The NA62
Calorimeter Level 0 Trigger
Operation and Performances

Andrea Salamon
INFN Sezione di Roma Tor Vergata
for the NA62 Level 0 Trigger Working Group
• Ultra-rare decays with the highest CKM suppression
• Very clean from the theoretical point of view
  – $\text{BR}_{\text{SM}}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$
  – $\text{BR}_{\text{SM}}(K_L \to \pi^0 \nu\bar{\nu}) = (3.4 \pm 0.6) \times 10^{-11}$
• Very sensible to many NP models
• Almost unexplored from the experimental point of view
  – $\text{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$
  – $\text{BR}(K_L \to \pi^0 \nu\bar{\nu}) < 2.6 \times 10^{-8}$ (90% C.L.)
• See G. Ruggiero’s talk: “Recent results from Kaon Physics”
The NA62 experiment at CERN SPS

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

Goal: $O(10\%)$ precision measurement of $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})$

- Statistics: $O(100)$ events
- $K$ decays $10^{12}$
- Signal acceptance $\sim 10\%$
- $> 10^{12}$ background rejection

Broader Physics program:

- G. Lanfranchi: Searching for hidden sectors particles at NA62
- M. Koval: New Limits on Heavy Neutrino from NA62

06/07/2017
The NA62 experiment at CERN SPS

400 GeV/c SPS protons
75 GeV/c secondary beam
6% K^+
3.3 \times 10^{12} \text{ppp}

Main backgrounds:

- K^+ \rightarrow \mu^+ \nu \quad (~64 \%)
- K^+ \rightarrow \pi^+ \pi^0 \quad (~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 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 ($<0.5\% X_0$) with $< 200$ ps time resolution per station.

**LAV**
Large Angle photon Vetos
12 stations with 4/5 lead glass rings (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 ($\Delta p/p \sim 1\%$)
- beam acc.: 12.7 mstr
- total rate: 750 MHz
- 4.5x10^{12} K^+ decays/year

**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, 18m long & 3m Ø
- segmented 17m focal length mirror
- ~2000 PM’s
- time resolution better than 100 ps
- $\pi/\mu$ separation with $< 1\%$ mls-ID

**Detector setup**

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

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

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

Three trigger levels:

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

L1: Software level. “Single detector”. 1 MHz to 100 kHz. Max latency: O(1 s).

L2: Software level. “Complete events”: 100 kHz to O(kHz). Max latency: spill period O(10 s).

12 sub-detectors, ~ 80 000 channels, 25 GB/s raw data.
The NA48 Liquid Krypton electromagnetic calorimeter

\[ K^+ \rightarrow \pi^+ \pi^0 \quad \text{VETO} \]

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

13248 channels
27 $X_0$

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

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

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

\[
\sigma_t = \frac{2.5}{\sqrt{E}}
\]

(GeV, cm and ns)
Calorimeter REAdout Modules (CREAMs)

14bit ADC @ 40 MHz

1M x 256bits

255M x 256bits

Circular Buffer

LO Buffer

Zero Suppress

PC Farm

Super cells (4 x 4)

Calorimetric Trigger

LO Event Builder

L0 accept

L0 accept (fixed latency)

L0 Trigger Processor

Other Inputs

(414 boards)
The NA62 Calorimeter L0 trigger

- Pixel based trigger processor with 4x4 calorimeter cell tiles
- Identifies electromagnetic clusters in the calorimeter and prepares a time-ordered list of reconstructed clusters (time, position and energy) for the L0 Trigger Processor
- Low granularity readout independent from CREAMs full granularity readout
- Fast readout for L1 software triggers and/or Region of Interest for the Lkr full granularity readout at L1

Inst. hit rate: 30 MHz
Time resolution: 2.5 ns
Latency < 100 us
Calorimeter L0 trigger implementation

- 37 9U TEL62 electronics modules + 111 dedicated mezzanines installed in 3 crates
- 864+20 input channels (tiles), 16 bit @ 40 MHz per tile from the calorimeter readout modules (CREAM) over 15 meters high quality Ethernet cables (560 Gbps)
- 1 trigger output channel (Gbit Ethernet) to the L0 Trigger Processor
- 29 raw data + 7 reconstructed clusters readout channels to L1 and DAQ
- Less than 100 µs output latency
Peak reconstruction

For each input channel:

- Threshold check: \( E_i[n] > E_{th} \)
- Peak in space: \( E_{i-1}[n] < E_i[n] \) AND \( E_i[n] > E_{i+1}[n] \), E ADC count, i tile number, n sample number
- Peak in time: \( E_i[n-2] < E_i[n-1] < E_i[n] \) AND \( E_i[n] > E_i[n+1] \)
- Parabolic interpolation in time around maximum
- Constant fraction discriminator with linear interpolation between samples n-2 and n-1
Peak reconstruction

2015 commissioning run: one missing FE board, one broken Ethernet cable, one broken channel

06/07/2017  Venice - EPS HEP 2017
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

280 MeV - 5% of intensity

560 MeV - 35% of intensity

σ = 2.5 ns
no T0 correction

χ² / ndf = 271.3 / 157
plateau = 0.9845 ± 0.0006624
stepness = 0.5231 ± 0.01783
threshold = 19.98 ± 0.1161

χ² / ndf = 564.7 / 157
plateau = 0.9784 ± 0.0004185
stepness = 0.4231 ± 0.007188
threshold = 22.24 ± 0.06662

χ² / ndf = 42.66 / 19
Constant = 1302 ± 13.7
Mean = 8.084 ± 0.217
Sigma = 24.69 ± 0.20
Conclusions

The NA62 calorimetric trigger processor (for $K^+ \rightarrow \pi^+ \pi^0$ rejection) has been designed, installed, commissioned and is taking data.

- Instantaneous hit rate: 30 MHz
- Time resolution: 2.5 ns
- Latency: < 100 $\mu$s

2016: Commissioning + Physics run (SM sensitivity)
2017-2018: Physics runs
Thanks a lot for your attention!