Development of a beam profile monitor using laser-wire systems

Thomas Aumeyr
Royal Holloway, University of London

DITANET International Conference, 9-11 November 2011

Overview

- Measuring the transverse beam profile
- Laser-wire systems
- PETRA-III
- Laser-wire at PETRA-III: laser, optical components, DAQ
- Scan types
- Example profiles
- Outlook

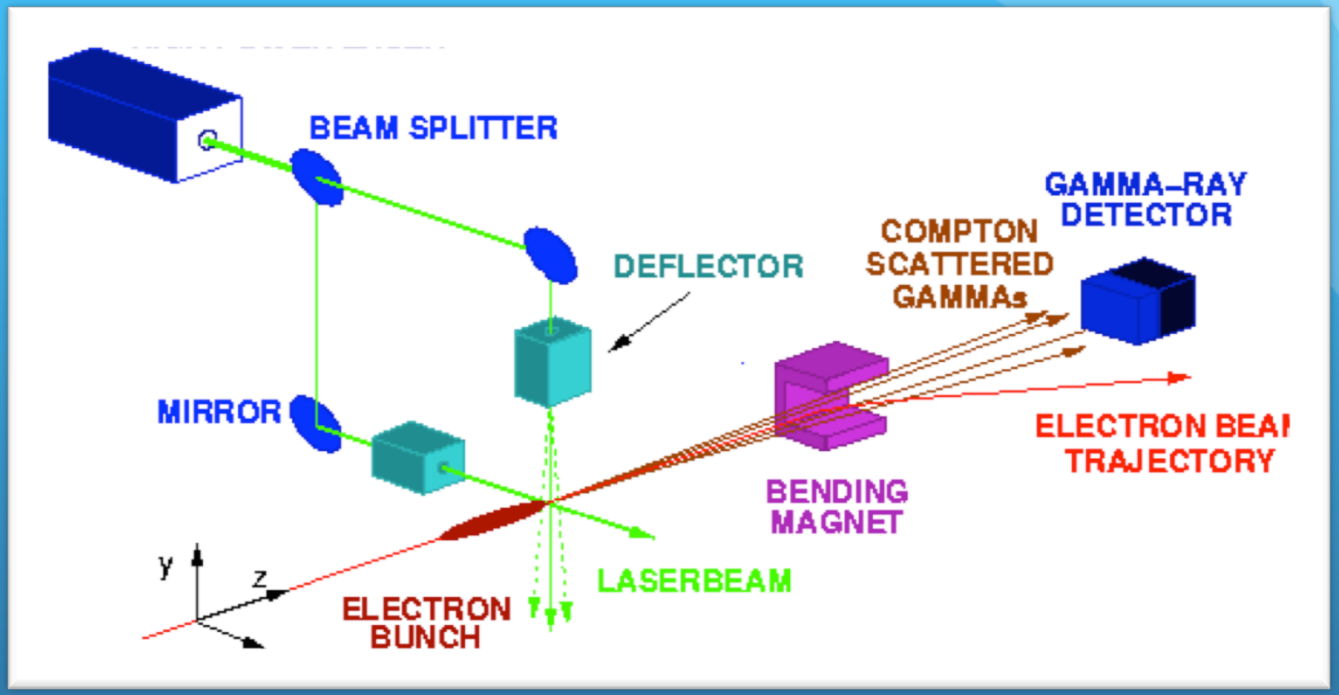
Measuring the transverse beam profile

- Essential for determining transverse beam emittance.
- Traditional method is to sweep a solid wire across the beam.
- Measure background vs relative position of wire and beam.
- Micron-scale precision required for linear colliders and synchrotron machines
- Solid wires would not stand the intense beams of such machines
- Solid wires could ablate, harming surfaces nearby

Laser-wire systems

- Focused laser beam scans across particle beam
- e^--machines: → Compton Effect
  - Laser photons scattered by e^- are detected as gamma rays in a calorimeter
  - Scattered e^- over-focused by magnets
- H^--machines: → Photo-ionisation of H^- into H^0
  - H^0 and/or released e^- detected downstream
- Plotting the change in the deposited calorimeter charge as a function of the transversal laser position → convoluted beam profile.
- Laser width must be subtracted from the convoluted profile to obtain an electron beam size measurement.

