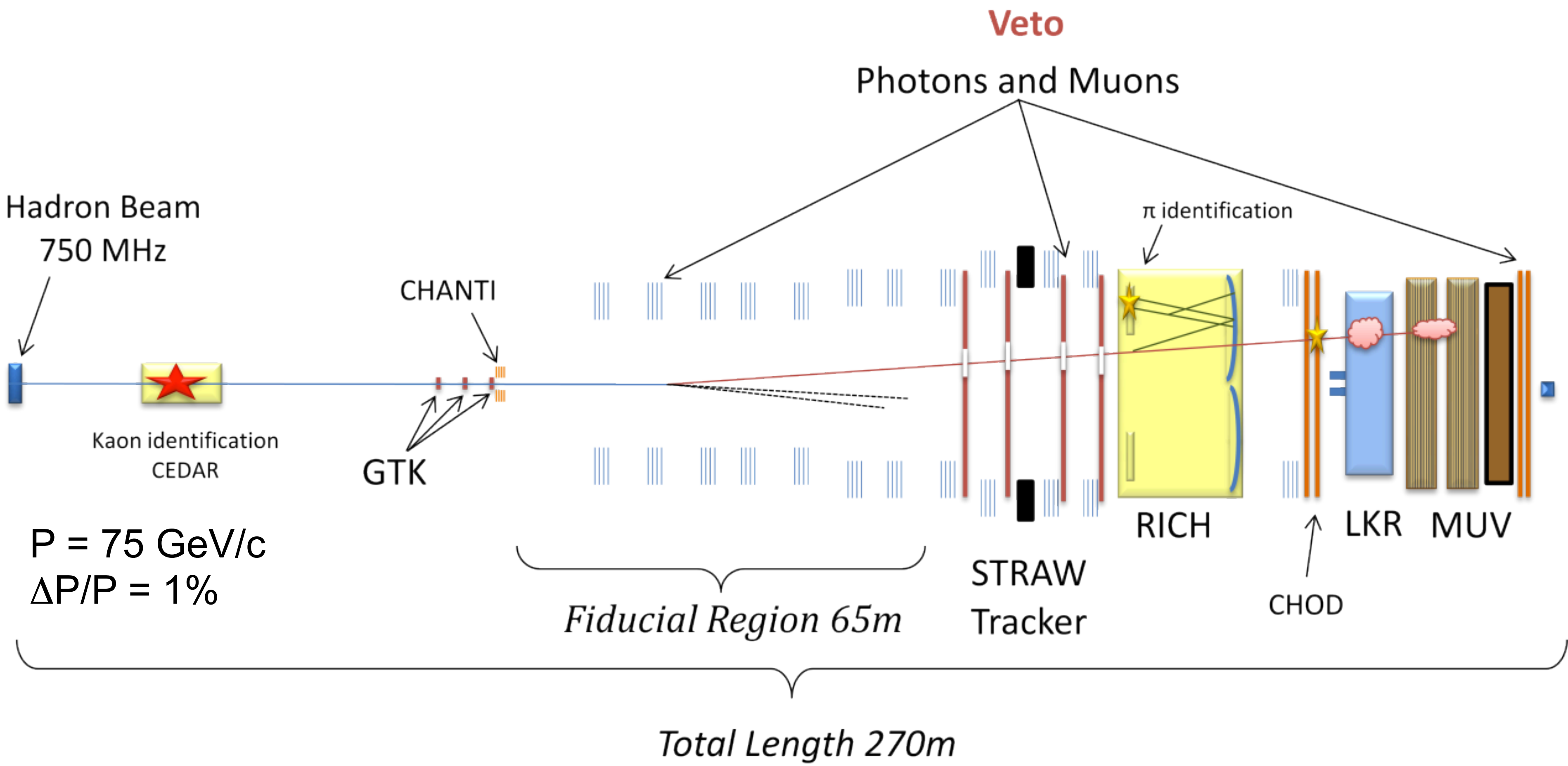


Probability that all 7 events are due to background: 10^{-3}

first experimental observation of $K^+ \to \pi^+ \nu\nu$

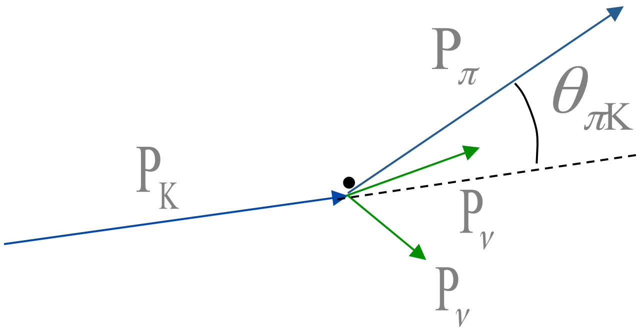
All physics background can be under control at 10^{-11} level !

$K^+ \to \pi^+ \nu \bar{\nu}$ @ NA62



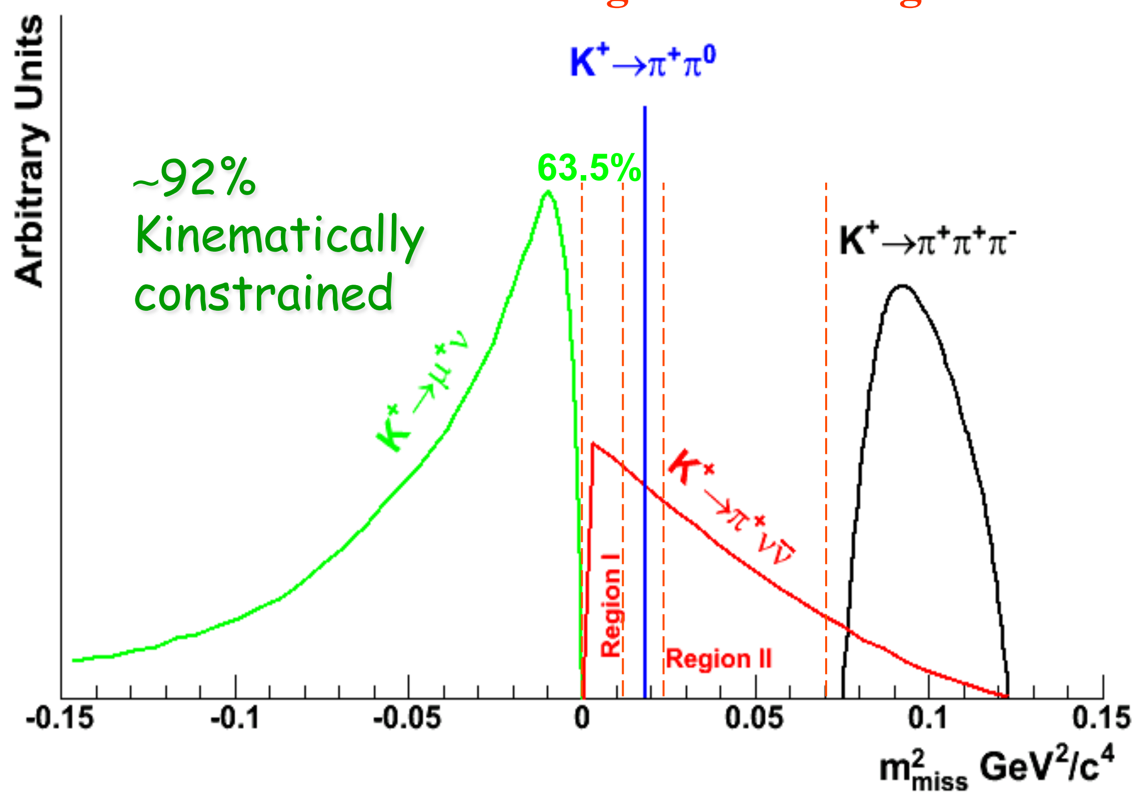
- High energy unseparated kaon beam
- Decay in flight technique
- Goal: **O(100) events with S/B ~10**

Kinematic reconstruction



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

two background free regions



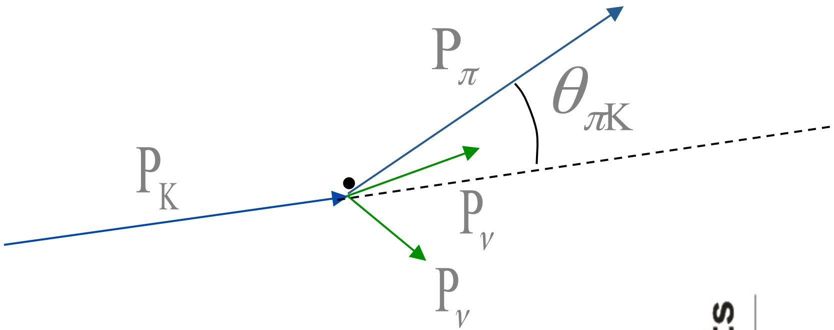
Requirements:

- low mult. Scattering → low mass tracker operating in vacuum
- good space resolution (~100 μm)

Detectors:

- GigaTracker
- Straw Chamber Spectrometer

PID and Veto



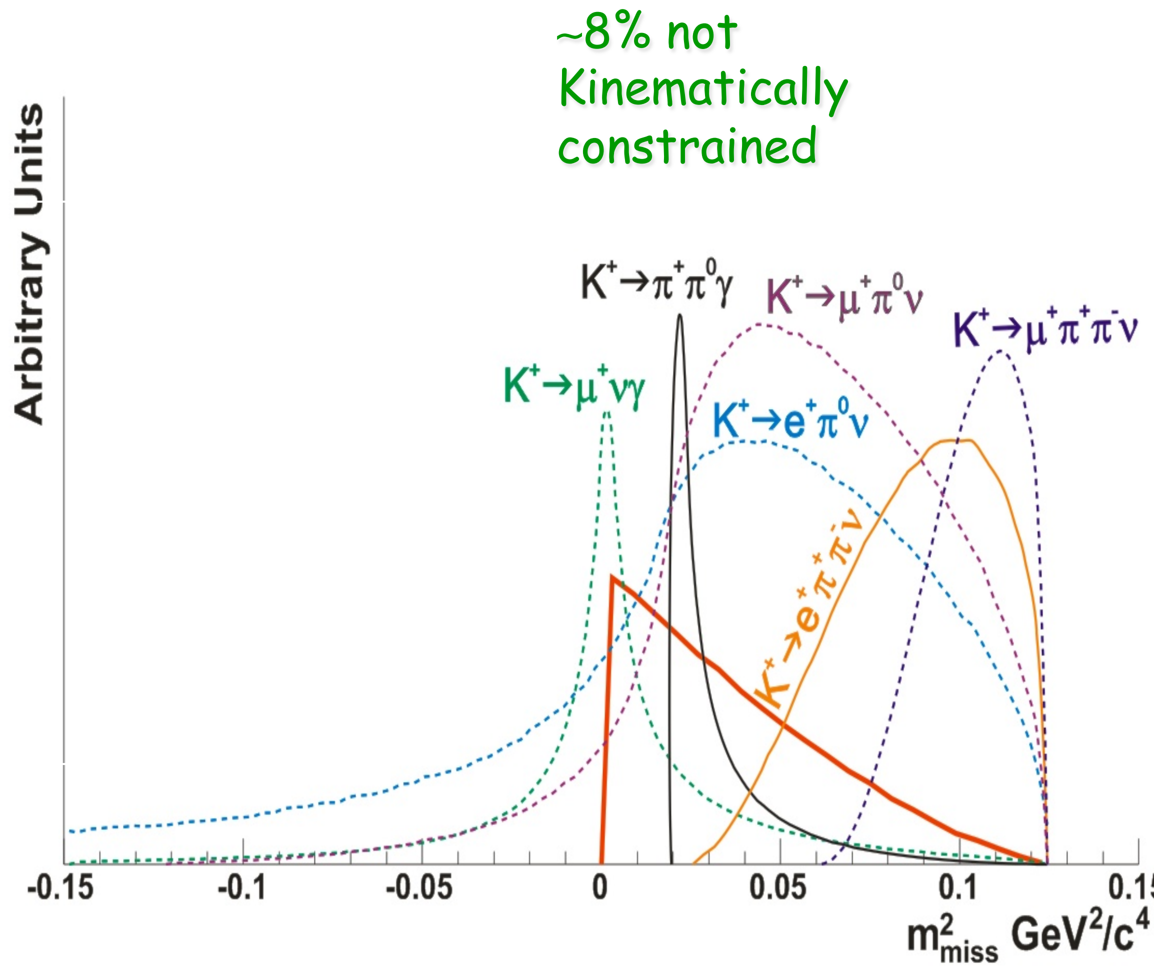
high efficiency detectors

Photon veto:

