Transition Radiation Spectroscopy with Prototypes of the ALICE TRD

Results from a Beam Test at CERN from 2004

Christian Lippmann

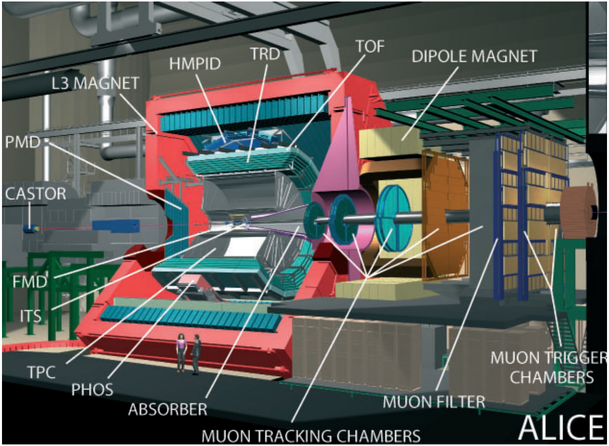
Department KP1
Gesellschaft für Schwerionenforschung mbH,
Darmstadt, Germany

DPG Spring Meeting, March 2005

bmb+f - Förderschwerpunkt
ALICE
Großgeräte der physikalischen Grundlagenforschung

Outline

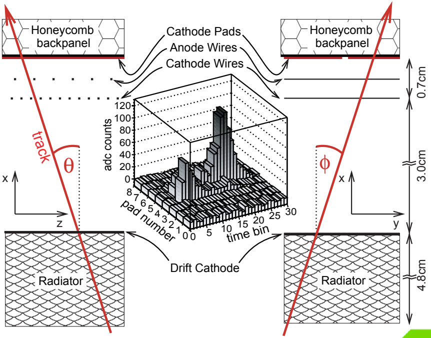
The ALICE Experiment



The ALICE TRD

The TRD [1]:

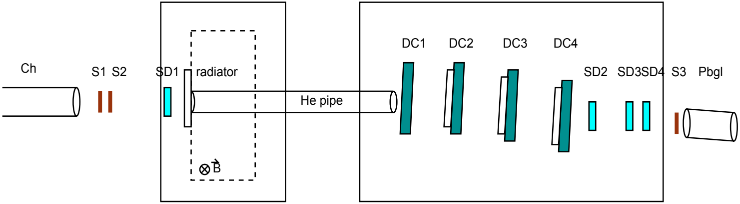
- See talk HK 35.2 by D. Emscher.
- A drift chamber filled with Xe, CO_2 (15 %).
- Electrons produce transition radiation (TR), which is absorbed by the heavy gas mixture.
- Ionization electrons drift towards the anode wires and create charge avalanches.
- Cathode pads are read out at 10 MHz.



The Importance of TR

- With the ALICE TRD we want to identify electrons.
- We use the information of the ionization energy loss and of transition radiation (TR).
- Different methods can be used: Likelihood and Neural Networks (see talk HK 35.5 by A. Wilk).
- Methods have to be practised also in the general ALICE simulations (AliRoot).
- One has to understand the momentum dependent TR performance and to refine simulations.

The Setup at CERN PS (T9)



- Beam of π^- and e^-, p = 1 to 10 GeV/c;
- Trigger: S1, S2, S3 (Scintillators);
- Particle Identification: Čerenkov Detector and Lead Glass Calorimeter;
- Tracking: SD1,..,SD4 (Silicon Detectors);
- Magnetic Field up to 0.5 T;
- Pipe with Helium to minimize absorption.
- Prototype TRD chambers with smaller area.

Setup at the CERN PS (T9)

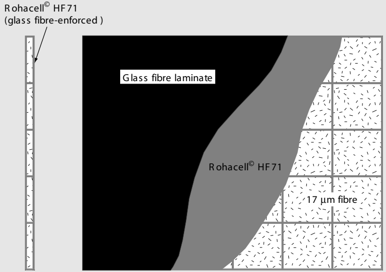
View of

- magnet,
- helium pipe,
- radiator,
- drift chambers
- and one silicon detector.

