Application of Diamond Based Beam Loss Monitors

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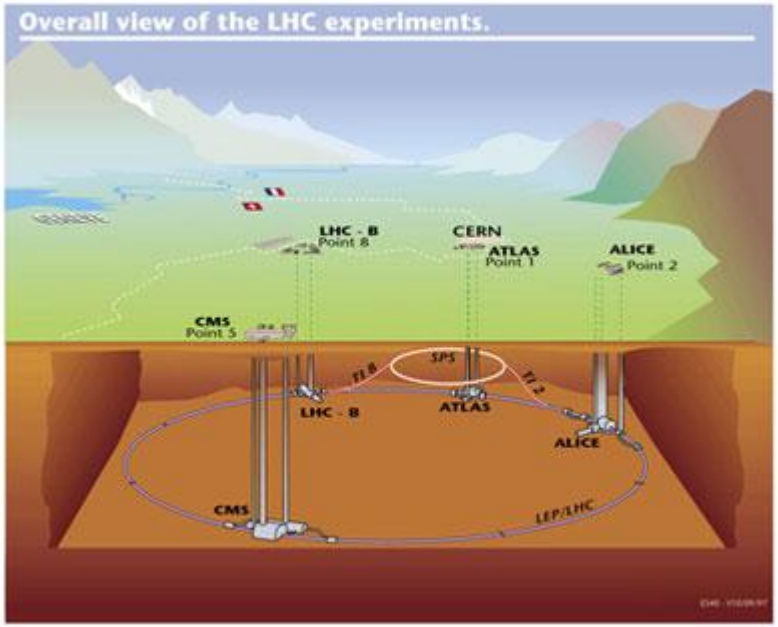
DESY

Content

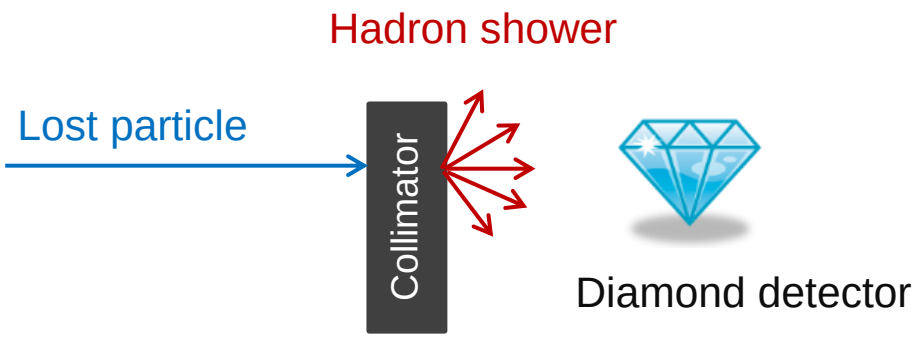
Challenges of the LHC

- LHC accelerates protons with large energy
- Operational proton particle momentum: 4TeV/c
- Operational stored beam energy: 130MJ
- Beam losses deposit energy in equipment
  - mJ/cm³ quench superconducting magnets
  - Larger beam losses can damage material
- Protection of equipment
- Interception of beam losses
- Large beam losses → beam dump



