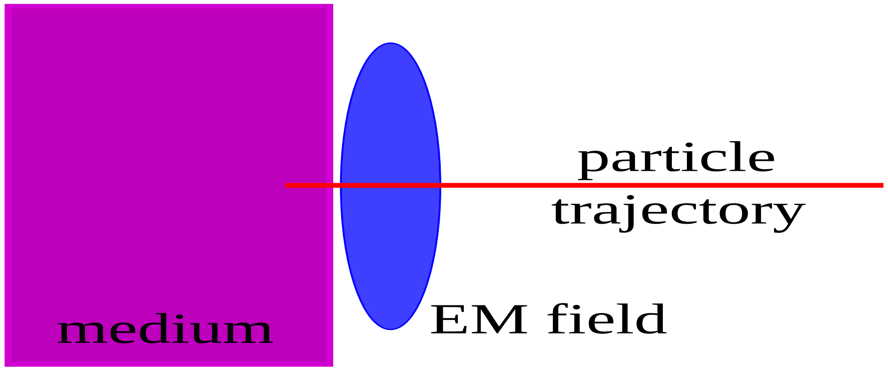
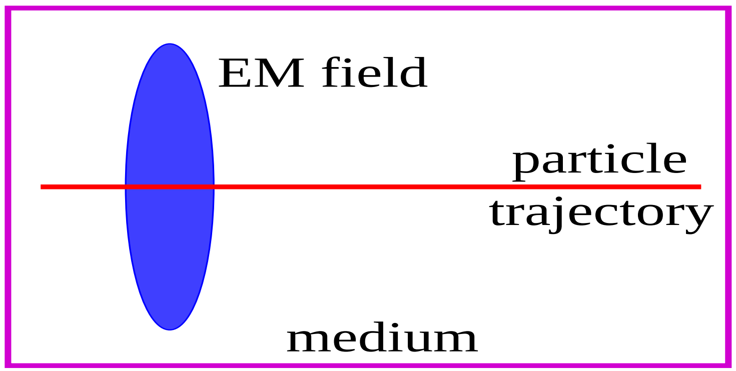
What is transition radiation ?

"Transition radiation is *omitted* whenever a charged particle crosses an interface between two media with different dielectric functions." — L. Durand, Phys. Rev. D 11, 89 (1975)

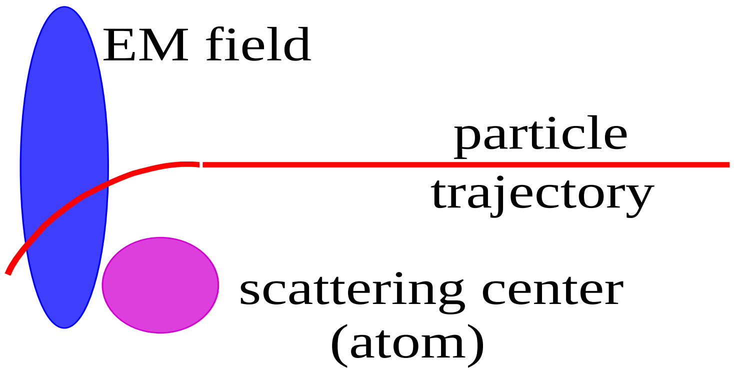
- Predicted: Ginzburg & Frank, 1946
- Observed: Goldsmith & Jelley, 1959 (optical)
- It's sizeable (X-rays) for relativistic particles



Cherenkov



Brehmsstrahlung



How does it look ?

$$\left(\frac{\mathrm{d}W}{\mathrm{d}\omega}\right)_{interface} = \frac{\alpha}{\pi}\left(\frac{\xi_1^2+\xi_2^2+2\gamma^{-2}}{\xi_1^2-\xi_2^2}\ln\frac{\gamma^{-2}+\xi_1^2}{\gamma^{-2}+\xi_2^2}-2\right)$$

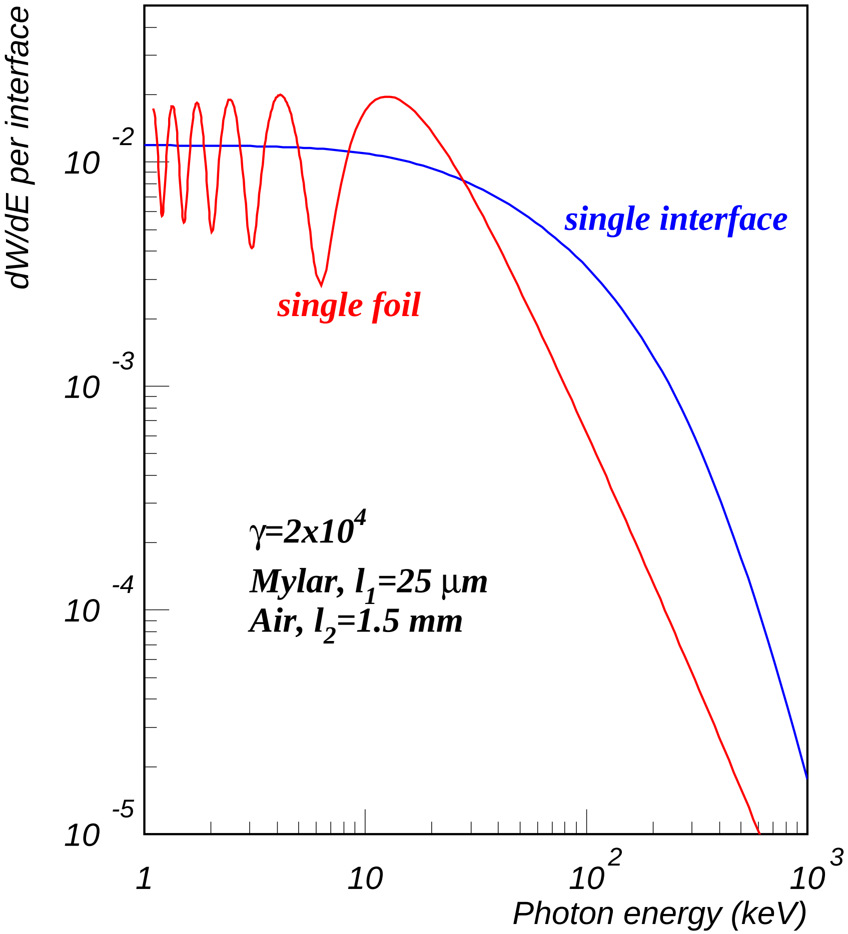
for : $\gamma \gg 1; \quad \theta \ll 1 \quad \xi_1^2, \xi_2^2 \ll 1 \quad (\xi^2 = \omega_P^2/\omega^2)$

ω_P =plasma frequency: $\omega_P^{CH_2}$=20 eV, ω_P^{Air}=0.7 eV

- $\theta \sim 1/\gamma$ radiation is colinear with particle
- $\omega \sim \gamma\omega_P$ the energy is several keV

$$\left(\frac{\mathrm{d}^2W}{\mathrm{d}\omega\mathrm{d}\Omega}\right)_{foil} = \left(\frac{\mathrm{d}^2W}{\mathrm{d}\omega\mathrm{d}\Omega}\right)_{interface} \times 4\sin^2(\phi_1/2)$$

many interfaces $\longrightarrow$ interference pattern



The yield per interface is proportional to α=1/137 $\longrightarrow$ a stack of foils ($\simeq$100) to get on average one photon !

