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European Organization for Nuclear Research  
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# UFOs in the LHC

*CERN MAC #4*  
*Tobias Baer*  
*August, 12<sup>th</sup> 2011*

*Acknowledgements: G. Arduini, W. Bartmann, M. Barnes, C. Bracco, M. Ferro-Luzzi, N. Garrel, B. Goddard, E.B. Holzer, S. Jackson, M. Jimenez, V. Mertens, M. Misiowiec, E. Nebot, L. Norderhaug Drosdal, A. Nordt, J. Uythoven, B. Velghe, J. Wenninger, C. Zamantzas, F. Zimmermann, ...*



# Content

1. UFO related Beam Dumps
2. UFO Observations and Studies
3. MKI UFOs
4. Outlook and Summary



# Content

**1. UFO related Beam Dumps**

**2. UFO Observations and Studies**

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# UFOs in the LHC

- Since July 2010, **35 fast loss events led to a beam dump.**

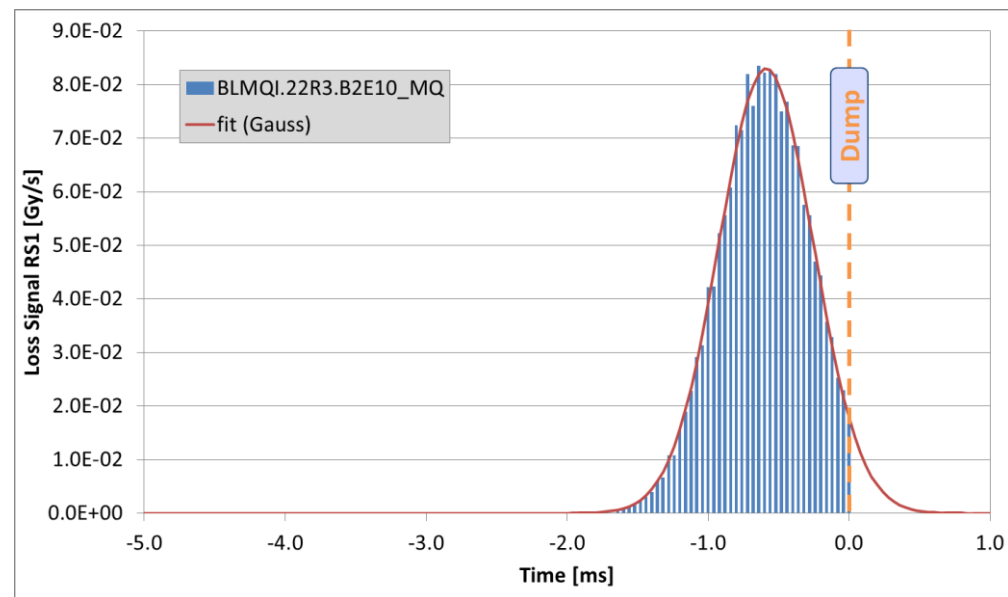
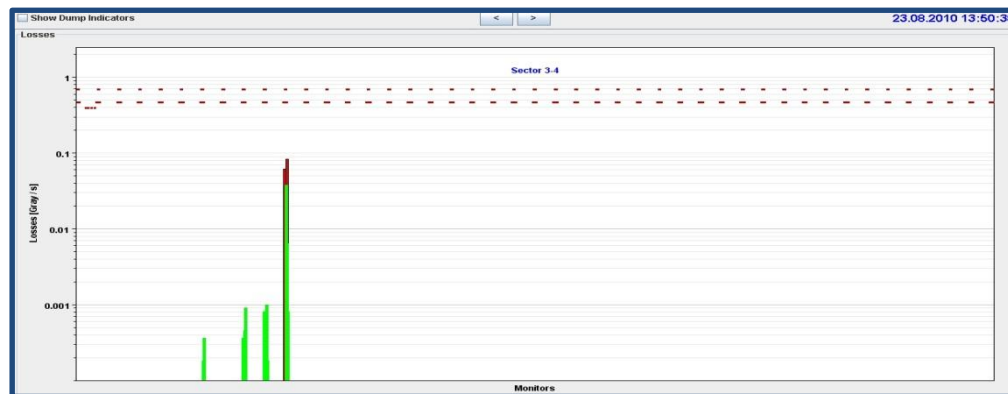
*18 in 2010, 17 in 2011.*

*13 around MKIs.*

*6 dumps by experiments.*

*1 at 450 GeV.*

- Typical characteristics:
  - Loss duration: about 10 turns
  - Often unconventional loss locations (e.g. in the arc)
- The events are believed to be due to (Unidentified) Falling Objects (UFOs).



*Spatial and temporal loss profile of UFO on 23.08.2010*



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1. UFO related Beam Dumps

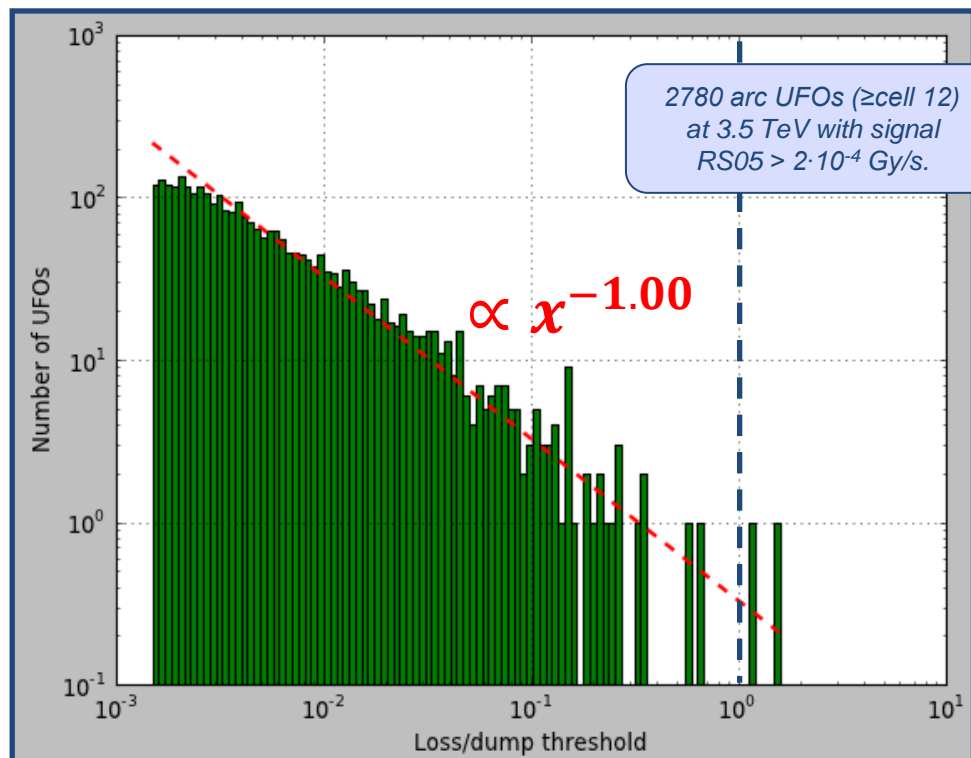
**2. UFO Observations and Studies**

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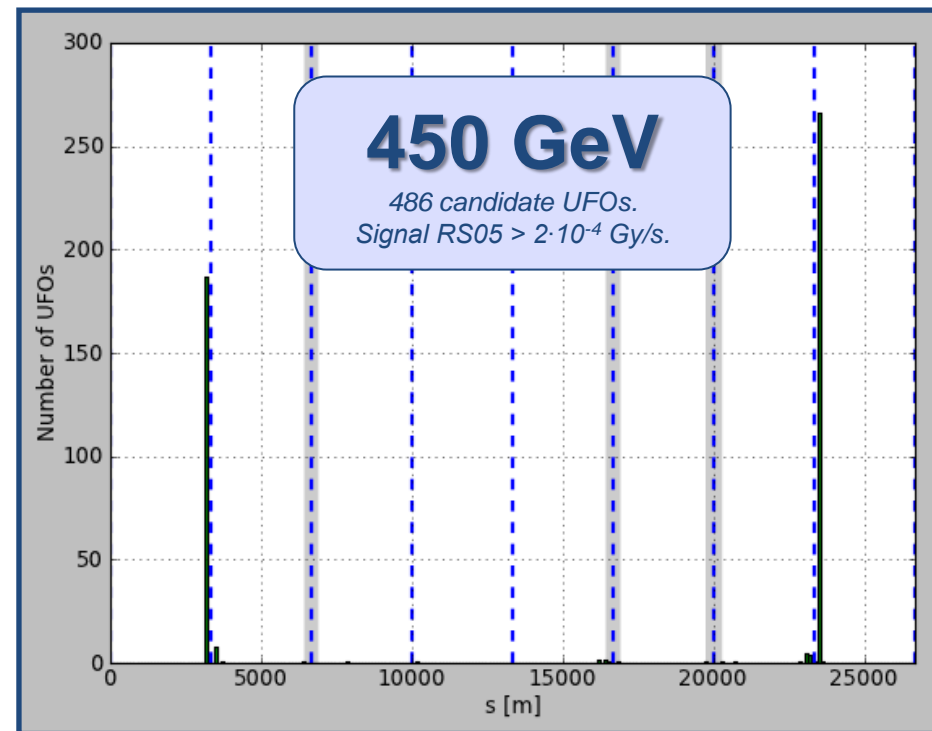
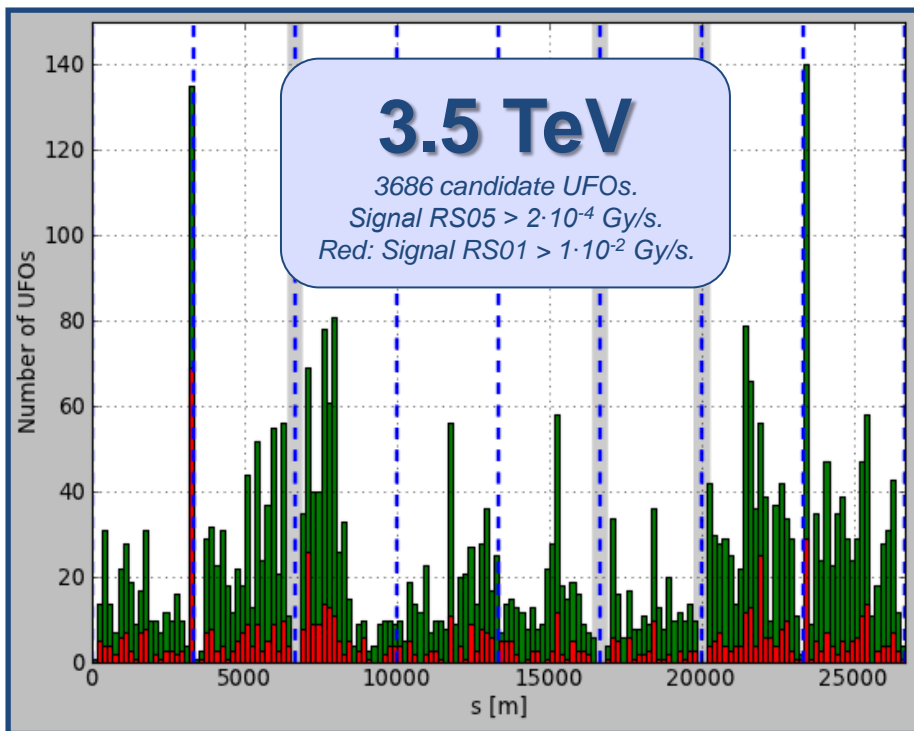
# UFOs Below Dump Threshold

- 2010: Logged BLM data was analyzed and 113 sub-threshold UFO events were found. (E. Nebot)
- For 2011: Online UFO detection in 1Hz BLM data.
- Over **10000 candidate UFOs** below threshold found.  
*Most events are much below threshold.*
- Between 2010 and 2011, UFO related beam dumps were reduced by increasing the BLM thresholds for losses on ms scale by a factor 5.



*Distribution of arc UFOs.*

# Spatial UFO Distribution



UFOs occur all around the machine.

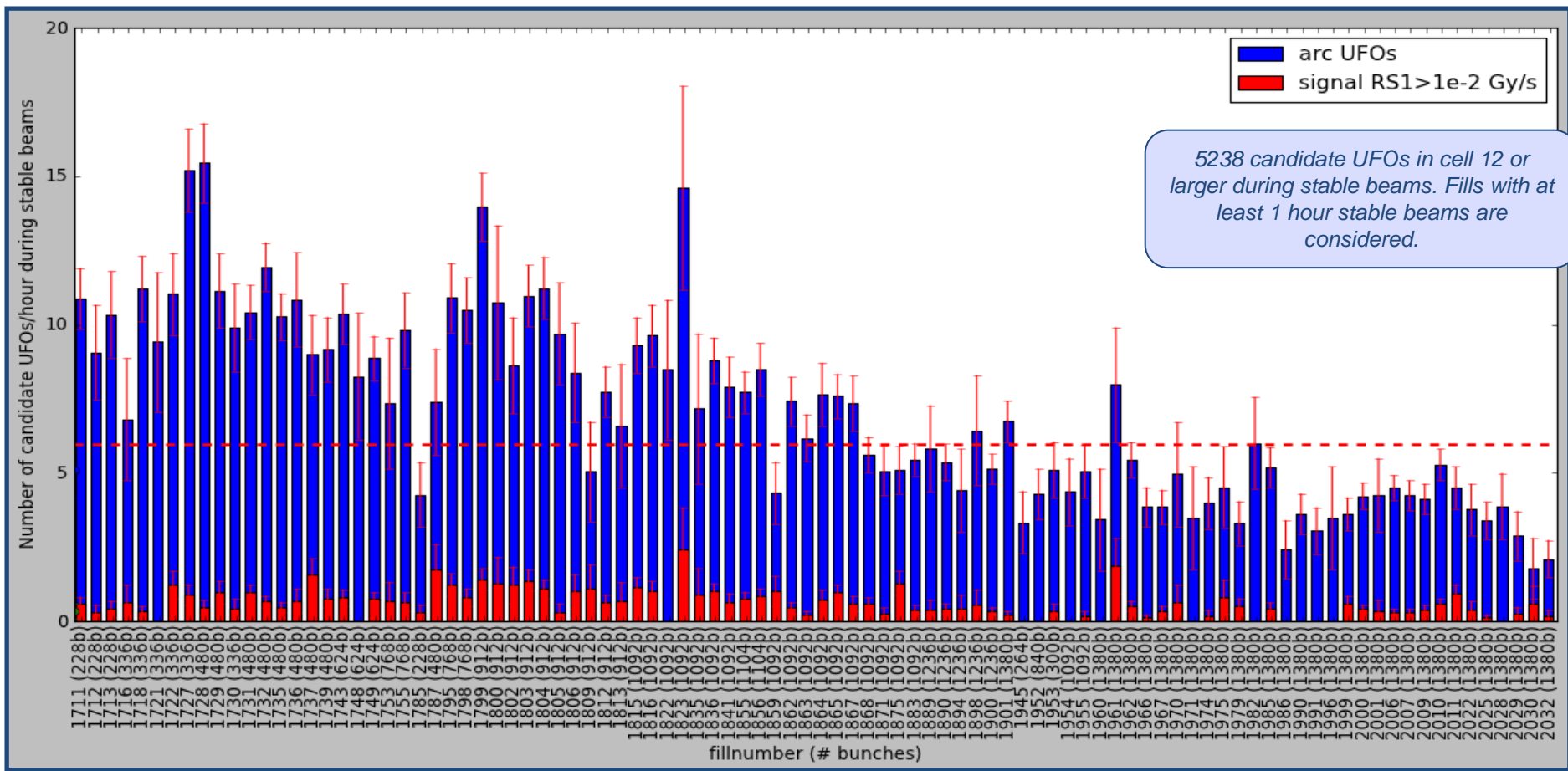
Many UFOs around **injection kicker magnets (MKIs)**.

Mainly UFOs around MKIs

*gray areas around IRs are excluded from UFO detection.*



# UFO rate

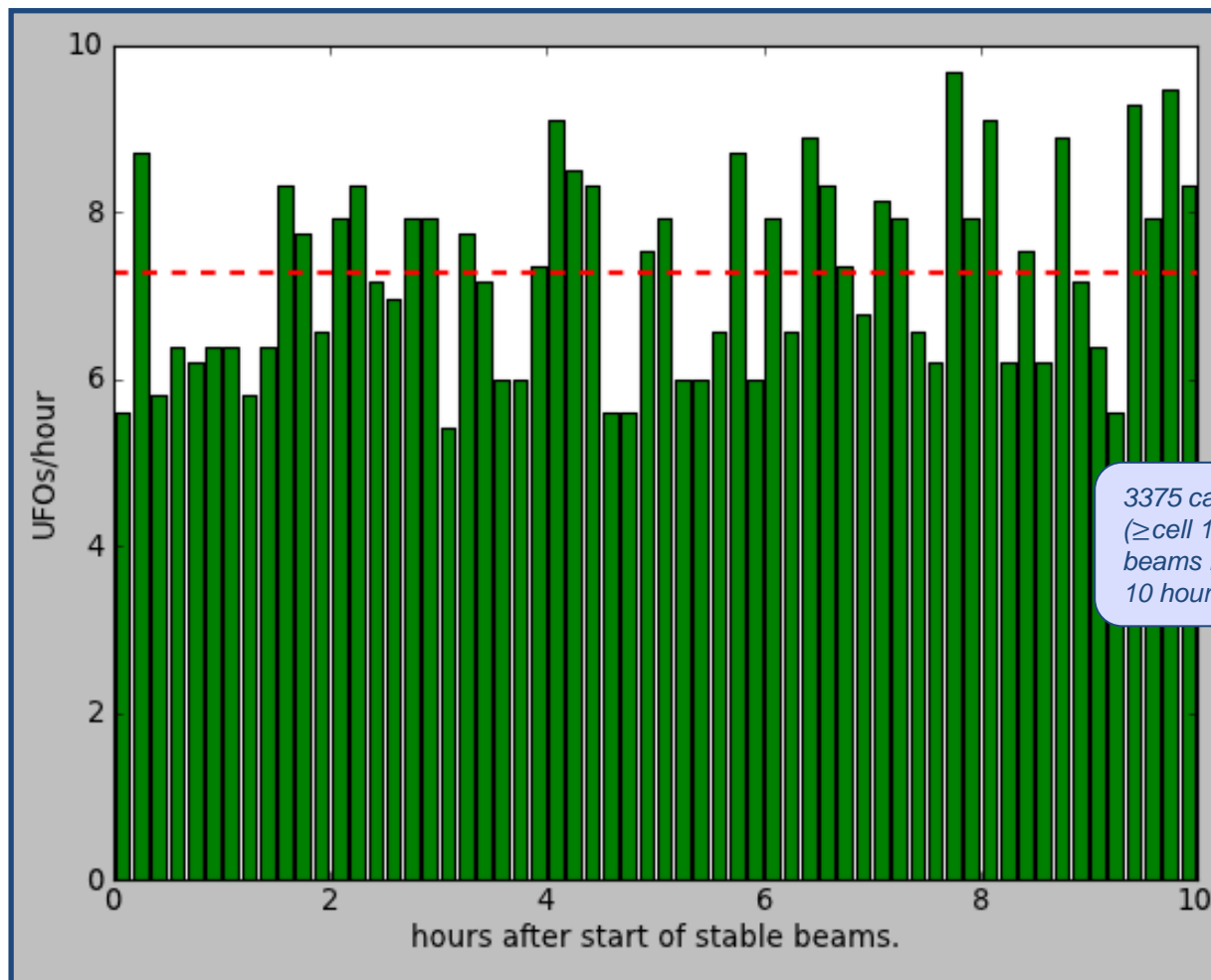


**On average 6.0 UFOs/hour.**

No intensity dependency for above a few hundred bunches.



# Intrafill UFO rate

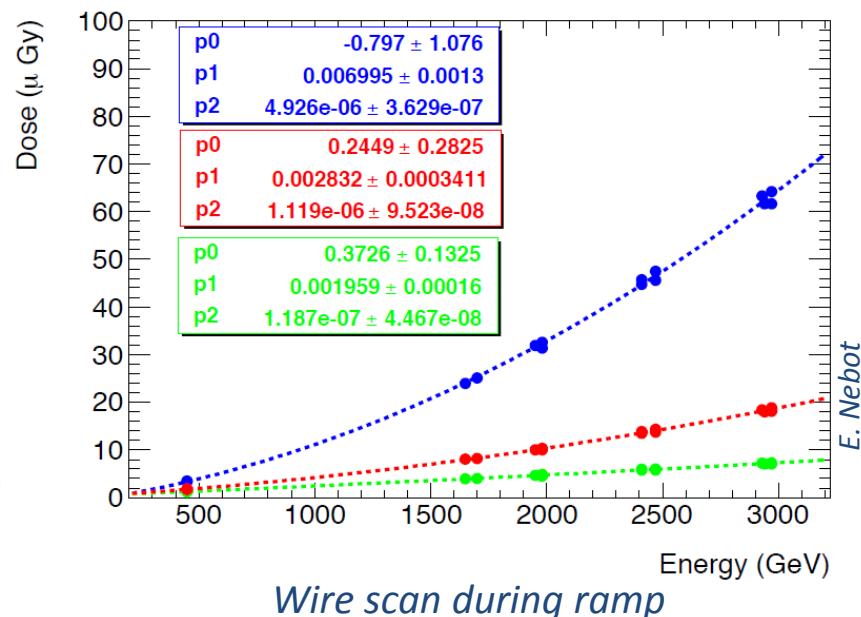


3375 candidate arc UFOs ( $\geq$  cell 12) during stable beams in 31 fills with at least 10 hours stable beams.

