The NA62 Calorimetric Level-0 trigger and readout electronics

Nico De Simone (CERN)
for the NA62 Level 0 Trigger Working Group
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Branching ratio measurement with $\mathcal{O}(10\%)$ precision

SM prediction [Buras et al. JHEP 1511 (2015) 33]

BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) = $(8.4 \pm 1.0) \cdot 10^{-11}$

Experimental status (E787, E949)


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Background Branching ratio

$$K^+ \rightarrow \pi^+ \pi^0 \quad 0.20$$
$$K^+ \rightarrow \mu^+ \nu \quad 0.64$$
$$K^+ \rightarrow \pi^+ \pi^+ \pi^- \quad 0.06$$
K^+ \to \pi^+\nu\bar{\nu} \text{ Branching ratio measurement with } \mathcal{O}(10\%) \text{ precision}

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\( \mathcal{O}(100 \text{ ps}) \) Timing between sub-detectors
\( \mathcal{O}(10^4) \) Background suppression from kinematics
\( > 10^7 \) Muon suppression
\( > 10^7 \) \( \pi^0 \) (from \( K^+ \to \pi^+\pi^0 \)) suppression

CHEF 2017 - Lyon
The NA62 experiment at CERN SPS


Secondary positive beam

- **Momentum**: 75 GeV/c, 1% bite
- **Divergence (RMS)**: 100 μrad
- **Transverse Size**: $60 \times 30 \text{mm}^2$
- **Composition**: $K^+(6\%)/\pi^+(70\%)/p(24\%)$
- **Nominal rate**: $33 \times 10^{11}$ ppp on T10 (750 MHz at GTK3)

Decay region

- **Fiducial region**: 60 m
- **$K^+$ decay rate**: $\sim 5 \text{ MHz}$
- **Vacuum**: $\mathcal{O}(10^{-6})$ mbar
<table>
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<tr>
<th>Year</th>
<th>Run Description</th>
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<tr>
<td>2014</td>
<td>Pilot run</td>
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<td>2015/2016</td>
<td>Commissioning run</td>
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<td>2016/2107</td>
<td>Physics run</td>
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The detector
- 10 m³ liquid Krypton calorimeter, 1.25 m deep (27 $X_0$)
- 13284 2x2 cm² cells, projecting geometry
- Preamplifiers inside the LKr tank
- Calibration system mounted on the LKr tank

Use
- Veto in the forward direction
- High-precision measurement of the electromagnetic energy deposit
The Trigger and DAQ System

Trigger levels:

L0: Hardware synchronous level. 10 MHz to 1 MHz. Max latency: 1 ms.

L1/L2: Software level. 1 MHz to Ω(kHz).

12 sub-detectors, ~ 80 000 channels, 25 GB/s raw data.
Calorimeter TDAQ

Analog Inputs → 14bit ADC @ 40 MHz

ADC → Circular Buffer

Super cells (4 x 4)

Calorimetric Trigger

1M x 256 bits

255M x 256 bits

L0 Buffer

Zero Suppression

PC Farm

L1 accept

L0 accept (fixed latency)

Other Inputs

L0 Trigger Processor
THE Calorimeter Readout Board (CREAM)

6U VME board developed by CAEN upon CERN specifications.
16 CREAMs per crate.
28 CREAM crates in 8 racks.
TTC-LKr board handles Timing, Trigger and Control.
TEL62: the NA62 TDAQ motherboard
TEL62/L0Calo: I/O Mezzanines

TELDES
16 ch
(16 bit @ 40 MHz)
LVDS over Ethernet

Internal TX board
2 ch
(48 bit @ 70 MHz)

Internal RX board
4 ch
(48 bit @ 70 MHz)
The NA62 Calorimeter L0 trigger

3D trigger information: time, position, energy of reconstructed clusters. Independent from CREAMs readout.

Inst. hit rate: 30 MHz
Time resolution: 2.5 ns
Latency ~ 20 us
Calorimeter L0 trigger implementation

- 37 9U TEL62 electronics modules
- 111 dedicated mezzanines
- 884+20 input channels, 16 bit @ 40 MHz over Ethernet LVDS
- 1 trigger output channel (Gbit Ethernet) to the L0 Trigger Processor
Peak reconstruction (parallel on all channels)

\[ d[2] > \text{threshold} \]
Liquid Kripton Calorimeter

- **1 D + 1 D pixel based algorithm:** LKr divided in slices parallel to the y axis.
- **Front-End boards** (28): peaks in space and time **indipendently** searched in each vertical slice: digital constant fraction discriminator + linear interpolator for fine timing.
- **Merger boards** (7): peaks close in space and time merged and assigned to the same electromagnetic cluster. **Overlap resolution** to avoid double counting: only clusters with maximum along x axis in the yellow area are reconstructed.
Calorimetric trigger performances

Efficiency 98% for $E_{\text{tot}}(\text{LKr}) > 20$ GeV

$\sigma = 2.5$ ns
Conclusions

The NA62 calorimetric trigger and readout are performing as by specifications and taking data.

