NA62 experiment

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- Trigger
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Kaon physics at CERN

- Charge-Parity (CP) symmetry violation
  - – NA31 (1986-89) - first evidence of direct CP violation
  - – NA48 (1997-2001) – confirmation

The NA48 experiment at CERN has recently obtained the final result on the ε'/ε parameter, that quantifies direct CP violation in the $K^0 - \bar{K}^0$ system. The total data sample, acquired during five years of data-taking, corresponds to 5.3 million $K_L \to \pi^0\pi^0$ decays. The result, $Re(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$, confirms unambiguously the occurrence of direct CP violation. Converting this number in a precision test of the Standard Model picture of CP violation is an open challenge for non-perturbative QCD calculations.

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- NA62 search for new physics beyond Standard model

NA62 physics goals

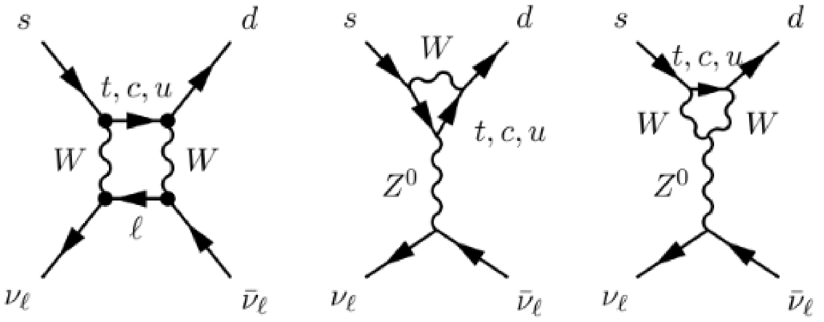
- NA62 main physics goal:
  measure the BR of the ultra-rare decay K+ →π+νν with

  ~10% precision

- Theory – Standard model:
  - well understood uncertainty < 10%
    - The Standard model expectation is

      BR(K+ →π+νν) = (8.4 ± 1.0) x 10-11

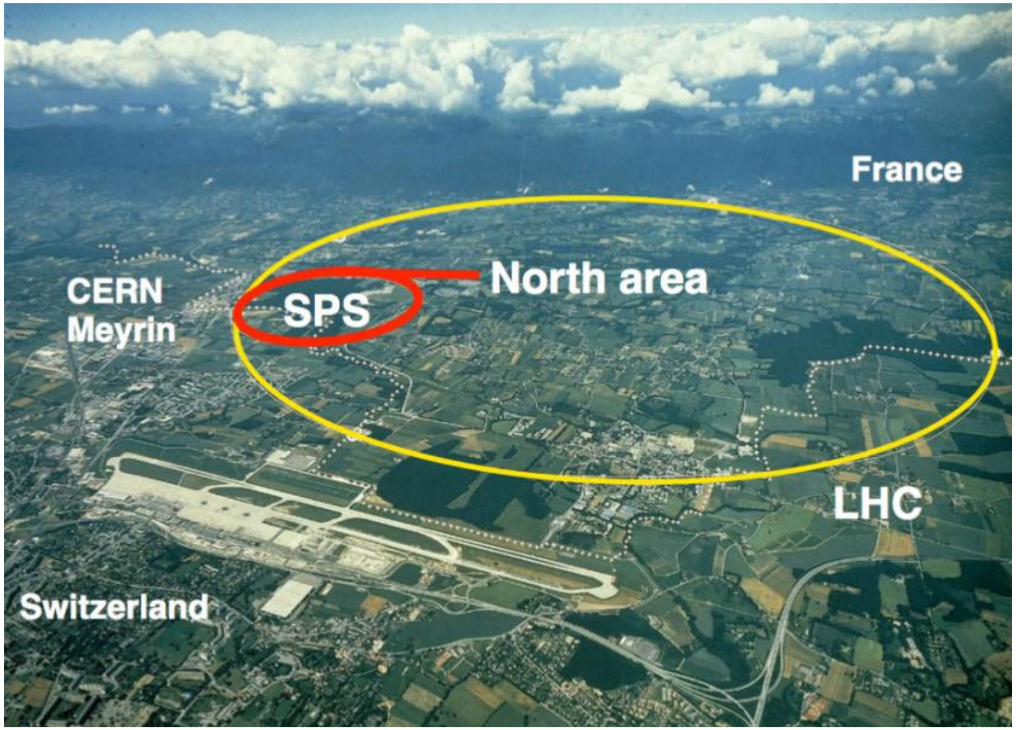
  - Sensitive to the new Physics



Trigger challenges

- Needs high intensity kaon beam → 10^{+12} Kaons
- Huge background (~ 11 orders of magnitude higher than signal) to be rejected
- Weak $K^+ \rightarrow \pi^+ \nu\nu$ signature: difficult to trigger on signal

NA62 – fixed target experiment



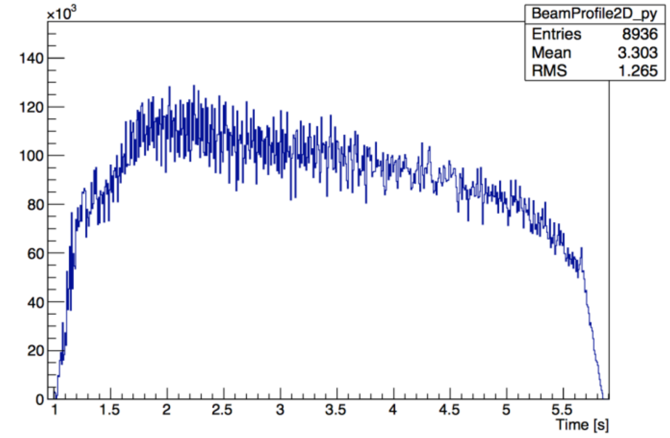
Fixed target experiment at CERN SPS

Secondary 75 GeV/c hadron beam (6% kaons) produced by 400 GeV/c primary SPS protons impinging on a Beryllium target

Beam structure

Very different environment wrt LHC:

- Continuous beam from SPS => bunched in spills of 4.8s



Asynchronous trigger: no bunch crossing!

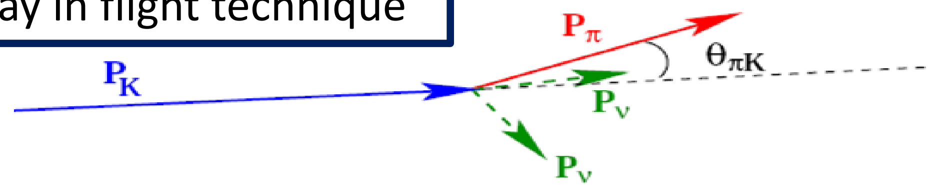
High-intensity hadron beam (~ 750 MHz!)

=> excellent time resolution (<1ns) needed at trigger level!

