Preamble/Disclaimer

- This is the offline version of the presentation
- The „real version” exists as an interactive program, please contact me for further info
- Most of the content (in particular the images) is ***copyrighted*** material. Please contact me for details, if you want to copy anything.
- The resonance movie is online: https://indico.cern.ch/event/491202/contributions/2249987/attachments/1327648/1993694/go
- Reach me at: Magnus.Mager@cern.ch for any questions

The TPC Instrument

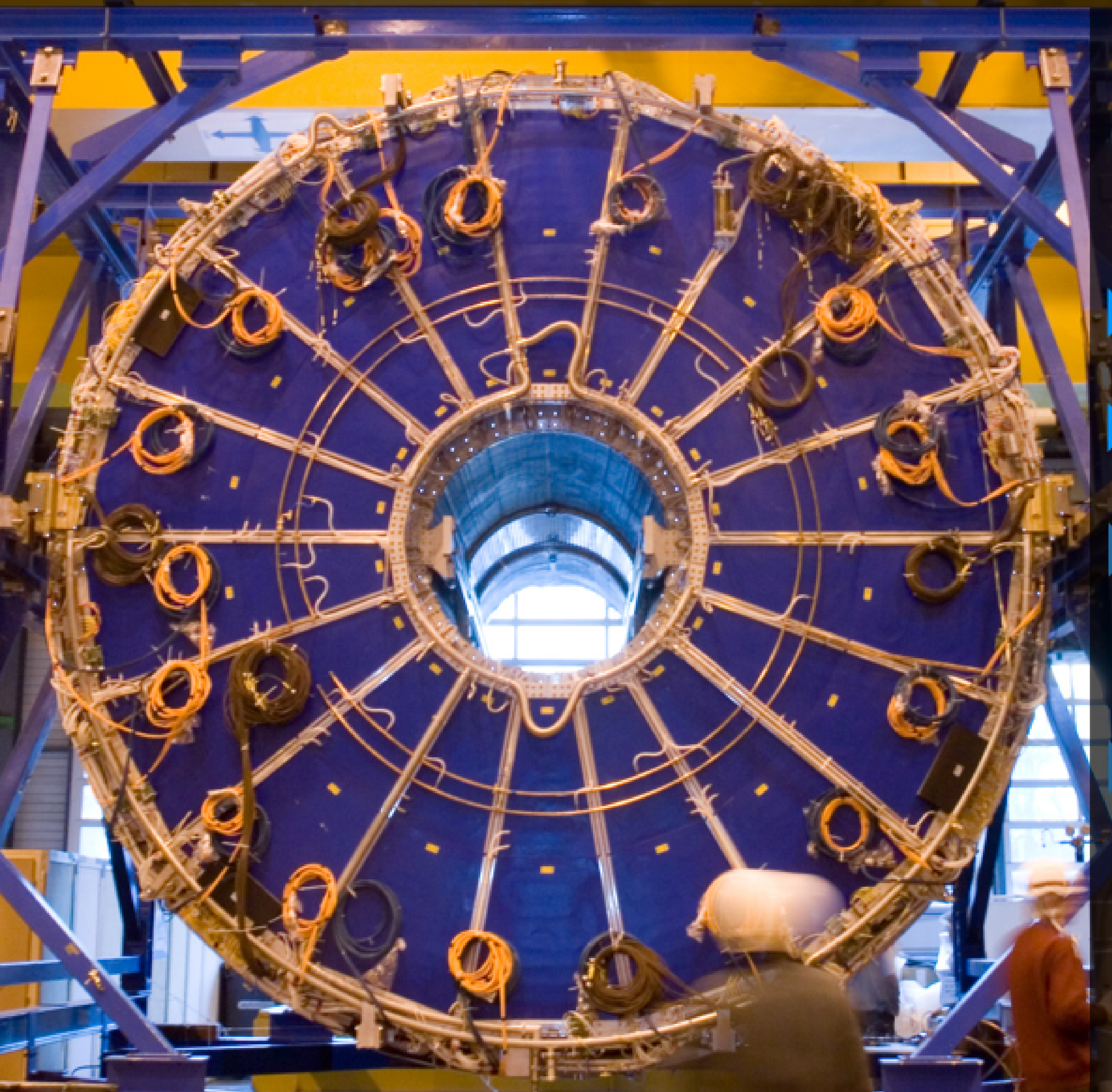
Magnus Mager
(CERN)

PBM's PhD student 2008–2012

QCD thermodynamics – pressure and passion
Schloss Waldthausen
24–26 August 2016

[image: CERN CDS]

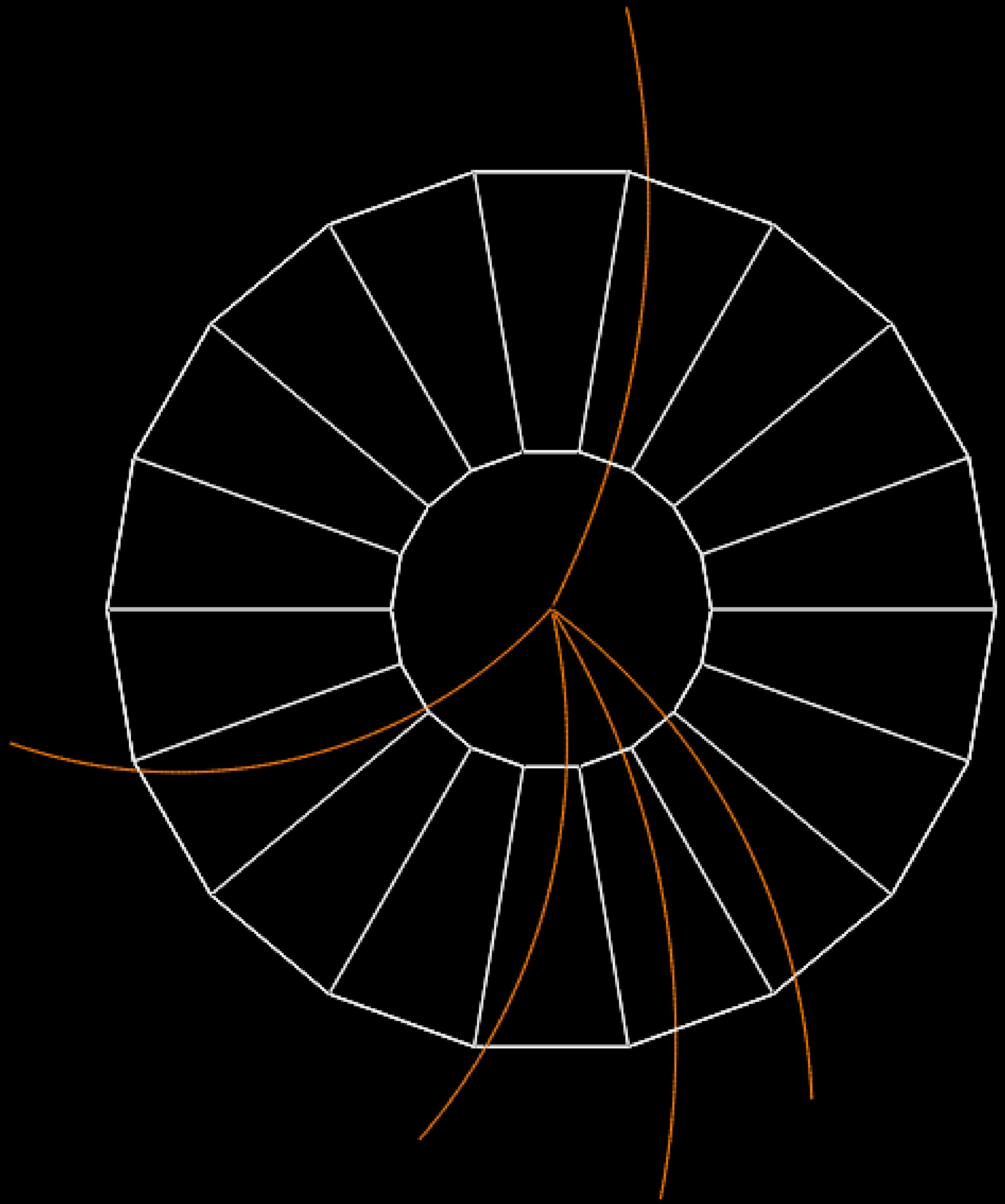
The ALICE TPC



- 5 by 5 m
- pad readout
- 557,568 readout channels
- few 100 Hz read-out rate in Pb–Pb

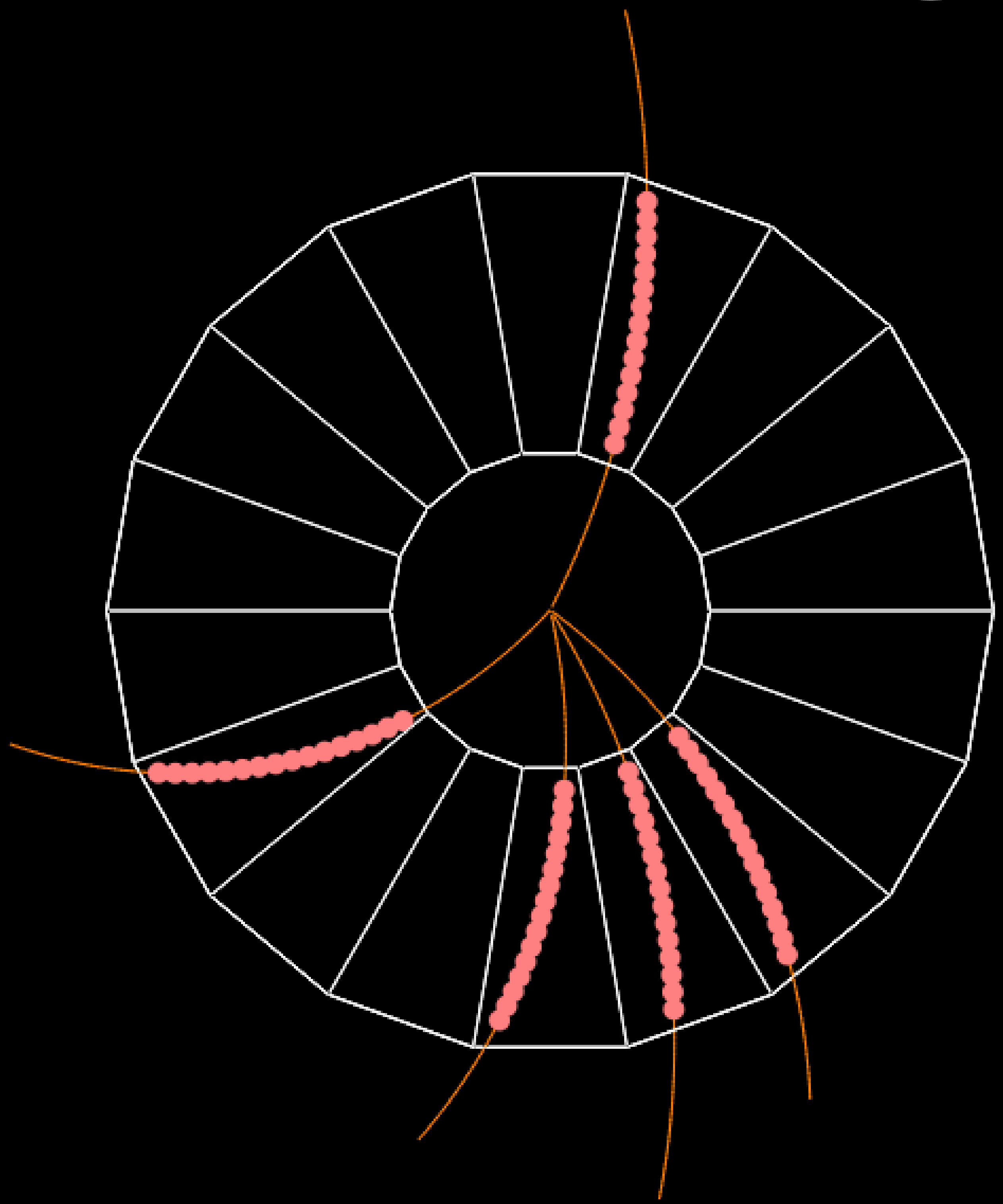
[image: CERN CDS]

Working principle



- Charged particles ionize gas along their trajectories

Working principle



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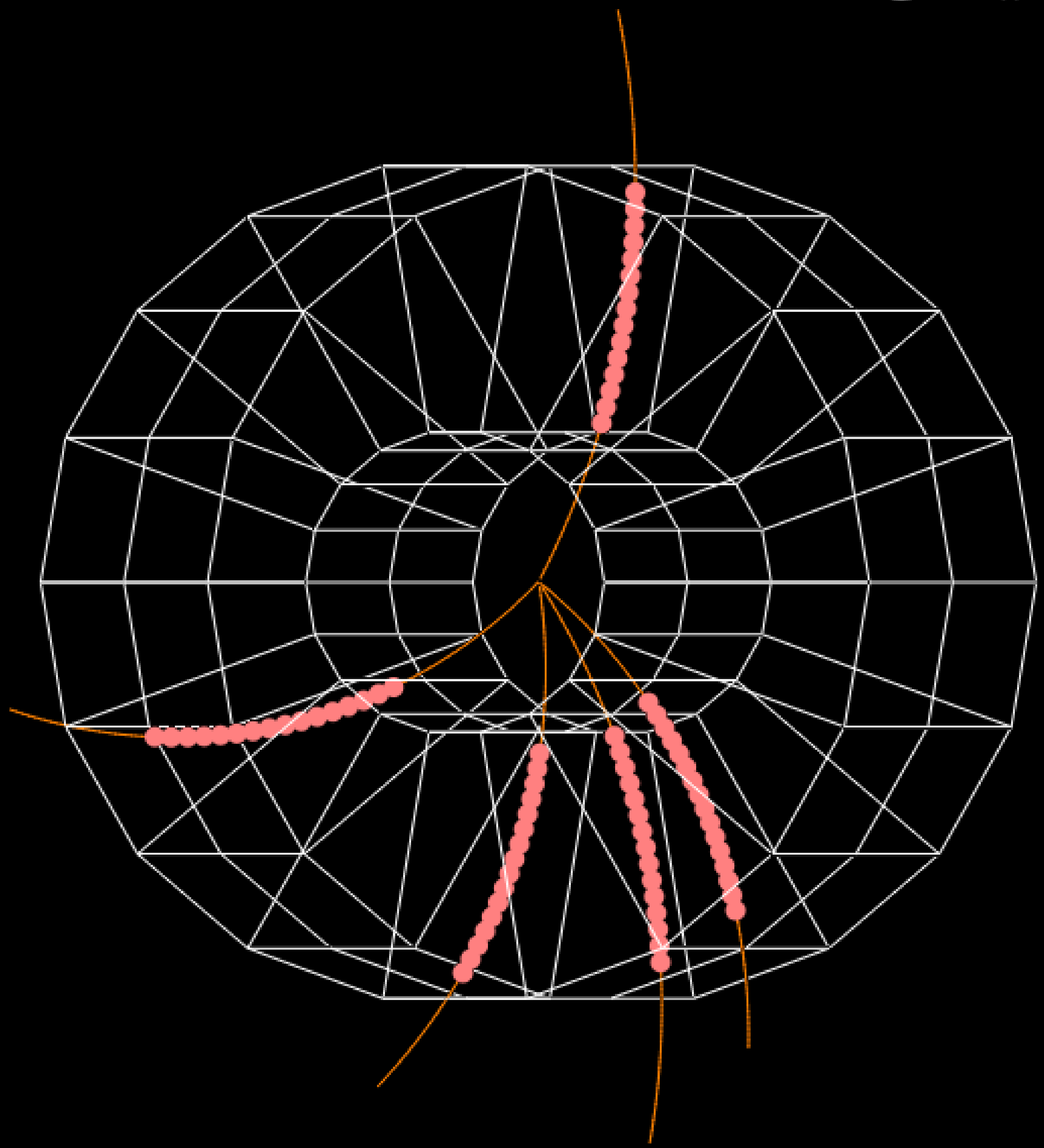

- Charged particles ionize gas along their trajectories
- Liberated electrons drift towards readout chambers

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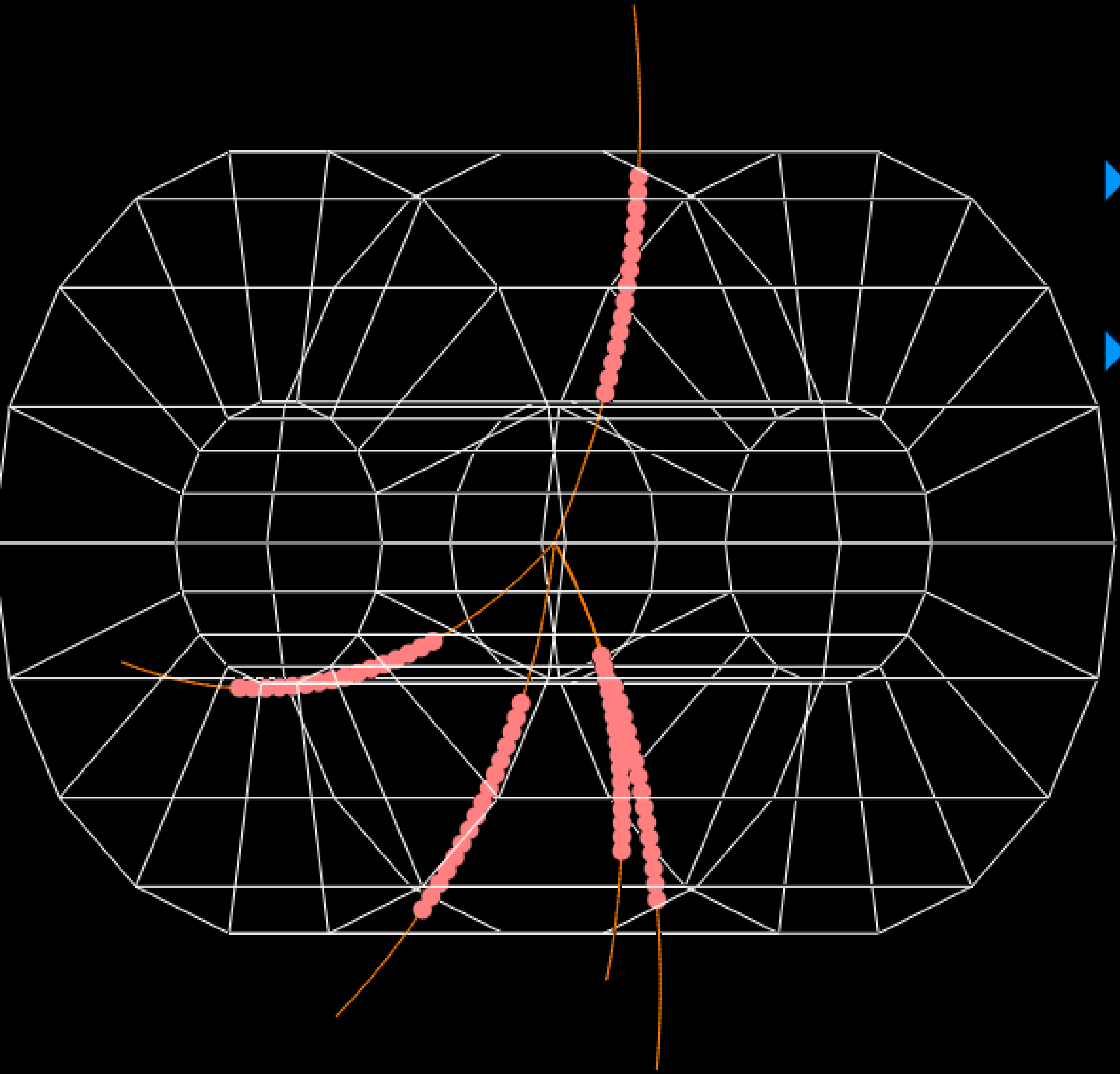

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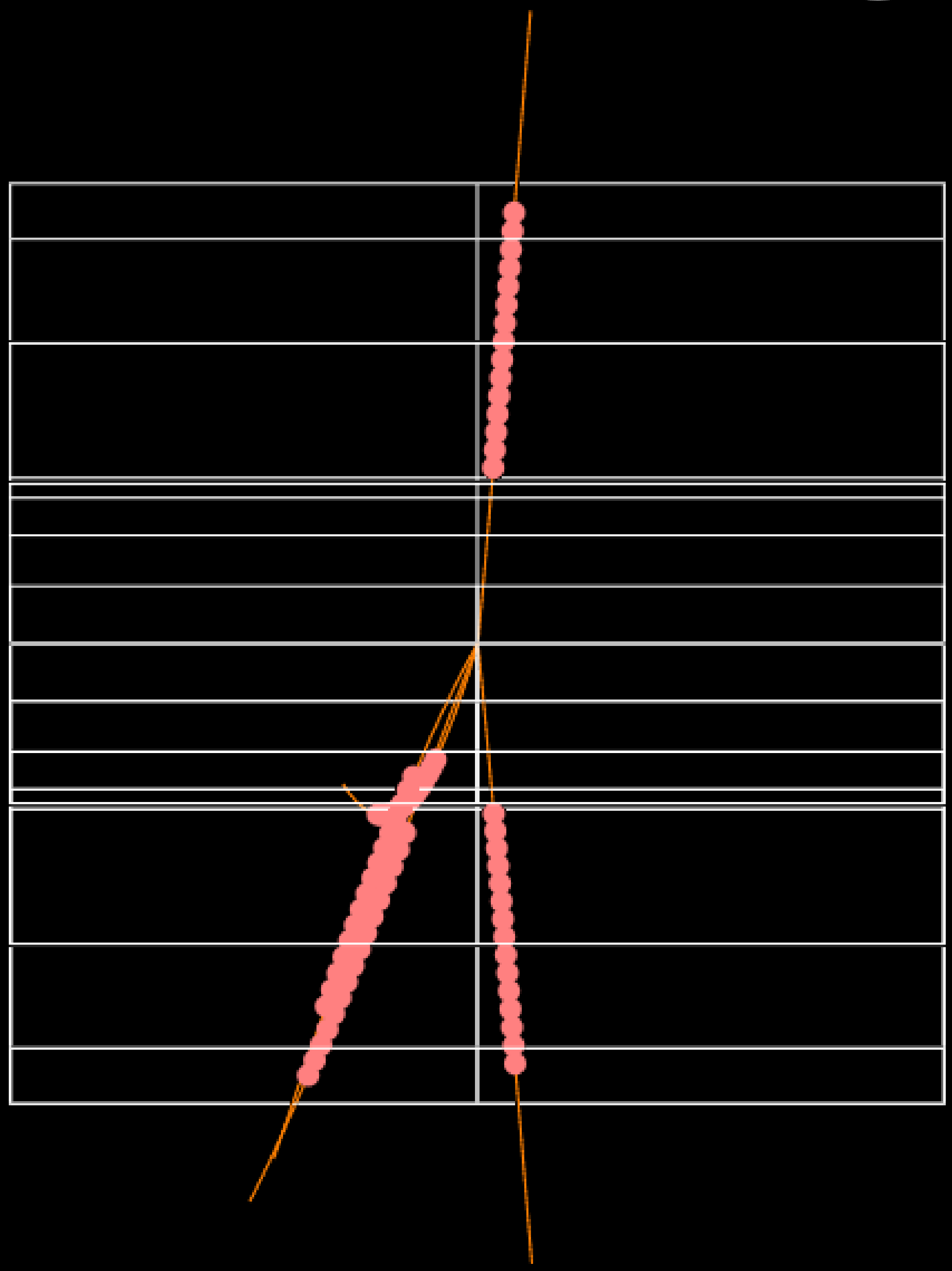

