Study on
a Synchrotron Radiation Detector in Space

M.W. Lee, G.N. Kim, D. Son
School of Physics and Energy Science, Kyungpook National University, Daegu 702-701, Korea
K. S. Kim, J. Yang
Department of Physics, Ewha Womans University, Seoul 120-750, Korea
S.C. Commichau, G.M. Viertel
ETH-Zurich, Laboratory for High Energy Physics, CH-8093 Zurich, Switzerland

DPF meeting, Hawaii

November 01, 2006

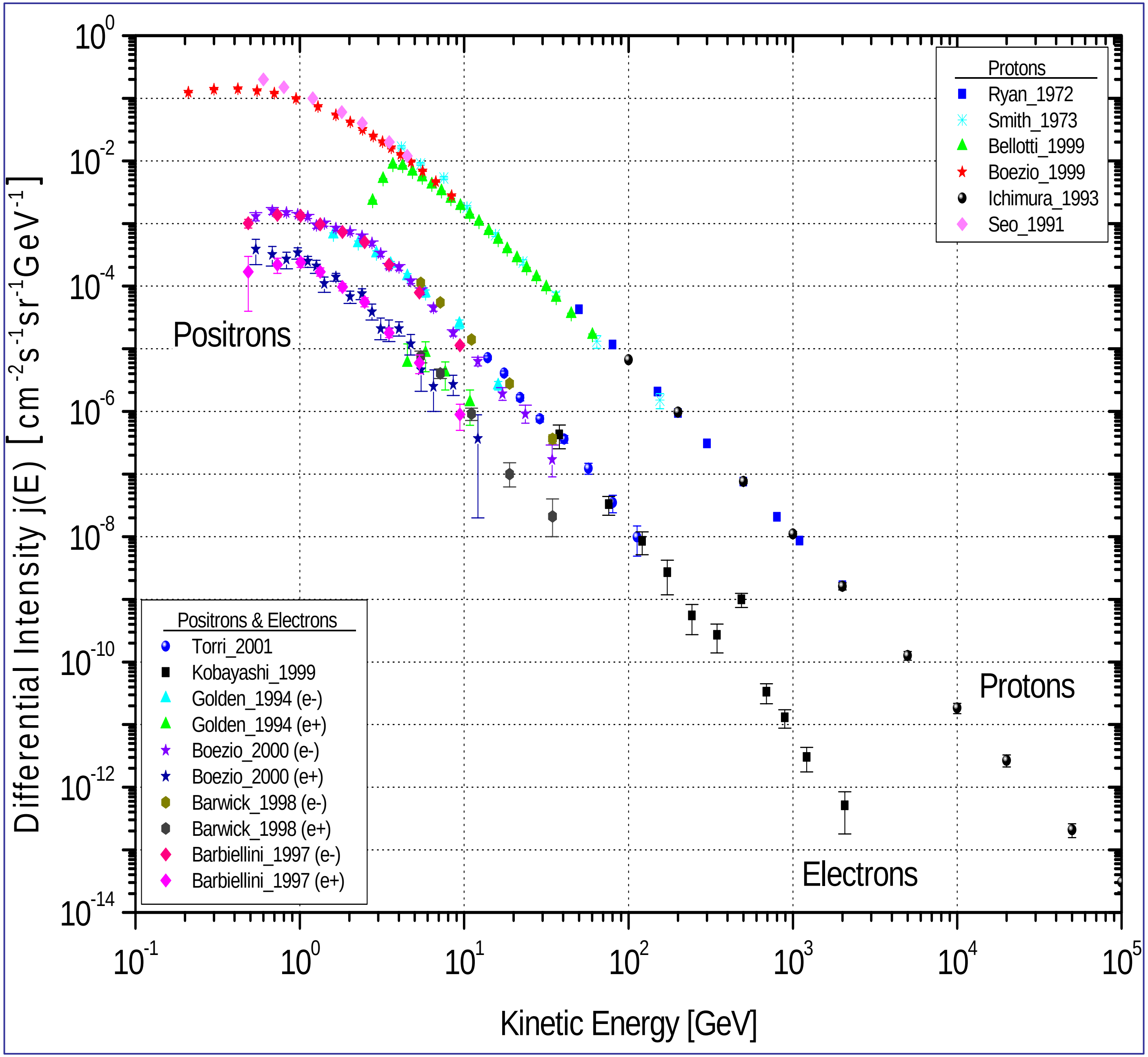
ABSTRACT

We studied the space-based synchrotron radiation detector (SRD) to detect high energy cosmic ray electrons and positrons up to several tens of TeV by detecting their emitted synchrotron radiation in the Earth's magnetic field.

In the combination of SRD and an electromagnetic calorimeter (ECAL), the SRD is heavily loaded by back scattered particles from the ECAL. The problem may be solved by timing if the SRD plane and the calorimeter position are 1.5 m apart and crystals with a short decay times are chosen. If the time-of-flight is larger than 10 ns and a SRD time resolution is a few ns, we can reject the background due to back scattered particles. For a stand-alone experiment in space, the configuration might be too heavy.

A better solution is to replace the ECAL by a Transition Radiation Detector (TRD) to reduce the back scattering and to lower the weight. In addition the TRD delivers a trigger for high energy electrons and positrons, suppressing to some extent the large proton background. The standard readout of the TRD by a gas chamber could be simplified by a scintillator crystal-PMT readout. Results from Monte Carlo simulations of this option are presented.

Electron, Positron and Proton Spectra



Current experimental techniques to measure the energy of cosmic ray electrons rely on calorimeters and transition radiation detectors which reach their limit at about 500 GeV.

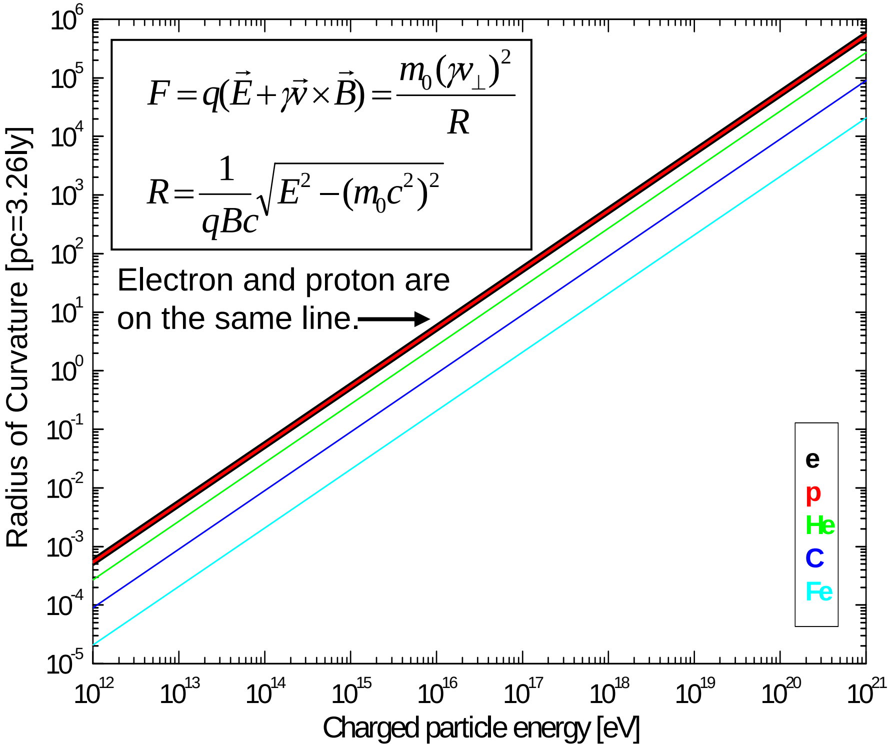
The proposed synchrotron radiation detector (SRD) is an attempt to extend the energy range of detected electrons towards several tens of TeV in presence of a large background of protons.

High Energy Electrons

- Electrons are the only component of the cosmic radiation for which there is direct evidence (synchrotron X-rays) of acceleration in supernovae.
- The transported electrons through the Galaxy are subject to synchrotron and inverse Compton energy losses that limit the age of high-energy electrons.
- The transport through the Galaxy of cosmic rays, including electrons, is understood to be a diffuse process. The diffusion coefficient determines the lifetime of particles.

The curvature of the charged particles in a galactic magnetic field without considering other interactions.

