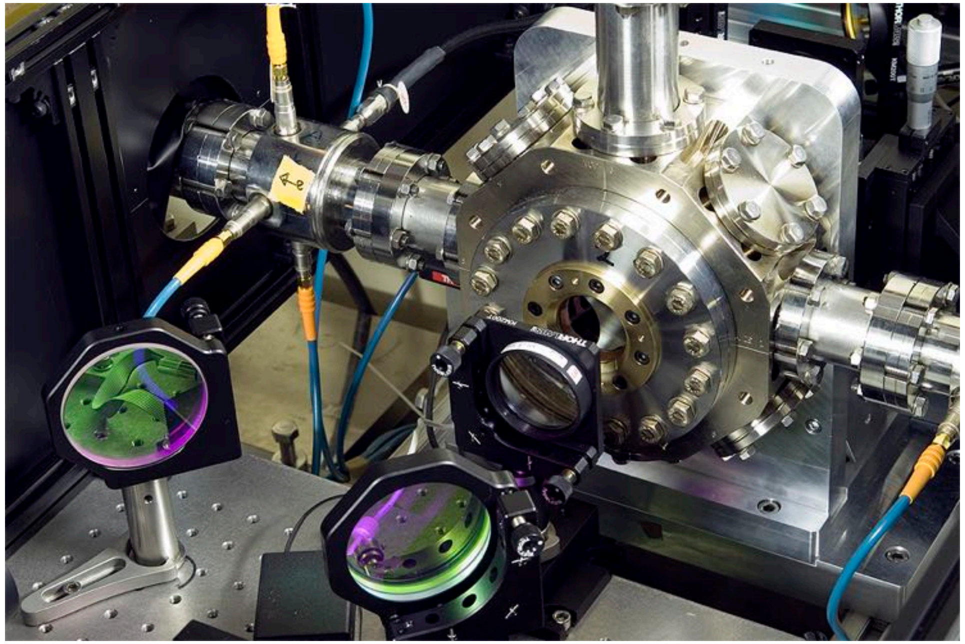
Application of Lasers in Beam Instrumentation (diagnostics)

The CERN Accelerator School

Beam Instrumentation
Tuusula, Finland
2 - 15 June 2018



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Laser applications: talk overview

Outline

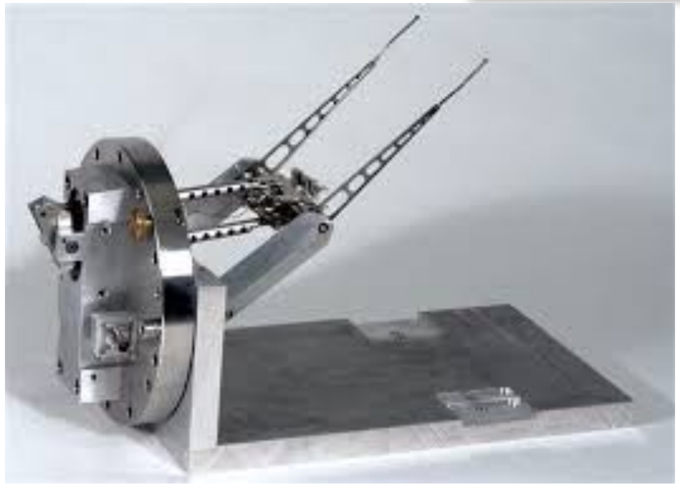
- ***Laserwires***
  - e^- laserwire profiles
  - H^- transverse emittance
  - Longitudinal
- ***Polarimetry at LEP***
- ***Shintake monitor at KEK***
- ***Electro-Optic BPMs***
  - *Other eo -> see A. Gillespe's talk*
- ***High bandwidth signal transmission***

Disclaimer: focus is on ***laser based*** beam diagnostics, not radiation from the particle beam.

Laserwires – general concept

How to measure the transverse beam profile?

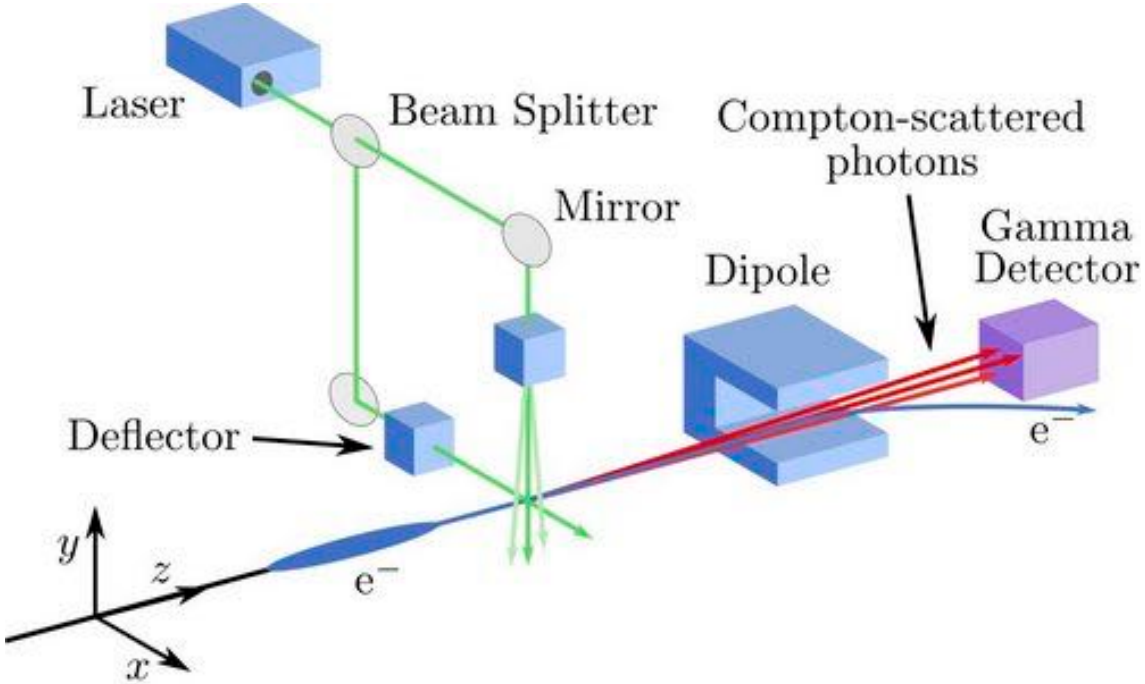
- Traditional method is to sweep a solid wire across the beam
- Measure the background vs wire position of wire and beam
- High power and/or very small beams (micron scale at LC) present challenges for conventional, invasive diagnostics:
  - Solid wires may ablate, harming SC surfaces nearby.



Replace the *wire* with a *laser beam:*

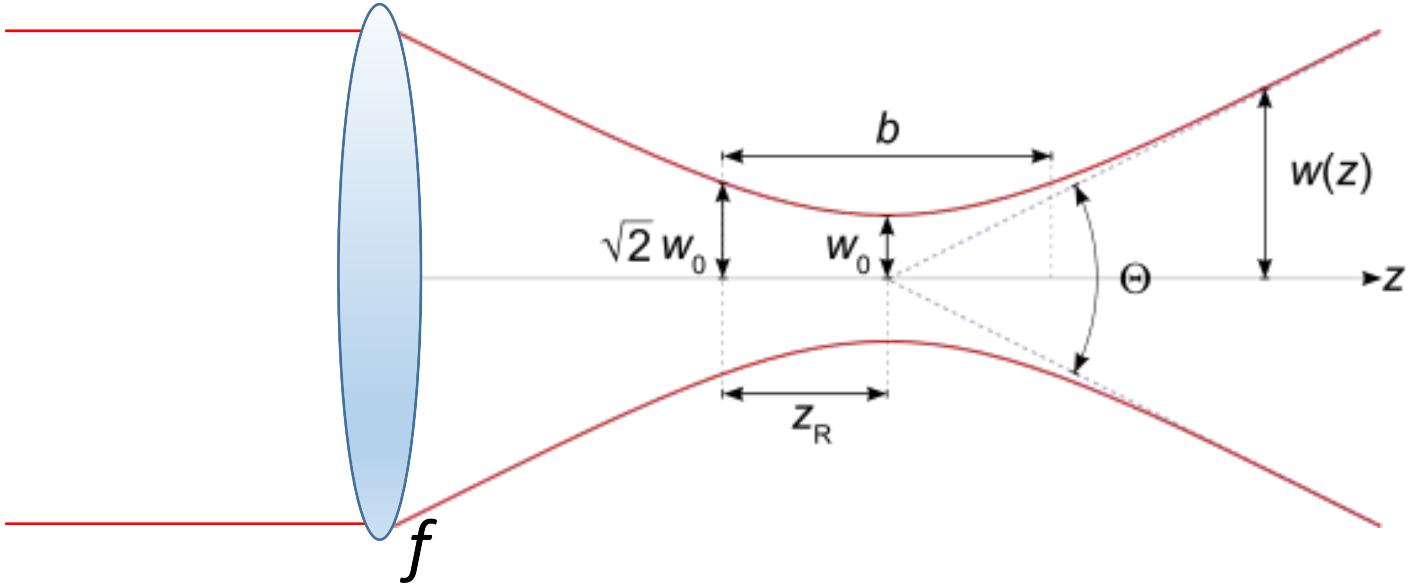
- **Electron beam laserwires**:
  - detect Compton-scattered photons
- **Hydrogen ion beam laserwires:**
  - detect product(s) of photo-detachment

$H^- + \gamma \rightarrow e^- + H^0$



Gaussian beam optics

Laser beam must be focused to a size compatible with the particle beam profile



- **Electron beam laserwires**:
  - μm level electron beam sizes requires μm level laserwire focus –> major challenge!
- **Hydrogen ion beam laserwires:**
  - mm level particle beam size, need <100 μm laser focus.

- Key parameters:

Beam waist

$$w_0 = \frac{\lambda}{\pi} M^2 \frac{2f}{d}$$

Rayleigh length

$$z_R = \frac{\pi {w_0}^2}{\lambda M^2}$$

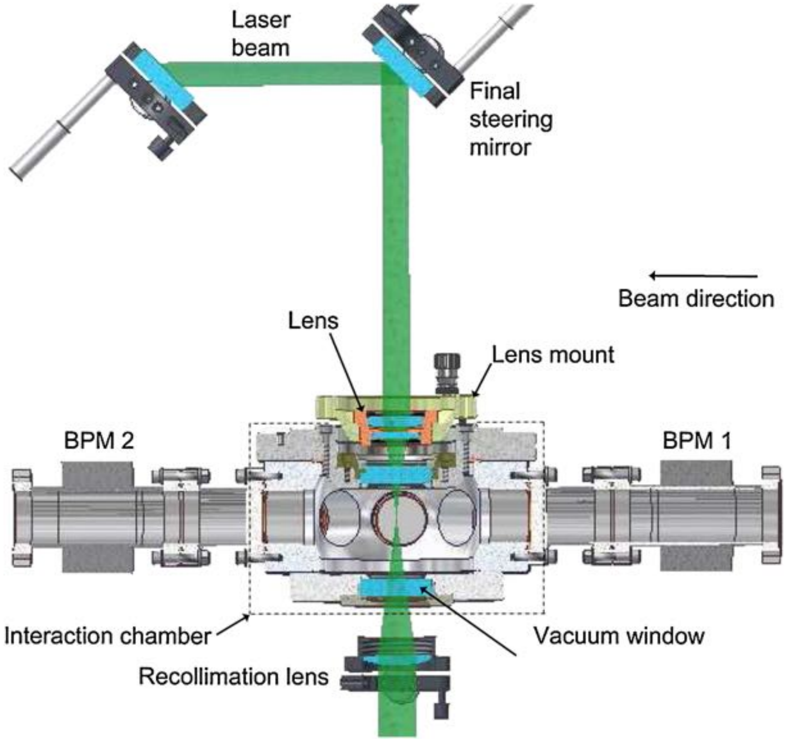
Beam transverse size ($1/e^2$)

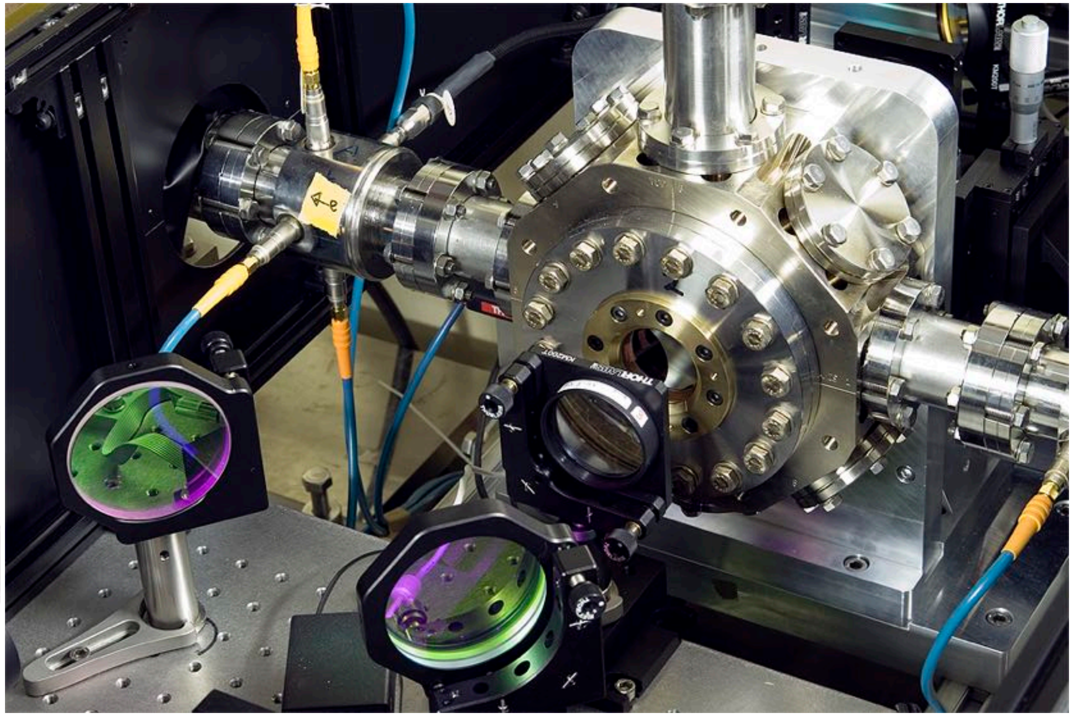
$$w(z) = w_0 \sqrt{1 + \left({}^{z}/_{z_R} \right)^2}$$

M^2 is measure of beam quality (M^2 = 1 would be an ideal Gaussian)

e- laserwires: ATF setup

- Light focused into interaction chamber through vacuum window required careful optics design to deliver beam with minimal aberrations:





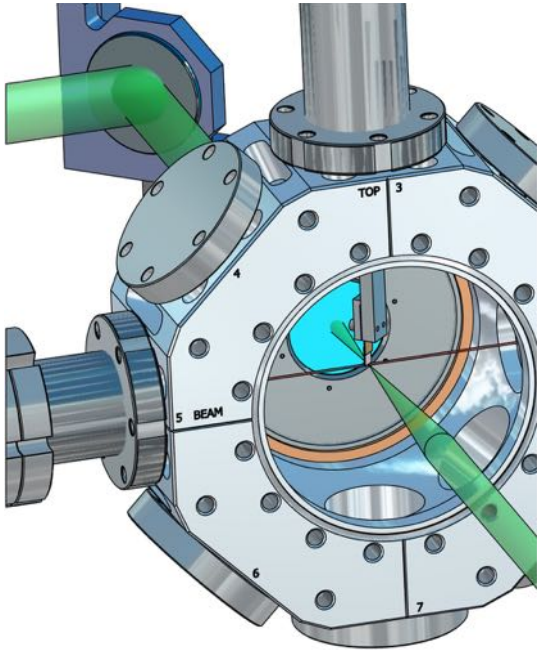
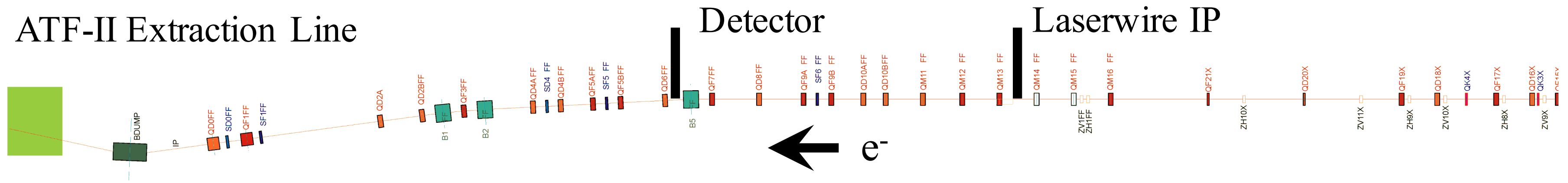


FIG. 10. View of the interaction chamber with the laser exit side flange removed, showing the 45° screen/knife edge.

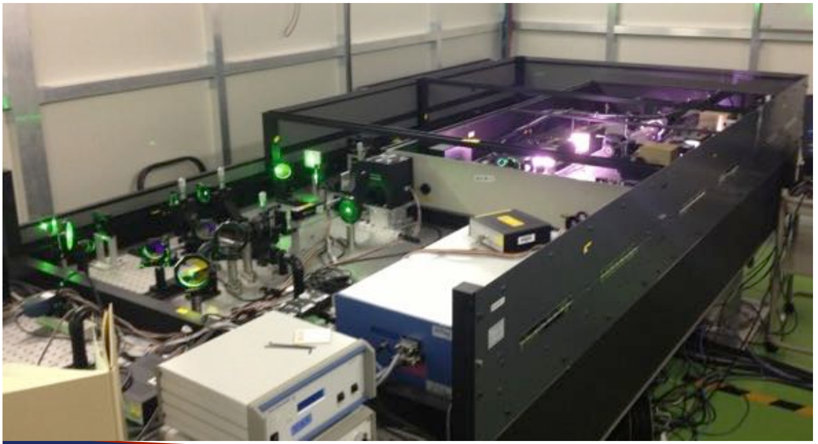
- S. Boogert et al: Micron-scale laser-wire scanner for the KEK Accelerator Test Facility extraction line Phys. Rev. Special Topics - Accel. Beams, 13, 122801 (2010)
- Beam emittance measurement with laser wire scanners in the International Linear Collider beam delivery system Phys. Rev. Special Topics - Accel. Beams, 10, 112801 (2007), Issue 11

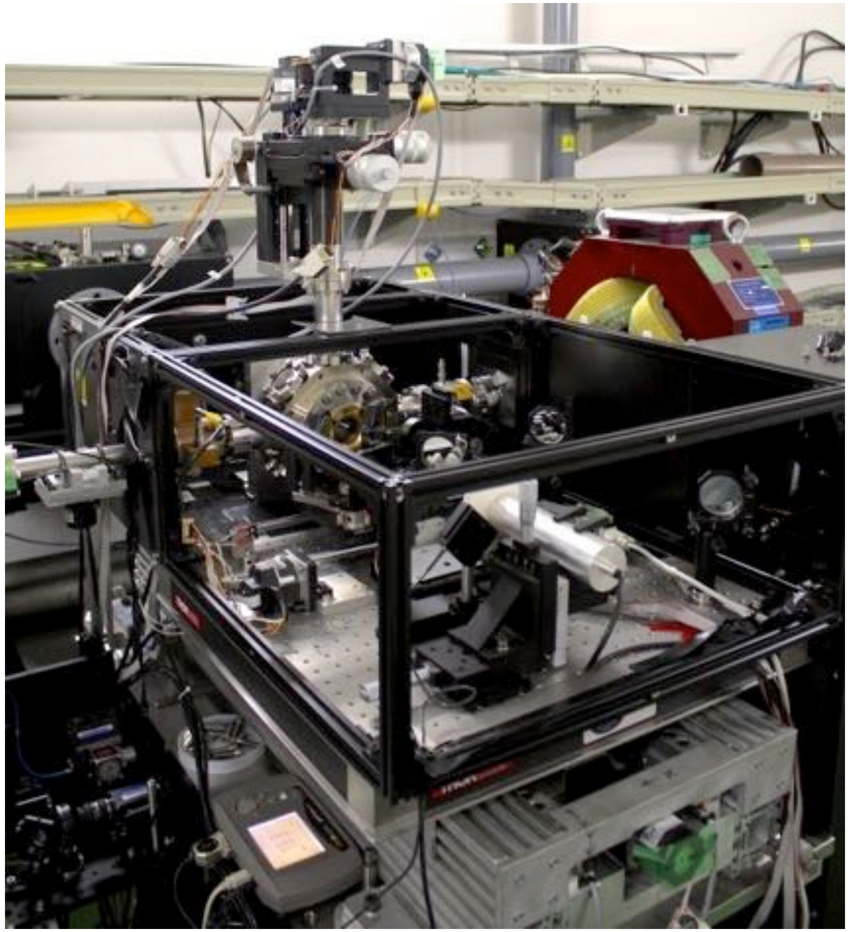
e- laserwires: ATF2 setup

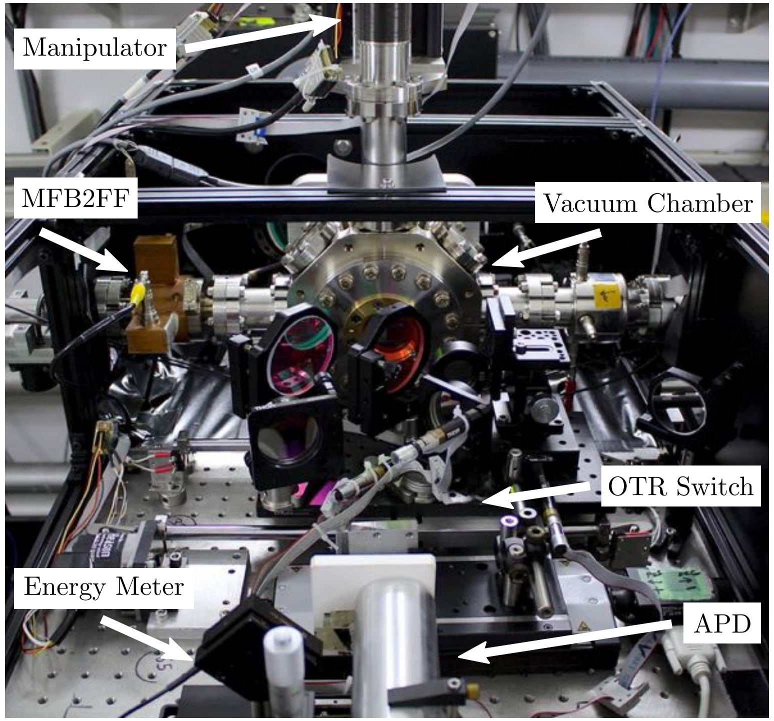


A. Aryshev, S. Boogert L. Corner, D. Howell, P. Karataev, K. Kruchinin, **L. Nevay**, N. Terunuma, J. Urakawa, R. Walczak

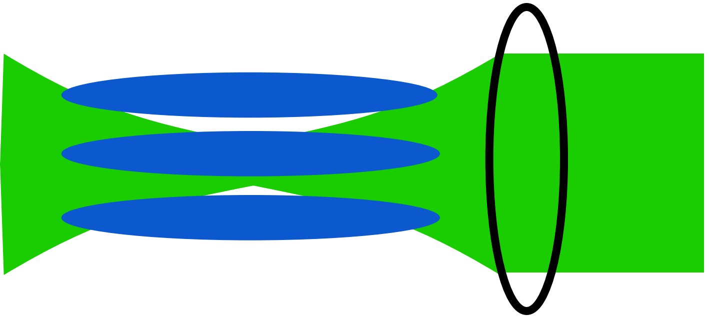
- Goal: Sub-micron resolution laserwire using transmissive optics
- Demonstrate 1μm vertical profile
- Use mode-locked Nd:YAG laser
- 1×10^{10} e^- and ~2GW peak power
- Cherenkov detector for γ-rays

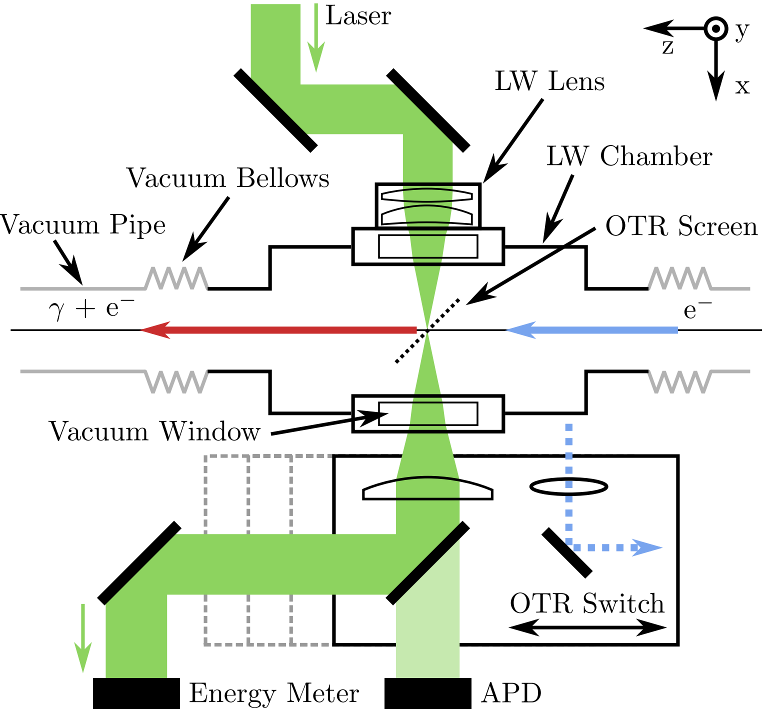






e- laserwires: *ATF2 laser beam characterisation*



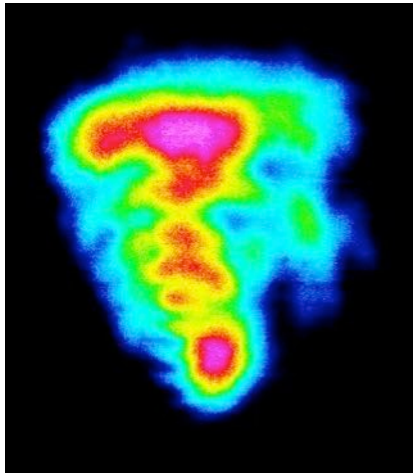


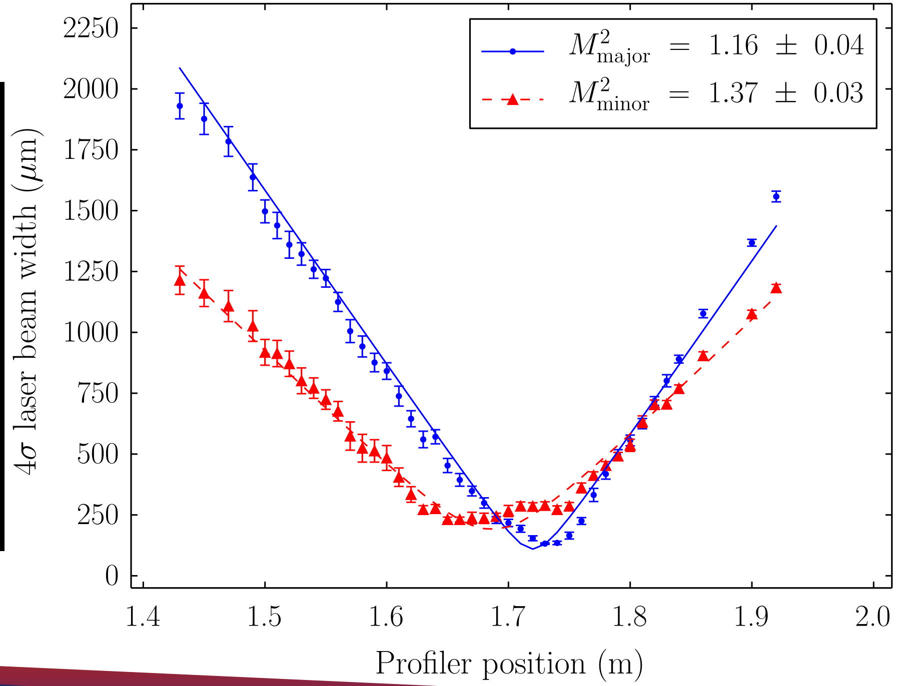
- Electron beam 1 x 250µm
- λ= 532nm laser, σ_0 = 1µm, M^2 (spatial quality) = 1.3
- Rayleigh range = 15µm
- laser σ ~ constant over 30µm << 250µm
- Vertical laserwire scan non-Gaussian
- Use measured laser propagation in overlap integral

A. Aryshev, S. Boogert L. Corner, D. Howell, P. Karataev, K. Kruchinin, **L. Nevay**, N. Terunuma, J. Urakawa, R. Walczak

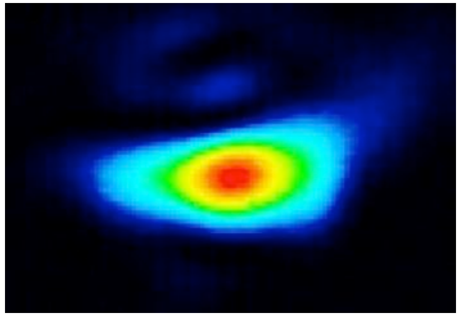
Laserwire at the Accelerator Test Facility 2 with submicrometer resolution Phys. Rev. Special Topics Accel. Beams, 17, 072802 (2014)

Input 4σ = 12mm





Scaled focus
4σ = 50µm



e^- laserwires: ATF2 results

A. Aryshev, S. Boogert L. Corner, D. Howell, P. Karataev, K. Kruchinin, **L. Nevay**, N. Terunuma, J. Urakawa, R. Walczak

Successful measurement of the 1.07 μm profile electron beam!

