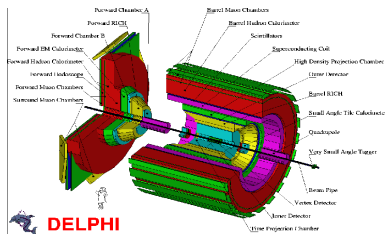
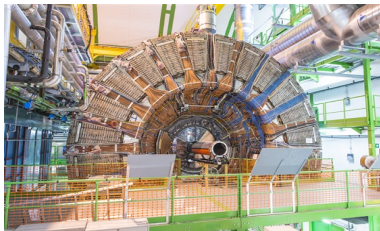


# Anomalous Cherenkov rings in the DELPHI detector: A search for tachyons

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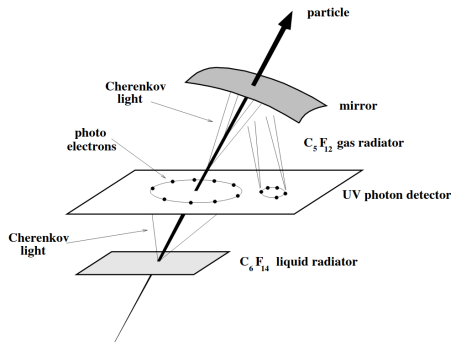


# Outline

- 1 Introduction
- 2 DELPHI and RICH
- 3 Tachyon particles
- 4 Event topologies and candidate selection
- 5 Analysis results
  - Correlation between RICH detectors
  - Tachyon mass parameters
  - Kinematic fit
- 6 Conclusion

- Physical interpretation of the anomalous Cherenkov rings observed with the DELPHI detector
  - [arXiv:2001.08576](#)
  - Retired HEP scientists?
  - Independent of DELPHI Collaboration
- Interpret large Cherenkov rings as tachyons
- Measure mass parameter

- DELPHI: Detector with Lepton, Photon and Hadron Identification
  - One of four main detectors at LEP
  - Operated from 1989 to 2000
  - Used RICH for PID
- DELPHI Barrel RICH:
  - Cherenkov angle:  $\cos(\theta) = \frac{1}{n\beta}$
  - $C_6F_{14}$  liquid radiator ( $n = 1.273 \implies \theta_{\max} = 667 \text{ mrad}$ )
  - $C_5F_{12}$  gaseous radiator ( $n = 1.00194 \implies \theta_{\max} = 62 \text{ mrad}$ )



**Figure 1:** Principles of the DELPHI RICH detector

- DELPHI strategy: Fit rings with five mass hypotheses ( $e$ ,  $\mu$ ,  $\pi$ ,  $K$ ,  $p$ )  
 $\implies$  obtain Cherenkov angle
- This paper: Fit each photon direction individually

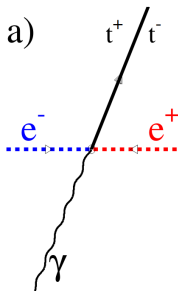
# Tachyon particles

- Particles moving at  $\beta > 1$
- $E^2 - p^2 = -\mu^2$
- $\mu$ : Mass parameter
- $\mu = p\sqrt{1 - n^2 \cos^2(\theta)}$

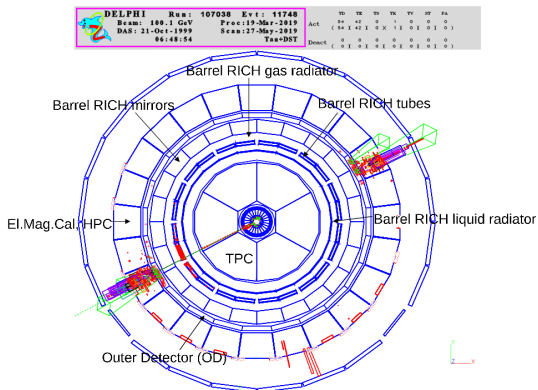
# Event topologies and candidate selection

Topology 1:  $e^+e^- \rightarrow \gamma t^+ t^-$

- High energy photon back-to-back with tachyons
- Signature:
  - One neutral and one charged jet
  - Use  $dE/dx$  to distinguish from single tracks
  - EM shower



