Facilities for BI Tests: CLEAR / Hiradmat / Diamond

T. Lefèvre on behalf of the BI team involved

BI technical board, CERN, 22nd February 2018

Outline

- Beam instrumentation tests at **CLEAR**
https://clear.web.cern.ch

- Beam instrumentation tests at **Hiradmat**
https://espace.cern.ch/hiradmat-sps/Wiki%20Pages/Home.aspx

- Beam instrumentation tests at **Diamond**

Beam Instrumentation Tests : Why ?

- Testing new technologies, new concepts, new ideas
- Perform systematic checks on existing technologies
  - Avoid surprises when commissioning operational systems
  - Validation of new design of known technologies
- Operational machines are not made for R&D
  - Easily accessible, Enough time for beam tests, Simple set-up

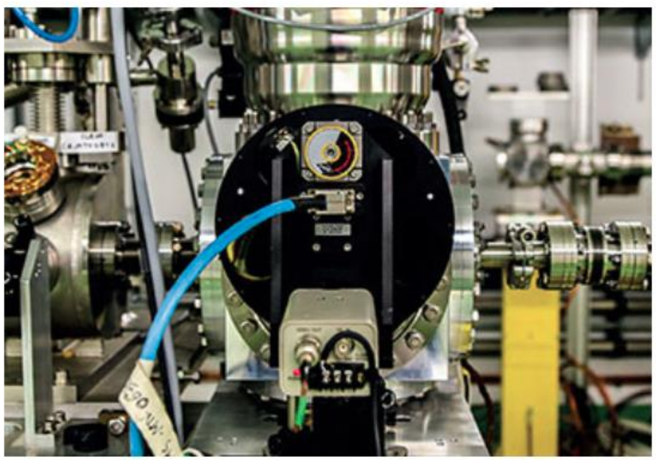
Beam Instrumentation at CLEAR:

clear

CERN COURIER

Oct 13, 2017

CLEAR prospects for accelerator research



CLEAR's plasma-lens experiment (expand for full image)

A new user facility for accelerator R&D, the CERN Linear Electron Accelerator for Research (CLEAR), started operation in August and is ready to provide beam for experiments. CLEAR evolved from the former CTF3 test facility for the Compact Linear Collider (CLIC), which ended a successful programme in December 2016. Following approval of the CLEAR proposal, the necessary hardware modifications started in January and the facility is now able to host and test a broad range of ideas in the accelerator field.

CLEAR prospects for accelerator research

by *Matthew Chalmers*

The CERN Linear Electron Accelerator for Research (CLEAR) will enhance and complement the existing accelerator R&D programme at CERN. (Image: Julien Ordan/CERN)

Beam Instrumentation at CLEAR:

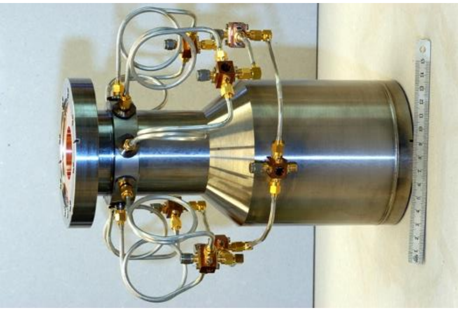
Beam parameters	Range	Comments
Energy	60 – 180 MeV	More flexible with 2 klystrons. > 220 MeV expected with pulse compression.
Energy Spread	< 1 MeV (FWHM)	
Bunch Charge	1 pC – 200 pC	Photocathode changed but limited laser power. Goal: 0.6 nC.
Bunch Length	2.4 ps – 8 ps	0.1 ps according to simulation. Velocity bunching studies to be resumed
Normalized emittances	3 μm to 30 μm	Bunch charge dependent
Repetition rate	0.8 to 5 Hz	25 Hz with klystrons and laser upgrade
Number of micro-bunches in train	1 to >150	Single bunch capability assessed
Micro-bunch spacing	1.5 GHz (Laser)	3.0 GHz: Dark current

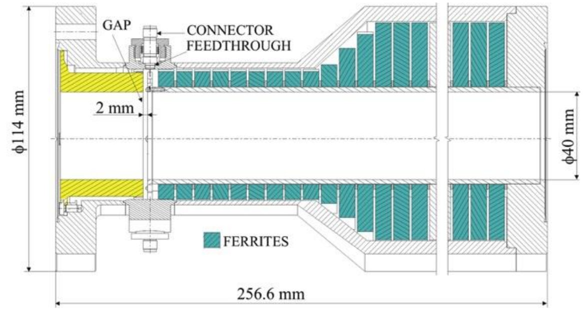
Beam Instrumentation at CLEAR:

BI Fellow working on CLEAR : Michele Bergamaschi

Beam Instrumentation at CLEAR
Existing BI equipments (1/3)

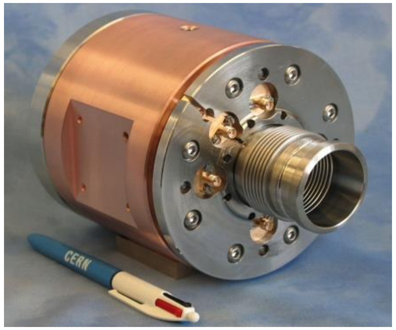
- Beam intensity: 1x WCM -High bandwidth (10kHz-7GHz) and High sensitivity





(P. Odier)

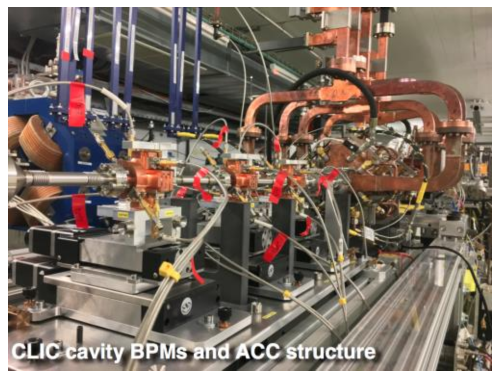
- Beam position: few Inductive BPMs (with modified electronic for better sensitivity)



(M. Krupa, F. Guillot-vignot, M. Gasior)

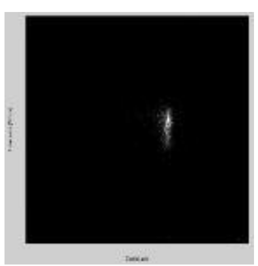
Beam Instrumentation at CLEAR
Existing BI equipments (2/3)

- High resolution (<1um) Cavity BPM for precise measurements

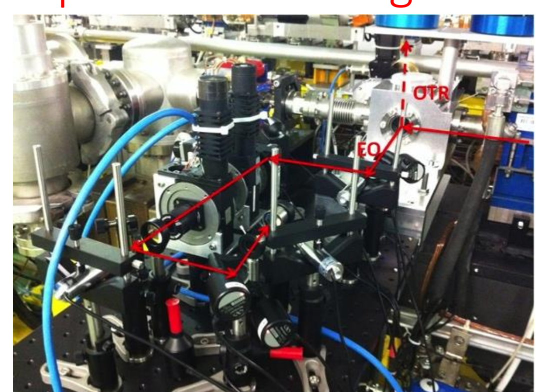


(J. Nadenau & M. Wendt)

- Streak camera (shared with AWAKE) / Electro-optical spectral decoding for Bunch length measurement (sub-ps to ps)

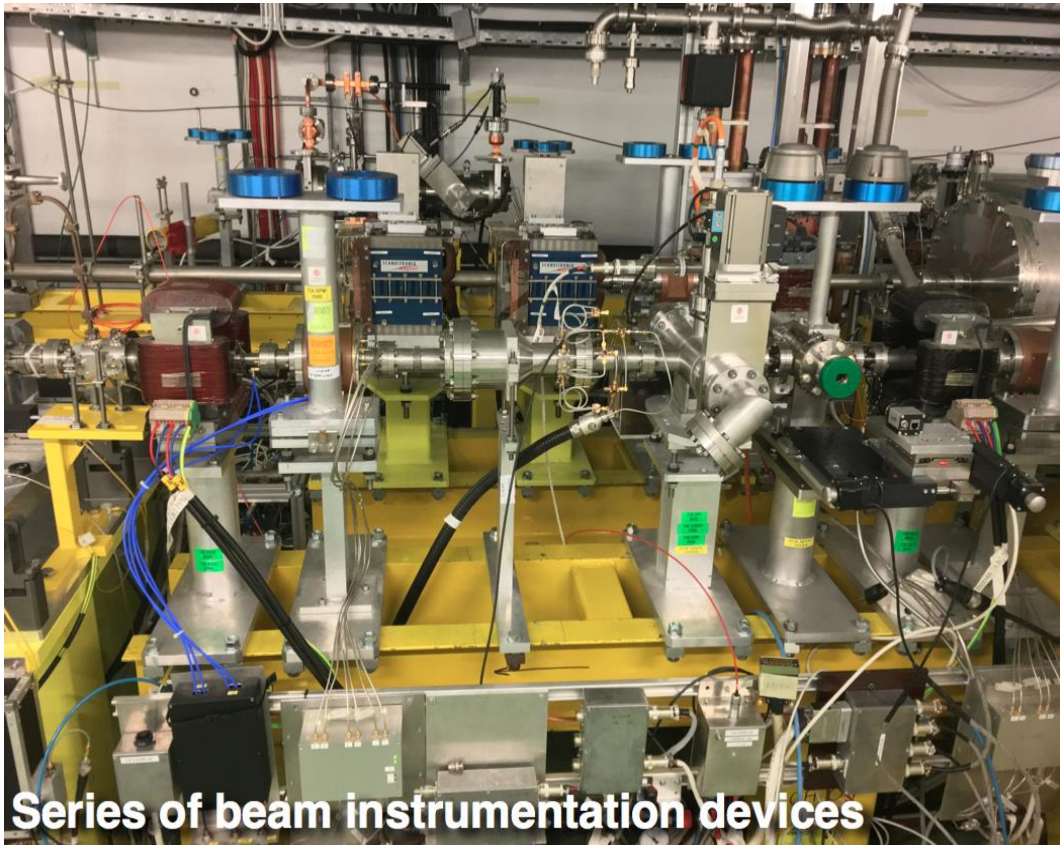


(I. Gorgisyan & S. Mazzoni)



