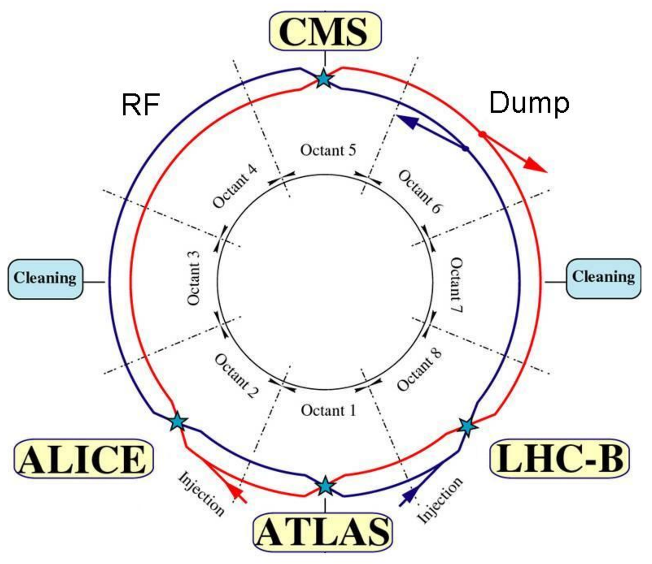
Measurements and Simulations of Ionization Chamber Signals in Mixed Radiation Fields for the LHC BLM System

Markus STOCKNER
CERN, AB Department, 1211 Geneva 23, Switzerland

Abstract: *The LHC beam loss monitoring (BLM) system must prevent the super conducting magnets from quenching and protect the machine components from damages. The main monitor type is an ionization chamber. About 3500 of them will be installed around the ring. The lost beam particles initiate hadronic showers through the magnets, which are measured by the monitors installed outside of the cryostat around each quadrupole magnet. They probe the far transverse tail of the hadronic shower. The specification for the BLM system includes a factor of 2 absolute precisions on the prediction of the quench levels. To reach this accuracy a number of simulations are being combined to calibrate the monitor signals. To validate the monitor calibration the simulations are compared with test measurements. This paper will focus on the development of the hadronic shower tail and the signal response of the ionization chamber to the various particle types and energies. Test measurements have been performed at CERN and DESY and compared to Geant4 simulations.*

LHC and it's BLM System



- **Circumference:** 26.7 km
- **Injection energy:** 450 GeV
- **Top energy:** 7 TeV in two counter rotating beams
- **~ 350 MJ** stored energy per beam (can melt 500 kg of copper)
- **~ 11 GJ** stored energy in the magnet system
- **~ 3x10^{14}** protons per beam
- Superconducting magnets
- Magnetic field **8.3 T** (**1.9 K**)
- Factor 4 – 20 more sensitive to beam losses compared to existing hadron machines

Quench Risk → **BLM System**

Purpose:
- Machine protection against damage of equipment and magnet quench
- Localization of beam losses and identification of loss mechanism
- Machine setup and studies

Location:
- BLM mounted outside of cryostat (transverse tail of hadronic showers), six around each quadrupole

Challenges:
- Reliability (tolerable failure rate 10^{-7} per hour per channel)
- Large dynamic range (10^{8}, pA - mA)

Calibration of the BLM System

Proton loss location

Hadronic showers
Detector response

Number of locally lost beam particles

Hadronic showers

Deposited energy in the machine component

Quench and damage levels as function of loss duration (heat flow in machine component)