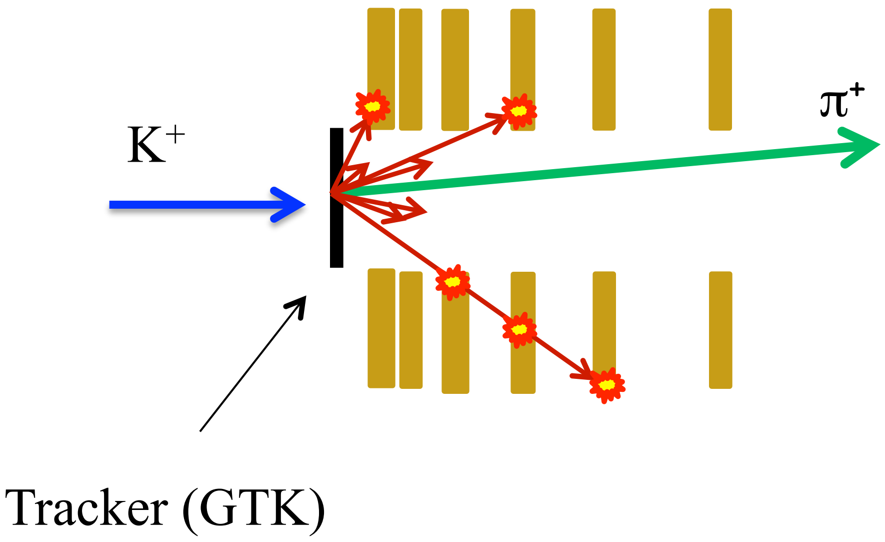
$K^+ \to \pi^+\pi^0$ supp

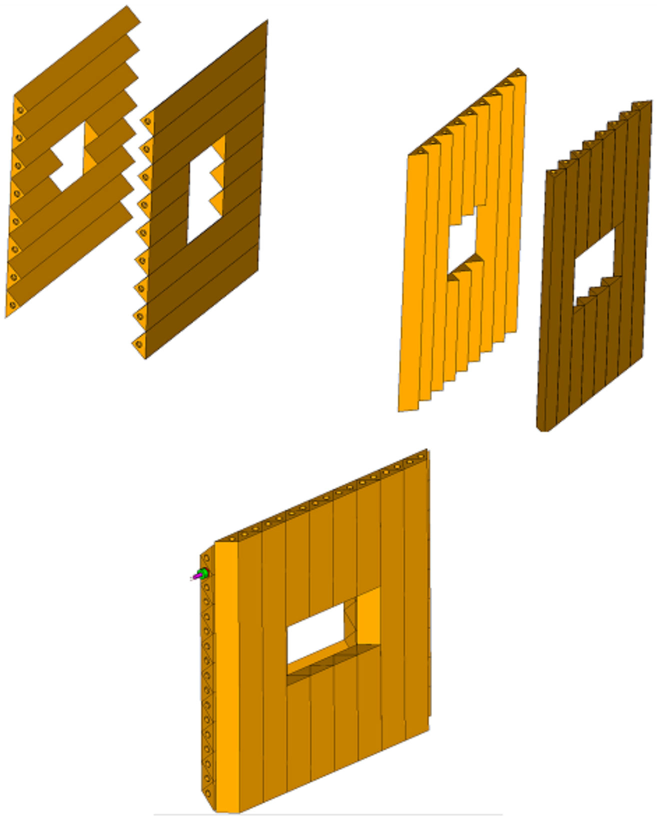
RICH and MUON VETO

for muon suppression

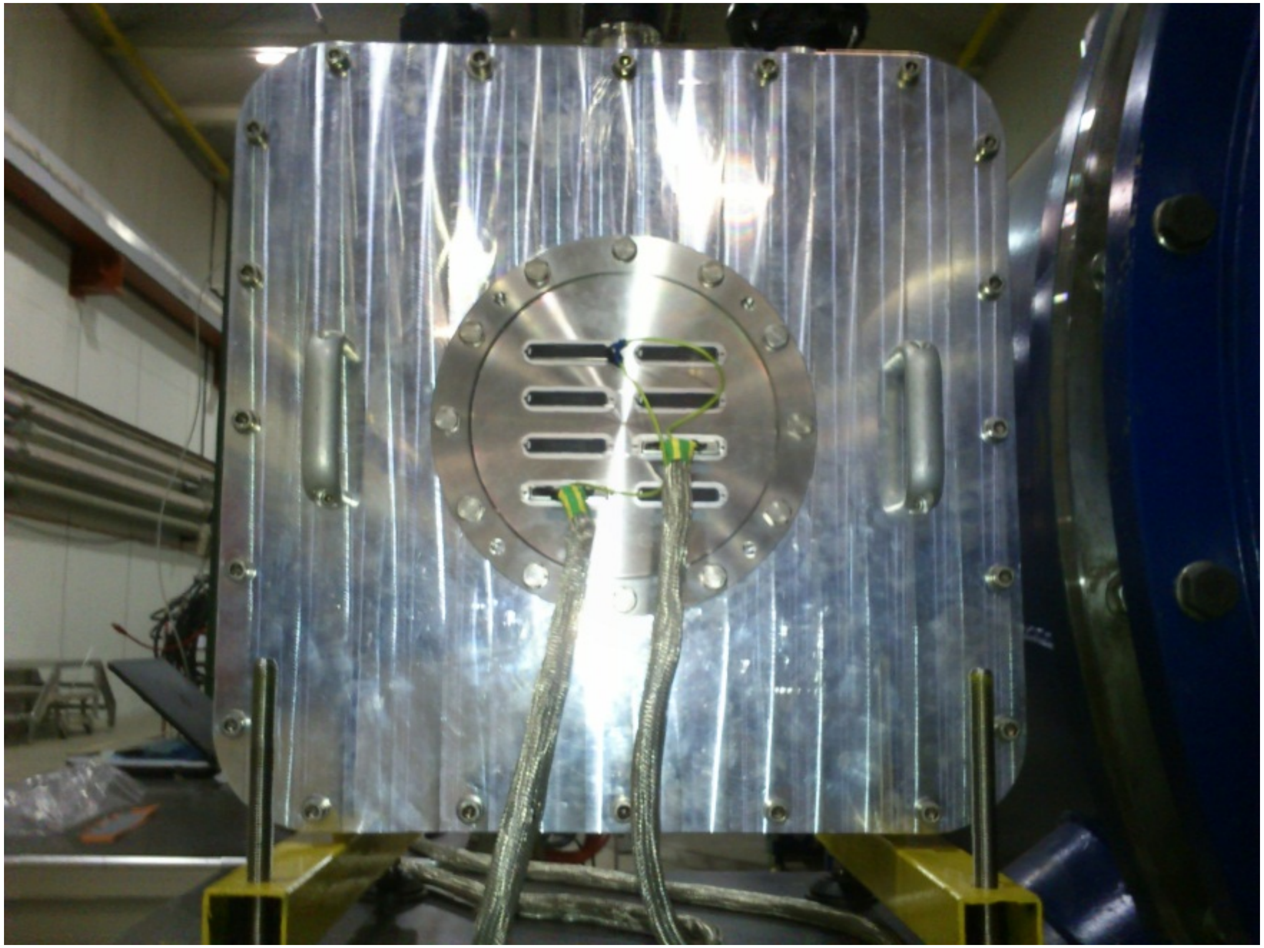


CHANTI





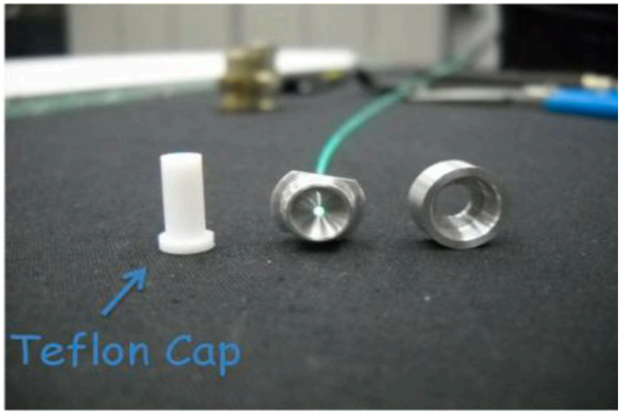
CHANTI



First station construction

Fibers – Bar Gluing

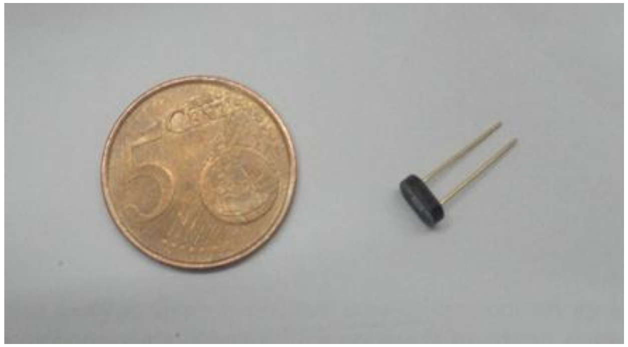
Fibers are glued into the scintillator bars using a low out-gassing optical glue.



SiPM

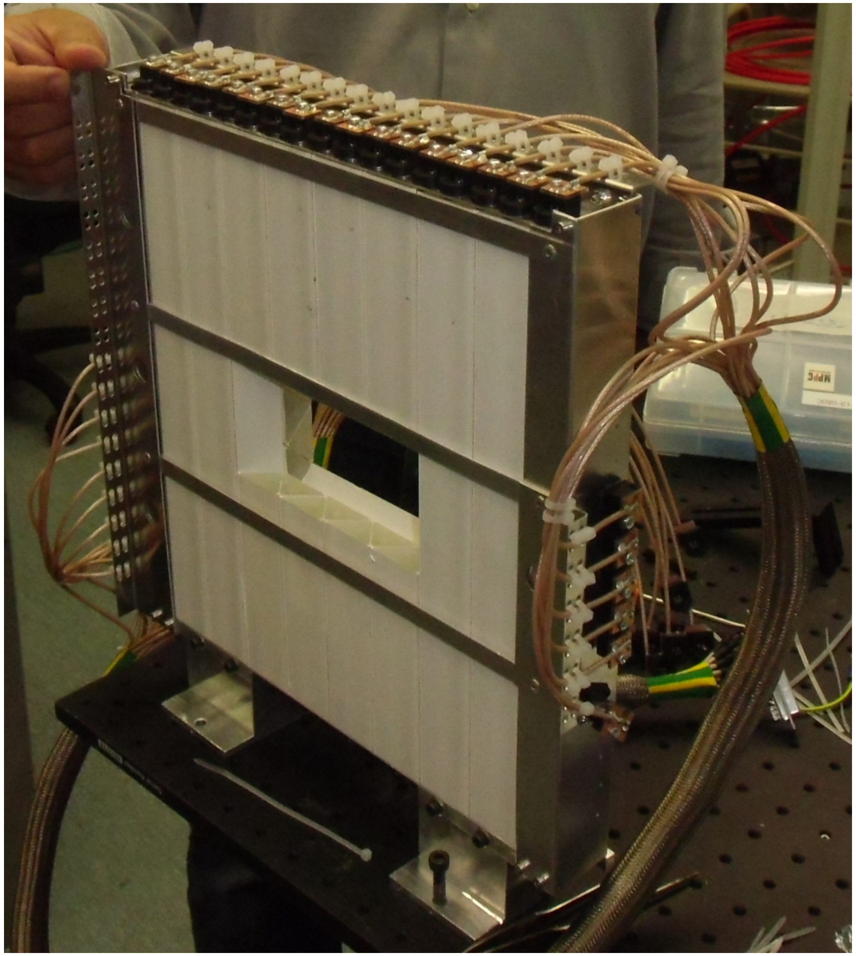
Hamamatsu MPPC 13-50 type
(1.3 X 1.3 mm^2, 50 μm pixel size)

Hamamatsu provides some info for each device (V_{op}, Gain, Dark Rates).
All info is related to operation at 25 °C
Need to use a thermostatic chamber to fix temperature



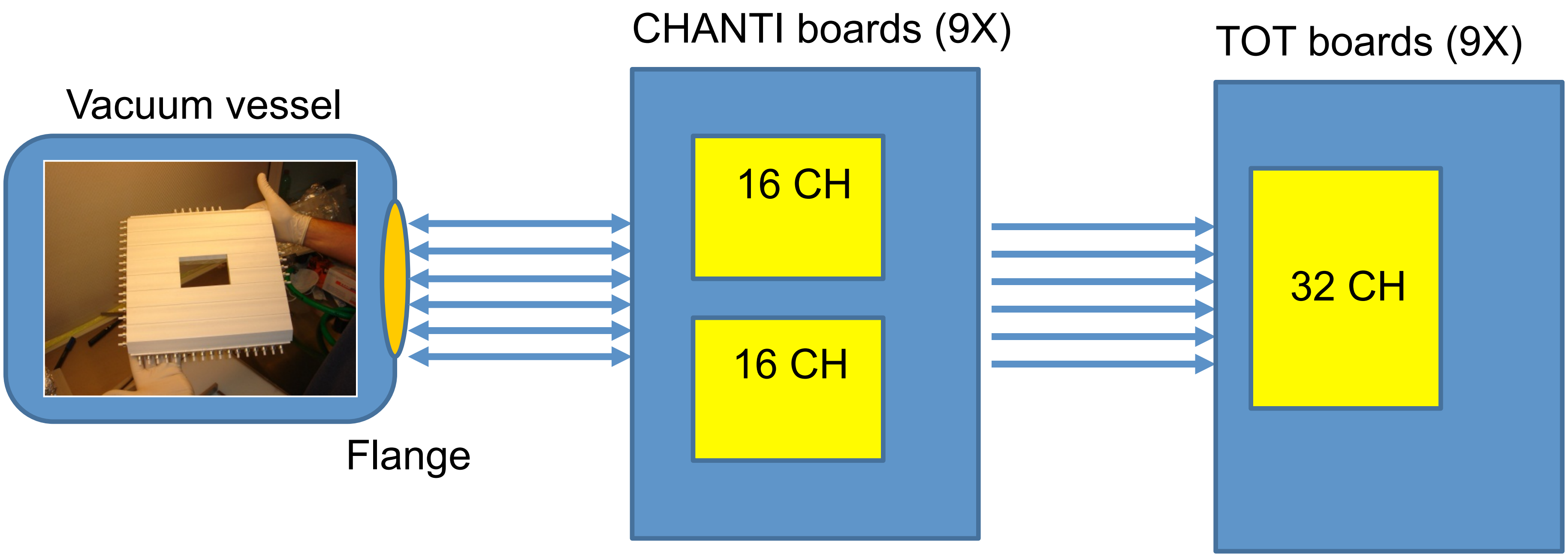
CHANTI-01 completed

- CHANTI-01 completely assembled and cabled
- 46 channels distributed on 3 DB37 connectors
- All SiPMs (46) characterized at 15-20-25 degrees in climatic chamber