***L. Nevay** et al: Laserwire at the Accelerator Test Facility 2 with submicrometer resolution*
Phys. Rev. Special Topics - Accel. Beams, 17, 072802 (2014)

Projected laser dimension at interaction point

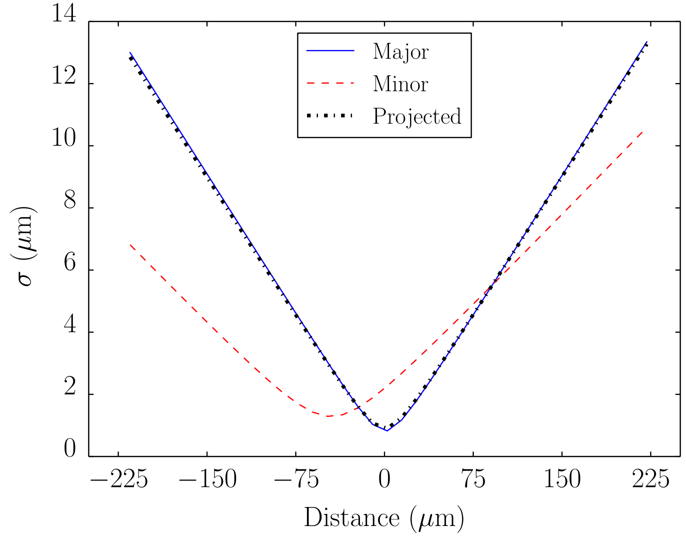


FIG. 12. Calculated projected vertical sigma for the laser as well as the two axes of propagation at the LWIP. The distance is

Measured vertical e- beam profile

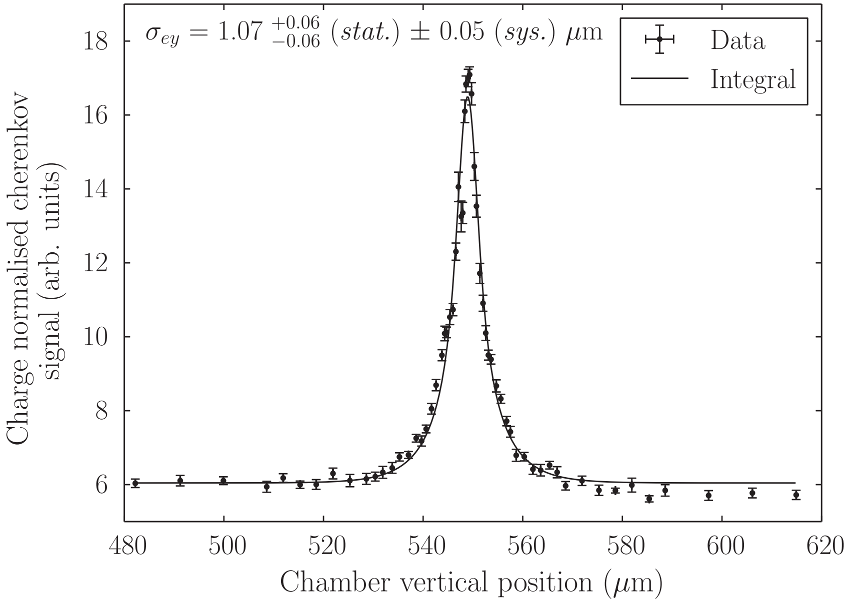


FIG. 19. Nonlinear step size laserwire scan with the smallest measured electron beam size.

Measured horizontal e- beam profile

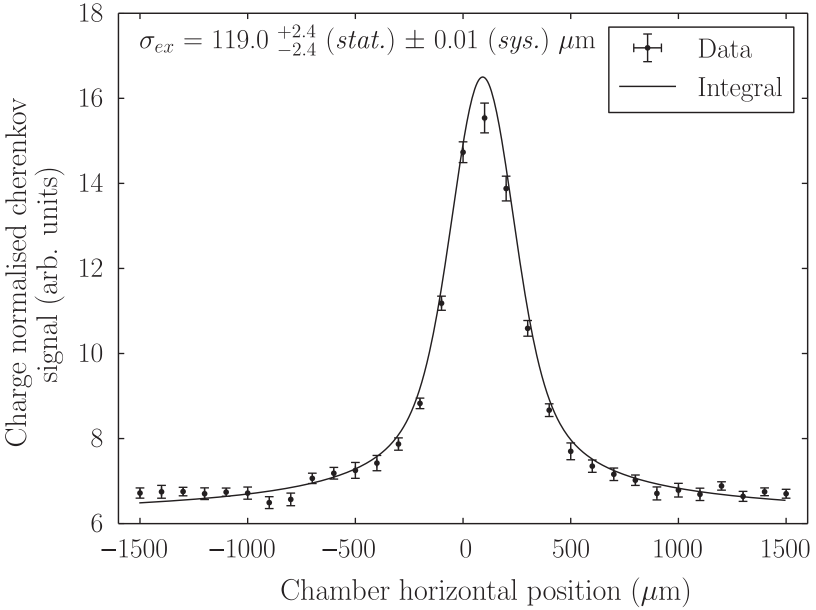
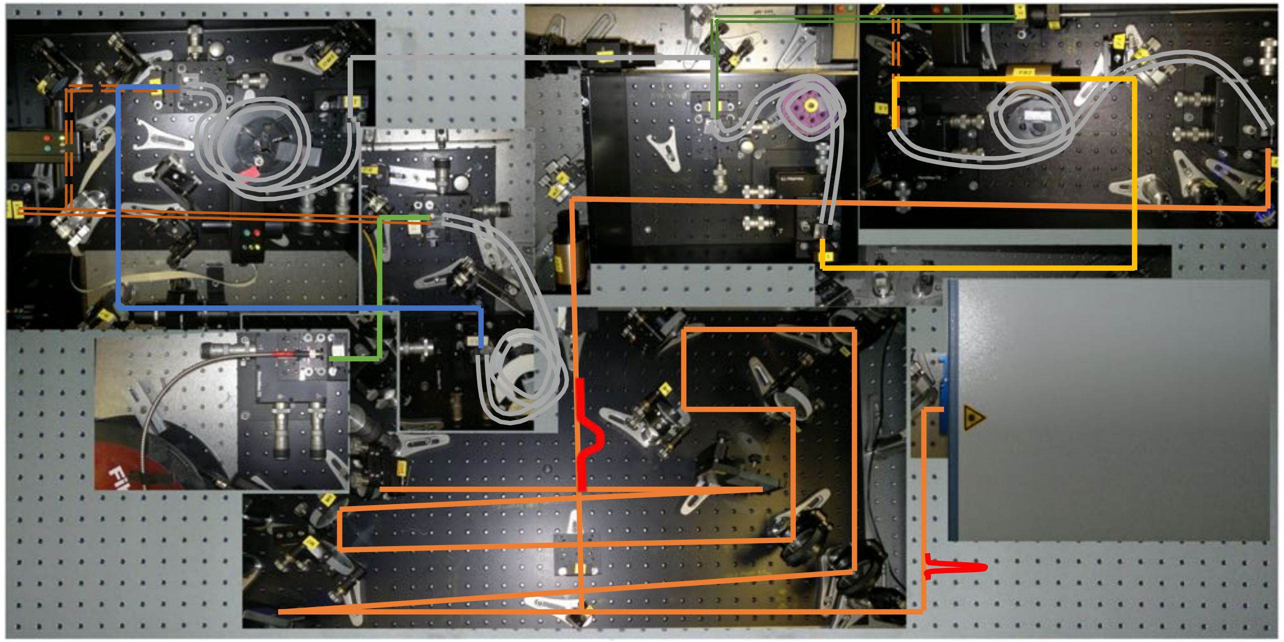


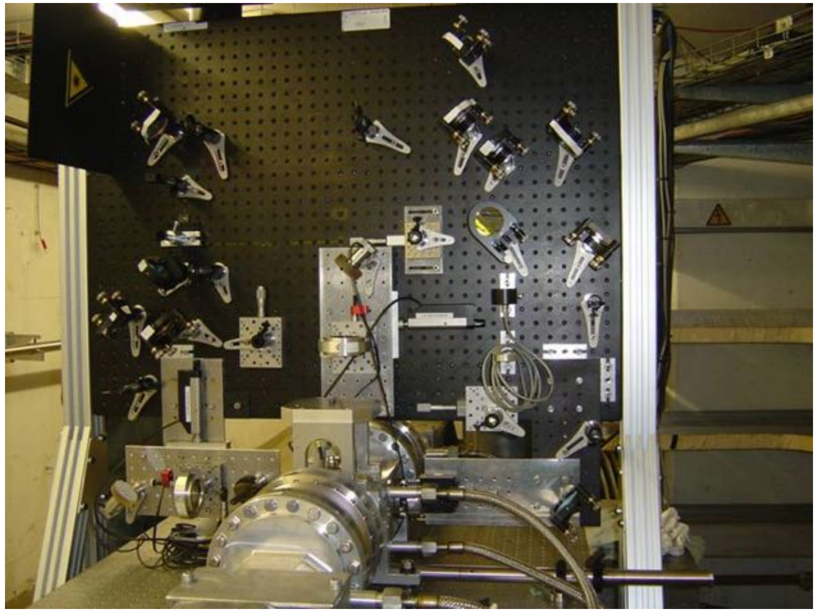
FIG. 20. The corresponding horizontal laserwire scan for the smallest vertical scan, which was required for the combined analysis.

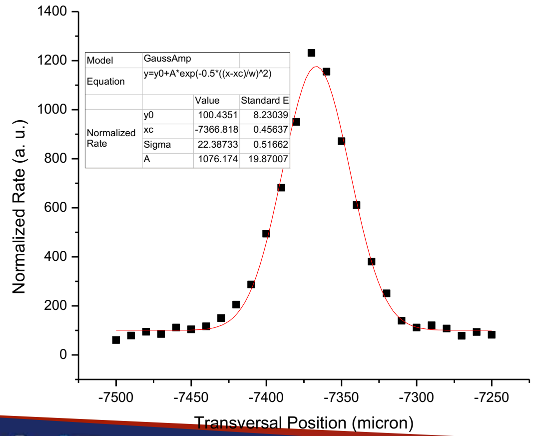
e⁻ laserwires: at PETRA-II & -III

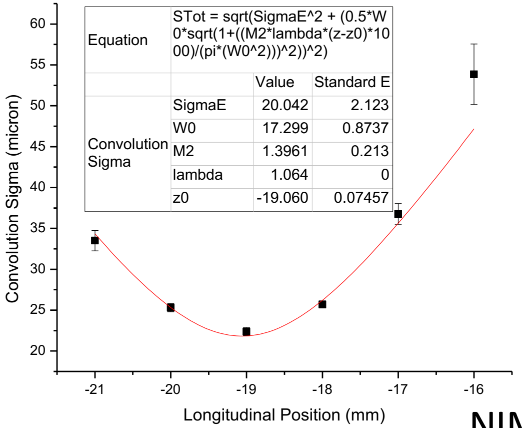
Chirp pulse amplification scheme as previously described



Vertical breadboard at beam pipe

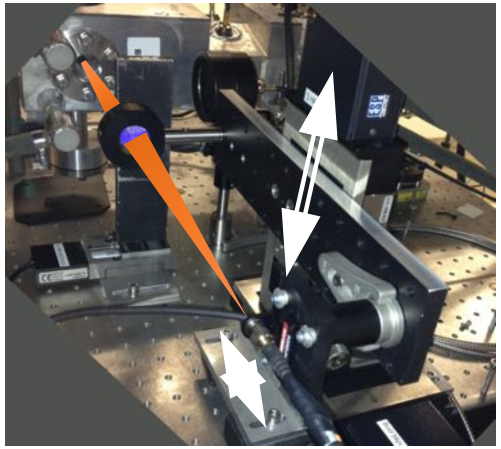






Fibre amplified laser transport to tunnel in photonic crystal fibre – large area single spatial mode.

Beam delivery optics:



NIM in Phys. Res. A 592(3):162-170 · July 2008

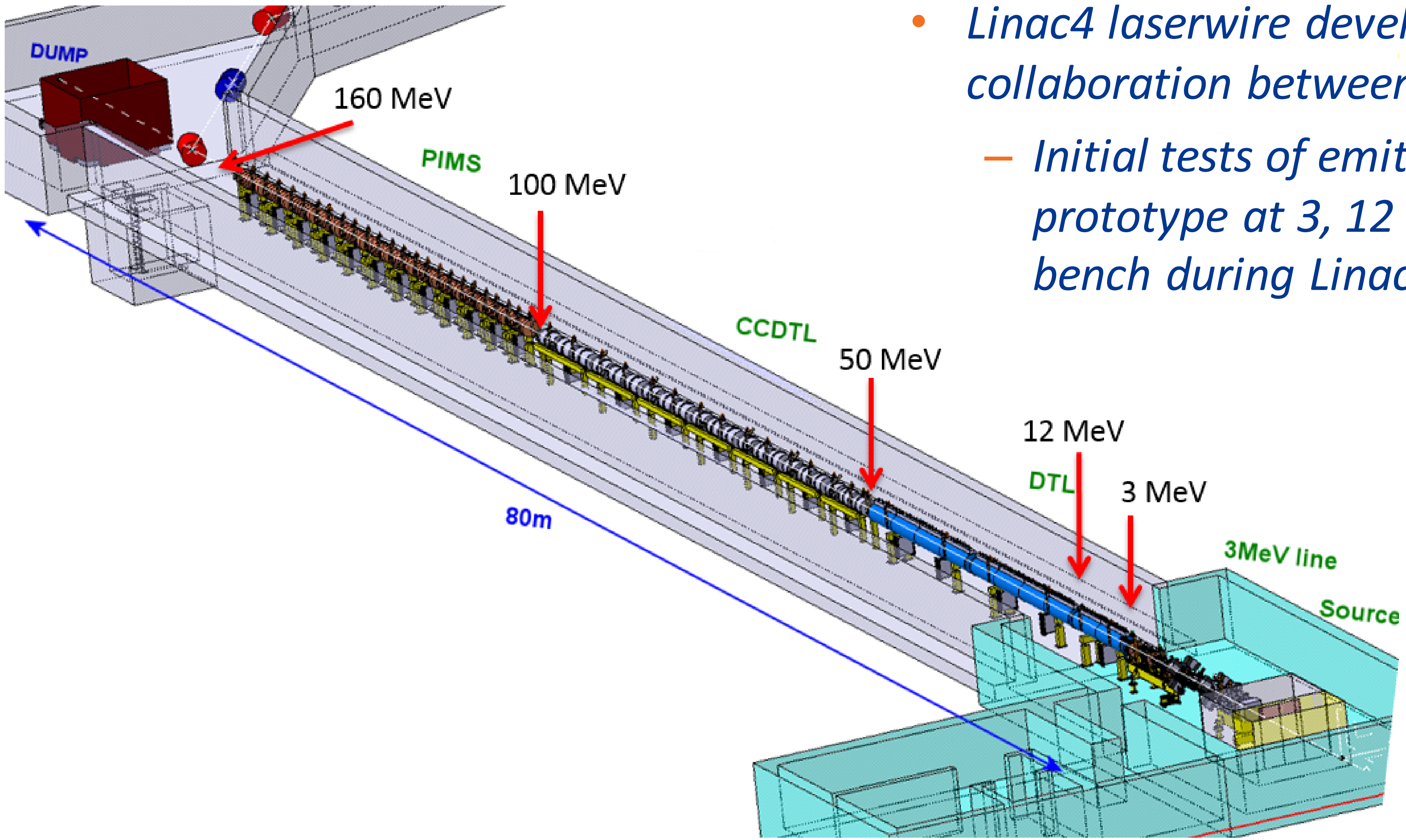
H^- laserwire: Linac4 transverse emittance scanner

- *Linear Injector Upgrade at CERN for the (HL-) LHC, Linac4 to replace Linac2 after LS2:*
- *Higher energy, intense H- beam requires non-invasive diagnostics: H- laserwire*

Linac2:
50 MeV protons

Linac4:
160 MeV H^- ions
http://home.cern/about/accelerators/linear-accelerator-4

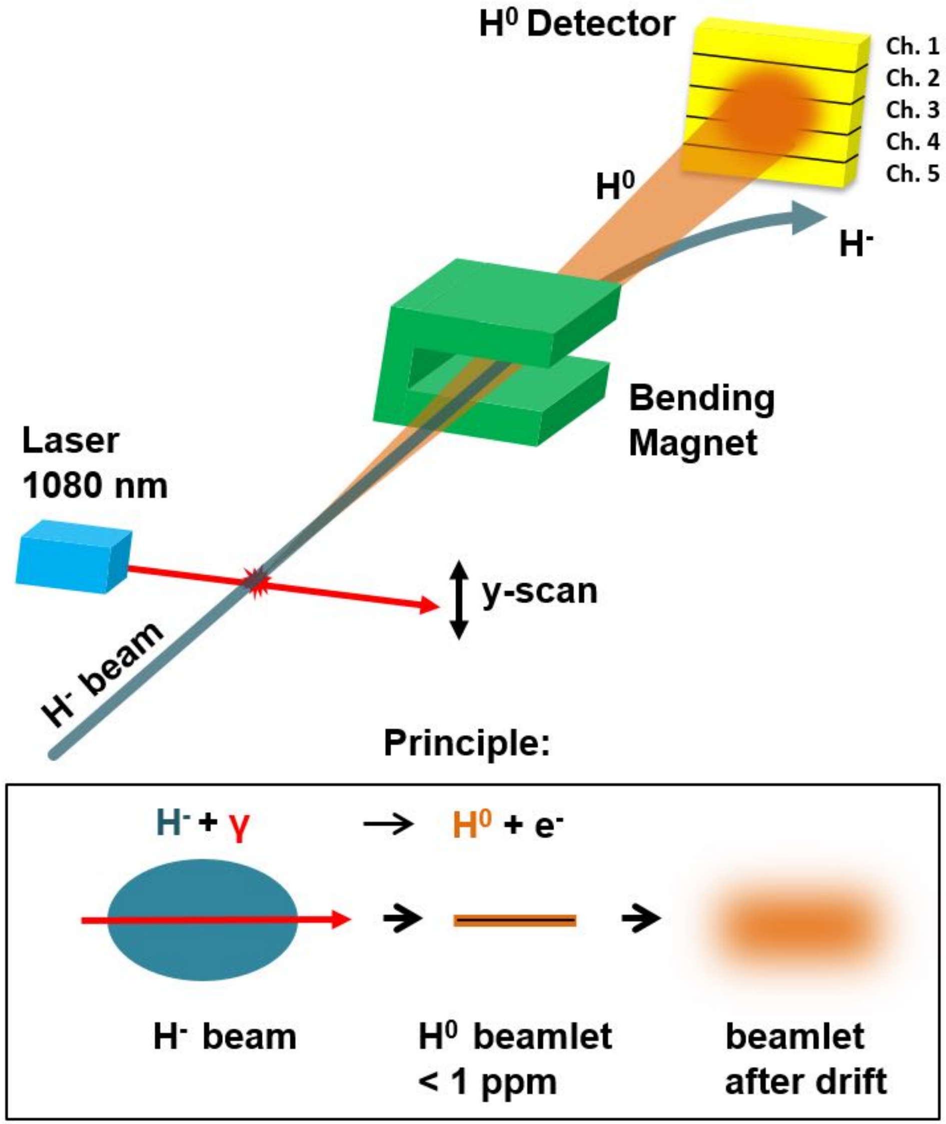
H^- laserwire: Linac4 transverse emittance scanner

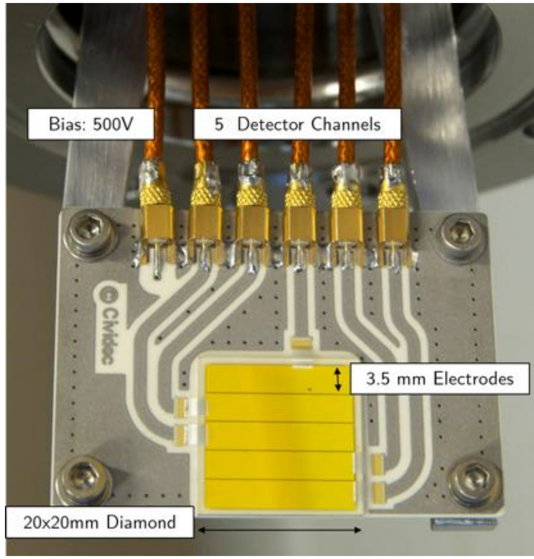


- *Linac4 laserwire developed in recent years in collaboration between CERN-RHUL:*
  - *Initial tests of emittance scanner prototype at 3, 12 MeV on diagnostic test bench during Linac4 commissioning*

H^- laserwire: transverse emittance scanner concept

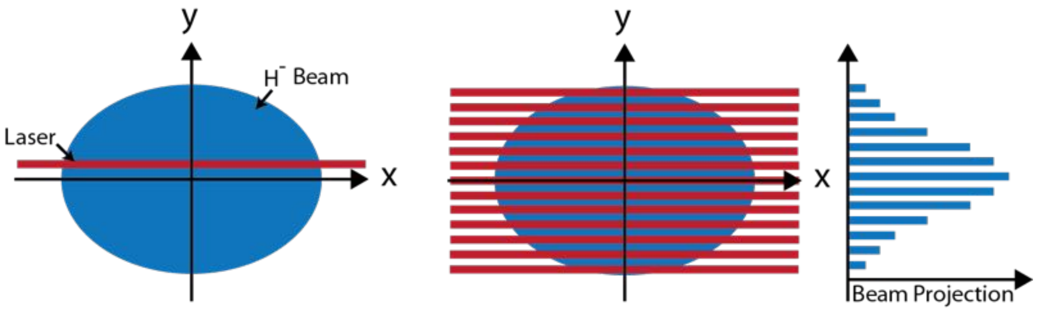
- *Laser neutralises H^0, which go straight to a downstream diamond detector.*
- *Main H^- beam deflected by spectrometer magnet.*

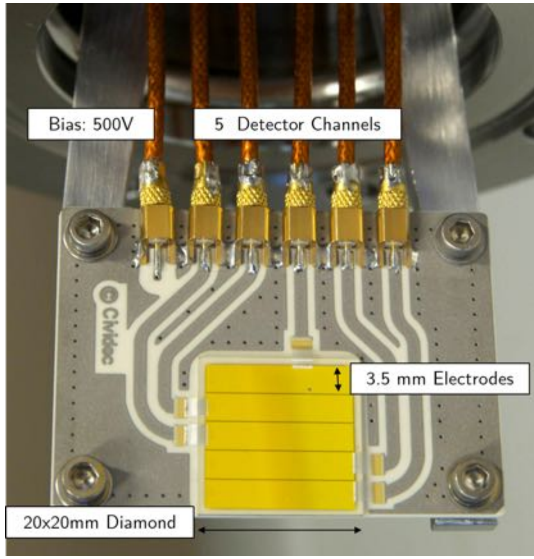




H^- laserwire transverse emittance scanner concept

- *Laser neutralises H^0, which go straight to a downstream diamond detector.*
- *Main H^- beam deflected by spectrometer magnet.*
- *Count the total H^0 arriving at the detector, as the laser position is scanned through the H^- beam -> **transverse profile.***





