The NA62 Spectrometer Acquisition System

TWEPP 2015, Lisbon

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On Behalf of NA62 Straw Working Group
Outline

- The NA62 Straw Tracker,
- System Overview,
- The Front-end,
- The Readout, control and parameterization,
- System Installation,
- System Performance,
- First Results from the NA62 Pilot Run (December 2014),
- Conclusions and Plans.
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The Location

NA62
The NA62 Straw Tracker

- NA62 aims at measuring the Branching Ratio (BR) of the process $K^+ \rightarrow \pi^+\nu\nu$ within a 10% total uncertainty (100 SM events in 2 years).
- A critical point is the identification of the Pion and its 4-momentum measurement, with high accuracy and precision. The last point represents the Straw tracker main task.
Detector Specifications

- Detector is working in vacuum and requires to fit the following experimental requirements:

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particles Rate (over all)</td>
<td>15 MHz</td>
</tr>
<tr>
<td>Max Straw Rate</td>
<td>700 kHz</td>
</tr>
<tr>
<td>Mean Straw Rate</td>
<td>60 kHz</td>
</tr>
<tr>
<td>Material Budget</td>
<td>≤0.5% X₀</td>
</tr>
<tr>
<td>△P/P</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Single Wire Resolution</td>
<td>~130 μm</td>
</tr>
<tr>
<td>Overall coord. Resolution</td>
<td>~80 μm</td>
</tr>
<tr>
<td>Total Number of Straws</td>
<td>7168</td>
</tr>
<tr>
<td>Total MIP charge generated</td>
<td>~100 fC</td>
</tr>
<tr>
<td>Effective charge</td>
<td>~10 fC</td>
</tr>
</tbody>
</table>
Straw Tracker in Place

Magnet ~ 0.5 T

September 2014
Bunched Beam

- Beam is extracted from SPS with a super-cycle of about 25-35s with 2 spills of ~4s,
- Start Of Burst (SOB) and End Of Burst (EOB) signals are provided by SPS.
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System Overview

COVER
Custom shape
Front-end 16 channels

Flexible PCB connector (WEB)

1/2 View
14(16) COVERs

14(16) ~10-15m CAT6 shielded cable

Straw Readout Board (SRB)
VME 9U size
16 covers
256 channels

VME bus
2xGb
System Overview

16 straws per COVER
30 COVERS per view
8 Readout boards per chamber

Straw Readout Board (SRB)
System Overview

Summary:

- 7168 Straws in Total
- 4 chambers
- 4 Views/Chamber
- 120 COVERs/Chamber
- 30 COVERs/View
- 8 SRBs/Chamber
- 1 SBC/Chamber
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Front-End: COVER

- Custom board designed to seal the gas volume and hold 1 bar of overpressure in case of leaks (4mm thick, buried vias, etc.),
- No clock source on the board
- CARIOCA chip used for signal analog processing and digitization
- TDC implemented in FPGA (Cyclone III, 40MHz clock and 0.23ns time resolution), rising and falling edges treated separately
- 16 channels DAC for setting thresholds
- Shielded CAT6 cable connects the COVERs to the readout board, all links use LVDS signals:
  - 2 data lines (8b10b, 400Mb/s)
  - 1 command line
  - 1 clock line
Front-End: COVER

- HV feed through
- TDC (FPGA)
- Link
- DAC for thresholds setting
- COVER power supply
- Gas mixture feed through
- amplifier
- shaper
- discriminator
- CARIOCA
- WEB
- TDC
- transmission
- FPGA
- Readout
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Straw Readout Board (SRB)

- VME 9U board
- 7 Cyclone V FPGAs
- Provides all the commands (e.g. SOB/EOB) and parameters (e.g. Thr) to FE
- Delays foreseen in order to align all the data from different channels
- Data receiver, concentrator, time order and trigger matching
- Event builder and transmission using 2x1 Gb Eth ports
- Monitoring features
- SBC controlled (CCT VP717)
Read-out: SRB
Parameters are sent to the Board Manager
FE Control and Parameterization

Command strings are sent to the COVERs trough the Front-end chips
Read-out: Data Flow

Data from max 16 COVERs are sent to the SRB
Read-out: Data Flow

Data are collected from the *Front-end* FPGA
Read-out: Data Flow

Data are sent to Event Manager and Board Manager.
Read-out: Data Flow

Trigger matched data are transmitted to pc farm with 1ms maximum latency, and at the same time are stored (for monitoring) to DDR3 to be read through VME.
Board Manager stores (on request) an unbiased data sample into the DDR3 memory (2GB).
The unbiased data sample can be read-out using the SBC at any time via VME.
Read-out: Trigger

Triggers, trigger type and Start/End Of Burst commands are received from the TTCrx optical connector.
The *Trigger Manager* FPGA is generating triggers time stamps and receiving triggers type, and redistributing them to *Event Manager* and *Board Manager*.
Read-out: Trigger Matching

FROM FRONTEND → INPUT FIFO

TIME REORDER 10us

OUTPUT FIFO → TO ETHERNET

25ns SLICE DEPTH MEMORY
(# of hits per time slice)

