Laser-wire Beam Profile Monitor

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for the LBBD Collaboration

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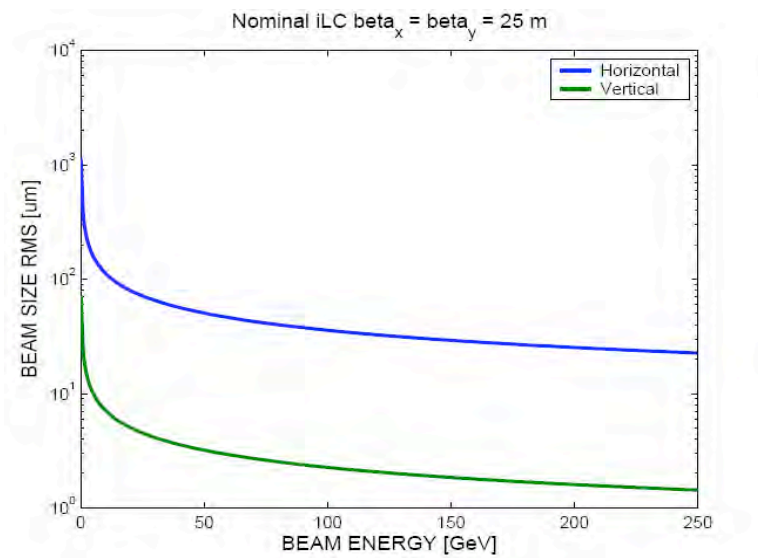
LBBD Laserwire

Target of the LBBD Collaboration

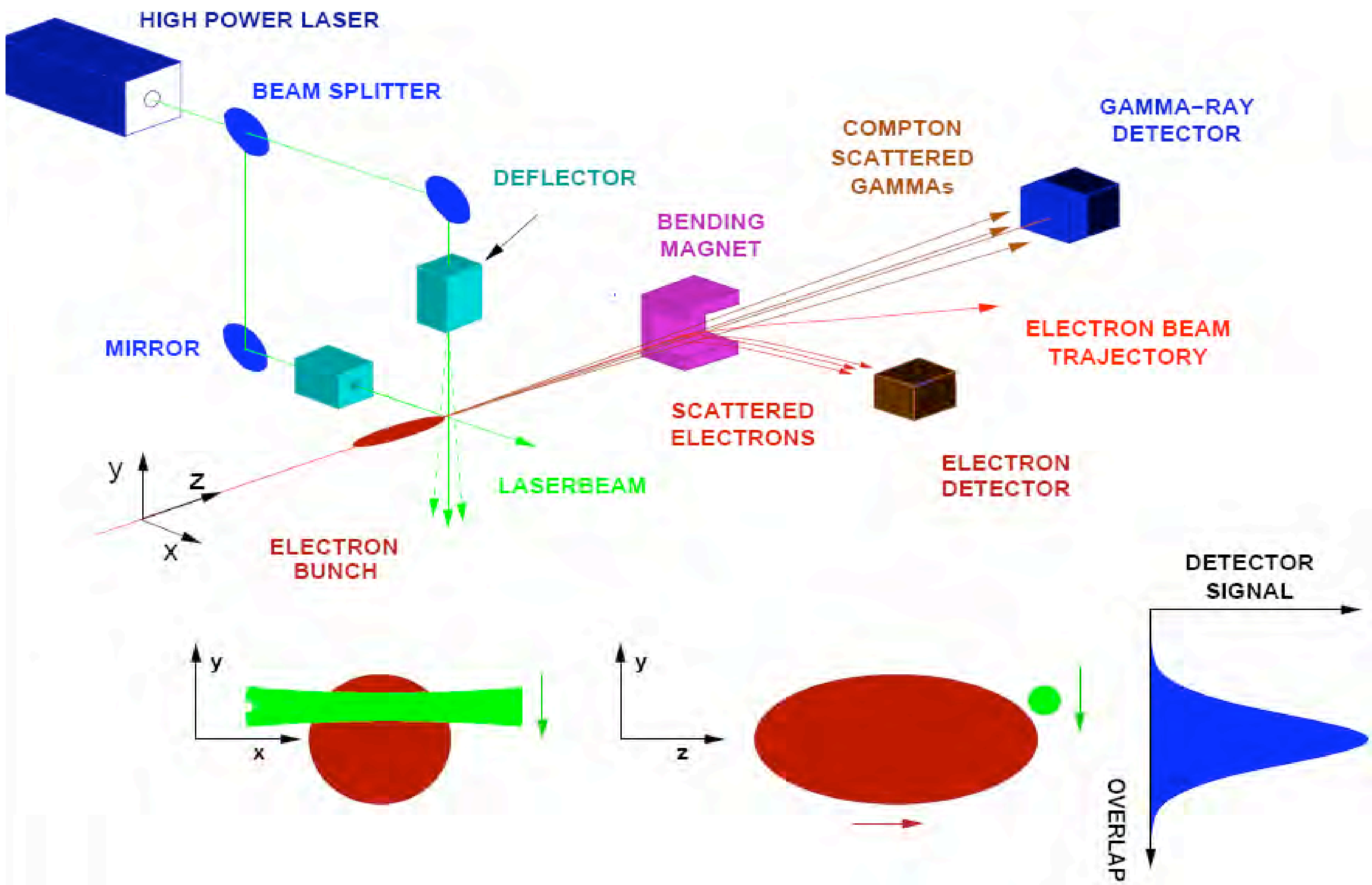
- Provide a non-invasive, high-precision beam profile monitor for the linac and beam delivery system of a linear collider
    - Non-invasive: low background for surrounding accelerator environment, surviving high energy and bunch charge electron beam
    - High-precision: measure spot sizes in the several ten μm range

		TESLA	Nom	LowQ
E	GeV	[0 250]	[0 250]	[0 250]
N	10^{10}	2	2	1
N_b		2820	2820	5640
T_{sep}	ns	336.9	307.7	153.8
—x,y	μm/nm	10/30	10/40	10/30



