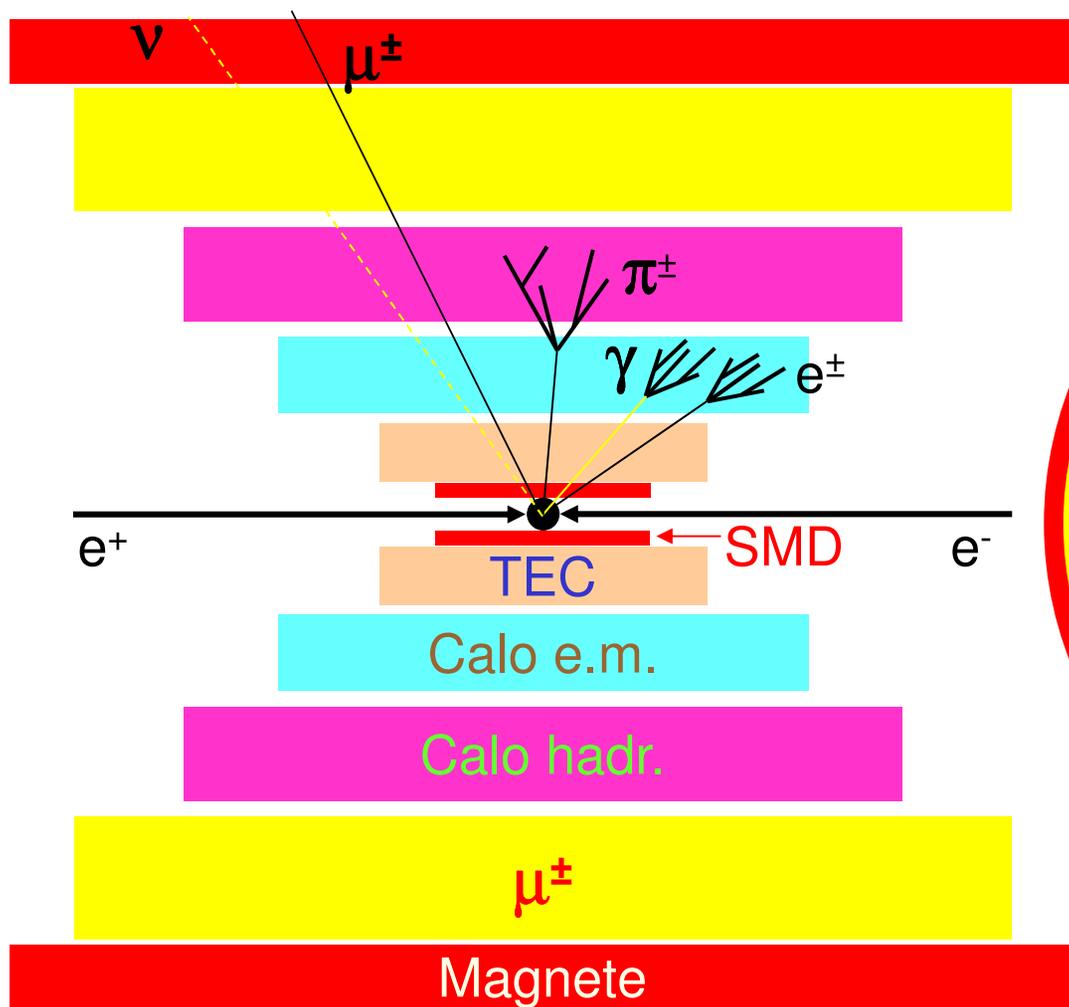
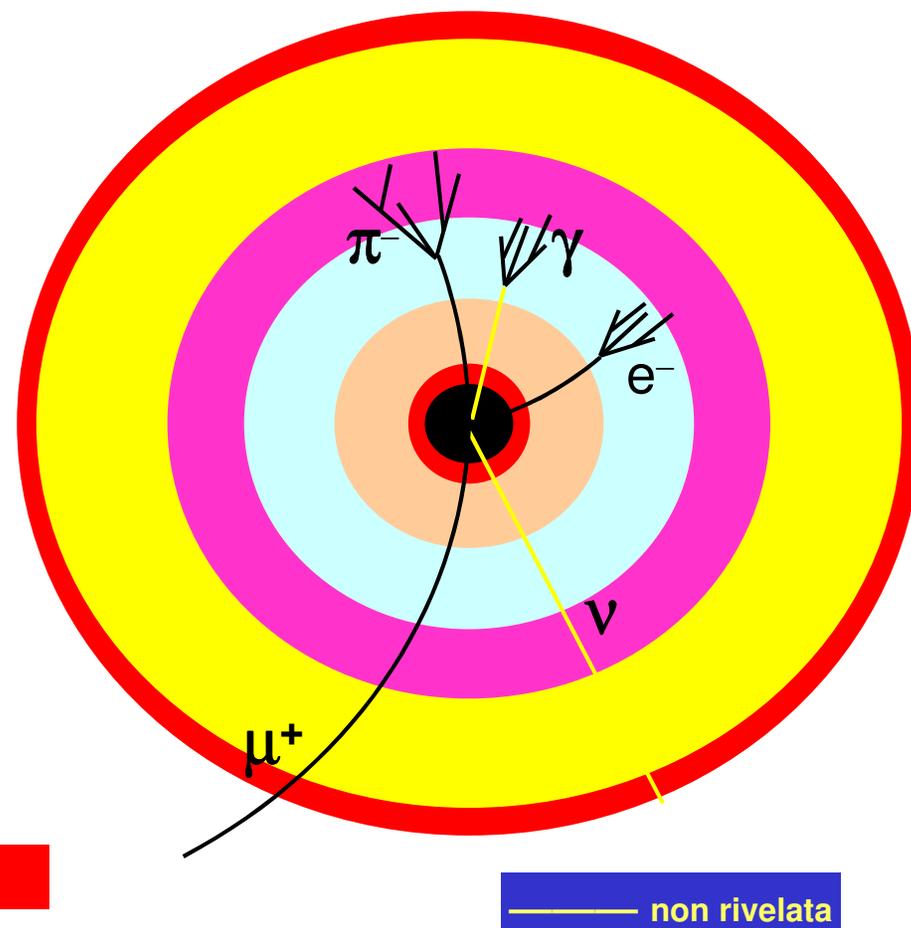