Schematic setup

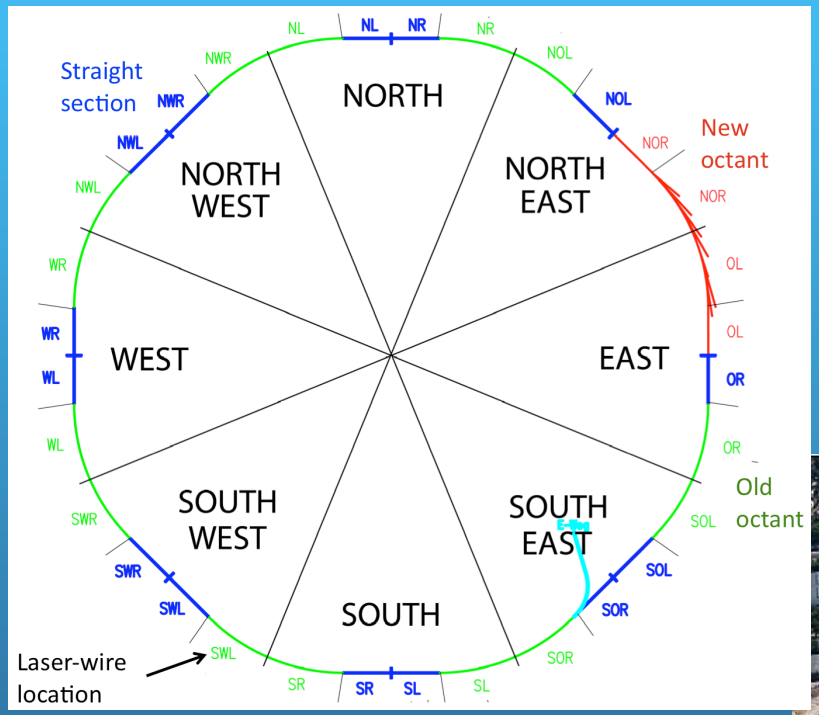


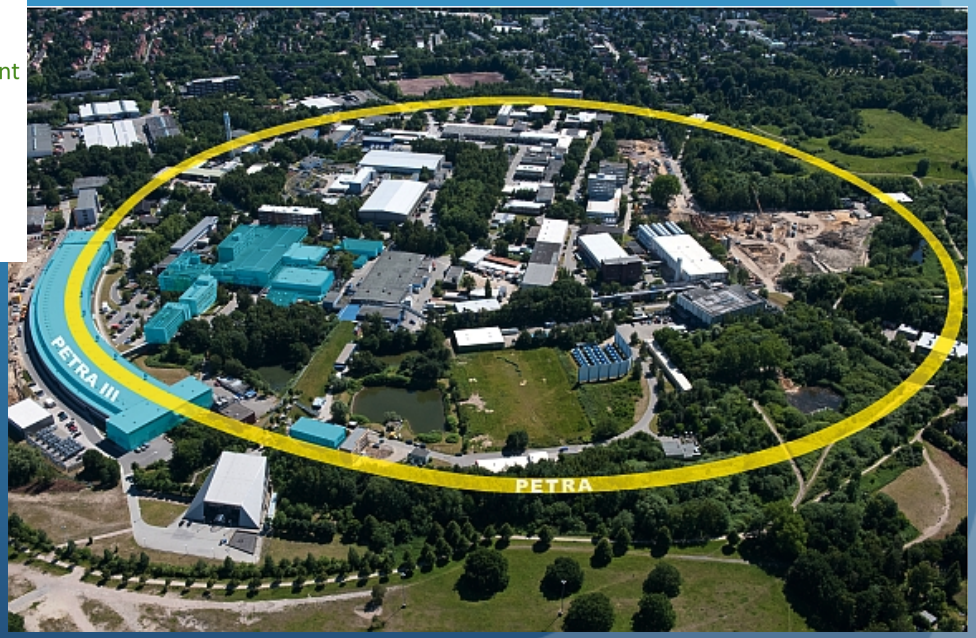
- Laser pulses synchronised with beam pulses
- Up-/downstream beam position monitors (BPMs) can be used to monitor beam fluctuations
- Post-IP power meter for laser power normalisation

PETRA-III

- Recently commissioned 2.3km storage ring at DESY, Hamburg
- High brilliance synchrotron light source
- Runs 6 GeV positrons, grouped into 40 bunches/100mA, evenly distributed over the ring, with 192 ns spacing
- Understanding emittance important to achieve ultimate performance
- Beam sizes x/y/z: 200 μm / 20 μm / 40 ps

PETRA-III


Straight section
NORTH
NORTH WEST
NORTH EAST
WEST
EAST
SOUTH WEST
SOUTH EAST
SOUTH
New octant
Old octant
Laser-wire location
NL
NR
NOL
NOR
OL
OR
SOL
SOR
SL
SR
SWL
SWR
WL
WR
NWL
NWR


PETRA III
PETRA

PETRA-III

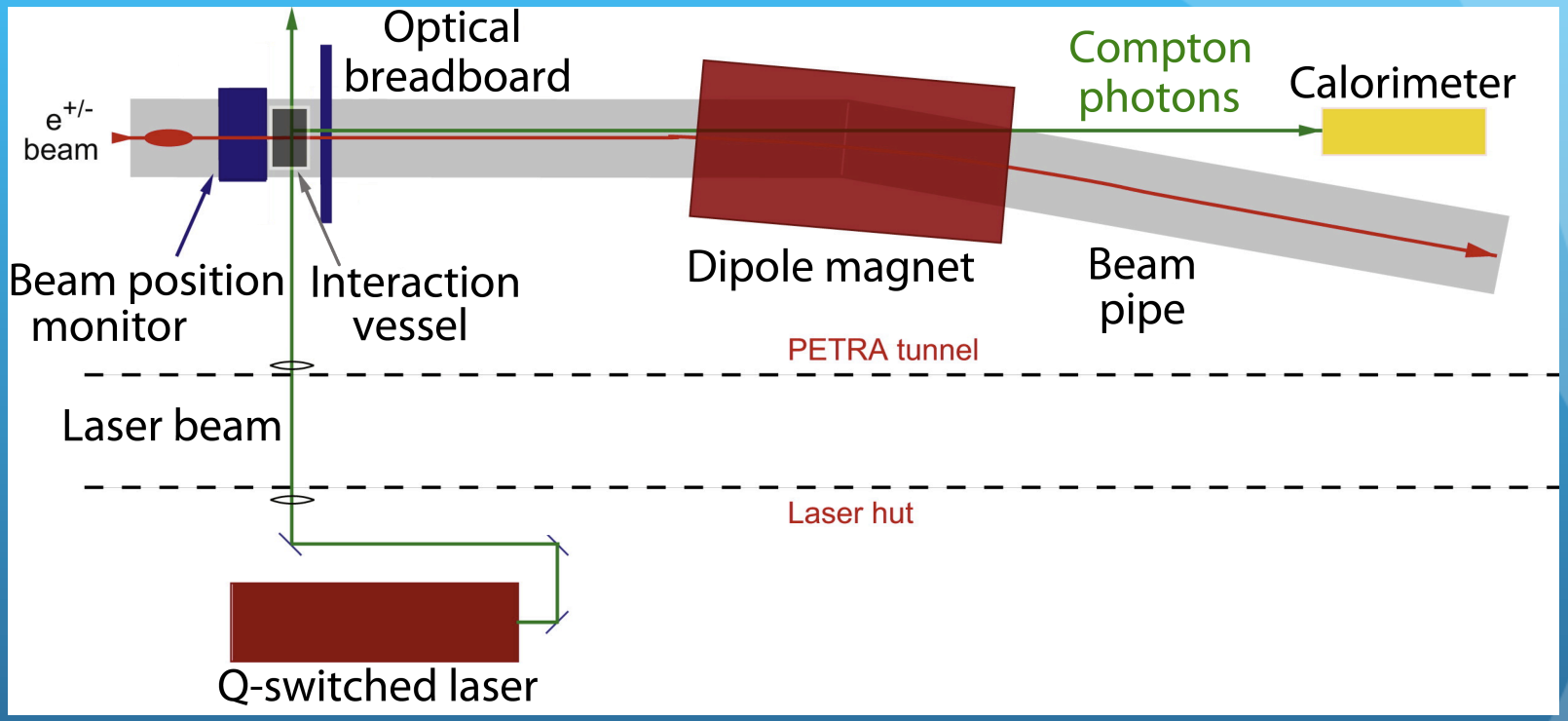
3rd generation synchrotron radiation source