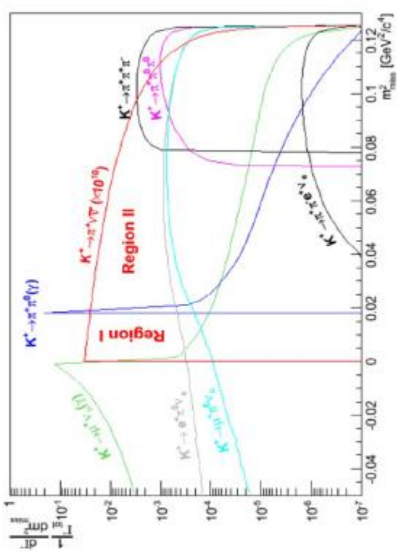
$K^+ \rightarrow \pi^+\nu\nu$ at NA62: strategy

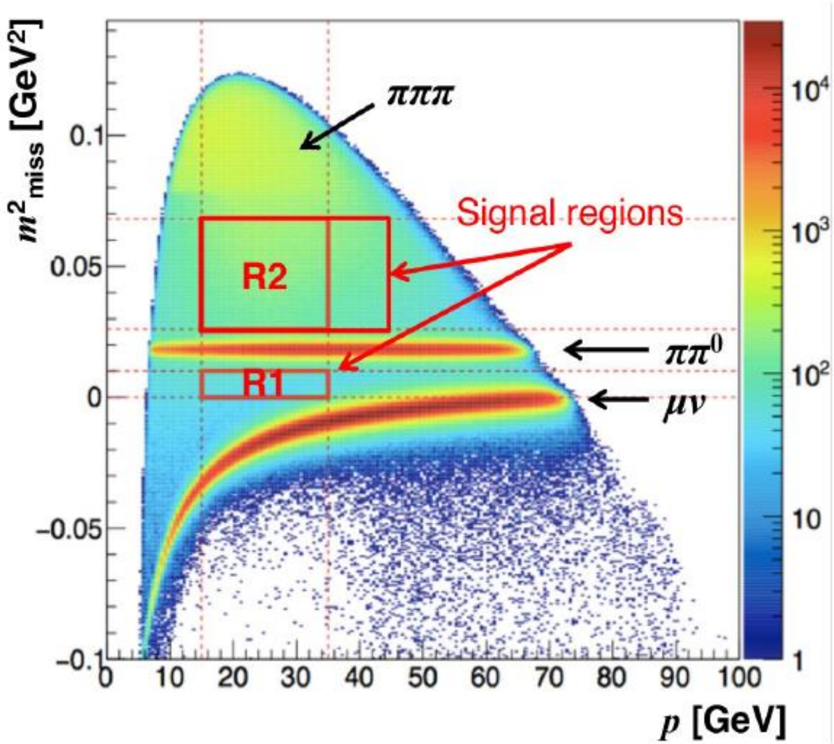
$K^+ \rightarrow \pi^+\nu\nu$ signature:
Kaon track +
Pion track +
NOTHING ELSE

Decay in flight technique



$$m^2_{miss} \approx m^2_K \left(1 - \frac{|p_\pi|}{|p_K|}\right) + m^2_\pi \left(1 - \frac{|p_K|}{|p_\pi|}\right) - |p_K||p_\pi|\theta^2_{\pi K}$$



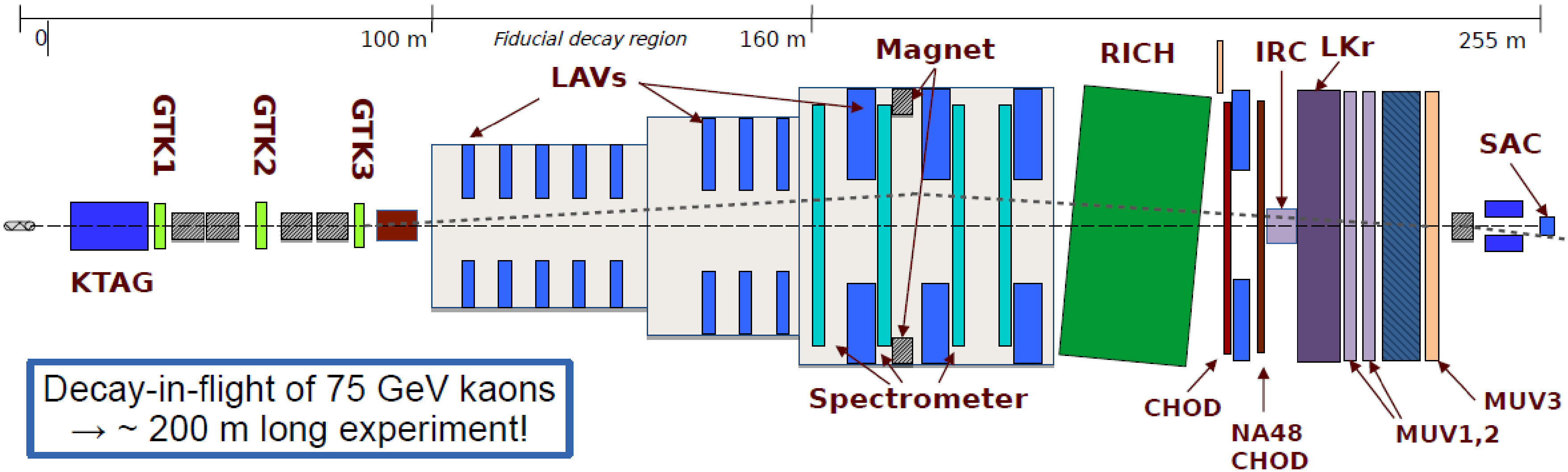


Main backgrounds:
BR($K^+ \rightarrow \mu^+\nu$) = 63.5%
BR($K^+ \rightarrow \pi^+\pi^0$) = 20.7%

NA62 Keystones:
- Precise tracking
- Photon rejection
- PID (in particular π/μ)
- Precise timing: O(100 ps)

