First results of UFO type 1 dynamics studies

Measurements and initial observations

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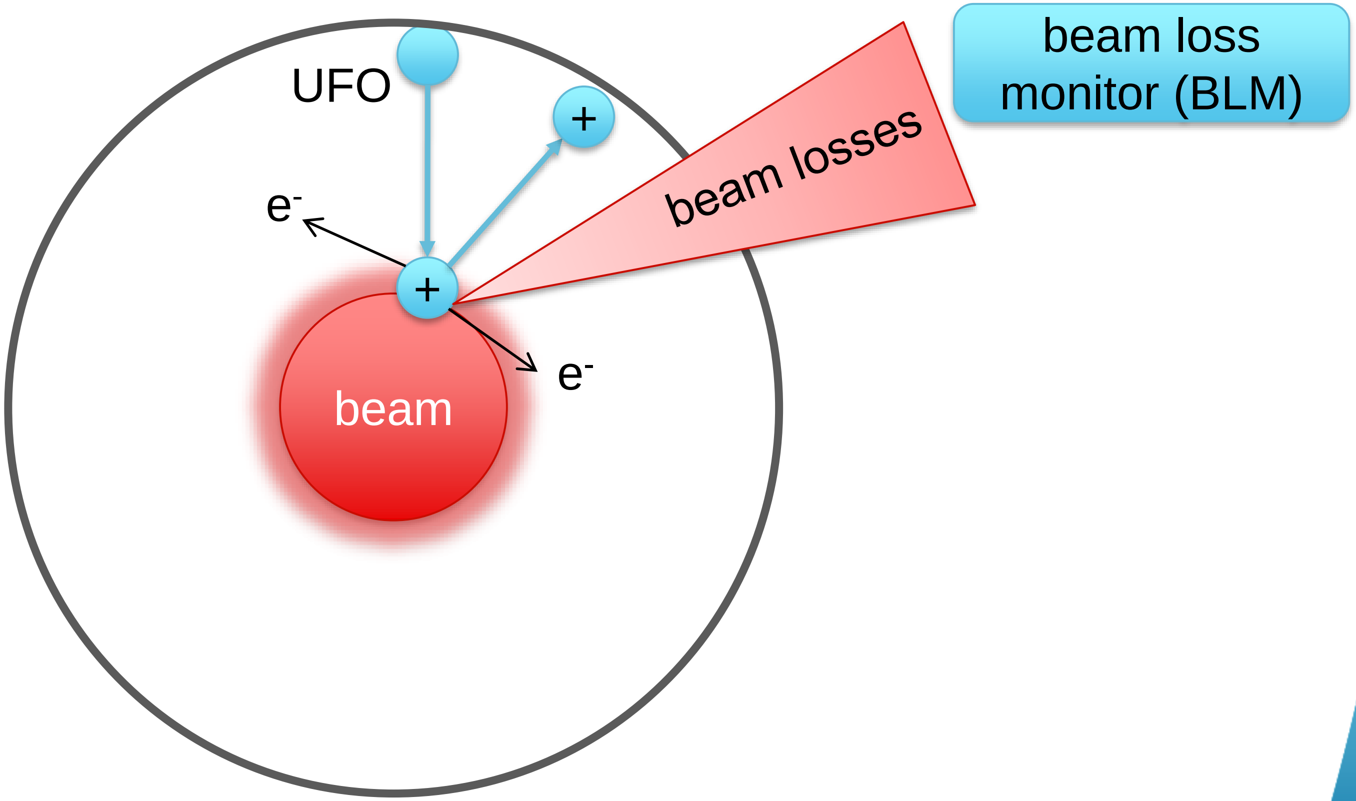
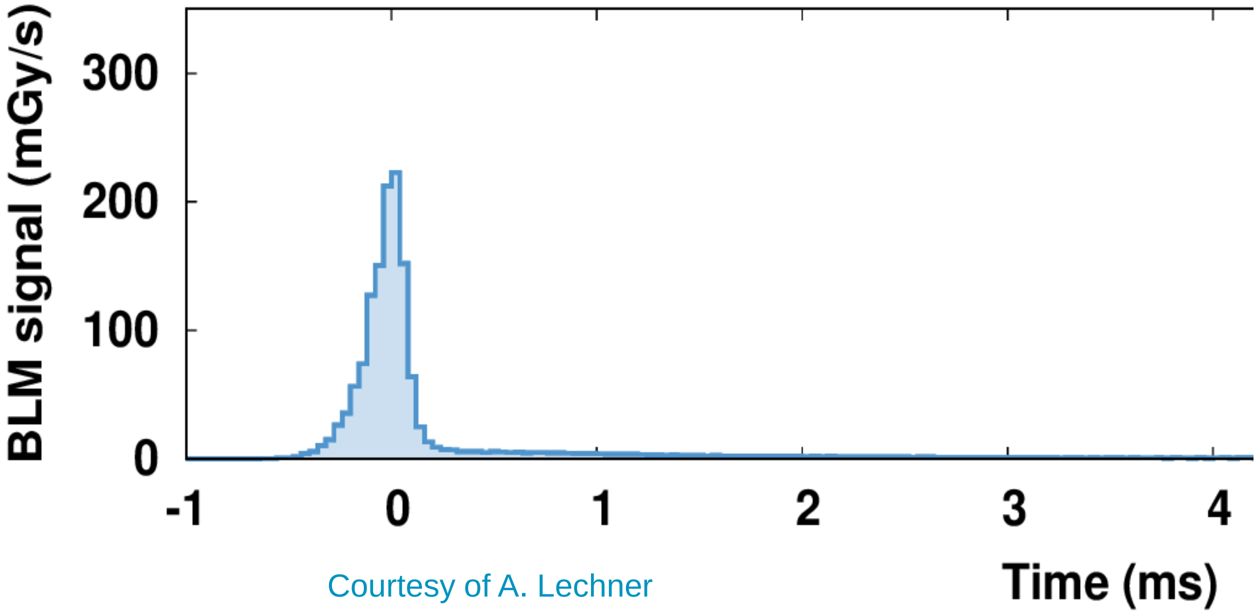
Beam-macroparticle interaction

- Dust particle falls into beam
- Intense Beam losses, duration ~1 ms
- Premature beam dumps and superconducting magnet quenches
    - **-> up to 12 hours downtime!**



UFO induced beam losses

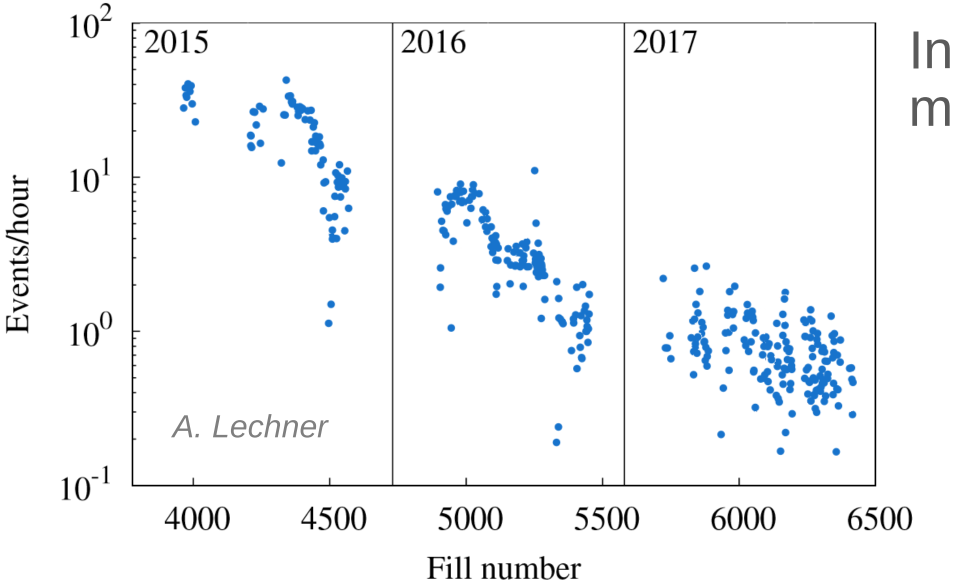
- Dust particle falls into beam
- Intense beam losses, duration ~1 ms
- Premature beam dumps and superconducting magnet quenches
  - **-> up to 12 hours downtime!**



Courtesy of A. Lechner

UFO impact on availability

LHC first proton accelerator to suffer from their impact



In 2017, new type of UFO at specific magnet interconnect

- different loss pattern
- **67** premature beam dumps (out of **~350** total)
- **significant impact on availability**
- Also seen in 2018

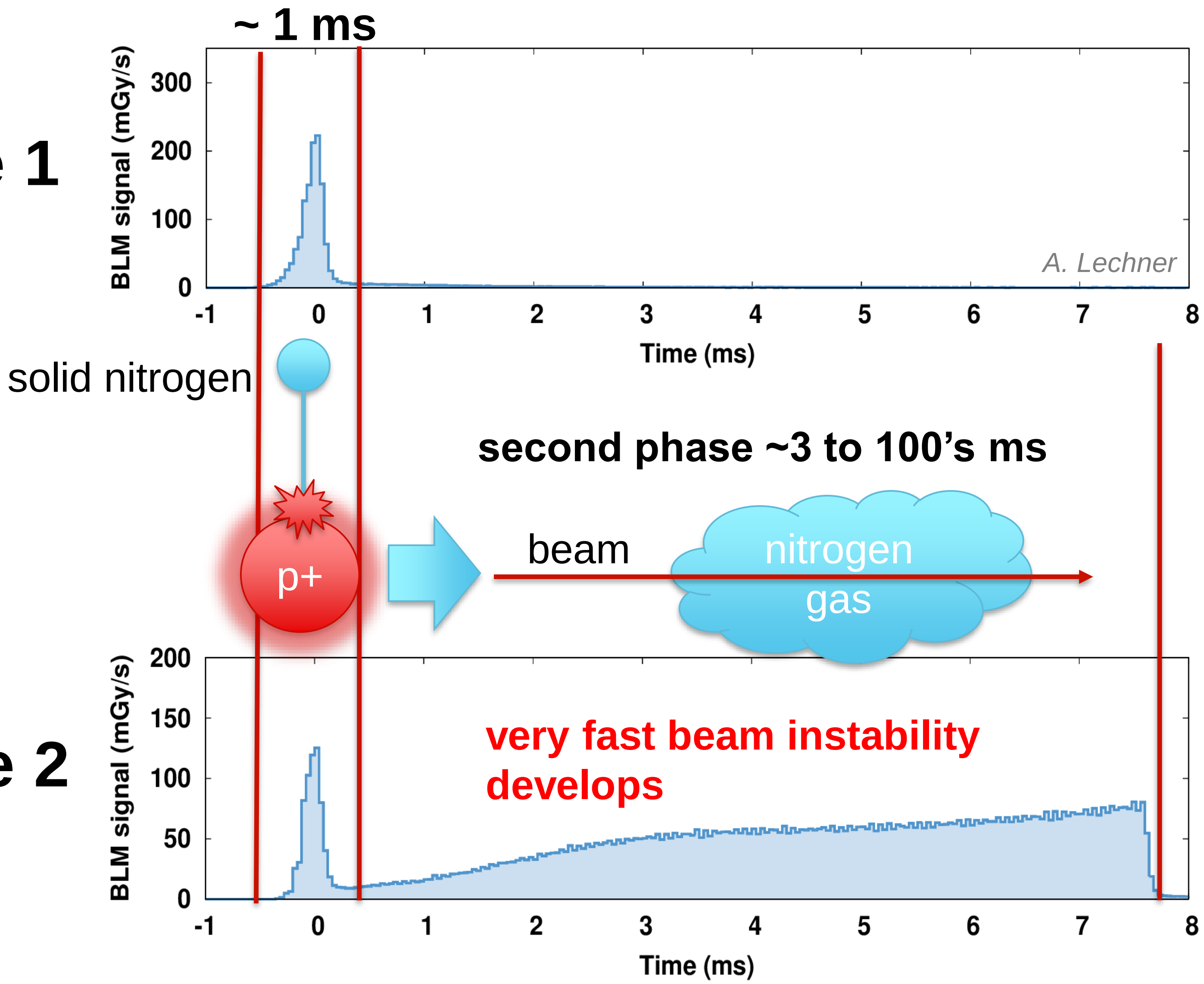
Still many unknowns, impact expected to increase in future (higher beam energy, higher beam intensity...)

