Separating p's, π's, and K's
Summary of TRD session

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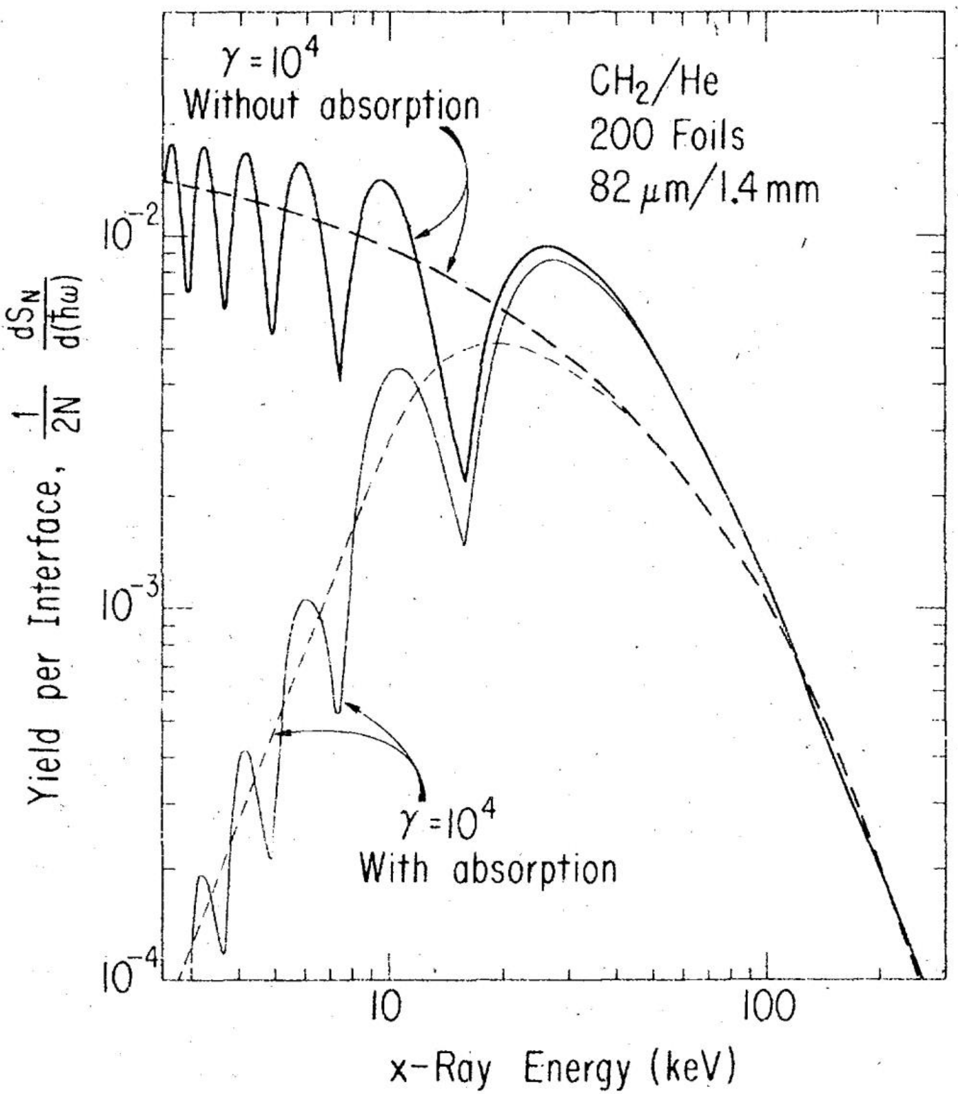
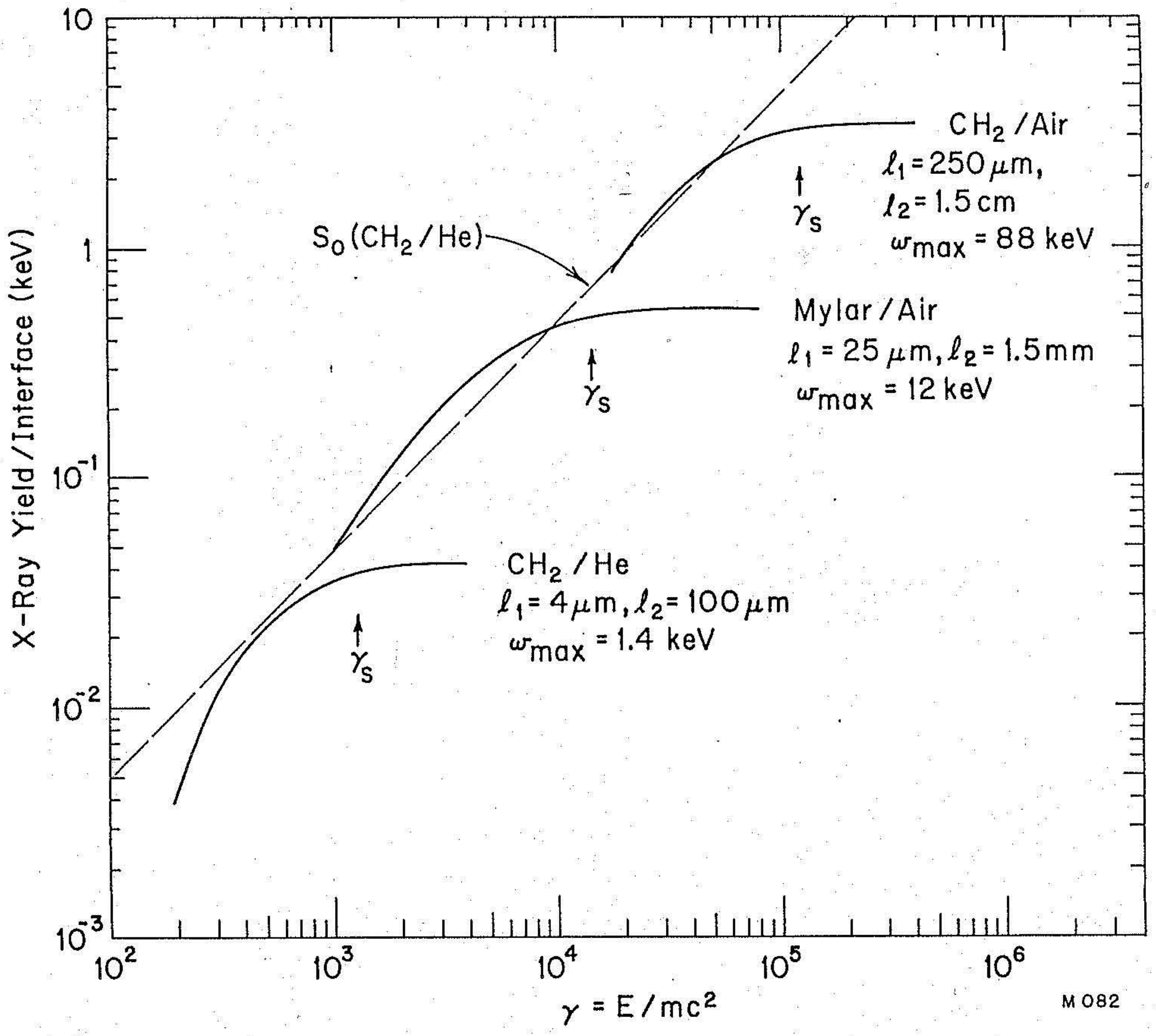
CERN, Oct. 2, 2015


$\gamma = 10^4$
Without absorption
CH_2/He
200 Foils
82 μm/1.4 mm
$\gamma = 10^4$
With absorption
Yield per Interface, $\frac{1}{2N} \frac{dS_N}{d(\hbar\omega)}$
10^{-2}
10^{-3}
10^{-4}
10
100
x-Ray Energy (keV)


CH_2/Air
$\ell_1 = 250\,\mu m$,
$\ell_2 = 1.5$ cm
$\omega_{max} = 88$ keV
γ_s
$S_0(CH_2/He)$
Mylar/Air
$\ell_1 = 25\,\mu m, \ell_2 = 1.5$ mm
$\omega_{max} = 12$ keV
γ_s
CH_2/He
$\ell_1 = 4\,\mu m, \ell_2 = 100\,\mu m$
$\omega_{max} = 1.4$ keV
γ_s
X-Ray Yield/Interface (keV)
10
1
10^{-1}
10^{-2}
10^{-3}
10^2
10^3
10^4
10^5
10^6
$\gamma = E/mc^2$
M082

Design criteria for tuning a high energy TRD:

- X-rays are emitted at energies below $\gamma\omega_1$.
- Highest frequency maximum in interference pattern occurs near

$$\omega_{max} = l_1\omega_1^2/2\pi c$$

- Total TR yield ~ γ up to saturation energy

$$\gamma_s = 0.6\ \omega_1(l_1 l_2)^{1/2}/c$$

- **Questions:**

Emphasize high frequencies where dependence on particle energy is highest, or

Emphasize lower energies where K-edge absorption is not such a large factor?

Use multiple detectors tuned to individual particle species, or just one configuration?

What is the most interesting TR energy range?

The largest dependence on the gamma factor is in the area close to the cut-off frequency.