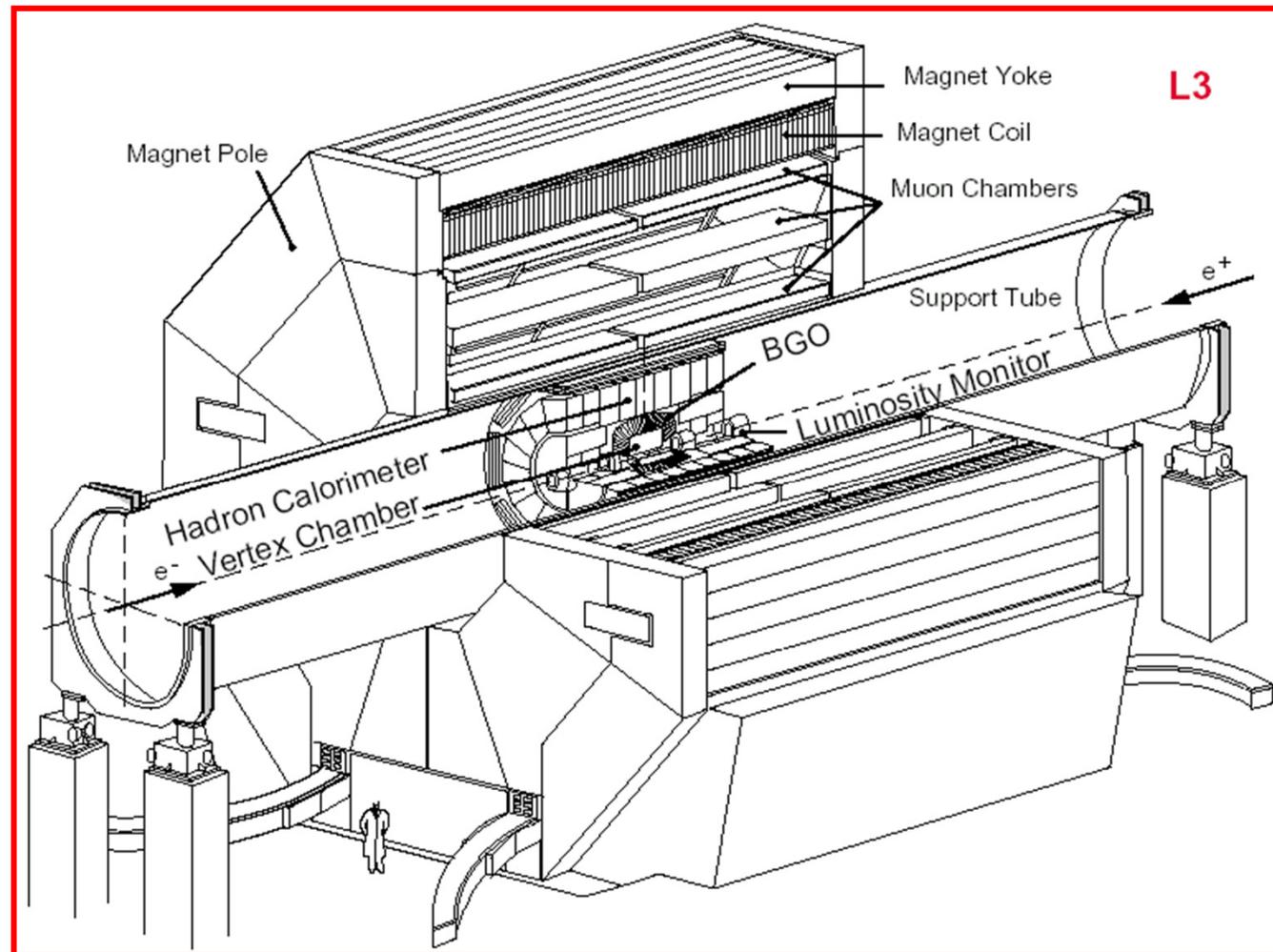
Funzionamento di un rivelatore a LEP



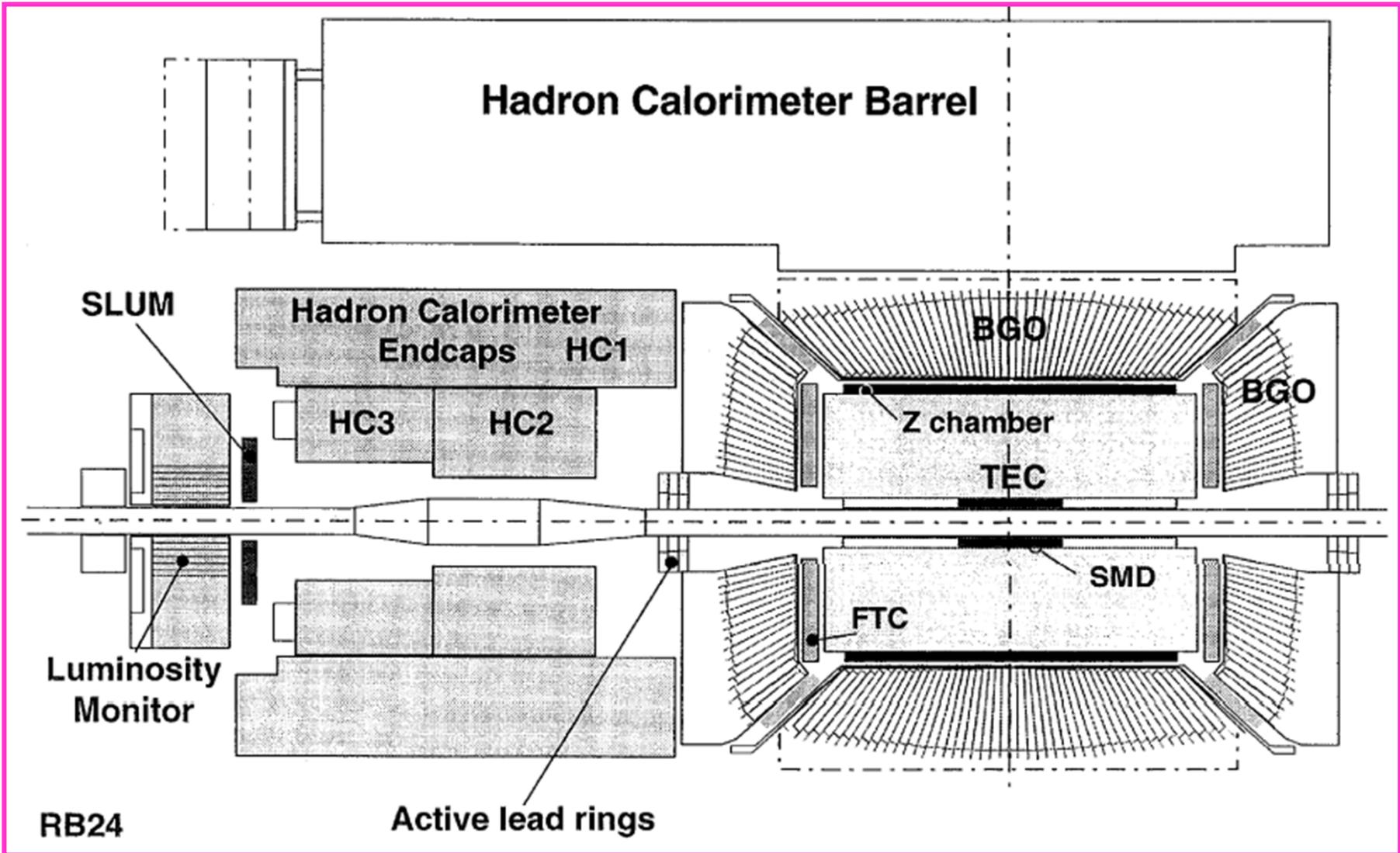
non in scala



L3 - 1

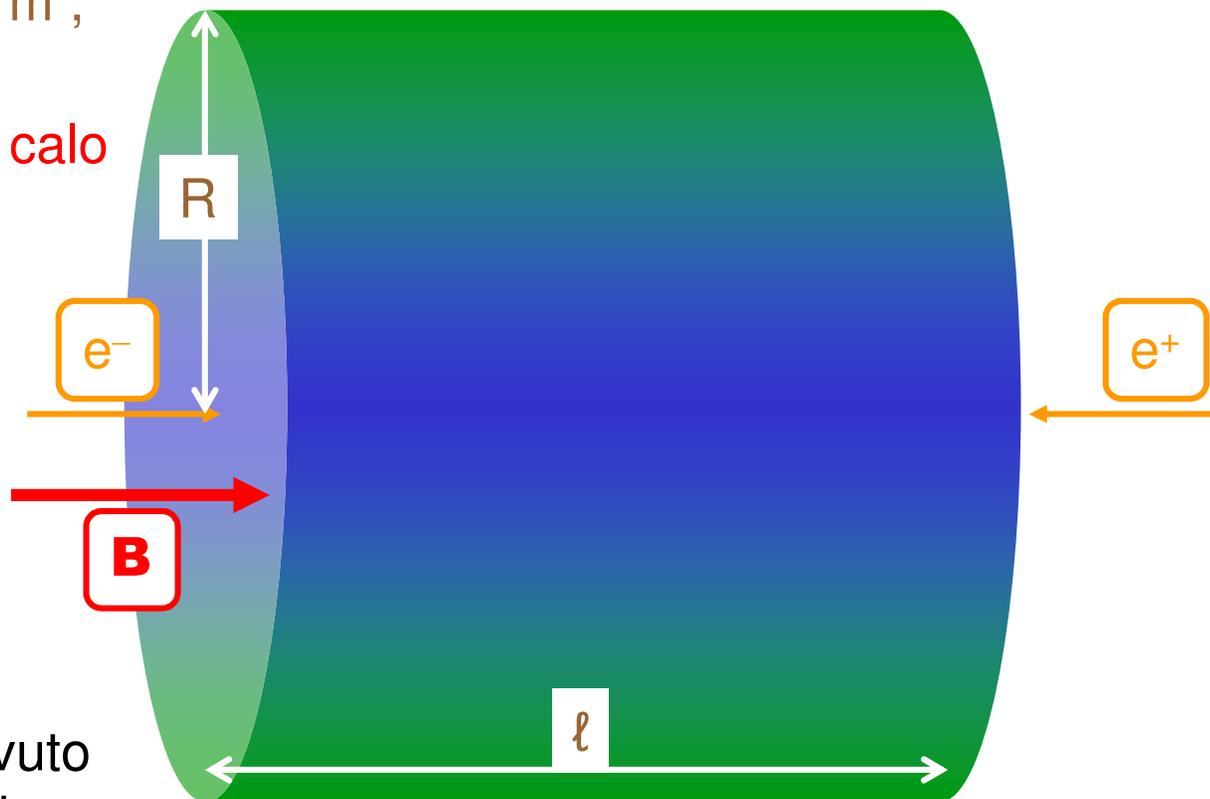


L3 - 2



Magnete

- $B \approx 0.5 \text{ T}$
- bobina $R = 5.93 \text{ m}$, $\ell = 11.90 \text{ m}$;
- la bobina è esterna a tutto il rivelatore (ADO differenti, tra calo e.m. e calo had);



- motivo [v. LHC] :

$$\Delta p/p|_{\text{misura}} \propto p_T / (B \ell^2)$$

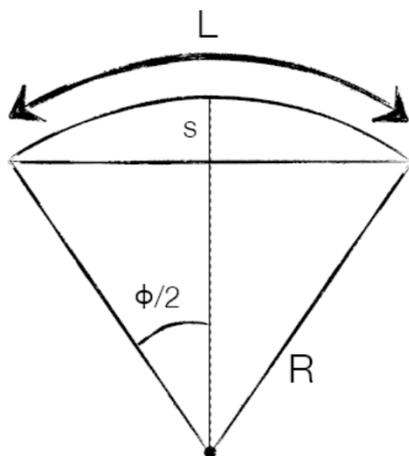
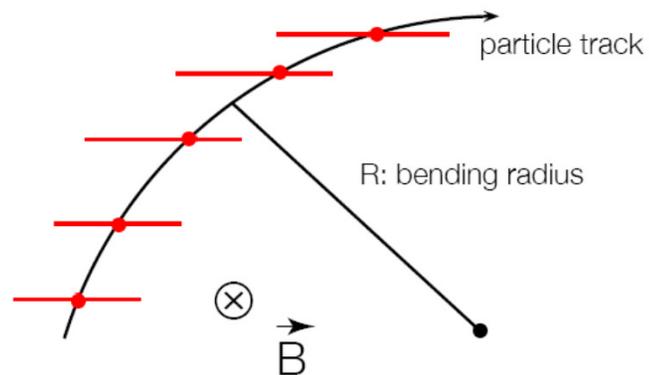
... però c'è anche l'errore dovuto all'attraversamento di strati di materiale (calorimetri) ...

Risoluzione in impulso - 1

Momentum determination
in a cylindrical drift chamber ...

$$\frac{mv^2}{R} = evB \quad \rightarrow \quad p = eB \cdot R$$

$$p \left[\frac{\text{GeV}}{c} \right] = 0.3B [\text{m}] \cdot R [\text{T}]$$



For Sagitta s:

$$s = R - R \cos \frac{\phi}{2} \approx R \frac{\phi^2}{8} \quad \text{with } \phi = \frac{L}{R}$$

$$s = R \frac{L^2}{8R^2} = \frac{L^2}{8R} \quad \text{and} \quad R = \frac{L^2}{8s}$$

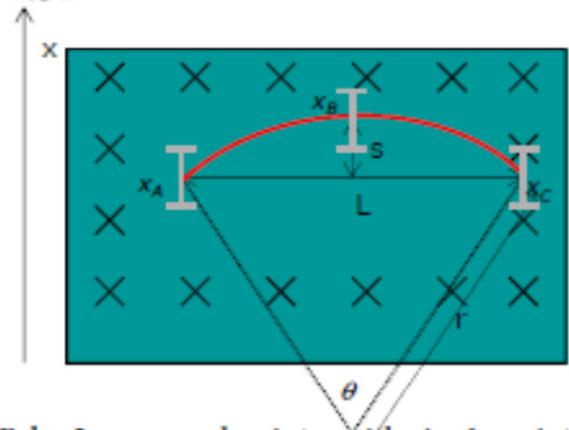
$$\rightarrow \frac{\Delta p}{p} = \frac{\Delta R}{R} = \frac{L^2}{8Rs} \cdot \frac{\Delta s}{s}$$

Risoluzione in impulso - 2

$$\frac{\sigma_p}{p} = \frac{L^2}{8Rs} \cdot \frac{\sigma_s}{s} = \frac{L^2}{8R} \cdot \frac{\sigma_s}{L^4/64R^2} = \frac{\sigma_s}{L^2} \cdot 8R = \frac{\sigma_s}{L^2} \cdot \frac{8p}{eB} \sim p \cdot \frac{\sigma_s}{BL^2} \quad \sigma_s = \frac{\sigma_r \phi}{8} \sqrt{\frac{720}{N+5}}$$

Motion of a charged particle in a uniform magnetic field: Cylindrical helix coaxial to B

$$r = \frac{p_{\perp}}{0.3B} \quad r: m, p_{\perp}: GeV, B: T$$



Get p from s

$$\sin \frac{\theta}{2} = \frac{L}{2r} \stackrel{L \ll 2r}{\approx} \frac{L}{2r} \rightarrow \theta \approx \frac{0.3BL}{p_{\perp}}$$

$$s = r - r \cos \frac{\theta}{2} \approx r \left[1 - \left(1 - \frac{\theta^2}{4} \right) \right] = r \frac{\theta^2}{8} \approx \frac{0.3BL^2}{8p_{\perp}}$$

$$\rightarrow p_{\perp} \approx \frac{0.3BL^2}{8s}$$

Take 3 measured points, with single point accuracy σ

Then:

$$s = x_B - \frac{x_A + x_C}{2} \rightarrow \sigma_s^2 = \sigma^2 + \frac{1}{2}\sigma^2 = \frac{3}{2}\sigma^2$$

