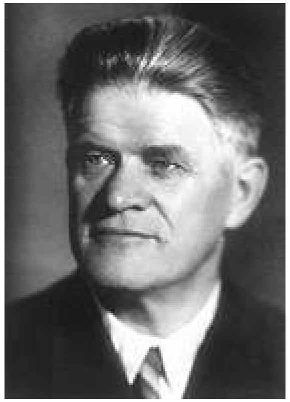
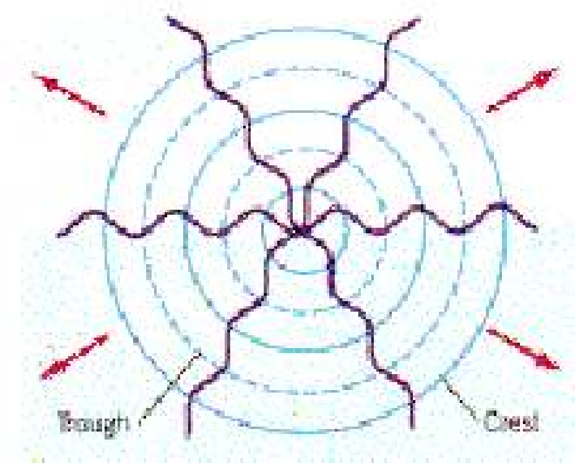
Rivelatori Čerenkov

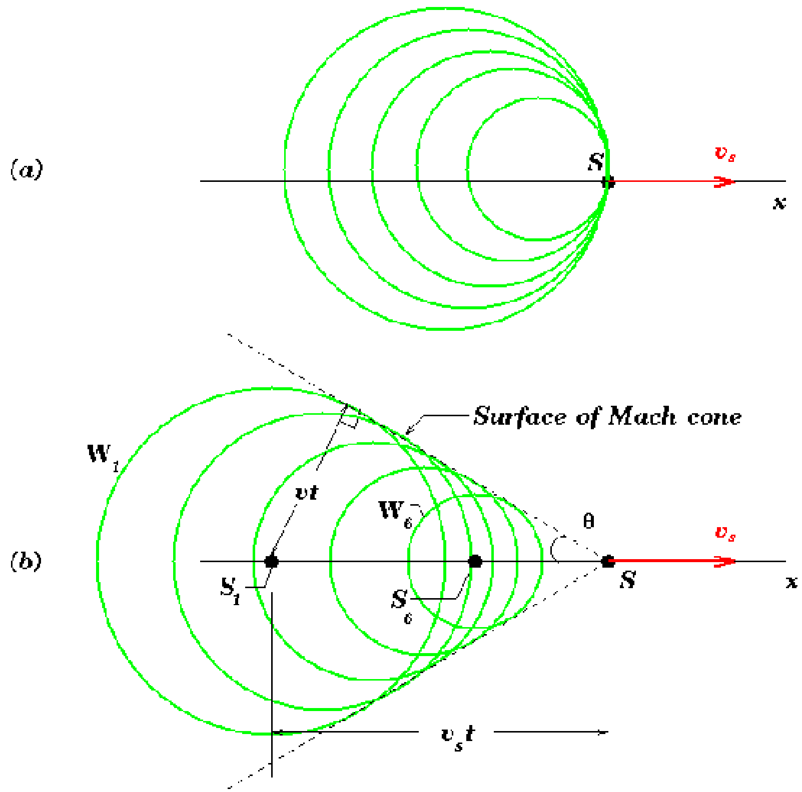
Effetto Черенков



Pavel Alekseyevich Cherenkov
(1904-1990)
Nobel 1958



Fronti d'onda per v<c/n



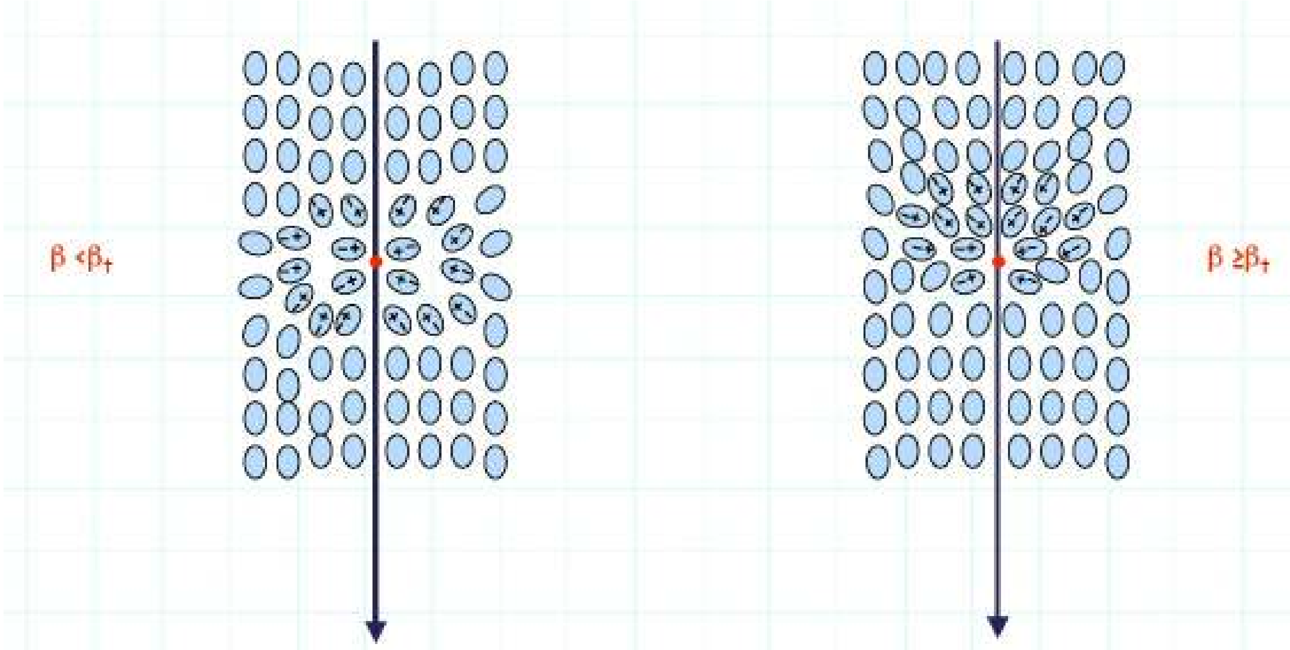
Fronti d'onda per v>=c/n

Analogie

Effetto Čerenkov (3)

Il'ja Mikhailovich Frank
(1908-1990)
Nobel 1958

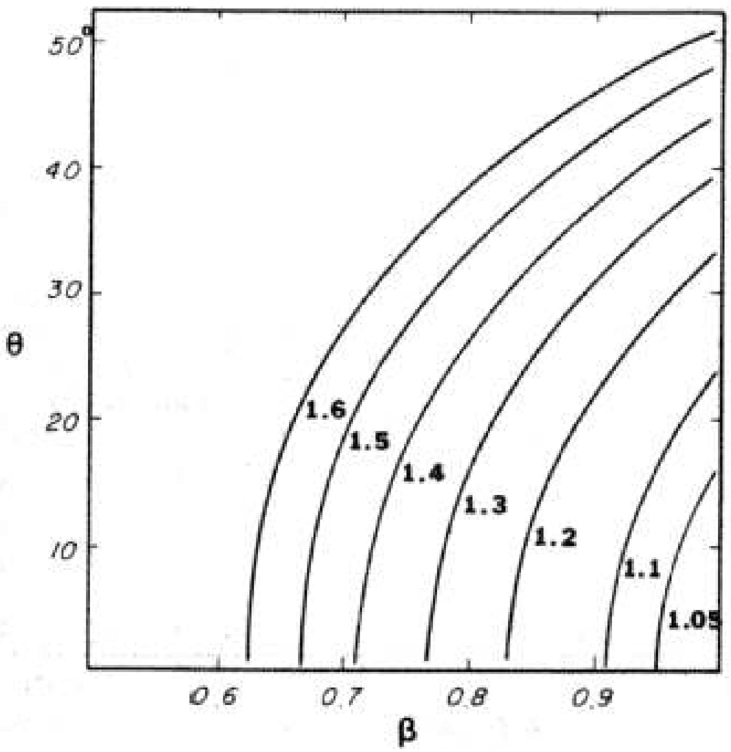
Igor Yevgenyevich Tamm
(1895-1971)
Nobel 1958

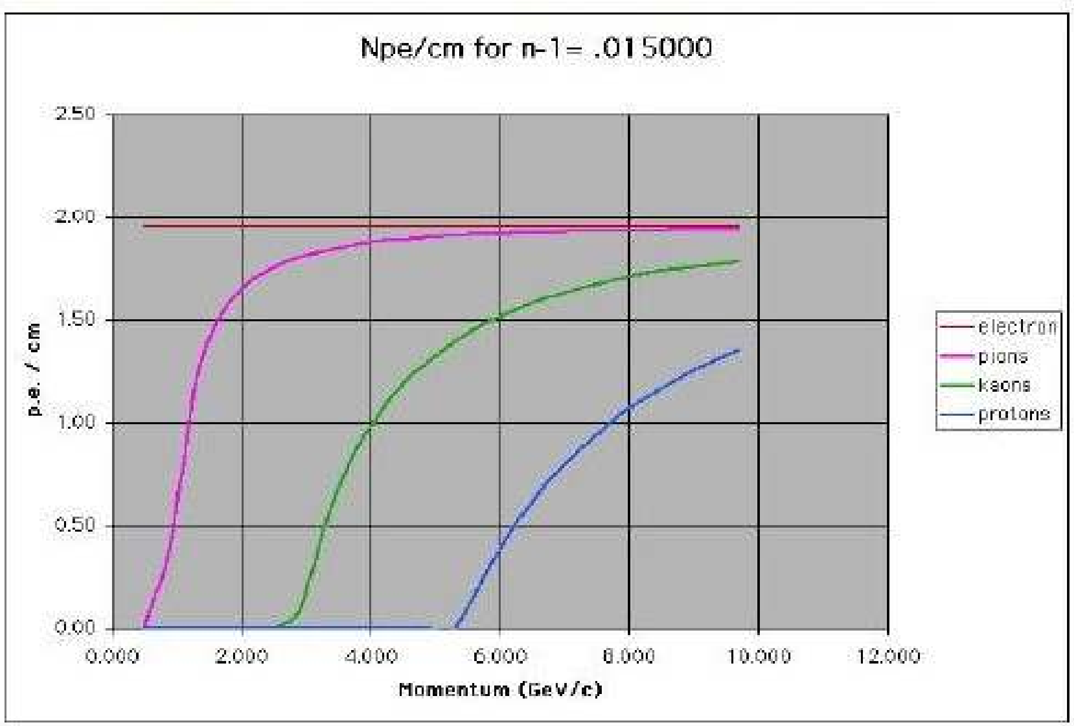


Dipoli orientati simmetricamente rispetto alla direzione del moto

Asimmetria rispetto alla direzione del moto

Effetto Čerenkov (4)

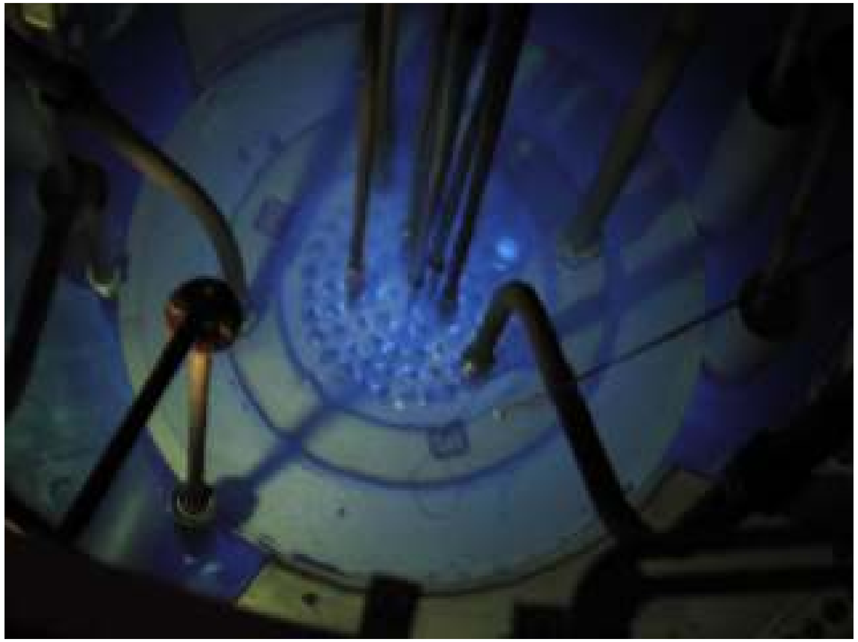




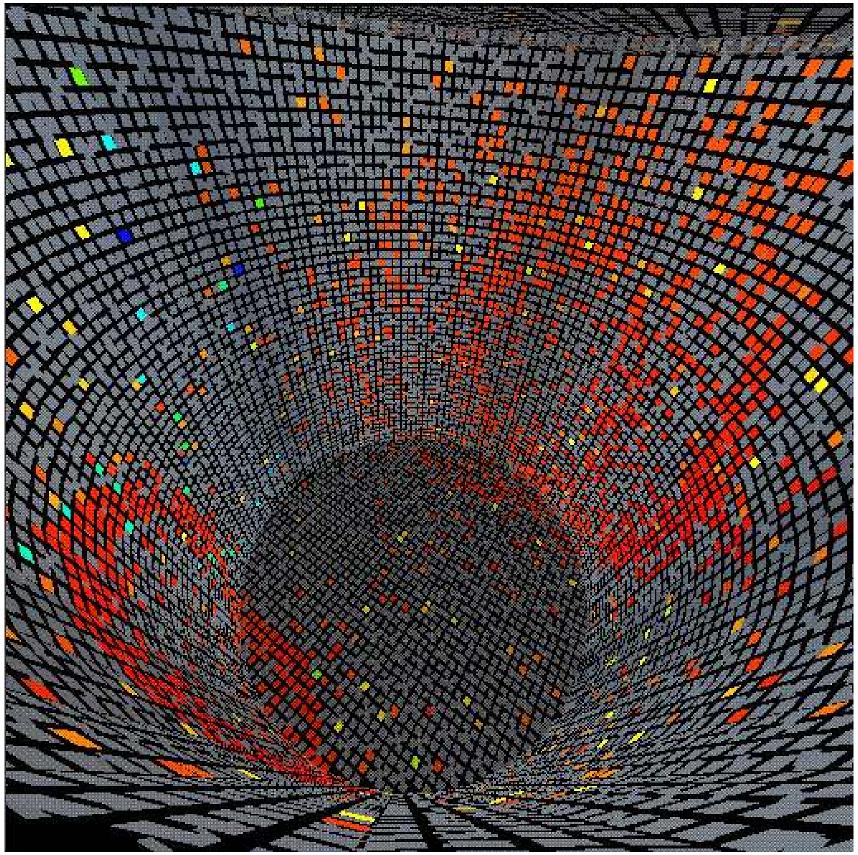
Angolo Cerenkov = f(β)

Numero di fotoni = f(β)

Effetto Čerenkov (5)

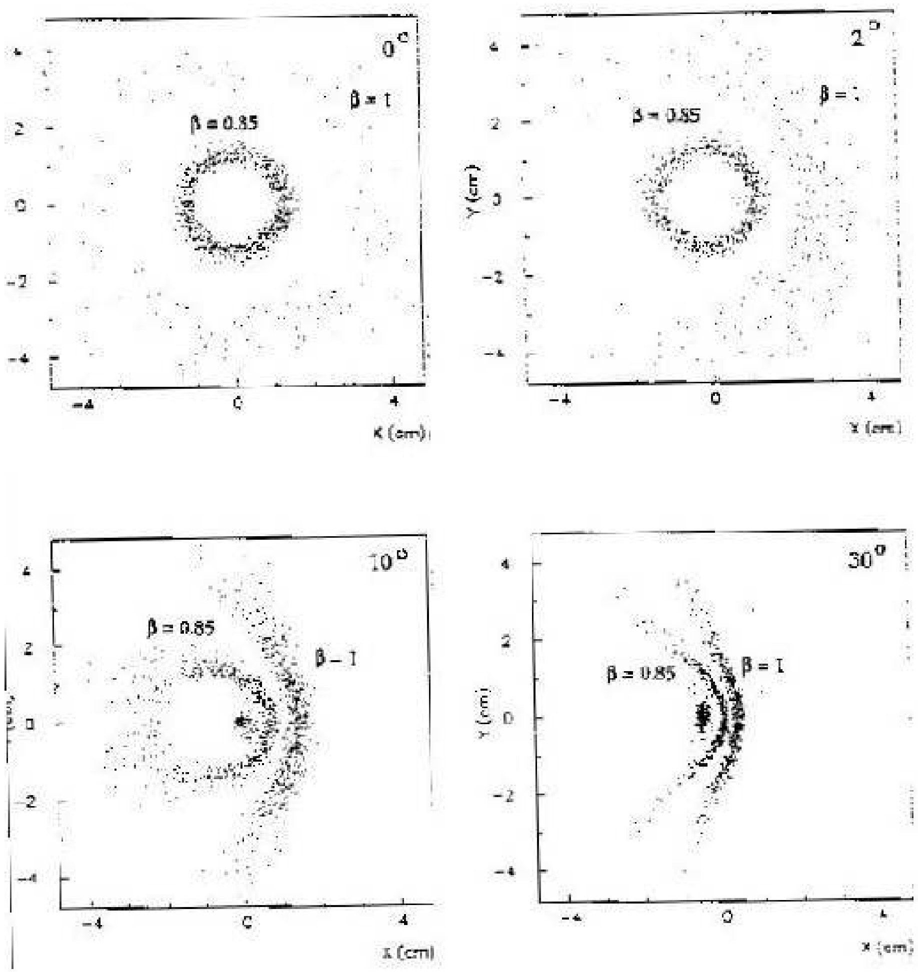


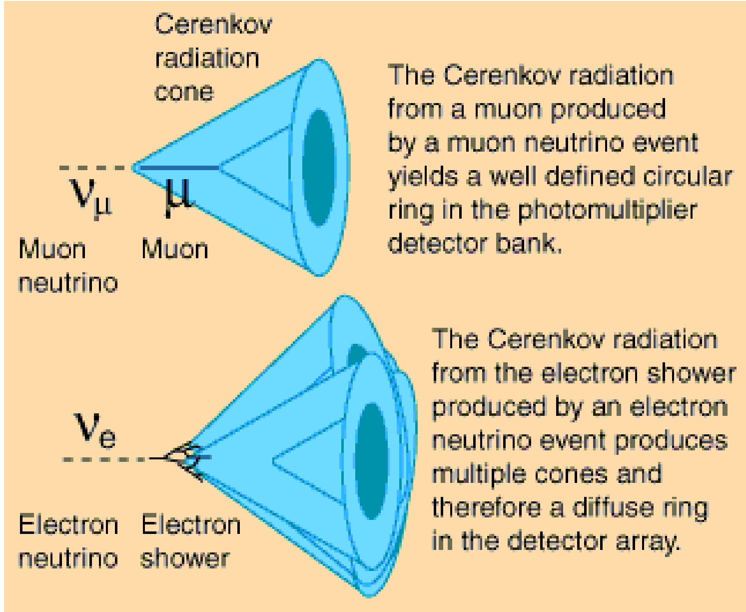
Luce Cerenkov in reattore nucleare

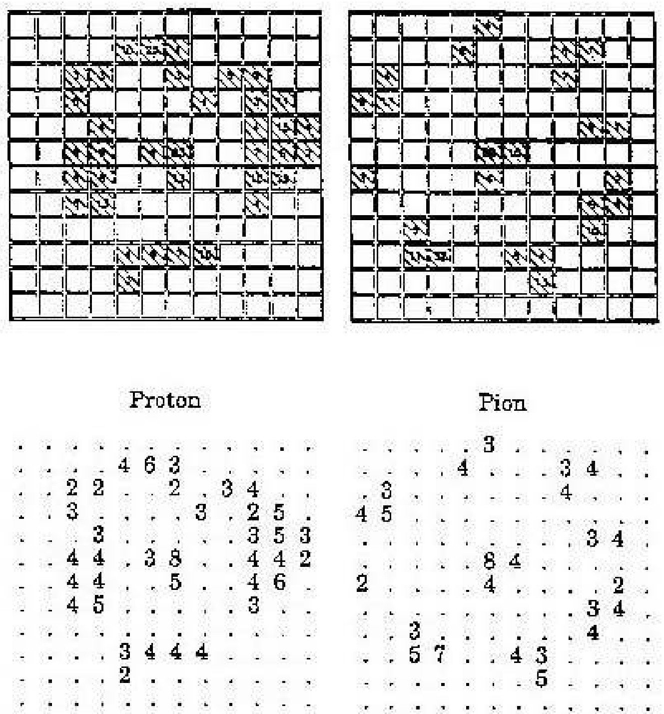


Anelli Cerenkov a SuperKamiokande

Anelli Čerenkov

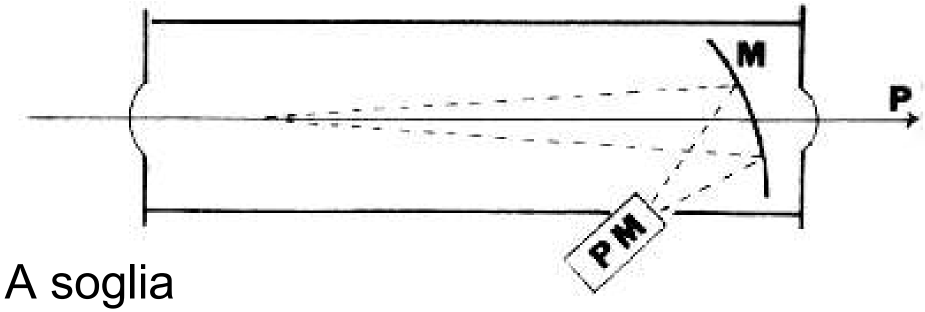




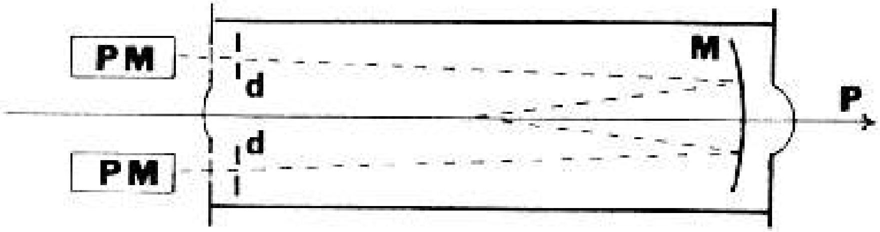


M. Sozzi

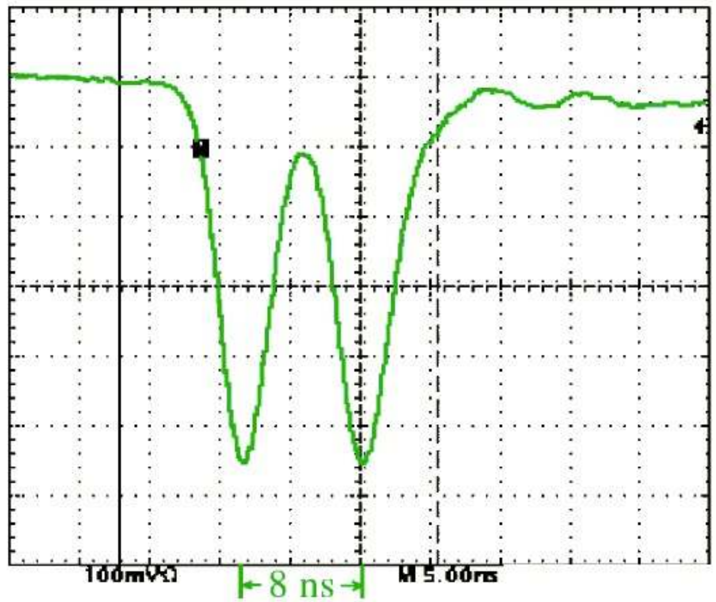
Rivelatori Čerenkov (1)



