Application of Diamond Based Beam Loss Monitors at LHC

1st ADAMAS Workshop

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Content

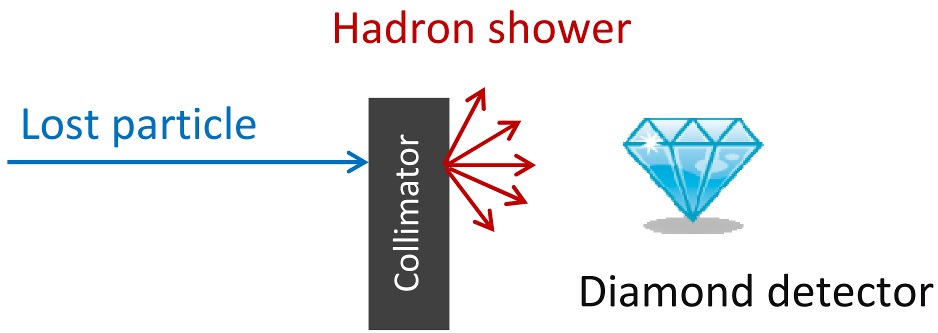
1. Challenges of the LHC

1a. Challenges of the LHC

- LHC accelerates protons with large energy
- operational proton particle momentum: 4TeV/c
- Operational stored beam energy: 130MJ
  - 35kg of TNT or 3 kg of Swiss Chocolate
- Beam losses deposit energy in equipment
  - mJ/cm^3 quench superconducting magnets
  - Larger beam losses can damage material
- Protection equipment
- Interception of beam losses
- Large beam losses => beam dump

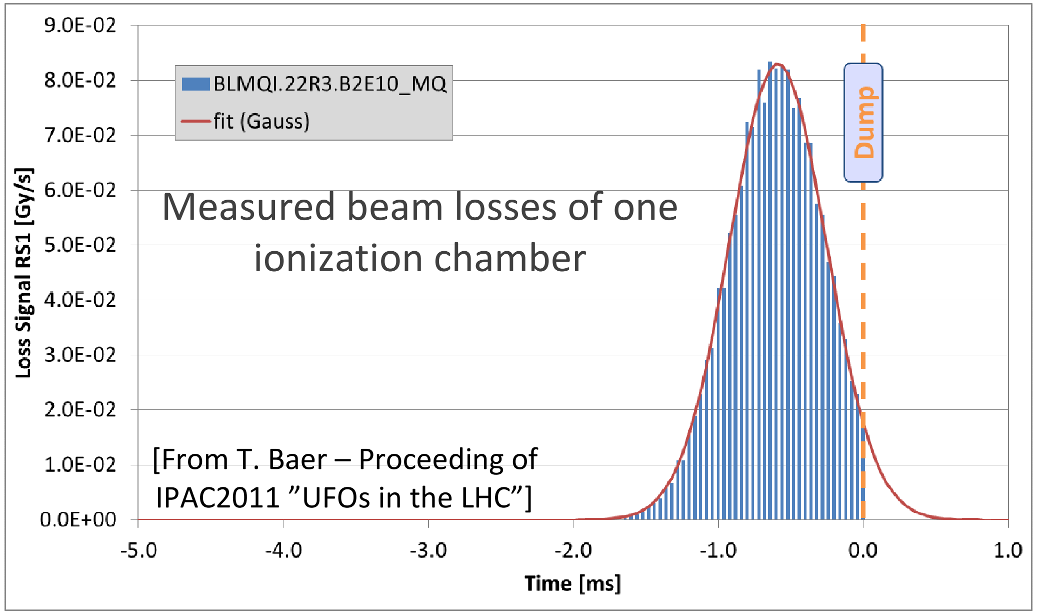
1b. Beam Losses in the LHC

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



1c. Beam Losses Caused by UFOs

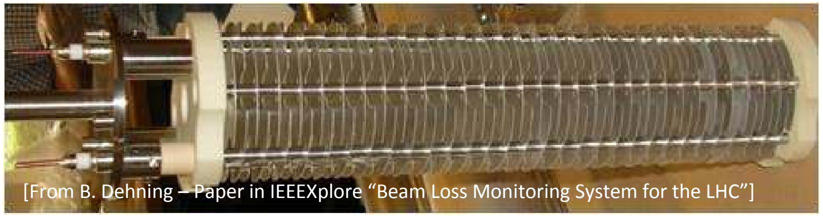
- Unidentified Falling Objects (UFOs) are dust particles with size of micrometer (10-100µm)
- Falling into the beam from above
- Scattering processes between UFO and proton
  - Inelastic scattering (localized showers)
  - Elastic scattering (over several turns)
- Losses profile is Gaussian
  - Several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



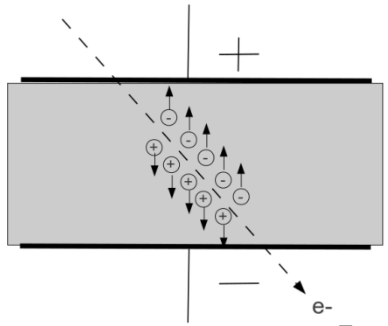
1d. Beam Loss Monitors in the LHC

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


[From B. Dehning – Paper in IEEEXplore "Beam Loss Monitoring System for the LHC"]