Beam Instrumentation at CLEAR

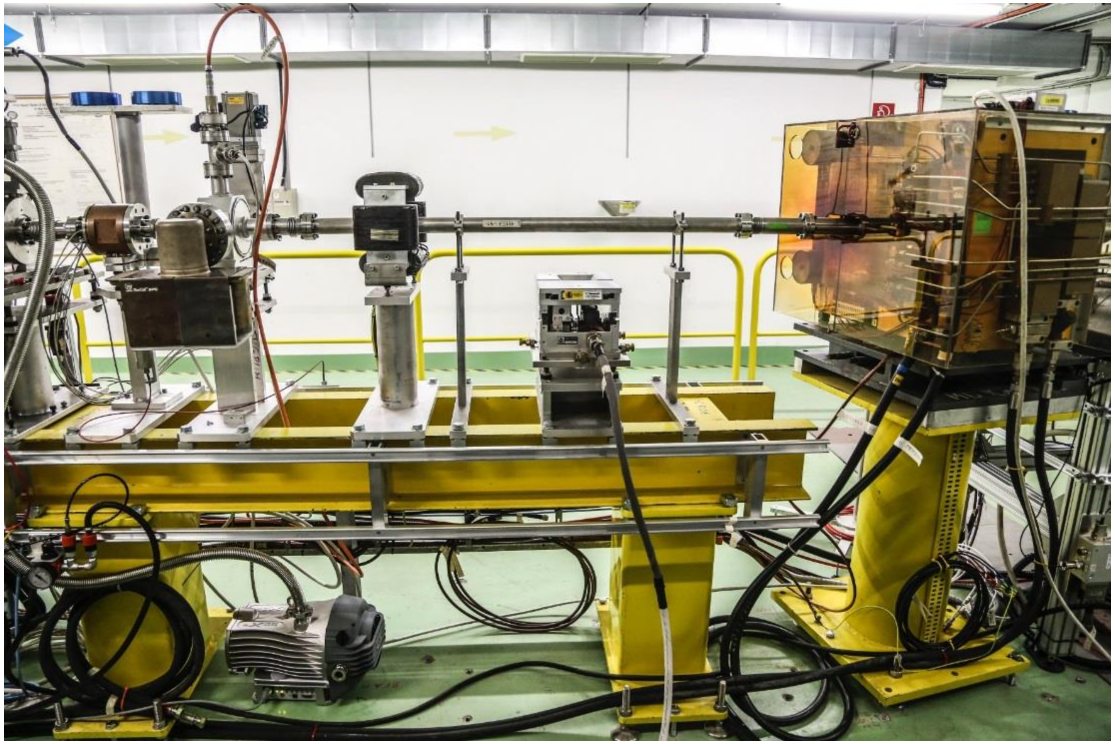
Existing BI equipments (3/3)



Series of beam instrumentation devices

Beam Instrumentation at CLEAR

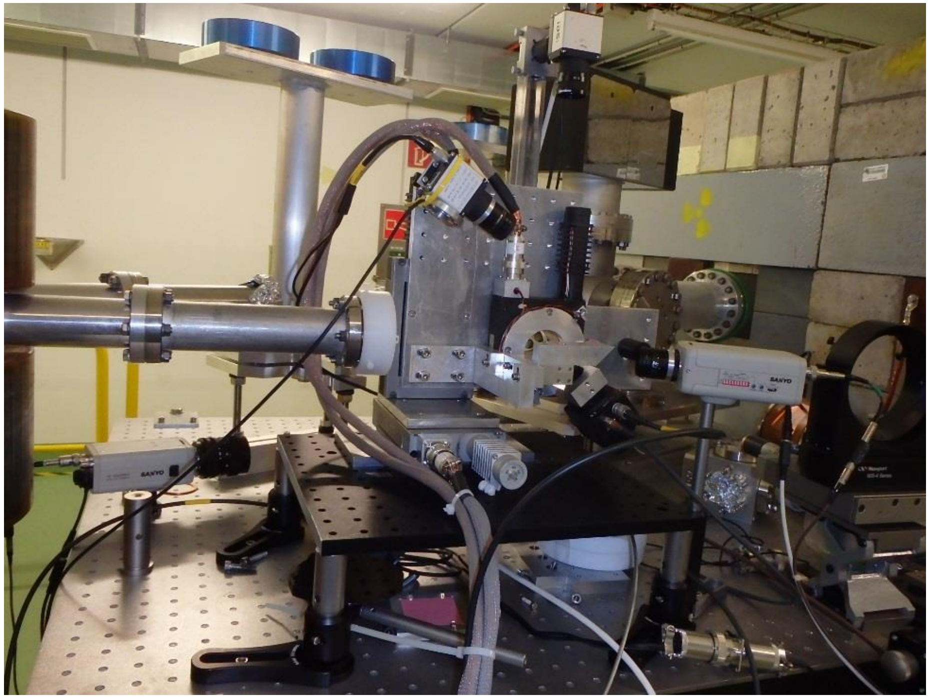
Testing Areas



In-vacuum test stand – 1m long equipped with a moving H&V stage

Beam Instrumentation at CLEAR

Testing Areas



In-air test stand - 1m long optical breadboard at the end of the beam line
Equipped with motor controllers for translation/rotation stages

