Università di Pisa

DIPARTIMENTO DI FISICA "ENRICO FERMI"
Corso di Laurea in Fisica

Tesi di laurea

Commissioning and first data analysis of the Mainz radius experiment.

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Contents

Abstract

short introduction

Chapter 1

Introduction

- explain neutron skin thickness.
- connection to neutron stars radious, and neutron stars description.
- Equation of state (EoS) for high density nuclear matter.
- Parity-violating scattering experiment for extracting neutron skin thickness.
- mention the weak form factor.
- Transverse asymmetry as background for Parity-violating experiment.
- Mention the other experiment, like PREX, that measure zero A_n for Lead.

1.1 Neutron skin thickness and EOS

In this section we have to explain what is the neutron skin thickness and why this parameter is related to the Equation of State for nuclear matter (in particular, the slope of the Symmetry energy in the semiempirical mass formula). Then, explain the parallelism between Neutron stars and Nuclear matter (the share the same EOS), and underline the relation between radius of the neutron stars and EOS.

1.2 Parity-violating scattering experiment

This section is for describing the way it's possible to extract the neutron skin thickness. Here I have to mention the weak form factor and the important fact that the neutrons are more important than the protons in the parity-violating scattering, because of the weak mixing angle.

1.3 Transverse asymmetry

Here we have to introduce the aim of this thesis: the transverse asymmetry is a source of background for the parity-violating experimets. Furthemore the theory is not working well for some nuclei (^{208}Pb), so mention PREX paper about the last mesurement on carbon and lead, the problem that they measure 0 trasverse asymmetry.

1.3.1 Motivation

Here present all the motivation for this thesis, so the fact that we want to measure the rates on lead for the future experiment, test the new electronics, measure another time the trasverse asymmetry on ^{12}C

1.3.2 Conventions used

It could be usefull, here, to have a subsection to explain the terminology for this thesis, to avoid misunderstanding.

Chapter 2

Transverse Asymmetry

- Physics behind the A_n asymmetry, dependence on Q^2, the formula $\frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$
- state of the art of the Exp.
- Model description: so scattering amplitude, theoretical prediction
- Expected error δA_t
- open question: problems with lead, dependence of E_{beam}, dependence from Z, Z/A

2.1 Description of the process

Explain the scattering process we are studying (at least one figure to visualize the kinematics of the scattering). Mention the link between this process and time-reversal operator. Add two figures for elastic and inelastic scattering.

2.1.1 Elastic scattering

Write the amplitude for the elastic (how to manipulate expression, maybe in the appendix).

2.1.2 Inelastic scattering

Explain how it's possible to compute the inelastic expression, what kind of approximations are used (optical theorem...)

2.1.3 Model description

Present the theoretical formula for the Transverse asymmetry, and comment on energy, Z, Z/A depencencies

2.2 State of the Experiment

Write down the formula $\frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$. Hints at how to measure the Transverse asymmetry (remember to mention we have a polarized beam against a unpolarized target). Explain the expected error for the recostructed asymmetry. Furthemore talk about the last mesurements obtained by the other collaborations, an outlook of the current situation. Maybe add also how we proceed to measure the transverse asymmetry, so the structure of the event, polarities patterns...

Chapter 3

Experimental setup

- description of MAMI, how the beam is produced, how the electrons are polarized.
- description of A1.
- description of beam stabilization, how the monitors measure the beam parameters.
- Electronics description, DAQ system, VFC monitors.
- Detectors A and B.

3.1 First description of the experiment

First description of the experiment, how we want to collect data, new picture of the kinematic of the experiment. Maybe here it's a good point to describe the structure of the event.

3.2 Mami

How Mami produces polarized electron and how the particle are accelerated (the way Mainz Mikroton is working is completely different from the other accelerators, so maybe this section will be too long).

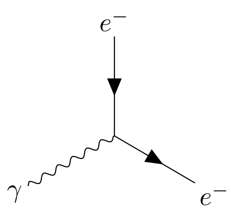
3.2.1 Acceleration stage

explain how electrons are accelerated, and sent to different experiments.

3.2.2 Polarized Beam

For the beam-normal single spin asymmetry a vertical polarized beam is necessary. At the MAMI electron accelerator is possible to produce a vertical polarized beam with energy in the range $180\,\mathrm{MeV} - 855\,\mathrm{MeV}$. In this section the procedure to orient the beam vertically, following an explanation of how the degree of polarizarion of the beam is measured.

