Laser Wire Scanner – review and prospect for FCCee

Thibaut Lefevre (CERN)

3rd June 2021 – FCCee meeting

Outline

- **Measuring small Beam Size at FCCee**
- **Laser Wire Scanner**
  - Concept
  - Past Achievements
- **Laser wire scanner opportunities at FCCee**

FCCee beam parameters

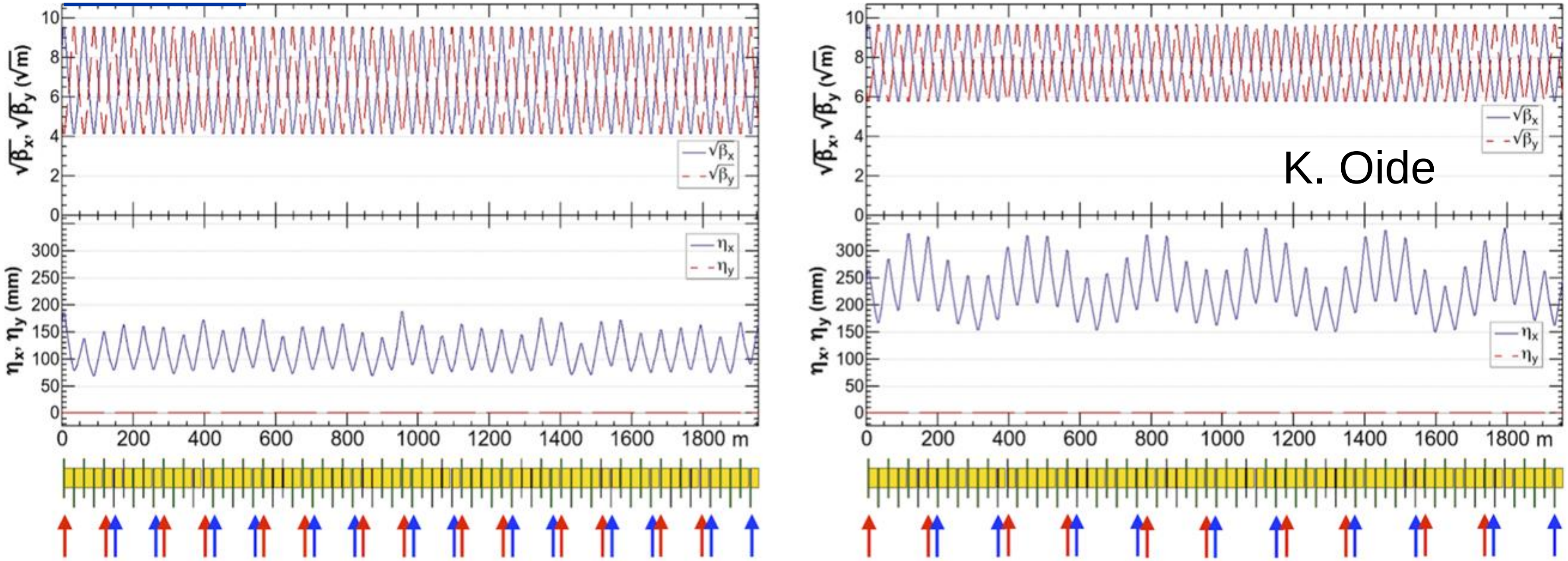
Small Emittances

parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5

FCCee beam parameters

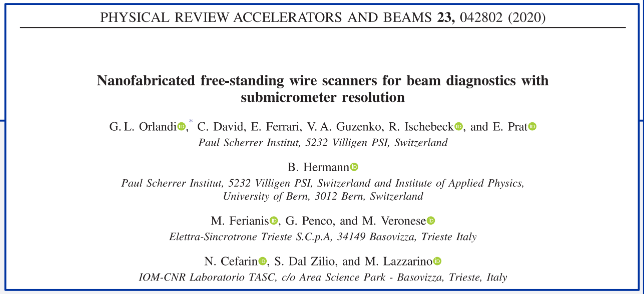
Small beam sizes

ZH and $\boldsymbol{t\bar{t}}$ **Z** and **WW**



< 10/100um beam sizes in ver/hor planes

Beam size monitors



PHYSICAL REVIEW ACCELERATORS AND BEAMS 23, 042802 (2020)

Nanofabricated free-standing wire scanners for beam diagnostics with submicrometer resolution

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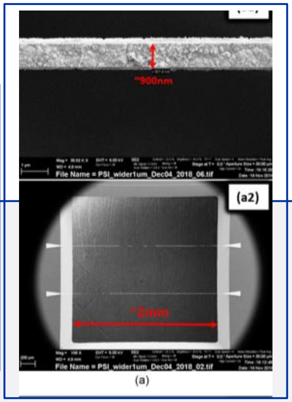
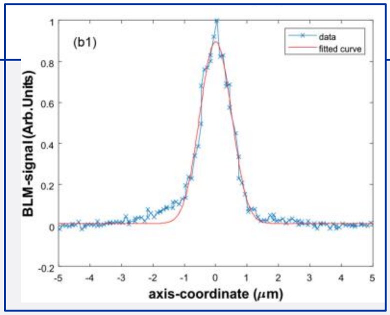
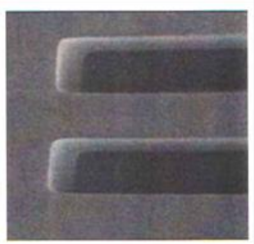


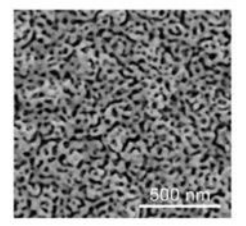


- **Wire Scanners :**
  - Resolution possibly
  - Will not withstand the full beam power

- **X-ray Synchrotron Radiation interferometry (to overcome diffraction limitations)**
  - using micro-slits **(KEK)**
  - using nanoparticles **(CERN)**