Different Radiator Configurations:

The radiators:

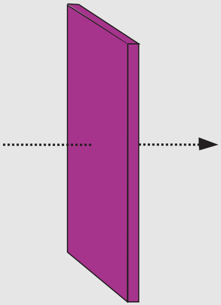
- Standard ALICE TRD Radiator (foam + fibers),
- Plexiglas Dummy,
- Pure Fiber Radiator (8 mats, about 4 cm thick),
- Pure Foam (4.2 cm thick),
- Regular1 (N=120, d1=20μm, d2=500μm),
- Regular2 (N=220, d1=20μm, d2=250μm),
- No Radiator (only helium pipe).



Different Radiator Configurations:

The radiators:

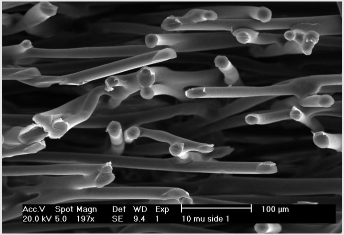
- Standard ALICE TRD Radiator (foam + fibers),
- Plexiglas Dummy,
- Pure Fiber Radiator (8 mats, about 4 cm thick),
- Pure Foam (4.2 cm thick),
- Regular1 (N=120, d1=20μm, d2=500μm),
- Regular2 (N=220, d1=20μm, d2=250μm),
- No Radiator (only helium pipe).



Different Radiator Configurations:

The radiators:

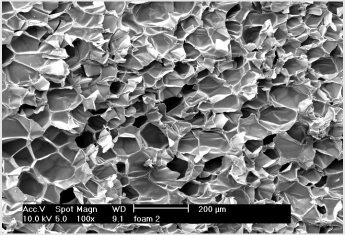
- Standard ALICE TRD Radiator (foam + fibers),
- Plexiglas Dummy,
- Pure Fiber Radiator (8 mats, about 4 cm thick),
- Pure Foam (4.2 cm thick),
- Regular1 (N=120, d1=20μm, d2=500μm),
- Regular2 (N=220, d1=20μm, d2=250μm),
- No Radiator (only helium pipe).



Different Radiator Configurations:

The radiators:

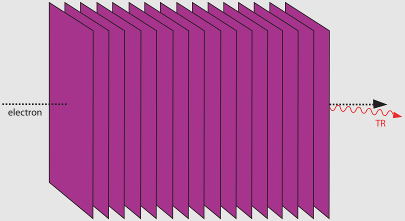
- Standard ALICE TRD Radiator (foam + fibers),
- Plexiglas Dummy,
- Pure Fiber Radiator (8 mats, about 4 cm thick),
- Pure Foam (4.2 cm thick),
- Regular1 (N=120, d1=20μm, d2=500μm),
- Regular2 (N=220, d1=20μm, d2=250μm),
- No Radiator (only helium pipe).



Different Radiator Configurations:

The radiators:

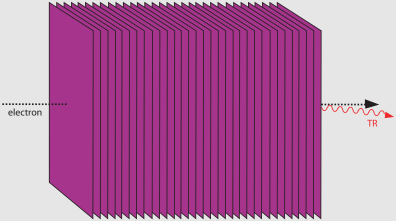
- Standard ALICE TRD Radiator (foam + fibers),
- Plexiglas Dummy,
- Pure Fiber Radiator (8 mats, about 4 cm thick),
- Pure Foam (4.2 cm thick),
- Regular1 (N=120, d1=20μm, d2=500μm),
- Regular2 (N=220, d1=20μm, d2=250μm),
- No Radiator (only helium pipe).



Different Radiator Configurations:

The radiators:

- Standard ALICE TRD Radiator (foam + fibers),
- Plexiglas Dummy,
- Pure Fiber Radiator (8 mats, about 4 cm thick),
- Pure Foam (4.2 cm thick),
- Regular1 (N=120, d1=20μm, d2=500μm),
- Regular2 (N=220, d1=20μm, d2=250μm),
- No Radiator (only helium pipe).

