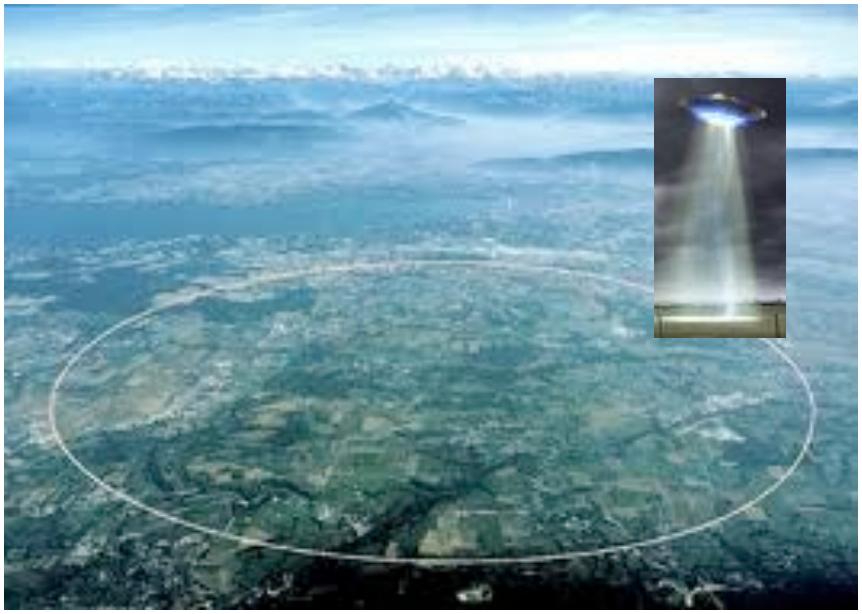
Detection of Unidentified Falling Objects at the LHC



2010
LHC, Geneva

E. Nebot, T. Baer, F. Day, B. Dehning, M. Hempel,
E. B. Holzer, A. Lechner, R. Schmidt, J. Wenninger,
C. Zamantzas, M. Zerlauth and F. Zimmermann.

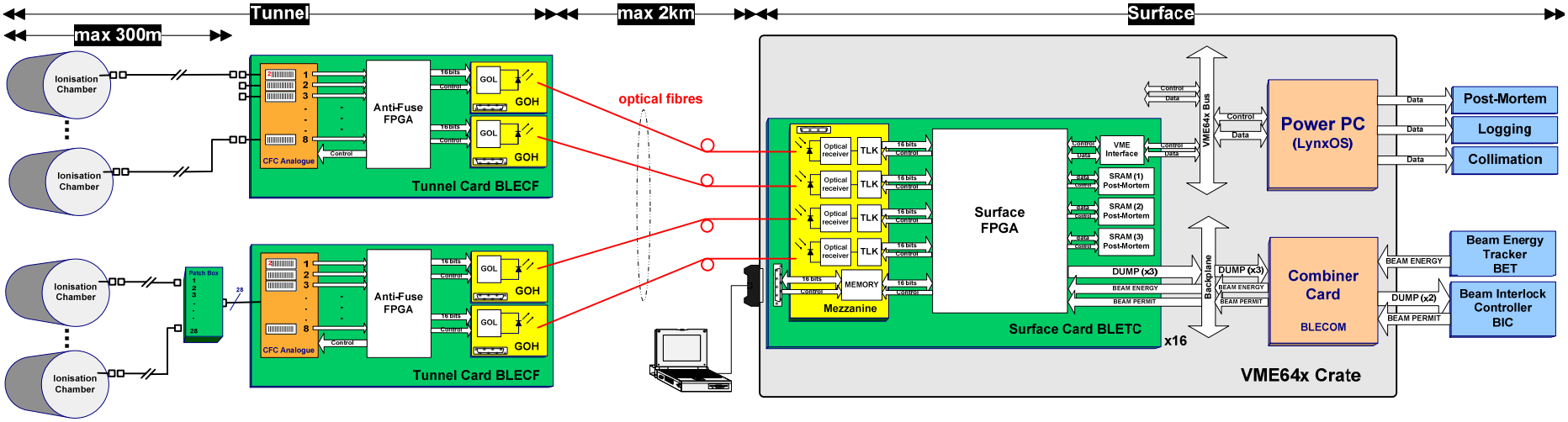
Outlook

- Introduction.
  - Beam Loss Monitoring System (BLM) overview.
  - Unidentified Falling Objects (UFO).
- UFO observations.
- Dump statistics.
- Mitigations and diagnosis.
- FLUKA simulations.
- The theoretical model.
  - The model.
  - Predictions and observations.
- Conclusions.

Introduction I. The BLM system

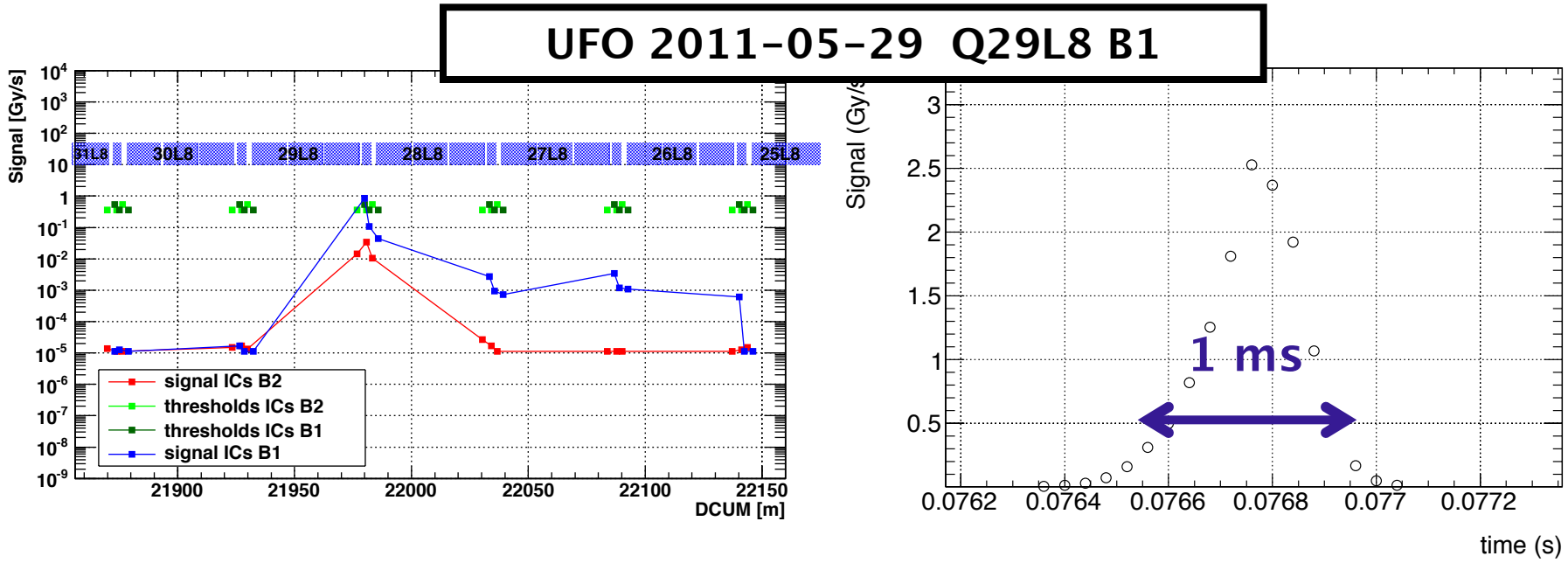
Main goal: Avoid quenches of superconducting magnets and any damage induced by beam losses.

