Pellet target tracking at PANDA

Introduction
• Physics programme
• Experimental setup
  • Targets

Pellet tracking concept

Prestudies and prototype tests at the Uppsala PTS

Design ideas for PANDA

Status and outlook
**Physics programme**

**pp collisions:**
- hadron spectroscopy
  - charmonium
- glueballs, hybrids, tetraquarks, molecules
- D mesons
- Strange and charmed baryons
- non-perturbative QCD dynamics
  - Baryon-Antibaryon production
  - Large angle annihilation into two-mesons

**\( \bar{p}A \) collisions:**
- \( \Lambda\Lambda \) hypernuclei
- hadrons in the nuclear medium

Some requirements on experimental conditions

+ High luminosity
+ High detection acceptance and efficiency
+ Low “nonphysical” background
+ Reliable determination of event topology
e.g. interaction point and secondary vertices:

Some particles with \( c\tau \approx 1-100 \text{ mm} \):

- \( D^{\pm}\approx(1869) \): 0.3 mm
- \( \Lambda(1116) \): 79 mm
- \( \Sigma^+(1189), \Sigma^-(1197) \): 24, 44 mm
- \( \Xi^+(1315), \Xi^-(1321) \): 87, 49 mm
- \( \Omega^-\approx(1672) \): 25 mm
HESR and PANDA

- $10^{11}$ Antiprotons from 1.5-15 GeV/c, fixed target  \( L = 2 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1} \)
- Stochastic and electron cooling  \( \Delta \sqrt{s} = 20...100 \text{ keV} \)

4\(\pi\) coverage
High rates $2 \cdot 10^7$ ann./s
PID (\(\gamma, e, \mu, \pi, K, \ldots\))
Mom. resol. ($\approx 1\%$)
Vertex recons. (Si MVD)
Efficient trigger (s-w).
 Targets for PANDA

**Target generators:**
- Cluster-Jet
  (Münster/GSI/…)
- Pellet stream
  (Moscow/Jülich/…)

**Pellet tracking***
(Uppsala/Jülich/…)

Some important features:
+ Possible target thicknesses
+ Size of interaction region
+ Space and time structure of interactions
+ Info for vertex position reconstruction
+ Improve track reconstruction
+ Background suppression
+ Identify secondary vertices ($c\tau = 0.1 – 100$ mm)

*Project supported by JCHP-FFE, EC FP7 and SRC*
Cluster jet generation

**At interaction region**

Jet size: \( \approx 1 \times 15 \text{ mm}^2 \)

Max target thickness:
\( \approx 1 \times 10^{15} \text{ at.}/\text{cm}^2 \)

Skimmer opening
A liquid hydrogen jet breaks up into a train of equidistant droplets due to a vibrating nozzle (frequency = 40-100 kHz).

The droplet velocity = 20-30 m/s.

The droplets freeze to solid pellets.

The pellets have very little spread in velocity and direction in the droplet chamber.

The pellets are accelerated to 60-80 m/s in connection with the injection into vacuum through the VIC (Vacuum Injection Capillary). A small, but significant, spread in velocity and direction arise during this process.

After collimation, the pellets continue down to the accelerator beam, at about 3 m below the VIC, and then further down to a dump.
Target thickness fluctuations

Number of pellets in accelerator beam vs time (during 5 ms) for pellet occurrence frequencies, 15 & 150 k/s, and different pellet velocity spreads:

MC results for pellet v=60 m/s and accelerator beam Φ=4 mm. (Pellet crossing duration ≈70 μs).

![Graphs showing number of pellets in the ion beam vs time for different frequencies and velocity spreads.](image-url)
Pellet target modes of operation

