UFOs

Will they take over?

Chamonix Workshop 2012

Tobias Baer
February, 9th 2012

Acknowledgements: W. Bartmann, M. Barnes, C. Bracco, F. Cerutti, B. Dehning, L. Ducimetière, A. Ferrari, N. Fuster Martinez, N. Garrel, A. Gerardin, B. Goddard, E.B. Holzer, S. Jackson, M. Jimenez, V. Kain, A. Lechner, V. Mertens, M. Misiowiec, R. Morón Ballester, E. Nebot del Busto, L. Norderhaug Drosdal, A. Nordt, S. Redaelli, J. Uythoven, B. Velghe, V. Vlachoudis , J. Wenninger, C. Zamantzas, F. Zimmermann, …

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1. Introduction and Arc UFO Observations
2. MKI UFO Studies and Observations
3. Extrapolation for after LS1
4. Outlook and Summary

Content

UFOs in the LHC

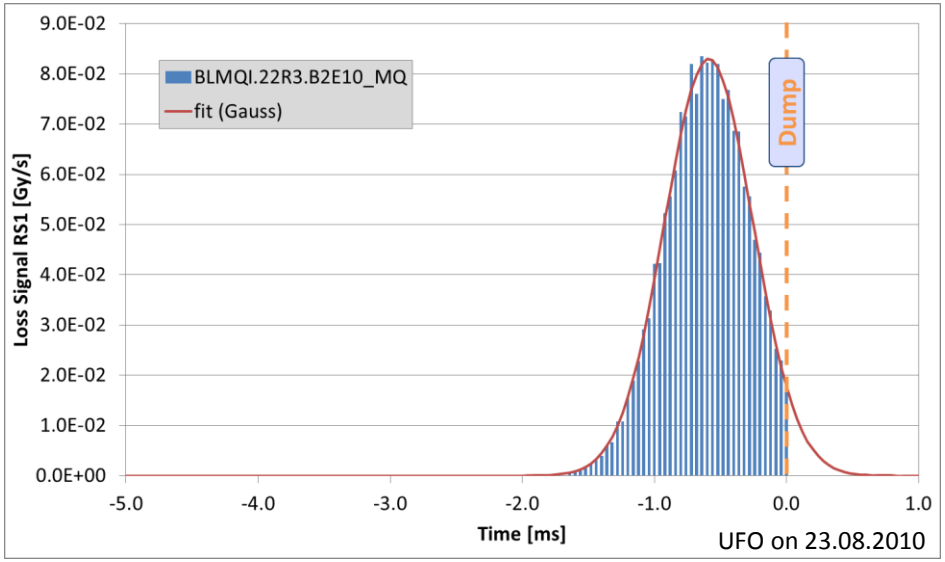
- Since July 2010, **35 beam dumps** due to (***U***n)identified ***F***alling ***O***bjects (17 in 2011).

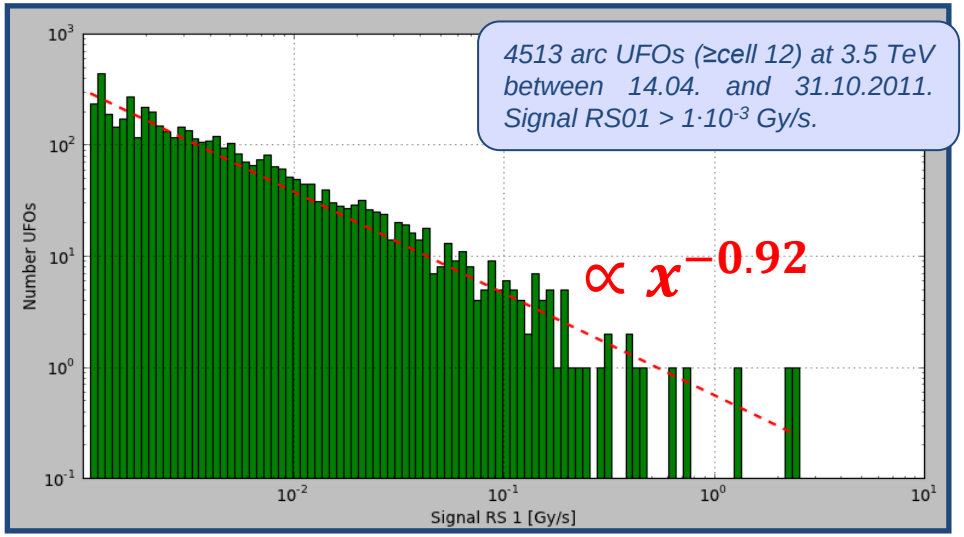
  Loss duration: about 10 turns.

  Often unconventional loss locations (e.g. in the arc).

- In 2011: **16,000 candidate UFOs** below BLM dump thresholds found.

- $\frac{1}{x}$ **distribution** of BLM signal is well explained by **dust particle size distribution** measured in SM12. *(T. Baer et al., Evian Workshop 2011)*





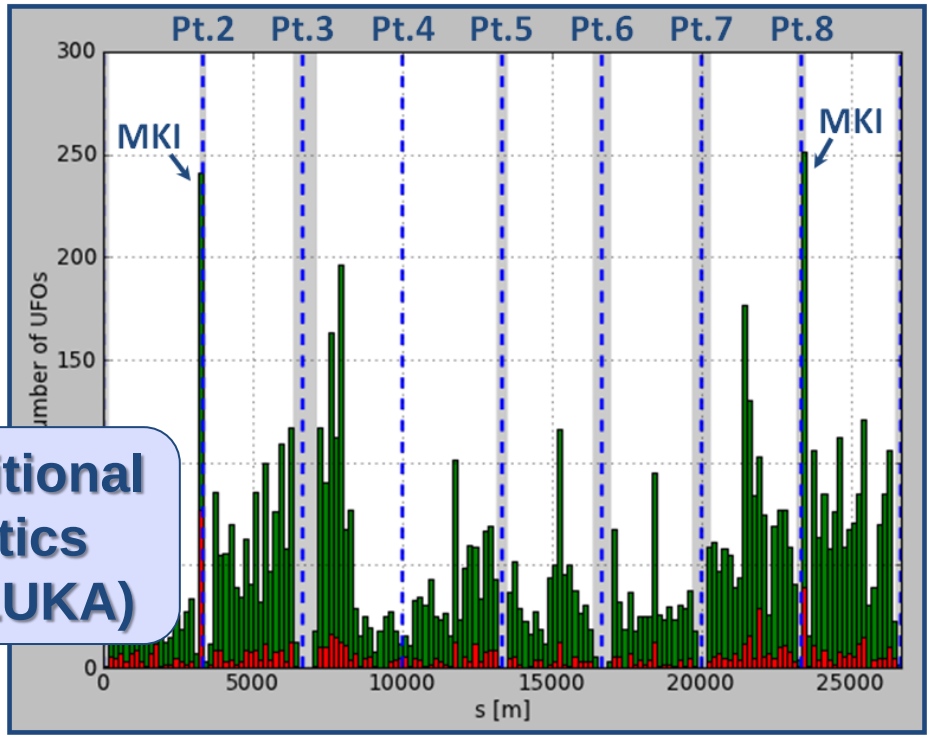
Spatial UFO Distribution

- UFOs occur all around the LHC.
- **Many UFOs around MKIs.**
- Some arc cells with significantly increased number of UFOs:

  25R3 B2: 144 UFOs
  19R3 B1: 126 UFOs.
  28R7 B2: 118 UFOs.

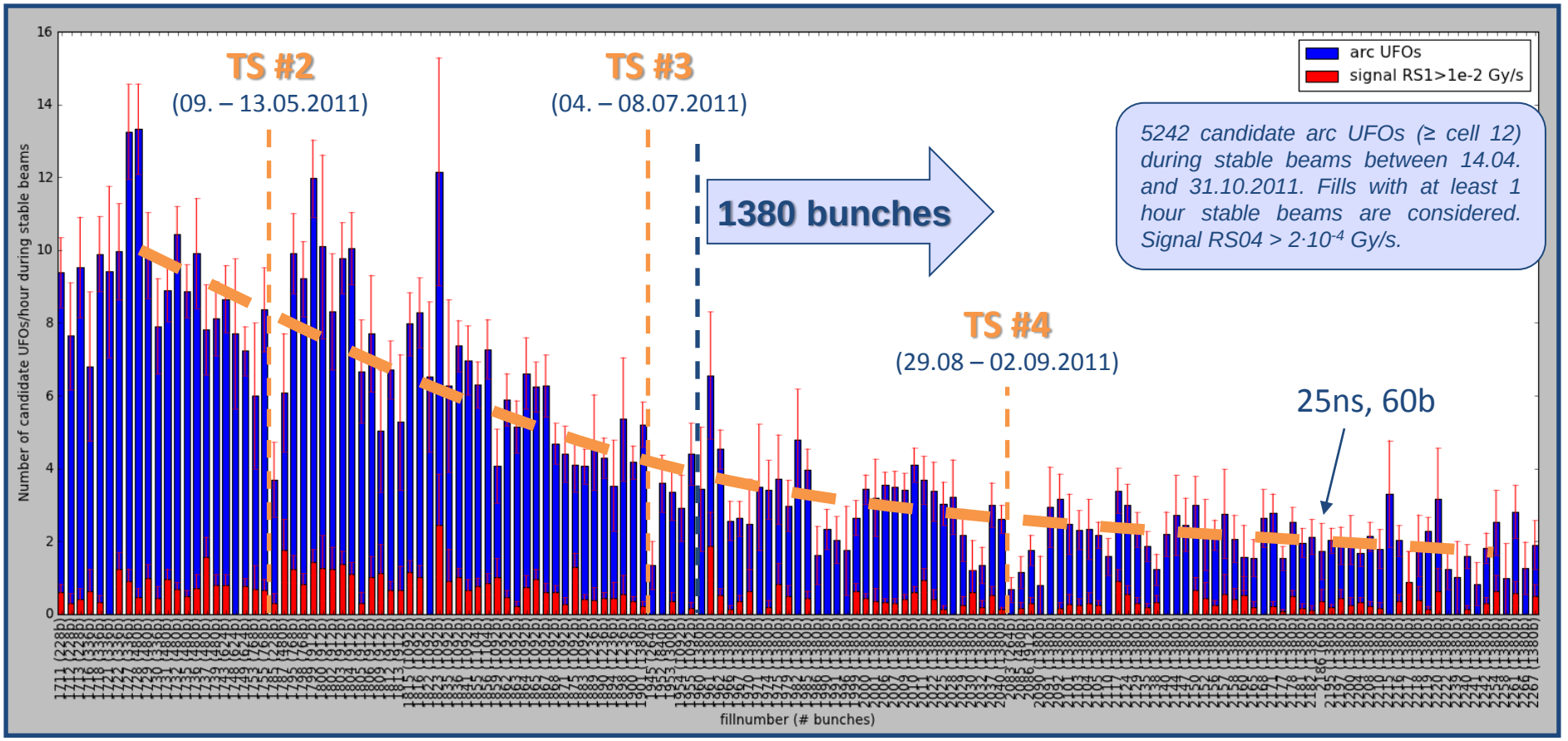
2012: Additional diagnostics (BLMs, FLUKA)

No correlation with sector 34 repairs has been identified.