A soglia

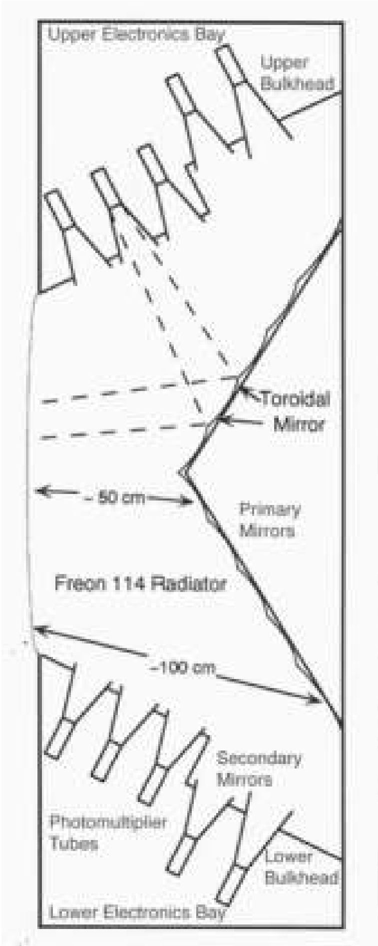


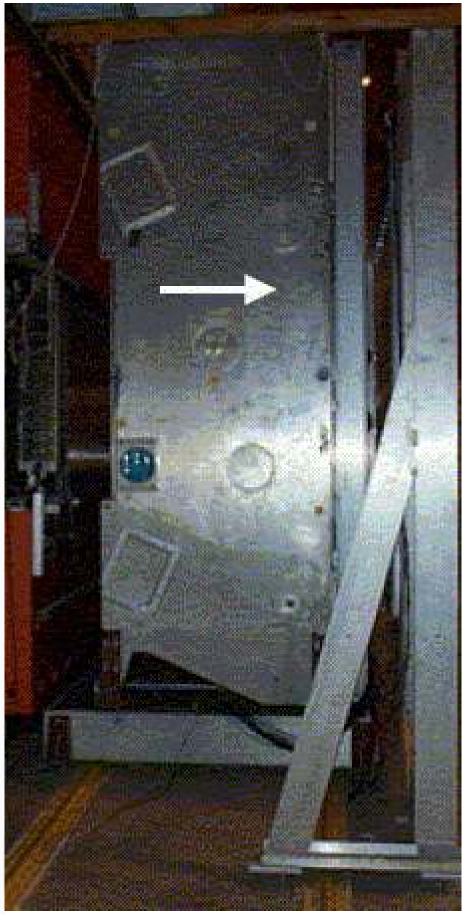
Differenziale



Risoluzione temporale

Rivelatori Čerenkov (2)



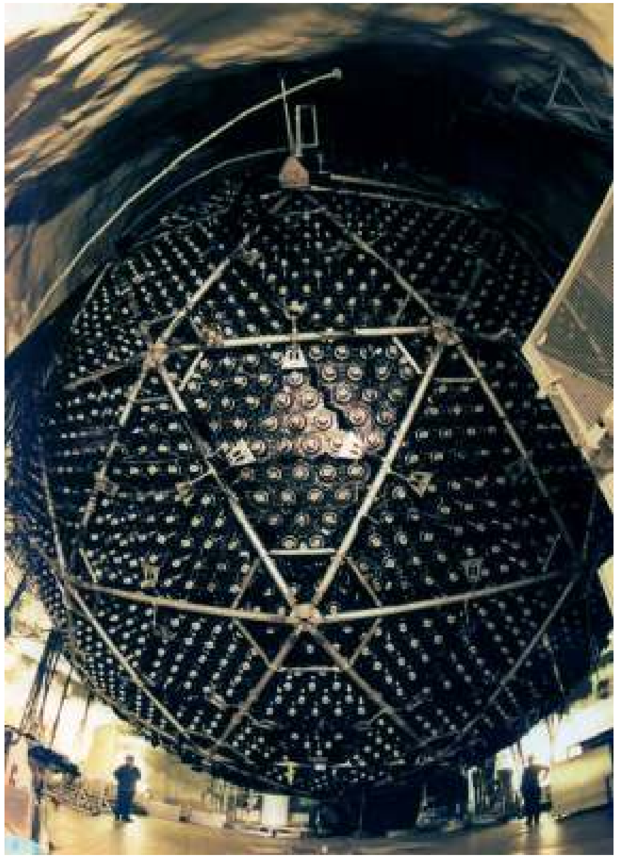


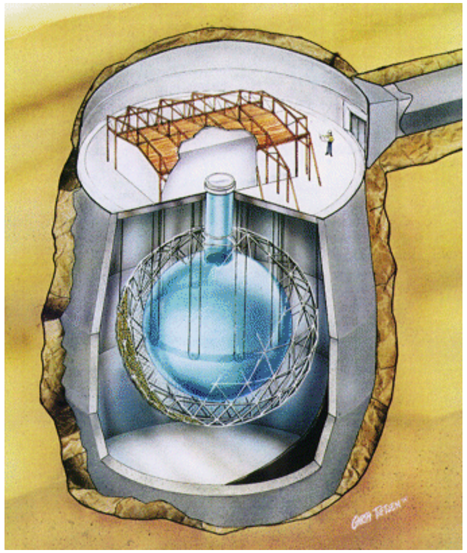
Rivelatore Cerenkov a soglia

M. Sozzi

Rivelatori Čerenkov (3)

Esperimento ANTARES

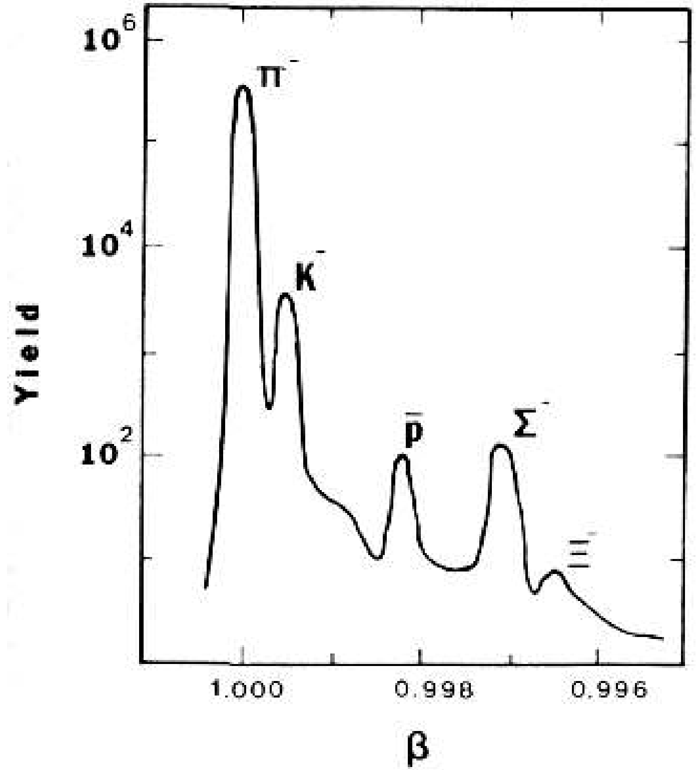




Sudbury Neutrino Observatory

Rivelatori Čerenkov (4)

Identificazione di particelle



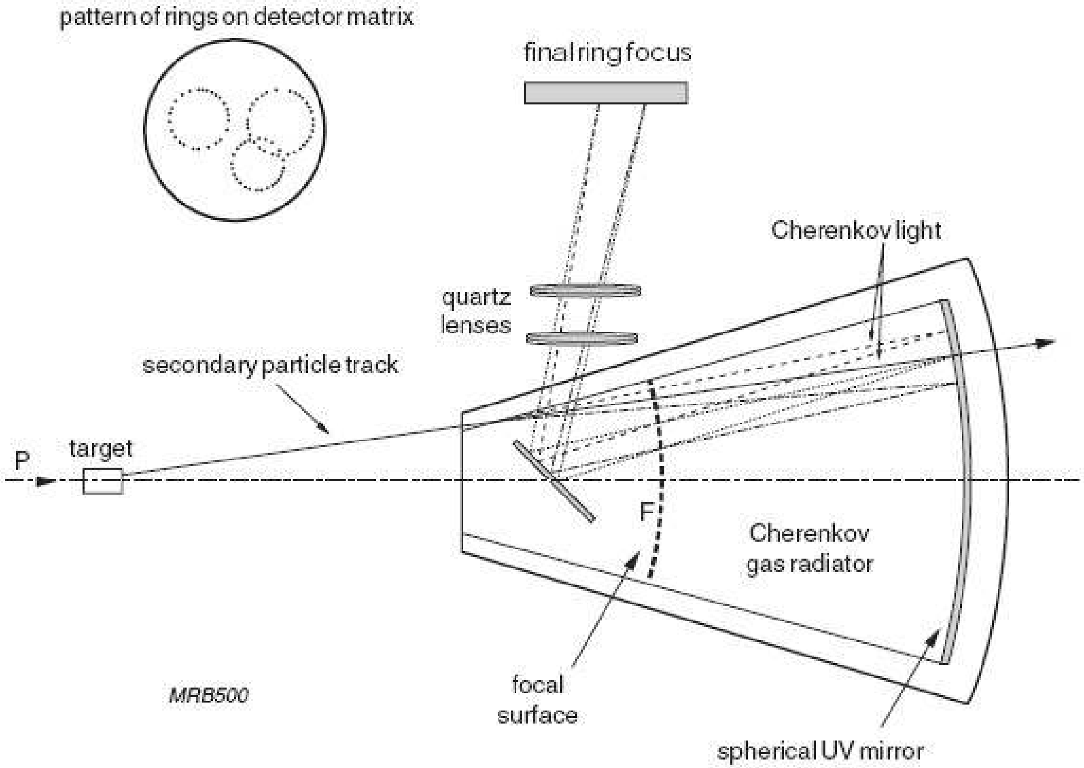
Scelta del gas

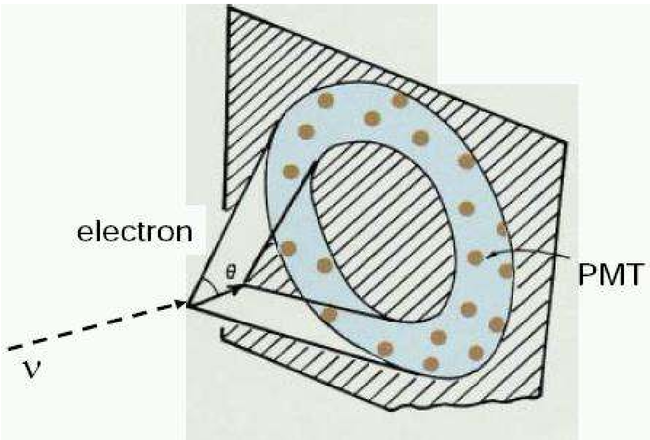
Gas name	Chemical composition		Refr. index
Freon 12	CCl_2F_2	[3]	1.001080
	CCl_2F_2	[4]	1.001127
Freon 13 B1	CCl_2F_2	[5]	1.000864
Freon 13	$CClF_3$	[4]	1.000782
Freon 114	$C_2Cl_2F_4$	[6]	1.0014 [7]
Freon 318	C_4F_8	[4]	1.001285
Perfluorobutane	C_4F_{10}	[8, 9]	1.00153
Perfluoropentane	C_5F_{12}	[8, 9]	1.00172

Tom Ypsilantis
(1928-2000)
e J. Seguinot

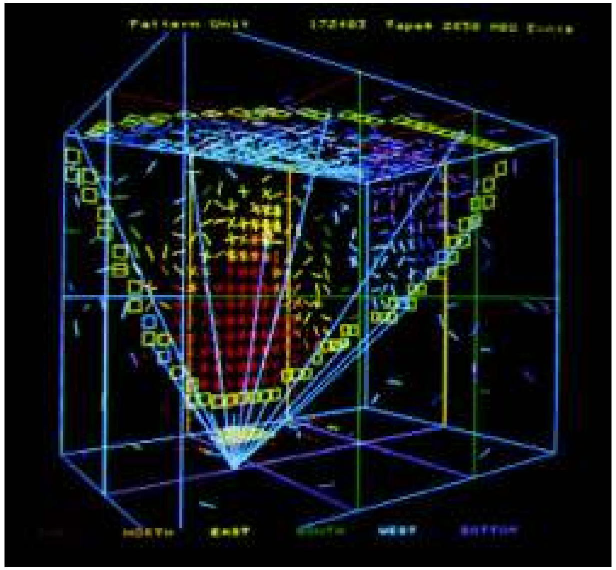
RICH (1)

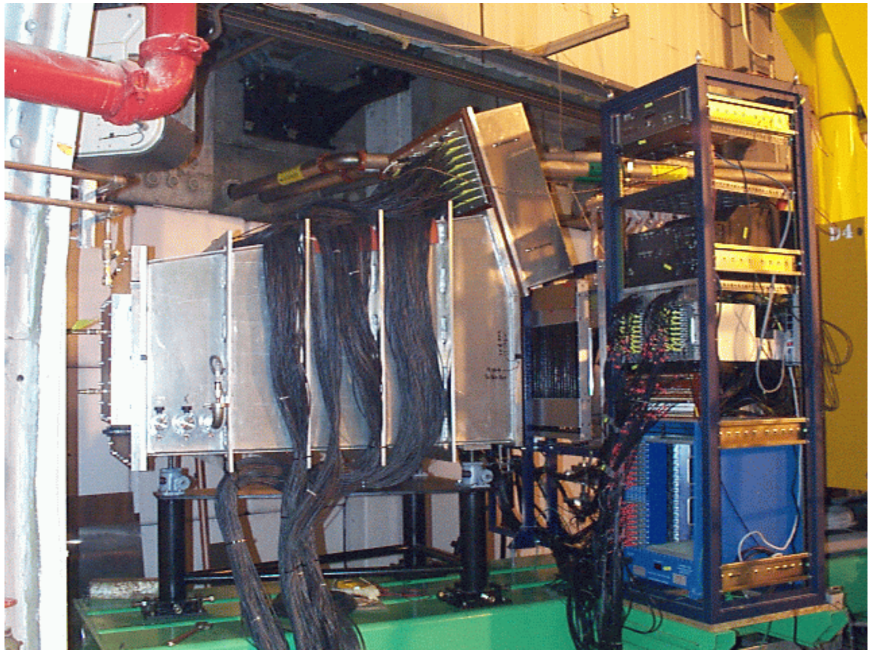
Ring **I**maging **CH**erenkov counter

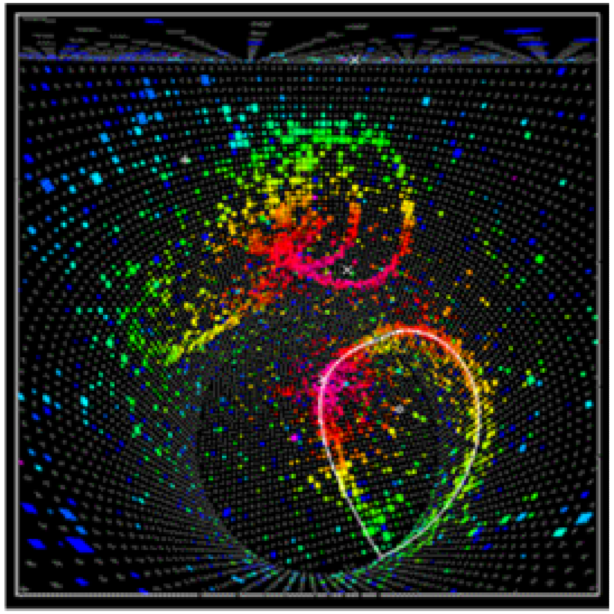




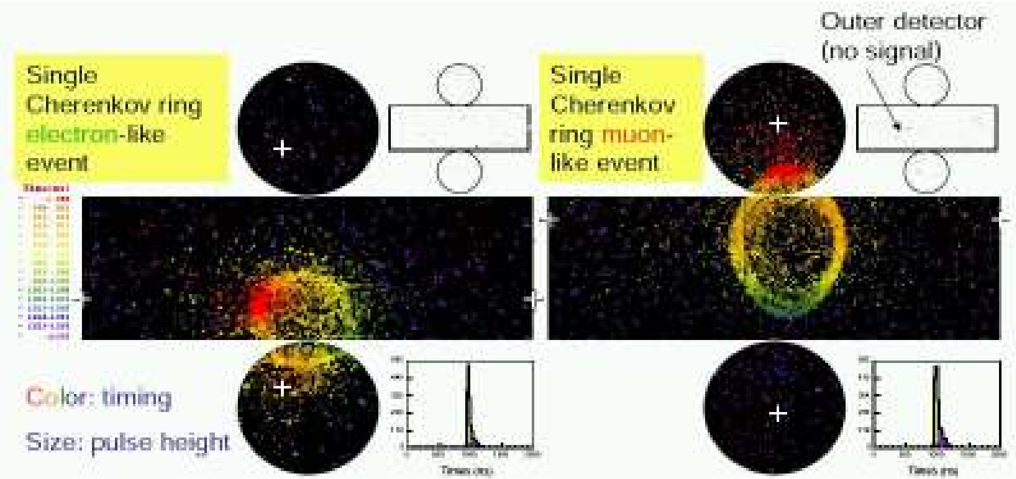
RICH (2)

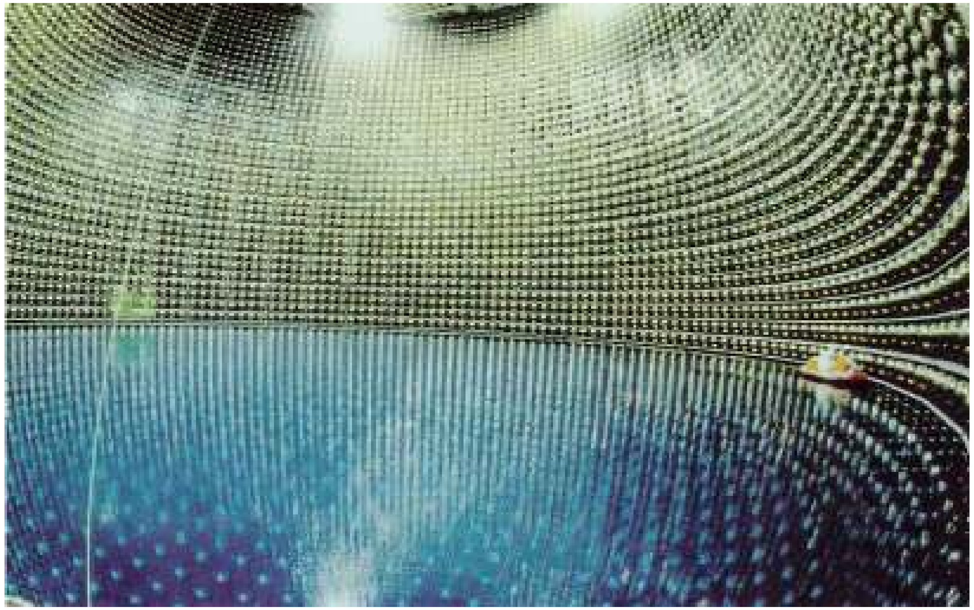


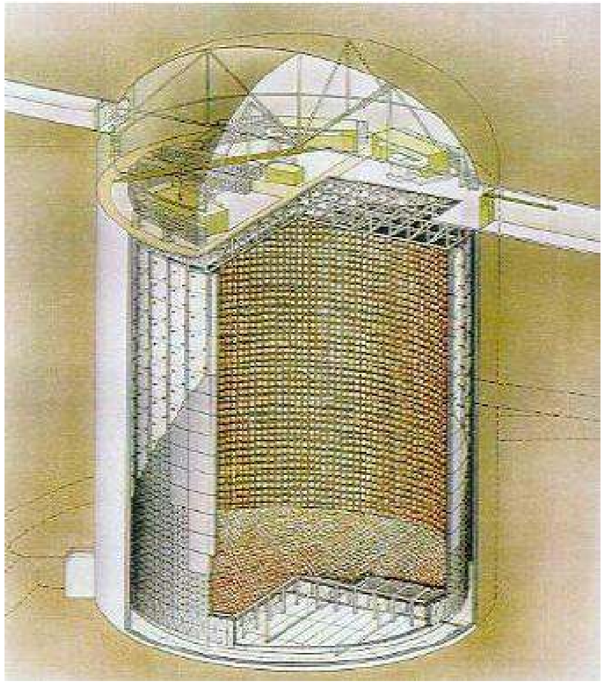




RICH: SuperKamiokande





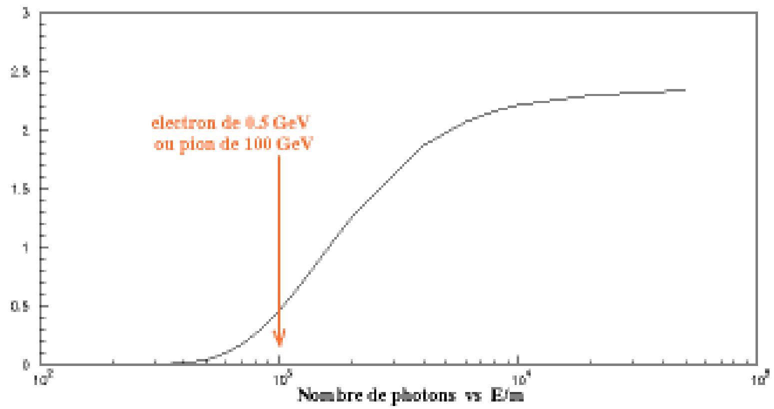


M. Sozzi

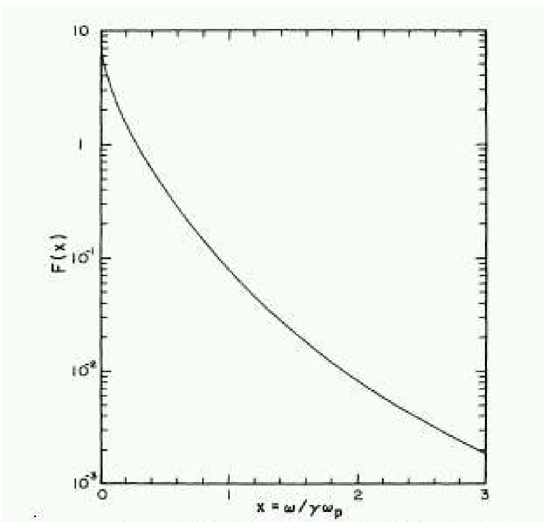
Radiazione di transizione

$$\frac{dE}{d\omega d\theta} = \frac{\alpha}{\pi^2}\theta\left|\frac{1}{1/\gamma^2+\theta^2+(\omega_{P1}/\omega)^2} - \frac{1}{1/\gamma^2+\theta^2+(\omega_{P2}/\omega)^2}\right|^2$$

$$\omega_{Pi} = \frac{4\pi\alpha n_{ei}}{m_e} \cong (28.8\,\mathrm{eV})^2\,\frac{Z\rho}{A}$$

