CLIC Beam Instrumentation

T. Lefevre on the behalf of the CLIC BI teams

CLIC project meeting – 9 June 2015

Outline

- Recap. of the BI work package program and main goals
  - Scientific program post-CDR as defined in 2011
- Status and Plans of the current developments
- Conclusions and Perspectives

BI workpackages – 2011-16

- R&D on intensity monitoring

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  - Recent development at CERN in the context of LHC operational need

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  - Design and validation of CLIC cavity BPM resolution – *On-going at Califes*
  - Cavity BPM impedance budget – *100% CLIC-UK activity - on-going at KEK*
  - DB stripline BPM working in the vicinity of PETS – *On-going at CLEX*

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  - Validation of Laser Wire Scanner performance at ATF2 - *100% CLIC-UK RHUL - Completed*
  - R&D on alternative non-interceptive method (Diffraction radiation)
  - R&D on ultra high-resolution Optical Transition Radiation monitor for single bunch operation
  - R&D on gas profile monitor / gas jet scanner for DB emittance monitoring

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  - R&D on gas profile monitor / gas jet scanner for DB emittance monitoring
- R&D on short bunch length monitoring (Dundee/Daresbury)
  - Development of 1ps bunch length monitor on Califes (Marie-Curie) - Completed
  - Prototyping of E-O bunch length monitor with 20fs time resolution - 100% CLIC-UK activity – To be completed by April 2017

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- R&D on BLM developments (U. Liverpool and Australian Synchrotron)
  - Cost effective Beam loss monitor based on Cherenkov fibres for CLIC module
  - Development of Beam loss monitor only sensitive to charged particle for Damping rings

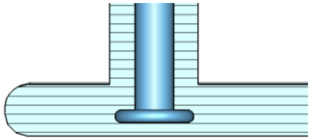
Status of the work & future plans

- R&D on Beam position monitor (IFIC and RHUL)
  - A cavity BPM with 50nm spatial resolution, 50ns time resolution
  - Stripline BPM insensitive to 12GHz RF power from PETS
- R&D on Emittance monitoring (RHUL, U. Liverpool)
- R&D on BLM developments (U. Liverpool and Australian Synchrotron)

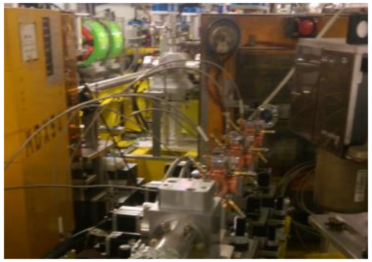
YEARS / ANS CERN

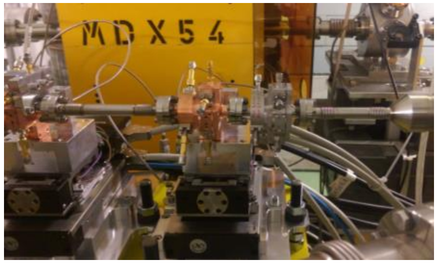
Cavity BPM - Status

- First prototype Cavity BPM prototype has been tested on Califes installed since end of 2013



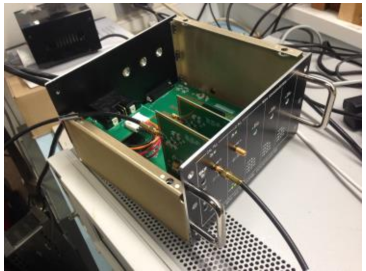
- 3 new BPMs (Higher Q to improve sensitivity/spatial resolution, new coupling antenna) have been recently installed in order to be able to assess the BPM resolution





- New RF FE electronic built by Fermilab being installed in CLEX
  - Detailed design and PCB fabrication by FNAL (N. Eddy, B. Fellenz, J. Bogaert)
  - Gain flexibility, remote control, custom IF filters
  - 9 downmixer and 2 LO modules (ref and position cavity frequency different)
  - Three units arrived at CERN and are currently being installed.

- New digitizers (12bit, 250MSa/s)



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Cavity BPM - Plans

2015:

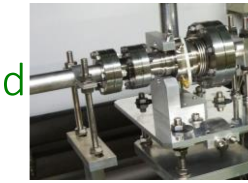
- Calibration of BPMs using movers/bumps, charge scans:
  - Charge sensitivity of reference cavity
  - Position sensitivity of position cavities
- Resolution measurements using three BPMs.
- Simultaneous demonstration of spatial and temporal resolution.

2016/2017:

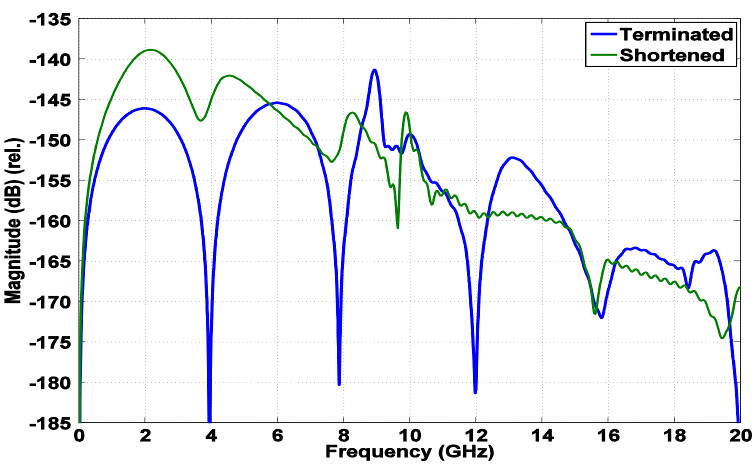
- Additional beam tests, improvements, modifications as necessary
- Alignment studies in framework of PACMAN
  - Stretched wire bench setup of quadrupole magnet and cavity BPM

Stripline DB BPM

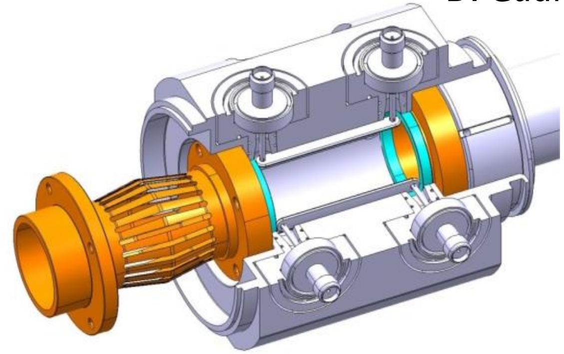
- Stripline prototype with short-circuited electrodes installed in TBL at CTF3 and successfully tested with beam (2013) with low and high current
  - Has shown a small but higher sensitivity to 12GHz PETS power than expected

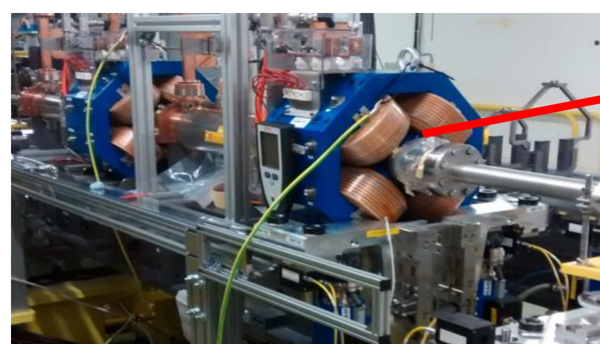


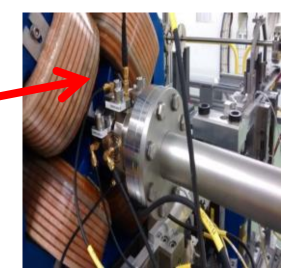
- 2 new striplines with 50Ω-terminated electrodes installed in CLIC TBM
  - Possibility to tune the notch accurately
  - Use the other port for loop-through calibration
  - Enhanced PETS interference suppression at 12 GHz