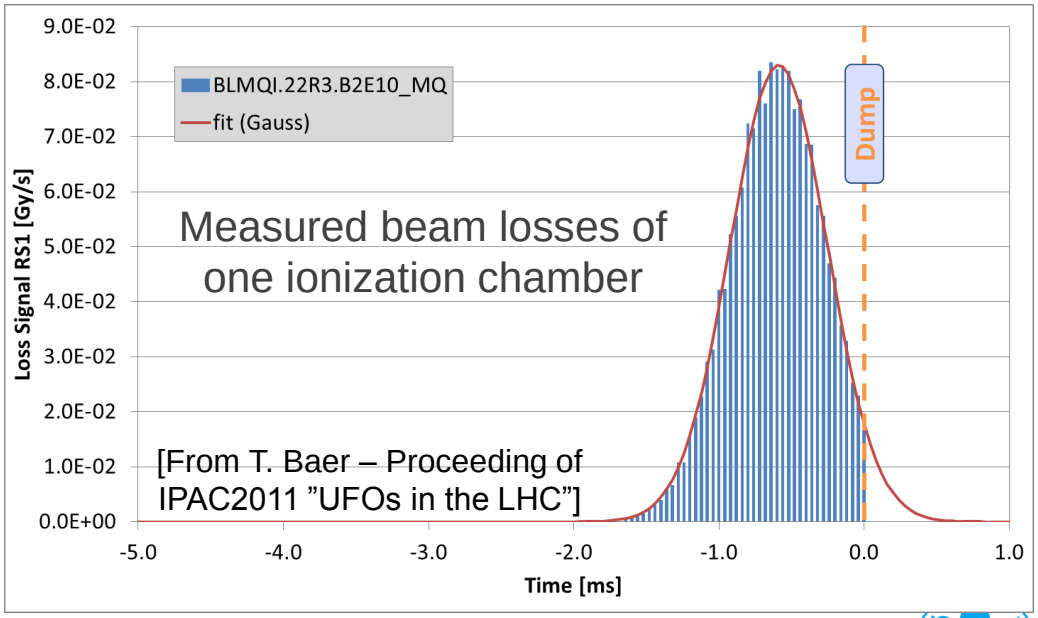
Beam Losses in the LHC

- Injection Losses
- Scattering Processes between residual gas particles and protons
- Scattering processes between dust particles and protons
- Particles with large betatron amplitude hit collimator and produce secondary shower
- Collision products
- Beam dump
- …



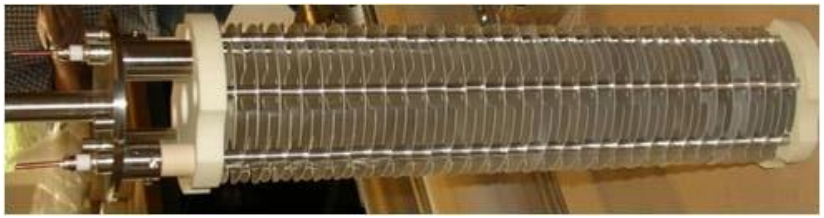
Beam Losses Caused by UFOs

- Unidentified Falling Objects (UFOs) are dust particles with size of micrometer (10-100µm)
- Falling into the beam from above
- Scattering processes between UFO and proton
  - Inelastic scattering (localized showers)
  - Elastic scattering (over several turns)
- Losses profile is Gaussian
  - Several turns
- UFOs lead to large losses
  - Beam dump

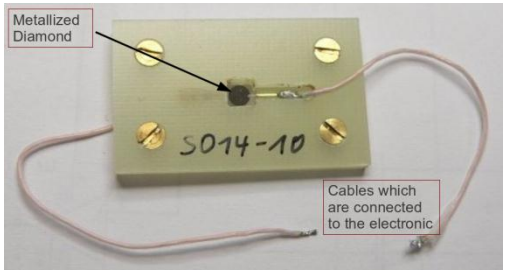


Beam Loss Monitors

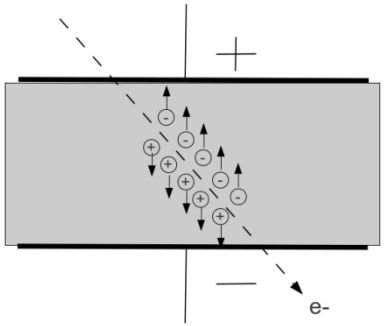
Features	Ionization Chambers	Diamond Detectors
sensors	nitrogen gas	• sCVD diamond • pCVD diamond
size	50cm x 9cm	• 5mm x 5mm (sCVD) • cm^2 (pCVD)
time resolution	40µs (half LHC revolution)	Nanoseconds (bunch-by-bunch)
Measurement	Integration of beam losses	• Integration of beam losses (sCVD) • Observation of beam losses with oscilloscope (pCVD)
function	included in the protection system	Bunch-by-bunch beam loss analysis



