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

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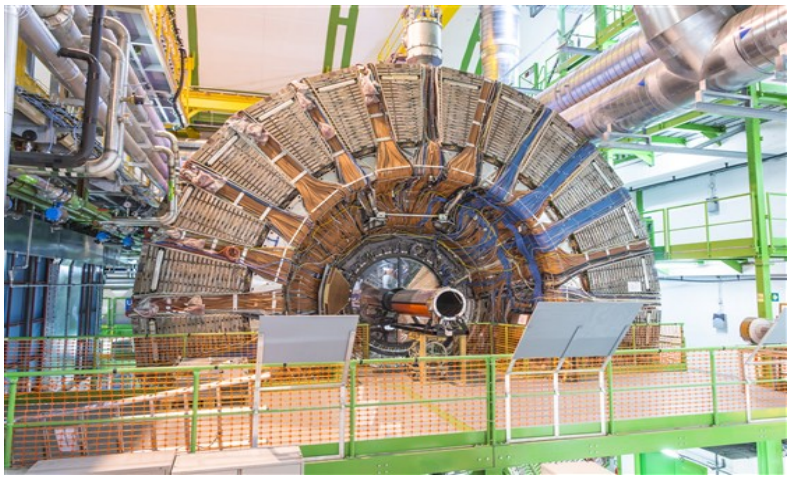
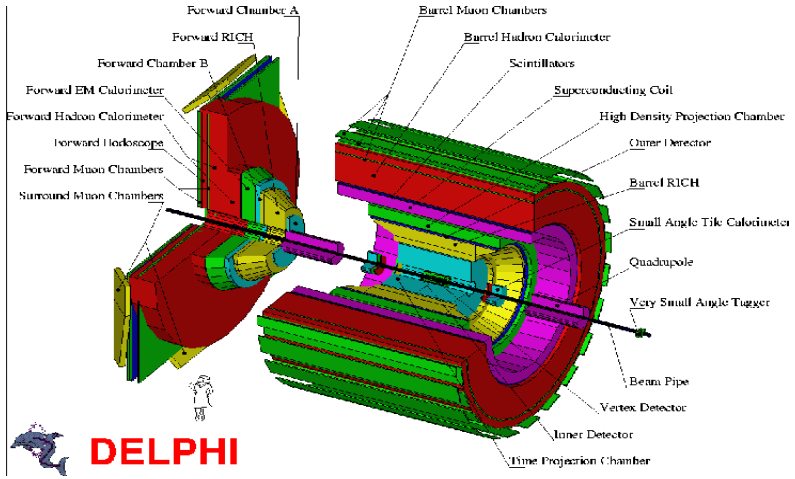




Outline

Introduction

- Physical interpretation of the anomalous Cherenkov rings observed with the DELPHI detector
  - arXiv:2001.08576
  - January 2020
  - V. F. Perepelitsa (ITEP Moscow)
  - T. Ekelof (Uppsala University)
  - A. Ferrer (Valencia University)
  - B. R. French
  - Retired HEP scientists?
  - Independent of DELPHI Collaboration
- Interpret large Cherenkov rings as tachyons
- Measure mass parameter

DELPHI and RICH

- DELPHI: Detector with Lepton, Photon and Hadron Identification
  - One of four main detectors at LEP
  - Operator from 1989 to 2000
  - Vertex detector (VD), EM calorimeter (HPC), hadronic calorimeter (HCAL)
  - Used RICH for PID
- DELPHI Barrel RICH:
  - Cherenkov angle: $\cos(\theta) = \frac{1}{n\beta}$
  - C_6F_{14} liquid radiator ($n = 1.273 \implies \theta_{\text{max}} = 667\,\text{mrad}$)
  - C_5F_{12} gaseous radiator($n = 1.00194 \implies \theta_{\text{max}} = 62\,\text{mrad}$)
  - UV photons converted into photoelectrons $\implies$ Signal!