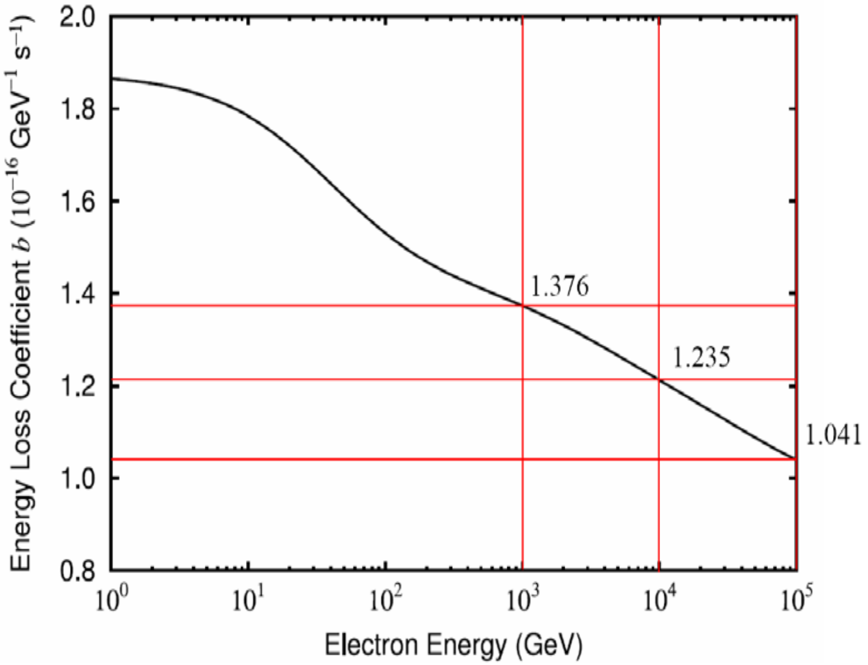
Standard Diffusion rate $-\frac{dE}{dt} = bE^2$ $\xrightarrow{\text{Integration}}$ **Lifetime** $T = \frac{1}{bE}$



$$F = q(\vec{E} + \gamma\vec{v}\times\vec{B}) = \frac{m_0(\gamma v_\perp)^2}{R}$$

$$R = \frac{1}{qBc}\sqrt{E^2 - (m_0c^2)^2}$$

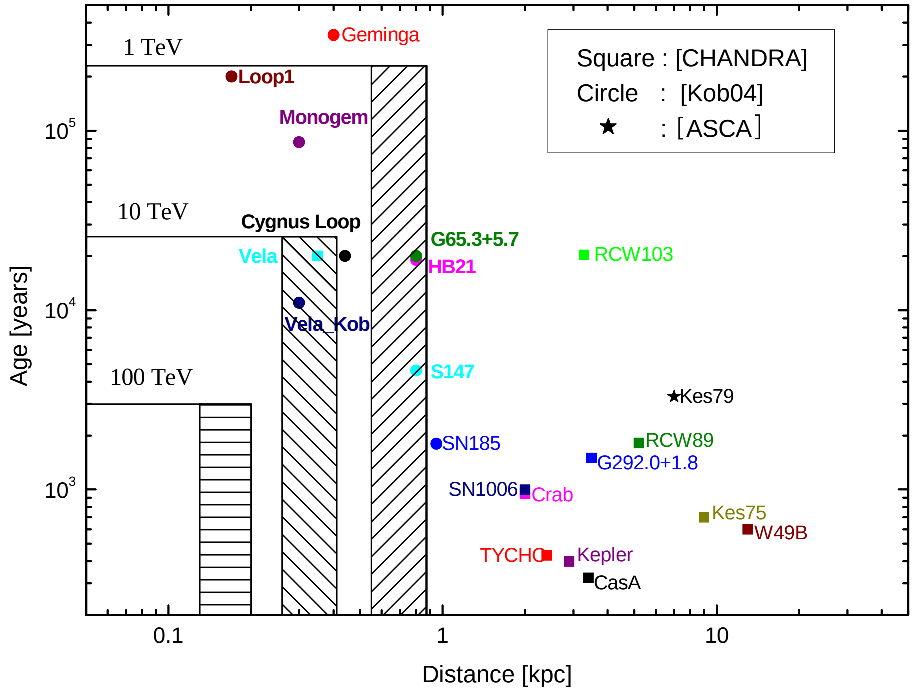
Electron and proton are on the same line.



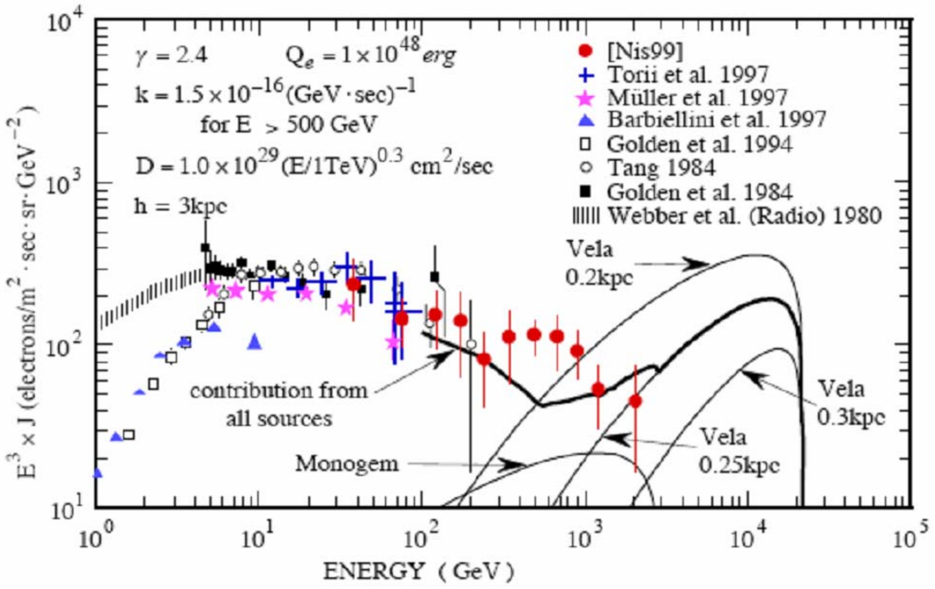
Energy loss coefficient *b* of cosmic ray electrons in the Galaxy.

High Energy Electrons Source

- The electron lifetime calculated from the diffusion coefficient will depend upon the photon density and magnetic field in the path. Electrons above 1 TeV energy will have lifetimes of less than 2.3*10^5 years.
- High energy electrons that reach the Earth will come from a region smaller than that from which low-energy electrons or hadrons reach the Earth [Left figure].
- The precise measurement of the high energy electron spectrum would constrain the cosmic-ray diffusion coefficient [Right figure].



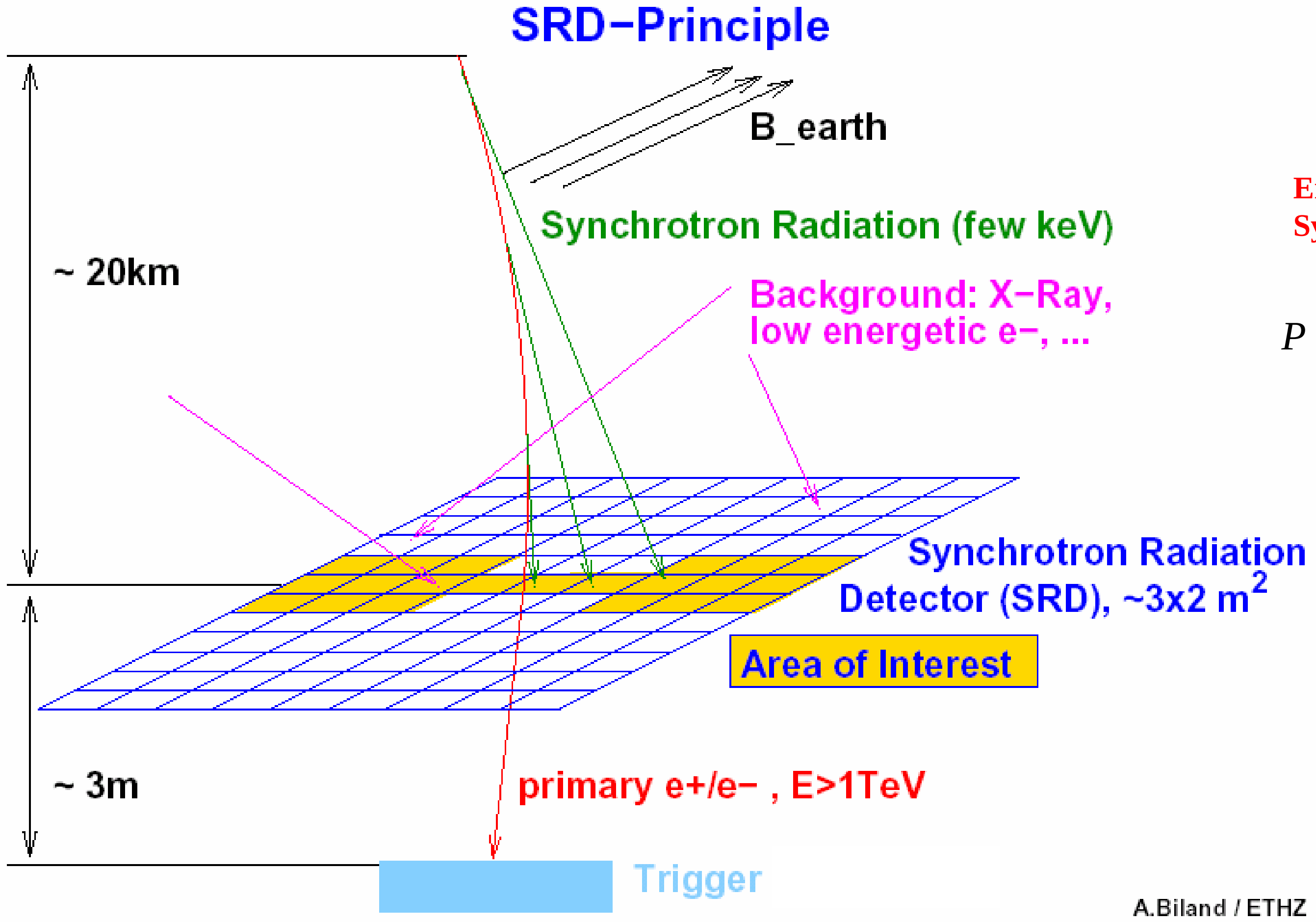
A cross-correlation of distance and age of several nearby SNRs and pulsars with the diffuse distance and the lifetime of the accelerated electrons.