D. Gudkov







- Tests foreseen on TBM in 2015-16

Status of the work & future plans

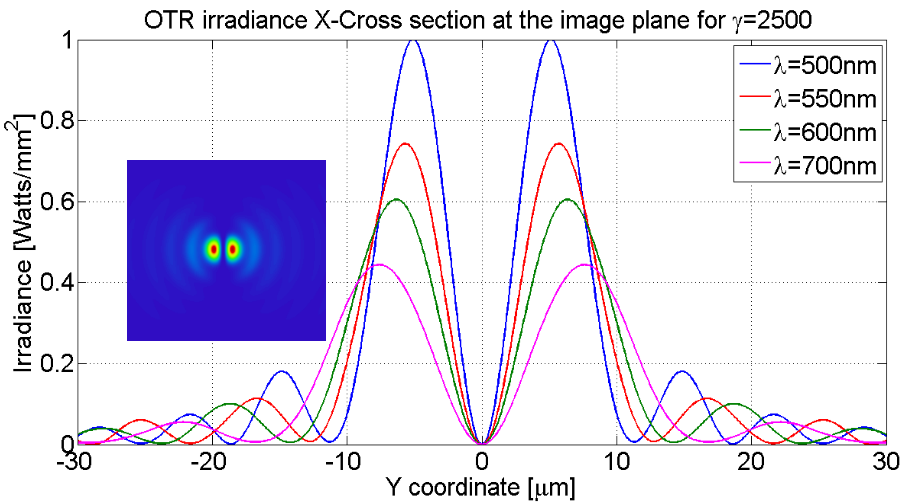
- R&D on Beam position monitor (IFIC and RHUL)
  - A cavity BPM with 50nm spatial resolution, 50ns time resolution
  - Stripline BPM insensitive to 12GHz RF power from PETS

- R&D on Emittance monitoring (RHUL, U. Liverpool)
  - Resolution limit (sub-micron) of Optical Transition
  - Non-interceptive Diffraction monitor with highest possible resolution
  - Gas jet study / profile monitor for Drive Beam injector complex

- R&D on BLM developments (U. Liverpool and Australian Synchrotron)

OTR development (1/2)

Simulation of Optical Transition Radiation imaging system



1- Point Spread Function of OTR imaging system ~ Image generated by a single particle (propagating the OTR Efield in ZEMAX)

$$E_y \propto \frac{y}{Z}\left[\frac{2\pi}{\gamma} K_1\left(\frac{2\pi}{\gamma} Z\right) - \frac{J_0\left(\frac{2\pi}{\lambda} Z\right)}{Z}\right] \text{ with } Z = \sqrt{x^2 + y^2}$$

OTR development (1/2)

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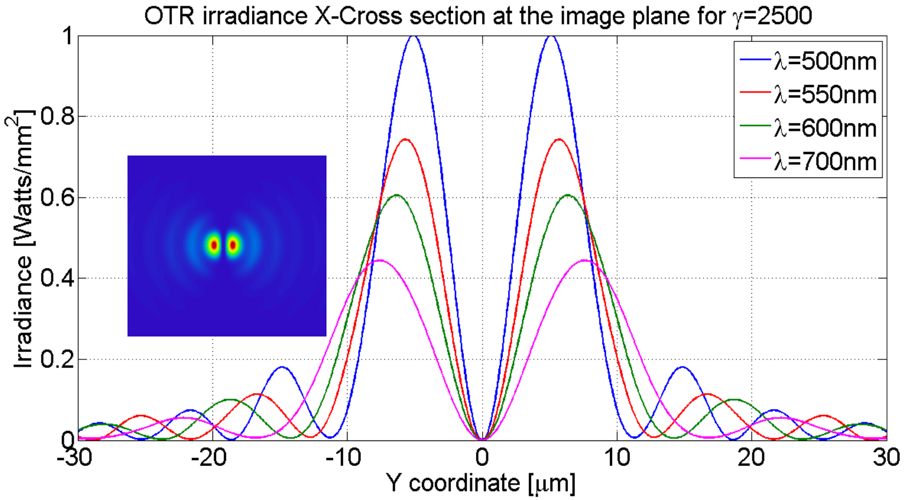

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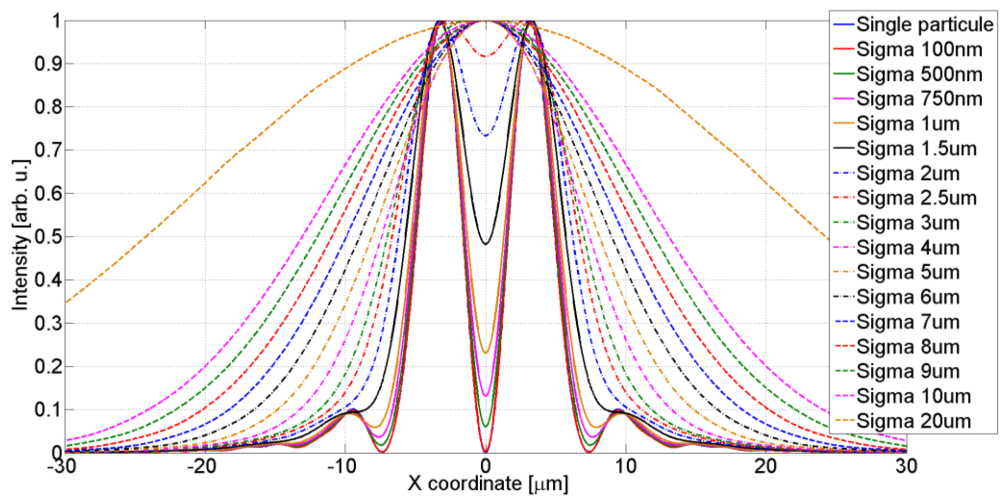
2- Simulation of images obtained for realistic beam size

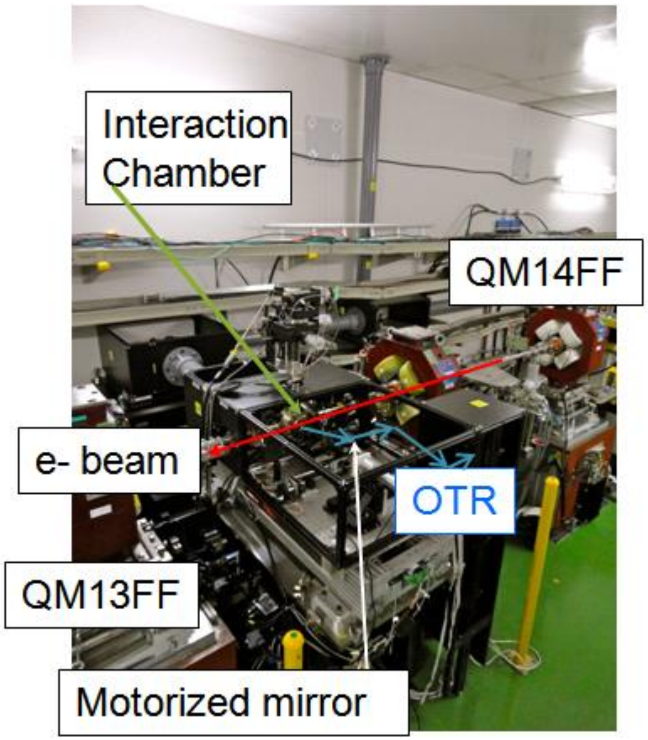
Sub-micron Beam size can be measured via the visibility of the PSF



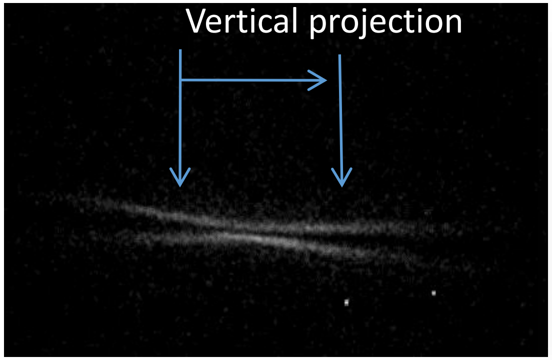
OTR development (2/2)

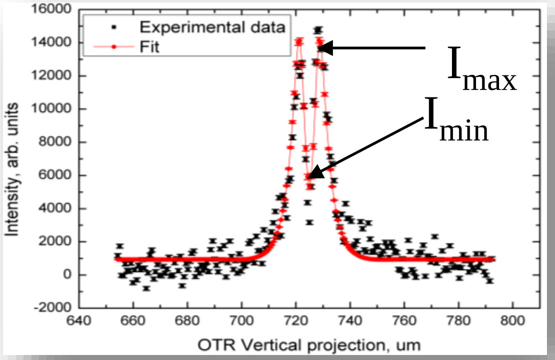
Hi-Res beam size monitor using Optical Transition Radiation PSF visibility