DELPHI and RICH

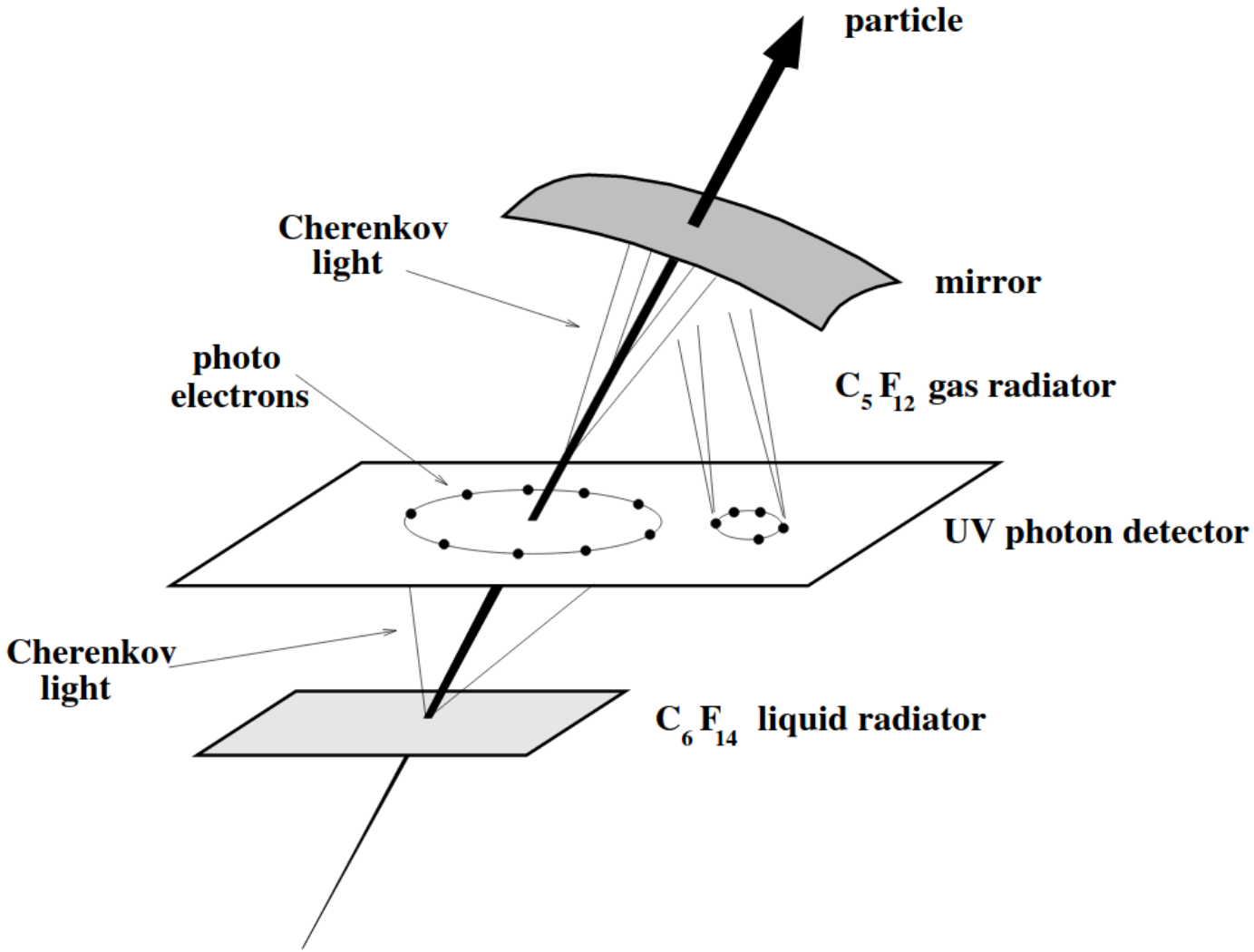


Figure 1: Principles of the DELPHI RICH detector

Tachyon particles

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

Event topologies and candidate selection

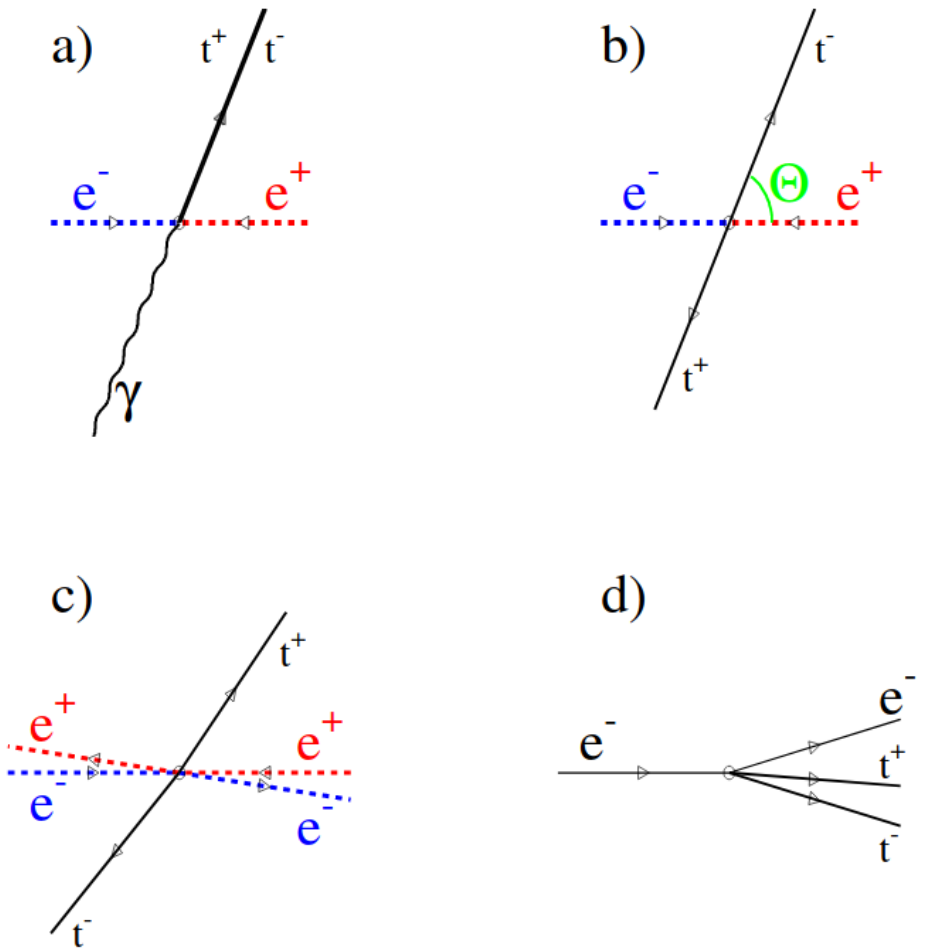


Figure 2: Tachyon event topologies considered

Event topologies and candidate selection

- Topology 1: $e^+e^- \to \gamma t^+ t^-$
  - High energy photon back-to-back with tachyons
  - Tachyons may look like a single track, use $\mathrm{d}E \,/\, \mathrm{d}x$ to distinguish
  - Signature:
    - One neutral and one charged jet
    - Hits in the first layer of VD
    - Charged jet should shower in HPC

Event topologies and candidate selection

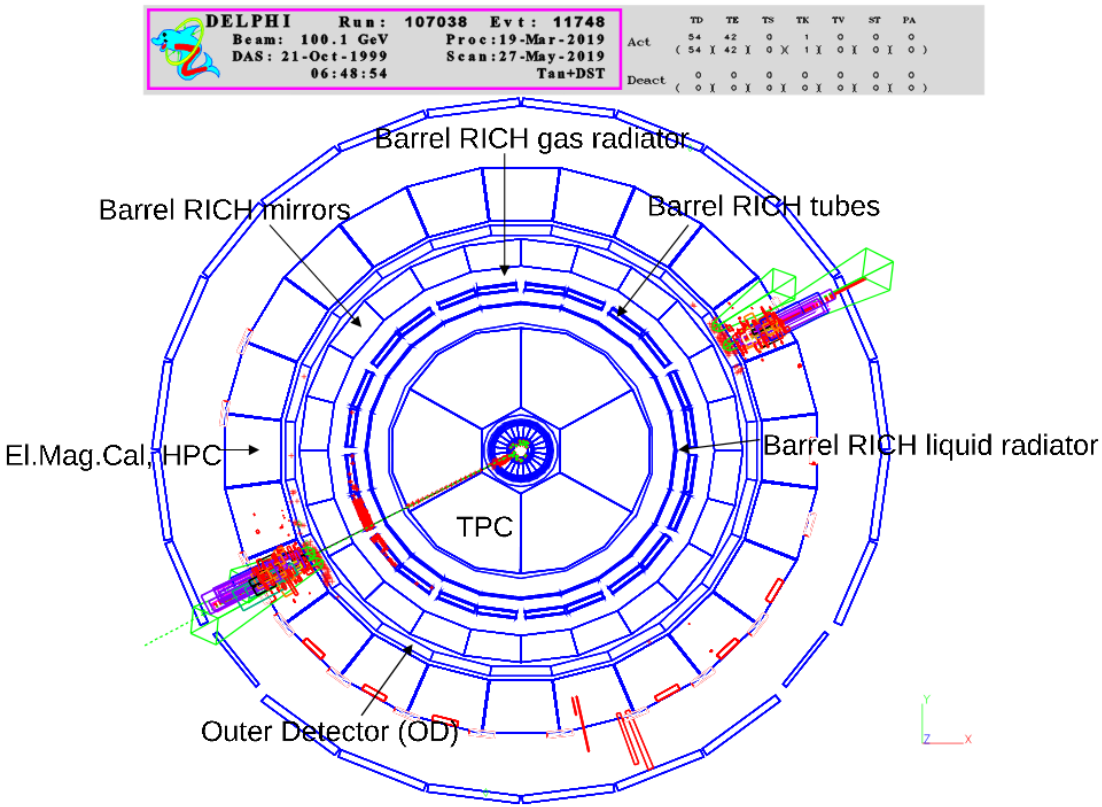


Figure 3: $e^+e^- \rightarrow \gamma t^+ t^-$ event

Event topologies and candidate selection

- Topology $2a$: $e^+e^- \to t^+t^-$
- Topology $2b$: $e^+e^- \to e^+e^-t^+t^-$
  - Two back-to-back jets with opposite charge and one single track per jet
  - Signature:
    - Both tracks should have showers in HPC
    - Tracks in opposite directions in x-y plane