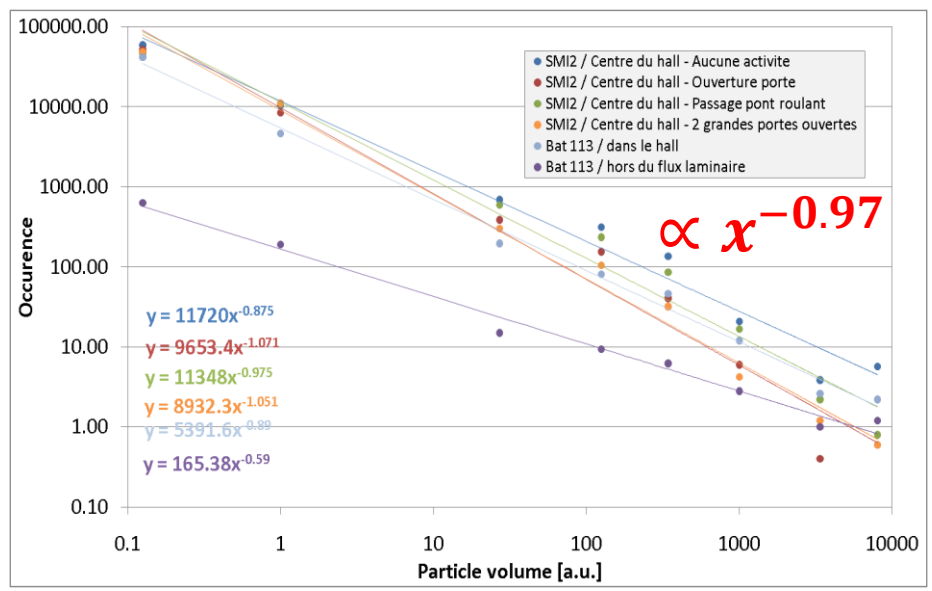
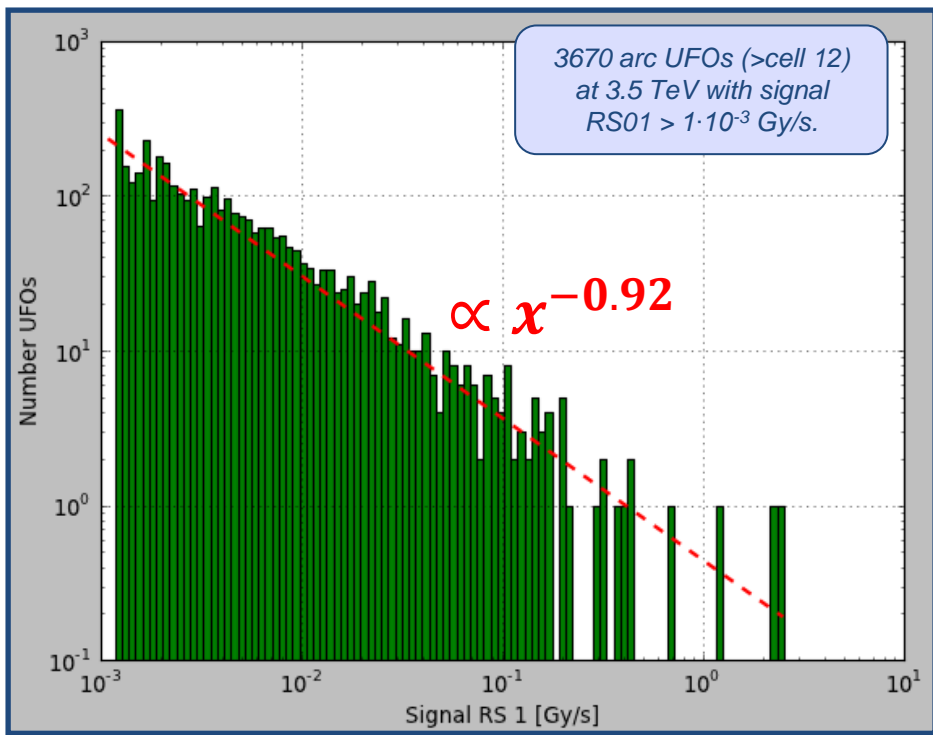
The UFO rate stays constant during a fill.

# Energy Dependency

- **Ufo amplitude:** At 7 TeV about **3 times higher** than at 3.5TeV. (from wire scans). *(E. Nebot, IPAC 2011)*
- **BLM thresholds:** Arc thresholds at 7 TeV are about a **factor 5 smaller** than at 3.5 TeV.
- **UFO rate:** No energy dependency would be competitive with observations. *(E. Nebot, IPAC 2011)*
- **From 2011 data: 82 UFO beam dumps by arc UFOs for 7 TeV** (compared to 2 actual dumps at 3.5 TeV).



# UFOs and Dust Particle Distribution



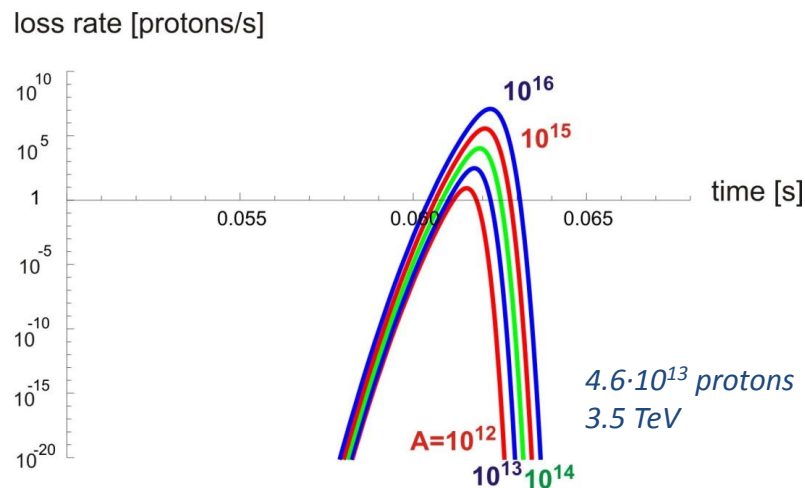
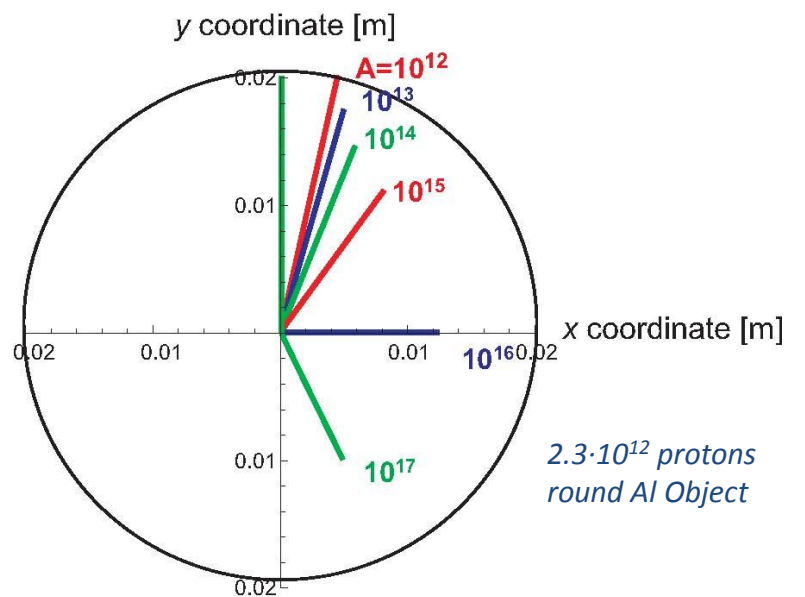
courtesy of  
J. M. Jimenez

The measured  $\frac{1}{x}$  distribution of dust particles in SM12/Bat113 would explain the UFO distribution.

# Dynamics of Dust Particles

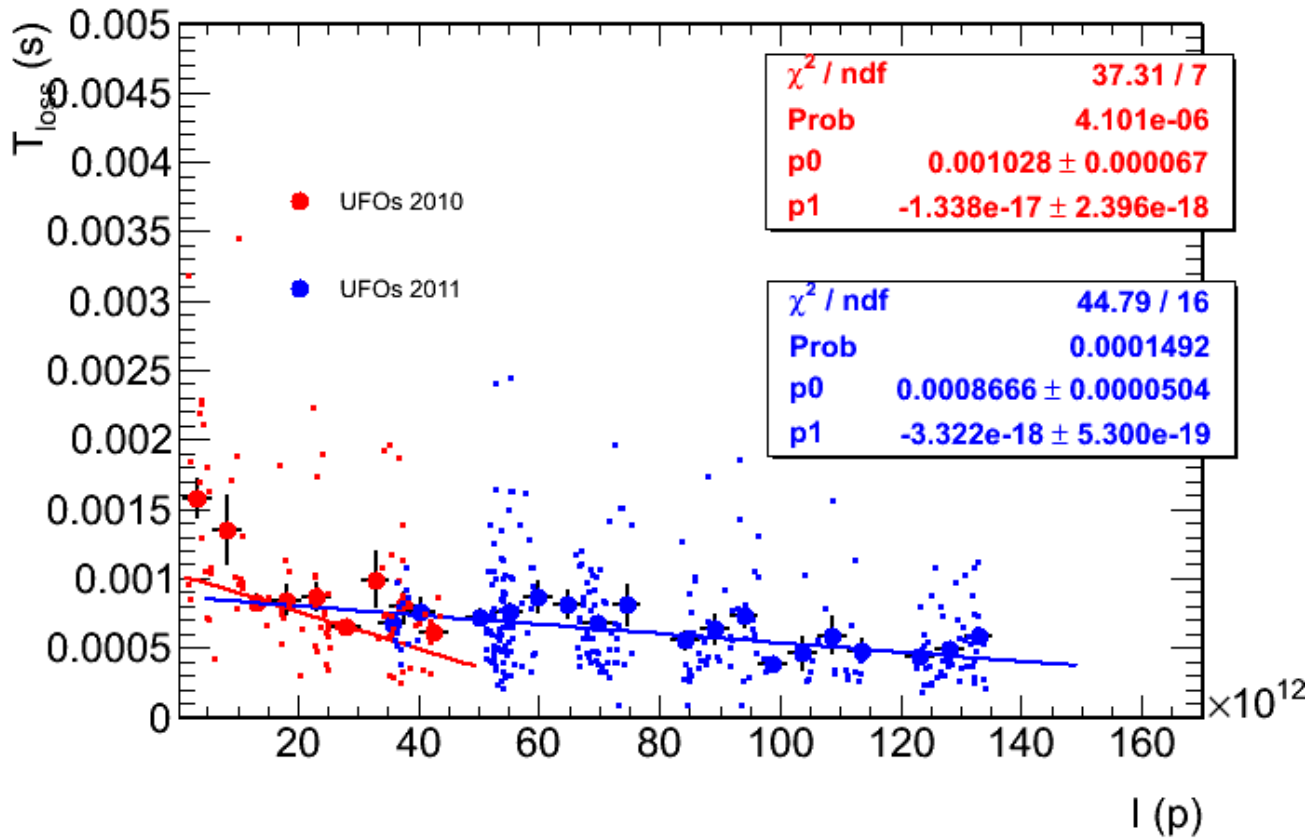
## From simulations:

- Dust particle will be positively ionized and be repelled from the beam.
- Loss duration of a few ms. ✓
- Losses become faster for larger beam intensities. ✓



courtesy of  
F. Zimmermann

# Loss Duration



UFOs have the tendency to become faster with increasing intensity.

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

courtesy of  
E. Nebot



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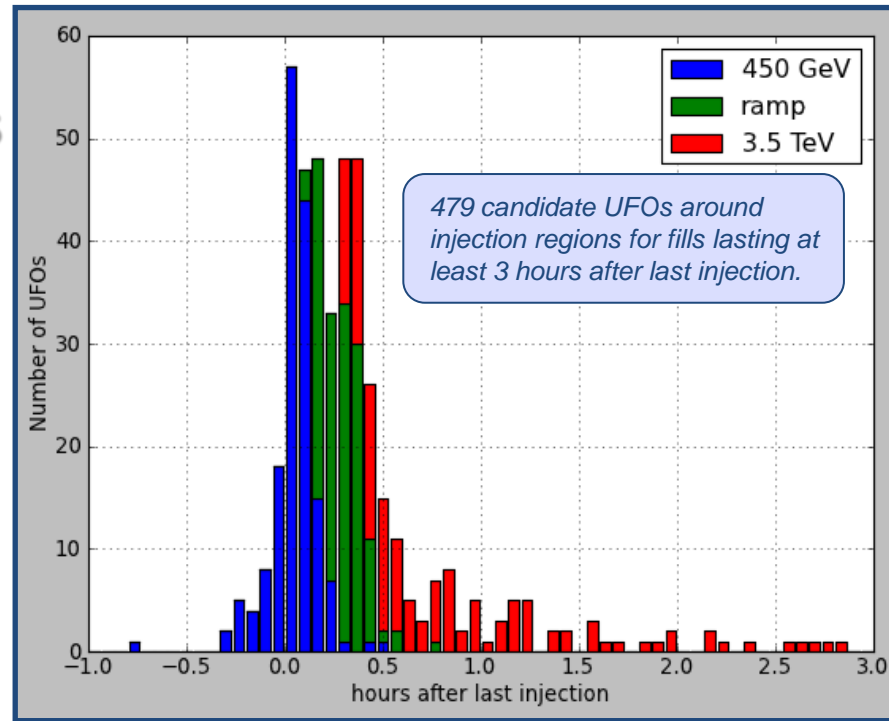
- **13 beam dumps** due to UFOs around the injection kicker magnets (MKIs)

*10 dumps at **MKI.D5L2***

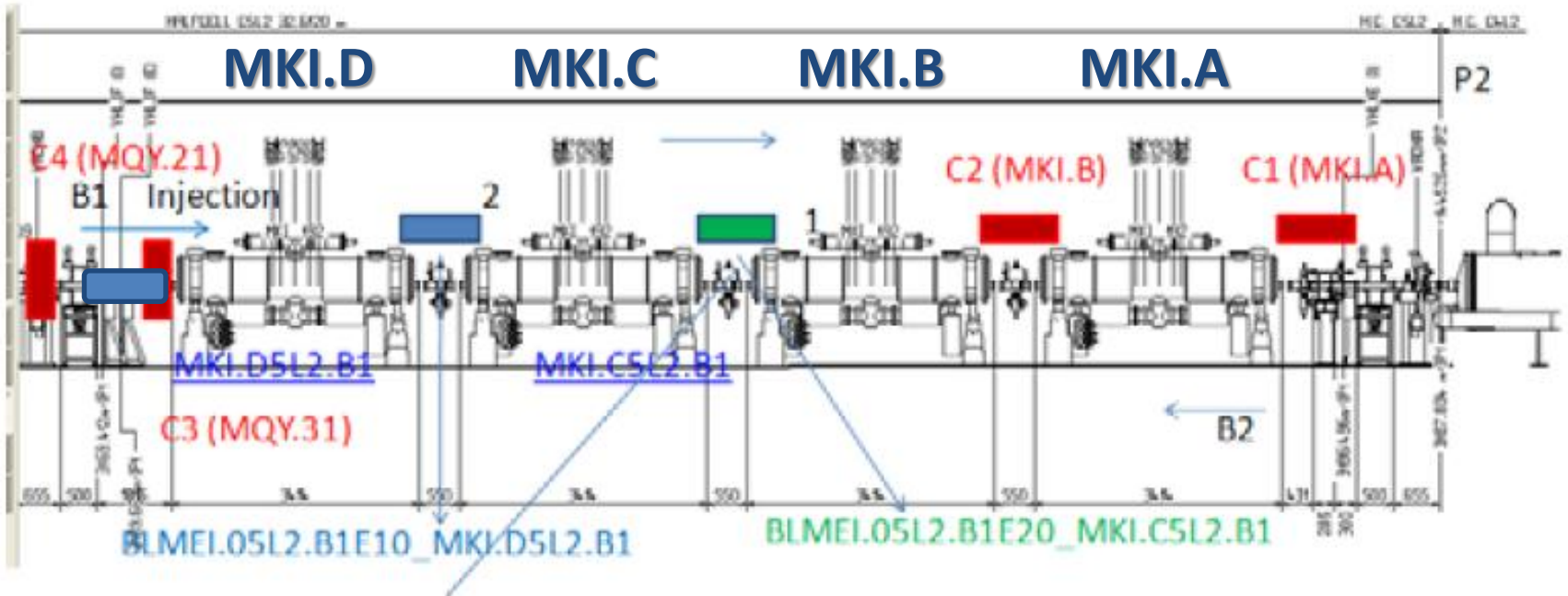
- In total **≈1500 UFOs around MKIs**

*614 in Pt.2 and 874 in Pt.8*

*Most events within 30min after the last injection.*



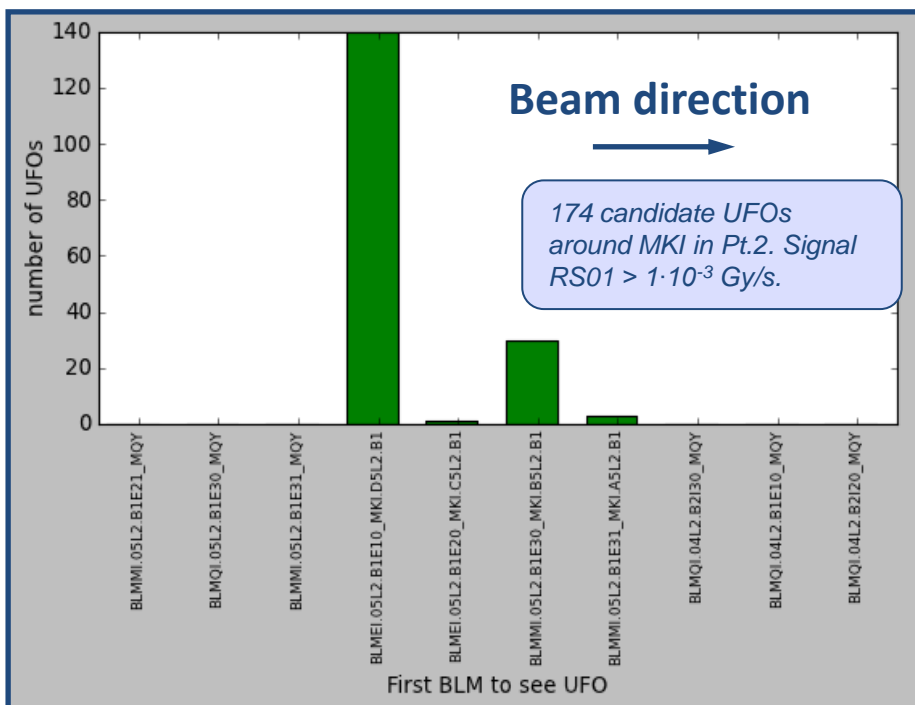
# Layout of MKI Region



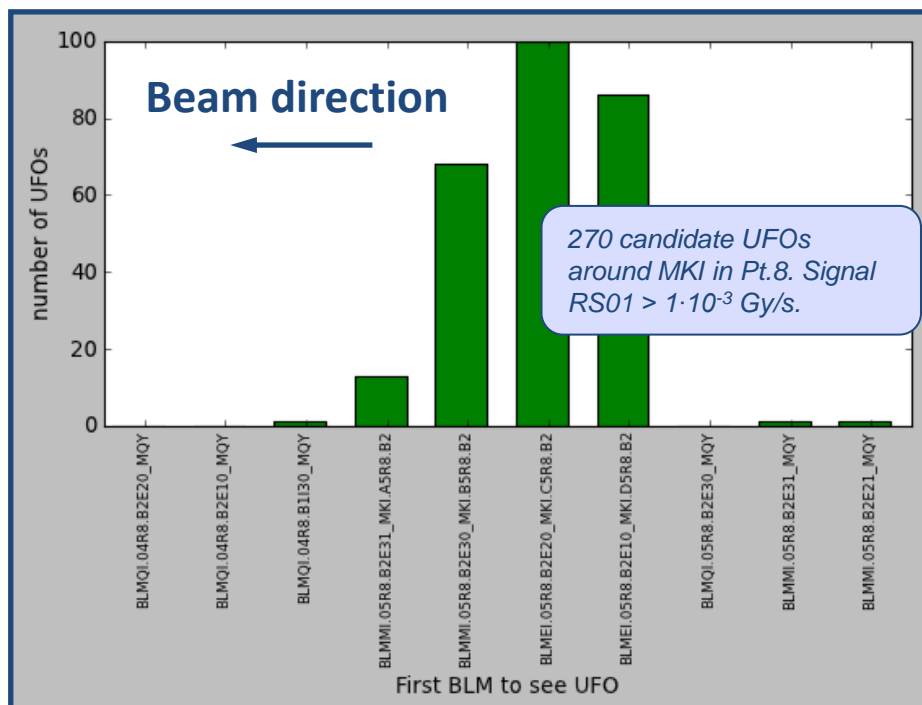


# UFOs at MKIs

- In Pt.2 most MKI UFOs start at the BLM after MKI.D5L2.
- In Pt.8 less UFOs start at the MKI.A5R8.