Ionization chamber

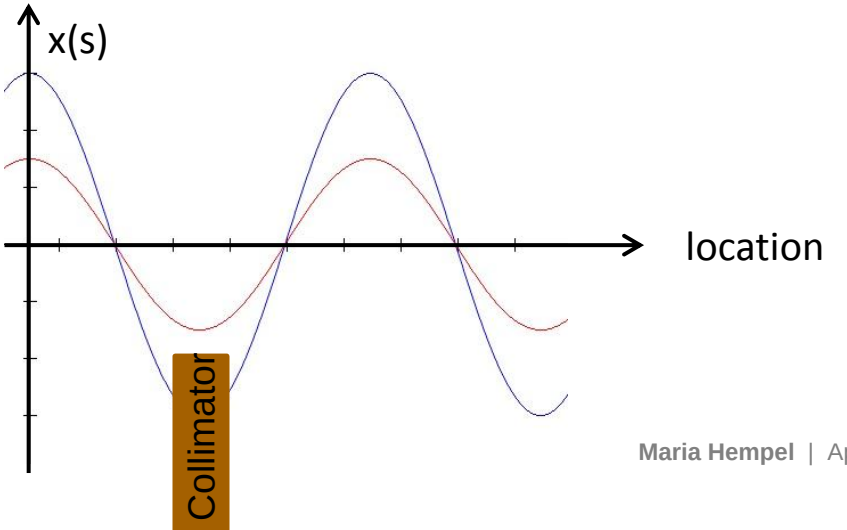


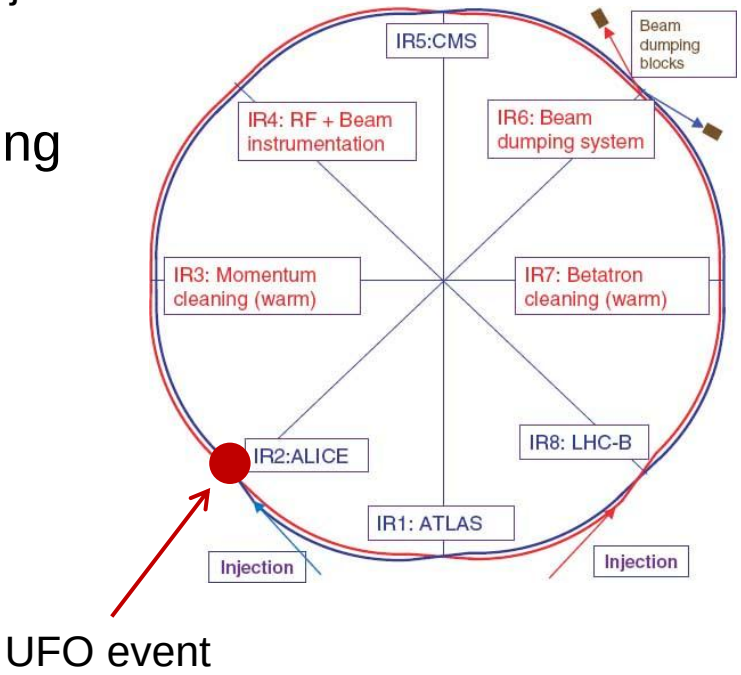
sCVD Diamond



Simulations of Beam Losses Caused by UFOs

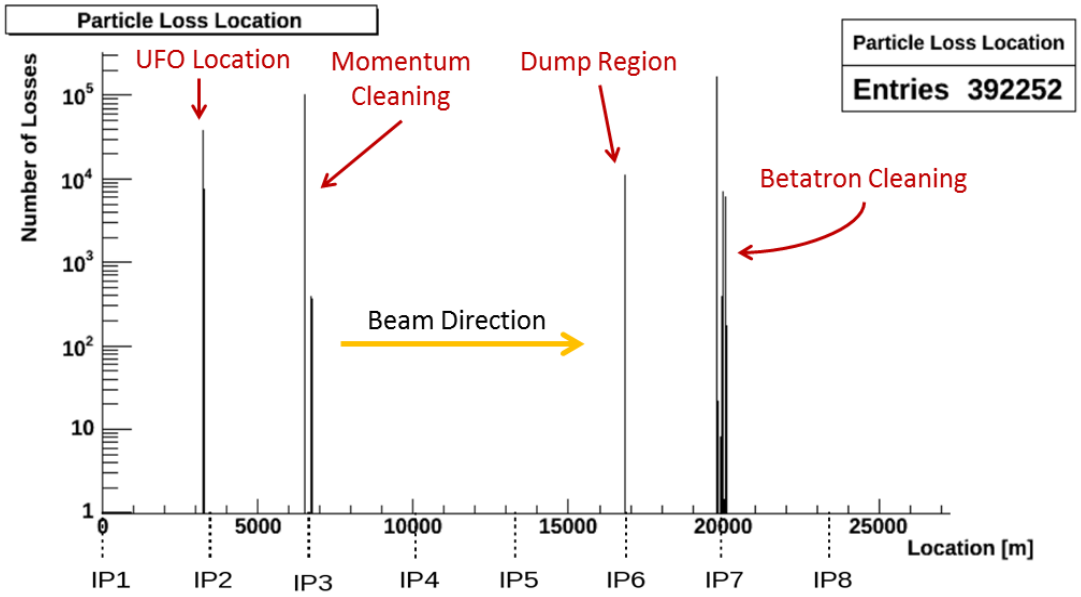
- Simulation of UFO event at the injection region
  - Losses over threshold → beam dump
- FLUKA simulated the elastic scattering process between Al and 60k protons
  - Al was used due to the ceramic chambers at the injection
  - An angular distribution of protons was provided
- MadX tracked all protons around the LHC ring
  - Simulation of proton trajectory
  - Provides the loss location

