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FP7-HP3: FutureJet Pellet Tracking System

Main HP3 WP20 activities 2012 - 2014:

- **High efficiency pellet detection** **(task 3.5, milestone 12, Dec13).**
- **Pellet track processing and optimization of pellet detection points** **(task 3.6, milestone 13, Dec14).**
- **Multi-camera readout system** **(task 3.7, milestone 14, Dec14).**
- **Feasibility of laser-induced droplet production** **(task 3.8, milestone 15, Dec14).**

UPPSALA team

Senior researchers:	Hans Calén, Kjell Fransson, Pawel Marciniewski
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Project supported by JCHP-FFE, EC FP7, FNP(eu-MPD) and SRC

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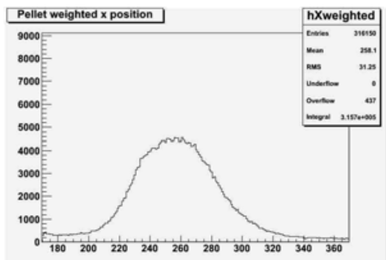
UPTS performance August 2012

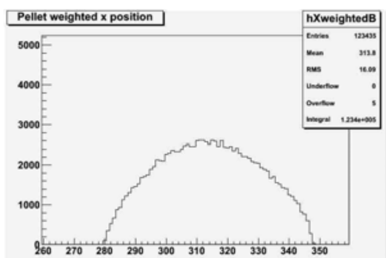
Pellet generation conditions:
Nozzle 270 (Φ=12.9 μm), T_N=14.1 K
$f_{droplet} \approx$ 63kHz, $p_{H2} \approx$ 400 mbar
$p_{droplet\_chamber} \approx$ 21mbar (H_2 + He)
$v_{droplet}$ =22 m/s, $d_{droplet}$ = 0.34 mm

pellet Φ=25-30 micron (guess)
v_{pellet} =77.9 m/s, σ_v/v_{pellet} = 0.42%

$P_{pump\_block} \approx$ 1.2 e-3 mbar

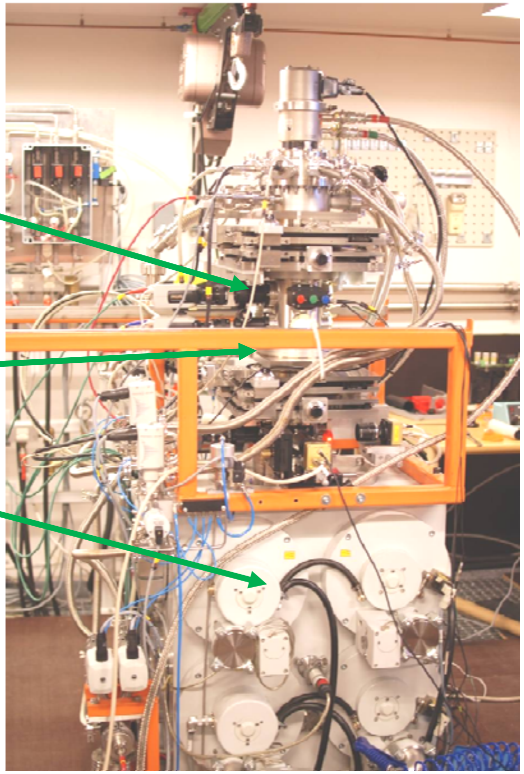


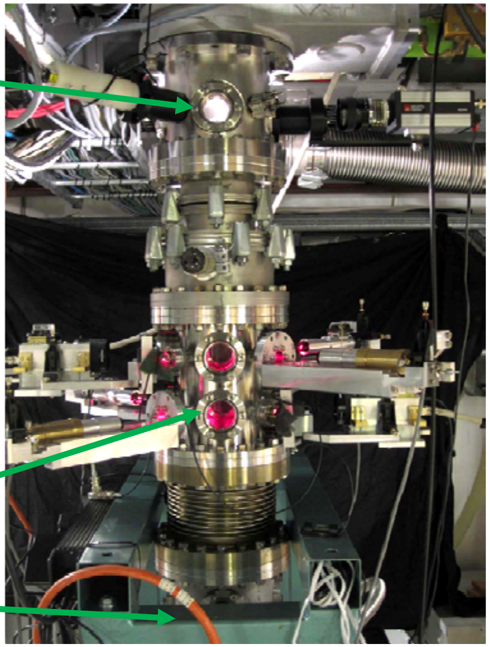
Above skimmer: PR ≈ 57 kHz
FWHM=2.1mm FW ≈ 3.7 mm



PTR chamber: PR ≈ 22.5 kHz
FW=2.5 mm

$p_{dump} \approx$ 2.e-2 mbar





Windows center vert. dist. (mm)

-76.5 DC
0 VIC exit
271.5 PTR gen
1513.0 Skimmer
Φ=2 mm
1860.2 PTR up
1939.7 PTR low
(2690 Cosy beam)
(3500? HESR beam)

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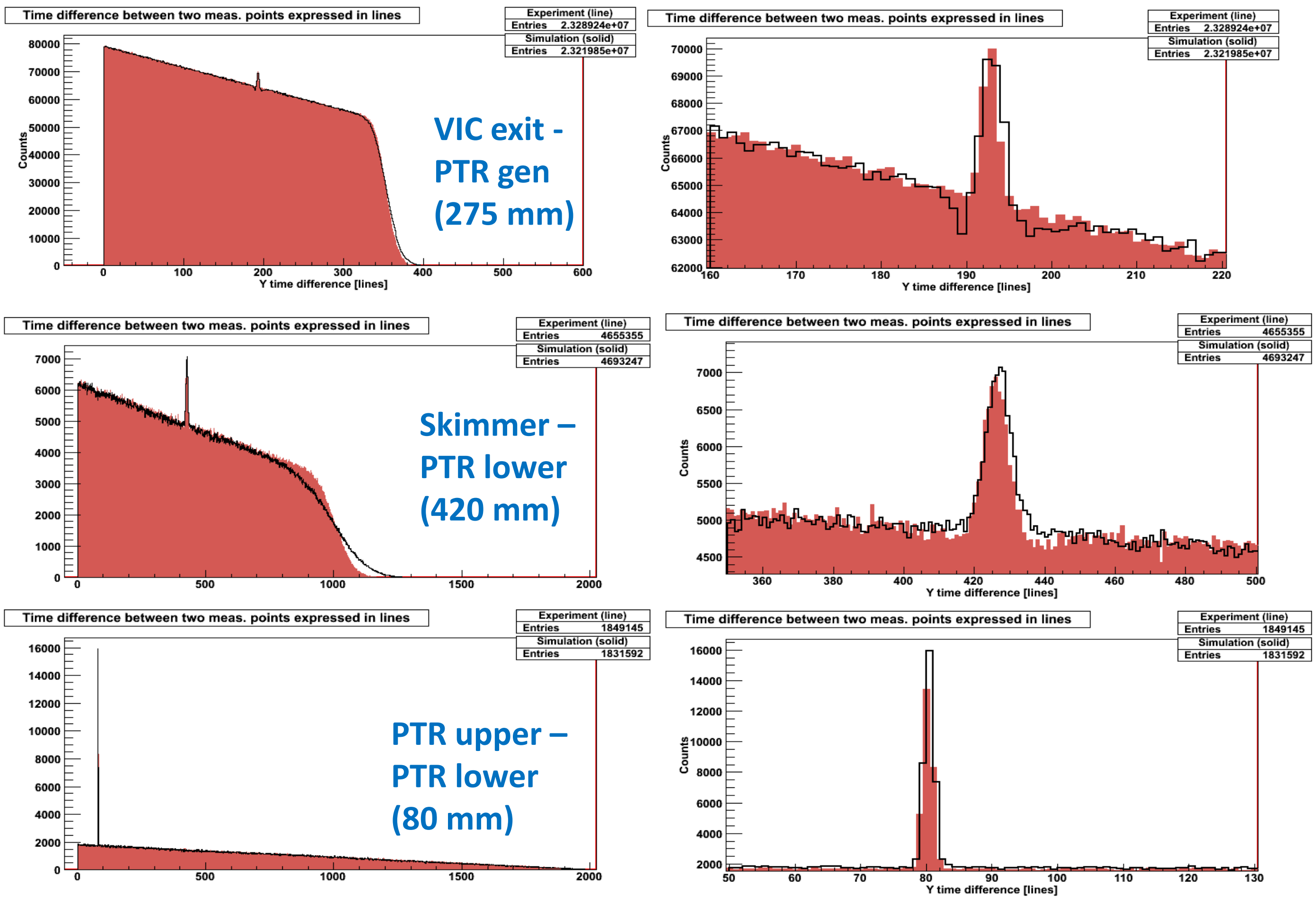
UPTS measurements   Signal time differences lower-upper camera