Understanding their dynamics important clue for employing countermeasures

UFO types

Type 1

Type 2



~ 1 ms

second phase ~3 to 100's ms

very fast beam instability develops

UFO types

Type 1

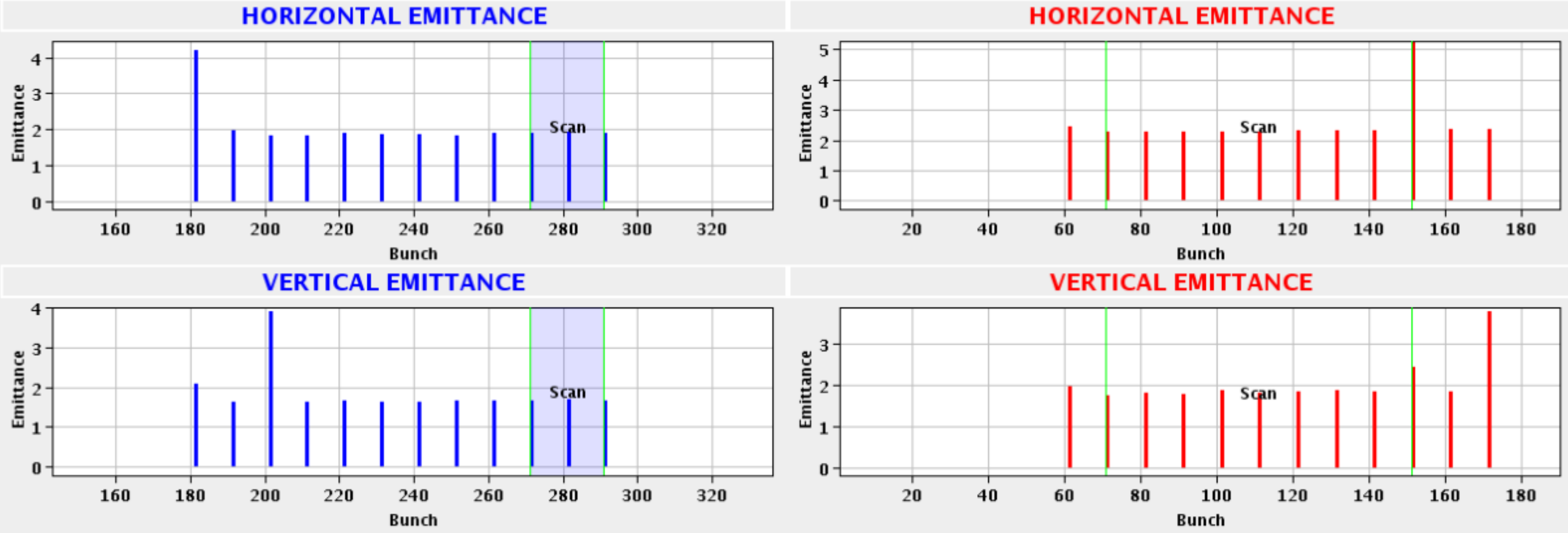
- Traditional type, present since high-intensity operations
- Short loss spike (~1 ms)
- Sporadic
- Along the entire length of the LHC

Type 2

- Present at specific magnet interconnect (16L2)
- Hypothesis: caused by frozen nitrogen macroparticle
  - Contamination of beam vacuum by air at 16L2 confirmed
- Fastest observed beam instability in the LHC

UFOs at end of run 2 proton physics

- Special beam configuration during ~3 weeks of normal physics fills
  - In non-colliding 12b train, two blown-up bunches: one horizontally, one vertically
- Number of events during this time: 14
  - Confirmed by existing UFO detection system: 7
- 3 at top energy, rest at 1096-4522 GeV



Beam loss monitors

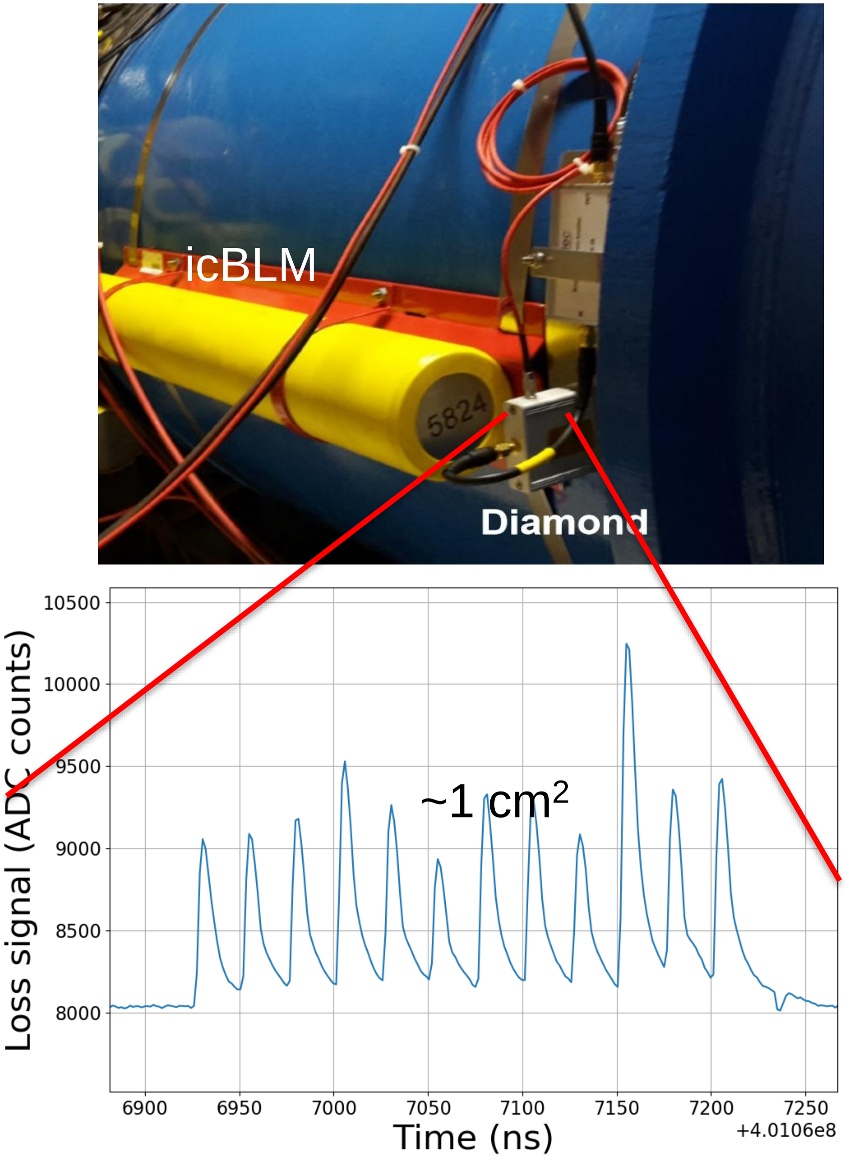
icBLM

- Good signal to noise ratio
- 3600 distributed around ring
- 40 μs temporal res

dBLM

- Low signal to noise ratio, fluctuating signal
- 2 per beam at primary collimators

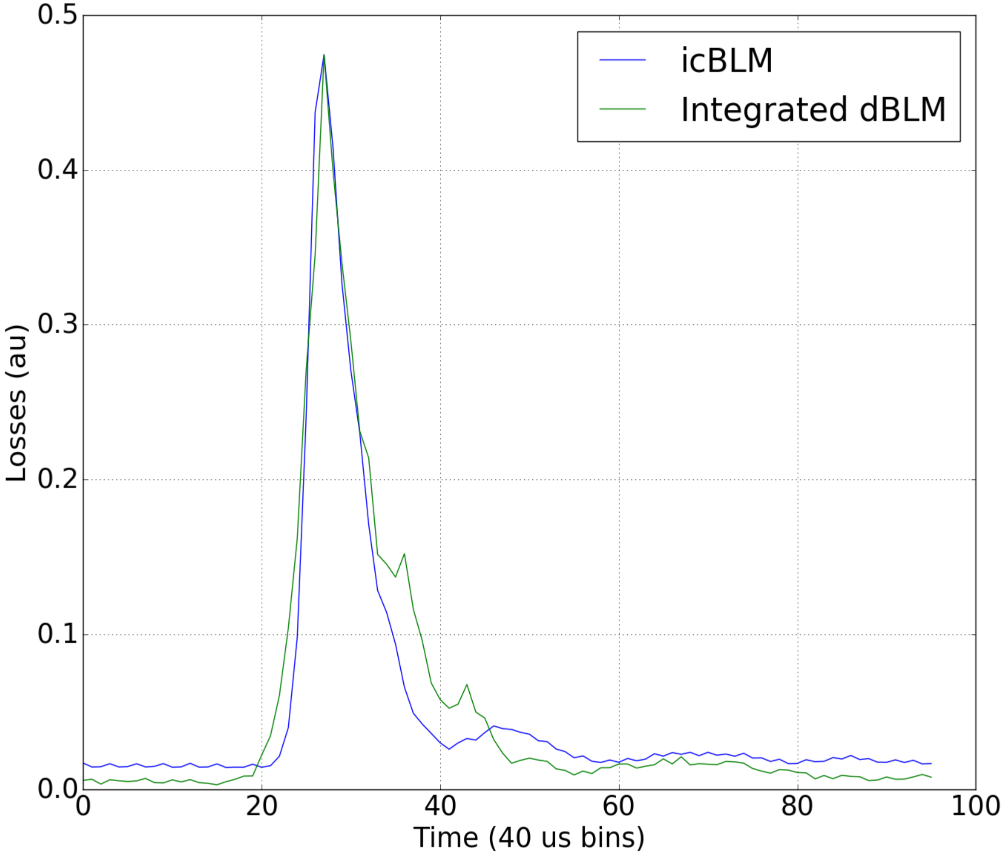
1.5ns temporal resolution



icBLM vs dBLM correlation (30 Sep 2018)

icBLMs are a trusted system

dBLM signal integrated in 40 us bins correlates well with icBLM data

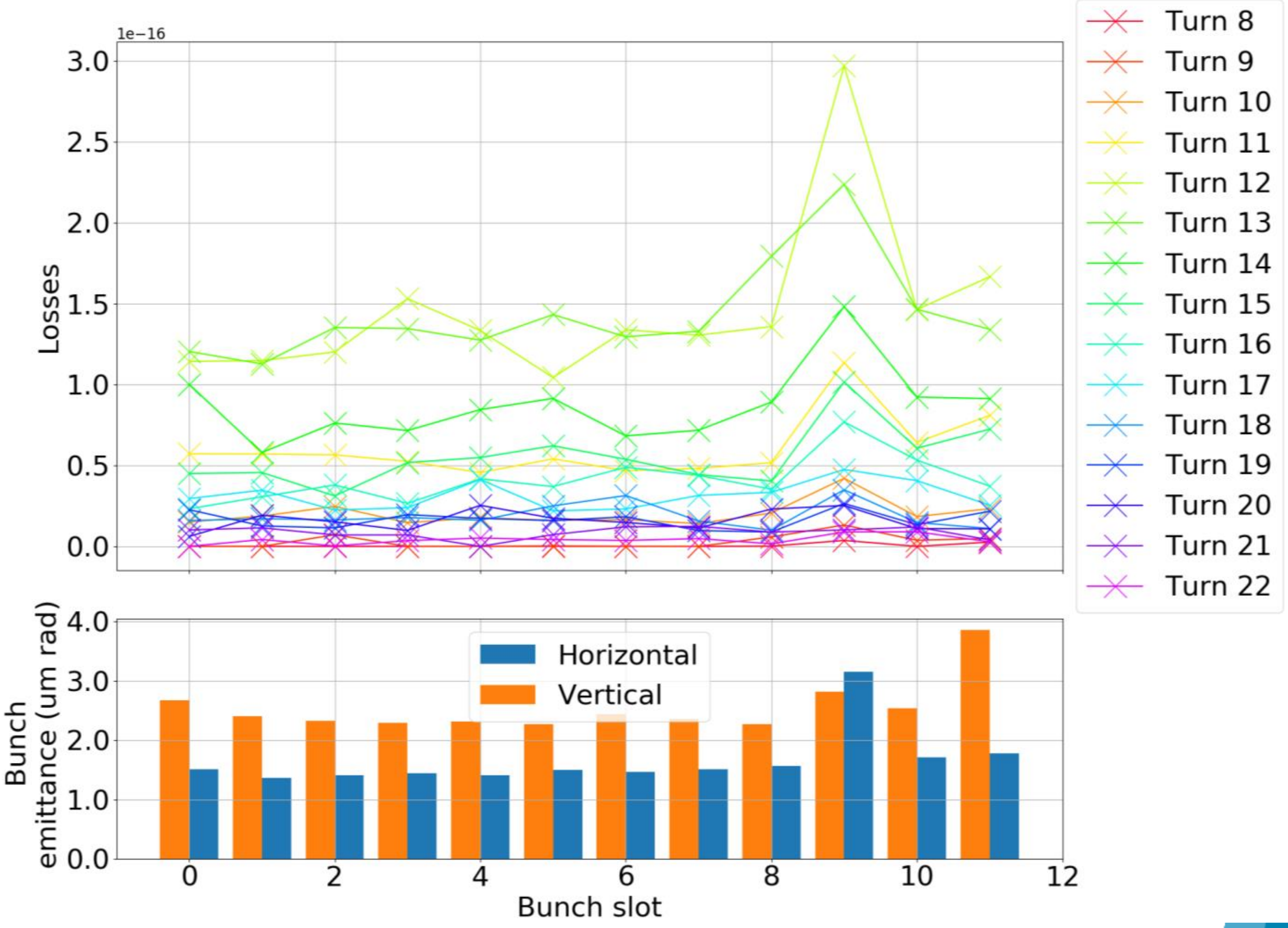


Turn by turn, bunch by bunch losses (30 Sep 2018)

Elevated losses in horizontally blown-up bunch

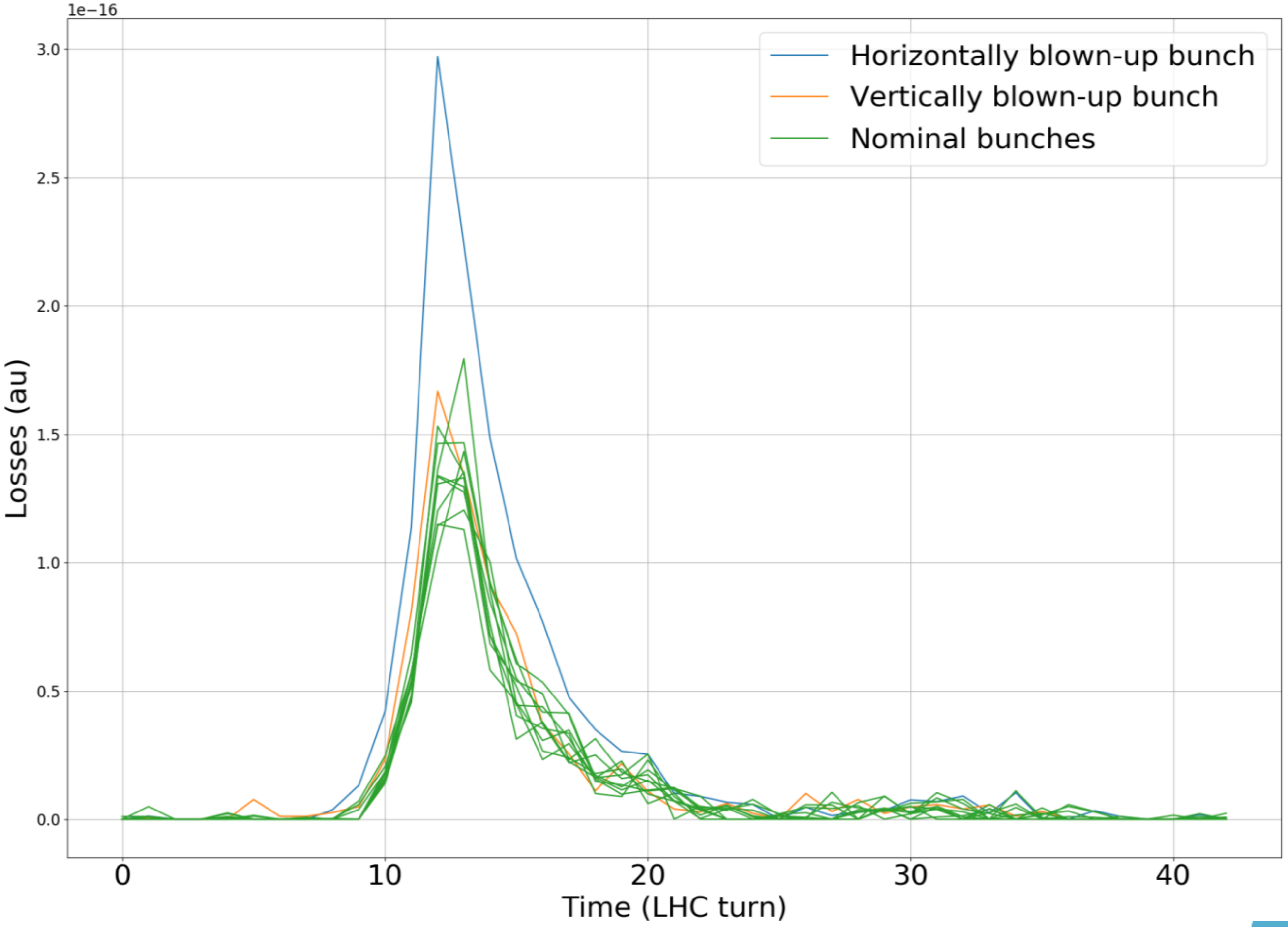
High amplitude, long event

Best signal we had



Bunch-by-bunch losses (30 Sep 2018)