H$^-$ laserwire transverse emittance scanner concept

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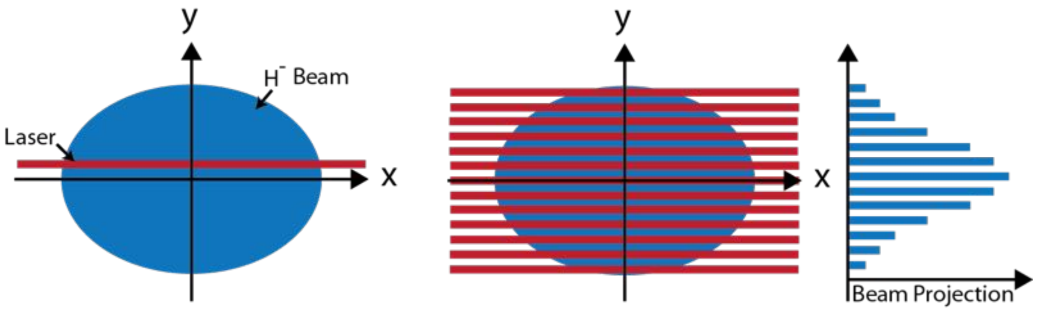
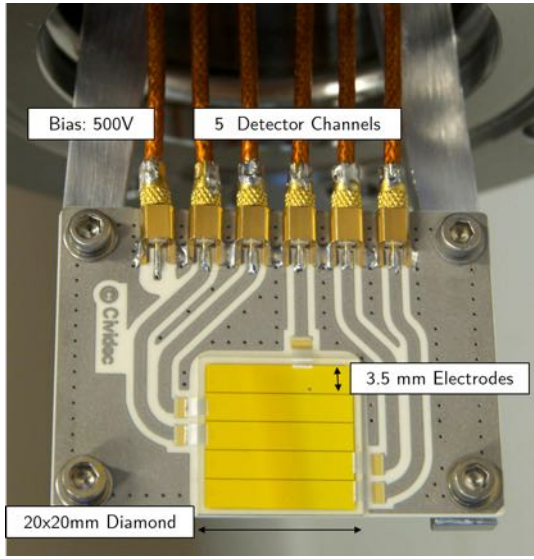
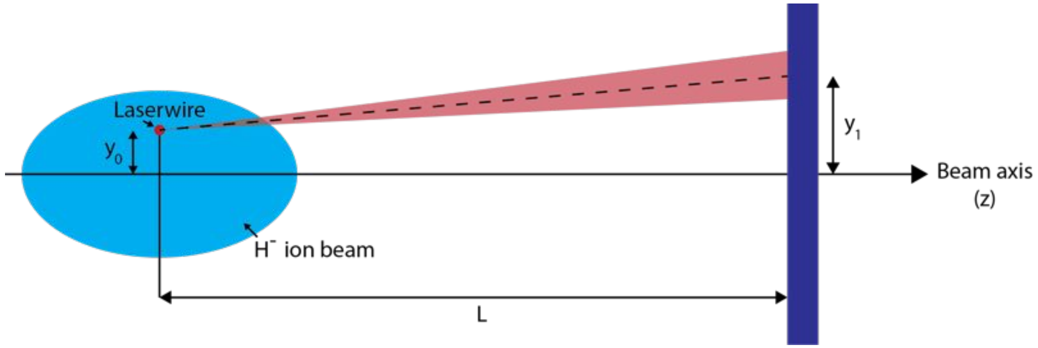
- *Laser neutralises H^0, which go straight to a downstream diamond detector.*
- *Main H$^-$ beam deflected by spectrometer magnet.*
- *Count the total H^0 arriving at the detector, as the laser position is scanned through the H$^-$ beam -> **transverse profile.***
- *Can also assess the beamlet distribution at each laser position to find the angular information, thus reconstruct **transverse emittance.***







H^- laserwire: Linac4 prototype, focus optics tests

- *Fibre-coupled laser with beam expander and lenses to focus beam to <60 μm: beam quality assessed on test bench.*

Fibre

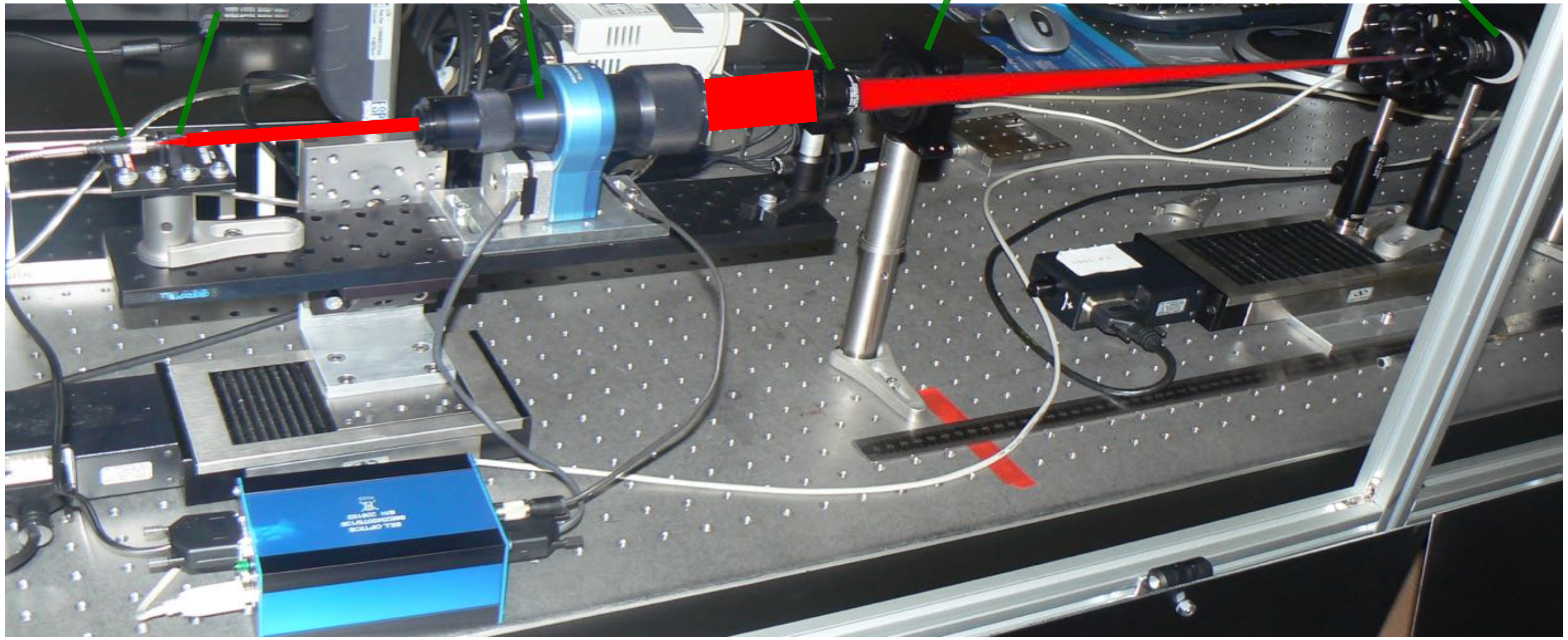
collimating Lens f=6.4mm

motorized beam expander

focusing lens f=500mm

Iris for alignment

camera and filter wheel on translation stage around beam focus



BE control

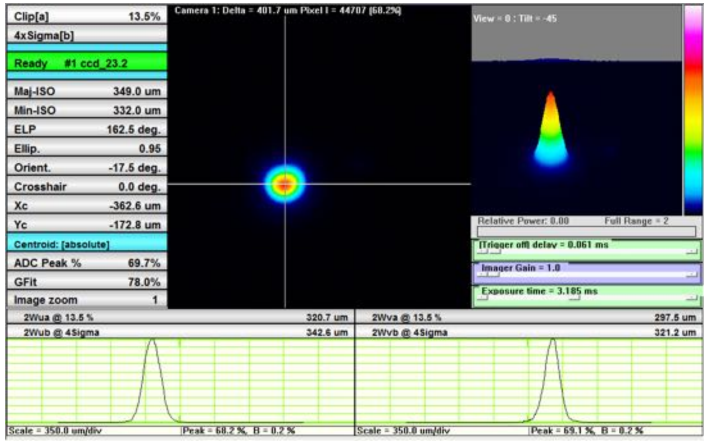
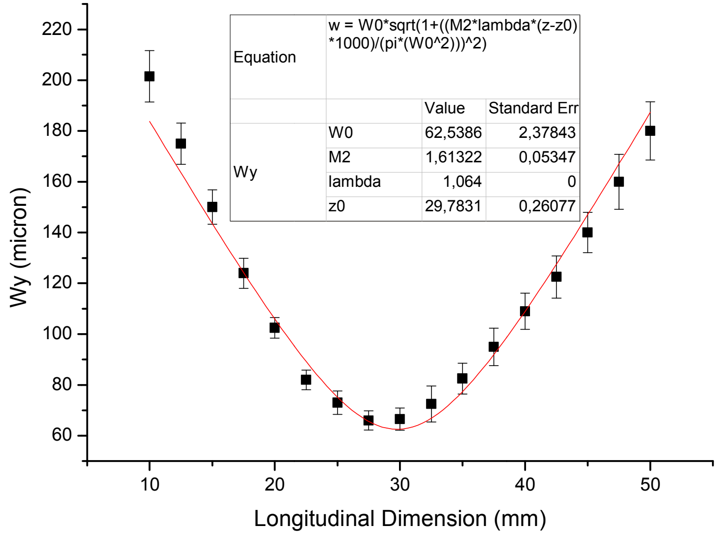
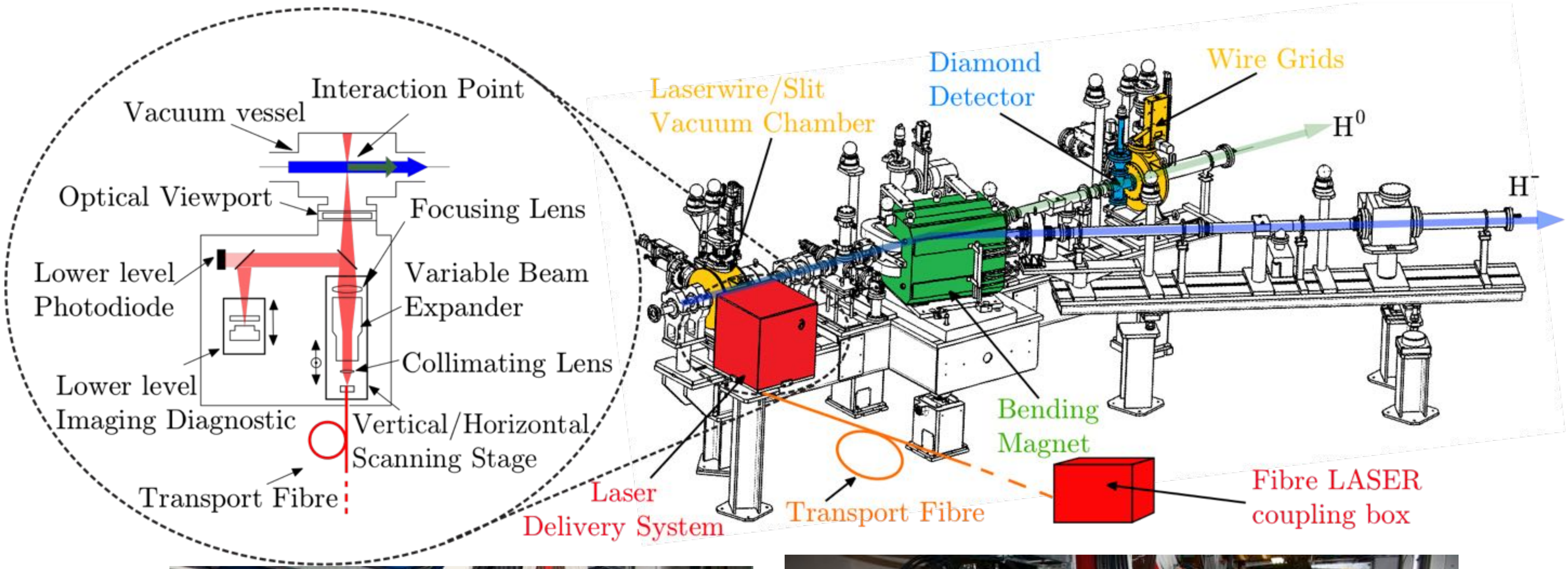


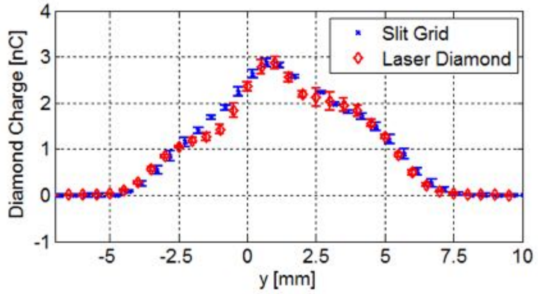
Figure 6: Picture of the laser at the focal plane.

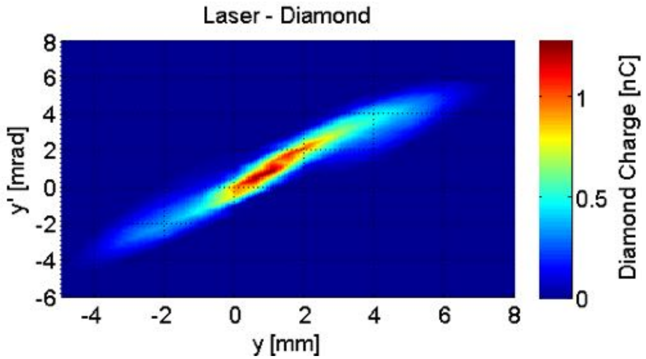


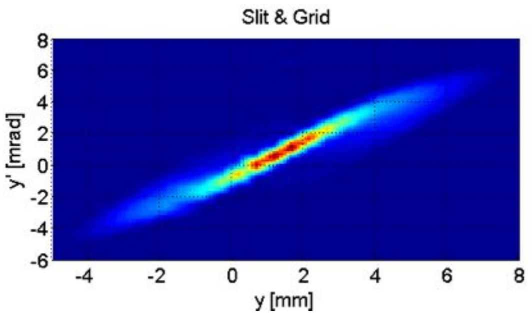
H^- laserwire: Linac4 prototype emittance scanner

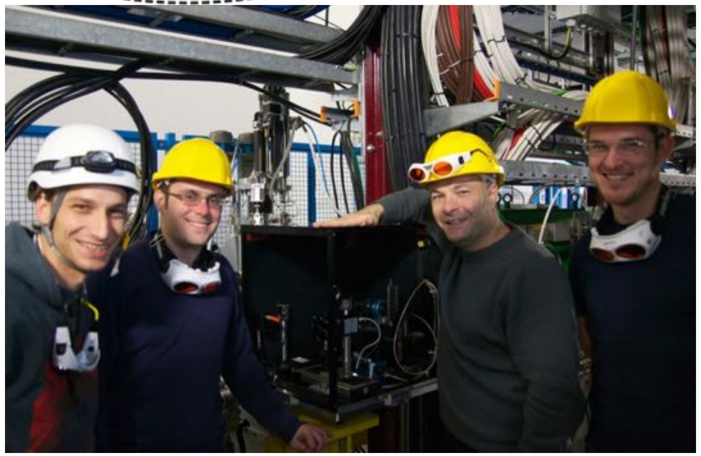


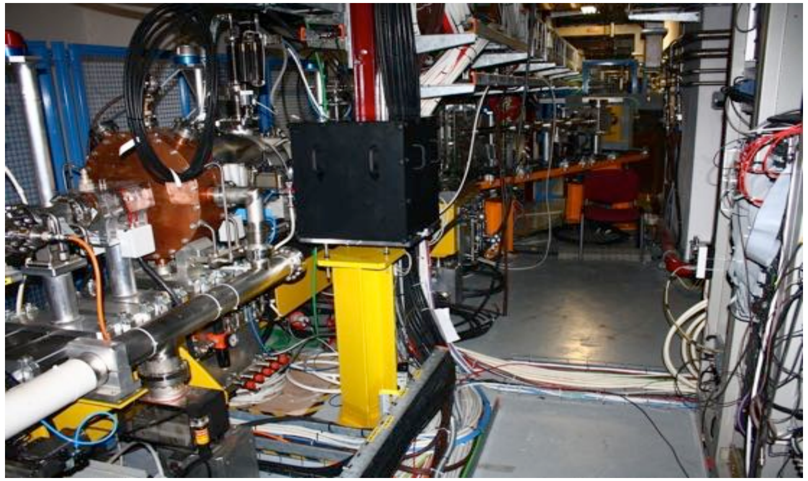
12 MeV results





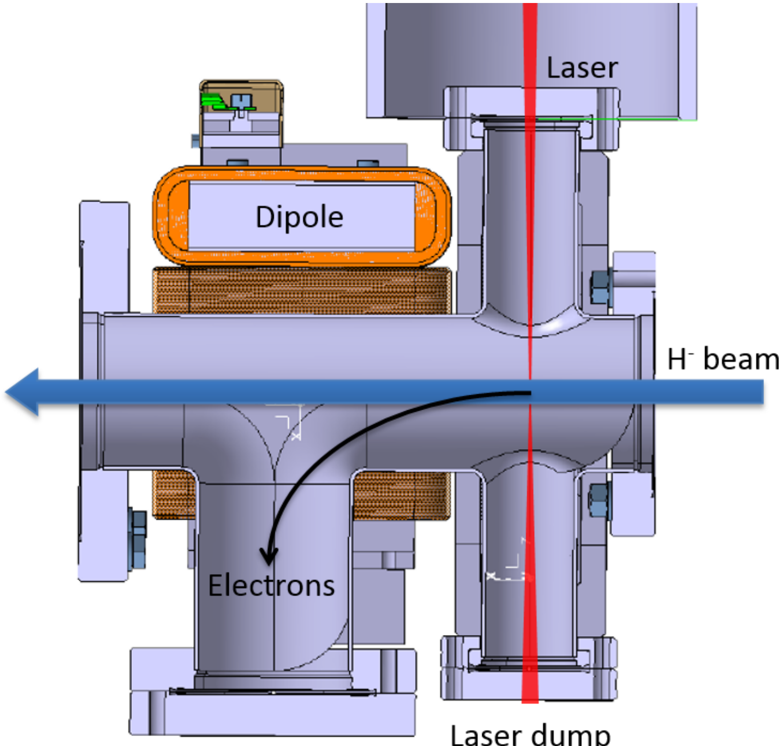


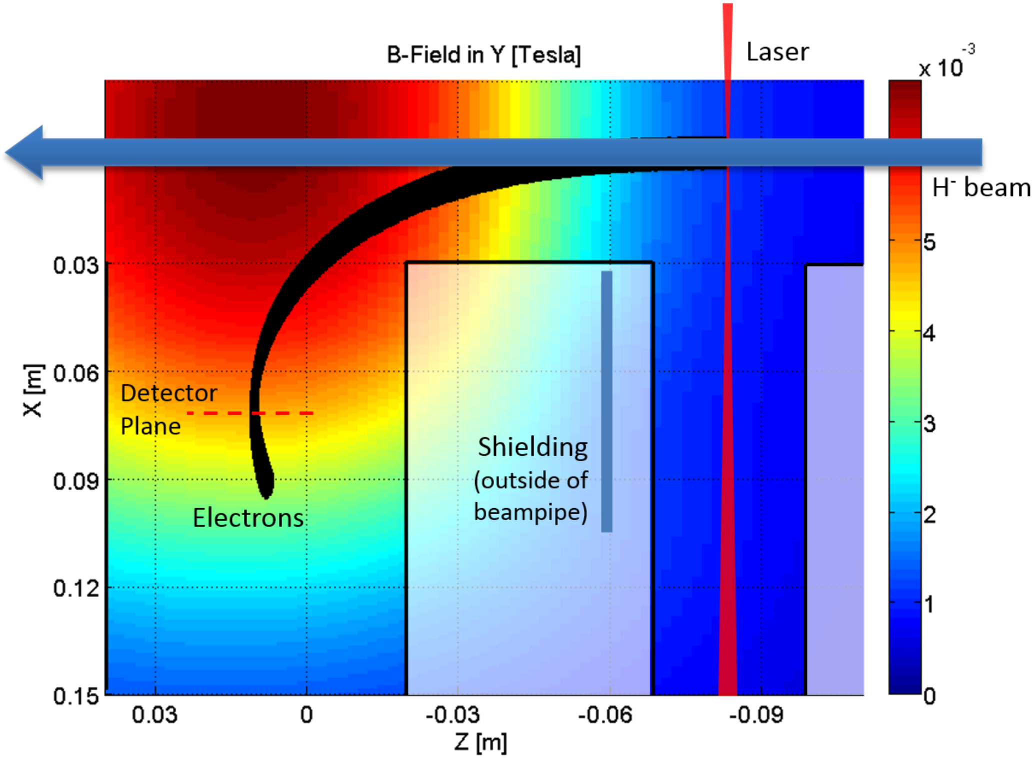




H⁻ laserwire: Linac4 prototype profile scanner

- *New configuration for 50, 80, 107 MeV, as diagnostics dipole was unavailable: instead count liberated electrons deflected using a small steerer magnet.*





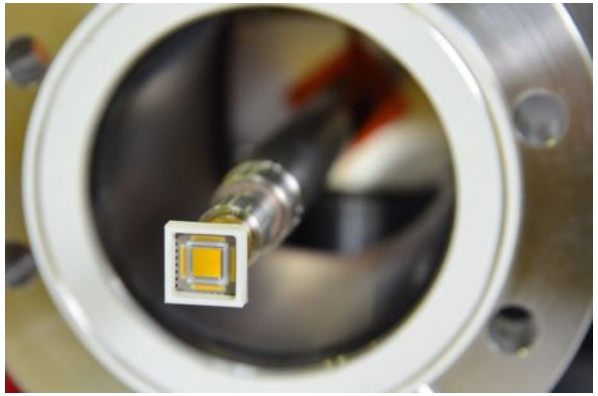
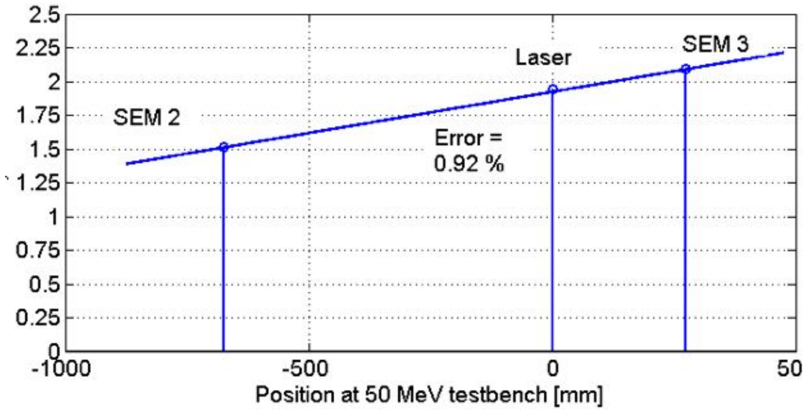


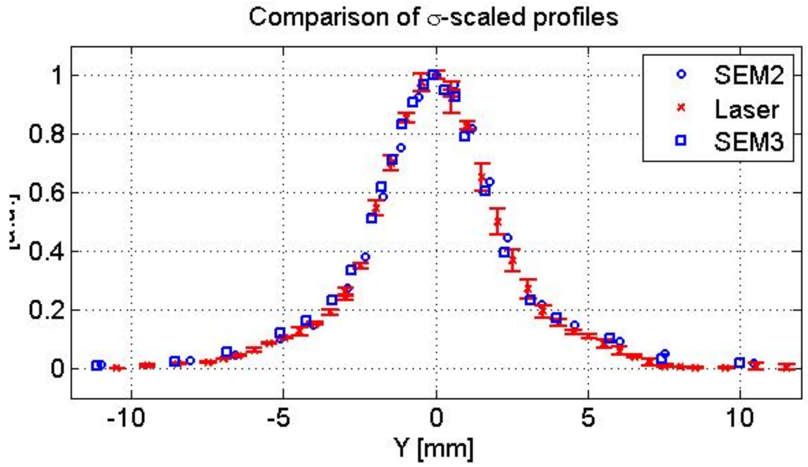
Figure 8: sCVD diamond detector [12] mounted on the actuator that is part of the laser monitor assembly for the 50 MeV experiment.

T. Hofmann et al, *'Design of a laser based profile monitor for Linac4 commissioning at 50 MeV and 100 MeV'*, TUPB005, IBIC 2015. http://ibic.synchrotron.org.au/papers/tupb055.pdf

H^- laserwire: Linac4 prototype profile scanner results

50 MeV





80 MeV

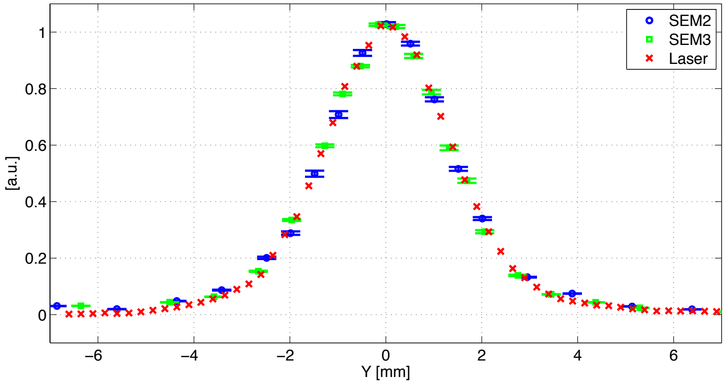


Figure 10: Comparison of SEM-grid σ-scaled profiles with the laserwire profile for the 80 MeV H^- beam.