- 3600 ionization chambers situated at likely-loss locations.
- Signals integrated in 12 intervals (Running Sums, RS) spanning from 40μs to 83s.
- Continuous comparisons of signals (S) with a set of predefined thresholds (T). Beam aborted if S>T.
- Data sent to on-line applications for monitoring and databases for offline analysis.



Introduction II. UFOs

- 7th of July 2010. The BLM system requested a beam dump due to beam losses on the millisecond scale.
- Since then, 48 events have produced beam dumps (operational limitation for the LHC).
- Hypothesis: Interaction of micron-size particles with the LHC beam.



Introduction III. UFO detection

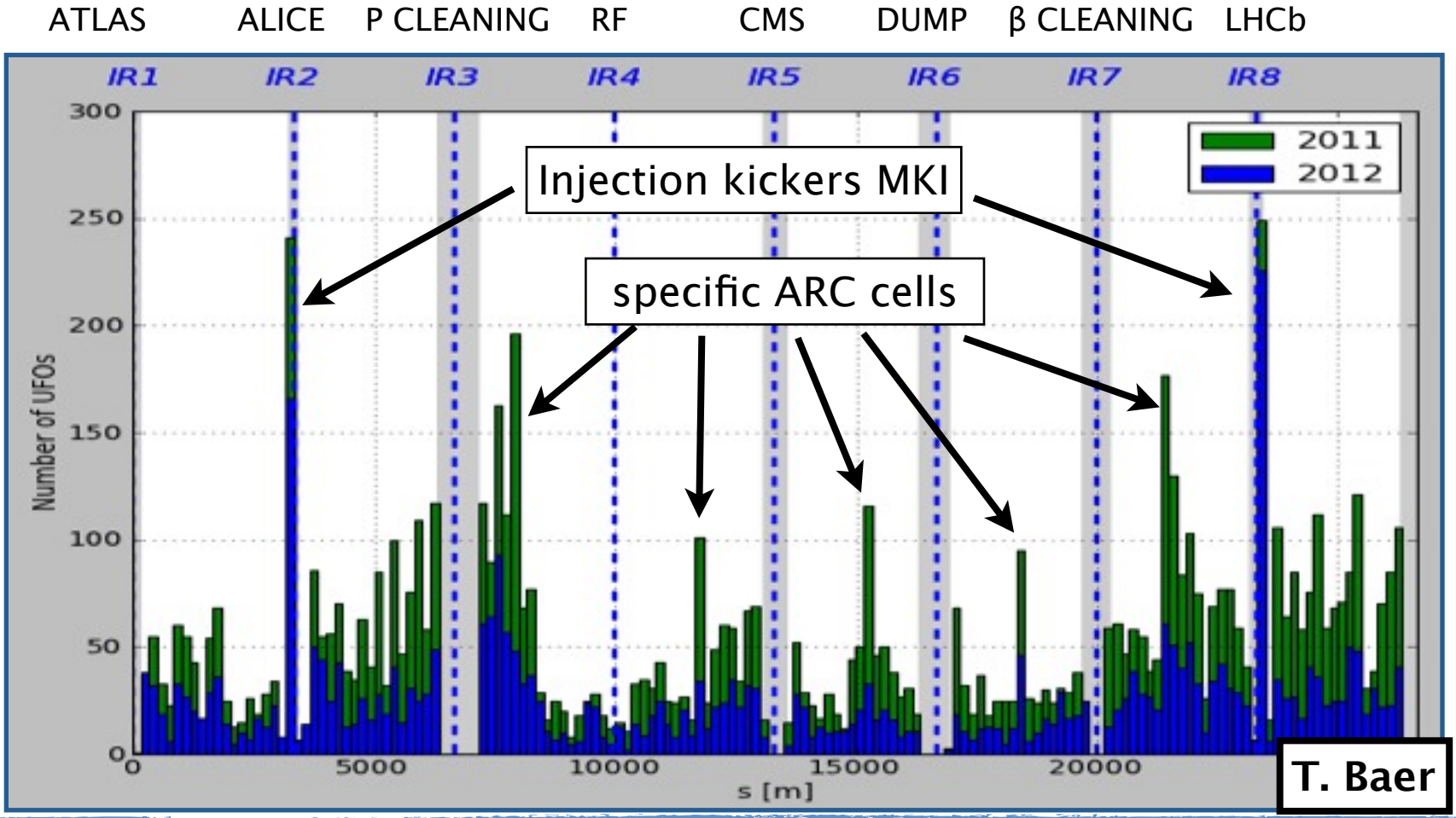
- Systematic (on-line) search of below dump threshold UFOs.
- Request 2 LOCAL BLMs (within 40m and protecting same beam) with significant signals (S > 10^{-4} Gy/s in RS4, 0.640 ms).
- Constrains on ratio of signals in RS2 (80 μs) and RS3 (320 μs) to RS1:
  - RS1/RS2 > 0.55.
  - RS3/RS2 > 0.45.

Signals in 12 RS for all BLMs stored for offline analysis:

- 2011. ~8000 UFO candidates at 3.5 TeV.
- 2012. ~ 4000 UFO candidates at 4 TeV.

