Instrumentation Challenges for CLIC

T. Lefevre on behalf of the CLIC beam instrumentation team

CLIC workshop, 21-25 January 2019, CERN

What have BI teams done since the CDR ?

T. Lefevre on behalf of the CLIC beam instrumentation team

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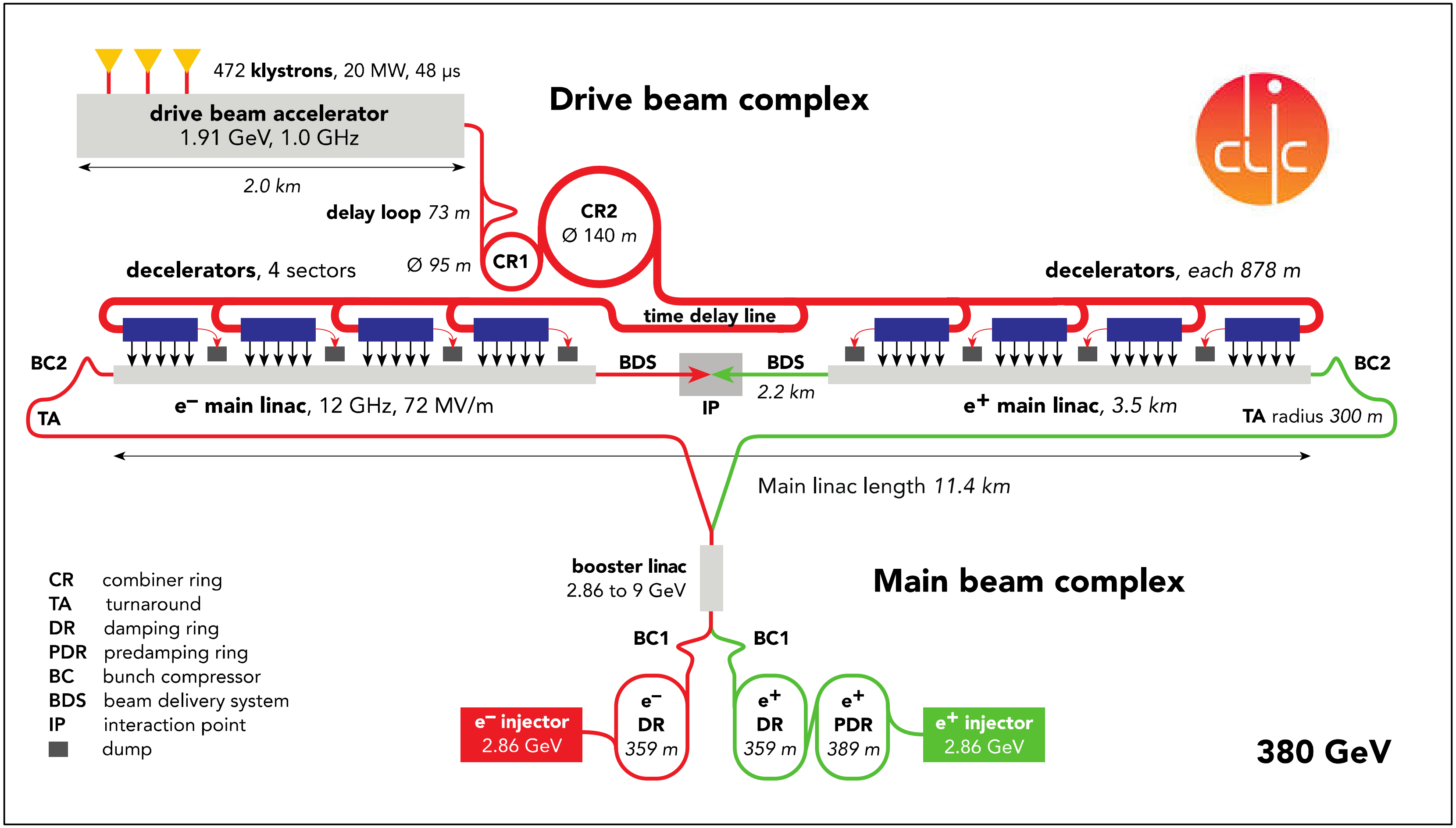
Outline

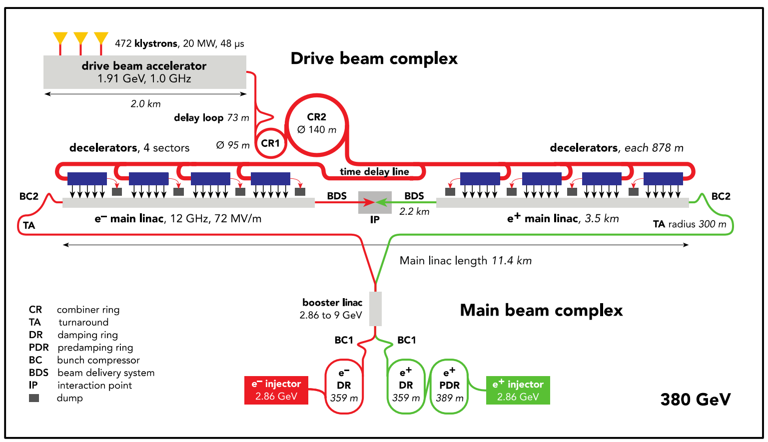
- CLIC @ 380GeV - PIP
- **Update on Instrumentation challenges**
  - High precision/resolution beam instruments
  - R&D towards simpler & cheaper alternative solutions
  - R&D on Non-invasive beam instrumentation
- Conclusions

CLIC PIP - 2018



CLIC PIP - 2018

Beam instruments



Instrument	Drive Beam	Main Beam
Intensity	50	130
Position	7,875	4,165
Beam Size	80	110
Energy	50	30
Energy Spread	50	30
Bunch Length	60	30
Beam Loss /Halo	7,790	4,950
Beam Polarization		20
Tune		6
Luminosity		2
Total	15,955	9,475

Instrumentation challenges

- Producing and measuring beams with **small emittance (i.e. micron spot size)**
- Producing and measuring **short Bunches (i.e 20fs time resolution)**
- Conserving small emittance over long distances put very strict requirements on the **beam position monitor precision (i.e. 5microns) and resolution (i.e. 10s nm)**

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- Manipulating **high charge beams**
  - Impact on **Machine Protection** issues
  - Impact on **Radiation hardness** issues
  - Require **non-intercepting beam diagnostics**

Instrumentation challenges

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  - … on **Machine Protection** issues
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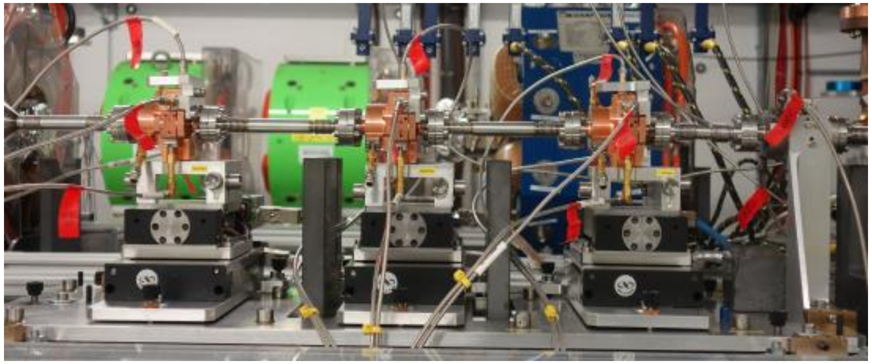
As **cheap** as possible !
As **simple** as possible !

High resolution BPM

High resolution BPM

- CLIC cavity BPM prototype tested on CALIFES / CLEAR
  - Aperture: 8mm - Operating frequency: 15 GHz



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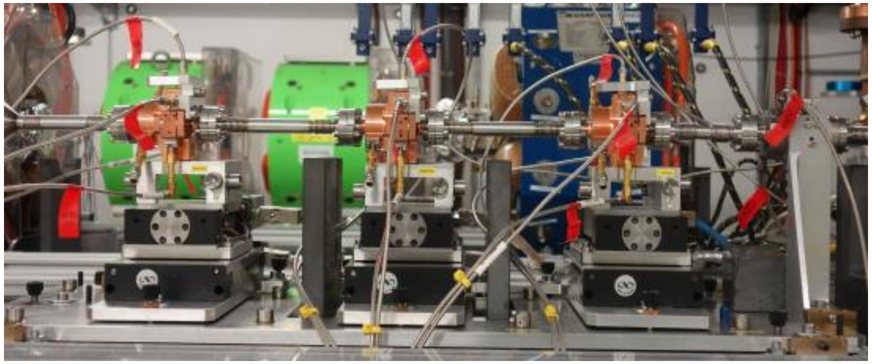

  - Investigating the time response for long Bunch train observation

F. J. Cullinan *et al.*, *Long bunch trains measured using a prototype cavity beam position monitor for the Compact Linear Collider*, Phys. Rev. STAB 18 112802 (2015)

  - Some issues of radiation hardness observed requiring an optimization of the read-out electronic

High resolution BPM

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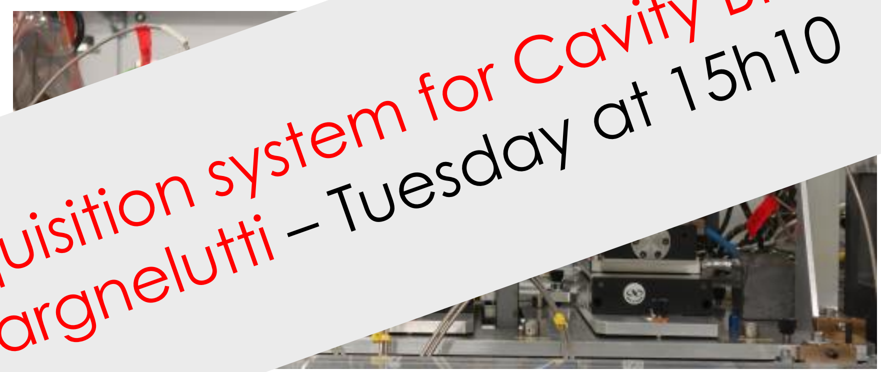

Talk on '**An acquisition system for Cavity BPM**'
by **Manuel Cargnelutti** – Tuesday at 15h10

ain observation

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Compact Linear Collider, Phys. Rev. STAB 18 112802 (2015)