The electron source used at MAMI is made by a strained GaAs/GaAsP superlattice photocathode illuminated by circular polarized light. A Pockels cell changes the helicity of the photons impinging on the electrons. The extracted electron has the same helicity of the incoming photon, let's suppose as an example:



$$(Jz)_\gamma = \pm 1 \qquad (Jz)_{e^-} = \mp\frac{1}{2} \to \pm\frac{1}{2} \tag{3.1}$$

With the fast change of the Pockels cell it is possible to alternately revert the sign of the polaritazion. By the insertion of a $\lambda/2$ plate between the laser system and the photochatode the polarization orientation of the electron beam can be reversed for each sub-event, useful later for the estimation of systematic errors.

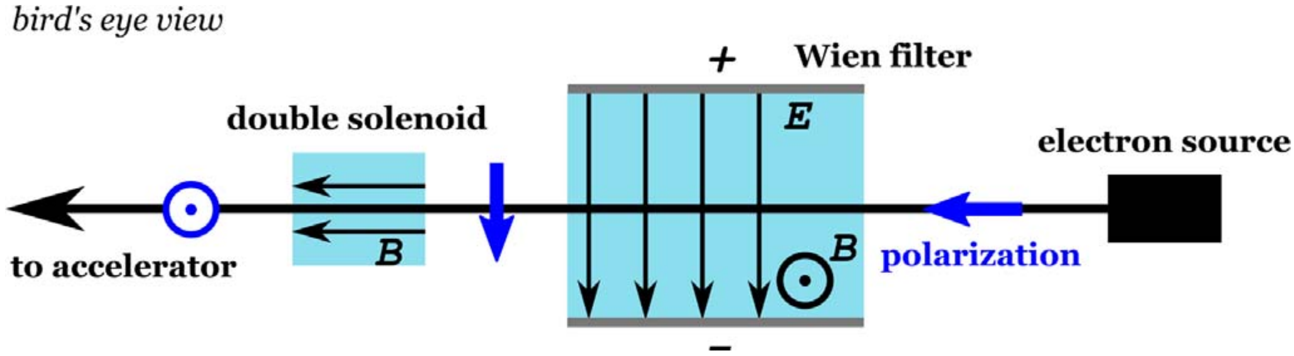


Figure 3.1: Setup for the trasverse polarization.

To switch from longitudinal polarization to transverse polarisation, two devices are used: the **Wien filter** and a **double solenoid** located in the injection beam line.

Following the picture, the longitudinal polarized electron from the source are rotated first in the XY plane, to obtain the trasverse polarization, then with subsequent double solenoid the spins are rotate in the vertival direction. After this allignement the electrons go through the accelerator to the experimental hall. The spins then precesses during this time in the magnetic fields of the accelerator's bending magnets, following the BMT equation. In our experiment, because of the vertical polarization, only the residual horizontal component precedes during the motion. For conventional experiment the polarization vector is rotated by the Wien filter with an angle such that the polarization si longitudinally aligned in the experimental hall, considering that after the rotation, the polarization is affected by another rotation due to the spin precession. The rotation angles of the polarization vector through the accelerator are known from simulations and are also directly measured for relevant energies, for a beam of 570 MeV the rotation angle is 55° with an accuracy of ±2° At the beginning MAMI was not developed with the aim a trasverse beam. So it's not possible to measure directly the polarization for the vertical axis. However it's possible, with the existing setup, to exstimate the degree of polarization. For this purpose a Moller, Comport and Mott polarimeters are used. The vertical polarization alignment can be accomplished by the minimization of the horizontal components.

3.2.3 Mott, Compton and Moller polarimenters

To Measure the polarization of an electron beam different polarimeters can be used. Here we explain briefly the physics underlying the *Mott* polarimeter, used in the experiment. Consider an electron beam that is sent towards a nucleus of charge Ze. We know from theory that the spin of the incident electron is affected by the electromagnetic field produced by the nucleus. This can be described as:

$$\vec{B}_{nucleus} = \frac{-1}{c}\vec{v} \times \vec{E}_{nucleus} = \frac{Ze}{mcr^3}\vec{L}$$
$$V = -\mu \cdot B_{nucleus} = \frac{Ze}{mcr^3}\vec{L} \cdot \vec{S}_{e^-}$$

We can recognize the spin-orbit interaction here. This term yields the polarization dependence of the cross section. The cross section can be model in the following way

$$\sigma(\theta) = I(\theta)[1 + S(\theta)\vec{P} \cdot \vec{n}]$$

Here a scheme to identify the scattering process:

The direction of $\vec{n}$ dependso on whether scattering to the left or right is being considered. Let's suppose our initial beam has a polarization P, and so we compute the asymmetry $A(\theta)$ of the scattered electrons between left (N_L) and right (N_R). N_L and right N_R will be proportional respectively:

$$N_L = N_\downarrow[1 + S(\theta)] + N_\uparrow[1 - S(\theta)]$$
$$N_R = N_\uparrow[1 + S(\theta)] + N_\downarrow[1 - S(\theta)]$$
$$A(\theta) = \frac{N_L - N_R}{N_L + N_R} = \frac{N_\downarrow(1 + S(\theta)) + N_\uparrow(1 - S(\theta)) - N_\uparrow(1 + S(\theta)) + N_\downarrow(1 - S(\theta))}{N_L + N_R} = ... = P \cdot S(\theta)$$

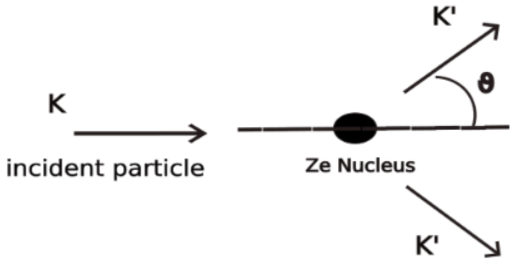


Figure 3.2: Scheme of the Mott scattering, the polarization is ortogonal to the plane, $\vec{n}\frac{\vec{k}\times\vec{k'}}{|\vec{k}\times\vec{k'}|}$

The total beam polarization is measured by a Moller polarimeter, in the experimental hall, with the beam polarization oriented longitudinally in the experimental hall. The Moller polarimeter can measure the longitudinal polarization of the beam.The other two polarimeters, Compton and Mott, located behind the injector linear accelerator (ILAC), are sensitive to the longitudinal and the trasverse horizontal components of the beam (with an energy around 3,5 MeV at this stage). The procedure for the allignment is the following: at the beginning of the beam time the Mott polarimeter is used for different settings of the solenoidal field, with the Wien filter angle equal (nominal) to 90°. The aim is to minimize the horizonal polarization component after the rotation performed by the double solenoid, changing the solenoidal magnetic field. Then a second optimization follows, using the Moller polarimeter for different Wien filter angles is performed. With the new Wien filter settings, another measurement is performed with the Mott polarimeter.

3.3 A1 spectrometers hall

Describing the A1 room, how the spectrometers are operating (+ figures), a picture of the target and the important parameters, like thickness. Also mention the convention to use target with10% of the radiation lenght, to avoid double scattering. Mention that we need the Wobbler magnet to change the hitting position of the beam to prevent the target from melting. Then add a picture of the beam-line.

3.4 Detectors and beam monitors

3.4.1 Detectors A and B

Describe the two detectors we placed inside the spectrometers, the Q^2 for our mesurement. The way the counts are collected, so the expected signal for the Čerenkov detector. Explain also how we will use the old detectors of the two spektrometers to align the elastic scattering plane to our detectors.

3.4.2 Monitors and stabilization

Explain how the monitors for the beam parameters work. (this section could be long, however the way these parameters are measured is particular, so it's important to explain everything properly).

3.5 Electronics

Short introduction about the old electronics setup and why a new versions is needed, then describe all the electronics used for our experiment:

- Nino board for collecting the data from the pmts
- VFCs for collecting the data from X21,X25,Y21,Y25,ENMO,I21,I13
- master board for collecting the monitors data/controlling the source/wobbler magnets.
- small boxes for switching from new electronic read-out to the old electronics read-out (spectrometers DAQ)

Chapter 4

Test and beam time analysis

1. development of the analysis program (description of the Levenberg-Marquardt-Algorithmus.
2. testing the analysis program with montecarlo data.
3. Test of the detectors in the Lab.
4. Beam line description.
5. Data Analysis
   (a) thresholds scan
   (b) Rates on Pb^{208}.
   (c) Beam related asymmetry correction.
   (d) C^{12} Asymmetry.

4.1 Model for fitting the data

Here I have to explain the model used for describing the data, so the problem of the false asymmetry induced by variations in beam position, angle, current and energy. Here is a good point to explain the De Brujin sequence for the polarity patterns

4.2 Data tree

Explain how we compute all the values for the data tree, the position of the beam on the target, the angle, the correlated-difference values...

4.3 Detectors test

Explain the test of the two detectors in the lab, how we select the threshold, the correlation of the pmts and coincidence to select the threshold. Mention also that we observed two knees in the plot of counts vs. attenuation.