Parameter		Value		Unit
Energy	E	6		[GeV]
Circumference	C	2304		[m]
Horizontal emittance	ε_x	~1		[nmrad]
Vertical emittance	ε_y	~0.01		[nmrad]
Train repetition rate	f	130.2		[kHz]
Number of bunches per train	N_{train}	960	(40)	
Interbunch spacing		8	(192)	[ns]
Bunch length RMS	L_b	~12		[mm]
Number of electrons per bunch	N_e	0.25	(12)	$\times 10^{10}$

Laser-wire @ PETRA-III

- Installed in early 2009
- Green laser light (λ=532 nm)
- Using a vertical optical table: vertical and horizontal scans possible
- Current emphasis:
  - Integrating into PETRA system
  - Taking and analysing data in the context of P3 optimisation

Overview of LW layout



The laser-wire system at PETRA-III is 2D bunch profiler: laser beam can be sent to collision in horizontal or vertical plane.

Laser

- Nd:YAG laser (1064 nm, frequency doubled)
- Linearly polarised laser intensity is controlled using a waveplate

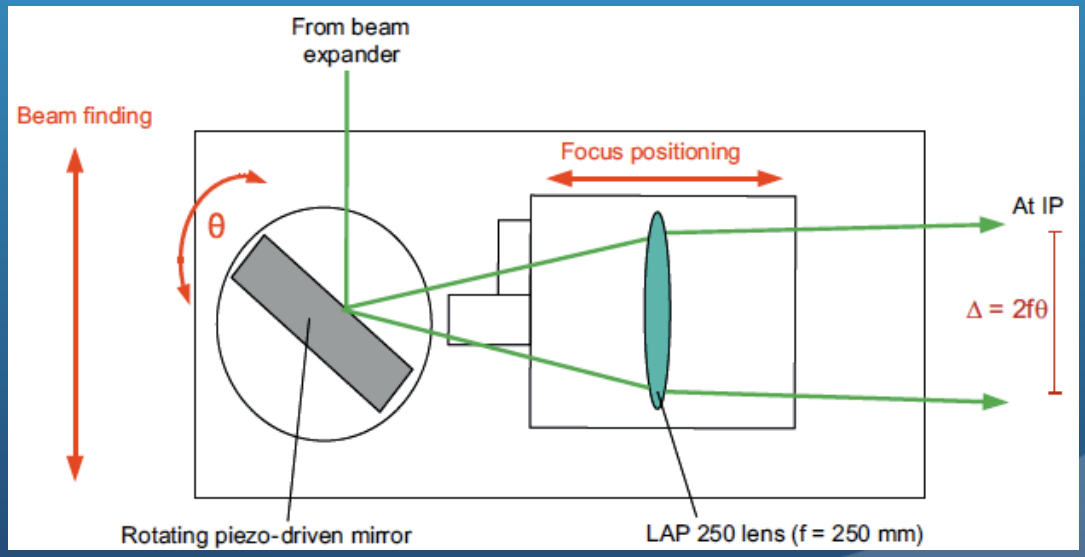
Parameter	Value	Unit
Pulse energy at 532 nm	60 ± 5	mJ
Peak power at 532 nm	12 ± 1	MW
Repetition rate	20	Hz
Pulse duration	5 ± 1	ns
RMS pulse jitter (rel. to ext. trigger)	1	ns
Mode quality factor (M^2)	2.68 ± 0.05	
Horizontal angular jitter	18.8	μrad
Vertical angular jitter	9.4	μrad