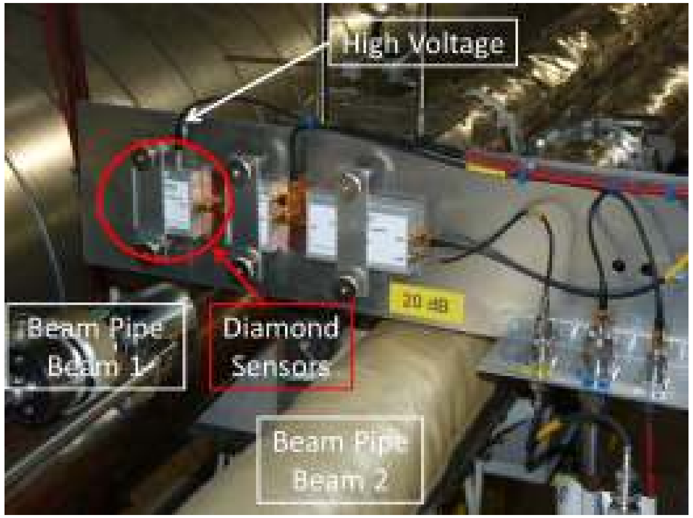
sCVD diamond frame



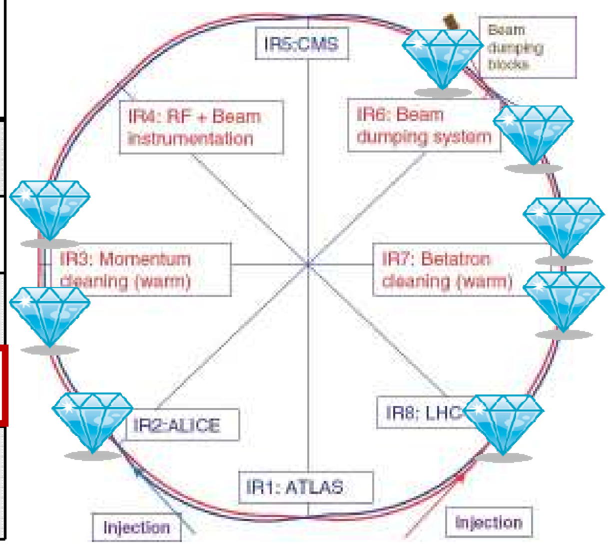
2. Diamond Sensors at LHC

2a. pCVD Diamond Sensors

- Installed in LHC tunnel
- Readout with oscilloscope
- Triggered by external signal or internal
- Important diamond in IR7
  - Collimator close to beam
  - Different beam losses visible



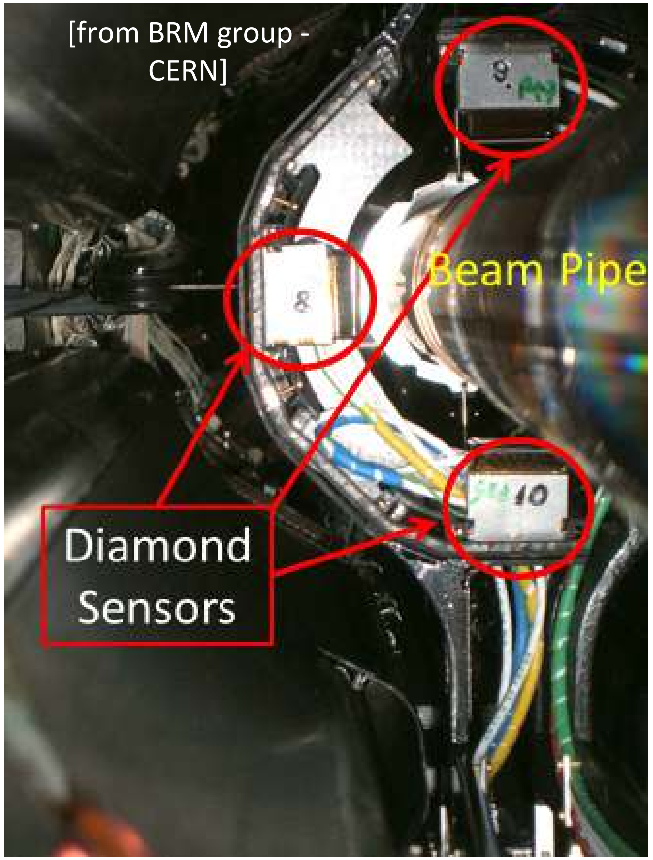
Location	Number	Trigger	Measurement of beam losses during
IR2	1	Injection signal	Injection
IR3	2	Post Mortem trigger	Beam dump
IR6	2	Post Mortem trigger	Beam dump
IR7	2	Internal	Operation
IR8	1	Injection signal	Injection



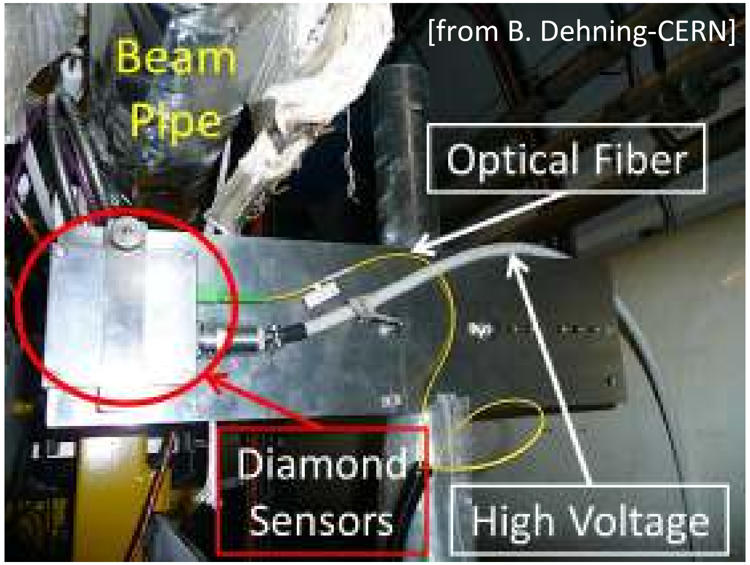
2b. sCVD Diamond Sensors

- Installed in CMS and LHC tunnel
- Readout with readout modules:
  - Time-to-Digital Converter (arrival time)
  - Scaler (beam losses per second)
  - Analog-to-Digital Converter
    (signal sampling)