The calculated and observed energy spectrum of cosmic ray electrons.
Qe is the assumed energy output in electrons beyond 1 GeV by a Supernova with a supernova rate of one every 30 years.

Synchrotron Radiation Detector (SRD)

- In space the high energy charged particles emit the synchrotron radiation photons along their path bent in the Earth’s magnetic field.
- When these photons are detected in a detector, photons will be observed on either side of the trajectory depending on the sign of the particle’s charge.
- Since the synchrotron light energy spectrum depends strongly on the primary particle’s energy, the mean energy of the detected photons gives a rough estimate of the primary momentum.

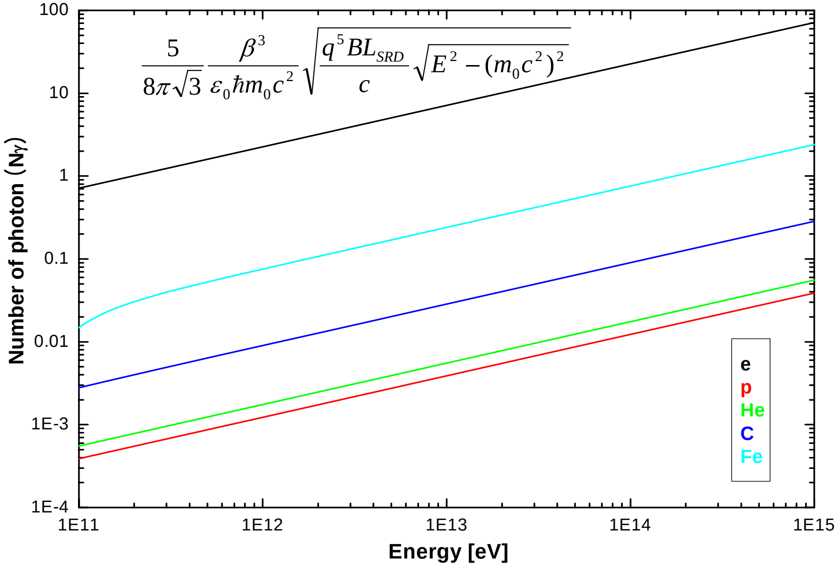


Energy Loss by Synchrotron Radiation

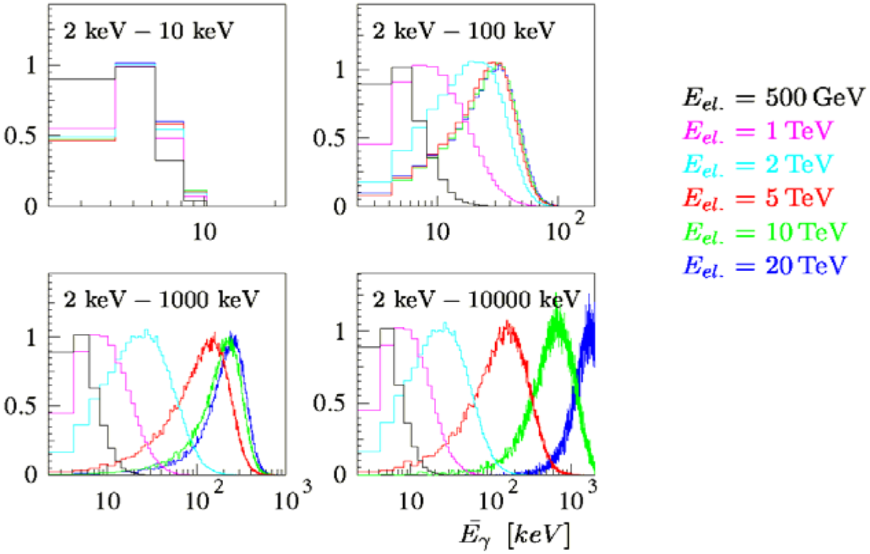
$$P = \frac{1}{4\pi\varepsilon_0}\frac{2}{3}\left(\frac{q^2a^2}{c^3}\right)\gamma^4$$

A.Biland / ETHZ

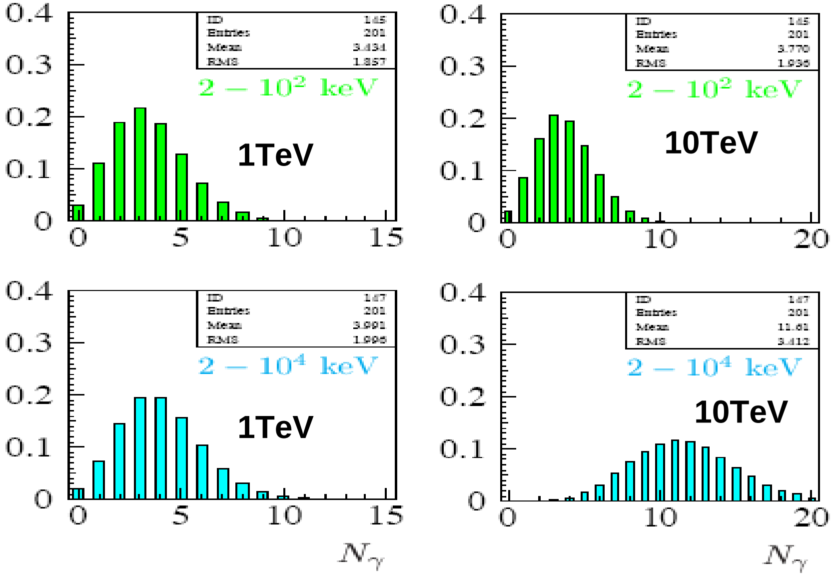
SRD Simulations (M. Kraeber / ETHZ / 2002)