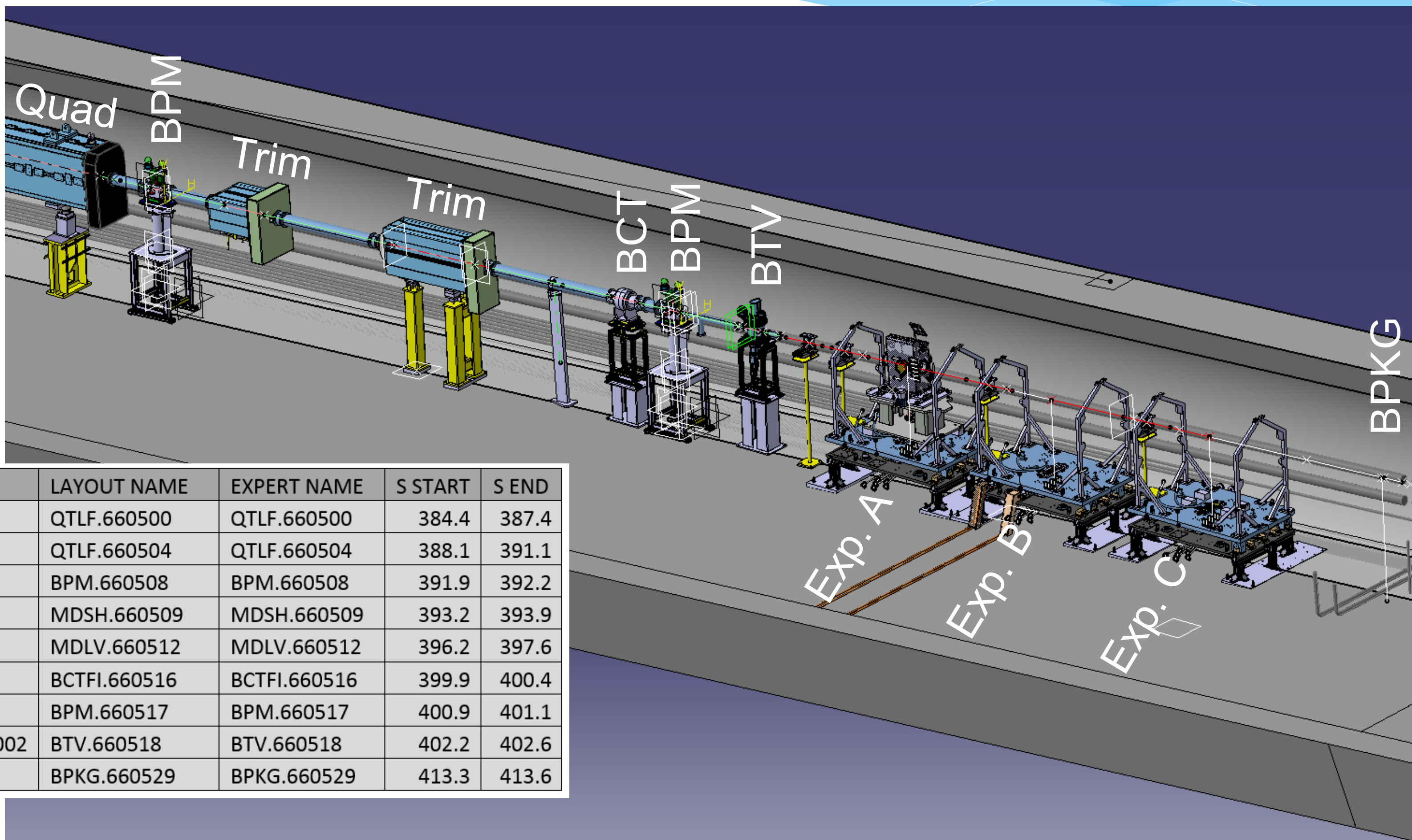
Beam Instrumentation at Hiradmat

HiRadMat
High-Radiation to Materials

Beam Instrumentation at Hiradmat

Beam Energy	450 GeV
Pulse Energy	up to 3.4 MJ
Bunch intensity	up to $1.2 \cdot 10^{11}$ protons
Number of bunches	1 to 288
Maximum pulse intensity	$4.0 \cdot 10^{13}$ protons
Bunch length	11.24 cm
Bunch spacing	25, 50, 75 or 150 ns
Pulse length	7.2 μs
Minimum cycle length	18 s[c]
Beam size at target	variable around 1 mm^2

Beam Instrumentation at Hiradmat

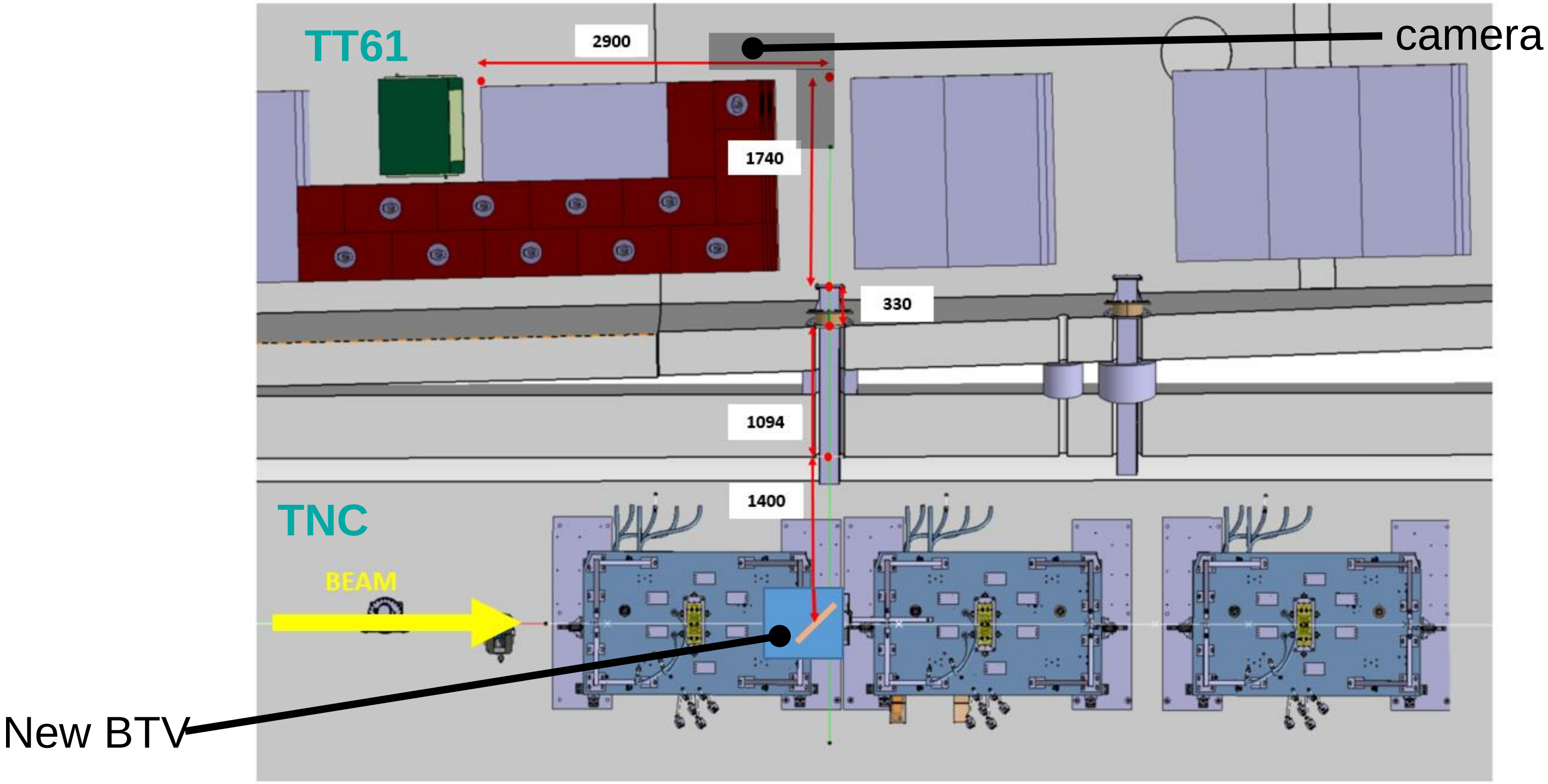


TYPE	LAYOUT NAME	EXPERT NAME	S START	S END
QTLF	QTLF.660500	QTLF.660500	384.4	387.4
QTLF	QTLF.660504	QTLF.660504	388.1	391.1
BPM	BPM.660508	BPM.660508	391.9	392.2
MDSH	MDSH.660509	MDSH.660509	393.2	393.9
MDLV	MDLV.660512	MDLV.660512	396.2	397.6
BCTFI	BCTFI.660516	BCTFI.660516	399.9	400.4
BPM	BPM.660517	BPM.660517	400.9	401.1
BTV__002	BTV.660518	BTV.660518	402.2	402.6
BPKG	BPKG.660529	BPKG.660529	413.3	413.6

Beam Instrumentation at Hiradmat

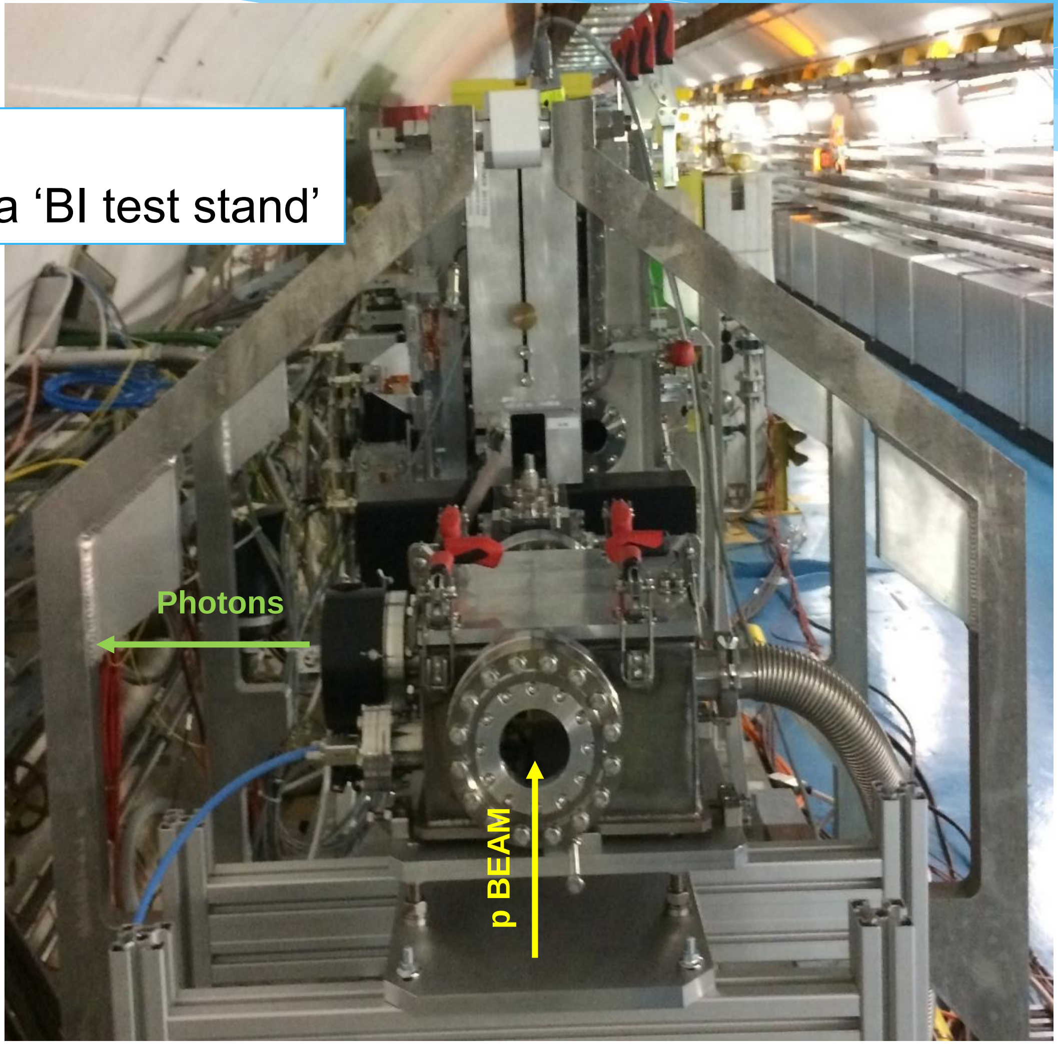
In 2017, Installation of camera in TT61 to move away from the irradiated zone

