Results on UFO dynamics from 16L2 events

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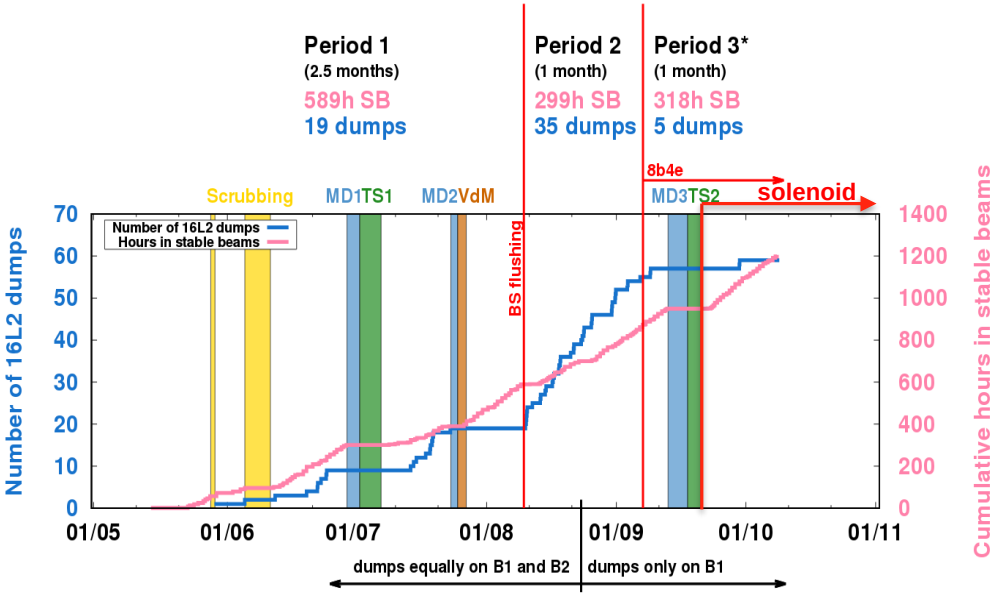
LHC Beam Operation Committee 6 Feb 2018

16L2 events summary

- Total of 67 induced dumps by 16L2
  - IR7 dBLM data: 43 events
  - Local (16L2) dBLM data: 8 events
    - UFO spike not visible in IR7 dBLMs for 16L2 type UFOs
    - Main focus on my part has been on local data due to the MD
- 1 event during MD with blown-up bunches
- Solenoid on in all events with local data, except MD

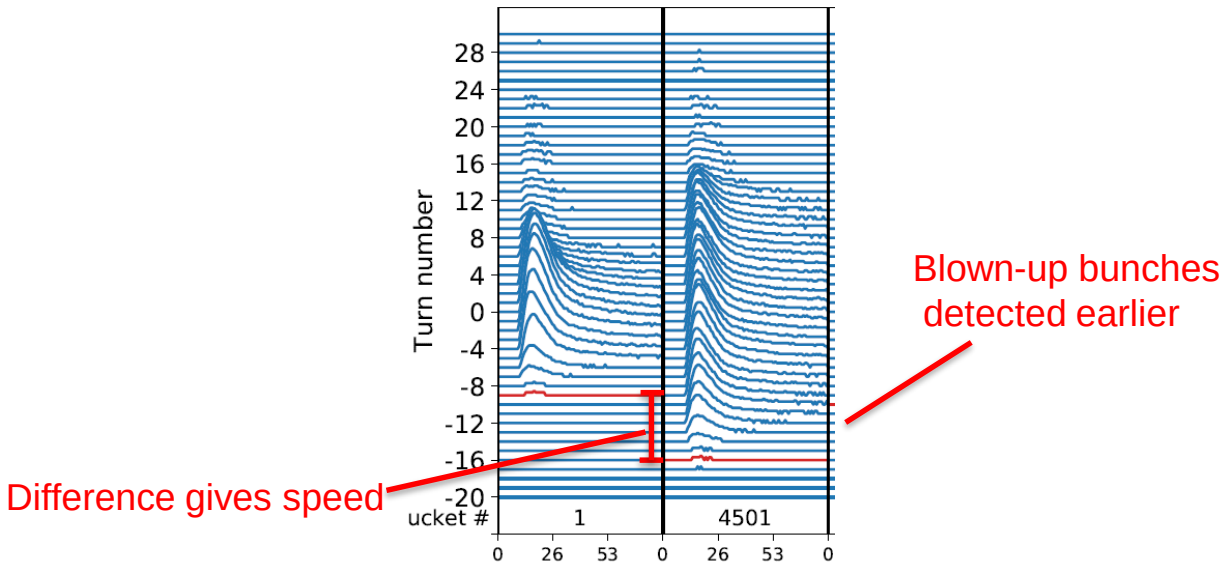


fill	Mode	Energy [TeV]	Beam	# bunch	Beam intensity [10^13]
6256	FT	6.5	B1	1916	25.4
6257	FT	6.5	B1	1916	24.5
6316	SQ	6.5	B1	1868	24.9
6392	SB	2.51	B2	1836	19.7
6393	Ramp	1.48	B2	1836	21.5
6394	Ramp	0.745	B2	1836	18.0
6395	Ramp	0.979	B2	1836	18.9
6442	Ramp	5.5	B1	1868	23.7

Courtesy of A.Lechner

Motivation for 16L2 MD

- Successful demonstration that blown-up bunches can be used to determine UFO dynamics in MD2036
- Wirescanner was used to simulate a UFO
  - Elastically scattered protons create showers in IR7, detected by dBLMs with bunch-by-bunch resolution
- Can reconstruct WS velocity (by assuming a bunch distribution)