On what does it depend ?

- Lorentz factor γ ($\rightarrow$ particle mass and momentum)
- Media:
  - production: plasma frequency $\omega_P = 28.8\sqrt{\rho\frac{Z}{A}}$, thickness (formation length)
  - absorption: density, Z, thickness

pick: CH_2-air radiator

Approximate (10%) formula for a radiator, including absorption ($\rightarrow$ TR yield at the exit of radiator)

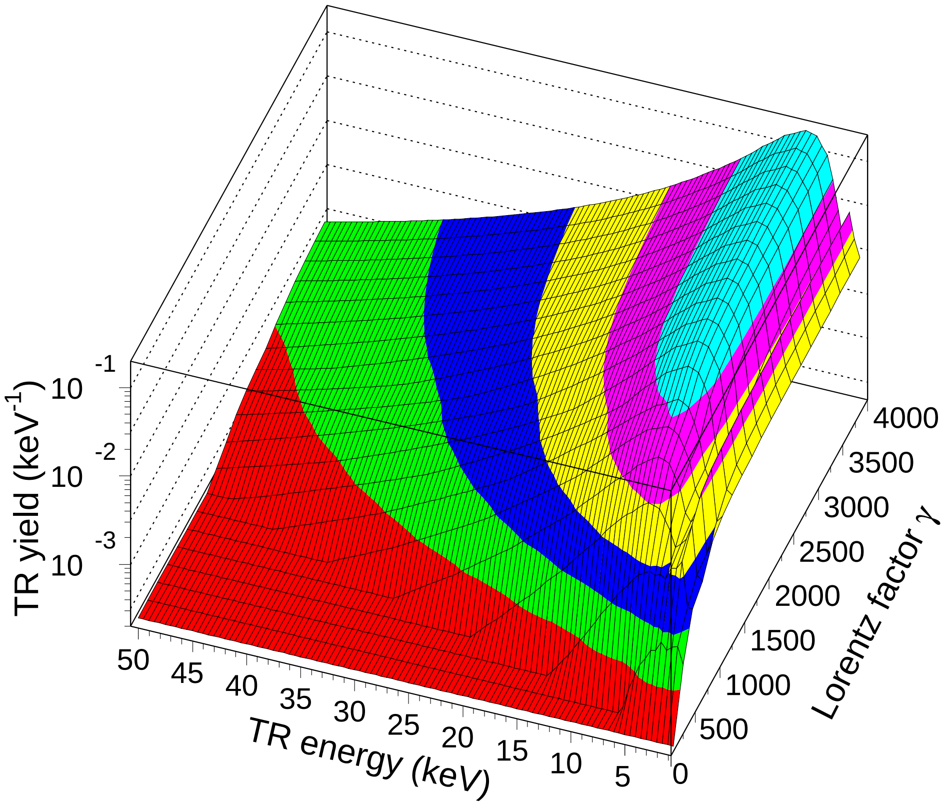
C.W. Fabjan and W. Struczinkski, Phys. Lett. B 57, 483 (1975)

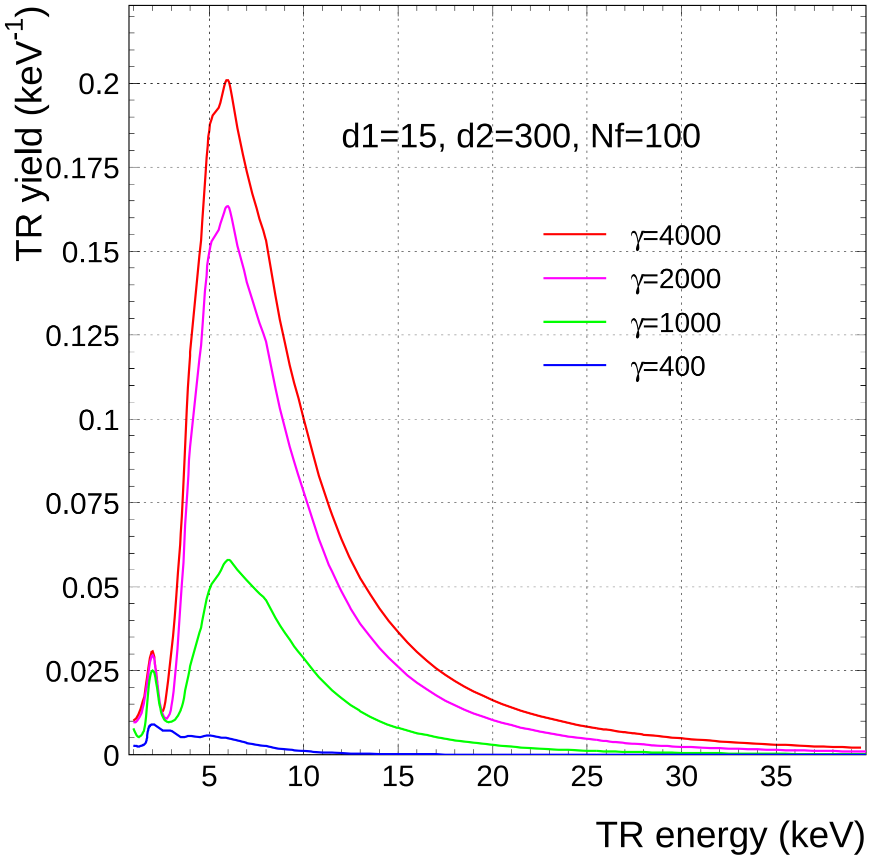
$$\frac{\mathrm{d}W}{\mathrm{d}\omega} = \frac{4\alpha}{\sigma(\kappa+1)}(1-\exp(-N_f\sigma)) \times \sum_n \theta_n \left(\frac{1}{\rho_1+\theta_n} - \frac{1}{\rho_2+\theta_n}\right)^2 [1-\cos(\rho_1+\theta_n)]$$

where:

$$\rho_i = \omega d_1/2c(\gamma^{-2}+\xi_1^2), \quad \kappa = d_2/d_1, \quad \theta_n = \frac{2\pi n - (\rho_1+\kappa\rho_2)}{1+\kappa} > 0, \quad \sigma = \sigma_1+\sigma_2 \quad (\text{one} \quad \text{foil} + \text{gap})$$