(MC in solid red)



Correlate signals on different levels => **Starting point for pellet track reconstruction.**

Measure velocity : **v ≈ 80 m/s (typically)**

Measure velocity spread : **$\sigma_v/v < 1\%$.**

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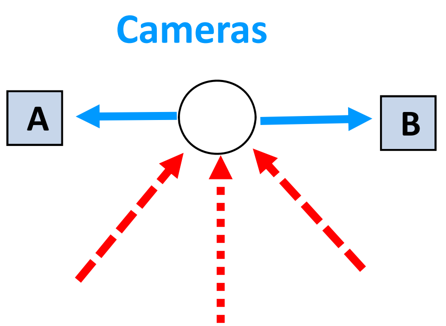
Illumination conditions.



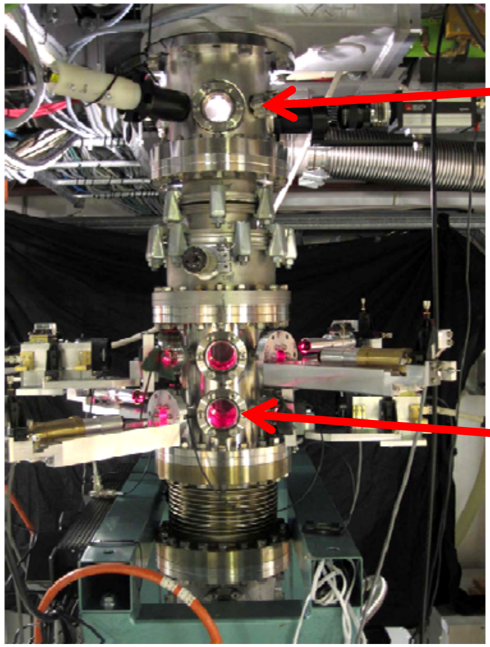
Laser(s)

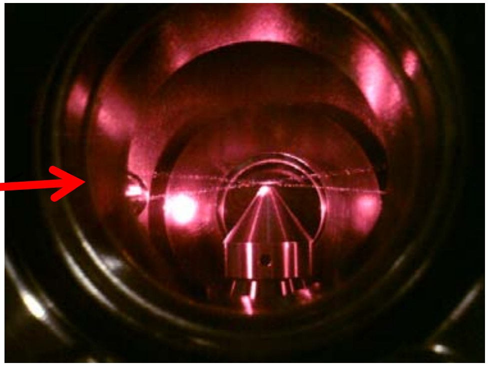
... strong / many enough to give full detection possibility.

Different configurations with two laser beams give possibility to estimate the inefficiency due to limited illumination….

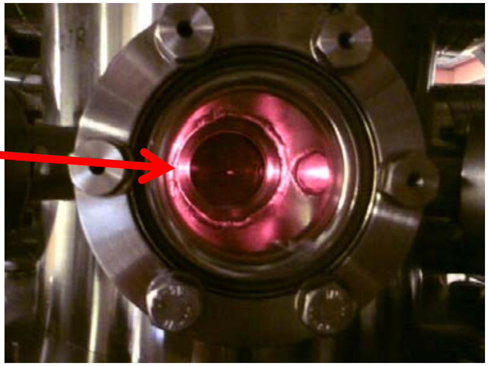
E.g. with one laser in 135^{o} configuration it seems that one have an illumination inefficiency of 5-20%.

First detailed measurements to study this have been done ….





Two laser beams seen (thanks to bouncing pellets) above the skimmer.



Pellet beam crossing laser beams in the center of the tracking chamber.

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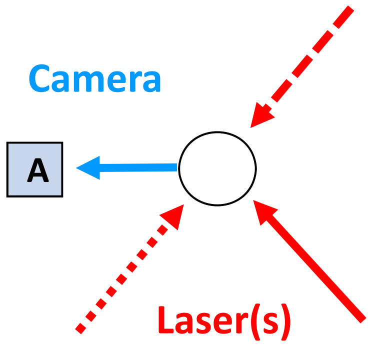
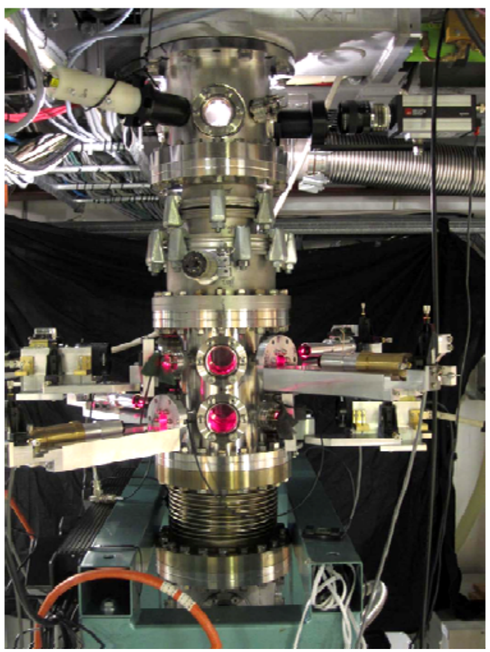
Illumination conditions.



SNF lasers, 50 mW,
1^o fan angle,
185 mm work distance



Different configurations with two laser beams give possibility to estimate the inefficiency due to limited illumination….

Measurement were done with two cams, one at each of the two levels of the PTR prototype chamber

- Both lasers ON at both levels give similar PelletRates.
- As reference PRs from one level is used.

- Comparison of rates with different combinations of two laser beams give possibility to estimate the (relative) inefficiency due to limited illumination….
  With the laser beam at 135^o (transmission) we got <10 % inefficiency and at 45^o (reflexion) we got 5-30%.
  The lasers are individuals ….. and this shows up most in reflexion mode since the pixel signal amplitudes are typically one third compared to transmission.

- By comparing number of reconstructed tracks with the PRs one can get an estimate of the absolute efficiency.
  For each level we got an efficiency of 80-85%.
  (From the camera cycle deadtime alone one expects an inefficiency in the range 5-15%).

Pellet track reconstruction and extrapolation

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Method:

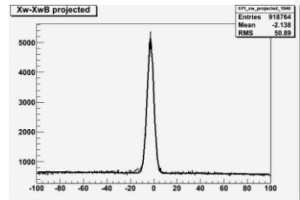
Measure pellet positions at two levels at the dump floor.

Select hits from pellets with "right" velocity.

Reconstruct tracks.

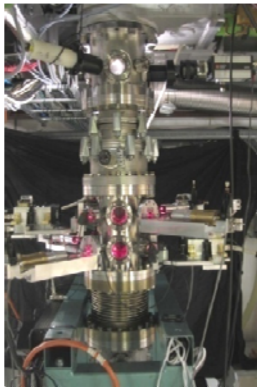
Extrapolate the tracks to the VIC exit where the pellet beam is known (seen on monitor) to have a diameter of 50-100 μm.

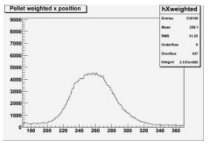
Extrapolated track positions at VIC : σ ≈ 100 μm

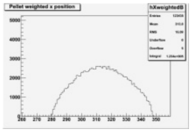


=> Position accuracy: σ ≈ 20 μm at measurement

Positions measured just above skimmer and in PTR chamber.
Lever arm = 427 mm.
Pellet beam size ≈2 mm.

