Simulations and Measurements of Secondary Electron Emission Beam Loss Monitors for LHC

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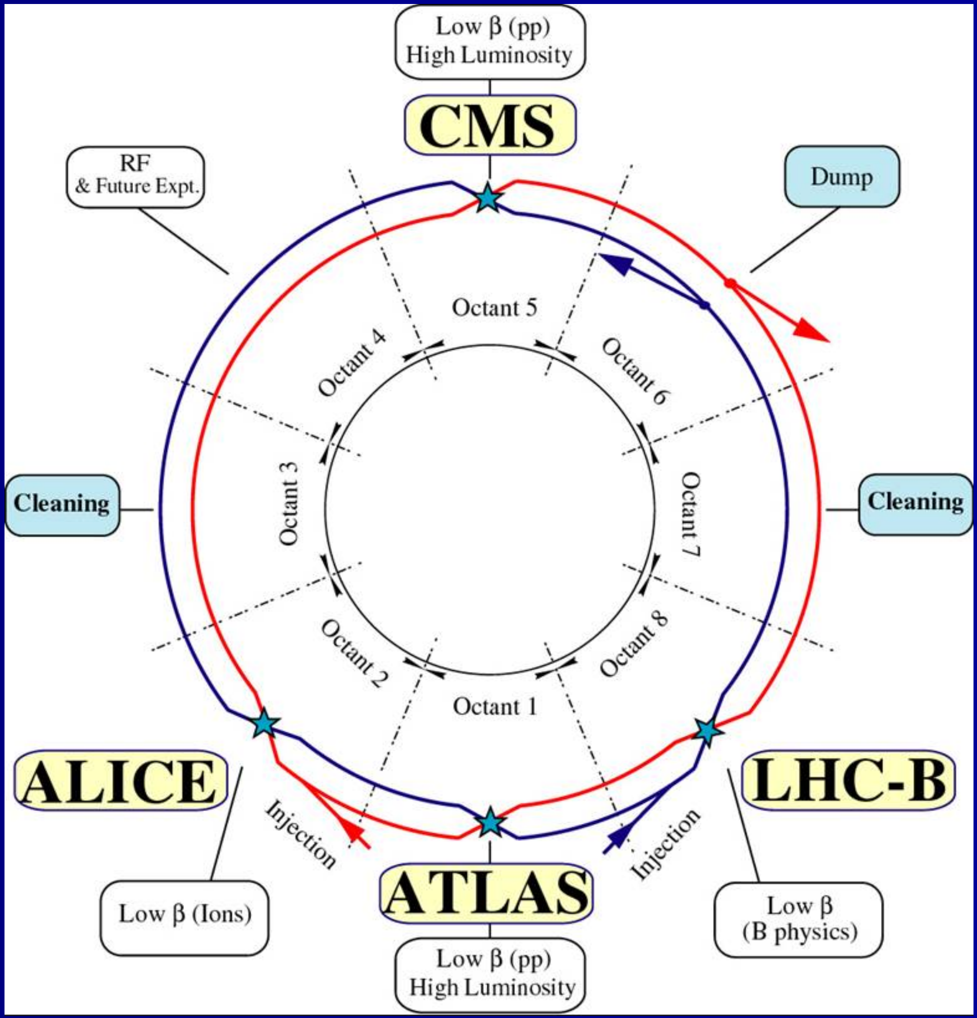
Outline

- LHC BLM system
- BLMS design requirements
- Working principle of SEM
- Prototype design and vacuum issues
- Simulations in Geant4
- Measurements at 63 MeV
- Measurements at 1.4 GeV

LHC Beam Loss Monitoring system

- ~ 3700 BLMI chambers installed along LHC
- ~ 360 BLMS chambers required for high radiation areas:
  - Collimation
  - Injection points
  - Aperture limits
  - IPs
  - Beam Dump