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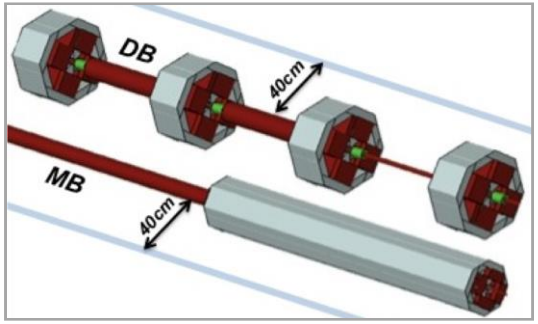
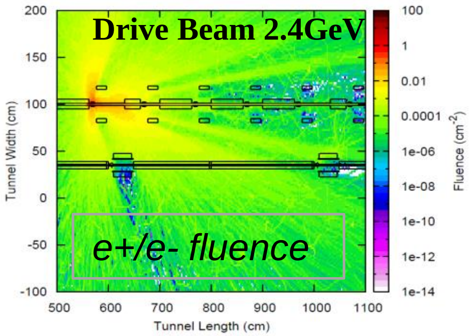
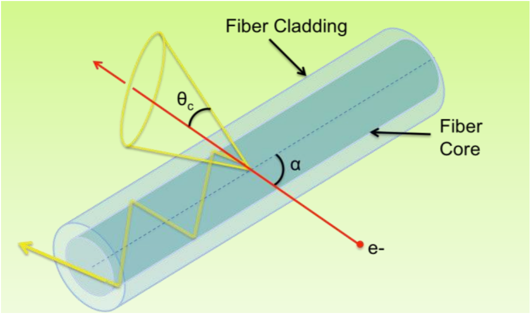
Beam Loss Monitors

Beam Loss Monitors

- Simulations and Design of optical BLM system for CDR in 2012







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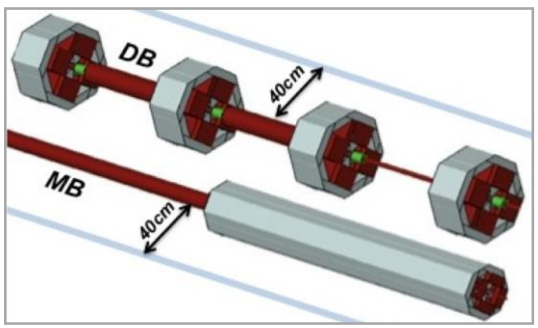
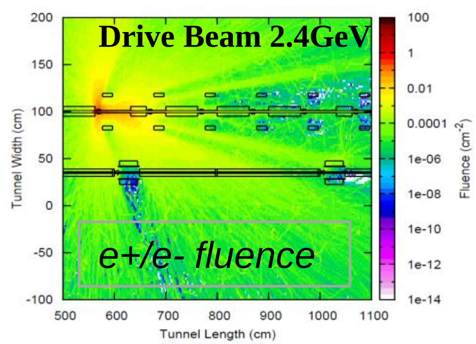
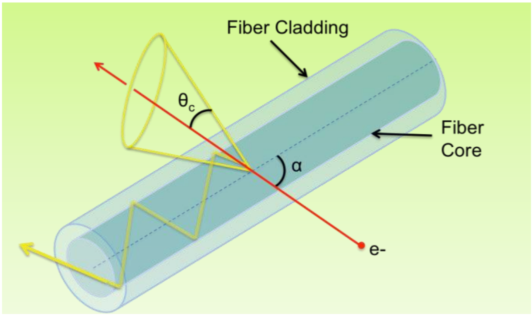






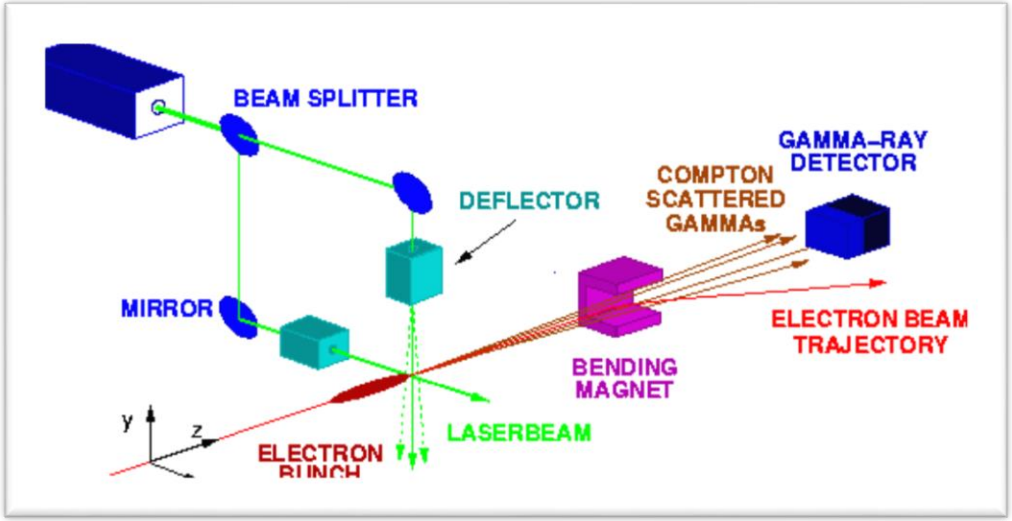
- Since then, … Many experimental studies
  - Crosstalk between beam losses from MB and DB : *M. Kastriotou et al, "BLM crosstalk studies on the CLIC two-beam module", IBIC, Melbourne, Australia (2015) pp. 148*
  - Position resolution of a distributed oBLM system : *E. Nebot del busto et al, "Position resolution of optical fibre-based beam loss monitors using long electron pulses", IBIC, Melbourne, Australia (2015) pp. 580*
  - RF studies (Breakdown and Dark current): *M. Kastriotou et al., "A versatile beam loss monitoring system for CLIC", IPAC, Busan, Korea, 2016, pp. 286*

Australian Synchrotron
CERN
UNIVERSITY OF LIVERPOOL

High resolution transverse beam size monitors

High resolution transverse beam size monitors

- Using **Laser Wire scanners** as a Baseline in CDR-2012
  - Based on Compton scattering using high power lasers



High resolution transverse beam size monitors

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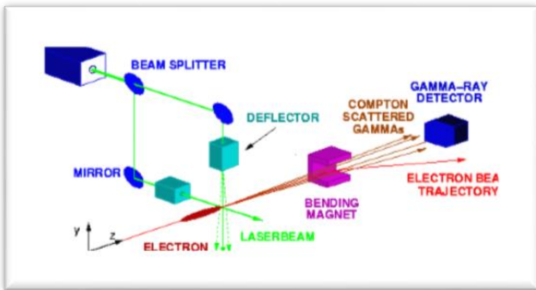
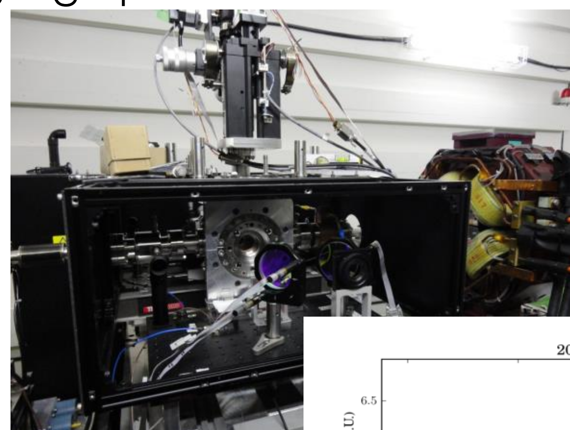
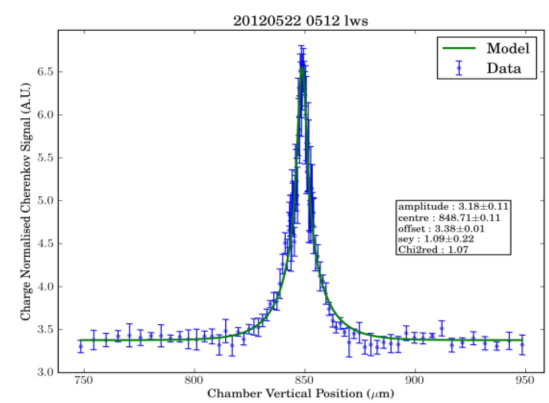




  - **10 years on R&D** in the 2000s (ATF2)

S. T. Boogert *et al.*, PRSTAB 13, 122801 (2010)

L. Corner *et al.*, IPAC, Kyoto, Japan (2010) pp3227



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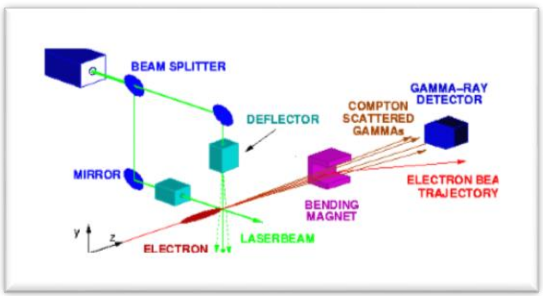

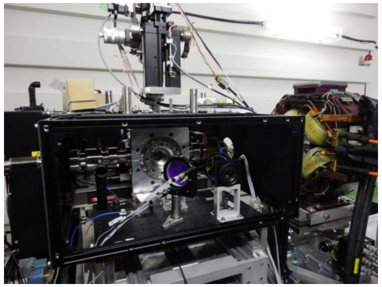

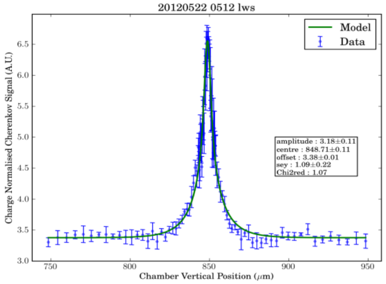

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L. Corner *et al.*, IPAC, Kyoto, Japan (2010) pp3227

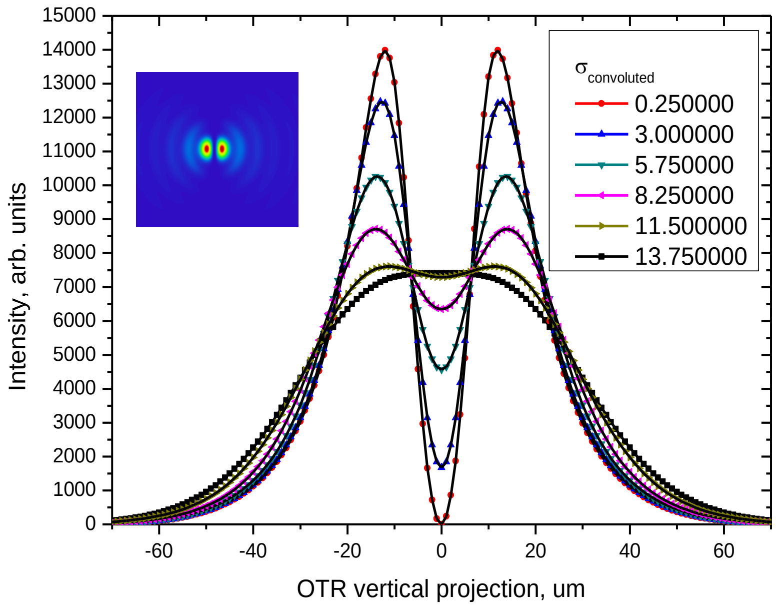
  - **Works well** but **expensive and complex**
  - Study **alternative solutions** to reduce the number of LWS in complex