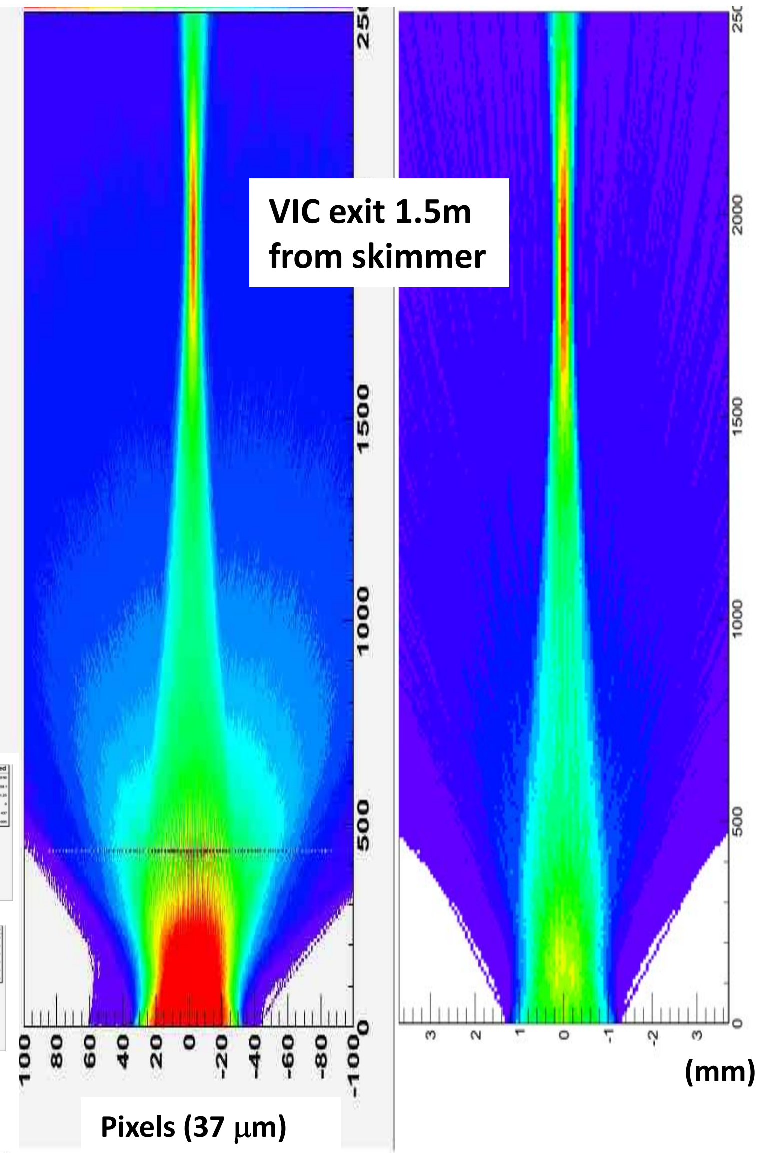






Pellet track x-distribution versus vertical position

Data **MC**



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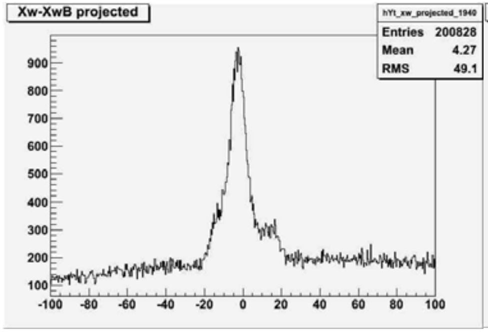
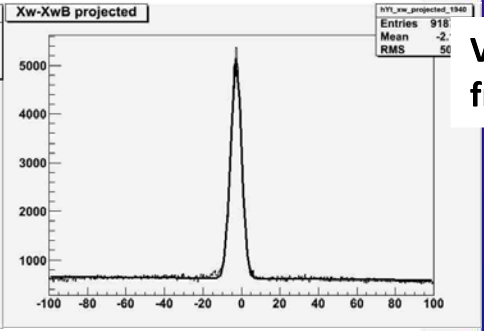
DOF study with camera optics f=50mm, bl.=1.4, d(pelletstream – focalplane) ≈250mm.

High efficiency pellet detection

Pellet beam a few mm out of camera focus ….

Pellet beam in camera focus





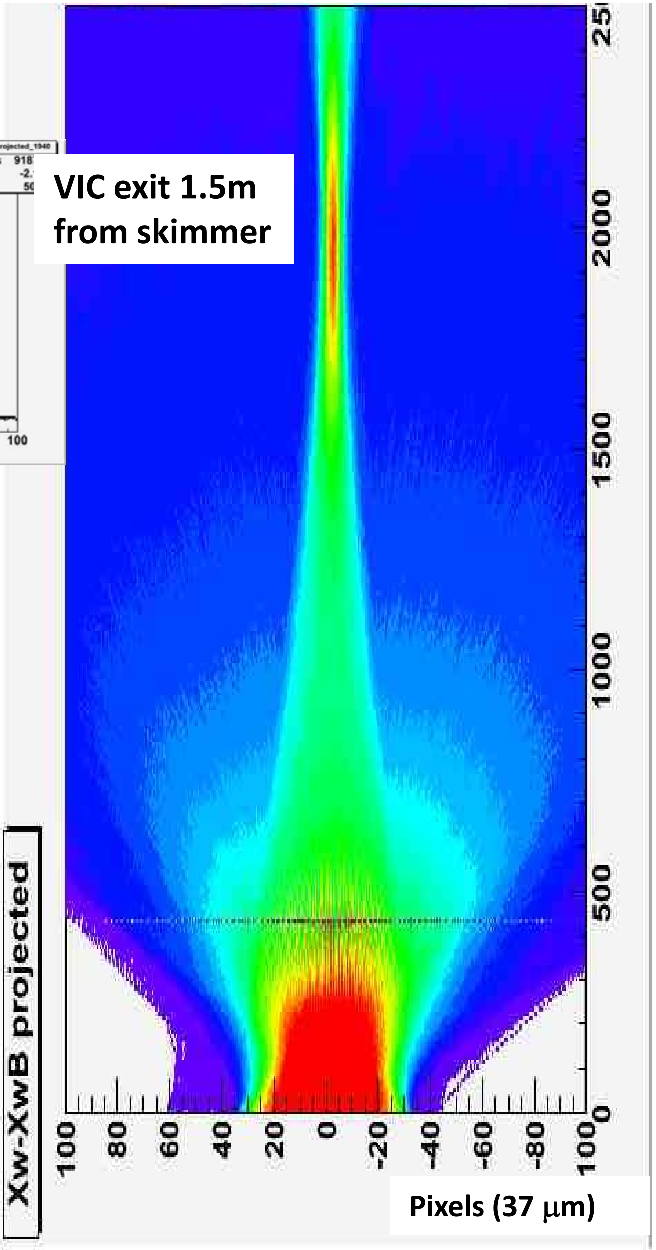
Out of field effects are severe outside +/- 2 mm of focus

Extrapolated track positions at VIC : $\sigma \approx 100\ \mu m$

This causes problems when measuring a pellet stream with bigger diameter than 2-3 mm e.g. at the dump at PANDA where the pellet stream diameter would be about 6 mm.

Tests with camera optics with f=25mm are in progress to determine the possible tracking performance.
The DOF (in measurement conditions) has been verified to be about the double compared to optics with f=50mm.