double slit



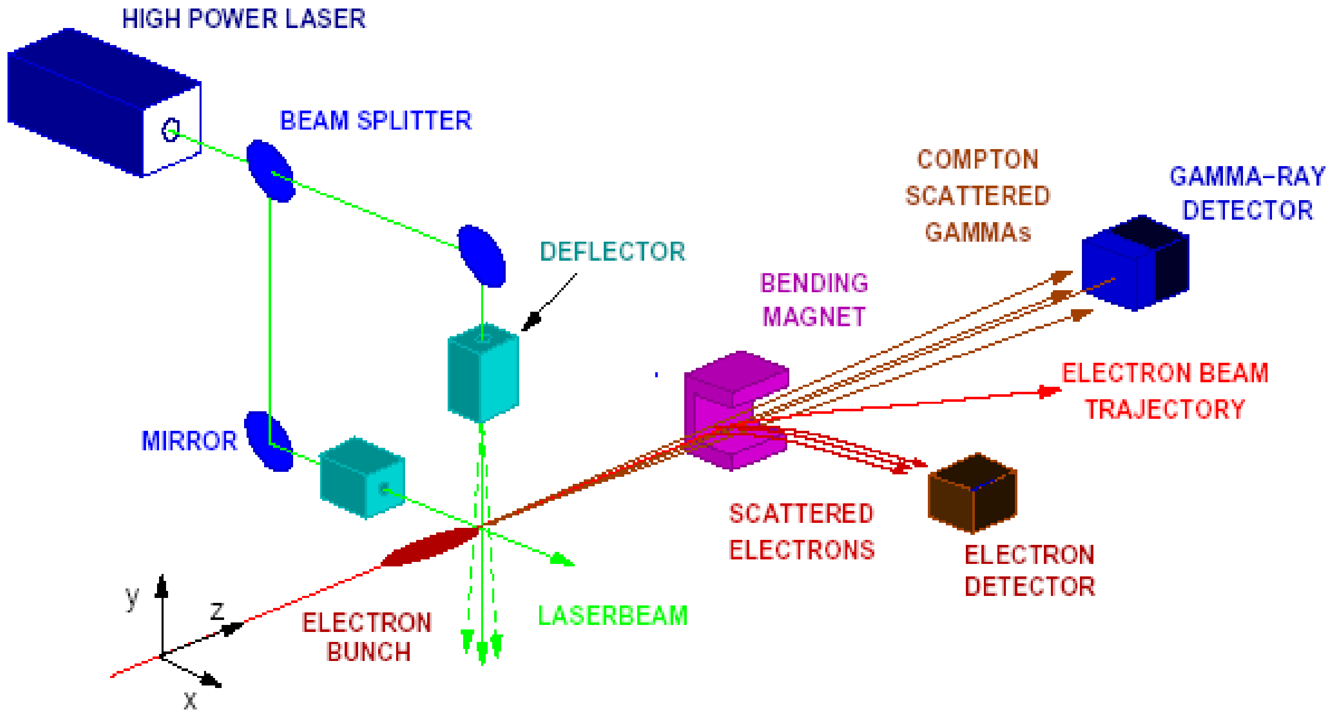


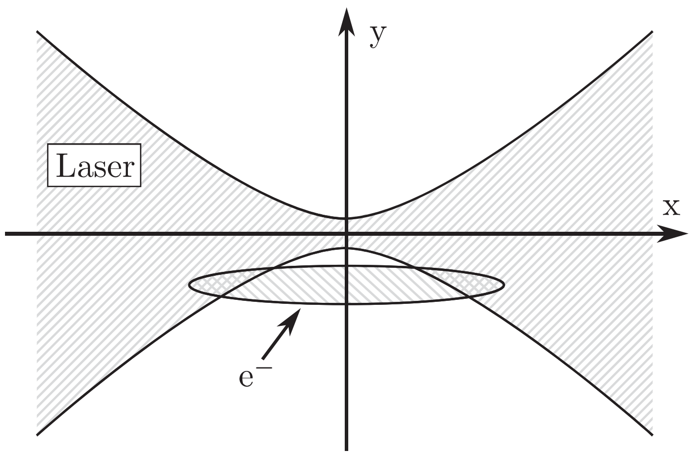
Nanoporous material

- **Laser wire scanner**

Laser Wire Scanner : Principle

Based on Compton scattering using high power lasers





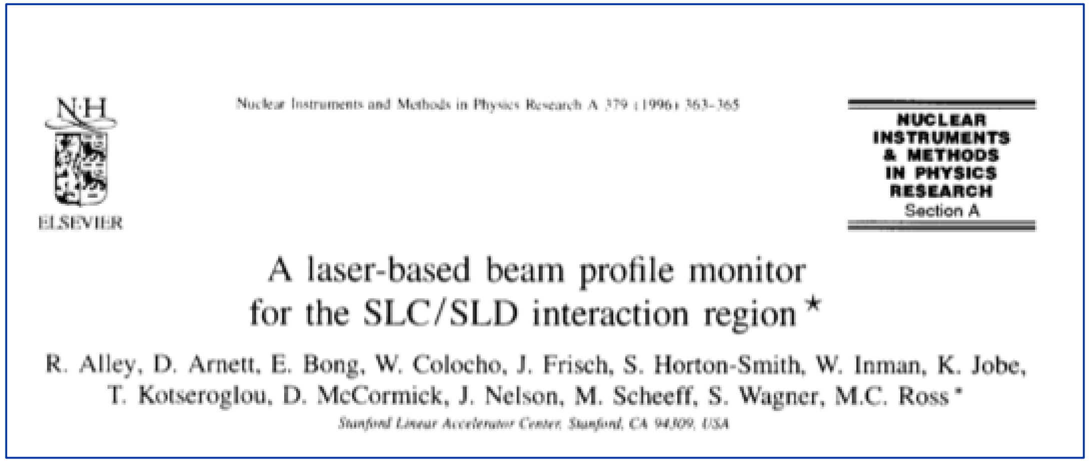
Laser Wire Scanner : motivation and history

Non-invasive sub-micrometre resolution beam diagnostics

- 3rd and 4th generation light sources and
- High energy electron/positron linear colliders

Development of high-power laser optics

- Ultra-strong focusing (F#2 and F#1) elements
- Laser delivery and manipulation



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Nuclear Instruments and Methods in Physics Research A 379 (1996) 363-365

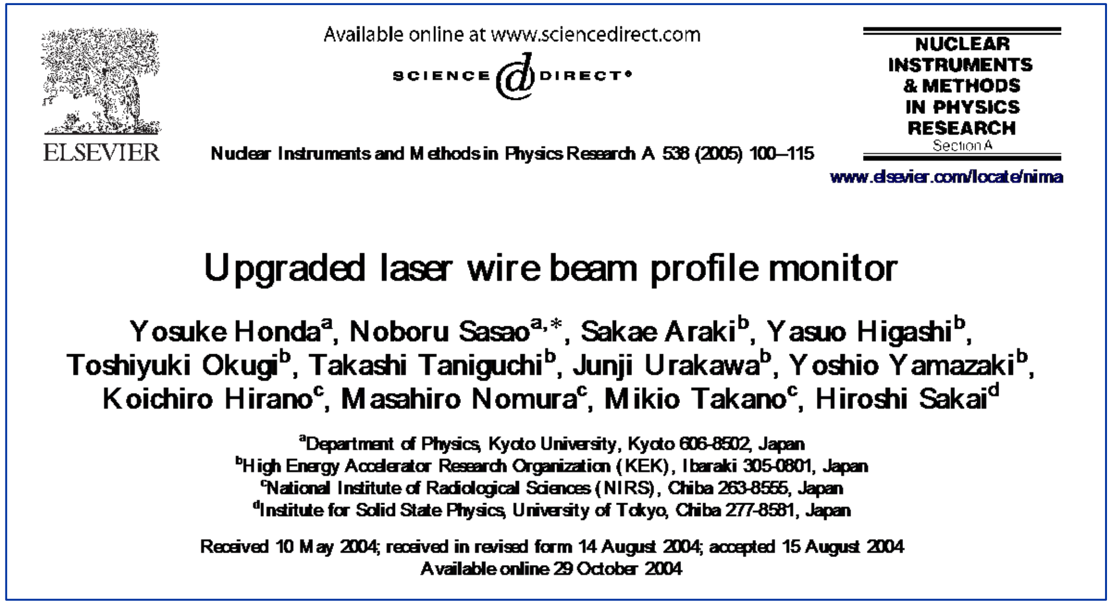
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

A laser-based beam profile monitor for the SLC/SLD interaction region ★

R. Alley, D. Arnett, E. Bong, W. Colocho, J. Frisch, S. Horton-Smith, W. Inman, K. Jobe, T. Kotseroglou, D. McCormick, J. Nelson, M. Scheeff, S. Wagner, M.C. Ross *

Stanford Linear Accelerator Center, Stanford, CA 94309, USA

ATF ring – KEK LWS



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Nuclear Instruments and Methods in Physics Research A 538 (2005) 100–115
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Upgraded laser wire beam profile monitor

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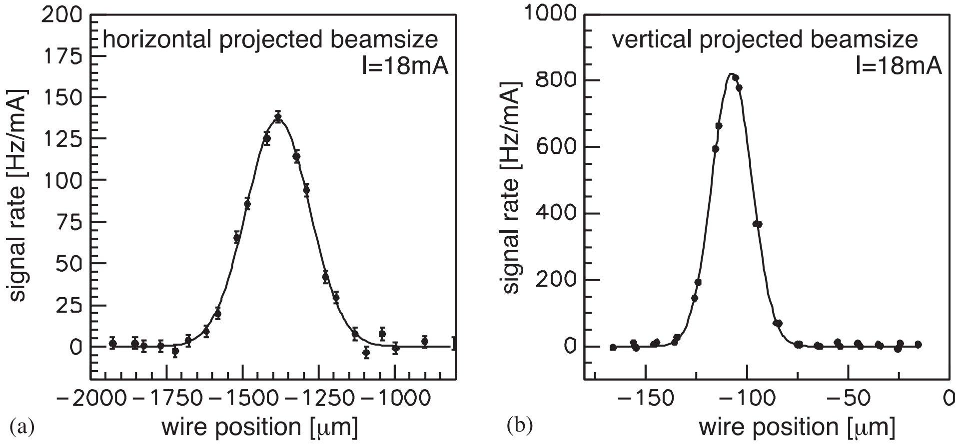

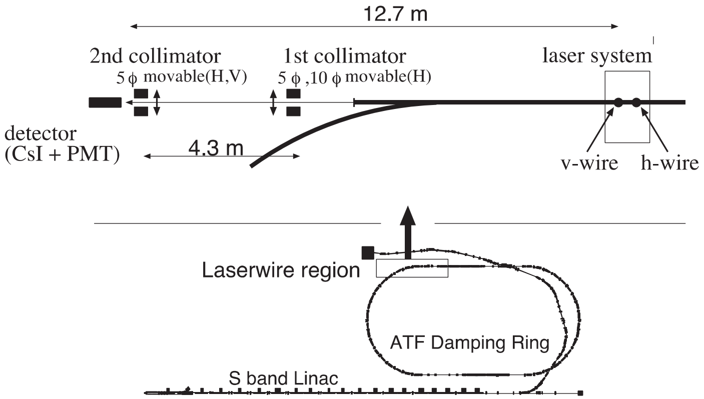

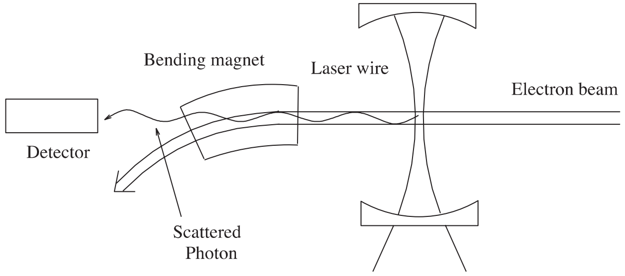

Optical cavity

Parameter	Horizontal wire	Vertical wire
Mirror reflectivity (front)	99.1%	99.8%
Mirror reflectivity (rear)	99.9%	99.9%
Mirror curvature	20 mm	20 mm
Finesse (measured)	~620	~1700
Power gain (S)	~660	~1300
Effective laser power	79 ± 7 W	156 ± 13 W
Waist size (w_0)	11.3 ± 0.2 μm	29.4 ± 0.5 μm
Rayleigh range	760 μm	5100 μm

ATF2 – KEK LWS

Parameter	Symbol	Value	Units
Beam energy	E	1.30	GeV
Horizontal emittance	$\gamma\epsilon_x$	4×10^{-6}	m rad
Vertical emittance	$\gamma\epsilon_y$	4×10^{-8}	m rad
Bunch repetition rate	f_{bunch}	3.12	Hz
Bunch length	σ_{ez}	~30	ps
Electrons per bunch	N_e	$0.5\text{–}10 \times 10^9$	e^-
Fractional momentum spread	$\Delta p = p$	0.001	

