Transition Radiation Spectra of Electrons from 1 to 10 GeV/c in Regular and Irregular Radiators

Results from the Beam Test at CERN from 2004

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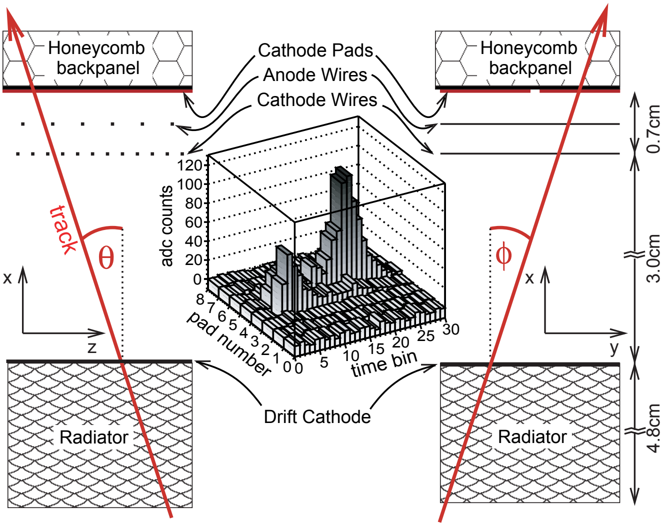
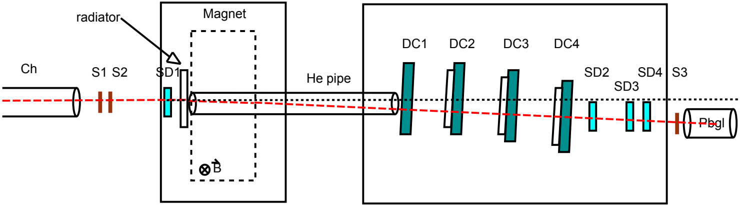
Outline

The ALICE TRD



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 about 1 T;
- Pipe with Helium to minimize absorption.
- Small prototype TRD chambers.

Setup at the CERN PS (T9)

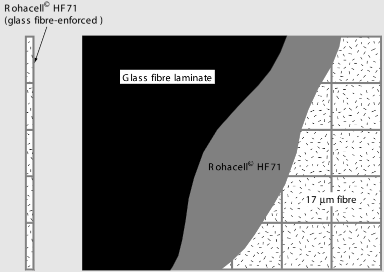
View of

- 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).



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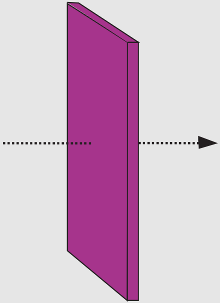

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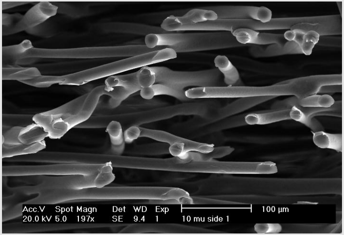

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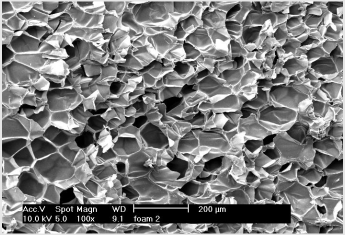

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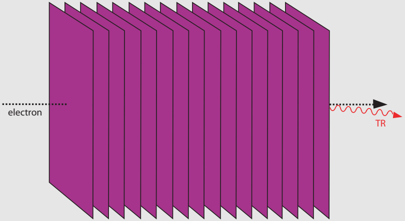

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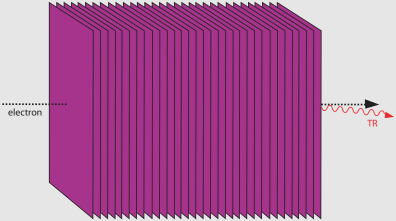