107 MeV

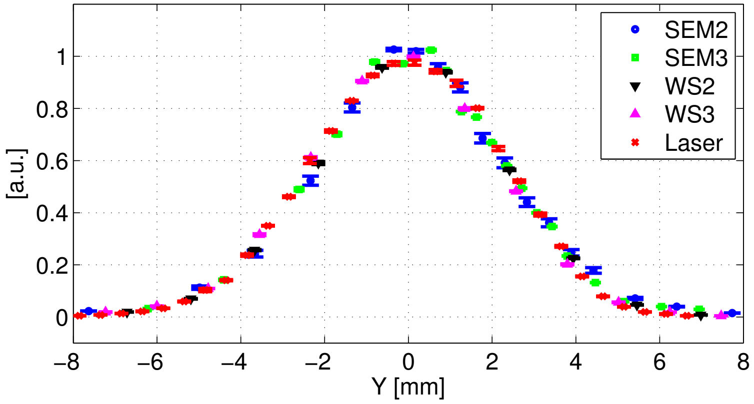


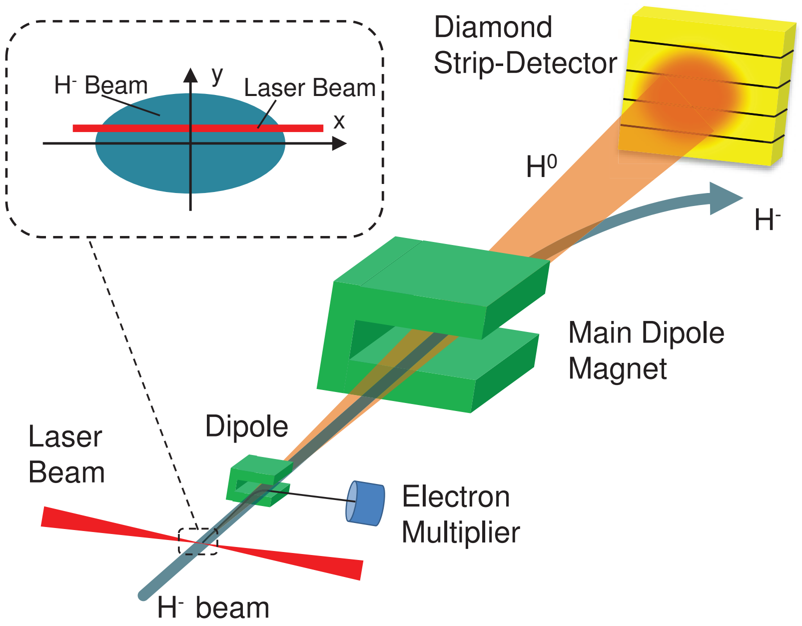
Figure 11: Overlay of 107 MeV H^- beam σ-scaled profiles recorded with different devices.

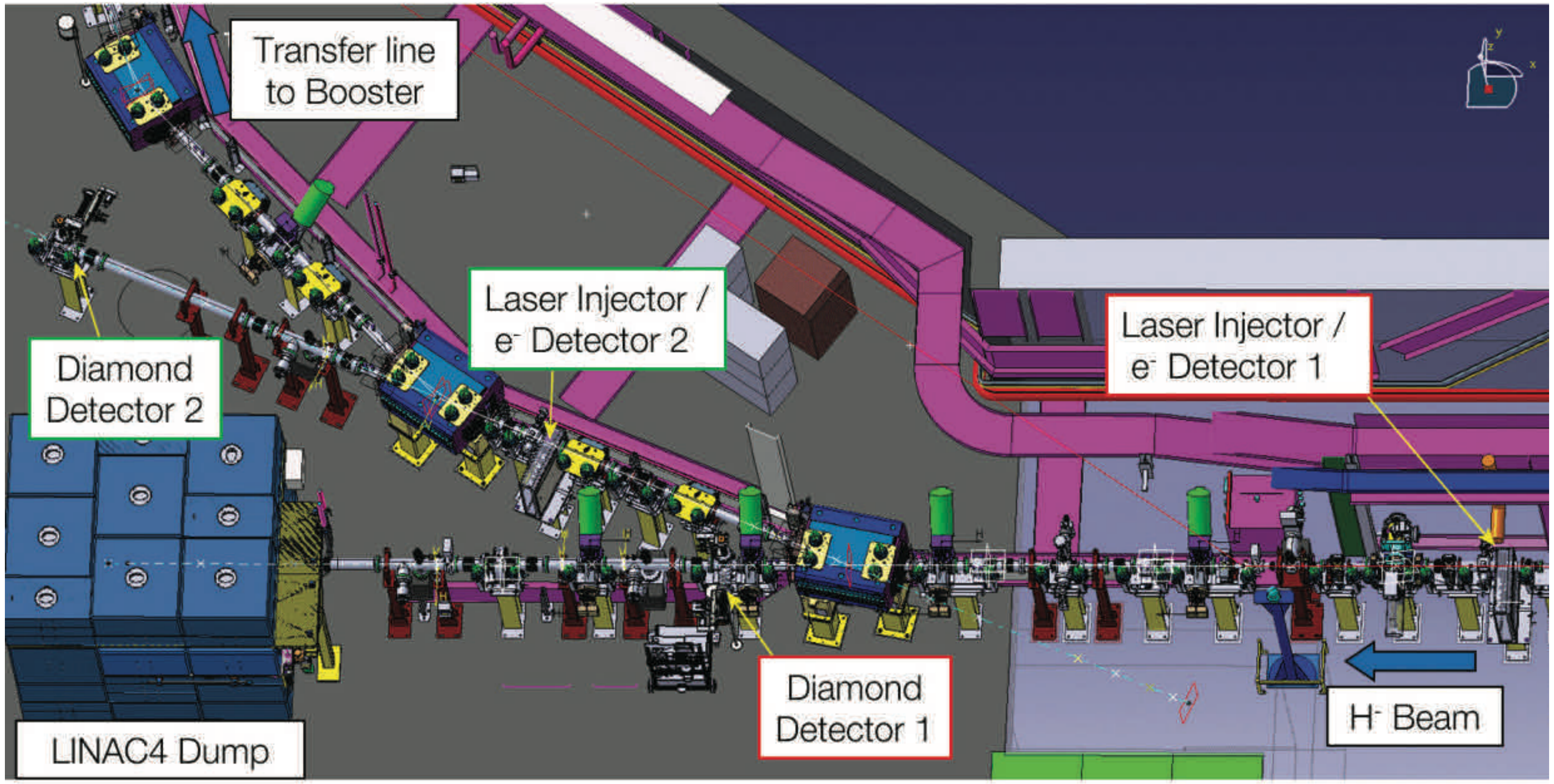
Laserwire profiles in good agreement (<2%) with nearby conventional diagnostics

S. Gibson et al, *'Experimental results of a compact laserwire system for non-invasive H- beam profile measurements at CERN"s LINAC4'*, TUPB005, IBIC 2016.

H^- laserwire: Linac4 final system concept

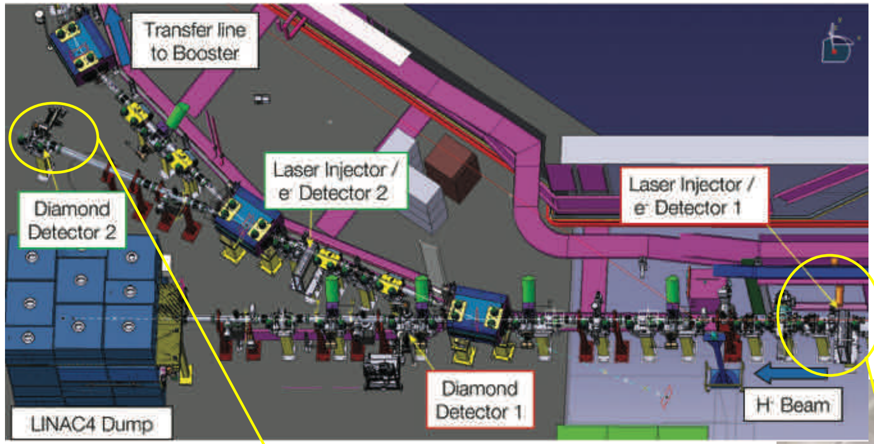
- *Measurement of electrons and neutralised H, wit two laser locations:*



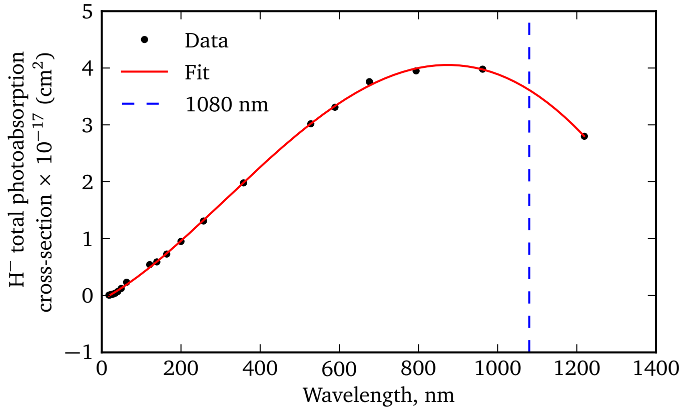


H^- laserwire: Linac4 profile & emittance scanners

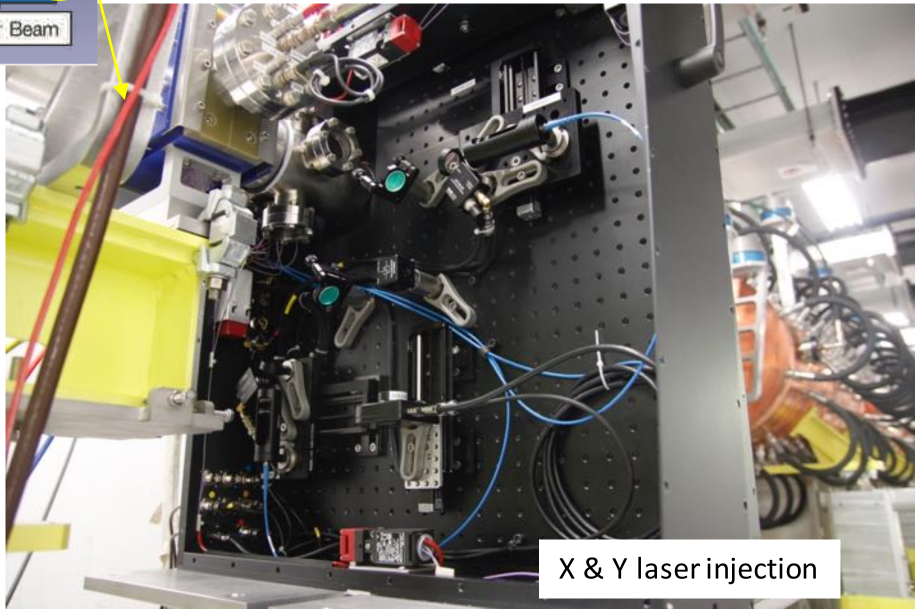
- *Final dual-station laserwire was installed in 2017 for operation at 160 MeV*

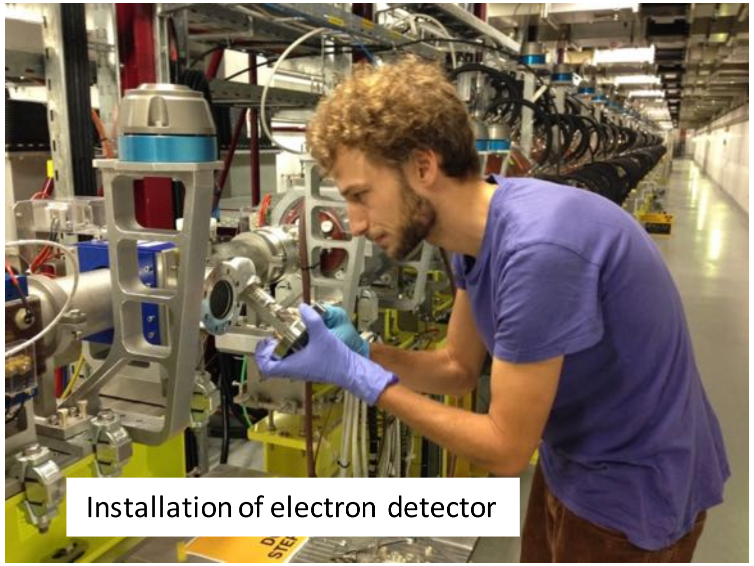


- *4 laserwires in X and Y at two locations*
- *Detectors measure stripped electrons and H^0*




Orthogonal diamond strip detectors

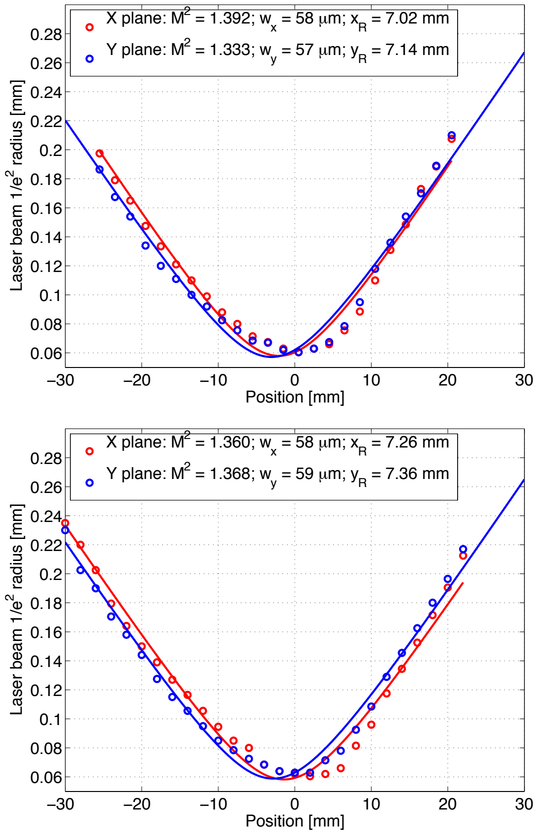

X & Y laser injection


Installation of electron detector

H^- laserwire: Linac4 profile scanner first results

- First electron detector profile results from commissioning at 160 MeV presented at IPAC18:

Well aligned laser beams with tightly focused waist <60um



Fibre lengths set to illuminate IP in X & Y at slightly different times:

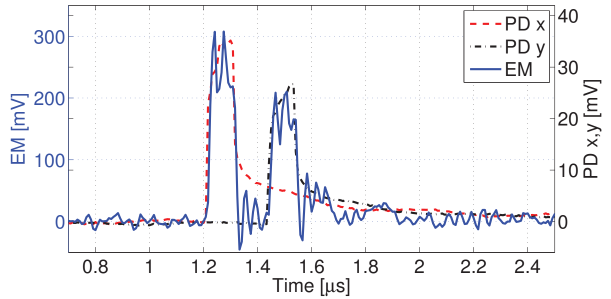


Figure 5: Signal of electron multiplier (EM) and photodiodes of horizontal and vertical laser beam (see PD in Fig. 3).

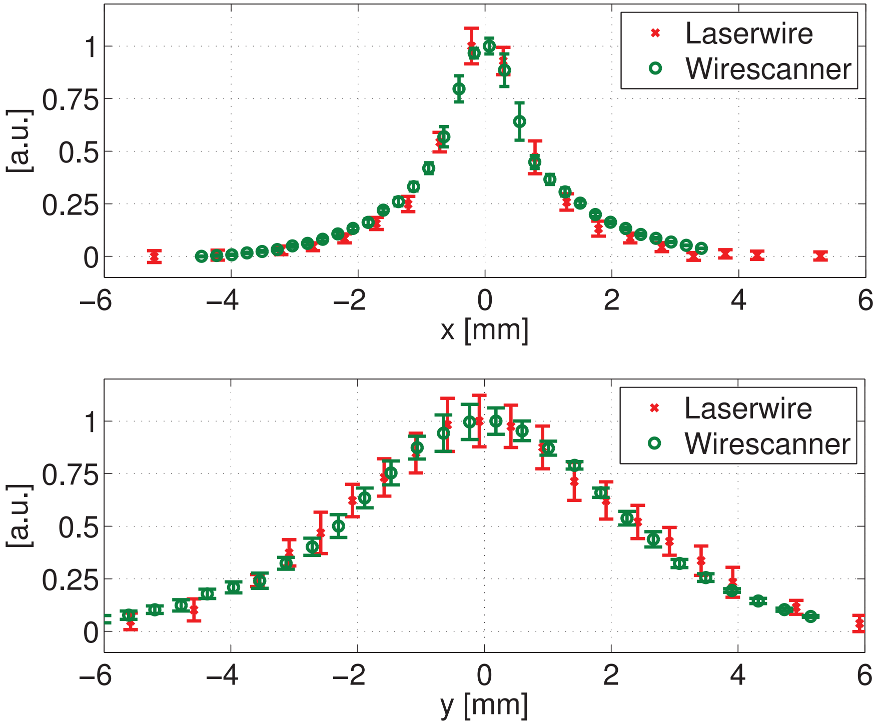
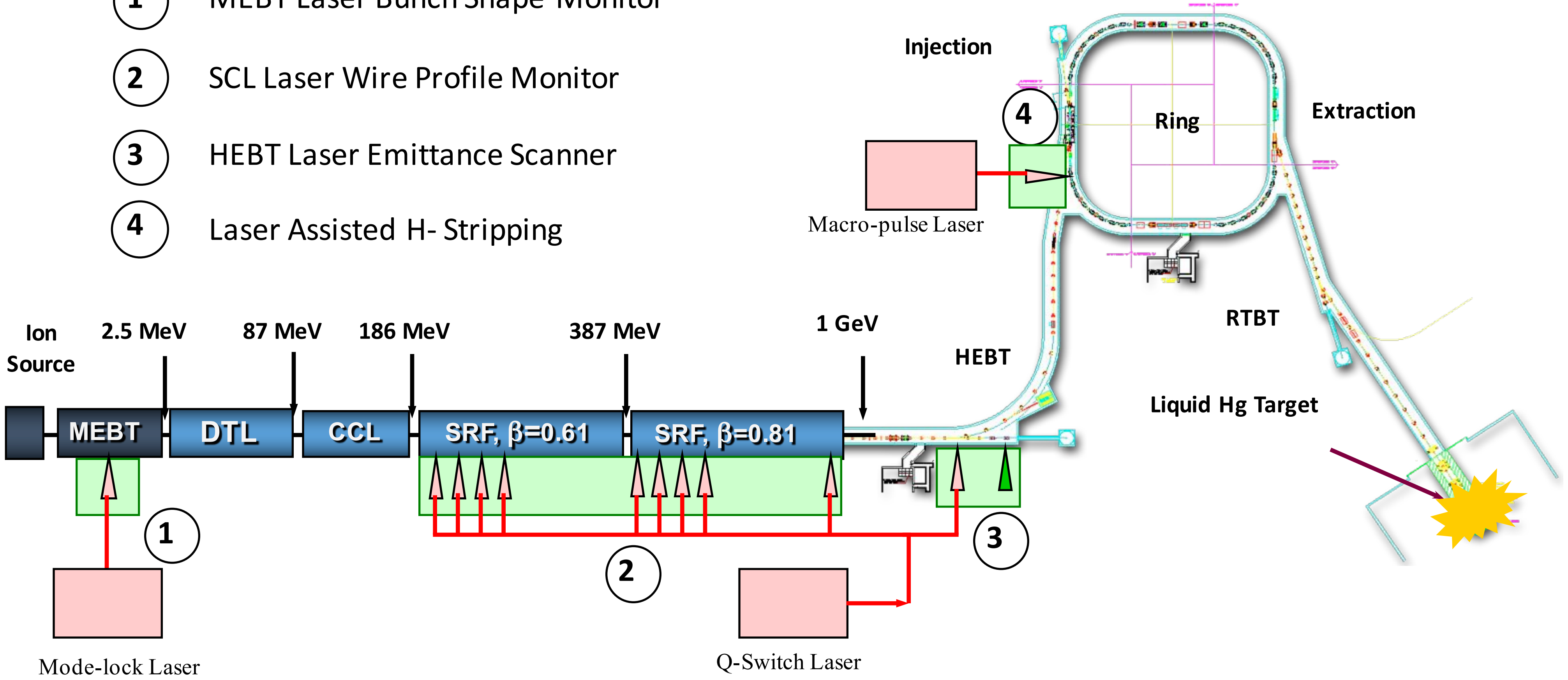


Figure 6: Beam profiles recorded with the laserwire and a wire-scanner in both planes. As the wire scanner is located 2.7 m downstream of the laserwire, its profile is scaled according to the beta-function ratio of both locations.

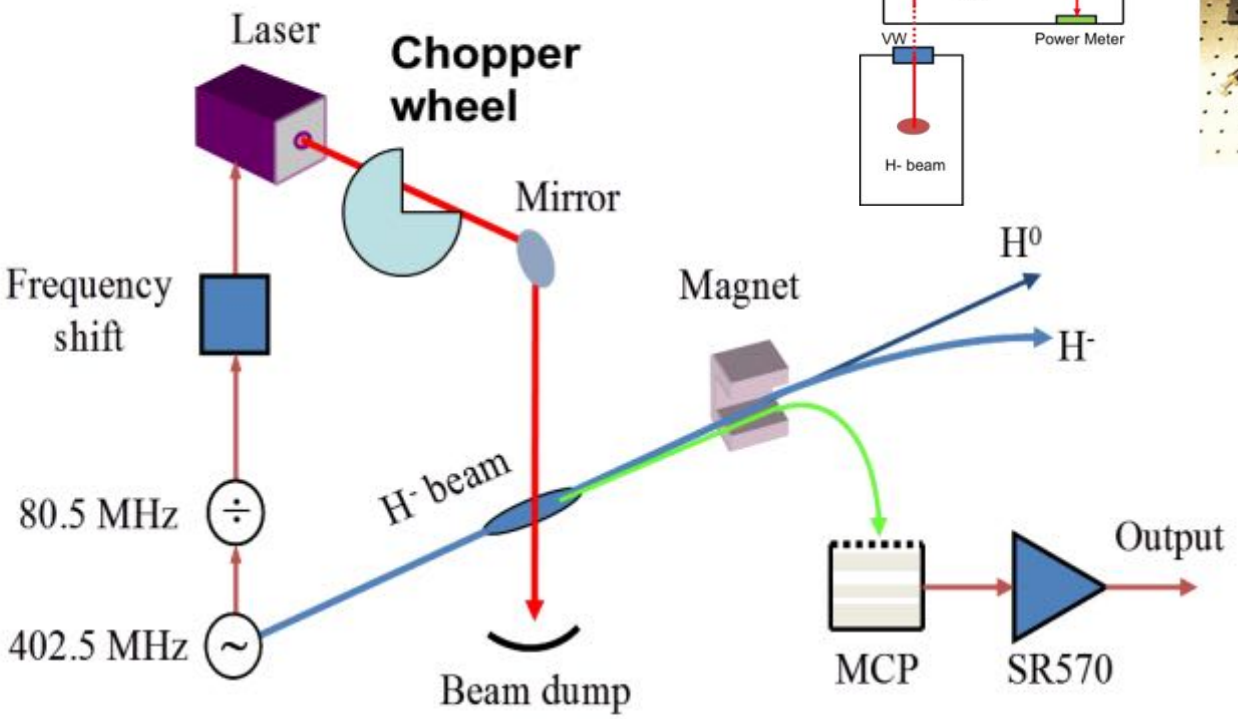
H$^-$ diagnostics at SNS

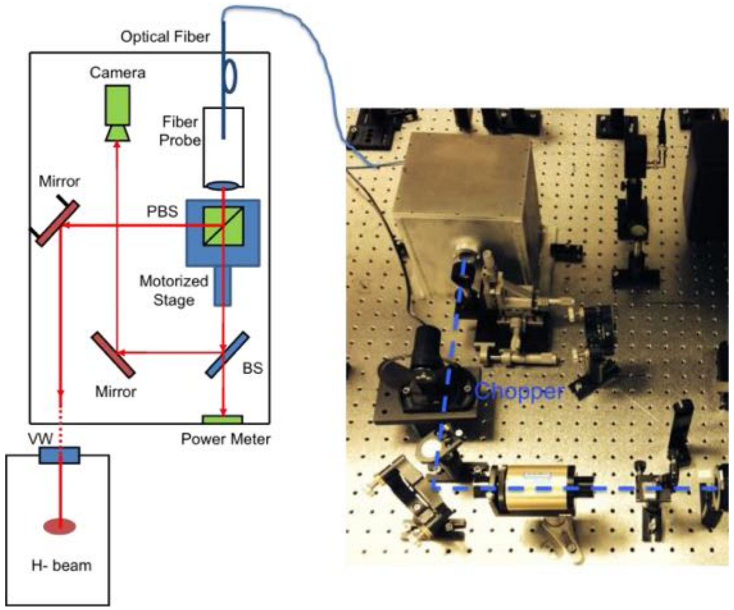
1. MEBT Laser Bunch Shape Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance Scanner
4. Laser Assisted H- Stripping



