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

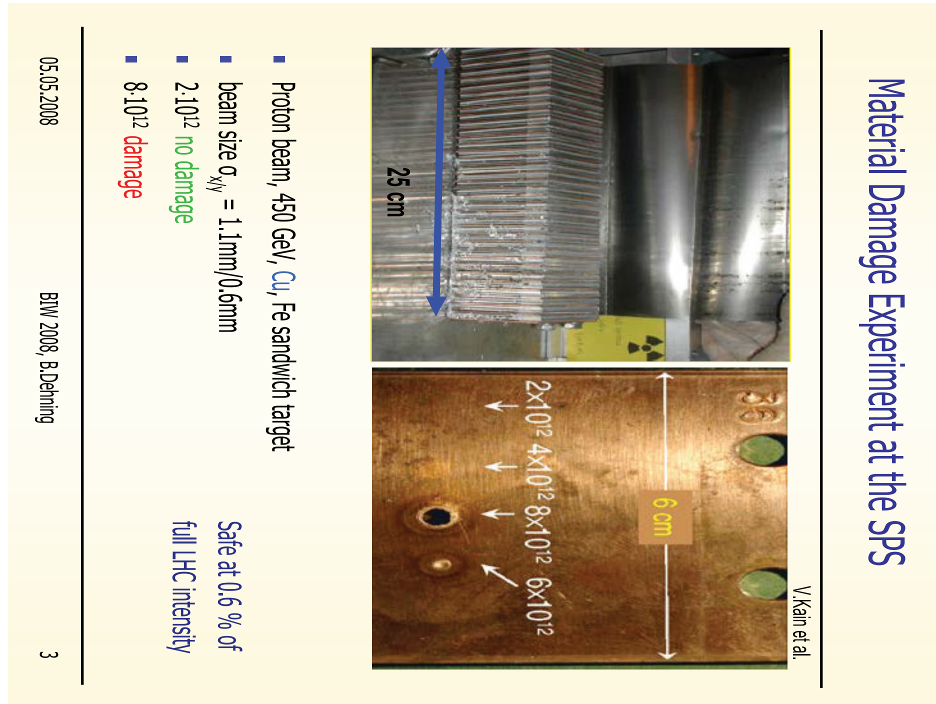
EUROPEAN SPALLATION SOURCE

RuPAC
2 October 2018

Viatcheslav Grishin on behaulf of BLM team

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



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

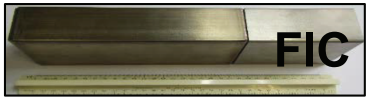
Beam loss monitors, produced by CERN-IHEP collaboration

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

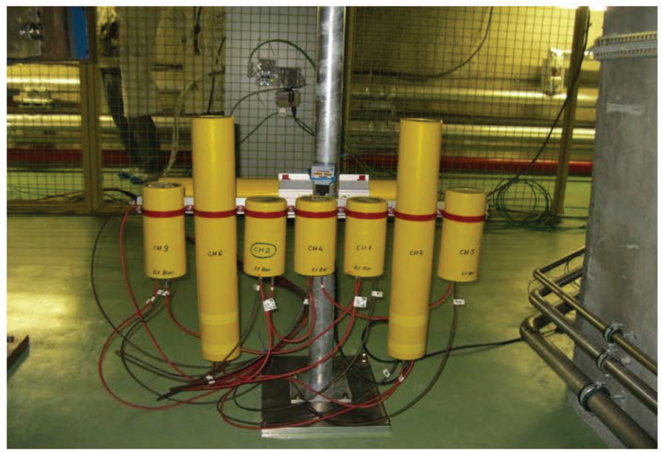
- Secondary Emission Monitor (SEM) – detector at very high dose rates locations.

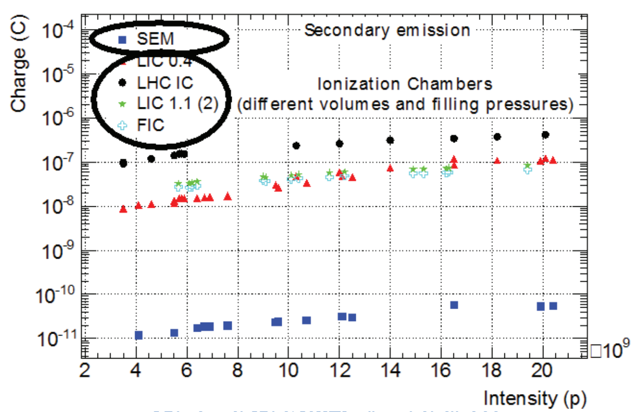
- Little Ionization Chamber (LIC) – detector, designed to reduce the sensitivity to saturate for higher losses.

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

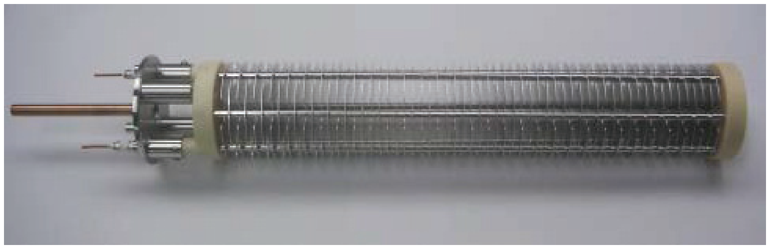


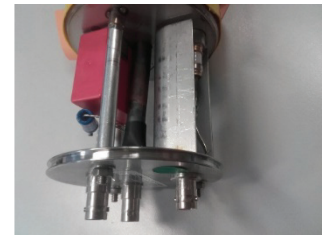
Families of BLM



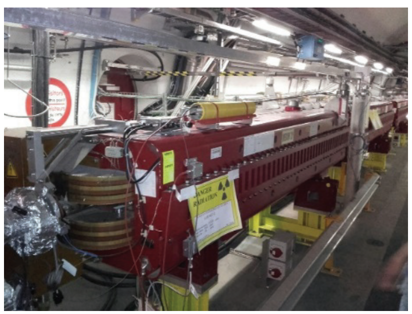


BLM Ionization Chambers and SEM at CERN



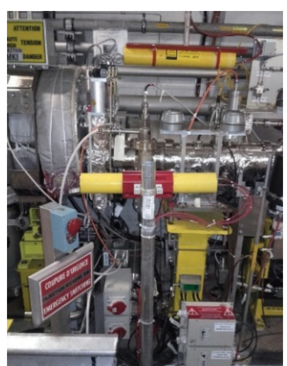


BLM LHC system had ~3929 monitors
with 3518 Ionization Chambers (IC), 108 LIC and 191 SEM



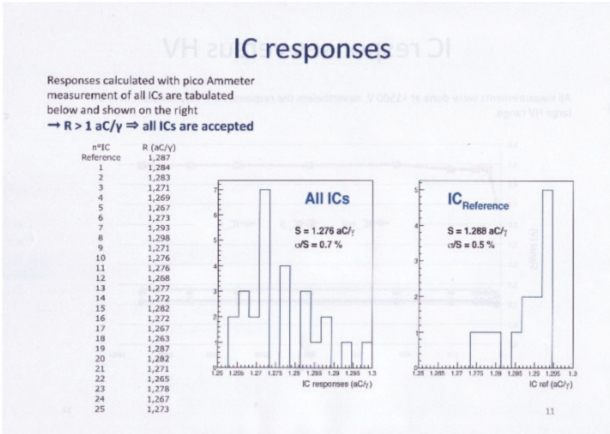
BLM PSB system had 32 installed IC and 32FIC.