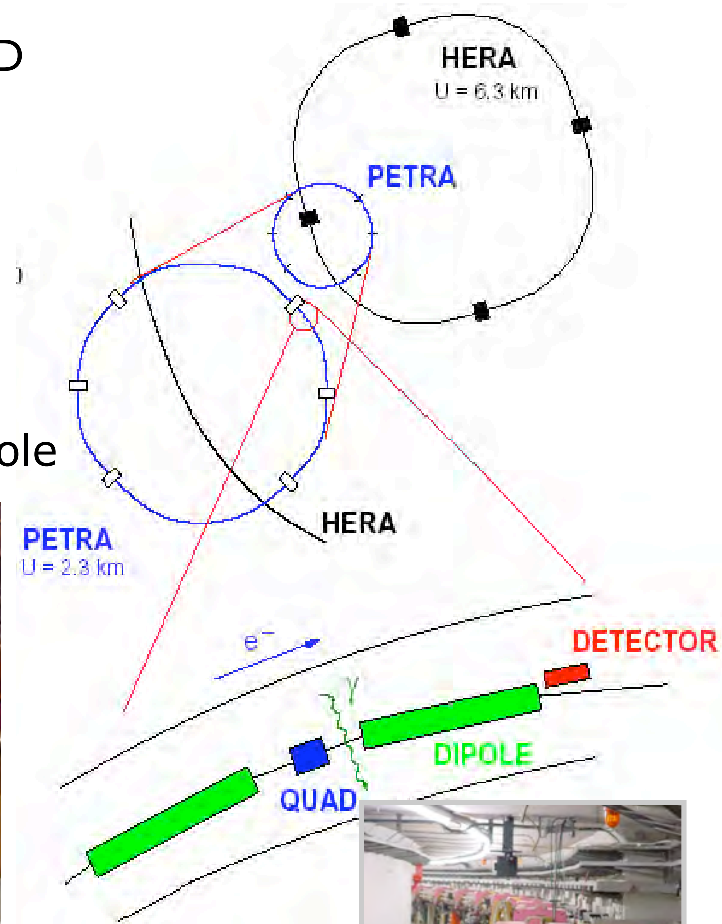
- Groups of three (or four) monitors in FODO channel for emittance measurement, each monitor measures vertical, horizontal size and coupling
- Desirable to measure beam size within bunch train
- Standard beam size monitors as OTR screens or wirescanners are at their resolution and operational limit _ Compton Scattering based monitor

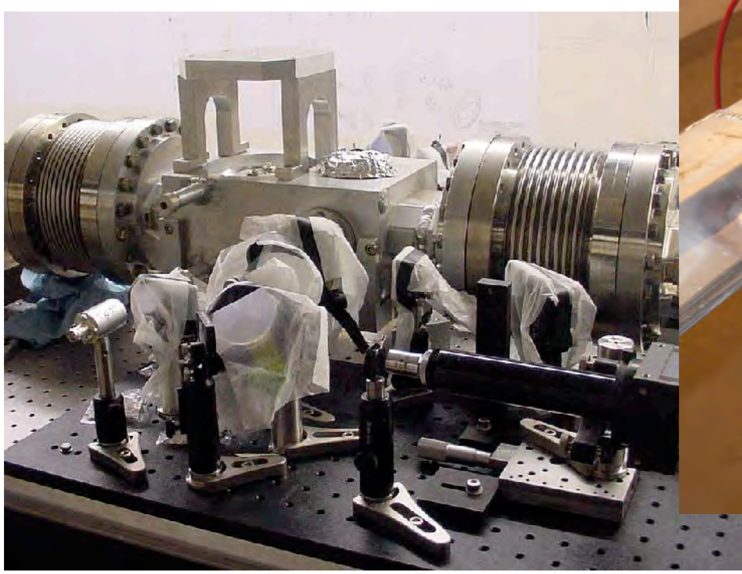
Laser-wire as Beam Profile Monitor

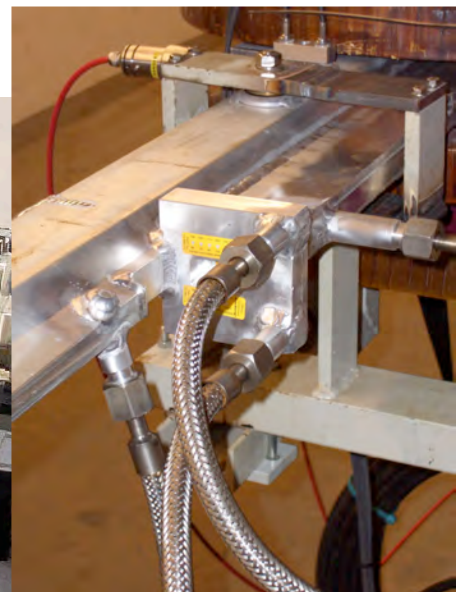


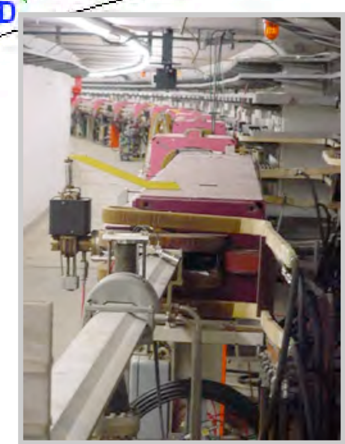
Laser-wire at PETRA2

- Design and setup of a testbed for laserwire R&D in a high energy accelerator environment
- PETRA2 is a pre-accelerator for protons and electrons for the HERA collider
- Machine available between HERA fills and HASYLAB synchrotron radiation runs
- New infrastructure: interaction chamber with viewports and BPM, exit chamber at end of dipole magnet