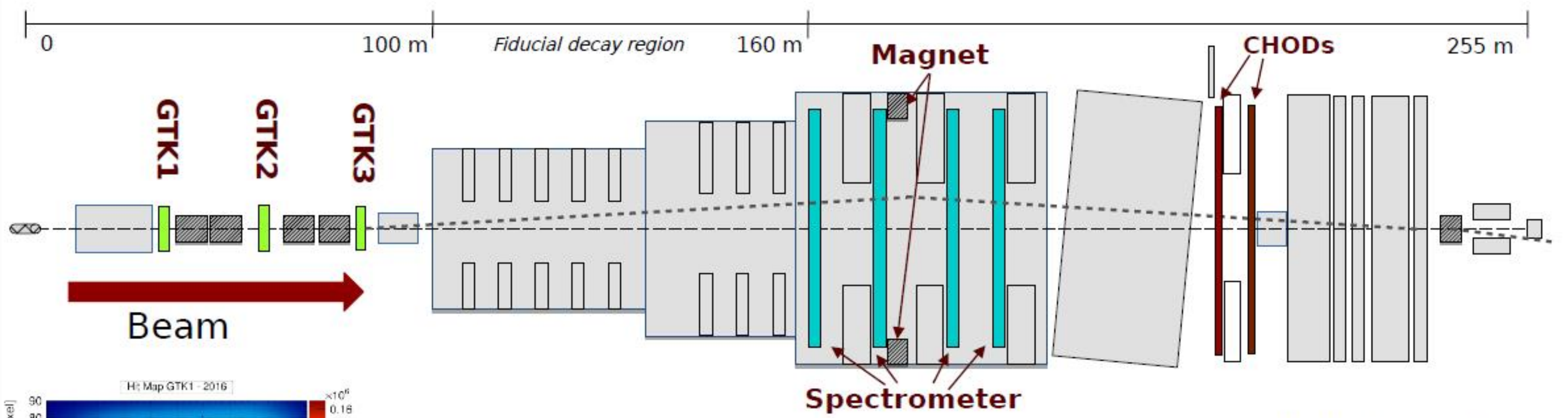
Background rejection at ~ 10^{11} level

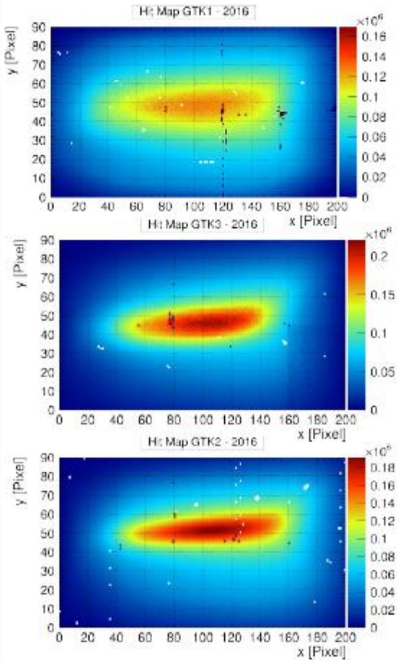
The NA62 Experiment



Decay-in-flight of 75 GeV kaons
→ ~ 200 m long experiment!

Tracking





Beam Spectrometer (GigaTracker - GTK):

- 3 stations of Silicon pixel detectors inside an achromat;
- Time : σ ≈ 130 ps per station;

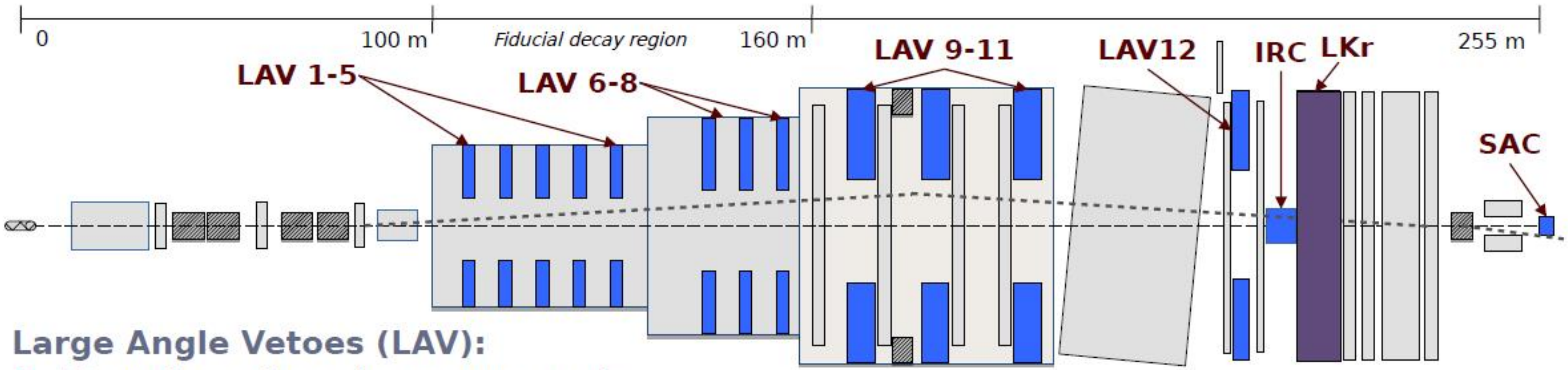
Direction: $\sigma_{dx,dy} \approx 0.016$ mrad
Momentum: $\Delta P/P < 0.4\%$;

Straw Spectrometer:

- 4 straw chambers in vacuum;
- Each chamber measuring 4 coordinates (views);
- High accuracy: 130 μm/view;
- Straws participate to level-1 trigger selection.

STRAW4 installation

Photon rejection



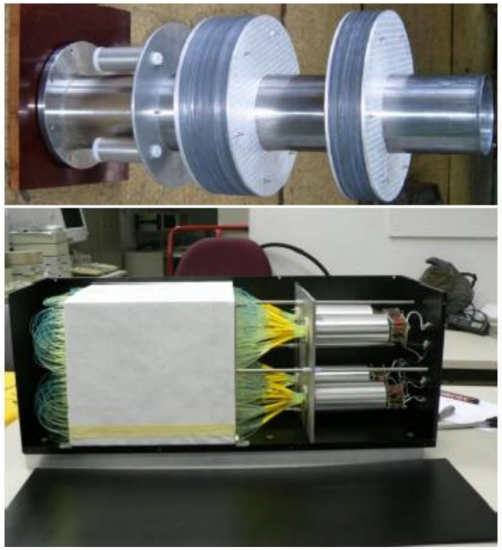
Large Angle Vetoes (LAV):