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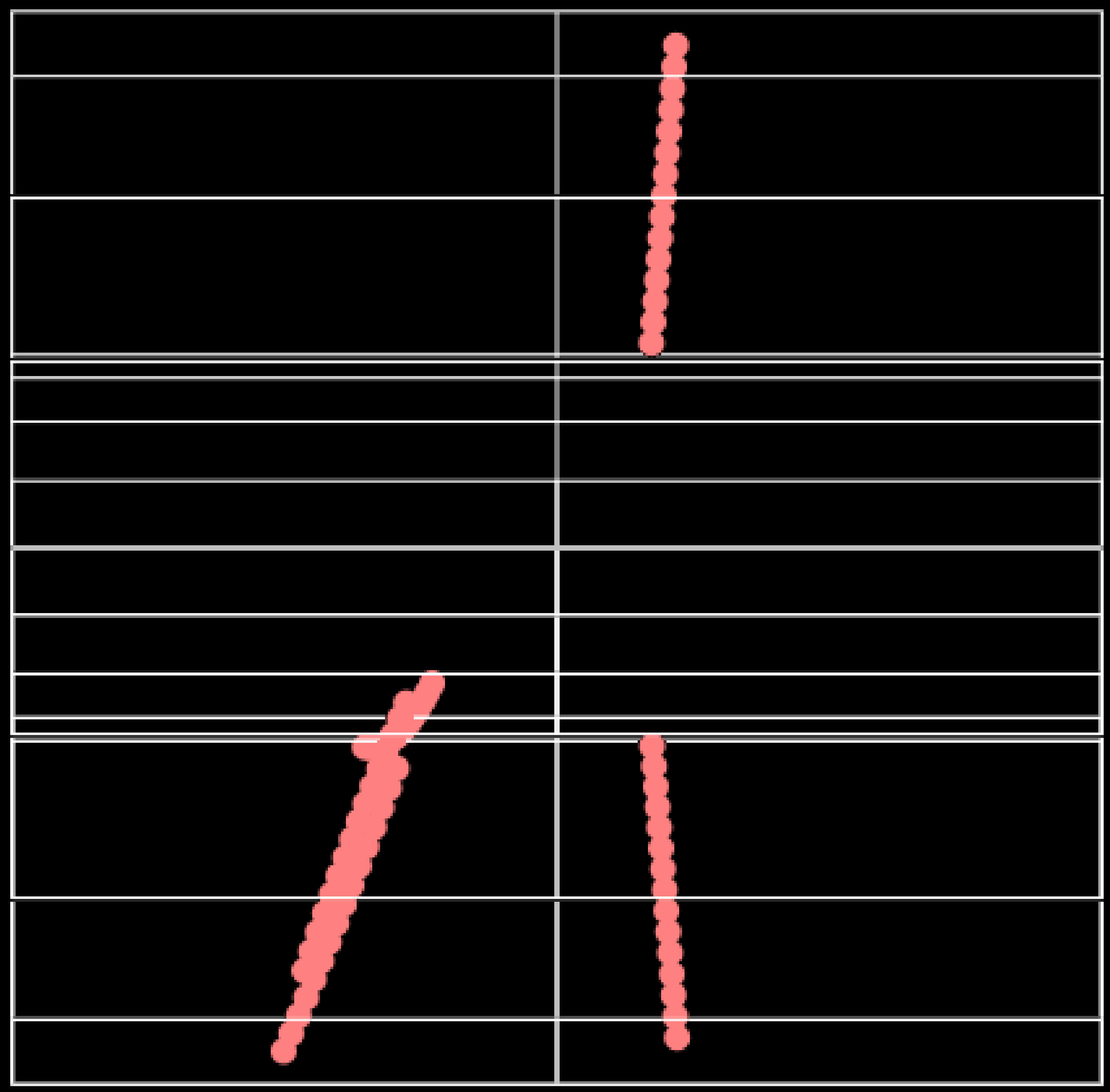

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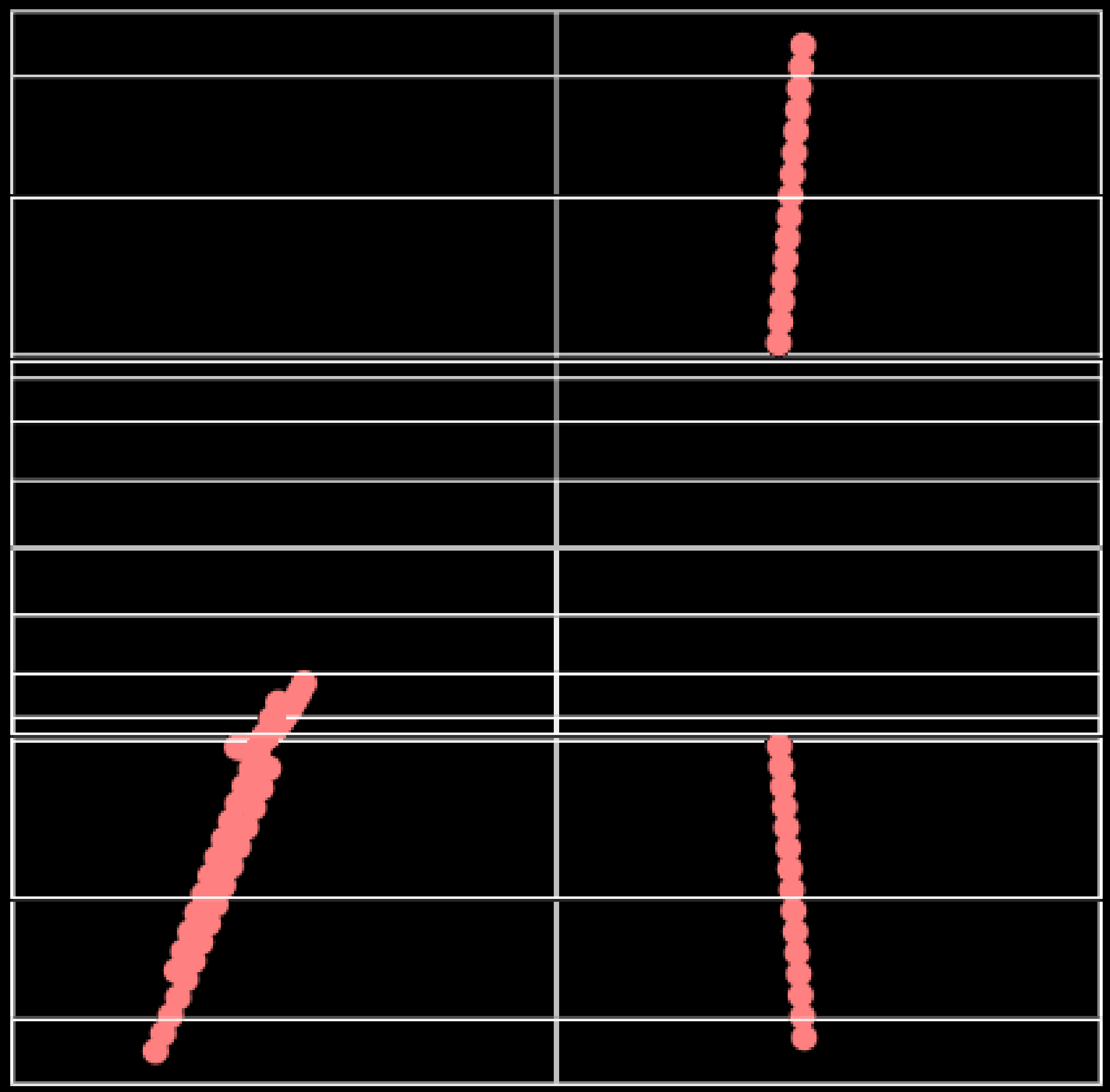
- Their position, density and arrival time get recorded

Working principle



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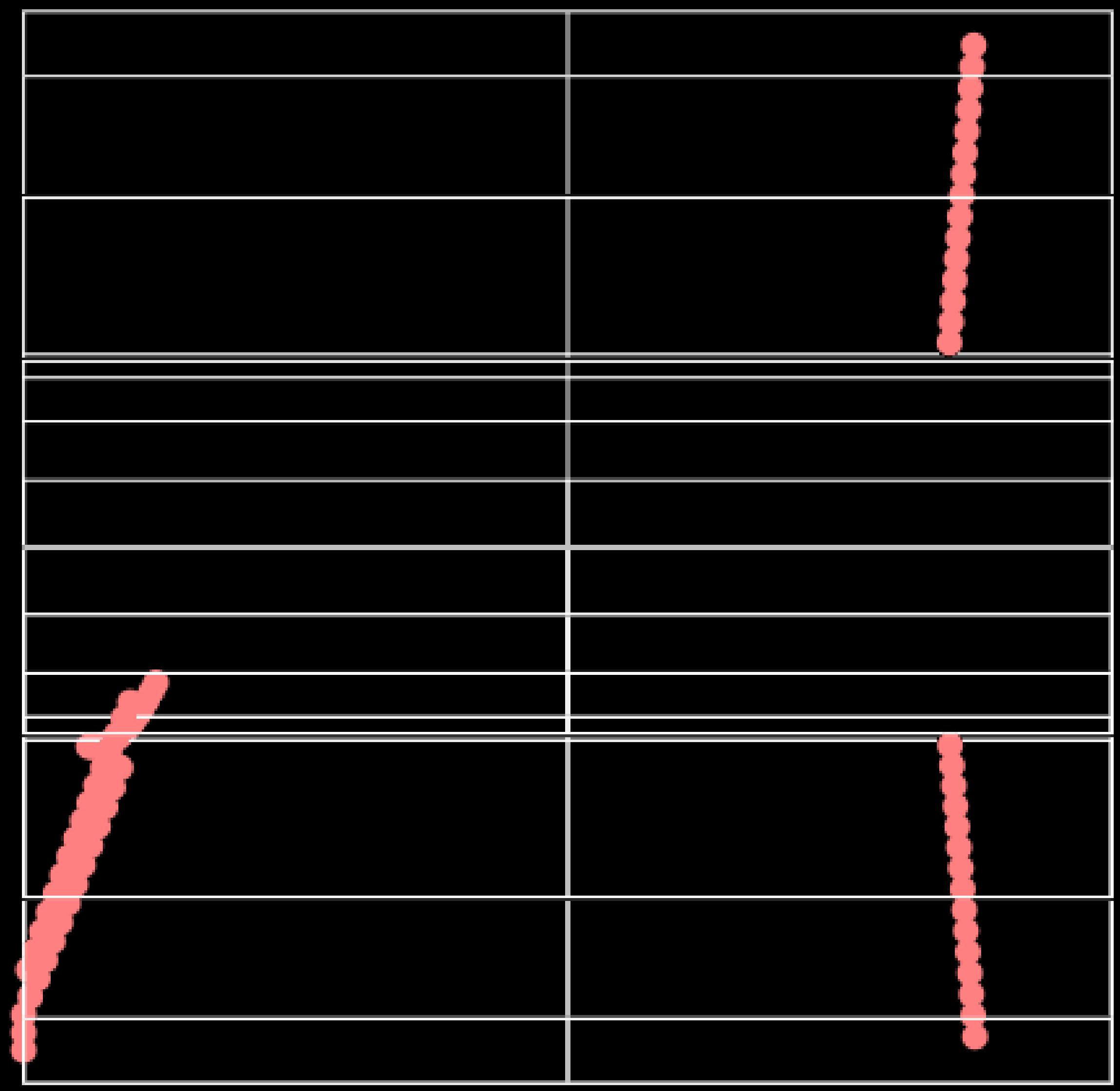

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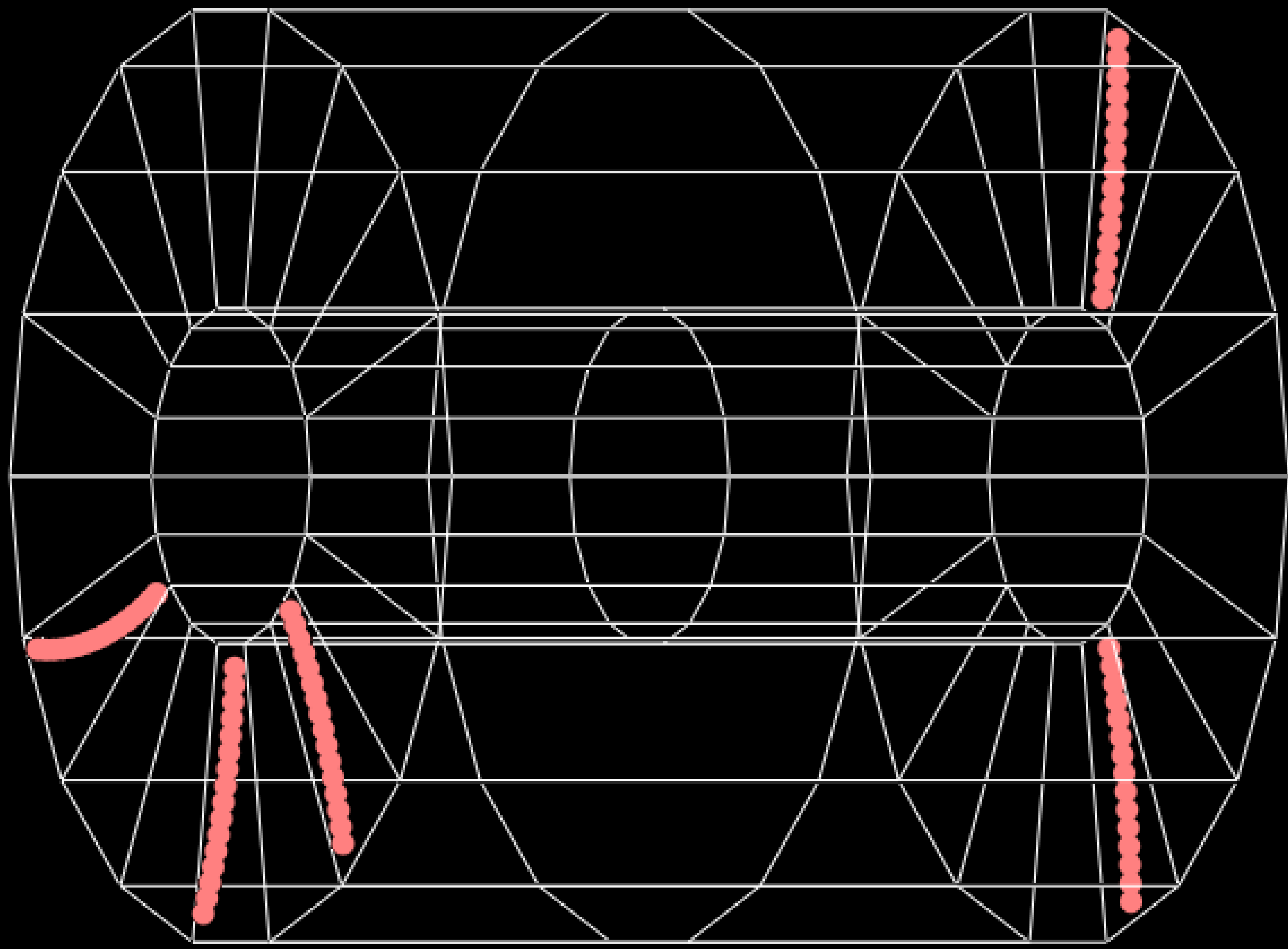

- Charged particles ionize gas along their trajectories
- Liberated electrons drift towards readout chambers
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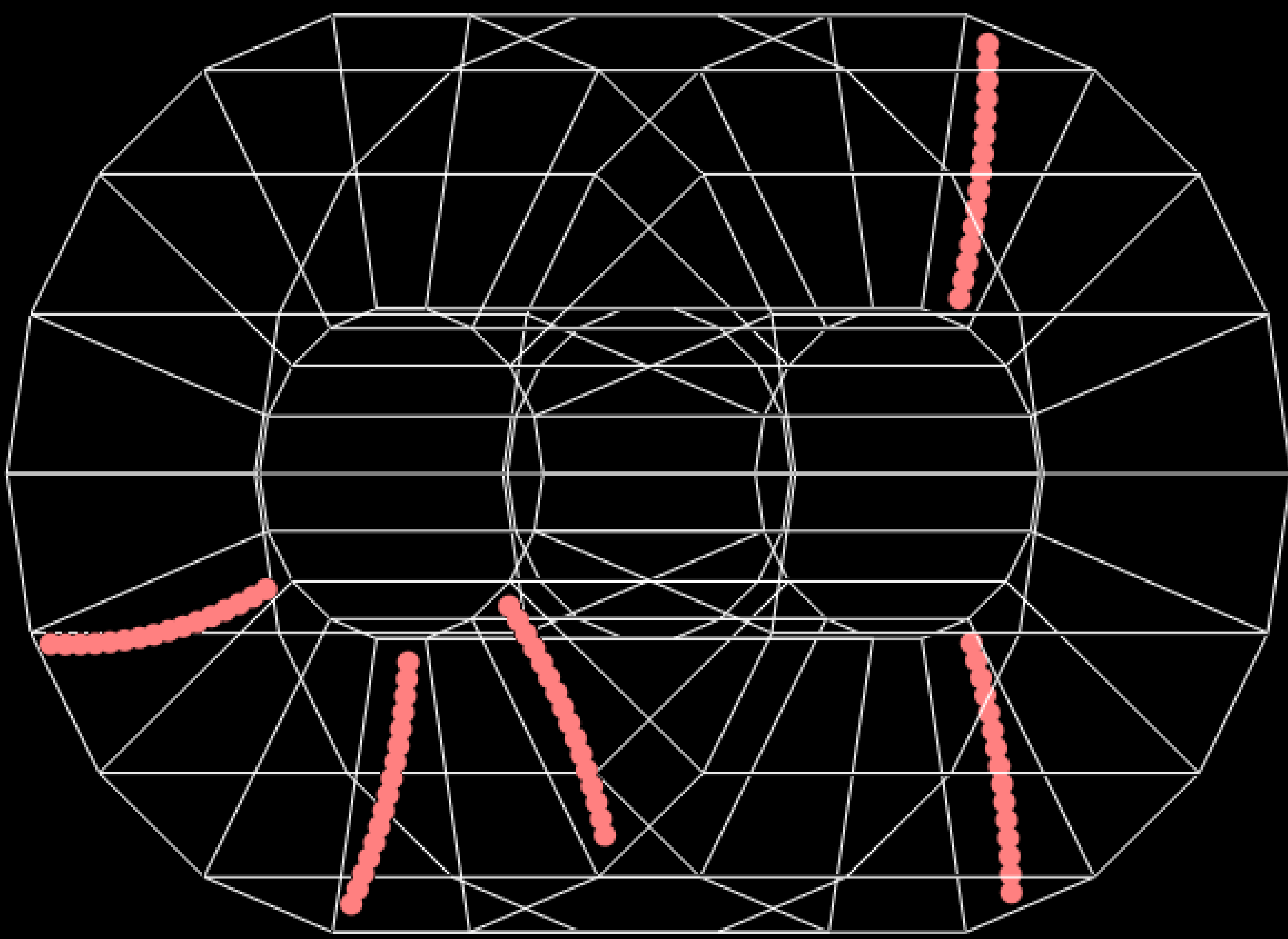
- Together with the collision time, this allows for a full 3D-reconstruction of the event

Working principle



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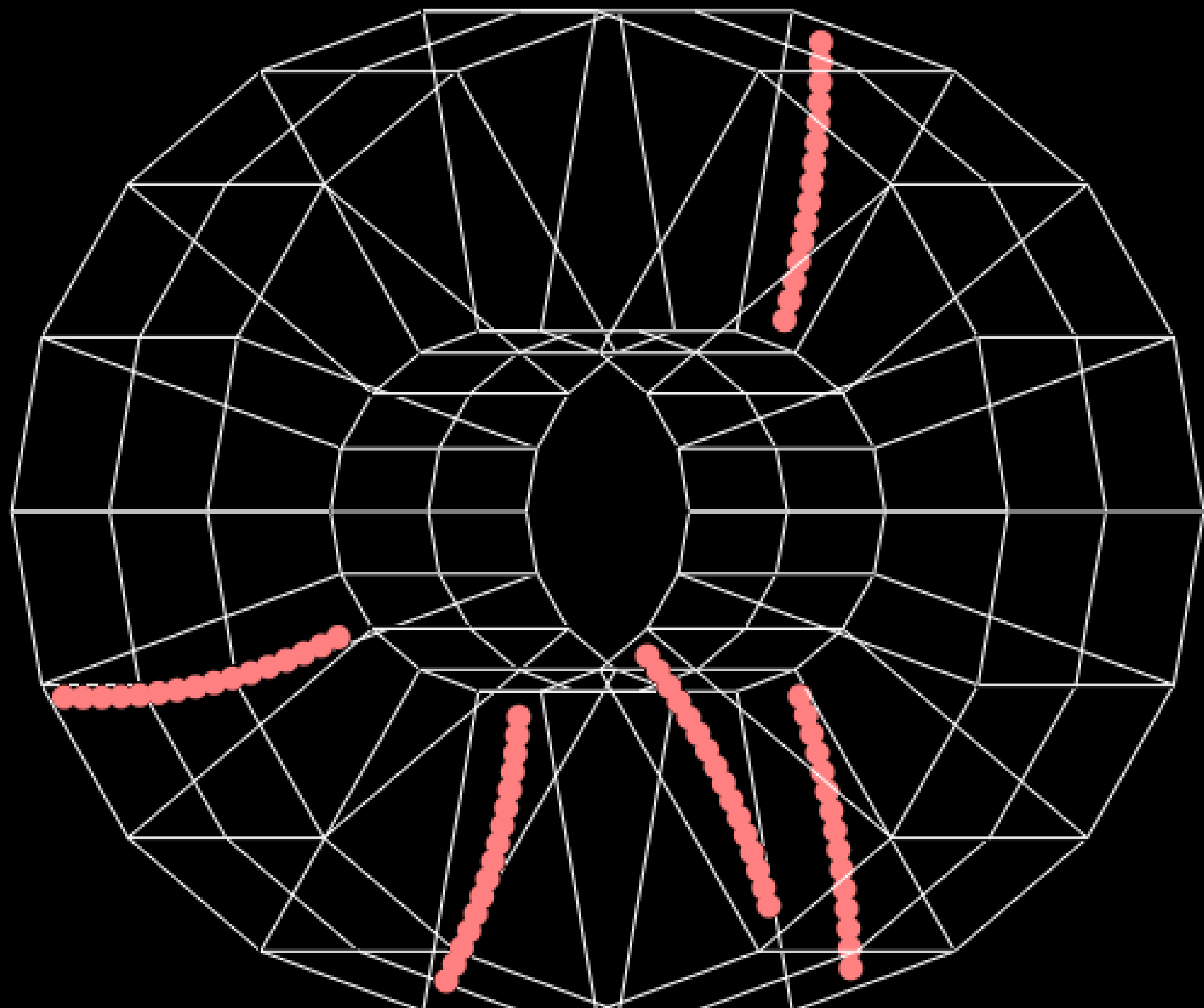

