HiRadMat
High-Radiation to Materials

Beam Instrumentation developments at HiRadMat

T. Lefevre on behalf of the BI Team involved

Thanks to the contributions of J. Albertone, M. Bergamaschi, C. Boccard, T. Bogey, S. Burger, A. Curcio, L. Jensen, R. Kieffer, M. Krupa, S. Mazzoni, A. Sounas, A. Topaloudis, E. Senes, M. Turner and M. Wendt

International HiRadMat Workshop, 10-12 July 2019, CERN

Outline

- Existing beam instrumentation
- Beam instrumentation R&D
  - Test-stand
  - Example of future developments
- Conclusions

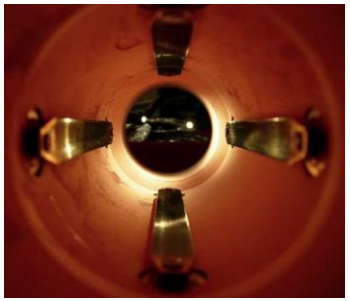
BI close to experiments

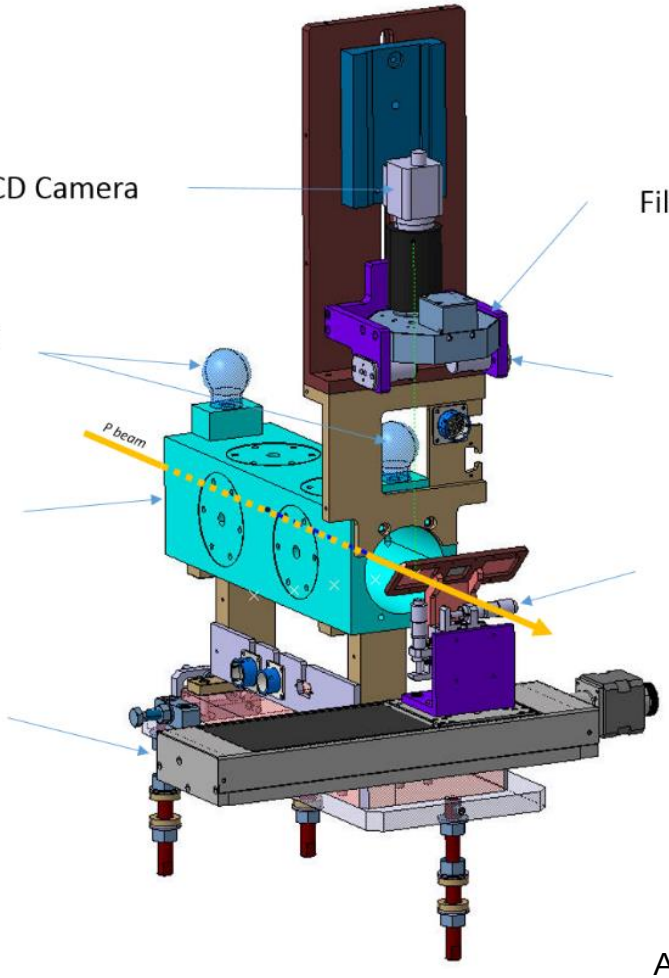
In October 2014, a request came to improve the Beam monitoring at experiment

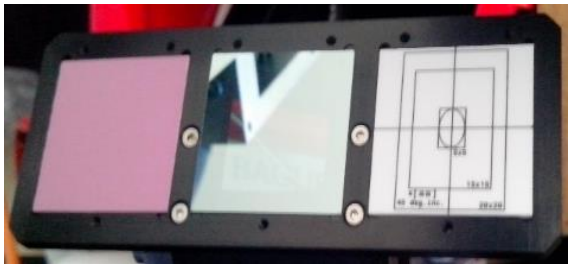
- Motivation :
  - Measure the Beam position w.r.t experiments better than 0.1mm
  - Measure shot-to-shot beam position fluctuations
  - Measure transverse beam size on target

- Decided to built a combined BTV/BPM station
  - 3 ensembles built and mounted on HiRadMat experiments

BTV/BPM assembly

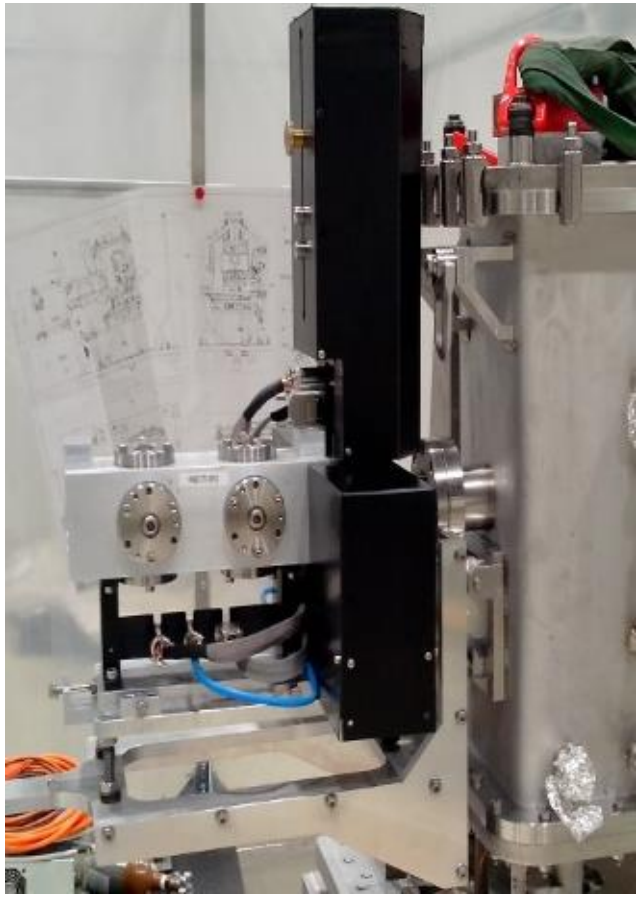






Al_2O_3:CrO_2, SiC and Al2O3 (target) screens

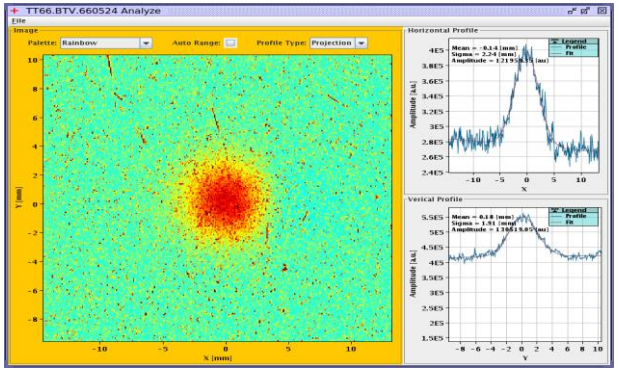
BTV/BPM assembly



- BTV is used for setting up and absolute calibration
  - Calibration Screen pre-aligned to the experiments on surface – Used for reference
  - Offset between BTV and BPKG measured using low beam intensities
- BPM providing bunch-by-bunch on-line measurements up to highest beam intensities
- No beam profile for high intensity beams

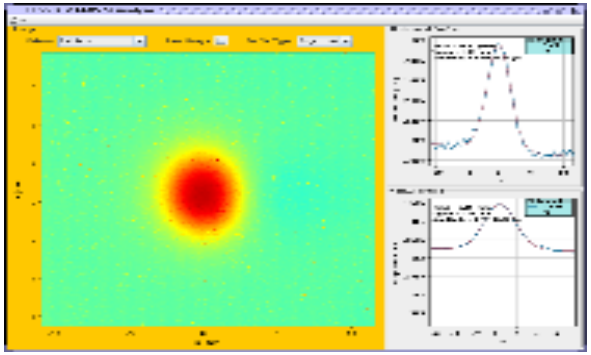
Particle showers affecting BTV

- Scintillating screen - Image acquired synchronously with beam



back-scatterred shower from the target

- Scintillating screen - Image acquired with 100ms delay after beam passage

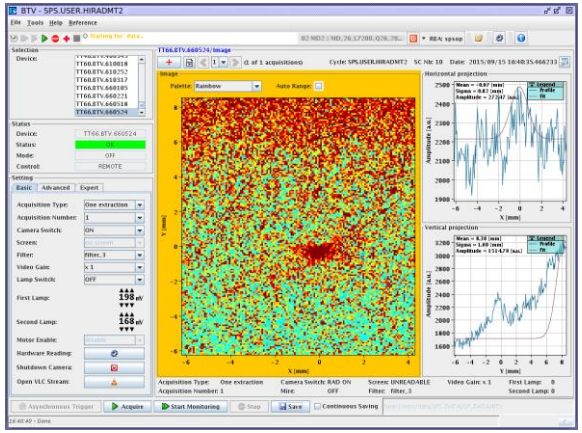


- No noise on the image
- Observing the light emitted during the decay time of the screen

- Scintillating screen - $Al_2O_3:CrO_2$
  - Non linearity above 1E12 p/mm²
  - Damage above 1E13 p/mm²

Particle showers affecting BTV

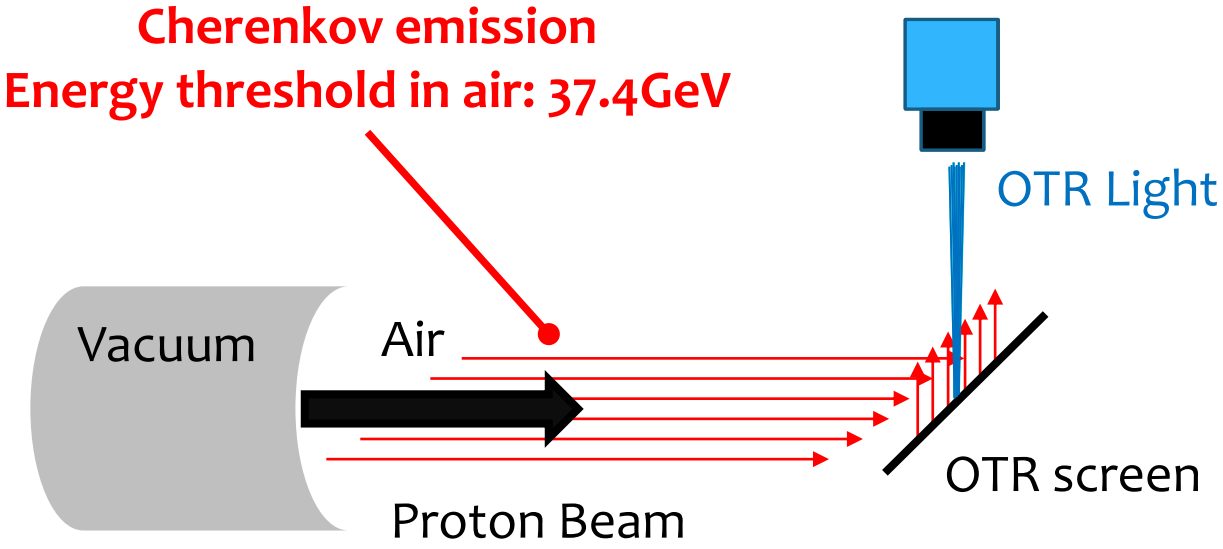
- **Use of OTR screens** is limited as acquisition must be synchronized with beam (backscattering particles gives high background on camera !)



12 bunches (1.2E12p)
SiC screen
T 0.001%

Cherenkov background in -air

- Strong background from Cherenkov light emitted in air



Cherenkov background in -air

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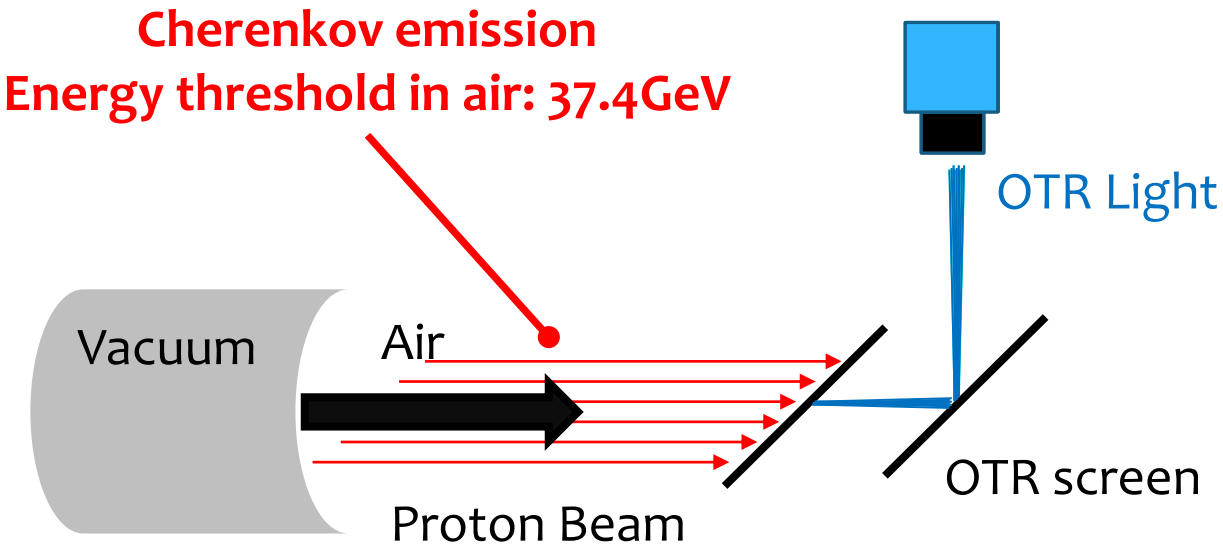

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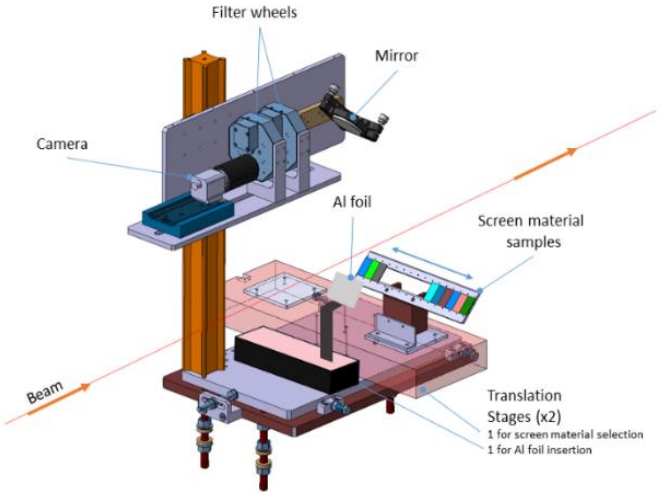
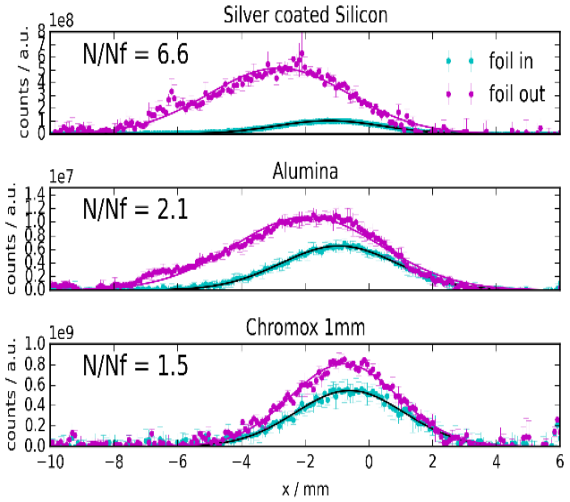




