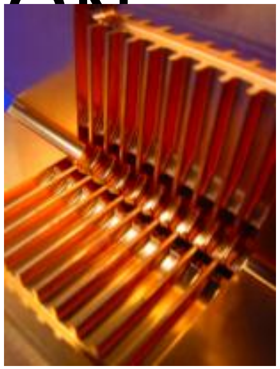
Institute of Electrical and Electronics Engineers
2012 IEEE NSS/MIC/RTSD Anaheim, California
27 October - 3 November 2012

LINEAR COLLIDER BEAM INSTRUMENTATION



T. LEFEVRE, CERN
ON THE BEHALF OF THE LC BEAM INSTRUMENTATION COMMUNITY

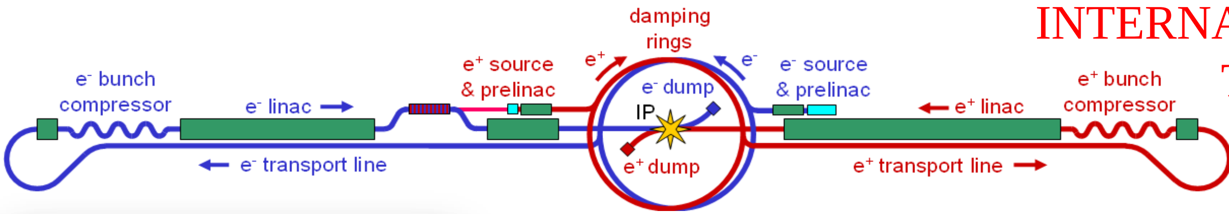
LINEAR COLLIDER BEAM INSTRUMENTATION

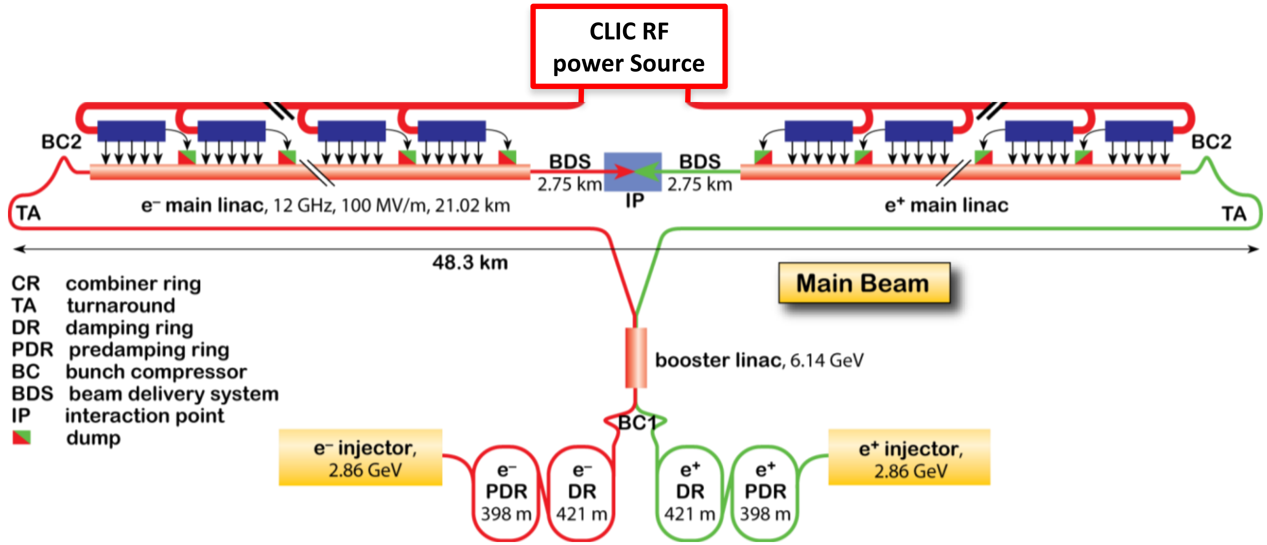
- Overview of Beam Instrumentation for Linear Collider
- Selection (5) of the main beam instrumentation R&D
- Conclusion and perspectives

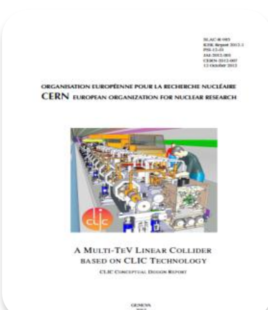
Linear Collider Projects

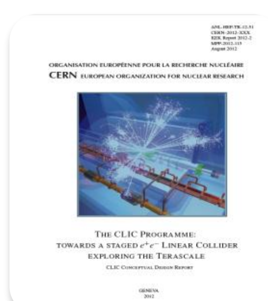
INTERNATIONAL LINEAR COLLIDER
Technical Design Report in 2013

