UFOs in the LHC

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Acknowledgements: E. Elsen, E. B. Holzer, S. Jackson, M. Misiowiec, E. Nebot, A. Nordt, J. Wenninger, C. Zamantzas

Content

1. Introduction to LHC Machine Protection System

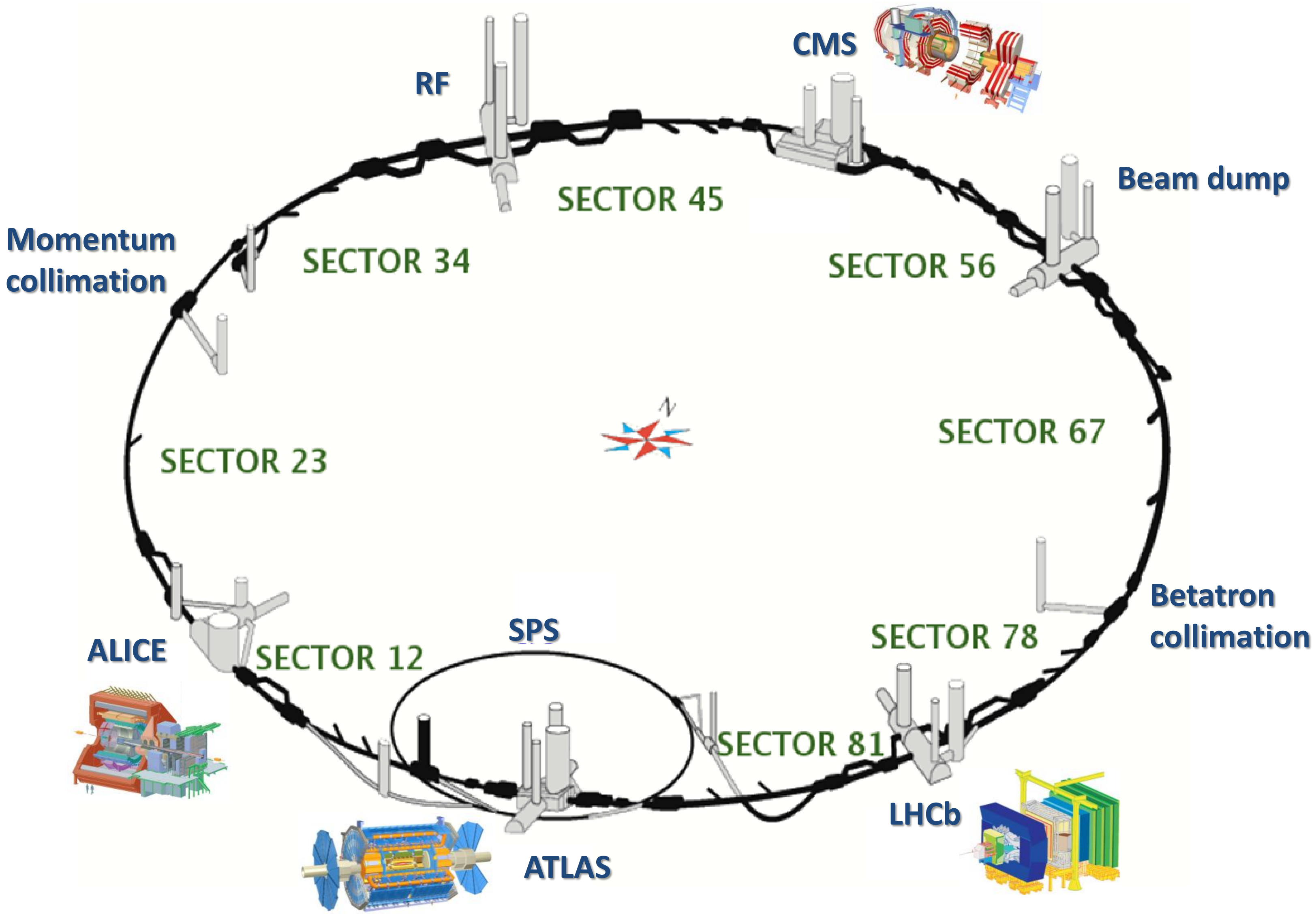
2. Fast Loss Events (UFOs)

3. Outlook and Mitigation

Content

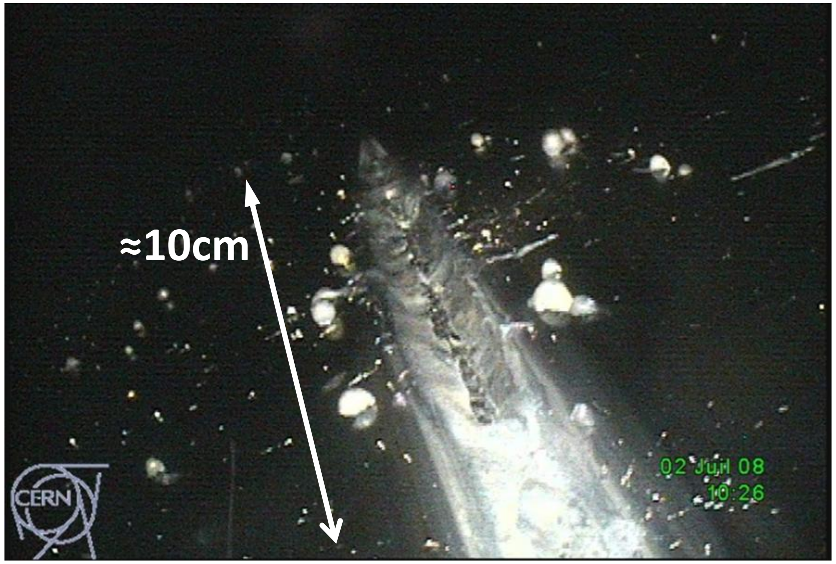
1. Introduction to LHC Machine Protection System
2. Fast Loss Events (UFOs)
3. Outlook and Mitigation

LHC Layout


CMS
RF
Beam dump
SECTOR 45
SECTOR 34
SECTOR 56
Momentum
collimation
SECTOR 23
SECTOR 67
Betatron
collimation
SPS
SECTOR 78
ALICE
SECTOR 12
SECTOR 81
LHCb
ATLAS

Challenge: Stored Energy

- SPS incident in June 2008:
  *400 GeV beam with **2 MJ***
  (J. Wenninger, CERN-BE-2009-003-OP)

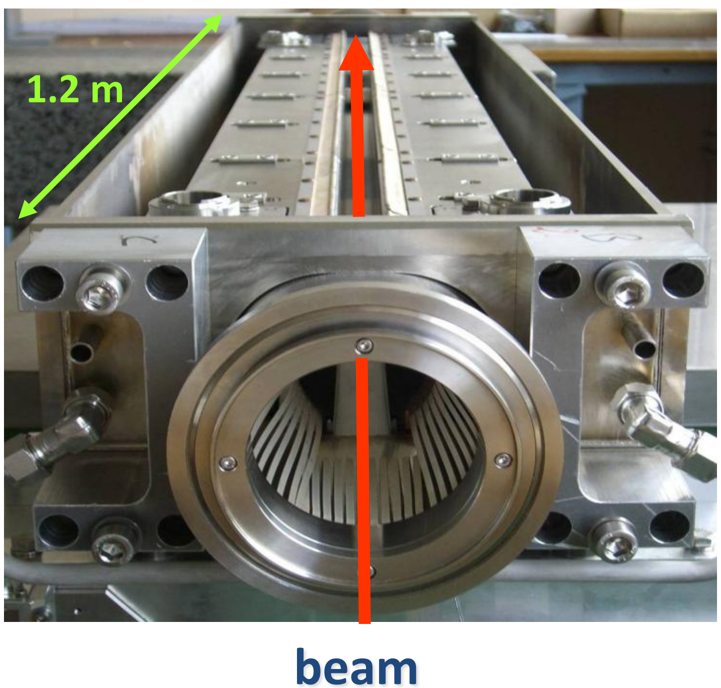


- LHC stored beam energy:
  Nominal intensity: $3.2\cdot10^{14}$ protons.
  (2808 bunches)
  Nominal beam energy: 7 TeV
  Nominal stored energy (beam): **362 MJ**
- Stored energy in magnets (nominal): **over 10 GJ**
- Damage threshold: **≈10 kJ** (5% of single bunch). *(R. Schmidt, PAC07)*
- Quench limit: **few mJ/cm³**
- Now 3.5 TeV, 35 MJ. In 2011 up to 100 MJ.

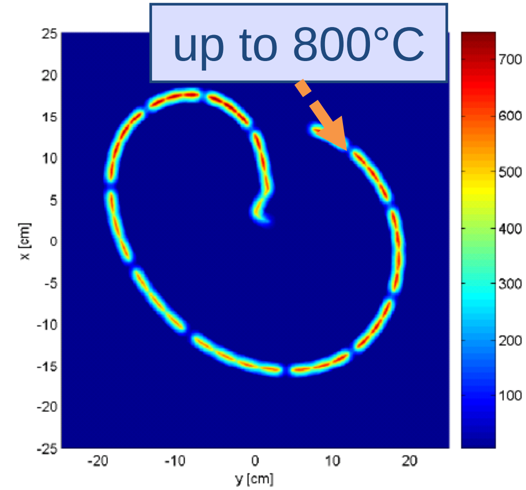
Beam Collimation

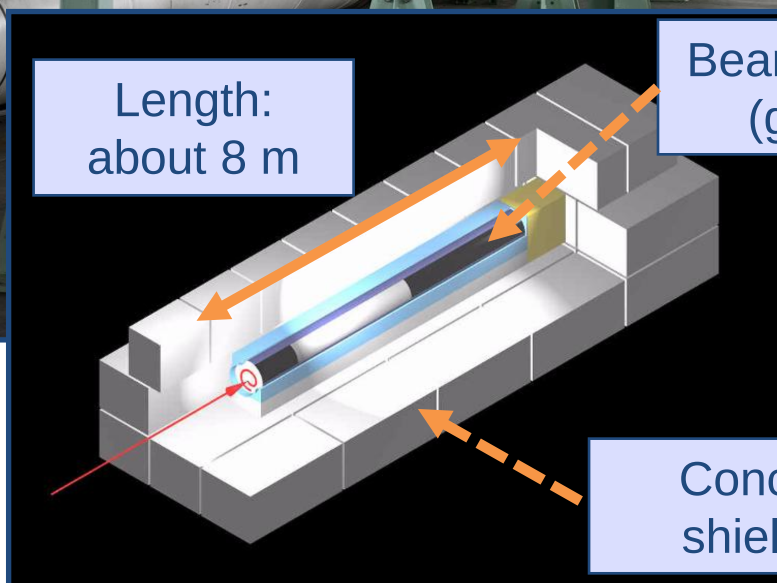
- Three stage collimation system (≈100 collimators and absorbers)

  primary (5.7σ): deflection
  secondary (8.5σ): absorbtion
  tertiary (15σ): triplet protection
  special dump and injection protection collimators



Beam Dump System





Beam Interlock System

- Over 200 systems can request a beam dump:

