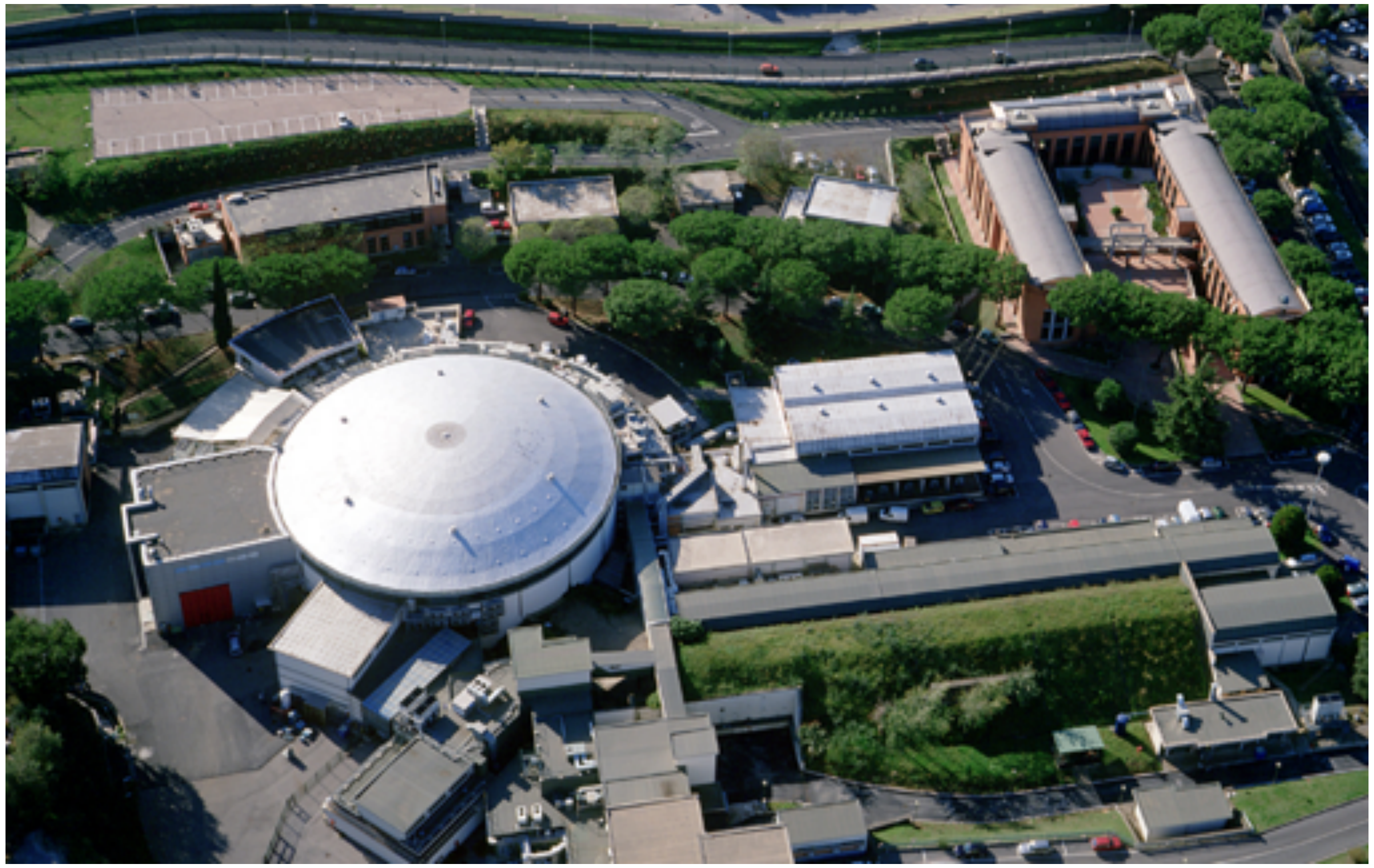
50th meeting of the LNF Scientific Committee



INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

NA62 status and activities

CERN

Silvia Martellotti

Frascati 2015, November 23rd

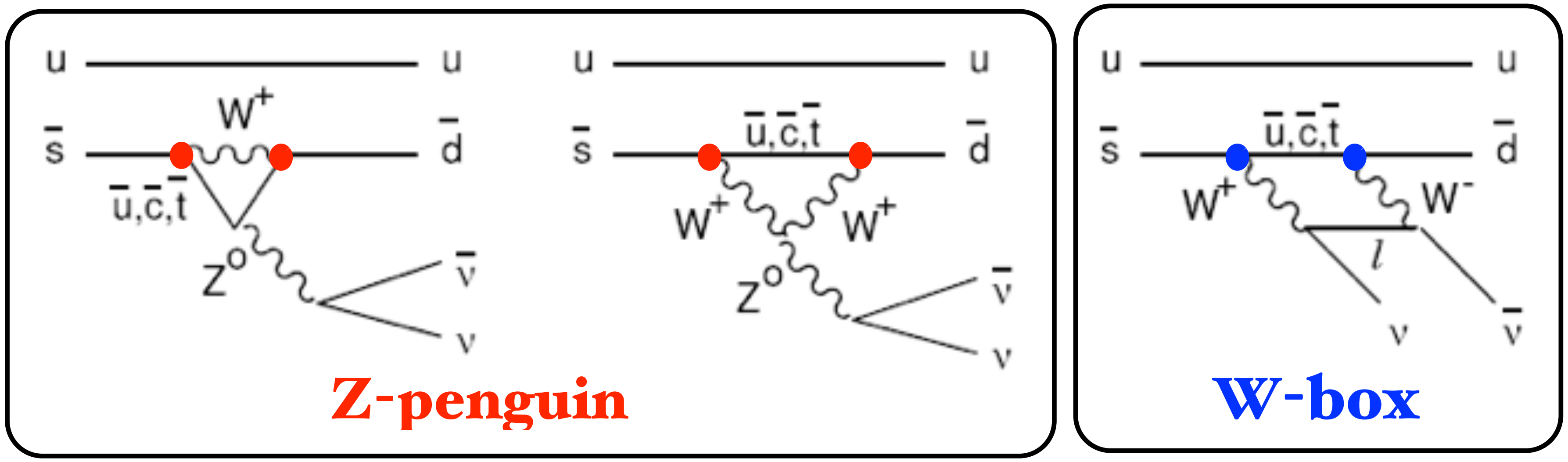
P326 NA62

Outline

- Theoretical introduction to the $K^+ \to \pi^+\bar{\nu}\nu$ rare decay
- NA62 experiment aim and strategy
- Frascati group responsibilities
- Photon Veto detectors
- Detector efficiency and performance after commissioning Run
- Trigger study
- Data Analysis
- Parallel projects

SM theoretical framework

The **$K^+ \to \pi^+\nu\bar{\nu}$** decay is extremely suppressed and is characterized by a theoretical cleanness in the SM prediction of the BR($K^+ \to \pi^+\nu\bar{\nu}$)



Flavor-changing neutral current quark transition $s \to d\nu\nu$.

Forbidden at tree-level, dominated by short-distance dynamics (GIM mechanism)

SM prediction takes in to account:

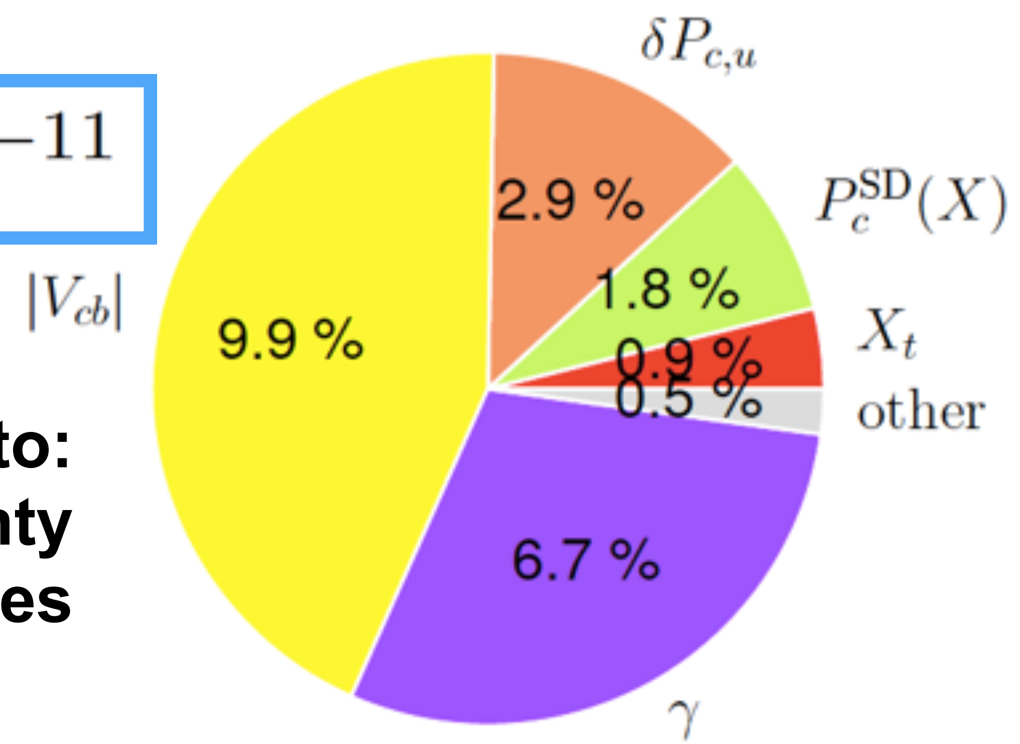
- 1-loop contributions at the leading order.
- NLO QCD corrections to the top quark contributions
- NLO electroweak corrections to both top and charm contributions
- NNLO QCD corrections to the charm contributions
- isospin breaking and non-perturbative effects

Stringent test of the SM and possible **evidence for New Physics**, complementary to LHC

Past measurement and prediction

Current theoretical prediction [1]

$$\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu}) = (9.11 \pm 0.72) \times 10^{-11}$$



8% error due to:
- input parameters uncertainty
- intrinsic theoretical uncertainties

Experimental status: most precise results have been obtained by E787 and E949 experiments at BNL by studying stopped kaon decays [2]:

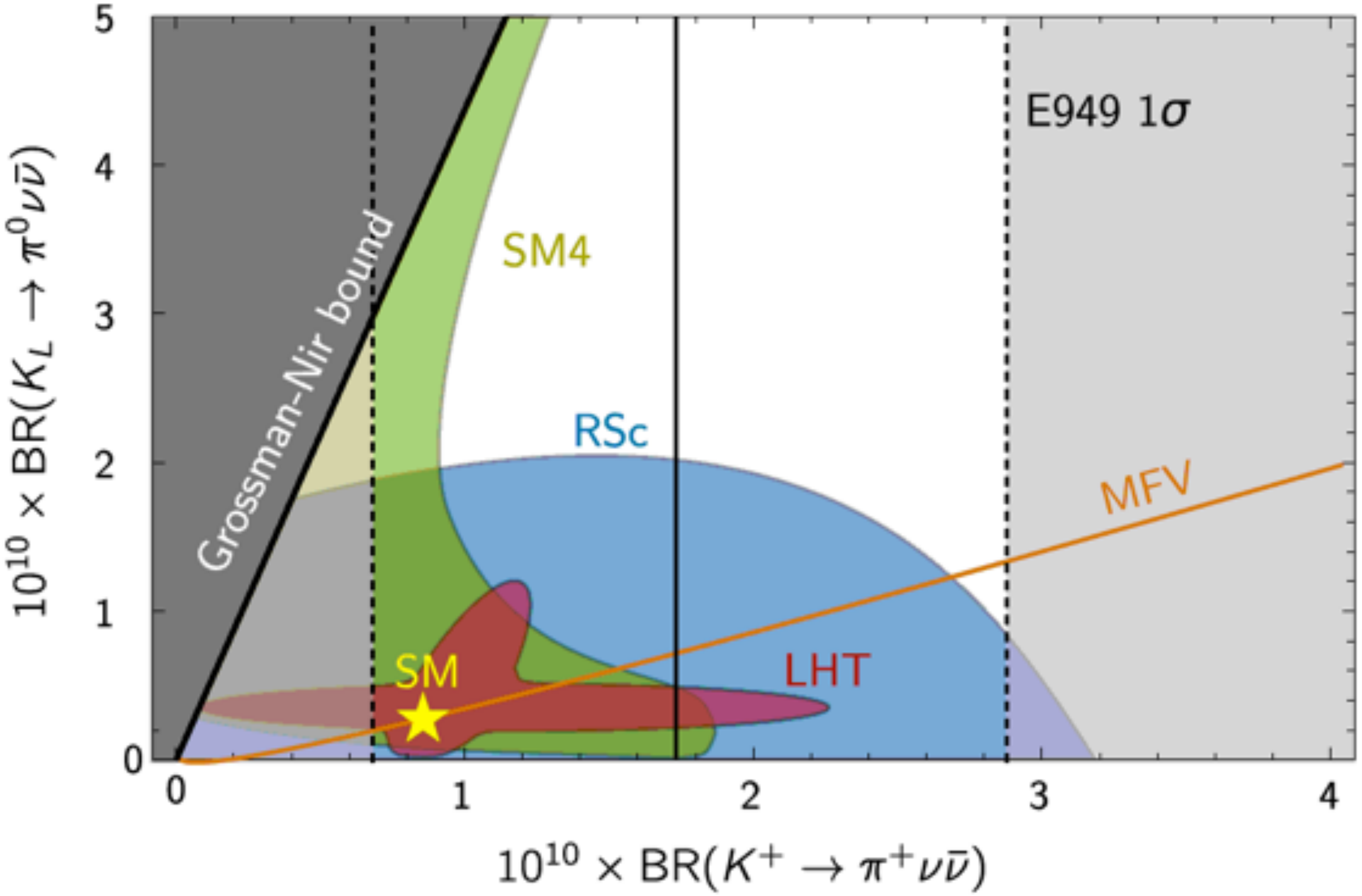
$$BR(K^+ \to \pi^+ \nu \bar{\nu})_{exp} = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$