7784 UFOs at 3.5 TeV between 14.04. and 31.10.2011.
Signal RS04 > $2 \cdot 10^{-4}$ Gy/s.
Red: Signal RS01 > $1 \cdot 10^{-2}$ Gy/s.
Gray areas around IRs are excluded from UFO detection.

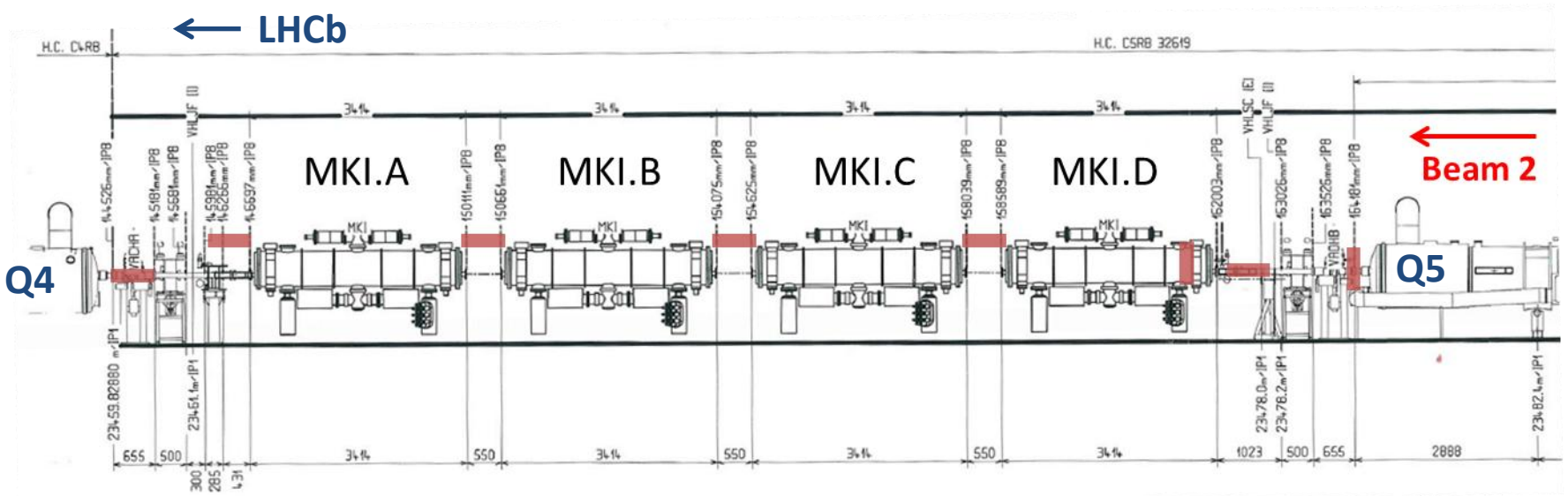
UFO rate 2011

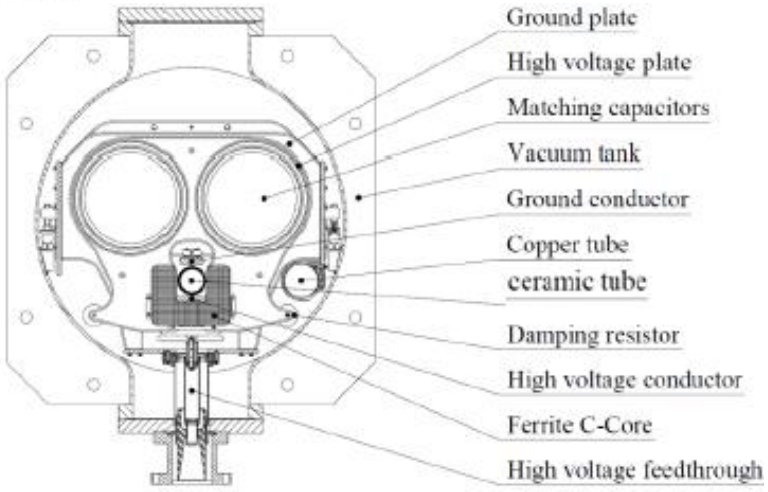


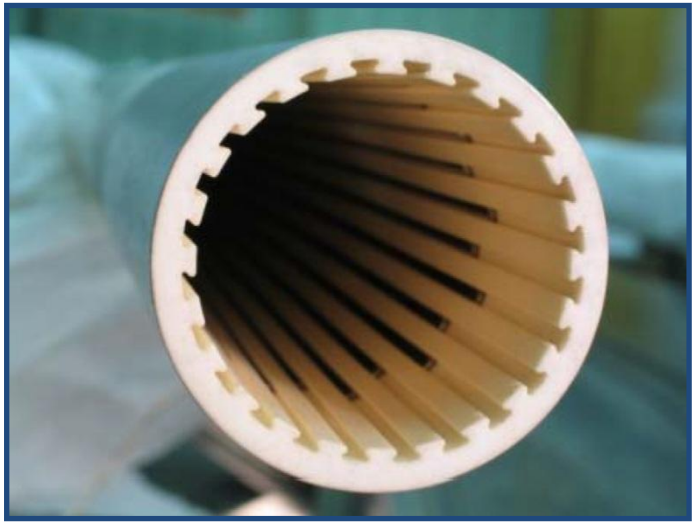
Decrease of UFO rate from ≈10 UFOs/hour to ≈2 UFOs/hour.

