The ALICE Transition Radiation Detector
A large Particle Identification, Tracking and Trigger Detector

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Outline

1. Introduction
   - The ALICE Experiment
   - The TRD
   - Test Beam Setup

2. Electron Identification with the TRD
   - Requirements
   - $dE/dx$ and TR Measurements
   - Electron Identification Performance

3. Tracking with the TRD
   - Requirements
   - Position Reconstruction
   - Global Tracking Performance

4. Triggering with the TRD
   - Requirements
   - The TRD Front-End-Electronics

5. The TRD Gas System
LHC: The Large Hadron Collider

- Located at CERN in Geneva, Switzerland.
- Pb-Pb (5.5 TeV per nucleon pair) and p-p (14 TeV) collisions.
ALICE: A Large Ion Collider Experiment

- The dedicated heavy ion experiment at the LHC.
- Aim: Studies of the physics of strongly interacting matter at extreme energy densities.
The ALICE Transition Radiation Detector (TRD)

Physics Motivation [1]: Probing the plasma of quarks and gluons in heavy ion collisions

1. with heavy quarks:
   - quarkonia ($J/\Psi$, $\Psi'$, $\Upsilon$, ...),
   - open charm, open beauty.
   - Decay channel: e.g.
     $J/\Psi \rightarrow e^+ e^-$.  

2. with jets.

Detector Requirements

1. Offline: Electron-Pion Separation and tracking.
2. Online: Provide trigger decision (find stiff $e^-$ and $e^+$ tracks).
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The ALICE TRD: Design

The TRD surrounds the large TPC in the central barrel

- In total 540 large area drift chambers.
- 1.18 million readout channels;
- chamber sizes: \( \approx 1.2 \times 1.4 \text{ m} \);
- arranged in 18 \textit{Supermodules} with
- 5 longitudinal stacks and
- 6 radial layers each.
Transition Radiation

Transition radiation (TR)

- is produced by fast ($\gamma \gtrsim 1000$) particles at the crossing of boundaries between materials with different dielectric constants.
- In our momentum range ($1 < p < 10 \text{ GeV/c}$) only electrons produce TR.
- TR production probability $\sim \alpha = \frac{1}{137}$ per boundary.
- Thus many boundaries are added: e.g. about 100 foils to produce $\approx 1$ photon.
- We use an irregular radiator structure made of foam and fibers.
Electrons produce TR photons.
Xe gas mixture: efficient TR photon absorption.
Cathode pad sizes: $\approx 0.8 \times 70$ mm.
Cathode pad readout at 10 MHz.
The ALICE TRD: Working Principle (1)

The Drift Chambers:

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Mean Detector Signals:
- Peak at small drift times: Amplification region.
- Peak at large drift times for electrons: TR.

Average pulse height [mV]
Drift time [μs]

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**Graph:**
- Average pulse height [mV] vs. Drift time [μs]
- Symbols:
  - Red circles: $e, dE/dx + TR$
  - Green squares: $e, dE/dx$
  - Blue triangles: $\pi, dE/dx$

**Legend:**
- $p = 2 \text{ GeV/c}$
- Mean Detector Signals:
  - Peak at small drift times: Amplification region.
  - Peak at large drift times for electrons: TR.
Beam of $e^-$ and $\pi^-$, $p = 1$ to 10 GeV/c;
Scintillators S1, S2, S3 and Silicon Detectors SD1,..,SD4;
Particle Identification: Čerenkov Detector and Lead Glass Calorimeter;
Prototype TRD chambers, detachable radiators.
Magnetic Field up to 1 T;
Pipe with Helium to minimize absorption.
Magnet later replaced by six final real-sized chambers.
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Electron - Pion Separation

**Requirements**

- A pion rejection factor of $\approx 100$ at an electron efficiency of 90%.

**How?**

1. Different $dE/dx$ for electrons and pions.
2. Production and detection of transition radiation (TR) for electrons.

- Use Likelihood method.
- Thus we need detailed understanding of $dE/dx$ and TR (spectral shapes!).
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![Graph showing data and simulations for electron and pion yields]
1) $dE/dx$ Spectra

Spectral shapes are important:
- Input to the electron ID algorithm (Likelihood method).
- Good agreement with simulation.
- Also as function of momentum.
- Published in [2].
2) Pure TR Measurements

Example TR Event

- Two TR photons are well separated from the electron track.