Cut-off frequency

$$\omega_c=\omega_p{}^*\gamma$$

90% of energy in the range of

$$0.1\omega_c < \omega < \omega_c$$

Low number of photons can be compensated by the length of the detector. Radiators with low ω_p are preferable!

$$\gamma_{sat} = 0.6\ \omega_p\sqrt{l_1 l_2}/c.$$

At low ω_p we can push γ_{sat} up using l_1 nd l_2

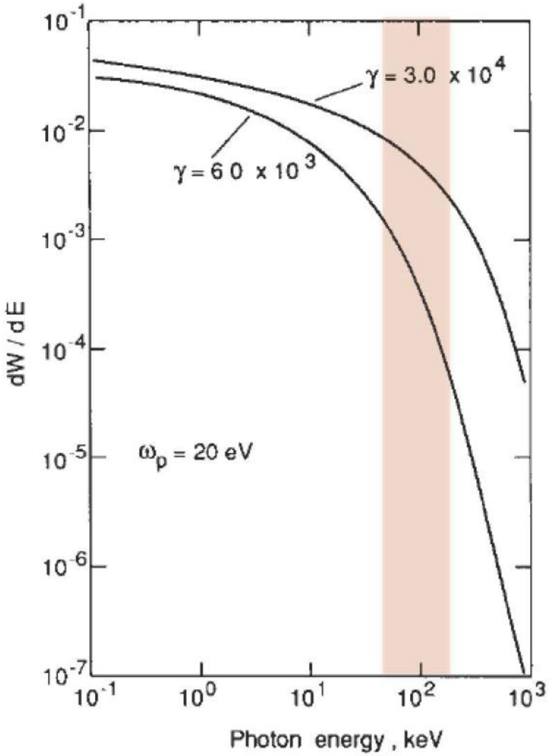
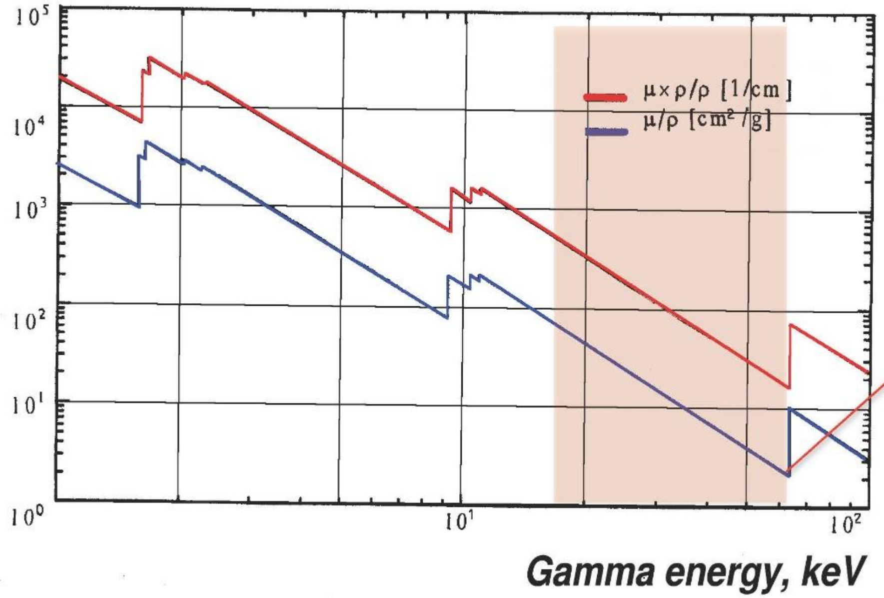
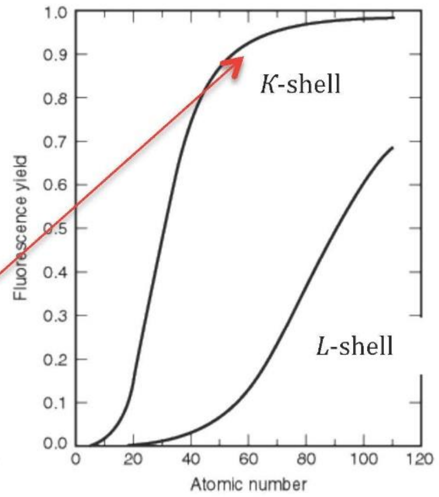


Fig. 3. The radiated TR spectrum from a polyethylene surface.

Why 20-60 keV energy range?





LSO: $Lu_2SiO_5:Ce^{3+}$:

- •Density -7,41 г/см3
- •Effective Z 66
- •Light yield 30 photons=keV
- •Fast response 40 ns
- •Emission spectrum with lmax 440 nm
- •Typical dE/dx loss in10 μm of LSO is 10 keV

Thin Layer of plastic (100 – 400 μm) with $Lu_2SiO_5:Ce^{3+}$ powder (granules 0.3-0.8 μm), LSO thickness 4.0 - 21.0 mg/cm^2, LSO

Separating electrons and pions
SLAC, 1973

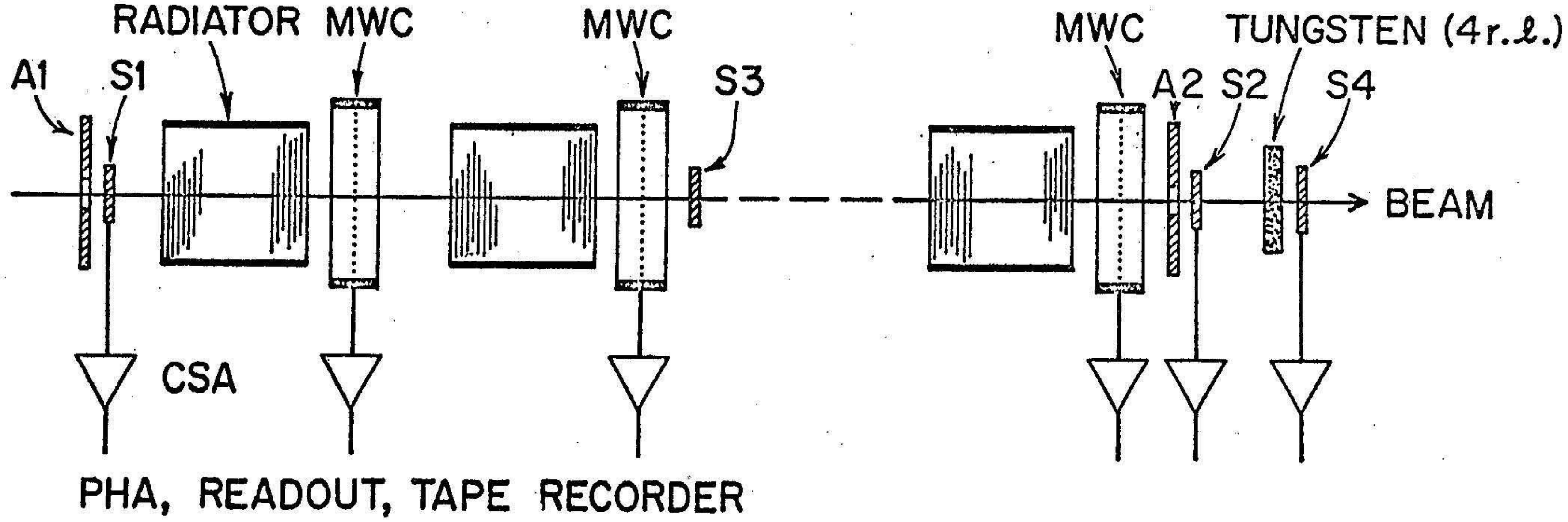
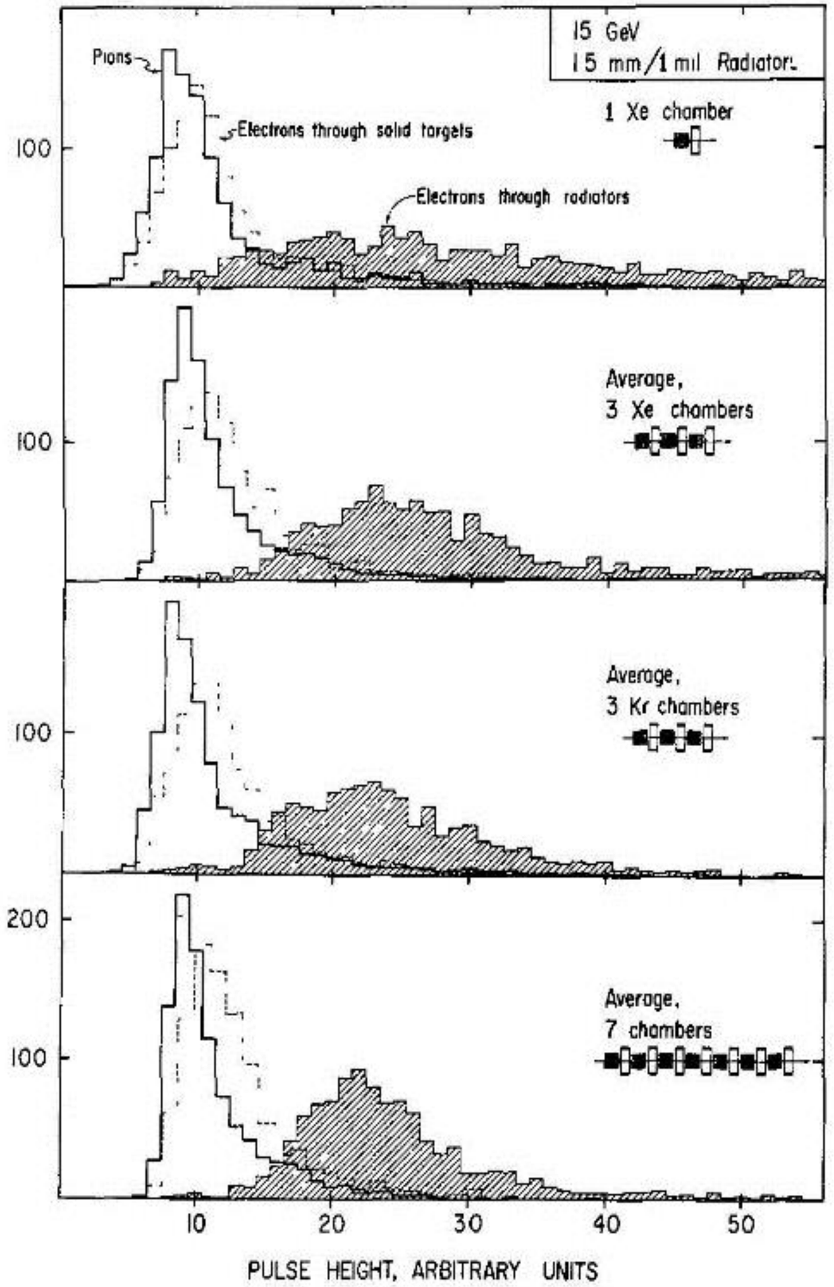


