Monte–Carlo Simulation of the Luminosity Measurement of the HERMES Experiment

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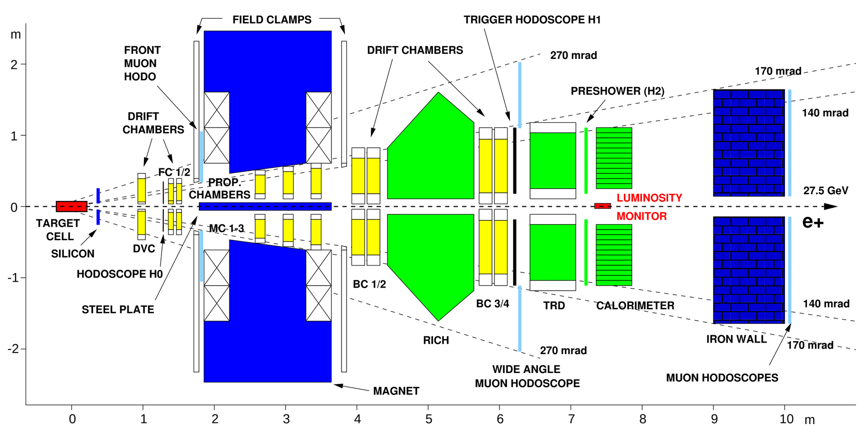
Measurement of the Luminosity

The Hermes Experiment



- Scattering of positrons at a fixed internal gas target
- Good particle identification (RICH, TRD, H2, CALO)
- Investigation of inclusive, semi inclusive, quasi exclusive processes
  - asymmetry measurements
  - cross section measurements

require precise relative and absolute knowledge of the luminosity

$$\text{Luminosity} \quad \mathcal{L} = \frac{R}{\sigma} \quad \frac{\text{measured scattering rate}}{\text{cross section}}$$

- In principle determined:

$$\mathcal{L} = \frac{I \cdot \rho_T}{e} \sim \text{beam current} \cdot \text{target areal density}$$

But: limited by target areal density measurement

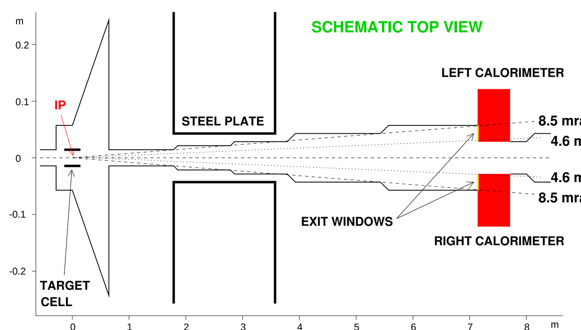
Luminosity Measurement

Use a reference scattering reaction with a cross section, which is exactly calculable in theory:

Beam particle scattering off target shell electrons.

e^+ beam: Bhabha–scattering and annihilation
e^- beam: Møller–scattering

Coincident detection of the two final particles at small scattering angles in two electromagnetic calorimeters at $z_{\mathrm{LUMI}} = 7.2\,\mathrm{m}$



$$\text{Luminosity:} \quad \mathcal{L} = \frac{R_{\mathrm{ref}}}{\sigma_{\mathrm{ref}}}$$

with

$$\sigma_{\mathrm{ref}} = \int_{A_{\mathrm{Ac}}} \epsilon \frac{d\sigma_{\mathrm{ref}}}{d\Omega} d\Omega$$

σ_{ref} : effective cross section
A_{Ac} : spatial acceptance
ϵ : detector efficiency
θ_x, θ_y : beam slope at the IP
$x_{\mathrm{IP}}, y_{\mathrm{IP}}$: beam position at the IP

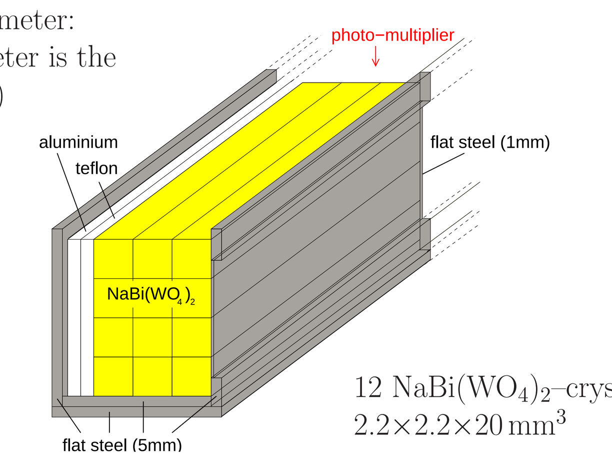
Acceptance is sensitive on the beam parameters:

$$A_{\mathrm{Ac}}(\theta_x, \theta_y, x_{\mathrm{IP}}, y_{\mathrm{IP}}) \Rightarrow \sigma_{\mathrm{ref}}(\theta_x, \theta_y, x_{\mathrm{IP}}, y_{\mathrm{IP}}) = \sigma_{\mathrm{Ac}}$$

$\Rightarrow$ Studies of σ_{Ac} with a Monte Carlo Simulation.

