The ALICE Transition Radiation Detector

A large Particle Identification, Tracking and Trigger Detector

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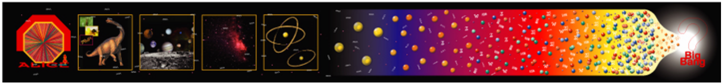
April 5th, 2006

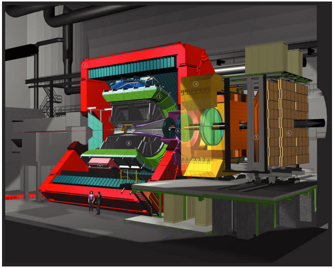
Outline

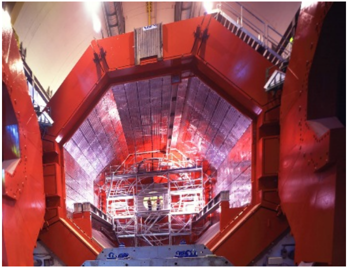
LHC: The Large Hadron Collider

- Located at CERN in Geneva, Switzerland.
- Pb-Pb (5.5 TeV per nucleon pair) and p-p (14 TeV) collisions.

ALICE: **A** **L**arge **I**on **C**ollider **E**xperiment





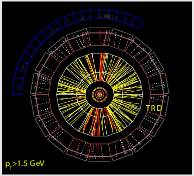


- The dedicated heavy ion experiment at the LHC.
- Aim: Studies of the physics of strongly interacting matter at extreme energy densities.

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/Ψ, Ψ', Υ, ...),
   - open charm, open beauty.
   - Decay channel: e.g. $J/\Psi \rightarrow e^+ \, e^-$.
2. with jets.



Simulated (AliRoot) Event showing only high p_T tracks.

Detector Requirements

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

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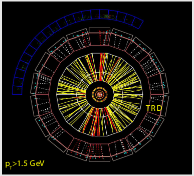

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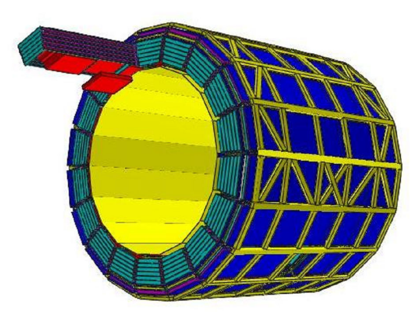
The ALICE TRD: Design

The TRD surrounds the large TPC in the central barrel

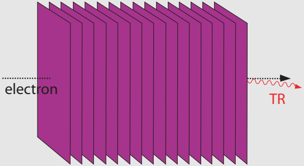


- In total 540 large area drift chambers.
- 1.18 million readout channels;
- chamber sizes: $\approx 1.2 \times 1.4\,\mathrm{m}$;
- arranged in 18 *Supermodules* with
- 5 longitudinal stacks and
- 6 radial layers each.

Transition Radiation

Transition radiation (TR)

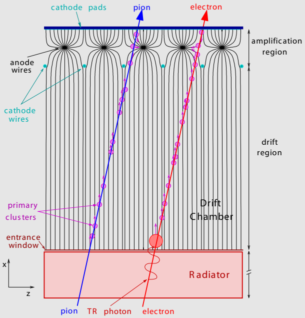
- is produced by fast ($\gamma \gtrsim 1000$) particles at the crossing of boundaries between materials with different dielectric constants.



- In our momentum range ($1 < p < 10\,\mathrm{GeV/c}$) 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 ≈ 1 photon.
- We use an irregular radiator structure made of foam and fibers.

The ALICE TRD: Working Principle (1)

The Drift Chambers:



- Electrons produce TR photons.
- Xe gas mixture: efficient TR photon absorption.
- Cathode pad sizes: $\approx 0.8 \times 70\,\mathrm{mm}$.
- Cathode pad readout at 10 MHz.