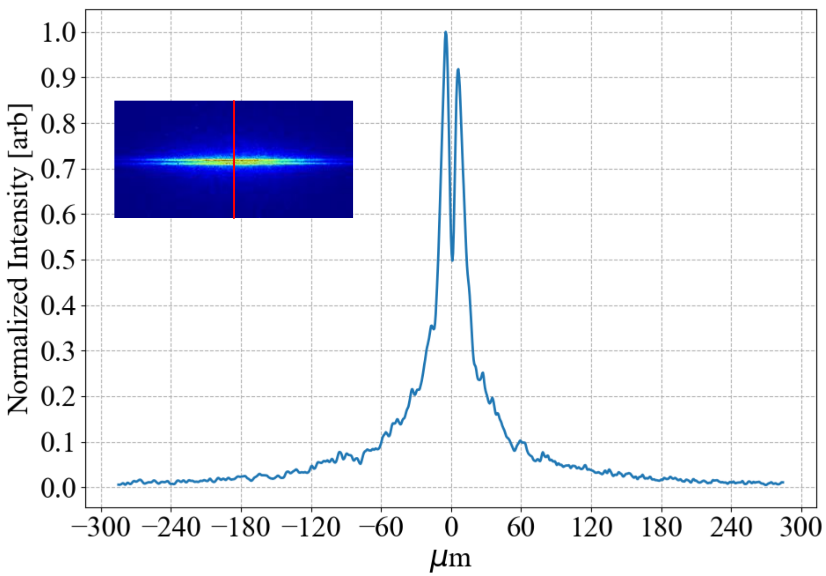
High resolution transverse beam size monitors

- Investigating very high resolution imaging system using **Optical transition radiation** as a simple and cheap solution

High resolution transverse beam size monitors

- Investigating very high resolution imaging system using Optical transition radiation as a simple and cheap solution
- Work started in KEK in 2010 : Measuring beam size as **visibility of the OTR Point(Particle) Spread Function** (P. Karataev *et al.*, PRL **107**, 174801 (2011))





High resolution transverse beam size monitors

- Investigating very high resolution imaging system using Optical transition radiation as a simple and cheap solution
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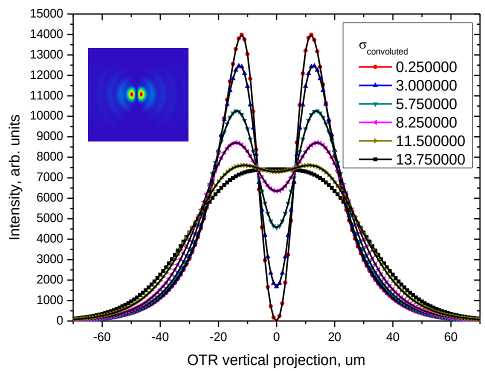

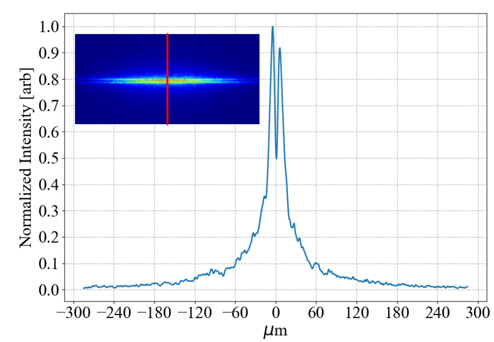

- **Sub-micron resolution demonstrated** and used since 2015 regularly on our test-stand at ATF2 (B. Bolzon *et al.*, PRSTAB **18**, 082803 (2015))

High resolution transverse beam size monitors

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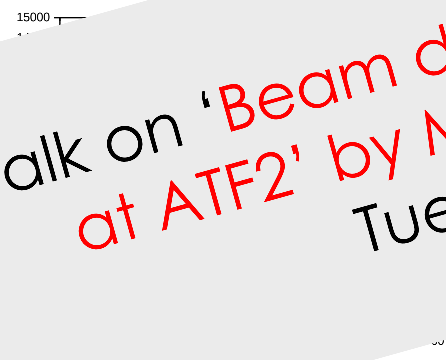
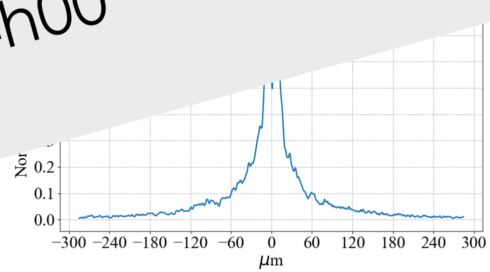


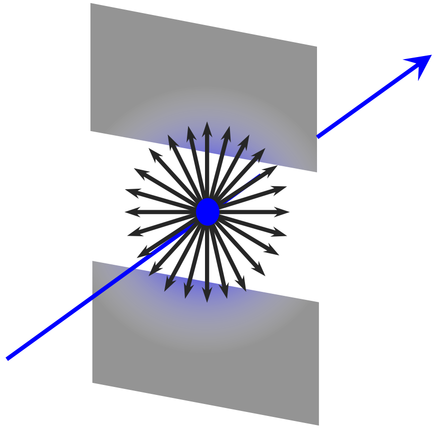


Talk on '**Beam diagnostic developments at ATF2**' by **Michele Bergamaschi** – Tuesday at 14h00

- Sub-micron resolution demonstrated and used since 2015 regularly on our test-stand at ATF2 (B. Bolzon *et al.*, PRSTAB **18**, 082803 (2015))

Non-invasive beam size using ODR

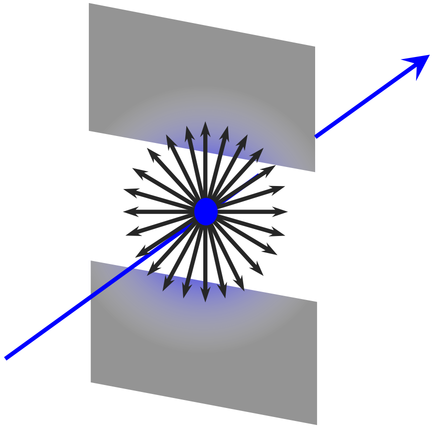
- Studying non-invasive beam size measurements using **Optical diffraction radiation from thin dielectric slits**

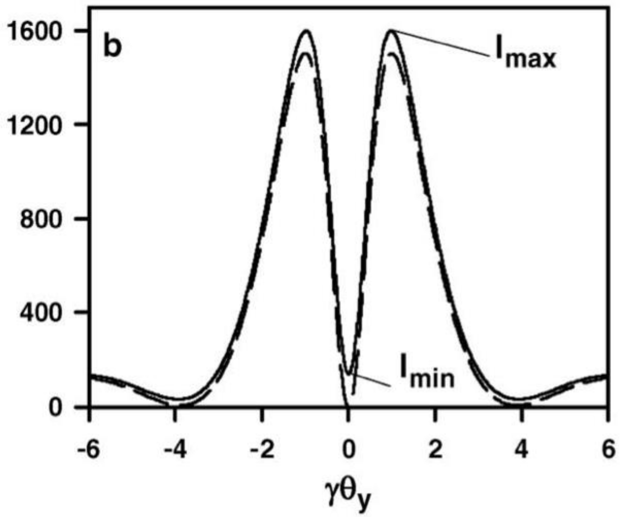


Non-invasive beam size using ODR

- Studying non-invasive beam size measurements using Optical diffraction radiation from thin dielectric slits

The **beam size** is extracted from the **visibility I_{min}/I_{max}** of the projected vertical component of the **ODR angular distribution**



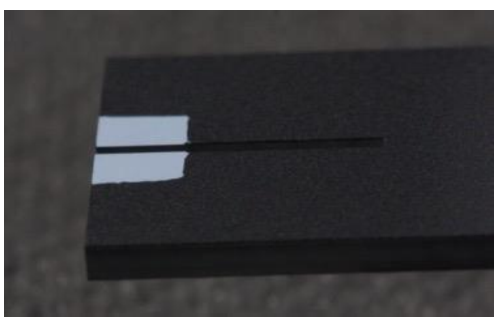


Non-invasive beam size using ODR

- Studying non-invasive beam size measurements using Optical diffraction radiation from thin dielectric slits

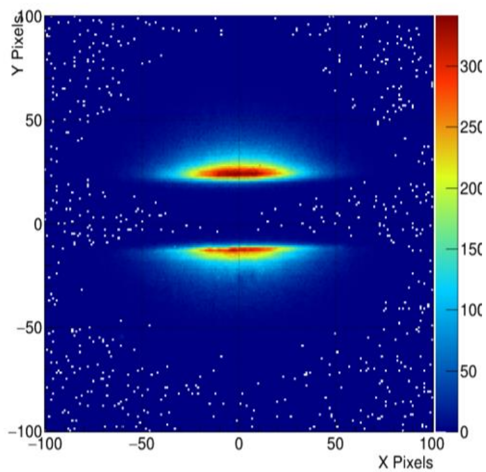
- Work started in **2011 at CESR** and then **ATF2 since 2015**

R&D on slit configurations and technology

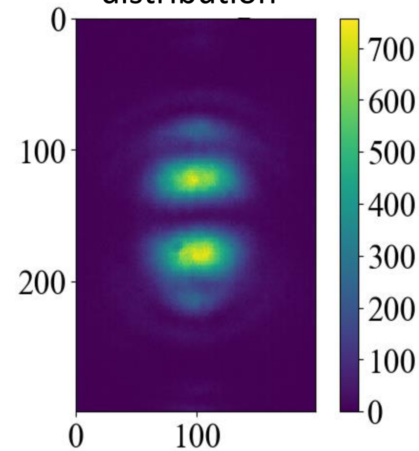


Maximizing emission of DR
Minimizing reflection of SR

Direct Image



2D Angular distribution



Non-invasive beam size using ODR

- Studying non-invasive beam size measurements using Optical diffraction radiation from thin dielectric slits
- Work started in 2011 at CESR and then ATF2 since 2015
- Develop also **simulations using Zemax** suite (T. Aumeyr *et al.*, PRAB **18**, 042801 (2015))
- **Few microns resolution** recently **demonstrated** at ATF2 (L. Bobb et al., PRAB **21**, 032801 (2018) and M. Bergamaschi, PhD thesis, 2018)

Non-invasive beam size using ODR

- Studying non-invasive beam size measurements using Optical diffraction radiation from thin dielectric slits
- Work started in 2011 a…
- D… …18, 042801 (2015))
- **Fe**… …**demonstrated** at ATF2 (L. Bobb et al., PRAB **21**, 03280… …thesis, 2018)

Talk on 'Beam diagnostic developments at ATF2' by Michele Bergamaschi – Tuesday at 14h00

Looking for better non-invasive monitor !