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 072802 (2014)

Laserwire at the Accelerator Test Facility 2 with submicrometer resolution

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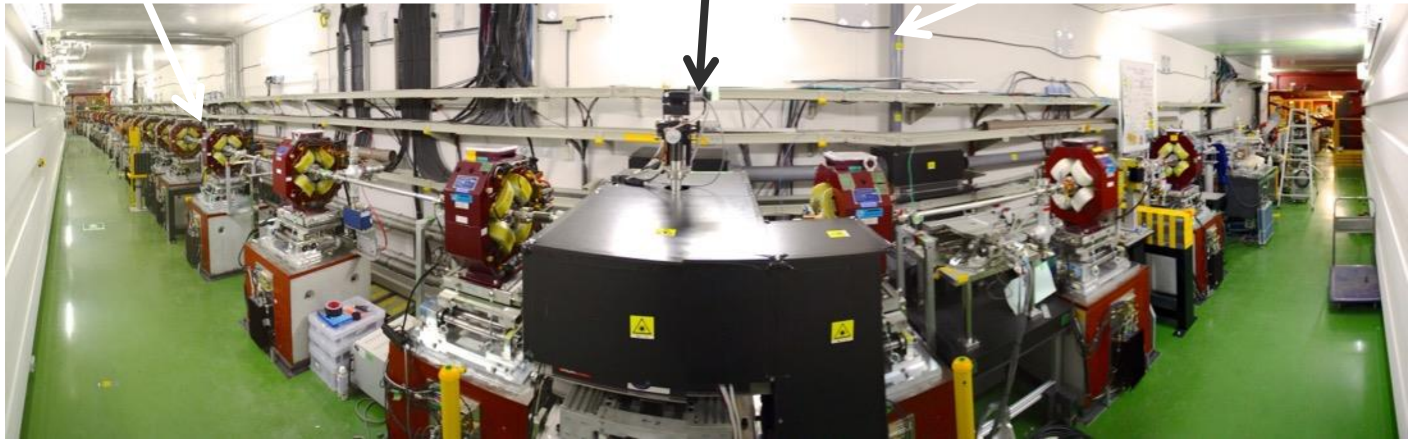
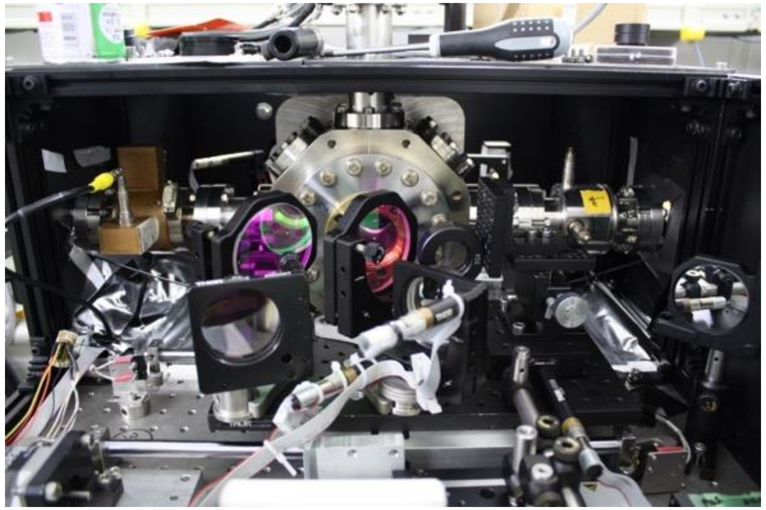
(Received 2 April 2014; published 9 July 2014)

Detector

Laserwire IP

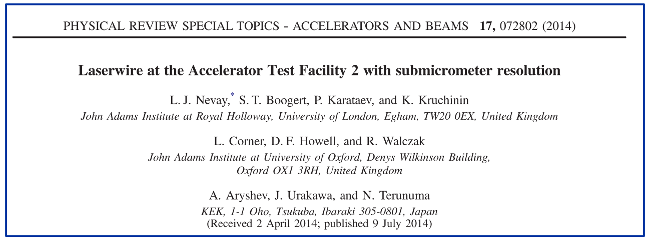
Laser beam transport





LWS using single pass high power laser

ATF2 – KEK LWS – Lens design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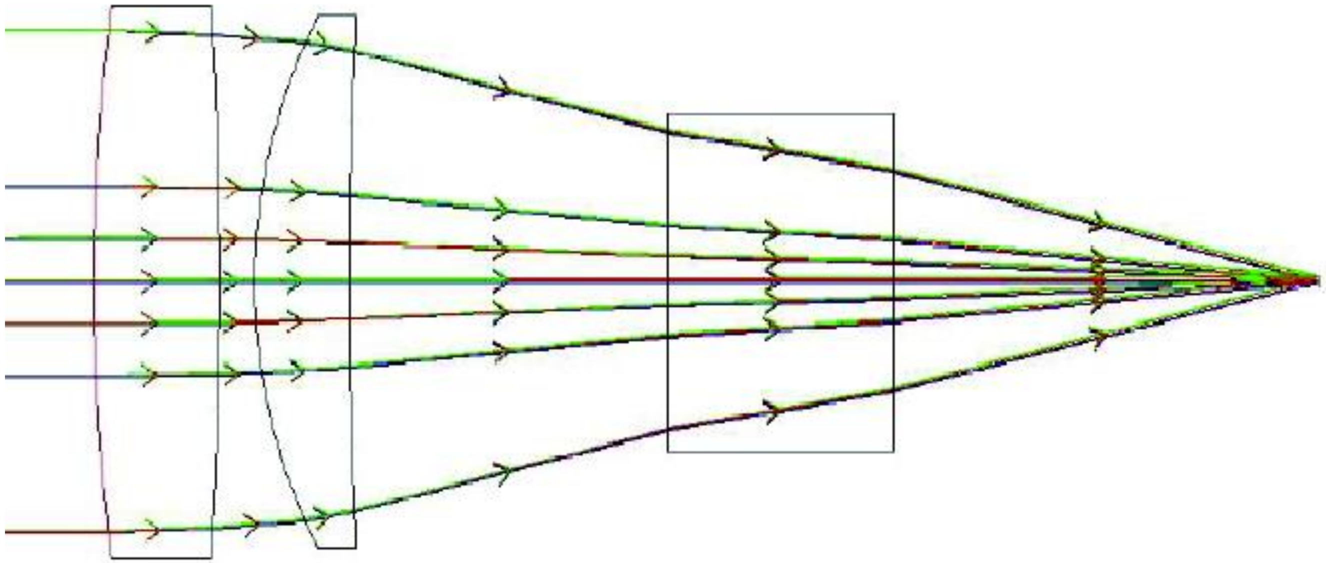