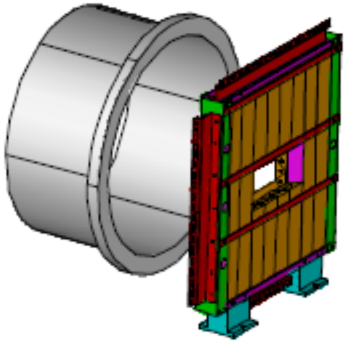


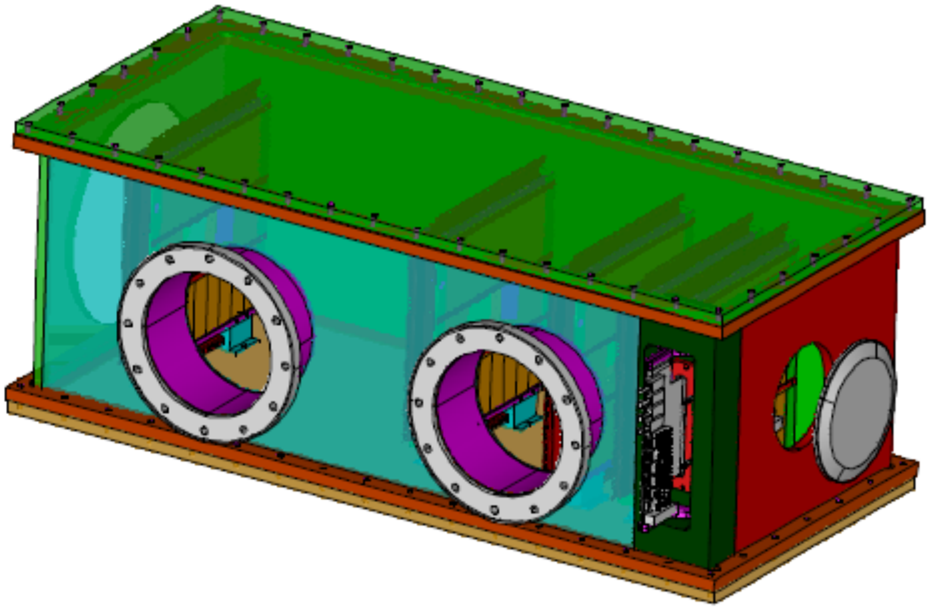
Chanti FEE scheme

- Use LAV ToT boards in a two level scheme
- CHANTI boards: Set V_{bias} (mV), FAST amplification, Single ch current (nA) , read temp probes



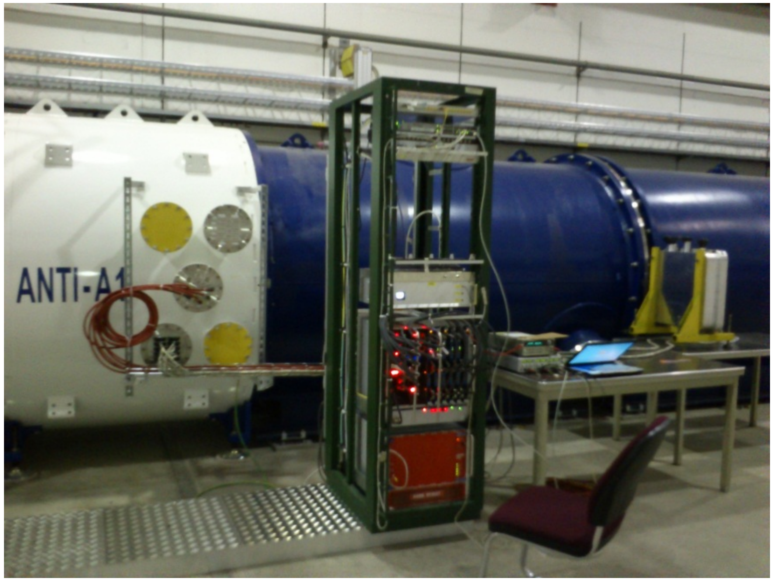
New layout: the vessel(s)



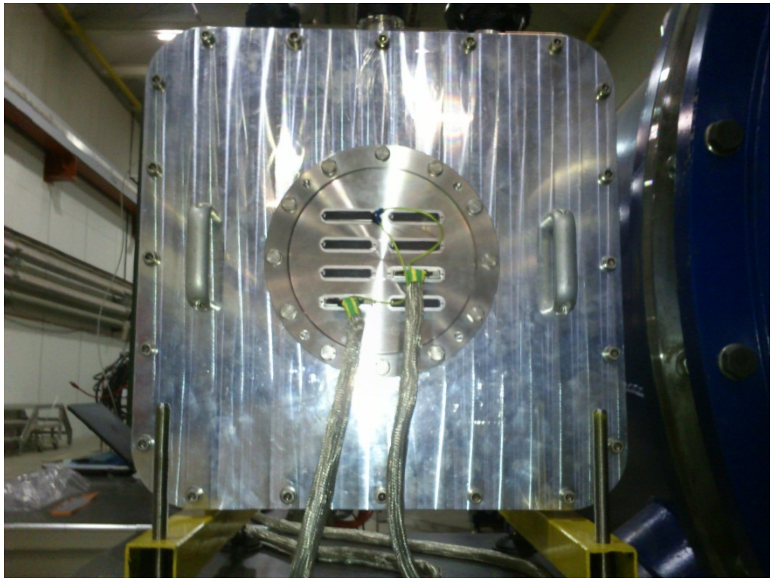


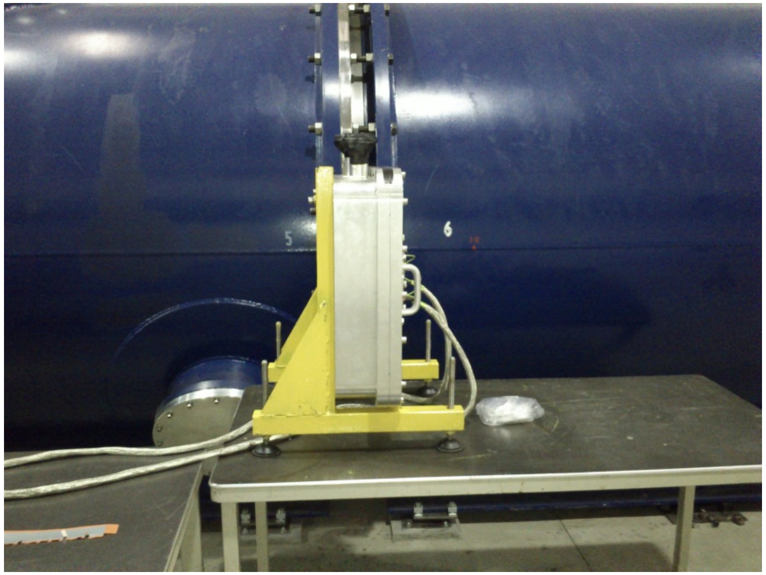
Hard work done by Lorenzo Roscilli

CHANTI TR setup



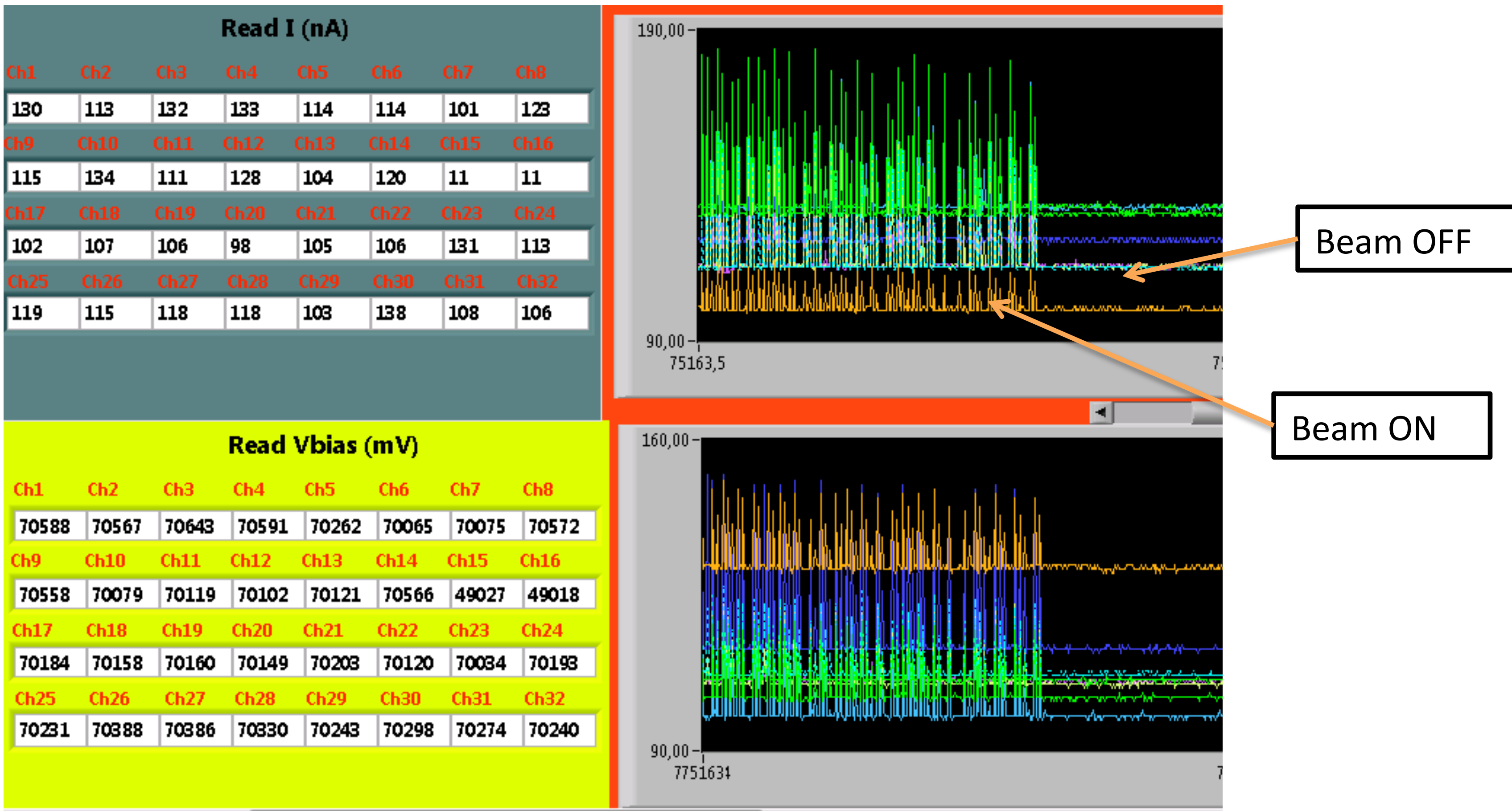
- Outside the beam next to LAV1
- Inside a vacuum capable tank which has been emptied in 29th November
- Using LAV signal flange to set V_{bias} and read signals from the station inside the tank





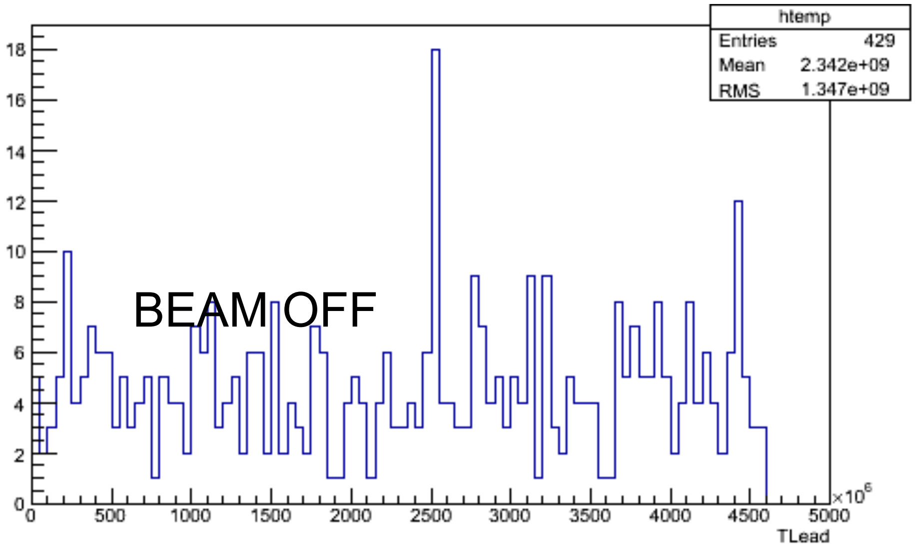
CHANTI TR DCS/ Readout

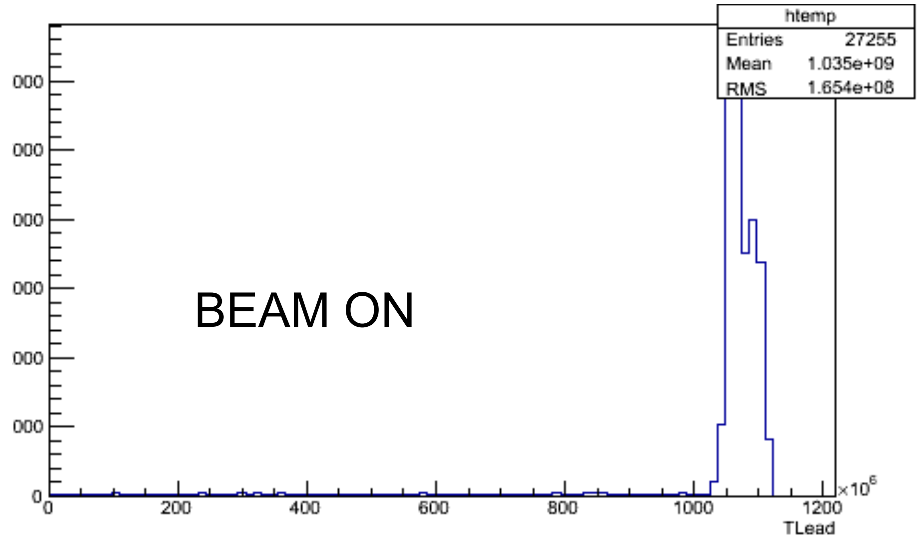
- Standalone DCS using a laptop with serial communication and LabView to drive CHANTI prototype board and serial comm to LAV-ToT board
- Only 32 out of 46 ch can be powered and read simultaneously.
- 1 TEL62 + 1 TDCB (64 ch, high and low th)