Newly installed optical system designed using Zemax simulations



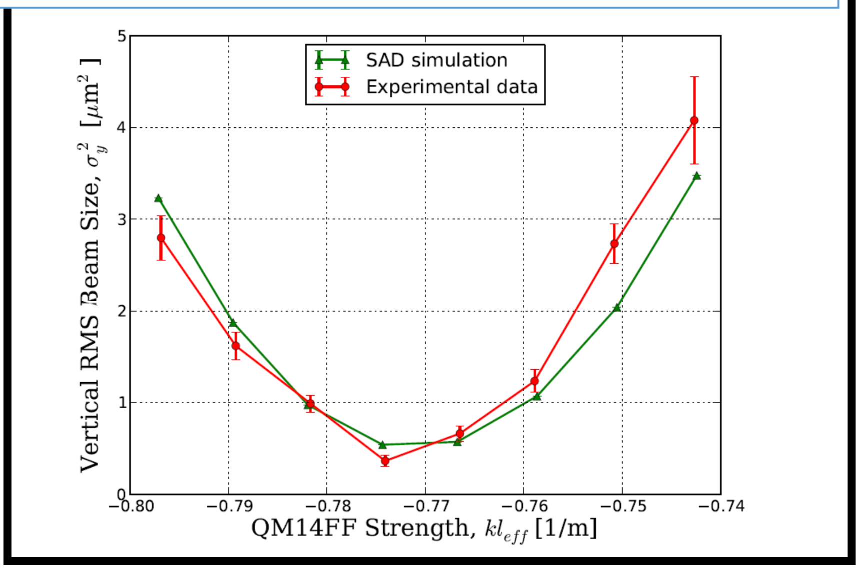
<u>ATF2 OTR @ KEK in 2013</u>





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

Minimum measured beam size of 0.75 μm



ODR development (1/4)

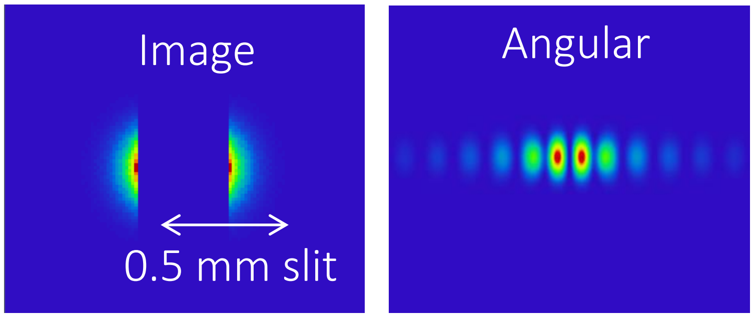
Non-invasive beam size measurements using DR from slit

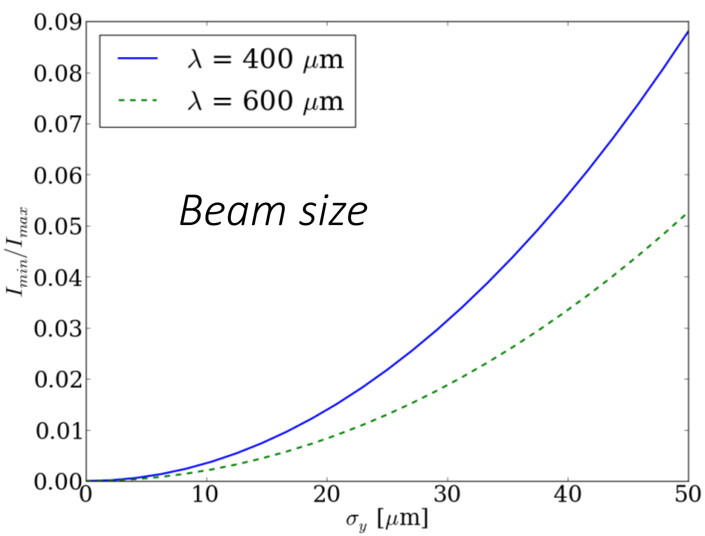
ODR development (1/4)

Non-invasive beam size measurements using DR from slit

- Simulation using ZEMAX

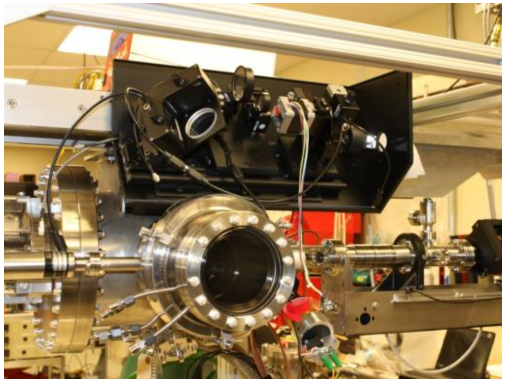
Single particle images

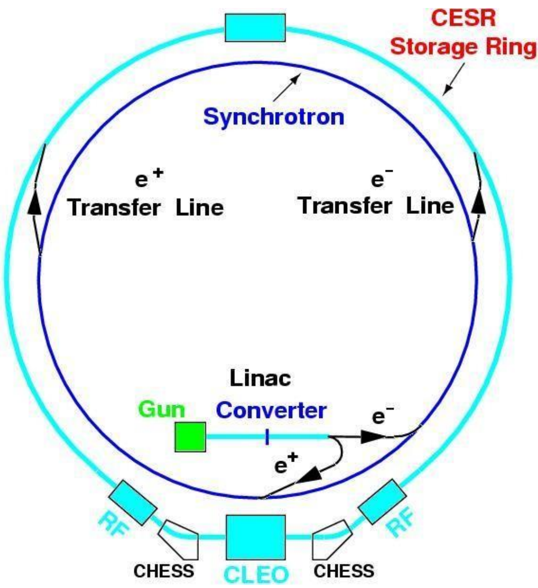




- Beam tests on Cornell Electron Storage Ring since December 2012

(18 shifts of 10h =180h of beam time)



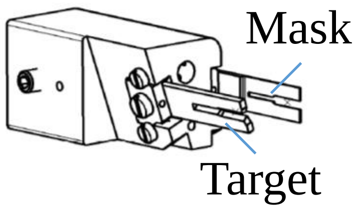


E (GeV)	σ_H (µm)	σ_V (µm)
2.1	320	10

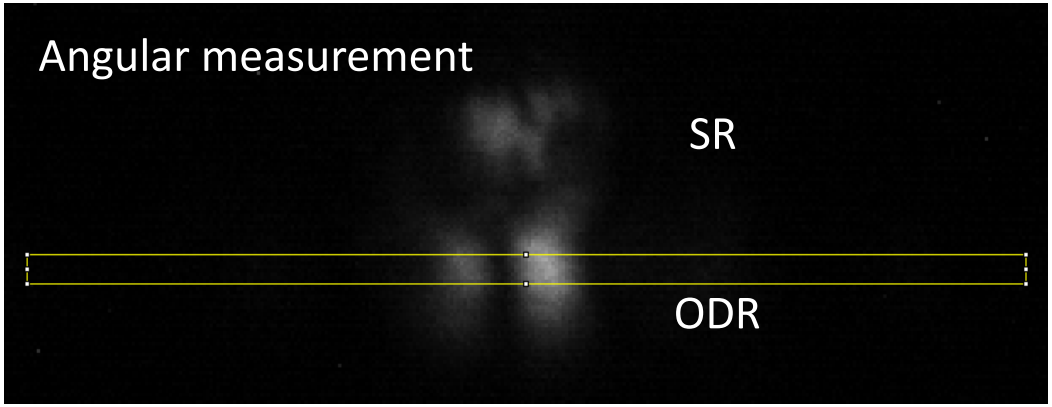
Royal Holloway University of London

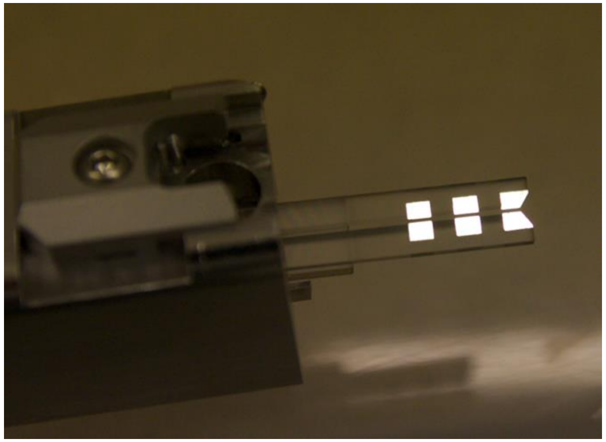
ODR development (2/4)

