PID - Programma INFN per Docenti

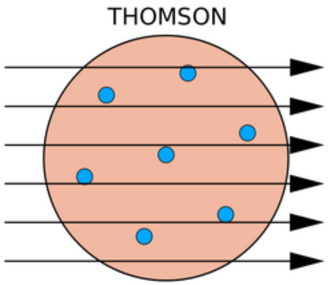
18-22 February 2019
Laboratori Nazionali del Sud

Tecniche di rivelazione in fisica nucleare

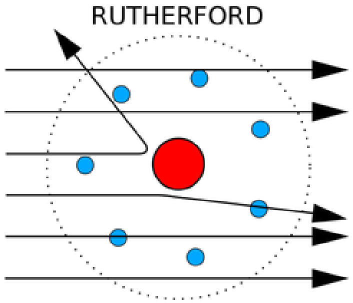
P. Russotto

INFN-Laboratori Nazionali del Sud

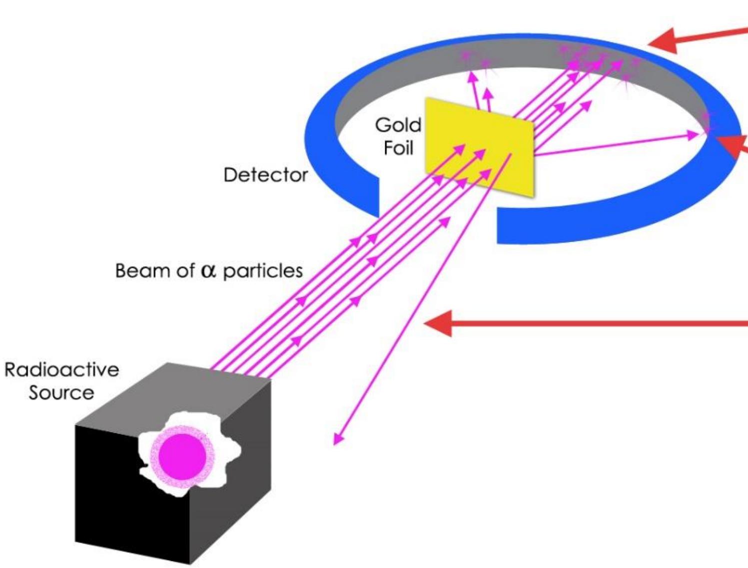
L’inizio della fisica nucleare



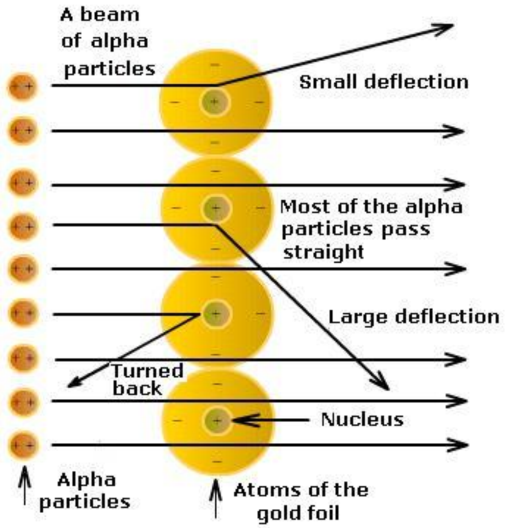
Primi del 1900
Atomo:
Panettone o planetario?



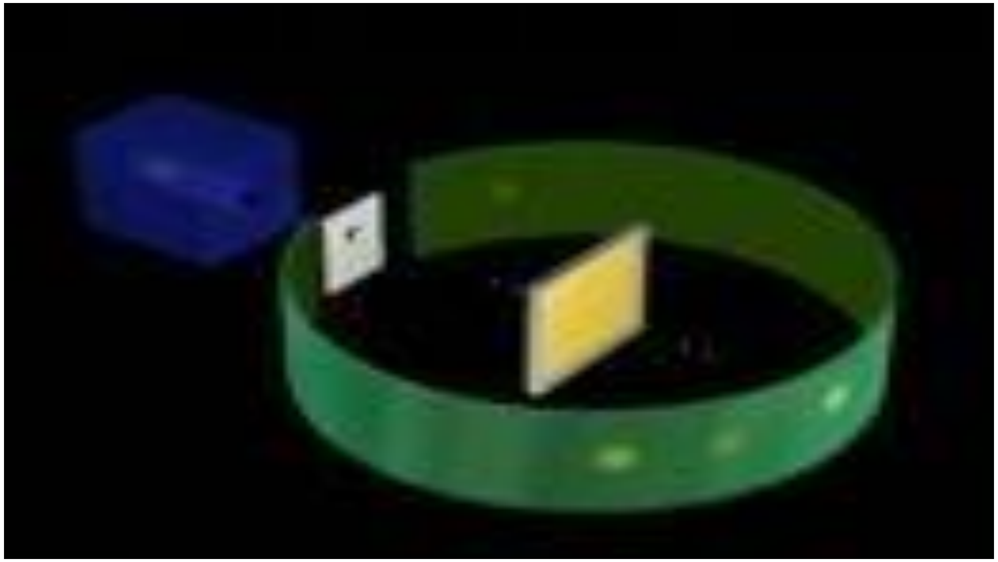
Rutherford’s Gold Foil Experiment (1908-1913)

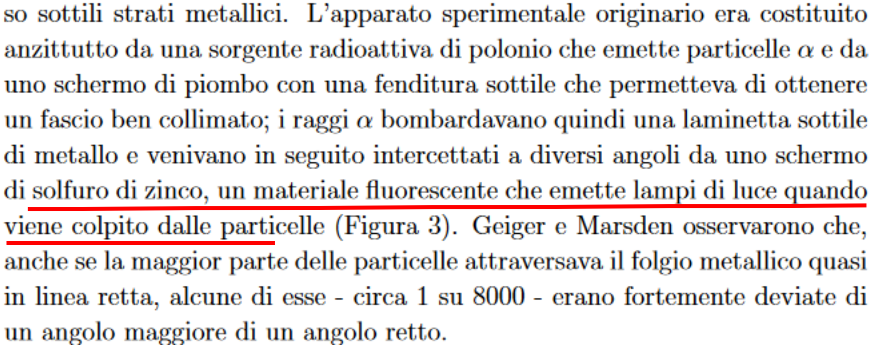


Observation	Interpretation
Most α particles travel through the foil undeflected	The atom is mostly empty space
Some α particles are deflected by small angles	The nucleus is positively charged, as is the α particle
Occasionally, an α particle travels back from the foil	The nucleus carries most of the atom’s mass



L’esperimento di Rutherford





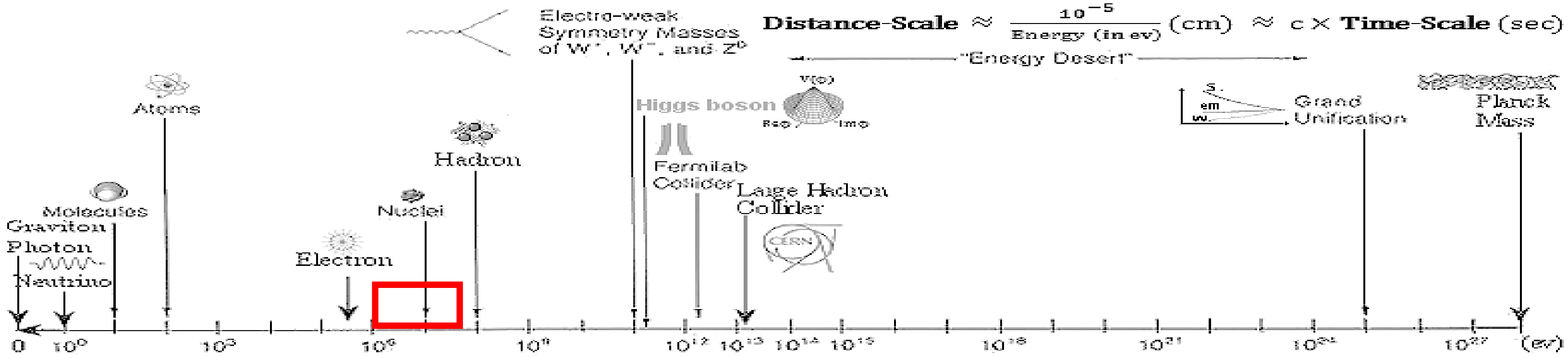
so sottili strati metallici. L’apparato sperimentale originario era costituito anzittutto da una sorgente radioattiva di polonio che emette particelle α e da uno schermo di piombo con una fenditura sottile che permetteva di ottenere un fascio ben collimato; i raggi α bombardavano quindi una laminetta sottile di metallo e venivano in seguito intercettati a diversi angoli da uno schermo di solfuro di zinco, un materiale fluorescente che emette lampi di luce quando viene colpito dalle particelle (Figura 3). Geiger e Marsden osservarono che, anche se la maggior parte delle particelle attraversava il folgio metallico quasi in linea retta, alcune di esse - circa 1 su 8000 - erano fortemente deviate di un angolo maggiore di un angolo retto.

http://www.dmf.unicatt.it/~sangalet/PLS/Buone_pratiche/Esperimento_Rutherford.pdf

IERI: Uomo che guarda lampi di luce su uno schermo in una stanza buia…situazione non facile

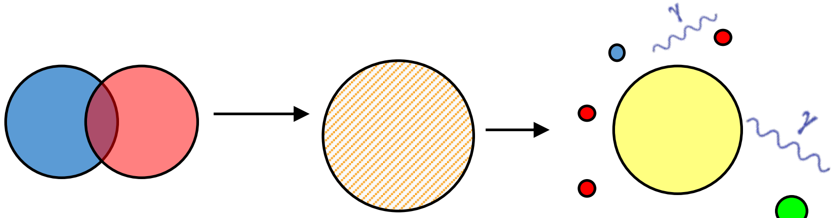
OGGI: Sistemi-elettronici digitali che processano i lampi di luce o gli impulsi di corrente prodotti nei **rivelatori** avvisandoci dell’arrivo di un nucleo e fornendoci, a seconda dei casi, quante più informazioni su di esso situazione anch’essa non facile

Fisica nucleare e particellare, molta varietà in base all’energie in gioco (dal KeV al TeV)



Focalizziamoci però, in maniera non esaustiva, su ciò di cui abbiamo esperienza ai LNS

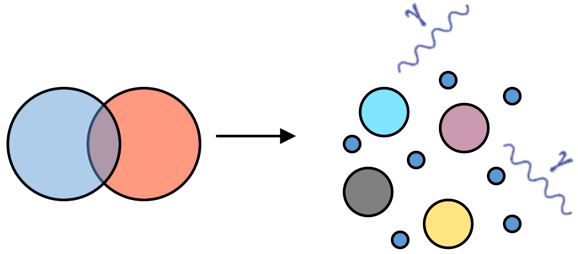
Collisioni tra Ioni Pesanti (centrali):…una schematizzazione bruta



Nucleo Composto

Residuo di evaporazione

Basse energie **(E/A < 10 MeV/A), si forma un nucleo composto eccitato che si diseccita emettendo particelle leggere, neutroni e gamma (p, n, d, t, α, γ), oppure fissionandosi**



Frammenti di massa Intermedia e protoni neutroni, alfa, deutoni …

Energie Intermedie **(10 MeV/A < E/A <100 MeV/A), produzione di particelle leggere (p, n, d, t, α, γ) e di diversi nuclei di piccola taglia (C, N, O, Al)**

(multiframmentazione)

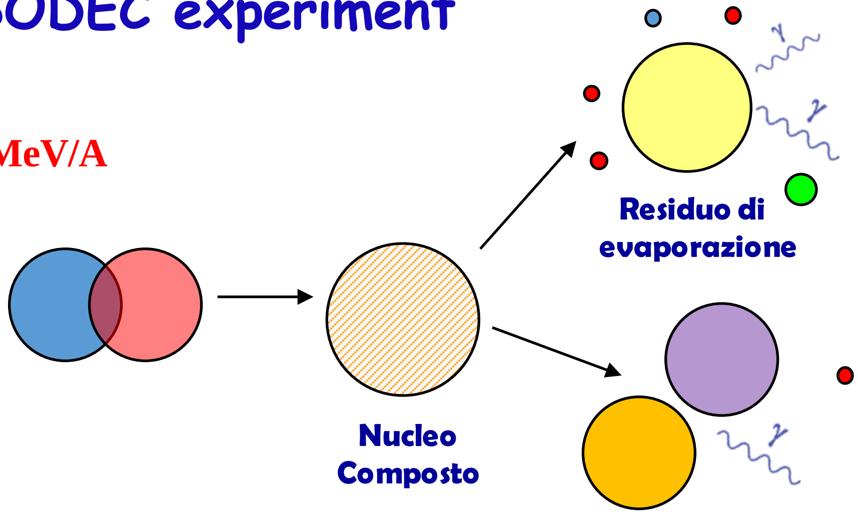
ISODEC experiment

$^{78}\mathrm{Kr} + {}^{40}\mathrm{Ca} \rightarrow {}^{118}\mathrm{Ba}^{*}$

$^{86}\mathrm{Kr} + {}^{48}\mathrm{Ca} \rightarrow {}^{134}\mathrm{Ba}^{*}$

@E/A=10 MeV/A

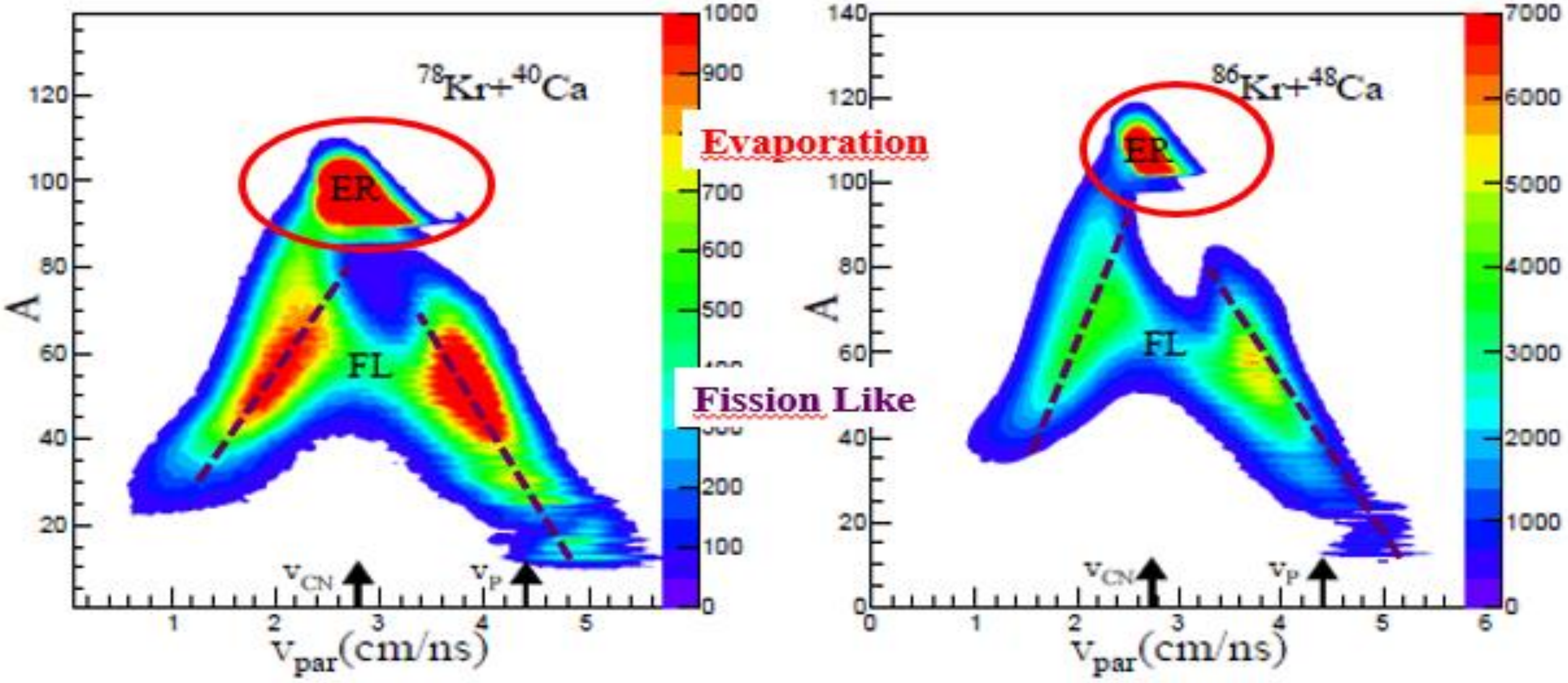
ISODEC Experiment



Residuo di evaporazione

Nucleo Composto

Fissione

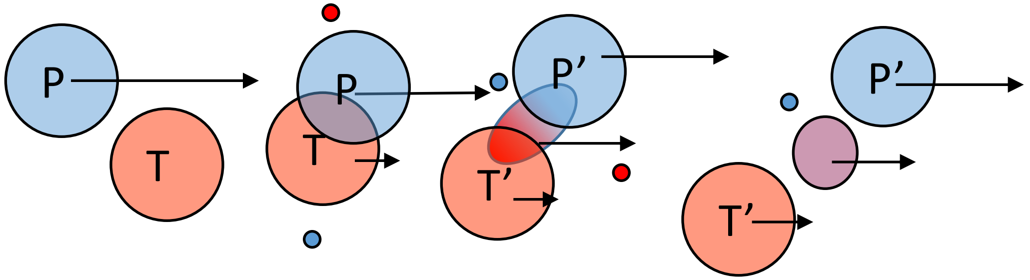


Evaporation

Fission Like

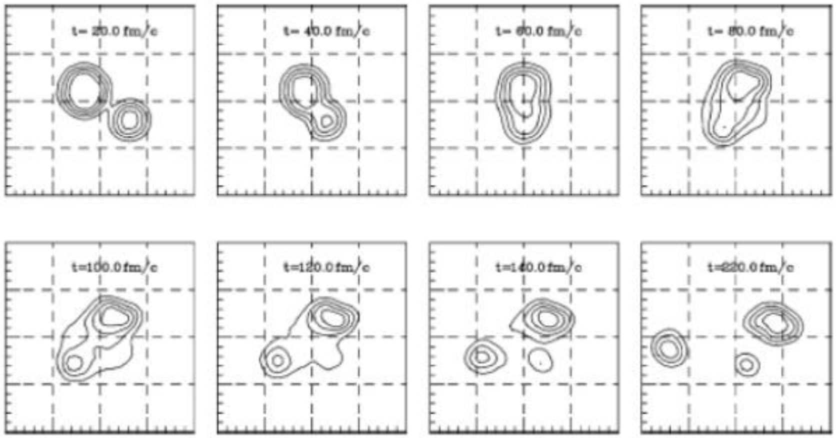
S. Pirrone et al., EPJ Web of Conf. 122, 13001 (2016)
B. Gnoffo et al., Nuovo Cimento C 39, 403 (2016).

IMF emission mechanism in ternary events

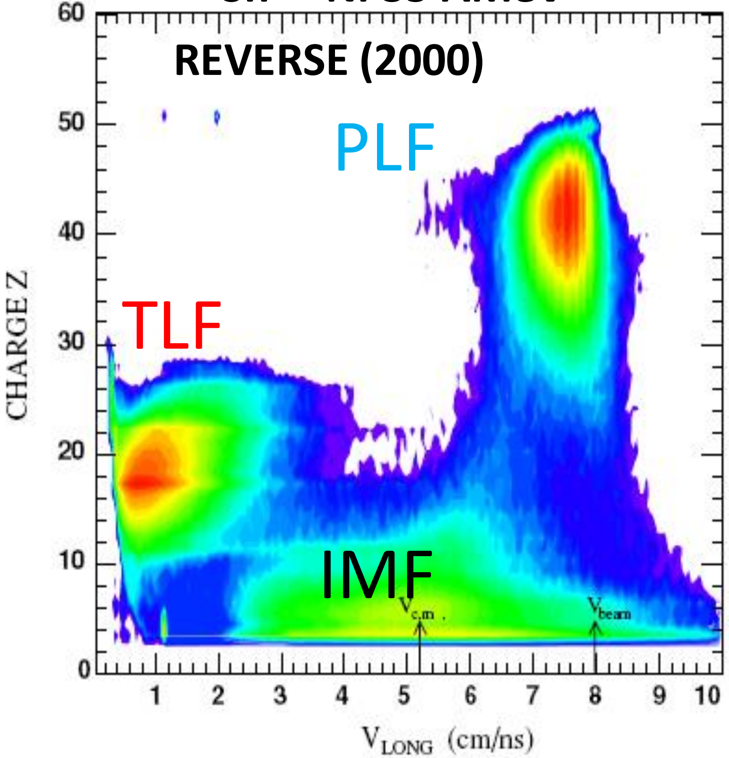


$^{124}Sn+^{64}Ni$ 35 AMeV

M. Colonna (LNS) SMF calculation



$^{124}Sn+^{64}Ni$ 35 AMeV



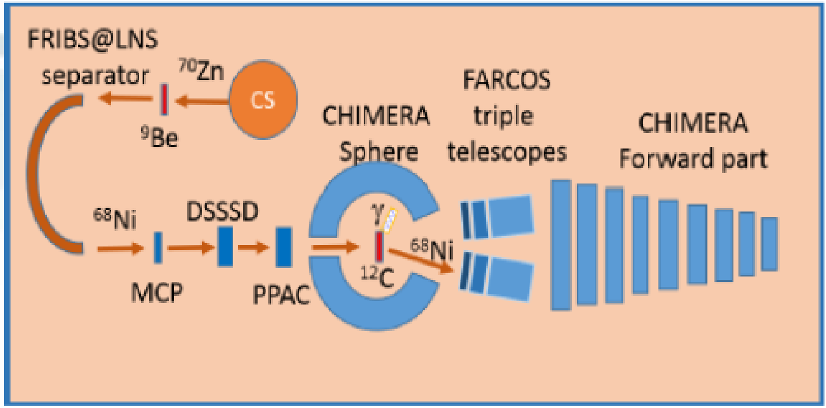
Semi-peripheral collisions:

- Projectile-Like Fragment (PLF)
- Target-Like Fragment (TLF)
- Intermediate Mass Fragments (IMF)

E. De Filippo et al,. Phys. Rev. C71 044602 (2005)
E. De Filippo et al., Phys. Rev. C86 014610 (2012)

Pygmy Dipole Resonance in ^{68}Ni ---- ^{68}Ni +^{12}C at E=40 AMeV (CHIMERA+FARCOS @LNS EXOTIC Beam)

First isoscalar excitation of Pigmy Dipole Resonance (PRD) in neutron rich ^{68}Ni, already studied with isovector probe

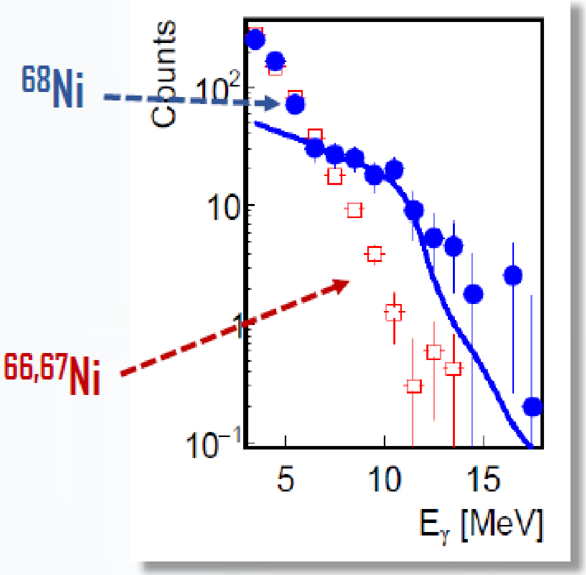


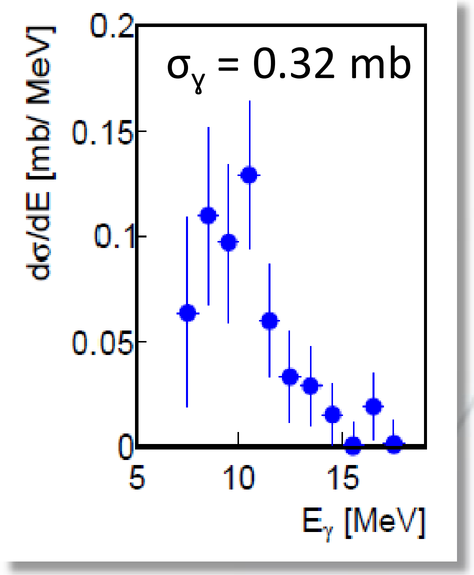
^{68}Ni produced and tagged at 40 AMev by Fragmentation system at LNS

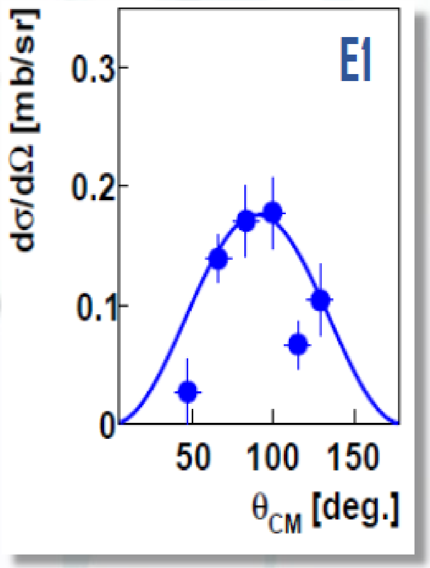
Reaction ^{12}C target -> detected by FARCOS

γ rays measured with CHIMERA

-> PDR with max at 10 MeV and E1 behaviour



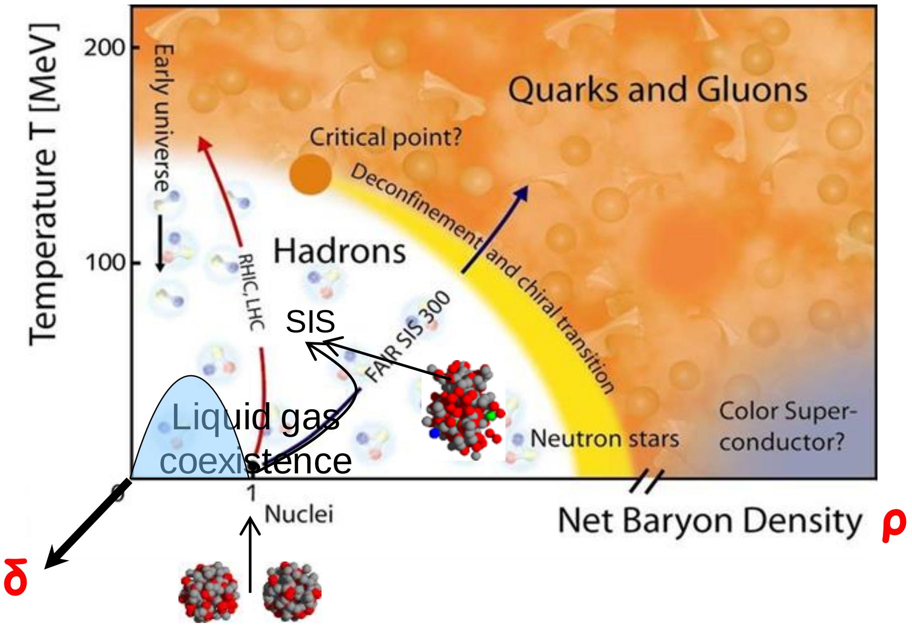




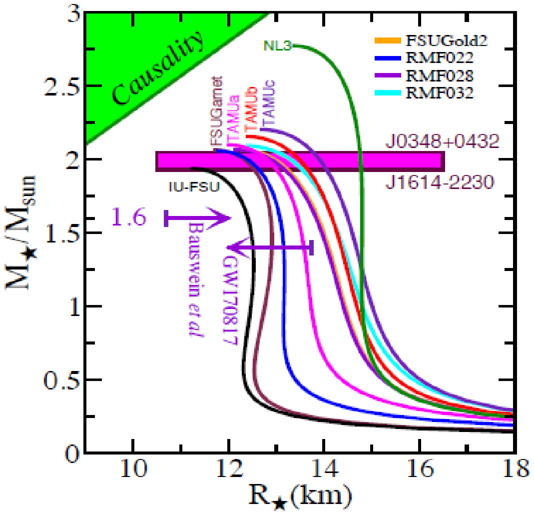
N.S. Martorana et al., Phys. Lett. B 782 (2018)

The nuclear EOS describes the relation among energy, pressure, density, temperature and isospin asymmetry. It is a fundamental ingredient in nuclear physics and astrophysics.

Nuclear matter phase diagram (schematic)



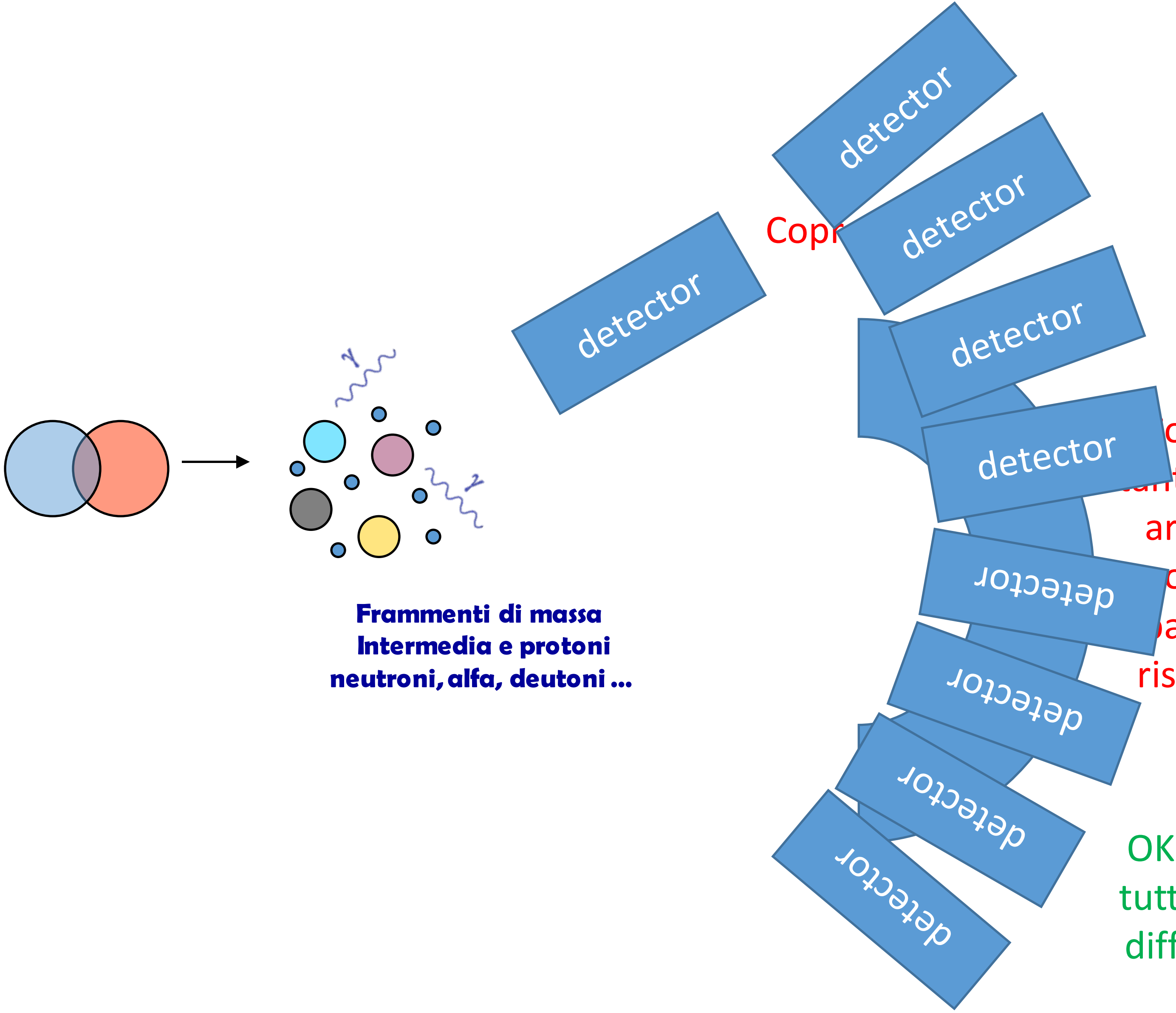
$$\delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p} = \frac{N-Z}{A}$$



Fattoyev, Piekarewicz, Horowitz

arXiv:1711.06615v2 [nucl-th]

Sistemi di rivelazione…idea di base



Frammenti di massa Intermedia e protoni neutroni, alfa, deutoni …

Copr

opro
nto ma
arriva
oppa
a…non
risolvo

OK…ma
tutto più
difficile!