CHANTI standalone acquisition

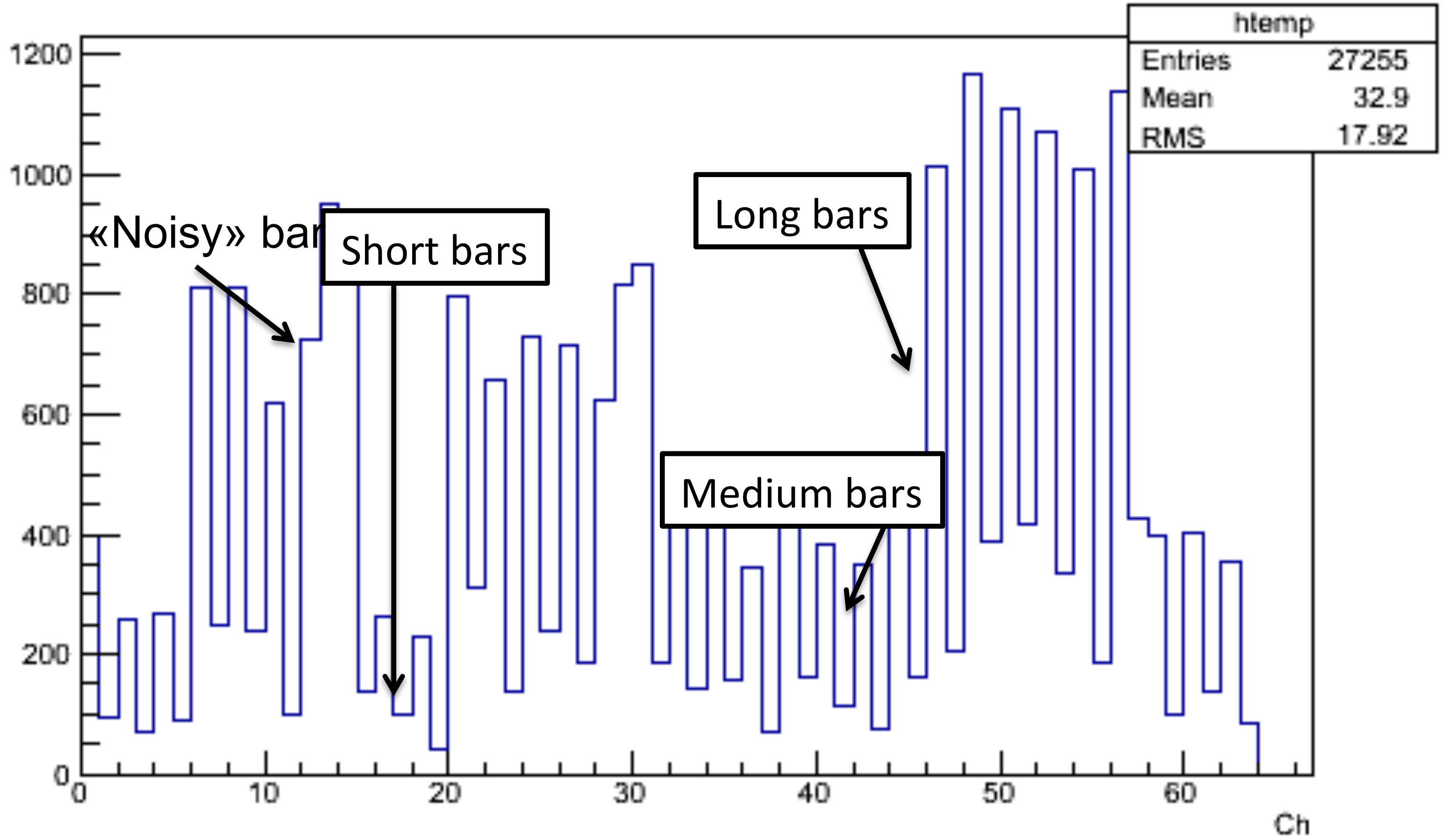
- Very simple scripts with both .txt and .root output created by D. Di Filippo, M.Mirra and F.A.
- Always matches well the start of burst
- Able to collect about 600 CHANTI evts/burst.
- Acquisition limited to first ≃100 ms of the burst due to filling up of the buffer
- «Event» is defined offline since it is acquired triggerless





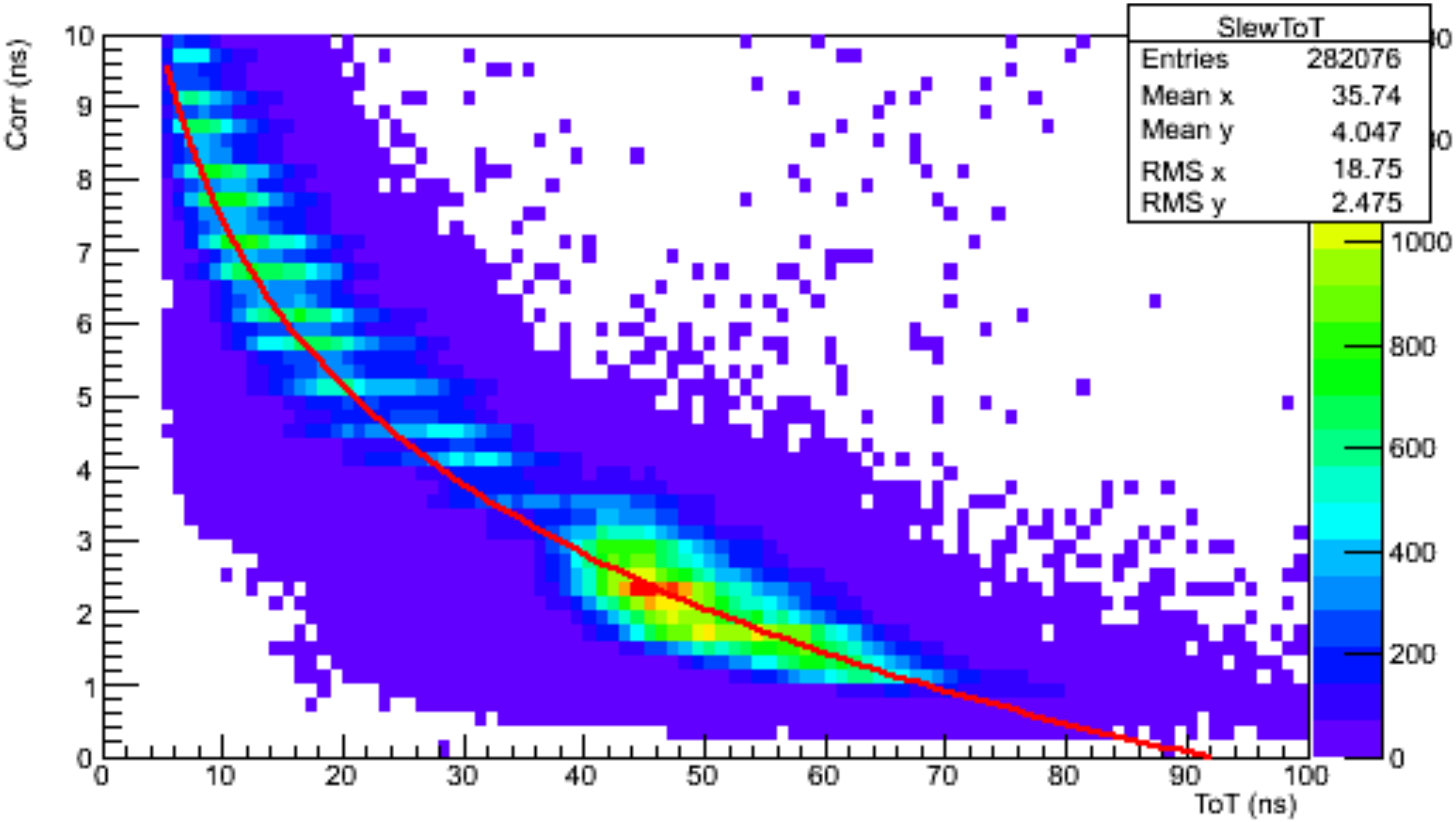
Occupancy

- 64 electronic channels , with alternating Low/High thresholds (=80/250 mV) corresponding to 32 physical channels. Occupancy coherent with the type of bar used.



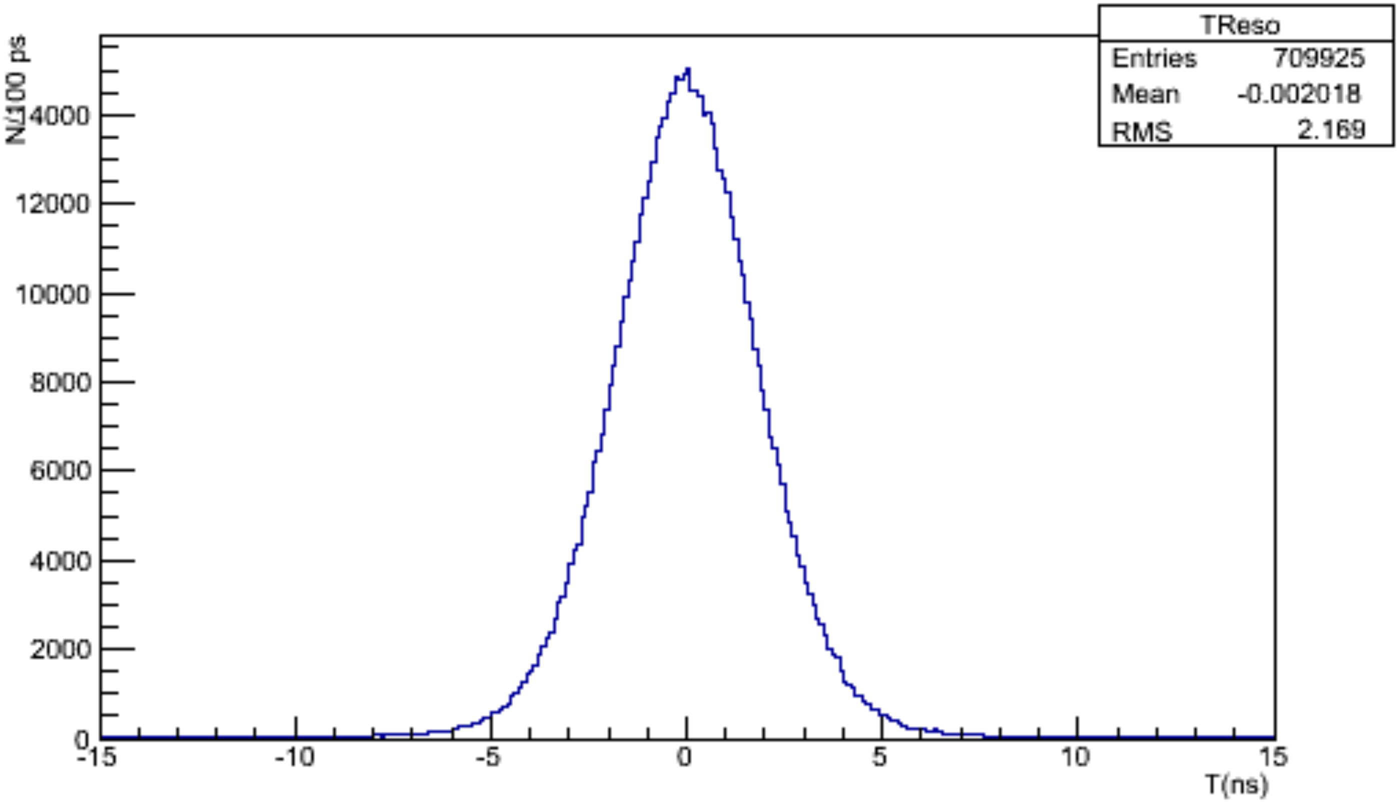
Time slewing

Events with hits from both thresholds used to find average time slewing correction using logarithmic fit



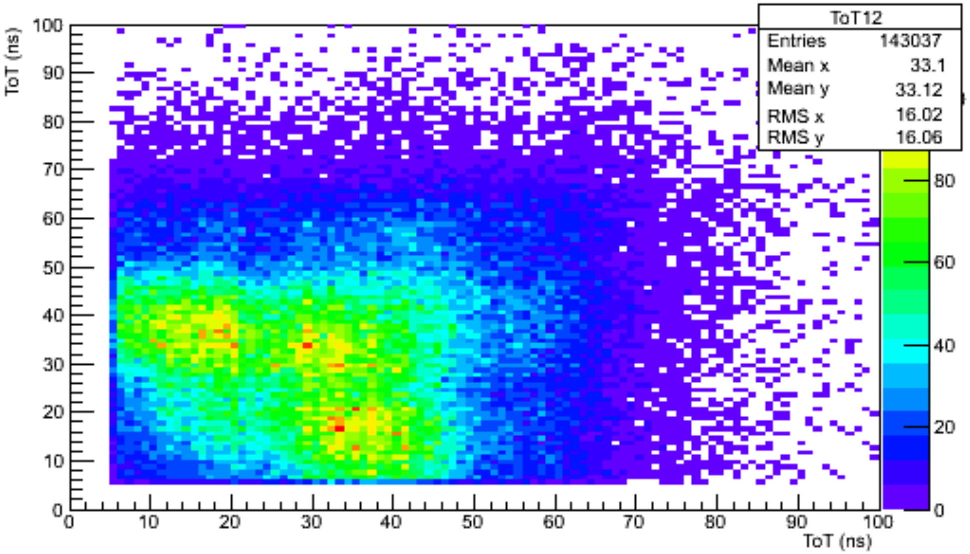
Time resolution

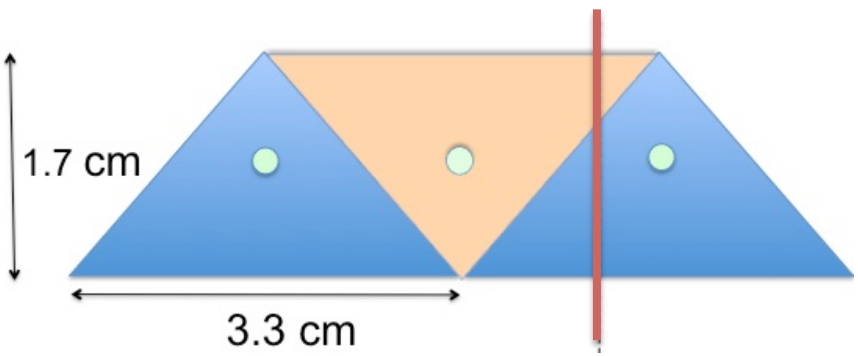
- With slewing corrections.
- RMS 2.17 ns means about 1.3 ns single channel resolution.
- No XY correction applied yet
- Expect 4 channels will be actually fired by a MIP

