Detectors in Particle and Nuclear Physics

Laboratory Exercises

This laboratory course series gives an introduction for some well-known detectors in particle physics, with simple exercises to understand their main characteristics and applications.

The Laboratory Course could include the following sections (usually 3 of these 4) :

A) Scintillators and PhotoMultiplier Tubes
B) Multi-Wire Proportional Chamber
C) Tracking with Gaseous Detectors
D) MicroPattern Technology and Photon Detection

Recommended knowledge for the course:
General : Using digital oscilloscope, basic linux commands, plotting graphs, statistics, ionization of charged particles, beta/gamma radiation, cosmic rays.
A : basics of scintillator detectors, photo-multiplier tube.
B,C,D : basics of gaseous detectors: ionization, electron avalanche, gas gain.
D : micropattern technology, photo-effect.

Most is covered by the standard lectures, brief introduction can be found in wiki sites; while mandatory details can be found in:
For gaseous detectors from Fabio Sauli “Principles of Multiwire and Drift Chambers” the following chapters : 2.1, 2.2, 2.6; and the first parts of chapters 5.1,6.1,7.1.
For micropattern detectors from Serge Pinto “Micropattern gas detector technologies and applications” (arxiv:1011.5529) section I.

Location: The course takes place in the Gaseous Detector Laboratory of the Department of High Energy Physics in the Wigner Research Centre for Physics.
Address: Blg.2. at KFKI, 29-33. Konkoly-T.M.str. 1121 Budapest.

Notifications, and precaution.
The used particle physics detectors are extremely sensitive. Scintillators, photo-multipliers, and gaseous detectors all shall be dealt with care to avoid risky situations:
- Do not move detectors when under high voltage!
- In case of any suspicious accident, please switch of the HV, and notify the laboratory supervisor.

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Course on
Scintillators and PhotoMultipliers

Scintillators are intended for fast tagging of the presence of particles: that is, with a good time resolution (order of 10ns) give a short pulse if the particle traverses a relatively large sensitive surface. For a typical particle physics setting, the light is created in plastic scintillator, and detected by a photo-multiplier tube (PMT). This gives the electric signal, that needs preamplification preferably close to the PMT to reduce noise.

0. Introduction, basic operation

The laboratory setup consists of 3 or 4 counters, each connected to an individual high voltage (HV) channel (negative voltage between 1000 – 1300V . Do NOT exceed 1350V).
The scintillators can be called A,B,C, and D, according to their specific role (see later).
Please take a note of the individual ID-s of the scintillators in the lab report for each measurement!
Observe the pulses from the scintillator devices, without and with amplifier. Observe the difference between background and radioactive Sr-90 beta source. Check the typical signal amplitude on oscilloscope with two scintillators above each other, using beta source. For all the scintillators, check for a ”baseline” voltage, which give 20mV amplitude for a crossing beta.

1. Synchronization in time

Compare the units and observe the difference in time delay. Include a delay lines so that the pulses arrive at the same moment. Set up a discriminator system for the units, and observe the coincidences and the time delay as well for this setup.

2. Determining the detection efficiency with cosmic rays

Put the scintillators above each other with maximum overlap, such the the selected one is in the middle. Measure the count numbers for the coincidences with and without the selected one, and compute its efficiency. Determine this efficiency as a a function of the HV applied to the selected one (and not changing the others). The interesting range is between 60-70% efficiency (lower is not relevant) up to 100V above the 95% efficiency value. Calculate the efficiency measurement error – note that the counting is binomial distribution, not Poissonian.
Repeat the measurement, for confirmation, for the other scintillators, such that the order is changed. The counter under study must be between the other reference ones.

4. Estimate the vertical cosmic ray flux

Determine the apparent vertical cosmic ray flux by appropriately placing the scintillators (in full efficiency mode) above each other. Measure the geometrical parameters directly.

5. Determine the detection efficiency with beta source

Using a high energy beta source the electron can pass a scintillator and hit the following one. Place them in order: Source, Selected, Reference; and measure the coincidence and count ratio for the relevant HV range. Measure at least two of the four scintillators.
Compare the two methods and the results.

Course on
Multi-Wire Proportional Chambers

Multi-wire proportional chambers are well known and most wide-spread technology for tracking charged particles. Applications range from basic research in high energy physics to medical imaging and muography.

0. Introduction to the used electronic devices and the MWPC itself.

The course starts with a brief introduction and recalling the recommended literature. Hardware-wise a semi-classical multi-wire proportional chamber will be used, with a small thin window for low-energy irradiation, and a set of scintillators from the former course.
List of used devices : MWPC detector; Scintillators and PhotoMultiplier Tubes; Digital Oscilloscope; NIM modules: Preamplifier, Discriminator, Coincidence unit, Dual gate generator; RaspberryPi microcomputer; Personal computer with linux system.

1. Measurement of the energy deposit of traversing particles, using an Sr-90 beta source

Set up the MWPC in between the Sr-90 source and a plastic scintillator. The radioactive source produces electrons that can cross the MWPC and hit the scintillator, thus energy deposit in the gaseous chambers becomes possible. The preamplified signal from the chamber is measured with an analog-digital-converter. The trigger for the measurement shall comes from the fast scintillator, after preamplification, discrimination and proper timing; later can be tuned and observed via the oscilloscope.
Exercises : Set up the mentioned measurement using the NIM units, and tune the proper timing. Take energy-deposit spectra with various HighVoltage on the MWPC.
Taks : Draw the schematics of the setup, including the logic gates. Examine the similarities of the taken spectra. Compute the dependence of the gas gain wtr the high voltage.