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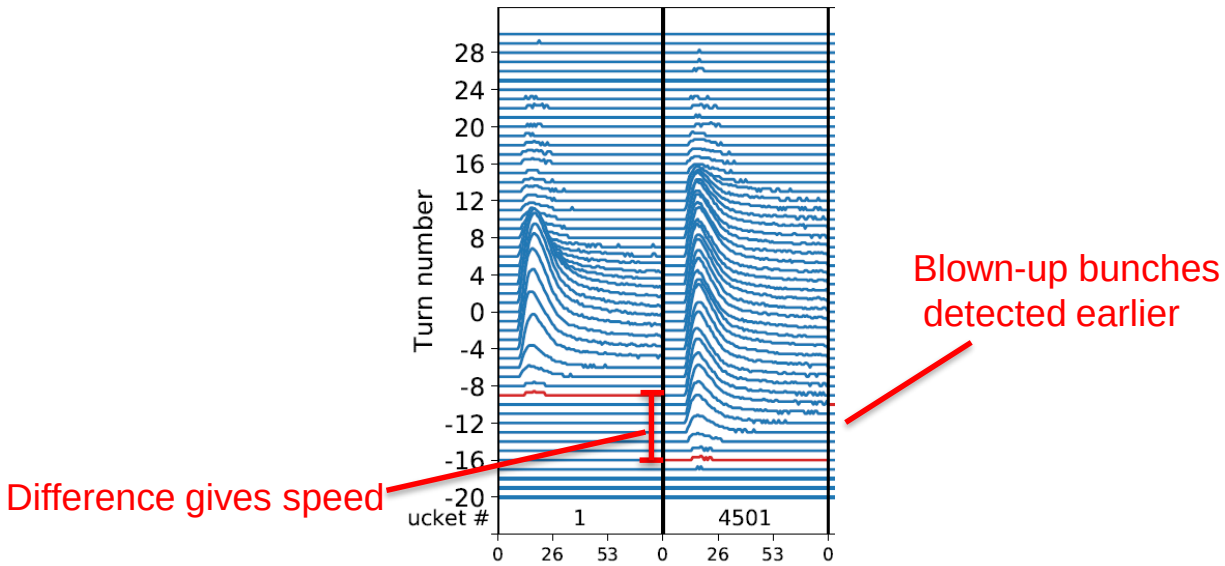
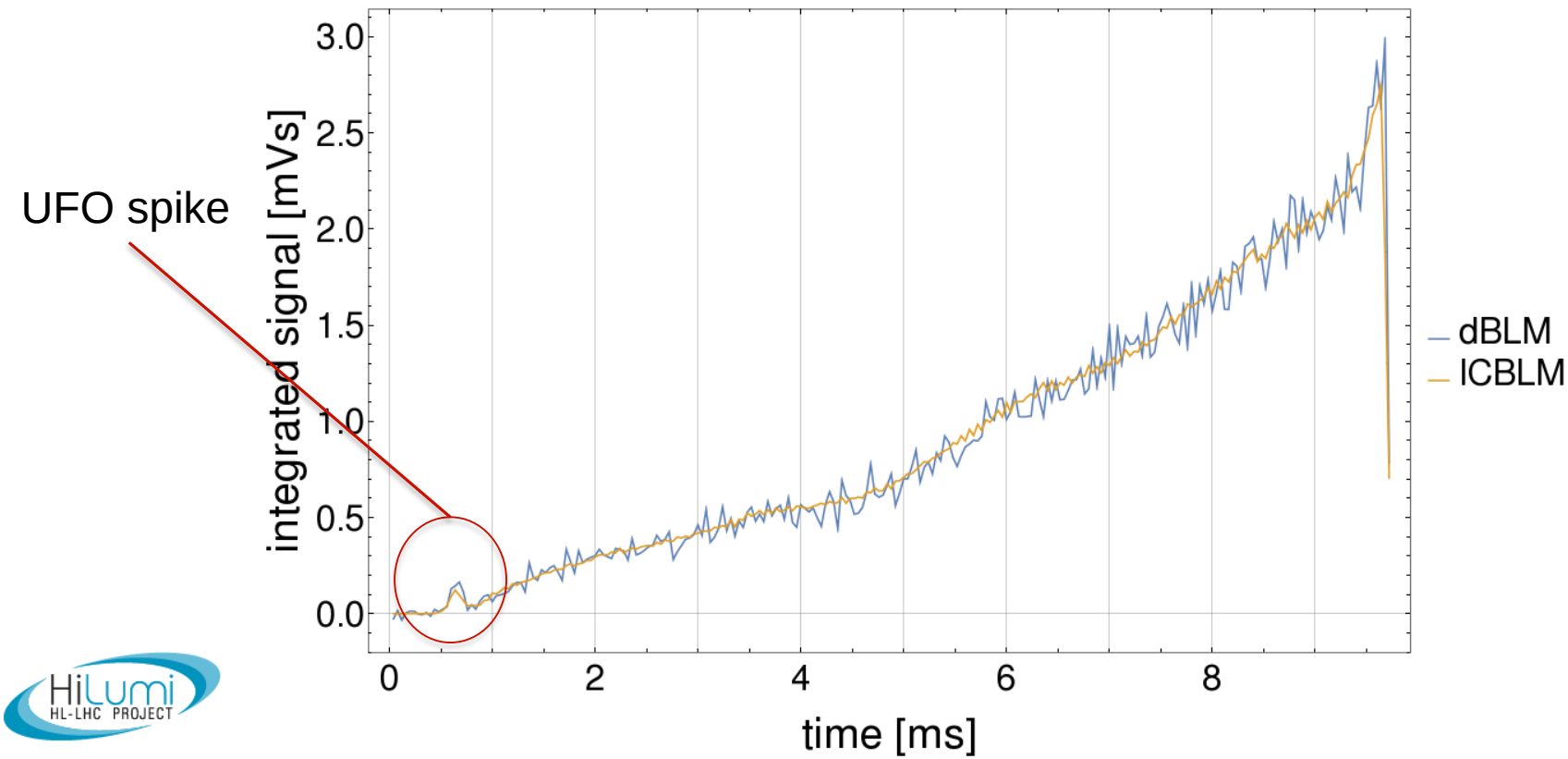
- Can reconstruct WS velocity (by assuming a bunch distribution)
- 16L2 gave opportunity to study real UFOs
- 16L2 events fastest observed failures in the LHC (dump threshold in ~10 turns)
  - Imperative to understand and be able to diagnose
- Study what kind of materials lead to evaporation and instability build-ups



Signal acquisition

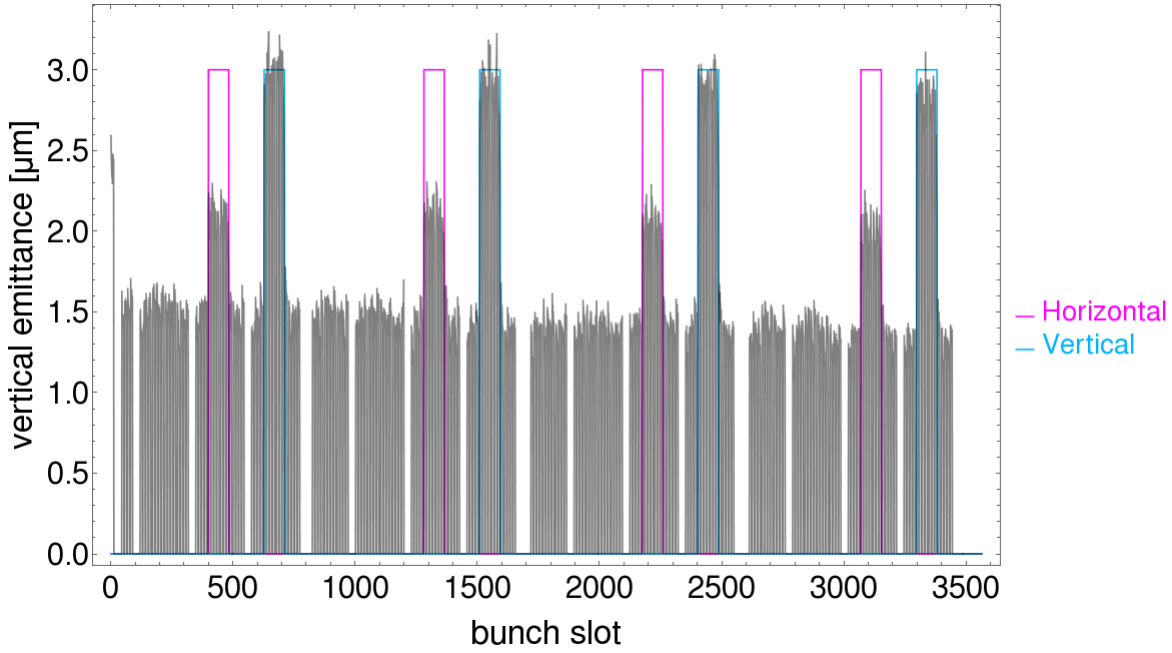
- Local losses relatively low
- dBLM only 1 cm^2; small angular acceptance
  - Significant probability to not detect signal
- Solution: use many bunches
- Integrating in 40 µs shows good **linear** correlation with ICBLM



16L2 MD procedure (MD#2889)

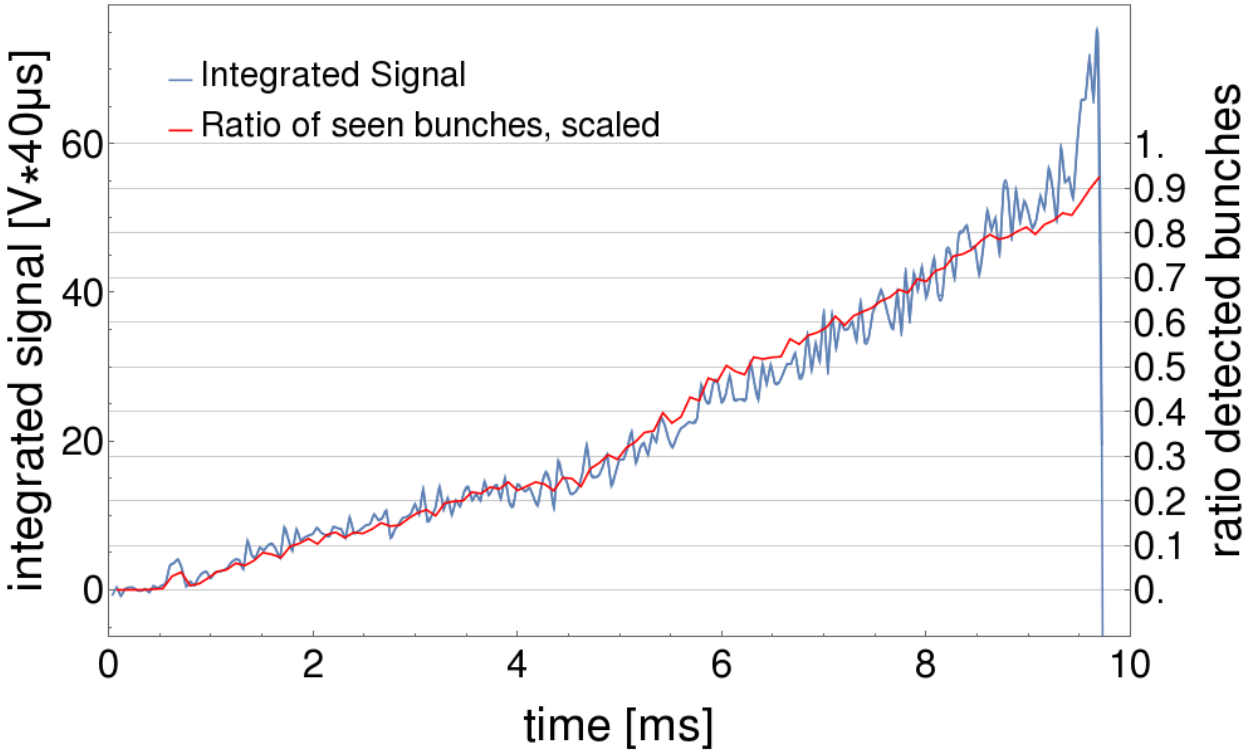
- 8b4e beam of 1868 bunches * 1.25e11 protons, ramp to 6.5 TeV, solenoid off
  - Parameters chosen for high probability of triggering 16L2 event
- Total of 512 bunches blown up to ~1.4x beam size (256 per plane) before ramp using ADT
  - Many bunches required for statistical significance