- 12 stations along the vacuum tank
- Coverage: 8.5 – 50 mrad

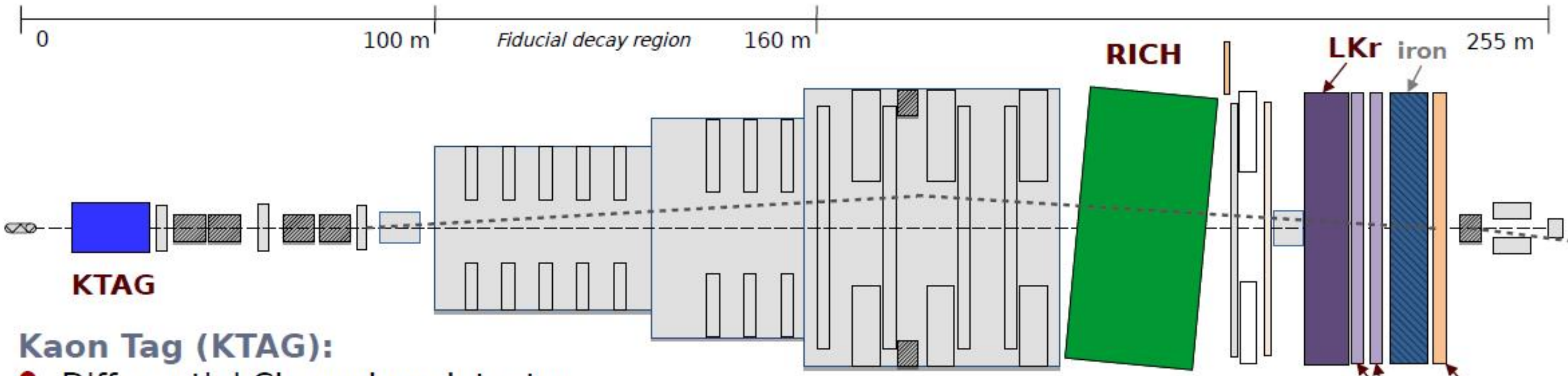
Liquid Krypton Calorimeter (LKr):

- Electromagnetic calorimeter
- Coverage: 1 – 8.5 mrad

Small Angle Vetoes (SAV):
Coverage: <1 mrad



Particle ID



Kaon Tag (KTAG):
- Differential Cherenkov detector selecting Kaons
- ~80 ps time precision

RICH:
- Cherenkov detector filled with Neon
- 70 ps of time resolution

Hadronic Calorimeters MUV1/MUV2:
- Readout with LKr electronics

MUV3: Muon Veto
- Placed after an iron wall
- Rate: > 10 MHz muons.

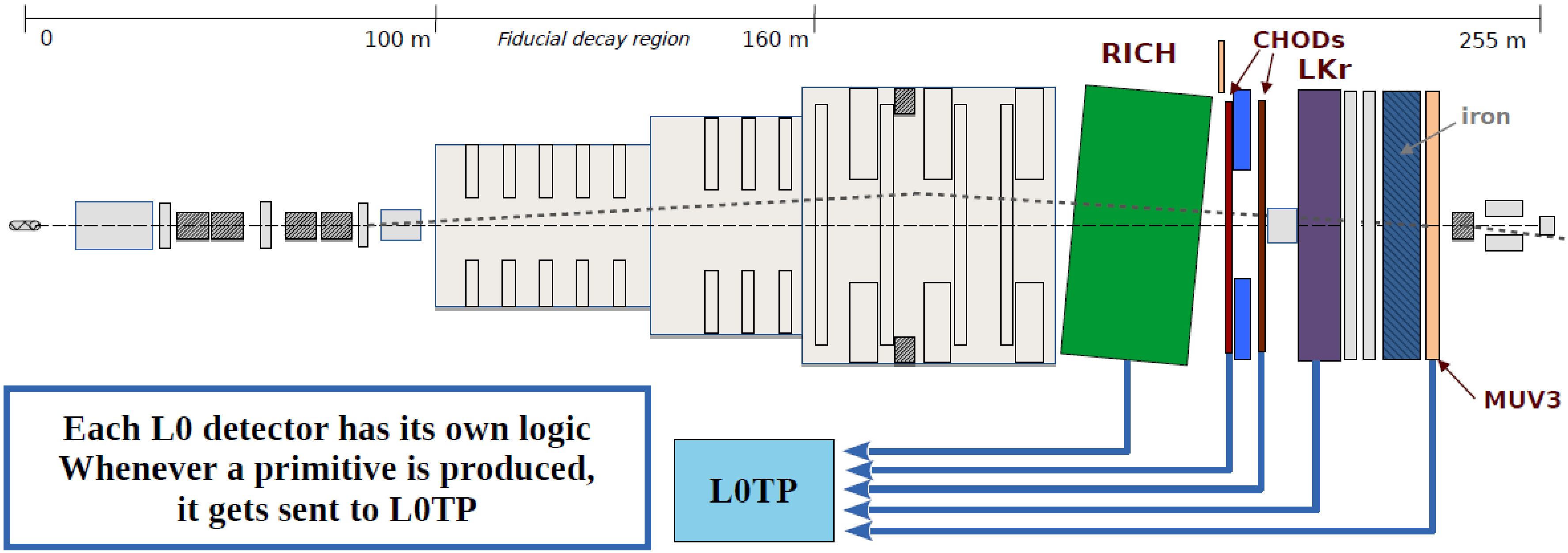
Trigger and DAQ system

- Two level trigger
  - Hardware L0 based on custom program electronics
  - Software L1running on a dedicated DAQ computing cluster

L0 Trigger Processor (L0TP)

NA62 PC Farm: 30 PCs for HLT and event building + 4 mergers for raw data file building

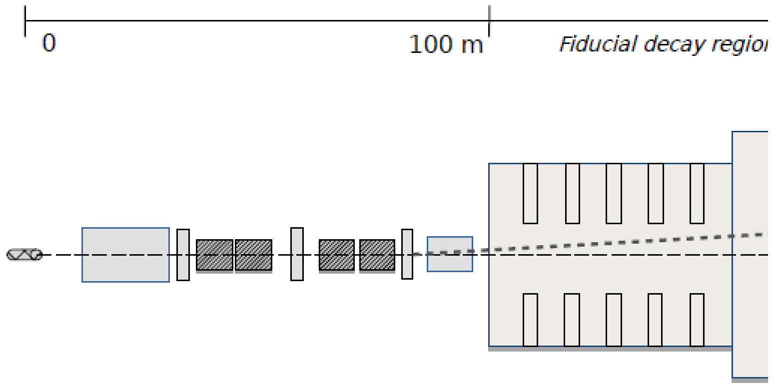
NA62 DAQ and Trigger



Detector used for L0 trigger:

- RICH – Cerenkov for Particle ID – pions wrt muons
- CHOD – Charge Hodoscope
- NA48-CHOD
- MUV3 – muon veto
- LKr – Liquid krypton calorimeter (muon veto)

NA62 DAQ and Trigger



Detector	Condition	Description
RICH	RICH	At least two signals in the detector
CHOD	Q1	At least one signal in any quadrant
	Q2	At least one signal in each of two different quadrants
	QX	At least one signal in each of two diagonally-opposite quadrants
	UTMC	Upper multiplicity condition: fewer than five signals in the detector
NA48-CHOD	NA48-CHOD	At least one signal in any quadrant
MUV3	M1	At least one signal in the detector
	MO1	At least one signal in the outer tiles
	MO2	At least two signals in the outer tiles
	MOQX	At least one signal in each of two diagonally-opposite quadrants
LKr	E10	At least 10 GeV deposited in the LKr
	E20	At least 20 GeV deposited in the LKr
	E30	At least 30 GeV deposited in the LKr
	C2E5	At least 5 GeV deposited in the LKr by at least two clusters
	LKr30	Logical OR between E30 and C2E5
LKr (beam dump)	E1	At least 1 GeV deposited in the LKr
	E2	At least 2 GeV deposited in the LKr
	E4	At least 4 GeV deposited in the LKr
	C2E2	At least 2 GeV deposited in the LKr by at least two clusters

Table 1: List of L0 trigger conditions. The LKr conditions differ between K^+ and beam-dump configuration.