sCVD in CMS

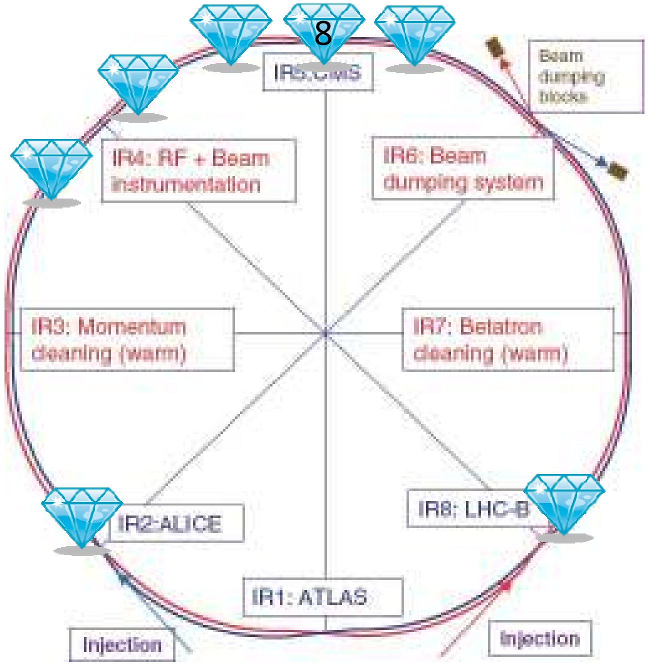


sCVD in LHC tunnel

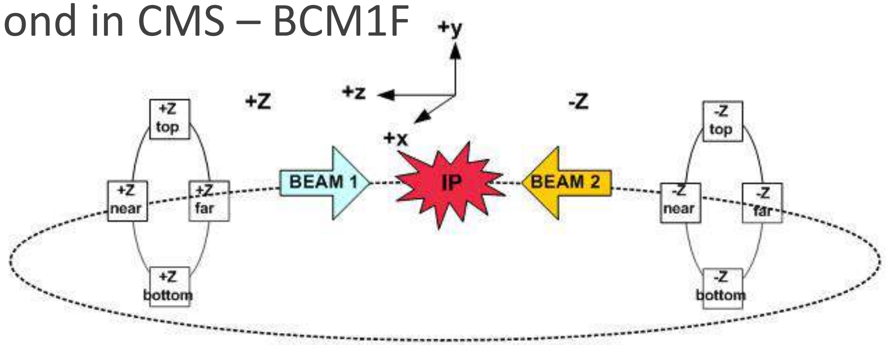


2b. sCVD Diamond Sensors

Location	Number	Purpose
IR2	1	Arrival time at injection
IR4	2	Arrival time
IR5 outside CMS	2	Arrival time, collision products outside of CMS
IR5 inside CMS	8	Collision products, background
IR8	1	Arrival time measurement at injection



Diamond in CMS – BCM1F

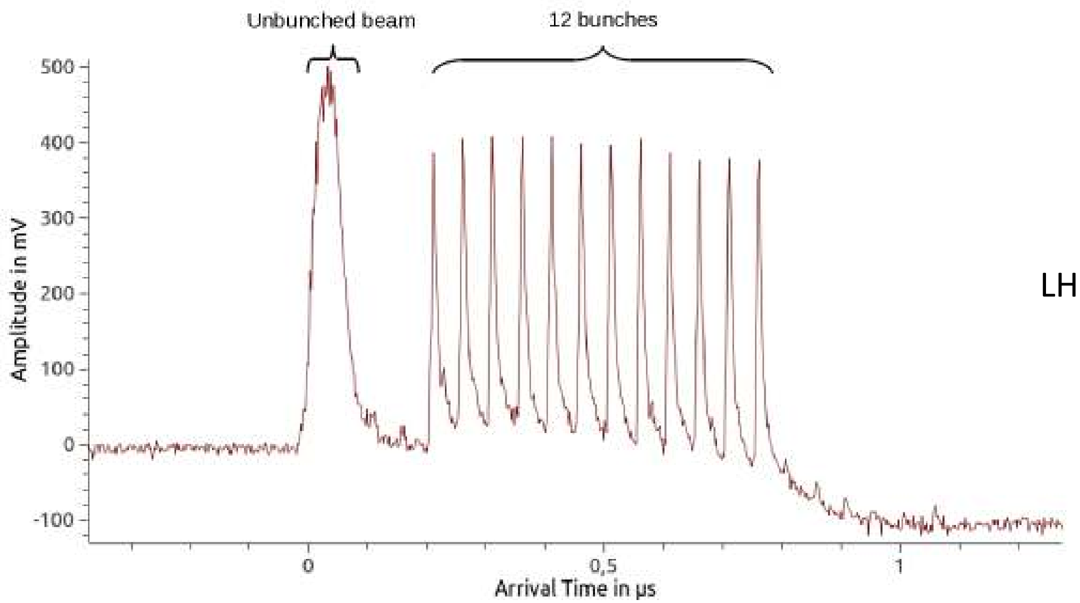


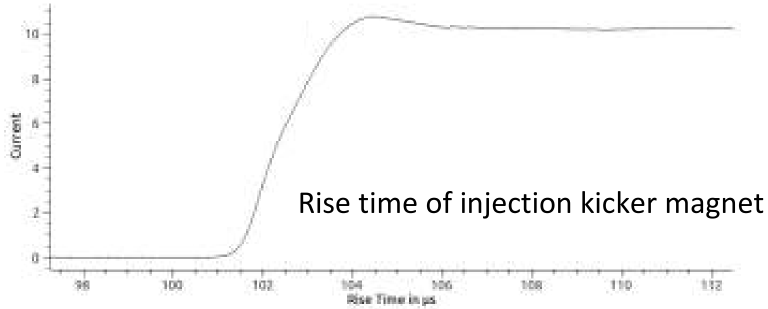
- BCM1F provides beam parameters
  - Background rates
  - Collision rates