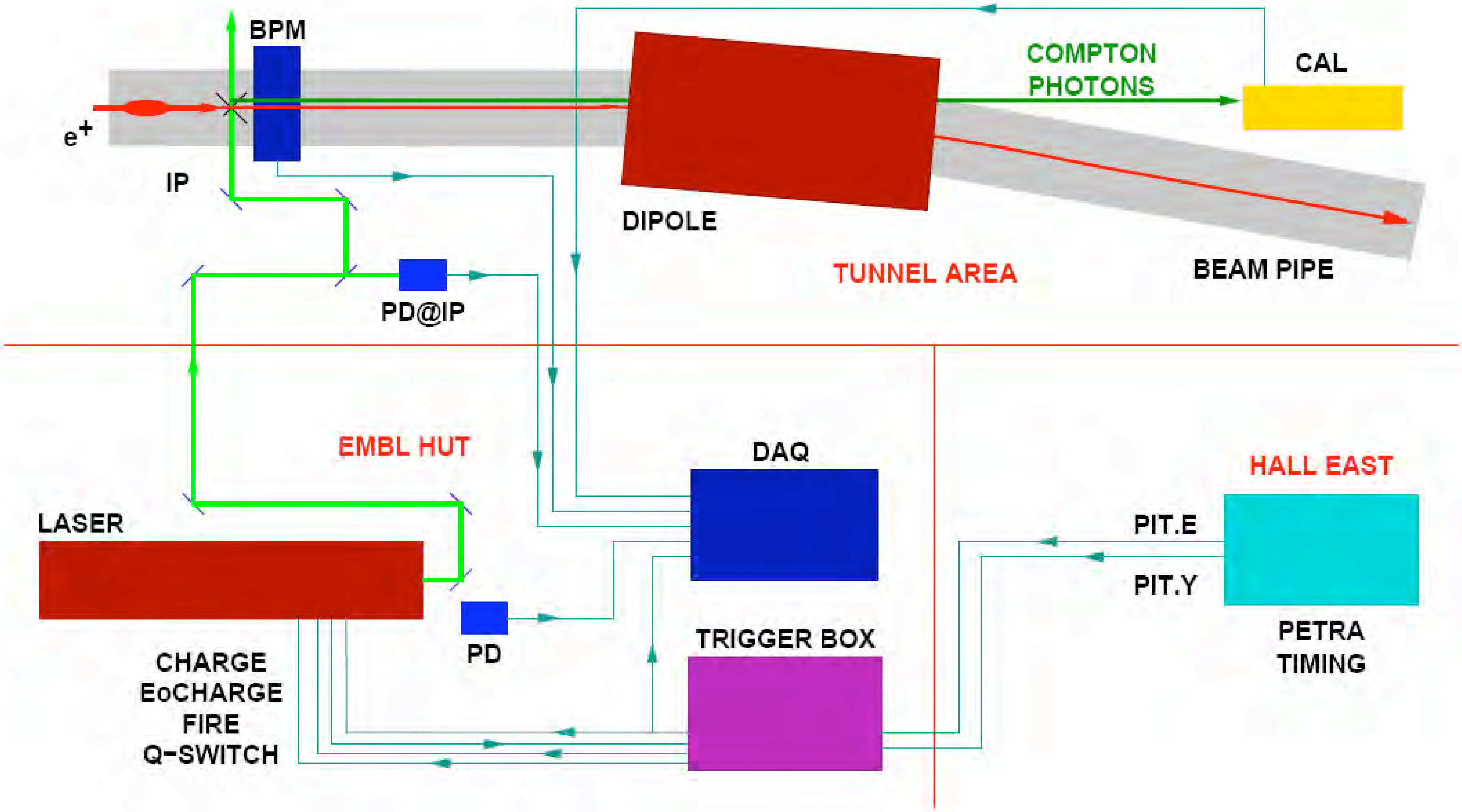






LBBD Laserwire

Setup of Laser-wire at PETRA2



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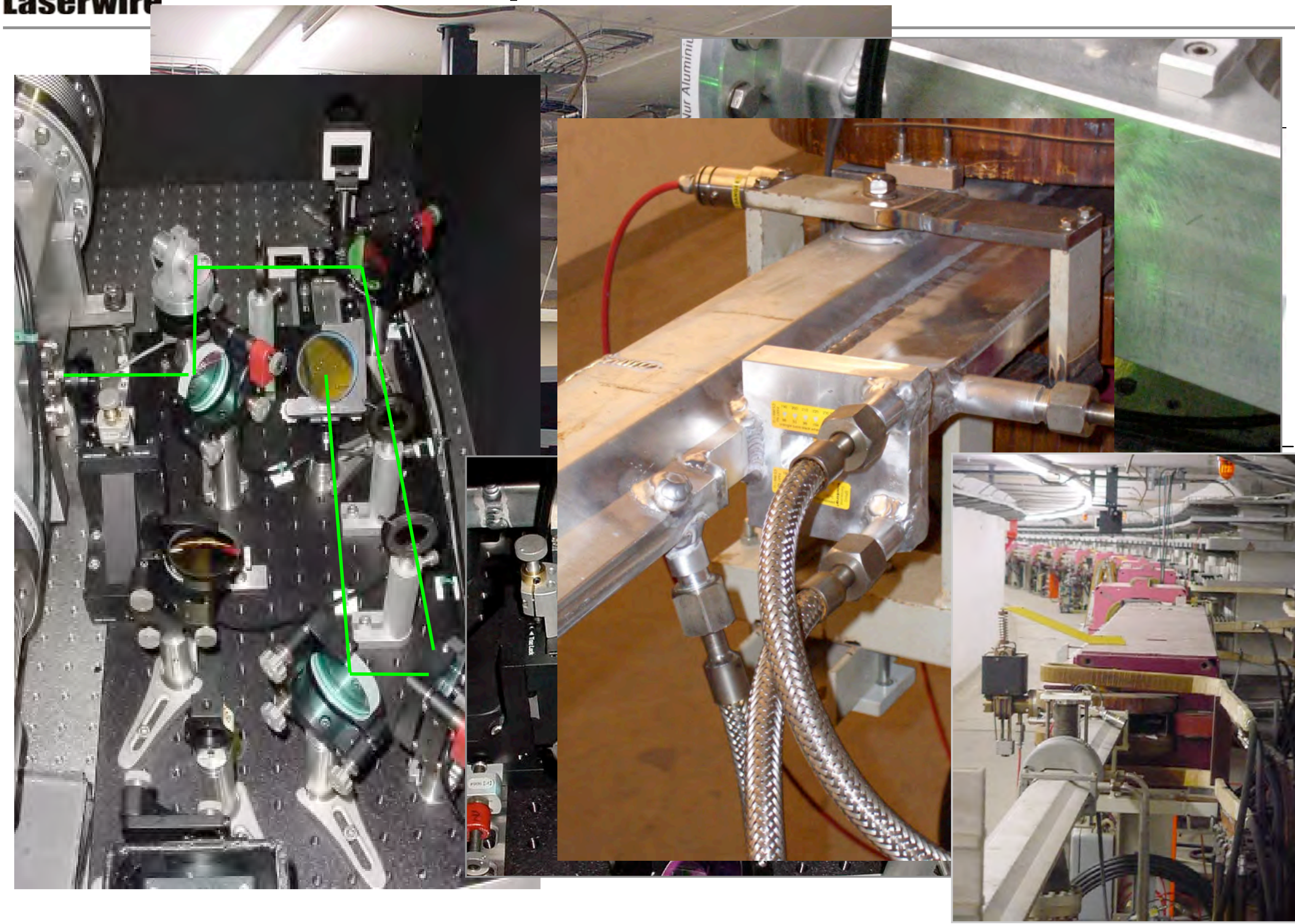
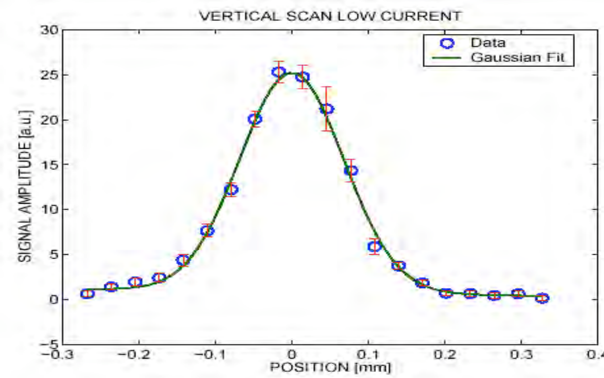
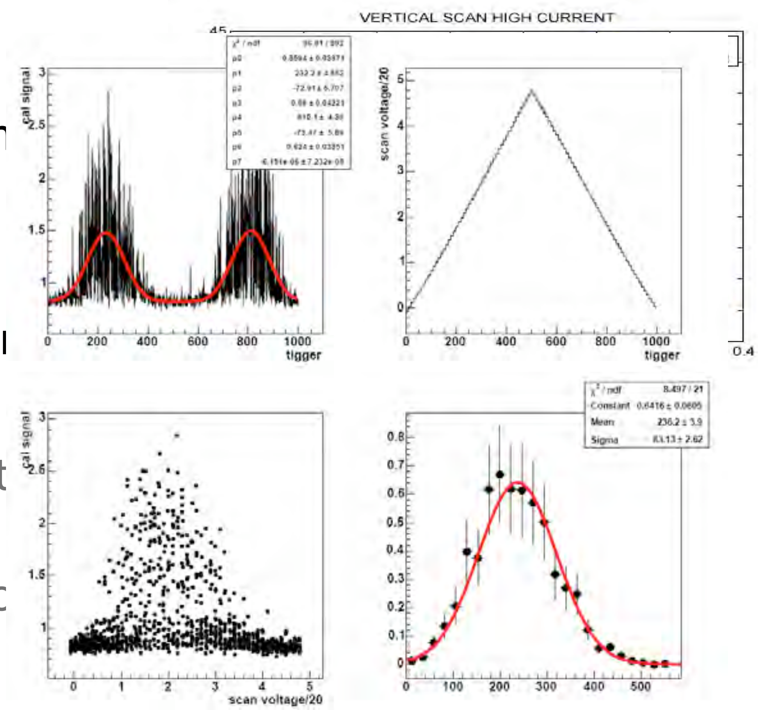


LBBD Laserwire

Results from Operation at PETRA2

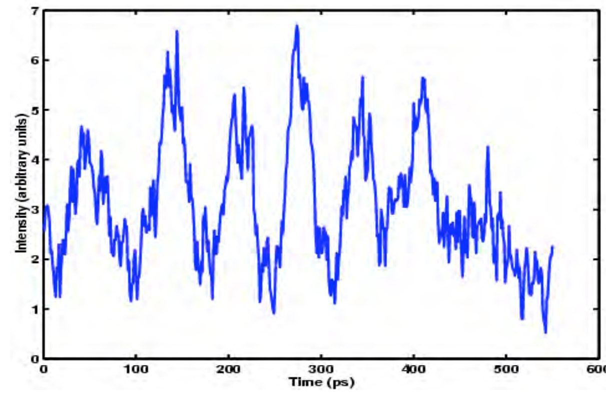
- **Dec 2003**: two runs at 7 GeV
- Bunch pattern 14 x 1 bunch evenly filled
- Low current with 7.1 mA, 1st bunch 0.46 mA
- High current with 40.5 mA, 1st bunch 2.69 mA
- Gaussian approximation with constant and slopey background
  - $\sigma_m = (68 \pm 3 \pm 14)\ \mu m$
  - $\sigma_m = (80 \pm 6 \pm 16)\ \mu m$
- Manual control of scanner and DAQ system
- Single scan 30 min
- **Feb 2005**: same setting for PETRA, but
- New exit chamber at dipole before detector
- Upgrade in DAQ system
  - Trigger for all components and readout derived from PETRA timing system
  - Synchronisation jitter _t_{rms}< 300 ps frc PETRA timing