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



BLM Ionization Chambers at CEA, GSI, ESS

CEA /LIPAC


IC responses

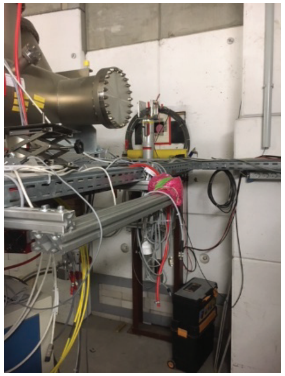
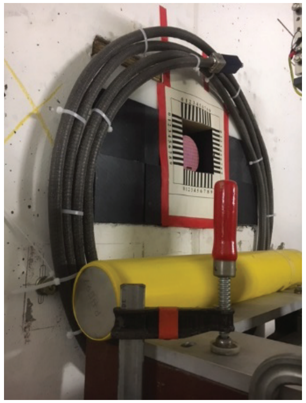
Responses calculated with pico Ammeter measurement of all ICs are tabulated below and shown on the right

→ R > 1 aC/γ ⇒ all ICs are accepted

n°IC	R (aC/γ)
Reference	1,287
1	1,284
2	1,283
3	1,271
4	1,269
5	1,267
6	1,273
7	1,293
8	1,298
9	1,271
10	1,276
11	1,276
12	1,268
13	1,277
14	1,272
15	1,282
16	1,272
17	1,267
18	1,263
19	1,287
20	1,282
21	1,271
22	1,265
23	1,278
24	1,267
25	1,273

11

GSI

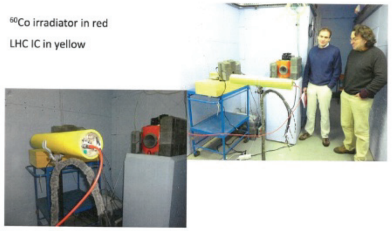
Courtesy and thanks to P.Boutachkov and P.Kowina

Experiment... the proof by the pictures!

CoCase Gallery

^{60}Co irradiator in red

LHC IC in yellow

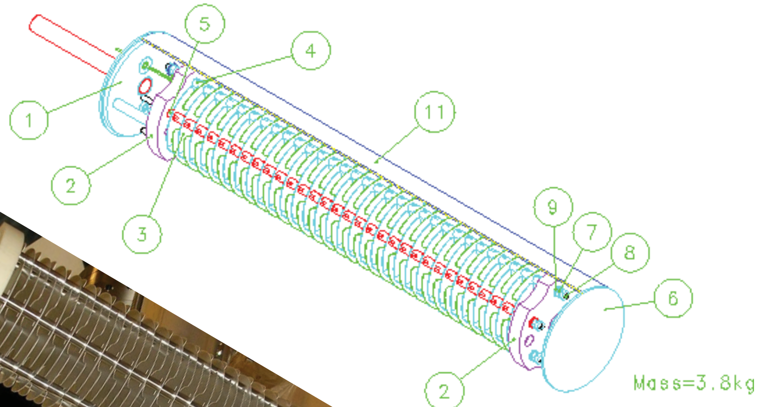


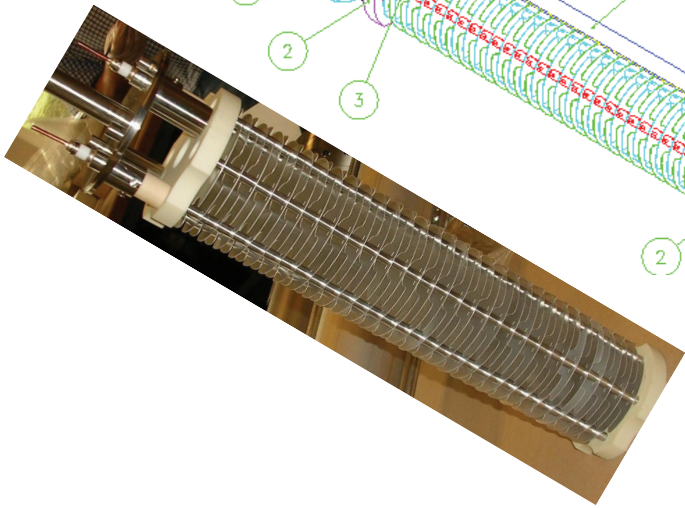
ESS

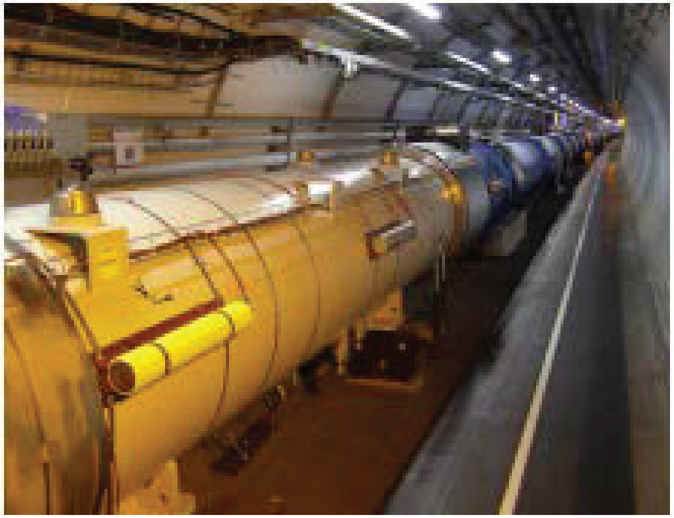
Courtesy and thanks to J.Marroncle and CEA team

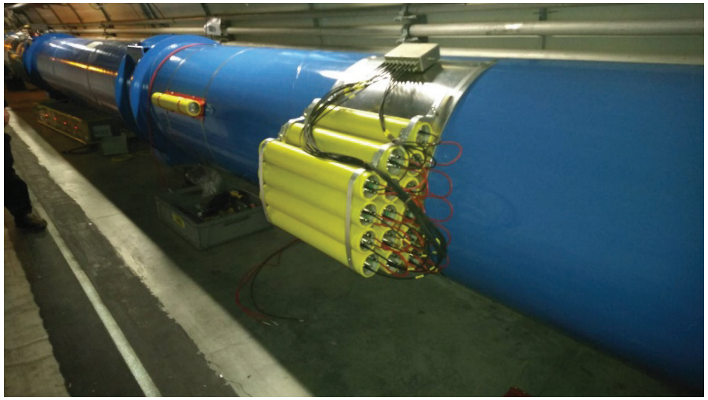
Thanks to A. Jansson, L. Tchelidze
T. Shea, C. Derrez

Ionization Chamber









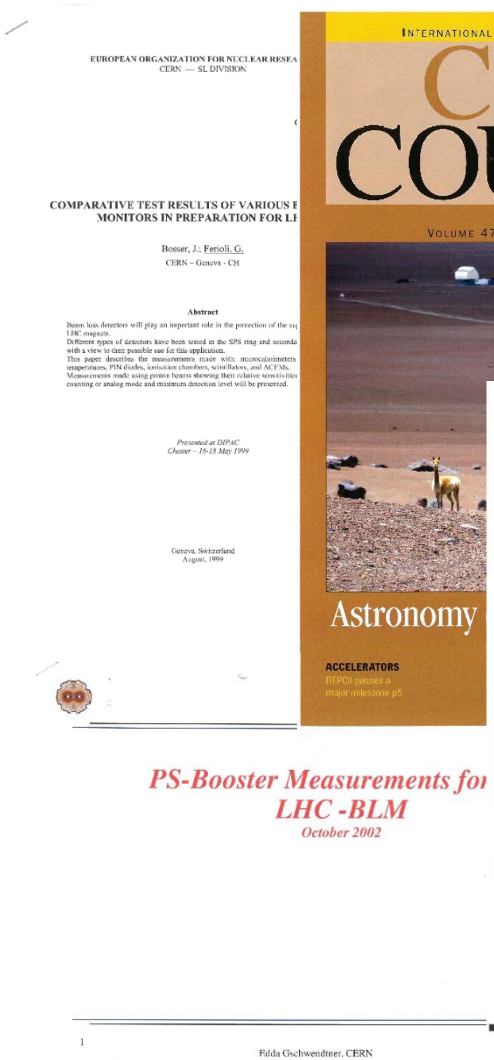
- Ion-chambers can be build from **radiation hard** materials (ceramic, metal), with no aging. Take care about the feedthroughs. No problems up to more than 10^8 rad