Dump occurred at 5.5 TeV due to 16L2 event (only one event)



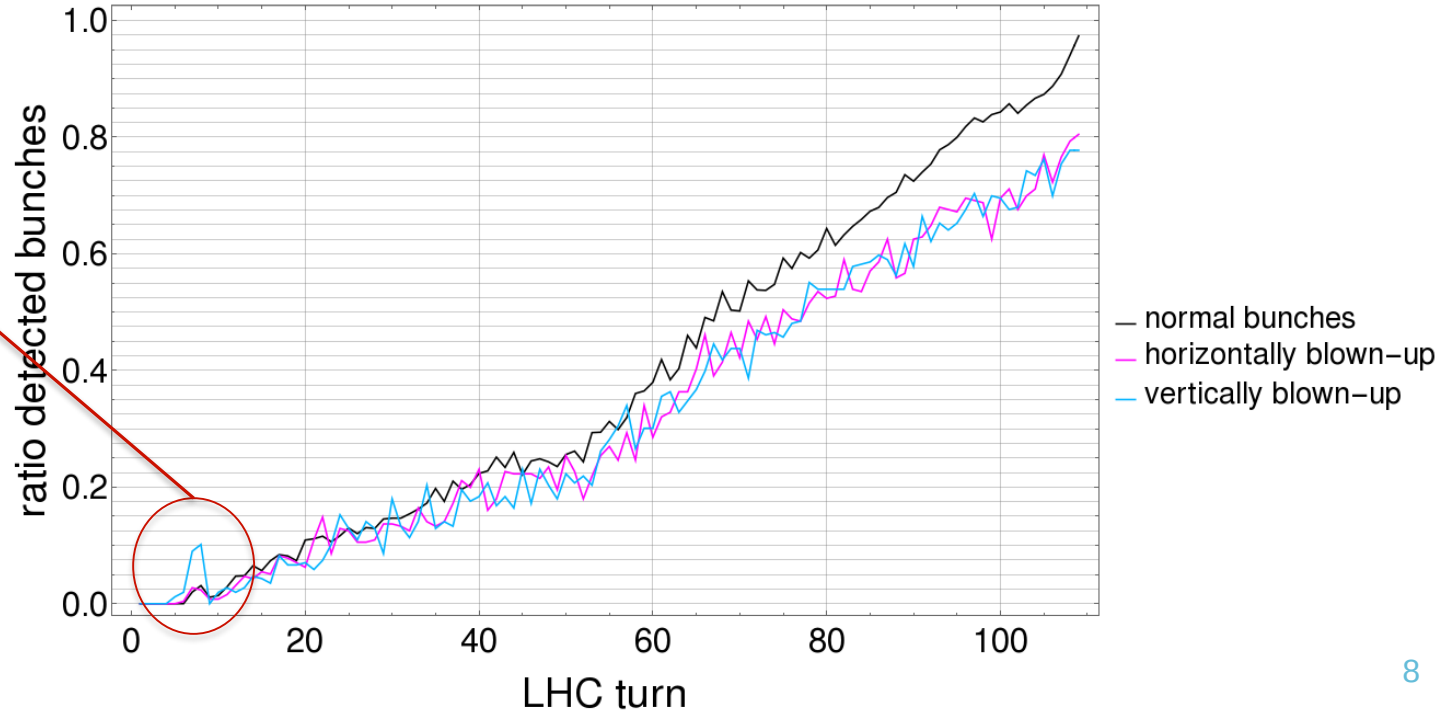
16L2 Bunch detection probability

- Probability of detecting a bunch is related to the total losses per bunch, which in turn is related to the bunch particle density at interaction point
- Ratio of detected bunches is a good measure of the per bunch losses



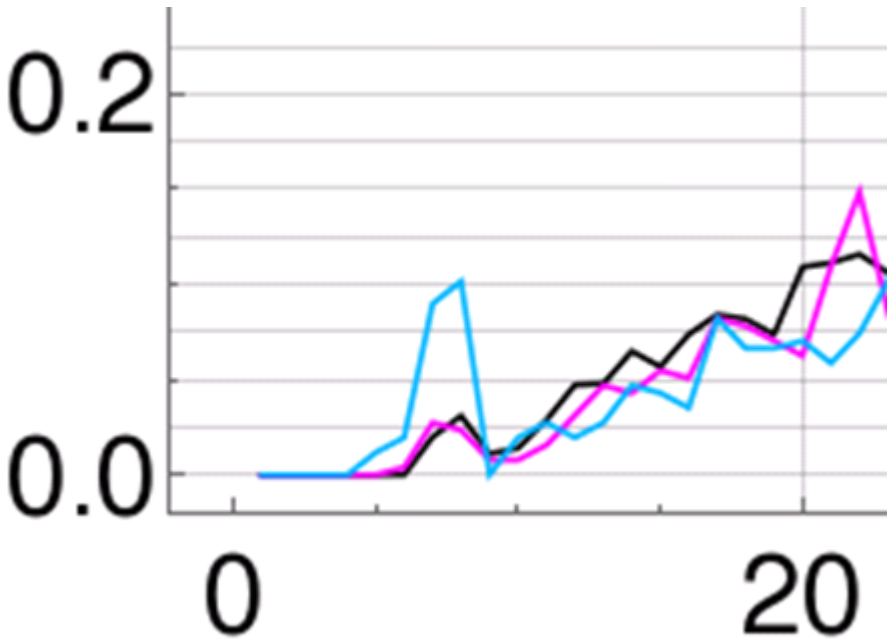
UFO plane of movement

UFO spike



UFO plane of movement

- Vertically blown-up bunches are detected earlier (~1.5 turns)
  - **UFO movement in vertical plane**
- Vertically blown-up bunches more probable to detect throughout UFO spike
  - **UFO particle does not enter beam core (repelled or evaporated)**
- Sudden drop for all bunches after UFO-spike implies dust particle disappeared quickly