TR vs. Lorentz factor

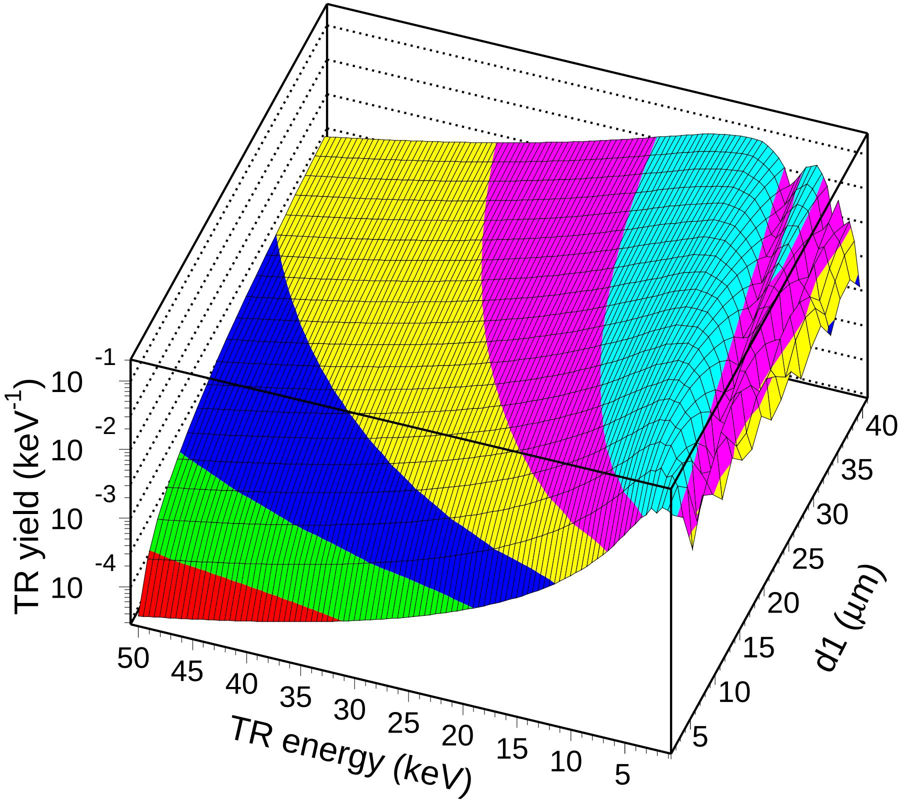


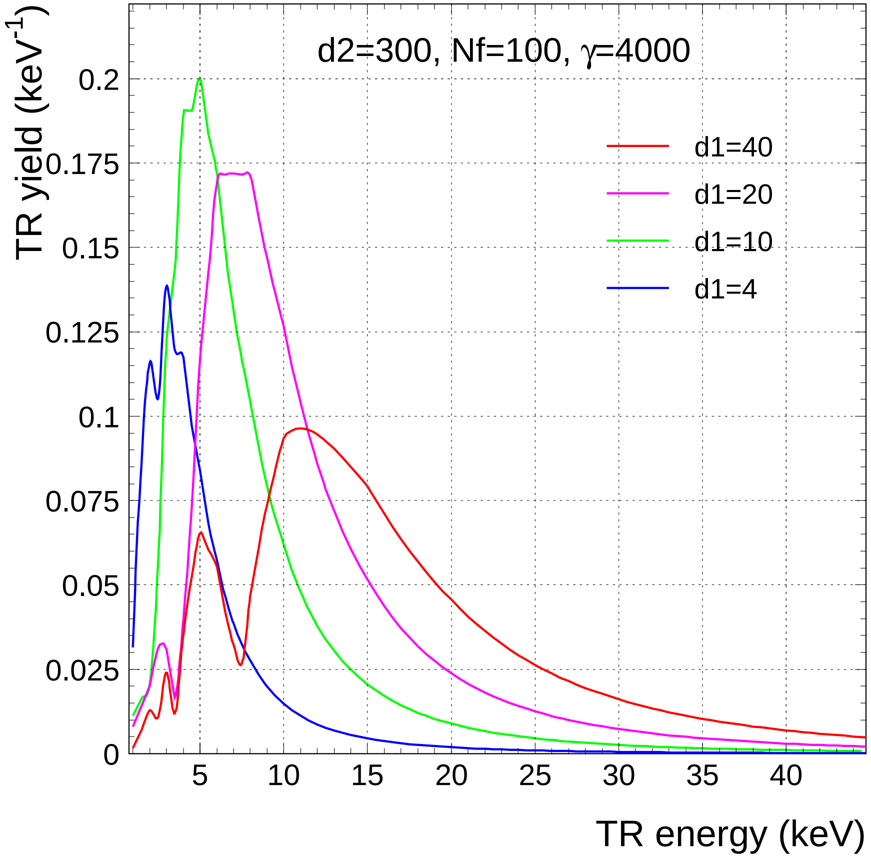


▷ onset at $\gamma \simeq 1000$ and proportionality to γ in the onset region

▷ for large γ the yield saturates and the spectrum is harder

TR vs. foil thickness (d_1)