Yun Liu, H- stripping workshop

H⁻ diagnostics at SNS: longitudinal bunch profile





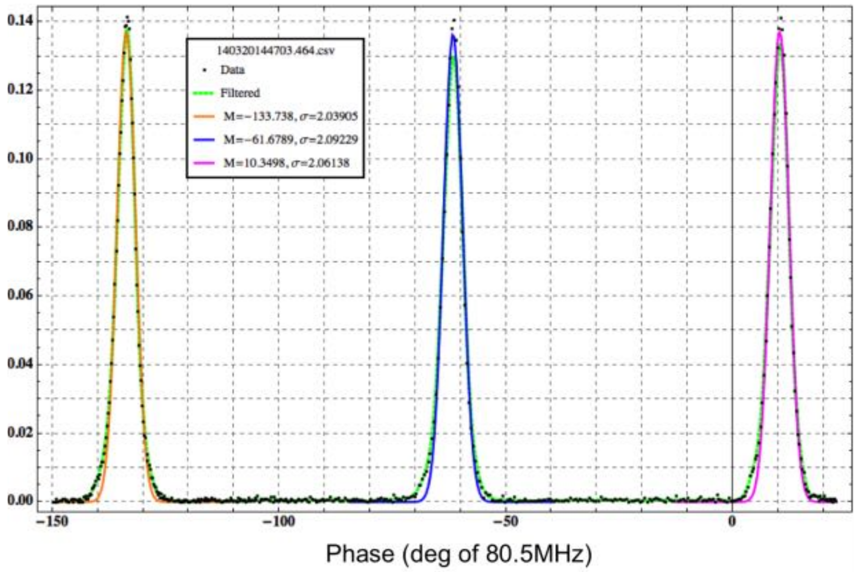
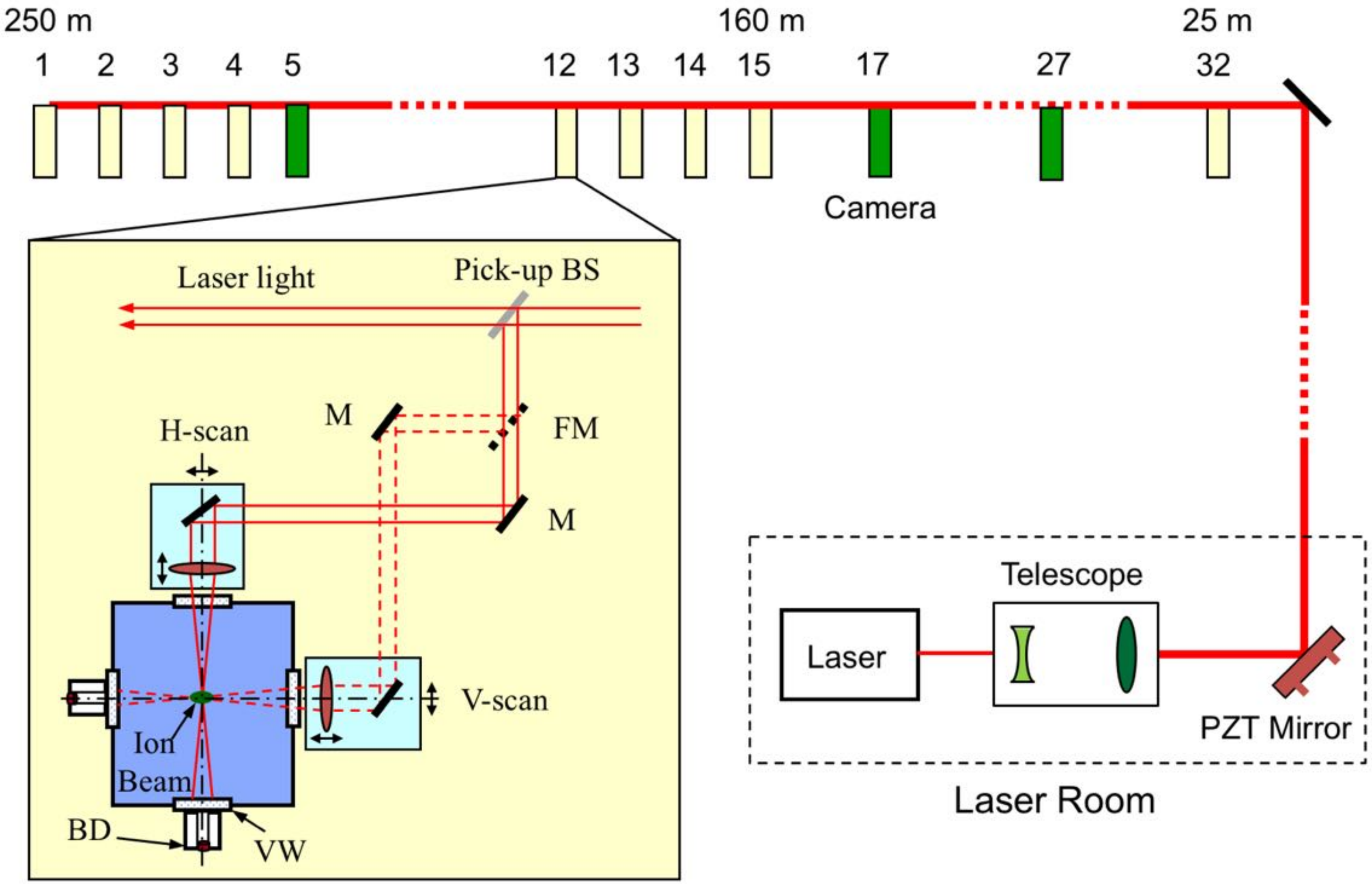


Figure 3: Typical bunch profile taken with phase shift technique. Peaks are distributed 72° apart.

Longitudinal laser wire at SNS, IBIC 2013

H⁻ diagnostics at SNS: laserwire transverse profiles



Liu et al, *NIMA* **612** (2010) 241–253;
Appl. Opt. **49** (2011) 6816-6823.

Yun Liu, H- stripping workshop

H^- stripping at SNS: first demonstration in 2017

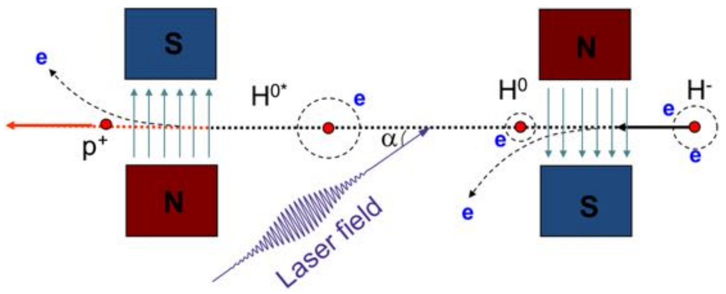


FIG. 1. Schematic of the laser stripping concept in this experiment, showing Lorentz stripping of the first electron by a dipole magnet in the first step (the far right), resonant excitation of the second electron by the laser in the second step (the middle), and, finally, stripping of the excited electron by the second dipole magnet (the left).

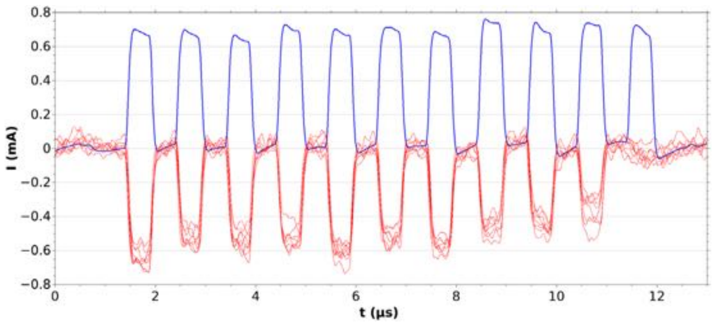
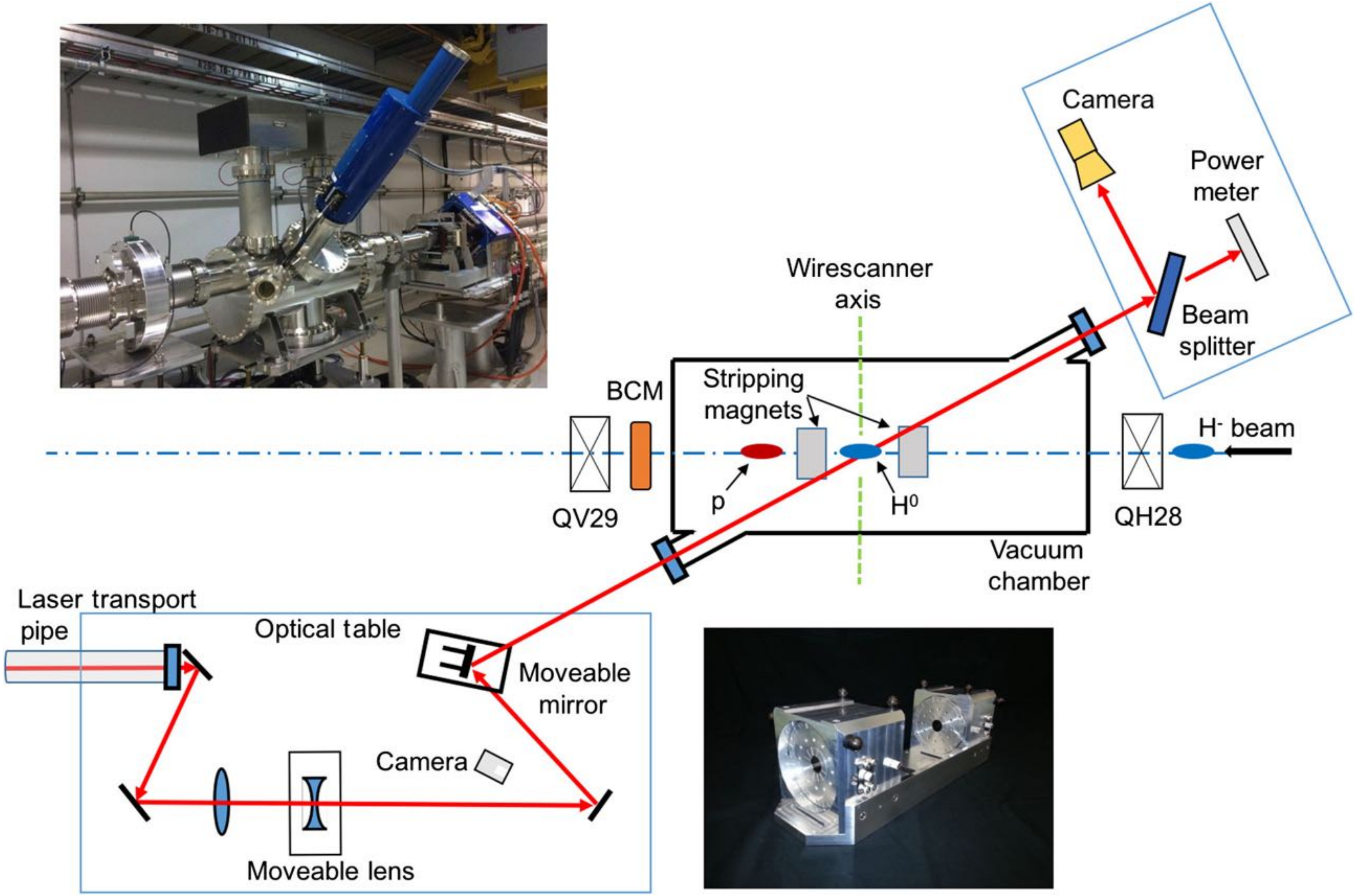


FIG. 4. The experimental results. The average beam current for a 11 μs H^- beam measured by the beam current monitor at the interaction point before stripping (blue), and eight separately measured stripped proton beam pulses on the same beam current monitor during stripping (red).



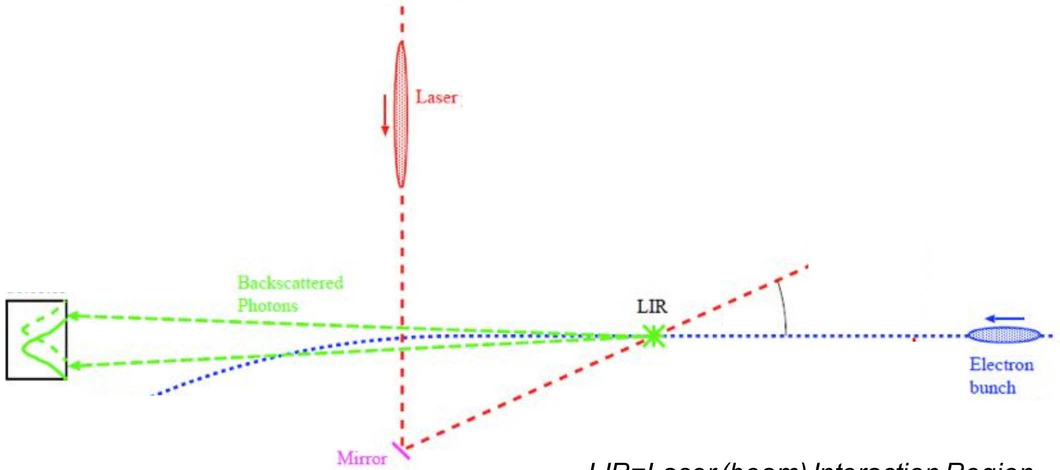
PRL **118,** 074801 (2017)

Polarimetry at LEP: & future FCC-ee?

Polarimeter principle

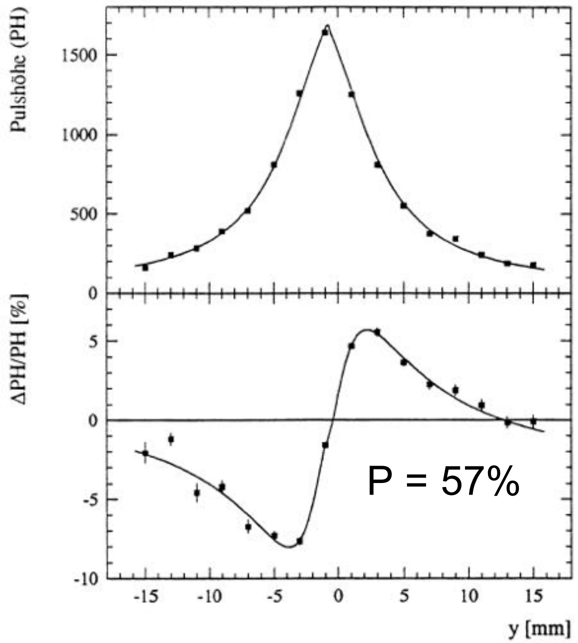
- Scattering circularly polarized light on a transversely polarized e-/c+ beam (assume vertical P_T) generates a polarization depend shift of the out-coming photon profiles.
  - The beam polarization can be assessed from the scattered photon distribution.

- Typical sensitivities at the Compton photon detector: $\Delta y = S \times P_T$
  - *$S \sim 5 – 10\ \mu m / \%$ (depends on lever arm LIR – detector).*
  - *By flipping the laser helicity one only has to measure a relative shift.*



LIR=Laser (beam) Interaction Region

γ profile and asymmetry (R/L laser helicity) at LEP



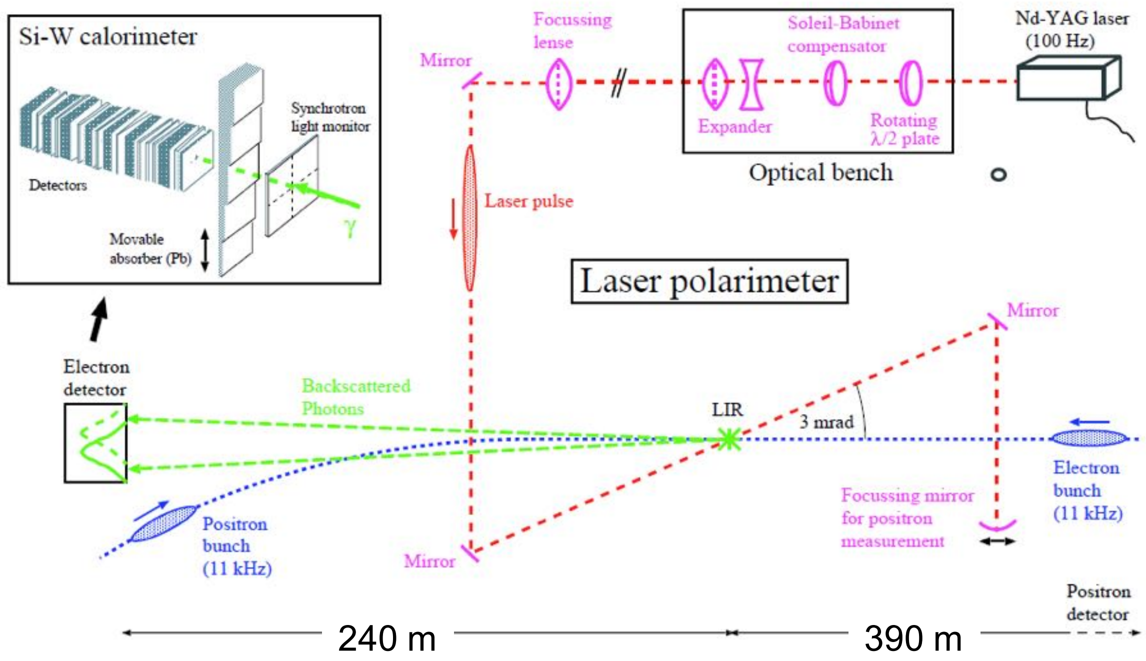
R. Assman (PHD)

2 J. Wenninger

The LEP polarimeter

- The LEP polarimeter was installed in LEP point 1 (now in the middle of the ATLAS detector).
  - ND-YAG laser @ 100 Hz, interleaved right / left circularly polarized laser light (optical bench),
  - Laser light path into the LEP vacuum chamber, in vacuum mirrors,
  - Si strip detector (2 mm strips) for gamma profile measurement.

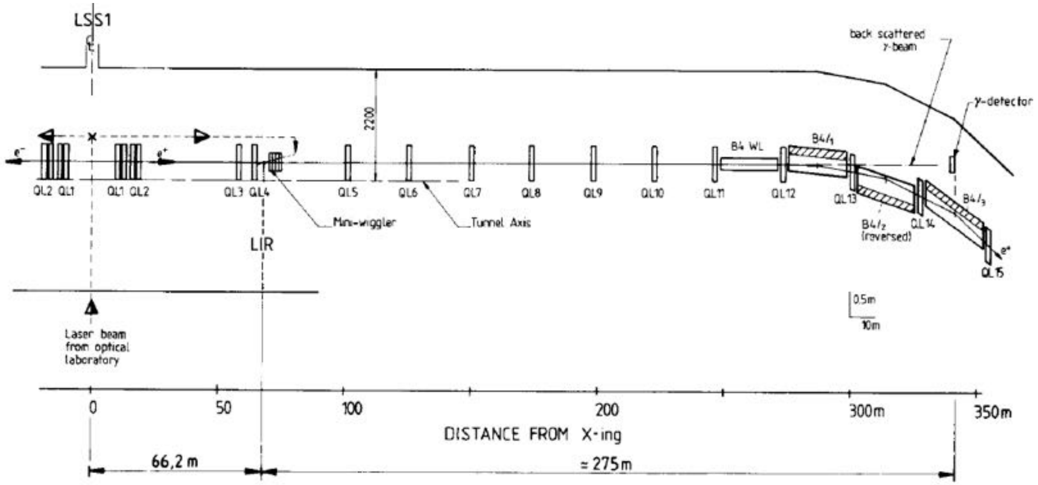
- Both e- (primary) and e+ polarizations could in principle be measured.
  - e+ measurement difficult due to mirror vibration issues, performed only 2-3 times during the entire LEP area.
- Distances to photon detectors of 240m and 390m.

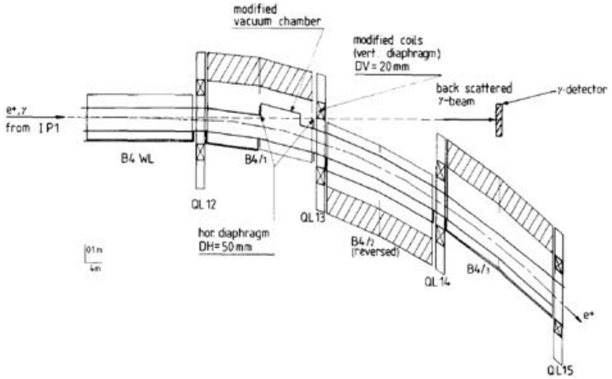


J. Wenninger

The LEP polarimeter (2)

- The backscattered Compton photons were extracted at the entrance of the arc (Al window in the vacuum chamber ~ 50 x 25 mm^2).
  - Note that the actual layout was actually reversed (design drawing !).
  - β functions at LIR (Laser-beam IR) ~40-120 m, beam sizes ~0.4 -1 mm.



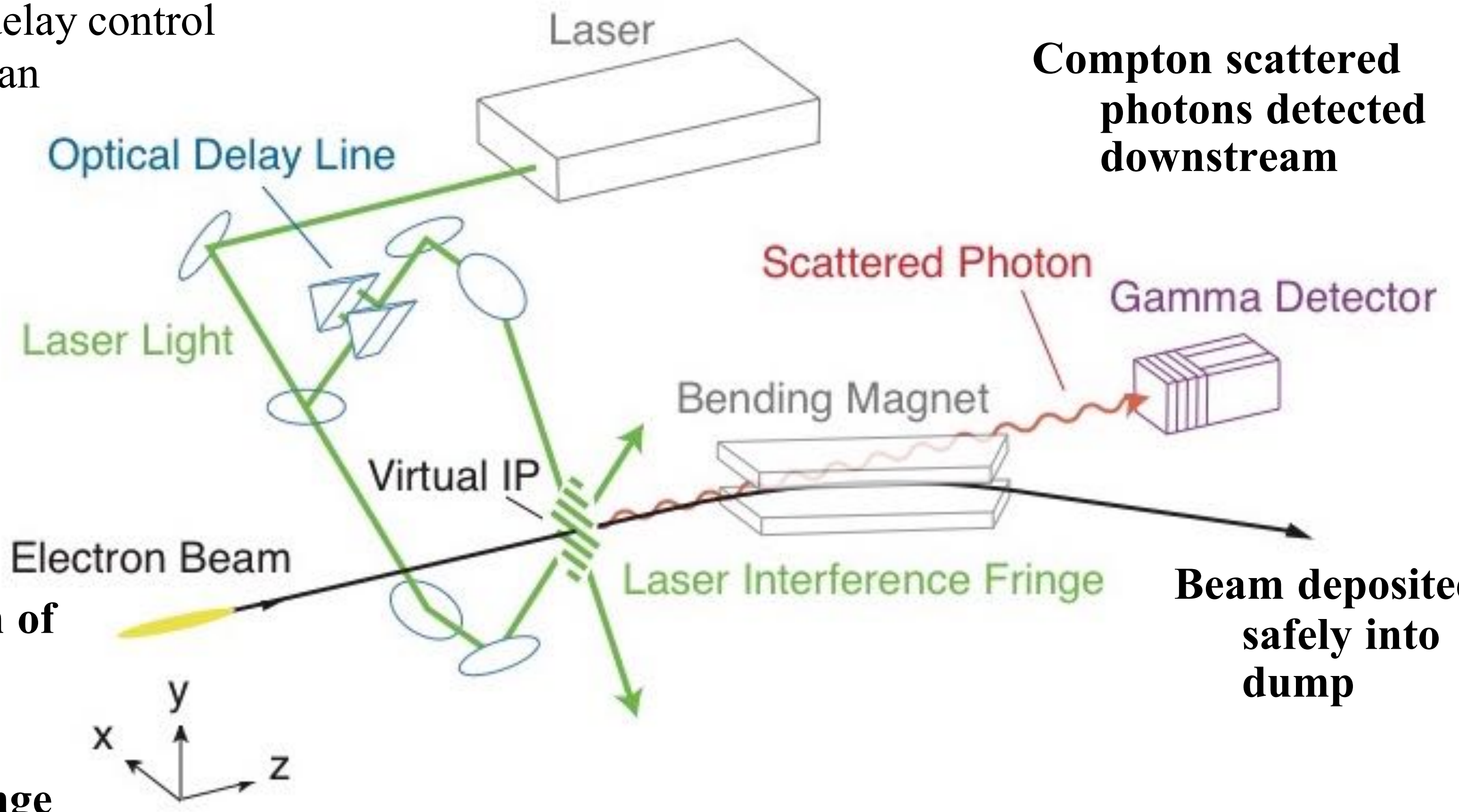


Shintake Monitor: prinicple

- *Aims at measuring σ_y = 37 nm beams for future linear collider. Installed at ATF2 in KEK.*

Split into upper/lower path
Optical delay control
phase scan

Compton scattered photons detected downstream



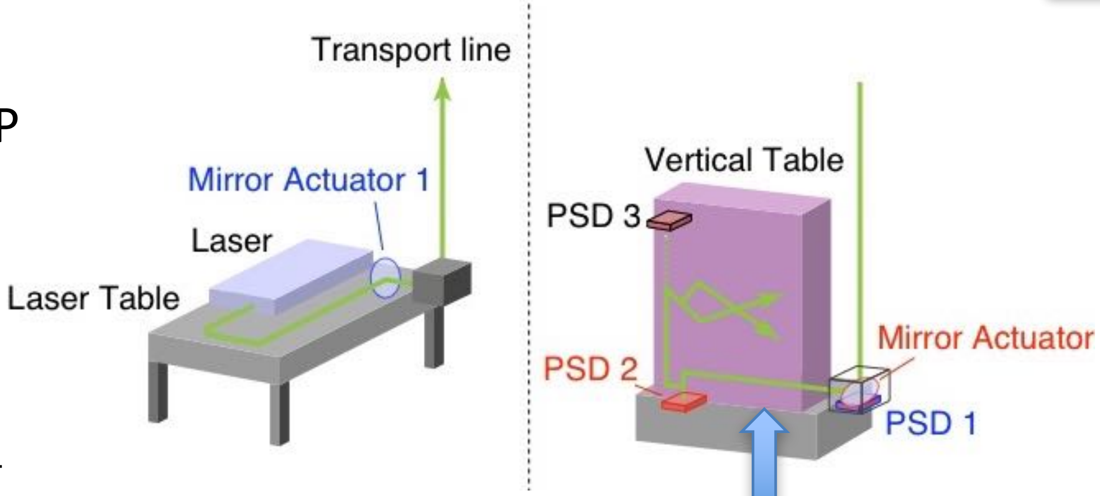
Beam deposited safely into dump

Collision of e- beam with laser fringe

Shintake Monitor: layout

Laser table → vertical table @ IP

20 m transport line



Vertical Table (Main Optical Table)