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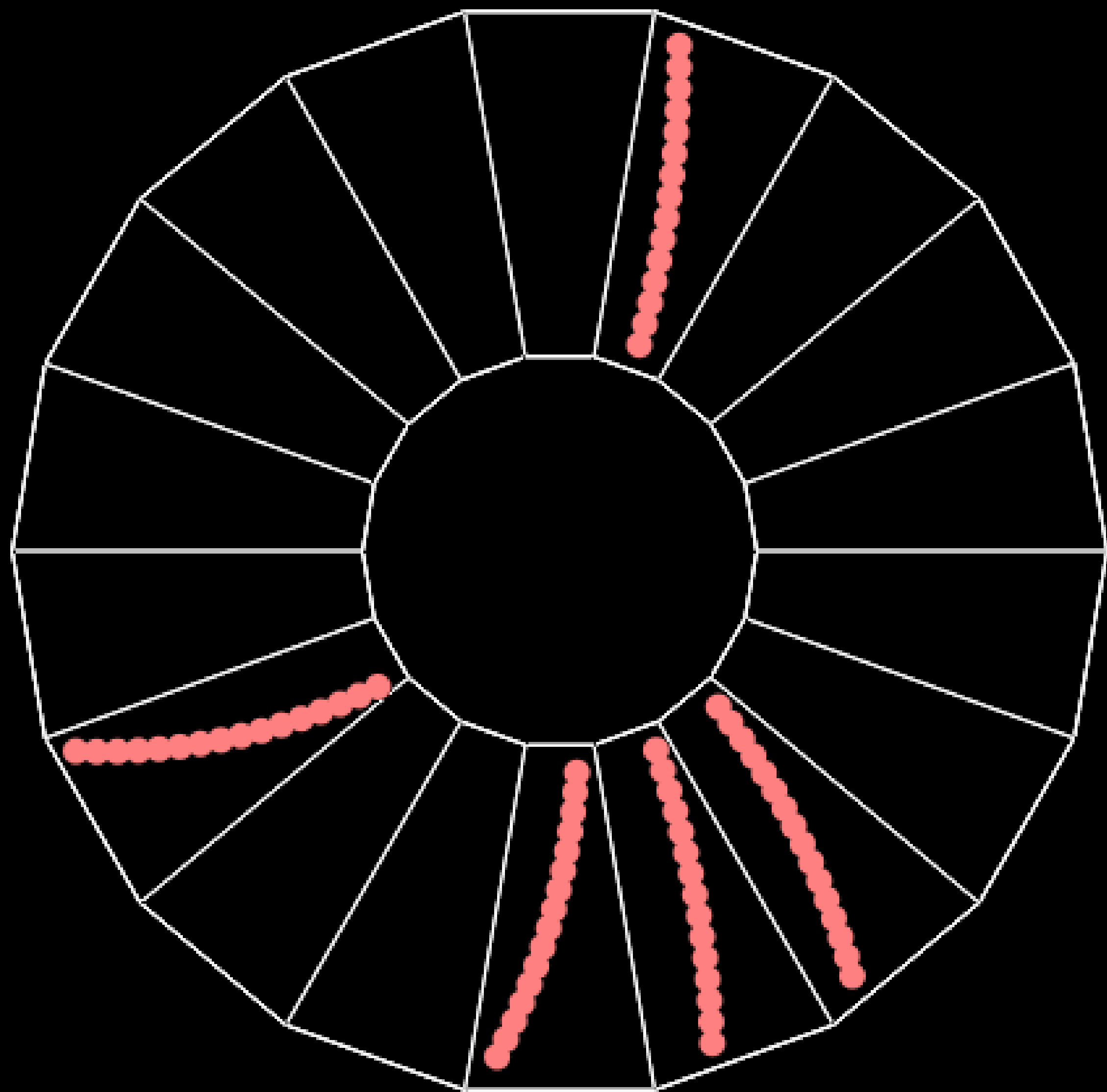

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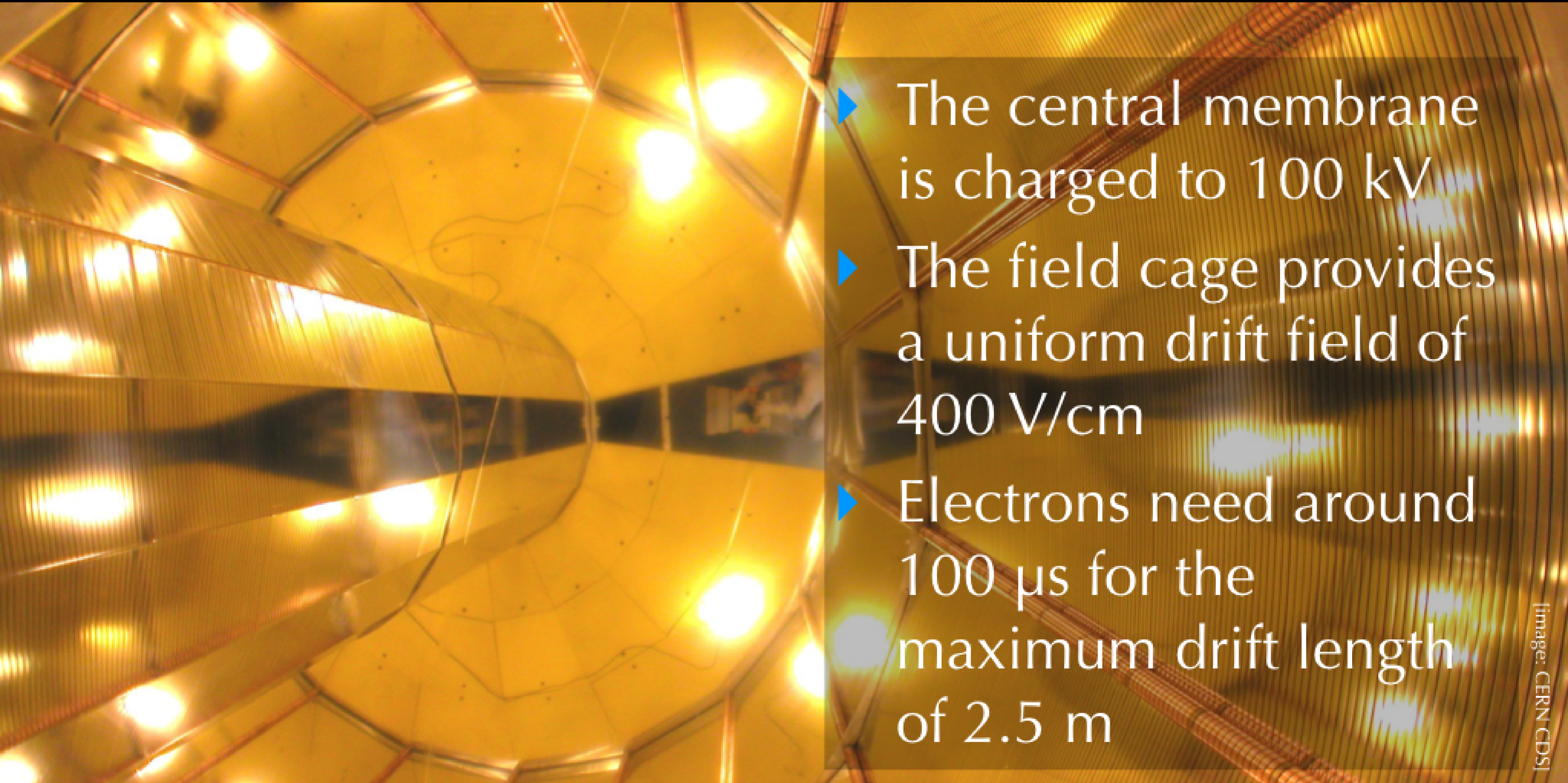
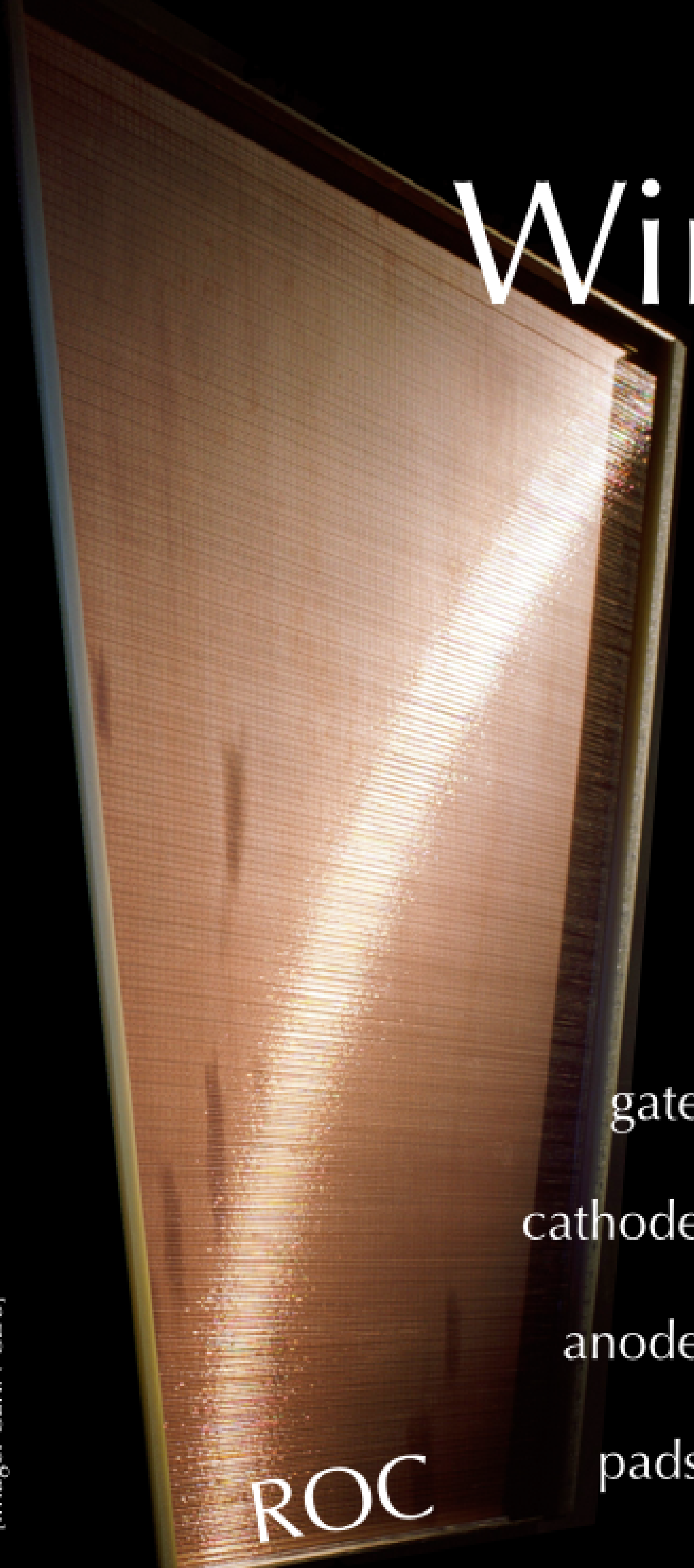
Field cage



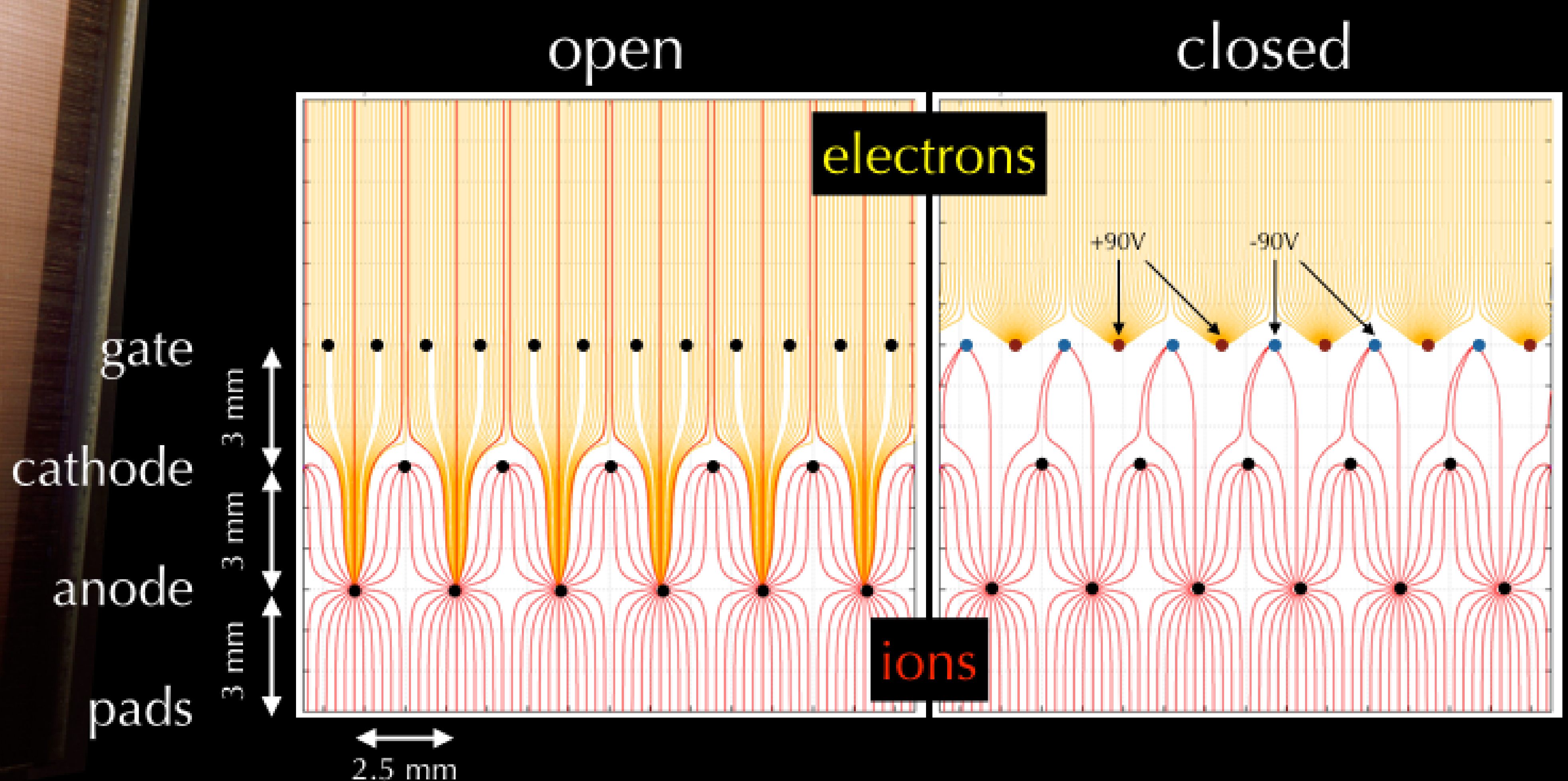
- The central membrane is charged to 100 kV
- The field cage provides a uniform drift field of 400 V/cm
- Electrons need around 100 μs for the maximum drift length of 2.5 m

Wire chambers



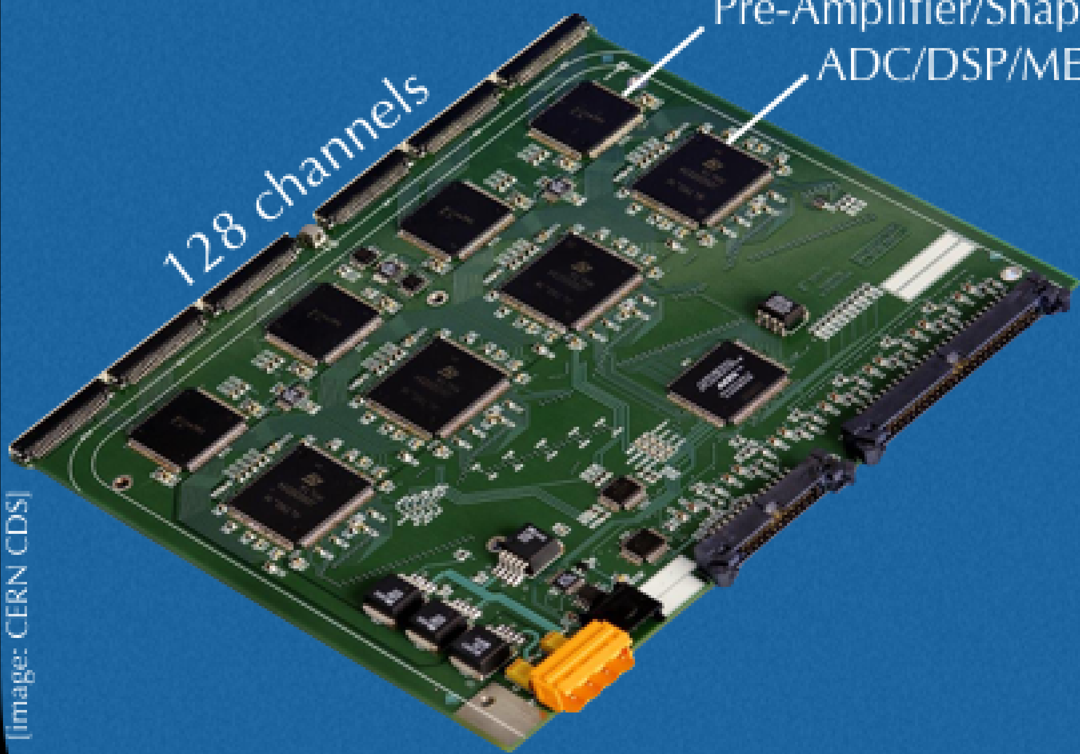
[image: CERN CDS]

- ALICE TPC is (currently) using Multi-Wire Proportional Chambers (MWPCs)
- Ion back-flow is eliminated by a gating grid:

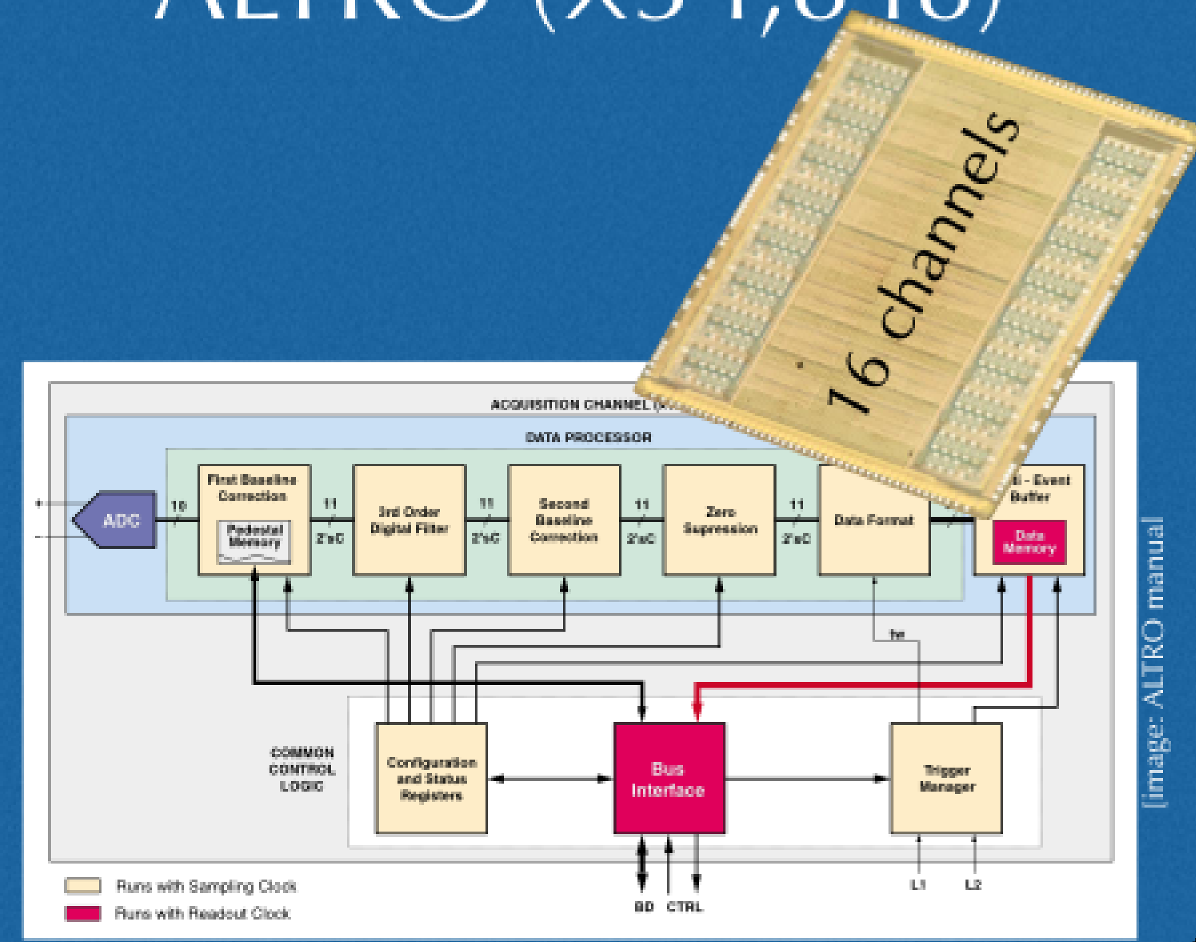


Readout electronics

Front-end cards (×4,356)



ALTRO (×34,848)

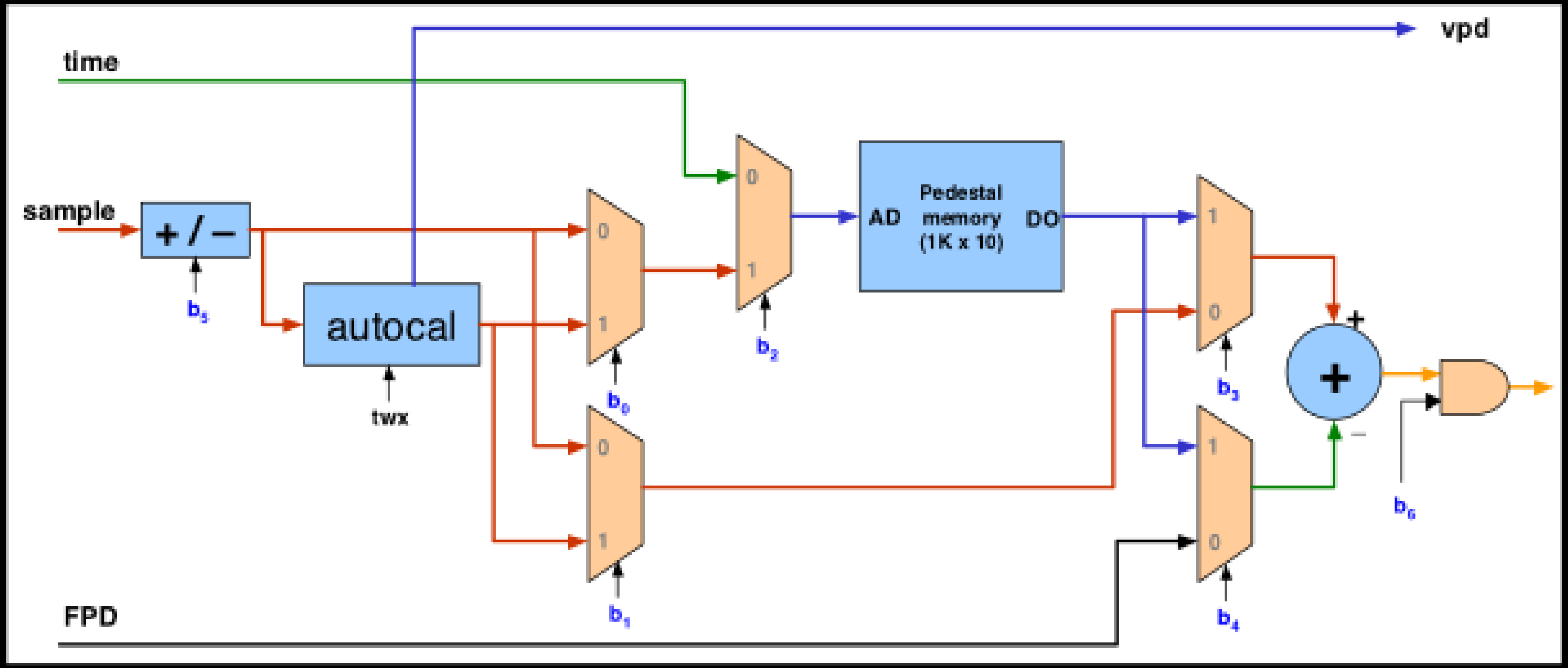


- Highly integrated and customized
- Samples 557,568 channels simultaneously at 10 MHz
- MWPC tailored on-detector DSP for data equalization and reduction