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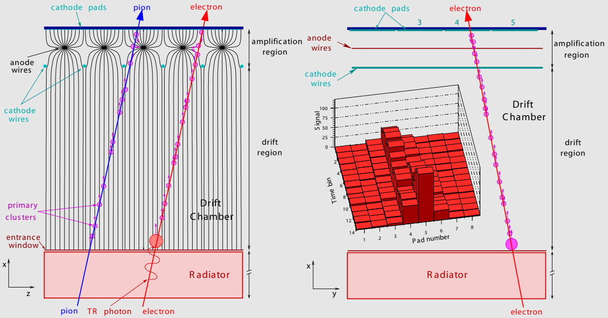

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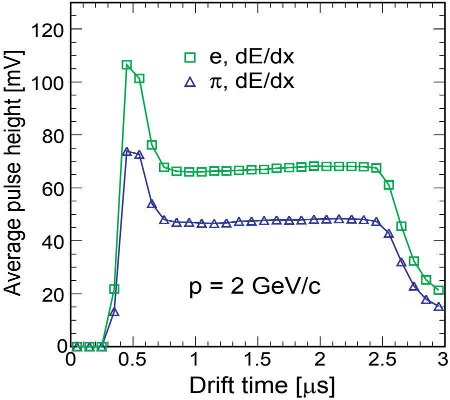
The ALICE TRD: Working Principle (2)



Mean Detector Signals:

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

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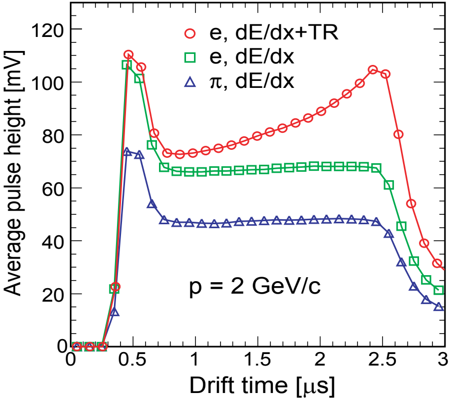

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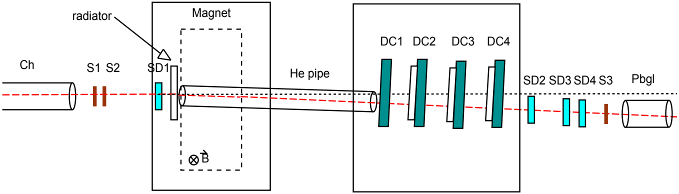
Setup for our Measurements



- Beam of e^- and π^-, $p = 1$ 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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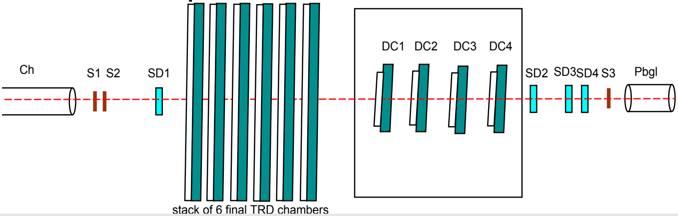

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Electron - Pion Separation

Requirements

- A pion rejection factor of ≈ 100 at an electron efficiency of 90 %.

How?

1. Different $\mathrm{d}E/\mathrm{d}x$ for electrons and pions.
2. Production and detection of transition radiation (TR) for electrons.

- Use Likelihood method.
- Thus we need detailed understanding of $\mathrm{d}E/\mathrm{d}x$ and TR (spectral shapes!).

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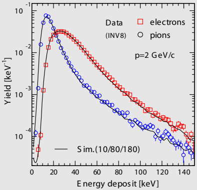
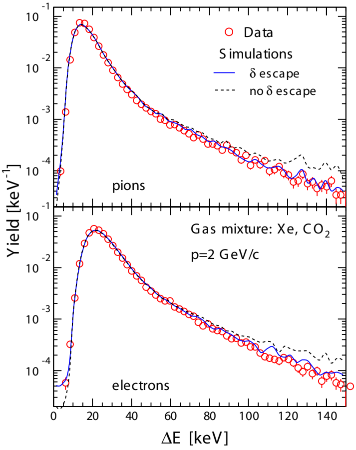


1) dE/dx Spectra



Spectral shapes are important:

- Input to the electron ID algorithm (Likelihood method).
- Good agreement with simulation.
  - also as function of momentum
- Published in [2].