Fraction of quench and damage level of the machine component

BLM signal

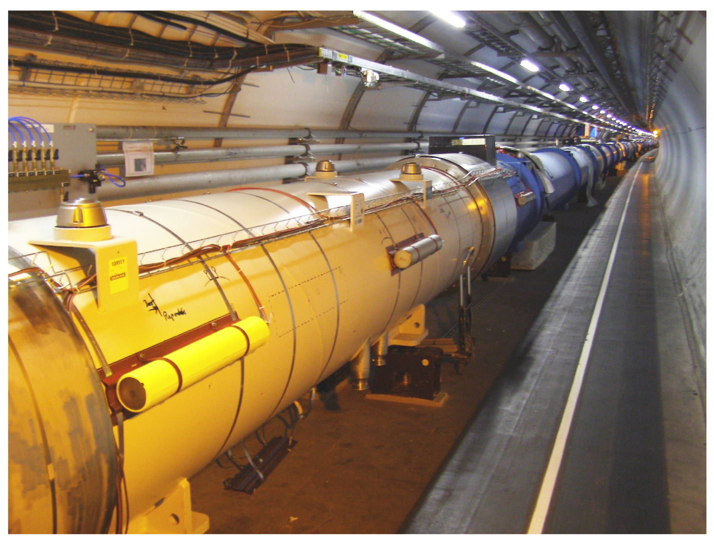
Precision Factor 2–5

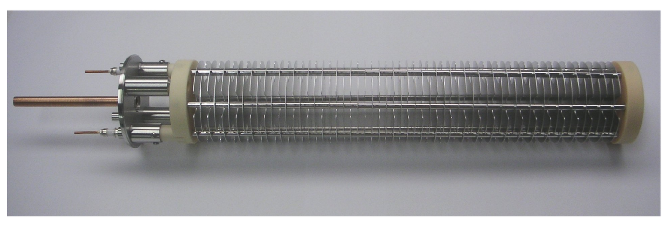
Dump at 30% of damage level

Simulations performed
Presented in this poster

Dump threshold values
- Machine component
- Loss location
- Detector position
- Beam energy
- Loss duration

BLM Tunnel installation:
4000 detectors outside of the cryostat in the horizontal plane of the beam





Ionization chamber design:
Diameter = 8.9 cm
Length: 60 cm
Volume: 1.5 litre
60 Al disks, 0.5 mm
Gas: N_2 (1.1 bar)
Bias voltage: 1500 V

Ionization Chamber Response Simulation

Characterization of the LHC BLM detector

Detector response can be folded with spectra → Detector signal

Verification of simulation by analytic calculations for muons with Bethe-Bloch formula

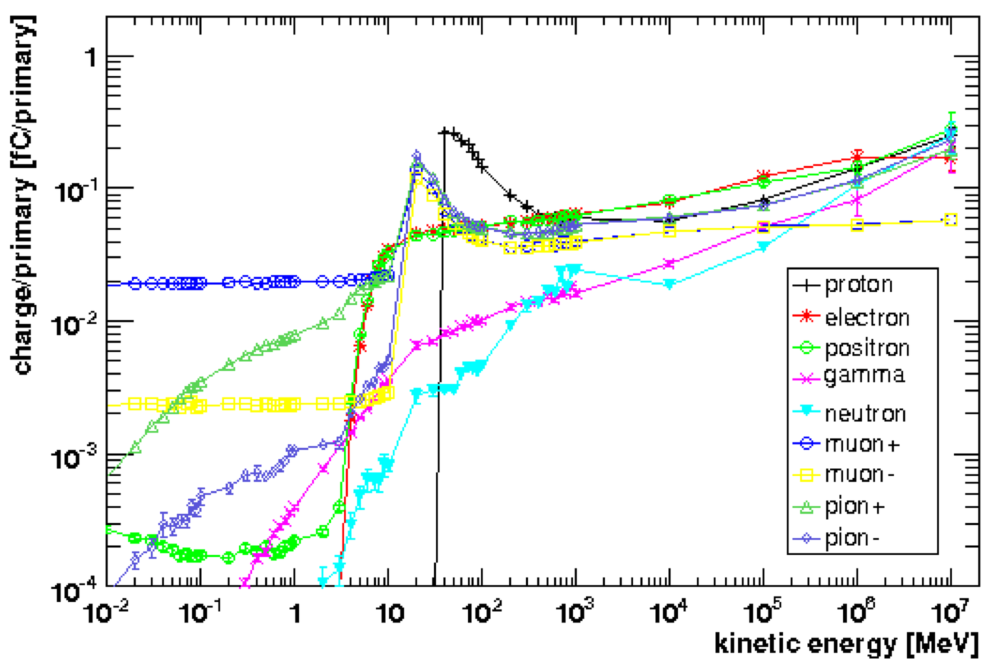
Agreement:
- 1 GeV mu^{+}: 95%
- 35 MeV mu^{+}: 75%