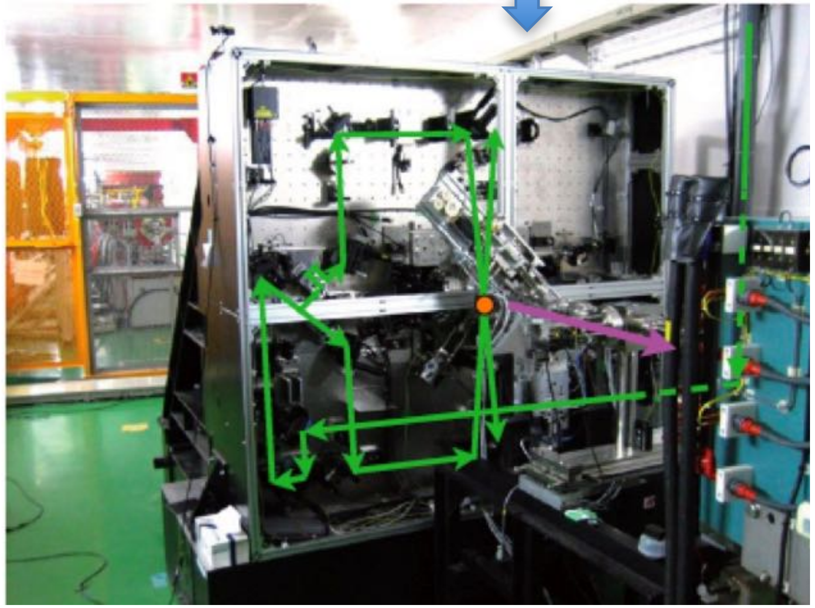
- Emerge from bottom right
- First enter reflective mirror

- **Reflected light split into upper/lower path**
- optical path created for each mode

  ➔ Interference fringe

- **Transmitted light to diagnostic section**

  PSD, photodiode (PD), PIN-PD, phase monitor



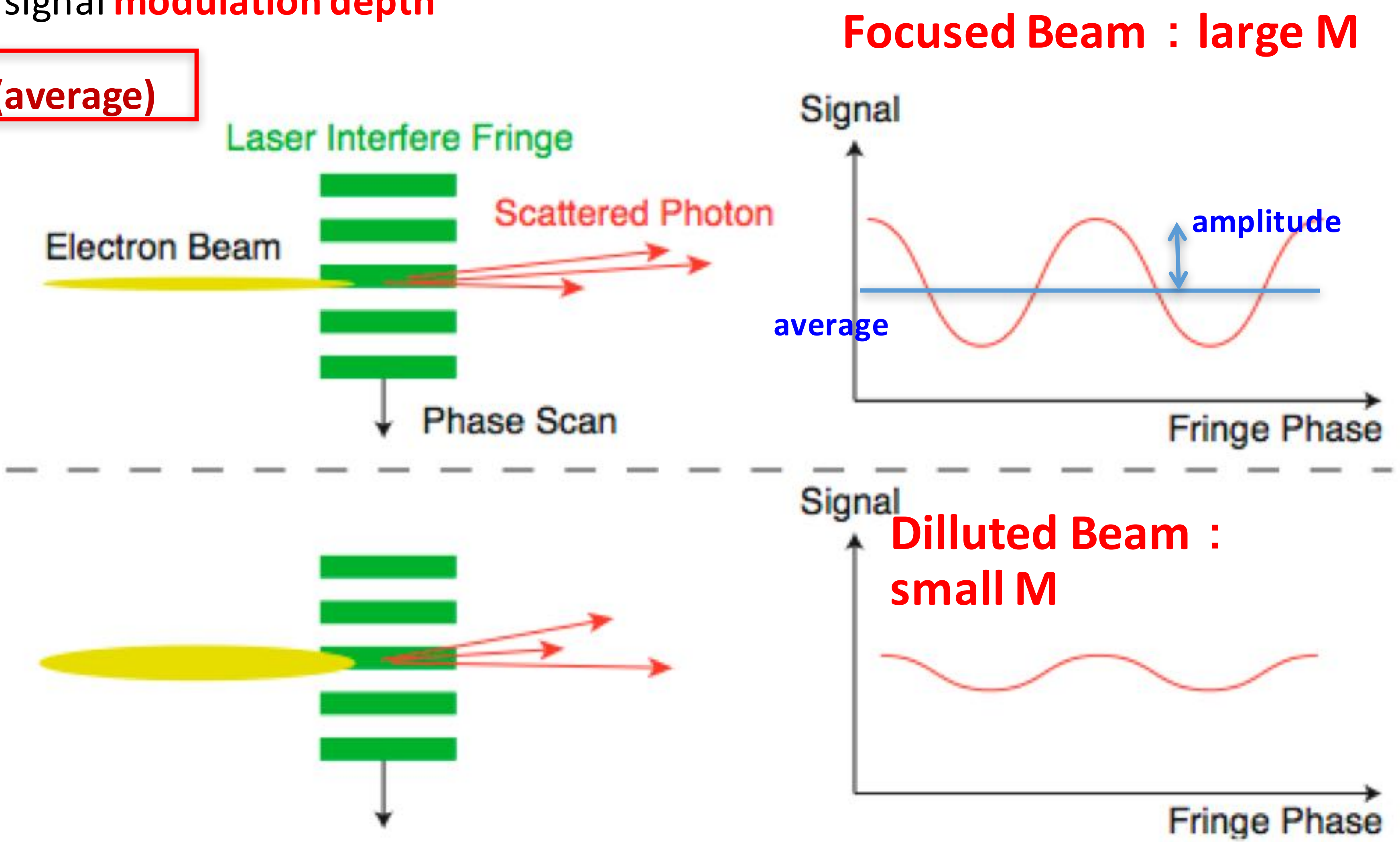
1.7 m × 1.6 m

Jacqueline Yan, Univ of Tokyo TIPP2011

Shintake Monitor: modulation depth

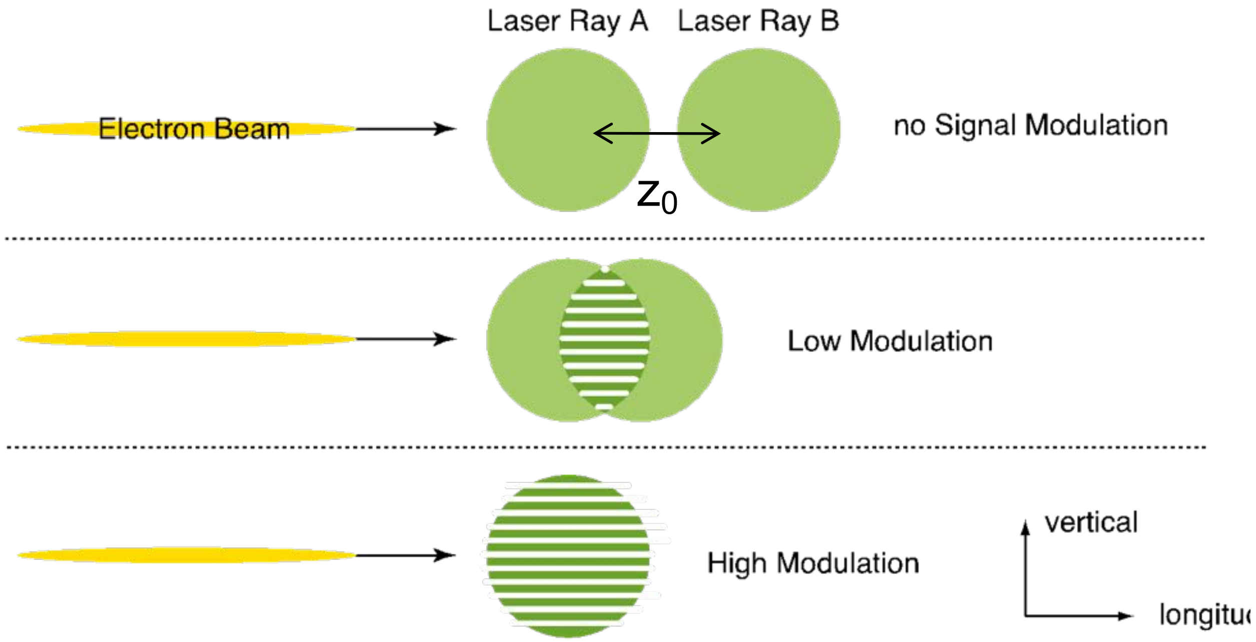
Detector measures signal **modulation depth**

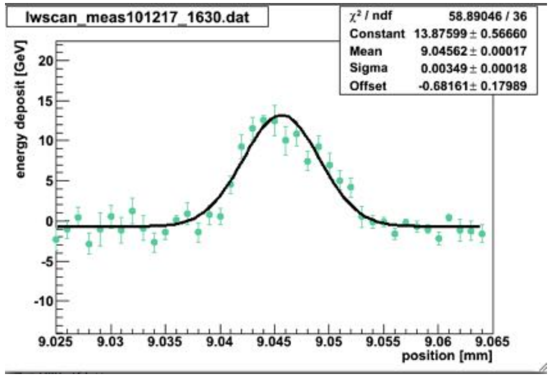
M = (amplitude) / (average)



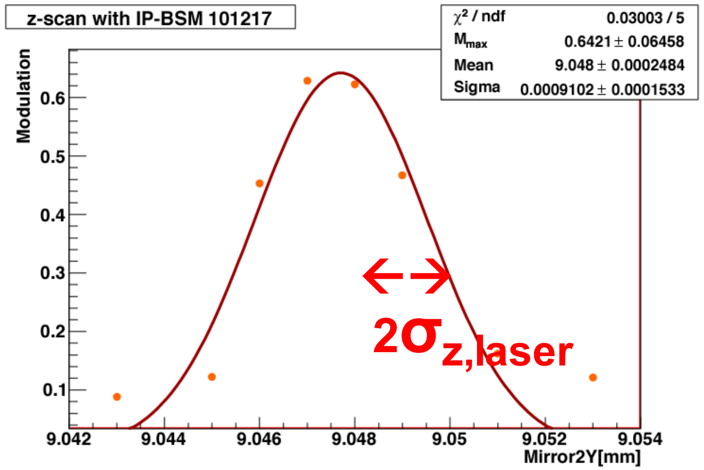
Shintake Monitor: alignment

Longitudinal laser alignment : z-Scan





$$M_{\text{meas.}} = \exp\left(-\frac{z_0^2}{8\sigma_{\text{laser}}^2}\right) M_{\text{ideal}}$$



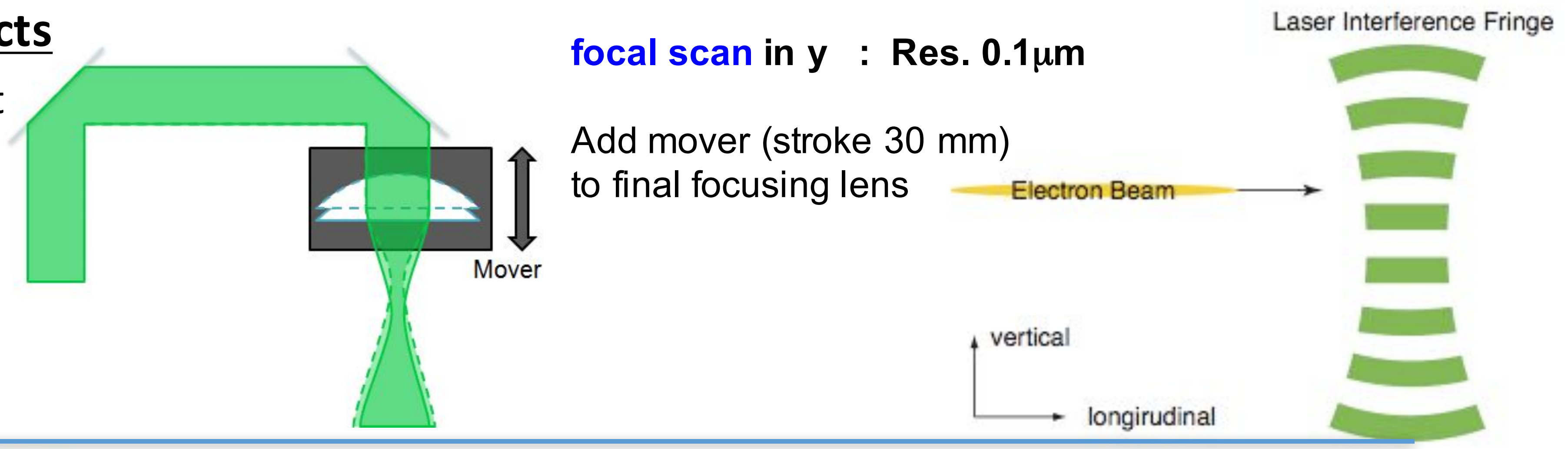
- **find position of max M**
- ***can also get z laser spot size***

Shintake Monitor: systematics

Spherical Wavefront Effects

- offset from laser focal point

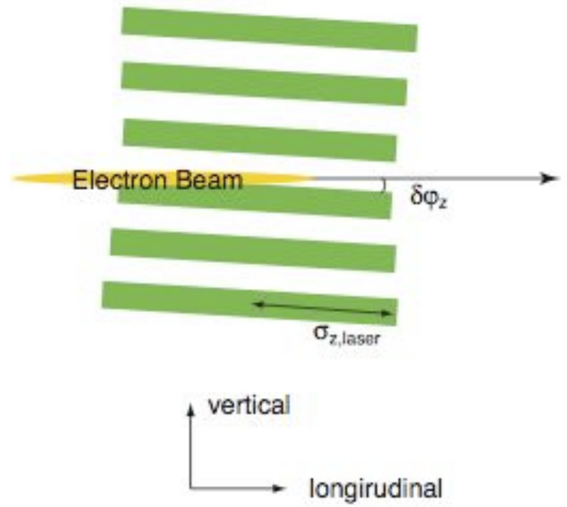
  → beam "feels" distorted fringes



focal scan in y : Res. 0.1μm

Add mover (stroke 30 mm) to final focusing lens

Fringe Tilt



$$\text{longitudinal}: \quad \sigma^2_{meas} \rightarrow \sigma^2_{ideal} + \delta\varphi_z{}^2 \sigma^2{}_{z,laser}$$

$$\text{transverse}: \quad \sigma^2_{meas} \rightarrow \sigma^2_{ideal} + \delta\varphi_t{}^2 \sigma^2_x$$

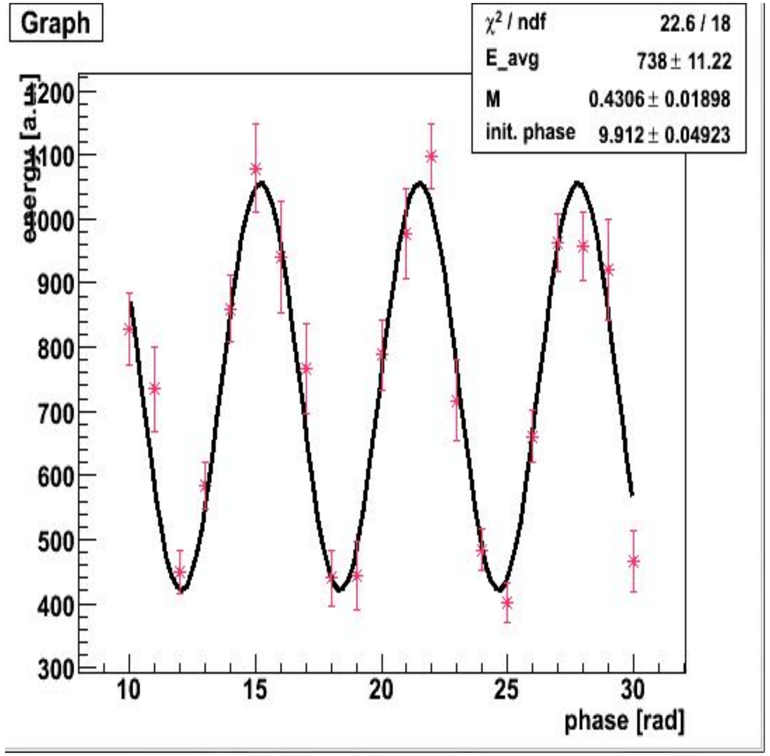
Tilt monitor:

PSD resolution 10 μm

→ Δφ ~0.3 mrad

Jacqueline Yan, Univ of Tokyo, TIPP2011

Shintake Monitor: results



M,meas = 0.43 +/- 0.02
(σy,meas = 55 +/- 2 nm)

M,meas = 0.54 +/- 0.04
(σy,meas = 47 +/- 3 nm)

Assumptions:
- Gaussian – like profile
- pointing jitter ～15% of σlaser
- Alignment precision based on lwscan & zscan

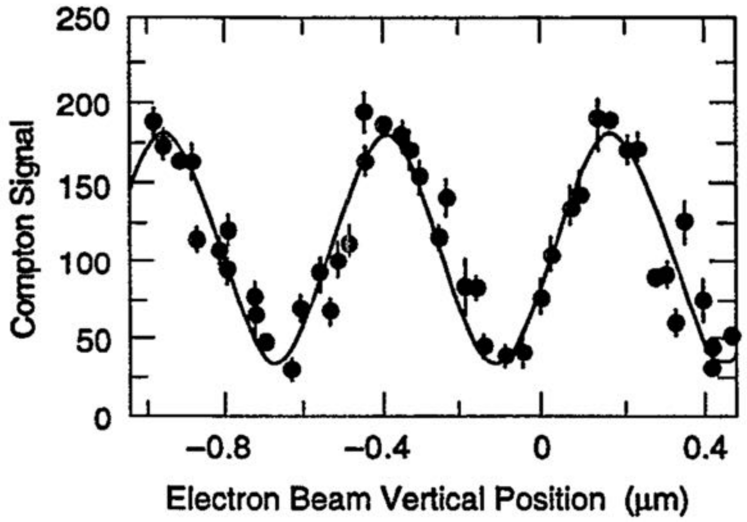


FIG. 2. Measurement of the vertical height of the beam at the FFTB focal point with the laser-Compton spot monitor. The observed fringe spacing agrees well with the 0.5 μm expected from the wavelength of the laser. The beam height is determined from the ratio of the Compton signal at the minima of the fringe pattern to the signal at the peaks of the pattern. In this case, the beam height is 73 nm.

Stability Studies Based on IPBSM Fringe Pattern Analysis
FJPPL-FKPPL ATF2 Workshop Mar 17-19, 2014 LAPP
Jacqueline Yan, S. Komamiya, K. Kamiya（The University of Tokyo）
T.Okugi, T.Terunuma, T.Tauchi, K.Kubo (KEK)

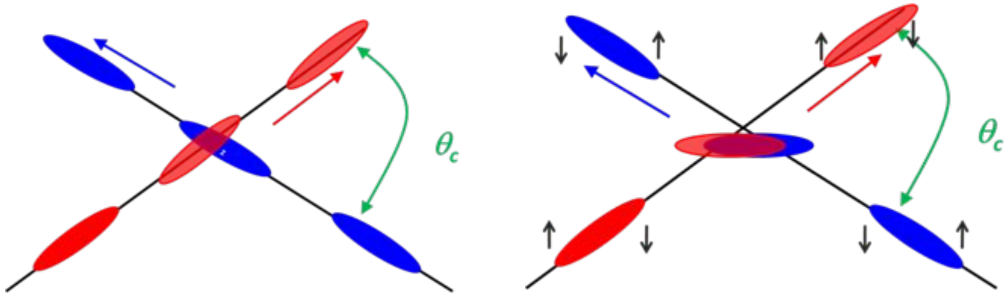
Focusing of Submicron Beams for TeV-Scale e^+e^- Linear Colliders
PRL 754 13 2479-82(1995)

Motivation: Crab bunch rotation and pile-up at HL-LHC

- LHC luminosity is currently limited by geometrical overlap, due the crossing angle (285μrad) between beams:

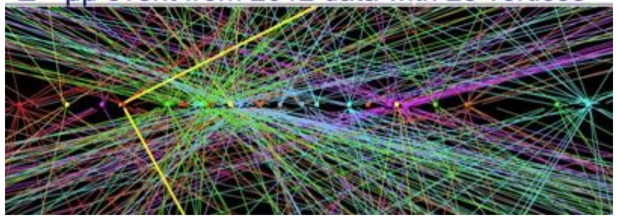
$$\mathcal{L} = \frac{N_1 N_2 f N_b}{4\pi\sigma_x\sigma_y} \qquad R(\theta) = \frac{1}{\sqrt{1+(\frac{\sigma_s}{\sigma_x}tan\frac{\theta}{2})^2}}$$

- At HL-LHC, RF crab cavities will rotate the bunches to collide head on:

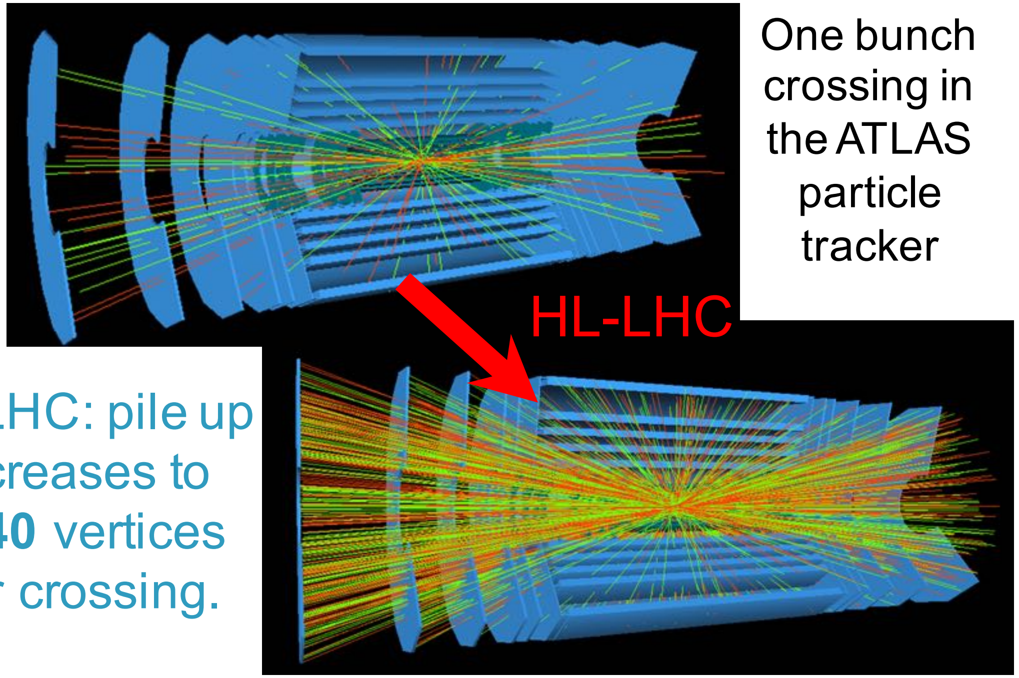


23 interactions per bunch crossing at nominal LHC

Z→μμ event from 2012 data with 25 vertices



One bunch crossing in the ATLAS particle tracker



HL-LHC: pile up increases to **~140** vertices per crossing.

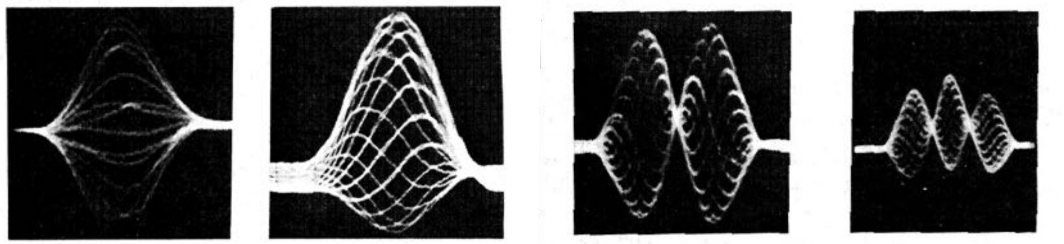
Distribution in beam direction matters when identifying vertices.