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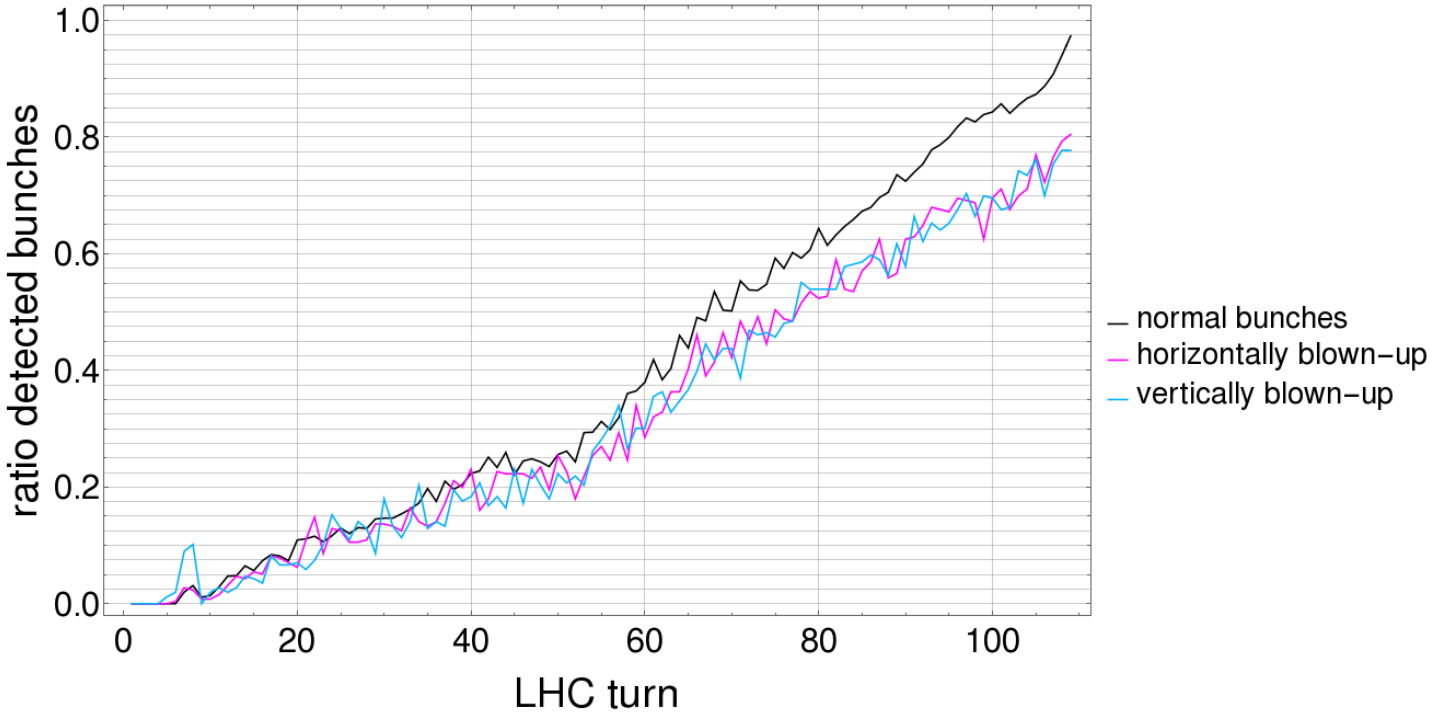
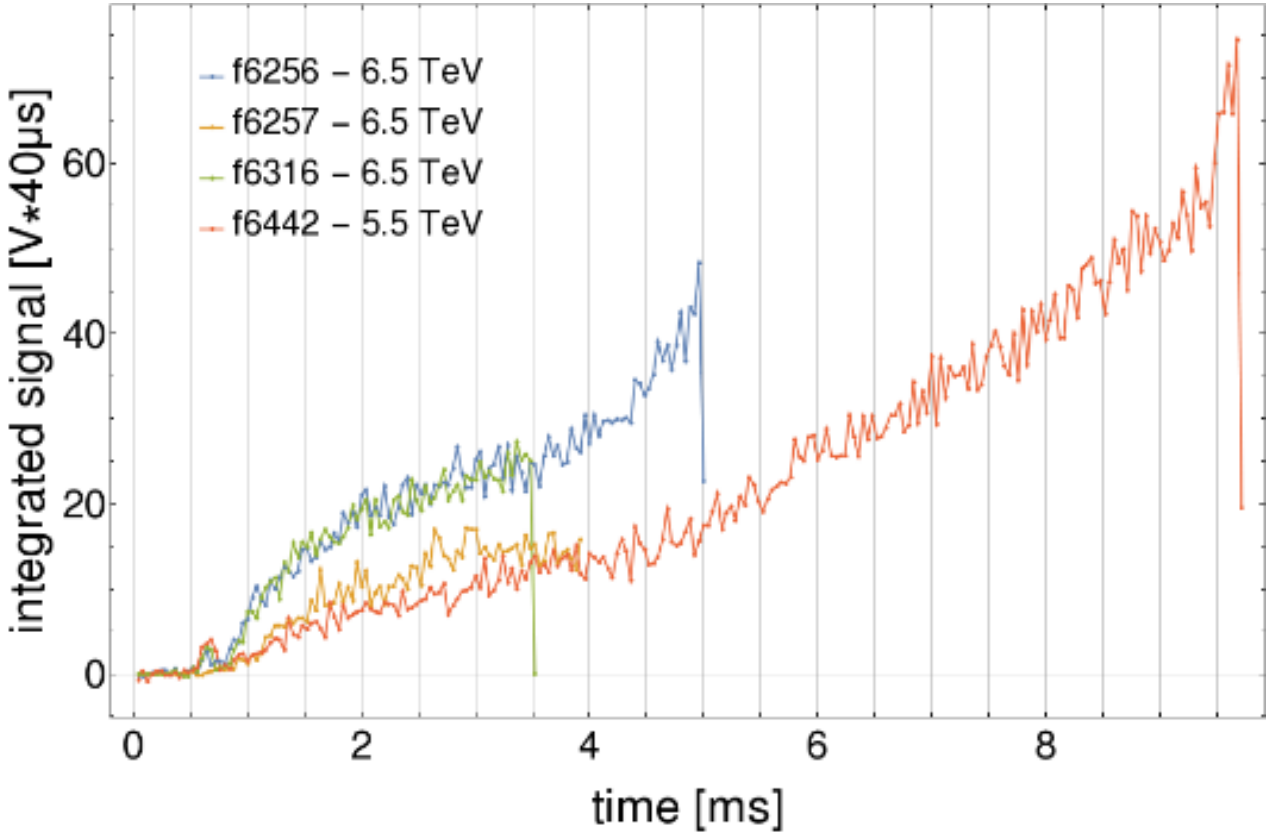
- We have model of UFO movement, working on simulating how deep macroparticle can enter the beam
- Normal and blown-up bunches diverge towards the end (to be explained)



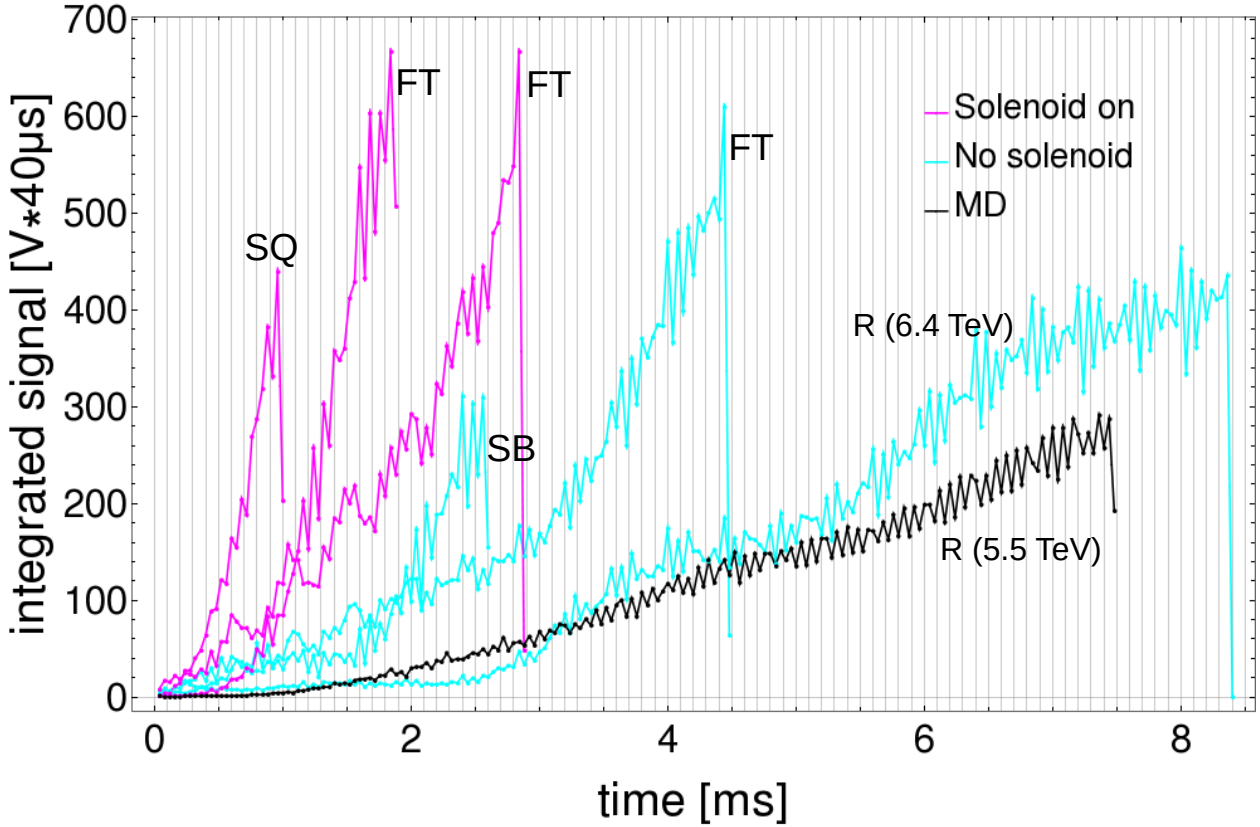
Integrated 16L2 dBLM data

- MD event was slower
  - Possibly because solenoid was switched off
- Otherwise similar pattern
  - No obvious difference in beam parameters to explain scale difference between fills 6256/6316 and 6257/6442



IR7 integrated data

- Comparing 8b4e events with solenoid off/on indicates that solenoid might lead to quicker instability build-up
- Loss pattern different between MD fill and the others
  - Due to ramp optics?
- All 8b4e b2 events had solenoid on



