R&D Towards a Laser Based Beam Size Monitor for PETRA and the FLC

Thorsten Kamps, Royal Holloway, FLC Group

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The next 30 minutes

Motivation for the Project
History and Status of Laserwire
Laserwire at PETRA
- Environment
- Detector Simulations, Design and Calibration
- Laser Scanning, Transport and Focusing
- Installation − Tunnel, IR and Procedure

Conclusion and Discussion

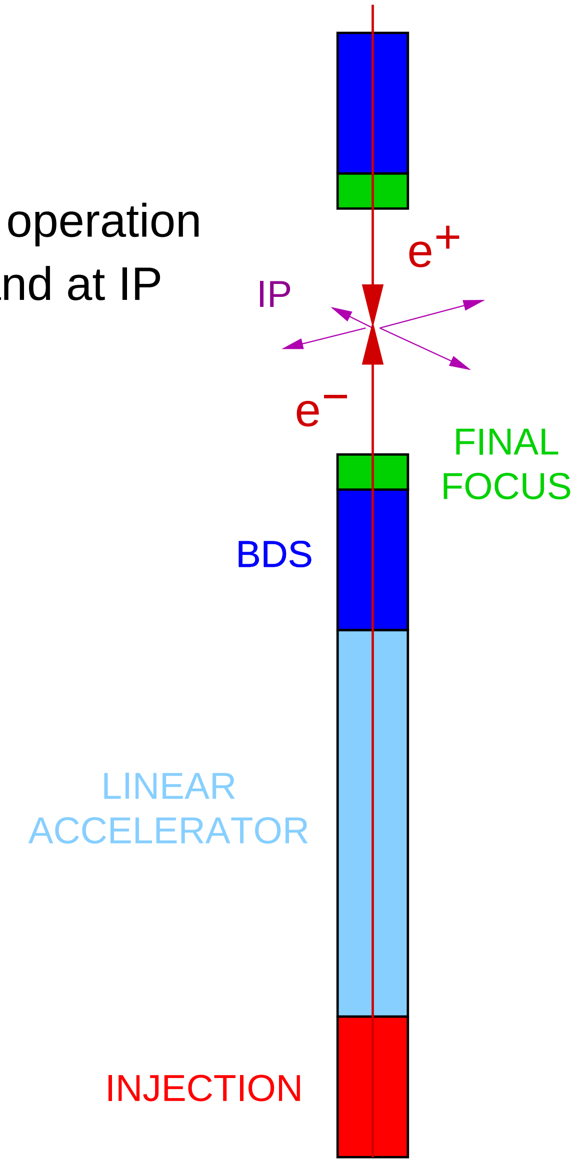
Motivation

Maximise Luminosity performance of LC

$$L = \frac{n_b N_e^2 f_{rep}}{4\pi\sigma_x^\star \sigma_y^\star} \times H_D$$

Development of a standard diagnostic tool for LCTF and LC operation
Control of the transverse beam size and emittance in BDS and at IP

		CLIC	NLC/JLC	TESLA
BDS	$\sigma_x[\mu\text{m}]$	3.4 to 15	7 to 50	20 to 150
	$\sigma_y[\mu\text{m}]$	0.35 to 2.6	1 to 5	1 to 25
IP	$\sigma_x^\star[\text{nm}]$	196	335	535
	$\sigma_y^\star[\text{nm}]$	4.5	4.5	5



with features

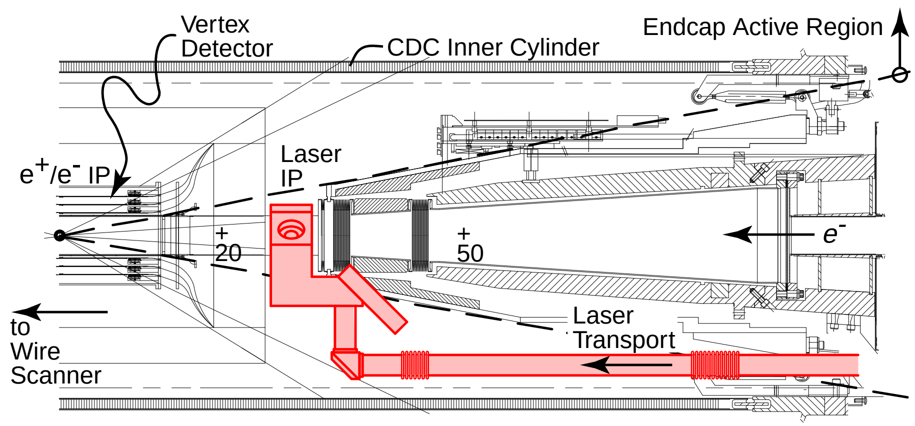
- full reconstruction with error smaller than 10%
- fast (intra−train) scanning
- non−destructive for the electron beam