**PELLET TRACKING (PTR) MODE:**
- Useful tracking information available for most interaction events

**PELLET HIGH LUMINOSITY (PHL) MODE:**
- High and even target thickness for highest luminosity

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<thead>
<tr>
<th></th>
<th>PTR</th>
<th>PHL</th>
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<tbody>
<tr>
<td>Pellet diameter</td>
<td>≥ 20 μm</td>
<td>≤ 15 μm</td>
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<tr>
<td>Pellet frequency</td>
<td>≈ 15k plt/s</td>
<td>≥ 150k plt/s</td>
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<tr>
<td>Average pellet velocity</td>
<td>≈ 60 m/s</td>
<td>≈ 60 m/s</td>
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<tr>
<td>Total spread in pellet relative velocity</td>
<td>σ ≤ 2 %</td>
<td>as small as possible</td>
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<tr>
<td>Average distance between pellets</td>
<td>≥ 4 mm</td>
<td>&lt;&lt; 4 mm</td>
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<tr>
<td>Effective target thickness (10^{15} at./cm^2)</td>
<td>≤ 1.5</td>
<td>≥ 4</td>
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<tr>
<td>Pellet stream diameter</td>
<td>≈ 3 mm</td>
<td>≤ 3 mm</td>
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<tr>
<td>Accelerator beam vertical diameter</td>
<td>≥ 3.5 mm</td>
<td>≤ 3.5 mm</td>
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<tr>
<td>Average no. of pellets in acc. beam</td>
<td>≈ 1</td>
<td>≈ 10</td>
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</table>
PELLET TRACKING MODE:

**Goal:** To know interaction point accurately, $\sigma \approx 150 \, \mu m$ in $3d(xyz)$, for a big fraction (> 50%) of the hadronic reaction events.

**Basis:** Pellets $\Phi = < 30 \, \mu m$, $v \approx 70 \, m/s$, $\Delta v/v = \text{a few \%}$

Pellet stream $\Phi<10 \, \text{mm}$, intensity 10-20k plts/s

Possible pellet tracking detector positions 1.5-2 m from int. point

**Need:** Pellet detection accuracy $\leq 50 \, \mu m$ (xyz) and $< 1 \, \mu s$ in time at pellet generator (and maybe detectors also at pellet dump)

**Idea:**
- Use **lasers** and fast **line-scan (linear CCD) cameras** for pellet detection.

**Challenges:**
- Detection efficiency
- Position and Time resolution
- Handle pellet velocity spread
- Data processing
- Calibration, alignment, control
FP7-Futurejet  Pellet Tracking in Uppsala

Main HP2 WP19 activities 2009 - 2011:
- Synchronized readout of LS-cameras.
- Pellet tracking system design ideas.
- Time and position correlation studies. Velocity measurements.
- Tracking system prototype at UPTS.
- Pellet tracking studies.

Goals for HP3 WP20 activities 2012 - 2014:
- Close to 100% efficiency pellet detection.
- Pellet track processing and optimization of pellet detection points.
- Multi-camera readout system.
- Feasibility of laser-induced droplet production.
( - Preparation of one tracking section for PANDA. )

Senior researchers: Hans Calén, Kjell Fransson, Pawel Marciniewski
PhD student: Andrzej Pyszniak
Engineers: Carl-Johan Fridén, Elin Hellbeck
Mechanics: Lars-Olof Andersson, Masih Noor (design)
Exam/Project worker: Malte Albrecht (Spring 2011)
The Svedberg Laboratory

UPTS ("Uppsala Pellet Test Station")
2004 - ......

WASA

A Cyclotron hall
B CESLIUS hall
C Crypt
D Marble hall
E Blue hall
F Gamma cave
G Biomedical area
H Control room,cyclotron
I Control room,CESLIUS
J Counting room,CESLIUS experiments
K Ion source building
Activities at UPTS:
- Pellet diagnostics with single LS camera
- Understand LS camera performance
- Improve light yield from pellets
- Develop synchronized r/o for 2 cameras
- Time and position correlation studies
- Exploratory pellet velocity measurements

Example of pellet beam diagnostics with one LS camera

Beam profile

Time between pellets

*) Design ideas for pellet tracking systems for PANDA and WASA

Milestone
FP7 report*
December 09
**Time between pellets**

**Case:**

1) Short distance / low vel. spread **Gaussian!**
2) Longer dist. / higher vel. spread **Gauss (truncated)**
3) Longer dist. / higher vel. spread **Gauss (tail) / Exp ?**
4) Long dist. / high vel. spread **Gauss (tail) / Exp!**

**Distance 300 mm**

**UPTS measurement**

300 mm below VIC exit.

\[ f \approx 40 \text{kHz}, \ p(H_2) \approx 400 \text{mbar}, \ p(DC) \approx 25 \text{mbar} \]

(total loss = camera deadtime + illumination ineff. + lost pellets)

**Simulation Studies for the Pellet Tracking System**

Pascal Scheffels (Erasmus project report 2010)

Curve = Exp w. slope \( \Leftrightarrow 17 \text{ k/s} \)
Intra-beam pellet-pellet collisions

Fraction of “primary” pellets that collides vs beam divergence for different velocity spreads $\sigma_v/v = 0.05, 0.1, 0.5, 1, 2 \%$.

