ICFA Mini-Workshop on Slow Extraction, 2022

24-28 January 2022

Asia/Tokyo timezone

Status and plans for beam instrumentation for SX at CERN

F.Roncarolo, CERN SY-BI

Many thanks to:
M. Duraffourg , S.Mazzoni, S. Burger, M.Martin, L.Parsons Franca, A.Navarro Fernandez
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N.Emriskova, R.Garcia Alia, F.Ravotti, K.Bilko
V.Kain, M.Fraser, F.M.Velotti
T.Lefevre

Contents - Introduction

- Overview of CERN diagnostics installed for the slow extraction regions and primary transfer lines in the SPS and PS.
  - Status and main limitations, including 2021 experience
  - SPS North Area CONS program

- On-going studies and R&D

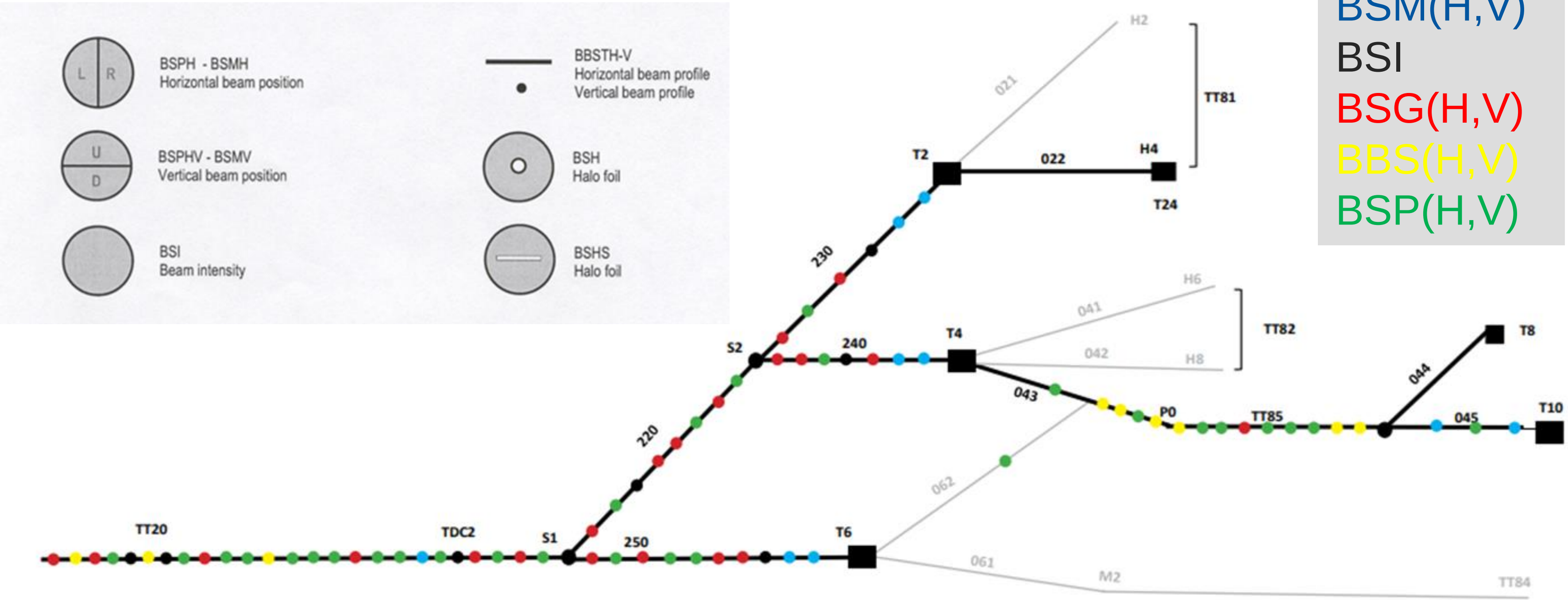
General remark (as also mentioned by M.Fraser and V.Kain on first day):
  - PS EA recently renovated → renewed interest for optimizing extraction and transmission → implies reviewing diagnostics status and limitations
  - SPS NA consolidation approved → also implications on diagnostics

Quite a lot of work ongoing and ahead of us!

BI @ SPS-SX – Secondary Emission Monitors

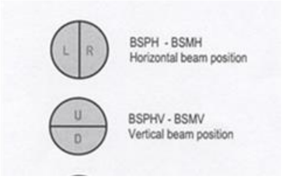
~80 monitors + ~50 in target boxes

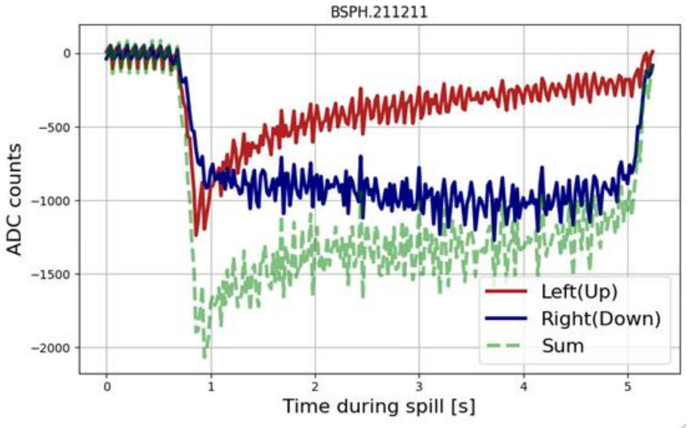
BSM(H,V)
BSI
BSG(H,V)
BBS(H,V)
BSP(H,V)



BI @ SPS-SX - New SEM electronics (2021)

New electronics: signals during slow extraction sampled with t=20ms





DAQ can be swapped to 'fast' mode able to integrate fast extractions (and used for SPS bunched beam in injection line)

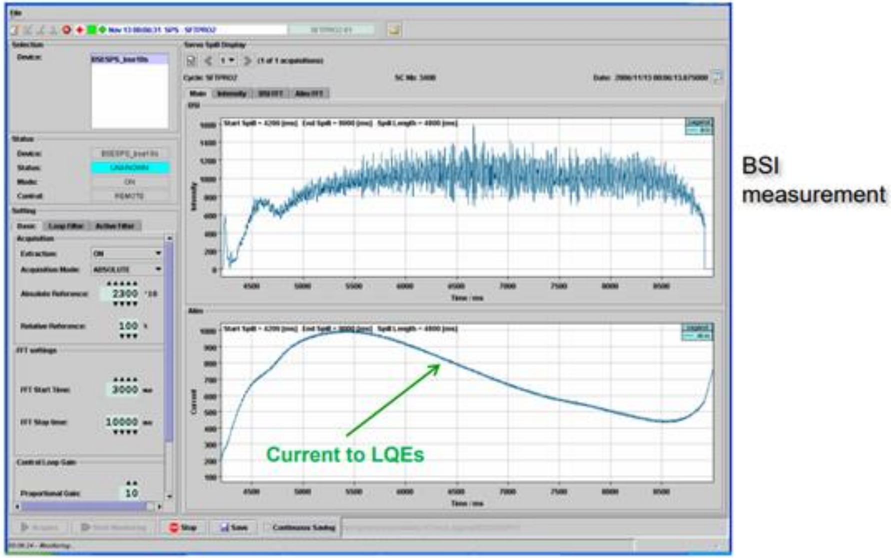
Split foil example: can see that beam is moving during spill (not possible before 2021)

BI @ SPS-SX - SEM – status/limitations

- Absolute calibration for intensity meas. very tricky (see PS and BSI studies slides later)
- Proper optics and transmission optimization difficult with present park
  - NA consolidation program to replace/add instruments, e.g. to have grids for better optics measurements
  - Possible new requests after 2021 experience (to complement approved consolidation)
- Robust systems, nevertheless not necessarily optimized for precise measurements (mechanical layout with stack of foils → cross talk, etc..)
  - See later slide on ongoing PhD
- Noise and ageing due to radiation are a ~constant concern, not improved after LS2

BI @ SPS-SX 'Fast' SEM detector (aka ServoSpill)

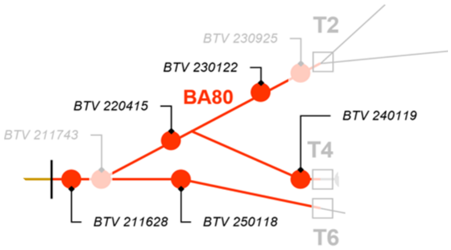
- 1 'fast' (kHz) spill detector based on SE foil @ extraction
- Can be (and was) used to directly compensate spill intensity ripples
- Detector itself (SEM foil) installed since many years
- 2021: signal resulted to be very noisy, amplifier change did not solved the problem, suspect some short or leakage inside vacuum
  - Plan to refurbish detector end of 2022