- Single scan 30 sec





Lessons from Laser-wire Operation at PETRA2

- Reliable operation of laser mandatory to concentrate on laserwire issues
  - Transverse profile: measured with knife edge scans showed M^2 = [4 8]
  - Longitudinal profile: measured with streak camera, envelope _t = 12 ns with mode-beating of 70 ps peak-to-peak distance



- Operational DAQ system essentiell to take mass data
- Calibration of detector for all settings mandatory to compare data with simulations, testbeam at DESY around the corner
- Add second dimension
- CCD cameras and firewire infrastructure prone to failure under operation in PETRA2 tunnel
- Coarse scanning through focusing lens to find electron limited affair
- Change of laser spot size for different operation conditions would be nice
- Items will be adressed by upgrade of the current system and with the laserwire at PETRA3

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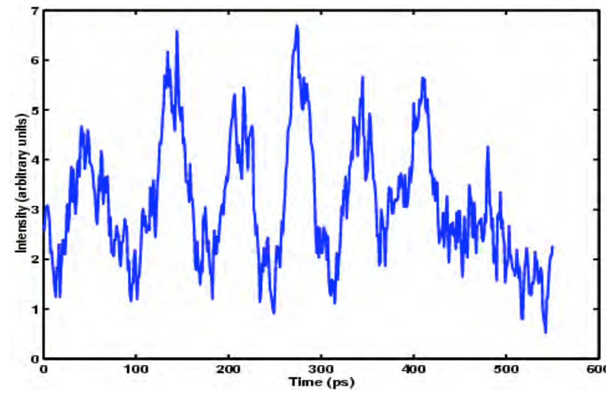
New laser