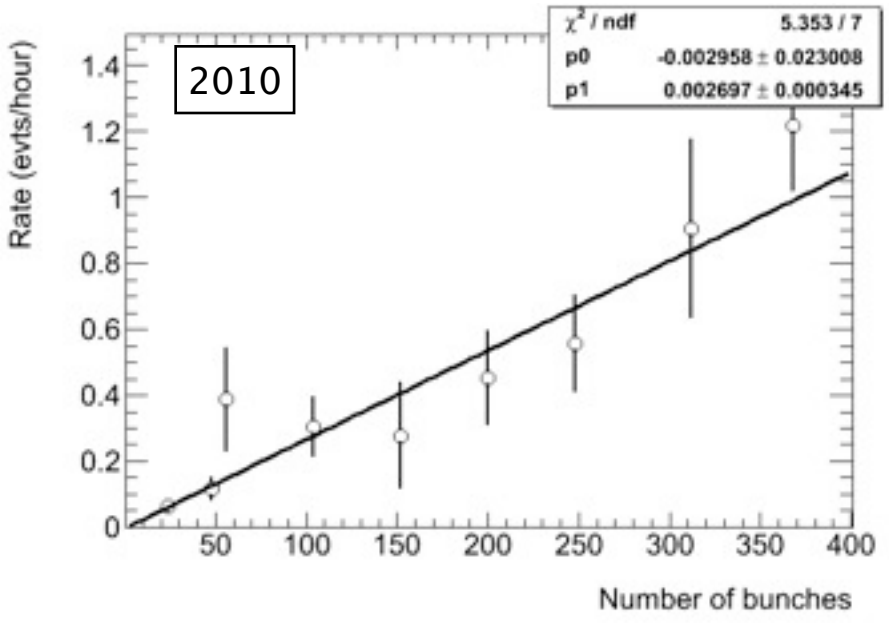
UFO observations I

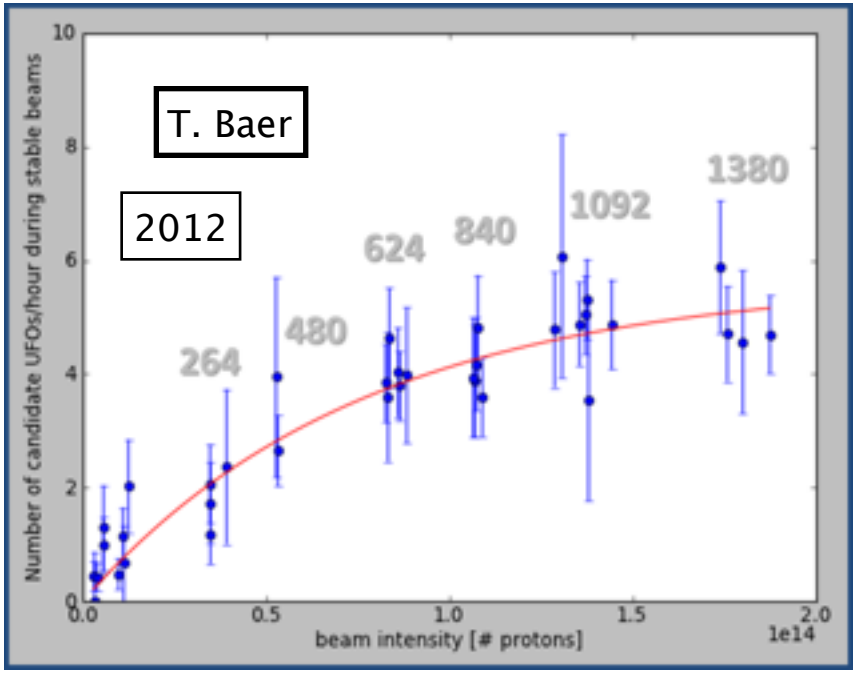
Observation all around the LHC ring



UFO observations II

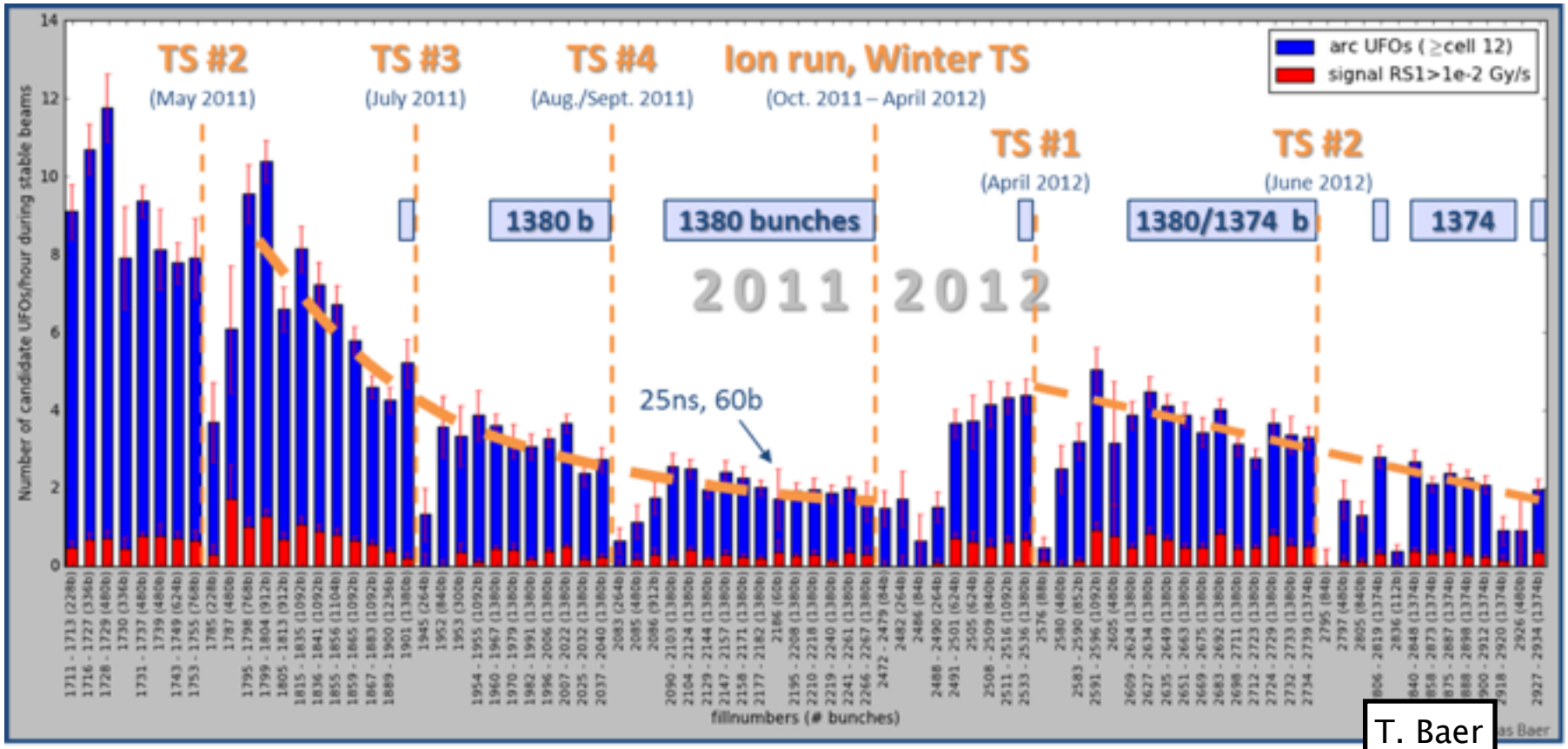
- Same tendencies observed from 2010→2012.
- Linear increase of UFO rate with beam intensity up to a few hundred nominal bunches.
- Saturation effect for larger intensities.





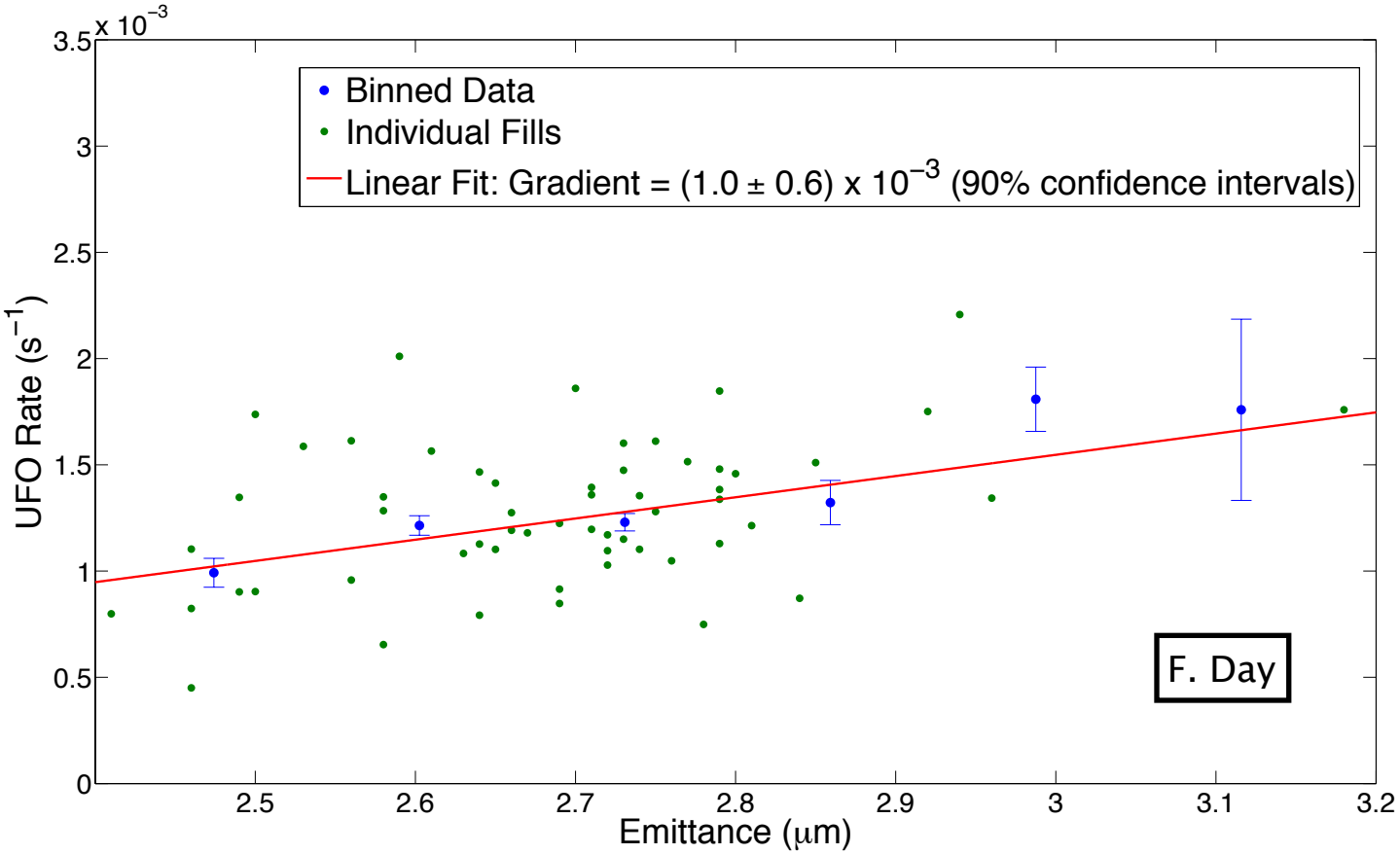
UFO observations III

Clear conditioning effect. UFO rate decreases over time (ARC UFOs only)



