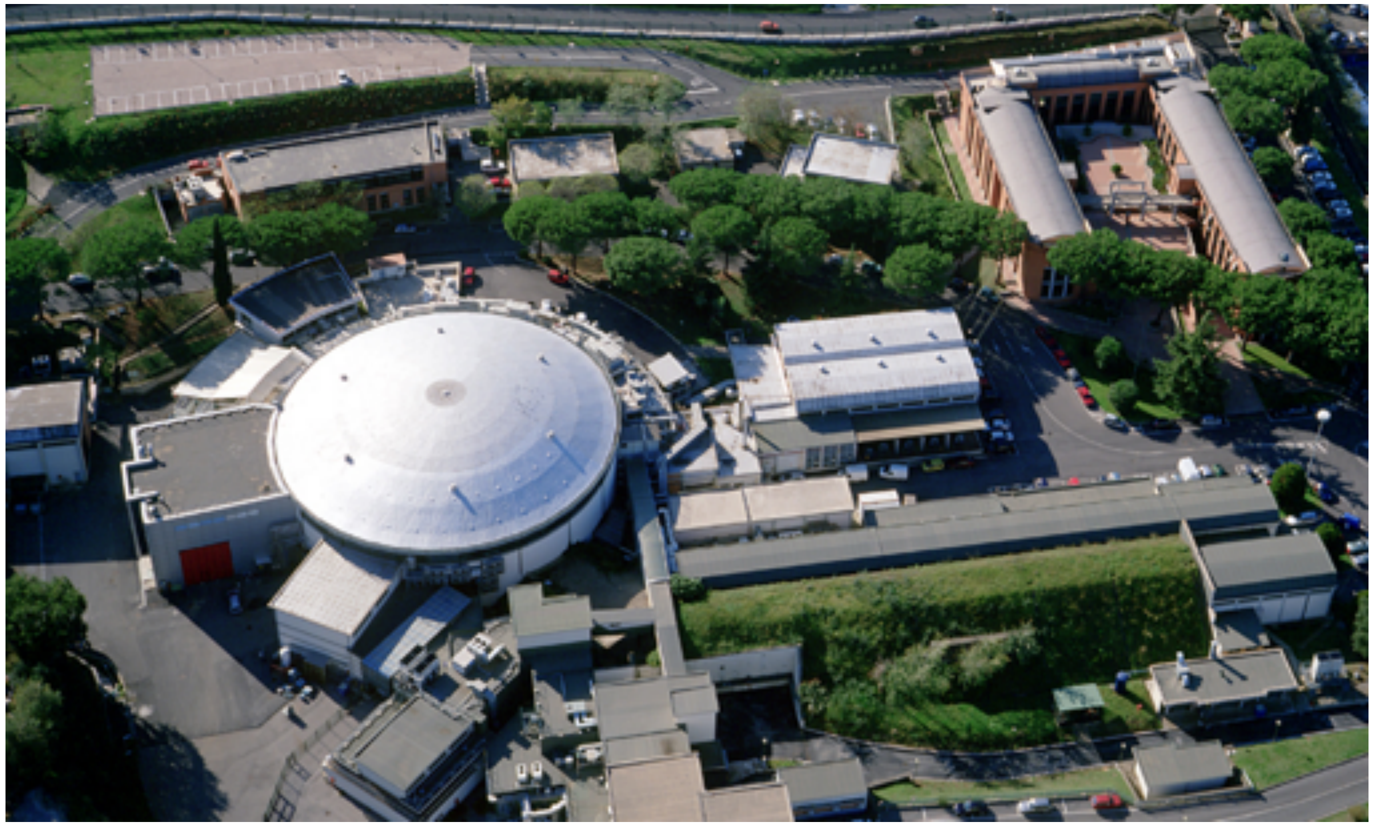
52nd LNF Scientific Committee



Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Frascati

NA62 status and activities

Silvia Martellotti

Frascati 2016, November 21st

Outline

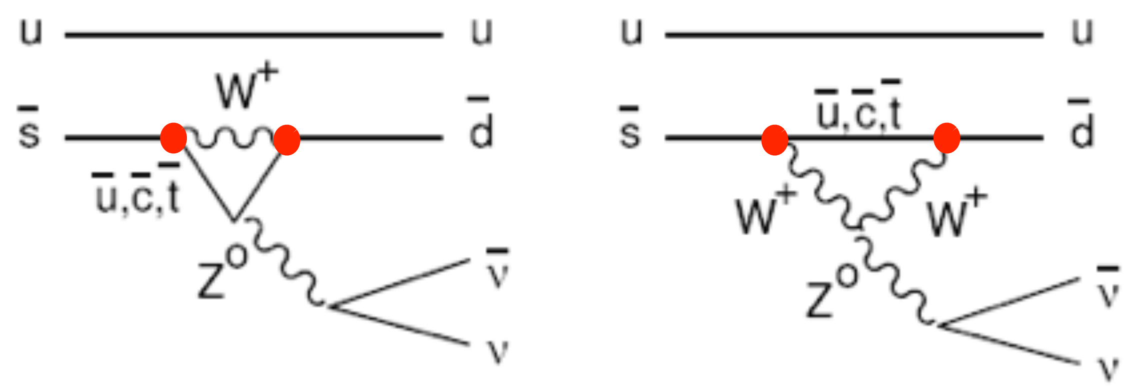
- Theoretical introduction to the $K^+ \rightarrow \pi^+\nu\nu$ rare decay
- NA62 experiment
  - Aim and strategy
  - Results and prospects
- Frascati group activity
  - Responsibilities
  - Photon Veto detectors: performance
  - Data Analysis
  - Other activities

SM theoretical framework

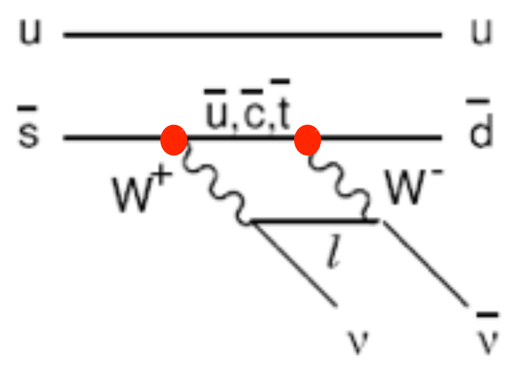
The $K^+ \to \pi^+ \nu\nu$ decay is extremely suppressed

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

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



Z-penguin



W-box

Is characterized by a theoretical cleanness in the SM prediction of the BR($K^+ \to \pi^+ \nu\bar{\nu}$)

Loops and radiative corrections are under control

Highly suppressed	→	Excellent laboratory complementary to LHC
Very well predicted		

Stringent test of the SM and possible **evidence for New Physics**

Past measurement and prediction

Current theoretical prediction:

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11},$$

$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) = (3.4 \pm 0.6) \times 10^{-11}.$$

A.J. Buras, D.Buttazzo, J. Girrbach-Noe and R.Knegjens arXiv:1503.02693

Main contribution to the errors comes from the uncertainties on the SM input parameters

Intrinsic theoretical uncertainties (1-3%) slightly larger for the charged channel because of the corrections from lighter-quark contributions

Experimental status:

Charged decay: only measurement obtained by E787 and E949 experiments at BNL with stopped kaon decays (7 events):

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

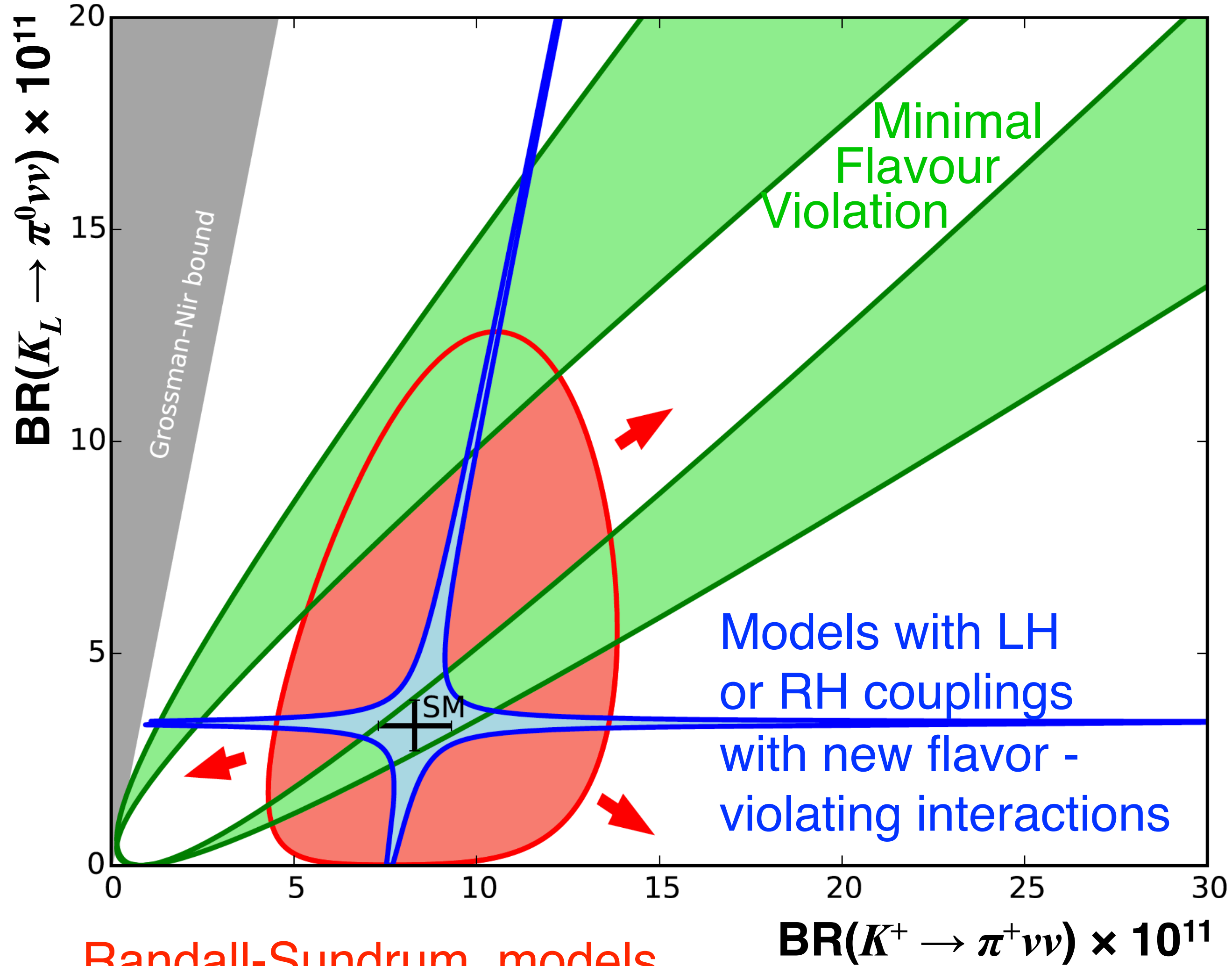
Gap between theoretical precision and large experimental error motivates a strong experimental effort. Significant new constraints can be obtained.

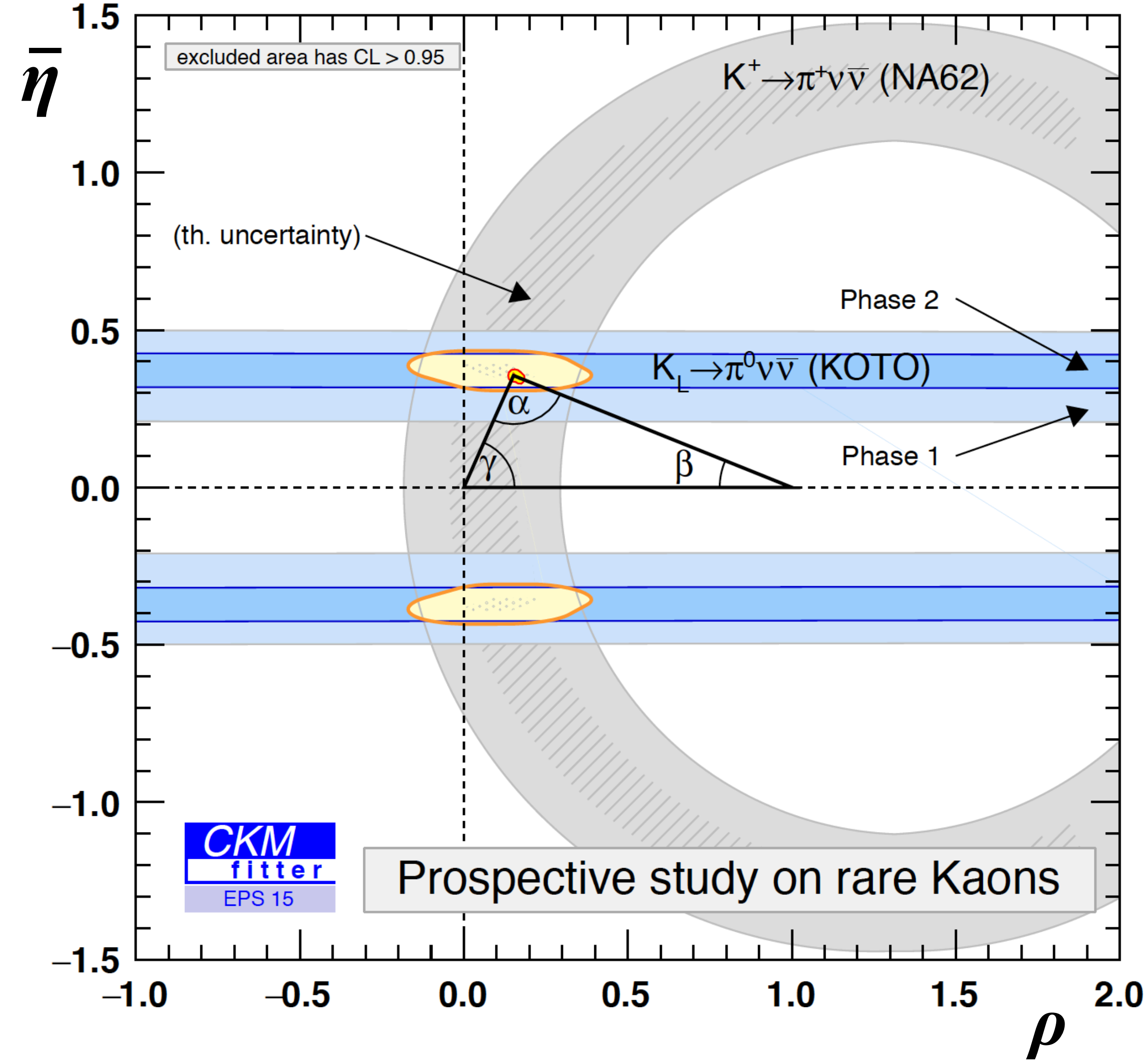
Neutral decay $K_L \to \pi^0 \nu\nu$ has never been measured