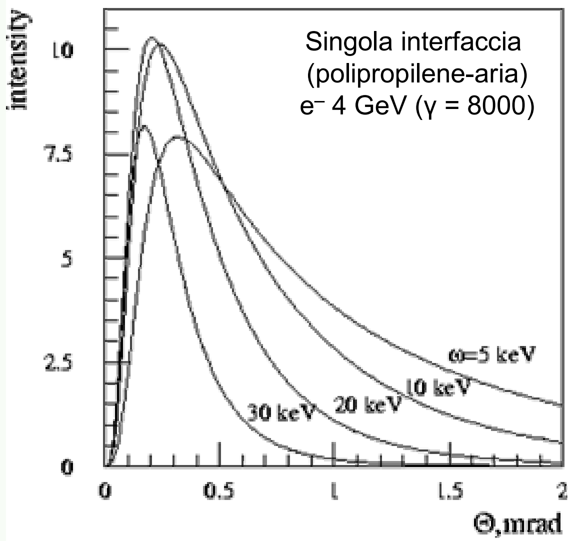


Spettro in frequenza

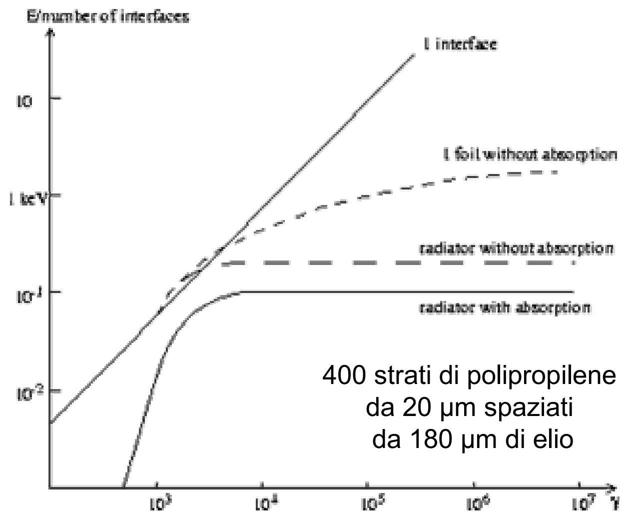


Variation of the spectral distribution function $F(x)$, Eq. (35), with the parameter $x = \omega/\gamma\omega_p$. The frequency spectrum of the transition radiation from a thick slab is given by $d\mathcal{E}/d\omega = (2e^2/\pi c)F(x)$.

Distribuzione angolare



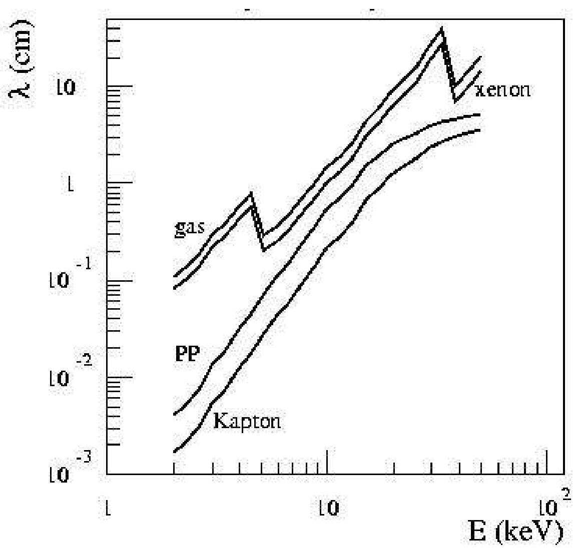
Energia

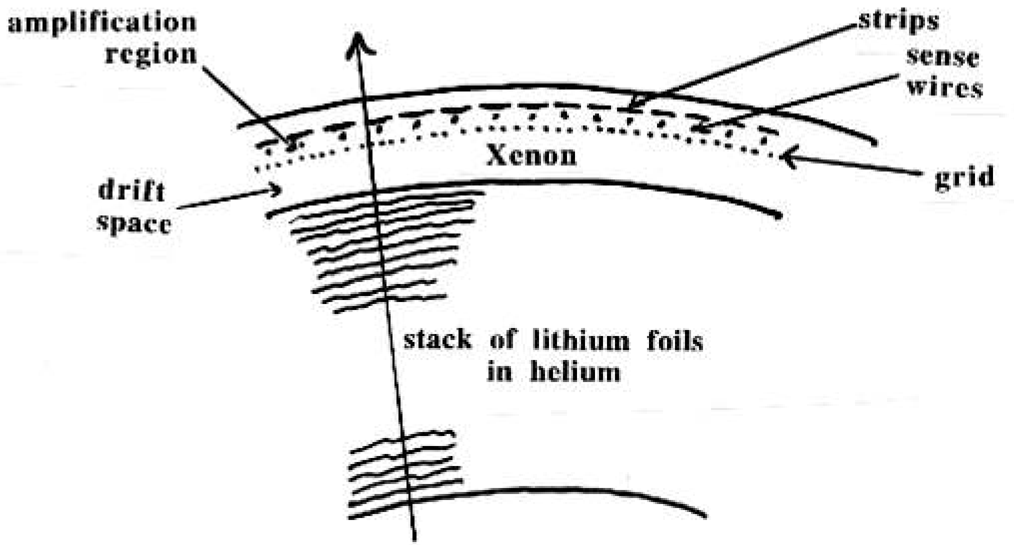


TRD
Transition Radiation Detector

$$\frac{dE}{d\omega} = \frac{\alpha}{\pi}\left(\frac{\omega_{P1}^2+\omega_{P2}^2+2\omega^2/\gamma^2}{\omega_{P1}^2-\omega_{P2}^2}\log\frac{\omega^2/\gamma^2+\omega_{P1}^2}{\omega^2/\gamma^2+\omega_{P2}^2}-2\right) \qquad E=\frac{2\alpha\gamma\omega_{P1}}{3} \qquad (\omega_{P2} << \omega_{P1})$$

Intrerfacce multiple
Rivelatore a gas pesante
(Xe) per rivelare fotoni X

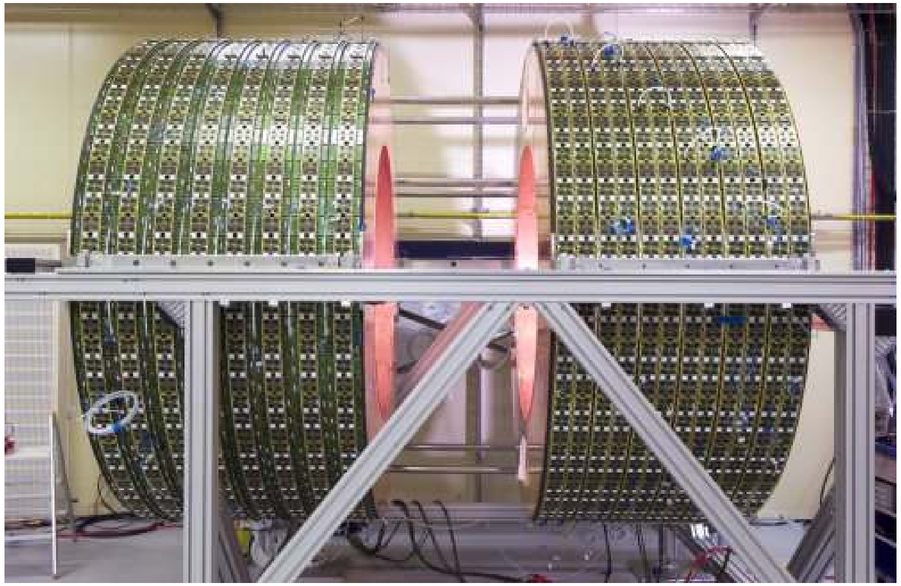




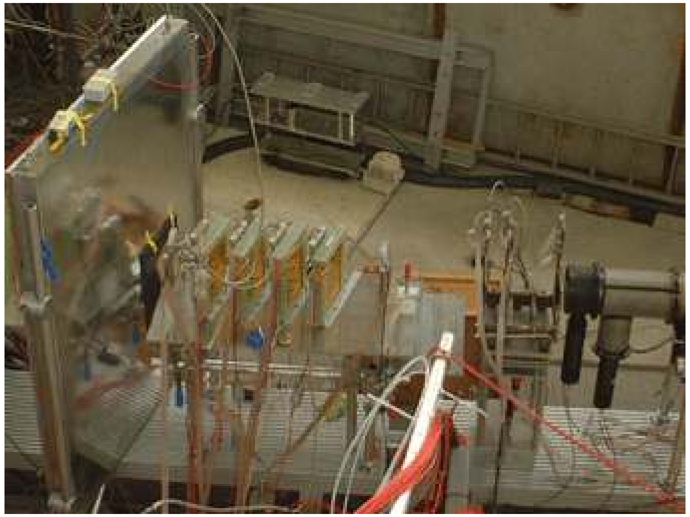
TRD

ATLAS Transition
Radiation Tracker

420000 straws
polipropilene-CO_2
Fotoni da 10 keV
Risoluzione 130 μm



Prototipo TRD
esperimento ALICE



M. Sozzi

Rivelatori a gas

Moto nei gas

Moto coerente $$\vec{v}_d = \mu \vec{E}$$

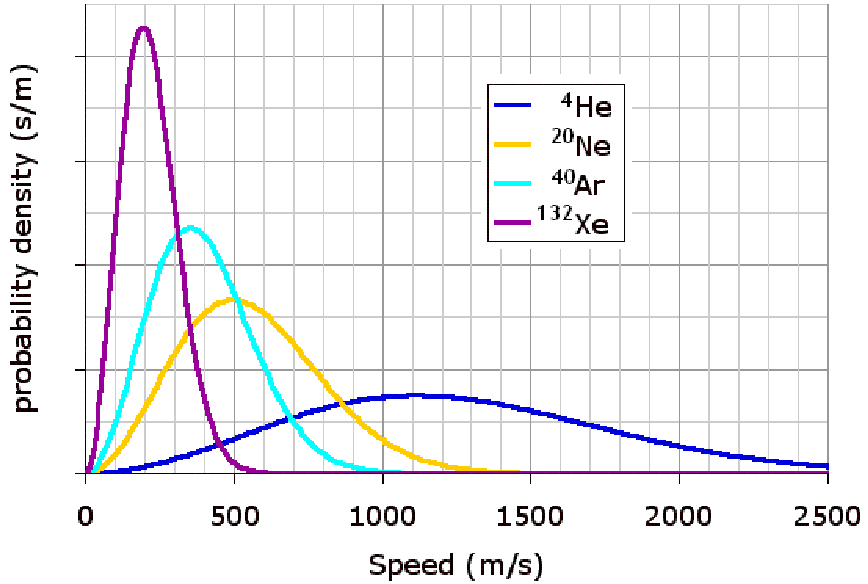
Moto termico $$\frac{dn}{dv} = 4\pi \left(\frac{m}{2\pi kT} \right)^{3/2} e^{-mv^2\,2kT} v^2$$

$$\langle E \rangle_{STP} = \frac{3}{2} kT \approx 0.04\,\mathrm{eV}$$

James Clerk Maxwell (1831-1879)

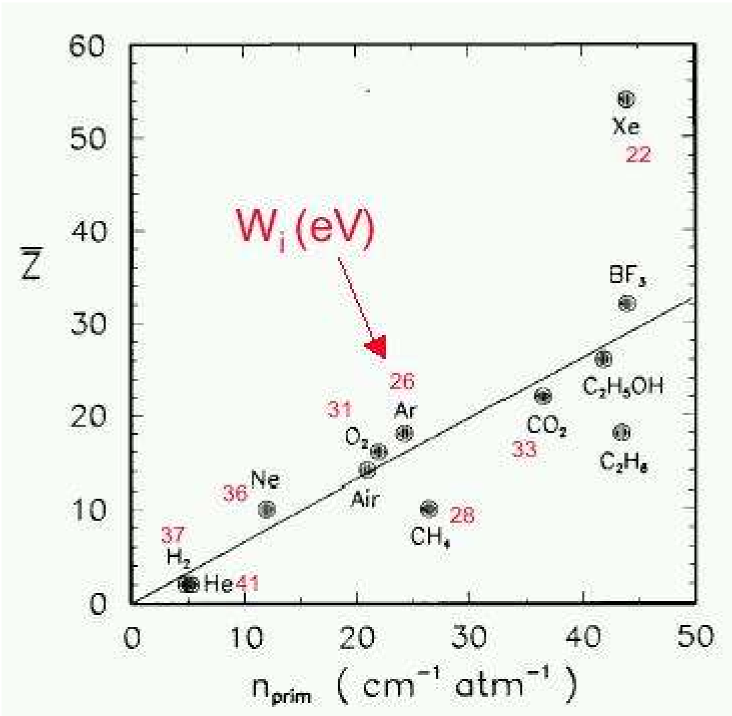
Ludwig Eduard Boltzmann (1844-1906)

Distribuzione di Maxwell-Boltzmann

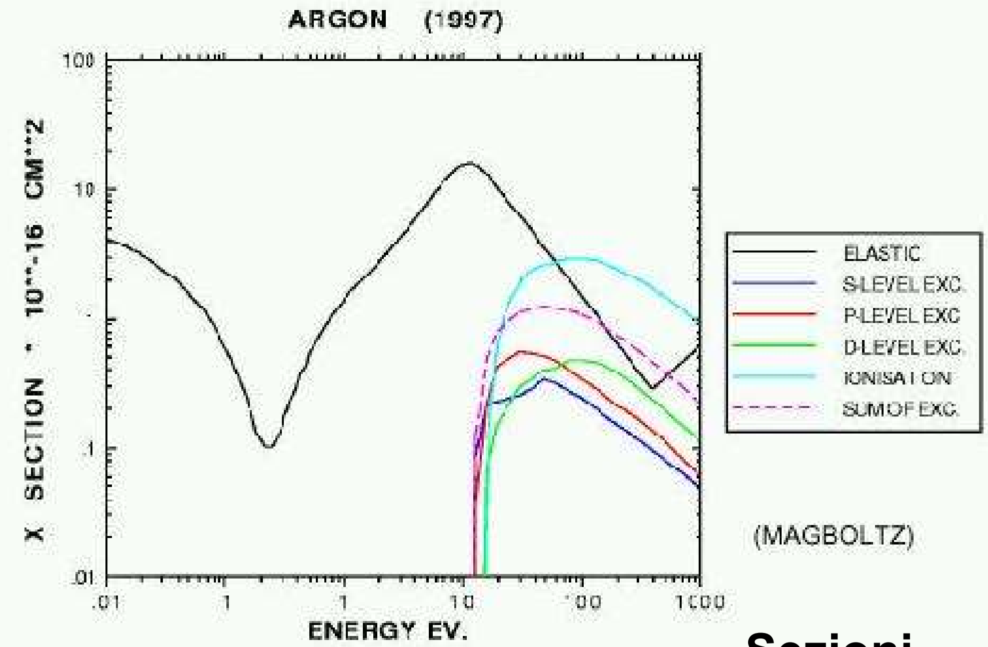


Ionizzazione nei gas

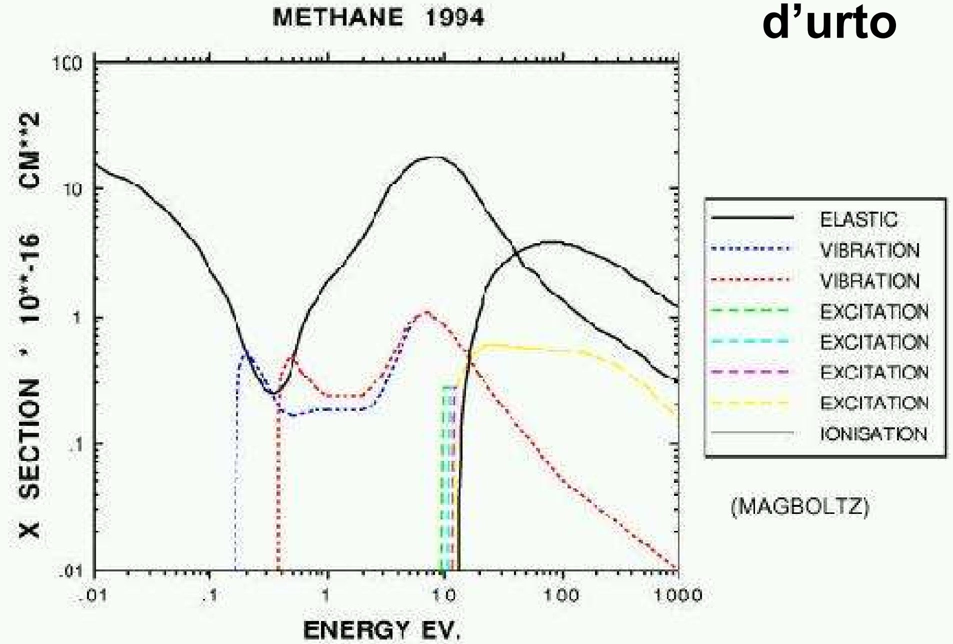
Gas nobili



Ionizzazione primaria



Sezioni d'urto



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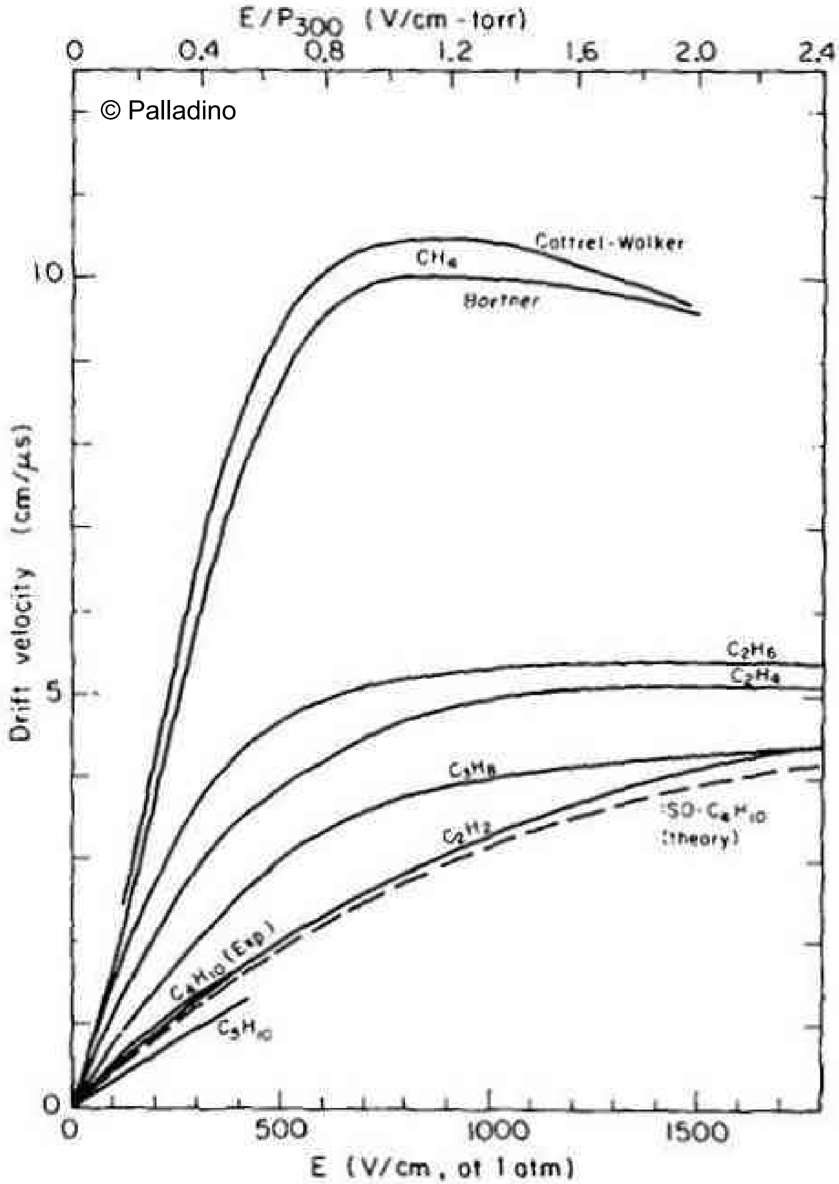
Deriva



E / P300 (V/cm - torr)
0
0.4
0.8
1.2
1.6
2.0
2.4
© Palladino
Cottrel - Walker
CH4
Bortner
10
Drift velocity (cm/µs)
C2H6
C2H4
5
C3H8
C2H2
ISO-C4H10
(theory)
C4H10 (Exp)
C5H10
0
0
500
1000
1500
E (V/cm, at 1 atm)

Trasporto e diffusione

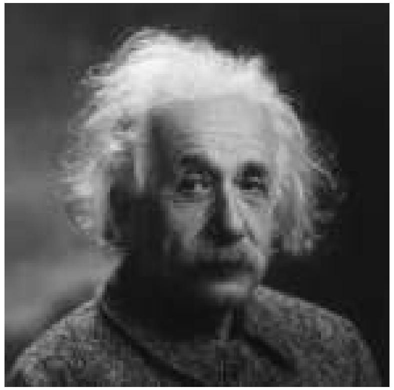
$$\frac{\partial \rho}{\partial t} = D\nabla^2 \rho$$

Seconda legge di Fick

$$\mu = \frac{qD}{kT}$$

Relazione di Einstein-Smoluchowski

Adolf Fick
(1829-1901)