→ Optical line up to TT61



Beam Instrumentation at Hiradmat

Table A:
To become a 'BI test stand'



(S. Burger)

Beam Instrumentation at Hiradmat

Schedule and beam time requests : 8 - 10 experiments / year

-ID	Title	Description	Contact person	Beam
HRMT 32	MicOpt	Measure performance of new radiation hard optical microphone	Daniel Deboy	2018 W??
HRMT 37	SextSc	Measure damage limit of superconducting magnets	Daniel Wollmann	2018 W34
HRMT 38	Flex MAT	Test range of carbon material and target with intense proton beam	Marinela Tomut	2018 W36
HRMT 47	Atlas PixRad	Estimate damage threshold of ATLAS inner detector & electronics	Antonio Sbrizzi	2018 W19
HRMT 48	PROTAD	Test Prototype for future antiproton production target	Claudio Torregrosa, Marco Calviani	2018 W21
HRMT 46	Ntof-Target	Evaluate two different solution for n-ToF Target	Marco Calviani, Raffaele Esposito	2018 W23
HRMT 45	TDIS-TZM	Validation test of TDIS jaw sub assembly	David Perez, Antonio Perillo-Marcone	2018 W30
HRMT 44	TCDIL-DEEP	Test 2 designs of TCDIL collimator jaw	Francois-Xavier Nuiry	2018 W28
HRMT 43	BeGrid 2	Test Thermal shock response of conventional and novel materials-	Marco Calviani	2018 W41
HRMT 19	BLM2	Verification of ionization chamber	Slava Grishin	2018 W??

Beam Instrumentation at Diamond

Beam Instrumentation at Diamond

Technical | Injection systems

Injection Systems

In the linac, the electrons are grouped together into "bunches". A number of different modes of operation are possible.

Single-bunch mode: a single bunch of electrons, containing around 10 billion electrons, orbits around the storage ring.

Multi-bunch mode: numerous bunches of electrons are grouped together into a "train" of bunches. The total length of each train and the spacing between consecutive trains can be varied.

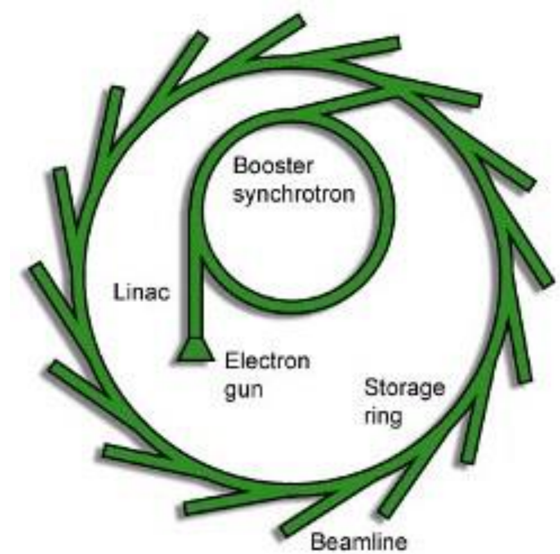
Transfer lines are used to transport the 100 MeV electrons from the linac to the booster synchrotron. Another set of transfer lines are used to transport the 3 GeV electrons from the booster synchrotron to the storage ring.

Linac Specifications

Pre-injector energy:	100 MeV
Modulated thermionic gun:	500 MHz, 90 keV
Repetition rate:	2-5 Hz
Pulse length:	1-700 nS
Pulse charge (single pulse or long pulse):	<1.5 or <3 nC
Normalised emittance:	Less than 50 p mm*_mrad
Energy spread:	Less than ± 1.5%
Top-up capability:	Low charge, variable pulse sequences

Booster Specifications

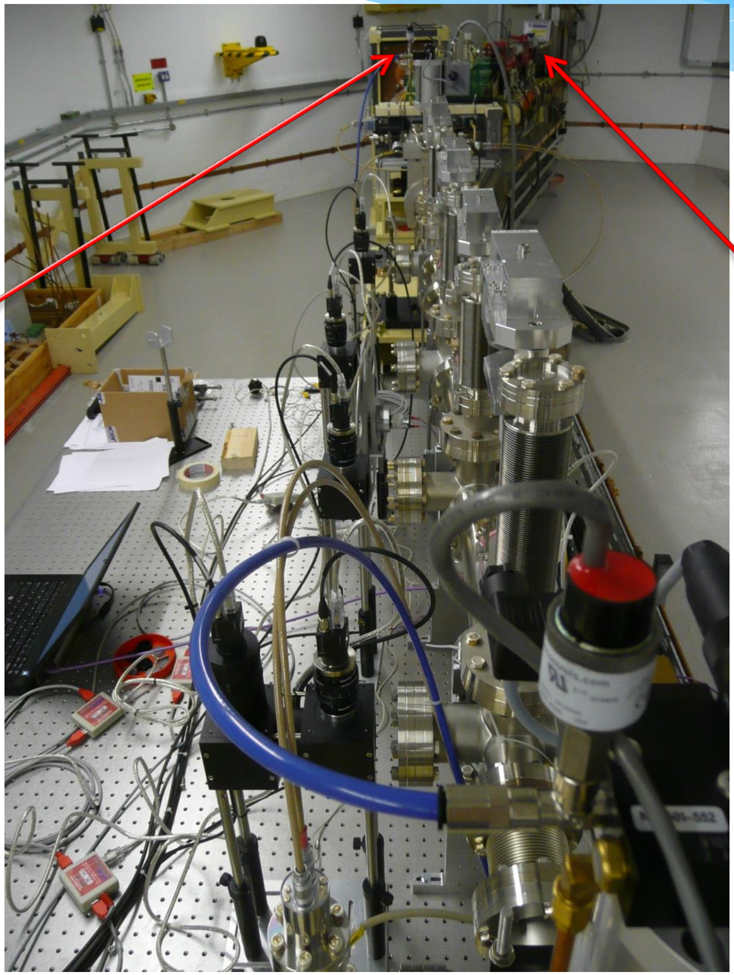
Lattice:	22 cell FODO arrangement, 36 dipole magnets
Injection energy:	00 MeV
Extraction energy:	3 GeV
Circumference:	158.4 m
Current:	6 mA (max)
Emittance:	0.135 p mm*mrad
Tunes:	7.16, 4.11
Frequency:	2-5 Hz