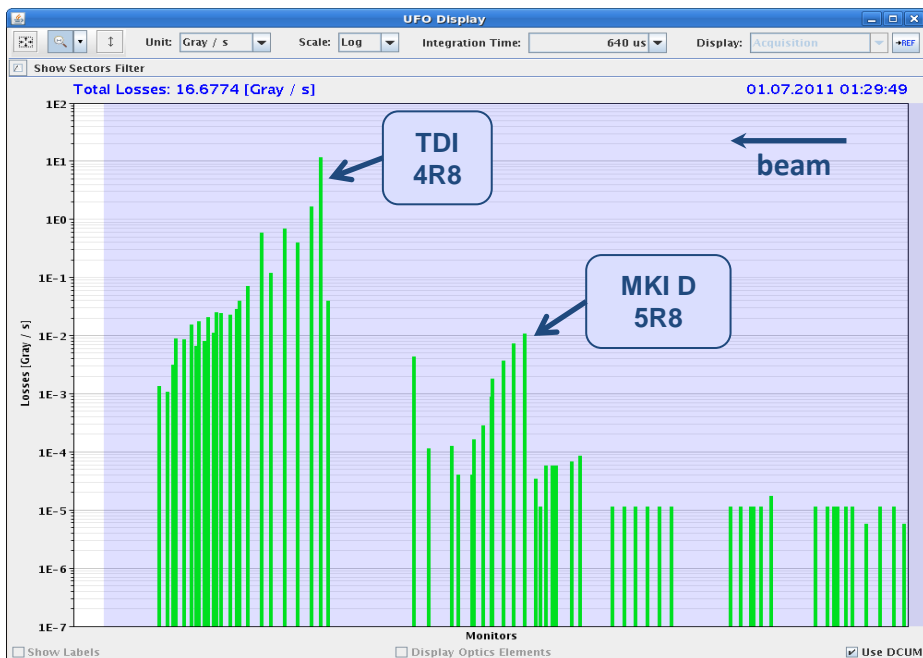
Left of IP2



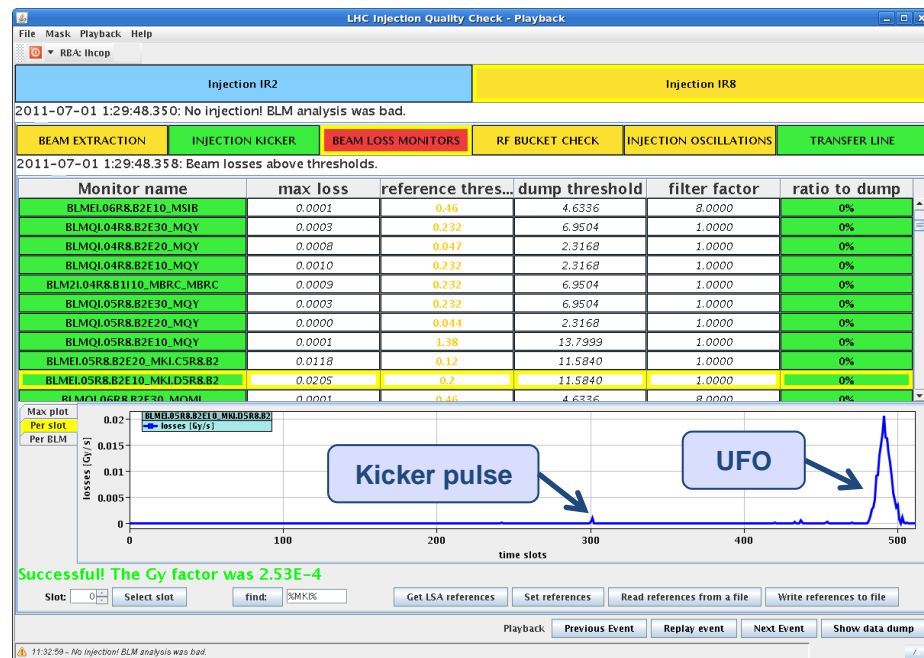
Right of IP8



# MKI UFO MD



*Spatial loss pattern*



*Temporal loss pattern*

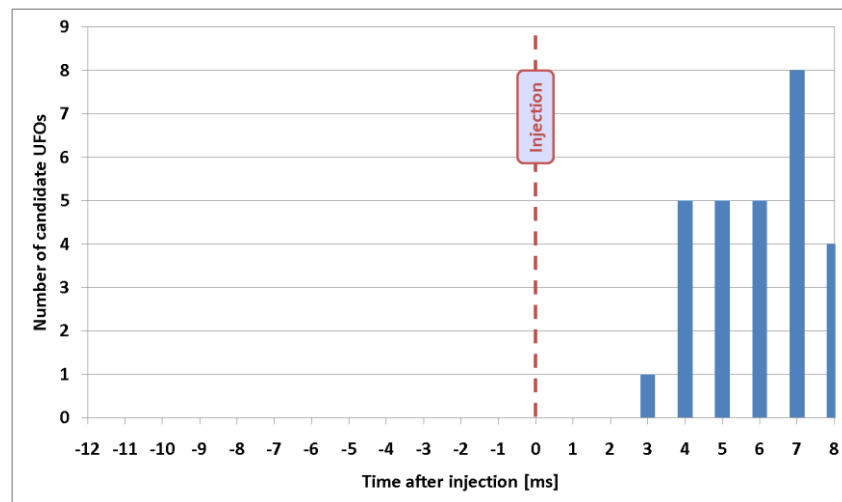
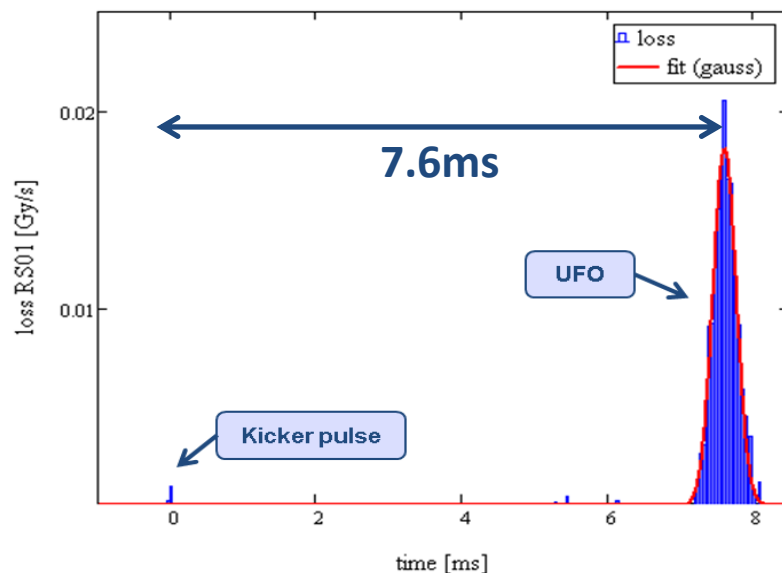
21 pulses of MKIs, 43 UFO type loss pattern observed.

In 17 cases: **UFO type loss pattern within the second of MKI pulse.**

**In 2 cases: UFO recorded by BLM injection capture buffer.**

# UFO Dynamics

- From fit to losses (MKI-D):
  - Amplitude:  **$1.8 \cdot 10^{-2}$  Gy/s**  
(Threshold: 11.6 Gy/s)
  - Temporal Width: **160  $\mu$ s**
  - Time delay to kicker pulse: **7.6 ms**
    - resulting acceleration (constant particle acceleration): **658 m/s<sup>2</sup>**
    - resulting speed during interaction with beam: **5.0 m/s**
- UFO type loss signal observed after many normal injections.





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# Next Steps

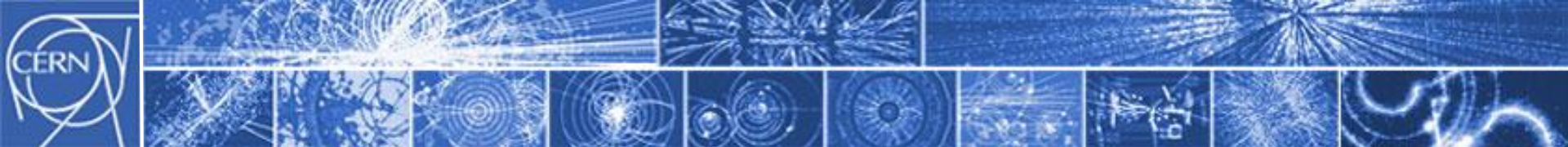
- MKI UFO MD (28.08.).
  - *Study MKI/MKQA UFOs with improved diagnostics and better statistics.*
  - *Study dust particle dynamics.*
- Improve diagnostics (during next TS).
  - *Dedicated turn-by-turn BLM Study Buffer.*
  - *Improved BLM data logging.*
- FLUKA simulations on MKI UFOs.
- Open MKI and search for dust particles.
- Dust particle dynamics model.
- Better understanding of Quench Limit.
- **Mitigation:** Further increase of BLM thresholds...
  - *But: Do we have enough margin at higher energies?*





# Summary and Conclusion

- **17 beam dumps** due to UFOs in 2011 so far (18 in 2010).
- **Over 10000 candidate UFOs** below threshold detected.  
*On average 6.0 UFOs/hour during stable beams in the arcs.  
Micrometer sized macroparticles are the most plausible explanation.*
- Many UFOs around injection kicker magnets.  
*Many MKI UFOs observed directly after kicker pulsing/injection.*
- Observations show an **aggressive scaling with beam energy!**  
*Situation could be significantly worse above 3.5TeV.  
Intermediate energy step would be very helpful for extrapolations to nominal energy.*
- Large effort underway to understand UFO mechanism.  
*Measurements in LHC, lab measurements, simulations, theories.*



# Thank you for your Attention

**Tobias Baer**

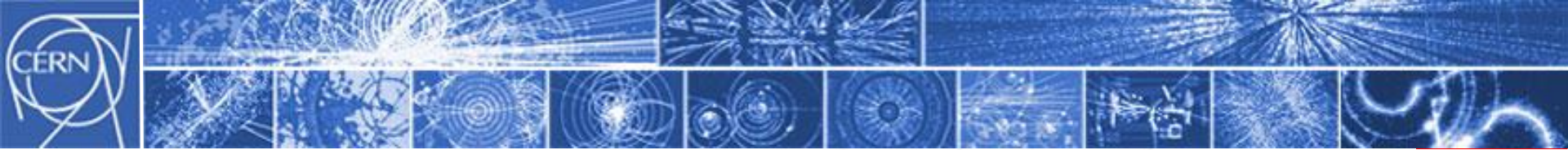
CERN BE/OP

Tobias.Baer@cern.ch

Office: +41 22 76 75379

## Further information:

- T. Baer, "UFO update", Mini-Chamonix Workshop, July 2011.
- R. Ballester, "Vibration analysis on an LHC kicker prototype for UFOs investigation", EDMS Report No. 1153686, August 2011.
- M. Sapinski, "Is the BLM system ready to go to higher intensities?", Workshop on LHC Performance, Chamonix, Jan. 2011.
- F. Zimmermann, "Interaction of macro-particles with the LHC proton beam", IPAC'10.



# Backup slides





# Content

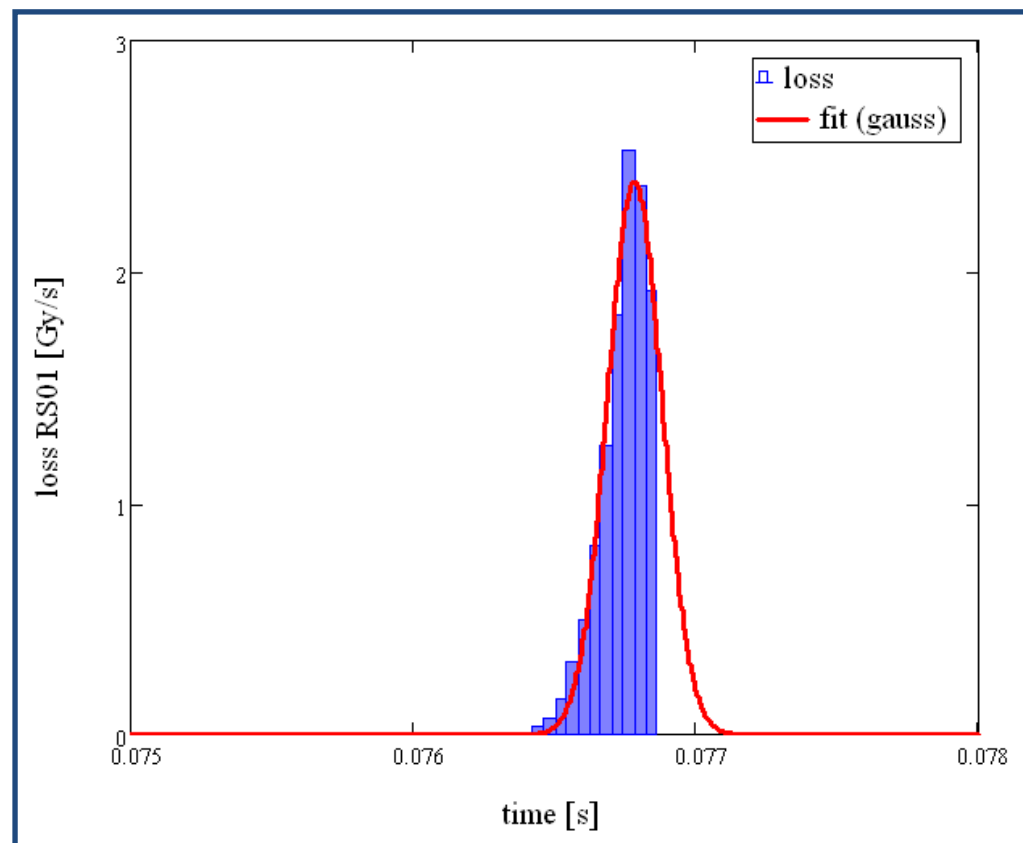
**UFO Dumps 2010/2011**

# Beam dump on 29.05.2011



Dump on running sum 1-6.

- From fit to losses  
(BLMQI.28L8.B1E10\_MQ):
  - Amplitude: **2.4 Gy/s**  
*(Threshold: 2.1 Gy/s)*
  - Temporal Width: **97  $\mu$ s**  
resulting speed of  
transiting dust particle  
= **3.6 m/s.**  
(assuming  $\epsilon^n = 2.5 \mu\text{m} \cdot \text{rad}$ )



*(also cf. J. Wenninger at MPP March 2011)*

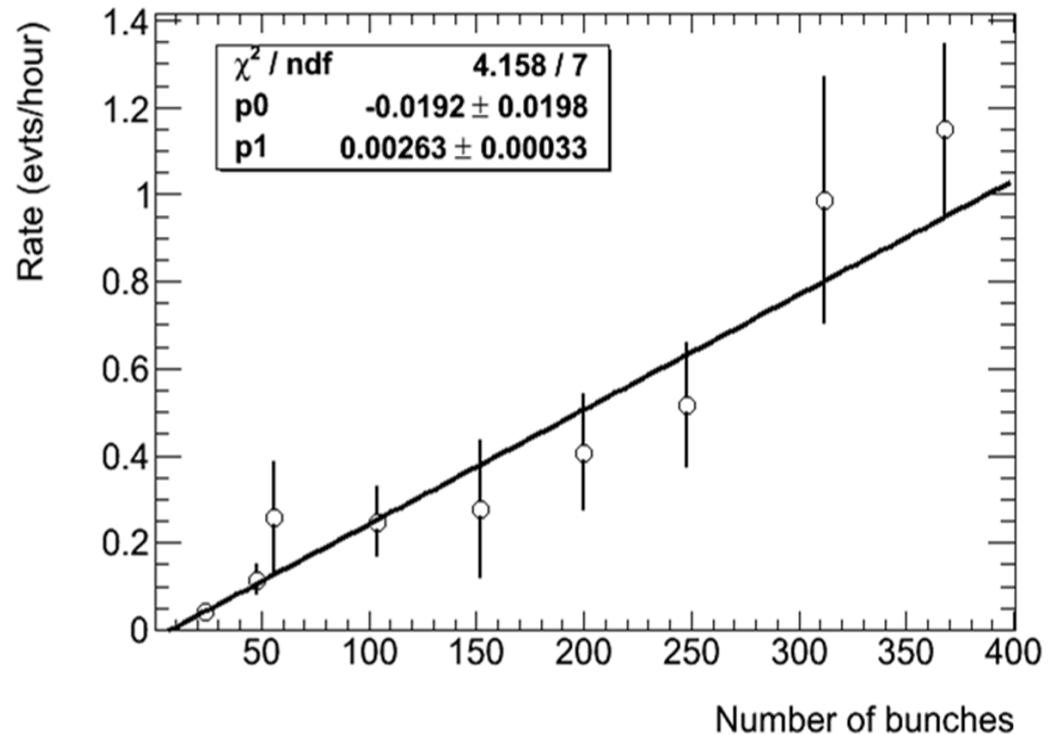


# Content

## UFO Observations and Studies

# Event Rate 2010

- 113 events below threshold found in 2010.  
*(E. Nebot)*
- **UFO rate**: proportional to beam intensity.