Looking for better non-invasive monitor !

- **Looking for higher light yield !**
  - Diffraction radiation from slits do not generate much photons

- **Minimizing Synchrotron radiation background** → cleaner signal
  - DR and SR are emitted at similar angles

Looking for better non-invasive monitor !

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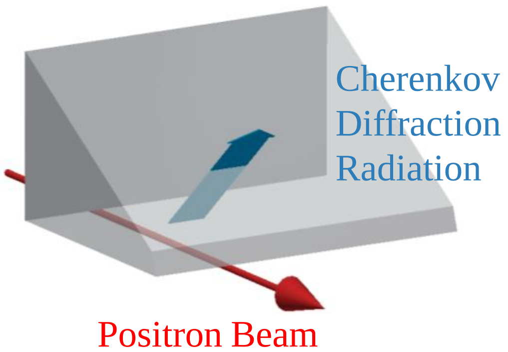
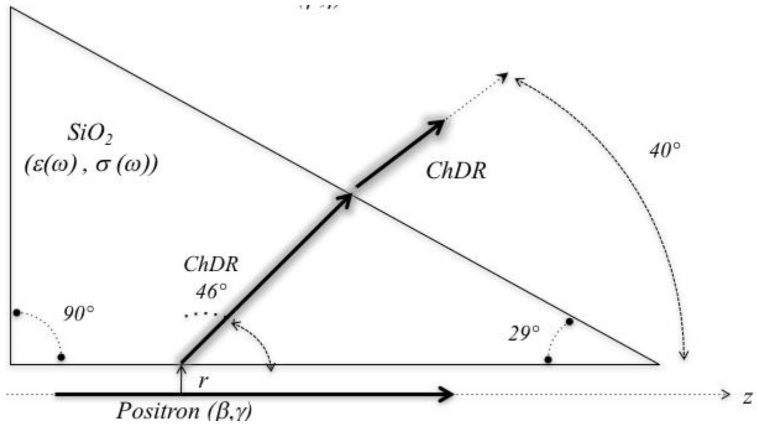
⇨ In 2016, we started investigating **Cherenkov diffraction radiation** in **longer dielectrics**

Cherenkov diffraction radiation as a non-invasive monitor

- Prototype installed in 2017 on CESR at Cornell University
  - Measuring Incoherent Cherenkov diffraction radiation emitted from Positrons in a 2cm long fused silica prism





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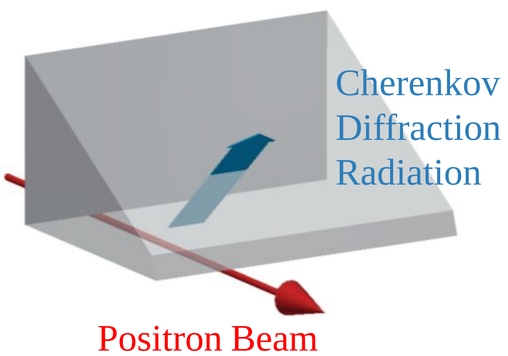
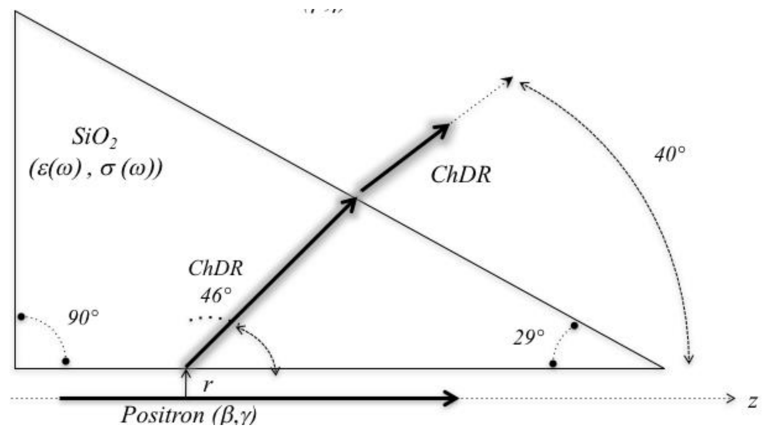
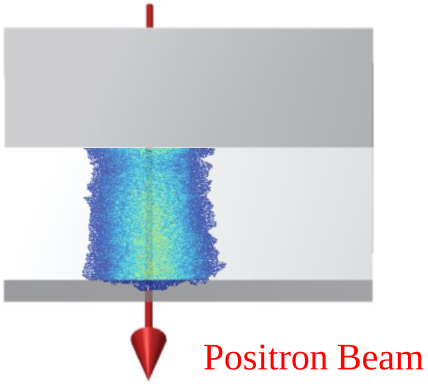






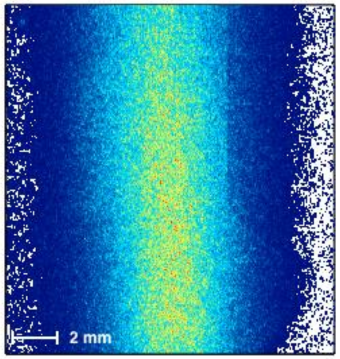
  - Tests performed using 2.1 and 5.3 GeV particles

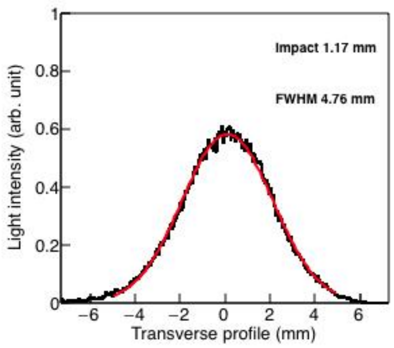
*R. Kieffer et al., "Direct Observation of Incoherent Cherenkov Diffraction Radiation in the Visible Range", PRL **121** (2018) 054802*

Cherenkov diffraction radiation as a non-invasive monitor

- **Measuring Beam size** :

Large Horizontal beam size at Cornell





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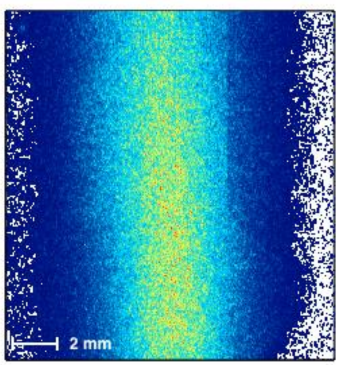
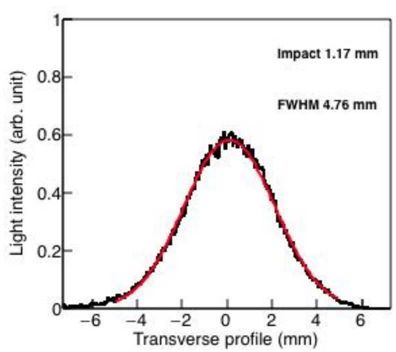
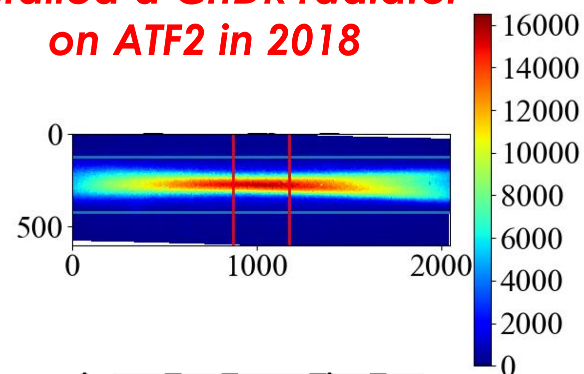
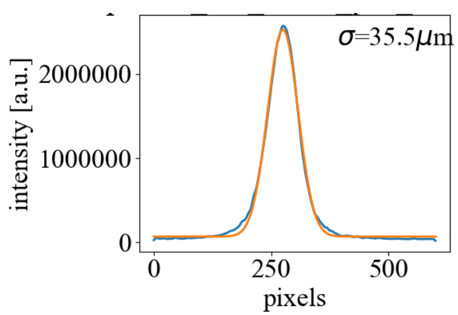




Installed a ChDR radiator on ATF2 in 2018





*On-going investigation on the **resolution limit** of such system using very small vertical beam size*

Cherenkov diffraction radiation as a non-invasive monitor

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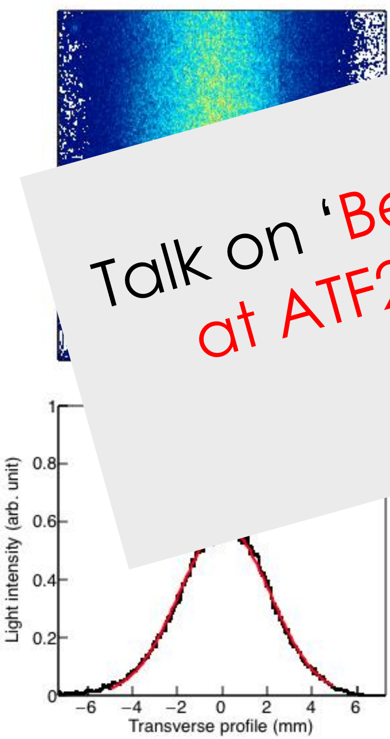
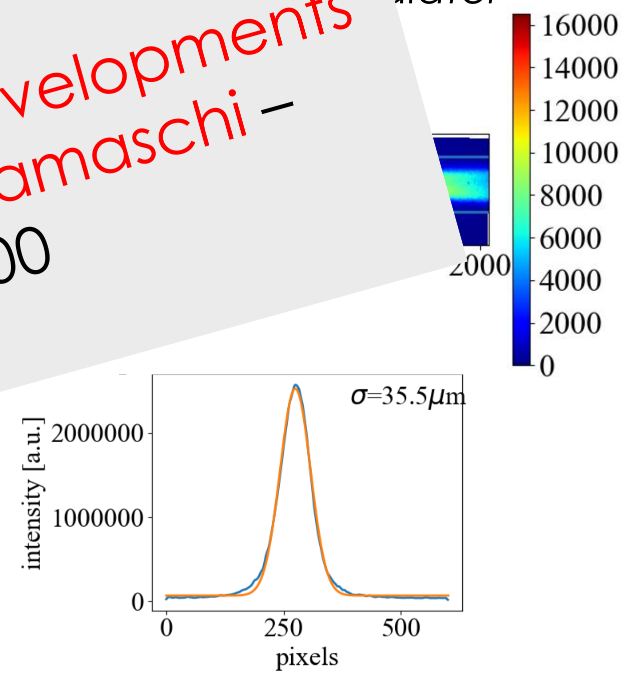