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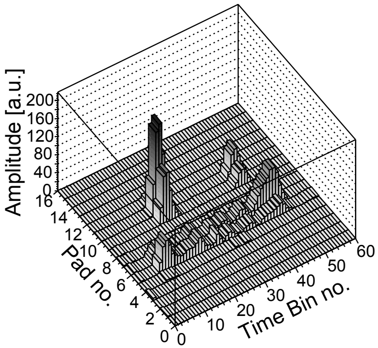
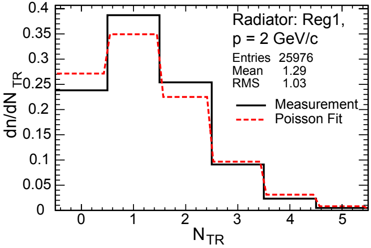
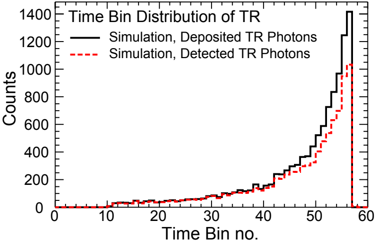
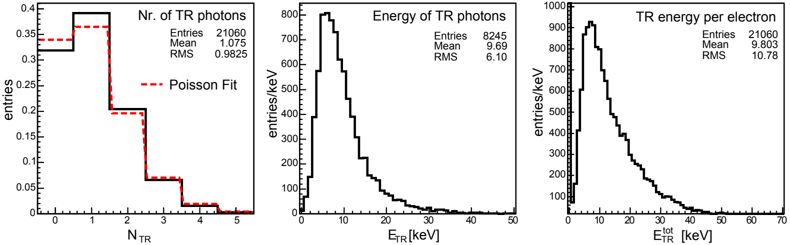
Example Event & Number of TR photons





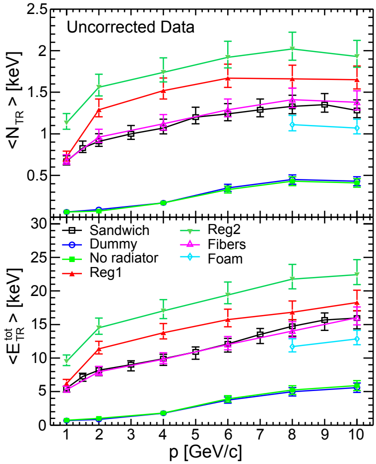


4 GeV/c, sandwich radiator



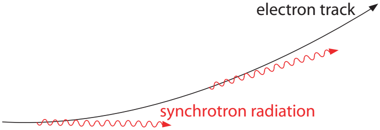
- N_{TR}: Number of TR photons detected per electron event.
- E_{TR}: Charge per TR photon.
- $E^{tot}_{TR} = E_{TR} \cdot N_{TR}$: Charge deposited by TR per electron.

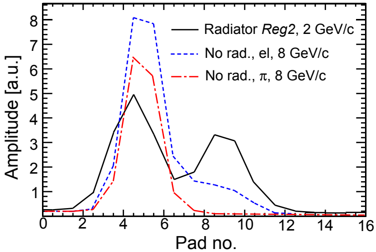
Mean Number of Photons & Mean Energy per Electron



- The regular radiators have the highest TR yield.
- We find some photons also if no radiator is present.
- Synchrotron radiation the reason for the momentum dependence?

Hints at Synchrotron Radiation (SR)





Bottom Plot:

- Distribution of the average signal amplitudes on the 16 pads.
- The charge deposit by TR photons is well separated from the ionization energy deposit by the beam particles.
- SR photons are emitted continuously along the curved track.