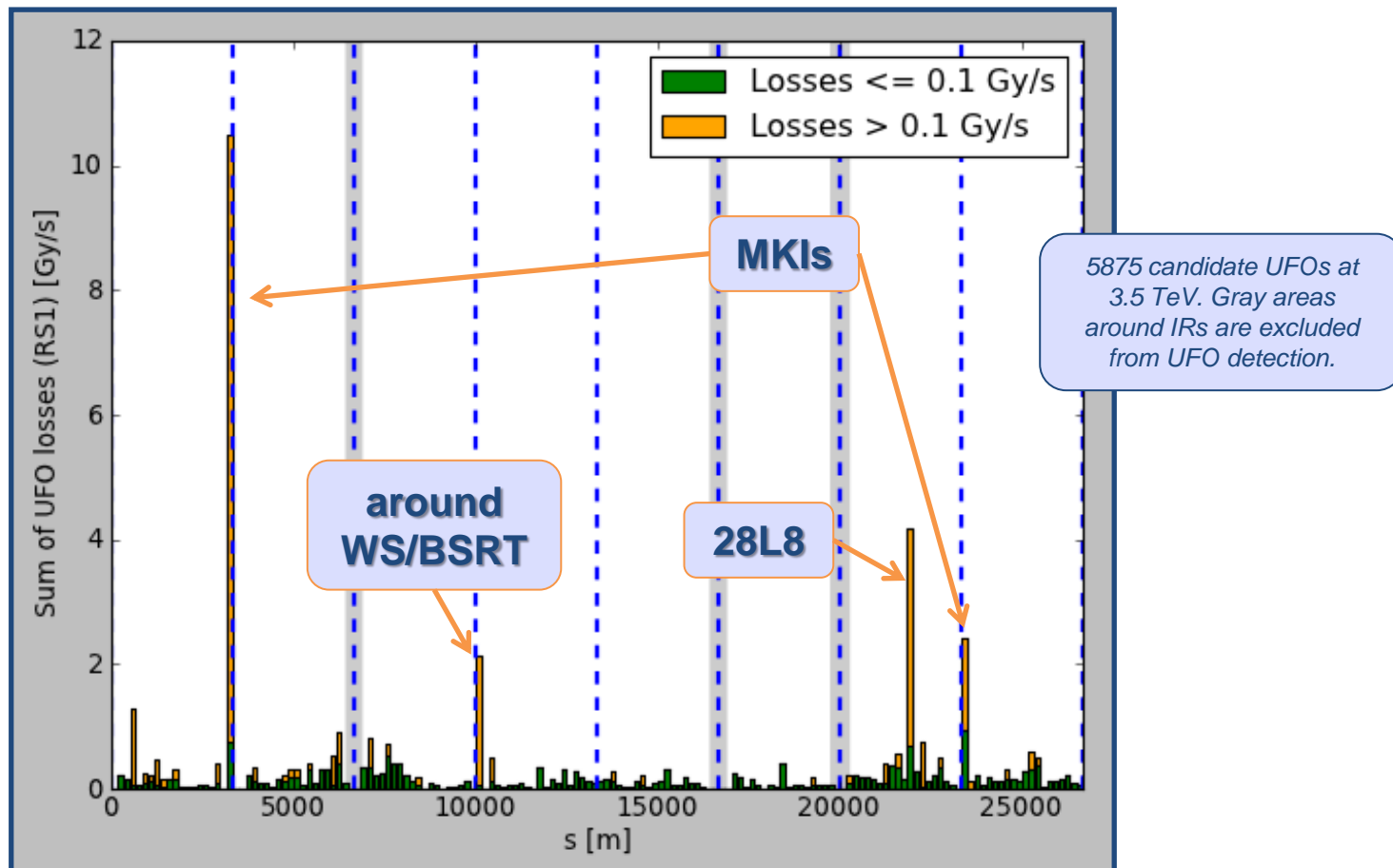
courtesy of  
E. Nebot



# UFOs Detection in 2011

- 2010: 113 UFOs below threshold found in logging database. (E. Nebot)
- 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 10000 triggers** so far.
  - From subset of about 300 manually verified triggers:
    - About 65% are UFOs, 15% ambiguous cases, 20% are false triggers.*
  - For most analysis additional cut. E.g.:
    - Only flat top UFOs, loss of UFO BLM (RS05) >  $2 \cdot 10^{-4}$  Gy/s ( $\approx 2$  % of threshold).*
    - 74 events remain of subset, of which 71 are clear UFOs (96%) and 3 are ambiguous cases.*

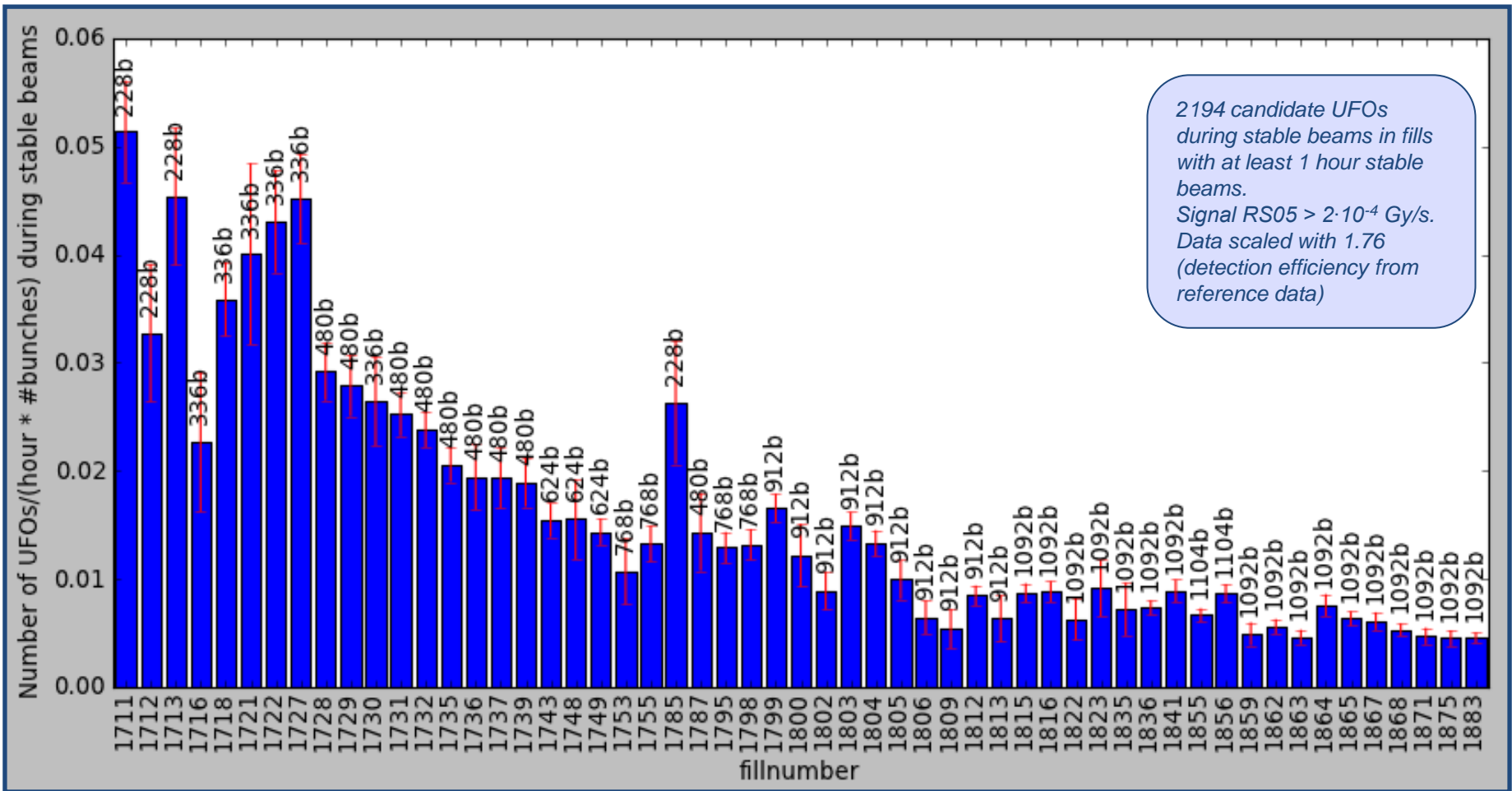
# Weighted Spatial UFO Distribution



The weighted spatial distribution is dominated by a few large amplitude UFOs.



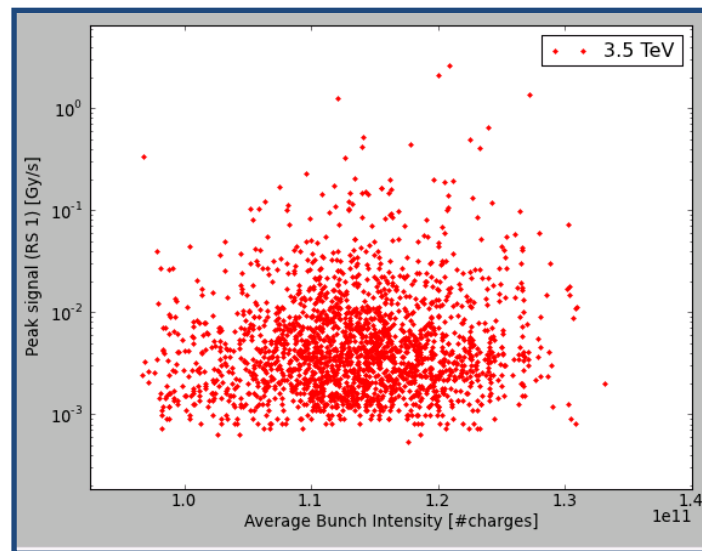
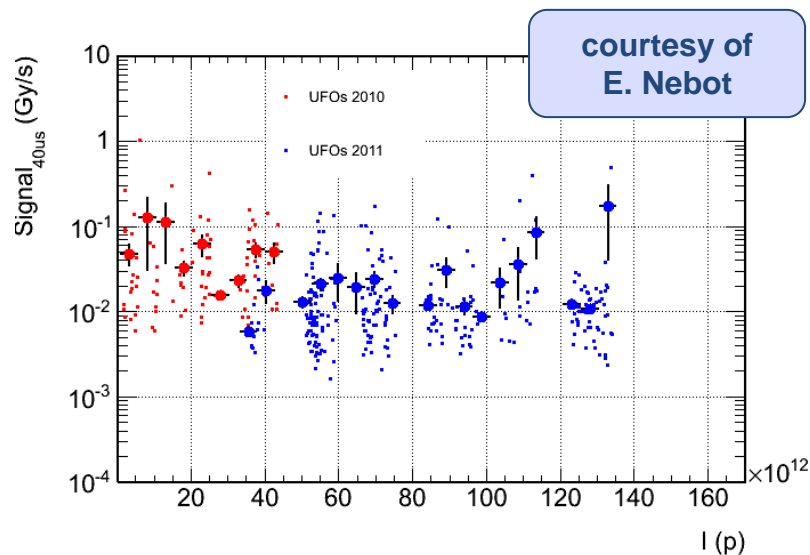
# Normalized UFO rate



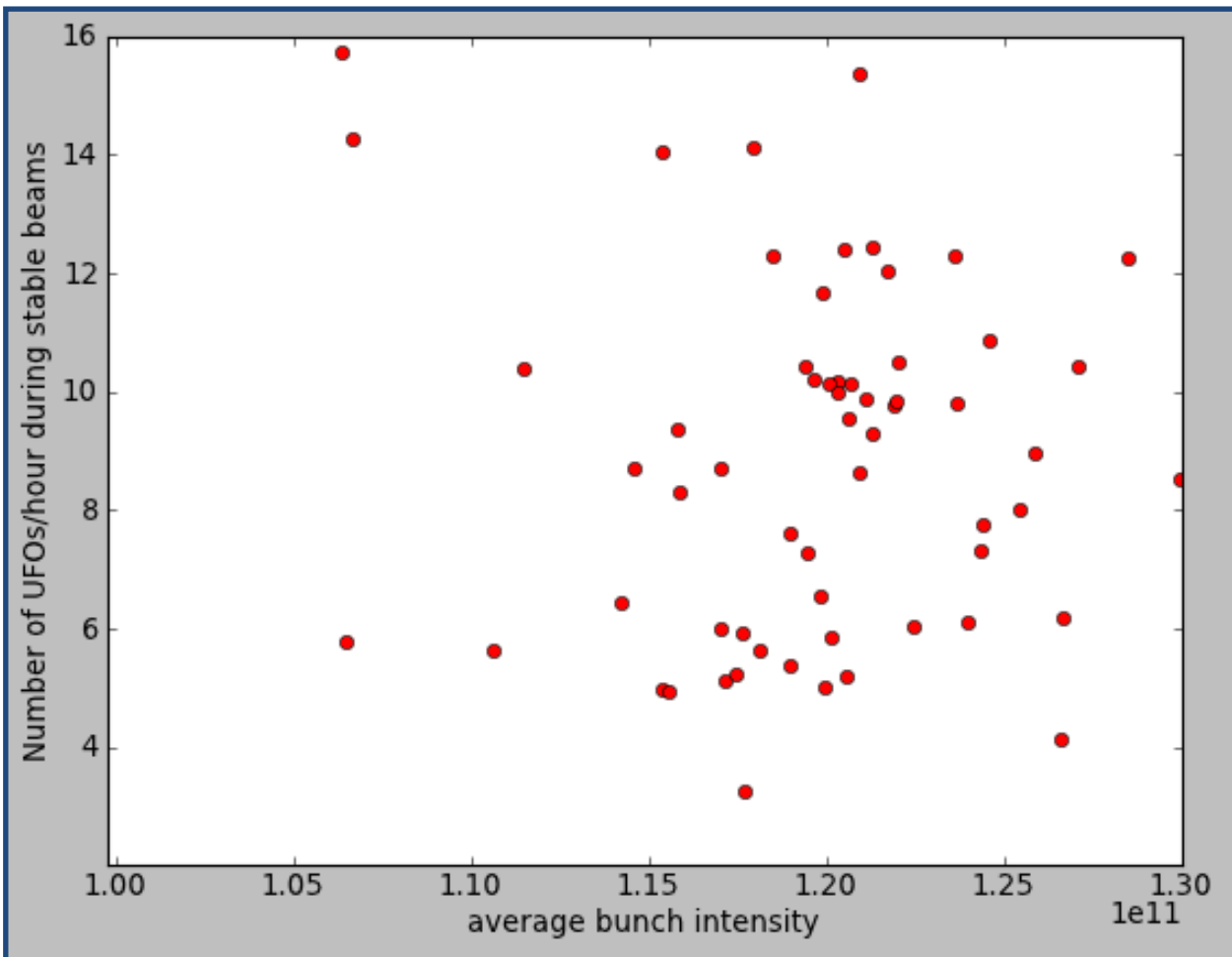


# Peak Signal

- No clear dependency of peak loss on intensity.  
*(cf. E.B. Holzer at Evian Dec. 2010)*
- No clear dependency of peak loss on bunch intensity.

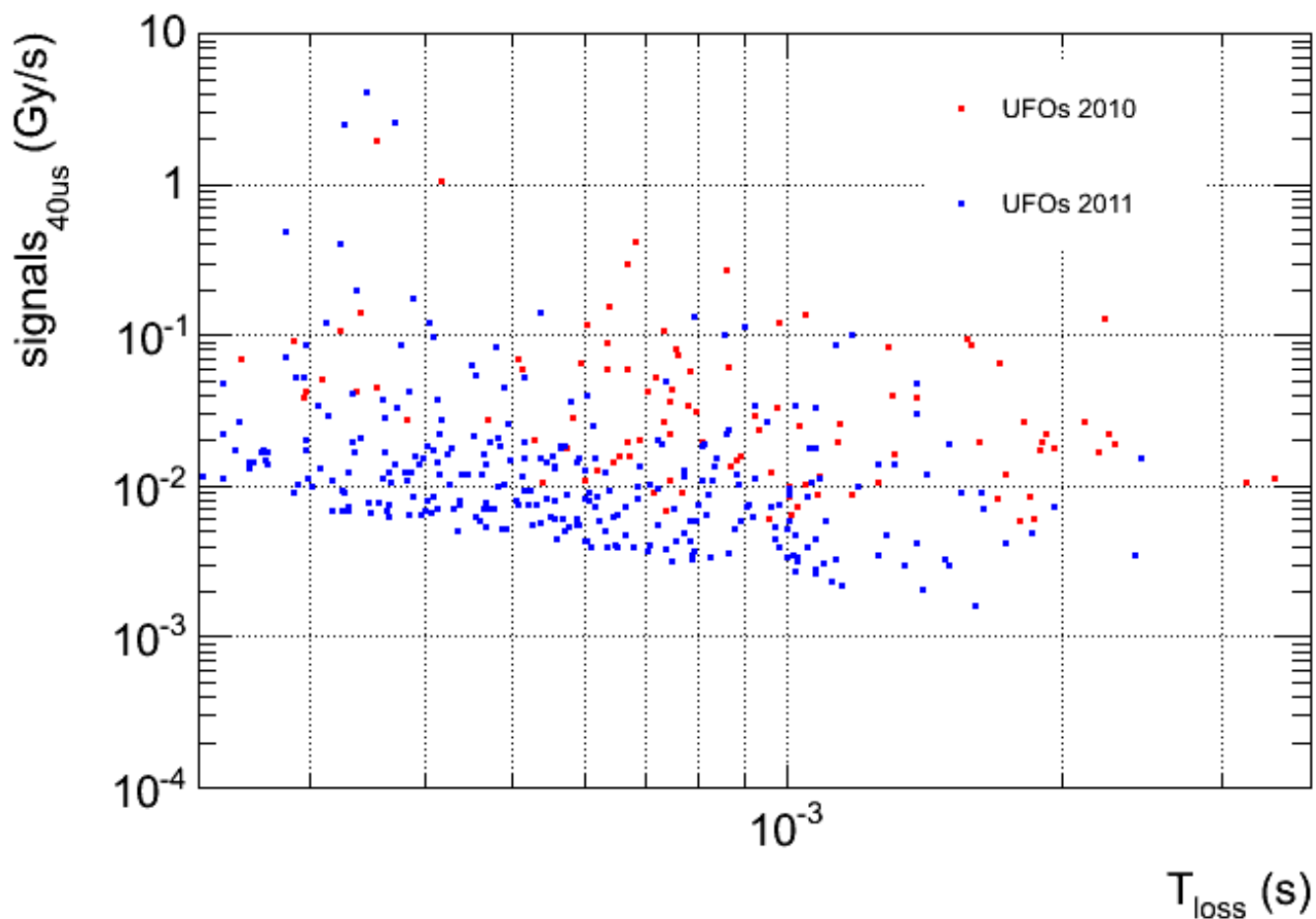


# UFO rate vs Bunch Intensity



No dependency of UFO rate on bunch intensity.

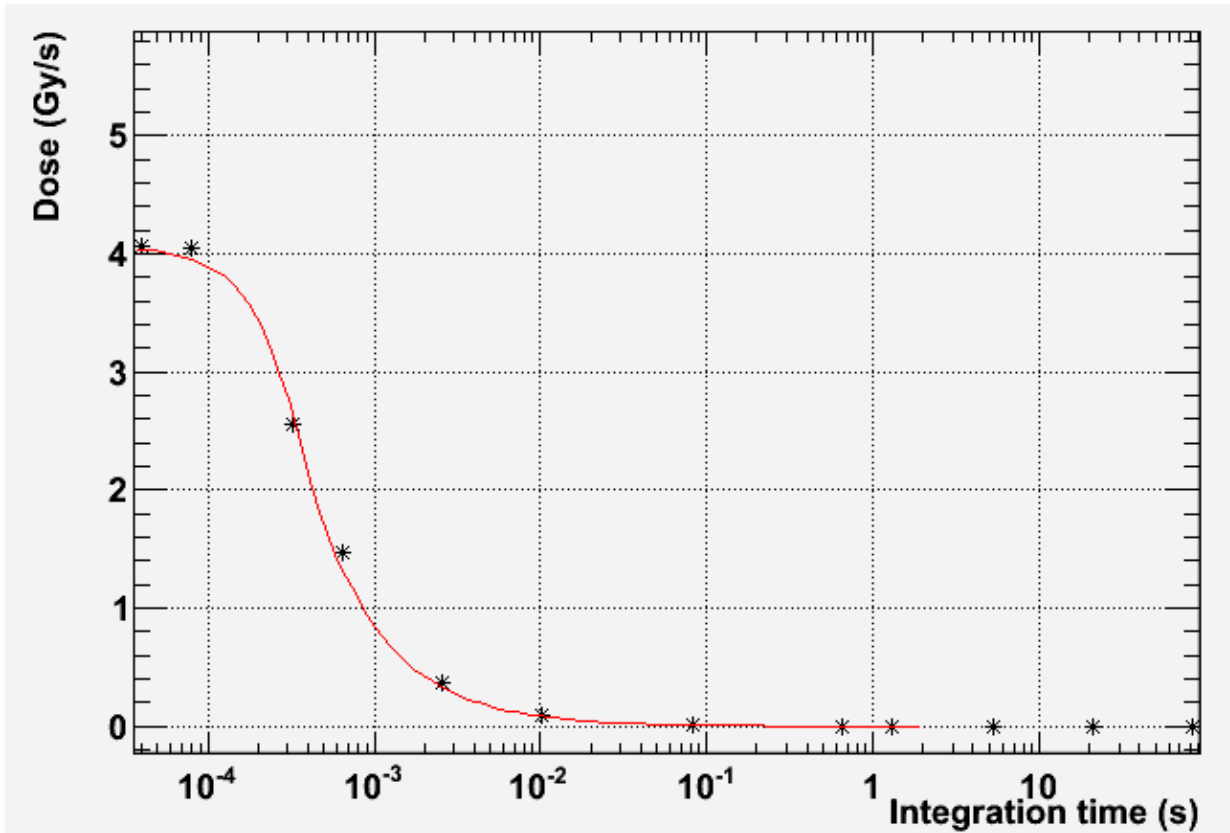
# Peak Signal vs Loss Duration



Tendency that harder UFOs are faster.