1868 bunches in MD and Squeeze events

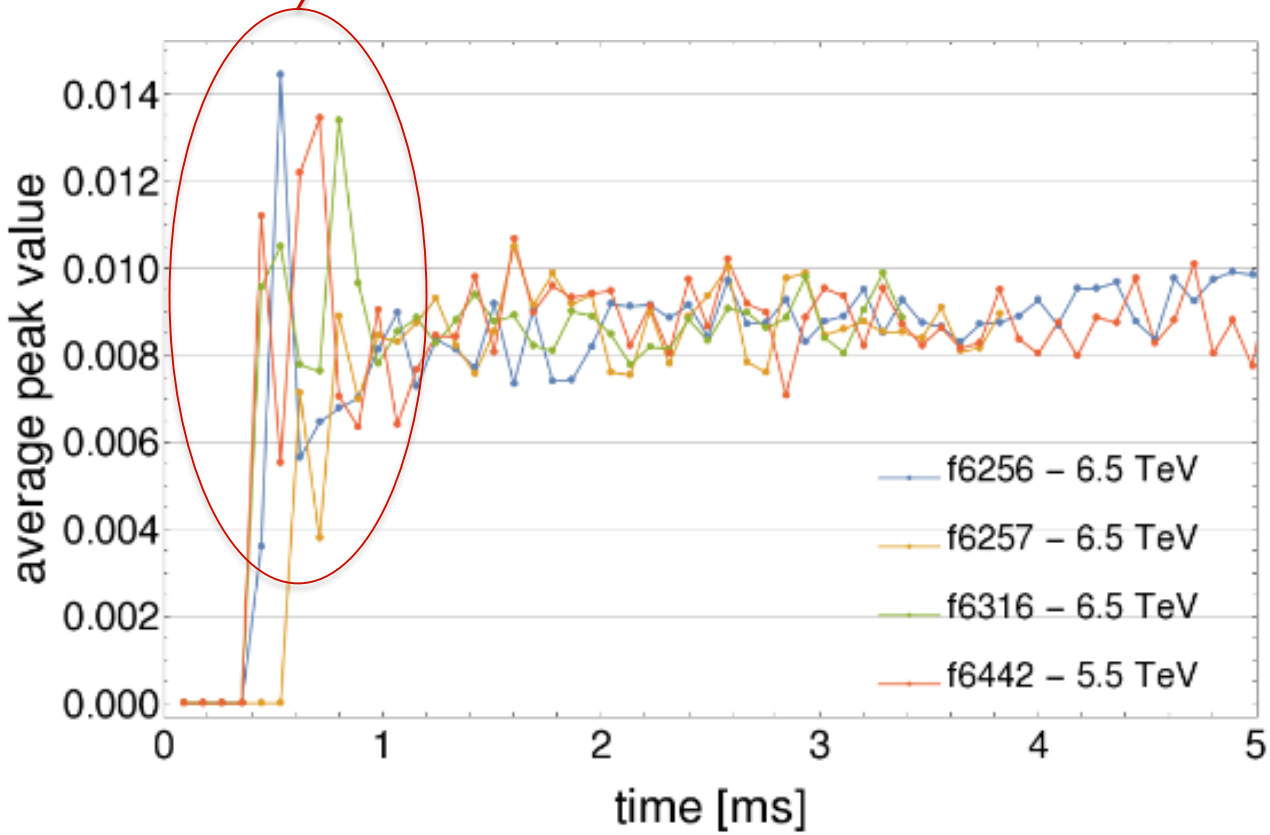
1916 bunches in the others

Similar beam intensities (23-25e13)

Average signal per detected peak (16L2 dBLM)