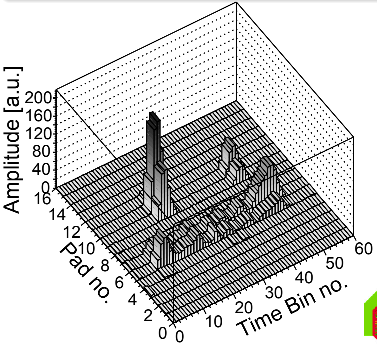
2) Pure TR Measurements

View of

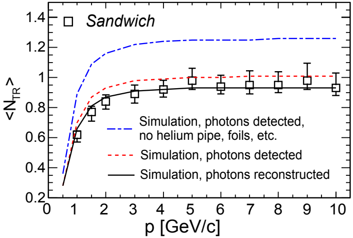
- magnet, helium pipe,
- radiator, drift chambers.
- Method from [3], our results published in [4]

Example TR Event

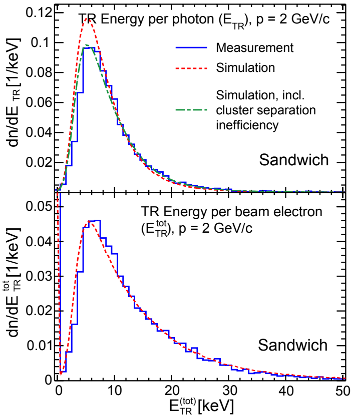
- Two TR photons are well separated from the electron track.



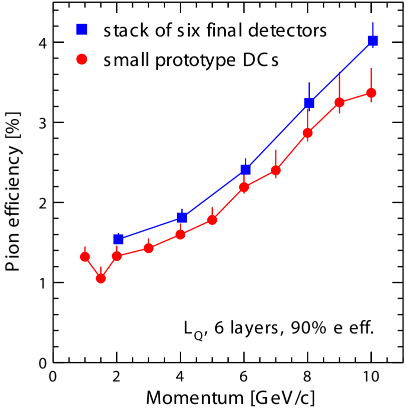
TR: Mean number of photons and spectra



- ALICE TRD sandwich radiator (many other tested).
- Simulation parameters [3] chosen to best fit our measurements.
- 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.
- Reason: Noise problem.

- 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.

$\Rightarrow$ In the bending plane:

- Hit resolution $\sigma_y \lesssim 400\,\mu\text{m}$ (for each time bin).
- Angular resolution $\sigma_\phi \lesssim 1^\circ$ (for each TRD layer).

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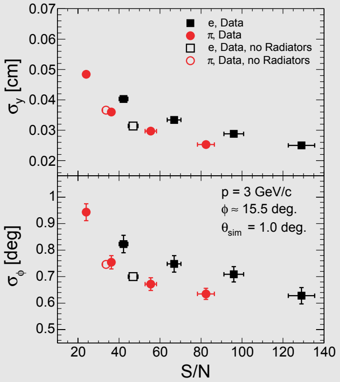
Position Reconstruction

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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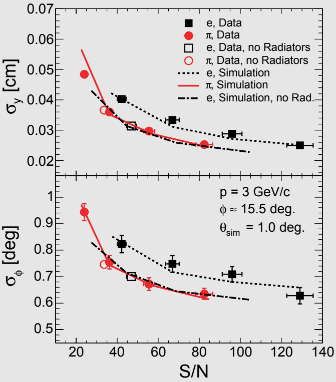

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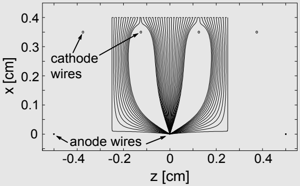
Nonlinearities



- Drift lines around the wires [6] (simulated with GARFIELD):
- The drift time depends on z-position.
- Thus the position determination is influenced.
- This systematic effect is visible in the reconstructed angle.

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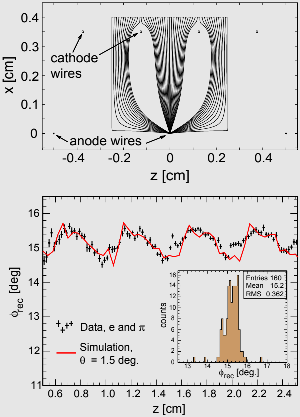

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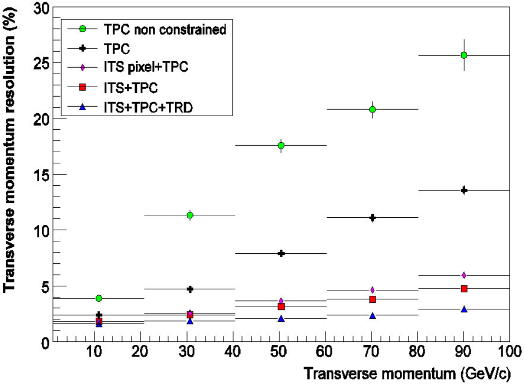
Global Tracking Performance



- Simulated data (AliRoot).
- Global momentum resolution: $\mathrm{d}p/p < 3\%$.