4.4 Analysis

4.4.1 Alignment of the scattering plane

4.4.2 Calibration of the VFCs monitors

Maybe it's important to divide this sections in two different part: the first part where I explain the Vfc convert the input voltage signal to a digital signal. In the second part just mention how we tuned the resistences (for X,Y monitors directly at the output signal with the oscilloscope, while for I21 and I13 monitors we used the data, so I'm able to produce plots only for the second ones).

4.4.3 Calibration of the PIMO monitors

For the calibration of the X Y monitors, we used a target made by three carbon wires placed at a certain distance from each other (that is measuered and is equal to : ...). The position of the beam is made slowly changed first in the horizontal direction and then in the vertical direction. We observe that the pmts counts increase to a maximum, that is reached when the beam spot is centered on a carbon wire, and then decrease until the next carbon wire is hit by the beam. With a fit using a gaussian model, is possible to identify the position of the peak of the counts distribution, and from that we can directly derive the scaling factor for the XY monitors:

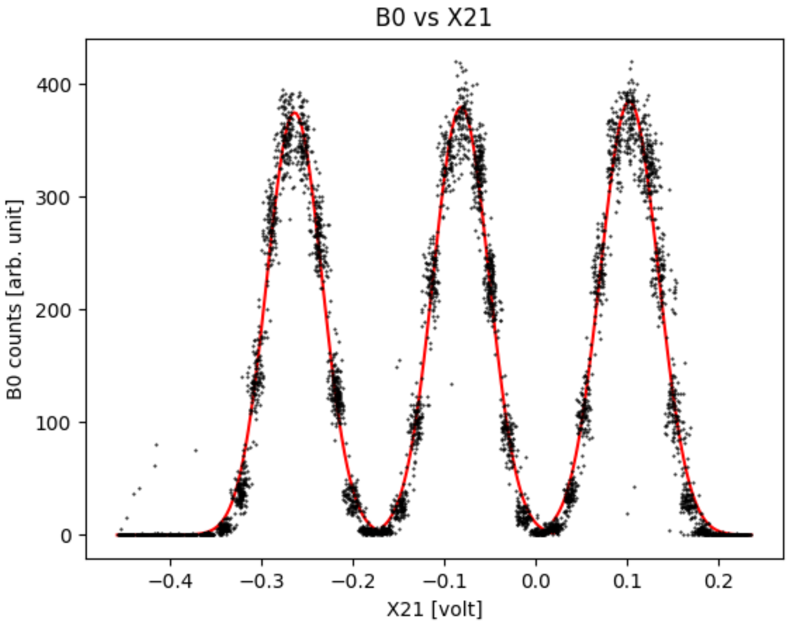


Figure 4.1: •

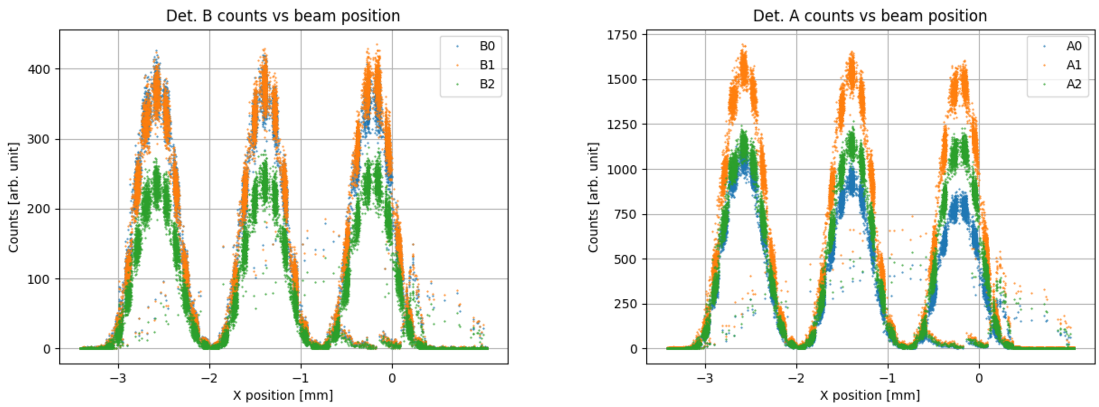


Figure 4.2: •

4.4.4 Current and ENMO monitors

For the current monitors I13 and I21, we perform the calibration changing the current of the beam and observing the output values of the monitors (Voltage values). The we perform a fit (for the beam current, we used the nominal values that we communicate to MAMI, has the values for the x-axis).