  Power converter

  BPMs

  Collimators

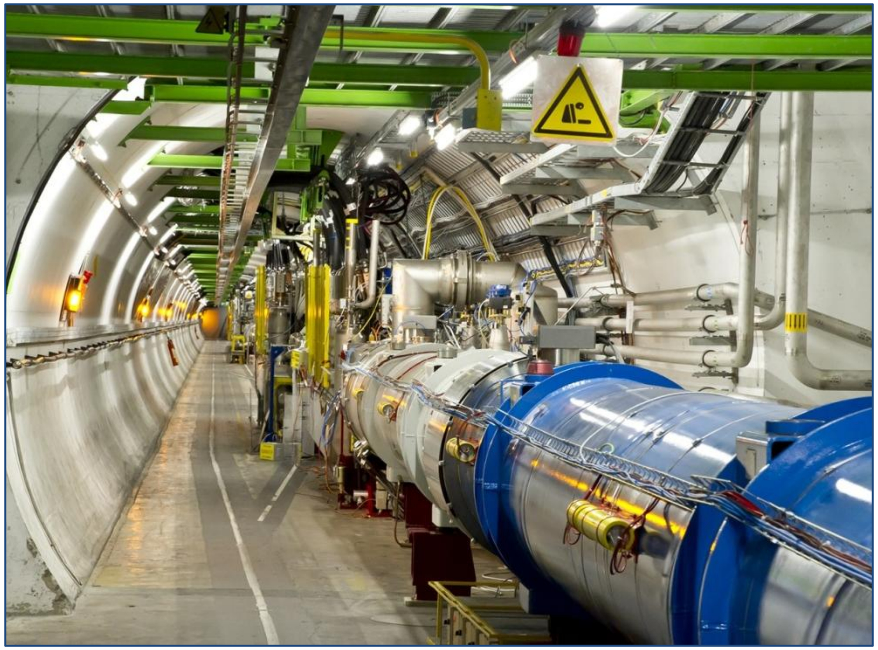
  Software Interlock System

  Vacuum

  Access system

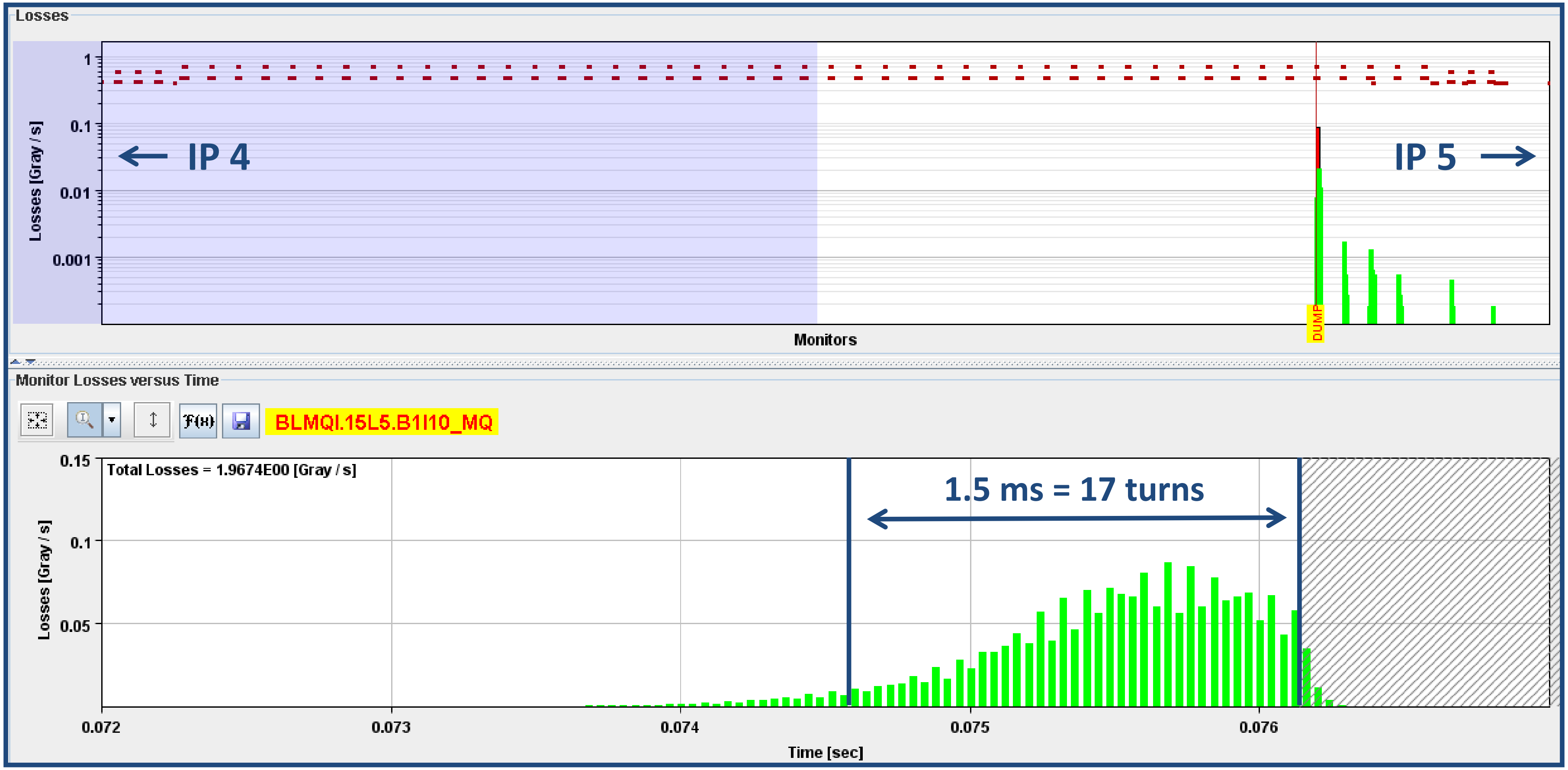
  BLMs

  - ≈ 4000 BLMs
  - 12 different integration times (40µs – 83.8s)



Content

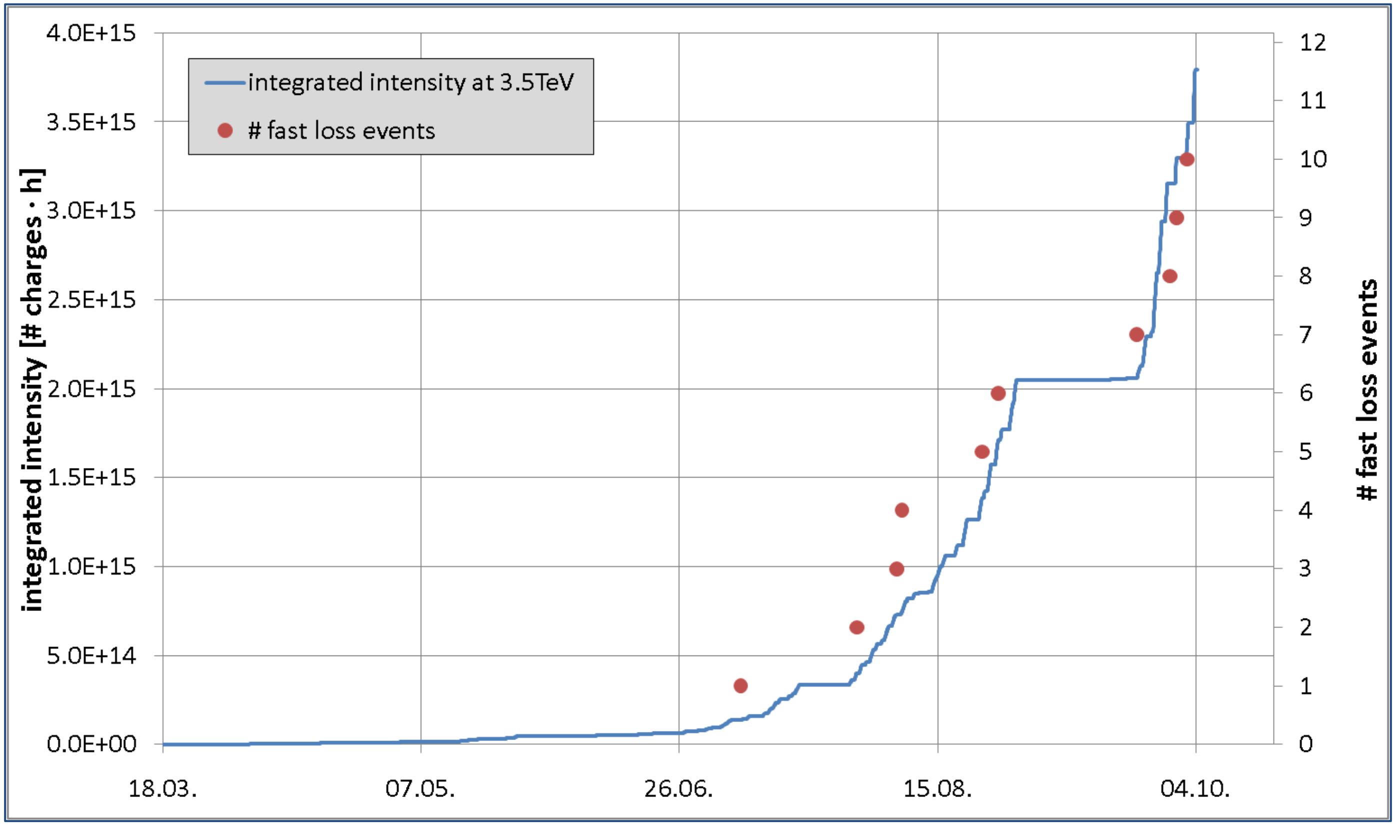
Fast Loss Event (UFO)



Unconventional loss pattern:

Loss location often in the arc, timescale: 10 turns.

Fast Loss Events vs. Intensity

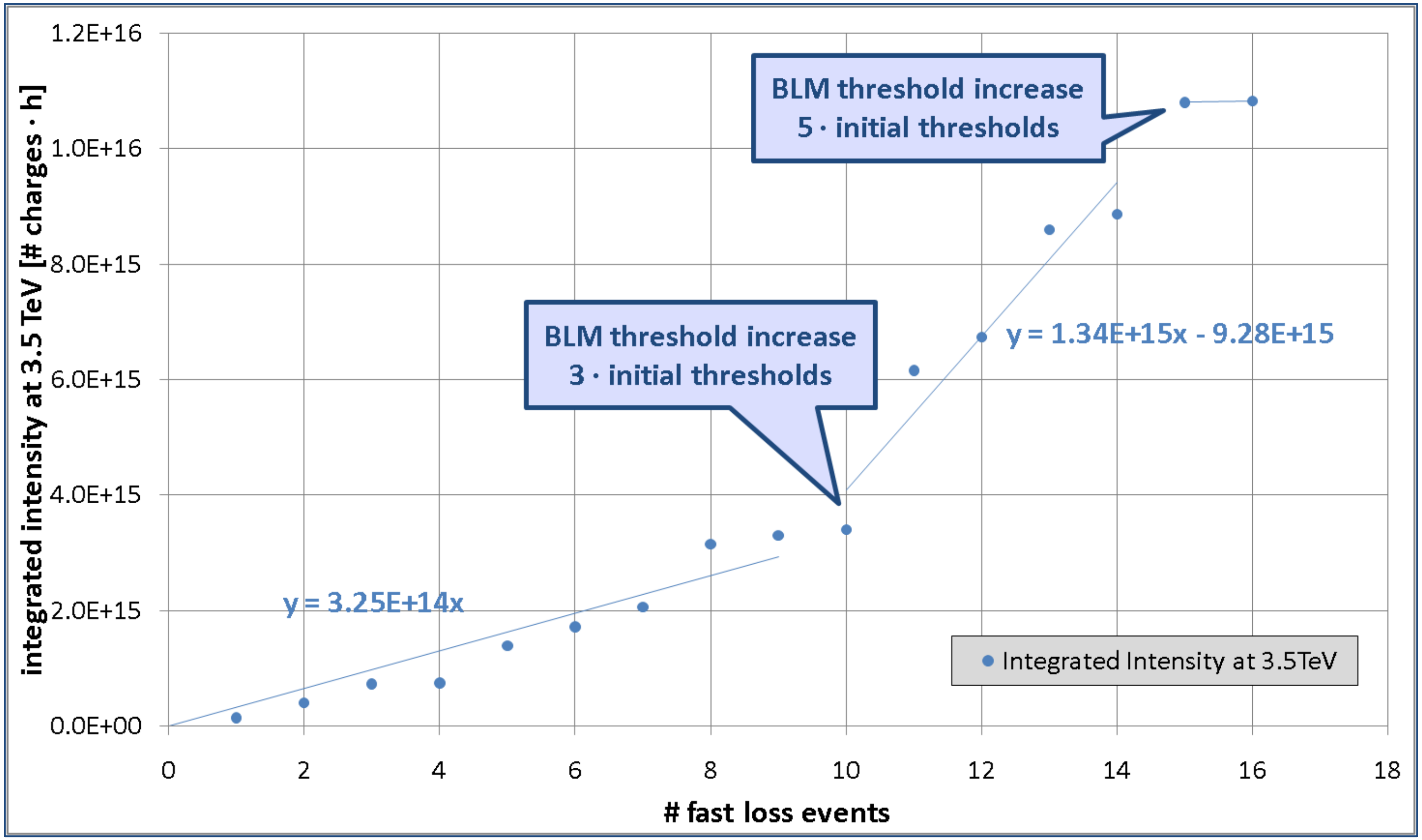


Until now: **20 emergency beam dumps** due to fast loss events.