Losses highest and longest-lasting in horizontally blown-up bunch

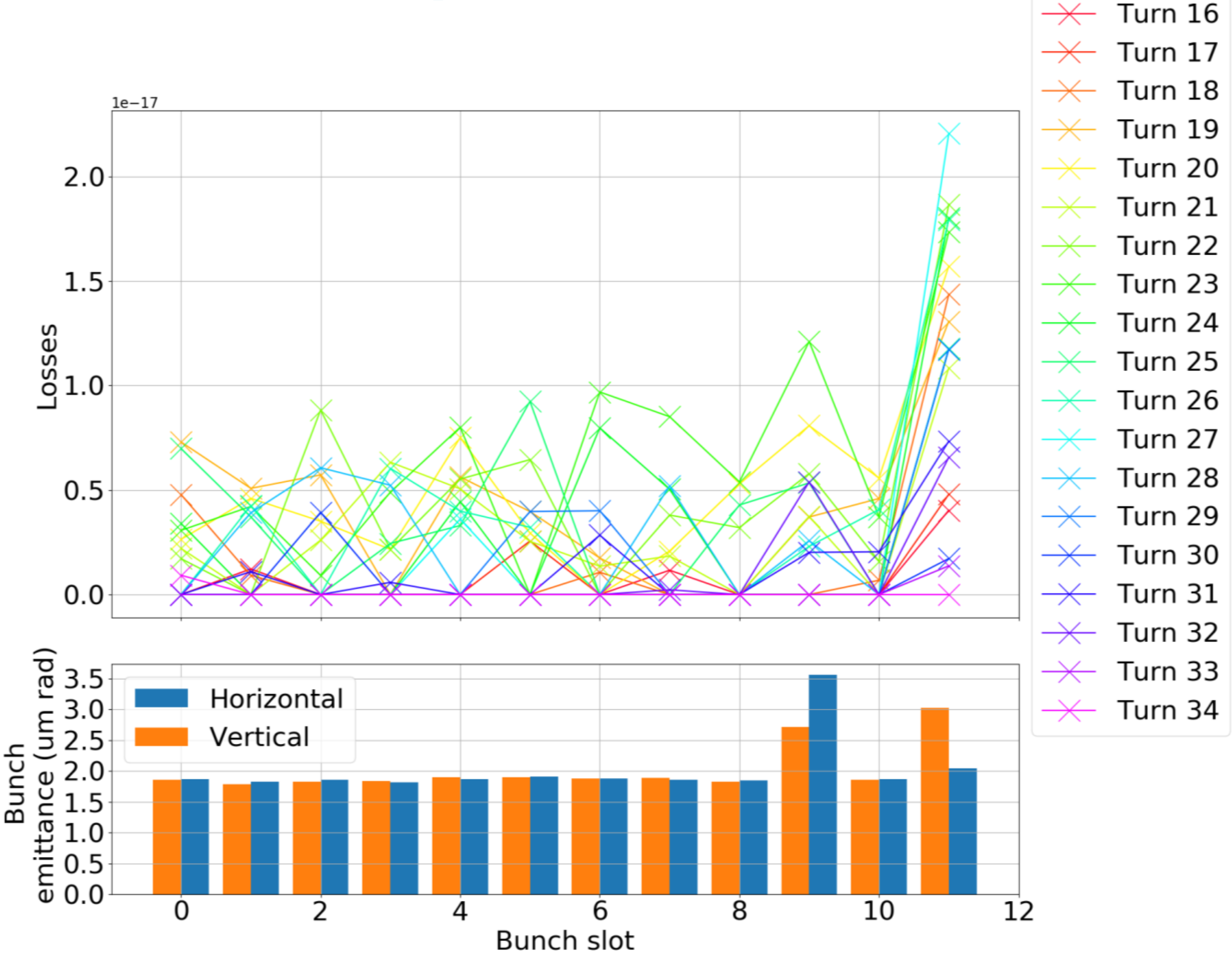


Turn by turn, bunch by bunch losses (17 Oct 2018)

Elevated losses in vertically blown-up bunch

Losses in other bunches very low

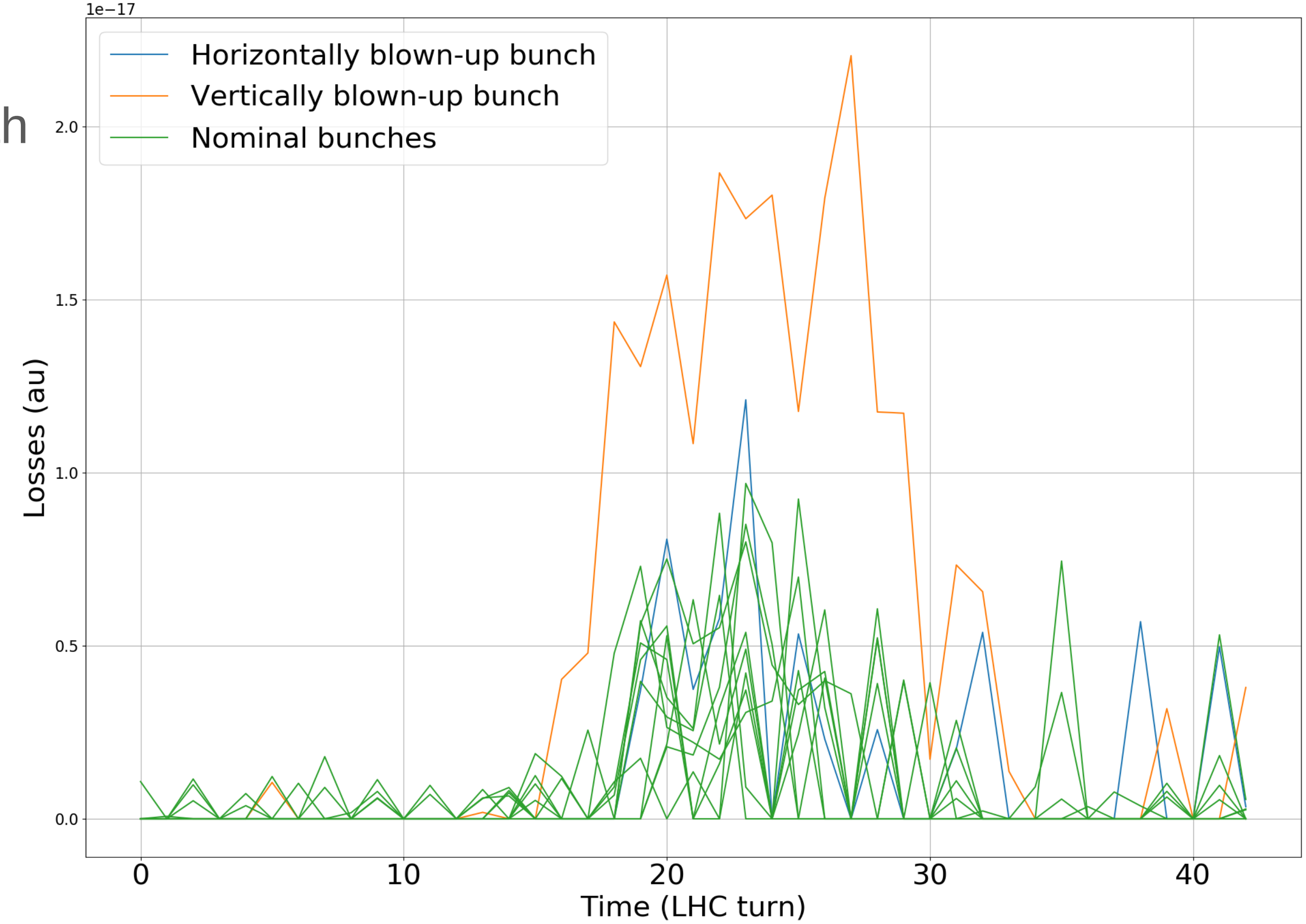
At the limit of what we can observe



Bunch-by-bunch losses (17 Oct 2018)

Longest event with increased losses from vertically blown-up bunch

Note: factor ~10 lower signal than in previous event



Insight into UFO dynamics

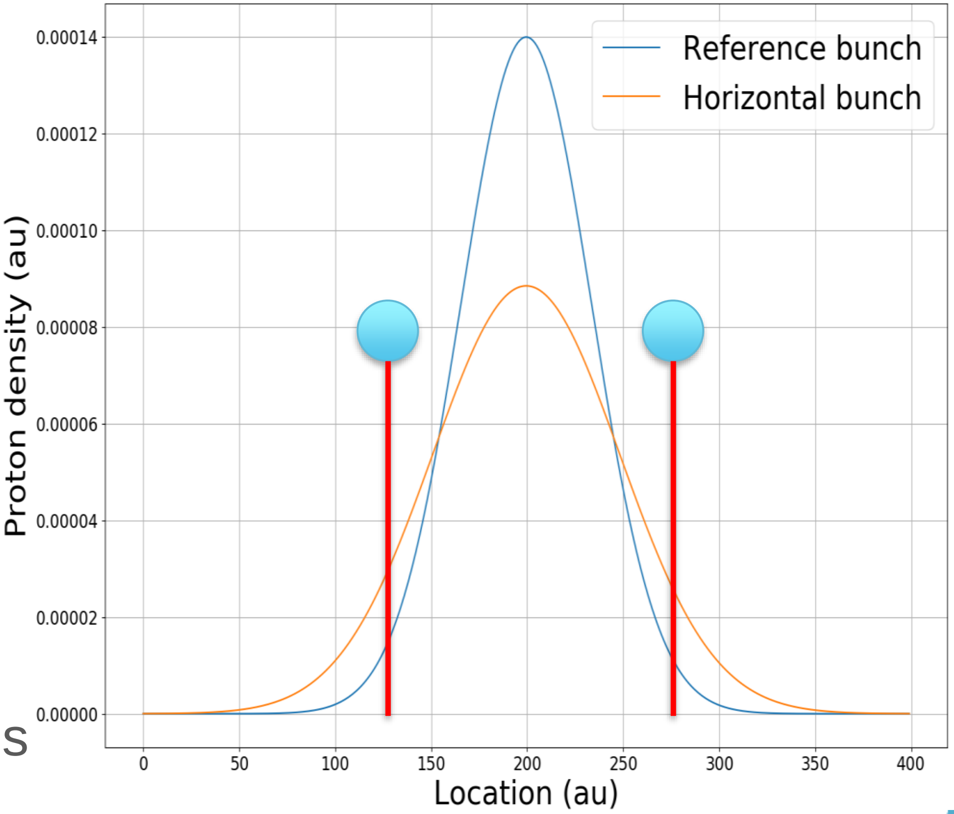
Aim is to study UFO dynamics

We want to reconstruct dust particle trajectory

Losses proportional to proton density

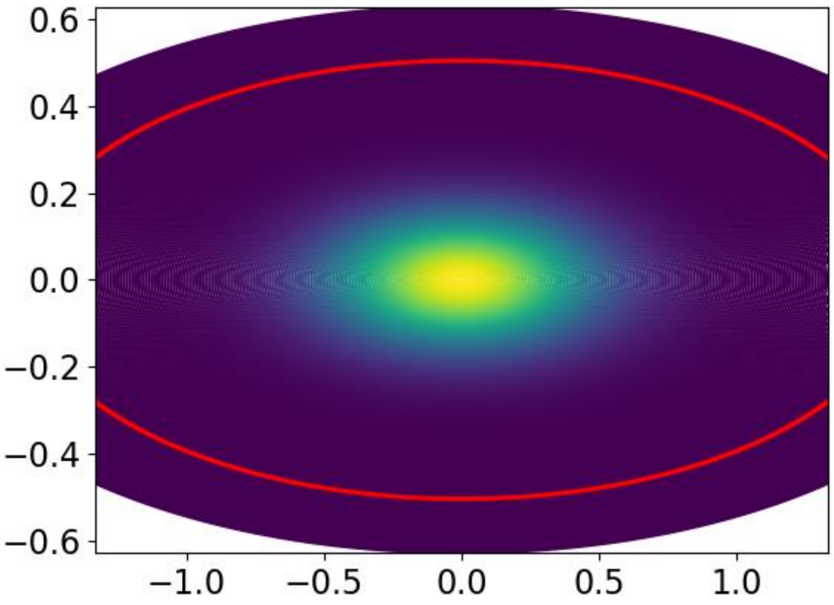
Proton density proportional to distance from beam center