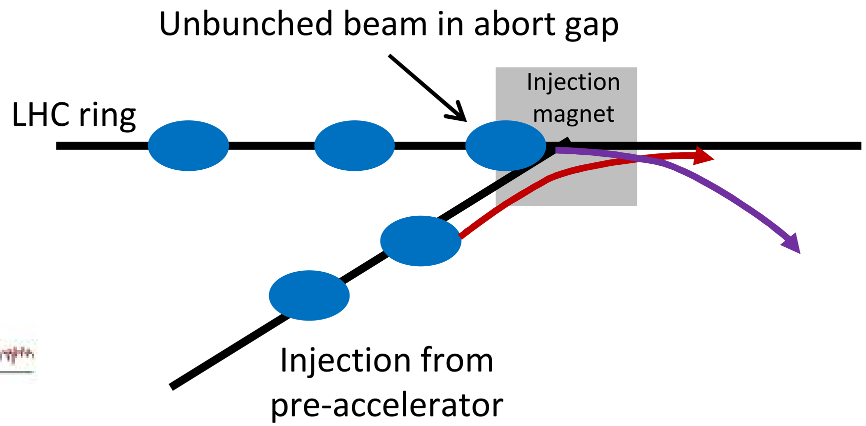
3. Measurements of Beam Losses with pCVD Sensors

3a. Injection

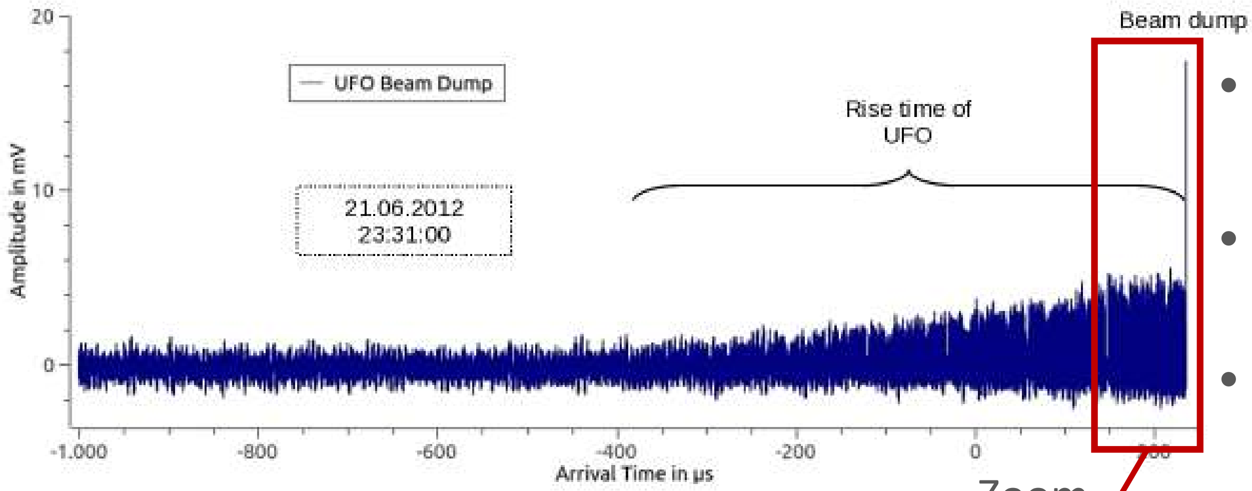
- Beam losses during 12 injected bunches from pre-accelerator
- Reason: injection oscillations
  - Injection of particles close to closed orbit
- Unbunched beam in abort gap due to pilot beam (test beam)