- 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 ORGANIZATION FOR NUCLEAR RESEA[RCH]
CERN — SL DIVISION

COMPARATIVE TEST RESULTS OF VARIOUS [...]
MONITORS IN PREPARATION FOR L[HC]

Bosser, J.; Ferioli, G.
CERN – Geneva - CH

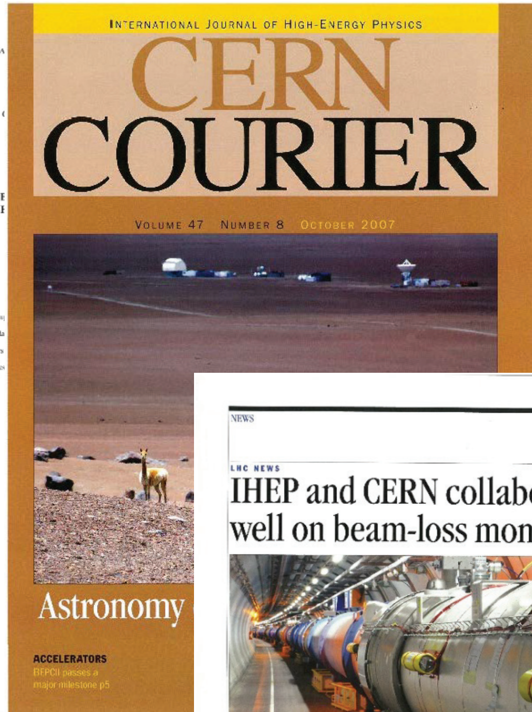
Abstract

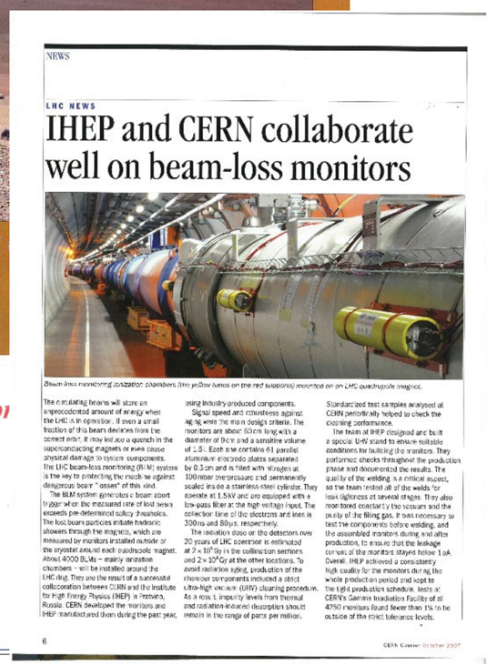
Presented at DIPAC
Chester – 16-18 May 1999

Geneva, Switzerland
August, 1999

PS-Booster Measurements fo[r]
LHC -BLM
October 2002

Edda Gschwendtner, CERN




NEWS

LHC NEWS

IHEP and CERN collaborate well on beam-loss monitors


НАУЧНОЕ ПРИБОРОСТРОЕНИЕ

ОСОБЕННОСТИ ПРОИЗВОДСТВА В ИФВЭ ДЕТЕКТОРОВ ВТОРИЧНОЙ ЭМИССИИ ДЛЯ СИСТЕМЫ МОНИТОРИРОВАНИЯ ПОТЕРЬ ПУЧКА БОЛЬШОГО АДРОННОГО КОЛЛАЙДЕРА ЦЕРН

[M]ANUFACTURE IN IHEP DETECTORS [...]Y EMISSION FOR BEAM LOSS [SYS]TEMS LARGE HADRON COLLIDER CERN

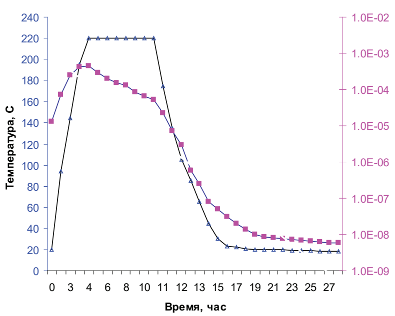
V.N. GRISHIN, A.V. KOSHELEV, A.V. LARIONOV, YE. N. LOMAKIN, YU.A. MISHAGIN, V.S. SELEZNEV, M.A. SLEPTSOV, A.N. SYTIN, YU.S. HODYREV
Institute for High Energy Physics (IHEP)

IHEP VACUUM STAND

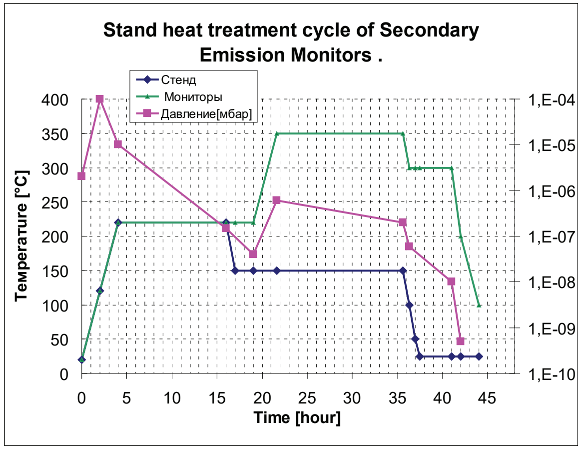
2005

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



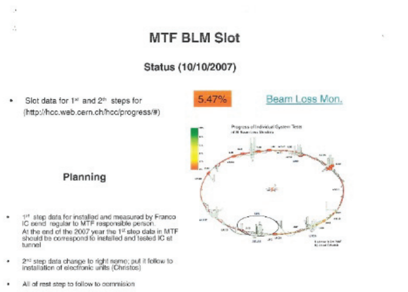
Stand heat treatment cycle of the ionization chambers

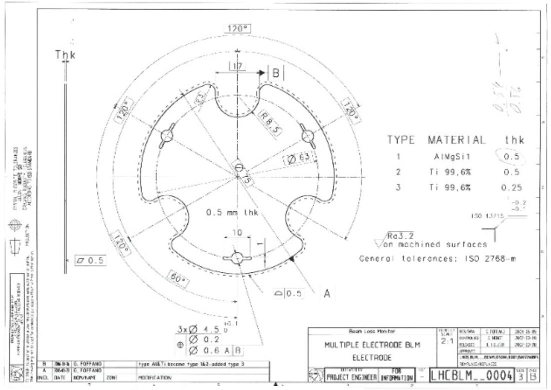


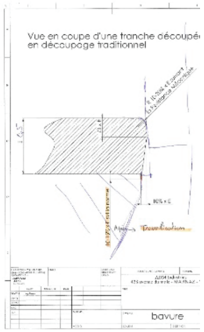
Courtesy A.Larionov

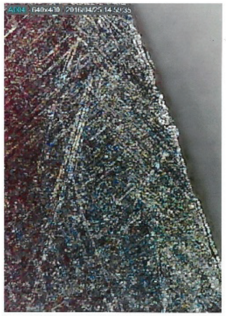
QUALITY TEST AT DETECTORS PRODUCTION

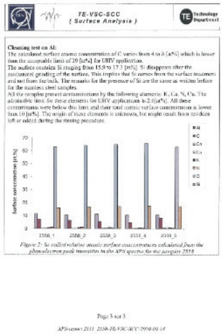
The various tests were performed at IHEP before, during and after the production to verify the quality of chambers. All welds are He leak tested, including the head.