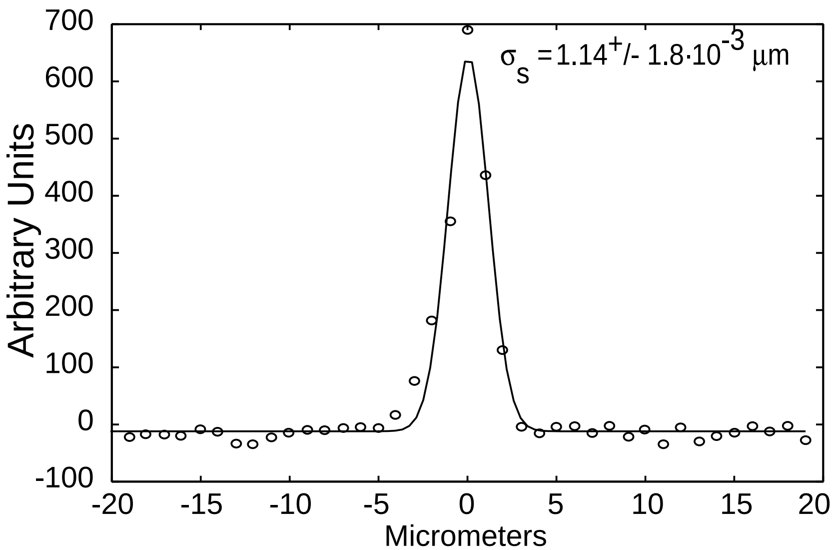
→ Optical scattering structures

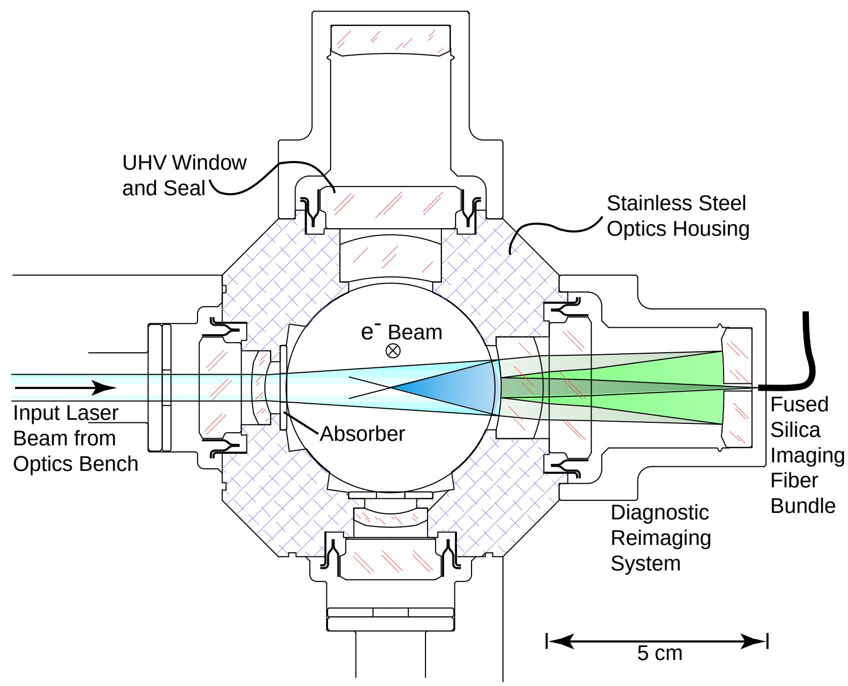
SLC/SLD Laserwire

Succesful test of laserwire principle for LC

- Complex installation inside SLD detector during shutdown
- Measure electron spot sizes small as 2.1 x 0.6 µm at the IP
- Laser spot size 380 nm with Rayleigh range of 5 µm







Laserwire Interest Group

Elevate existing designs of laser based beam size monitors
Standard diagnostic tool for LC and LCTF operation

RHUL Involvement

Collaborations

SLAC and KEK on existing laserwire experiments
DESY on the development of a fully operational laserwire for PETRA
CERN on subsystems for a laserwire for CTF2
RAL on laser systems, optics, and diagnostics

RHUL activities

Design and test of a laser focusing and fast scanning system
Photon calorimeter studies (also with regards to TESLA detector)

Experiments

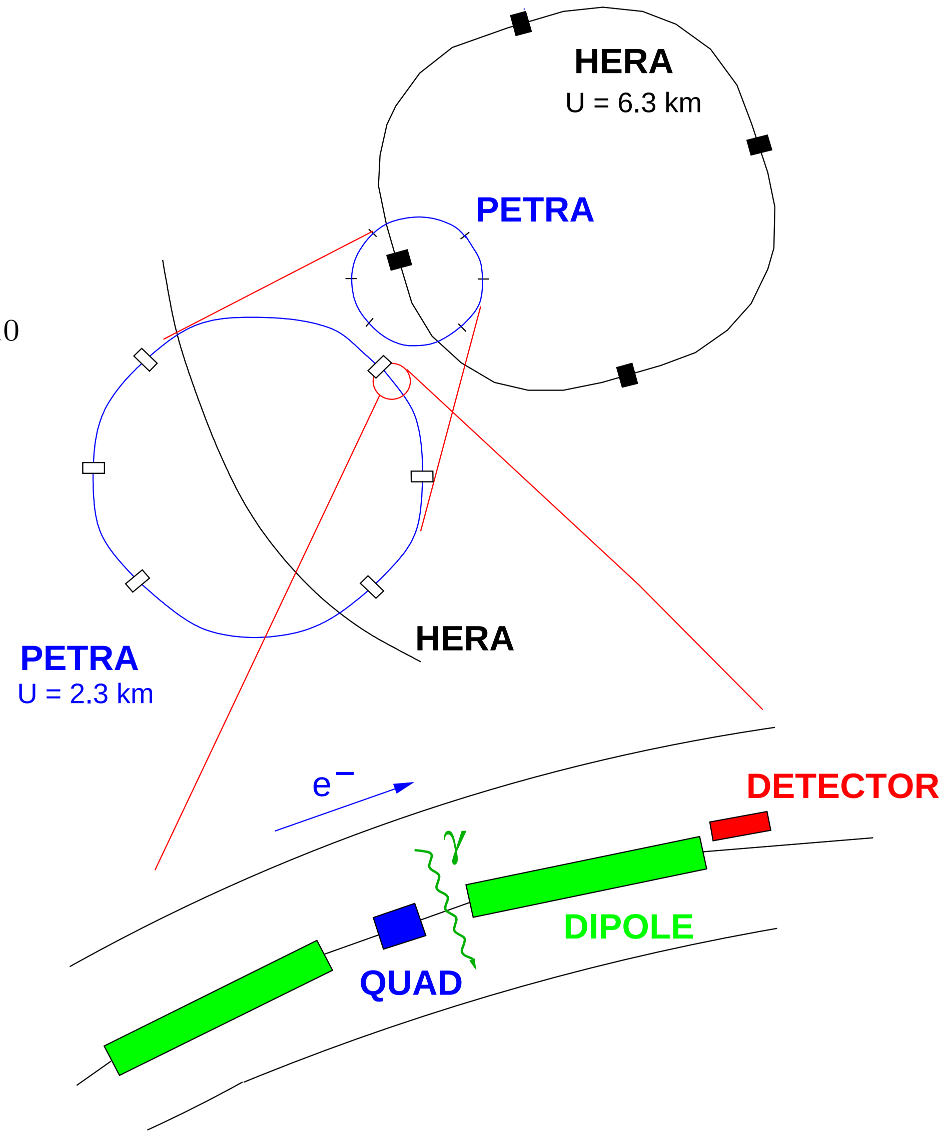
Test of laser optics at a laserwire at CTF2
Full laserwire system test according to TESLA specs at PETRA

