Results of UFO dynamics studies with beam in the LHC

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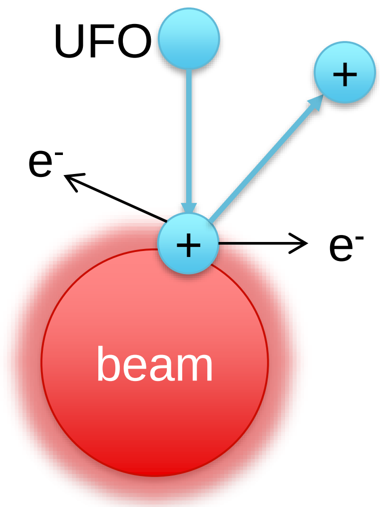
Unidentified Falling Objects (UFO)

- Beam-Macroparticle interaction
  - Beam protons scattered (beam losses)
  - Loss duration < 1 ms
  - Intense losses can cause premature beam dumps and superconducting magnet quenches
    - **-> up to 12 hours downtime!**



- LHC first hadron accelerator to suffer from their impact
  - Initially very limiting, but UFO rate decreased over time **(conditioning)**
  - 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**

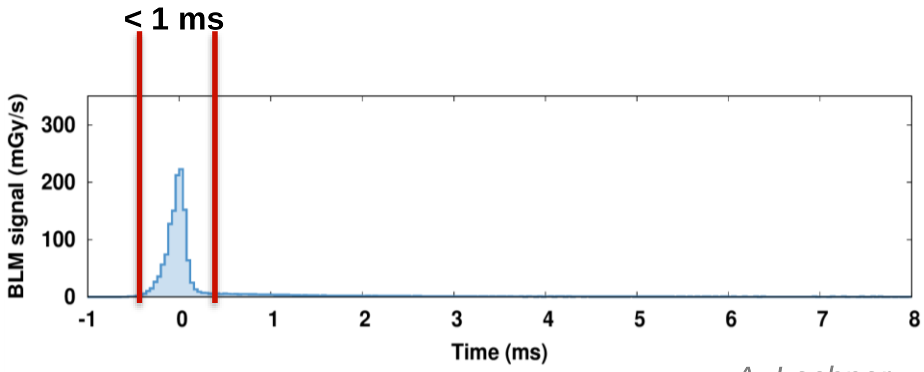
- Still many unknowns, impact expected to increase in future (higher beam energy, higher beam intensity...)

Understanding their dynamics important clue for employing countermeasures

UFO types

Type 1

- Traditional type, present since high-intensity operations
- Short loss spike (<1 ms)
- Sporadic
- Present throughout whole LHC



A. Lechner

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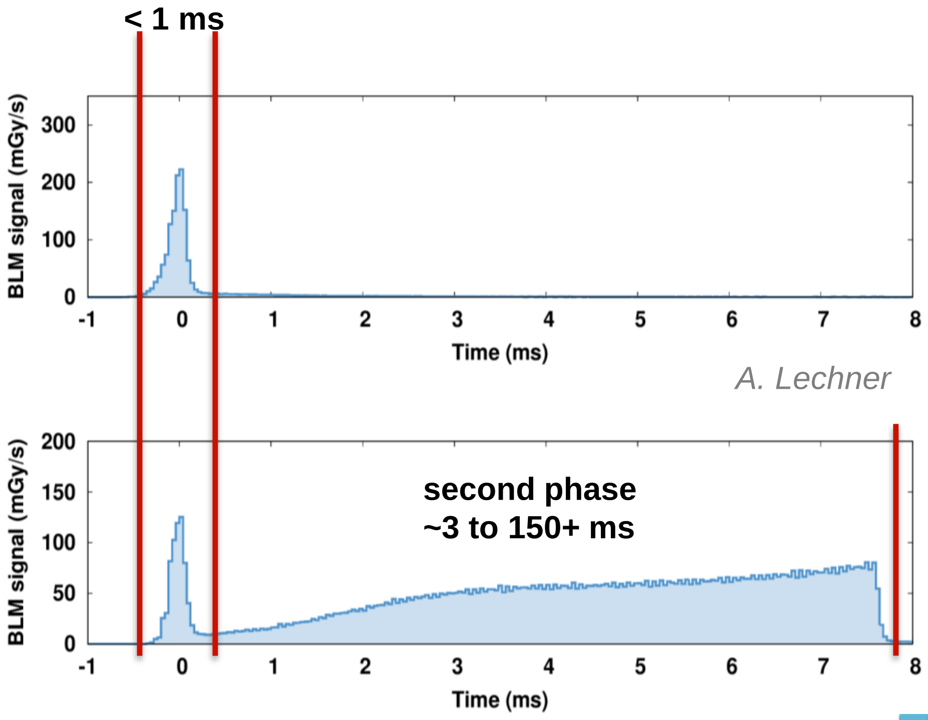


Type 2

- Present at specific magnet interconnect (16L2)
- Short loss spike, followed by continuous losses
  - In second phase, very fast beam instability develops
- Hypothesis: caused by frozen gas macroparticle
  - Contamination of beam vacuum at 16L2 confirmed
- Macroparticle evaporates due to the beam
  - Beam interacts with remaining gas cloud in second phase
  - Believed to lead to electron clouds, driving beam instability
- Rate is correlated to beam parameters (e.g. beam intensity) and well-defined source
  - **-> Unique opportunity to study real macroparticle interactions, 'UFOs on demand'**

How to study?