For the two monitors we are able to compute the offset and scale factor:

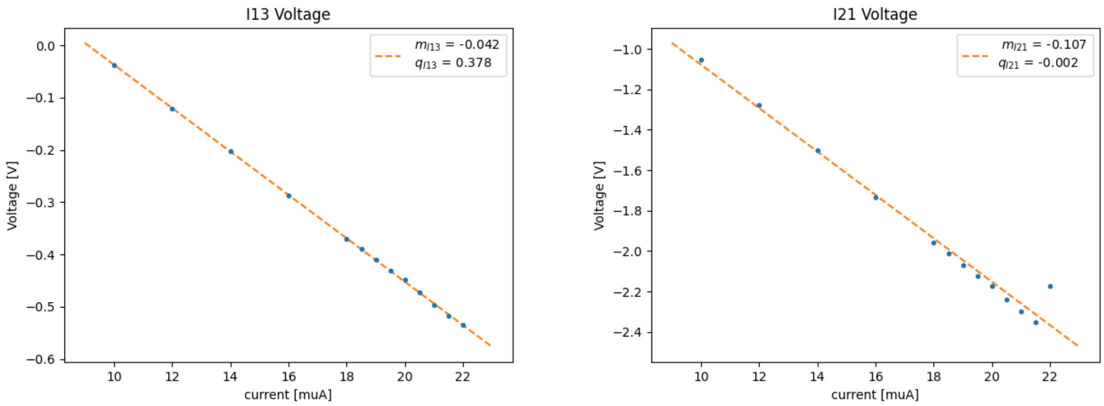


Figure 4.3: •

$$
\begin{aligned}
I_{13}^{volt} &= m_{13} \cdot I_{13}^{Nom} + q_{13} \\
c_{13} = \frac{1}{m} &\qquad offset = -\frac{q_{13}}{m}
\end{aligned}
\tag{4.1}
$$

The same formula for current monitor I21.

The Enmo calibration is performed in a different from the other monitors. The polarity signal is sent to MAMI, and they produce a signal for the ENMO that somehow (need to investigate exactly how they do that) shows a difference between the first two subevents and the last two. This difference is equal (nominal) to 22,6 keV. The idea now is to produce an histogram for the quantity δE (with E_{18} being the energy monitor):

$$\delta E = \frac{E_{18}[2] + E_{18}[3]}{2} - \frac{E_{18}[0] + E_{18}[1]}{2}$$

The data should be distributed with a peak around 22,6 keV. To obtain the correct scaling factor for the values stored in the data tree we plot the voltage values mesured by the ENMO monitor. 3 runs of data where taken with different Beam current, to study the dependence of the measured quantity from the beam current. From the mean of the distribution it is possible to exstimate the scaling factor for the ENMO monitors, obtaining the physical quantity in the following way:

$$C_{E18} = \frac{22{,}6\,\mathrm{keV}}{\overline{\delta E}}$$

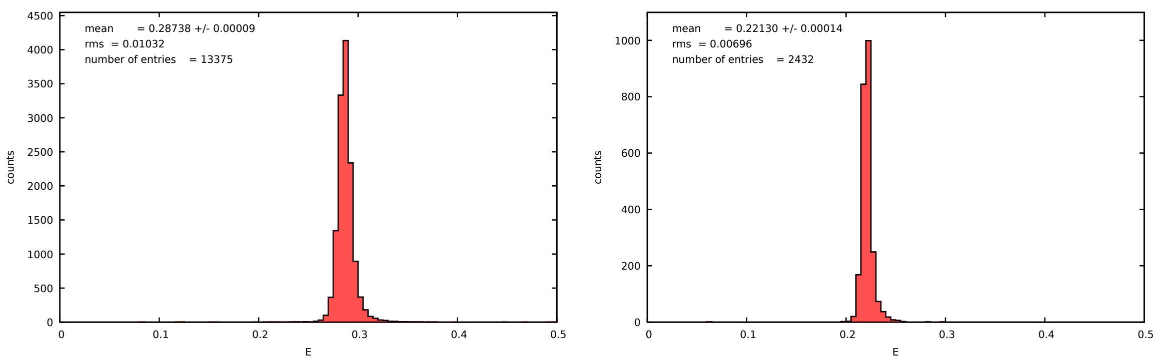


Figure 4.4: δE for 20 20 µA

Taking the average over E_{18} voltage values, and using the formula above, we obtain the coefficient C_{E18}. To take care of the current depencende of the monitors, the scaling factor to be placed in the standard.config file is: $C_{E18}\overline{I}_{\mu A}$. The calibration was performed taking three short acquisitions with different beam current : 20 µA, 15 µA and a run without beam.