Laserwire for PETRA

- Positron Electron Tandem Ring Accelerator

Beam Energy	E	[GeV]	4.5 to 12
Beam Current	I	[mA]	1.55 to 1.77
Particles/Bunch			7.5 to 8.5 $\cdot 10^{10}$
Horizontal Beam Size	σ_x	[μm]	300 to 100
Vertical Beam Size	σ_y	[μm]	30 to 10

- Currently used as injector for HERA ring
- Upgrade to synchrotron light source
- Vertical beam size comparable to TESLA BDS beam
- Interest in beam size monitor for operation of the light source
- Hardware installation easy with existing access pipe and laser hut



Laser System

- Q−switch Nd:YAG Laser from CERN LEP polarimeter
- Output parameter:

Wavelength	λ	[nm]	1064	532
Energy	E	[mJ]	250	90
Pulselength	Δt	[ns]	11-12	8-9
Reprate	f_{rep}	[Hz]	30	30
Beam Divergence (full)	θ_L	[mrad]	0.7	
Beam Diameter	d_L	[mm]	7	
Rayleigh Range	z_R	[m]	10	5

- Laser beam emittance of fundamental mode

$$d_o \cdot \theta_o = \frac{4\pi}{\lambda} = 1.354 \cdot 10^{-6}\ \mathrm{mrad} \longrightarrow M^2 = \frac{d_L \theta_L}{d_o \theta_o} = 3.62$$

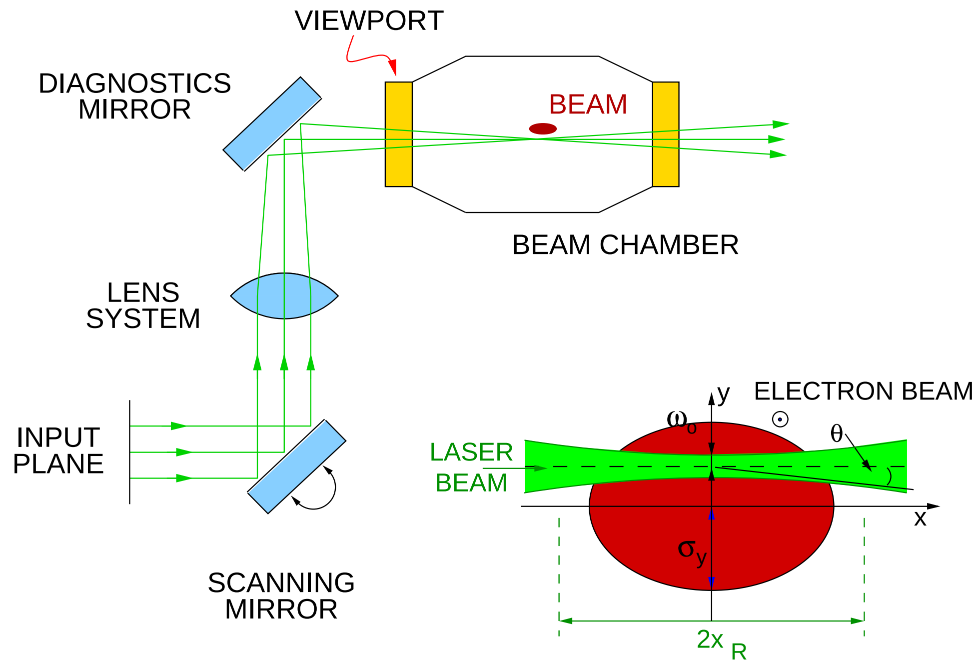
- Laser currently at workshop for complete overhaul (i.e. new crystal)
- Not diffraction limited
- No clean longitudinal mode (mode−beating)