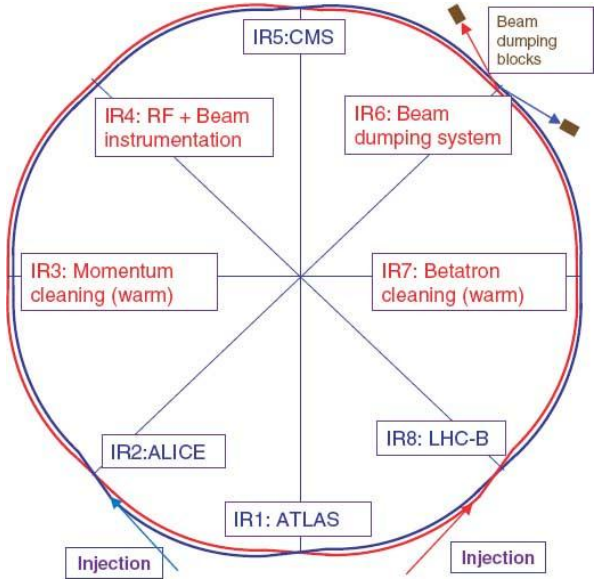




Beam Loss Distribution

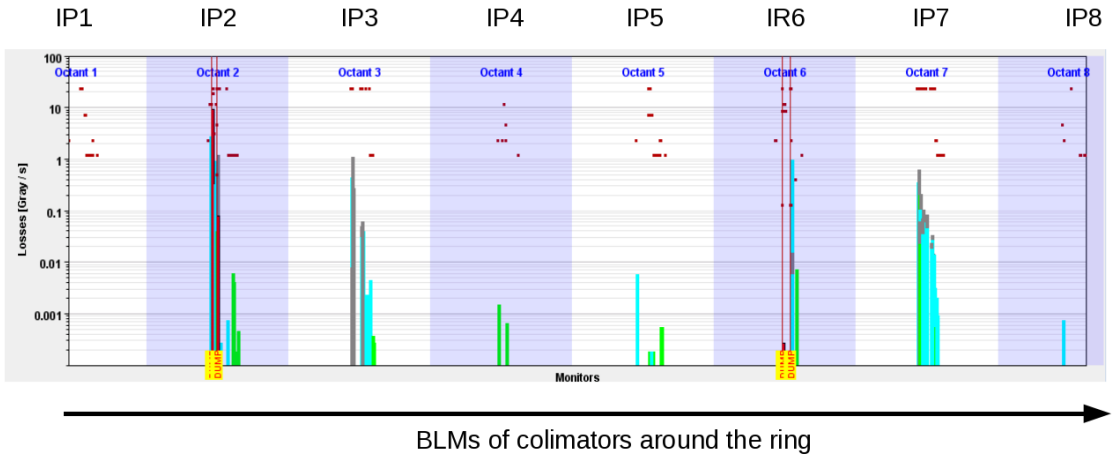
- Loss locations:
  - IR2: protons with large betatron amplitude
  - IR3: protons with deviated amplitude in the horizontal plane
  - IR6: protons smaller amplitude than in IR3
  - IR7: collimators define the global aperture limitation
- Most losses in IR7 → important location for beam loss observation