Pellet track x-distribution versus vertical position



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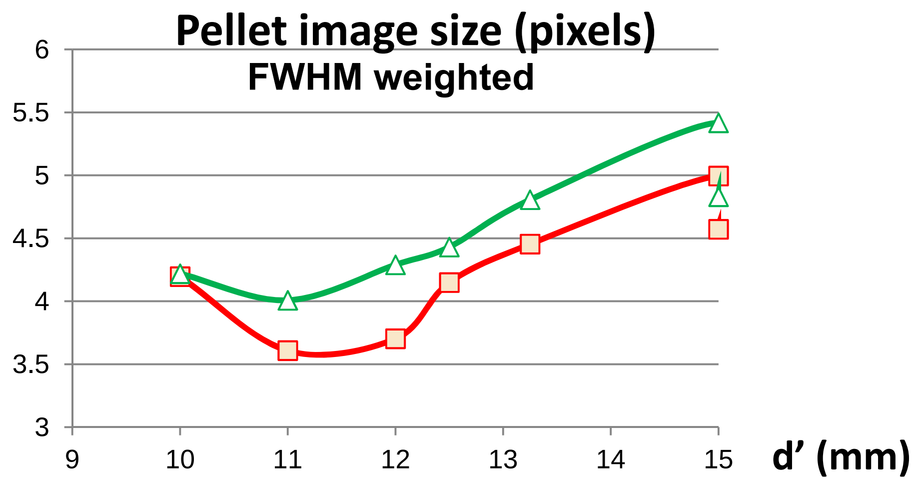
Blurring due to limited DOF

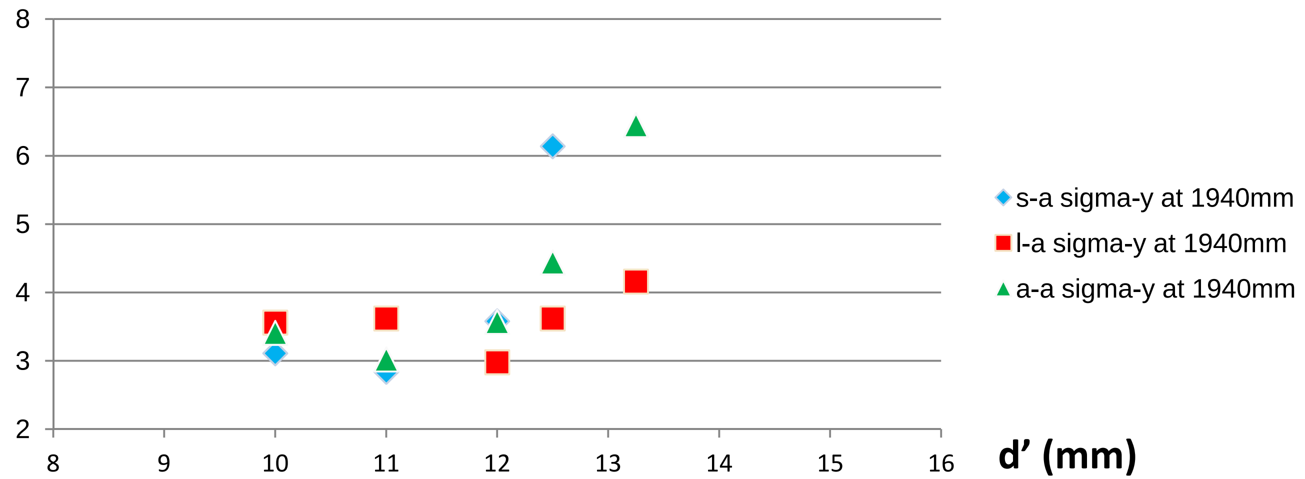
DOF study with cam optics f=50mm, bl.=1.4, d(pelletstream – focalplane) ≈250mm.



Expect (geometrically) image size of 1-2 pixels

Out of field effects are severe outside +/- 2 mm of focus

Extrapolated position distribution σ(pixels) at 1940 mm



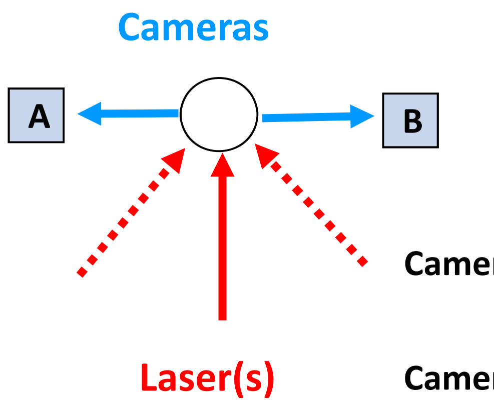
Time resolution, efficiency & measurement dead time

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 (σ ≈ 0.25 μs) which is the goal for PANDA.

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

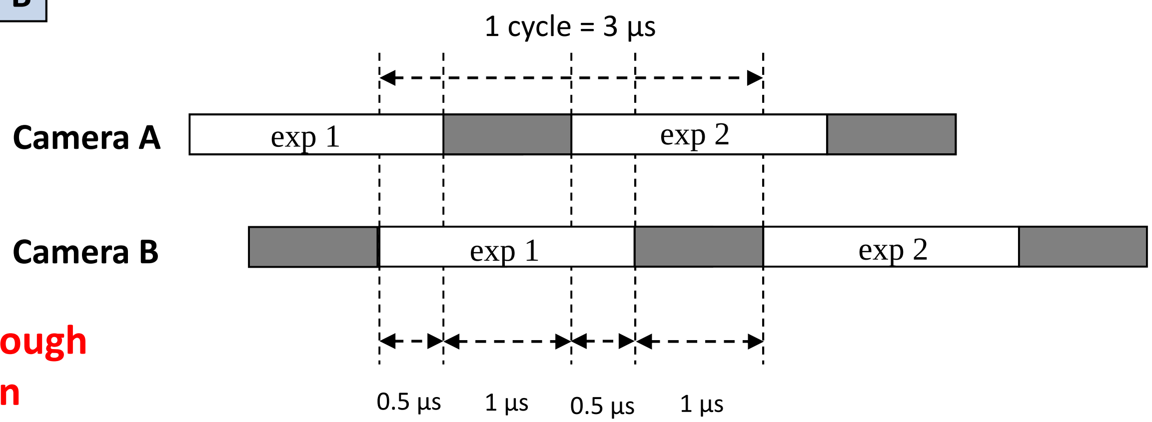
Plan to test a new camera model (EM4, 4 tap) which has a shortest period of 5 μs.

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

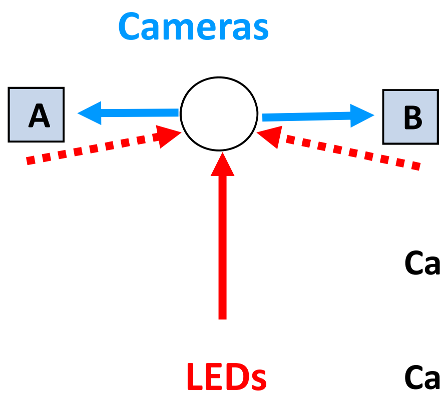


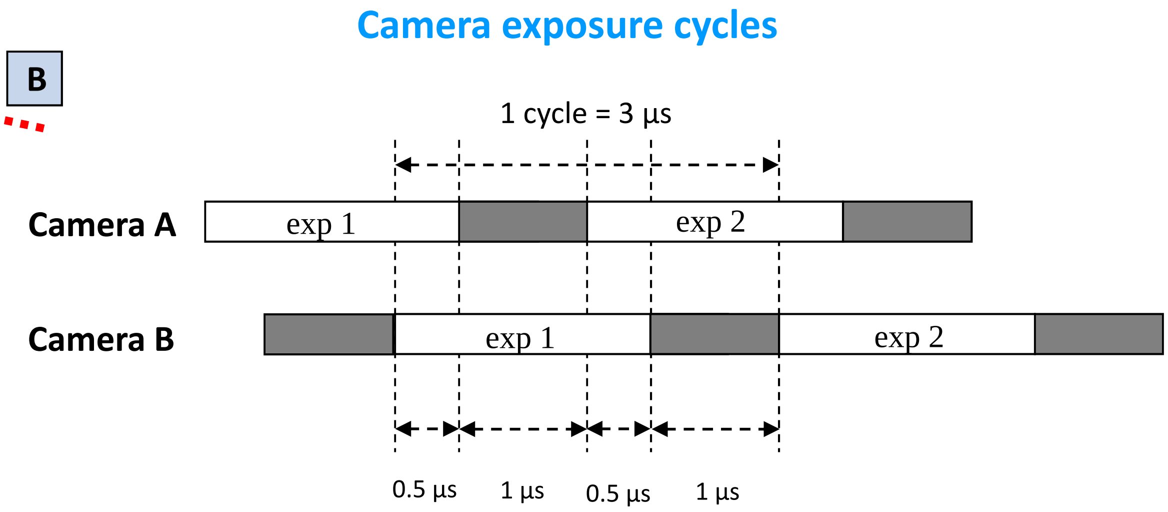
... strong / many enough to give full detection possibility.