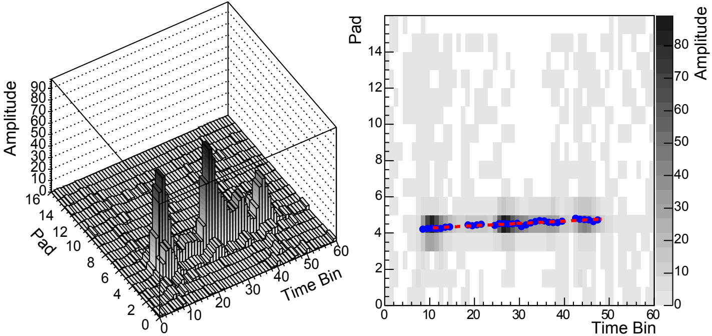


Different Radiator Configurations:

The radiators:

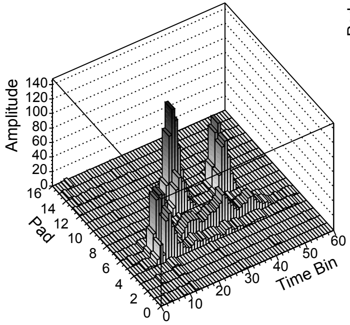
- Standard ALICE TRD Radiator (foam + fibers),
- Plexiglas Dummy,
- Pure Fiber Radiator (8 mats, about 4 cm thick),
- Pure Foam (4.2 cm thick),
- Regular1 (N=120, d1=20μm, d2=500μm),
- Regular2 (N=220, d1=20μm, d2=250μm),
- No Radiator (only helium pipe).

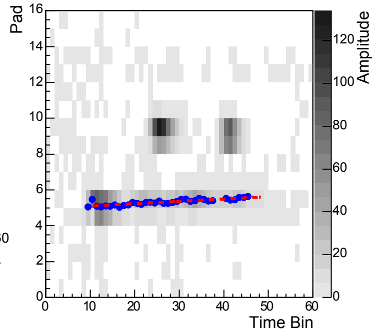
Example Events



- The ionization energy loss produces a tracklet in the TRD.
- On top of that we find for electrons in some cases TR.
- Due to the magnet it is well separated from the track.

Example Events

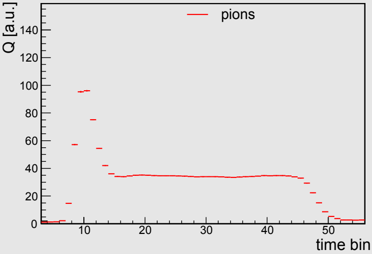


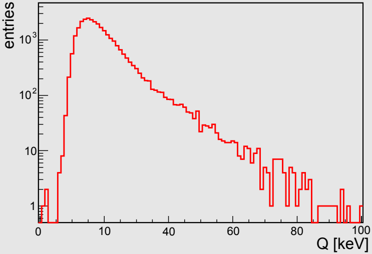


- The ionization energy loss produces a tracklet in the TRD.
- On top of that we find for electrons in some cases TR.
- Due to the magnet it is well separated from the track.

Average signals & charge spectra at 4 GeV/c

Sandwich radiator



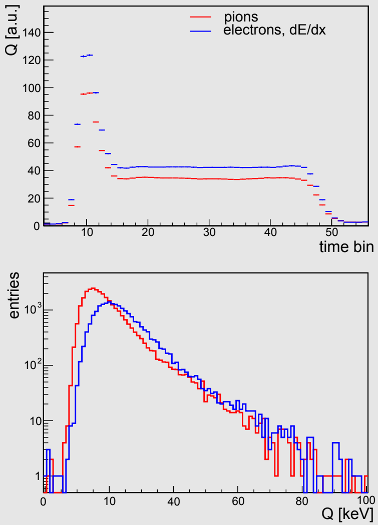


Different energy deposit is used to identify particles:

- Ionization energy loss for pions;
- Ionization energy loss for electrons;
- Energy deposited by TR for electrons;
- Energy deposited by dE/dx + TR for electrons;