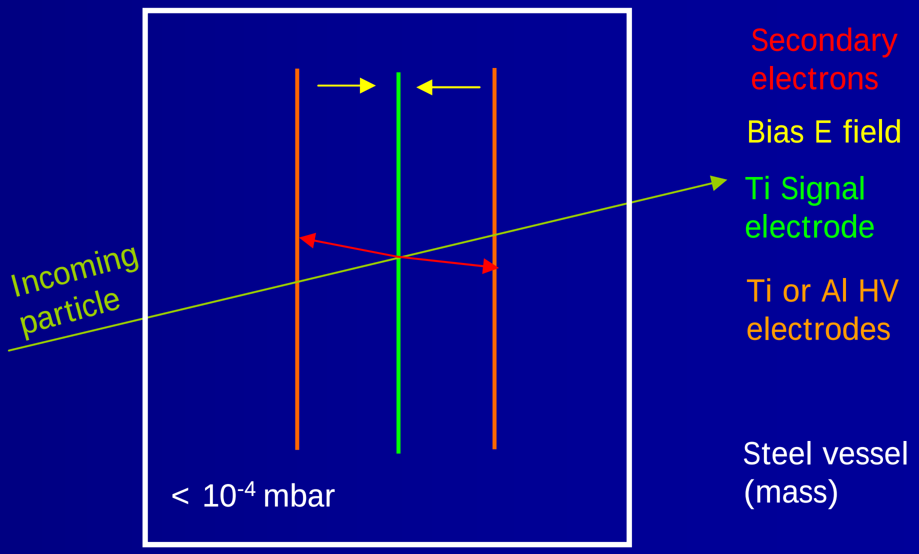


BLMS design requirements

- Output limits given by electronics (Current to Frequency Converter)
  - > 2pA to 1mA for DC currents
- Worst case to measure: nominal SPS injection lost in a magnet
  $3\ 10^{13}$ p^+ in 20us
  - > $1.5\ 10^{18}$ p^+/s
- Sensitivity ~ $3\ 10^4$ times lower than ionization chambers (BLMI)
- Lifetime 20 years (very difficult or impossible to replace due to high radiation)
- Radiation hardness up to 70 MGy/year

Secondary Emission Monitor principle

- Secondary Electron Emission is a surface phenomenon
- Energy of SE (below ~ 50 eV) is independent on primary energy
- SE are pulled away by HV bias field (1.5kV)
- Current integrated between Signal and HV electrode (not between HV and Mass)
- Delta electrons do not contribute to signal due to symmetry



- VHV necessary to eliminate ionization inside the detector
- Very careful insulation and shielding of signal path to eliminate ionization in air
- No direct contact between Signal and Bias (guard ring)

BLMS prototype assembly

- All components cleaned by standard UHV process
- Steel parts vacuum fired
- Fully penetrated TIG welds
- Pinch off after 300°C vacuum bake out at 10^{-9}mbar
- No trapped gas volumes

- Production version will contain 170 cm^2 of NEG St707 to keep the vacuum < 10^{-4} mbar during 20 years
- All electrodes will be from Ti