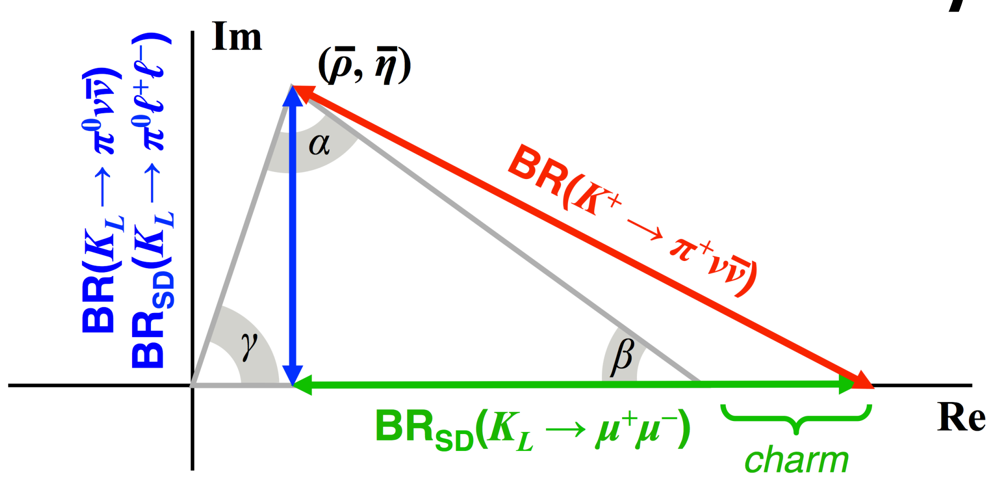
New Physics from K→πνν decays

Measurement of BR of charged ($K^+ \to \pi^+\nu\nu$) and neutral ($K_L \to \pi^0\nu\nu$) modes can determine the **unitarity triangle** independently from B inputs

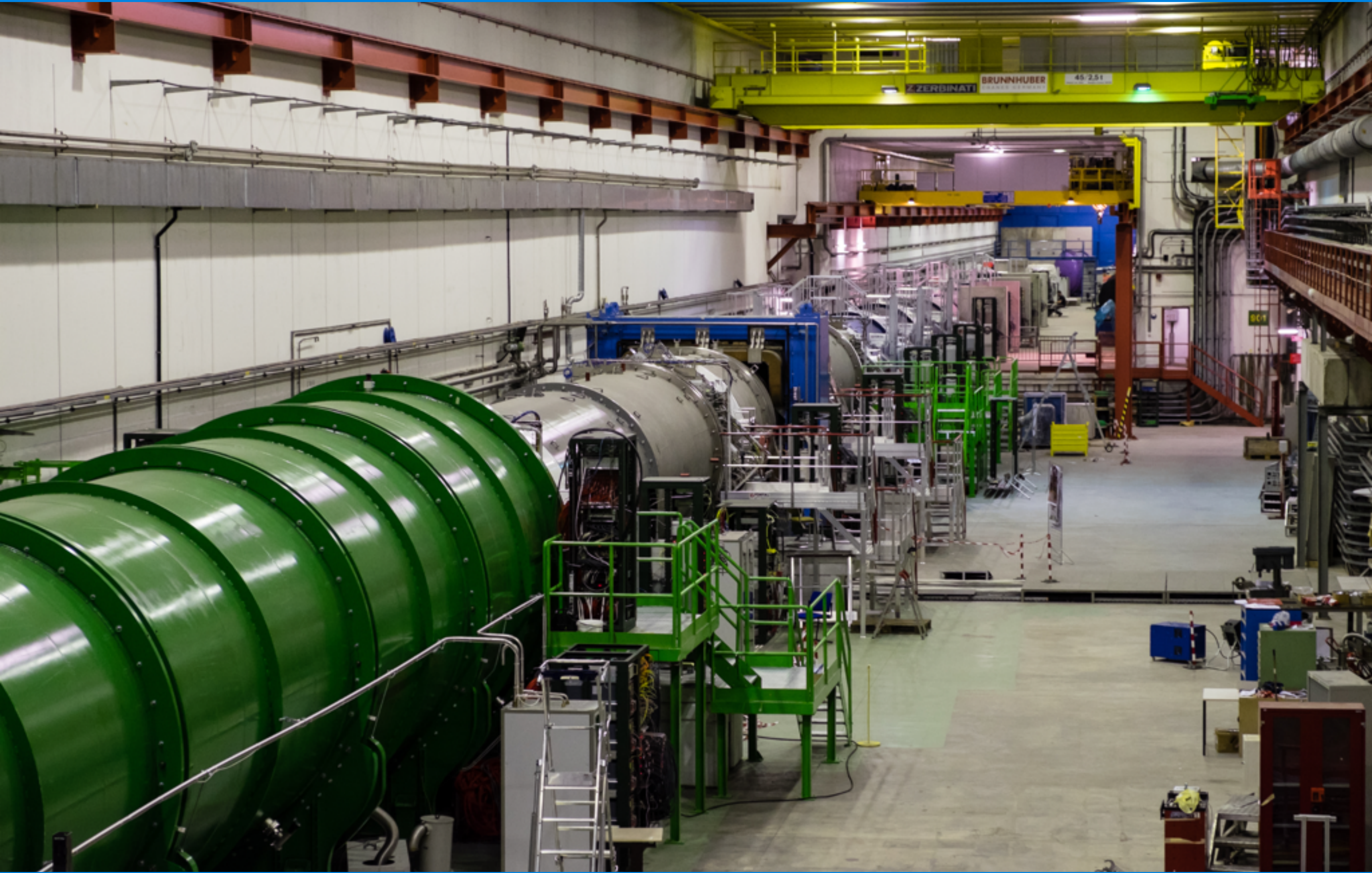
and can discriminate among NP scenarios:







NA62 Experiment



Experimental requirements

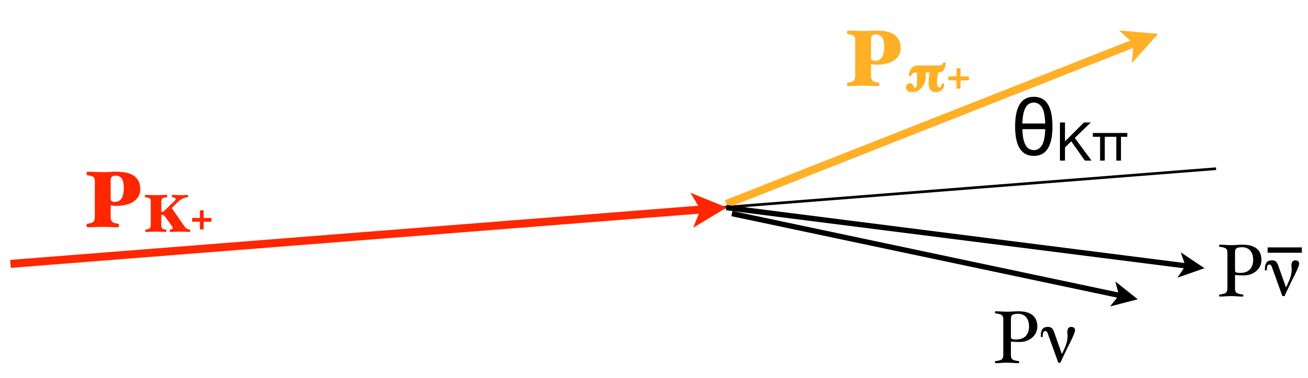
GOAL: measure BR($K^+ \to \pi^+ \nu\nu$) with 10% accuracy

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

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

Design criteria: **kaon intensity, signal acceptance, background suppression**

Decay in flight technique. Kaons with high momentum



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

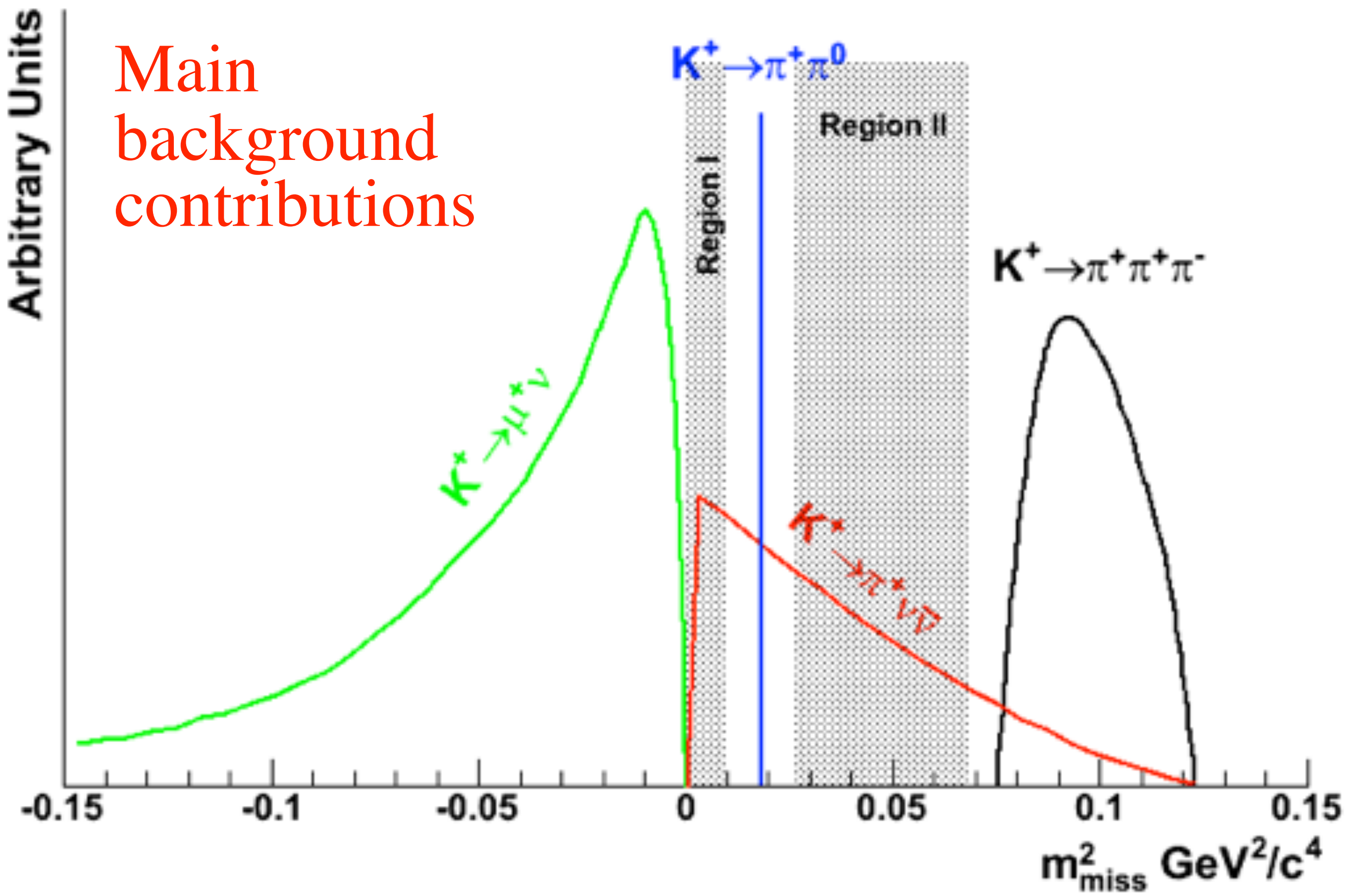
Basic ingredients:
precise timing, kinematic cuts, particle ID & hermetic photon vetoes

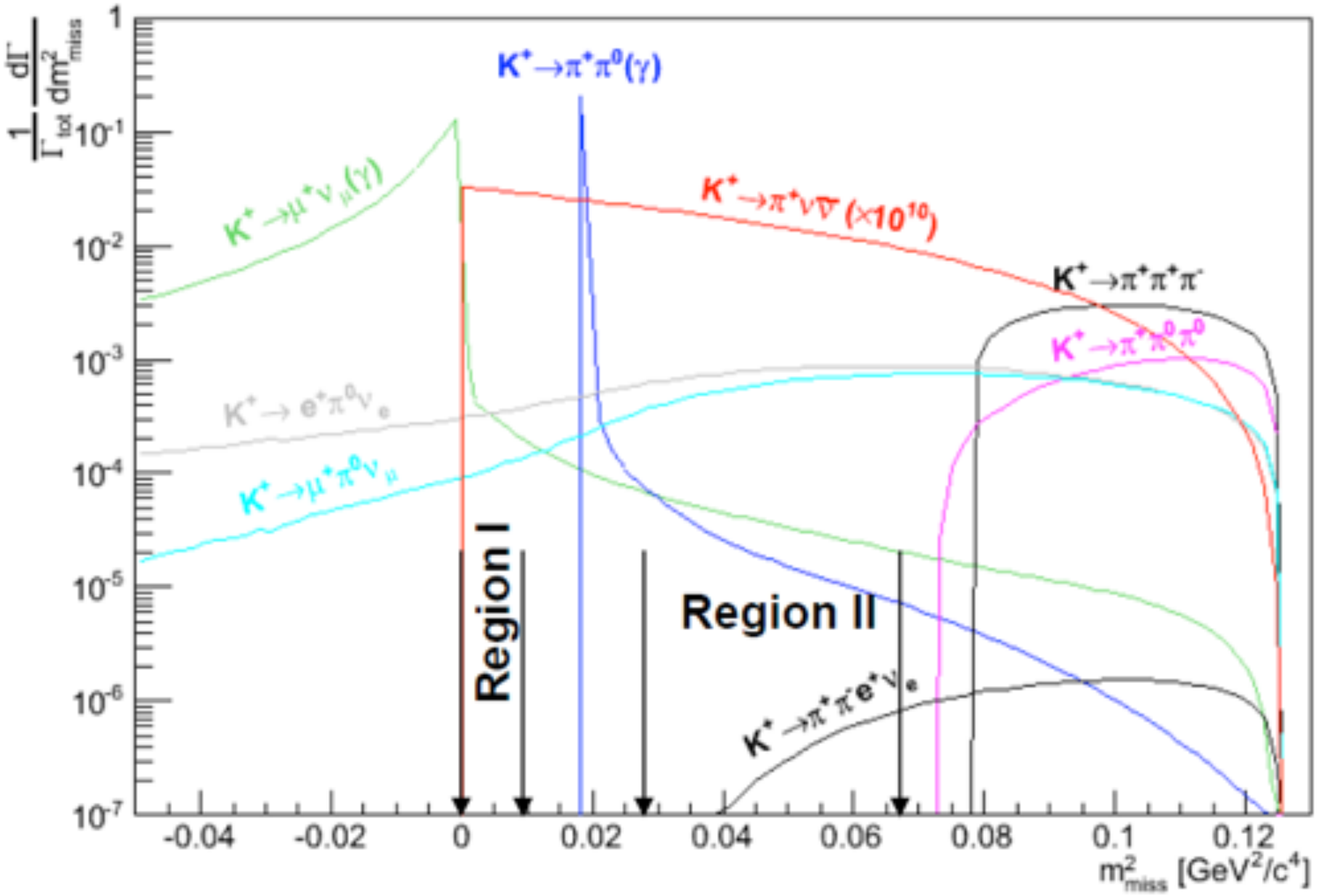
Analysis Strategy

Most discriminating variable:

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

Where the daughter charged particle is assumed to be a pion



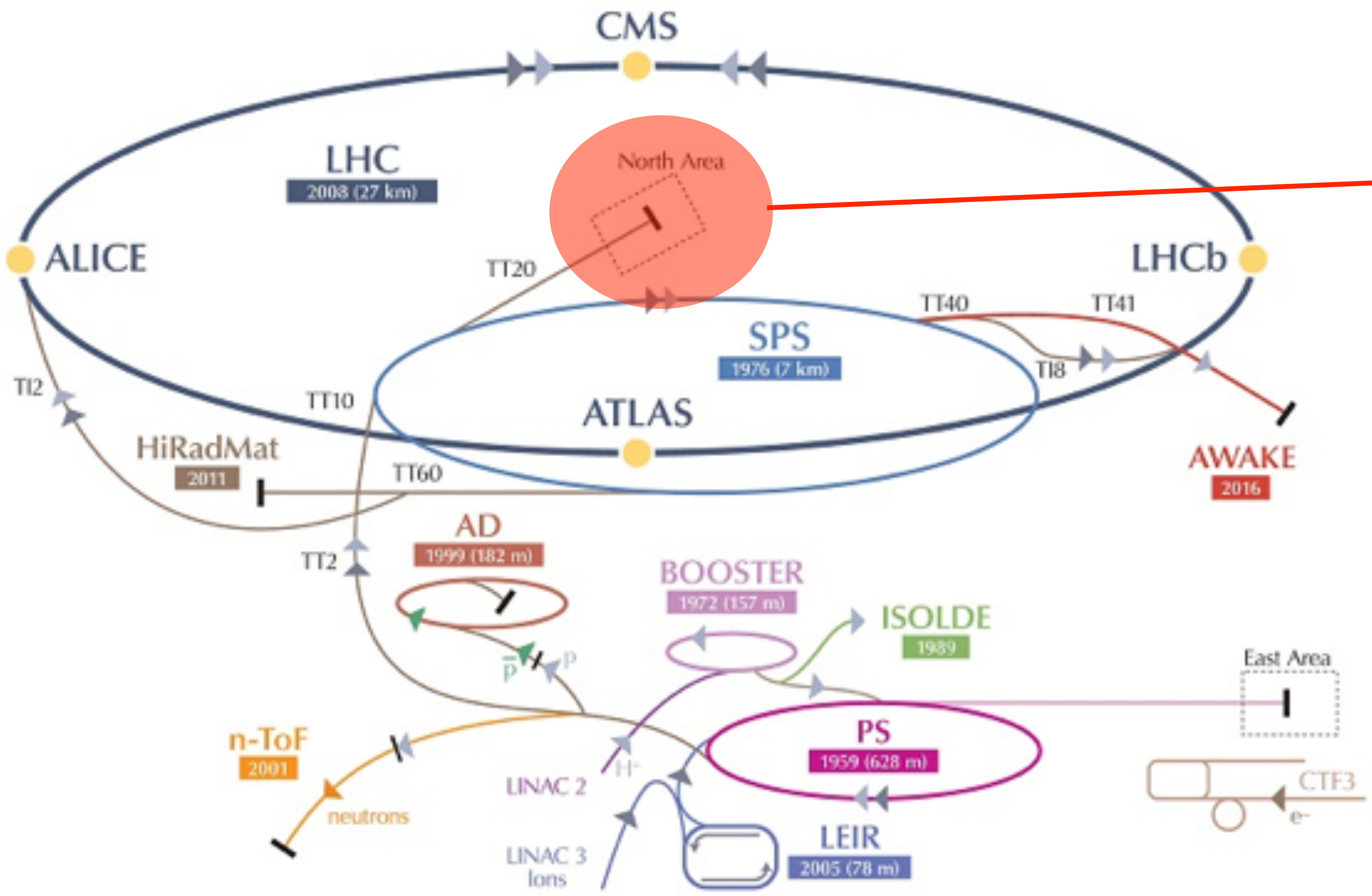


2 signal regions, on each side of the $K^+ \to \pi^+\pi^0$ peak, are chosen to eliminate background from dominant 2-body decays (84% of the K^+ width)

- $15 < P_{\pi+} < 35$ GeV/c
- 65 m long decay region

Kaon at CERN SPS

The **CERN-SPS secondary beam line** already used for the NA48 experiment can deliver the required K+ intensity



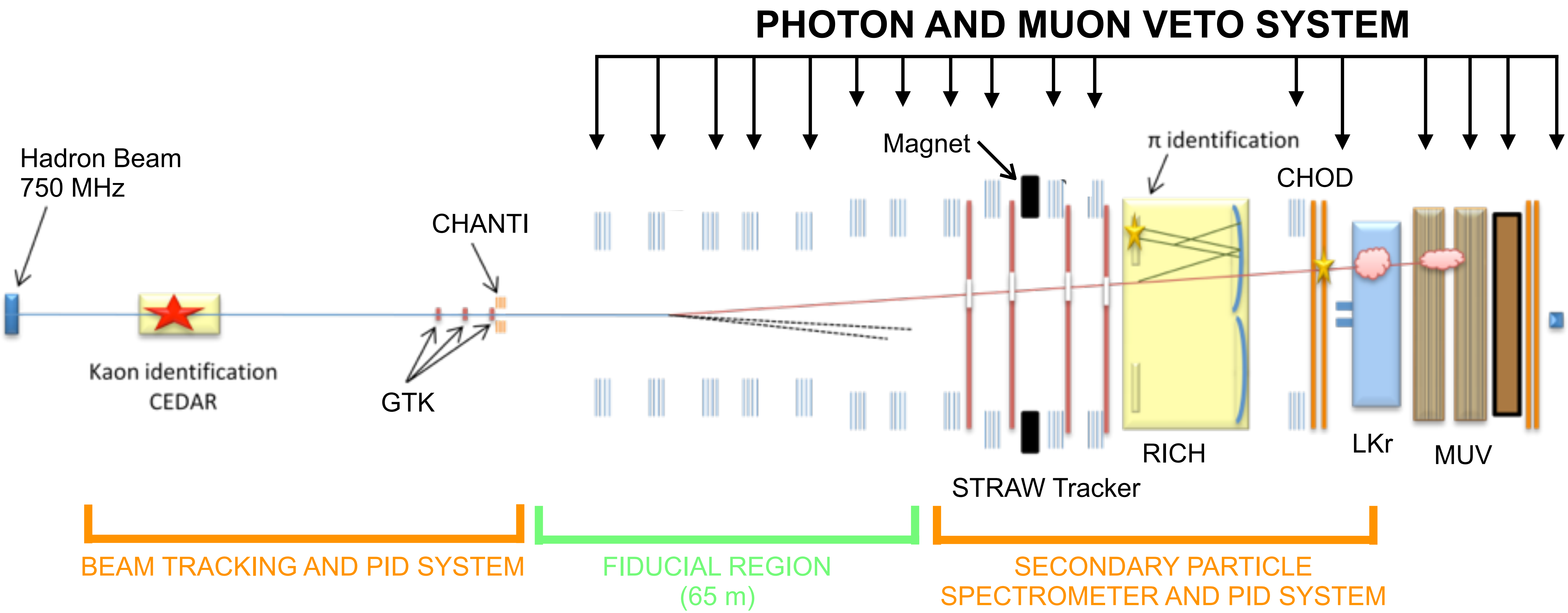
NA62 is housed in the CERN North Area. A new beam line will provide a secondary charged hadron beam 50 times more intense than in the past, with only 30% more SPS protons on target.

data taking foreseen till LHC LS2 (end 2018)

400 GeV/c protons impinge on a beryllium target and produce a secondary charged beam: **6% are K^+** (mixed with π and protons).
Signal acceptance considerations drive the choice of a **75 GeV/c K^+**
(1% momentum bite, ~ 100 μrad divergence)

NA62 Apparatus

270 m long region starting about 100 m downstream of the beryllium target. Useful K^+ decays will be detected in a **65 m long fiducial volume.**



Approximately cylindrical shape around the beam axis for the main detectors. Diameter varies from 20 to 400 cm.

The overall rate integrated over these detectors is ~ 10 MHz

NA62 LNF Group responsibilities

Full responsibility of
Large Angle Veto (LAV) and Small Angle Veto (SAV) detectors

- **Coordination** of the photon Veto System
- Construction and commissioning of the LAV system
- Front End electronics and Calibration system
- Monitoring, performance evaluation
- Experts during Data taking

L1 Trigger

- **Algorithm study and Monitoring**
- Experts during Data taking

Run Coordination

PHYSICISTS: Antonella Antonelli, Gianluca Lamanna, Gianpaolo Mannocchi, Silvia Martellotti, Matteo Martini, Matthew Moulson, Mauro Raggi, Tommaso Spadaro.
TECHNICIANS: Rosario Lenci, Vincenzo Russo, Massimo Santoni, Sauro Valeri, Tania Vassilieva, Giovanni Corradi, Diego Tagnani, Cesidio Capoccia, Aldo Cecchetti, Emilio Capitolo.

NA62 Status

✓	2006	Proposal
✓	2009	Approved
✓	2010	Technical Design
✓	2012	Technical Run
✓	2014	Pilot run
✓	2015-2018	Physics run

2014 Pilot Run

- Detectors only partially installed

2015 Run

- **All detectors installed and active**
- First L1 trigger algorithms tested
- **Beam commissioned up to nominal intensity**

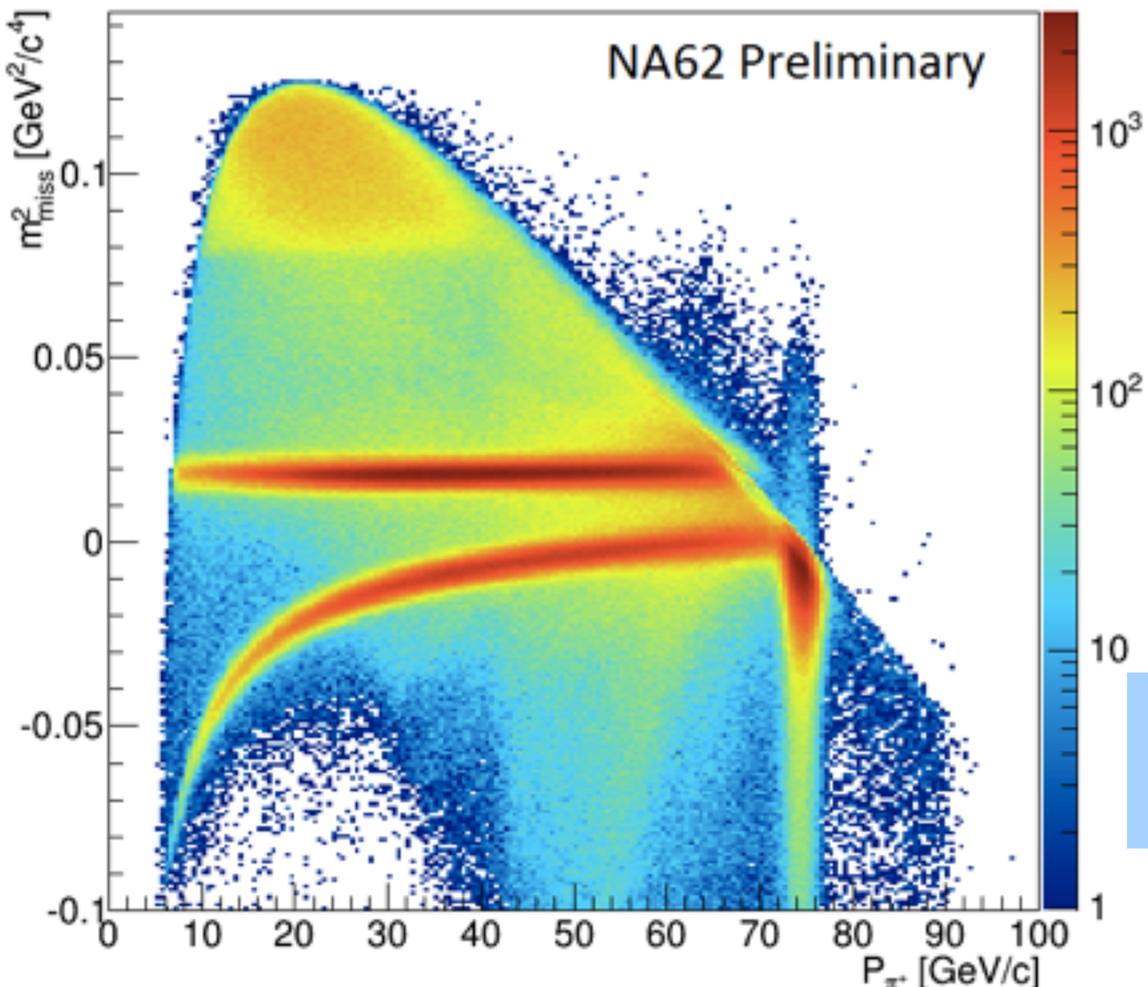
2016 Run

- Readout improvements to enhance stability at high rate
- Tracking included in L1 software trigger
- **Extensive running at 50% intensity for $K^+ \rightarrow \pi^+\nu\nu$ and secondary programs**
- **Readout tested up to 80% intensity**

Results timescale:

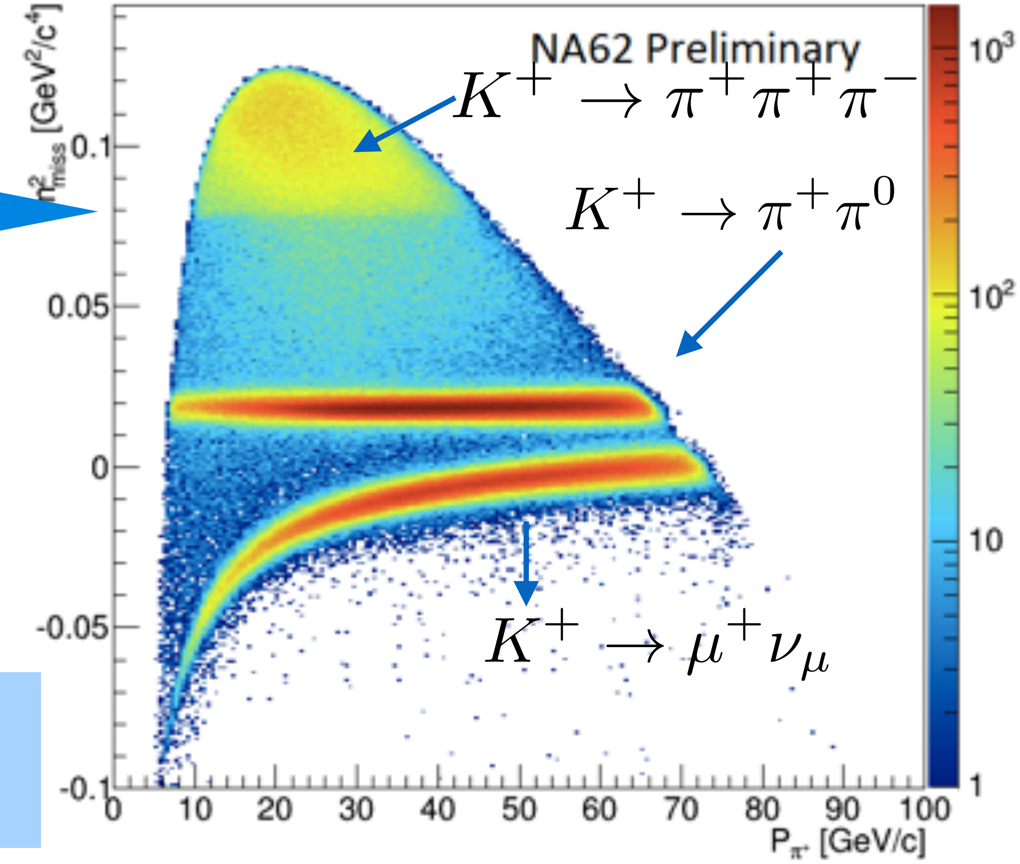
- 2016 data: reach SM-expectation sensitivity $O(10^{-10})$
- End of 2017 run: improve (by much) on the present state of the art (BNL measurement)
- End of 2018 run: measurement of BR at 10%

2015 Data: Signal topology and Kaon ID

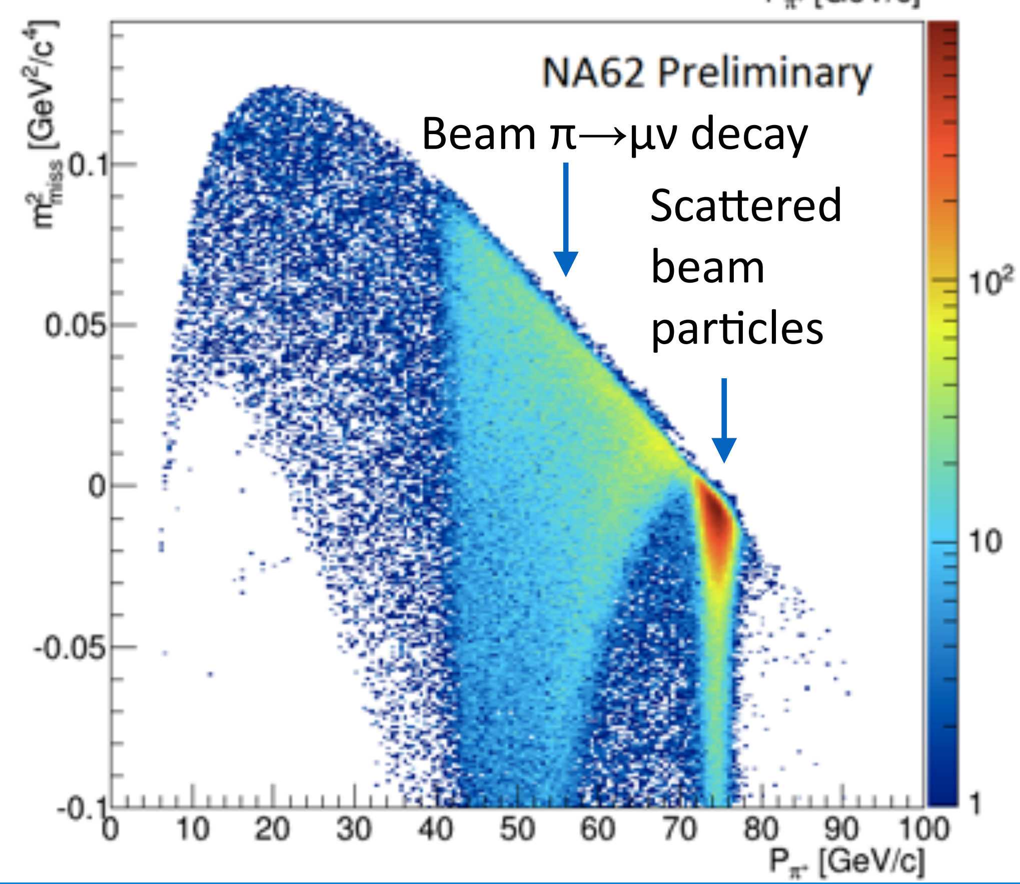


With Kaon ID matching

Track origin in the fiducial region



Anti-coincidence with a Kaon track



One track selection

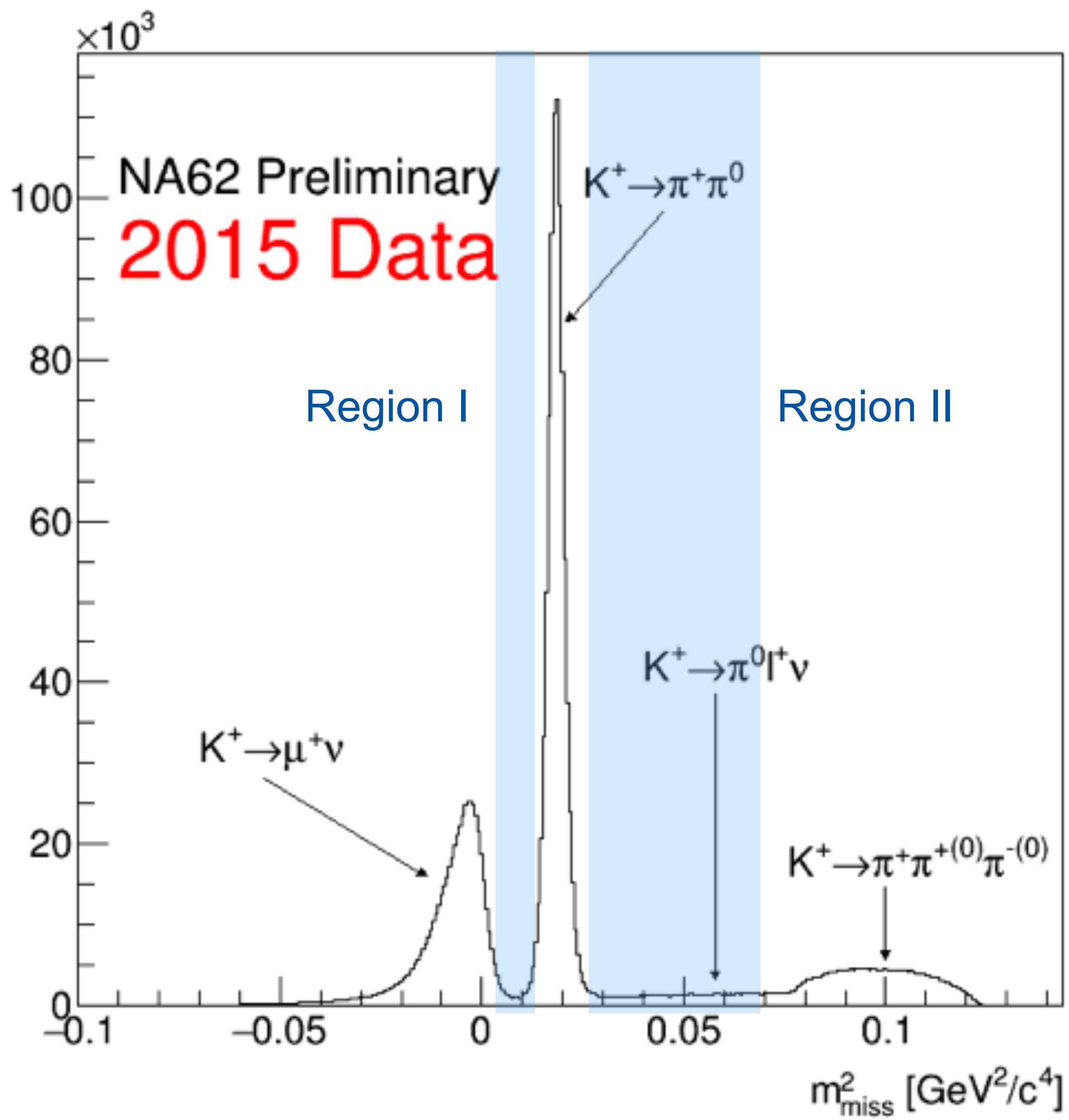
- Single downstream track
- Beam track matching the downstream track
- Beam track matching a K^+ signal in Kaon ID
- Downstream track matching energy in calorimeters

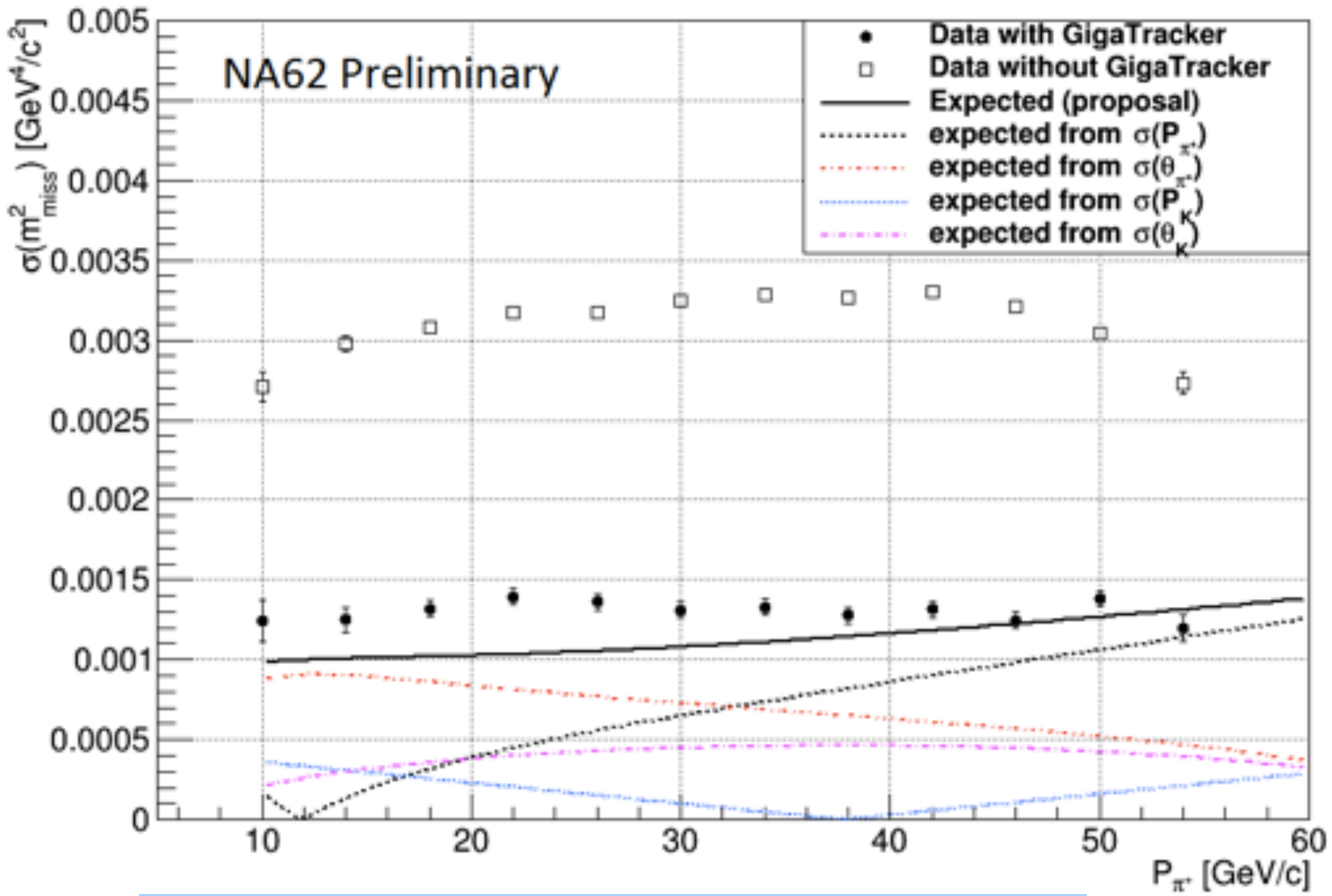
Time resolutions

- Kaon ID < 100 ps, downstream track < 200 ps
- Calorimeters < 1-2 ns

2015 data: Kinematics $m^2_{miss} = (P_K - P_{\pi+})^2$

GOAL: $O(10^4)$ suppression factor of the main K^+ decay modes





Resolution near to design value

Selection

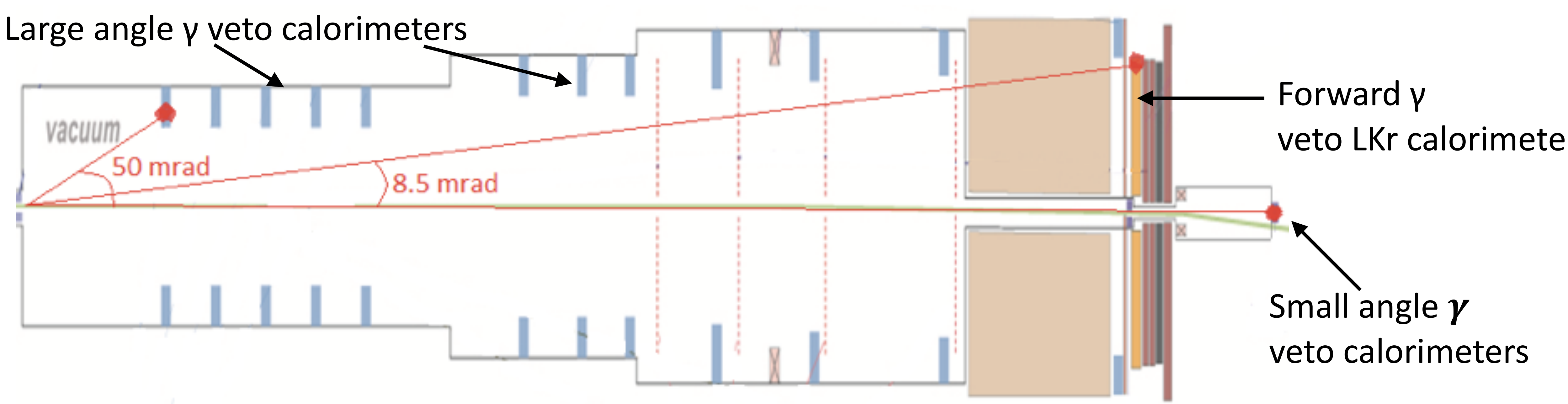
- Kaon identification
- One secondary track identification
- Vertex reconstructed in the fiducial region (105 m < Z_{vertex} <165 m)
- $P\pi^+$ < 35 GeV/c (best $K^+ \rightarrow \mu^+\nu$ suppression)