Motivation: intra-bunch diagnostics / crabbed bunches

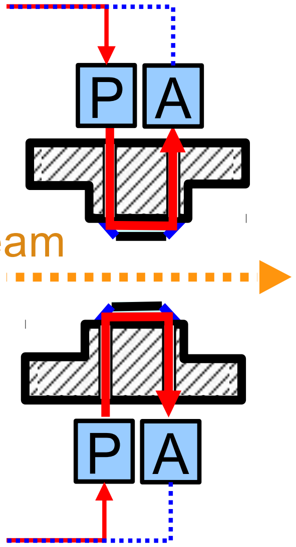
- The EO-BPM project grew out of idea to upgrade the Head Tail monitor; to visualize and study beam instabilities as they occur.
- Applicable at HL-LHC to monitor effects on crabbed bunches.
- Standard approach:
  - Stripline BPMs + fast sampling oscilloscopes.
- Limitation:
  - Bandwidth up to a few GHz, limited by the pick-up, cables, and acquisition system.
- A new technology is needed:

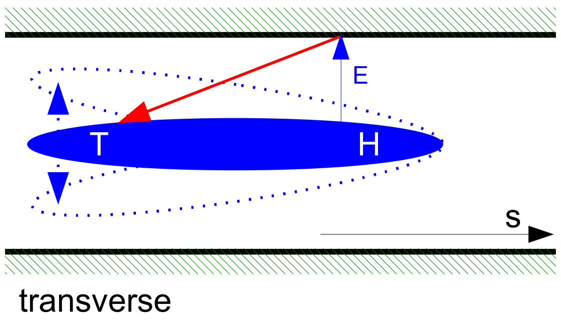
Fast electro-optic pick-up

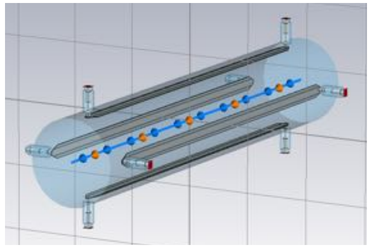
e.g. J. Gareyte, "Head-Tail Type Instabilities in the PS and Booster", CERN, 1974

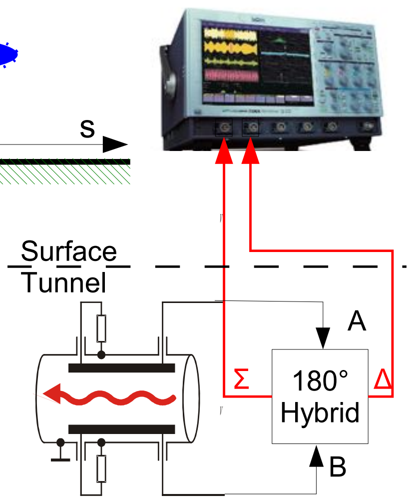


a) mode m = 0, χ = 0   b) m = 0, χ = 2.3 radians   b) m = 1, χ = 6.9 radians   d) m = 2, χ = 6.9 radians



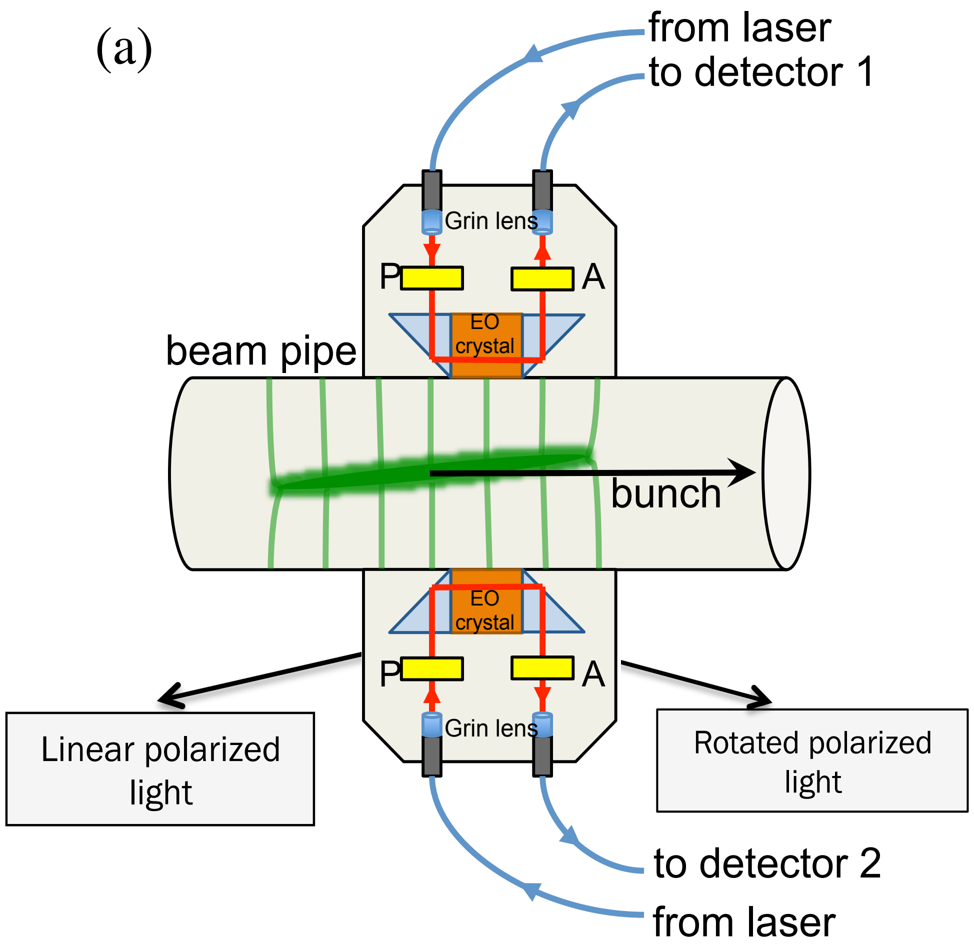






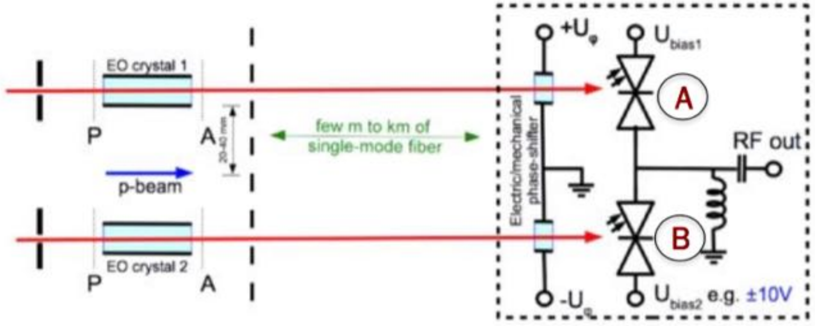
Electro-Optic Beam Position Monitors

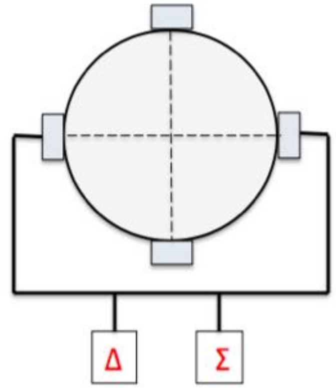
Aim to develop fast, intra-bunch diagnostics to monitor crab-rotation of bunches.



- Replace pick-ups in a button BPM with electro-optic crystals.
- The electric field from a passing bunch induces a ***polarization change*** of light through the crystal.
- Fibre-coupled design with laser and detectors 160 m away from accelerator tunnel.
- Transverse position along the 1ns LHC bunch is monitored.

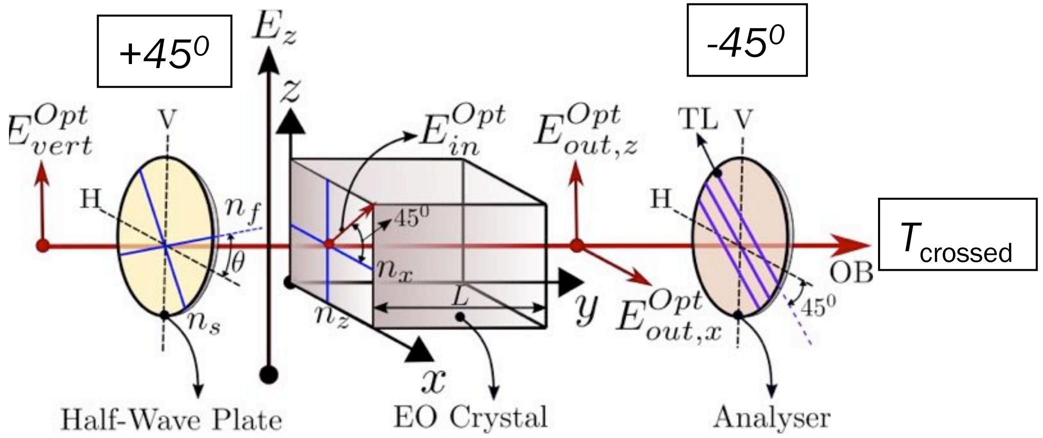
Δ / Σ

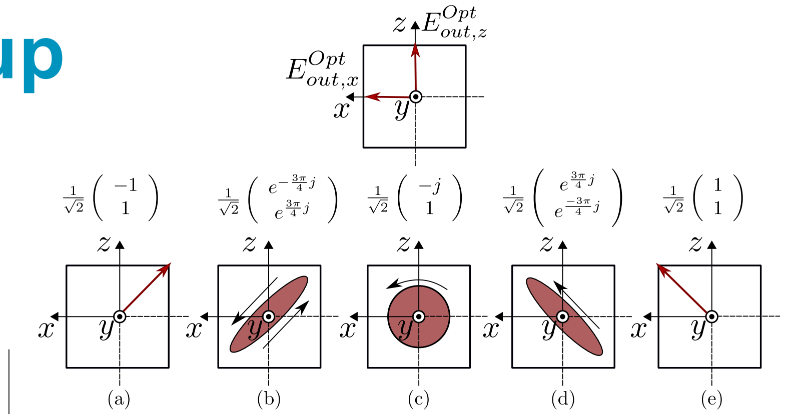




EO pick-up

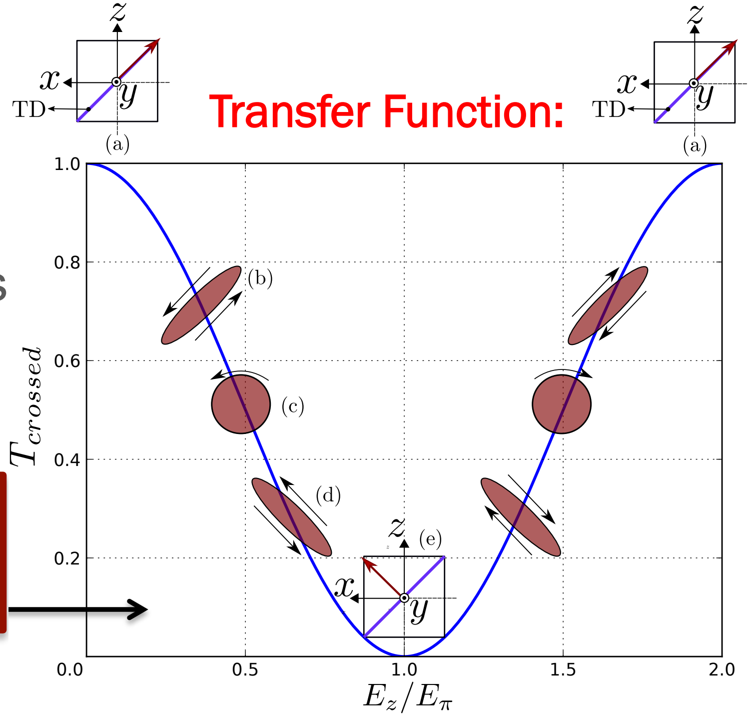
Amplitude EO modulator:





- Different input and output polarisations.
- Major and minor axes always at 45 and –45 degrees
- LNB: natural birefringence -> Thermal drift.
- Transfer function:

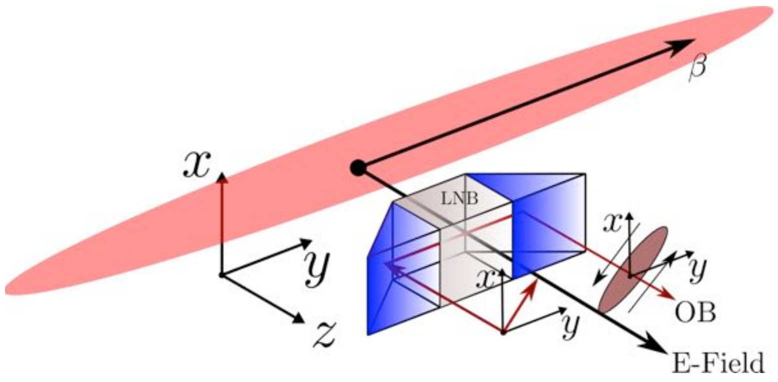
$$T_{crossed} = \sin^2\frac{\Gamma}{2} = \sin^2\left(\frac{\Gamma_o}{2} + \frac{\pi}{2}\frac{E_z}{E_\pi}\right)$$

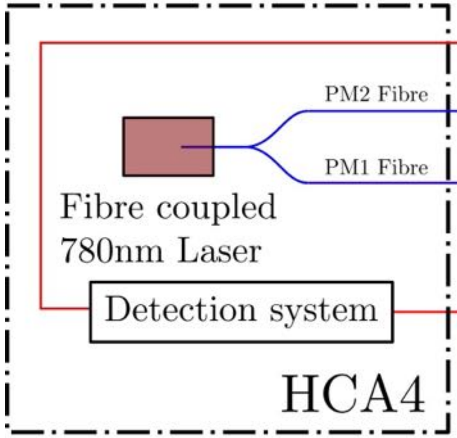


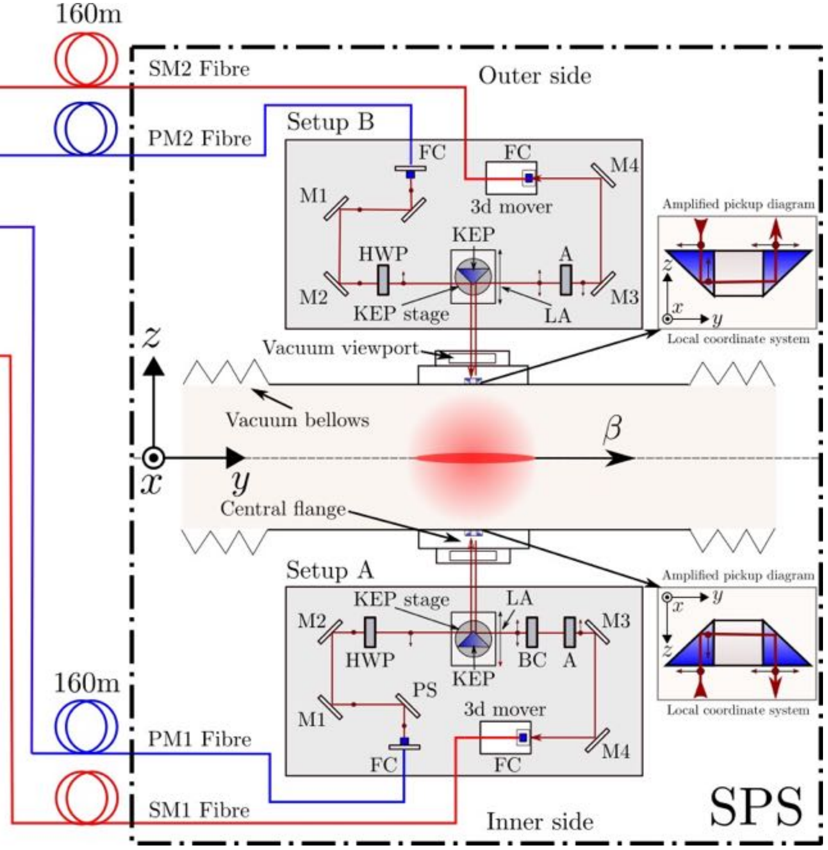
ROYAL HOLLOWAY UNIVERSITY OF LONDON

Optical setup

- Bunch Coulomb field as modulating field
- Optical arrangement must replicate an amplitude modulator:

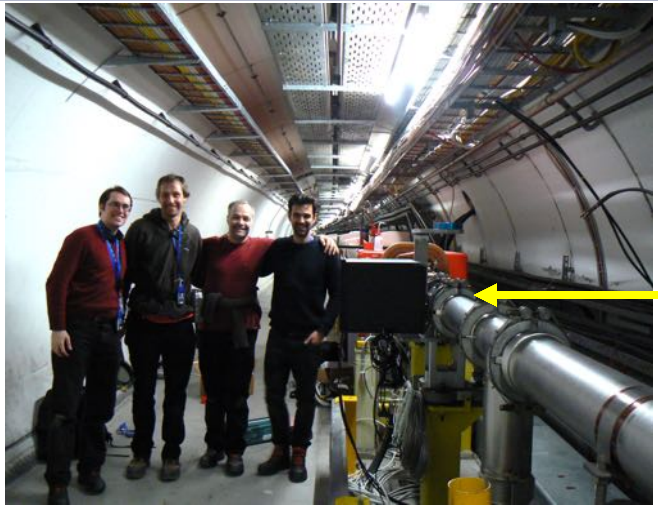


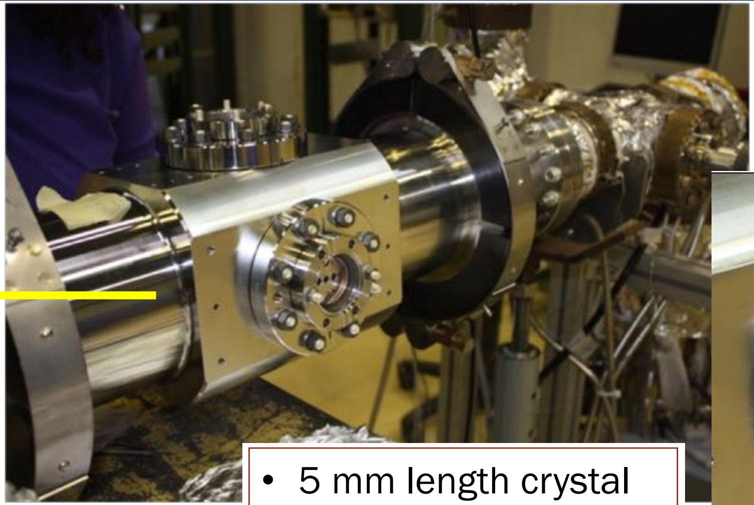




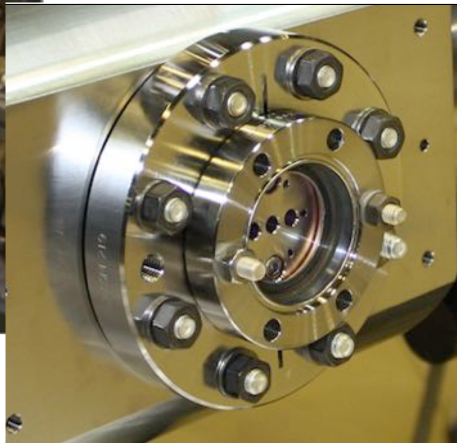
- 160m separation between the rack room and pickup prototype.
  780nm light carried by PM fibre and SM fibre for return.
- Polariser splitter, HWP and Analyser to set a crossed polarisers configuration.
- Arrangement of set of mirrors for alignment.

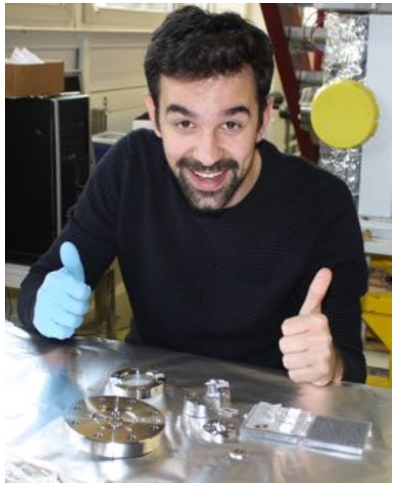
EO-BPM: prototype system at SPS since 2016

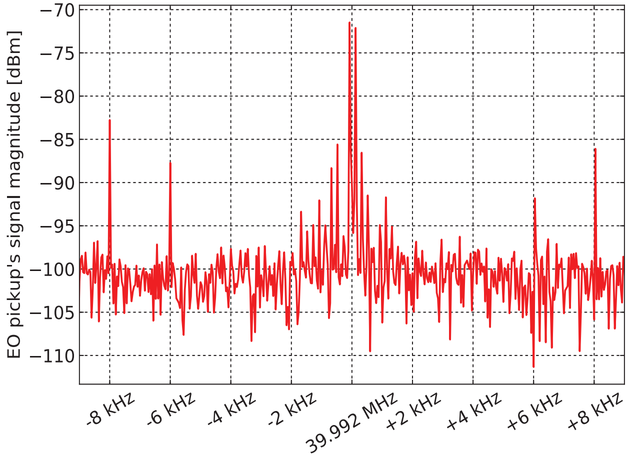




- 5 mm length crystal
- 66.5 mm radius
- 780 nm wavelength





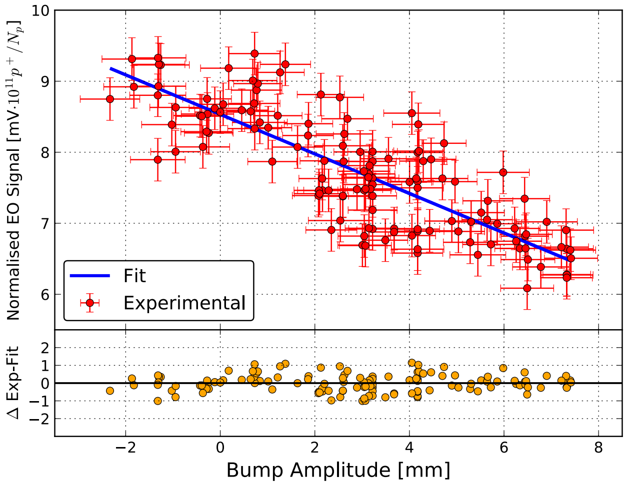


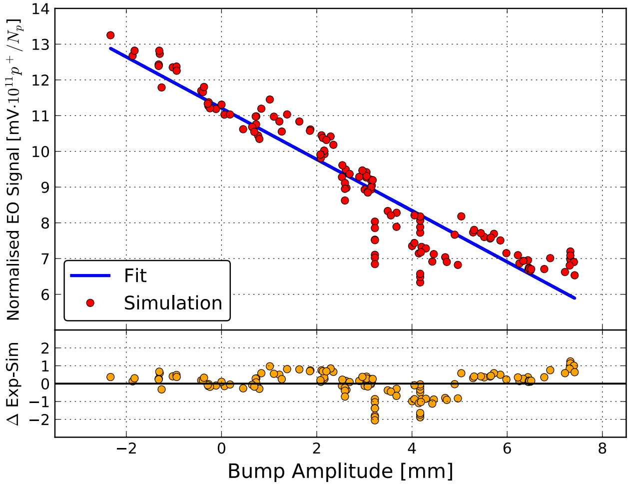
Betatron amplitude sidebands:

$$\frac{6}{43.375} = 0.138 \qquad \frac{8}{43.375} = 0.184$$

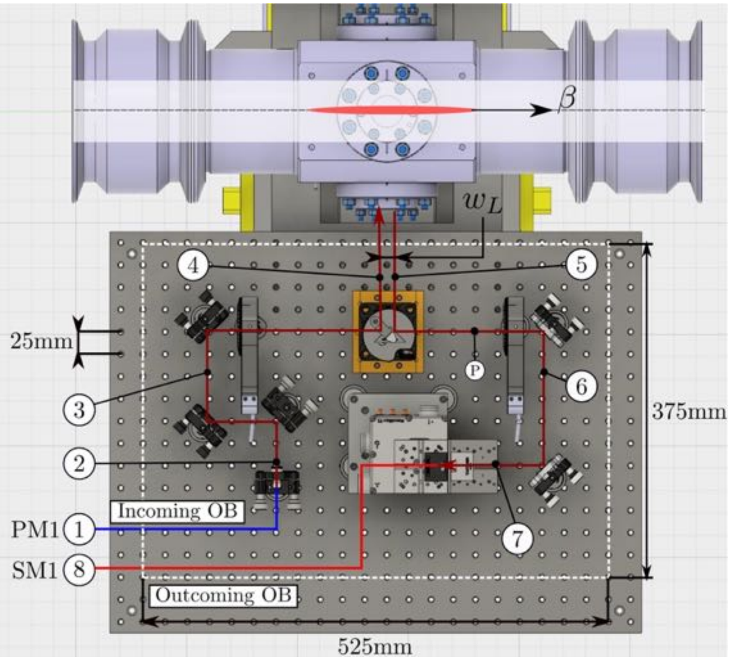
SPS coasting beam tests demonstrated that the system is ***sensitive to the transverse displacement*** of the bunch by measurin of the ***tune of the SPS***.

Artehe et al, IBIC 2017

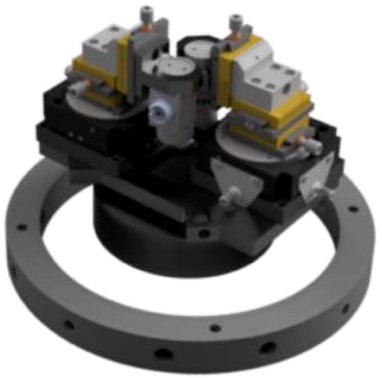




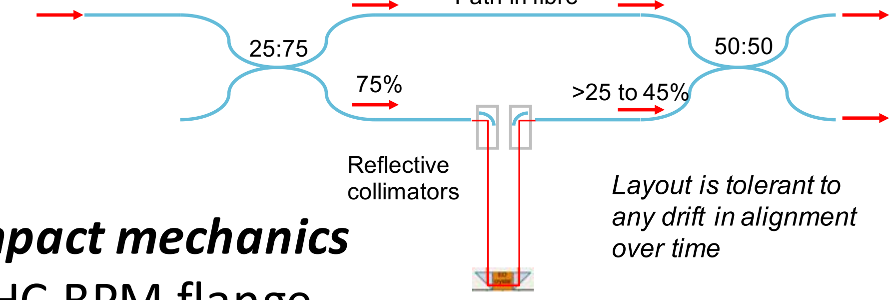
EO-BPM: compact interferometric design

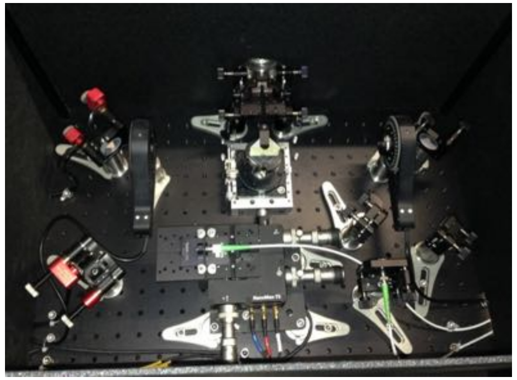


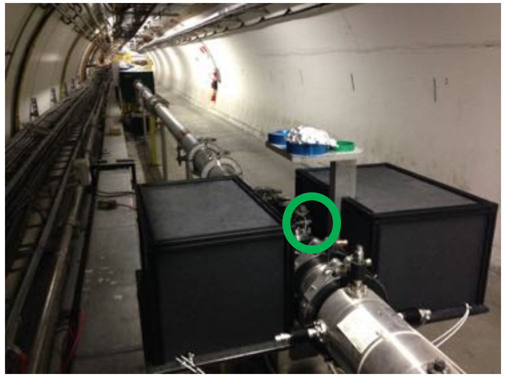
- A pair of fibre-splitters was used to create an interferometer around one EO-crystal as shown.
- Alternatively, as interferometer between opposing EO-pick-ups allows direct optical measurement of the beam position difference signal

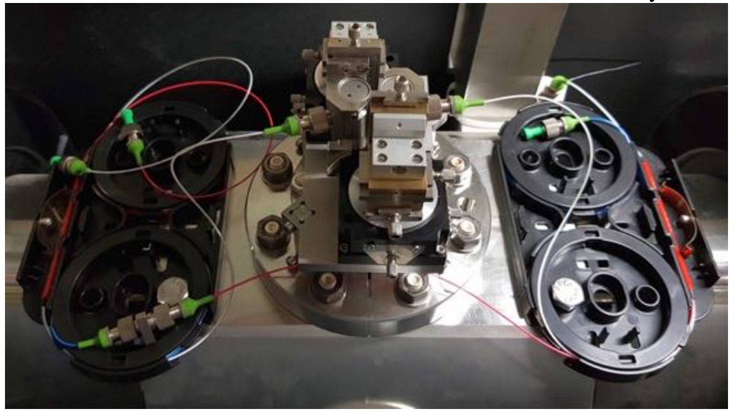


Compact mechanics
fit LHC BPM flange.