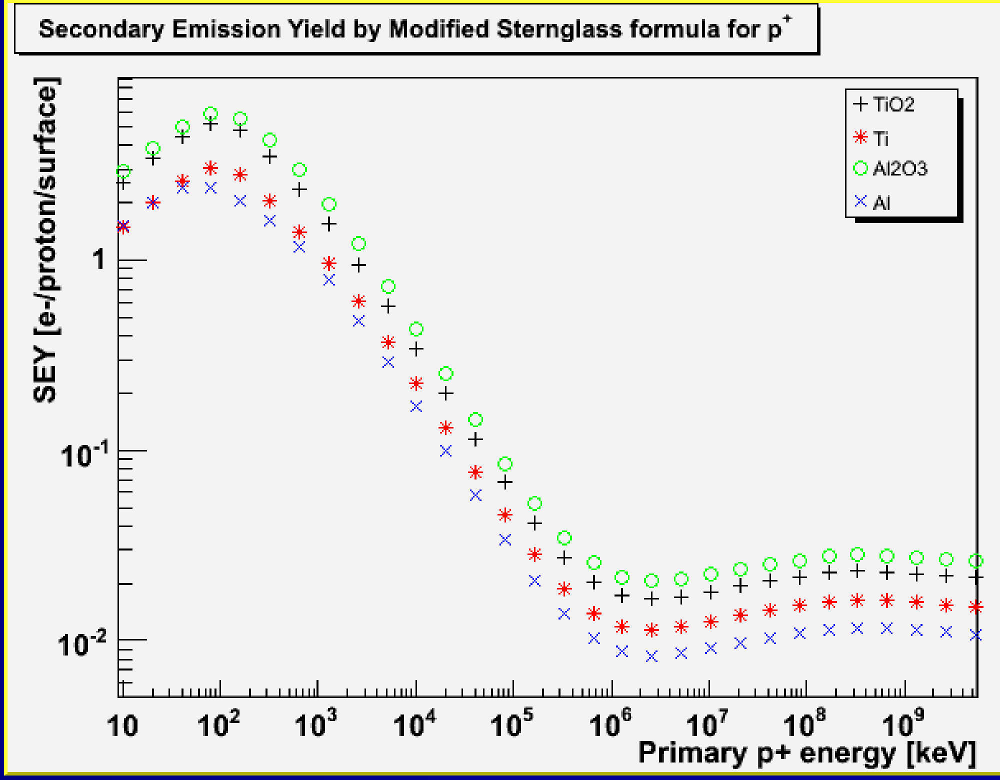
Simulations in Geant4

- Geometry of BLMS F type implemented including E fields
  - Signal electrode covered by layer of TiO_2 (NIST predefined materials used)
- QGSP physics list used
- Readout done in UserSteppingAction by counting produced escaping electrons
- Photo-Absorption-Ionization module tested for production of low energy secondaries
  - Produces only energetic delta electrons >~1keV (binary encounter)
  - => Not suitable for this study :o(

Semi empirical approach Sternglass formula

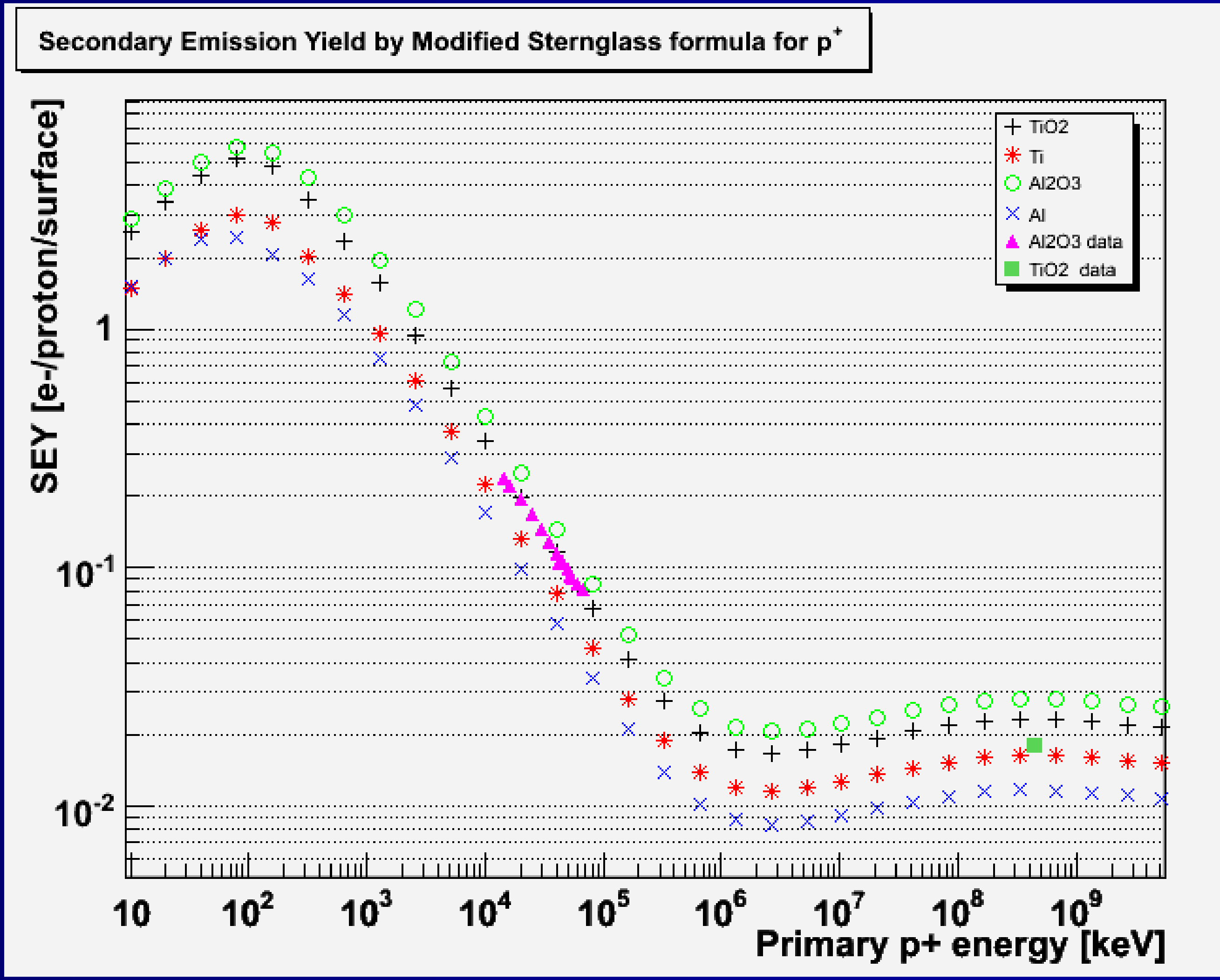
- Secondary Emission Yield is proportional to electronic dE/dx in surface layer
  - Material parameter Λ calculated from effective penetration distance of SE
- SEY of each particle crossing TiO_2/vacuum boundary calculated and SE ‘generated’ with this probability
- Low energy correction not used (to match literature values)