# Event topologies and candidate selection



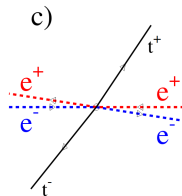
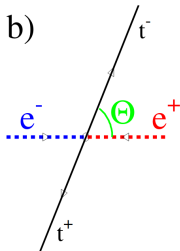
**Figure 2:**  $e^+e^- \rightarrow \gamma t^+ t^-$  event



# Event topologies and candidate selection

Topology 2a:  $e^+e^- \rightarrow t^+t^-$ , 2b:  $e^+e^- \rightarrow e^+e^-t^+t^-$

- Tachyon pair production
- Signature:
  - Tracks in opposite directions and opposite charge
  - EM shower



# Event topologies and candidate selection

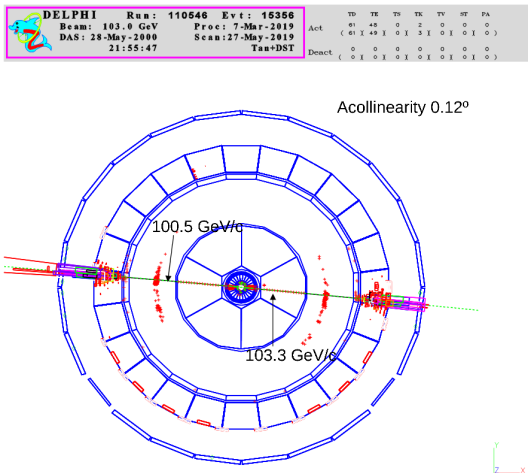


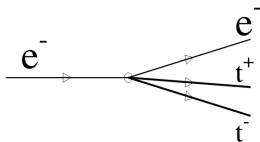
Figure 4:  $e^+e^- \rightarrow t^+t^-$  event

# Event topologies and candidate selection

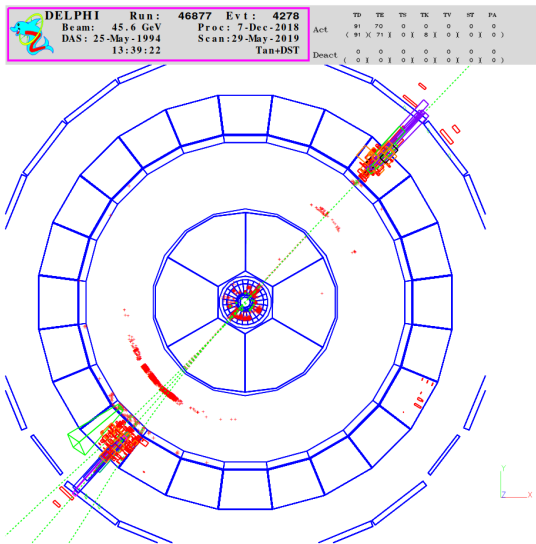
Topology 3:  $eX \rightarrow eX't^+t^-$

- $e^\pm$  interaction with matter to produce tachyons
- Signature:
  - 1 single track jet, one with 3 charged tracks
  - Non-zero impact parameters in the three-particle jet
  - EM shower

d)



# Event topologies and candidate selection



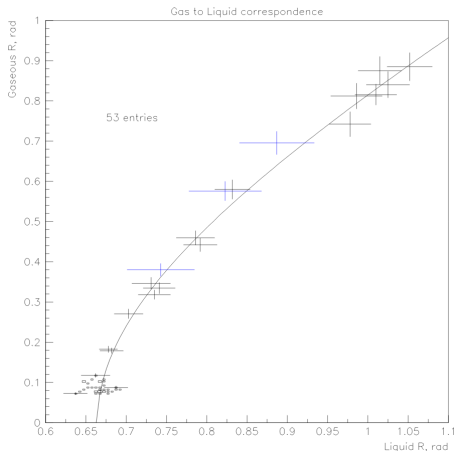
**Figure 5:**  $eX \rightarrow eX't^+t^-$  event

- Other general selection criteria: No hadrons, no muons, good track quality, etc...
- Result after selection:
  - 53 events with at least one anomalous Cherenkov ring
  - 29 candidates had two anomalous rings per track