Fast loss event rate proportional to intensity

Fast Loss Event Rate

- After the increase of the BLM Threshold by a factor of 3 there were about **4.1 times less beam dumps** due to fast loss events.

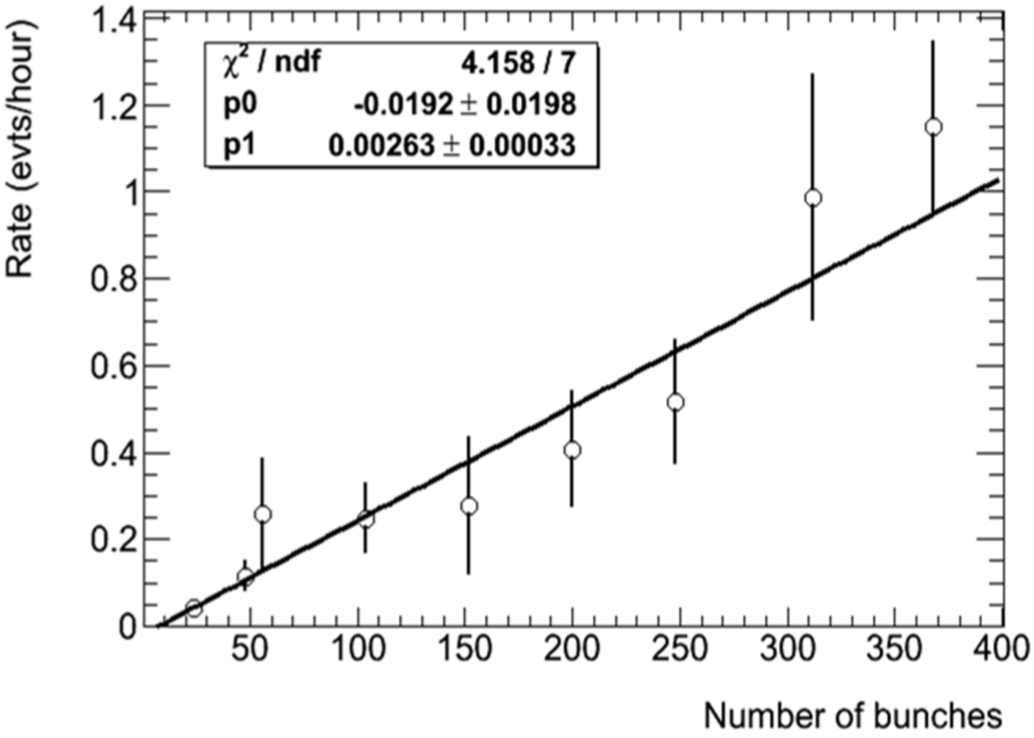


Content

Event Rate

- 113 events below threshold found in 2010. *(E. Nebot)*

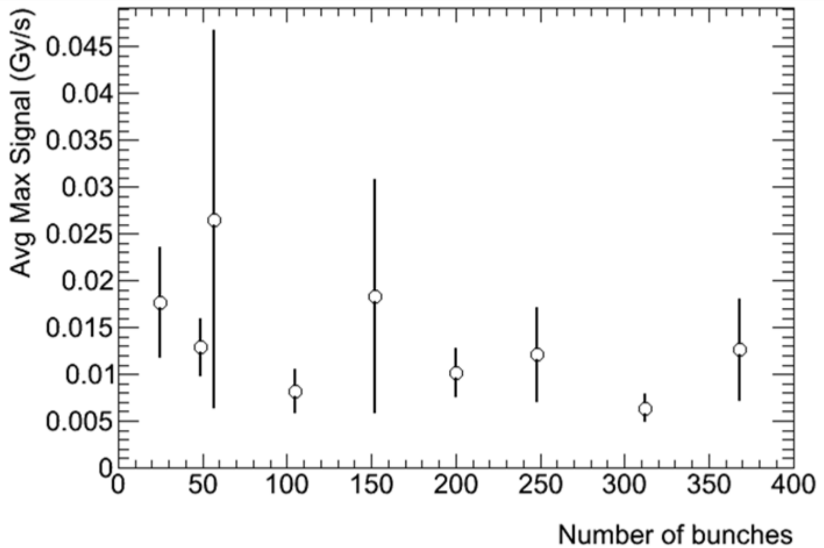
- **UFO rate**: proportional to beam intensity.



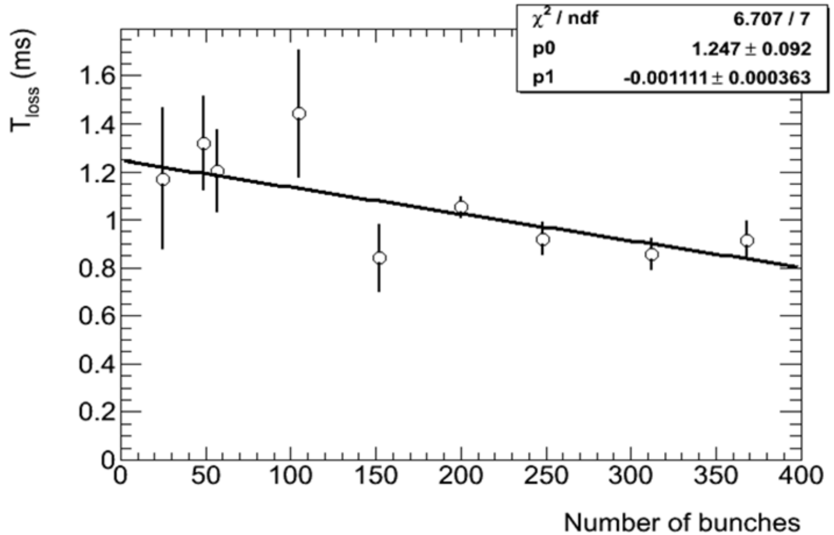
courtesy of E. Nebot

Events Below Threshold

- **Average signal**: no clear dependence on intensity



- **Loss duration**: tendency to decrease with intensity



courtesy of
E. B. Holzer and E. Nebot

UFOs Detection in 2011

- Online UFO detection from live BLM data.

  *Losses (RS 4) of **two BLMs in 40m** are above **1E-4 Gy/s.***

  RS 2 / RS 1 > 0.55 (UFO average : 0.89).

  RS 3 / RS 2 > 0.45 (UFO average: 0.79).

- **Over 4000 triggers** so far.
  - From subset of 230 manually verified triggers:

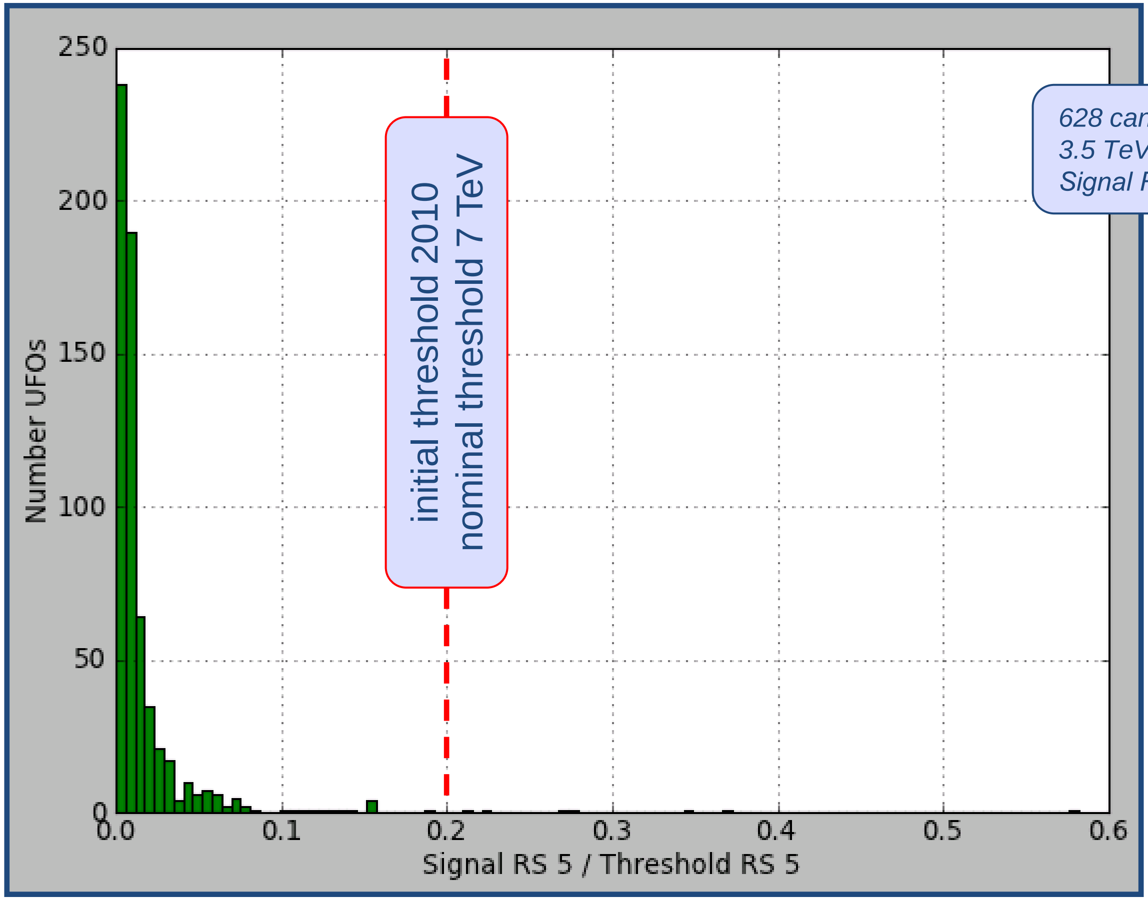
    About 70% are UFOs, 10% ambiguous cases, 20% are false triggers.

  - For most analysis additional cut. E.g.:

    Only flat top UFOs, loss of UFO BLM (RS05) > $5\cdot10^{-4}$ Gy/s (≈ 5 ‰ of threshold).

    53 events remain of subset, of which 51 are clear UFOs (96%) and 2 are ambiguous cases.