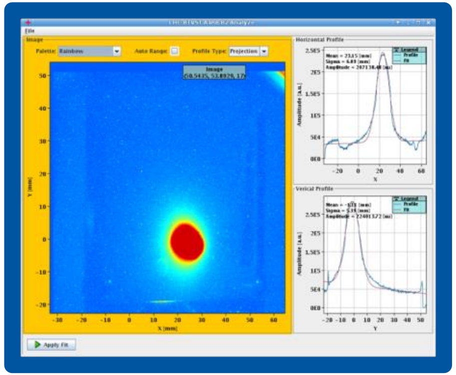


BI @ SPS-SX

Imaging systems (BTV)

1	BTV211628	BA80/TCC2
2	BTV211743	BA80/TCC2
3	BTV220415	BA80/TCC2
4	BTV230122	BA80/TCC2
5	BTV230925	BA80/TCC2
6	BTV240119	BA80/TCC2
7	BTV250118	BA80/TCC2





- Interceptive
- mainly used for steering
- 2021: noisy images (noise source identified, mitigation measures under test)

BLMs (ionization chambers) 15 units at ‘strategic’ locations around extraction septa and splitters

Cables-Connectors ageing critical in most locations

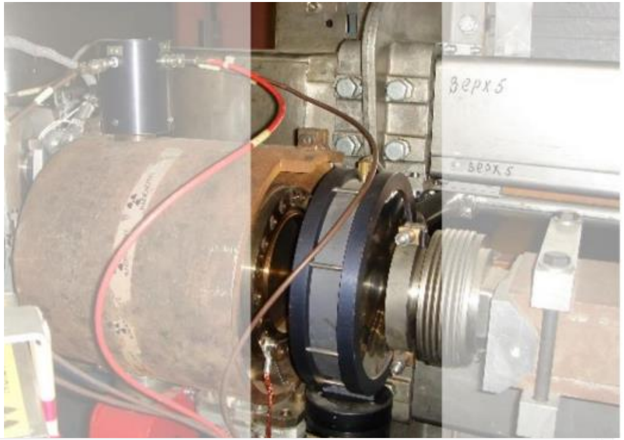
BI@SPS NorthArea Consolidation   List of BI items

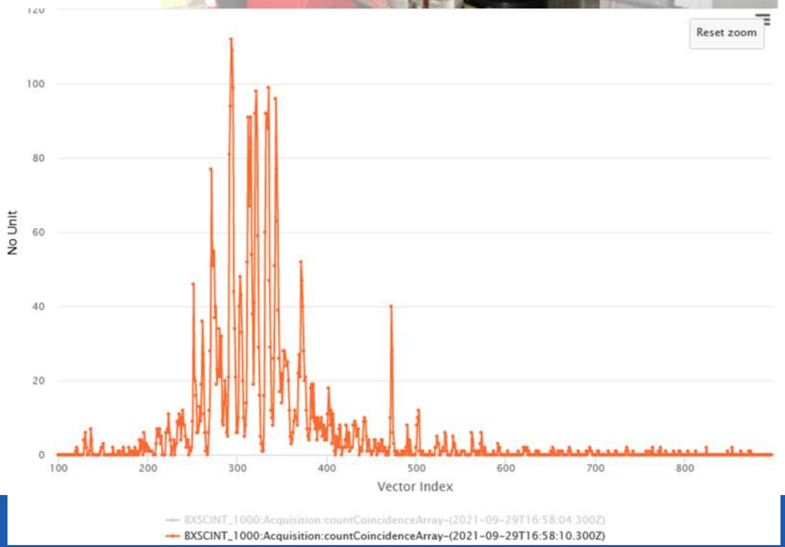
Monitor	Required works	#Units	Projects affected	Consequences of non-upgrade
BSI	Consolidation	4	NA operation, BDF	Uncertain POT, poor TT20 splitting efficiency
BSP	Replace by SEM grids	4	NA operation, BDF	Loss of OP time for TT20 re-steering and source of inefficiency for switching extraction energy during ion run, lack of TL optics measurements
BTV	Consolidation	3	NA operation, BDF	OP time for TT20 re-steering, poor TT20 splitting
BLM	Detectors	30	NA operation, BDF	OP downtime, risk of increased beam loss
	Electronics	30		
	Cabling / installation	30		
Fast Spill Detector	Produce a new system (OTR or Cherenkov)	1	NA operation, Prerequisite for BDF	OP blind to high freq. spill quality from CCC, limiting planned machine studies to improve spill quality
Long. BLM LSS2	Produce new longitudinal BLM	1	NA op, Prerequisite for BDF	Quantification of SPS extraction efficiency limited
P42 SEM Upgrade	Produce 3 new dual plane SEM grid for P42	3	K12	No intrumentation for P42, optics issue with large beam spot on T10 cannot be diagnosed

2021 experience: not enough diagnostics to measure optics and transmission, NA CONS may be complemented by further diagnostics requests, waiting for specs

BI@PS-SX - Longitudinal Spill Gas Detector

- Based on detecting light emitted by beam-gas interaction
- Tank filled with Nitrogen, ~22m from extraction point
- Two PMTs in coincidence (to suppress noise)
- DAQ: 10 kHz possible, now set to 2.5kHz
  - Ultimate BW now anyhow limited by present cables and VME bus
- TDC based DAQ under study, could reach 1 MHz





BI@PS-SX –Secondary Emission Monitors (SEM)

- Very similar to SPS monitors, since 2021 equipped with new SPS electronics
- Used to control extraction/transmission and monitor ProtonsOnTarget
- Absolute calibration critical (As for SPS), see next slide

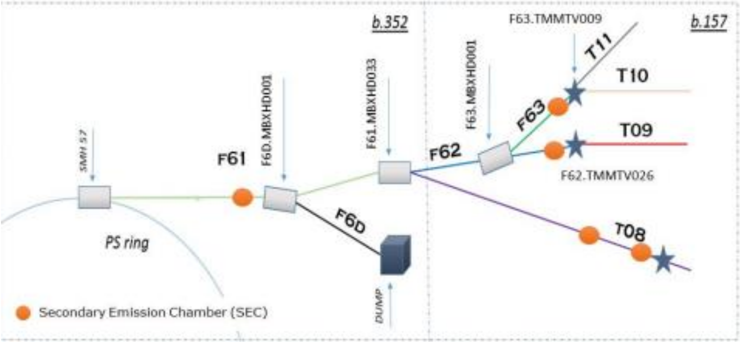
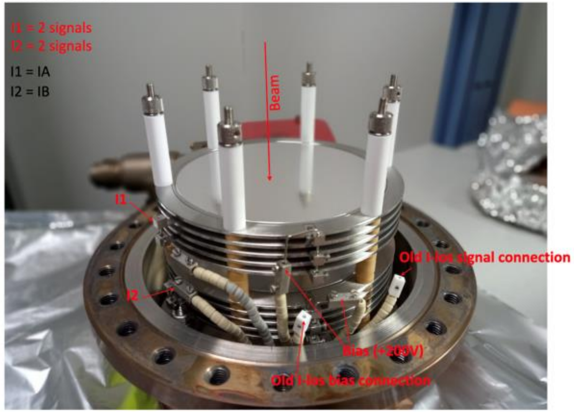
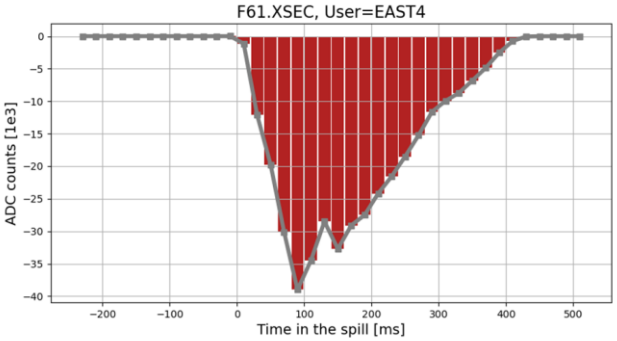
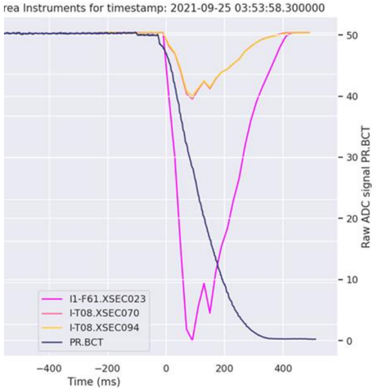


Fig. 4-26: Position of XSEC on the new East Area lines.