CHIMERA @LNS

A. Pagano et al, Nucl. Phys A 734, 504 (2004)

A. Pagano, Nucl. Phys. News 22, 28 (2012) and references therein.

E. De Filippo & A. Pagano EPJA 50 (2014) and references therein.

MAGNEX spectrometer @ LNS

Camera di scattering

$P_i = (x_i, y_i, \theta_i, \phi_i, \delta_i)$

Quadrupole

Dipole

Focal Plane Detector (FPD)

$P_f = (x_f, y_f, \theta_f, \phi_f)$

Optical characteristics	Values
Maximum magnetic rigidity	1.8 T m
Solid angle	50 msr
Momentum acceptance	-14.3%, +10.3%

Good compensation of the aberrations:
Trajectory reconstruction

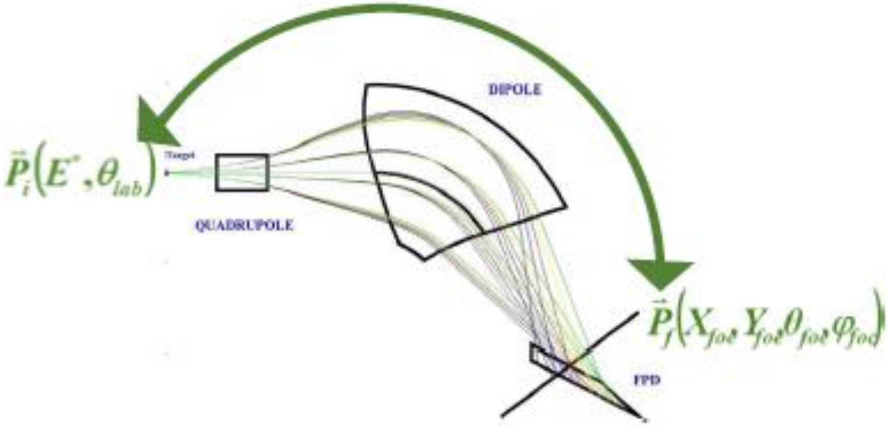
Measured resolutions:

- Energy $\Delta E/E \sim 1/1000$
- Angle $\Delta\theta \sim 0.3°$
- Mass $\Delta m/m \sim 1/160$

Transport Matrix

M: $P_i \rightarrow P_f$

M^{-1}: $P_f \rightarrow P_i$

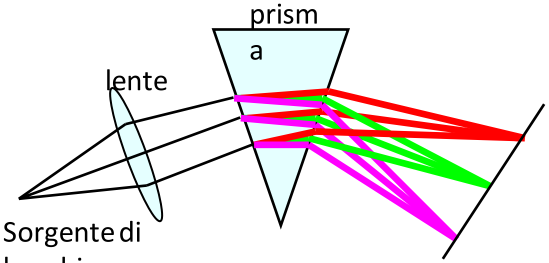


$$qvB = m\frac{v^2}{\varrho}$$

$$\varrho B = \frac{mv}{q}$$

Come funziona uno spettrometro

Spettrometro di luce

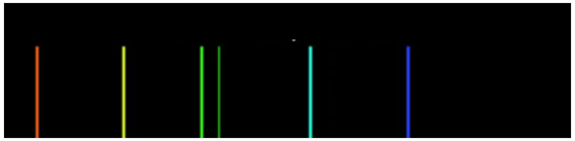


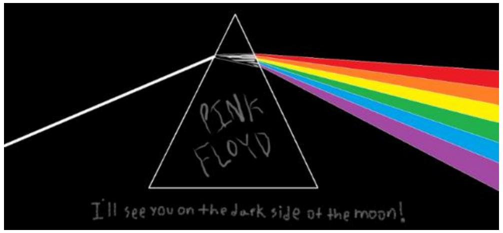
prism
a

lente

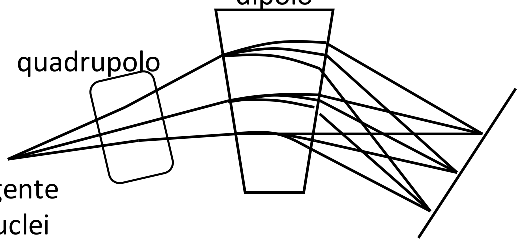
Sorgente di
luce bianca

La posizione dipende dal «colore»





Spettrometro magnetico



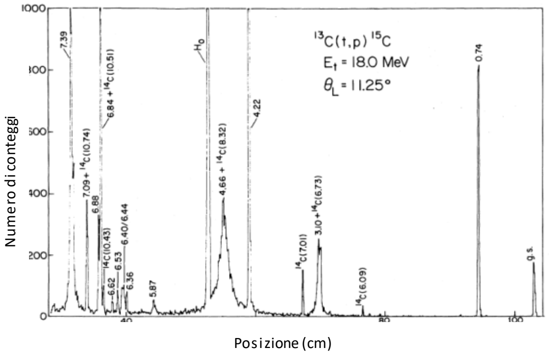
dipolo

quadrupolo

Sorgente
di nuclei

La posizione dipende da
(velocità*massa)/(stato di carica)

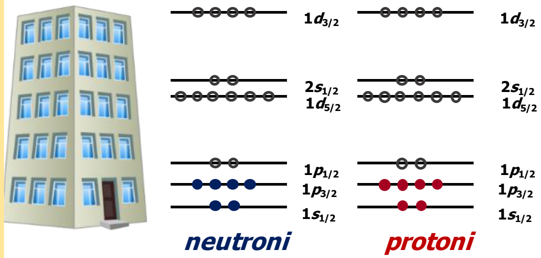
Lavora con fasci CS e Tandem



Carta d'identità del nucleo

Studi di struttura nucleare

Il modello a shell



Funziona come un filtro selezionando il tipo di nuclei desiderato

Caratteristiche generali dei rivelatori

Scopo della rivelazione delle particelle:

- Rivelare la presenza e la posizione
- Misurare energia - impulso
- Misurare l'istante di arrivo
- Identificare la particella

La rivelazione si basa sull'interazione tra particella e materiale del rivelatore

- particelle cariche e p n $k^{+,-}$ $\pi^{+,-}$ nuclei
- particelle neutre γ π^0 k^0 n

Caratteristiche generali dei rivelatori

- **Sensitivity**: capacità di produrre un segnale «valido» per un certo tipo di particella ed energia

- **Detector Response**: capacità del rivelatore di fornire informazioni aggiuntive alla presenza della particella, ad es., misurarne l'energia

- **Energy resolution**:

$$\text{Resolution} = \Delta E/E\ .$$

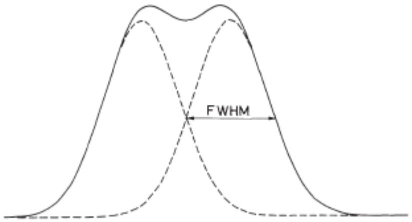


Fig. 5.1. Definition of energy resolution. Two peaks are generally considered to be resolved if they are separated by a distance greater than their full widths at half maximum (FWHM). The *solid line* shows the sum of two identical Gaussian peaks separated by just this amount

- **Response function:**

120

5. General Characteristics of Detectors

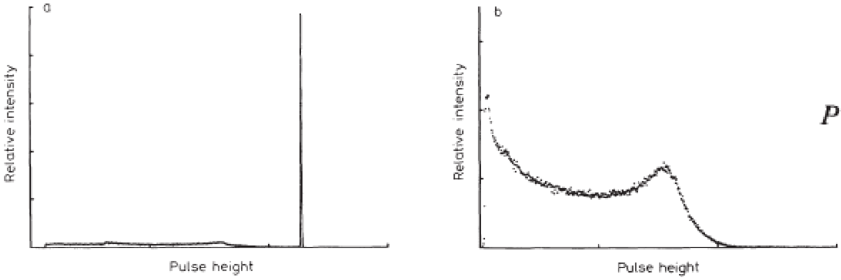


Fig. 5.2 a, b. The response functions of two different detectors for 661 keV gamma rays. **(a)** shows the response of a germanium detector which has a large photoelectric cross section relative to the Compton scattering cross section at this energy. A large photopeak with a relatively small continuous Compton distribution is thus observed. **(b)** is the response of an organic scintillator detector. Since this material has a low atomic number Z, Compton scattering is predominant and only this distribution is seen in the response function

$$PH(E) = \int S(E')R(E, E')\,dE'\ ,$$

Caratteristiche generali dei rivelatori

- **Response time:** tempo che il rivelatore impiega a rispondere; importante per mantenere informazione temporale sull'arrivo della particella

- **Efficienza geometrica e intrinseca**:

$$\mathscr{E}_{\text{tot}} = \frac{\text{events registered}}{\text{events emitted by source}} .$$

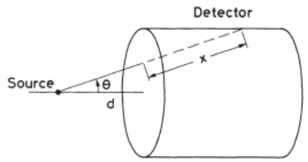


Fig. 5.3. Calculating the detection efficiency of a cylindrical detector for a point source

$$\mathscr{E}_{\text{tot}} \simeq \mathscr{E}_{\text{int}}\, \mathscr{E}_{\text{geom}} .$$

$$\mathscr{E}_{\text{int}} = \frac{\text{events registered}}{\text{events impinging on detector}} .$$

- **Tempo morto:** tempo che il sistema di rivelazione impiega per tornare pronto a rivelare una nuova particella

5.7 Dead Time

125

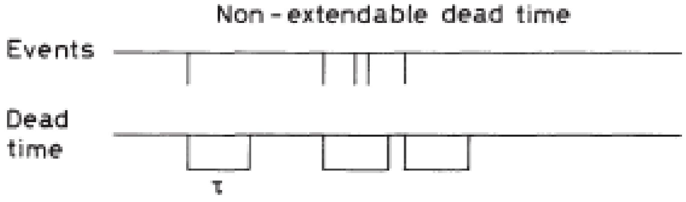
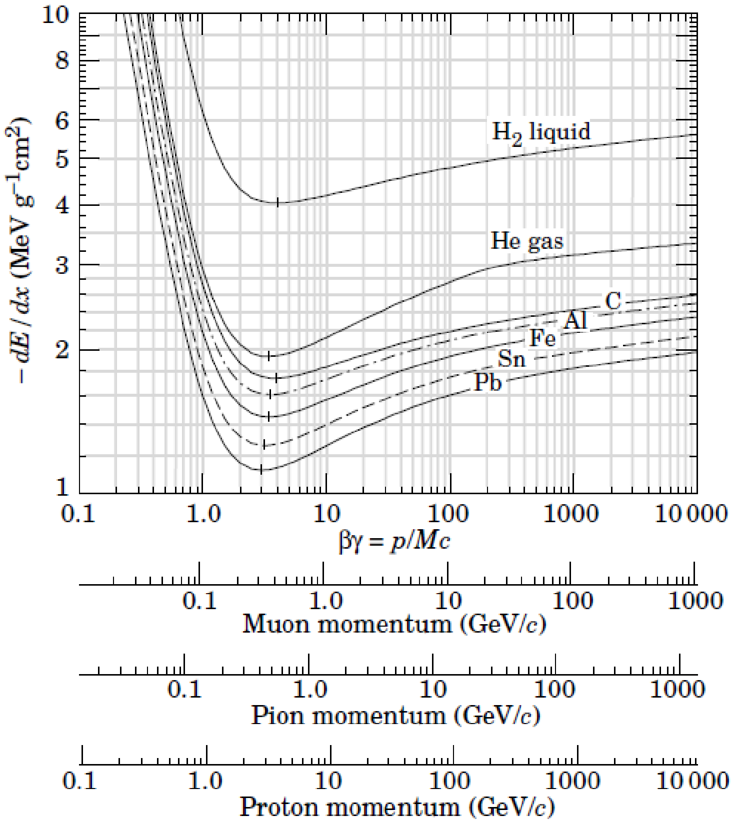


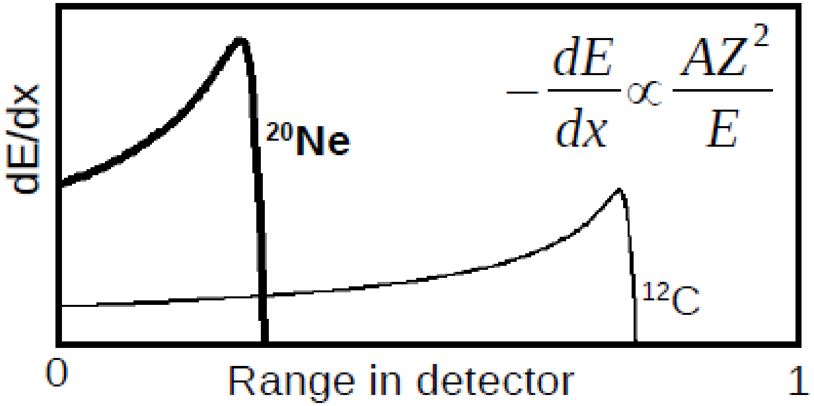
Fig. 5.4. Extendable (paralyzable) and non-extendable (non-paralyzable) dead time models

Interazione particelle/onde materia

Particelle cariche:
perdita di energia per ionizzazione

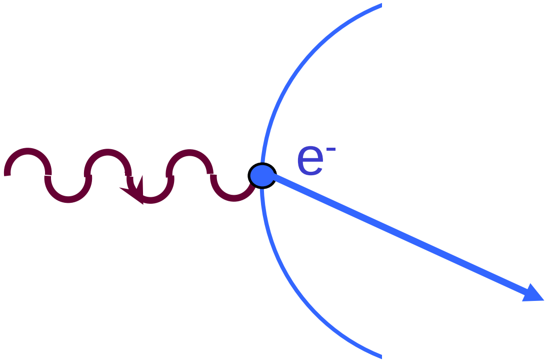
formula di Bethe-Bloch
$$\frac{dE}{dx} = C\,\frac{Z}{A}\,\frac{z^2}{\beta^2}\left(\ln\frac{2m_e c^2\beta^2\gamma^2}{\langle I\rangle} - \beta^2\right)$$





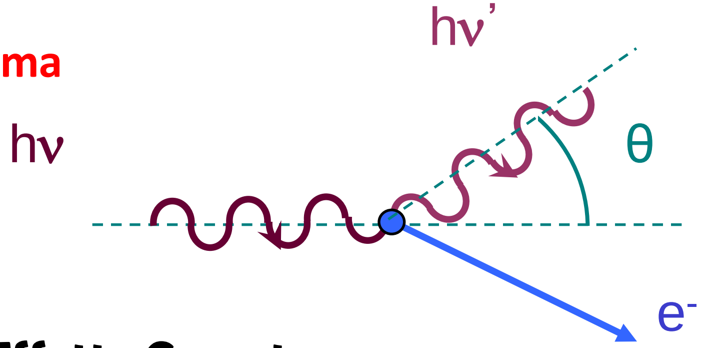
Interazione particelle/onde materia

Particelle neutre: raggi gamma



Effetto fotoelettrico

$$E_e = E_\gamma - E_b = h\nu - E_b$$



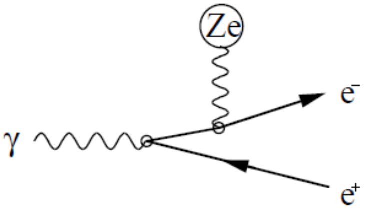
Effetto Compton

$$\lambda' - \lambda = \frac{h}{m_e c}\left(1 - \cos\theta\right)$$

Produzione di coppie

$$\gamma \rightarrow e^+ + e^-$$

$$E_{e-} + E_{e+} + K_{nuc} = E_\gamma - 2\,m_e c^2$$



può avvenire se l'energia del fotone è $E > 2m_e c^2$.

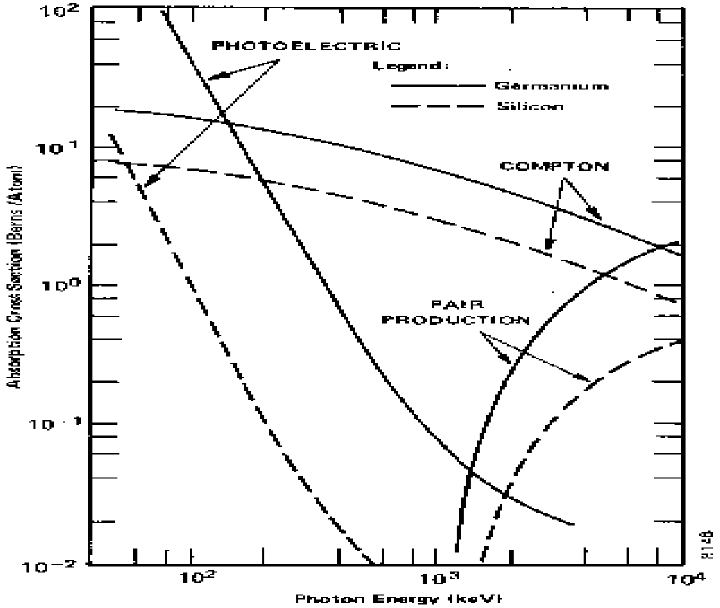
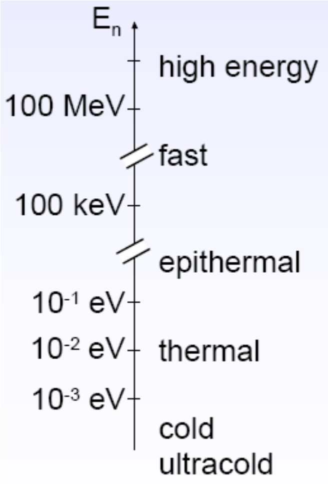


Fig. 7.2. Relative Probability of Each of the Three Types of Interactions as a Function of Energy.

Interazione particelle/onde materia

Particelle neutre: neutrone

I neutroni vengono classificati in base all'energia



Unica interazione possibile con i nuclei mediante la forza nucleare, per dare

- **diffusione elastica $n+A \rightarrow n+A$ ed inelastica $n+A \rightarrow n+A^*$ (H è il moderatore ideale)**

- **cattura radiativa: Il nucleo cattura il neutrone assorbendo la sua energia ed emette particelle o γ oppure si spacca**

  $n + p \rightarrow d + \gamma$, $n + {}^{3}He \rightarrow {}^{3}H + p$

  $n + {}^{10}B \rightarrow \alpha + {}^{7}Li$, $n + {}^{6}Li \rightarrow \alpha + {}^{3}He$
- **fissione $n + {}^{233,235,238}U$, ${}^{209}Bi$, ${}^{237}Np$, ${}^{239,241}Pu \rightarrow$ fissione**

- **Reazioni, importanti per neutroni veloci**

  $n + {}^{12}C \rightarrow \alpha + {}^{9}Be$, $n + {}^{12}C \rightarrow p + {}^{12}B$, $n + {}^{12}C \rightarrow n' + 3\alpha$

Rivelazione di particelle cariche

Processo di interazione con la materia in vari stati gas - liquido - solido

eccitazione/ionizzazione -> portatori di informazione

Processo continuo che avviene sempre nel mezzo:

-> probabilità di rivelazione ~ 1

Misura dell’energia rilasciata nel rivelatore se il segnale è legato a quest’ultima

Rivelazione di particelle neutre

- Decadimento o conversione in particelle cariche
- Interazione con la materia con una data probabilità

Con l’interazione si generano particelle cariche

gamma -> elettroni

neutroni -> particelle cariche pesanti o γ

Due stadi: decadimento/conversione –> rivelazione

-> probabilità di rivelazione < 1

Misura corretta dell’energia solo se essa viene rilasciata per intero nel processo di conversione

Le proprietà dei semiconduttori

Solido: reticolo con elettroni in stati energetici raggruppati in bande

Banda di valenza: elettroni fissi nel reticolo

Banda di conduzione: elettroni liberi

Metalli: bande praticamente sovrapposte, elettroni presenti in banda di conduzione $n \approx 10^{28}$ el/m^3

-> passaggio agevole di corrente

Isolanti: bande molto distanti separate da un gap energetico $E_{gap} \approx 5$ eV dove non vi sono stati permessi, non vi sono elettroni in conduzione

-> passaggio di corrente bloccato

Il drogaggio

I semiconduttori vengono solitamente drogati con l'aggiunta di impurità (oltre quelle già presenti)

Effetto del drogaggio

- equilibrio delle cariche perturbato
- livelli energetici presenti nella zona proibita

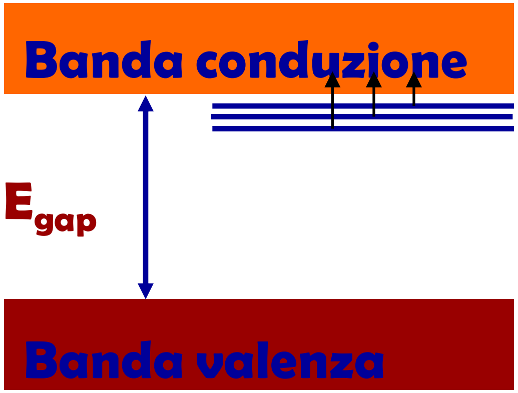
Drogante pentavalente (P, As, Sb)

Elemento con un elettrone in più, debolmente legato

-> livelli appena sotto la conduzione

passaggio in banda di conduzione a T ambiente

-> donore con concentrazione N_d



Banda conduzione

E_{gap}

Banda valenza

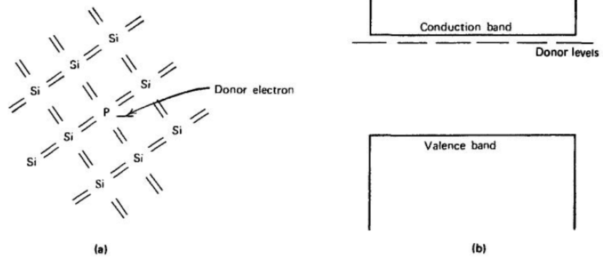


Figure 11.3 (*a*) Representation of a donor impurity (phosphorus) occupying a substitutional site in a silicon crystal. (*b*) Corresponding donor levels created in the silicon bandgap.

-> aumento delle cariche negative libere

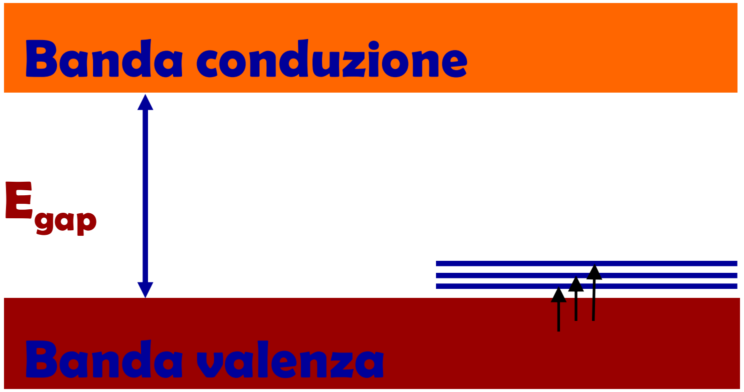
$$n = n_i + N_d \approx N_d = 10^{15} \text{ atomi/cm}^3$$

Drogante trivalente (B)

Elemento con un elettrone in meno, i cui atomi catturano un e che si mette nei livelli sopra la valenza

L'elettrone è bloccato nell'accettore e lascia una lacuna libera in valenza

-> accettori con concentrazione N_a



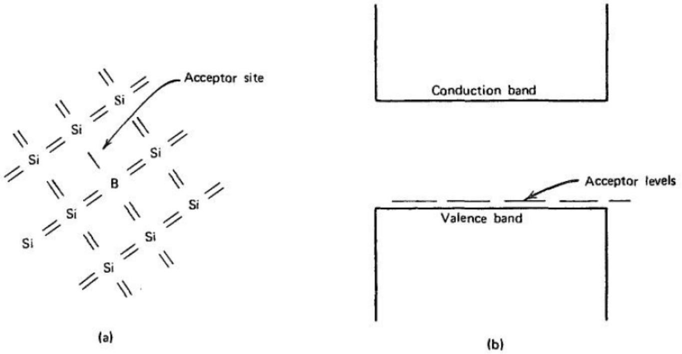


Figure 11.4 (*a*) Representation of an acceptor impurity (boron) occupying a substitutional site in a silicon crystal. (*b*) Corresponding acceptor levels created in the silicon bandgap.

-> aumento delle cariche positive libere

$$p = p_i + N_a \approx N_a = 10^{14} \text{ atomi/cm}^3$$

Le giunzione n-p

Unione di un materiale di tipo **n** con uno di tipo **p**, maggiormente drogato -> **p+** in modo che le cariche siano libere di migrare da uno all'altro

Tipo **p** -> eccesso cariche libere **positive**

Tipo **n** -> eccesso cariche libere **negative**

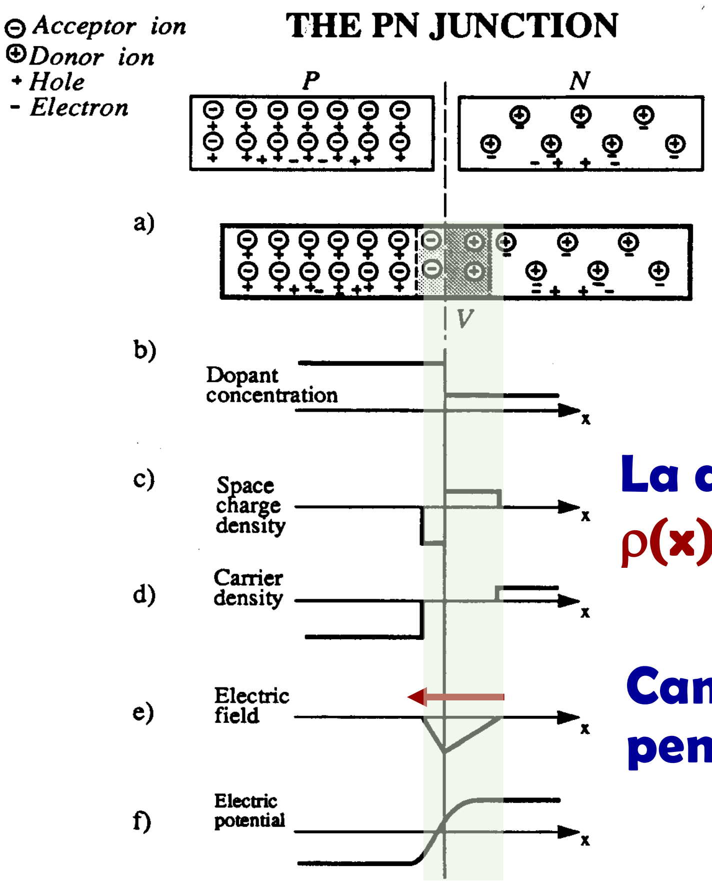
Al contatto le cariche libere in eccesso migrano da un tipo all'altro -> **diffusione e ricombinazione**

Il processo si ferma quando si genera un campo elettrico che si oppone a tale moto

-> **equilibrio dinamico**

Regione di svuotamento dove le cariche libere si ricombinano lasciando solo le cariche fisse

-> densità di carica fissa -> campo elettrico -> ddp



La densità di carica fissa è uniforme

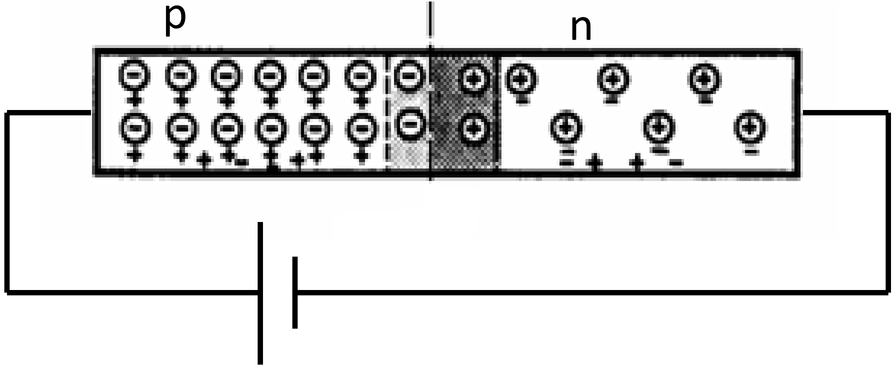
$\rho(x)=qN_d$ $\rho(x)=qN_a$

Campo elettrico lineare con pendenza ~ N_d e N_a

$W = X_p + X_n$

La polarizzazione

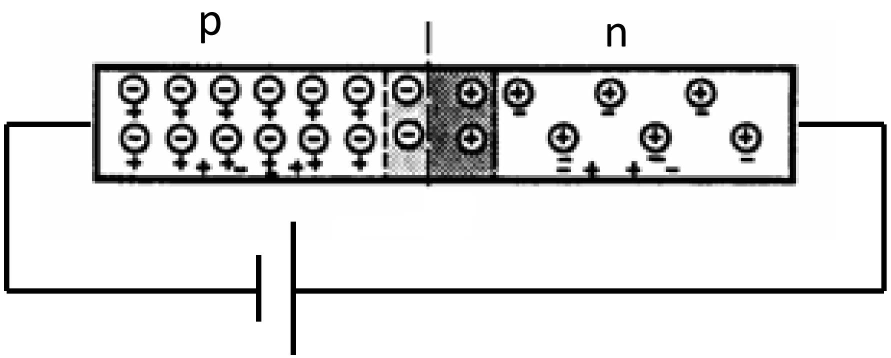
Se ai capi di una giunzione n-p viene posta una tensione V_e ossia vengono iniettate delle cariche:



- polarizzazione diretta: p positivo e n negativo

Il moto della cariche maggioritarie è favorito-> alta corrente anche a piccole V_e

Lo svuotamento si riduce ed la ddp si abbassa a V_i-V_e

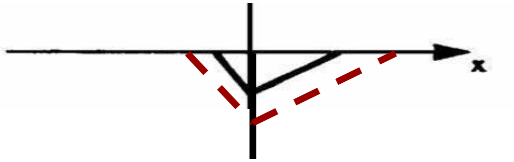


- polarizzazione inversa: **n** positivo e **p** negativo

Il moto delle cariche maggioritarie è bloccato dal campo interno -> bassa corrente anche ad alte **V**

Le cariche iniettate fanno aumentare la zona di svuotamento **W** ed il potenziale diventa $V_i + V_e$

Il campo elettrico si estende mantenendo la sua pendenza all'interno della giunzione



La rivelazione

Se delle particelle cariche attraversano la zona di svuotamento vi lasciano energia -> ionizzazione

Coppie elettrone/lacuna n coppie = Energia/w

w = Energia media di ionizzazione

Silicio w = 3,6 eV Germanio w = 3 eV

-> portatori liberi in una zona vuota

Tali coppie si muovono sotto l'effetto del campo elettrico della giunzione (V_i o V_t) verso i poli di segno opposto elettroni -> n lacune -> p+

-> segnale di corrente misurabile

I Rivelatori a Scintillazione

Introduzione

Principio di base:

- le particelle cariche (primarie o secondarie) rilasciano energia **E** eccitando il mezzo rivelatore
- il mezzo si diseccita emettendo luce ~ **100eV/fotone**
- la luce viene raccolta e trasformata in un segnale che contiene varie informazioni

Mezzi scintillanti **organici** ed **inorganici**, in vari stati fisici (gas, liquidi, solidi)

Strumenti di lettura della luce di vario genere

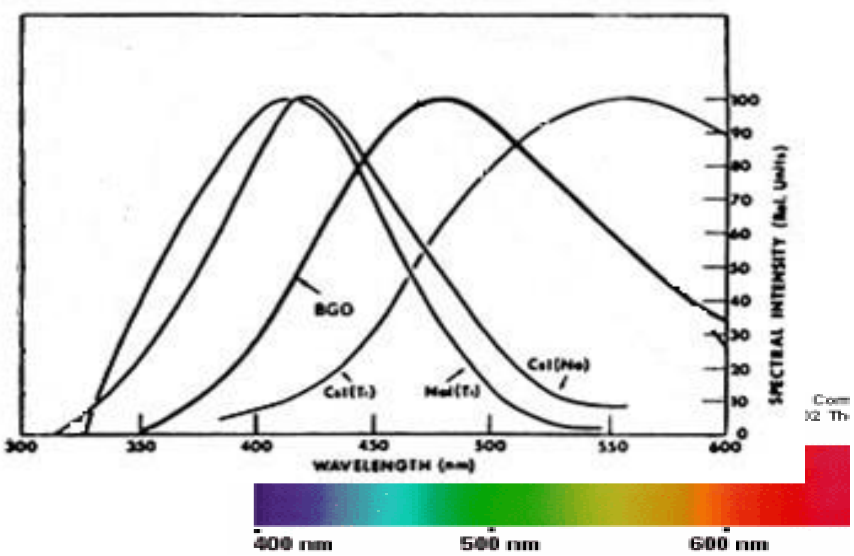
Scintillatore ideale:

- Alta efficienza e linearità nella conversione E - luce
- Trasparenza alla luce prodotta
- Semplicità di manipolazione e lavorazione
- Indice di rifrazione simile allo strumento per la rivelazione della luce per migliore accoppiamento
- Spettro di emissione in luce accoppiato con la sensibilità dello strumento di lettura
- Tempi brevi di emissione della luce

Compromesso tra esigenze e prestazioni

Gli spettri di emissione variano in base al materiale

Alcuni scintillatori inorganici più comuni



Ioduro di sodio NaI(Tl)
- elevata resa di luce
- igroscopico, fragile

Ioduro di cesio CsI(Tl)
- alti Z e ρ
- componenti lenta/veloce
- facile lavorazione, resistenza
- spettro luce spostato ad alta λ

Fluoruro di Bario BaF2
- alto Z, componenti lenta/veloce

Risposta di scintillazione

Parte dell'energia è convertita in luce ma molta si perde eccitazione non radiativa

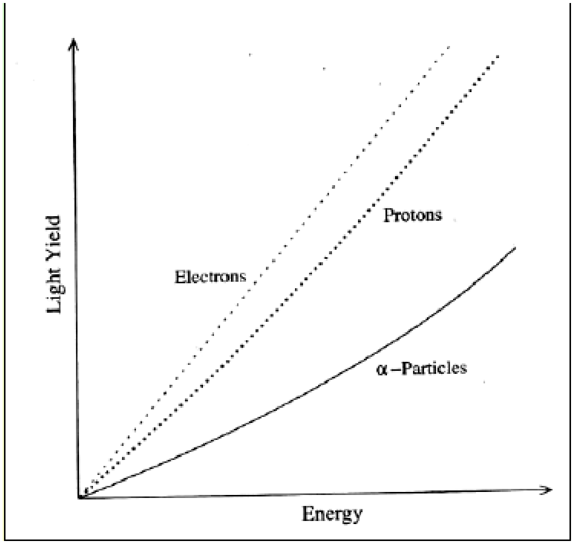
Efficienza di conversione

S = frazione di energia convertita il luce $$\frac{dL}{dx} = S\frac{dE}{dx}$$

Se S non è costante la risposta L(E) dello scintillatore non è lineare

Inoltre tale risposta dipende dal tipo di particella

Es.: NE102

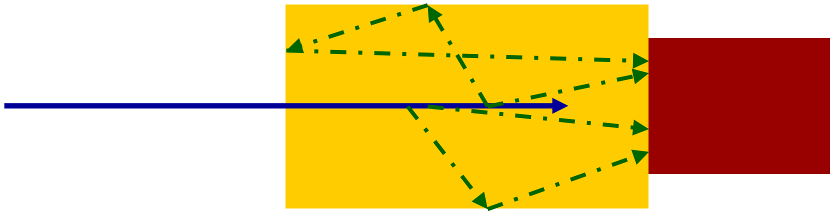


La raccolta della luce

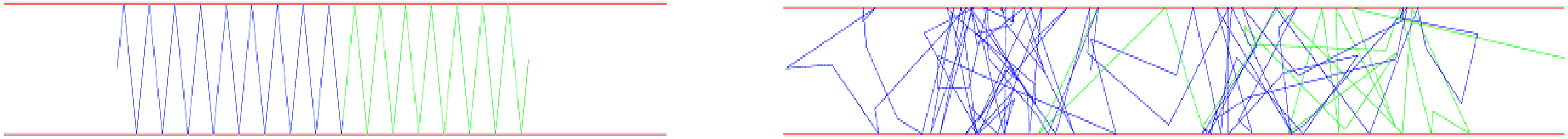
La luce prodotta viene raccolta in uno strumento di lettura che genera un segnale -> tempo, energia, Z/A

Emissione isotropa della luce lungo la traccia

Una parte della luce raggiunge subito lo strumento, una parte per eventuali riflessioni successive nelle pareti



Scintillatore avvolto in materiale riflettente speculare (alluminio) o diffuso (teflon bianco)



Finitura della superficie che può essere liscia o rugosa

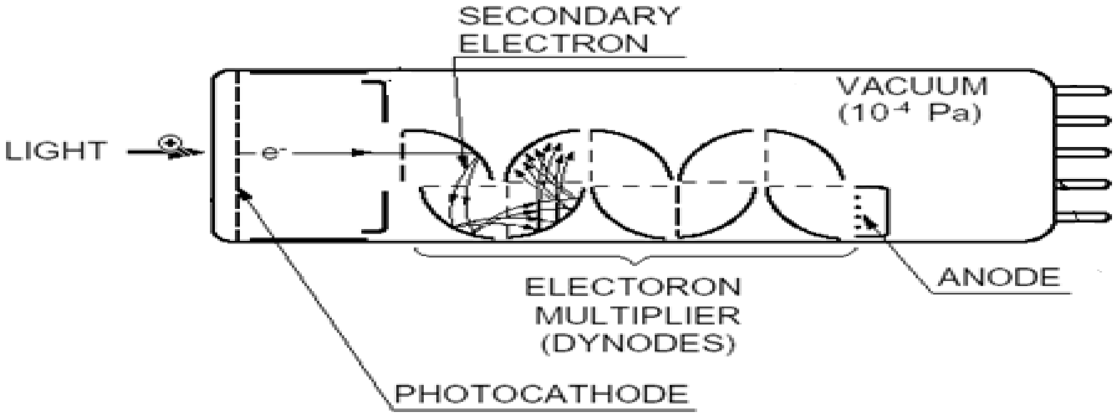
Avvolgimento esterno con materiale nero per impedire l'ingresso della luce dall'esterno

Accoppiamento cristallo/fotolettore con indici di rifrazione simili -> $n_c < n_f$ per evitare la riflessione totale per i fotoni in uscita

Una eventuale interfaccia deve avere n intermedio

Fotosensori 1: Fotomoltiplicatori

La luce raccolta può generare un segnale elettrico grazie ad un fotomoltiplicatore-fototubo PMT



Tubo sotto vuoto con:

Fotocatodo -> produce elettrone per e.f.