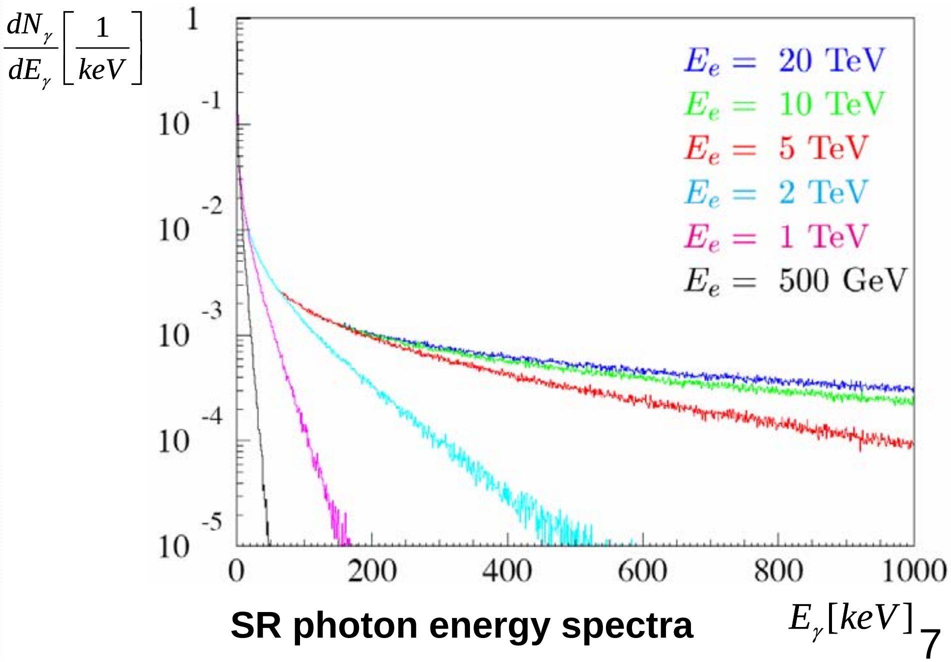
Number of SR photons



SR photon energy distribution

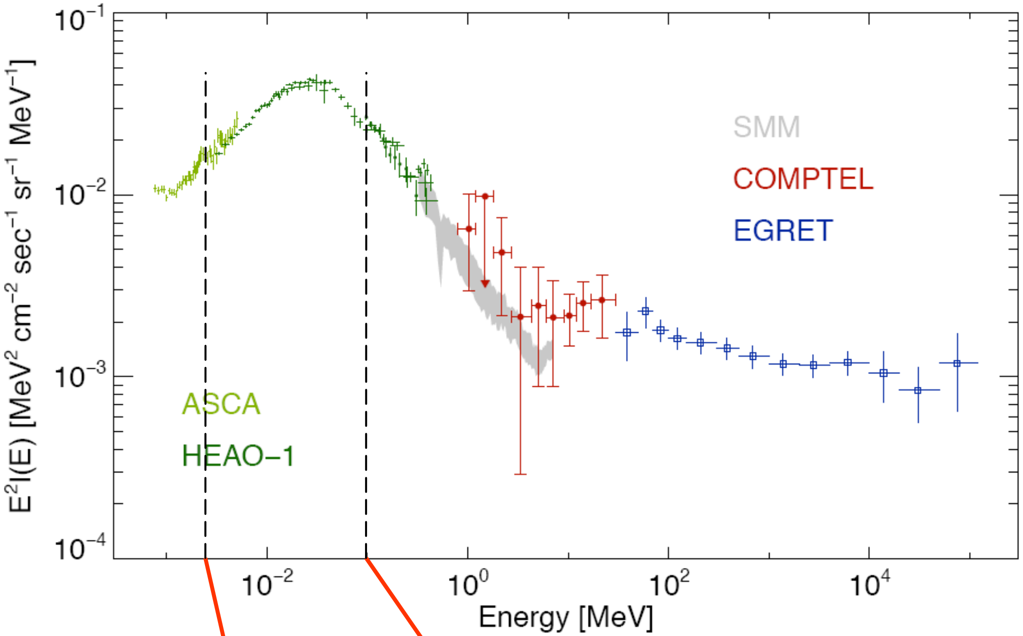


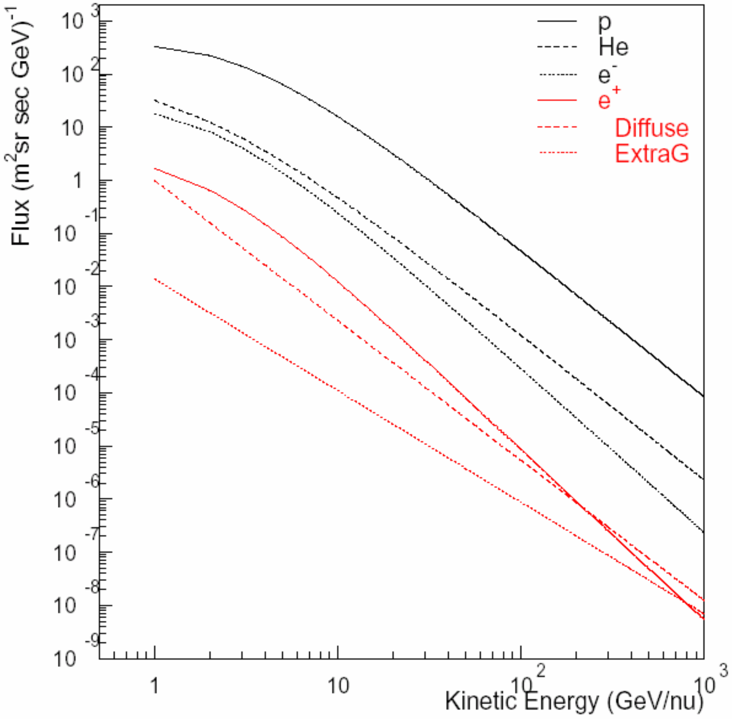
The detected number of photons by the SRD for various electron energies and detection windows