Content

Layout of MKI Region

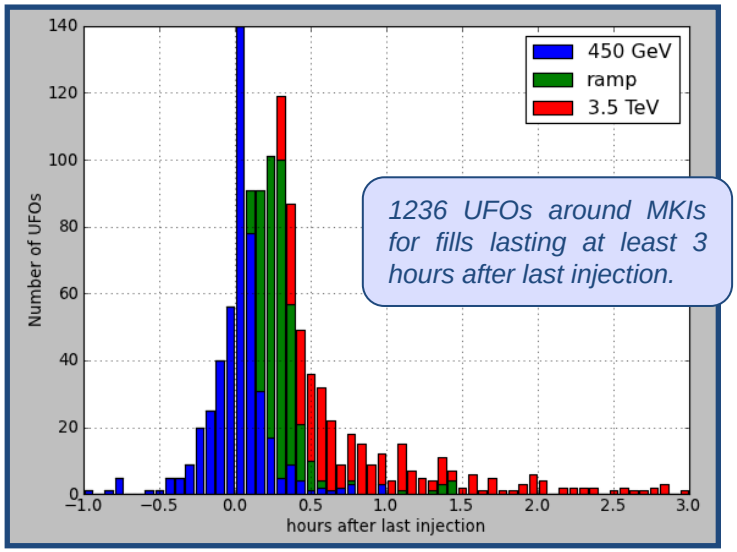


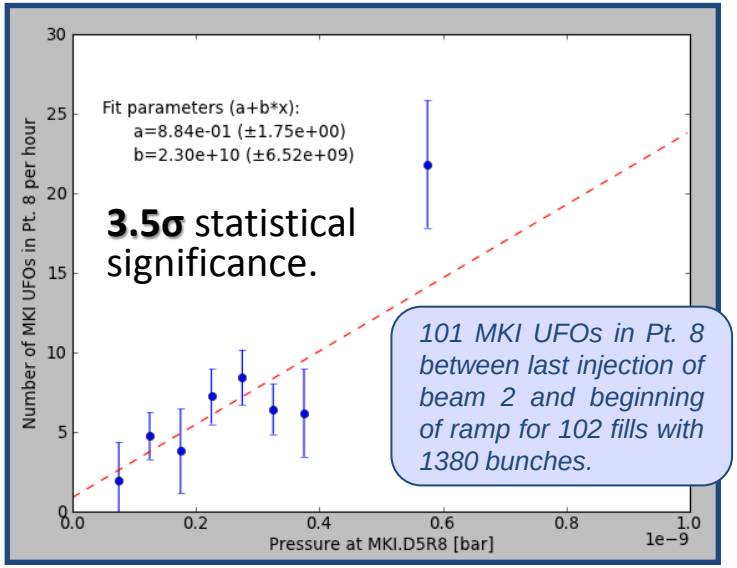




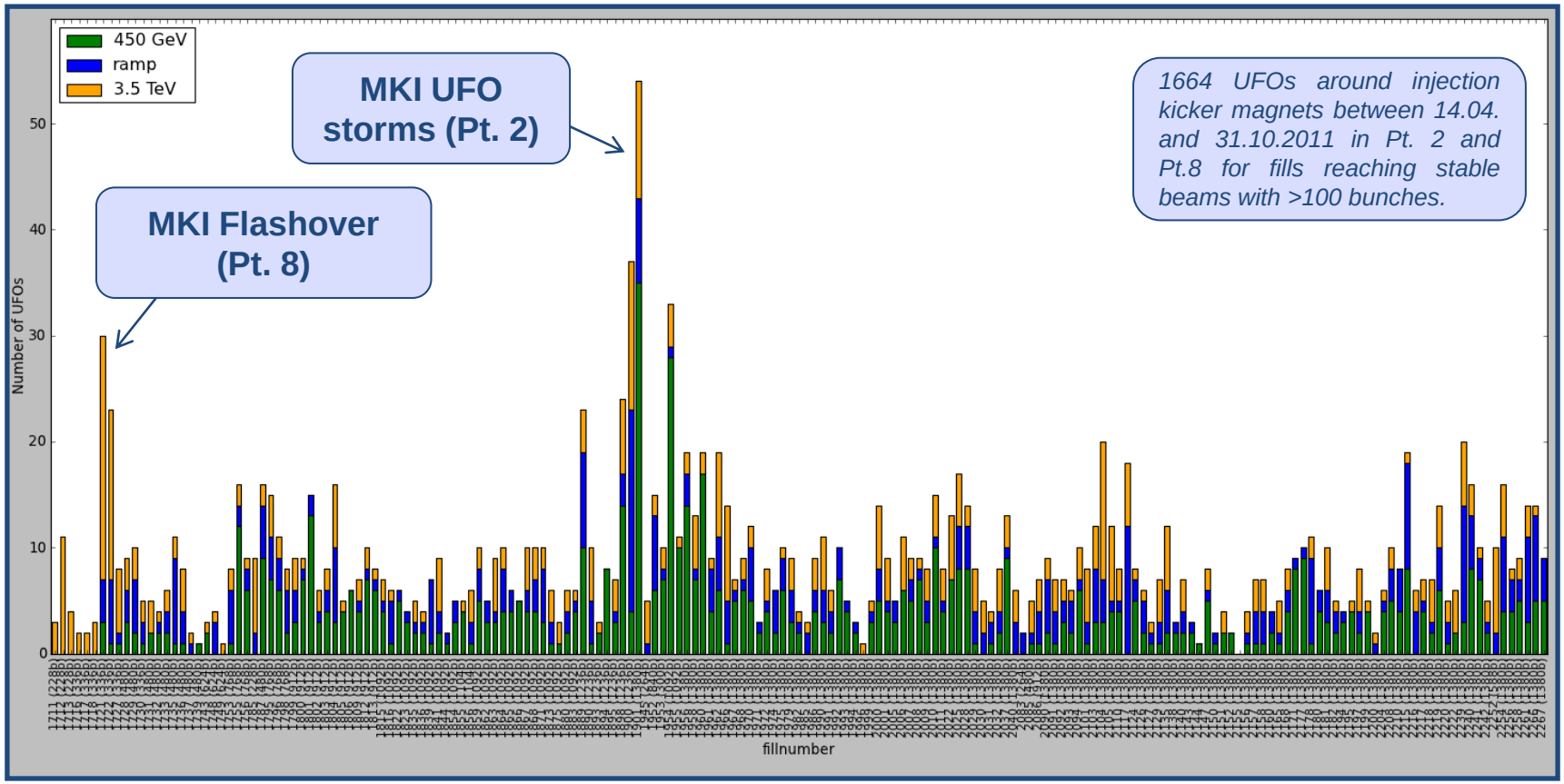
MKI UFOs

- **11 dumps** due to MKI UFOs in 2011.
  8 dumps at 3.5 TeV,
  2 dumps during stable beams.
- In total **2340 UFOs around MKIs**
  847 in Pt.2 and 1493 in Pt.8.
- Temporal distribution:
  *Mainly within **30min after last injection.***
  *Many events within a **few hundred ms after MKI pulse**, some **cannot be explained by gravitational force alone** (negatively charged macro particles?).*
  (T. Baer et al., CERN-ATS-Note-2012-018 MD)
  (F. Zimmermann, 66th LIBD Meeting)
- Positive correlation between **MKI UFO rate** and **local pressure** at 450 GeV.





Number of MKI UFOs



No general conditioning effect obvious for MKI UFOs.

On average: **8.9 MKI UFOs per fill.**

(3.4 at MKIs in Pt. 2 and 5.5 at MKIs in Pt. 8)

MKI UFO Studies

- **FLUKA: UFO location must be in MKIs** (or nearby upstream).

  (A. Lechner, 3rd LHC UFO Study Group Meeting)

  Minimum particle **radius of 40µm** needed to explain large UFO event on 16.07.2011.

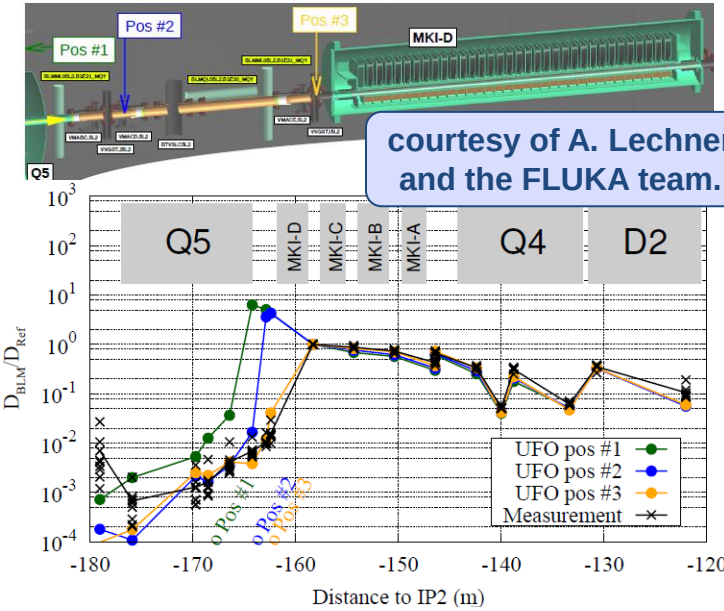
  (T. Baer et al., Evian Workshop 2011)

- **Vibration measurements:** Mechanical vibrations (≈10nm) of ceramic tube during MKI pulse.

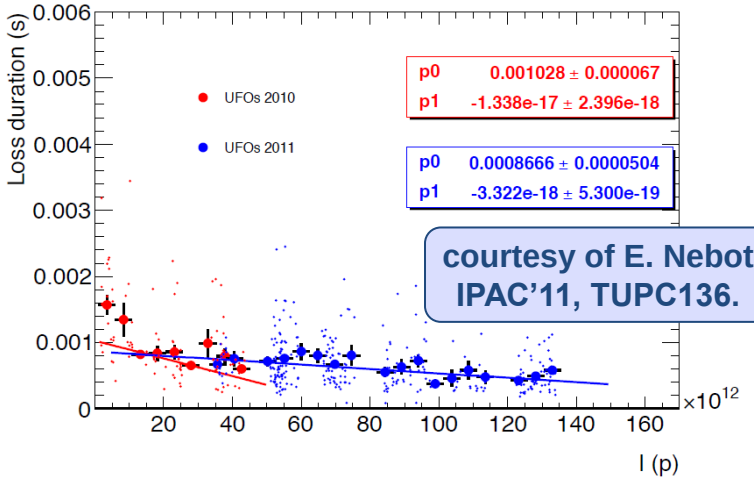
  (R. Morón Ballester et al., EDMS: 1153686)

- **Particle dynamics model:** Many predictions. E.g. UFO duration is shorter for larger beam current.

  (F. Zimmermann et al., IPAC'11, MOPS017)



courtesy of A. Lechner and the FLUKA team.



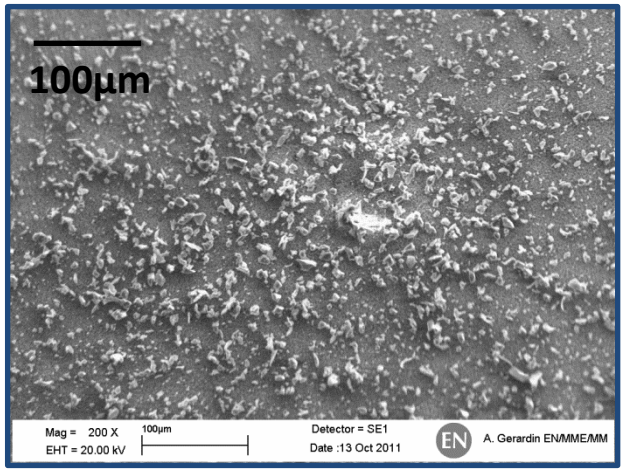
courtesy of E. Nebot IPAC'11, TUPC136.

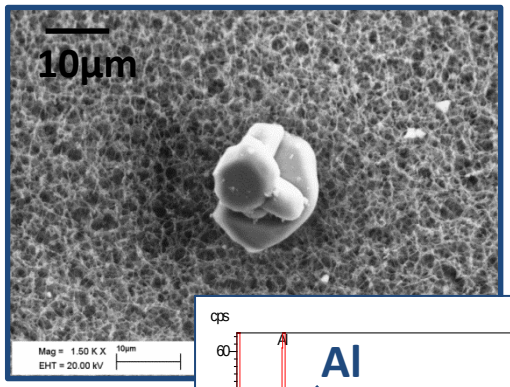
Macro Particles in MKIs

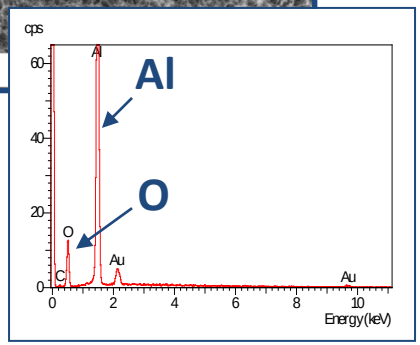
- MKI.C5L2 (removed from LHC in winter TS 2010/11) was opened and inspected for macro particles including energy-dispersive X-ray spectroscopy (EDS).
- Reference measurements:

  clean room air: 100 particles on filter

  new ceramic tube: 10‘000 particles on filter
- **5‘000‘000 particles on filter** found during inspection of removed MKI.
- Typical macro particle diameter: **1-100µm.**
- From EDS spectra: **Most particles originate from the Al_2O_3 ceramic tube.**