Talk on '**Beam diagnostic developments at ATF2**' by Michele Bergamaschi – Tuesday at 14h00

diator



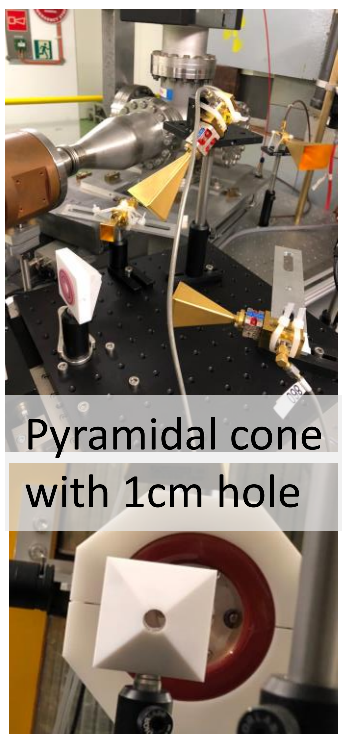
On-going investigation on the resolution limit of such system using very small vertical beam size

Cherenkov diffraction radiation as a non-invasive monitor

- Investigating also **Coherent** Cherenkov diffraction radiation for beam diagnostic of **short bunches**

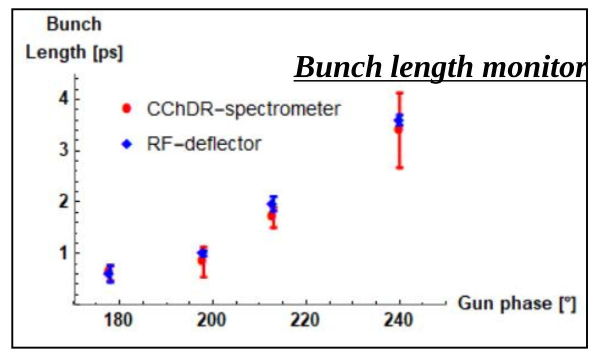
Cherenkov diffraction radiation as a non-invasive monitor

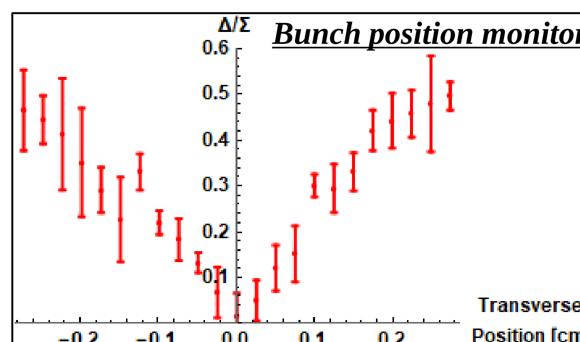
- Investigating also Coherent Cherenkov diffraction radiation for beam diagnostic of short bunches
- **First tests performed on CLEAR** performed in 2018 using **Teflon radiator**



Pyramidal cone with 1cm hole

Measuring in 3 bands (60-90-110GHz)

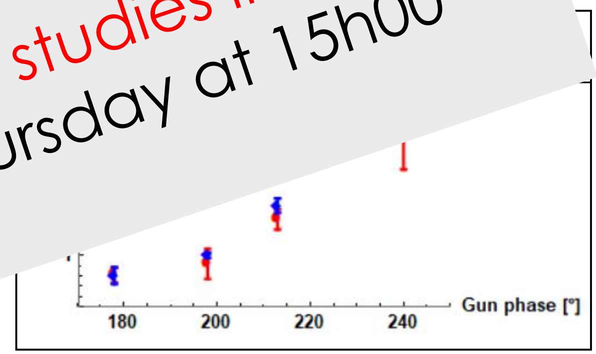




Cherenkov diffraction radiation as a non-invasive monitor

- Investigating also Coherent Cherenkov diffraction radiation f… beam diagnostic of short bunches
- First tests performed on CLEAR performed i… iator

Meas…

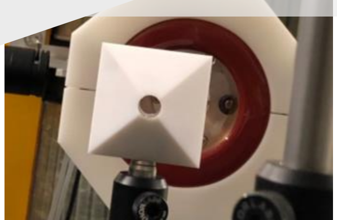


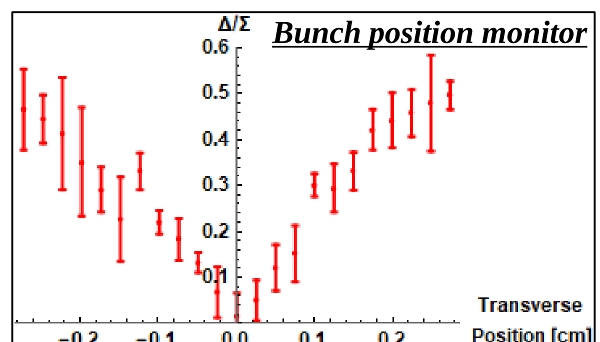
Gun phase [°]

180 200 220 240

Talk on '*THz radiation emission studies in CLEAR*' by *Alessandro Curcio* – Thursday at 15h00

…m hole

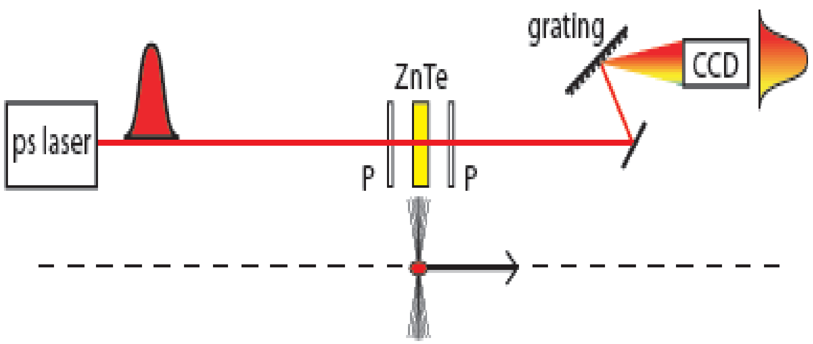


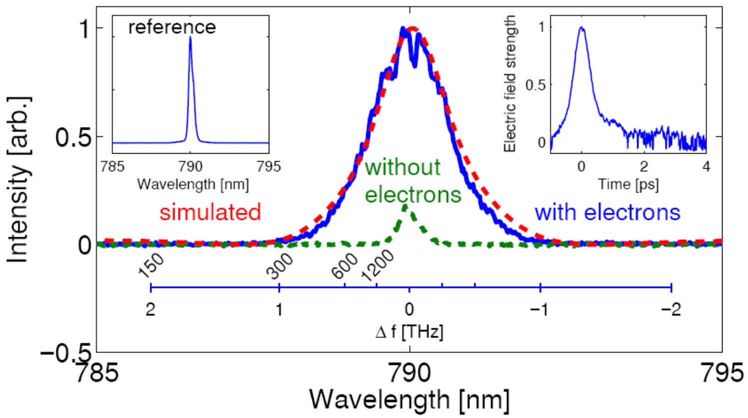


EO detection system for very short bunches

EO detection system for very short bunches

- **EO Transposition developed** at Daresbury lab and Dundee University





S .P. Jamison *et al.*, "*Upconversion of a relativistic Coulomb field THz pulse to the near-IR*", Applied Physics Letters **96** (2010) 231114 :

D.A. Walsh *et al.*, "*The time resolved measurement of ultrashort terahertz-band electrical field without an ultrashort probe*", Applied Physics Letters 106, 181109 (2015)

EO detection system for very short bunches

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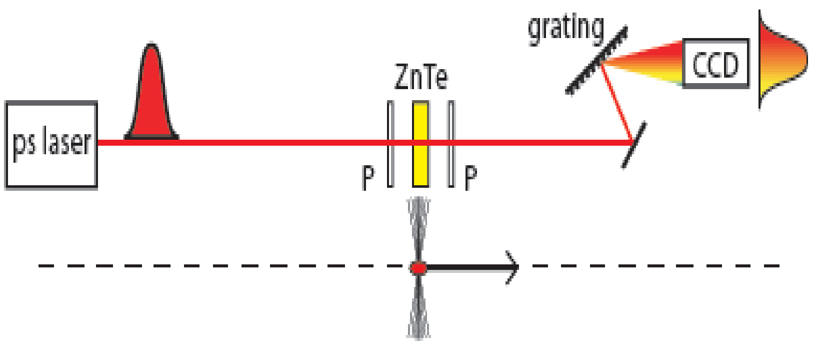

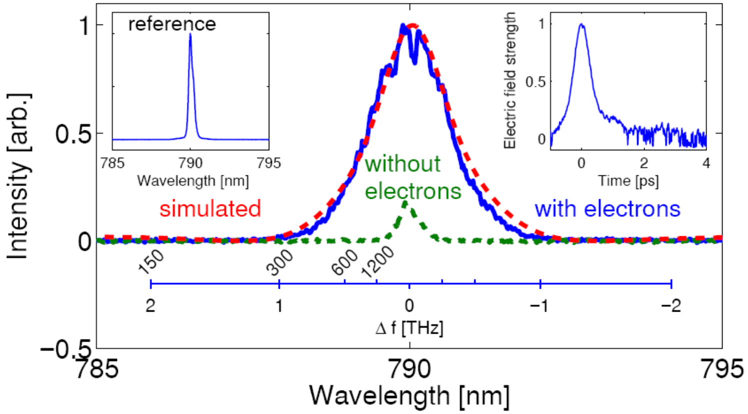

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- **Moving EOT outside of vacuum system by creating a THz replica of the bunch field using Coherent Cherenkov radiation**

Science & Technology Facilities Council

University of Dundee

Conclusions

- CLIC has funded a **very wide and rich R&D program** since the CDR in 2012
- Many studies has led to **substantial improvements** in cost and performance, simplicity and reliability.
- Some R&D Studies are being co-financed by LHC and FCC :
  - Supersonic Gas Jet : A. Jeff *et al.*, "*A quantum gas jet for non-invasive beam profile measurement*", IBIC, Monterey, USA (2014) : A. Jeff *et al.*, "*A gas-jet profile monitor for the CLIC Drive Beam*", IBIC, Oxford, UK (2013) : V. Tzoganis *et al.*, "*Design and first operation of a supersonic gas jet based beam profile monitor*", PRAB 20, 062801 (2017)
  - Synchrotron radiation interferometry using random structures : M. Siano *et al.*, "*Characterizing temporal coherence of visible synchrotron radiation with heterodyne near field speckles*", PRAB 20 110702 (2017)
- Several **Beam instrumentation test facilities** have been put in place at **CLEAR**@CERN, **ATF2**@KEK and at **Diamond.** *Talk on 'Diagnostic R&D in the CLEAR facility' by T. Lefevre – Thursday at 15h20*
- Next steps towards a **realistic implementation of BI in CLIC** !