Albert Einstein
(1879-1955)
Nobel 1921

Marian Ritter
von Smolan
Smoluchowski
(1872-1917)

Diffusione

$$\rho(\mathbf{x},0) = \rho_0(\mathbf{x})$$

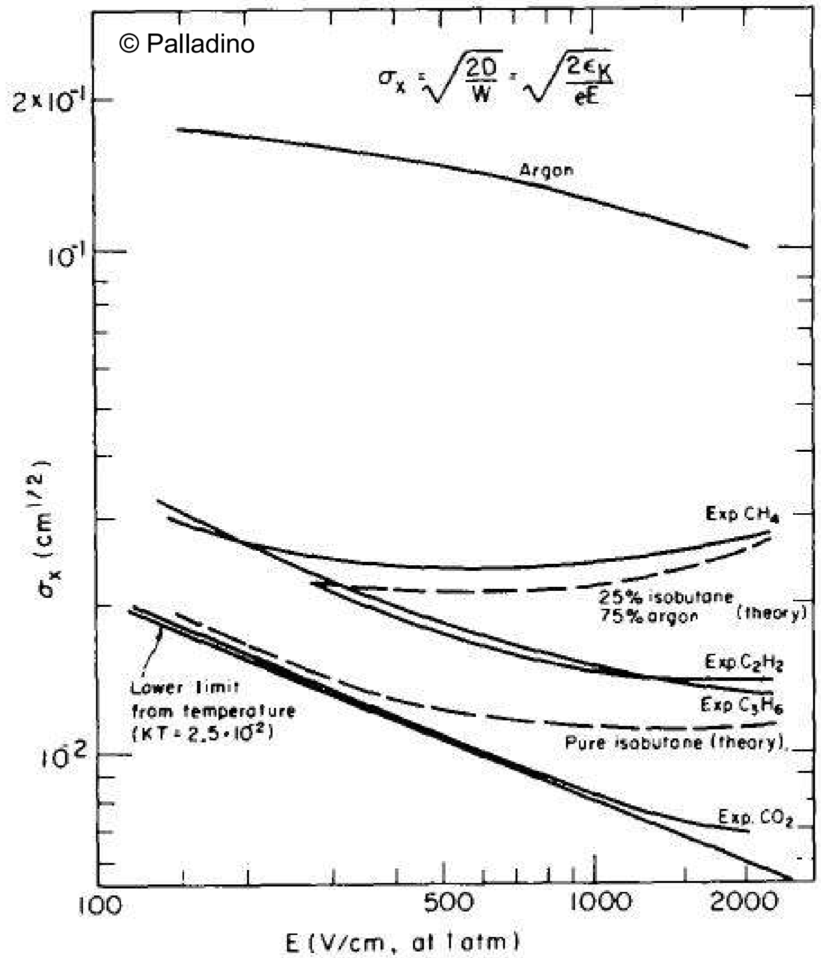
$$\rho(\mathbf{x},t) = \frac{1}{\left(2\sqrt{\pi D t}\right)^3} \int d\mathbf{x}' \rho_0(\mathbf{x}') e^{-(\mathbf{x}-\mathbf{x}')^2/4Dt}$$

$$\sigma_x = \sqrt{2Dt} = \sqrt{\frac{2Dx}{v_d}}$$

$$D = \frac{1}{3}\langle \lambda v \rangle$$

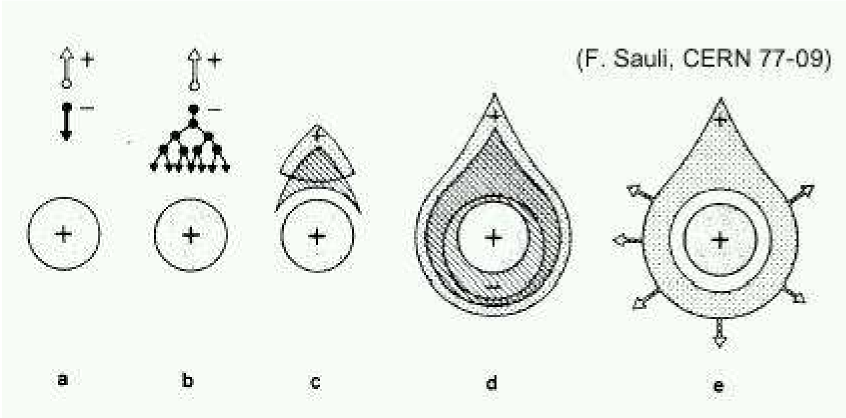
Coefficiente di diffusione

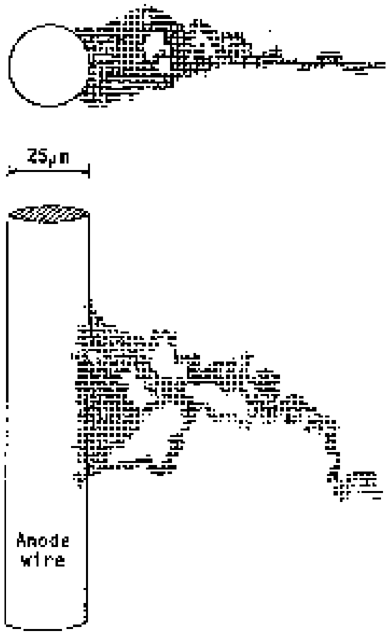
σ_x (diffusione dopo 1 cm)

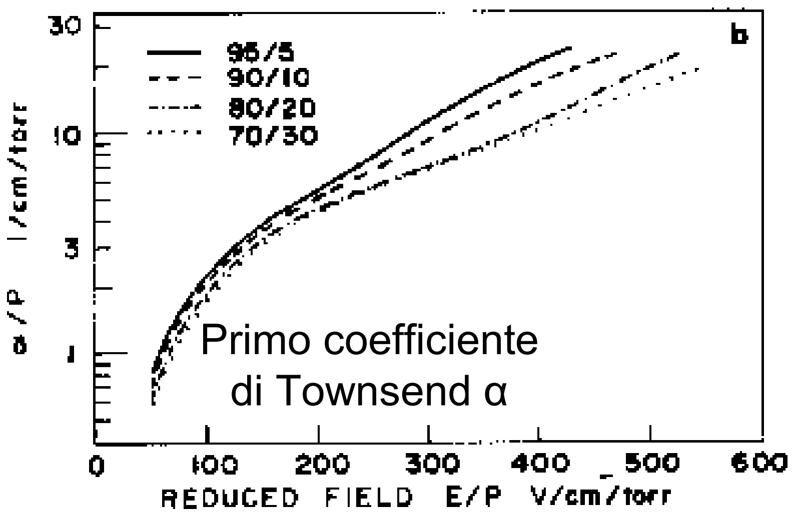


Moltiplicazione (1)

Formazione
valanga
in < 1 ns

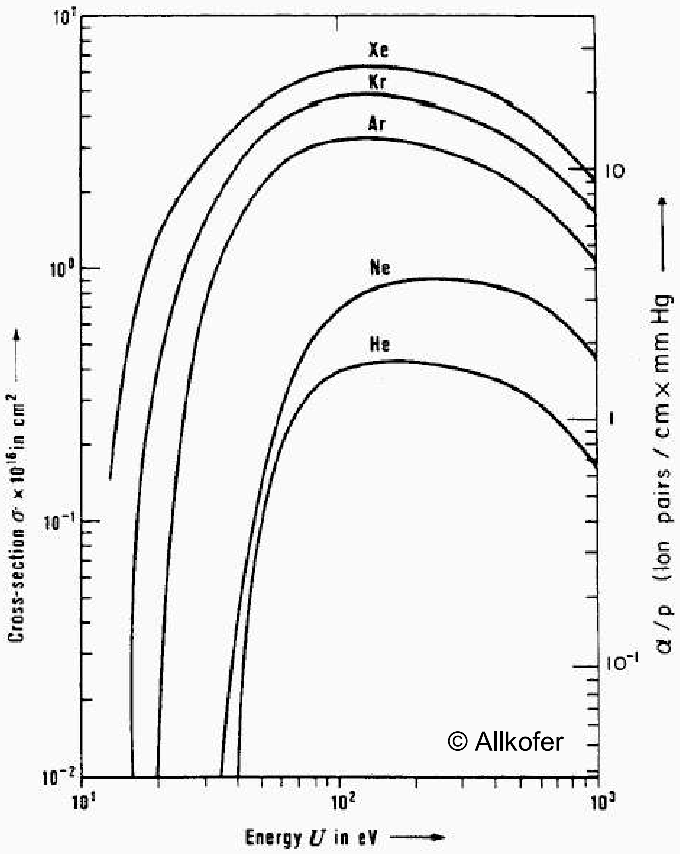






Primo coefficiente
di Townsend α

Moltiplicazione (2)

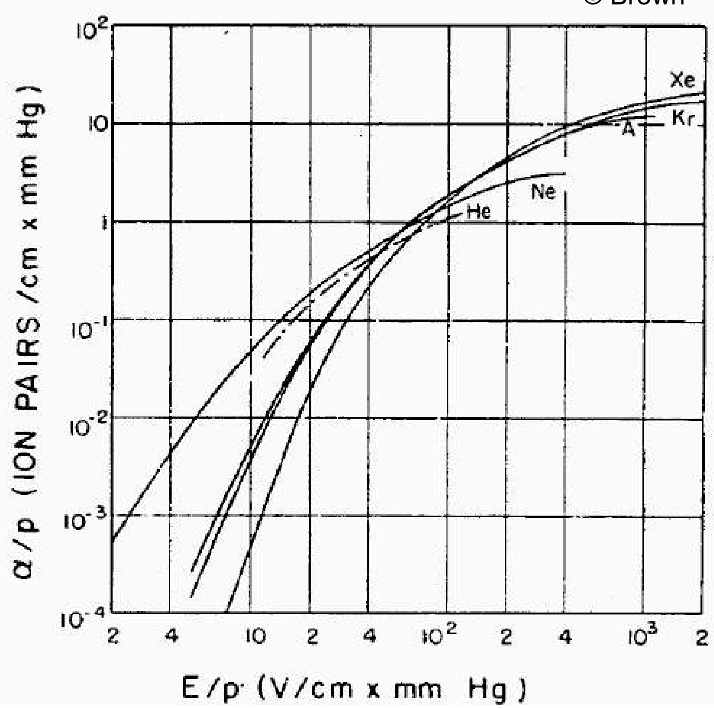


Mean free path for ionization

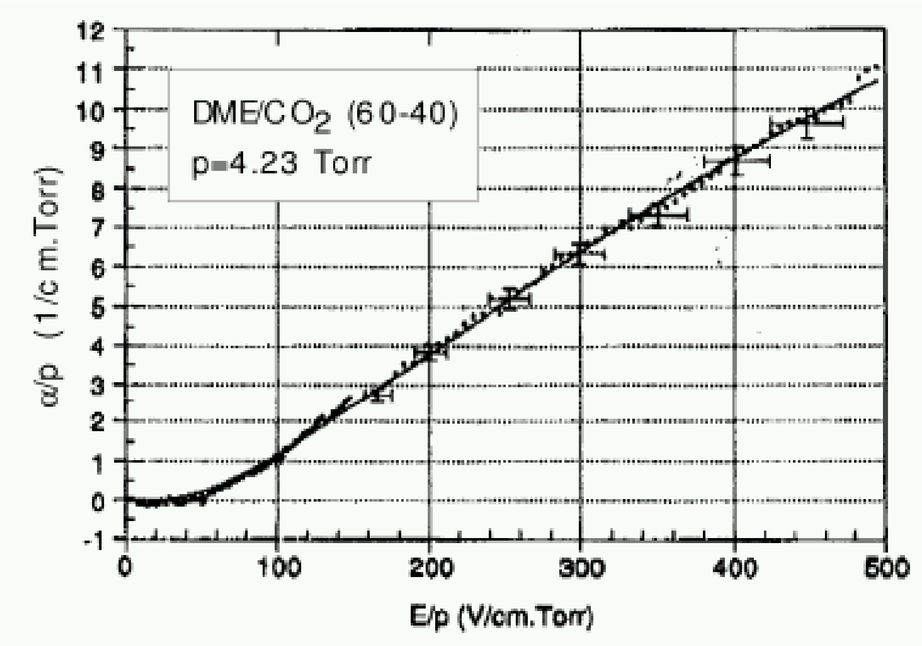
$$\lambda = \frac{1}{N\sigma}$$ *N: molecules/cm^3*

Townsend coefficient

$$\alpha = \frac{1}{\lambda}$$ *Ionizing collisions/cm*

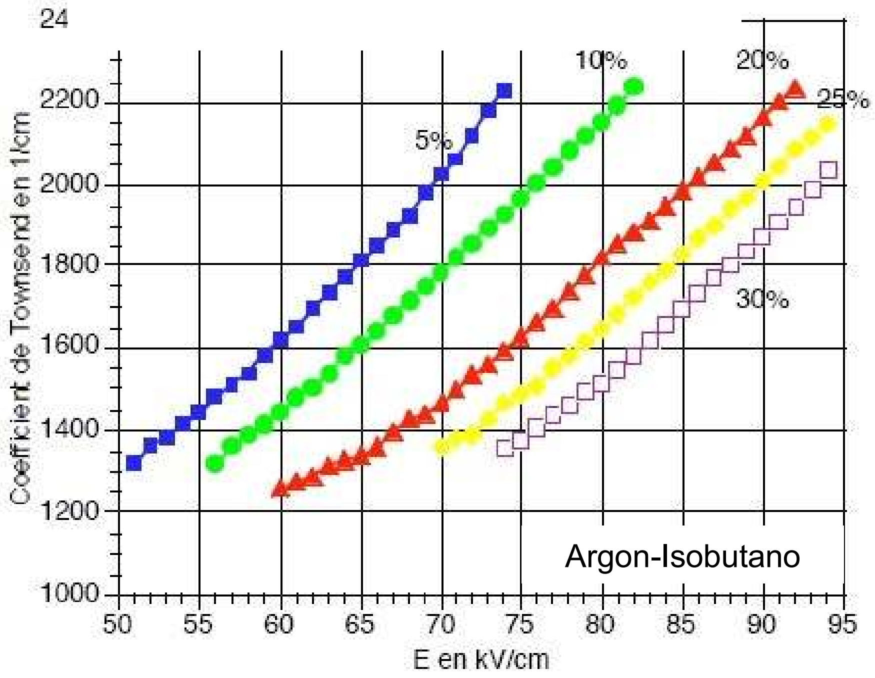


Moltiplicazione (3)

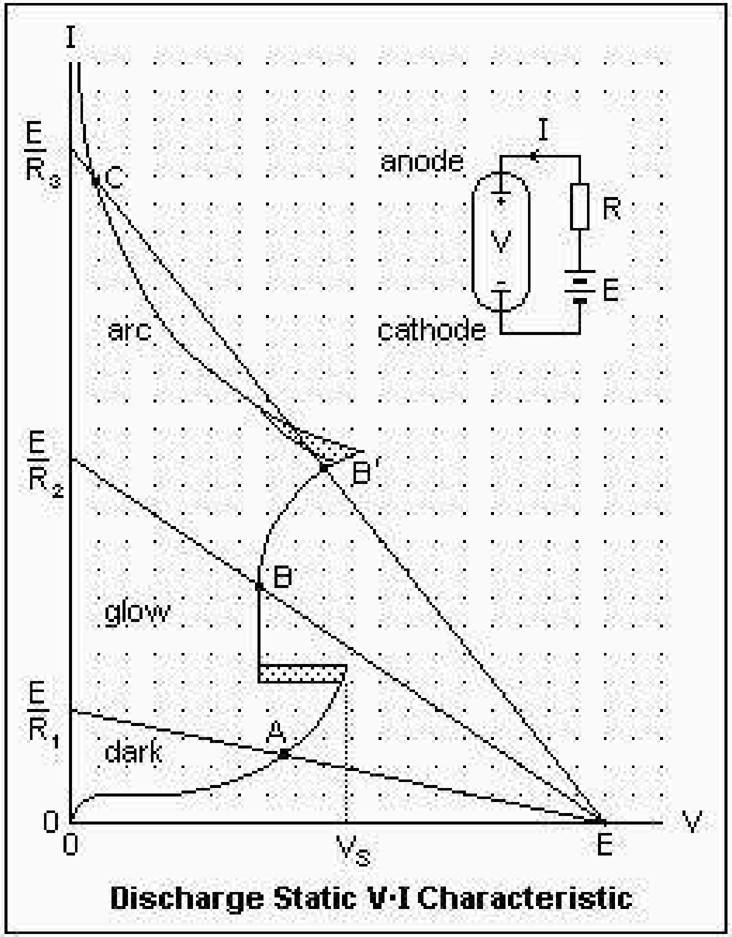


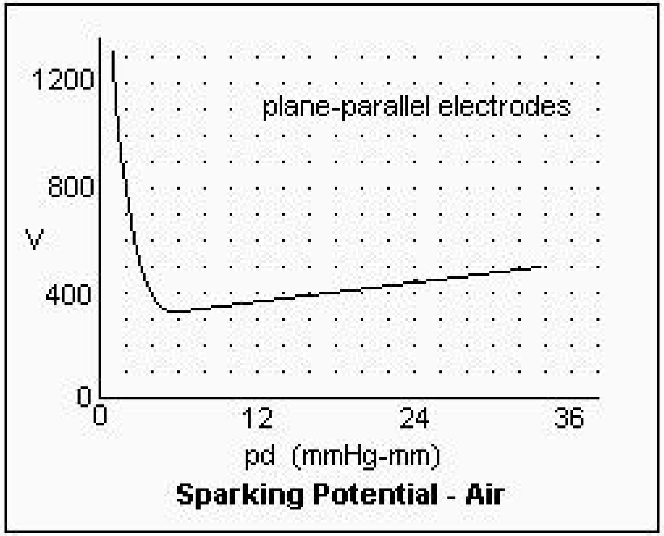
$$\frac{\alpha}{p} = Ae^{-Bp/\left|\vec{E}\right|}$$

Coefficient de Townsend en fonction du champ



Scarica elettrica

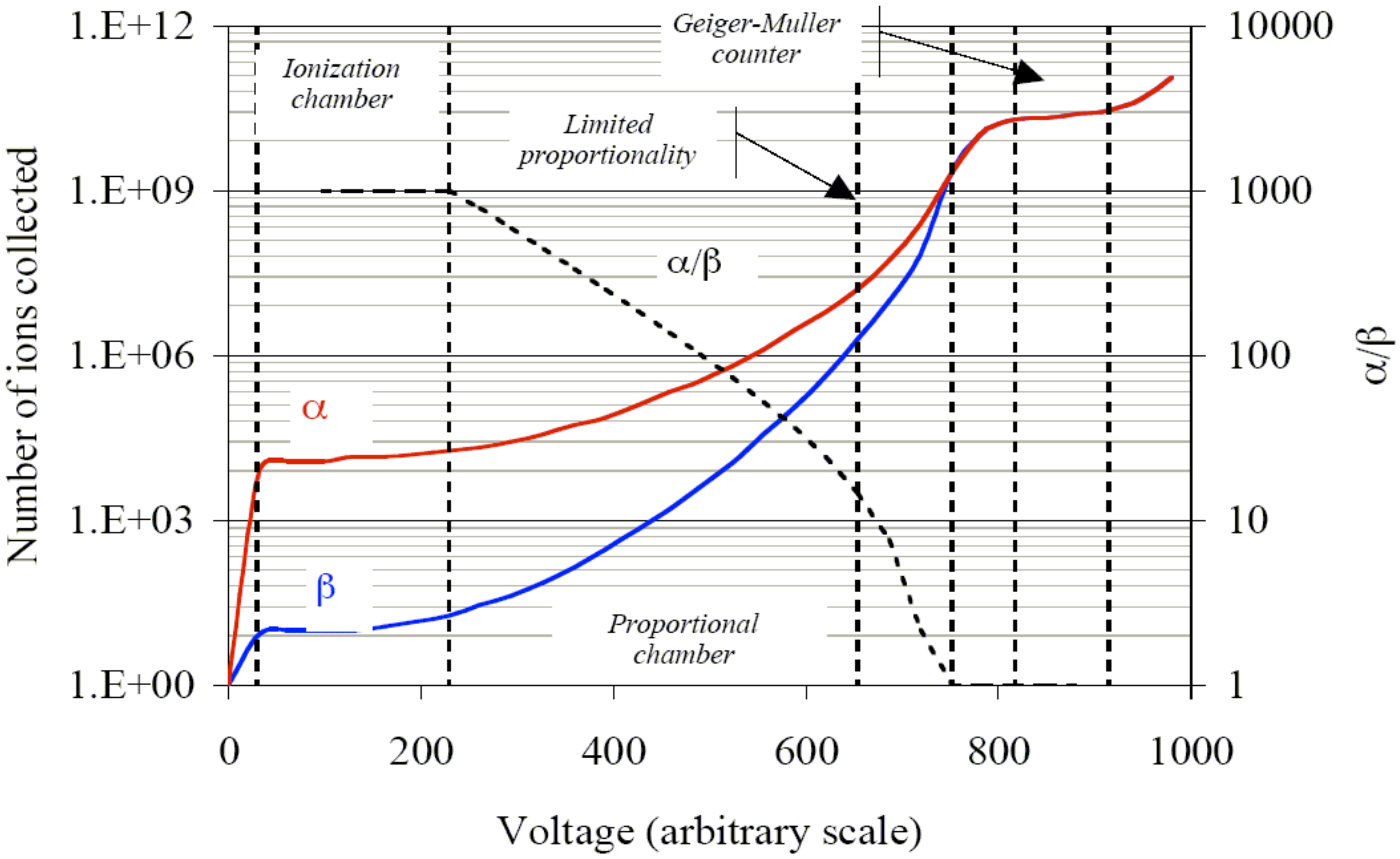




Gas	Vs min (V)	pd at Vs min (torr cm)
Air	327	0.567
Ar	137	0.9
H2	273	1.15
He	156	4.0
CO2	420	0.51
N2	251	0.67
N2O	418	0.5
O2	450	0.7
SO2	457	0.33
H2S	414	0.6