Dinodi -> moltiplicazione di elettroni

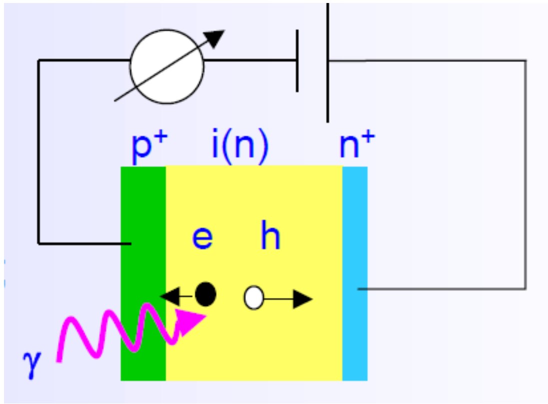
Anodo -> raccolta elettroni e produzione del segnale

Fotosensori 2: Rivelatori a Semiconduttore

I rivelatori a semiconduttore possono essere utilizzati per la lettura della luce di scintillazione

Fotodiodi (Photo Diode PD)

I fotoni incidono su una giunzione pn generando coppie elettrone-lacuna che sono raccolte dal campo elettrico presente nella giunzione



Caratteristiche

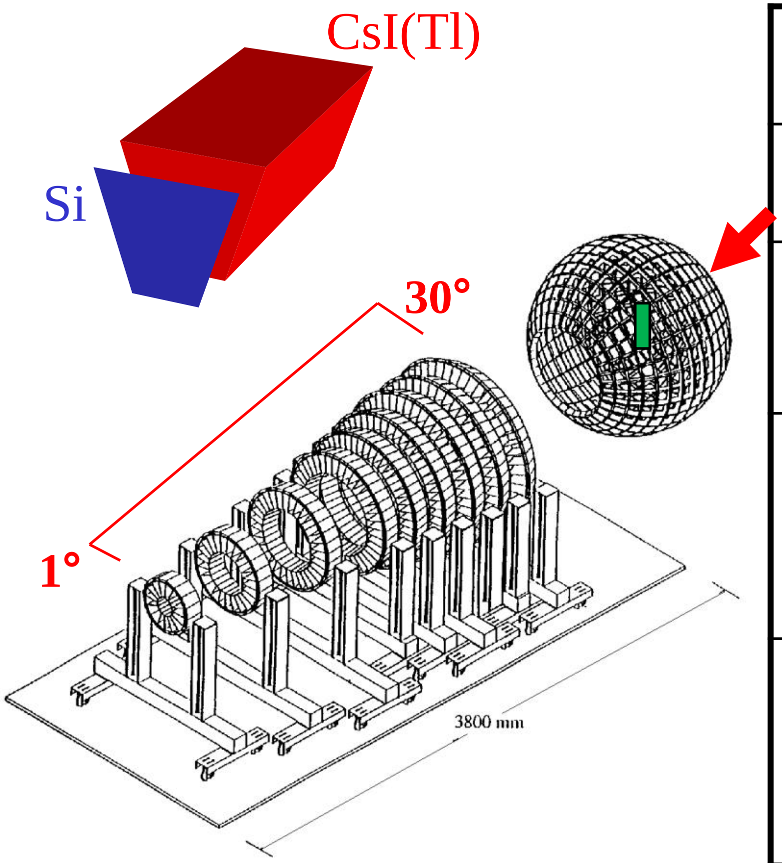
- **QE** molto elevata su un vasto dominio di λ $QE(\%) = \frac{N_{pe}}{N_{\gamma}}$
- basse tensioni operative **< 100 V**
- segnale proporzionale al numero di fotoni senza alcuna moltiplicazione

  -> stabile ma non adatto a basso numero di fotoni

Infiniti esempi di utilizzo in fisica nucleare e subnucl

CHIMERA

Charge Heavy Ion Mass and Energy Resolving Array

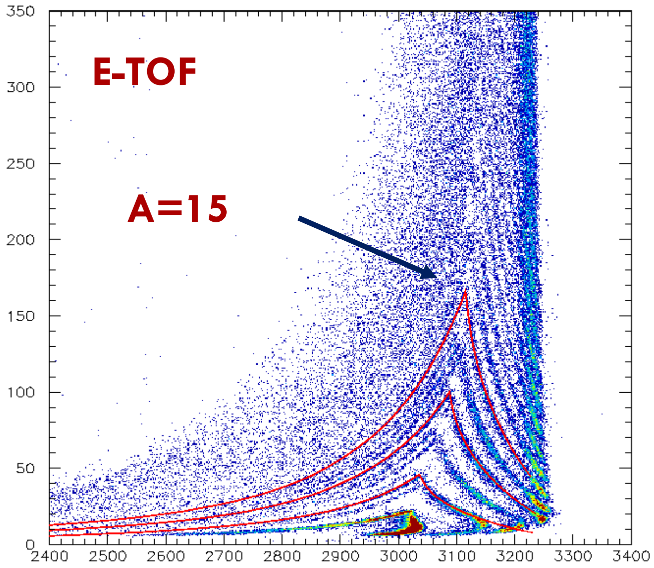


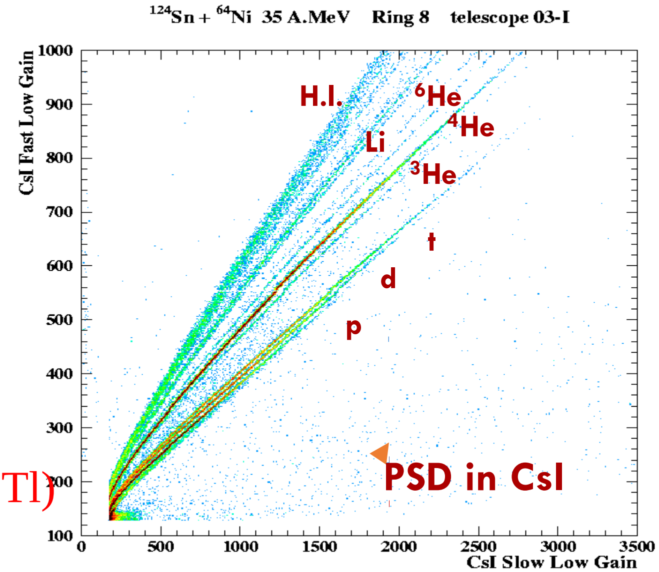
Granularity	1192 telescopes Si (300μm) +CsI(Tl)
Geometry	RINGS: 688 telescopes 100-350 cm SPHERE: 504 telescopes 40 cm
Angular range	RINGS: $1^\circ < \theta < 30^\circ$ SPHERE: $30^\circ < \theta < 176^\circ$ 94% of 4π
Identification method	ΔE-E E-TOF PSD in CsI(Tl) PSD in Si (upgrade 2008)
Experimental observables and performances	TOF $\delta t \leq 1$ ns $\delta E/E$ LCP (Light Charge Particles) ≈ 2% $\delta E/E$ HI (Heavy Ions) ≤ 1% Energy, Velocity, A, Z, angular distributions
Detection threshold	≈ 1 MeV/A for H.I. ≈ 2 MeV/A for LCP

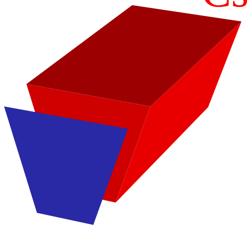
Dynamical range : from fusion, fusion-fission to multifragmentation reaction

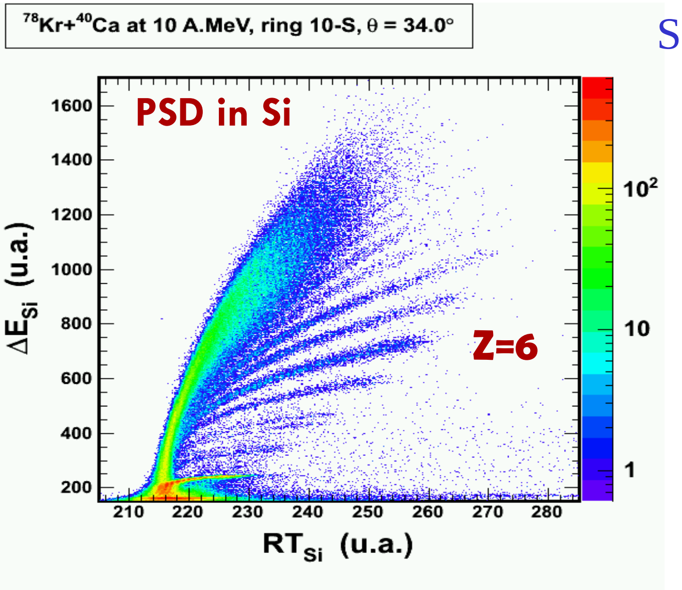
A. Pagano et al, Nucl. Phys A 734, 504 (2004)
A. Pagano, Nucl. Phys. News 22, 28 (2012) and references therein.
E. De Filippo & A. Pagano EPJA 50 (2014) and references therein.

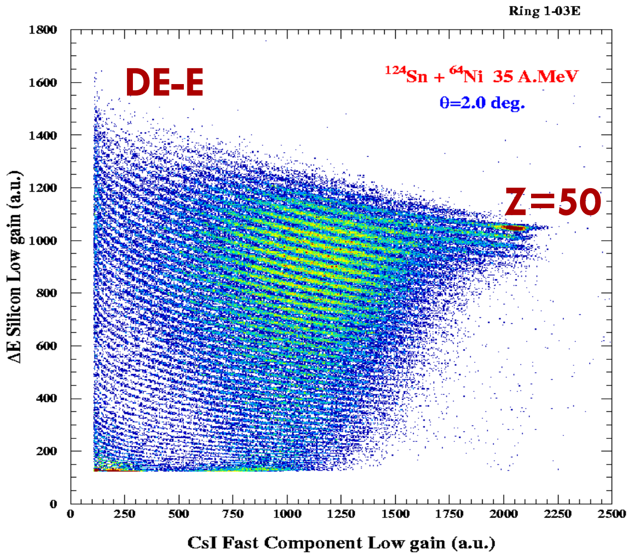
CHIMERA identification methods: Z and A





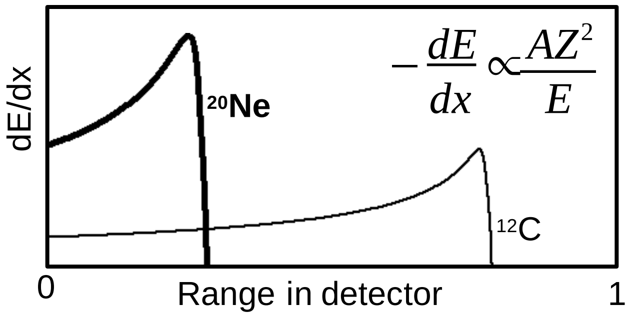






Isotopic identification with the ΔE-E method

- **Stopping power**
  Stopping power depends on the charge (Z), mass (A), and energy (E) of the particle



$$-\frac{dE}{dx} \propto \frac{AZ^2}{E}$$

Isotopic identification with the ΔE-E method

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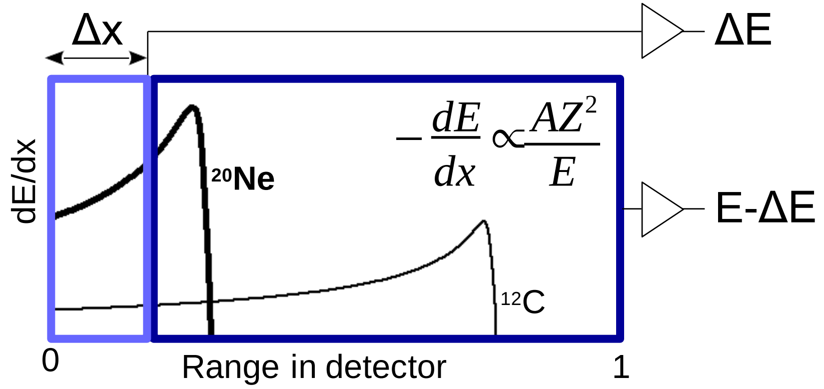
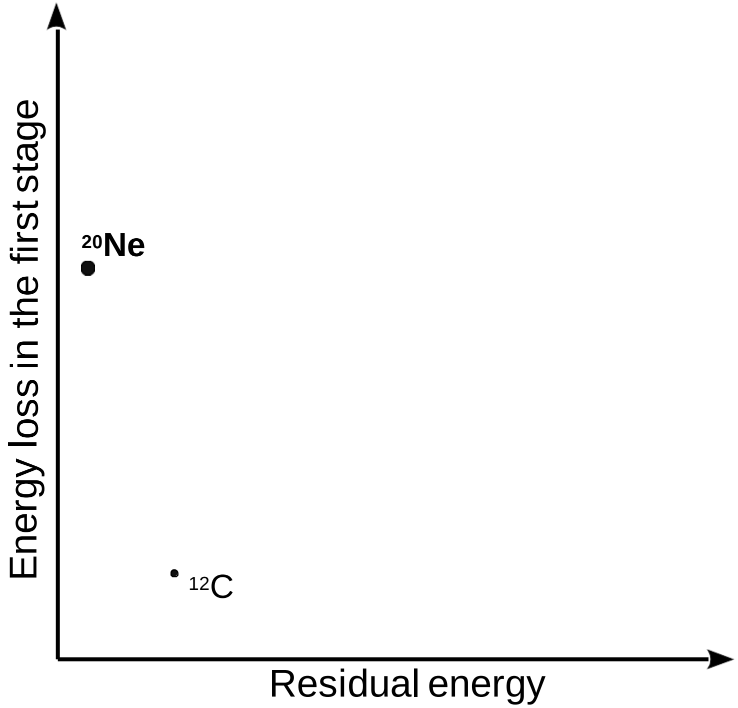
  Stopping power depends on the charge (Z), mass (A), and energy (E) of the particle

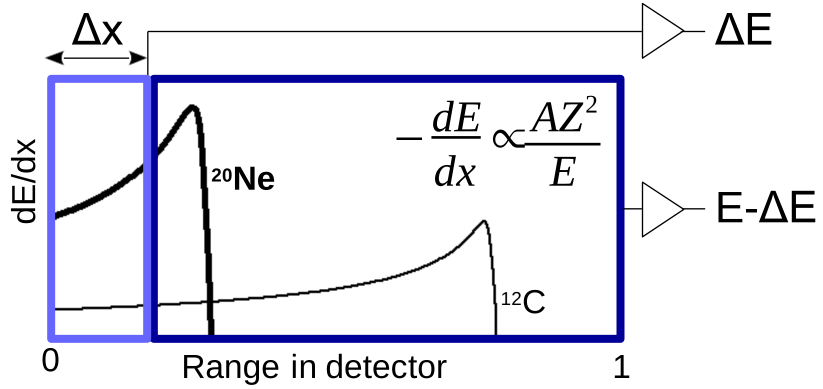




- **ΔE-E method**
  Divide the material in ΔE and E layers
  In the ΔE-E plot, particles populate lines characteristic of their charge and mass

Isotopic identification with the ΔE-E method

- **Stopping power**
  Stopping power depends on the charge (Z), mass (A), and energy (E) of the particle



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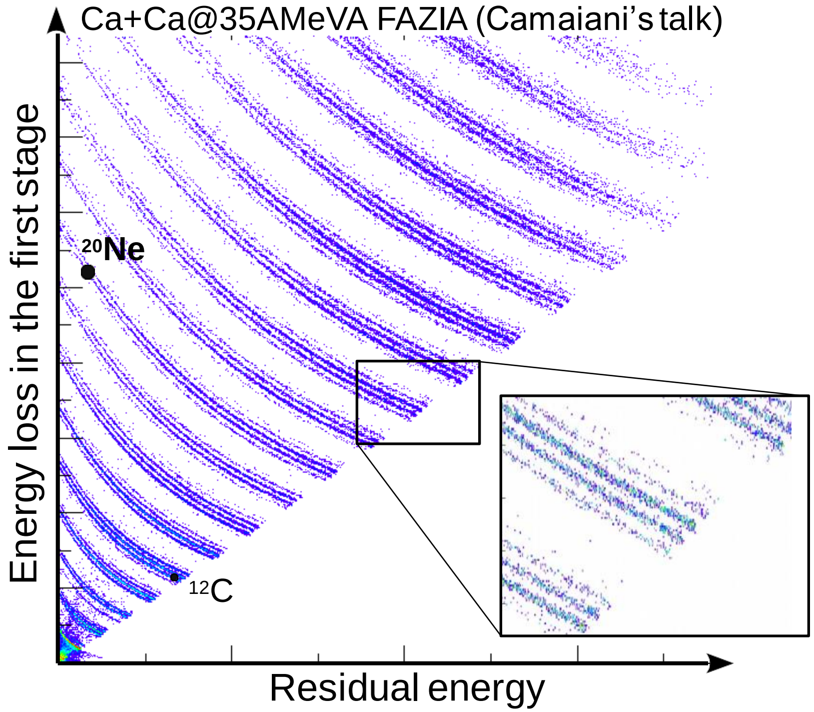
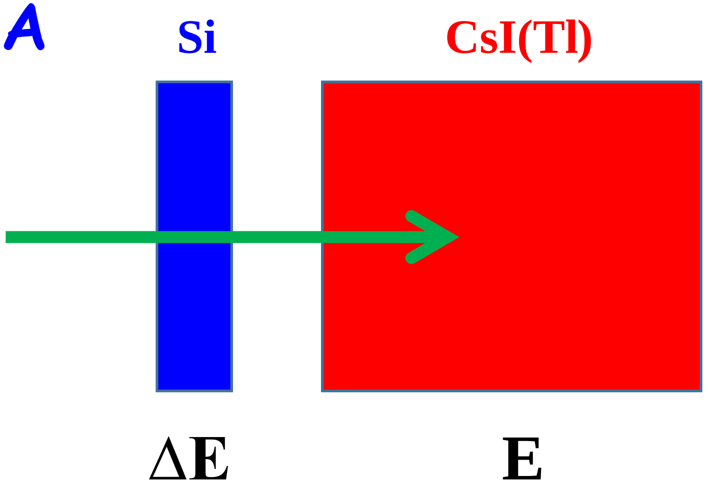
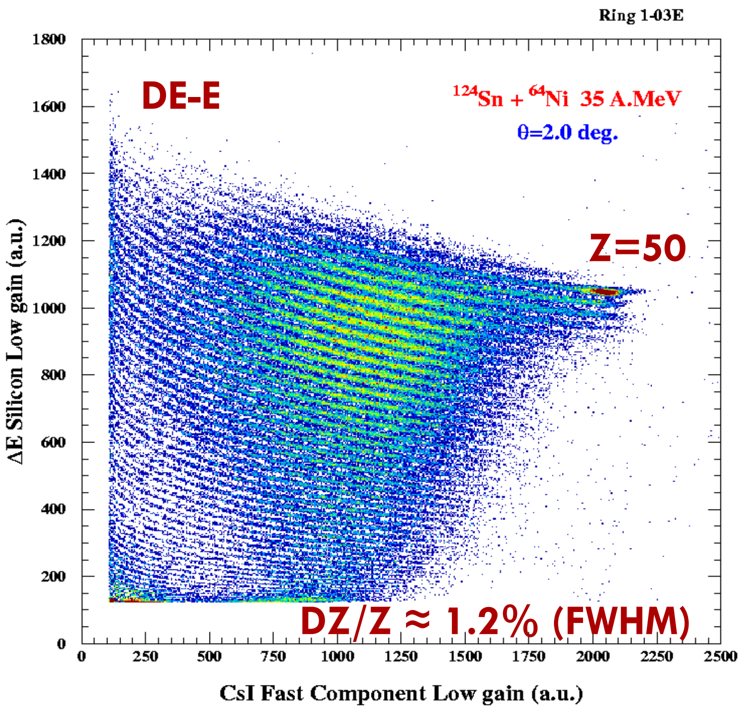
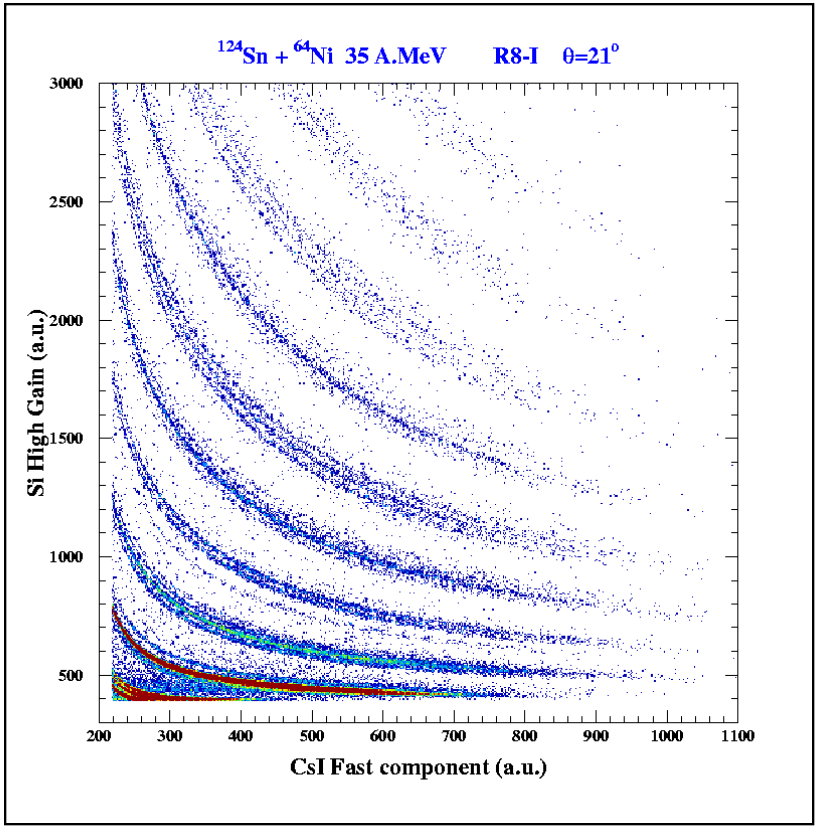

Ca+Ca@35AMeVA FAZIA (Camaiani's talk)

IDENTIFICAZIONE IN CARICA



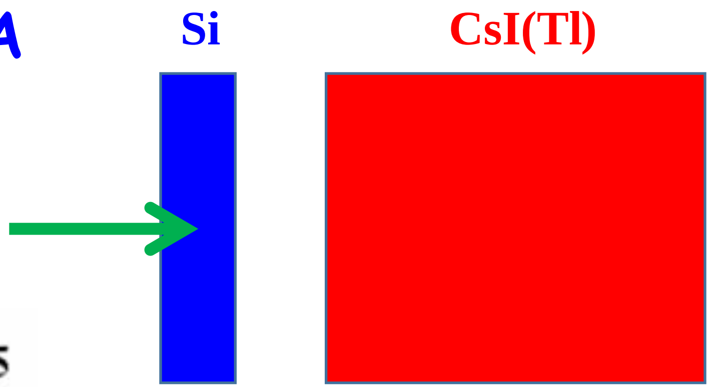


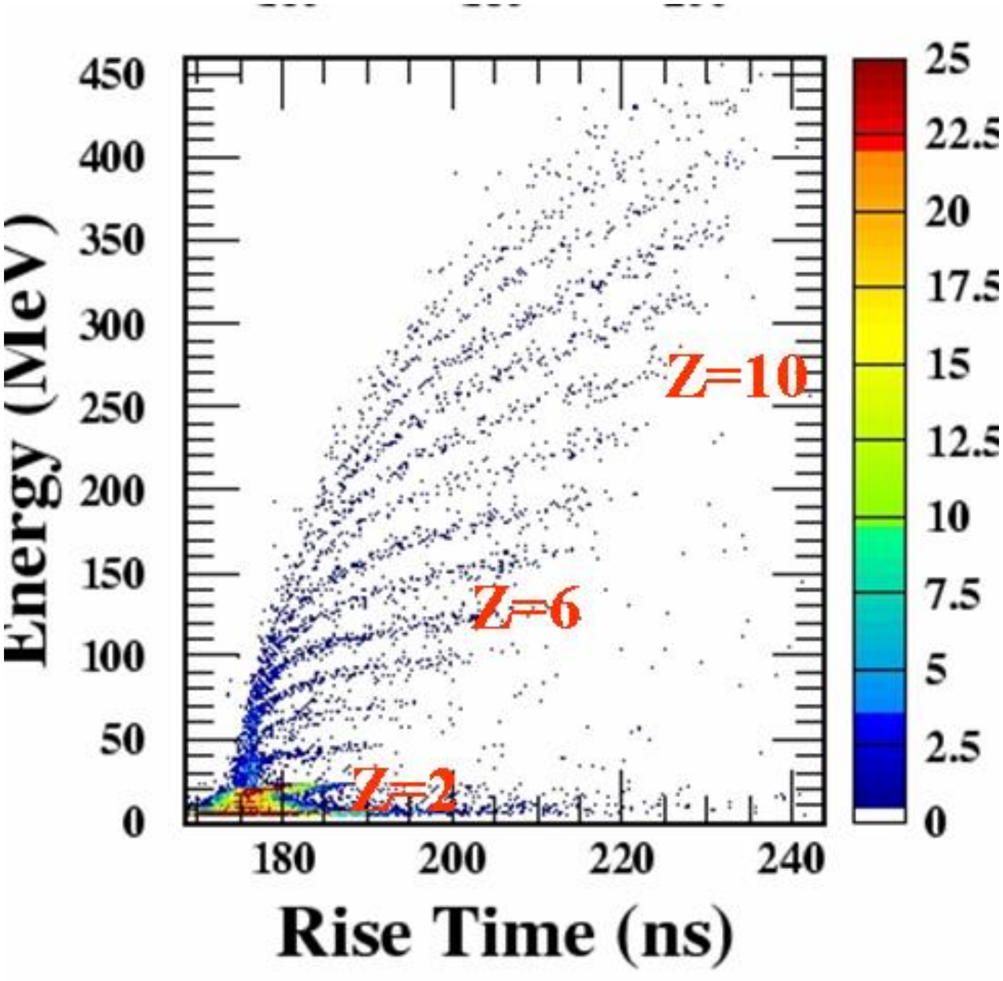


Dalla formula di Bethe – Bloch

$$\Delta E \propto \Delta x(AZ^2)/E$$

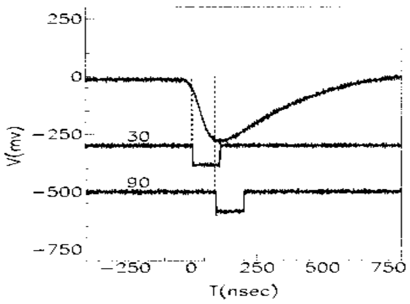
IDENTIFICAZIONE IN CARICA





E- Rise Time (PSD_Silicio)

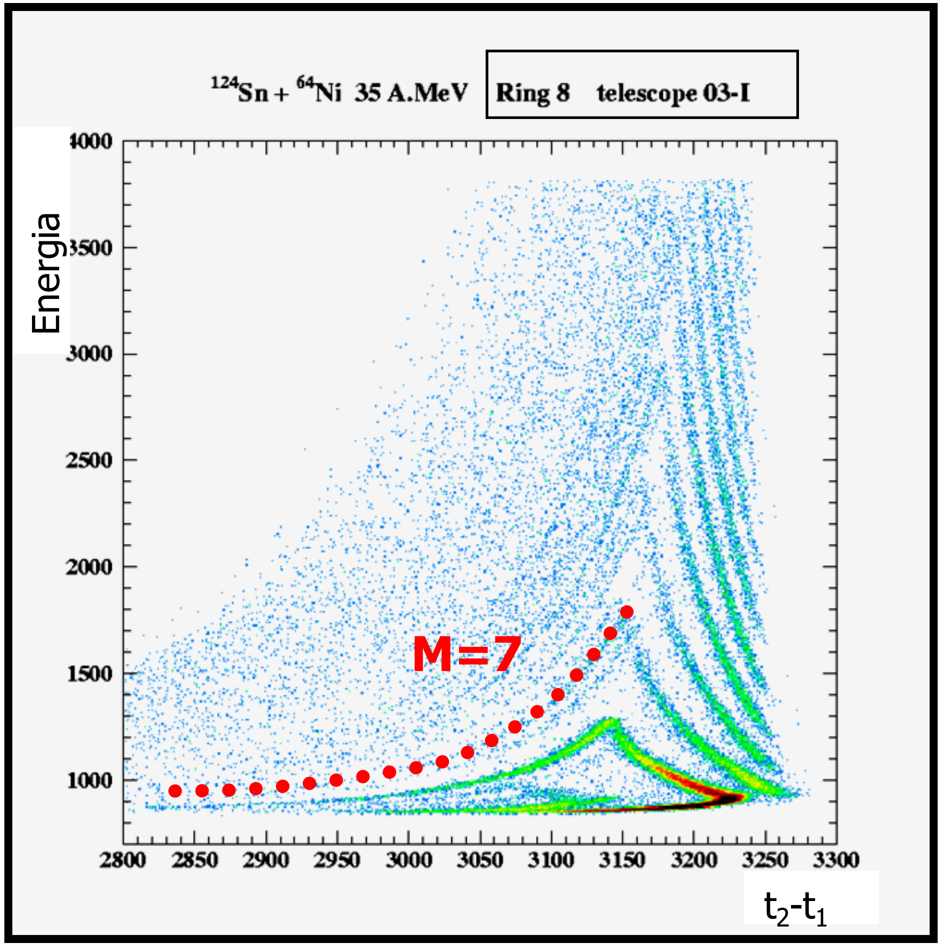
Rise time = f (Z, E)