$$\gamma_b = \Lambda \frac{dE}{dx}_{el} \left(1 + \frac{1}{1 + \frac{E_p}{0.1836\, A_p}} \right)$$



Comparison with published data

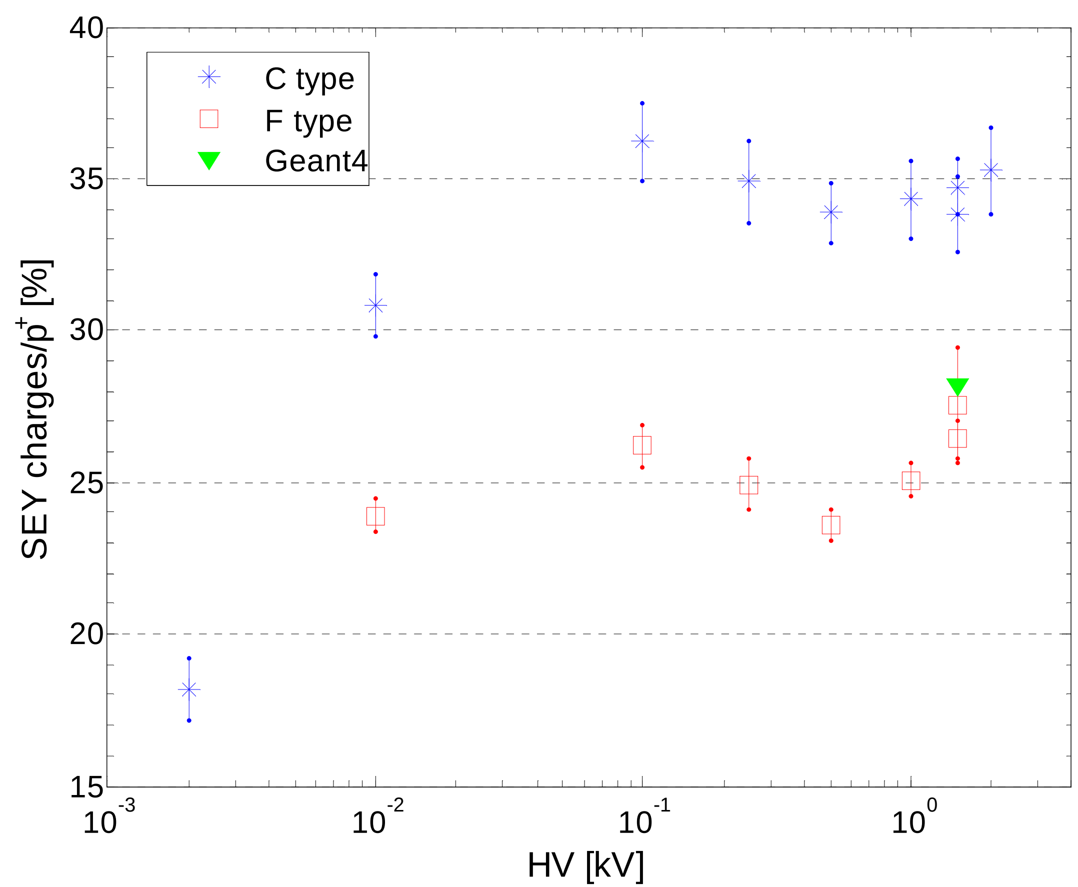
- Al_2O_3 data from C.M.Castaneda 1997
  - Thin foil measurements
- TiO_2 (Ti) data from G. Ferioli 1996
  - SPS transfer line SEM calibration