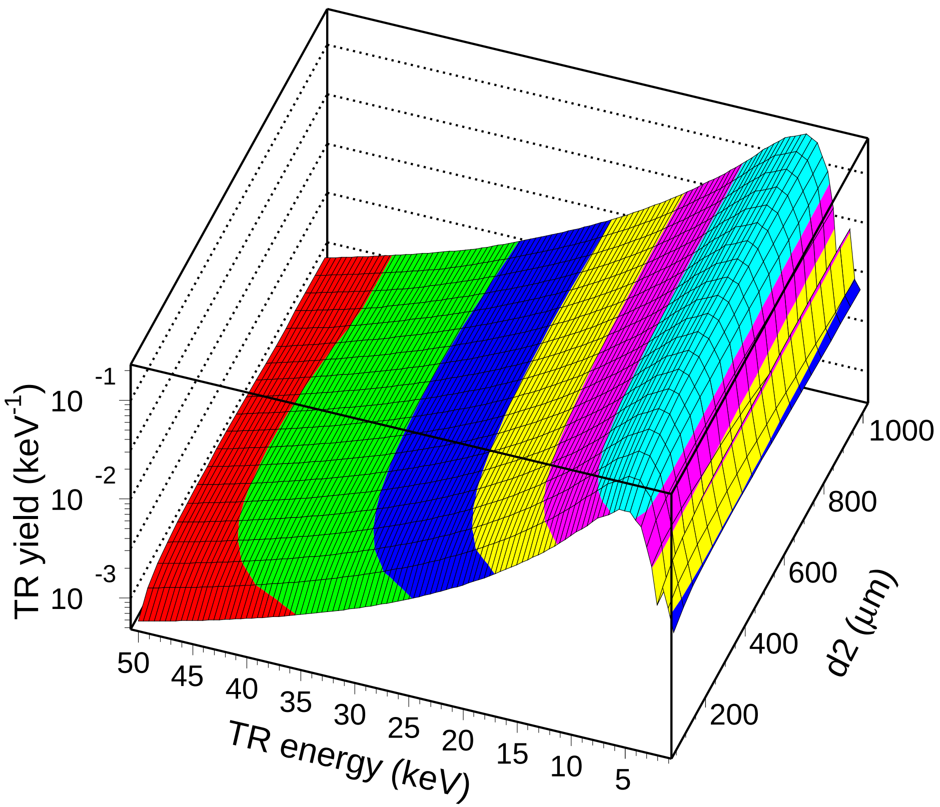


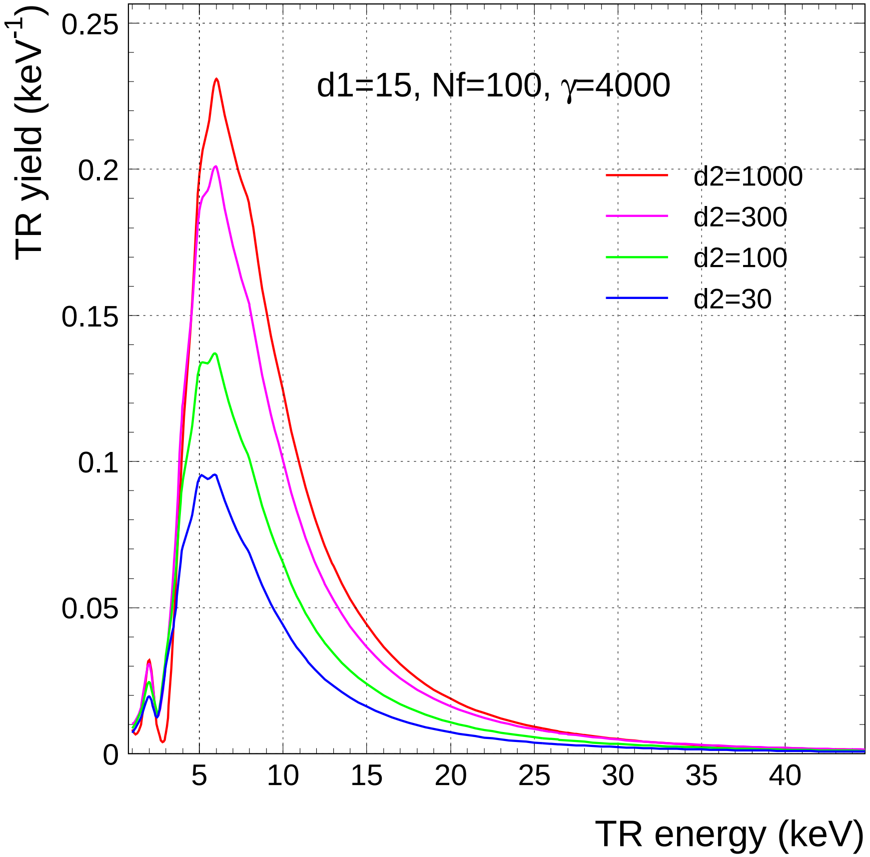


▷ the yield saturates quickly with d_1 (formation length for $CH_2 \simeq 7\mu$m)

▷ the average TR energy is proportional to d_1

TR vs. gap thickness (d_2)

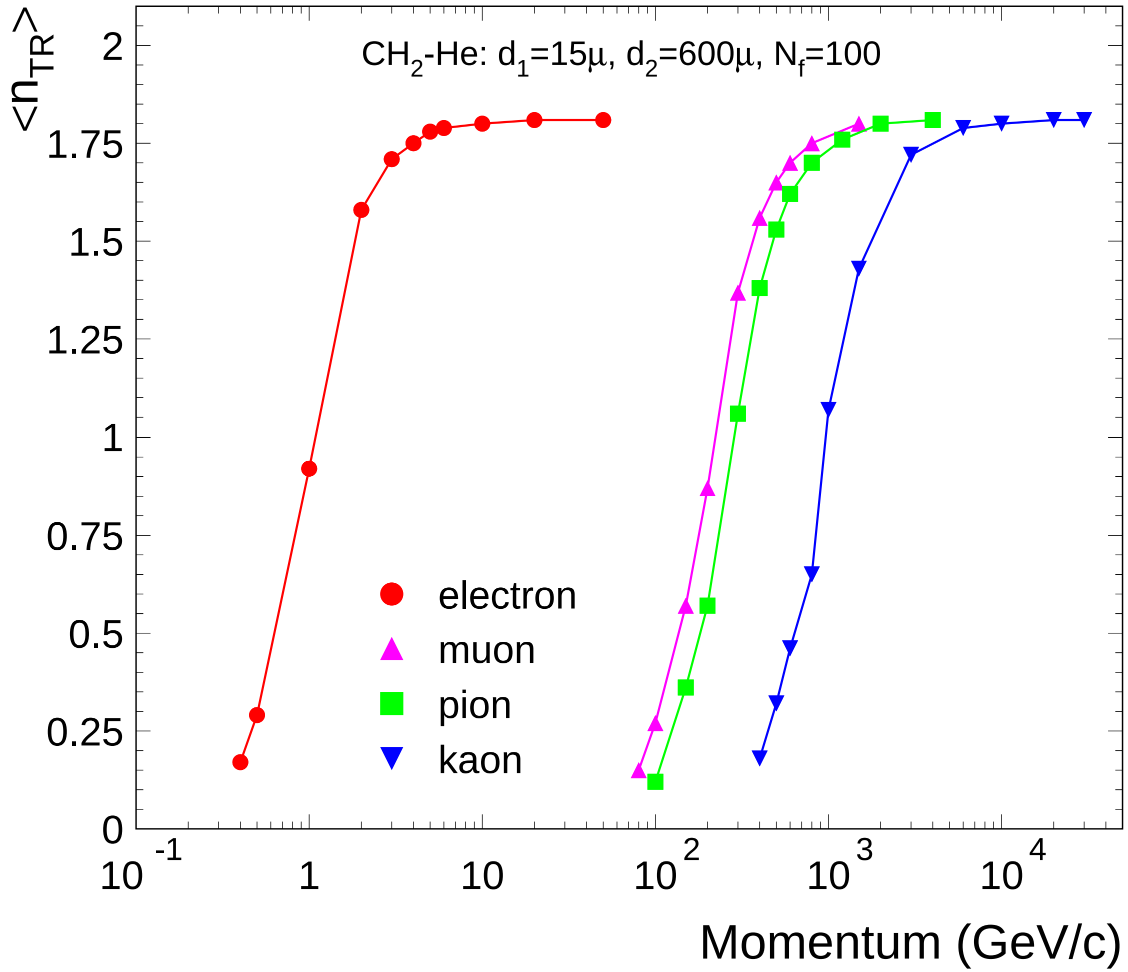




▷ the yield saturates slowly with d_2 (formation length for air $\simeq 700\mu$m)

▷ the TR yield is proportional to d_2; the spectrum gets slightly harder

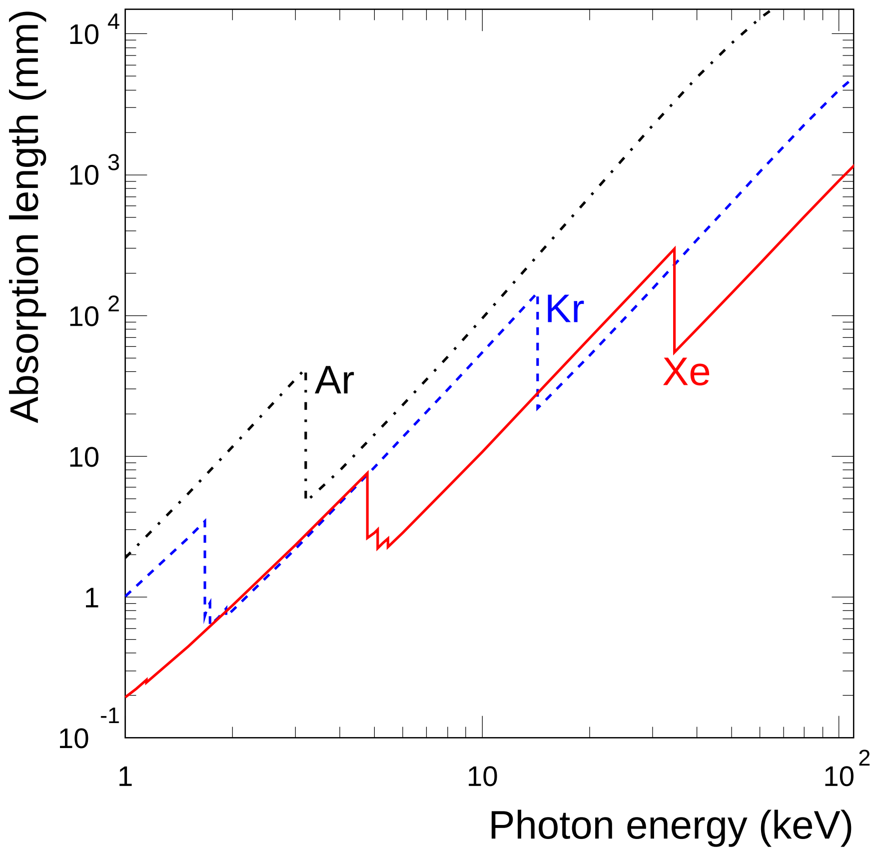
Why TR is useful (for electrons) ?