TTC
L0

TRIGGER QUEUE

TTC SOB

COARSE TIME COUNTER

CIRCULAR BUFFER ~ 1 ms

CLEARING

8, 16 or 32 hits

8bit straw addr
5b fine time
1b edge
2b monitoring
1-2b coarse time

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System Installation

- Chambers come with FE electronics and HV/LV distribution already installed and commissioned in the lab (cleaner environment)
- Final stage in the experiment:

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014_08_04</td>
<td>last chamber is installed</td>
</tr>
<tr>
<td>2014_09_25</td>
<td>1st SRB production delivered (24 boards)</td>
</tr>
<tr>
<td>2014_10_02</td>
<td>station 1 instrumented</td>
</tr>
<tr>
<td>2014_10_15</td>
<td>station 2 instrumented</td>
</tr>
<tr>
<td>2014_10_31</td>
<td>1st fully successful data transmission test</td>
</tr>
<tr>
<td>2014_11_03</td>
<td>1st run with central run control</td>
</tr>
<tr>
<td>2014_11_26</td>
<td>2nd SRB production delivered (24 boards)</td>
</tr>
<tr>
<td>2014_12_03</td>
<td>stations 3 and 4 instrumented</td>
</tr>
<tr>
<td>2014_12_04</td>
<td>1st run with a fully instrumented detector</td>
</tr>
<tr>
<td>2014_12_05</td>
<td>1st high intensity run with a fully instrumented detector</td>
</tr>
</tbody>
</table>
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System Performance

- Detector DAQ is performing as expected and is stable and reliable.
- The detector is fully integrated into NA62 Run control system.
- High intensity test (~7MHz overall particle rate) give us new inputs to improve the detector DAQ.
- First Results from Physics analysis are aligned with the designed performances.
- On line monitoring (matched and raw data) in order to spot possible problems even not detector related (beam)
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Online Monitor

Chamber 1
Chamber 2
Chamber 3
Chamber 4

Leading time (burst zoom)

Entries / 1 ns

Leading time (burst)

Entries / 1 μs

Time [ns]

Entries

Mean

RMS

Time [ns]
Tracks reconstructed at the height of chamber 1
Some Real Physics Data

- Missing squared mass

\[ K^+ \rightarrow \pi^+ \pi^0 \]

\[ K^+ \rightarrow \mu^+ \nu \]

\[ K^+ \rightarrow \pi^+ \pi^+ \pi^- \]

\[ P < 35 \text{GeV} \]

Analytical computation

Entries: 10897
Mean: 0.02742
RMS: 0.0321
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Conclusions and Plans

- The STRAW detector is fully commissioned and operational
- System stable and reliable (tested up to 50% of beam intensity)
- FW improvements and bug fixing are still needed
- The first NA62 physics run is ongoing (end run: mid November) \(\rightarrow\) consolidation of the spectrometer readout and monitoring

- Possible upgrades:
  - Participation to the L0 trigger decision using FPGA based tracking algorithm
  - 3-5 years new front end chip \(\rightarrow\) improve detector resolution
Spares
Chambers Illumination

Chamber 1

Chamber 2

Chamber 3

Chamber 4
The Straw Detector

- 4 views per station
- 7168 mylar straws (Ø 0.8mm x 2.1 m), Cu-Au metallization (50-20nm)
- 15 km of ultrasonic welding in vacuum
- 30 µm gold-plated inner wire (200µm position accuracy)
- Gas mixture Ar-CO₂ 70:30
- 10-15mbar overpressure
- ~460l/h total flow
Calibration: $r$-$t$ curve (Autocalibration)

\[ r(t) = \frac{R}{N_{tot}} \int_0^t \frac{dn}{dt'} \, dt' \]

Dots: MC

Drift time [ns]

\[ N_{hits} / 2 \text{ ns} \]

Drift time [μs]

\[ R \text{ [mm]} \]
The NA62 Apparatus

- Guidelines of NA62 apparatus design:
  - High intensity => Rare decay
    - $3 \times 10^{12}$ protons per pulse
    - 10MHz of K decay in the fiducial region
  - High Energy beam (unseparated 75GeV secondary SPS hadronic beam) => $\gamma$ veto, $\pi/\mu$ separation
  - Precise timing

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Hadron Beam
800 MHz

Kaon identification
In CEDAR

CHANTI

GTK

Fiducial Region 65m

Total Length 270m
The Straw Detector

- Challenging detector:
  - Operate in vacuum ( < 10^{-5}\text{mbar} )
  - Low material budget ( < 0.5\%X_0 \text{per station} )
  - $\Delta P/P \leq 1\%$
  - $\Delta\Theta_{K\pi} \leq 60\mu\text{rad}$
  - Single view resolution: 130\(\mu\text{m}\)
  - Full reconstructed coordinate resolution: 80\(\mu\text{m}\)
The Straw Detector Milestones

- **2007**: first preliminary meeting
- **2010**: construction & test of a proof of concept prototype
- **2010**: first prototype of the front-end board
- **2011**: straw massive production starts
- **2011**: straw readout board 6U prototype
- **2012**: technical run (module 0 installed on the beam-line)
- **September 2014**: last station installed
- **October-December 2014**: NA62 Pilot Run