Prototype tests with 63MeV cyclotron beam in Paul Scherer Institute

- Current measured with electrometer Keithley 6517A
- HV power supply FUG HLC14
- Pattern not yet fully understood
  - Simulation of delta electron contribution to be made with different HV
- SEM usable from U > 2V!
- Comparison with BLMI
  - ~ 1nA with BLMS
  - ~ 3 uA with BLMI
- Geant4 simulation SEY = 28.2%

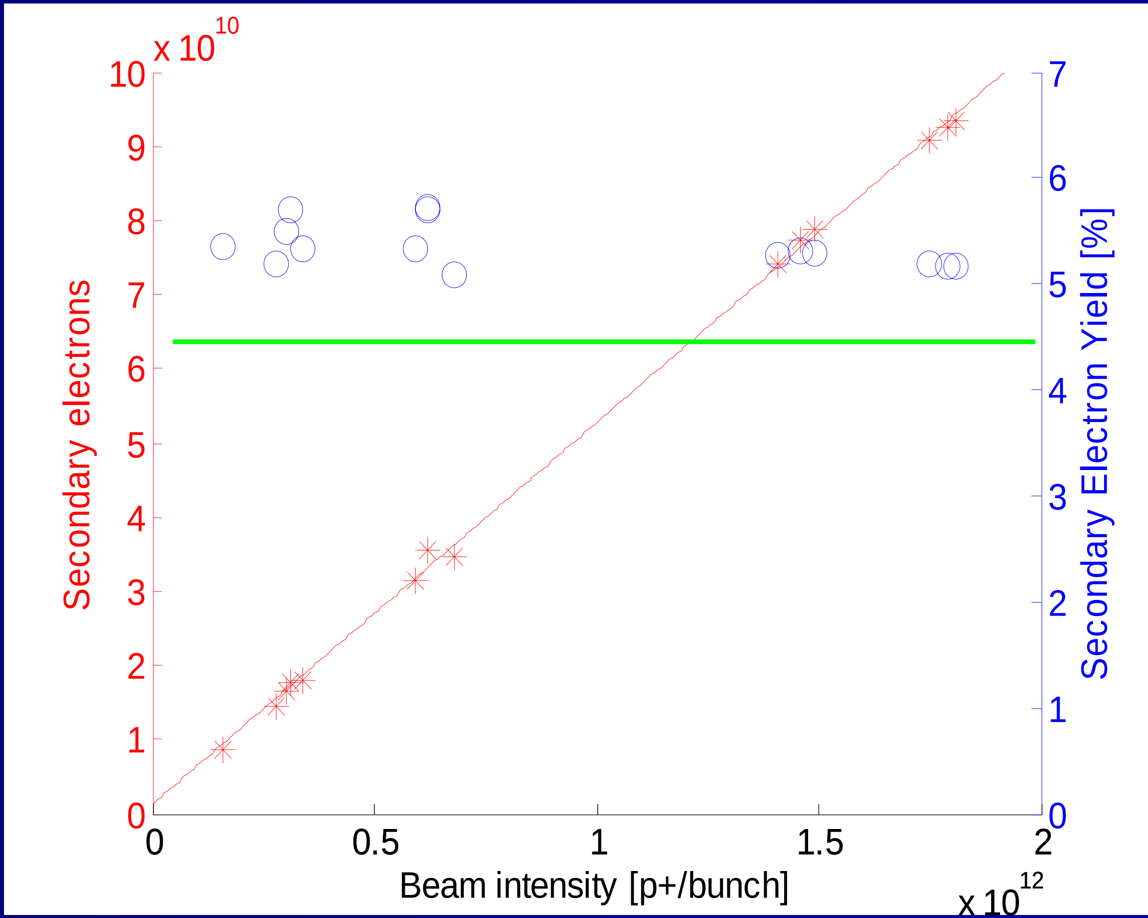
PSI proton beam 62.9MeV 30JUN06 BLMS prototypes F & C Type HV dependence of SEY



