

2016 NA62 STATUS REPORT SPSC121 APRIL 19, 2016

CERN-SPSC-2016-016 SPSC-SR-183

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, 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)



THE $K \rightarrow \pi v \overline{v}$ decays: a theoretical clean environment

 \bigcirc FCNC loop processes: s \rightarrow d coupling and highest CKM suppression



- Very clean theoretically: Short distance contribution. No hadronic uncertainties
- SM predictions [Buras et al. arXiv:1503.02693], [Brod, Gorbahn, Stamou, Phys. Rev.D 83, 034030 (2011)]

$$BR(K^{+} \to \pi^{+} \nu \bar{\nu}) = (8.39 \pm 0.30) \cdot 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2^{\circ}}\right)^{0.74} = (8.4 \pm 1.0) \cdot 10^{-11}$$
$$BR(K_{L} \to \pi^{0} \nu \bar{\nu}) = (3.36 \pm 0.05) \cdot 10^{-11} \left(\frac{|V_{ub}|}{0.00388}\right)^{2} \left(\frac{|V_{cb}|}{0.0407}\right)^{2} \left(\frac{\sin \gamma}{\sin 73.2}\right)^{2} = (3.4 \pm 0.6) \cdot 10^{-11}$$

• Experiments:

 $BR(K^{+} \to \pi^{+} \nu \bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11} \text{ Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)} \text{ E787/E949, BNL}$ $BR(K_{L} \to \pi^{0} \nu \bar{\nu}) < 2.6 \times 10^{-8} (90\% \text{ C. L.}) \text{ Phys. Rev. D 81, 072004 (2010)} \text{ E391A, KEK}$

NA62 DATA TAKING IN 2015



Kaon decays in flight Secondary beam K12 Positive polarity, 75 GeV/c 750 MHz [6% *K*⁺]

NA62

- Hermetic photon coverage
- Full Particle identification
- EM & Hadron calorimetry
- K and π tracking in vacuum

- Beam time 2015: June 22 November 15
- ~2 10¹⁰ triggers on tape
- Reached nominal beam intensity by the end of the run



STATUS OF THE ANALYSIS OF THE 2015 DATA

- Performance of the detectors in line with the expectations at low intensity
- The next four slides summarize the situation as recently presented by Giuseppe Ruggiero at Moriond EW, 2016
- Study of the data taken at higher intensity is in progress



 Calorimeters 1-2 ns

13/03/2016



- **×** Technique: Si pixel tracker; Straw tube tracker in vacuum
- ***** Goal: $O(10^4 \div 10^5)$ suppression factor of the main kaon decay modes
- × P_{π^+} < 35 GeV/c: best K^+ → $\mu^+\nu$ suppression.
- ★ Kinematics studied on $K^+ \rightarrow \pi^+ \pi^0$ selected using LKr calorimeter.
- **×** Resolutions close to the design.
- × $O(10^3)$ kinematic suppression factor in 2015.



Downstream Particle Identification



- Technique: RICH and calorimeters
- Goal: O(10⁷) μ/π separation to suppress mainly $K^+ \rightarrow \mu^+ \nu$
- $15 < P_{\pi^+} < 35 \text{ GeV/c: best } \mu/\pi \text{ separation in RICH}$
- Pure samples of pions and muons selected using kinematics
- RICH: O(10²) π/μ separation, 80% π^+ efficiency in 2015.
- Calorimeters: $(10^4 \div 10^6) \mu$ suppression, $(90\% \div 40\%) \pi^+$ efficiency in 2015 using a cut analysis. Room for improvements.



NA62 ACTIVITIES IN 2016

- Preparations for the new run are being completed
 - LAV: long term solution for HV flanges / Connectors / Power Supplies
 - RICH: hexagonal mirrors exchange and piezo-motor maintenance
 - LKr: Replacement of the electrolytic capacitors on the transceivers (TX) power supplies
 - Start "Industrial" production of 25 Gigatracker detectors
 - Strengthen the Online system and the analysis
- Stable data taking (from April 25) and analysis
 - Collect an unprecedented number of K decays...
 - Aim to stable data taking for $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ @ 50% of nominal beam intensity [Nominal: 3.3 x 10¹² ppp on T10, flat top 4.8 s]
- Also: investigate possible new opportunities for the future (e.g. neutral kaons, pions, dark sector)



BEAM

- In 2015 the P42 beamline operated with correct transmission
- Extra shielding wall has been installed for 2016
- Modification to head motorization introduced on all targets
- Airlock modification of T10 zone and ECN3 area
- KTAG infrastructure for possible operation with Hydrogen gas completed