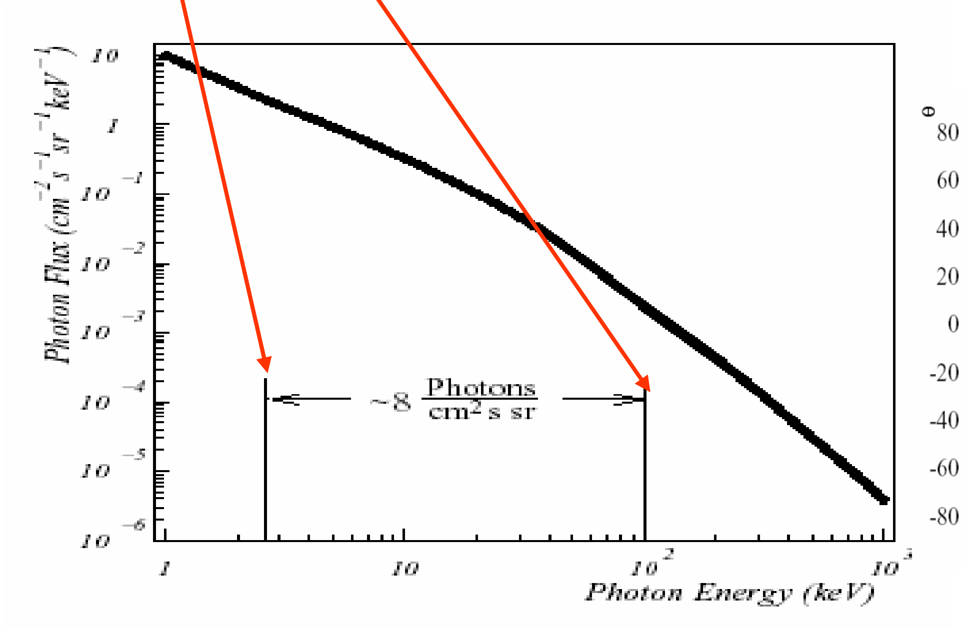


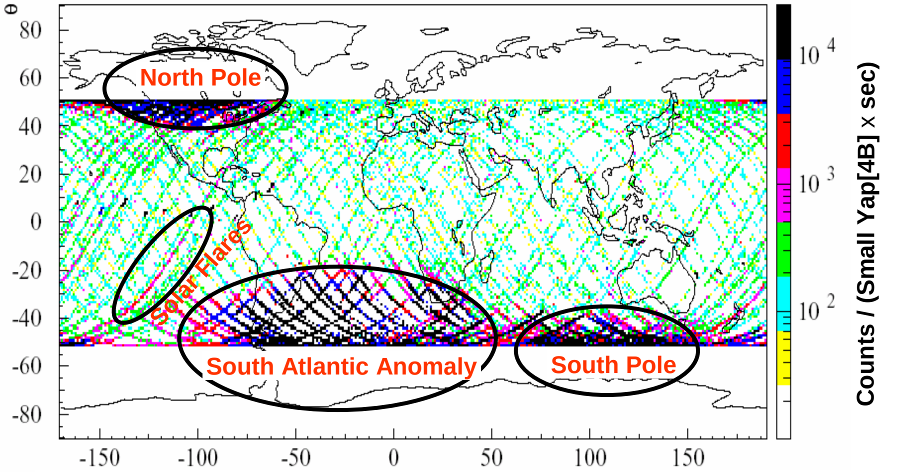
SR photon energy spectra

SRD Background



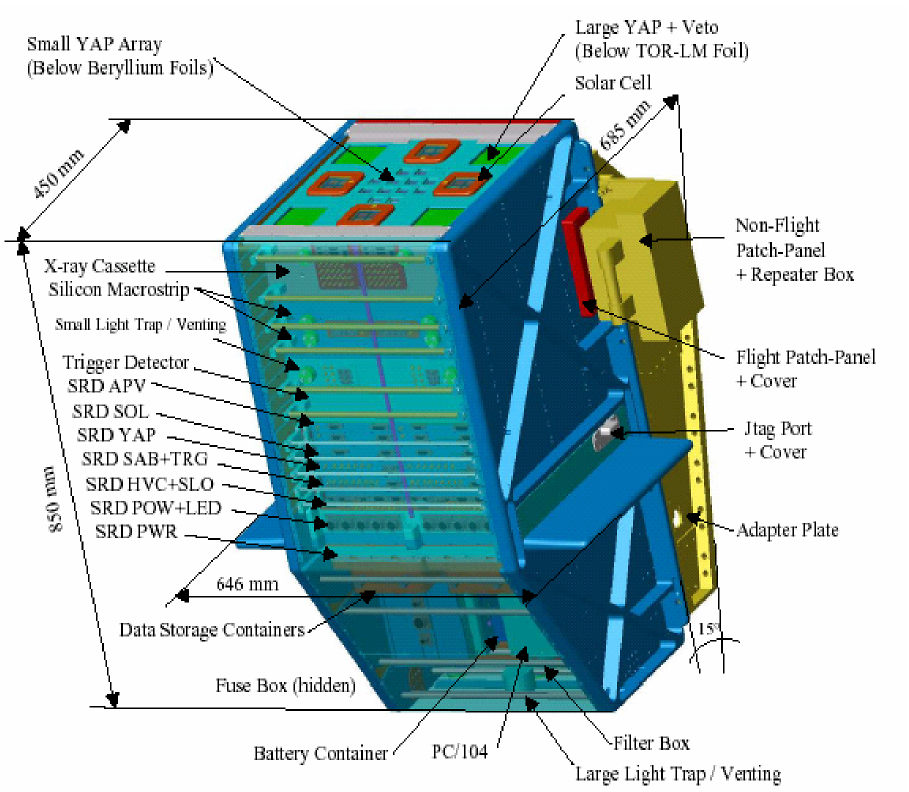




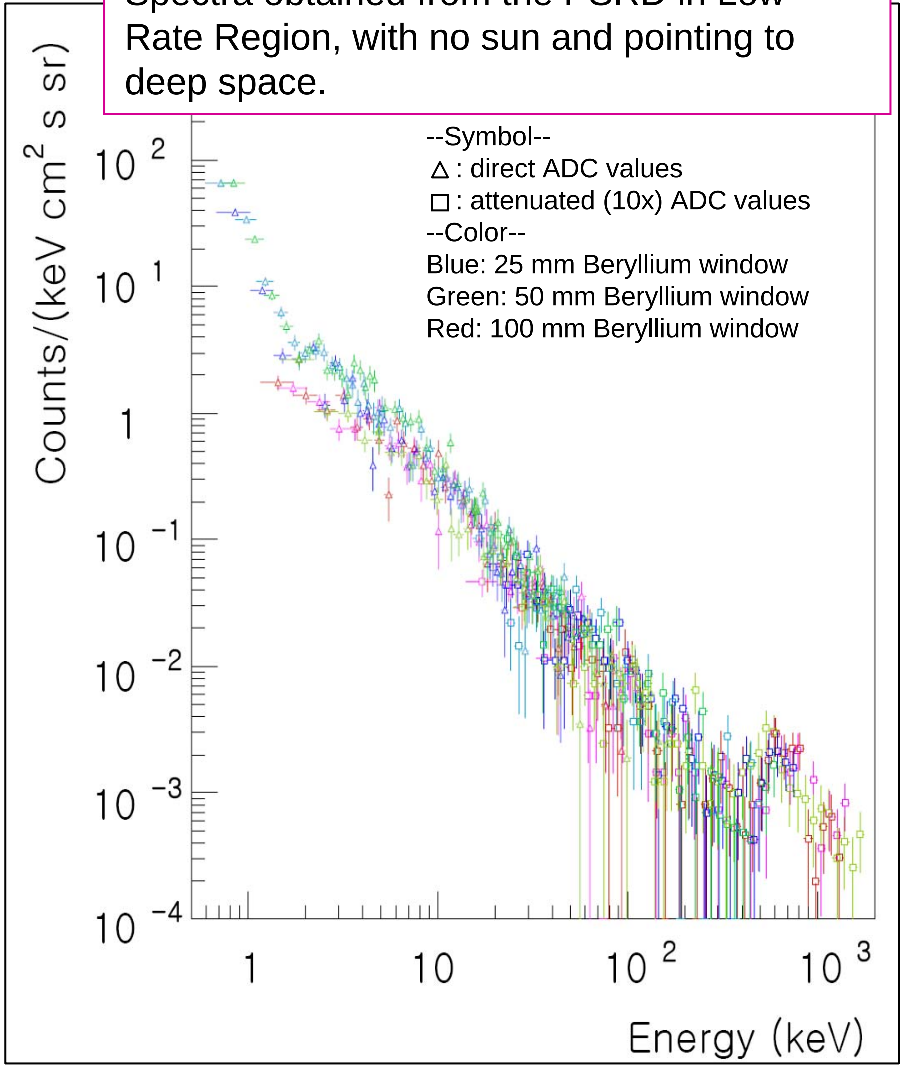


PSRD (Small YAP): All Attitudes, No Direct Sun

Prototype SRD (PSRD) Experiment



Technical Publication: H. Anderhub et al., NIM A491 (2002) 98-112

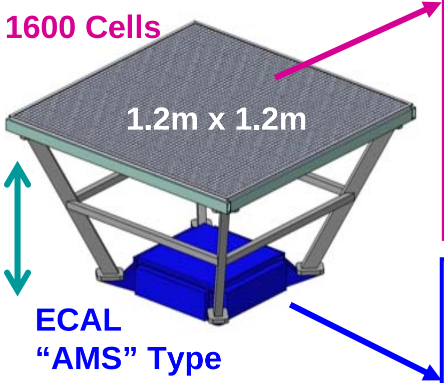


Spectra obtained from the PSRD in Low Rate Region, with no sun and pointing to deep space.

Results from the PSRD Mission

- Measurement of the background: Outside the polar regions, the South Atlantic Anomaly and during years of low sun activities: The SRD concept can be realized.
- APV readout for space application is proven.
- Space qualified detector components

Stand-Alone SRD with ECAL Trigger Device

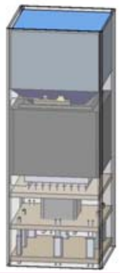


SRD
1600 Cells

ECAL
“AMS” Type

Distance SRD- ECAL:
150 cm

Single Cell

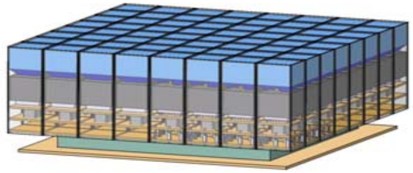


Crystal (3x3x3 cm^3)

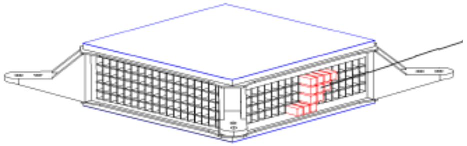
PMT (Hamamatsu R5900)

PreAmp & Bias

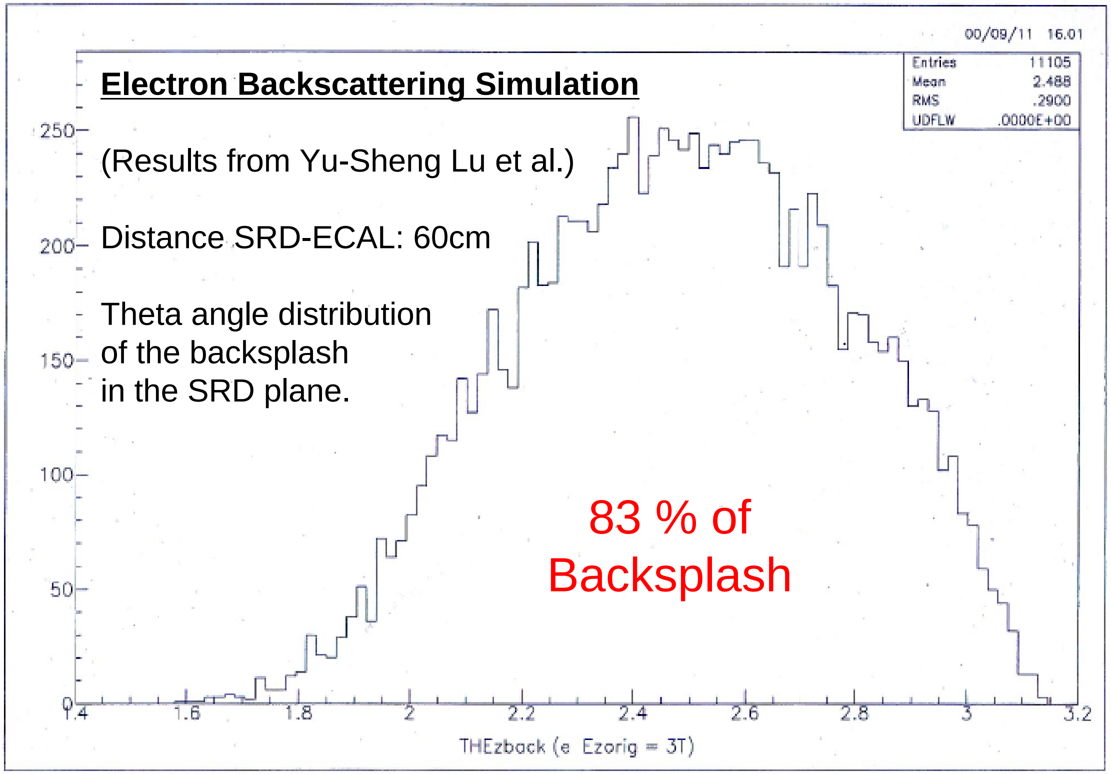
Subsegment 64 Cells



AMS-02 electromagnetic calorimeter



The three dimensional sampling electromagnetic calorimeter consists of alternating layers of scintillating fibers and lead absorbers with in total 16.5 radiation lengths.



Electron Backscattering Simulation

(Results from Yu-Sheng Lu et al.)

Distance SRD-ECAL: 60cm

Theta angle distribution
of the backsplash
in the SRD plane.

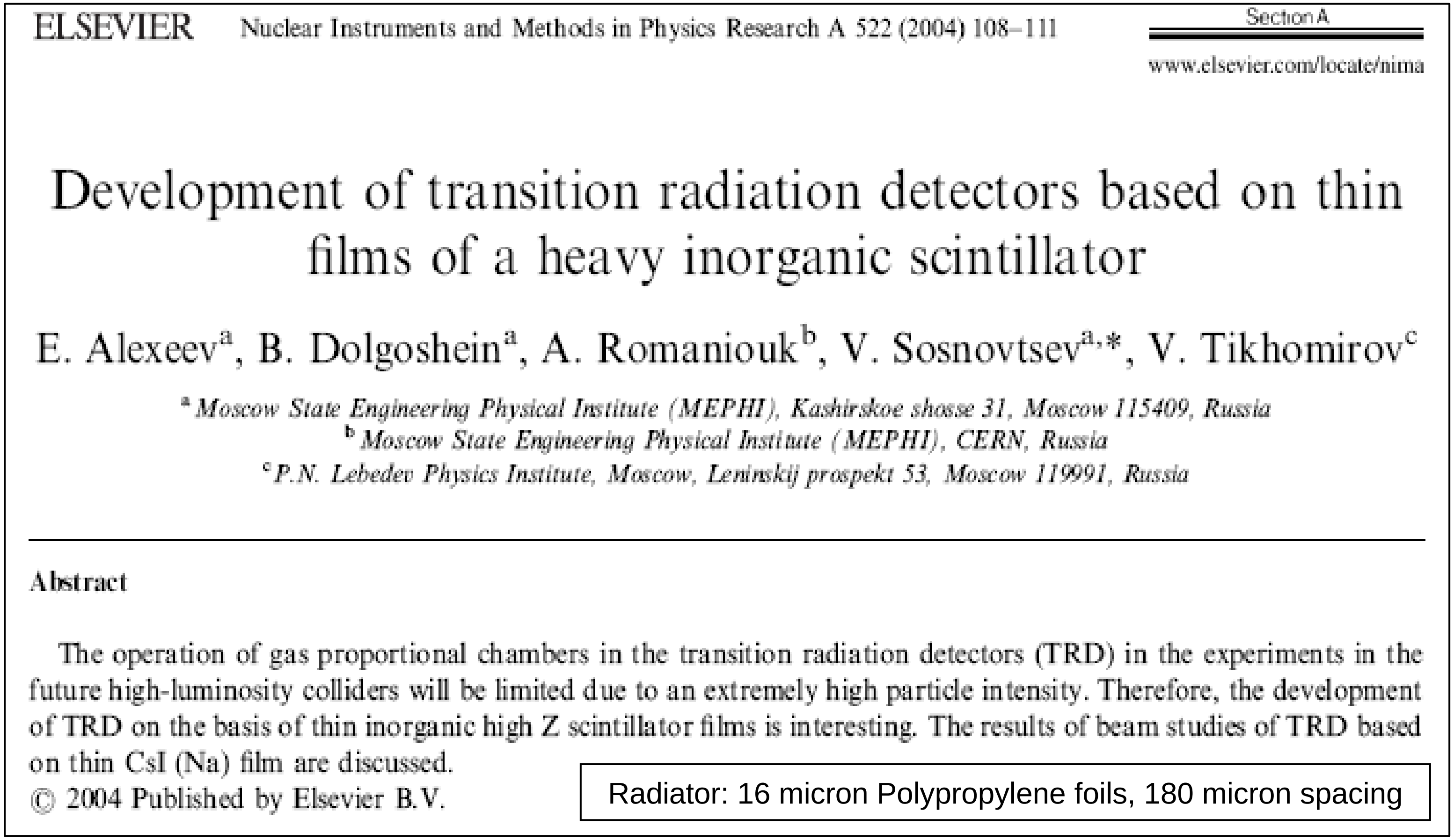
83 % of
Backsplash

SRD is heavily loaded by back scattered particles from ECAL.
Problem may be solved by timing if the SRD plane and the calorimeter position are at least 1.5 m apart.
(The time of flight is larger than 10 ns and a SRD time resolution of a few ns rejects the background.)