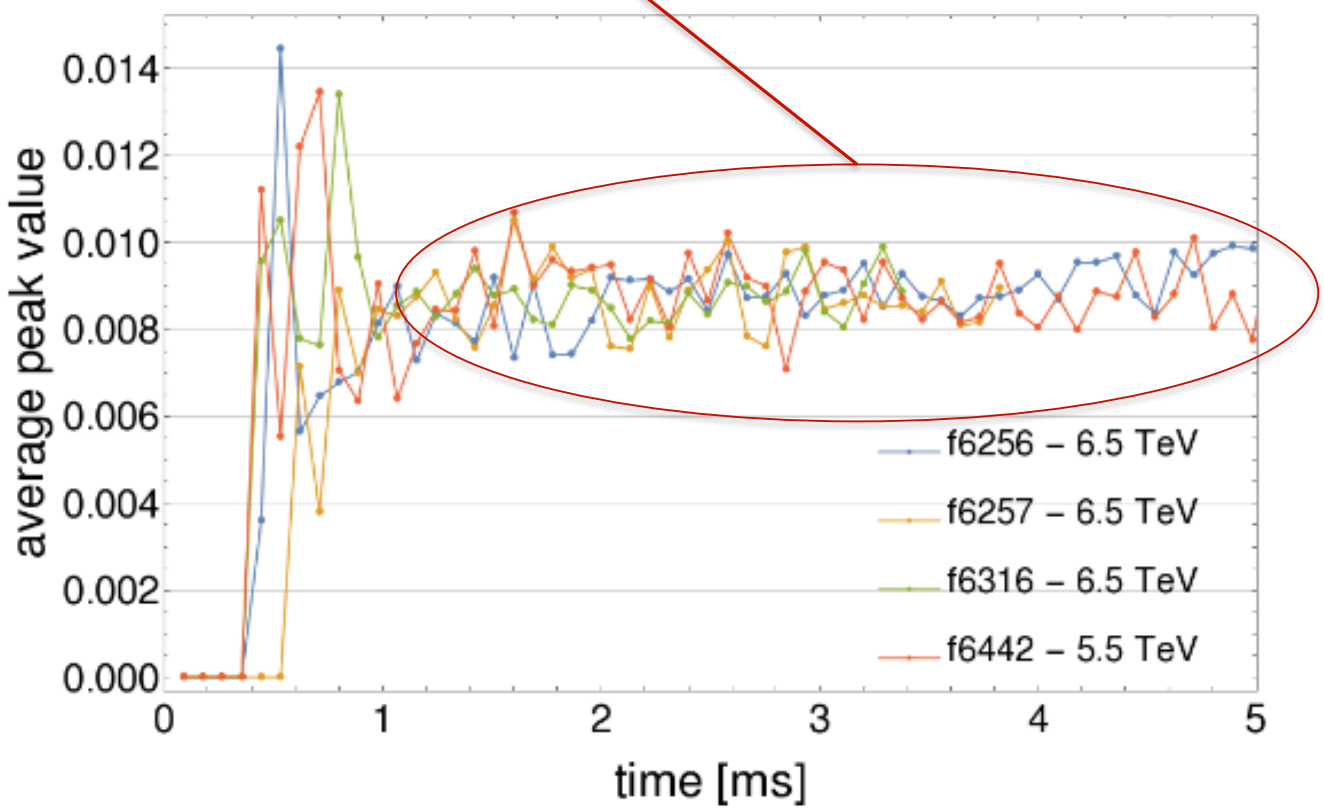
- Average value higher during UFO spike

*f6257 did not have initial UFO spike



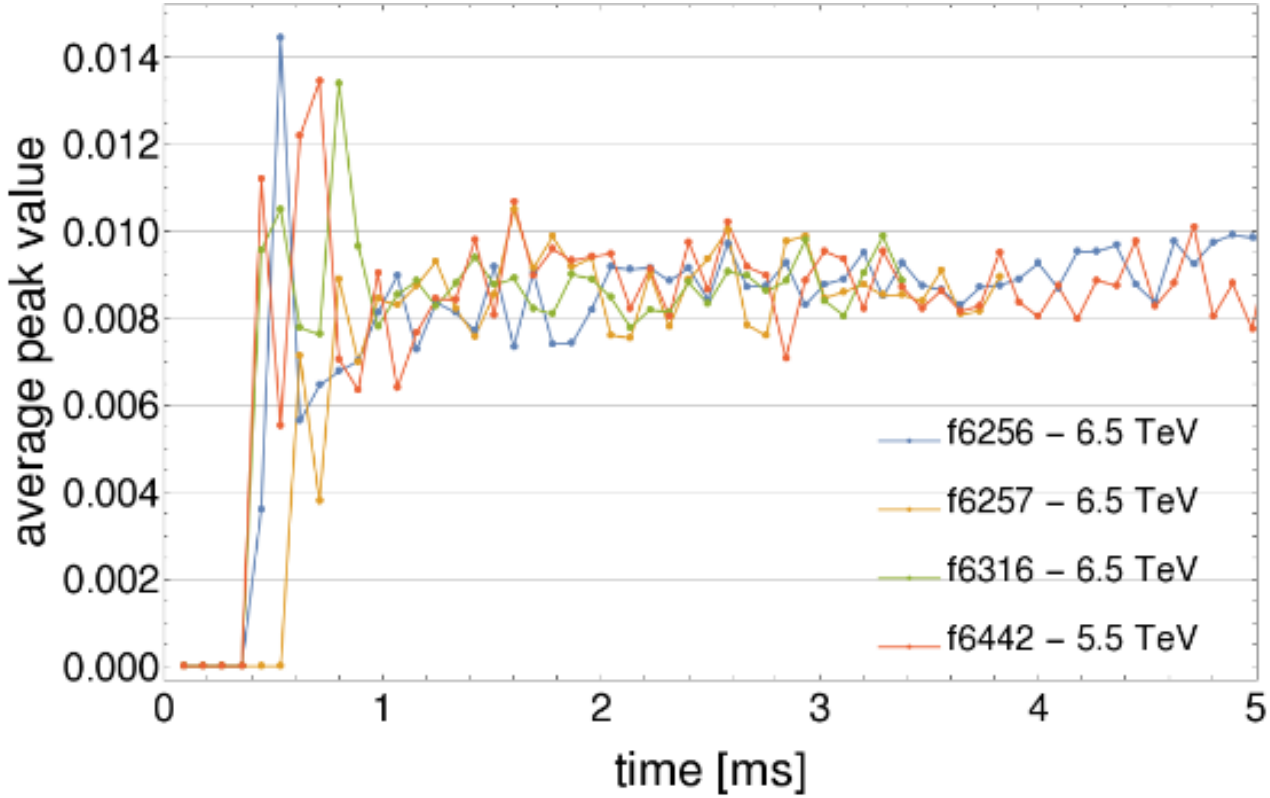
Average signal per detected peak

- Average value higher during UFO spike
- During the instability phase the contribution to higher integrated signal (in dBLM) comes from more bunches being detected, and not higher signal per bunch



Average signal per detected peak

- Average value higher during UFO spike
- During the instability phase the contribution to higher integrated signal (in dBLM) comes from more bunches being detected, and not higher signal per bunch
- Deposited energy in diamond per bunch-crossing on average the same



Conclusions

- First successful study of (real) UFO movement with blown-up bunches and fast loss detection system
- UFO particle was moving in **vertical plane** and **did not enter beam core** before being repelled/evaporated
- MD was comparable with other 16L2 events, but relatively slow
  - Possible explanation that solenoid was off in MD event

Outlook

- Further compare MD event with simulation model
- Further studies of UFOs possible using IR7 diamonds and ”normal” UFOs
  - Detectable in IR7 (contrary to 16L2 type UFOs)
  - Blown-up non-colliding bunches
  - Early in the year for high UFO rate

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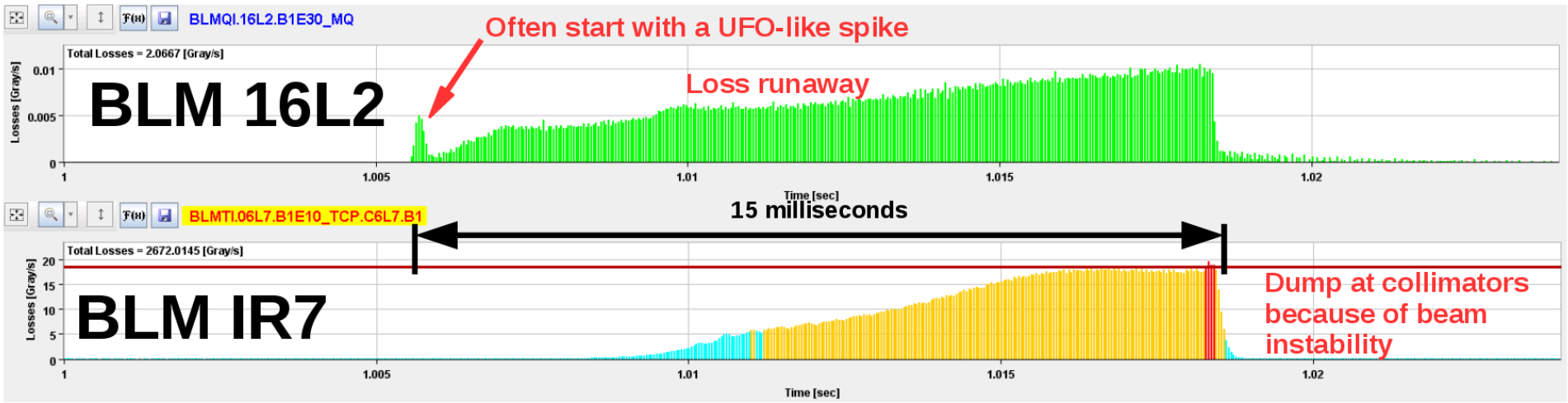
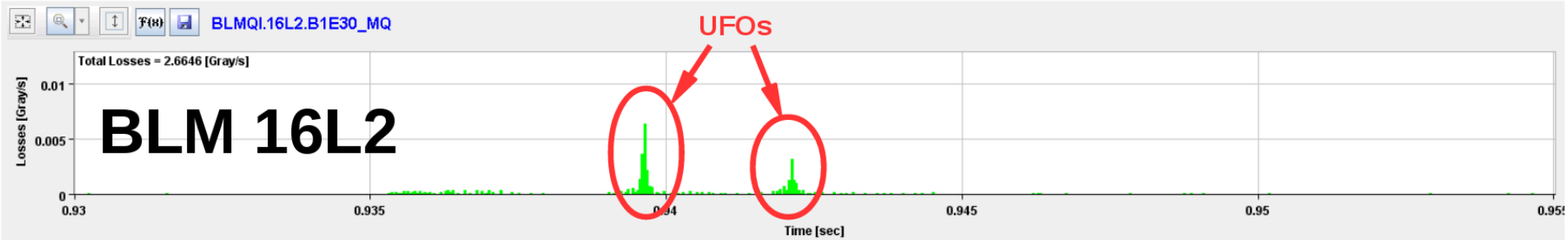
Recap on 16L2 events

- 16L2 refers to loss events in an interconnection in LHC sector 16L2
- Three types:
  - Steady state losses
  - UFO-like losses causing beam instability (fast loss rise, beam dump, quench)
  - UFO-like losses not causing instabilities (do not dump)



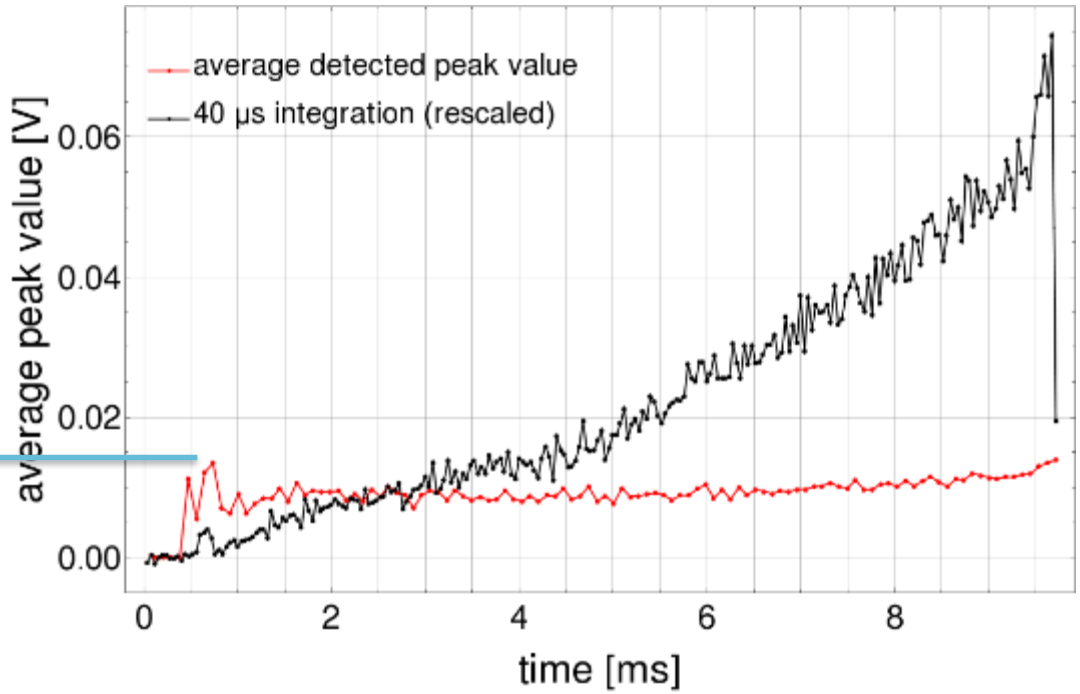


Courtesy of A.Lechner

UFO average signal per detected peak

- Average value higher during UFO spike
- During the instability phase the contribution to higher integrated signal (in dBLM) comes from more bunches being detected, and not higher signal per bunch