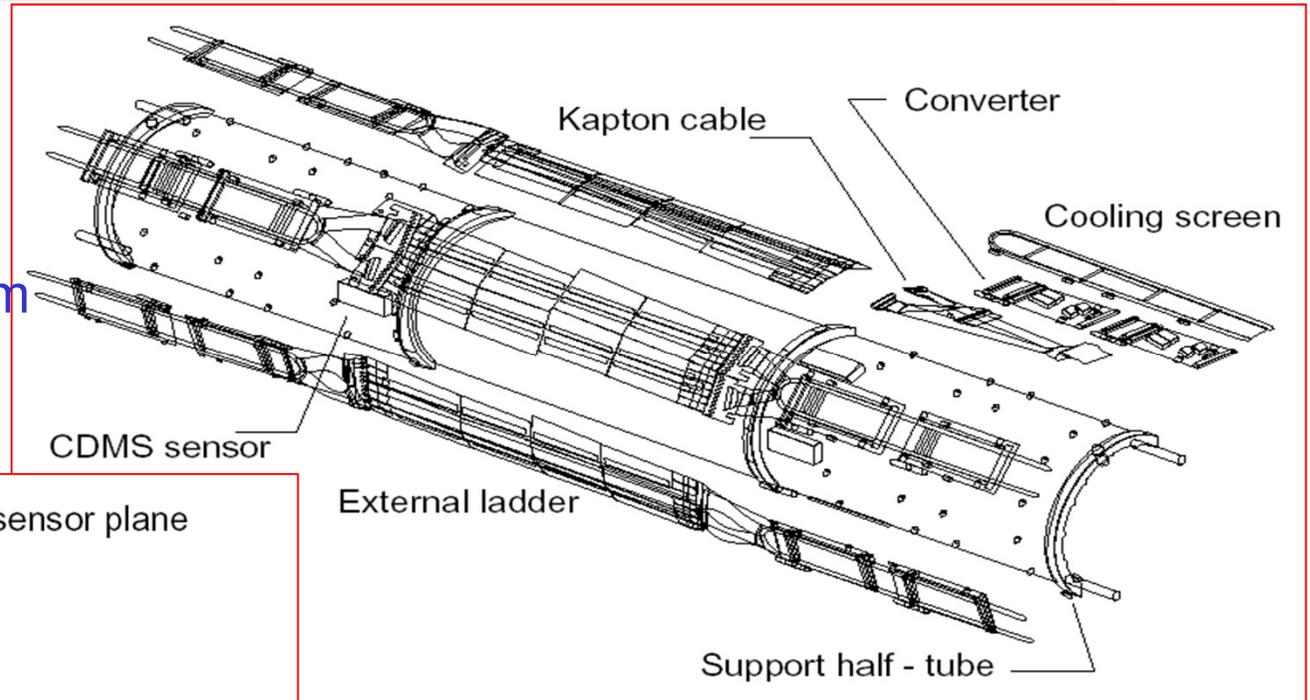
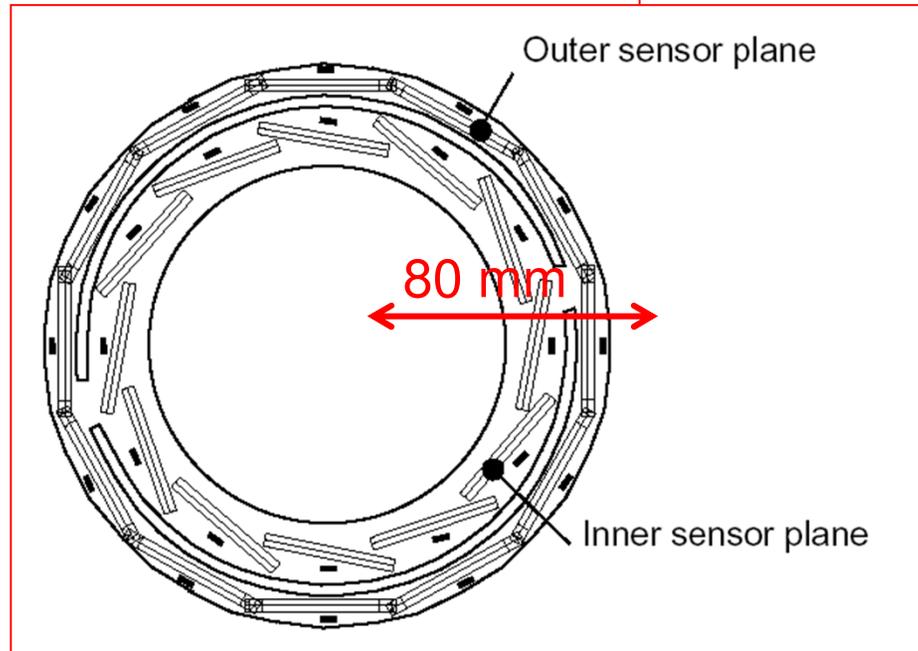
$$\frac{\sigma_{p_{\perp}}}{p_{\perp}} = \frac{\sigma_s}{s} = \sqrt{\frac{3}{2}} \frac{\sigma}{s} = \sqrt{\frac{3}{2}} \frac{\sigma}{0.3BL^2} = \sqrt{\frac{300 \cdot 64}{18}} \frac{\sigma p_{\perp}}{BL^2} \approx 32.7 \frac{\sigma p_{\perp}}{BL^2}$$

$N \geq 10$, uniformly spaced points:

$$\frac{\sigma_{p_{\perp}}}{p_{\perp}} \approx 28.3 \frac{\sigma p_{\perp}}{BL^2 \sqrt{N+4}}$$

SMD : silicon μ -vertex detector - 1

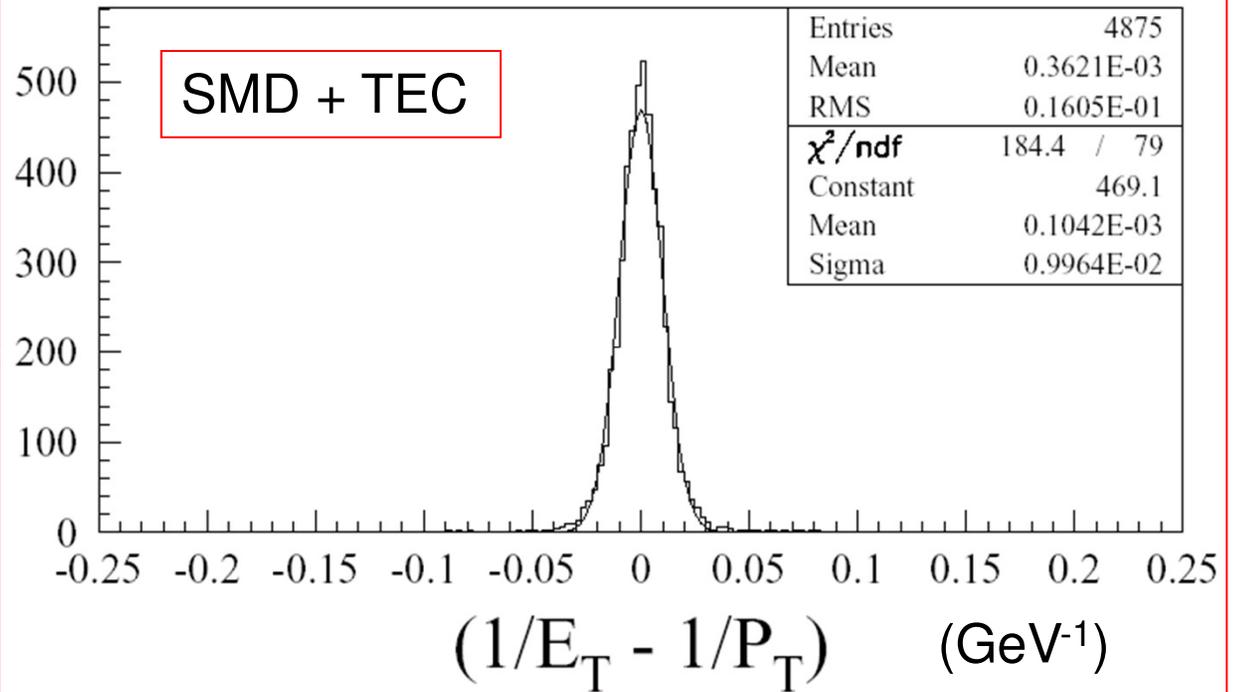
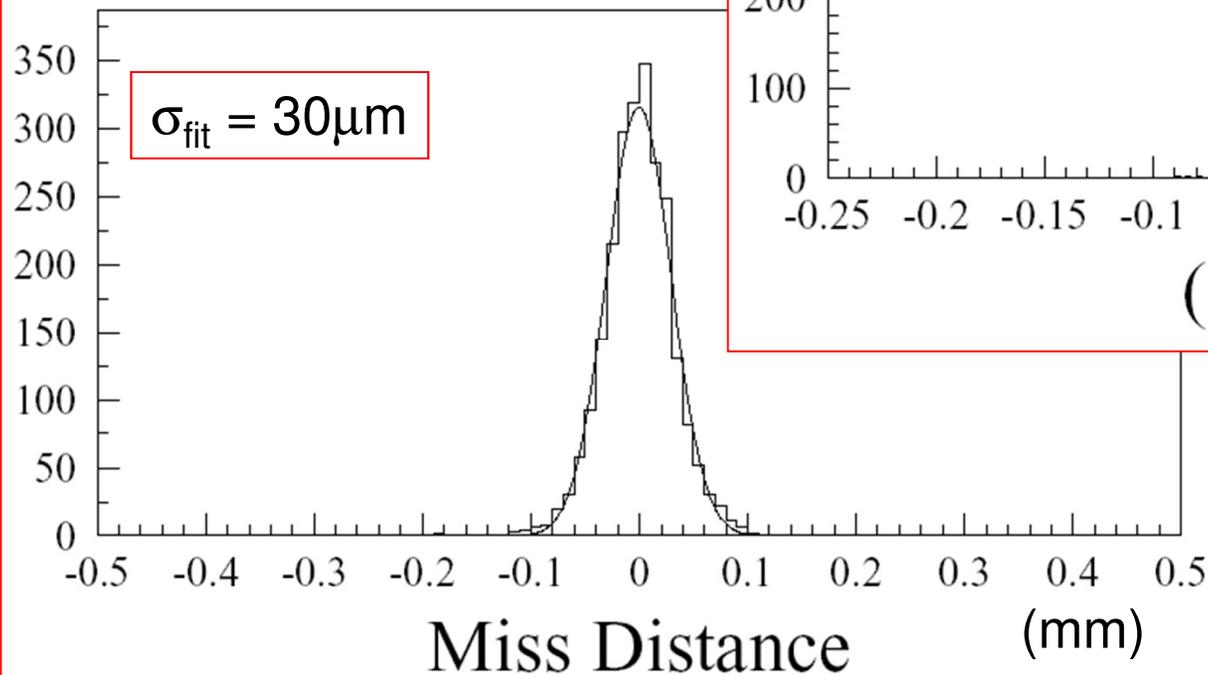
96 tavolette di silicio
70 mm \times 40 mm \times 300 μ m