$O(10^3)$ kinematic suppression factor in 2014

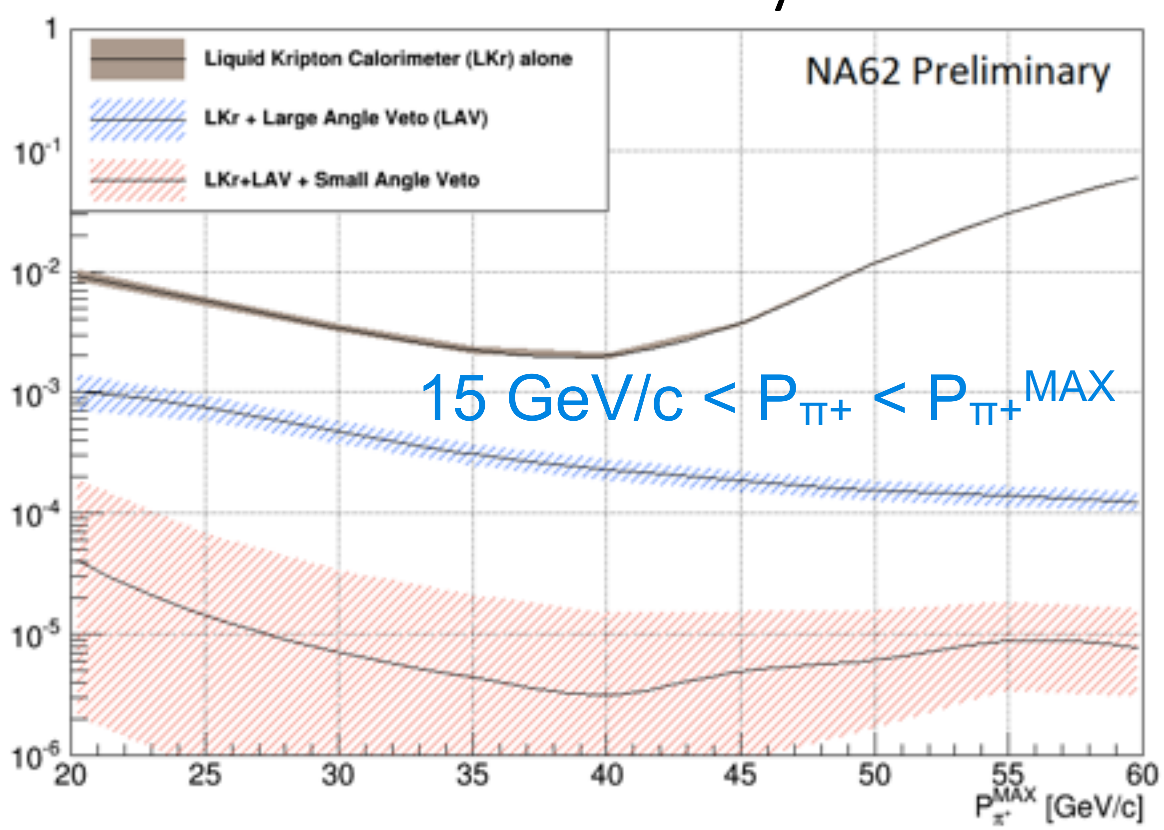
$K^+ \to \pi^+\pi^0$ rejection

$BR(K^+ \to \pi^+\pi^0) = 21\%$

GOAL: $O(10^8)$ rejection power of π^0 from $K^+ \to \pi^+\pi^0$



Overall π^0 veto inefficiency:



$P_{\pi+} < 35$ GeV/c $\to E_{\pi 0} > 40$ GeV

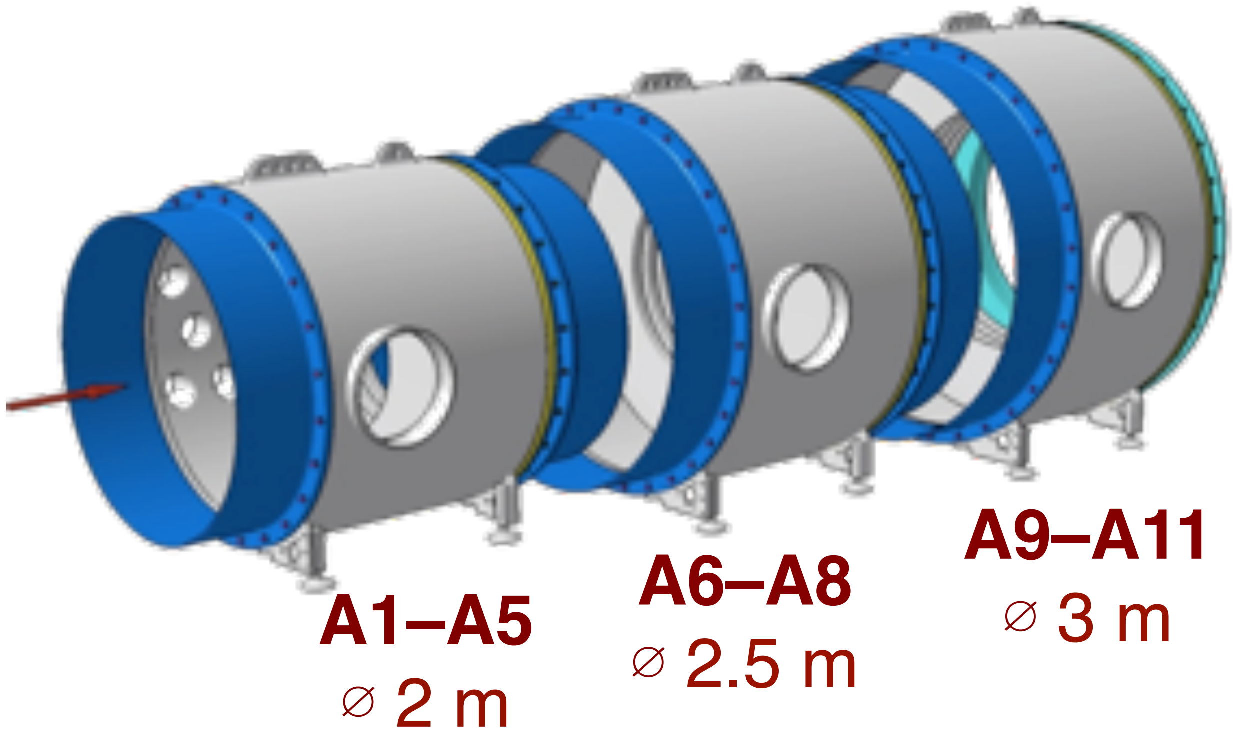
- efficiency measured on data using $K^+ \to \pi^+\pi^0$ selected kinematically
- $O(10^6)$ π^0 rejection already obtained

2015 measurement statistically limited, minimum bias data

Large Angle Photon Vetoes: LAV

LNF: Design, assembly and installation of 12 LAV stations.

Placed along 120 m decay region. Angular coverage: $8.5 < \theta\gamma < 50$ mrad.

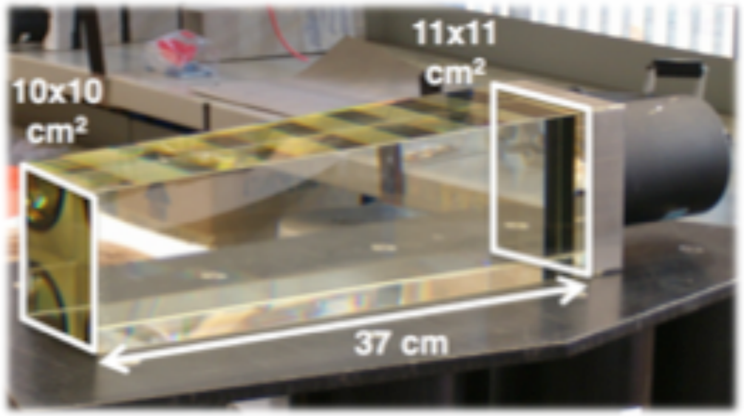


Each LAV station is made of 4 or 5 rings of lead glass crystals (from OPAL) with attached PMTs.

Expected performance:
- 10^{-4} inefficiency on γ down to 200 MeV
- 1 ns time resolution

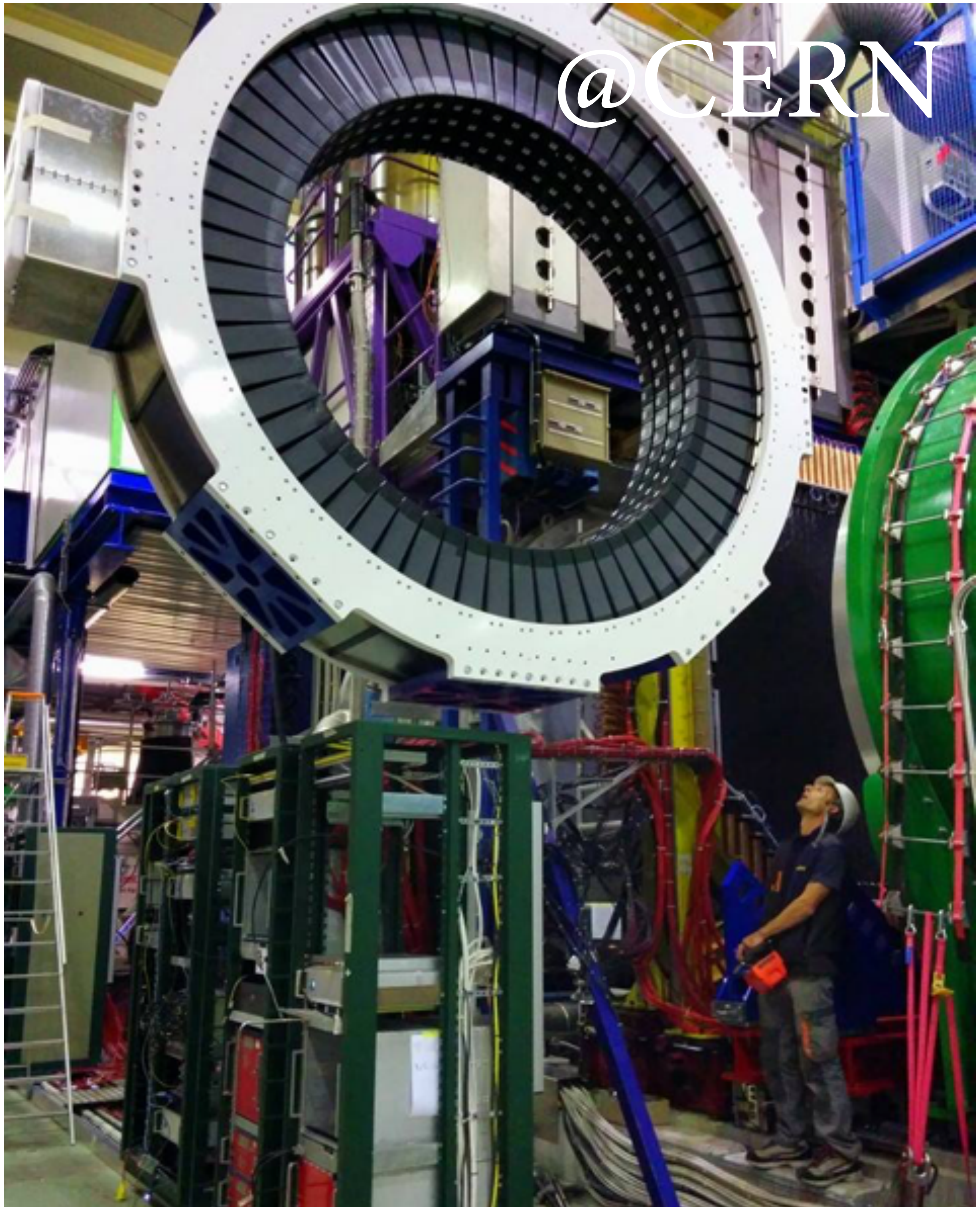
Design, production, and validation of the final FEE board

TDC-based readout with TOT measurement. Rate capability 1 MHz



2500 crystals (Schott SF57 lead glass) with R2238 76-mm PMT µ-metal case

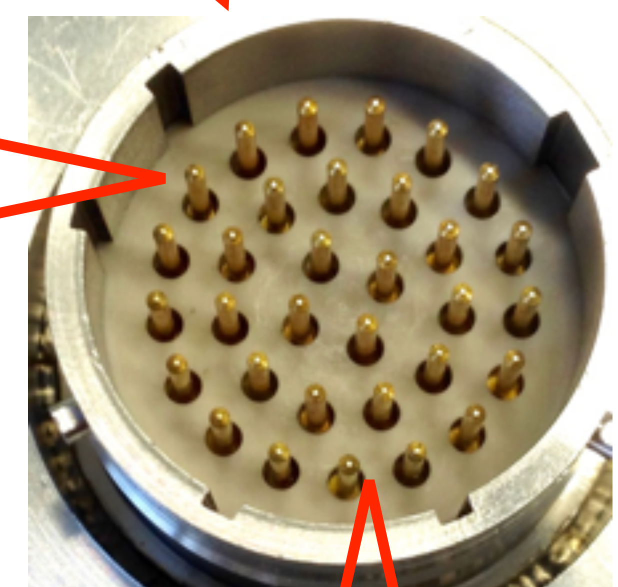
LAV construction at LNF 2008-2014



Installation finished in August 2014 with LAV12. On schedule.