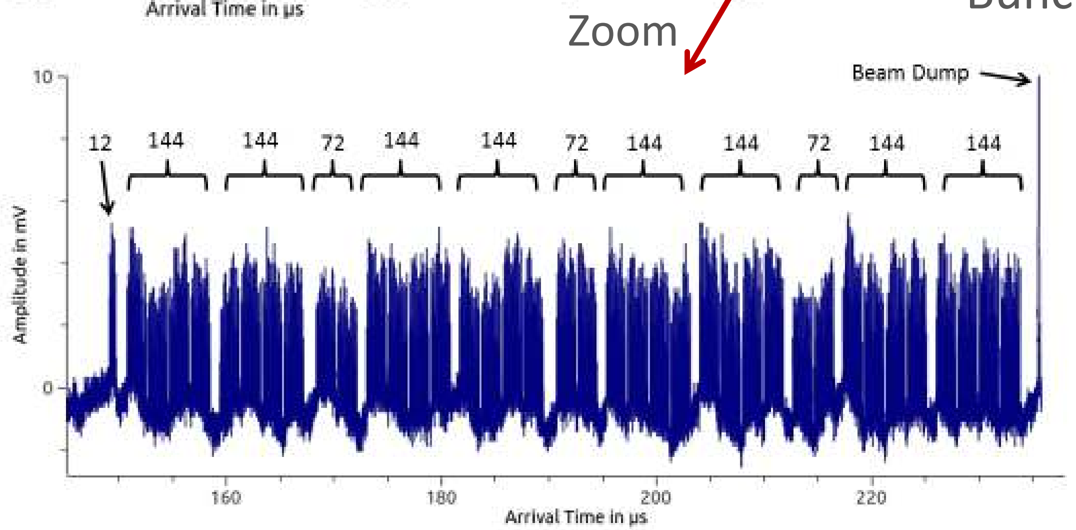




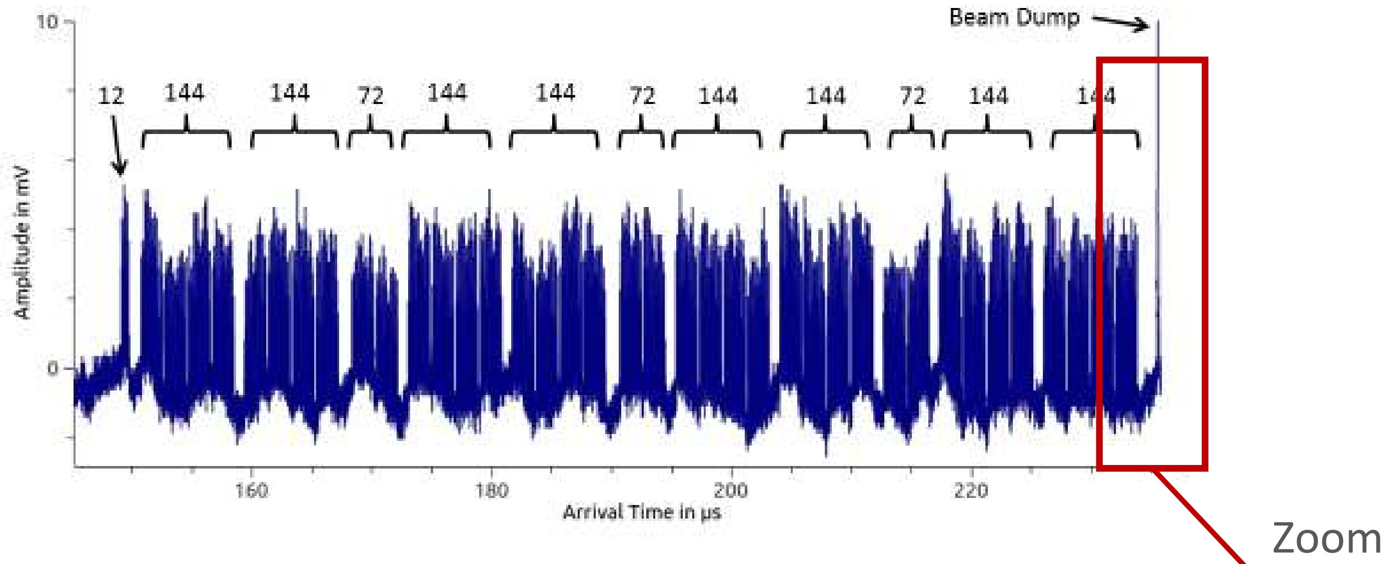
3b. UFO Events



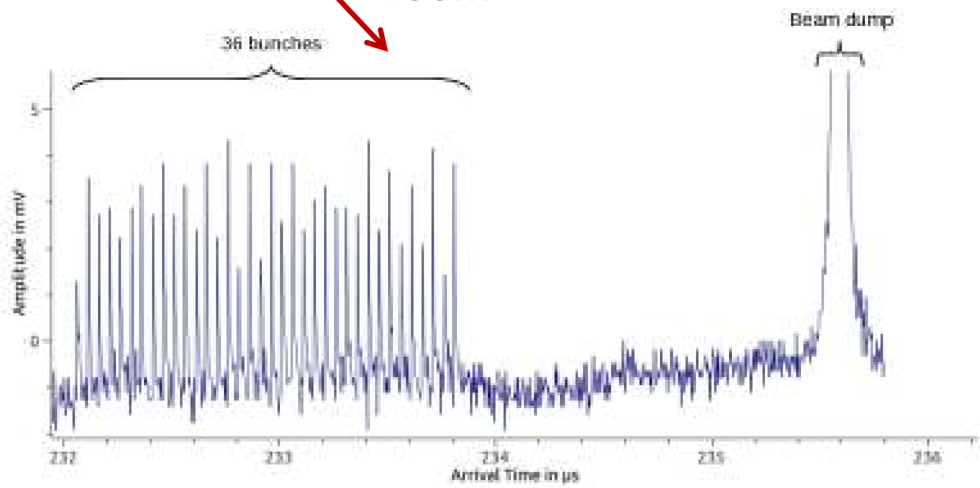
- Rise time of UFO is visible
  - Gaussian like
- Large beam losses lead to beam dump
- fill pattern is visible
  - Bunch configuration