“Before skimmer”
0 - 700mm

“After skimmer”
700 – 2700 mm

Simulation studies 2010
Marek Jacewicz
Two-cameras setup. Synchronized measurement of x and z

135 degrees laser illumination geometry (refraction)
Two camera synchronization with pellets

- Line scans triggered from external pulse generator
- Frames of 5000 lines each, analyzed in real time

Lines between signals in camera A & B vs time (during 25 s)

2d profile of the pellet beam

Same pellet seen by both cameras?
Frames out of synch
Synchronized LS cameras at two levels

Laser Camera Upper

Laser Camera Lower

Droplet chamber VIC exit

Distance ≈ 30cm

Time and position correlation studies
Pellet velocity estimate at UPTS May 2010

Studies of pellet signal correlations in a high intensity beam were used to get a hook on pellet velocity distributions ...

\[ \Delta T \text{ (Lower-Upper) for all combinations of pellet time signals} \]

Pellet generation conditions
- \( f_{\text{droplet}} \approx 50\text{kHz} \)
- \( p(H_2) \approx 400\text{mbar}, p(\text{droplet.ch.}) \approx 25\text{mbar} \)
- droplet velocity 25 m/s
- pellet diameter 20-30 micron (guess)

MC simulation

Indicates that a “big” fraction of the pellets have a velocity \( v \approx 80 \text{ m/s} \) …… with a small spread \( \sigma_v/v \approx 1\% \).

Winter 2010-11:
Observed smaller spread (\( \approx 0.5\% \)) for some parameter settings.
Need more systematical studies.
Measurements at UPTS September 2010

Droplet velocity vs driving pressure and generation frequency

- Droplet velocity (m/s) vs Driving pressure $P_{H2}$ (mbar)
  - $f = 40227$ Hz
  - $f = 47616$ Hz
  - $f = 65732$ Hz

Pellet generation conditions
- $p$ (droplet.ch.) $\approx 25$ mbar
- Pellet diameter 25-35 micron (guess)

Higher driving pressure
- $\Rightarrow$ faster (and bigger droplets)
- $\Rightarrow$ slower pellets

$\Delta \phi / \phi \approx 1\% \Leftrightarrow \Delta v / v \approx 1.5\%$

Studies winter 2010-11:

- Higher dropchamber pressure (gas flow through VIC)
- $\Rightarrow$ faster pellets

$\Delta P_{DC} / P_{DC} \approx 1\% \Leftrightarrow \Delta v / v \approx 0.3\%$

Variation over beam profile:
- $\Delta v / v$ a few permille
A liquid hydrogen jet breaks up into a train of equidistant droplets due to a vibrating nozzle (frequency = 40-100 kHz).

The droplet velocity = 20-30 m/s.

The droplets freeze to solid pellets.

The pellets have very little spread in velocity and direction in the droplet chamber.

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Pellet tracking system prototype

**Camera system**

Two line scan cameras
Model AViiVA M2 CL manufacturer e2v
512 pixel line-CCD, dual tap
Pixels: 14 μm squared, 12 bit resolution
Maximum line rate: 98 kHz (claimed)
Maximum readout rate of 60 Mpixels/s via cameralink

**Optics**
Focal length 50 mm
Working distance: 250 mm to the focal plane corresponding to ~40 μm pixel size
Maximum aperture: 1.4 f.

**Lasers**

Two Lasiris™, type SNF, structured light, diode laser module, single line beam profile
Power 40 mW at 656 nm
Working distance: 185 mm
Fan angle of 1 degree (line length of ~3 mm at the focus).
Line thicknesses 40-60 μm at a DOF of 15 mm

**Mechanics**

Tracking chamber (130 mm diameter)
A total of 16 observation ports in 2 levels (A and B) separated by 80 mm
8 camera ports (35 mm windows)
8 laser ports (16 mm) windows

Camera support with 3d linear adjustment
Laser support with 3d linear + angle adjustment
**Readout**

2 frame grabbers, model mvTITAN-CL, PCI card, manufacturer: Matrix vision.
Line synchronization and trigger by external gate generator in NIM
Maximum line rate with continuous readout: ~50 kHz, limited by pci bus capacity
With triggered frames ~80 kHz

**Software**

Monitoring and control software from manufactures.
Readout C++ software based on Matrix vision software development kit and root.
**Example of measurements**

Time difference between signals in the upper and lower PTR chamber level

Pixel position correlation between signals in the upper and lower level

The peak is due to the signals from the same pellet at both levels. Its width corresponds to a small velocity spread in the pellet beam.