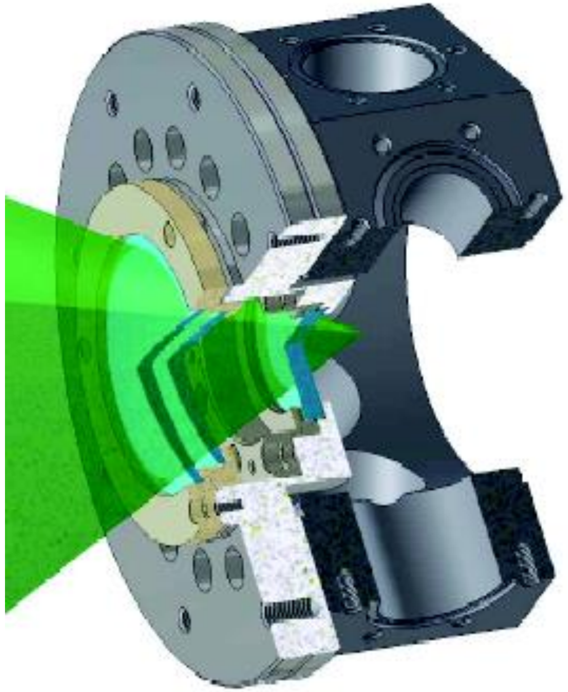

- f2 lens at 50 mm focal distance
- Aberration free at 532 nm
- Micron spot size

ATF2 – KEK LWS – System design

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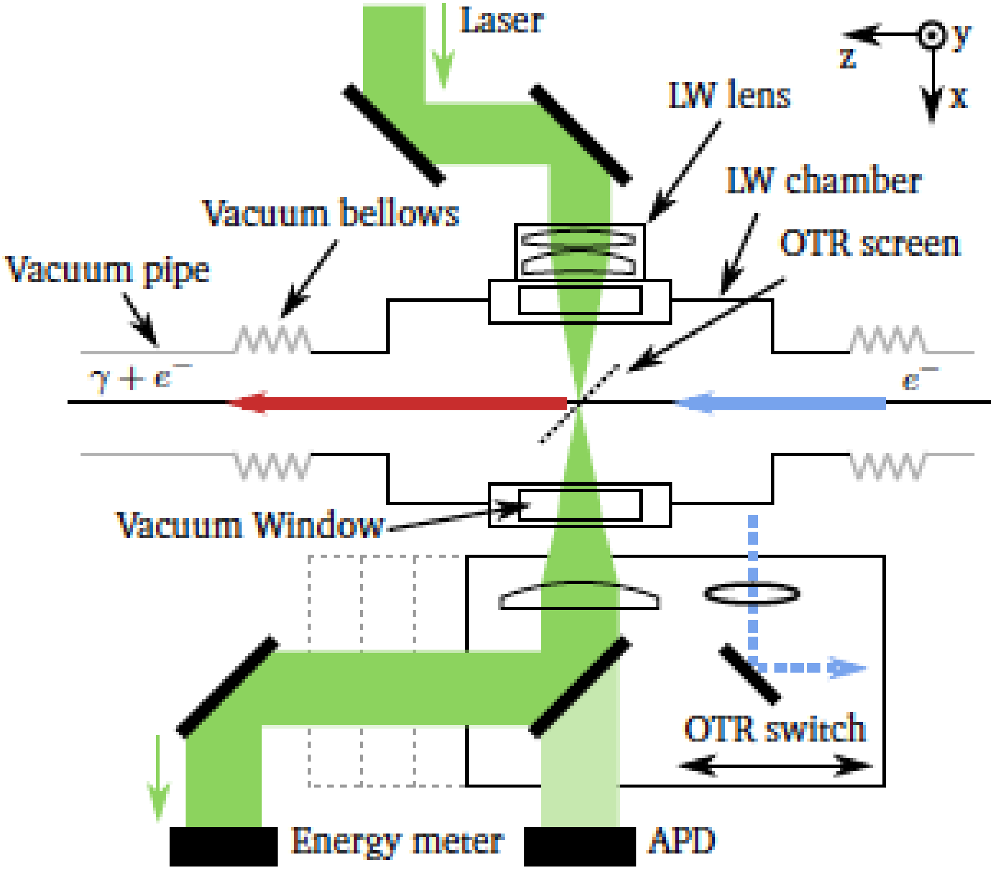
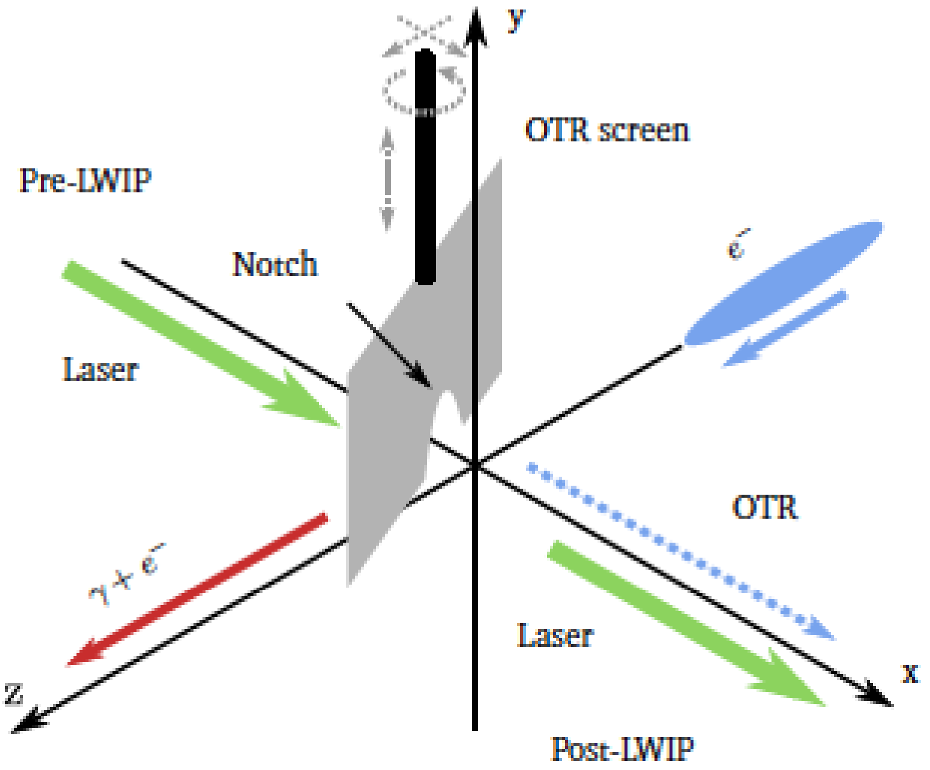
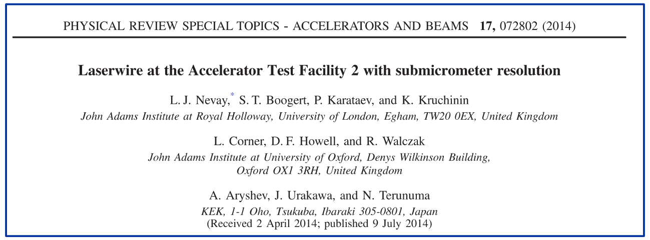




Spatial and temporal alignment using OTR screen

ATF2 – KEK LWS – System design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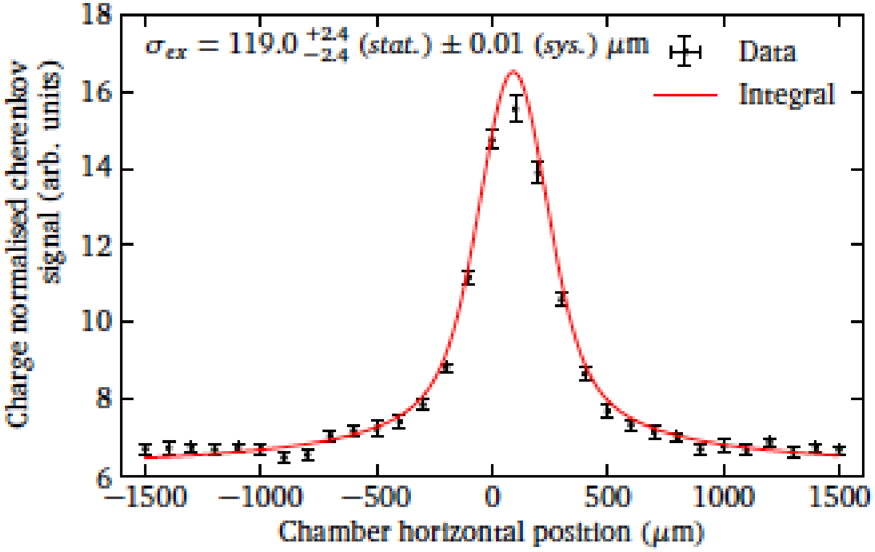
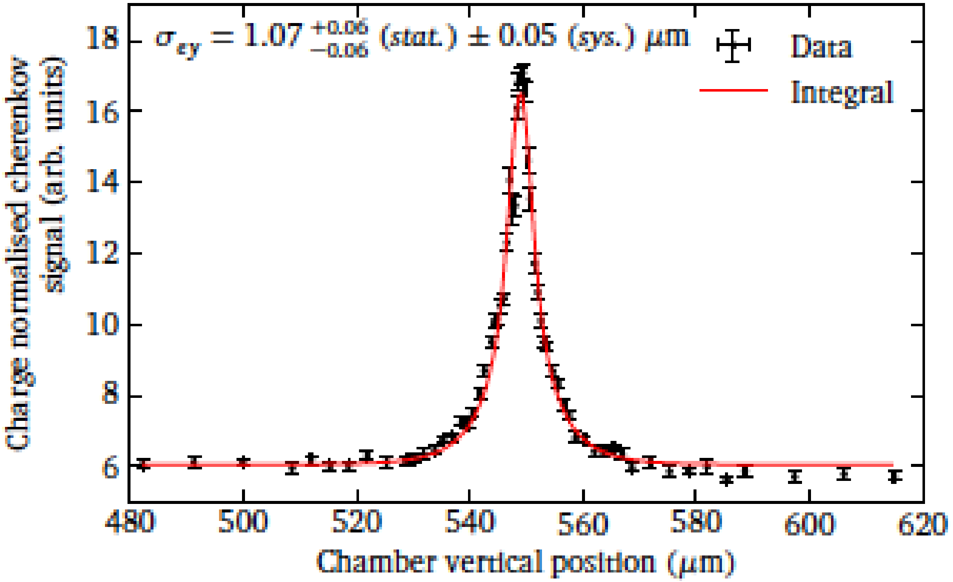
Horizontal



Vertical



Micron resolution achieved !