Wire-scanner experiment

Wire-scanner: thin carbon wire (~30 μm)

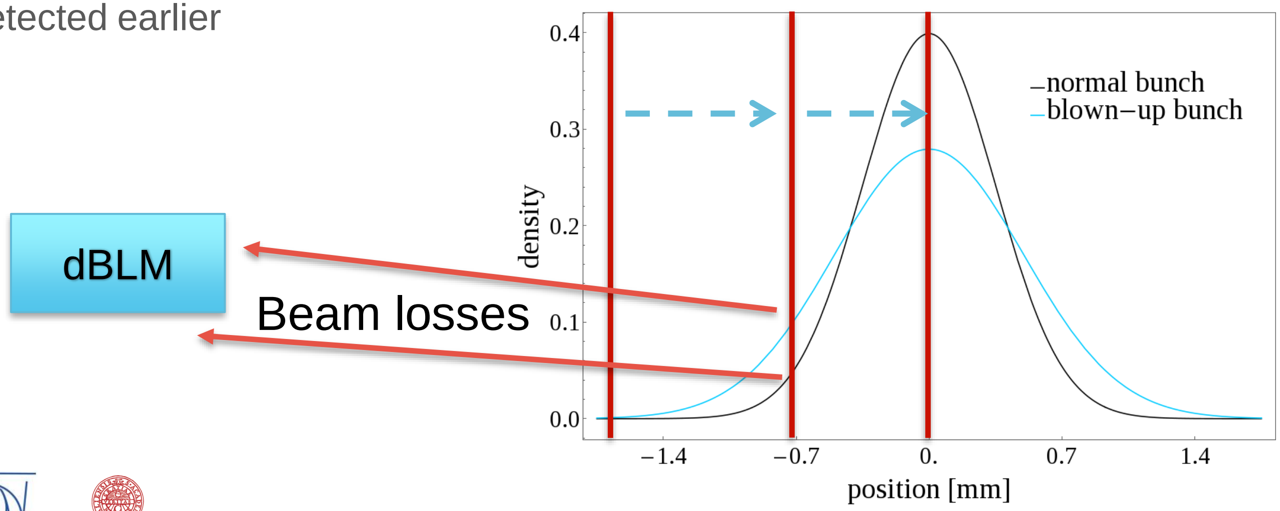
- Similar dimensions to macroparticles
- Controlled movement (ideal for experiment)

diamond Beam Loss Monitors (dBLM) measure beam losses in collimation region

Mixture of normal bunches and bunches with increased transverse size in the beam

Losses proportional to proton density at position of wire

- blown-up bunches higher density in the tails
- -> give more losses when wire in tails than the normal bunches
- -> detected earlier