Optical scanning components

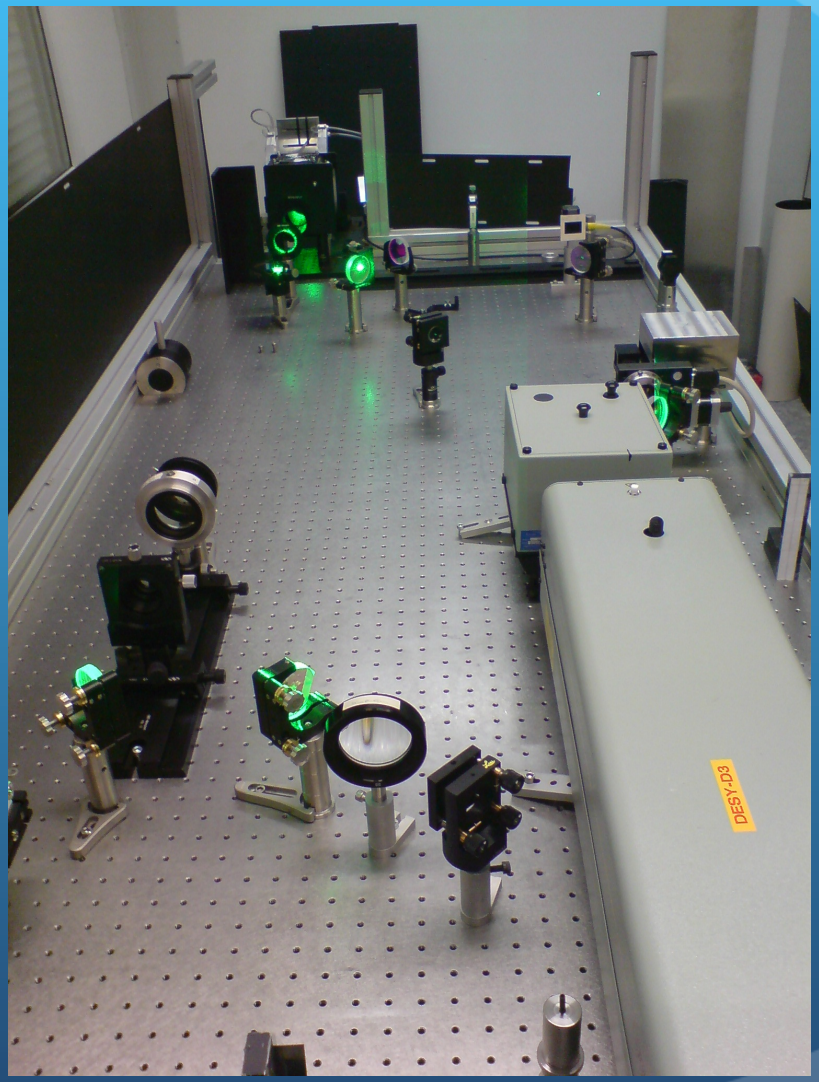
- 2" high reflective static mirrors, 2 scanning mirrors
- Horizontal scan: 750 mm lens
- Vertical scan: 250 mm lens
- 3 webcams with alignment crosses (monitor laser-alignment remotely)

Scanning mirrors

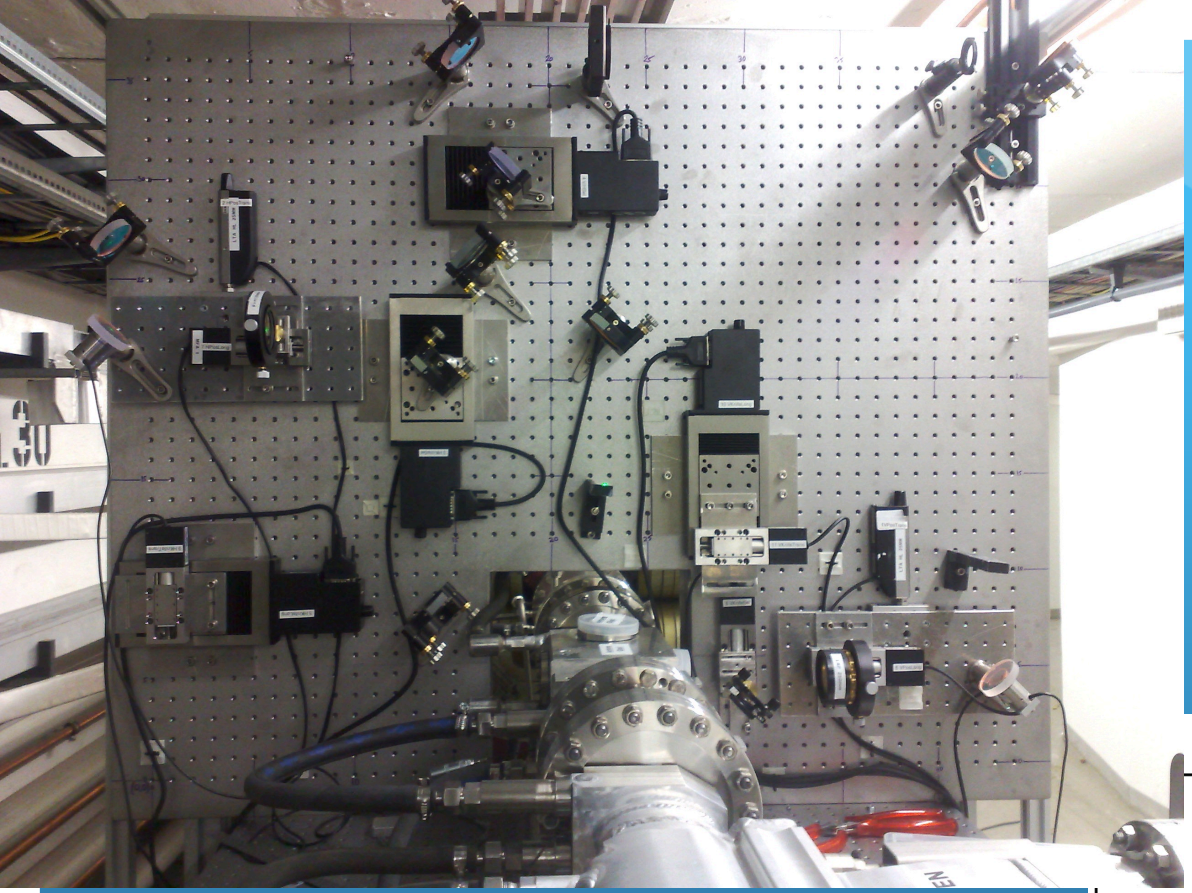
- Mounted on translation stages
- 2” multilayer coated mirror mounted on piezo-electric stack
- Deflection by max. angle of 2.5 mrad (with 100 V applied voltage)
- Vrange 1.25mm; Hrange 3.75mm