courtesy of  
E. Nebot

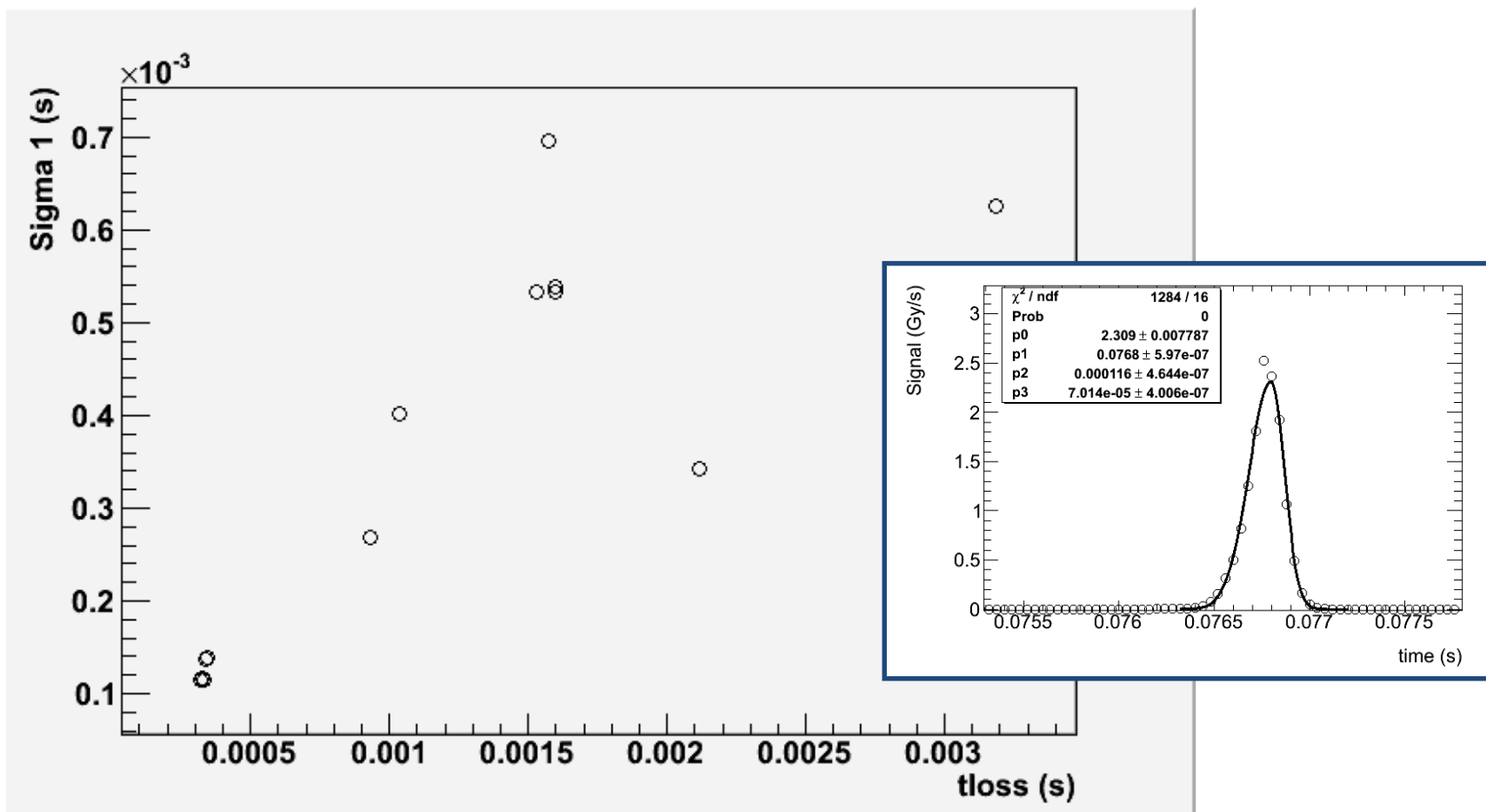
# Loss Duration



$T_{loss}$ : Given by fitting single function  
(Gaussian up to  $t=T_{loss}$ ,  $1/t$  afterwards) to data.

courtesy of  
E. Nebot

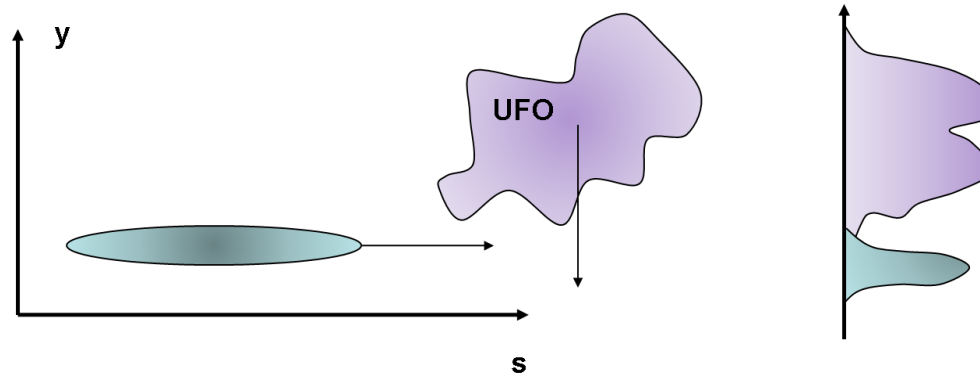
# Calibration of $T_{loss}$



Correlation of  $T_{loss}$  and width of Gaussian fitted to post mortem turn-by-turn data.

courtesy of  
E. Nebot

# 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  $\approx 1 \mu\text{m}$ .  
 (cf. M. Sapinski, F. Zimmermann at Chamonix 2011)

courtesy of  
 J. Wenninger  
 (cf. MPP 25.03.2011)

# UFO Speed

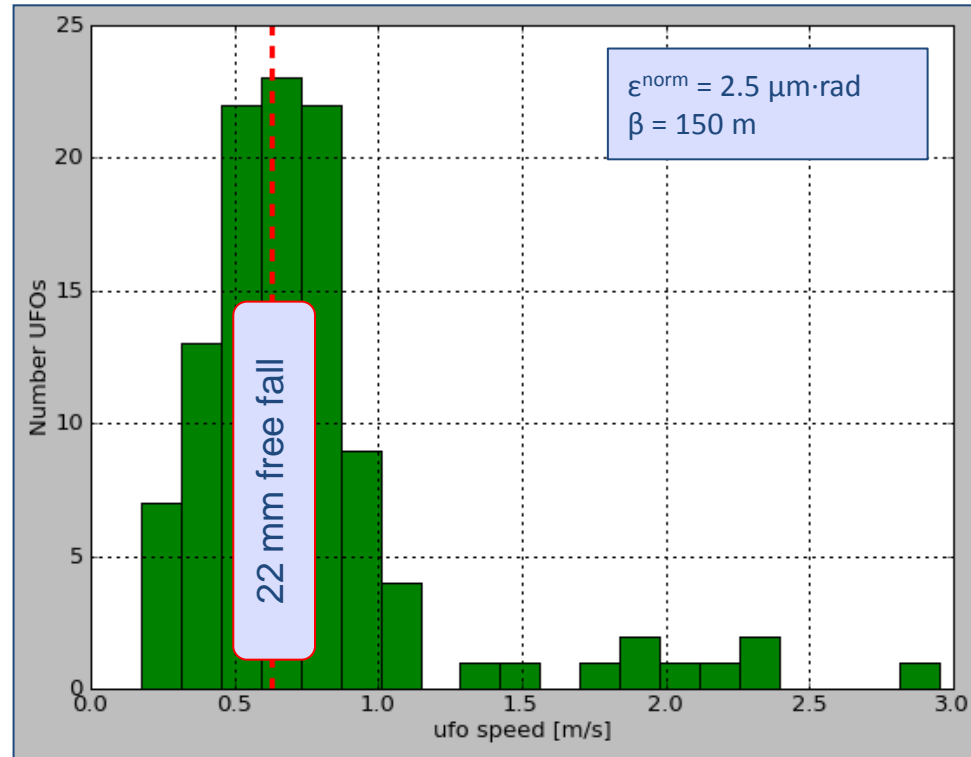
- UFO speed:

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

$v_U$ : UFO speed,  $\sigma_b$ : transverse beam size,  $\sigma_U$ : UFO size,  $\sigma_T$ : 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.*

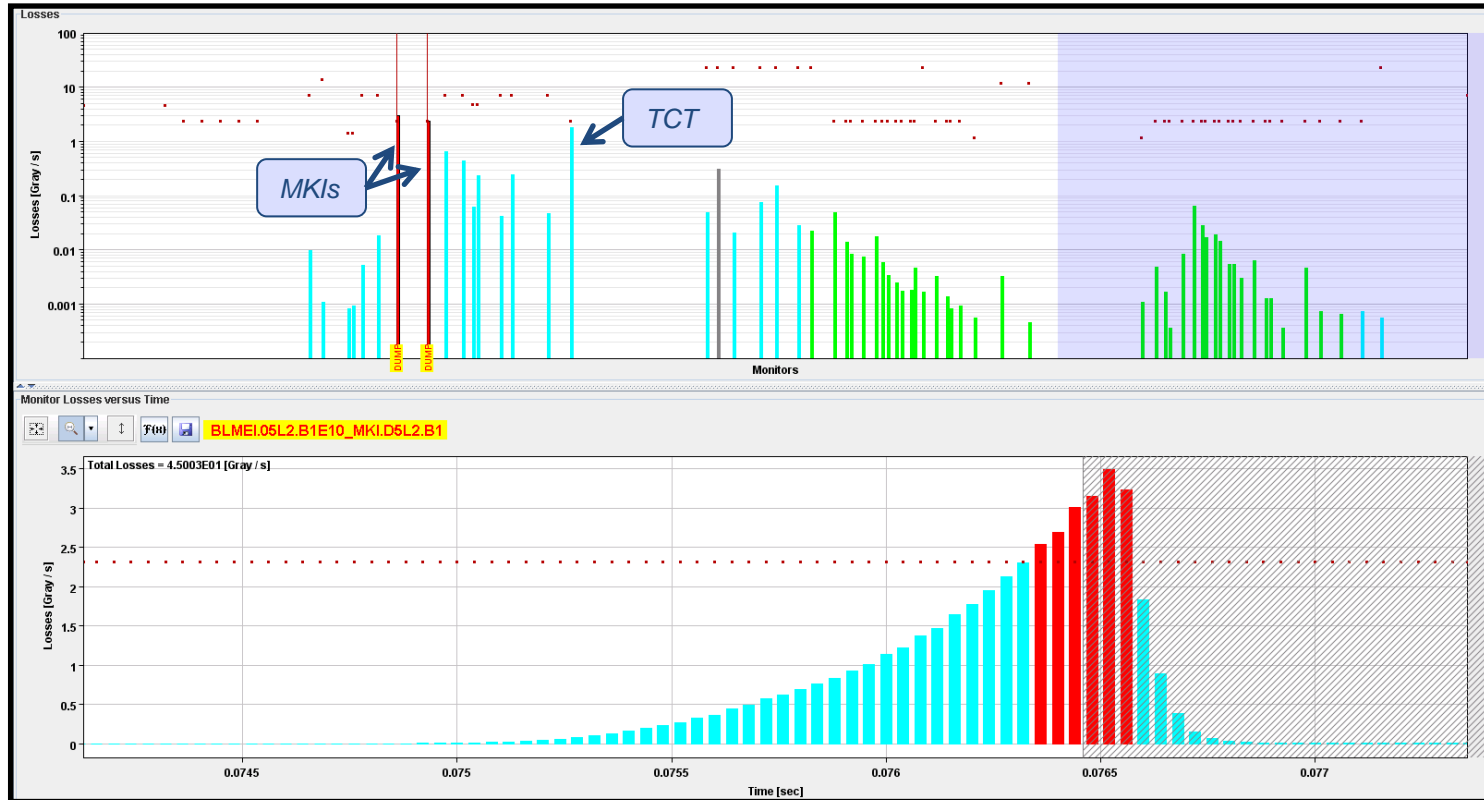


# Content

**UFOs around MKIs**



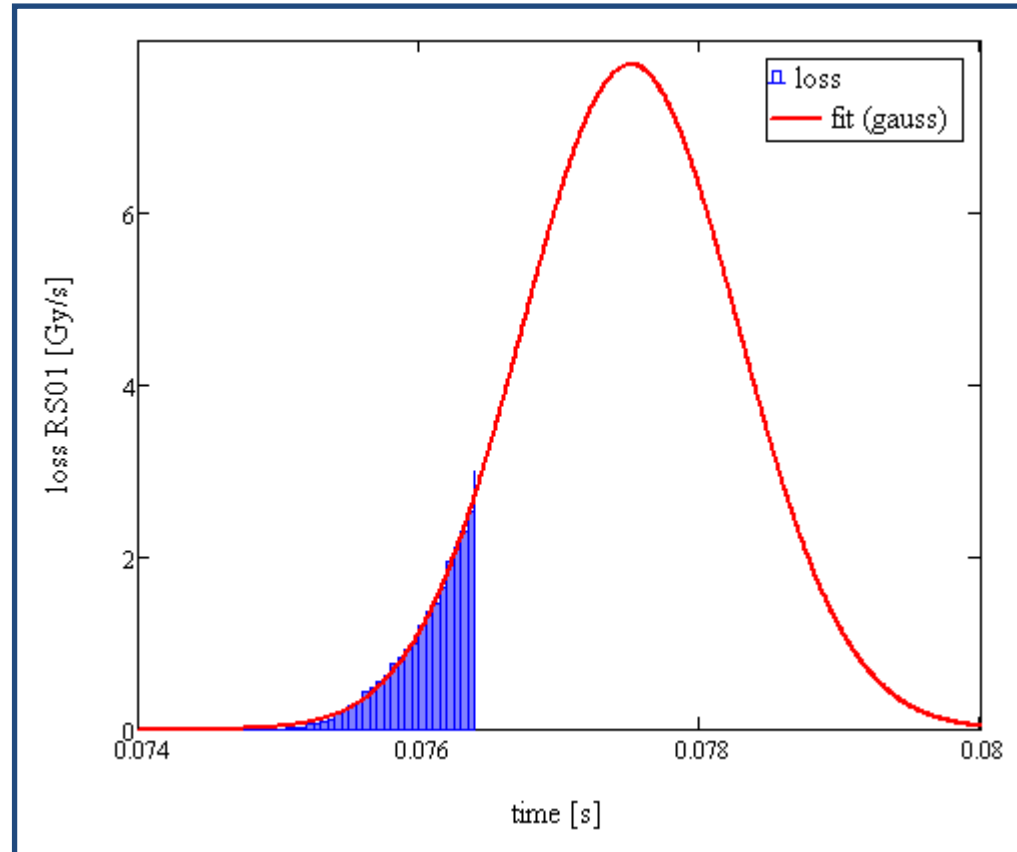
# Beam dump on 6.6.2011



UFO at MKI in Pt. 2, at **450 GeV**.  
Small loss signal at Q5 (backscattering?).

# Beam dump 06.06.2011

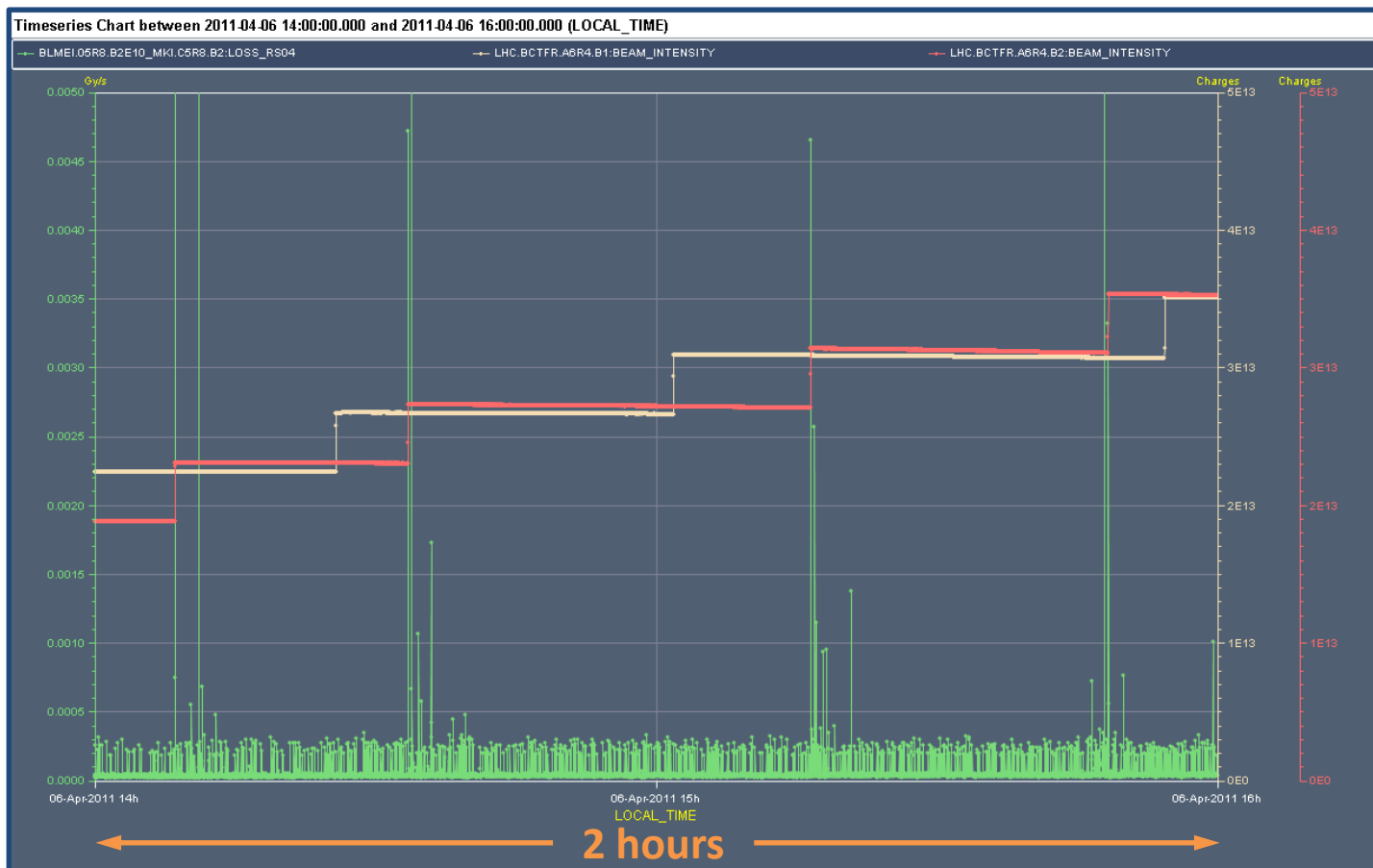
- From fit to losses  
(BLMEI.05L2.B1E10\_MKI.D5L2.B1):
  - Amplitude: **7.73 Gy/s**  
*(Threshold: 2.3 Gy/s)*
  - Width: 0.77 ms  
resulting speed of  
transiting dust particle  
= **0.47 m/s.**  
(assuming  $\epsilon^n = 2.2 \mu\text{m} \cdot \text{rad}$ )  
*(Brennan Goddard)*





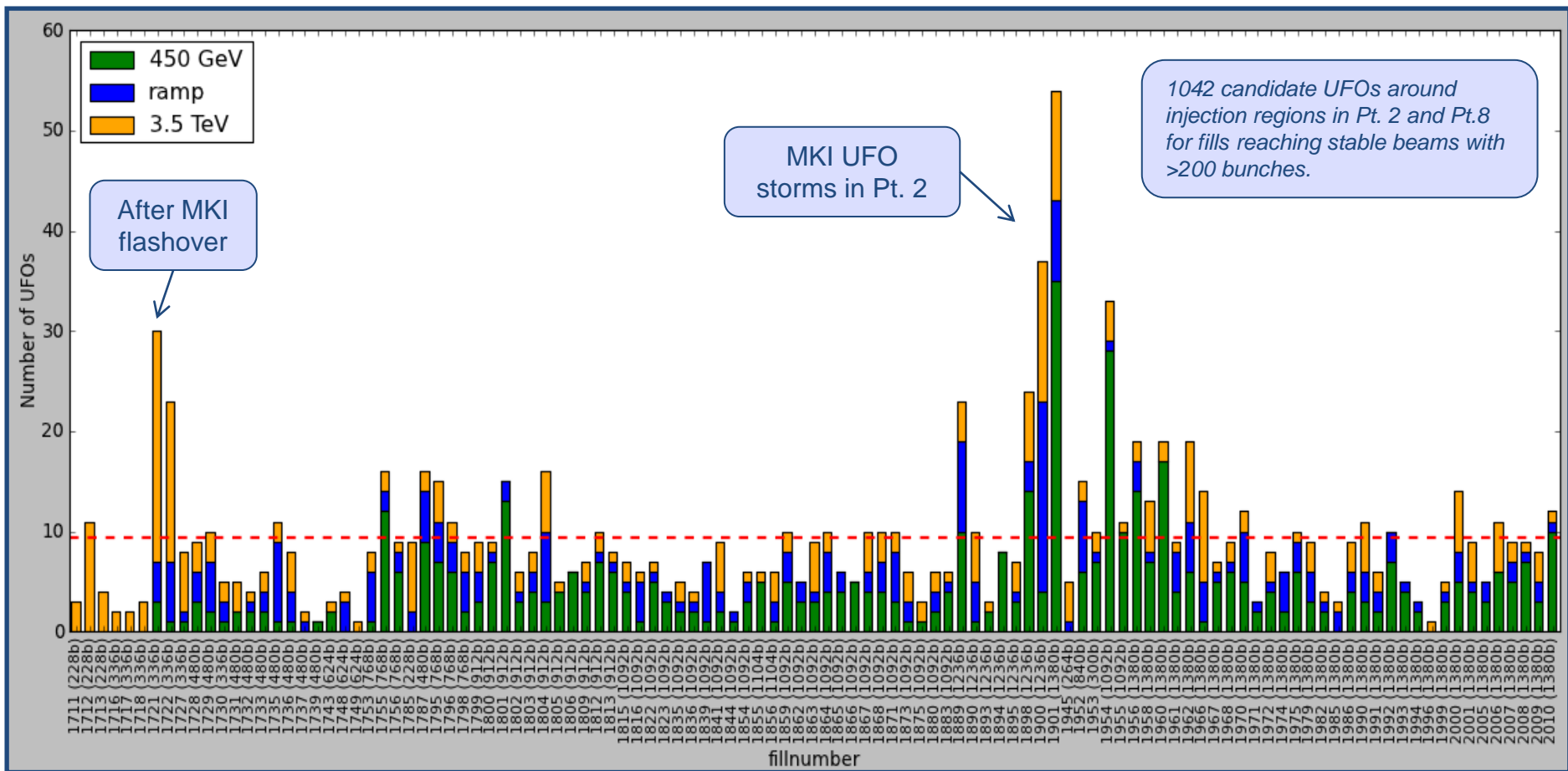
# MKI UFOs During Scrubbing

- Typical scenario for MKI UFOs during scrubbing: The MKI UFO rate is increased for about 10 minutes after each injection.