F61.XSEC-023





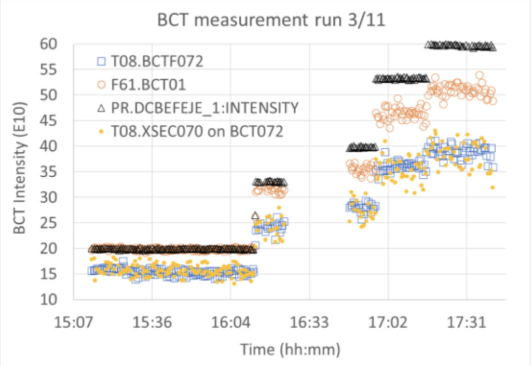


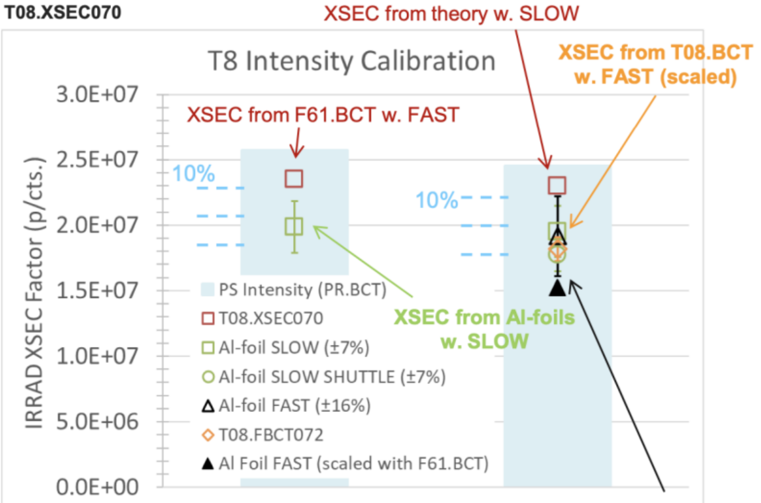
F.Ravotti et (MANY) al.

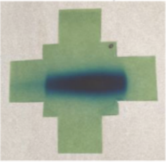
SEM detectors Calibration

- Fast extraction: compare BCT to XSEC and Al foils activation
- Slow extraction: compare XSEC and Al foils activation
- Lot of work going on, more in 2022, converging to smaller and smaller uncertainties

Device T08.	IRRAD SEC F. (old)	New SY-BI SLOW (2021)	New SY-BI FAST (2021)
XSEC070	2.30×10^7	1.27×10^8	3.81×10^8
XSEC094	1.03×10^8	5.08×10^8	
	4.48	4.8	Assumption!



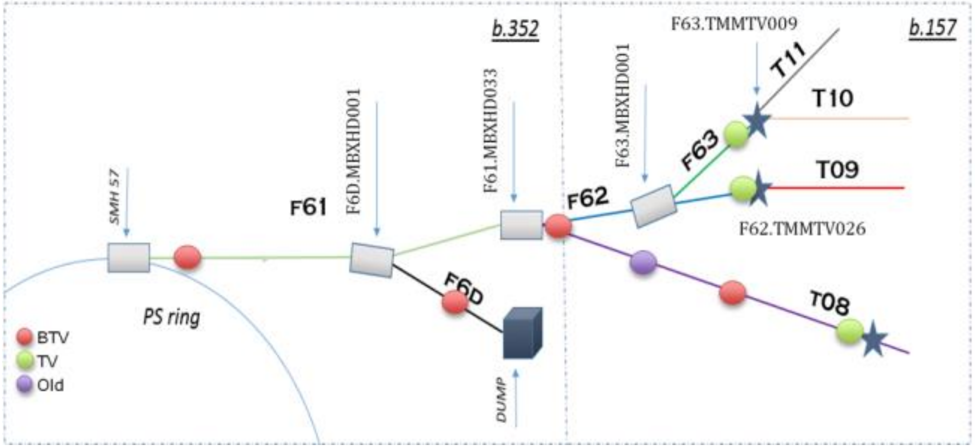




Thanks to Romain, Federico, Ana, Michel! (SY-BI)

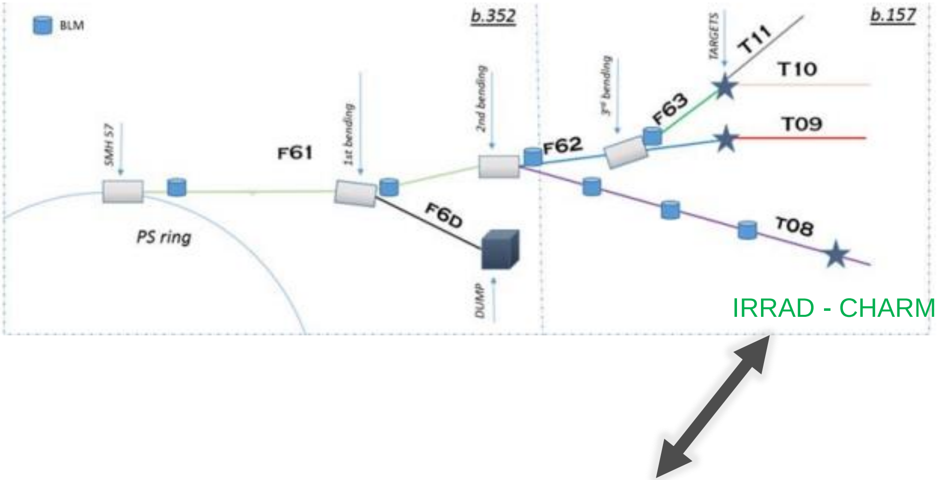
BI@PS-SX – BTVs

- Like for the SPS: interceptive and used for setting up/steering
- 2021 attempt to use for optics measurements
  - Resolution limited by saturated images
  - For 2022: aim at add optical filters
- For longer term: possible request to add wire grid(s) dedicated to optics measurements – waiting for specs



BI@PS-SX – Beam Loss Monitors BLMs

- Ionization chambers at strategic locations in transfer lines
  - Can give 100kHz in capture mode
- Fast Diamond BLMs requested for installation at PS extraction to characterize spill quality
  - Detectors as ones described later for SPS
  - 2021 request: being processed

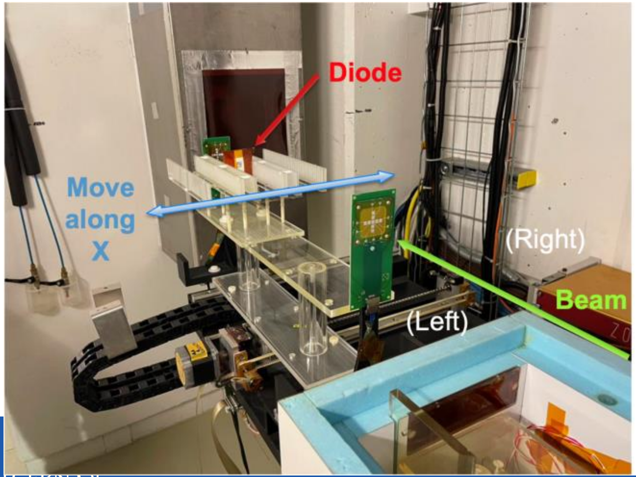


Next slide == potential of these monitors as fast spill monitors inferred from Si-diodes tests at IRRAD

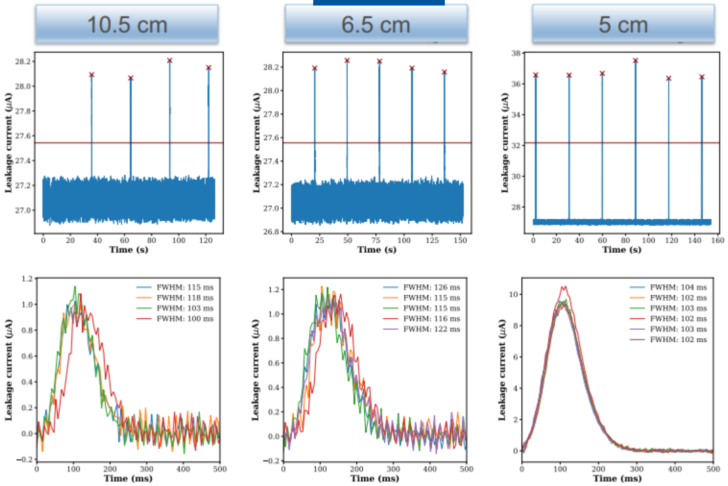
K. Bilko, N. Emriskova, R. Garcia Alia et al.