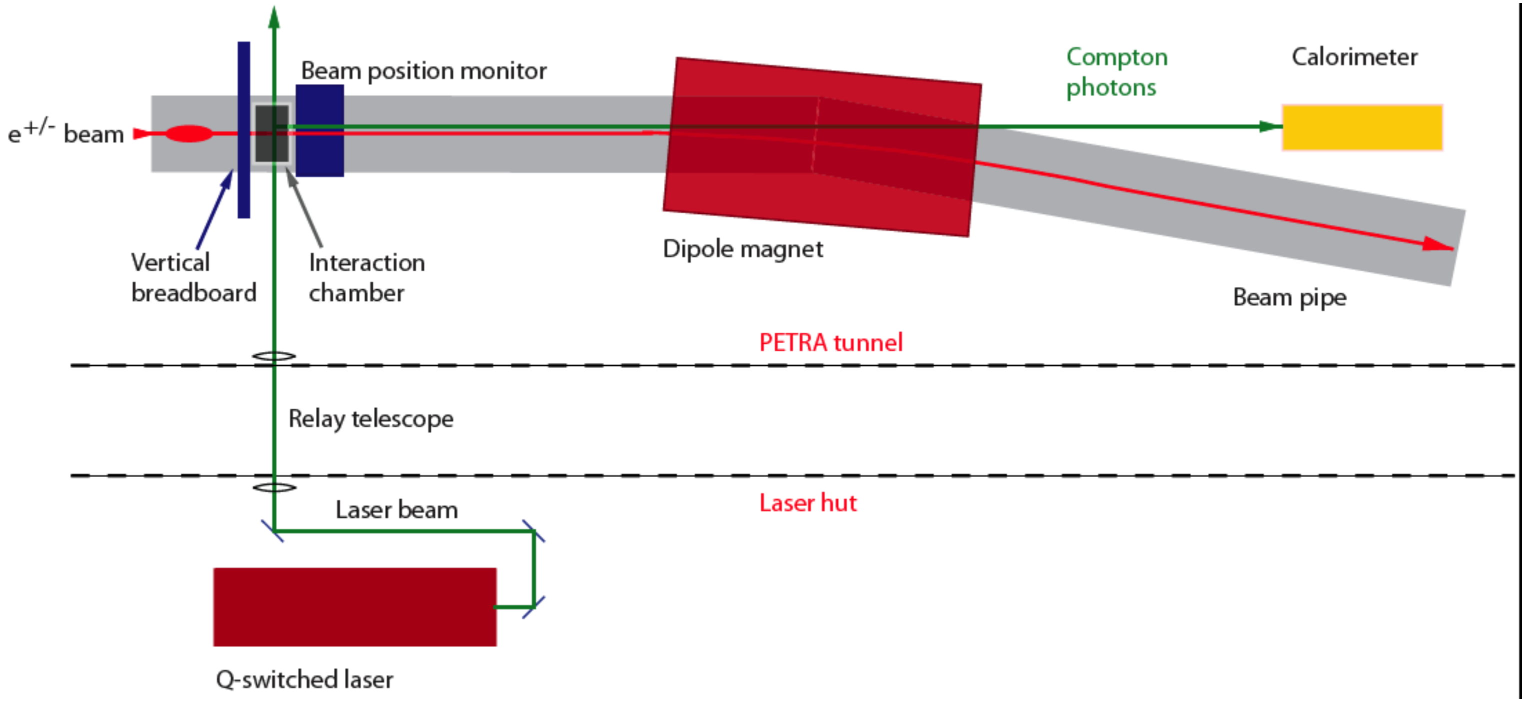
Petra III - LWS

Development of a Laser-Wire Beam Profile Monitor for PETRA-III and CLIC

Thomas Aumeyr

Department of Physics
Royal Holloway, University of London

Ring LWS using single pass high power laser



Parameter	Symbol	Value	Unit
Positron energy	E	6.0	GeV
Circumference	C	2304	m
Revolution frequency	f_{rev}	130.1	kHz
No. of bunches / fill	N_{fill}	960 and 40	
Bunch separation	Δt_b	8 and 192	ns
Positron beam current	I_B	100	mA
No. of positrons / bunch	N_{e+}	0.5 and 12	10^{10}
Horizontal emittance	ϵ_x	1	nm·rad (rms)
Coupling factor	κ	1	%
Vertical emittance	ϵ_y	0.01	nm·rad (rms)
Energy spread	$\frac{\Delta E}{E}$	0.1	% (rms)
Exp. hor. beam size	σ_x	~175	µm
Exp. vert. beam size	σ_y	~15	µm

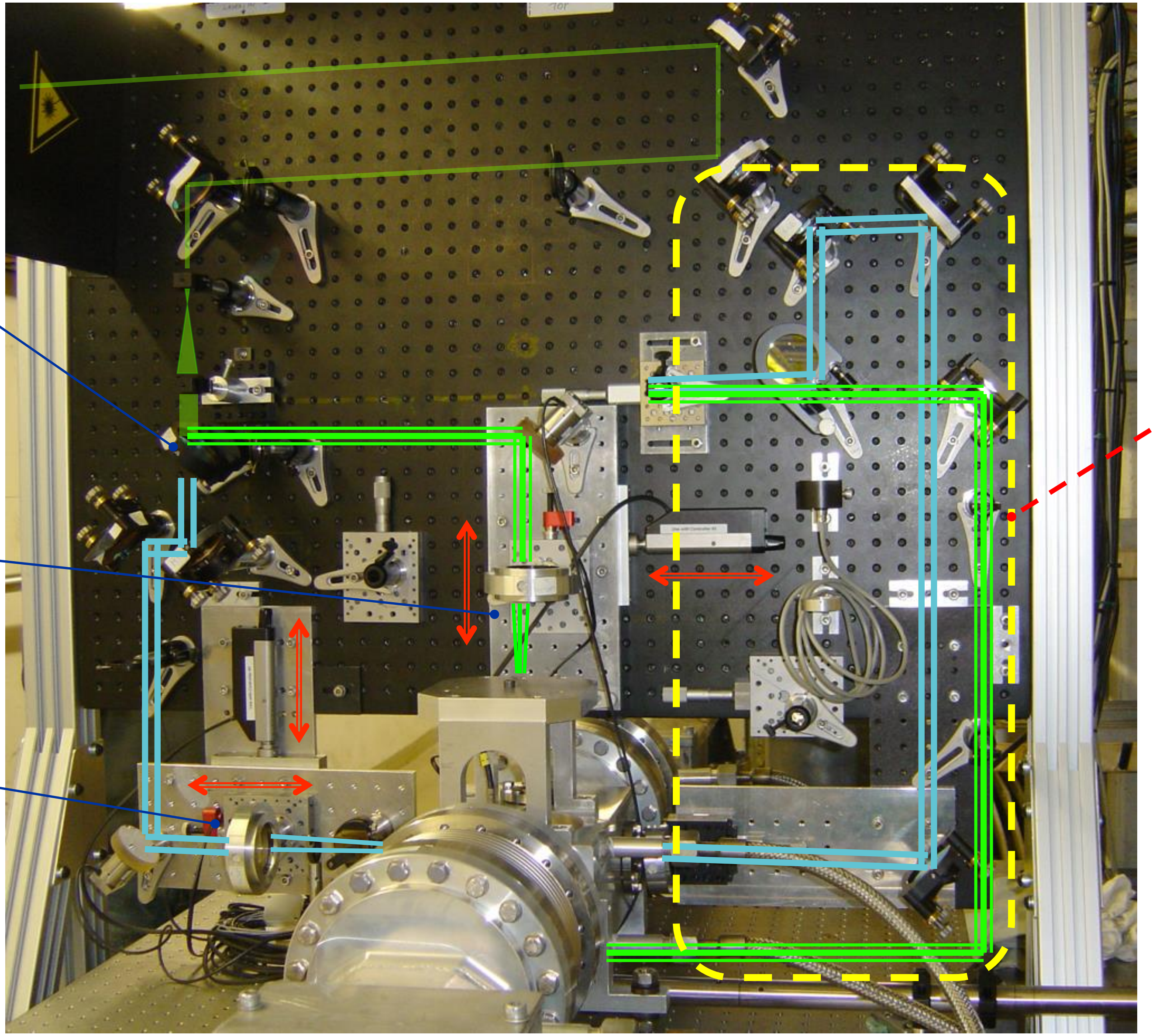
Temporal and spatial algnment done using BPM