http://www.linearcollider.org/



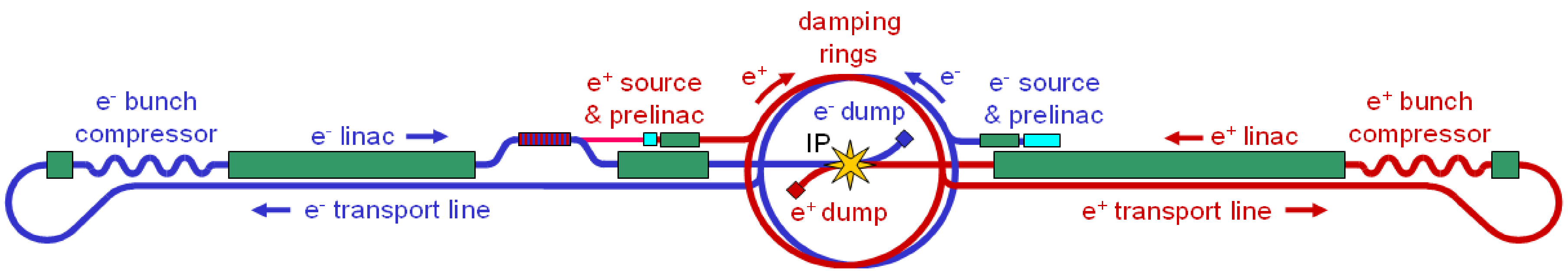






http://clic-study.org/

COMPACT LINEAR COLLIDER
Conceptual Design Report in 2012

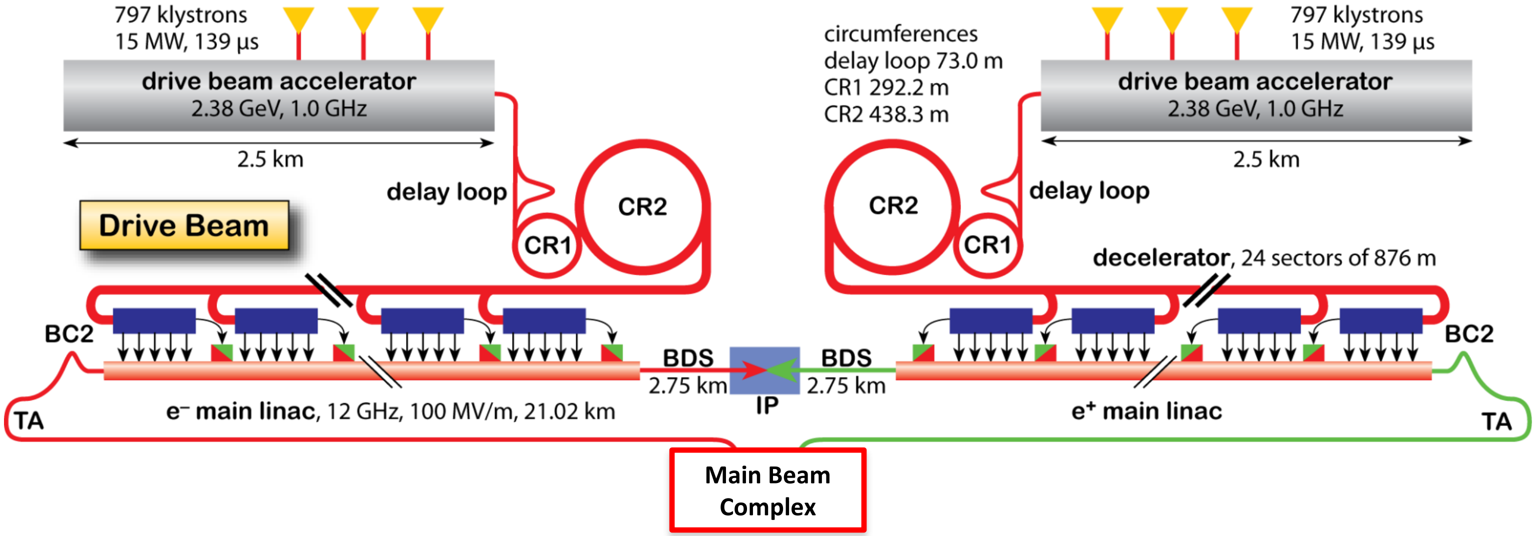


- As far as Beam Instrumentation is concerned, Colliding beams have very similar issues and requirements for both projects *(CLIC always little more demanding)*
- Collect requirements for the whole accelerator complex
  - Injector complex – Damping rings – long transfer lines – long main linacs – beam delivery system and dump lines (in CLIC ~ 100kms of beam line)
  - Most of the instruments in underground tunnel (in CLIC it accounts for 2/3 of the total)
  - In the tunnel, the number of instruments scales linearly with length (Energy) of the linac : 250/km
- Chosen instruments and diagnostics with corresponding technology choice
- Study alternative solutions which would impact either on cost or performance

CLIC Drive Beam

- CLIC RF power source based on Drive Beams
- High intensity (100A) high frequency (12GHz) beams
- Accounts for another 100kms of beam lines and ~ 10^5 beam instruments (>95% in tunnel)
- Large number but more relaxed requirements

DB Instruments	Surface	Tunnel	Total
Intensity	38	240	278
Position	1834	44220	46054
Beam Size	32	768	800
Energy	18	192	210
Energy Spread	18	192	210
Bunch Length	24	288	312
Beam Loss	1730	44220	45950



Instrumentation challenges for Linear Collider

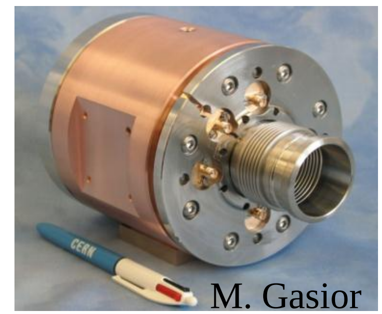
- Measuring small emittance and small beam size (non-intercepting devices)
  ~ 1um spatial resolution Transverse Profile Monitors
- Measuring short bunch length
  ~ 20fs time resolution Longitudinal Profile Monitors
- Conservation of emittance over long distances relies on precise beam alignment
  high accuracy (5um) high resolution (50nm) Beam Position Monitor
- Cost effective Beam position and Beam loss monitors for CLIC Drive beams

CLIC Drive Beam Decelerator Position monitor

Requirements:

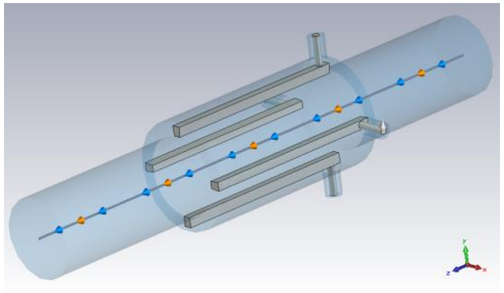
- High current 100A – high bunch frequency 12GHz
- In the vicinity of an RF structure producing 100MW @12GHz
- Temporal resolution of 10ns
- 2 micron resolution over an aperture of 23mm (accurate calibration)
- Simple and Cheap ~ 40k units

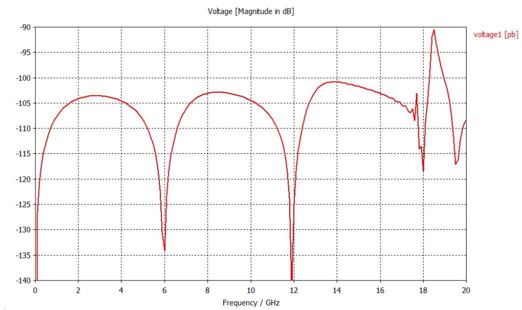
CLIC TEST FACILITY 3 uses Inductive Pick-ups
~60 Units ~ 5um resolution measured

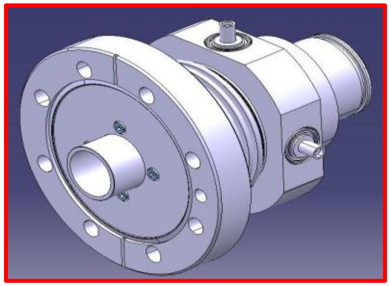


M. Gasior

Cheaper alternative based on Stripline Pick-ups *(A. Benot-Morell, S. Smith, M. Wendt, L. Soby)*



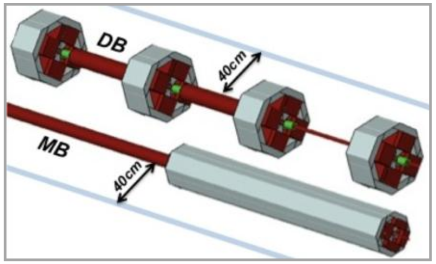




To be tested on CTF3 in 2013

CLIC Beam Loss monitors

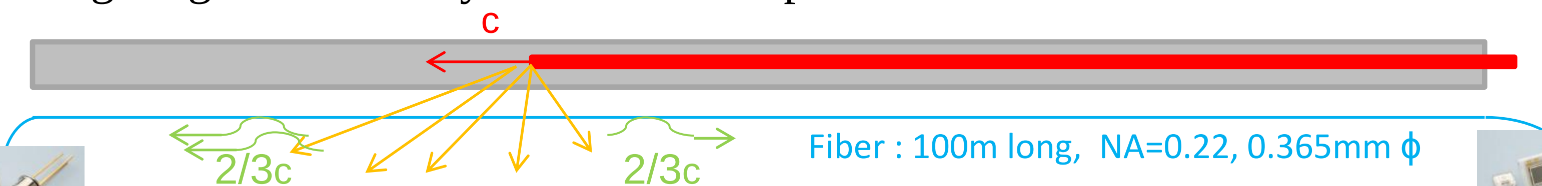
FLUKA model to simulate secondary particle shower distributions requirements