If we know bunch-by-bunch losses and proton distributions, we can derive location of UFO

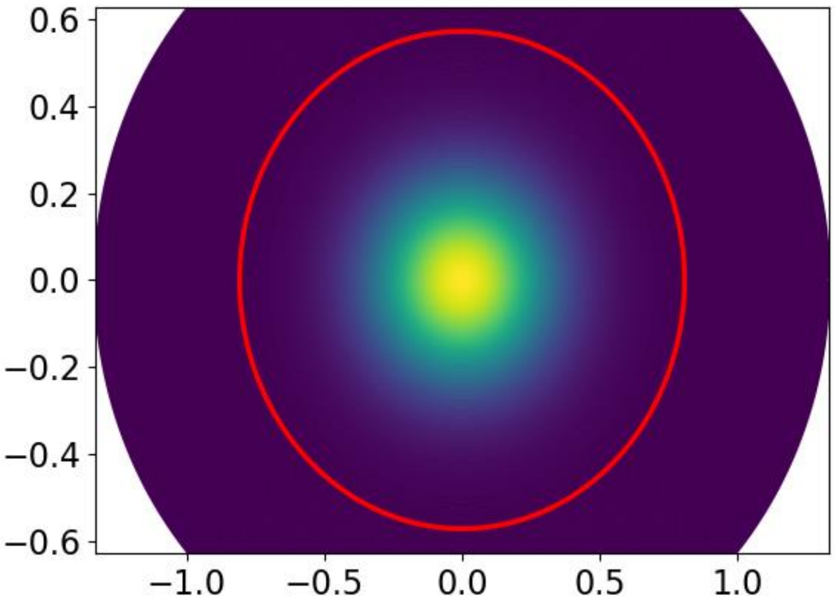


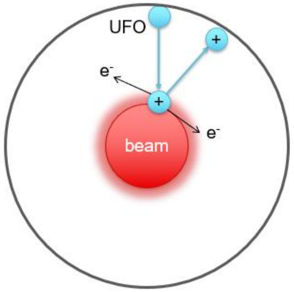
Possible locations in both planes

Location based on losses from horizontally blown-up bunch



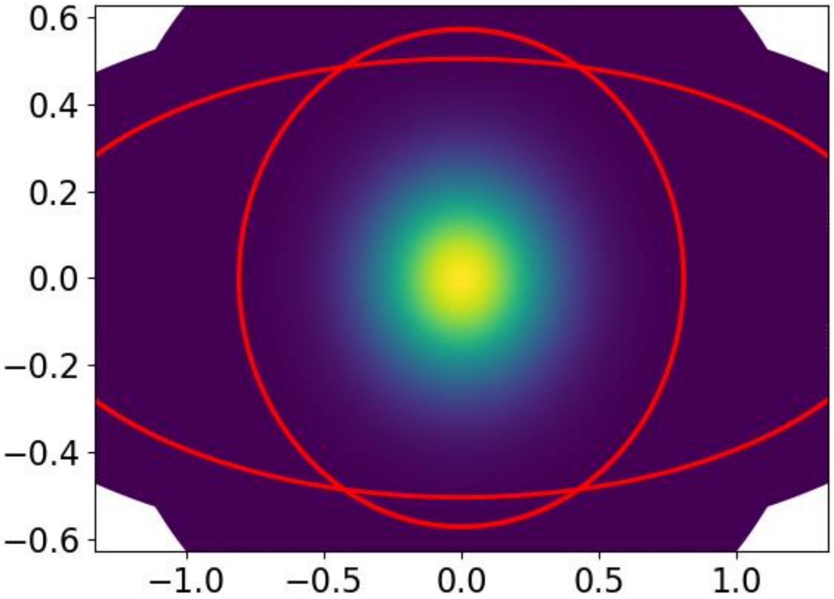
Location based on losses from vertically blown-up bunch

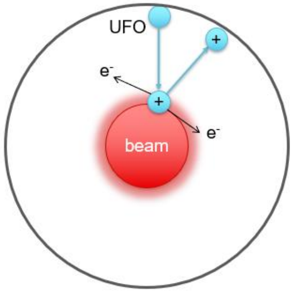




Possible locations in both planes

Intersections are possible UFO locations



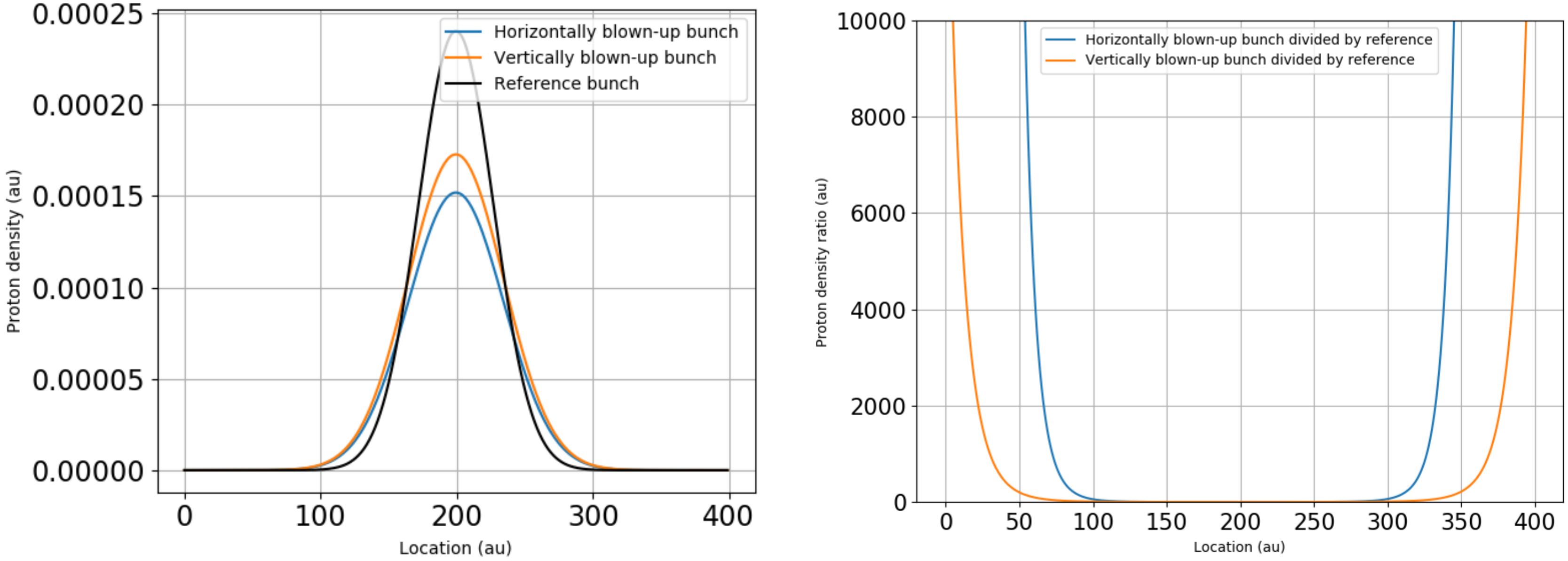


Applying the method to measurements

- Correlating BLM signal to number of protons lost difficult
- A single lost proton should still always give the same signal
- Thus, correlate ratio between loss signals of blown-up and nominal bunches to proton distributions of blown-up and nominal bunches
- Still some challenges remain:
  - Signals not clean, low signal-to-noise ratio, erratic loss spikes

Ratio of proton densities between bunches

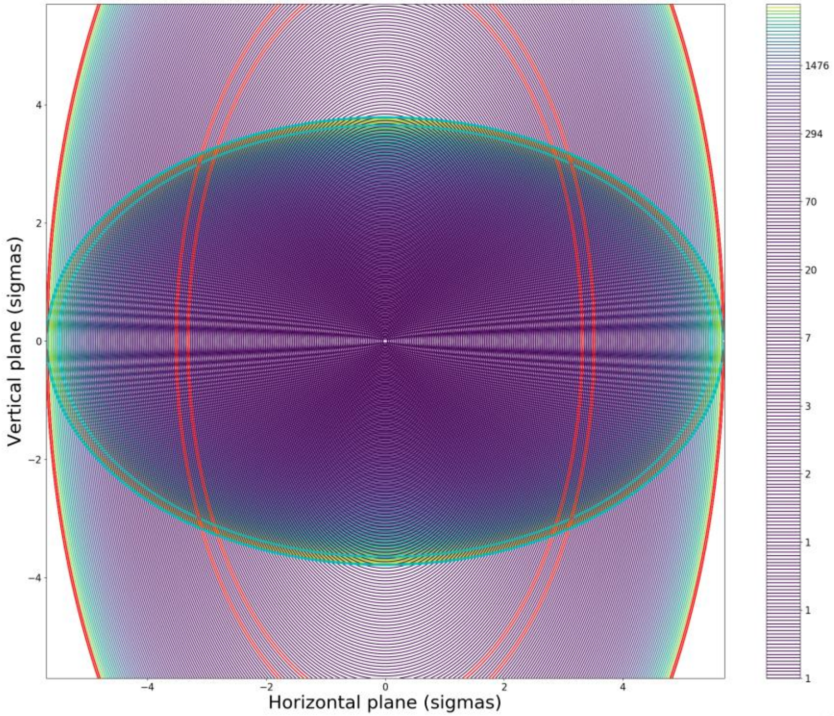
The ratio of losses between normal and blown-up bunches are measured
This is correlated to the ratio of the proton distributions, assuming they are Gaussian
 -> allows deriving the UFO location within the beam, despite not knowing the absolute loss values from each bunch



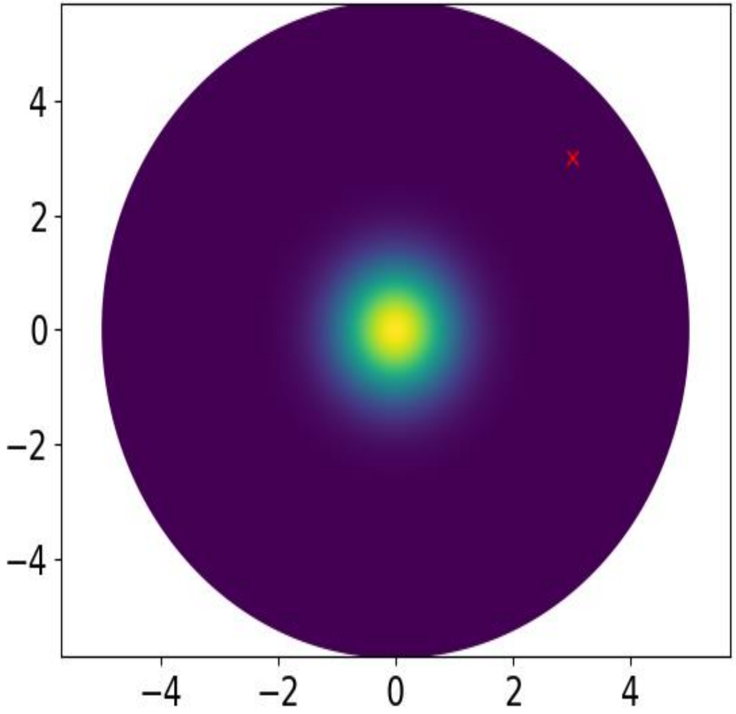
Trajectory reconstruction (30 Sep 2018)

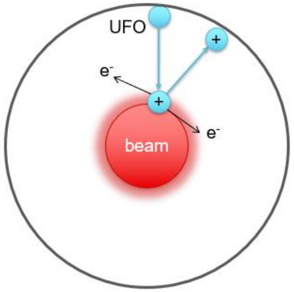
Turn 8

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



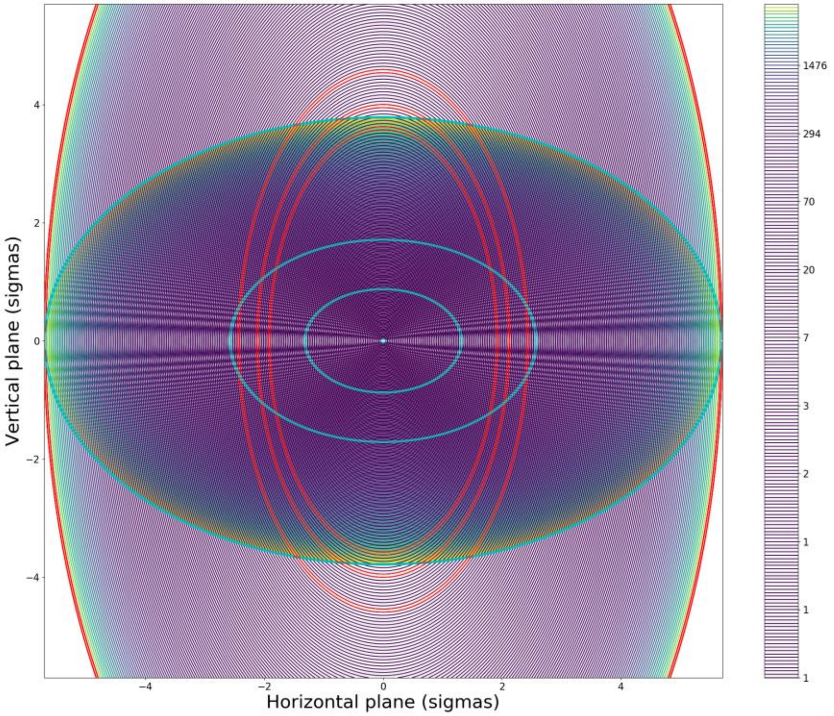


Note: just one possible trajectory within error bars!