Si-detectors @ IRRAD for CHIMERA

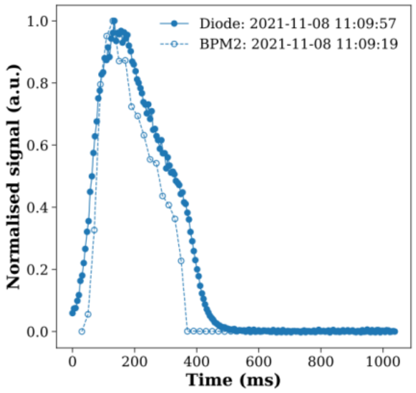
- Si diodes connected to 'standard' BI amplifiers (see SPS part), movable, tested via different scope/digitizers (custom made setup)
- Analysis of very recent proton and ions runs Nov 2021 on-going, here an example of 'low frequency' acq. (limited BW), 'high frequency' data being analyzed



IONS



PROTONS



CERN BI@SX – Studies and R&D

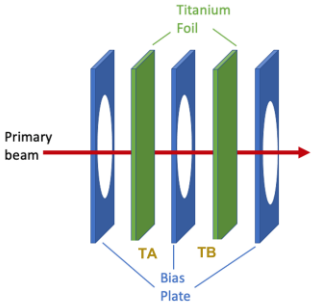
- SEM optimization – BSI calibration
- Fast Spill monitor
  - OTR + PMT
  - Cherenkov detector (CpFM)
  - Diamond Beam Loss Monitors (dBLMs)
- Longitudinal (Optical) Beam Loss Monitors (oBLMs)
- Electro-Optical DC Beam Position Monitor (EO-DC-BPM)
- Beam-Gas Monitor (Timepix) for beam halo

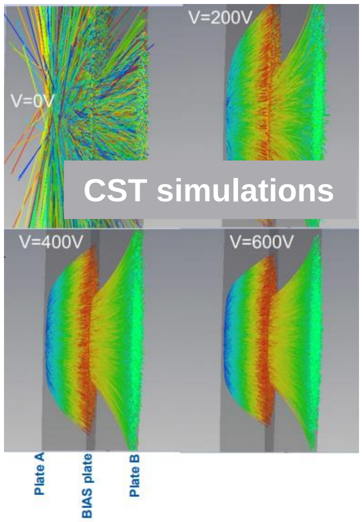
L.Parsons Franca, F.Roncarolo et al.

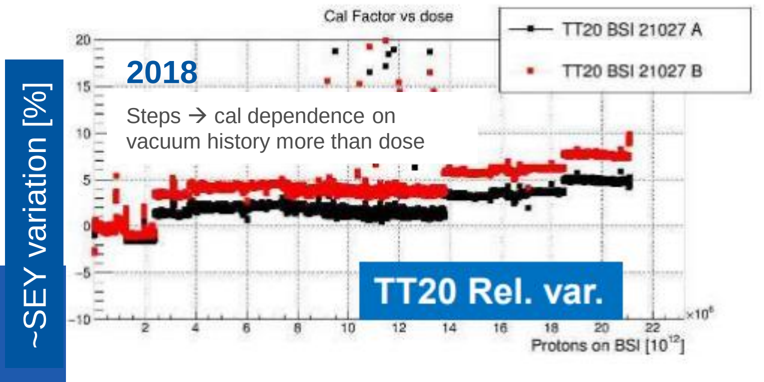
SEM detectors studies

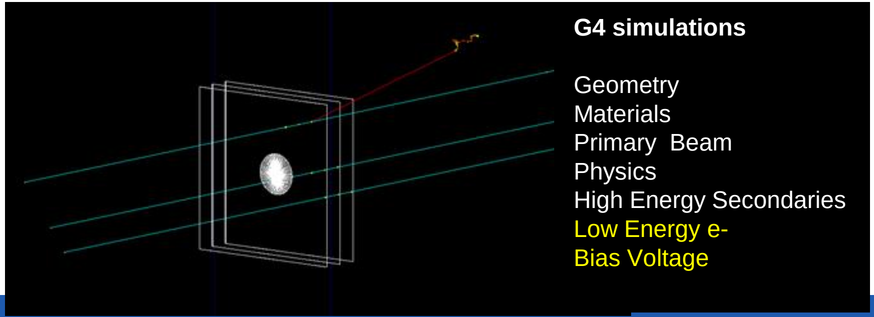
Ongoing PhD for

1. assessing absolute calibration of single foils (for intensity meas.)
   – Theory (SEY hard to determine) + experiments / cross - calibrations
2. proposing new methods and possibly new detectors layout
3. Investigating Machine Learning techniques for full exploitation of present and future detectors
   – E.g. Started discussion with F.M.Velotti on training of split-foils to better determine beam size and position









S.Mazzoni, S.Burger, F.Roncarolo et al.

Fast Spill Monitor I

Optical Transition Radiation from thin screen (Ti, 12um thick), focused on PMT

- Expect to have enough S/N and be in the 100-200MHz range of overall system BW (PMT+Head-Ampl+Cables)
- Prototype installation completed, DAQ via fast scope to characterize S/N in 2022
  - In parallel: will start designing 1-channel fast digitizer, possibly FMC mezzanine on ‘BI standard’ VFC

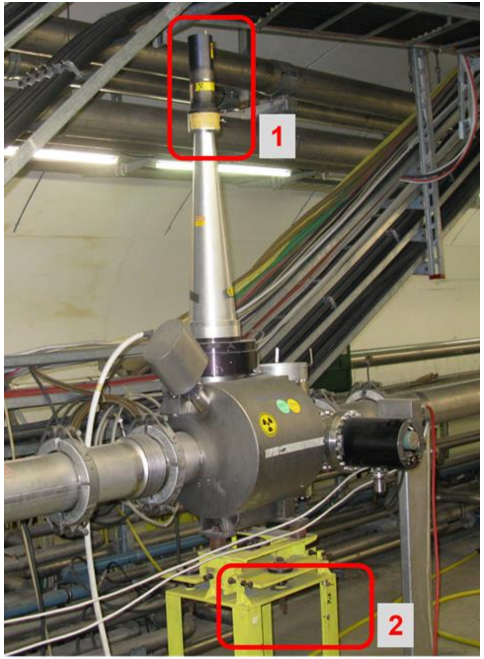


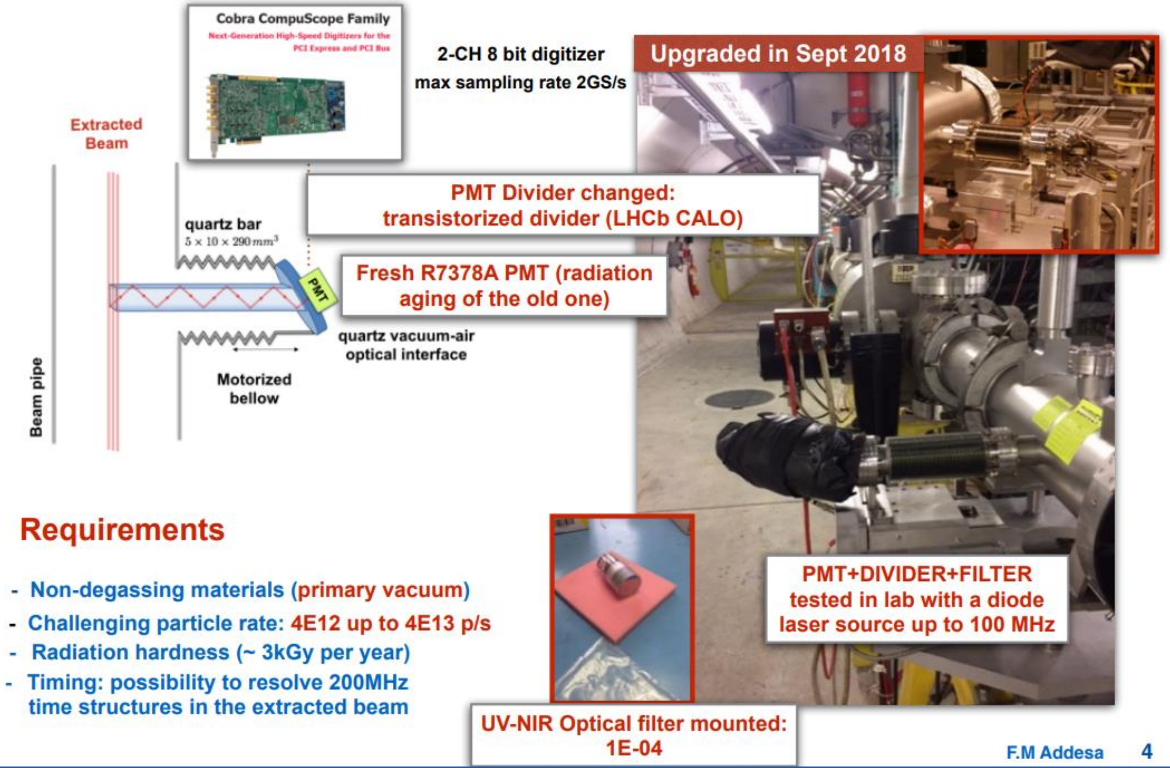
Figure 4 - Photo of BSTL.210272 (bottom). The PMT to be replaced (1) is visible at the top of the ‘cone’. The new amplifier will be fixed to the girder (2).