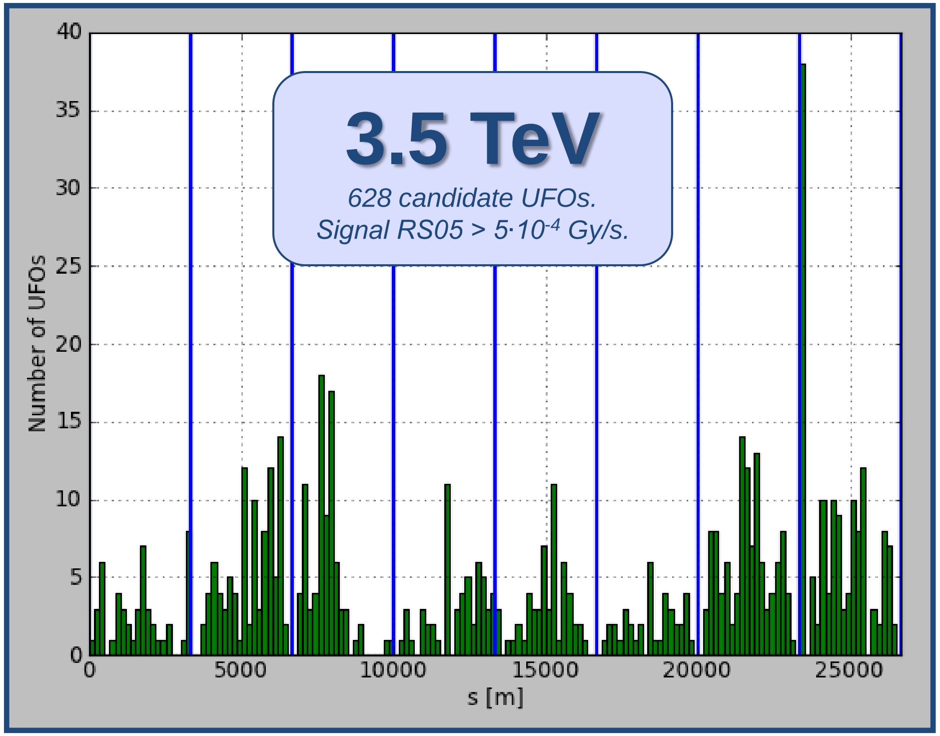
Events Below Threshold

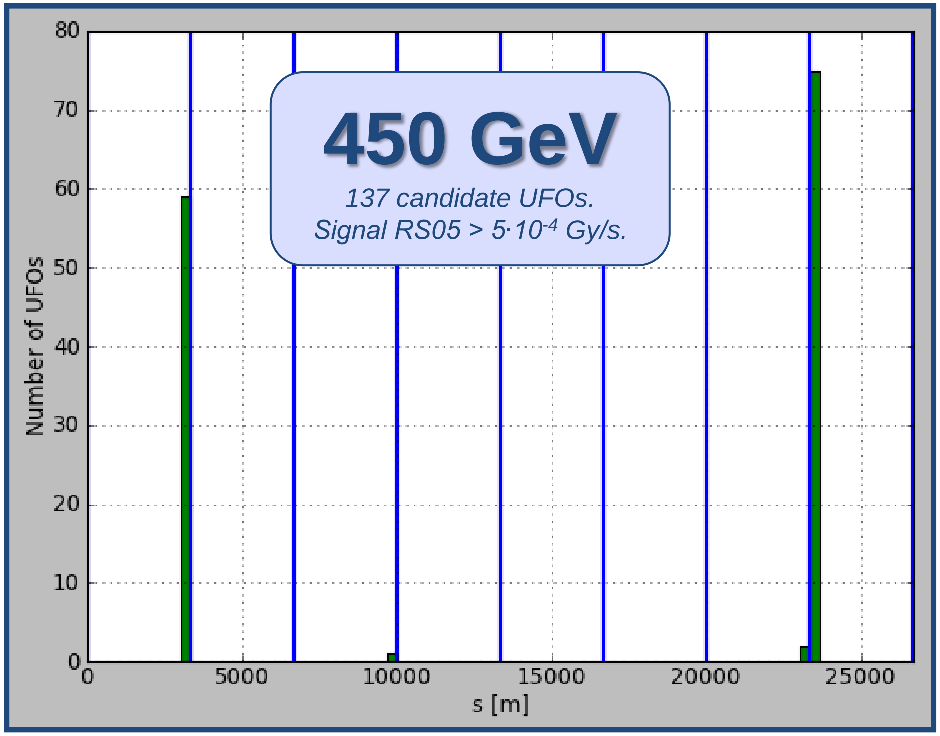


628 candidate UFOs at 3.5 TeV.
Signal RS05 > 5·10⁻⁴ Gy/s.

Most events are much below threshold.

Spatial UFO Distribution



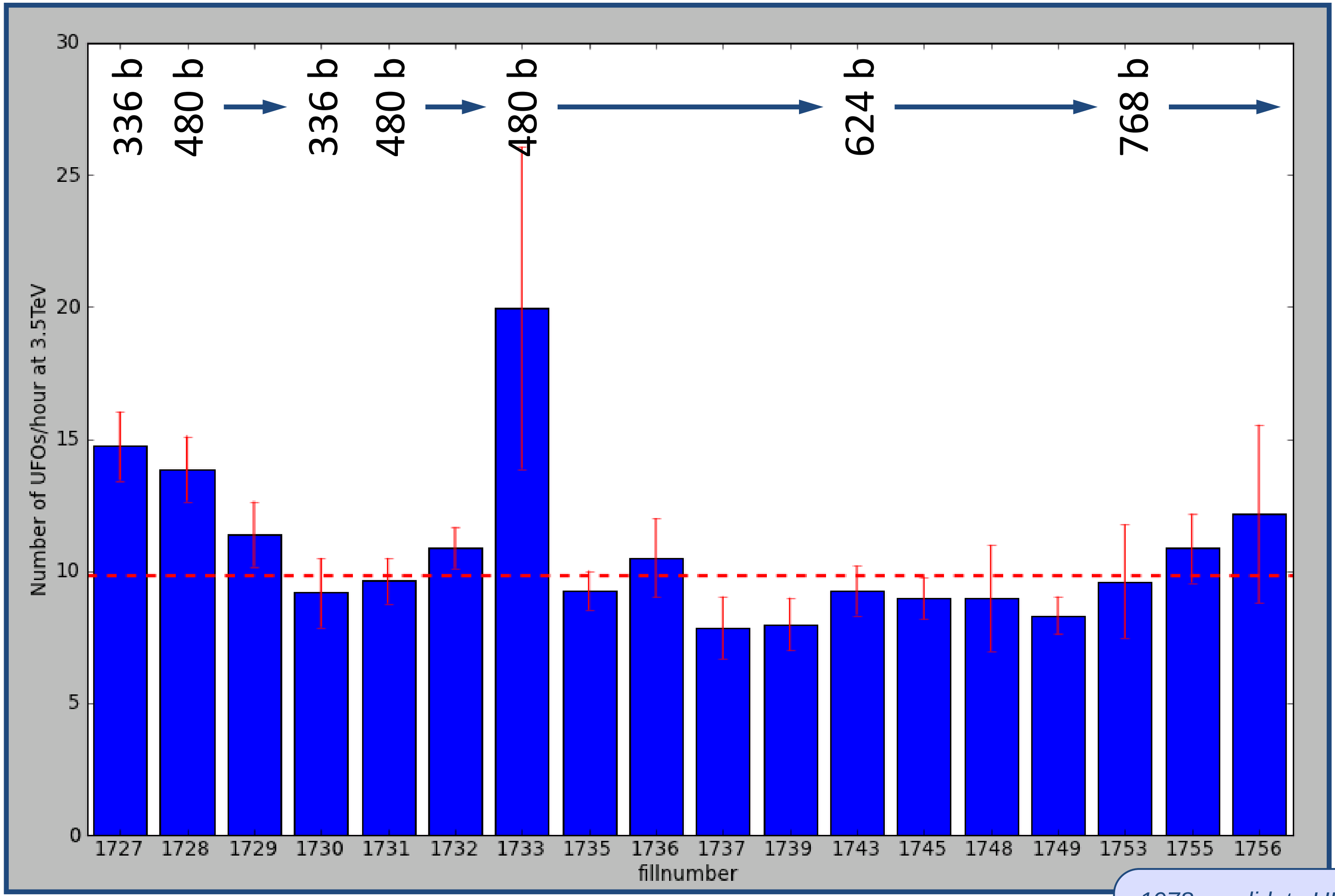


The UFOs are distributed all around the machine.

38 candidate UFOs at injection kicker magnet for Beam 2.

Mainly UFOs at injection kicker magnets.

UFO rate



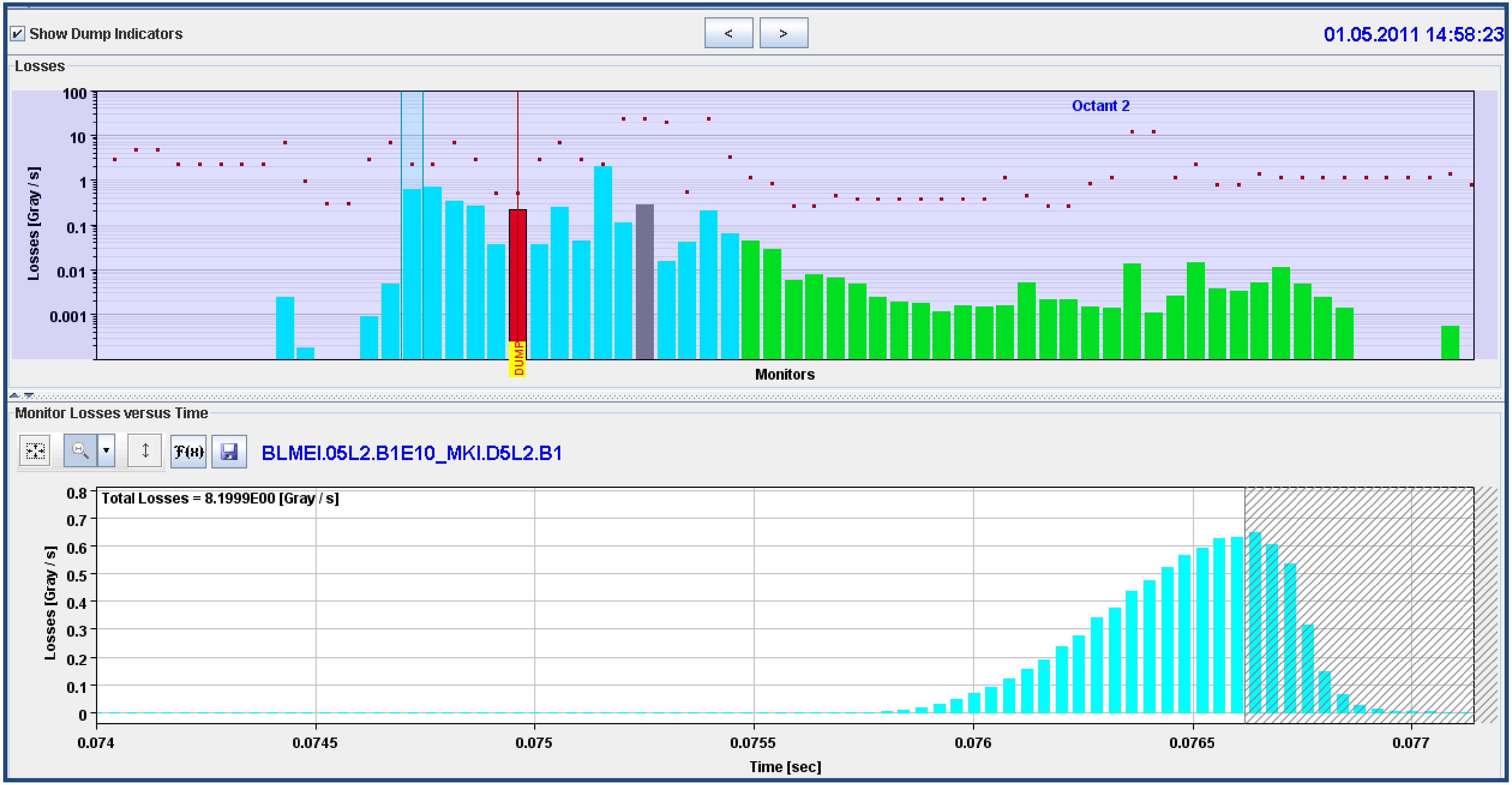
1978 candidate UFOs at 3.5 TeV. Data scaled with 0.7669 (detection efficiency from reference data)