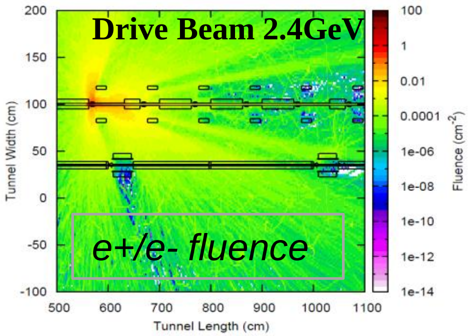
- Large dynamic 10^5 to cover destructive and operational losses
- Annual dose ≤ 50 kGy at detector location
- Ionization chambers as baseline choice : 1 detector/quadrupole

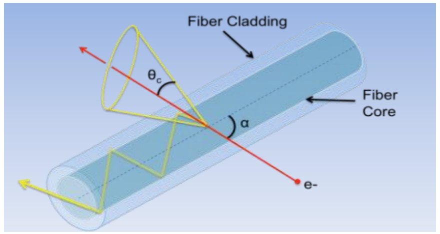
Based on LHC ionization chamber and readout electronics with dynamic range 10^5 (10^6 under investigation) and sensitivity 7e10^{-9} Gy

Considering long distributed system based of optical fibers used as Cherenkov detectors



SiPM as photon detector





Analytical model

≈ 50% more photons downstream

Sensitivity requirements: ≈ $10^4 – 10^5$ N_{ph}/train

Dynamic range: ≈ 10^4

Cherenkov model validated on beam tests (angular dependence)

Loss longitudinal localization works for single bunch

Quartz fibers tested ok up to 22 MGy

Length cannot be longer than 100m (attenuation)

UNIVERSITY OF LIVERPOOL *E. B. Holzer, J. van Hoorne, S. Mallows*

High Resolution Beam Position Monitors

Nanometer BPM's using RF Cavities have been developed since the last 15 years (ATF2)

Output RF signal proportional to the beam offset

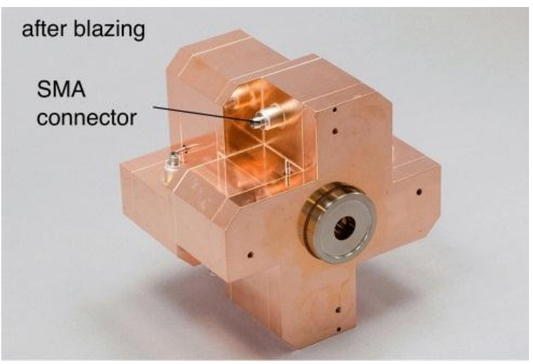
High precision mechanical machining of RF disks – brazing technique

IP BPM system

(BPM + Ref) Cavity : **1 unit**

Target : 2 nm

Aperture: 6 mm



Resolution 8.72 +-0.28(stat) +-0.35(sys) nm

@ 0.7×10^{10} electrons/bunch, @ 5μm dynamic range

Y. Inoue et al., Phys. Rev. ST-AB 11, 62801 (2008)

C-band BPM system

BPM cavity: **units**

Reference cavity: **4 units**

Target resolution: 100 nm

Aperture: 20 mm

Resolution 15.6 nm

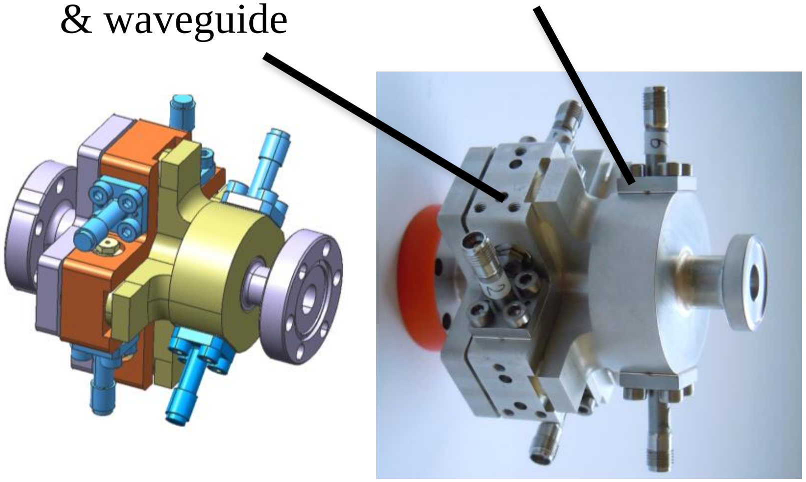
@dymamic range $\pm 20\mu$m

S. Walston *et al*, NIM A578 1 (2007)

Excellent resolution using low bandwidth cavity design !

Collaboration KNU / PAL / KEK / RHUL / SLAC

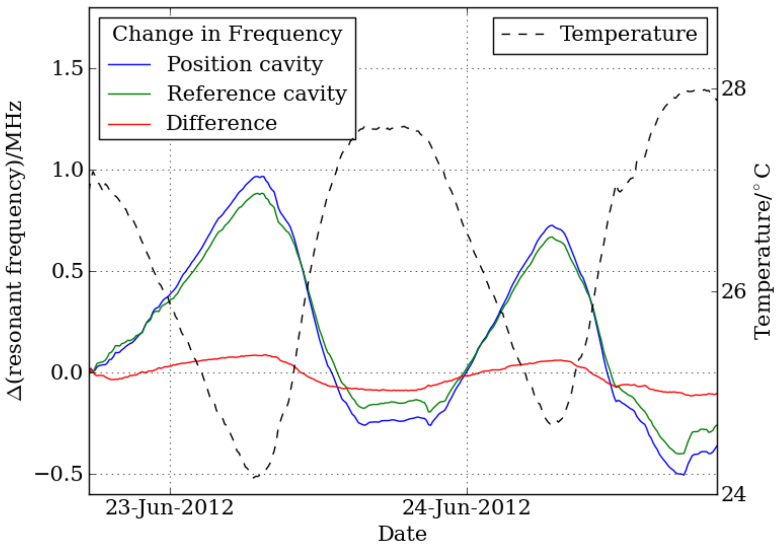
High Resolution Beam Position Monitors



- Low quality factor to provide multiple position measurements within a single train

- RF characterization before and after brazing:

Cavity	Position	Reference
Resonant frequency/GHz	15.012	14.997
Loaded quality factor	198	150



Temperature stability of both cavities measured

Cavity	Temperature stability/kHz/°C
Position	-359
Reference	-308
Difference	51

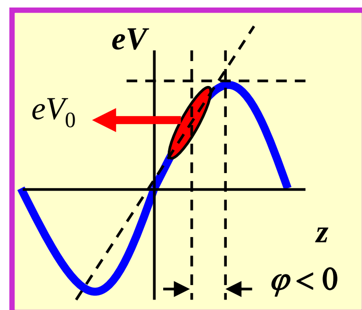
Beam Tests foreseen in 2012/13 @ CTF3-TBTS

Royal Holloway University of London
Fermilab
CERN
S. Boogert, F. Cullinan, A. Lunin, A. Lyapin, S. Smith, L. Soby, M Wendt