Average signals & charge spectra at 4 GeV/c

Sandwich radiator

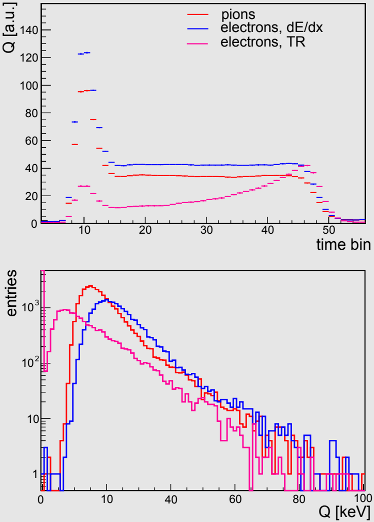


Different energy deposit is used to identify particles:

- Ionization energy loss for pions;
- Ionization energy loss for electrons;
- Energy deposited by TR for electrons;
- Energy deposited by dE/dx + TR for electrons;

Average signals & charge spectra at 4 GeV/c

Sandwich radiator

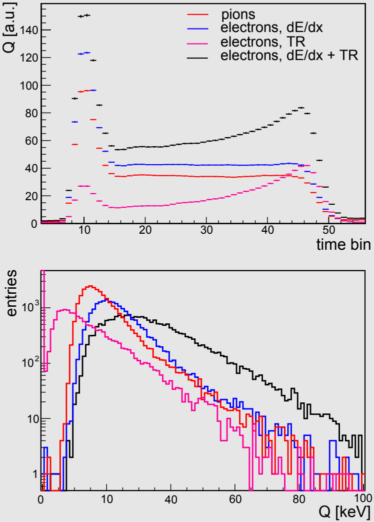


Different energy deposit is used to identify particles:

- Ionization energy loss for pions;
- Ionization energy loss for electrons;
- Energy deposited by TR for electrons;
- Energy deposited by dE/dx + TR for electrons;

Average signals & charge spectra at 4 GeV/c

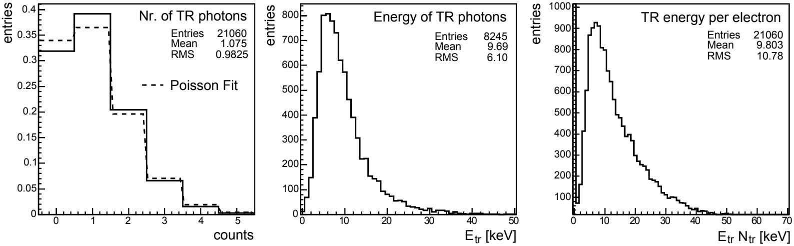
Sandwich radiator



Different energy deposit is used to identify particles:

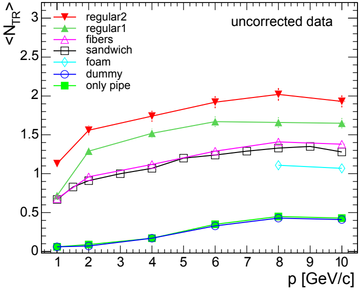
- Ionization energy loss for pions;
- Ionization energy loss for electrons;
- Energy deposited by TR for electrons;
- Energy deposited by dE/dx + TR for electrons;

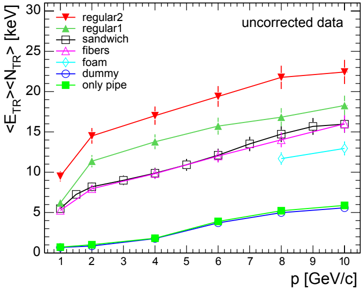
4 GeV/c, sandwich radiator



- N_{tr}: Number of TR photons detected per electron event.
- E_{tr}: Charge per TR photon.
- $E_{tr}N_{tr}$: Charge deposited by TR per electron.

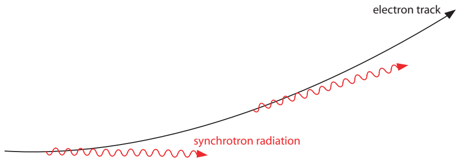
Mean Number of Photons & Mean Energy per Electron





- The regular radiators have the highest TR yield.
- The fibers and foam have different thicknesses than the sandwich.
- We find some photons also if no radiator is present ("only pipe"). Possibly synchrotron radiation or unwanted beam interaction? Has to be subtracted.