On average: **10 UFOs/hour**

Content

1. Introduction to LHC Machine Protection System
2. Fast Loss Events (UFOs)
   - Observations
   - UFOs below threshold
   - **UFOs at injection kicker magnets**
   - Theories
3. Outlook and Mitigation

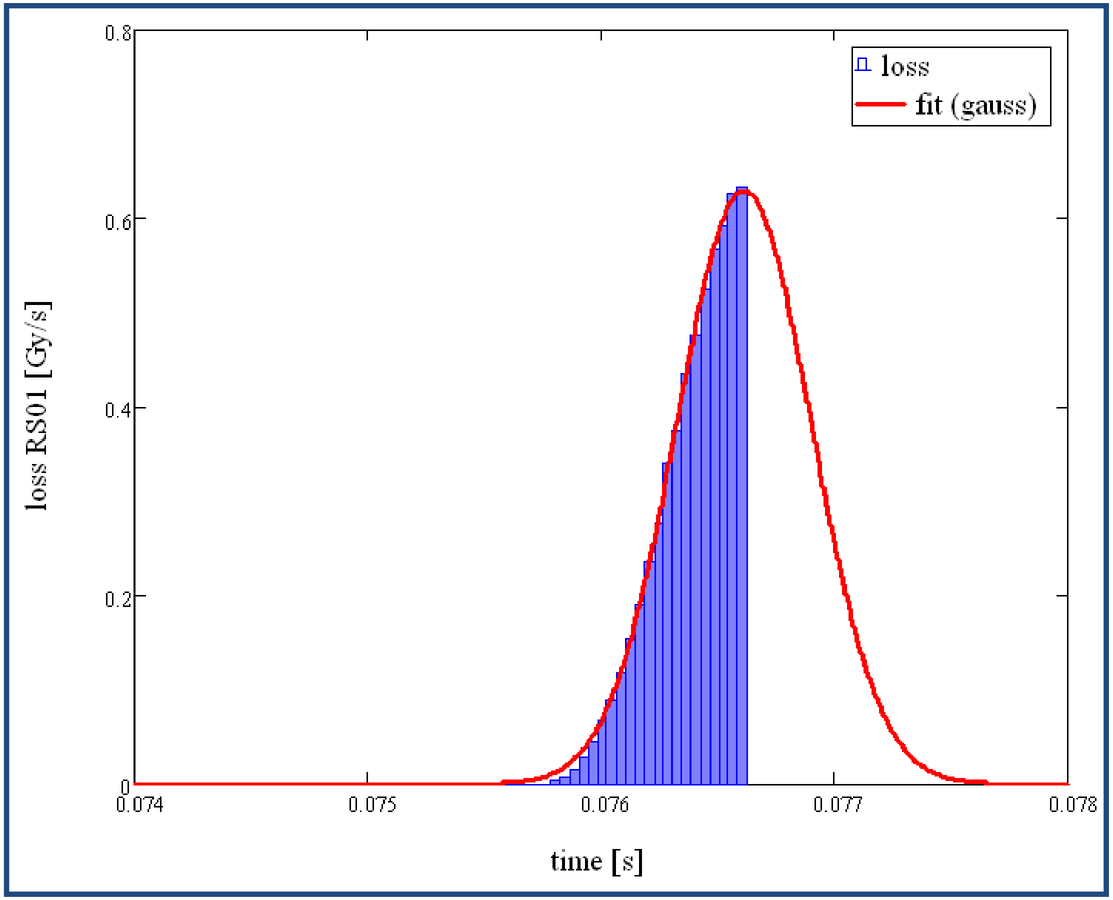
Dump on 01.05.2011



Dump of BLMQI.04L2.B1E20_MQY on 320µs, 640µs and 2.5ms integration time

Dump on 01.05.2011

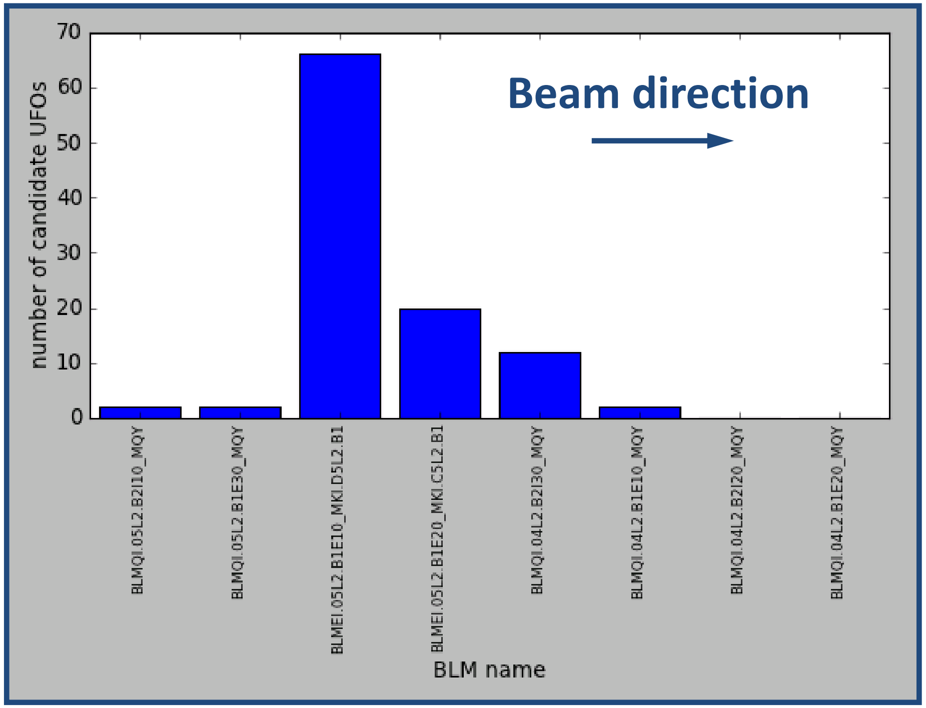
- From fit to losses
  (BLMEI.05L2.B1E10_MKI.D5L2.B1):
  Amplitude: 0.63 Gy/s
  Width: 0.29 ms



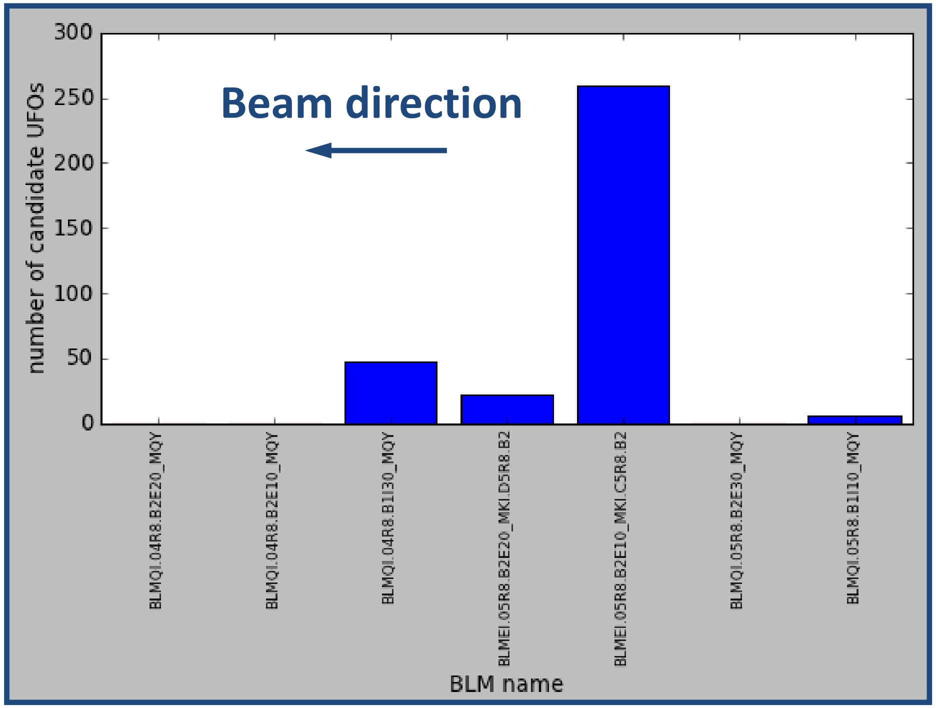
UFOs at MKIs

- Since 08.04.2011 in total **460** fast loss events around MKIs.
  (**104** around MKI in IP2, **336** around MKI in IP8).

Distribution of first BLM which sees the loss:



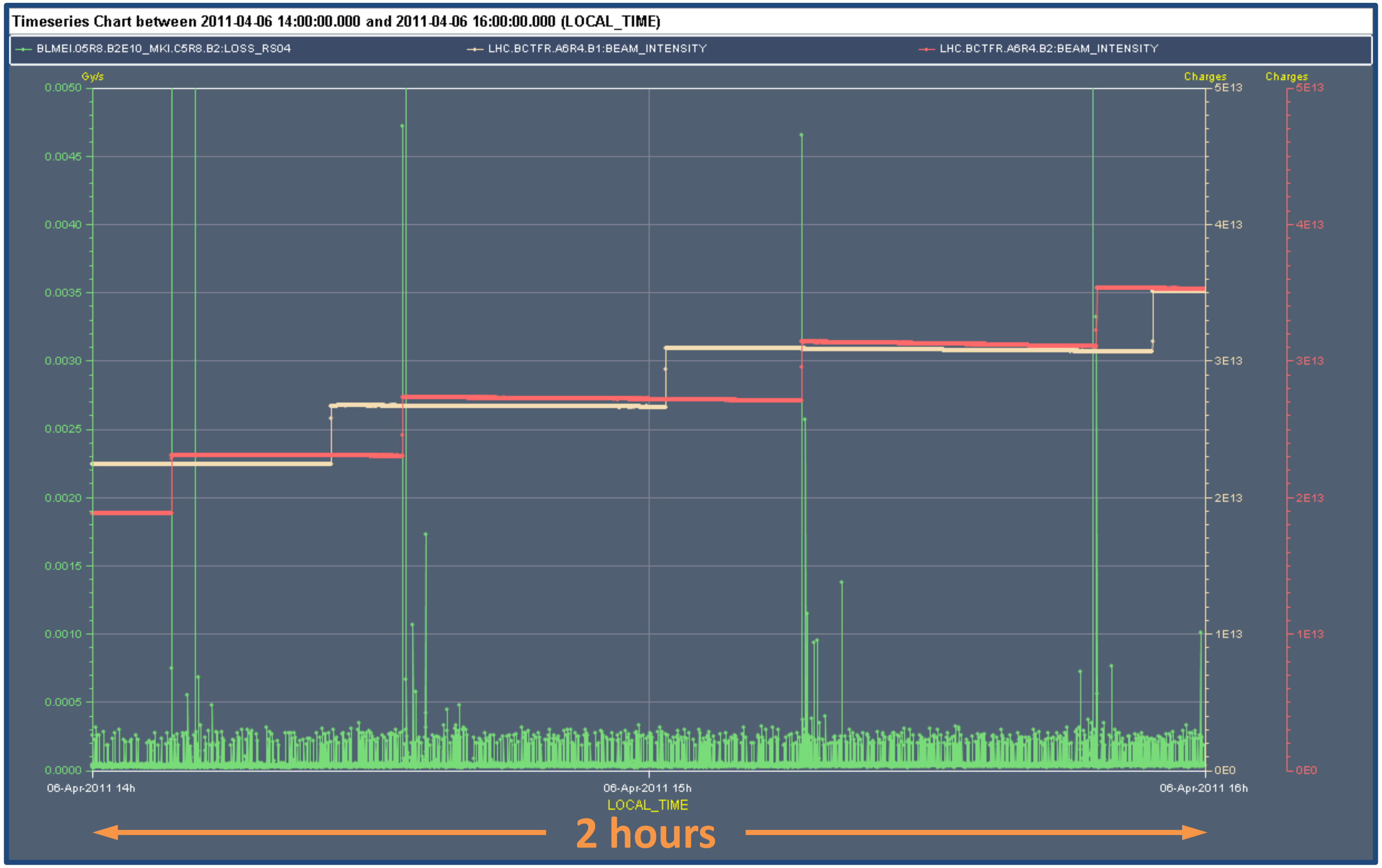
Left of IP2



Right of IP8

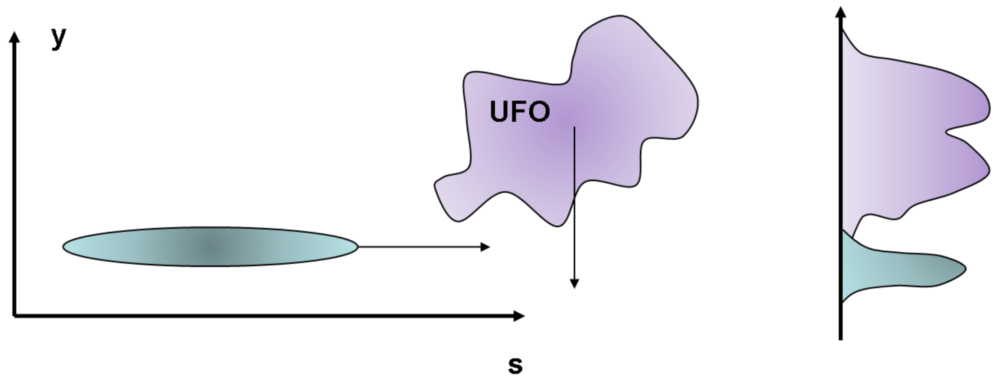
MKI UFOs During Scrubbing

- Typical scenario for MKI UFOs during scrubbing: Loss spikes occur in first few minutes after an injection and go away then.



Content

UFO size



- Two extreme cases:
  - UFO much larger than beam: the beam is imaging the UFO.
  - UFO much smaller than beam: the UFO is imaging the beam.

Most UFO shapes are Gaussian, thus most UFOs are expected to be smaller than the beam.

- From FLUKA simulations: size ≈ 1 µm.

(cf. M. Sapinski, F. Zimmermann at Chamonix 2011)

courtesy of
J. Wenninger
(cf. MPP 25.03.2011)

UFO Speed

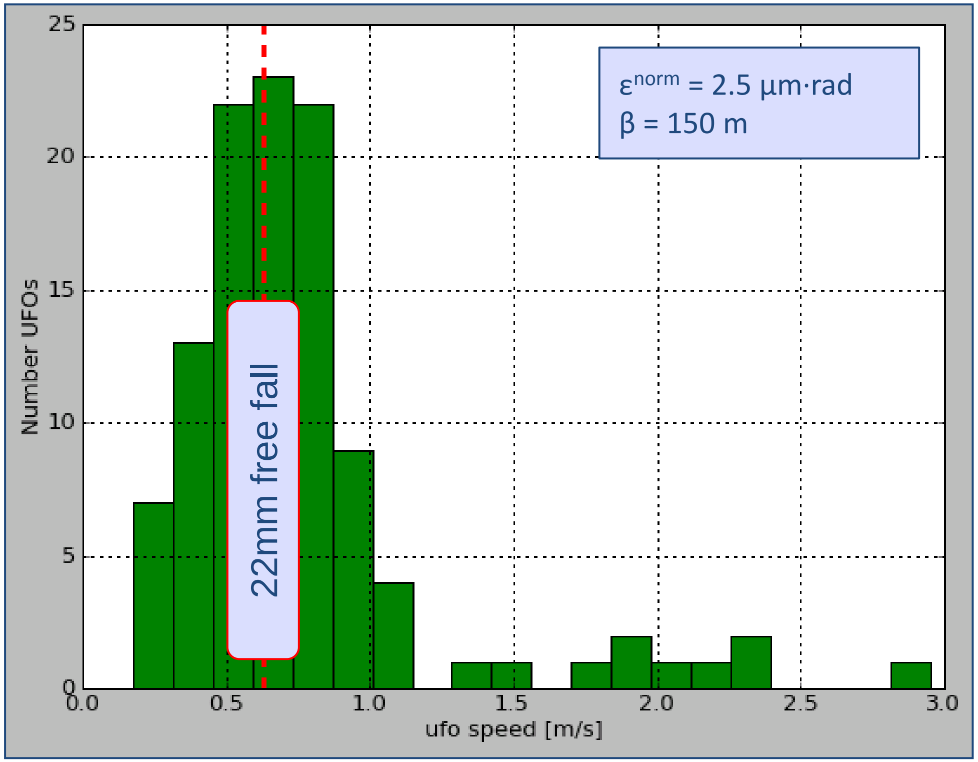
- UFO speed:

$$v_U = \frac{\sqrt{\sigma_b^2 + \sigma_U^2}}{\sigma_T} > \frac{\sigma_b}{\sigma_T}$$

v_u: UFO speed, σ_b: transverse beam size, σ_u: UFO size, σ_T: temporal width of loss.

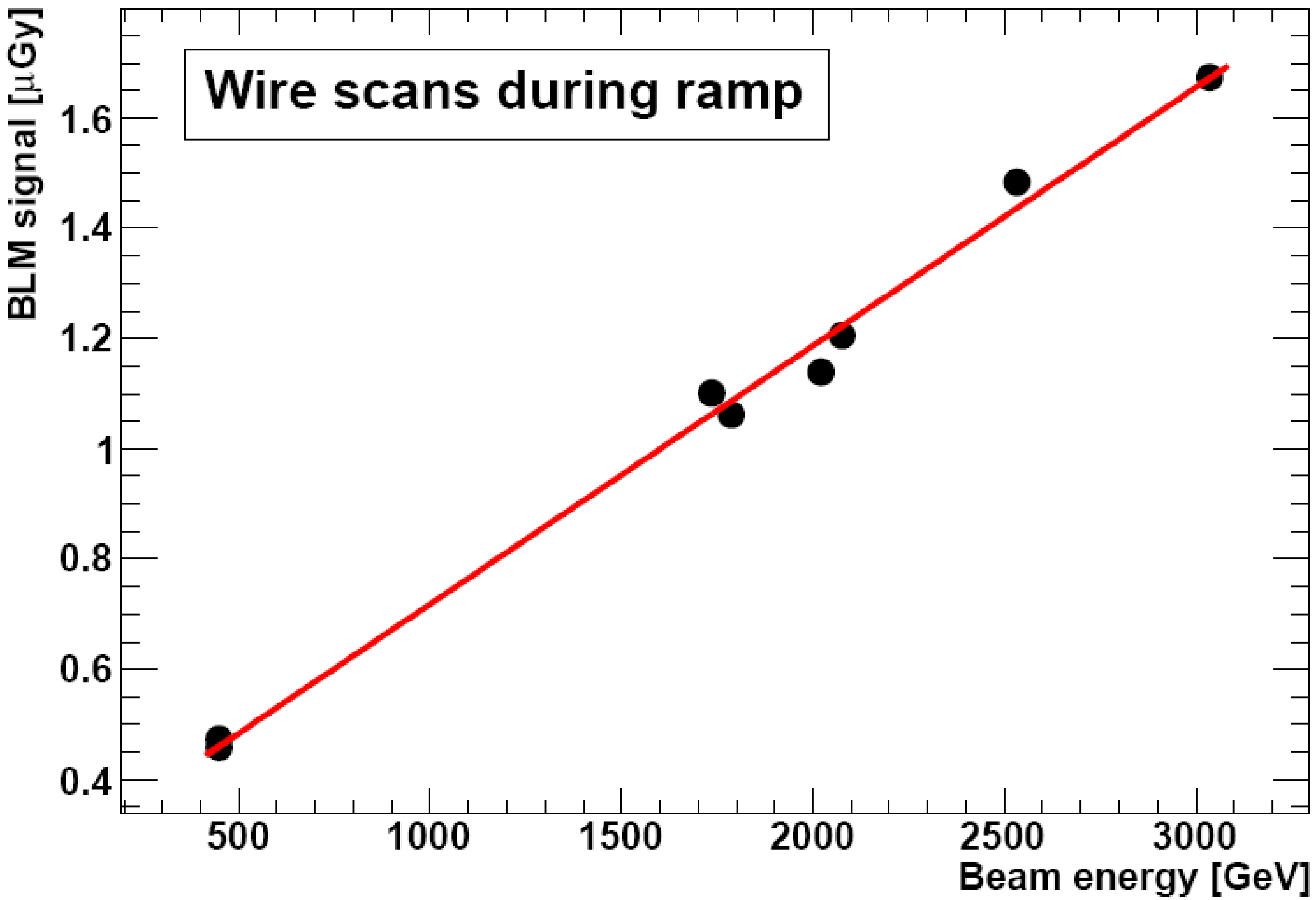
- From free fall:

$$v_U = \sqrt{2 \cdot g \cdot h} = 0.63 \frac{m}{s}$$



The UFO speed corresponds to the expected speed for a free fall from the aperture.

Correlation with Wire Scanner



From wire scans: linear dependency of BLM signal on beam energy

Content

Next Steps and Mitigation

- Next Steps:
  - *Improve diagnostics (acquisition of turn-by-turn data)*
  - *Better localization of UFOs at injection kicker magnets (simulations, additional BLMs)*
  - *Determine real quench limit*.

- Mitigation Strategy:

?

  - *Increase BLM thresholds further*
    (For higher energies thresholds need to be decreased)

Summary

- **20 emergency beam dumps** due to UFOs so far.
- **Over 4000 candidate UFOs** detected in 2011 so far.
  - *2 UFOs were dumping the beam.*
  - *Most events at 3.5 TeV.*
  - *Increased UFO rate around injection kicker magnets.*
- UFOs are prospectively micrometer sized dust particles.
- Next step: improve the diagnostics.
  - *Acquisition of turn-by-turn BLM data.*
  - *Installation of additional BLMs.*

Thank you

for your Attention

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Further information:

- T. Baer, "Update on UFOs", LHC Machine Protection Panel, Geneva, May 2011.
- T. Baer, "LHC Machine Protection and UFOs", DPG Spring Meeting, Karlsruhe, March 2011.
- M. Sapinski, "Is the BLM system ready to go to higher intensities?", Workshop on LHC Performance, Chamonix, Jan. 2011.