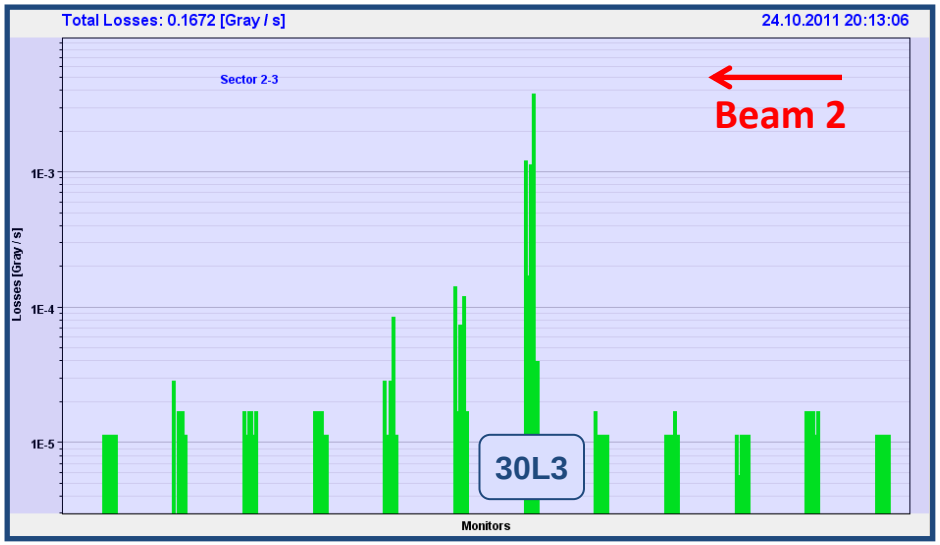


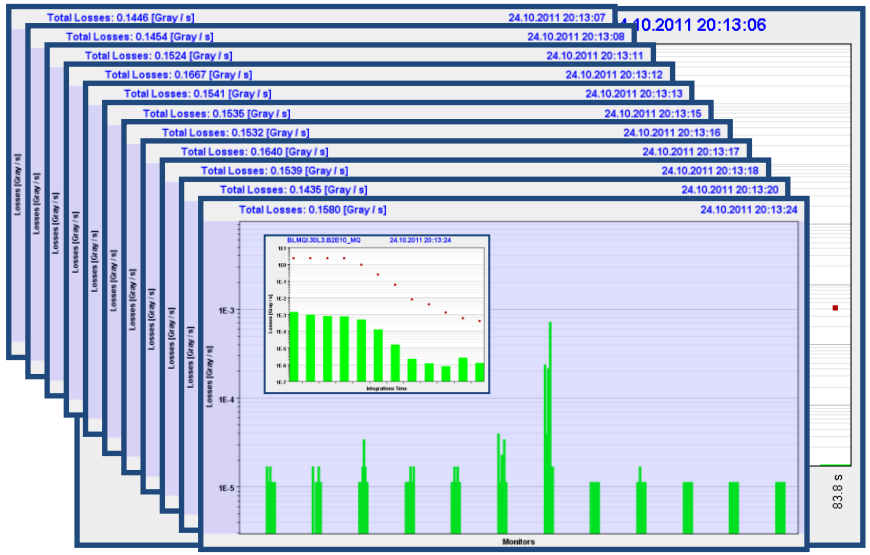
courtesy of
A. Gerardin, N. Garrel
EDMS: 1162034

Content

25ns Operation

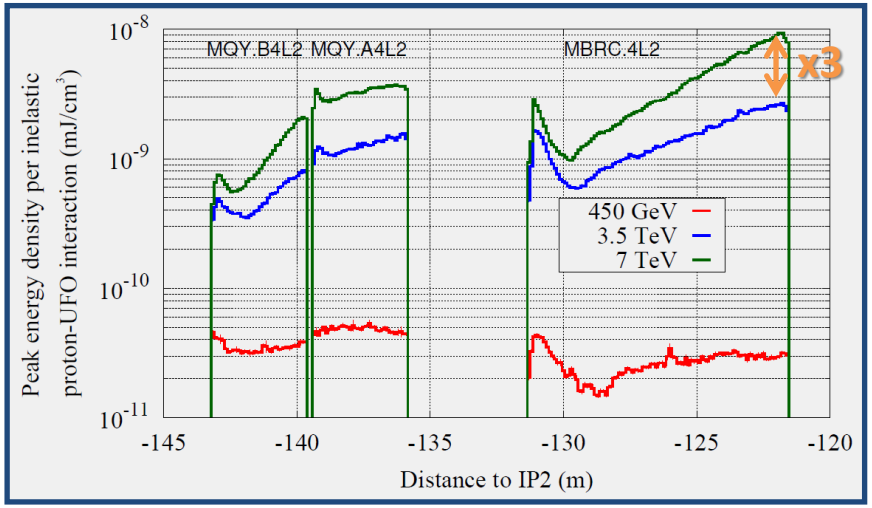
- Heavy UFO activity during 25ns MDs (450 GeV). In 9.1/13.3 (B1/B2) hours with at least $1 \cdot 10^{13}$ protons per beam:
  - ***159 MKI UFOs.***
  - ***22 arc UFOs.***
  - *normal rate < 0.5 UFOs/hour.*
    (E. Nebot et al., IPAC'11, TUPC136)
- **UFO cascade** observed in 30L3 B2 (450 GeV)
  - *12 UFOs at same location within 20 seconds.*





Energy Dependence

- **UFO amplitude:** At 7 TeV about **3 times higher** than at 3.5 TeV (from wire scans and FLUKA simulations of MKI UFOs).
  Arc FLUKA simulations underway.
- **BLM thresholds:** Arc thresholds at 7 TeV are about a **factor 5 smaller** than at 3.5 TeV.
- **UFO rate:** No energy dependence would be consistent with observations. *(E. Nebot et al., IPAC'11, TUPC136)*



Peak energy density simulated by FLUKA for an UFO in MKI.D5R8.

courtesy of A. Lechner and the FLUKA team.

Energy Extrapolation

From 2011 UFOs (full cycle):

- **Arc UFOs: 81 UFO related beam dumps for 7 TeV.**

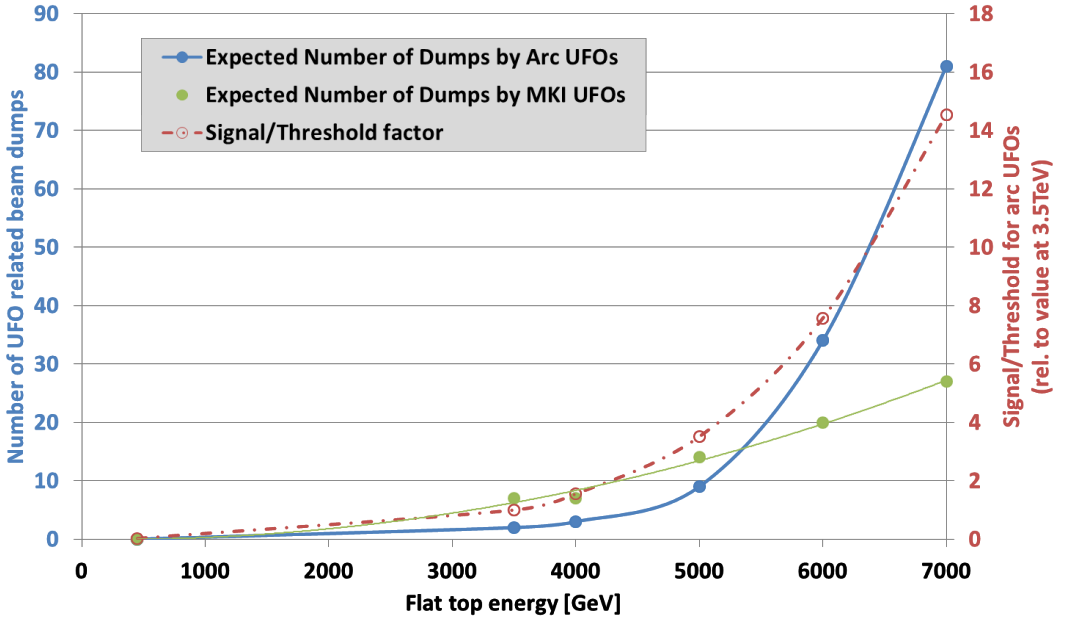
  3 dumps for 4 TeV.

  2 dumps for 3.5 TeV (observed).

- **MKI UFOs: 27 UFO related beam dumps for 7 TeV.**

  7 dumps for 3.5 TeV and BLM thresholds from 31.10.2011.

  11 dumps observed in 2011.



Expected number of UFO related beam dumps and the expected scaling of arc BLM signal/threshold with energy.

Based on UFO events between 14.04. and 31.10.2011 and the applied threshold table from 31.10.2011. For MKI UFOs, only the BLMs at Q4 and D2 are considered. The energy scaling applies only to events at flat top, but (for MKI UFOs) the full cycle is taken into account for the extrapolation. Identical running conditions as in 2011 are assumed. Several unknowns are not included: margin between BLM thresholds and actual quench limit, 25ns bunch spacing, intensity increase, beam size, scrubbing for arc UFOs.

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Plans for 2012 and Beyond

- Better **localization of arc UFOs** by **mobile BLMs** in cell 19R3.
- FLUKA simulations for arc UFOs (underway).
- Better **temporal resolution** of UFO events (dust particle dynamics).
  80µs time resolution of BLM study buffer.
  Bunch-by-bunch diagnostics for UFO events by diamond detectors.
- Study impact of **25ns operation.**
  25ns high intensity (> 1000 bunches) beam for several hours at flat top.
- MKI UFO MD.
  ***25ns**, e-cloud correlation, **UFO production mechanism**, particle dynamics.*
- Possibly installation of shaker device.
  Study production mechanism of UFOs.

Mitigation Strategies

- **MKI UFOs:**

  Metallization *of ceramic tube not feasible (significantly increased rise time, problems with beam induced power deposition).* *(M. J. Barnes, 64th LIBD Meeting)*

  Change MKI.D5R8 in August TS *(heating problems), better cleaning, reduced electrical field due to 24 metal wires (instead of 15).*

- **Arc UFOs:** Mainly increase BLM thresholds towards **quench limit**.

  Wire scanner quench test.

  Increase selected BLM thresholds to probe quench limit.

	Sector	Measured at 1A at:	Largest R_excess measured (uOhm at warm)	Approximate Emax (5 magnet quenches)
✓	**12**	warm	39±9	**4.5TeV**
	23	cold	80±40	-
✓	**34**	warm	36±8	**4.8TeV**
	45	warm	53±15	**3.6TeV**
✓	**56**	warm	20±7	**5.8TeV**
✓	**67**	warm	31±9	**4.8TeV**
	78	cold	90±30	-
	81	cold	120±40	-

A. Siemko, Chamonix Workshop 2012.

Proposal

- For 2012 operation:
  - **Increase BLM thresholds for all arc BLMs in sectors 12, 34, 56, 67 by a factor 3.3.**
    (Proposed thresholds correspond to expected quench limit)
  - If a quench occurs: **reduce BLM thresholds** according to observations.
- **Not many large UFO events expected** (2 arc UFOs above BLM thresholds in 2011), but a large event would provide **very valuable** information on the **real quench limits**.
- Could lead to **maximally one quench**.