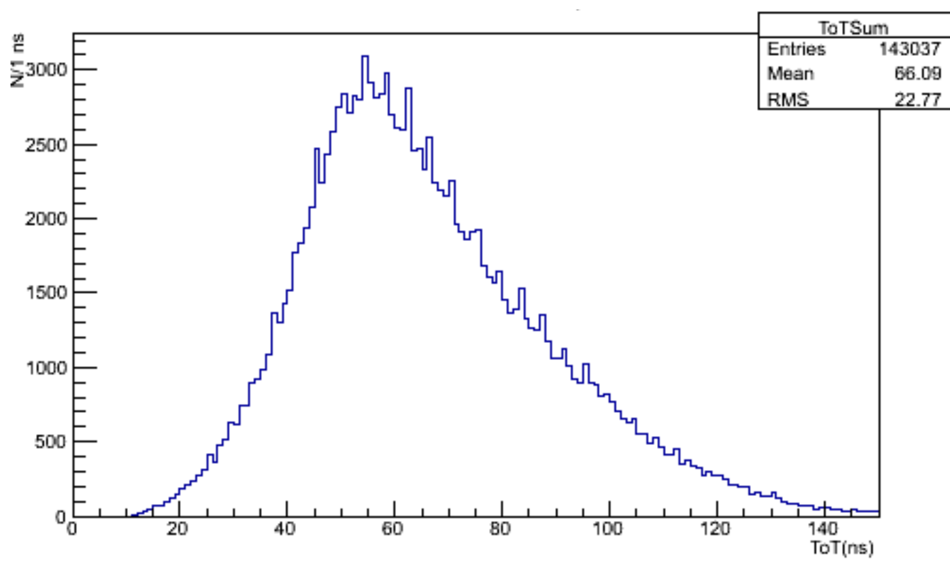


ToT response

- Due to triangular shape of the bars adjacent bars should show anticorrelated response (i.e. anticorrelated ToT at same threshold)





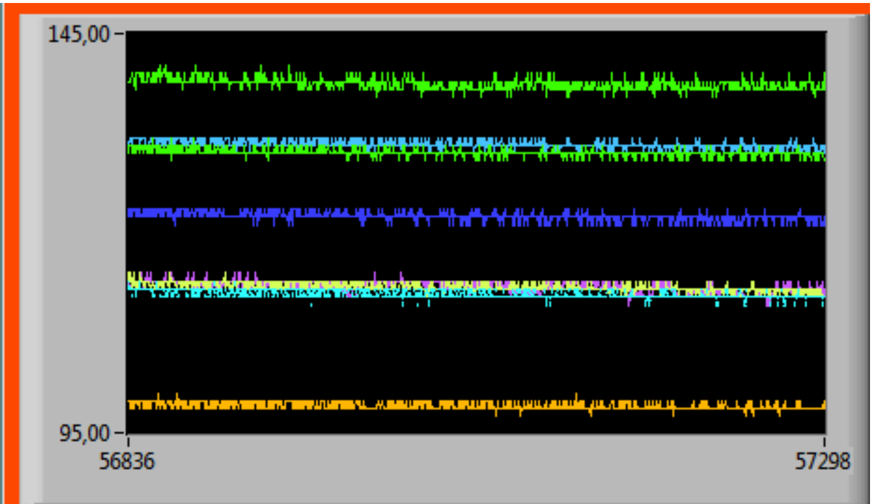


Vacuum Test

- Al least 10^{-4} mbar immediately reached and no changes in the currents. Now al least 10^{-5} mbar reached. In the next days a outgassing test planned

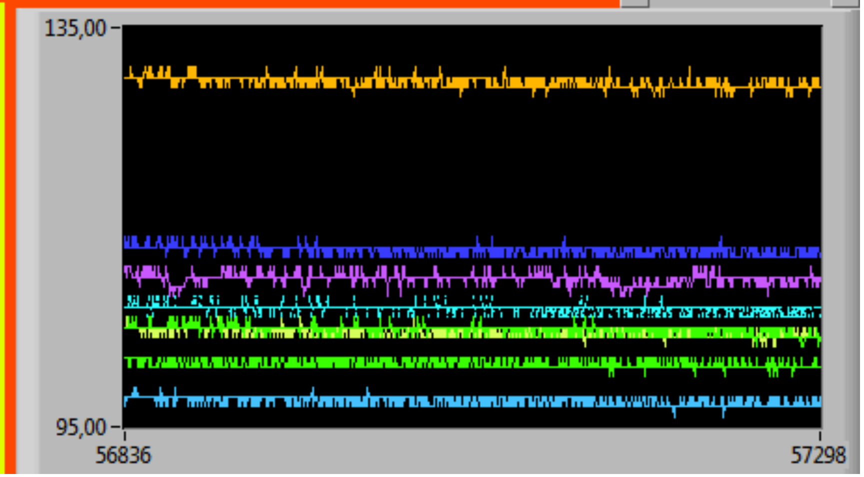
Read I (nA)

Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8
129	112	138	131	112	113	98	121
Ch9	**Ch10**	**Ch11**	**Ch12**	**Ch13**	**Ch14**	**Ch15**	**Ch16**
114	134	109	127	103	120	11	11
Ch17	**Ch18**	**Ch19**	**Ch20**	**Ch21**	**Ch22**	**Ch23**	**Ch24**
101	106	104	97	104	110	129	112
Ch25	**Ch26**	**Ch27**	**Ch28**	**Ch29**	**Ch30**	**Ch31**	**Ch32**
118	115	117	117	106	139	107	105



Read Vbias (mV)

Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8
70588	70567	70658	70591	70262	70065	70075	70572
Ch9	**Ch10**	**Ch11**	**Ch12**	**Ch13**	**Ch14**	**Ch15**	**Ch16**
70558	70079	70119	70102	70121	70566	49027	49018
Ch17	**Ch18**	**Ch19**	**Ch20**	**Ch21**	**Ch22**	**Ch23**	**Ch24**
70184	70158	70160	70149	70203	70120	70034	70193
Ch25	**Ch26**	**Ch27**	**Ch28**	**Ch29**	**Ch30**	**Ch31**	**Ch32**
70231	70388	70386	70330	70243	70298	70274	70240



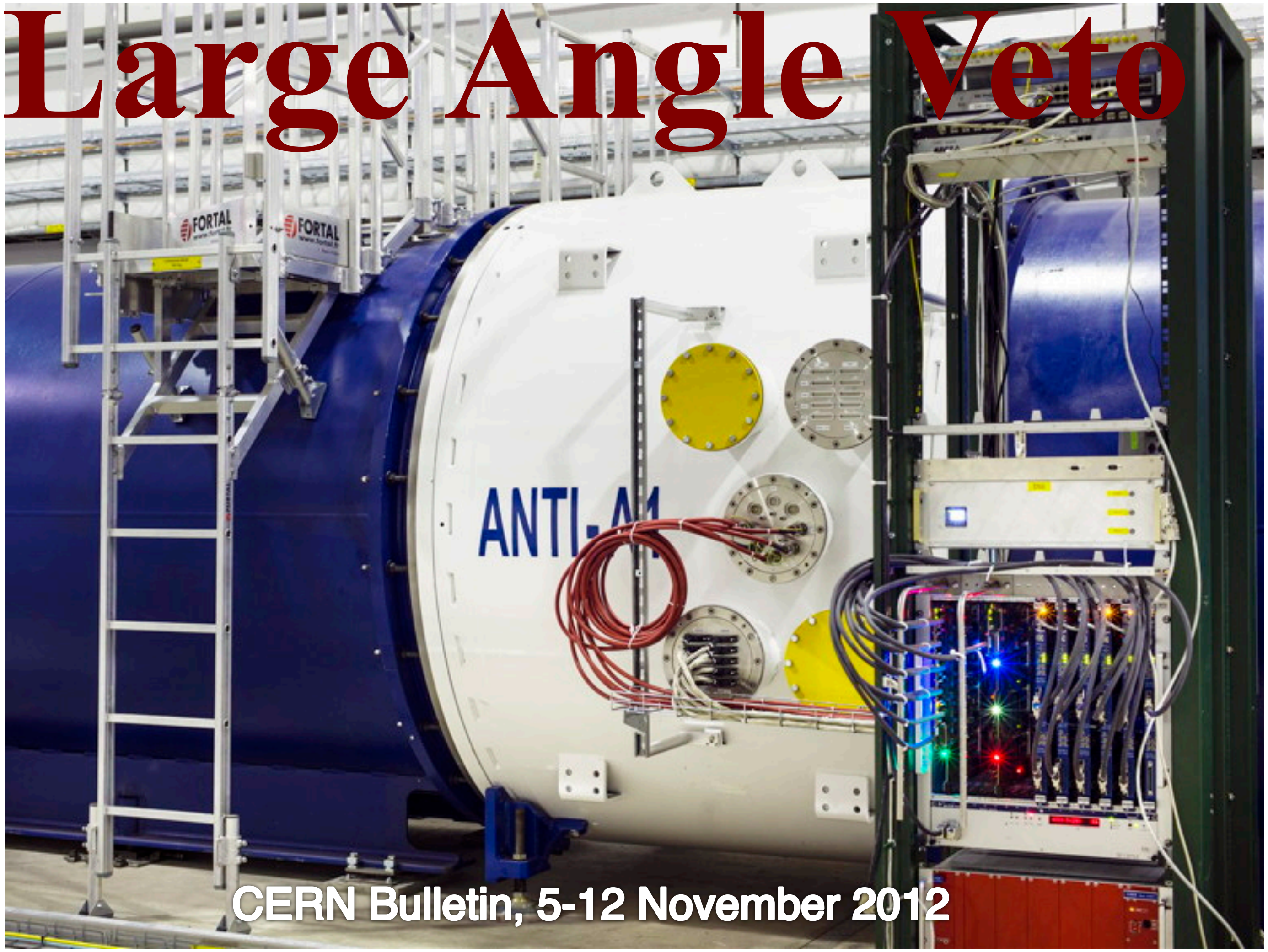
Conclusion

- Acquired data with different thresholds (more than 100k events for each configuration) both in standalone acq and in common acq
- Acquired data different V_{bias} (nominal V_{bias} ± 250 mv and 500 mv)
- Tested the detector operation and response in vacuum
- Good response from the prototype board
- We have to analyse data collected using both the acquisitions

Construction status

- Bars for three station have been already tested
- CHANTI Vessel design ready
- As soon as possible there will be a meeting in Frascati in order to discuss of the CHANTI board finalization

Large Angle Veto

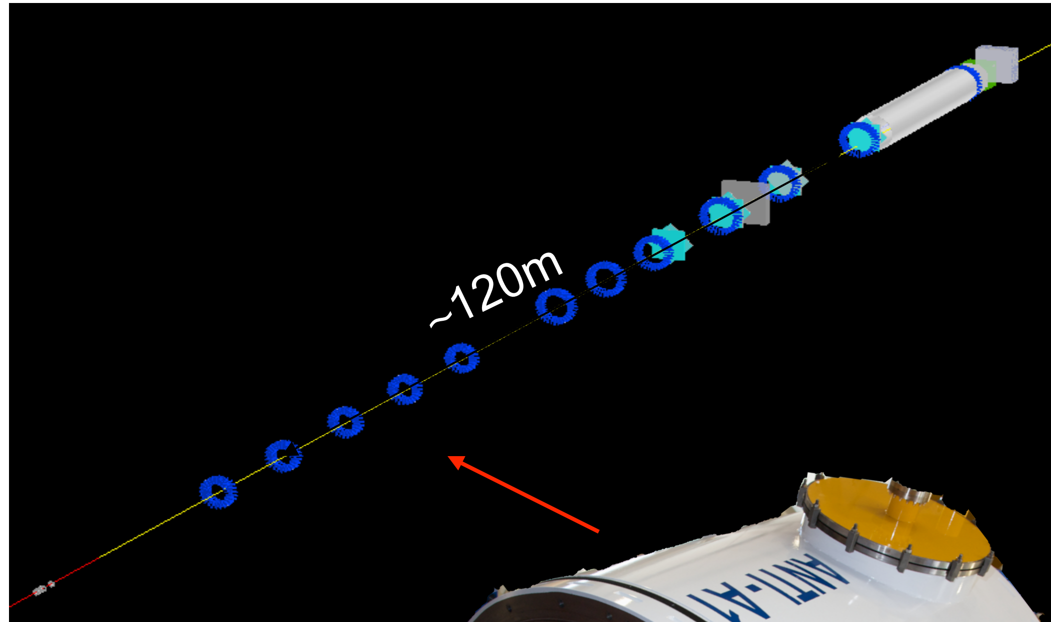


CERN Bulletin, 5-12 November 2012

Large Angle Veto (I)

12 rings to cover the large angle photons requirements:

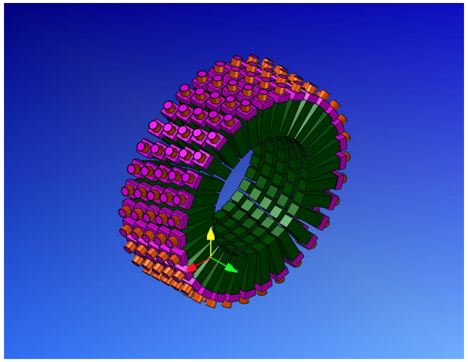
- Inner-outer radii: 60-96 to 90-140 cm
- Almost hermetic
- Large area: ~30 m^2
- Good efficiency down to "low" energy (200 MeV) photons
- Operating in vacuum

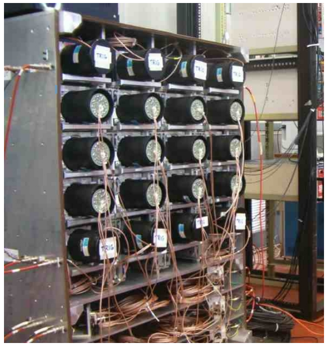


Large Angle Veto (II)

3606 blocks available (thanks to Tokyo-OPAL coll.)
2946 needed for the 12 stations
each station has 4/5 layer with a relative phase

All the blocks have to be polished, tested, re-cabled, reinforced and wrapped again
Gain and PeY are measured by LED and Cosmic





Nine stations assembled at LNF and arrived to CERN for the installation in the vacuum tube

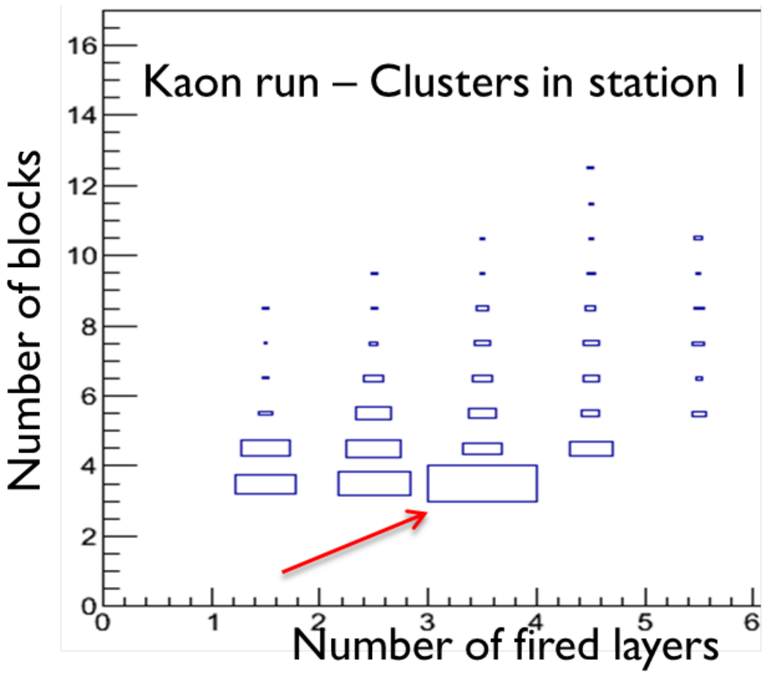
Large Angle Veto (pictures)

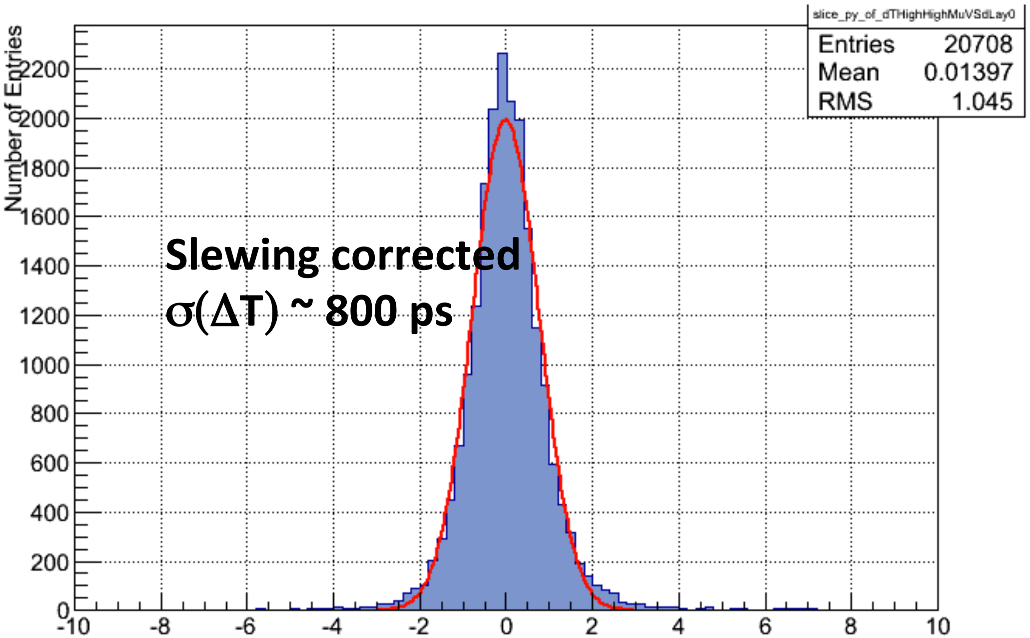
Summary: Where we stand

A1-A3	Installed, cabled, read-out in technical run
A4-A8	Installed, ready for cabling
A11	At CERN, ready to install
A9 & A10	Vessels under construction at Fantini Bananas under construction at Frascati

LAV: Technical Run

- A lot of statistics for LAV1&2 (less for LAV3)
- Dedicated muon runs
- Several studies on the "noise" (low and high beam intensity)
- Time alignment, time resolution, occupancy, correlation



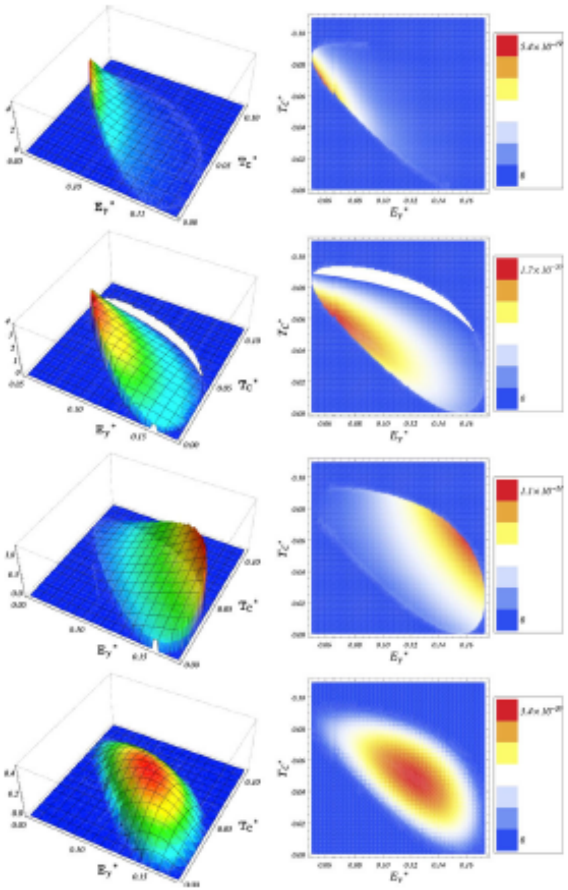


Kaon decays @NA62

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}e^{+}e^{-}$ theory

$$\frac{d^3\Gamma}{dE_\gamma^* dT_c dq^2} = \frac{d^3\Gamma_{IB}}{dE_\gamma^* dT_c dq^2} + \frac{d^3\Gamma_{E}}{dE_\gamma^* dT_c dq^2} + \frac{d^3\Gamma_{M}}{dE_\gamma^* dT_c dq^2} + \frac{d^3\Gamma_{int}}{dE_\gamma^* dT_c dq^2}$$

The interference thanks to the possibility of measuring the plane of polarization of the e+e- pair is splitted into 3 terms:
IB/E, IB/M and E/B.
Where IB/M cancels when integrated over ϕ as in $\pi\pi\gamma$, while E/B is only non-zero if CP violation is allowed.

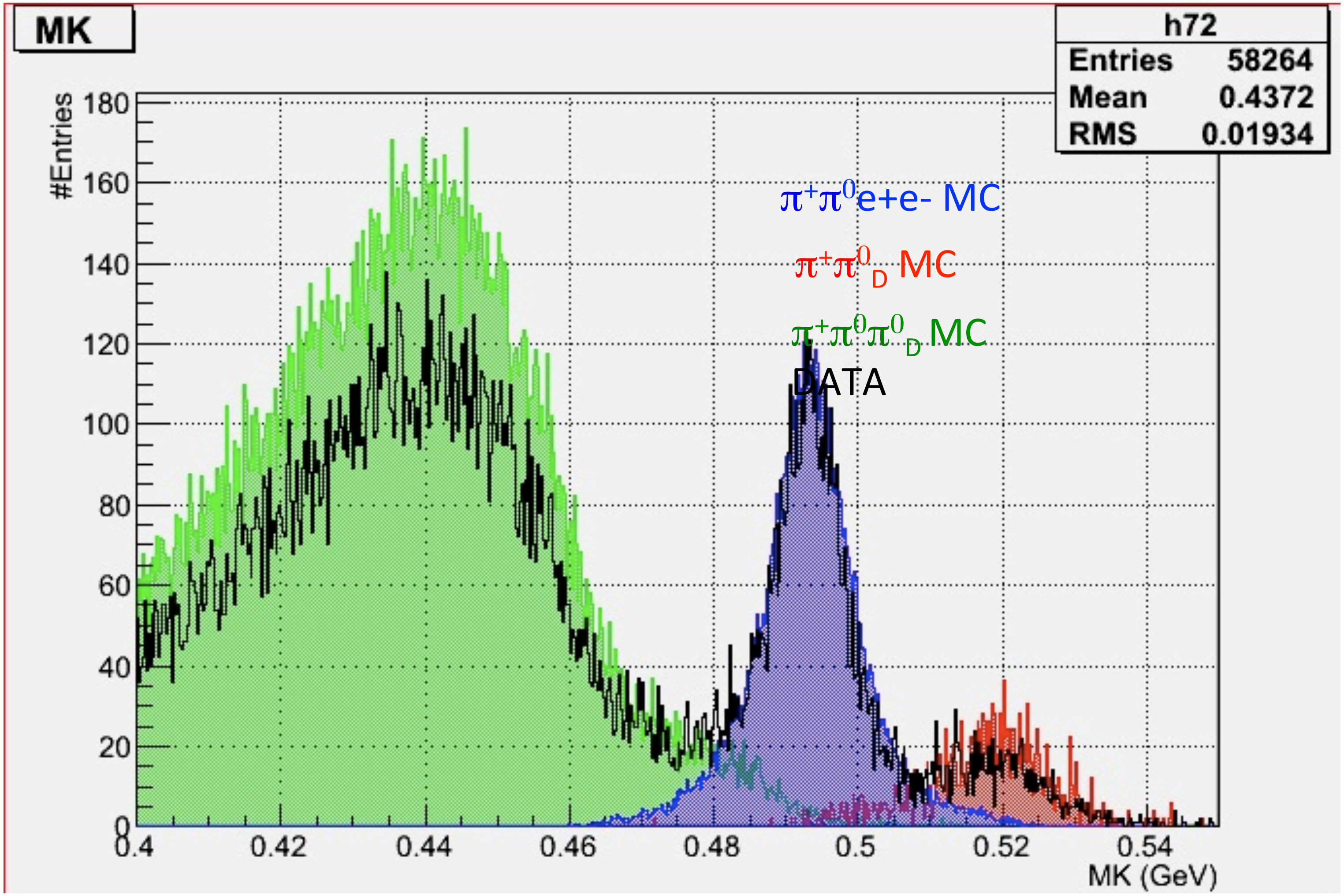


The generator implemented is based on:

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}e^{+}e^{-}$: a novel short-distance probe.
L. Cappiello, O. Cata, G. D'Ambrosio, Dao-Neng Gao Dec 2011. 25 pp.
Published in Eur.Phys.J. C72 (2012) 1872

NA48: Signal and BG estimate puzzle

Both BG normalized to the KAON flux.
Overestimating 3 π_D BG ~25% this way

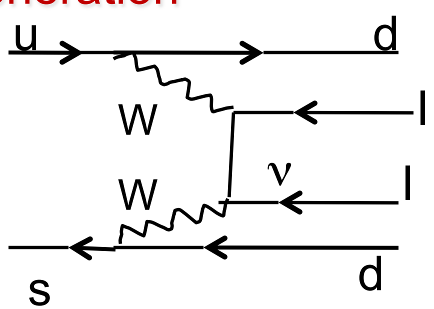


Forbiddens list

Process	Violates	90% C.L. limit	Experiment
$K^+ \to \pi^+ \mu^+ e^-$	LF	$< 1.3 \times 10^{-11}$	E865
$K^+ \to \pi^+ \mu^- e^+$	LF	$< 5.2 \times 10^{-10}$	E865
$K^+ \to \pi^- \mu^+ e^+$	LF , LN	$< 5.0 \times 10^{-10}$	E865
$K^+ \to \pi^- \mu^+ \mu^+$	LN	$< 3.0 \times 10^{-9}$	E865
$K^+ \to \pi^- e^+ e^+$	LN	$< 6.4 \times 10^{-10}$	E865
$K^+ \to \pi^+ \gamma$	H	$< 2.3 \times 10^{-9}$	E949
$\pi^0 \to \mu^- e^+$	LF	$< 3.4 \times 10^{-9}$	E865
$\pi^0 \to \mu^+ e^-$	LF	$< 3.8 \times 10^{-10}$	E865
$\pi^+ \to \mu^- e^+ e^+ \nu$	LF	$<1.6 \times 10^{-6}$	JINR-SPEC