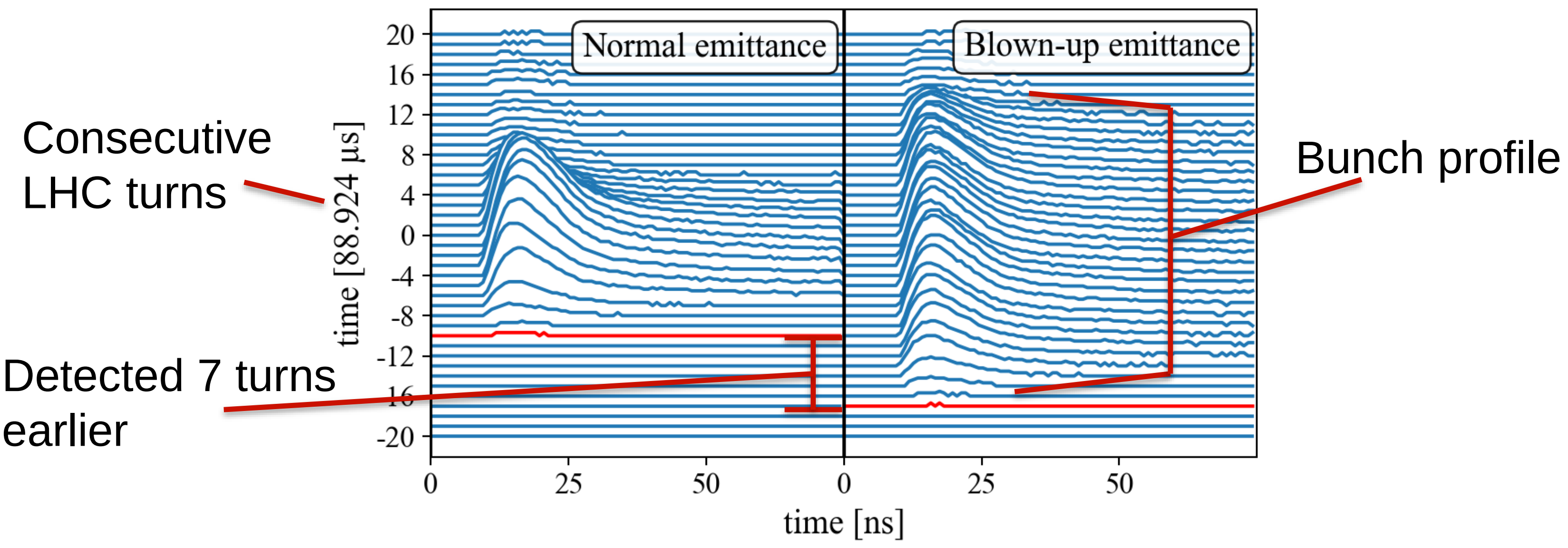


Wire-scanner results

Blown-up bunches detected earlier

Bunch profile can be reconstructed

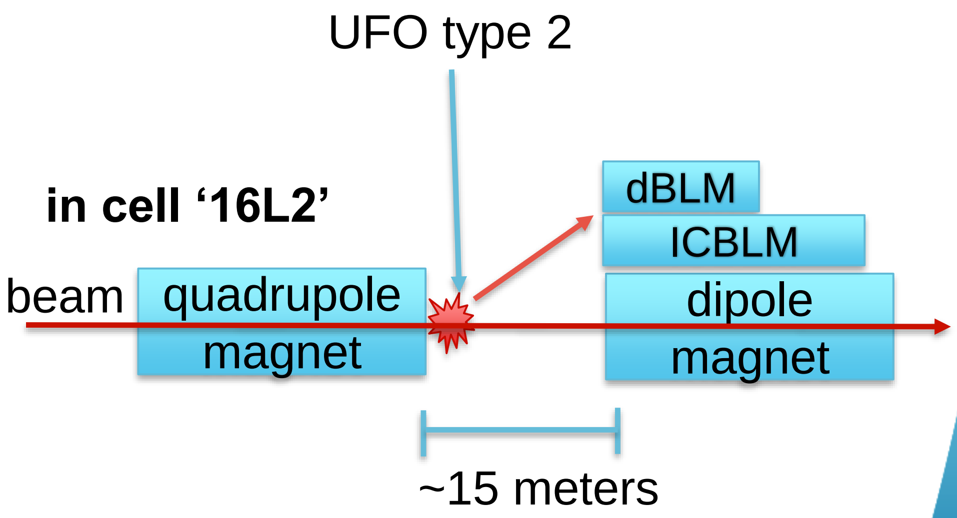
Movement of wire can be reconstructed



Can study movement of matter intercepting the beam

UFO type 2 experiment

- ICBLM:
  - Main beam loss monitoring system of LHC
  - 3600, covers all 27 km
  - Dumps beams when anomalous beam losses detected



UFO type 2 experiment

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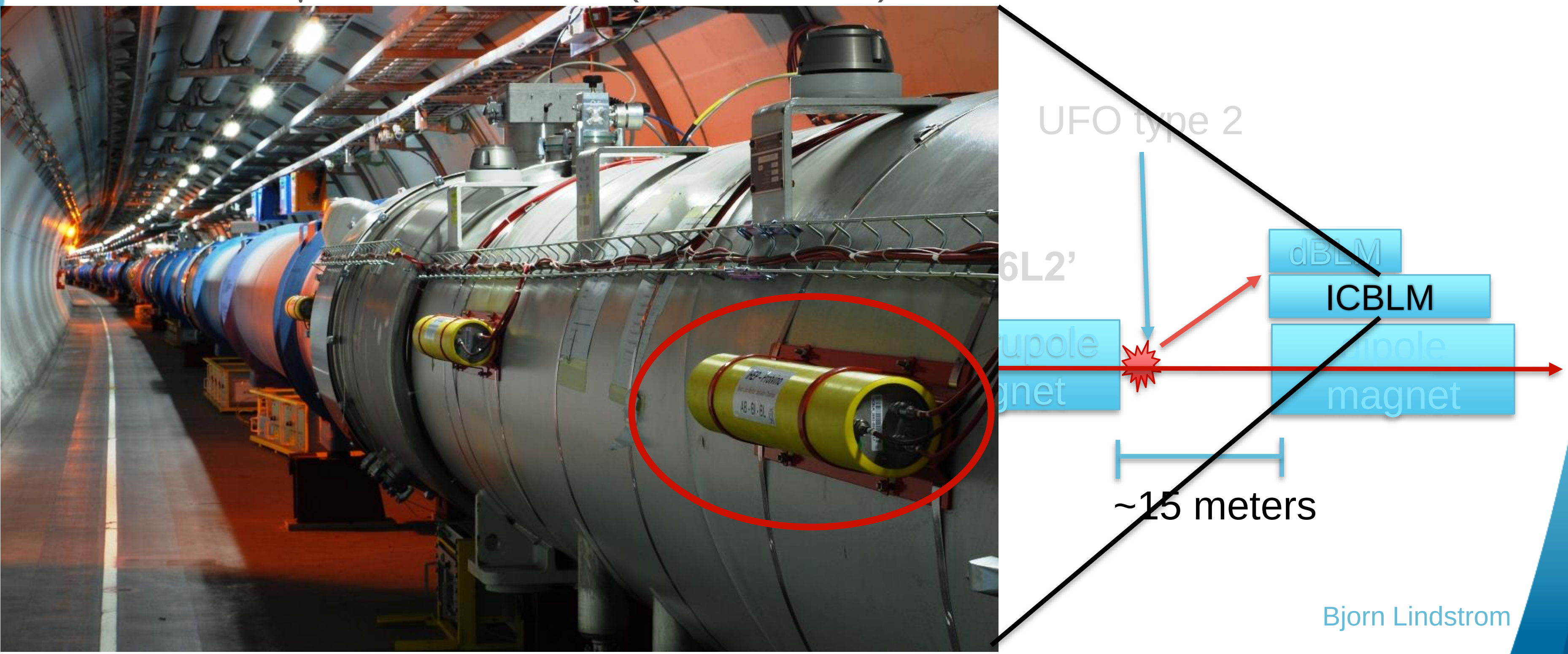
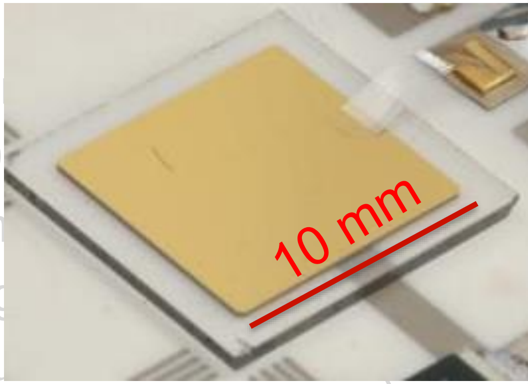
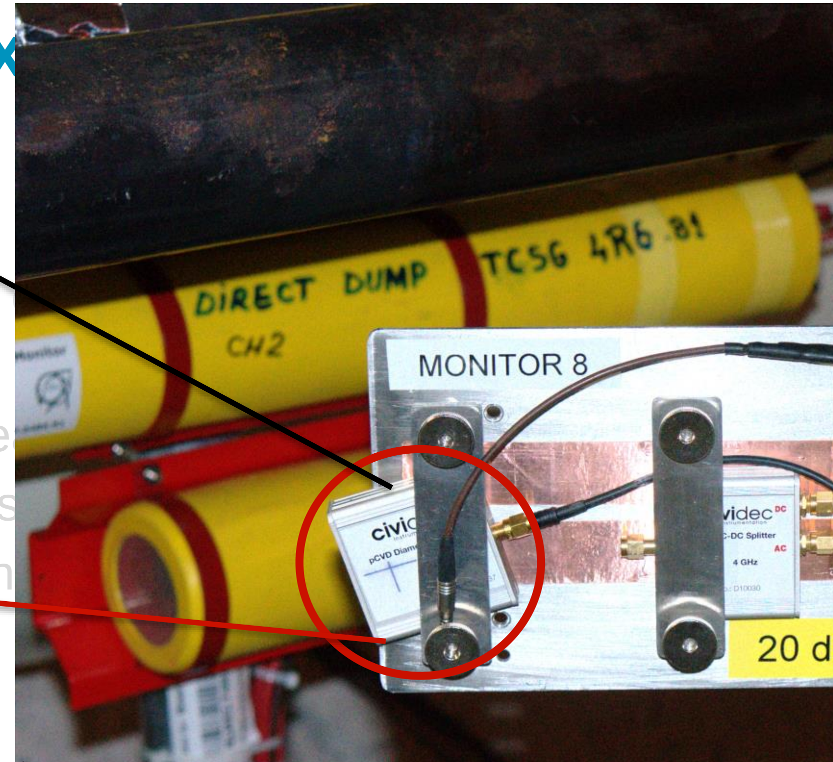
  - Large volume -> good signal to noise
  - 40 μs time resolution (half LHC turn)