Synchrotron Radiation Theory

- Radiation which occurs when charged particles are accelerated in a curved path or orbit.
- A track with radius R, length L produces photons [1]:

$$\langle N_{SR}^{prod} \rangle \approx 10^{-2} \frac{L\gamma}{R} . \qquad (1)$$

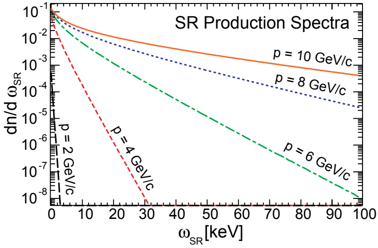
- The spectral distribution of the radiated photons:

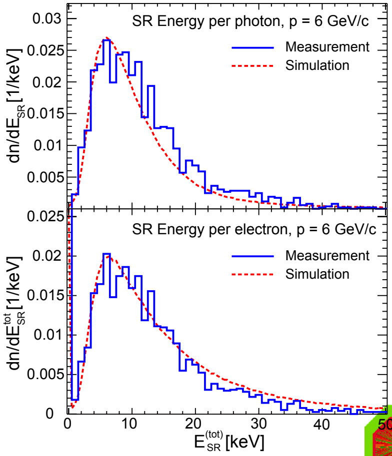
$$\frac{dn}{d\omega}\Big|_{SR} = \frac{\sqrt{3}}{2\pi} \alpha \frac{L\gamma}{R} \frac{1}{\omega_C} \int_{\omega_{SR}/\omega_C}^{\infty} K_{5/3}(\eta)\, d\eta . \qquad (2)$$

- The *critical energy*:

$$\omega_C = 1.5 \frac{\beta \hbar c}{R} \gamma^3. \qquad (3)$$

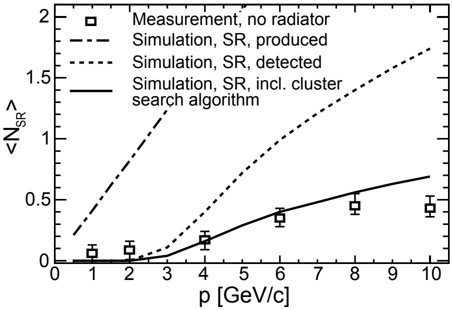
Synchrotron Radiation Simulation (1)





- Top: The spectral distribution of the radiated SR photons.
- Right: Measured and simulated spectra of the detected SR energy per photon E_{SR} and of the total SR energy E_{SR}^{tot}.

Synchrotron Radiation Simulation (2)



- Measured number of detected photons with no radiator as a function of the beam momentum together with simulations for synchrotron radiation.

Synchrotron Radiation Simulation (3)

Analysis Procedure:

- At up to 2 GeV/c there is no synchrotron radiation present.
  $\Rightarrow$ We can investigate spectra at these momenta!
- We can subtract the background when looking at mean values above 2 GeV/c.

Theory of regular foil transition radiators

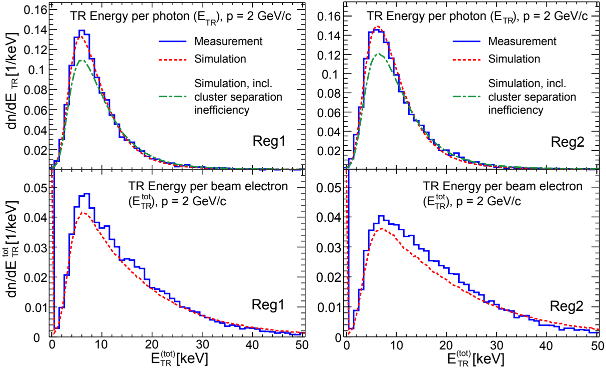
The differential energy spectrum [2] is given by

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

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.