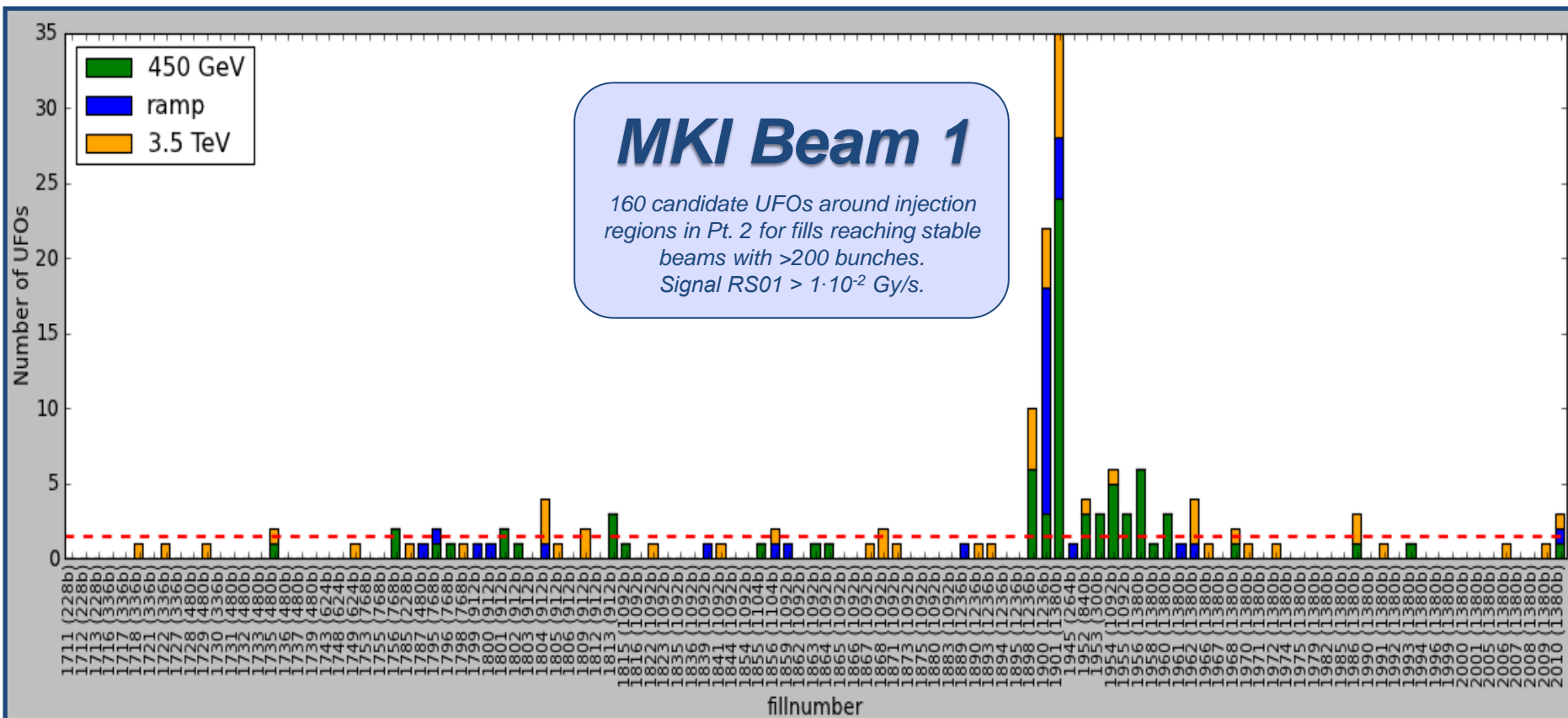
# Number of MKI UFOs



On average: **9.4 MKI UFOs per fill** (5.4 at MKI.L2 and 3.9 at MKI.R8).



# Number of Large MKI UFOs B1



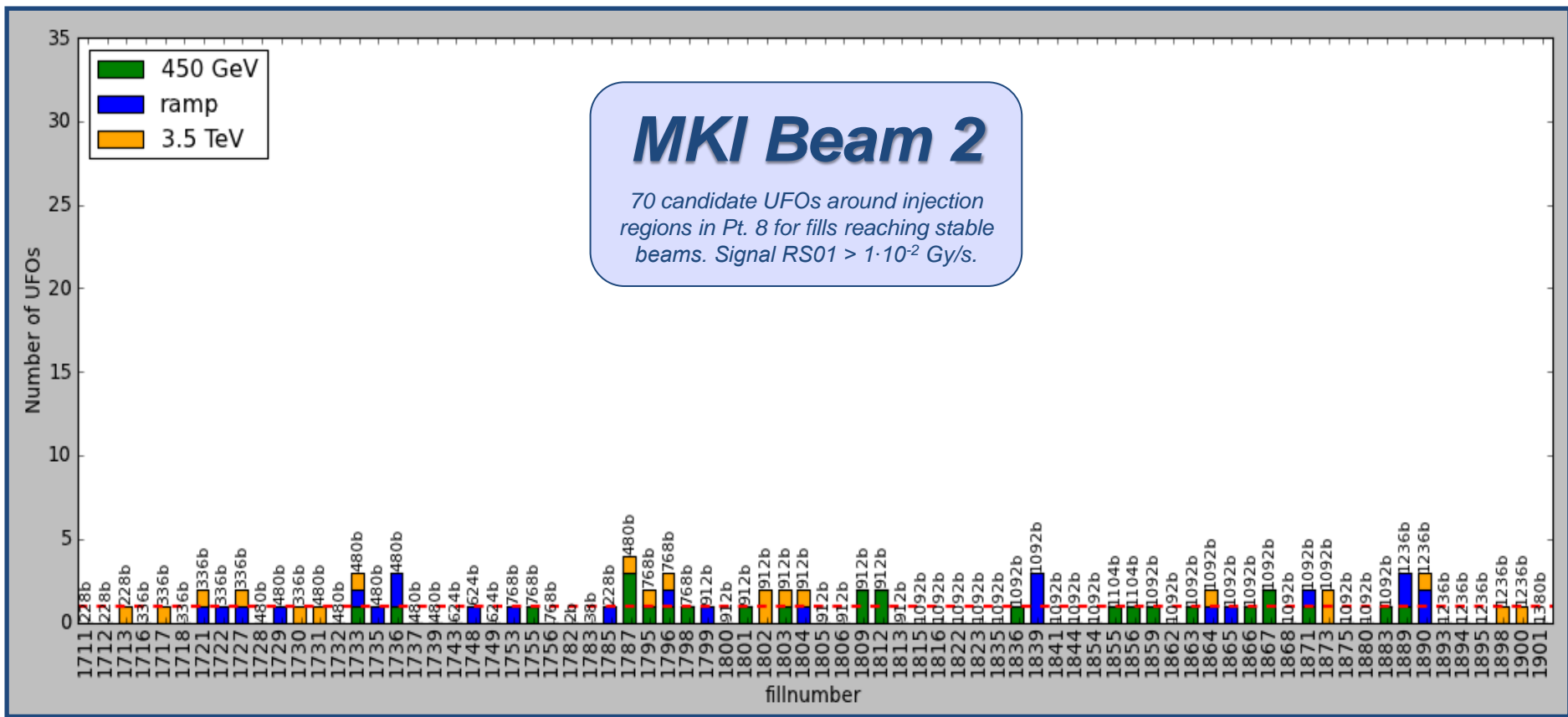
The large number of strong MKI UFOs in Pt. 2 disappeared in the fills after the technical stop.



# MKI UFO Storms

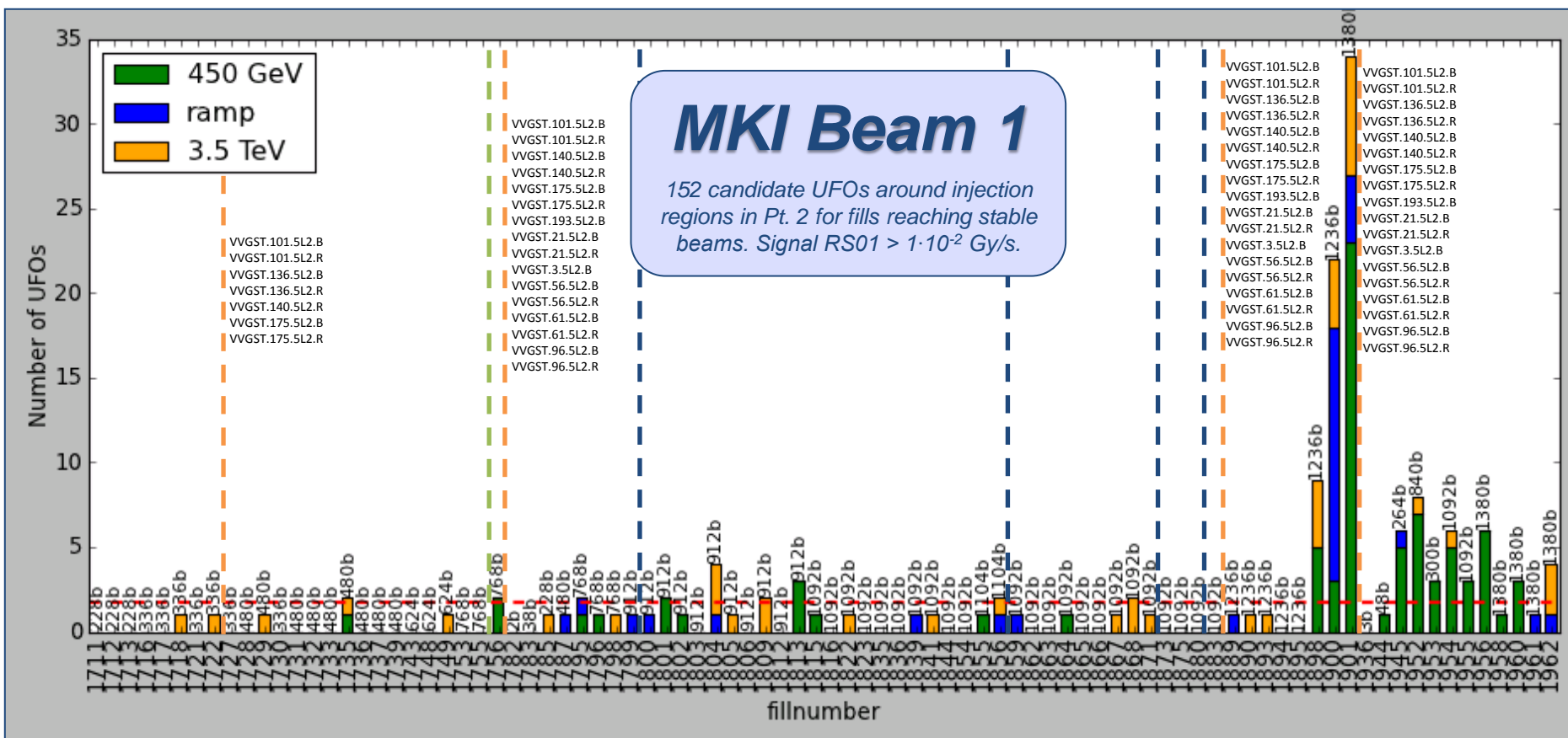
- Fill 1898 (26<sup>th</sup> June): 15 UFOs MKI B1, 7 UFOs MKI B2.
  - 14 UFOs at MKI B1 within 40 min.
  - Highest UFO: 34% of Threshold at TCTH.4L2 (RS1, RS2) at 3.5 TeV.
- Fill 1900 (27<sup>th</sup> June): 32 UFOs MKI B1, 5 UFOs MKI B2.
  - **17 UFOs at MKI B1 within 6 min.**
  - Highest UFO: **65%** of Threshold at MQY.04L2 (RS6) at 3.5 TeV.
- Fill 1901 (28<sup>th</sup> June): 41 UFOs MKI B1, 12 UFOs MKI B2.
  - **16 UFOs at MKI B1 in 2:20 min.**
  - Mostly at 450 GeV (12 min. at 450 GeV after last injection).
  - Highest UFO: **63%** of Threshold at TCTH.4L2 (RS8) at 450 GeV.

# Number of large MKI UFOs B2



The number of large MKI UFOs in Pt. 8 did not increase.

# Vacuum Valve Movement



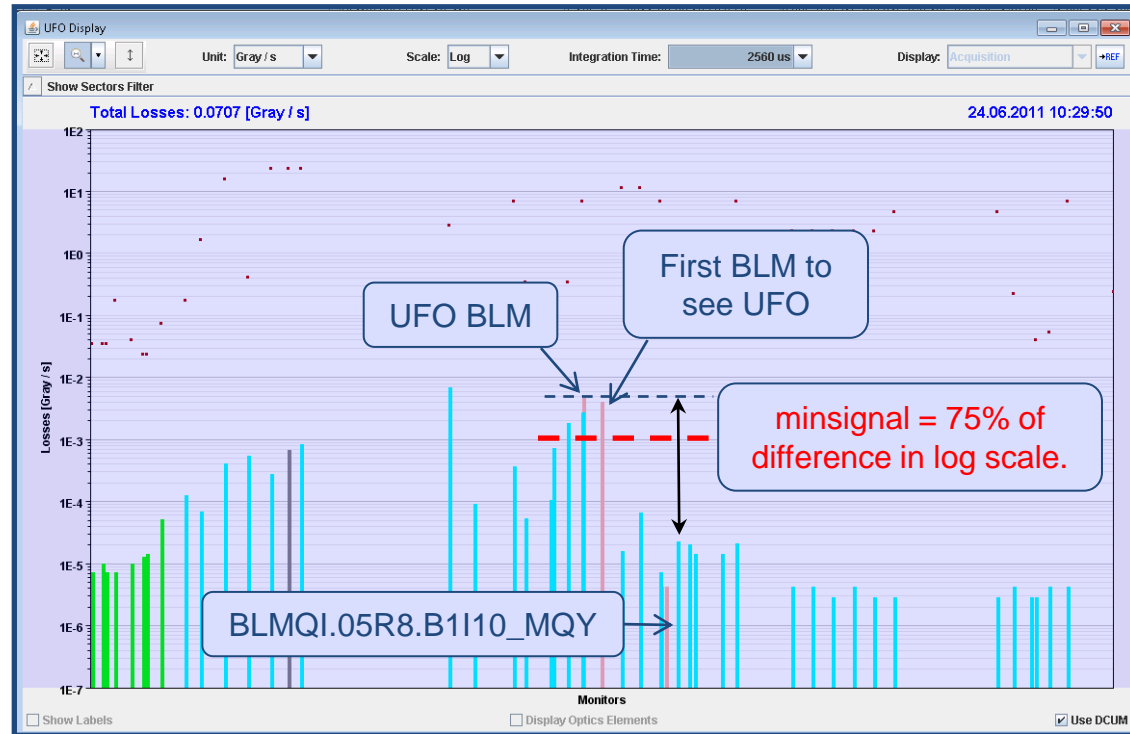
Closure of vacuum valves.

**orange:** Several valves closed, **blue:** VVGST.193.5L2 and VVGST.3.5L2 closed, **green:** status unknown for several valves.



# UFO Location

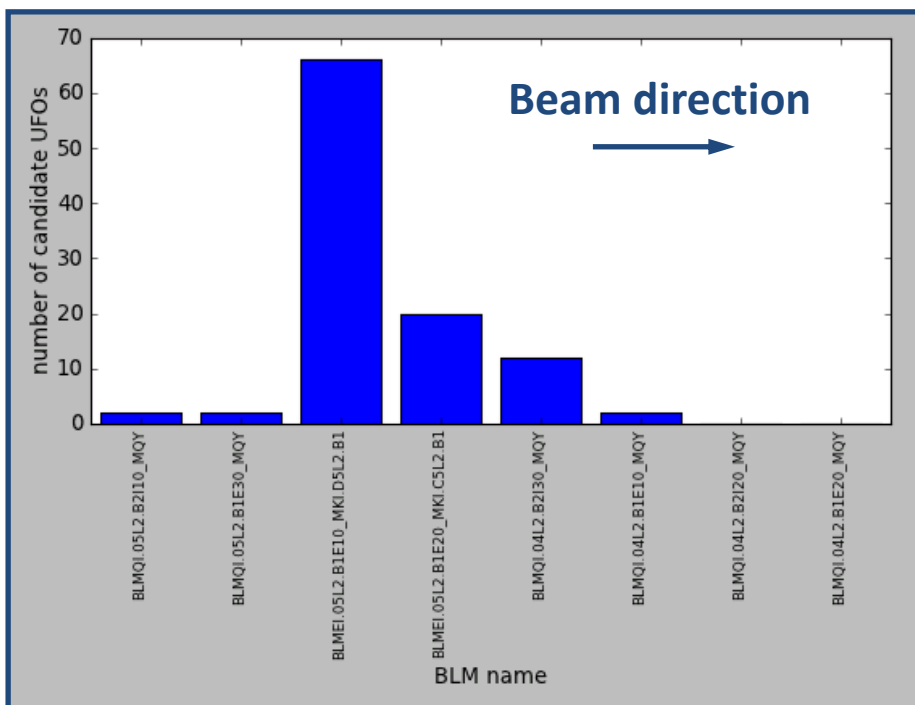
- Sometimes BLMs upstream of the BLM with the highest have only slightly smaller losses.
- → Analyzing first BLM above minsignal (as defined in plot)