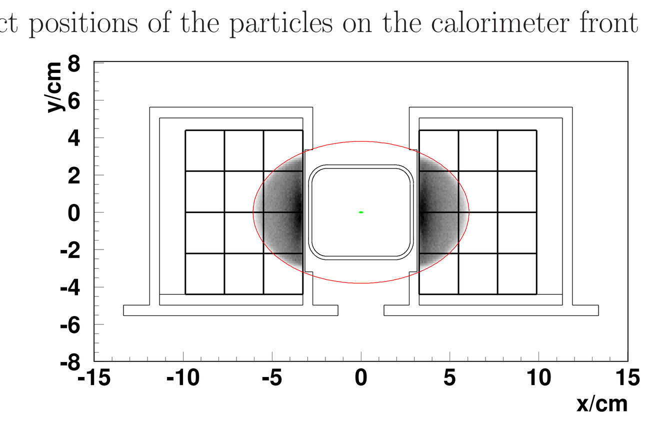
The Luminosity Monitor

- The left calorimeter:
  (right calorimeter is the mirrored copy)



12 $NaBi(WO_4)_2$–crystals
$2.2 \times 2.2 \times 20\,\mathrm{mm}^3$

- Impact positions of the particles on the calorimeter front faces:



Elliptical acceptance boundary: projection of elliptical beam pipe inside the steel plate → if the beam is out of the center between the calorimeters, variation of A_{Ac}.

Analysis Methods and Results of the Simulation

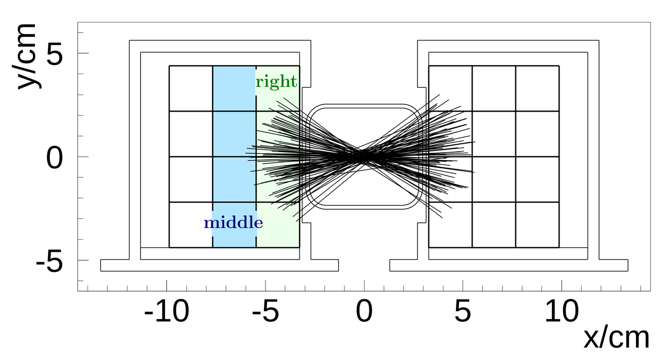
Reconstruction of The Beam Position

- Reconstruction of a particle impact position using an asymmetry η between signals of adjacent rows or columns:

$$\text{e.g.:} \quad \eta(x) = \frac{A_{\mathrm{middle}} - A_{\mathrm{right}}}{A_{\mathrm{middle}} + A_{\mathrm{right}}}$$

$\eta(x)$–function determined with a test beam and in a simulation.

- Connection of the two impact positions of coincident signals with a straight line.
- Determination of the intersections of all lines:



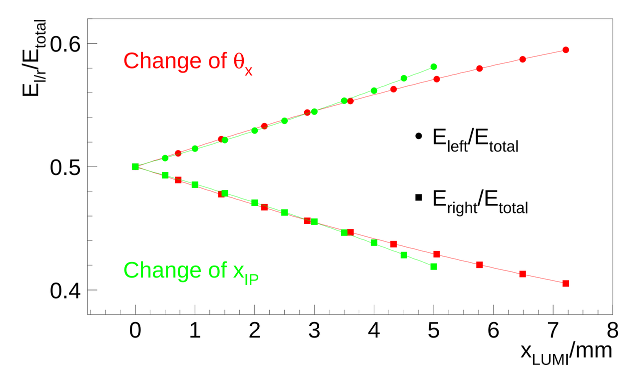
$\Rightarrow$ Beam position at the luminosity monitor ($z_{\mathrm{LUMI}} = 7.2\,\mathrm{m}$)