Solution: replacing the ECAL by a TRD (low back scattering and low weight)
In addition the TRD delivers a proton suppression.

The readout of a standard TRD by a gas chamber could be simplified by a scintillator crystal-PMT readout.

Transition Radiation Detector (TRD) with Scintillator Readout



ELSEVIER Nuclear Instruments and Methods in Physics Research A 522 (2004) 108–111

Section A

www.elsevier.com/locate/nima

Development of transition radiation detectors based on thin films of a heavy inorganic scintillator

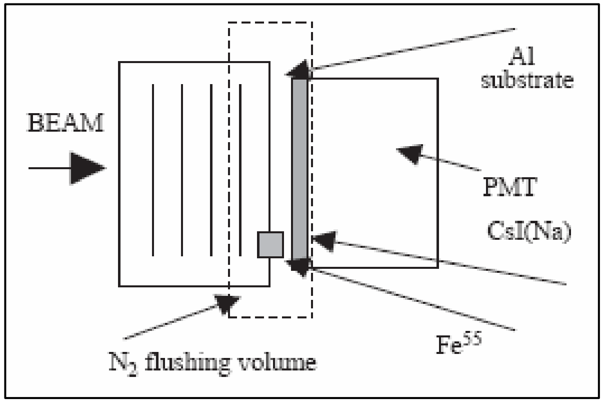
E. Alexeev[a], B. Dolgoshein[a], A. Romaniouk[b], V. Sosnovtsev[a,*], V. Tikhomirov[c]

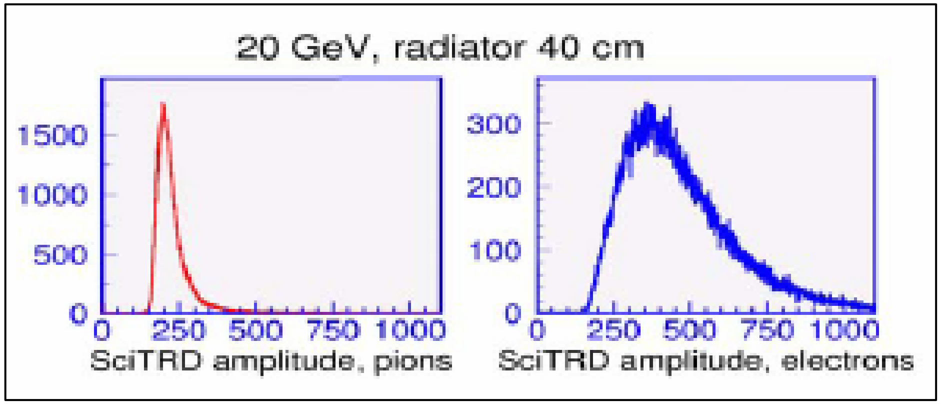
[a] *Moscow State Engineering Physical Institute (MEPHI), Kashirskoe shosse 31, Moscow 115409, Russia*
[b] *Moscow State Engineering Physical Institute (MEPHI), CERN, Russia*
[c] *P.N. Lebedev Physics Institute, Moscow, Leninskij prospekt 53, Moscow 119991, Russia*

Abstract

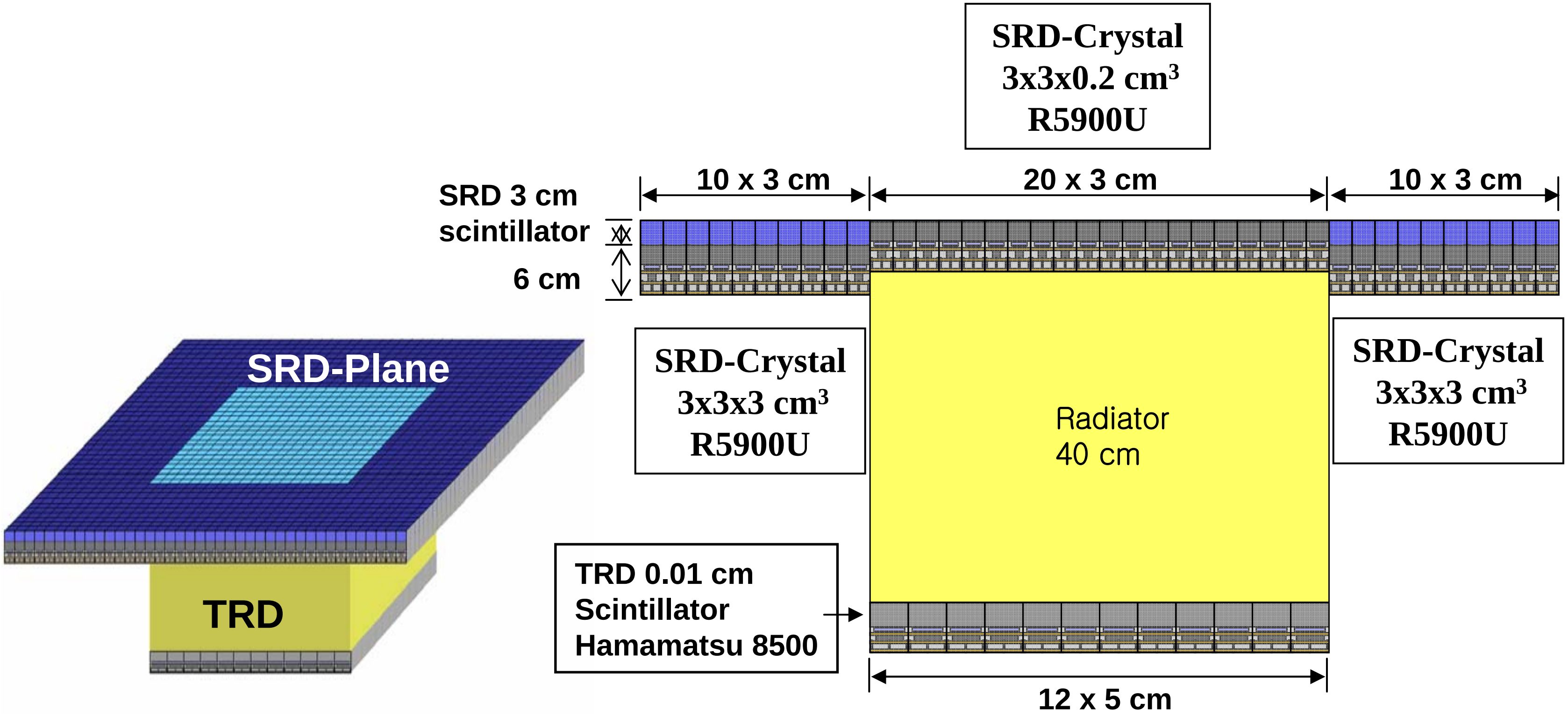
The operation of gas proportional chambers in the transition radiation detectors (TRD) in the experiments in the future high-luminosity colliders will be limited due to an extremely high particle intensity. Therefore, the development of TRD on the basis of thin inorganic high Z scintillator films is interesting. The results of beam studies of TRD based on thin CsI (Na) film are discussed.