- TRD stand-alone momentum resolution (Trigger): $\mathrm{d}p/p \approx 5\%$ at around p=3 GeV/c. More

TRD Trigger: Requirements

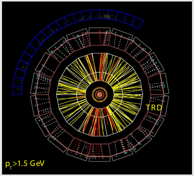
Requirements

Trigger on

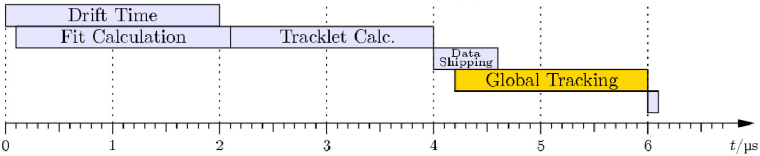
- electrons and electron pairs
- with high p_T (typically above 2 GeV/c).

Challenges:

- Need to track all of the up to 16,000 charged particles within the six detector layers.
- Tight time budget: 6 μs.



The TRD Trigger



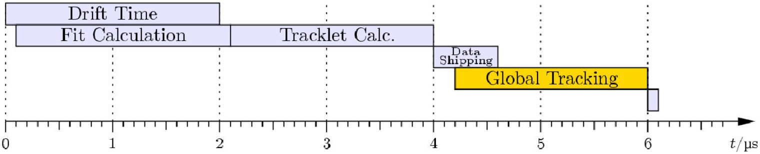
Local Tracking Unit (LTU):

- On detector.
- Linear tracklet fits.
- Ship Tracklets to GTU.

Global Tracking Unit (GTU):

- Find high momentum tracks through all 6 layers.
- Generate trigger.

The TRD Trigger



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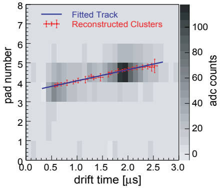

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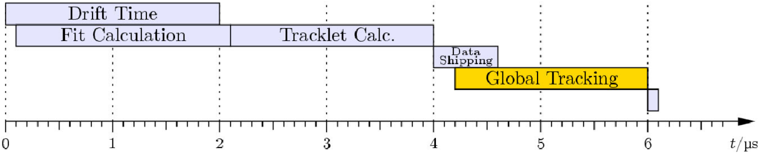

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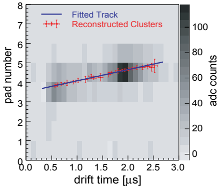
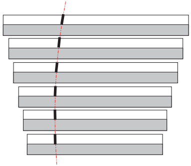
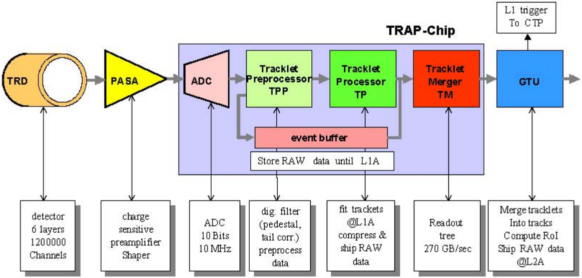


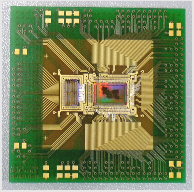


The TRD Electronics Chain



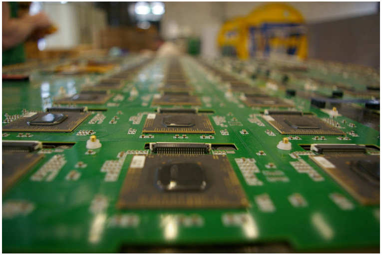
Multi-Chip Modules [7] (MCMs):

1. Analog part:
   - Preamplifier/Shaper (PASA).
2. Digital part:
   - ADC and
   - Tracklet Processor (TRAP).

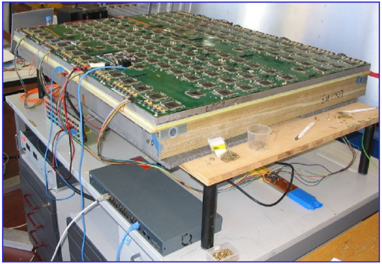


▸ More information

Readout Boards



Many MCMs connected to signal cables from a chamber.



