Charged particles beam intensity monitoring

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Introduction

Particles physics is often a matter of processes cross sections measurements. In typical particle physics experiments, an intense beam of particle is sent on a thin target. Secondary particles produced by the interaction of incident beam on target nuclei are detected. Given the target surfacic atomic density, the efficiency of the detectors and the beam intensity, one can calculate the cross section of a given process (collision cross section for instance). The first parameter is easy to calculate with uncertainties on the order of a few percent. The second one mainly depends on secondary particles. For charged particles, the quantum efficiency is generally close to 100% and you just have to calculate the solid angle the target sees your detector. The last one, ie beam intensity, should be carefully measured as its relative uncertainty directly affects cross section uncertainties.

Particle counting methods are not easy to use in the field of beam monitoring. In fact, the cross section is generally so small that the majority (typ. > 99,99%) of incident beam ions don't even hit target atoms. Only a small fraction of incident ions comes into collision with target atoms. So, if you adjust your beam in order to have, say a few thousand particles per second in your detectors, the incident beam intensity is at least hundreds to thousands times greater, generally exceeding particles counting capabilities.

A solution consists of integrating the beam intensity dumped in a Faraday cup (FC) for instance. Despite its apparent simplicity, this method often provides poor quality results due to the response of the FC. We will explore the use of an X ray counting approach that consists of detecting X rays emitted by a thin metallic foil (when crossed by the beam) inserted in the beam pass after the target.

What will you find in this educational document?

- An example of detectors setup providing absolute beam intensity measurements
- How to properly count beam piled-up events in a plastic scintillator
- How to integrate scintillation ion counting and high resolution Si(Li) detector spectroscopy in the FASTER data acquisition and processing system.

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1. The device and its electronic

When a high energy beam travels thru metallic foils, it generally produces a small amount of characteristic X rays. The X rays energy and intensity depends on the foil composition and thickness, beam nature (particles A, Z and energy) and last but not least, beam intensity. For a given set of parameters (foil and beam nature), the X ray emission intensity is perfectly proportional to beam intensity. Thus, if we find a way to calibrate this proportionality coefficient, we possess and absolute beam intensity measurement device!

First of all, we need a X ray detector. This device, being in the experimental hall, is submitted to "environmental" radiations that produce a background count. In order to cope with this background, the detector choice can be guided by resolution considerations. The better the resolution, the better the peak count for a given background. The experiment below used a lithium compensated silicon detector (Si(Li) detector, see Fig. 1).

Fig. 1: a Si(Li) detector from Ortec

The X ray emission foil was a 7µm argent foil producing characteristics X rays of precise energy:

Ag → X ray	$K_{\alpha 1}$	$K_{\alpha 2}$	$K_{\beta 1}$	$K_{\beta 2}$
Energy (keV)	22.163	21.990	24.943	25.455

This foil was 45° from the beam line and from Si(Li) axis, #50cm apart from the detector. This way, the solid angle the X rays emission area sees the detector doesn't change much with beam position.

The calibration of the proportionality between beam intensity and X rays detection intensity must be performed by a particles counting detector located after the metallic foil. At full beam intensity, this detector would be destroyed in a few minutes or hours. In fact, it is operated at moderate beam intensity, low enough in order to perform correct particles counting and high enough to have good X rays counting. This detector is a simple plastic scintillator sheet (two millimeters thickness) coupled to a photomultiplier (PM) tube. Each time a beam particle crosses the detector, the PM tube produces a pulse that is counted a special way by FASTER (we will see why later). The detector is mounted on an insertion device which puts the detector IN the beam line or OUT the beam line (Fig. 2).

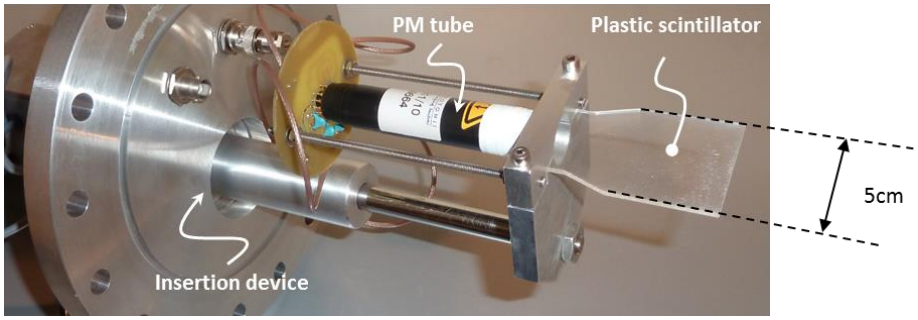

Fig. 2: The scintillator and its PM tube mounted on the insertion device

During calibration, both the metallic foil and the plastic scintillator are inserted in the beam line and the beam intensity is moderate. Once the foil emission calibrated, the plastic scintillator is extracted and the beam intensity can be increased to its nominal level.