Thanks for your attention

CERN

UNIVERSITY OF OXFORD

TOMSK POLYTECHNIC UNIVERSITY

JAI John Adams Institute for Accelerator Science

Science & Technology Facilities Council

University of Dundee

ROYAL HOLLOWAY UNIVERSITY OF LONDON

UNIVERSITY OF LIVERPOOL

CORNELL UNIVERSITY FOUNDED A.D. 1865

Australian Synchrotron

diamond www.diamond.ac.uk

IFIC INSTITUT DE FÍSICA CORPUSCULAR

ALBA Synchrotron Light Facility

Thanks for your attention

Many thanks to all the great Students,
Postdocs and Collaborators

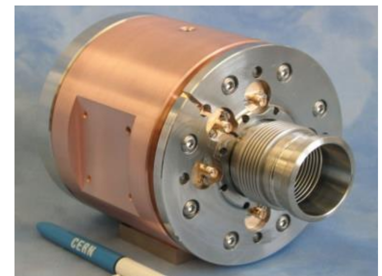
Spares

CLIC Drive Beam BPM

Requirements:

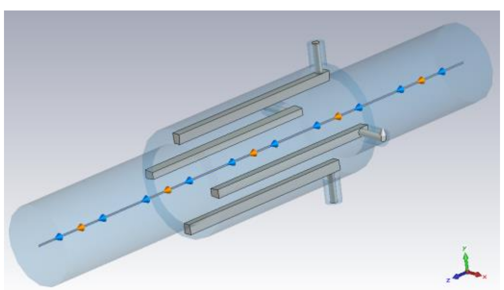
- High current 100A – high bunch frequency 12GHz
- In the vicinity of an RF structure producing 100MW @12GHz
- Temporal resolution of 10ns
- 2µm resolution over an aperture of 23mm (accurate calibration)
- Simple and Cheap ~ 40k units

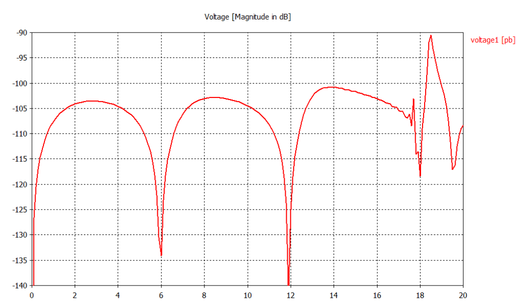
CLIC TEST FACILITY 3 uses Inductive Pick-ups
~60 Units ~ 5um resolution measured

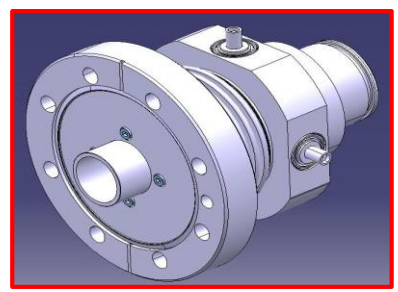


M. Gasior

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

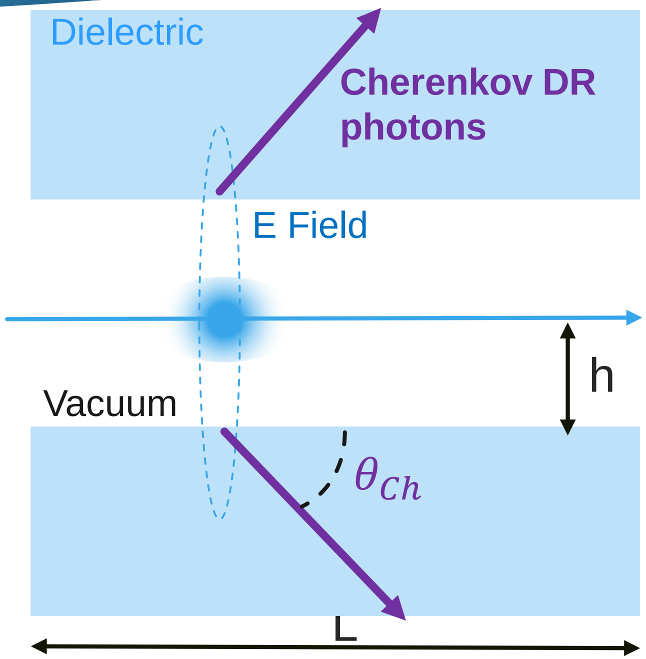






To be tested on CTF3 in 2013

Incoherent Cherenkov Diffraction Radiation



Incoherent Cherenkov Diffraction Radiation (ChDR)

The electric field of ultra-relativistic charged particles passing in the vicinity of a dielectric radiator produce photons by Cherenkov mechanism (polarization effect).

- Large emission angle: $\cos(\theta_{Ch}) = \frac{1}{\beta n}$
- Photons emitted along the target

For a cylindrical geometry

Cherenkov emission

Exponential decay of the particle field

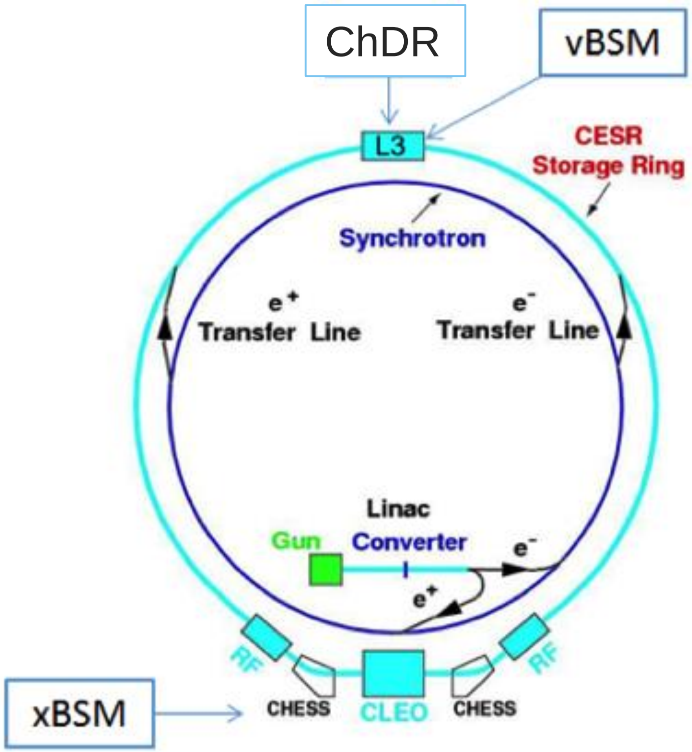
$$\frac{d^2N_{Dcph}}{d\Omega d\lambda} = \frac{\alpha n}{\lambda}\left(\frac{L}{\lambda}\right)^2\left(\frac{\sin\left(\frac{\pi L}{\beta\lambda}(1-\beta n\cos\theta)\right)}{\frac{\pi L}{\beta\lambda}(1-\beta n\cos\theta)}\right) sin^2\theta \,.\, e^{\left(-4\pi\frac{h}{\gamma\beta\lambda}\right)}$$

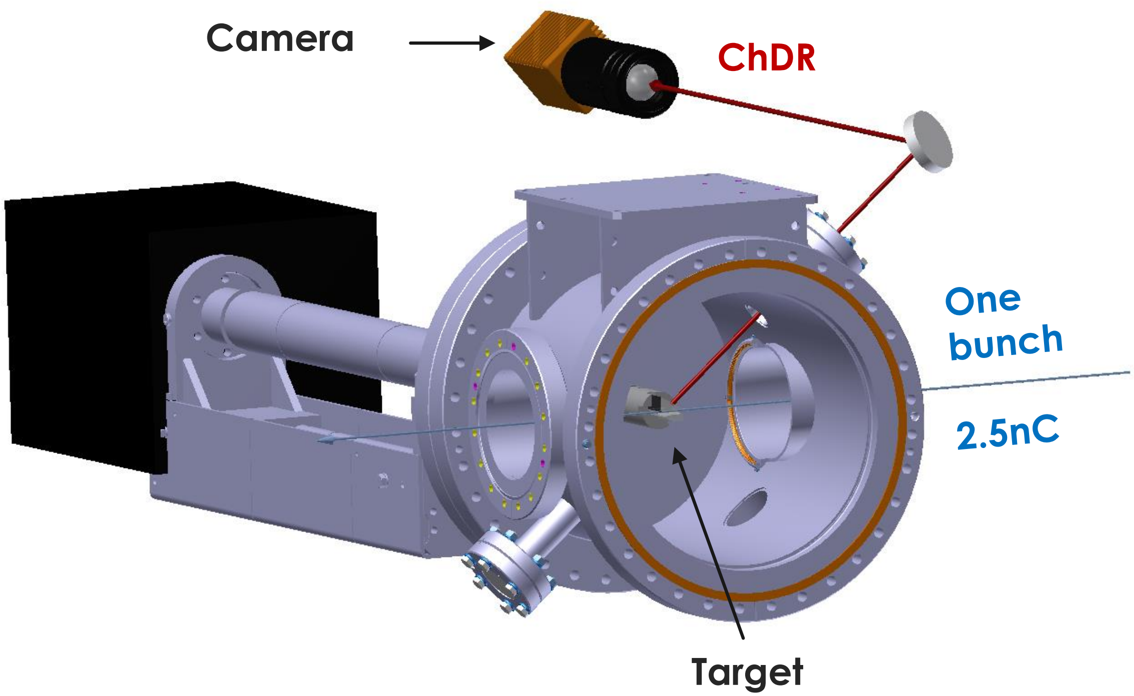
α, fine structure constant
β, normalised beam velocity
γ, beam relativistic factor
θ, angle of observation

T. Lefevre, CLIC workshop 2018, CERN

Experimental set-up on CESR (1/3)