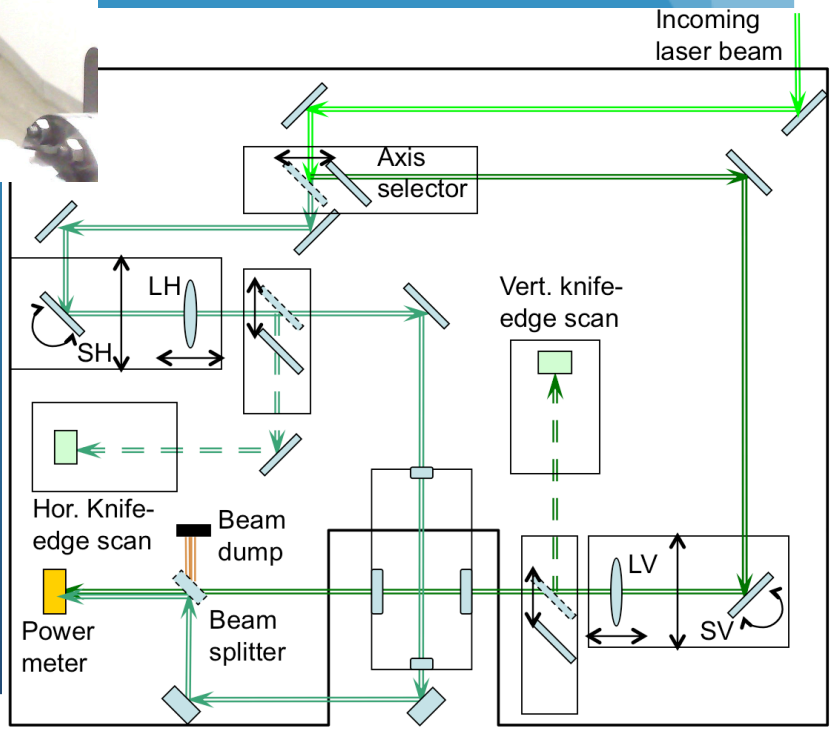
Laserhut



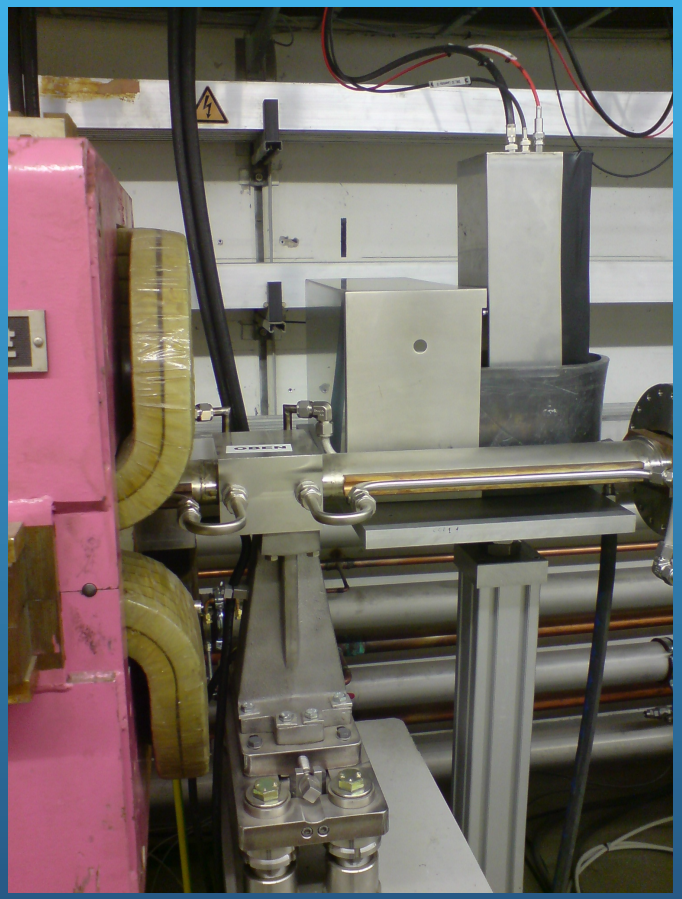
Breadboard



During shutdown in May 2009 motorised translation stages were positioned with laser aligned for IP.