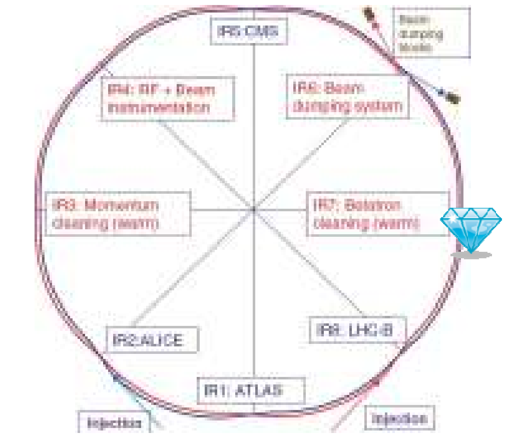
3b. UFO Events



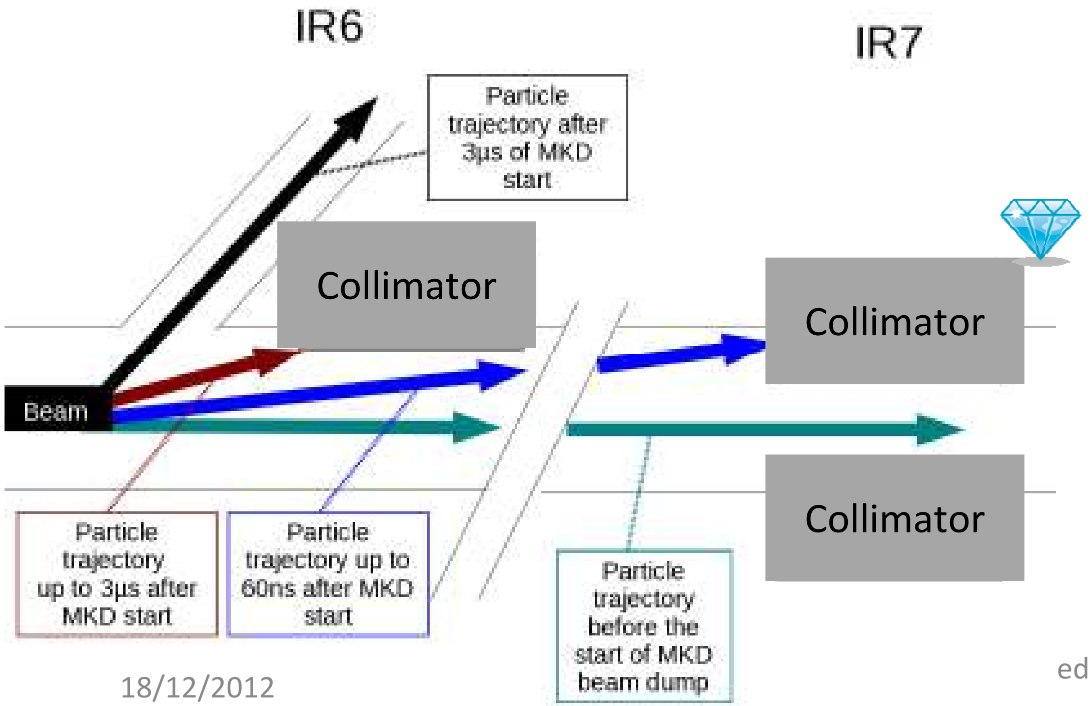
- Clear bunch structure visible
- Beam losses in each bunch
  - Predicted by simulations
- Additional losses during beam dump

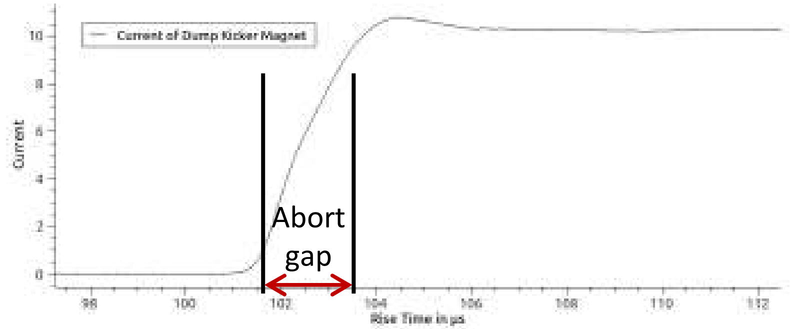


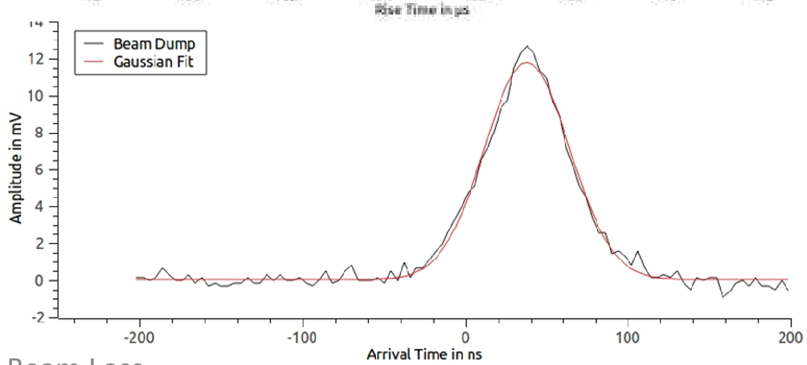
3c. Beam Dump



- Beam losses during beam dump
- Gaussian loss profile
  - Typical width: σ= 50-60 ns
- Reason:
  - particles in the abort gap (unbunched beam)
  - Rise time of kicker magnet for extracting