Summary

- **17 beam dumps due to UFOs in 2011** (18 in 2010).
  By large-scale increases/optimization of the BLM thresholds and UFO scrubbing, ***the impact of UFOs was mitigated in the second half of 2011.***
- **16'000 candidate UFOs** below BLM dump thresholds detected.
- In 2011, much knowledge gained, especially on MKI UFOs.
  Improved diagnostics, MDs, laboratory measurements, FLUKA simulations, macro particle dynamics studies.
- For 2012: No sign that the situation should become much worse.
  Plan to replace one MKI in August and increase selected arc BLM thresholds.
- After LS1:
  Aggressive energy scaling: 81 dumps by arc UFOs *and* ***27 dumps by MKI UFOs*** *expected for* ***7 TeV*** *operation (based on 2011 observations).*

  High UFO activity observed during ***25ns*** *MDs.*

  2012 studies needed for better understanding, extrapolation and mitigation.

Thank you
for your Attention

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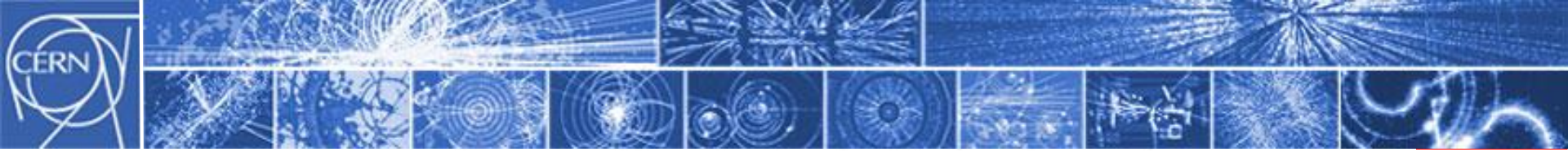
Further information:

- T. Baer et al., “UFOs: Observations, Studies and Extrapolations”, Evian Workshop 2011.
- T. Baer et al., “UFOs in the LHC”, IPAC’11, TUPC137.
- E. Nebot et al., “Analysis of Fast Losses in the LHC with the BLM System”, IPAC’11, TUPC136.
- N. Fuster et al., “Simulation Studies of Macroparticles Falling into the LHC Proton Beam”, IPAC’11, MOPS017.
- A. Gerardin et al., “EDS Analyses of Filters used for UFO Sampling”, EDMS Report No: 1162034.

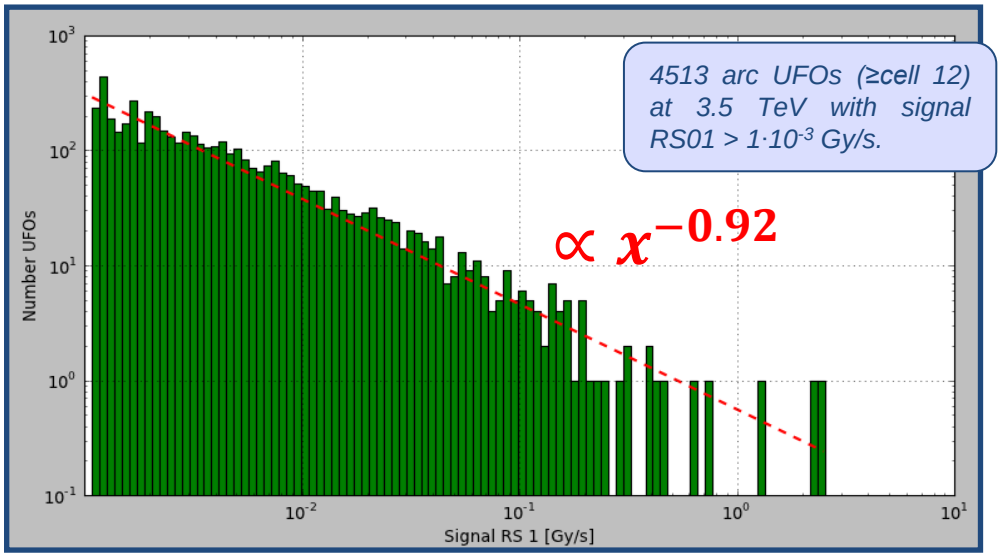


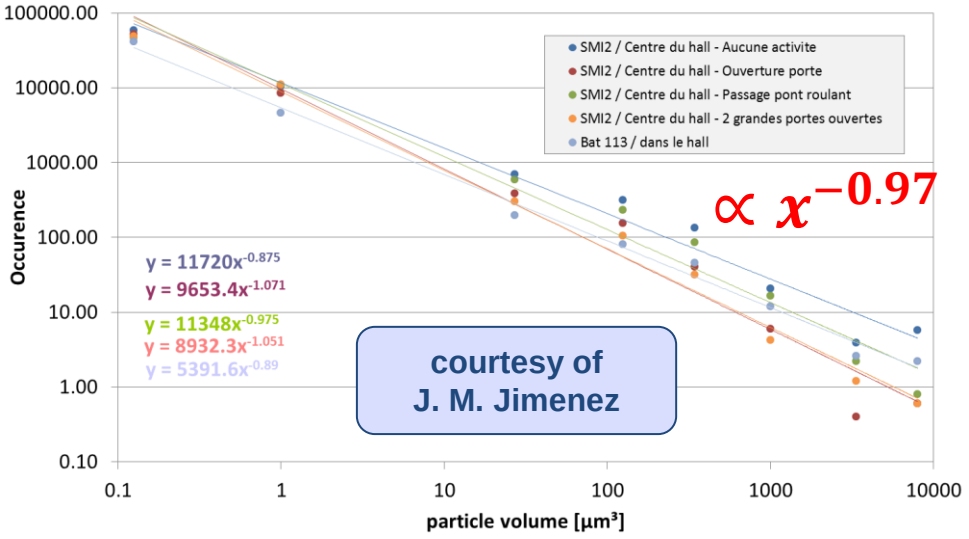
Backup slides

Below Threshold UFOs

- Measured $\approx \frac{1}{x}$ **distribution** of BLM signal is consistent with **measured dust distribution** in SM12/Bat113.

Linear dependency of UFO signal on particle volume shown by N. Fuster et al., IPAC'11, MOPS017.



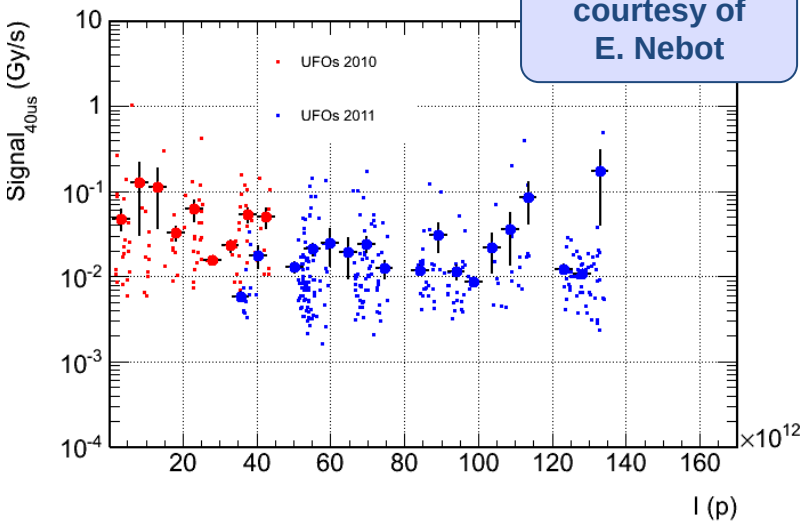


Peak Signal

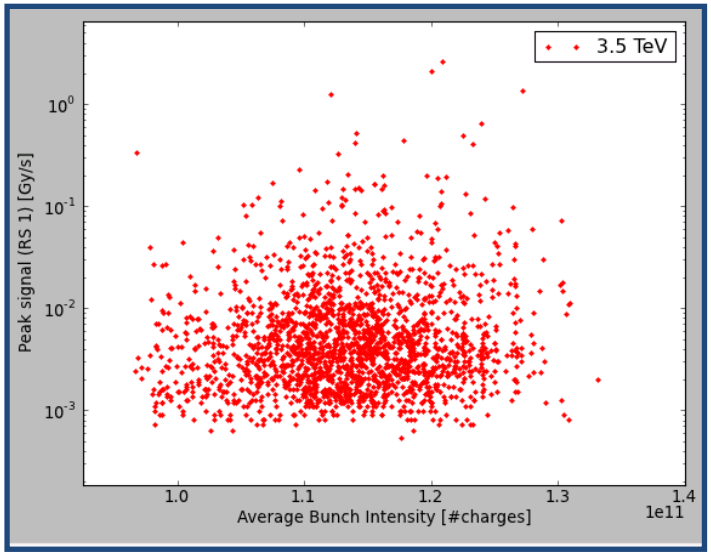
- No clear dependency of peak loss on intensity.

(cf. E.B. Holzer at Evian Dec. 2010)