Contact : Lorraine Bobb

Beam Instrumentation at Diamond

Beam dump



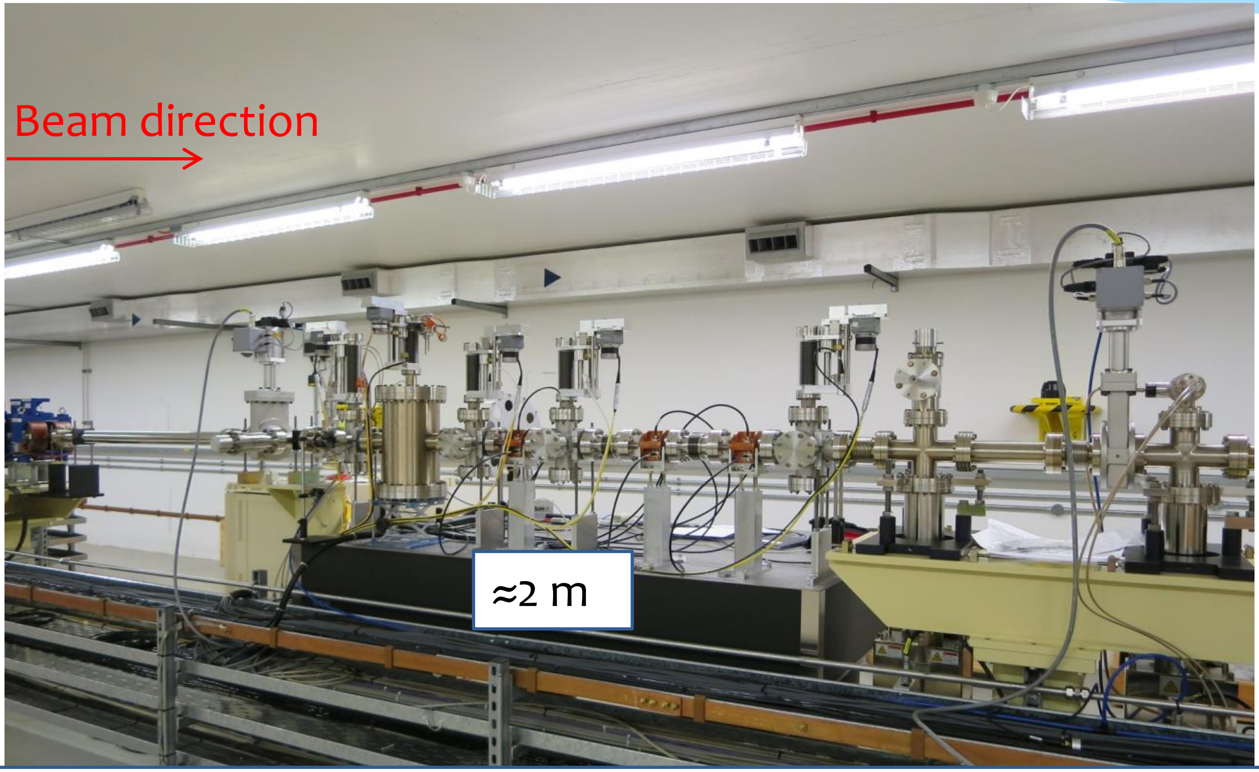
To storage ring

Test-stand 'BTS' in the transfer line from the booster to the main ring

Beam Instrumentation at Diamond

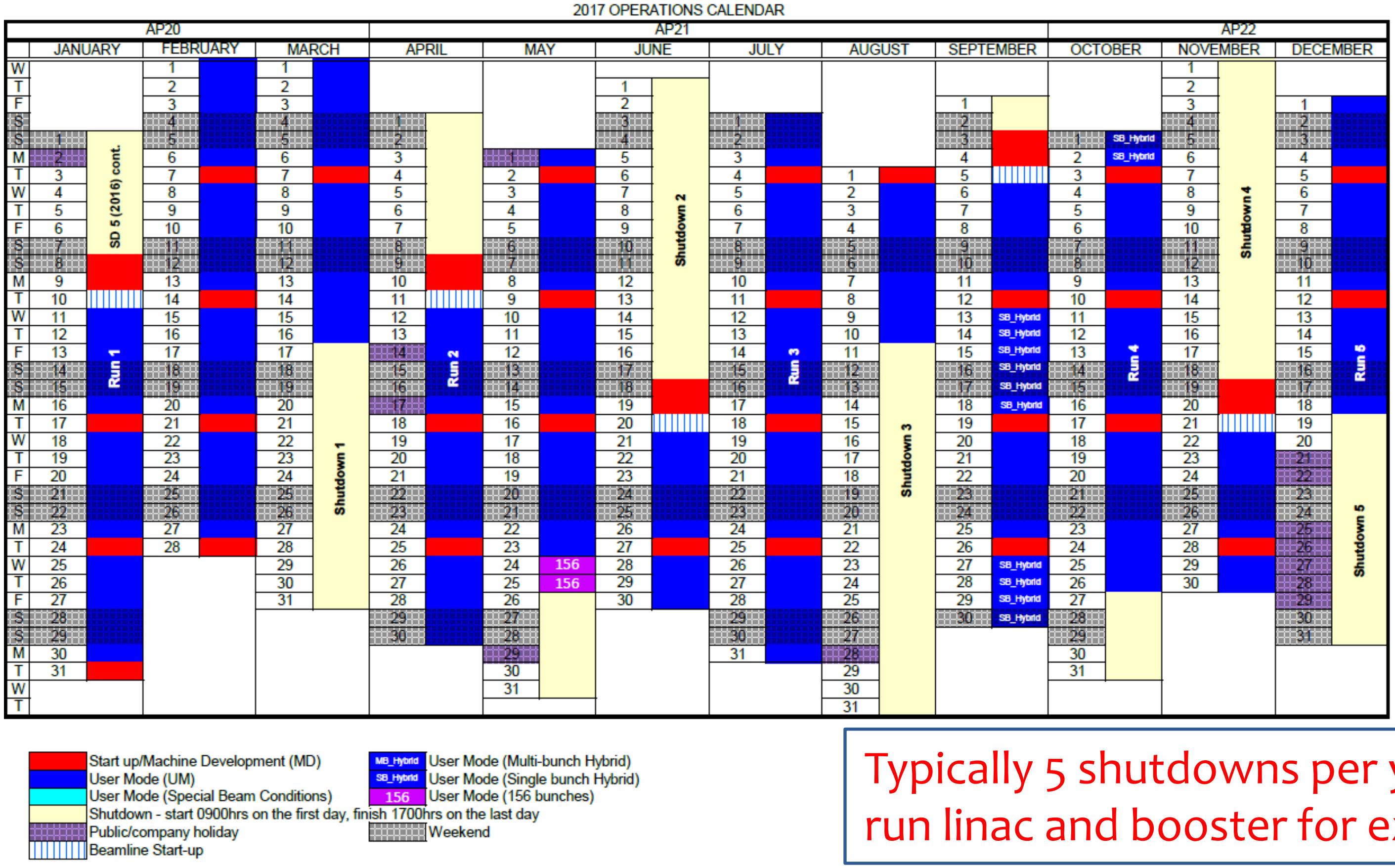
Beam Parameter at BTS Test Stand	Value
Max. charge per bunch (single bunch mode) [nC]	0.3
Charge per 120 bunch train [nC]	1.3
Bunch spacing [ns]	2
Beam size (h,v) [mm]	1.27 - 1.42, 0.57-0.60
Alpha (h,v)	-0.72 - -0.96, -0.71 - -0.82
Beta (h,v) [m]	11.00 - 13.93, 23.86-26.53
Emittance (h,v) [nm.rad]	134.5, 13.4
Dispersion [m]	0.5
Energy [GeV]	3
Energy spread	0.00073
Bunch length [mm]	≈2.5

Beam Instrumentation at Diamond



Four OTR monitors and cavity BPMs from previous experiments are still installed. All instrumentation in this 2m region can be replaced for other experimental tests.

Beam Instrumentation at Diamond



Typically 5 shutdowns per year where we can run linac and booster for experimental tests.

Beam Instrumentation at Diamond

- Recuperating hardware from CTF3 to install inductive BPMs and Vacuum chamber with target manipulator
- Installation foreseen in June 2018
- First beam tests could happen by end of June 2018

A strategy for BI R&D

- **Start R&D at CLEAR** using low intensity bunches
  - Easiest access, low level of radiation , both in-air/in-vacuum test stand

- Test and Validate the ‘best’ design with **high intensity protons** at Hiradmat
  - In-air test area on Table A

- Test and **Validate** design the ‘best’ design with **higher energy** electrons (γ = 6000, i.e. LHC at flat top) at Diamond/BTS

Conclusions

- CLEAR offers both in-air/in-vacuum testing capabilities with some flexibility
  - Already existing cable/fiber infrastructure, motor controllers, acquisition systems,..

- CLEAR is equipped with a full suite of beam instruments to guarantee its normal operation and to provide cross-calibration
  - More this year with Streak camera and EOS back in operation

- Testing at Hiradmat and Diamond also give the opportunity to complement the R&D with high intensity protons or highly relativistic beams

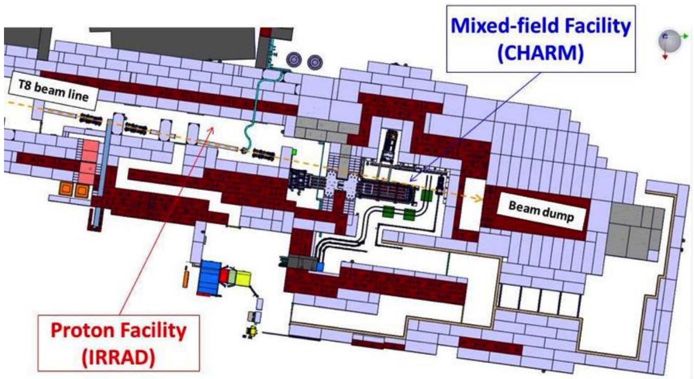
Thanks for your attention

Developing Beam diagnostics at CERN

- Testing on **CERN PS Complex Area**
  - IRRAD – Proton irradiation (24GeV, max 5.10^{11} protons per spill, Up to 10^{18} protons)

    see https://irradiation.web.cern.ch/irradiation/
  - CHARM (CERN High-energy AcceleRator Mixed field facility) : mimic radiation environment found in the accelerator chain

    see https://charm.web.cern.ch/CHARM/



- Testing on **CERN SPS Area**
  - High Radiation to Material – 450GeV Protons with up to 288 Bunches with 25ns spacing ($3\ 10^{13}$ protons per pulse)

    see https://espace.cern.ch/hiradmat-sps/Wiki%20Pages/Home.aspx

    HiRadMat High-Radiation to Materials
  - Gamma Irradiation Facility in NA with a 15 TBq ^{137}Cs source

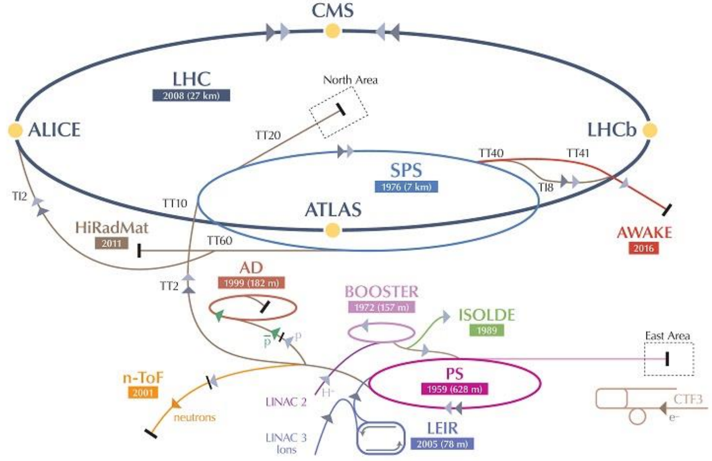
    see https://gif-irrad.web.cern.ch/gif-irrad/