UFO observations IV

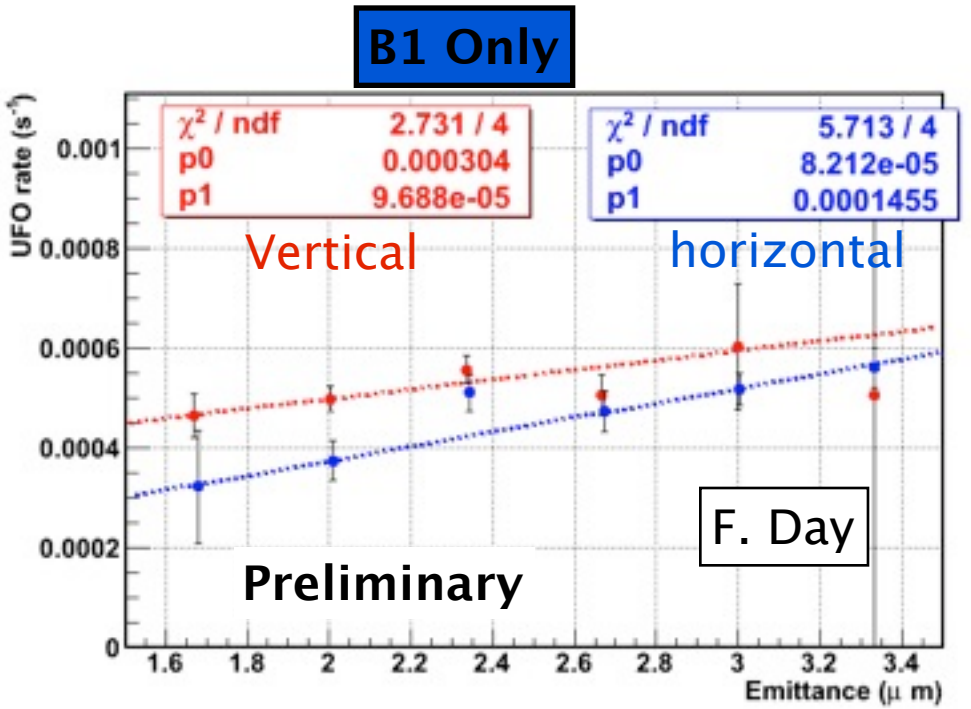
Dependence on beam emittance (calculated from luminosity at the beginning of the fill)



UFO observations V

- Dependence of UFO rate on beam emittance ϵ calculated from Beam Synchrotron Radiation Telescope at the moment of UFO).

$$Rate(\epsilon) = \frac{N_{UFOs}(\epsilon_L < \epsilon < \epsilon_H)}{\Delta t(\epsilon_L < \epsilon < \epsilon_H)}$$



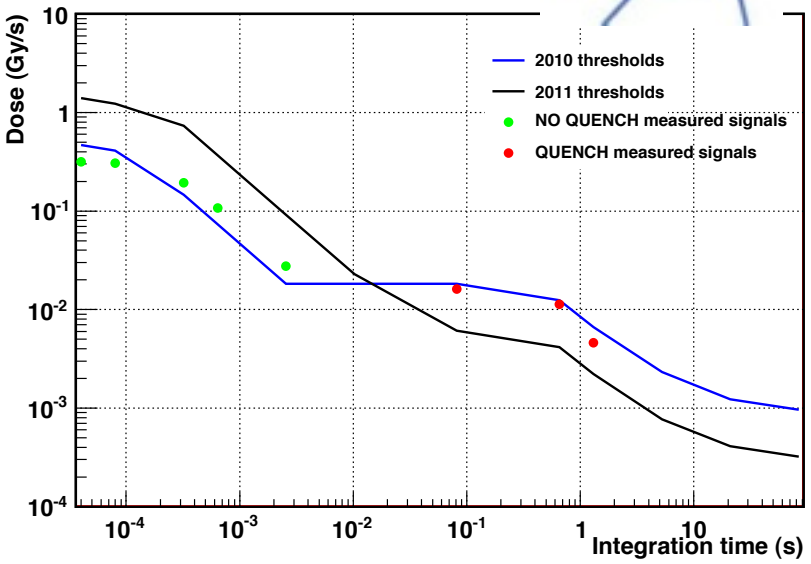
- Slightly stronger dependence (increasing behaviour) observed with horizontal emittance.

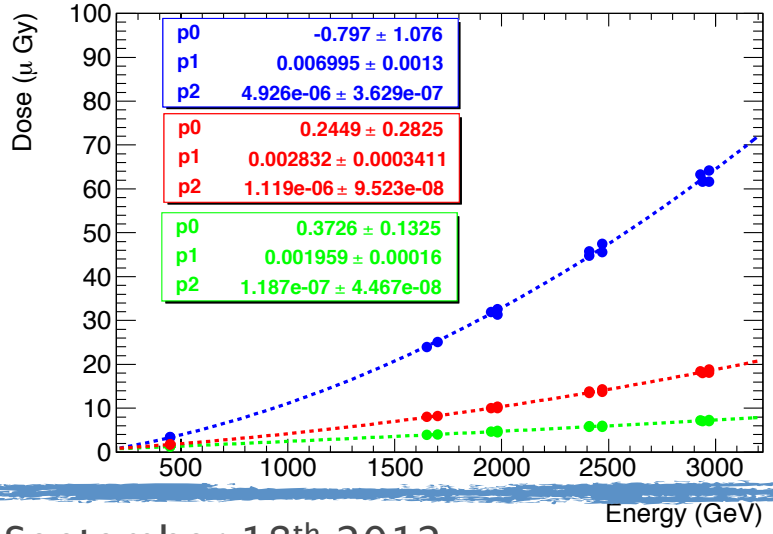
- Particle reaches the beam due to gravity.