Gap between theoretical precision and large experimental error motivates a strong experimental effort. Significant new constraints can be obtained with a measurement of the BR at the level of 10% or better

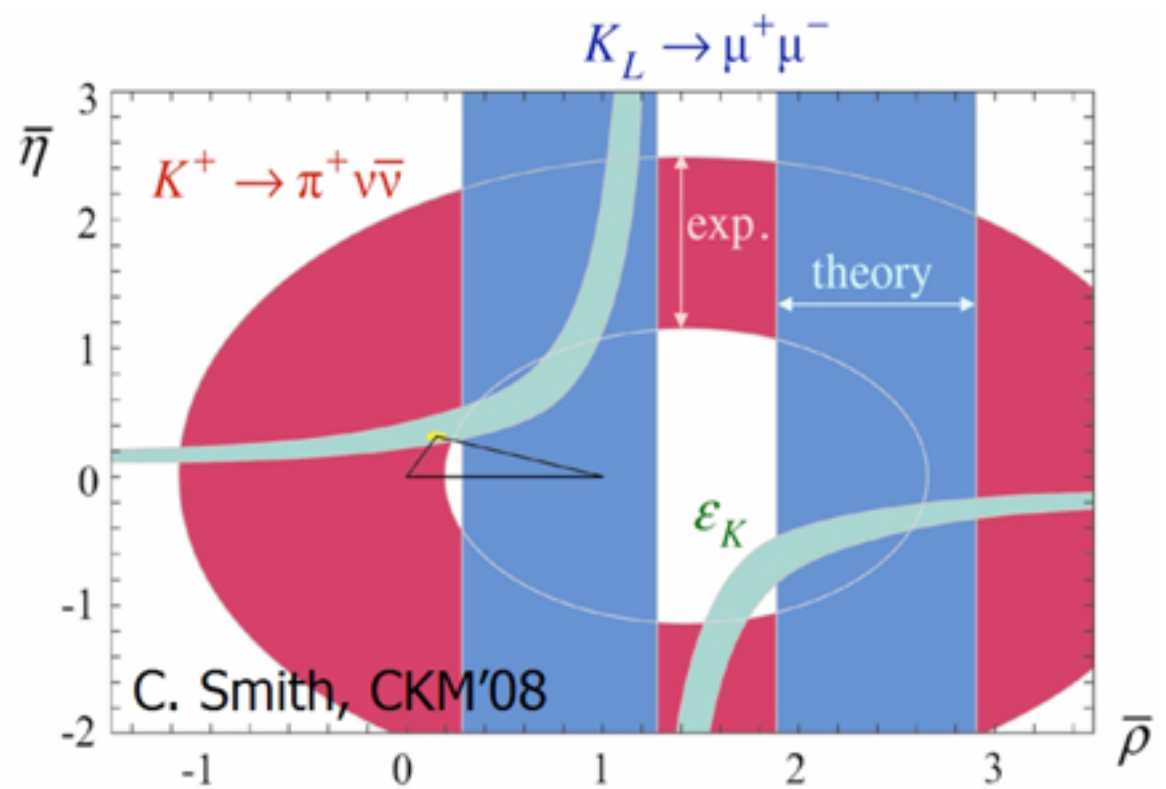
[1] *A. J. Buras et al. arXiv:1503.02693v1, 2015.*
[2] *E949 COLLABORATION. Phys. Rev. Lett. 101 191802, 2008.*

New Physics from K→πνν decays

Measurement of BR of charged ($K^+ \to \pi^+\nu\nu$) and neutral ($K_L \to \pi^0\nu\nu$) modes can discriminate different NP scenarios



SM4:
SM with 4th generation
RSc:
Randall Sundrum mechanism
LHT:
Littlest Higgs with T-parity
MFV:
Minimal Flavor Violation



Measurement of $|V_{td}|$ complementary to those from B-$\bar{B}$ mixing

δ(BR)/BR = 10% would lead to
δ($|V_{td}|$)/$|V_{td}|$ = 7%

Experimental requirements

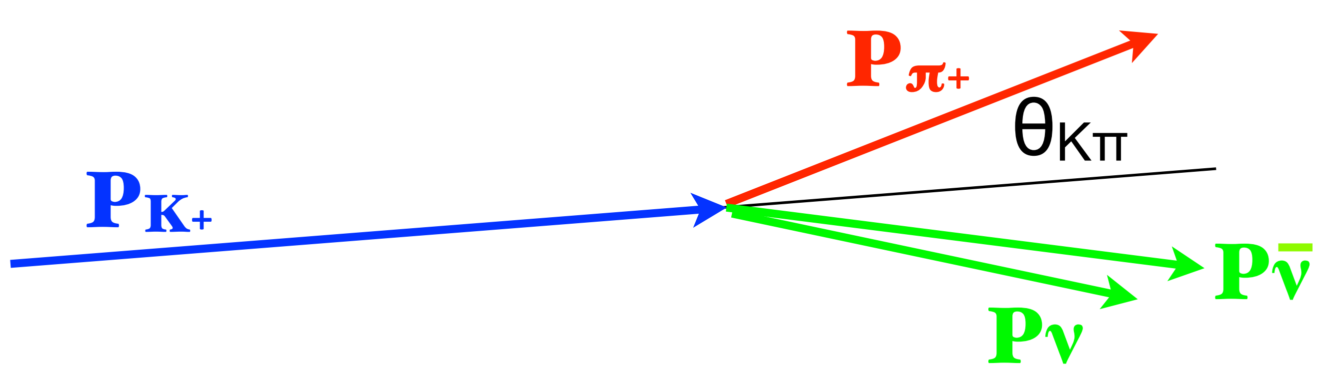
GOAL: measure BR($K^+ \to \pi^+\nu\bar{\nu}$) with 10% accuracy

O(100) SM events + systematics control at % level

- Assuming a 10% signal acceptance and a BR($K^+ \to \pi^+\nu\nu$) ~10^{-10} at least 10^{13} K^+ decays are required
- Required a rejection factor for dominant kaon decays of the order of 10^{12} (to have less than 20% of background)

NA62 design criteria: **kaon intensity, signal acceptance, background suppression**

Decay in flight technique, Kaon with high momentum

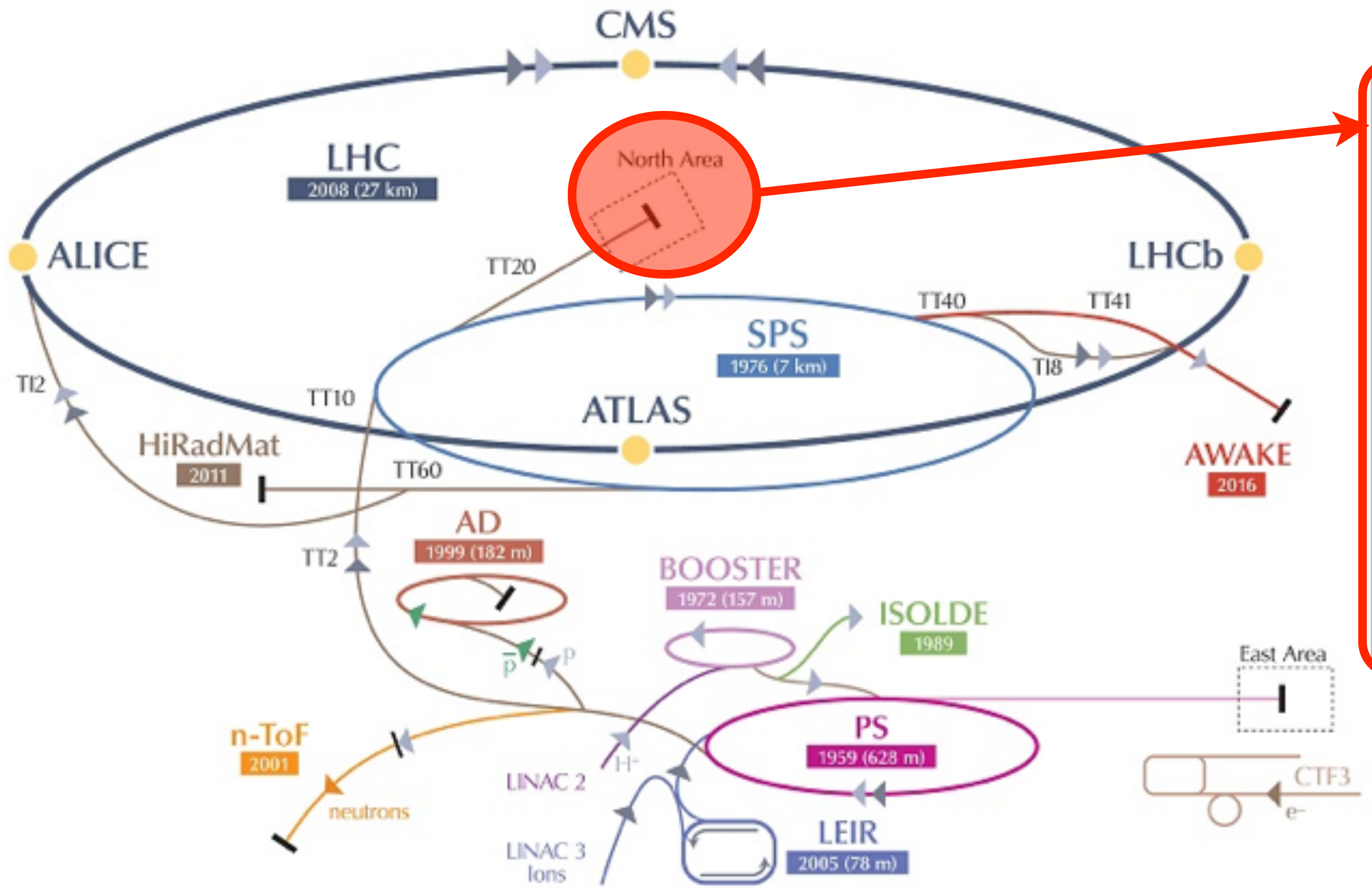


Signal signature:
one K^+ track & one π^+ track

Basic ingredients:
precise timing, kinematics cuts & hermetic photon vetoes

Kaon at the CERN - SPS

An evolution of the NA48 beam line at the **CERN-SPS** can deliver the required K^+ intensity



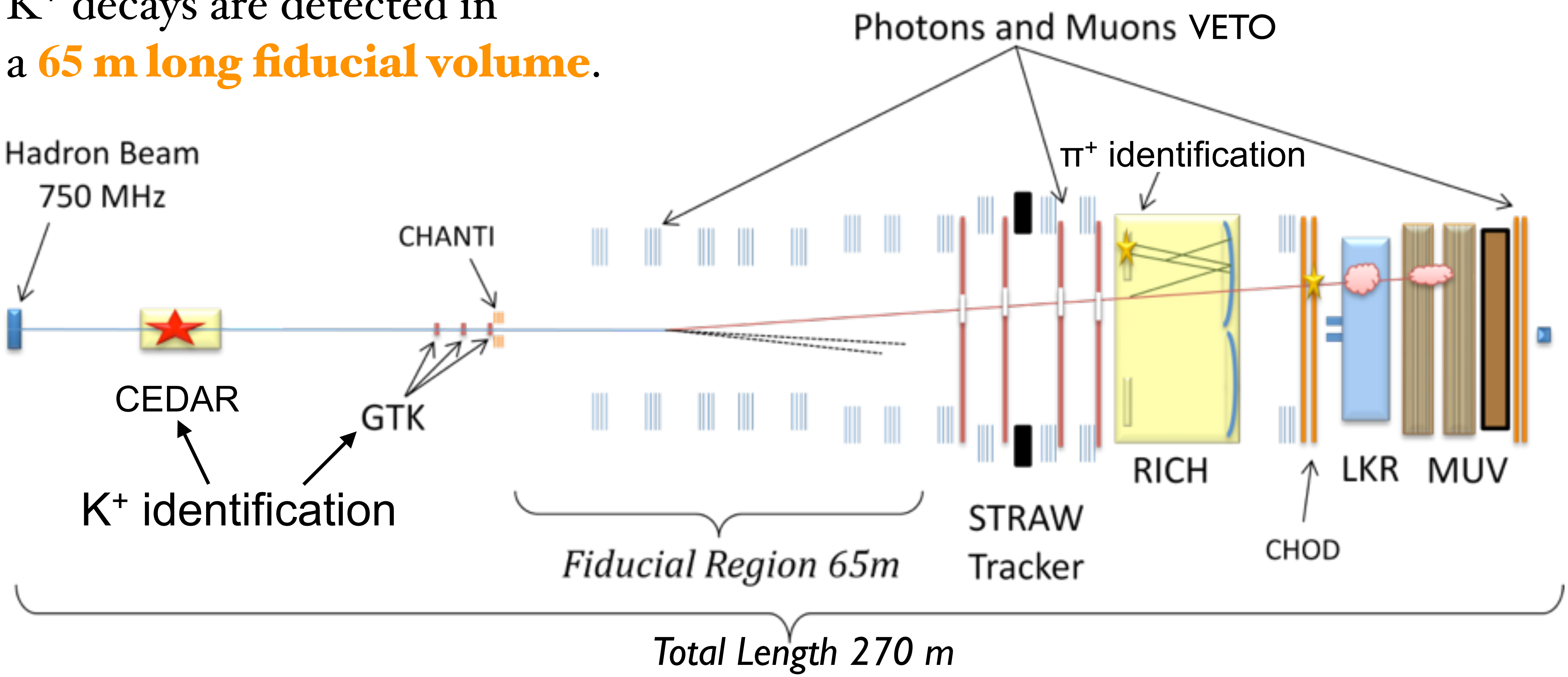
The NA62 is housed in the CERN North Area. A new beam line provides a secondary beam of charged hadrons 50 times more intense than in the past, with only 30% more SPS protons on target

we expect to run for 3 more years

Protons from the SPS at 400 GeV/c impinge on a beryllium target and produce a secondary charged beam. 6% are K^+ (mixed with π^+ and protons).
Signal acceptance considerations determined the choice of a **75 GeV/c K^+** with a 1% momentum bite and a divergence ~ 100 μrad (in x and y)