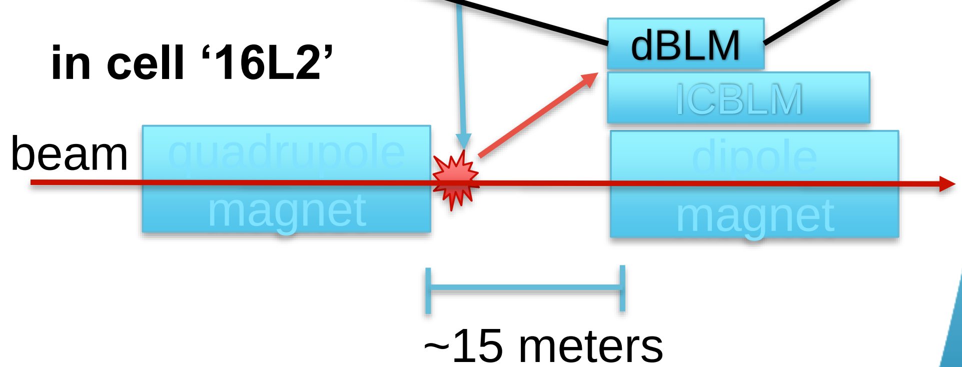
UFO type 2 ex

- ICBLM
  - Mai ystem
  - 360
  - Dur ous be
  - Larg to nois
  - 40 µ HC turn





- dBLM:
  - Small size -> signal fluctuations
  - ns resolution (bunch-by-bunch, 25 ns)



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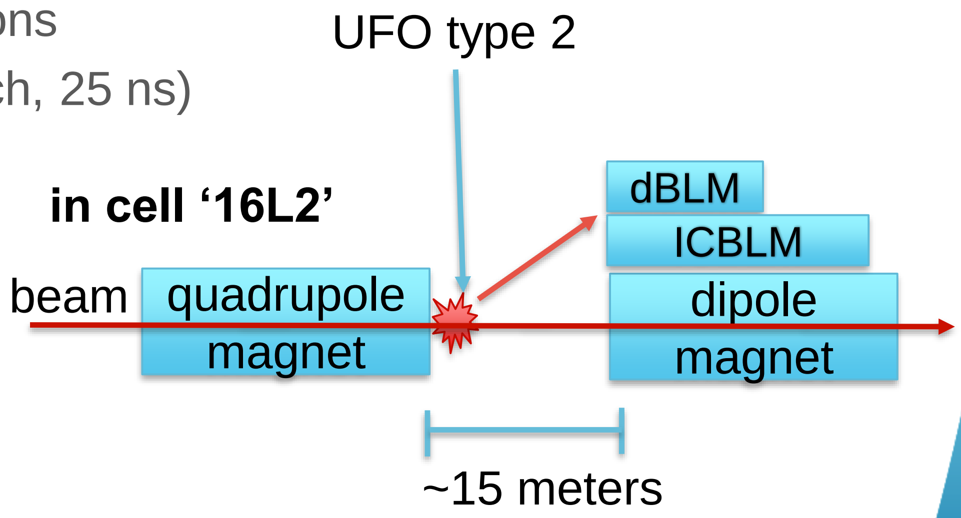
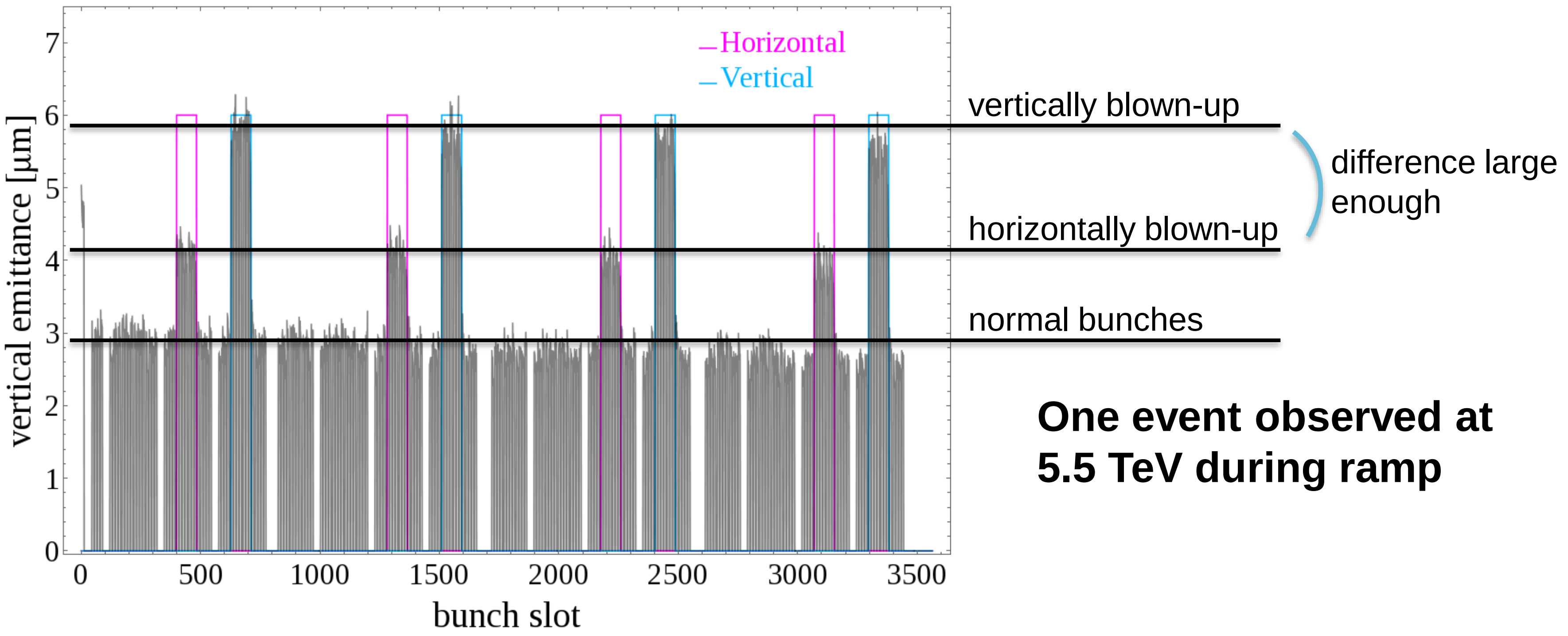