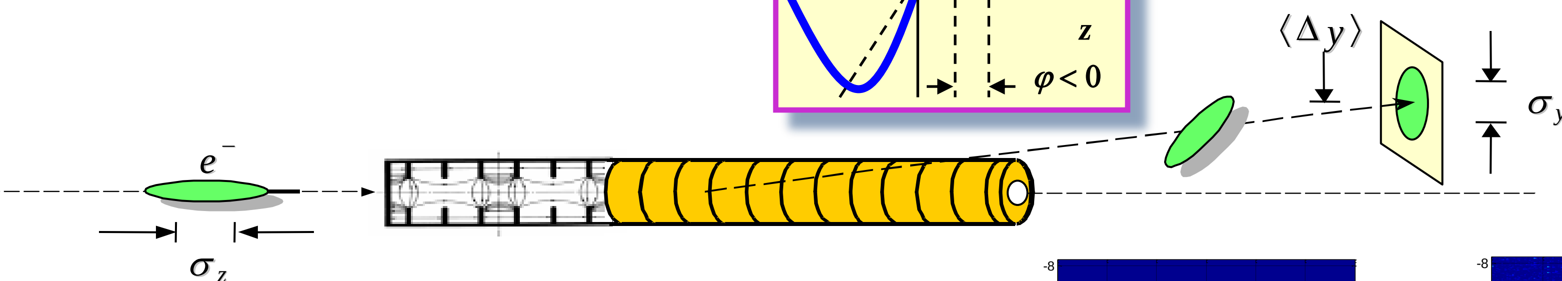
Short Bunch Length Monitors

	ILC	CLIC linac	XFEL	LCLS
Beam Energy (GeV)	250	1500	20	15
Linac RF Frequency (GHz)	1.3	12	1.3	2.856
Bunch charge (nC)	3	0.6	1	1
Bunch Length (fs)	700	150	80	73

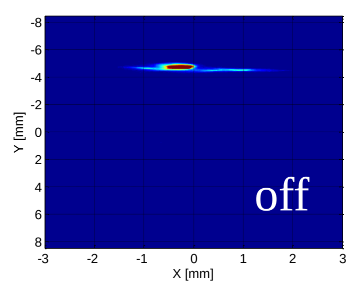
- High resolution and single shot longitudinal measurement:
  - Baseline solution using RF deflector : Excellent time resolution

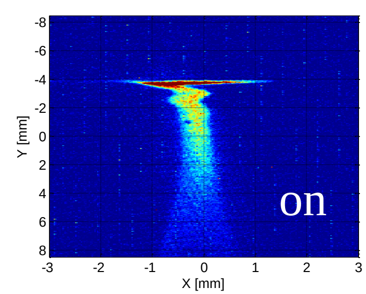


- *Old idea from the 60's*
- *RF Deflector ~ relativistic streak tube*
- *Used in almost all short bunch length facility*



!! But destructive method !!





Resolution of 4fs/pixels @ FLASH

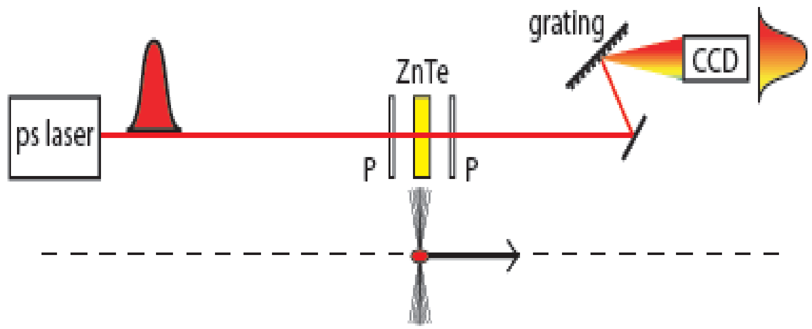
P. Emma et al, LCLS note LCLS-TN-00-12, (2000)

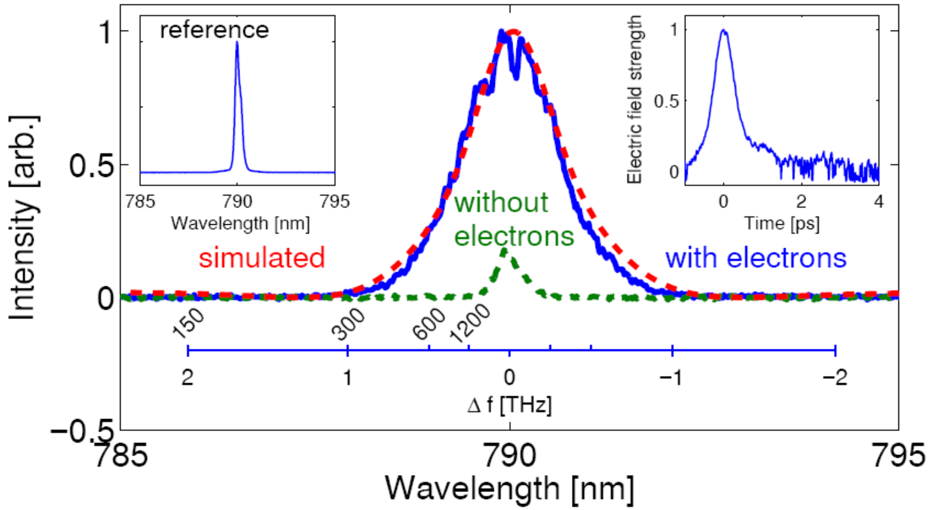
M. Hüning *et al*, Proceeding of the27th FEL conference, Stanford, 2005, pp538

Short Bunch Length Monitors

- **<u>EO - Spectral Upconversion Techniques</u>** - Convert the far-IR → mid-IR spectrum to an optical spectrum
  - Bandwidth reduction [10μm – 1mm] → [740-800]nm

*Phys Rev Lett **99**, 164801 (2007)*
*Phys. Rev. ST, **12**, 032802 (2009)*





- **Laser-generated THz pulses as mimic of electron bunch (Daresnury)**
- **Plan for beam tests at short test facility (PSI)**

- **<u>EO Detection solution in advanced materials</u>:** Very high bandwith material (phonon resonances in far THz)

Materials, Photonics & Smart Systems (MAPS) Group at Dundee

Fabrication & Applications of Nanocomposites

High resolution Beam Size monitors

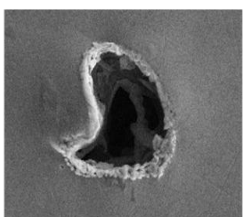
- Required high precision from the Damping ring to the Interaction Point (IP)
  - Beam energy ranges from 2.4GeV → 1.5TeV
  - Tens of km of beam lines – Big number of instruments

- Flat Beams ($\sigma_x >> \sigma_y$)

	ILC	CLIC	CLIC DB
Beam Charge (nC)	7875	190	1.2 10^6
Hor. Emittance (nm.rad)	10^4	660	10^8
Ver. Emittance (nm.rad)	40	20	10^8

- Small beam size
- High beam charge

→ High Charge Densities > 10^{10} nC/cm^2
Thermal limit for 'best' material (C, Be, SiC) is 10^6 nC/cm^2