Camera exposure cycles



Time resolution & measurement dead time





Test bench setup including camera holders with reference LEDs and vacuum windows .

Two cameras look on a fishing-line illuminated by an LED.

(Erasmus work M. Kümmel).

System design and simulations

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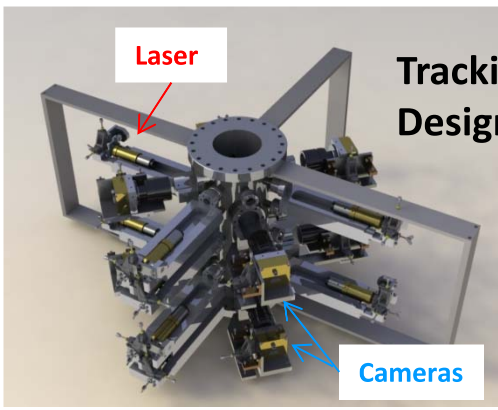
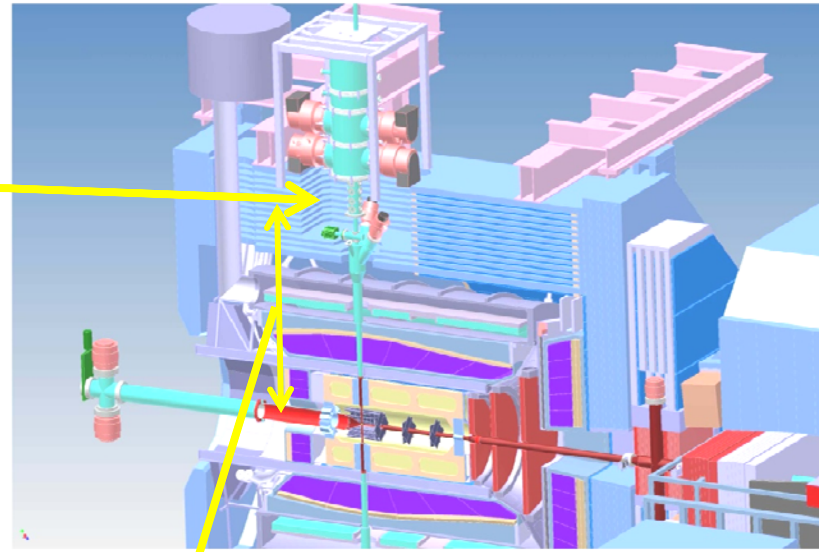
panda

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.



Tracking section
Design idea



PTR section – Interaction region ≈ 2 meters

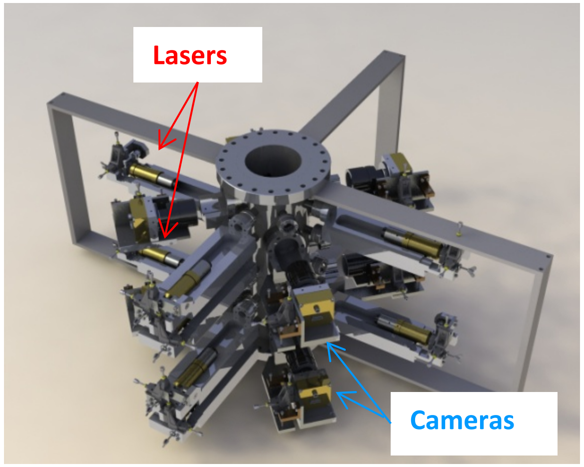
Four levels for measurements, each with two lasers and two LS-cameras. Level spacing: 60 mm

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

Detailed system design

(Andrzej Pyszniak)



Version 0 tracking section:

4 levels (2x,2z) , each with 2 lasers and 2 LS-cams.

- Total height 400 mm. Radial size r_{max} = 500 mm.

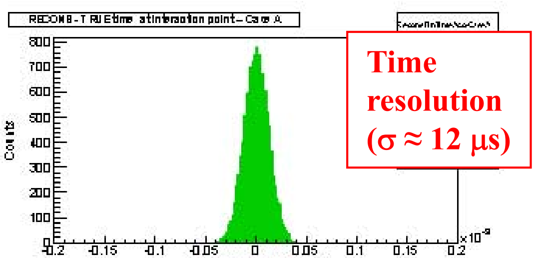
- Distance for velocity determination 60 – 260 mm.

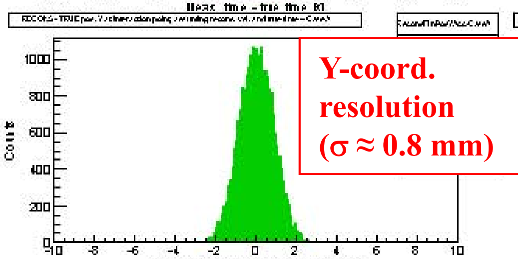
- Distance for direction determination 200 mm
(…internally… if one use VIC exit: > 500 mm).

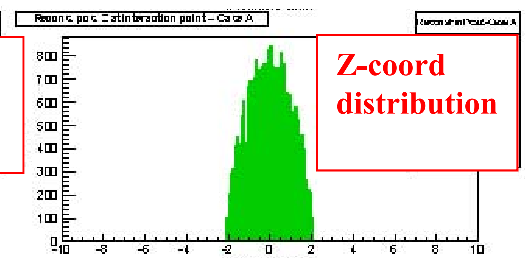
Pellet Tracking Example study for Panda (A. Pyszniak)

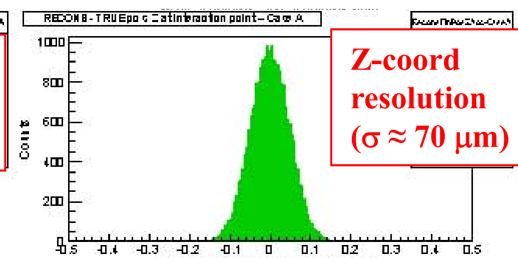
Generation point (VIC) at 3000 mm
VIC position used for XZ tracking
Measurement point 1 at 2300 mm (X)
Measurement point 2 at 2240 mm (Z)
Measurement point 3 at 2100 mm (X)
Measurement point 4 at 2040 mm (Z)
Interaction point at 0 mm
Number of generated pellets: 100k
Generation frequency: 14, 20, 40 kHz
Velocity mean: 70 m/s, sigma: 1%
Stream divergence: ≈ 1 mrad
Skimmer: 1mm diam @ 2301 mm
Pellet 25 µm, Pixel: 37 µm, Exp. Thr: 0.05
Camera cycle/exposure: 4/4 µs
Surv. prob. at gen.: 1 => Eff pel. rate at meas. points: » 14 k/s
Half width of the search window: 2 vel. sigma
Size of acc. beam: 5, 10 mm (sigma ≈ 1, 2 mm)

Examples of some pellet tracking distributions at the interaction point.









[Date: 20120530] Camera cycle: 4/4 µs; Eff pel rate at meas. points: ≈14k/s, Gravity NOT used in generation
CASE A
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Pellet tracking Step-by-Step

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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.

At the 1st levels in the upper tracking section.

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

It takes ≈100 ms for a pellet to pass all measurement points.

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.

It takes ≈100 μs for a pellet to pass 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.

A common time scale is needed for matching with the experiment DAQ.

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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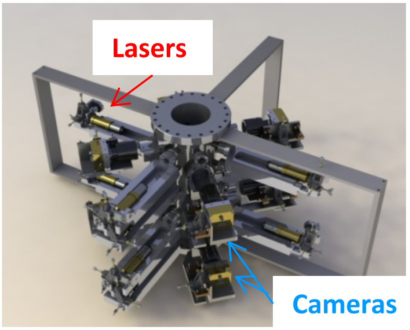
Position resolution at the interaction region.