Dump Statistics and mitigation

Dumps in different locations. Evolution follow the implementation of mitigations (BLM threshold increase)

Run	ARC	DS and SS	MKI	BCM
2010	3	11	2	2
2011	2	1	11	3
2012	0	3	7	3





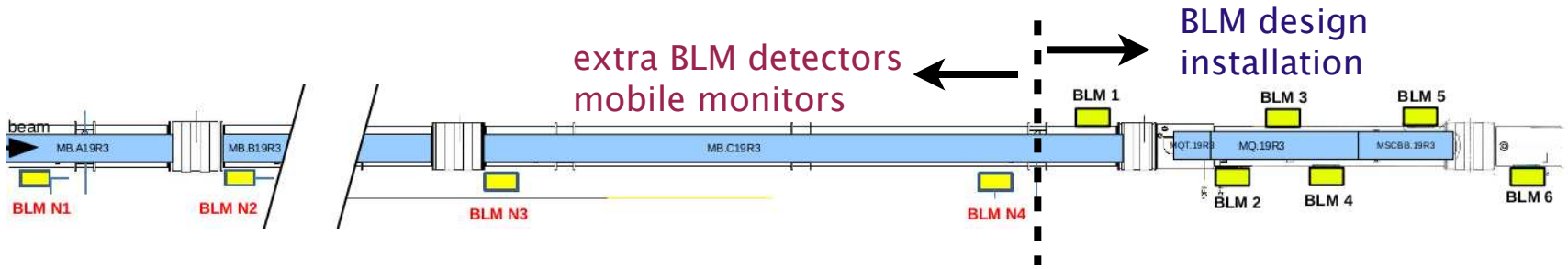
Energy (E) dependence understood:

- BLM dose increases with E
- Longer time at top E

Run	Injection	Ramp	Top Energy
2010	0	1	17
2011	1	2	14
2012	2	1	10

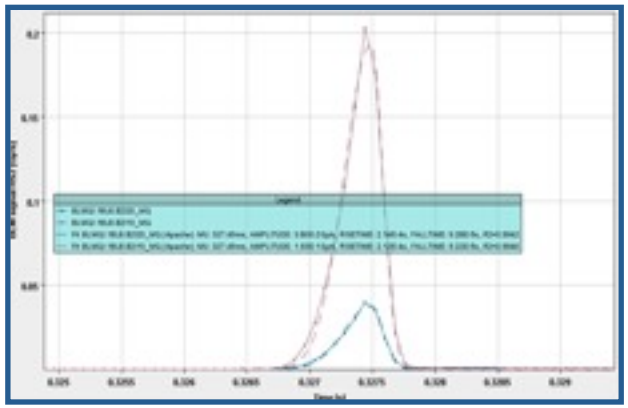
Diagnosis improvement

- Location of new BLMs. Arc cell (19R3) and around MKI magnets



- UFO event detection triggers the UFO capture buffer:

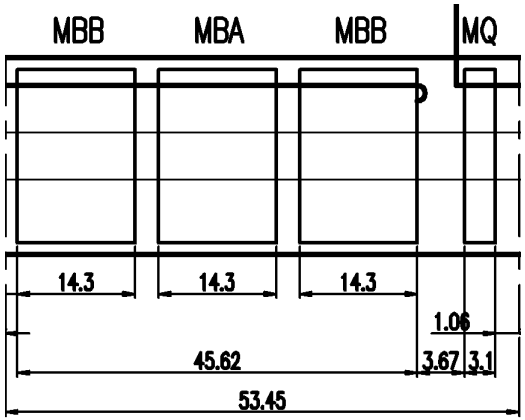
Improvement on time resolution. Signals for all 3600 BLMs saved for ~1000 turns every 80 μs



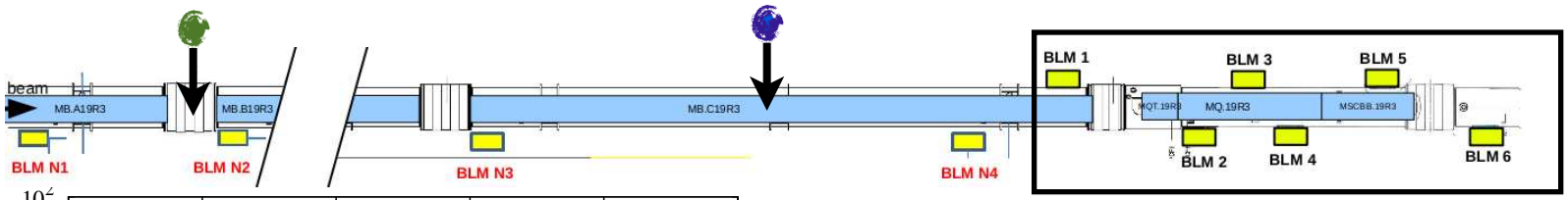
- Diamond detectors. Bunch by bunch diagnosis. M. Hempel, MOP203.

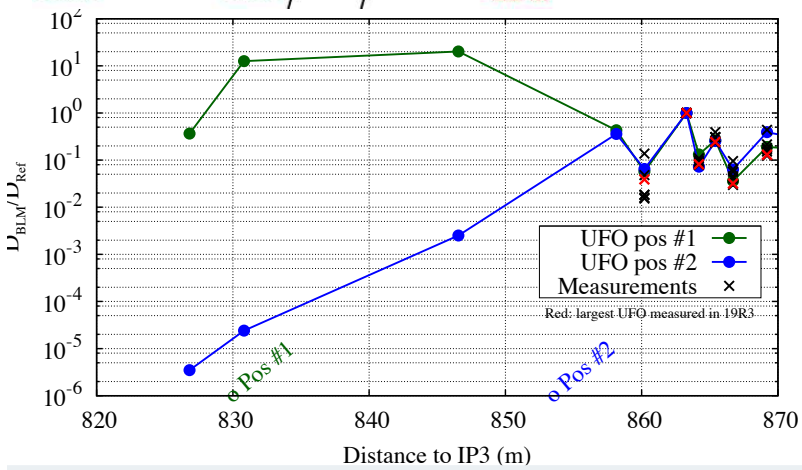
FLUKA simulations

A. Lechner



- Implementation of ARC geometry and simulation of several potential UFO locations