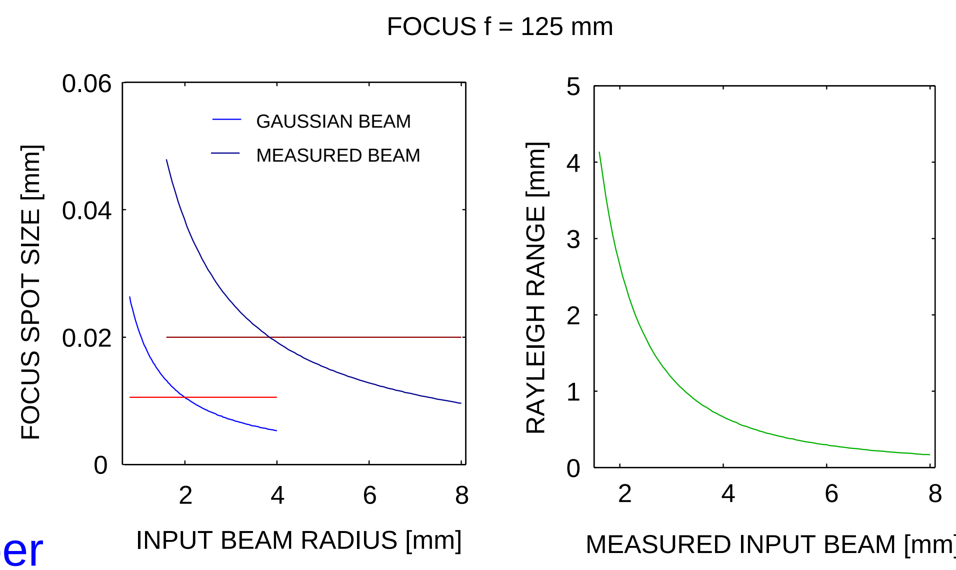
Laser Focusing

- Requirements
- RMS spot size at interaction smaller than vertical electron beam size, for PETRA 10 to 30 µm
- Rayleigh Range larger than horizontal electron beam size, for PETRA 100 to 300 µm
- Resistant against high power laser beam
- Beam stay clear distance of 100 mm due to vacuum chamber construction
- First order, spot size determined by

$$\omega_o \simeq M^2 \lambda f\# = \frac{M^2 \lambda f}{\pi \omega_{in}}$$

- Solution
- Commercially available laser objective with 125 mm focal length
- 1:1 to 1:2 imaging of laser output for transport from hut to interaction chamber

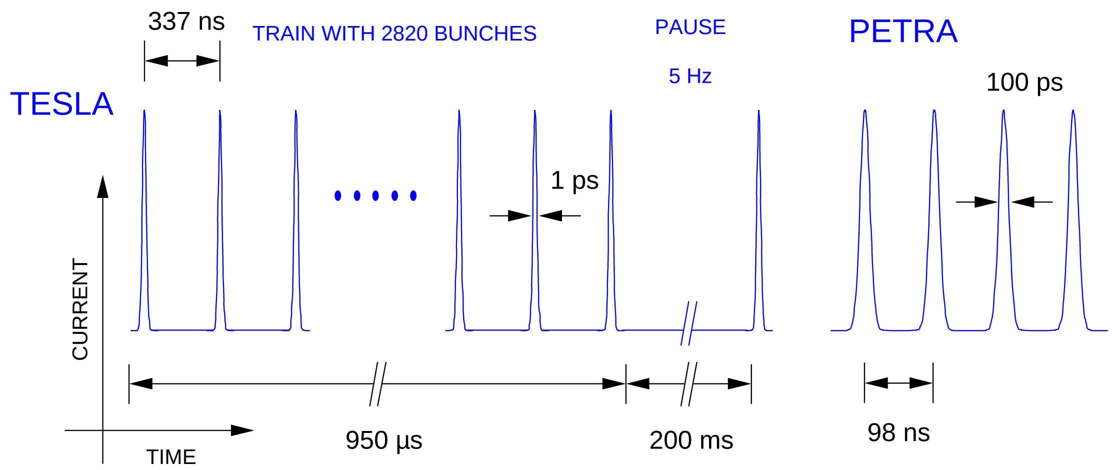




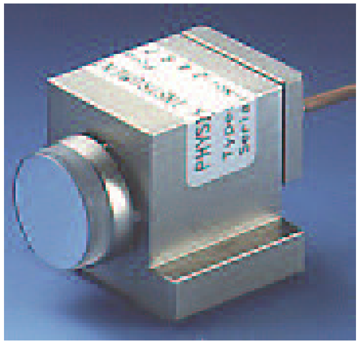
Fast Scanning

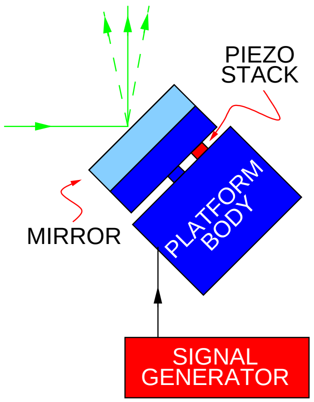
Fast scanning system required, enabling beam profile scans within on bunch train

- Total scan range larger than the beamsize under measurement in order to accomodate jitter or drifts
- Scan resolution better than the electron beam size to measure
- Scan pattern matching the bunch timing of linac/storage ring
- Mode quality preserving (diffraction limit) and resistant against high power of pulsed laser system



TESLA σ_y = 1 − 25 µm PETRA σ_y = 20 − 30 µm





- Piezo driven platform with mirror
- Operation in discrete or continuous mode (up to 5 kHz) possible
- High damage threshold and diffraction limited performance
- Tests with this platform on beam quality and scanning speed in RHUL lab

Signal and Backgrounds

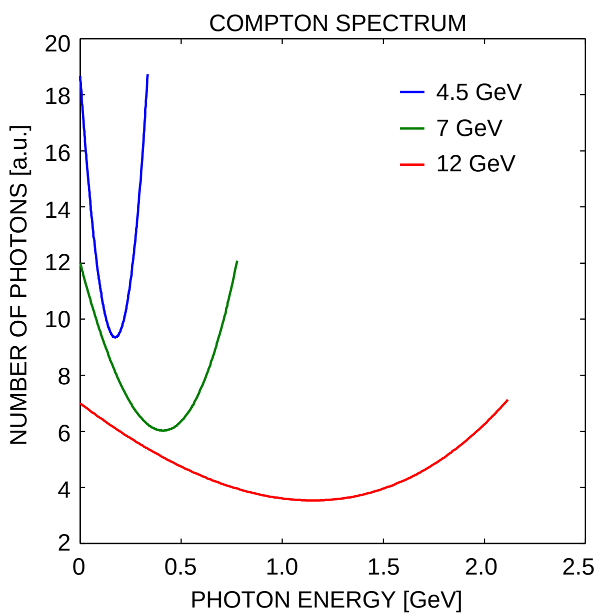
- Photon Electron Scattering of moving electrons on high energy photons of laser beam
- Background sources
  - Synchrotron Radiation and Cosmic Rays
  - Elastic and Inelastic Gas Scattering
- Simulation of all relevant processes using the Geant4 package with tool kits
- Aiming at full simulation with realistic setup