Event topologies and candidate selection

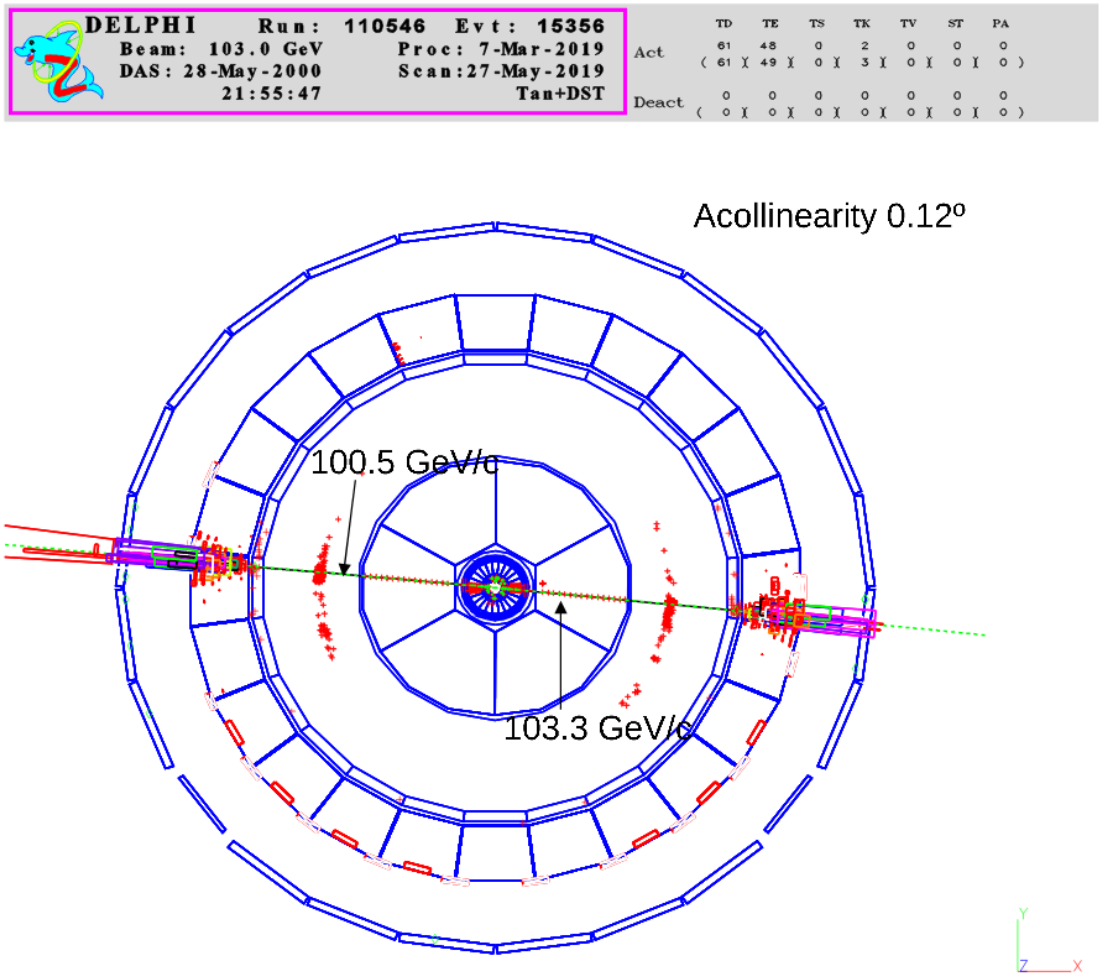


Figure 4: $e^+e^- \rightarrow t^+t^-$ event

Event topologies and candidate selection

- Topology 3: $eX \to eX' t^+ t^-$
  - Two jets, one with a single track, one with 3 charged tracks
  - Signature:
    - All tracks should shower in the HPC
    - Tracks with non-zero impact parameters in the three-particle jet
    - Tracks in opposite directions in x-y plane