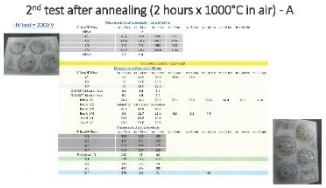






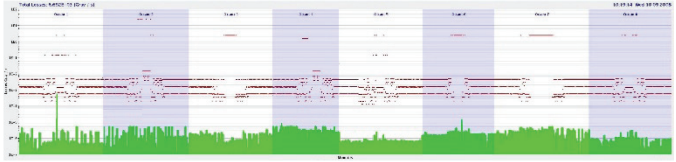






IONIZATION CHAMBERS

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



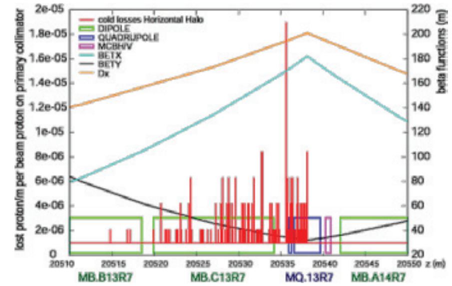
  - ESS, GSI, LUPAC
  - Length 50 cm; Sensitive volume 1.5 l
  - 61 electrodes
  - N_2 gas filling at 1.1 bar
    - Composition of the chamber is the only component in the BLM system which is not remotely monitored online: Properties of the chamber gas are sufficiently close to air at ambient pressure (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 / 80μs
  - Monitor dynamic range (> 10^8):

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

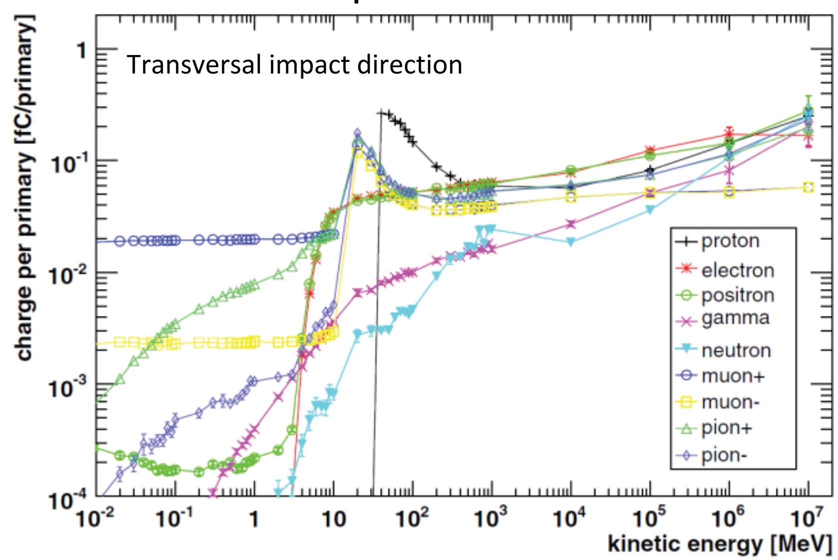
IONIZATION CHAMBERS

- 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



PhD Markus Stockner. Courtesy B.Holzer

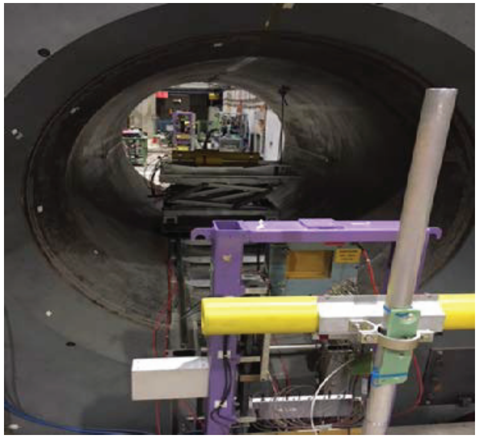
Tests of IC

Dose rate to current conversion for ionization chambers:

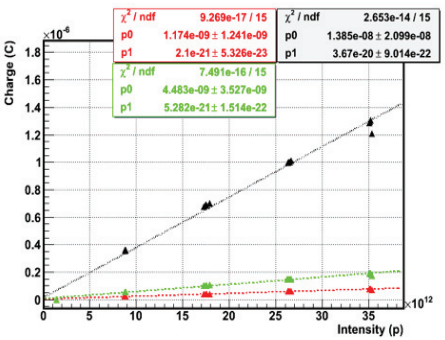
energy deposited by ionizing particles in the chamber gas is converted to a signal current.

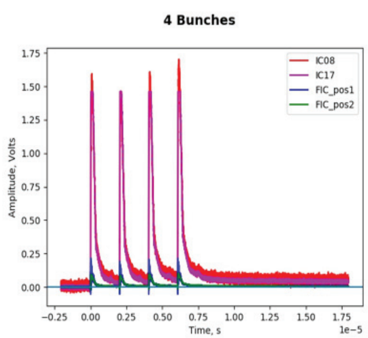
1 Gy/s = 5.4E-5 A (for IC)   1 Gy/s = 3.86E-6 A (for LIC)

H2



HRM





Courtesy E. Nebot del Busto

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.

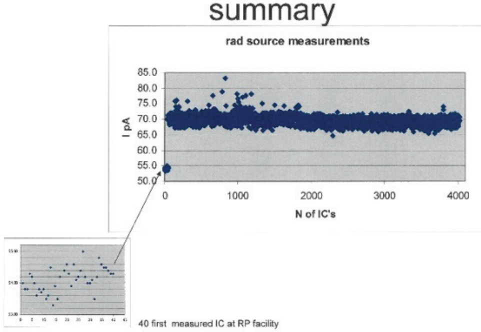
DETECTORS VERIFICATION

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

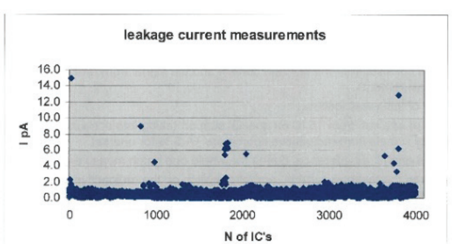
For each detector the tests consists of leakage current and radioactive source induced signal measurements.