Oct 2015 – HRMT30

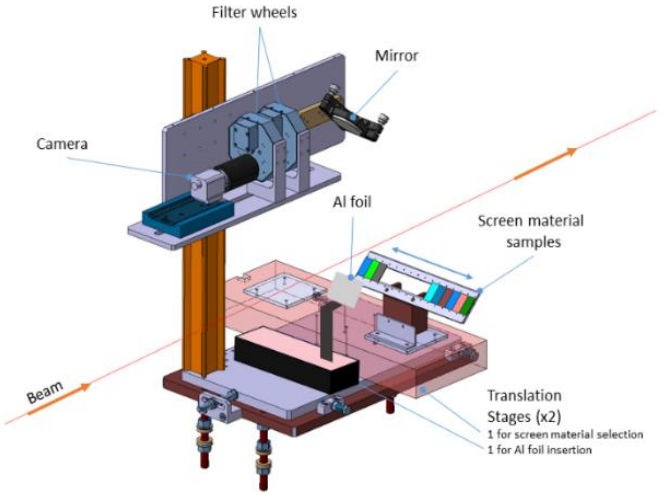
June 2016 – HRMT32

*** SCINTILLATION AND OTR SCREEN CHARACTERIZATION WITH A 440 GEV/C PROTON BEAM IN AIR AT THE CERN HIRADMAT FACILITY**

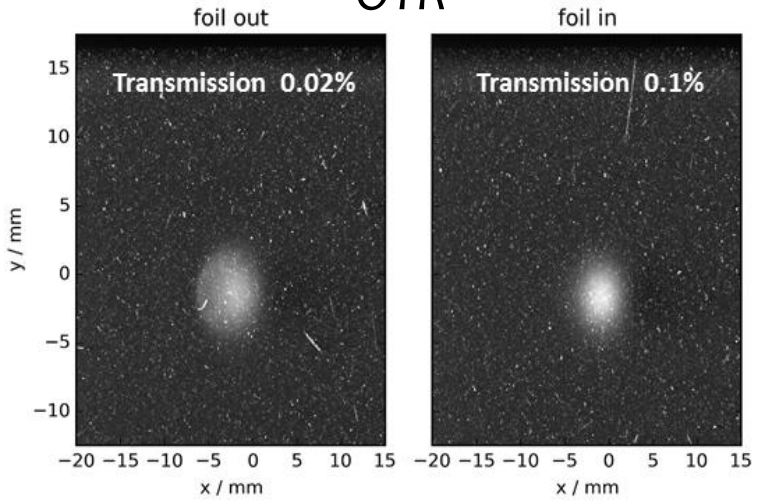
S. Burger†, M.Turner[2], B. Biskup[1], S.Mazzoni, CERN, Geneva, Switzerland
[1]also at Czech Technical University, Prague, Czech Republic
[2]also at Graz University of Technology Theoretical Physics Institute, Vienna, Austria

Cherenkov background in -air

- Strong background from Cherenkov light emitted in air



OTR



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BPM Performance

- Some issues observed in fall 2015 when testing high-Z targets
  - Traced to be due to backscattered particles affecting the electronic
  - Mitigation found by relocating the electronic in a radiation safe zone during YETS 2015-2016

- Still some perturbations observed on the beam position signal resulting in large fluctuations in the BPM readings (±mm)

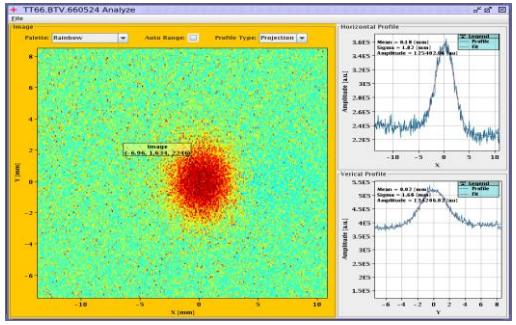
BPM Performance

* Some issues observed in 201[illegible]h-Z target
  * Traced to be du[illegible]ing the electronic
  * Miti[illegible]adiation safe zon[illegible]
* Still son[illegible]bserved on the beam position signal resulting[illegible]e fluctuations in the BPM readings

Development of a BTV system capable of measuring in all beam conditions
Small beam size at high intensities

BTV for all beam conditions

- Long optical line to install the camera in a radiation-friendly location (showers and ageing)

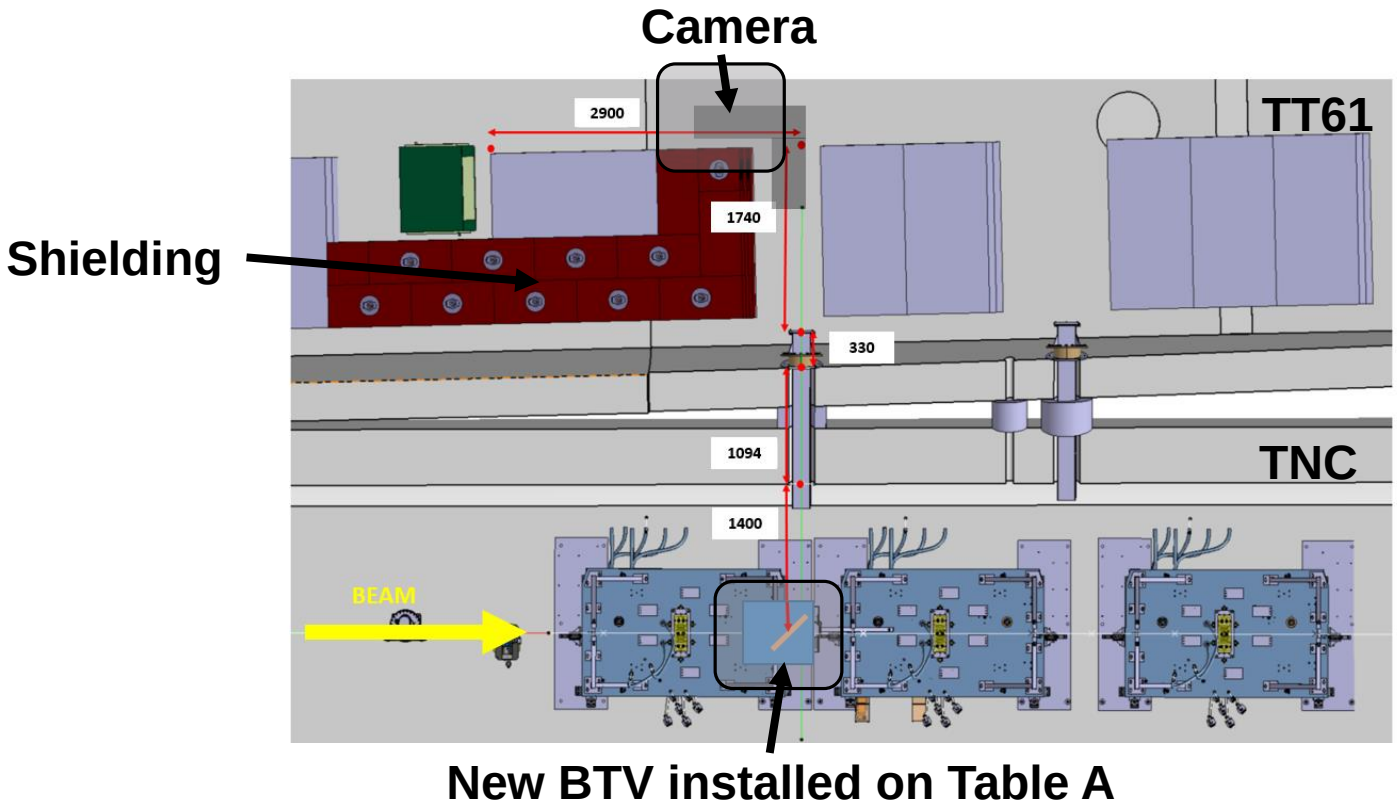


Aging of the Camera damaged by radiation by the end of HRMT27

- Thermal resistant OTR screen in primary vacuum to suppress Cherenkov background light (<10^{-3} Torr)

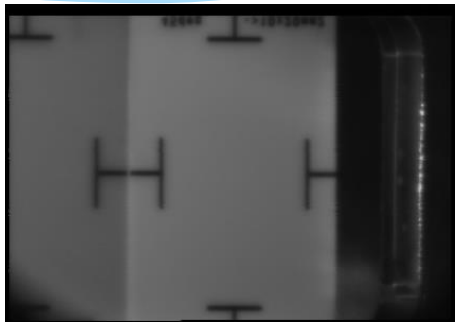
BTV for all beam conditions

- Camera installed in TT61 parallel tunnel

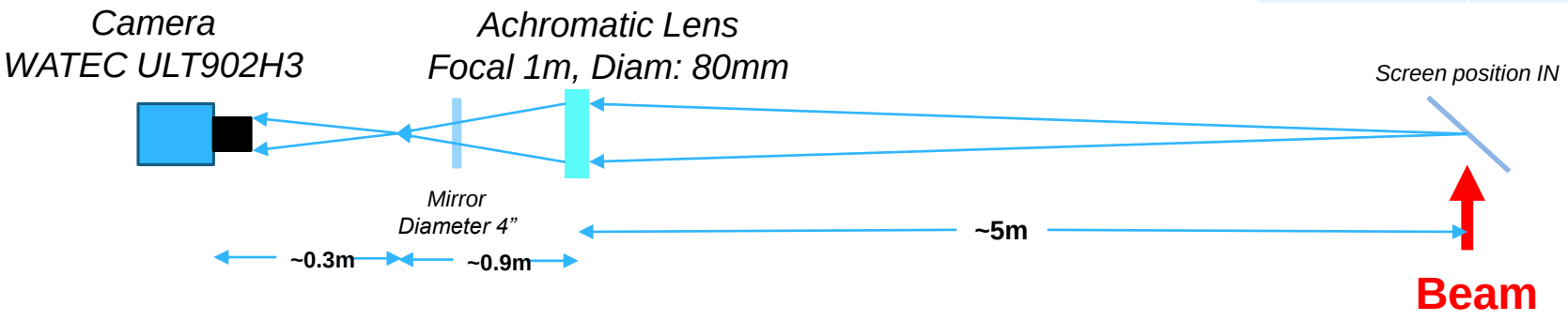


BTV for all beam conditions

- > 5m long optical line
- Optical magnification 0.2

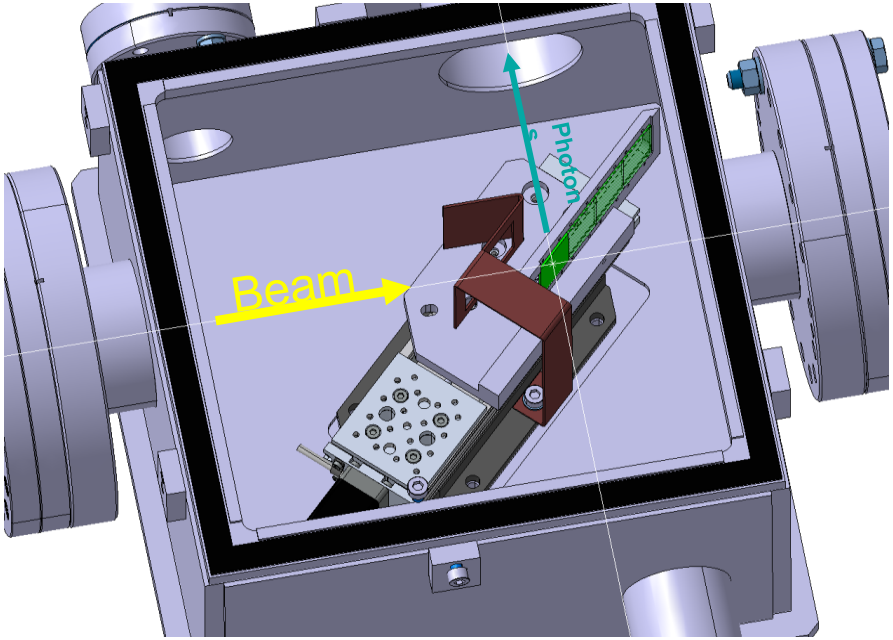


Resolution [um/px]	
Horizontal	72
Vertical	79

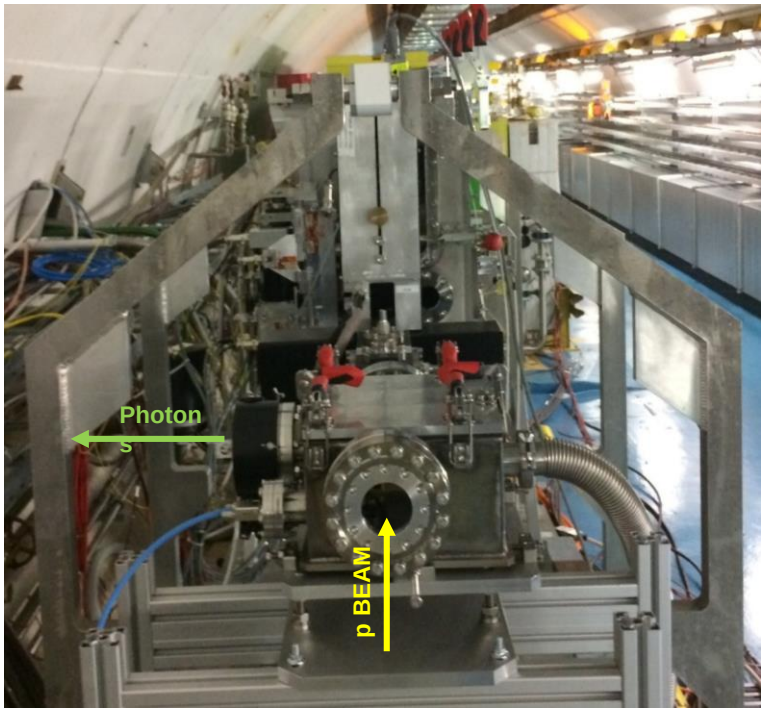


BTV for all beam conditions

Image from V. Clerc

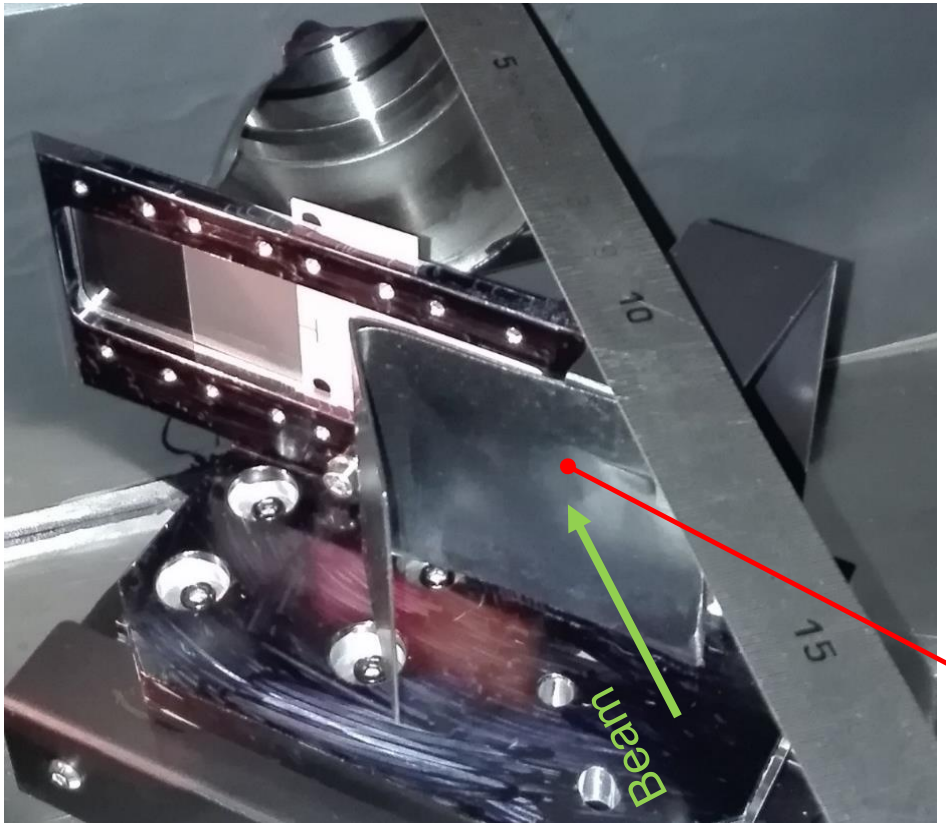


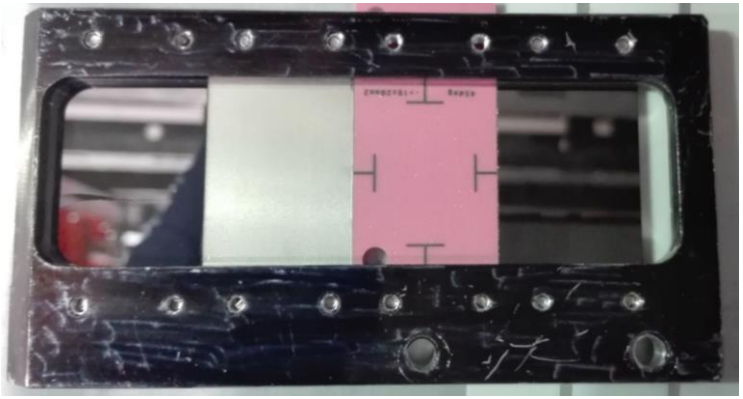
CATIA 3D drawing of the new BTV for HRM



Installation of the new BTV HRM from 2017 Located end of experimental table A

BTV for all beam conditions





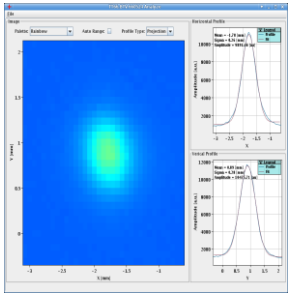
SiC 0.5mm | Ti 0.1mm | Chromox 0.5mm | Sigradur G Glassy C 0.5mm