Event topologies and candidate selection

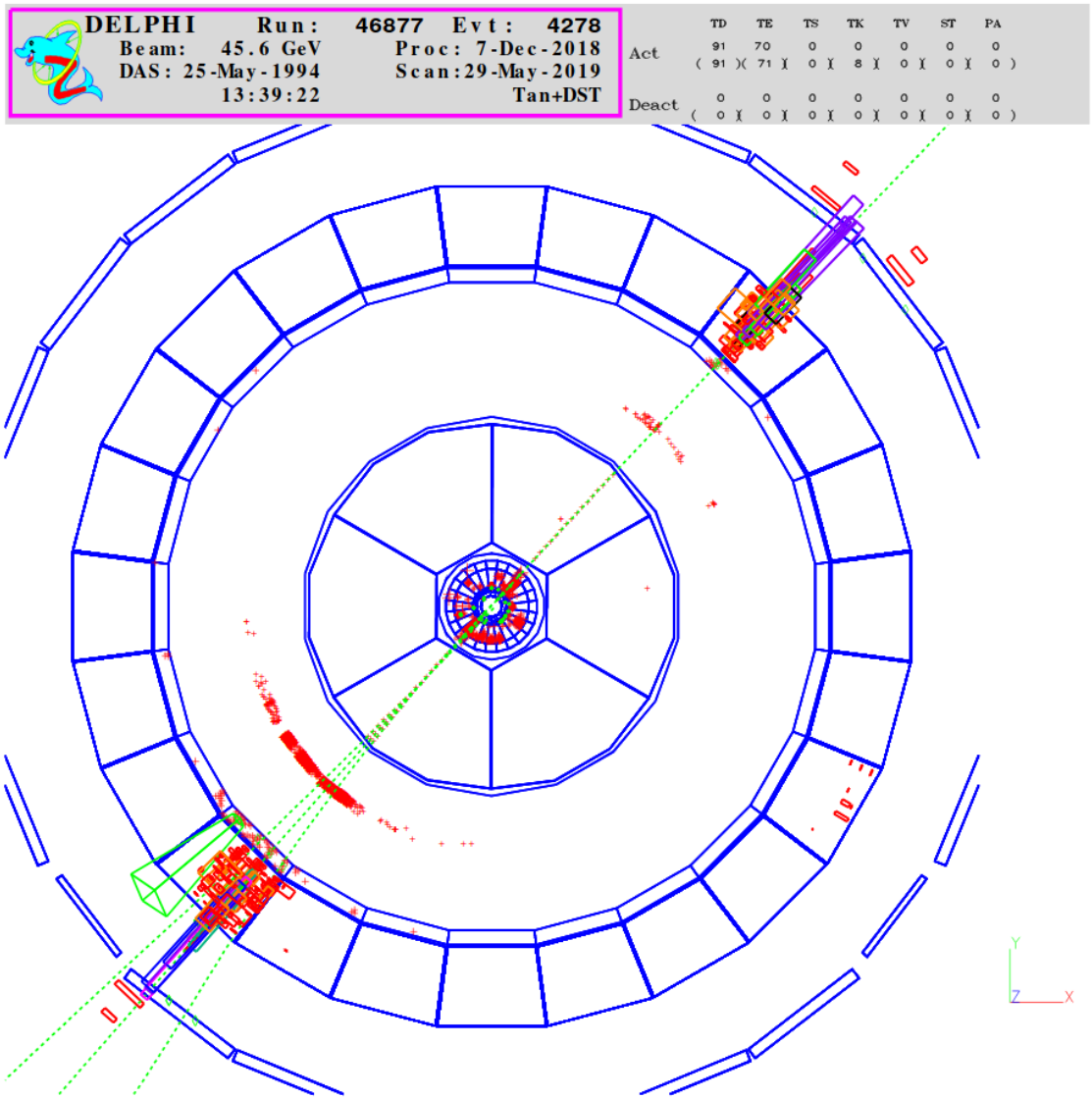


Figure 5: $eX \to eX' t^+ t^-$ event

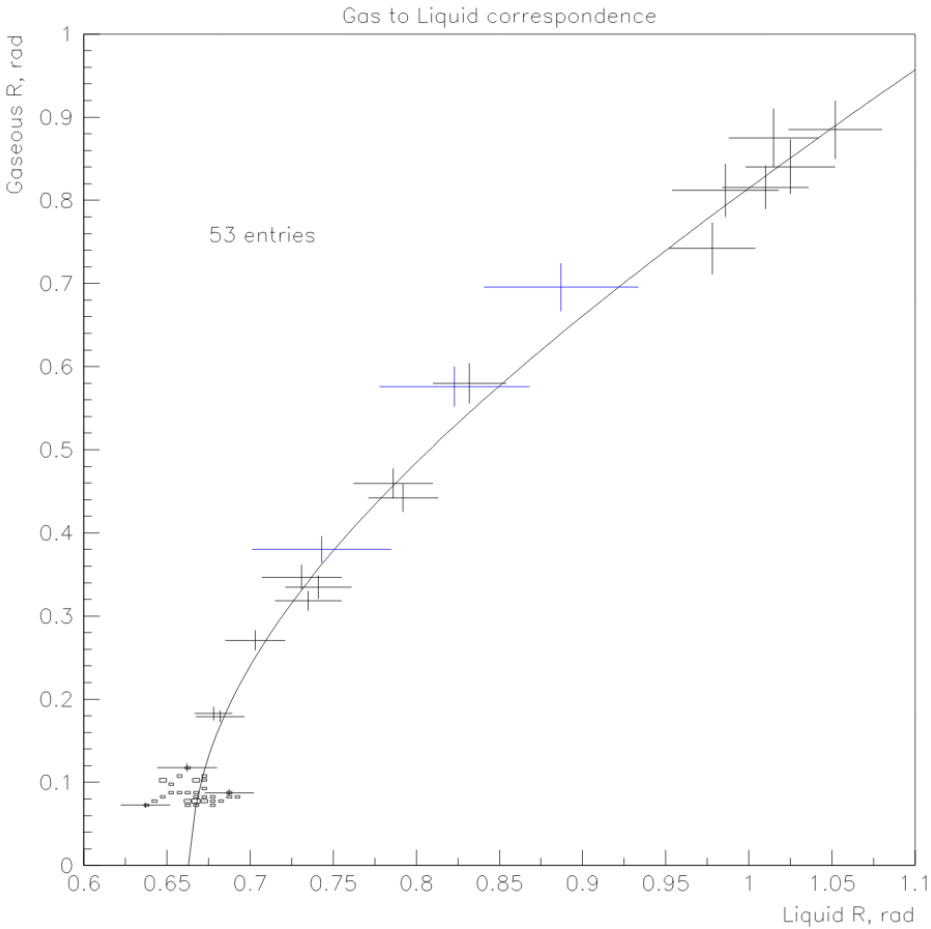
Event topologies and candidate selection

- Other general selection criteria:
  - Non-hadronic events
  - No muons
  - Good quality tracks inside geometric acceptance
  - Kinematic cuts to reduce background
- 395 candidates satisfied all these criteria
- 53 candidates had at least one anomalous Cherenkov ring with background below 10%
- 29 candidates had two gaseous anomalous rings per track
- Require background probability less than 10^{-3}:
  - 9 events in topology 1
  - 6 events in topology 2
  - 12 events in topology 3