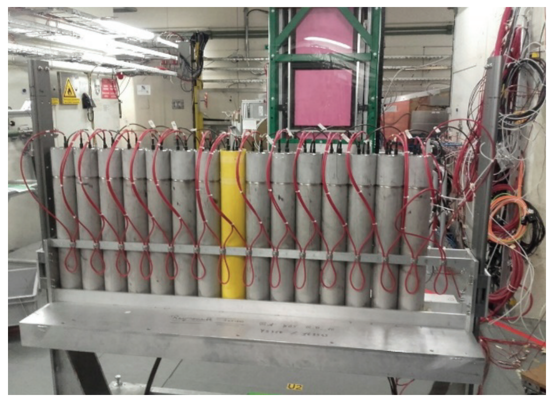
4250 IC -2008

Rad source signal : summary

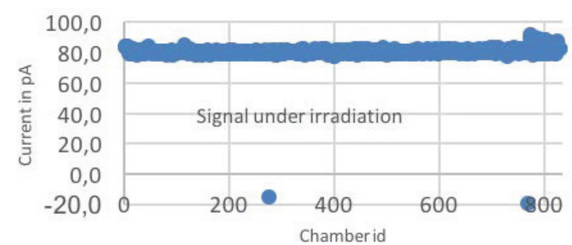


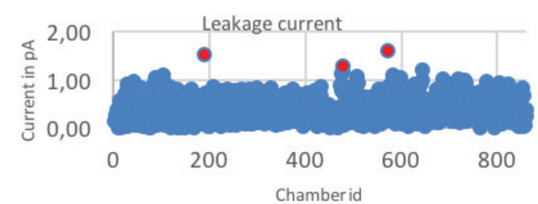
Leakage Current Measurements: summary



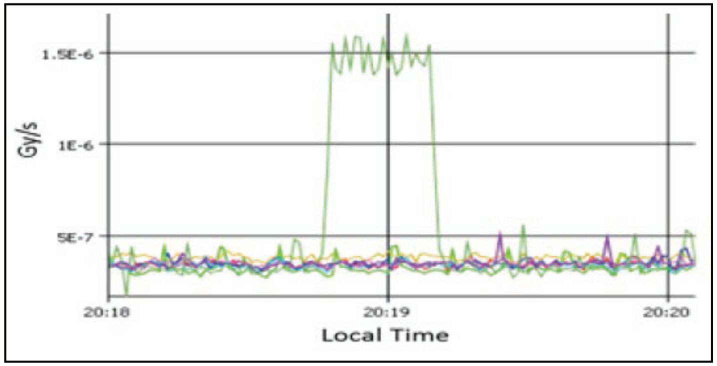


830 IC -2017
830 IC -2017





Verification of IC in LHC tunnel



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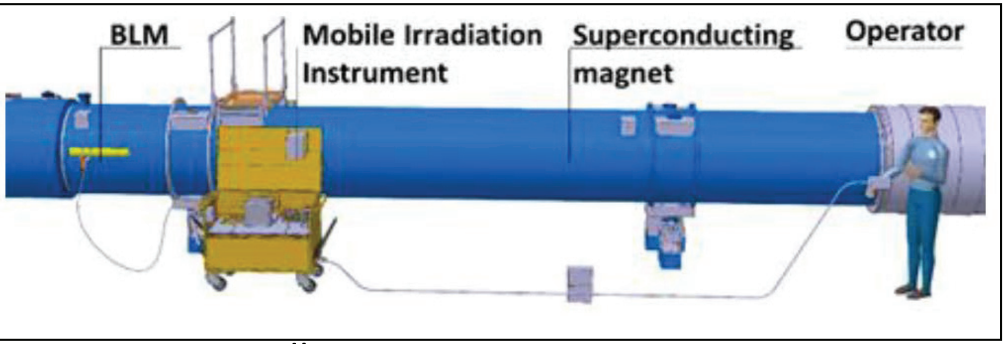


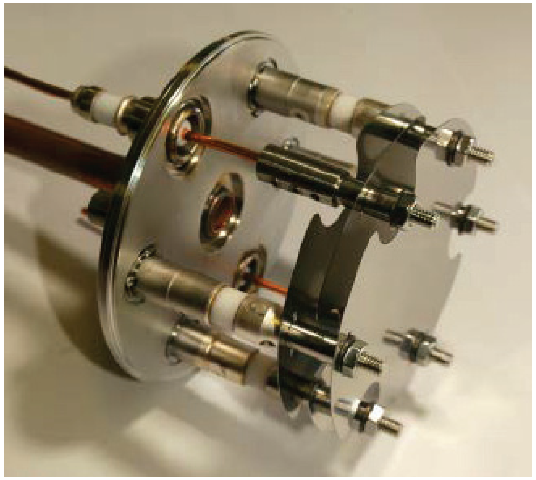
Courtesy D. Gudkov

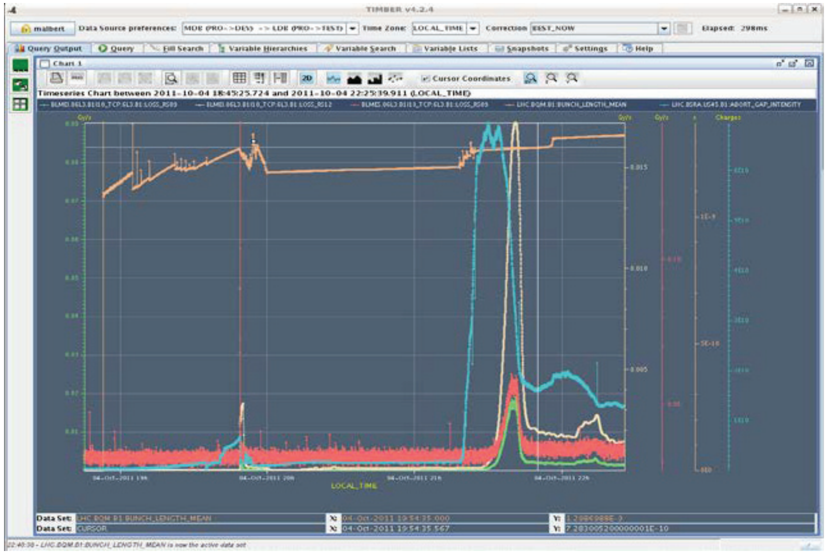
Secondary Emission Monitor

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 he components and to an additional active pumping realized by a getter pump (NEG). The sensitivity is about a factor of 3-7 x 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 satured 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.

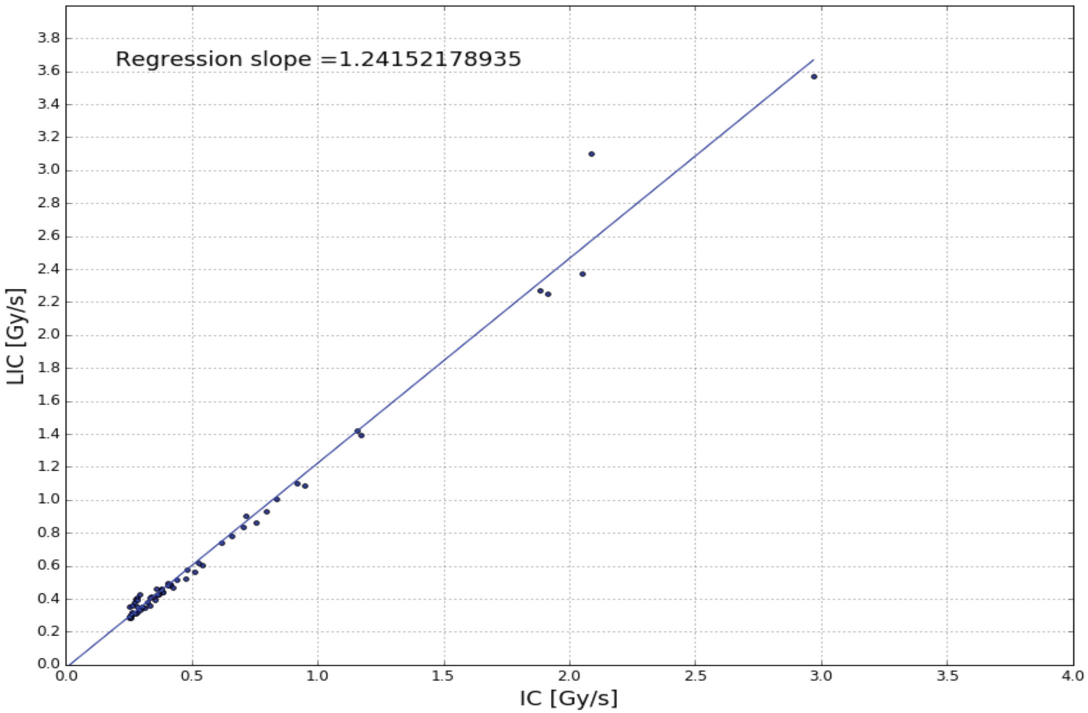
Pressure N2, [mbar]	U, [kV]				Current, [pA]
100	1,5				< 1
100		2,0	2,3		spark
200		2,0		3,0	< 1
200			2,5		spark
300			2,5	3,0	< 1
300				3,0	spark
400				3,0	< 1
500				3,0	< 1

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.