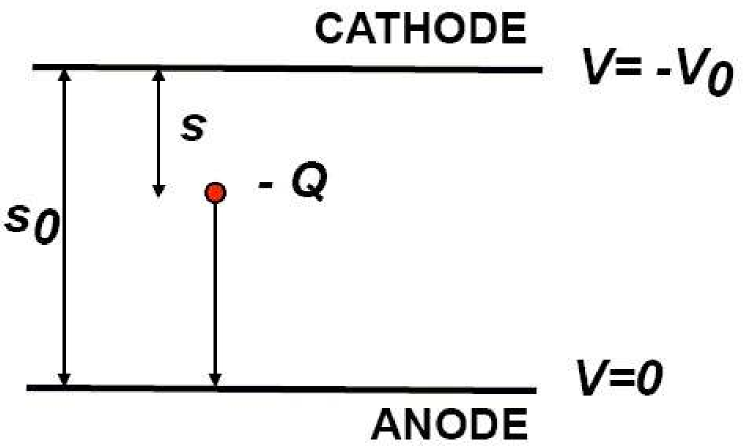
(C) Naidu

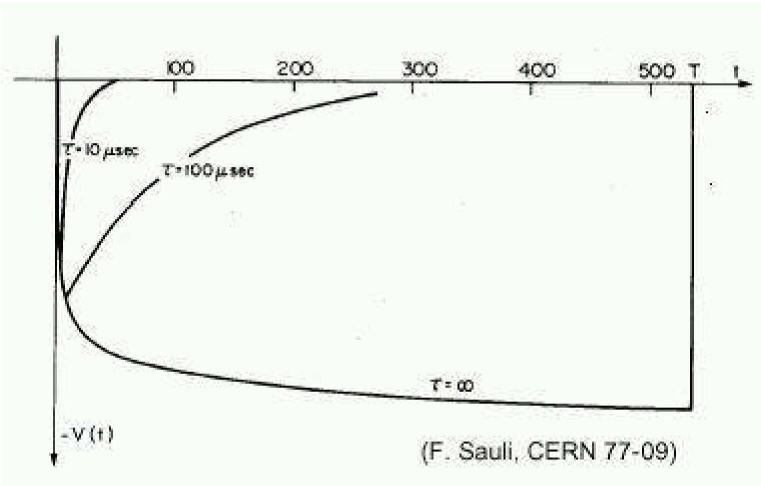
Regimi



1.E+12
1.E+09
1.E+06
1.E+03
1.E+00
Number of ions collected
10000
1000
100
10
1
α/β
0
200
400
600
800
1000
Voltage (arbitrary scale)
Ionization chamber
Limited proportionality
Geiger-Muller counter
Proportional chamber
α/β
α
β

Camera a ionizzazione



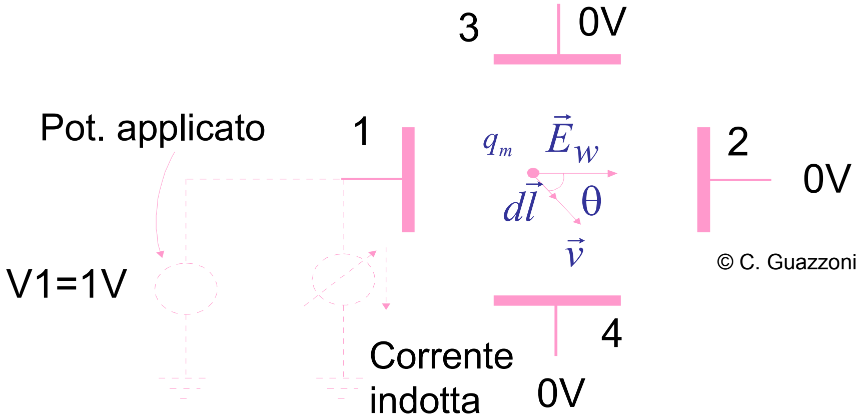


Necessaria “formatura” del segnale

Segnale indotto (1)

William Shockley
(1910-1989)
Nobel 1956

Simon Ramo
(1913-)



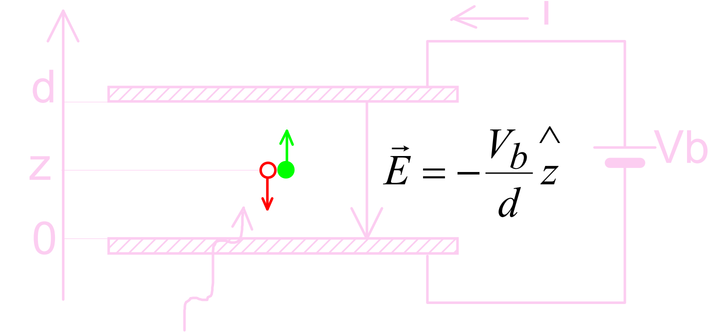
$$q_m V_m = Q_1 V_1 \xrightarrow{V_1 = 1V} Q_1 = q_m V_m$$

$$\boxed{i_1(t) = -q_m \vec{E}_w \cdot \vec{v}}$$

Segnale indotto (2)

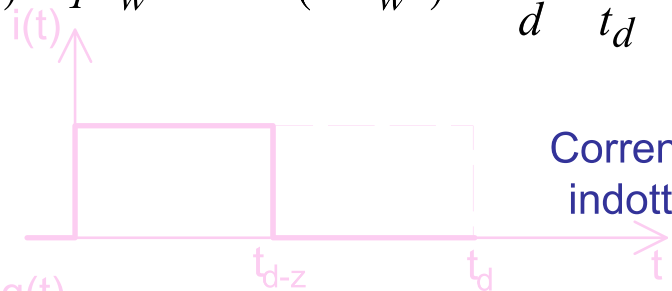
© C. Guazzoni

Singola ionizzazione

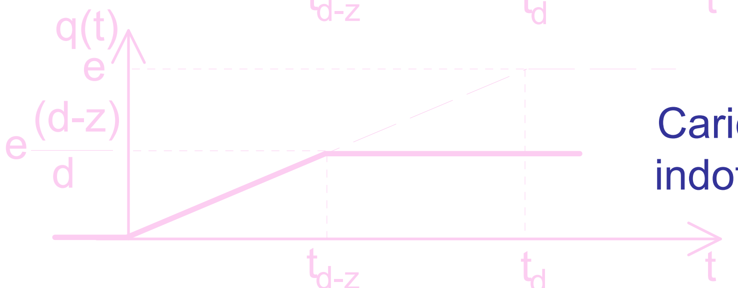


$$\vec{E} = -\frac{V_b}{d}\hat{z} \qquad \vec{E}_w = -\frac{1}{d}\hat{z}$$

$$i(t) = q\vec{E}_w \cdot \vec{v} = -e(-E_w v) = e\frac{v}{d} = \frac{e}{t_d} \qquad 0 \le t \le t_d$$

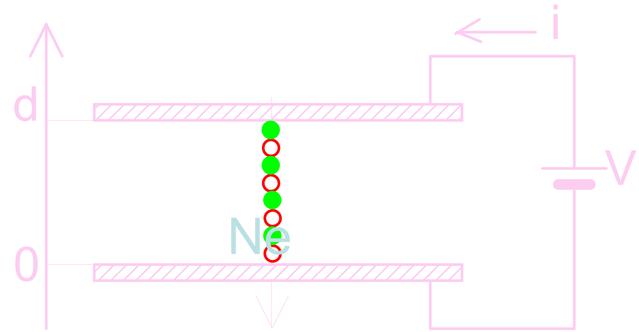


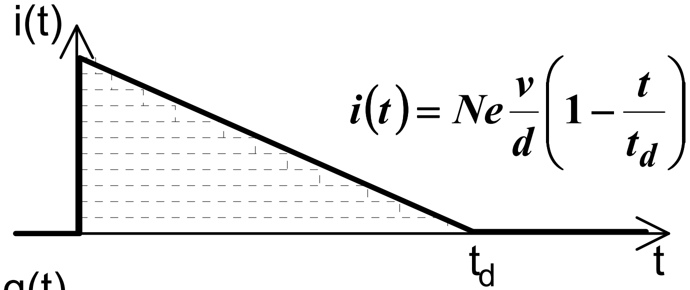
Corrente indotta



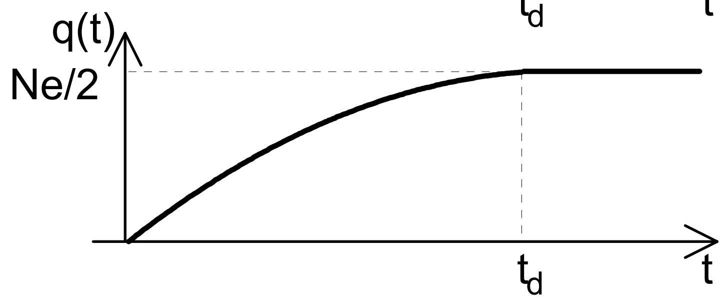
Carica indotta

Ionizzazione continua



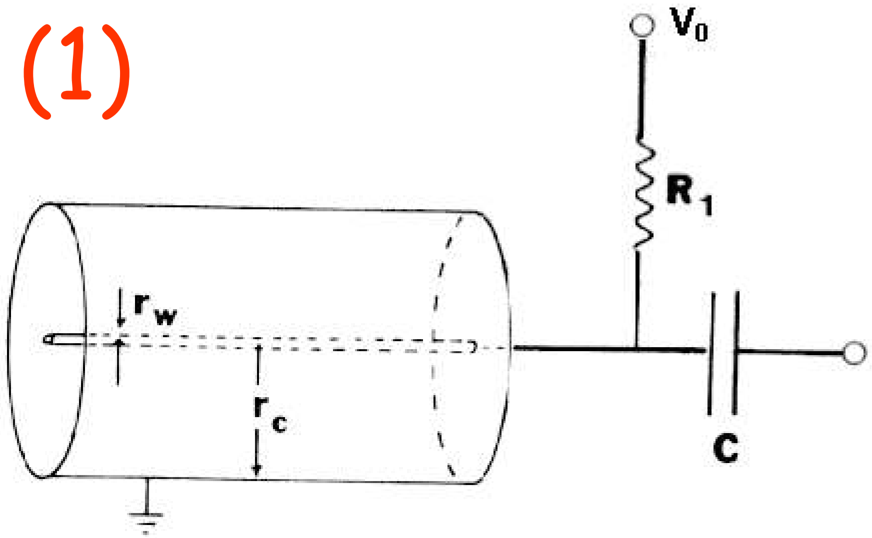


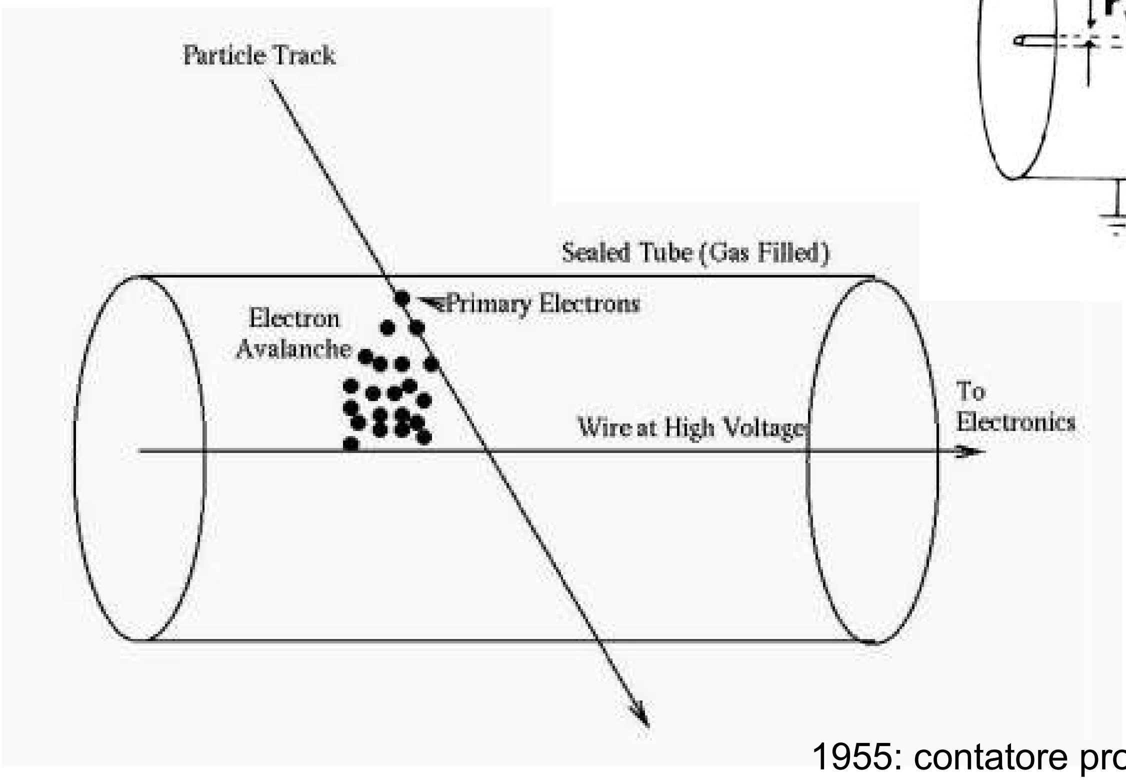
$$\boldsymbol{i(t) = Ne\frac{v}{d}\left(1 - \frac{t}{t_d}\right)}$$



$$Q_s(t) = \int_0^t i(\tau)\,d\tau = Ne\left[\frac{t}{t_d} - \frac{1}{2}\left(\frac{t}{t_d}\right)^2\right]$$

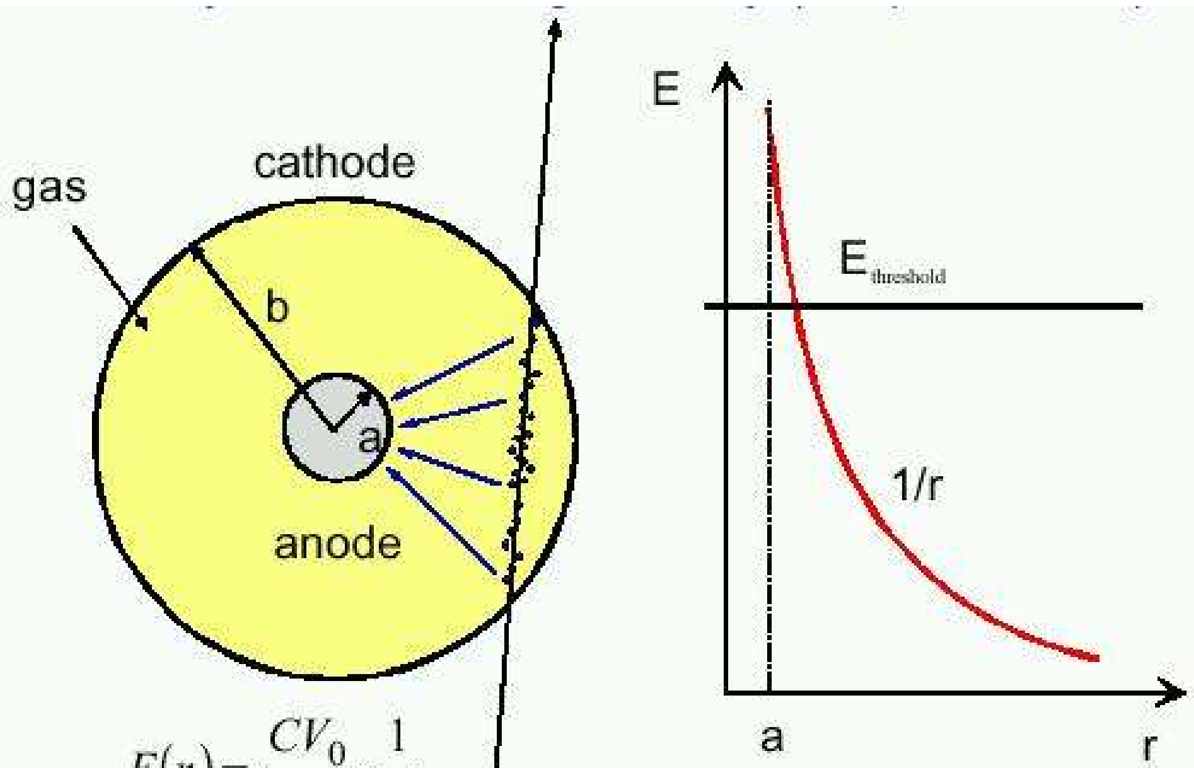
Tubi proporzionali (1)





1955: contatore proporzionale (metano, 3kV), o G-M (elio-isobutano, 1.3kV)

Tubi proporzionali (2)

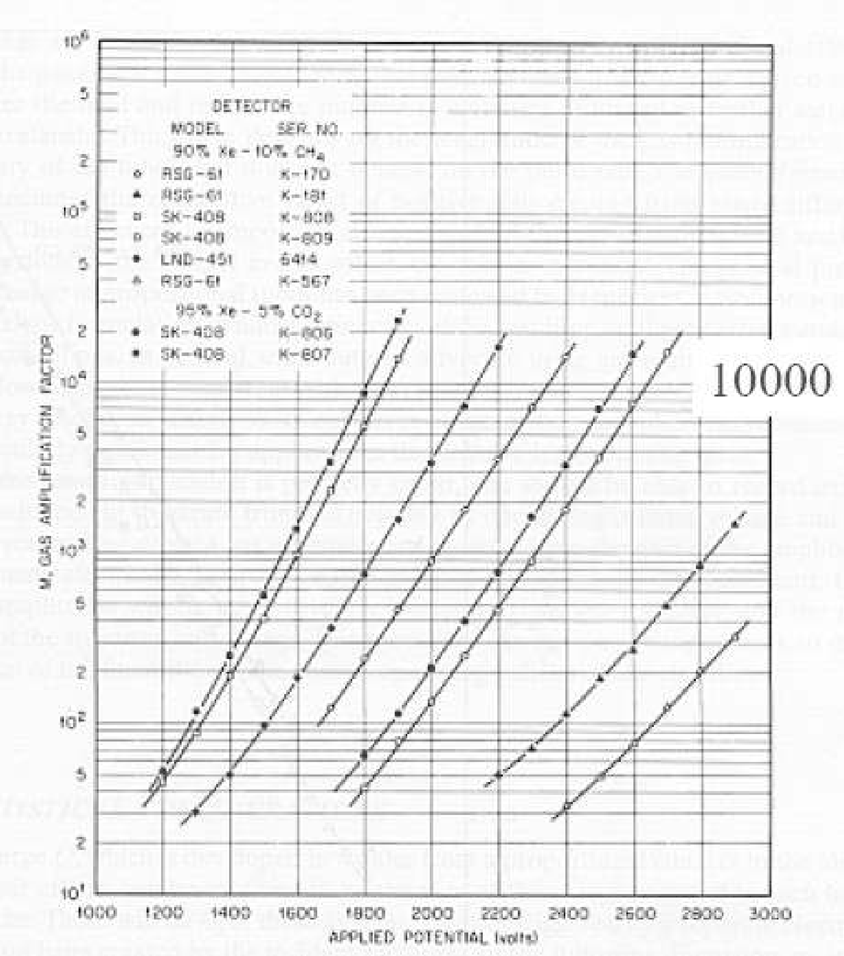


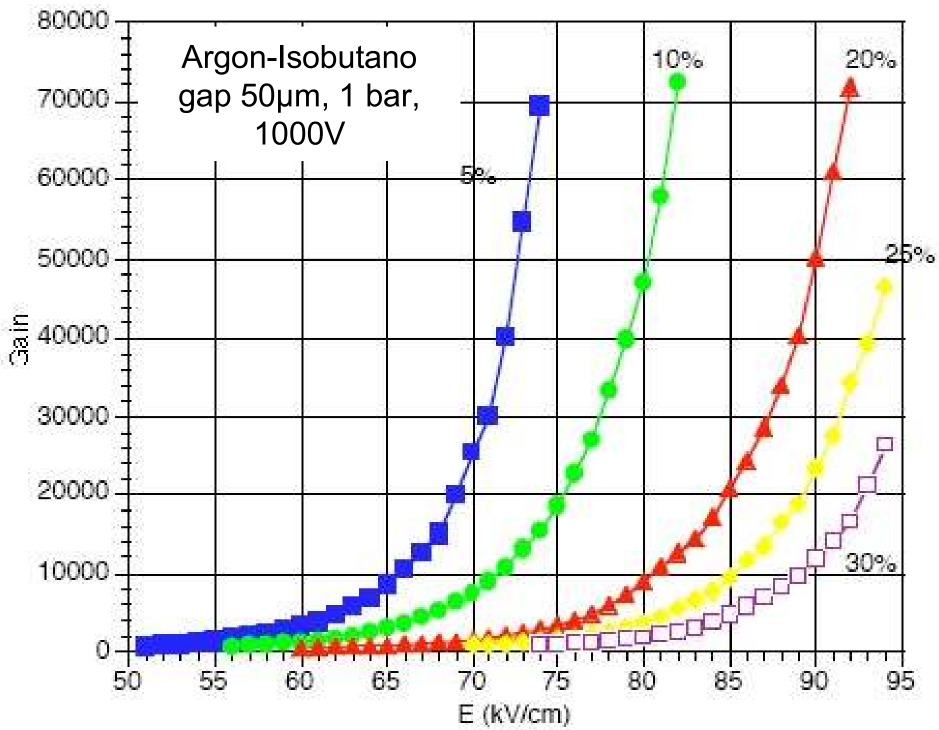
$$E(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \frac{1}{r}$$

$$V(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \ln\frac{r}{a}$$

C = capacitance / unit length

Tubi proporzionali (3)

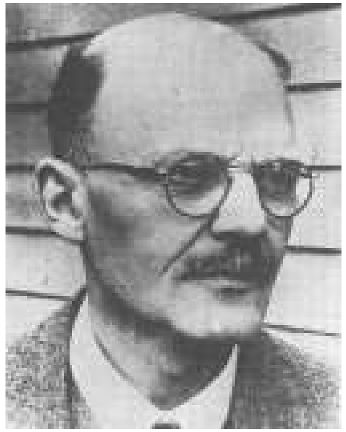




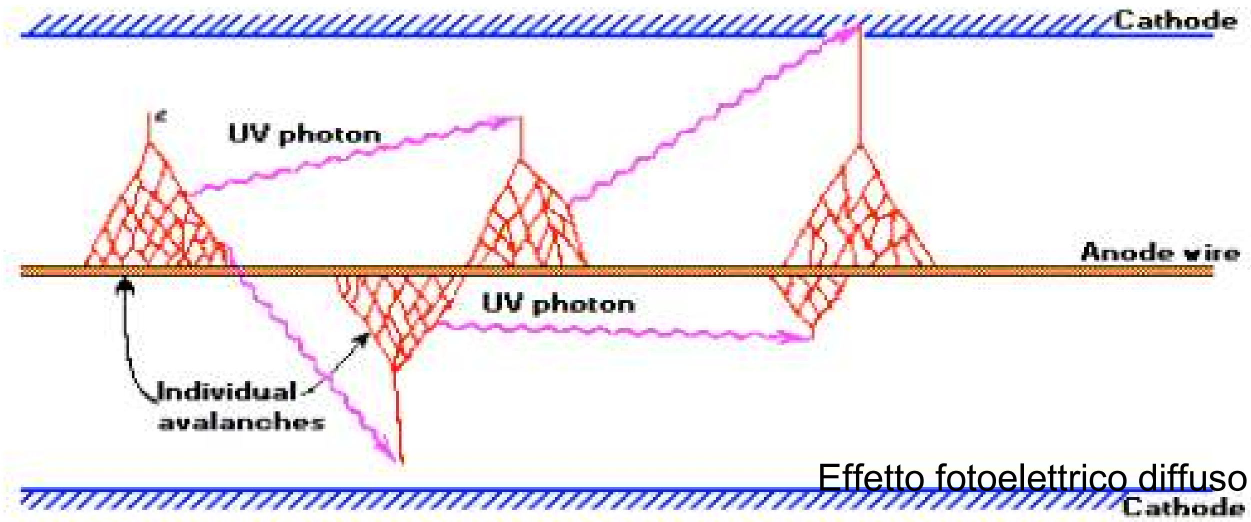
Gain versus electric field of the 50μm amplification gap for several Isobutane/Ar mixtures. Pressure is equal to 1 bar. Drift electrode voltage = 1000V.