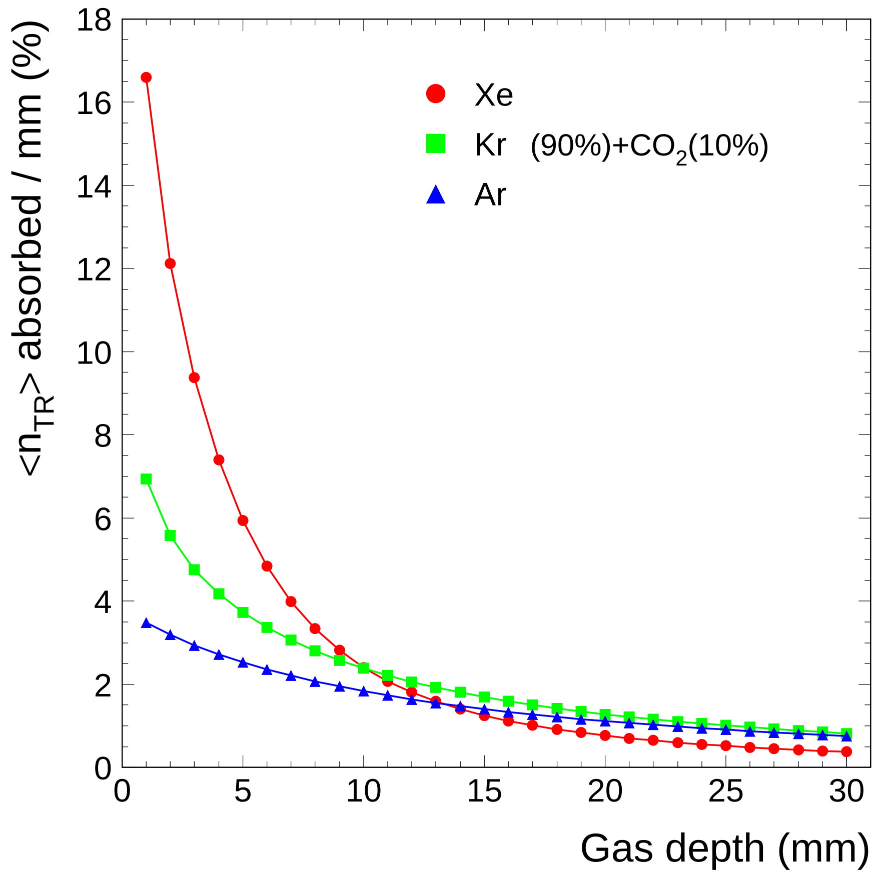


▷ TR dependence on $\gamma \longrightarrow$ p=1-100 GeV/c electrons are active and π's aren't

From TR to TRD: enter the detector

...which is a (multi-)wire proportional chamber filled with a heavy gas





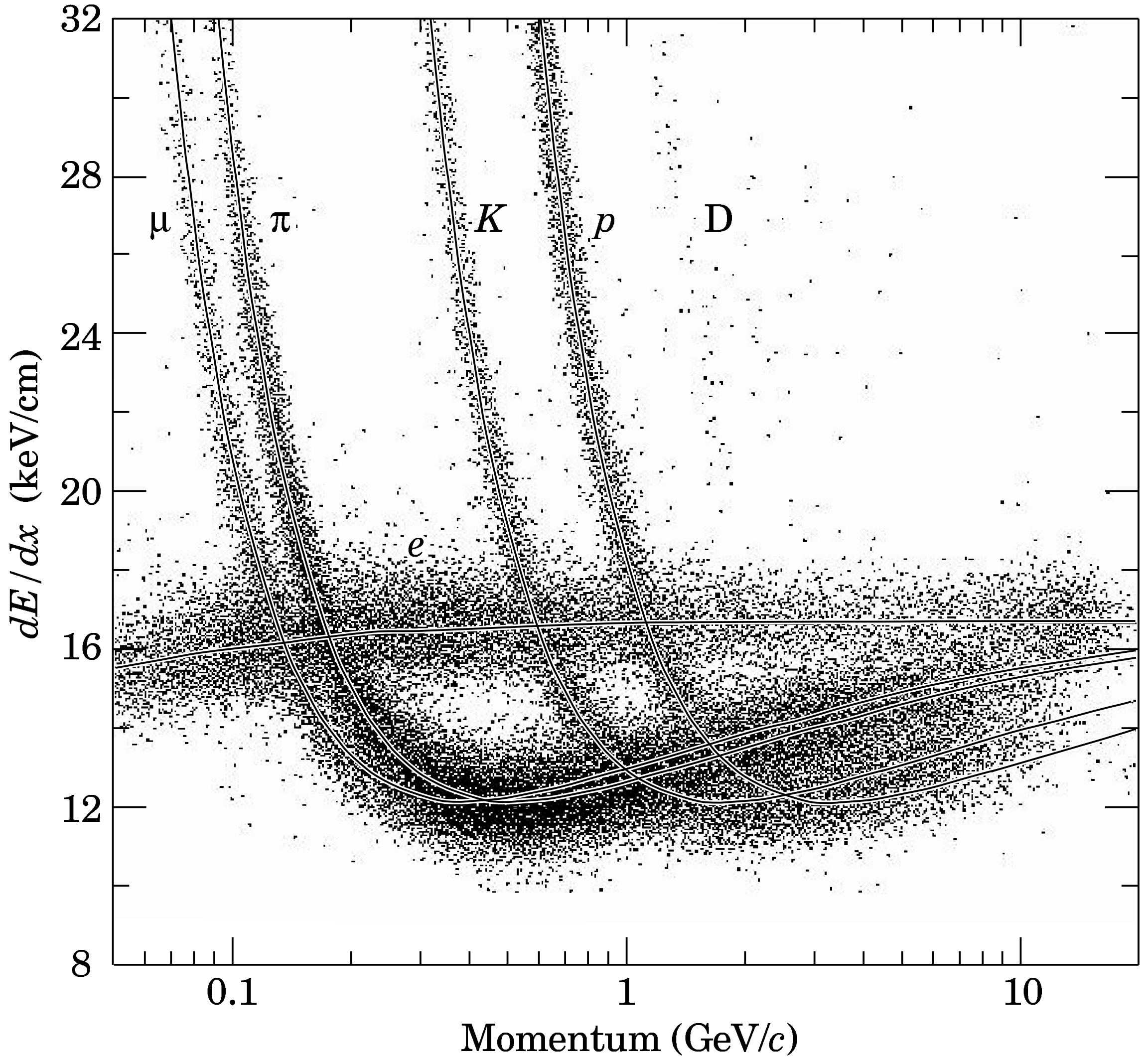
▷ a Xe-based mixture is the choice; 10-20 mm is enough to get the bulk TR