One chamber equipped with readout electronics.

- 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)

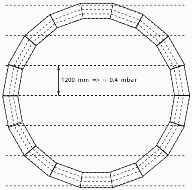
Gas System: Requirements

Requirements

- Geometrical stability of chambers
  $\Rightarrow$ Working overpressure < 1 mbar;
- Xe-price (5,50 Euro/l) and large gas volume ($27.2\,m^3$)
  $\Rightarrow$ gas tightness, recirculation (closed loop) and purification.

Challenge:

- Heavy Gas mixture (Xe, 15% CO_2) leads to pressure difference due to Xe hydrostatic pressure up to 2.5 mbar in detector (7 m height span).



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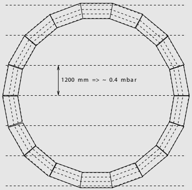

Gas System (1)

1. Segmentation into 14 individually pressure-regulated height sections (▸ tested successfully).
2. Xe-CO_2 mixing with membranes.
3. O_2 removal with copper catalyzers.
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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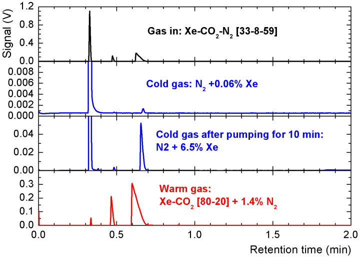
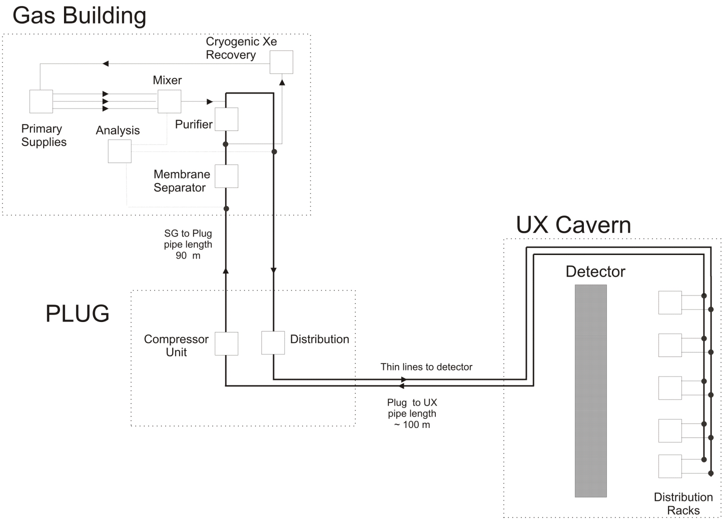


Gas System (2)

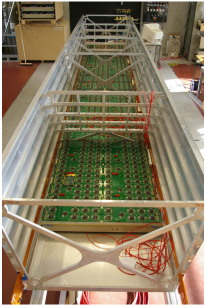

Gas Building
Cryogenic Xe Recovery
Mixer
Primary Supplies
Analysis
Purifier
Membrane Separator
SG to Plug pipe length 90 m
PLUG
Compressor Unit
Distribution
Thin lines to detector
Plug to UX pipe length ~ 100 m
UX Cavern
Detector
Distribution Racks

Summary

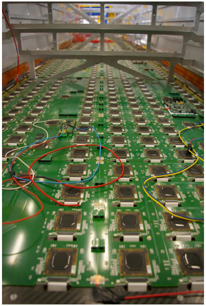
- The ALICE TRD is composed of large drift chambers with drift direction perpendicular to the wire planes.
- It implements 1.2 million analog channels, which are digitized during the 2 μs drift time.
- It provides
  - Electron ID: A pion refection factor of 100 at (2 GeV/c);
  - Tracking: A stand-alone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

Outlook

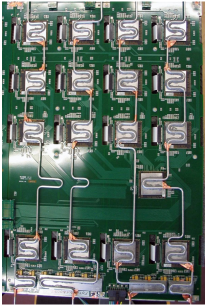
- For the first beam in summer 2007 we will have four out of 18 supermodules ready.
- The first supermodule is currently constructed at KIP, Heidelberg, Germany.



Supermodule No.1



First layer of chambers



Cooling on readout board

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 Develoipment, 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.
ALICE TRD Technical Design Report.
CERN/LHCC 2001-021, ALICE TRD 9, 3 October 2001.

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
NIM A 519 (2004), 508.

