

A Family of Gas Ionization Chambers and SEM for Beam Loss Monitoring of LHC and Other Accelerators

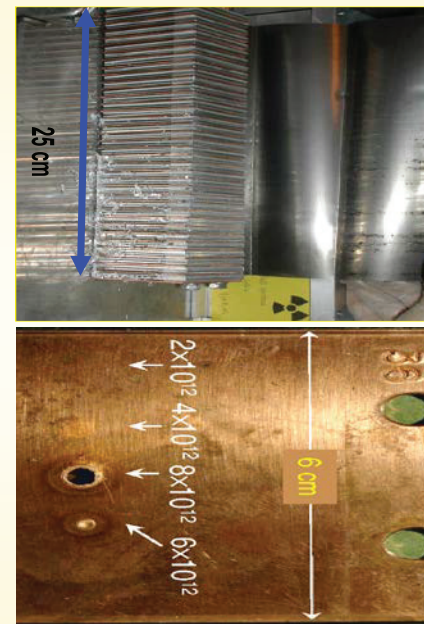
Beam Loss Monitoring



A serious problem for high current accelerators is high density of the beam, which is able to destroy the equipment and to make a quench of super conductive magnets.

Loss of even a small fraction of the intensive beam would results in high radiation and destruction of the equipment.

Material Damage Experiment at the SPS



V.Kain et al.

- Proton beam, 450 GeV, Cu, Fe sandwich target
 - beam size $\sigma_{xy} = 1.1\text{mm}/0.6\text{mm}$
 - $2 \cdot 10^{12}$ no damage
 - $8 \cdot 10^{12}$ damage
- Safe at 0.6 % of full LHC intensity

05.05.2008

BLW 2008, B.Dehning

3

The Beam Loss Monitor (BLM) system must be sensitive to different level of losses in different accelerator locations. BLM system protection should limit the losses to a level, which ensures hands-on-maintenance or intervention. On the other side, the BLM system should be sensitive enough to enable the fine tuning and the machine studies with the help of BLM signals. Beam loss monitoring is the cornerstone element in the accelerator protection and beam setup.

The requirements for BLM system



Sensitivity

Dynamic range

Time response

Type of radiation

Shield-ability (from unwanted radiation)

Response to excessive radiation (saturation effects)

Physical size of BLM

Test-ability

Calibration techniques

System end to end online test

Cost

Families of BLM

Beam loss monitors, produced by CERN-IHEP collaboration

- Ionization chambers (IC) , which are installed at local aperture minimum and loss locations.

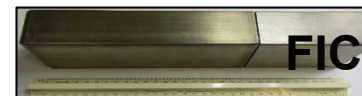


- Secondary Emission Monitor (SEM) – detector at very high dose rates locations.

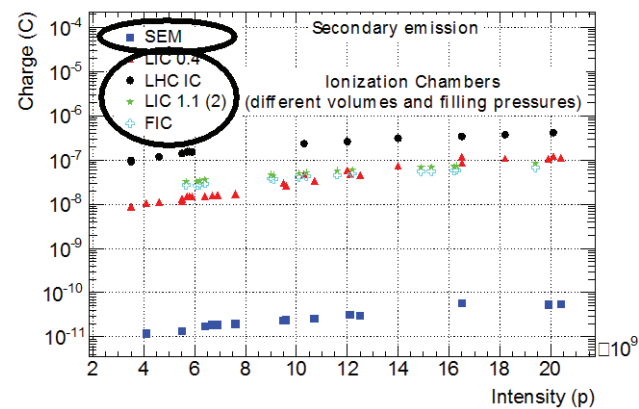
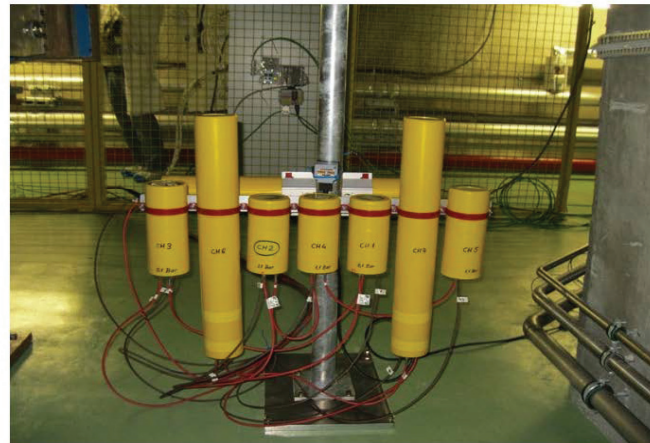
- Little Ionization Chamber (LIC) – detector, designed to reduce the sensitivity to saturate for higher losses.



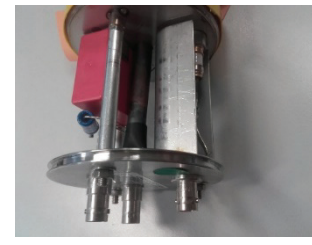
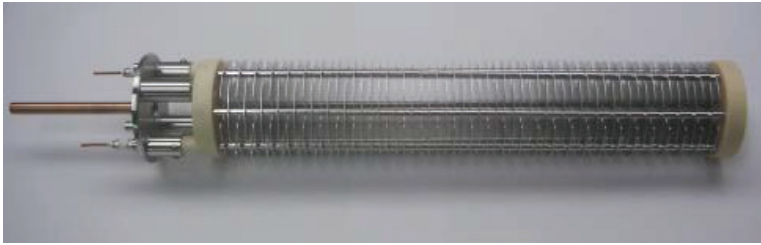
- Flat Ionization Chamber (FIC) -detector designed to geometry considerations.



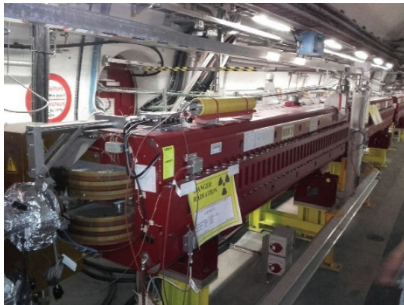
Families of BLM



BLM Ionization Chambers and SEM at CERN



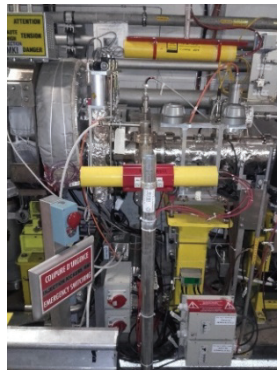
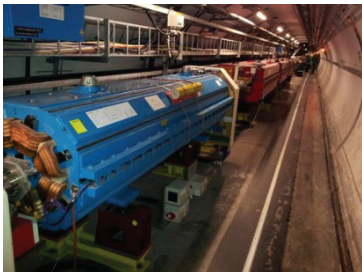
BLM LHC system had ~3929 monitors
with 3518 Ionization Chambers (IC), 108 LIC and 191 SEM



BLM PSB system had 32 installed IC and 32FIC.



LINAC 2 had 5 IC
LINAC 4 installed 24 IC
~100 ICs are in PS

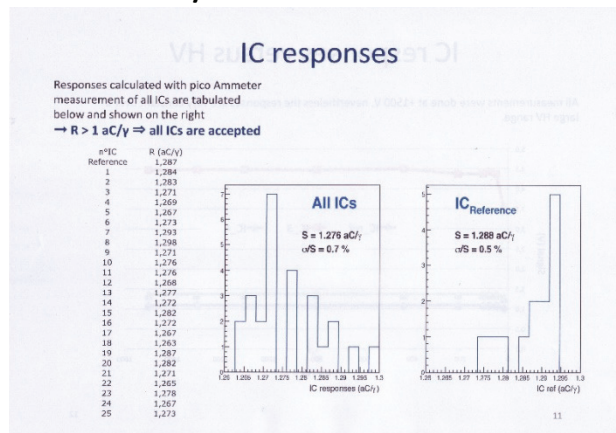


BLM Ionization Chambers at CEA, GSI, ESS

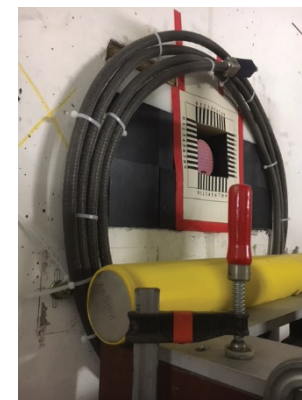
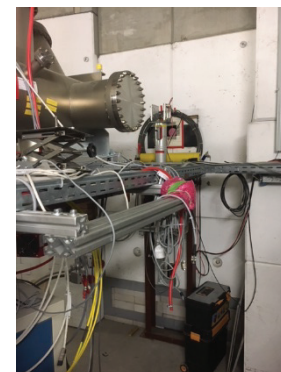


EUROPEAN
SPALLATION
SOURCE

CEA /LIPAC



GSI

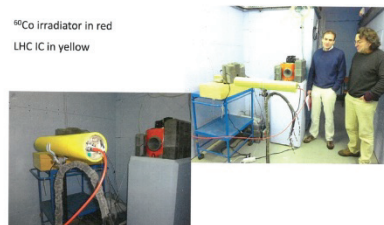


Courtesy and thanks to P.Boutachkov and P.Kowina

Experiment... the proof by the pictures!