Petra III - LWS

Profiler Selector

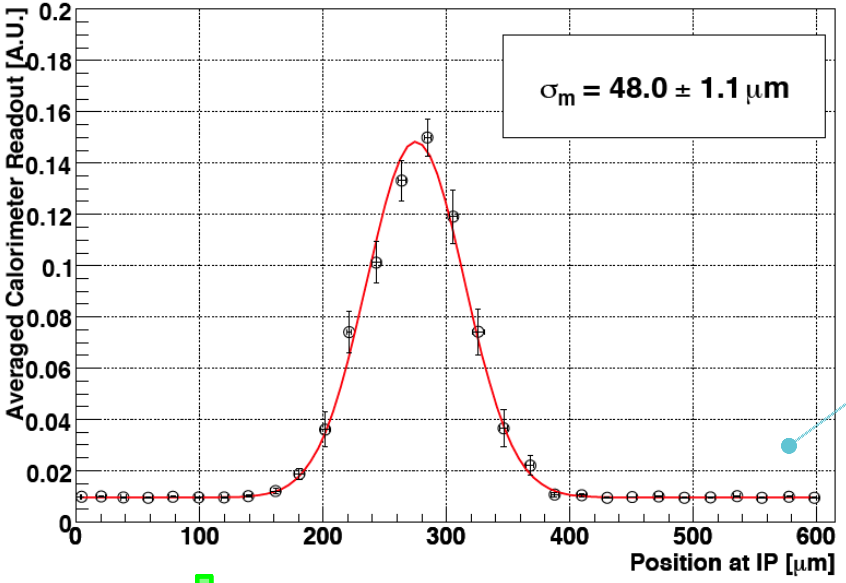
Horizontal Scanning Unit

Vertical Scanning Unit

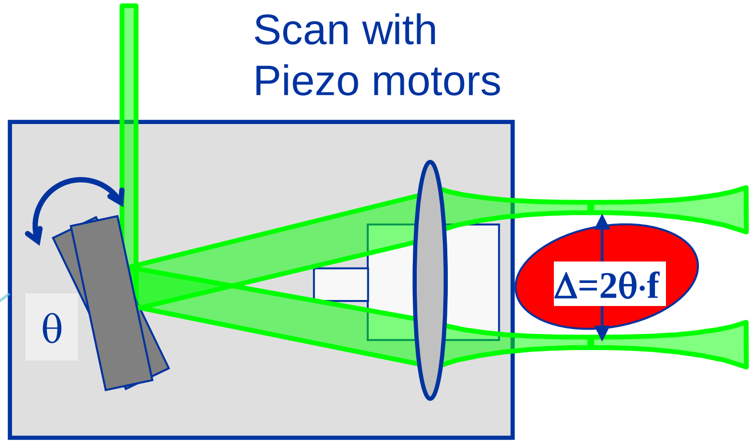


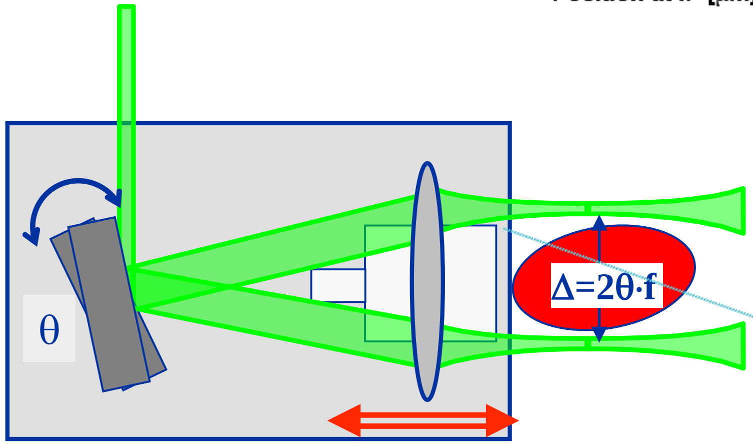
Post-interaction Imaging system

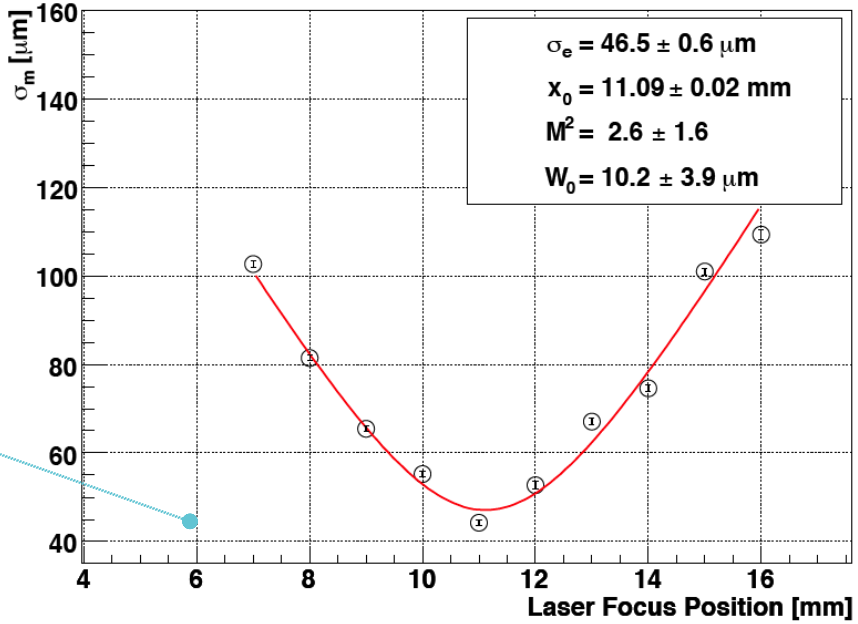
Petra III - LWS – Vertical scans



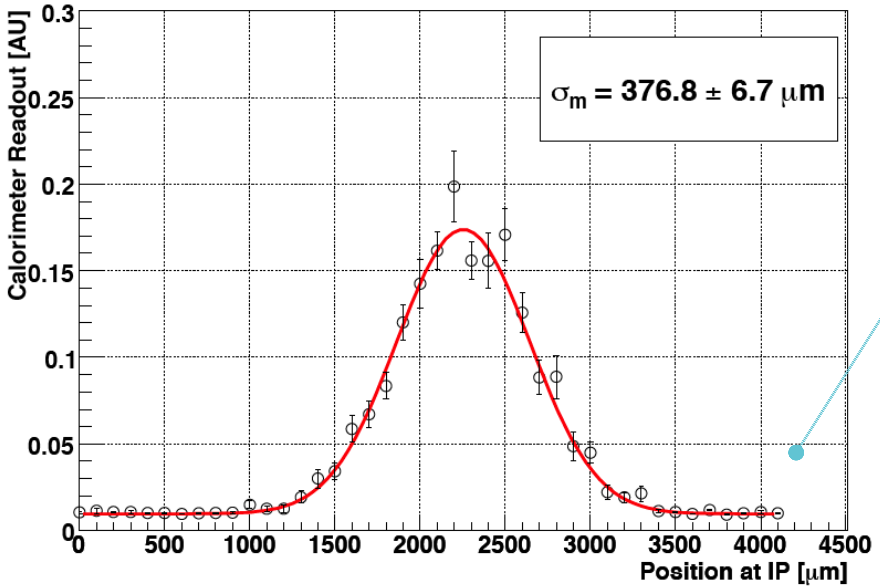
Scan with
Piezo motors



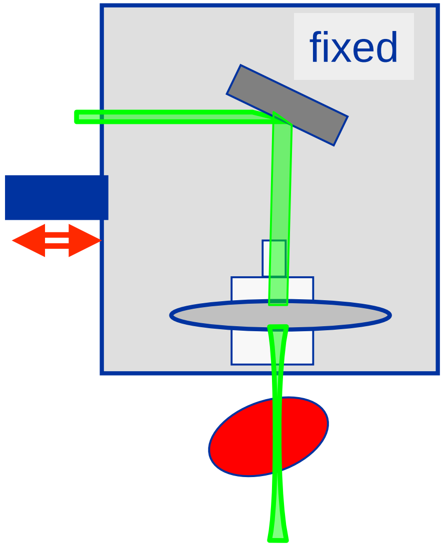




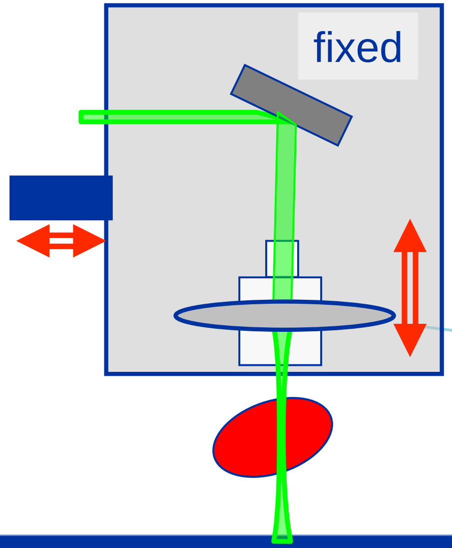
Petra III - LWS – Horizontal scans

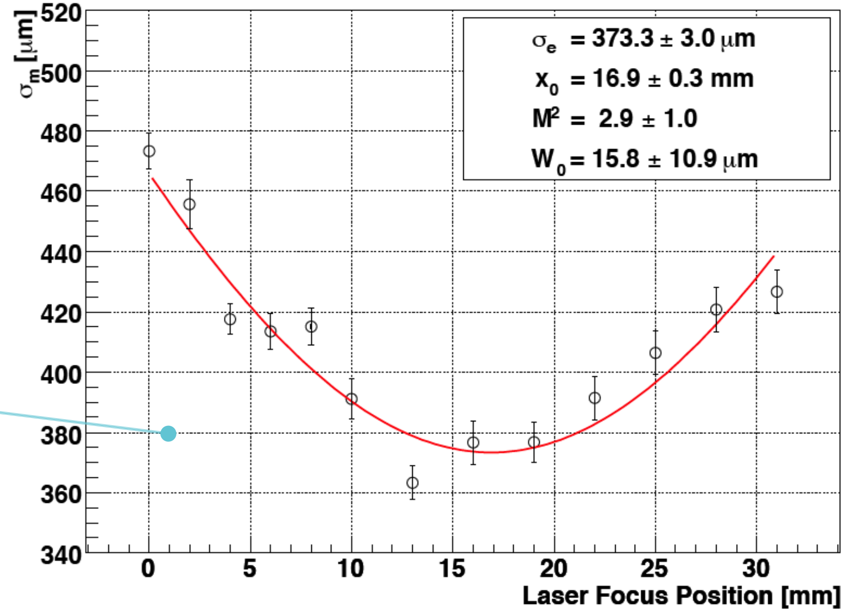


Scan with translation stage



Scan with translation stage





R&D on Fiber laser amplifier for LWS

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 072801 (2014)