View of

- magnet, helium pipe,
- radiator, drift chambers.
- Method from [3], our results published in [4]
TR: Mean number of photons and spectra

- ALICE TRD sandwich radiator (many other tested).
- Good reproduction of data [4].
Measured Electron Identification Performance

Test beam data:
- We reach a pion rejection factor of 100 at 90% electron efficiency.
- Stack of 6 real-sized detectors performs a bit worse than small prototypes.

Further improvement: $L_{QX}$ method (analyze also position of largest energy deposit) and neural network [5].
Tracking: Requirements

Requirements

1. Fast stand-alone tracking:
   - Momentum resolution $\frac{\Delta p_T}{p_T} \approx 5\%$.

2. Global tracking:
   - Increase tracking capability of the ALICE barrel detectors.

⇒ In the bending plane:
   - Hit resolution $\sigma_y \lesssim 400\,\mu$m (for each time bin).
   - Angular resolution $\sigma_\phi \lesssim 1^\circ$ (for each TRD layer).
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Position Reconstruction

Test Beam Data [6]: Resolution as a function of signal-to-noise ratio

- Secondary effects after TR absorption influences position reconstruction performance:
- L-Shell *fluorescence photons* (∼ 5 keV) have ∼ 0.4 cm absorption length in our gas mixture.
- Reproduced by simulation.
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Drift lines around the wires [6] (simulated with GARFIELD):

- The drift time depends on z-position.
- Thus the position determination is influenced.
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Nonlinearities

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  - This systematic effect is visible in the reconstructed angle.
Global Tracking Performance

- Simulated data (AliRoot).
- Global momentum resolution: $\frac{dp}{p} < 3\%$.
- TRD stand-alone momentum resolution (Trigger): $\frac{dp}{p} \approx 5\%$ at around $p=3$ GeV/c.
## TRD Trigger: Requirements

### Requirements

Trigger on
- electrons and electron pairs
- with high $p_T$ (typically above 2 GeV/c).

### Challenges:

- Need to track all of the up to 16,000 charged particles within the six detector layers.
- Tight time budget: 6 $\mu$s.
The TRD Trigger

**Local Tracking Unit (LTU):**
- On detector.
- Linear tracklet fits.
- Ship Tracklets to GTU.

**Global Tracking Unit (GTU):**
- Find high momentum tracks through all 6 layers.
- Generate trigger.
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Multi-Chip Modules [7] (MCMs):

1. Analog part:
   - Preamplifier/Shaper (PASA).

2. Digital part:
   - ADC and
   - Tracklet Processor (TRAP).

More information
Readout Boards

- Many MCMs connected to signal cables from a chamber.
- One MCM processes 18 channels;
- Electronics is located in active detector area.
- Measured Noise on chamber: $\approx 1200 \, e^-$.
- Also on each chamber:
  - Detector Control System (DCS)
  - Optical Readout Interface (ORI)
Gas System: Requirements

Requirements

- Geometrical stability of chambers => Working overpressure < 1 mbar;
- Xe-price (5,50 Euro/l) and large gas volume (27.2 m³) => gas tightness, recirculation (closed loop) and purification.

Challenge:

- Heavy Gas mixture (Xe, 15% CO₂) leads to pressure difference due to Xe hydrostatic pressure up to 2.5 mbar in detector (7 m height span).
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Gas System (1)

1. Segmentation into 14 individually pressure-regulated height sections (tested successfully).
2. Xe-CO$_2$ mixing with membranes.
3. O$_2$ removal with copper catalysts.
4. N$_2$ removal with Cryogenic Xe recovery plant.