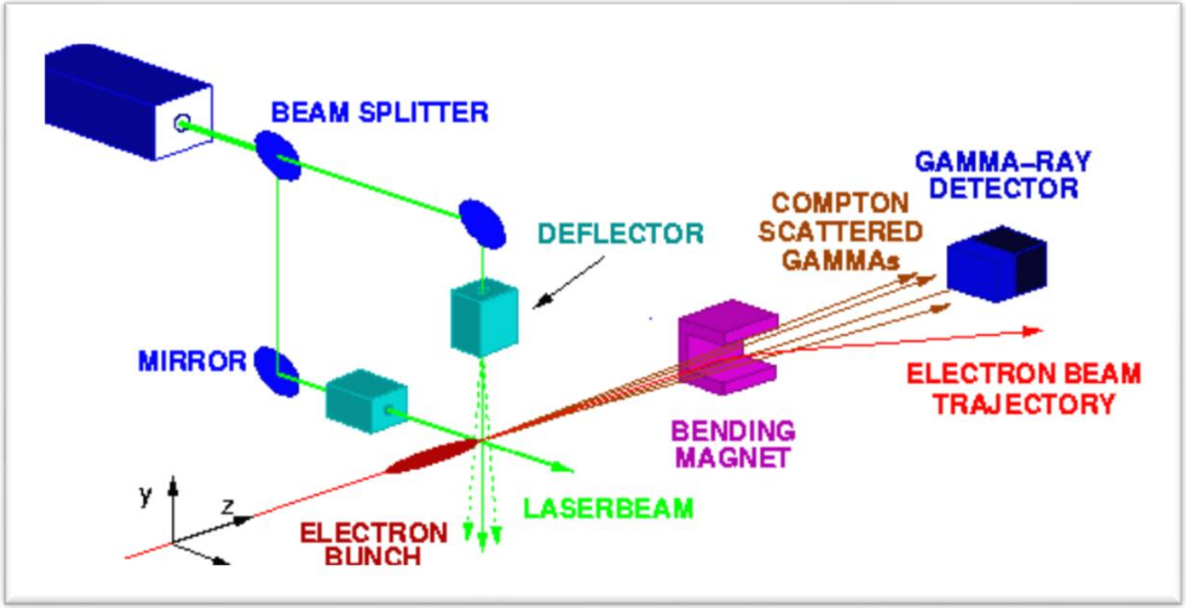


→

- Intercepting devices limited to single (or few) bunch
- Strong need for non-intercepting devices
- Require two different systems to cover the large beam intensity dynamic range (commissioning and production beams)

Laser Wire Scanners

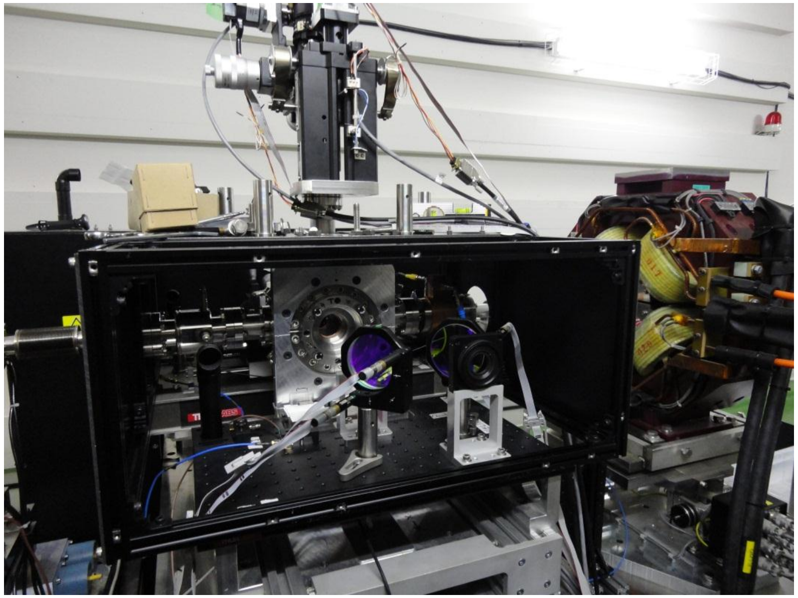
- High resolution non-interceptive transverse profile measurements using LWS
  - Goal to measure 1um beam profile (resolution demonstrated on SLC in 90s)
  - Small Compton scattering cross section → High power laser (10MW)



10 Years of R&D

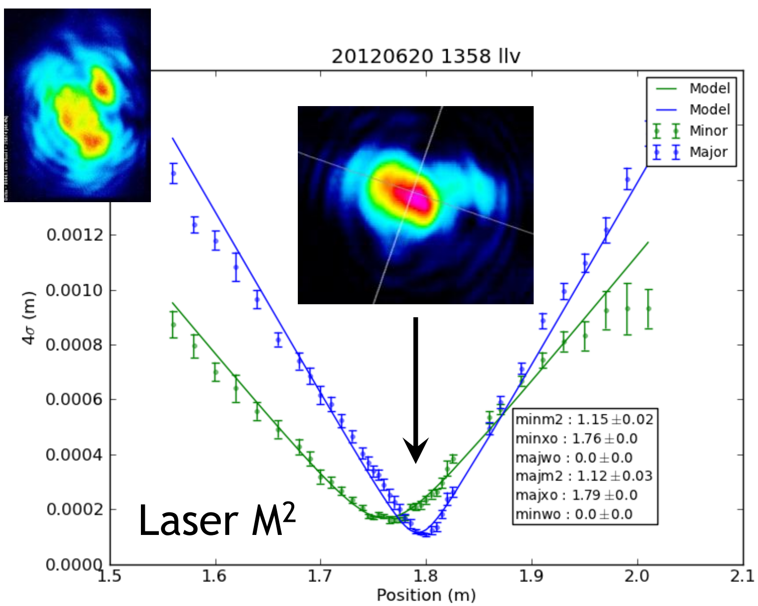
- Spatial resolution requires strong laser focussing: (High quality fiber laser and optics, Diffraction limited spot size using large F#)
- Complexity and reliability: 'Make it easy to operate'

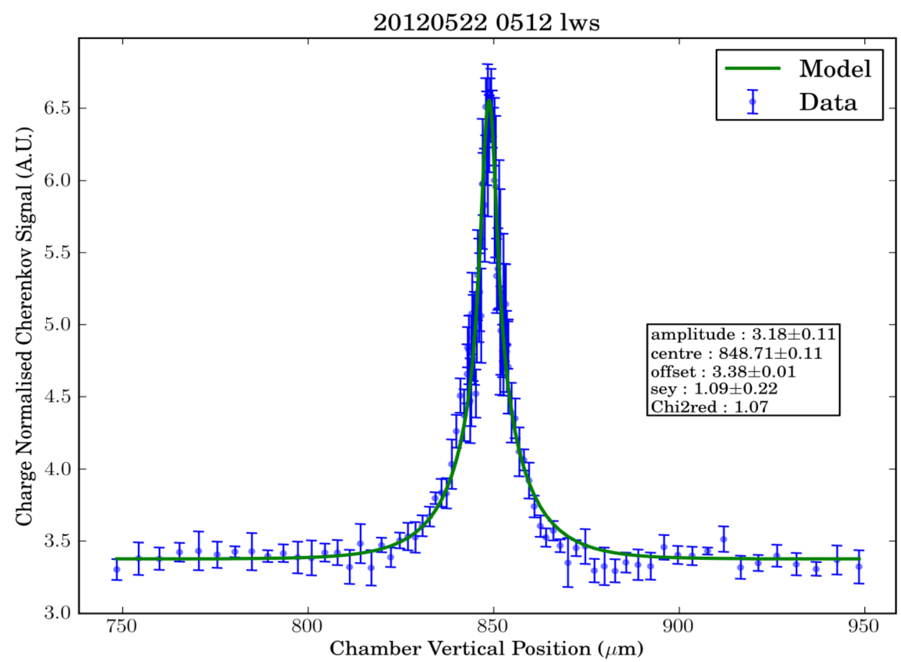
S. T. Boogert et al, Phys. Rev. S. T. – Accel. and Beams 13, 122801 (2010)
L. Corner *et al*, Proc. of IPAC, Kyoto, Japan (2010) pp3227