CoCase Gallery



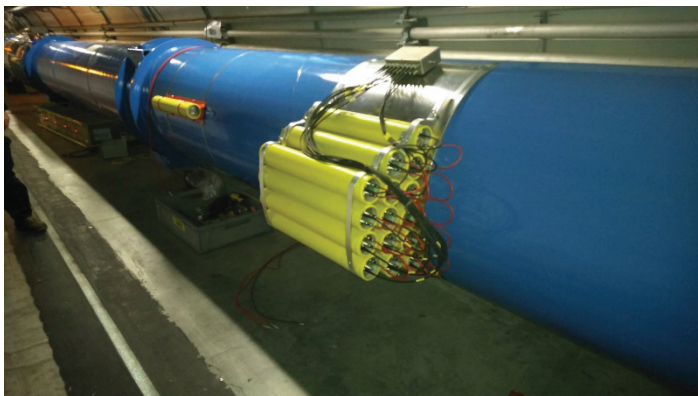
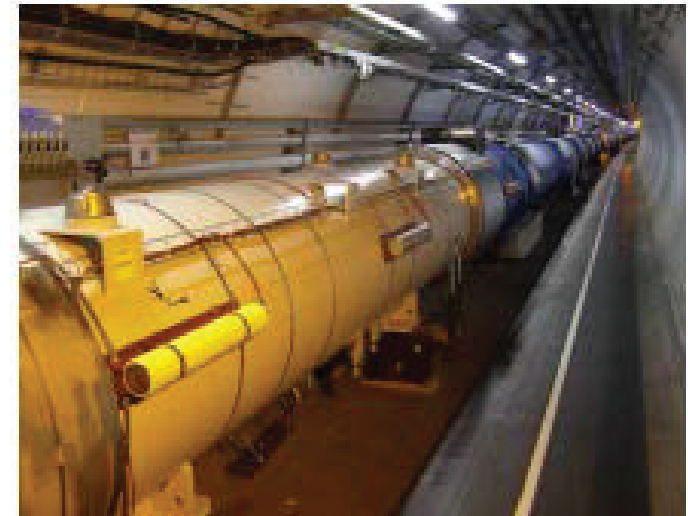
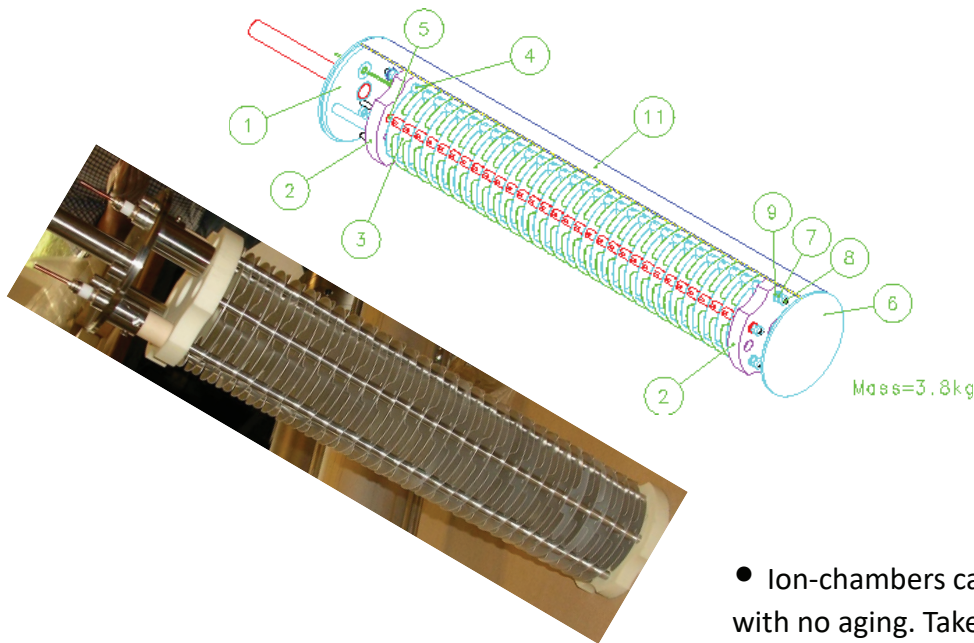
ESS



Courtesy and thanks to J.Marroncle and CEA team

Thanks to A. Jansson, L. Tchelidze
T. Shea, C. Derrez

Ionization Chamber



- Ion-chambers can be build from **radiation hard** materials (ceramic, metal), with no aging. Take care about the feedthroughs. No problems up to more than 10^8 rad
- Large numbers >4000 for CERN => **cheap**
- **LHC:** It is necessary to periodically verify the connection to the corresponding channels of the electronic system and the **signal quality of all detectors by radioactive source.**

Ionization Chamber



First publications



EUROPEAN
SPALLATION
SOURCE

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — SL DIVISION

COMPARATIVE TEST RESULTS OF VARIOUS MONITORS IN PREPARATION FOR LHC

Bosser, J., Ferelli, G.
CERN — Geneva, CH

Abstract

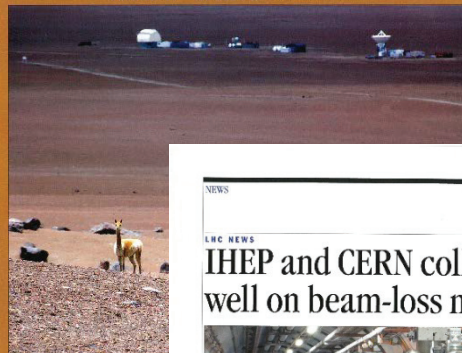
Beam loss detectors will play an important role in the protection of the LHC magnets. Different types of detectors have been tested in the SPS ring and several with a view to their possible use for this application. This paper describes the measurements made with: microcalorimeters, superconducting, PIN diodes, scintillation chambers, scintillators, and AC-FMs. Measurements made using proton beams showing their relative sensitivity to existing or analog mode and minimum detection level will be presented.

Presented at DIPAC
Chamonix — 16-18 May 1999

Geneva, Switzerland
August, 1999

CERN COURIER

VOLUME 47 NUMBER 8 OCTOBER 2007



Astronomy

ACCELERATORS
HEPFA opens a
major milestone p3

NEWS

LHC NEWS

IHEP and CERN collaborate well on beam-loss monitors



Beam-loss monitoring (BLM) chambers, two yellow tubes on the red secondary monitor on an LHC quadrupole magnet.

The existing beams will store an unprecedented amount of energy when the LHC is in operation. If there is a small fraction of this beam deviates from the correct axis, it may lead to a quench in the superconducting magnets or even cause physical damage to system components. The LHC beam-loss monitoring (BLM) system is the key to entering the crucial high-energy era of the LHC.

The BLM system generates a beam about 100 ns after the maximum rate of loss has exceeded pre-determined safety thresholds. The loss beam sources enable beam-loss monitors through the magnets, which are measured for monitors installed outside of the tunnel and not inside the tunnel. About 4000 BLMs — mainly sensitive chambers — will be installed around the LHC ring. They are the result of a successful collaboration between CERN and the Institute for High Energy Physics (IHEP), in Beijing, China. CERN developed the monitors and IHEP manufactured them during the past year.

using industry-produced components. Signal speed and threshold against noise were the main design criteria. The monitors are about 10 cm long with a diameter of 10 cm and a sensitive volume of 1.5. Each one contains 61 parallel channels, each with a signal level of 0.1 cm and is filled with nitrogen at 100 mbar pressure and a sensitivity of 1000 counts per cm² per second. The signal level is 1.5 kV and is equipped with a two-stage filter to the high voltage. The resolution time of the detectors is 20 ns. The LHC operation is estimated at 2 × 10¹⁶ p/pb in the collision region, and 2 × 10¹⁶ p/pb at the other locations. To avoid detector noise, production of the monitor components indicated a direct change in the LHC design. The LHC design is a major step from thermal and not from detector design should remain in the range of parts per million.