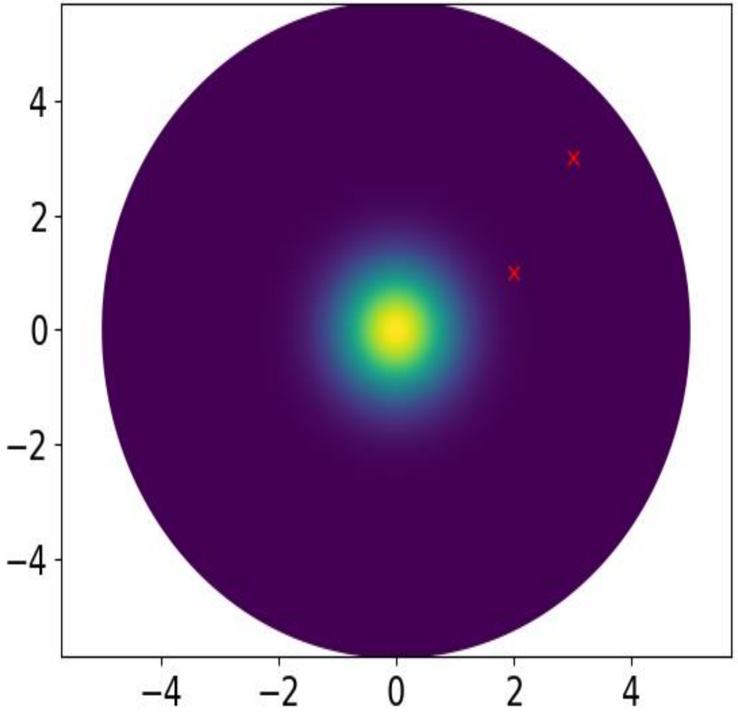
Trajectory reconstruction (30 Sep 2018)

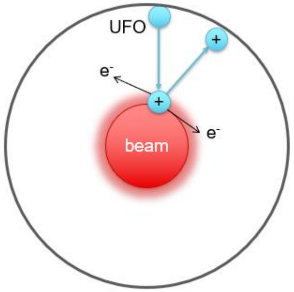
Turn 9

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



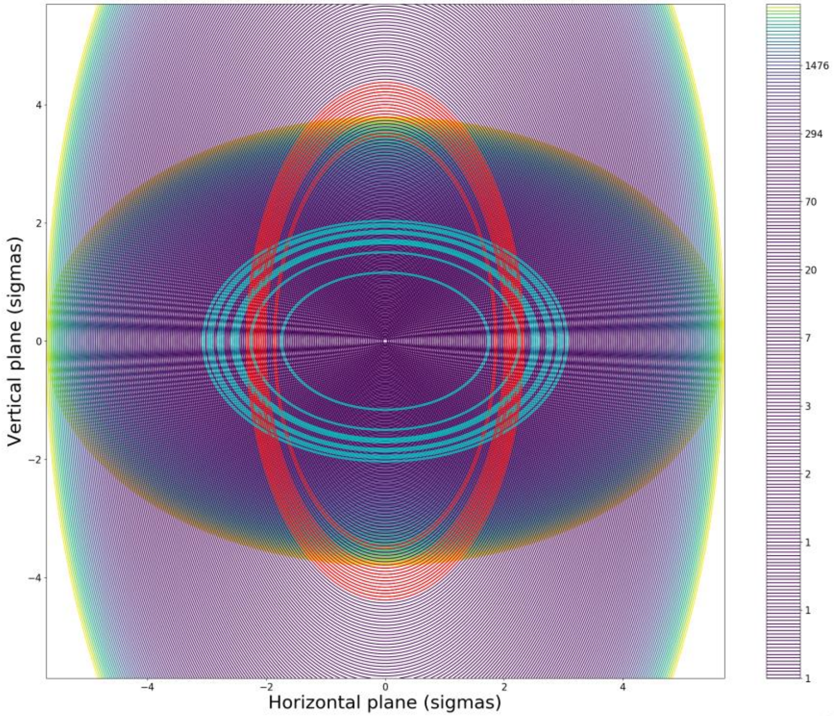


Note: just one possible trajectory within error bars!

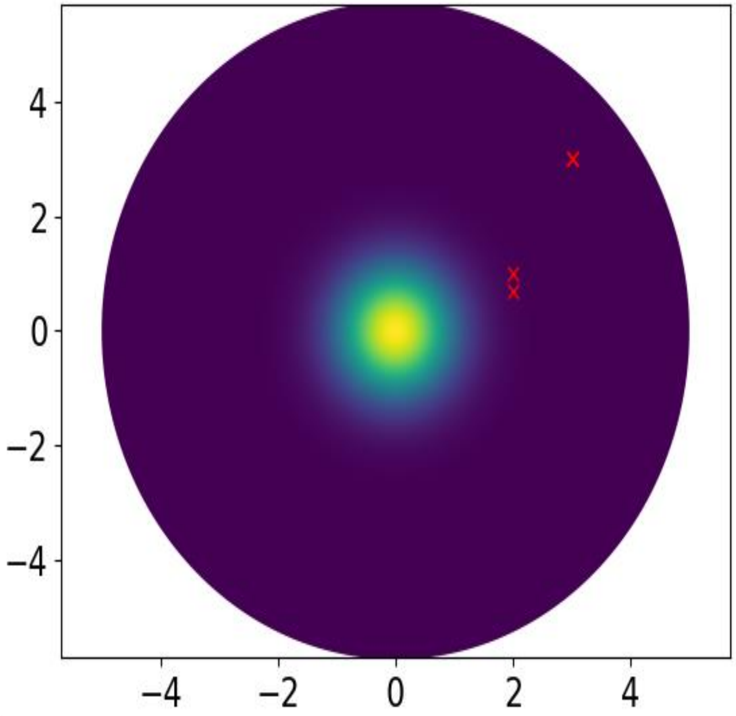
Trajectory reconstruction (30 Sep 2018)

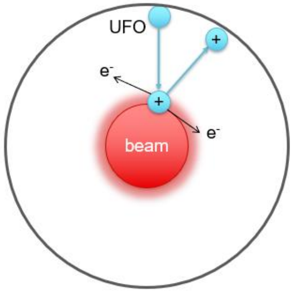
Turn 10

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



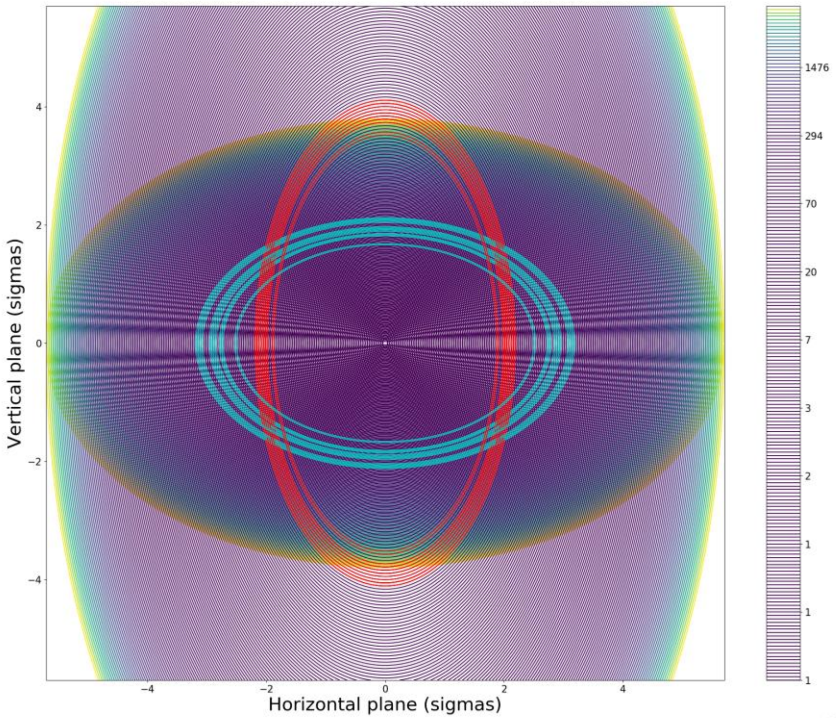


Note: just one possible trajectory within error bars!

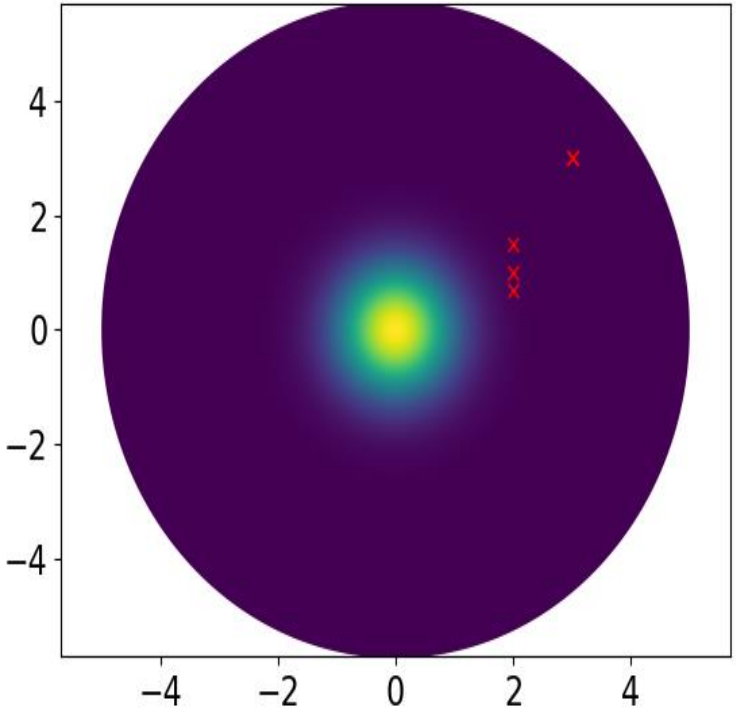
Trajectory reconstruction (30 Sep 2018)

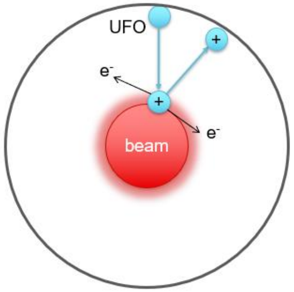
Turn 11

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



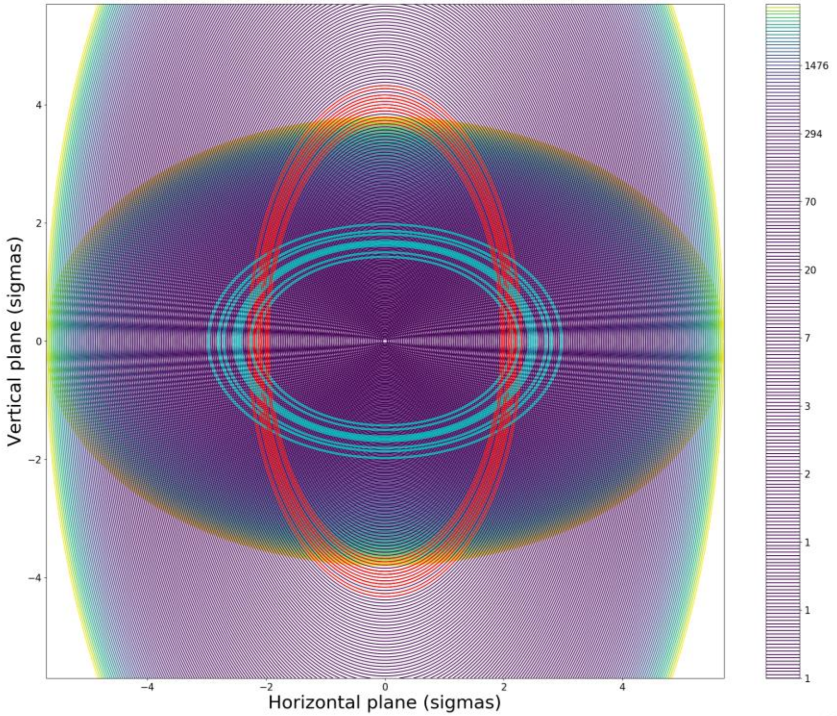


Note: just one possible trajectory within error bars!

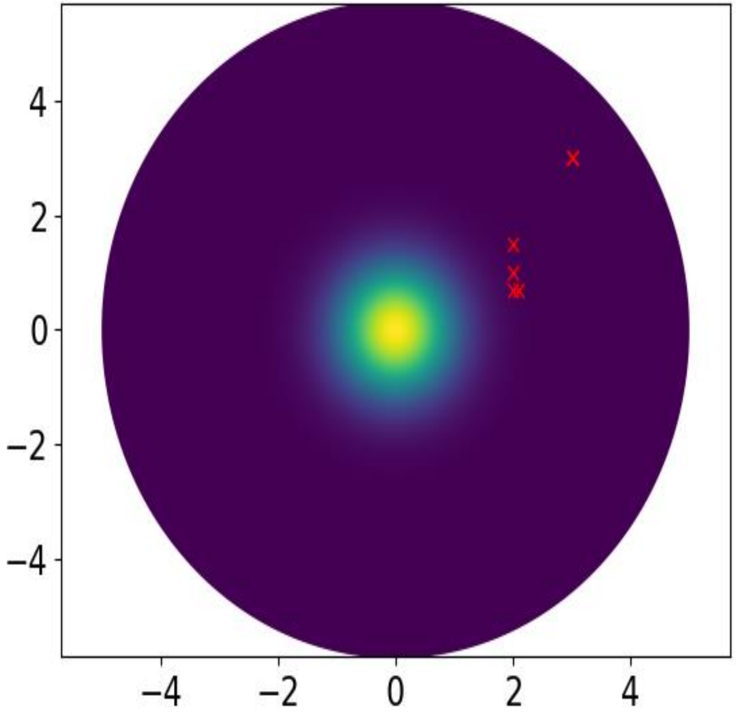
Trajectory reconstruction (30 Sep 2018)

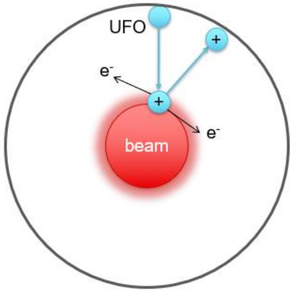
Turn 12

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



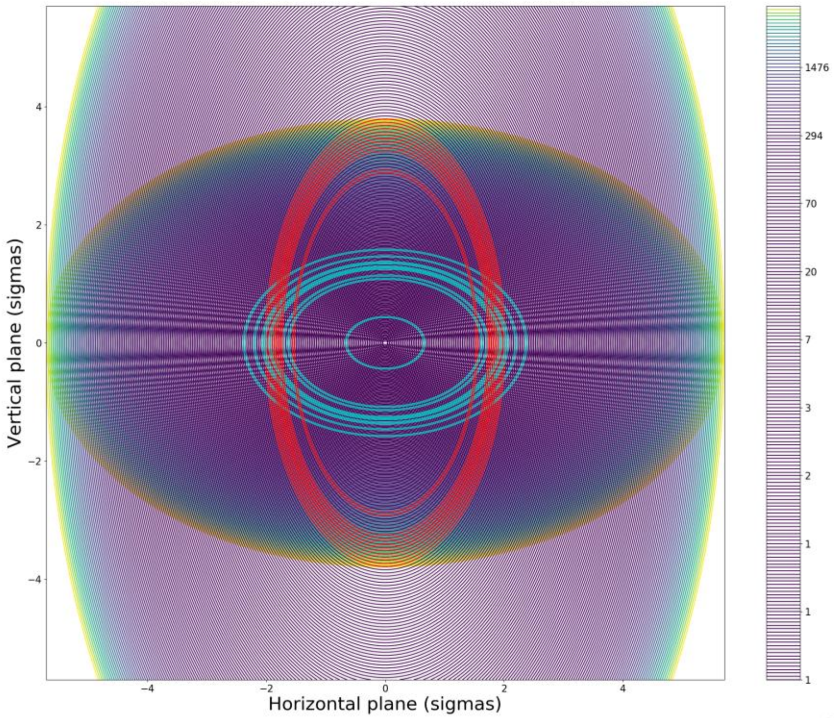


Note: just one possible trajectory within error bars!