ATF2 Laser-wire @ KEK in 2012

- LW moved during 2011 shutdown
- e^- optics V:1μm x H:200μm
- Lower background
- Laser focus characterised in depth
- Further analysis on-going



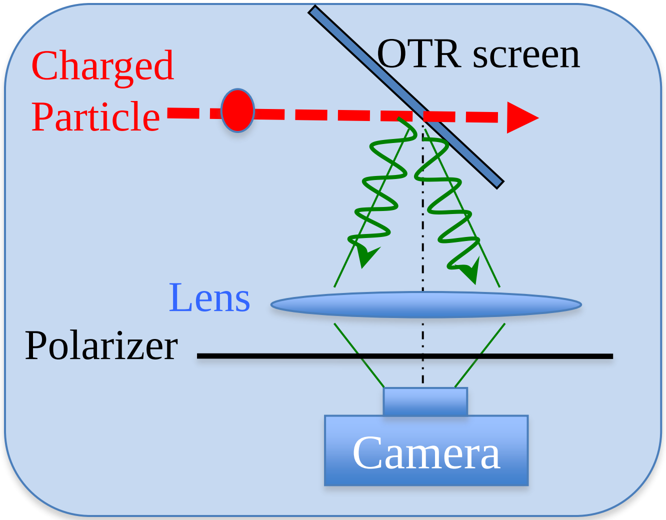


L. Nevay, L. Corner, S. Boogert, P. Karataev, A. Aryshev

High resolution OTR measurements

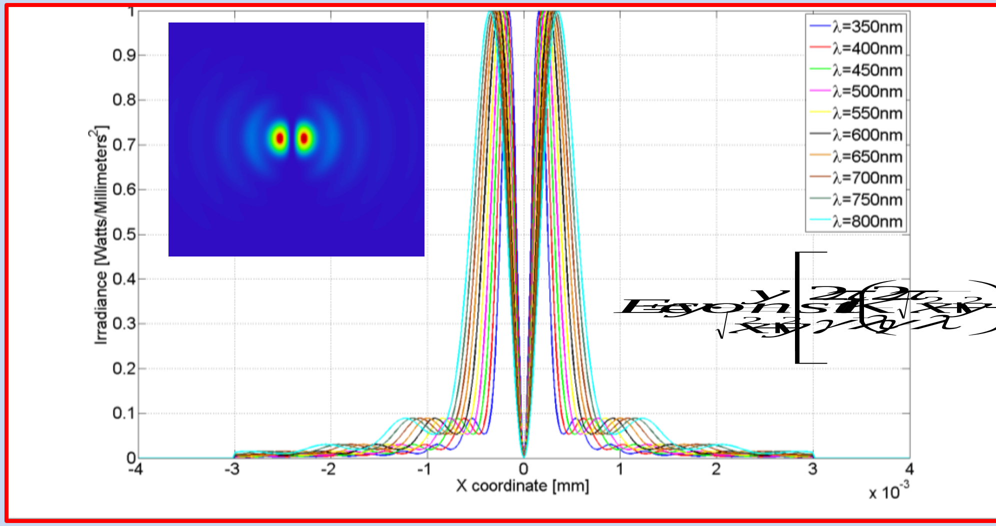
Optical Transition Radiation

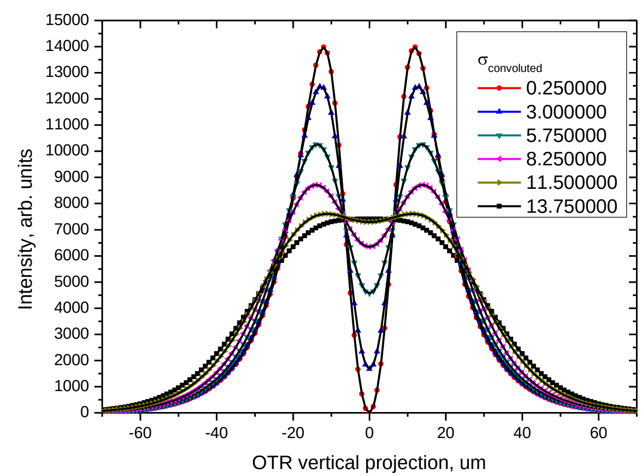
- Charged Particle passing through a dielectric material (high reflectivity)
- Interceptive method limited to single bunch
- Simple, reliable and cheap



Point spread function of OTR imaging system

~ Image generated by a single electron (Zemax simulations)