Why do we really need a TRD

Because other techniques are:

- too expensive (calorimetry) or
- too big (ToF, RICH)
- or don't work at all (dE/dx for p > few GeV/c)

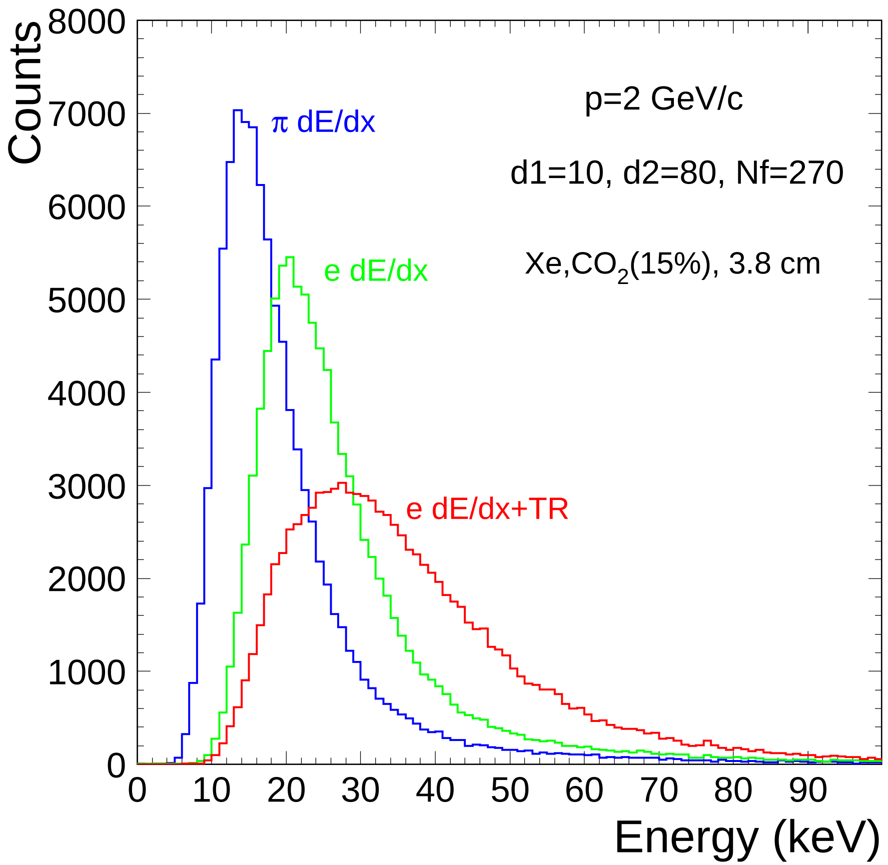
dE/dx (PEP4/9–TPC) ⟶

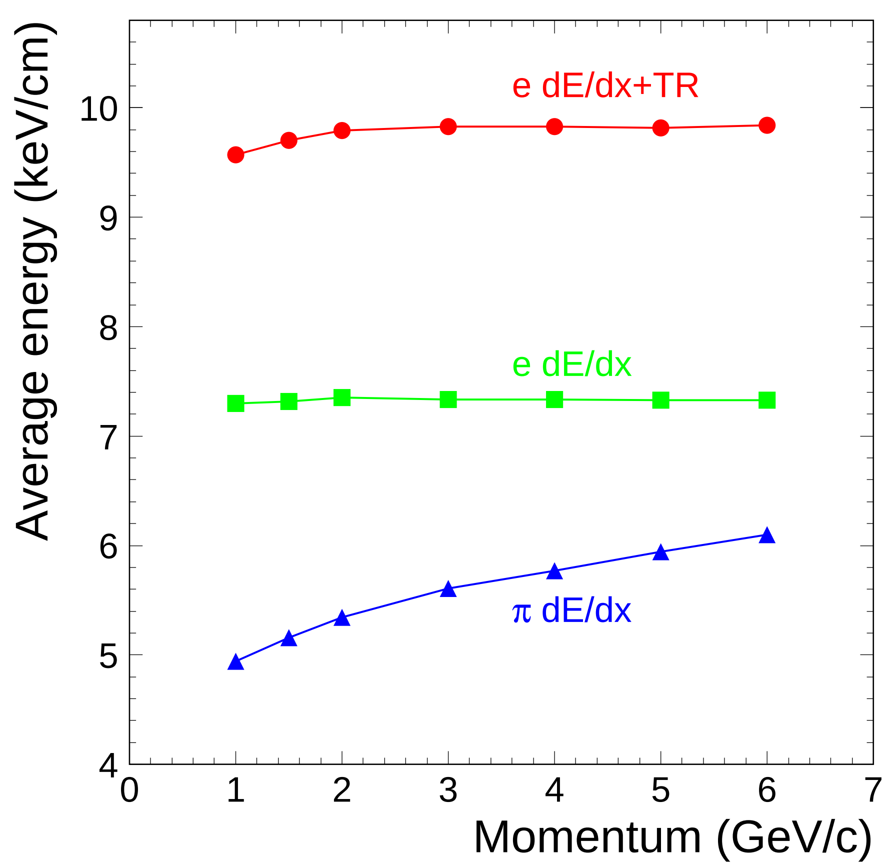


How does it work

▷ TRDs are not "hadron-blind" ! they see all charged particles dE/dx

▷ TR gives a much needed boost to dE/dx of electrons





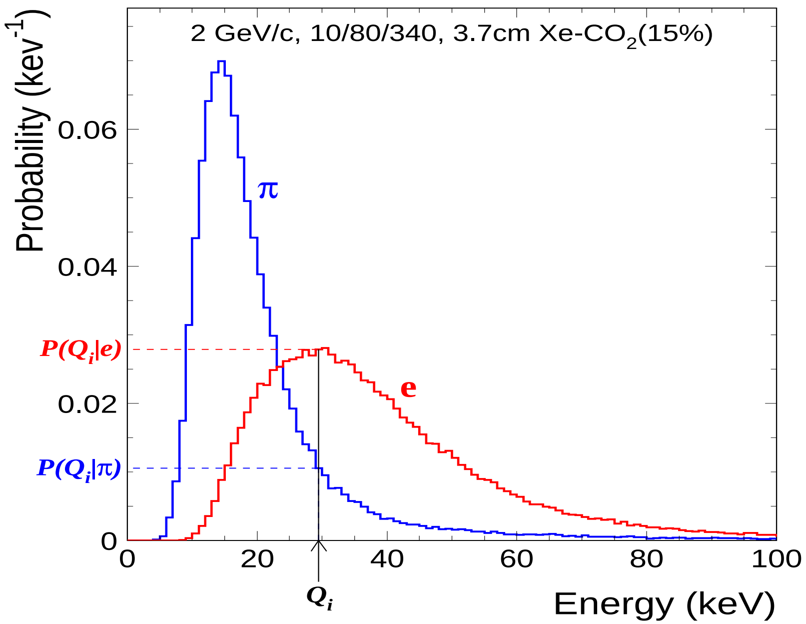
The final recipe

1. Take:

- N radiators (regular foils or random fibres)
- N detectors (MWPC with Xe-based mixture)