Xe recovery:
- Plant reused from ALEPH experiment.
- Freeze the gas, pump out N$_2$, warm up and compress Xe into gas bottles.
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Gas System (2)

Gas Building

- Cryogenic Xe Recovery
- Mixer
- Purifier
- Membrane Separator
- Primary Supplies
- Analysis
- Compressor Unit
- Distribution
- SG to Plug pipe length 90 m
- Plug to UX pipe length ~ 100 m

UX Cavern

- Detector
- Distribution Racks

Thin lines to detector
Summary

- The ALICE TRD is composed of large drift chambers with drift direction perpendicular to the wire planes.
- It implements 1.2 million analog channels, which are digitized during the 2 $\mu$s drift time.
- It provides
  - Electron ID: A pion refection factor of 100 at (2 GeV/c);
  - Tracking: A stand-alone momentum resolution of 5% (at 2 GeV/c);
  - Trigger: Track up to 16,000 charged particles online and find stiff electron tracks within 6 $\mu$s.
- The heavy gas mixture ($Xe, CO_2$) and the need of small overpressure require a sophisticated gas system.
Outlook

- For the first beam in summer 2007 we will have four out of 18 supermodules ready.
- The first supermodule is currently constructed at KIP, Heidelberg, Germany.
The Institutes (TRD only):

- University of Athens: High Voltage Supplies;
- NIPNE, Bucharest, Romania: Chambers;
- Fachhochschule Cologne, Germany: Software for Detector Control System;
- JINR, Dubna, Russia: Chambers, Cosmic test stand, Supermodule Mechanics;
- University of Frankfurt, Germany: Chambers, Padplanes, Electronics Integration, Software and Data Analysis;
- GSI, Darmstadt, Germany: Chambers, Material Distribution, Gas System, Prototype Development, Test Beams, Software and Data Analysis, Supermodule Integration;
- PI, University of Heidelberg, Germany: Chambers, PASA, Readout boards, Supermodule Mechanics, Supermodule Integration;
- KIP, University of Heidelberg, Germany: TRAP, Detector Control System, Trigger System, Readout Software, Supermodule Integration;
- University of Kaiserslautern, Germany: ADC;
- FZ Karlsruhe, Germany: Readout board and MCM production;
- University of Münster, Germany: Radiators, Supermodule Integration;
- University of Tokyo, Japan: Data Analysis,
- Fachhochschule Worms, Germany: Communication software for Detector Control System.
For Further Reading (1)

1) The ALICE Collaboration.

2) A. Andronic et. al.
Energy loss of pions and electrons of 1 to 6 GeV/c in drift chambers operated with Xe,CO2(15

3) C.W. Fabjan and W. Struczinski.
Coherent Emission of Transition Radiation in Periodic Radiators.

4) A. Andronic et. al.
Transtion Radiation Spectra of Electrons from 1 to 10 GeV/c in Regular and Irregular Radiators.
For Further Reading (2)

5) C. Adler et. al.
Electron/pion identification with ALICE TRD prototypes using a neural network algorithm.

6) C. Adler et. al.
Position Reconstruction in Drift Chambers operated with Xe,CO₂ (15%).

7) V. Lindenstruth and L. Musa
Fast on-detector integrated signal processing, status and perspectives.
Measurements and simulation:

- Our measurements published in [2].
- Good agreement with Geant4.
The TRD Electronics Chain

1. PASA:
   - AMS 0.35 \( \mu \)m technology,
   - conversion gain 12.4 mV/fC,
   - shaping time 120 ns (FWHM), shaping type: CR-RC,
   - equivalent input noise (on the bench): \( \approx 700 \ e^- \),
   - power consumption < 10 mW/channel.

2. ADC:
   - UMC 0.18 \( \mu \)m technology,
   - 10 bit, 10MSPS
   - power consumption \( \approx 6 \) mW/channel.

3. TRAP:
   - ASIC in 0.18 \( \mu \)m CMOS technology,
   - Preprocessor: digital filters (gain, pedestal, nonlinearity, ion tails), hit selection
   - 4 RISC processors: Tracklet processing at 120 MHz.
TRD Stand-alone Momentum Resolution

- Momentum Resolution of TRD stand-alone for electrons and positrons from $J/\Psi$ (momentum range 2-3 GeV/c).
TRD Gas System Test

- Realistic test with two volumes 7 m apart in height and 40 m below pump.
Detector Control System (DCS)

1 DCS board per chamber:
- FPGA and ARM core running Linux OS.
- Control voltage regulator shutdown,
- MCM configuration and
- Clock and trigger distribution.
Optical Readout Interface (ORI)

2 ORI boards per chamber:
- Connects 3 or 4 readout boards to GTU.
- High speed readout: 2.5 GBit optical links.
- In total 1080 for whole TRD.