UFO type 2 experiment

Beam: **1868** bunches, **1.25e11** protons/bunch *(high probability of triggering event)*

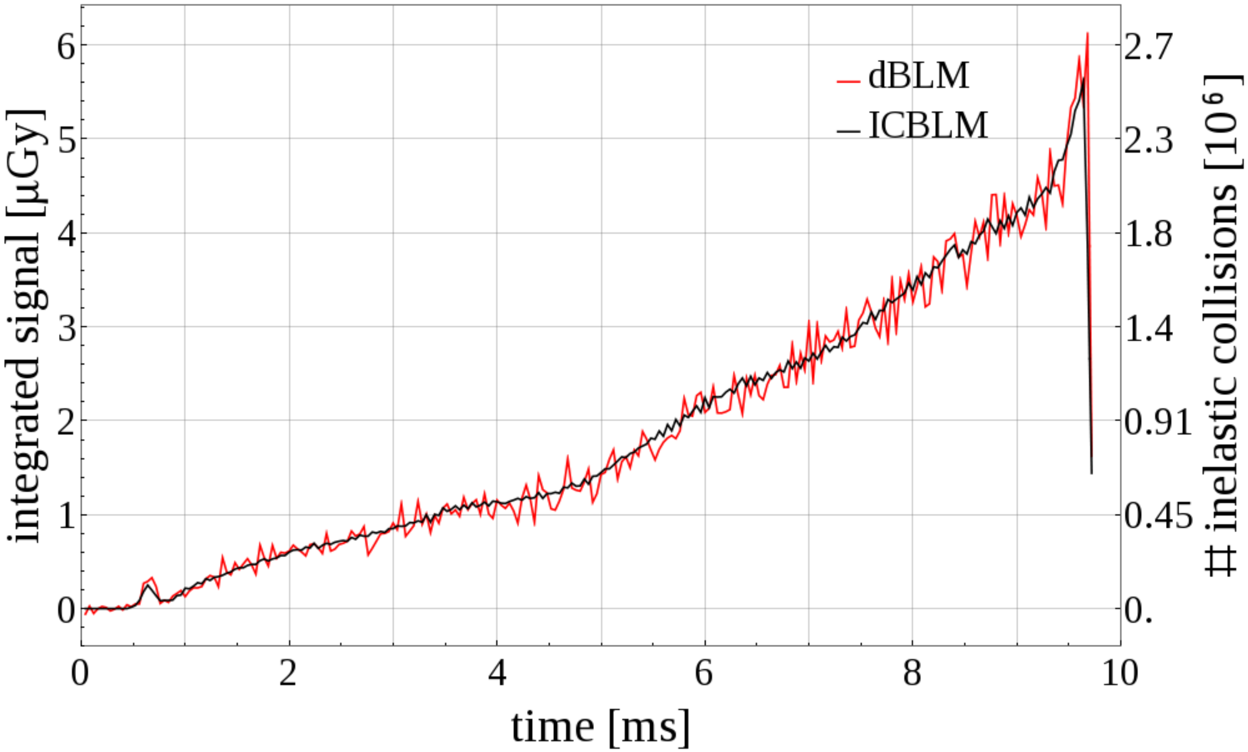
- **448 blown-up** bunches (horizontal and vertical separately)
- Horizontally blown-up bunches slightly blown-up vertically and vice versa due to coupling



One event observed at 5.5 TeV during ramp

UFO type 2 - signal

- Integrating dBLM in 40 µs and comparing to ICBLM
  - -> good linear correlation
- Allows estimating statistical error