- Beam in the center between the calorimeters → reconstructed beam position $x_{\mathrm{rec}} = y_{\mathrm{rec}} = 0$
- Method 1 tested with the simulation:
  uncertainty of the obtained central beam position: $< 0.1\,\mathrm{mm}$

Energy Depositions

- The relative energy depositions in the calorimeters depend on the beam positions at the luminosity monitor (x_{LUMI}, y_{LUMI}).
- In the case of the central beam position (x^0_{LUMI}, y^0_{LUMI}):
  - horizontal direction:

$$\frac{E_{\mathrm{left}}}{E_{\mathrm{total}}}(x^0_{\mathrm{LUMI}}) = \frac{E_{\mathrm{right}}}{E_{\mathrm{total}}}(x^0_{\mathrm{LUMI}}) = 0.5$$



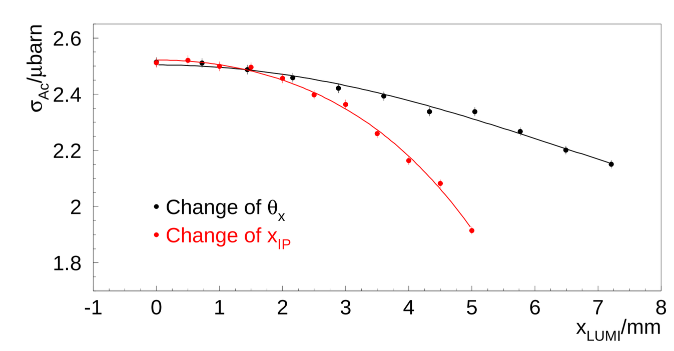
- vertical direction: compare the six upper with the six lower crystals of both calorimeters:

$$\frac{E_{\mathrm{up}}}{E_{\mathrm{total}}}(y^0_{\mathrm{LUMI}}) = \frac{E_{\mathrm{down}}}{E_{\mathrm{total}}}(y^0_{\mathrm{LUMI}}) = 0.5$$

- Method 2 tested with the simulation:
  uncertainty of the obtained central beam position also $< 0.1\,\mathrm{mm}$

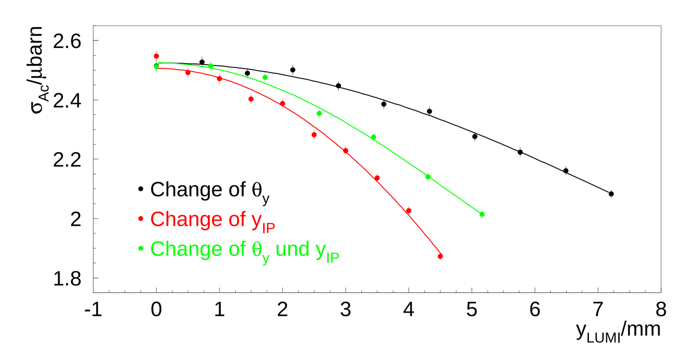
The Spatial Acceptance

- horizontal:



$$x_{\mathrm{LUMI}} = x_{\mathrm{IP}} + z_{\mathrm{LUMI}} \cdot \tan\theta_x$$

- vertical:



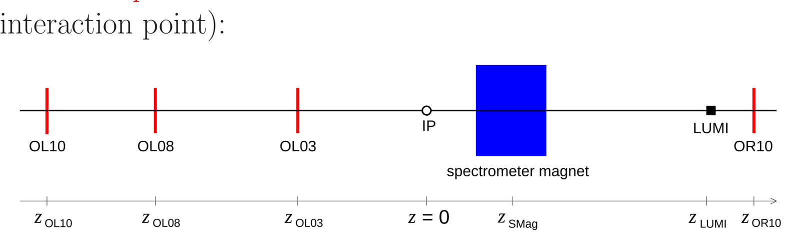
$$y_{\mathrm{LUMI}} = y_{\mathrm{IP}} + z_{\mathrm{LUMI}} \cdot \tan\theta_y$$

$\Rightarrow$ Full knowledge of x_{IP}, y_{IP}, θ_x and θ_y is necessary

Analysis of the HERMES Data

Measurement of x_{IP}, y_{IP}, θ_x and θ_y

- Four beam position monitors close to the HERMES IP (interaction point):



- Absolute x– and y–positions unknown
  → Measurement of relative positions und slopes at the IP by combining information of two beam position monitors usually: OR10 and OL08, optinally: e.g. OL10 and OL03

Goal of the data analysis: determine the offset of the beam position at the luminosity monitor = measure the central beam position by the beam position monitors