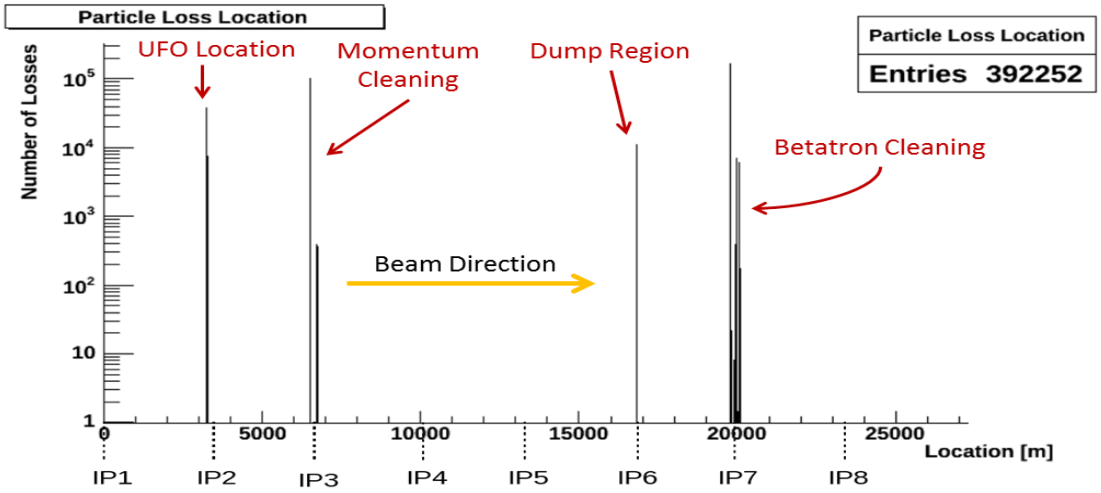




Comparison with Ionization Chambers

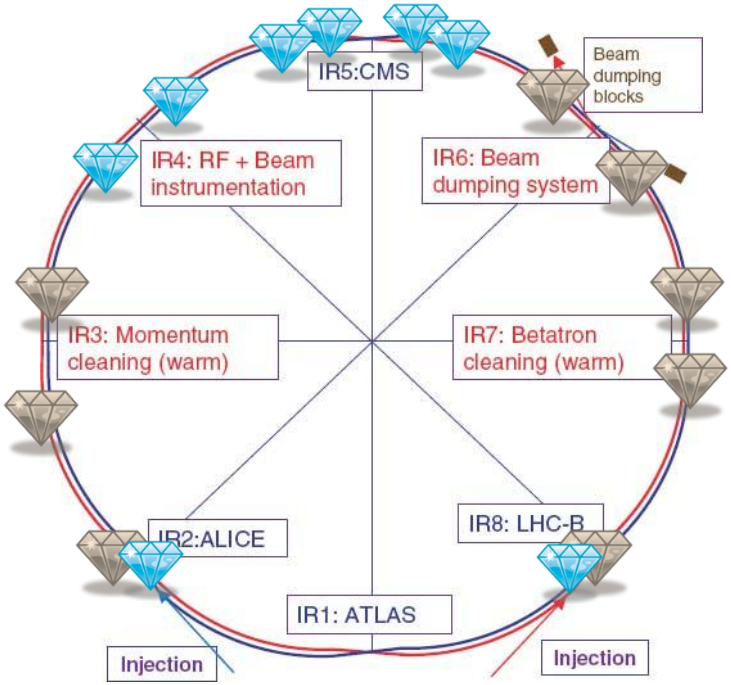
- Measurements from ionization chambers next to collimators
- Secondary showers are visible at the ionization chambers
  - Protons hit a collimator and produce a secondary shower
  - Not simulated by MadX (no simulation of interaction with matter)
- Same loss locations for ionization chambers and MadX simulation





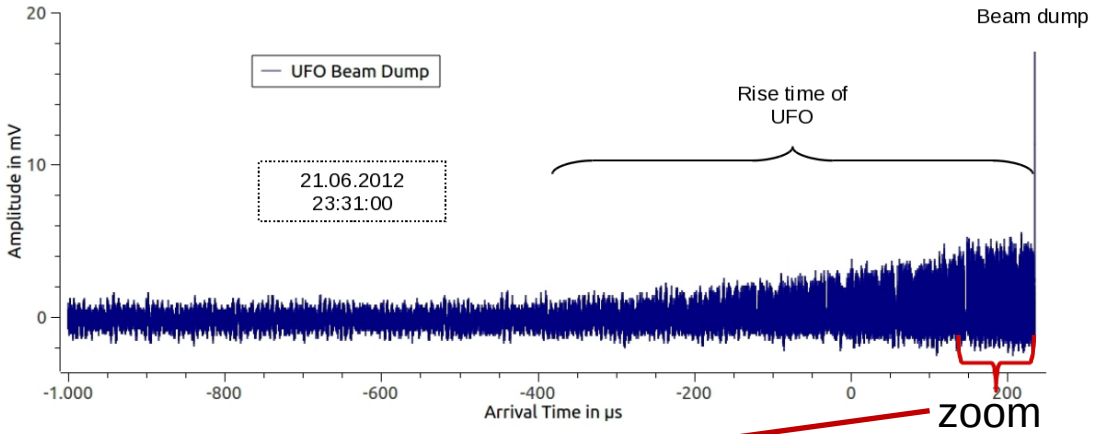
Diamond Measurements

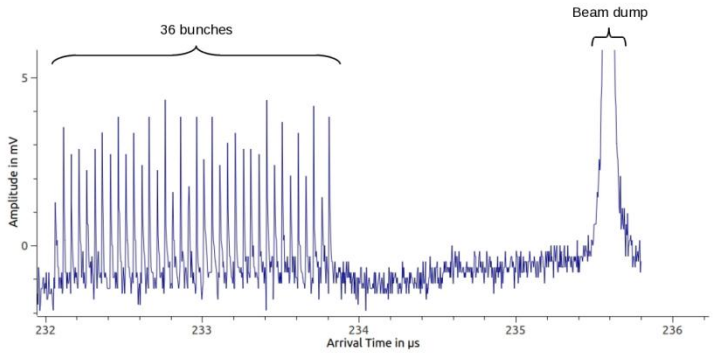
- Two types of diamond systems are installed
  - Based on pCVD (8 diamonds): readout with oscilloscope
  - Based on sCVD (14 diamonds) : readout with TDC, ADC, Scaler
- Different locations in the LHC tunnel
- Important location of pCVD: IR7
  - Observation of different beam loss types
  - Global aperture limitation
- Important location of sCVD: IR4
  - Measurement of abort gap population
  - No collimators in IR4