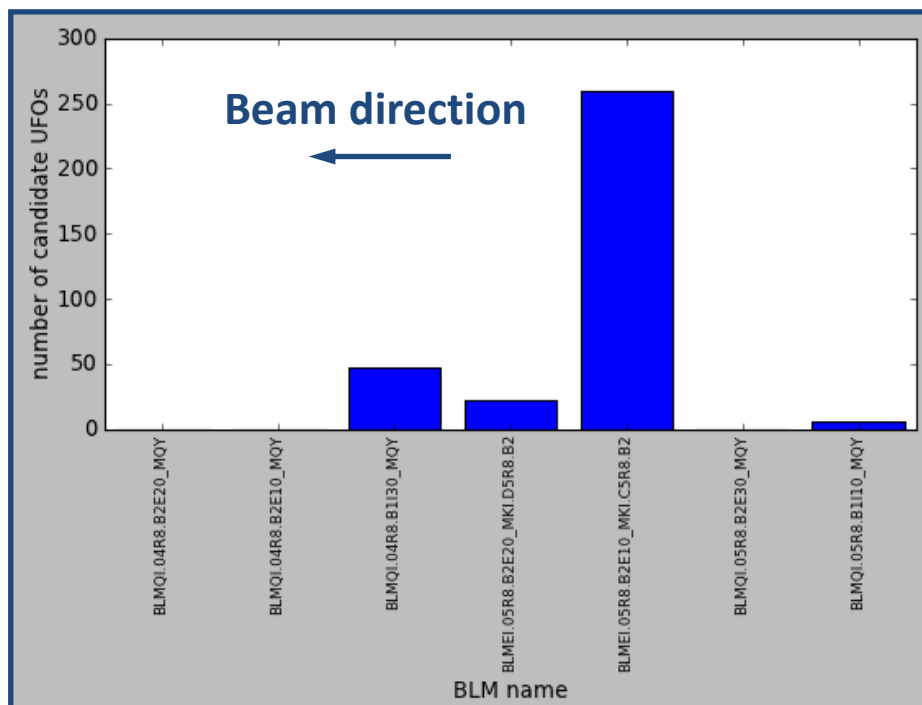
# UFOs at MKIs

- 08.04. – 05.05. 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:*

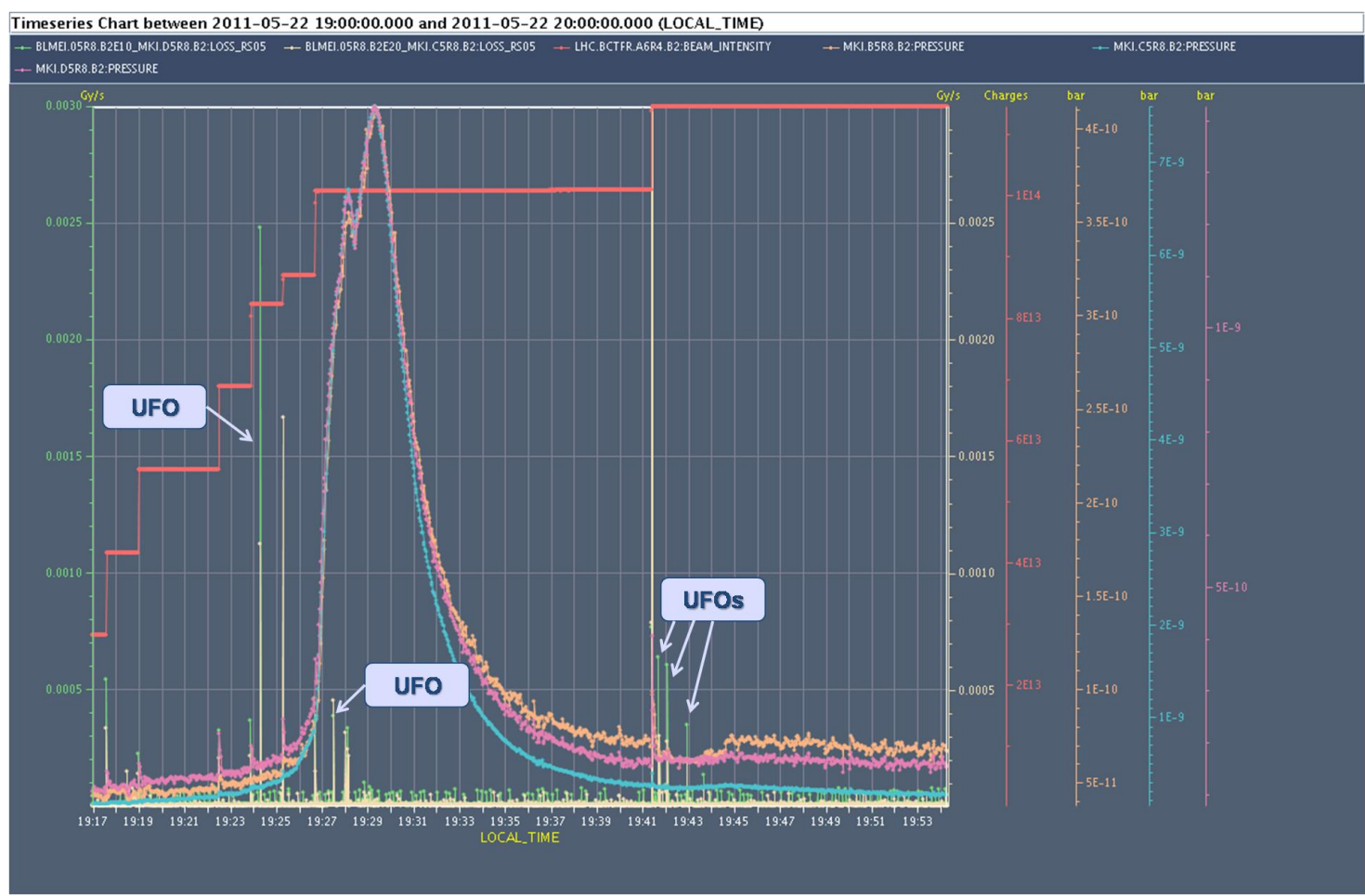


Left of IP2



Right of IP8

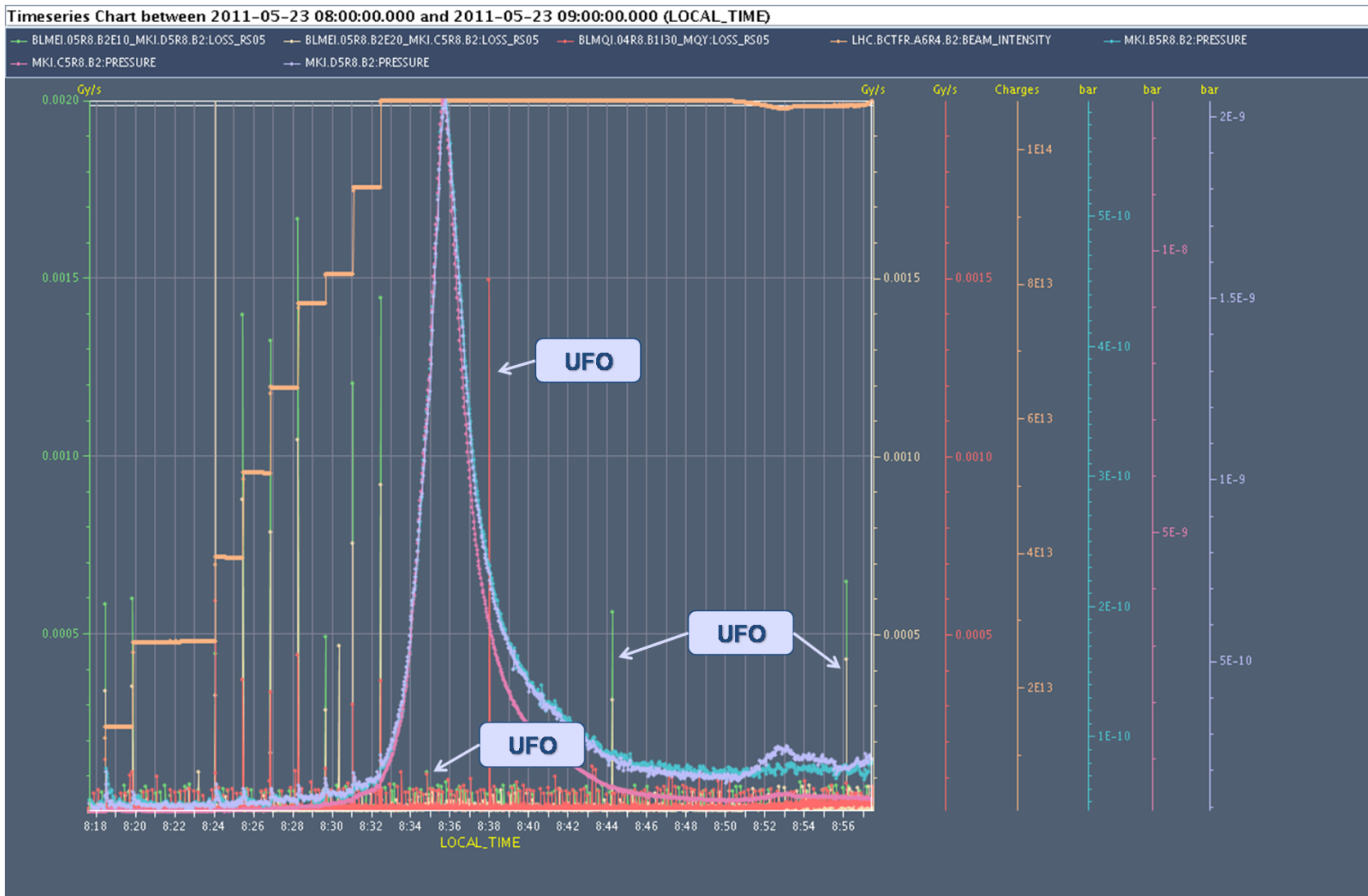
# Correlation with Vacuum



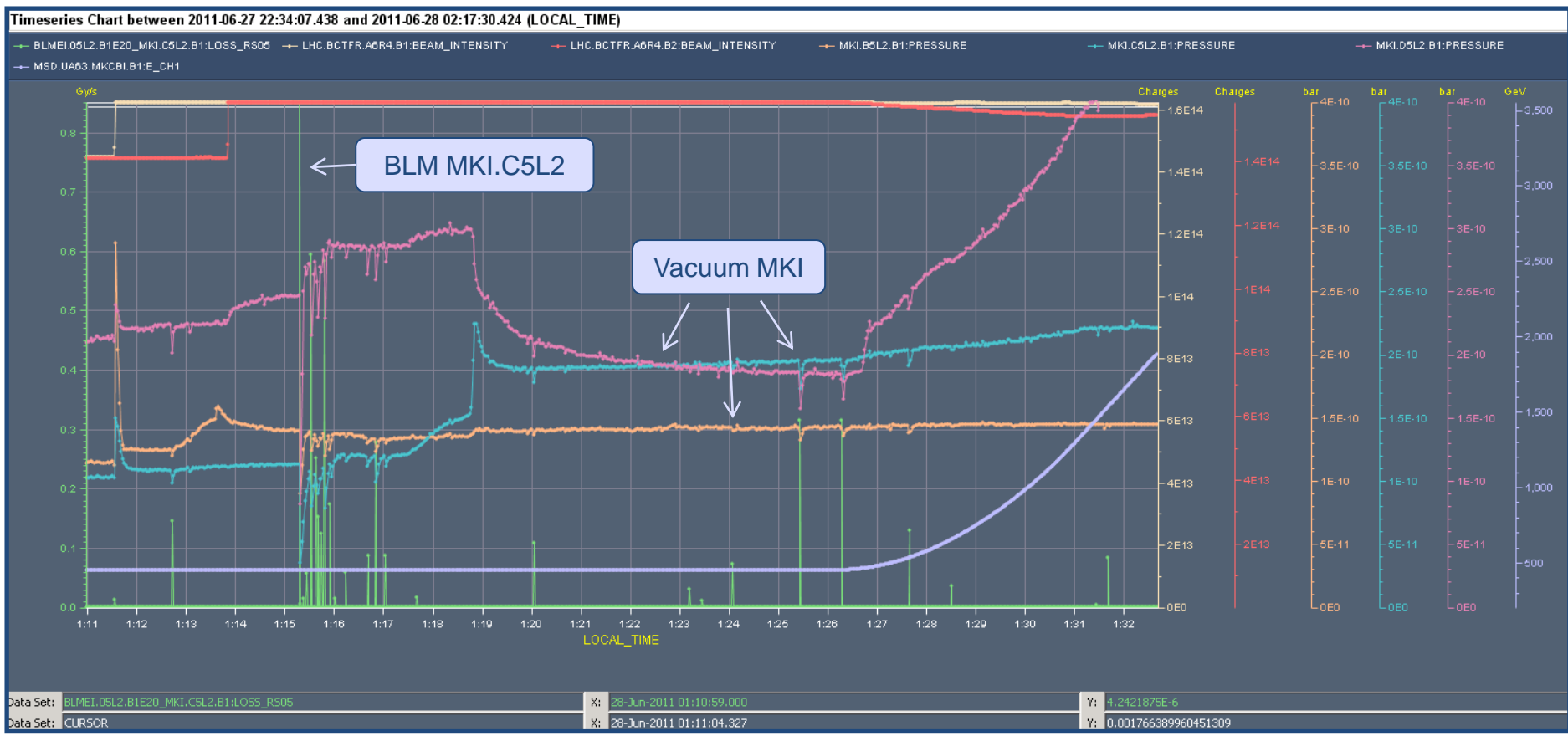
Despite a large vacuum spike, there is no clear correlation with UFOs



# Correlation with Vacuum

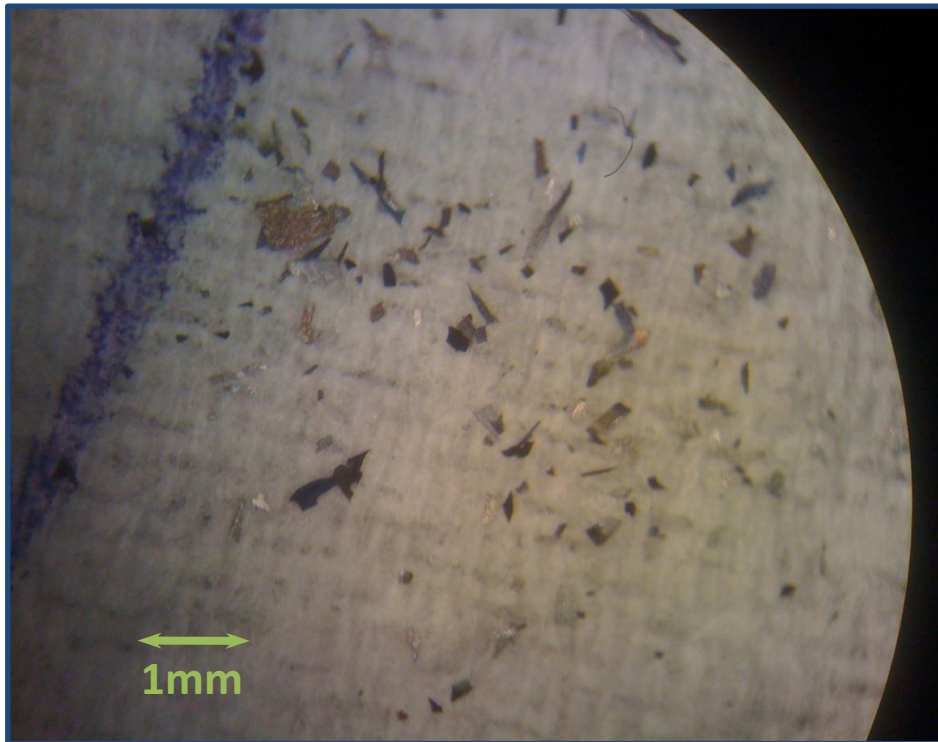


# Vacuum Correlation

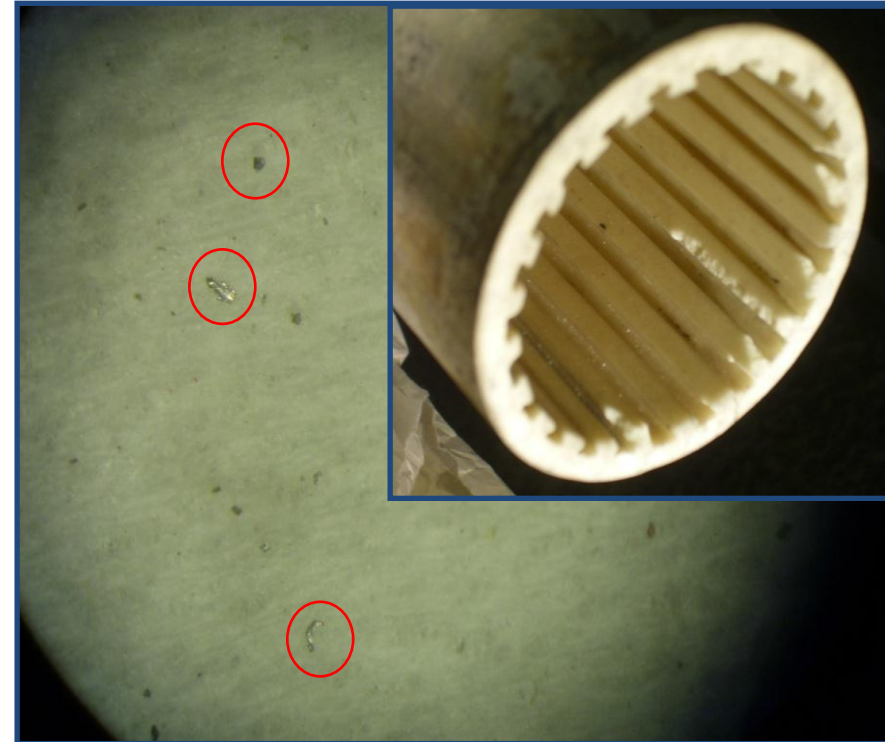


The pressure spike is seen on all MKI magnets.

# Dust Particles in the LHC



*Dust particles in Penning gauge from lab.*



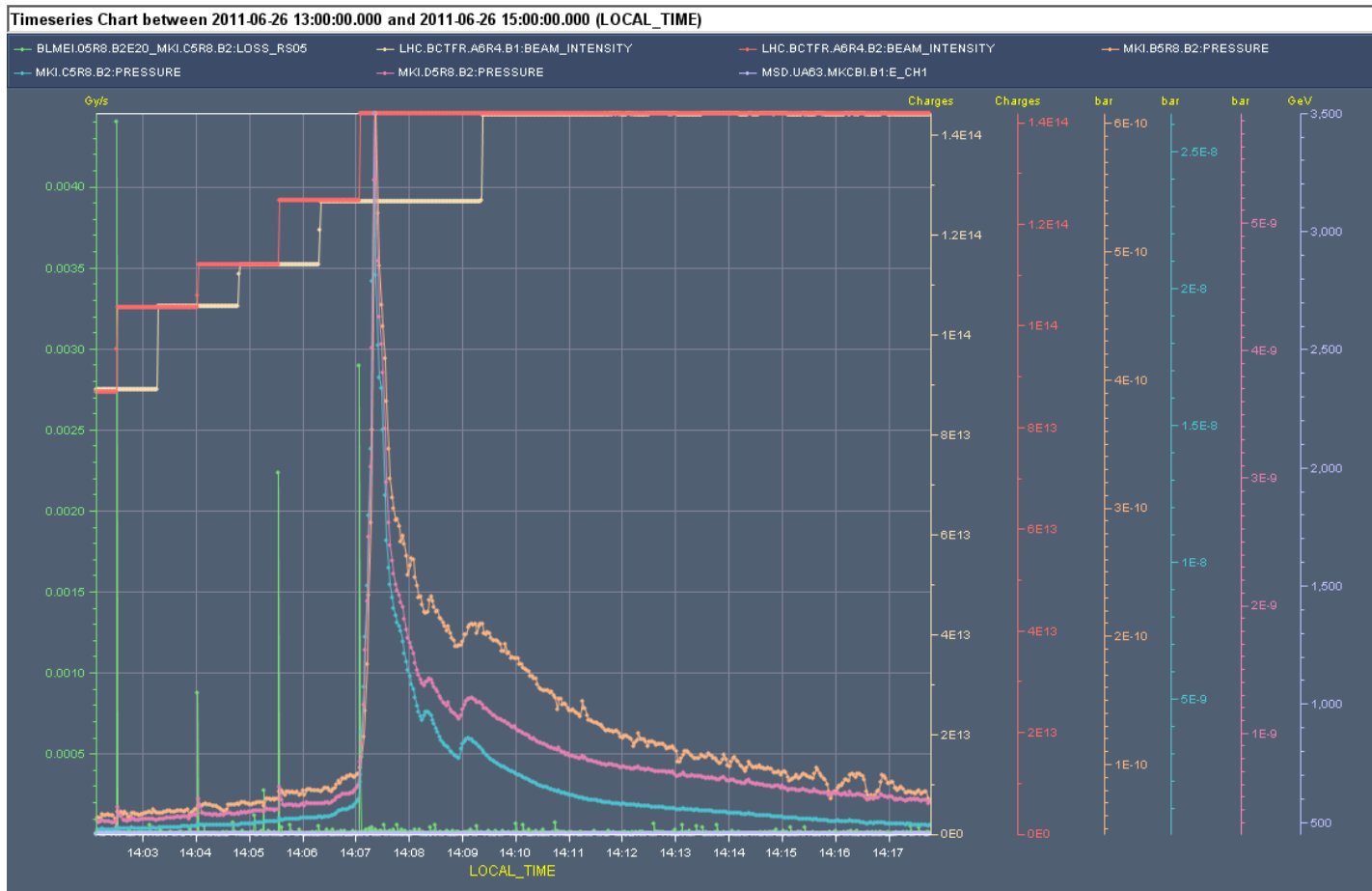
*Dust particles in ceramic test beam tube.*

Samples from non-operational and old equipment.  
But not representative for the LHC...

courtesy of  
N. Garrel and  
V. Mertens



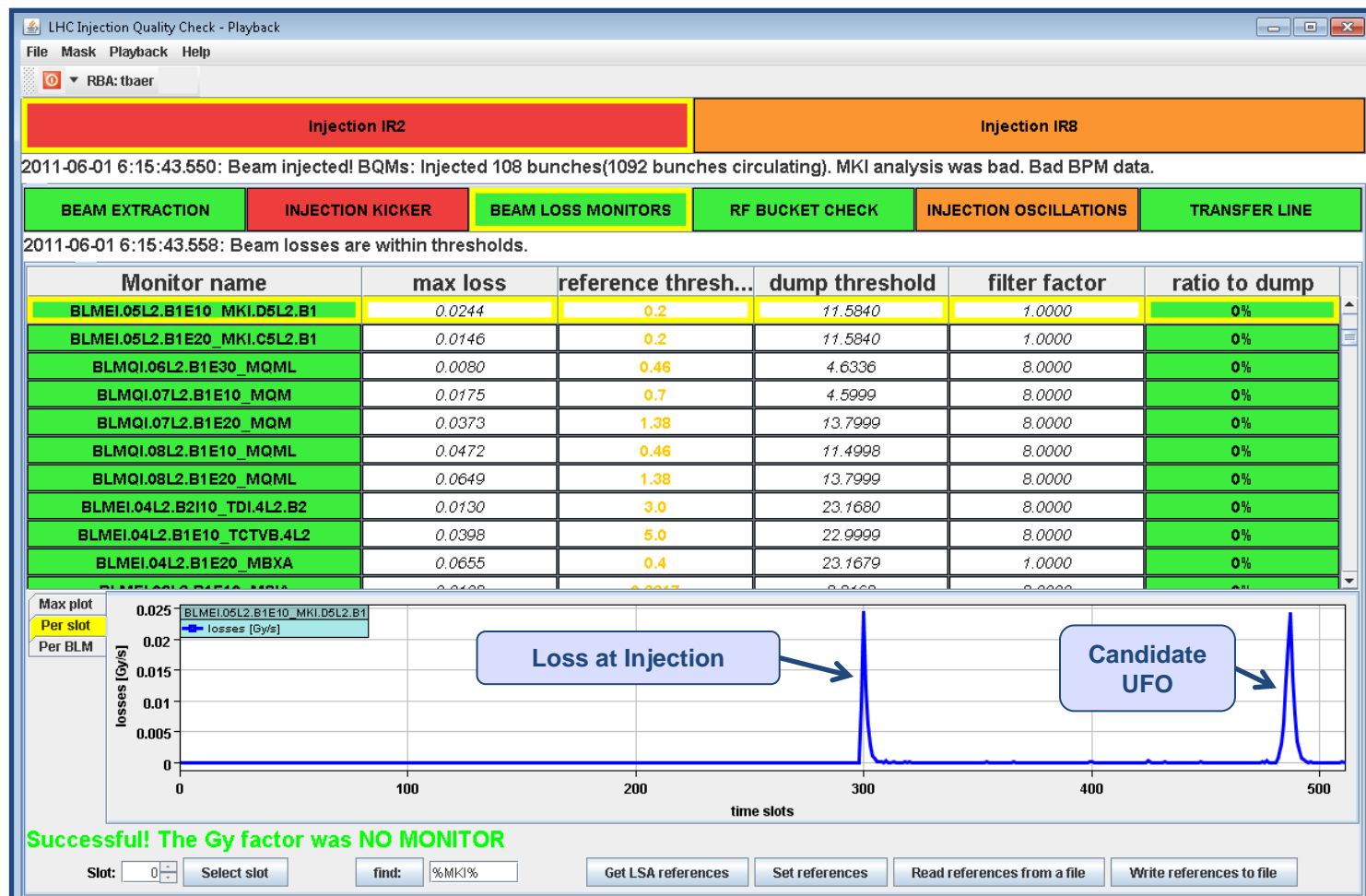
# Vacuum correlation (slow)



The slow vacuum spike is correlated to the last injection.