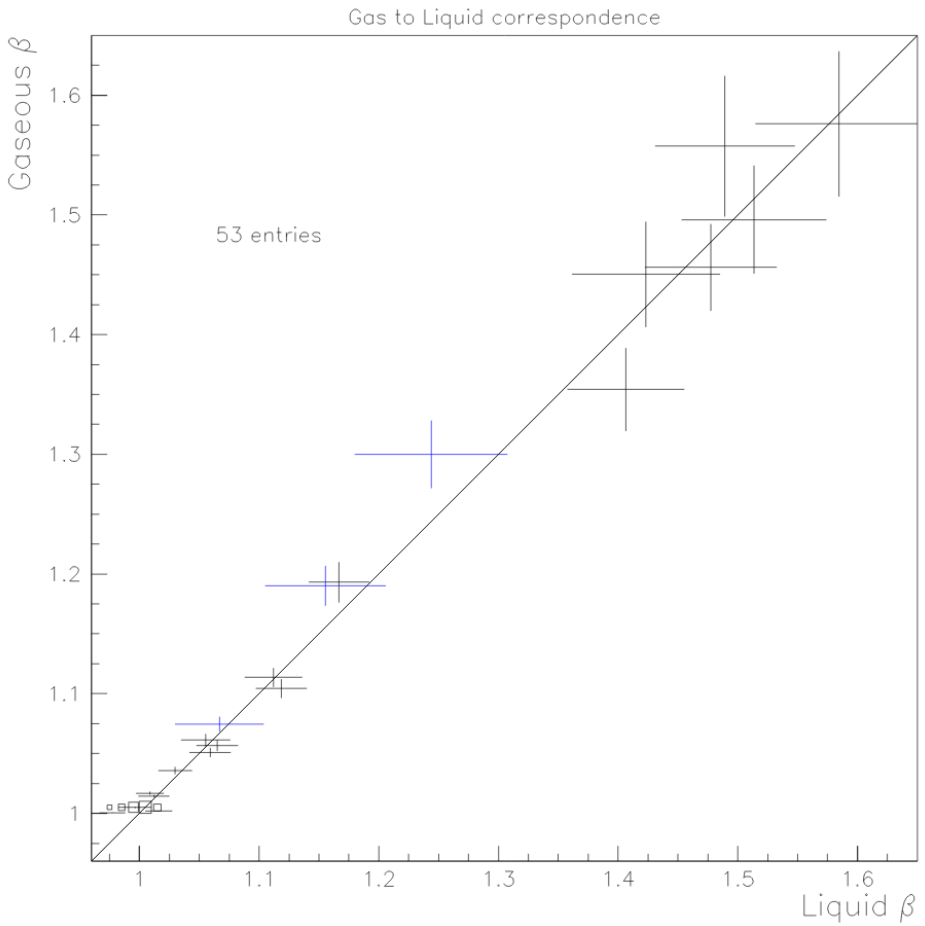
Correlation between RICH detectors

- 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 θ_1 vs θ_2 plane
- Or plot the predicted speeds β_1 and β_2

Correlation between RICH detectors



(a) Gas to liquid angle correlation



(b) Gas to liquid speed correlation

Tachyon mass parameters

- Calculate the mass parameters μ from Cherenkov angles
- Found excess events at $\mu = 0.28\,\text{GeV}$ and $\mu = 5\,\text{GeV}$