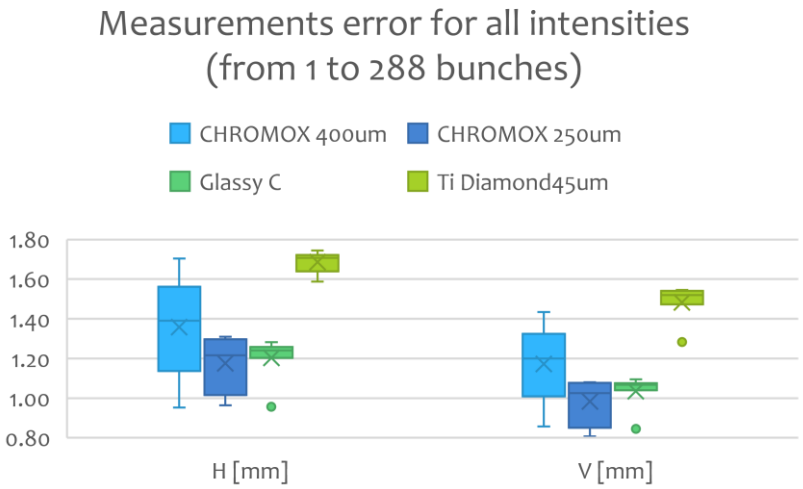
Fixed 75um Carbon foil

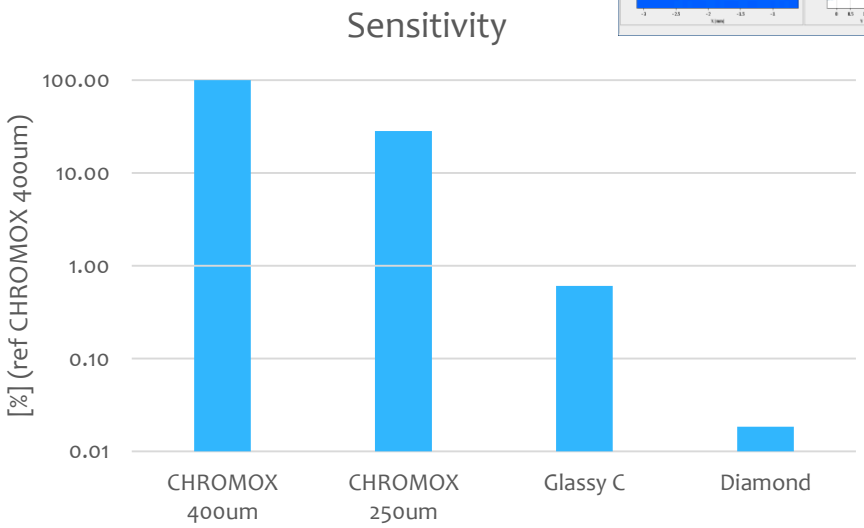
BTV for all beam conditions

- SiC broken after 3 impacts at full beam power density

  288 bunches at 1E11 with σ_H = 0.26mm and σ_V = 0.28mm







BTV for all beam conditions

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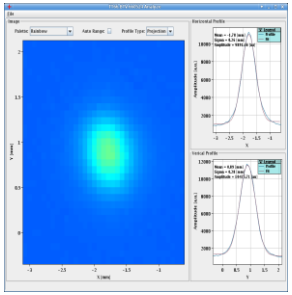
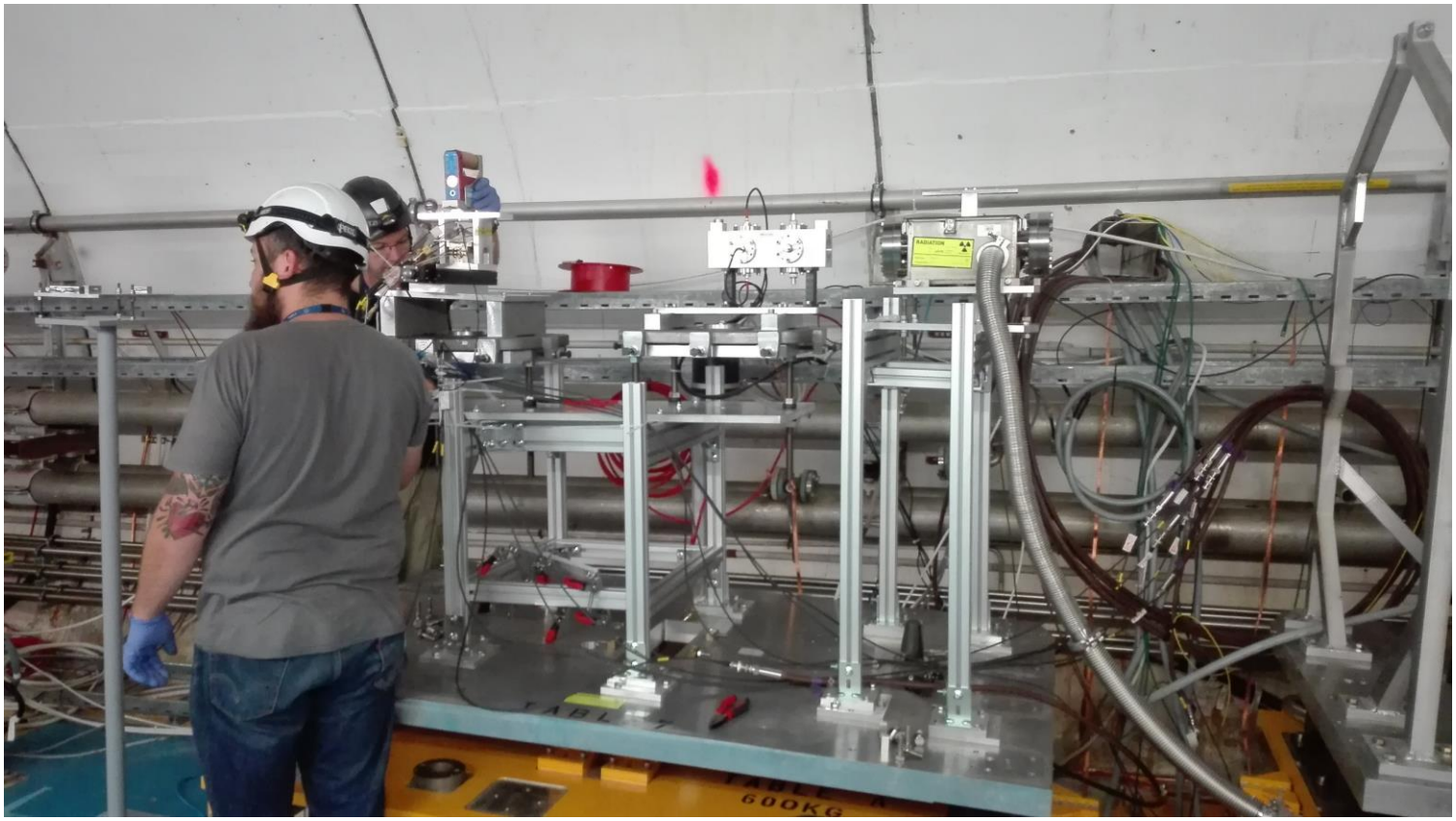


- Glassy C has shown reliable measurements down to smallest beam sizes of 0.25mm
  - Systematic over-estimation due to Forward OTR from blocking foil simulated using ZEMAX to be less than 10%

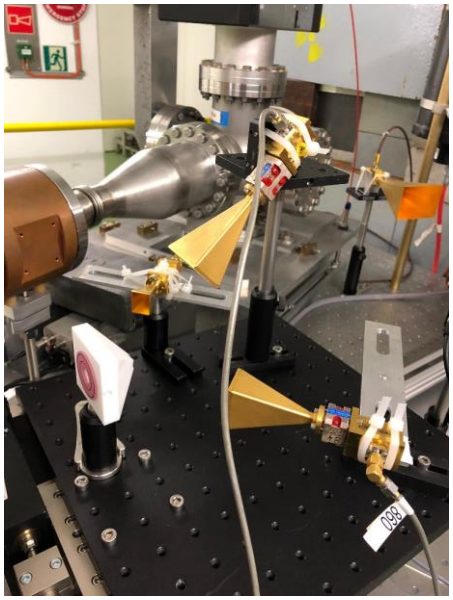
BI developments at HiRadMat

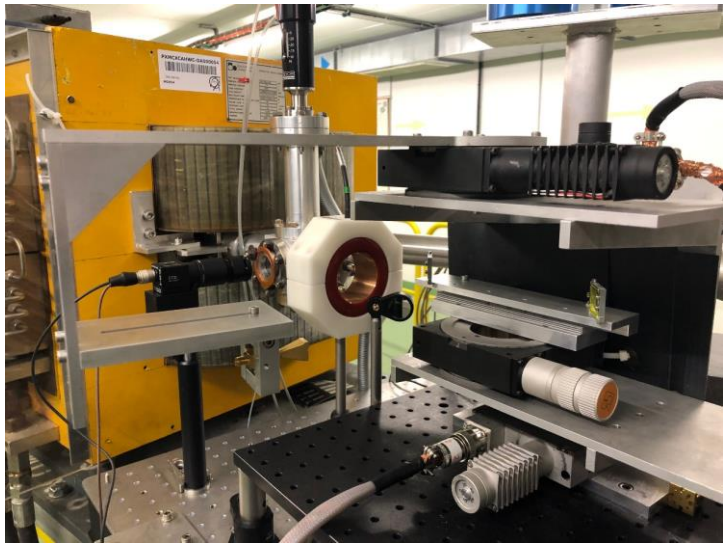
BI developments at HiRadMat

Using Table a as an in-air BI test-stand



BI developments at HiRadMat



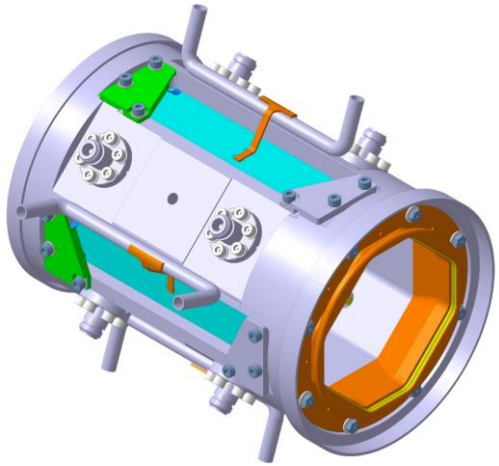


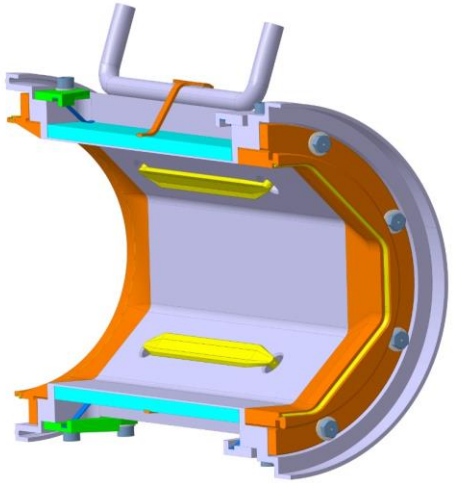
1m long in-air testing area on CLEAR/CERN (200MeV electrons – low charge)

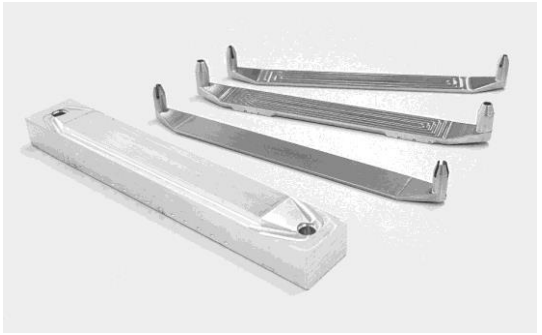
- Equipped with beam position monitor and Screen/camera
- Equipped with movers and motor controller

BI developments at HiRadMat

- Testing Directivity of Hilumi **new cold Stripline BPM**
  - Expected directivity better than > 25dB



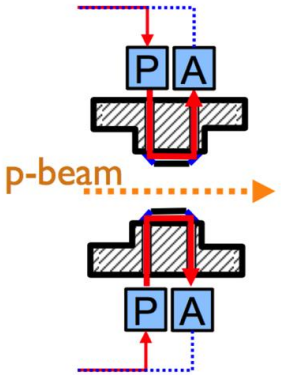


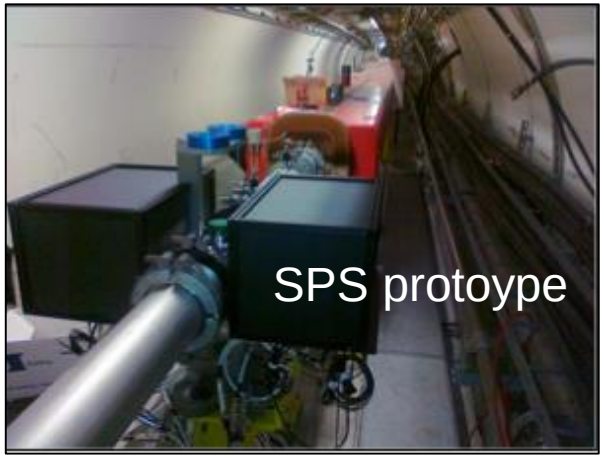


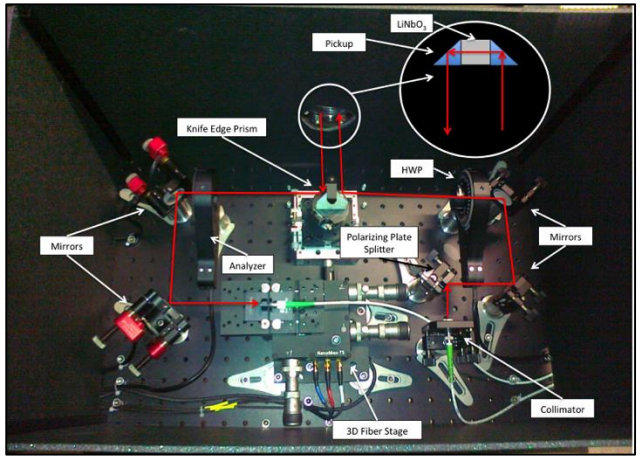
  - Prototype under fabrication

BI developments at HiRadMat

- Testing **Electro-optical BPM for Hilumi**
  - Prototype tested in SPS for measuring intrabunch instability





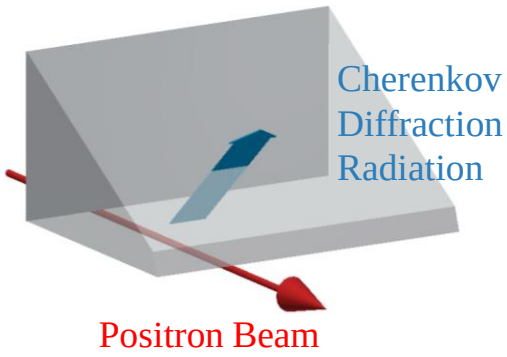


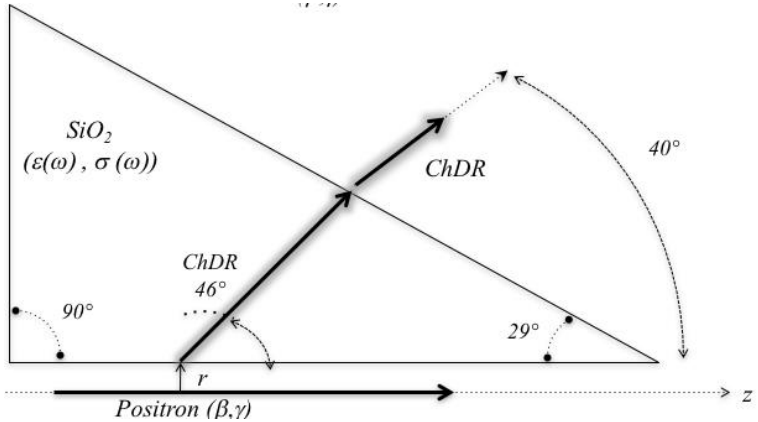
  - New compact design underway – prototype expected in 2020

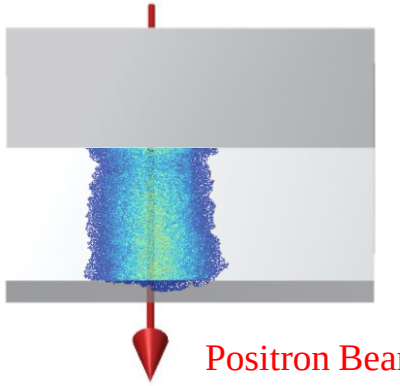
BI developments at HiRadMat

- R&D on Incoherent Cherenkov-Diffraction Radiation
  - Beam profile monitoring for highly relativistic particles

5.3GeV Positrons at CESR propagating at 3mm from the surface of a 2cm long fused silica prism