Calibration

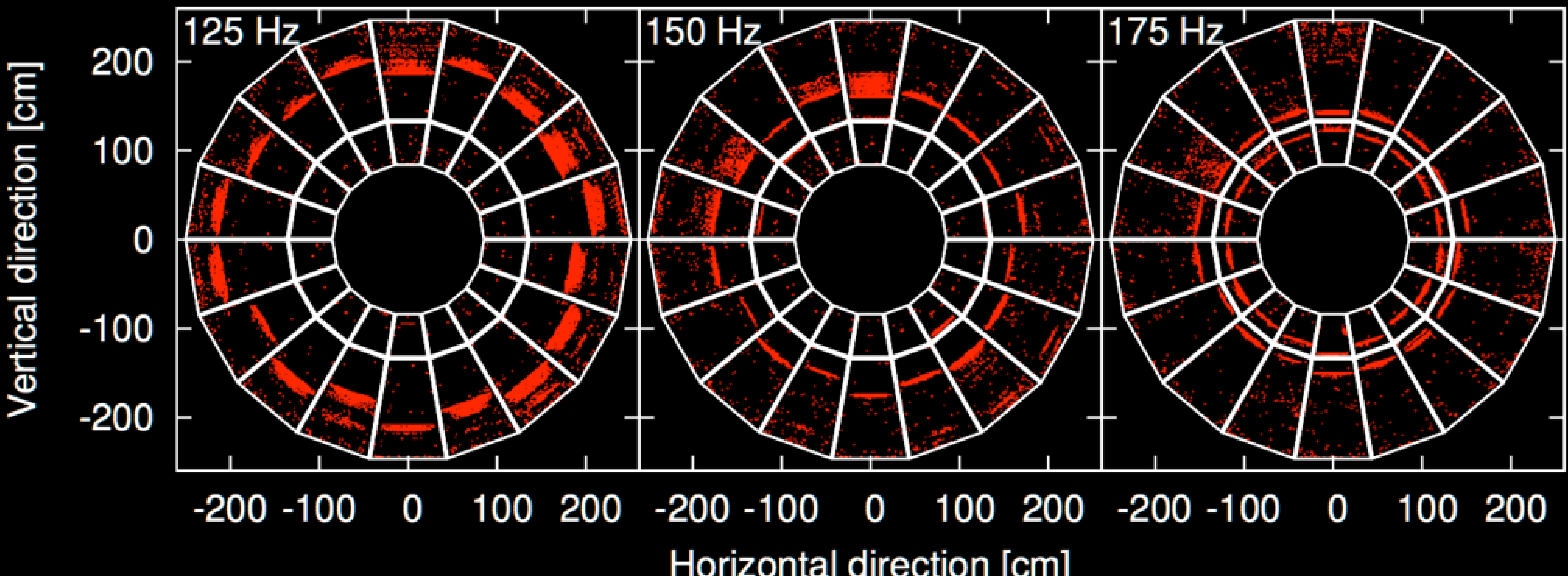
- The on-detector signal processing chain has many parameters to tune
- Dedicated runs are taken to determine them
- For instance, the residual signal of the gating-grid opening is recorded in uncompressed, empty events (→„pedestal runs")
- It is saved in the „pedestal memory" and subtracted from future events

ALTRO base line correction circuit



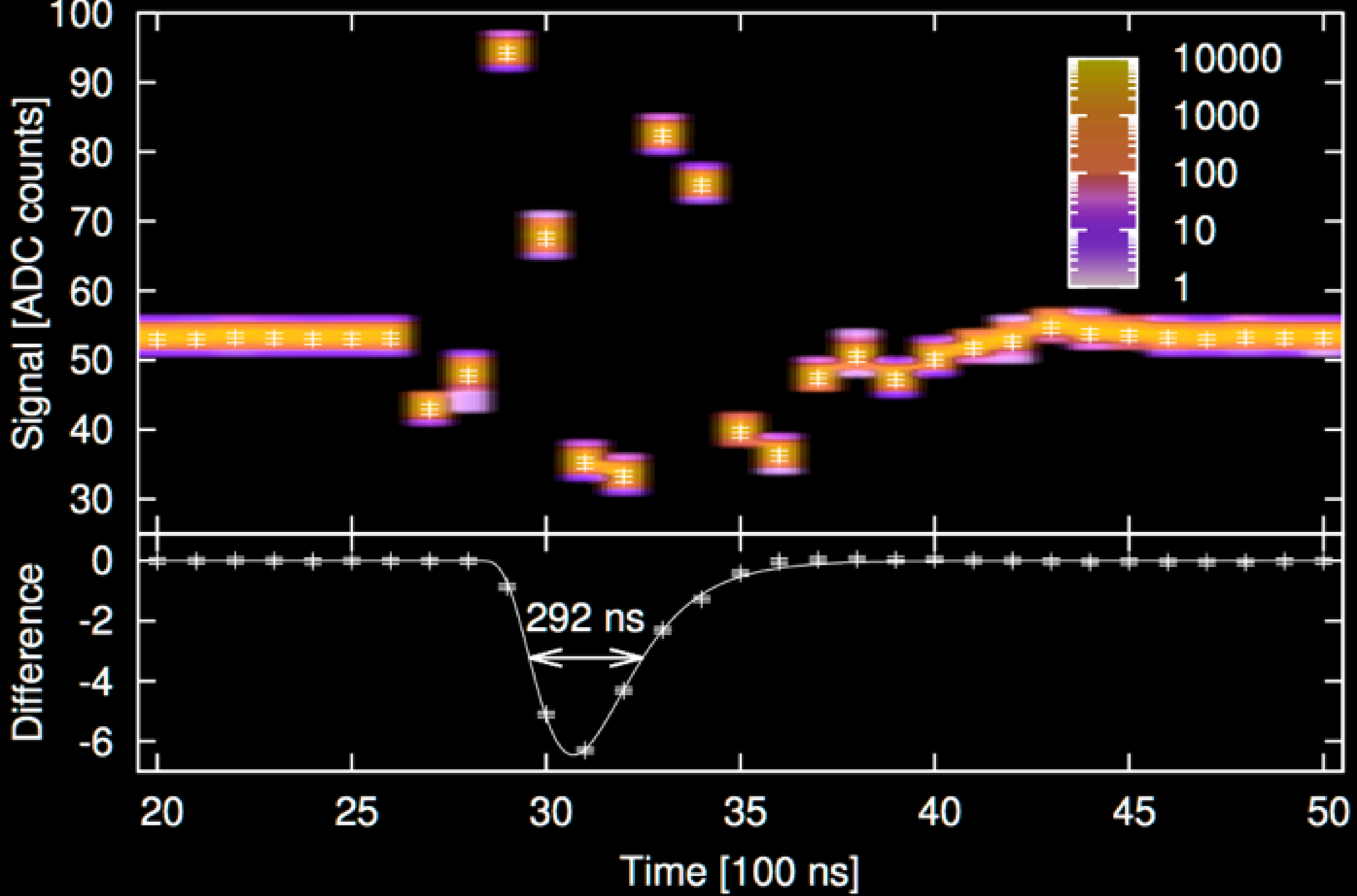
[image: ALTRO manual]

Surprise!



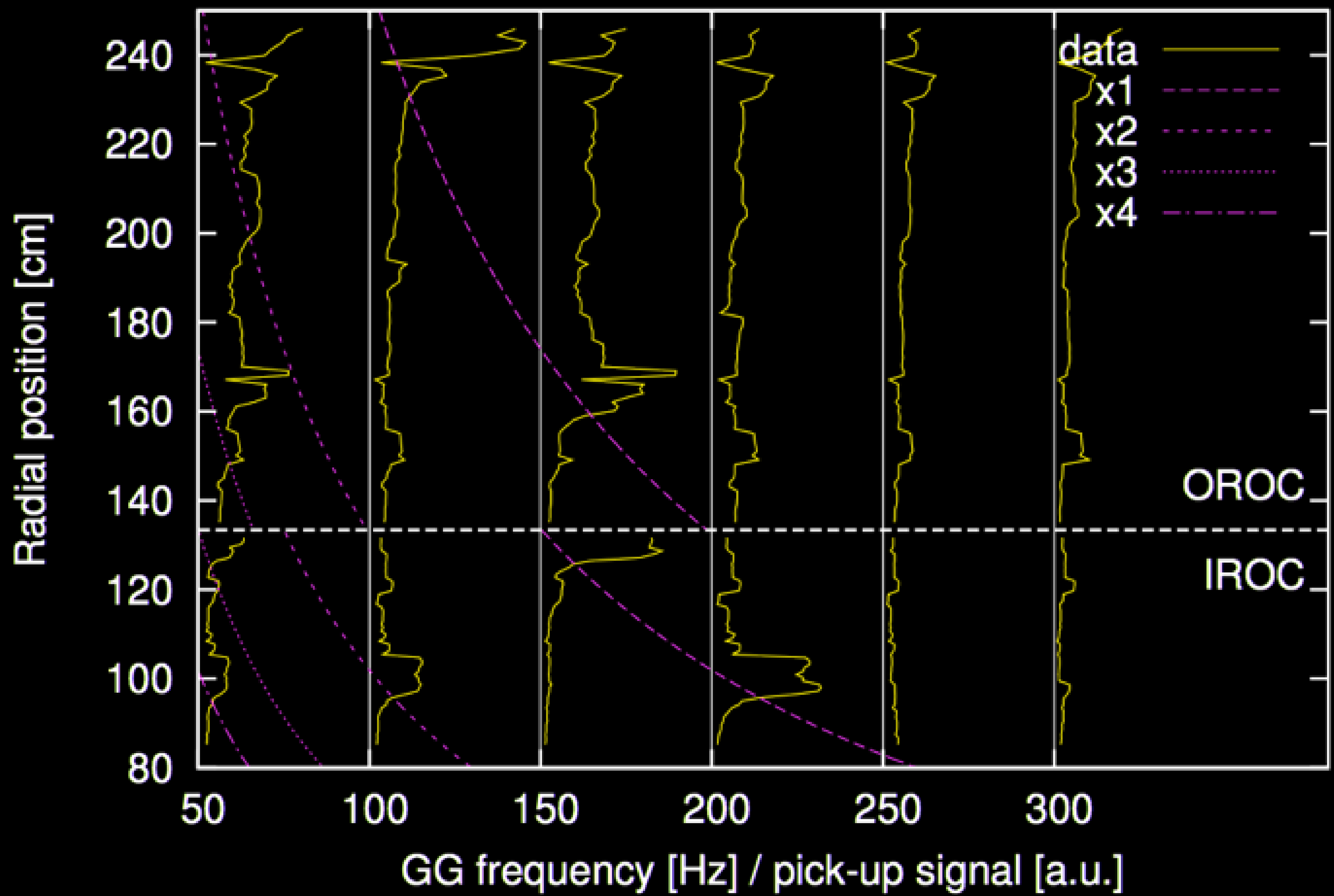
- Extra „noise" appeared when trying to test the newly obtained calibration
- It shows up as lines
- It depends on the trigger rate

Induced signal



- The noise appears on top of the induced gating grid signal

Frequency-dependence



- There is a clear (n × 1/R)-dependence

The ALICE Trigger

- To understand this better, we need to understand the triggering of calibration events.
- How do we trigger without physics events?

Trigger black box

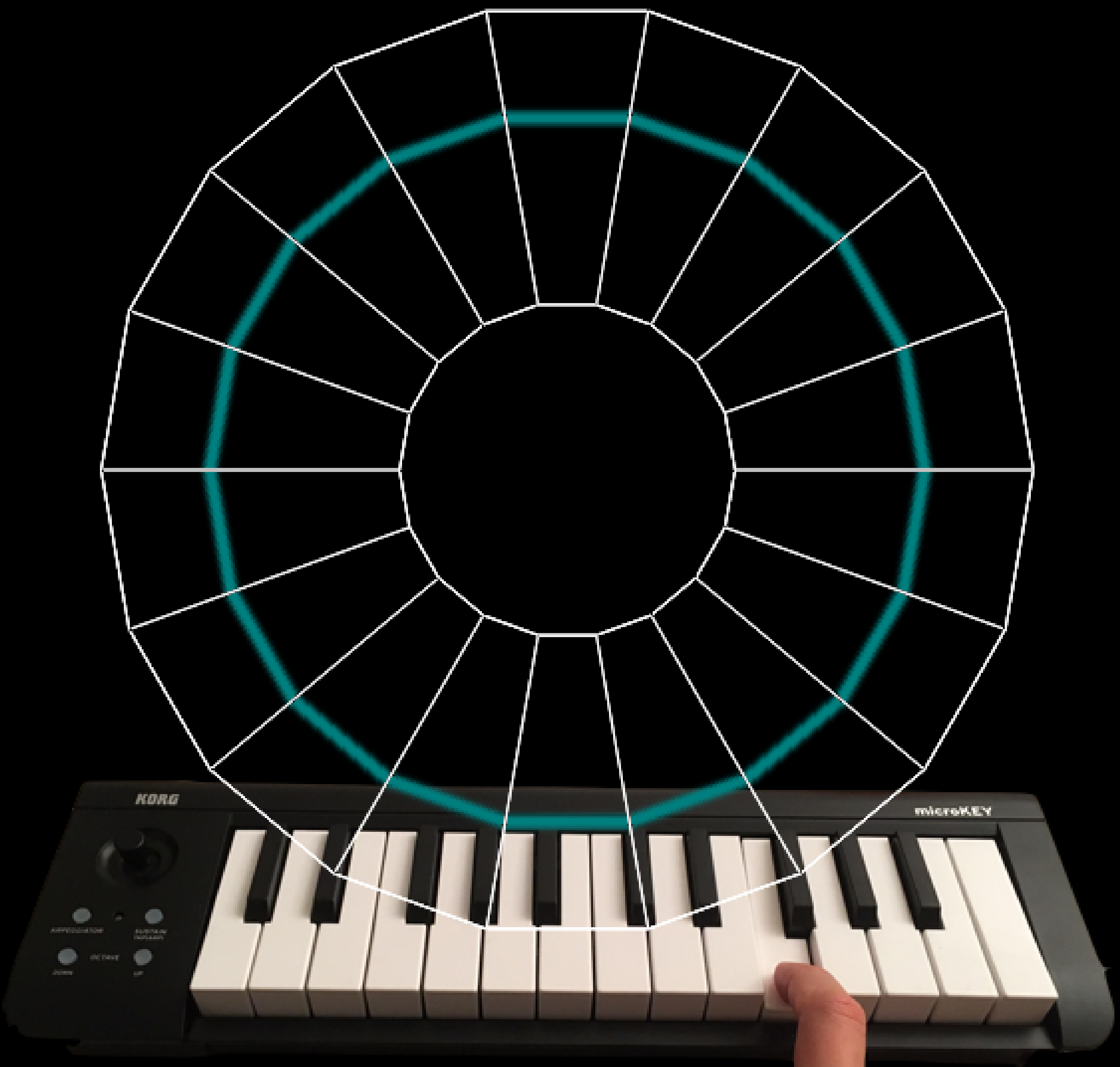
The ALICE Trigger

- To understand this better, we need to understand the triggering of calibration events.
- How do we trigger without physics events?
- We use a fixed trigger frequency…

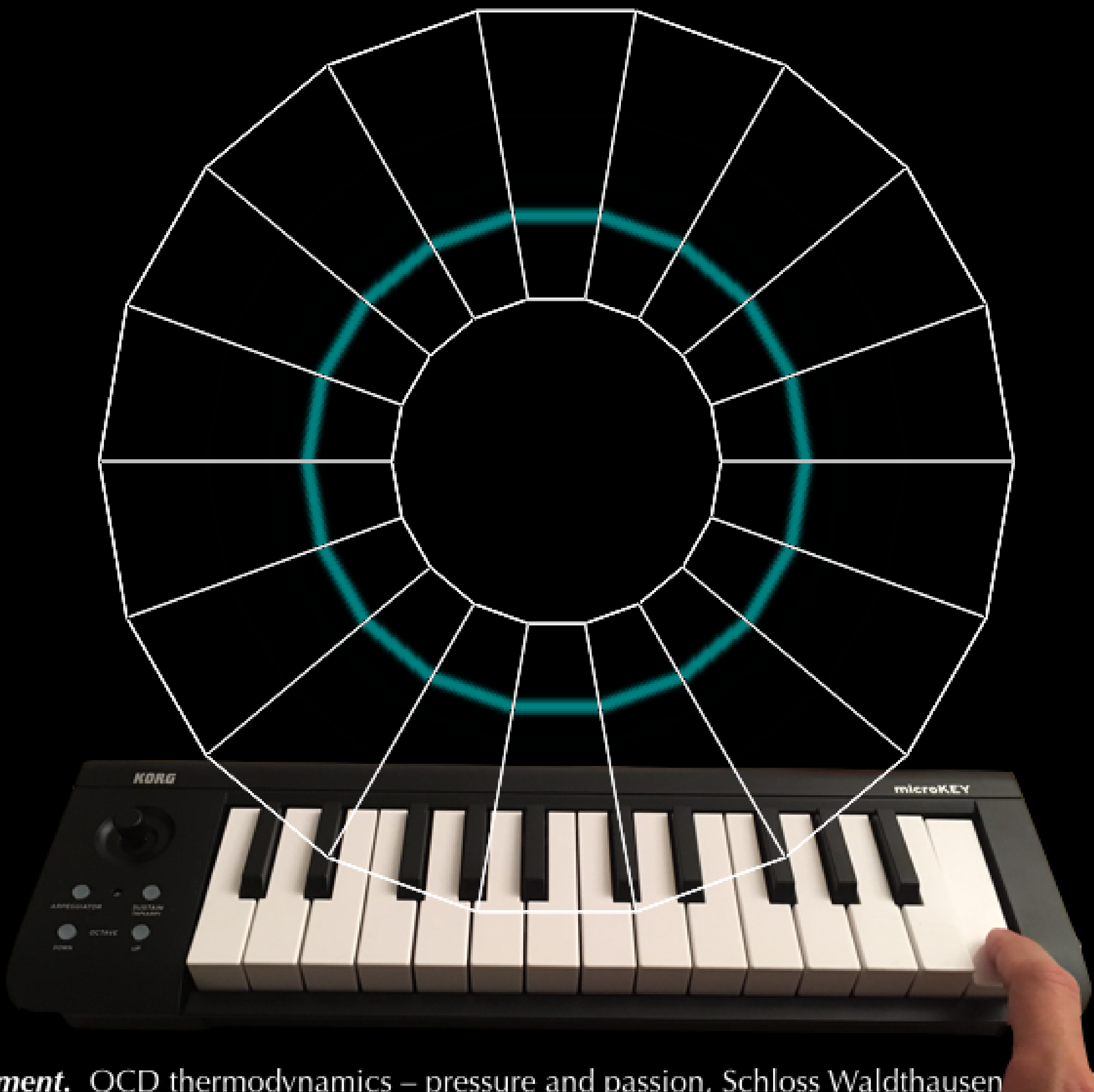
Demonstration

Demonstration

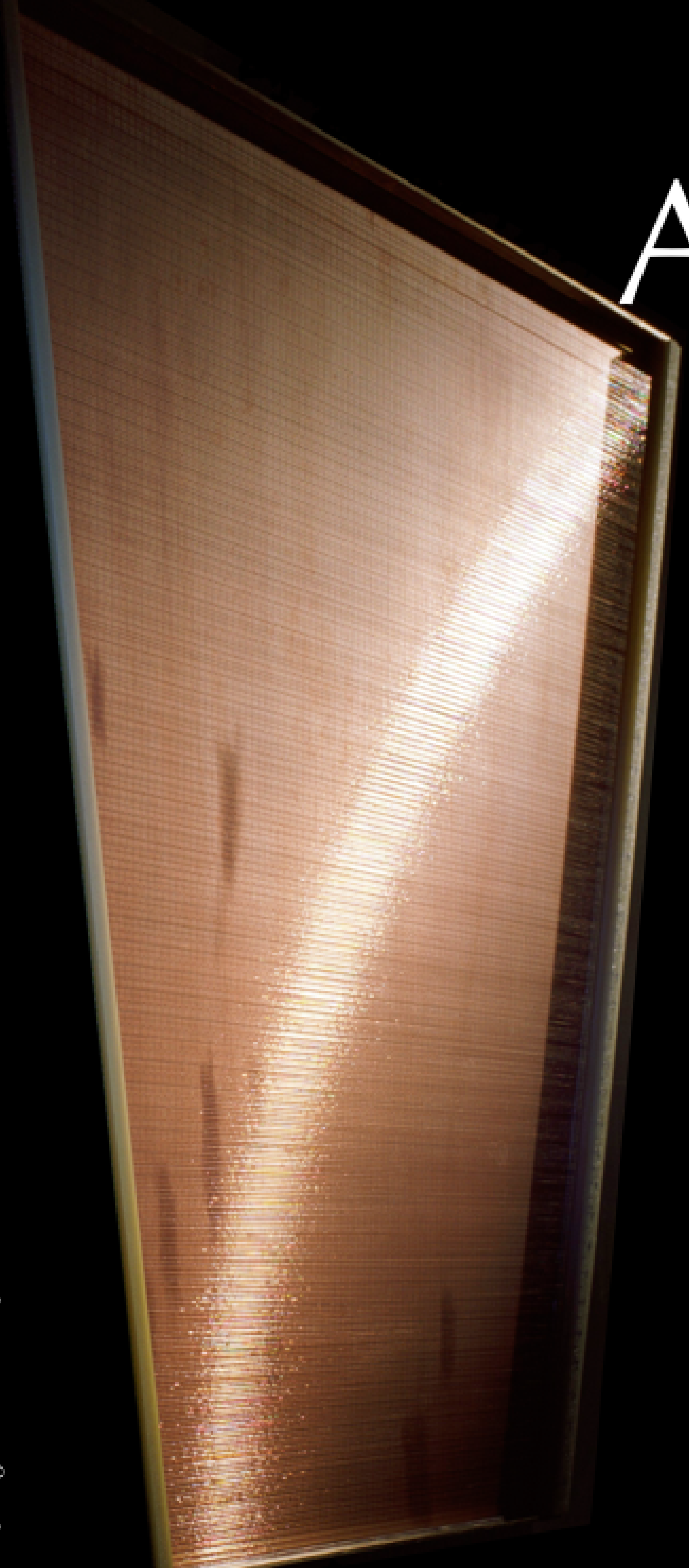
Demonstration



Demonstration



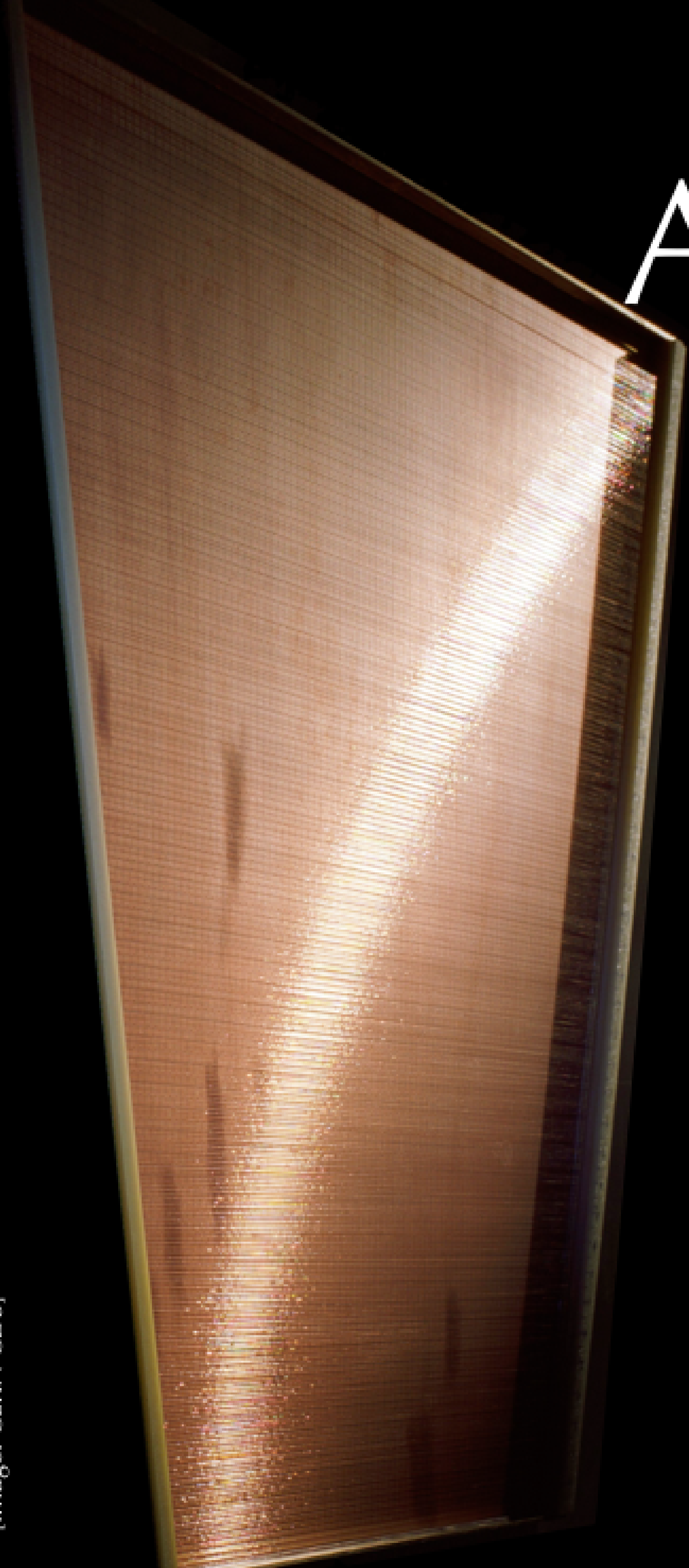
Analogies?