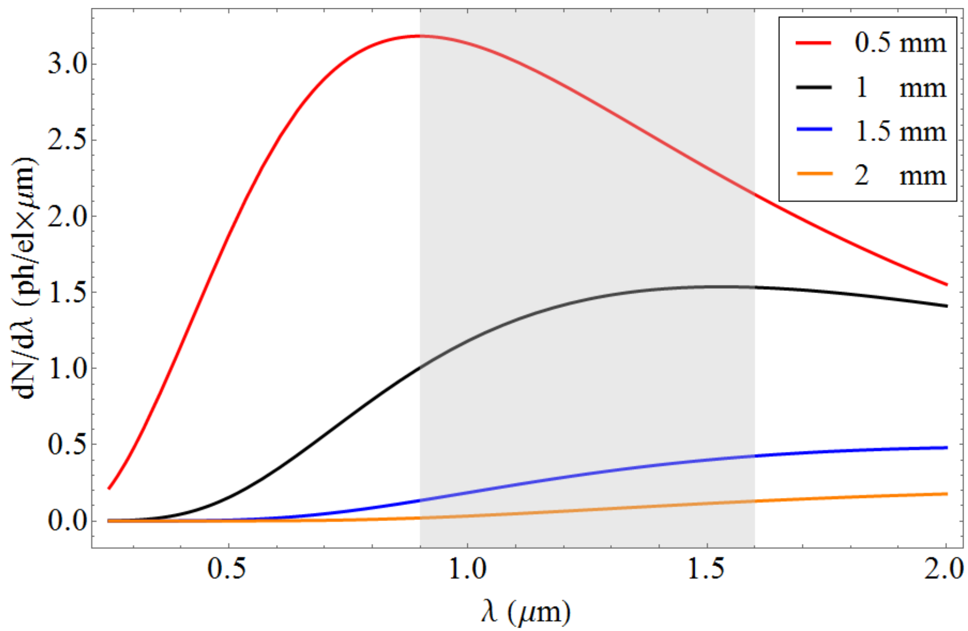
- Re-using the DR vacuum chamber and optical system





Experimental set-up on CESR (2/3)

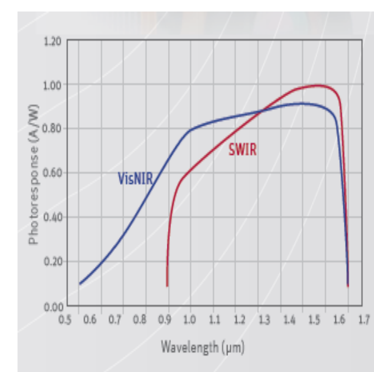
- Design a 2cm long SiO_2 (n=1.46) Cherenkov Diffraction Radiation target
  - Testing with 2.1GeV e^- and measuring in IR (0.9-1.7um) – April 2017



'The red curve as been scaled down by 1/3 for better presentation

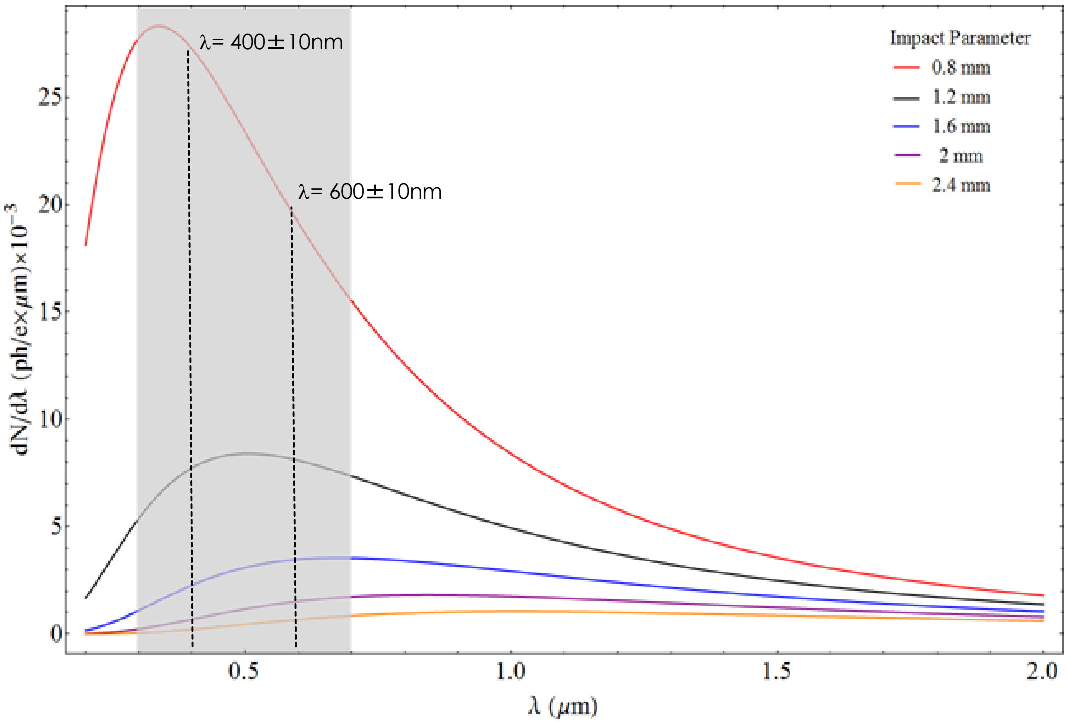
Xenics Bobcat 640 GigE

- Cooled InGaAs 640x512 pixels : 20um pixel pitch
- QE up to 80% at 1.6um
- 14bit ADC
- 1us-40ms integration window

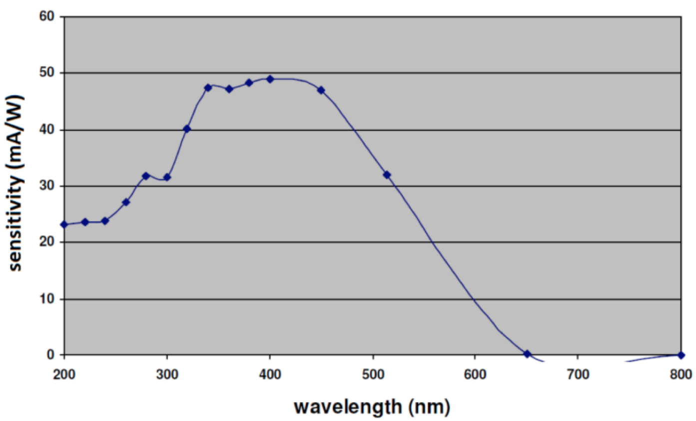


Experimental set-up on CESR (3/3)

- Design a 2cm long SiO_2 (n=1.46) Cherenkov Diffraction Radiation target
  - Testing with 5.3GeV e^- / e^+ and measuring in visible (0.3-0.7um) – October 2017



Gated and intensified camera

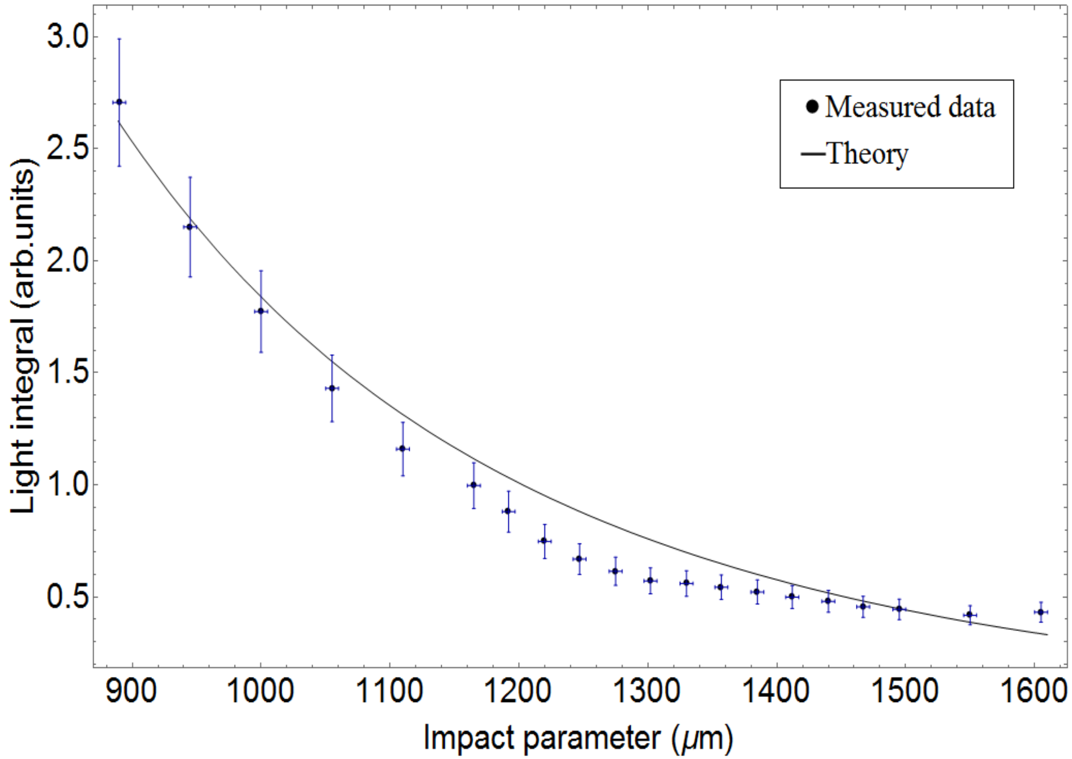


M.V. Shevelev and A.S. Konkov, JETP **118,** 501 (2014)

Experimental data : Electron at 2.1GeV

- Steering the beam vertically : comparison with simulations

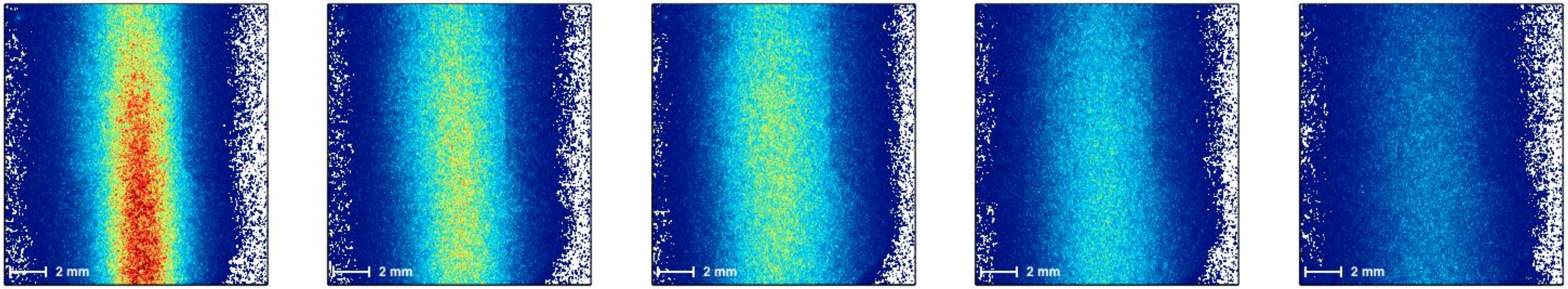
No wavelength filter – No polarizer



Experimental data : Positron at 5.3GeV

- Steering the beam vertically
  - Wavelength 600±10nm
  - Vertical Polarization component