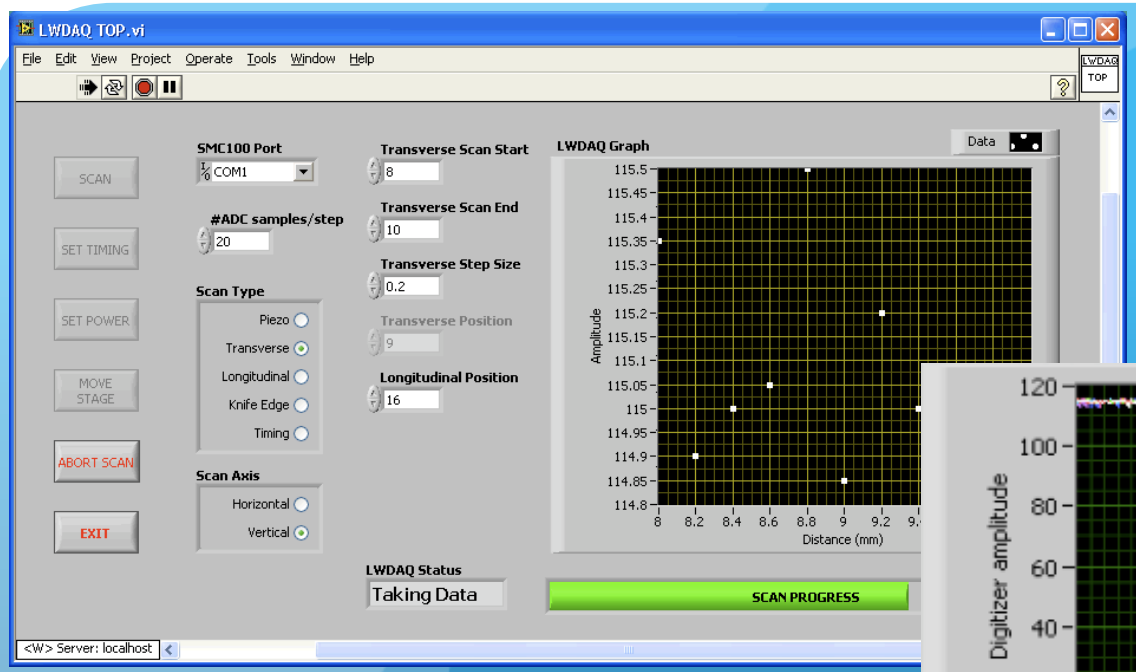
Calorimeter

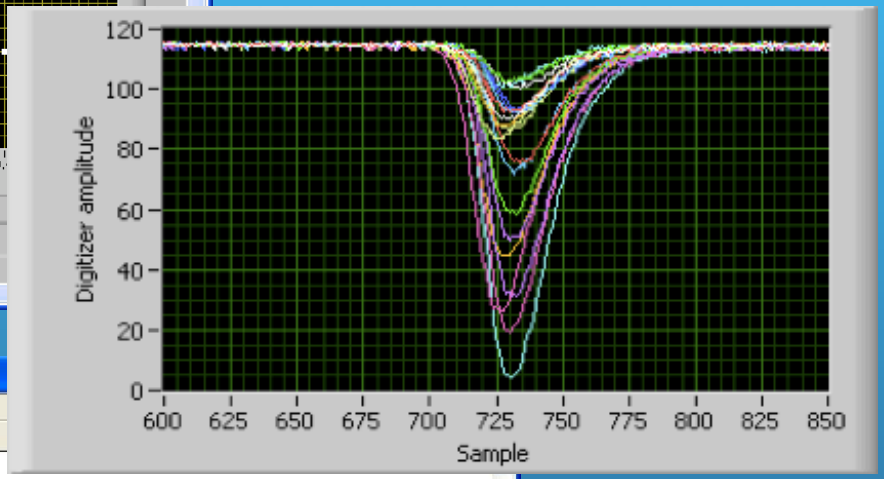


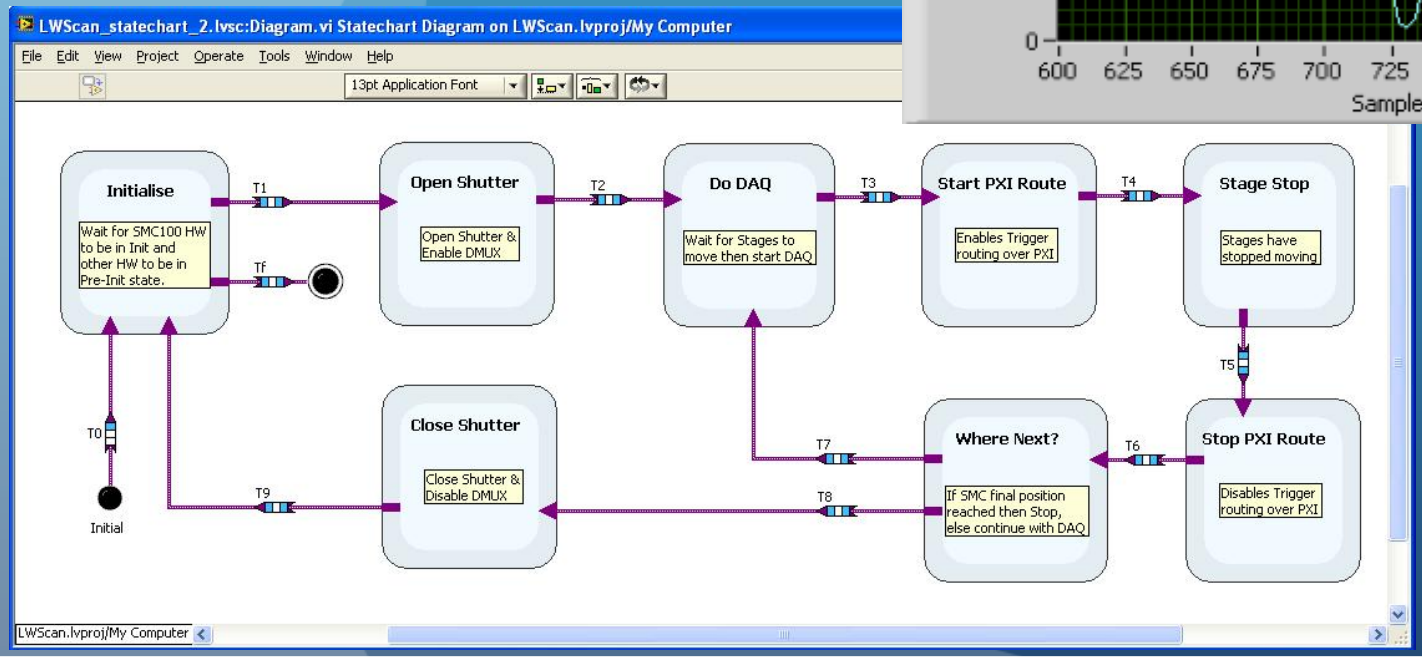
- 9 lead tungstate crystals (18 x 18 x 150 mm) arranged in 3x3 matrix
- Scintillation light detected by photomultiplier (PMT)
- Lead housing to shield from stray synchrotron light

LWDAQ hardware

- Uses National Instruments (NI) PXI system
  - 2 GS/s two-channel digitizer (PXI-5152)
  - Precision timing module (PXI-6653)
  - General-purpose DAQ (PXI-6251)
  - accesses other HW via RS232 & GPIB
- Written in LabVIEW (v8.5) with Statechart and DSC modules
- Reads TINE database for local BPM positions, current etc.