Standardized test samples analysed at CERN periodically helped to check the design performance. The beam at IHEP designed and built a special LHC plant to ensure reliable conditions for testing the monitors. They performed checks throughout the production phase and documented the results. The quality of the welding is a critical aspect, as the beam is not at all of the walls for loss lightness at several points. They also installed detector 1 to the vacuum and the assembled monitors during and after production. To ensure that the leakage current of the monitors stays below 100 nA, IHEP achieved a consistently high quality for the monitors during the whole production period and kept the LHC production schedule. Tests at CERN's Geneva Radiation Facility of 4750 monitors found fewer than 1% to be outside of the strict tolerance limits.

НАУЧНОЕ ПРИБОРОСТРОЕНИЕ

В.В. ГРИНОВ, А.В. КОШЕЛ, А.В. ЛАРИОНОВ, Е.Н. ЛОМАКИН,
Ю.А. МИНАВИН, В.С. СЕЛЕЗНЕВ, М.А. СЕЛЮКОВ, А.Н. СЫТН, Ю.С. ХОДЯКОВ
Институт физики высоких энергий, г. Прованс

ОСОБЕННОСТИ ПРОИЗВОДСТВА В ИФЭВ ДЕТЕКТОРОВ ВТОРИЧНОЙ ЭМИССИИ ДЛЯ СИСТЕМЫ МОНИТОРИРОВАНИЯ ПОТЕРЬ ПУЛКА БОЛЬШОГО АДРОННОГО КОЛЛАЙДРА ЦЕРН

ИФЭВ специализируется на производстве и ИФЭВ детекторов вторичной эмиссии, используемых для мониторинга потерь пучка в туннеле. Проблемы, связанные с производством вторичных эмиссионных детекторов, описаны в статье. Представлены результаты тестовых образцов. В заключение даны рекомендации по работе с мониторами на туннеле.

**MANUFACTURE IN IHEP DETECTORS
OF SECONDARY EMISSION FOR BEAM LOSS
MONITORS LARGE HADRON COLLIDER CERN**
V.V. GRINOV, A.V. KOSELOV, A.V. LARIONOV, E.N. LOMAKIN,
YU.A. MINAVIN, V.S. SELEZNEV, M.A. SELUYKOV, A.N. SYTN, YU.S. KHODYAKOV
Institute for High Energy Physics (IHEP)

The process of production in IHEP detectors of the second emission is written up in the article, focus of beam observation used in the system of monitoring in most problems areas of Large Hadron Collider in European organization of nuclear researches. Description of a special vacuum technology is presented on cleaning and pumping out of detectors of the second emission on a stand. The construction of stand is presented. In a graphic form the results of measurements are revealed during work with monitors on a stand.

Най представлено описание технологии производства детекторов вторичной эмиссии, используемых для мониторинга потерь пучка в туннеле. Представлены результаты тестовых образцов. В заключение даны рекомендации по работе с мониторами на туннеле.

В ИФЭВ специализируются на производстве и ИФЭВ детекторов вторичной эмиссии, используемых для мониторинга потерь пучка в туннеле. Проблемы, связанные с производством вторичных эмиссионных детекторов, описаны в статье. Представлены результаты тестовых образцов. В заключение даны рекомендации по работе с мониторами на туннеле.



CHENNA 2. 2009.

PS-Booster Measurements for LHC-BLM October 2002

IHEP VACUUM STAND

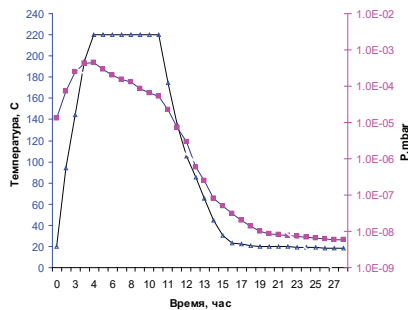


2005

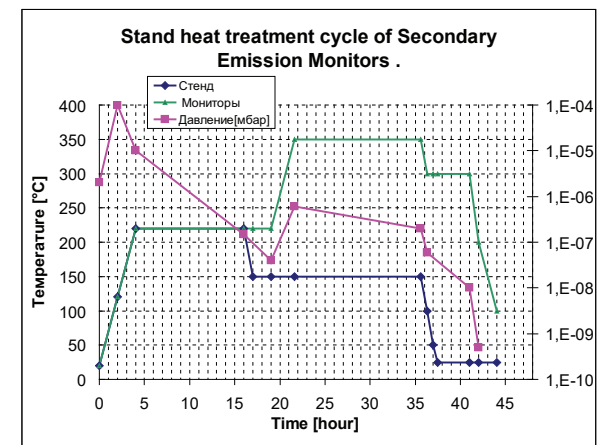


IHEP designed and built the Ultra High Vacuum production stand, which is equipped by quadrupole mass spectrometer, detecting the composition of the gases inside the system. The pumping system consists of two arms – manifolds with 18 connection ports with individual valves for each ionization detector of different types and dimensions, SEM or proportional chambers.

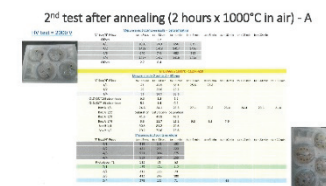
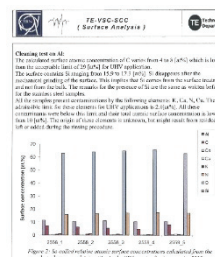
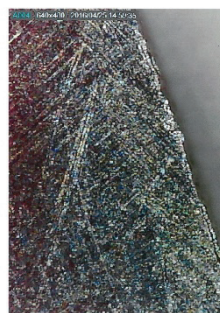
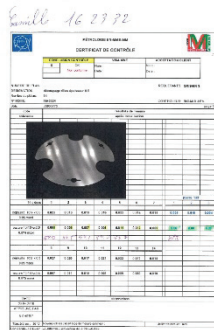
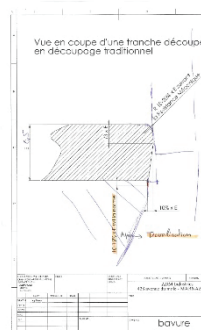
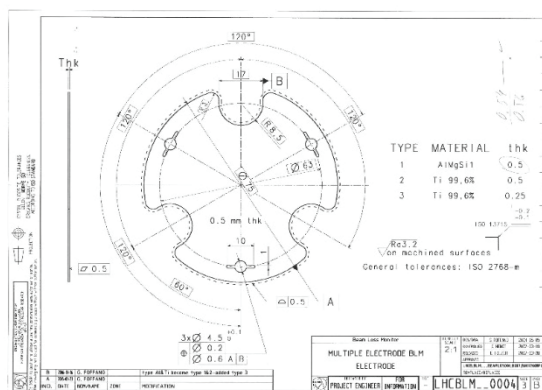
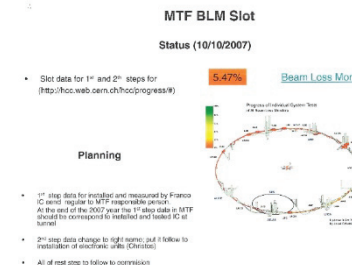
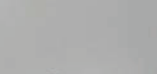
2018



Stand heat treatment cycle of the ionization chambers



Courtesy A.Larionov



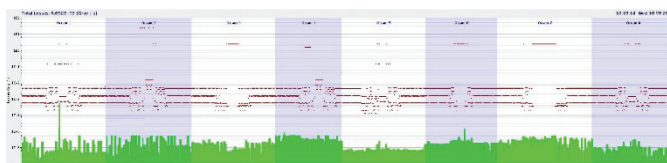
IONIZATION CHAMBERS



EUROPEAN
SPALLATION
SOURCE

- Design criteria: Signal speed and robustness
- Parallel electrodes (Al) separated by ~ 0.5 cm
- Voltage 1.5 kV

- Standard LHC



- ESS, GSI, LUPAC

- Length 50 cm; Sensitive volume 1.5 l

- 61 electrodes

- N₂ gas filling at 1.1 bar

- Composition of the chamber is the only component in the BLM system which is not remotely monitored online: Properties of the chamber gas are sufficiently close to air at ambient pressure (i. e. inside a detector which has developed a leak) in order not to compromise the precision of the BLM system, but sufficiently different to detect a leak during the annual test of all the chambers with a radioactive source.