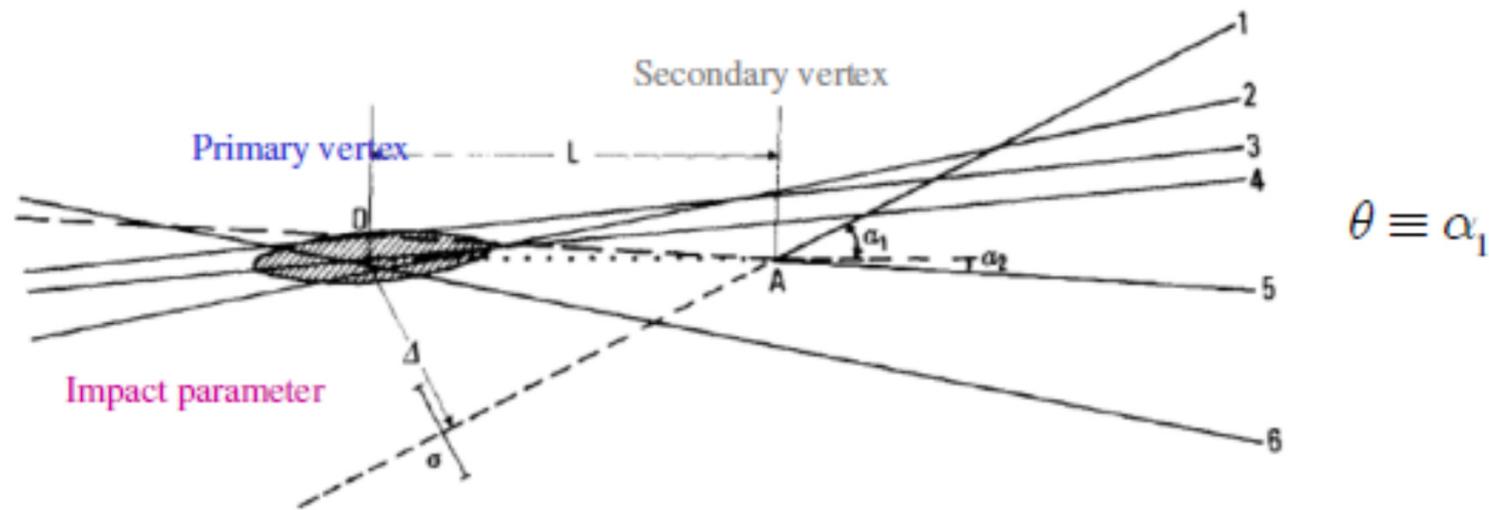
2 letture :

- 50 μ m in $r\phi$;
- 150÷200 μ m in z

SMD : silicon μ -vertex detector - 2



Misura vita media $b, c, \tau - 1$



Plane defined by primary vertex, track direction

Consider a particle produced at primary vertex with speed β

When it decays to another particle, call speed β^* , decay angle in CM θ^*

$$\tan \theta = \frac{\sin \theta^*}{\gamma \cos \theta^* + \beta / \beta^*} \quad \text{Lorentz transformation to LAB}$$

Misura vita media $b, c, \tau - 2$

$L = \beta\gamma\tau$ Decay length

Define impact parameter Δ in terms of decay length, L , and angle θ :

$$\Delta = L \sin \theta = L \frac{\tan \theta}{\sqrt{1 + \tan^2 \theta}} = L \frac{\frac{\sin \theta^*}{\gamma(\cos \theta^* + \beta/\beta^*)}}{\sqrt{1 + \left(\frac{\sin \theta^*}{\gamma(\cos \theta^* + \beta/\beta^*)}\right)^2}} = L \frac{\sin \theta^*}{\sqrt{(\gamma(\cos \theta^* + \beta/\beta^*))^2 + \sin^2 \theta^*}}$$

$$\rightarrow \Delta = L \frac{1}{\gamma} \frac{\sin \theta^*}{\sqrt{(\cos \theta^* + \beta/\beta^*)^2 + \frac{1}{\gamma^2} \sin^2 \theta^*}} = \beta\tau \frac{\sin \theta^*}{\sqrt{(\cos \theta^* + \beta/\beta^*)^2 + \frac{1}{\gamma^2} \sin^2 \theta^*}}$$

$$\Delta \xrightarrow{\beta, \beta^* \rightarrow 1} \beta\tau \frac{\sin \theta^*}{1 + \cos \theta^*} = \beta\tau \tan \frac{\theta^*}{2}$$

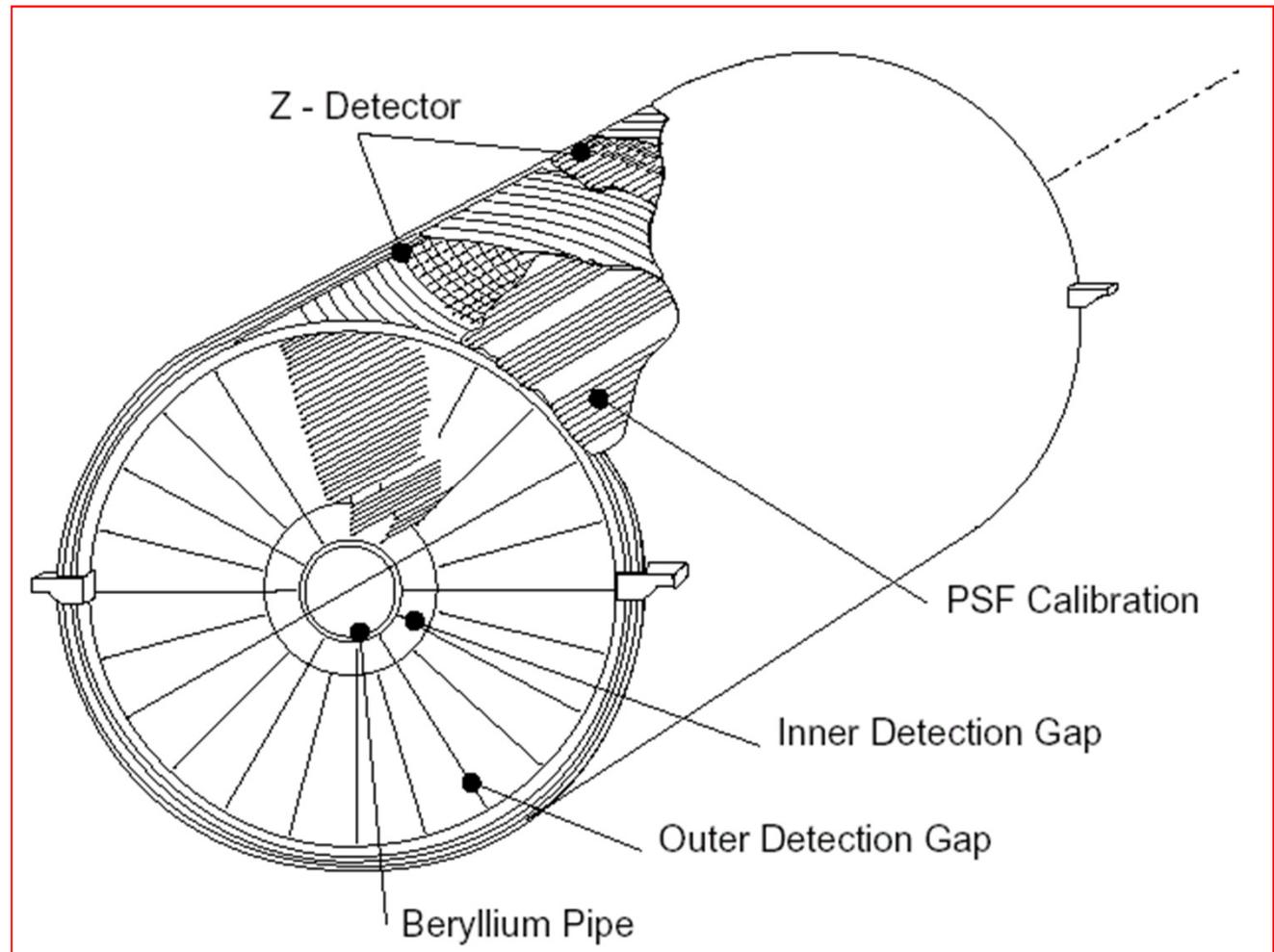
$y \equiv \frac{\Delta}{\tau} \rightarrow$ Find statistical distribution of y for isotropic θ^* , exponential τ

$\rightarrow \langle y \rangle = \frac{\pi}{2} \rightarrow \langle \Delta \rangle = \frac{\langle \tau \rangle \pi}{2}$ Get a measurement of the decay lifetime

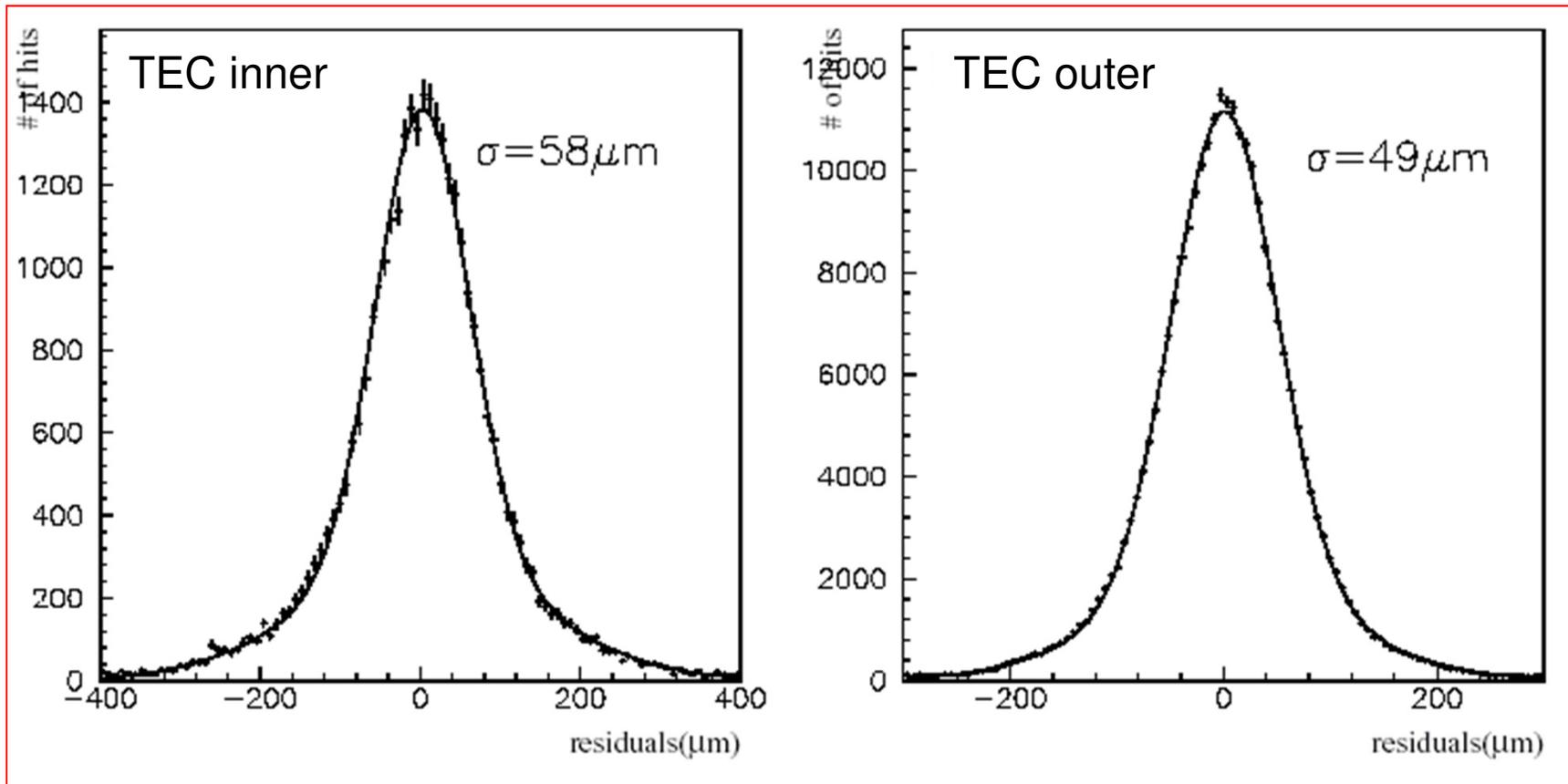
In the limit of relativistic speeds, only from impact parameter !
Full decay reconstruction not required