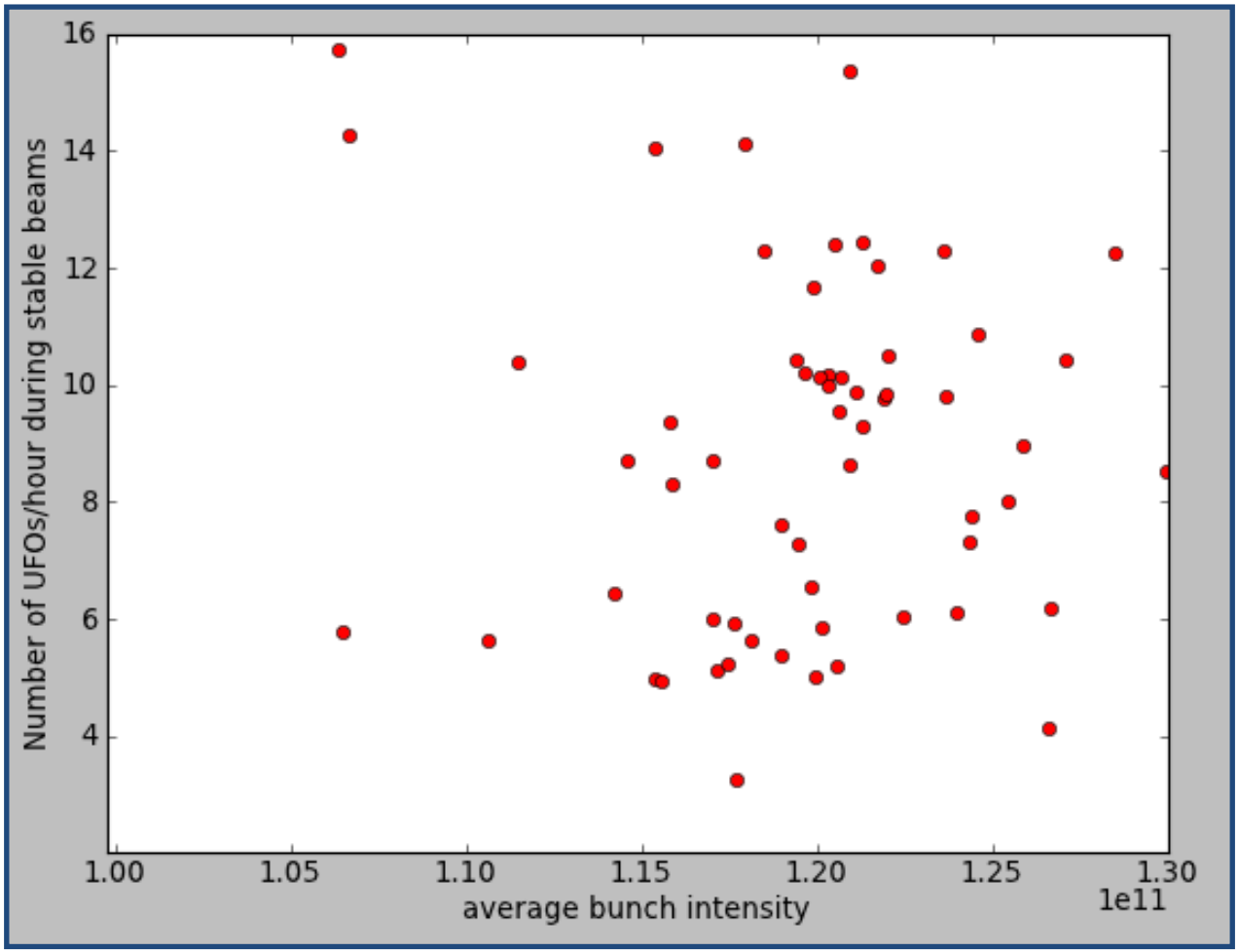
courtesy of E. Nebot



- No clear dependency of peak loss on bunch intensity.

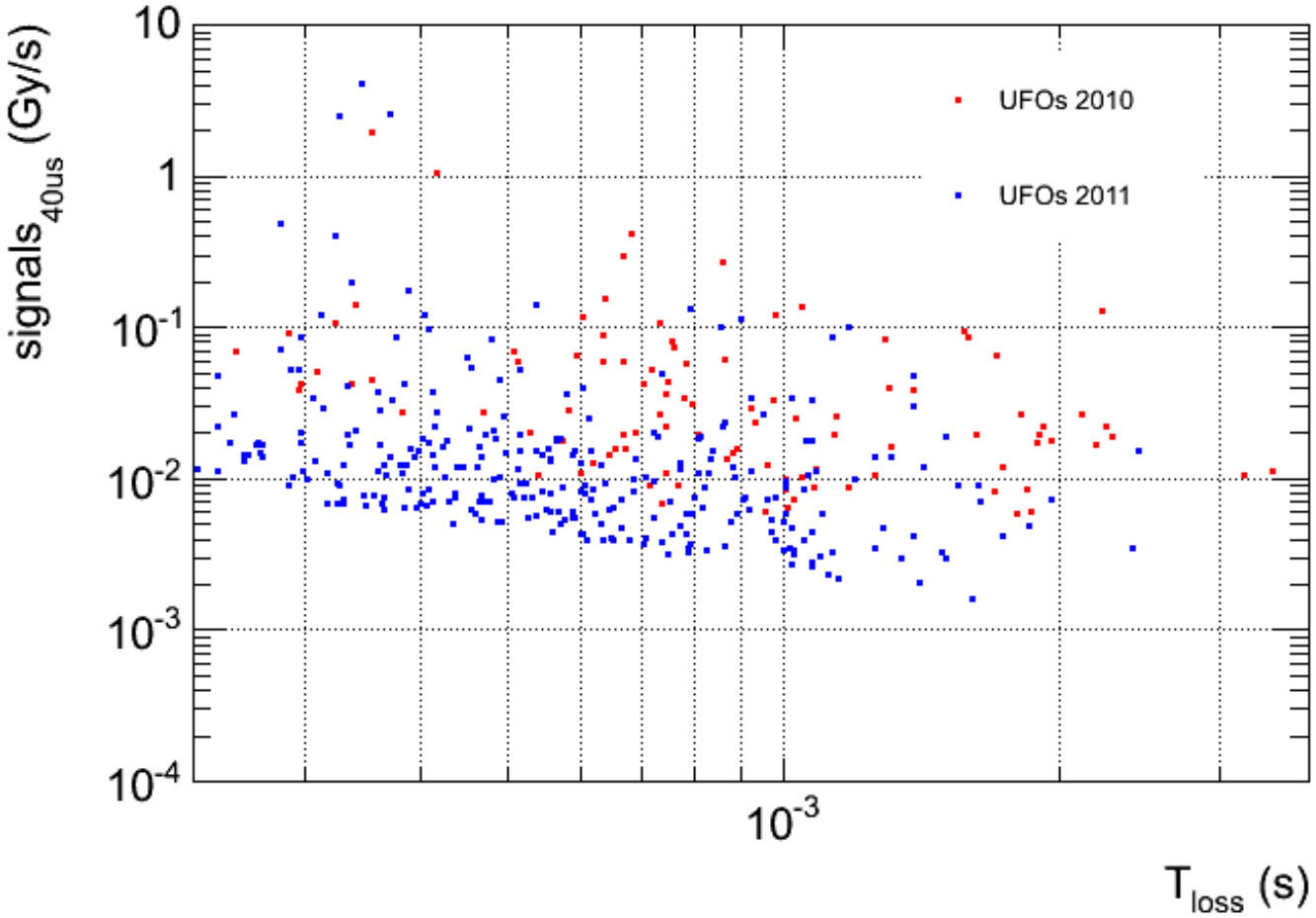


UFO rate vs Bunch Intensity



No dependency of UFO rate on buch intensity.

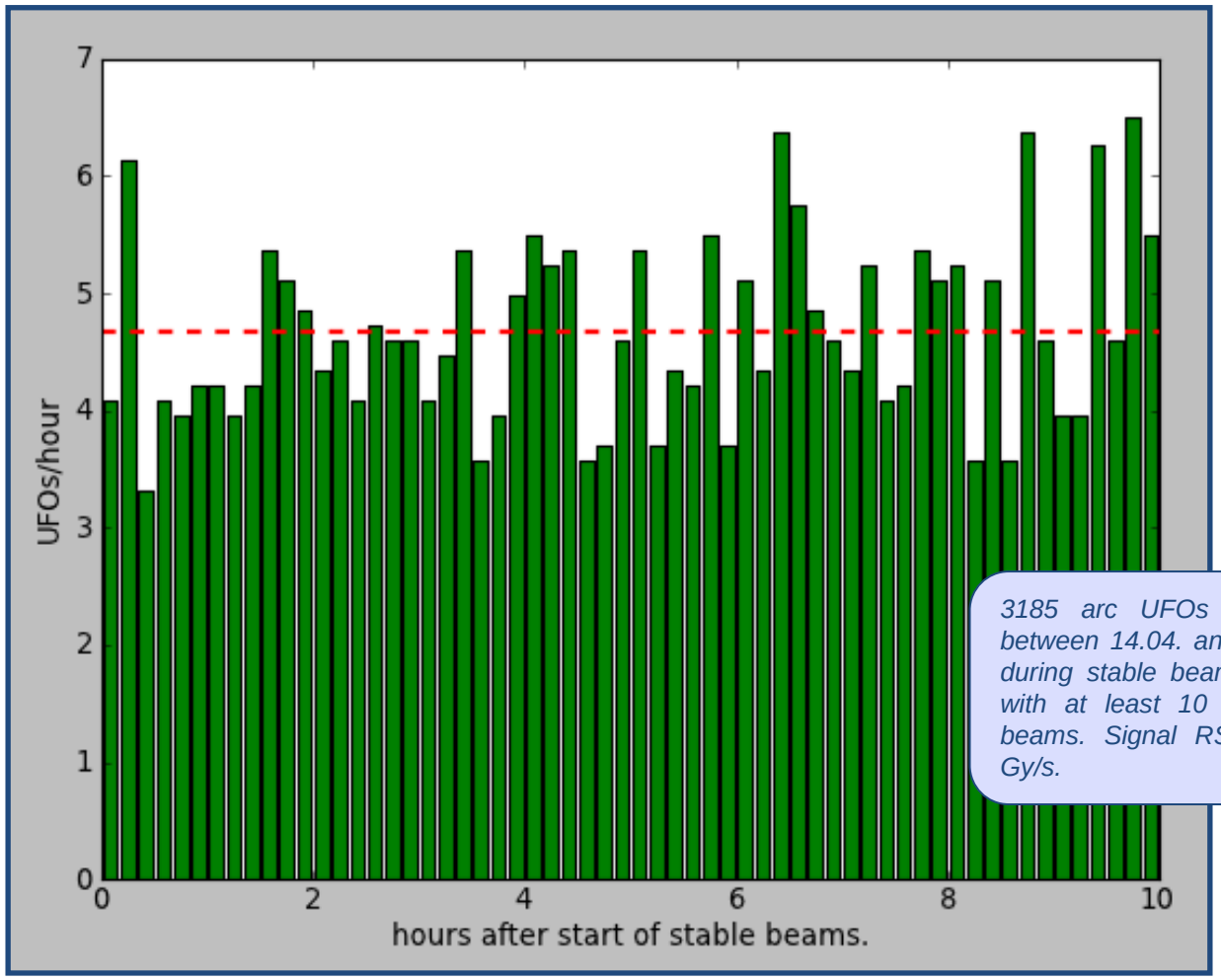
Peak Signal vs Loss Duration



courtesy of E. Nebot

Tendency that harder UFOs are faster.