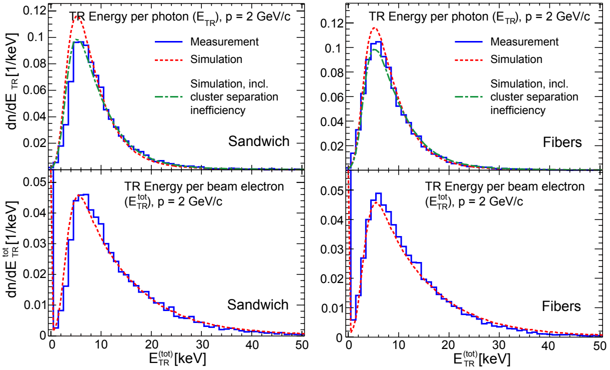
The Regular Radiators *Reg1* and *Reg2*



The TR energy spectra:

- When introducing the limited cluster separation efficiency in the simulations, the agreement is less good.

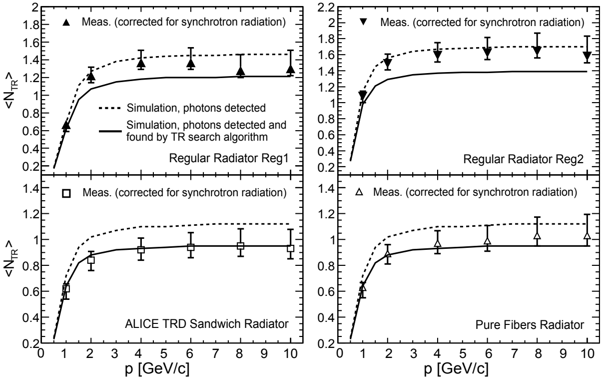
The Irregular *Sandwich* and *Fiber* Radiators



The TR energy spectra:

- Simulation parameters chosen to best fit measurements, including the cluster separation inefficiency.

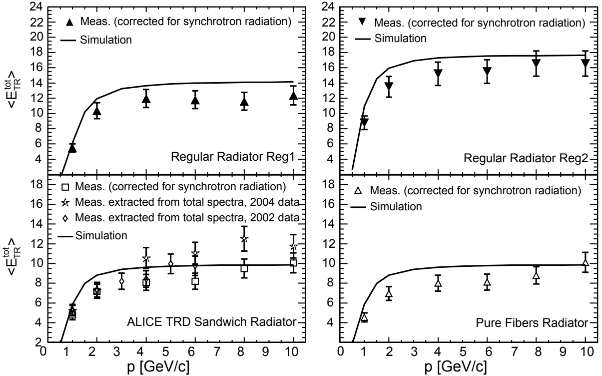
Comparison with Calculation 1



The mean number of TR photons:

- Data is corrected for synchrotron radiation.
- Good reproduction of the momentum dependence.

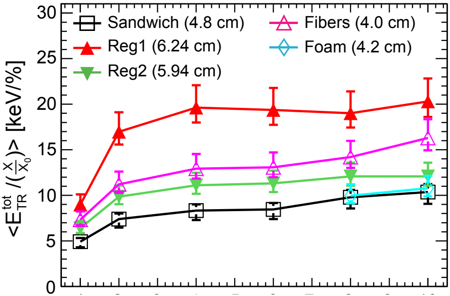
Comparison with Calculation 2



The mean total energy of TR:

- Data is corrected for synchrotron radiation.
- For the sandwich data extracted from total charge spectra with and without radiator is added.

Data scaled with X/X_0



Performance comparison:

- The thin regular foil radiator *Reg1* has highest TR yield per radiation length.
- The *sandwich* and the pure *foam* radiators perform similarly.

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 ...
- ... two regular foil radiators.
- We find a considerable background due to synchrotron radiation from the magnet used in the setup. It is well understood.
- The spectral shapes and momentum dependence of the TR shows nice agreement with theory.

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Open Questions

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- The presented data suggests an essentially flat TR yield above 2 to 3 GeV/c.
- The data from total energy loss spectra and the pion efficiency results suggest a slight increase in that region.

For Further Reading

- S. Agostinelli et al.
  ALICE TRD Technical Design Report.
  Nucl. Instr. Meth. Phys. Res. A 506, 2003, 250-303.
- 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.