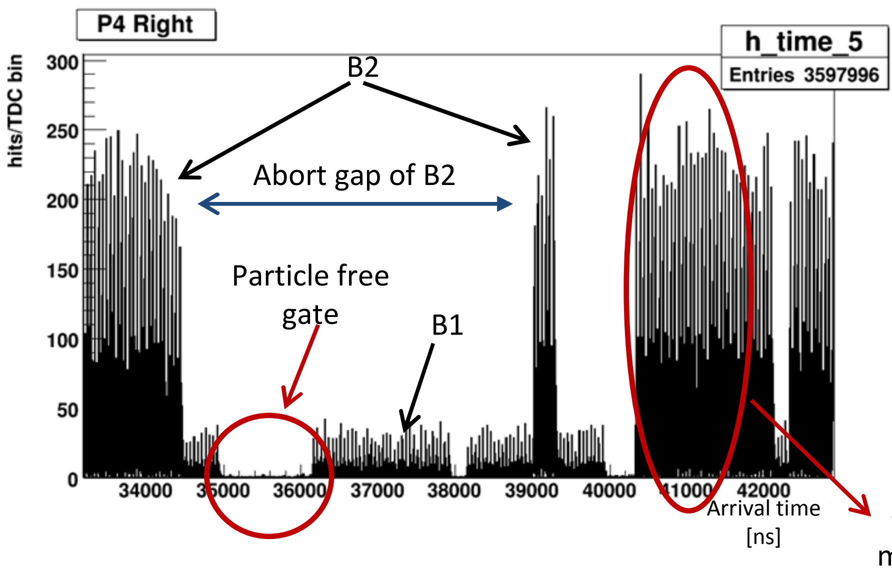


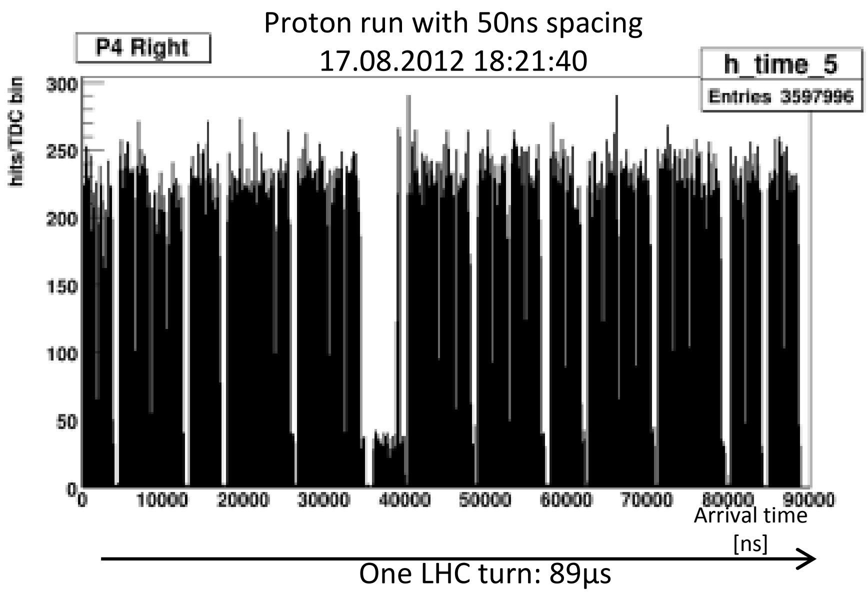


4. Measurements of Beam Losses with sCVD Sensors

4a. Abort Gap Measurement

- 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

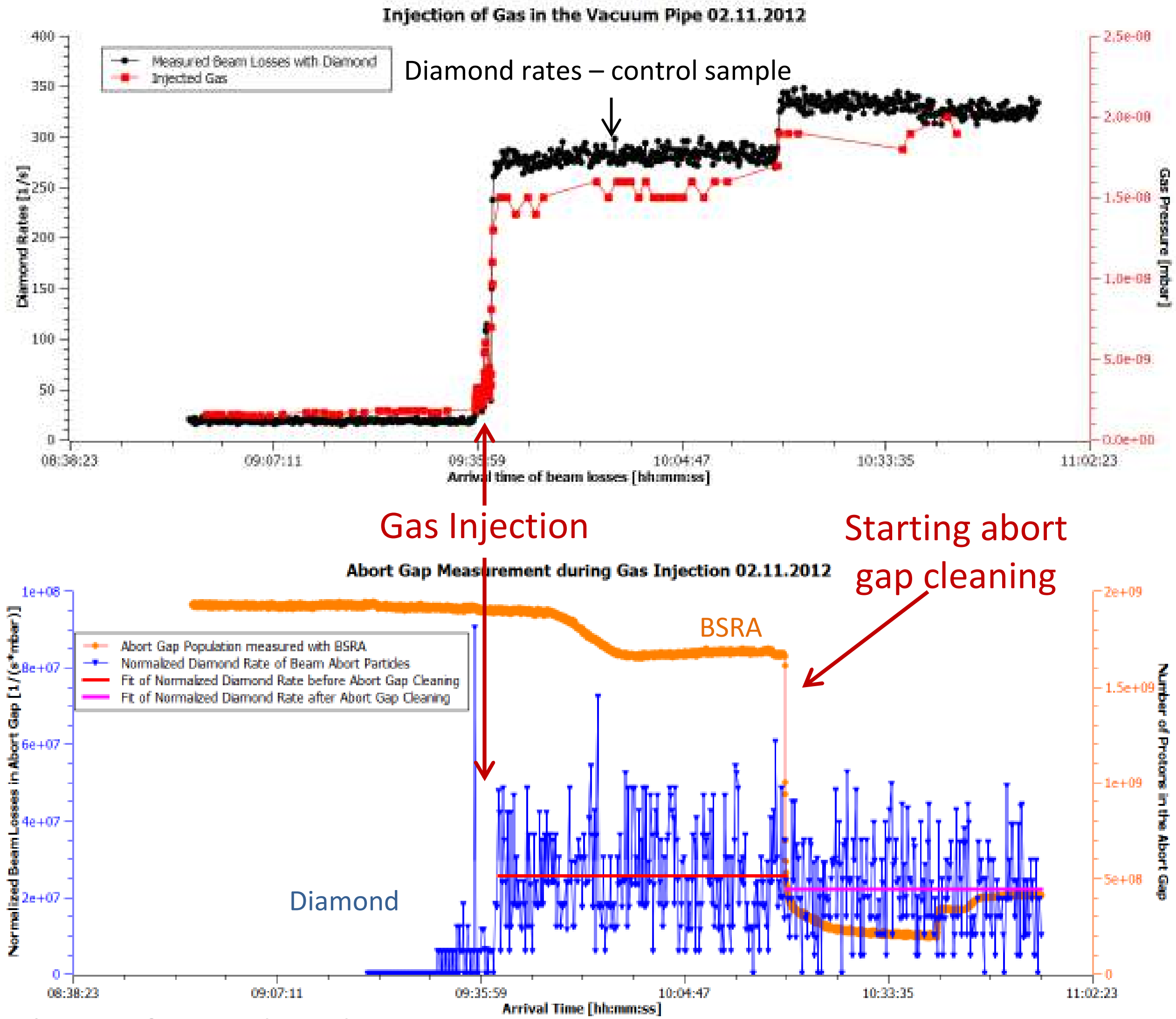




sCVD diamonds: An abort gap monitor for B2 in IR4?