Figure 5



$$P_1 = P_e^{(1)}(x_1)\,P_e^{(2)}(x_2)\,\ldots\,P_e^{(n)}(x_n).$$

Similarly, the probability that a pion will produce this same set of signals is:

$$P_2 = P_\pi^{(1)}(x_1)\,P_\pi^{(2)}(x_2)\,\ldots\,P_\pi^{(n)}(x_n).$$

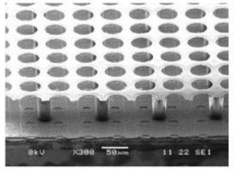
If we wish to decide whether or not the event defined by the pulse heights characterizes an electron or pion, we can define the quantity

$$P_e = P_1/(P_1+P_2).$$

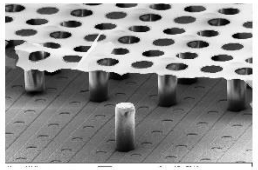
This quantity defines the probability of interpretation of the event as an electron. (This definition assumes equal a priori probability for electrons and pions.) Similarly, the quantity

$$P_\pi = P_2/(P_1+P_2) = 1-P_e$$

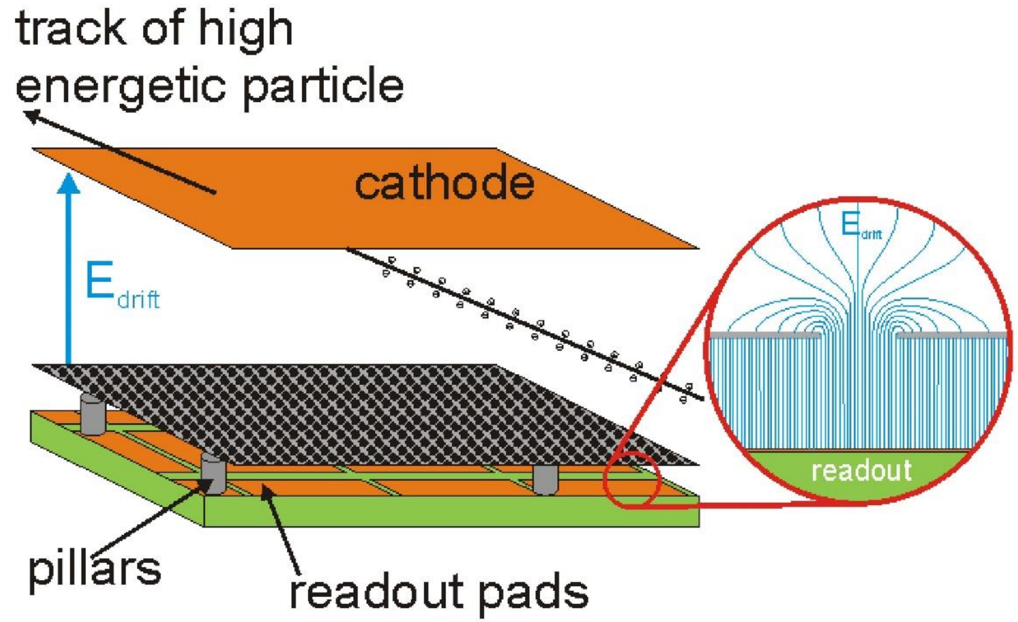
is the probability of interpretation of the event as a pion.



From Micromegas to GridPix



MM invented by Y. Giomataris, et al. (NIMA 376, p. 29-35, 1995)



Two stage parallel plate detector:
- Ionization in drift volume
- Gas amplification in thin gap with high electric field

Standard charge collection:
- Pads of several mm²
- Long strips (l~10 cm, pitch ~200 µm)

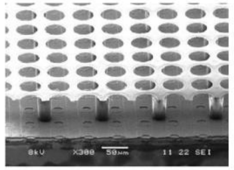
Could the spatial resolution of single electrons be improved?

Ar:CO_2 70:30 → $D_t = 187\ \mu m/\sqrt{cm} \rightarrow \sigma = 21\ \mu m$

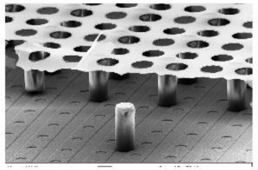
Ar:CH_4 90:10 → $D_t = 208\ \mu m/\sqrt{cm} \rightarrow \sigma = 24\ \mu m$

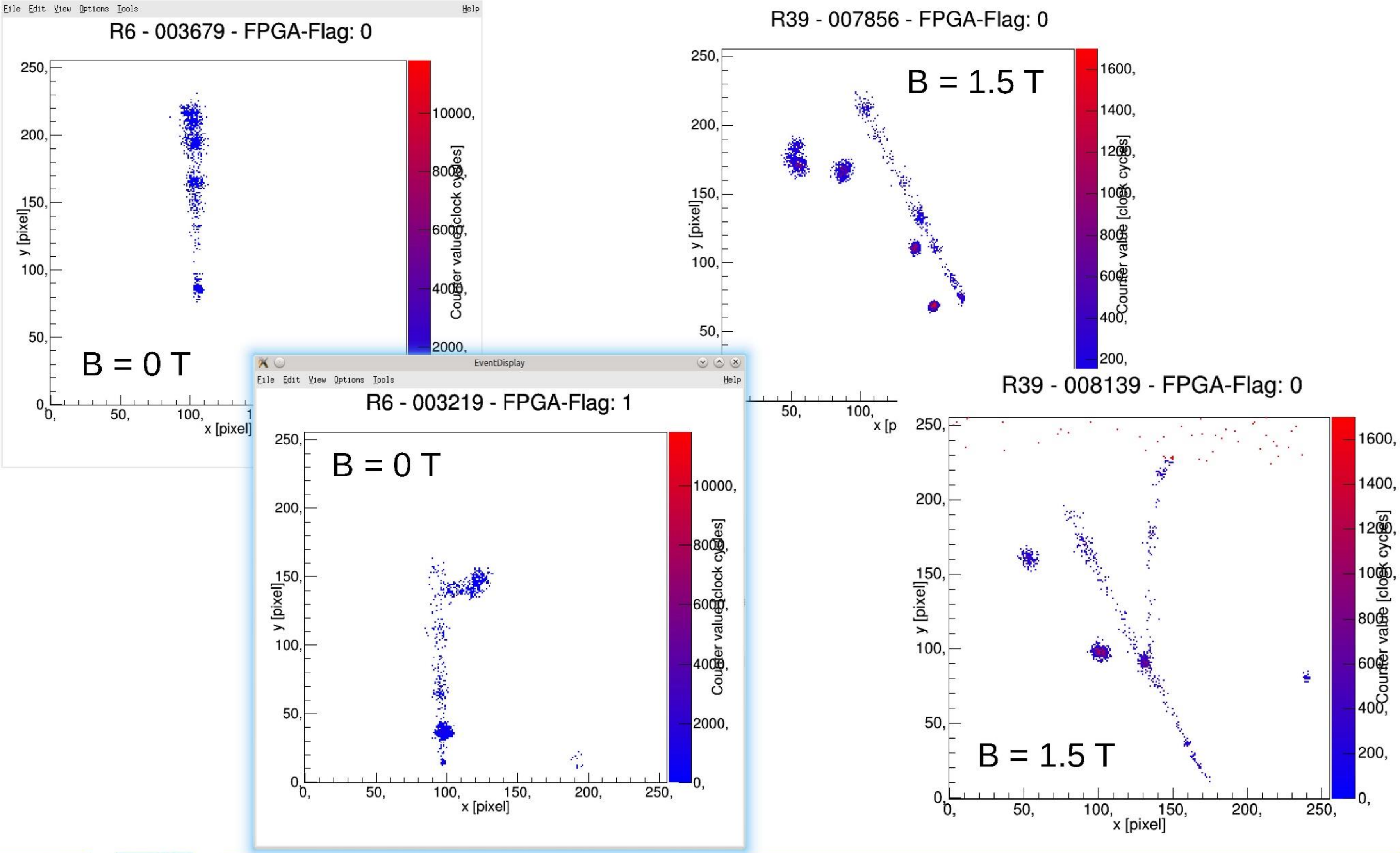
Ar:iButan 95:5 → $D_t = 211\ \mu m/\sqrt{cm} \rightarrow \sigma = 24\ \mu m$

Smaller pads/pixels could result in better resolution!
At NIKHEF the GridPix was invented.