Guadagno del tubo

Effetto Geiger-Muller

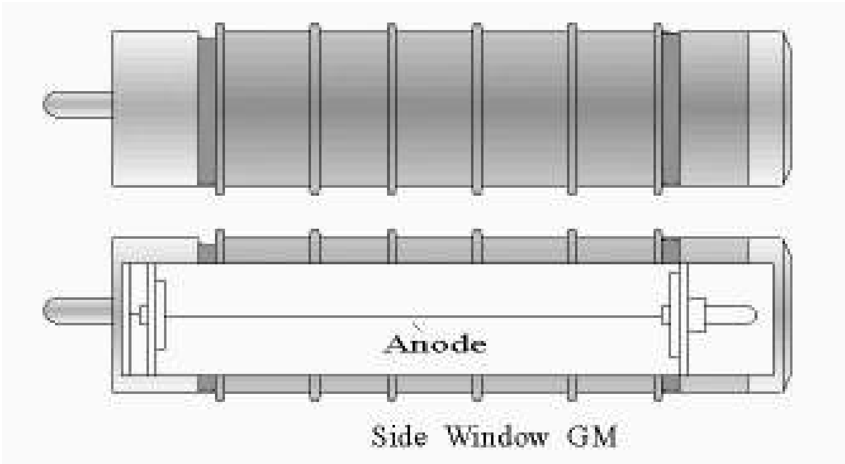


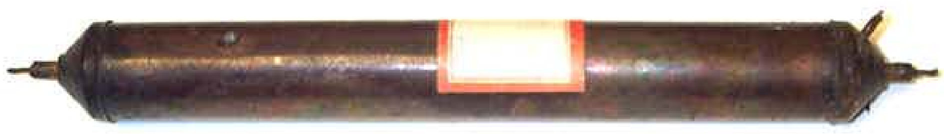
Hans Geiger
(1882-1945)
[e Walther Müller
(1905-1979)]

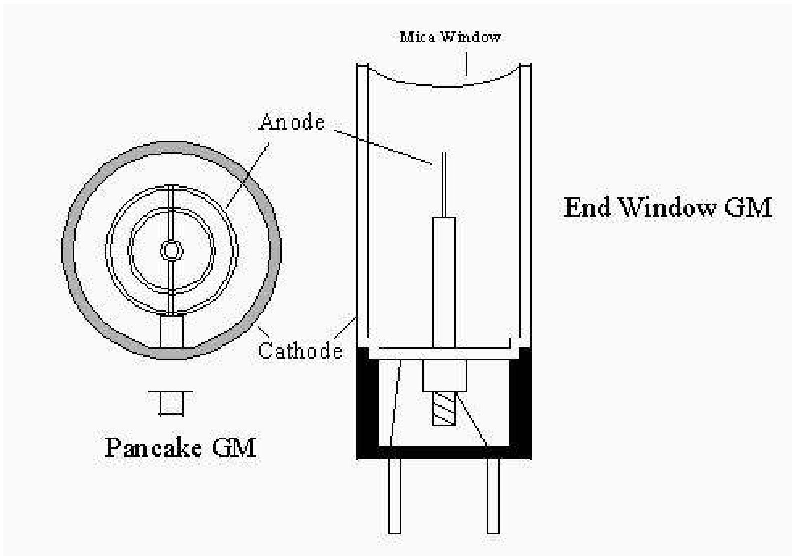


Effetto fotoelettrico diffuso

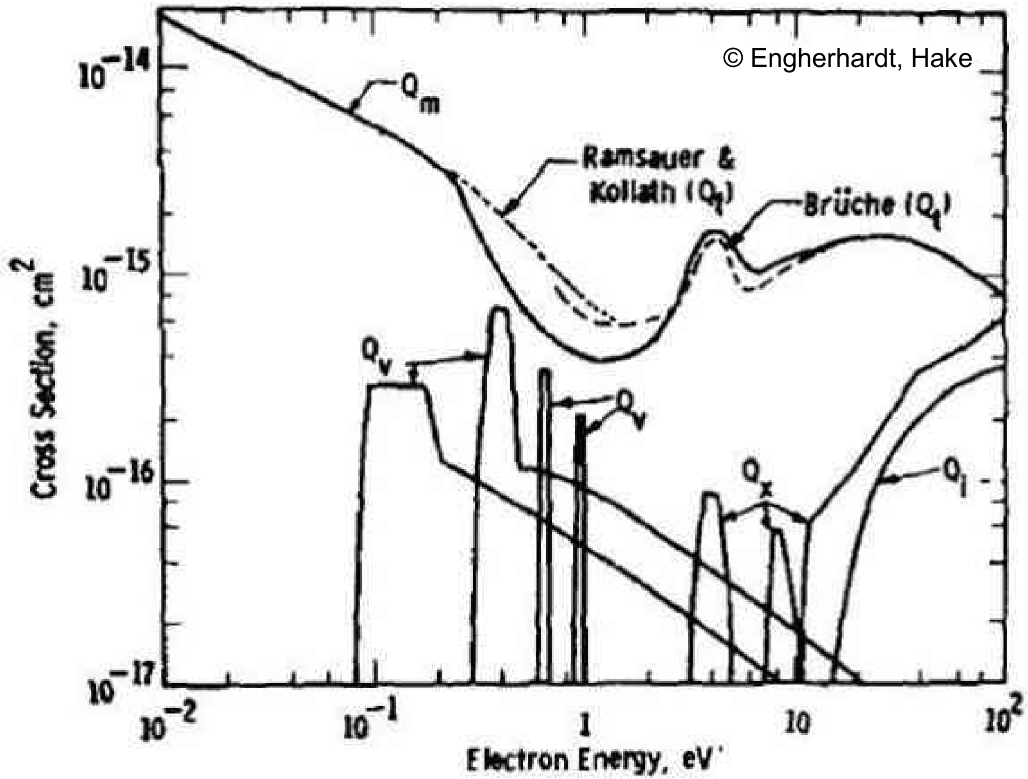
Contatori Geiger







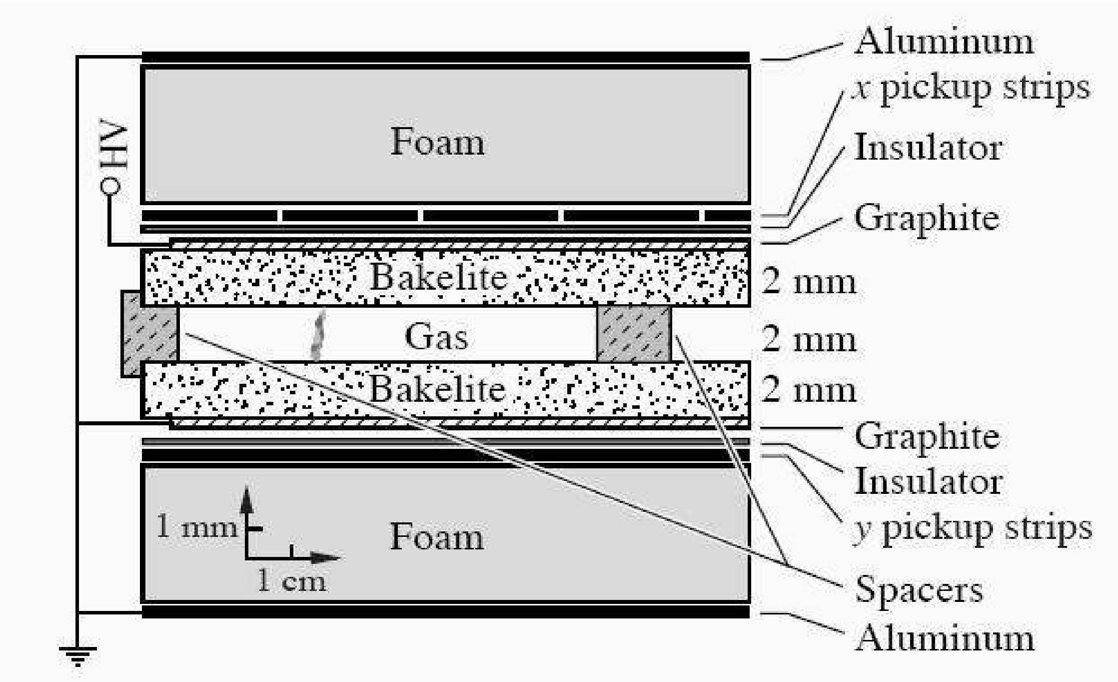
Quenching

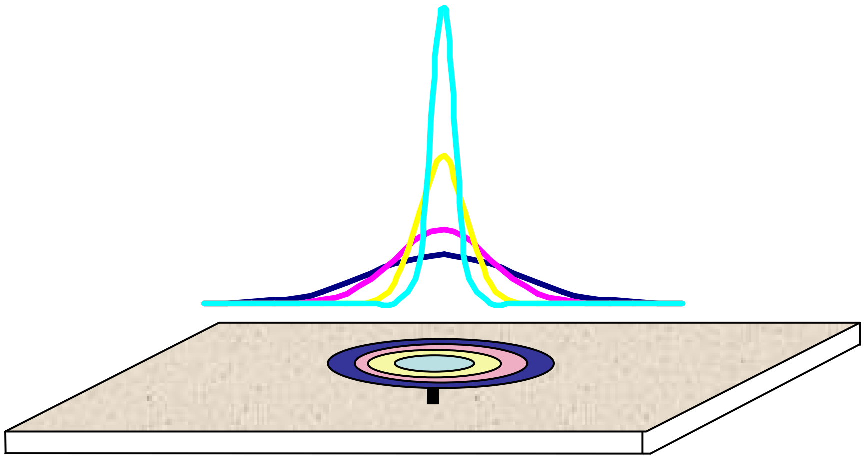


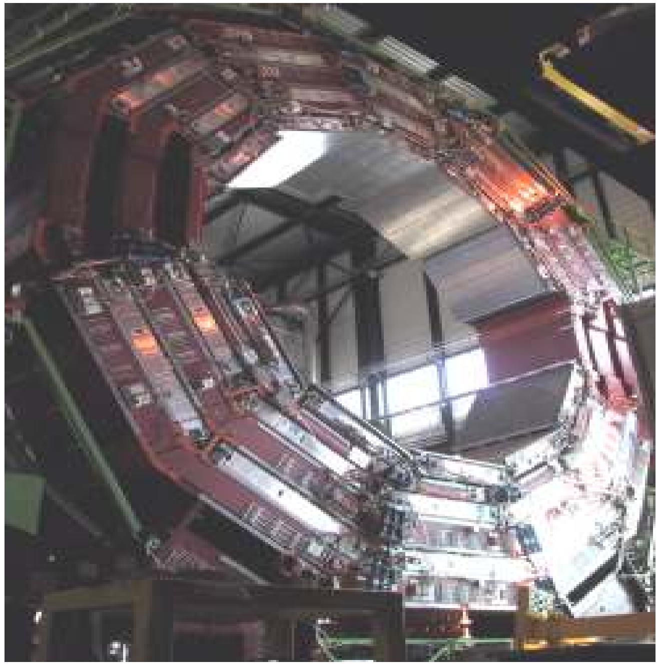
Spettro di eccitazione di CO_2
Qm: trasferimento di impulso, Qv: vibrazione,
Qx: elettroni, Qi: ionizzazione

RPC

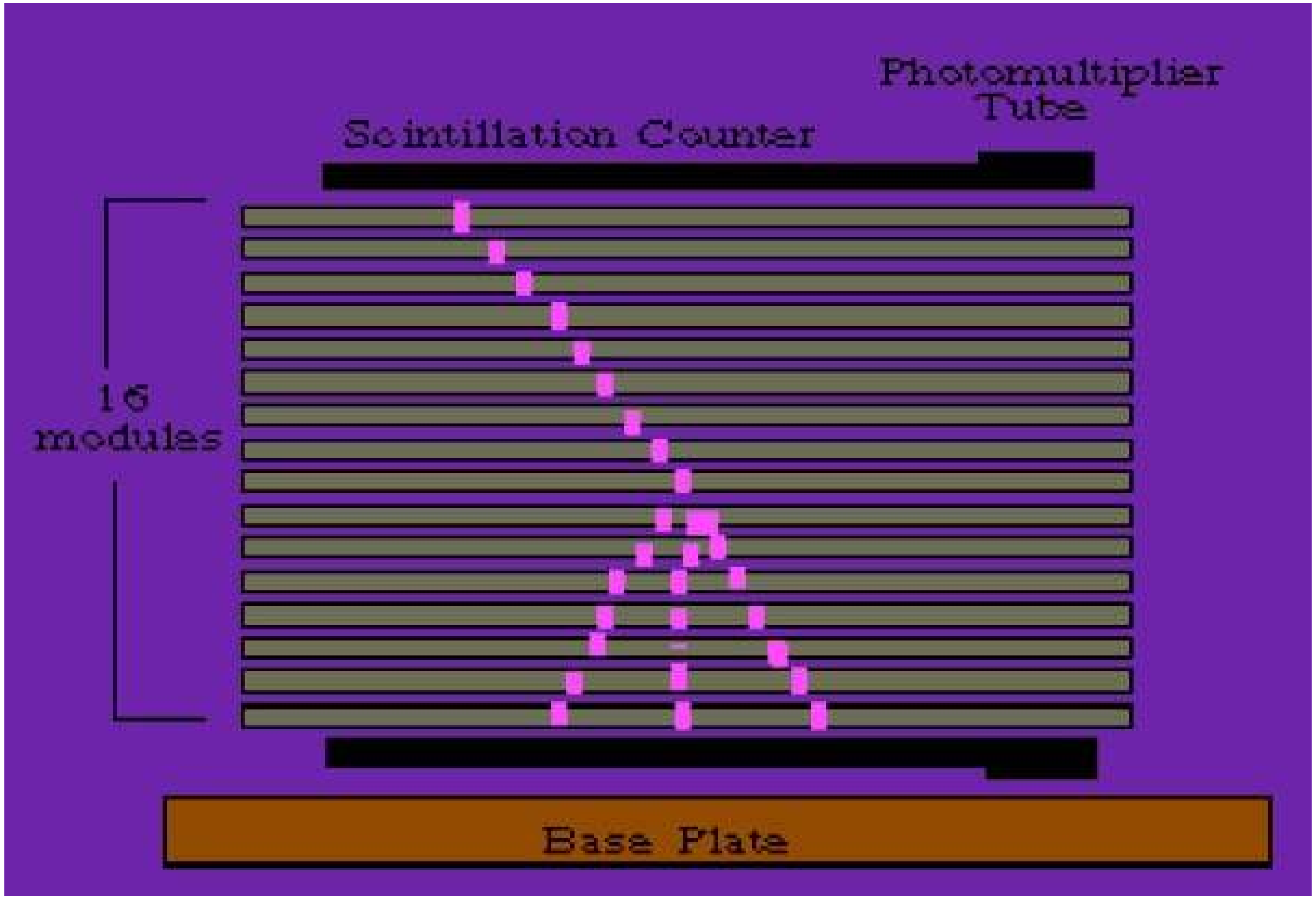
(Resistive Plate Chamber)



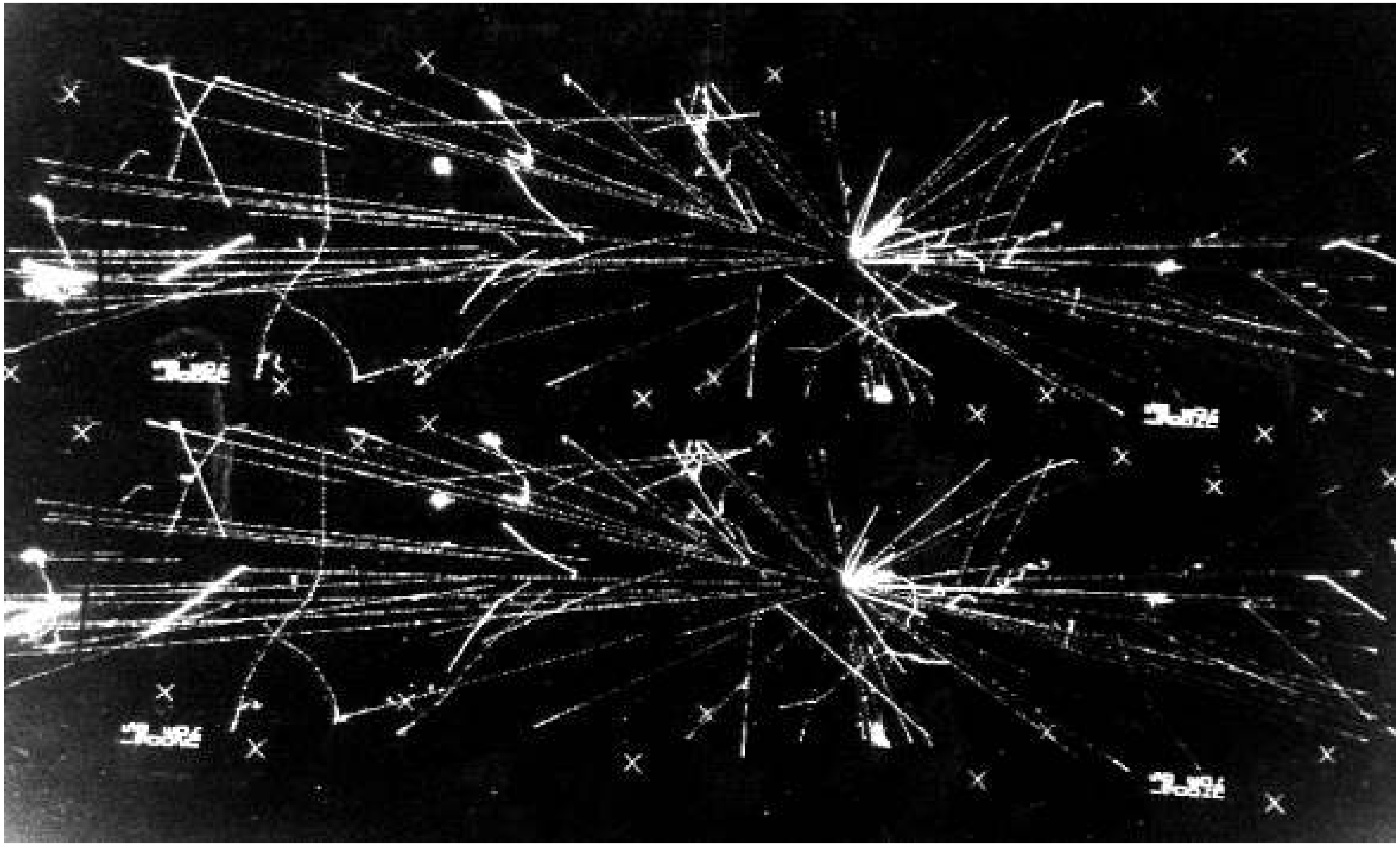




Camere a scintilla



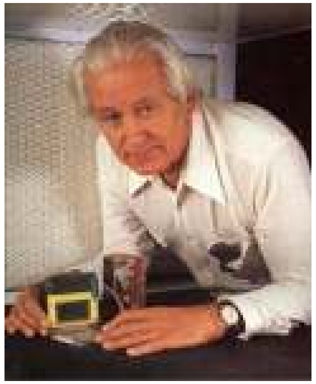
Camere a streamer



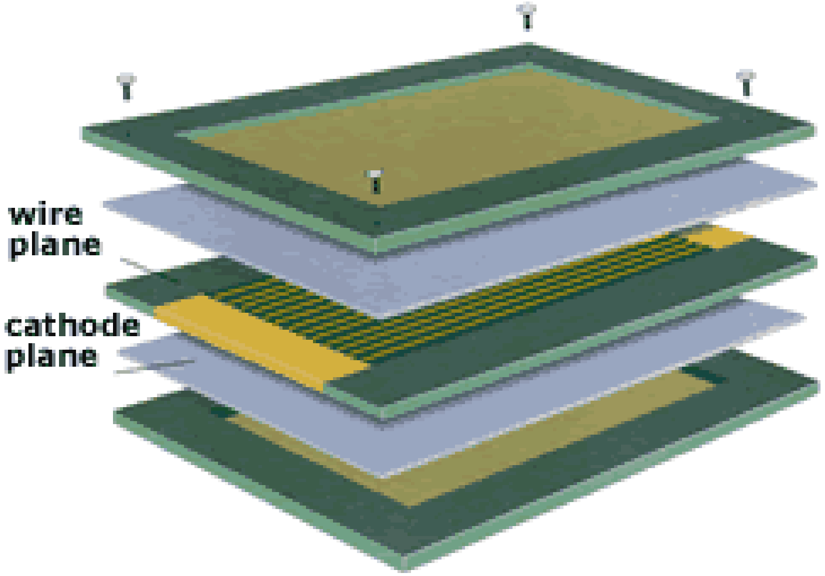
HV impulsata

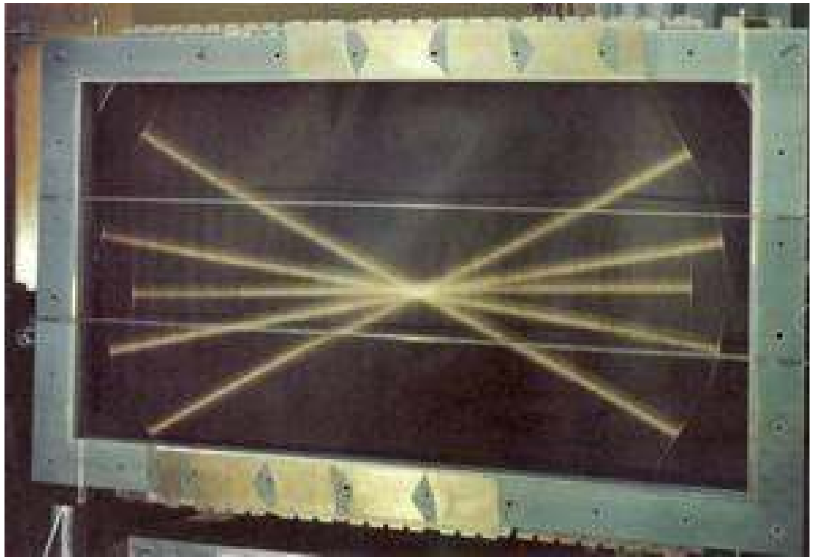
MWPC

(Multi-Wire Proportional Chamber)