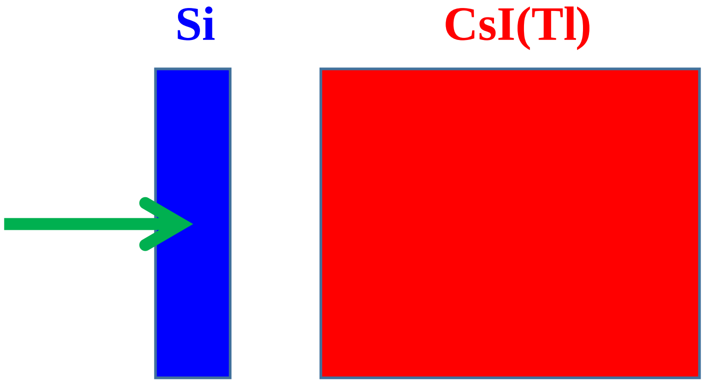


Rise time measurement with two CFD with different fractions: 30% and 90%

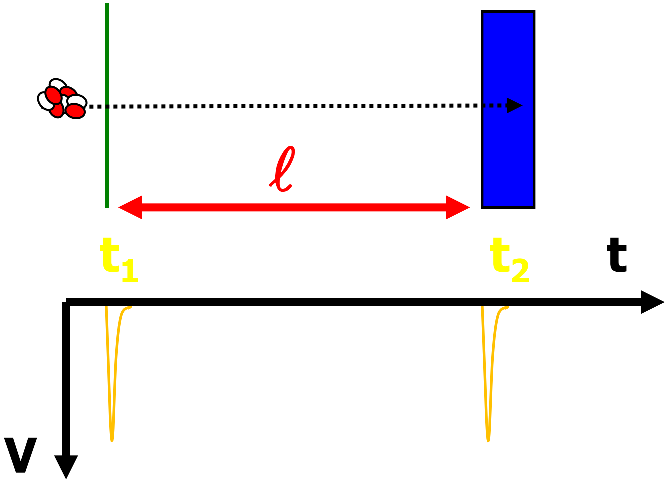
time difference t90%-t30% is prop. to signal rise time

IDENTIFICAZIONE IN MASSA





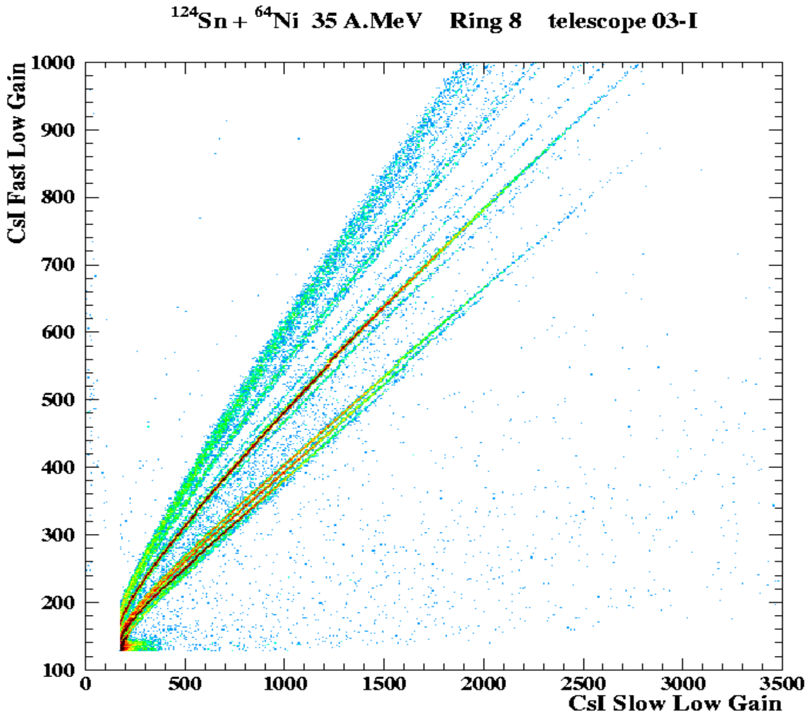
E -TOF

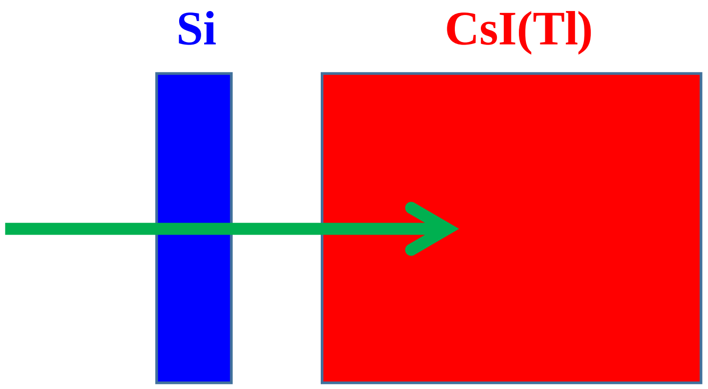


$$E = \frac{1}{2}MV^2 = \frac{1}{2}M\frac{\ell^2}{(t_2-t_1)^2}$$

$$M = \frac{2}{\ell^2}\cdot E(t_2-t_1)^2$$

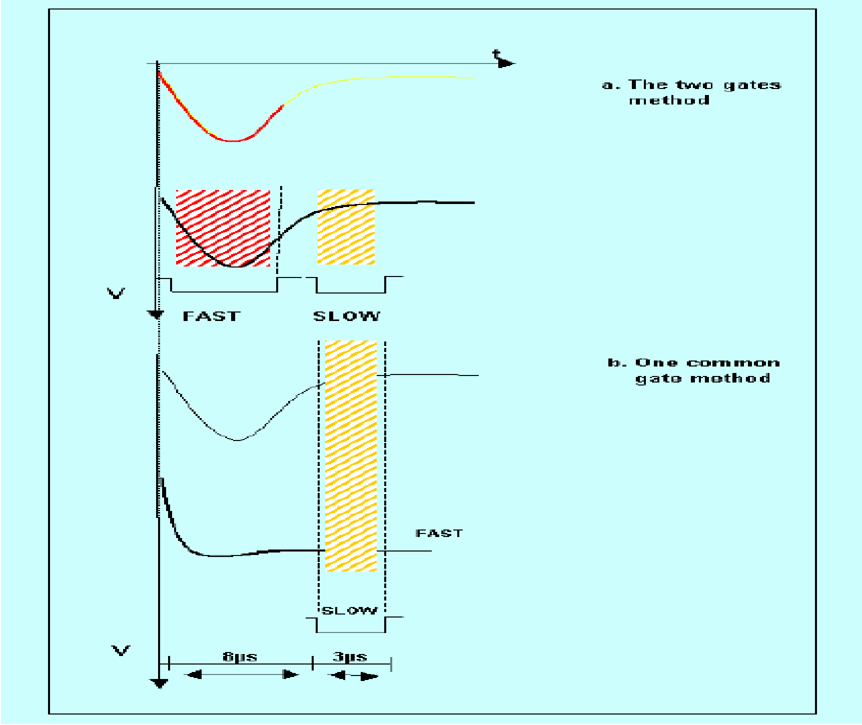
IDENTIFICAZIONE LCP (A,Z)

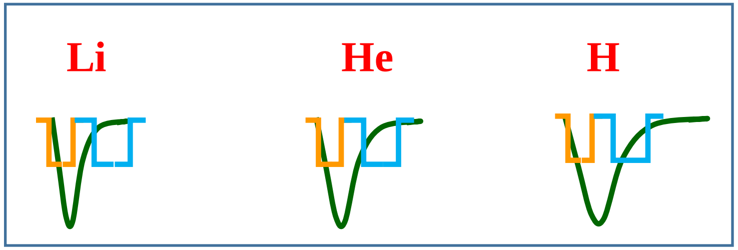




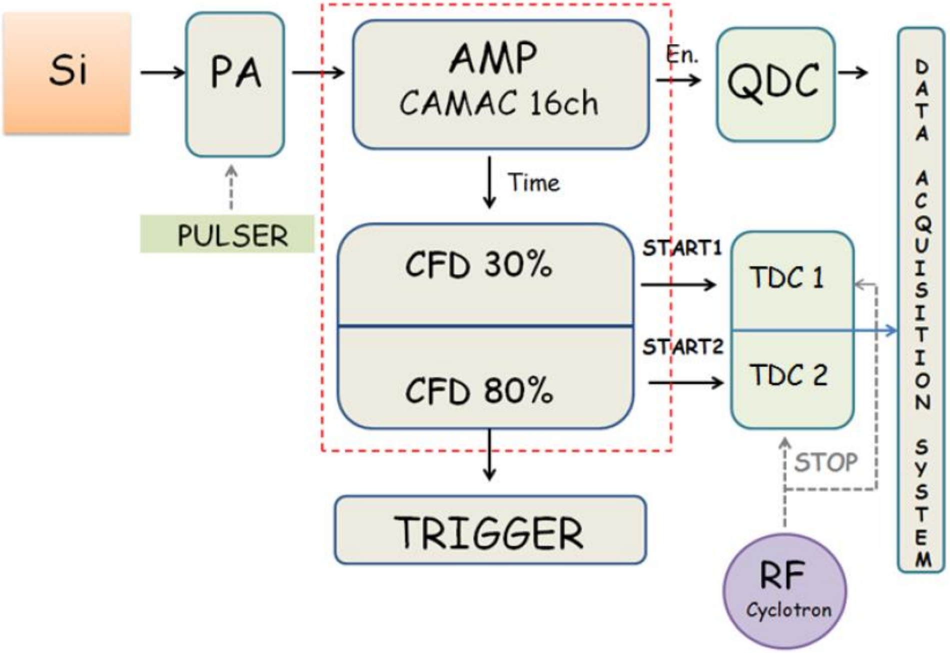
E Fast- E Slow

PSD CsI(Tl)





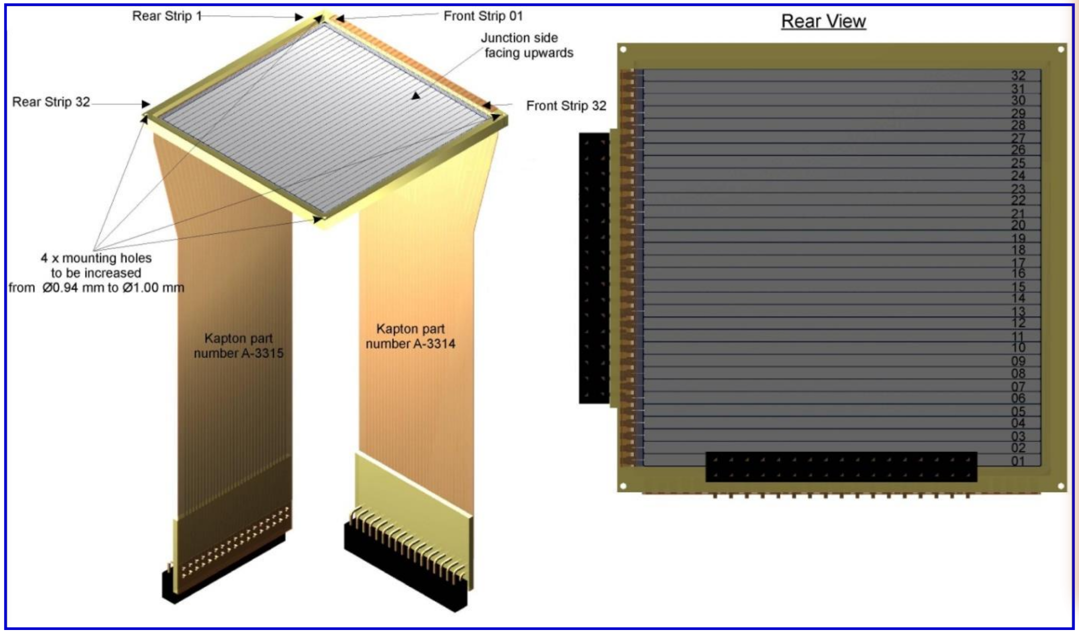
Catene elettroniche (front-end)



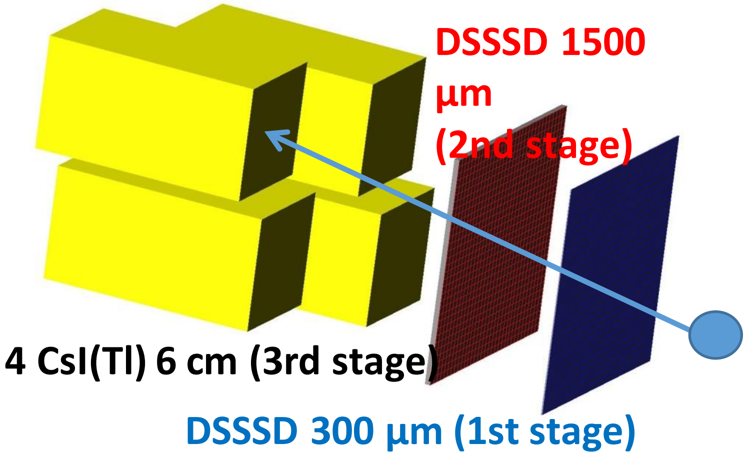
Trigger mainly based on
Silicon multiplicity
with geometry
modularity

FARCOS

See Technical Design Report (TDR) https://drive.google.com/file/d/0B5CgGWz8LpOOc3pGTWdOcDBoWFE/view



132 channels by each cluster



High angular and energy resolution

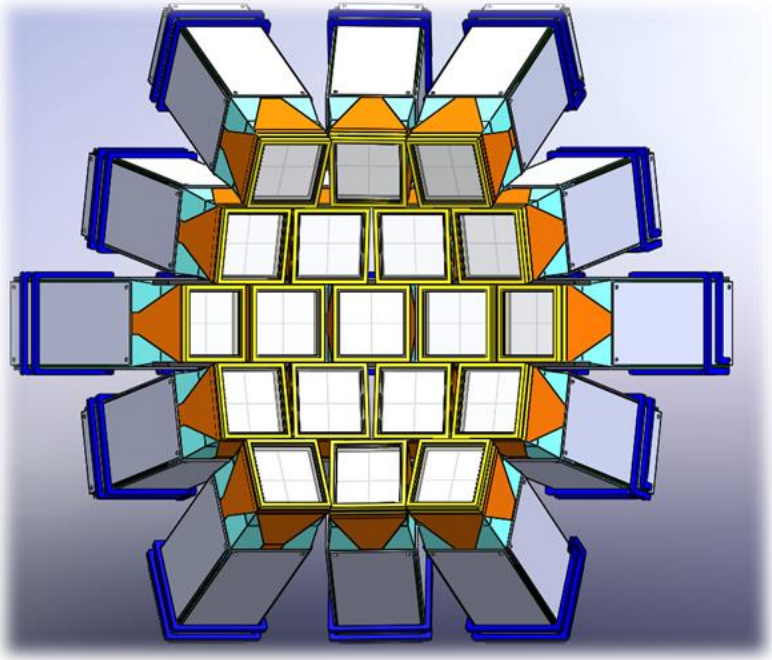
Double-Sided Silicon Strip Detectors produced by Micron Semiconductor.
(300 and 1500 µm / C= 25pF and 5pF)
Capton cable 2x32pin connectors
Minimum PCB
frame-area thick, 4 mm,
frame-thick 6.5 mm
ΔE= 20KeV (α 5.48 MeV) **ΔE/E (elastic)=0.2-0.3%**

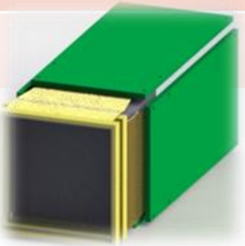
Highly homogeneous CsI(Tl) crystals produced by SCIONIX.
Wrapped with 0.12 mm thick white reflector +50 µm aluminized mylar.
Aluminized mylar window 2 µm thick. Read by Photodiode Hamamatsu 300 µm
ΔE/E=2-3% (α 5.48 MeV)

Assembling of the «real» FARCOS: high modularity

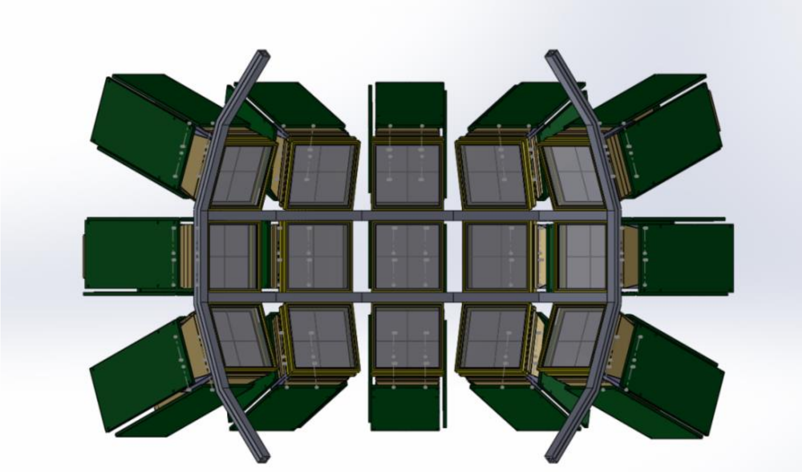
Starting prototype: 4 telescopes : NEWCHIM (2015-2019 final planning 20 telescopes)

Year	Tel.	Operation
2015	6	test acq. GET for FARCOS construction of 2 telescopes purchase of final GET electronics
2016	10	test dual gain module test GET electronic +DAQ Study of alignment system
2017	14(10)	test new asic pre-amplifiars final design modular support implementation asic pre-amplifier new DAQ VME+ GET running First experiments with new Chimera+Farcos front-end
2018	18(?)	Construction of new telescopes
2019	20+2	20 telescopes ready
. . . . .		



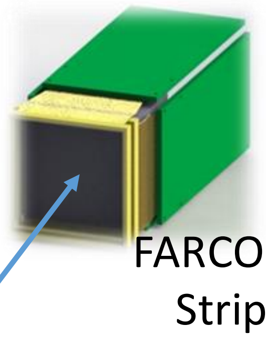


Final cost prediction: ≈< 1 M€



Design simulation: Luis Acosta

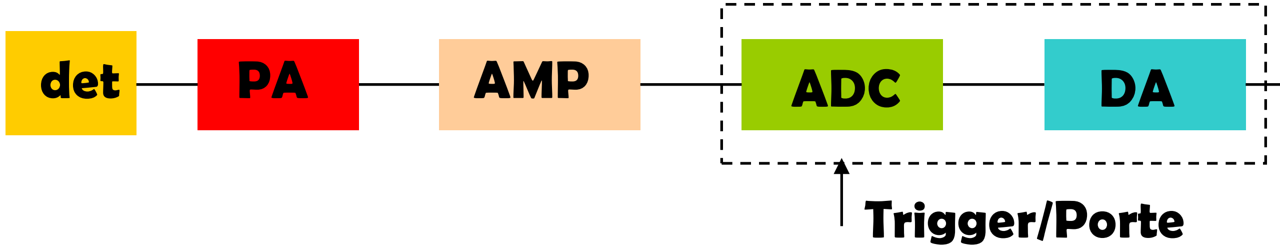
Lab 1: Misura dell’energia



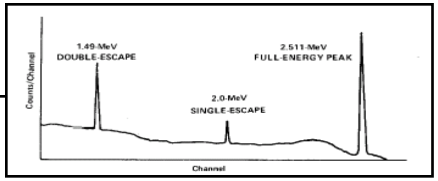
FARCOS 300 µm
Strip Silicon
detector

α particles from
spectrometric source

Catena tipica analogica



Trigger/Porte



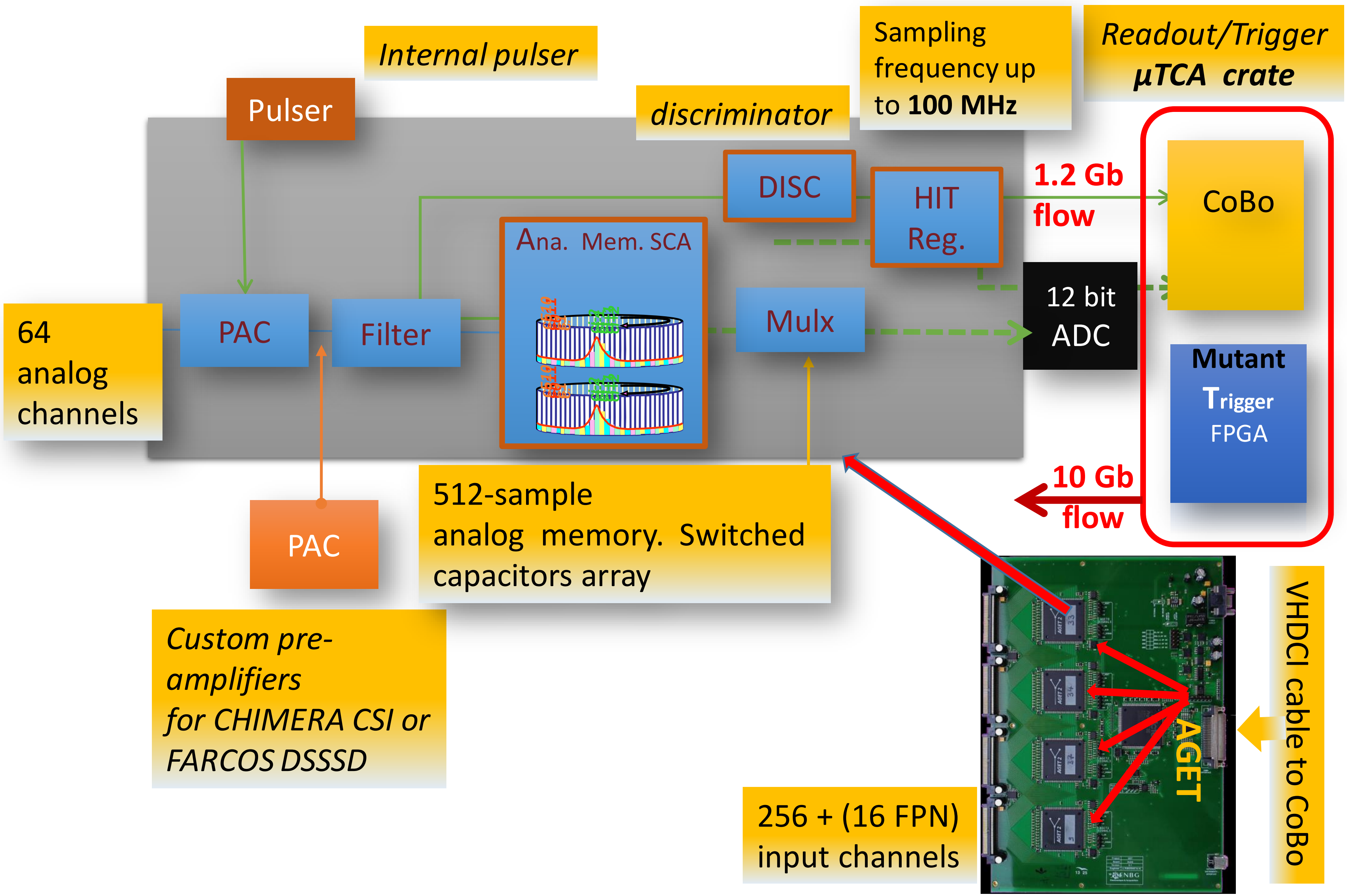
Preamplificatore: raccolta (integrazione) e prima amplificazione del segnale

Amplificatore: amplificazione e formazione del segnale di PA

Codificatore (ADC): conversione dell’informazione in dato digitale (numeri)

Acquisizione: registrazione e visualizzazione dei dati

THE AGET ASIC in the ASAD board



Internal pulser

discriminator

Sampling frequency up to **100 MHz**

Readout/Trigger ***µTCA crate***

1.2 Gb flow

10 Gb flow

64 analog channels

512-sample analog memory. Switched capacitors array

Custom pre-amplifiers for CHIMERA CSI or FARCOS DSSSD

256 + (16 FPN) input channels

VHDCI cable to CoBo

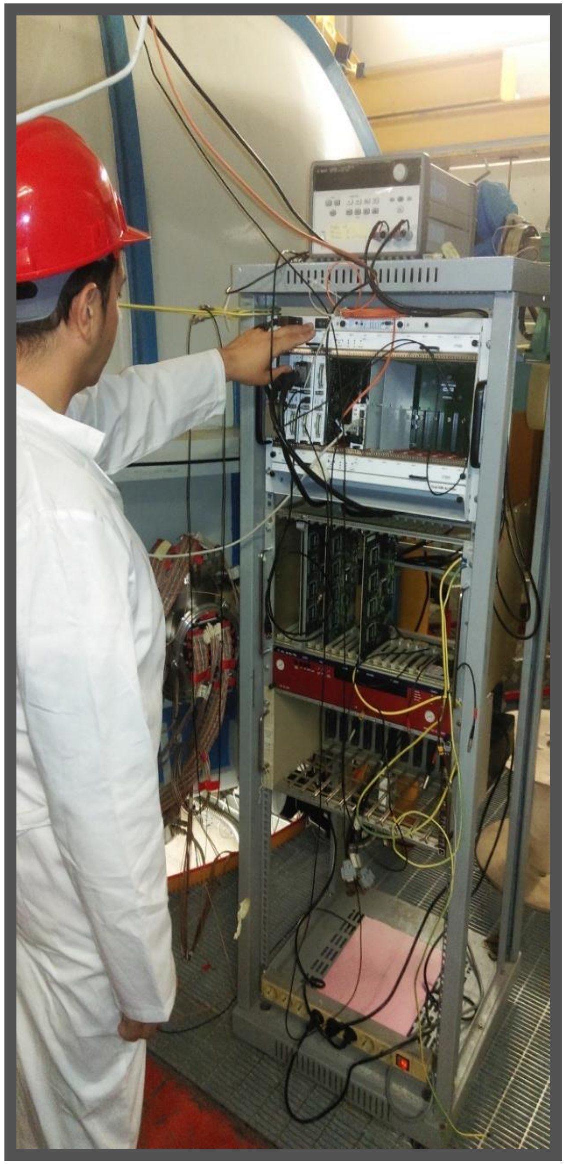
More advantages

Standard CHIMERA **GET**

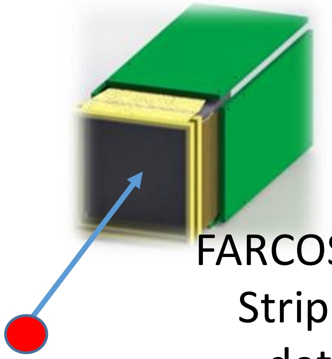
COMPACT
1+1/2 crate all chimera+ farcos electronics

5W for 256 channels

With CHIMERA we need now about 60 kW power on 10 Racks

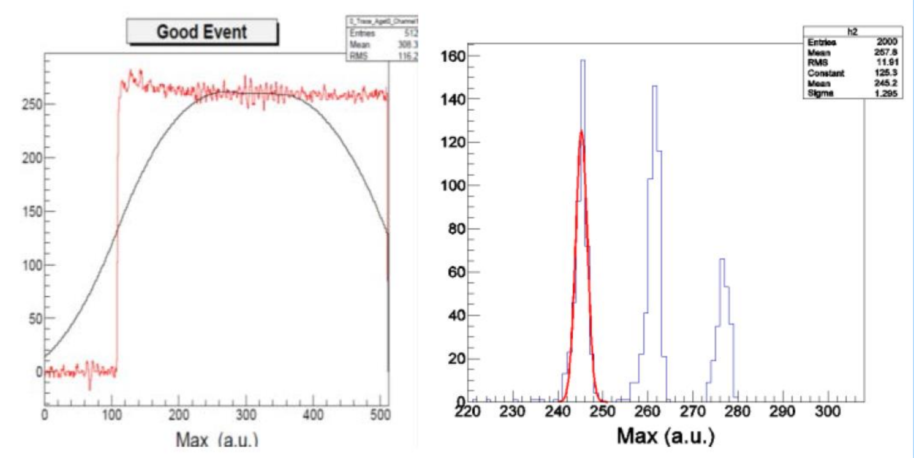


Lab ???

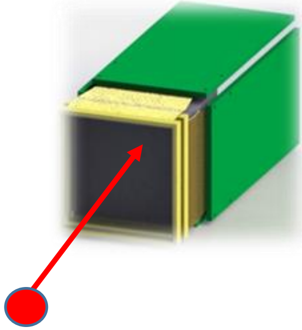


FARCOS 300 μm Strip Silicon detector

α particles from spectrometric source

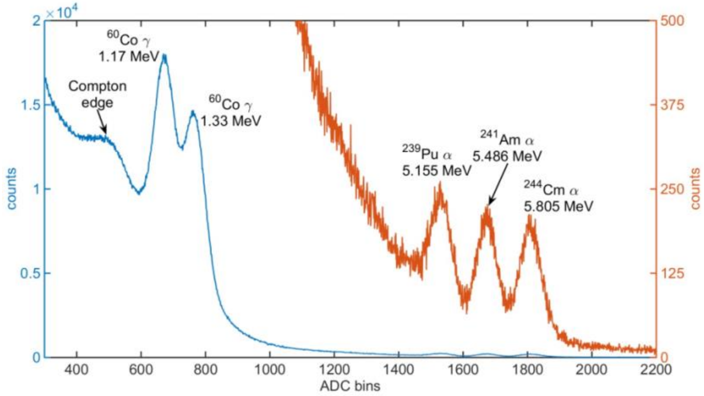


Digitized pre-amplifier (10 mV/MeV, 100 MeV dynamical range) signal after baseline restore and triangular filter and resulting three peaks alpha source (data obtained with R-Cobo readout) on a FARCOS strip



FARCOS 6 cm CsI scintillator

γ from ^{60}Co source

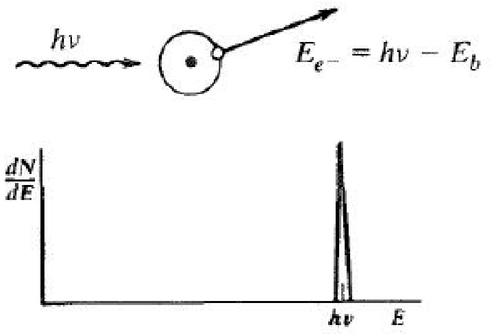


Energy spectrum of the ^{60}Co γ source and of the mixed nuclei α source measured with the VLSI charge preamplifier coupled with scintillator A. The right axis (orange curve) shows the zoom of the same data.

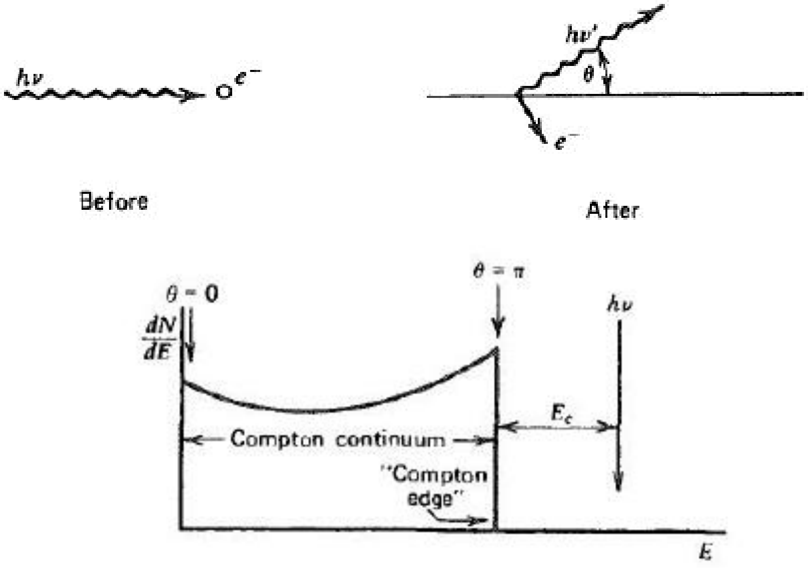
THE END

Spectra from γ particle

Eff. fotoelettrico

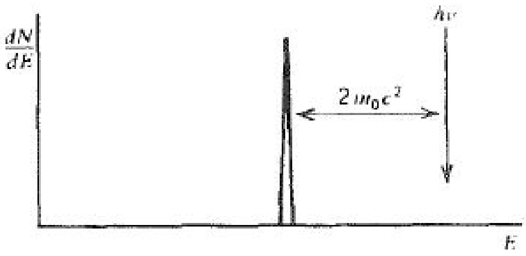


Eff. Compton



Produzione di coppie

$$E_{e^-} + E_{e^+} = h\nu - 2m_0c^2$$



$$\mathbf{E_e = E_\gamma - E_\gamma^{'} = \frac{E_\gamma}{1 + \frac{m_e c^2}{E_\gamma (1 - \cos\theta)}}} \begin{cases} = \mathbf{0} & \boldsymbol{\theta = 0} \\ = \mathbf{\dfrac{E_\gamma}{1 + \frac{m_e c^2}{2E_\gamma}}} & \boldsymbol{\theta = \pi} \end{cases}$$

Small detector

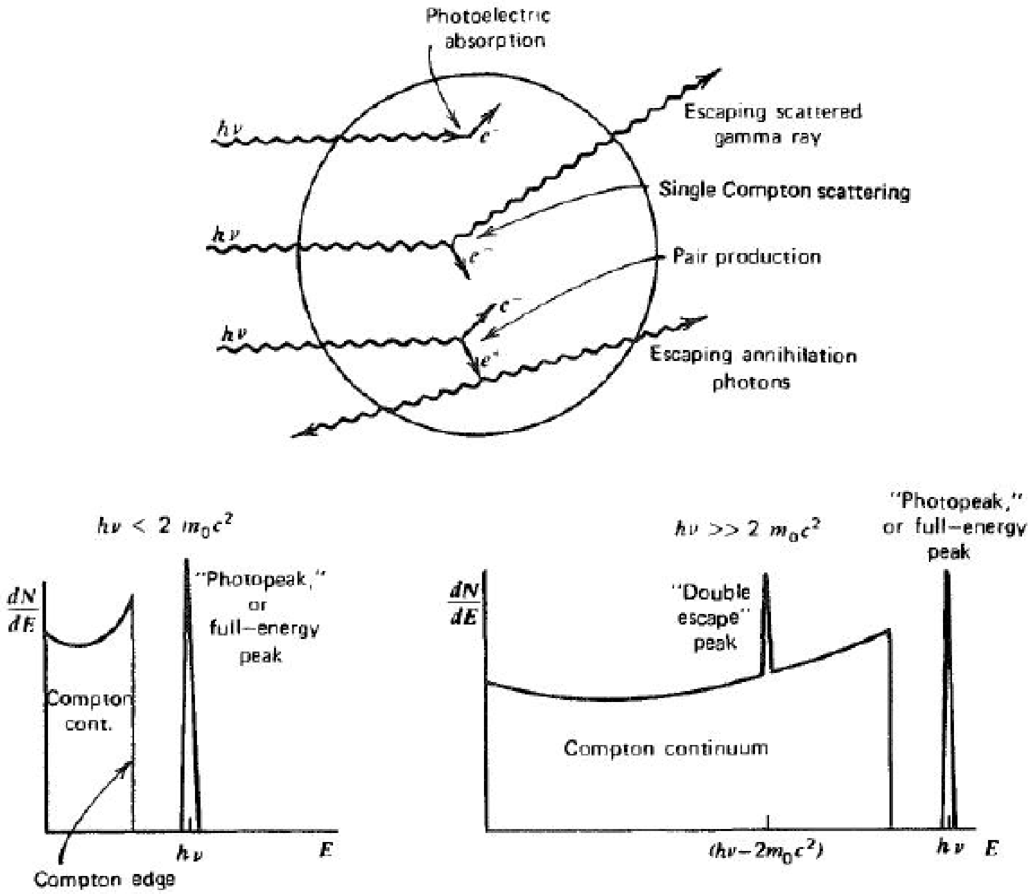


Figure 10.2 The "small detector" extreme in gamma-ray spectroscopy. The processes of photoelectric absorption and single Compton scattering give rise to the low-energy spectrum at the left. At higher energies, the pair production process adds a double escape peak shown in the spectrum at the right.