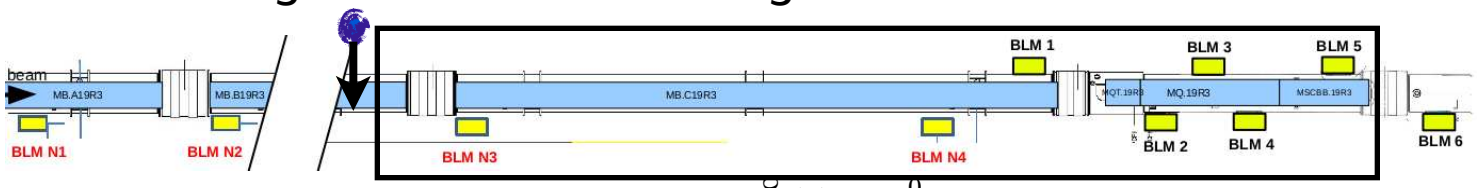


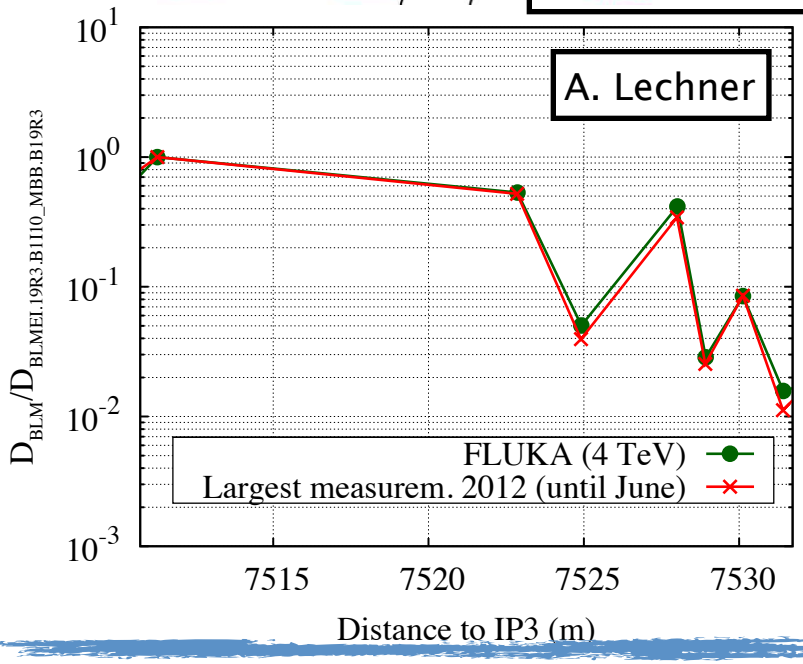


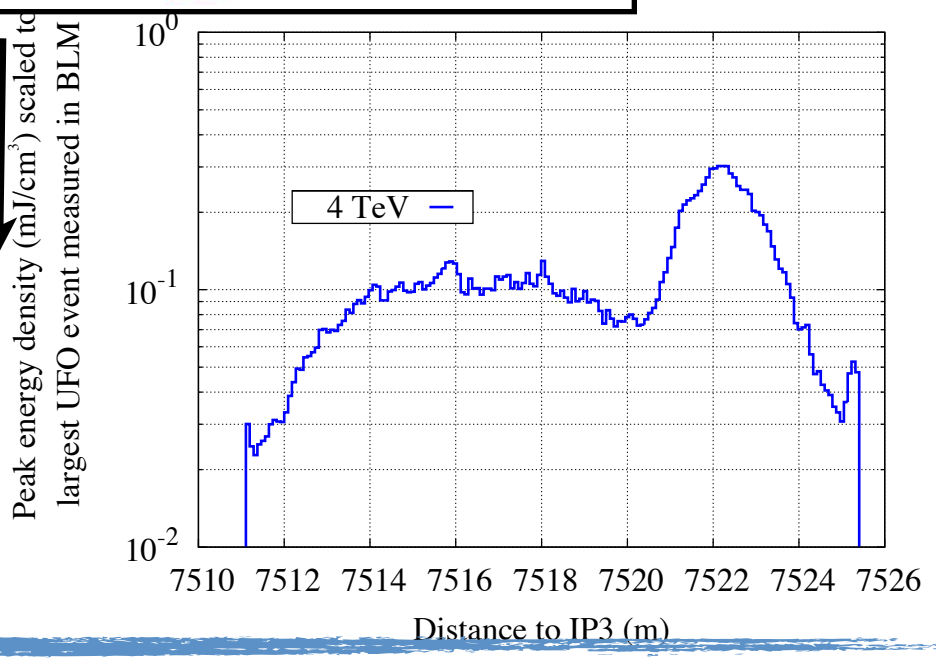
- Design BLMs not able to disentangle UFO location.

FLUKA simulations

- Good agreement between observation and simulation
- Estimation of peak energy density on MB
- Confirmation of UFOs originating in multiple location
- BLM re-arrangement under investigation







The theoretical model

Assumes particle with mass A and (variable) charge Q>>1. Particle influenced by four forces:

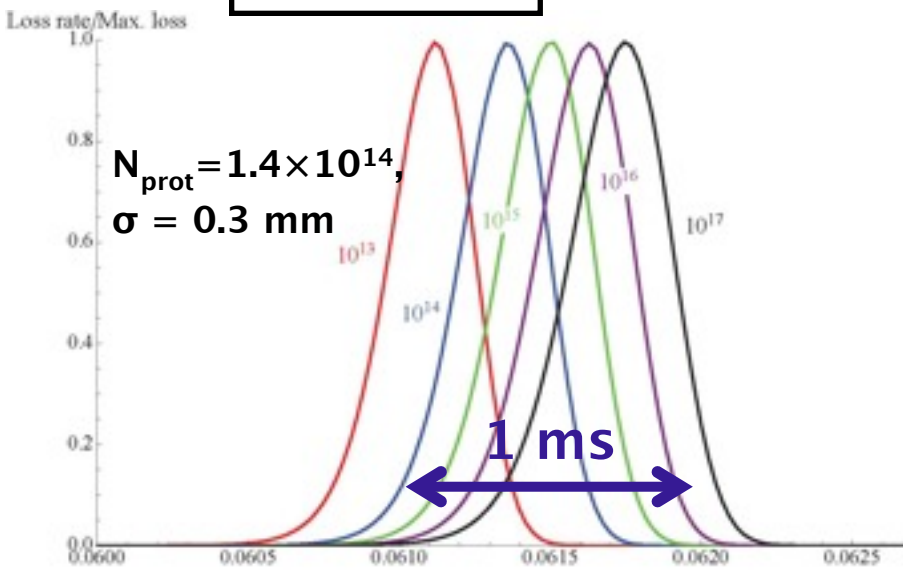
- Gravity.
- Beam electromagnetic.
- Beam image.
- Magnetic (negligible due to particle slow motion)

Model predictions:

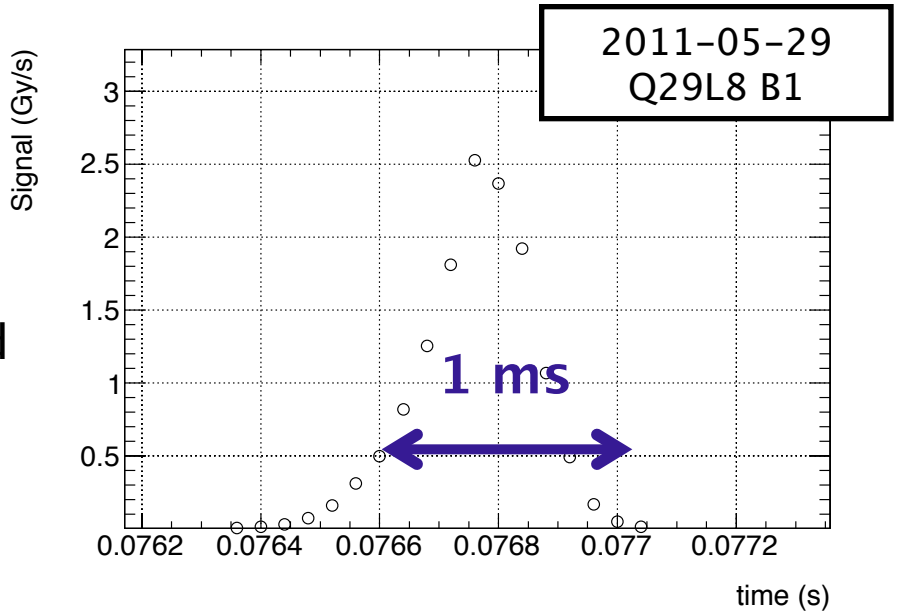
- Particle trajectory.
- Charge rate.
- Beam loss rate.

Predictions and observations

F. Zimmermann



Qualitative agreement between temporal loss rate predicted and measured. Comparable loss duration

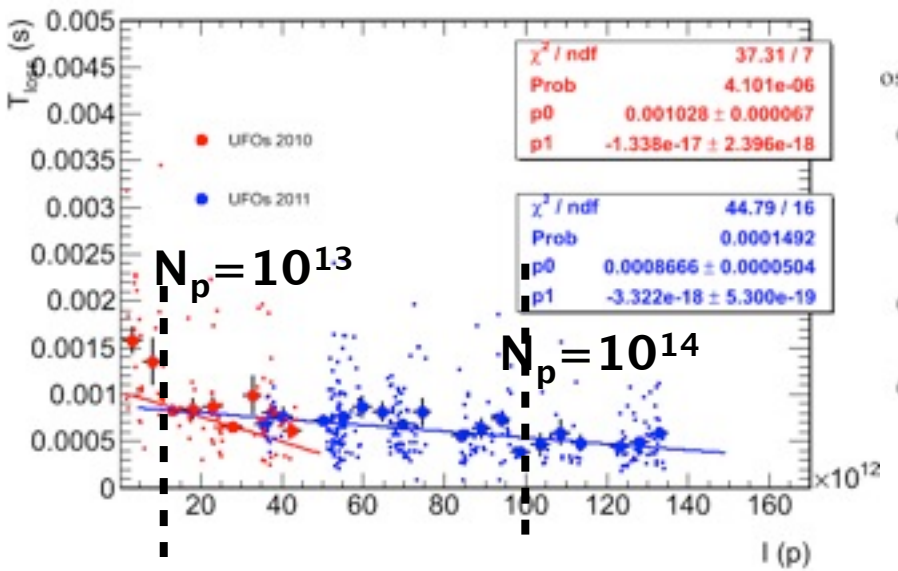


According to the model, the observed asymmetries contain information about the particle (mass).