Georges Charpak
(1924-)
Nobel 1992

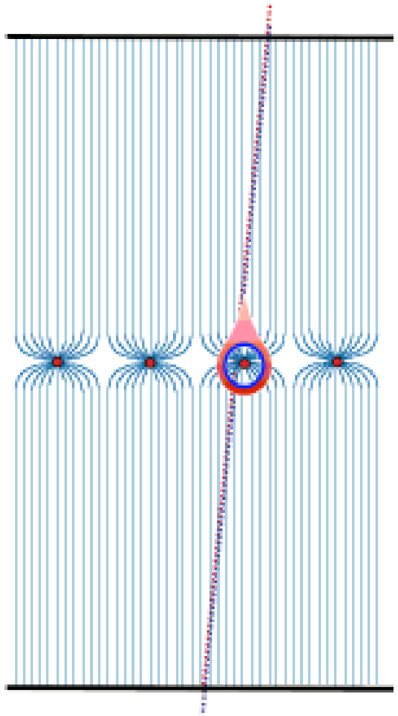


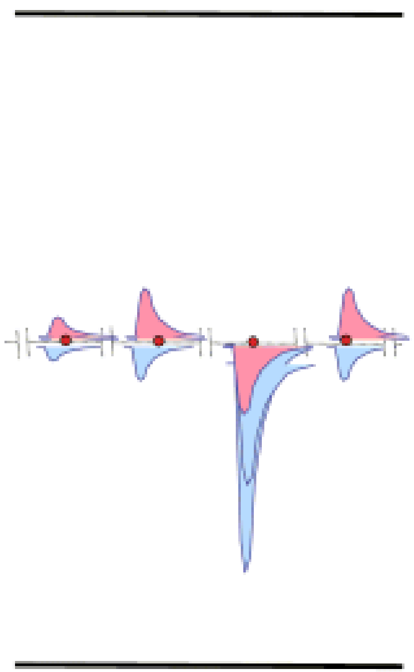


MWPC

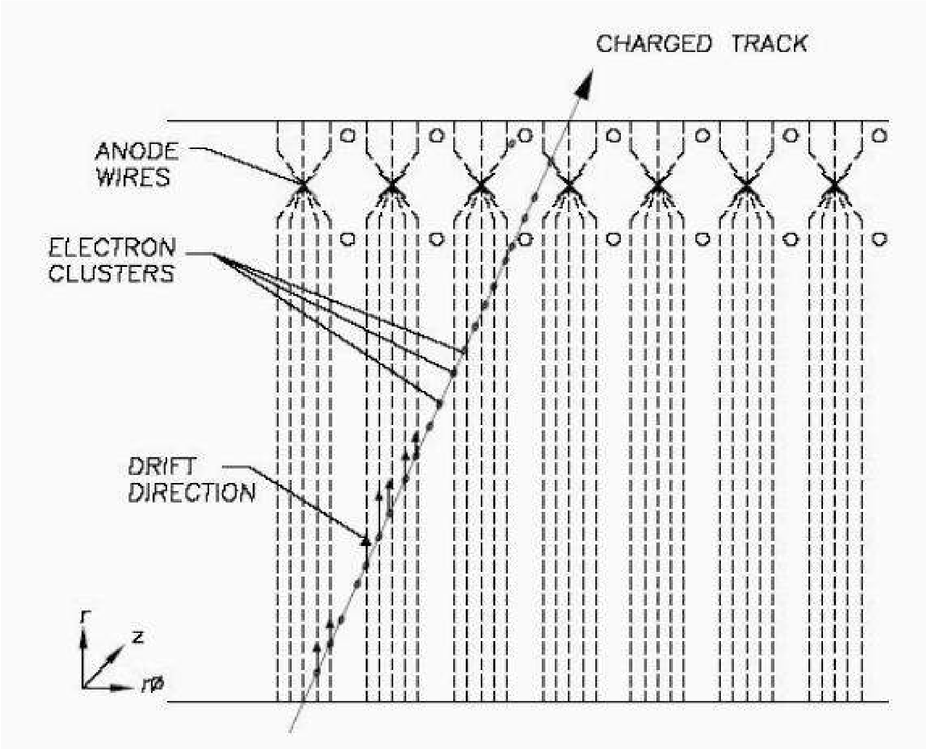
$$V_s(z) \underset{d\to 0}{\approx} \frac{2\pi l}{s} - \ln\left\{4\sin^2\left(\frac{\pi x}{s}\right) + 4\sinh^2\left(\frac{\pi y}{s}\right)\right\} \qquad E_0 = \frac{sV_0}{\frac{\pi d}{2}\left[l - \frac{s}{\pi}\ln\frac{\pi d}{s}\right]}$$

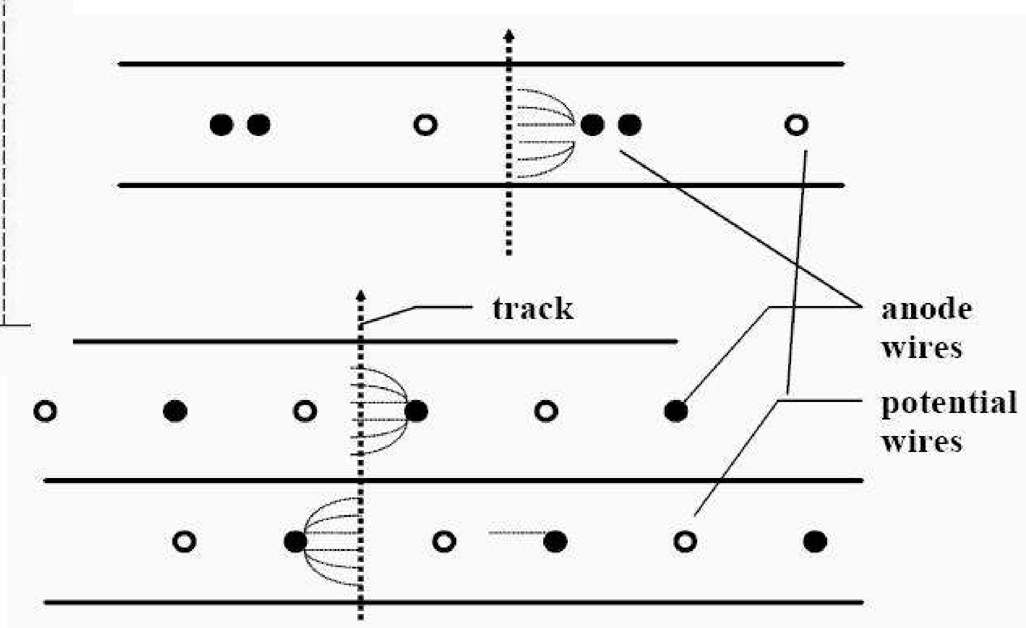
l = distanza A-K ~ 5mm, *s* = spaziatura fili ~ 2-4mm, *d* = diametro anodi ~ 20μm





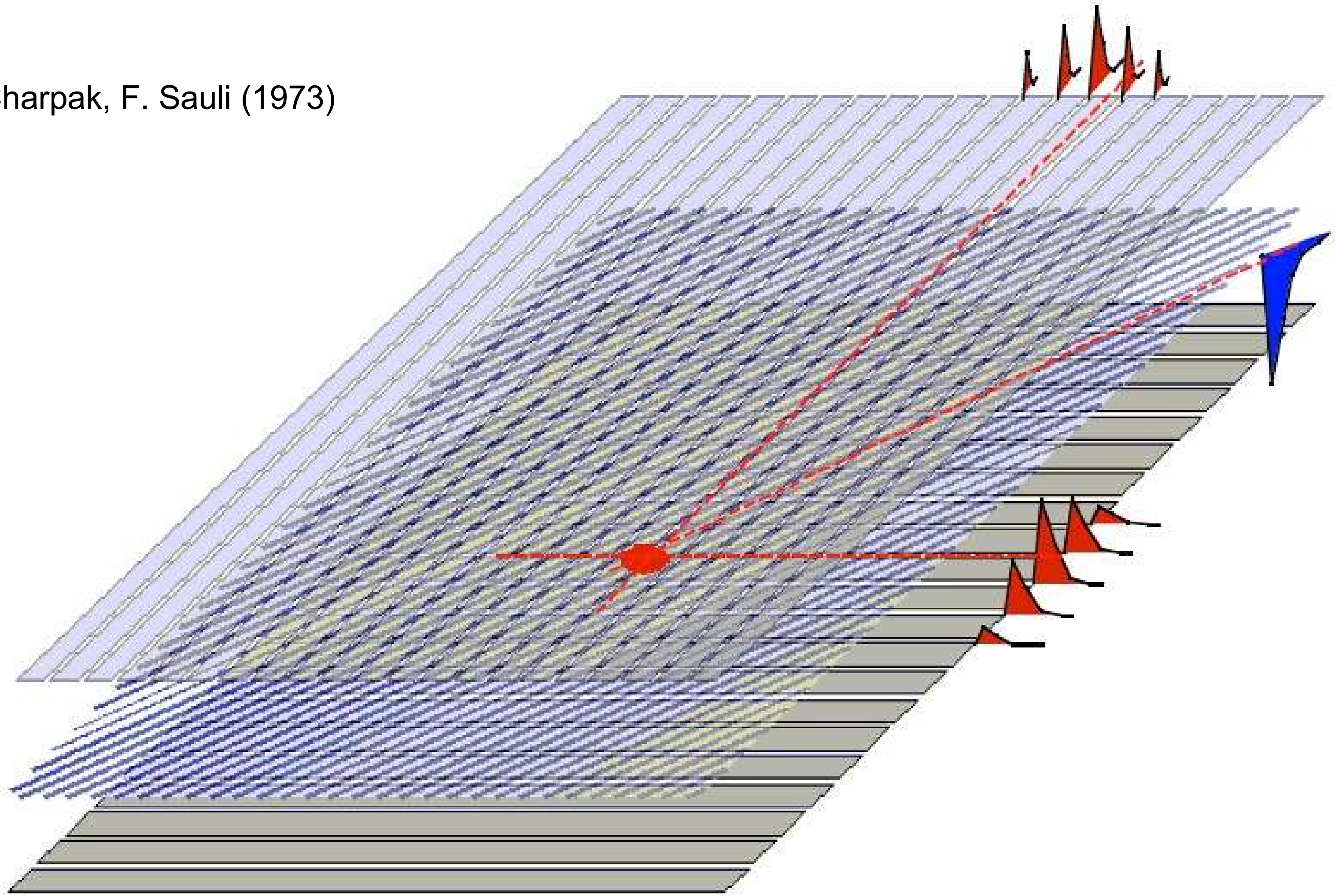
MWPC


CHARGED TRACK
ANODE WIRES
ELECTRON CLUSTERS
DRIFT DIRECTION
r
z
rø


track
anode wires
potential wires

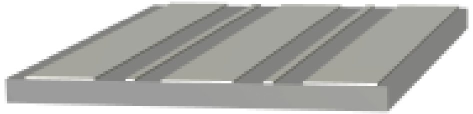
Lettura catodica (2D)

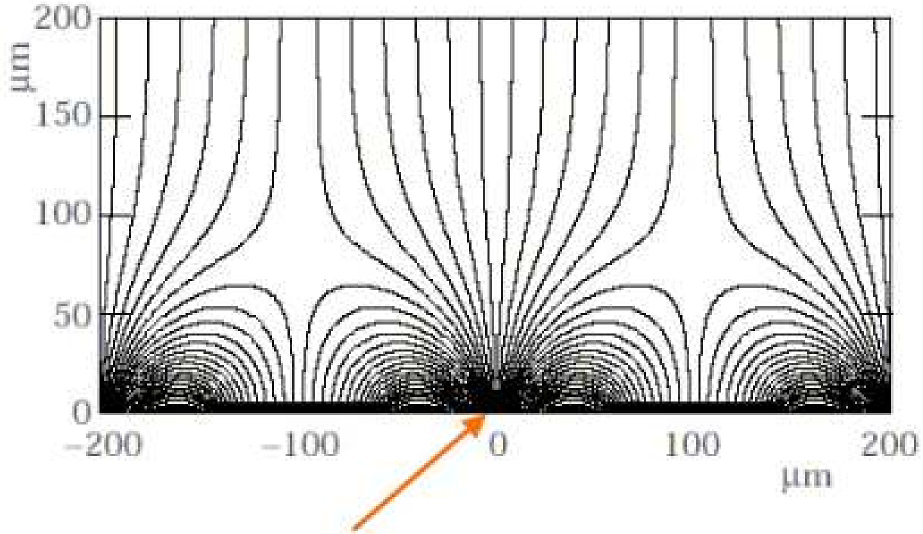
G. Charpak, F. Sauli (1973)



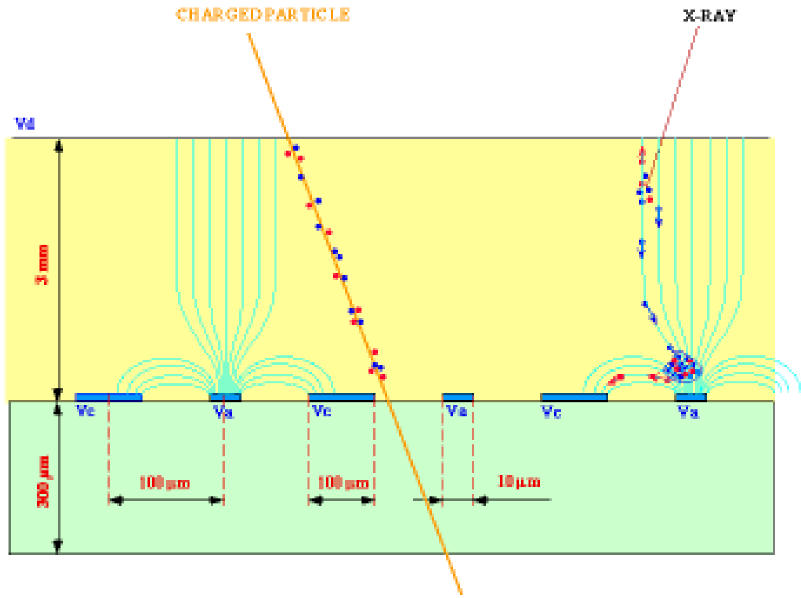
MicroStrip Gas Chamber

A. Oed (1988)

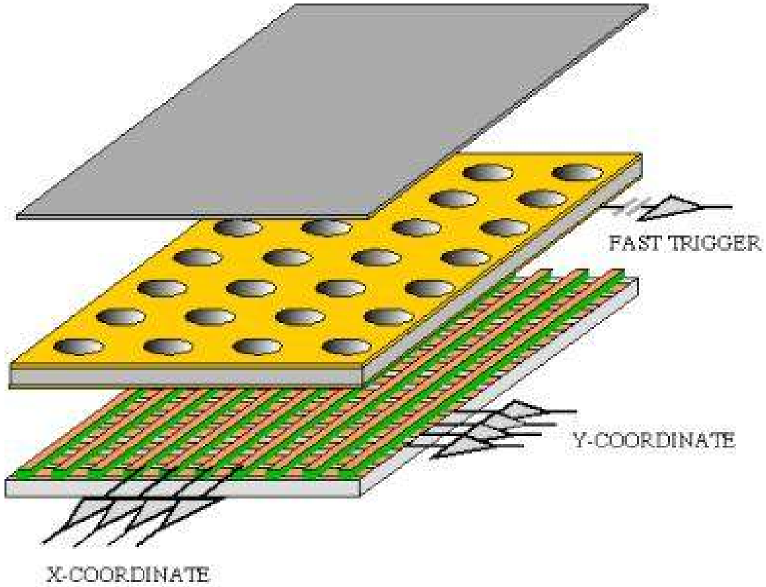




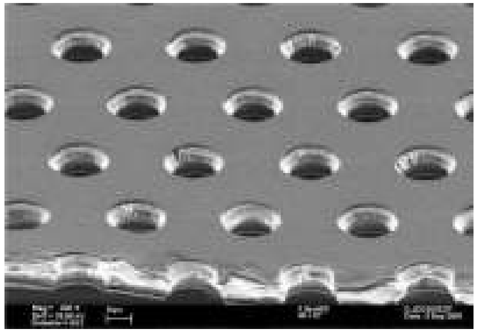
Anode strips

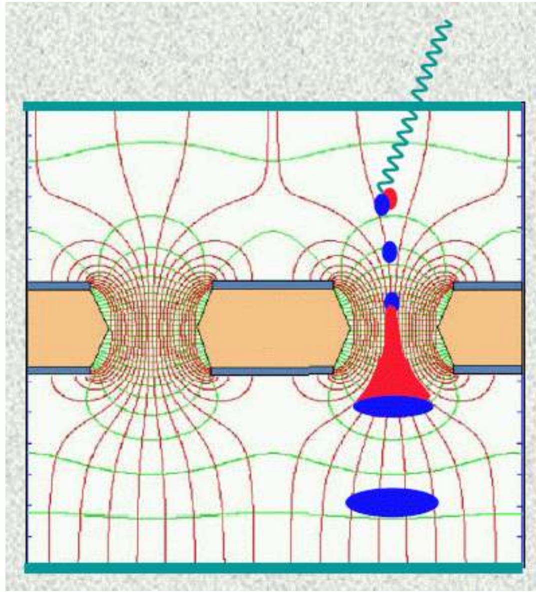


Gas Electron Multiplier (GEM)

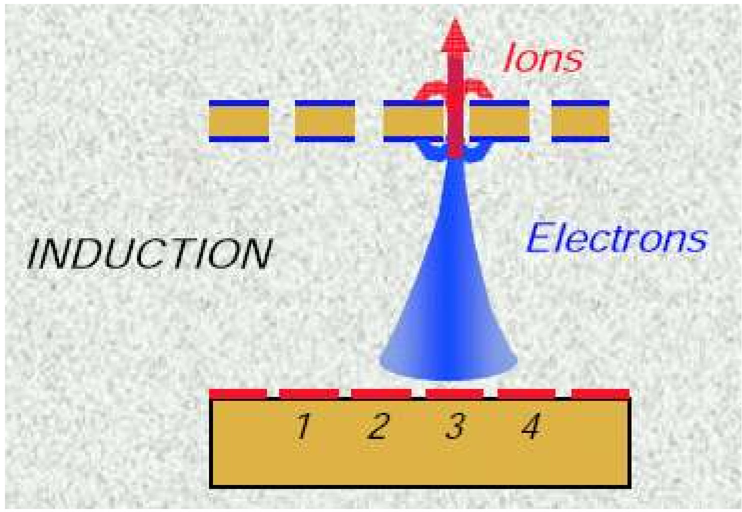


F. Sauli et al.





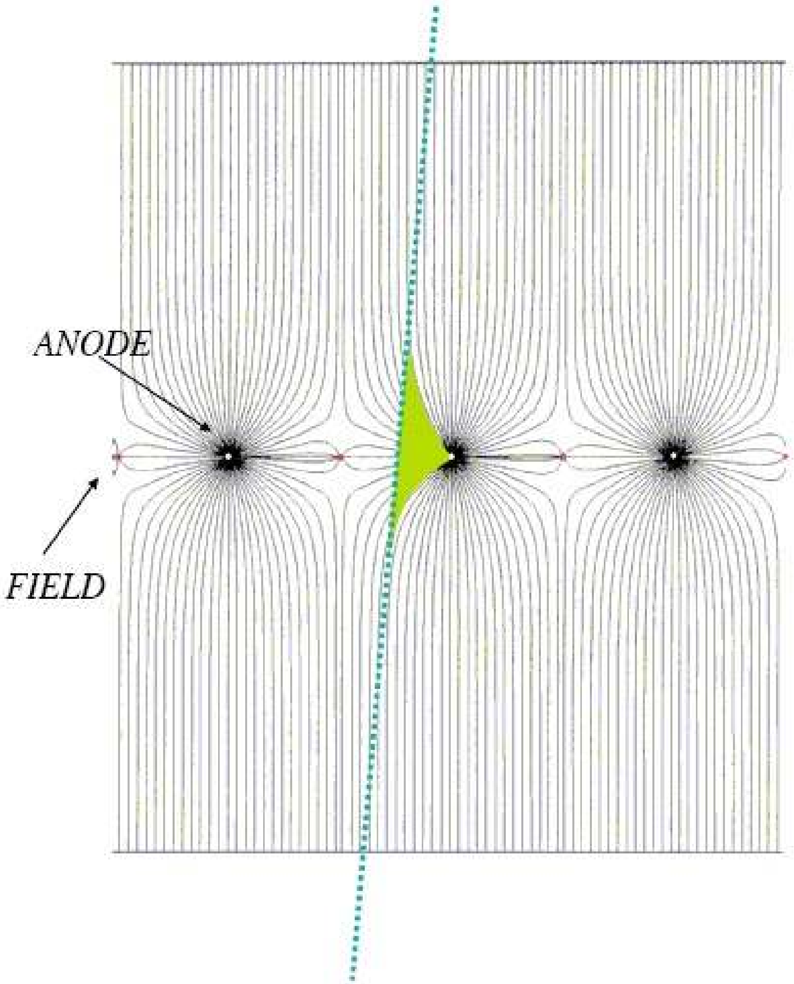
Foglio metallizzato con 5-100 fori/mm^2
Diametro 70 μm
Separazione 140 μm
Contatori proporzionali indipendenti
frequenze di conteggio elevate

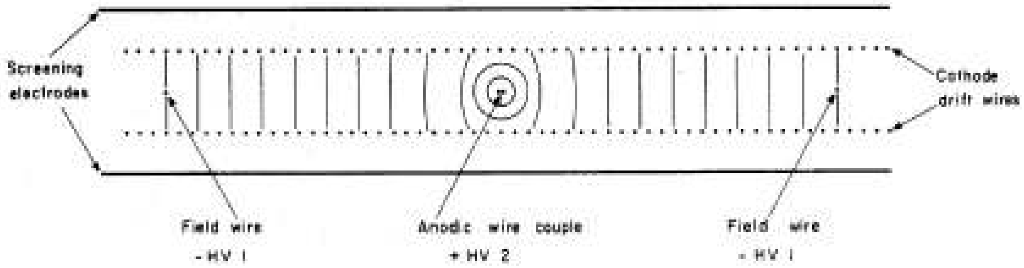


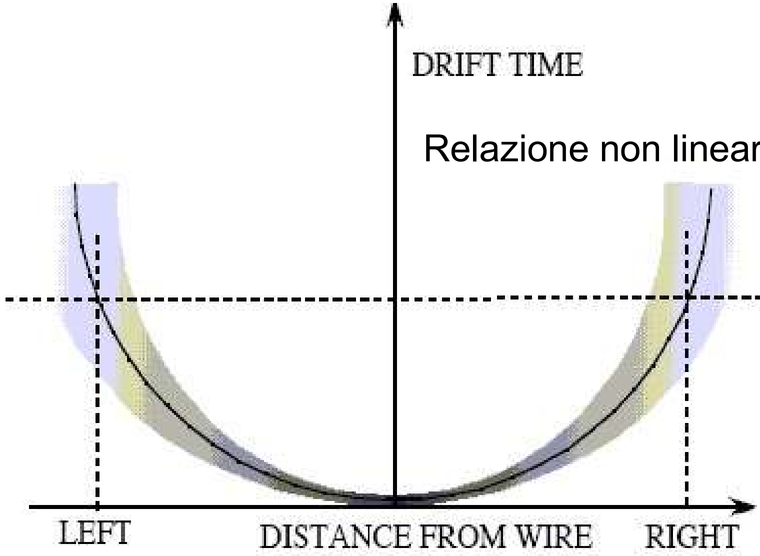
M. Sozzi

Camere a deriva (1)