The new shielding wall just upstream of the T10 target



NA62

2015 K12 Beam profiles measured in the FISC filament counter downstream of the LKr calorimeter



GIGATRACKER (GTK)

- In 2015 three detectors were used with TDCpix thickness of 450 (GTK1) and 100 μ m (GTK2 and GTK3)
- The DAQ was operated in L0 trigger match mode. Thus, only the data associated to a given L0 trigger were read out and sent to the PC farm
- The detector temperature was kept at about °0 C, with the cooling plant operating continuously to provide a 2 g/s flow of liquid C₆ F₁₄ at -25 °C.
- The Detector Control System was operational
- Data have been taken continuously and merged into the NA62 data stream

Note on the way the GTK detectors are numbered: GTK1 = any GTK detector installed in position 1 GTK_1 = the first GTK to be built

INVESTIGATION OF THE GTK NOISE

- During the 2015, an anomalous noise developed on the GTK stations
- This noise is independent of the reverse bias voltage
- The list of noisy pixels changes as a function of time
- Event after a few months w/o beam the anomaly remains present (also in the lab)
- To exclude damage by radiation, we irradiated a bare chip and an assembly (sensor plus chip) to a much higher dose with X-rays: the chips behave correctly after irradiation
- The investigation is continuing
- New GTK detectors will be used in 2016: much better control of the operating conditions will be available

GTK: BUMP-BONDING

- For the second production, TDCpix wafers were probed before shipment to IZM
- The production is ongoing:
 - 9 full-module and 9 single-chip assemblies
 - 100 micron thin TDCpix
 - using the last 9 wafers (n-in-p) from the FBK sensor production

GTK: NEW VERSION OF THE CARRIER

- Main features of new boards:
 - Decoupling capacitors added close to TDCpix
 - Power Supply distributions on the board have been duplicated
 - Ability to change working mode of the TDCpix remotely
 - Analog out signal bonded to a pin connector
 - Optical reset input now available on the board
 - Wire bonding scheme has been optimized by creating a step on the SND connection inside the GTK PCB





GTK: MICRO-CHANNEL COOLING

- The damage of the GTK_1 detector (June 18, 2015) was due to a hydraulic shock (understood)
- On GTK_2 a bad thermal contact was identified between the micro-channels cooling plate and the tip of one of the TDCpix read-out chips. A dedicated tool was designed and manufactured to improve the thermal contact between the chip and the cooling plate
- GTL_4 and GTK_5 were assembled in 2015
 - GTK_4 was assembled with a new support for the wire-bonding
 - GTK_5 was assembled with a new brazing procedure and a new gluing jig



Cross-section of the cooling plates of (left) Option A and (right) Option B

Schematic representation of the TDCpix detached from the cooling plate

GTK INTEGRATION: GTK_4

GTK_4 was assembled with a new support for the wire-bonding



3D-printed support structure positioned on the backside of the cooling plate during wire-bonding.



GTK INTEGRATION: GTK_5



New Gluing Jig



Weights applied on the cooling jig



Brazed connectors on the cooling plate of GTK_5



Au plated KOVAR connectors with underlying Cu layer



GTK: TDCpix TEST



- The behavior of the single TDCpix assembly was fully studied with a high precision laser
- The absolute calibration of pixel thresholds of the assemblies installed on the GTK Carrier was performed with a ¹⁰⁹Cd source
- Commissioning of the wafer probe was completed. Three full TDCpix wafers were probed, with a measured yield of 81% giving 146 known good chips, which is amply sufficient for the second round of bump-bonding
- Significant effort was invested in the preparation of the GTK Carrier Card production testing laboratory
- GTK_4 was extracted from the beam line for testing of a spurious noise with the investigation ongoing

"OFF-DETECTOR" GTK DAQ

- Firmware for FPGAs on the GTK-RO was upgraded
- Upgrade to the PC systems
 - 3 to 6 GTK-PC
 - Possibility to read out the detector at Level 1

GTK: RESULTS

 The operation of the GTK system in 2015 confirmed that the mechanics, the cooling, and the electronics were properly working



Time resolution for the GTK stations, when operated at a bias voltage of: GTK1 and 2 at 300 V, GTK3 at 216 V



The squared missing mass distributions for $K^+ \rightarrow \pi^+ \pi^0$ decays computed without (blue line) and with (red line) the GTK track reconstruction



LARGE ANGLE VETO (LAV)