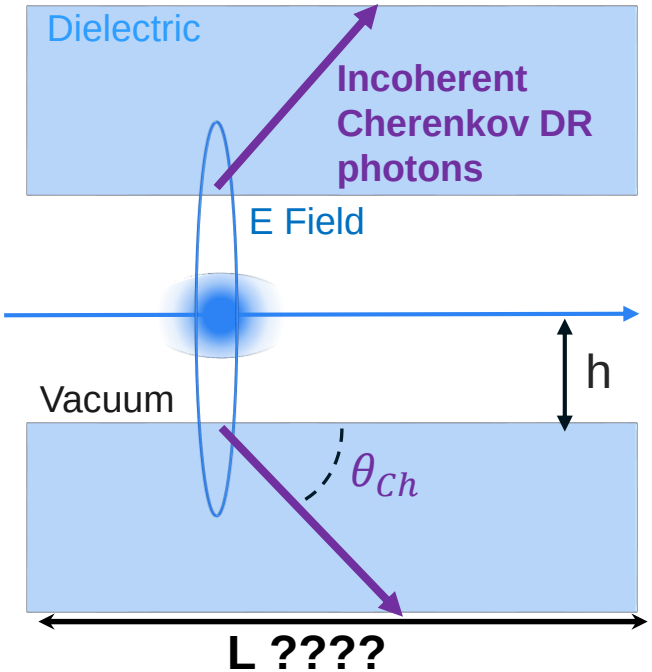




*R. Kieffer et al., "Direct Observation of Incoherent Cherenkov Diffraction Radiation in the Visible Range", PRL **121** (2018) 054802*

BI developments at HiRadMat

- R&D on Incoherent Cherenkov-Diffraction Radiation
  - Beam position monitoring in long(er) dielectrics

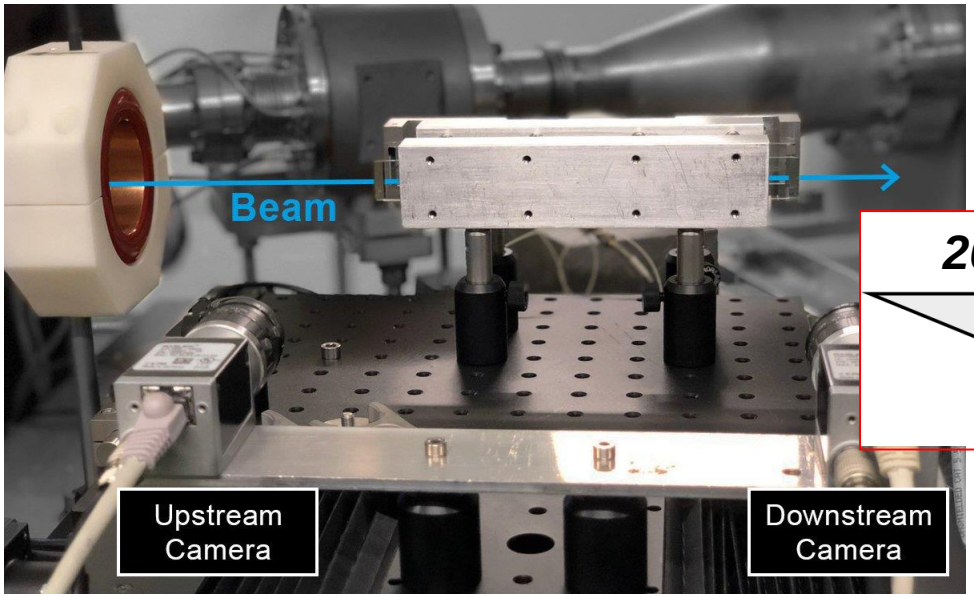


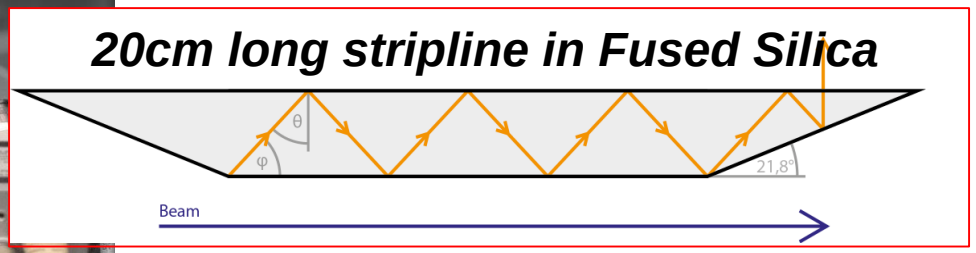
Motivation

- Increasing the photon yield to detect particles sitting at **larger distances (h > 1cm)**
- Investigating measuring ChDR in longer wavelength **(NIR)** for **low(er) beam energies** (e^- @200MeV or H^+@400GeV)

BI developments at HiRadMat

- R&D on Incoherent Cherenkov-Diffraction Radiation
  - Beam position monitoring in long(er) dielectrics

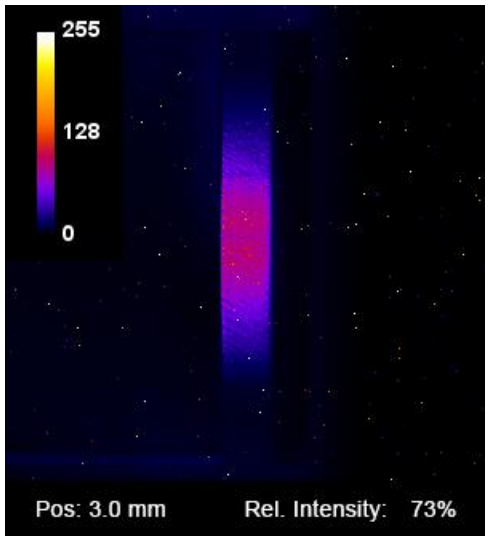


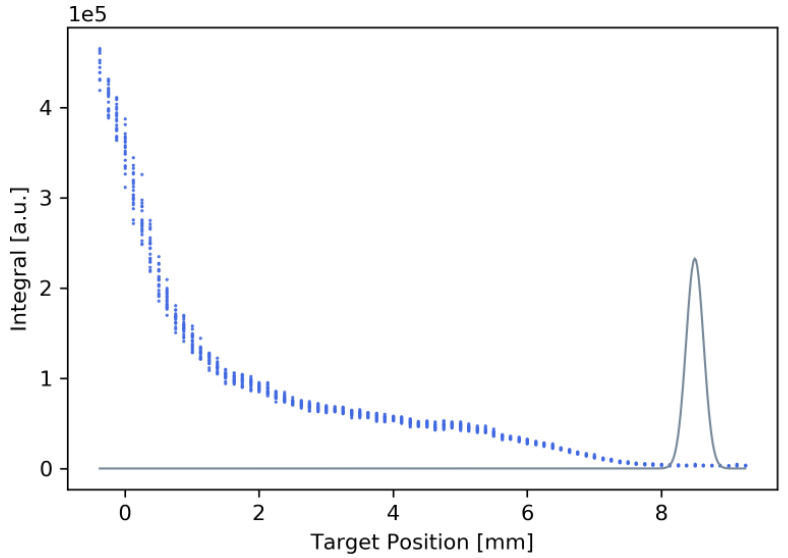


BI developments at HiRadMat

- R&D on Incoherent Cherenkov-Diffraction Radiation
  - Beam position monitoring in long(er) dielectrics

First test in dec. 2018 at CLEAR using a train of 50pC electron bunches (1nC total)

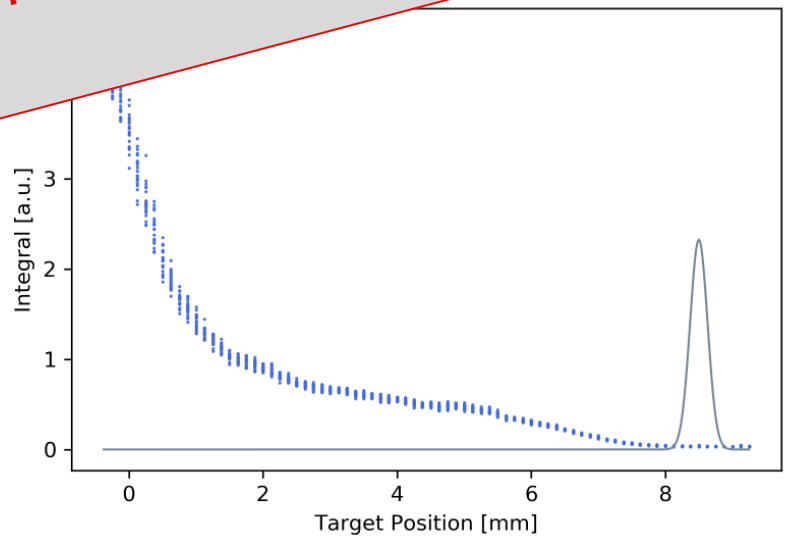




BI developments at HiRadMat

- R&D on Incoherent Cherenkov-Diffra
  - Beam position monitori

R&D for high energy collider studies (LC or FCC)
But also instrumentation for crystal collimator @ LHC



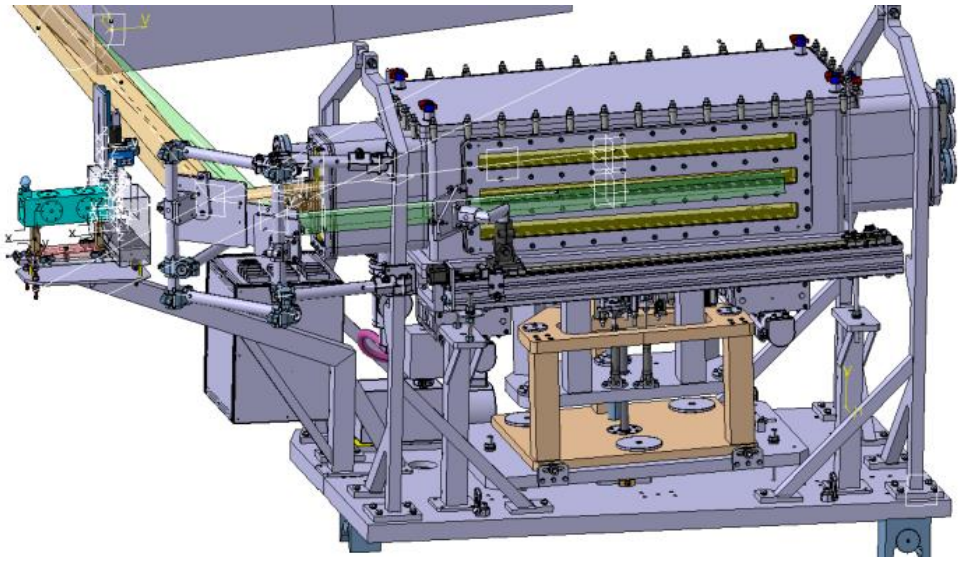
Conclusions

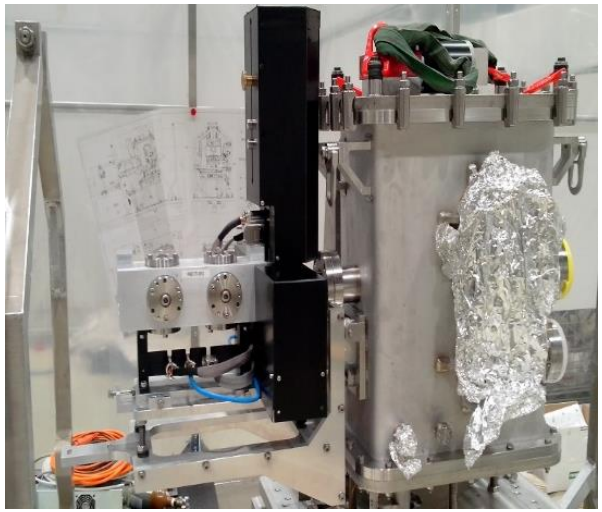
- Since 2014, significant improvements in measuring high intensity beam properties in HiRadMat
- Very useful R&D performed already on screen and imaging systems (Many thanks to the HiRadMat team for help and support)
- Instrumenting Table A with an in-air test-stand is an efficient and unique opportunity for beam instrumentation developments !
- Most of the testing can be run almost parasitically to other HiRadMat experiments.
- LoI under preparation

Thanks for your attention

Many Thanks to all colleagues involved !

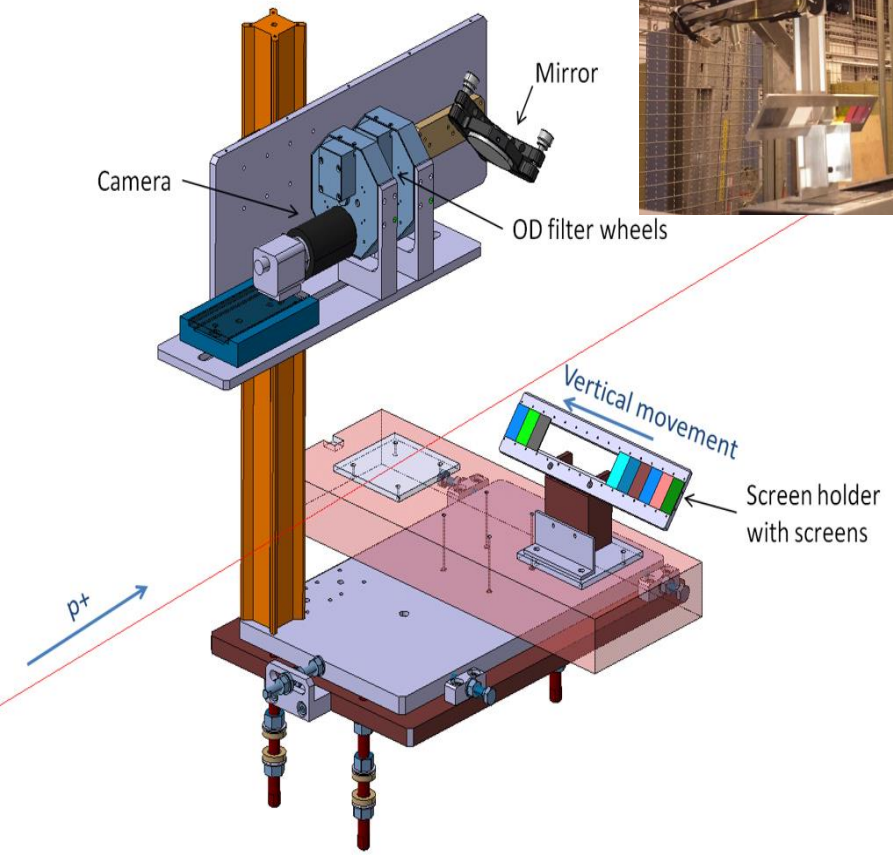
BTV/BPKG assembly



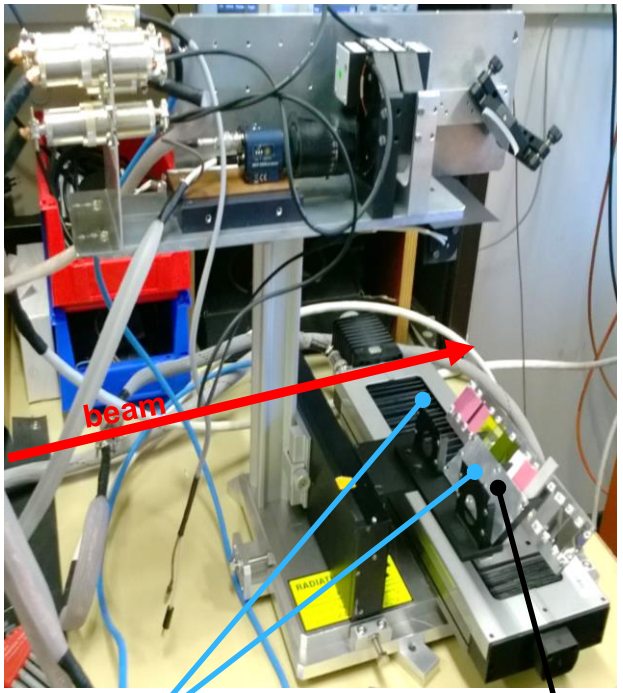


Measurement setup

Oct 2015 – HRMT30



June 2016 – HRMT32

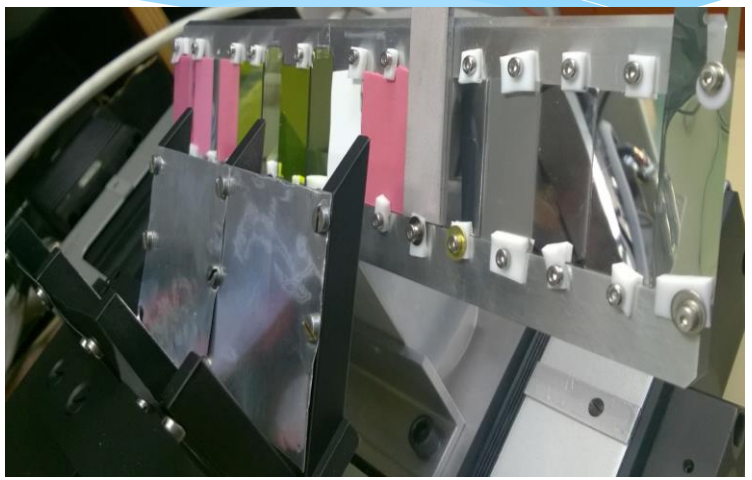


Screens tested

* Scintillator:
  * Alumina (Al_2O_3) – Purity: 96% & 99%
  * Chromox (Al_2O_3:Cr_2O_3)

  thicknesses: 3 mm, 1 mm, 0.5 mm
  * YAG – thicknesses: 0.1 mm, 0.5 mm

  both coated and uncoated
* OTR
  * Titanium, Aluminium, Silicon coated by aluminium & silver