Intrafill UFO rate

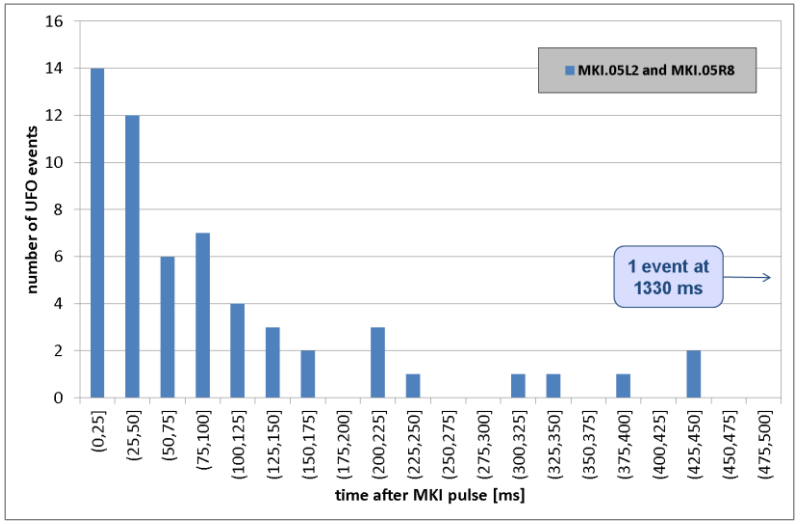


3185 arc UFOs (≥ cell 12) between 14.04. and 31.10.2011 during stable beams in 47 fills with at least 10 hours stable beams. Signal RS04 > $2 \cdot 10^{-4}$ Gy/s.

The UFO rate stays constant during a fill.

UFOs after MKI Pulse

- Many events within a few hundred ms after MKI pulse.

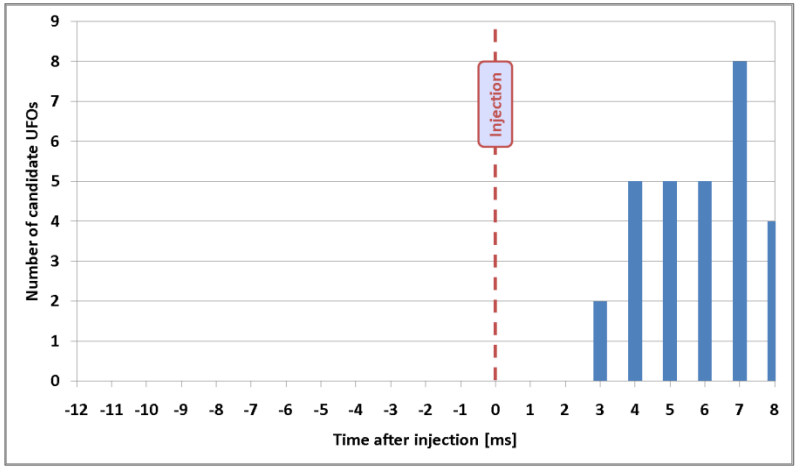


T. Baer et al., CERN-ATS-Note-2012-018 MD

- First event **3ms** after MKI pulse. Compared to **62ms for free fall** from aperture.

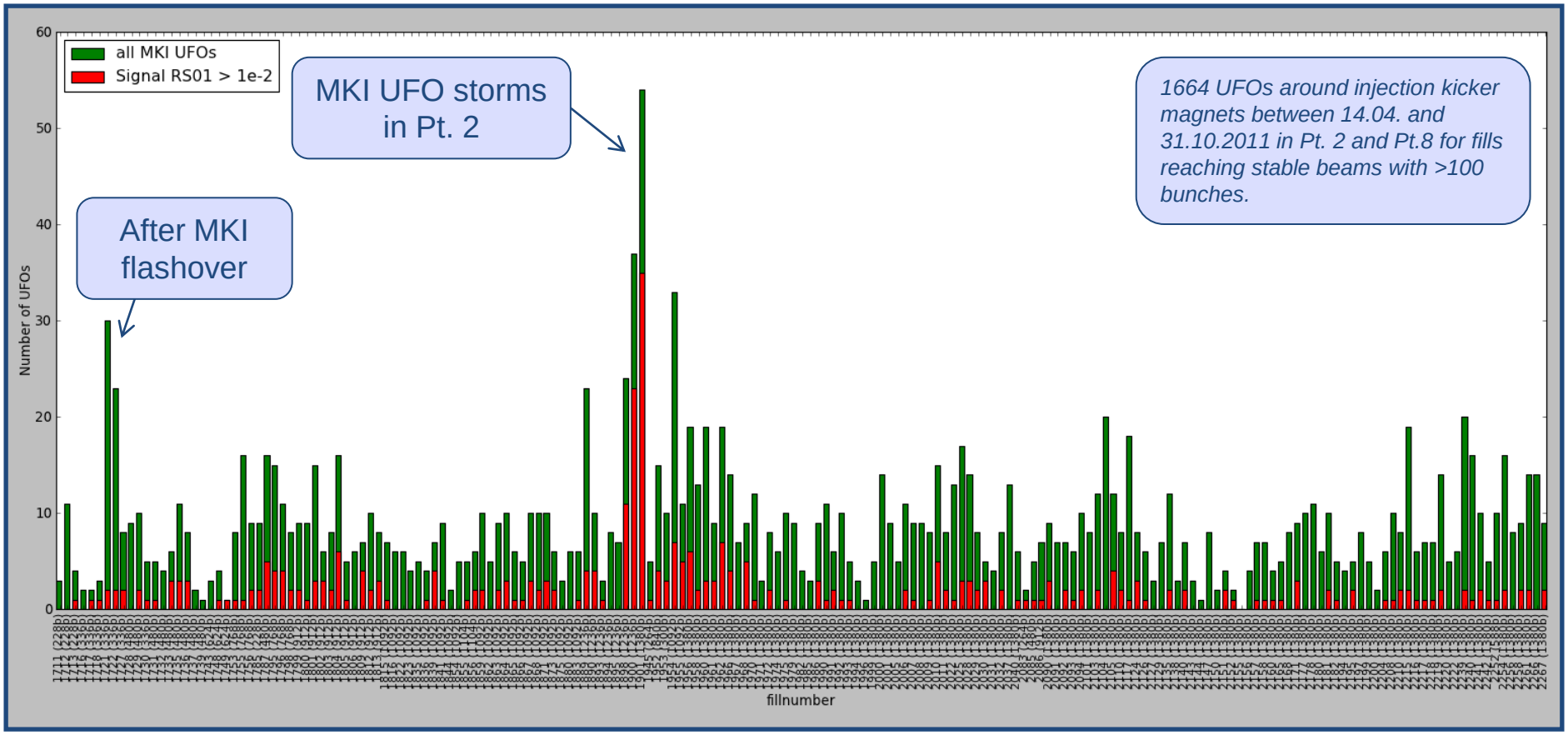
  Could be explained by negatively charged particles.

  (F. Zimmermann at LIBD, 29th Nov. 2011)



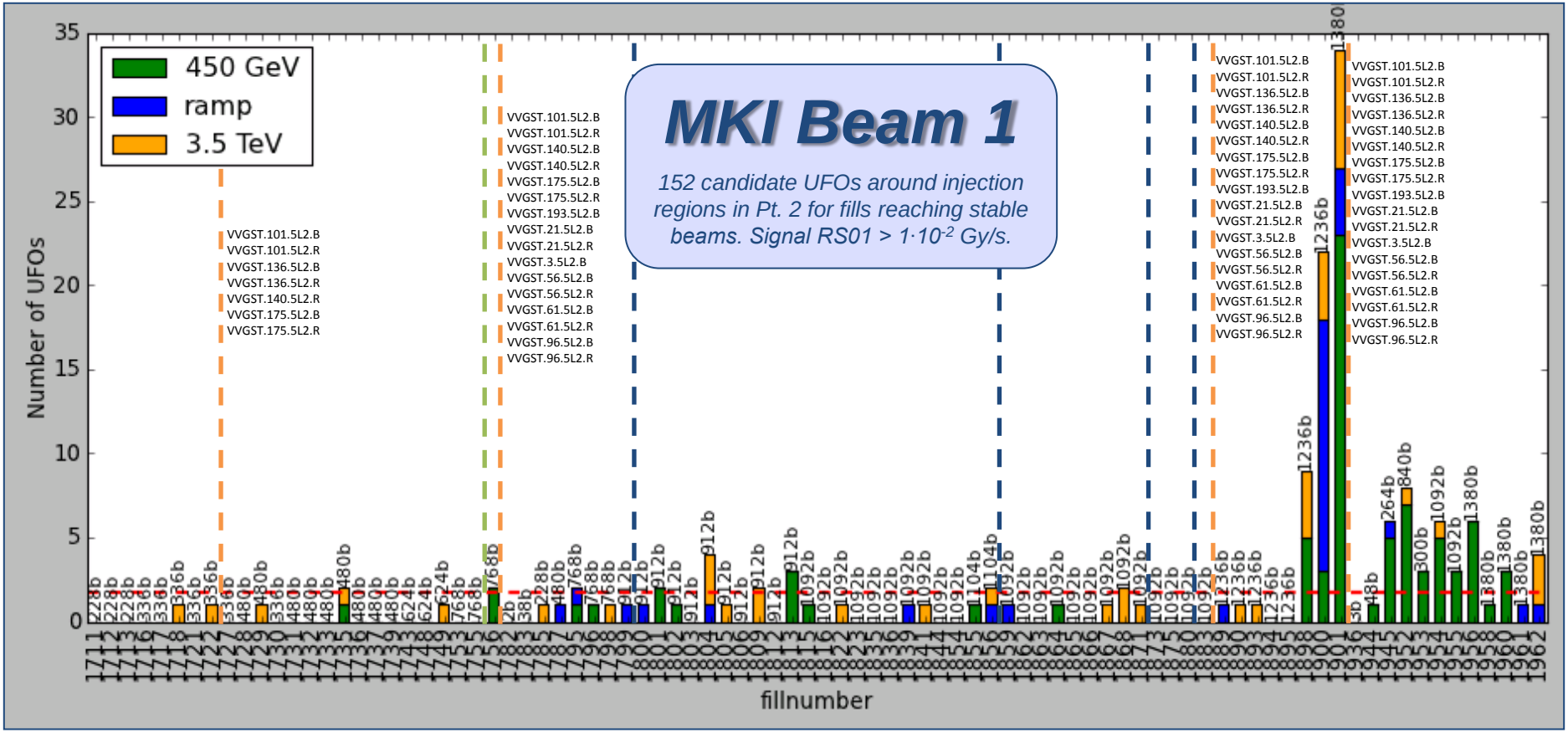
T. Baer et al., IPAC'11, TUPBC137

Number of MKI UFOs



During the UFO storms in July 2011 there was an increased number of UFOs with large signal. The cause is still not understood.