NA62 Apparatus

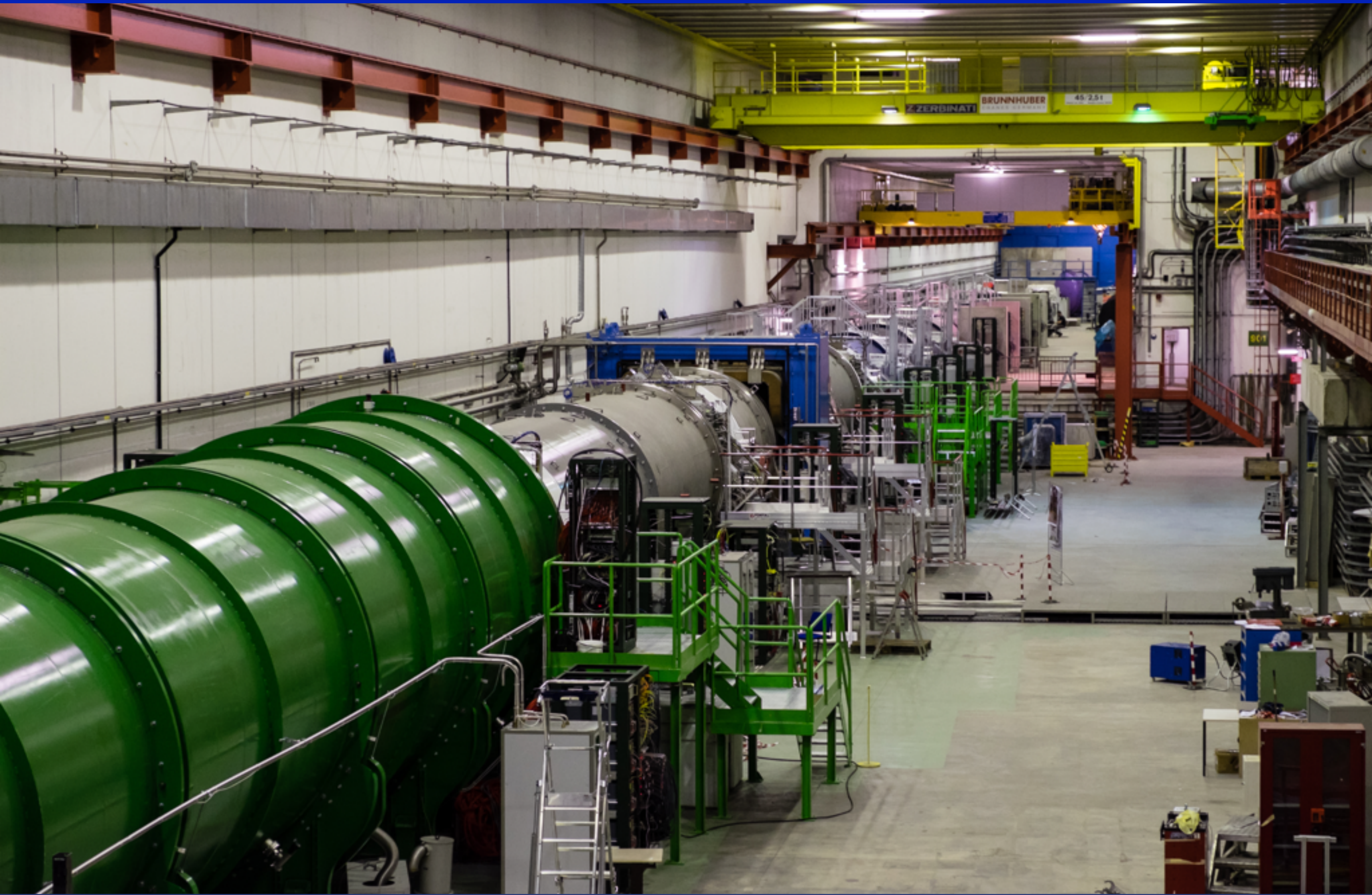
The main elements for the detection of the K^+ decay products are spread along **a 270 m long** region starting about 100 m downstream of the beryllium target.
K^+ decays are detected in a **65 m long fiducial volume**.



Approximately cylindrical shape around the beam axis for the main detectors. Diameter varies from 12 to 220 cm, in order to let the very intense flux of **undecayed beam particles passing through**.

The overall rate integrated over these detectors is ~ 10 MHz

NA62 Experiment



NA62 Collaboration

INSTITUTIONS:

Birmingham, BNL, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, **Frascati**, George Mason, Glasgow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP), Rome I, Rome II, San Luis Potosi, Stanford, Sofia, TRIUMF, Turin, UBC

NA62 LNF group

Antonella Antonelli, Francesco Gonnella, Venelin Kozhuharov, Gianluca Lamanna, Gianpaolo Mannocchi, Silvia Martellotti, Matteo Martini, Matthew Moulson, Mauro Raggi, Tommaso Spadaro

LNF SPAS:
Cesidio Capoccia, Aldo Cecchetti, Emilio Capitolo

GROUP TECHNICIANS:
Rosario Lenci, Vincenzo Russo, Massimo Santoni, Sauro Valeri, Tania Vassilieva

LNF SELF: Giovanni Corradi, Diego Tagnani

LNF vacuum service:
Paolo Chimenti, Valerio Lollo

LNF group responsibilities: Photon Vetos

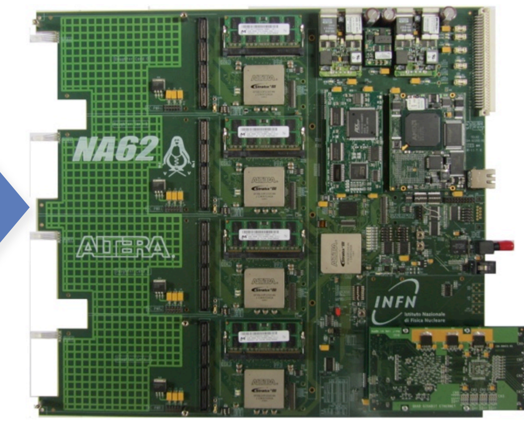
Large Angle Veto detectors (LAV):

- Coordination of the photon Veto System
- Design of the LAV vessel & construction equipment
- Test and calibration of the PbGl blocks
- Assembly of the LAV stations
- Vacuum, HV and electronics tests
- Installation of the LAVs in the ECN3 cavern

(*)

LAV FEE board

Readout TEL62



PC farm

L0TP

LAV readout(*):

- Design, production, and validation of the final FEE board
- Installation and commissioning of the LAV readout in ECN3
- Firmware for the L0 LAV trigger primitive generation

Small Angle Veto Inner Radius Calorimeter (IRC):

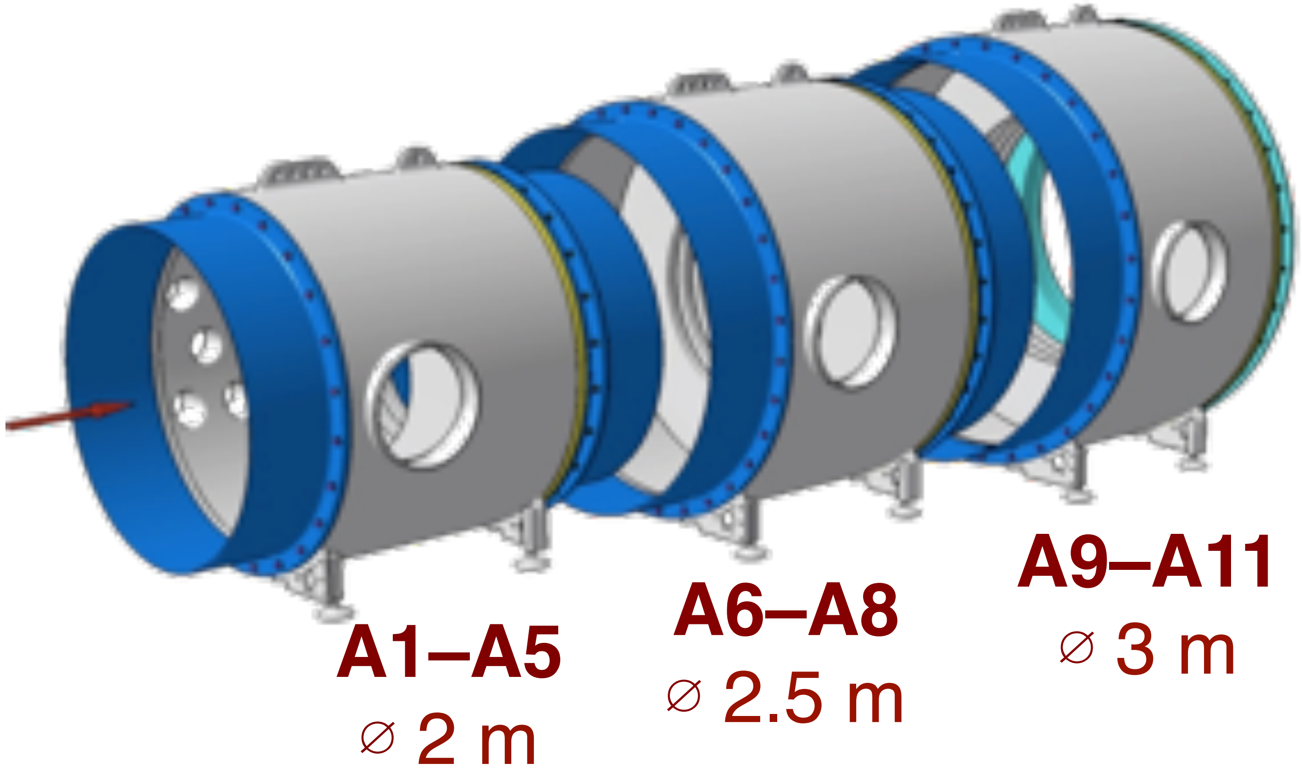
- Final design assembly and installation

Software and MC:

- Leading role in the LAV MC and Reconstruction

Large Angle Photon Vetoes: LAV

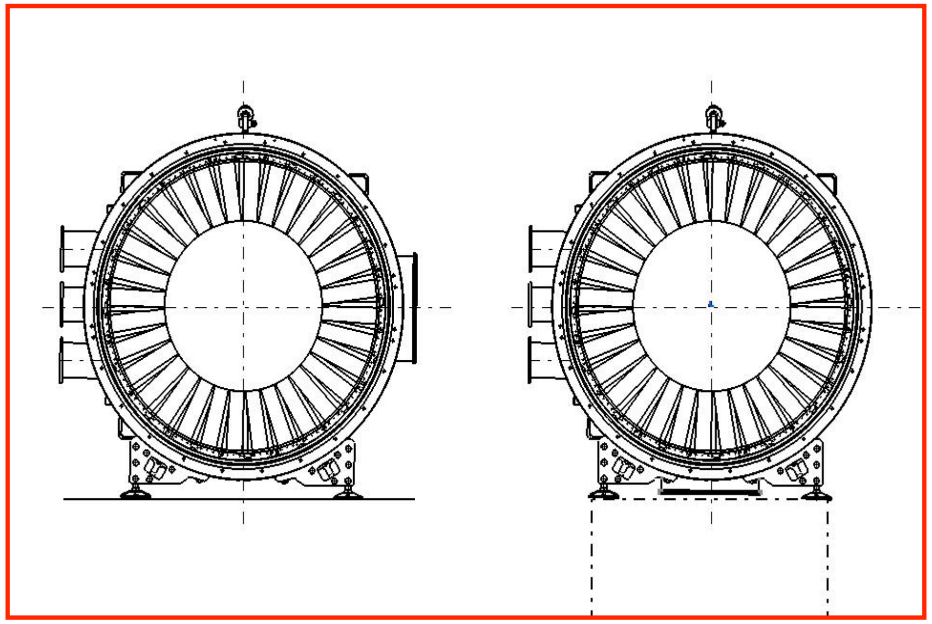
12 LAV stations mounted along 120 m decay region



Building blocks: OPAL calorimeter lead glass blocks (Schott SF57 lead glass)

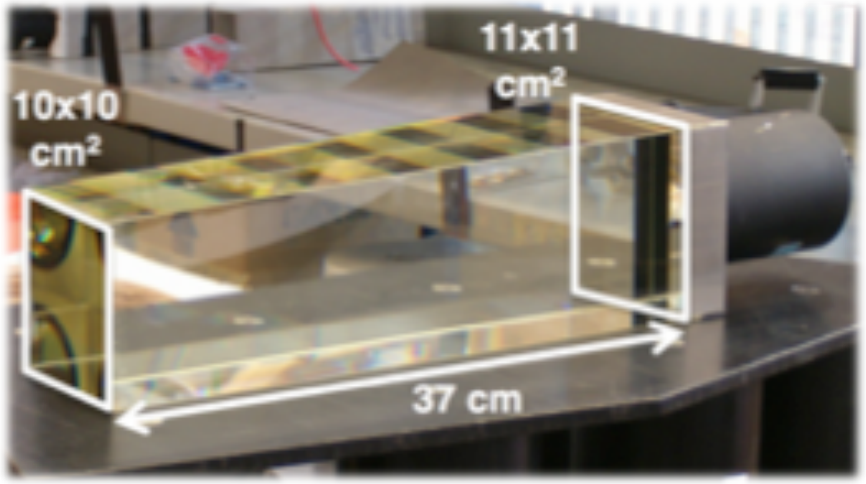
4 different types:
Stations 1-5: 160 blocks, 5 layers, in vacuum
Stations 6-8: 240 blocks, 5 layers, in vacuum
Stations 9-11: 240 blocks, 4 layers, in vacuum
Station 12: 256 blocks, 4 layers, in air