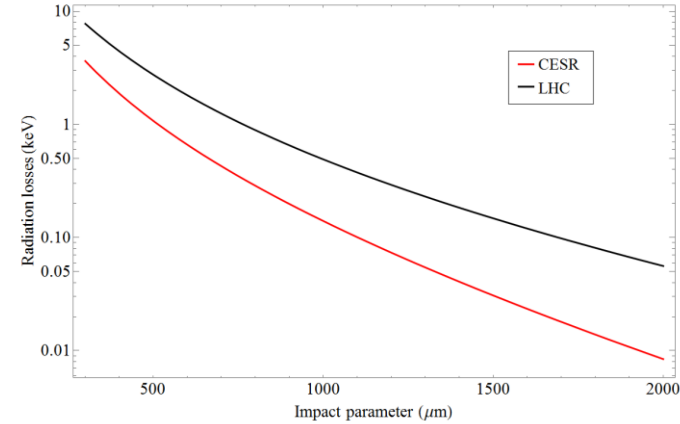
h= 0.96mm 1.17mm 1.52mm 2.09mm 2.43mm



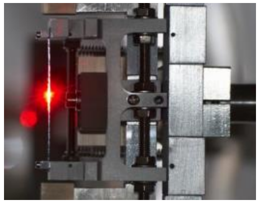
Cherenkov photons yield increasing strongly for smaller impact parameter

Perspectives for beam instrumentation

- Imaging system for relativistic beam
  - What is the the smallest beam size measurable ?
    - The Cherenkov diffraction PSF should be smaller than transition radiation PSF
      → possible tests in 2018 with micron beam sizes on ATF2

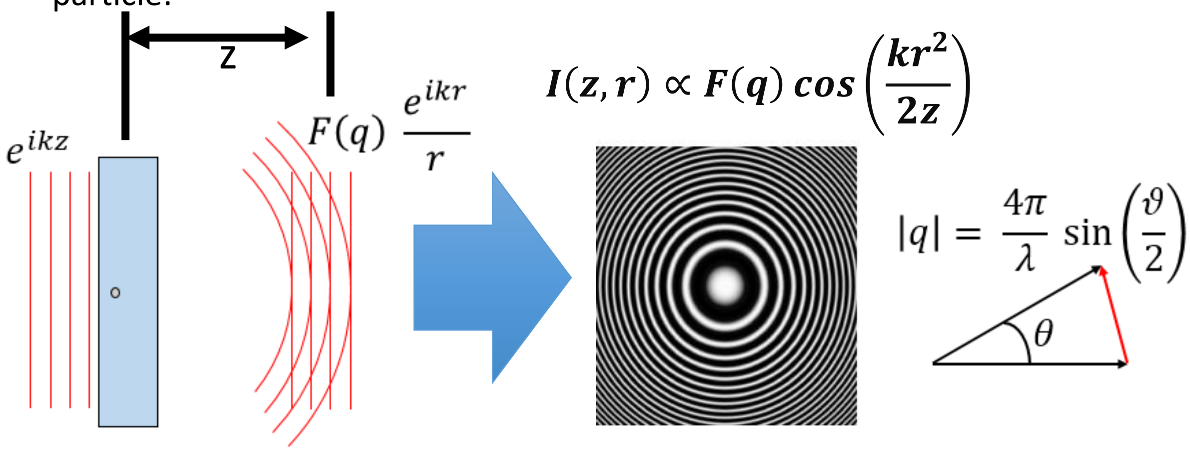


- What is the smallest the beam tilt angle measurable ?
  - A non linear response depending on wavelength, beam energy and impact parameter
- Measuring counter-propagating beams with very high directivity : BPM for FCC, HE-LHC, …
- A Beam Position Monitor for Crystal collimator on LHC



The HNFS technique

- Heterodyne Near Field Speckles is a novel stochastic interference technique that gives 2D coherence / beam size information
- Measures visibility of interference fringes between transmitted beam (synchrotron radiation) and spherical waves produced by nanoparticles
- 3 years collaboration between ALBA, U. Milan and CERN funded by CLIC & FCC
- In HNFS: intensity is measured at distance z from the scatterers. In case of a single particle:



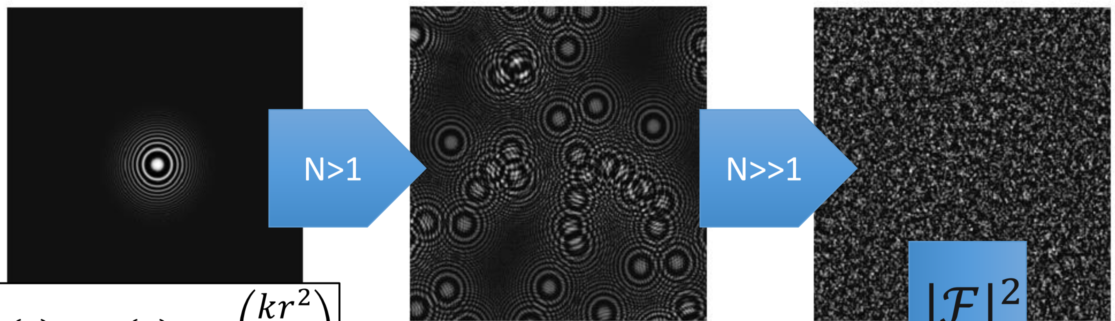
$$I(z,r) \propto F(q)\cos\left(\frac{kr^2}{2z}\right)$$

$$|q| = \frac{4\pi}{\lambda}\sin\left(\frac{\vartheta}{2}\right)$$

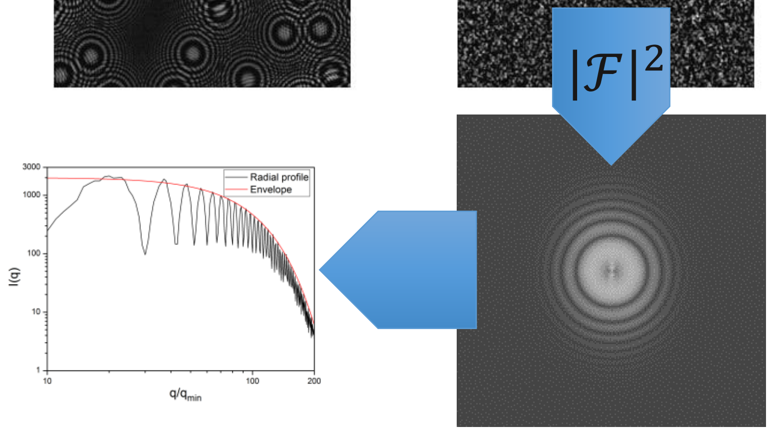
Where F(q) is the particle form factor, **q** the scattering wave vector

The HNFS technique

- When number N of scatterers is LARGE, scattered intensity can be retrieved through the square modulus of Fourier Transform:



$$I(z) \propto F(q)\cos\left(\frac{kr^2}{2z}\right)$$



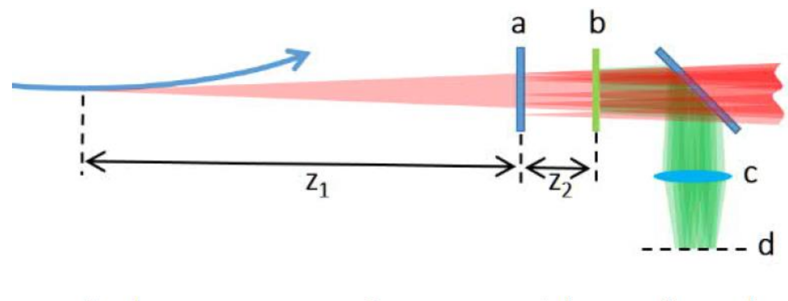
$$I(q) \propto S(q)\sin^2\left(\frac{zq^2}{2k}\right)$$

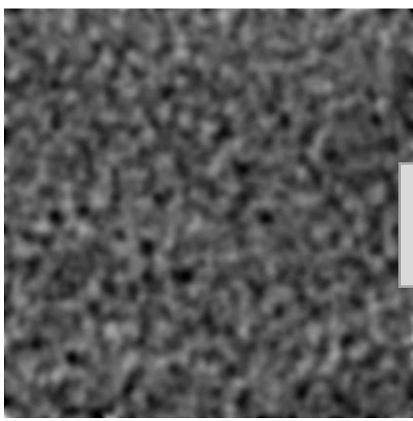
Single particle interferogram modulated by particle form factor

From analysis of I(q) the transverse coherence is measured

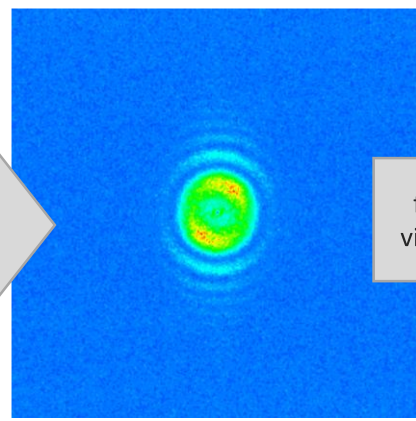
intensity profile of the source through Van Cittert Zernike Theorem!

- Beam size tests based on HNFS at NCD-SWEET beamline at ALBA in July and Sept. 2018
- 12.4 KeV X-ray radiation from undulator
- Target (a): 500 nm SiO_2 spheres suspended in water at z_1 = 32.5 m from the source. (b) 0.1 mm thick YAG:Ce crystal at z_2 = 252 mm, imaged with a 20X microscope objective (c) onto a CCD camera (d)

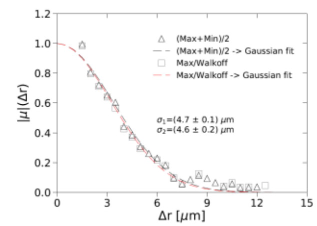




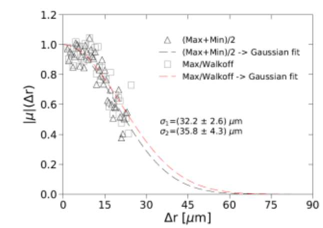
2D |FFT|^2



fringe visibility



H coherence: 4.7 μm



V coherence: 34 μm

H beam size: 115 ± 6 μm (expected 131 μm)

V beam size: 14.7 ± 1.8 μm (expected 8 μm)

PRELIMINARY!