2016: Commissioning + Physics run (SM sensitivity)
2017-2018: Physics runs

Radiation induced effects on the electronics are being observed and managed.
Thanks!
The NA62 detector

**CEDAR**
Gas differential Cerenkov counter (built for SPS beams) to tag beam kaon with $O(-100)$ ps time resolution

**GTK**
3 hybrid silicon pixel detector stations ($<0.5\% \times_0$) with $< 200$ ps time resolution per station

**LAV**
Large Angle photon Veto (blocks from OPAL @ LEP) in vacuum covering angular range 8.5 – 48 mrad

**Beam**
- Primary SPS Beam: 400 GeV/c protons, 3x10^{12} protons/pulse
- 4.8/16.8 s duty cycle
- Secondary Beam: ~ 6% K+ p=75 GeV/c ($\Delta p/p - 1\%$)
- Beam acc.: 12.7 mstr
- Total rate: 750 MHz
- 4.5x10^{12} K+ decays/year

**SAC/IRC**
Small Angle / Inner Ring photon veto Calorimeters (lead-plastic scintillator) for angular region close to beam pipe below 1 mrad

**LKr**
20T Liquid Krypton calorimeter (from NA48) & new readout as forward photon veto in range 1-8.5 mrad

**CHANTI/CHOD**
- CHANTI: guard ring counters to veto beam induced inelastic interactions: triangular shape scintillators & SiPM readout
- CHOD: scintillator hodoscope to trigger on single charged

**STRAW**
4 straw chambers (4 views each) operating in vacuum as tracker stations of the magnetic Spectrometer

**RICH**
Neon gas Ring Imaging Cerenkov counter, 18 m long & 3 m Ø
- segmented 17 m focal length mirror
- $\sim 2000$ PM's
- time resolution better than 100 ps
- $\pi/\mu$ separation with $< 1\%$ mls-ID

**MUV**
Muon Veto system
- MUV1 (25 layers)/MUV2 (23 layers, from NA48): iron-plastic scintillator calorimeters
- MUV3: after 80 cm iron, 5 cm thick single layer of scintillator tiles + PM readout, fast signal for trigger
The NA62 experiment at CERN SPS

Main backgrounds:
\( K^+ \rightarrow \mu^+ \nu \) (~64 %)
\( K^+ \rightarrow \pi^+ \pi^0 \) (~21 %)

In flight kaon decay technique:
K tagging (CEDAR)
Cinematic rejection: \( K^+ \) momentum (GTK) and \( \pi^+ \) momentum (STRAW)
Particle ID and veto: CHANTI, \( \gamma \) veto (LAV, LKr, IRC, SAC), \( \pi/\mu \) separation (RICH and muon detector), multi-track event veto (STRAW)
The NA62 experiment at CERN SPS
Peak in time spatial Distribution

ADC sums

Fit max

- samples
- fit

α Fit max

finetime

0 50 100 150 200 250

0 1 2 3 4

Sample no.


\[ d[2] > \text{threshold} \]
The NA48 Liquid Krypton electromagnetic calorimeter

For $K^+ \rightarrow \pi^+ \pi^0$ decays in the decay fiducial region and for $E_\pi < 35$ GeV 80% of the photons are in the Lkr acceptance.
The NA48 Liquid Krypton electromagnetic calorimeter

13248 channels
27 $X_0$

$$
\frac{\sigma_E}{E} = \frac{0.032}{\sqrt{E}} + \frac{0.09}{E} + 0.0042
$$

$$\sigma_{X,Y} = \frac{0.42}{\sqrt{E}} + 0.06$$

$$\sigma_t = \frac{2.5}{\sqrt{E}}$$

(GeV, cm and ns)

Photon veto in the angular decay region 1-8.5 mrad

For $K^+ \rightarrow \pi^+ \pi^0$ decays in the decay fiducial region and for $E_\pi < 35$ GeV 80% of the photons are in the Lkr acceptance

Inefficiency $< 10^{-5}$ for $E_\gamma > 10$ GeV
THE CREAM BOARD FUNCTIONS

- **INPUT SIGNAL SHAPING**: the 2.7 μs long triangular signal from LKr channels is shaped into a 70 ns FWHM pseudo-Gaussian signal
- **DIGITISATION**: shaped signals are digitised @ 40 MHz by octal 14 bit ADCs and copied in a circular buffer
- **FIRST TRIGGER LEVEL (L0T)**: upon reception of the L0T signal through the custom P0 VME backplane, data is moved from the circular buffer to the L0 buffer
- **SECOND TRIGGER LEVEL (L1T)**: when a L1T signal is received through a Multiple request UDP packet (MRP) data is sent to the PC farm
- **TRIGGER SUM LINKS**: the sums of the digitised samples from two groups of 16 channels each are serialized inside the FPGA and sent to the LKr L0 processor
CREAM CRATE ORGANIZATION

- 16 CREAMs will be housed in a VME crate
- 28 CREAM crates, organised in 8 racks, will readout the whole calorimeter
- The TTC-LKr board is placed in the 11th slot of each crate
NA62 status

• 2015: Commissioning run
• 2016: Commissioning + Physics Run (40% nominal intensity)
• 2017: Physics Run (55-60% nominal intensity)
• 2018: Physics Run
• SM Sensitivity with 2016 data

2016 integrated statistics for $\pi^+\bar{\nu}\bar{\nu}$