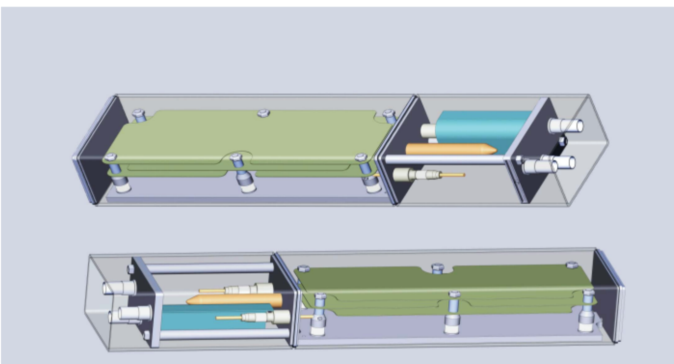
Courtesy M. Kalliokoski

Flat Ionization Chamber

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



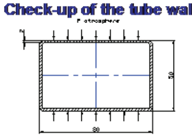
Design and production of the first flat ionization chamber.

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.

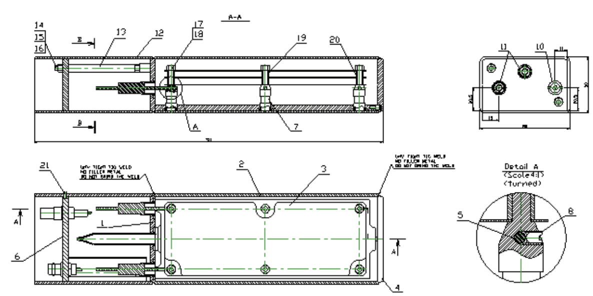
It was executed check-up of the tube wall strength as flat chamber is pumping during production time.

Check-up of the tube wall strength

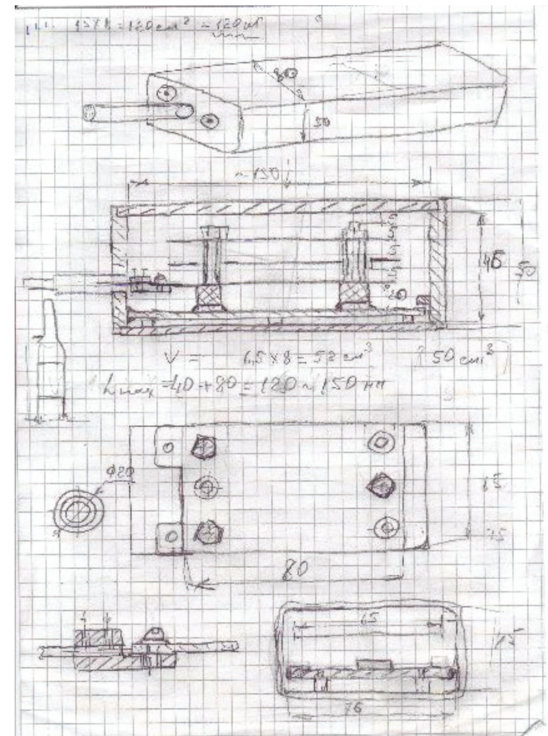


- For st.steel 304L: yield strength – σ_T=170MPa, coefficient of strength stock n_T = 1,5.
- Permissible stress for yield strength: $\sigma_{y.p} = \sigma_T / n_T$=113MPa
- The wall thickness is as $S = 224b/\sqrt{\sigma_{y.p}} + c$ = 2,1mm, where b=80mm –wall length, C=0,4 –thickness tolerance.
- Finally rectangular tube with 2mm wall is suitable.

Flat IC assembly

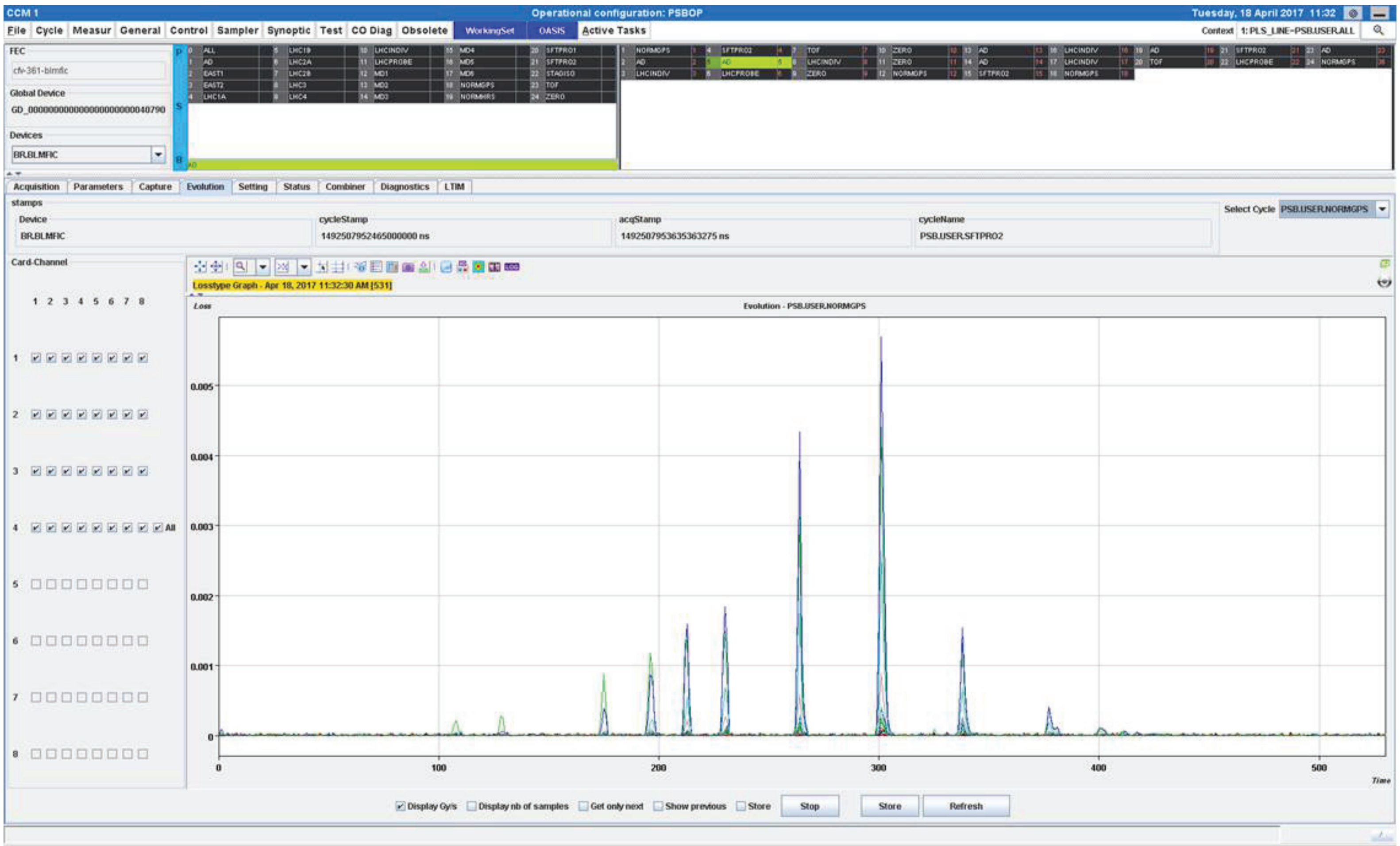


- Outer dimensions: 50x80x310mm.
- Working volume ~100 sm³.