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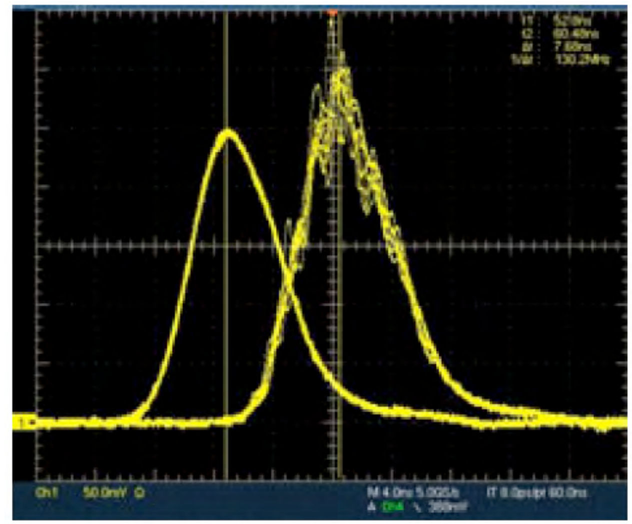
- Deliver the standard diagnostic tool

New Laser for the Laser-wire at PETRA2

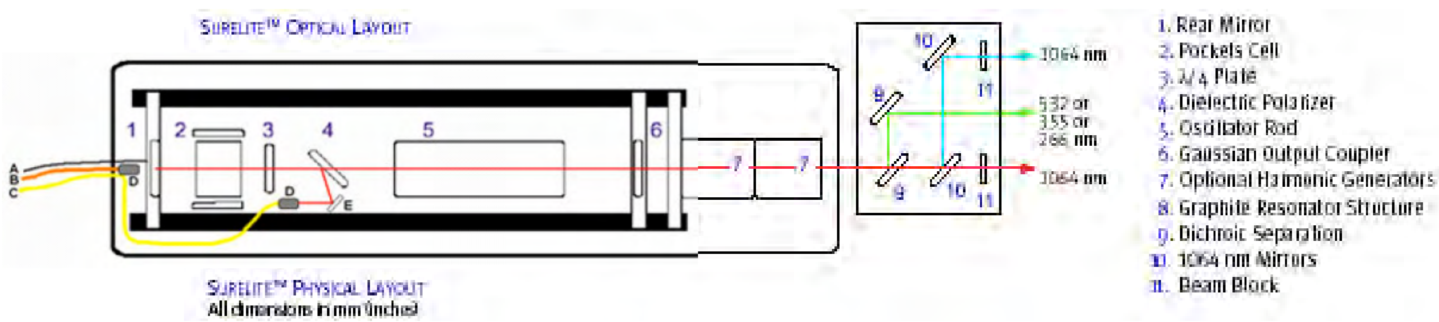
- Experience with the Quantel system at PETRA shows
  - At least 1 MW peak power is required to obtain a good SNR, meaning 100 photons per interaction
  - Smooth longitudinal pulse shape decreases the scanning time, smooth transverse profile to save optics
  - Low maintenance laser essentiell to concentrate on other issues like scanning, focusing, signal detection, DAQ,...
- Possibilities for a new laser system
  1. Injection seeded flash-lamp (or diode pumped) Q-switch laser with high power and rep rates up in the range [10 100] Hz
  2. Mode-locked short pulse high power laser matching the bunch structure of PETRA/iLCTFs/iLC/X-Ray FELs
- Decision was made to follow the first two
  1. Short-term: Obtain an injection seeded Q-switch laser for the PETRA laserwire and concentrate on scanning, detection, DAQ, implementation → standard diagnostic tool
  2. Long-term: Pursue R&D to develop a laser/amp fitting the iLC pulse structure, derived from photogun laser and high speed intra-train scanning system → prototype and special tool

New Laser for the Laserwire at PETRA2

- Q-switched Nd:YAG laser with diode pumped injection seeding
- Second harmonic generation for 532 nm
- Smooth transverse and longitudinal profile
- Peak power 1 MW for single mode and 16 MW for multi-mode laser