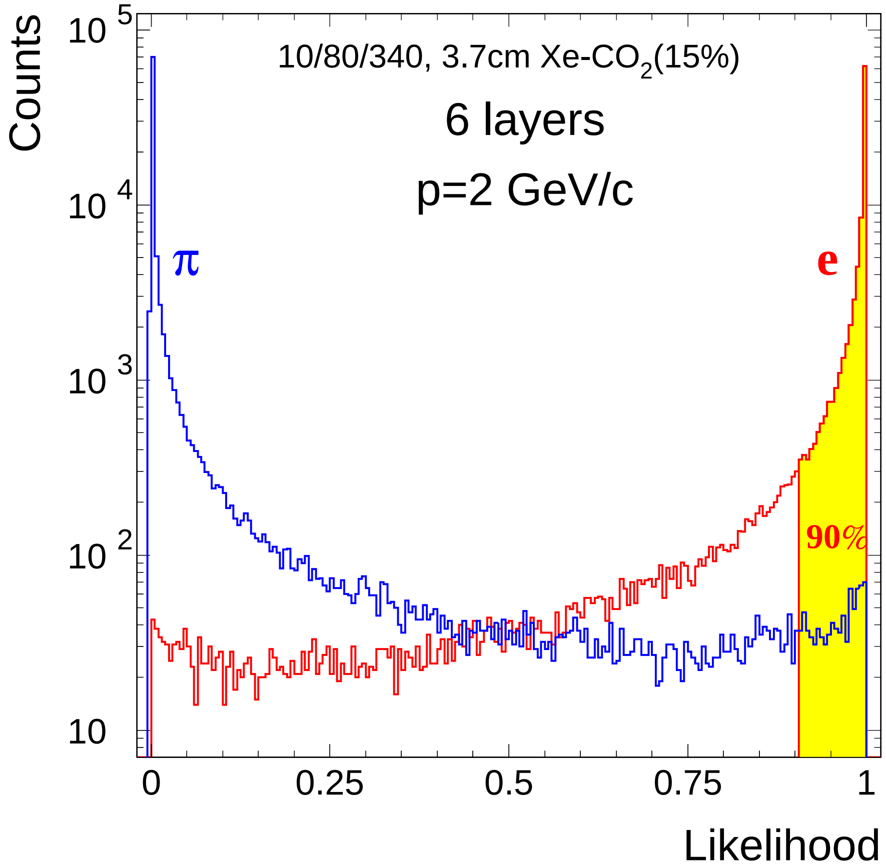
2. Shake well ...into N layers radiator+detector