3) C.W. Fabjan and W. Struczinski.
Coherent Emission of Transition Radiation in Periodic Radiators.
Phys. Lett. B57 (1975), 483-486.

4) A. Andronic et. al.
Transtion Radiation Spectra of Electrons from 1 to 10 GeV/c in Regular and Irregular Radiators.
NIM A 558 (2006), 516-525, physics/0511229.

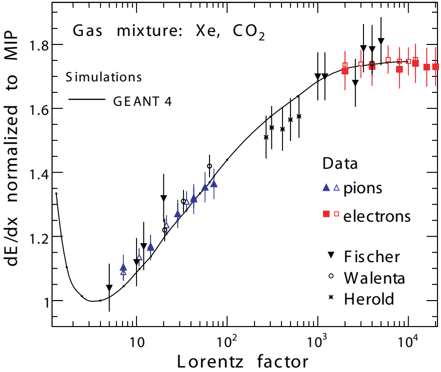
For Further Reading (2)

5) C. Adler et. al.
Electron/pion identification with ALICE TRD prototypes using a neural network algorithm.
NIM A 552 (2005), 364-371.

6) C. Adler et. al.
Position Reconstruction in Drift Chambers operated with Xe,CO_2 (15%).
NIM A 540 (2004), 140-157.

7) V. Lindenstruth and L. Musa
Fast on-detector integrated signal processing, status and perspectives.
NIM A 522 (2004), 33-39.

dE/dx, Average Values



Measurements and simulation:

- Our measurements published in [2].
- Good agreement with Geant4.

Return

The TRD Electronics Chain

1. PASA:
   - AMS 0.35 μm 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 μm technology,
   - 10 bit, 10MSPS
   - power consumption ≈ 6 mW/channel.
3. TRAP:
   - ASIC in 0.18 μm CMOS technology,
   - Preprocessor: digital filters (gain, pedestal, nonlinearity, ion tails), hit selection
   - 4 RISC processors: Tracklet processing at 120 MHz.

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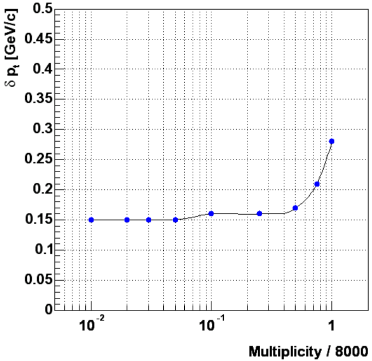
TRD Stand-alone Momentum Resolution



- Momentum Resolution of TRD stand-alone for electrons and positrons from J/Ψ (momentum range 2-3 GeV/c).

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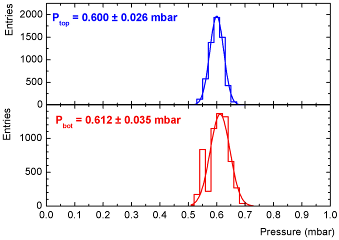
TRD Gas System Test



- Realistic test with two volumes 7 m apart in height and 40 m below pump.

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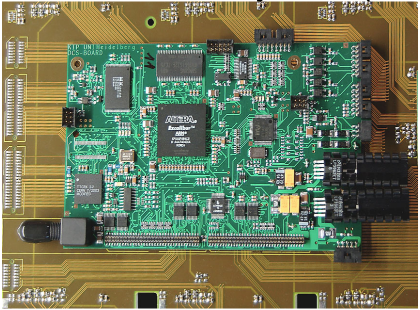
Detector Control System (DCS)



1 DCS board per chamber:

- FPGA and ARM core running Linux OS.
- Control voltage regulator shutdown,
- MCM configuration and
- Clock and trigger distribution.

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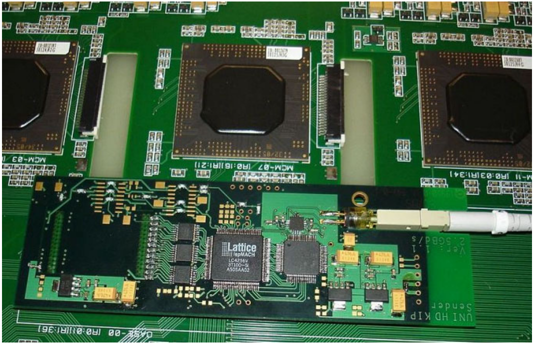
Optical Readout Interface (ORI)



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.

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