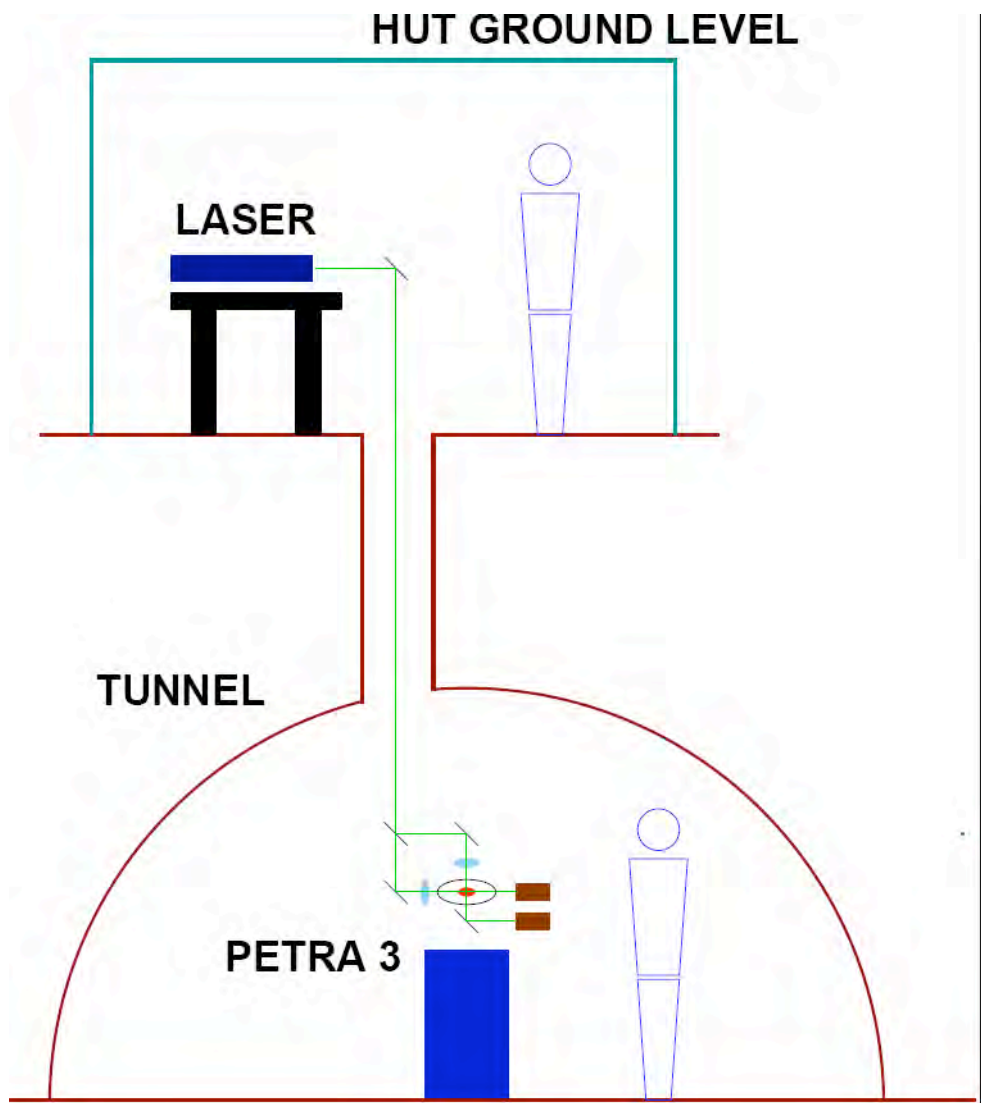


Temporal Profile of Seeded vs Unseeded Surelite



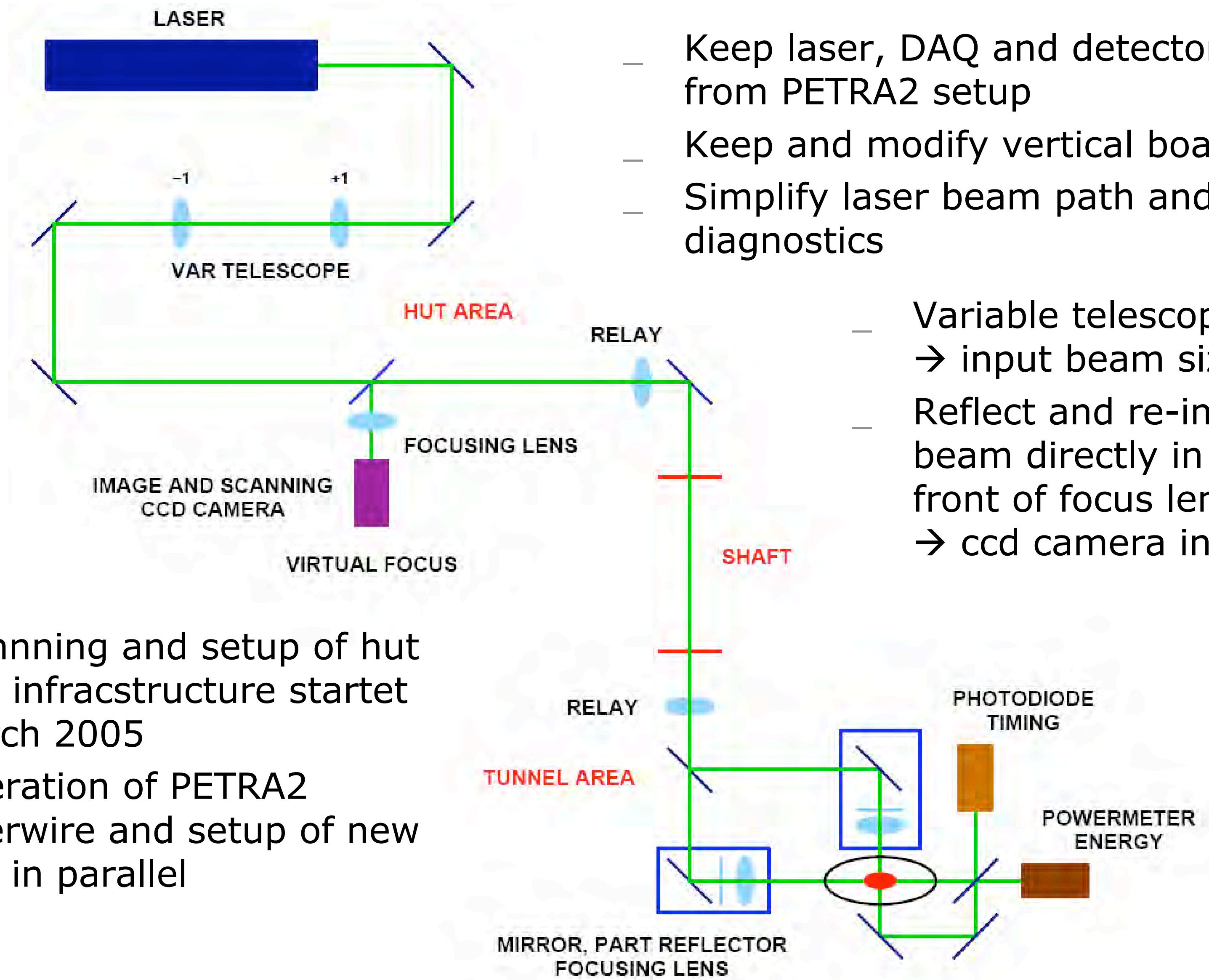
Transition to PETRA3

- PETRA2 stops operation until June 2007 (end of HERA)
- Turning the accelerator into a high brilliance synchrotron radiation source (2009/2010)
- PETRA3 crew want laser-wire to measure transverse beam profile and emittance in straight section, in absence of dispersion
- Beam sizes are in the order of several ten µm
- Re-cycle laser and vertical board solution from upgrade
- New optical beam path and focusing lens
- Move all sensitive diagnostics in hut and only robust technology in tunnel



Laser-wire at PETRA3

- Keep laser, DAQ and detector from PETRA2 setup
- Keep and modify vertical board
- Simplify laser beam path and diagnostics
  - Variable telescope → input beam size
  - Reflect and re-image beam directly in front of focus lens → ccd camera in hut