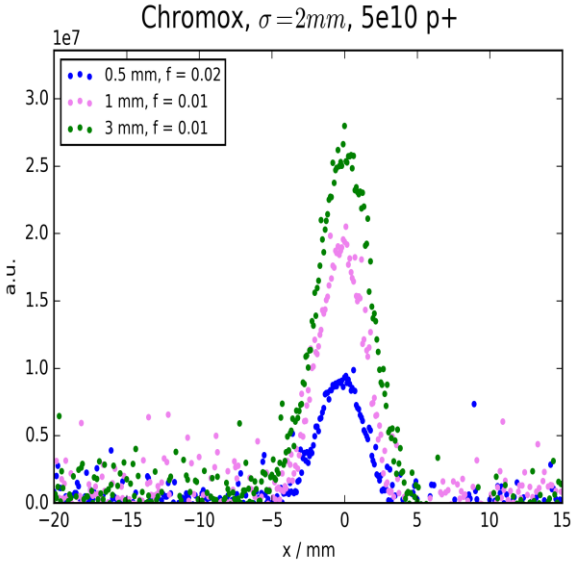


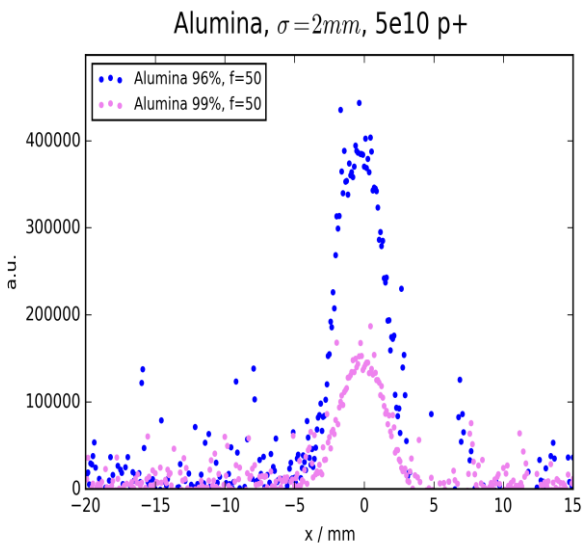
SCREEN Setup HRM 2016_06

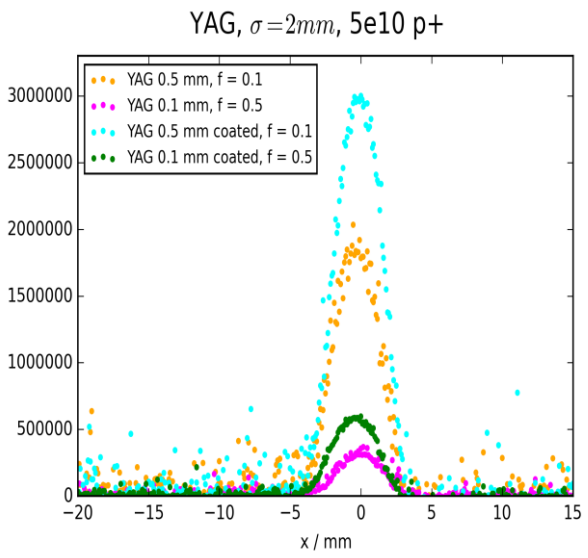
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Material	[mm]	No	Chromox*	Chromox*	Al	Chromox*	YAG:Ce	YAG:Ce	YAG:Ce	YAG:Ce	Alumina**	Chromox***	Al	Al	Ti	Si	Si	SS
Coating			-	-	-	-	-	-	Al	Al	-	-	Chromox	-	-	Al	Ag	
Width	[mm]	30	15	15	5	15	17	12.2	17	12.2	16	21	14	12.5	15	15	15	13
Thickness	[mm]		3	1	1	0.5	0.5	0.1	0.5	0.1	0.5	1	0.045/0.15	1	0.1	0.25	0.3	0.02
Position	[mm]	0	37.5	52.5	62.5	72.5	88.5	103.1	117.7	132.3	146.4	164.9	182.4	195.65	209.4	224.4	239.4	253.4
Position******	[Step]	0	7500	10500	12500	14500	17700	20620	23540	26460	29280	32980	36480	39130	41880	44880	47880	50680
			7500	**10600**	**12580**	**14640**	**17600**	**20950**	**23700**	**26550**	**29500**	**33240**	**36800**	**39400**	**42250**	**45250**	**48250**	**55750 (end)**

Results (Nov. 15-HRMT30)

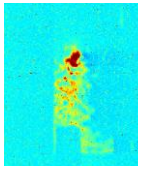
Different luminescent/scintillating screens



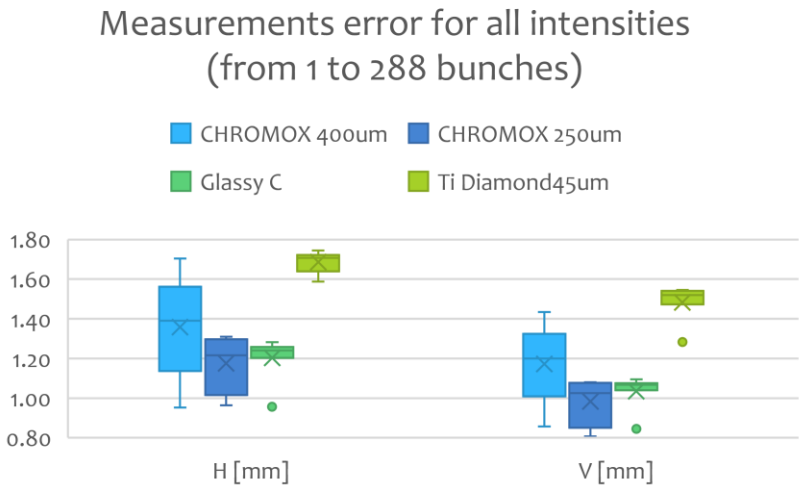


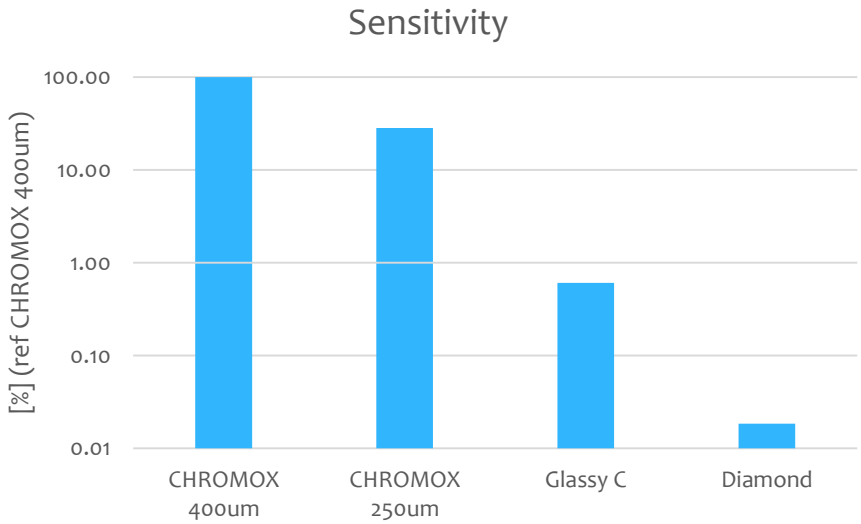


* Chromox 1 mm thick screen was chosen to be used for the AWAKE halo measurement (as the best compromise between a high light yield and sufficient resolution)
* For reflective OTR screens, measurements limited by some parasitic light of unknown origin (cherenkov in air ?)



BTV for all beam conditions





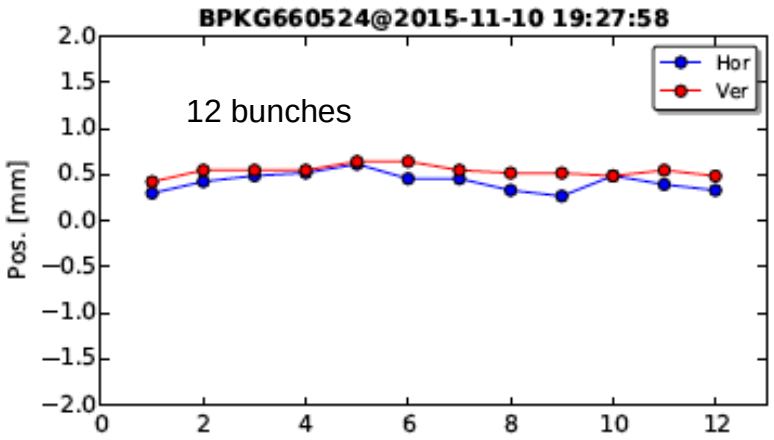
Issues with BPKG (1/4)

- Cross-calibration between BTV ad BPKG went well

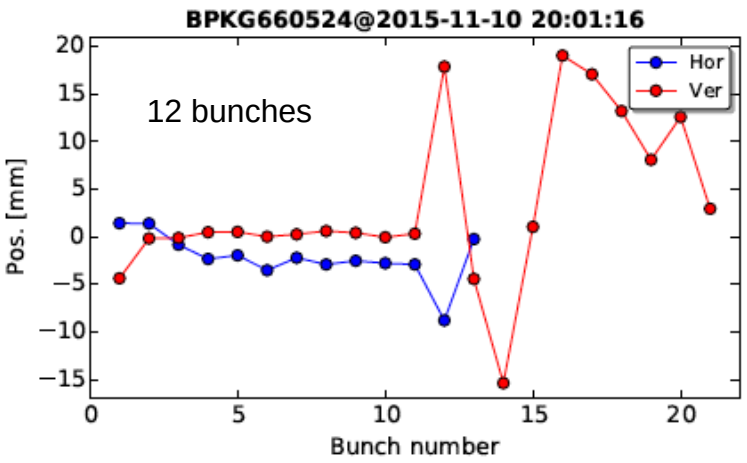
But we then discovered an issue while using long(er) bunch trains with large unreal beam offsets measured

Published BPM data is the average of the beam position of all bunches

Target out



Target in

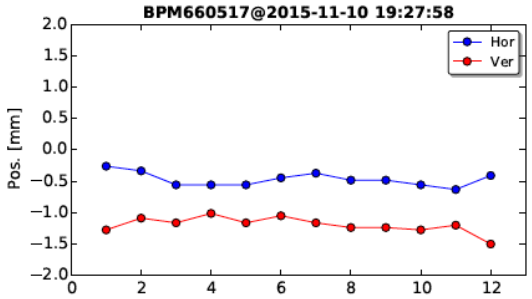


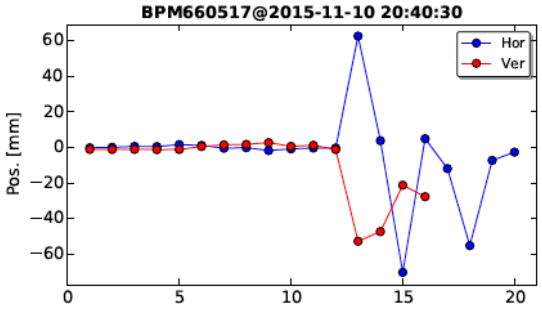
Issues with BPKG (2/4)

Target out

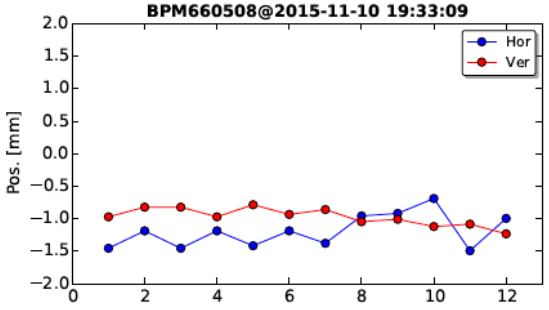
Target in

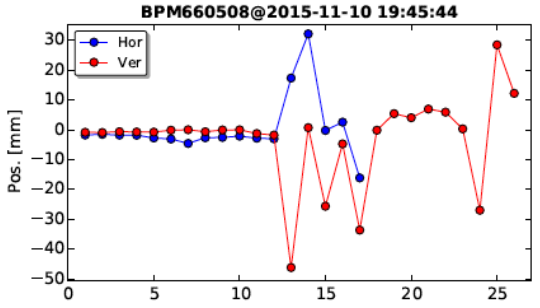
BPM517



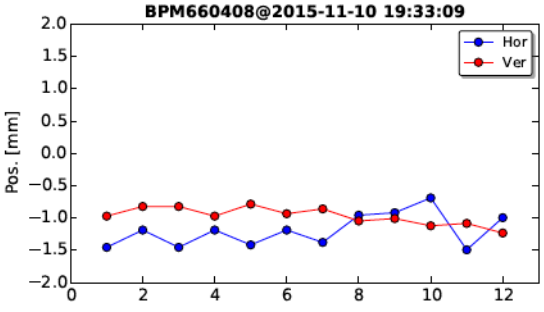


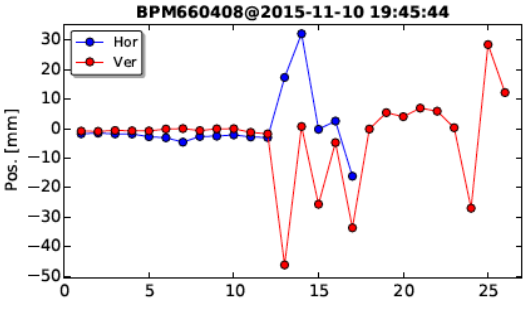
BPM508





BPM408

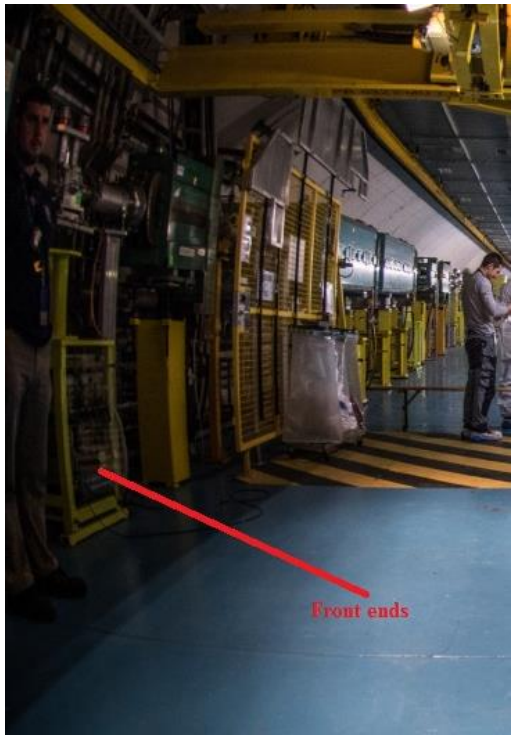




- Strong perturbations coming after the first 9 bunches
- Seen on all BPMs down to the BPM408 in TJ7

Issues with BPKG (3/4)