HV intervention

32 pin: HV supply for PMTs



pin base in PEEK

11/12 LAV stations are in vacuum

During 2015 Run the HV vacuum feedthrough suffered from **breakdown**

HV vacuum flanges have been redesigned and substituted during the 2016 shut down

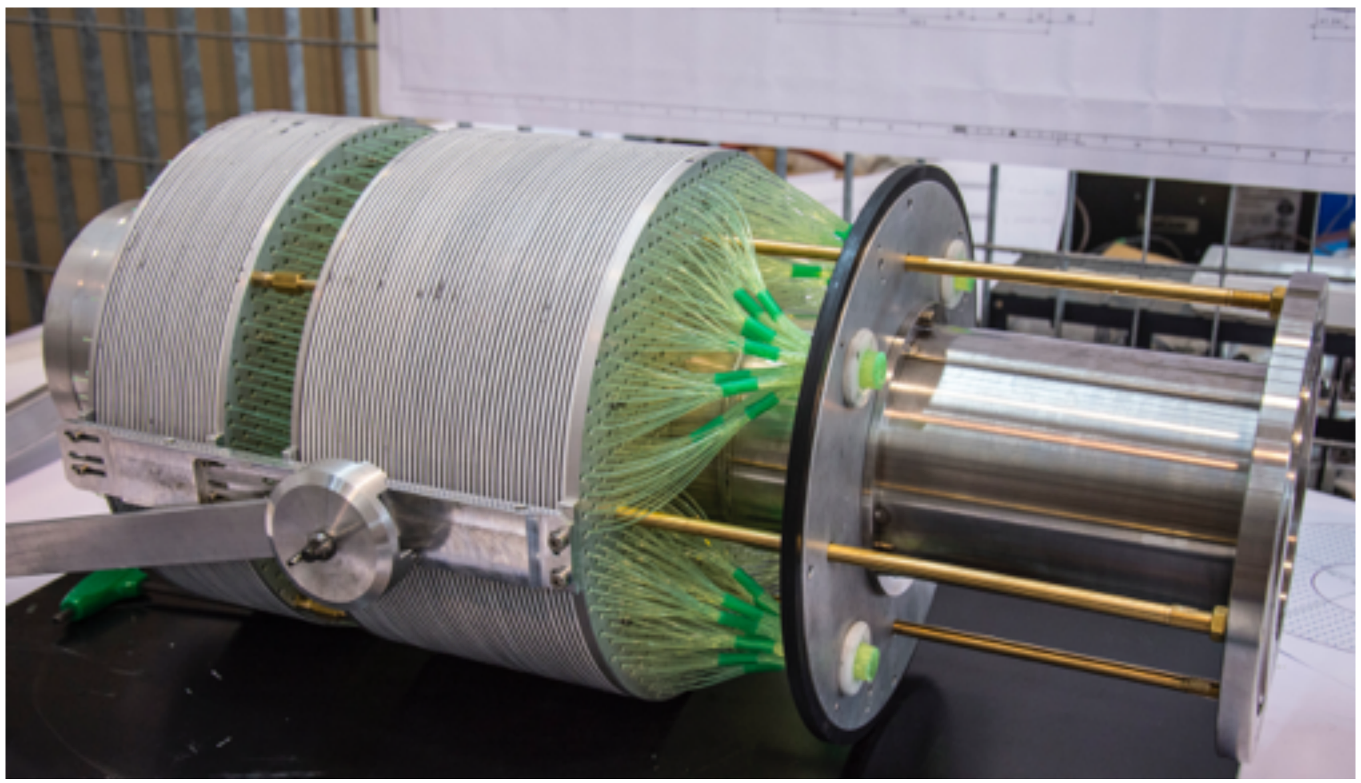
Custom feedthrough developed by us
in collaboration with industry.

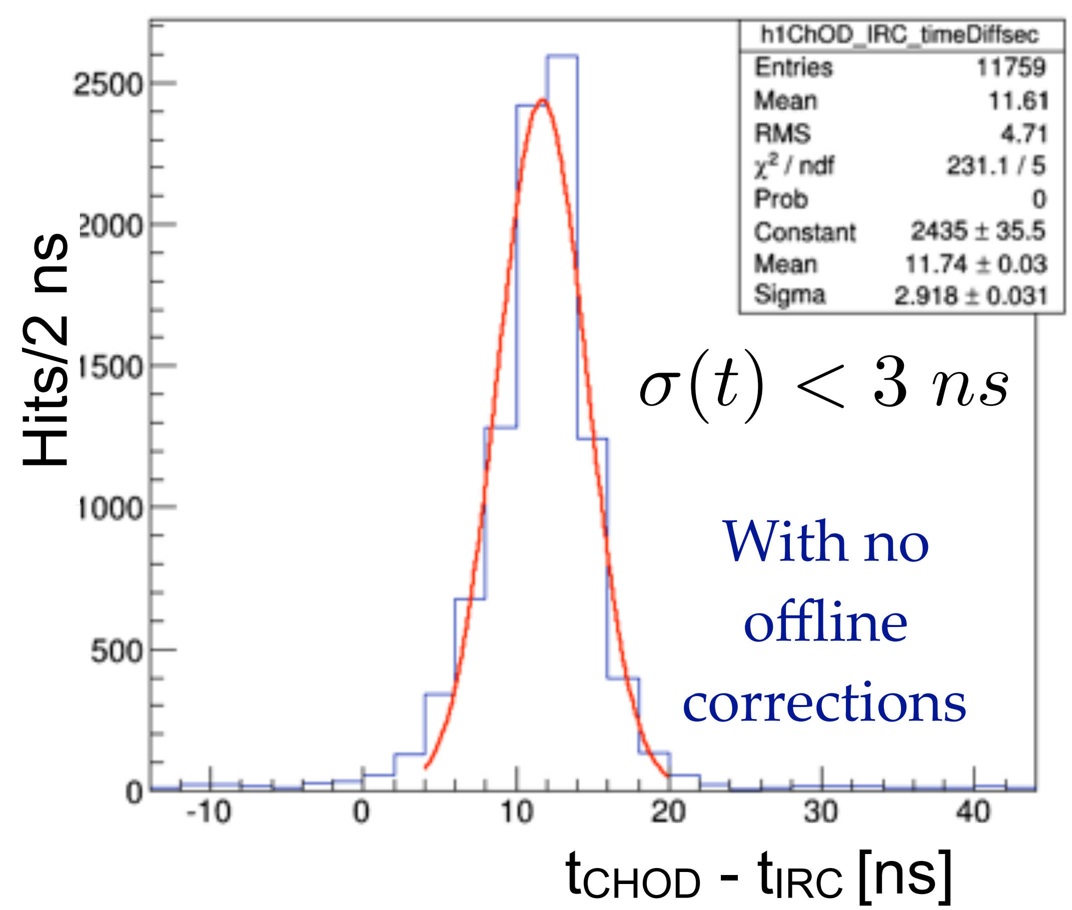
Small Angle Photon Veto: IRC

Entirely realized at LNF with collaboration from Sofia.

Inner Ring Calorimeter (IRC). Angular coverage: $\theta\gamma < 1$ mrad.

Shashlik calorimeters with lead/plastic scintillator plates





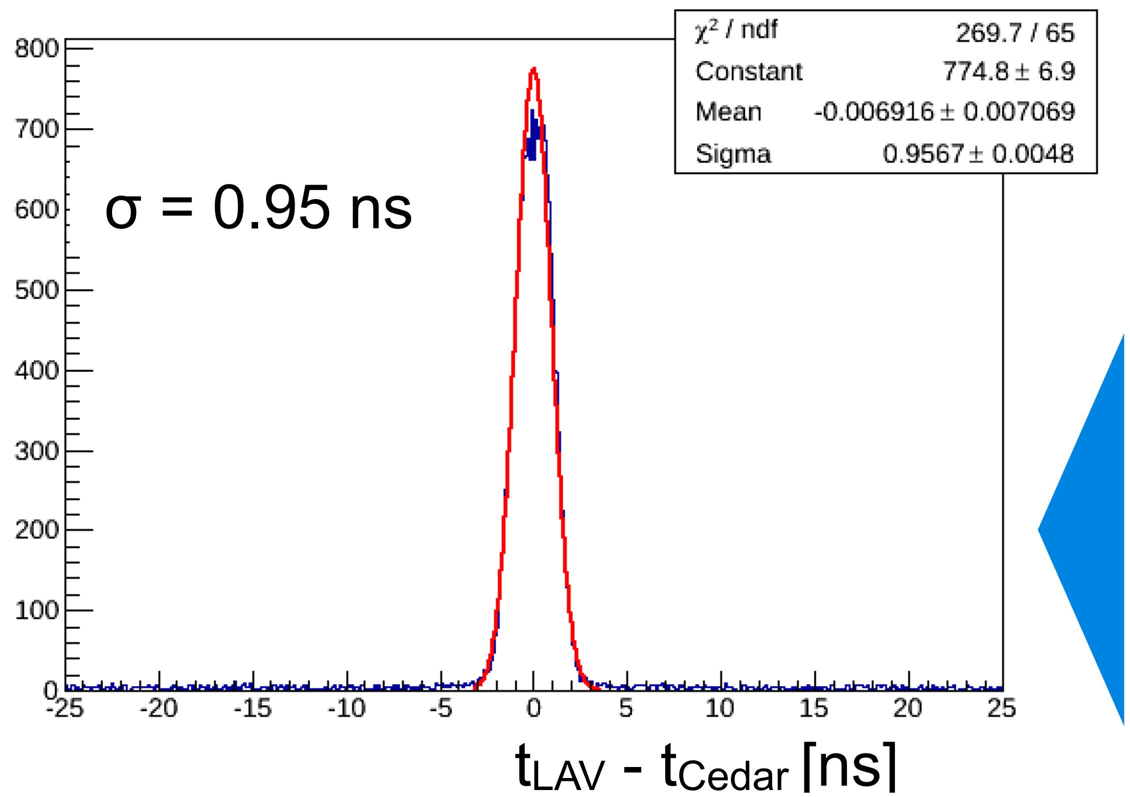
Expected performance:

- 10^{-4} inefficiency on E > 1 GeV photons
- few ns time resolution
- Rate Capability Few MHz