- Plannning and setup of hut and infracstructure startet March 2005
- Operation of PETRA2 laserwire and setup of new one in parallel

LBBD Laserwire

Conclusion and Outlook

- Laserwire at PETRA2 operational after 3 years of R&D
  - 2000 – 2002: Learning, design studies and lab measurements at RHUL, participation at CTF2 laserwire
  - 2002 – now: continouus setup of laserwire at PETRA2
  - Aug 2003: first Compton photons
  - Dec 2003: first slow scans (30 min/scan)
  - Feb 2005: fast scans (30 sec/scan), big breakthrough due to installation of dedicated exit chamber
  - Next steps installation of new laser and vertical breadboard with second scanning dimension
- Started collaborative effort with colleagues from CERN, DESY, KEK, SLAC and UK universities on laserwire diagnostics
- Training of UK students at PETRA2/DESY: 3 MSc students, 3 PhD students plus conversions of HEP PostDocs into AccPhys
- Efforts at PETRA2/3 complementary to ATF Laserwire (aiming at μm spotsizes and iLC bunch trains)

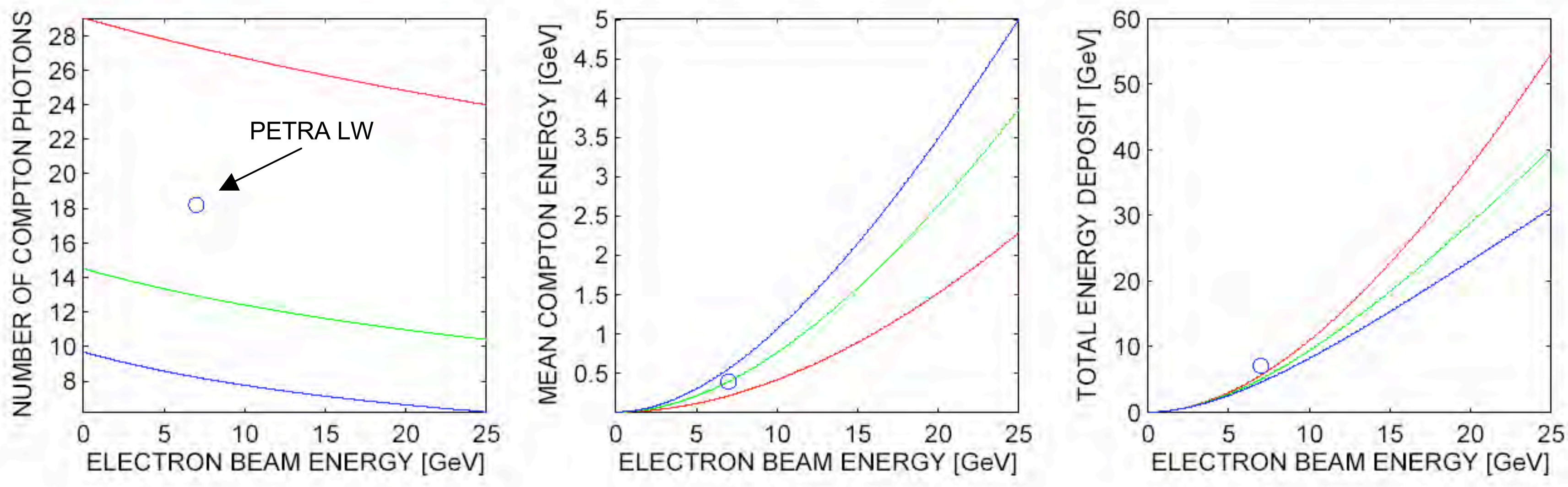
Laser-wire at X-Ray FELs

<u>Electron Beam Parameters</u>

		xFEL	LCLS	TTF2/VUVFEL
Energy	E/GeV	[10 30]	[4 14]	[0.5 1]
Betafunction	_$_{x,y}$/m	50	30	10
Emittance	_$_{x,y}$/µm	[1.5 3]	[1 3]	[1.5 3]
BunchCharge	q/nC	[0.2 1]	[0.2 1]	[0.2 1]
BeamSize	_$_{x,y}$/µm	[65 30]	[67 33]	[123 86]

- Reduce to two scenarios with high and low energy
  - 15 GeV, emittance 1µm, spotsize 50 µm, charge 0.5 nC
  - 500 MeV, emittance 1.5 µm, spotsize 50 µm, charge 0.5 nC
- Laser Nd:YAG at fundamental and harmonics, standard optics, 1MW peak power
- Compute Compton spectrum, number and energy of scattered photons