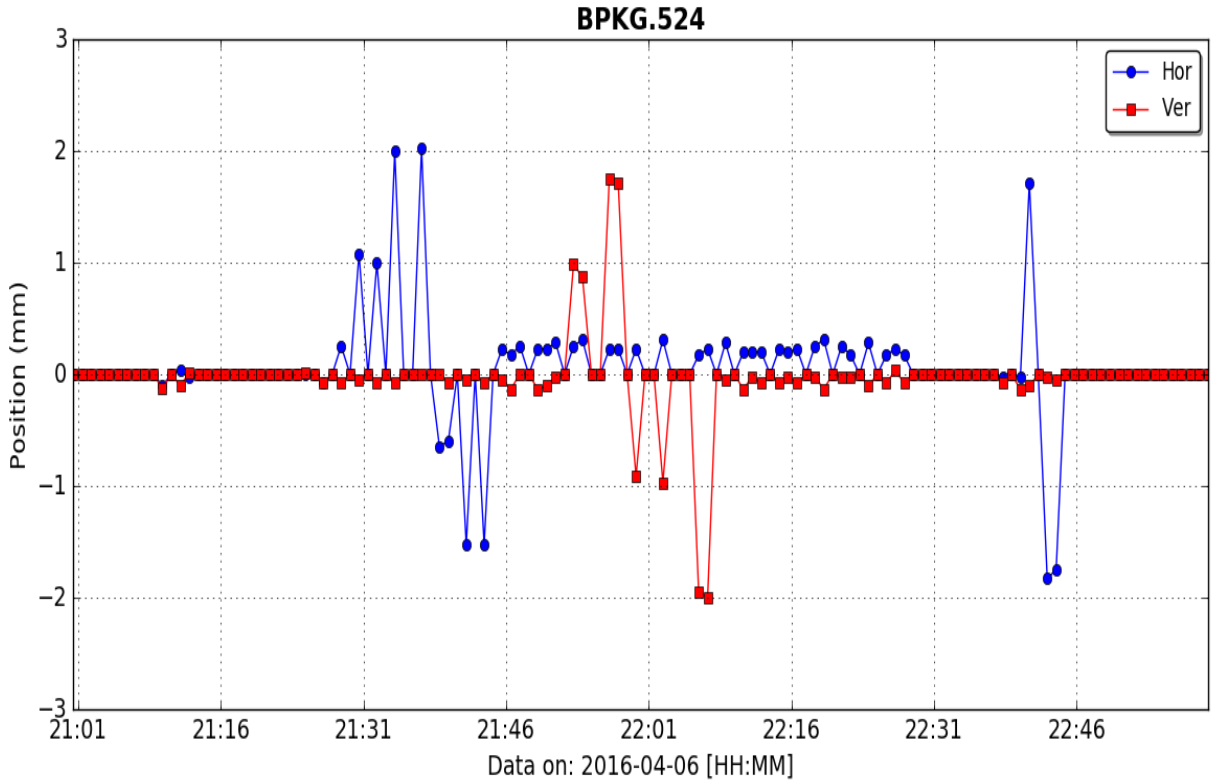
- The electronics of all these BPMs sit in TJ7 underneath the BPM408



- Perturbations compatible with backscattered shower affecting the electronic. *Confirmed by time of flight*
- *Relocation of BPM electronic in less exposed area*
  - *Tunnel access to TJ7*
  - *Done during EYETS 15-16*

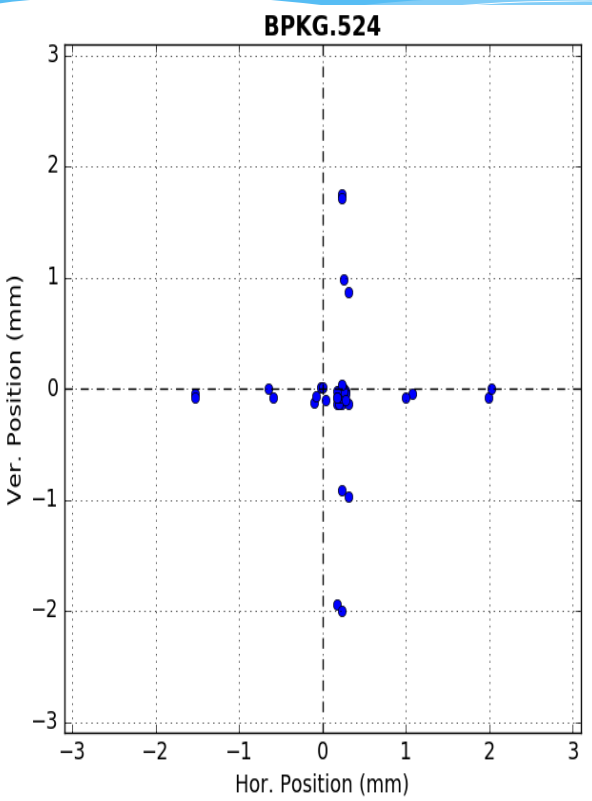
BTV/BPKG cross-calibration @HRMT28

- Cross-alignment between BPKG.524 & BTV.524
- Bumps ±1,2 mm
- Identifying central offsets and scaling issues