Resolution in the vertical (Y) position, for different camera cycle times

Camera cycle [μs]	Y resolution [mm]	time resolution [μs]
time4/exp4	0.85	12.0
time2/exp2	0.45	6.5



Resolution in the horizontal (X and Z) position, for different measurement setup configurations …… with and without using the VIC exit position in the track reconstruction

Configuration	X resolution [μm]	Z resolution [μm]
XZXZ with VIC	75	65
ZXXZ with VIC	70	70
XZXZ w/o VIC	245	240
ZXXZ w/o VIC	265	215

No difference with VIC

+/- 10% difference w/o VIC

Level arms XZXZ -> 200-200 mm, ZXXZ -> 140-260 mm

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Example of some pellet tracking performance numbers.
Occupancy of acc. beam region (ϕ=5 mm).
Compare tracking prediction (trk) with mc reality (plt).

Note: In this example a "trk" is based on full and correct information from all detection levels, a condition which is very strong….. There is also room for improvement of the tracking procedure …..

Cam cycle (μs)	Plt rate (k/s)	Prb for no plt when no trk	Prb for 1 plt when 1 trk	Correct match when 1 plt & 1 trk
t4/e4	5	0.87	0.76	0.98
t2/e2	5	0.88	0.82	0.99
t4/e4	14	0.61	0.57	0.92
t2/e2	14	0.63	0.62	0.96

Low pellet rate and high time resolution improves tracking performance (as expected).

Effect of detection inefficiency.

Camera deadtime fraction of 20% in this example gives about 20% reduced tracking performance.

Cam cycle (μs)	Plt rate (k/s)	Prb for no plt when no trk	Prb for 1 plt when 1 trk	Correct match when 1 plt & 1 trk
t4/e4	5	0.87	0.76	0.98
t6.25/e5	5	0.82	0.68	0.95
t4/e4	14	0.61	0.57	0.92
t6.25/e5	14	0.52	0.48	0.83

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Status of simulations for the detailed design of a system for PANDA

The MC reproduce well the results of UPTS pellet experiments

The MC is being used to estimate the resolution and efficiency of the pellet tracking system for PANDA* (using upper section):

- **the transverse position resolution is adequate**
- **the vertical resolution with 3-4 μs cycle may be sufficient, but it would be better with 2 μs (cameras commercially available)**
- **efficiencies according to TDR can be achieved i.e >70 % useful info with a proper combination of Pellet Rate (around 10 k/s) and Accelerator Beam size (5-10 mm)**

Further optimization work in progress, both for equipment and procedures.

Design simulations for the lower tracking section are planned.

This section will be important for tuning and monitoring of the tracking performance and might also improve the resolution. A complication is the size of the pellet stream (Φ ≈ 6 mm). It requires a larger depth of field of the camera optics and a wider laser beam than what will be used in the upper section. To get sufficient pellet detection efficiency, optics with shorter focal length can be used, but then the position resolution becomes worse and also the time resolution will be affected.

*) For details see the project report :
Simulation studies for design of pellet tracking systems, A. Pyszniak et al., January 2013
(http://www.physics.uu.se/en/np/panda/pub/)

Simulation studies for design of pellet tracking systems

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[2]Institute of Physics, Jagiellonian University, PL-30-059 Cracow, Poland

January 2013

Abstract

Frozen microspheres of hydrogen, so called pellets, are planned to be used as targets in the future hadron physics experiment PANDA at FAIR. The identification and measurement of rare and interesting events can be significantly improved if the primary reaction vertex is known with high accuracy independently of the reaction products. This is possible by reconstruction of the position of the pellet at the time of a reaction with a so called pellet tracking system using lasers and line scan cameras. This report presents a detailed simulation of such a system for PANDA. Using realistic constraints from PANDA, the vertex resolution and reconstruction efficiency is calculated for a range of possible parameters. It is shown that a resolution of better than 0.1 mm in the plane transverse to the pellet stream and 0.5 mm in the vertical direction can be achieved. The efficiency for reconstructing the pellet position at the accelerator beam is found to be in the order of 70% or better.

(www.physics.uu.se/np/panda/pub)

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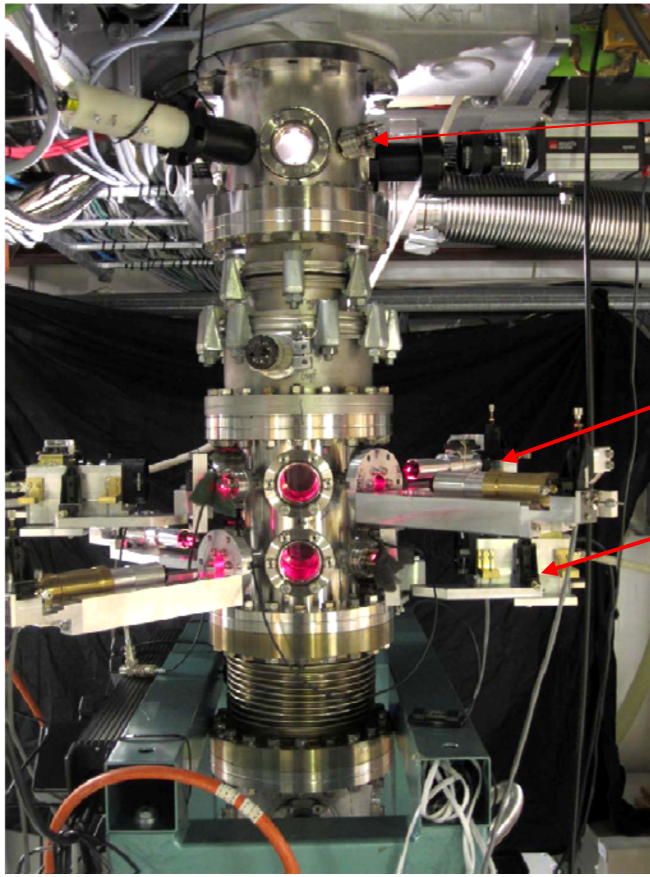
Multi camera system at UPTS



New laser ports
=> 3 useful levels

Mechanics ready for
6 lasers and 6 cameras

6 lasers and 6 cameras
are available
(+ a 200 kHz camera)

3 levels can be instrumented in different configurations

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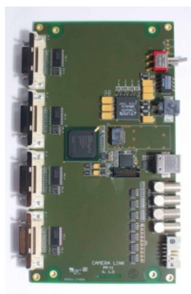
Multi camera readout development: status

Multi-camera system

Software: Project works by Malte Albrecht, Madhu Thelajala and Geng Xiaoxiu

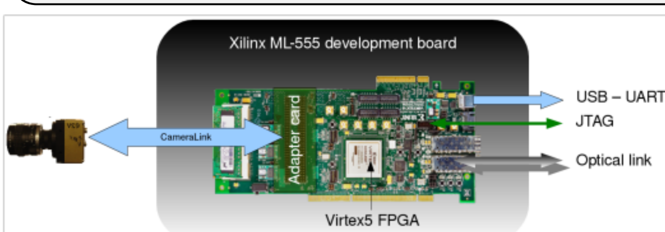
VME FPGA board (developed for WASA trigger) is used for readout of up to 8 CamLink FPGA boards.
FPGA Software:
- **Control and readout of camera link board ready**
- **VME readout ready**



CamLink FPGA board is used for readout of 2-4 cameras:
1'st prototype board debugged and software developed
2 boards of a modified version were produced and tested
FPGA Software:
- **Camera link readout and pellet recognition implemented**
- **Communication with camera and VME board works**

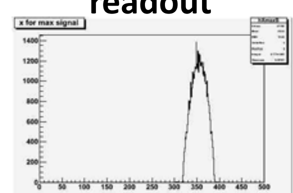
Remaining tasks
- **Work on synchronization of boards and cameras needed**
- **Implementation in the PTR readout system**
- **(Camera link readout for 200 kHz camera)**