The dark line is due to straight pellet tracks pointing to the pellet generator (1.5 m above the PTR chamber).

**Further details can be found in references:**


- Simulations for design of a pellet tracking system for PANDA and WASA, Marek Jacewicz, January 2011, Project report, www5.tsl.uu.se/panda/pub
High-efficiency pellet detection.

**Time resolution, efficiency & measurement dead time**

Two specially designed cameras (3 µs period time), measuring same coordinate at the same y-level being synchronized with cycles shifted half a period time, would give a time bin of 0.5 - 1 µs ($\sigma \approx 0.25$ µs) which is in the region of the final goal for PANDA.

The present (M2, 2 tap) camera performance of 12 µs period and 9 µs exposure time gives a $\sigma \approx 1$ µs would give an interaction position vertical (y) coordinate $\sigma \approx 1$ mm.

Plan to test a new camera model (EM4, 4 tap) which has a shortest period of 5 µs.

With a two-camera arrangement one would also get rid of inefficiencies due to the camera cycle dead times.

... strong / many enough to give full detection possibility.
PTR at UPTS
Present measurement levels
.. planned extension 2012.

- Below VIC one level for a cam and a laser at 90 deg.
- Generator floor with one level for two cams (x,y) and one laser at 135 deg.
- .. add possibility for one more laser at 135 deg.
- Dump floor at top of skimmer one level for one cam (x or y) and one laser at 90 deg.
- .. add possibility for two lasers at 135 deg.
- Dump floor with two levels for 2-4 cams (x,y) with lasers at 135 deg.

Windows center position
vertical distance (mm)

-76.5 DC
0 VIC exit
273.5 PTR gen

1503.5 Skimmer 0
1843.5 PTR upper 340
1923 PTR lower 419.5
(2690 Cosy beam 1166.5)
Measurements 2011: Signal time differences lower-upper camera

Simulations (by A. Pyszniak) include:
- Direction smearing
- Velocity and velocity smearing
- Generation position smearing
- Acceleration due to gravity
- Loss at generation (in VIC)
- Loss/disturbance on the way
- Stream collimation at the skimmer
- Camera cycle and dead time
- Detection inefficiency caused by insufficient illumination conditions
- etc
System design and simulations

At PANDA two sections of the target pipe, one at the generator and one at the dump are planned for tracking equipment.

The sections are 40 cm long.

Simulations are used to determine the optimal use of the tracking sections and they are also needed in the development of tracking algorithms.

Some main points of the design simulations concern:
- Camera and laser configuration within each level
- Number of levels and the distance between the levels

Planned HP3 activities: Multi-camera system

PTR section – Interaction region ≈ 2 meters
PTR for PANDA

Design idea: Multi-camera pellet tracking section for determination of velocity and 3-d direction for individual pellets

Four levels for measurements, each with two lasers and two LS-cameras.
- Distance for velocity determination 60 – 260 mm.
- Distance for direction determination 200 mm (…internally… one can use VIC exit also).

Total height 400 mm.
Space requirement radially: \( r_{\text{max}} = 500 \text{ mm} \).

Design Masih Noor, CAI (Center for Accelerator and Instrument Development), Uppsala University
Initial determination of velocity for the individual pellets

The measurements at the 1st levels are crucial … … for catching a pellet and determine its velocity correctly.

For a pellet rate of 10k/s an “efficiency” > 90% is obtained for a velocity spread of 1% and a distance of 50 mm between the measurement points.

For 100 mm distance the efficiency has dropped to 85%.
**Pellet tracking Step-by-Step**

**A:** Determine mean velocity \((v_0)\) & spread in the pellet stream

**B.1:** Determine “roughly” time, position, direction and velocity of a pellet candidate using \(v_0\).

**B.2:** Extrapolate pellet track to the other measurement positions and pick up matching information. Improve velocity determination.

**B.3:** Use all info (including geometrical constraints like point of exit from the VIC) to reconstruct the final track. Determine the time and path for passage through the interaction region.

**B.4:** Store info for all pellets, sorted by the time of passage through the interaction region. Put a time stamp from the experiment clock used for interaction events.