TEC – Time Expansion Chamber - 1

- raggio esterno 317 mm;
- due strati (inner 8 fili + outer 54 fili);
- 80% CO₂, 20% iC₄H₁₀ a 1.2 bar (abs);
- $v_{\text{drift}} = 6\mu\text{m} / \text{ns}$ (“TEC”);
- $\alpha_{\text{Lorentz}} = 2.3^\circ$;
- z-detector ($\sigma = 320\mu\text{m}$);

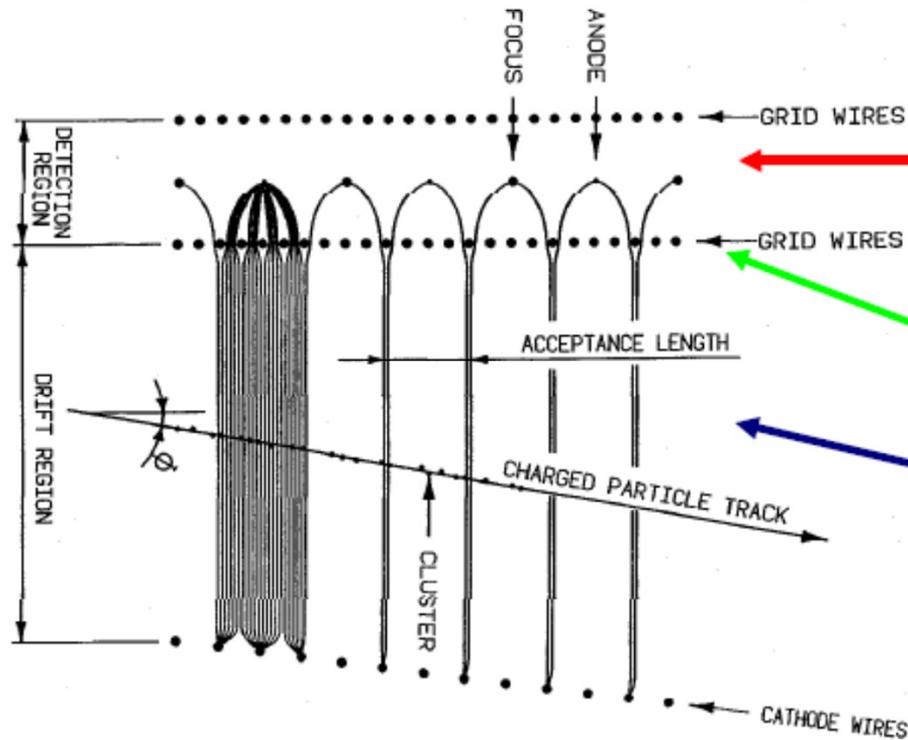


TEC – Time Expansion Chamber - 2



- insieme a SMD per la misura dei vertici secondari;
- usata anche nel trigger di 1 livello;
- richiede una continua calibrazione della velocità di drift;

Risoluzione spaziale



Sense/Focus wires

Amplification gap

Drift region: Low E field

→ Reduced drift speed $\approx 5 \mu\text{m/ns}$

→ Detect single ionization clusters

→ Drift time: $\sigma \approx 10 \text{ ns}$

→ Distance: $\sigma \approx 50 \mu\text{m}$

Sciami elettromagnetici - 1

- Alte energie: e/γ perdita di energia per bremsstrahlung-pair production
- Sviluppo di cascata elettromagnetica:

Moltiplicazione esponenziale

X_0 lunghezza di radiazione, X_γ lunghezza di conversione

$$dE/dx = E/X_0$$

$$X_0 = \frac{(716.4 \text{ g} \cdot \text{cm}^{-2}) A}{Z(Z+1) \ln\left(\frac{287}{\sqrt{Z}}\right)}$$

$$X_\gamma = \frac{9}{7} X_0$$

En. Critica: Ionizzazione = Radiazione

$$E_c = 610/(Z+1.24) \text{ MeV.}$$

$$E_c = 710/(Z+0.92) \text{ MeV}$$

Sciame elettromagnetici - 2

- Sviluppo longitudinale:

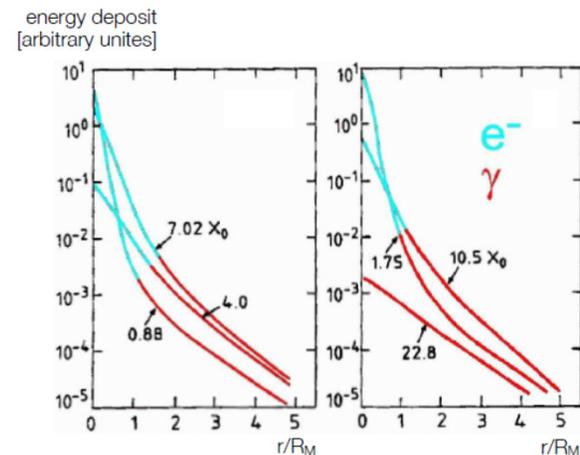
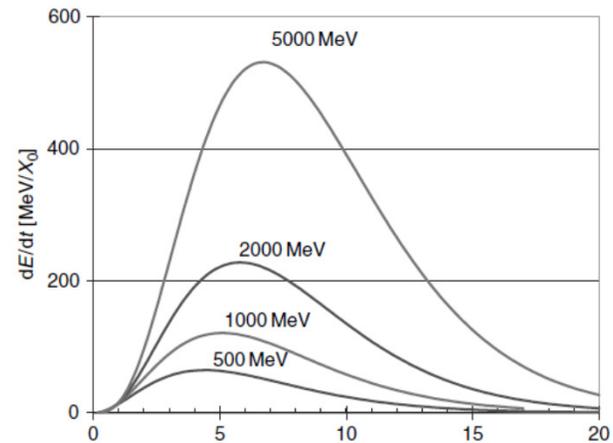
$$\frac{dE}{dt} \propto t^\alpha e^{-t}$$