Optimization of Target Assembly



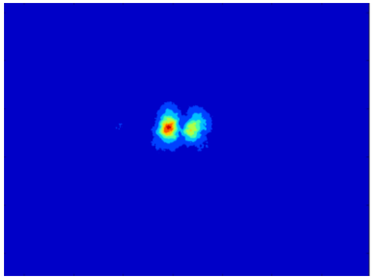
- Al-coated SiO_2 Target for Diffraction Radiation
  - Ultra high precision *0.1nm* roughness, *40nm* coplanarity
  - Slit size 0.5mm
- SiC Mask to suppress background from Synchrotron radiation
  - Mask aperture of 1 and 2 mm
  - Small mask aperture leads to stronger destructive interference between the DR of the mask and target
- New target with an improved design tested in April 2015
  - Partial Al coating on the edge of the slit (90% reflection for DR)
  - Rest of the target surface was sand-blasted (0.1% reflection for SR)
  - Possibly suppressing the mask (improved the DR light yield)



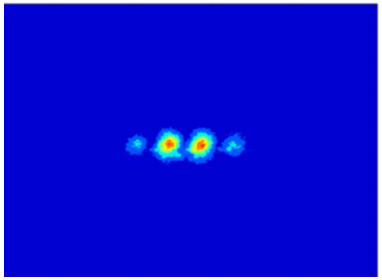


ODR development (3/4)

Angular distribution @600nm

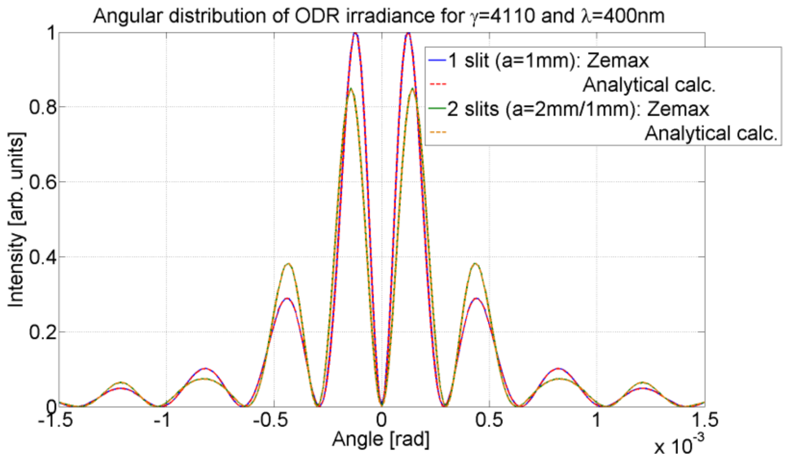


2mm mask aperture
ODR



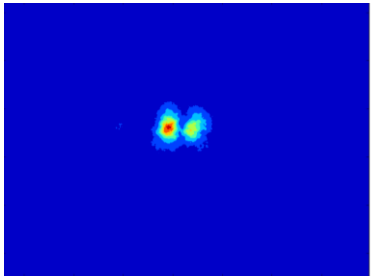
1mm mask aperture
ODRI

ZEMAX simulations ODR/ODRI

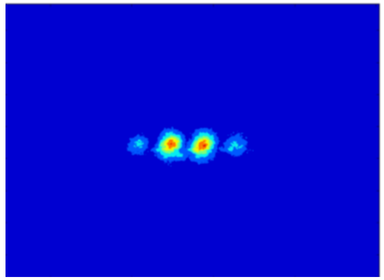


ODR development (3/4)

Angular distribution @600nm



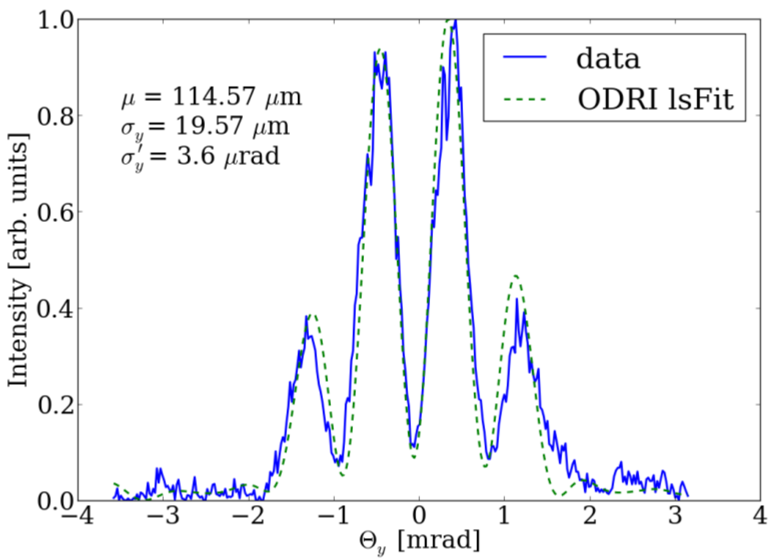
2mm mask aperture
ODR



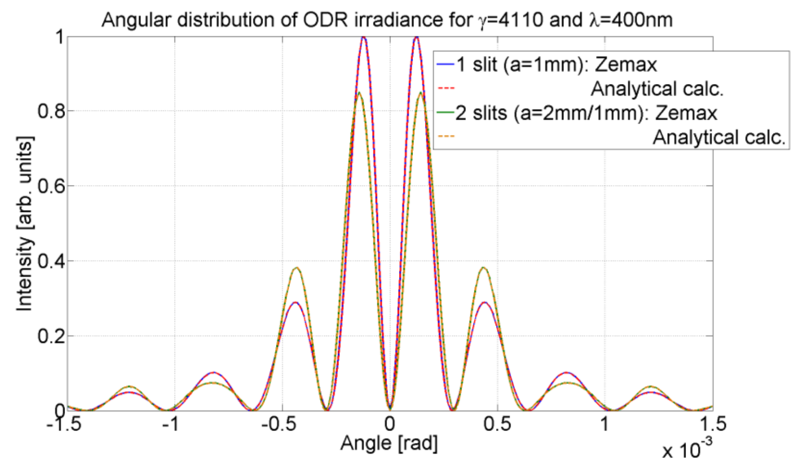
1mm mask aperture
ODRI

Least Square Fit Analysis

- Taking into account the coplanarity of the target of 40nm
- Fitting 3 parameters/ position, size and divergence

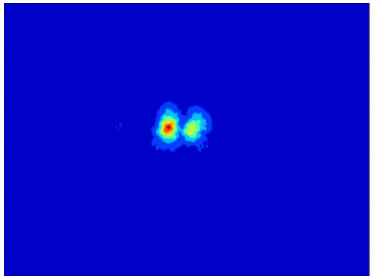


ZEMAX simulations ODR/ODRI

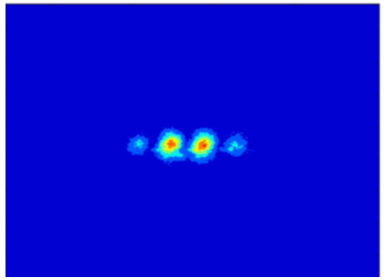


ODR development (3/4)

Beam size measurement : Angular distribution @600nm



2mm mask aperture
ODR



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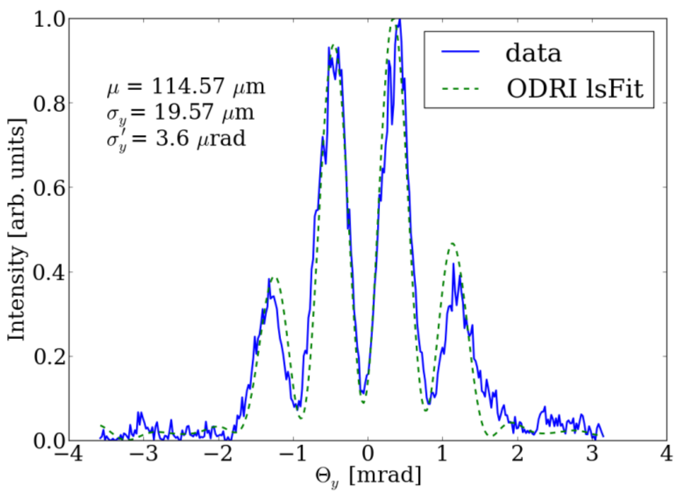
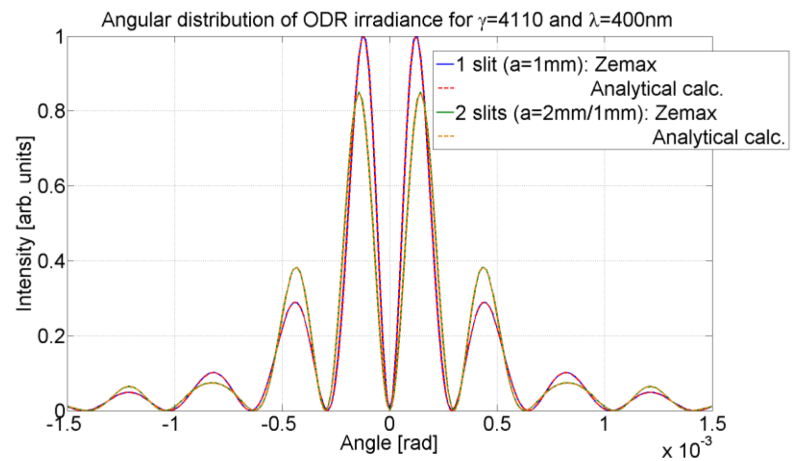


