Development of Pellet Monte Carlo

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Pellet Target

- Pellet size: 25 - 45 \( \mu m \)
- Pellet frequency
  - at the nozzle: 45 - 70 kHz
  - at the interaction point: 2 - 10 kHz
- Pellet velocity: 70 - 100 m/s
- Pellet-pellet distance: \( \approx 5 - 10 \) mm
- Pellet stream divergence: \( \approx 0.04^\circ \)
- Pellet stream diameter at beam: 2 - 4 mm
Goal: improving the accuracy of data analysis by precise determination of the interaction vertex (helping in charged particle track reconstruction and background suppression)

Method: measuring positions and velocities of the pellets in a few planes along the pellet stream

Means: lasers and line scan CCD cameras
<table>
<thead>
<tr>
<th>PTS y [mm]</th>
<th>Plt time @70 m/s [ms]</th>
<th>Plt beam diam [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-76.5</td>
<td>nozzle</td>
<td>0.02</td>
</tr>
<tr>
<td>0</td>
<td>VIC exit</td>
<td></td>
</tr>
<tr>
<td>273.5</td>
<td>PTR Gen</td>
<td>3.91</td>
</tr>
<tr>
<td>1503.5</td>
<td>skimmer</td>
<td>21.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.9)</td>
</tr>
<tr>
<td>1843.5</td>
<td>PTR upper</td>
<td>26.34</td>
</tr>
<tr>
<td>1923</td>
<td>PTR lower</td>
<td>27.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.7)</td>
</tr>
<tr>
<td>(2690)</td>
<td>interaction point</td>
<td>38.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.1)</td>
</tr>
</tbody>
</table>
Measurements at UPTS

- taking one dimensional pictures of pellets by fast cameras (one line of 512 pixels, frequency up to almost 100 kHz, effective pixel size $\approx 40\mu m$)
- preprocessing the images online to extract only information about passing pellets, e.g. time, position, size, amount of recorded light
- analyzing the data offline
Velocity measurement

By measuring the time difference between pellets recorded by the cameras

Time measured in camera lines (cycles)

- Compare time of recording a pellet by lower camera with times of recording a number (e.g. 200) of preceding pellets by upper camera. Put the time differences into a histogram.
- Repeat for every pellet recorded by lower camera. Add to the histogram.

Most of the resulting histogram is a combinatorial background, but

A peak is seen when we look at the same pellet

Figure:

- Mean time of flight between cameras: 193.1 lines (3.86 ms) – 69.9 m/s
- Width of the peak (sigma): 1.13 lines – 0.59%
- Conditions: $p_{drv} = 400$ mbar, $p_{dc} = 23$ mbar, $f_{gen} = 41,090$ Hz

<table>
<thead>
<tr>
<th>hYtimediff</th>
<th>Entries</th>
<th>2.457423e+007</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>165.3</td>
</tr>
<tr>
<td></td>
<td>RMS</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>$\chi^2$/ndf</td>
<td>99.15/60</td>
</tr>
<tr>
<td>p0</td>
<td>7.932e+004±</td>
<td>3.258±7.932e+004</td>
</tr>
<tr>
<td>p1</td>
<td>-77.04±1.68</td>
<td></td>
</tr>
<tr>
<td>p2</td>
<td>5855±219.6</td>
<td></td>
</tr>
<tr>
<td>p3</td>
<td>193.1±0.1</td>
<td></td>
</tr>
<tr>
<td>p4</td>
<td>1.129±0.043</td>
<td></td>
</tr>
</tbody>
</table>

Y time difference [lines]

Counts

0 10000 20000 30000 40000 50000 60000 70000 80000
0 10 20 30 40 50 60
What is modeled in the MC simulation?