Tachyon mass parameters

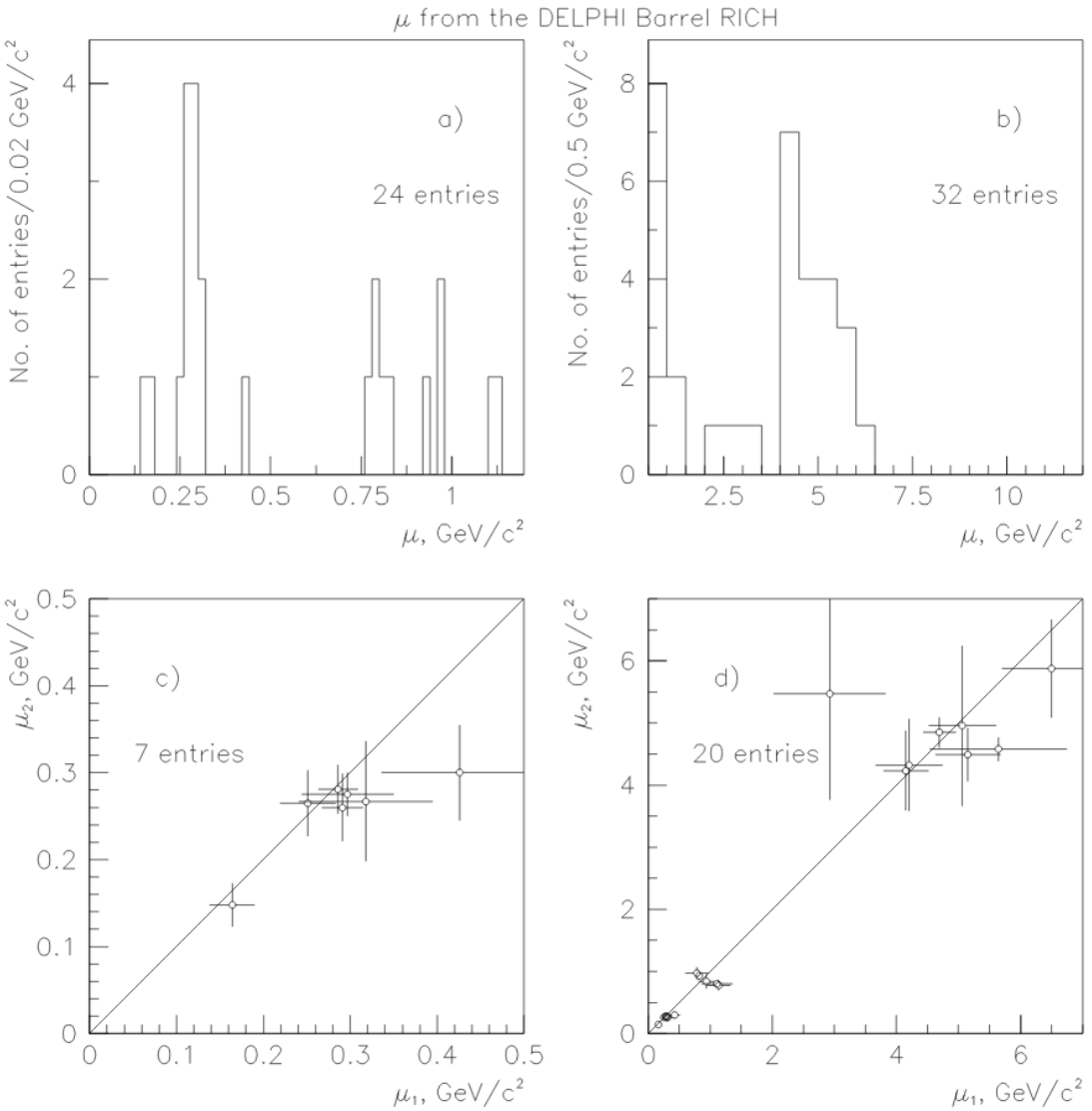


Figure 7: Tachyon mass parameters μ

Kinematic fit

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