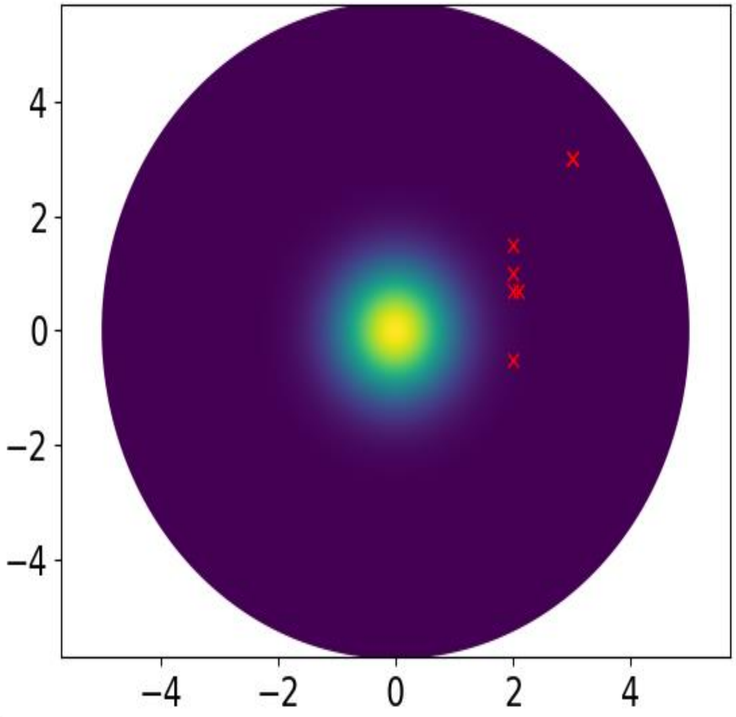
Trajectory reconstruction (30 Sep 2018)

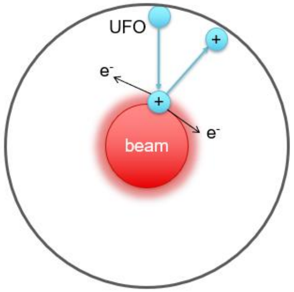
Turn 13

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



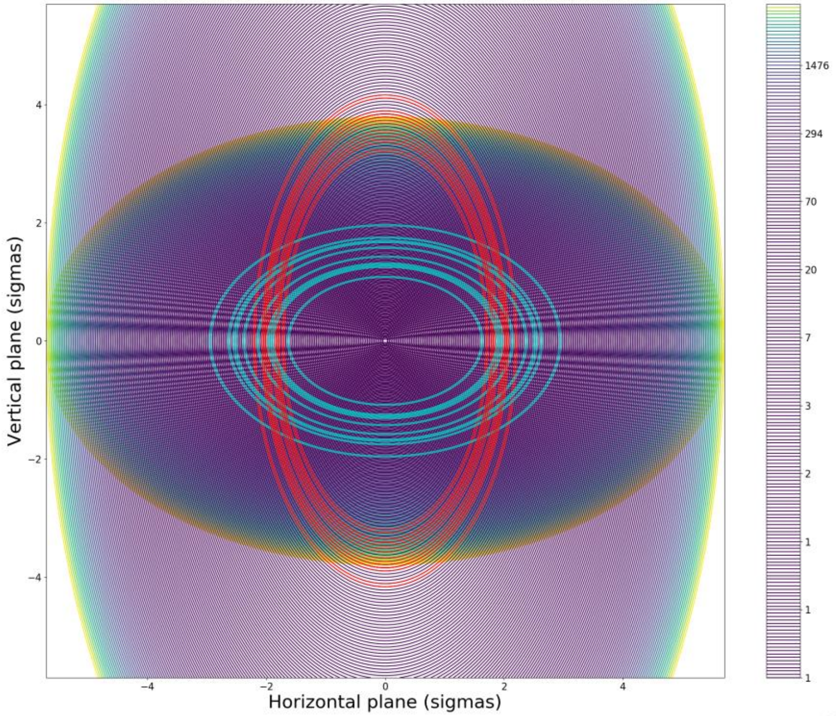


Note: just one possible trajectory within error bars!

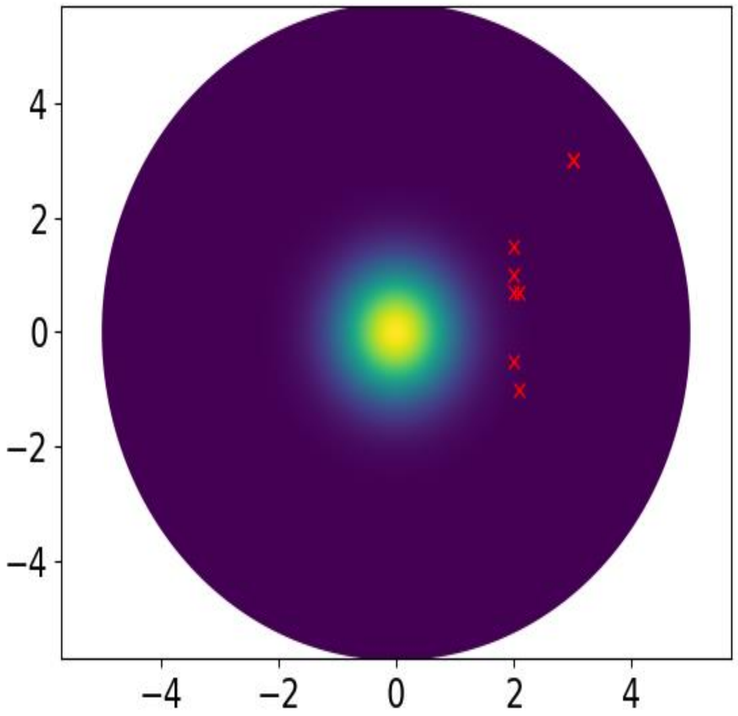
Trajectory reconstruction (30 Sep 2018)

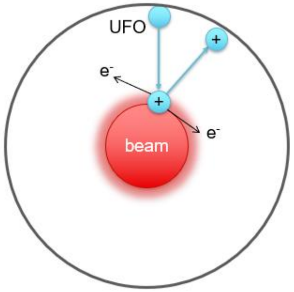
Turn 14

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



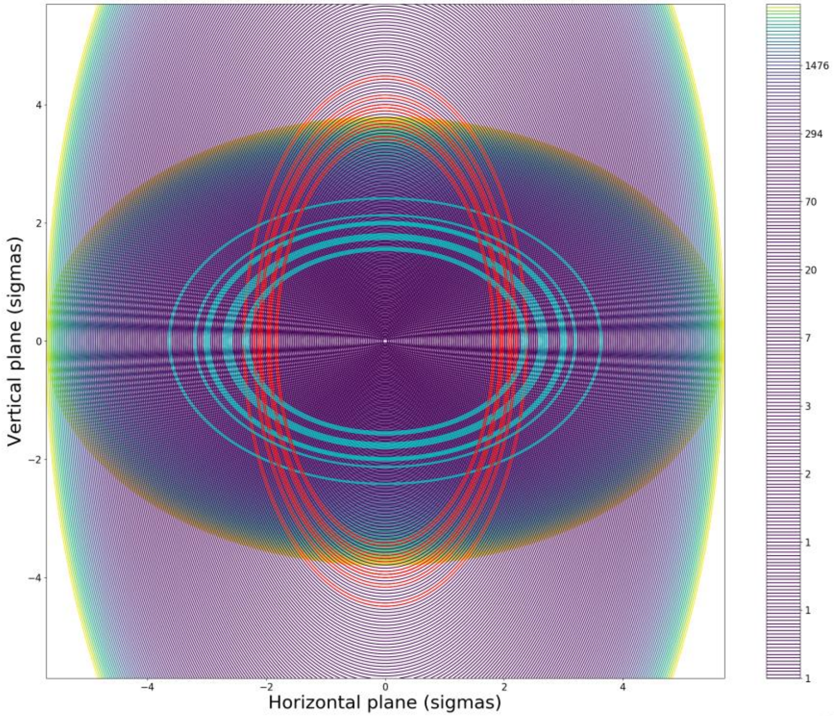


Note: just one possible trajectory within error bars!

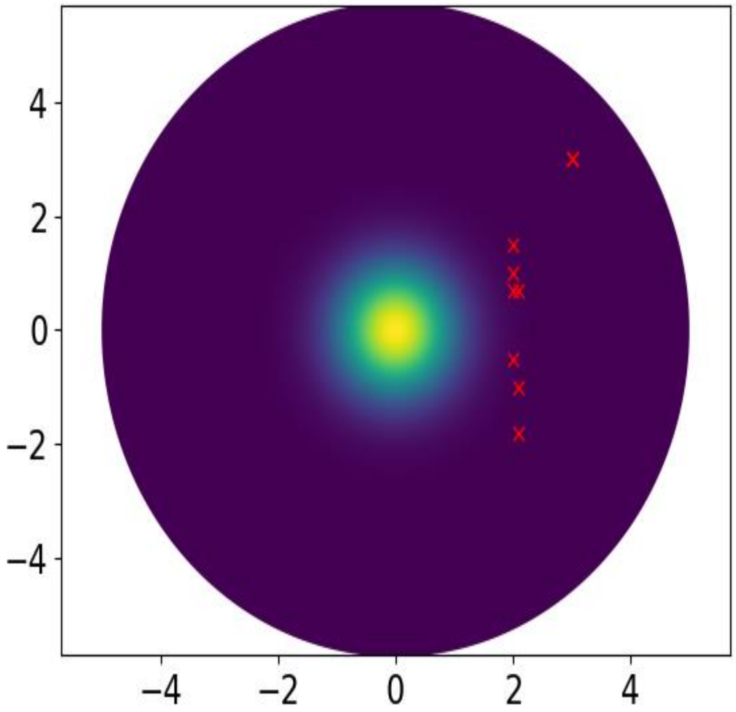
Trajectory reconstruction (30 Sep 2018)

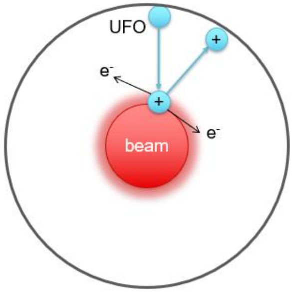
Turn 15

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



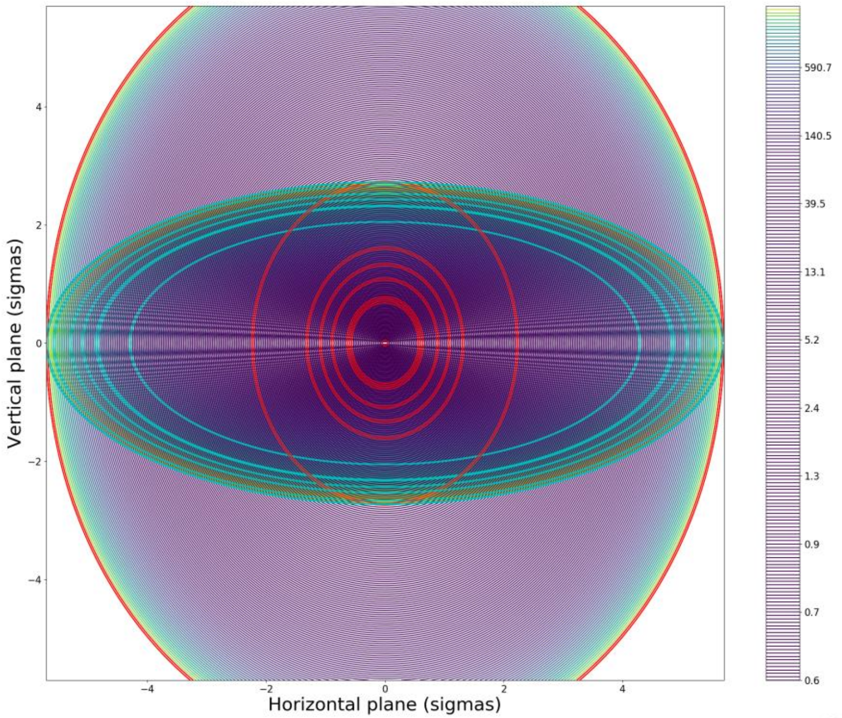


Note: just one possible trajectory within error bars!