    GIF++

Developing Beam diagnostics at CERN

- Testing directly on the Operational Machines themselves
  - Limited time for hardware installation/modification in the tunnel (i.e. Technical stops)
  - Limited beam time available for tests during MDs
  - R&D is not always compatible with the strict requirements for Operational Machines

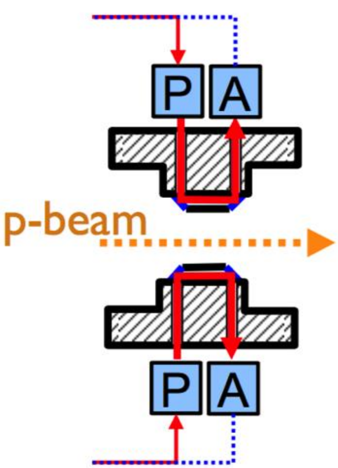
e.g. Testing gas jet monitor and their performance as function of gas pressure would conflict with vacuum requirements

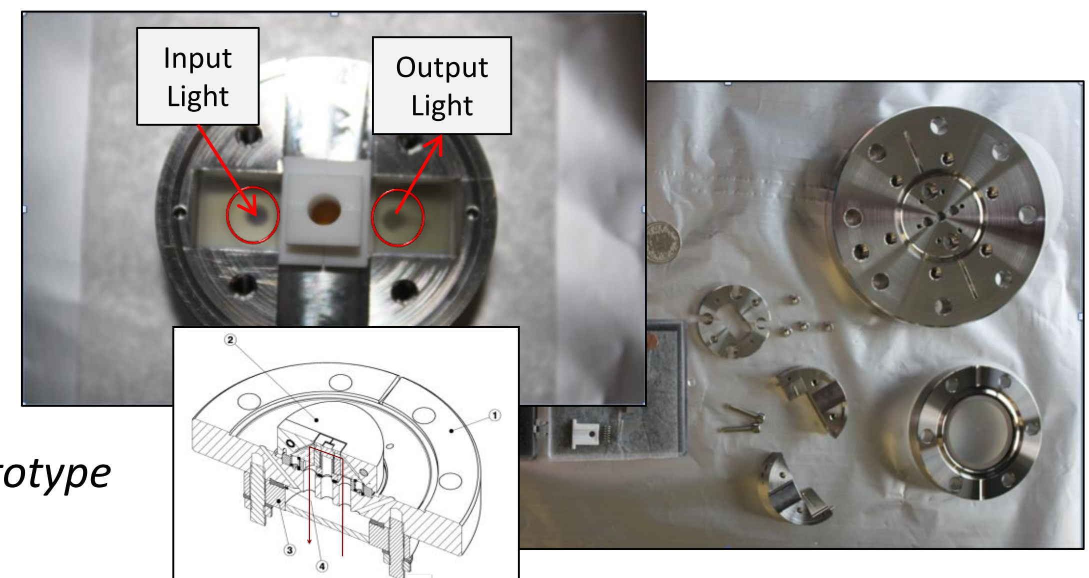


Instrumentation Test on CLEAR

Electro-Optical Beam Position Monitor (1/2)

- Motivation – in the framework of HL-LHC
  - Providing an all-optical BPM using birefringent crystal and optical fiber
    - More compact, lower impedance, good time resolution, no expensive/big cable
- Concept and current development
  - Encoding the beam field onto a continuous laser beam using LiNbO3 crystal
  - Two configurations – either through **polarization change** or using interferences



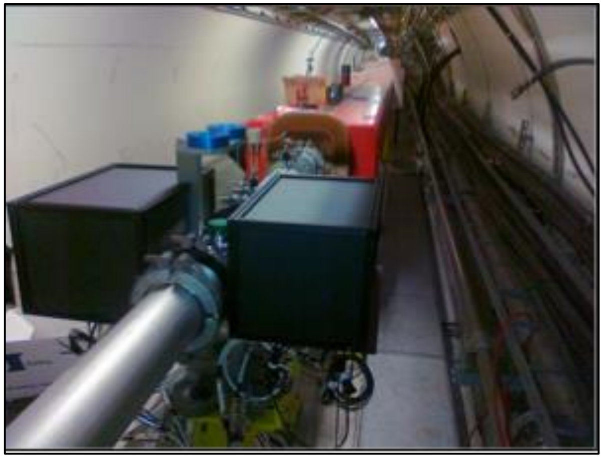


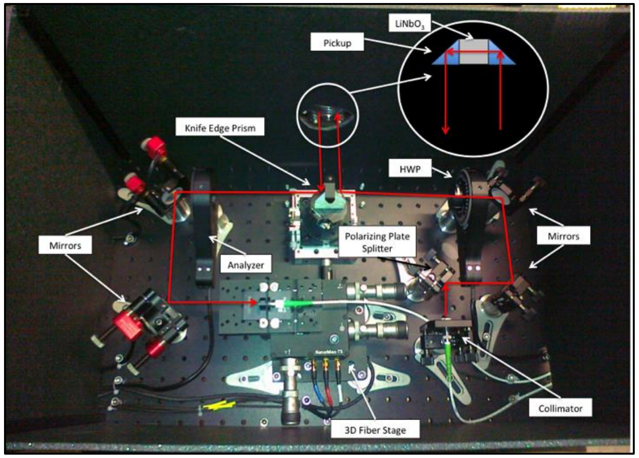
SPS prototype

Instrumentation Test on CLEAR

Electro-Optical Beam Position Monitor (2/2)

- Proposed test (*second part of the year*)
  - Install a spare SPS Pick-Up and optical set-up to perform detailed studies on CLEAR
    - Testing different crystal configurations: crystal with metal coating or not, special electrode,..
    - Perform beam position sensitivity curve
    - Develop the detection scheme: P/A method or interferometer





  - Re-using some of existing CLEAR infrastructure: motor controller, optical fiber, ..
  - Investigate the possibility to test in-air ?

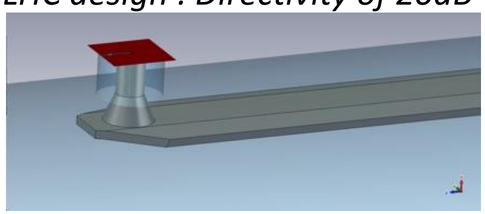
Instrumentation Test on CLEAR

HL-LHC Stripline BPM

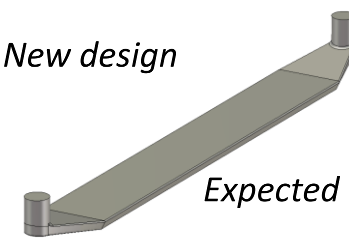
- Series of 40 BPMs being designed for upgraded interaction regions in LHC (IP1&5)
  - Cryogenic BPMs – in common beam pipe region (measuring counter-propagating beams)

- Testing the directivity of newly designed stripline using an existing LHC BPM in 2017

LHC design : Directivity of 20dB



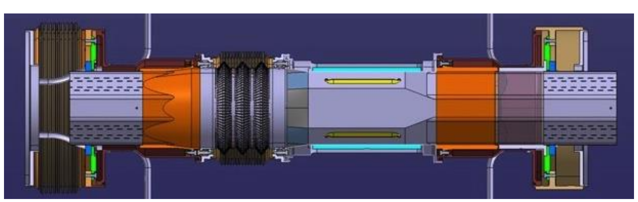
New design



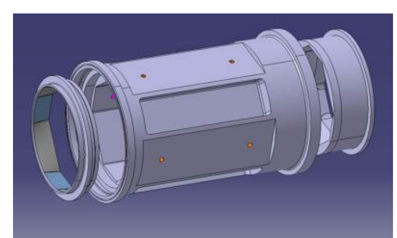
Expected Directivity of >30dB

- Validation of prototype in 2018 (in-air ?): Octagonal BPM with Inermet (W-alloy)

Interconnection between Quadrupoles



Beam screen *PIM (RF bellow)* *BPM* *Beam screen*



3D design of BPM under validation

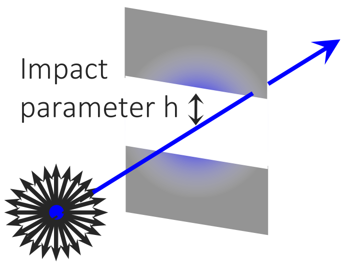
Instrumentation Test at CLEAR

Diffraction Cherenkov Radiation studies

- Motivation and Concept
  - Similar radiation process (Coherent Diffraction Cherenkov radiation effect) as in **Dielectric loaded waveguides** proposed for high gradient acceleration, THz source and micro-bunching generation (Cherenkov FEL) and for short bunch length diagnostics

  - **Studying the properties of incoherent diffraction cherenkov radiation** (DChR) in dielectric materials for ultra relativistic beams
    - Radiation yield scales with $\gamma\lambda$ (i.e. large flux of photons for relativistic protons compared to Synchrotron radiation)
    - Radiation intensity proportional to the length of the dielectric
    - Radiation emitted in well defined Cherenkov angle (practical aspect)
    - Recent experiment on Cornell Electron Storage Ring demonstrated

    large flux of photons in NIR emitted in 2cm long SiO2 radiator by 2.1GeV electrons