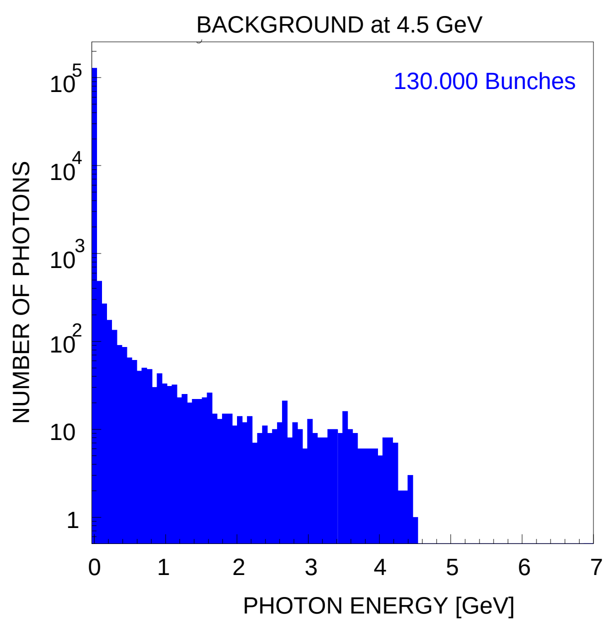
$$N_C = N_b \frac{P_L \sigma_C \lambda}{c^2 h} \frac{1}{\sqrt{2\pi}\sigma_s} \exp\left(\frac{-y^2}{2\sigma_s^2}\right)$$

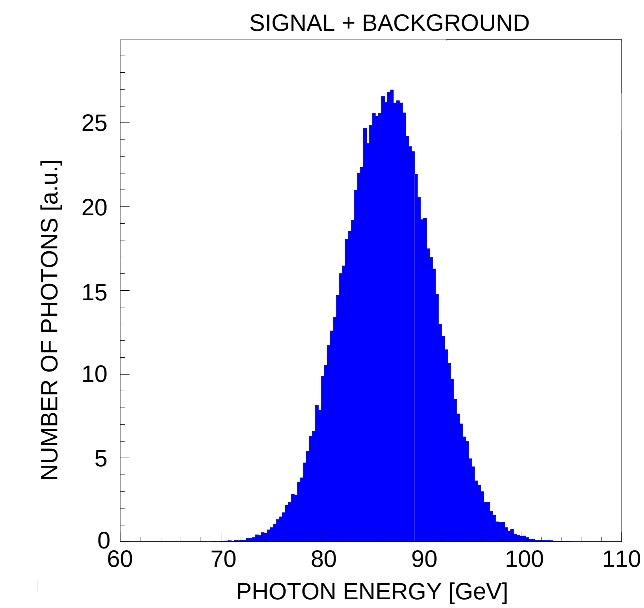
P = 2 MW

σ_x/σ_y [μm]	Beam Energy [GeV] 4.5	7	12
500/50	115/689	257/664	685/619
300/30	185/1111	416/1070	1056/998
100/10	415/2485	930/2393	2362/2231

E_{tot}[GeV]/N_γ



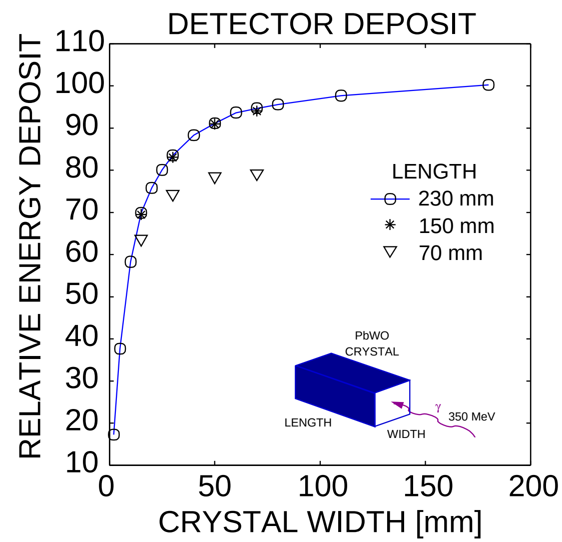


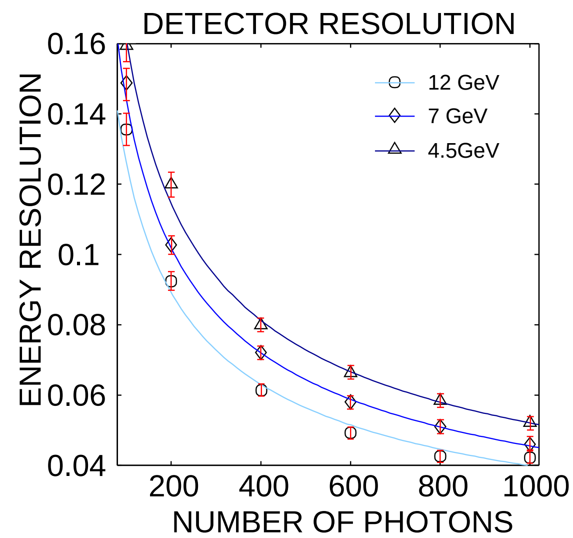


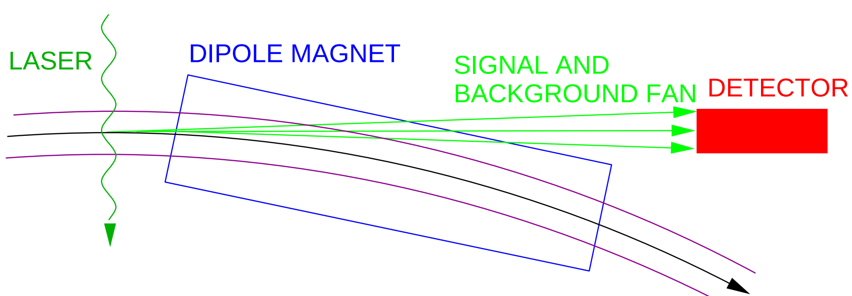
Detector Simulation

Full simulation required of all relevant processes (Compton and background) in order to specify detector design and location