$$t_{\max} = \ln \frac{E_0}{E_c} \frac{1}{\ln 2}$$

$$t_{95\%} \approx t_{\max} + 0.08Z + 9.6$$

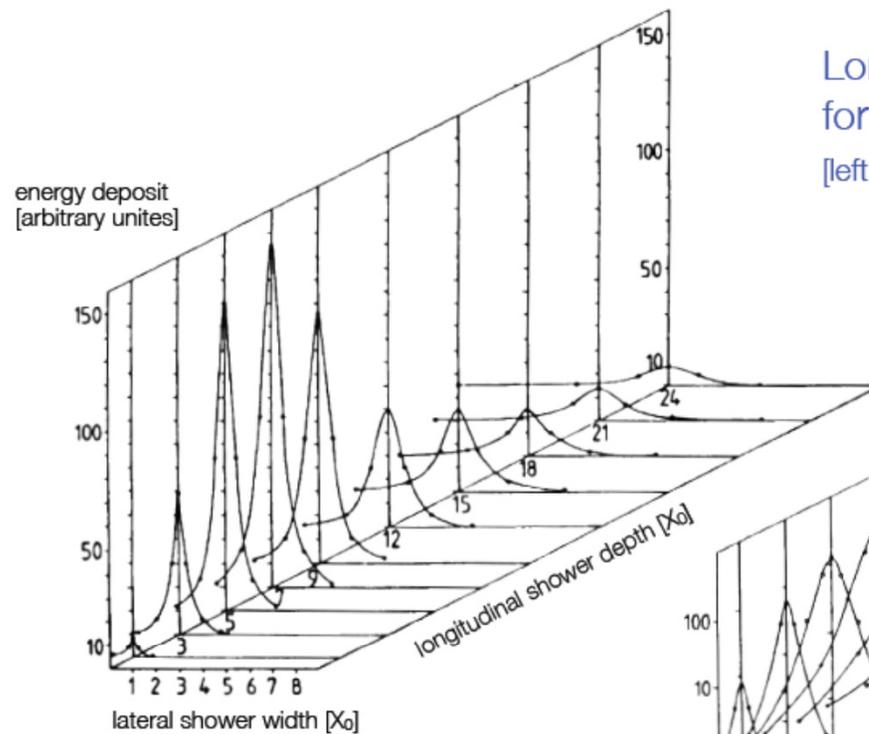
- Sviluppo trasversale

$$R_M = \frac{21 \text{ MeV}}{E_c} X_0 \left[\text{gr} / \text{cm}^2 \right]$$

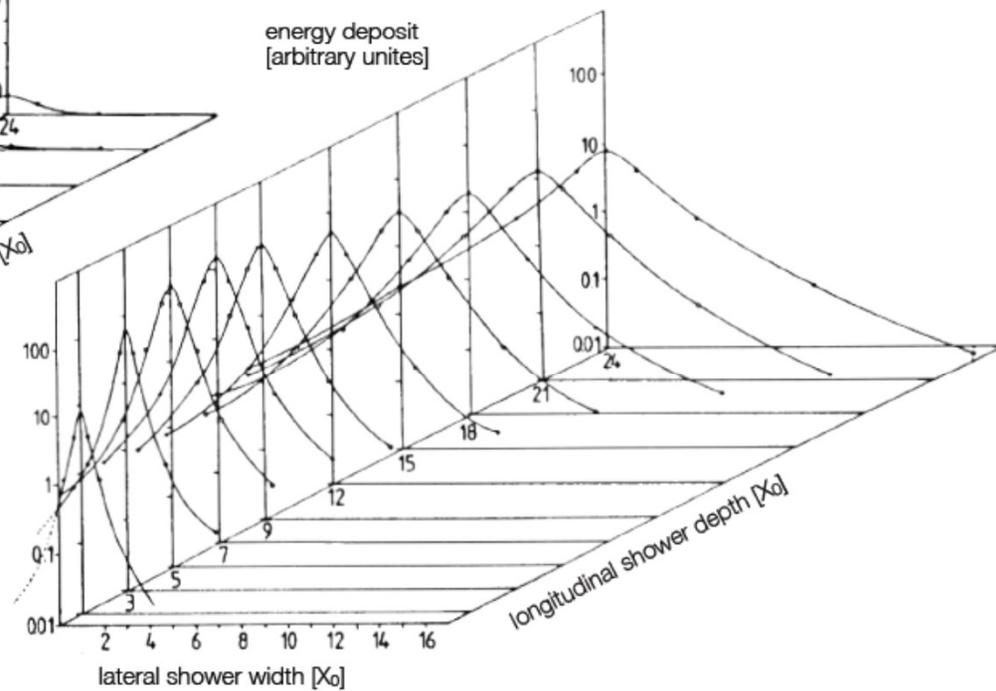


Raggio di Moliere . 2 R_M contengono il 95% dello sciame

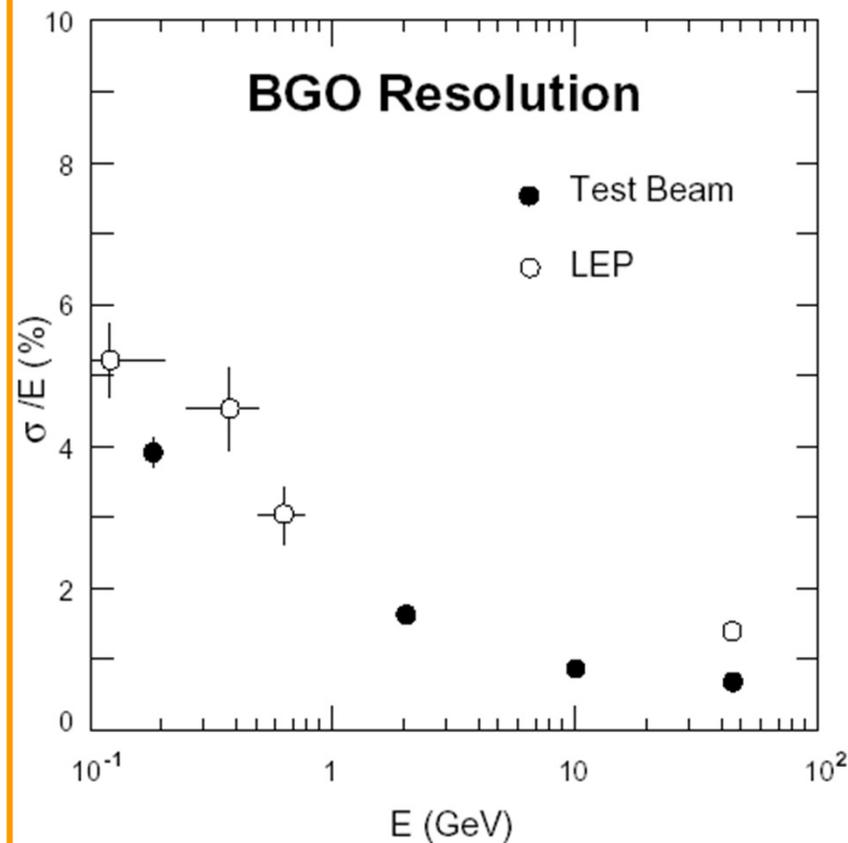
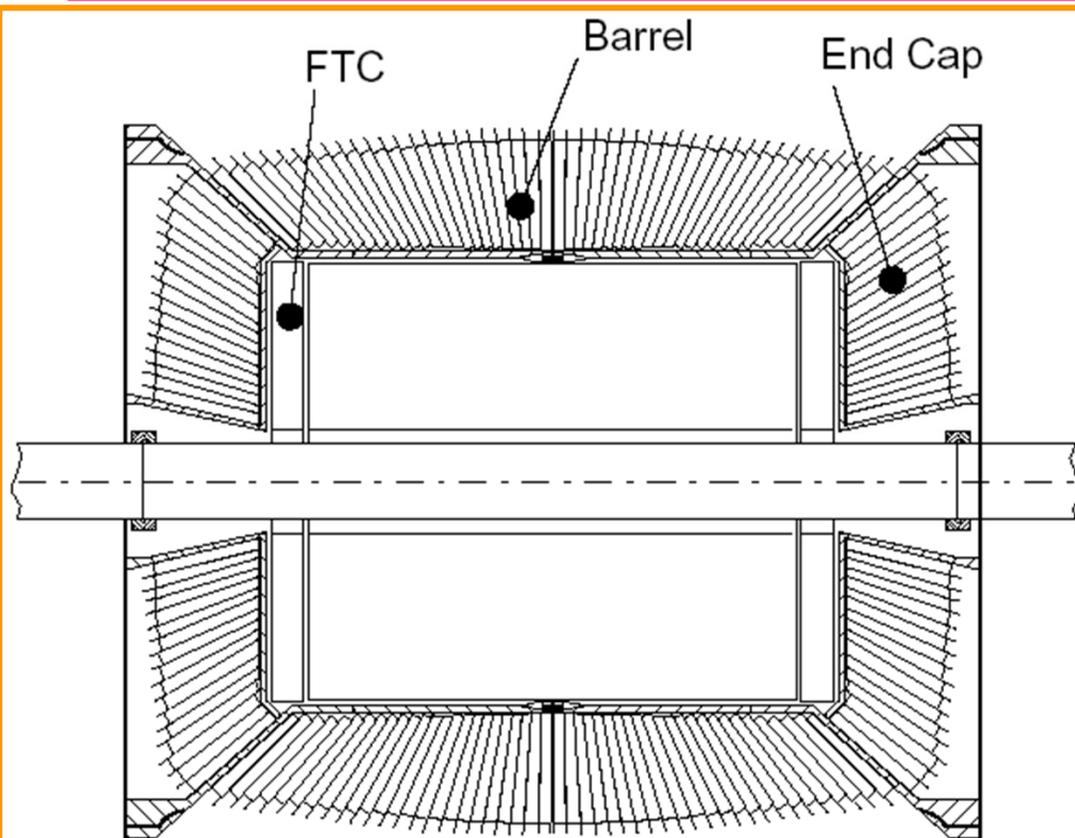
Sciami elettromagnetici - 3



Longitudinal and transversal shower profile
for a 6 GeV electron in lead absorber ...
[left: linear scale; right: logarithmic scale]

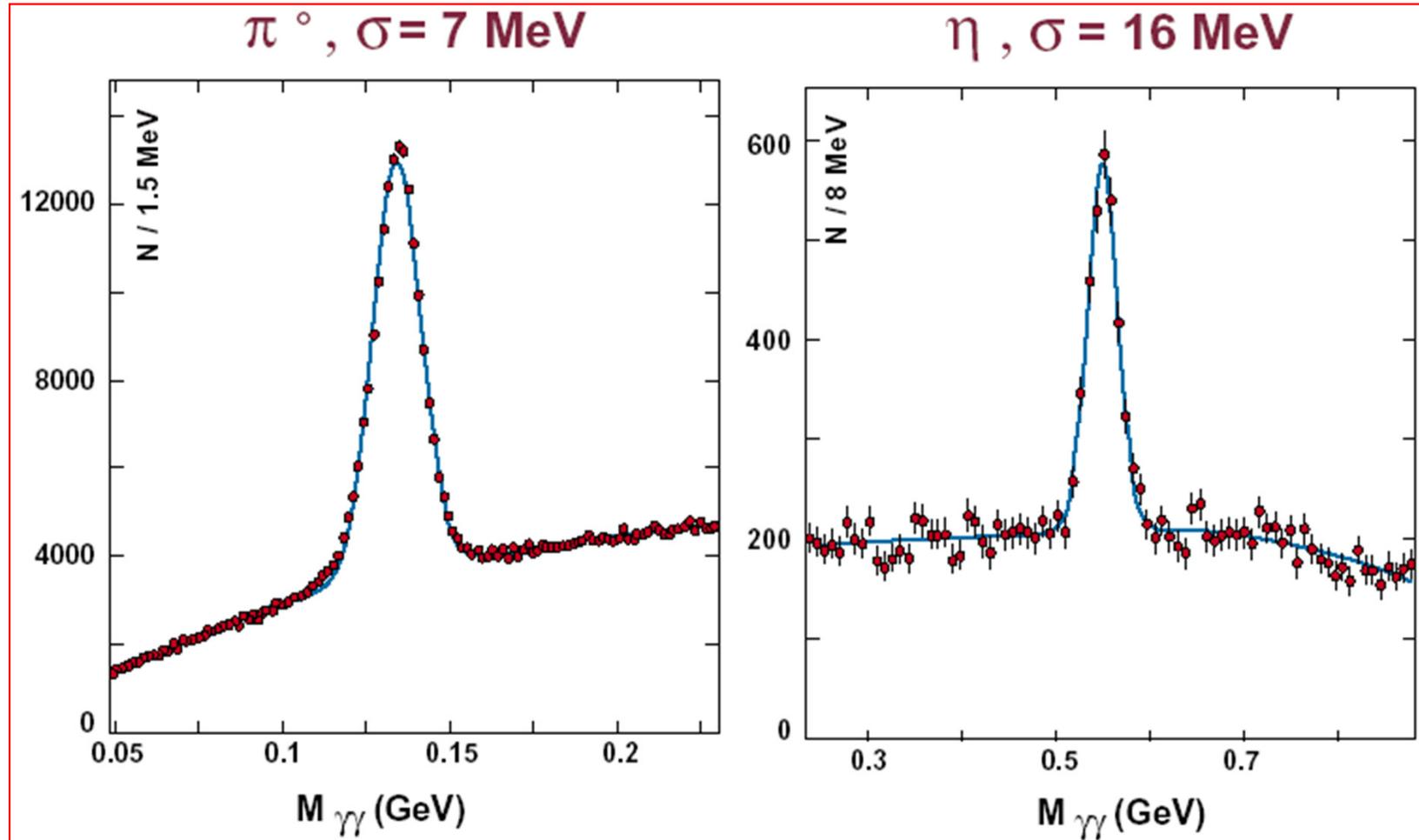


calo e.m. (BGO) - 1



- 11,000 cristalli di BGO (orto-germanato di bismuto) scintillante;
- piramidi $20 \times 20 \rightarrow 30 \times 30$ mm², lunghe 240 mm;
- $X_0 = 11.3$ mm $\rightarrow 21 X_0$;

calo e.m. (BGO) - 2



Sciame adronici - 1

Molti tipi di interazione → Sciame molto più lungo e largo

- Sviluppo longitudinale:

$$t_{\max}(\lambda_T) \approx 0.2 \ln E[\text{GeV}] + 0.7$$
$$t_{95\%}(\text{cm}) \approx a \ln E + b$$