Large detector

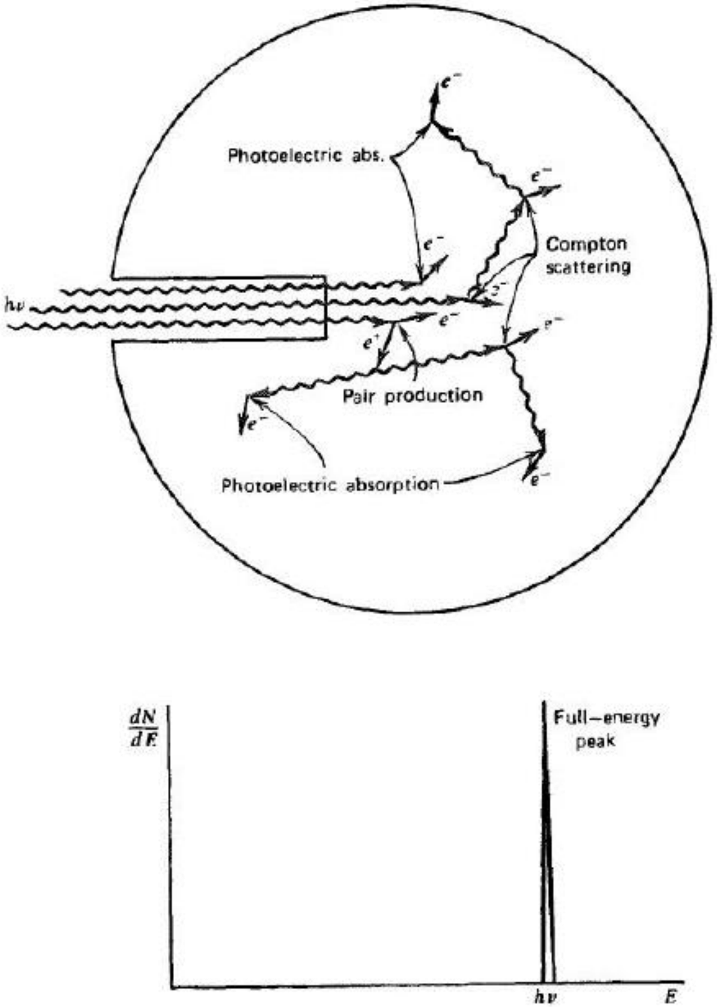


Figure 10.3 The "large detector" extreme in gamma-ray spectroscopy. All gamma-ray photons, no matter how complex their mode of interaction, ultimately deposit all their energy in the detector. Some representative histories are shown at the top.

Intermediate size detector

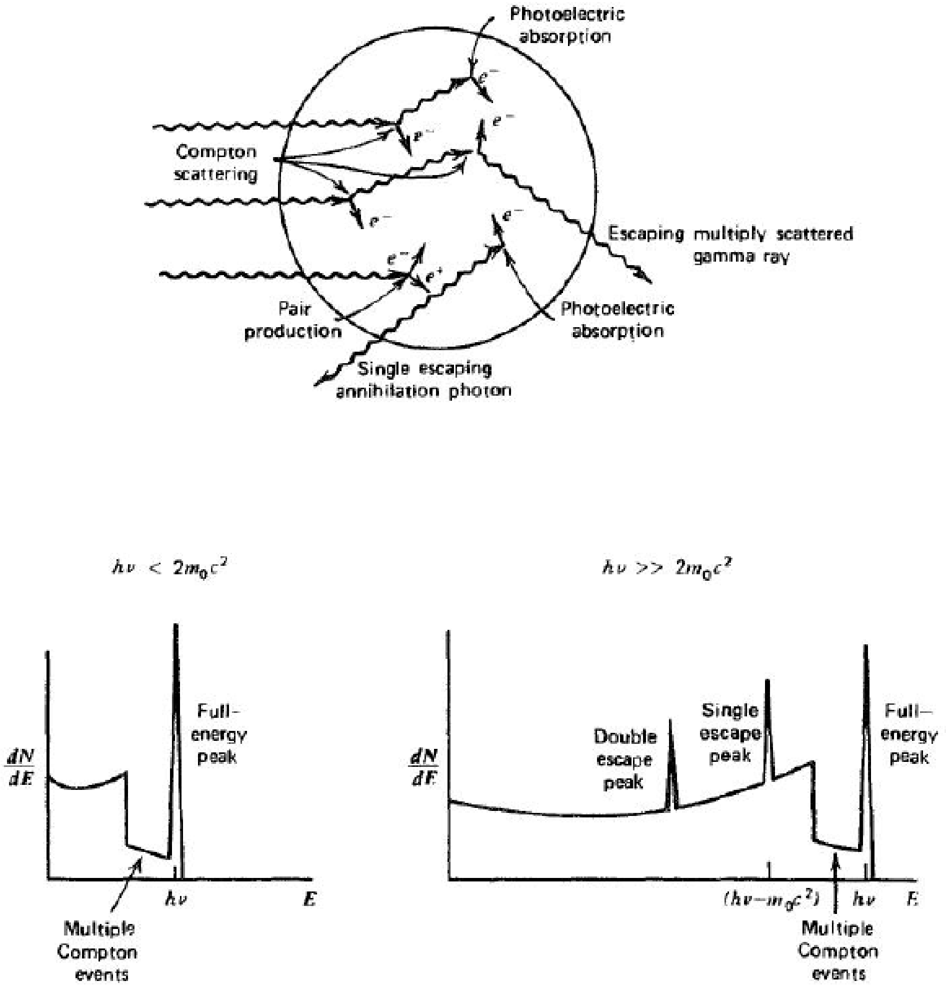
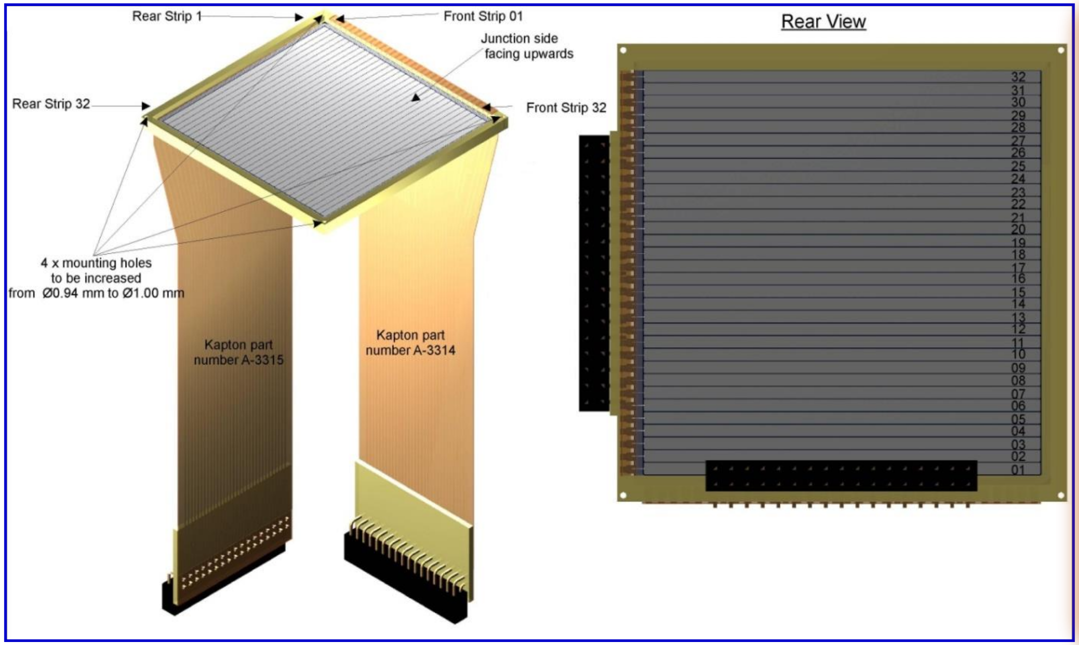


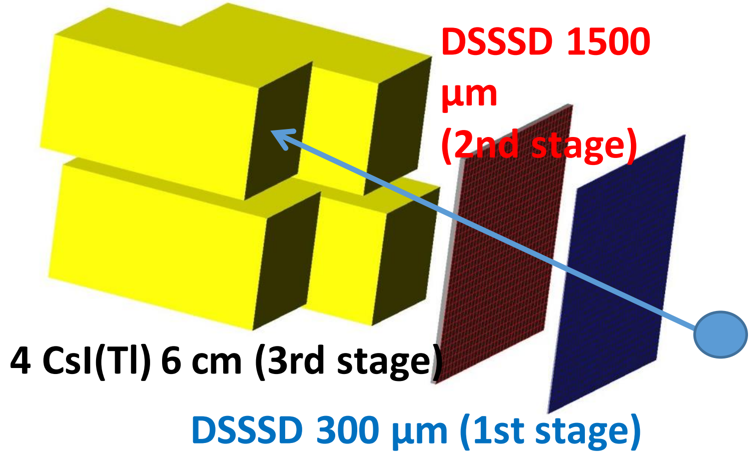
Figure 10.4 The case of intermediate detector size in gamma-ray spectroscopy. In addition to the continuum from single Compton scattering and the full-energy peak, the spectrum at the left shows the influence of multiple Compton events followed by photon escape. The full-energy peak also contains some histories that began with Compton scattering. At the right, the single escape peak corresponds to initial pair production interactions in which only one annihilation photon leaves the detector without further interaction. A double escape peak as illustrated in Fig. 10.2 will also be present due to those pair production events in which both annihilation photons escape.

FARCOS: **F**emtoscope **A**rray for **CO**rrelations and **S**pectroscopy

Technical Design Report (TDR): https://drive.google.com/file/d/0B5CgGWz8LpOOc3pGTWdOcDBoWFE/view



132 channels by each cluster



DSSSD 1500 µm (2nd stage)

4 CsI(Tl) 6 cm (3rd stage)

DSSSD 300 µm (1st stage)

High angular and energy resolution

64 mm, 32 strips, Double-Sided Silicon Strip Detectors
produced by Micron Semiconductor.
(300 and 1500 µm / C= 25pF and 5pF)
Capton cable 2x32pin connectors
Minimum PCB
frame-area thick, 4 mm,
frame-thick 6.5 mm
ΔE= 20KeV (α 5.48 MeV) **ΔE/E (elastic)=0.2-0.3%**
Rise time<20ns

Highly homogeneous CsI(Tl) crystals produced by SCIONIX.
Wrapped with 0.12 mm thick white reflector +50 µm aluminized mylar.
Aluminized mylar window 2 µm thick (0.29 gr/cm^2). Read by Photodiode Hamamatsu 300 µm
ΔE/E=2-3% (α 5.48 MeV)

Per scintillatori organici si assume comunemente la

Legge di Birk

lungo una traccia con alta densità di ionizzazione dE/dx diminuisce l'efficienza di scintillazione a causa del danneggiamento delle molecole

-> quenching

Questo porta ad una relazione

$$\frac{dL}{dx} = \frac{S\frac{dE}{dx}}{1 + K_B \frac{dE}{dx}}$$

K_B = parametro ricavato dai dati

(costante di Birks)

MAGNEX spectrometer @ LNS

Camera di scattering

$P_i = (x_i, y_i, \theta_i, \phi_i, \delta_i)$

Quadrupole

Dipole

Focal Plane Detector (FPD)

$P_f = (x_f, y_f, \theta_f, \phi_f)$

Optical characteristics	Values
Maximum magnetic rigidity	1.8 T m
Solid angle	50 msr
Momentum acceptance	-14.3%, +10.3%

Good compensation of the aberrations:
<u>Trajectory reconstruction</u>

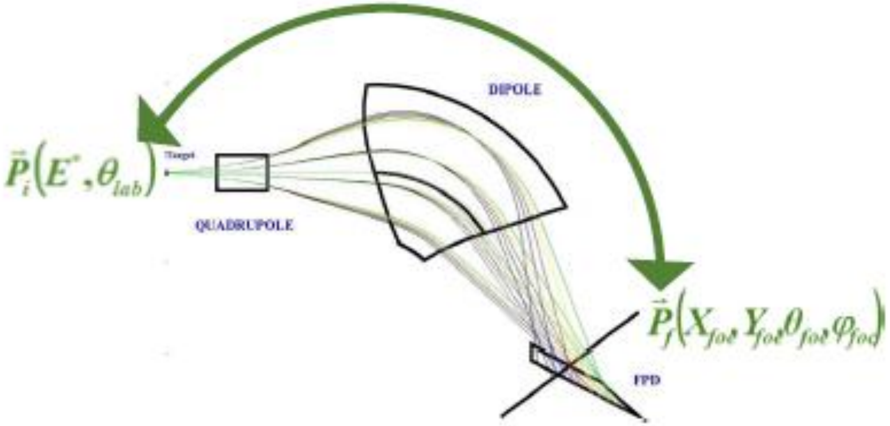
Measured resolutions:

- Energy ΔE/E ~ 1/1000
- Angle Δθ ~ 0.3°
- Mass Δm/m ~ 1/160

Transport Matrix

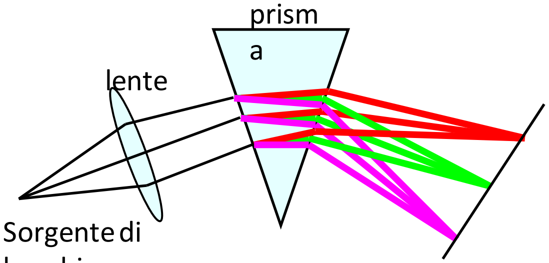
$M: P_i \rightarrow P_f$

$M^{-1}: P_f \rightarrow P_i$

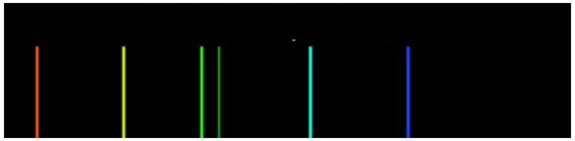


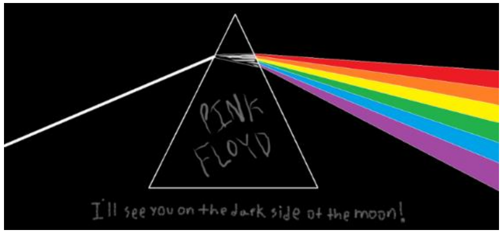
Come funziona uno spettrometro

Spettrometro di luce

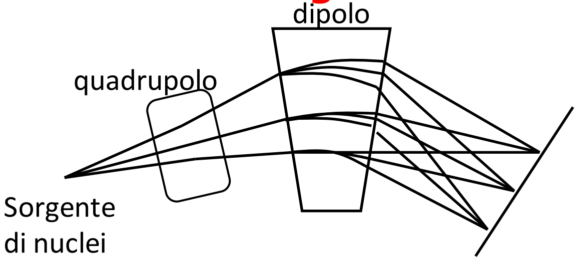


La posizione dipende dal «colore»



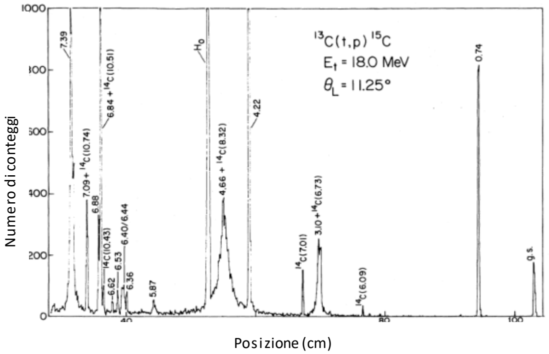


Spettrometro magnetico



La posizione dipende da
(velocità*massa)/(stato di carica)

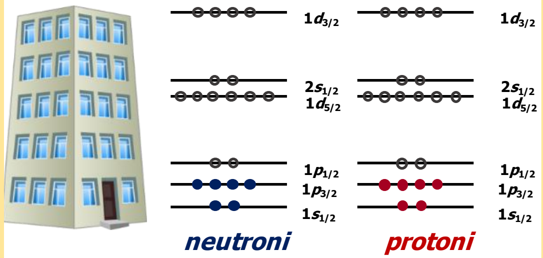
Lavora con fasci CS e Tandem



Carta d'identità del nucleo

Studi di struttura nucleare

Il modello a shell



Funziona come un filtro selezionando il tipo di nuclei desiderato

THE END

Il Preamplificatore

Utilizzato sempre, ad eccezione di alcuni rivelatori con moltiplicazione interna (PMT, CP, Geiger)

Raccoglie-integra il segnale in corrente/tensione del rivelatore e dà una prima amplificazione

PA di tensione/corrente

Raccolta della carica Q(t): risposta legata ai tempi

se $R_{in}C_{in} \ll t_{det}$ la C_{in} si “scarica” rapidamente

$V_{out} \sim Q(t)$ -> sensibilità alla corrente

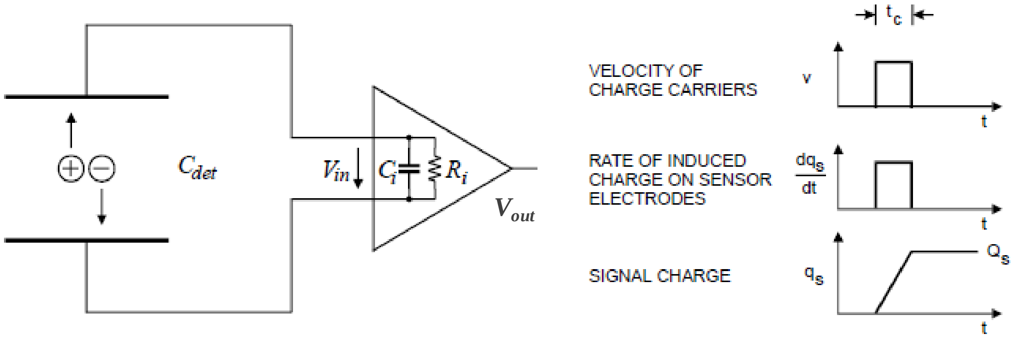
se $R_{in}C_{in} \gg t_{det}$ la C_{in} si carica interamente -> tensione

$V_{in} = Q_{in}/C_{in} \quad V_{out} = GV_{in} = GQ_{in}/C_{in}$

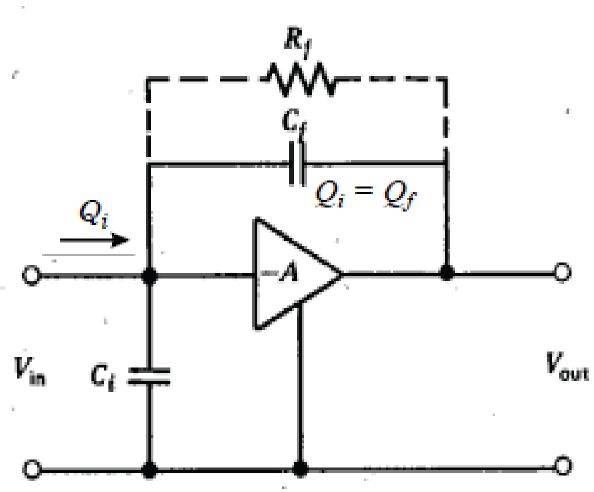
C_{in} capacità del rivelatore, cavi, PA ($C_{det}+C_i+..$)

L’uscita V_{out} è legata

alla $Q_{in} \div E$ e alla C_{in}



PA di carica



Amplificatore invertitore alta Z

Il circuito integra la Q(t) su C_f

$$V_{out} = -A\,V_{in}\ ;\ Q_{out} = Q_{in}\ (Z_i \sim \infty)$$

$$V_{out} = -A\,Q_{in}\ /\ [C_i + (A+1)\,C_f\,]$$

$$V_{out} \sim -Q_{in}\ /\ C_f$$

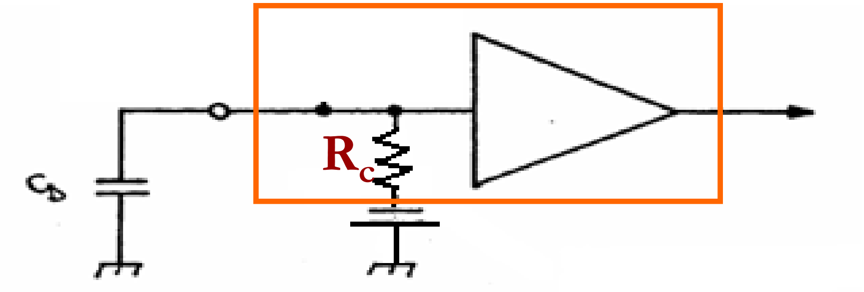
Se $C_i << AC_f$ V_{out} non dipende dal sistema ma solo da $Q_{in} \div E$ e da C_f -> scelta opportuna del PA

Il segnale in uscita ha un tempo di salita che dipende in principio da Q(t) ma in parte anche dal PA

Il ripristino del PA avviene attraverso una resistenza R_f e quindi $R_fC_f >> t_{det}$

Il **PA** può anche fornire la tensione di lavoro al rivelatore, attraverso la resistenza di carico **R_c**

-> cavo unico verso il rivelatore



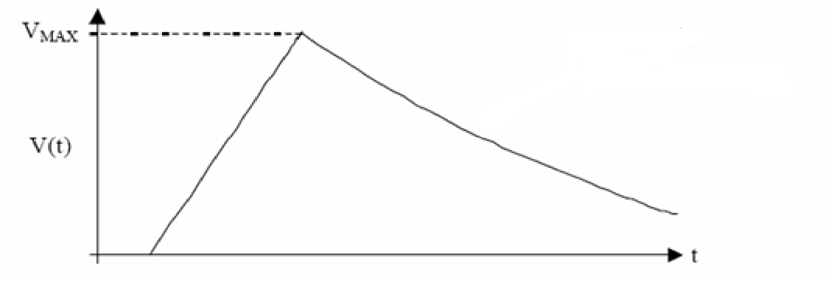
R_c dovrebbe essere elevata per avere minore rumore e poter raccogliere tutto il segnale prodotto

Resistenze troppo alte danno problemi:

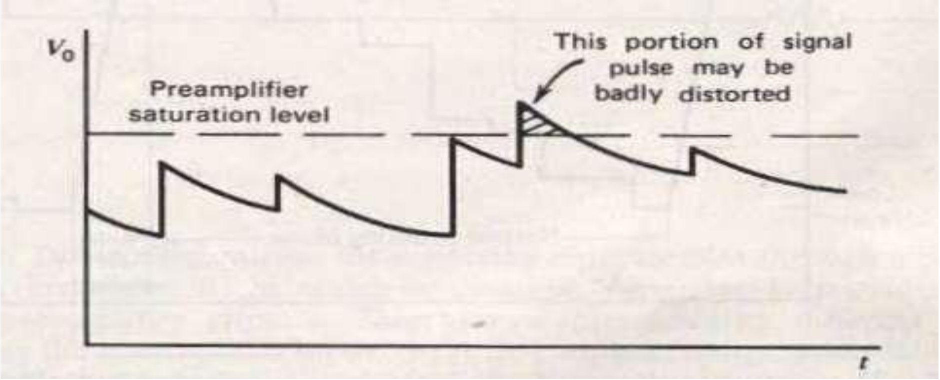
- Caduta di tensione in **R_c** per correnti parassite elevate -> si deve recuperare la tensione effettiva
- Tempi di recupero (fall time) grandi

Segnale del PA

- Rise time ~ 10 ns -> 10 μs
- Fall time ~ 100 μs



Rate elevati -> impilamento dei segnali (pile-up) di particelle che arrivano prima del recupero totale della tensione in uscita

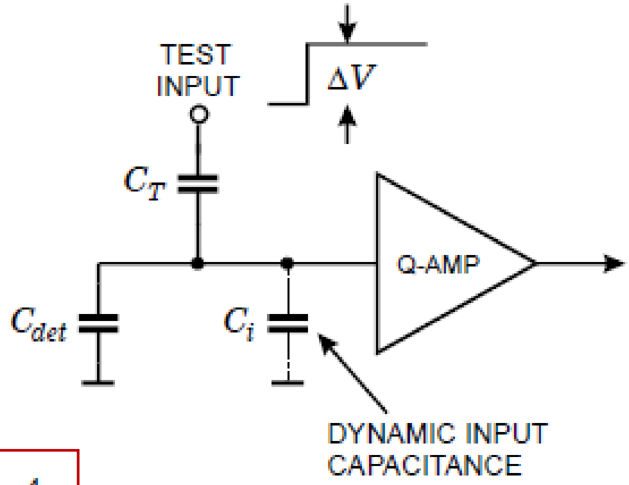


Problemi:

- Saturazione del segnale
- Identificazione e lettura dell'ampiezza in punta

Ingresso test

In molti PA si può iniettare direttamente all'ingresso una carica Q scelta con ΔV



$$Q_T = \frac{C_T}{1+\frac{C_T}{C_i}} \cdot \Delta V \approx C_T \left(1 - \frac{C_T}{C_i}\right) \Delta V$$

$$C_T / C_i = 10^{-3} - 10^{-4}$$

$$Q_T = \Delta V \cdot C_T$$

$$C_i = C_f (A+1)$$

- Controllo funzionamento **PA** e stabilità catena elettronica (derive di guadagno)

- Misura del rumore elettronico, con il rivelatore in condizioni operative (tensione, capacità)

- Calibrazione dell'intera catena, con impulsi di ampiezza relativa nota e cfr con segnali di **E** note

L’amplificatore formatore

Il segnale di uscita del **PA** ha certe caratteristiche:

- Ampiezza ridotta -> amplificazione

- Tempo di salita (molto) piccolo che rende difficile determinarne il valore massimo

- Tempo di discesa troppo lungo -> possibile pile-up

-> Formazione (shaping) del segnale per ovviare a tali problemi e per ottimizzare il segnale/rumore

Il segnale di **PA** somiglia molto ad un gradino che lo shaping dovrebbe rendere più morbido e in salita e rapido in discesa

1. CR DIFFERENTIATOR OR HIGH-PASS FILTER

A basic *CR* differentiator network is diagrammed in Fig. 16.9. From the circuit equations, the input voltage E_{in} and output voltage E_{out} are related by

$$E_{\text{in}} = \frac{Q}{C} + E_{\text{out}} \tag{16.3}$$

where Q represents the charge stored across the capacitor. Now, differentiating with respect to time,

$$\frac{dE_{\text{in}}}{dt} = \frac{1}{C}\frac{dQ}{dt} + \frac{dE_{\text{out}}}{dt} \tag{16.4}$$

$$\frac{dE_{\text{in}}}{dt} = \frac{1}{C}i + \frac{dE_{\text{out}}}{dt} \tag{16.5}$$

Noting that $E_{\text{out}} = iR$ and setting $RC = \tau$, we obtain

$$E_{\text{out}} + \tau\frac{dE_{\text{out}}}{dt} = \tau\frac{dE_{\text{in}}}{dt} \tag{16.6}$$

Now, if we make RC sufficiently small, we can neglect the second term on the left and

$$E_{\text{out}} \cong \tau\frac{dE_{\text{in}}}{dt} \tag{16.7}$$

Thus, in the limit of small time constant τ, the network acts to produce an output E_{out} that is proportional to the time derivative of the input waveform E_{in}—hence the name *differentiator*. In order to meet these conditions, the time constant should be small compared with the duration of the pulse to be differentiated.

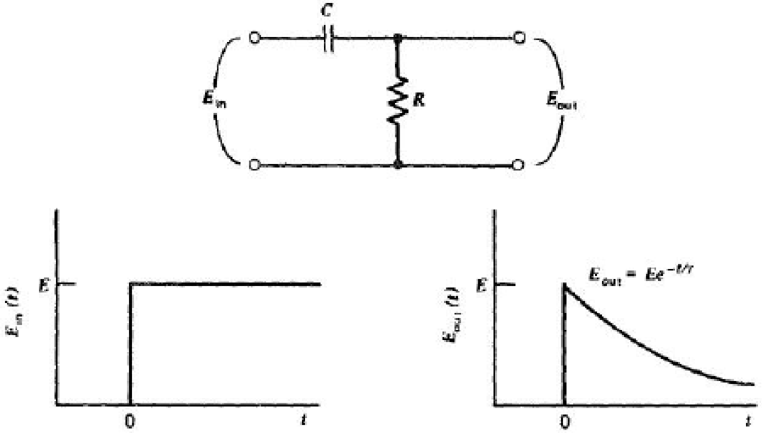


Figure 16.9 A high-pass *CR* filter or differentiator network. The response to a step function input is illustrated.

In the opposite extreme of large time constant, the first term on the left of Eq. (16.6) can be neglected and we have

$$\tau\frac{dE_{\text{out}}}{dt} \cong \tau\frac{dE_{\text{in}}}{dt} \tag{16.8}$$

and setting the constant of integration equal to zero

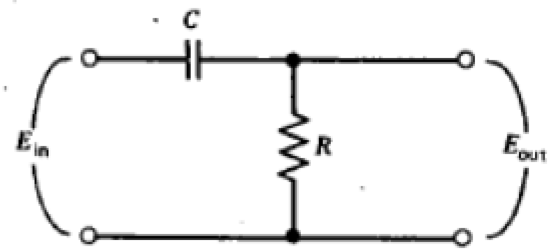
$$E_{\text{out}} \cong E_{\text{in}} \tag{16.9}$$

Therefore, if the conditions for differentiation are not met, the network will tend to pass the waveform without alteration.

We can solve Eq. (16.6) for arbitrary E_{in} waveforms. Let us state two specific results.

Differenziazione – circuito CR

Il segnale viene passato per un filtro CR che lo differenzia con un tempo caratteristico τ_1 = CR



$$\tau \frac{dV_{in}}{dt} = V_{out} + \tau \frac{dV_{out}}{dt} \qquad \tau = RC$$

$$\tau \frac{dV_{out}}{dt} \approx \tau \frac{dV_{in}}{dt}$$

per piccoli valori di τ_1

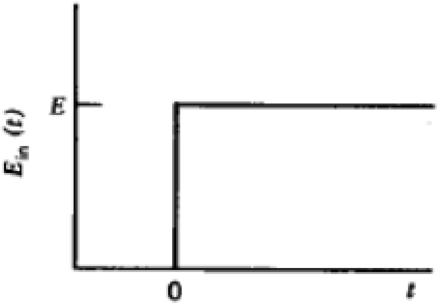
$$V_{out} \approx \tau \frac{dV_{in}}{dt}$$

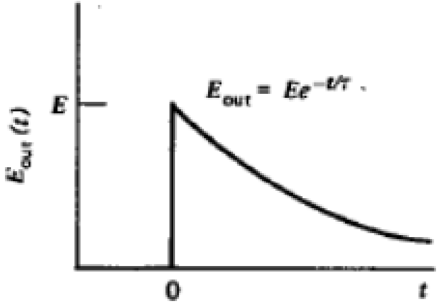
per grandi valori di τ_1

-> in output si ha un segnale legato alla derivata del segnale in input

Input gradino -> output decadimento esponenziale con costante τ_1 = CR

-> tende a tagliare la coda lunga





Segnali lunghi rispetto a τ_1 (basse frequenze) non danno nulla in uscita

-> filtro passa alto

Il segnale diventa meno lungo in coda

Con opportune scelte di τ_1 è possibile limitare il problema del pile-up

2. *RC* INTEGRATOR OR LOW-PASS FILTER

When configured as shown in Fig. 16.10, a passive *RC* network can also serve as an integrator. The circuit equation is now

$$E_{\text{in}} = iR + E_{\text{out}} \tag{16.13}$$

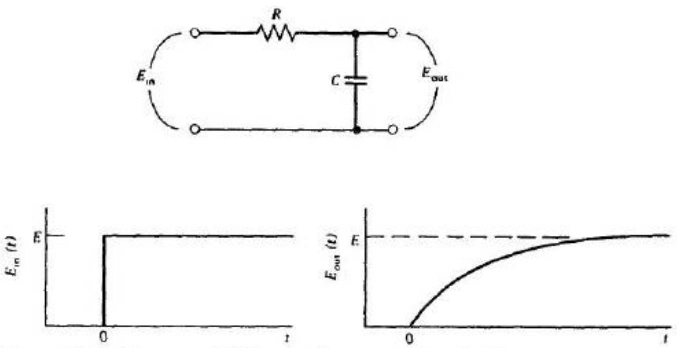


Figure 16.10 A low-pass *RC* filter or integrator network. The response to a step function input is illustrated.