Some online event display pictures





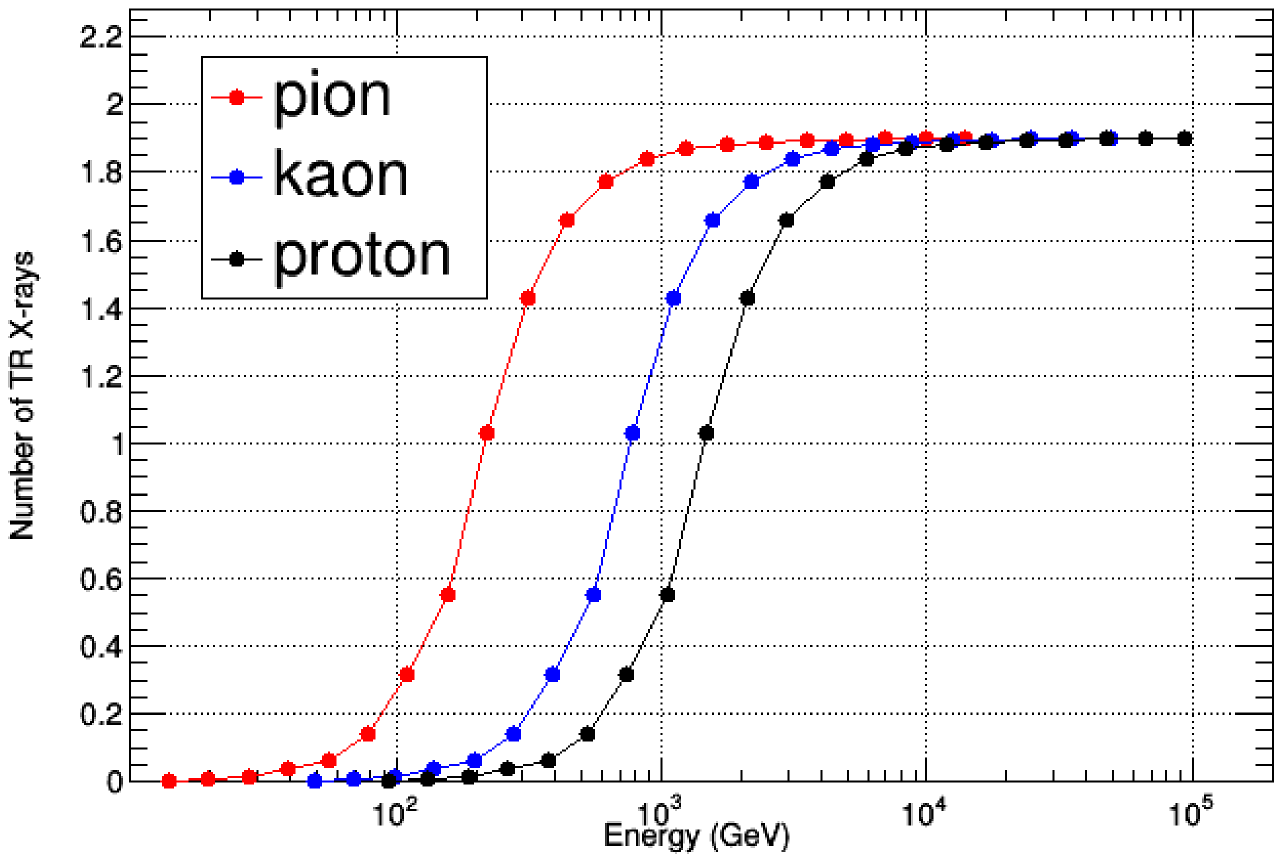
R6 - 003679 - FPGA-Flag: 0

R39 - 007856 - FPGA-Flag: 0

R6 - 003219 - FPGA-Flag: 1

R39 - 008139 - FPGA-Flag: 0

Pol/Air, 15 µm/ 300 µm, Nf=100 - **200 ?**

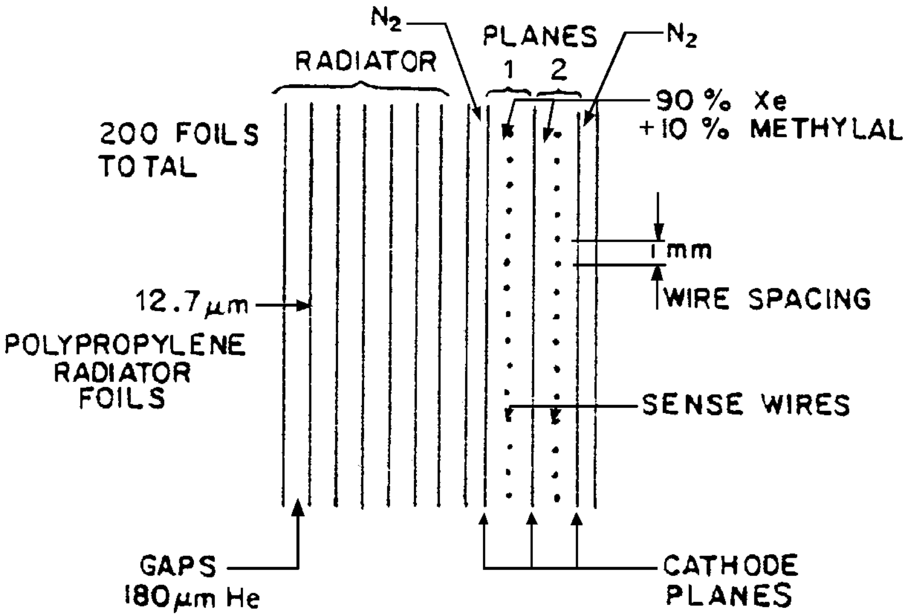


-we assume that the collected photons are **≈ 2** per TRD set **at best**

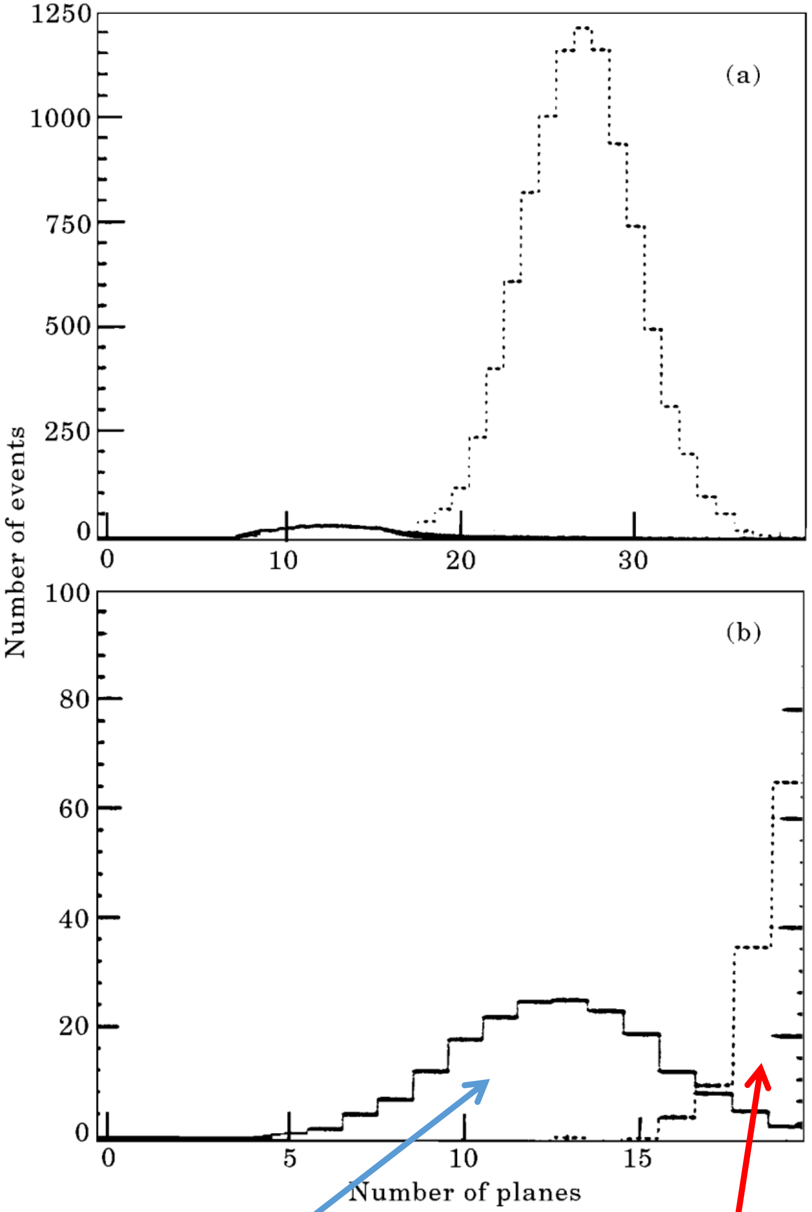
→ we need **50** sets (each with **200** foils radiator) to get **100 TR photons**

Fermilab E 769 @250 GeV (1991)
24 sets - **L = 2.79 m**
π contamination =**2%** @ **87%** **p** acceptance

simulation at @ 500 GeV/c **k**(2%) π (98%)
π contamination = **3%** @ **90%** **k** acceptance