- Electron / ion collection time 300ns / 80 μ s

- Monitor dynamic range ($> 10^8$):

limited by leakage current through insulator ceramics (lower) and saturation due to space charge (upper limit).

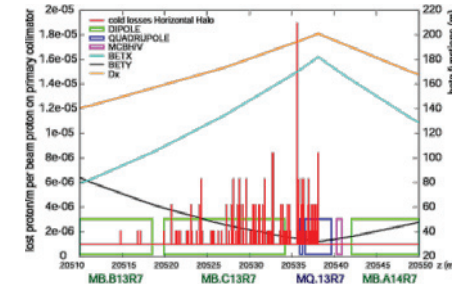


IONIZATION CHAMBERS

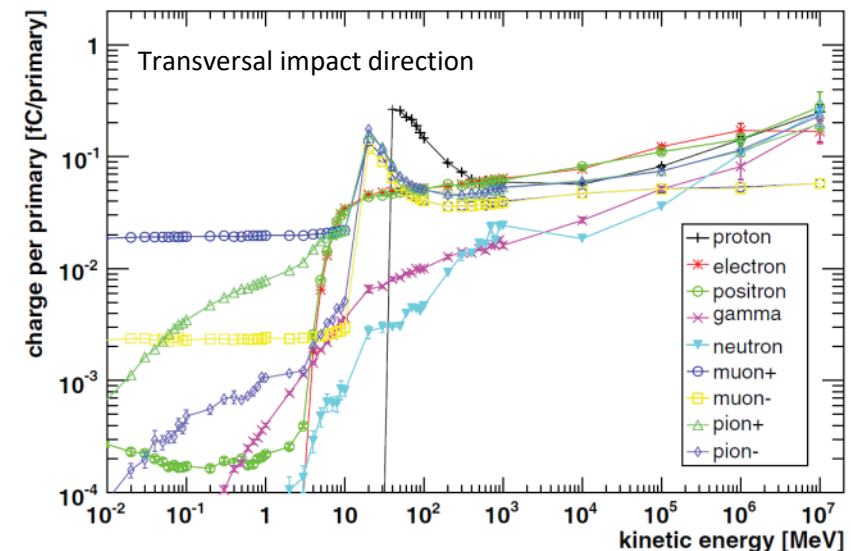


EUROPEAN
SPALLATION
SOURCE

- Relate the BLM signal to the:
 - Number of locally lost beam particles
 - Deposited energy in the machine
 - Quench and damage levels
- Extensive simulations and experiments during system design and beam tests in the LHC
 - **Proton loss locations** (tracking codes: MAD-X, SIXTRACK)
 - **Hadronic showers through magnets** (GEANT, FLUKA)
 - **Magnet quench levels** as function of beam energy and loss duration
 - **Chamber response to the mixed radiation field** (GEANT, FLUKA, GARFIELD)
 - **Collimators region simulation** (Talanov, Baishev, Kurochkin, Protvino)



IC response function



Tests of IC



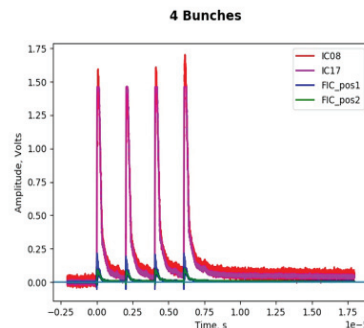
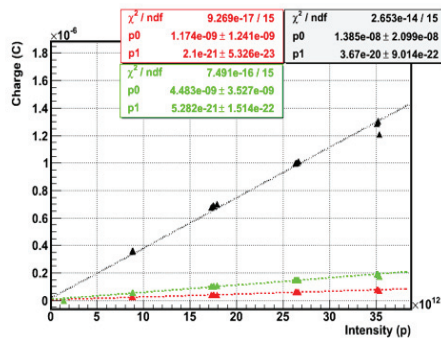
Dose rate to current conversion for ionization chambers:

energy deposited by ionizing particles in the chamber gas is converted to a signal current.

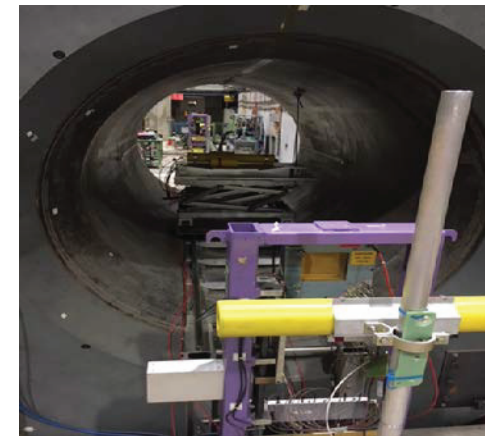
$$1 \text{ Gy/s} = 5.4\text{E-}5 \text{ A (for IC)}$$

$$1 \text{ Gy/s} = 3.86\text{E-}6 \text{ A (for LIC)}$$

HRM



H2



The monitors are testing at different environment:

Xrays measurement in Spiral2 by J.Marroncle (CEA) and ESS team in Uppsala (Sweden),
in magnetic field at 1.5 Tesla in H2 channel at CERN.

DETECTORS VERIFICATION



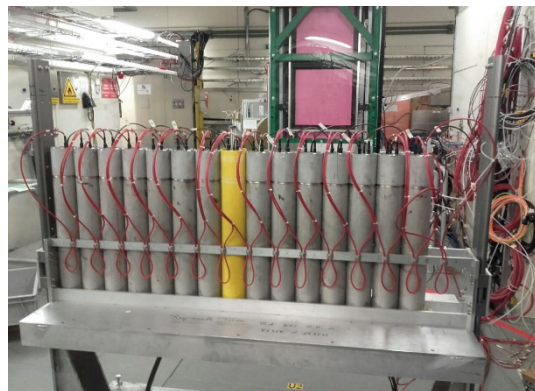
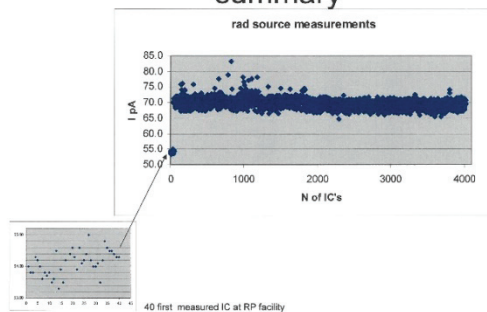
EUROPEAN
SPALLATION
SOURCE

Each detector is calibrated by using a strong gamma source in the CERN Gamma Irradiation Facility (GIF and next generation GIF++).

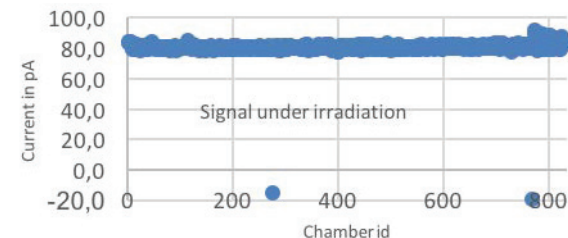
For each detector the tests consists of leakage current and radioactive source induced signal measurements.