**Generation**
- Pellet size
- Random pellet parameters
  - Direction
  - Velocity
- Acceleration due to gravity
- Pellet loss
  - at generation (in VIC)
  - on the way
  - collimation at the skimmer
- Fluctuations of pellet rate

**Detection**
- Camera pixel size
- Camera cycle
- Detection inefficiencies
Fluctuations of pellet rate

Distribution of time between a given number of pellets in experiment is broader than if it would result only from Bernoulli distribution.

There has to be some kind of fluctuations of pellet rate.
Modulation with inverse of error function

$$\text{inv \, erf}(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{t^2} dt$$

$$z(x) = \begin{cases} 
-4x + 1a, & x \in [0, 0.5) \\ 
4x - 3, & x \in [0.5, 1) 
\end{cases}$$

$x$ - fraction of current modulation cycle, $x \in [0, 1]$

Survival probability at generation

Distribution of time between certain number of pellets
Exposure threshold

Pellet may be detected even if it is in exposure only for a short time.

Time, when pellet is seen by the camera $t$:

$$t = E + \frac{x_{pel} x_{pix}}{v} (1 - 2k_{thr})$$

where: $E$ - exposure time, $x_{pel}$ - pellet size, $x_{pix}$ - pixel size, $v$ - pellet velocity, $k_{thr}$ - exposure threshold - ratio of time when pellet is seen to the total time when pellet is in front of the camera.

Actual camera efficiency is higher than the Exposure Time / Cycle Period ratio.
Parameters which has to be adjusted in simulations:

- Direct
  - time
  - frequency
- Indirect
  - number of pellets
  - height of correlation peak
  - distribution of pellet rate

What can we learn about experiment by making a simulation?

- loss ratio at different positions
- detection efficiency
Simulations of dT spectrum

VIC – PTRgen

Skmr – PTRlow

PTRupp – PTRlow
Conclusions of time difference spectra analysis

- The peak seen in the spectra (correlation peak) indicates that we compare the times of the same pellet at the two cameras. The background is a result of comparing the times of different pellets.
- The position of the correlation peak indicates pellet time of flight between measurement levels, i.e. given by mean velocity \( \nu \approx 70 \text{m/s} \) and the peak width is a result of velocity spread \( \Delta \nu/\nu \approx 0.5\% \).
- The linear slope of the background comes from the current data taking technique. By limiting the time interval of compared pellets, we obtain an edge at the right part of the spectrum.
The height of the correlation peak depends on the detection efficiency. For lower efficiency the peak is smaller, because there is a smaller chance to record the same pellet at both measurement levels.

The detection efficiency is currently limited mainly by the camera dead time.

The efficiency is also limited by the illumination conditions. This happens, for example, when the lasers do not illuminate the whole pellet stream, or when the amount of light refracted by a pellet is not enough to record it.
Pellet tracking system would allow for precise determination of interaction region

At Uppsala Pellet Test Station there are conducted works at Pellet Tracking System and precise pellet generation

It is necessary to reproduce in simulations behavior of pellets along their way

We have MC which is able to reproduce behavior of pellet stream and its measurement

Reliable MC will be used in a design of fully optimized pellet tracking system
  - double camera detection
  - pellet identification
  - velocity and direction reconstruction
  - determination of pellet position in the beam
Plan for this beamtime

Study "pellet" long-range TDC spectra

Rate of WASA elastic trigger

- Pellet crosses COSY beam at its center in \( \approx 70\mu s \)
- Structures of such duration are visible in the spectra
- One can obtain the following information:
  - Number of pellets in the interaction region
  - Vertical position of a pellet
  - Position of a pellet transverse to the accelerator beam

Most straight-forward use of the TDC information

Select time intervals when single well sized pellets pass the central part of the COSY beam
Structure of the time-difference spectrum

- Time-difference spectrum consists of many peaks, which overlap when generation frequency is high enough.
- Peaks around coincidence peak are peaks resulting from incorrect combinations.
Details of preparing time-difference spectra

Pellet queue (certain number of pellets)
Result of current data taking method - usage of separate frames

Data divided into frames (MC)

Data in one stream (MC)