2 mm thick detector wall of stainless steel leads to an **energy cut-off**: (particle above this level start to deposit energy in the detector)

- protons ~ 30 MeV
- electrons ~ 1 MeV
- gammas ~ 100 keV

Deposited energy is converted with the w-value to produced charges (Nitrogen: 35 eV per electron-ion pair, ICRU report 31)

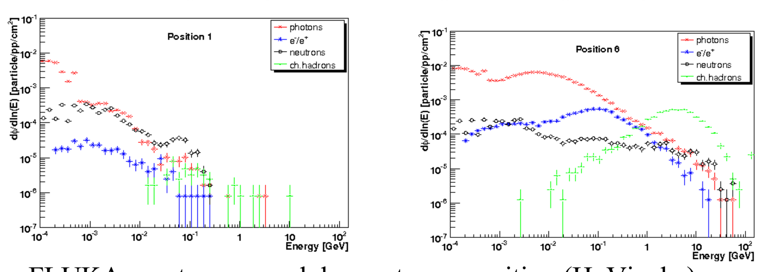
Detailed detector simulation with Geant4:
- 9 different particle types
- kinetic energy range: 10 keV – 10 TeV
- transverse and longitudinal irradiation



Verification Measurements

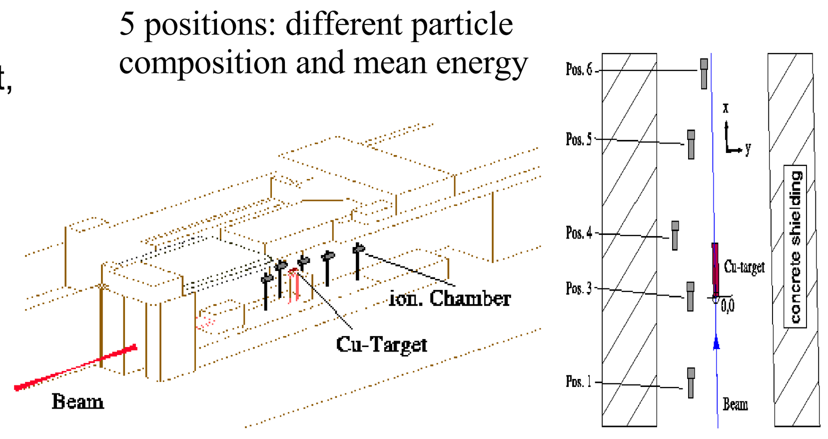
1 Mixed radiation field measurements at CERF target area (CERN-EU High Energy Reference Field Facility), simulation agrees with measurement, except position 1 (lower energetic spectra, 21%). Linearity of the detector verified over 1 order of magnitude

lower energetic spectra — higher energetic spectra



FLUKA spectra: up- and down-stream position (H. Vincke)

5 positions: different particle composition and mean energy



[pC]	Geant4 simulation		measurement		ratio	
position	SPS BLM	error	SPS BLM	error	sim/meas.	error
1	91.13	0.35	115.33	11.78	0.79	0.08
2	281.22	5.98	---	---	---	---
3	1656.38	18.21	1577.75	196.94	1.05	0.11
4	2386.62	21.53	2121.52	251.89	1.12	0.12
5	3943.99	23.12	3531.98	390.87	1.12	0.12
6	6495.5	17.54	7091.16	1442.22	0.92	0.14

2 Protons at 400 GeV/c
SPS extraction line at CERN systematic error of 23%, due to beam position uncertainty

[q/(p*cm)]	extraction line sim.		extraction line meas.		ratio	
	SPS BLM	sys. error	SPS BLM	error	sim/meas.	error
	124.84	25	110	0.06	1.13	0.23

3 Gamma Calibration at TIS-RP Calibration Laboratory for Radiation Protection Instruments (CERN) with Cs137 sources (662 keV)

[aC/γ]	gamma calibration sim.		gamma calibr. meas.		ratio	
	SPS BLM	error	SPS BLM	error	sim/meas.	error
	0.27	0.02	0.28	0.003	0.96	0.07