[image: CERN CDS]

- It has wires,
- of different lengths,
- tuned to right tensions

Analogies?



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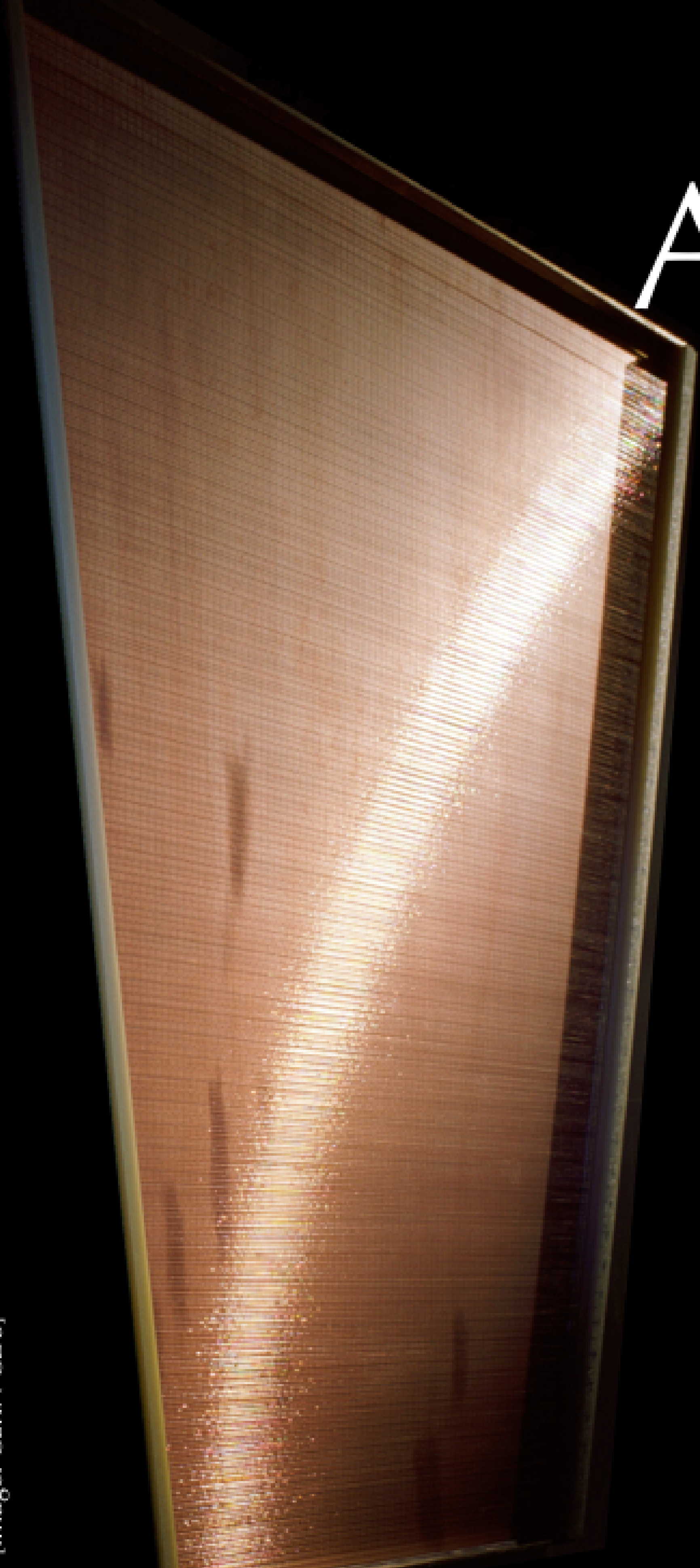

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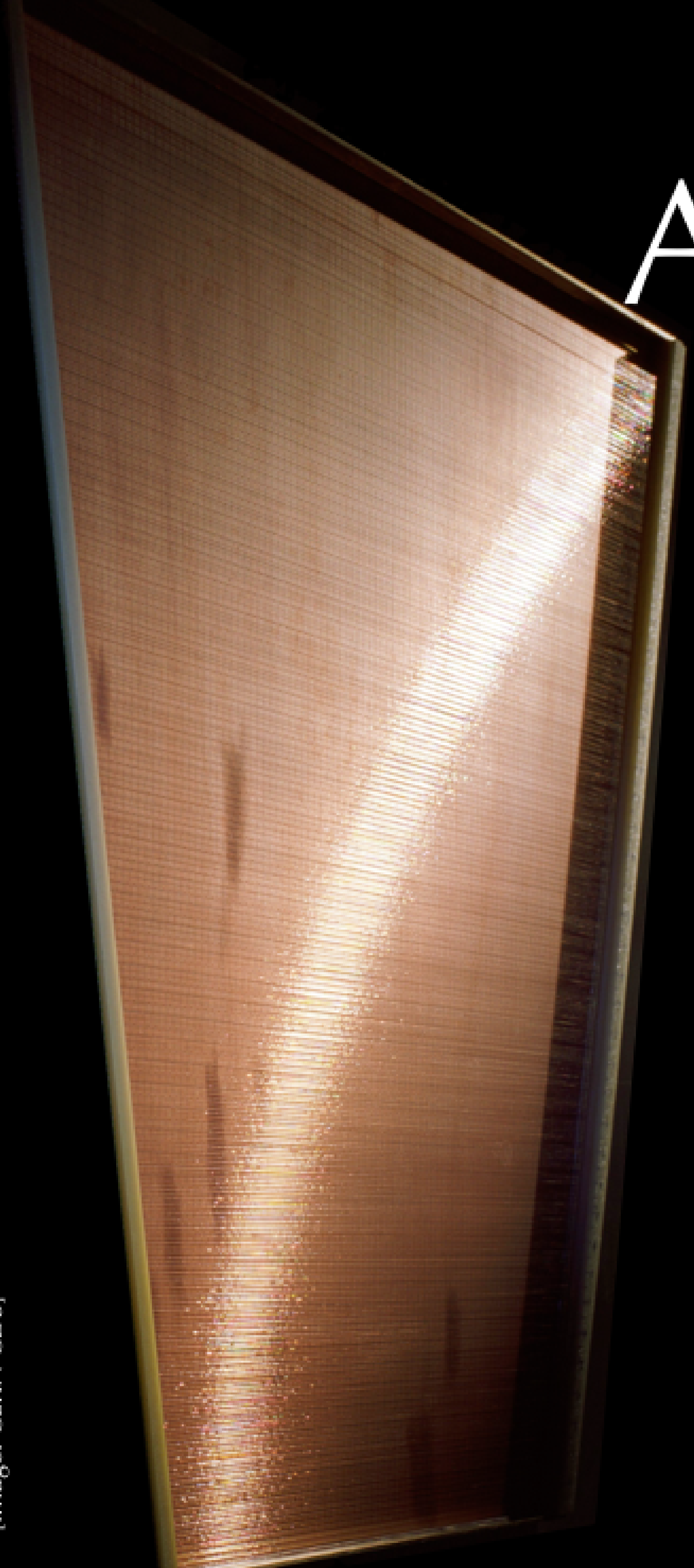
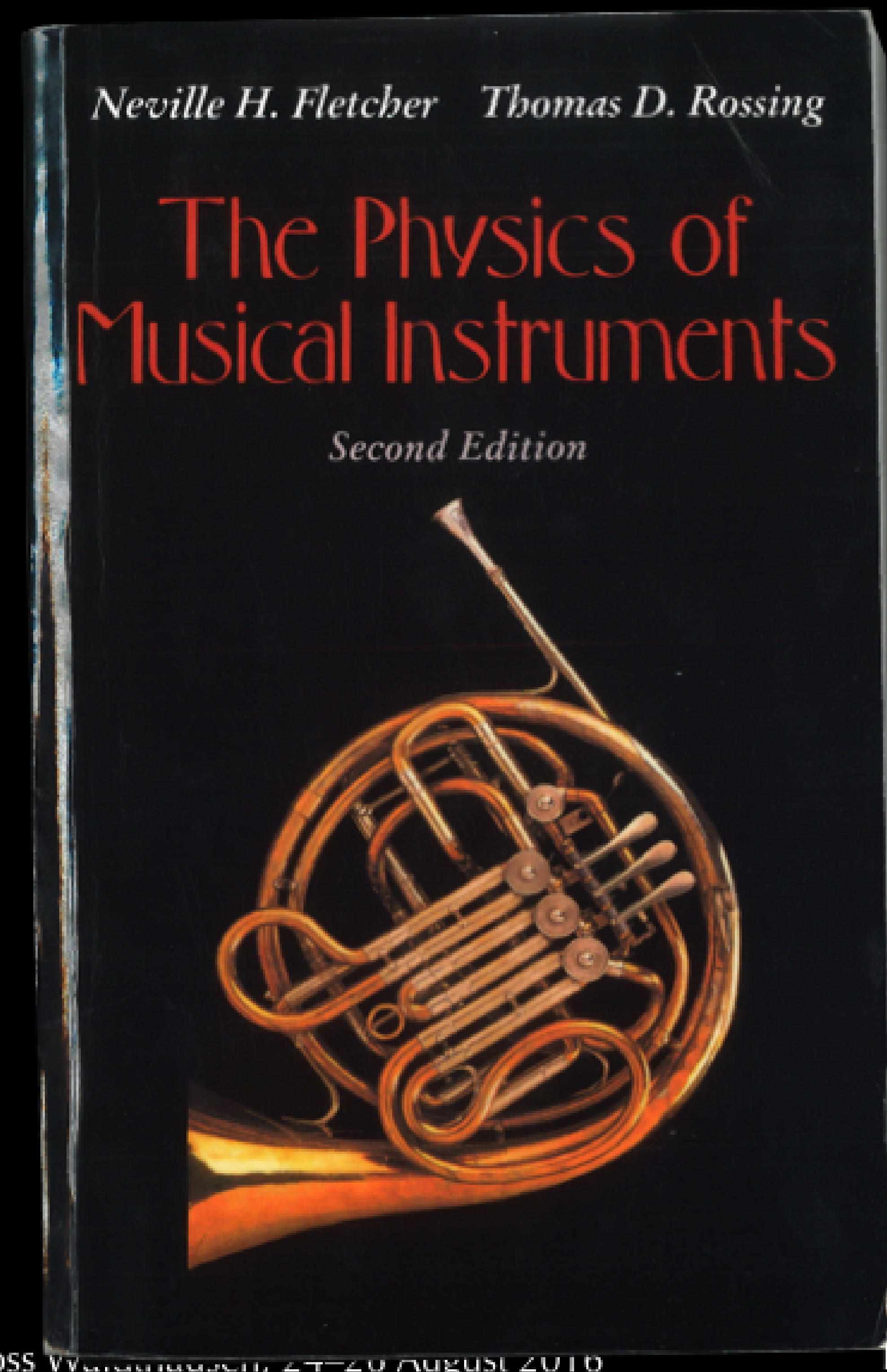


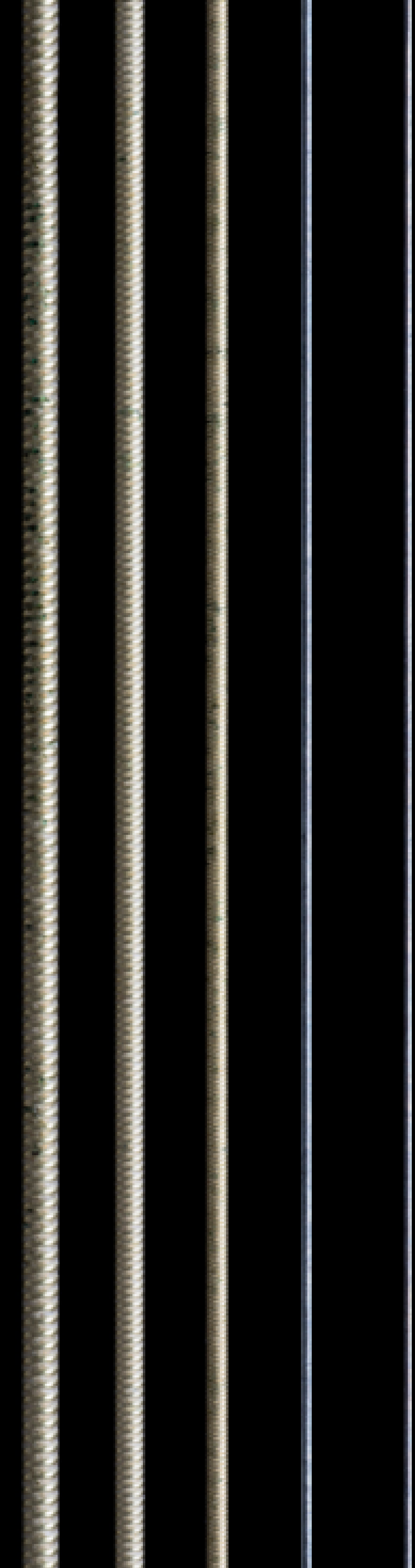
[image: CERN CDS]

- It has wires,
- of different lengths,
- tuned to right tensions

Back to the books...

- There exists literature!
- Sometimes a few shortcuts are taken
- Rarely, high voltages or Ne-CO_2-N_2-atmosphere are considered





Reminder: string theory

- PDE of the vibrating string:

$$\left(\frac{\partial^2}{\partial t^2} + \frac{2}{\tau}\frac{\partial}{\partial t} - c^2\frac{\partial^2}{\partial y^2}\right) z(y,t) = \frac{\mathrm{d}F/\mathrm{d}y}{\mathrm{d}m/\mathrm{d}y}$$

- Solution:

$$z(y,t) = \sum_{n,l\geq 1} a_{n,l}\cos(n\omega t + \varphi_{n,l}) \cdot \sin(l\pi/L \cdot y)$$

- Eigen frequency:

$$f_0 = \frac{1}{2L}\sqrt{\frac{T}{\varrho_w \pi r^2}}$$

Wire properties

	IROC		OROC	
	anode	cathode, gate	anode	cathode, gate
Material	Au plated W	Cu/Be (98/2)	Au plated W	Cu/Be (98/2)
Density ϱ_w (g/cm^3)	19.25	8.80	19.25	8.80
Diameter 2r (µm)	20	75	20	75
Length L (cm)	27–44	27–44	45–84	45–84
Tension T (N)	0.45	0.6	0.45	1.2

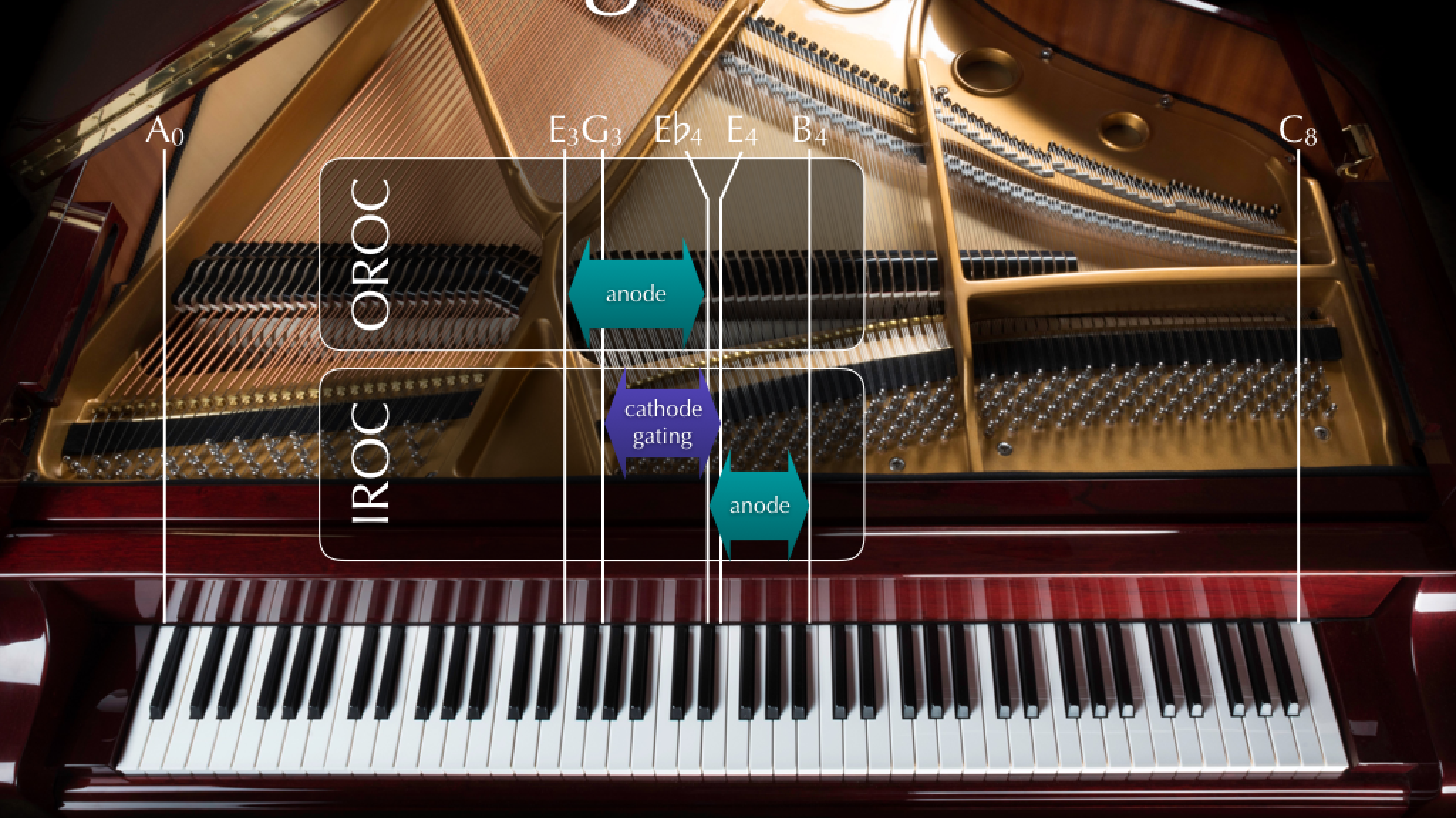
Fixing the scale

Fixing the scale

Fixing the scale

Fixing the scale

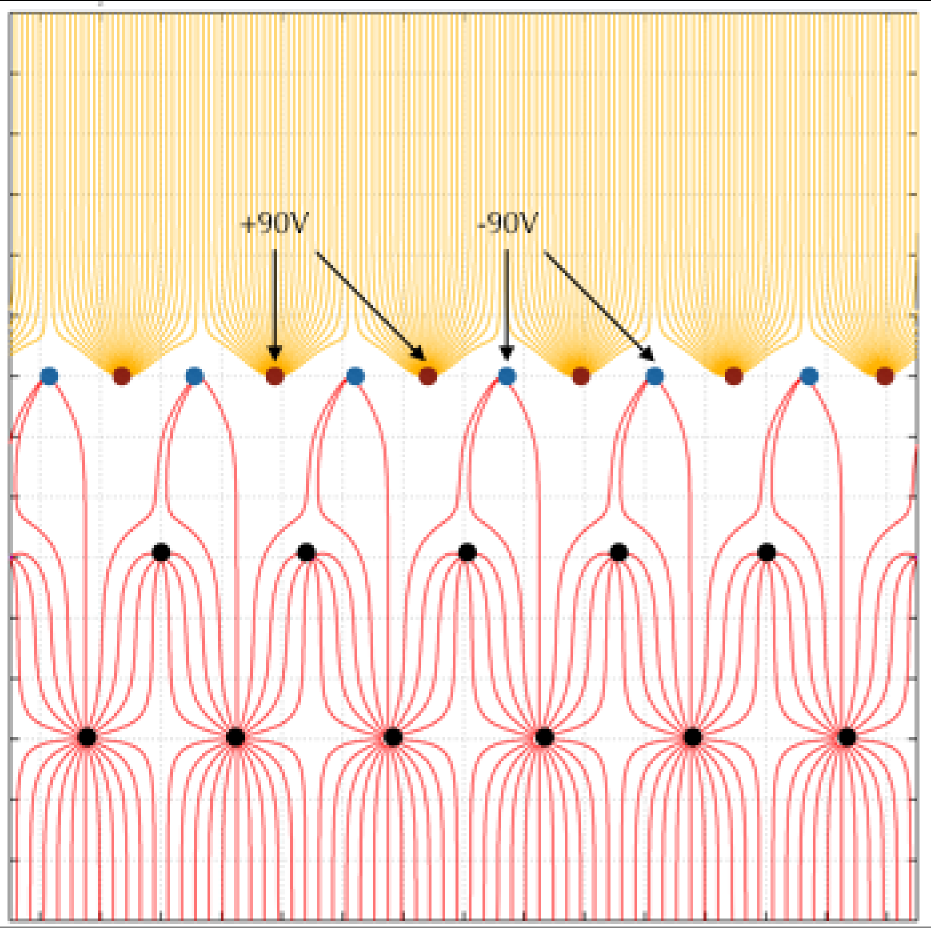
Fixing the scale



Fixing the scale

Drive and damping

- Drive:
  - Quasi-electrostatic forces
- Damping:
  - **„Air" friction** (typically dominant)
  - (Internal heating)
  - (Coupling to support)