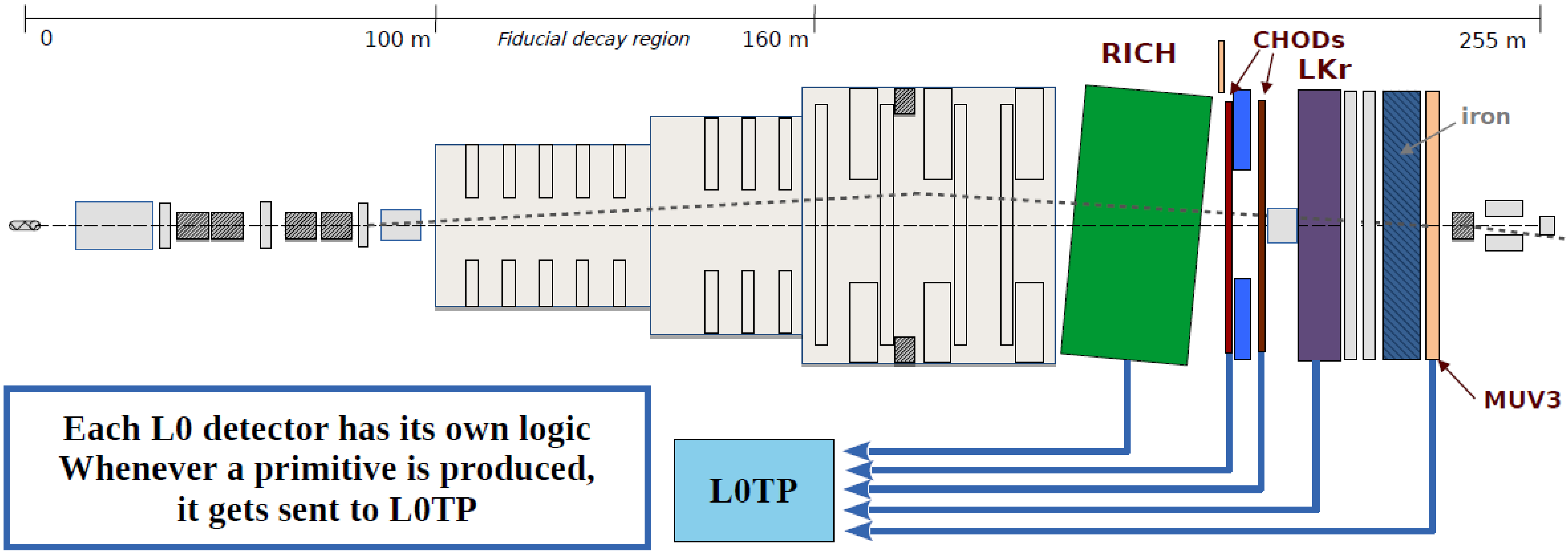
Each L0 detector has its own logic
Whenever a primitive is produced, it gets sent to L0TP

Trigger line	L0 trigger conditions	L1 trigger conditions
PNN	RICH · Q1 · UTMC · $\overline{\text{QX}}$ · $\overline{\text{M1}}$ · $\overline{\text{LKr30}}$	KTAG · $\overline{\text{LAV}}$ · STRAW
Non-μ	RICH · Q1 · $\overline{\text{M1}}$	KTAG · STRAW-1TRK
MT	RICH · QX	KTAG · STRAW-Exo
2μMT	RICH · QX · MO2	KTAG · STRAW-Exo
eMT	RICH · QX · E20	KTAG · STRAW-Exo
μMT	RICH · QX · MO1 · E10	KTAG · $\overline{\text{LAV}}$ · STRAW-MT
DV-μ	RICH · Q2 · MO1 · E10	$\overline{\text{KTAG}}$ · STRAW-DV
DV-2μ	RICH · Q2 · MO2 · $\overline{\text{E10}}$	STRAW-DV
Neutrino	RICH · Q1 · MOQX · $\overline{\text{Q2}}$	KTAG · $\overline{\text{LAV}}$ · STRAW-1TRK
Control	NA48-CHOD	None

Detector used for L0 trigger:

- RICH – Cerenkov for Particle ID – pi
- CHOD – Charge Hodoscope
- NA48-CHOD
- MUV3 – muon veto
- LKr – Liquid krypton calorimeter (m