Synchrotron radiation

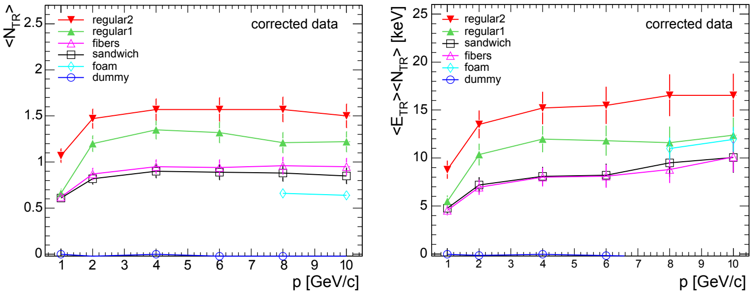


- The number of photons emitted by synchrotron radiation by an electron on a track with radius R on length L is

$$< N_{sync} > \approx \; 10^{-2}\frac{\gamma \, L}{R} \; . \tag{1}$$

- In our case that would be $< N_{sync} > \approx \; 0.7$ photons at 5 GeV/c.
- More investigations are needed, including spectral distributions and absorption.

Data after subtracting background



- Between 1 and 2 GeV/c: onset of TR production.
- Then TR yield is essentially flat.
- Yield is highest for regular foil radiators.

Theory of regular foil transition radiators

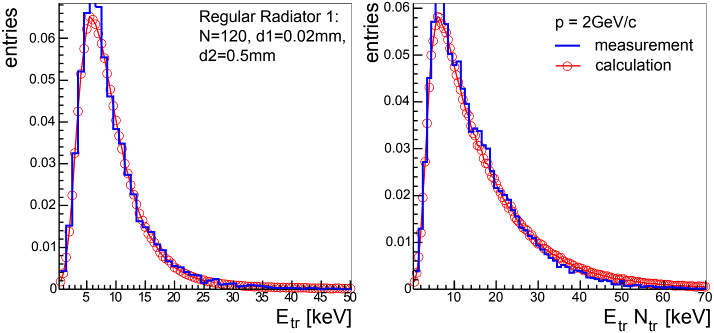
The differential energy spectrum [2] is given by

$$\frac{dW}{d\omega} = \frac{4\,\alpha}{\sigma\,(\kappa+1)}(1-\exp(-N_f\sigma)) \times \sum_{n=1}^{\infty}\Theta_n\left(\frac{1}{\rho_1+\Theta_n}-\frac{1}{\rho_2+\Theta_n}\right)^2[1-\cos(\rho_1+\Theta_n)] \quad (2)$$

with:

- α - fine structure constant,
- σ - total absorption cross section (foils and gaps),
- $\kappa=\frac{d_2}{d_1}$ - ratio of thickness of gaps (d_1) and foils (d_2),
- N_f - the number of foils,
- $\Theta_n = \frac{2\pi\,n-(\rho_1+\kappa\rho_2)}{1+\kappa} > 0$,
- $\rho_i = \frac{\omega\,d_1}{2\,c}\left(\gamma^{-2}+\xi_1^2\right),\quad \xi_i^2=\omega_{P,i}^2\omega^2$,
- $\omega_P = 28.8\sqrt{\rho\frac{Z}{A}}$ eV.

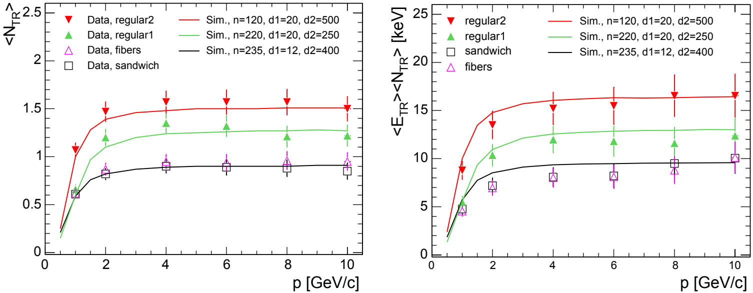
Comparison with Calculation



The TR energy specta:

- The theory reproduces the measurements very nicely, also for the second regular radiator.
- No scaling has been done!