High power fiber laser system for a high repetition rate laserwire

L. J. Nevay,* R. Walczak, and L. Corner
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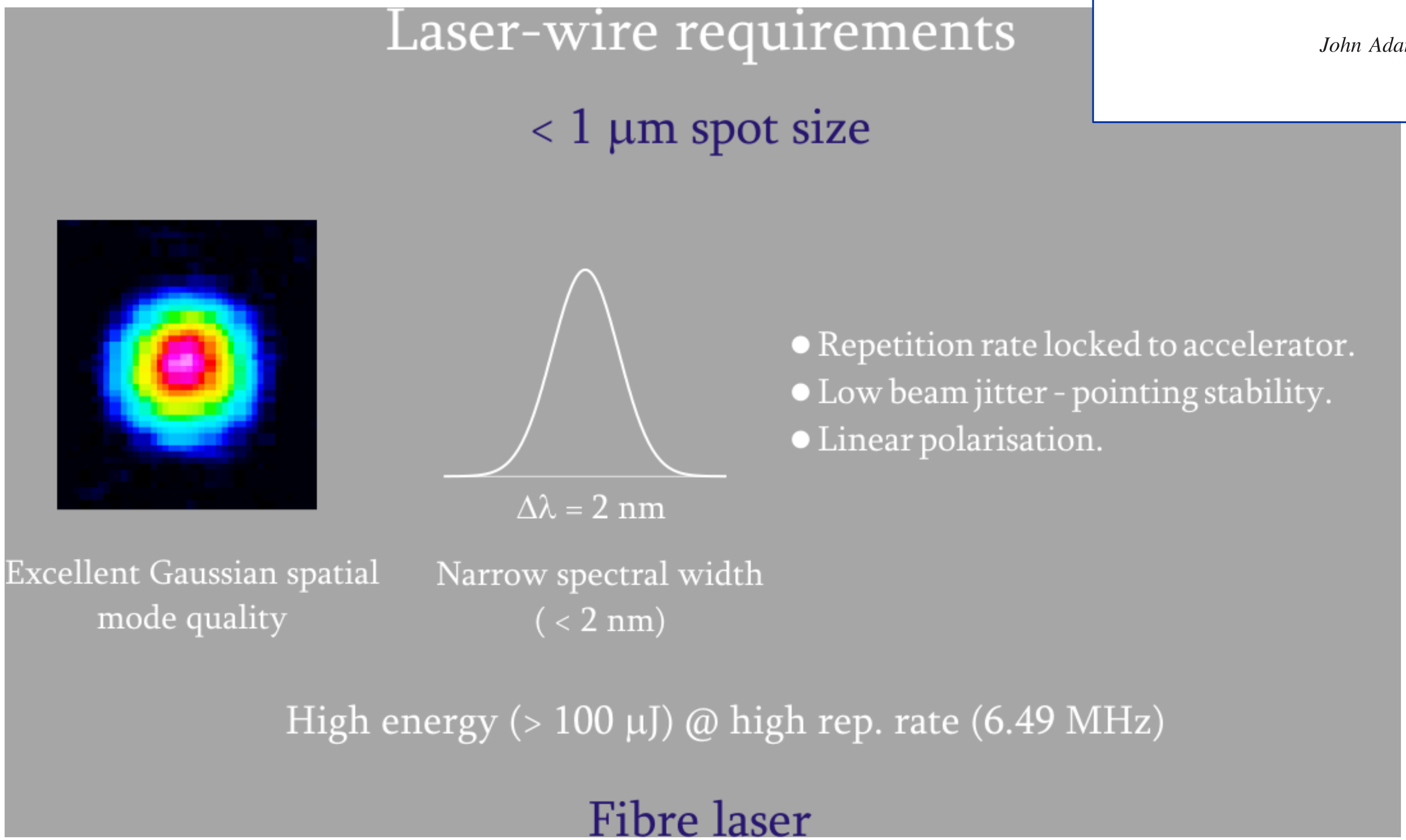
(Received 1 October 2013; published 9 July 2014)



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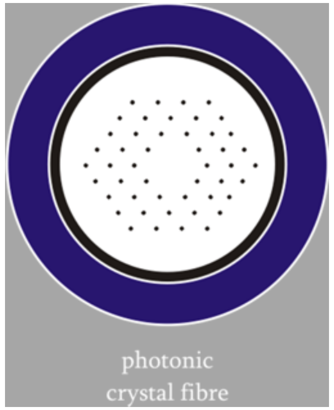

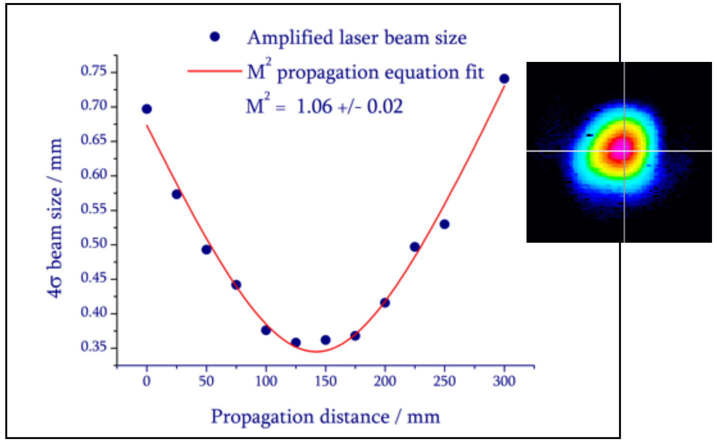

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 072801 (2014)

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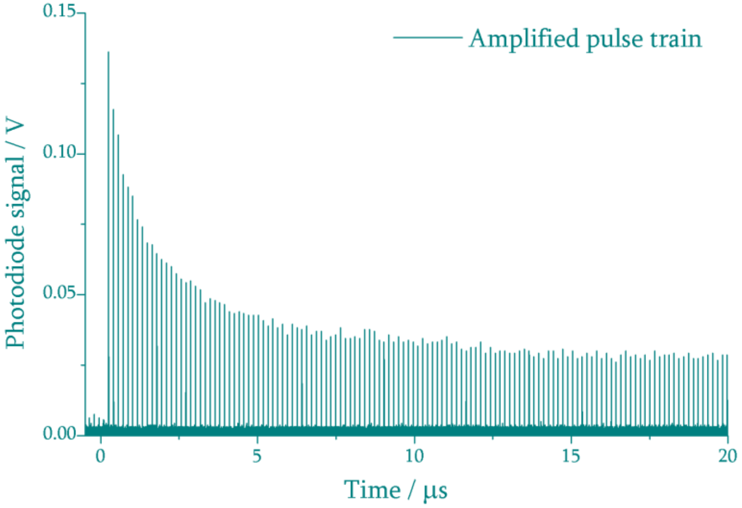
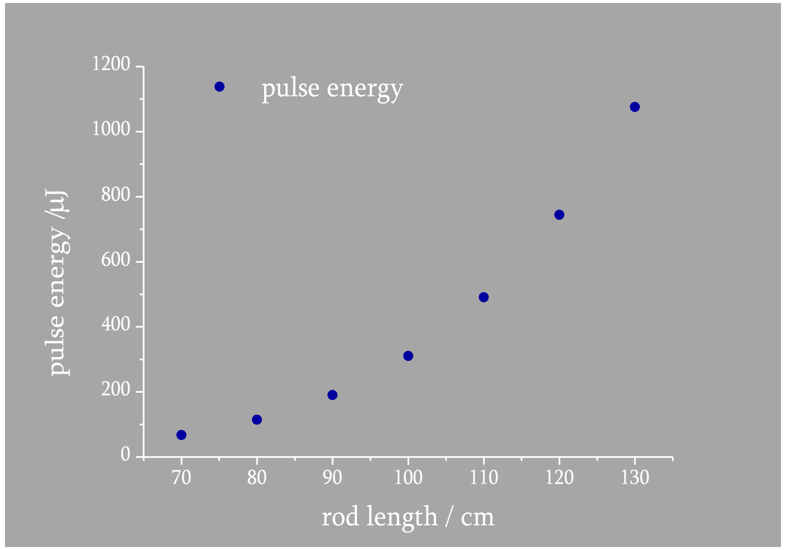
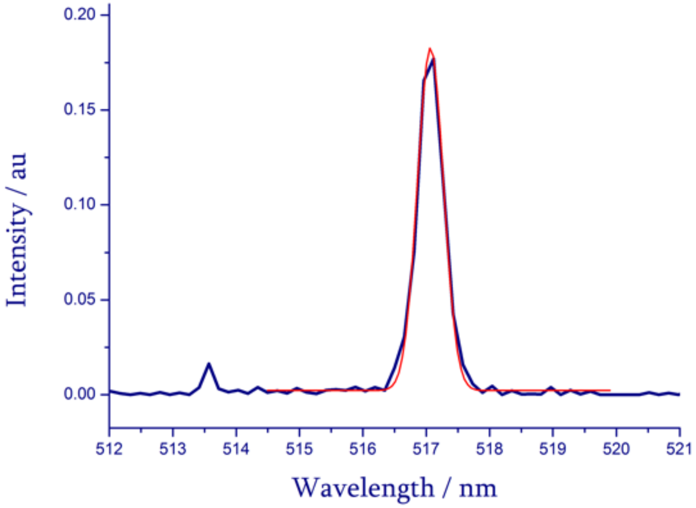






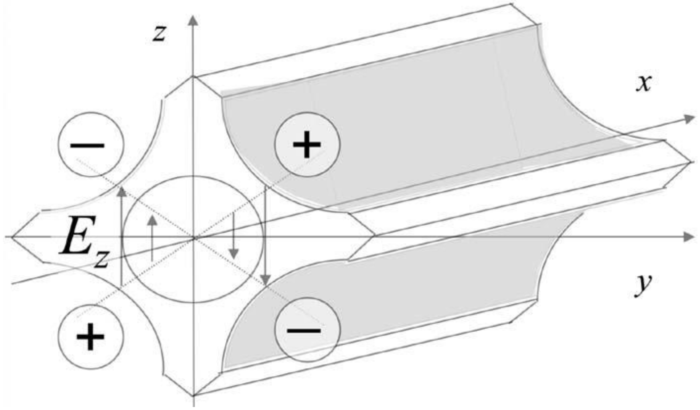
R&D on fast scanning system

APPLIED PHYSICS LETTERS **94**, 211104 (2009)