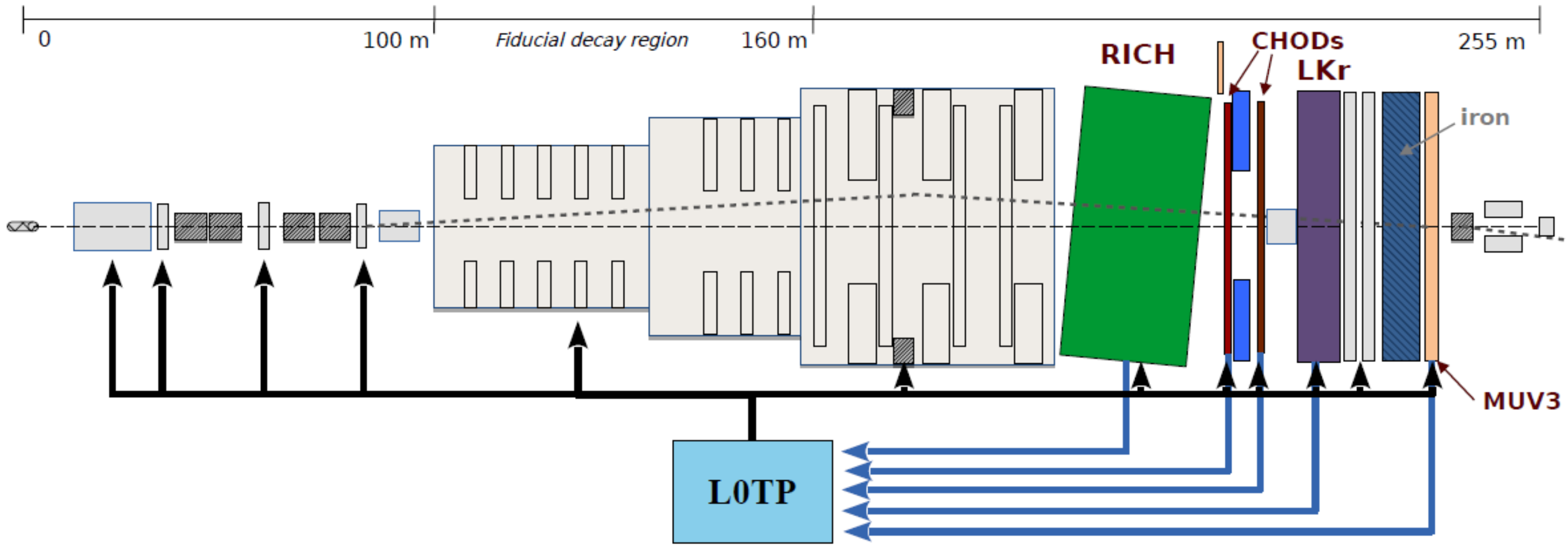
NA62 DAQ and Trigger



Trigger inputs are called **L0 Primitives (64 bits):**

- Timestamp (32) bits – 25 ns resolution - 40 MHz clock is used using LHC TTC system and ALICE like Local Trigger Unit
- Fine time (8 bits) – 0.1 ns resolution – synchronised with 40 MHz clock
- Primitive ID (16 bits) – detector information (energy, multiplicity, position)

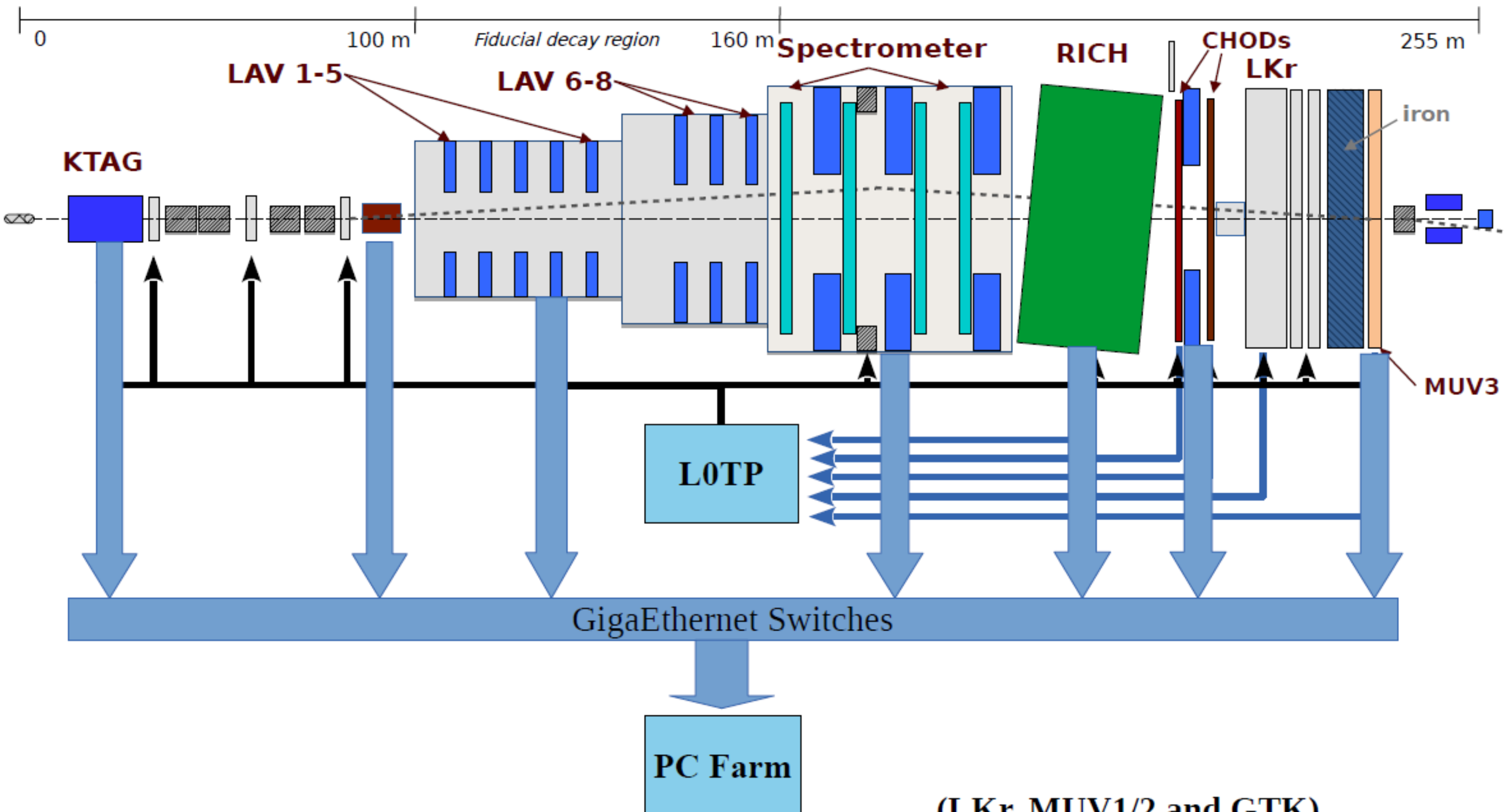
Trigger and data flow



If primitives received in a certain time interval satisfy any of the implemented L0 trigger conditions, a L0 trigger is produced by L0TP and is sent to ALL detectors [Maximum latency: 1 ms]