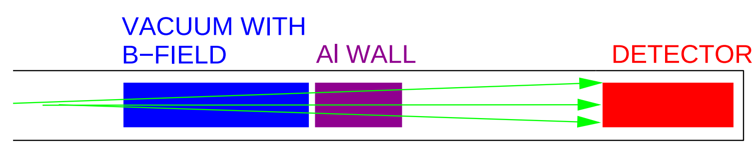
- Requirements for material include short decay time (avoid pile up) and small radiation length and Moliere radius (compactness)
- Frameweork Geant4 with model of accelerator environment and parameter set for PETRA
- Cuboid shaped detector crystal made of $PbWO_4$
  3 by 3 matrix of 18x18x150 mm sized crystals
- Energy resolution of better than 5% achievable







CLOSE EXPERIMENTAL SETUP

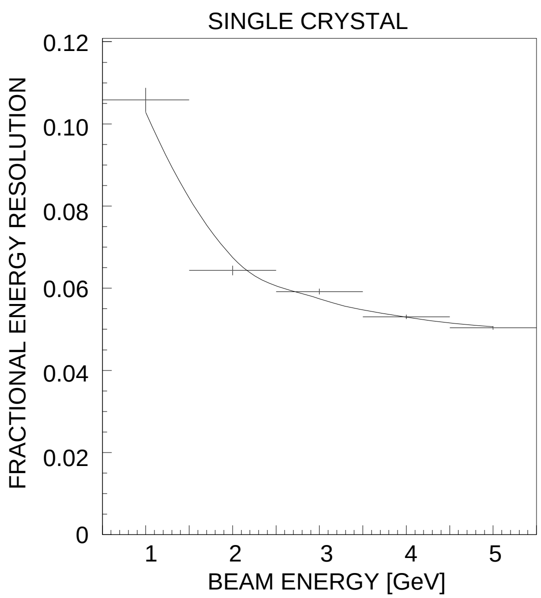


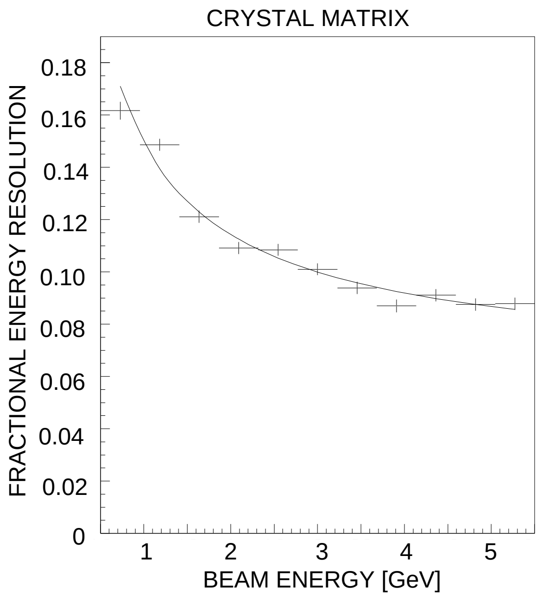
SIMULATION SETUP

Detector Calibration

- Detector studies with testbeam from DESY II
- DESY II supplies beamline with electrons with energy between 450 MeV and 6 GeV
- Energy and energy width of particles are well known
- Ten detector crystals made from PbWO4 were used attached to single PMT
- Individual tests of all crystals
- Combination of nine in detector matrix
  - Resolution $R^2 = \left(\frac{\sigma_E}{E}\right)^2 = \left(\frac{p_1}{\sqrt{E}}\right)^2 + \left(\frac{p_2}{E}\right)^2 + p_3^2$