LWDAQ TOP.vi
File Edit View Project Operate Tools Window Help
LWDAQ TOP
SCAN
SET TIMING
SET POWER
MOVE STAGE
ABORT SCAN
EXIT
SMC100 Port
COM1
#ADC samples/step
20
Scan Type
Piezo
Transverse
Longitudinal
Knife Edge
Timing
Scan Axis
Horizontal
Vertical
Transverse Scan Start
8
Transverse Scan End
10
Transverse Step Size
0.2
Transverse Position
9
Longitudinal Position
16
LWDAQ Graph
Data
Amplitude
Distance (mm)
LWDAQ Status
Taking Data
SCAN PROGRESS
<W> Server: localhost

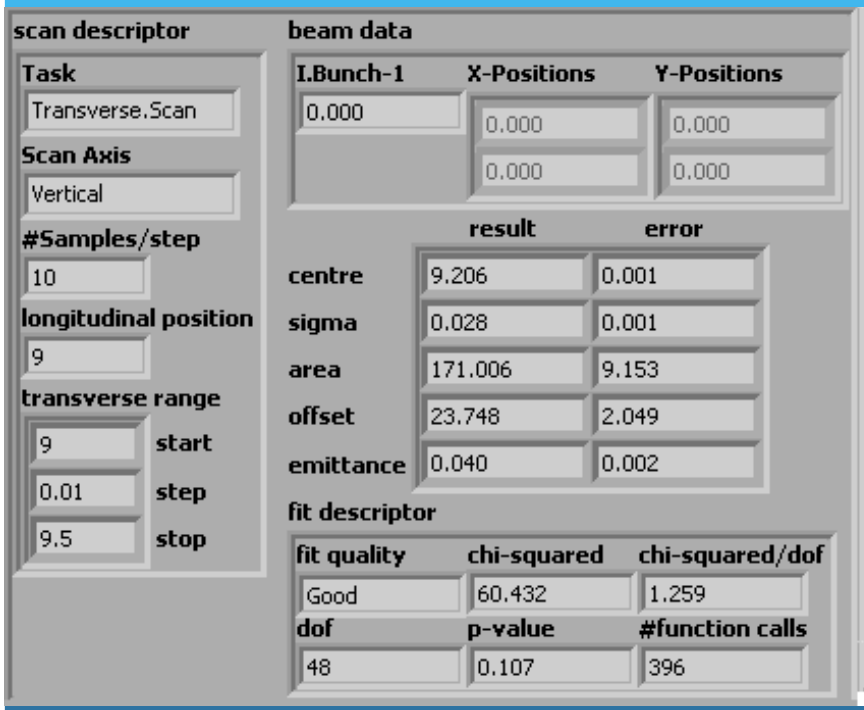

Digitizer amplitude
Sample

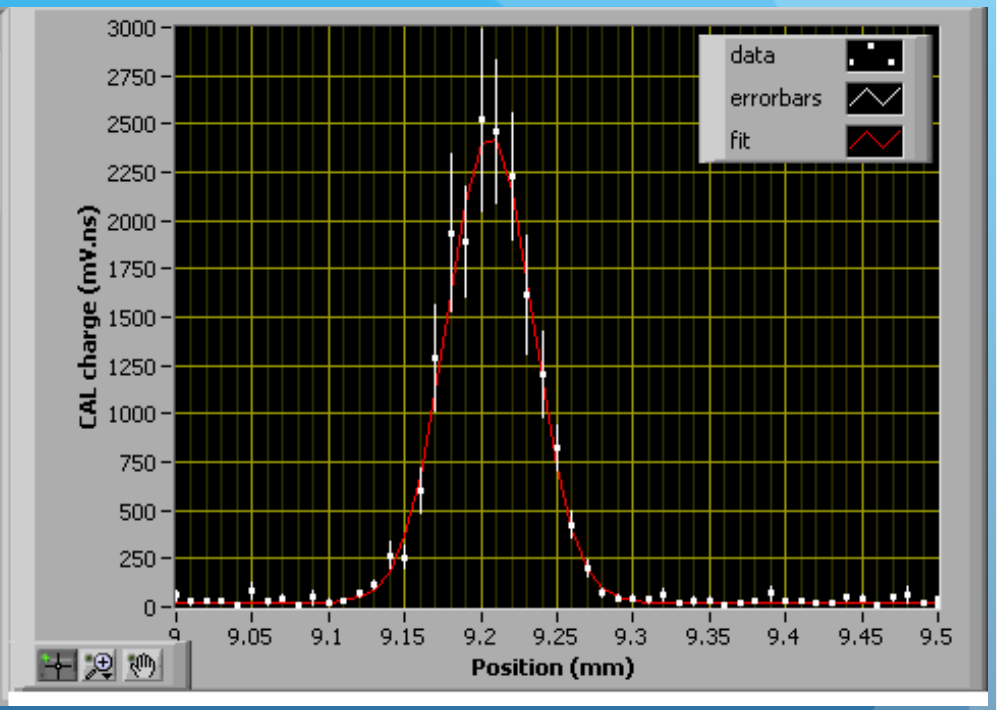

LWScan_statechart_2.lvsc:Diagram.vi Statechart Diagram on LWScan.lvproj/My Computer
File Edit View Project Operate Tools Window Help
13pt Application Font
Initialise
Wait for SMC100 HW to be in Init and other HW to be in Pre-Init state.
Open Shutter
Open Shutter & Enable DMUX
Do DAQ
Wait for Stages to move then start DAQ
Start PXI Route
Enables Trigger routing over PXI
Stage Stop
Stages have stopped moving
Close Shutter
Close Shutter & Disable DMUX
Where Next?
If SMC final position reached then Stop, else continue with DAQ
Stop PXI Route
Disables Trigger routing over PXI
T0
T1
T2
T3
T4
T5
T6
T7
T8
T9
Tf
Initial
LWScan.lvproj/My Computer