2. Measurement of the energy resolution, using an Fe-55 gamma source

Using a lower energy gamma source the ionization will be roughly point-like, and the energy resolution can be examined. In this case a self-triggering mode shall be used.
Exercises : Set up the described measurement. Take spectra with various HV.
Tasks : Schematics of the measurement. Examine similarities of the spectra. Compute gain dependence, and correlate with the one from the beta source. Estimate energy resolution.

3. Detection of cosmic muons

The comic origin particle (mostly muons) have high energy and can cross multiple detector layers. Place the MWPC in between two scintillators, and set trigger for scintillator coincidence.
Exercises : Set up the described measurement, and take data.
Tasks : Schematics of the measurement. Compare spectrum to ones from the beta source. Estimate the flux of the cosmic muons. Examine the time-difference distribution of the measurements.

Course on
Gaseous Tracking Detectors

Gaseous tracking detectors are favoured as being low material-budged and cost efficient technology even in large volumes. Most simple solution is tracking via several layers of position sensitive detectors, that is to be studied in this course.

0. Introduction to the used tracking detectors

The tracking system consists of a set of MWPCs, similar as studied in the former course, equipped with 2x1 dimensional readout electronics. The data acquisition system is a compact portable one with a RPi and some custom designed elements, with functions as in large detector systems.
List of used devices : Set of MWPC tracker detectors with position-sensitive readout; Scintillators and PhotoMultiplier Tubes; Digital Oscilloscope; RaspberryPi microcomputer; Personal computer with linux system.

1. Setup and data acquisition system

Inspect the MWPC based tracking tower, and get to know the system. Each chamber has three electrodes, two used for X and Y position information, while the third gives info about the whole detector; this is divided into three parts: analog, digital, and ADC. Start dummy data taking and investigate the monitoring and the data stream.
Exercises : Examine the analog and digital signals of the middle chamber, tune the threshold and the high voltage. Investigate the timing features. Confirm tracks of the cosmic muons.
Tasks : Draw the schematics of the setup and the data acquisition system. Record timing features via the scope. Show screenshot example of cosmic tracks.

2. Measure efficiencies of a chamber

With various applied high voltage on the middle chamber (others intact) take data with cosmic muons, and observe the changing of the efficiencies (trigger,X,Y) and the gain.
Exercises : Take data as described.
Tasks : Versus the applied HV compute gain variation, trigger efficiency, tracking efficiencies in both direction (X and Y) and combined. Correlate these results.

3. Tracking and muography

Set a good-efficiency and low-noise configuration for the detector system, and examine the distribution of the cosmic muon tracks. In low-noise mode simplified tracking is enough.
Exercises : Investigate and reduce the electronic noise. Examine tracking capability. Start long data taking to collect large statistics. Compute angle of incidence based on first+last chamber data.
Tasks : Determine the angular distribution of the cosmic muons. Prove existence of target on the roof via compare the measured flux to the reference.

Course on
MicroPattern Technology and
Detection of Single Photons

MicroPattern Gaseous Detector (MPGD) technology is the most recent and advanced family of gaseous chambers, featured for tracking, triggering, and Cherenkov applications as well.

0. Introduction to MPGDs and the used detector

Brief introduction to micropattern technology, GEMs, ThickGEMs, and UV photon detection. For measurements in this course a ThichGEM + WireChamber hybrid will be used, with UV-transparent quartz window.
List of used devices : ThickGEM+CCC Photon Detector; Custom designed preamplifiers; Triggered UV LED; Fast DAQ system; RaspberryPi microcomputer; PC with linux.

1. Absolute gain of a ThickGEM

The TCPD chamber is irradiated with an Sr-90 beta source, additional scintillator is placed below to trigger on. Timing of trigger and analog signal shall be checked on the scope, and tuned if needed, similarly as in the MWPC course. The electron ionized below and above the ThickGEM, from the resulted two peaks the absolute gain of the layer can be computed.
Exercises : Set up the measurement, and tune the timing. Confirm the double peak via the scope. Take data with various HV on the ThickGEM.
Tasks : Draw the schematics of the setup. Compare the spectra of the various HV data. Compute the absolute gain of the ThickGEM, and plot wrt the HV.

2. Collection efficiency and MIP suppression

Using the former setup measure the collection efficiency for MIP with various electric field applied to the cathode region.
Exercises : Take data with scan on cathode voltage with low and high TGEM gain.
Tasks : Compare the spectra. Determine the suppression of MIP signals wrt cathode field. Compare results for the low and high gain, and discuss the findings.

3. Detection of single UV photons

Using a pulsed UV LED single electrons can be emitted from the surface of the ThickGEM, and can be detected with the system. Timing shall be tuned for the new trigger. Light intensity shall be reduced multi-electron probability. Signal for single photo-electrons will be observable.
Exercises : Setup the UV LED. Tune proper timing and light-flux. Measure the signal spectrum for single photo-electrons. Take data with several TGEM voltage. Take data as in cathode-voltage scan.
Tasks : Draw schematics of the setup. Compare the spectra of single photo-electrons in various HV and determine photo-efficiency and gain, compare later with former measurements. Check effect of MIP suppression on photo-efficiency.