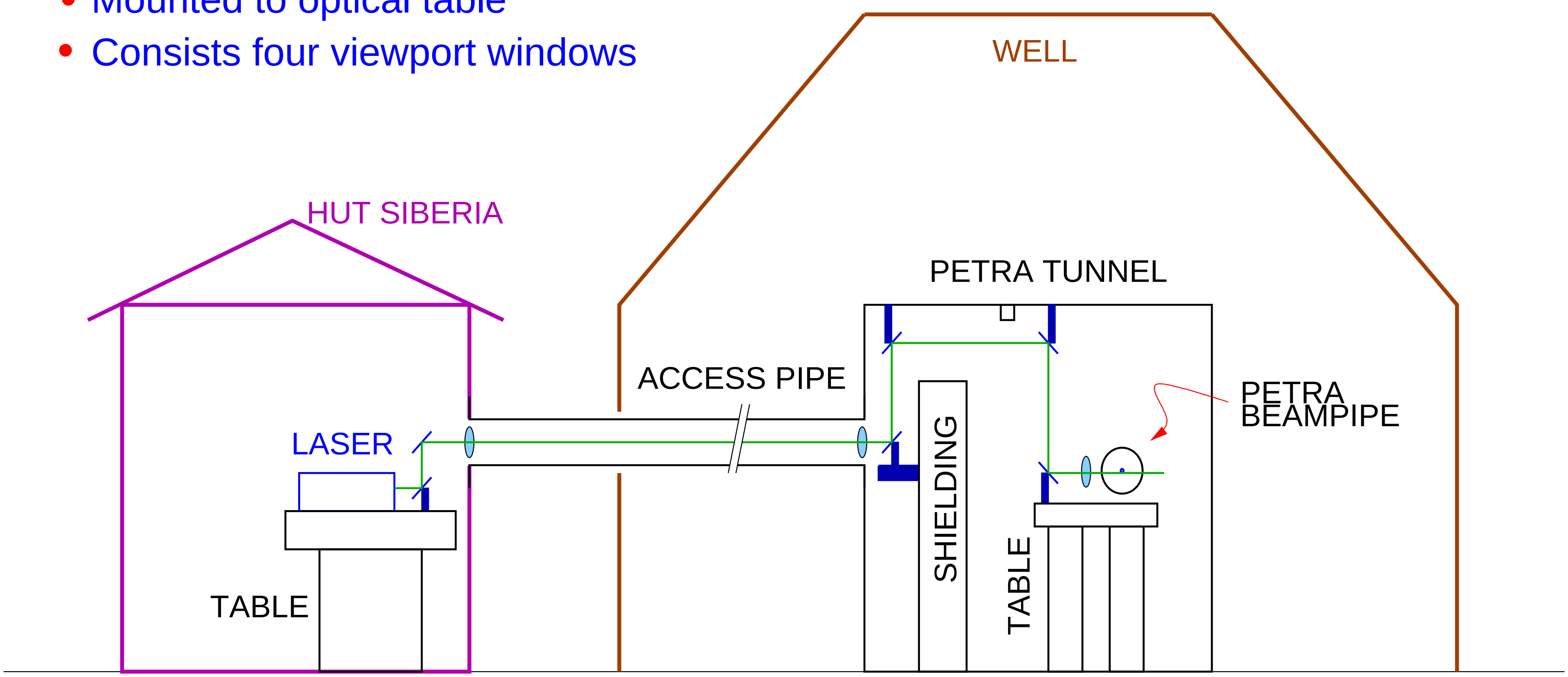
    p1: stochastic contributions
    p2: noise (electronics, pile up, radioactivity)
    p3: constant (inhomogenity, non−linearities)
  - High intrinsic fractional resolution
  - Full matrix less good due to variations of individual crystals
  - Well within specs for PETRA experiment
- Facilitate high individual resolution by using seperate PMT for each crystal



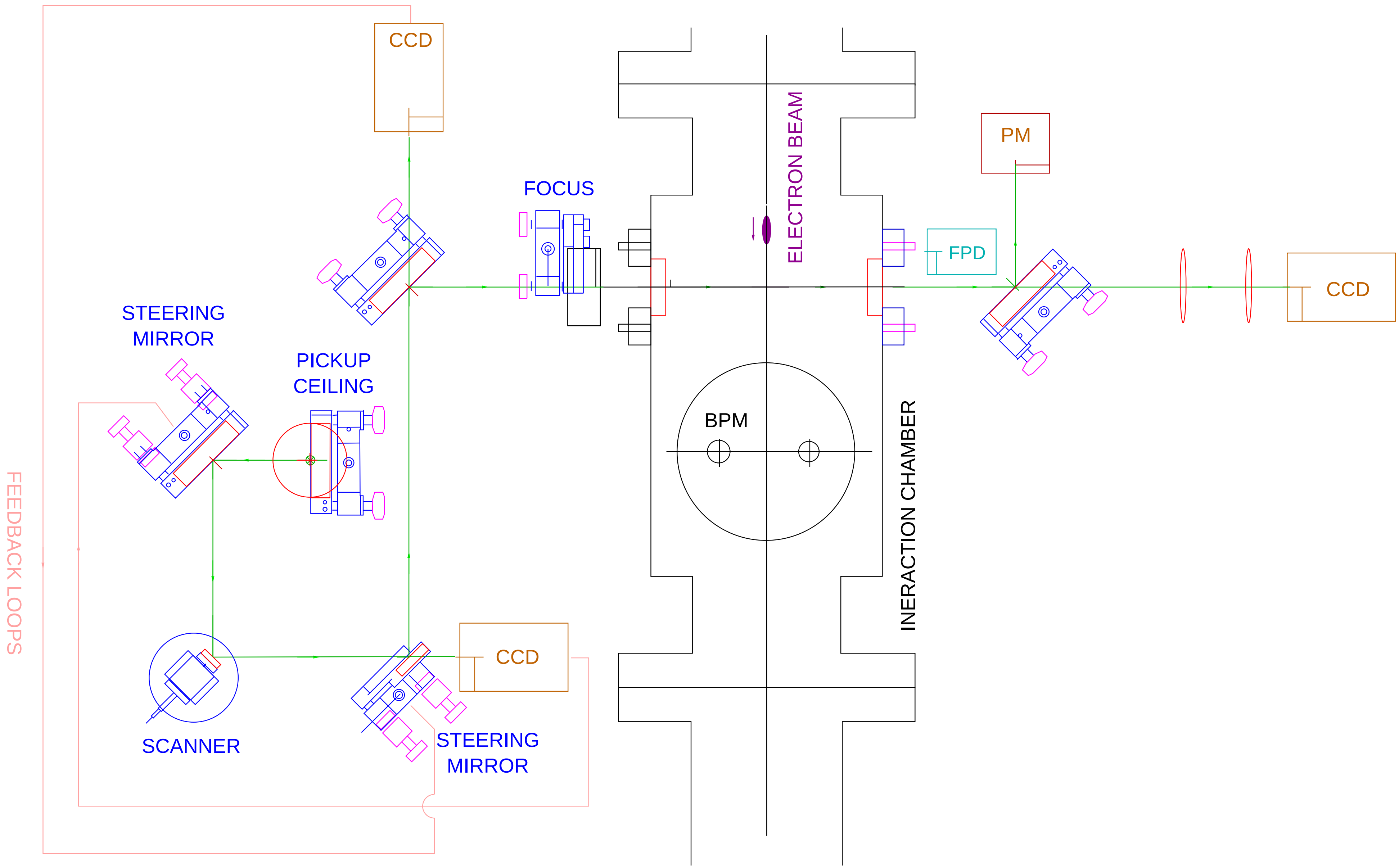


Installation – Hut and Tunnel

- Room in hut and tunnel area readily available
  - Some work in hut necessary before installation of laser
  - Concrete base, water cooling, power
  - Girder for optical table under beam pipe
- Construction of interaction chamber under way
  - Mounted to optical table
  - Consists four viewport windows