Angular coverage: 7 < θ_γ < 50 mrad



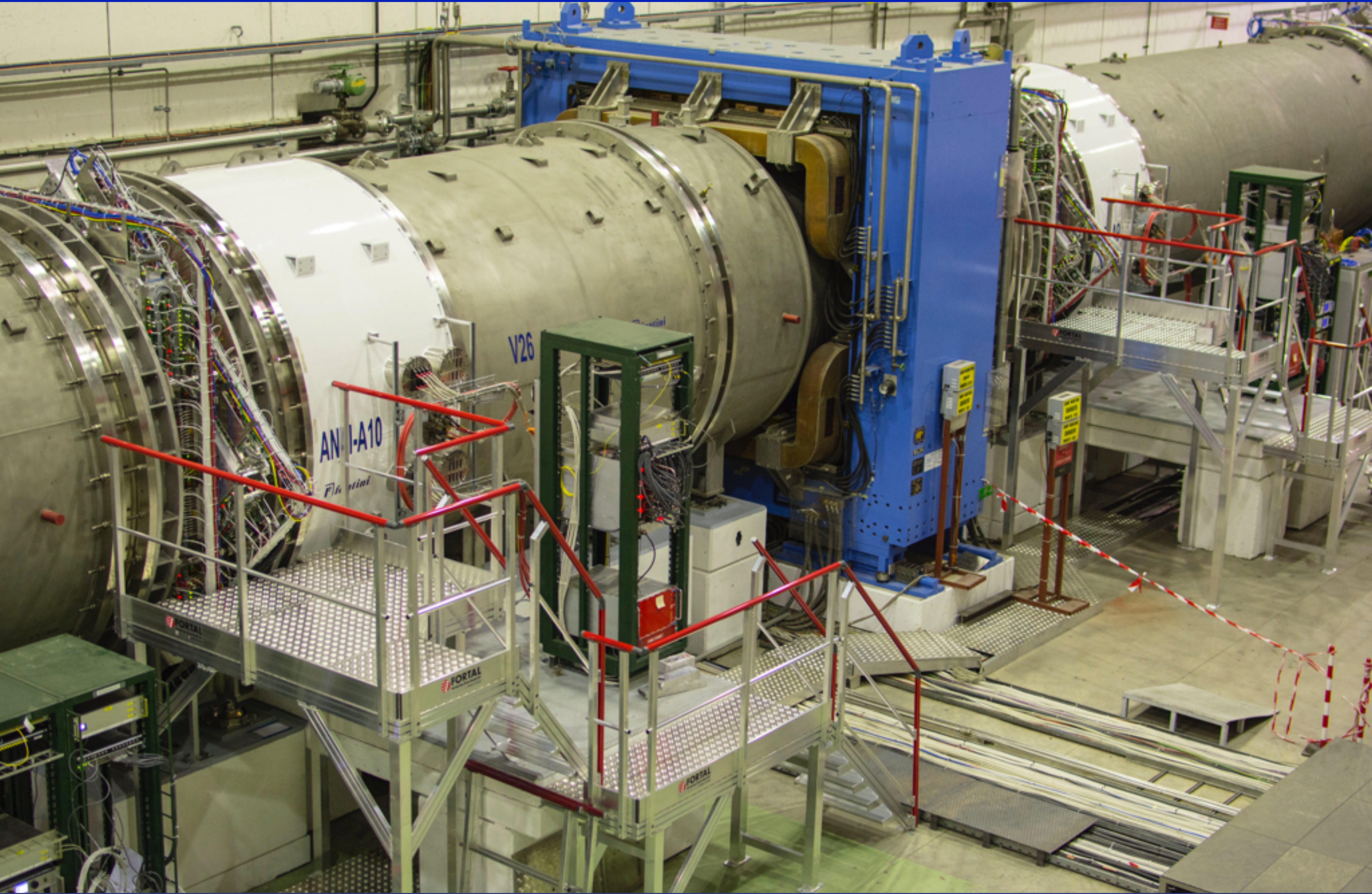
Expected performance: 10^{-3} to 10^{-4} inefficiency on γ down to 150 MeV

total of 2500 crystals with attached PMTs (R2238 76-mm PMT μ-metal case)

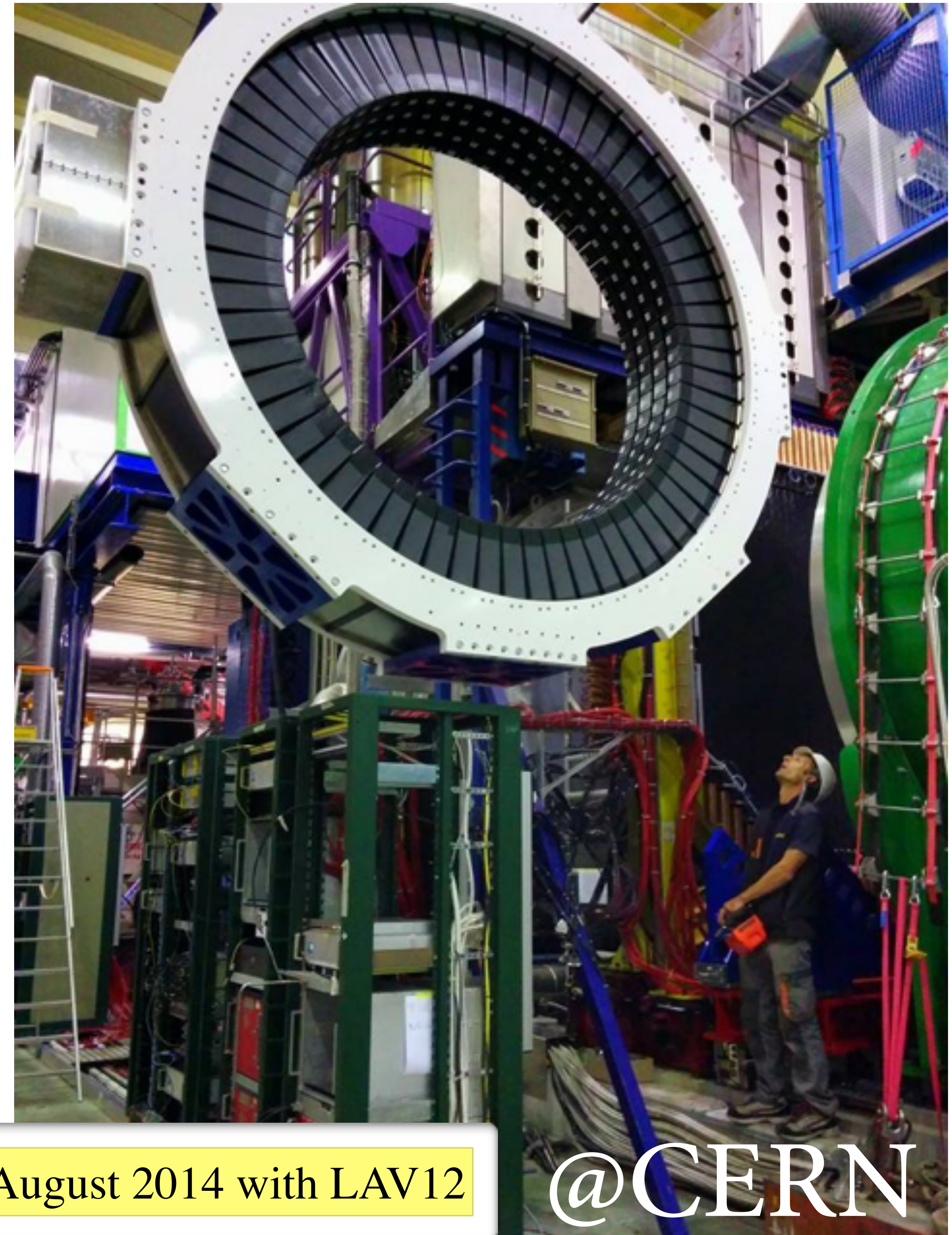


LAV 2

LAV9 & LAV10



LAV construction at LNF 2008-2014



Installation finished in August 2014 with LAV12

Small Angle Photon Veto: IRC

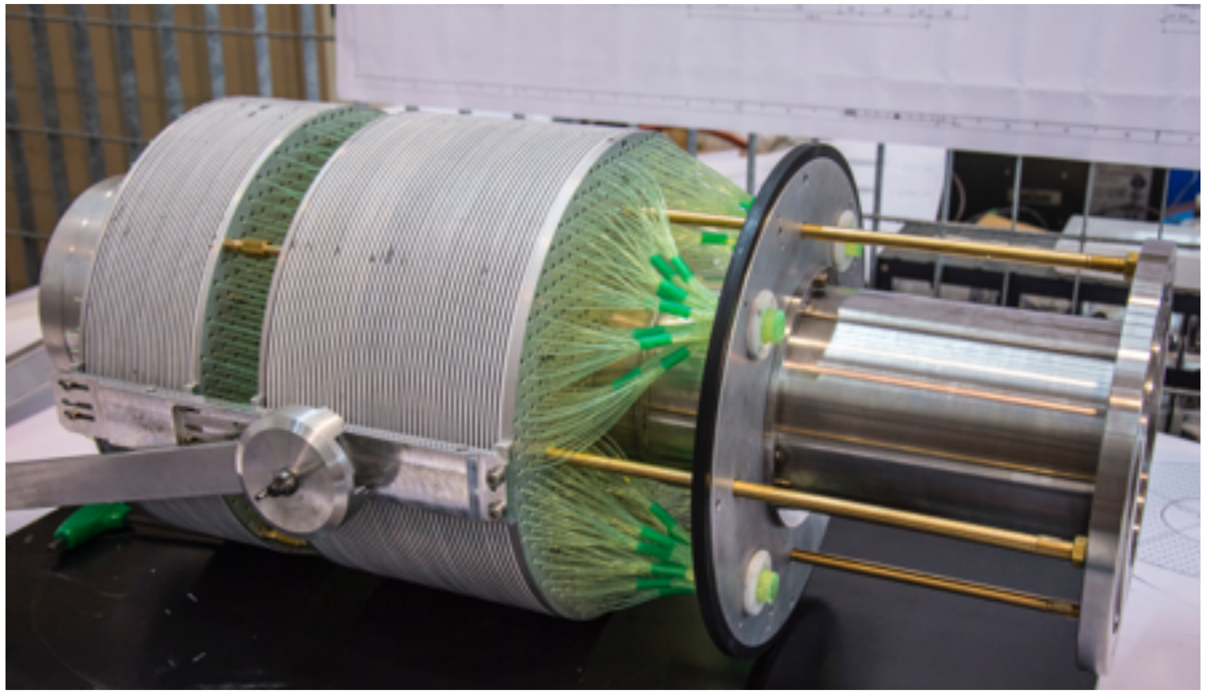
Inner Radius Calorimeter (IRC)

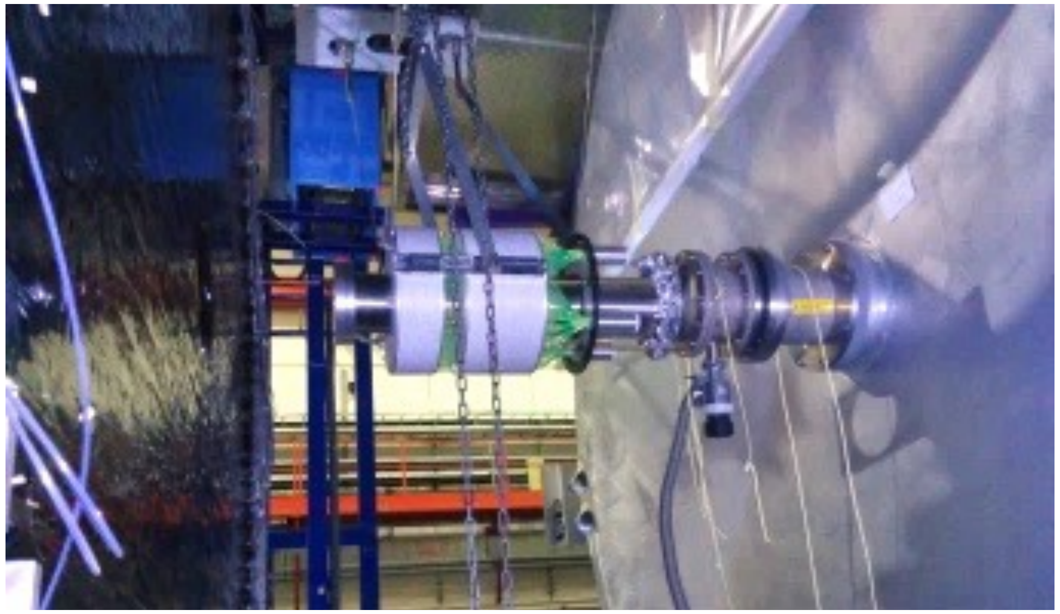
Entirely realized at LNF with collaboration from Sofia. The FADC-based readout system was tested at the BTF.