Signal Estimate

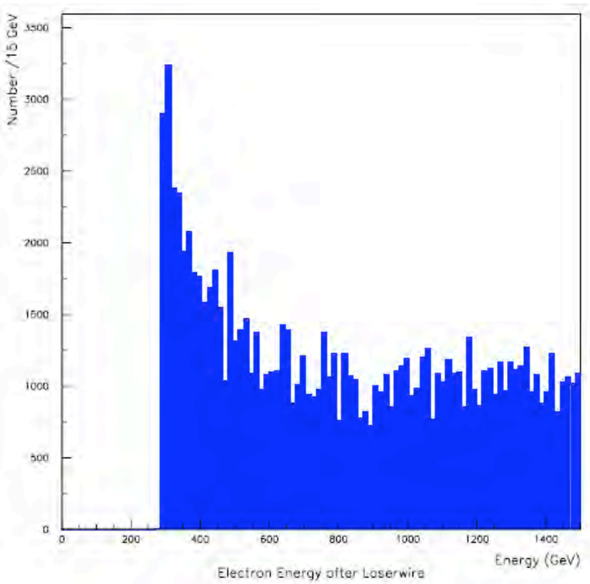


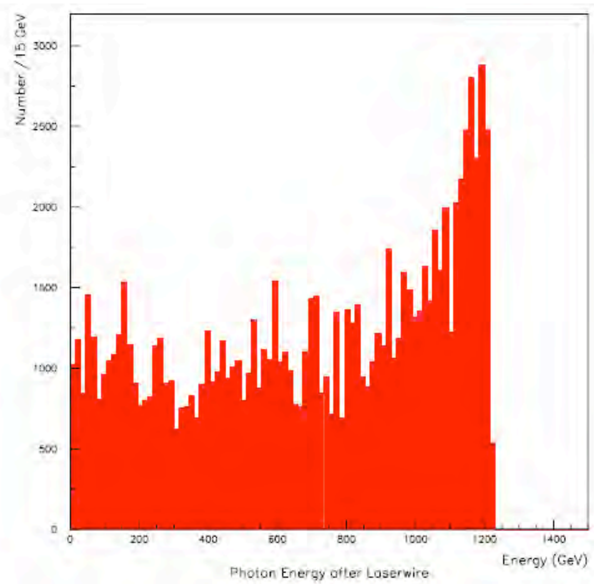
- Plots show number of Compton scattered photons, mean energy and energy deposit for three different harmonics of Nd:YAG (IR, Green and Blue)
- Signal comparable with light yield from PETRA laserwire experiment
  - Old school Nd:YAG laser interacts with 7 GeV electron beam
  - Dedicated exit pipe for Compton photons
- Scaling

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

Signal Extraction

- Compton scattered photons contained in small opening angle cone
  - Need bend magnet to get electron beam out of straight
  - Exit chamber with thin window
  - Lead Tungstate detector with PMT for calorimetry
- Scattered electrons may leave beam pipe chamber at distinct locations depending on the beam optics
  - Study for CLIC (1.5 TeV) nominal long BDS
  - BDSIM (developed by G. Blair, RHUL) combining accelerator style tracking and Geant4 interactions

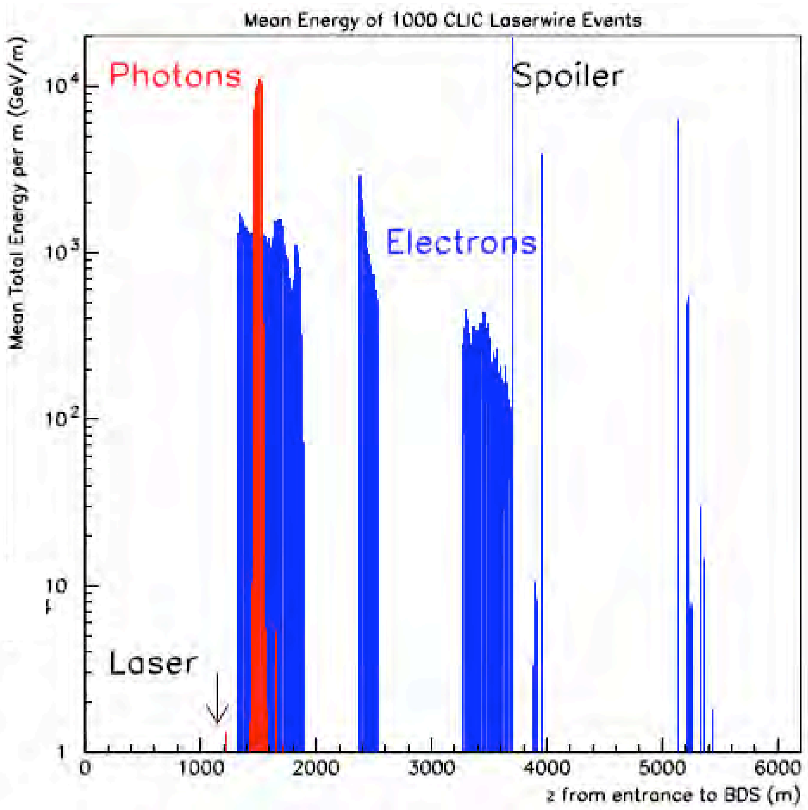




Energy distribution for electrons and photons after Compton scattering between 1.5 TeV electron beam on 532nm laser beam

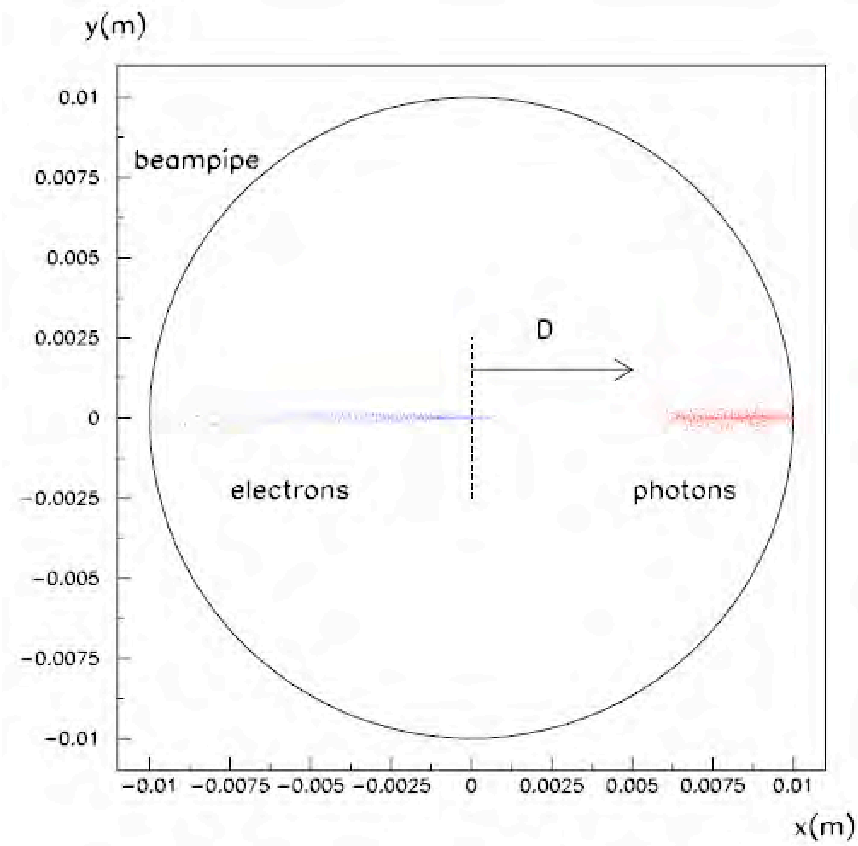
LBBD Laserwire

Signal Extraction (cnt‘d)



- Energy deposition as function of beamline length in BDS

- Compton-scattered photon and electron distribution at 325m after laser-wire
- Intra-beampipe calorimeter distance D to detect photons



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