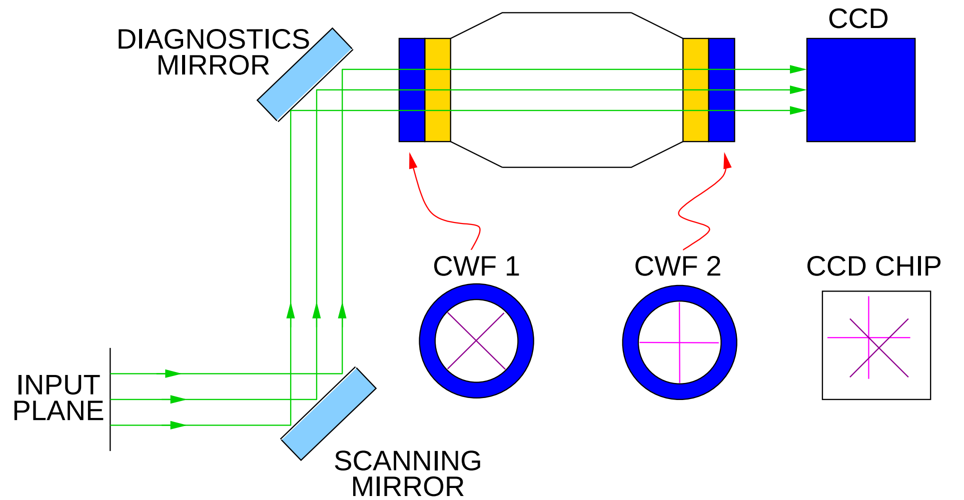
Installation – Interaction Region



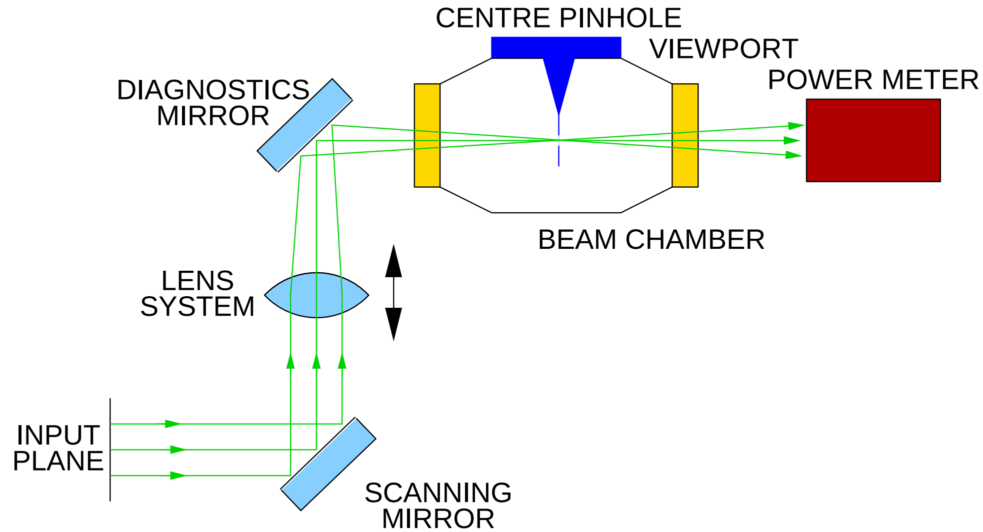
Installation – Procedure

- Laser operational
- Establish beam transport to chamber
- Check beam profile on scanning mirror
- Center and straighten beam in interaction chamber using tools
  - → Cross hair tool
  - → Pinhole
  - → PSD
- Install focus lens and check for straightness and center position
- Chamber under vacuum
- Use FPD and pickup for timing
- Scan to establish overlap between electron and photon beam

CROSSHAIR FLANGE TOOL



CENTRE HOLE TOOL



Conclusion and Outlook

Laserwire project for PETRA well underway

Laser transport and focusing plan finished

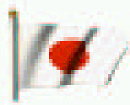
Detector calibrated with testbeam

Installation of hardware during next general HERA/PETRA shutdown

People

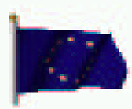
Grahame Blair (RHUL)
Stewart Booget (UCL)
Gary Boorman (RHUL)
Thorsten Kamps (RHUL)
Alexander Muir (RHUL)
Freddy Poirier (RHUL)
Ian Ross (RAL)

Josef Frisch (SLAC)
Marc Ross (SLAC)



Yosouke Honda (Kyoto University)
Hiroshi Sakai (KEK)
Noboru Sasao (Kyoto University/KEK)
Jyunji Urakawa (KEK)

Klaus Balewski (DESY)
Hans-Christoph Lewin (DESY)
Peter Schmueser (University of Hamburg/DESY)
Siegfried Schreiber (DESY)
Kay Wittenburg (DESY)



Jacques Bosser (CERN)
Enrico Bravin (CERN)
Steve Hutchins (CERN)
Thibaut Lefevre (CERN)