Flat Ionization Chamber

The nice first signals from BLM FIC at PSB



Courtesy W. Vigano

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- This paper is dedicated to the memory of the project leader, Dr. Bernd Dehning, who passed away in January 2017

Conclusion

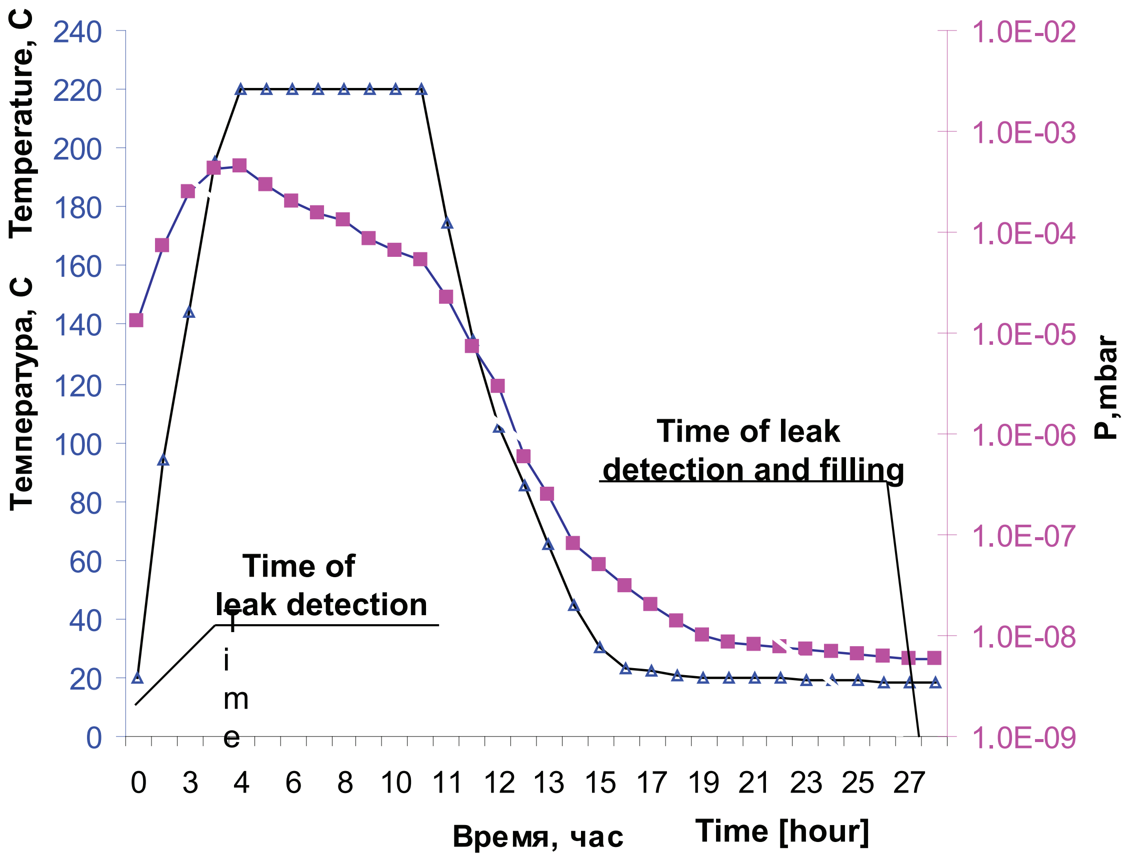
- ~15 years CERN-IHEP colloboration
- More than 6 000 beam loss monitors of different type have been designed, tested, produced in 2005-2018 at IHEP for the CERN, ESS, GSI, LIPAC, BNL
- The detectors are working perfectly (no damages, no quenches…)
- The vacuum stand are in working conditions
- The plans for future:

~ 1000 BLM for SPS, ~100 LIC with IC ceramics

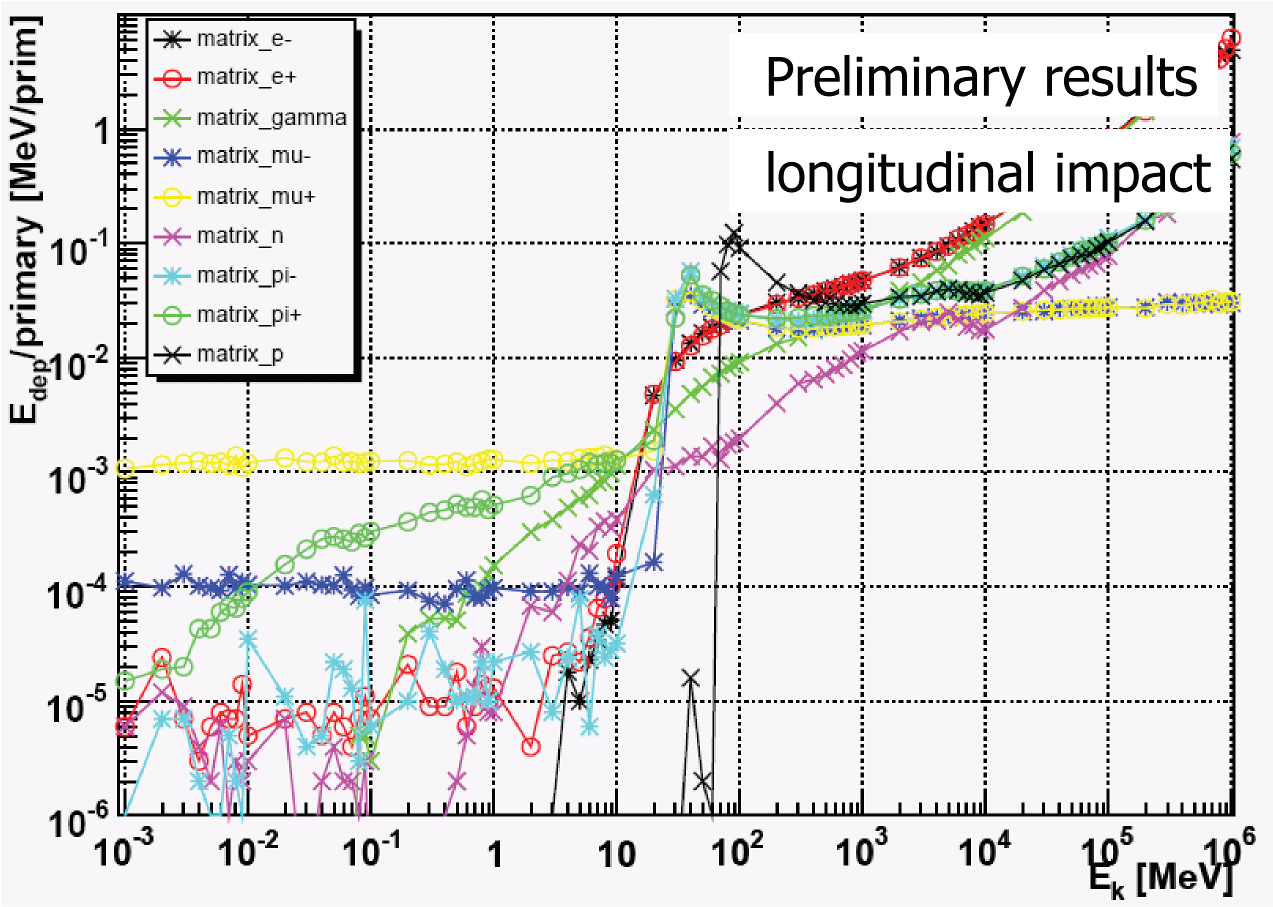
~ designed by IHEP the proportional chambers