2. Data acquisition:

In fact, as usually, detectors connection to FASTER data processing and acquisition system is very simple (see Fig. 3).

We need to process a low noise signal coming from the Si(Li) detector, more precisely, from its charge sensitive preamplifier. In order to do this job near the optimal way, we need a spectroscopy amplifier followed by a peak hold ADC. All these devices are already integrated as digital processing boxes in FASTER. So, we just have to connect the preamplifier output to FASTER input and find the correct settings for the internal shaper! For the best shaping performances one should use MOSHAR (14bits, 125MHz) daughter boards, but one can also use a CARAS (12bits, 500MHz) board. Beware that daughter board input should be high impedance for spectroscopy purposes (as low noise charge sensitive preamplifiers generally don't like 50Ω matched inputs!).

We also need to process fast signal coming from the PM tube. The best way to perform this job is to use a CARAS board. Here also, the FASTER data processing and acquisition system contains all the necessary signal processing we need for the experiment, ie

low-pass or high-pass filters connected to Threshold or Constant Fraction Discriminators and to up to four gated integrators for charge measurements.

The complete system is represented on Fig. 3.

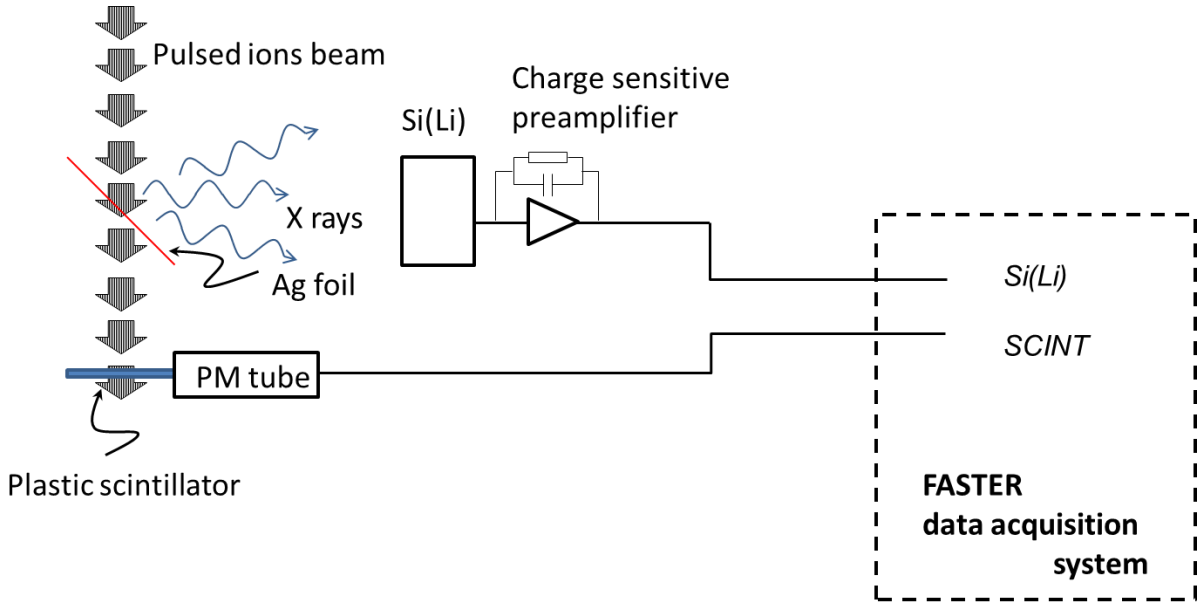

Fig. 3: complete setup for beam intensity monitoring

3. Data analysis

We will now expose the calibration technics and some results of beam monitoring at the GANIL facility.

3.1. Absolute incident ions counting

GANIL generates high energy ions beam by the mean of two cyclotrons. The main consequence is that ions emerging the machine are “bunched” (ie in small time packets). When an ions bunch crosses the plastic scintillator, it produces a quantified light pulse proportional to the number of ions in the bunch and there is no light emission between two consecutive bunches. This situation is clearly visible on Fig. 4.right which is an oscilloscope capture of the PM tube signal.