F.Addesa. L.Esposito et al.

Fast Spill Monitor II

In vacuum quartz bar producing Cherenkov light

- System evolution of one used with low particle flux for crystal assisted extraction
- Can go to ~200 MHz
- Validated in 2018 with custom made DAQ
- Plan: equip it with ‘BI standard’ DAQ for systematic studies



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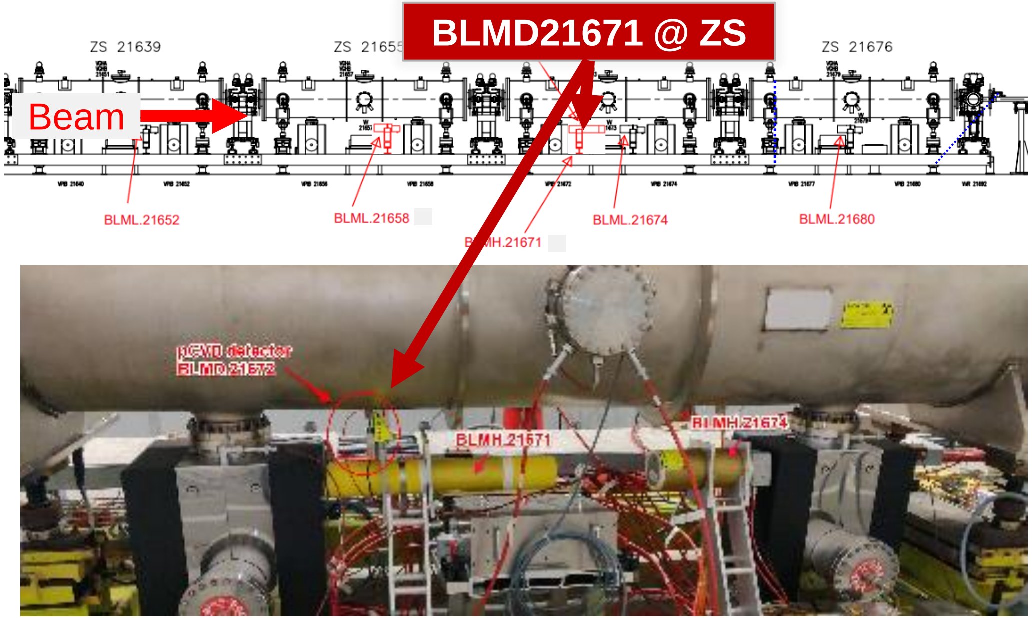
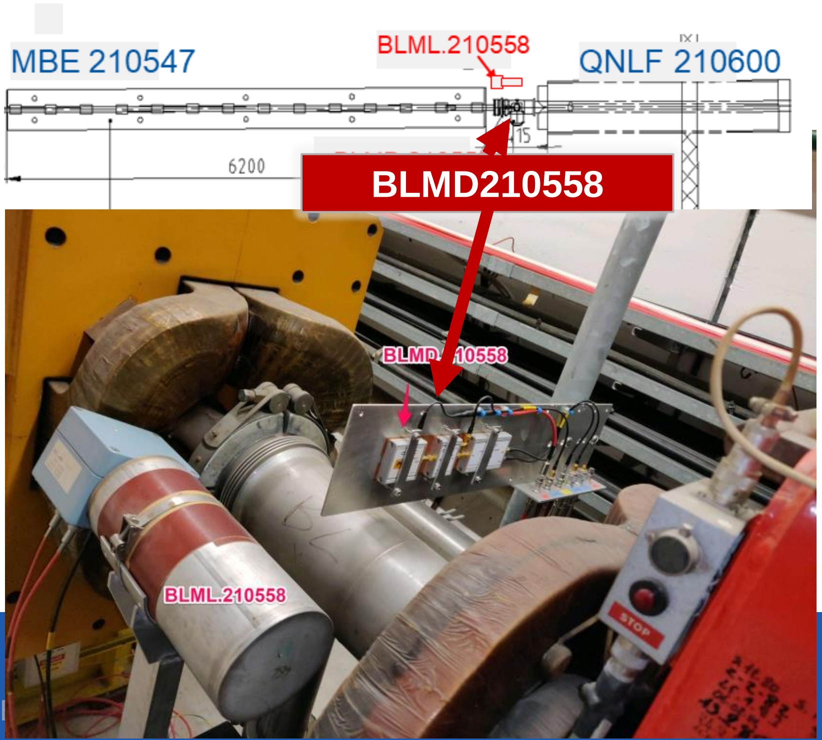
Diamond – Beam Loss Monitors (dBLM)

pCVD crystals, for beam loss monitoring and potentially Fast Spill monitor III)

2 dBLM installed in SPS (@electrostatic septum and @transf. line quad)





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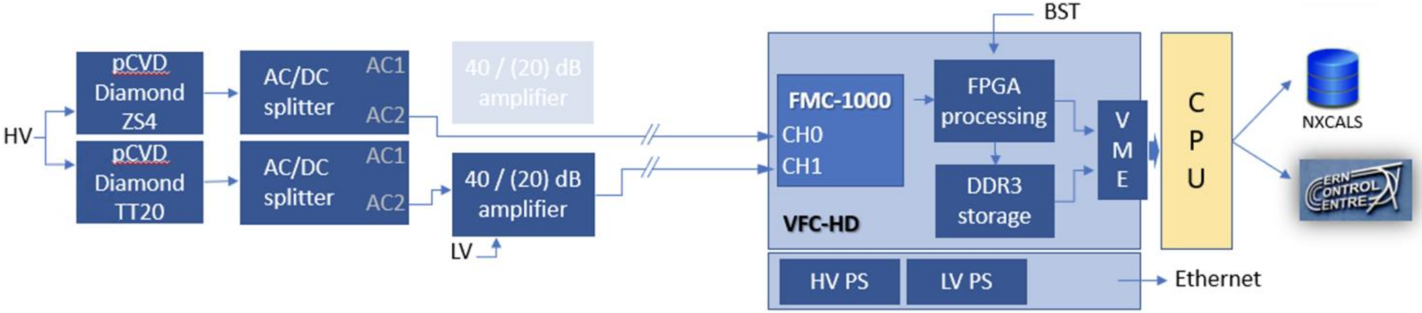
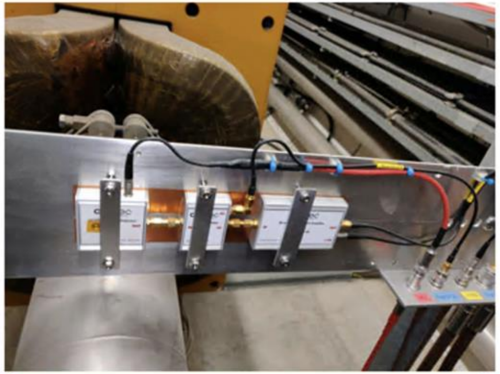
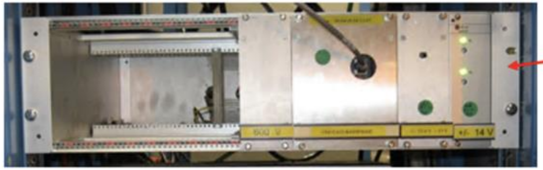
dBLM DAQ

Designed to be fully integrated into standard control system and logging







ELMA VME crate
+ MEN A25 CPUs
+ CTRP module
+ VFC-HD
+ FMC-1000

High and Low Voltage Supply
Controlled via an Ethernet Controller

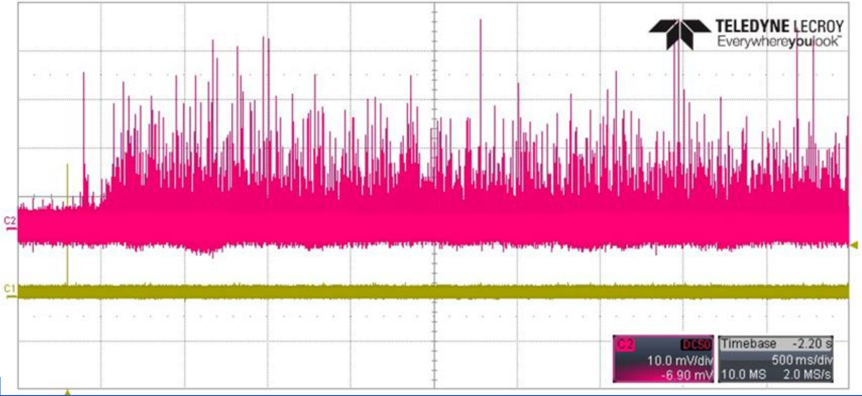
Detector + Analog Front-end (Near observed element) | Cabling (hundreds m) | Digital Back End (In service tunnel)