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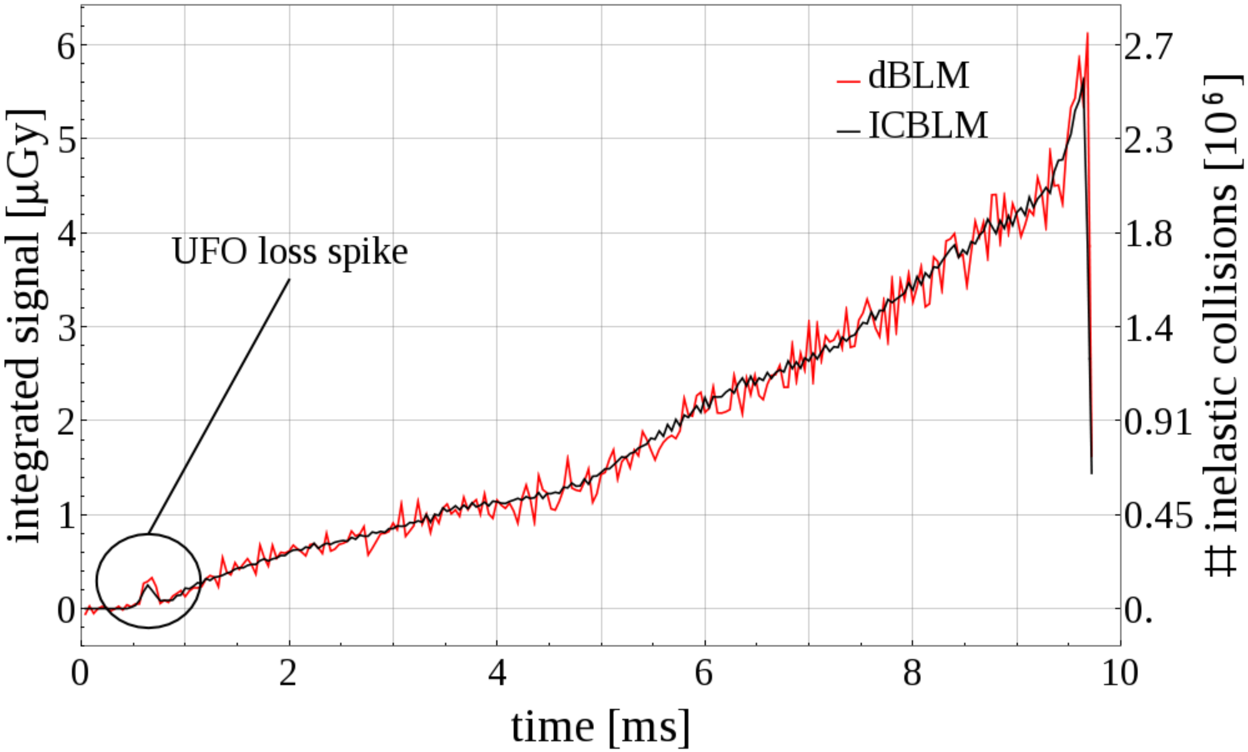

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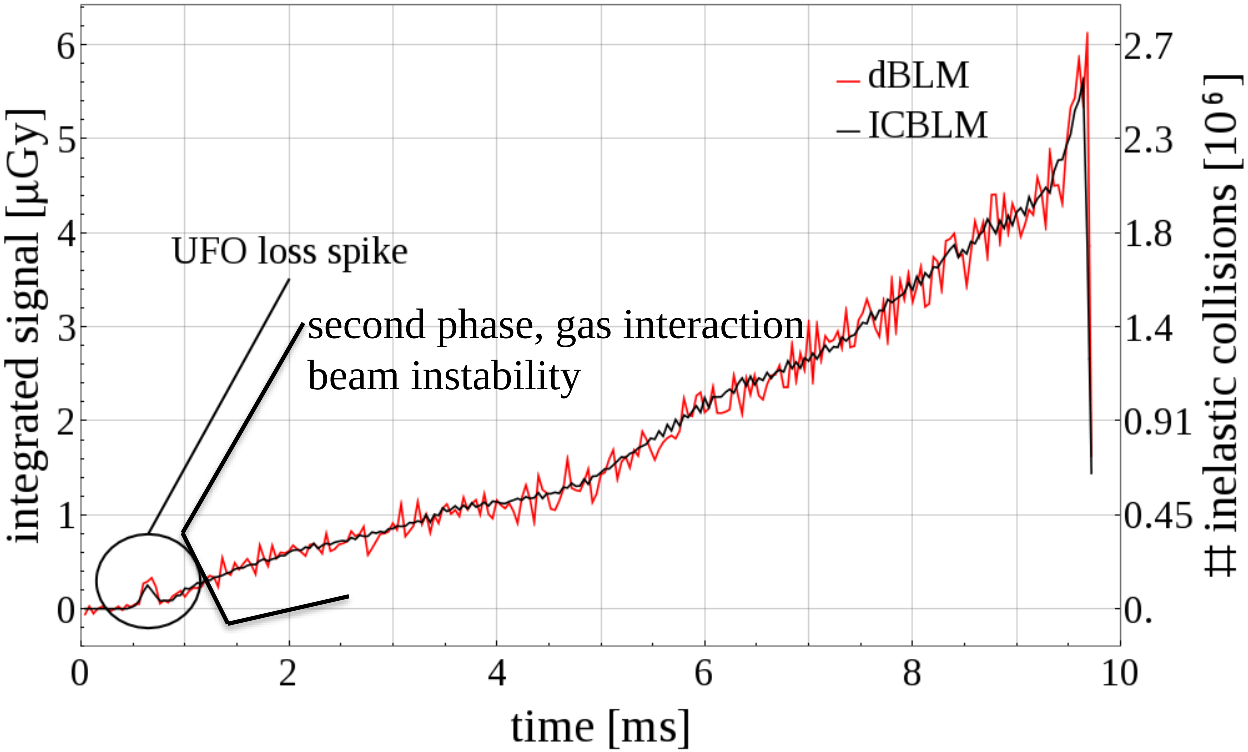
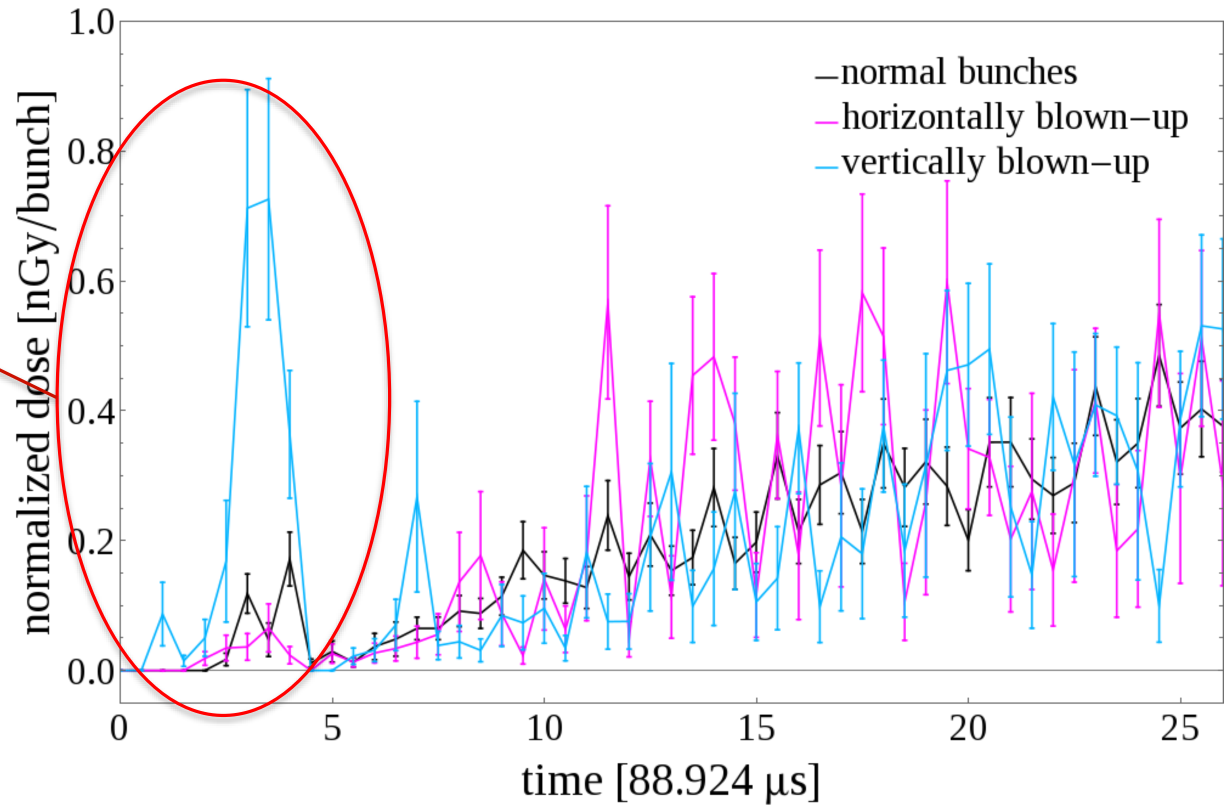