**C:** For each interaction event, process (offline) the pellet info stored and check pellet candidates responsible for the interaction and if possible make use of the position information.

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**At the 1st levels in the upper tracking section.**

**It takes \(\approx 100 \text{ ms}\) for a pellet to pass all measurement points.**

**It takes \(\approx 100 \mu\text{s}\) for a pellet to pass the interaction region.**

**A common time scale is needed for matching with the experiment DAQ.**
Multi camera readout and synchronization

Adapter cards (1 per camera)
Convert data to optical links
Synchronize all cameras

Virtex5-FXT data processing board

16 optical receivers 1.6 Gbits/s
64 Mbyte of DDR ram
8 Mbyte of Flash rom
USB, Ethernet
VME-64x or LVD –bus readout

Pellet identification and storage with time stamp
Experiment triggers stored with timestamp

A few Mbyte/s output data rate for 16 cameras

Up to 16 cameras

Camera links 120 Mbytes/s each

Experiment trigger

Timestamp to DAQ

Planned HP3 activities: Multi-camera readout system
Multi camera readout
development prestudies

Planned HP3 activities: Multi-camera readout system

CameraLink bus
Signal converter card
“Serial” ⇒ parallel bus

Virtex-5 development board
Study of camera signal behavior

Pixel signal monitoring
for 22.5 μs camera cycle
Signal amplitudes 2 x 256 pixels
Readout idle time (exposure)

22.5 μs

N&P physics seminar
IFA 2011-12-01
Hans Calén
Multi camera readout development prestudies

Erasmus work by M. Albrecht. FPGA code for pellet detection:
• Automatic pedestal correction
• Pellet detection with position amplitude and timestamp output
• Data output via USB for tests

Prototype board with four CameraLink inputs and one FPGA (SPARTAN-6) .......being debugged ..... ... for further development work during 2012 .....
## Plan for the pellet tracking system developments 2011-2016

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<tbody>
<tr>
<td>1</td>
<td><strong>Pellet tracking system</strong></td>
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<td>2</td>
<td><strong>Measurement configuration</strong></td>
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<td>3</td>
<td>Pre-studies with UPTS PTR prototype 2-level setup</td>
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<td>Design an operation scheme for (2) cameras at a measurement level</td>
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<td>Design a measurement level with mechanics for cameras and lasers</td>
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<td>Design the (2) multi-level measurement sections</td>
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<td>Prepare a PANDA prototype (upper) section</td>
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<td>Prepare and test both sections</td>
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<td>Ready to install mechanics in PANDA</td>
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<td>11</td>
<td><strong>Readout system</strong></td>
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<td>12</td>
<td>Design multi-camera readout electronics</td>
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<td>13</td>
<td>Test readout system with 2-4 cameras at UPTS</td>
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<td>14</td>
<td>Test a complete system at the PANDA prototype section</td>
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<td>Ready to install readout system (and cameras) at PANDA</td>
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<td>16</td>
<td><strong>Procedures and software</strong></td>
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<td>17</td>
<td>Design track processing and interfacing with event information</td>
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<td>18</td>
<td>Design alignment procedures for all the parts of the system</td>
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### Personnel and Material
- **FP7 HP2-3 (personnel+mtr)**
- **JU PhD student**
- **SRC (personnel+mtr)**
- **JCHP-FFE (personnel)**
- **Need for new funding (personnel+equipment)**
- **(UPTS at TSL)**
Status and Conclusions November 2011:

- LS camera performance basically understood ....
- Synchronized operation with two cameras works (12 μs cycle)
- Illumination/detection conditions good ... but should be improved
- Required transverse position resolution reachable with present cameras. Solution for good time (⇒ y position) resolution and high camera efficiency exists.
- Pellet velocity spread $\sigma_v/v <<1\%$ should be possible to obtain

- A first prototype PTR system for UPTS is in operation since March:
  - Tracking chamber with two levels of pellet detection
  - 2-3 LS-cameras with lasers
- Development of a new readout system in progress.
- Design & preparation of tracking systems with more LS-cameras started.
- Preparing simulations for the design of a full scale system for PANDA.

Goals for 2012 - 2014:

- Close to 100% efficiency pellet detection
- Pellet track processing and optimization of pellet detection points
- Multi-camera readout system
- A tracking section for PANDA/WASA (hopefully tested at UPTS).
- Feasibility of laser-induced droplet production.