Collaboration with Sofia is continuing on the PADME project

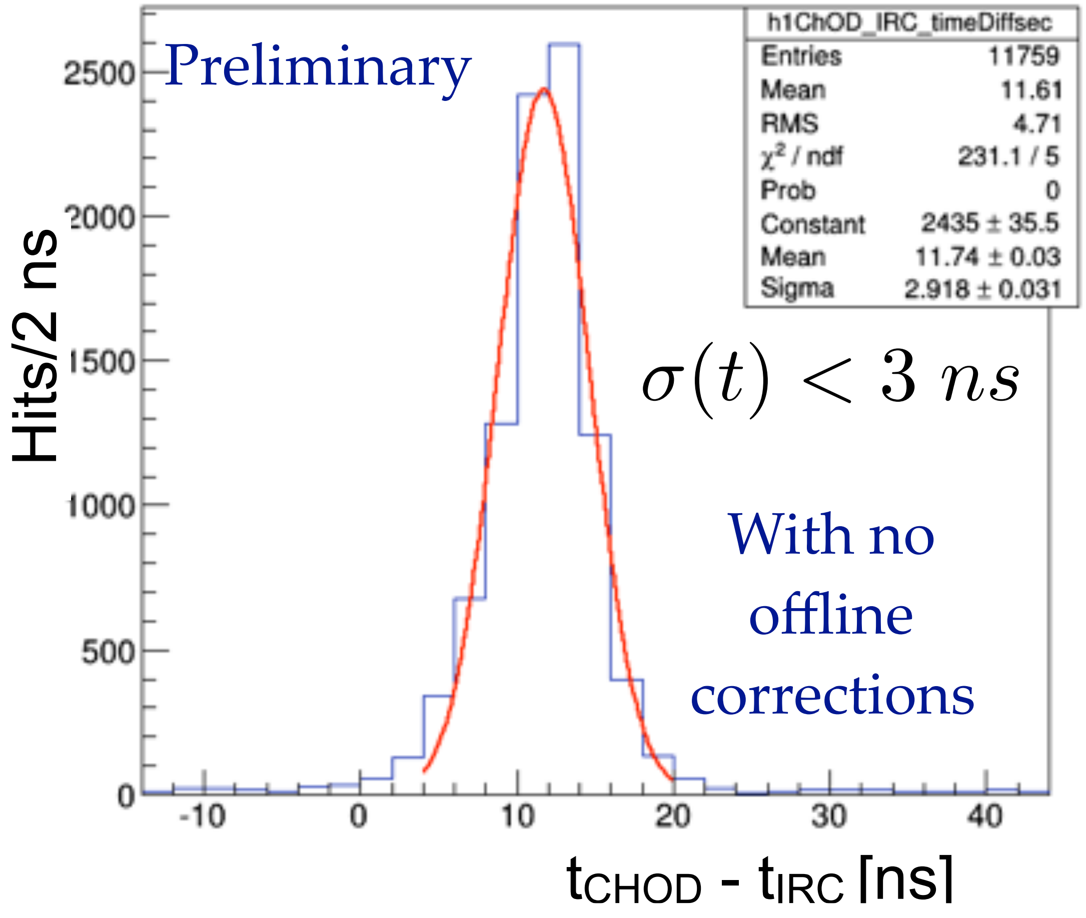
- Lead and plastic scintillator plates
- Electromagnetic showers detected through Shashlik calorimeters

Expected performance:
10^{-4} inefficiency for $E\gamma > 1$ GeV





Angular coverage: $\theta_\gamma < 1$ mrad



Commissioning in 2014 and 2015 runs

2014 Run (~3 months)

Preliminary conditions:

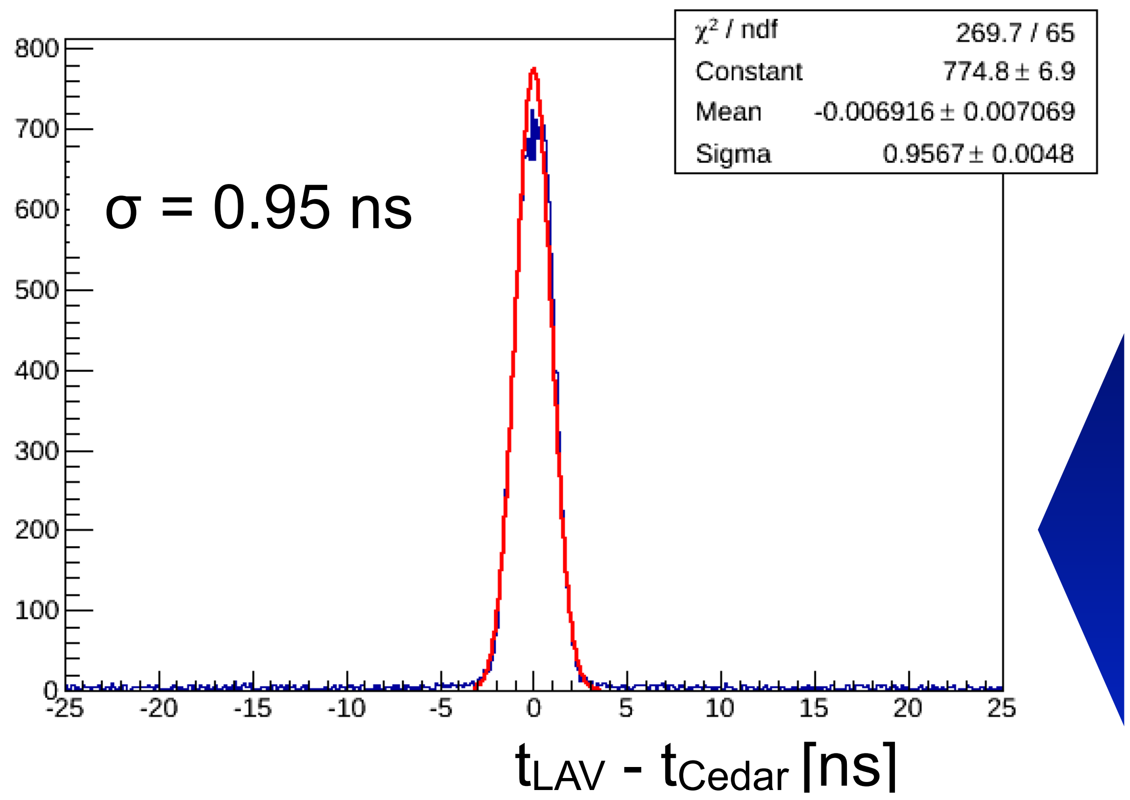
- No Kaon Tracker
- Only partial pion tracking system
- Preliminary Time alignment and calibration of the detectors
- Photon veto not yet applied
- Only L0 trigger active and downscaling for the acquisition

2015 Run (~5 months)

Hardware completed:

- All detectors installed and active
- Kaon and Pion tracking system included in the trigger
- Improvements in the readout
- First L1 trigger algorithms tested

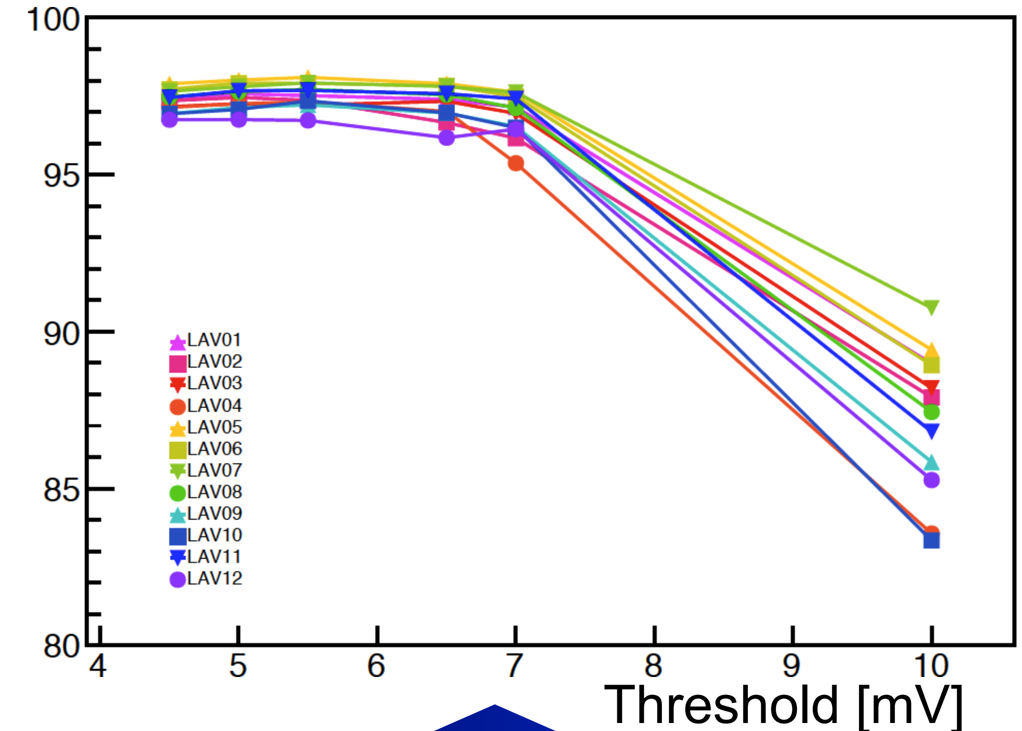
LAVs performance



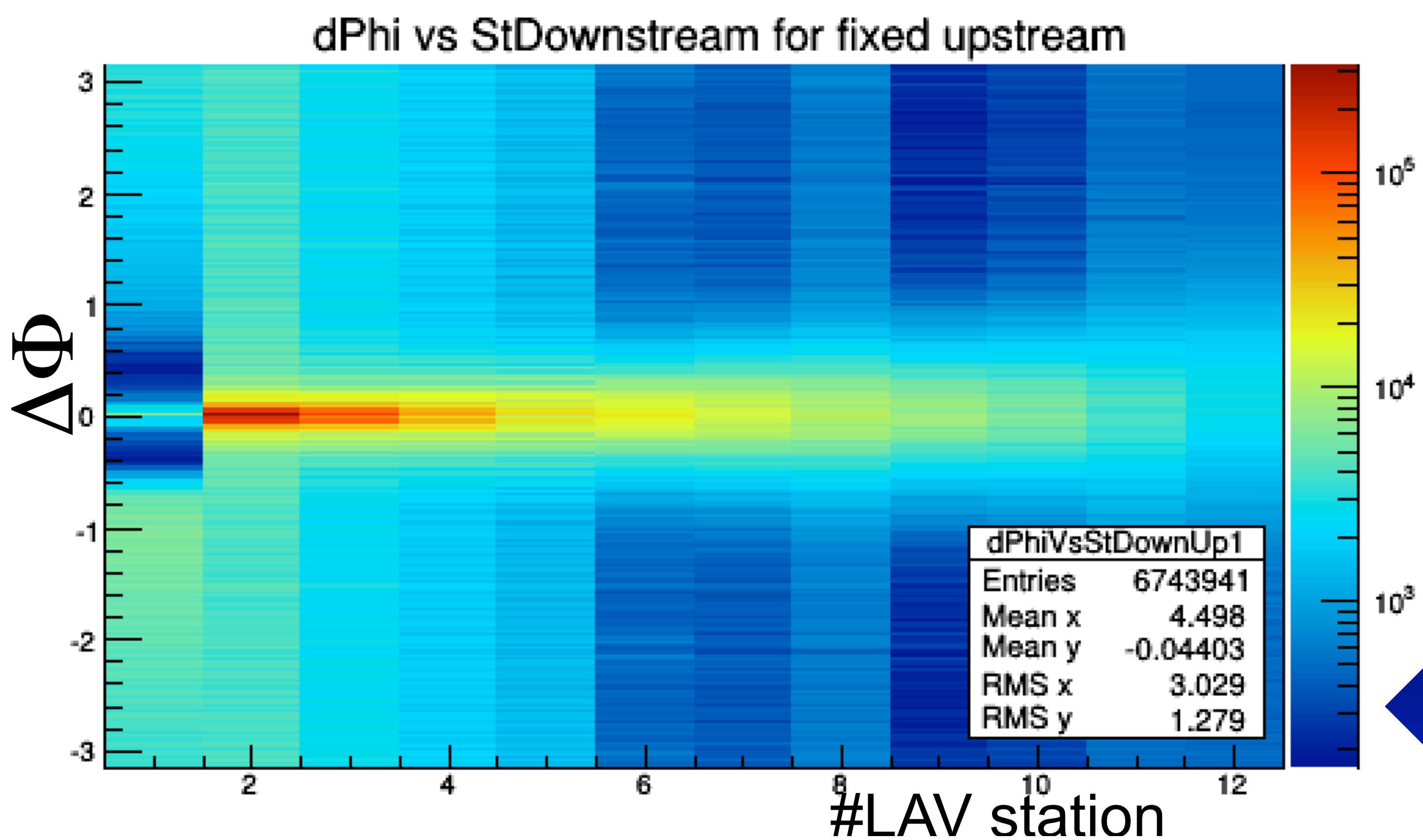
1% of dead or noisy channels essentially due to readout electronics.