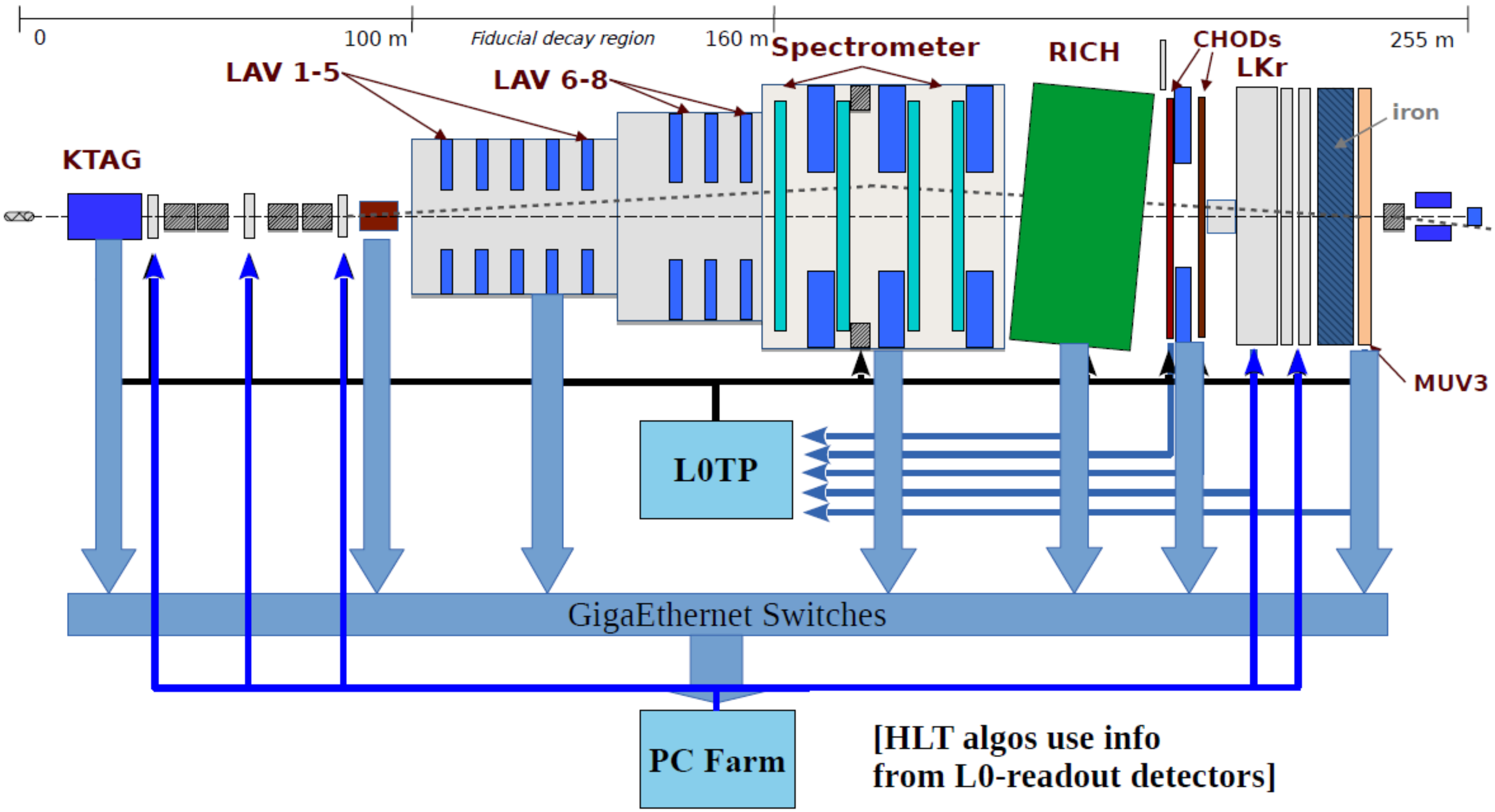
L0 input: 10 MHz → **L0 output:** 1 MHz

Trigger and data flow



All detectors except for L1-readout detectors send data to the PC Farm
[L1-readout detectors store the data for each L0 trigger internally]

Trigger and data flow

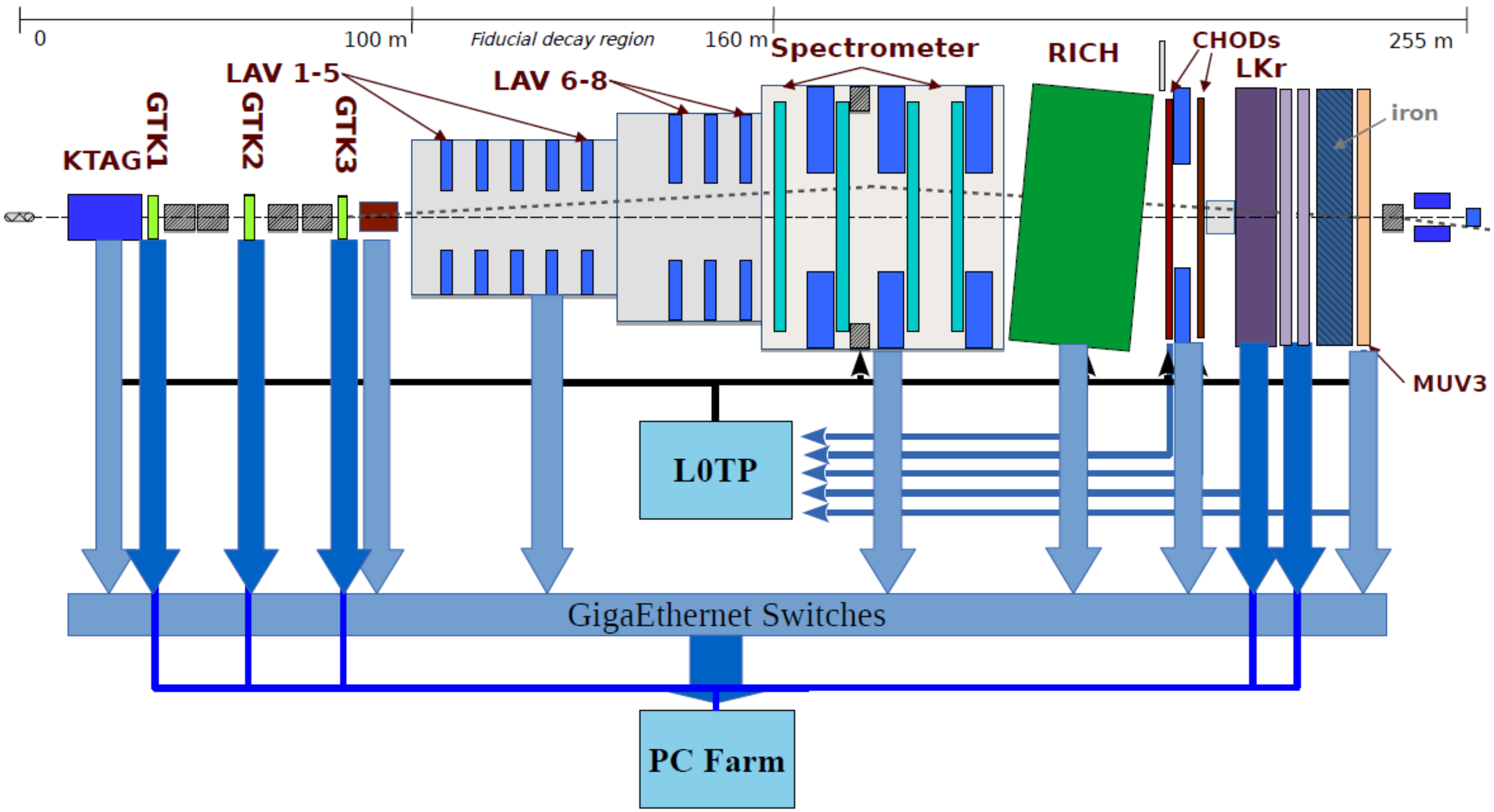


[HLT algos use info
from L0-readout detectors]

If a certain L1 trigger condition is satisfied, a L1 trigger is sent to the L1-readout detectors