From this we obtain the value $scaling_{E18} = -1595.2$, to obtain the physical quantity from the analysis. As a final check the final histogram for the physical quantity is shown:

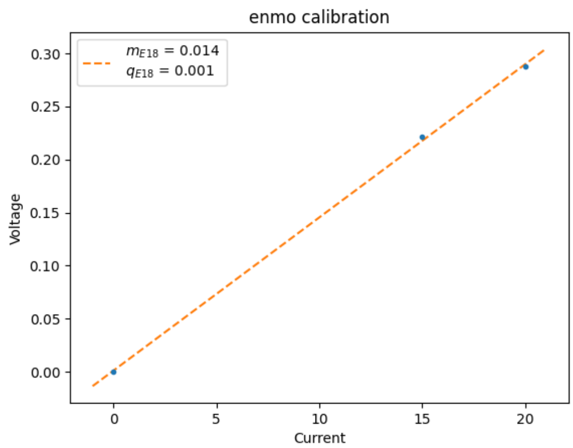


Figure 4.5: Calibration of ENMO monitor

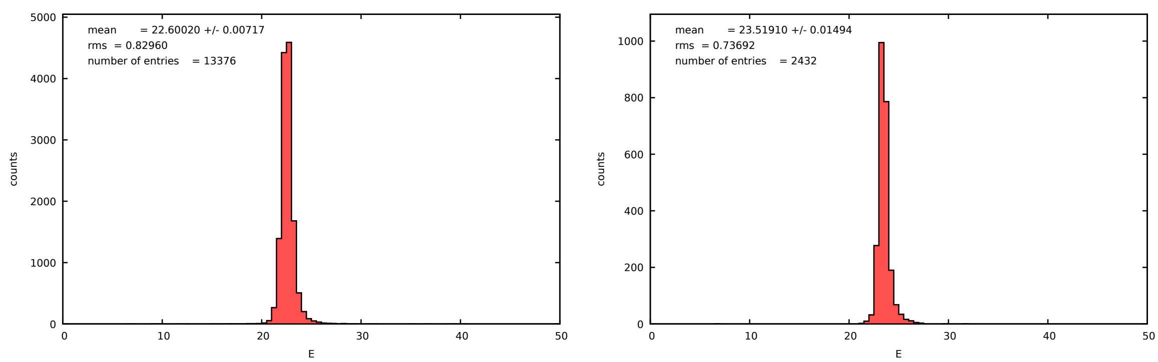


Figure 4.6: Plot for the physical quantities computed in the data tree, for two different current of the beam (on the left 20 µA, 15 µA on the right)

4.4.5 Calibration of the pmts

Here it's important to show the plots I made during the beam time. I have to mention the Leo tecniques for the correct interpretation of counts vs attenuation.

4.4.6 Rates on lead

This section is straightforward. Basically I have to show the single plot of the pmts counts vs. beam current for lead target. However it's possible to do some preliminary studies, for example to calculate the time needed for measuring the asymmetry on lead with a certain error and maybe check from Mott cross section that the observed rate are fine.

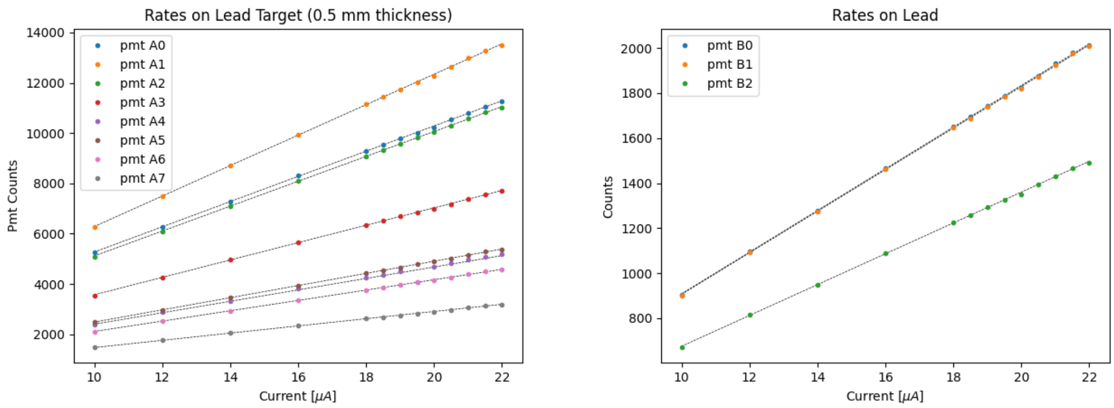


Figure 4.7: Rates on lead Target, for Detector A (left)

4.5 ^{12}C asymmetry

4.5.1 Autocalibration procedure

4.5.2 least square fit

When all the calibrations are performed, it is possible to proceed to generate the datafiles fot the fit program. (spiegare in dettaglio come è fatto il programma di analisi)

For a better visualization of the data, especially to observe the dependence of the asymmetry on the Beam parameters measured, it is useful to take the average asymmetry at regular intervals. From the raw plots of the asymmetries (see below 4.8), it is clear that the statistical error associated to the asymmetry is the main one, and it's not possible to identify a linear dependence.