4250 IC -2008

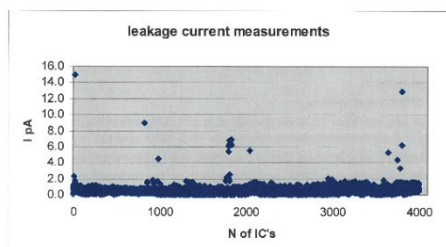
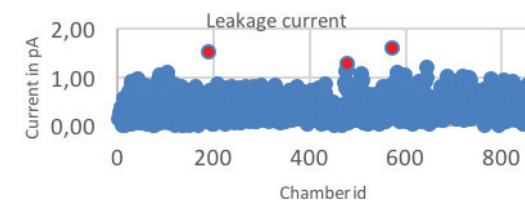
Rad source signal :
summary



830 IC -2017
830 IC -2017



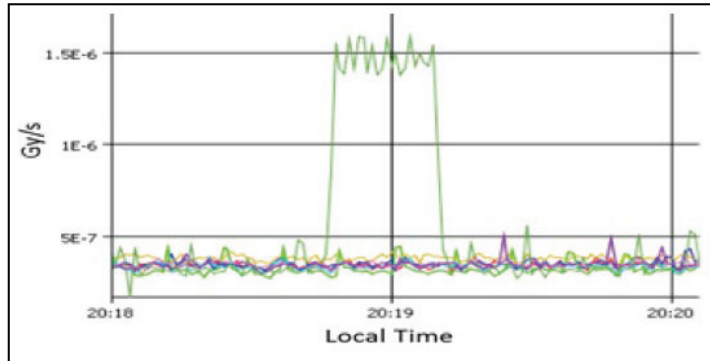
Leakage Current Measurements:
summary



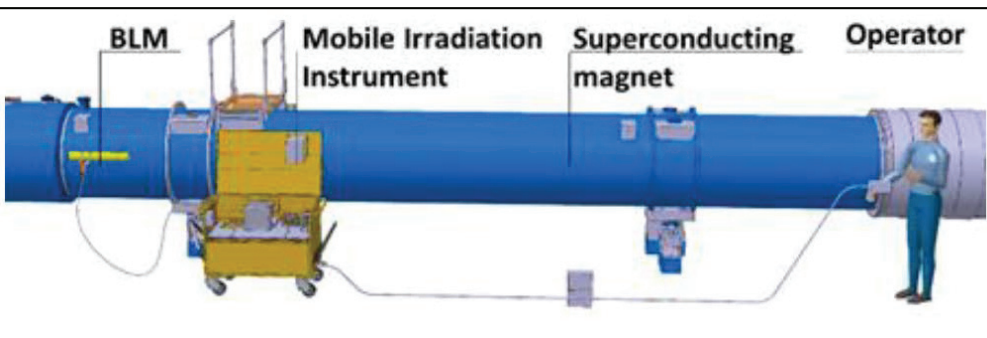
Verification of IC in LHC tunnel



EUROPEAN
SPALLATION
SOURCE



- **LHC:** It is necessary to periodically verify the connection to the corresponding channels of the electronic system and the **signal quality of all detectors by radioactive source.**



Courtesy D. Gudkov



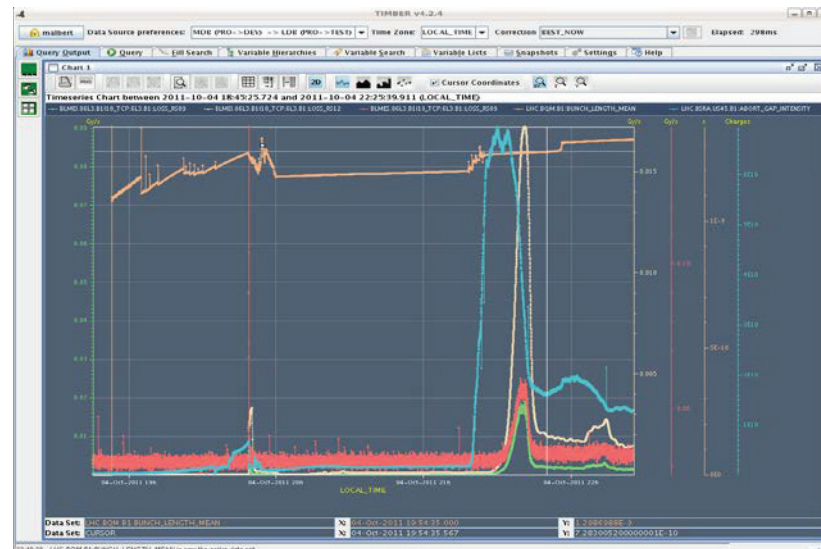
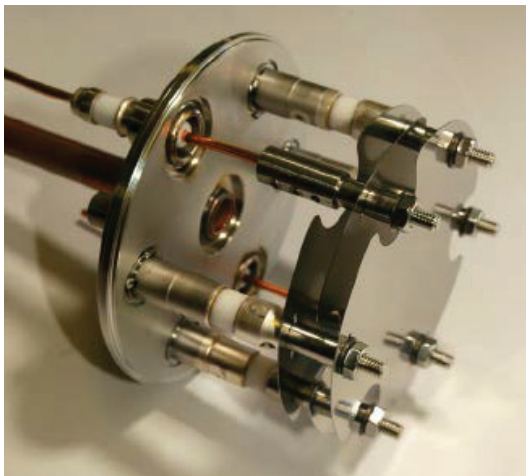
Secondary Emission Monitor



In accelerator areas with very high dose rates SEM chambers are employed to increase the dynamic range. The SEM is characterized by a high linearity and accuracy, low sensitivity, fast response and a high radiation tolerance. The signal and bias electrodes are made of Ti to make use of Secondary Emission Yield stability. The emission of the electrons from surface layer of metals by the passage of charged particles is only measurable in a high vacuum, which leads to an ultra high vacuum preparation of the components and to an additional active pumping realized by a getter pump (NEG). The sensitivity is about a factor of $3\text{--}7 \times 10^4$ smaller than in the ionization chamber.

$<10^{-7}$ bar

$< 1\%$ ionization to avoid nonlinearities

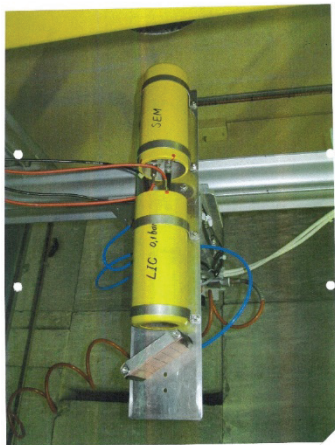
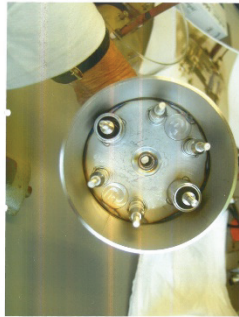


A nice signal of a SEM and IC at IP3 in 2011

Little Ionization Chamber



- The LIC detectors have been designed to reduce the sensitivity to saturate for higher losses with respect to LHC IC and to be a good extension to the IC. While IC performance works well for protection, the limited dynamic range of read-out electronics are saturated for high losses and LIC is the most feasible detector. The LIC active zone consists of 3 parallel Aluminium electrodes, nitrogen filled with ceramics insulator SEM type.



Pressure N2, [mbar]	U, [kV]				Current , [pA]
100	1,5				< 1
100		2,0	2,3		spark
200		2,0		3,0	< 1
200			2,5		spark
300			2,5	3,0	< 1
300				3,0	spark
400				3,0	< 1
500				3,0	< 1



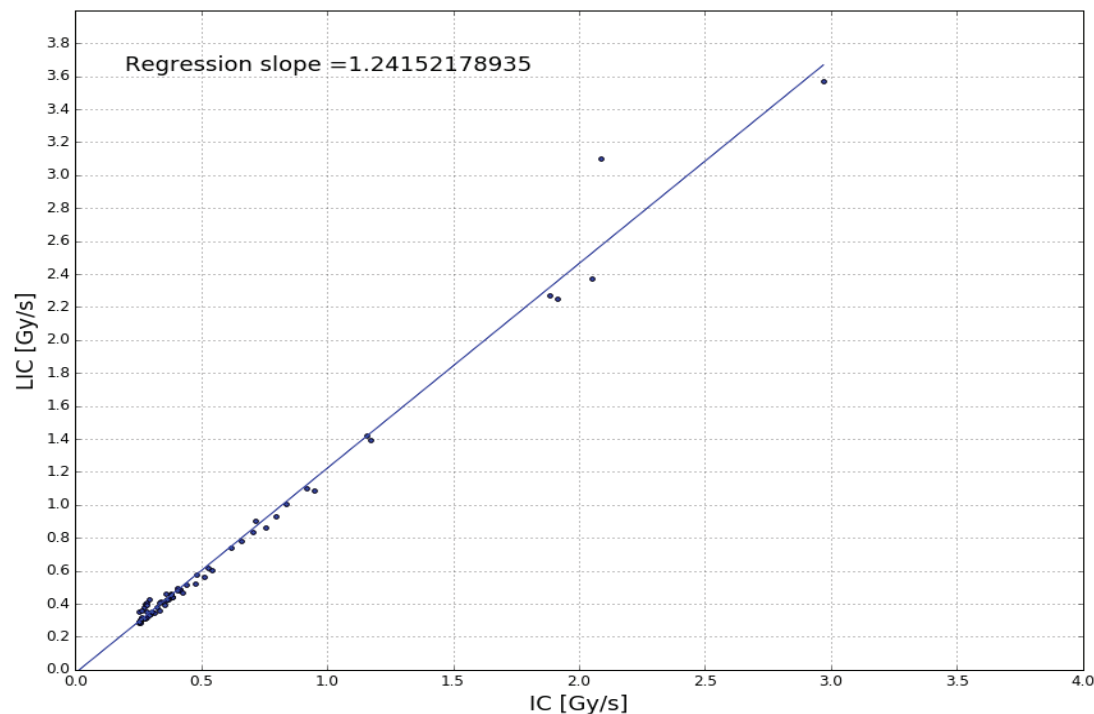
Choice of LIC working pressure with two and one shieldings

Finally – 1.1 bar and 280 LICs refilled

Little Ionization Chamber



108 LICs are installed in LHC injection regions. The comparison of measured absorbed dose rates in IC and LIC in LHC location behind a collimator in Interaction Region 7 of the LHC. with similar impact angle. In this case the IC/LIC ratio appears to be close to 1.