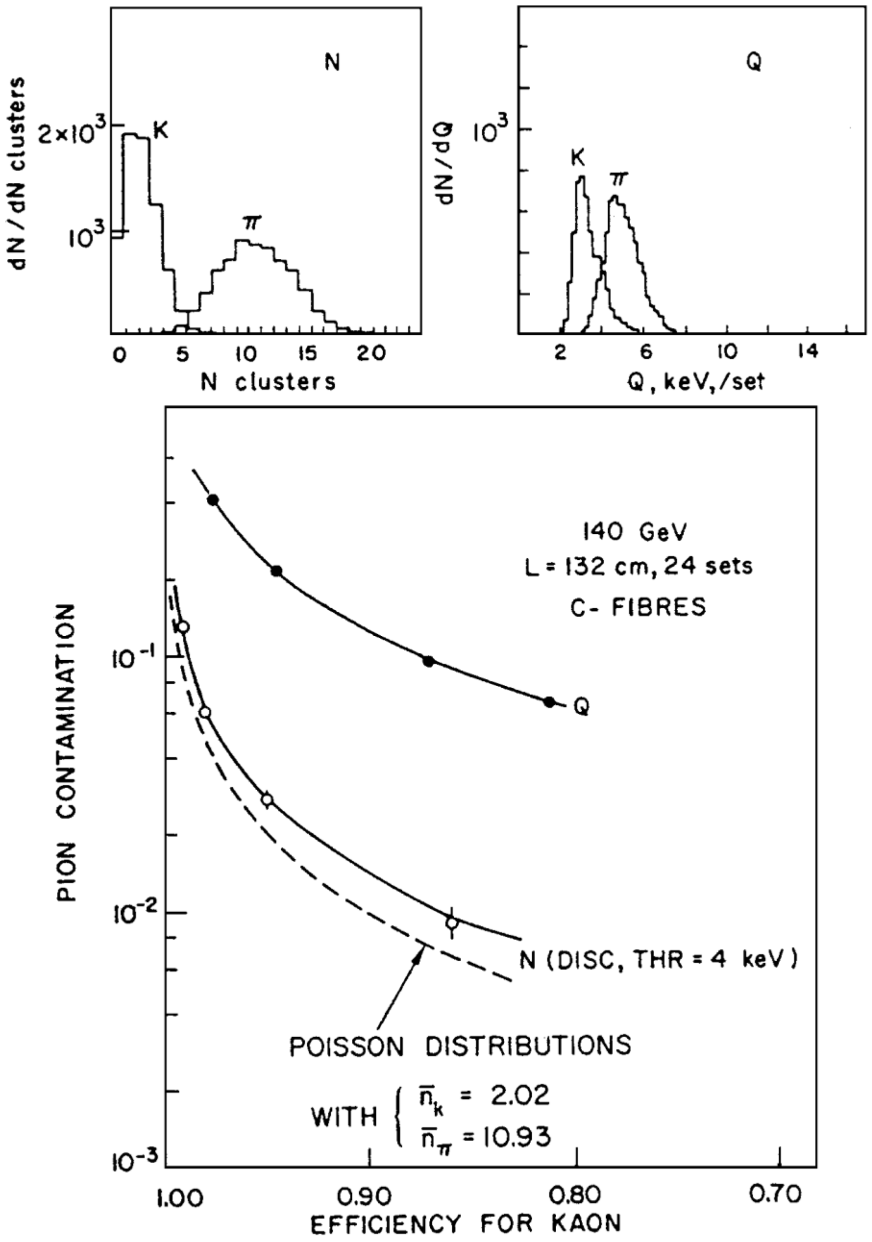


k/p separation ability not quoted…



kaons

pions



π/**k** becomes ≈ **1%** with

24 sets, **L = 1.32 m**

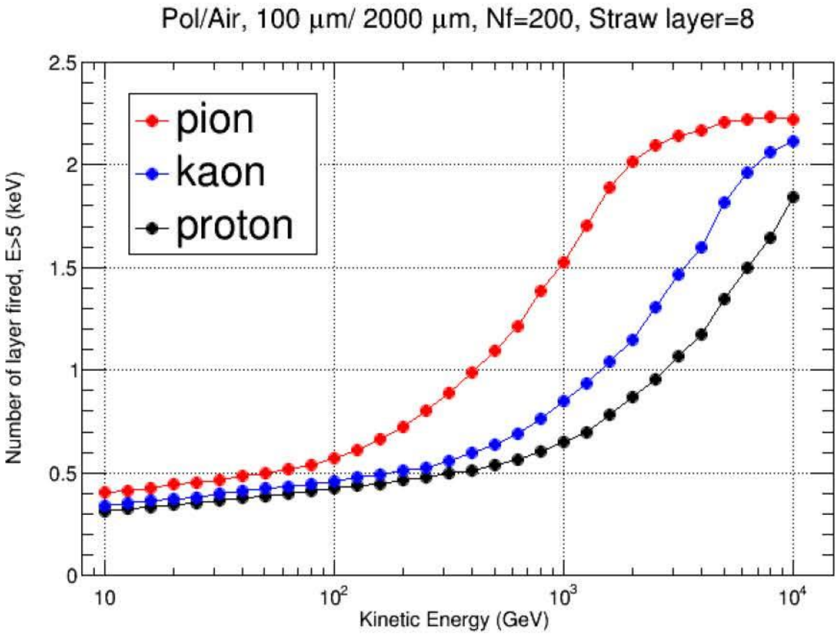
but note:
k/p separation is not quoted …

What happened

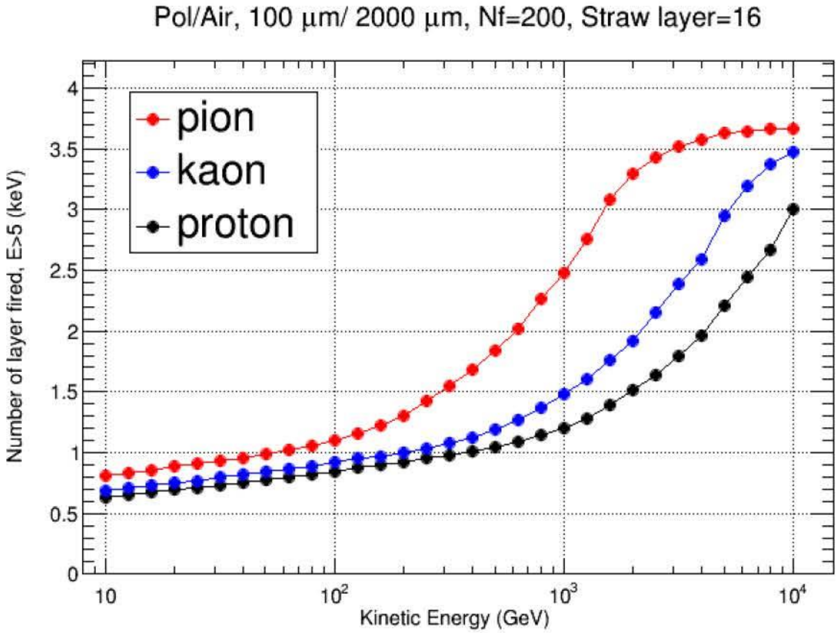
later at **higher**

energies?