Radiator: 16 micron Polypropylene foils, 180 micron spacing





Design Concept: Stand-Alone SRD with TRD



SRD-Crystal
3x3x0.2 cm^3
R5900U

SRD 3 cm
scintillator

6 cm

10 x 3 cm

20 x 3 cm

10 x 3 cm

SRD-Plane

TRD

SRD-Crystal
3x3x3 cm^3
R5900U

Radiator
40 cm

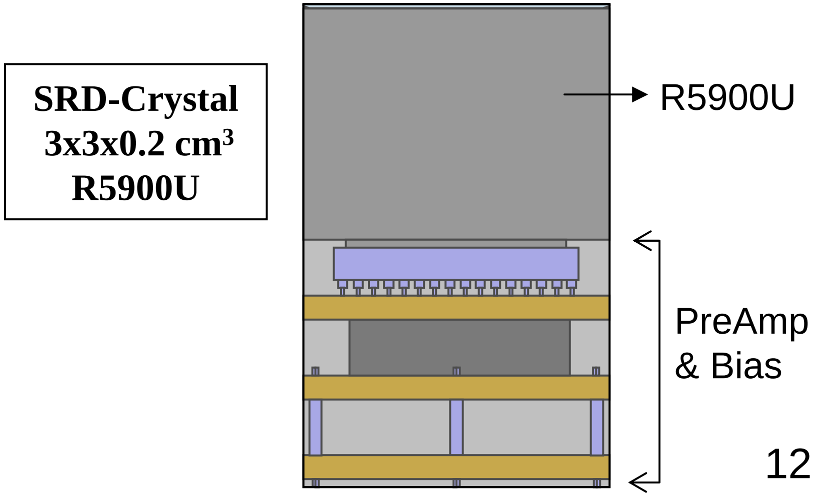
SRD-Crystal
3x3x3 cm^3
R5900U

TRD 0.01 cm
Scintillator
Hamamatsu 8500

12 x 5 cm

Material in front of the TRD

Item	Material	Thickness [mm]	Radiation Length [%]
Crystal	$LaBr_3$	2	10
PMT	R5900U	30	5
PCB	G10	5	3
Infrastructure	Mixed	2	2
Total			**20**



SRD-Crystal
3x3x0.2 cm^3
R5900U

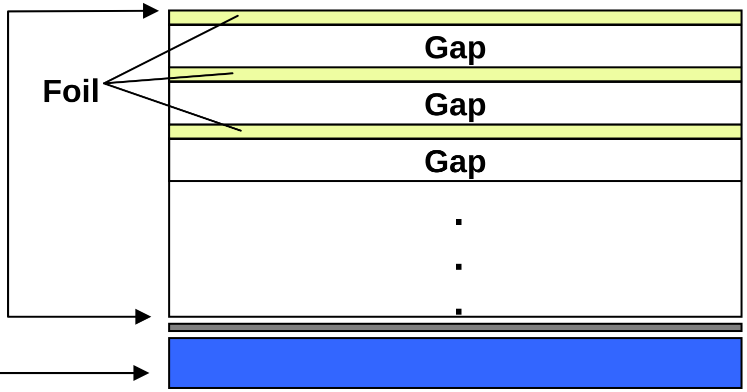
R5900U

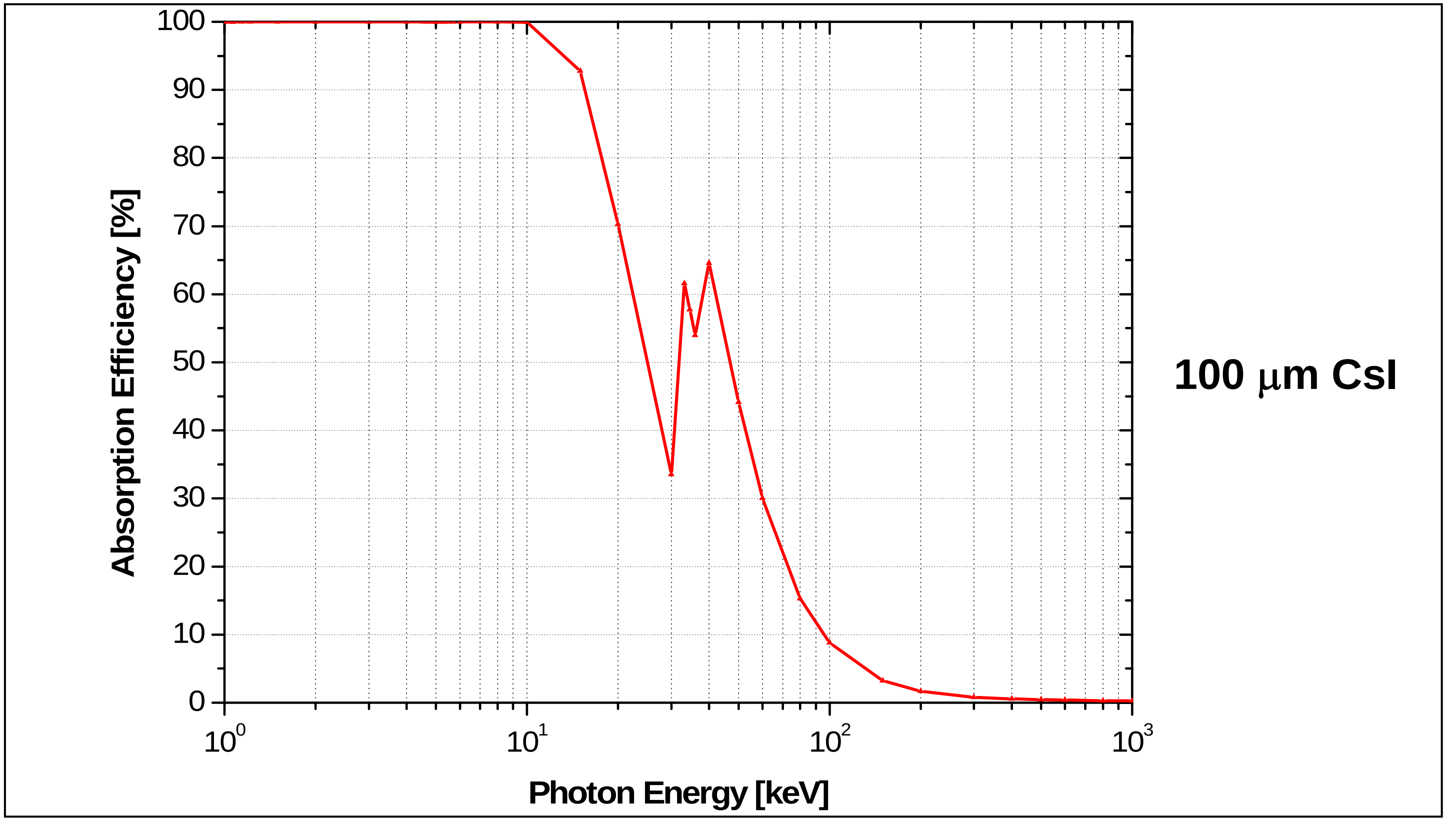
PreAmp
& Bias

TRD Monte Carlo Simulations: Set-up Geometry

Geometry of the prototype:

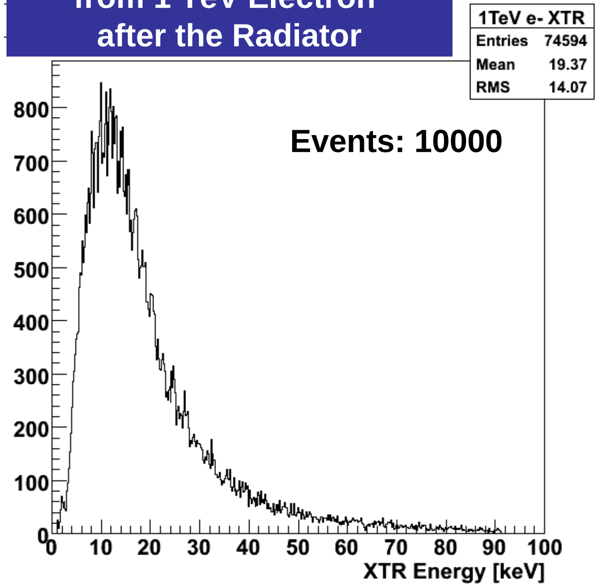
- TRD Radiator (Single layer)
  - Size: 15 x 15 cm^2
  - Radiator thickness in beam direction: 40 cm
  - Foil: Polypropylene (0.91 g/cm^3, 0.016 mm width)
  - Gap: Vacuum (0.180 mm width)
  - Number of gap and foil configurations: 2040
- 12 μm Aluminum plate
- TRD Readout scintillator
  - Material: CsI
  - Scintillator width in beam direction: 100 μm





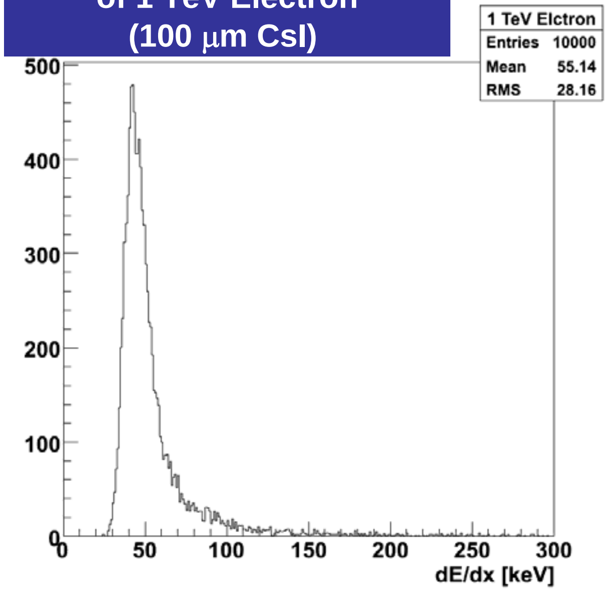
TRD Monte Carlo Simulations

X-ray Energy from 1 TeV Electron after the Radiator

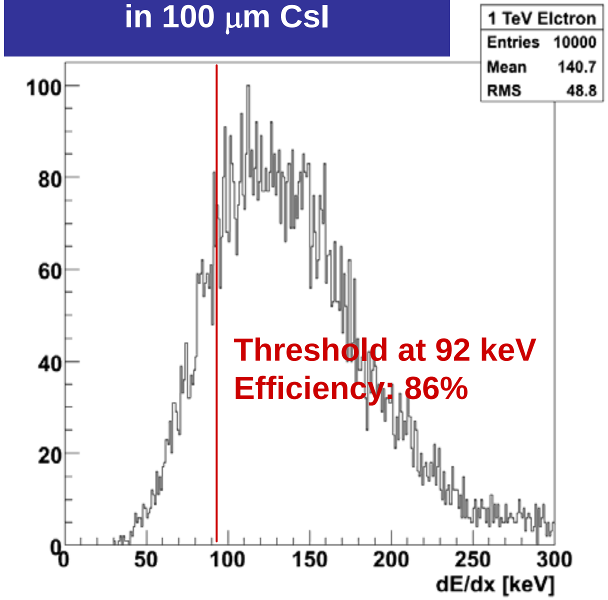


Events: 10000

Ionization Energy Loss of 1 TeV Electron (100 μm CsI)