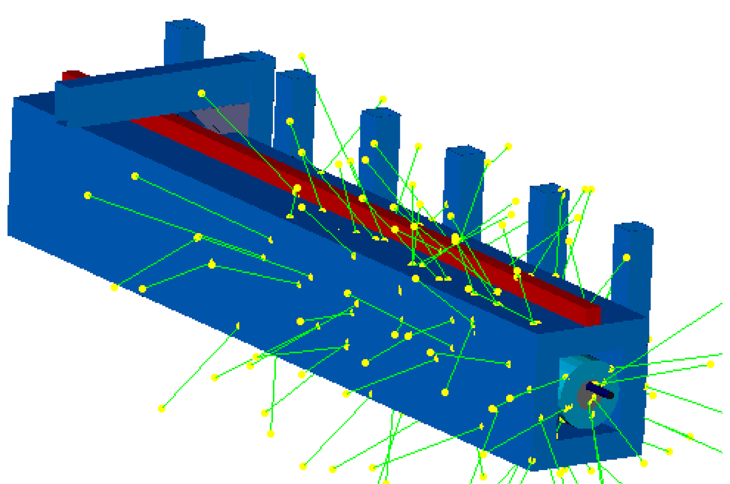
Hadronic Shower Measurements at HERA

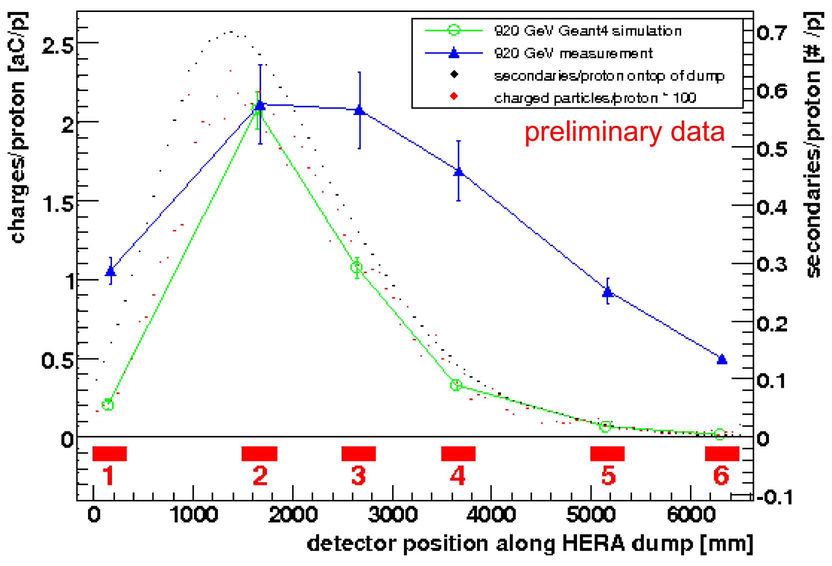
Part of the error estimation of the LHC BLM system calibration with Geant4: Verification of far transverse hadronic shower tail simulations