E. Calvo, E.Effinger, C.Zamantzas et al.

SPS dBLMs – Features and Status

SPS detectors read out via BI standard carrier board (VFC) + 2 Ch-**650 MS/s digitizer mezzanines** (detector installed in PS EA IRRAD acquired through an oscilloscope)

- Plan to use FW&SW capture mode for SX:
  - Circular buffer of 2GB (1GB per channel)
  - ~500 Msamples/channel @ 650MS/s → ~0.8 sec (full memory readout can take minutes
  - Different gating/sampling strategies under study
  - DAQ SW and logging protocols being finalized



First measurements during 2021 via scope

- Signal integrity issues (interference/ground loop) suspected to corrupt the signals of the ZS4 detector → To be followed up

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Longitudinal Beam Loss Monitors

- Part of SPS North Area Consolidation requests
- On-going development: system based on Cherenkov emission fibers coupled to photo-detectors
- Status:
  - Design, modelling, comprehensive simulations (energy deposition, light yield and transmission)
  - Tests at CERN CLEAR facility (electrons)

Table 3: Longitudinal BLM specification

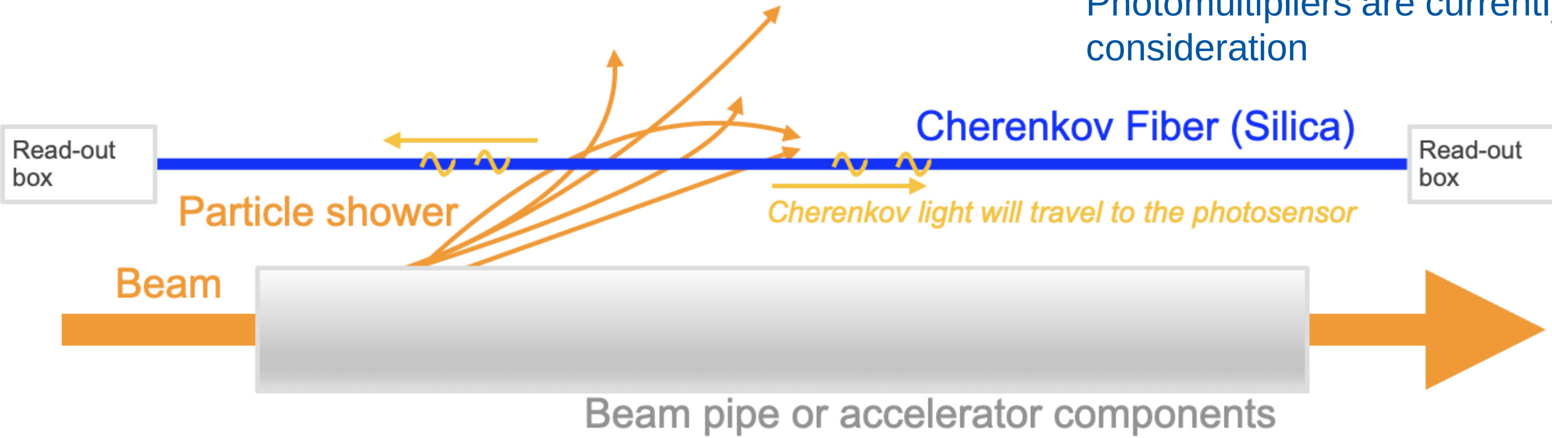
Parameter	Value	Unit	Comment
No. of systems	3	-	1x LSS2 (extraction), 2x in TDC2 and TCC2 (next to MSSB's, splitting)
Longitudinal coverage	~150	m	For example, spanning LSS2 from QD215 to QF220
Longitudinal resolution	~ 1	m	Not critical for loss efficiency measurement: highly desirable to identify hotspots
Short-term reproducibility	~ 1	%	Shot-to-shot stability on the order of a %
Long-term reproducibility	~ few	%/yr	Long term drift needs to be controlled to minimise the number of beam-based calibrations needed per year
Absolute dose measurement			Loss signal needs only to be reproducible: it will be calibrated versus beam intensity measurements, see [10]

S. Benitez, E. Lima, B. Salvachua, E.Effinger, C.Zamantzas et al.

Cherenkov Optical Beam Loss Monitor (oBLM)

- Silica optical fibers coupled to photo-sensors to detect Cherenkov light produced by secondary (from beam losses) charged particles.
- Beam loss measurement of instantaneous beam losses over meters
- Possible loss localization with data post-processing

Photo-sensors: SiPM and Photomultipliers are currently under-consideration



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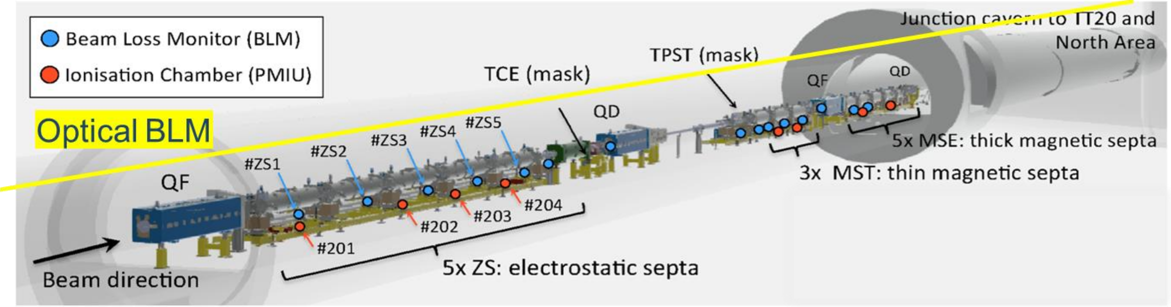
oBLM for the SPS

SPS installation: Develop a long fiber based BLM detector to measure Beam Losses over ~200 meters from QF.216 to QDA.219 along the extraction line in order to optimize the machine settings and minimize radiation levels.

Multimode optical Fiber (200um core) couple to SiPM to each fiber-end



Prototype fiber installation completed, preparing DAQ

Simulate particles interaction
FLUKA

Simulate Cherenkov light generation, capture and transport
Specific python-based code

Benchmark simulation results in CLEAR

oBLM @ CLEAR

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB021

DEVELOPMENT AND TESTING OF A CHERENKOV BEAM LOSS MONITOR IN CLEAR FACILITY

S. Benítez*[1], E. Lima[2], E. Effinger, W. Farabolini[3], A. Gilardi[4,5], P. Korysko[6], P. Lane[1], B. Salvachua, W. Viganò, CERN, Geneva, Switzerland
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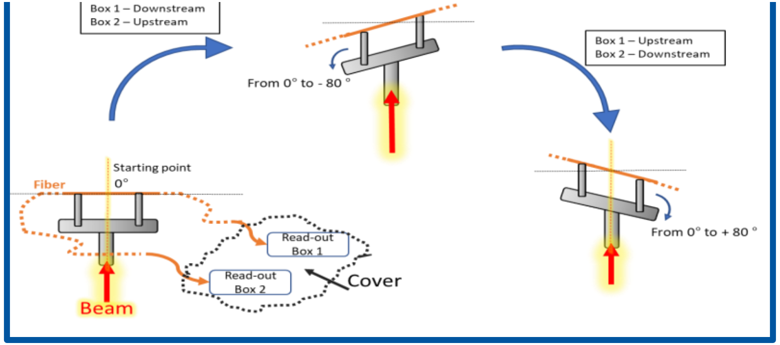
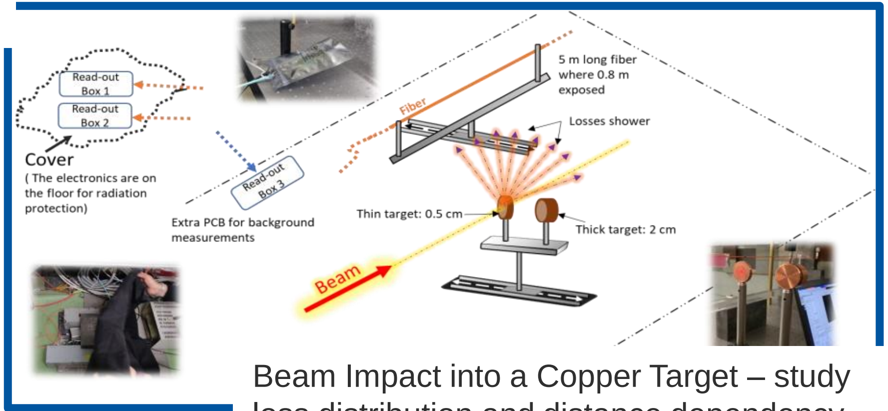
[3]also at CEA-Saclay, Gif-sur-Yvette, France
[4]also at University of Naples Federico II, DIETI - IMPALab, Napoli, Italy
[5]also at Istituto Nazionale di Fisica Nuclare (INFN) Sezione di Napoli, Napoli, Italy
[6]also at University of Oxford, Oxford, United Kingdom