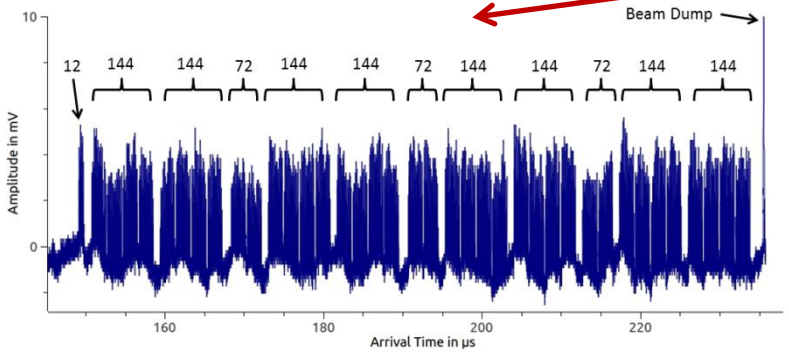


UFO Observation with pCVD in IR7

- Large UFO dumped the beam during increase of losses
- A clear bunch structure is visible
- UFOs lead to beam losses in each bunch
  - Predicted by simulations
  - Proofed by the diamond measurements
- Losses during beam dump
  - Reason: unbunched beam

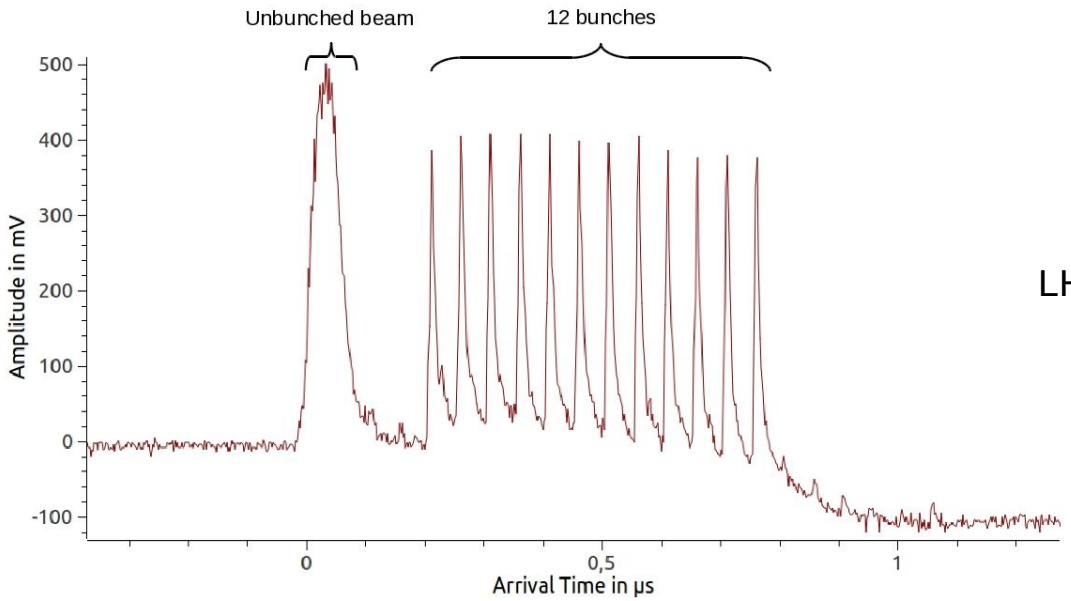


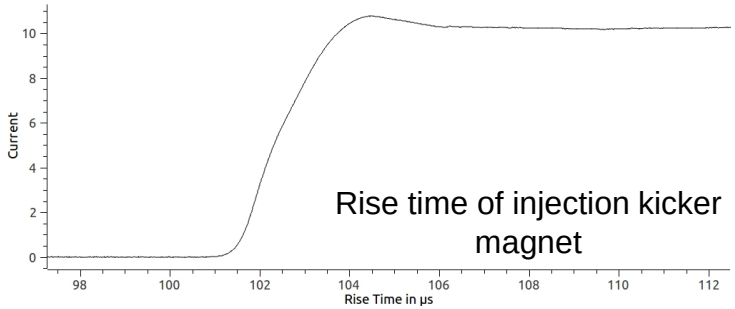


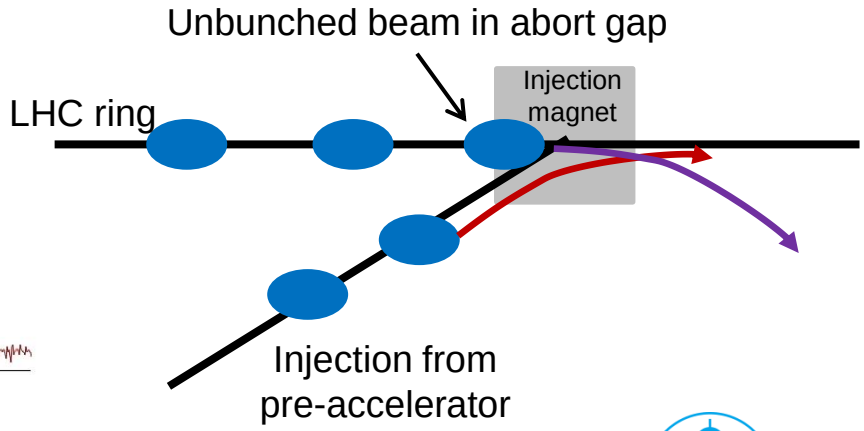


Injection Beam Losses Measured with pCVD in IR7

- Beam losses during 12 injected bunches from pre-accelerator
- Reason: injection oscillations