Design performance achieved

Time alignment after slewing correction



Muon efficiency vs threshold

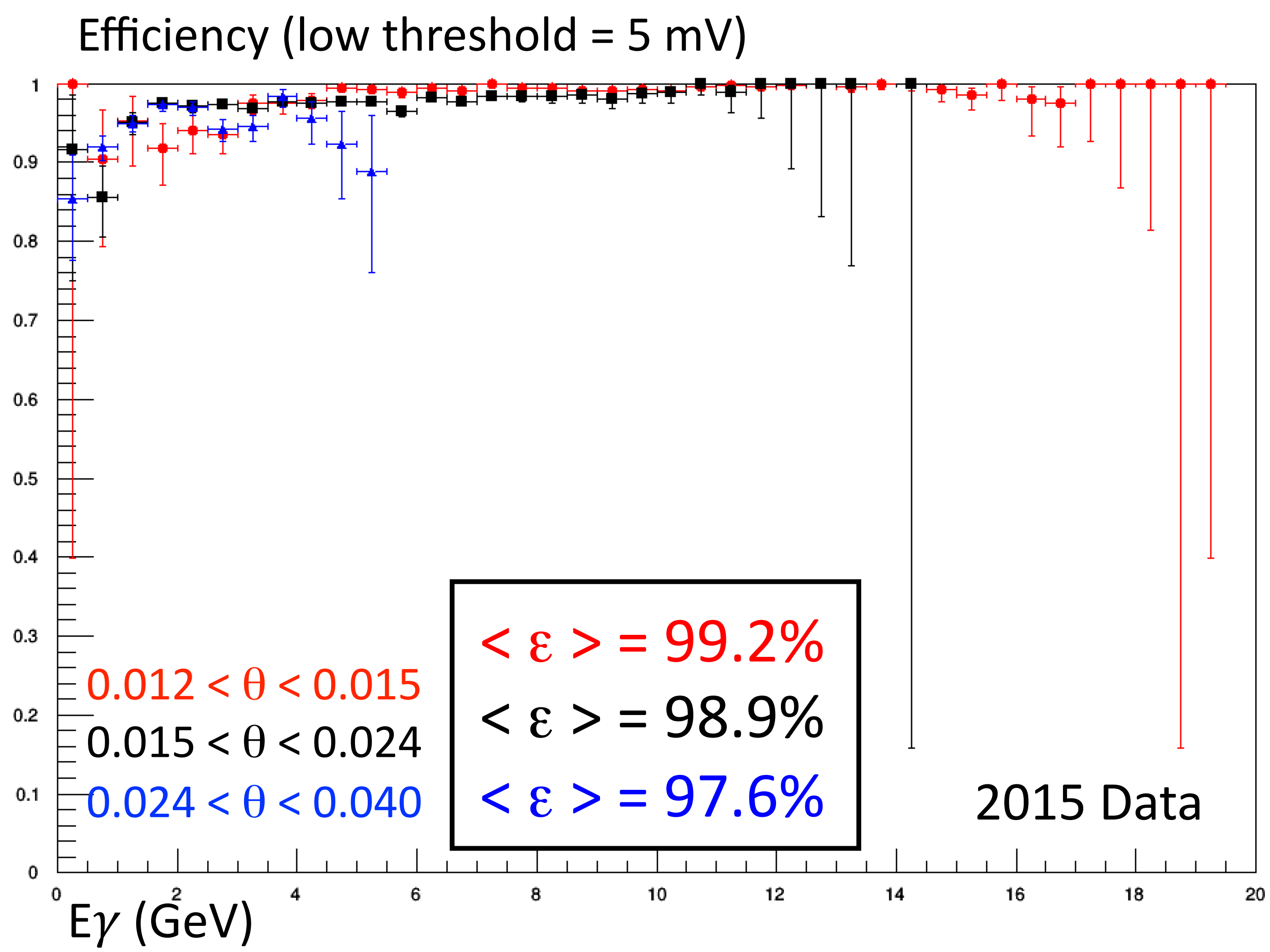


Tracks from halo muons crossing many stations (hits clusterized in time)

LAV photon efficiency first estimation

The intrinsic detector inefficiency for photons has been evaluated.
Events with one photon of a given energy with expected impact on LAV were selected.

From $K^+ \to \pi^+\pi^0$ events:



- Good K identification
- 1 Good-quality secondary track
- 1 and only 1 cluster (γ from π^0) in time in the LKr downstream calorimeter above 3 GeV, far from the track impact point
- Cut on kinematics to select $K^+ \to \pi^+\pi^0$ events

Closing the kinematics determines the energy and direction of the missing γ.
A hit is found if at least 1 block is fired within 5 ns of the expected time.

MC study shows that <1/6 of the apparent inefficiency is due to LAV itself
In MC: $<\varepsilon> = 99.7\%$, $<\varepsilon> = 99.4\%$, $<\varepsilon> = 98.2\%$.

Trigger Study

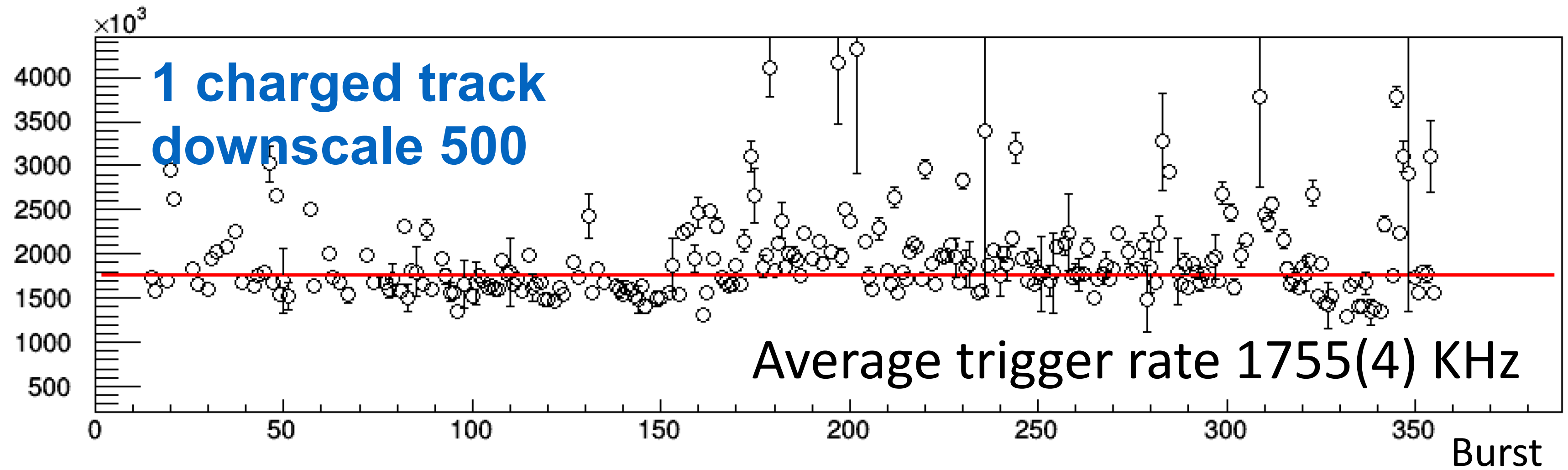
NA62 trigger system:

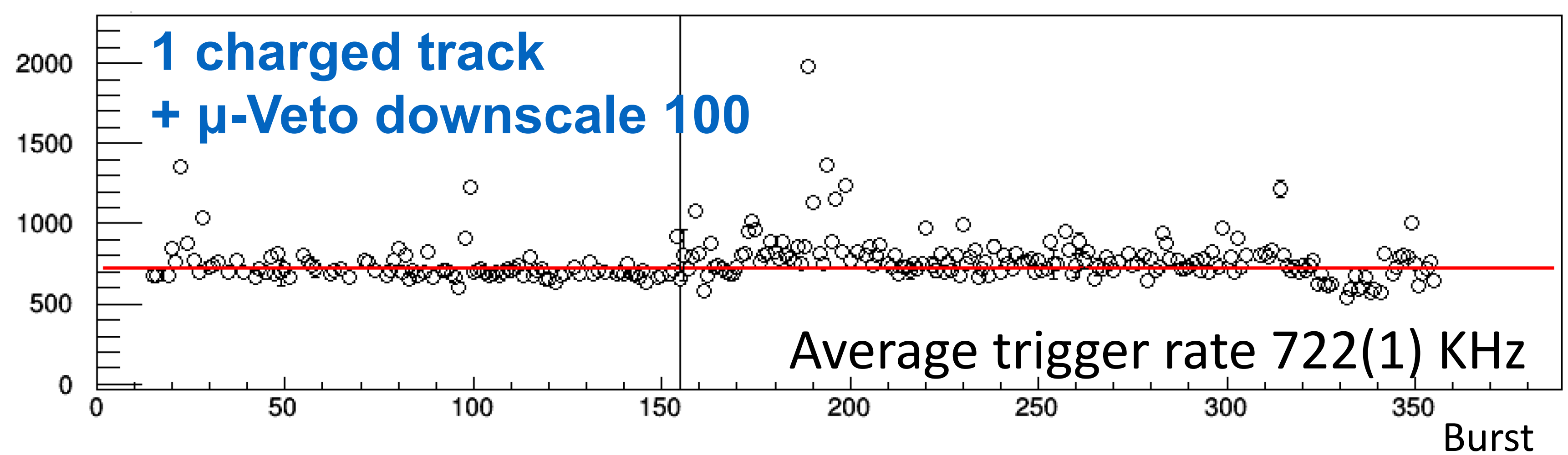
L0 trigger:	**L1 & L2 triggers**:
Implemented in **hardware** (FPGA)	**Software** based: running on a PCfarm.
Rate reduction from 10 to ~ **1 MHz**	Rate reduction to **~10 kHz**

Our group dedicated a special effort to study and test L0 and L1 trigger algorithms

L0 trigger has been simulated using minimum bias reconstructed events:

- to evaluate the different trigger rates
- to apply the L1 selection algorithms





Trigger Study: Level 1

Performance of L1 trigger algorithms given an L0 trigger are evaluated

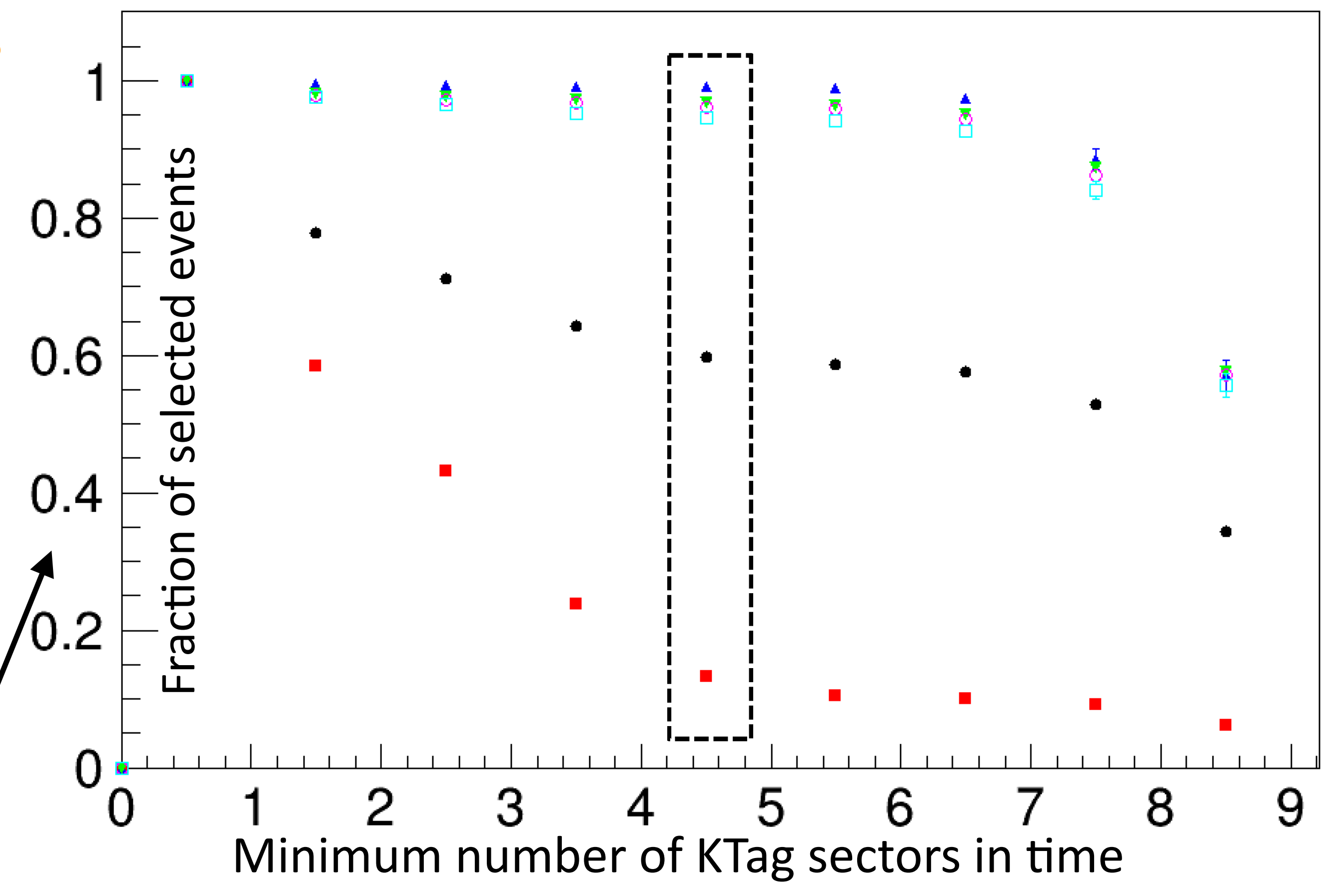
Various algorithms are being tested

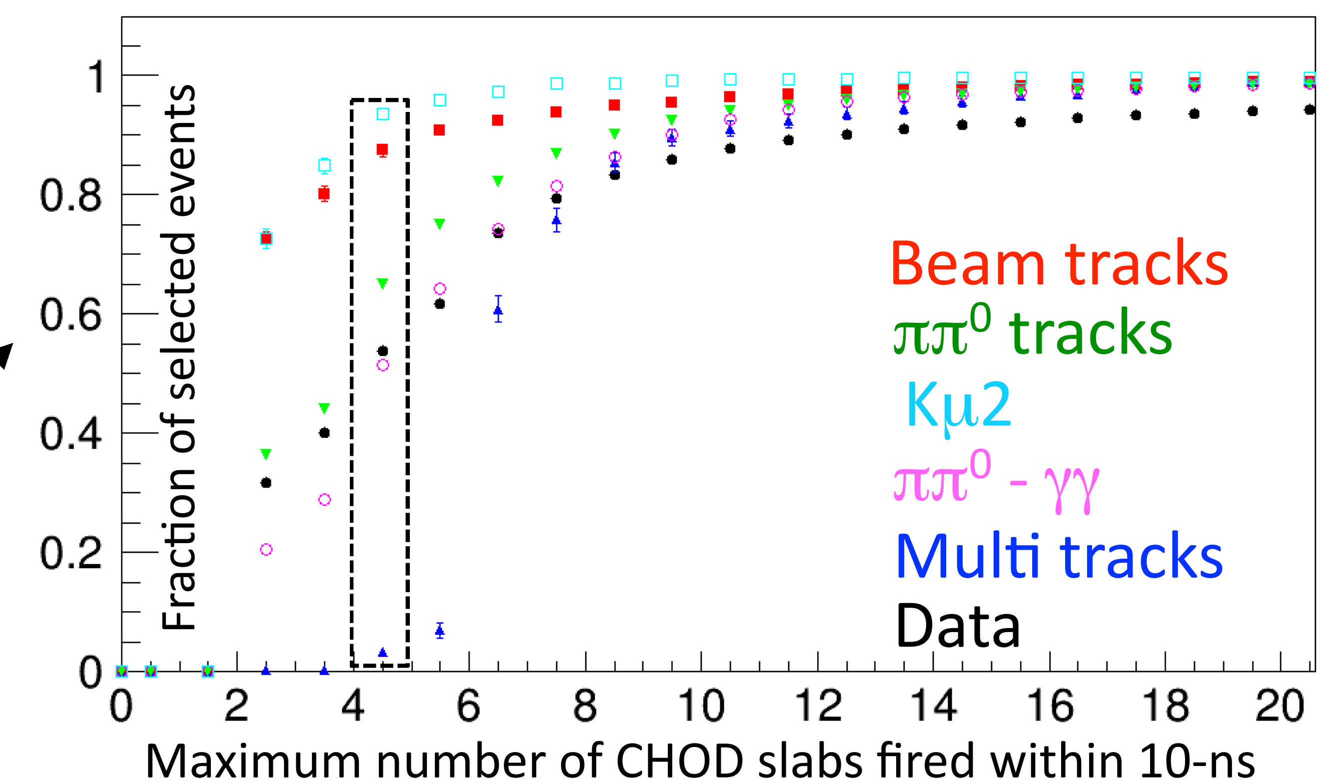
Purpose:

- reject multi-track events
- reject the non-kaon beam component
- reject decays with photons at large angle and inelastic interactions

Requiring > 4 fired sector in the Ktag rejects events in which beam particle is not a Kaon (60% retention)

Requiring a maximum number (<5) of slabs in the forward charged track hodoscope (CHOD) reduces the acceptance for multi-track decays (55% retention)





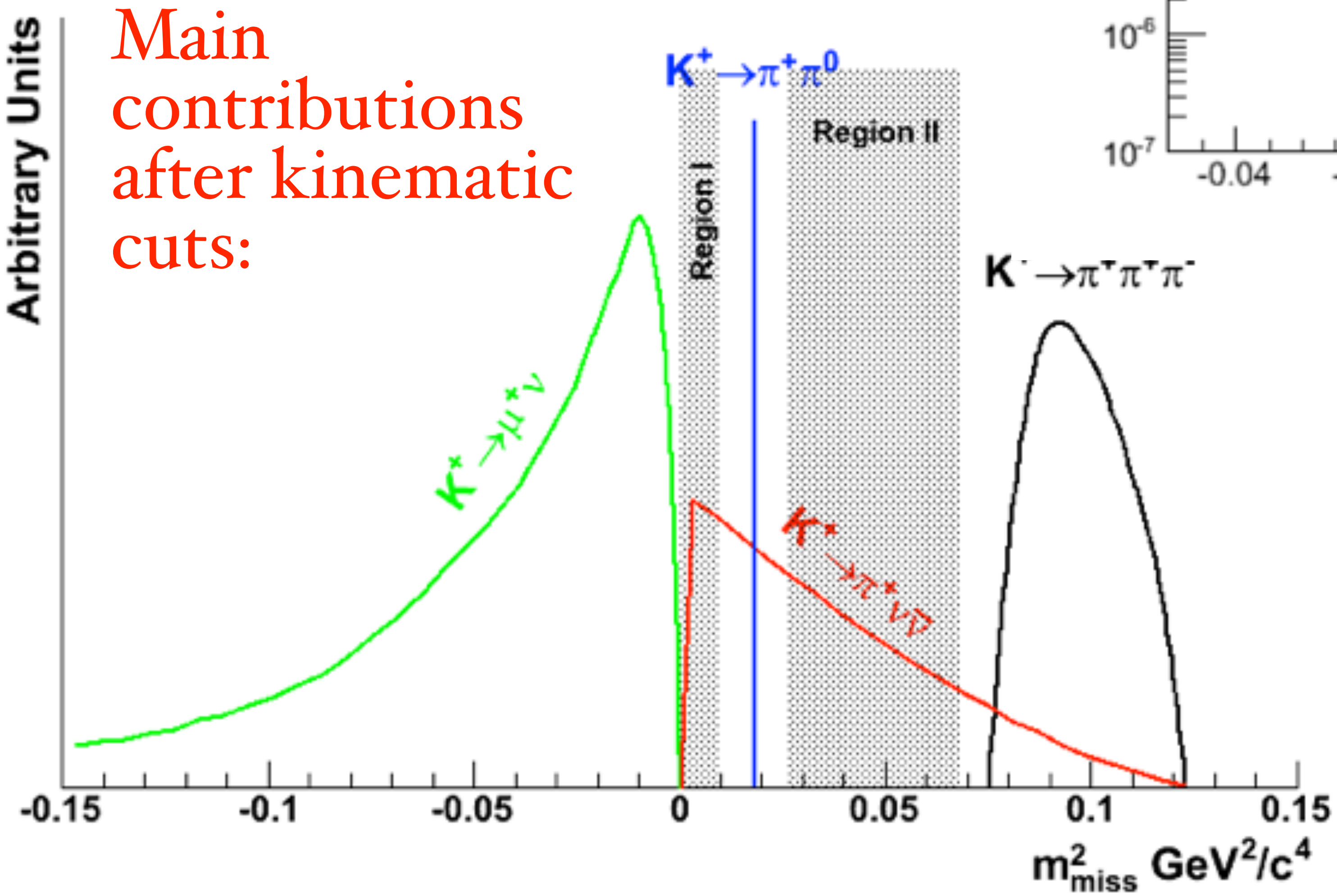
Analysis strategy

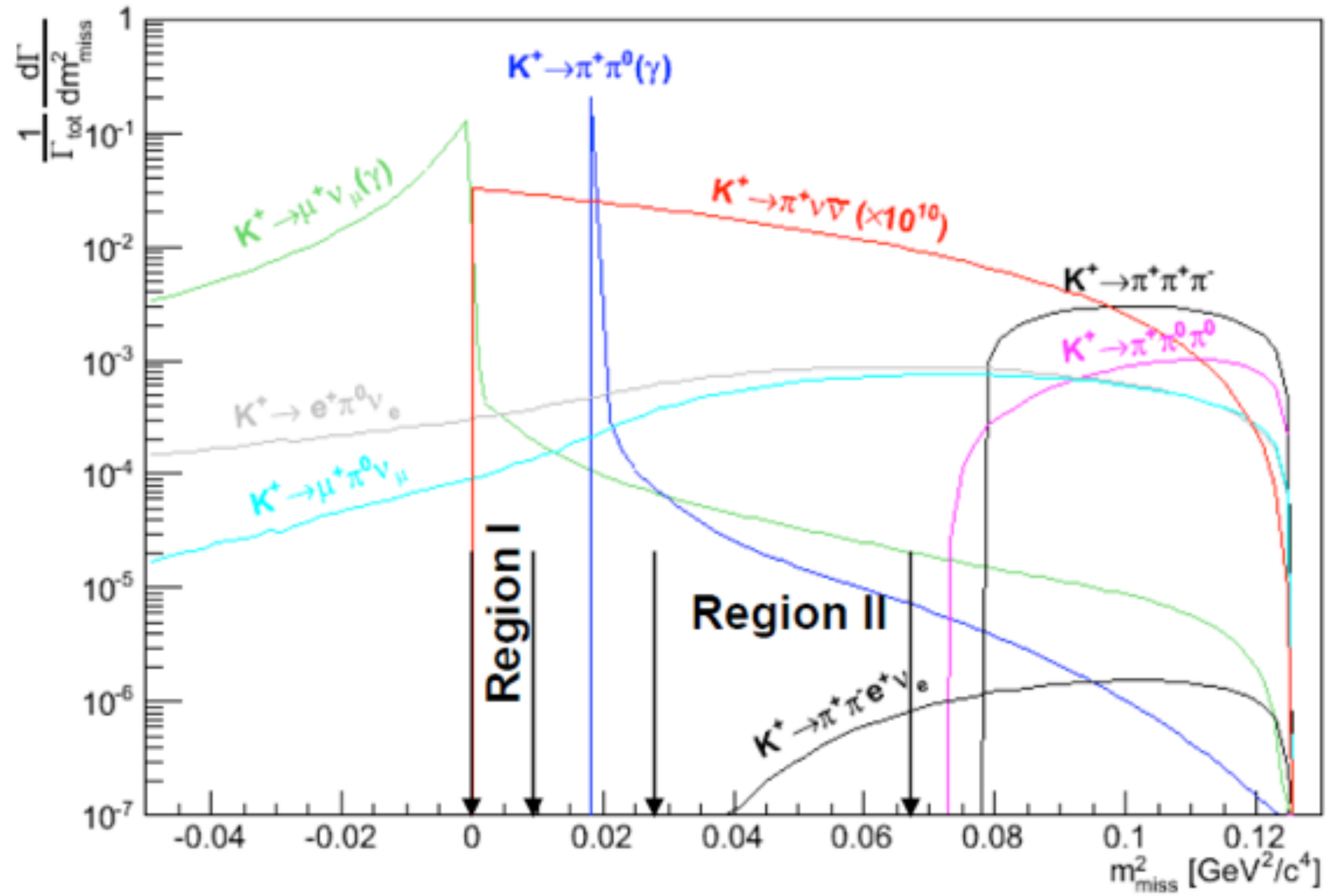
$K^+ \to \pi^+ \nu\nu$ search:

Most discriminating variable:
$m^2_{miss} = (P_{K+} - P_{\pi+})^2$

Where the daughter charged particle is assumed to be a pion

Main contributions after kinematic cuts:



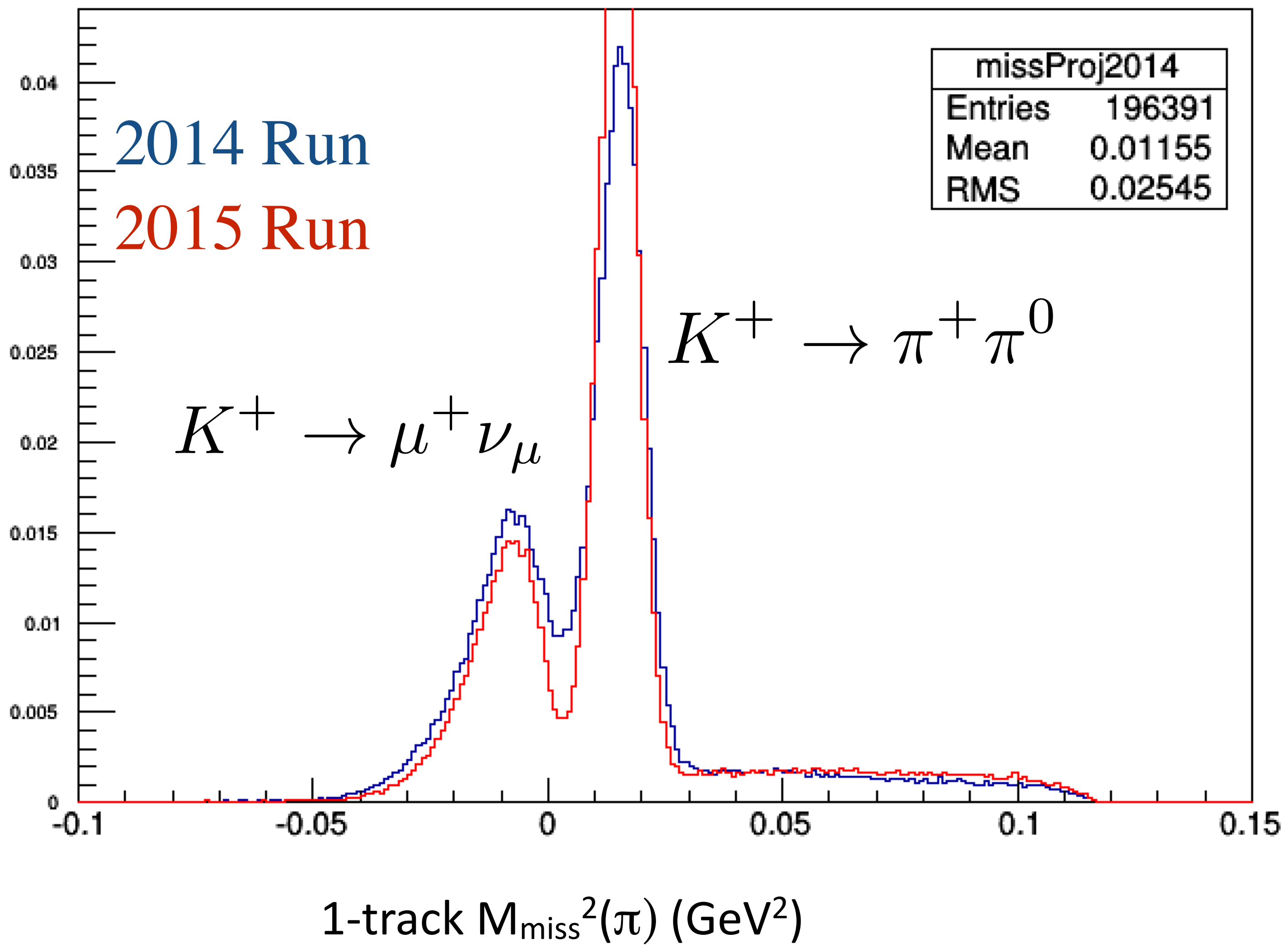


2 signal regions, on each side of the $K^+ \to \pi^+ \pi^0$ peak, are chosen, where more than 90% of main K^+ decays are not contributing.