Thick configuration – Number of hit layers

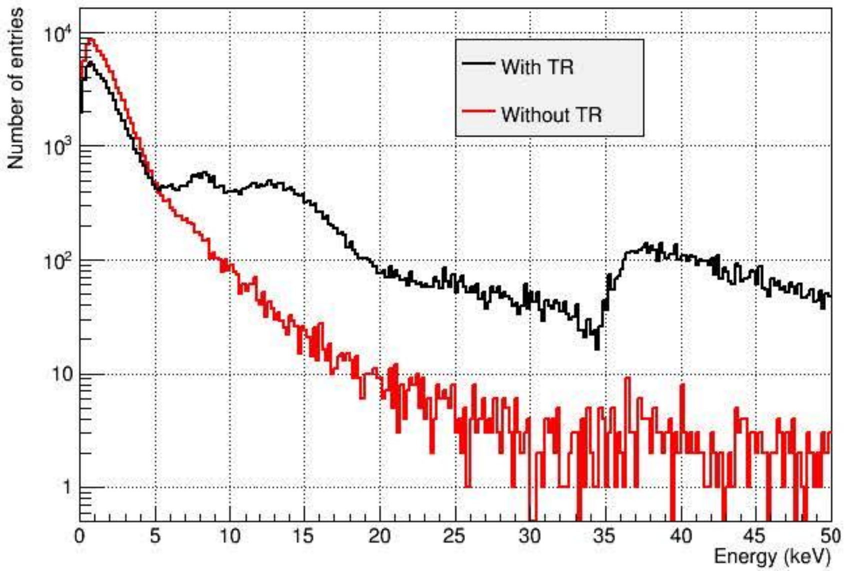


Straw tube simulation results

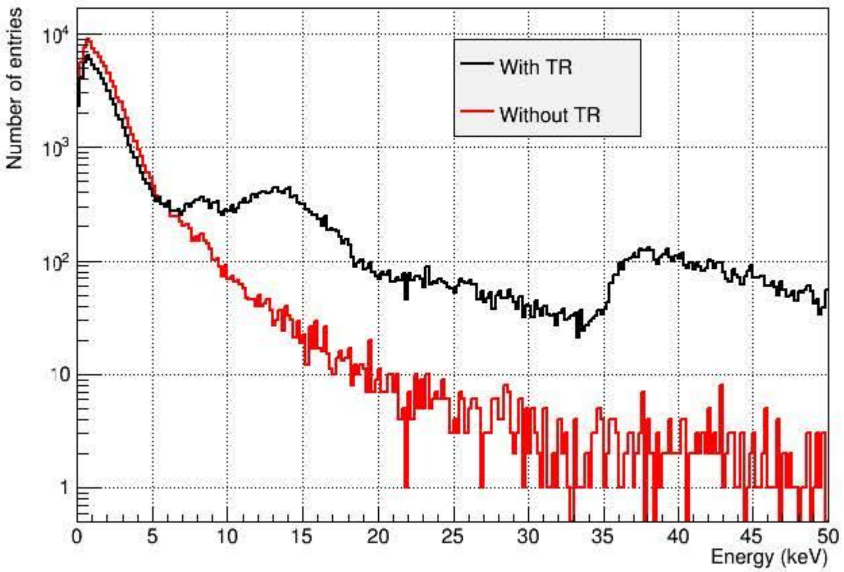


Thick configuration – Energy loss

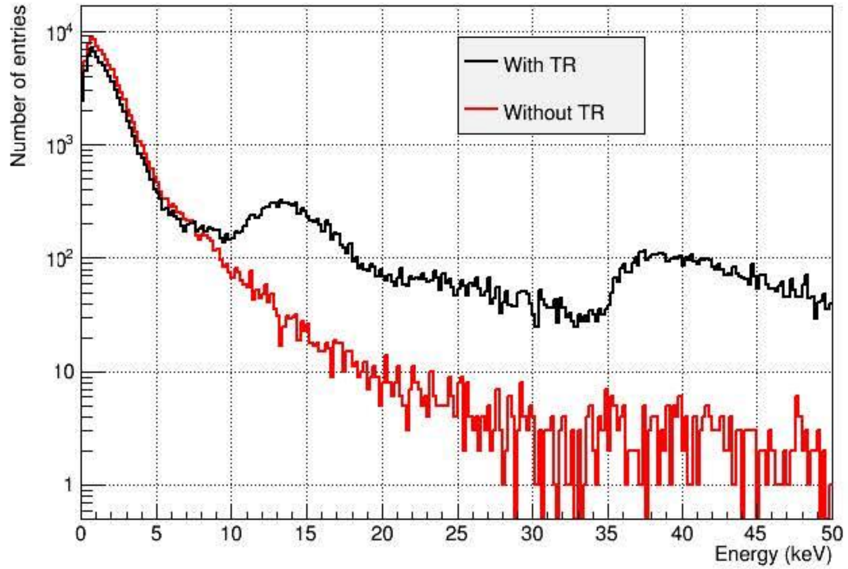
Energy deposition in the 1st layer



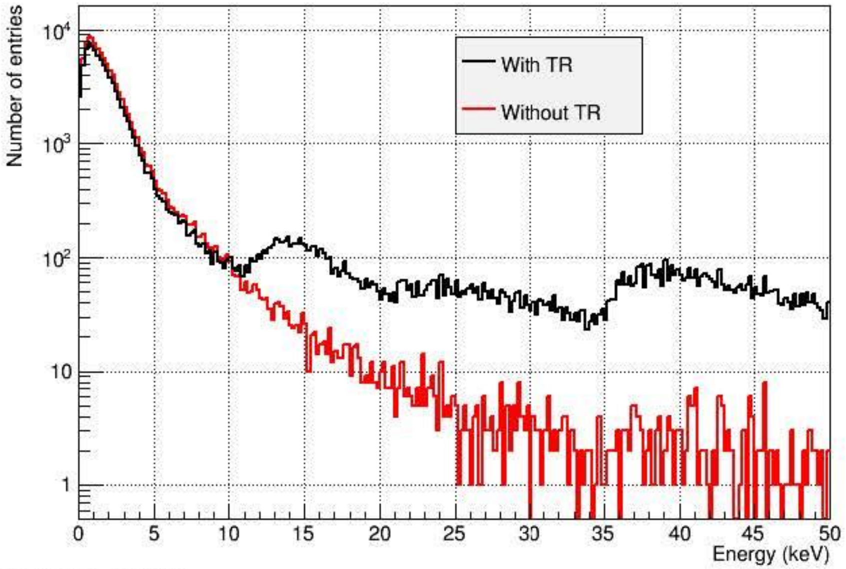
Energy deposition in the 2nd layer



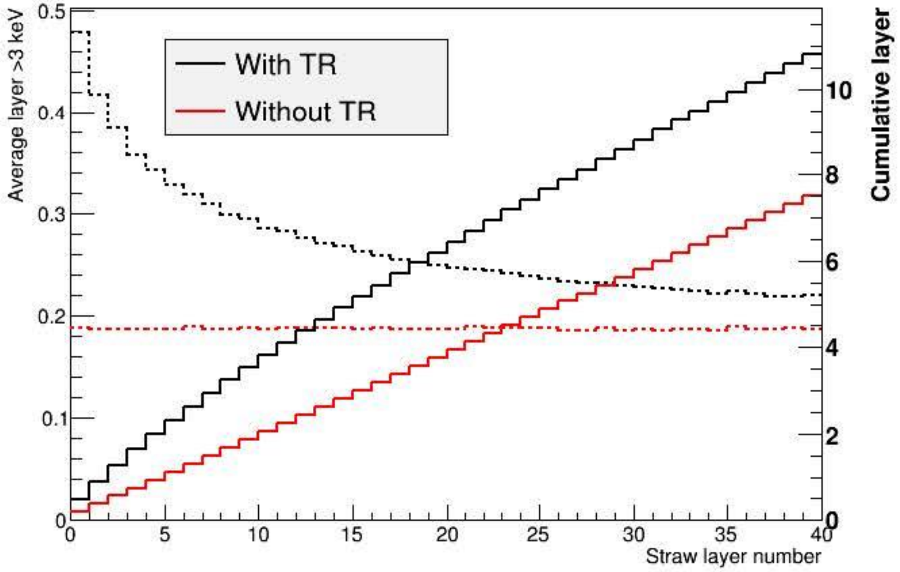
Energy deposition in the 4th layer

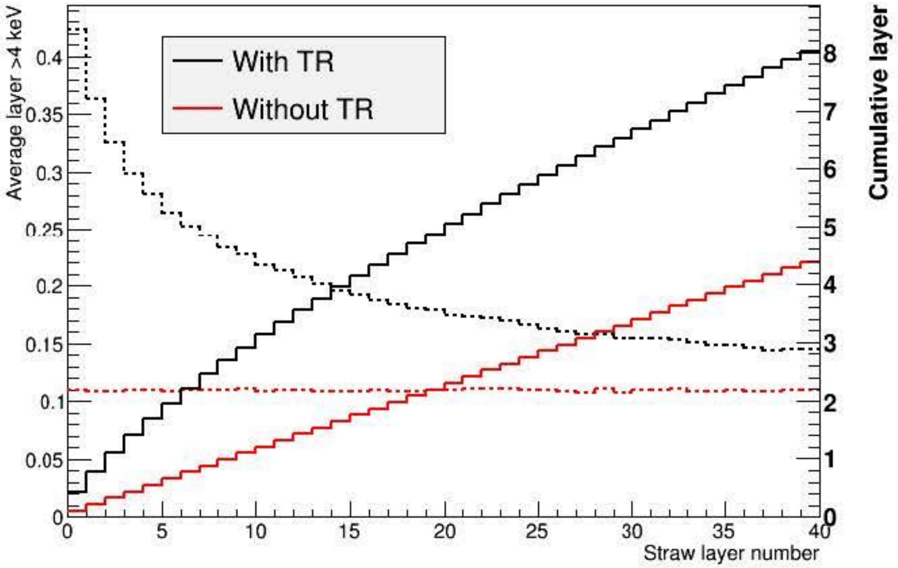


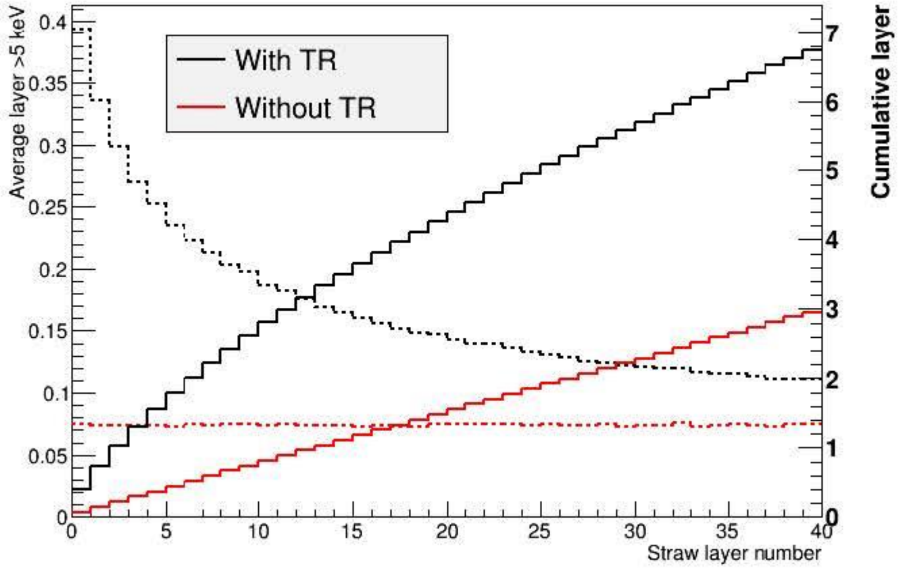
Energy deposition in the 10th layer

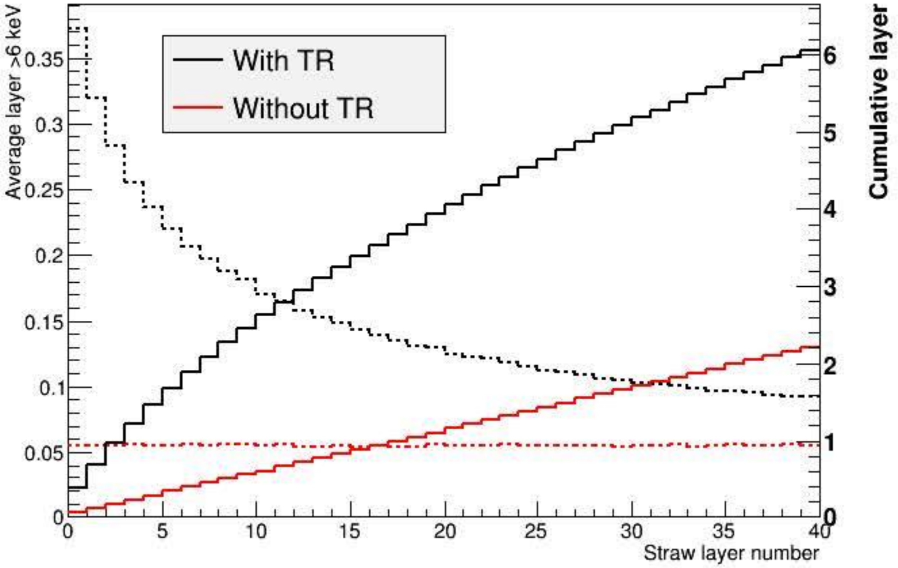


Thick configuration – Fired layers









Example radiator/detector configuration #3:

20 modules

N = 50 teflon foils, $\omega_1 = 28.5$ eV

foil thickness $l_1 = 50\ \mu$, spacing $l_2 = 6$ mm

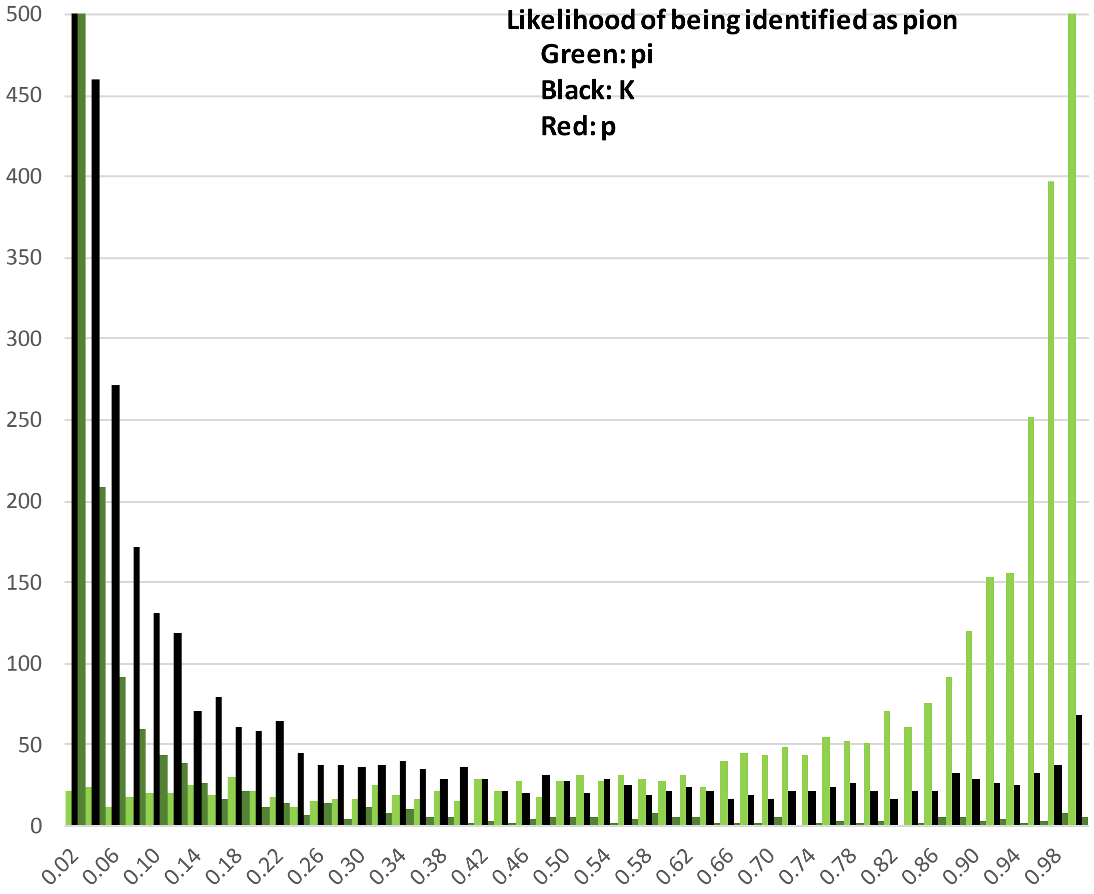
$\omega_{max} = 32.7$ keV $\gamma_s = 4.8 \times 10^4$