- A problem was discovered with the HV connectors. All the connectors have been replaced with a modified version
- Progress on LAV reconstruction code and on data analysis has been made
- First attempt at estimating the global efficiency of the for the entire LAV system made: the intrinsic inefficiency is found to be smaller than the expected geometrical one



Difference between LAV hit time and event time from KTAG (ns) for different thresholds, for the twelve stations



Distribution of difference in azimuth, $\Delta \phi$, between clusters on different stations vs. the number of stations between the most upstream and downstream clusters



STRAWS

- 1 out of 7168 straw is not operational; it was sealed and disconnected after small leak was found in 2014
- In 2015 the detector could be efficiently readout at 50% of the nominal intensity
- The readout firmware and DAQ have been improved to stand higher beam rates
- In 2016 the Straws should become an important player in the Level 1 trigger





Time resolution for single-track event. The t_{track} is obtained from tracks having at least 27 straw hits per track and at least four hits in every chamber.

Illumination of the Straws

RICH MAINTENANCE

- RICH emptied of Neon in November and prepared for access
- All 38 motors were tested and checked
- The two semi-hexagonal mirrors were replaced with new ones of slightly different geometry
- Mirror system aligned with a laser









RICHPERFORMANCE



Squared particle mass reconstructed using the velocity estimated by the Cherenkov angle measured by the RICH and the momentum measured by the spectrometer for electrons, muons and charged pions selected using spectrometer and calorimetric information, with particle momentum between 15 and 35 GeV/c



Number of hits per Cherenkov ring as a function of particle momentum; samples of electrons, muons and charged pions are selected using spectrometer and calorimetric information. The number of hits in the electron case is not exactly constant due to the limited acceptance of the photo-multipliers



LKr: CREAM READOUT UPDATES

- The initialization software was carefully tuned and completely integrated with the run control
- A specific baseline restore procedure was set up
- As an additional network monitor tool, all the CREAM switches are configured to have a port which mirrors one of the CREAM outputs
- Ethernet switches can now be remotely powered up
- Improvement of the zero suppression
- Addition of a programmable detector ID in order to use the CREAMs for MUV1 and MUV2 readouts
- Increase of the depths of the L1 input FIFOs to avoid situations where the data was not sent to the correct PC
- Implementation of selectable ways of forming the trigger sums, in order to find the best one for the
 optimal synchronization of the CREAMs with the TELDES boards in the LKr LO system
- Possibility of having event packing in output from CREAM for optimizing network traffic has been studied and is being implemented



LKr: CREAM FIRMWARE MODIFICATIONS

- Improvement of the zero suppression threshold with a cut on the difference between the minimum and maximum sample, like it was done for the 2012 run with the old CPD readout
- Addition of a programmable detector ID in order to use the CREAMs for MUV1 and MUV2 readouts also
- Increase of the depths of the L1 input FIFOs to avoid situations where the data was not sent to the correct PC
- Implementation of selectable ways of forming the trigger sums, in order to find the best one for the optimal synchronization of the CREAMs with the TELDES boards in the LKr LO system
- Possibility of having event packing in output from CREAM for optimizing network traffic has been studied and specification paper sent to CAEN to check feasibility and get an economical offer



LKR: CALIBRATION SOFTWARE AND OPERATION

- Calibration data was regularly taken to verify stability of the pedestals, slopes and the constants of the digital filter
- Plan to integrate the calibration procedure in the standard runs, constantly acquiring pedestal and calibration data together with physics data, to have a tool for better monitoring of the parameter variation



Linearity plot as a function of the calibration voltage



Average value of the pedestals, as a function of run number

LKr: Cal-LOTRIGGER

- Upgraded to process data from all the experiment's electromagnetic and hadronic calorimeters
- The new configuration is used to select events with a π^+ in the final state
- All Cal-L0 hardware was installed before the beginning of the 2015 run
- Firmware and software were continuously improved during the run
- After the end of the run, the Run Control software was completed and an automatic procedure was developed to detect and eventually correct Single Events Upset in the system
- Trigger clustering algorithm and readout firmware are being implemented
- Some preliminary measurements were performed and in particular a good agreement between the off-line reconstructed energy and the trigger energy threshold was found both for the LKr and the MUV1 calorimeters.