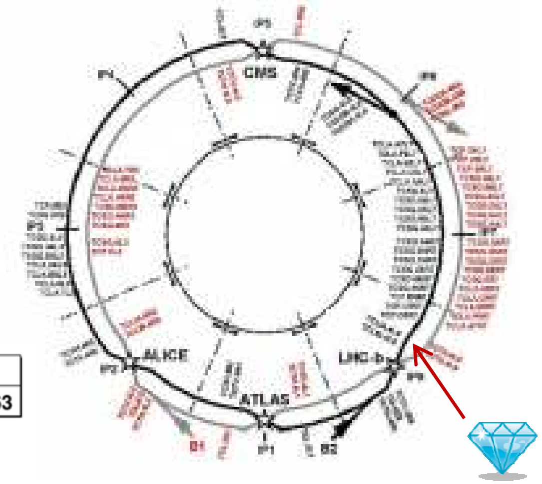
4a. Abort Gap Measurement

- 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 (18%)
  - Normalized diamond rates decrease (fit) (13%)
- Very low statistic for diamond

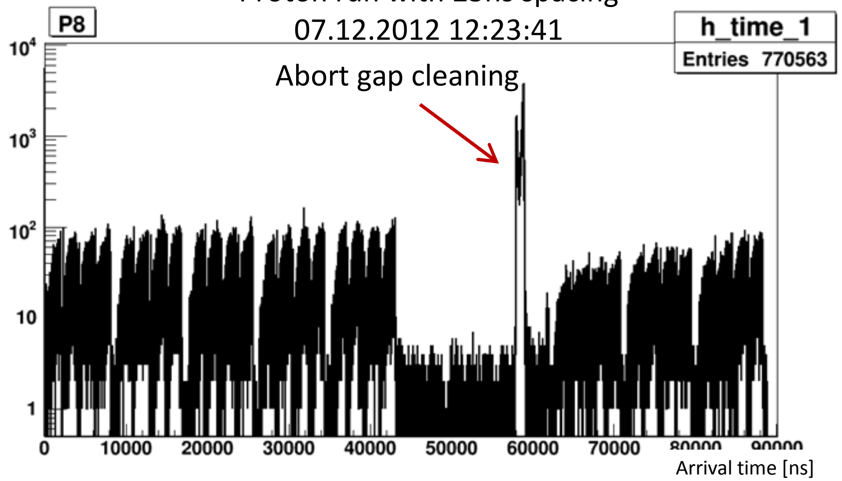


4b. Abort Gap Cleaning during 25ns Run

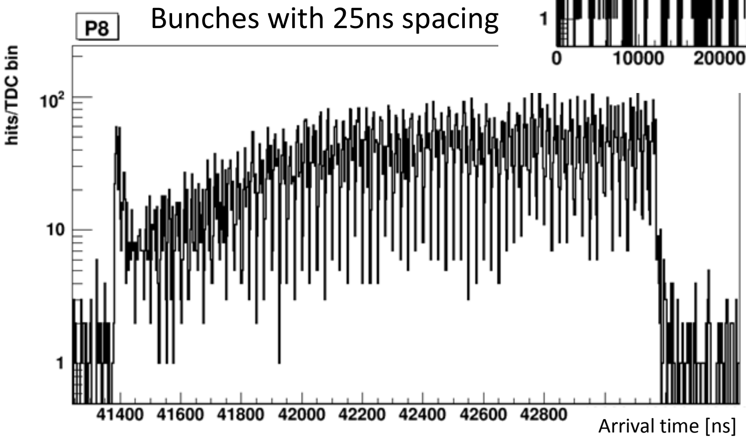
- sCVD diamond rates during 25ns run from IR8
- LHC injection structure of 25ns run is visible
- Beam losses in abort gap due to abort gap cleaning
  - Secondary particles crossing collimators in IR8



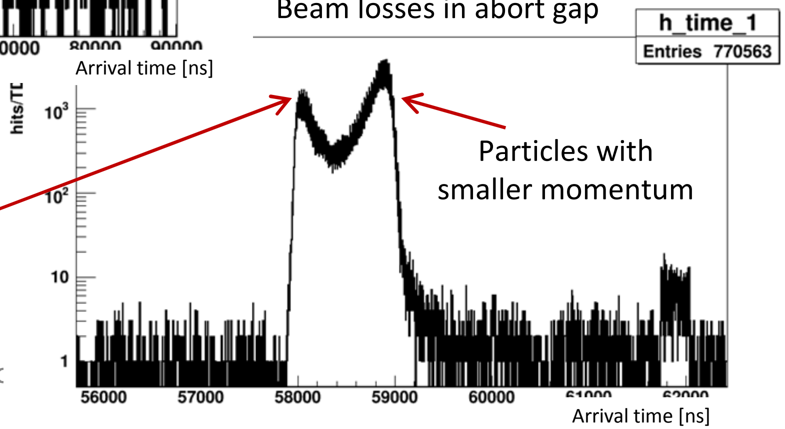
Proton run with 25ns spacing
07.12.2012 12:23:41



Bunches with 25ns spacing



Beam losses in abort gap



Particles with
larger momentum

Particles with
smaller momentum

5. Conclusion

5. Conclusion

- Observation of beam losses with ns time resolution
  1. Bunch-by-bunch beam loss analysis
  2. 25ns structure is visible
- Beam loss observation
  1. Scattering process between proton and dust particle => UFO
     - Gaussian loss profile
     - Fill pattern can be observed => losses appear in each bunch
  2. Beam losses during injection and beam dump
     - before injection: unbunched beam in abort gap
     - during beam dump: unbunched beam in abort gap
- Abort gap measurements
  1. Control sample (rates of B2) show agreement with gas pressure
  2. After abort gap cleaning less particles in abort gap
     - BSRA rate decreases
     - Normalized diamond rates decrease (fit)
     - Very low statistic => moving the diamond to get higher statistic
  3. Beam losses due to abort gap cleaning are visible in IR8 because of collimators

Acknowledgment

Wolfgang Lohmann, Rudiger Schmidt, Tobias Baer, DESY-Zeuthen group, BRM CERN group, TE-MPE-PE CERN group, Bernd Dehning, Ewald Effinger, Erich Griesmayer

Backup

6b. UFO Events

- Observation of UFO with diamond sensor
- Two events after each other
- Small losses, no beam dump
- Time resolution: 1ns