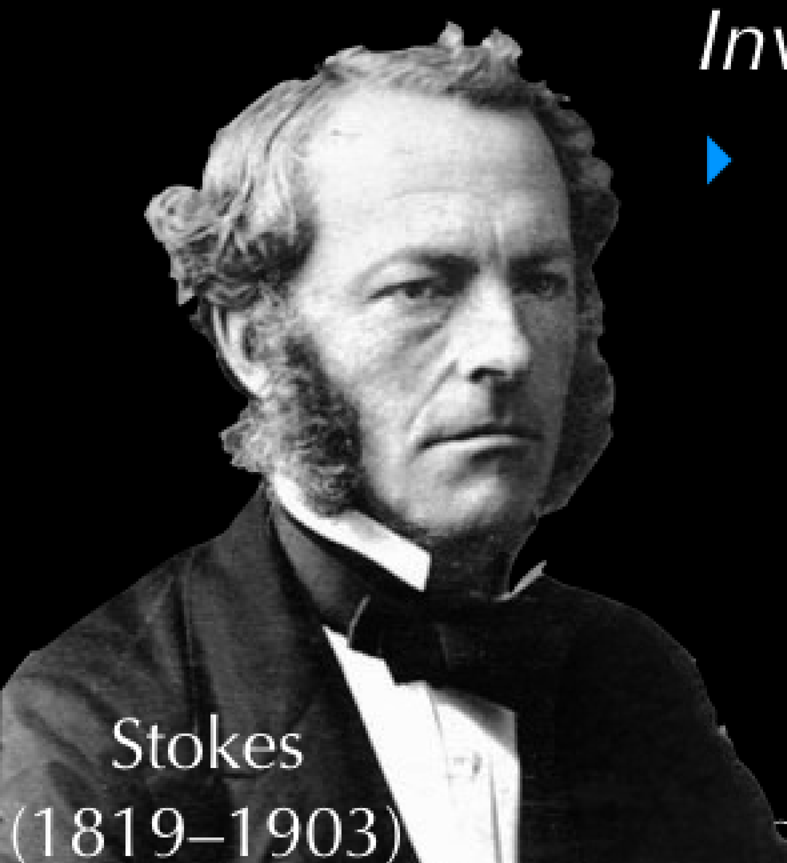


Residual GG switch forces

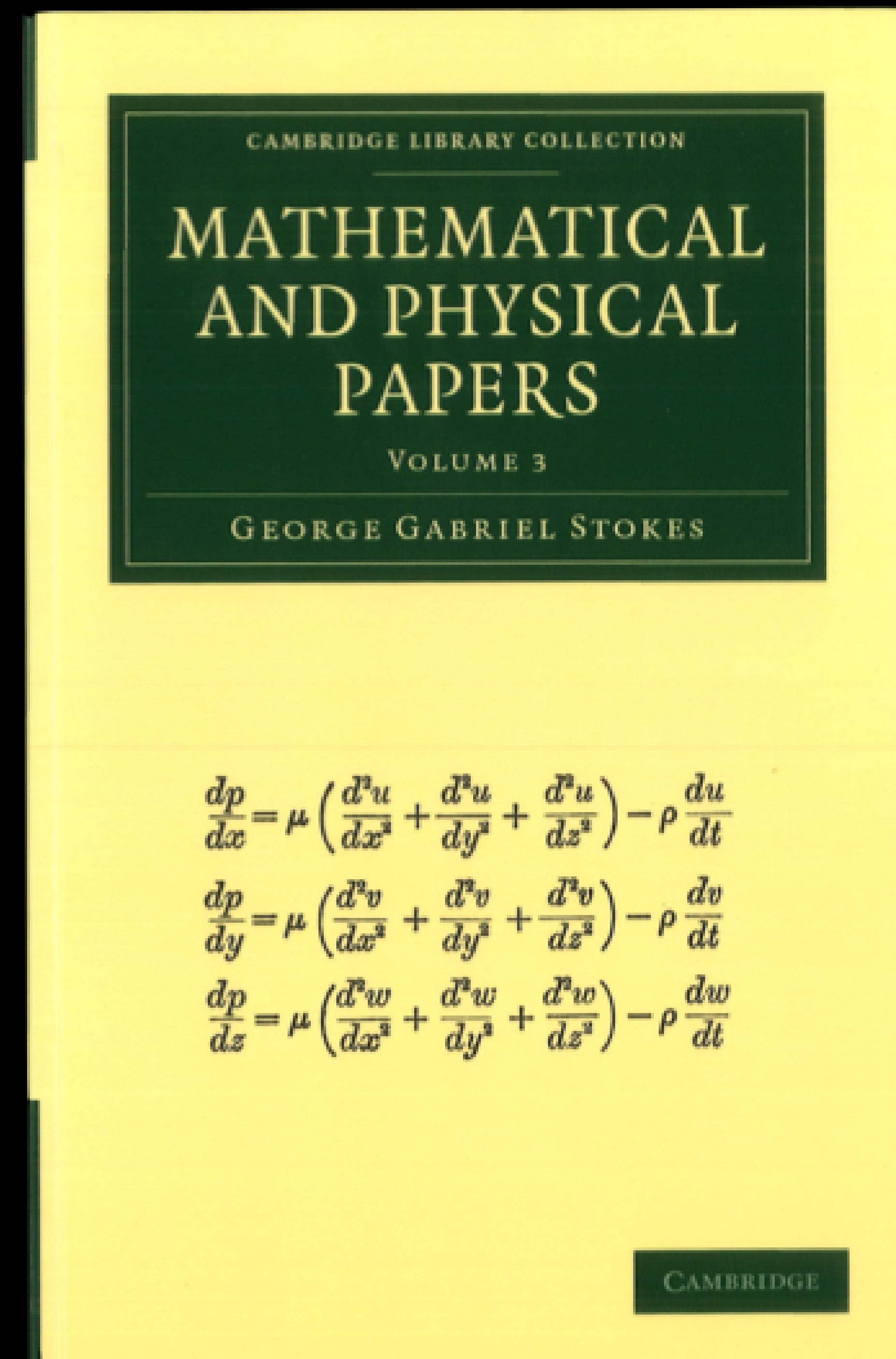
	ΔF_x (N/cm)	ΔF_z (N/cm)
Gate (±)	$\mp 1.4 \times 10^{-9}$	$\pm\mathbf{8.9} \times \mathbf{10^{-7}}$
Cathode	-2.7×10^{-11}	0
Anode	-5.9×10^{-11}	0

… really back to the books!

- *„On the Effect of the Internal Friction of Fluids on the Motion of Pendulums"*
  - *PART I. Analytical Investigation.*
    - *SECTION III. Solution of the equations in the case of an infinite cylinder oscillating in an unlimited mass of fluid, in a direction perpendicular to its axis.*



Stokes
(1819–1903)



Some formulas

- Damping time: $$\tau = 2\frac{\varrho_w}{\varrho_a}\frac{1}{\omega}\frac{1}{k'}$$

ϱ_w: wire density
ϱ_a: gas density
ω: angular frequency

- Stokes defines: $$\mathfrak{m} = \frac{a}{2}\sqrt{\frac{n}{\mu'}} = \frac{a}{2}\sqrt{\frac{\pi}{\mu'\tau}} \quad \ldots(100)$$

$a=r$: wire radius
$n=\omega$: angular frequency
μ': kinetic viscosity

Stokes (1819–1903)

- For large values of m, he derives:

$$k' = \sqrt{2} \, . \, \mathfrak{m}^{-1} + \tfrac{1}{2}\,\mathfrak{m}^{-2}.$$

– which is the typically used formula, but often, like here, m is small.

Some formulas

- But, he also gives the exact solution:

$$\mathfrak{m} = \frac{a}{2}\sqrt{\frac{n}{\mu'}} = \frac{a}{2}\sqrt{\frac{\pi}{\mu'\tau}} \quad \ldots(100)$$

$$\log_e 4 + \pi^{-\frac{1}{2}}\,\Gamma'(\tfrac{1}{2}) = -\Lambda \quad \ldots(102)$$

$$\left.\begin{aligned}
&\frac{\mathfrak{m}^2}{1} - \frac{\mathfrak{m}^6}{1^2.2^2.3} + \ldots = M_0, \quad \frac{\mathfrak{m}^4}{1^2.2} - \frac{\mathfrak{m}^8}{1^2.2^2.3^2.4} + \ldots = M_e \\
&\frac{\mathfrak{m}^2}{1^2} - \frac{\mathfrak{m}^6}{1^2.2^2.3^2} + \ldots = M_0', \quad \frac{\mathfrak{m}^4}{1^2.2^2} - \frac{\mathfrak{m}^8}{1^2.2^2.3^2.4^2} + \ldots = M_e' \\
&\frac{\mathfrak{m}^2}{1}S_1 - \frac{\mathfrak{m}^6}{1^2.2^2.3}S_2 + \ldots = N_0, \quad \frac{\mathfrak{m}^4}{1^2.2}S_2 - \frac{\mathfrak{m}^8}{1^2.2^2.3^2.4}S_4 + \ldots = N_e \\
&\frac{\mathfrak{m}^2}{1^2}S_1 - \frac{\mathfrak{m}^6}{1^2.2^2.3^2}S_3 + \ldots = N_0', \quad \frac{\mathfrak{m}^4}{1^2.2^2}S_2 - \frac{\mathfrak{m}^8}{1^2.2^2.3^2.4^2}S_4 + \ldots = N_e'
\end{aligned}\right\} . \quad (103)$$

$$\log_e \mathfrak{m} + \Lambda = L \quad \ldots(104)$$

$$k + \sqrt{-1}\,k' = 1 + \frac{2}{\mathfrak{m}^2}\,\frac{-LM_0 + \frac{\pi}{4}M_e - \frac{1}{2}M_0' + N_0 + \left\{\frac{\pi}{4}M_0 + LM_e - \frac{1}{2}(1 - M_e') - N_e\right\}\sqrt{-1}}{-\frac{\pi}{4}M_0' + L(1 - M_e') + N_e' + \left\{-LM_0' - \frac{\pi}{4}(1 - M_e') + N_0'\right\}\sqrt{-1}} \quad \ldots\ldots\ldots(105).$$

Stokes
(1819–1903)

A „modern" touch

- There is an easier way, using (now well-established) Bessel functions:

$$k - (-1)^{1/2}k' = 1 - \frac{2(-1)^{3/4}K_1\left(2(-1)^{1/4}\mathfrak{m}\right)}{\mathfrak{m}K_0\left(2(-1)^{1/4}\mathfrak{m}\right)}$$

Back to the lab!

SECTION II.

Suggestions with reference to future experiments.

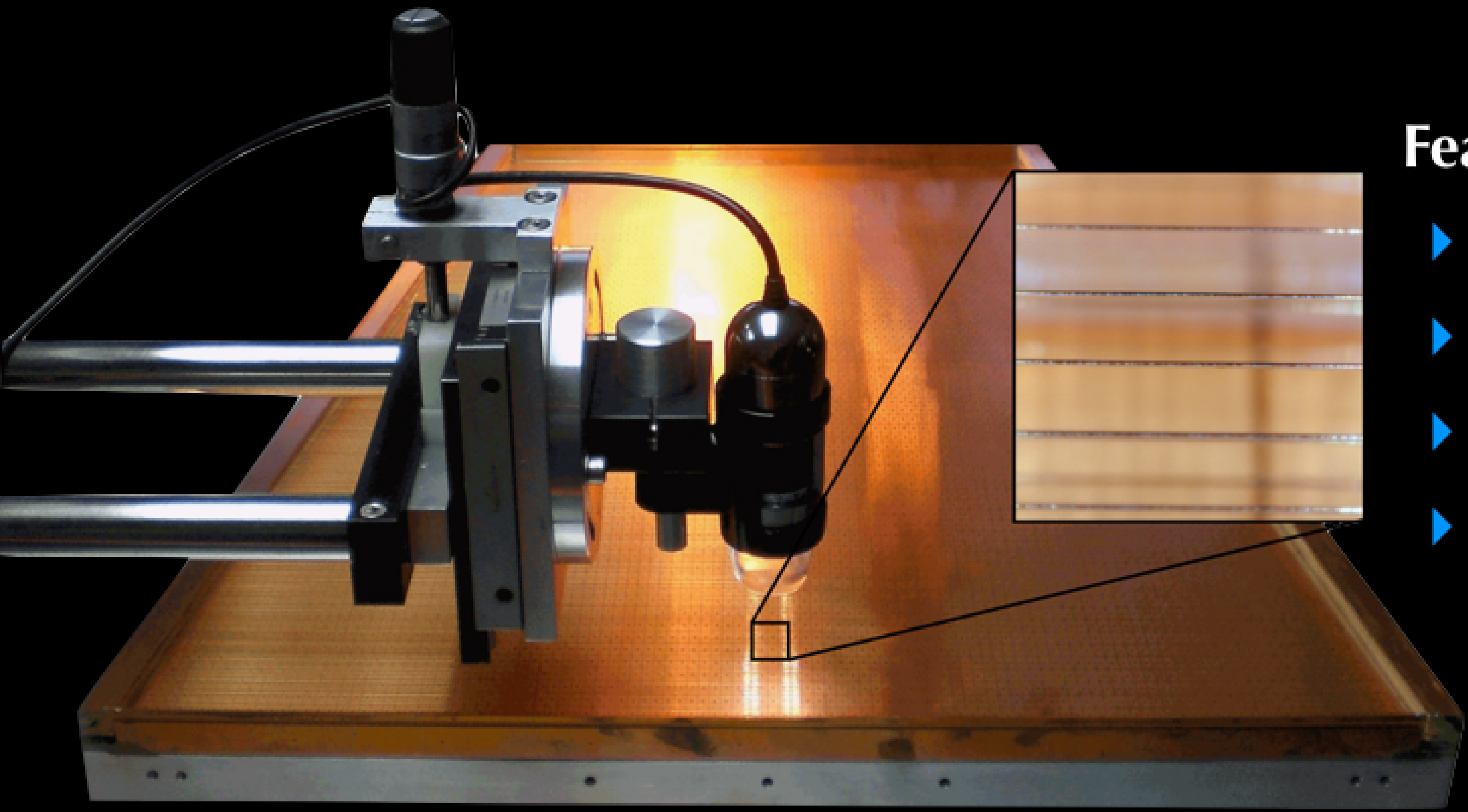
80. I am well aware that the mere proposal of experiments does not generally form a subject fit to be brought before the notice of a scientific society. Nevertheless, as it frequently happens in the division of labour that one person attends more to the theoretical, another to the experimental investigation of some branch of science, it is not always useless for the theorist to point out the nature of the information which it would be most important to obtain from experiment. I hope, therefore, that I may be permitted to offer a few hints with reference to experiments in which the theory of the internal friction of fluids is concerned. I shall omit all details, since they would properly come in connexion with the experiments.

Stokes
(1819–1903)

– even though, TPCs are not explicitly mentioned after, let's continue…

Laboratory set-up

- An IROC was placed under a microscope

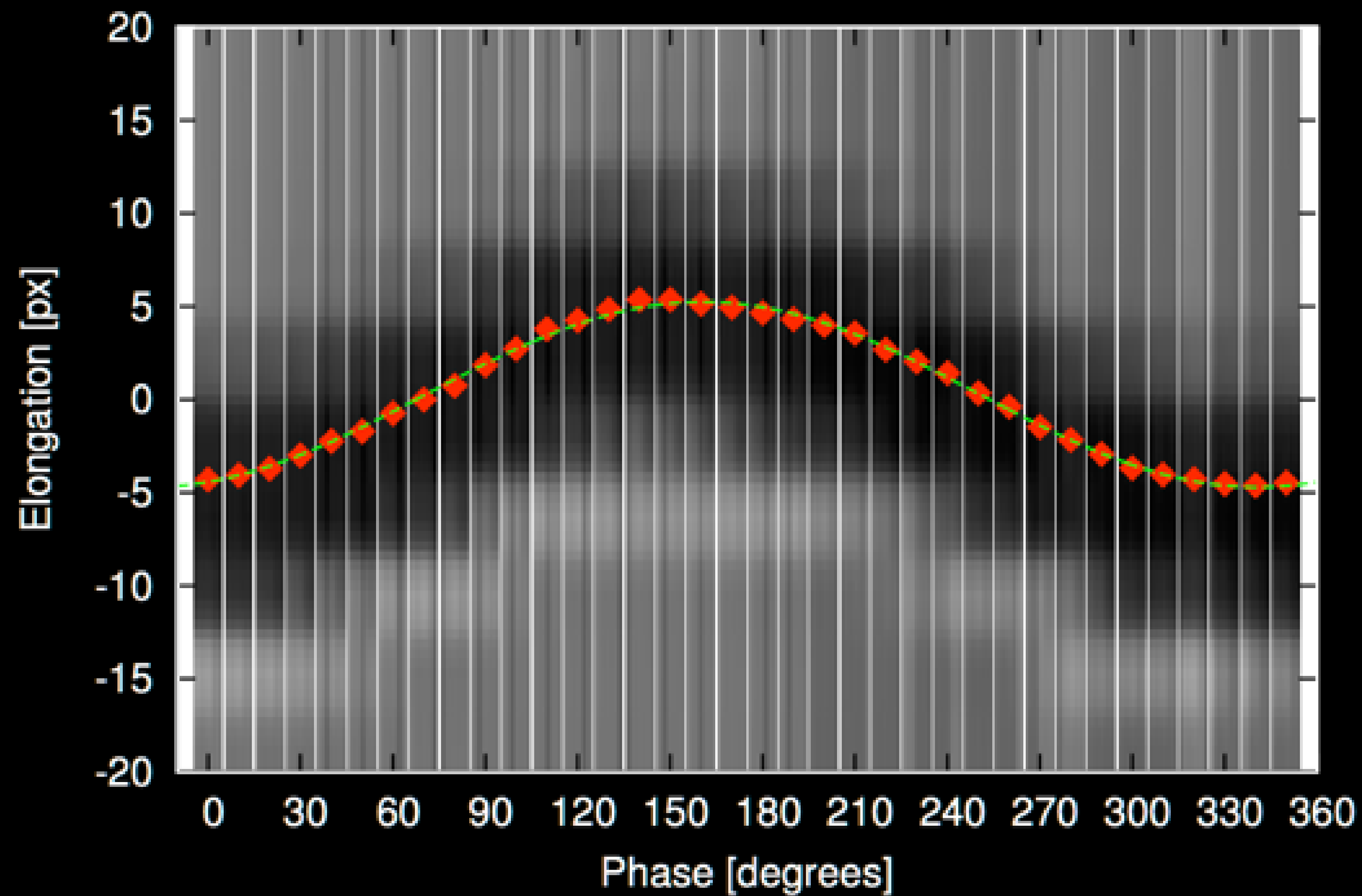


Features:

- Anode HV supply
- Gating grid pulser
- Tiltable mount
- Computer vision

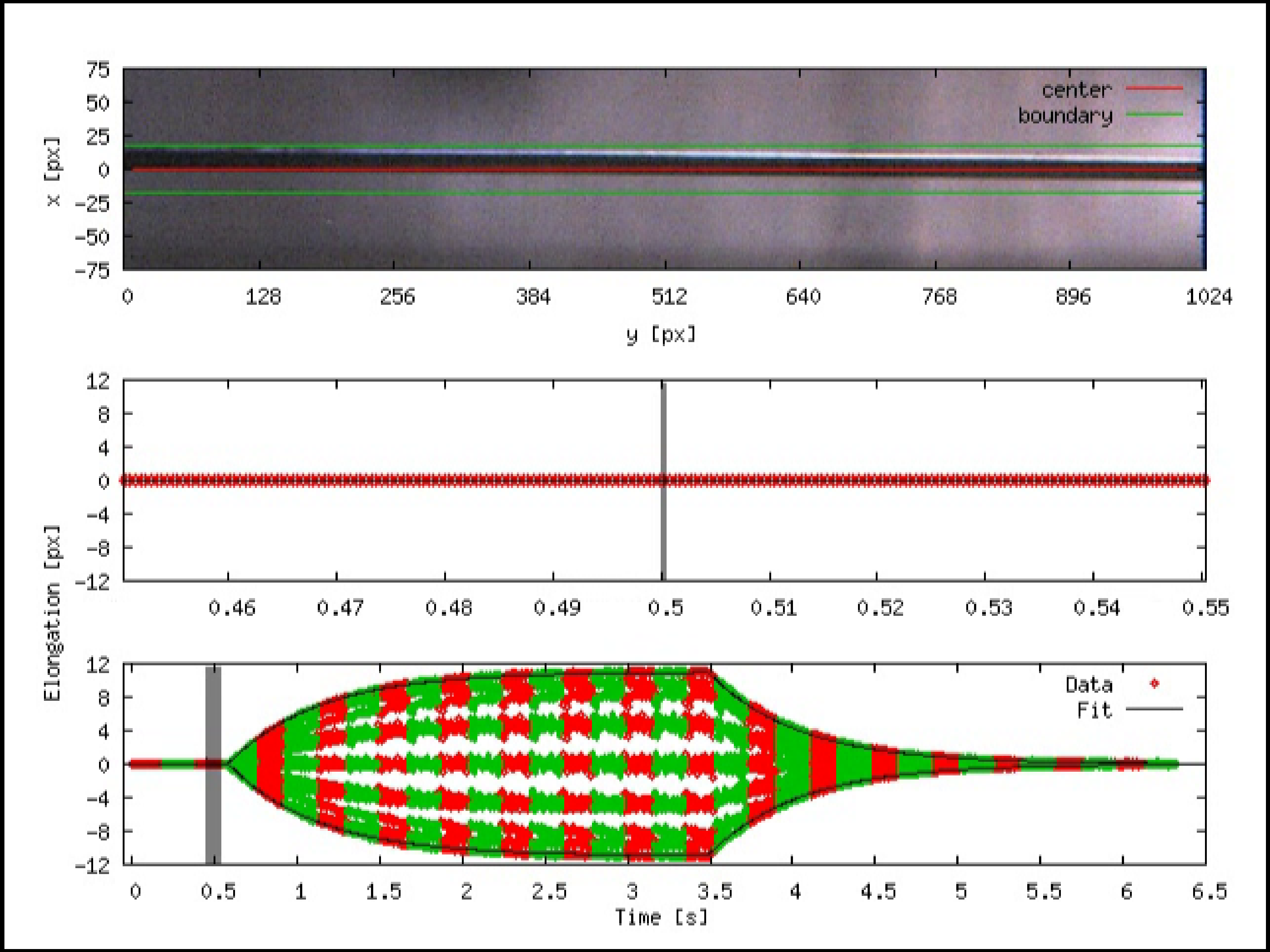
Vibrations

- Quasi-static images can be obtained using a phase-coupled stroboscopic light



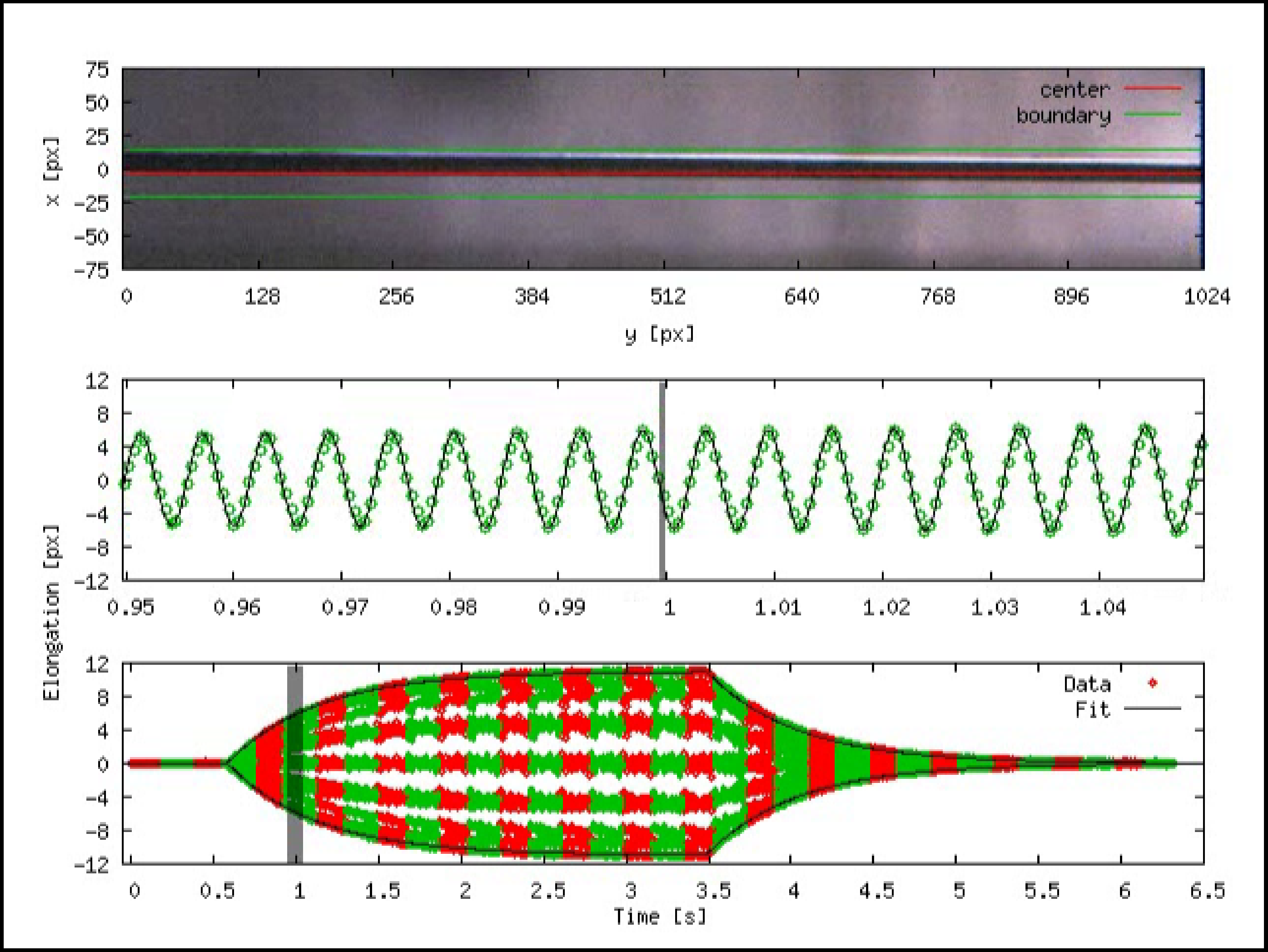
- Motion observed!
- Gating grid wires oscillate in drift direction