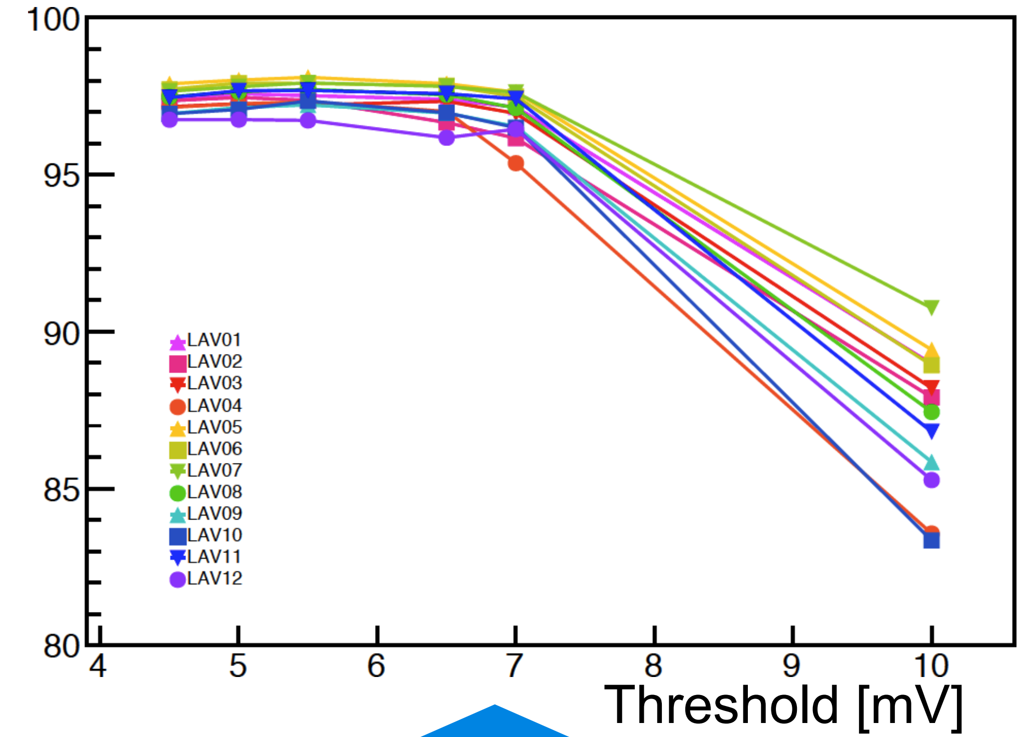
LAV performance

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

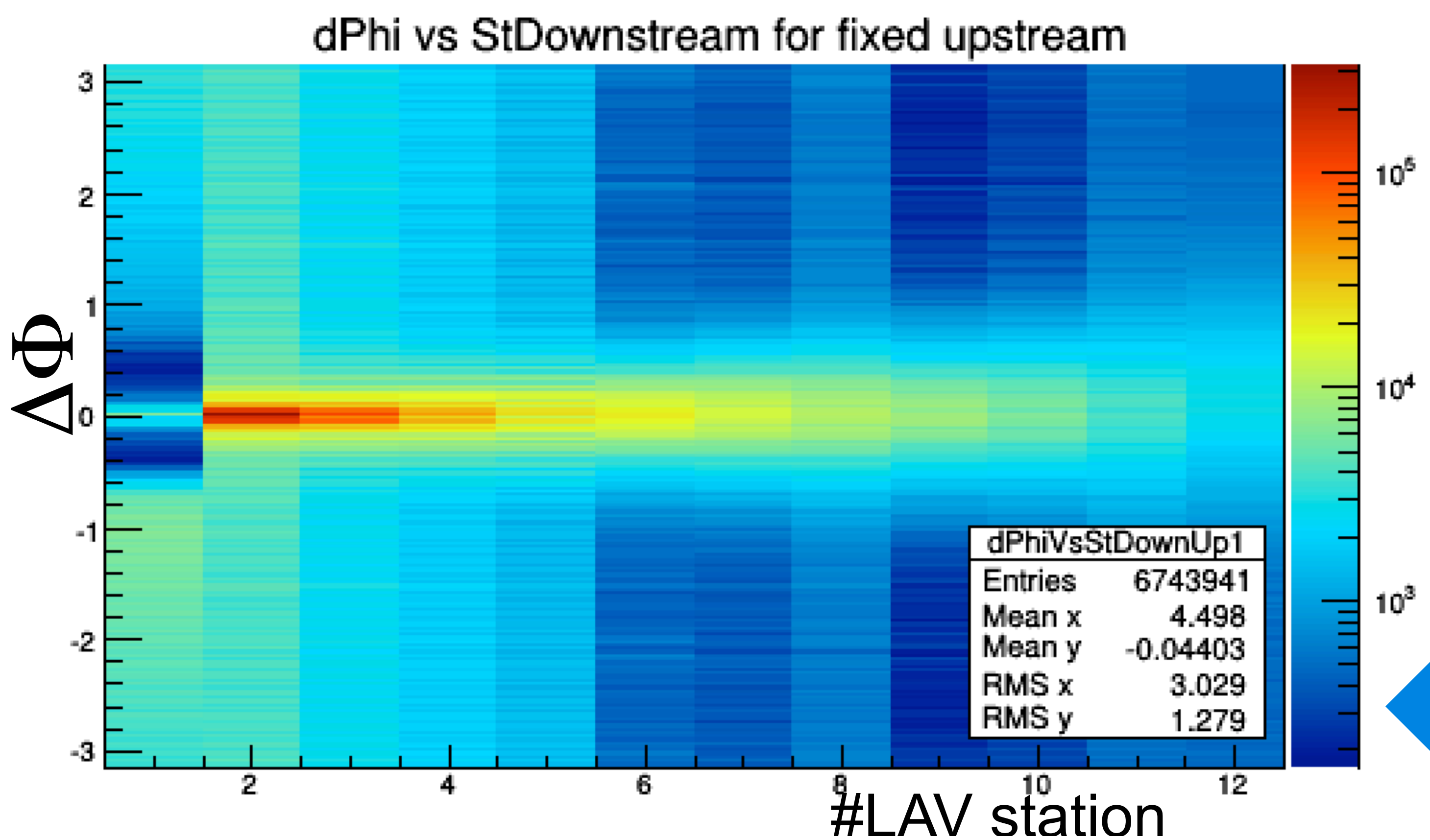
Design performance achieved



Time alignment after slewing correction



Muon efficiency vs threshold

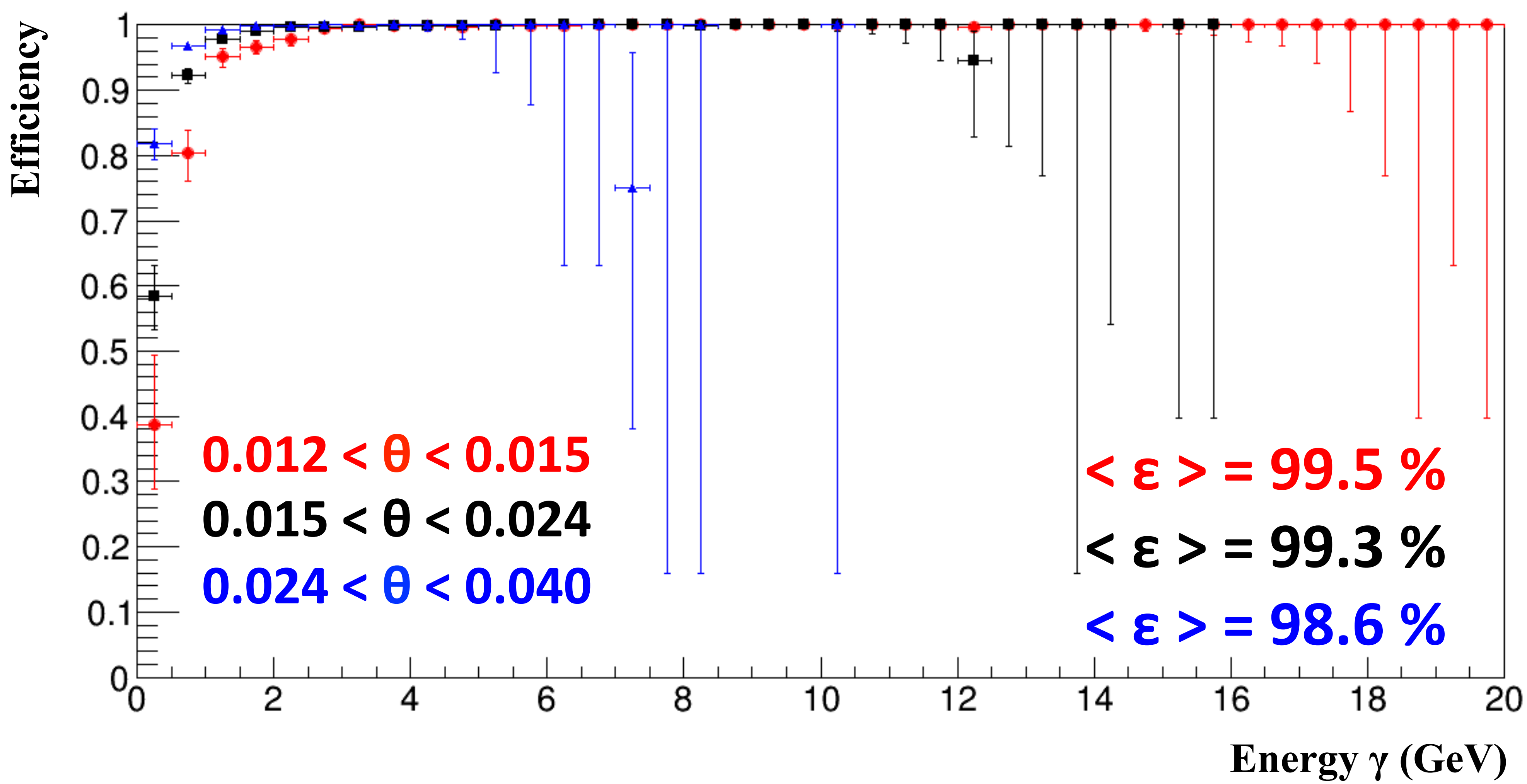


Tracks from halo muons crossing many stations (hits clusterized in time)

LAV photon efficiency

Intrinsic detector inefficiency for photons evaluated with **tag and search method**

From $K^+ \rightarrow \pi^+ \pi^0$ events



- Good K identification
- 1 Good-quality secondary track
- 1 and only 1 cluster (γ from π^0) in time in the LKr
- Cut on the missing mass to select $K^+ \rightarrow \pi^+ \pi^0$ events

K^+, π^+ and 1 γ reconstructed in LKr with the 2nd γ expected to hits LAVs.
A hit is found if at least 1 block is fired within 5 ns of the expected time.

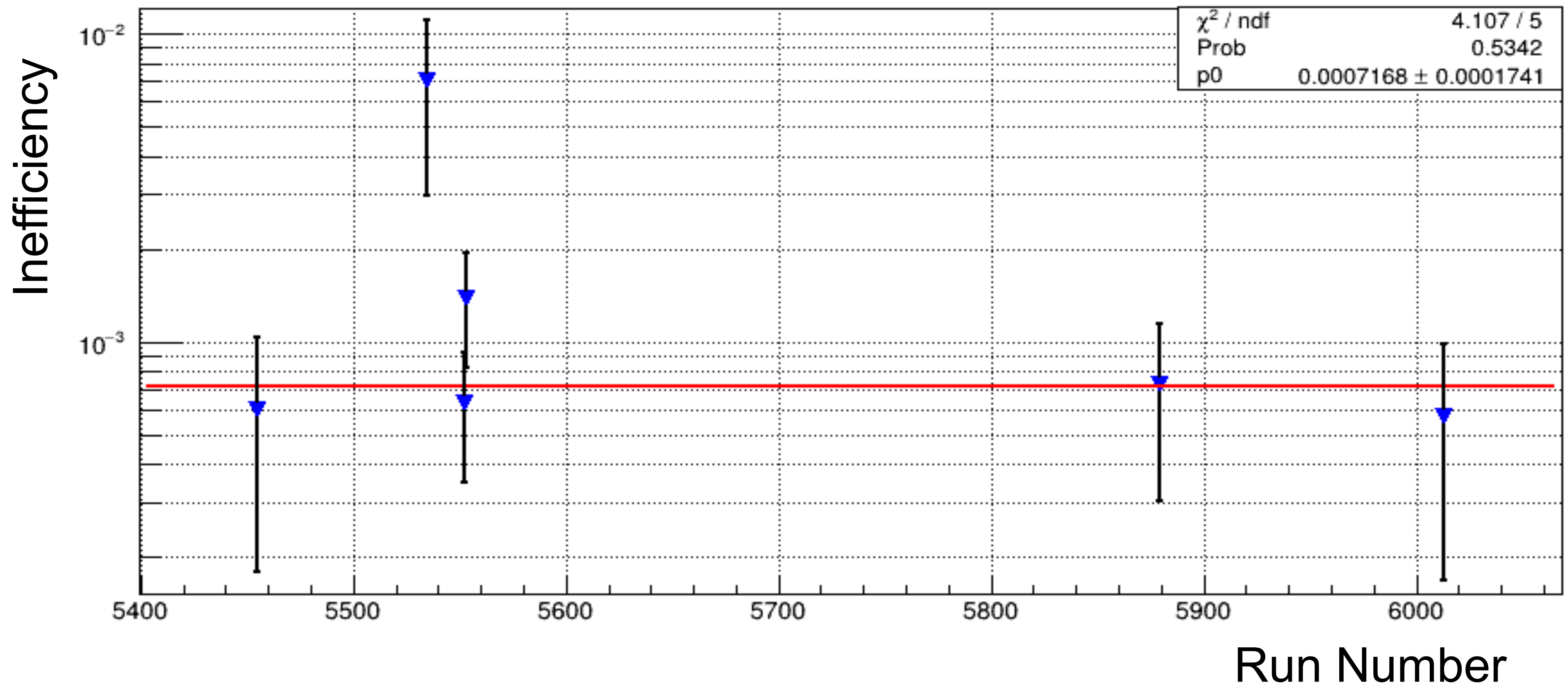
MC study shows that <1/6 of the apparent inefficiency is due to LAV itself

In MC: **< ε > = 99.7%, < ε > = 99.4%, < ε > = 98.2%.**

Small Angle photon efficiency

Small Angle calorimeters inefficiency for photons evaluated with **tag and search method**

From $K^+ \rightarrow \pi^+ \pi^0$ events



K^+, π^+ and 1 γ reconstructed in LKr with the 2nd γ expected at small angle.

Inefficiency:
~ 7×10^{-4}
Stable with the data taking.

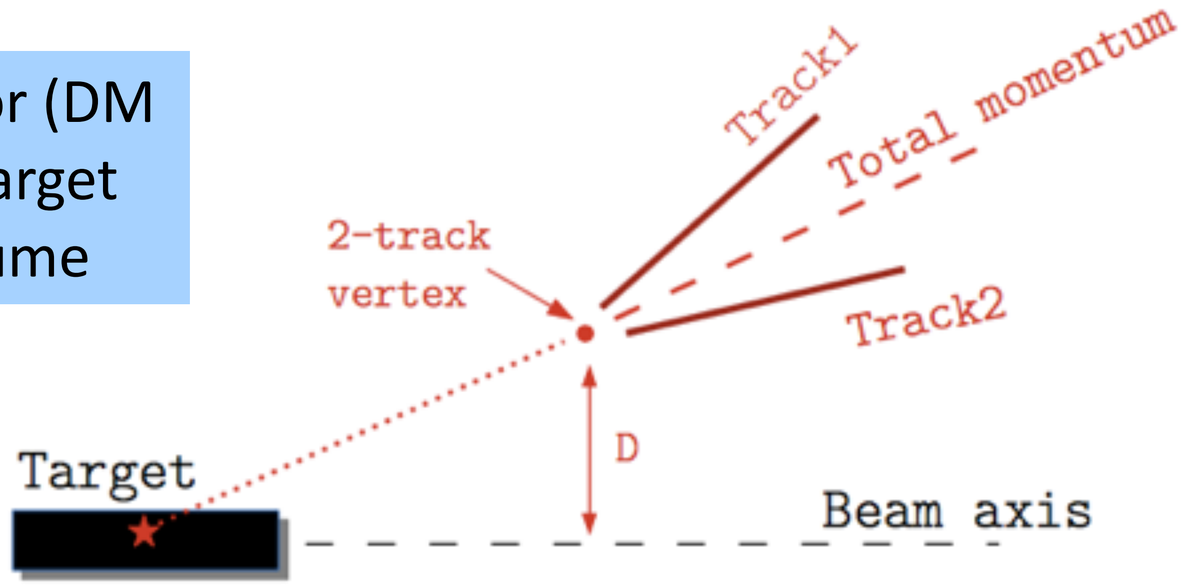
Preliminary

Exotic searches at NA62

Beside $K^+ \to \pi^+ \pi^0$, thanks to the high beam intensity, NA62 can do further searches for other K decays and not only

Long-lived exotic particles from Hidden Sector (DM candidates) may be created in the proton-target interaction and reach the NA62 decay volume

Assuming DM decays to SM particles with universal coupling, we can be sensitive to possible mediator-SM interactions:



1) Heavy Neutrinos (Neutrino portal HN') with mass up to the D meson

- **HN'$\to \pi e$, HN'$\to \pi\mu$**: two, oppositely-charged, in-time, tracks reconstructed as originating from the 60-m long fiducial volume, one-lepton final states.