- Determination of the beam position monitor measurements of different years → e.g. February 2000:

$$\Delta\theta_x^{\mathrm{OR10\&OL08}} = 100\,\mu\mathrm{rad} \;\longrightarrow\; \Delta\theta_x^{\mathrm{OL10\&OL03}} = 161\,\mu\mathrm{rad}$$

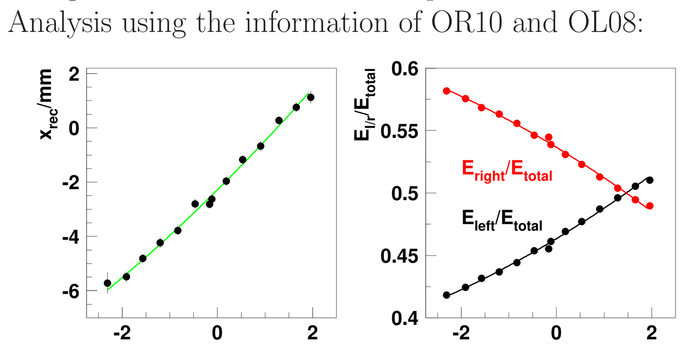
$\Rightarrow$ relative measurements are inconsistent

$\Rightarrow$ Calibration of the beam position monitors are required

Systematic Studies during Data Taking

- Several systematic studies performed in the data taking period 2000:
  - ▷ movements of the calorimeter from the beam pipe outwards
  - ▷ change of the vertical beam slope θ_y
  - ▷ change of the horizontal beam slope θ_x

  Analysis using the information of OR10 and OL08:



→ central beam position at the luminosity monitor x^0_{LUMI}:

Method 1: $x_{\mathrm{rec}} = 0 \;\Rightarrow\; x^0_{\mathrm{LUMI}} = 1.27 \pm 0.07\,\mathrm{mm}$

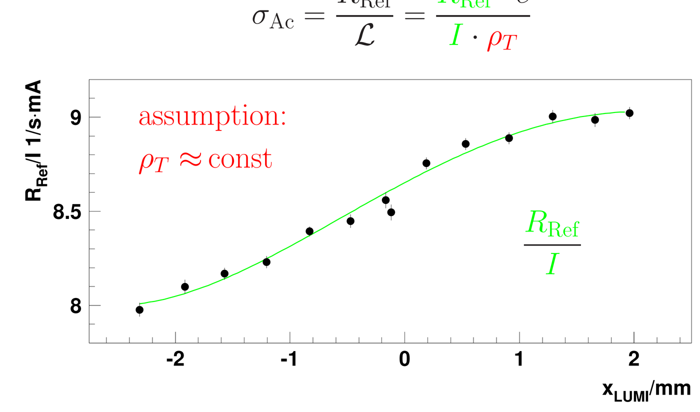
Method 2: $\frac{E_{\mathrm{left}}}{E_{\mathrm{total}}} = \frac{E_{\mathrm{right}}}{E_{\mathrm{total}}} \;\Rightarrow\; x^0_{\mathrm{LUMI}} = 1.46 \pm 0.01\,\mathrm{mm}$

- Results of both methods show same trend, but do not agree within the quoted uncertainties.
  - ▷ Nonlinearity in the beam position measurements?
  - ▷ Uncertainty of the energy calibration of the 24 photomultipliers?
  - ▷ New determination of η–function with the test beam required?

Results for Cross Sections

- Spatial acceptance:

$$\sigma_{\mathrm{Ac}} = \frac{R_{\mathrm{Ref}}}{\mathcal{L}} = \frac{R_{\mathrm{Ref}} \cdot e}{I \cdot \rho_T}$$



- Simulated cross section for $\theta_x = \theta_y = x_{\mathrm{IP}} = y_{\mathrm{IP}} = 0$:

$$\sigma_{\mathrm{Ac}}(0) = 2.54\,\mu\mathrm{barn} \pm 0.4\%(\mathrm{stat}) \pm 5\%(\mathrm{syst})$$

- Average beam setting in 2000:
  - beam parameters at the IP unknown
  - beam position at the luminosity monitor can be reconstructed
    - determine limits of σ_{Ac}: set the beam position at the luminosity monitor once as position and once as slope at the IP
    - take the average:

$$\Rightarrow \sigma^{2000}_{\mathrm{Ac}} = 2.40\,\mu\mathrm{barn} \pm 0.4\%(\mathrm{stat}) \pm 6.7\%(\mathrm{syst})$$

→ uncertainty of HERMES cross section measurements is 6.7 %

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