Predictions and observations II

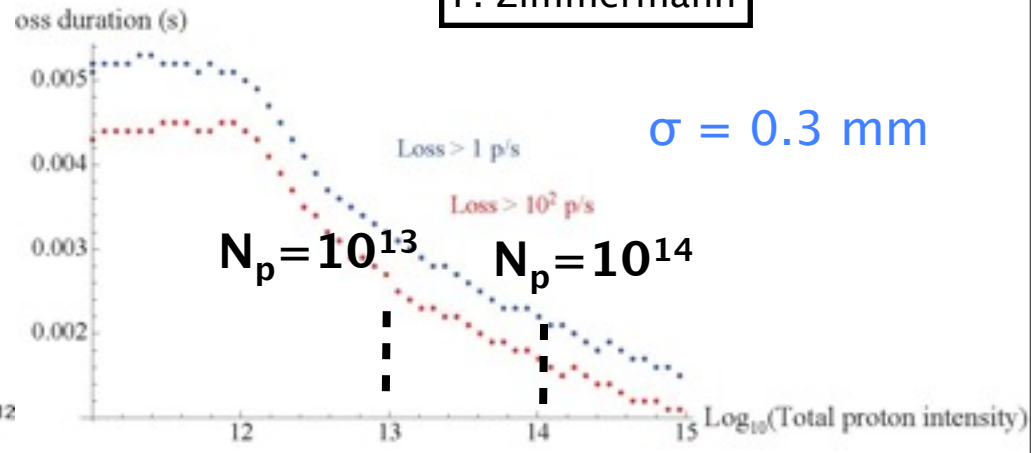
According to model the loss duration get shorter with intensity

Observed loss duration



Predicted loss duration

F. Zimmermann



Conclusions

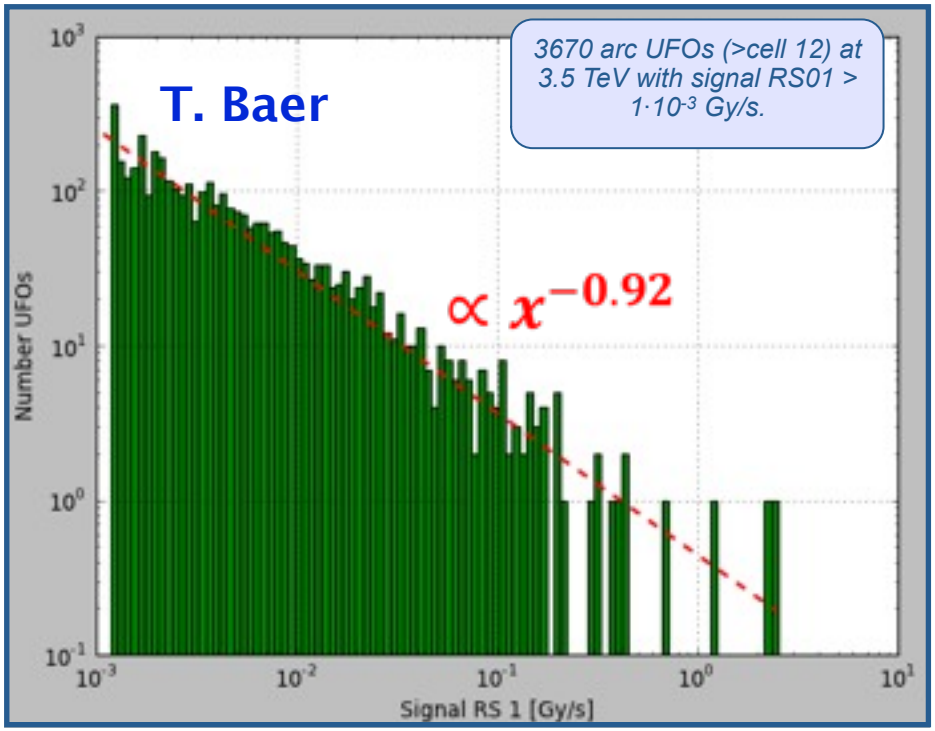
- Unforeseen beam losses on the millisecond time scale have been observed in the LHC.
- Cause: Unidentified Falling Objects, dust particles of sizes 1-100 μm interacting with the LHC beam.
- Multiple observations that allow us to estimate the expected number of UFOs/dumps.
- Some mitigations and diagnosis improvements have been/will be needed.
- UFO-like events have been simulated with FLUKA finding a good agreement with observation.
- Theoretical model predicts several of the observed features.

Thank you for your attention.

And if you have a proton collider...

...look out for UFOs!