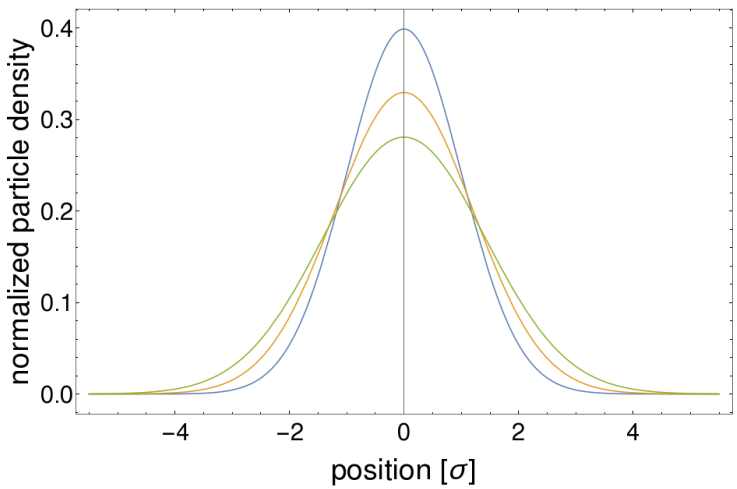
50 % higher



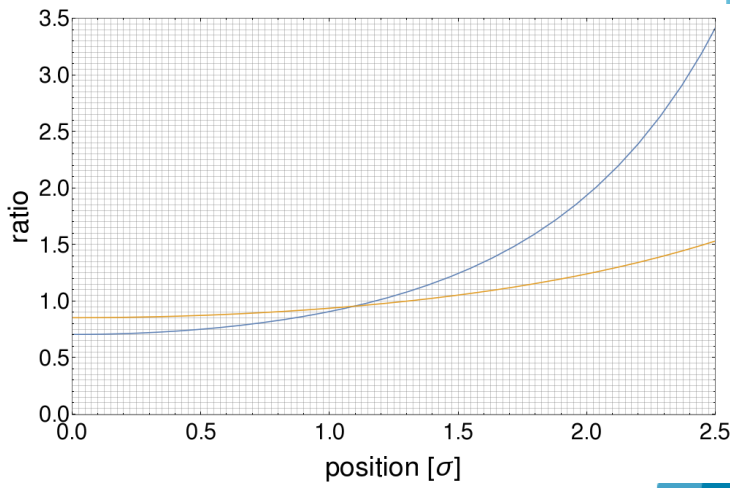
UFO dynamics simulation model

- By assuming a bunch distribution, the position of the UFO particle can be estimated for different moments in time
- Can be compared with the predictions of the simulation model
- Ongoing work

Bunch distribution

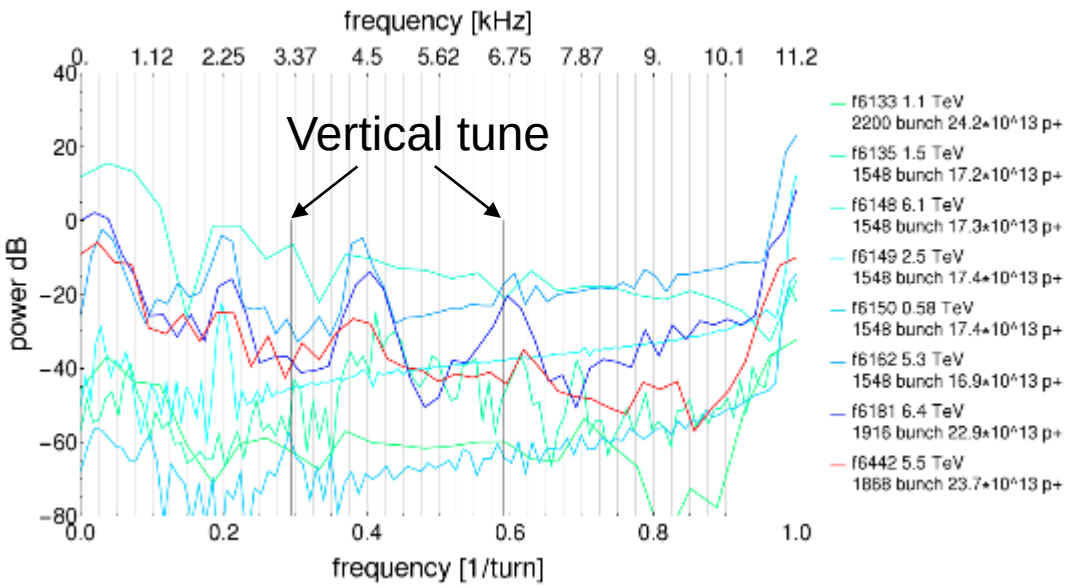


Ratio between bunch signal gives position



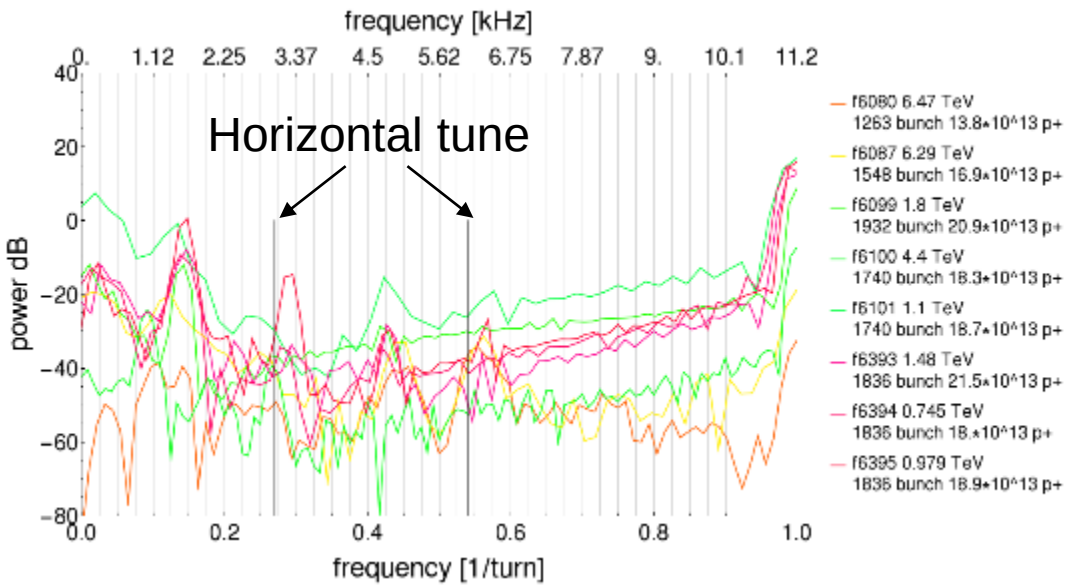
Spectral analysis of IR7 losses – b1

- A peak at ~2x betatron tune present in most fills (expected, since TCP has two jaws, giving twice the frequency as a bunch oscillates transversally)
- A peak at ~0.2 (=5 turn period) and ~0.4 is present for b1
  - Unexplained, has not been reported from ADT ObsBox data