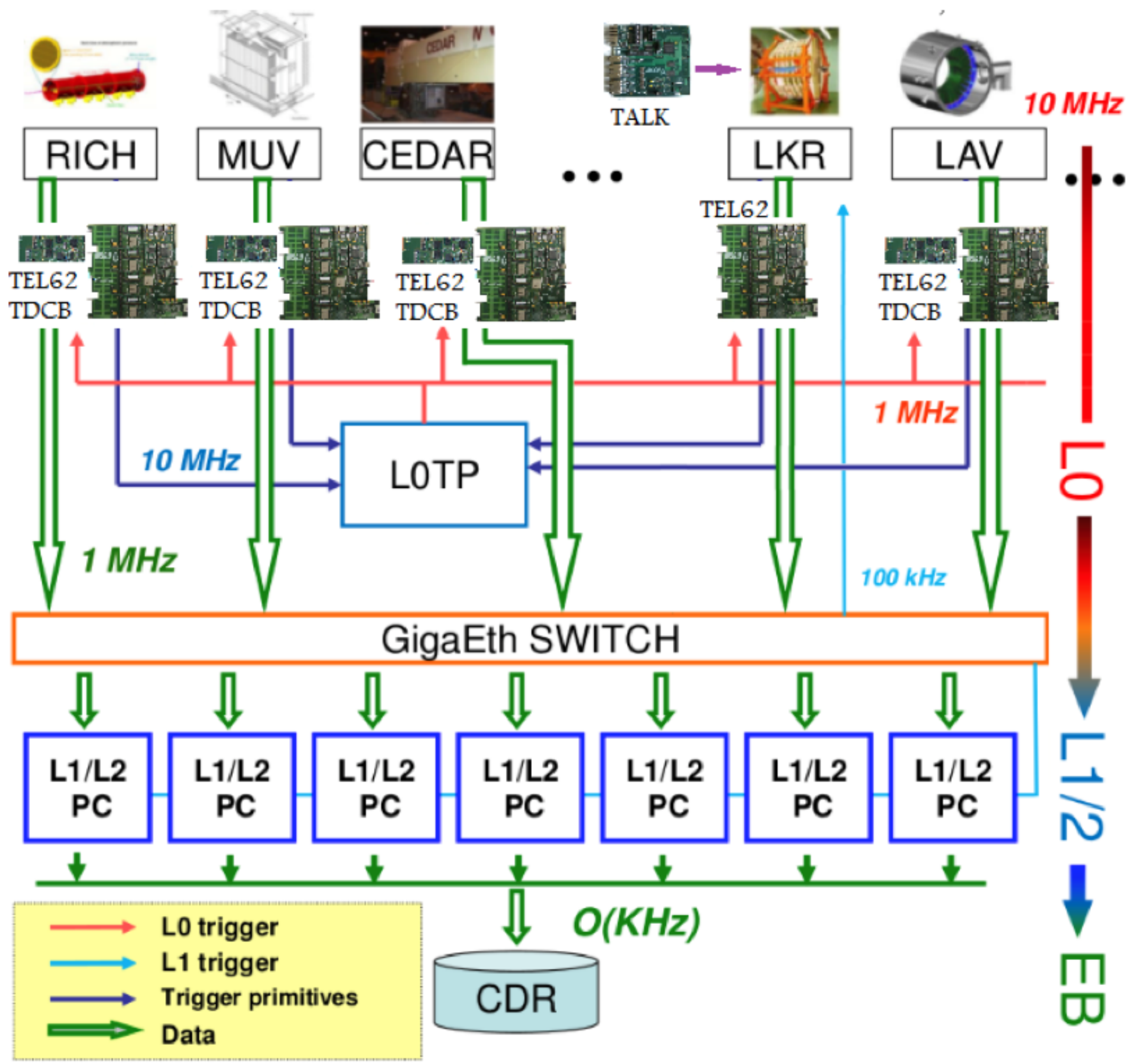
L1 input: 1 MHz → **L1 output:** < 100 kHz

Trigger and data flow



L1-readout detectors send the selected event data to the PC Farm

NA62 TDAQ schema



Number of trigger per spill

[counts measured at 60% beam intensity]

Trigger line	Downscaling	L0 triggers [10^3]	L1 triggers [10^3]
PNN	1	1540	74
Non-μ	200	30	12
MT	100	39	4
2μMT	2	150	30
eMT	8	193	22
μMT	5	99	10
DV-μ	5	140	0.3
DV-2μ	3	160	5
Neutrino	15	10	3
Control	400	94	94
Total:	–	2455	254.3

Corresponds to ~ 1 MHz L0 and ~ 100 kHz L1 at 100% beam intensity

Trigger efficiency

Efficiency evaluated using minimum bias data

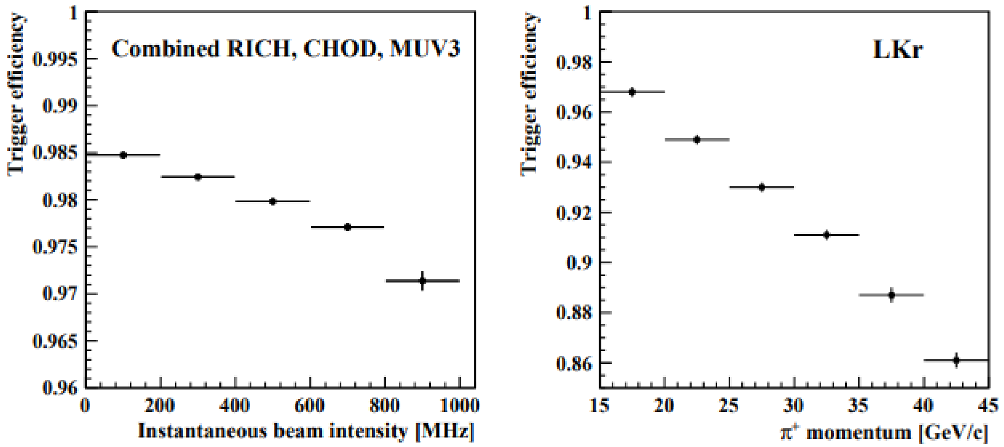


Figure 4: Efficiency of the combined RICH, CHOD, and MUV3 conditions of the PNN trigger line evaluated using $K^+ \to \pi^+\pi^0$ events as a function of instantaneous beam intensity (left), and efficiency of the LKr condition of the PNN trigger line evaluated using $K^+ \to \pi^+\pi^0$ events as a function of the π^+ momentum (right).

Summary

- Good time resolution is essential already at the level-0 trigger in order to reject the high background.
- All the systems involved in the trigger have a level-0 time-resolution < 2.5 ns.
- NA62 is able to handle ~10 MHz of decay-products, reducing the rate to 1 MHz after level-0 and to 100 kHz after level-1 triggers.
- Multiple trigger logic conditions to perform a broad physics programme