$K^+ \to \pi^- \mu^+ \mu^+$, $K^+ \to \pi^- e^+ e^+$, $K^+ \to e^+ \mu^\pm \pi^\pm$: status

- These decays violate LF and the generation number conservation
- The $K \to \pi^- l^+ l^+$ can proceed through the same double beta decay mechanism
- The $K \to \pi^- \mu^+ \mu^+$ is an unique opportunity to study the effects of Majorana neutrinos in second generation



decay	Accept.
$e^+ e^+ \pi^-$	1.54%
$\pi^+ \mu^- e^+$	1.9%
$\pi^- \mu^+ e^+$	1.97%
$\mu^+ \mu^+ \pi^-$	0.71%

$K \to \pi^- \mu^+ \mu^+$: Acceptance smaller (~ 3) with respect to $K \to \pi^+ \mu^+ \mu^-$
Background from $K \to \pi^- \pi^+ \pi^+$ with π decay in the spectrometer
5 events with 5.3 expected bkg
$BR(K \to \pi^- \mu^+ \mu^+) < 3.0 \cdot 10^{-9}$
Flux (3π): 10^8

$K^+ \to e^+ \mu^\pm \pi^\pm$: small background from Ke4 e 3π with mis-id. No events candidates with 0 bkg expected
$BR(K \to e^+ \pi^+ \mu^-) < 5.2 \cdot 10^{-10}$
$BR(K \to e^+ \pi^- \mu^+) < 5.0 \cdot 10^{-10}$
Flux (Ke4): $3.8 \cdot 10^8$

$K^+ \to \pi^- e^+ e^+$: small background from Ke4 e 3π with mis-id. No events candidates with 0 Bkg expected.
$BR(K \to \pi^- e^+ e^+) < 6.4 \cdot 10^{-10}$
Flux (Ke4): $3.8 \cdot 10^8$

[Appel, Phys.Rev.Lett.85:2877-2880,2000]

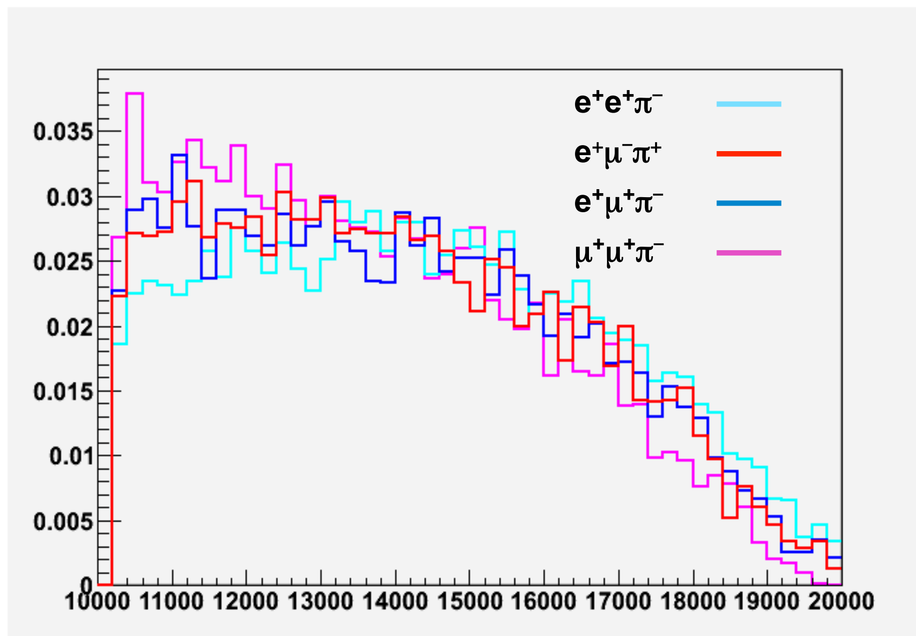
… @ NA62

decay	Accept.
$e^+e^+\pi^-$	17.5%
$\pi^+\mu^-e^+$	16.8%
$\pi^-\mu^+e^+$	17.9%
$\mu^+\mu^+\pi^-$	18.8%

Assuming 10^{13} decays in 2 years, and 0 events found with 0 events bkg expected:
BR(all the modes) < $1.3\cdot10^{-12}$

Assuming 100% trigger efficiency higher improvement with respect to the $\pi^+\mu^-e^+$ (because E865 used secondary triggers (Ke4, $\pi^+\mu^+\mu_-$) to evaluate the BR)

$5\cdot10^5$ Kaon decay produced with Flyo Montecarlo (only phase space)



Some of the interesting π^0 decays

One year of data taking corresponds to 1.3×10^{11} π^0's from $K\to\pi\pi^0$

[Assume 50-MHz K beam flux, 10% of K's decaying in fiducial volume, 200 bursts/hour, duty cycle of 4.8 s/16.8 s, 50% acceptance for the trigger conditions of $K\to\pi\pi^0$, $\pi^0\to x$]

This intense π^0 "tagged beam" should allow improvements on many channels

Here, focus on neutrals:

- A search for the C-violating $\pi^0 \to 3\gamma$ decay

  C-violating decay, forbidden in SM: BR ~ $10^{-31\pm6}$ [Dicus, Phys Rev D 12 (1975) 2133]

  Present limit: BR < 3.1×10^{-8} @ 90% CL
- A first measurement/observation of $\pi^0 \to 4\gamma$

  SM expectation: BR = $(2.6\pm0.1)\times10^{-11}$ due to light-by-light QED contribution

  [Schult and Young, Phys Rev. D 6, 1988 (1972), Bratkovskaya, et al., hep-ph/9506310]

  Present limit: BR < 2 10^{-8} @ 90% CL
- Improving the limit on the transition rate for $\pi^0 \to$ invisible

  Present direct experimental limit Br($\pi^0\to\nu\nu$) < 2.7×10^{-7} (E949, 2005)

Conclusions

- The 0(100) events measurement of the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay could be a good opportunity to found NP and to distinguish among NP models

- The NA62 is a challenging experiments aiming at O(100) events with S/B=10

- In the technical run very good response from all the detectors installed!!!!

- The data taking should start in the 2014

NA62-I

R_K with Kl2 decays published in **Phys.Lett.B698 :105-114,2011**

The first NA62 Physics paper !

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PH-EP-2011-004
21 January 2011

Test of Lepton Flavour Universality in $K^+ \to \ell^+\nu$ Decays

The NA62 collaboration *

Abstract

A precision test of lepton flavour universality has been performed by measuring the ratio R_K of kaon leptonic decay rates $K^+ \to e^+\nu$ and $K^+ \to \mu^+\nu$ in a sample of 59813 reconstructed $K^+ \to e^+\nu$ candidates with $(8.71 \pm 0.24)\%$ background contamination. The result $R_K = (2.487 \pm 0.013) \times 10^{-5}$ is in agreement with the Standard Model expectation.

Submitted for publication in Physics Letters B

Ke2: R_K and LFV

- The hadronic uncertainties cancel in the ratio $K_{e2}/K_{\mu 2}$ (no f_K)
- For this reason the SM prediction is very accurate $dR_K/R_K \sim 0.04\%$

$$R_K^{SM} = \frac{\Gamma(K \to e\nu_e)}{\Gamma(K \to \mu\nu_\mu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) =$$

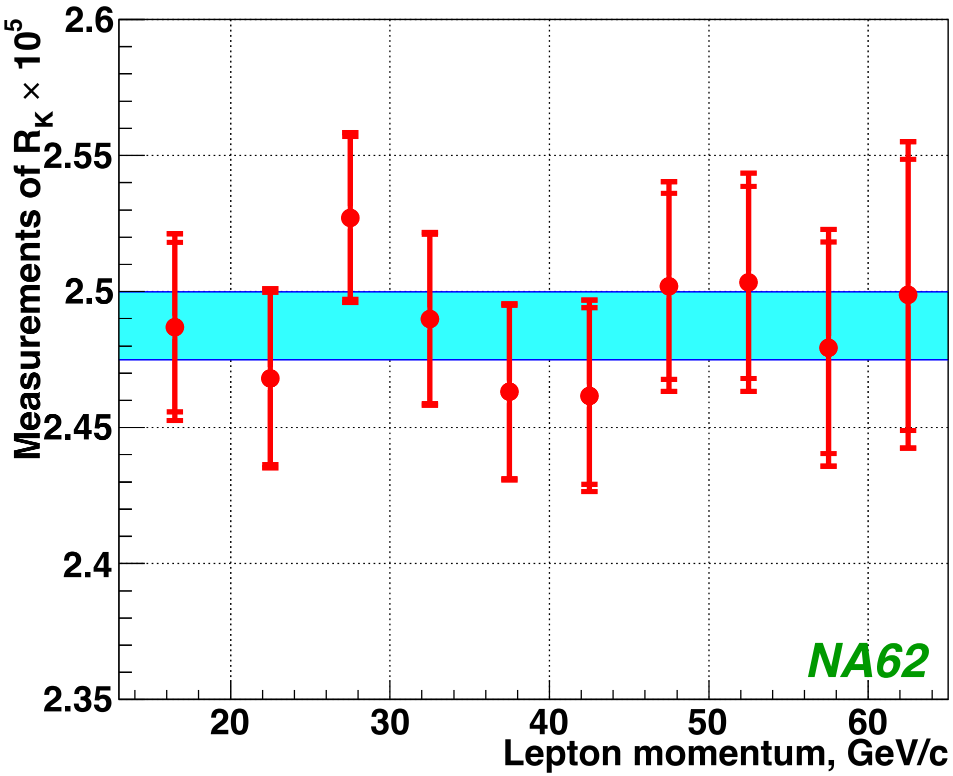
$= (2.477 \pm 0.001) \cdot 10^{-5}$

[V.Cirigliano, I.Rosell JHEP 0710:005(2007)]

- The only difference between electron and muon channel is due to the V-A coupling
- A small correction has to be included due to the IB part of the radiative decay

R_K Result (40% data set)

$$R_K = (2.487 \pm 0.011_{stat} \pm 0.008_{syst}) \times 10^{-5}$$
$$= (2.487 \pm 0.013) \times 10^{-5})$$



Source	$\delta R_K \times 10^5$
Statistical	0.011
$K_{\mu 2}$ background	0.005
$K^+ \to e^+\nu\gamma$ (SD$^+$) background	0.001
$K^+ \to \pi^0 e^+ \nu$, $K^+ \to \pi^+\pi^0$ backgrounds	0.001
Beam halo background	0.001
Helium purity	0.003
Acceptance correction	0.002
Spectrometer alignment	0.001
Positron identification efficiency	0.001
1-track trigger efficiency	0.002
LKr readout inefficiency	0.001
Total systematic	0.007
Total	0.013

Precision 0.52%

The whole sample will decrease the statistical uncertainty down to ~0.3% and a total uncertainty of 0.4%

$K^+ \rightarrow \pi^+ \nu\bar{\nu}$: motivation (II)

1) Short distance contributions (Wilson coefficients i.e. perturbative QCD) are dominant (hard GIM mechanism): $A_q \sim (m_q)^2/(m_W)^2 \mathbf{V_{qs} V_{qd}}$

top quark is dominant, smaller contribution from charm negligible from up

2) The hadronic matrix element (LD) uncertainty benefits from the Isospin symmetry and well measured semileptonic $K^+ \rightarrow \pi^0 e^+ \nu_e$ decays:

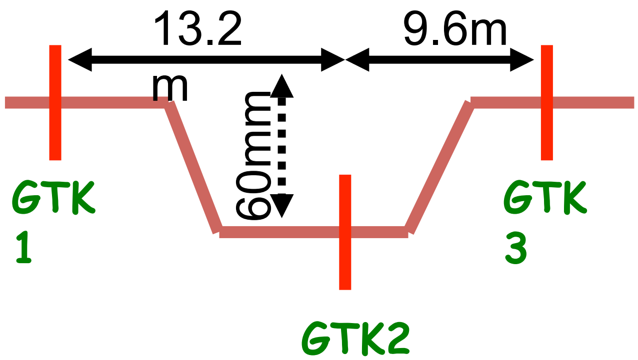
$$\left| \frac{\langle \pi^+ \nu\bar{\nu} | H_w | K^+ \rangle}{\langle \pi^0 e^+ \nu_e | H_w | K^+ \rangle} \right|^2 = \left| \frac{\langle \pi^+ | H_w | K^+ \rangle}{\langle \pi^0 | H_w | K^+ \rangle} \right|^2 = 2r_+$$

$$BR(K^+ \rightarrow \pi^+ \bar{\nu}\nu) = 6r_{K^+} BR(K^+ \rightarrow \pi^0 e^+ \nu) \frac{|G_l|^2}{G_F^2 |V_{us}|^2}$$

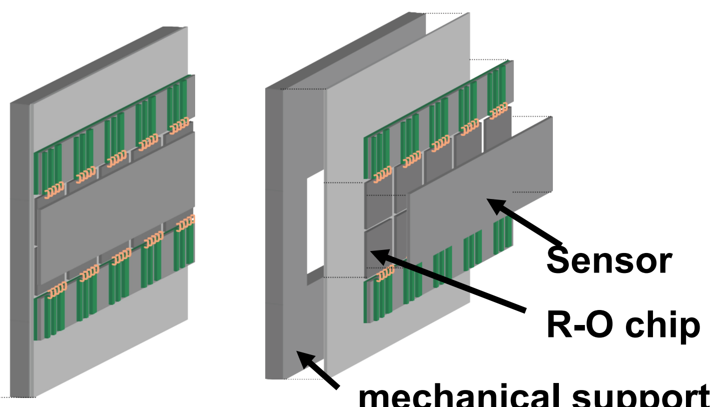
$$G_l = \frac{\alpha G_F}{2\pi \sin^2 \Theta_W} \left[V_{ts}^* V_{td} X(x_t) + V_{cs}^* V_{cd} X_{NL}^l \right]$$