Comparison with Calculation



- The momentum dependence is also reproduced.
- For the ALICE TRD sandwich radiators the theory can only be applied as a parameterization, since the radiator has no regularity!

Summary & Outlook

Summary

- We measured the momentum dependent transition radiation yield of the standard ALICE TRD sandwich radiator with small prototype TRD chambers.
- We also tested the fiber and foam components and..
- ... regular foil radiators.
- We find nice agreement with theory.
- The theory is very important for the general ALICE simulation efforts (pion efficiencies).

Outlook

- Understanding of background. Synchrotron radiation?
- Comparison to Geant4.

Summary & Outlook

Summary

- We measured the momentum dependent transition radiation yield of the standard ALICE TRD sandwich radiator with small prototype TRD chambers.
- We also tested the fiber and foam components and..
- ... regular foil radiators.
- We find nice agreement with theory.
- The theory is very important for the general ALICE simulation efforts (pion efficiencies).

Outlook

- Understanding of background. Synchrotron radiation?
- Comparison to Geant4.

Summary & Outlook

Summary

- We measured the momentum dependent transition radiation yield of the standard ALICE TRD sandwich radiator with small prototype TRD chambers.
- We also tested the fiber and foam components and..
- ... regular foil radiators.
- We find nice agreement with theory.
- The theory is very important for the general ALICE simulation efforts (pion efficiencies).

Outlook

- Understanding of background. Synchrotron radiation?
- Comparison to Geant4.

Summary & Outlook

Summary

- We measured the momentum dependent transition radiation yield of the standard ALICE TRD sandwich radiator with small prototype TRD chambers.
- We also tested the fiber and foam components and..
- ... regular foil radiators.
- We find nice agreement with theory.
- The theory is very important for the general ALICE simulation efforts (pion efficiencies).

Outlook

- Understanding of background. Synchrotron radiation?
- Comparison to Geant4.

Summary & Outlook

Summary

- We measured the momentum dependent transition radiation yield of the standard ALICE TRD sandwich radiator with small prototype TRD chambers.
- We also tested the fiber and foam components and..
- ... regular foil radiators.
- We find nice agreement with theory.
- The theory is very important for the general ALICE simulation efforts (pion efficiencies).

Outlook

- Understanding of background. Synchrotron radiation?
- Comparison to Geant4.

Summary & Outlook

Summary

- We measured the momentum dependent transition radiation yield of the standard ALICE TRD sandwich radiator with small prototype TRD chambers.
- We also tested the fiber and foam components and..
- ... regular foil radiators.
- We find nice agreement with theory.
- The theory is very important for the general ALICE simulation efforts (pion efficiencies).

Outlook

- Understanding of background. Synchrotron radiation?
- Comparison to Geant4.

Summary & Outlook

Summary

- We measured the momentum dependent transition radiation yield of the standard ALICE TRD sandwich radiator with small prototype TRD chambers.
- We also tested the fiber and foam components and..
- ... regular foil radiators.
- We find nice agreement with theory.
- The theory is very important for the general ALICE simulation efforts (pion efficiencies).

Outlook

- Understanding of background. Synchrotron radiation?
- Comparison to Geant4.

For Further Reading

- The ALICE Collaboration.
  ALICE TRD Technical Design Report.
  CERN/LHCC 2001-021, ALICE TRD 9, 3 October 2001.
- C.W. Fabjan and W. Struczinski.
  Coherent Emission of Transition Radiation in Periodic Radiators.
  Phys. Lett. B57 (1975), 483-486.
- O. Busch et. al.
  Transition Radiation Spectroscopy with Prototypes of the ALICE TRD.
  NIM A 522 (2004), 45-49.
- C. Lippmann.
  http://www-linux.gsi.de/~lippmann.