6 BLM detector are lonigudinally distributed on top of the HERA proton beam dump (red box)

proton energy:
- injection energy 40 GeV
- top energy 920 GeV

intensity range:
- 1.3×10^{11} to 1.3×10^{13} protons





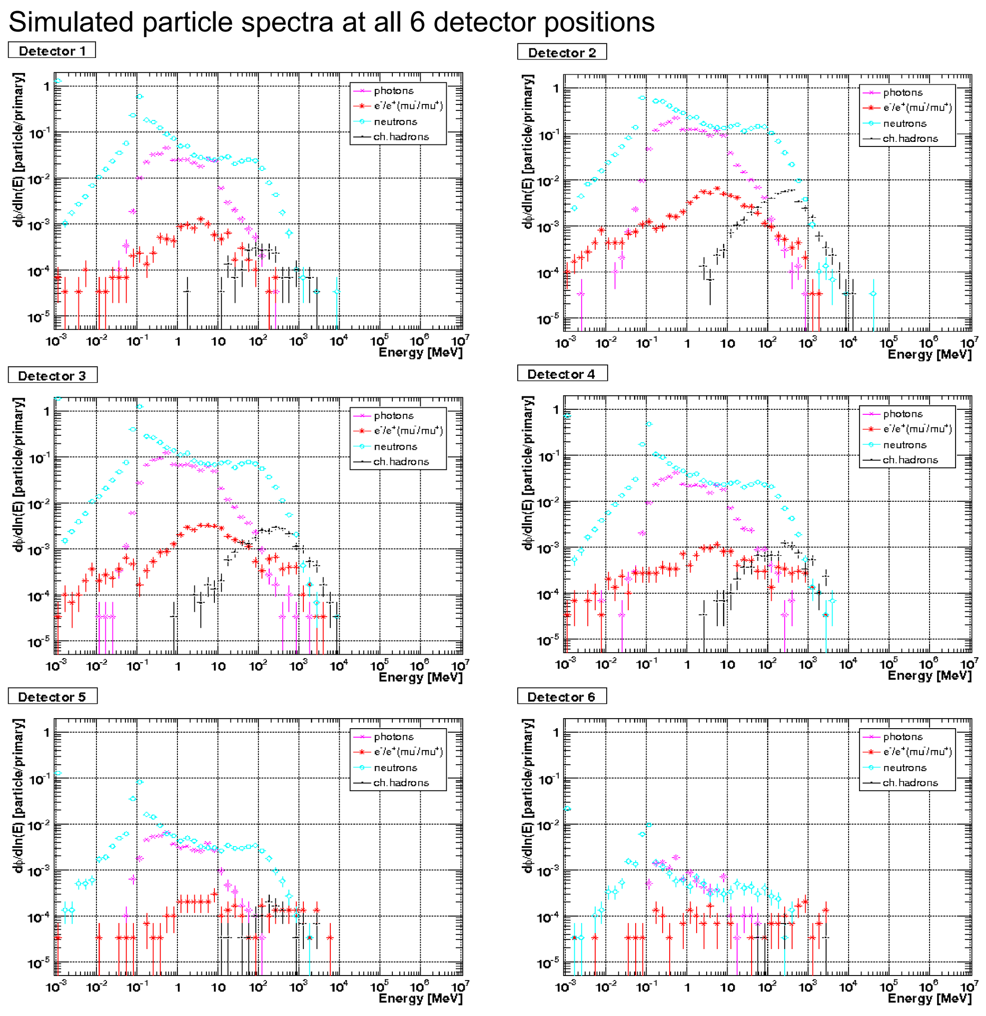
Difficulties:
- ionization chambers probe far tails of shower distribution (simulation uncertainties)
- high flux of low energy neutrons and gammas

Preliminary Results:
- significant difference in longitudinal shape between measurement and simulation

Successful longterm test of the complete LHC BLM System in real accelerator environment

Simulated Transverse Hadronic Shower Spectra

Simulated particle spectra at all 6 detector positions



Dump simulation in two steps:
- Simulation of spectra at detector position
- Simulation of detector signal

Simulation details:
- Geant4 8.0 (patch-01)
- Physics list QGSP
- Range cut value 1 mm

To do:
- Score deposited energy in dump
- Compare it to deposited energy in an LHC magnet

Results

BLM detector response simulation with Geant4 and verification by measurements: → Part of the BLM system calibration
- mixed radiation field (CERF) → ratio simulation / measurement within uncertainties, (except upstream position 21%)
- 400 GeV protons → comparison within 13%, determined by systematic uncertainty (23%) in beam position
- gamma calibration → within 4%

Simulation and measurement of far transverse hadronic shower tails at HERA proton beam dump (preliminary results):
- significant difference in longitudinal shape, longitudinally integrated signals differ by a factor of ~2

→ Part of the uncertainty estimation of the LHC BLM system calibration (factor of 5 accuracy requested for LHC startup end of 2007)

Outlook

- Detector calibration measurements with neutrons at Uppsala University (Sweden), November 2006
- Fine-tune calibration of the LHC BLM electronics and study saturation effects of ionization chamber
- Relate the detector signal to the deposited energy in HERA dump and to LHC beam abort thresholds

The author would like to thank: B. Dehning, E. B. Holzer, G. Ferioli and the whole LHC BLM team, H. Vincke from the CERF team for helpful discussions, K. Wittenburg form DESY and my PhD supervisor C. Fabjan from CERN.