Tests with pellets on development board

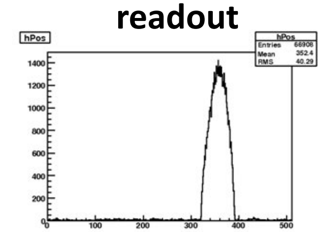


Pellet position in the PTR chamber

Frame grabber readout



FPGA readout



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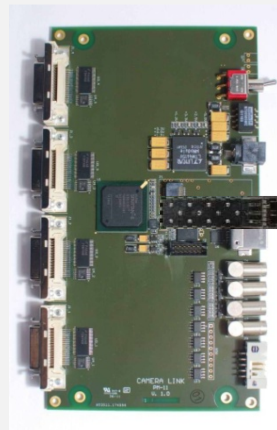
Multi camera readout and synchronization
Design idea


Camera links 120 Mbytes/s each

Up to 4, 100 kHz or 2, 200 kHz cameras on each card

Camera link cards

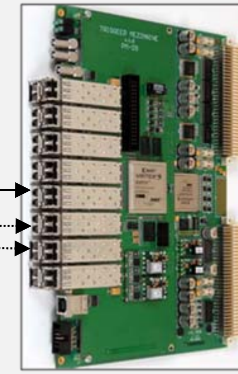


4 camlink inputs
Spartan 6 FPGA

- Convert camera link data
- Identify pellets
- and store with time stamp
- Synchronize cameras
- Send data optically
- Control cameras

Optical links < 10 Mbytes/s for 16 links And 20 kHz pellets

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

- Read out of pellet data over VME o other bus
- Synchronize the cards
- Camera control and set-up

A few Mbyte/s output data rate for 16 cameras

Feasibility of laser-induced droplet production

- Laser
  - Requirements …. power, time structure, beam size, wavelength ….
  - Market investigation

- UPTS liquid jet features
  - Stability ?
  - Spontaneous breakup into droplets …. jet length, time structure

- Possibilities of very exploratory tests with "available" equipment?

  To be investigated more:
  - Laser power and beam profile
  - Geometry / mechanics
  - Vibrations ….

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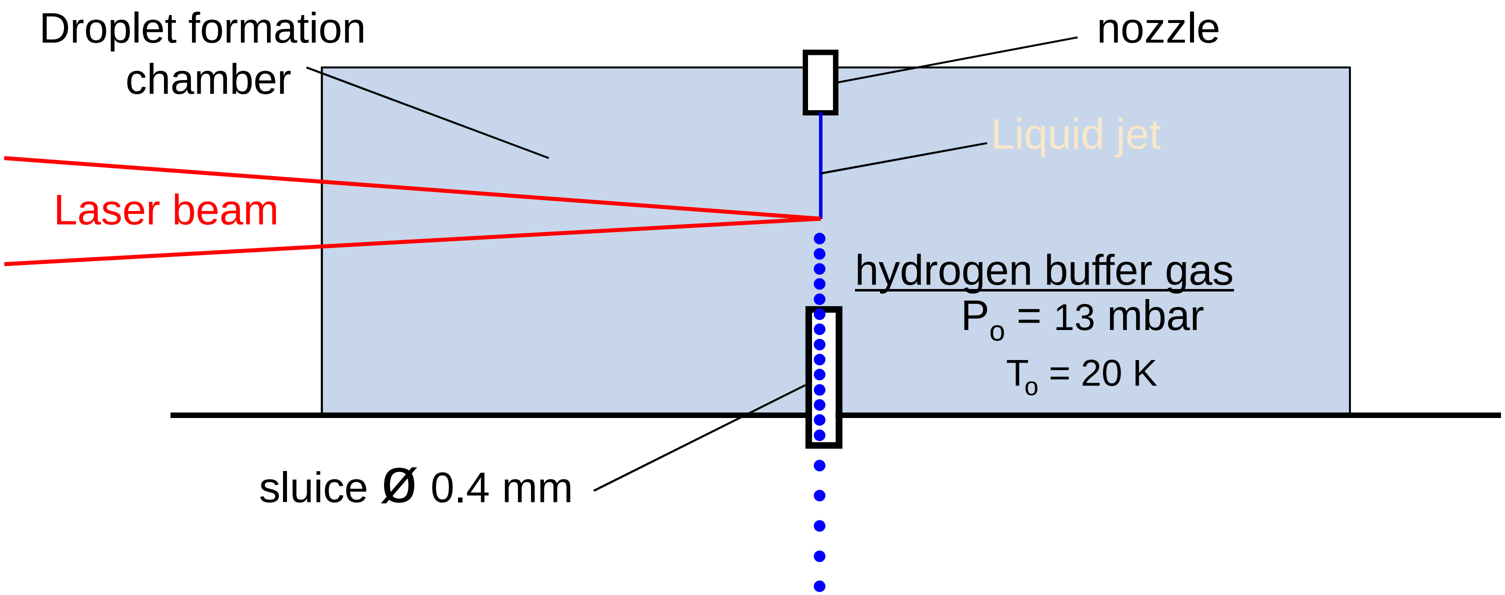
New laser-induced technique for a micro-droplet production

Victor Varentsov



The heat that is required for evaporation of 1g of liquid hydrogen is equal to $k(H_2) = 450$ J.

To evaporate a column with diameter 10 μm and height 100 μm of liquid hydrogen ($5.3 \cdot 10^{-10}$g) corresponds to an absorbed energy of:

$E_{evap} = 450 \cdot 5.3 \cdot 10^{-10} = 2.4 \cdot 10^{-7}$ J

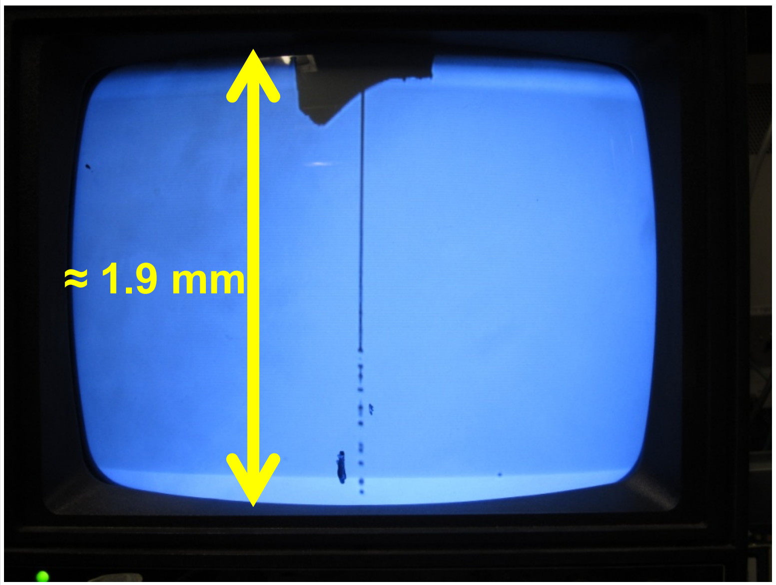
Assuming $d_{laser} = 100$ μm -> $E_{pulse} \sim 2 \cdot 10^{-6}$ J → $I_{laser} \sim 0.2$ W average at 100 kHz

Laser beam will need a focusing system

Borosilicate glass for the windows is ~90 % transparent between 350 and 1200 nm

Liquid H_2 jet breakup

Jet breakup with piezo-oscillator on and off, seen in stroboscopic light (LED).