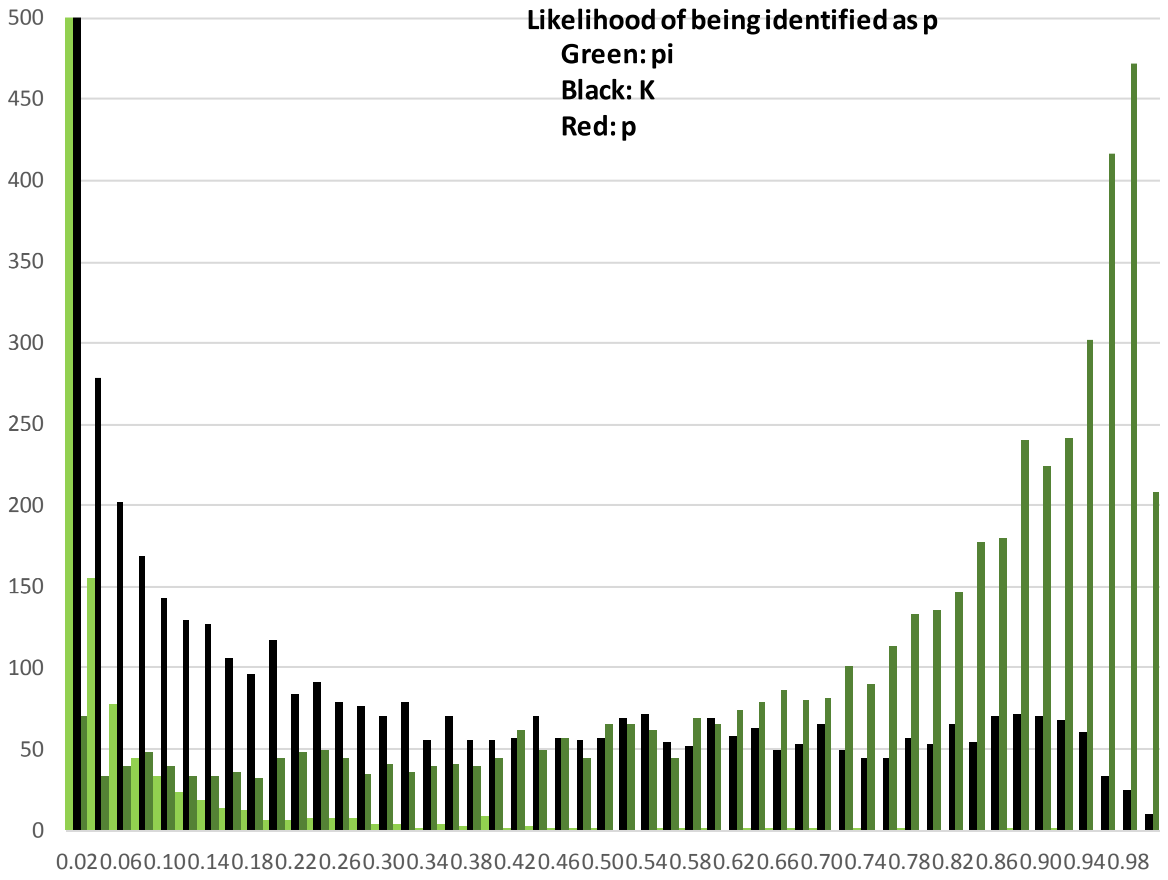
Total length 6.3 m Thickness 11 g

Modules 1-10: 1 cm Xe Modules 11-20: 2 cm Xe

Include Compton + photoelectric cross sections

Account for feedthrough from one module to next





78% pion efficiency
2.2% of K’s incorrectly identified as π’s
0.02% of p’s incorrectly identified as π’s

55% proton efficiency
4.2% of K’s incorrectly identified as p’s
0.8% of π’s incorrectly identified as p’s

Compton Scatter TRD

TR x-rays emitted with angle ~ 1/γ

→ difficult to spatially separate from ionization signal

Two Paths to take

1. Don't separate:

Layer with thin gas (xenon) detector can detect photons well below ~30 keV

Detection length sufficiently thin to keep ionization signal not much larger than TR signal

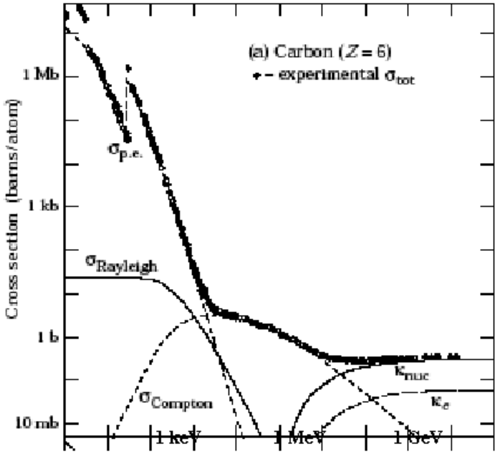
Maximal efficiency requires keeping ω's to be low and radiator foils to be thin

2. Separate via Compton Scattering

Employ 250 μm Al foils to push TR x-ray energies > ~50 keV where Compton scattering begins to dominate

Al radiator foils can then Compton scatter TR photons, separating them from ionization deposition

Detect scattered high-energy photons with scintillator (CsI) efficiently

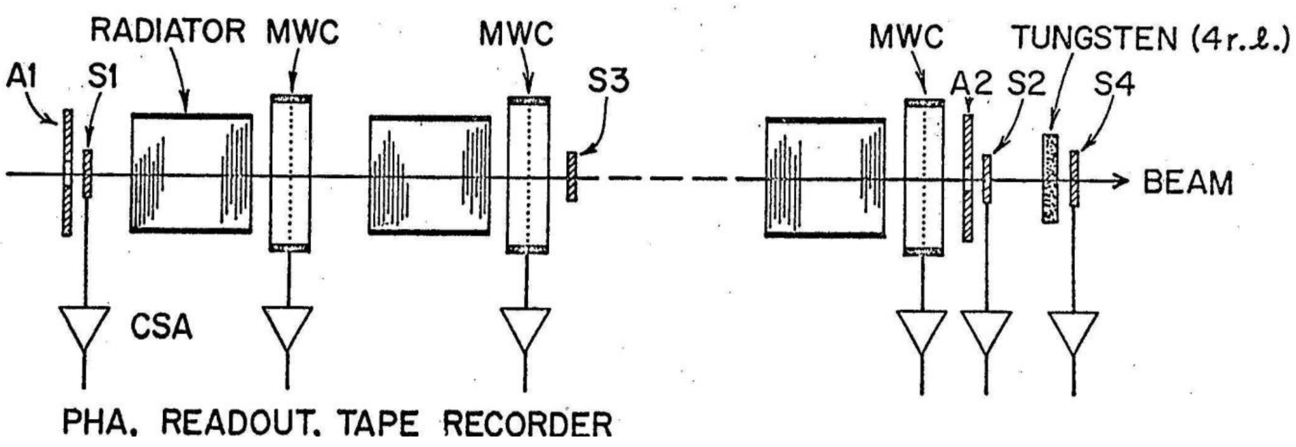


See

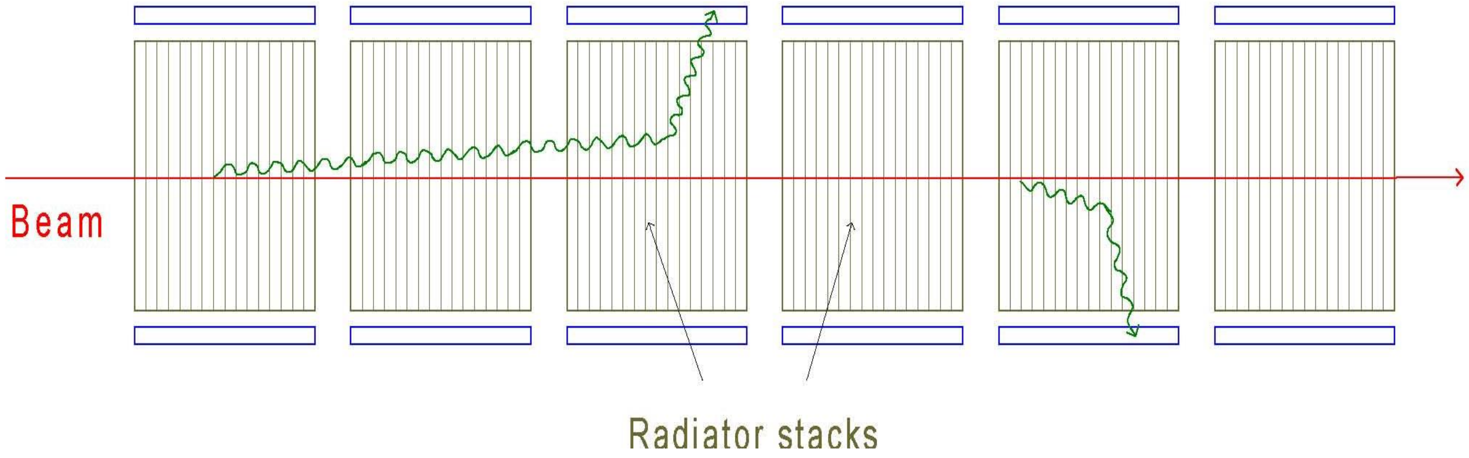
Measurement of Compton Scattered Transition Radiation at High Lorentz Factors, G. Case et al., hep-ex/0209038