3. Measure Q spectra in one layer (e,π)

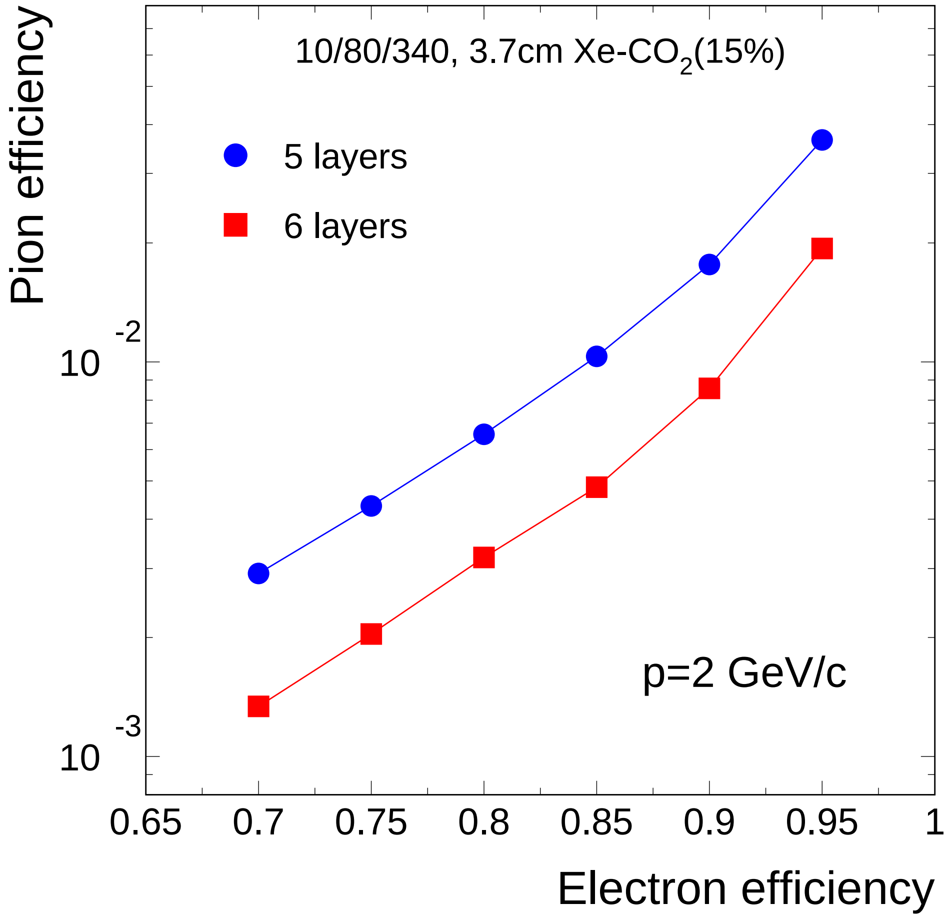


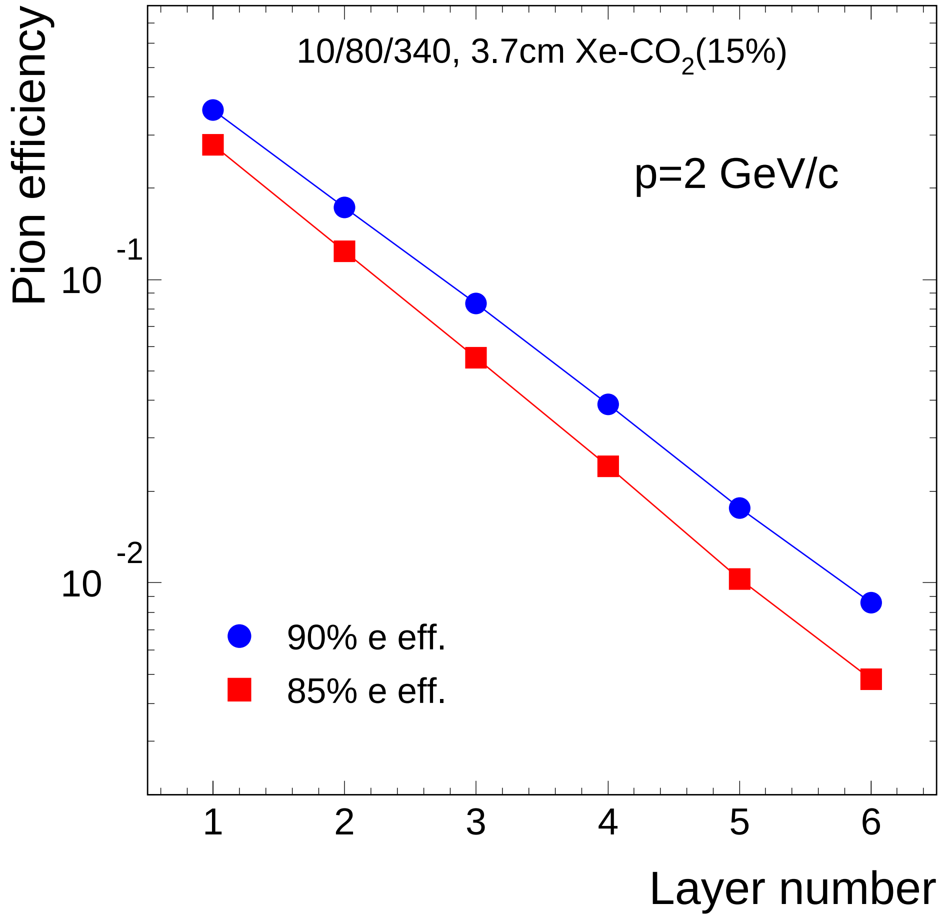
4. Construct **Likelihood** (*to be an electron*)

$$L = \frac{P_e}{P_e + P_\pi} \quad P_{e,\pi} = \Pi_{i=1}^{N} P(Q_i|e,\pi)$$



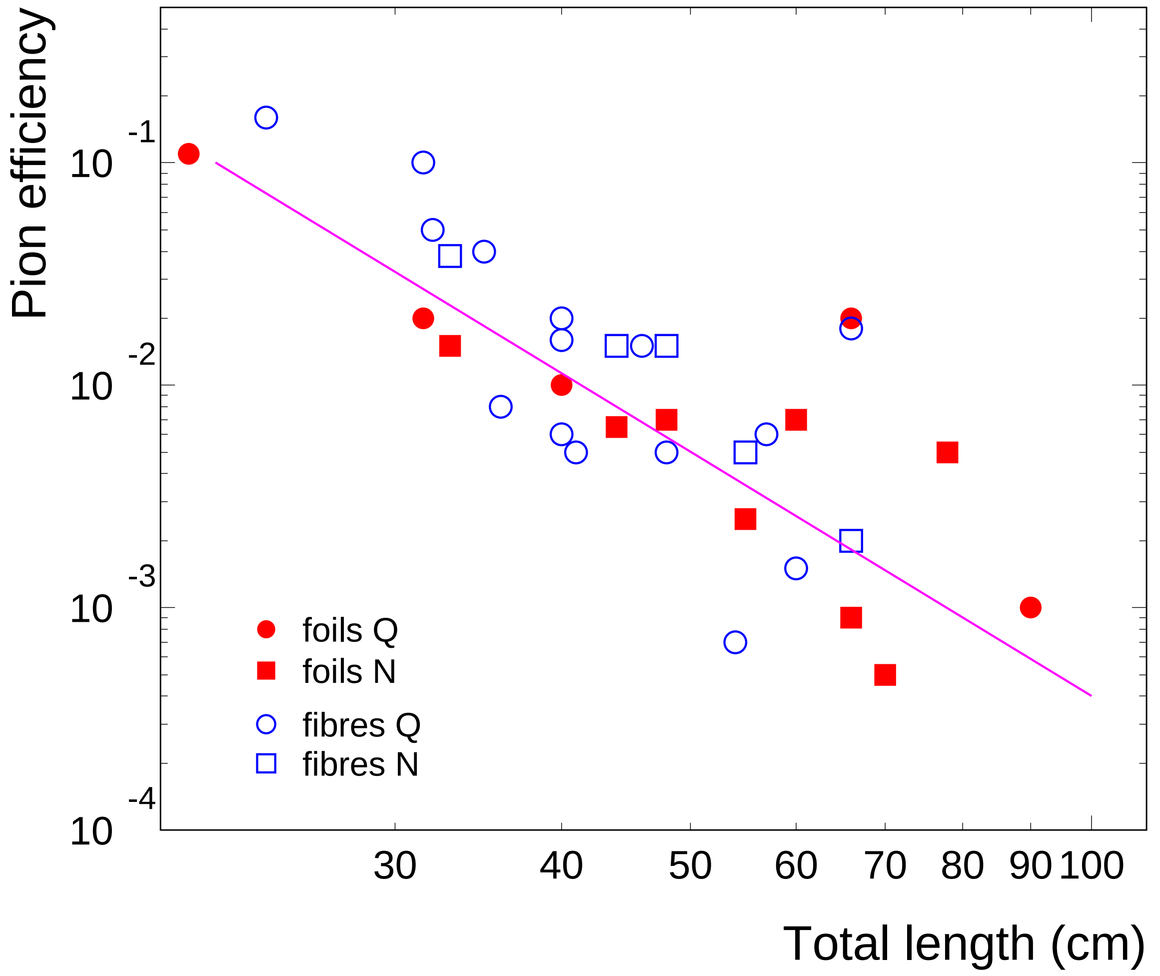
... and finally the outcome





▷ there is a choice for everybody

The grand picture



▷ find a nicer plot in Particle Physics Booklet (page 228)

A comparison of TRDs

Experiment	Radiator (x,cm)	Detector (x,cm)	Area(m^2) / N	L (cm)	N. chan.	Method	π_{rej}
HELIOS	foils (7)	Xe-C_4H_{10} (1.8)	4 / 8	70	1744	N	2000
H1	foils (9.6)	Xe-He-C_2H_6 (6)	5.3 / 3	60	1728	FADC	10
NA31	foils (21.7)	Xe-He-CH_4 (5)	18 / 4	96	384	Q	70
ZEUS	fibres (7)	Xe-He-CH_4 (2.2)	12 / 4	40	2112	FADC	100
D0	foils (6.5)	Xe-CH_4 (2.3)	11 / 3	33	1536	FADC	50
NOMAD	foils (8.3)	Xe-CO_2 (1.6)	73 / 9	150	1584	Q	1000
HERMES	fibres (6.4)	Xe-CH_4 (2.54)	28 / 6	60	3072	Q	1400
kTeV	fibres (12)	Xe-CO_2 (2.9)	39 / 8	144	∼10 k	Q	250
PHENIX	fibres (5)	Xe-CH_4 (1.8)	300 / 6	4	43 k	FADC	∼300
PAMELA	fibres (1.5)	Xe-CO_2 (0.4)	0.7 / 9	28	964	Q,N	50
AMS	fibres (2)	Xe-CO_2 (0.6)	30 / 20	55	5248	Q	1000
ATLAS	fo/fi (0.8)	Xe-CF_4-CO_2 (0.4)	1130 / 36	51-108	425 k	N,ToT	100
ALICE	fi/foam (4.8)	Xe-CO_2(3.7)	760 / 6	52	1.2 mil.	FADC	200

all radiator material CH_2