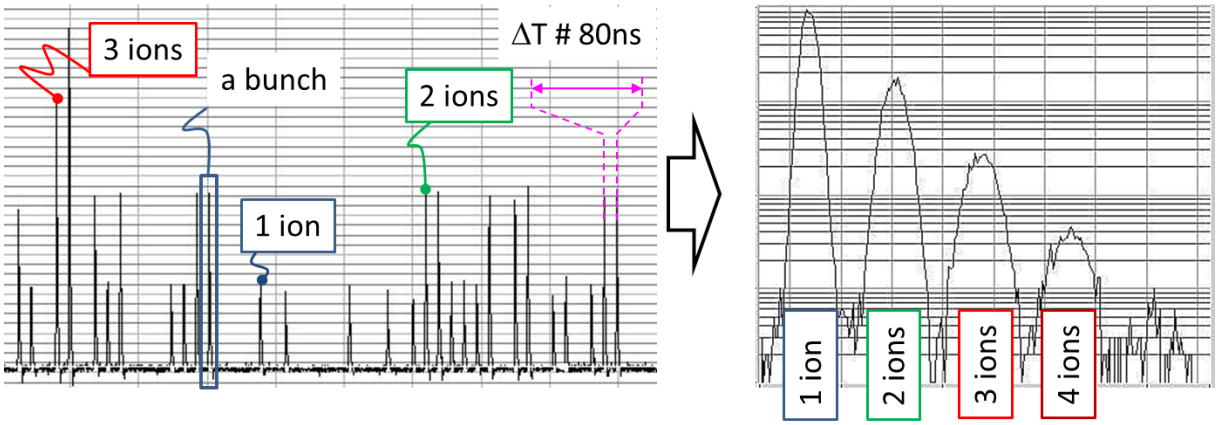

Fig. 4: fine structure of a GANIL beam in oscilloscope mode (left) and its amplitude histogram (right)

The histograming of several oscilloscope traces shows a clear separation between each bunch contents allowing the identification of the number of ions in each bunch (Fig. 4.left).

In real time applications, it is impossible to transfer every bunch contents as it would saturate the link between the acquisition system and the analysis computer. Two different strategies can be applied and are incorporated in the FASTER data processing and acquisition system:

(1) You can trig on each bunch and output only one result over 100, 1000 or 10000. This solution limits the bandwidth requirements but supposes that beam intensity is stationary (doesn't statistically change) between each result.

(2) Or you can select up to eight thresholds on the histogram and let FASTER count the total number of ions for a given period. You use what we called a multi levels scaler.

With the first solution, you get the spectrum and you have to analyze it, as with the second one, you just get the total count and must be confident in the counting capability of the system.

3.2. Si(Li) energy calibration

The Si(Li) detector energy calibration has been made by using a ^{109}Cd source. This radioelement falls on ^{109}Ag (which is stable) by electron conversion. This is the reorganization of Ag that produces Ag characteristic X ray used to calibrate the detector. That's the reason why we also used an Ag foil.

The energy resolution on Ag peaks is about 170eVrms.

3.3. Si(li) absolute ion counting calibration

A typical spectrum during beam intensity calibration is drawn on Fig. 5.

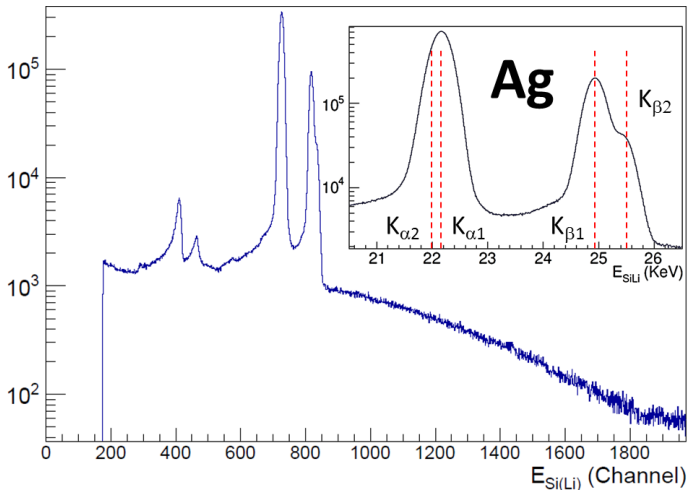

Fig. 5: typical Ag X rays measurement under beam irradiation

Integration of Ag peaks count vs plastic scintillator ions count during the same period gives the proportionality coefficient we need. Then for a given run, we just have to count Ag peaks in order to have a good estimation of incident ions with and uncertainty of about one percent.

4. Conclusions

It is generally important, for nuclear physics experiments, to have a good precision on absolute beam intensity. This use-case illustrates an elegant solution to this requirement, using a Si(Li) X ray detector as low efficiency sensor. This approach can be used in many cases with other kinds of detectors as ionization chambers for instance or even Faraday cups (both are far less expensive than Si(Li) detectors!). The only think to keep in mind is that absolute ion counting must be performed at low beam intensity. Thus, depending on detectors, the beam intensity must be adjusted in order to keep good measurements in the low efficiency sensor.

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