The current i also represents the rate of charging or discharging of the capacitor.

$$i = \frac{dQ}{dt} = C\frac{dV_c}{dt} \tag{16.14}$$

or

$$i = C\frac{dE_{\text{out}}}{dt} \tag{16.15}$$

Now combining Eqs. (16.13) and (16.15) and setting $RC = \tau$, we obtain

$$E_{\text{in}} = \tau\frac{dE_{\text{out}}}{dt} + E_{\text{out}} \tag{16.16}$$

Rearranging, we have

$$\frac{dE_{\text{out}}}{dt} + \frac{1}{\tau}E_{\text{out}} = \frac{1}{\tau}E_{\text{in}} \tag{16.17}$$

Now, if *RC* is sufficiently large, only the first term on the left is significant, and

$$\frac{dE_{\text{out}}}{dt} \cong \frac{1}{\tau}E_{\text{in}}$$

or

$$E_{\text{out}} \cong \frac{1}{\tau}\int E_{\text{in}}\,dt \tag{16.18}$$

Hence, the name *integrator*. The network will integrate provided the time constant τ is large compared with the time duration of the input pulse.

In the opposite extreme of small time constant only the second term on the left of Eq. (16.17) is significant, and therefore

$$\frac{1}{\tau}E_{\text{out}} \cong \frac{1}{\tau}E_{\text{in}}$$

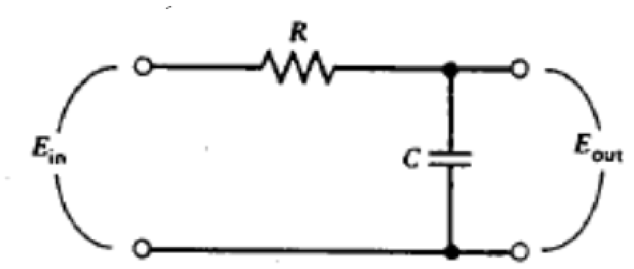
or

$$E_{\text{out}} \cong E_{\text{in}} \tag{16.19}$$

Thus, if the conditions for integration are not met, the network tends to pass the waveform without change.

Integrazione – circuito RC

Il segnale viene passato per un filtro RC che lo integra con tempo caratteristico τ_2 = RC



$$\frac{V_{in}}{\tau} = \frac{dV_{out}}{dt} + \frac{V_{out}}{\tau}$$

$$V_{out} \approx V_{in}$$

per piccoli valori di τ_2

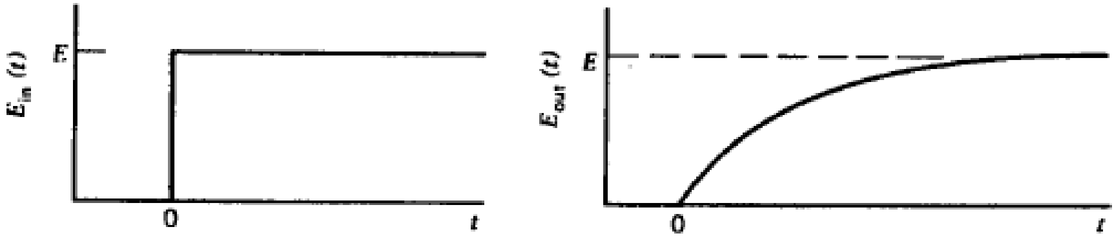
$$\frac{V_{in}}{\tau} \approx \frac{dV_{out}}{dt} \rightarrow \frac{1}{\tau}\int V_{in}dt \approx V_{out}$$

per grandi valori di τ_2

-> in output si ha un segnale proporzionale alla integrazione del segnale di input

Input gradino -> output accrescimento esponenziale con costante τ_2 = RC

-> tende a rallentare la salita



Segnali brevi rispetto a τ_2 (alta frequenza) non danno nulla in uscita

-> filtro passa basso

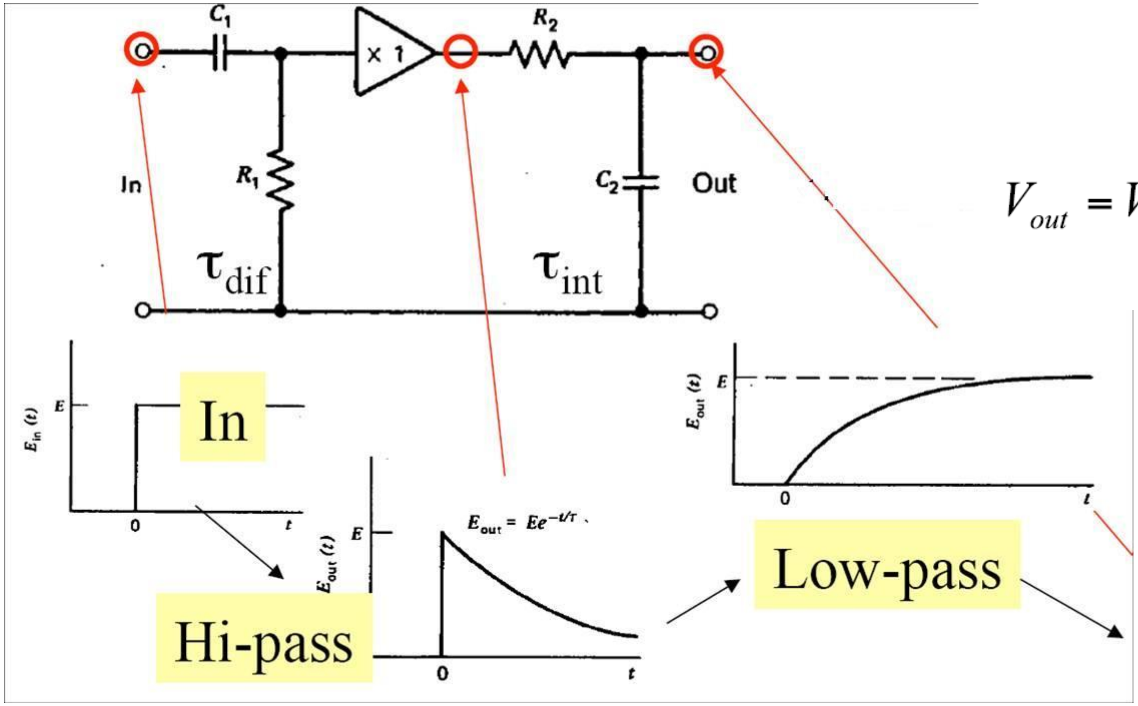
Il segnale diventa più lungo in testa

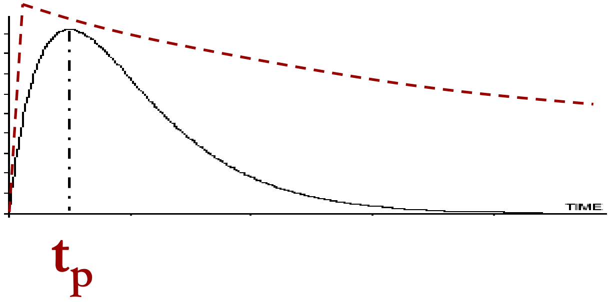
Shaping CR-RC

La combinazione dei due effetti di differenziazione ed integrazione produce

$$V_{out} = V_{in}\left(\frac{\tau_1}{\tau_1 - \tau_2}\right)\left(e^{-t/\tau_1} - e^{-t/\tau_2}\right)$$

$$V_{out} = V_{in}\left(\frac{t}{\tau}\right)e^{-t/\tau} \quad \text{for}\ \tau_{int} = \tau_{dif} = \tau$$



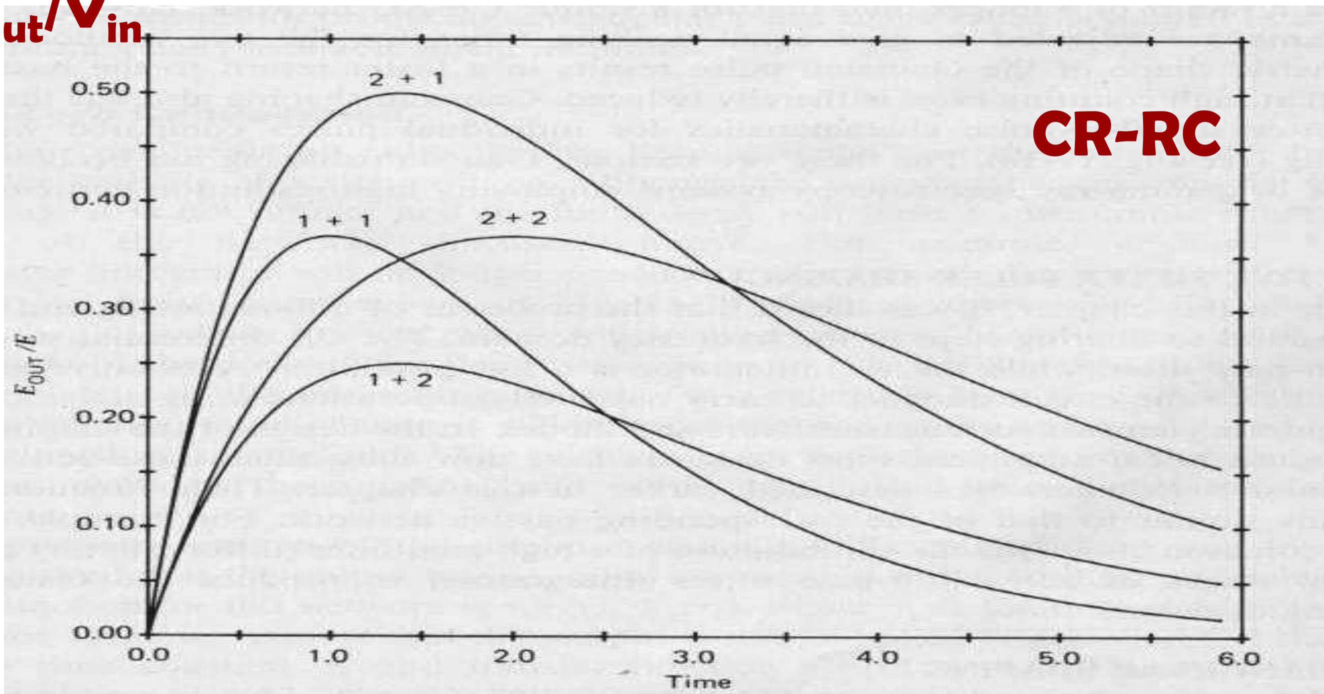


Input gradino

-> output massimo in $t_p = (\tau_1 + \tau_2)/2$ peaking time

Segnale monopolare: la forma dipende dal segnale di ingresso e da τ_1 e τ_2

V_{out}/V_{in}



CR-RC

t (unità di t_o)

Esempio di guadagno V_{out}/V_{in} per 4 coppie di combinazioni di τ_1 e τ_2, in unità arbitrarie t_o

Spesso si lavora con $\tau_1 = \tau_2 = \tau$ -> $t_p = \tau$

Shaping CR-(RC)^n

Alla differenziazione **CR** si fanno seguire **n** stadi di integrazione **RC**

Se $\tau_1 = \tau_2 = \tau$ il segnale in uscita diventa più simmetrico all'aumentare di **n**

Per $n \geq 4$ -> forma praticamente gaussiana

peaking /shaping time $\tau_p = n\tau$

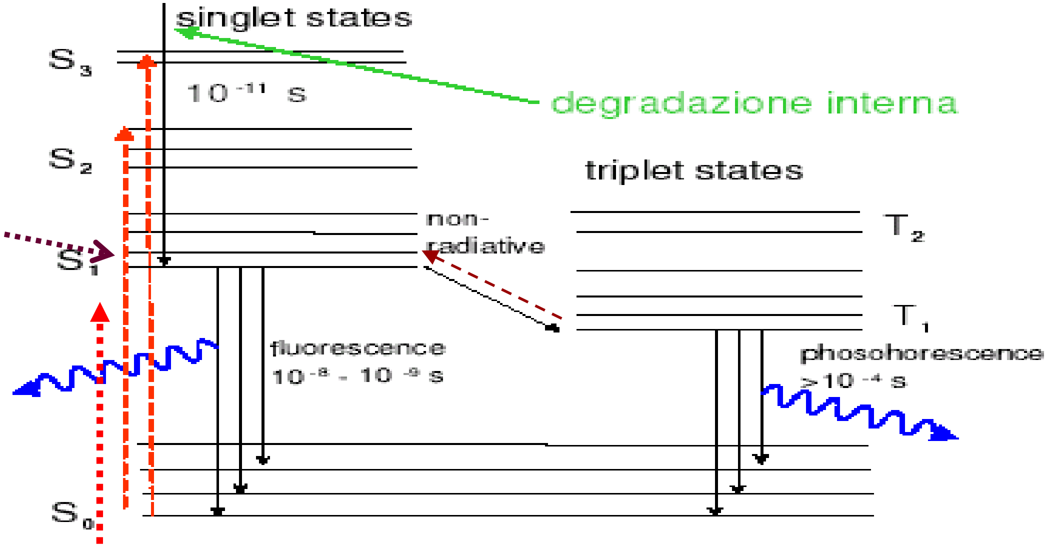
Lo shaping gaussiano aumenta il rapporto segnale/rumore rispetto al **CR-RC**

Il valore di t_p scelto dipenderà dal tipo di segnale da formare

Scintillatori organici

L'emissione di luce viene dal processo di eccitazione - diseccitazione delle molecole dello scintillatore

Assorbimento di energia -> eccitazione



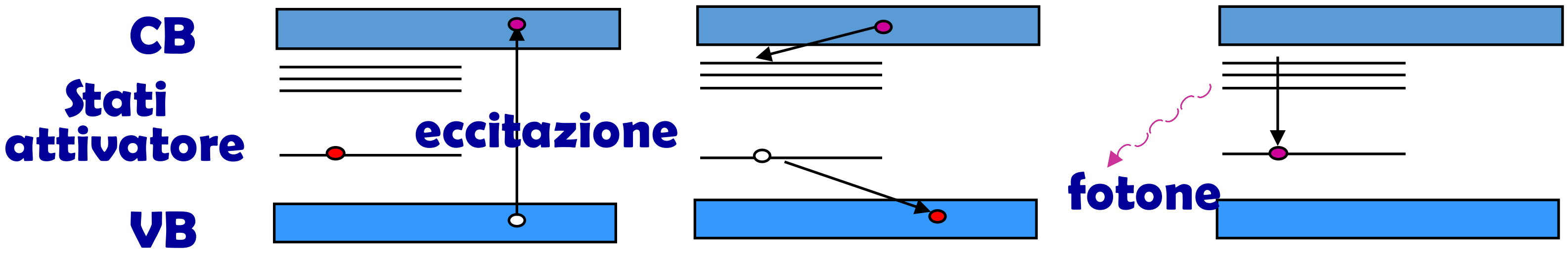
La luce è esponenziale con una o due componenti

Il processo è legato alla molecola e non al suo stato fisico (gas, liquido, solido); le molecole si distruggono a causa delle radiazioni

Scintillatori inorganici

Cristalli inorganici

L'emissione di luce viene dal processo di ionizzazione - ricombinazione nella struttura a bande del cristallo



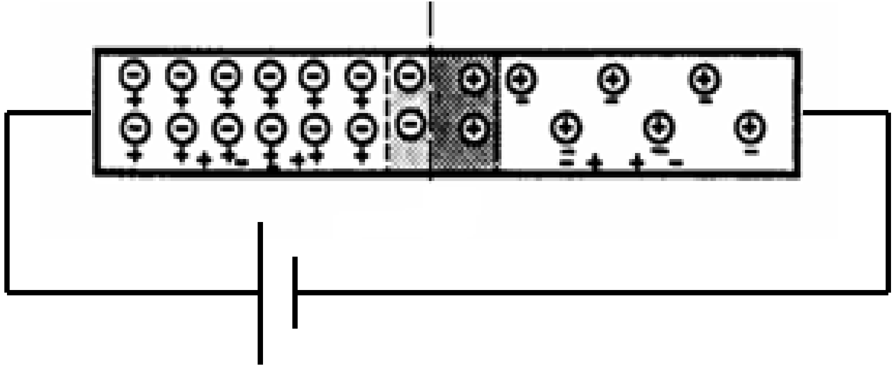
La struttura è modificata da un drogante che crea livelli in zona proibita -> attivatore del cristallo

Rilascio energia -> creazione elettrone/lacuna

Ricombinazione -> centro attivatore neutro creato in uno stato eccitato -> Emissione di luce a λ più bassa

La polarizzazione

Se ai capi di una giunzione n-p viene posta una tensione V_e ossia vengono iniettate delle cariche:



- polarizzazione diretta: p positivo e n negativo

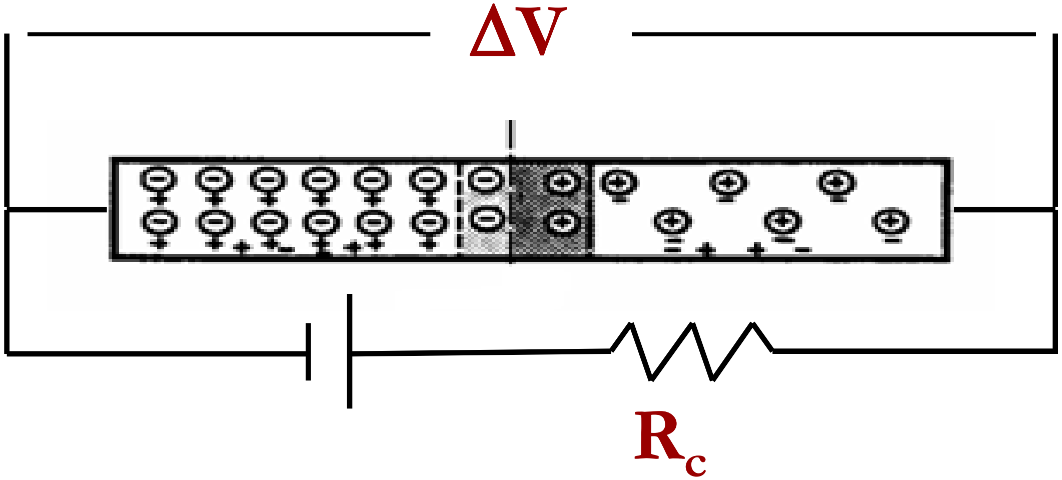
Il moto della cariche maggioritarie è favorito; le cariche iniettate si ricombinano al centro

-> alta corrente anche a piccole V_e

Lo svuotamento si riduce ed la ddp si abbassa a V_i-V_e

Il moto di elettroni e lacune genera delle cariche ai capi del condensatore ed una variazione che raggiunge il valore massimo ΔV alla raccolta

Il generatore di V_e tenderebbe a ripristinare subito lo squilibrio ΔV



La R_c impedisce il ripristino immediato permettendo la lettura del segnale ΔV

Why a new front-end electronic ?

The final FARCOS array constituted by 20 telescopes, in the final project needs the readout of about **4k** channels.

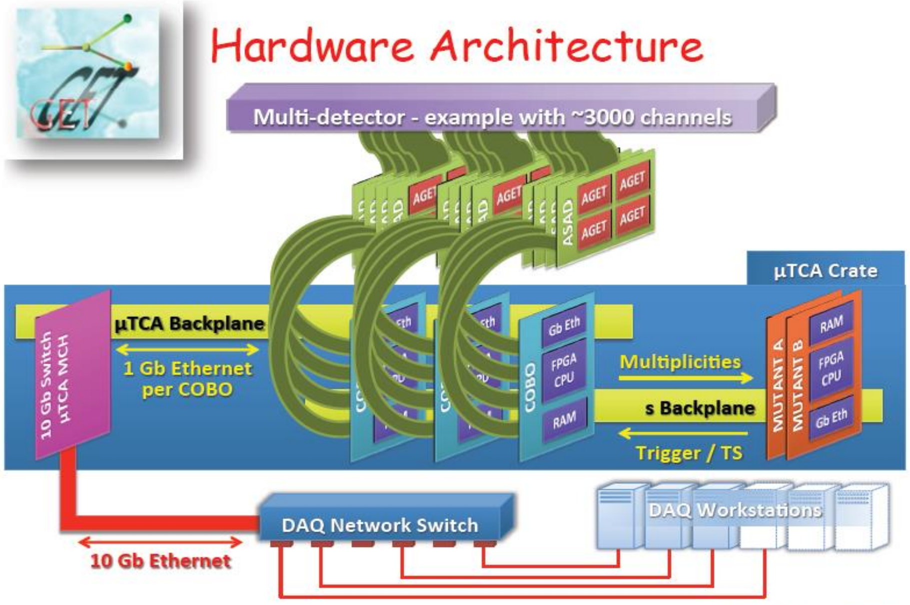
CHIMERA CsI(Tl) front-end (1192 detectors) is now obsolete, in particular the amplifiers and the **VME** QDCs for CsI fast-slow component integration (more than 15 years old technology).

Our choice was to develop a first stage front-end circuit for FARCOS (including new ASIC pre-amplifiers) and new dual-gain modules coupled to a compact hardware architecture covering digitalization and signal readout, syncronization and trigger functions. All these last aspects are covered by the GET project.

Consequences → digital DAQ for FARCOS and CHIMERA (CsI) + Analog DAQ (Silicons)

GET

- Especially designed for TPC (gas detectors) to be used with radioactive beams
- Integrated and low power consuming
- Configurable
- Digitalization of signals



Shebli Anvar IRFU

Some definitions . . . (useful for for the following) and numbers

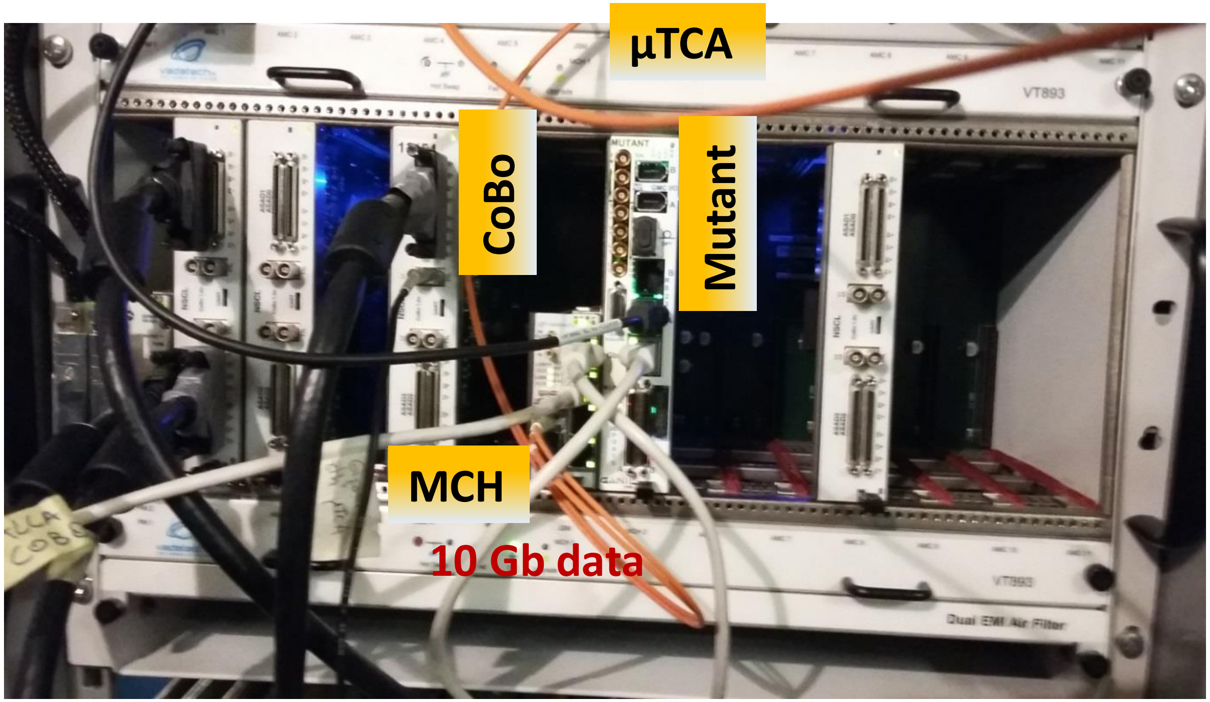
AGET: Asic for GET – 64 analog channels (+4 FPN) - 512 cells/channel

ASAD: AGET Support for Analog to Digital – 4 AGET

COBO: COllection BOard – 4 ASAD - 1024 digital channels

MUTANT: MUtiplicity, Trigger ANd Time (3 trigger levels)

MicroTCA: Micro Telecommunications Computing Architecture
MCH: Carrier Hub with 10 Gb and 1 Gb ethernet link



Chimera DAQ crate

Chimera CsI:
8 ASAD → 2 CoBo (<2k signals)

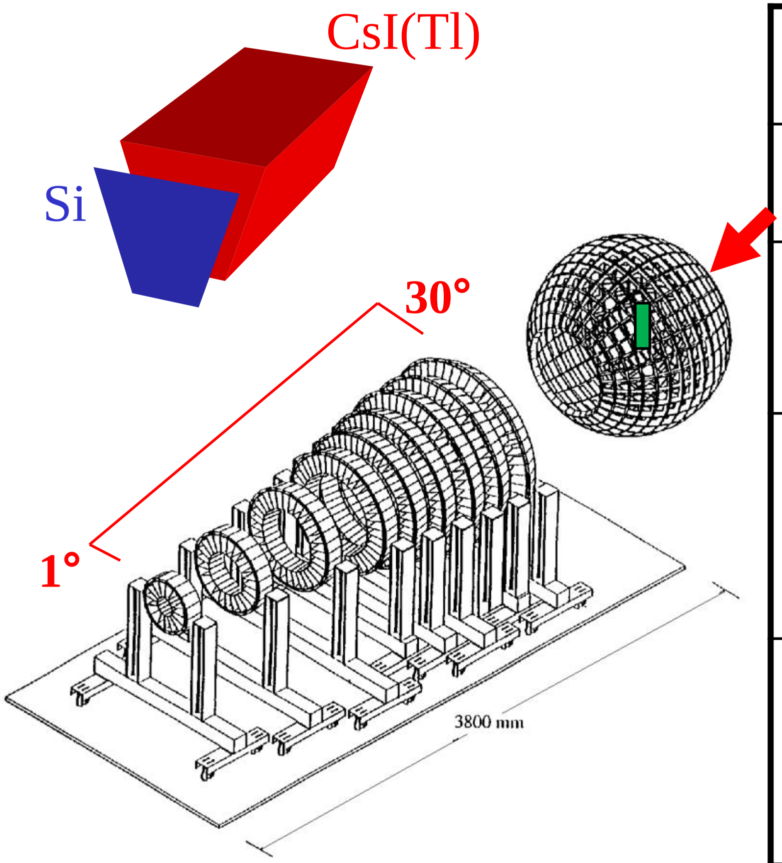
Farcos (5 modules):
14 ASAD → 4 CoBo (<4k signals)

1 µTCA crate
1 Mutant (three levels trigger)

Computer farm + Storage (disk server) + 10Gb/1Gb switch

CHIMERA

Charge Heavy Ion Mass and Energy Resolving Array



Granularity	1192 telescopes Si (300μm) +CsI(Tl)
Geometry	RINGS: 688 telescopes 100-350 cm SPHERE: 504 telescopes 40 cm
Angular range	RINGS: $1° < \theta < 30°$ SPHERE: $30° < \theta < 176°$ 94% of 4π
Identification method	ΔE-E E-TOF PSD in CsI(Tl) PSD in Si (upgrade 2008)
Experimental observables and performances	TOF $\delta t \leq 1$ ns δE/E LCP (Light Charge Particles) ≈ 2% δE/E HI (Heavy Ions) ≤ 1% Energy, Velocity, A, Z, angular distributions
Detection threshold	≈ 1 MeV/A for H.I. ≈ 2 MeV/A for LCP

Dynamical range : from fusion, fusion-fission to multifragmentation reaction

A. Pagano et al, Nucl. Phys A 734, 504 (2004)
A. Pagano, Nucl. Phys. News 22, 28 (2012) and references therein.
E. De Filippo & A. Pagano EPJA 50 (2014) and references therein.

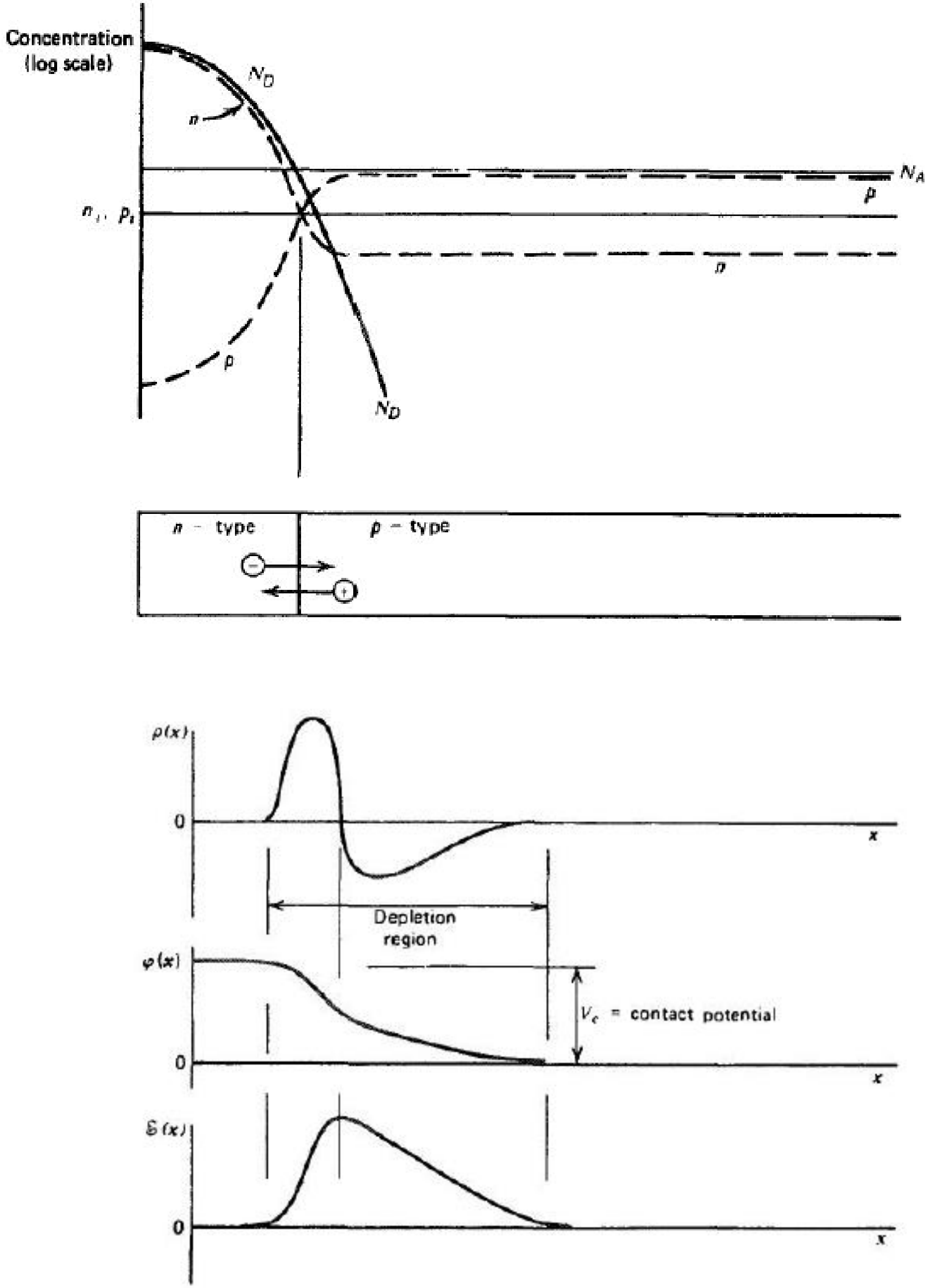
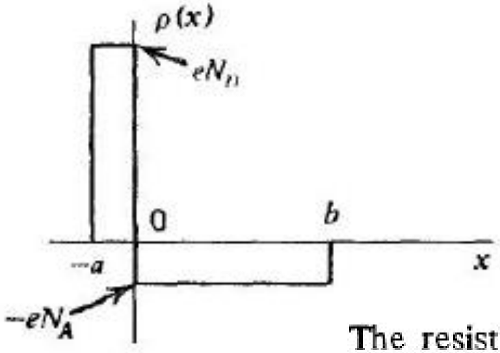


Figure 11.8 The assumed concentration profiles for the *n-p* junction shown at the top are explained in the text. The effects of carrier diffusion across the junction give rise to the illustrated profiles for space charge $\rho(x)$, electric potential $\varphi(x)$, and electric field $\mathscr{E}(x)$.

$$\rho(x) = \begin{cases} eN_D & (-a < x \leq 0) \\ -eN_A & (0 < x \leq b) \end{cases}$$

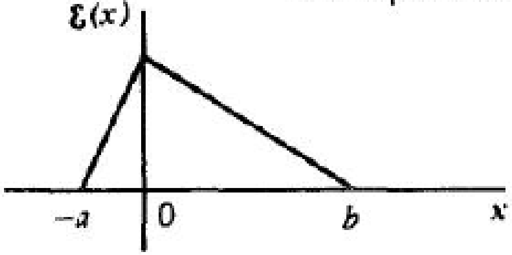
$$d \cong \left(\frac{2\epsilon V}{eN_A} \right)^{1/2}$$

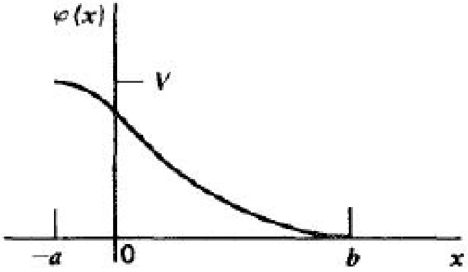
$$d \cong \left(\frac{2\epsilon V}{eN} \right)^{1/2}$$



The resistivity ρ_d of the doped semiconductor [see Eq. (11.11)] is given by $1/e\mu N$, where μ is the mobility of the majority carrier. Equation (11.18) may thus be written

$$d \cong (2\epsilon V \mu \rho_d)^{1/2} \tag{11.19}$$





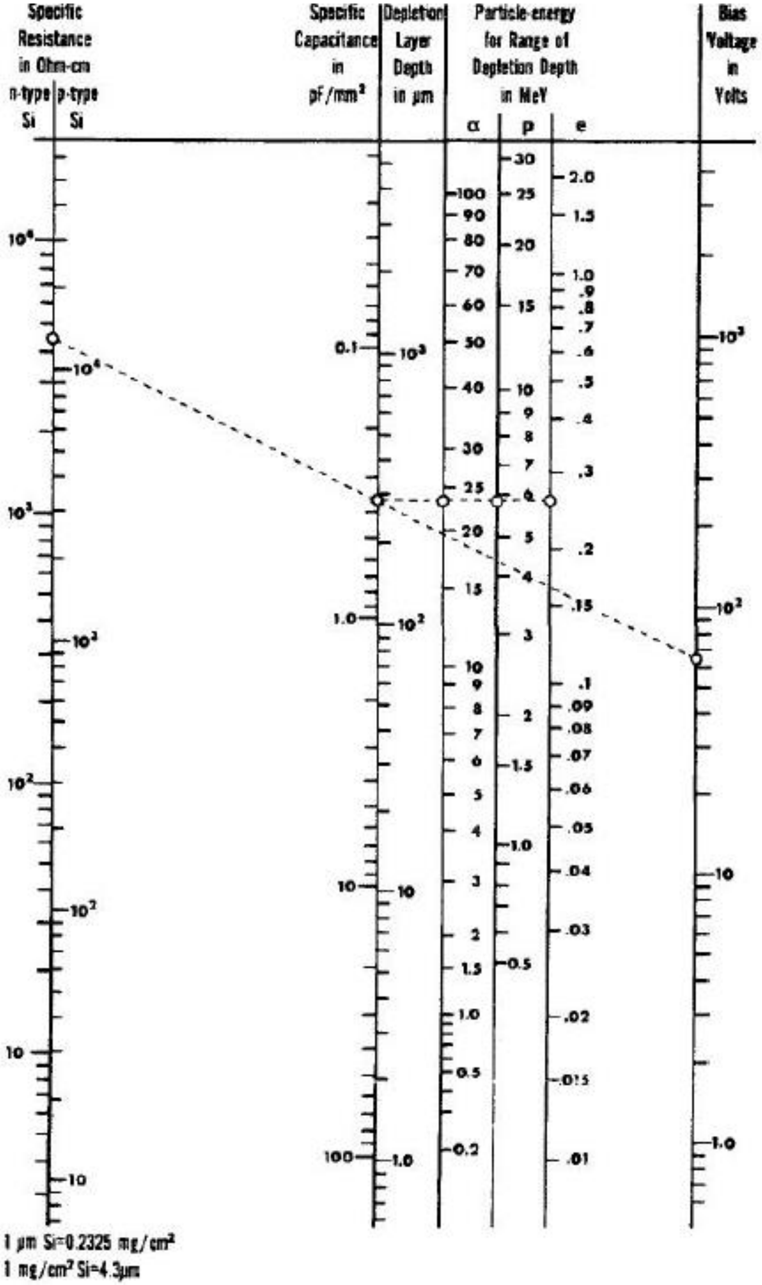


Figure 11.10 Nomogram illustrating interrelation between parameters for silicon junction detectors. (Similar to nomogram originally published by Blankenship.[26])

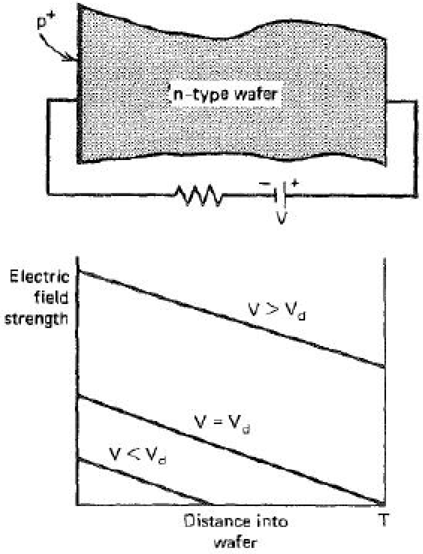


Figure 11.12 The electric field shape in a reverse bias semiconductor detector. Three plots are shown for bias voltages that are below, equal to, and above the depletion voltage V_d.