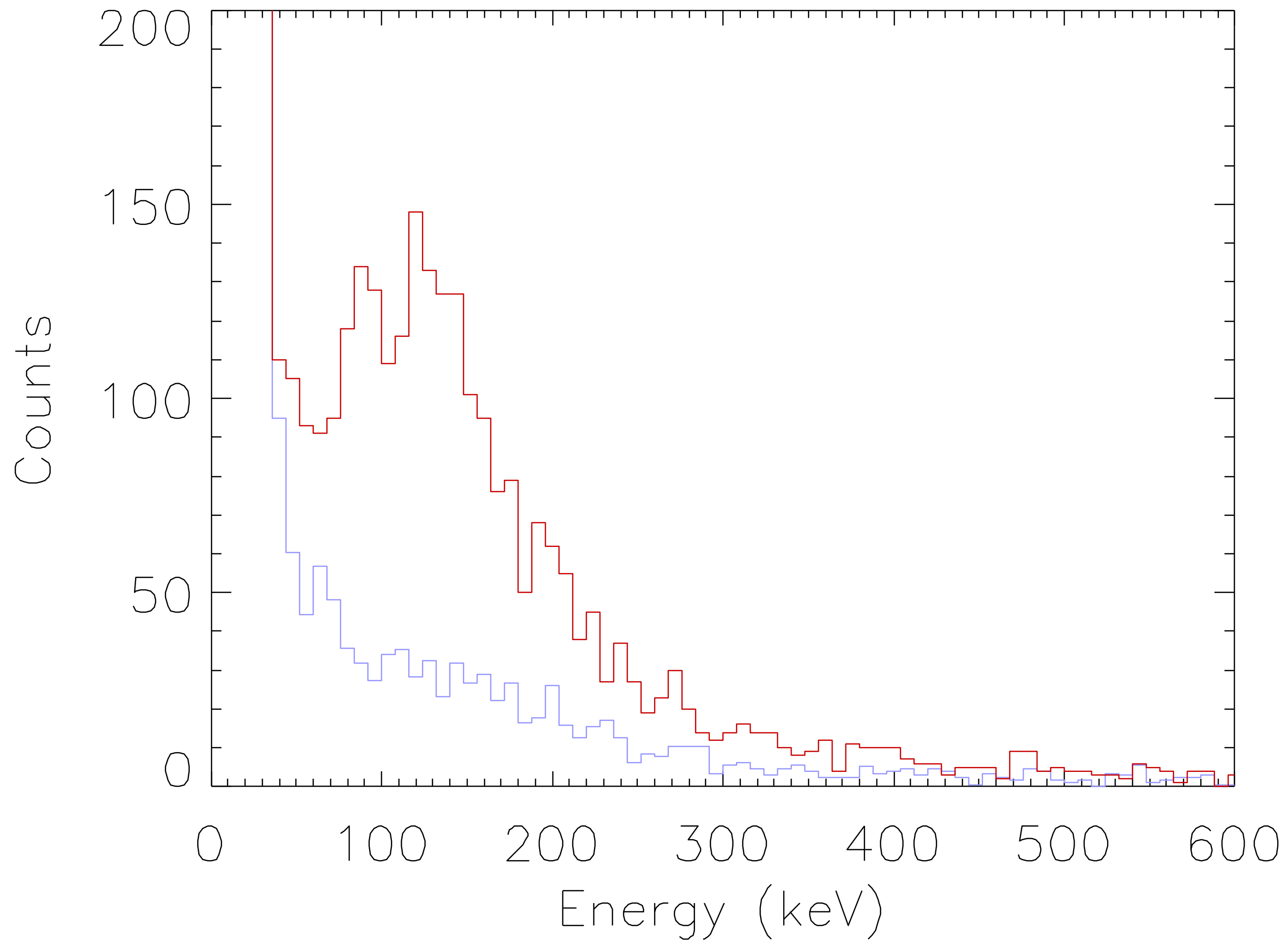
Compton Scattered Transition Radiation from Very High Energy Particles, M. Cherry & G. Case, astro-ph/02060663

"Standard" configuration – SLAC test w/plastic foils/foam, Xe



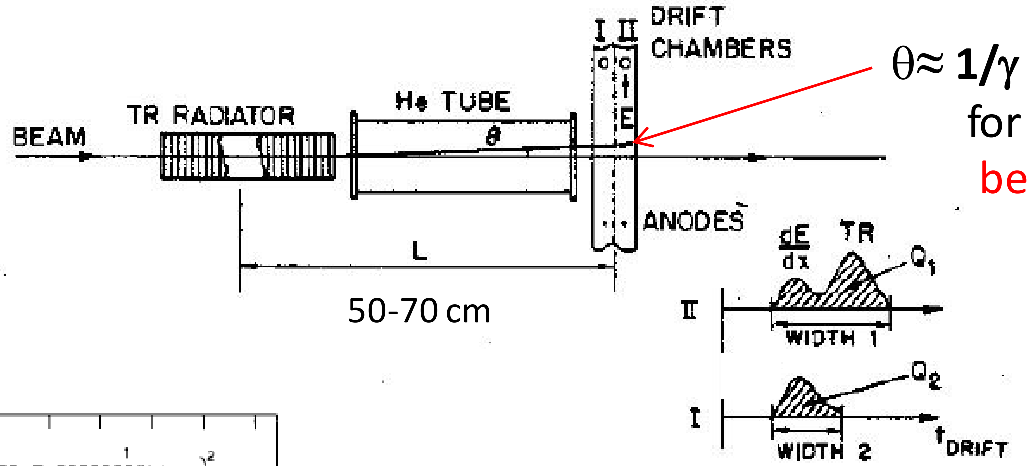
Compton scatter configuration – CERN test w/Al honeycomb, NaI





Measured spectrum, 150 GeV/c electrons with
Al honeycomb radiator (upper curve) and
solid background plates (lower curve)

M.Deutschmann et al.
Partice identification using the angular distribution of transition radiation
N.I.M. 180 (1981) 409-412



50-70 cm

$\theta \approx 1/\gamma \rightarrow \Delta x \approx 0.1–1$ **mm**
for γ = 10.000 -1000
beware: θ $_{\text{mult. scatt.}}$?

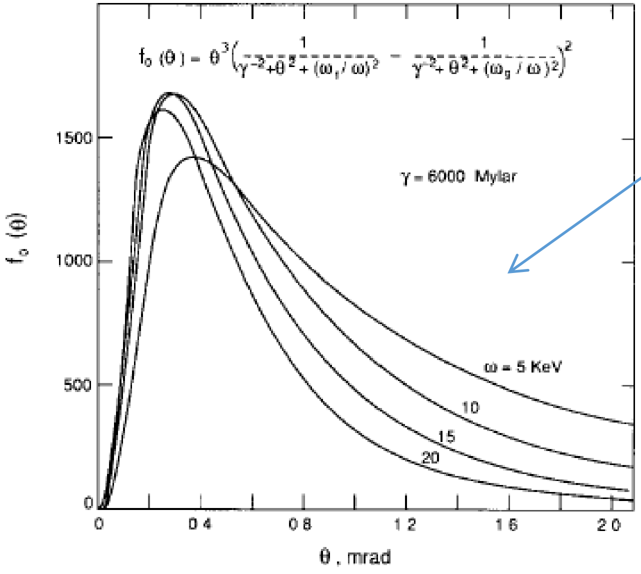


Fig. 2. Angular distribution of a single surface yield.

Single surface
γ = 6000

Single foil
γ = 2000

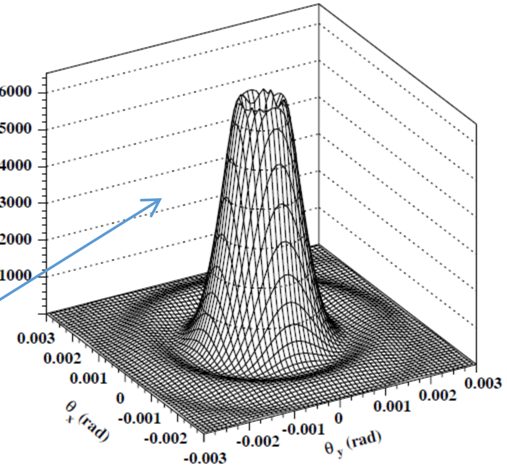
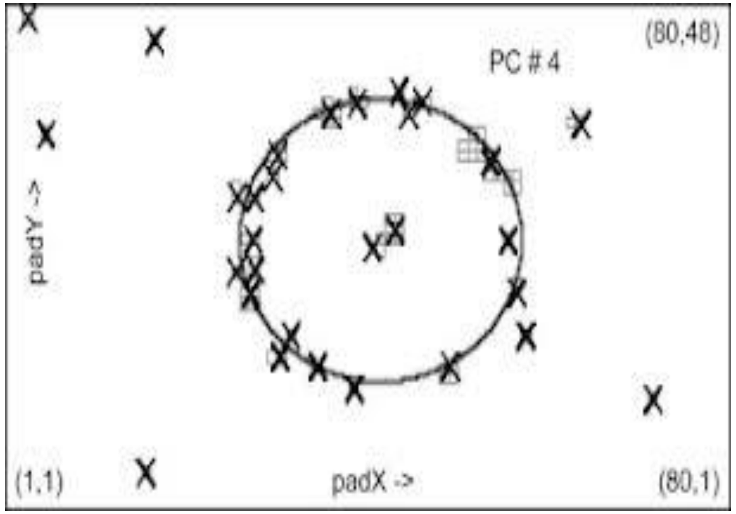


Figure 15. – Single-foil angular distribution for Li/He: $l_1 = 50$ μm, $\gamma = 2 \cdot 10^3$ and $\omega = \omega_1 \gamma_{\rm th}/\pi$: the particle moves upwards.



Can we envisage a
“miniaturized”

ring imaging TRD = RITRD?

now we have more
advanced pixel detectors !
(see next talk)

-we can collect with **10** sets radiator/pixel detector ≈ **20** TR photons (better than a conventional RICH) to **overlay** on a unique frame to reconstruct a ring

-conventional 15 μ foil radiators to let any hadron to radiate + 1 m “*espansion distance” in helium*→ L ≈ 10 m, still long, but X_0 and λ_I will be negligible!

-pixel size 50μ x 50 μ? (spatial resolution optimized by *centroid* calculation)

-the momenta , namely the rings radii per each kind of particle, are fixed by the calorimeter: at **1 m** of *espansion distance*→

R_p = 1mm @ γ= 1000 (1 TeV proton) or R_k = 0.5mm @ γ= 2000 (1 TeV kaon)

Questions that we need answered:

- What p-pi-K identification/rejection performance is required?
- What is energy range?
- What energy resolution is required?
- How much physical space is available, lateral and along the beam?
- What is maximum amount of material allowed in beam?
- How many particles expected per event, what event rate?