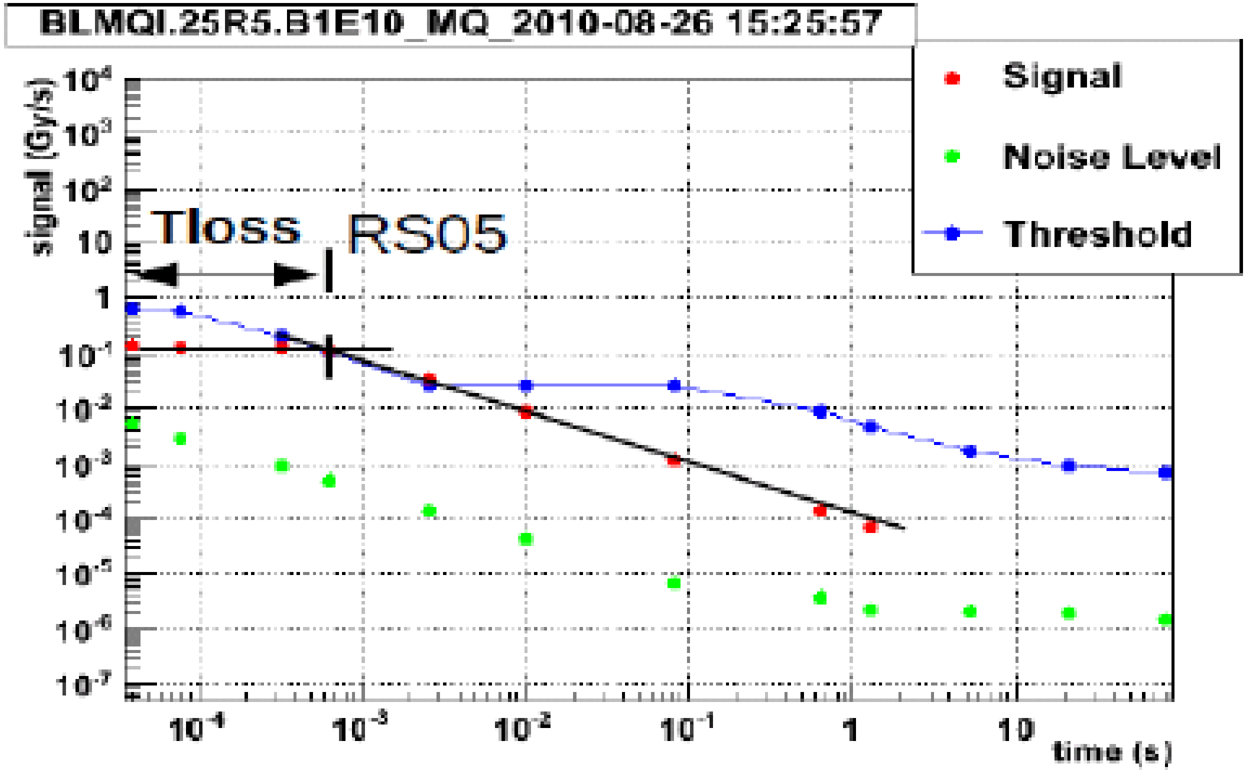
Backup slides

Known Dust Particle Sources

- Distributed ion pumps (PF-AR, HERA).
- Electrical Discharges (PF-AR).
- Movable Devices. (LHC)
- Particles frozen or condensated at cold elements. (ANKA)

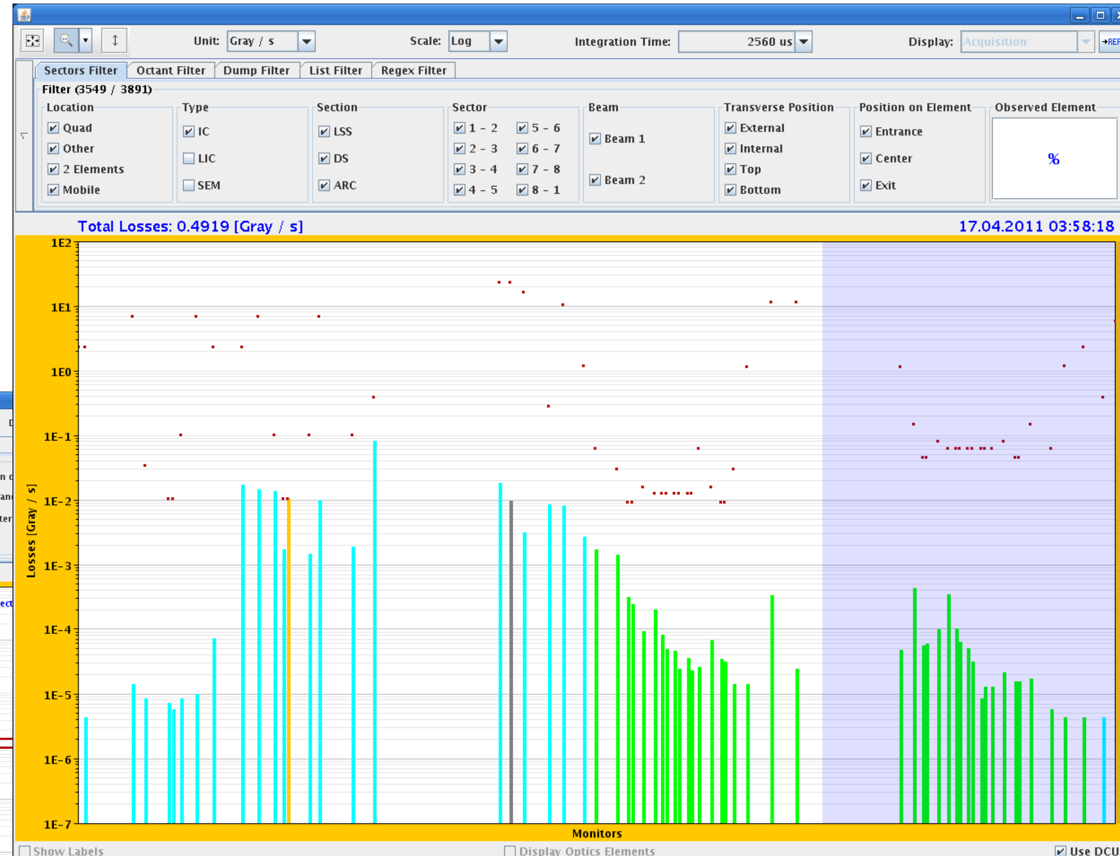
Loss Time

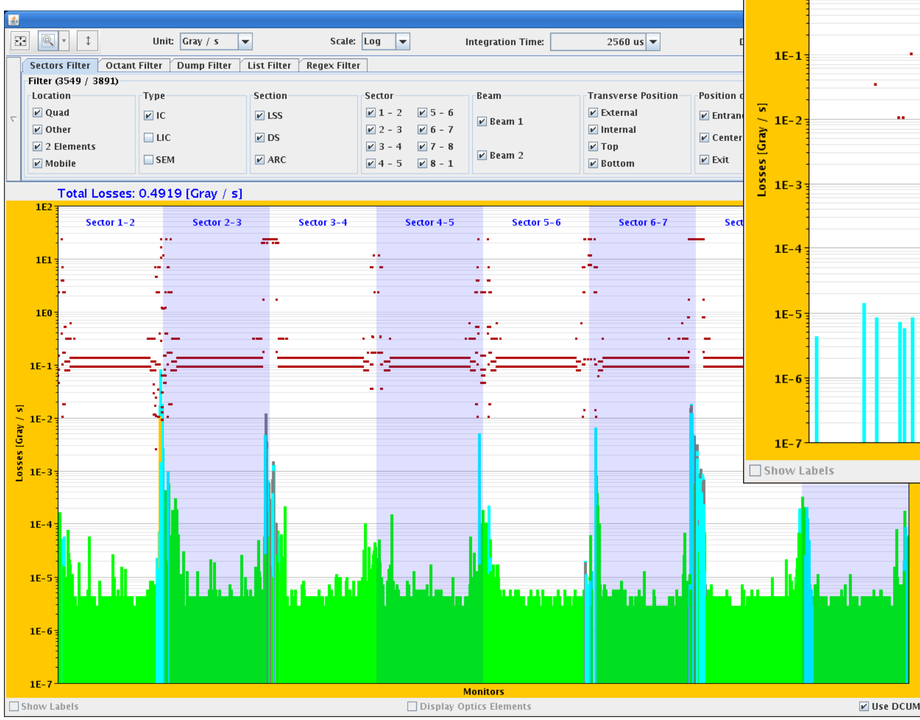
- **Definition of T_{loss}:**



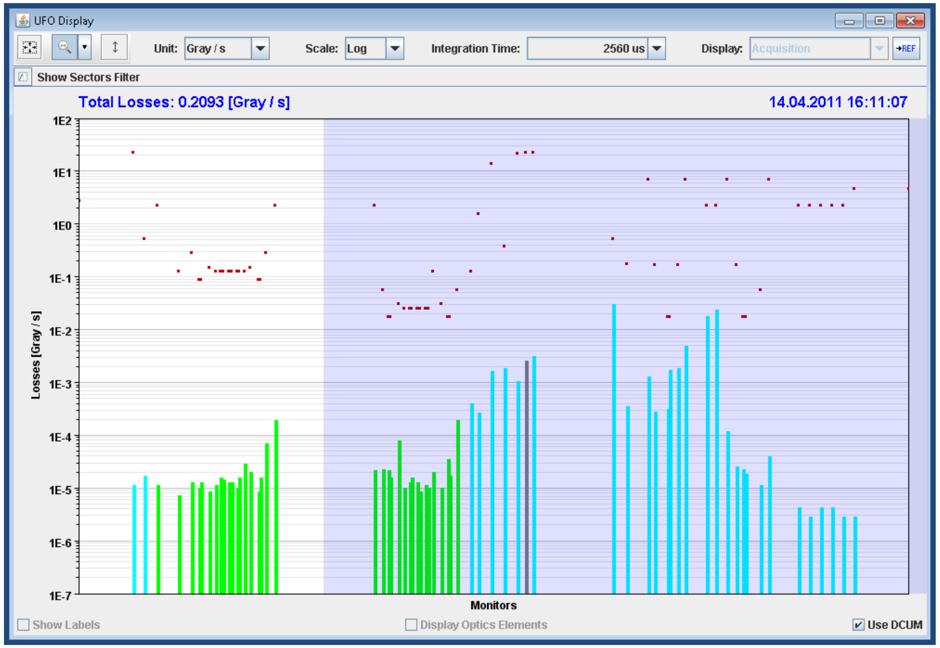
Example: Loss at MKI for B1

- Loss starts at BLMEI.05L2.B1E20_MKI.C5L2.B1
- BLMQI.04L2.B1E20_MQY at 98% of dump threshold (RS5)
- At 3.5 TeV stable beams.