dBLM equivalent to ICBLM

UFO type 2 dynamics

- Splitting integration into the three different bunch groups:
  - Vertically blown-up detected ~1.5 turns earlier
  - Significantly more signal from vertically blown-up throughout whole spike

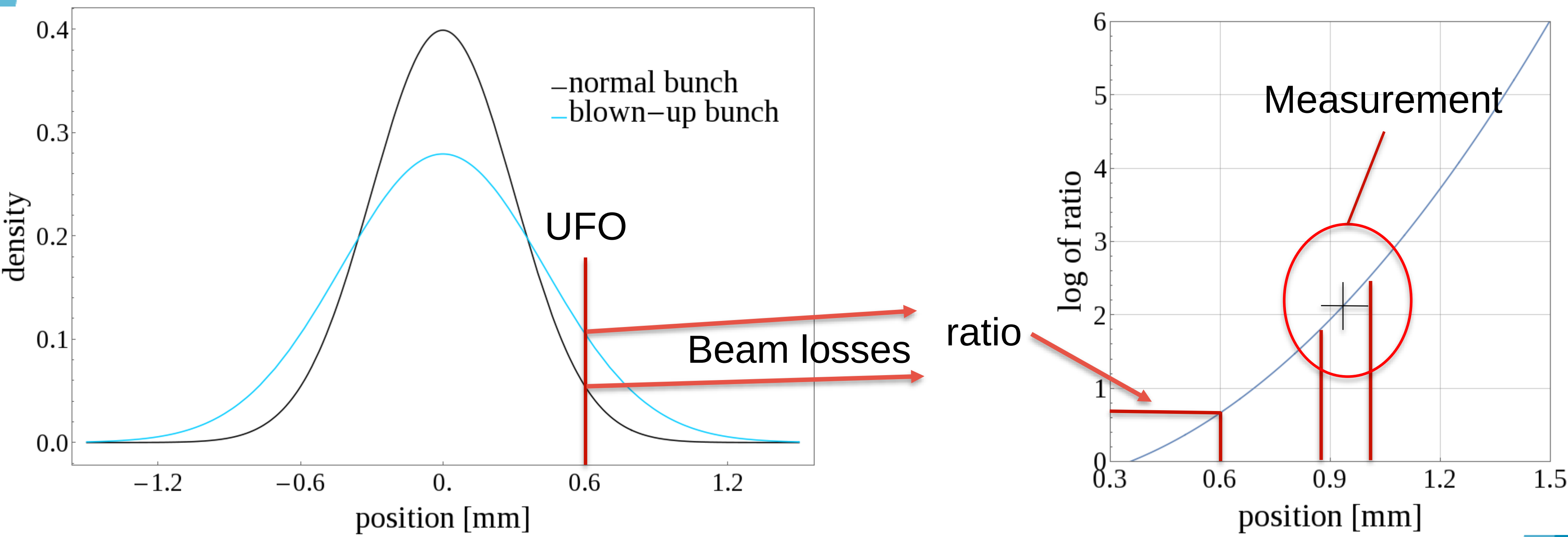
UFO spike



UFO enters beam in vertical plane, but how far?

Macroparticle position

- Bunch profiles assumed gaussian
- Losses proportional to proton density at macroparticle position



Position estimate: 0.9 to 1.1 mm, or 2.9 to 3.4 beam sigma
Is this reasonable?