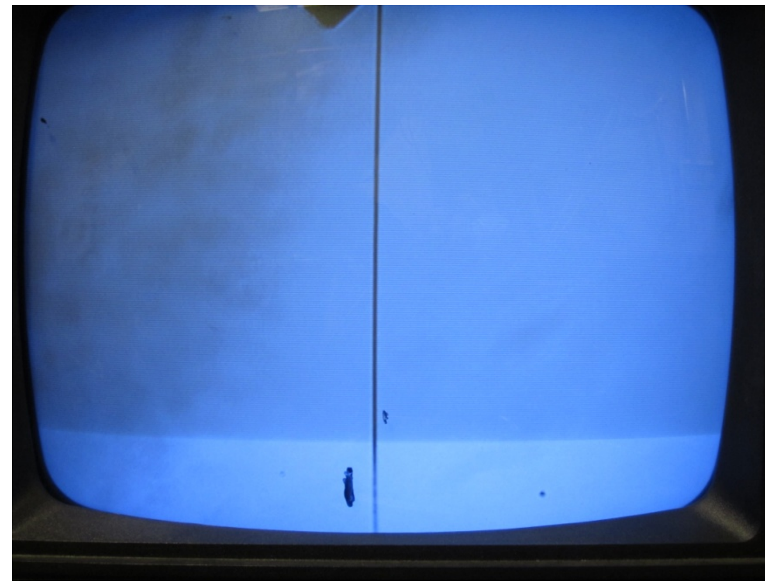


Weak oscillation

f = 67kHz

Light 67kHz

Jet breaks up after ≈ 1 mm
(<−> 40 microseconds)



No oscillation

Light 67kHz

Jet breaks up after ≈ 1.5 mm
(<−> 60 microseconds)

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“Spontaneous” liquid H_2 jet breakup

Laser-induced droplet production

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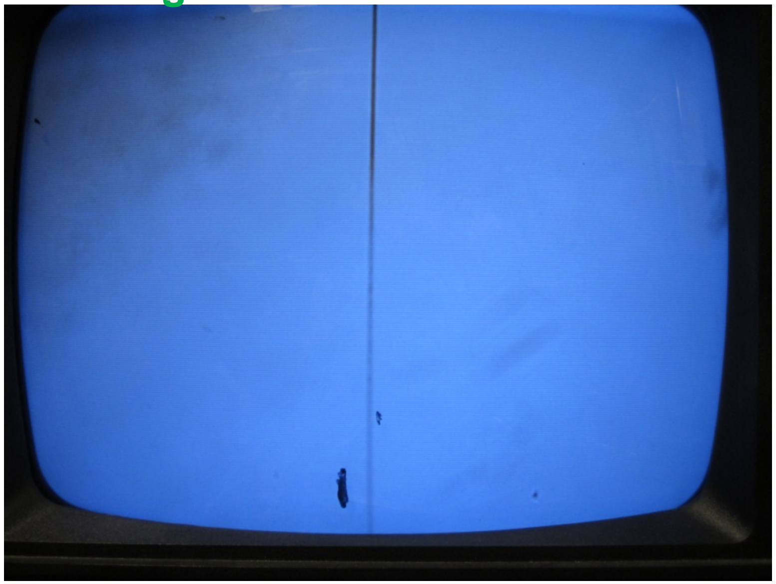
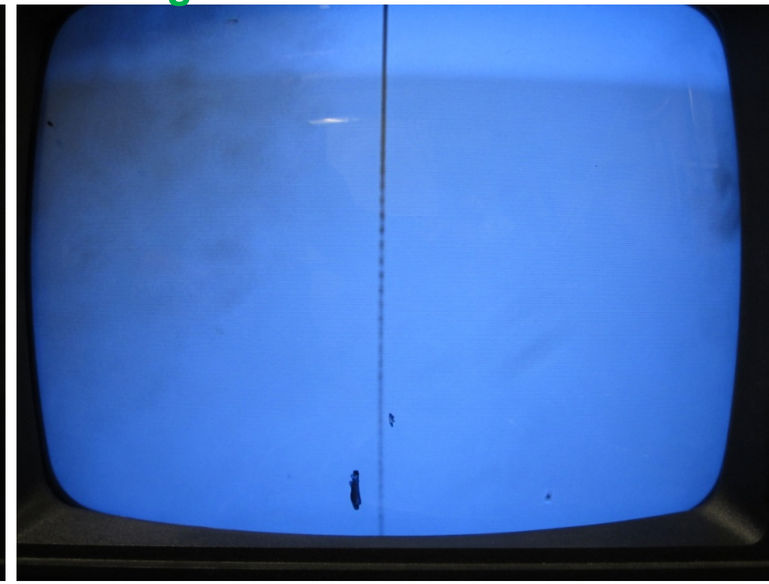
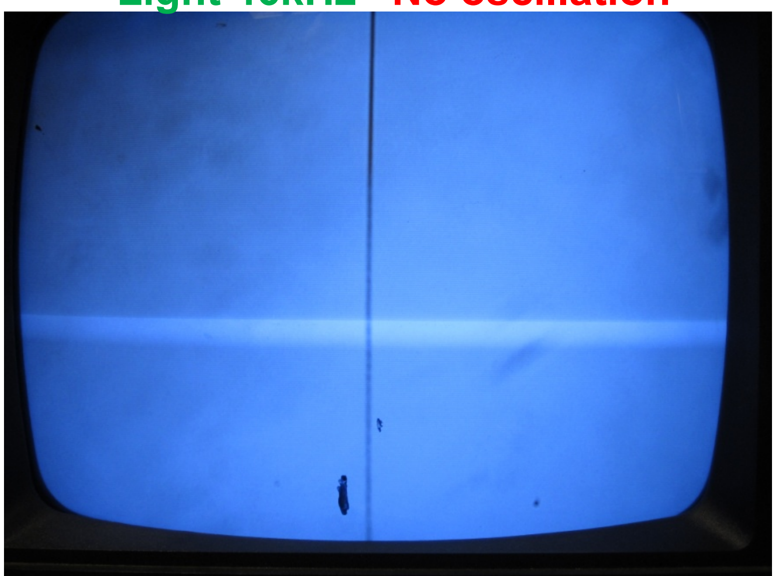
Light 67kHz No oscillation



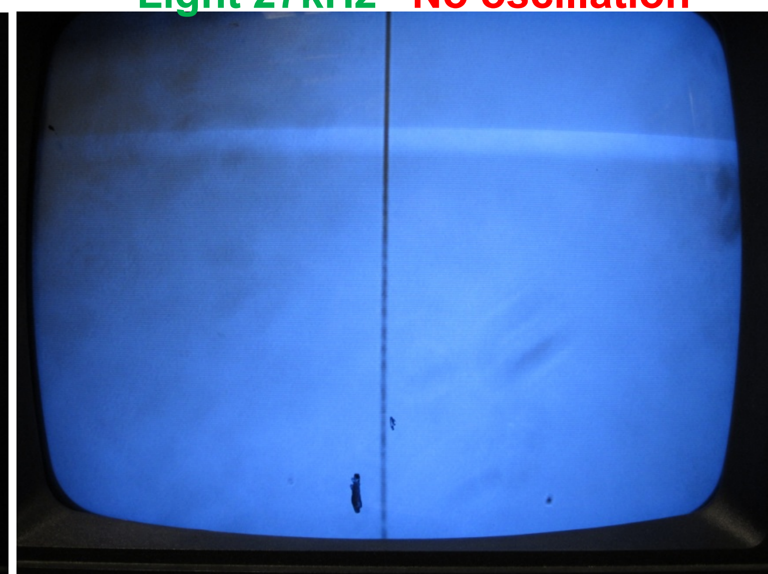
Light 58kHz No oscillation



Light 46kHz No oscillation



Light 27kHz No oscillation



Summary (April 2013)

UPTS with 1st prototype PTR system:

- Operates with PANDA PTR mode pellet stream conditions .
- Prototype tracking chamber with two levels of pellet detection.
- Two synchronized LS-cameras (12 μs cycle), with up to 3 lasers each.
- Transverse position resolution needed for PANDA demonstrated.
  (Pellet velocity spread σ_v /v <<1% should be possible to obtain.)

FutureJet tasks:

3.5 High efficiency pellet detection

- Detection / illumination conditions … being studied and optimized.

3.6 Pellet track processing and optimization of pellet detection points

- Detailed design simulations, based on a tracking section at the generator, for PANDA has been done (Milestone 13 report …) .

3.7 Multi-camera (readout) system

- Extended the UPTS tracking setup to 6 LS-cameras with lasers.
- Readout system h-w: 2nd version of CamLink FPGA board tested.
  s-w: Complete readout chain (camera-to-computer) tested.
  More work is needed, mainly on synchronization and optimization for operation under real conditions.

3.8 Feasibility of laser-induced droplet production

- Investigating test possibilities at UPTS ……..

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