Data Analysis

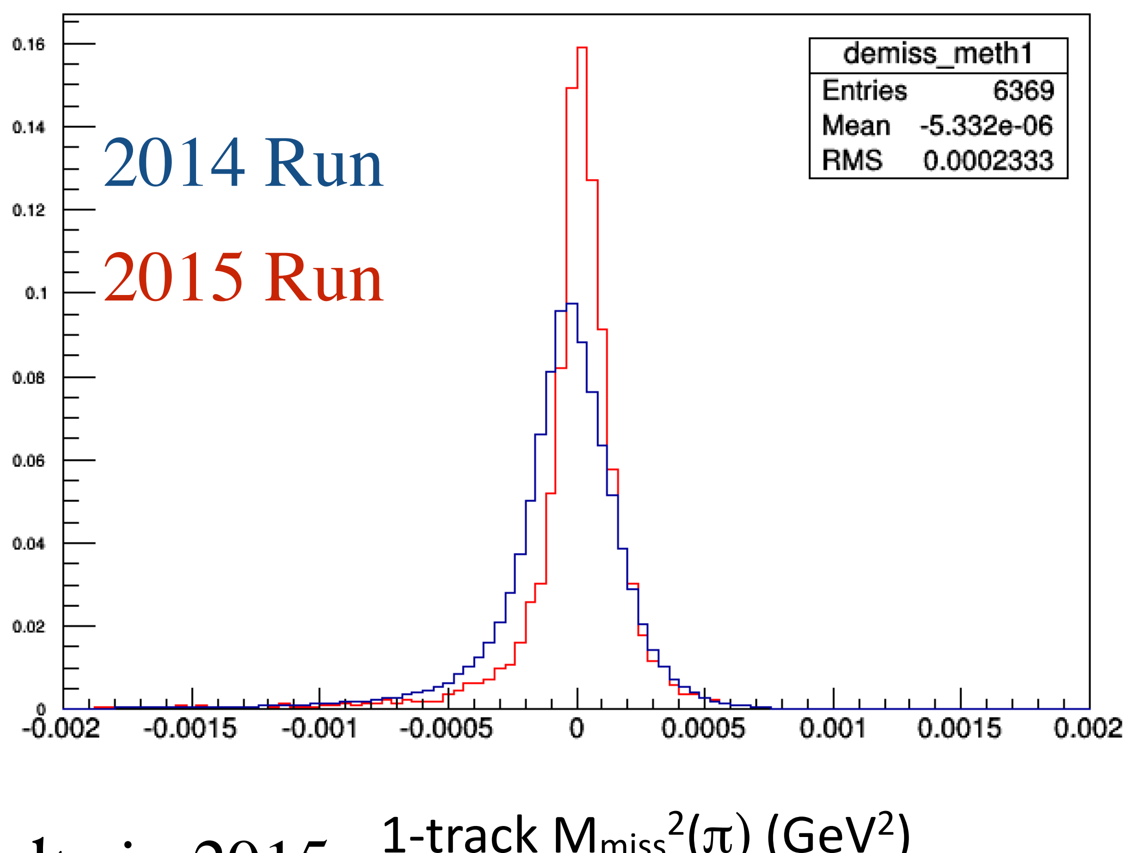
Up to now most of the data taking has been devoted to the commissioning of the beam, detectors and data acquisition and to the study of detectors and trigger performance

Only a small part of data has been taken for analysis with the “πνν-trigger”



On these Data the analysis method has been applied

$0.01 < M_{miss}^2(\pi) < 0.025$ GeV^2



The K tracking system information and the full π spectrometer installation strongly improved the results in 2015

Conclusion and What Next

- LAVs and IRC photon veto detectors are fully commissioned
- After 9 years of planning, design, and construction, NA62 collected data in 2014 and 2015 runs

2016 Run will start next April

- LAV photon efficiency evaluation will be improved with the new data
- Trigger algorithms of Level 1 under study will be fully applied
- Analysis tools will be improved

PRIN project: $K_L \to \pi^0 \nu\nu$ at the SPS

NA62 Italy subset has PRIN funding for study the feasibility of a K_L experiment
Ferrara, Firenze, Frascati, Napoli, Perugia, Pisa, Tor Vergata, Torino

Estimate cost, timescale, and performance
for an experiment to measure BR($K_L \to \pi^0 \nu\nu$) at the SPS

Frascati group is currently coordinating the simulation activities

- A moderately expensive (< 50M€) experiment might operate in ECN3 and make use of the NA48 Lkr calorimeter as primary veto. In 2 years of running (10^7 s/yr) at a beam intensity of 1.5×10^{13} ppp **10 $K_L \to \pi^0 \nu\nu$** events are expected with S/B ~ 1
- A new design for a **100-event** experiment with new detectors for a higher acceptance is also under evaluation

The PRIN will expire next February and a document with proposals of the experiment setups, acceptance estimates and background studies will be ready for that date

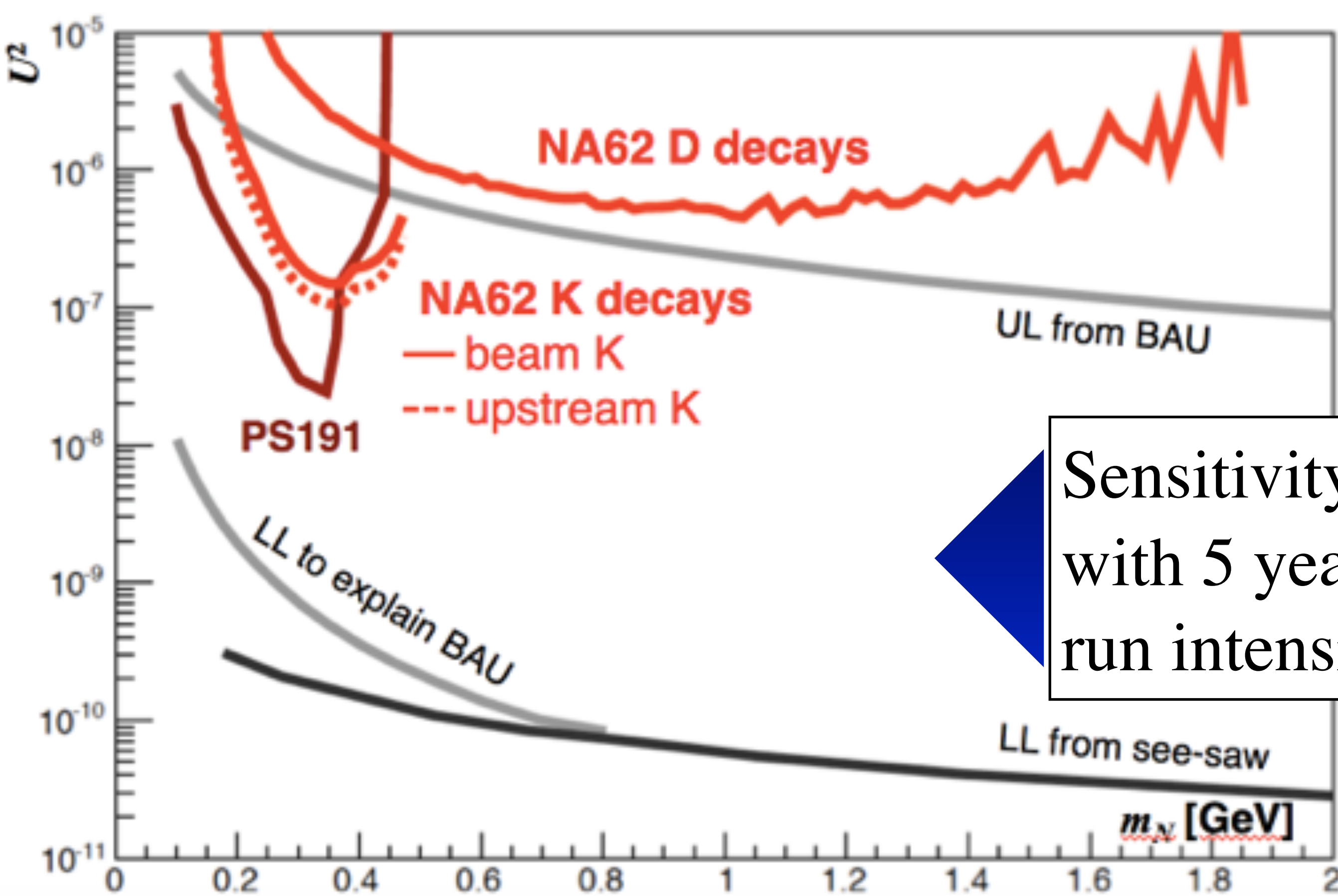
Heavy lepton searches at NA62

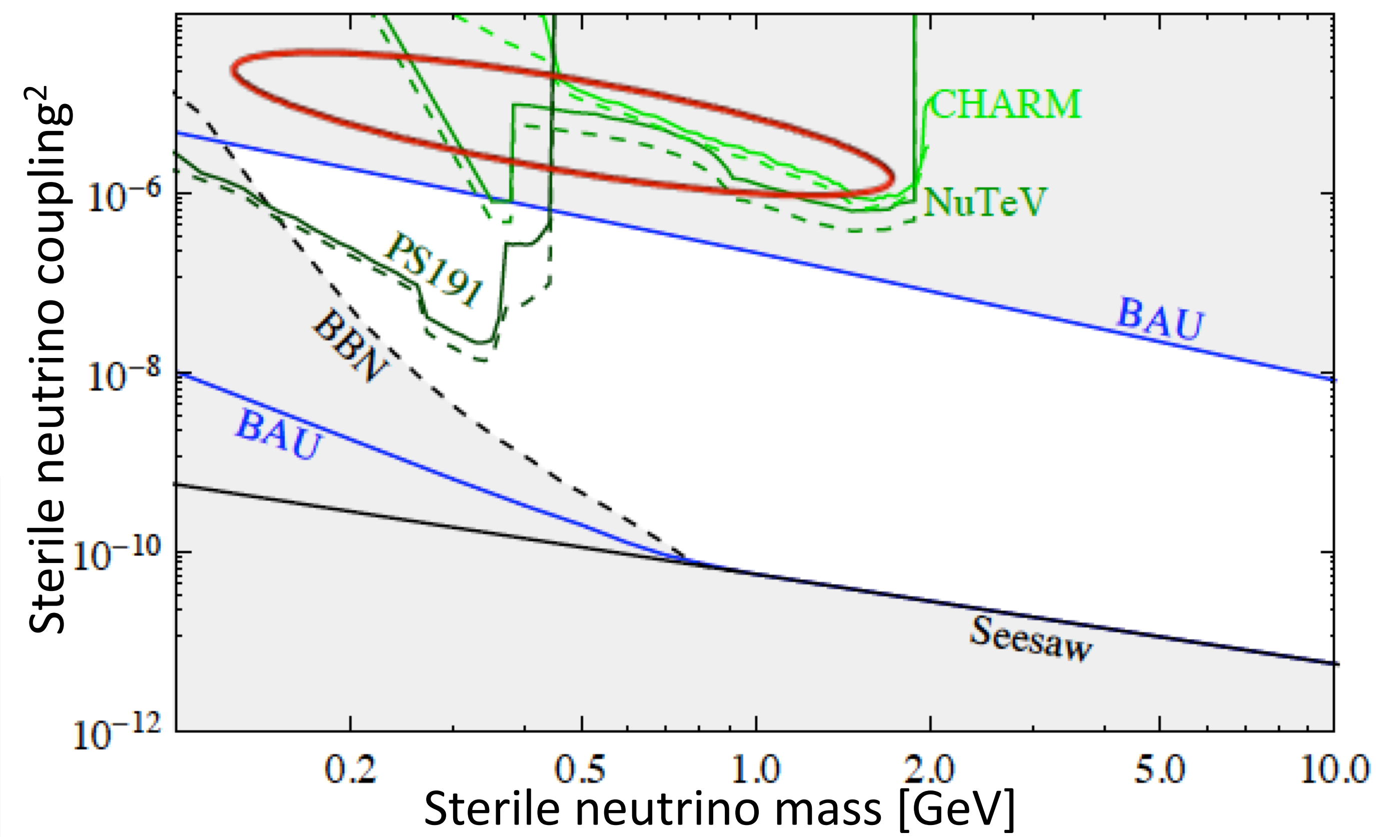
NA62 intensity allow LFV searches from K decays and from other mesons

Mesons produced at target might decay into long-lived exotic particles reaching the NA62 decay volume

The simplest signatures correspond to:

- two body semi-leptonic decay πe, πμ for the sterile neutrino
- two body leptonic decay ee, μμ for the dark vectors





Sensitivity for exclusive search for N → eπ or μπ with 5 years of data at nominal 3×10^{12} ppp NA62 K^+ run intensity ($O(10^{15})$ D^{+-}, D_S^{+-} produced per year)

Feasibility studies ongoing

Backup Slide

Minimum Bias Data

Measurement of the BR of the main K+ decay will give the ultimate detectors performance

MC quality check

"$\pi\nu\nu$-trigger" Data

Analysis method test

Assessment of the experiment sensitivity

Background study