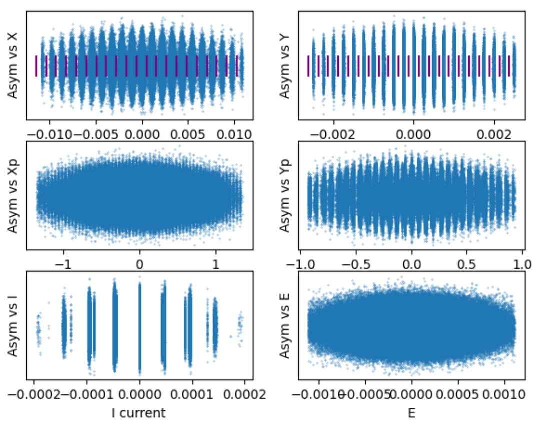
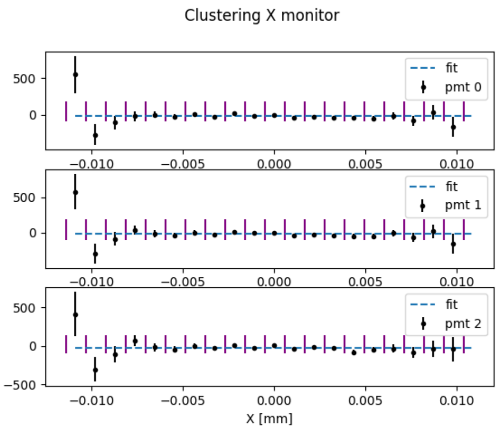


Figure 4.8: Asymmetries vs. Beam parameters

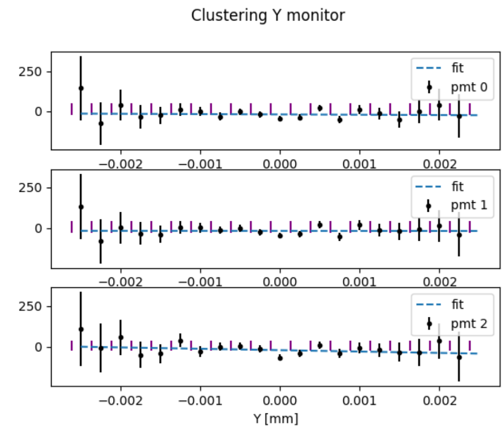
In some plots (X,Y and I) we can identify equally spaced cluster of data. So we decide to compute the averaged asymmetry for each cluster we were able to identify. In the following plots we decided to apply some cuts to the data, selecting only the events where the values of all the monitor are less then 3 standard deviation far from the mean. In all the figures the asymmetries are multiplied by a factor of $1e6$ to have the result in ppm (so each y-axis is in ppm).

$$(x_{monitor} - \overline{x}_{monitor}) \leq 3 \cdot \sigma_X$$

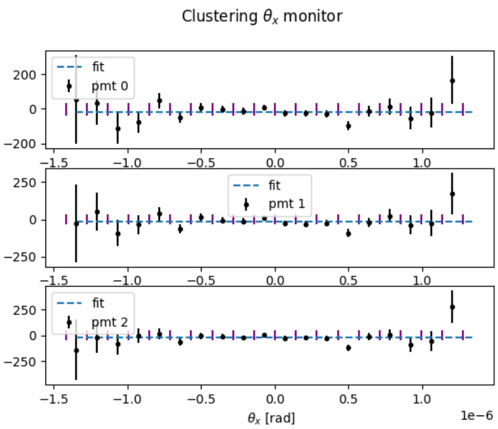
For each monitor we use the *curve fit* function of the python library scipy to fit the data. Each Beam parameter is treated separately now, so in principle we are ignoring possible effect of correlation between the X-values (however, from the correlation matrix *write that somewhere* the effects are negligible)