Measurements in PS Booster Dump line

- Older prototype used - Type C
- Profiles integrated with digital oscilloscope
  - 1.5kV bias voltage
  - 80m cable length
  - Single bunch passage
- SEY measurements
  - 4.9% (May 06)
  - 5.4% (June 06)
- Geant4 simulation
  - SEY = 4.4%

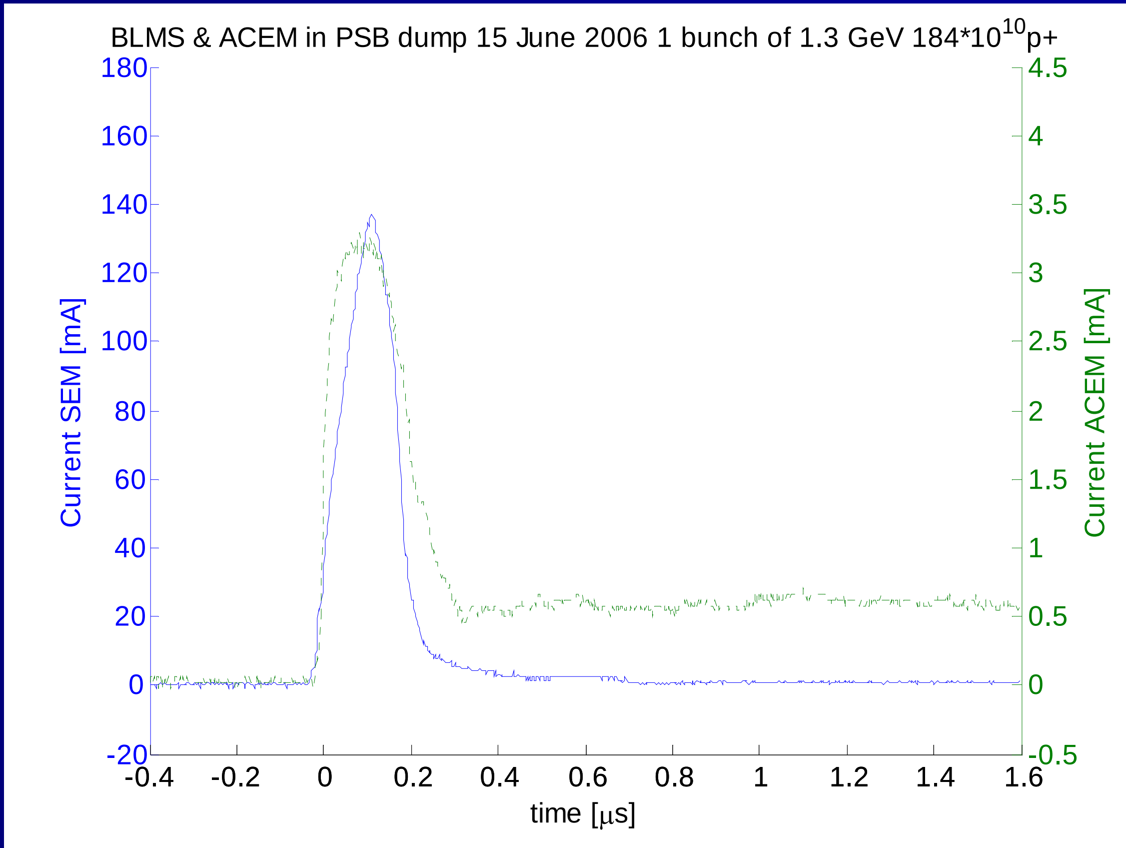
PSB Dump 16.6.06 1.4 GeV Linearity and Normalized response



Measurements in PS Booster Dump line

Time response with ~10^{19} protons/s 160ns bunch length

- BLMS compared to reference radiation monitor ACEM (Aluminum Cathode Electron Multiplier tube)
- ACEM not directly in the beam
- Rise/fall time < 50 ns
  - Dominated by unknown intensity distribution
- No undershoot or tail observed