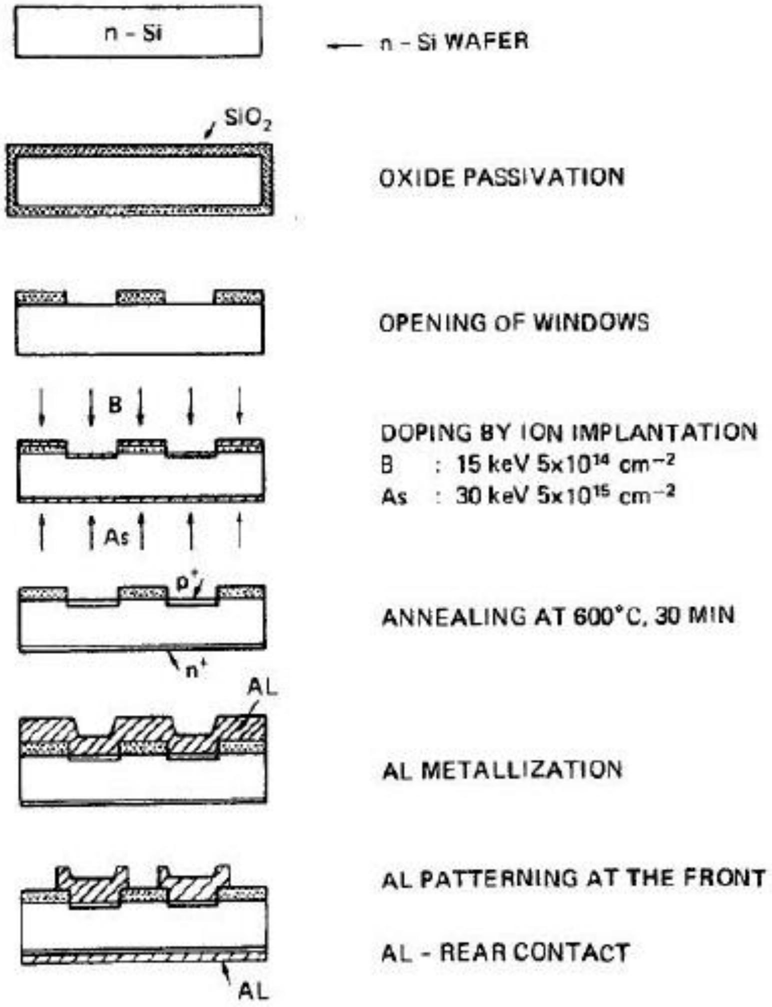
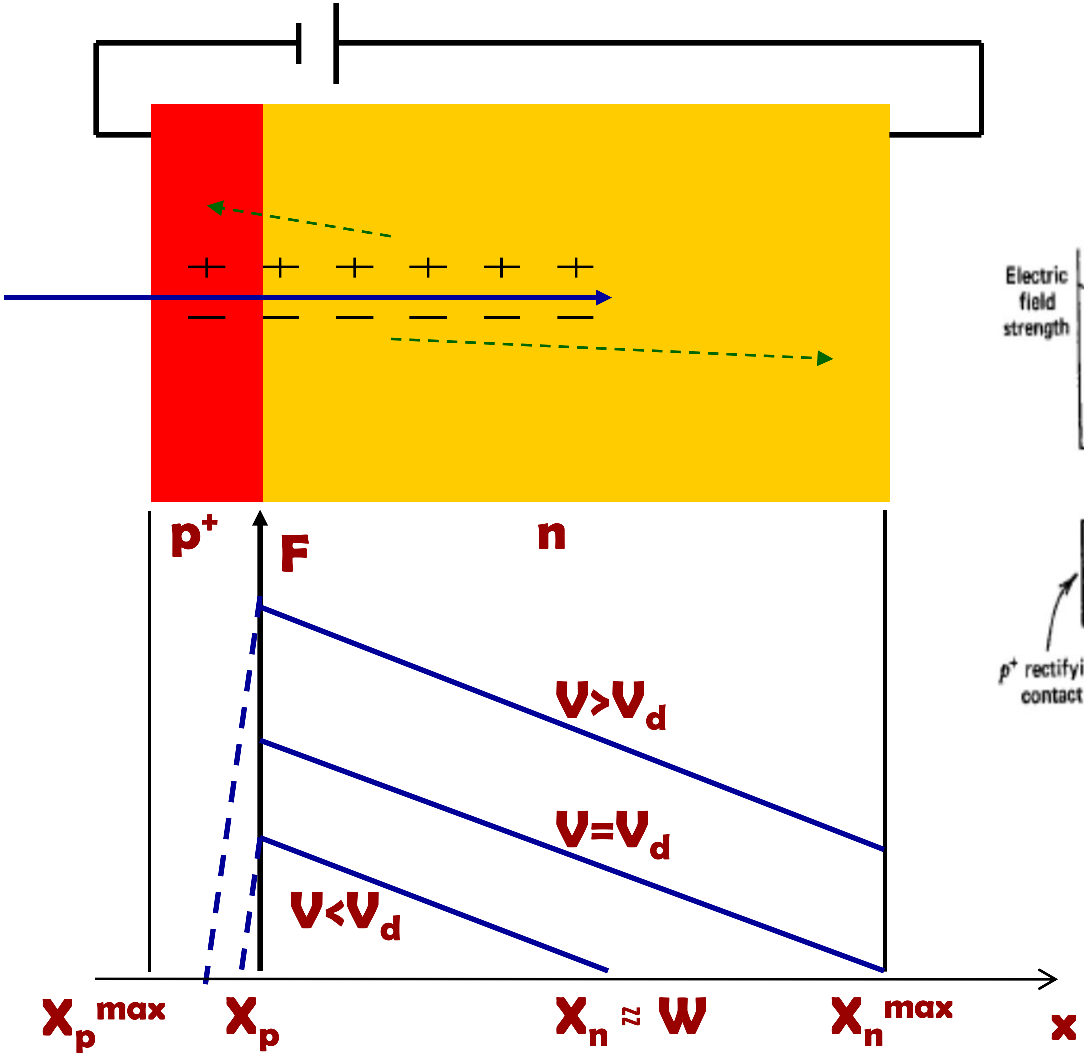
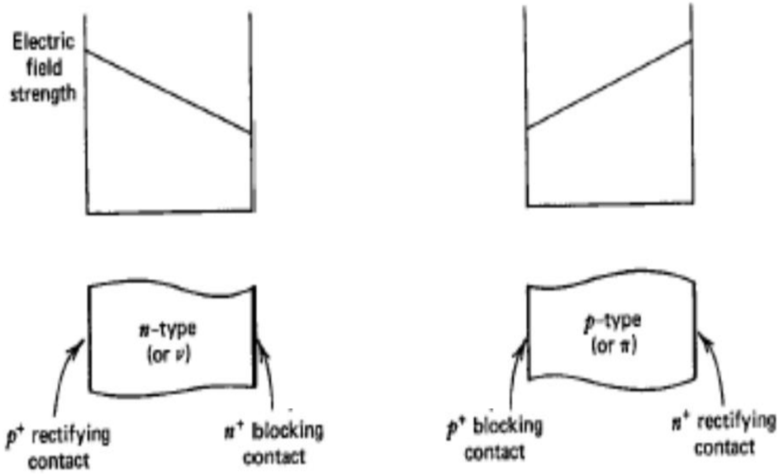


Figure 11.14 Steps in the fabrication of passivated planar silicon diode detectors. (From Kemmer.[34])

Ingresso particelle dal lato giunzione

-> finestra ingresso non svuotata





Possibili componenti della luce emessa:

Fluorescenza immediata: luce emessa subito dopo il processo di eccitazione 1-100 ns

Fosforescenza: luce a maggior lunghezza d'onda, emessa con tempi più lunghi ms-s

Fluorescenza ritardata: luce con uguale lunghezza d'onda della immediata, ma tempi ancora più lunghi

Processo di eccitazione istantaneo seguito da emissione di luce con andamento esponenziale

$I = I_o e^{-t/\tau}$ τ **tempo caratteristico**

I tempi variano in base al mezzo ed alla luce

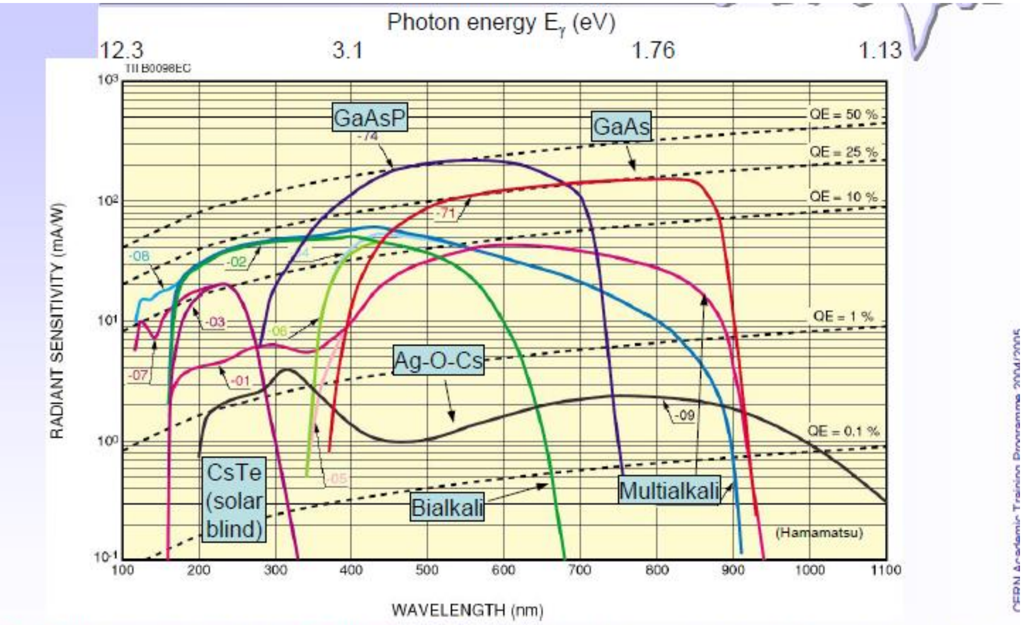
Il fotocatodo è fatto con un sottile (nm) strato di materiale che emette elettroni per effetto f.e.

Efficienza quantica

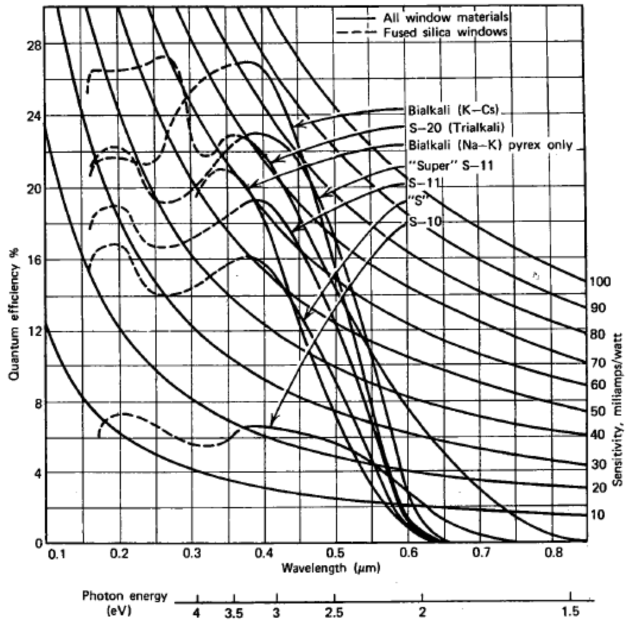
$$QE(\%) = \frac{N_{pe}}{N_{\gamma}}$$

Sensibilità radiante

$$QE(\%) \approx 124 \cdot \frac{S(mA/W)}{\lambda(nm)}$$

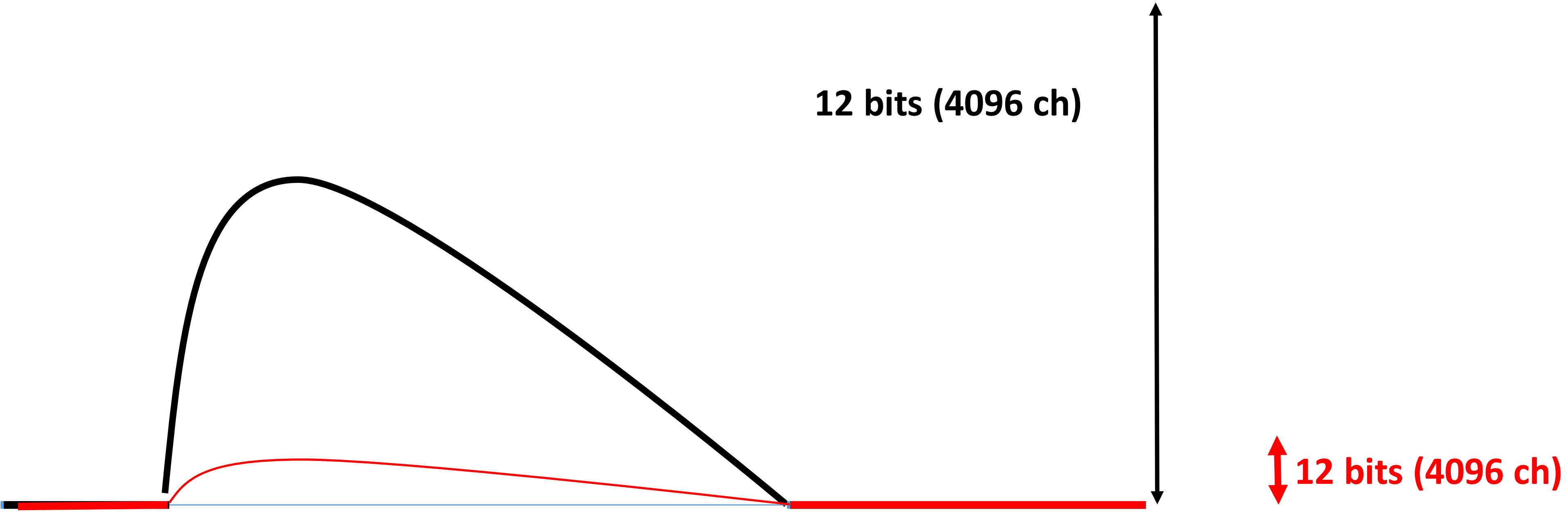


Bialkali: SbKCs, SbRbCs Multialkali: $SbNa_2KCs$ (alkali metals have low work function)



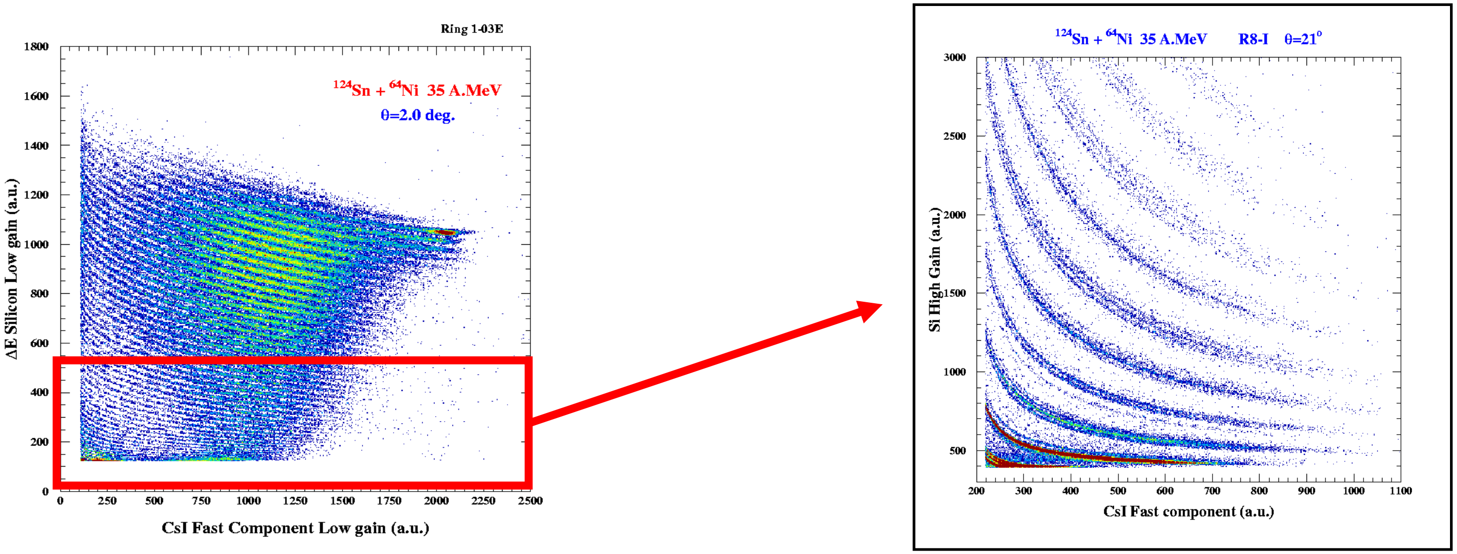
Dipendono dalla λ Taglio alte λ -> soglia fotoelettrica

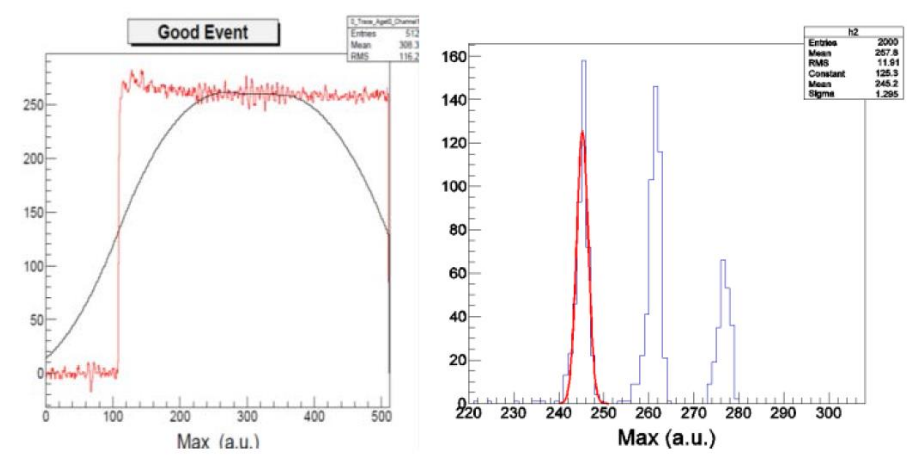
Large dynamic range: double encoding in QDCs



12 bits (4096 ch)

12 bits (4096 ch)

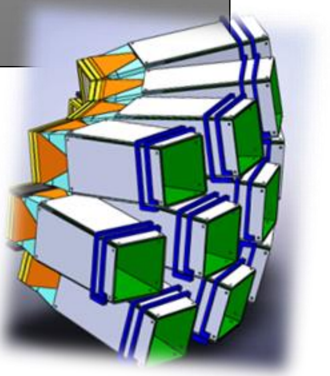




Digitized pre-amplifier (10 mV/MeV, 100 MeV dynamical range) signal after baseline restore and triangular filter and resulting three peaks alpha source (data obtained with R-Cobo readout) on a FARCOS strip

What is FARCOS and **why** we need it ?

High energy and angular resolution (Δϑ<1°)
Low thresholds (<1 MeV/A):
Pulse-shape on first Si layer for low energy experiments
High counting rate (1KHz)
Large Dynamic range (1 MeV to 2GeV)
Flexibility, Modularity, Trasportability
Easy coupling to 4π detectors or spectrometers
Integrated Electronics (GET)



The FARCOS prototype (4 telescopes, used in all experiments and test up to 2016)

Pre-Amplifier stage

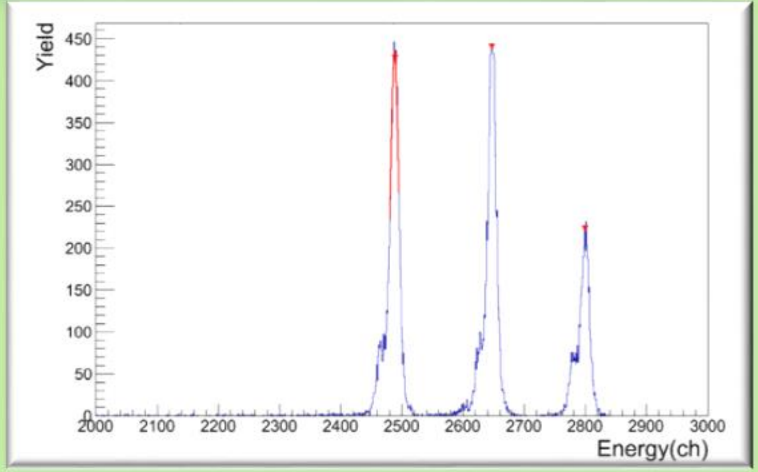
Mesytec MPR-64

300-1500 MeV full energy

NPA, C. Boiano, INFN-Milano)

32 channels, 10,20,45 mV/MeV

1500 µm DSSSD with Mesytec resolution ≈26 keV with 3 alpha source and standard DAQ

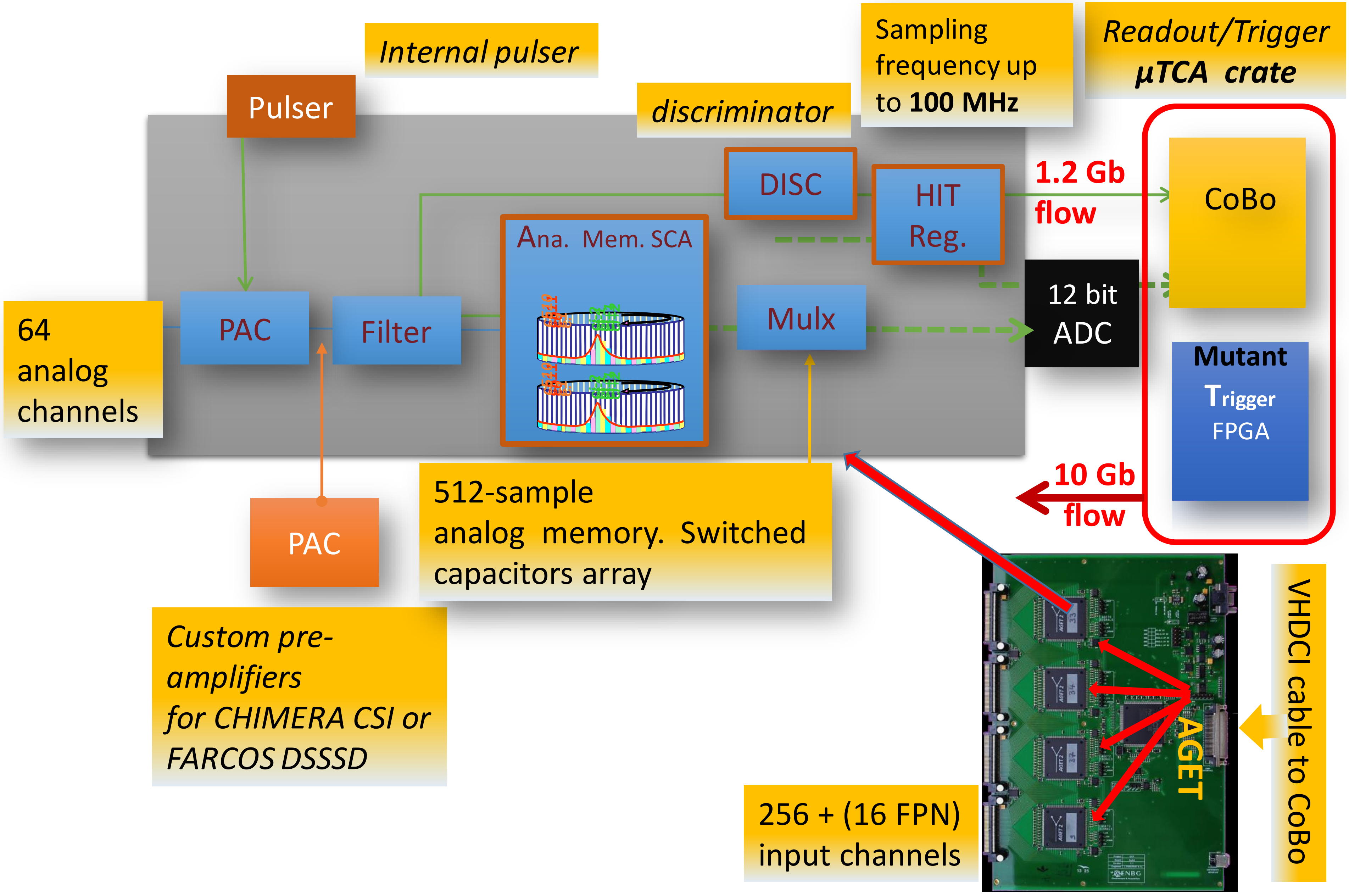


Front-end electronics in experiments for the FARCOS prototype:

Standard CHIMERA NIM (16 channels) pulse shape amplifiers + analog (VME) CHIMERA DAQ

or (few test channels) **Digital acquisition of PAC signals with GET electronics**

THE AGET ASIC in the ASAD board



Internal pulser

Pulser

discriminator

Sampling frequency up to **100 MHz**

Readout/Trigger
µTCA crate

DISC

HIT Reg.

1.2 Gb flow

CoBo

Ana. Mem. SCA

64 analog channels

PAC

Filter

Mulx

12 bit ADC

Mutant
Trigger
FPGA

10 Gb flow

PAC

512-sample analog memory. Switched capacitors array

Custom pre-amplifiers for CHIMERA CSI or FARCOS DSSSD

256 + (16 FPN) input channels

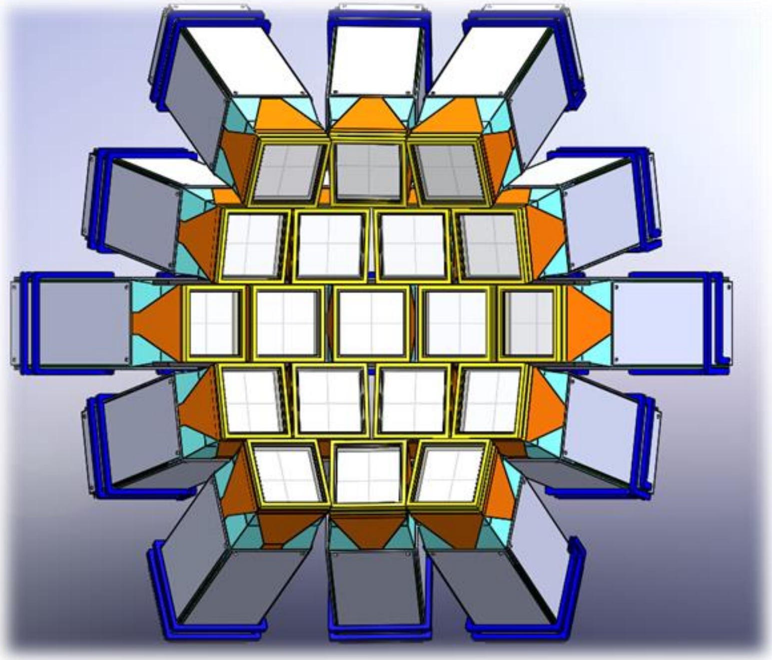
AGET

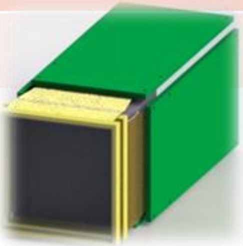
VHDCI cable to CoBo

Assembling of the «real» FARCOS: high modularity

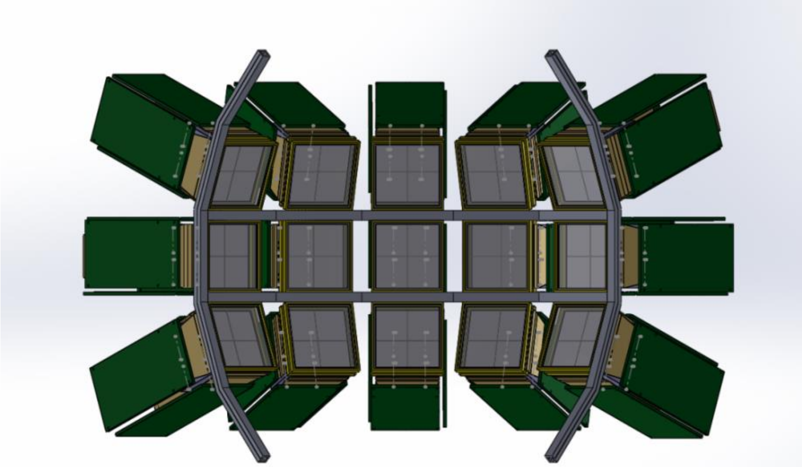
Starting prototype: 4 telescopes : NEWCHIM (2015-2019 final planning 20 telescopes)

Year	Tel.	Operation
2015	6	test acq. GET for FARCOS construction of 2 telescopes purchase of final GET electronics
2016	10	test dual gain module test GET electronic +DAQ Study of alignment system
2017	14(10)	test new asic pre-amplifiars final design modular support implementation asic pre-amplifier new DAQ VME+ GET running First experiments with new Chimera+Farcos front-end
2018	18(?)	Construction of new telescopes
2019	20+2	20 telescopes ready
. . . . .		