- Sviluppo trasversale

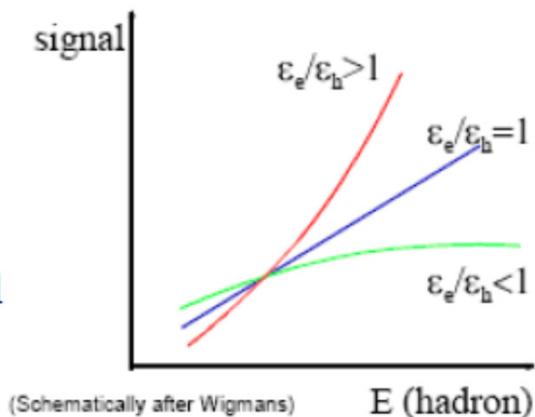
1 λ_T contiene il 95% dello sciame

Sciami adronici - 2

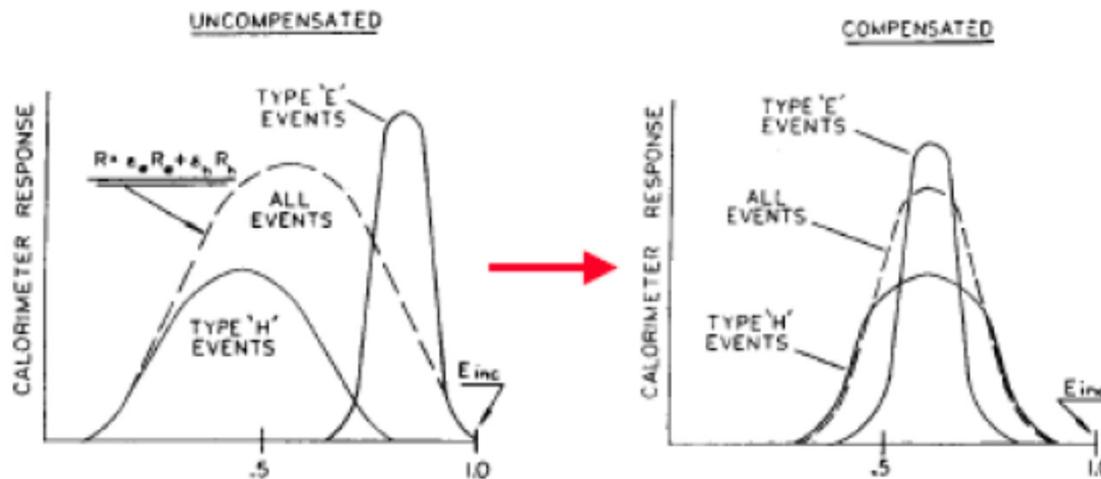
Perdita di linearita' e risoluzione

$$R_h = \varepsilon_h E_h + \varepsilon_e E_e$$

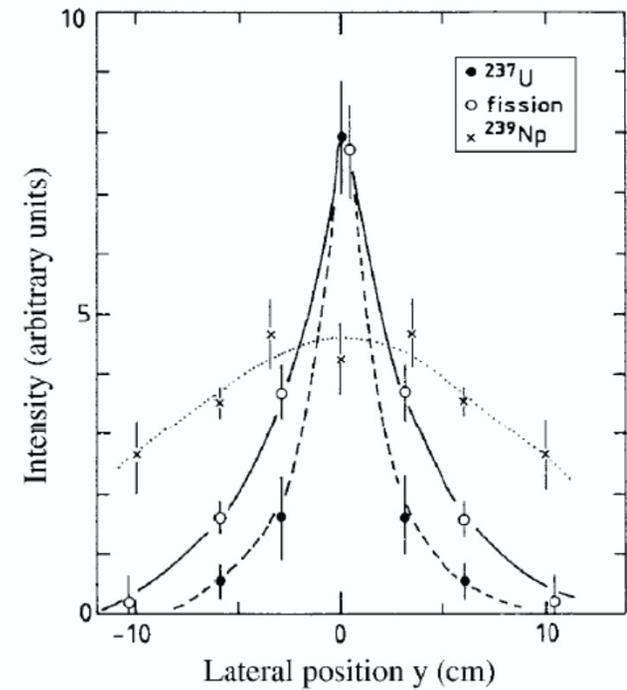
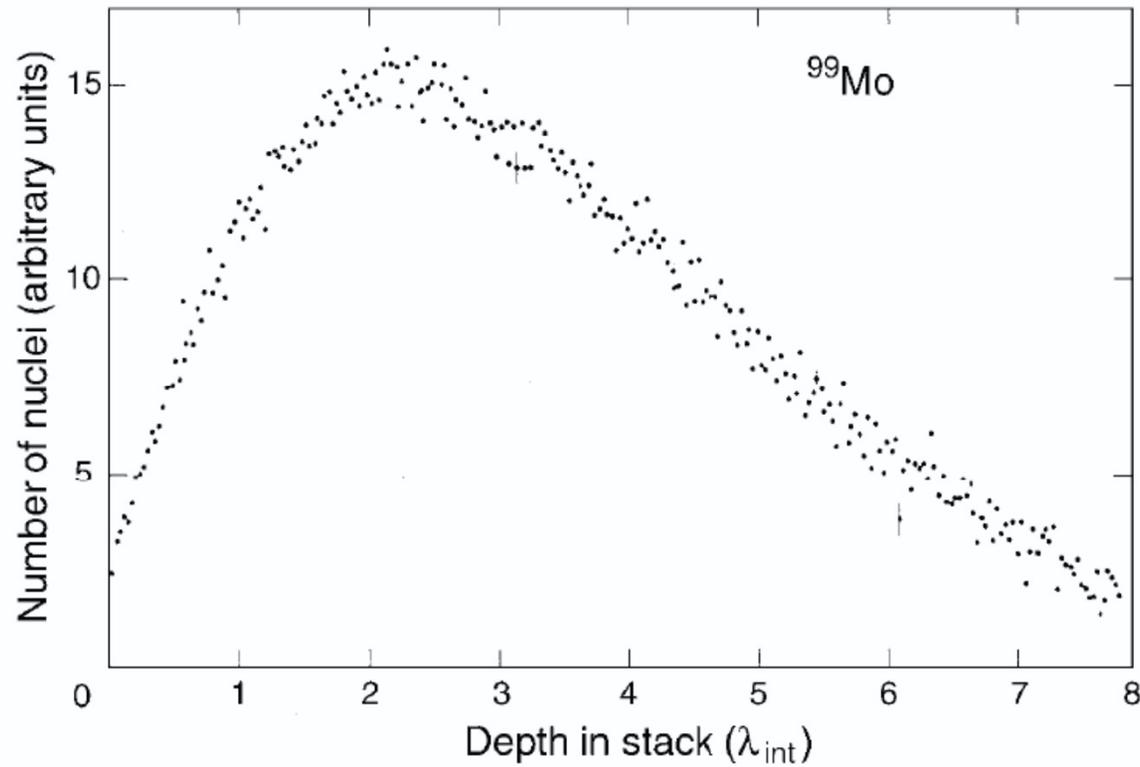
$$\frac{E_h}{E} = 1 - f_{\pi^0} = 1 - k \ln E \quad (GeV) \quad k \approx 0.1$$