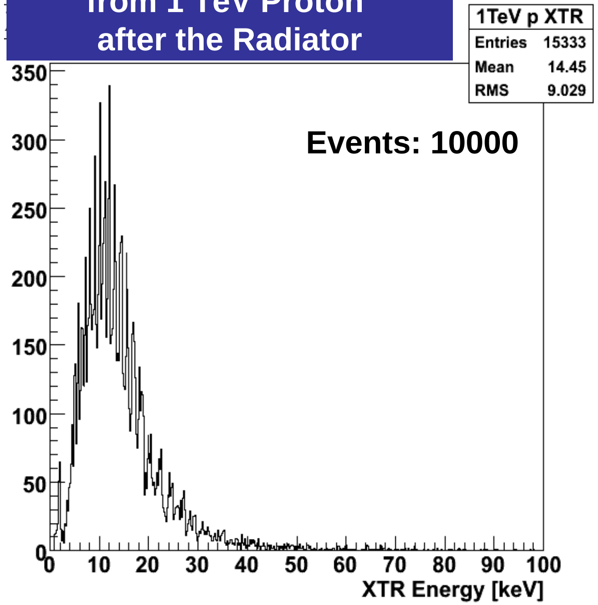


Deposited Energy in 100 μm CsI



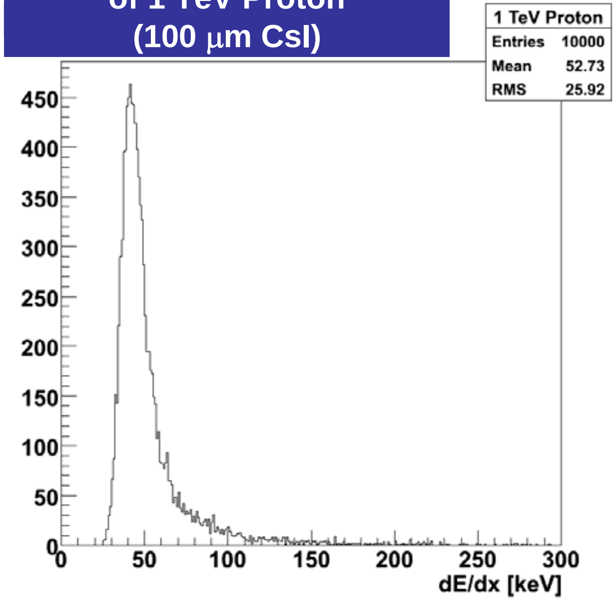
Threshold at 92 keV
Efficiency: 86%

X-ray Energy from 1 TeV Proton after the Radiator

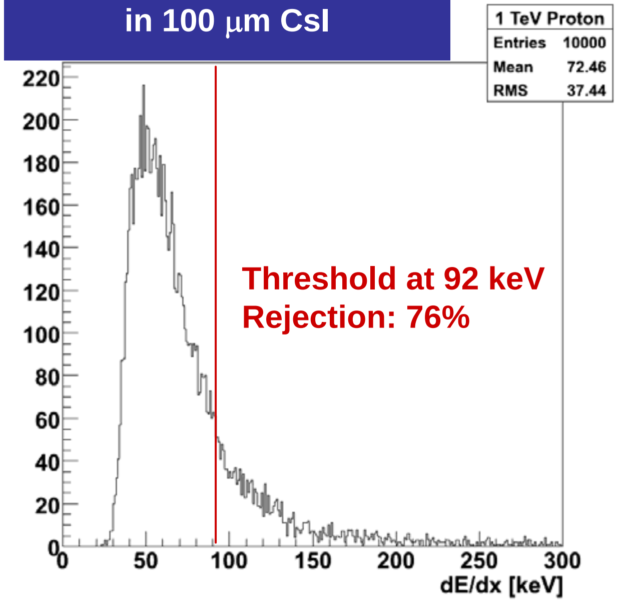


Events: 10000

Ionization Energy Loss of 1 TeV Proton (100 μm CsI)



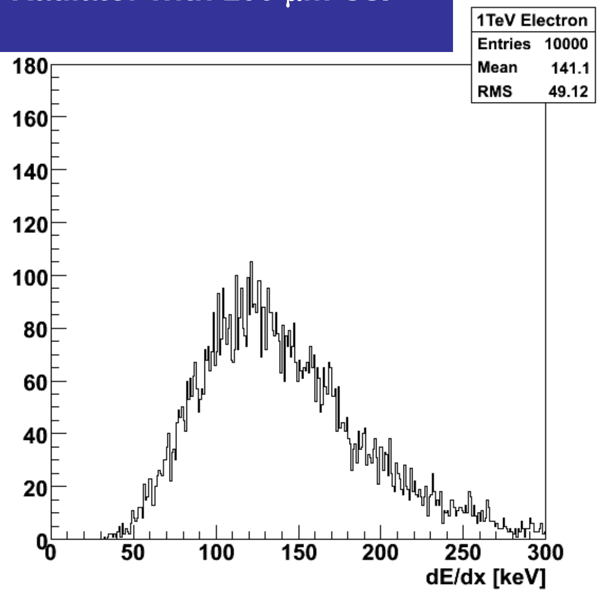
Deposited Energy in 100 μm CsI

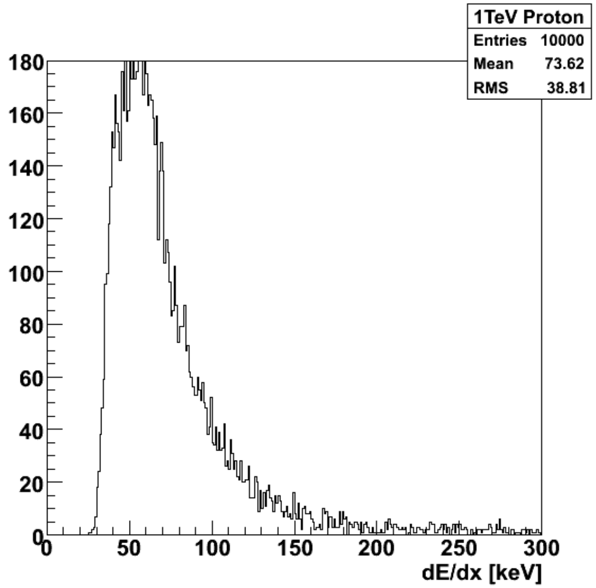


Threshold at 92 keV
Rejection: 76%

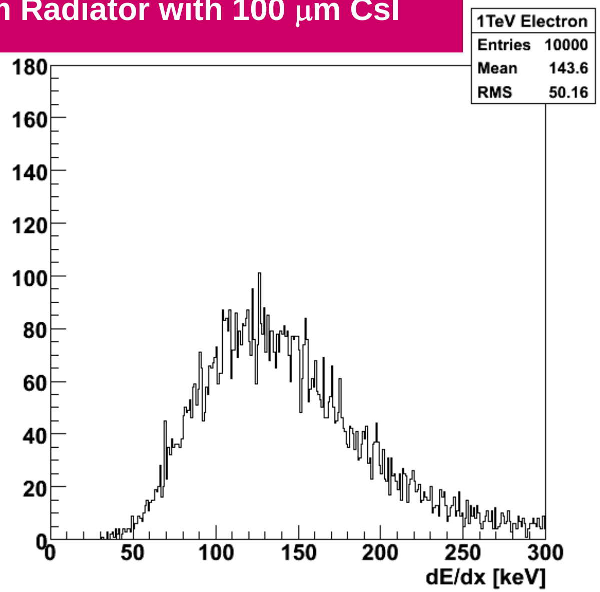
Impact of Material in front of the TRD

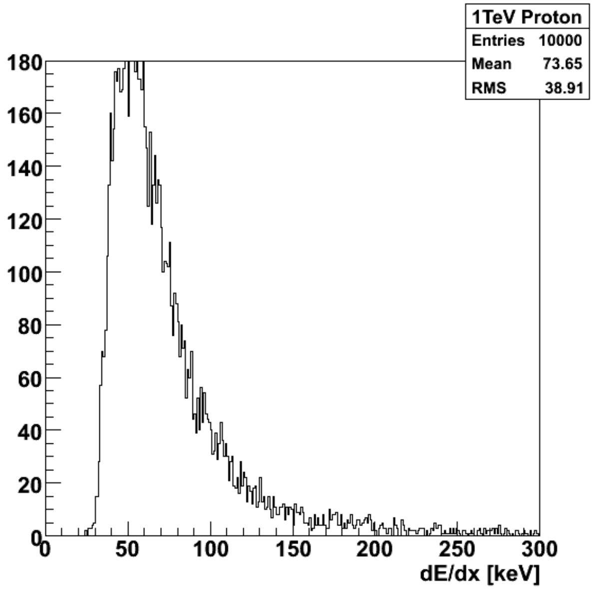
40 cm Radiator with 100 μm CsI





20% of a radiation length in front of 40 cm Radiator with 100 μm CsI





CONCLUSION

- From the simulations we conclude that a TRD as a trigger device fulfills its tasks.
- A prototype TRD will be put in a test beam.