No correlation with UFOs

# UFOs in IQC



Many additional events in IQC data for normal operation.

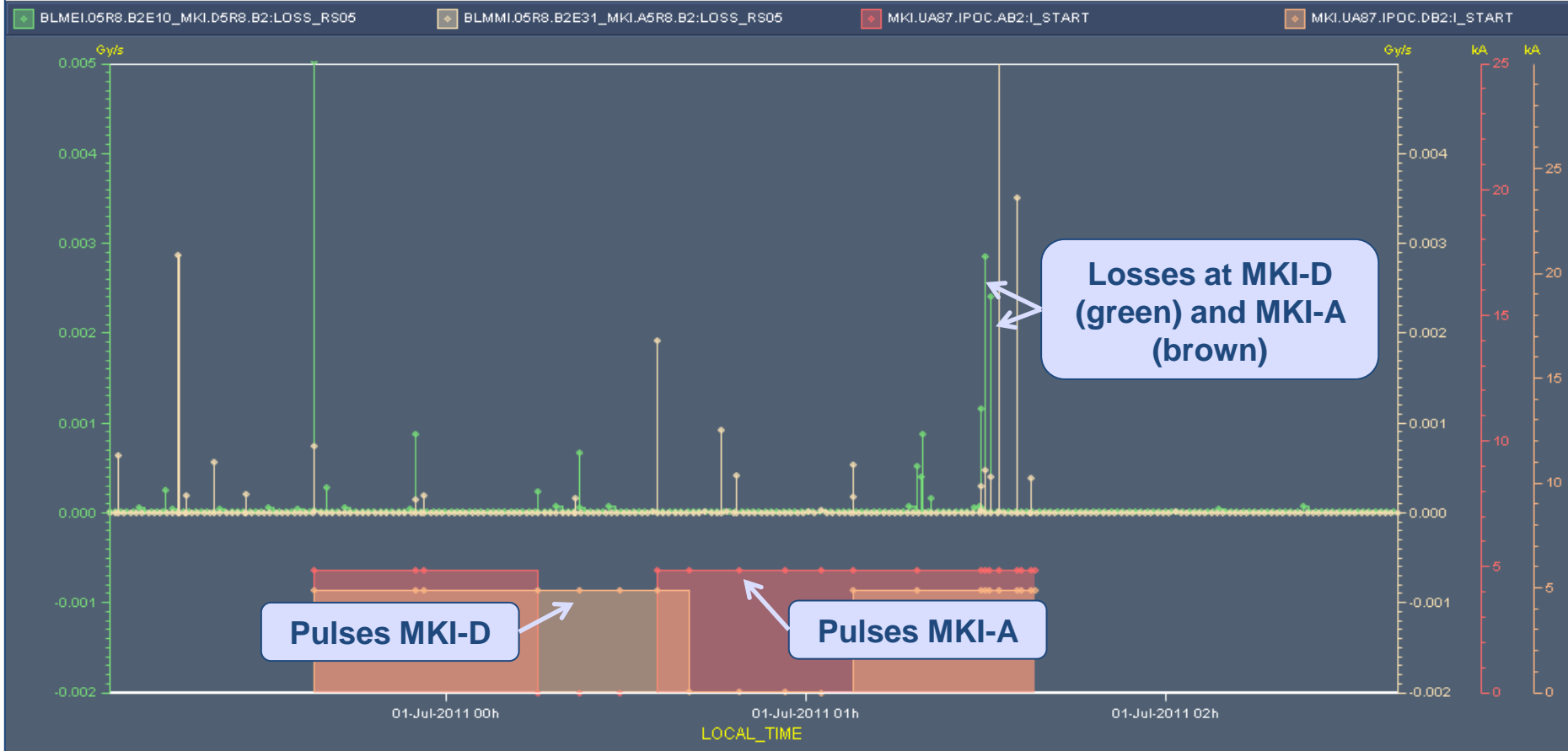




# Content

**MKI UFO MD**

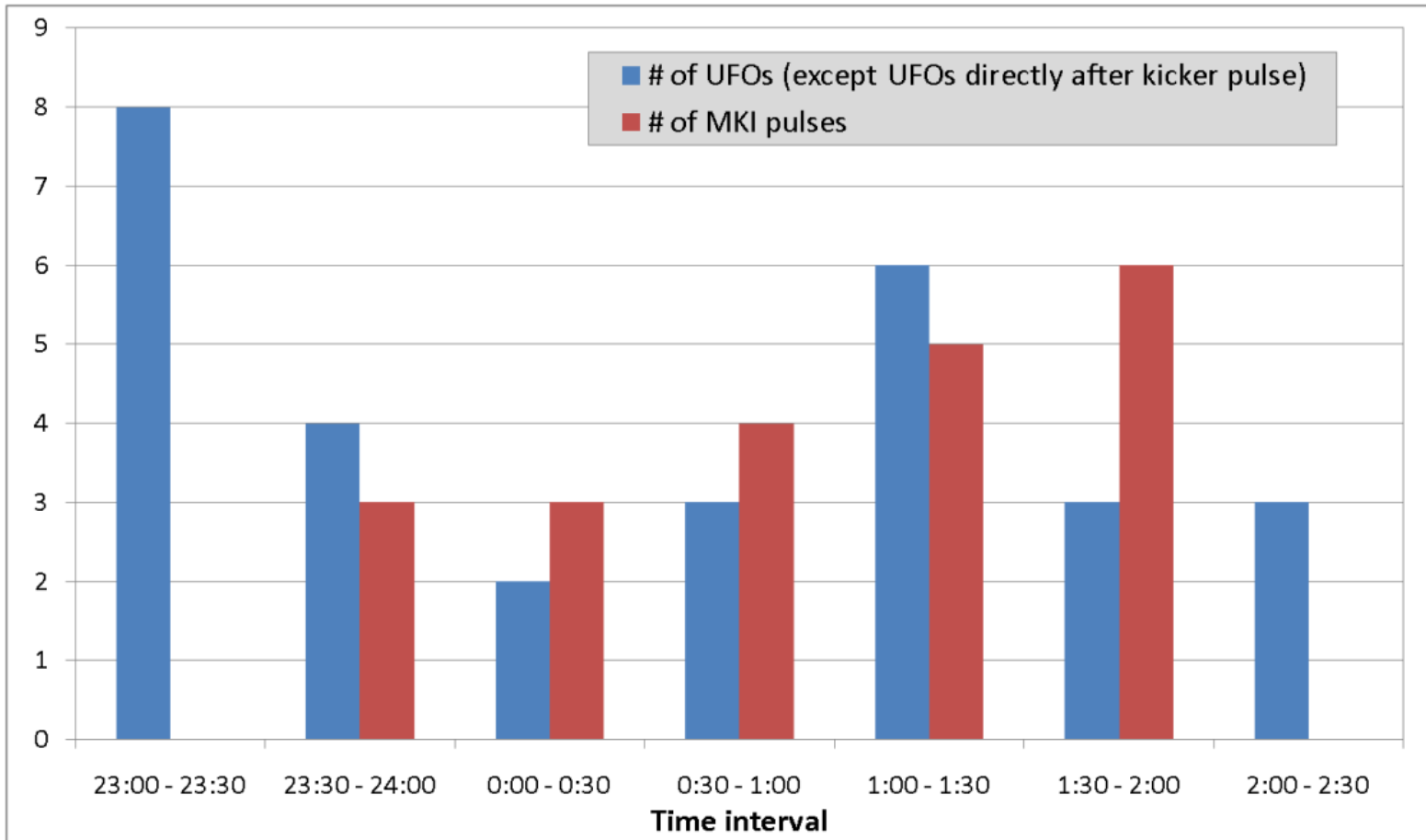
Timeseries Chart between 2011-06-30 23:03:52.000 and 2011-07-01 02:38:33.000 (LOCAL\_TIME)



21 pulses of MKIs, 43 UFO type loss pattern observed.

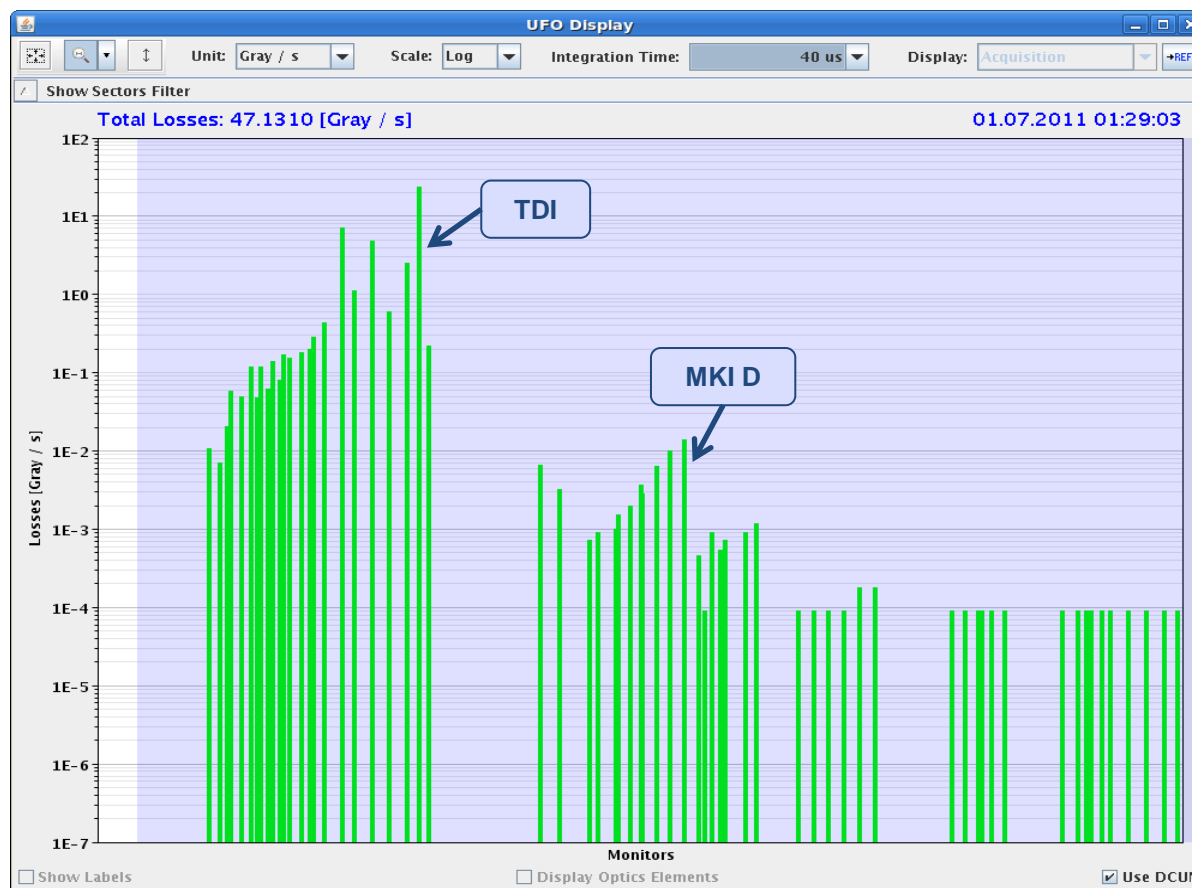
In 17 cases: **UFO type loss pattern within the second of MKI pulse.**

# UFOs between kicker pulses



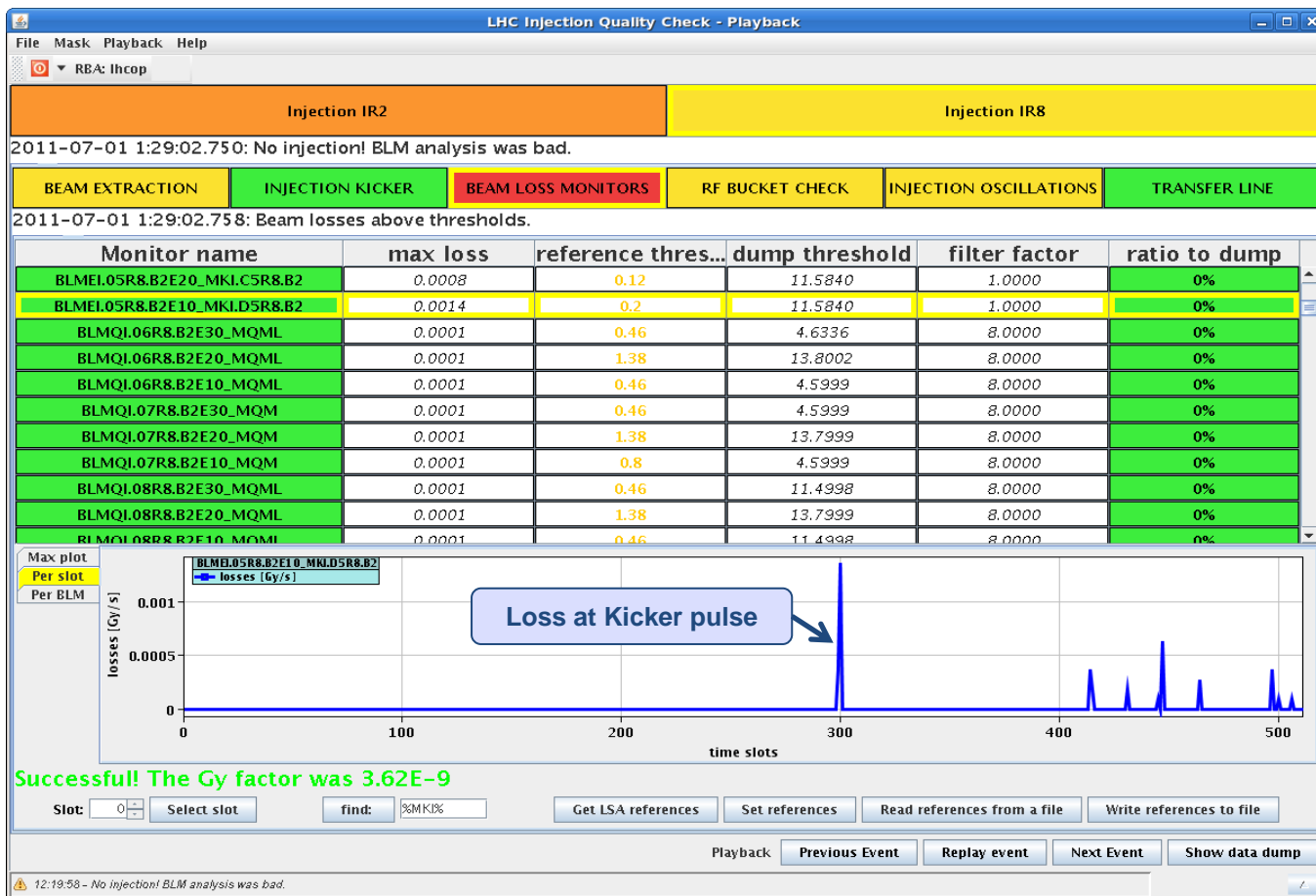
The number of UFOs between kicker pulses decreased over time after the last injection with beam.

# MKI UFOs at MKI pulse



The peak loss at the MKI D in the second of the kicker pulse are  **$1.4 \cdot 10^{-2}$  Gy/s** (40 $\mu$ s running sum).

# Losses at MKI

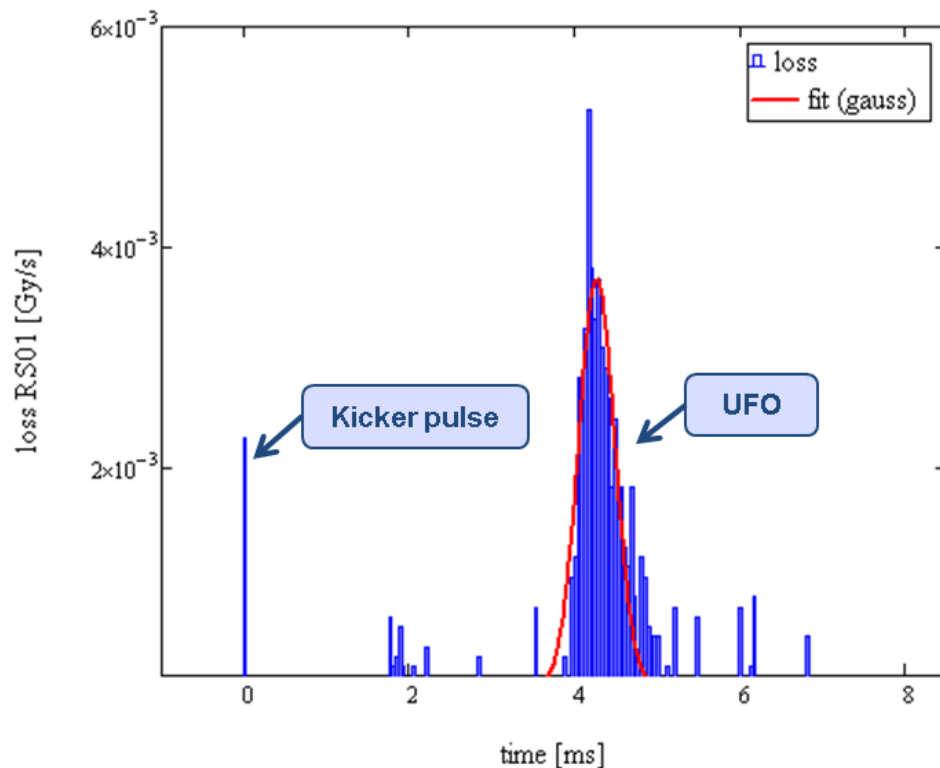


The peak loss at the MKI D at injection is one order of magnitude smaller ( $1.4 \cdot 10^{-3}$  Gy/s).

# UFO Dynamics

- From fit to losses (MKI-D):

- Amplitude:  **$3.7 \cdot 10^{-3} \text{ Gy/s}$**   
(Threshold:  $11.6 \text{ Gy/s}$ )
- Temporal Width:  **$218 \mu\text{s}$**   
resulting speed of transiting dust particle =  **$2.2 \text{ m/s}$** .  
(assuming  $\epsilon^n = 2.5 \mu\text{m} \cdot \text{rad}$ )



- Time delay to kicker pulse:  **$4.3 \text{ ms}$**   
resulting acceleration (assuming constant particle acceleration):  **$2055 \text{ m/s}^2$**   
resulting speed during interaction with beam:  **$8.8 \text{ m/s}$**



# Content

**Conclusion and Summary**



# Known Dust Particle Sources

- Distributed ion pumps (PF-AR, HERA).  
*No ion pumps in LHC arcs.*
- Electrical Discharges (PF-AR).
- Movable Devices (LHC).
- Particles frozen to or condensated at cold elements. (ANKA)



# Conclusion

- **For 2011:**
  - **Arc UFOs: No sign that the situation will become worse.** Few dumps are expected.
  - MKI UFOs: **MKI UFO Storms might be critical** (but observed storms disappeared again).  
*Large effort underway to understand mechanism, in lab and in LHC.*
- **Beyond 2011:**
  - Observations show an **aggressive scaling with beam energy!** Situation could be significantly worse above 3.5TeV.  
*Intermediate energy step would be very helpful for extrapolations to nominal energy.*