  - Injection of particles close to closed orbit
- Unbunched beam in abort gap due to pilot beam (test beam)

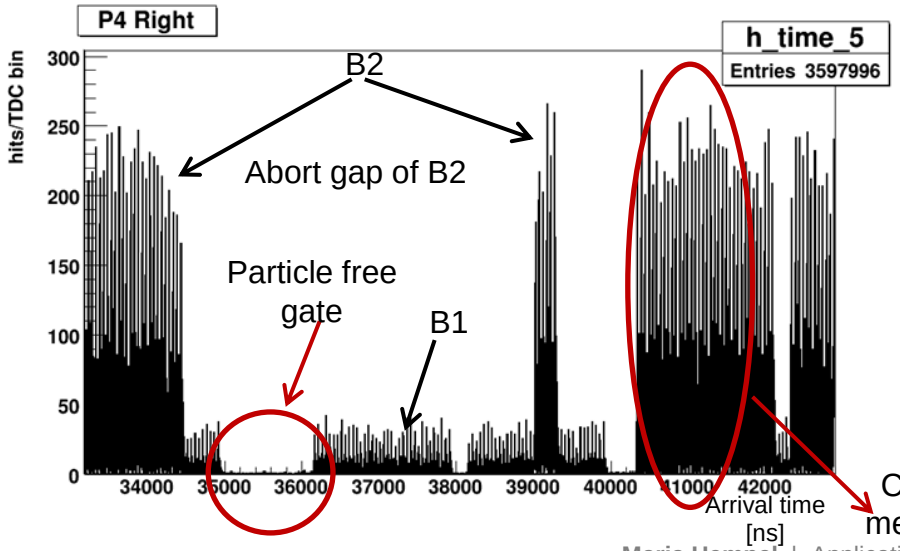


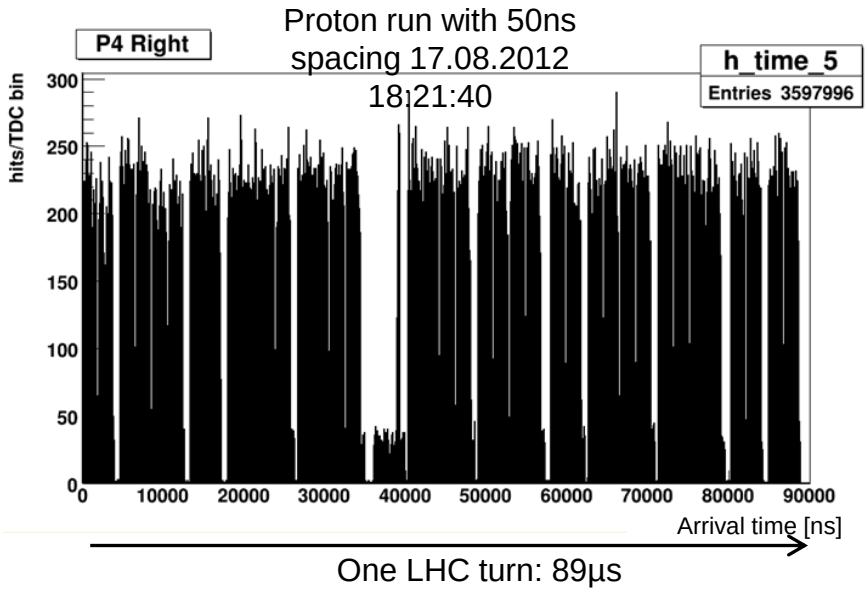




Beam Losses in the Abort Gap Measured with sCVD in IR4

- Abort gap monitor is BSRA (in IR4) that is based on synchrotron light
  - BSRA for B2 had a broken mirror => additional monitor is required
- Two sCVD are installed in IR4
  - Providing arrival time histograms filled over 10s
  - Rates of B2 are visible (large rates)
  - Rates of B1 are visible (small rates)
  - Particle free gate is visible