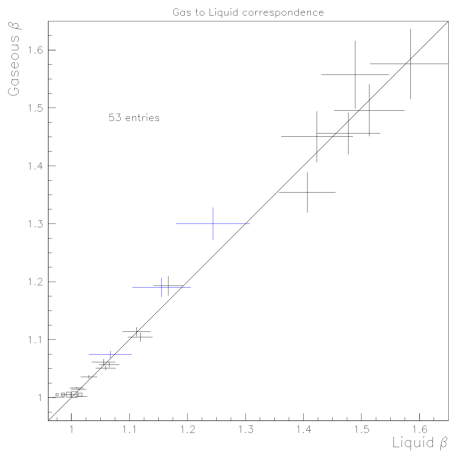
# Correlation between RICH detectors

- From Cherenkov angle formula:
  - $n_1 \cos(\theta_1) = \frac{1}{\beta} = n_2 \cos(\theta_2)$
  - Can plot this as a line in the  $\theta_1$  vs  $\theta_2$  plane
- Or plot the predicted speeds  $\beta_1$  and  $\beta_2$

# Correlation between RICH detectors



**(a)** Gas to liquid angle correlation



**(b)** Gas to liquid speed correlation

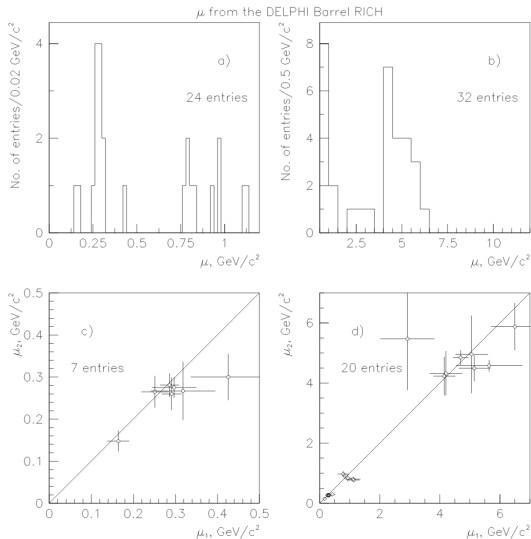
# Tachyon mass parameters

- Calculate the mass parameters  $\mu$  from Cherenkov angles
- Find correlation between liquid and gaseous radiators
- Found excess events at  $\mu = 0.3 \text{ GeV}$  and  $\mu = 5 \text{ GeV}$

$$\mu = p\sqrt{1 - n^2 \cos^2(\theta)}$$

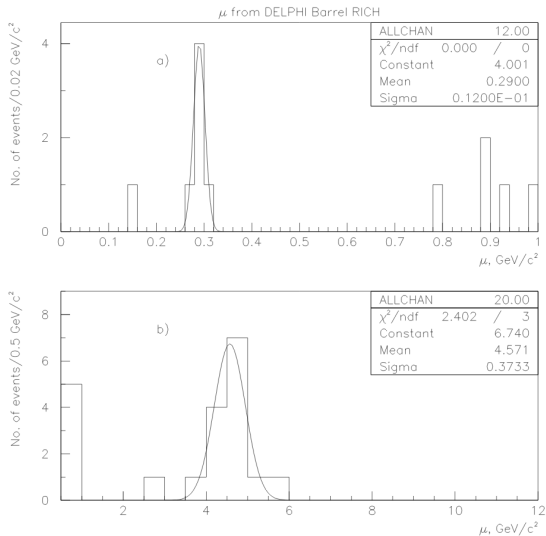


# Tachyon mass parameters



**Figure 7:** Tachyon mass parameters  $\mu$

- Do an over-constrained kinematic fit
- $\mu$  is a free parameter
- Constraints:
  - Energy-momentum conservation
  - $\mu = p\sqrt{1 - n^2 \cos^2(\theta)}$



**Figure 8:** Tachyon mass parameters  $\mu$  after kinematic fit

- Anomalous Cherenkov rings at DELPHI have been interpreted as tachyons
- Strong correlations between the gaseous and liquid RICH radiators
- Tachyon mass parameters show an excess at  $(0.29 \pm 0.01)$  GeV and  $(4.6 \pm 0.2)$  GeV
- Further experiments are needed to confirm or refute these findings
  - $\gamma\gamma$  interactions (topology 2*b*) at ALICE has  $Z^2$  enhancement in cross section
  - LHCb, with high RICH Cherenkov angle resolution, could use low multiplicity events