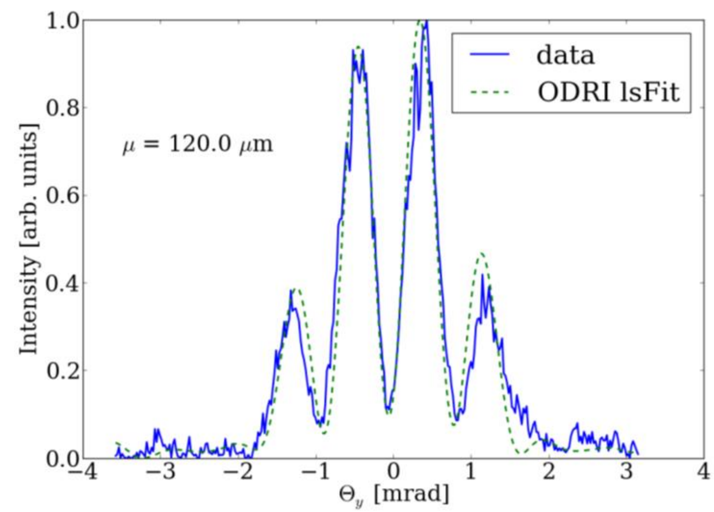
Difficult to measure smaller due to lifetime limitations if using smaller slit size

ZEMAX simulations ODR/ODRI



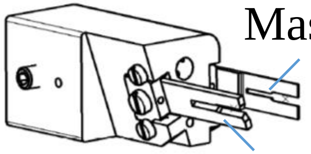
CESR measured beam parameters

ε_y [m]	σ_y(ODR) [um]	σ_y' (ODR) [urad]
3.96e-11	17.6	4.08

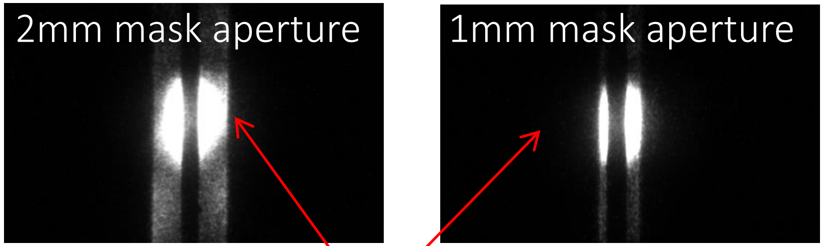


ODR development (4/4)

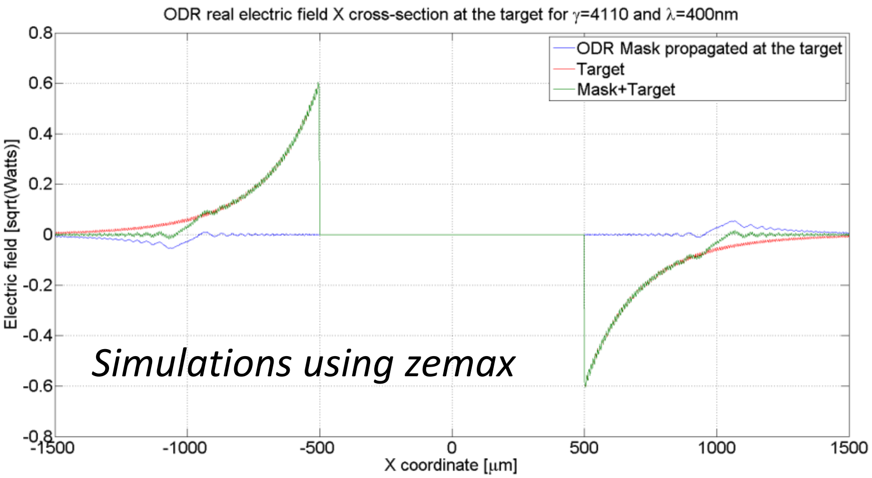
- Interference between Mask and Target (2014)



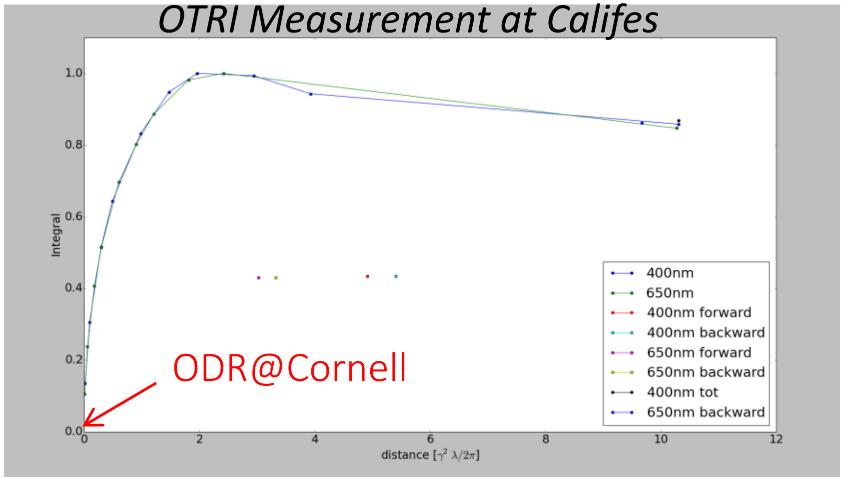
Target Imaging @600nm



What happens close to the edge of Mask !



- Shadowing effect observed already in mm wave range (sources of radiation interfering within a distance << $\gamma^2\lambda/2\pi$)

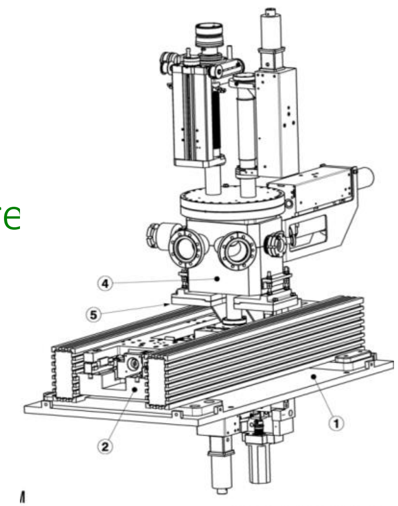


- Study in the optical domain was completed by a test of OTR interferometry @ Califes performed in 2014-15
  - OTR Light intensity as function of distance between screens

OTR/ODR Plans

2015:

- Design, manufacture and installation of a combined OTR/ODR monitor on ATF2 @ KEK
  - Newly designed high magnification OTR imaging system to measure beam size as short as 500nm
  - Pushing ODR beam size measurement in the sub-10microns range using down to 200nm wavelength and small slit size (50um)
- Finalizing the OTR interference tests at Califes with measurements in both optical and mm wave ranges to be compared with simulations
- Beam tests at Cornell with new target design – ODR study in imaging for beam positioning/size and shadowing effect

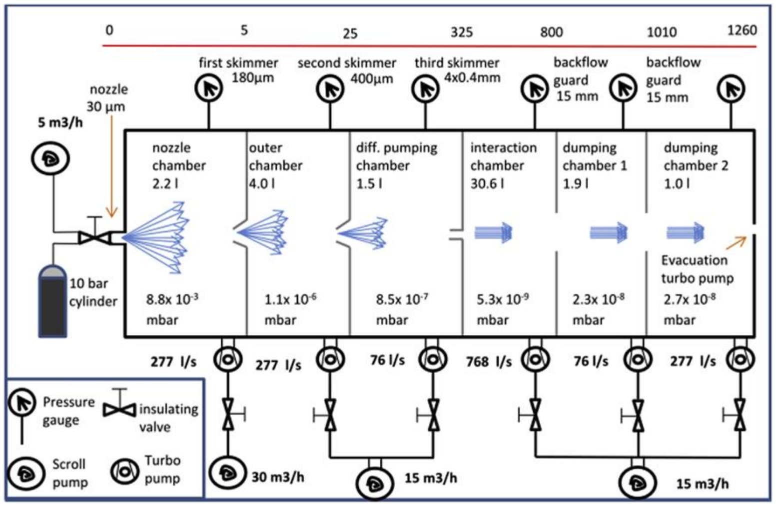


Isometric view

2016/2017:

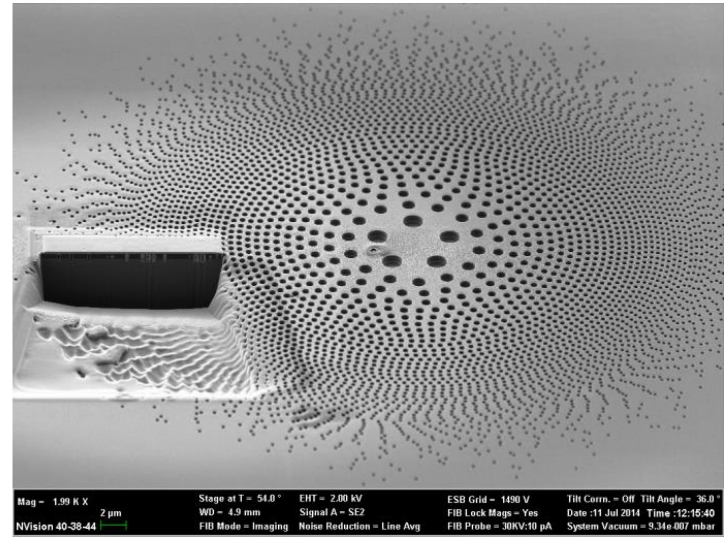
- Perform beam tests at ATF2, possibly at Cornell depending on budget available

Gas jet R&D with ULIV



Curtain Gas Jet

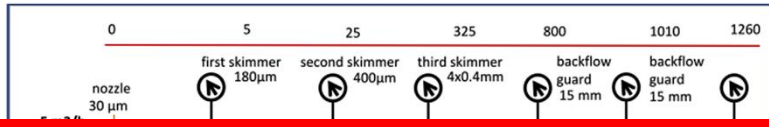
- Minimally invasive profile monitor for high-intensity beams
- Readout with ionisation or fluorescence
- Effect on beam vacuum minimised
- Limitations to measure small beam size due to space charge



Gas Jet Scanner

- Generation of ultra-thin jet by quantum focusing (Atomic Sieve)
- Non-interceptive version of wire scanner
- Immune to space charge

Gas jet R&D with ULIV



Gas jet formation
Reliable alignment and operation
Pulsed jet mode

} demonstrated

Gas jet characterisation
Skimmer tests for thinner jet
Jet dumping optimisation

} will continue at Cockcroft Institute and at CERN as part of HL-LHC e-lens test stand

- Minimally invasive profile monitor for high-intensity beams
- Readout with ionisation or fluorescence
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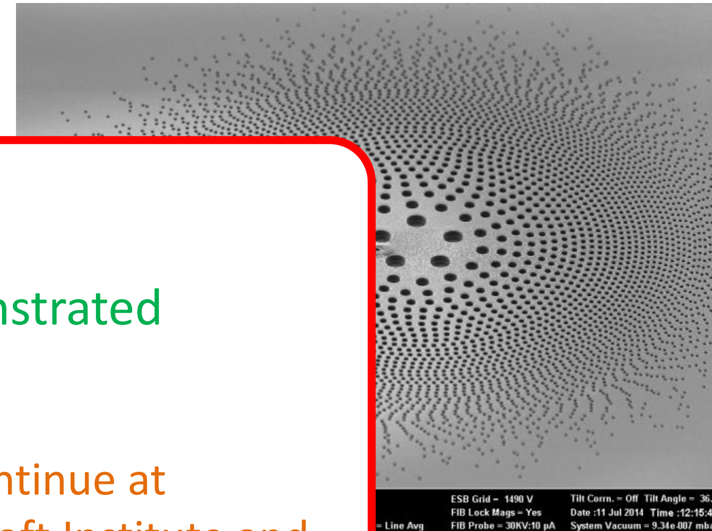
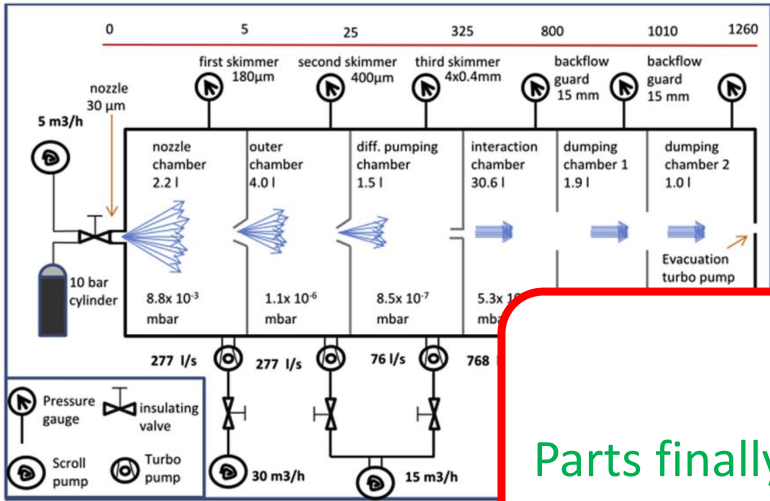


Scanner

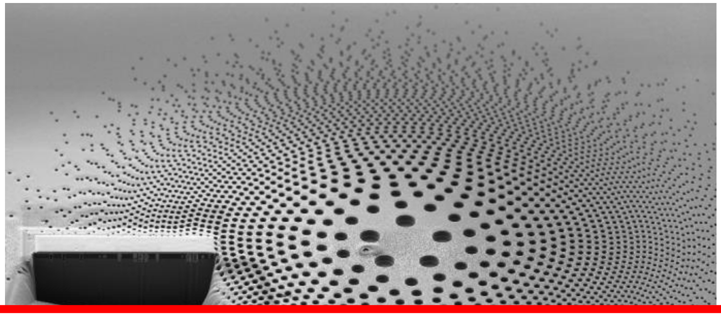
- Generation of ultra-thin jet by quantum focusing (Atomic Sieve)
- Non-interceptive version of wire scanner
- Immune to space charge

Gas jet R&D with ULIV



Curtain Gas

- Minimally invasive profi
  high-intensity beams
- Readout with ionisation
  fluorescence
- Effect on beam vacuum minimised
- Limitations to measure small beam size due to space charge



Parts finally available after long delay from supplier

Will be tested at Cockcroft Inst. over next 6 months

If successful could be taken up by other machines

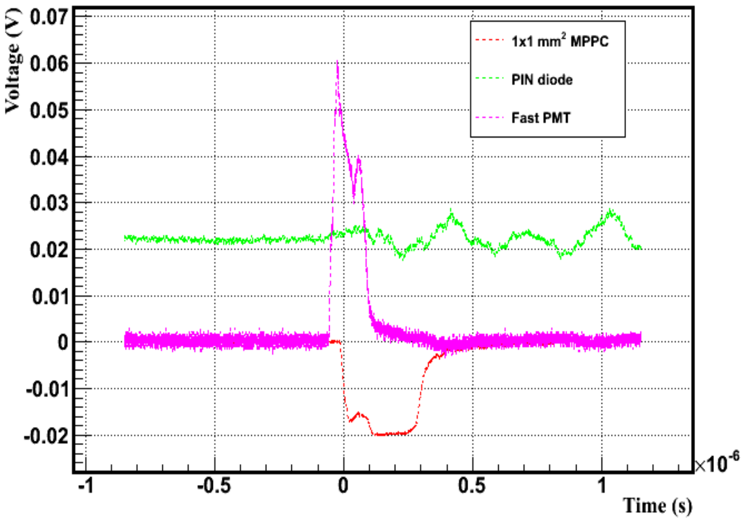
- Non-interceptive version of wire scanner
- Immune to space charge

Status of the work & future plans

- R&D on Beam position monitor (IFIC and RHUL)
  - A cavity BPM with 50nm spatial resolution, 50ns time resolution
  - Stripline BPM insensitive to 12GHz RF power from PETS
- R&D on Emittance monitoring (RHUL, U. Liverpool)
  - Resolution limit (sub-micron) of Optical Transition
  - Non-interceptive Diffraction monitor with highest possible resolution
  - Gas jet study / profile monitor for Drive Beam injector complex
- R&D on BLM developments (U. Liverpool and Australian Synchrotron)

BLM status and plans

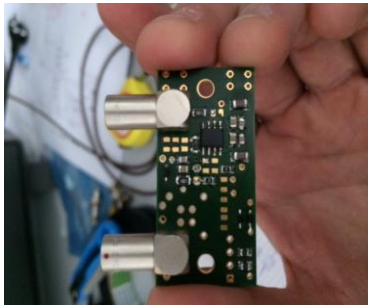
- Cherenkov fiber BLM (oBLM) system being deployed along TBL and TBM