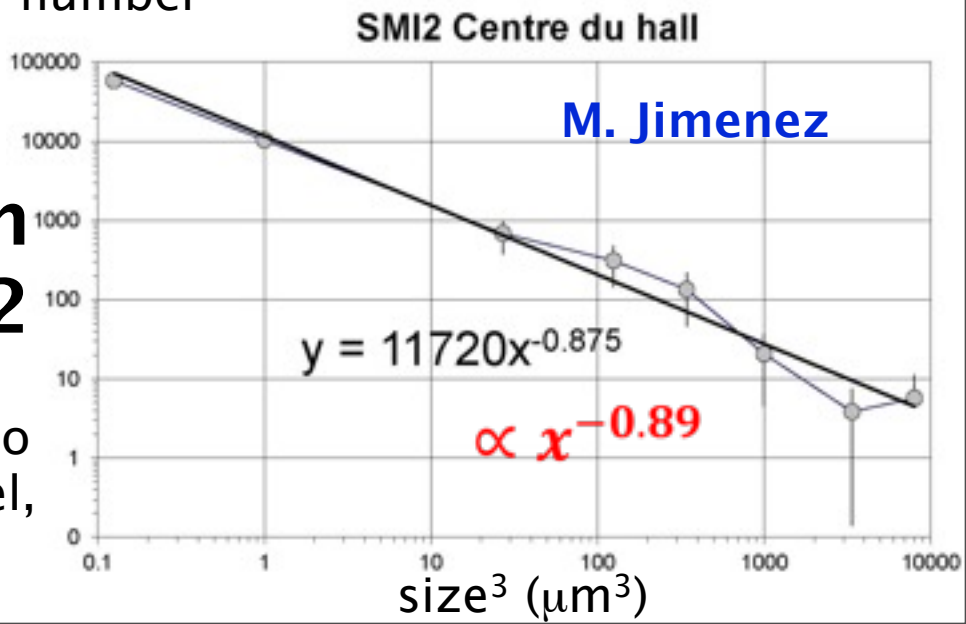
BLM signal and dust



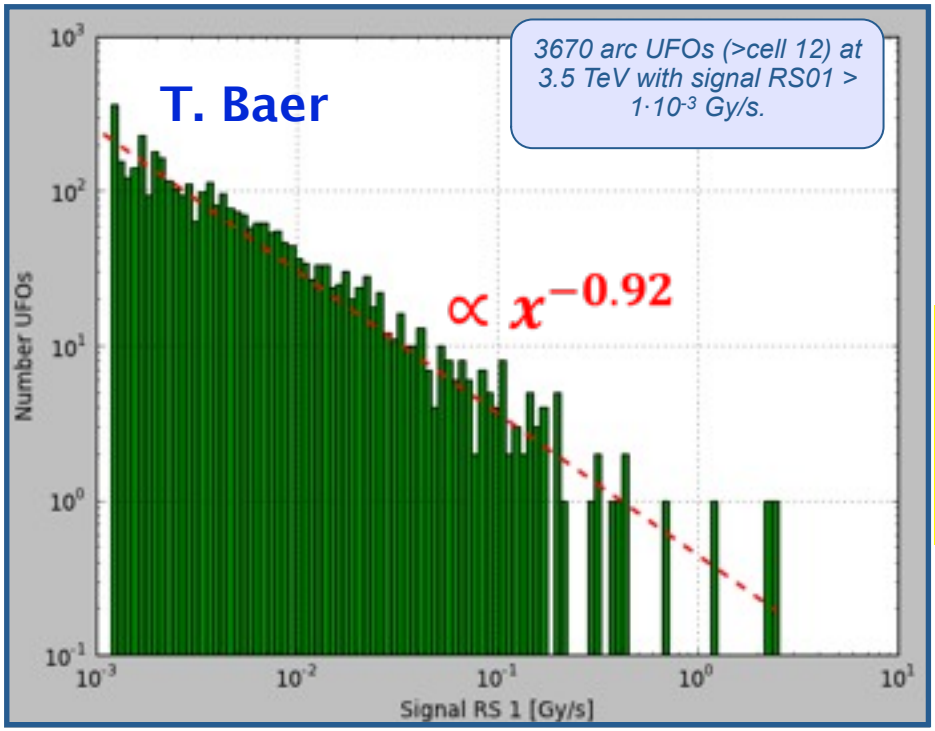
measured UFO strength distribution

dust contamination measured in SMI2

most of the dust consists of silica; deviations at large dust sizes are due to human interventions and could be steel, silver, Ti, etc



BLM signal and dust



measured UFO strength distribution

measured dust distribution consistent with observed UFO strength distribution

dust contamination measured in SMI2

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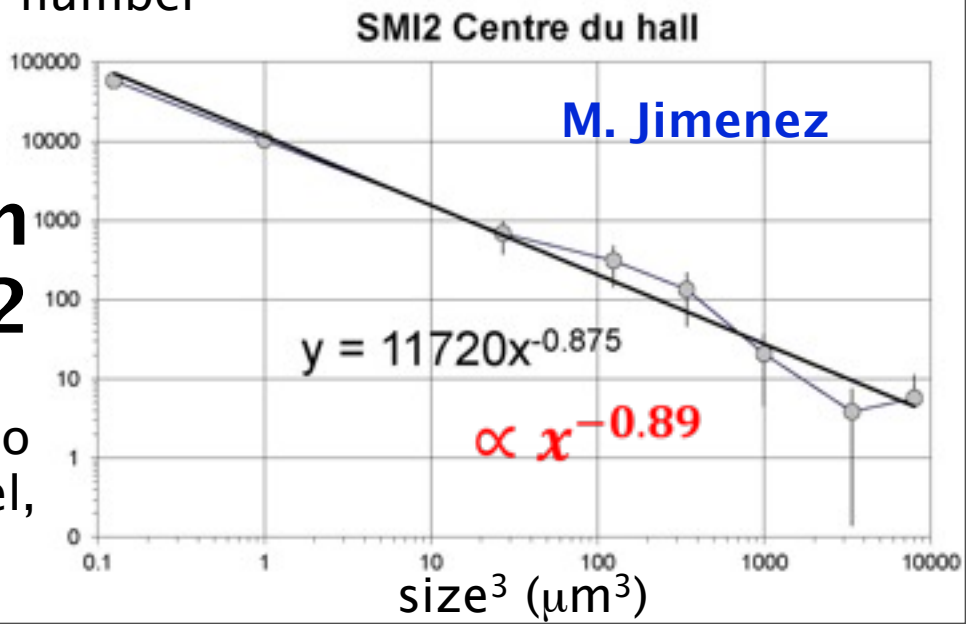
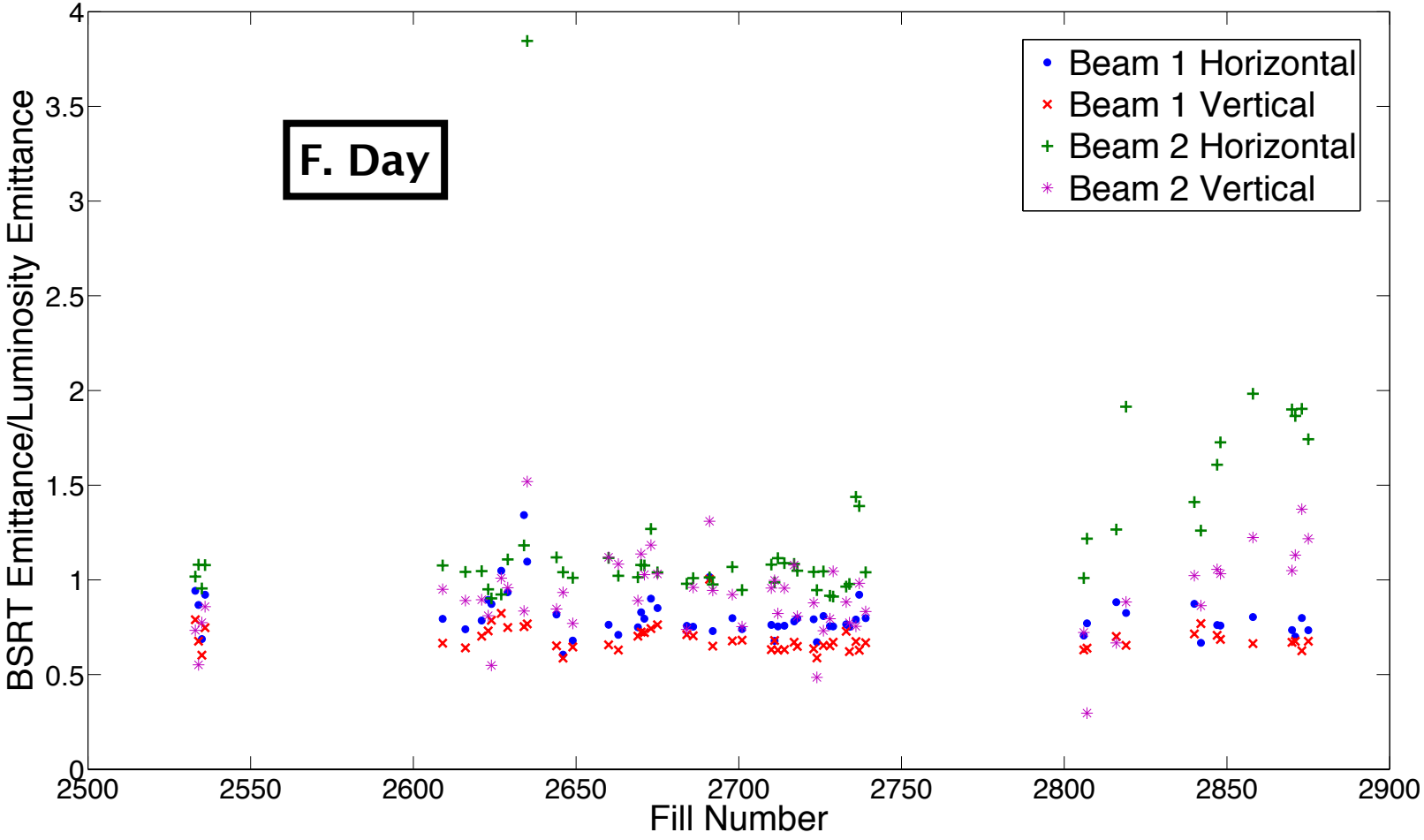


BSRT absolute calibration



Emittance growth