Albert H. Walenta (1971)

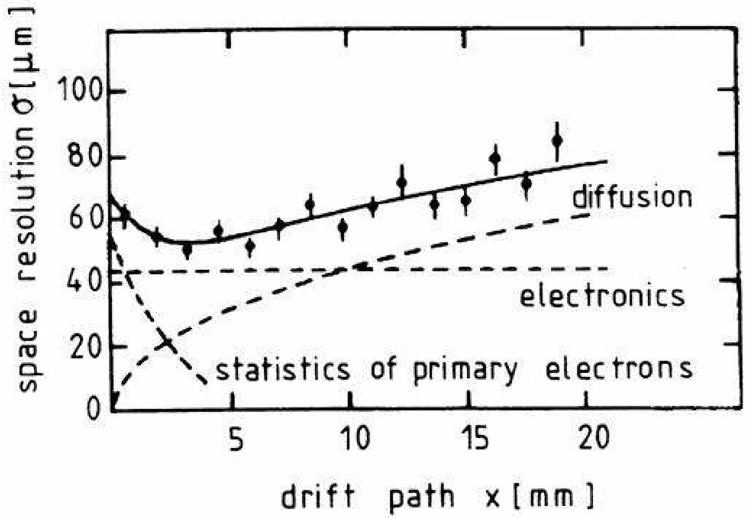


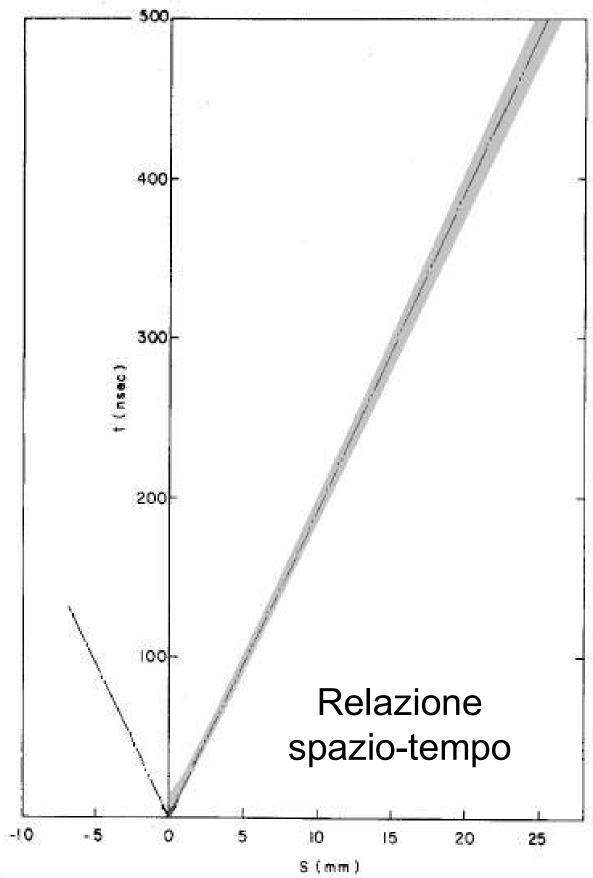




Relazione non lineare spazio-tempo

Camere a deriva (2)



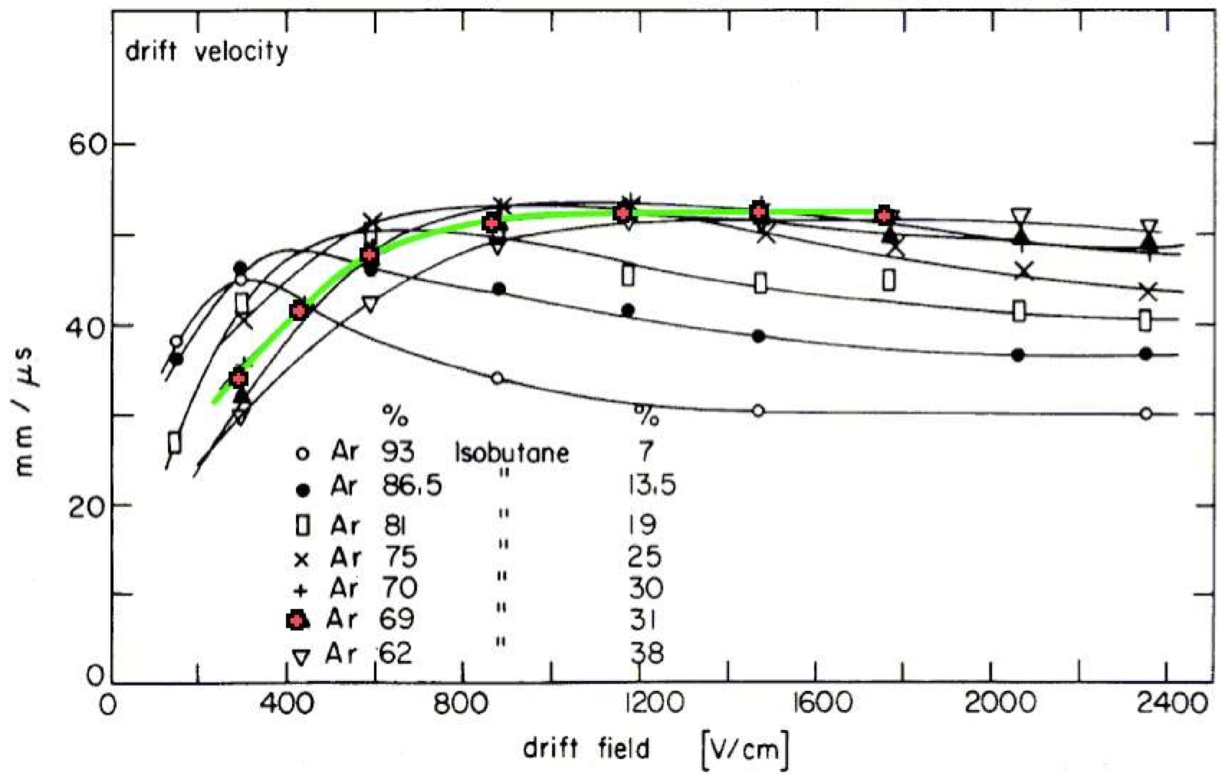


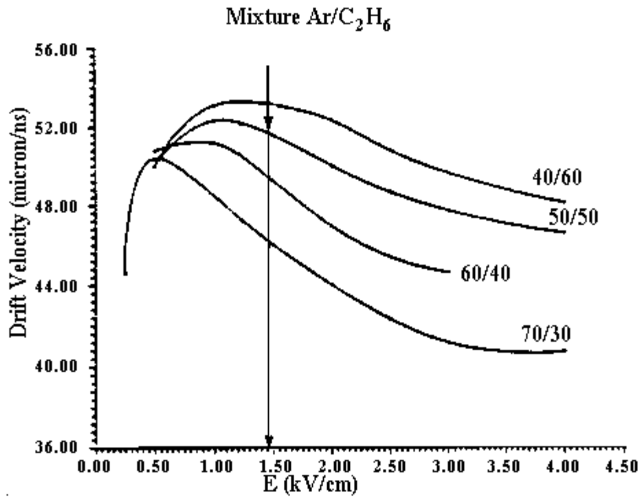
Relazione spazio-tempo

Gas	$\bar{v}$/(m s^{-1})	l/nm	τ/ps	σ/pm	
	at 0 °C and atmospheric pressure			η	B
Argon	380	62.6	165	342	340
Benzene	272	148.2	545	527	—
Carbon dioxide	362	39.0	108	390	407
Carbon monoxide	454	58.6	129	371	376
Chlorine	285	27.4	96	440	—
Chloroform	220	161.0	732	543	—
Ethylene	454	34.3	75	423	452
Helium	1202	173.6	144	258	256
Hydrogen	1694	110.6	65	297	293
Methane	600	48.1	80	380	382
Neon	535	124.0	232	279	275
Nitrogen	454	58.8	130	375	370
Nitrous oxide	362	38.7	107	388	459
Oxygen	425	63.3	149	354	358
Sulphur dioxide	300	27.4	91	429	—

Velocita' di deriva

Camere a deriva (3)



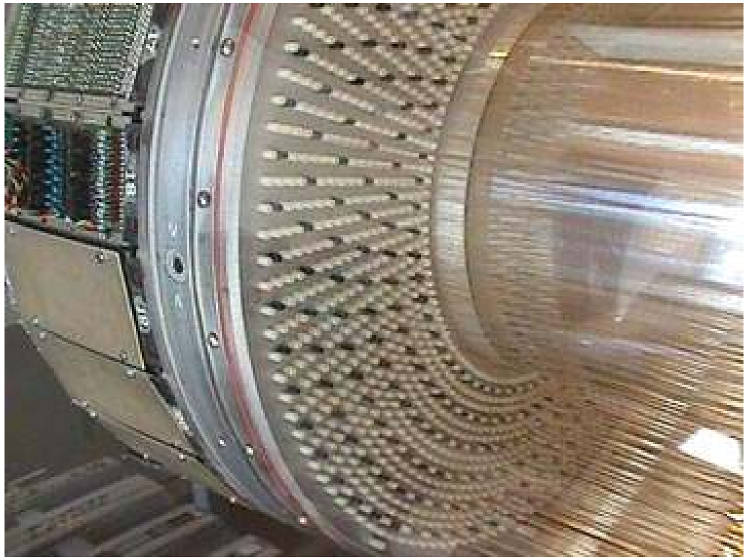


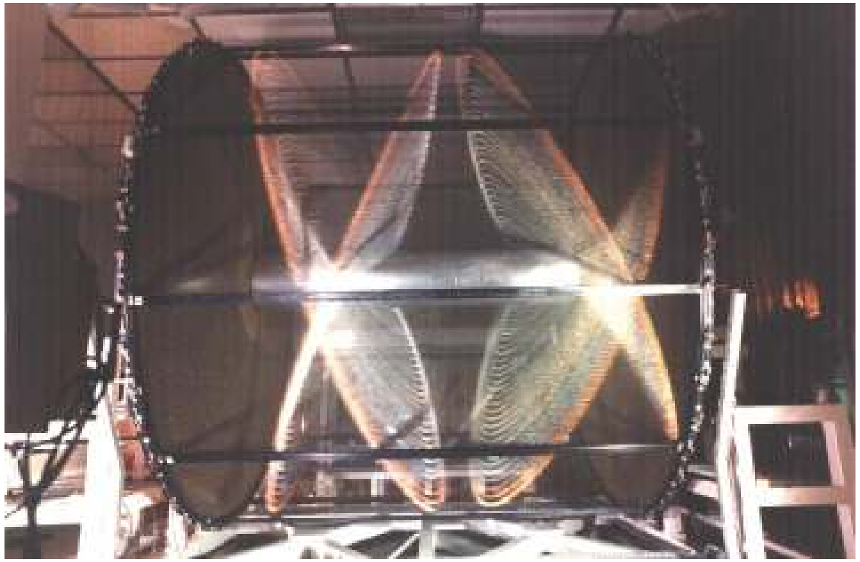
Velocita' di deriva: saturazione

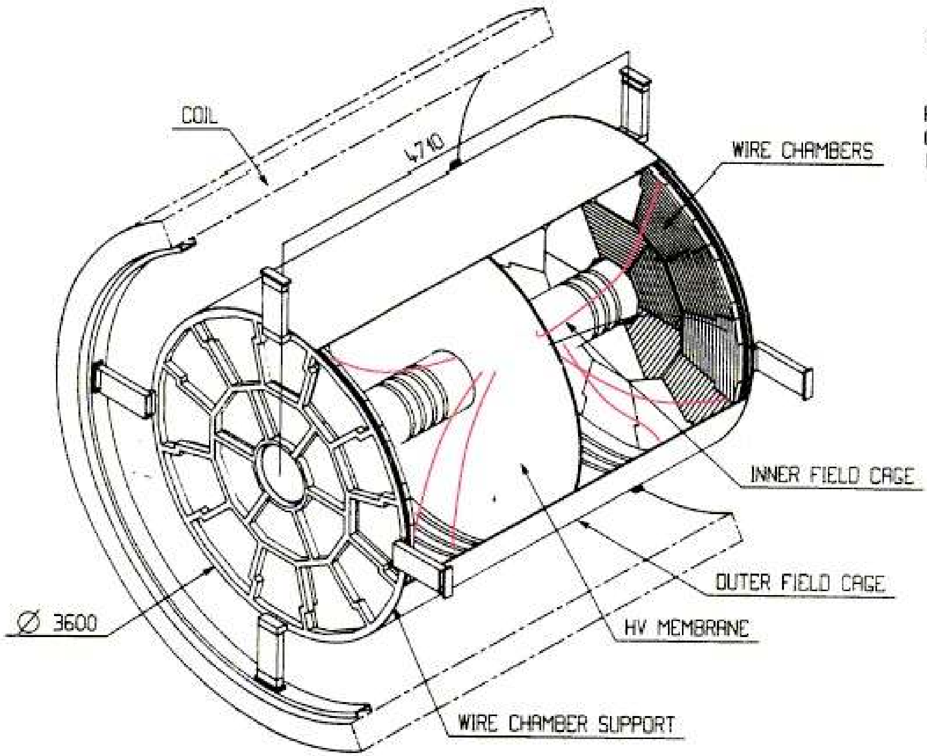
Camere a deriva

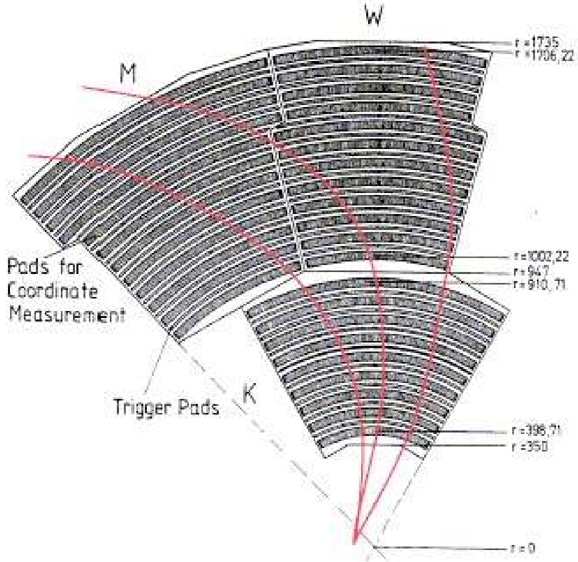
Camera a deriva di BaBar (SLAC)

Camera a deriva di KLOE (Frascati)



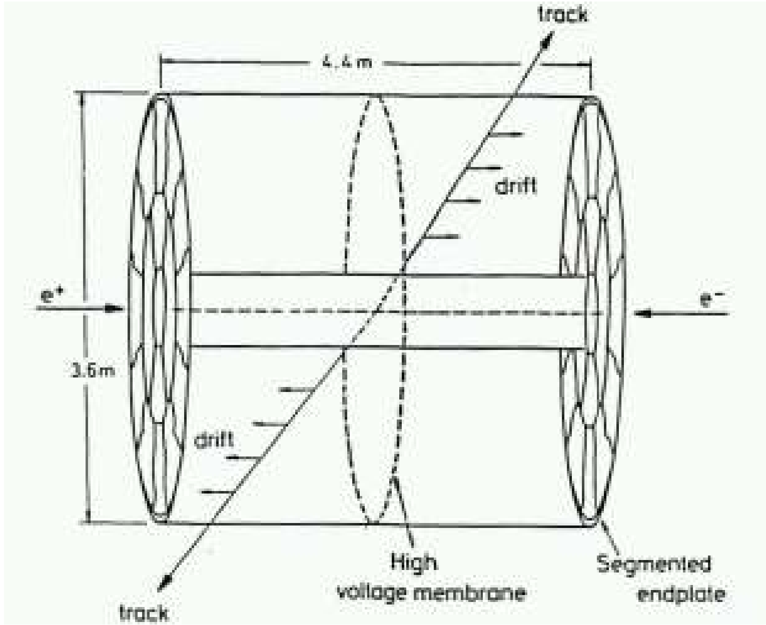




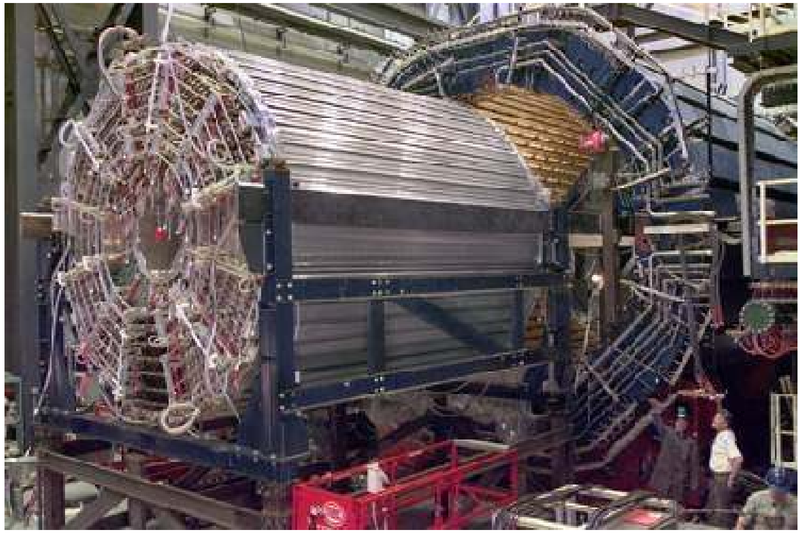


Time Projection Chamber

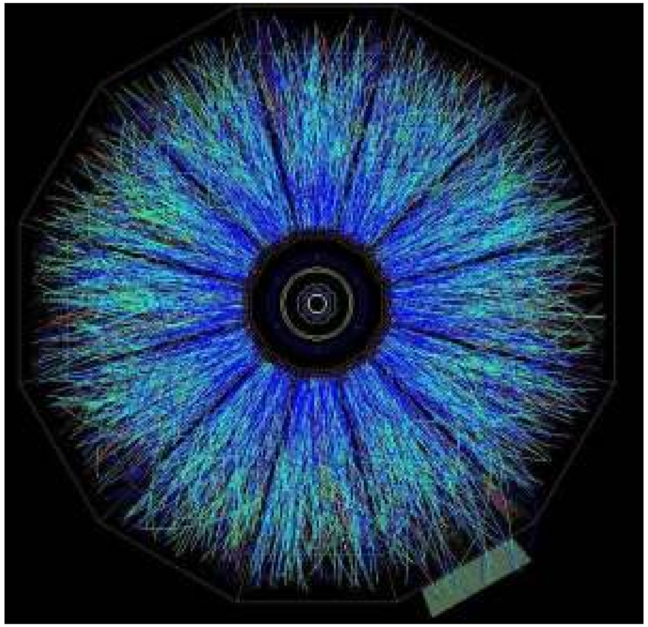
D. Nygren (1976)



TPC (STAR)

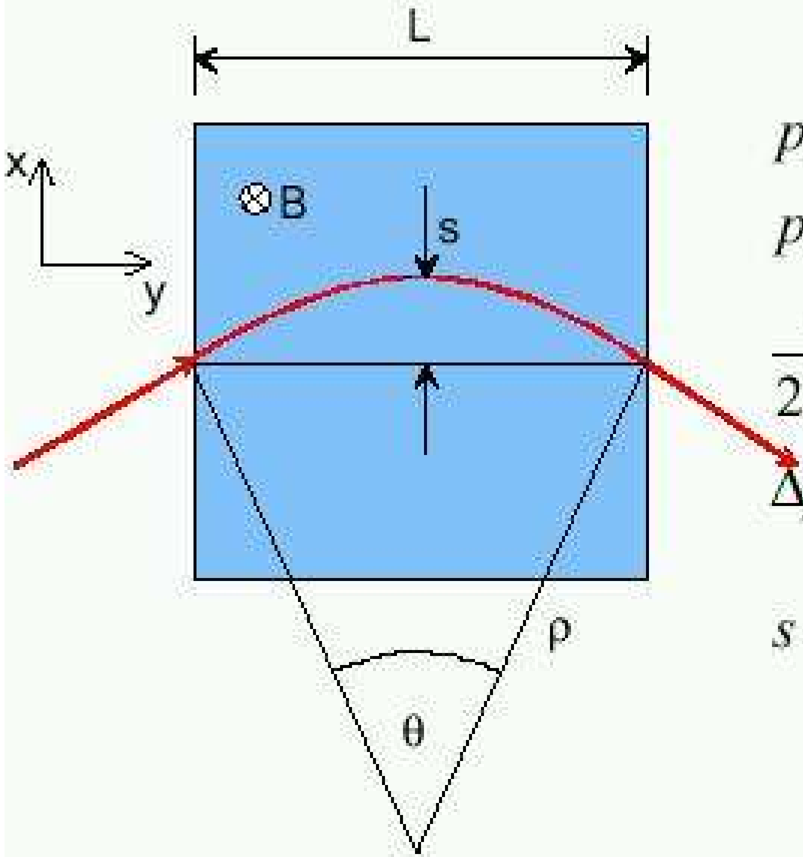


Brookhaven National Laboratory (USA)
Diametro e lunghezza 4m ca.
138000 pad lette da digitizzatori per la misura di dE/dx e la tracciatura.
70M elementi di volume a 10 bit



Au+Au (100 GeV+100 GeV)

Spettrometri magnetici



$$p_T = qB\rho$$

$$p_T\ (\mathrm{GeV/c}) = 0.3 B\rho \quad (\mathrm{T \cdot m})$$

$$\frac{L}{2\rho} = \sin\theta/2 \approx \theta/2 \quad \rightarrow \quad \theta \approx \frac{0.3 L \cdot B}{p_T}$$

$$\Delta p_T = p_T \sin\theta \approx 0.3 L \cdot B$$

$$s = \rho(1-\cos\theta/2) \approx \rho\frac{\theta^2}{8} \approx \frac{0.3}{8}\frac{L^2 B}{p_T}$$

Spettrometri magnetici: errore