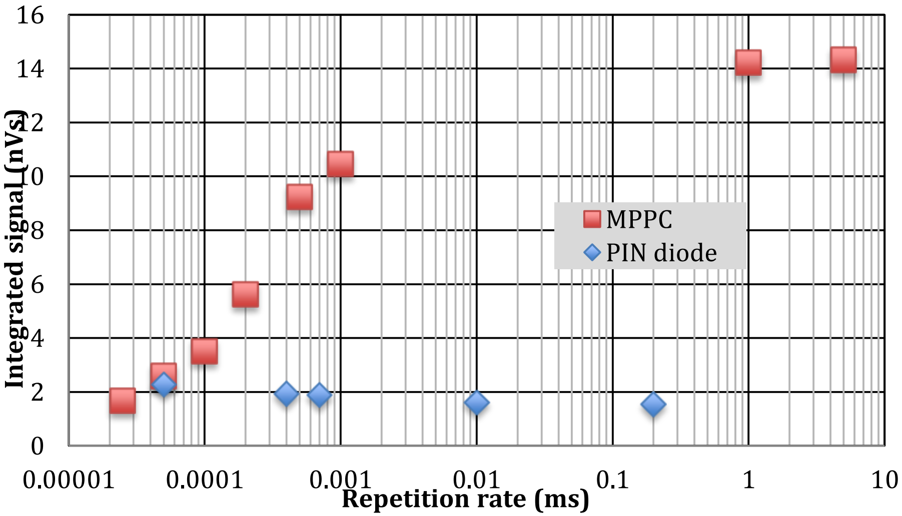
- Benchmarking beam loss simulations
- Studying the performance of distributed Optical fiber system versus localized detectors (reduced the number of monitors, better coverage of the loss)
- Test bed for light sensor: PIN diode, PMT, **SiPMT**

- Characterization of MPPC

(Silicon photomultiplier) with pulsed laser



Understand sensitivity, dynamic range and saturation



BLM status and plans

- Limitations due to dark current and voltage breakdown in Acc. Cavity and their impact of BLM performance*: Conclusion expected by end of 2015*
  - Ongoing: diamond vs oBLM
  - Expected: IC vs oBLM

- Measurement of maximum achievable position resolution of oBLM- *Conclusion expected by end of 2015*
  - At TBL with multi bunch train
  - At Califes with single bunch?
  - At Australian synchrotron with single bunch and multi bunch

- Beam based measurement of sensitivity and dynamic range: *Conclusion expected by early 2016*
  - Direct comparison of Ionization Chambers and oBLM (TBL)

- Beyond CTF3 shut down (2017-2018)
  - Development and implementation of BLM readout card (to merge within CLIC controls)

Conclusions and perspectives

- R&D on CLIC BPMs and BLMs is progressing well - expecting to finalize the detector design study and validation by the end of CTF3 running period
  - Future work, if budget permitted will be devoted to cost optimization, industrialization and read-out electronic development
  - On-going PACMAN studies on Cavity BPM alignment
  - Interest to continue the development of oBLM to improve the BLM efficiency and coverage in Linac and Tr. Lines.

- Development of a CLIC module acquisition system may benefit from on-going rad-hard developments currently initiated in framework for HL-LHC (2024)

- R&D work on Gas jet technology has a very interesting potential as non-destructive beam size monitor for high charge beams. The study will most likely continue through HL-LHC project

- Development of OTR/ODR simulation tools well advanced and Experimental validation at Cornell and Califes has already shown promising results

- Experimental program at ATF2 of a combined OTR/ODR Linear collider beam size monitor will start by end of 2015 and is expected to continue till 2018 at KEK

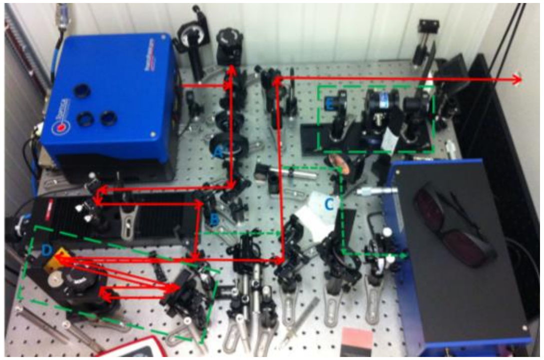
- Very valuable and proactive study by our Daresbury colleagues on short bunch length monitoring using EO techniques continuing through the CLIC-UK agreement till April 2017

Thanks BI colleagues, students and external collaborators

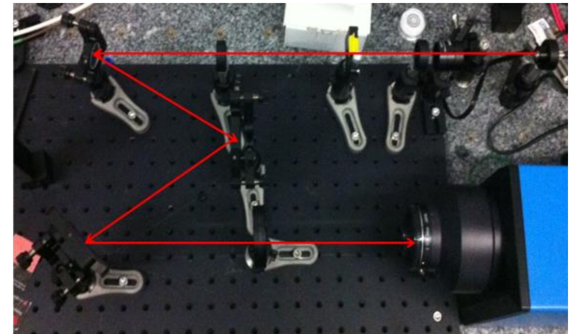
BI workpackage – 2011-16

- Budget estimates for 2011-2016 (Including CLIC-UK) : 6.9MCHF
- Spending profiles
  - CLIC-UK 1 : 1.5MCHF (including 1.2MCHF for Manpower)
  - CLIC-UK 2 : 1.1MCHF (including 0.9MCHF for Manpower)
  - Spending on 64779 from 2011-now : 2.7MCHF
  - Spending on 64778 from 2011-now : 0.8MCHF
  - Total CLIC (&CTF3) BI budget 5.1 MCHF already spent
  - Need another 1MCHF till end of 2017
- Resources since 2011
  - Total of 3 Fellows (*Robert Kieffer*), 2 Marie Curie Fellows, 4 Doct (*Jack Towler, Maria Kastriotou, Michele Bergamaschi*), 6 PJAS (*Adam Jeff, Eduardo Nebot del Busto*)
  - 1 Fellow and 1 Doctoral after 2016
  - CLIC-UK activities till april 2017
- Assuming BPM and BLM activities would stop with end of CTF3 and the contract of our PJAS
- Continuing on R&D at ATF2/Cornell on non-intercepting profile monitoring