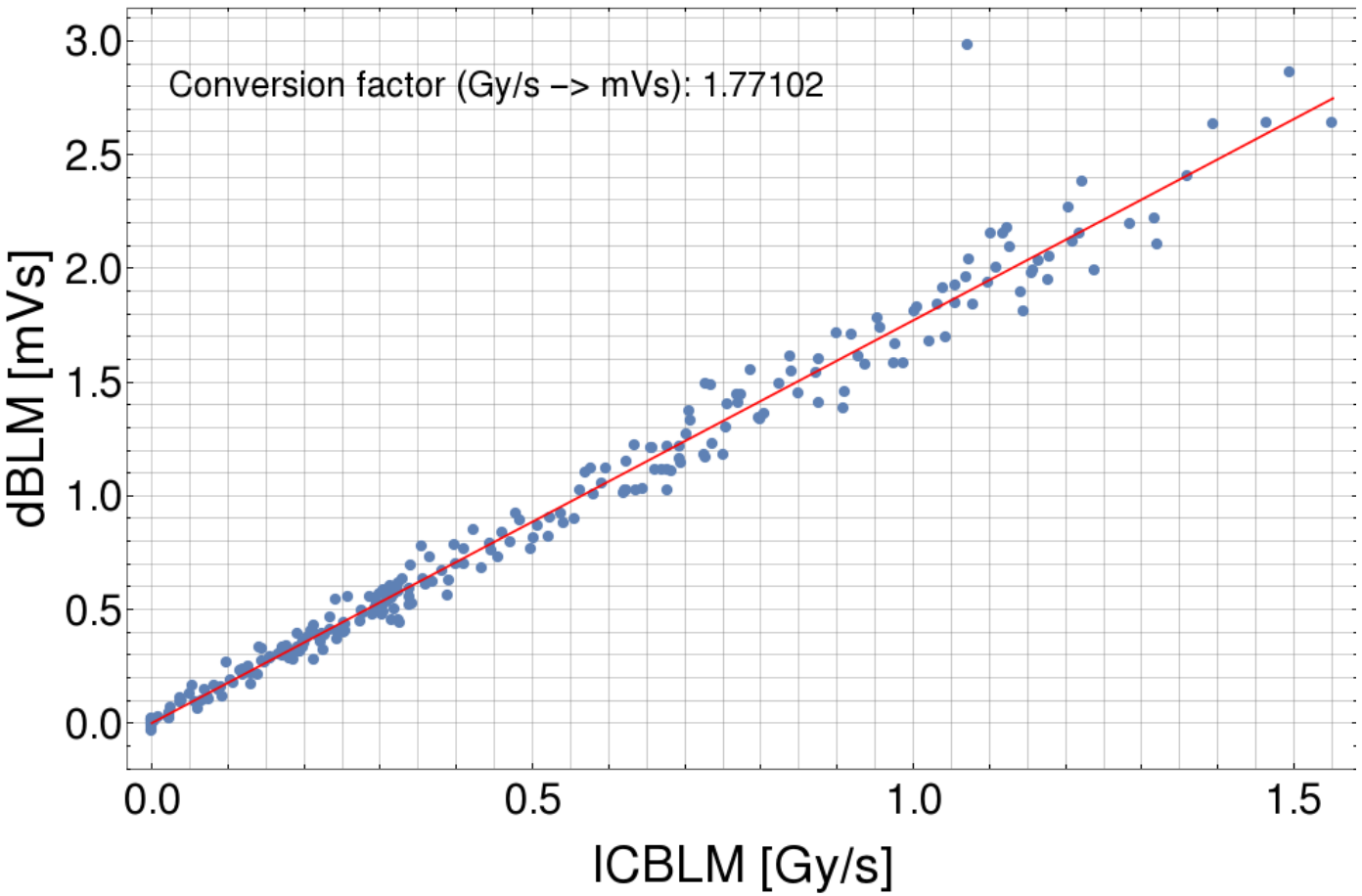


Spectral analysis of IR7 losses – b2

- In b2, peaks are seen at ~0.15 and ~0.3

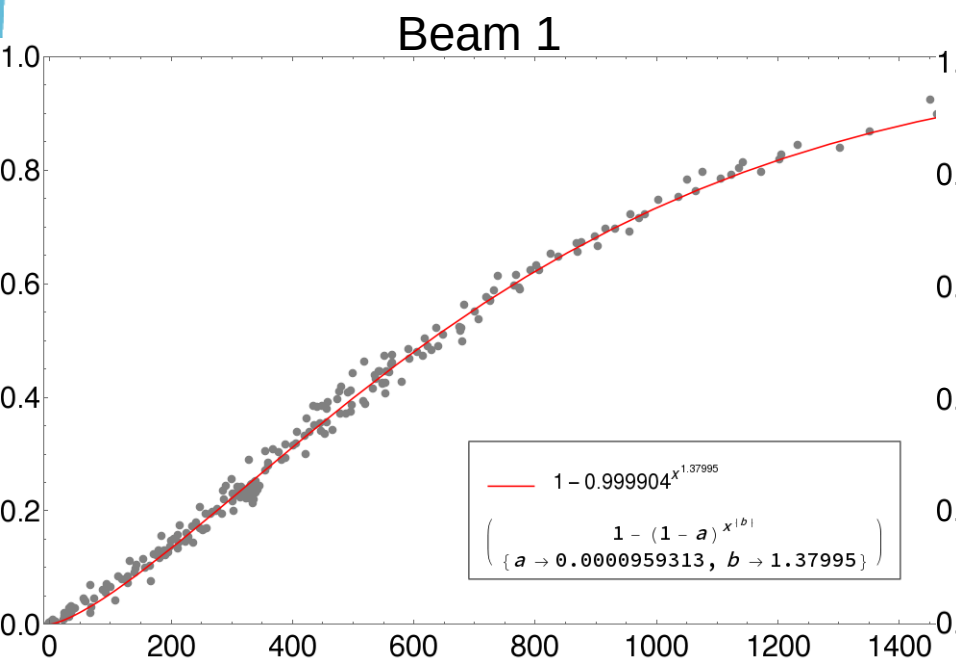


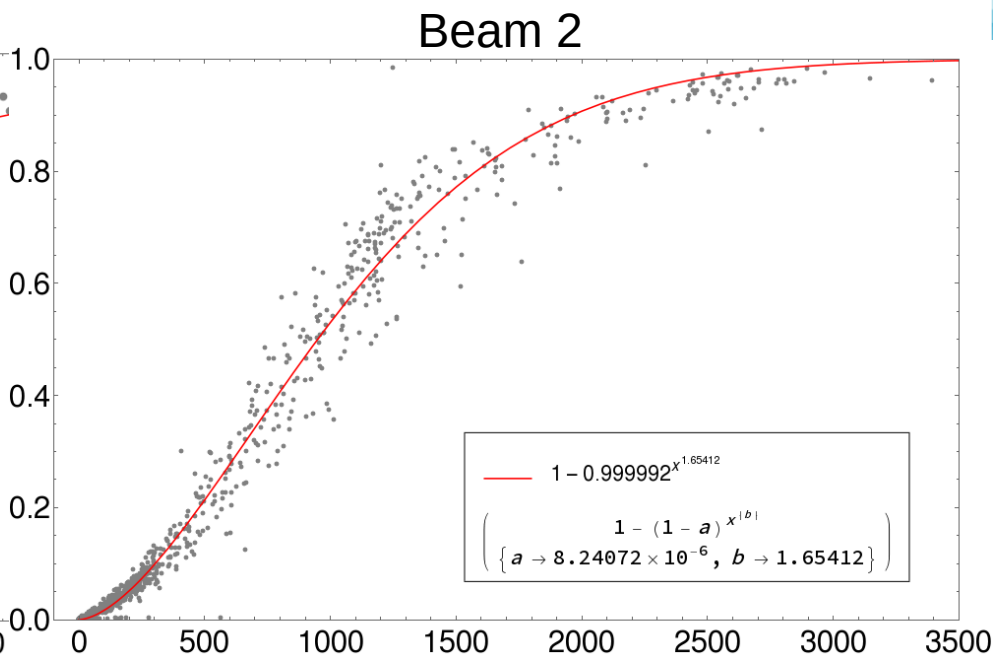
dBLM / ICBLM signal



Bunch Detection Probability

- Plotting ratio detected bunches vs ICBLM signal for all events shows good consistency between events
- Approximately linear for low losses
- For some probability p that a scattered proton leads to signal, the total detection probability is $p_{eff} = 1 - (1-p)^{x/c}$, where x is the total signal as measured by ICBLM and c is the average signal per detected bunch
  - However, for a good fit an exponent to the signal x is necessary
- Important to understand this for planning future measurements and modelling the time evolution of the event





Statistical test of losses during UFO-spike

Null hypothesis: Detection rate of vertically blown-up bunches is the same as of reference bunches
Assuming a constant probability that a bunch will be detected and that all bunches are independent (detection of one does not affect detection of others) -> **Binomial distribution**
Can use **a z test** to test the null hypothesis (since the number of bunches is large),

Test statistic $z = \frac{\widehat{p_1} - \widehat{p_2}}{\sqrt{\hat{p}(1-\hat{p})(\frac{1}{n_1}+\frac{1}{n_2})}}$

where p-hat is the estimated probability (ratio of detected bunches), n the number of bunches and

$$\hat{p} = \frac{n_1\widehat{p_1} + \mathrm{n}_2\widehat{p_2}}{n_1 + n_2}$$

for critical region $Z > \Phi^{-1}(1 - \frac{\alpha}{2}) \wedge \Phi^{-1}(\frac{\alpha}{2})$

Averaging over the UFO spike, the Z value for comparing vertically blown up with normal is 4.27, leading to significance level < 0.0001

Conclusion: measurement is statistically significant, vertically blown up bunches are more probable to detect during the UFO-spike