Time-resolved mesurement



- Several runs with phase offsets are merged to get the time resolution
- The fit is global using only equilibrium amplitude, phase-offset and damping constant as parameters

Time-resolved mesurement



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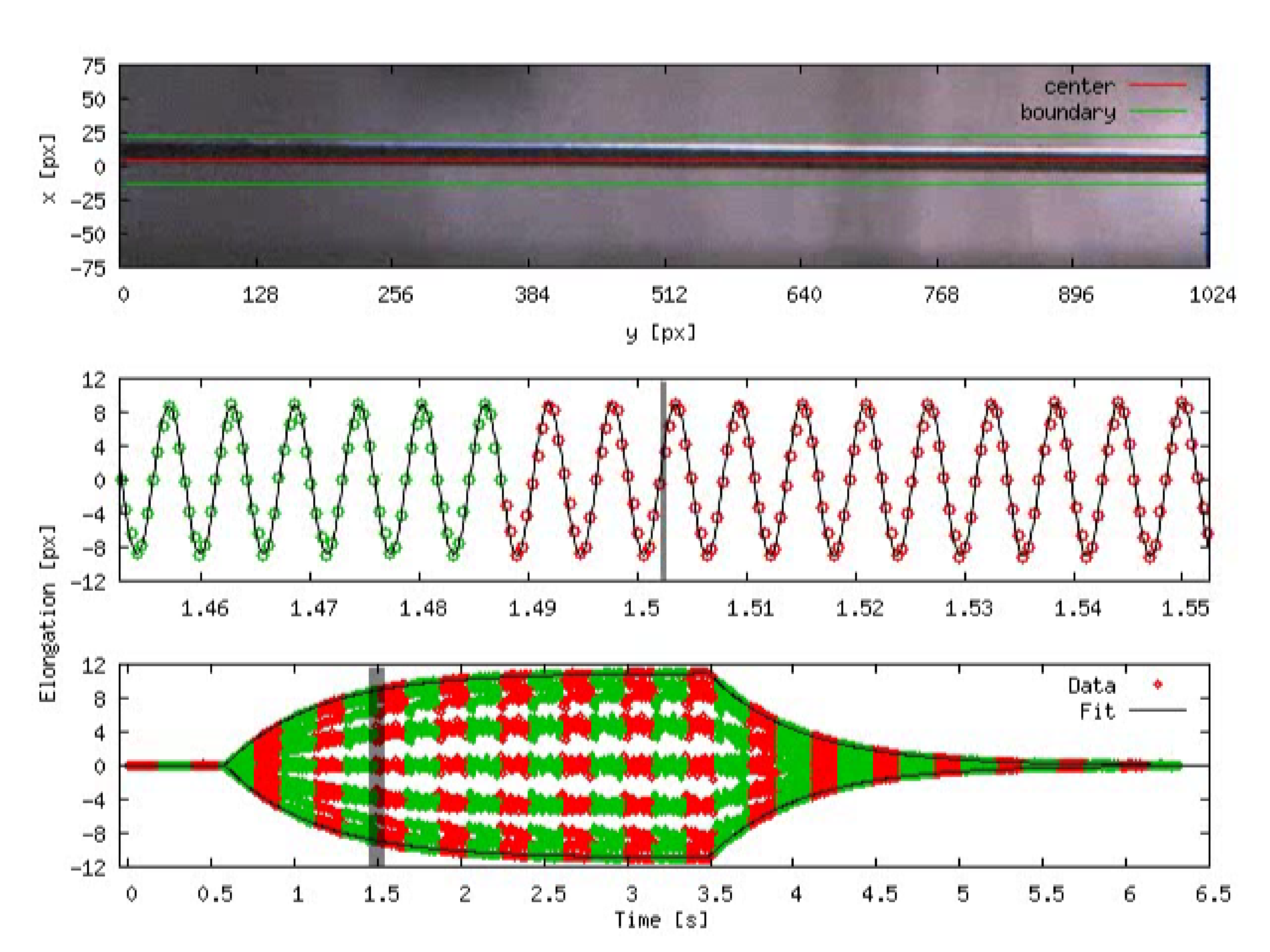

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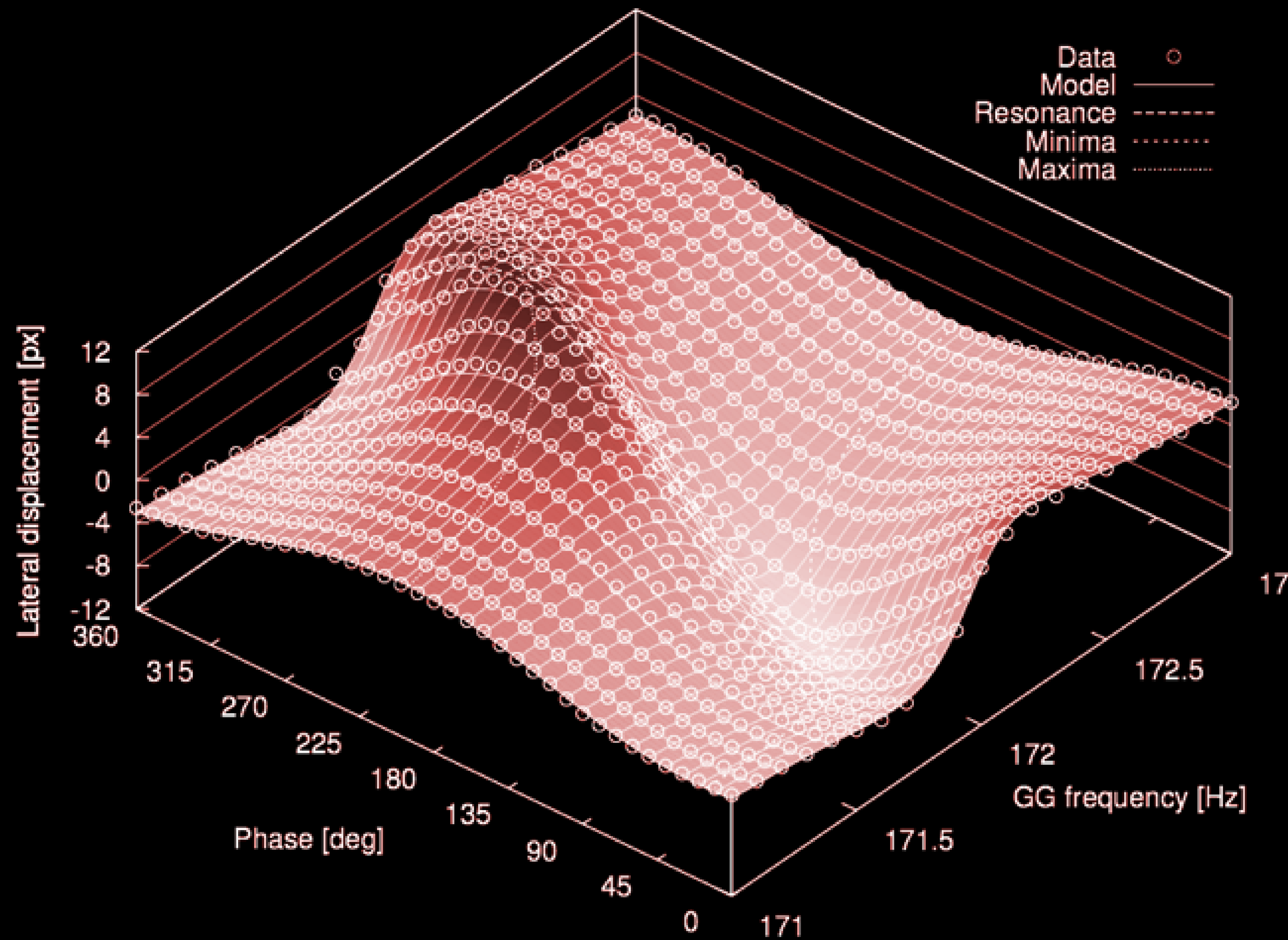
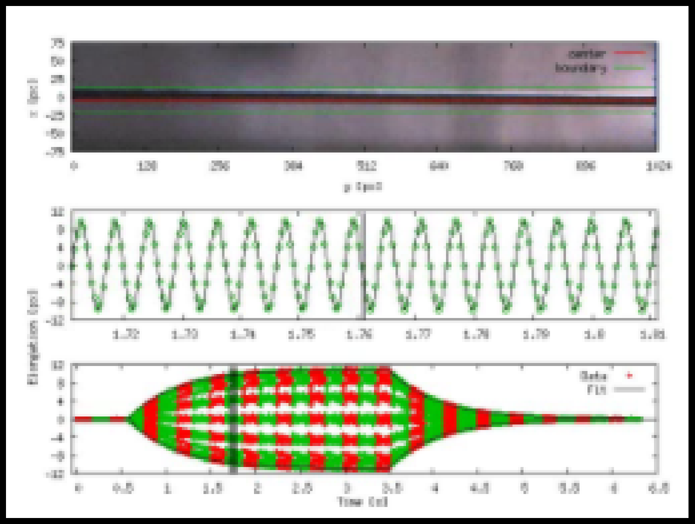
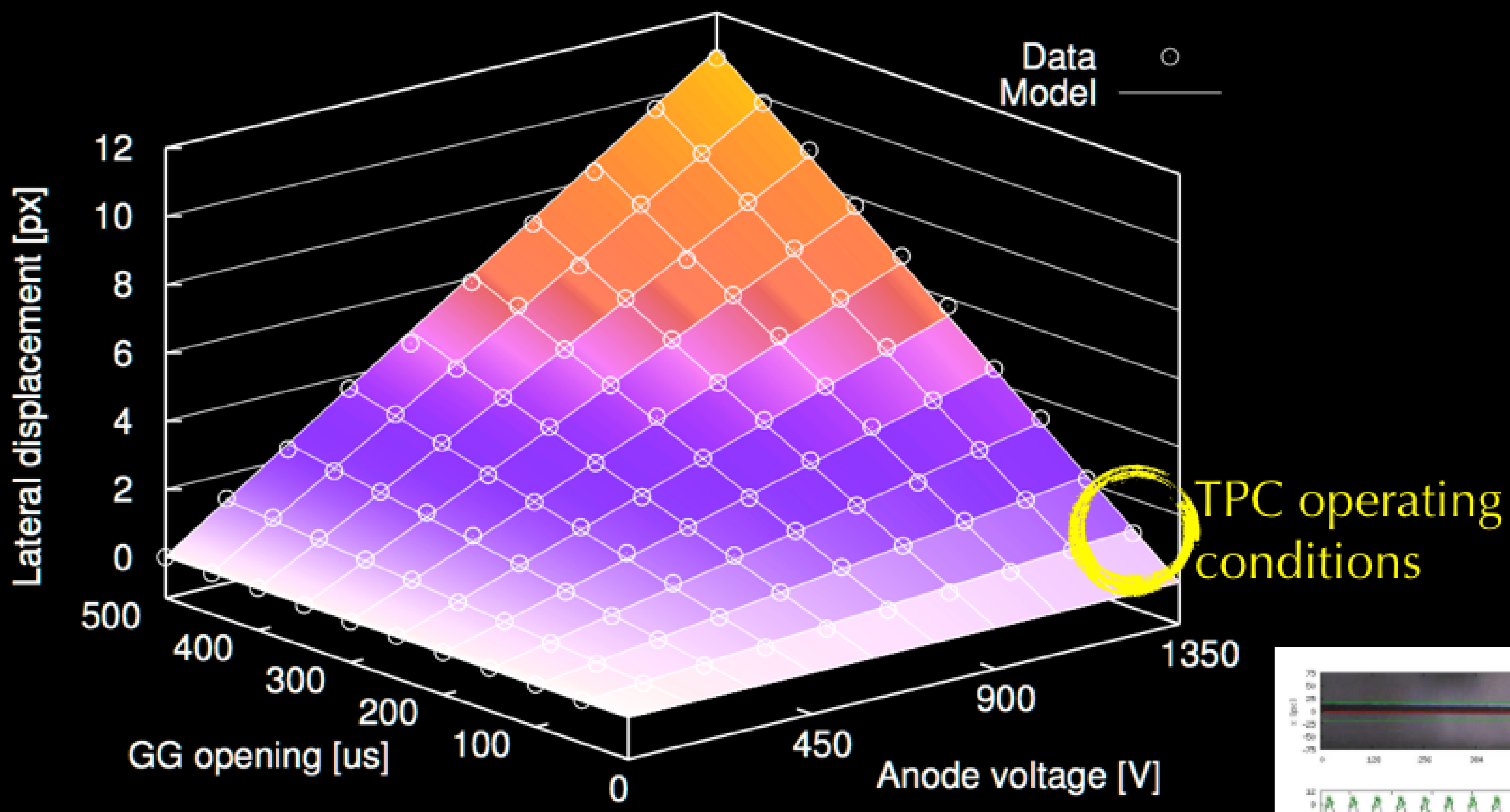
Phase dependence

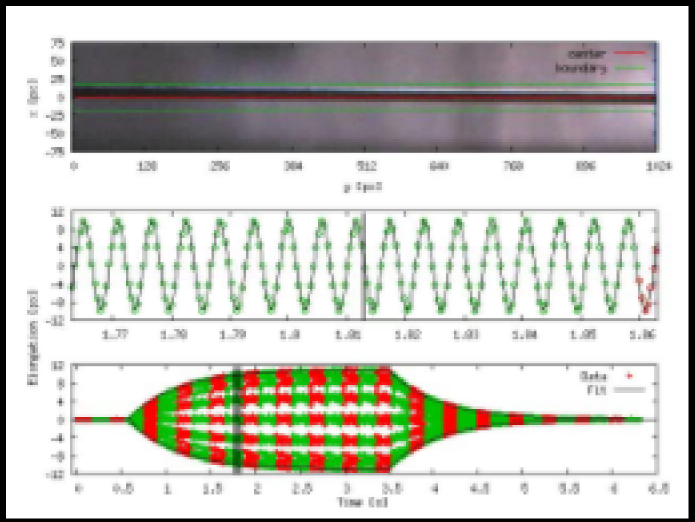




- The driven damped harmonic oscillator is a good model
- Resonance is sharp → high-Q!

Parametric dependence





- Driving power proportional to:
  - gating grid opening time, and
  - anode voltage
- TPC is normally operated in an uncritical regime!

Acknowledgements & References

- **Thanks to:** Christian J. Horn (project student 2011), Tuva Richert (summer student 2011), Rob Veenhof, Jeremi Niedziela, **2011-ALICE-TPC-crew, Luciano & Peter**

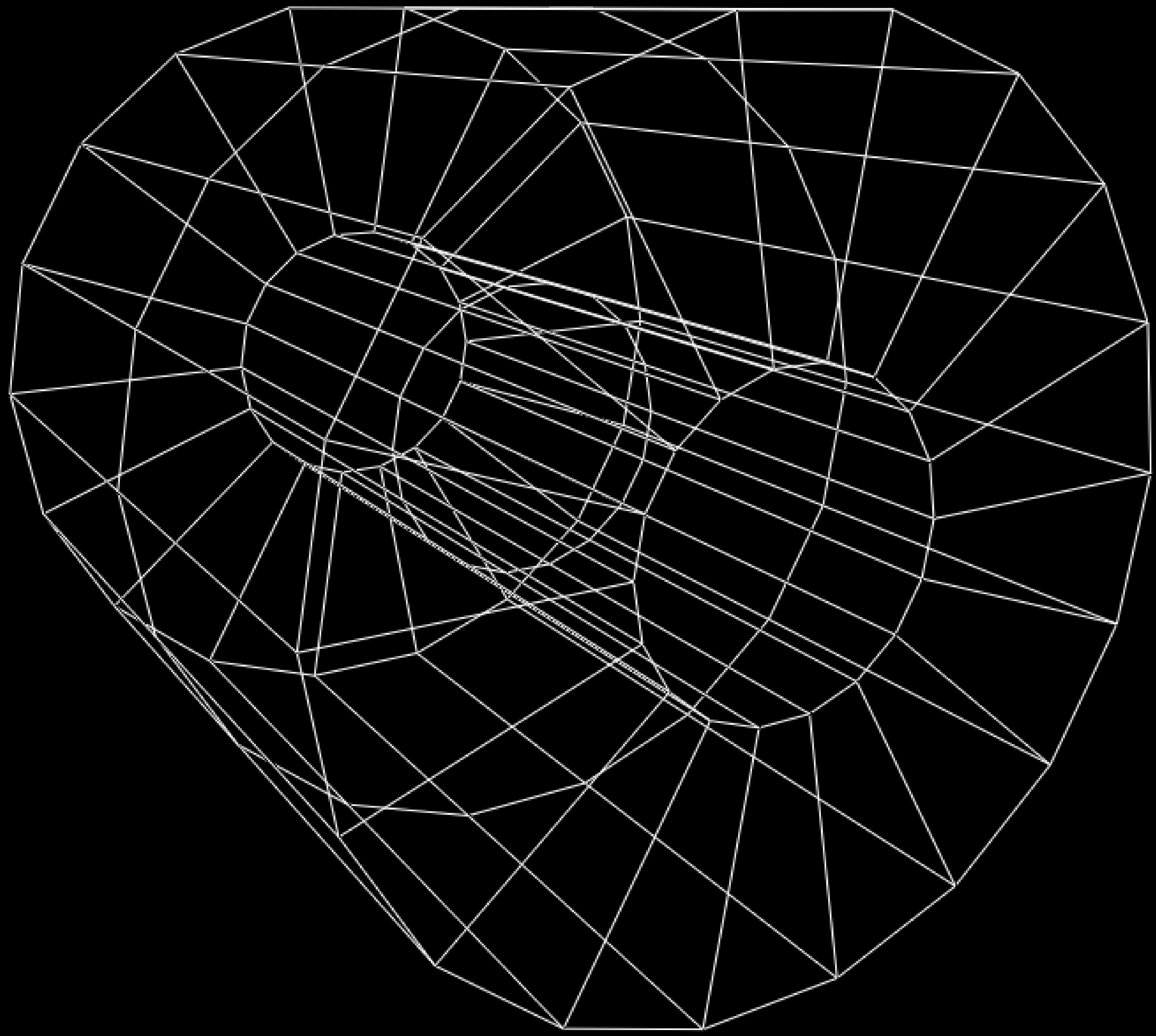
- *„Trigger-Induced Mechanical Resonances of Gating Grid Wires in the Multi-Wire Proportional Chambers of the ALICE TPC"*, Phys. Proc. **37**, 2012, 472–477 (TIPP 2011)
- *„Mechanical resonances in the read-out chambers of the ALICE TPC"*, World Scientific, The subnuclear series **49**, 2013, 417–426 (ISSP 2011)
- N. H. Fletcher, T. D. Rossing, *"The physics of musical instruments"*, Springer, 1998
- G.G. Stokes *"On the Effect of the Internal Friction of Fluids on the Motion of Pendulums"* Trans. Cambridge Phil. Soc. **9**, 1850