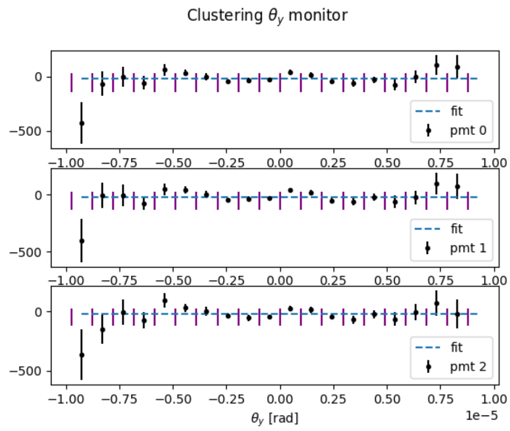
(a) *Asymmetries [ppm] vs X position [mm]*



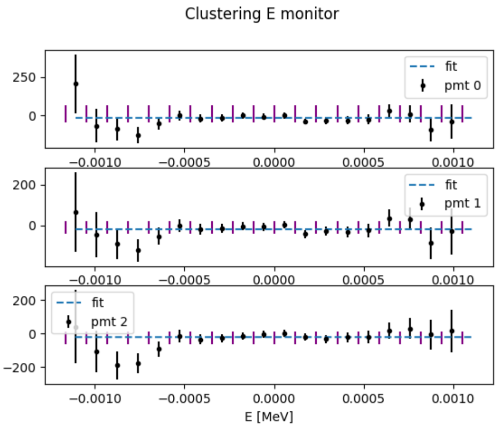
(b) *Asymmetries [ppm] vs Y position[mm]*



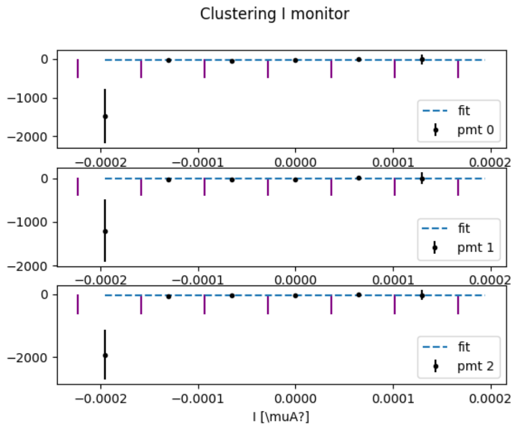
(c) *Asymmetries [ppm] vs θ_x angle [rad]*



(d) *Asymmetries [ppm] vs θ_y angle [rad]*



(e) *Asymmetries [ppm] vs E [keV]*



(f) *Asymmetries [ppm] vs I current [arb.unit]*

The error of each point is computed exploiting the same formula defined above (theory section; $N_{A/B}$ averaged pmt counts for each subevents and n number of event in each interval):

$$\sigma_{Asym} = \frac{1}{\sqrt{2N_{A/B}n}}$$

From this plots we can check if the linear model is good enough to descrive the depencence of out data and decide if the it should be useful to apply different cuts for certain beam parameters. We report now a first exstimation of the false asimmetries, later the data will be fitted without treat separately the beam parameters. From that we can learn the effects of the correlation between the data.

pmt:	B0	B1	B2
$\frac{dA}{dX}\frac{ppm}{\mu m}$	-3.0 ± 1.9	-3.15 ± 2	-3.28 ± 2
$\frac{dA}{dY}\frac{ppm}{\mu m}$	-2.00 ± 8	-0.16 ± 7	-8.45 ± 9
$\frac{dA}{d\theta_y}\frac{ppm}{\mu rad}$	-6.18 ± 31	-9.17 ± 32	-11 ± 31
$\frac{dA}{d\theta_x}\frac{ppm}{\mu rad}$	-18 ± 17	-18 ± 17	-15 ± 19
$\frac{dA}{dE}\frac{ppm}{keV}$	3.9 ± 16	9 ± 16	45 ± 18
$\frac{dA}{dI}$	282 ± 141	301 ± 128	281 ± 156

4.5.3 False asymmetries

Seems that is possible to obtain rough estimates of the beam related asymmetries with the results from the fit. For Energy and position it's achievable, while for the angles it's quite hard (in principle sounds possible to perform an analytic calculation of the asymmetry related to the incident beam angle, however Anselm told me that quite often those results are in disagrement with the observed even in the sign!).

4.5.4 ??Bootstrap??

Although Anselm was against it, now seems possible to increase the precision of the mesurement with a procedure similar to a bootstrap. Instead of computing all the quantities inside a single event, it's possible to compute all the important quantities also between different events. In this scenario the statistics can be increased artificially as mutch as we want, with the same amount of data. Of course, it's also simple to abuse of this method, so we should restrict using only events next to each other. However seem reasonable and promising.

4.5.5 ??interval estimation??

Chapter 5

Conclusion and outlook

- result of the Analysis

Appendices

Appendix A

Some Appendix

The contents...