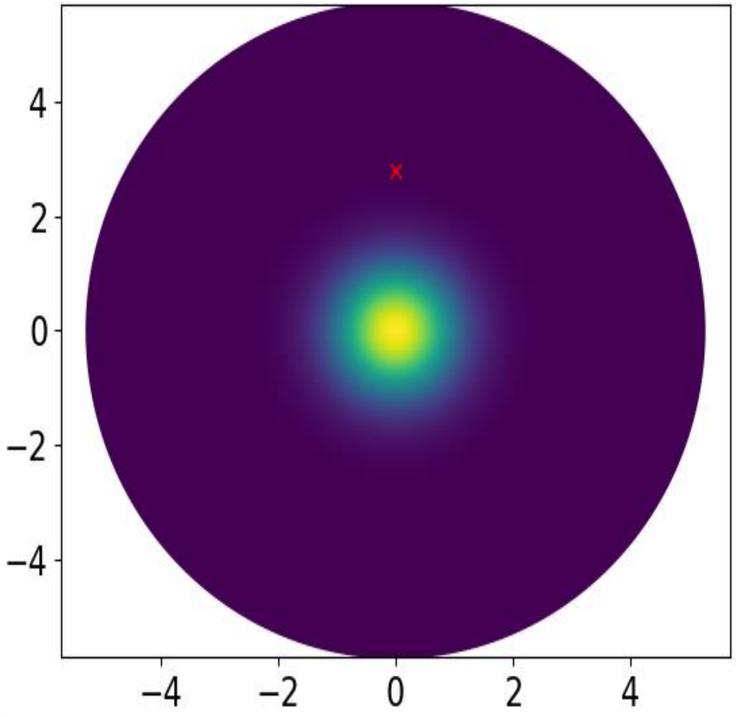
Trajectory reconstruction (17 Oct 2018)

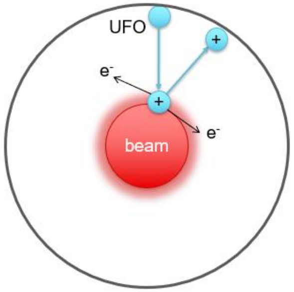
Turn 19

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



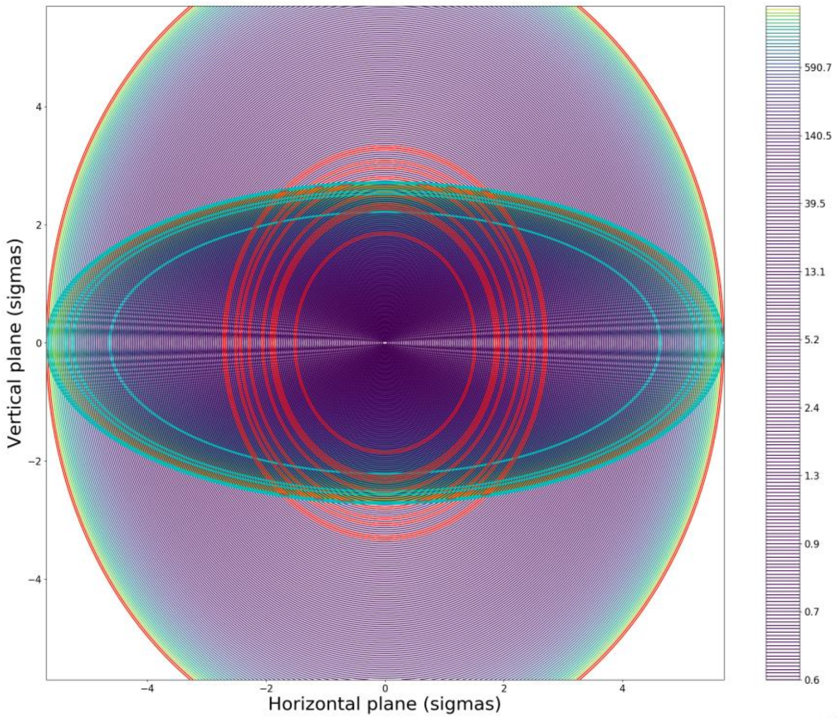


Note: just one possible trajectory within error bars!

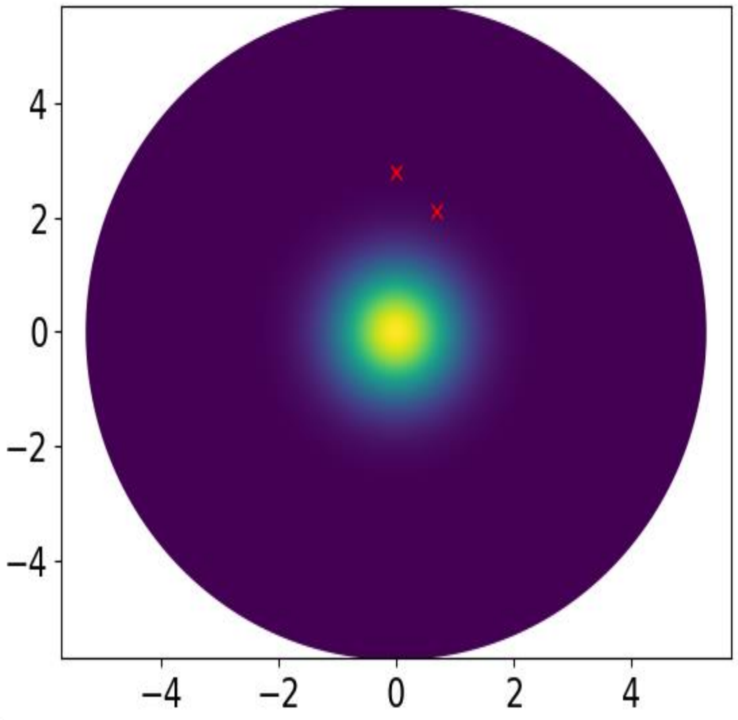
Trajectory reconstruction (17 Oct 2018)

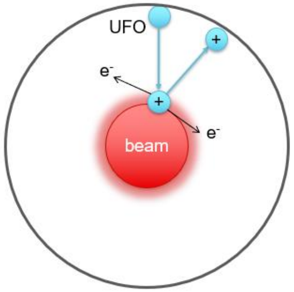
Turn 20

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



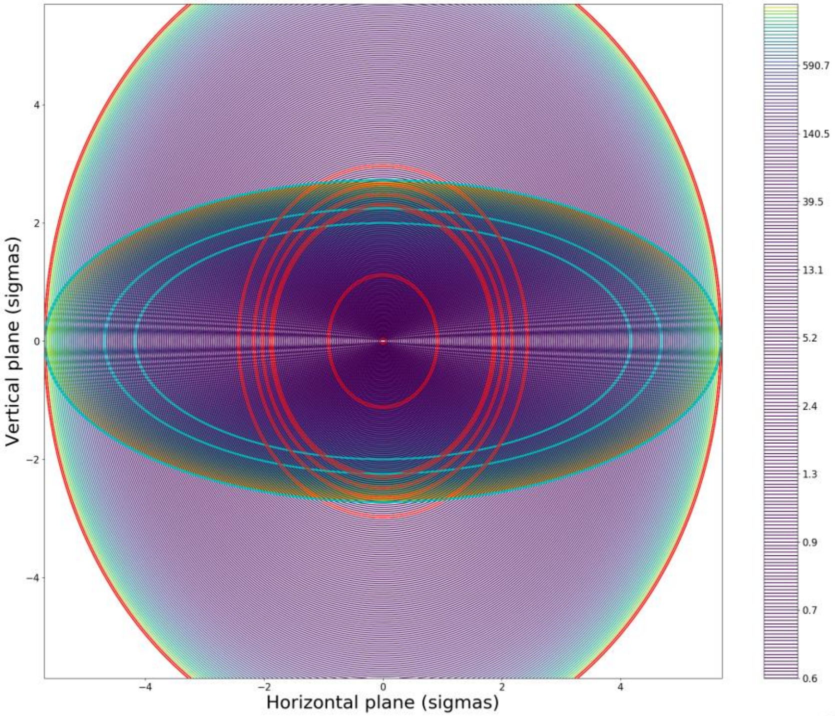


Note: just one possible trajectory within error bars!

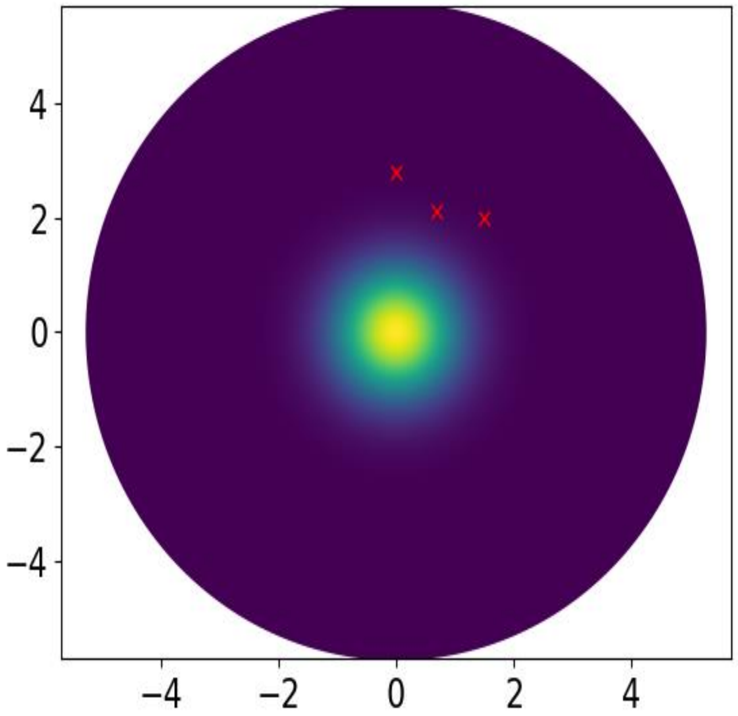
Trajectory reconstruction (17 Oct 2018)

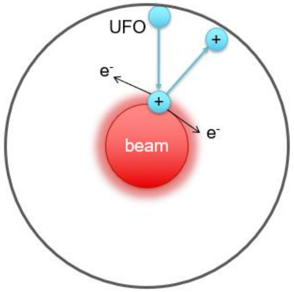
Turn 21

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



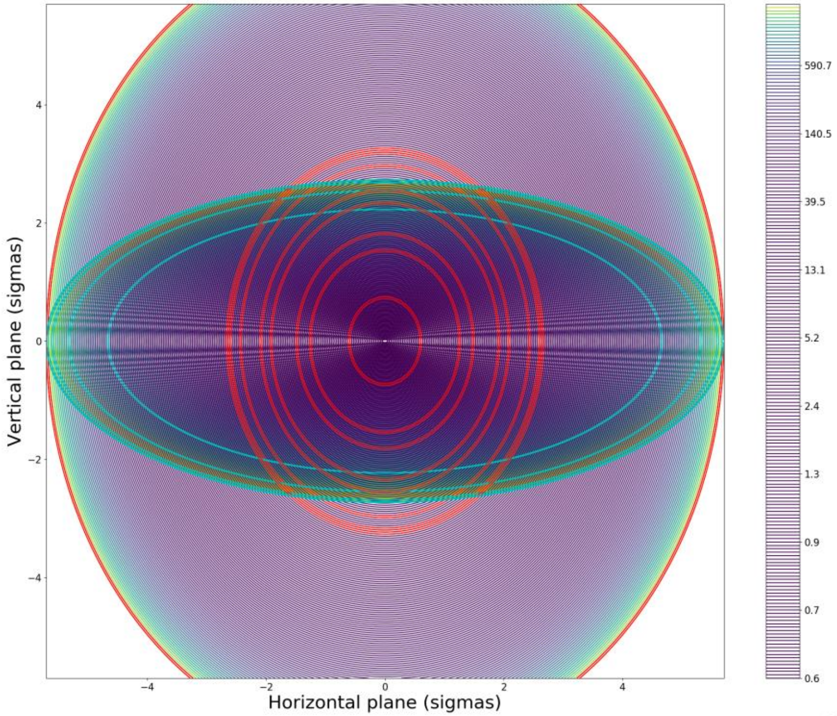


Note: just one possible trajectory within error bars!

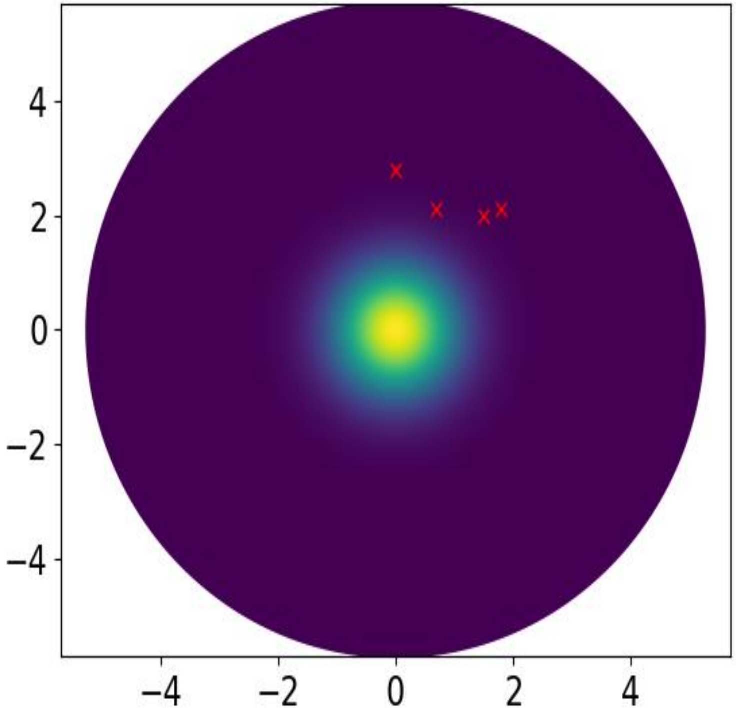
Trajectory reconstruction (17 Oct 2018)

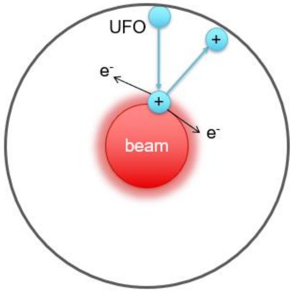
Turn 22

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location



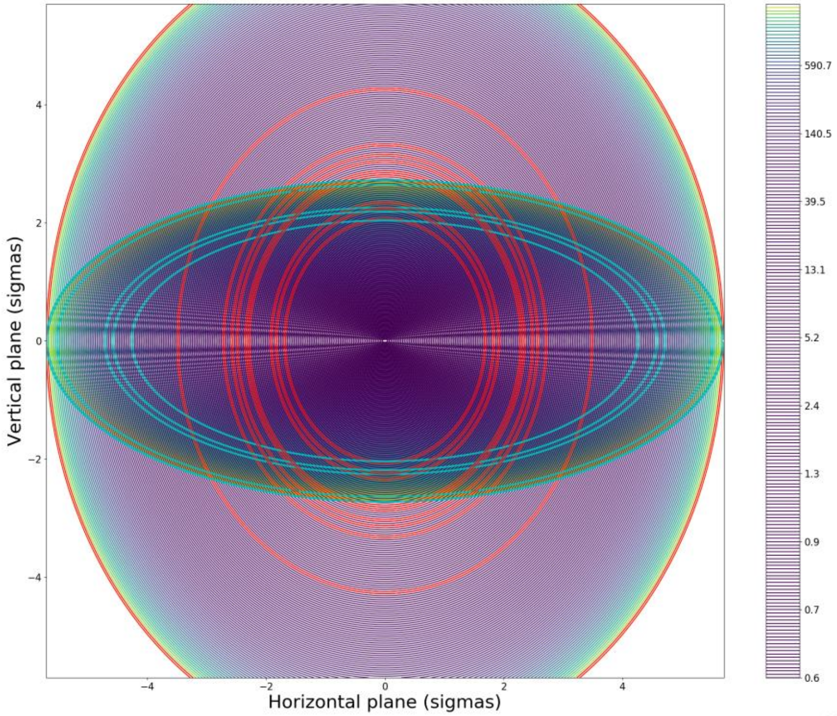


Note: just one possible trajectory within error bars!