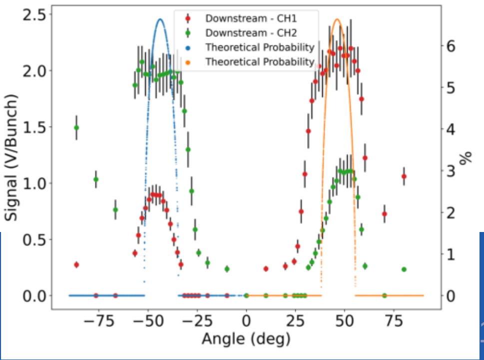
- Extensive set of studies, details presented at IPAC2021

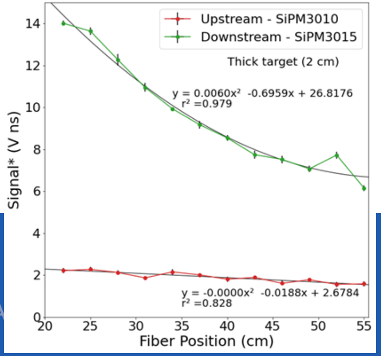
Direct beam impacting into the fiber – study angle capture





Beam Impact into a Copper Target – study loss distribution and distance dependency

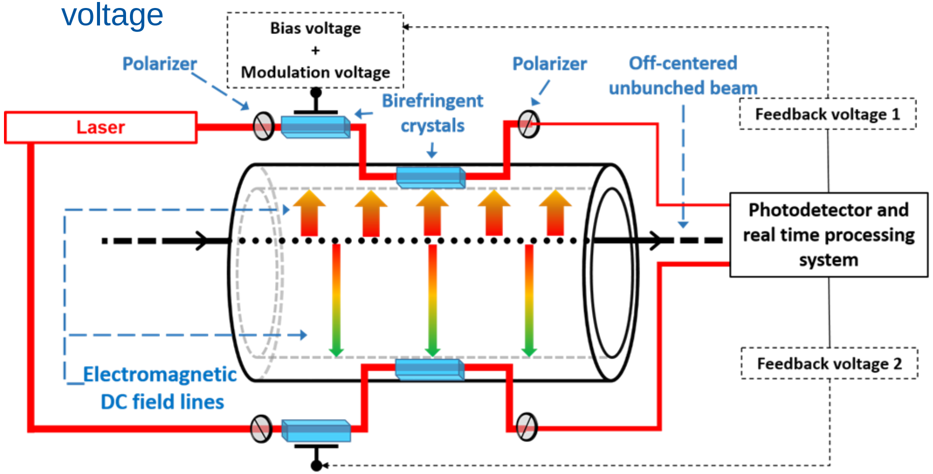




Electro Optical DC BPM in a Nutshell

Based on EO crystals: refractive index varies if exposed to E field

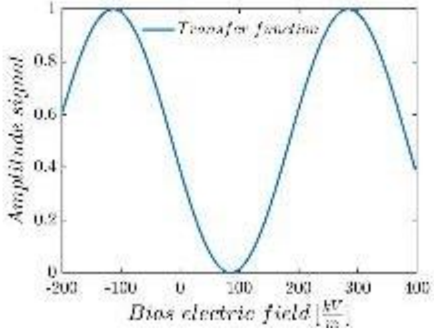
Each BPM ‘electrode’ == branch composed of two crystals
1. In vacuum: sensing the beam E field
2. Air side: for setting the working point (compensate space charge induced on first crystal) and modulate an external voltage



- A linearly polarized laser beam traverses the chain, its polarization state changes due to the E field(s)

→ Time-varying output light intensity measured with a photodetector

- Working point set to exploit the Transfer Function (TF)’s symmetry. Sinusoidal modulation on the first crystal



Public deliverable for the ATTRACT Final Conference

Detection of DC beams using electro-optical crystals and lasers (EO-DC-BPM)

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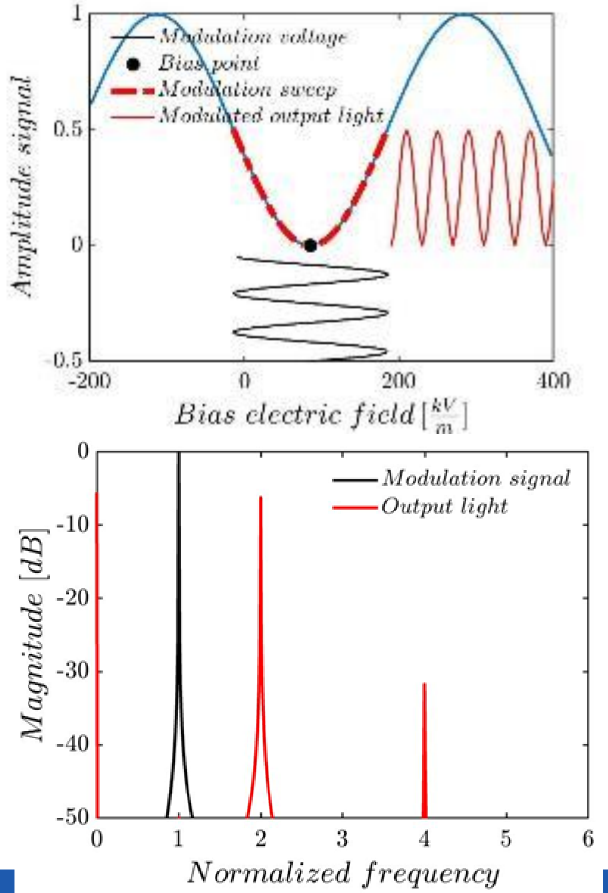
EO DC BPM – Simulations

External E field sinusoidal modulation (Bias E field)

- **Without particle beam**: output signal contains only even harmonics of the modulation frequency



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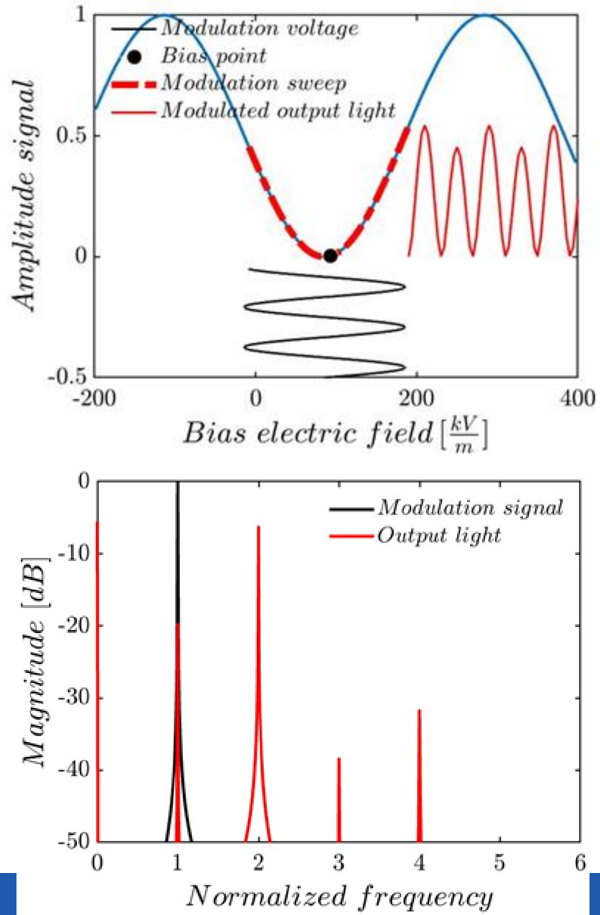
EO DC BPM – Simulations

External E field sinusoidal modulation (Bias E field)

– **With particle beam**: working point shifted transfer function symmetry lost, output signal contains even and odd harmonics of the modulation frequency

- **First harmonic magnitude**
  - Proportional to beam distance from crystal
  - Combination of 4 branches gives H & V **beam position**