2) Dark Photon (Vector Mediator A') with mass below (above) 600 MeV

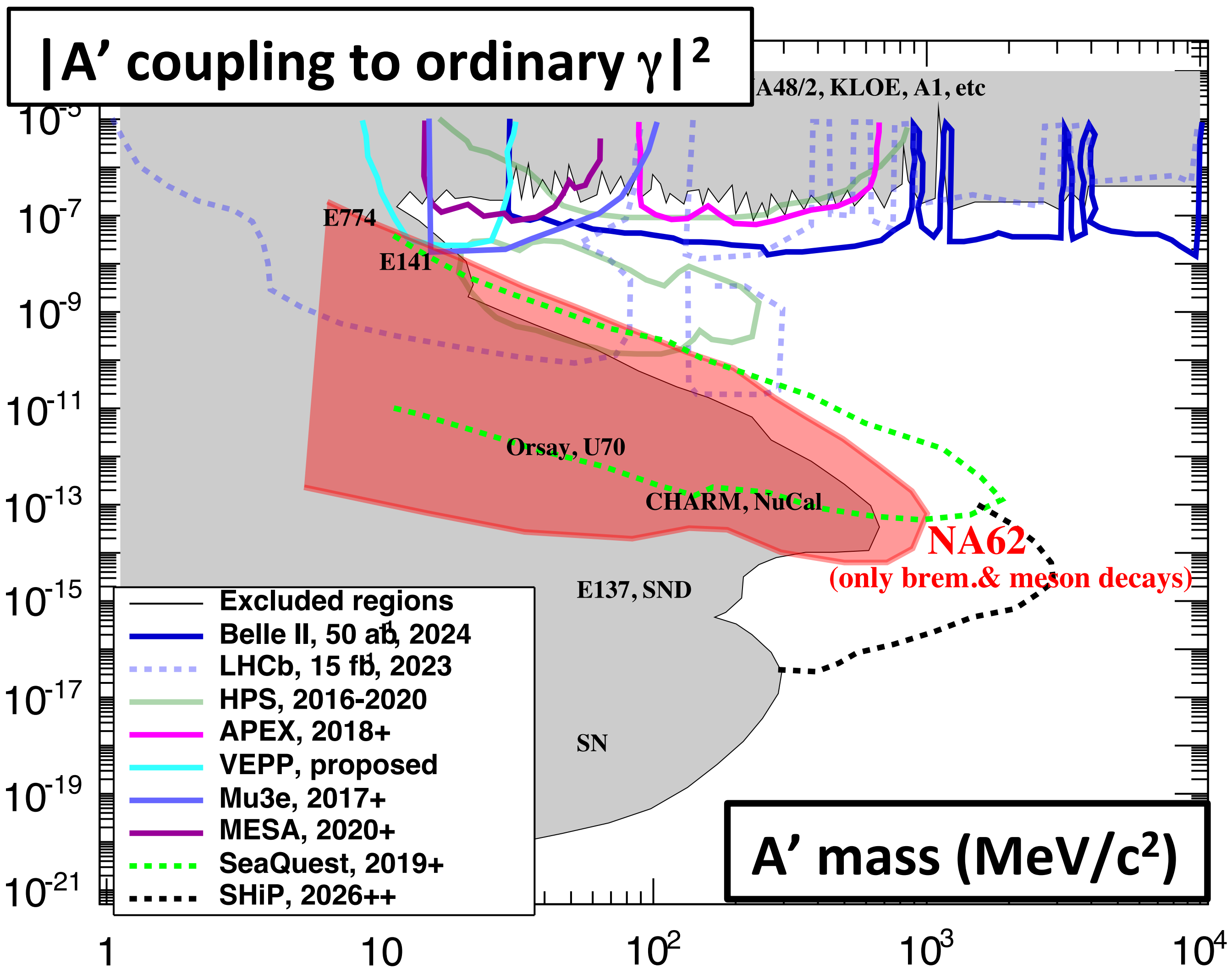
- **A'$\to e^+e^-$, A'$\to\mu^+\mu^-$**: two, oppositely-charged, in-time, tracks reconstructed as originating from the 60-m long fiducial volume, two lepton final states.

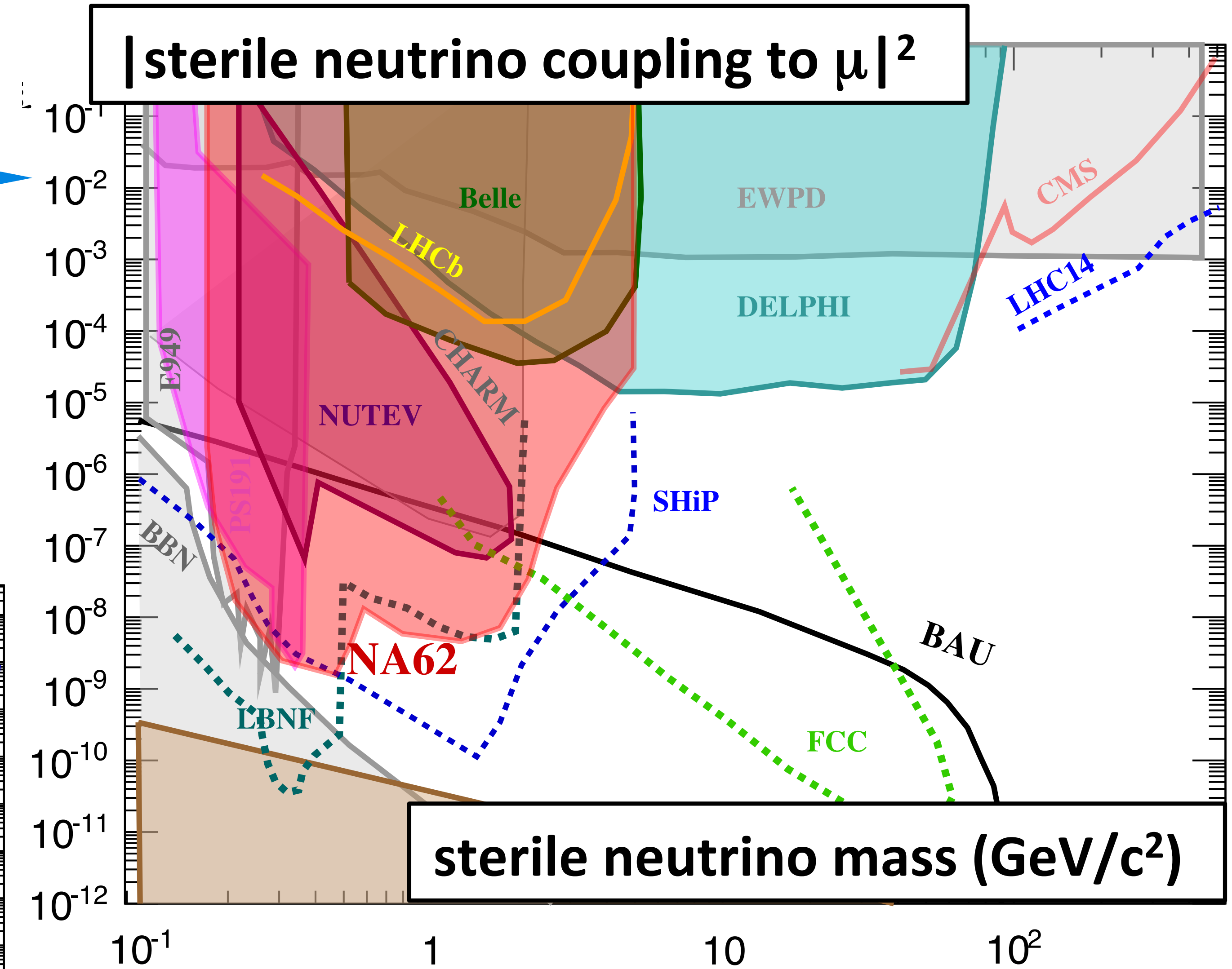
Exotic searches at NA62

Sensitivity studies

Sensitivity for exclusive search with 2×10^{18} POT (2 years of data taking)

MC demonstrate that NA62 can achieve interesting results





Future Sensitivity studies ongoing:

- In dump-mode regime
- With a minimally-modified beam line
- With a minimally-upgraded detector

Exotic searches at NA62

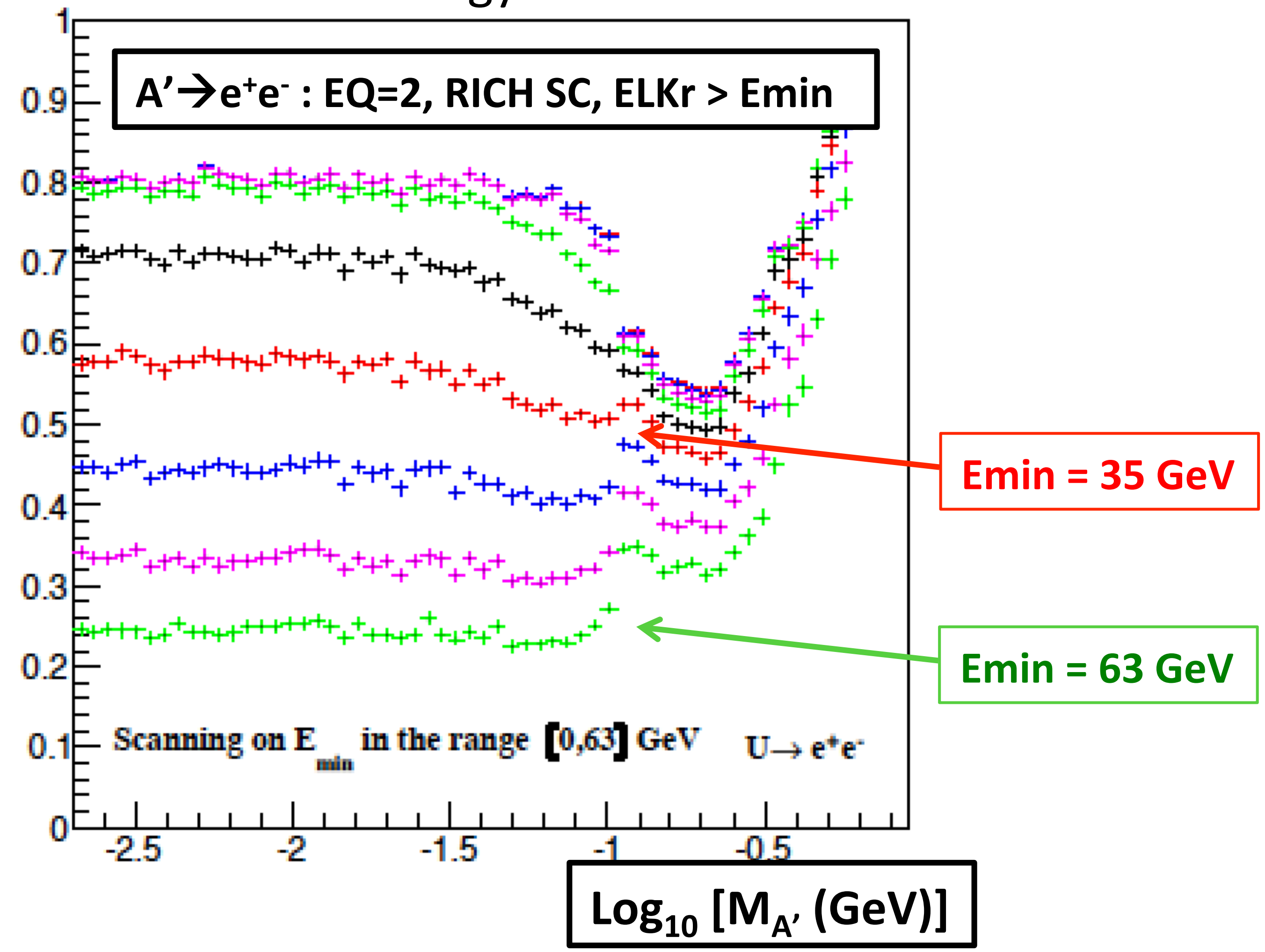
Frascati group is currently coordinating Hidden Sector searches

NA62 trigger:
L0 (FPGA): from 10 MHz to **1 MHz**
L1 & L2 (software): from 1 to MHz to **10 kHz**

Parallel trigger masks to detect possible dark-matter-decay final states has been developed: high efficiency, negligible efficiency reduction for the main stream

Various additional trigger streams have been tested and are under study.
Conditions suited for:
A'→μ+μ-, A'→e+e-, HN'→eπ, HN'→μπ

A'→e+e- Trigger efficiency for different LKr energy thresholds:



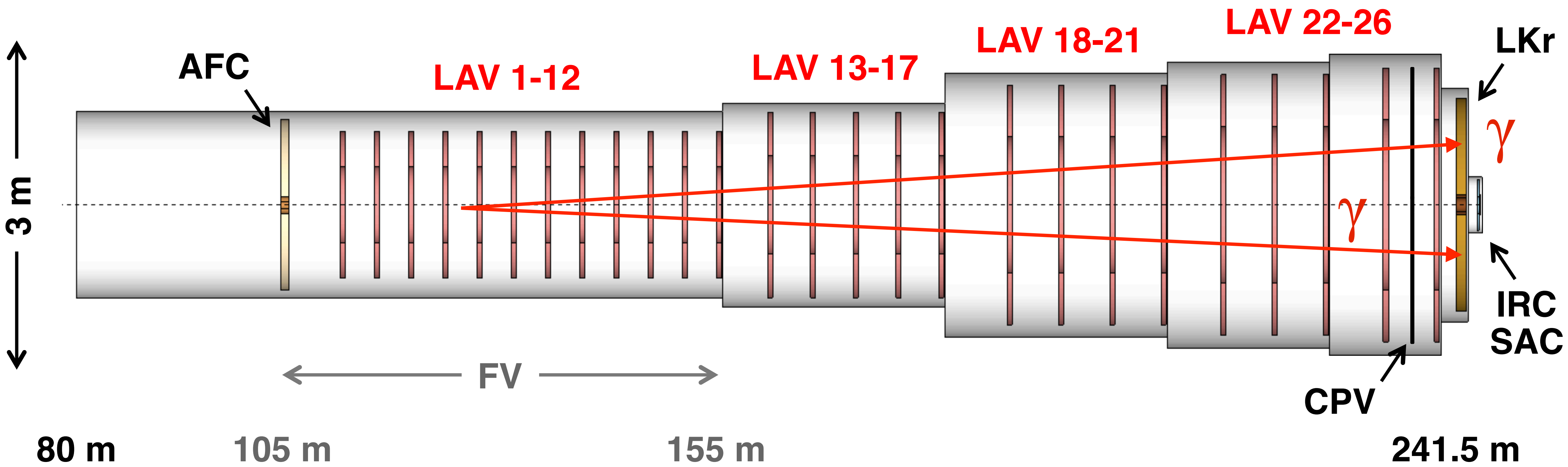
MC Study for the expected backgrounds evaluation are currently underway

- Expected background from K^+ and K_S, K_L decays
- Combinatorial background from beam HALO

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

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

Frascati group is coordinating the activities started with a PRIN project



Operate in ECN3 and make use of the NA48 LKr calorimeter as primary veto.
In 5 years of running (10^7 s/yr) at a beam intensity of 2×10^{13} pot/16.8 s
(6x of NA62, Target area and transfer lines would require upgrades):

65 $K_L \to \pi^0 \nu\nu$ events are expected with S/B ~ 1

Conclusion and What Next

- LAVs, IRC and SAC photon veto detectors meet design expectations. Efficiency and performance evaluation will be improved

- NA62 experiment is running and collecting data
  - Physics sensitivity for $K^+ \rightarrow \pi^+ \nu\nu$ measurement in line with the design.
  - A further compelling physics program is going to be addressed.
  - Analysis of data at high intensity is on going.

- LNF important role in the future plans beyond NA62:
  - Performance estimate (acceptance, background) for a hypothetical setup for $K_L \rightarrow \pi^0 \nu\nu$ measurement
  - Perspectives from NA62 and beyond for dark matter searches

Both presented at Physics Beyond Collider Workshop at CERN.