Courtesy M. Kalliokoski

Flat Ionization Chamber

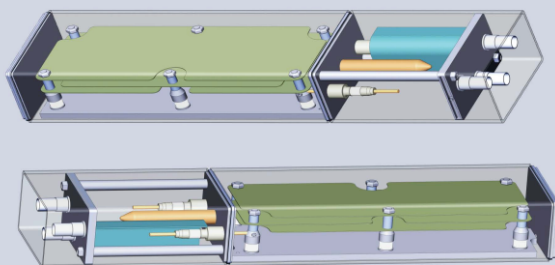


EUROPEAN
SPALLATION
SOURCE

The FIC detectors designed to geometry considerations and foreseen to be located and currently installed in LHC booster. The prism FIC active zone consists of 3 parallel Aluminium electrodes, nitrogen filled with special designed ceramics insulator SEM type.

Design and production of the first flat ionization chamber (FIC). CERN, IHEP (Protvino)

A. Larionov, B. Dehning, V. Grishin, V. Seleznev, A. Kopyrin



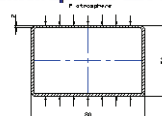
Design and production of the first flat ionization chamber.

Bernd's proposal:

- the flat ionization chamber with dimension in beam direction about 50mm for Booster;
- the standard rectangular st. steel tube with 50x80mm dimensions and 2mm wall thickness.

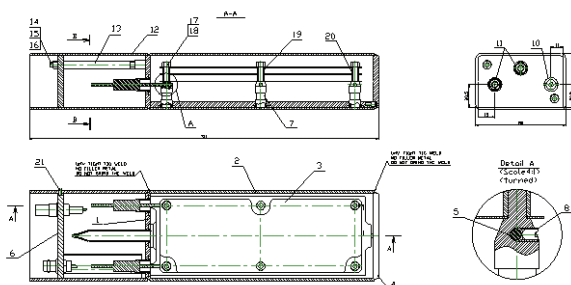
It was executed check-up of the tube wall strength as flat chamber is pumping during production time.

Check-up of the tube wall strength

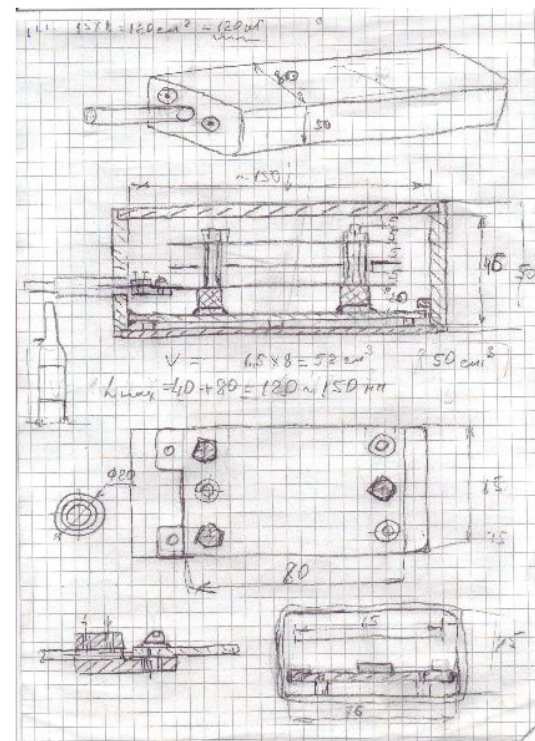


- For st. steel 304L: yield strength – $\sigma_y = 170 \text{ MPa}$, coefficient of strength stock $n_y = 1.5$.
- Permissible stress for yield strength: $\sigma_{yp} = \sigma_y / n_y = 113 \text{ MPa}$
- The wall thickness is as $S = 224b / \sqrt{\sigma_{yp} + c} = 2.1 \text{ mm}$, where $b = 80 \text{ mm}$ – wall length, $C = 0.4$ – thickness tolerance.
- Finally rectangular tube with 2mm wall is suitable.

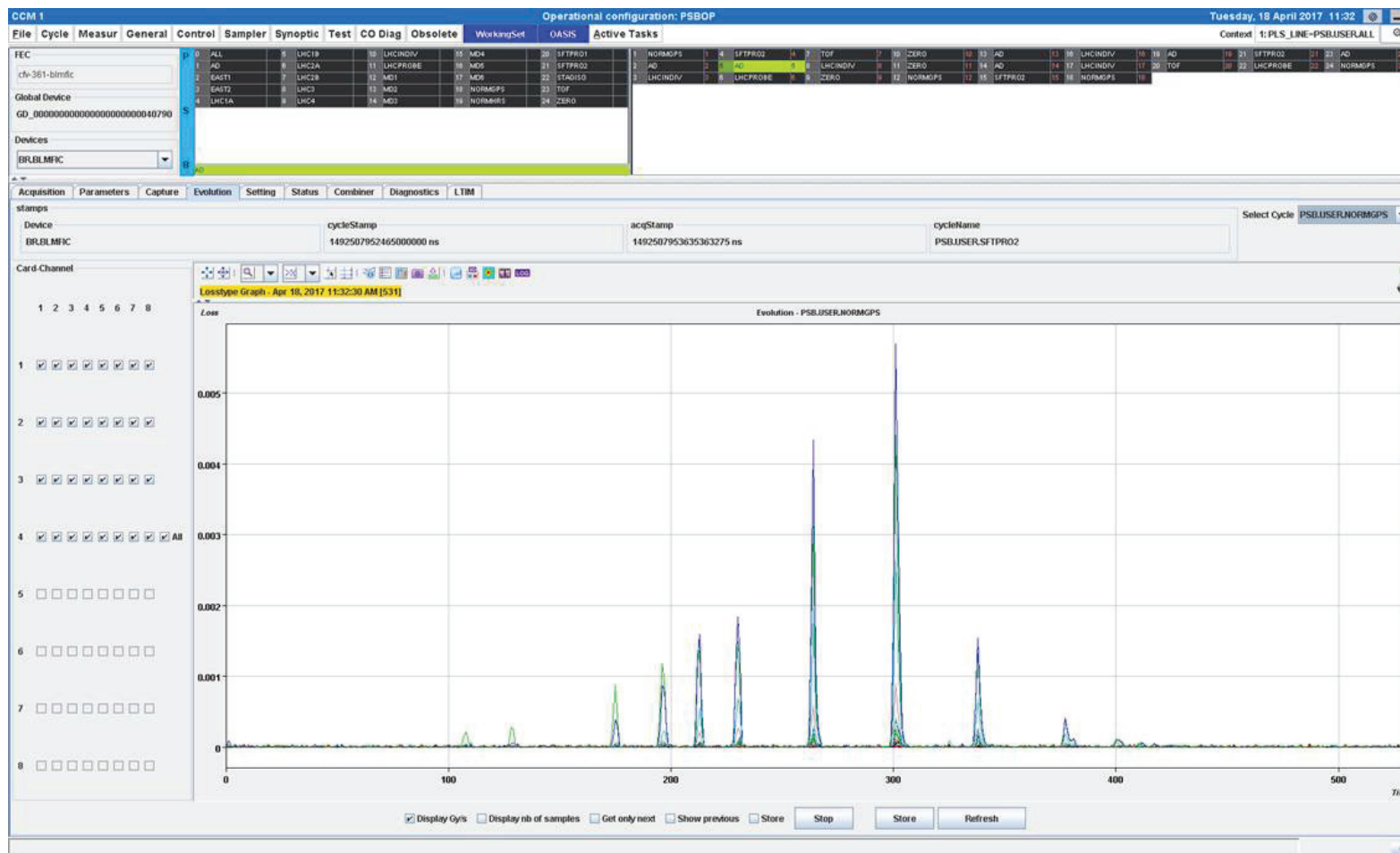
Flat IC assembly



- Outer dimensions: 50x80x310mm.
- Working volume $\sim 100 \text{ cm}^3$.