Kinematic fit

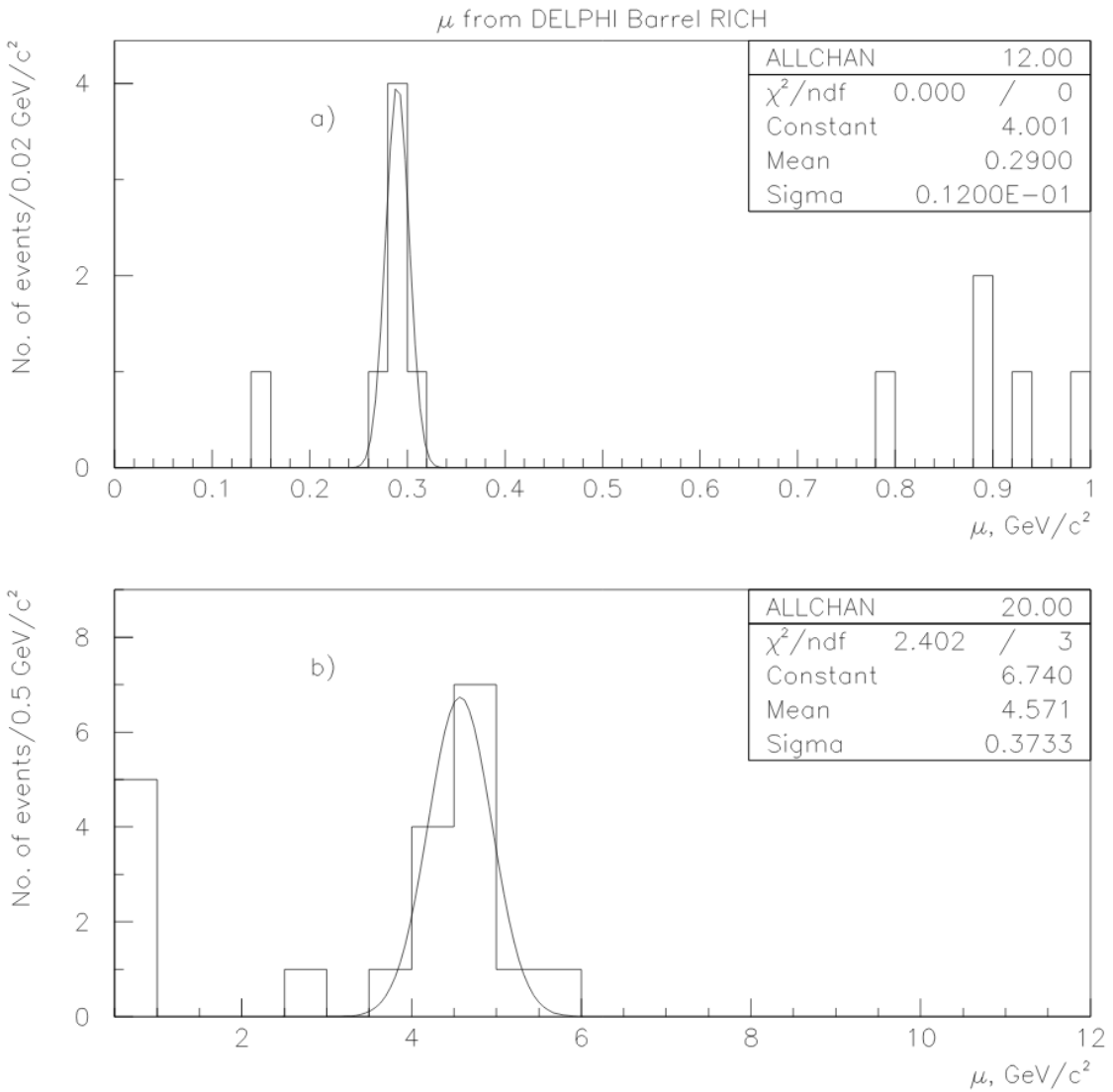


Figure 8: Tachyon mass parameters μ after kinematic fit

Conclusion

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