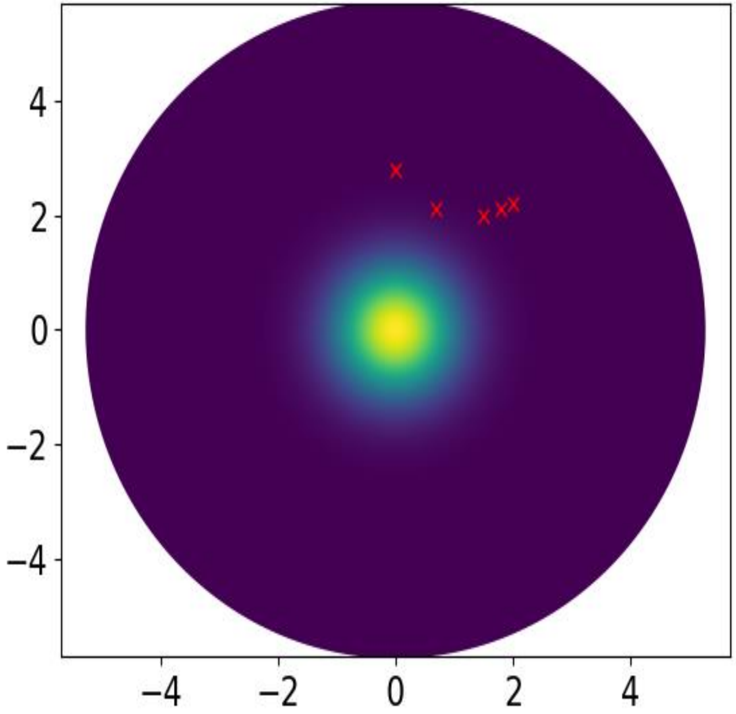
Trajectory reconstruction (17 Oct 2018)

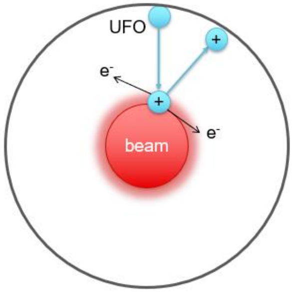
Turn 23

Blown up proton distributions divided by nominal bunch distributions



Reference bunch proton distribution with estimated UFO location





Note: just one possible trajectory within error bars!

Outlook

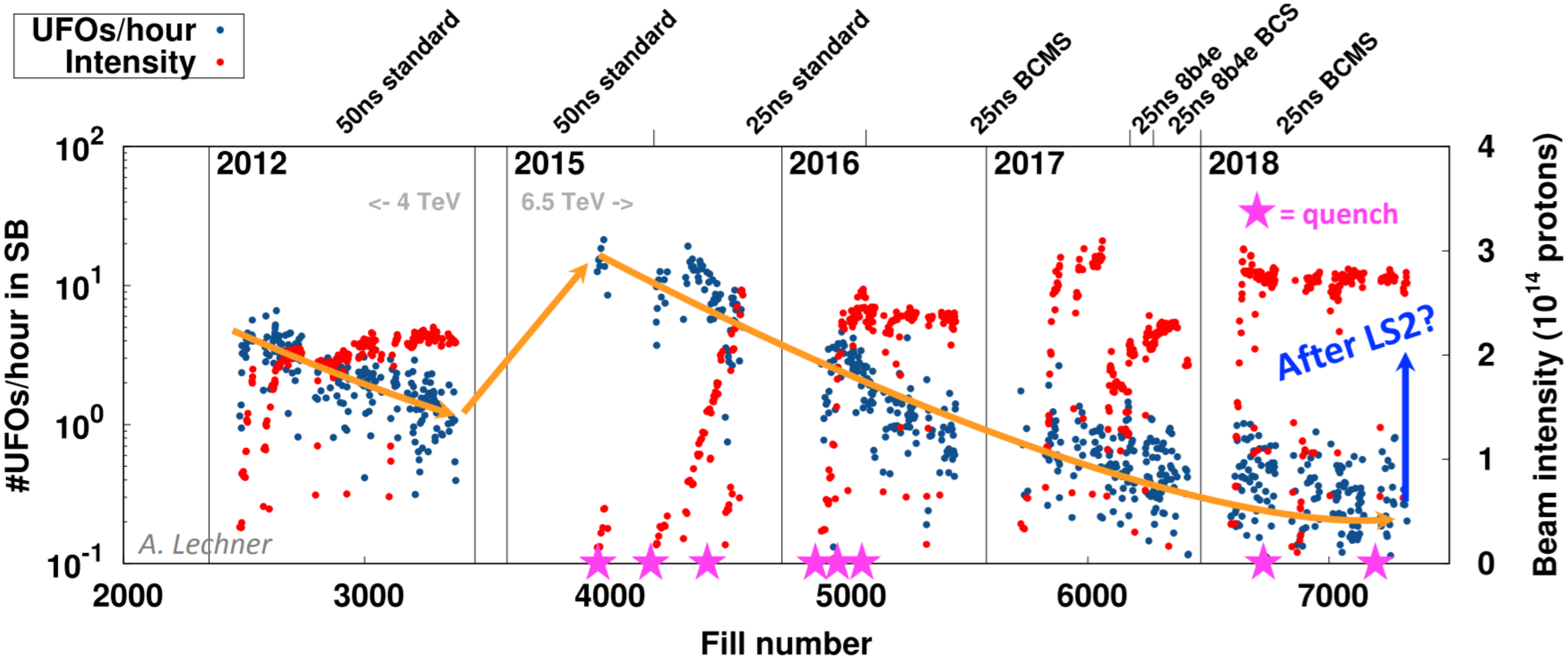
- Comprehensive parameter scan with simulation model
  - Compare with measurements
- Error quantification
- Look into the full beam
  - Eg. PACMAN bunches with orbit offset

Conclusions

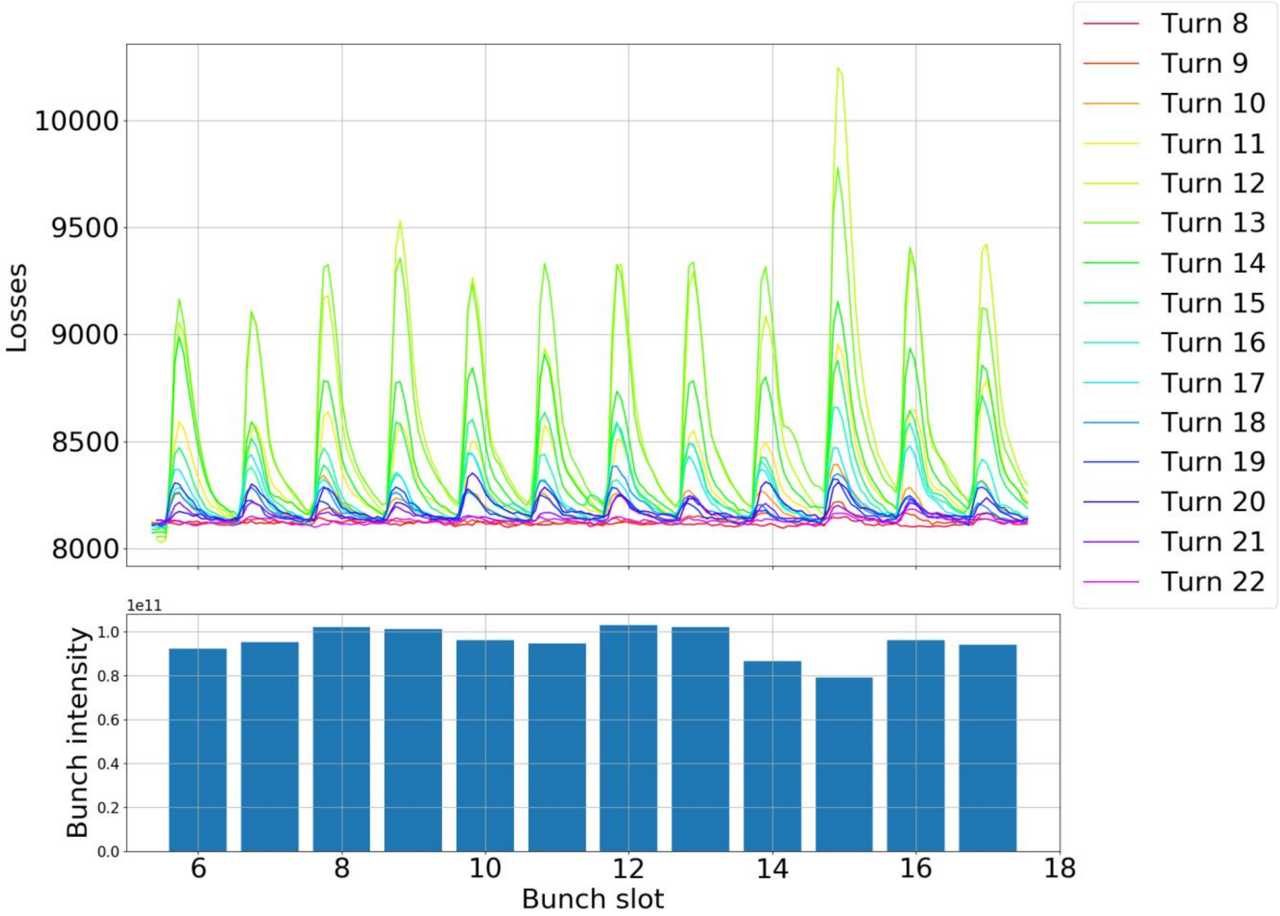
- UFOs have an important effect on LHC
  - Studied with bunch-by-bunch resolution and blown-up bunches
  - 14 events recorded with blown-up bunches
- With bunch-by-bunch losses and knowing proton distributions and bunch sizes, we can reconstruct UFO trajectories
- Large error bars from fluctuating signals, background losses, uncertainties in proton distributions
- Nevertheless: observed one event with interaction mainly in the horizontal plane and one with mainly in the vertical plane
  - Analysis ongoing
- Gravity alone is not enough to explain the observations
  - Dust particle can likely be negatively charged and attracted to the beam

Thank you!

Backup slide 1: UFO rate in 2018



Backup slide 2: Bunch intensities



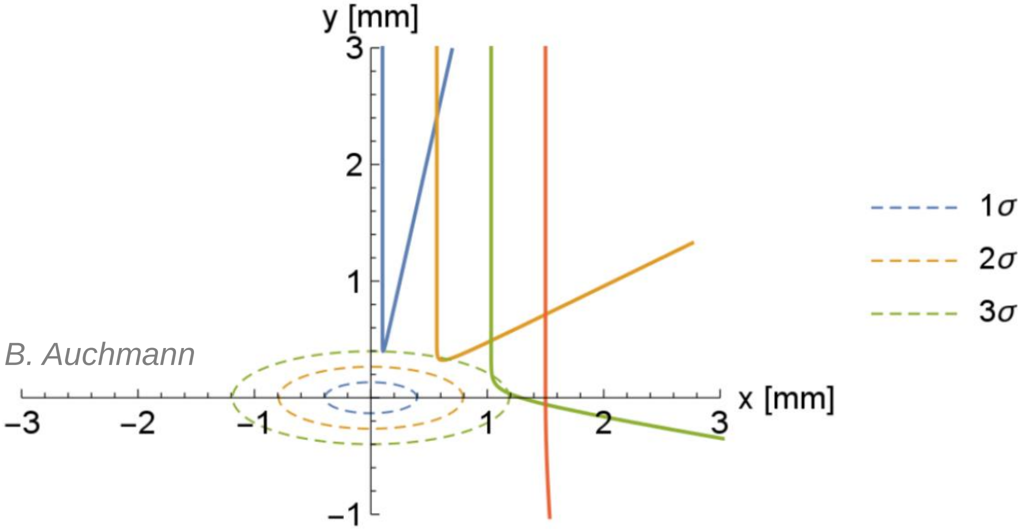
Backup slide 3: Possible trajectories

Physical model of beam-macroparticle interaction to study UFOs

- **Partially validated against UFO type 1 events** (temporal loss pattern, # inelastic collisions; assuming ~20-30 µm particles, Cu, C)

Comparing measured # of inelastic collisions with simulated:

- Estimate of macroparticle size -> radius **15-30 µm** (nitrogen, density 1.029 g/cm^3)



B. Auchmann

TITLE AND TWO CONTENT WITH SUBTITLES

TITLE