The nice first signals from BLM FIC at PSB



ACKNOWLEDGEMENTS



- B.Dehning, B.Holzer, G.Feroli, E.Effinger, C.Zamantzas, J.Emery, T.Stockner, D.Kramer, E.del Busto, A.Nordt, W.Vigano, J.Alvarez, T.Medvedeva, R.Tissier, I.Savu, D. Gudkov and many others from CERN
- V.Seleznev, A.Sytin,A.Larionov, M.Sleptsov, A.Koshelev and many others from Protvino
- N. Tyurin, A. Zaytsev and all administration of IHEP, Protvino
- R.Garoby, R.Jones, JJ Gras who attended the 1st meeting of CERN-IHEP collaboration in September 2005
- A. Jansson, T. Shea, C. Derrez, L. Tchelidze from ESS ERIC
- J. Marroncle (CEA), P. Boutachkov and P. Kowina (GSI) for collaboration
- We thank ARIES for receiving the funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement 730871 for HiRadMat tests
- This paper is dedicated to the memory of the project leader, Dr. Bernd Dehning, who passed away in January 2017

Conclusion



EUROPEAN
SPALLATION
SOURCE

- ~15 years CERN-IHEP collaboration
- More than 6 000 beam loss monitors of different type have been designed, tested, produced in 2005-2018 at IHEP for the CERN, ESS, GSI, LIPAC, BNL
- The detectors are working perfectly (no damages, no quenches...)
- The vacuum stand are in working conditions
- The plans for future:
 - ~ 1000 BLM for SPS, ~100 LIC with IC ceramics
 - ~ designed by IHEP the proportional chambers

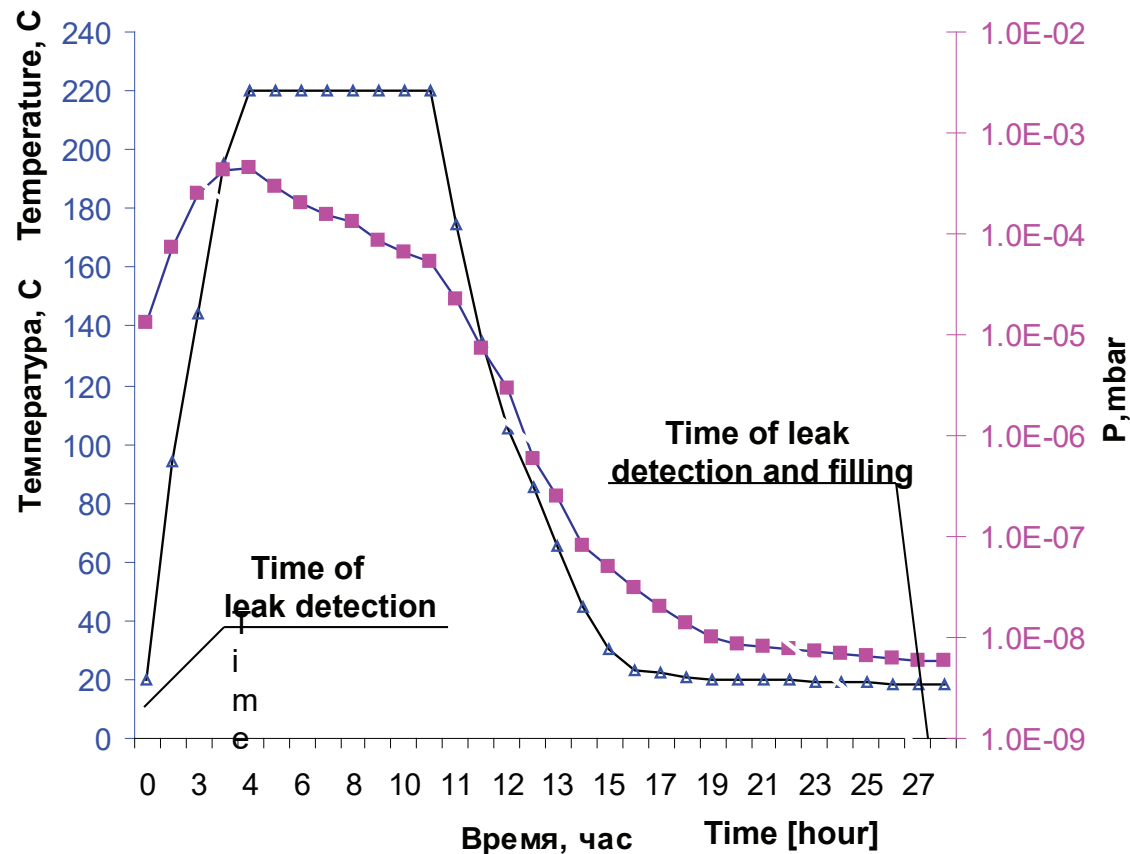


Backup



EUROPEAN
SPALLATION
SOURCE

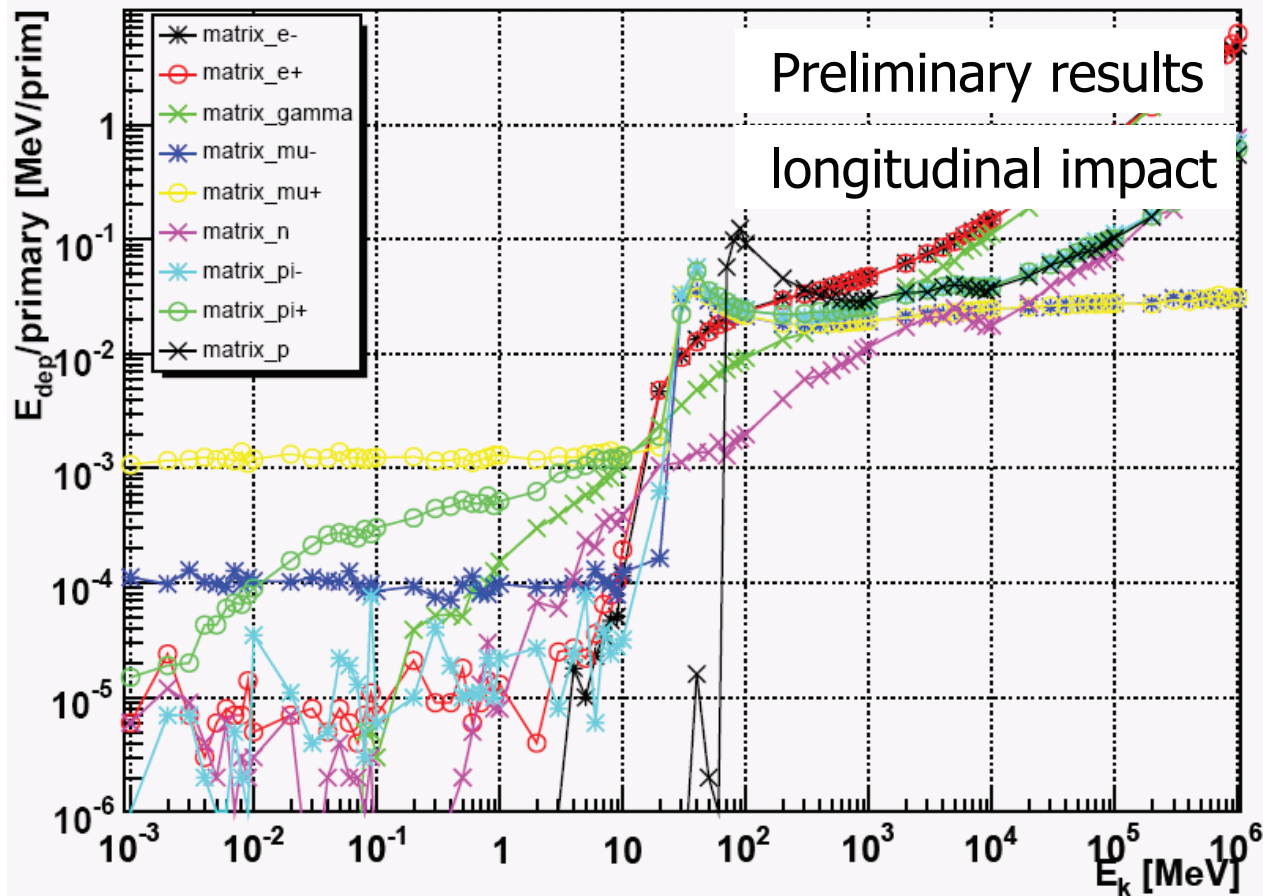
Stand heat treatment cycle of the ionization chambers