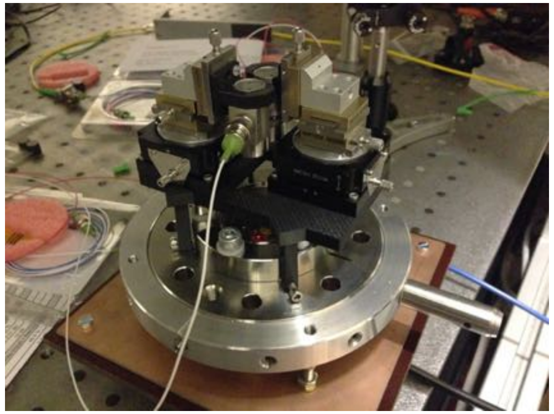








Installed on top flange of EO-BPM at SPS

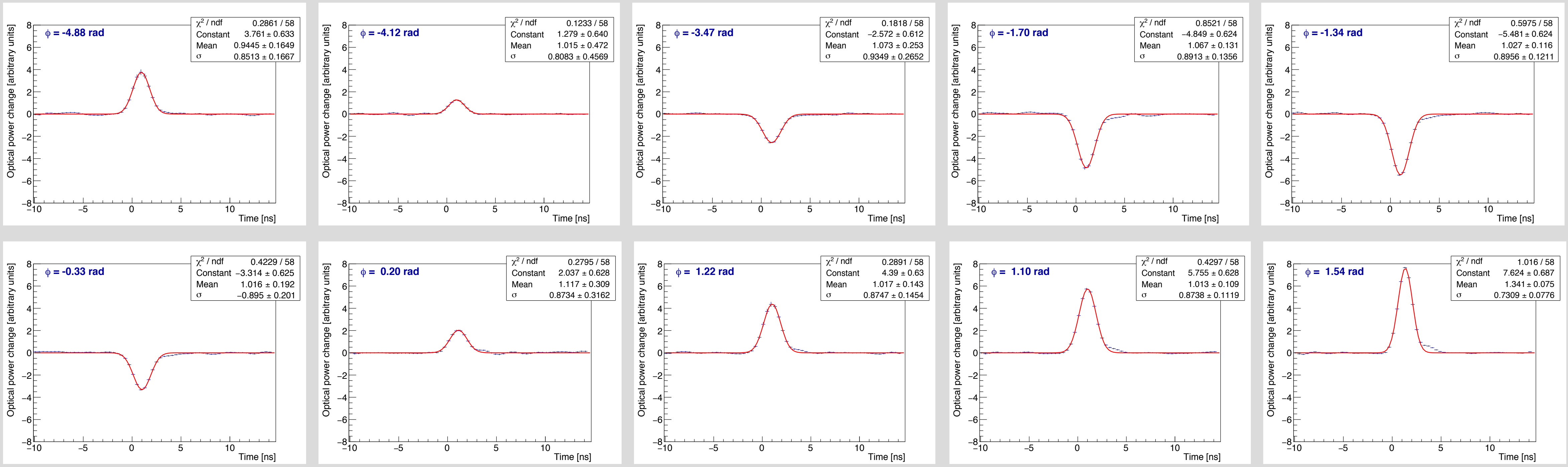


Mounted for bench tests

EO-BPM: compact interferometric design

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Optical response of the compact interferometer to an average SPS bunch as the laser frequency is scanned.



Bandwidth limited by prototype detection system

$$\phi(t) = \frac{2\pi}{\lambda} n_e l + \frac{\pi}{\lambda} n_e^3 r_{33} l E_{az}(t)$$

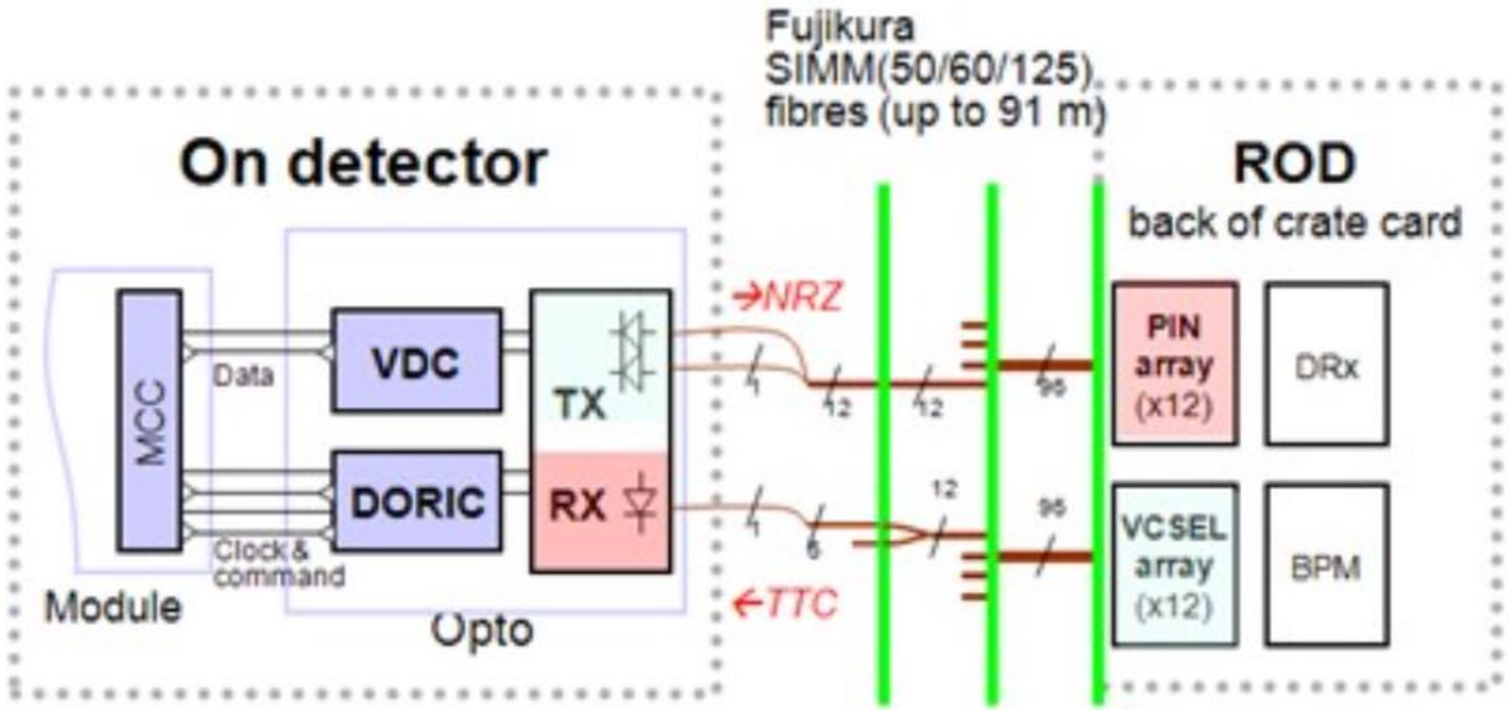
First results from compact setup presented at IPAC2018:
Tests with crabbed beams this year.

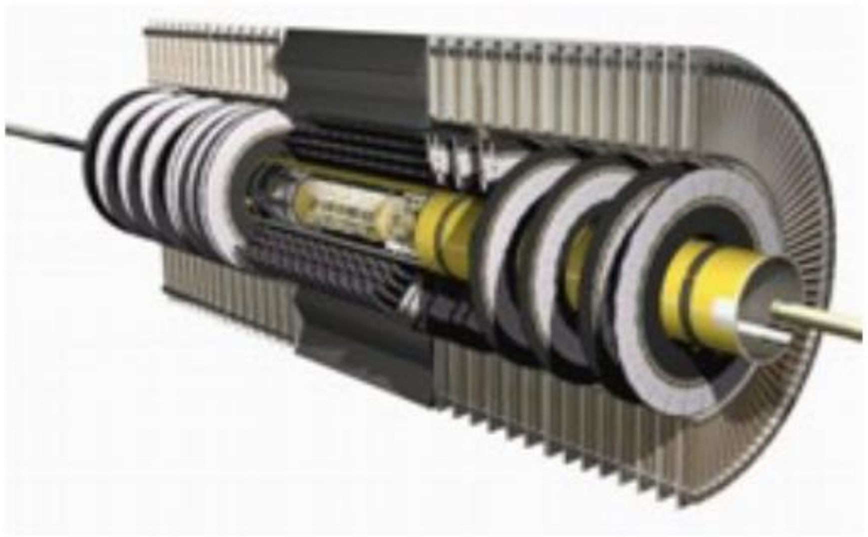
Enhanced bunch monitoring by electro-optic interferometric methods, WEP073, IPAC 2018

Optical links

Lasers can also be applied for the fast read-out of beam instrumentation

- Example from ATLAS: Optical-electronic links that bring data from the silicon trackers to the electronics in the counting room.





Optical links

Lasers can also be applied for the fast read-out of beam instrumentation

- Example from ATLAS: Optical-electronic links that bring data from the silicon trackers to the electronics in the counting room.

VCSEL array coupled to 12 fibres:

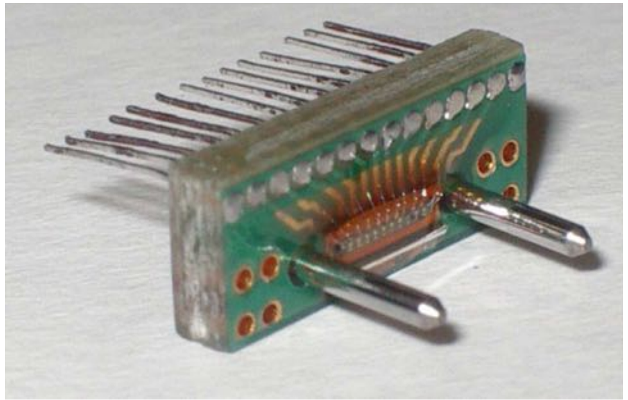
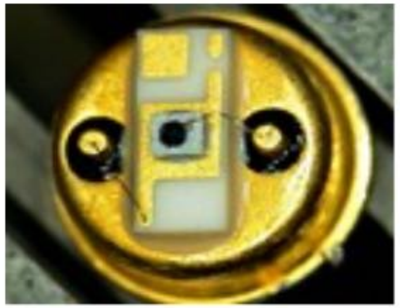


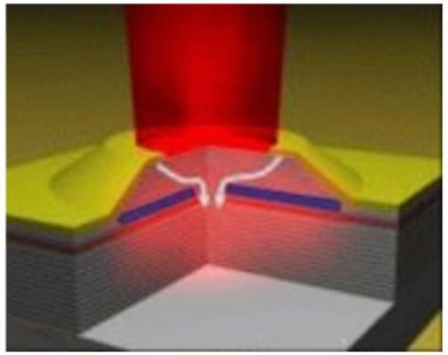
Fig. 3. Photograph of a VCSEL array mounted on a base PCB with the MT guide pins.



PIN diode

VCSEL: Vertical Cavity surface emitting laser diode
- **GaAs,** thin active layer ‹10 μm, **very rad-hard**
- high speed (>2GHz), 850 nm
  matching to thin epitaxial Si PIN diodes
- Little uniform temperature dependence

Two types (by Truelight inc.) in use
- **Proton implant** VCSEL (ATLAS on detector)
- **Oxide confined** VCSEL (off-detector on ROD)
  high power (mW), ch-ch performance is **very uniform**
  little temperature deviation



Nuclear Instruments and Methods in Physics Research A 530 (2004) 293–310

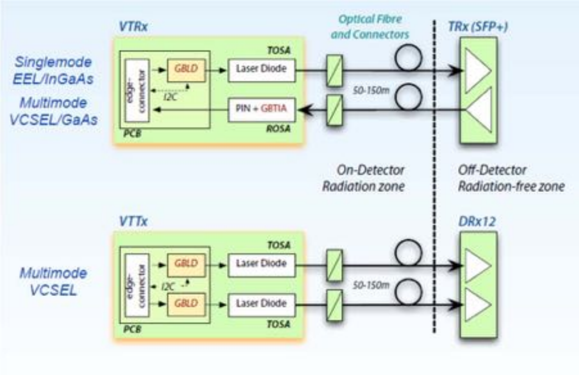
The off-detector opto-electronics for the optical links of the ATLAS Semiconductor Tracker and Pixel detector

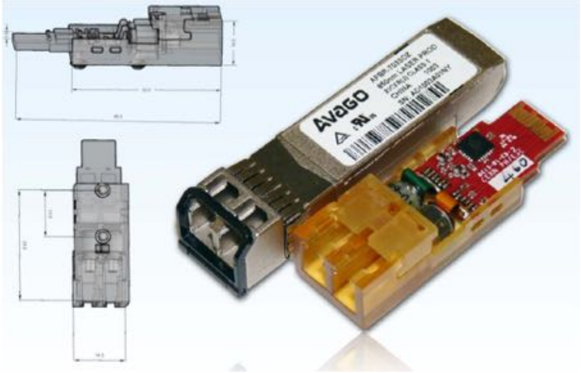
M.L. Chu[a], S.-C. Lee[a], D.S. Su[a], P.K. Teng[a], M. Goodrick[b], N. Kundu[c], T. Weidberg[c,*], M. French[d], C.P. Macwaters[d], J. Matheson[d]

Optical links

Developments for HL-LHC readout: data rate of 5 Gb/s

Versatile Link

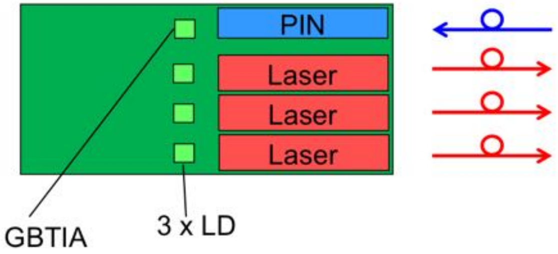


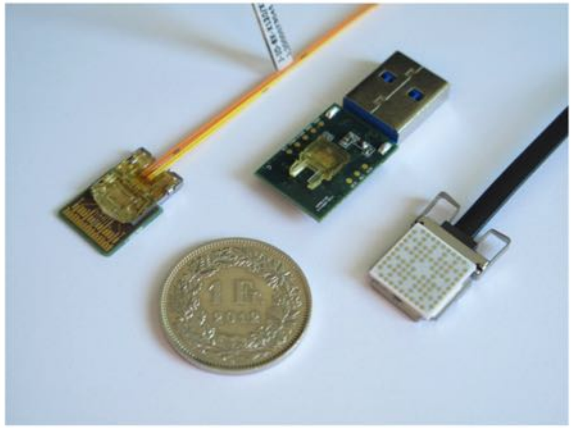


- Small Form Factor (SFP) Transceiver:
  - Data rate: 5 Gb/s
  - Wave length:
    - 850 nm, Multimode
    - 1310 nm, Single mode
  - Function:
    - Point-to-point
    - Point-to-multipoint
- Development of pluggable modules.
  - Two versions:
    - Transceiver (**VTRx**)
    - Double transmitter (**VTTx**)
  - Compatible with the commercial counterparts
  - LC connectors
  - Length reduced to 43.5 mm
  - Contains:
    - The GBTIA & GBLD
    - Radiation qualified PIN diodes and Lasers
  - Radiation tolerant:
    - 50 Mrad
    - 5 x 10^{14} n/cm^2
  - Prototyping phase concluded:
    - Prototypes available
    - Production planed for 2015
    - Target LS2 upgrades

The Versatile Link +

- Small form factor, high speed optical modules needed for:
  - CMS tracker modules
  - ATLAS EoS
- 5G downstream, 10G upstream:
  - Driven by GBTX evolution path
  - 10G laser driver ASIC
- Smaller
  - Revised optical interface
  - MM only
- Denser
  - Up to 4 channels
- Versatile
  - Common package
  - Number of up/down links
  - Configurable at assembly time or by turning off unused channels
- On-going work
  - 10 Gb/s tiny single/quad LD
  - Package, fibres, connectors
  - Feasibility study until fall 2015





See: Vasey et all, ACES 2014

P. Moreira, ECFA workshop 2014

Summary of 'Lasers Applications for BI'

Lasers have many interesting applications at accelerators!

- ***e- laserwires*** *enable ultra precise measurement of* ***micron sized*** *electron beams, demonstrated at ATF2.*
- ***H- laserwires*** *enable non-invasive measurements of transverse profiles, emittance and longitudinal bunch shape for high intensity H- beams:*
  - *Agreement with conventional diagnostics to <2%.*
  - *Dual laserwire system recently installed at CERN's Linac4.*
- ***Laser polarimetry*** *of e+ e- beams at LEP under consideration for FCC-ee*
- *Interferometry of the* ***Shintake monitor*** *to measure beam sizes down to* ***50 nm***
- ***Electro-optical Beam Position Monitors*** *are in development for HL-LHC: with first signals from prototype at SPS.*
- *Optical links at up to 10Gb/s for HL-LHC.*

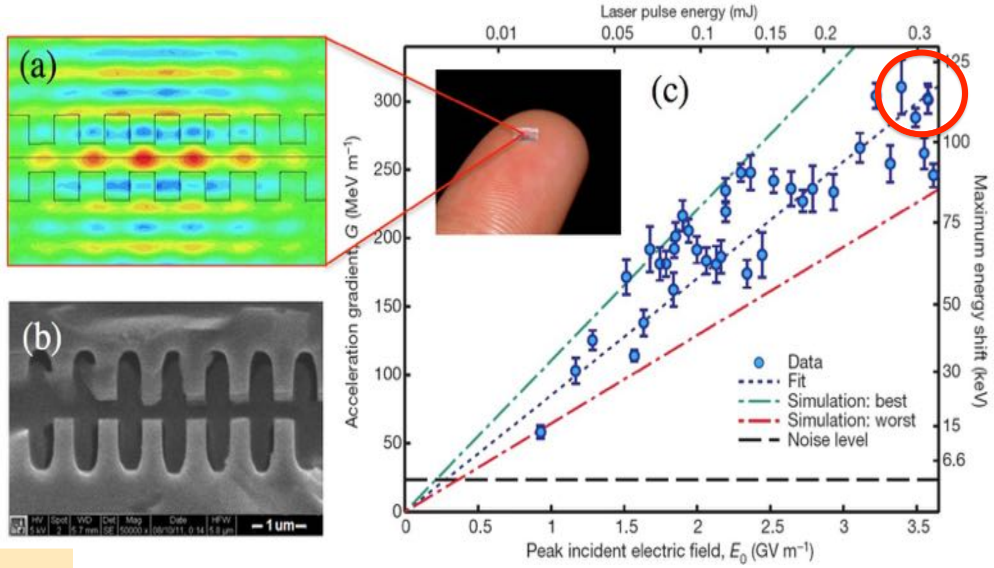
How might your application benefit from lasers?

Back up

Laser / THz accelerators

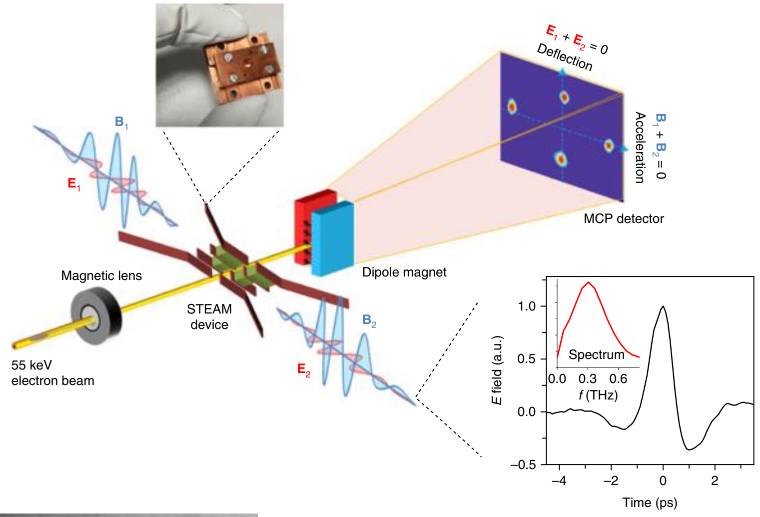
- ***Dielectric Laser Accelerators***
  - High electric field at optical wavelengths:
  - Gradients < 0.3-1 GeV/m
  - Staging rather inefficient, lowers average gradient
  - Laser efficiency -> high power requirements.

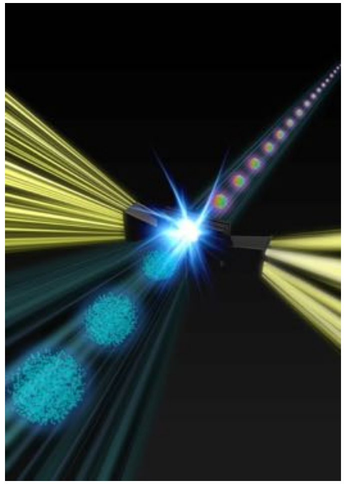
Peak gradient as a function of Laser Field

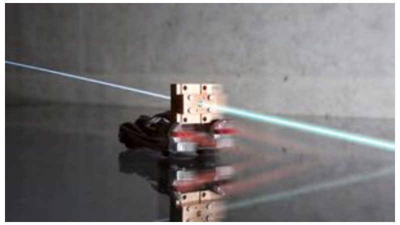


Peralta et al.,
Nature **503**, 91 (2013)

- ***THz structures***
  - Easier to manufacture / control at THz wavelength.
  - Recent demonstration of THz accelerated beams (>30 keV so far), + new developments in UK.







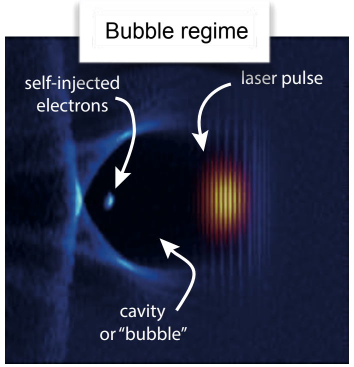
nature photonics ARTICLES
https://doi.org/10.1038/s41566-018-0138-z

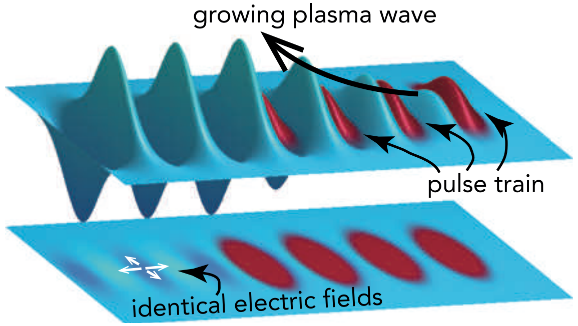
Segmented terahertz electron accelerator and manipulator (STEAM)

Dongfang Zhang[1,2,5*], Arya Fallahi[1,5], Michael Hemmer[1], Xiaojun Wu[1,4], Moein Fakhari[1,2], Yi Hua[1], Huseyin Cankaya[1], Anne-Laure Calendron[1,2], Luis E. Zapata[1], Nicholas H. Matlis[1] and Franz X. Kärtner[1,2,3]

Laser & beam driven plasma wakefield: **100 GV/m**

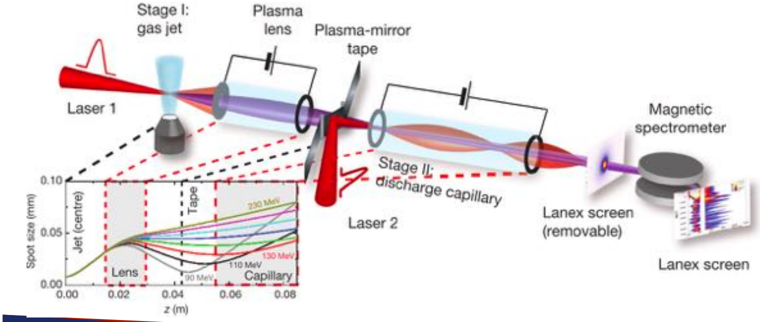
- ***Laser-plasma accelerators*** *(1 GeV demonstrated)*
  – Laser pulse in plasma filled capillary enables electrons to surf a plasma density wave.
  – Recent exciting developments in multi-pulse schemes and staging at low energies.





S.M. Hooker *et al. J. Phys. B* **47** 234003 (2013)

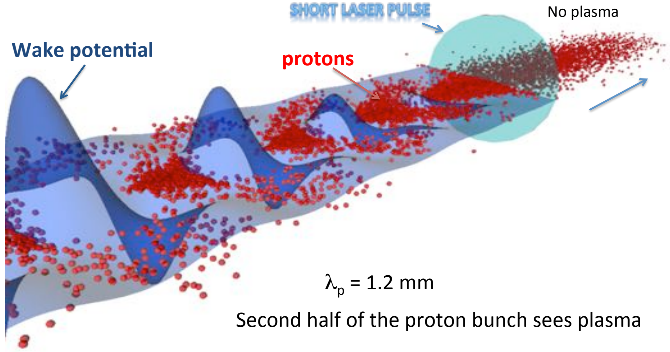
LBNL have demonstrated staging at low energies (~200 MeV increased to ~300 MeV).

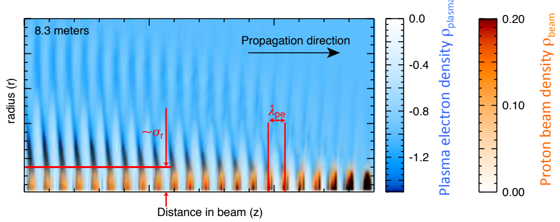


Steinke, S. et al. Multistage coupling of independent laser-plasma accelerators. Nature 530, 190–193 (2016).

Van Tilborg, J. et al. Active Plasma Lensing for Relativistic Laser-Plasma-Accelerated Electron Beams. Phys. Rev. Lett. 115, 184802 (2015).

- ***Proton driven plasma wakefield***
  – 12cm, 3×10^{11} proton bunch drives plasma wakefield in cell at SPS.
  – Acceleration of 15 MeV injected e- to >1GeV
  – Successful observation of self-modulation last year:





Self-modulated proton bunch resonantly driving plasma wakefields.