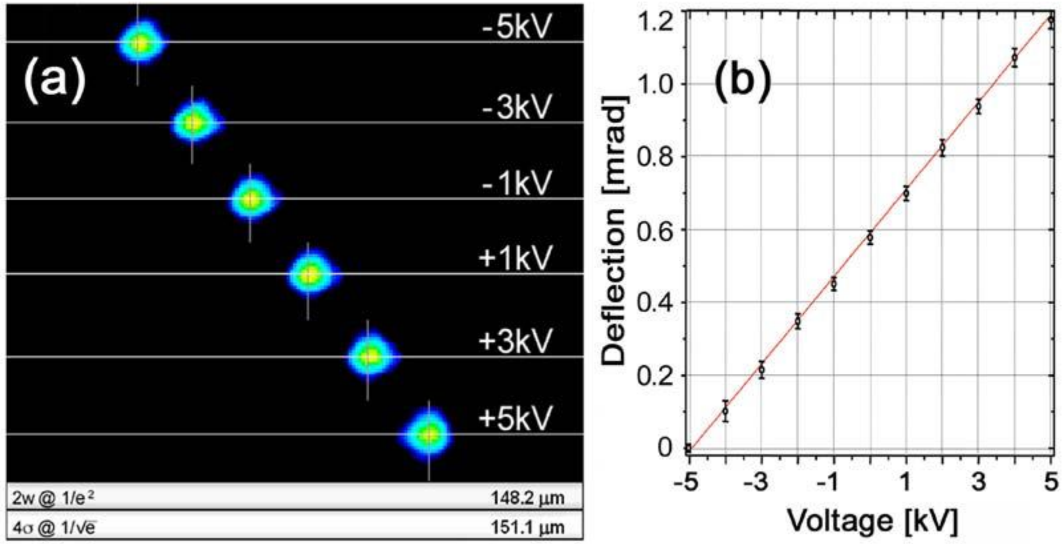
A large aperture electro-optic deflector

A. Bosco,[a] S. T. Boogert, G. E. Boorman, and G. A. Blair
John Adams Institute for Accelerator Science, Royal Holloway University of London, Egham Hill, Egham, Surrey TW20 0EX, United Kingdom

Developing a fast scanning system for high power laser



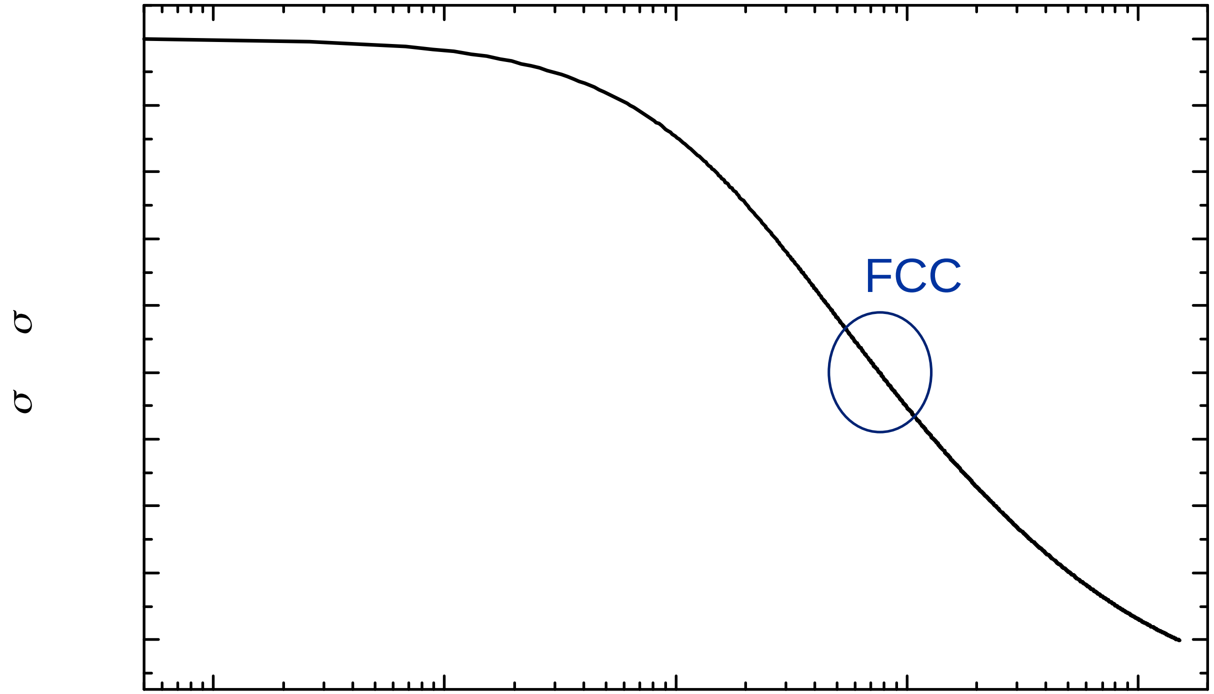
Schematic of an EO deflector with hyperbolically shaped electrodes.

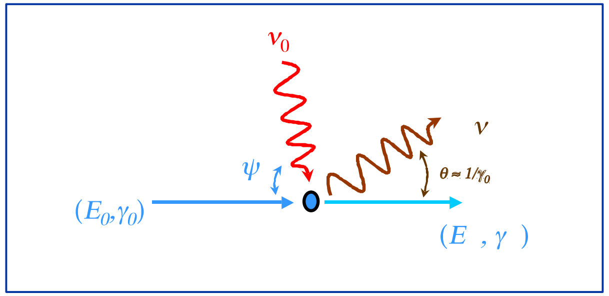


Demonstrating scan duration in 243us using 130kHz laser rep rate

Laser Wire Scanner for FCC

Compton Scattering at higher beam energies

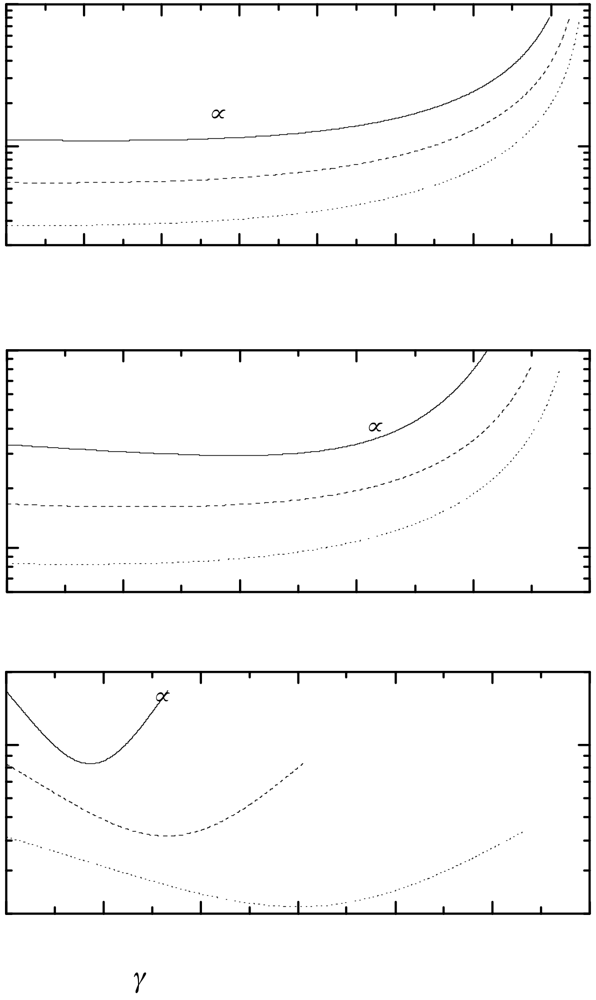


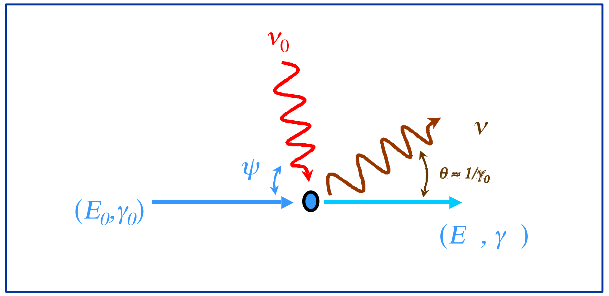


Cross section is decreasing for higher beam energy but still acceptable

Laser Wire Scanner for FCC

Compton Scattering at higher beam energies





- For high energy beams, the scattered photons steal most of the beam energy

- Detecting very high energy photons more efficient

Conclusion

- LWS can be positioned in the ring at any location and would work for any electron/positron beam energies without requiring modifications
- At high energy the Compton cross-section decreases but the detection of Compton photons becomes easier and cleaner
  - Done using Cherenkov gaseous detector that can be tuned to only detect high energy photons, less sensitive to photon background
- Optical diffraction radiation can be used in the ring to prealign the beams temporally and spatially
- Laser and optic technologies available
  - High power fibre laser can provide laser pulse trains at high repetition rate
  - Existing optical system demonstrated micron resolution
  - Fast scanning system could provide
- Similar hardware used for Compton polarimeter

Thanks for your attention

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Congratulations to all the teams

at KEK, DESY and JAI (RHUL, Oxford)

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