SPS Ionisation Chamber Spectrum Res

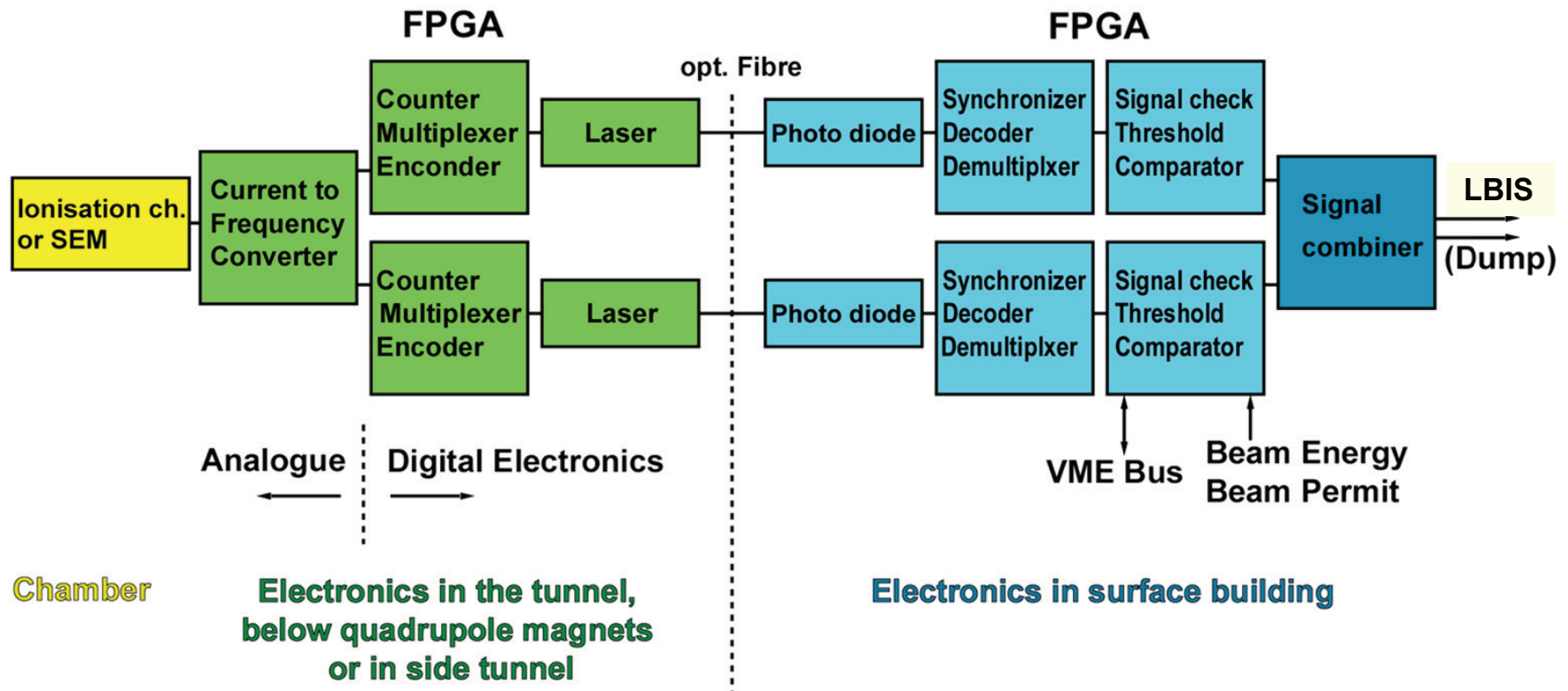


EUROPEAN
SPALLATION
SOURCE



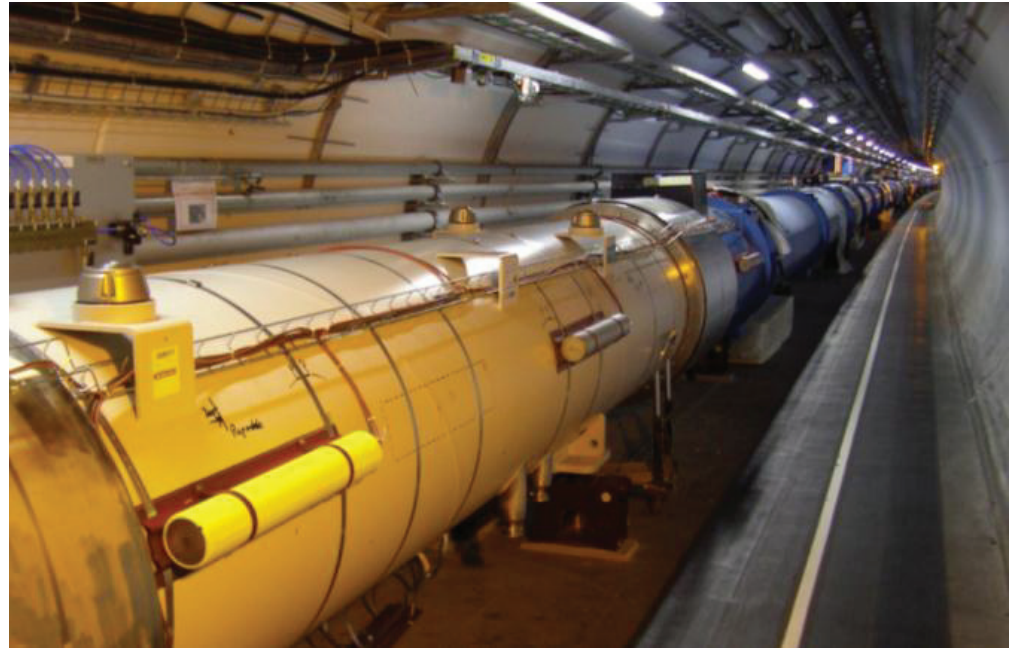
- Ionisation chambers:
 - H6 line measurements
 - HERA Dump
 - Response to mixed radiation field (chambers outside cryostat)
 - Comparisons with simulations (shown by H. Vincke)
 - Thesis M.Stockner
- SEM
 - Same procedure as for ion. ch.
 - BOOSTER
 - PSI
 - Thesis D. Kramer

System Layout



Threshold Comparator: Losses integrated and compared to threshold table (12 time intervals and 32 energy ranges).

- Main purpose: **prevent damage and quench**
- Beam abort thresholds:
 - 12 integration intervals:
40 μ s to 84s
 - 32 energy levels
→ 1.5 Million threshold values
- Each monitor aborts beam
 - One of 12 integration intervals over threshold
 - Internal test failed



$$1 \text{ [Gy/s]} \sim \frac{pV}{R_sTW} [\text{A}],$$

derived in Section 3.2.1.

With $R_s = 296.8 \text{ J Kg}^{-1} \text{ K}^{-1}$ as the specific gas constant of N_2 , $p = 1.1 \text{ bar} = 1.1 \text{ MPa}$, $T = 293.15 \text{ K}$ and $W = 35 \text{ eV}$ we find for the ICs

$$1 \text{ [Gy/s]} = 0.036 \text{ m}^{-3} \cdot V_{IC} [\text{A}] = 5.4 \times 10^{-5} \text{ A}, \quad (4.1)$$

and for the LICs

$$1 \text{ [Gy/s]} = 0.036 \text{ m}^{-3} \cdot V_{LIC} [\text{A}] = 3.86 \times 10^{-6} \text{ A}, \quad (4.2)$$

Table 4.4: Conversion factors used to convert the measured current to the dose rate deposited in the monitors and to the digitized signal. The conversion factors from gray to coulomb are derived from the properties of the monitors. The properties of the read-out electronics determine the conversion factor from bit to coulomb, while the factor between bits and grays follow from the other two.

	Gray to Coulomb	Bit to Gray	Bit to Coulomb
IC	$5.40 \cdot 10^{-5}$	$3.62 \cdot 10^{-9}$	$1.96 \cdot 10^{-13}$
LIC	$3.86 \cdot 10^{-6}$	$5.07 \cdot 10^{-8}$	$1.96 \cdot 10^{-13}$