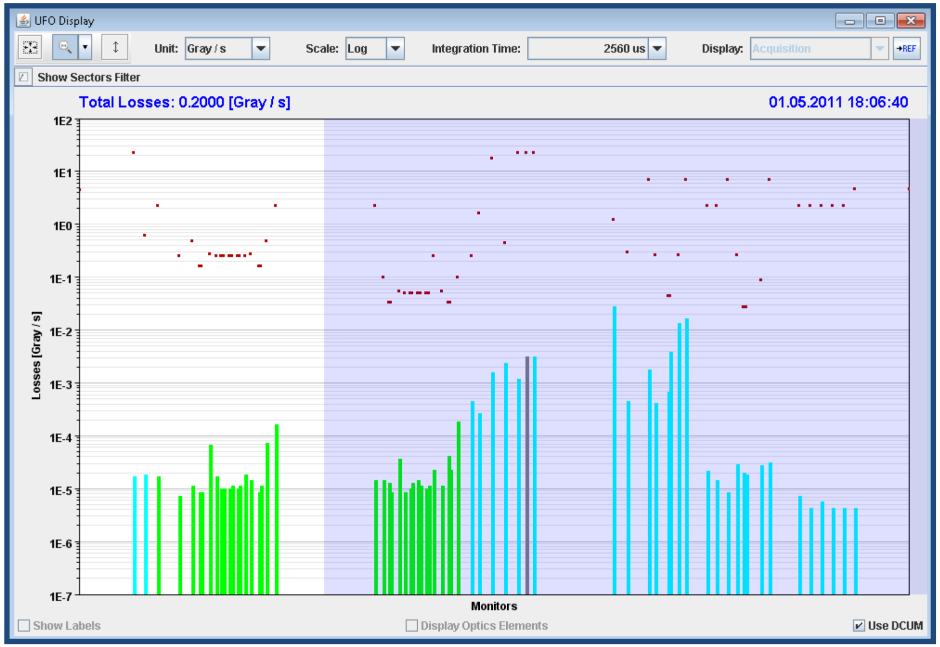




Example: UFOs at MKI R8

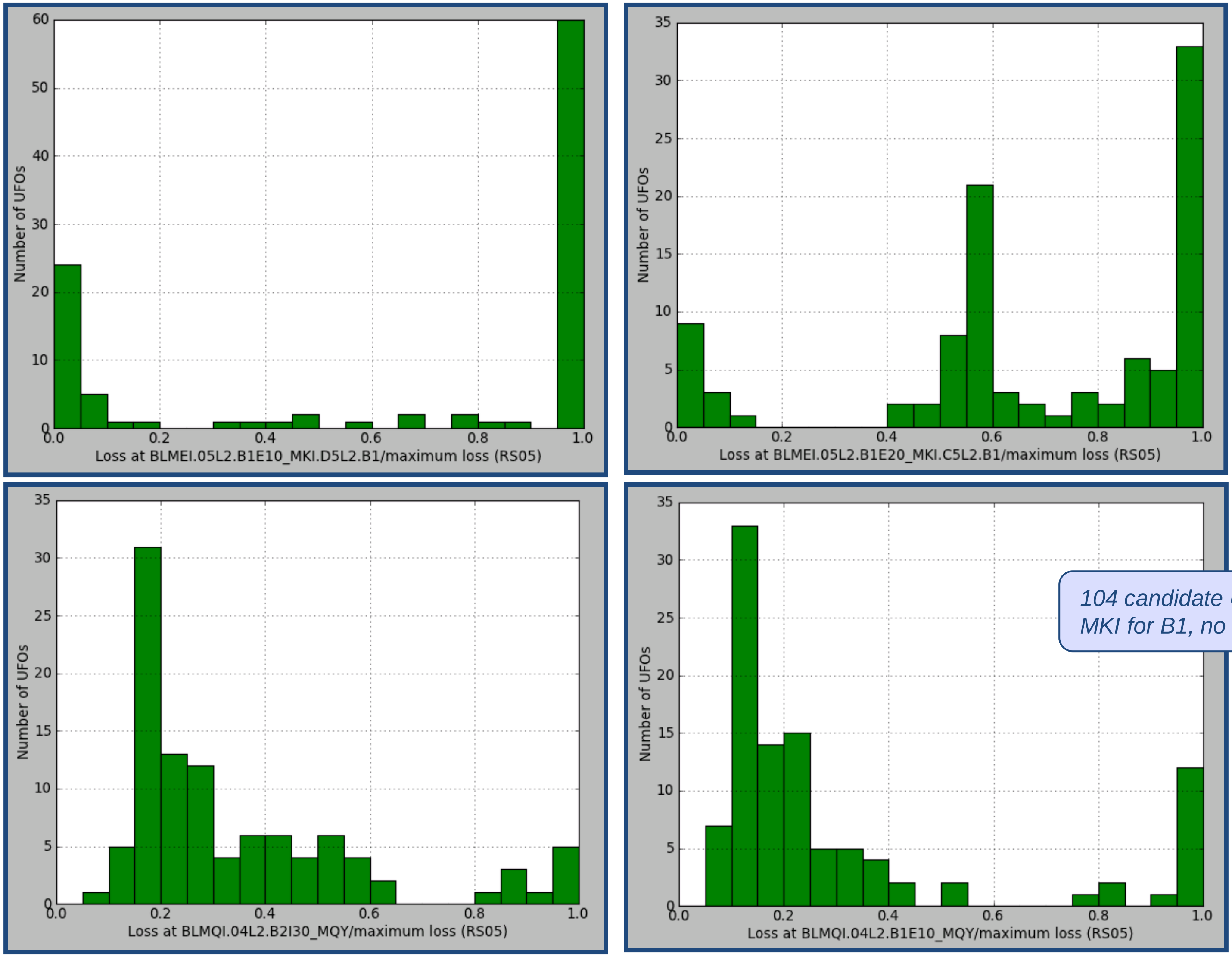


UFO at 2352 GeV, 228 bunches. Loss starts at BLMEI.05R8.B2E10_MKI.C5R8.B2.



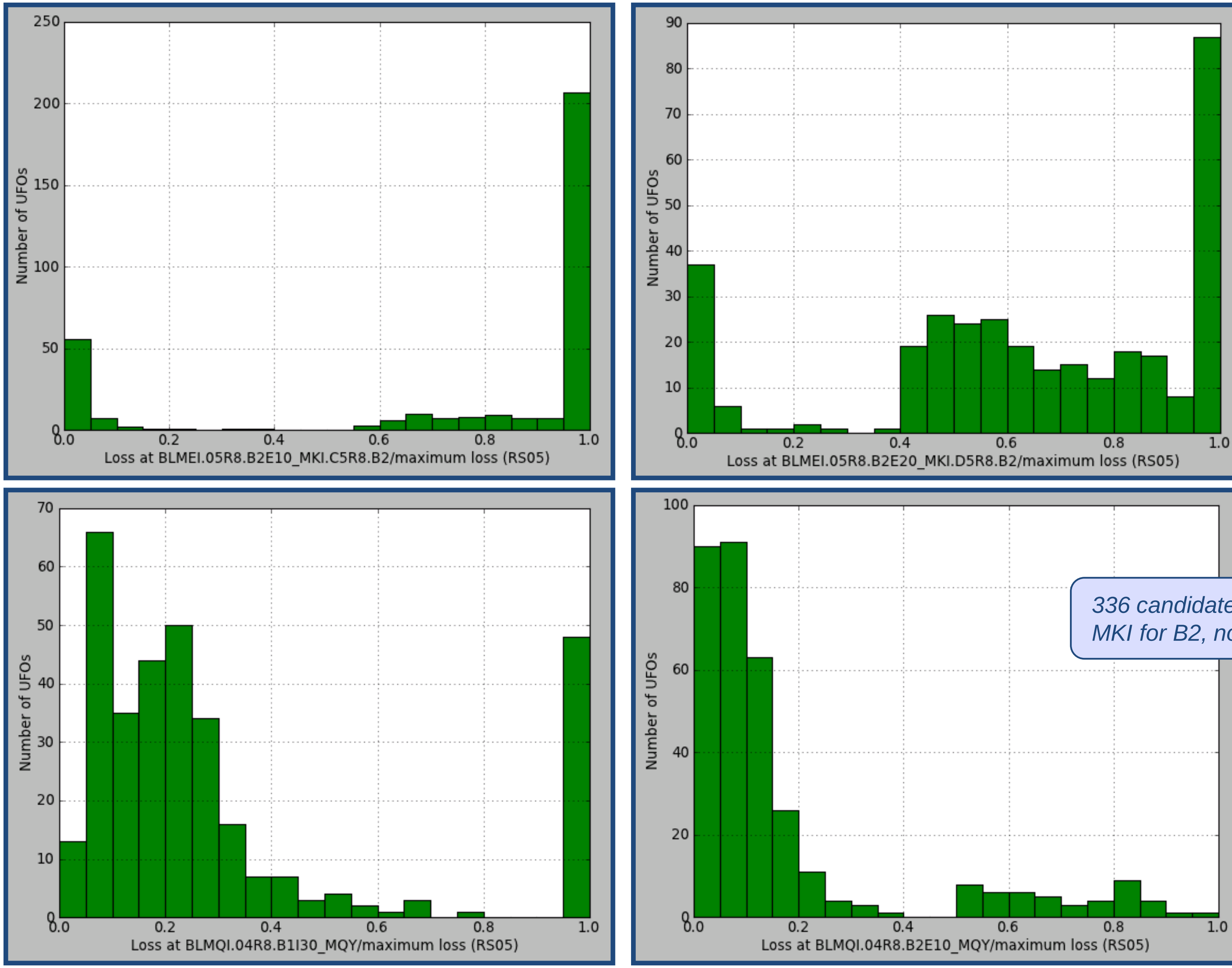
UFO at 1424 GeV, 768 bunches. Loss starts at BLMQI.04R8.B1I30_MQY.

Lossratio for MKI UFOs B1



104 candidate UFOs around MKI for B1, no cuts.

Lossratio for MKI UFOs B2



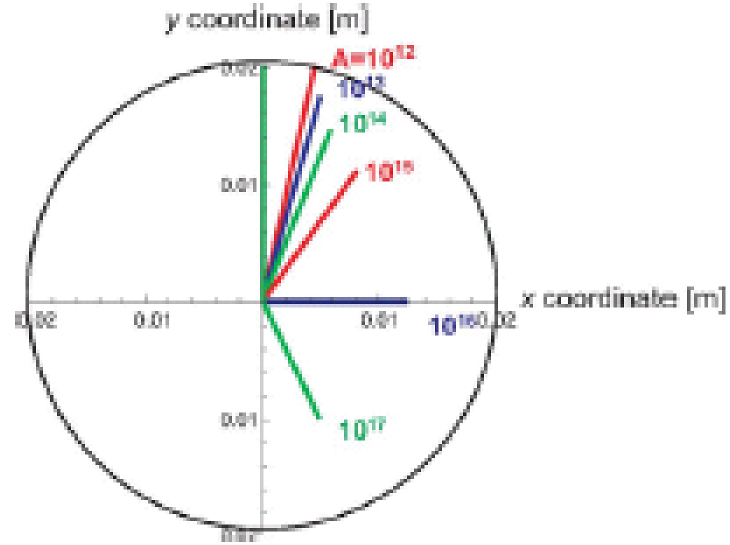
336 candidate UFOs around MKI for B2, no cuts.

Dynamics of Dust Particles

From **simulations**:

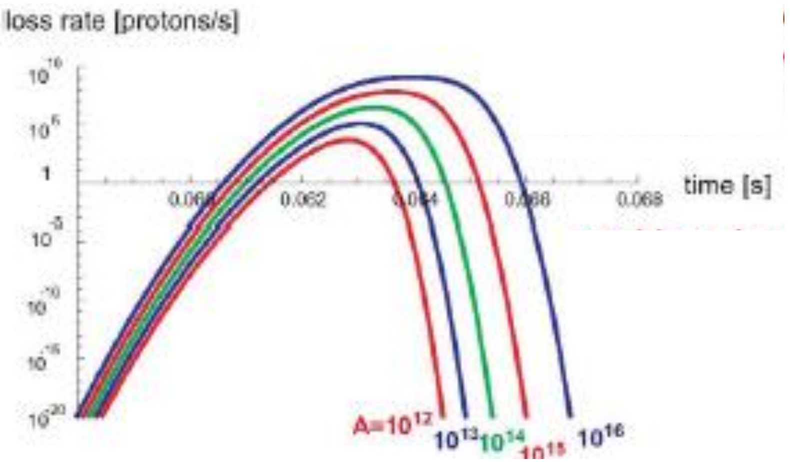
- Dust particle will be positively ionized and be repelled from the beam.

  Beam intensity: $2.3 \cdot 10^{12}$ protons, Al object.



- Loss duration of a few ms.

  Losses become shorter for larger beam intensities.



courtesy of
F. Zimmermann

Content