Scan Types

- Transverse scan using piezo
  - Scanning range: < 1 mm
  - After moving the stages into place:
    20 steps and 5 shots per step = 5 * 50ms * 20 = 5s
- Transverse scan using motorised stage
  - Scanning range: 25 mm
  - 500 ms overhead for stepping the stages:
    20 steps and 5 shots per step = (5 * 50ms + 500ms) * 20 = 15s
- Longitudinal scan using motorised stage
- Knife-edge scans to check waist and Rayleigh range of laser
- Can adjust laser timing and laser power

Vertical scan

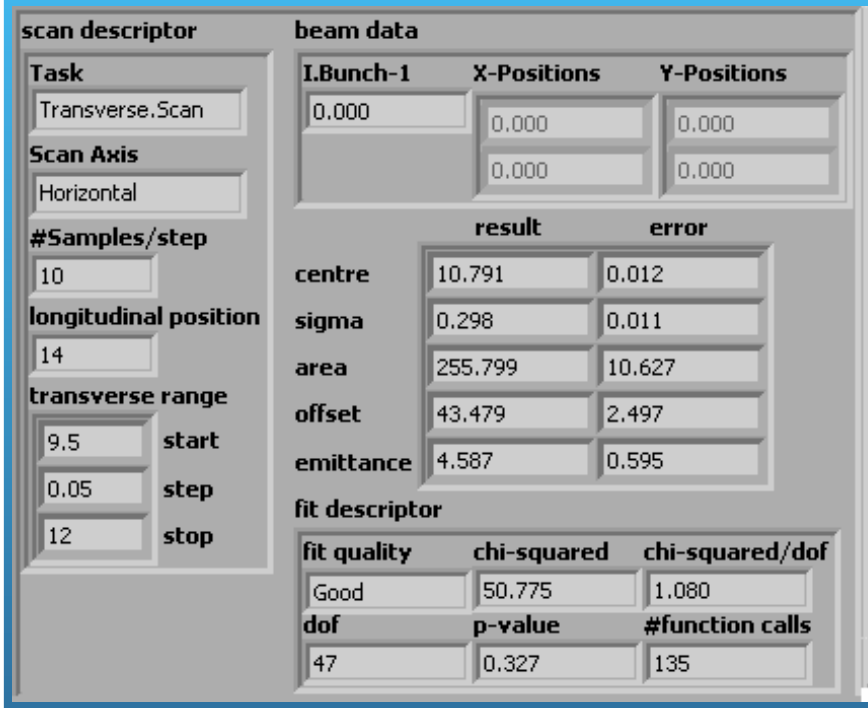


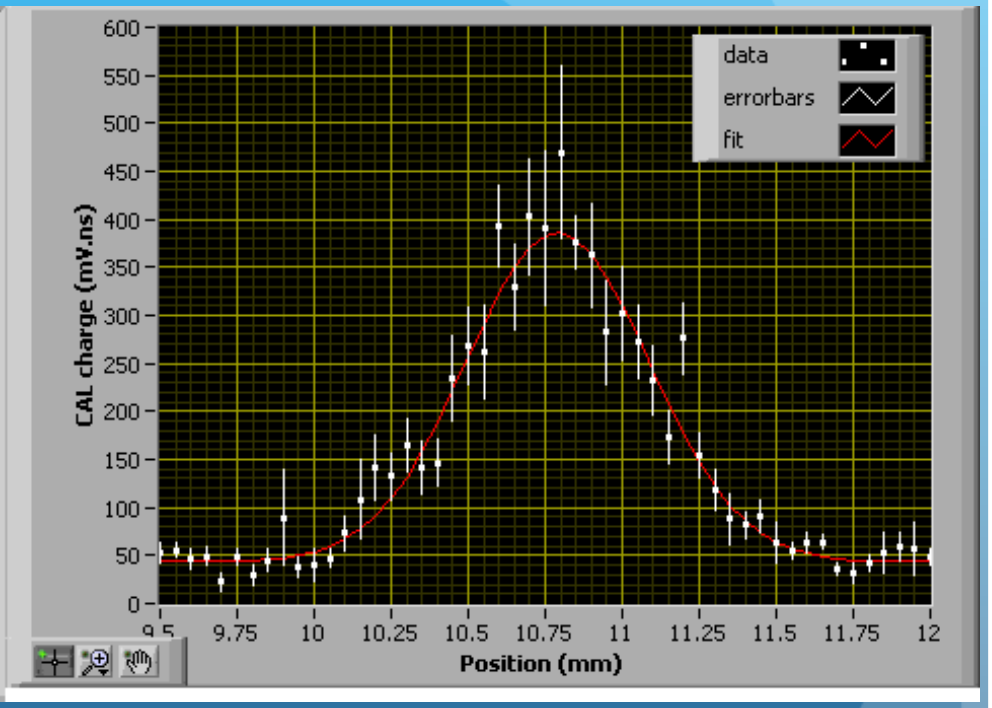


470 μA bunch current
10 Samples/Step

$\mu = 9.206 \pm 0.001$ mm
$\sigma = 0.028 \pm 0.001$ mm
$X^2/\mathrm{dof} = 1.259$

Horizontal scan





470 μA bunch current
10 Samples/Step

μ = 10.791 ± 0.012 mm
σ = 0.298 ± 0.011 mm
X^2/dof = 1.080

Outlook

- More automatic operation of LWDAQ (self-optimising scans, beam finding, laser timing adjustments, piezo calibration, etc.)
- Online analysis of beam size (understanding other errors and including corrections)
- Benchmarking studies: measuring machine characteristics (dispersion, compaction factor, beta functions, etc.)
- Displaying results (BKR, TINE)

Thank you for your attention!

Any questions?