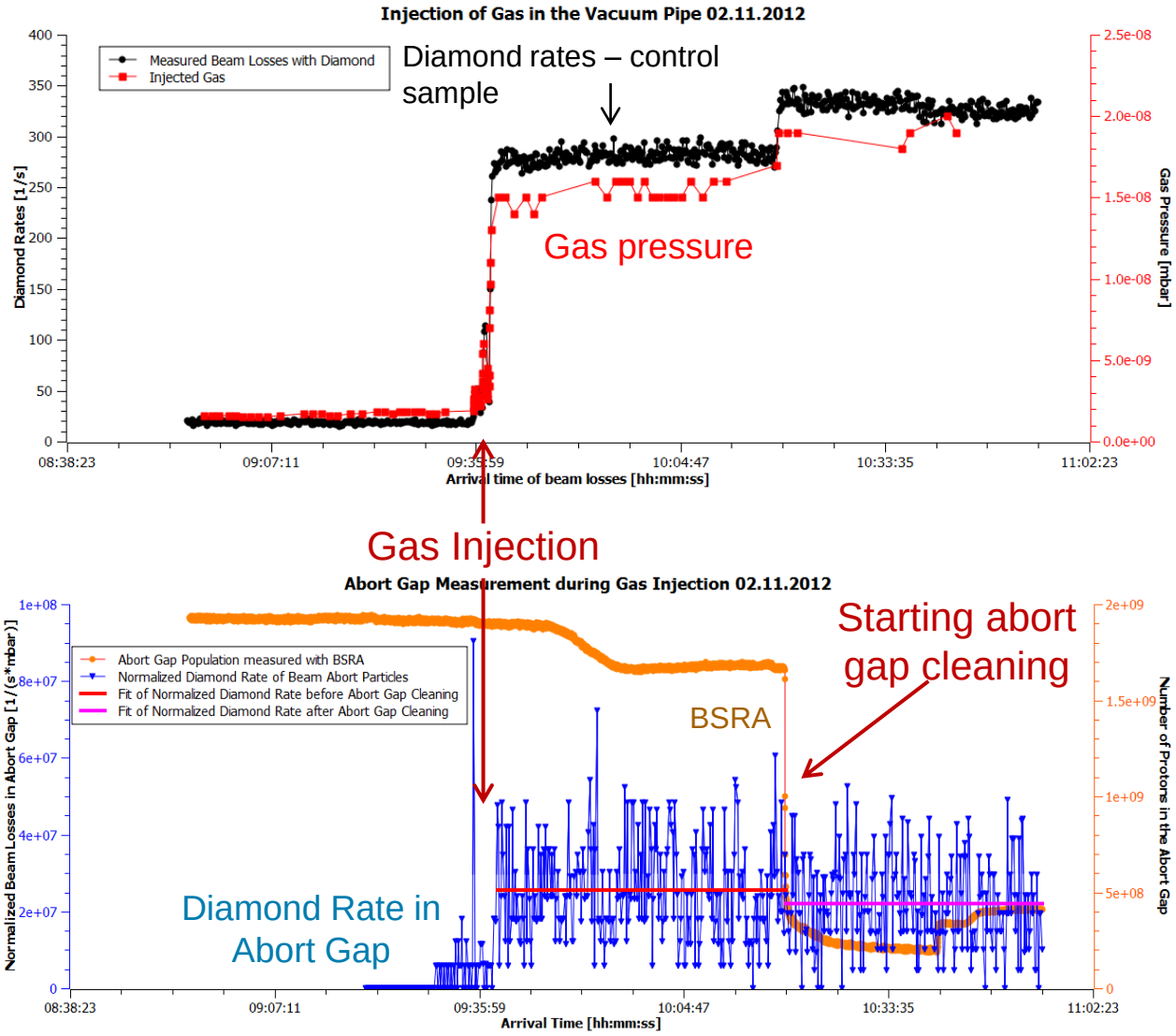




sCVD diamonds: An abort gap monitor for B2 in IR4?

Beam Losses in the Abort Gap Measured with sCVD in IR4

- Abort gap monitoring with sCVD diamond and BSRA during gas injection
  - Higher beam loss rates
- Control sample of B2 during gas injection
  - good agreement with gas pressure
- Abort gap cleaning
  - BSRA rates decreases (85%)
  - Normalized diamond rates decrease (fit) (13%)
- Very low statistic for diamond



Conclusion

- Many UFO events appear in the LHC ring
- Simulation of beam loss pattern were done
  - Good agreement with measurements
  - Many losses in IR7
- Observation of bunch-by-bunch beam losses is possible with diamond detectors due to nanosecond time resolution
- Analysis of different kind of beam loss were done
- UFO observation
  - UFOs lead to beam losses in each bunch
- Beam losses during injection
  - Unbunched beam lead to beam losses
- Abort gap population
  - Small statistic