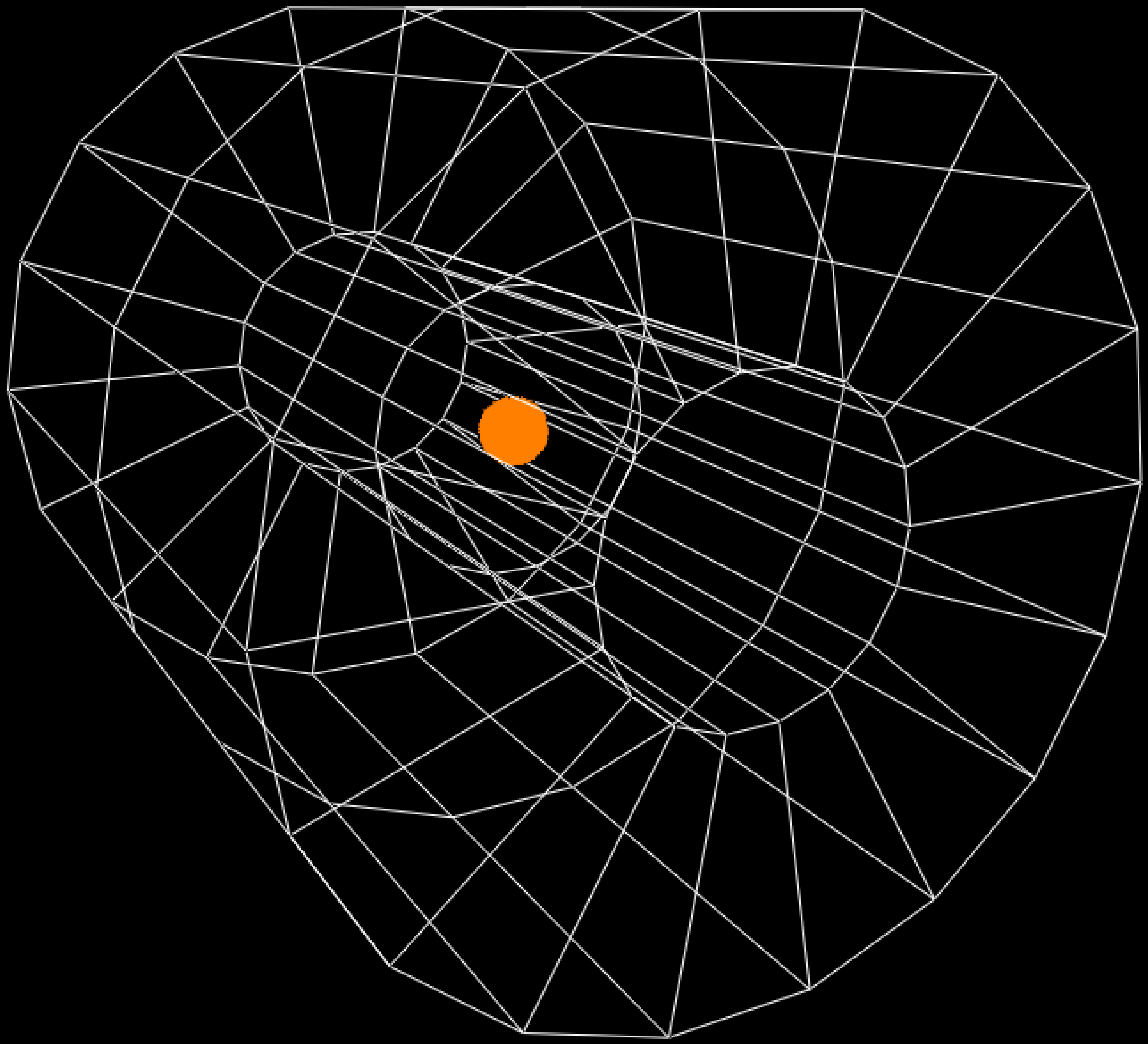
Conclusions

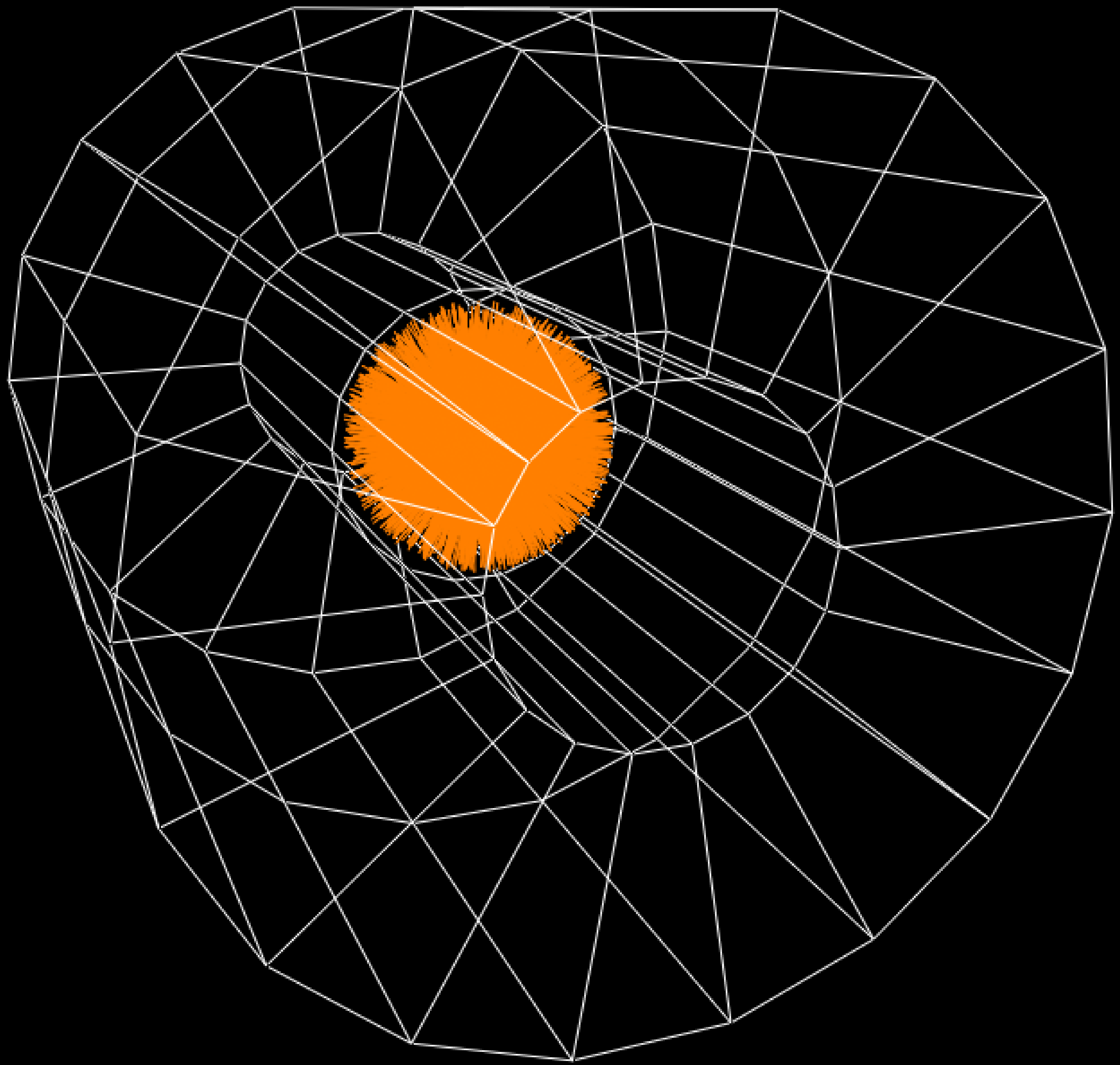
- The wire chambers were probably never in danger

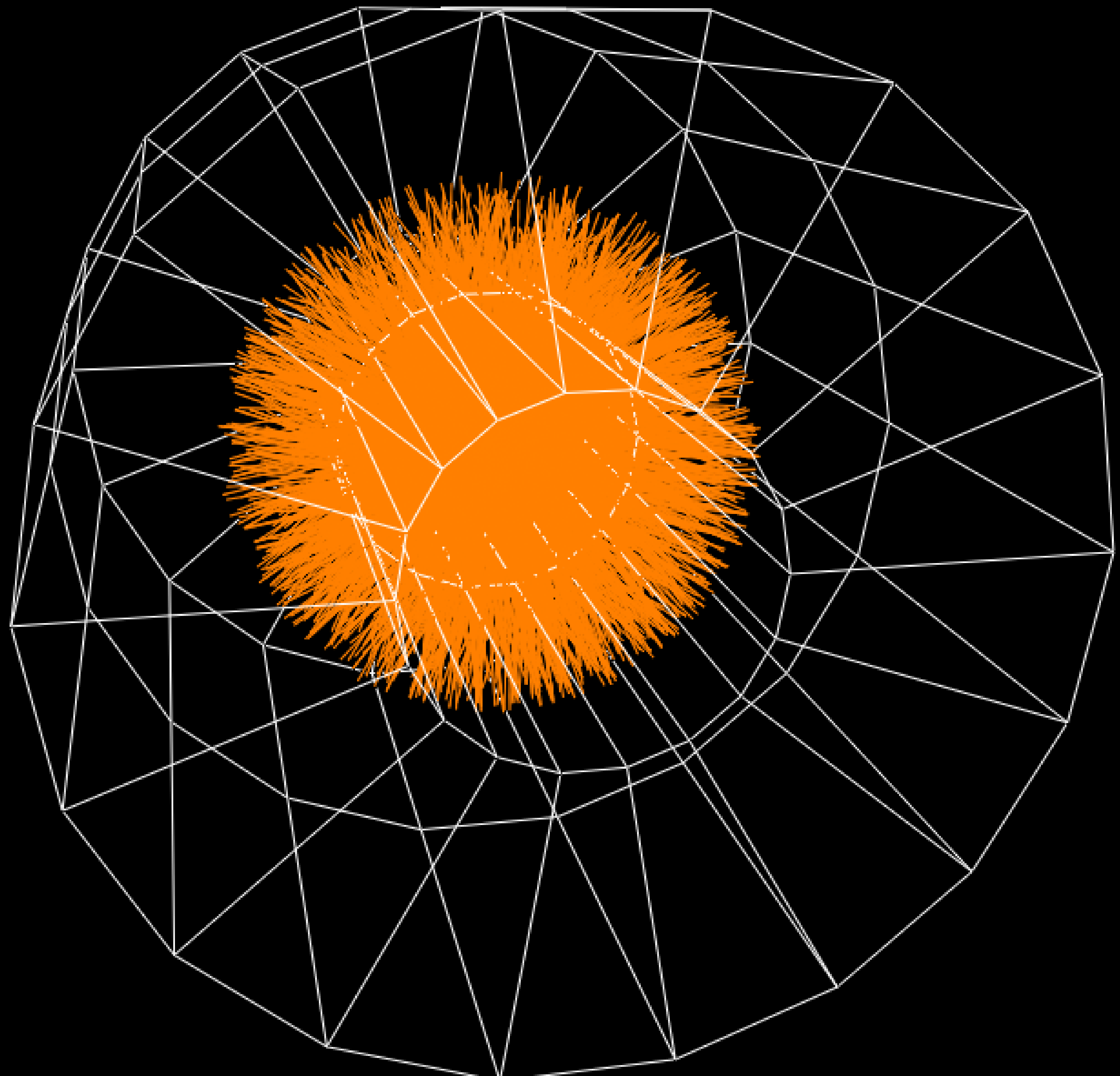
- The TPC is a marvelous instrument
- It has an adorable, hidden musical facet

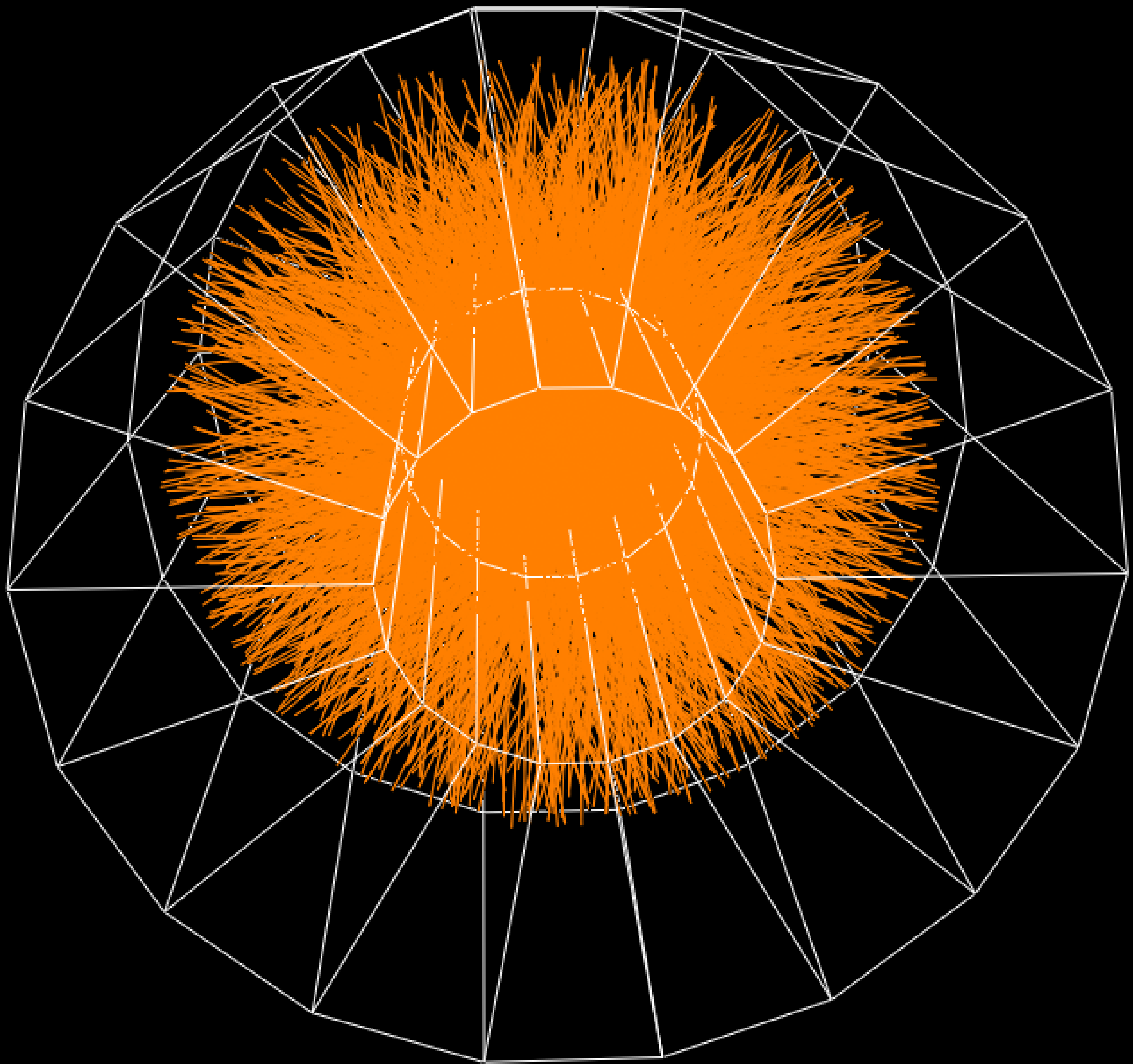
- HEP keeps being full of surprises on all levels
- I am grateful to have had the chance to look deeper into one of them

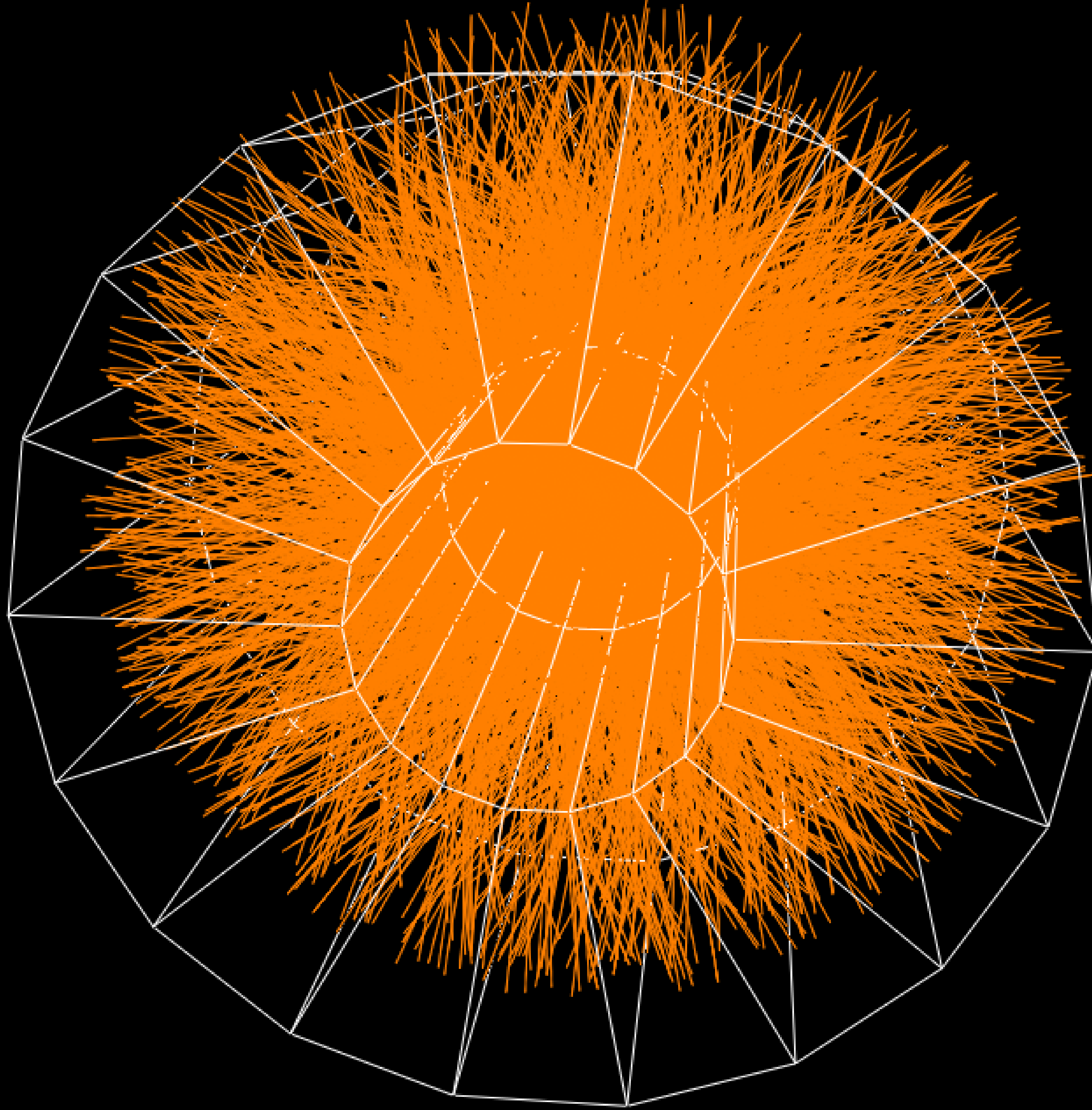






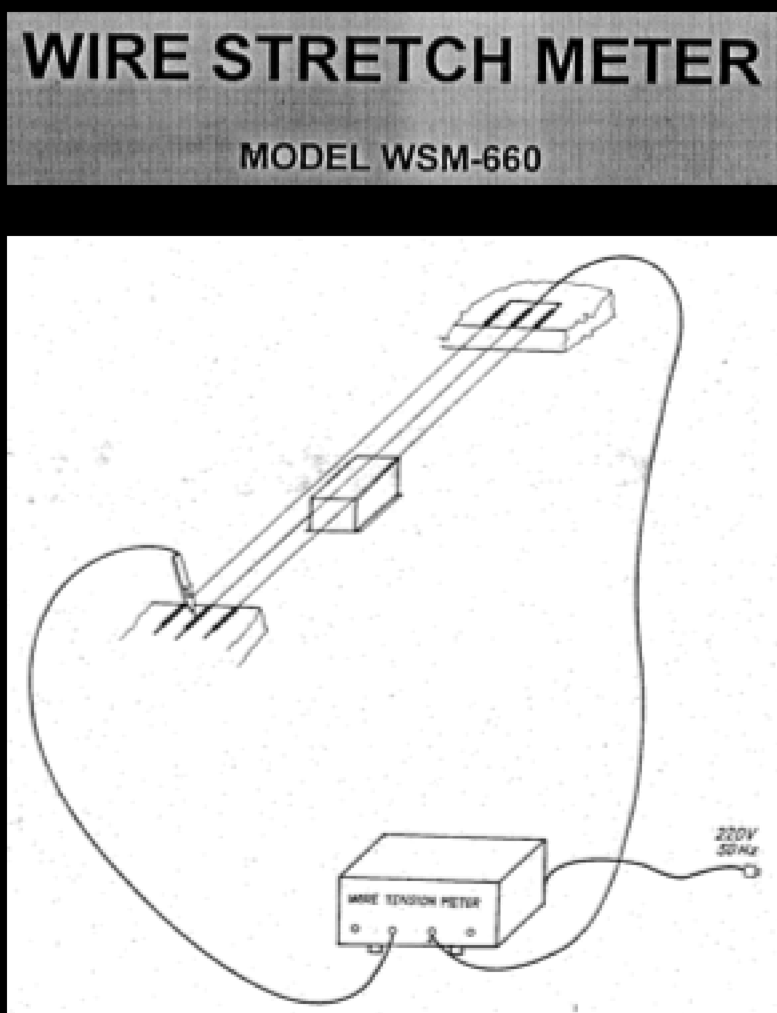


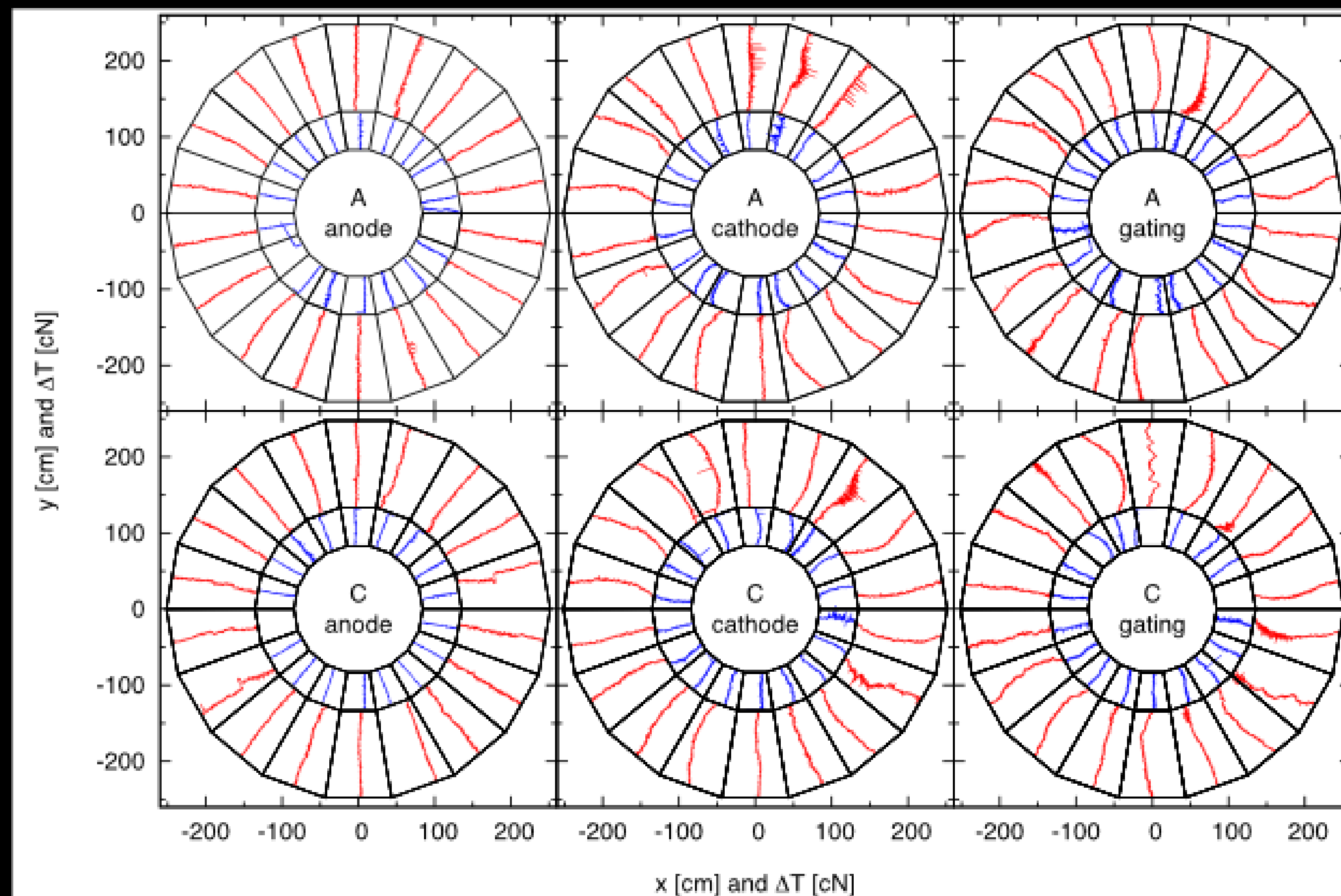




Thank you very much!

Wire tensions





Take away all floppy disks, then remove the enclosed magnet from the iron shield and place it at a distance of 2 mm - 12 mm to the middle of the wire you are going to check.

Full solution

- PDE of the vibrating string:

$$\left(\frac{\partial^2}{\partial t^2} + \frac{2}{\tau}\frac{\partial}{\partial t} - c^2\frac{\partial^2}{\partial y^2}\right) z(y,t) = \frac{\mathrm{d}F/\mathrm{d}y}{\mathrm{d}m/\mathrm{d}y}$$

- Solution:

$$z(y,t) = \sum_{n,l\geq 1} a_{n,l}\cos(n\omega t + \varphi_{n,l}) \cdot \sin(l\pi/L \cdot y)$$

$$F(y,t) = \sum_{n,l\geq 1} f_{n,l}\cos(n\omega t) \cdot \sin(l\pi/L \cdot y)$$

$$a_{n,l} = f_{n,l}\left[(n\omega)^2(2/\tau)^2 + ((n\omega)^2 - (l\omega_0)^2)^2\right]^{-1/2}$$

$$\varphi_{n,l} = \tan^{-1}\frac{(n\omega)(2/\tau)}{(n\omega)^2 - (l\omega_0)^2}$$

$$f_0 = \frac{1}{2L}\sqrt{\frac{T}{\varrho_w \pi r^2}}$$

Full solution II

- Driving force:

$$F(y,t) = \begin{cases} F_0 & |t| \le \Delta T_{GG}/2 \\ 0 & |t| > \Delta T_{GG}/2 \end{cases} \quad (+\ 2\pi/\omega \text{ per.})$$

$$f_{n,l} = \frac{8F_0}{nl\pi^2} \sin(n\omega\Delta T_{GG}/2) \cdot \begin{cases} 1 & n \text{ odd} \\ 0 & n \text{ even} \end{cases}$$