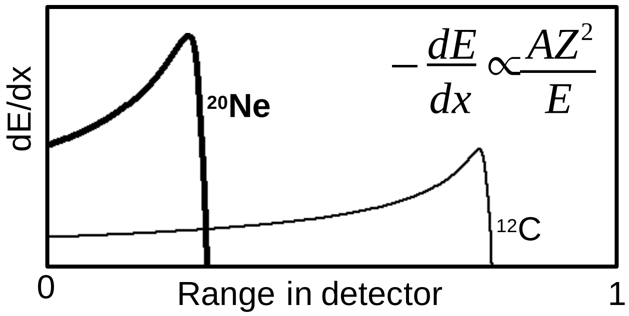
Final cost prediction: ≈< 1 M€



Design simulation: Luis Acosta

Isotopic identification with the ΔE-E method

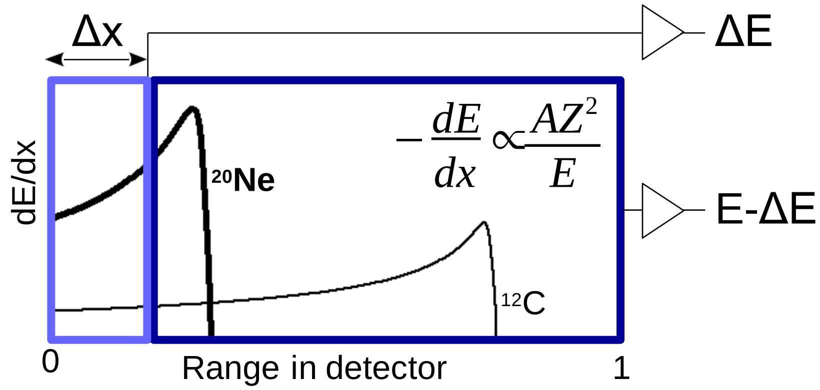
- **Stopping power**
  Stopping power depends on the charge (Z), mass (A), and energy (E) of the particle

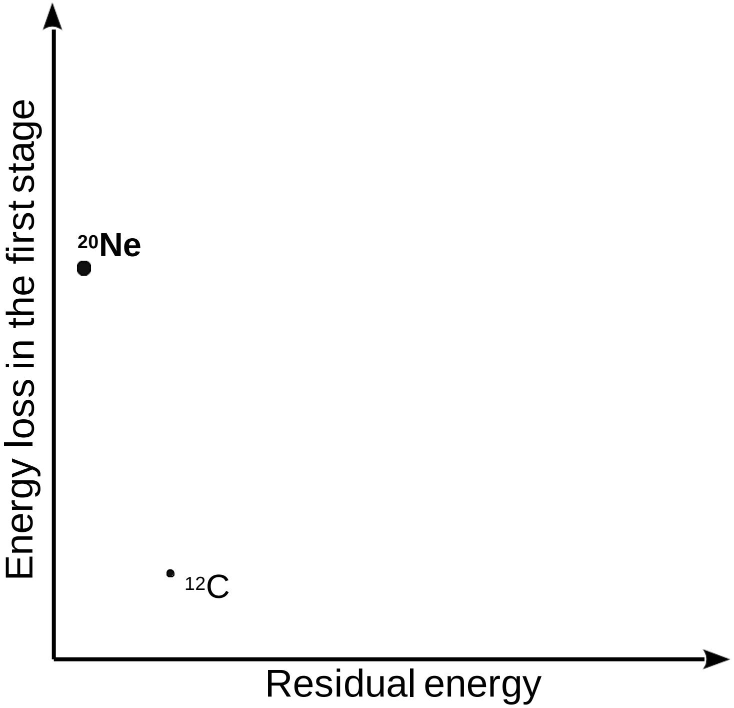


$$-\frac{dE}{dx} \propto \frac{AZ^2}{E}$$

Isotopic identification with the ΔE-E method

- **Stopping power**
  Stopping power depends on the charge (Z), mass (A), and energy (E) of the particle



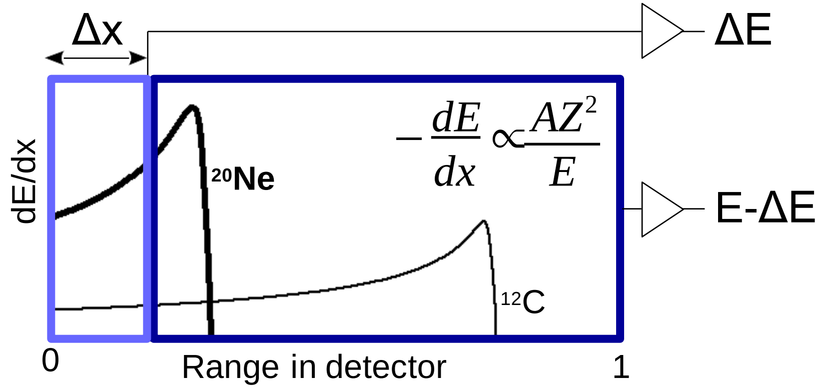


- **ΔE-E method**
  Divide the material in ΔE and E layers
  In the ΔE-E plot, particles populate lines characteristic of their charge and mass

Isotopic identification with the ΔE-E method

Stopping power

Stopping power depends on the charge (Z), mass (A), and energy (E) of the particle



ΔE-E method

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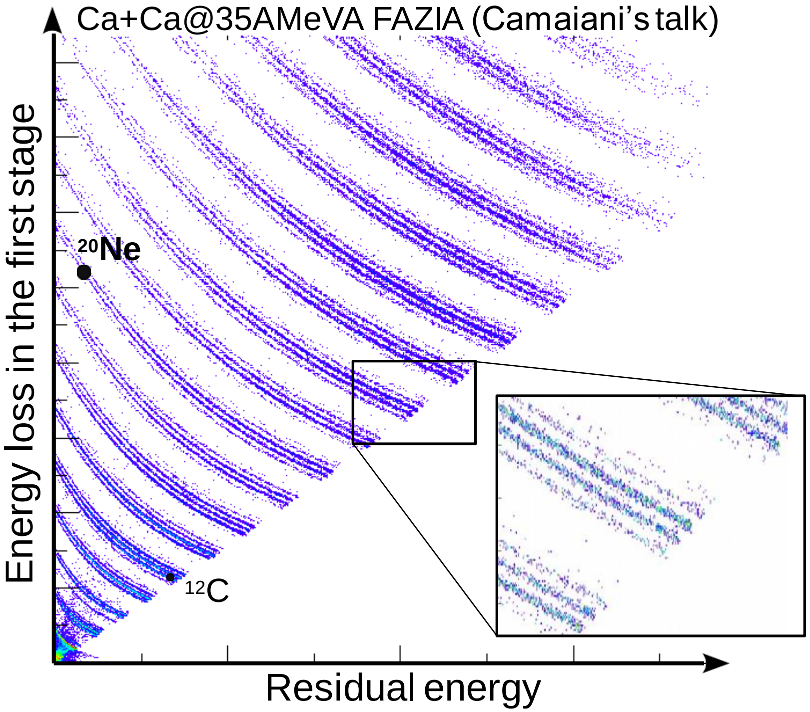

Isotopic identification with the ΔE-E method

- **Stopping power**
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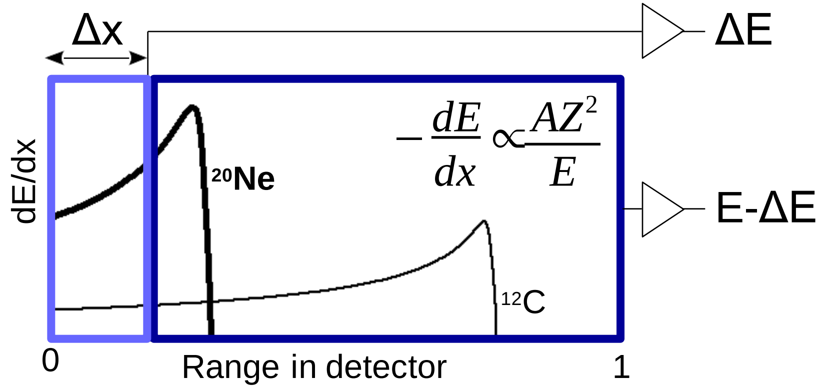
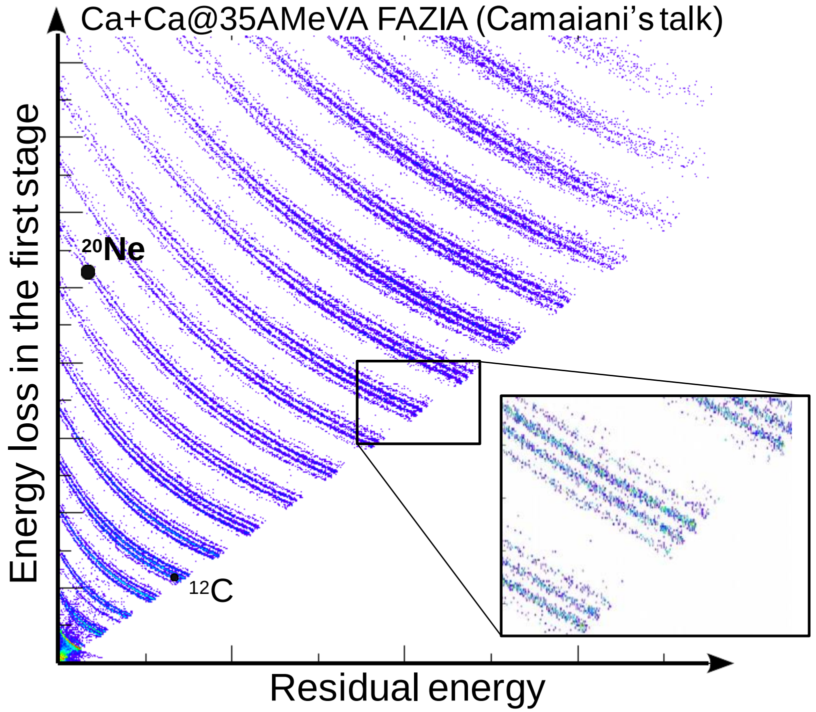


- **ΔE-E method**
  Divide the material in ΔE and E layers
  In the ΔE-E plot, particles populate lines characteristic of their charge and mass

- **Performances**
  No limit in charge ID (up to Z~92)
  Energy straggling limits mass ID (Z<25-30)
  Limited number of isotopes (~7) per element

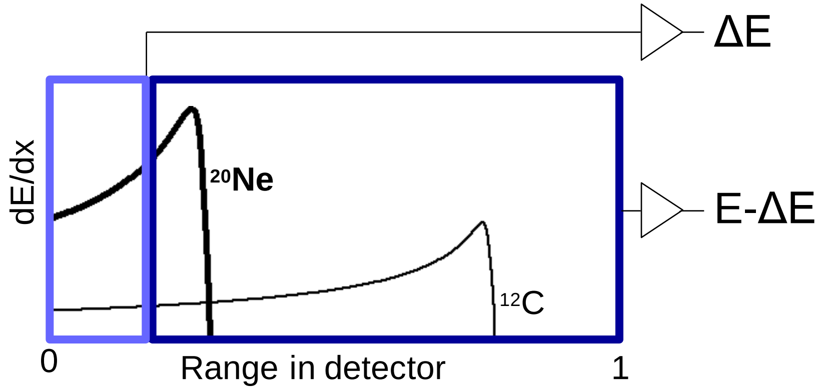


- **Measure ΔE and E**
  Electronics and signal processing
  Channeling effects in ΔE detector

- **Keep Δx under control**
  Detector thickness homogeneity

ΔE-E telescopes

- **Silicon detectors**
  Good energy resolution and fast signals (ToF)
  Good performances for Pulse Shape Analysis
  Can be divided in strips on both side
  Often used as thin ΔE layer (from few μm to few mm)



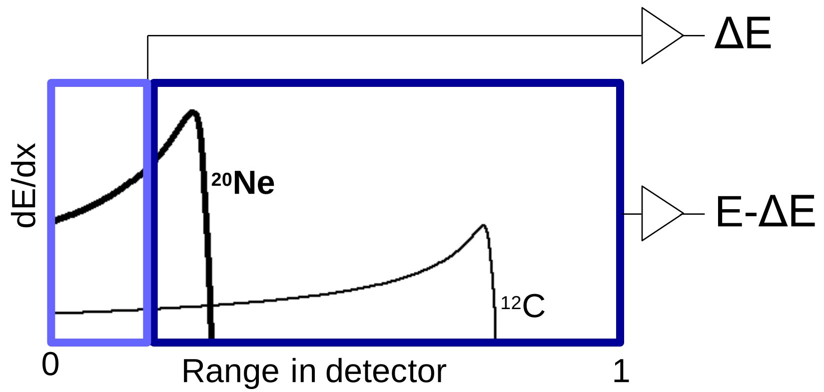
- **Scintillators**
  Robust and cheap very thick detectors (few cm)
  Mainly CsI(Tl) are used for many years
  Neutron sensitive plastic scintillator (Pagano’s talk)

- **Low pressure gas detectors**
  Not suitable for isotopic identification (E resolution)

ΔE-E telescopes

Silicon detectors

Good energy resolution and fast signals (ToF)
Good performances for Pulse Shape Analysis
Can be divided in strips on both side
Often used as thin ΔE layer (from few μm to few mm)



Scintillators

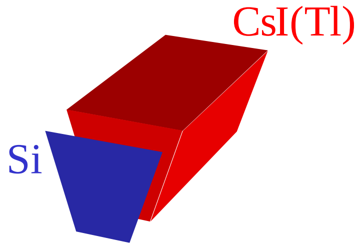
Robust and cheap very thick detectors (few cm)
Mainly CsI(Tl) are used for many years
Neutron sensitive plastic scintillator (Pagano's talk)

Low pressure gas detectors

Not suitable for isotopic identification (E resolution)

« Simple » telescopes

CHIMERA : Si-CsI
FAZIA : Si-Si-CsI
NIMROD : Si-Si-CsI



Silicon strip telescopes

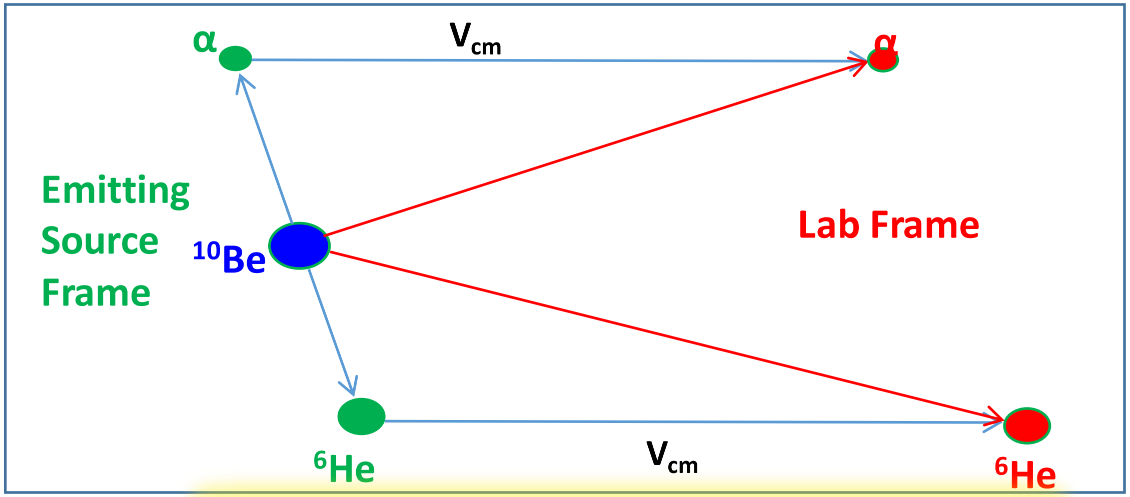
HiRA : Si-Si-CsI
OSCAR : Si-Si
GASPAR : Si-Si-Si
FARCOS : Si-Si-CsI

Less simple telescopes

KRATTA: Si-Si-CsI-CsI-Si

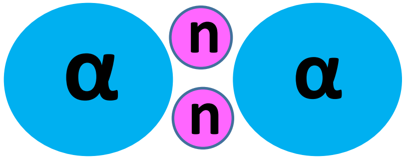
Spectroscopy

MonteCarlo simulations of the ^{10}Be* decay (α+^{6}He channel) in CHIMERA and FARCOS setup (as in the CLIR experimental setup: 4 telescopes placed symmetrically around the beam axis).



^{10}Be:

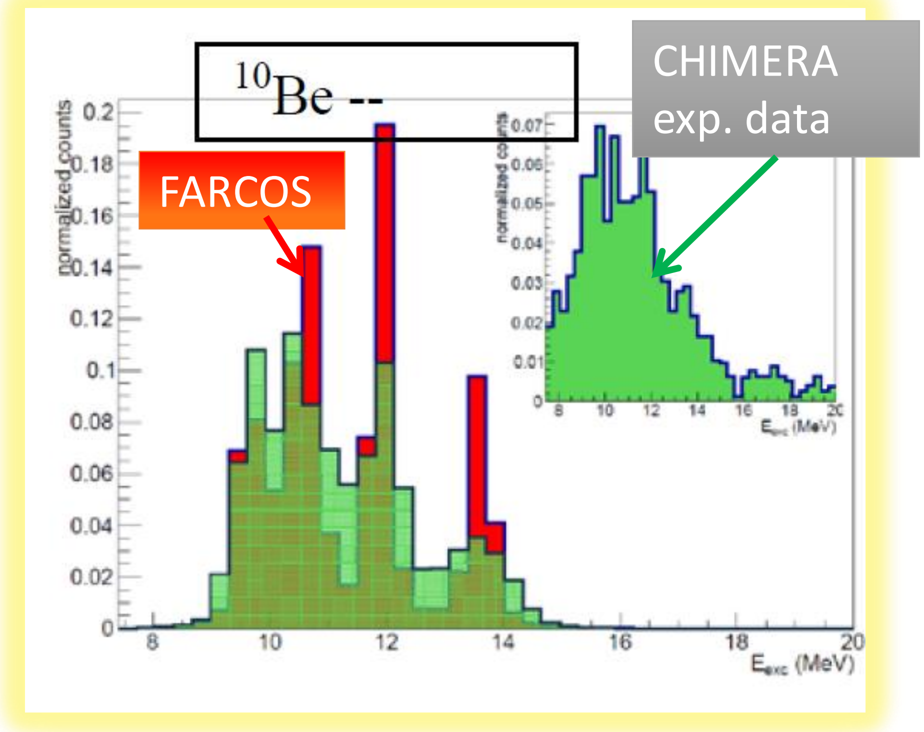
Signals of molecular structure



M. Freer et al., Phys. Rev. Lett. 96, 042501 (2006)

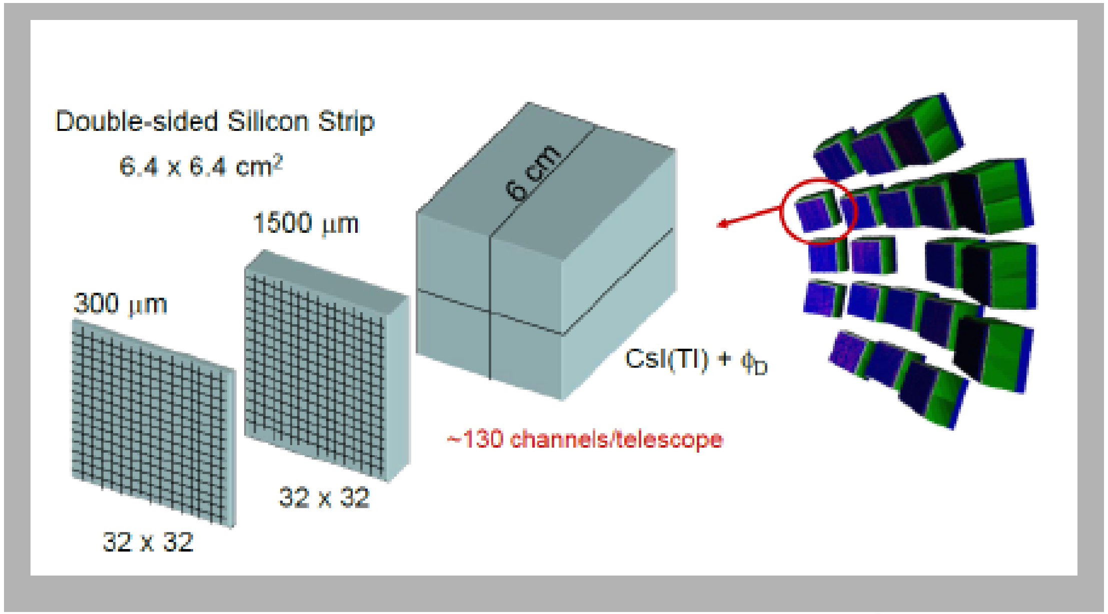
^{10}Be level structure from ^{4}He+^{6}He channel

E_x (MeV)	J^π	Γ_{tot} (MeV)
9.51	2^+	0.14
10.6		0.20
11.8	(4^+)	0.12
≈ 13.5	6^+	≈ 0.15



see: D. Dell'Aquila et al., Phys. Rev. C93, 024611 (2016)

FARCOS project (R&D 2013-15)



- High energy and angular resolution **(2*2 mm^2 pixel size)**
- Low thresholds
- Pulse-shape on … ments
- High counting ra
- Large Dynamic r
- Flexibility, Modularity, Transportability
- Coupling to 4π detectors or spectrometers
- Integrated Electronics **(GET)**

The project is going to be realized with 20 telescopes

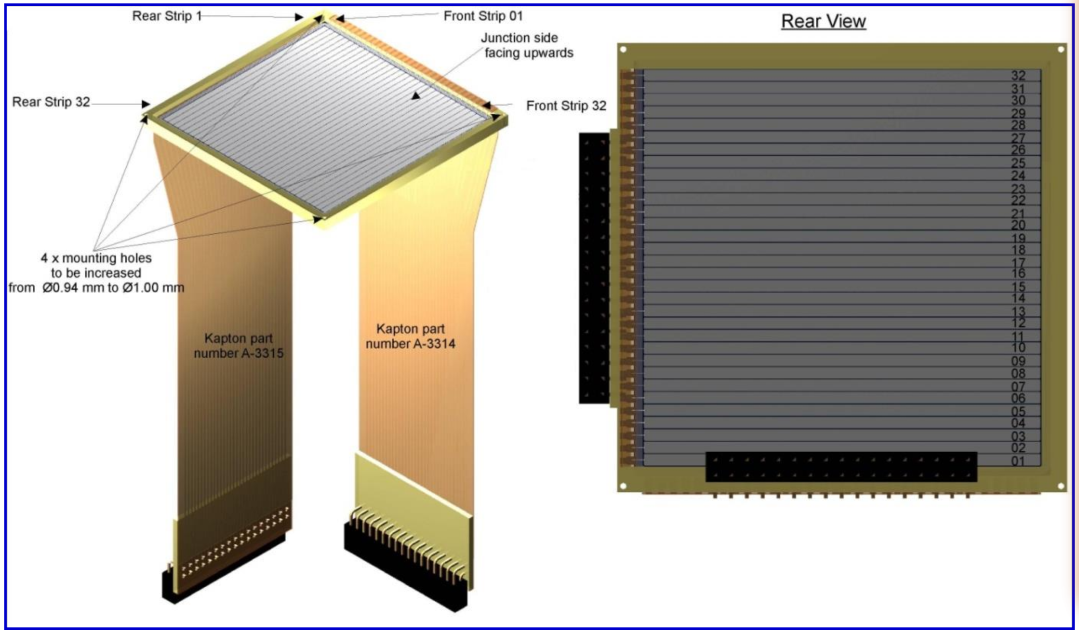
Supported by INFN- CSN3

NEWCHIM exp 2015-2019 (?)

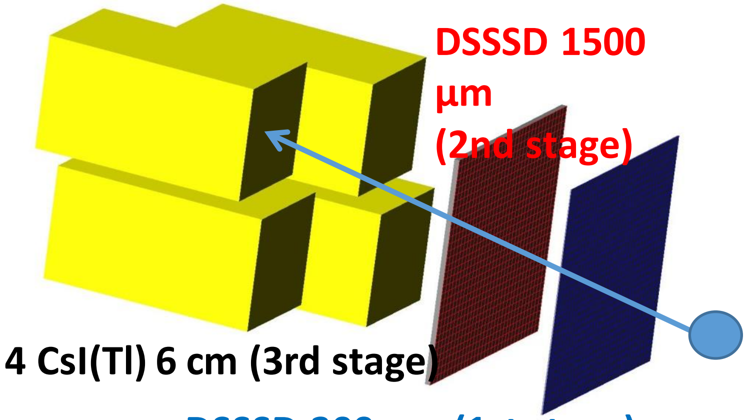
1M€ in 5 years

FARCOS

See Technical Design Report (TDR) https://drive.google.com/file/d/0B5CgGWz8LpOOc3pGTWdOcDBoWFE/view



132 channels by each cluster



DSSSD 1500 µm (2nd stage)

4 CsI(Tl) 6 cm (3rd stage)

DSSSD 300 µm (1st stage)

High angular and energy resolution

Double-Sided Silicon Strip Detectors produced by Micron Semiconductor.
(300 and 1500 µm / C= 25pF and 5pF)
Capton cable 2x32pin connectors
Minimum PCB
frame-area thick, 4 mm,
frame-thick 6.5 mm
ΔE= 20KeV (α 5.48 MeV) **ΔE/E (elastic)=0.2-0.3%**

Highly homogeneous CsI(Tl) crystals produced by SCIONIX.
Wrapped with 0.12 mm thick white reflector +50 µm aluminized mylar.
Aluminized mylar window 2 µm thick. Read by Photodiode Hamamatsu 300 µm
ΔE/E=2-3% (α 5.48 MeV)

The FARCOS prototype (4 telescopes, used in all experiments and test up to 2016)

Pre-Amplifier stage

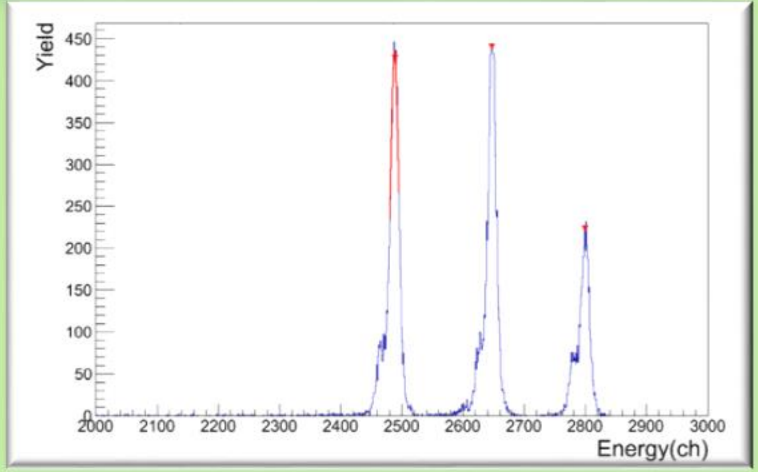
Mesytec MPR-64

300-1500 MeV full energy

NPA, C. Boiano, INFN-Milano)

32 channels, 10,20,45 mV/MeV

1500 µm DSSSD with Mesytec resolution ≈26 keV with 3 alpha source and standard DAQ



Front-end electronics in experiments for the FARCOS prototype:

Standard CHIMERA NIM (16 channels) pulse shape amplifiers + analog (VME) CHIMERA DAQ

or (few test channels) **Digital acquisition of PAC signals with GET electronics**

Why a new front-end electronic ?

The final FARCOS array constituted by 20 telescopes, in the final project needs the readout of about **4k** channels.

CHIMERA CsI(Tl) front-end (1192 detectors) is now obsolete, in particular the amplifiers and the **VME** QDCs for CsI fast-slow component integration (more than 15 years old technology).

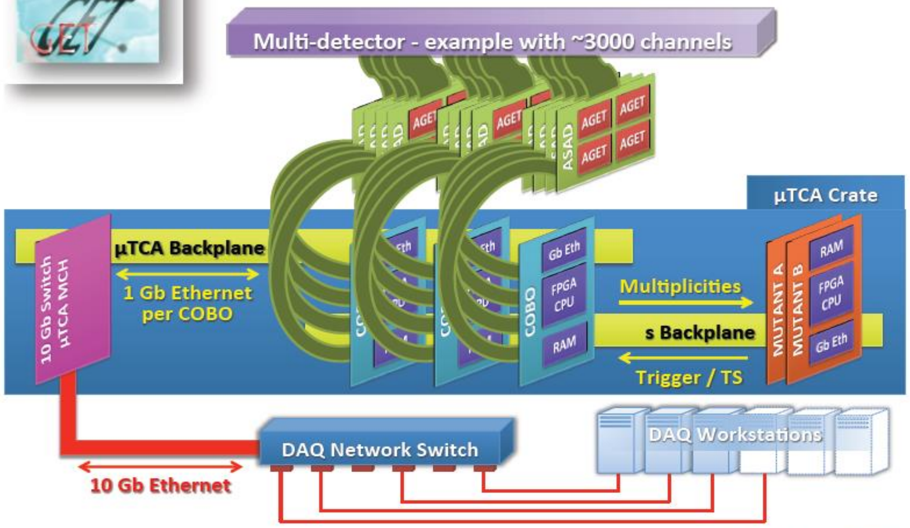
Our choice was to develop a first stage front-end circuit for FARCOS (including new ASIC pre-amplifiers) and new dual-gain modules coupled to a compact hardware architecture covering digitalization and signal readout, syncronization and trigger functions. All these last aspects are covered by the GET project.

Consequences → digital DAQ for FARCOS and CHIMERA (CsI) + Analog DAQ (Silicons)

GET

- Especially designed for TPC (gas detectors) to be used with radioactive beams
- Integrated and low power consuming
- Configurable
- Digitalization of signals

Hardware Architecture



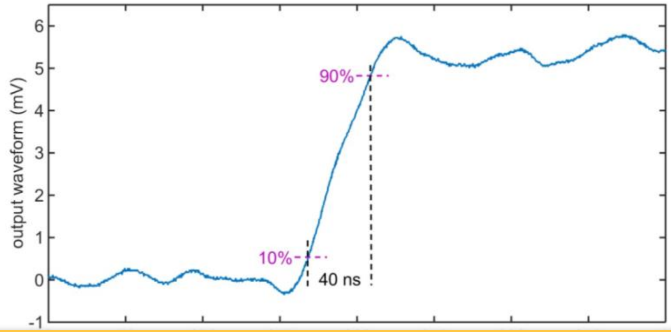
Shebli Anvar IRFU

PREV

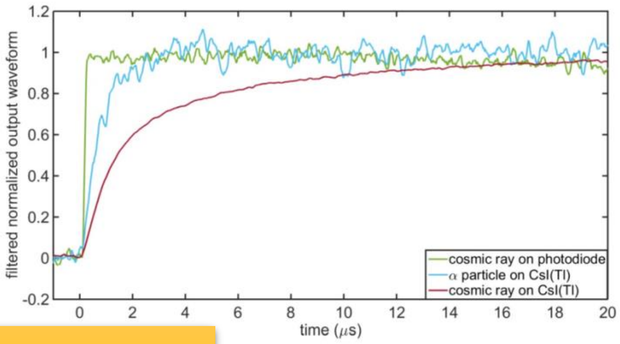
Selectable-Gain CMOS Charge Preamplifier for Pulse Shape Analysis FARCOS telescopes

❑ CsI(Tl) + PD (dynamic range 90 MeV Si-equivalent)

pulse rise time



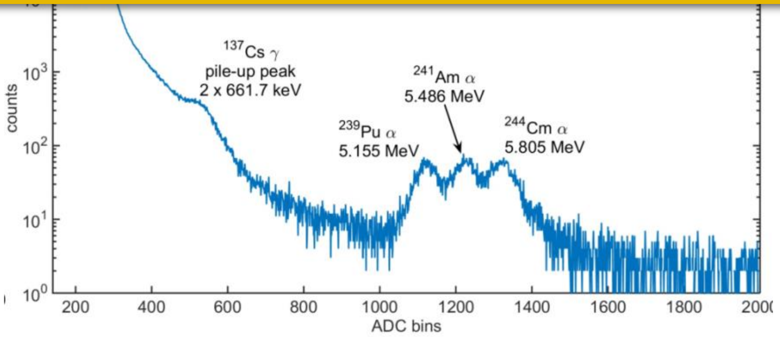
output waveforms



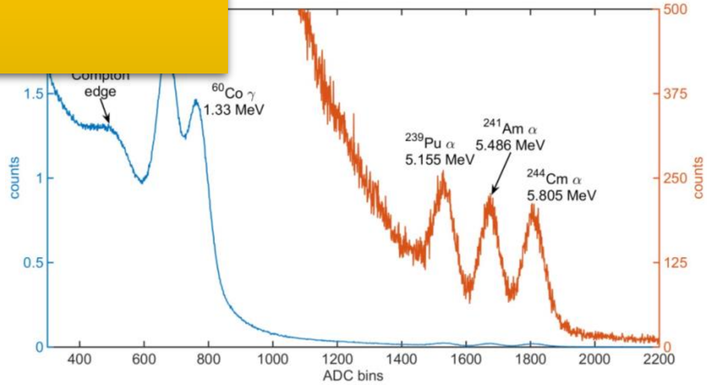
Beam tests at LNS (Tandem, p@20MeV, ^{16}O@100MeV) scheduled for February 7-16, 2017

waveforms (filtered with a moving a 700 point span) in the case of the particle and of a cosmic ray in the nd of a cosmic ray in the photodiode.

nd mixed nuclei α source



Energy spectrum of the ^{137}Cs γ source and of the mixed nuclei α source measured with the VLSI charge preamplifier coupled with scintillator B.



Energy spectrum of the ^{60}Co γ source and of the mixed nuclei α source measured with the VLSI charge preamplifier coupled with scintillator A. The right axis (orange curve) shows the zoom of the same data.

by C. Guazzoni & collaborators