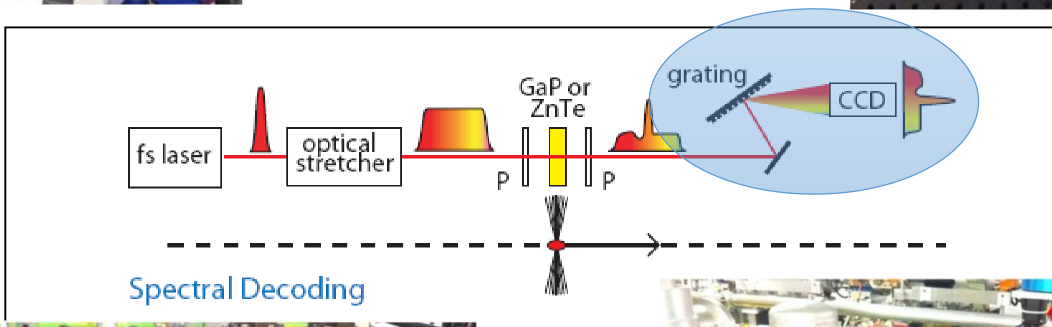
EO SD @Califes

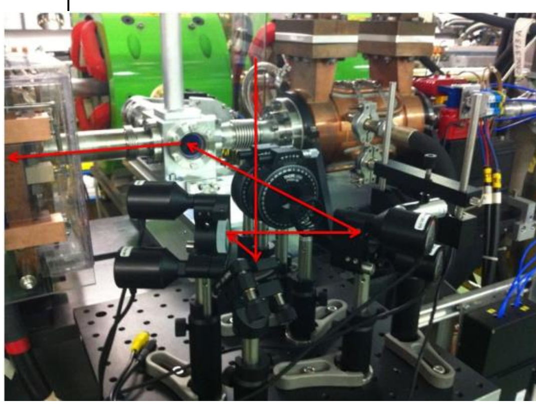


Er laser
780nm
150fs – 12ps

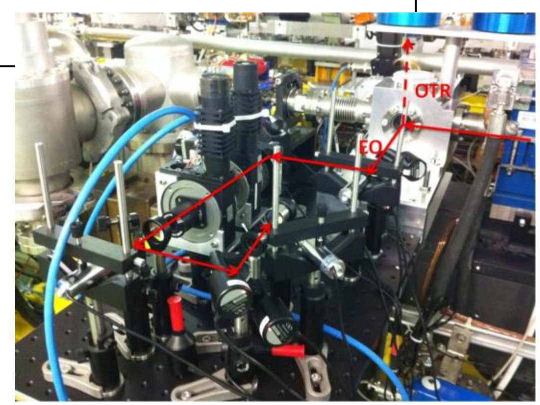


Spectrometer with grating and intensiifed gated CCD camera





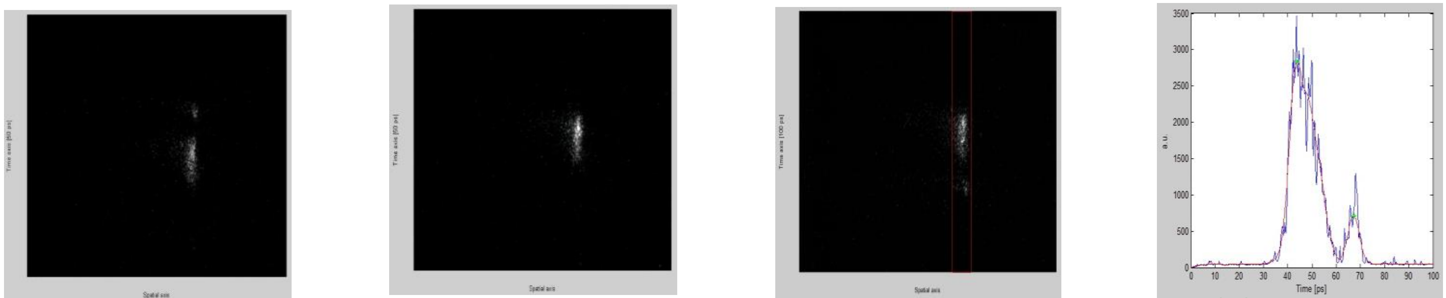
First polariser and
Laser injection Chamber



Crystal chamber (4mm ZnTe), crossed polariser and fiber coupling

EO SD @Califes

1 – Laser-electron beam synchronization

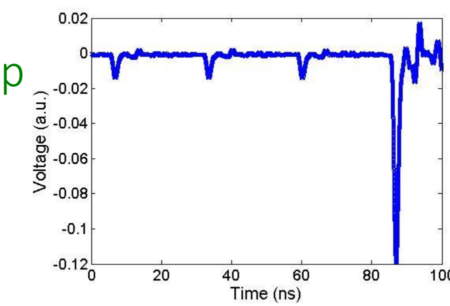


Done with Streak camera measurements with an accuracy of few ps

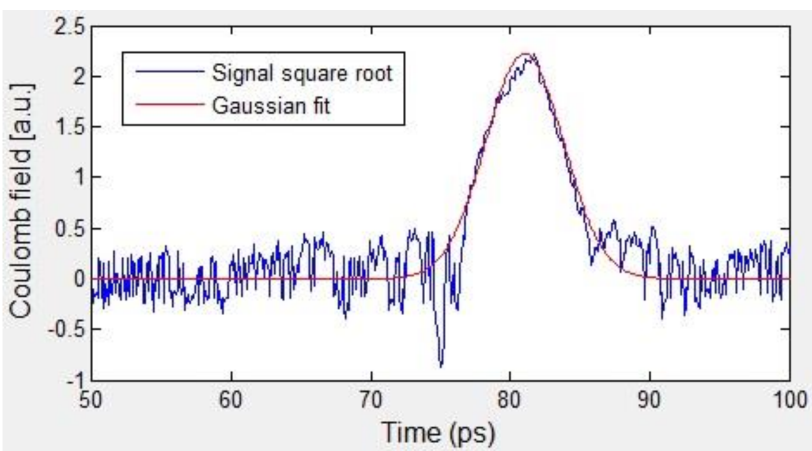
2 – EO measurements

- First optimizing the EO signal intensity using a PMT and scop

  The laser is pulsed every 26ns



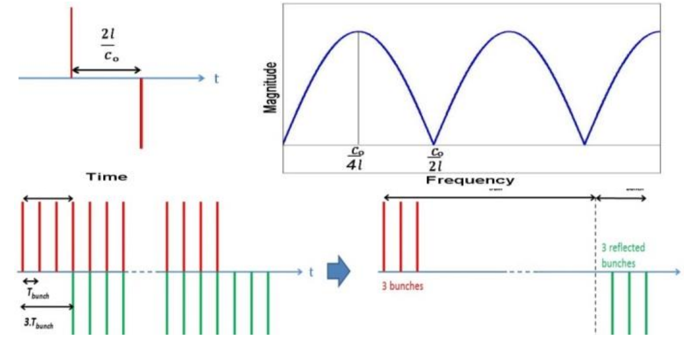
- Then measuring bunch length with spectrometer

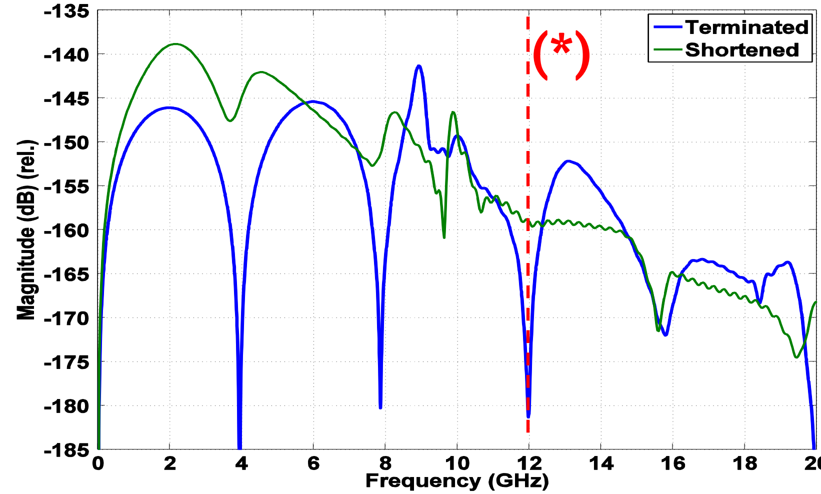


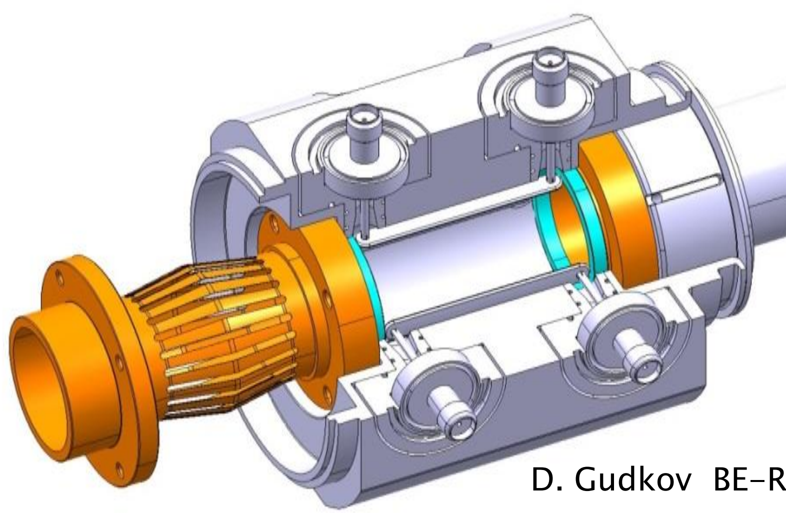
- 6.6ps FWHM, 0.35nC bunch charge
- Measured down to 0.1nC per bunch
- S/N ratio was 2-3 times better than streak camera measurements

Stripline BPM development for the CLIC Drive Beam

- 2 stripline prototypes with 50Ω-terminated electrodes developed for CLIC TBM.
- 8-port design for increased notch tunability and loop-through calibration.
- Enhanced PETS interference suppression at 12 GHz (*).
- Laboratory tests planned for June 2014.
- Beam tests planned for autumn 2014.







D. Gudkov BE-RF

Parameter	Shortened BPM	Terminated BPM
Stripline length	25 mm	37.5 mm
Angular coverage	12.5% (45°)	5.55% (20°)
Electrode thickness	3.1 mm	1 mm
Outer radius	17 mm	13.54 mm
Ch. Impedance	37 Ω	50 Ω
Duct aperture	23 mm	23 mm
Resolution	2 μm	2 μm
Accuracy	20 μm	20 μm
Time Resolution	10 ns	10 ns