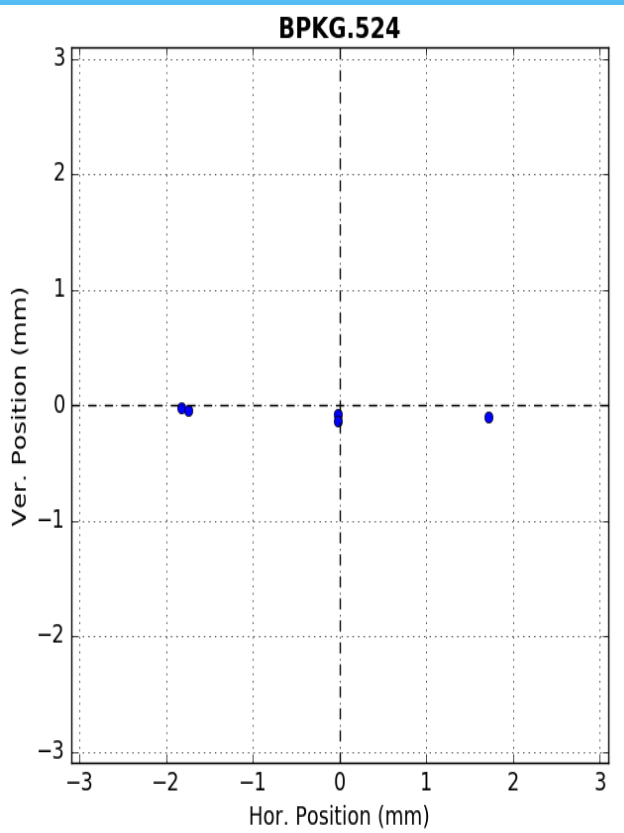
Intensity ~ 1e11 p

Correcting BPM geometrical offsets



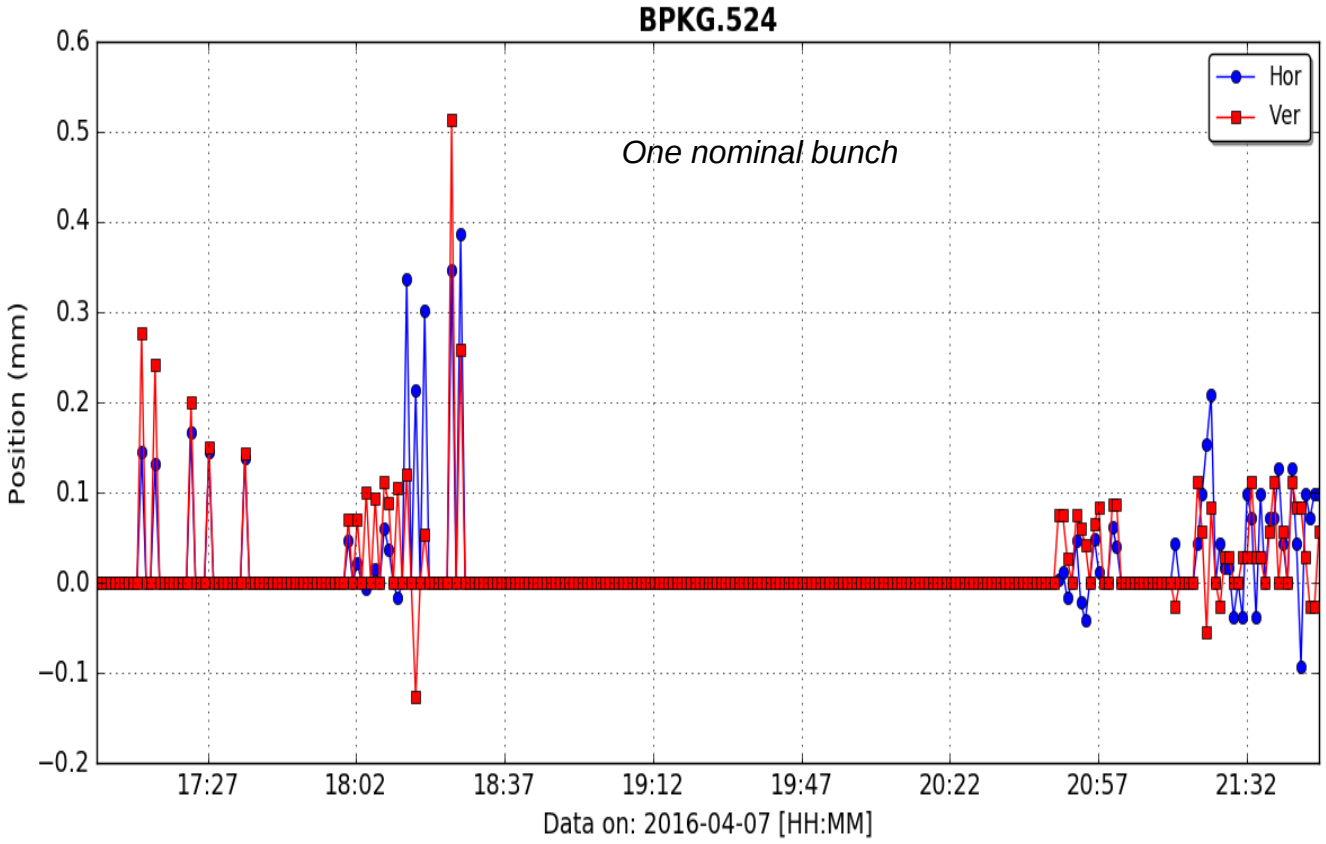
First shots before changing offsets

Offset on the horizontal position

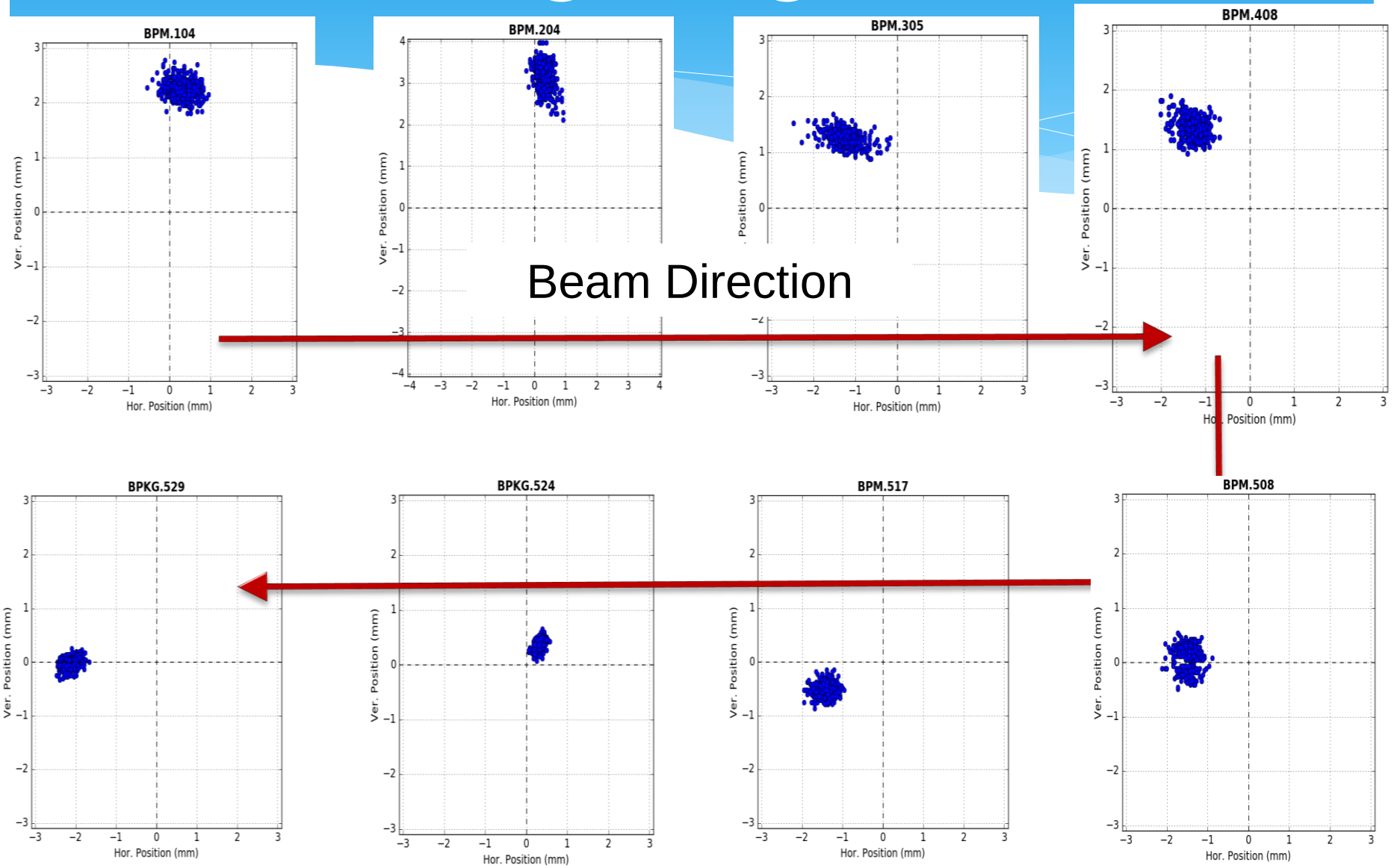


Shots after changing offsets

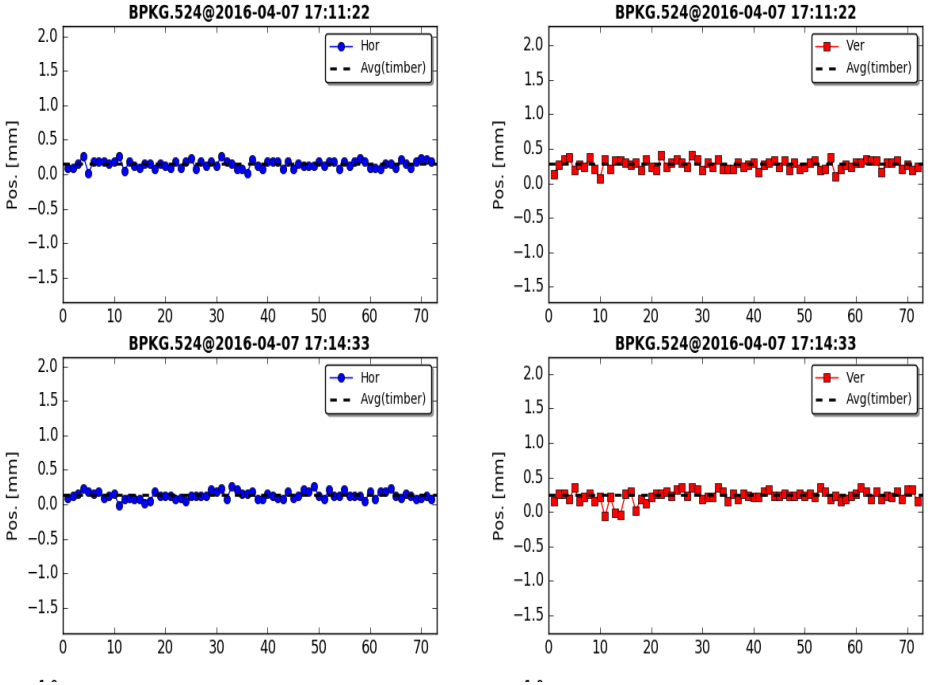
Reproducibility study



Steering along the line

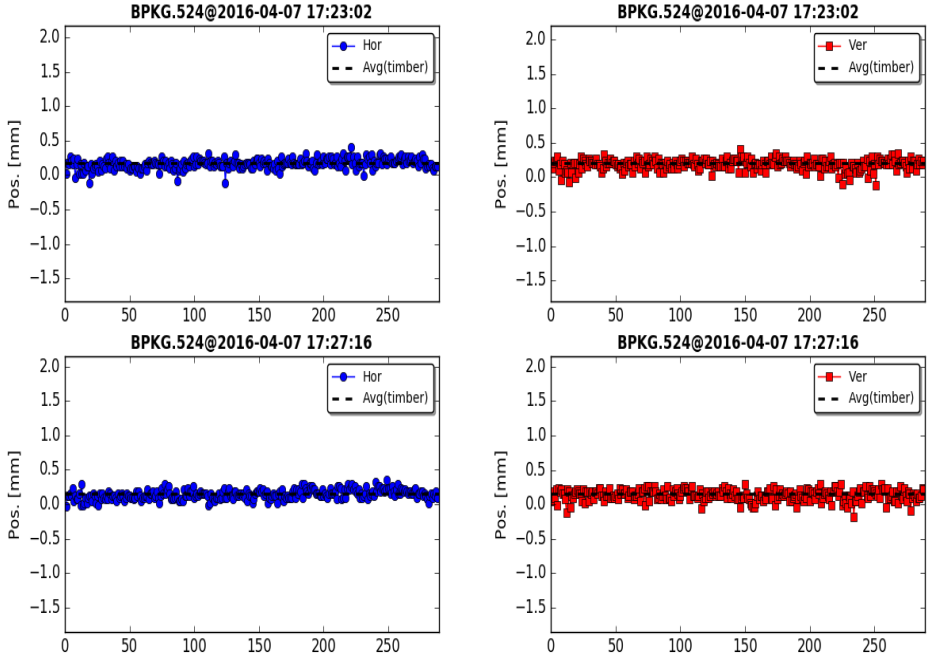


Reproducibility study – longer trains

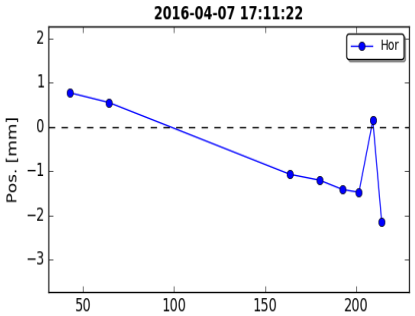


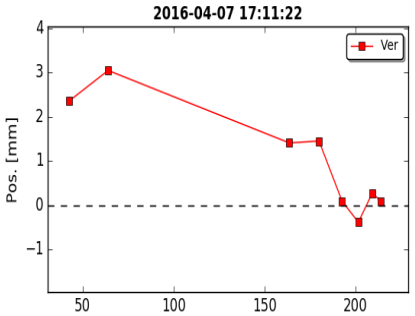
72 -bunches

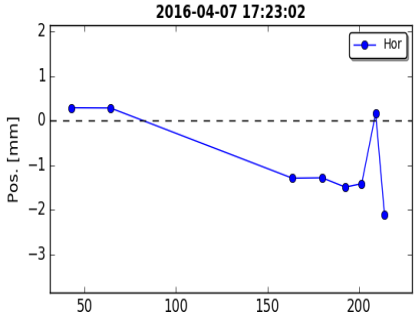
288 -bunches

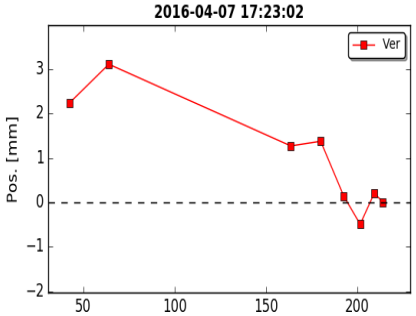


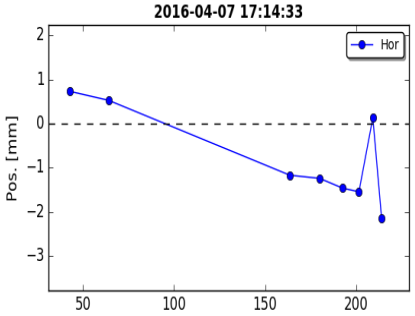
Steering along the line

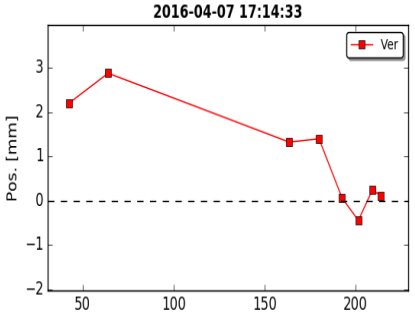


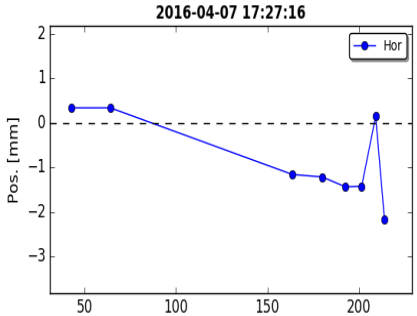


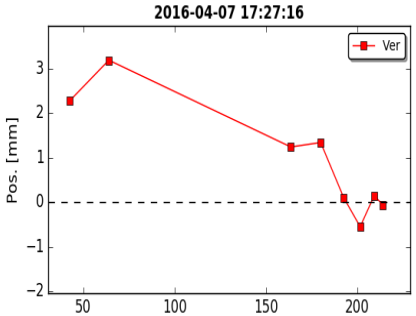












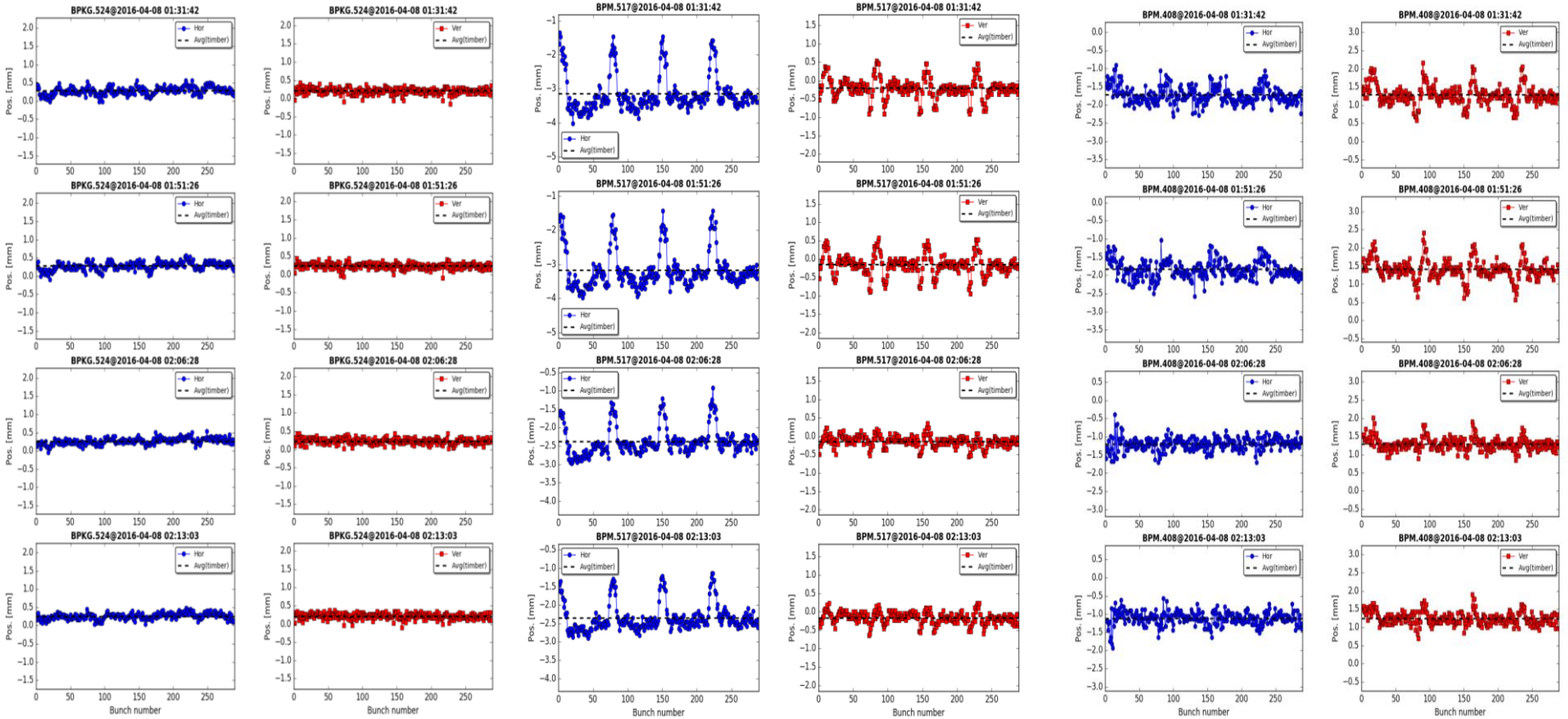
72 -bunches

288 -bunches

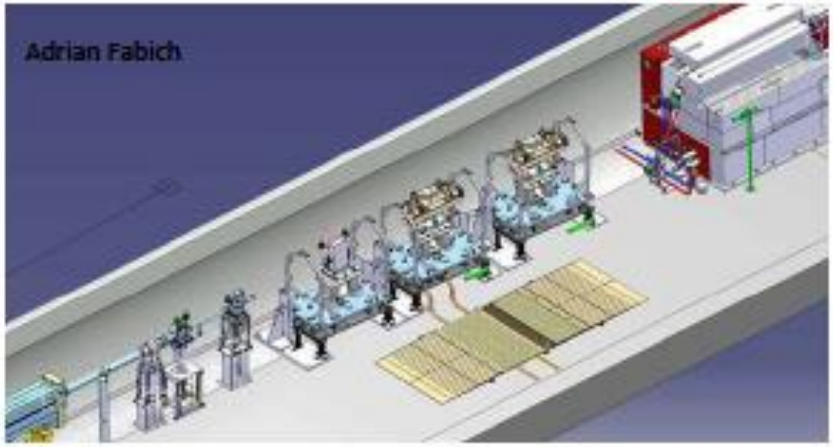
Test with Collimator in – long trains

No wrong reading anymore due to radiation effects

BPKG.524 **BPM.517** **BPM.408**



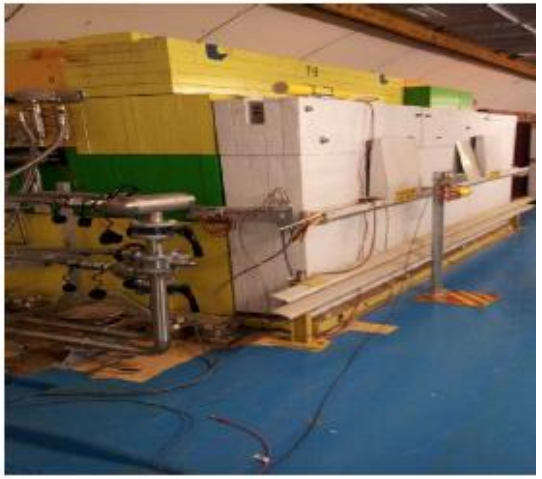
BLM test @ HRMT19-BLM2



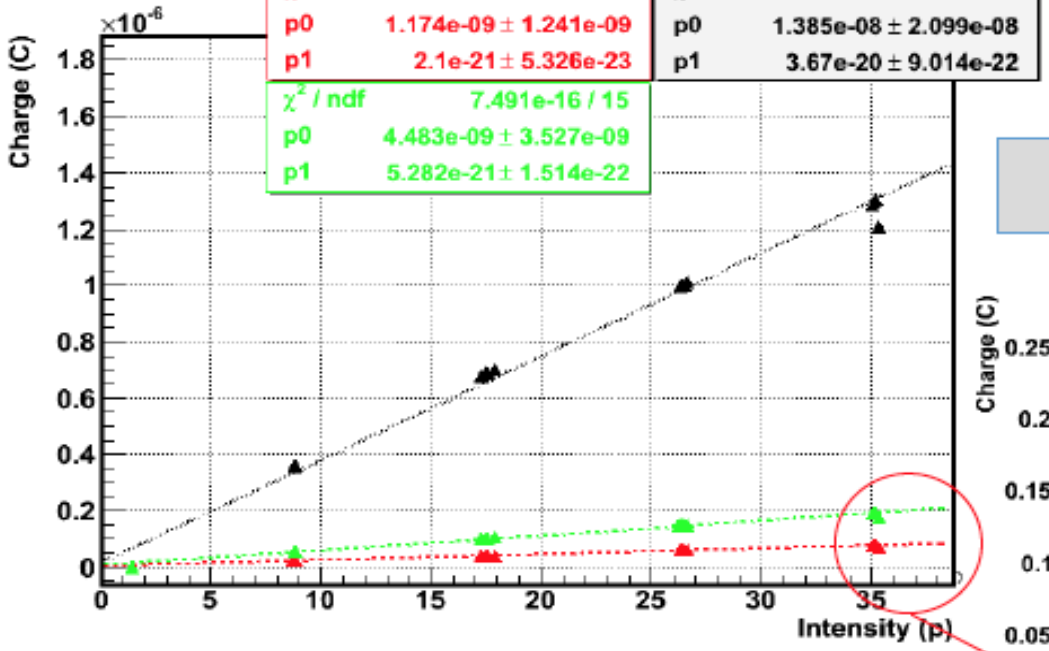
- LHC ionization chamber (IC) : 1.5l active vol.@ 1.1bar
- Little Ionization Chamber (LIC) : 0.05l active vol.@ 1.1bar for LHC in high losses region
- Flat Ionization Chamber (FIC) : 0.05l active vol.@ 1.1bar new detector for Booster

- Tested with 3-5 shots using respectively 1, 36, 72, 144, 216, 288 nominal bunches

- Measuring linearity and dynamic range



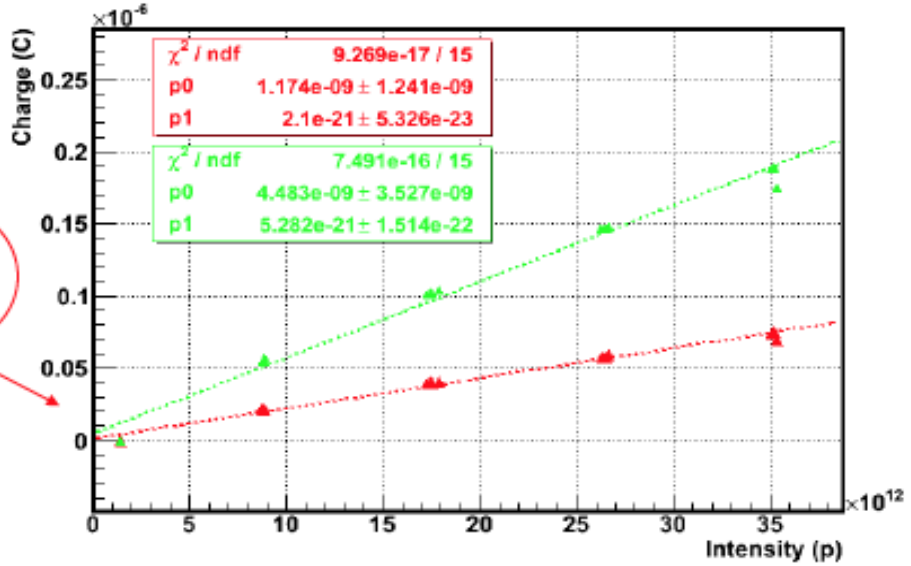
BLM test @ HRMT19-BLM2



green= FIC
red =LIC

Gain Ratio:
IC/FIC = 6.9
IC/LIC = 17.5

Results: 12,72,144,216,288 bunches

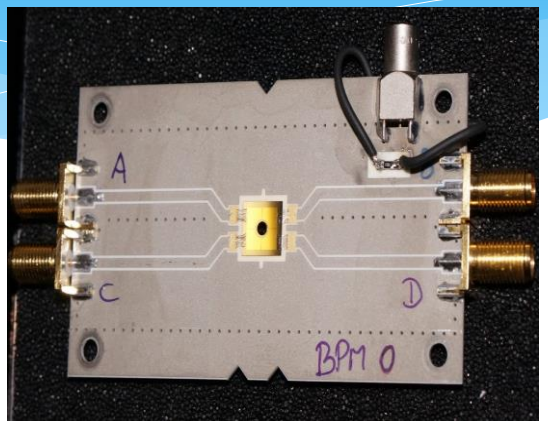


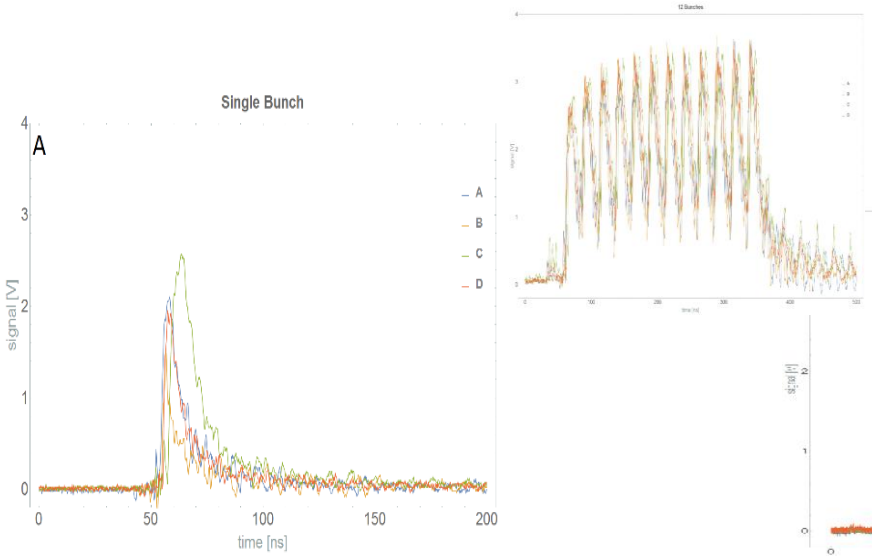
Linear dependence with intensity are in all chambers.