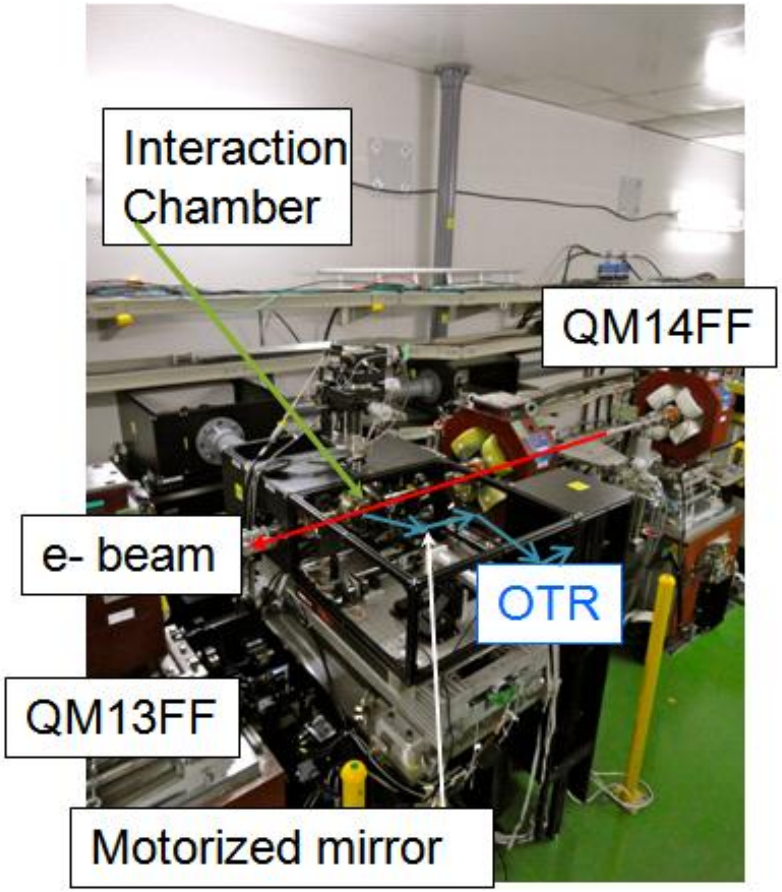


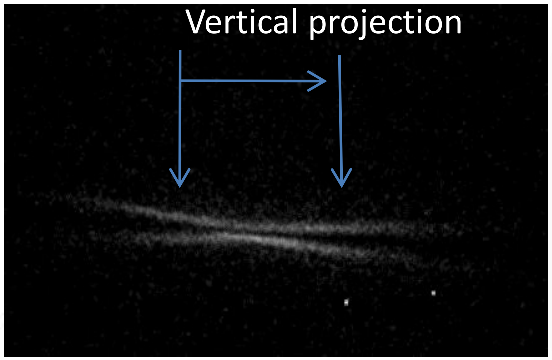
If we consider physical beam size, the resulting image on the camera is the convolution of the beam spatial distribution with the optical system PSF

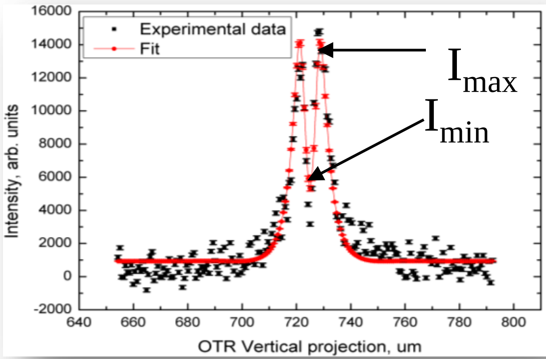
A. Aryshev, N. Terunuma, J. Urakawa, S. Boogert, P. Karataev, L. Nevay, T. Lefevre, B. Bolzon

High resolution OTR measurements

ATF2 OTR PSF @ KEK in 2012

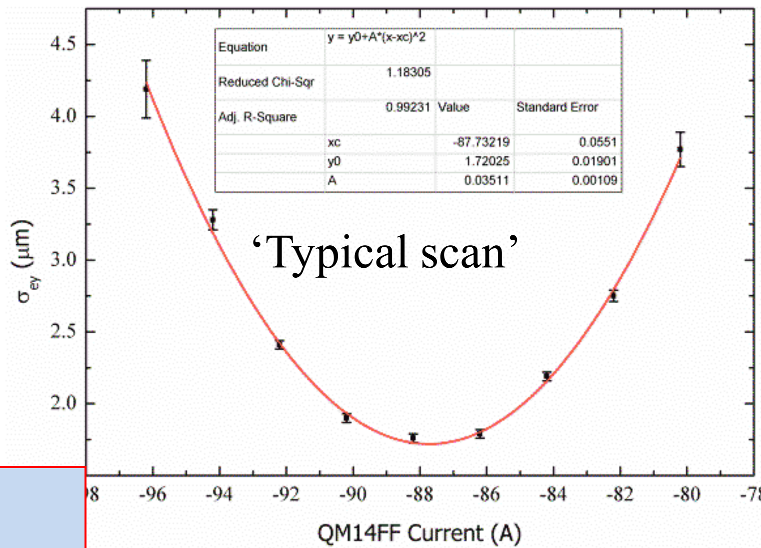






$$f(x) = a + \frac{b}{1+[c(x-\Delta x)]^4}\left[1 - e^{-2c^2\sigma^2}\cos[c(x-\Delta x)]\right]$$

a	522.981 +/- 4.43887
b	37773.1 +/- 116.182
c	0.231221 +/- 0.00049
Δx	786.905 +/- 0.00679
σ calibrated	1.28202 +/- 0.0479

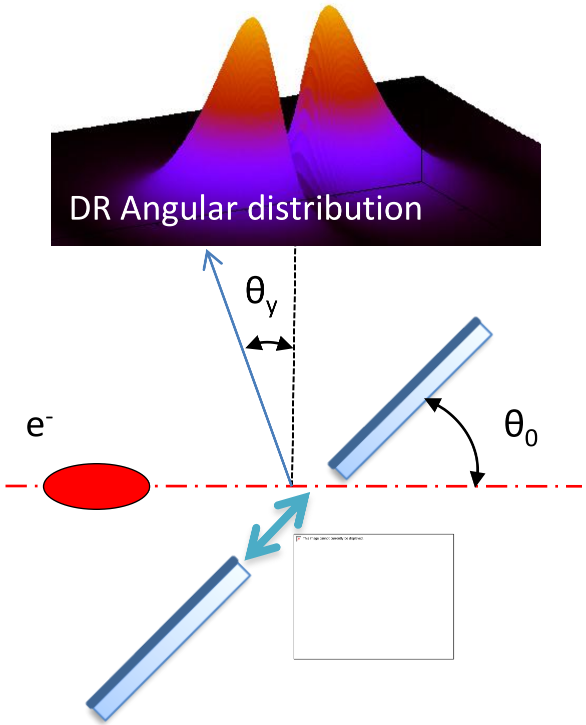


P. Karataev et.al, Phys. Rev. Letters ***107****, 174801 (2011)*
A. Aryshev, et.al, Journal of Physics: Conference Series ***236 (2010) 012008***

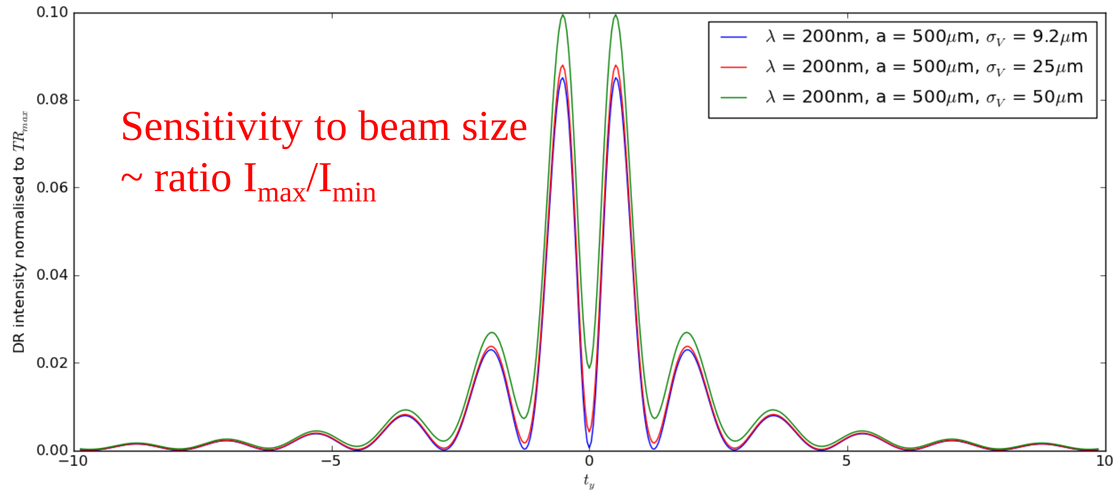
- Improving image quality (aberration, field of depth,..)
- Propose to test similar system close to final focus