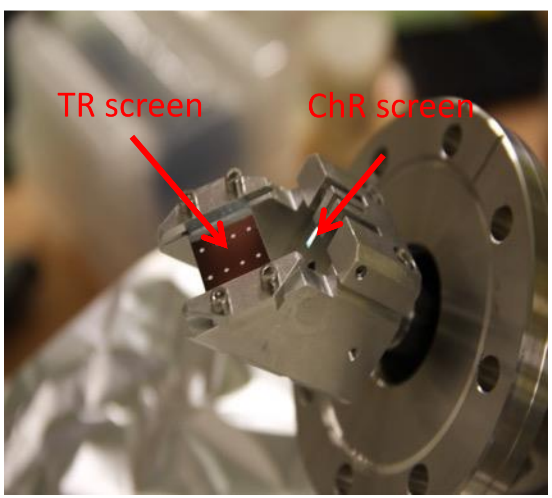


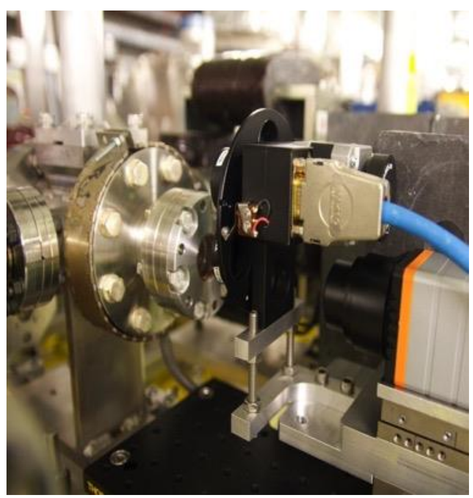
  - Possible use for future instrumentation projects (beam position and size)
    - Using diffraction cherenkov radiation for centering crystal collimator (LHC)
    - Developing a **very high directivity beam position monitor** for circular collider (Lepton, Hadron)

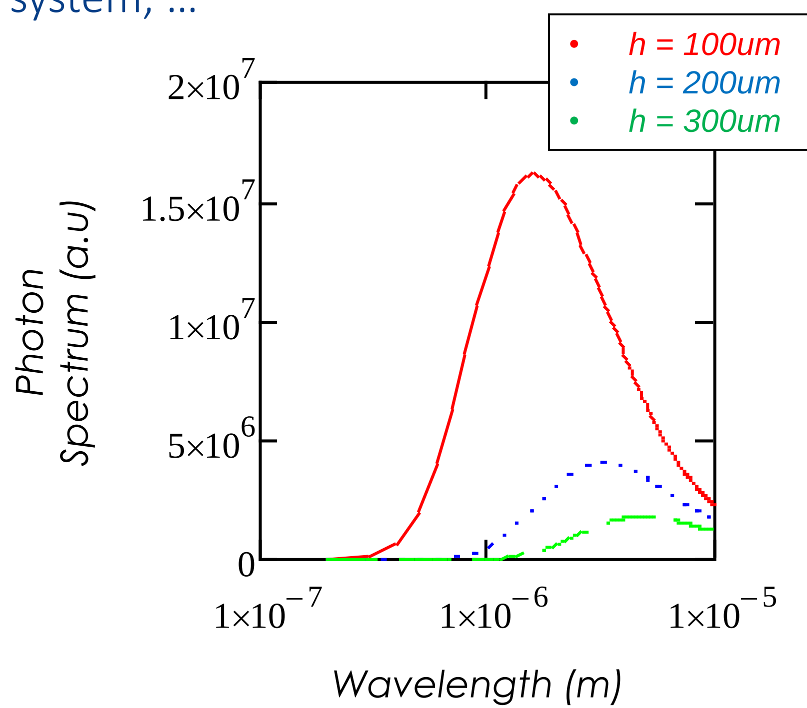
Instrumentation Test on CLEAR

Cherenkov Diffraction Radiation studies

- Testing with 200MeV electrons
  - Producing ChDR in a 15x2x1.2mm Diamond crystal detected by IR Camera and photodiode
  - Comparing **Transition, Cherenkov and Diffraction Cherenkov** radiation:
    - Photons spectrum, Light yield, Light collection system, …

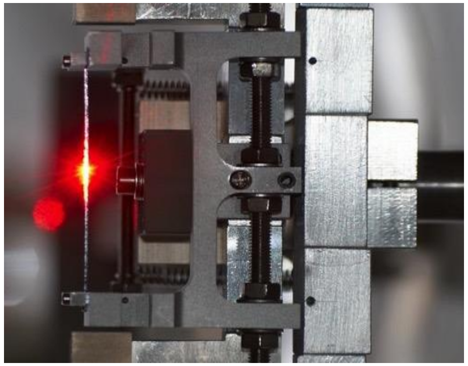


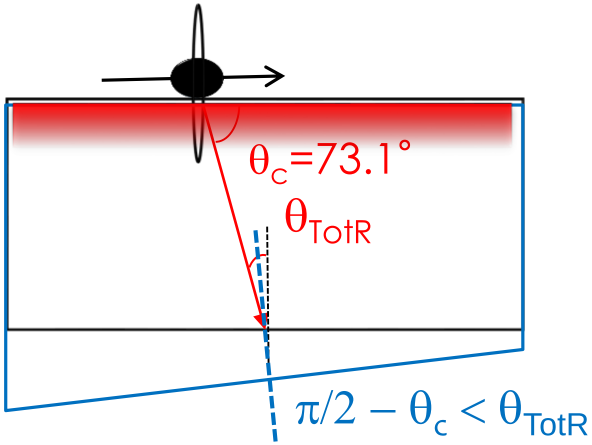




Instrumentation Test on CLEAR
Cherenkov Diffraction Radiation applications

- Bent Crystals (via channelling effect) are now seriously considered as primary collimators for LHC and FCC
  - Investigating the use of Cherenkov Diffraction Radiation as way to center the crystals around the beam
  - In a 3mm long Silicon Crystal and impact parameter of 1mm the LHC beam (7TeV p^+) would produce ≈5watts of radiation (1-10um wavelength)

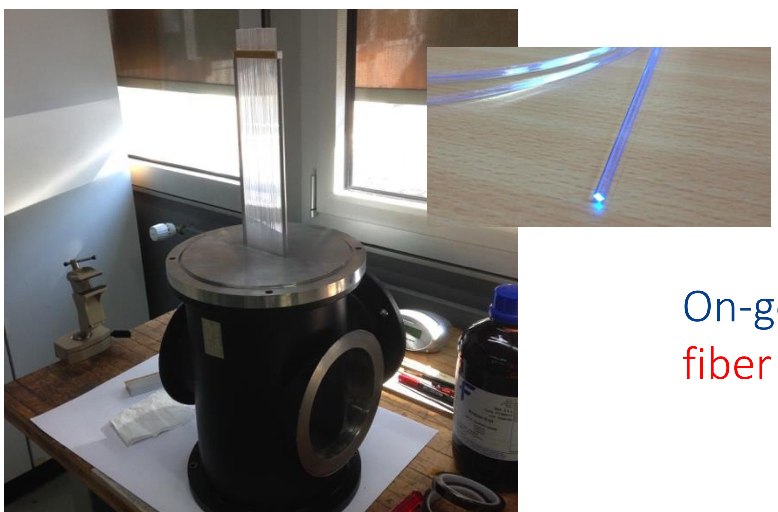




- Crystal outer face built with different angle or with a high roughness to diffusive the light out
- Studying the detection system: e.g. coupling photons in an optical fiber
- Possible set-up in-Air to allow flexible developments

Examples of possible future tests

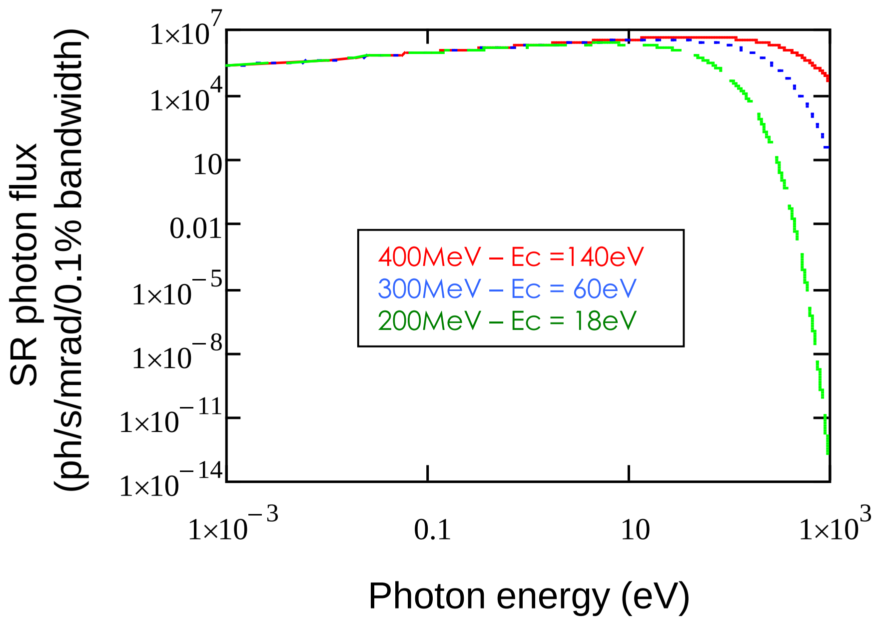
- Test and calibration of Secondary beam line monitors (EA), Particle detectors, Beam Loss Monitors
  - **Possibility to reach low beam density down to 10^5 electrons/cm^2 per pulse**
  - Study of detector performance: i.e. MIP response, Time response, Saturation effects