Detector	Physical channels	Trigger channels
LKr	13,248	864
IRC	4	1
SAC	4	1
MUV1	176	6 (vertical) + 6 (horizontal)
MUV2	88	3 (vertical) + 3 (horizontal)
Total	13,520	884



Schematic diagram of the Cal-L0 trigger



LKr Cal-LO TRIGGER



(a) Front-End crates receiving trigger sum linksfrom the CREAM system(b) Cabling between Front-End and Merger crates

(a) Offline reconstructed energy in the LKr calorimeter for different LKr energy trigger thresholds
(b) Offline reconstructed energy in the MUV1 calorimeter for different MUV1 energy trigger thresholds



NEWCHOD

- New CHOD detector mounted on the front of LAV12
- The expected track crossing rate at nominal beam intensity evaluated with Monte Carlo simulations is about 13 MHz

NA62 🍂

 The corresponding total hit rate over the counters is about 45 MHz, due to the high hit multiplicity events produced by interactions of photons and beam pions upstream of the detector



Left: the expected rates in CHOD tiles at nominal beam intensity, calculated with MC simulations (in MHz). Right: acceptances for $K^+ \rightarrow \pi^+ v \bar{v}$ decays satisfying the signal selection conditions 105 m < zvtx < 165 m and 15 GeV/c < P_{π} < 35 GeV/c in each tile, calculated with MC simulations (in percent)



TDAQ: COMMON TDC-BASED TDAQ SYSTEM

- All TEL62 and TDCB boards were produced; roughly 10% did not pass the initial acceptance tests
- Before the start of the 2015 run, a large effort was put in increasing the capabilities of the system, in order to allow it to fully handle the maximum hit rate which can be provided by the hardware, and allow controlled behavior when exceeding specifications
- The laboratory test system was improved to allow injecting high hit rates into a single-board system with variable space and time distributions
- Statistical off-line data checks allowed us to measure data anomalies related to the documented intrinsic nonlinearities of the HPTDC chips

TDAQ: LO TRIGGER SYSTEM



- Commissioning of the digital L0 trigger was the TDAQ priority for 2015
 - It was used exclusively throughout the run, starting with single elements and gradually growing to include more of them
 - it proved to be versatile, easy to control, and synchronize, although it also showed some limitations in the implementation, mostly related to manpower issues
- A thorough review of possible L0 triggers was done before the run
 - Implementation was limited by the actual performance of the primitive-generating firmware modules
- The calorimetric LO trigger hardware was fully installed, and energy-based primitives were available for triggering in the last weeks of the run.
- Both of the two alternative LO trigger processor systems were improved and tested
- The experimental GPU-based trigger was partially deployed in 2015 and ran throughout the run in a parasitic way, collecting data from half of the RICH detector and producing primitives, which were recorded but not used for actual triggering
- After the run, development of a completely new LO primitive generating firmware suitable to both NA48 CHOD and RICH was started
 - the system is now being tested, and is expected to be deployed for the 2016 run



TDAQ: ON-LINE FARM AND HIGH-LEVEL TRIGGER

- Several issues were found, such as difficulties in consistently recording End-Of-Burst events which contain precious monitoring information
- Understanding of the system was improved as the run progressed
- Some basic L1/L2 infrastructure was finally available, together with general required features such as downscaling, bypassing, and just-in-time decoding
- Simple L1 algorithms were implemented with no event rejection at the beginning of the run
- After the run, the implementation of a L1 algorithm working on the straw spectrometer's data took place



TDAQ: CONCLUSIONS

- Apart from some small parts, the TDAQ system was finally completed during 2015
- The LO digital trigger was implemented and exclusively used (no NIM trigger)
- Simple high-level triggers were implemented
- The performance suffered in general from fluctuating instantaneous hit rate (e.g. 75 Hz beam structure)
- Improvements for the 2016 run are being tested in dedicated dry runs
- Strategy for data taking: run at the highest beam rate consistent with good data quality and TDAQ capability
- Aim to reach stable and well controlled running conditions at 50% of the nominal intensity to collect a good sample of physics-grade data
- The importance for the experiment of a uniform SPS extraction is stressed

PUBLICATIONS AND ANALYSIS OF OLDER DATA

- The collaboration has completed the publication of the NA48/2, "Search for the dark photon in π^0 decays", PLB 746 (2015) 178
- Two physics analyses based in older data sets recorded by NA48/2 and NA62 were approved:
 - a search for Majorana Neutrinos in $K^{\pm} \rightarrow \pi^{\pm} v_H$ decays, based on 2003-2004 Data
 - a measurement of the π^0 transition form factor (from a large sample of $K^{\pm} \rightarrow \pi^{\pm} \pi_D^0$ with π^0 Dalitz decay), based on 2007 Data.

NA62

• More analyses of both NA62 and NA48/2 data are ongoing