Compensazione

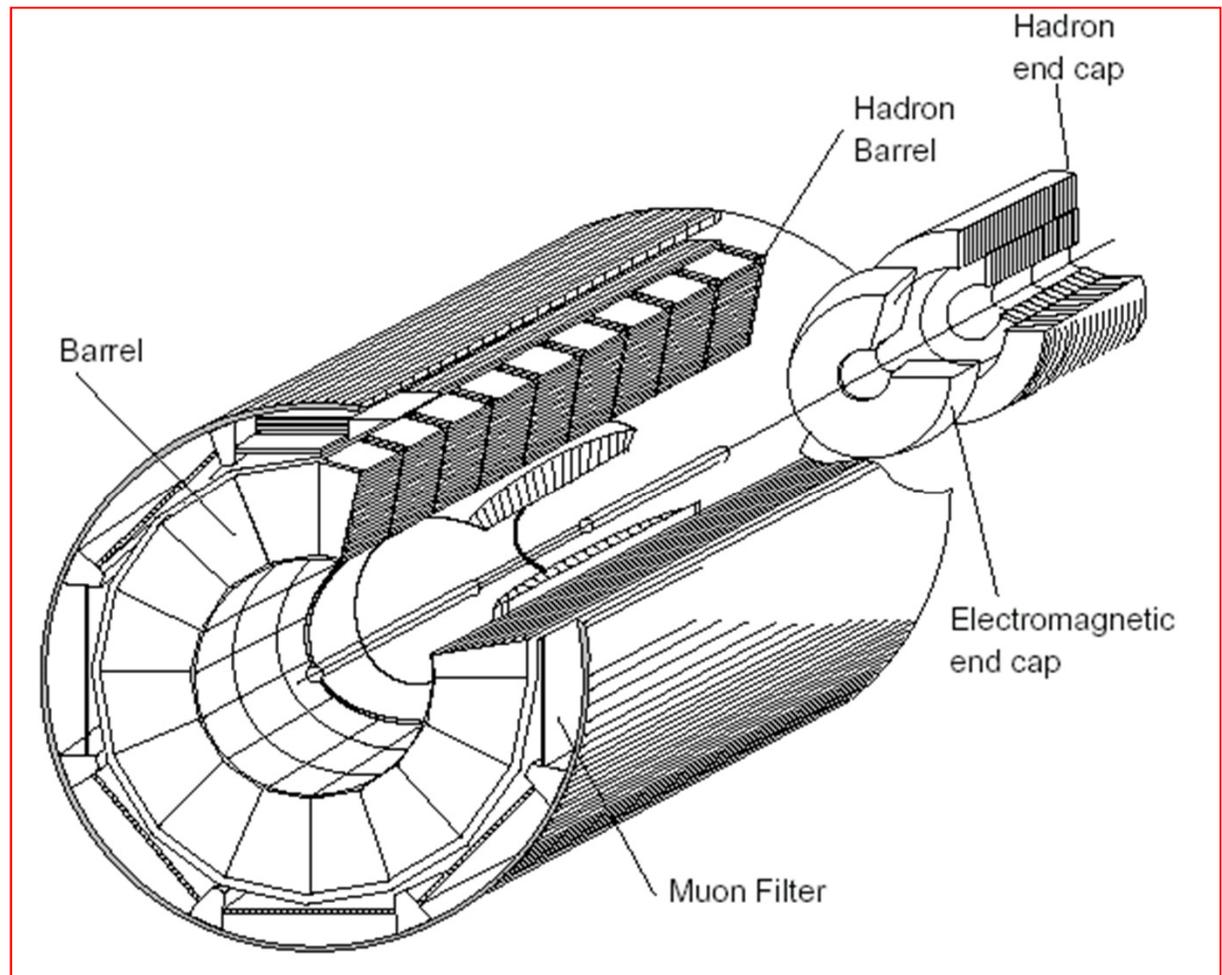


Sciami adronici - 3



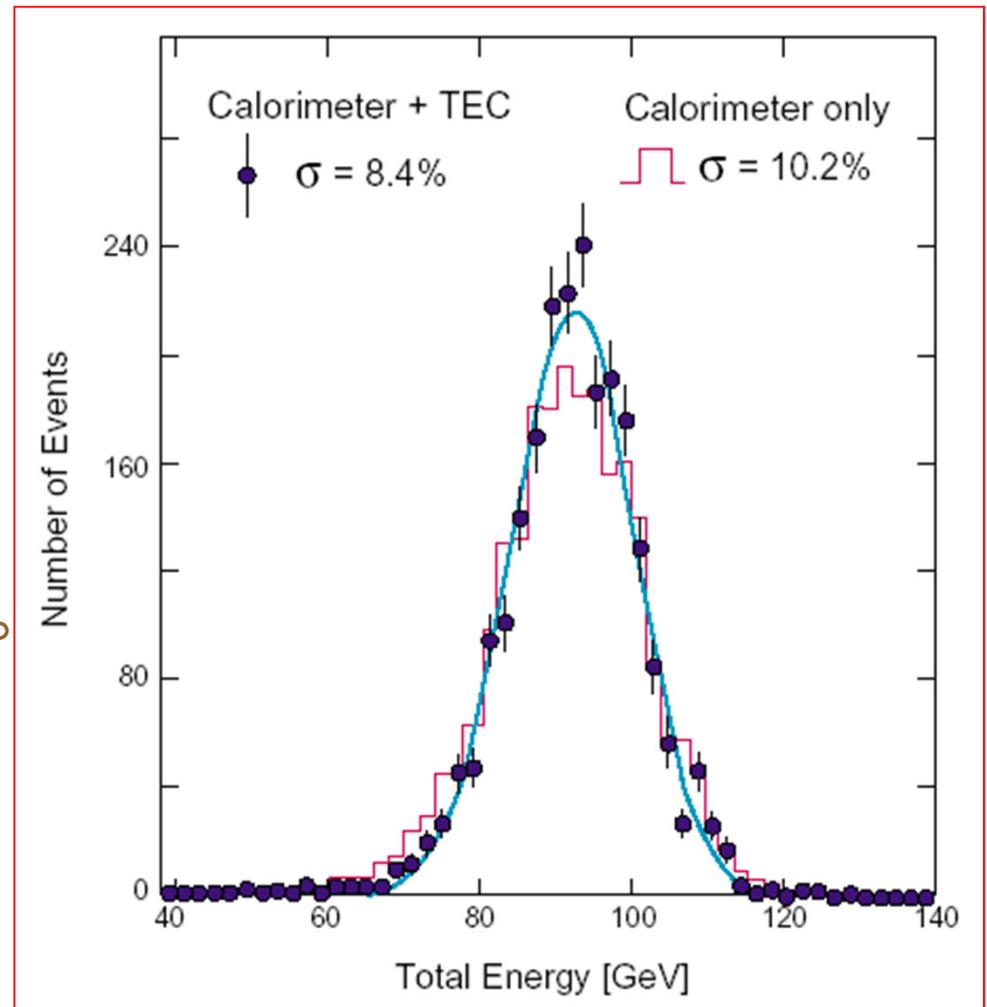
calo adronico

- lastre di U impoverito (U_{238}) + camere proporzionali (370,000 fili);
- μ -filter in ottone (65%Cu, 35% Zn) + tubi prop.;
- BGO e had nel trigger di calorimetria (molti algoritmi in .OR., ex. E_{tot} , E_{tot}^{BGO} , cluster, γ singolo, ...);



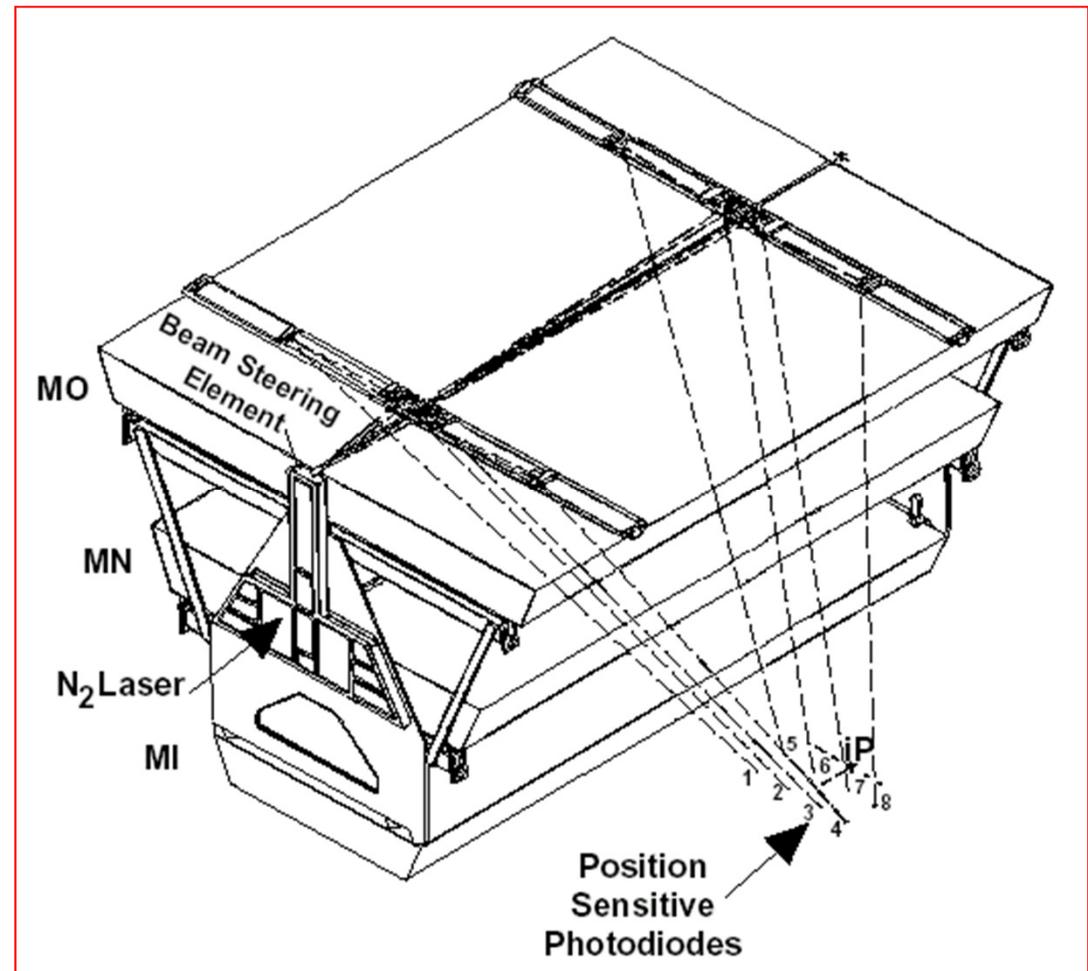
risoluzione in energia per eventi adronici

- eventi adronici a $\sqrt{s} = m_Z$;
- $E_{\text{vis}} / \sqrt{s} = \sum_i E_i / \sqrt{s}$ in due casi :
 - calo e.m. + had;
 - calo e.m. + had + TEC (no doppio-conteggio);
- la risoluzione “migliore” pari a 8.4% richiede l’uso dell’informazione di TEC.



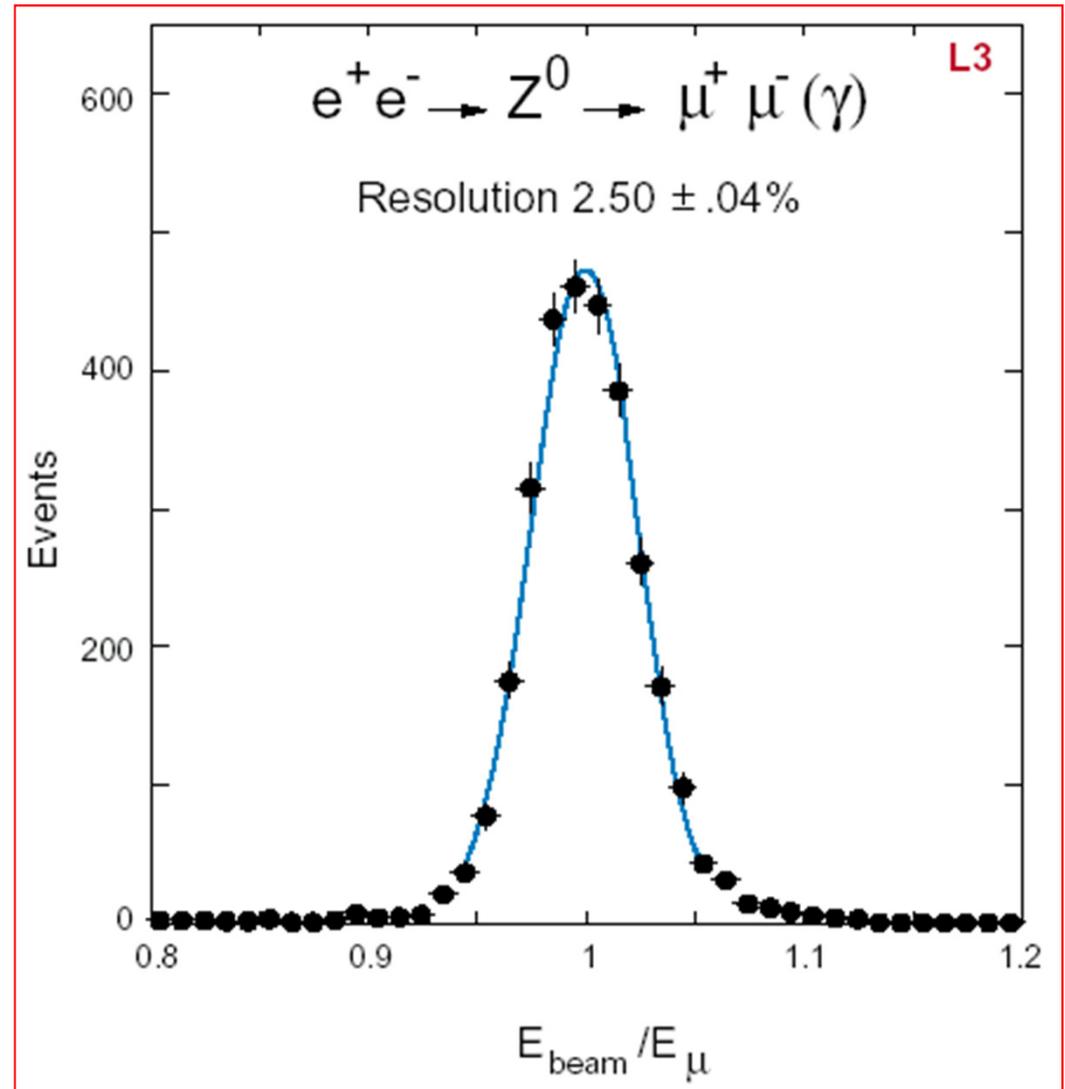
μ spettrometro - 1

- ottanti, ciascuno con tre tipi di camere : MO + MN + MI (16 + 24 + 16 fili);
- precisioni meccaniche $\sim 10\mu\text{m}$;
- allineamento con sistemi ottici;



μ spettrometro - 2

- si misura la sagitta $\propto 1/p$;
- pertanto $\sigma(1/p)$ è aspettato gaussiano, mentre $\sigma(p)$ ha distorsioni asimmetriche nelle code;
- istogramma $E_{\text{fascio}} / E_{\mu} = \sqrt{s} / (2 p_{\mu})$;
- $\sigma(m_Z)/m_Z = \sigma[\sqrt{s} / (2 p_{\mu})] / \sqrt{2}$.



trigger / daq

- problema : incroci 44/88 KHz \leftrightarrow fisica \sim 1 Hz;
- trigger di evento (no selezione sul tipo di processo, LHC è differente);
- 3 livelli in cascata;
- 1° livello : .OR. logico di molte condizioni :
 - TEC (ex. 2 tracce opposte);
 - μ (almeno un candidato);
 - ...
 - energia (v. pagine seguenti);
- sorgenti di falsi eventi (\sim 10÷20 Hz al 1° livello) :
 - rumore dell'elettronica;
 - interazioni casuali di particelle fuori fascio ("beam-gas"), fotoni di brem, ...;
 - cosmici, ...;
- 1° livello : cablato + processori costruiti in casa;
- 2° livello : processore (semi-)commerciale;
- 3° livello : calcolatore standard