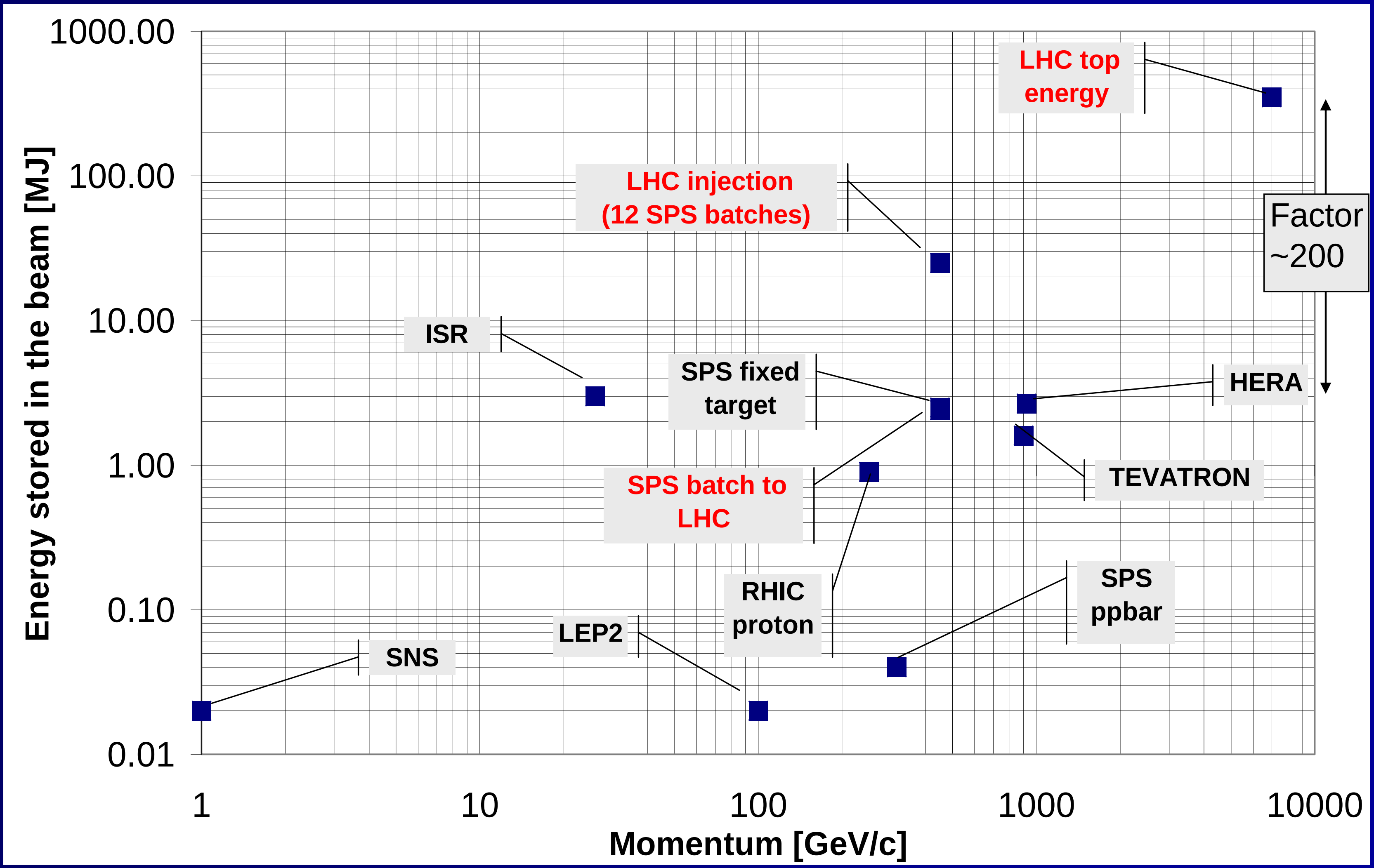


Future or ongoing experiments

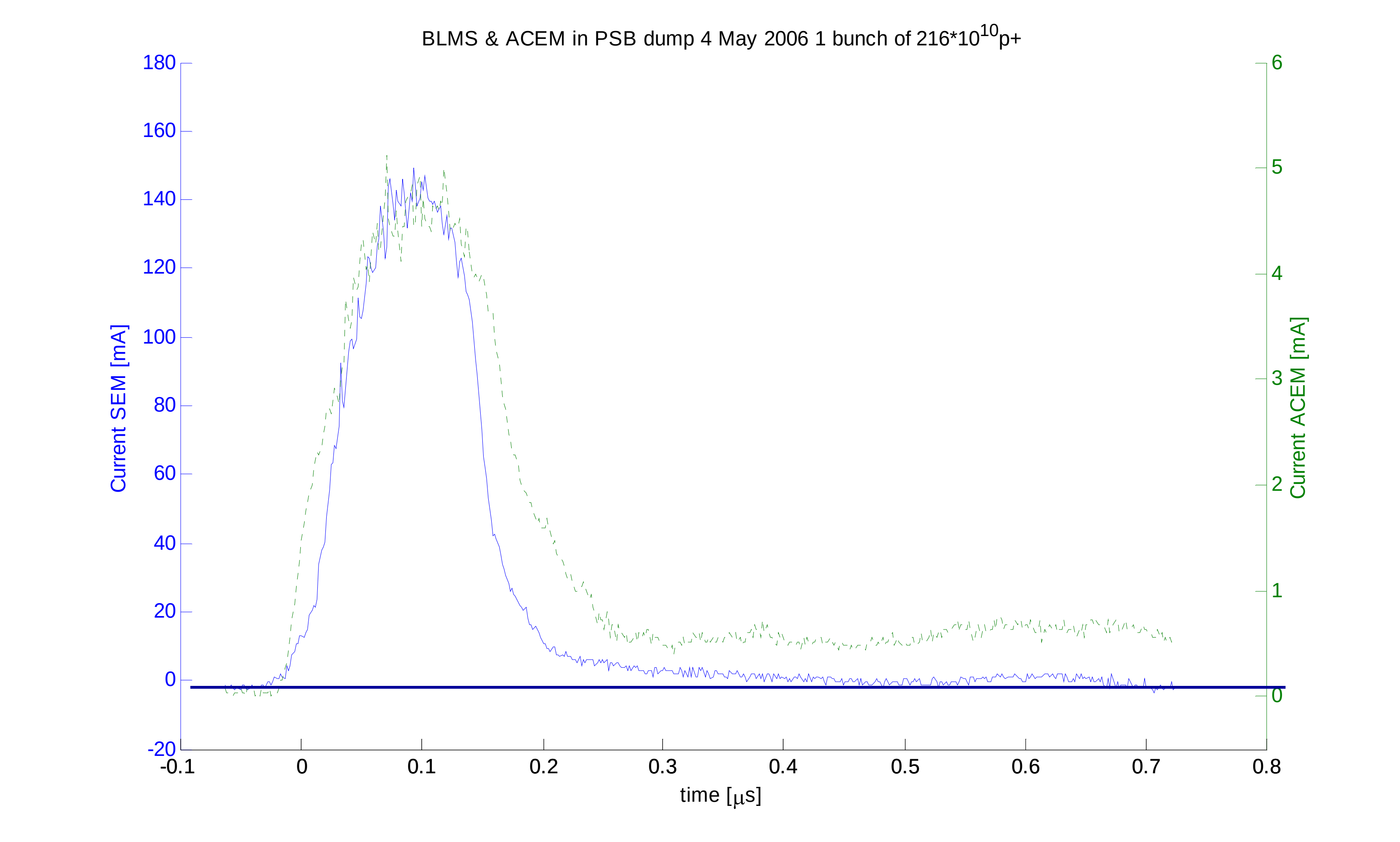
- BLMS and BLMI installed on SPS internal Dump – comparison in high flux mixed radiation field
- Scan through beam at 400 GeV in SPS transfer line
- Calibration in PSI by 250 MeV continuous proton beam
- High sensitivity outgassing test

Conclusions

- Prototype designs of BLMS were successfully tested with proton beams
- No saturation at maximum required flux
- Geant4 simulation approach gives satisfactory results
  - Results to be validated by measurements at different energies
  - Next step: prediction of SEM signal at the LHC Collimators in mixed radiation field
- Vacuum stability still to be verified


1000.00
100.00
10.00
1.00
0.10
0.01
Energy stored in the beam [MJ]
1
10
100
1000
10000
Momentum [GeV/c]
LHC top energy
LHC injection (12 SPS batches)
ISR
SPS fixed target
HERA
TEVATRON
SPS batch to LHC
RHIC proton
SPS ppbar
LEP2
SNS
Factor ~200

Reserve plots PSB 1.4GeV 4 May 06



Reserve plot PSB 1.4GeV 4 May 06