On-going development of high sensitivity Scintillating fiber for SPS NA and new EHN1 beam line

Examples of possible future tests

- Synchrotron light monitors
  - Imaging system for HL-LHC and FCC (visible, UV..)
  - Beam halo monitor, longitudinal density monitors, …

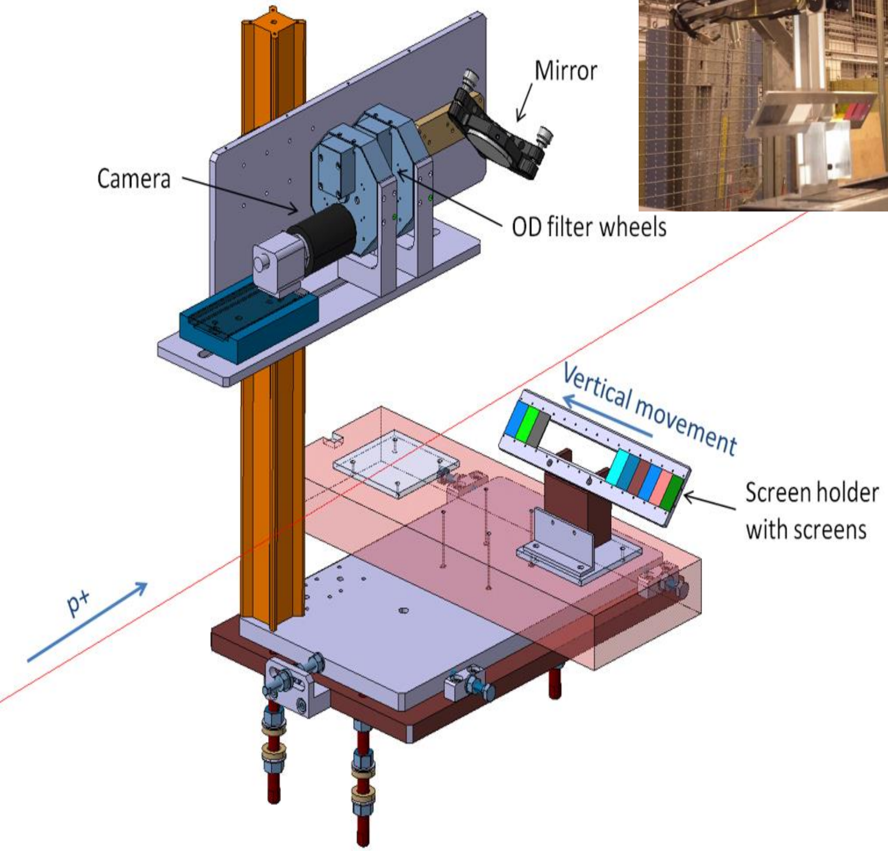


With 200MeV e⁻, similar photon spectrum as in LHC

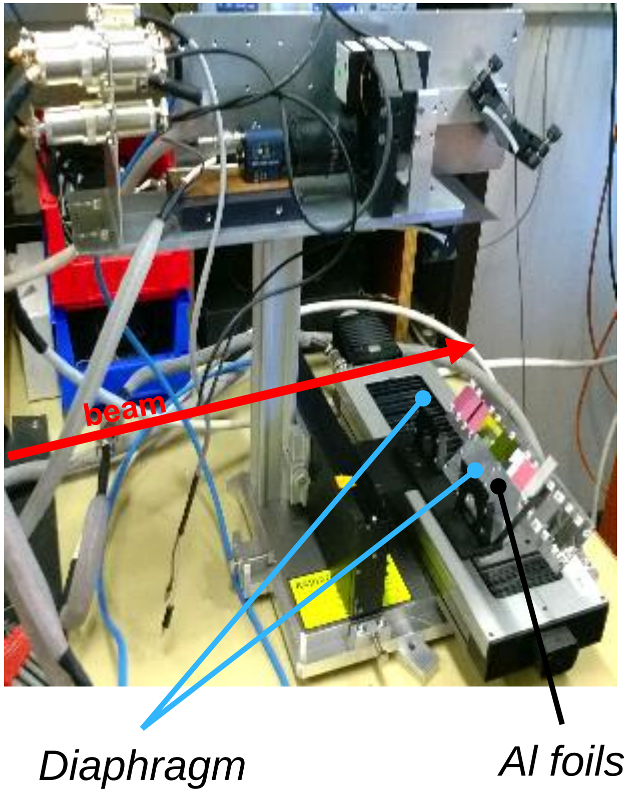
Possibly to go to EUV/low-energy X-ray if doubling the beam energy

Possible in-air BTV setup

Oct 2015 – HRMT30

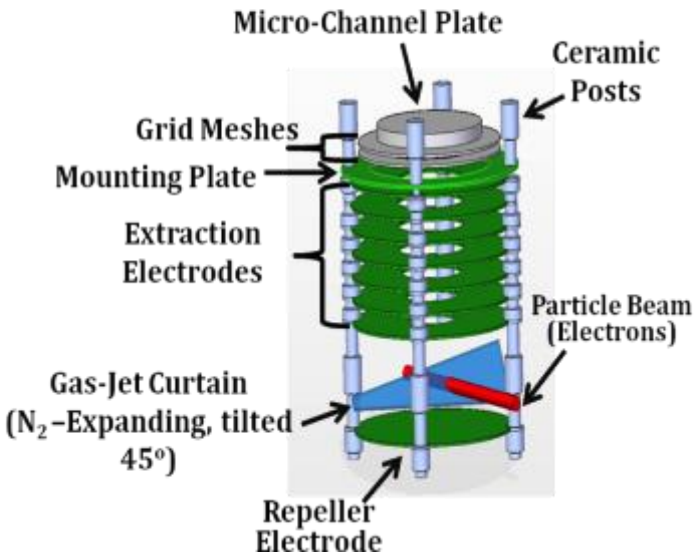


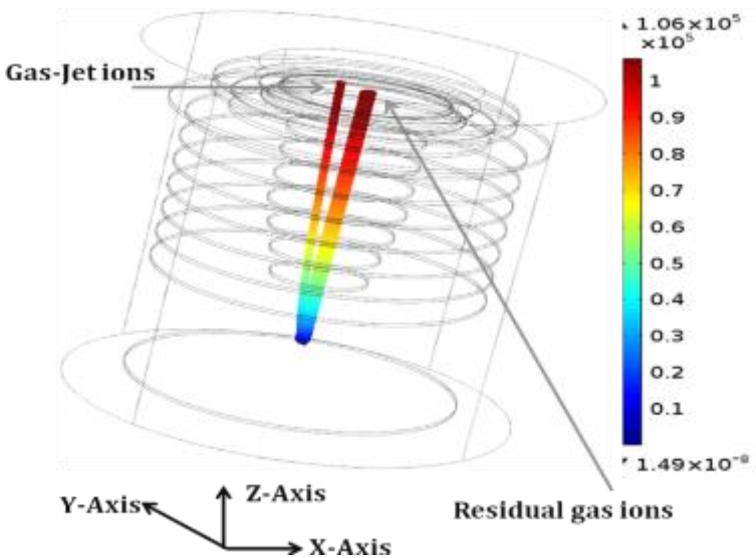
June 2016 – HRMT32



Gas-jet R&D with ULIV

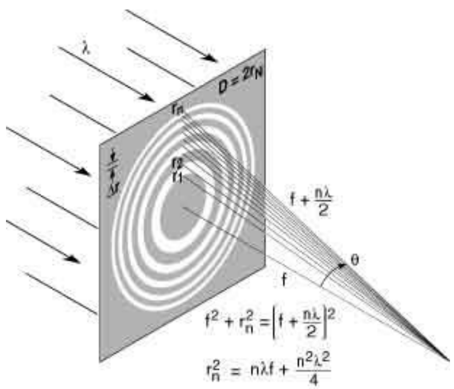
- Beam ionises gas molecules, ions are extracted by electric field
- Sufficiently thin gas jet would allow 2D image: if not used as a gas scanner
- Initial forwards momentum of gas jet separates gas jet ions from residual gas ions





Gas-jet R&D with ULIV

- Matter-wave focusing for a thin gas jet (down to Tens of micrometers) – Fresnel Zone plate principle



- The path difference between each successive light ring is equal to 1 wavelength (at the focal point) constructive interference.
- Each zone is equal in area
- Focal spot size is roughly the width of the narrowest (outer) zone
- Compared to traditional lens: no spherical aberration, large chromatic aberration

- Design (ZEMAX) and fabrication of **Apodised Photon Sieve** reduces higher order diffraction, increases central maximum