Effective coupling constant

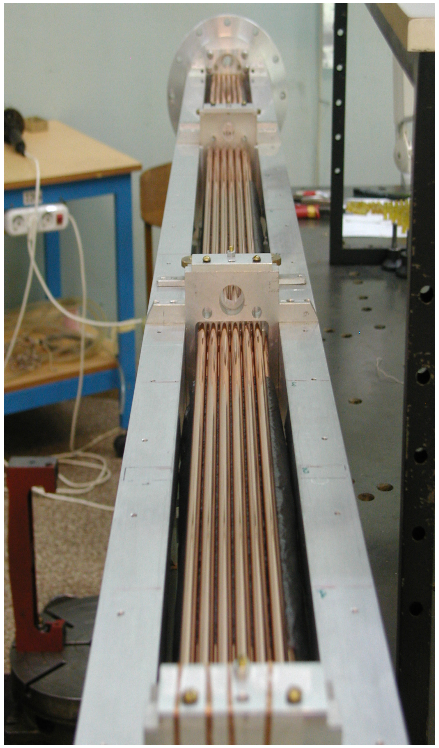
NA62: Gigatracker and Straw tracker



- Very thin silicon sensor and readout chip (200+100 μm ~ $0.5X_0$)
- On site bump bonded readout chip 0.13 μm CMOS tech
- 60x27 mm^2 per station
- 300μmx300μm pixels



- 4 views with staggered planes
- Straw tubes in alluminium ultrasonic welded
- measured resolution: 130μm per hit

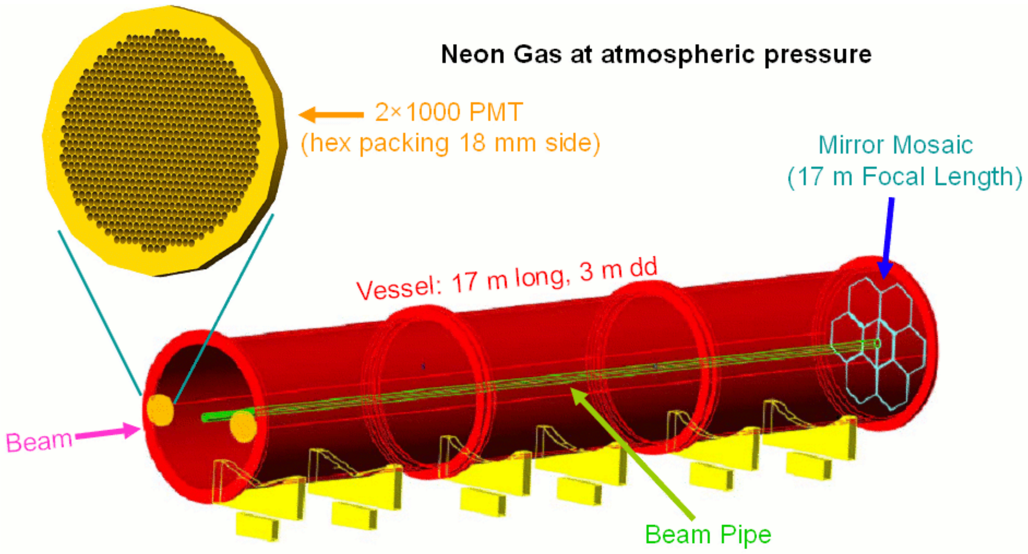


- Prototypes tested on vacuum with hadronic beam, muons and electrons
- Detector in construction
- Tested in November Technical Run

NA62: Rich

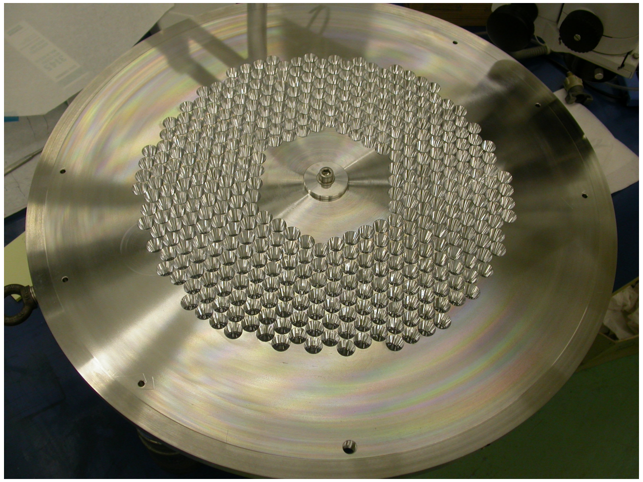
Requests:

- Provide π/μ separation at 5×10^{-3} in the range $15<p<35$ GeV/c
- Measure track time with 100 ps res
- Provide the main trigger for charged particle



Solution:

- **18 m** long tube filled with Neon
- Mirrors with **f=17 m**
- **2000 single anode PMTs**, 1 cm in diameter
- 18mm "pixel" with **Winston cones**



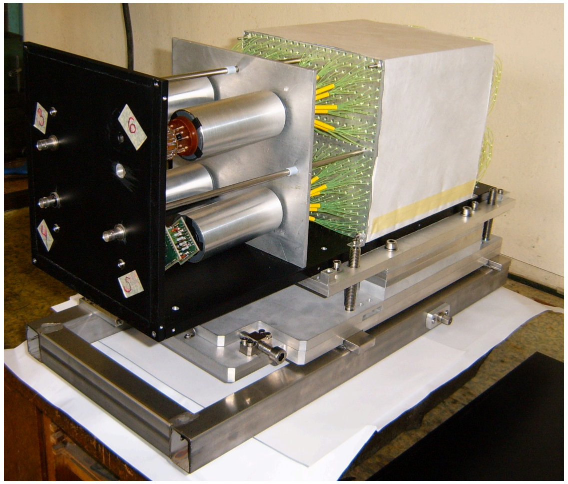
The Photon Veto System

To obtain the required rejection factor on **$K^+ \to \pi^+\pi^0$** a photon detectors system with **10^8 rejection factor on $\pi^0 \to \gamma\gamma$ is required**

Three different angular regions to be covered

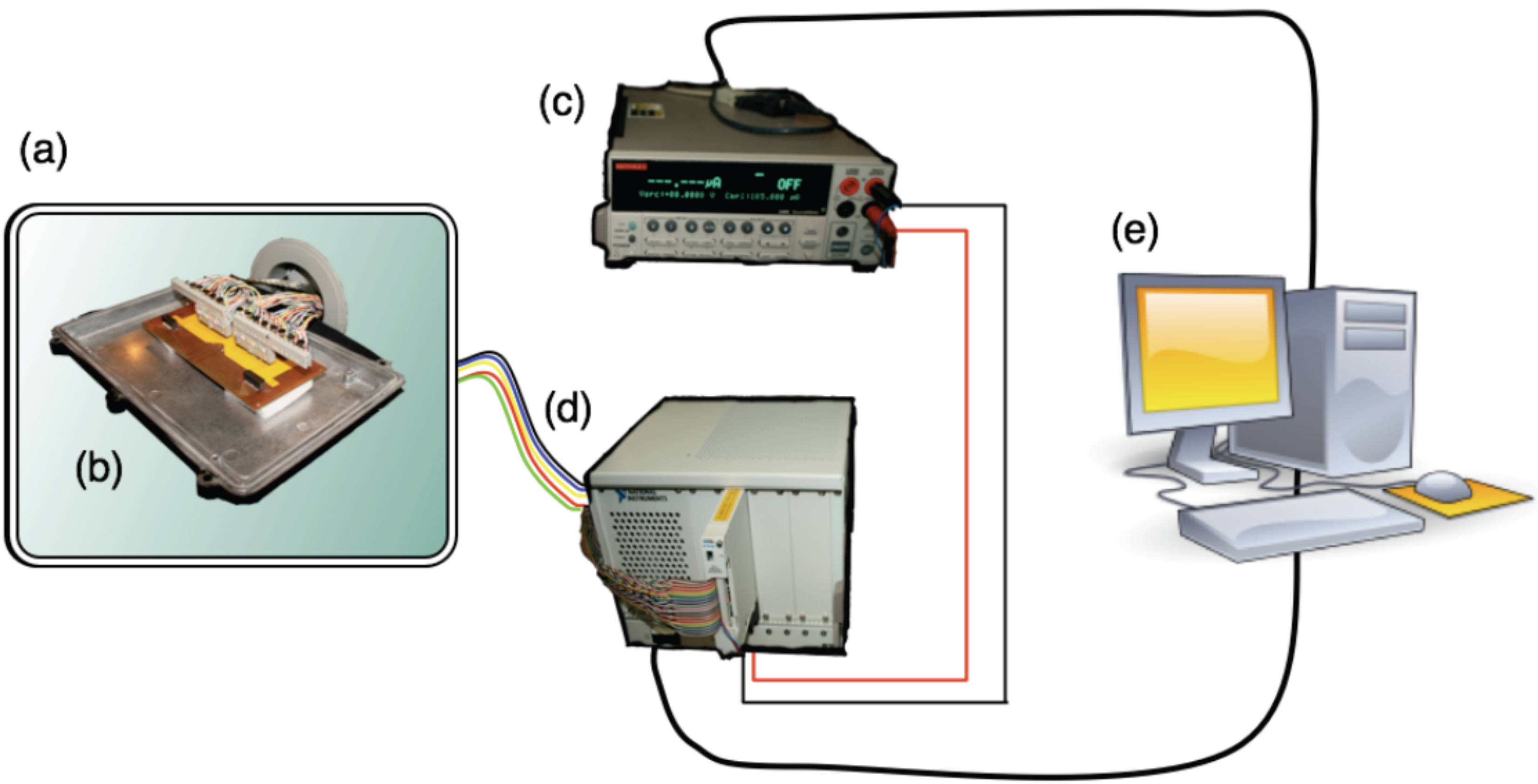
- LAV: Large Angle Veto: (10:50 mrad)
- LKr: Liquid Kripton calorimeter (1:10 mrad)
- IRC and SAC <1mrad

requiring $P(\pi^+) < 35$ GeV/c we get $P(\pi^0) > 40$GeV/c and high energy photons: photons > 1 GeV hit the LKr → high detection efficiency



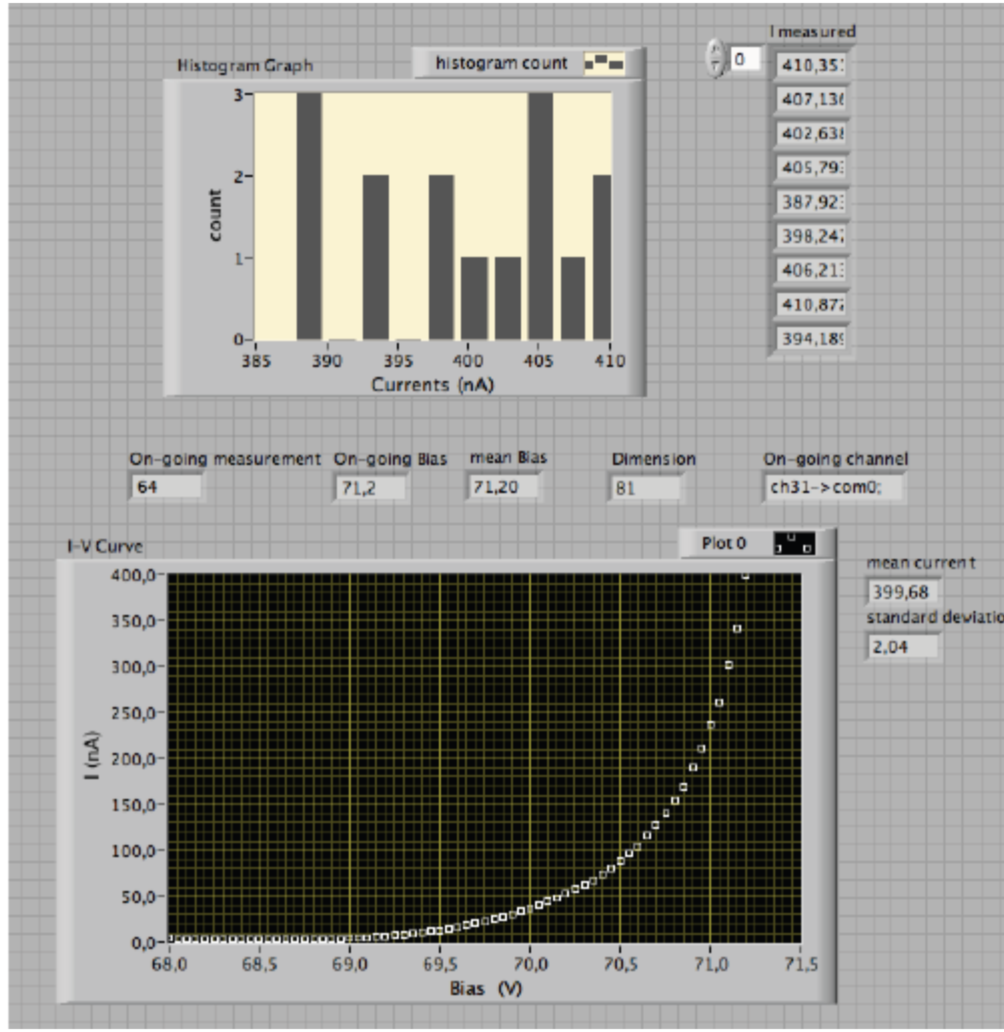
The SiPM test station

- Up to 32 sensors can be tested simultaneously
- Temperature stable and controlled within 0.1°C
- Voltage stability O(10mV), currents measured better than 1nA



Measurements

- At fixed temperature I-V curve approximatively described by relation
  $$I_{dc} = \alpha \left(V_{bias} - V_{bd}\right)^2$$
- Used to extract Vbd for each sensor with an automatic fit procedure in LabView
- Since gain depends linearly on Vbias-Vbd the info at Vop can be extrapolated at any Vbias after Vbd is known



Temperature dependence