Backup

Stand heat treatment cycle of the ionization chambers

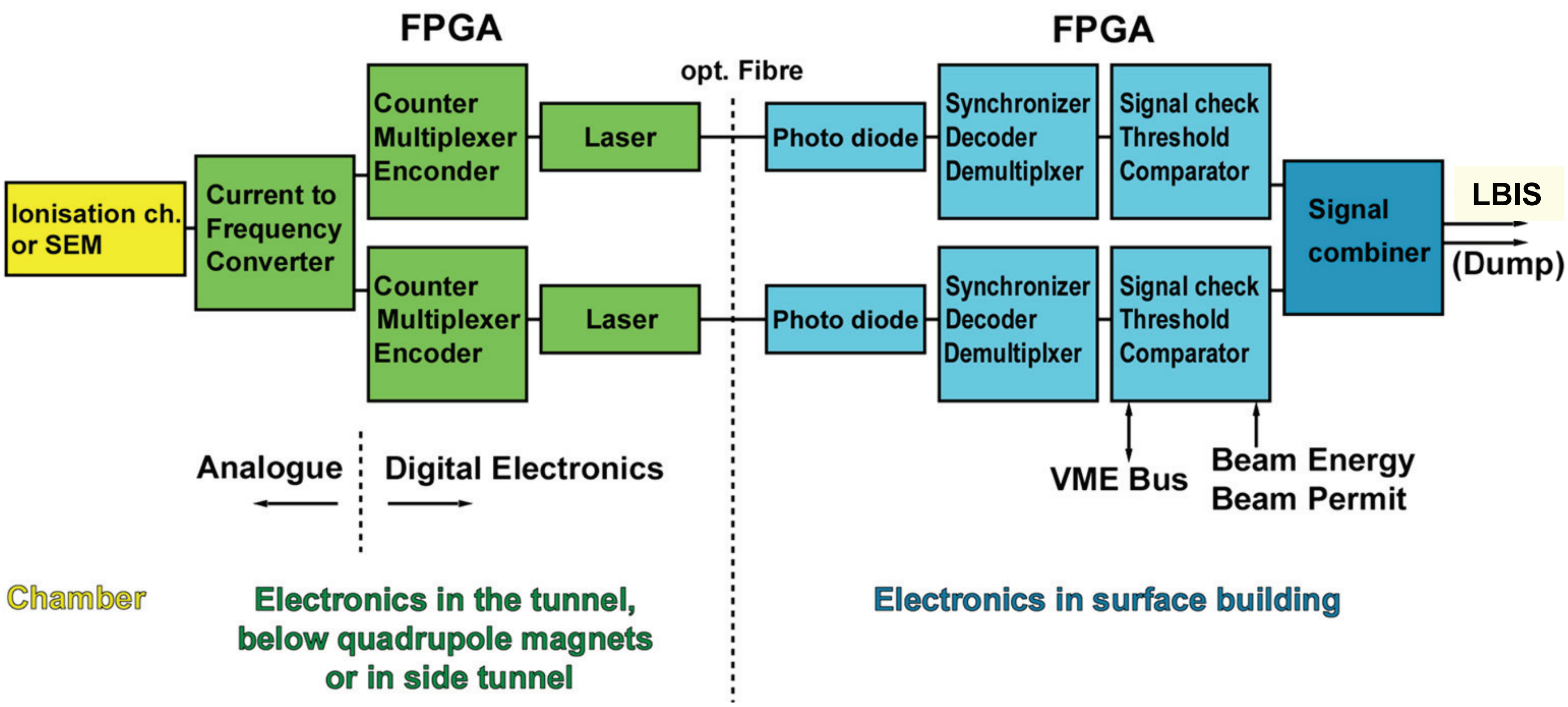


SPS Ionisation Chamber Spectrum Response

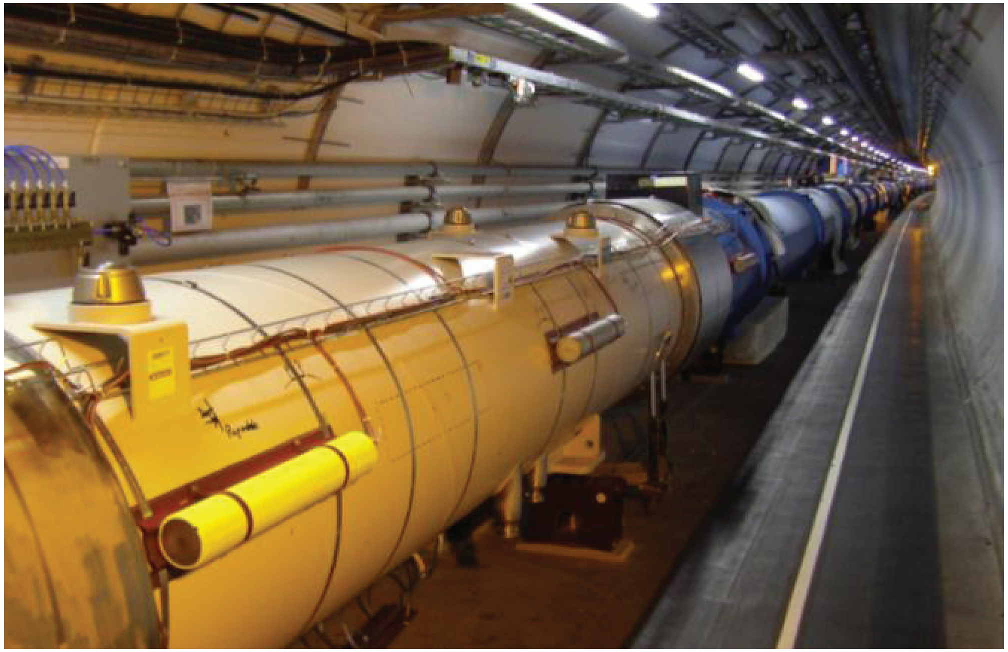


- Ionisation chambers:
  - H6 line measurements
  - HERA Dump
  - Response to mixed radiation field (chambers outside cryostat)
  - Comparisons with simulations (shown by H. Vincke)
  - Thesis M.Stockner
- SEM
  - Same procedure as for ion. ch.
  - BOOSTER
  - PSI
  - Thesis D. Kramer

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: 40µs to 84s
  - 32 energy levels
    → 1.5 Million threshold values

- Each monitor aborts beam
  - One of 12 integration intervals over threshold
  - Internal test failed

$$1\,[\mathrm{Gy/s}] \sim \frac{pV}{R_s T W}[\mathrm{A}],$$

derived in Section 3.2.1.

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

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

and for the LICs

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

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	$3.86 \cdot 10^{-6}$	$5.07 \cdot 10^{-8}$	$1.96 \cdot 10^{-13}$

e.g. thesis Kristian Hjorth