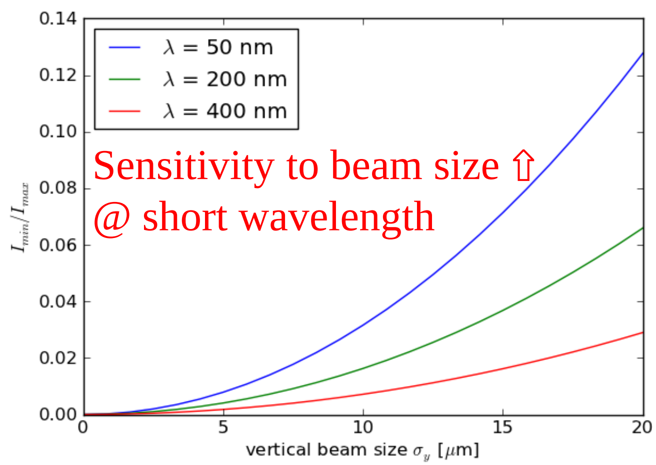
Diffraction Radiation

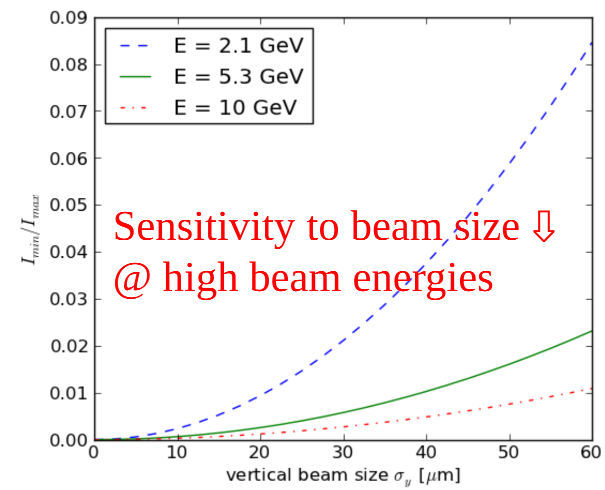
- Interference pattern between the diffraction radiation emitted by the edges of the slit
- Vertical beam size in DR vertical polarization



DR intensity ⇧ as slit size ⇩





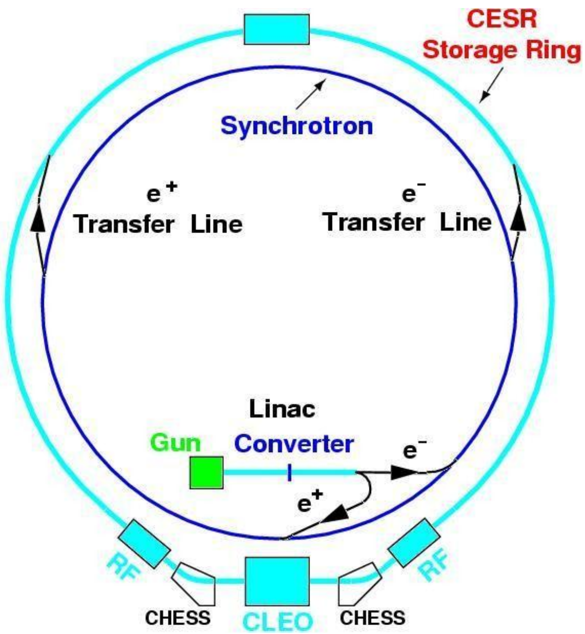


A. Cianchi et al., Phys. Rev. ST Accel. Beams 14 (10) 102803 (2011)
A.H. Lumpkin et al, Phys. Rev. ST Accel. Beams 10, 022802 (2007)
P. Karataev et al, Phys. Rev. Lett. 93, 244802 (2004)

L. Bobb, T. Aumeyr, M. Billing, D. Rubin, N. Chritin, P. Karataev, T. Lefevre

Diffraction Radiation for Beam Size Monitoring

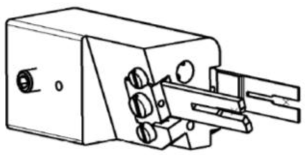
Test foreseen on Cornell Electron Storage Ring in 2012/13

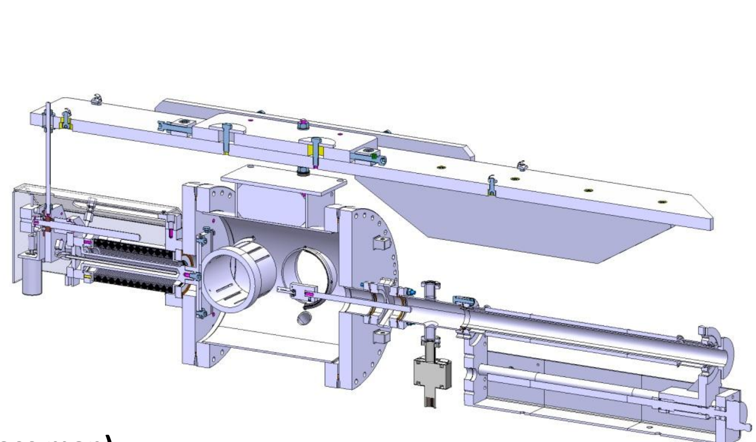


E (GeV)	σ_H (μm)	σ_V (μm)
2.1	320	~9.2
5.3	2500	~65

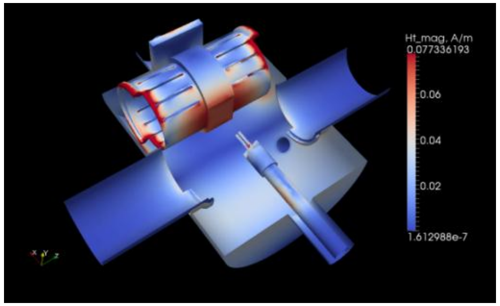
Target Assembly

- Mask to supress background from Synchrotron radiation
- Target for Diffraction Radiation: *λ/100* roughness, *λ/10* coplanarity





H-field surface tang complex magnitude (Loss map)
Mode Fr = 1.19 GHz, Q = 3309, Ploss = 0.075 W



Total power loss for single bunch = 0.6 W

- Phase 1 working at 400 and/or 200nm : beam size measurement ~30-50microns

- Phase 2 program to use shorter wavelength (< 50nm)

L. Bobb, T. Aumeyr, M. Billing, D. Rubin, N. Chritin, P. Karataev, T. Lefevre

Conclusions and Perspectives

- LC Beam Instrumention is a very active field relying on large collaboration

- No feasibility issues but still many technical challenges in wide range of disciplines

  Electronics, RF, Sensors, Radiation hardness, Laser and Optics, High precision machining and polishing,…

- Baseline choices have been made but R&D is going on in many areas
  - Reliability, Simplicity and Cost optimization driving the R&D efforts

    (not always compatible with tight tolerances as required)

- Large amount of devices to built and operate *(beyond what was already achieved in our field),*
  - Realistic Integration of instruments in the Machine layout to be finalized
  - Standardization is a key concept for operation and maintenance

Thanks all the ILC/CLIC contributors to the talk

Thanks for your attention