Vacuum Valve Movement



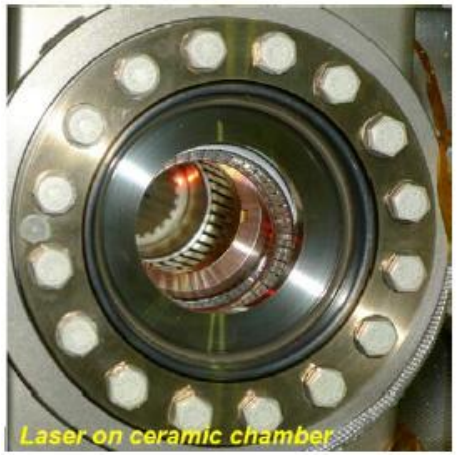
No correlation with closure of vacuum valves.

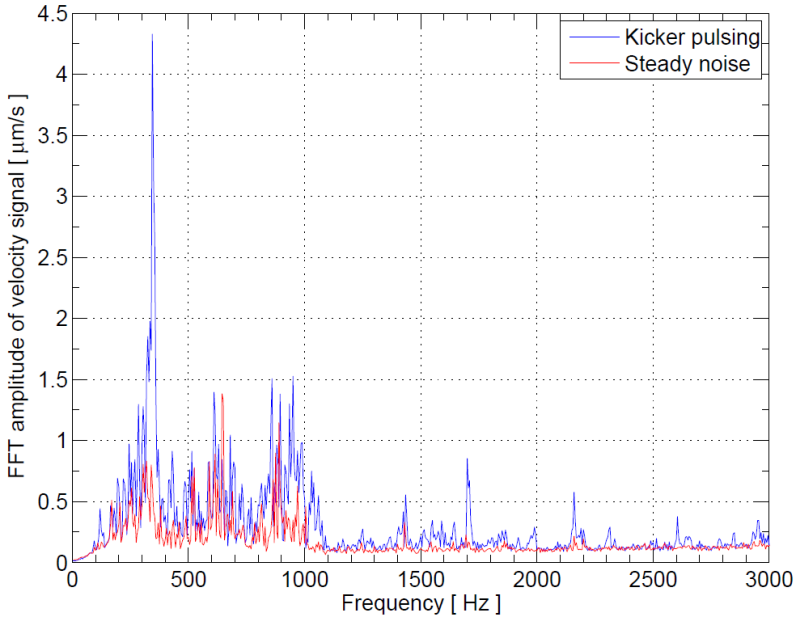
orange: Several valves closed, **blue**: VVGST.193.5L2 and VVGST.3.5L2 closed,

green: status unknown for several valves.

Vibration Measurements

- Measurements carried out on spare MKI with kicker pulsing at full voltage under vacuum using accelerometers and laser vibrometers.
- Many issues of electrical noise and spurious vibration (e.g. pumps)
- When the kickers fire, a **mechanical vibration in 60-300 Hz range** is measured. The amplitudes are but very small (**≈10 nm**).





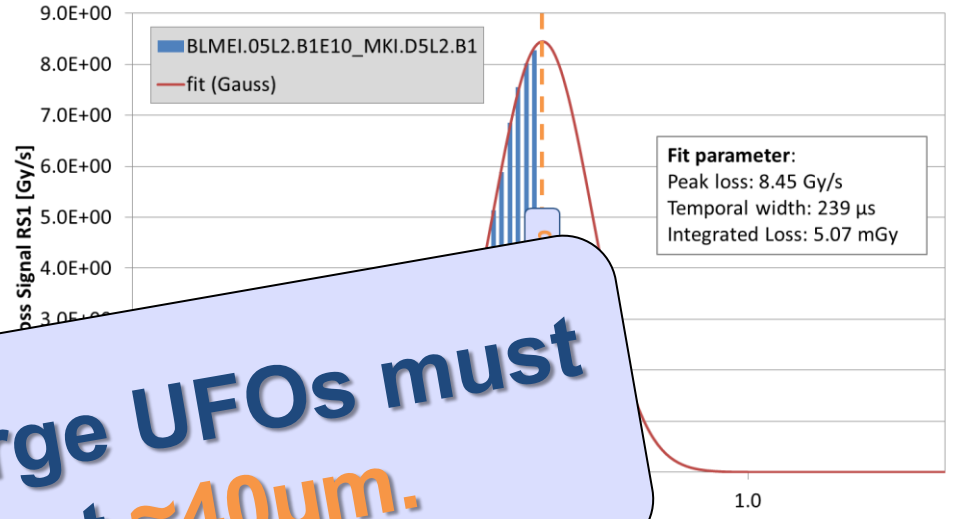
courtesy of
R. Moron Ballester, S. Redaelli
EDMS: 1153686

Macro Particle Size

- From FLUKA simulations:

  4.07·10[11] interactions per Gy at BLMEI.05L2.B1E10_MKI.D5L2.B1 at 3.5 TeV.

- Peak loss of 8.45 Gy/s corresponds t
  interacti
- With (r <<



Radius of large UFOs must be at least ≈40µm.

16.07.2011 14:09:18

$$\dot{N}_{p,max} = \frac{}{2\pi\sigma_x\sigma_y} \cdot \frac{}{l \cdot \rho}$$

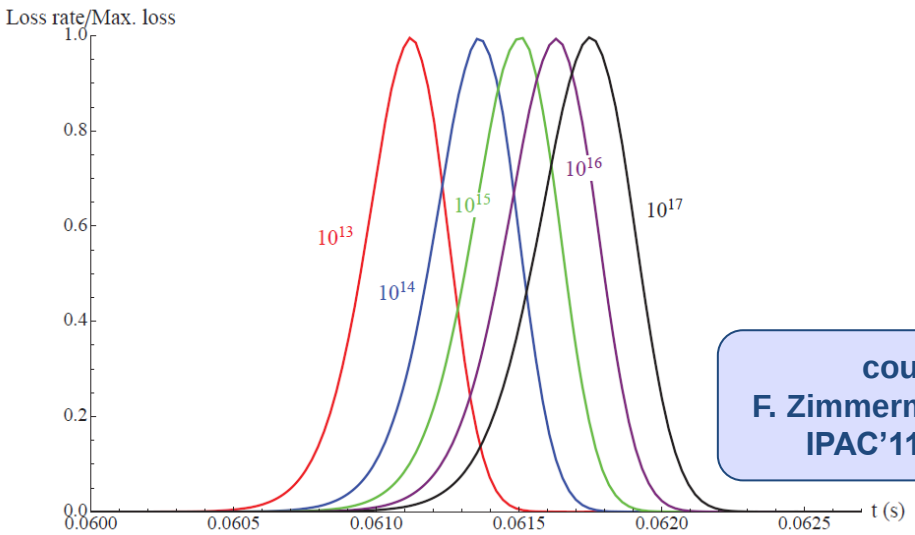
Nuclear interaction length

I=1.02·10[14] protons, E=3.5 TeV, with ε^n=2.5µm·rad, β_x=158.5m, β_y=29.5m, **σ_x=325µm, σ_y=140µm**.

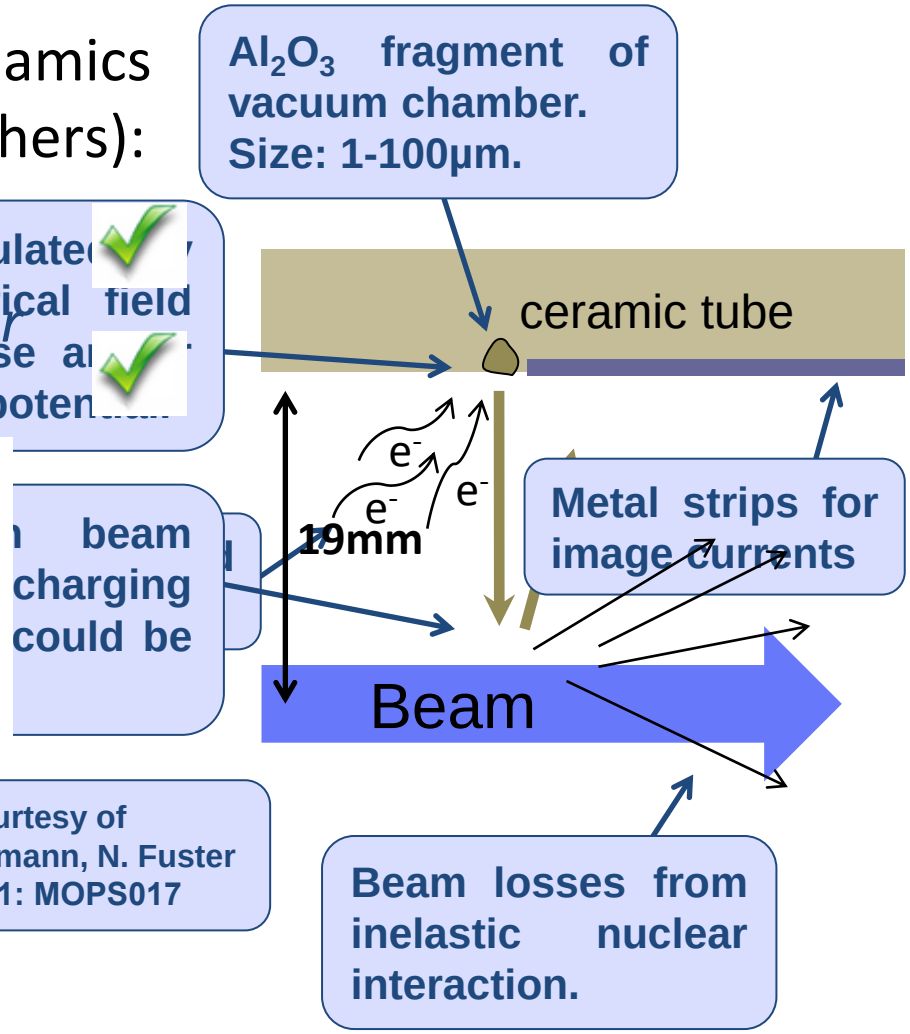
Material	Resulting mass (A)	Radius of spherical object
Al (l=39.7cm, ρ=2700kg/m^3)	**5.53·10^{17}**	**43µm**
Al_2O_3 (l=24.8cm, ρ=3970kg/m^3)	**5.08·10^{17}**	**37µm**

UFO Model

- Implemented in dust particle dynamics model, which predicts (among others):
  - *Loss duration of a few ms.*
  - *Losses become faster for larger beam intensities.*



Beam loss rate as a function of time for different macroparticle masses. Beam intensity: $1.6 \cdot 10^{14}$ protons.



Lead MKI UFOs

MKI UFO at MKI.D5R8.

- ***10 % of threshold*** *at MQML.10L8. Losses are not as localized as for protons.*
- *Highest loss is in the* ***dispersion suppressor*** *downstream of the IR (due to ion fragmentation).*