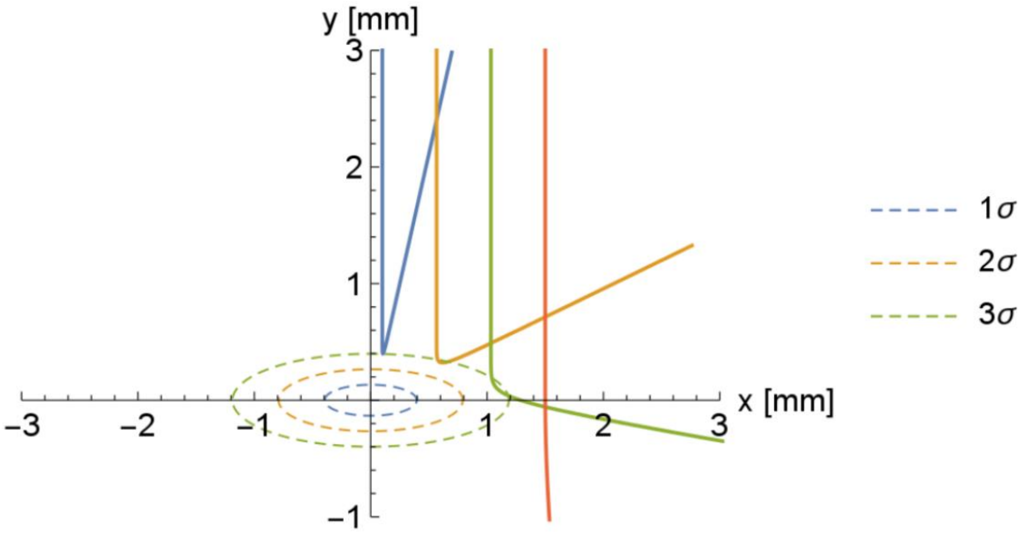
Simulation Model

Physical model of beam-macroparticle interaction to study UFOs

- **Partially validated against UFO type 1 events** (temporal loss pattern, # inelastic collisions)

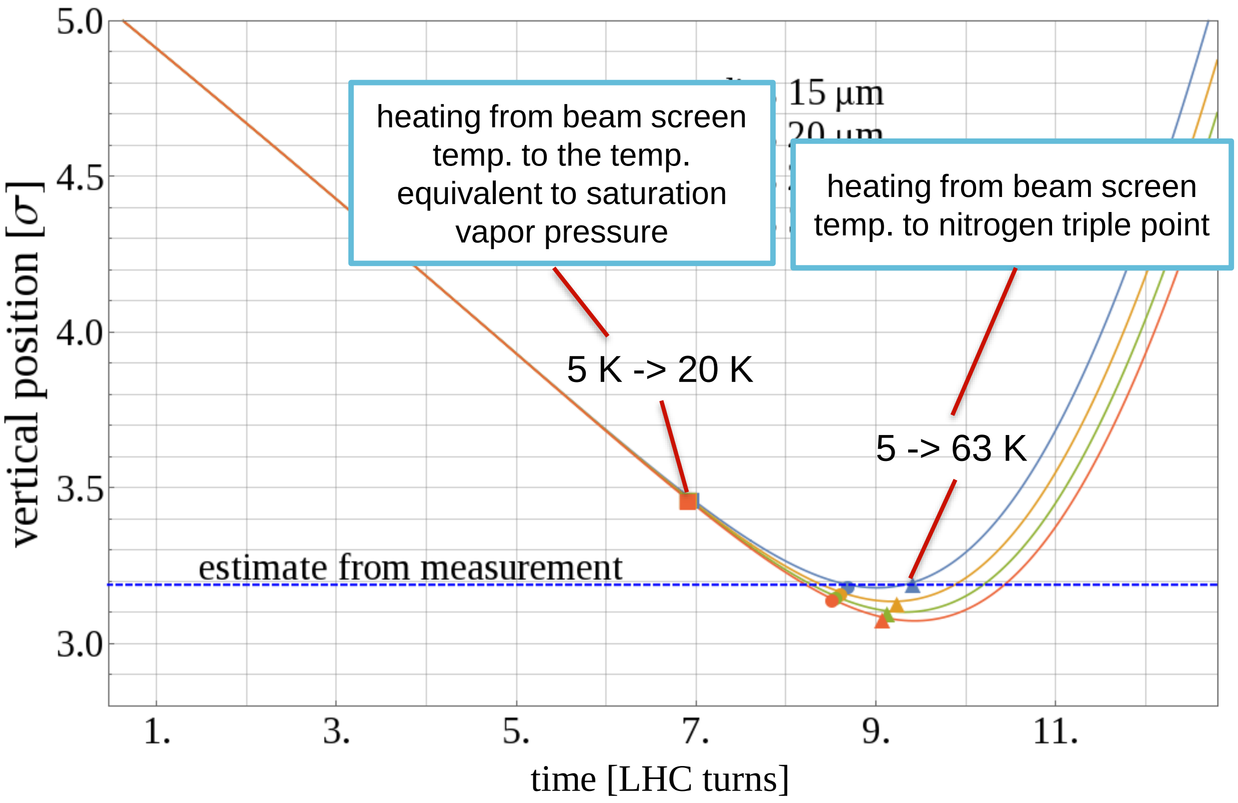
Comparing measured # of inelastic collisions with simulated:

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



Simulation Results

- Nitrogen particles assumed negatively charged (possibly from electron clouds), and **attracted from bottom**
- Phase change suspected, temperature increase simulated



Good agreement with measurements

Conclusions

- Understanding of macroparticle interaction significantly improved
- New measurement method works as expected
  - Allows studying dynamics of macroparticles intercepting the beam
- Demonstrated that UFO type 2 events come from a localized (transversally) source, since mainly transversally blown-up bunches interacted
- Could reproduce using simulations with reasonable assumptions and input taken from well-calibrated ICBLMs
- Only one event studied, not traditional UFO type 1, statistical fluctuations of signal
  - **Will conduct further studies this year**