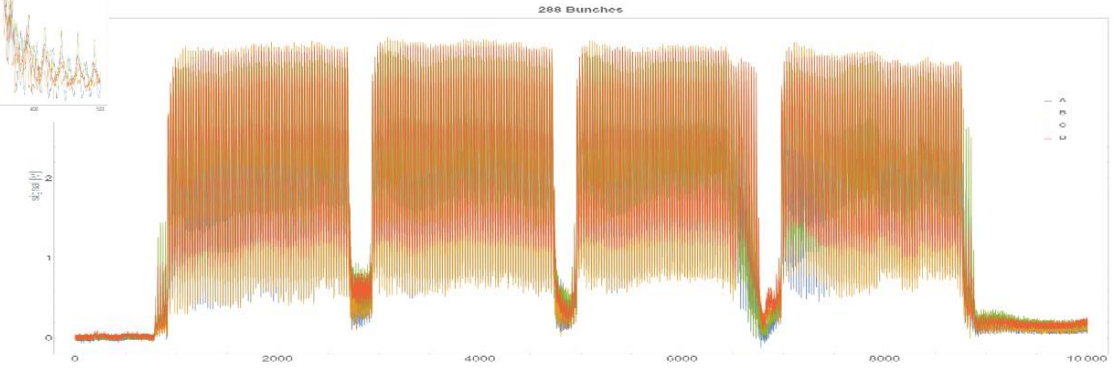
Diamond Detector (1/2)

Requirements:

- Position, and size precision of 0.1mm
- Simple real-time acquisition of beam parameters
- Single bunch resolution
- intensity range 1E9 to 5E13 p^+/pulse
- Based on Beam halo measurement



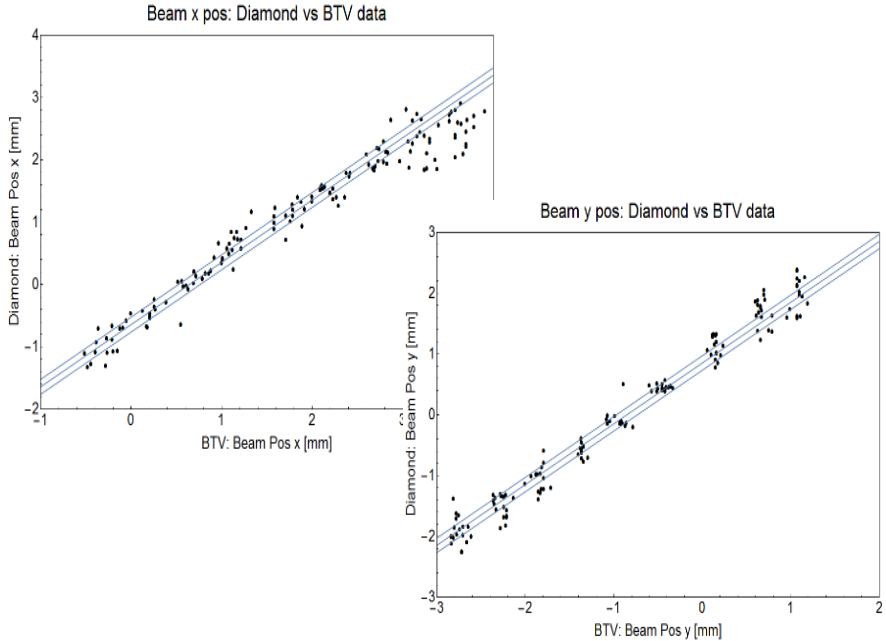




Diamond Detector (2/2)

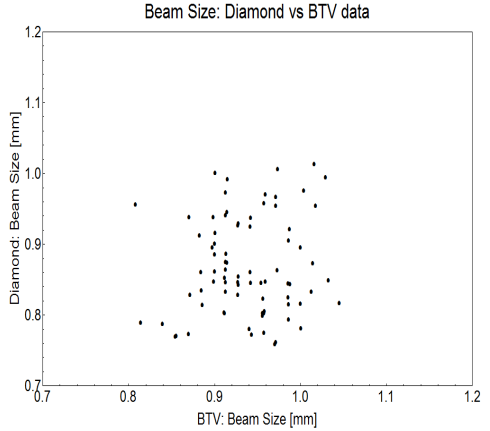
Measuring BEAM POSITION

* Comparing with BTV
* $\pm 1\sigma$ **standard deviation is plotted**
* 1σ = 0.12mm
* Working as well with W-target inserted with reduced resolution (temporal signal distorted by showers)



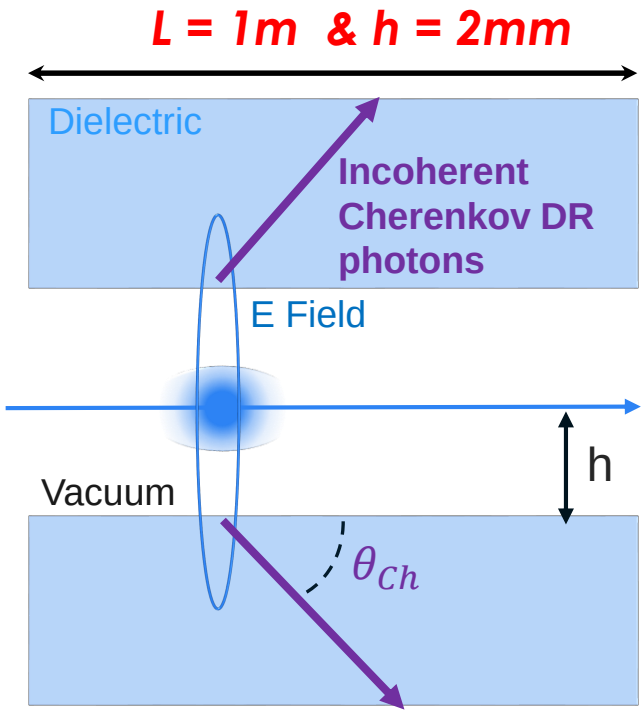
Measuring BEAM SIZE

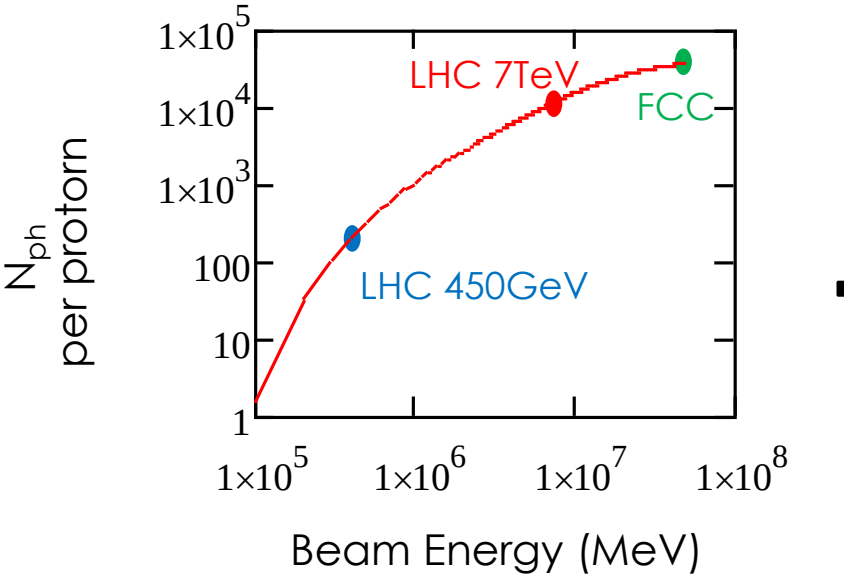
* Assuming circular spot
* Measurements for beam sizes of **1mm** and **2mm**
  * **2 mm** data taken with W-target in beam
* Standard deviation **0.07 mm** for 1 mm optics, **0.36 mm** for 2 mm optics



R&D performed in 2017-18

- Development of non-invasive beam instruments using incoherent Cherenkov Diffraction Radiation in long(er) dielectrics

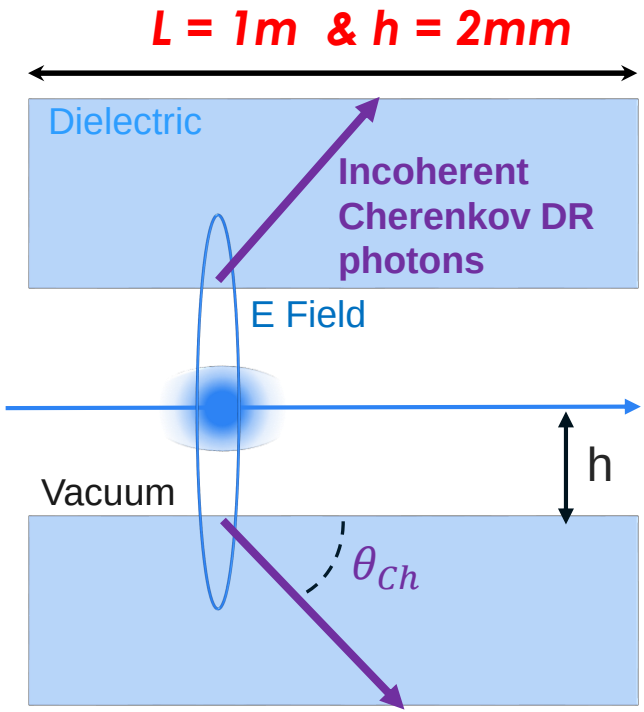


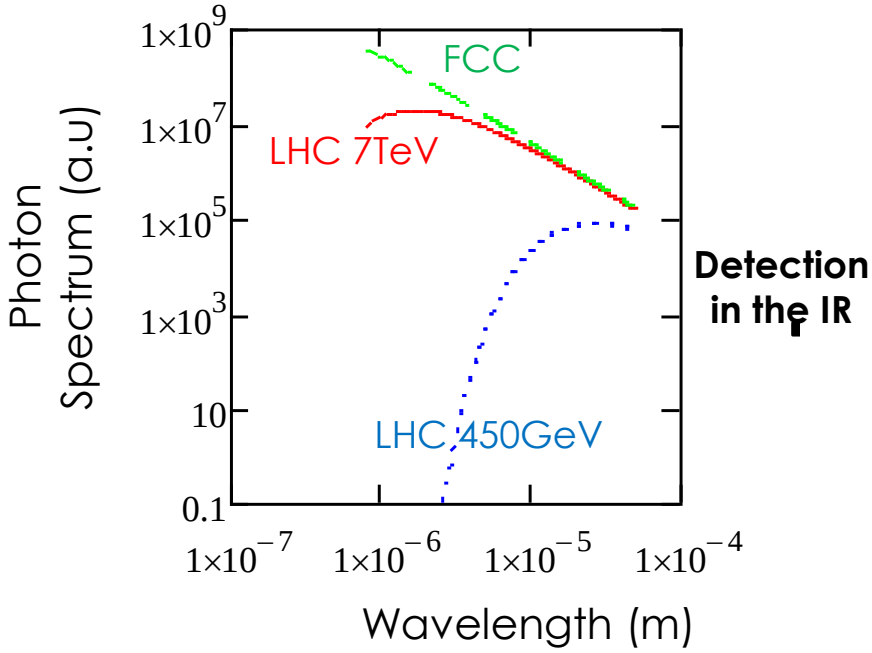


For comparison N_{ph} from OTR is 10^{-2} -10^{-3}

R&D performed in 2017-18

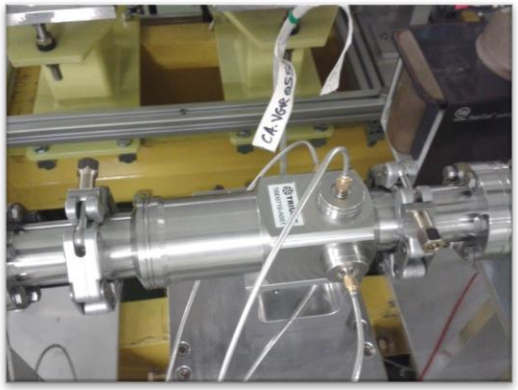
- Development of non-invasive beam instruments using incoherent Cherenkov Diffraction Radiation in long(er) dielectrics



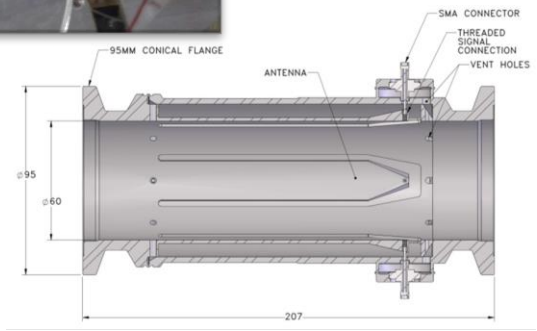


BI developments at HiRadMat

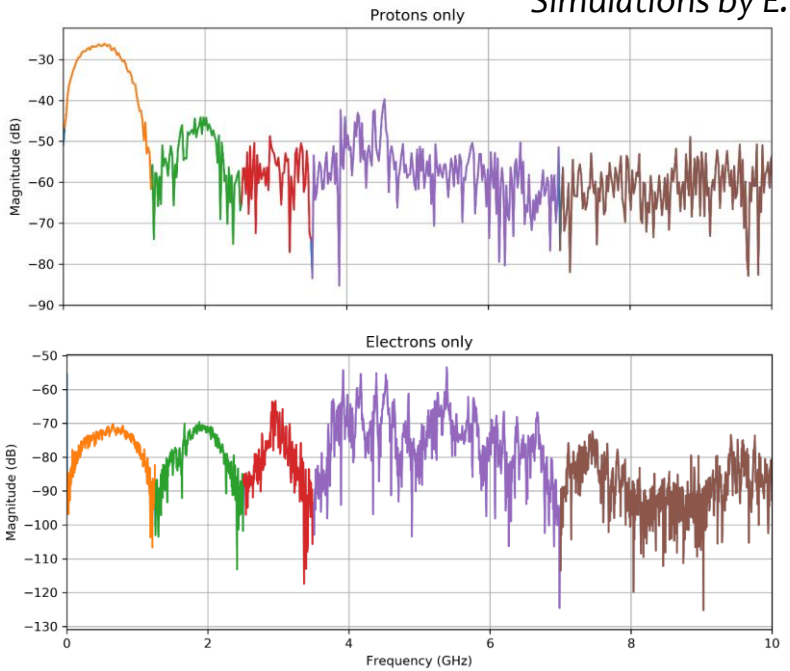
- R&D on Coherent Cherenkov-Diffraction Radiation
  - BPM for Electrons which should be insensitive to Protons



Current system not working !!



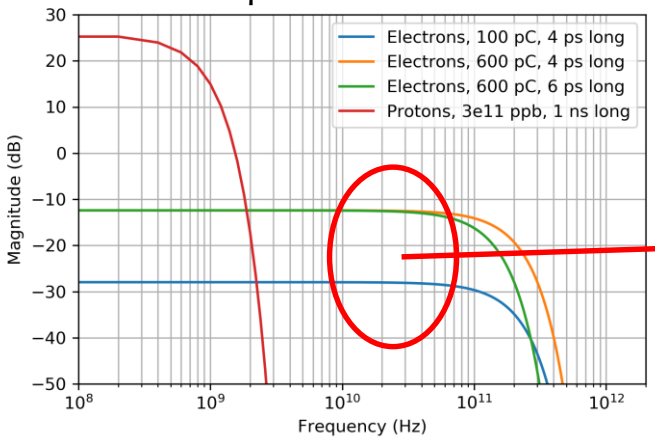
Simulations by E. Senes



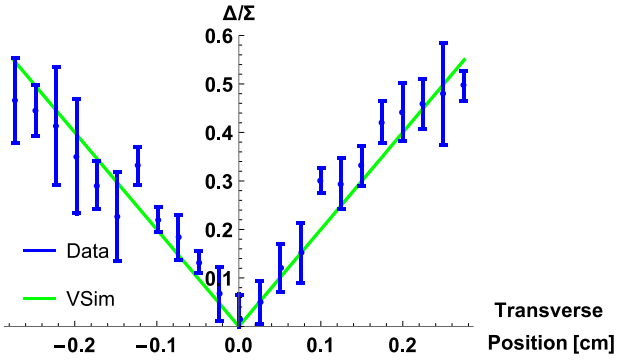
BI developments at HiRadMat

- R&D on Coherent Cherenkov-Diffraction Radiation
  - Bunch length and Beam position monitor for short bunches (sub-ns)

Bunch spectrum



Bunch position monitor using coherent Cherenkov-Diffraction radiation at >20GHz (in 2018)



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Developing Beam diagnostics at CERN

- Testing directly on the Operational Machines themselves
  - It works..but may lead to unpleasant surprises
    - *e.g. Beam position dependency of CERN Fast Beam Current Transformer on LHC*
  - Limited time for hardware installation/modification in the tunnel (i.e. Technical stops)
  - Limited beam time available for tests during MDs
  - R&D is rarely 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