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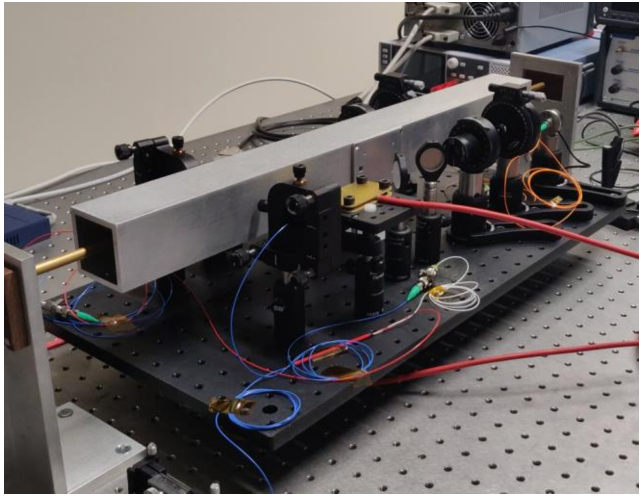
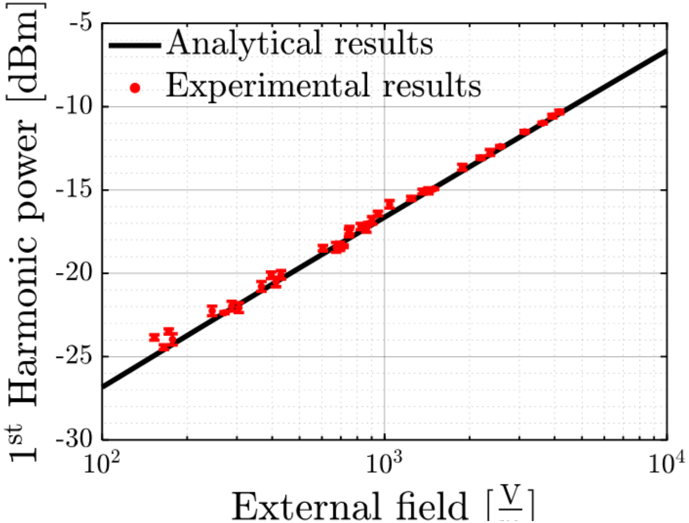
Electro Optical DC BPM





- Single-branch proof-of-concept test bench built in the laboratory
  - Beam Simulated by stretched wire
- First measurements (Nov 2021) show good match between the theory and obtained results
- Current bottleneck: limited dynamic range (30 dB) due to non-optimized acquisition
- Custom feedback and acquisition chain to improve the dynamic range under design

S.Levasseur, H.Sandberg, J.Storey et al.

Halo monitoring with an Ionisation Profile Monitor (IPM)

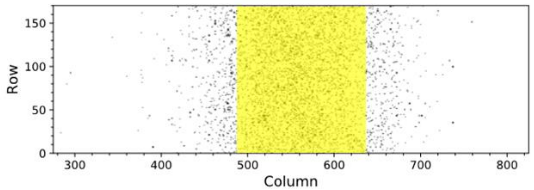
CERN PS IPMs: direct detection of individual electrons from beam-gas ionization with Timepix3 hybrid pixel detectors (TPX3 HPD).

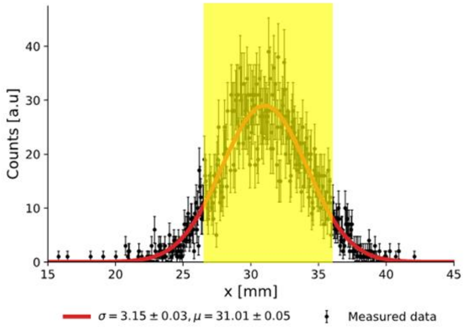
- provides the position (σs=16μm) & time (σt=1.6ns) of each ionisation electron.

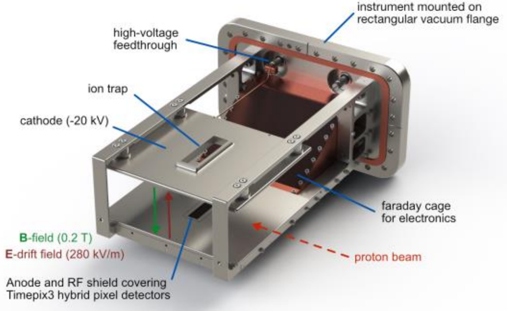
Idea: **digitally mask 'beam core' pixels** and play with:

- Residual (or injected) gas pressure;
- Integration time
- Digital mask pattern ⟷ Timepix3 detector readout: **maximum 160e6 electrons / s (from all pixels)**

to properly detect **halo signal**.







Proof-of-concept measurement with the PS in 2022.
Working on Timepix3-based IPM for the LHC is currently under development.
Further information: https://bgi.web.cern.ch/
Papers & talks: https://bgi.web.cern.ch/papers/

Summary

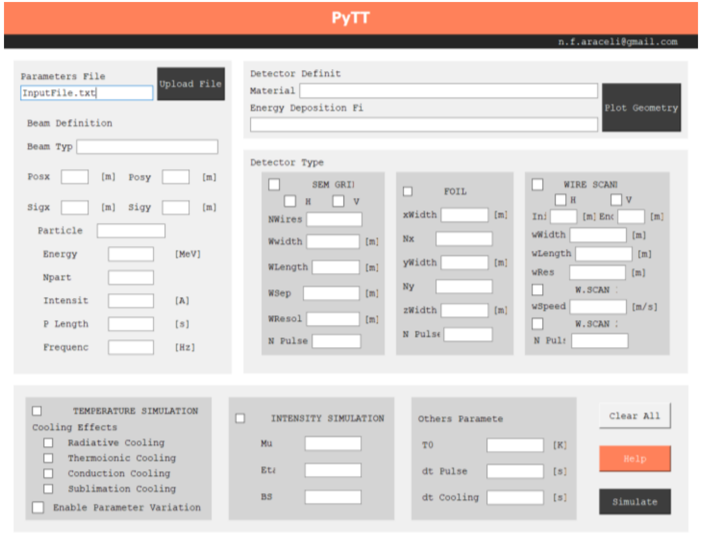
- Operational focus on SPS and PS during 2021 SX activities, required re-assessing present instrumentation performance
  - Some limitations known (SEM calibration), some other recently discovered (noise, room for DAQ FW improvements, etc..)
- New features, new detectors requested (e.g. SPS NA CONS) or specifications in preparation
- Showed how Beam instrumentation group is active in
  - renovation, optimization, upgrade of existing monitors / methods
  - R&D on new technologies
- In 2021 we identified room for synergies inside CERN teams (e.g. for fast spill monitor developments)
  - Wider collaborations (e.g. within SX workshops!) would also be very beneficial (e.g. partially already ongoing with GSI)

SPARE

Development of a Thermal Response Model for Profile Monitors and Benchmarking.

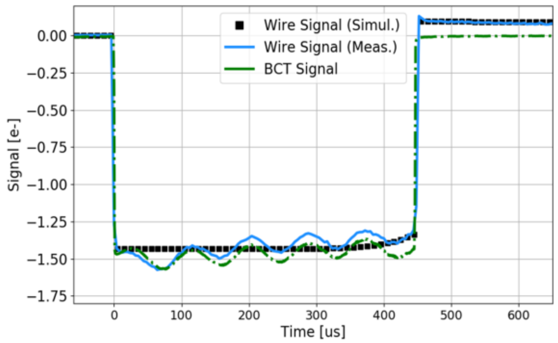
- A comprehensive model to describe interactions between thin target detectors and the beam of particles has been implemented. This tool has been based on the models implemented by M. Sapinski for fast wire scanners [1].

[1] M. Sapinski, Model of carbon Wire Heating in Accelerator Beams, Geneva, CERN, 2008.

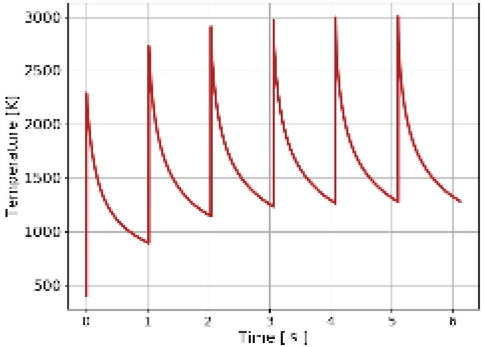


User friendly interface for the simulation tool.

- The output gives a prediction of detector signal, temperature evolution and Sublimation conditions (If applicable).
- The model has been applied to the wire grids of the CERN LINAC4 160 MeV H- beam and compared to experimental measurements.



Signal generated in the wire intercepting the beam core as a function of time. Simulated data in black, experimental data in blue.



Maximum wire temperature as inferred from the simulation during bench-marking experiments.

Check Me!

- This model has already been used at CERN LINAC4 and PSB to calculate beam power limits.

By: Araceli Navarro and Federico Roncarolo, CERN, 2021.